NuTau2021 Workshop Minutes

(Peter Denton taking notes)

Tuesday September 28th

Mary Bishai's introduction

Tau neutrino workshop fits within the Snowmass process. While it is for US funding agencies there are contributions from around the world. Whitepaper writing will start this afternoon at 2PM, see Peter's slides and the read-only whitepaper link on indico.

Jacobo Lopez-Pavon theory overview

New states: heavy (untestable), light (look to cosmology), intermediate (look to 0nubb, colliders, …)

Oscillation experiments: sensitive to havy new physics via unitary violation and light new physics via sterile oscillations

The alpha matrix is a model independent approach

Normalization and the near detector must be carefully accounted for

Possible connections with mass models and leptogenesis

John K asks about contamination in the beam

Laura Fields artifical source overview

Neutrino beams such as OPERA (past) and DUNE (future)

Beam dump such as DONuT (past) and SHiP (proposed)

Collider sources such as FASERnu and SND (upcoming) and FPF in general (proposed)

Muon collider tau neutrino production (see an LOI)

Flux uncertainty improves: 15%-10% from Opera to DsTau, DUNE should be better

The notion of a HE DUNE beam tune is not an official part of the plan but is something people are interested in

Ty DeYoung natural source overview

Most sources produce no tau neutrinos, and most detectors don't differentiate nu/nubar

Intrinsic nutau in atmospheric is below the astro flux

Atmospheric neutrinos: see nutaus from oscillations, threshold suppressions is still significant

Reconstruction at SK/IC is hard, but possible

Astrophysical: no kinematic suppression and favorable flavor mixing

Above 100 TeV tau neutrino regeneration in the Earth becomes important

At the EeV scale, earth-skimming nutaus is the dominant way to detect any neutrino.

Discussions

ANITA anomaly is an opportunity to motivate more work in that direction in the future such as PUEO

Motivations for tau neutrino physics include unitarity violation and cross sections, among a number of other things

Afternoon Session

(Nitish Nayak taking notes)

Stephen Parke nutaus and unitarity

Hierarchy in L/E, Unitarity built in to PMNS

Unitarity tested to high precision in quark sector. Corresponding unitarity triangle for neutrinos require unitarity assumption in PMNS because nutaus are hard to study, uses only numus and nues! Nutaus are involved in 14/18 unitary conditions.

Triangle tests are model independent and useful

PMNS goes to 13 free parameters from 4 if non-unitary. Experimental observables are heavily modified if so.

JUNO better potential to measure wiggles from U_e row than KamLAND. Better probe for unitarity

Similarly for OPERA for U_tau3. Has collected significantly more nutau events

We get very tight constraints from rare lepton decays (MEG etc)

Fairly tight constraint on non-unitarity from sterile neutrinos come from measurements at LBL + nue disappearance channels, again all using numus and nues – no nutaus

If non unitary encoded into Eta matrix + scale of unitarity breaking is high – get constraints at O(10^-3) - O(10^-5) level

E-mu unitarity triangle can be well constrained. Some studies indicate same for mu-tau. How?

Discussion

Andre d. G points out that non-unitary models can be built by realizing that mixing matrix elements are like couplings, so new interactions can be made to impact specific matrix elements similar to the CC interactions that originate them

Peter D points out the CKM unitary triangle plot assumes matrix unitarity, i.e each experimental measurement assumes triangle closes. Stephen points out however that the neutrino plot combines information from multiple experiments in a global fit

Milind D asks about normalization conditions for unitarity being possibly above 1. > 1 could come from lepton non-universality assumptions (NN : I think this was what was said) , non-standard interaction models etc that may already be constrained by data

Mu-tau triangle closure -- Peter D/Jacobo L-P/Pedro M/Sanjib K think this might come from atmospheric neutrinos because of sensitivity via matter effects/short baseline expts like nuTeV/NOMAD. Sanjib says the short baseline way may be model dependent however

Xin Q. asks about division of priorities for nutau measurement uncertainties. Flux/cross-sections etc. Peter D. says LHC can be helpful for the flux part. Cross-sections are much harder, lots of nuclear effects, old data etc.

Vladimir lepton flavor collider tests overview

LEP : Z couplings are universal, W had 2.5sigma tension – Atlas seems to have resolved this, However, other anomalies persist

R(D) and R(D*) [b-> c tau nu]

- Belle agrees with SM
- Post-hoc analysis points out possible b->clv discrepancy in some angular observables – Belle 2 will have sensitivity. LHCb might have it too

b->sll

- New probes with baryon channels are starting (pKee). Currently not much sensitivity at LHCb. ~1sigma compatibility with SM
- R_K – first evidence for LU breaking at LHCb. Acceptances in the ee channels are calibrated in multiple steps and cross-checked with J/psi -> reduced syst => 3.1 sigma discrepancy with SM
- Anomalies make sense in the context of other observables (such as angular) too. Coherent picture forming for overall wilson coefficients.
- Kmumu measurements at LHCb but also now coming in from CMS

- Phi mu mu coming in as well from LHCb
- b-> s nu nu – Belle 2 has unique sensitivity

B -> mu mu

- Legacy LHC branching fraction measurements – good compatibility with SM. Affected by C_10, prev anomalies in C_9 so not incoherent

LFV tests

- b -> s tau nu -- branching fraction limits
- Z-decay
- Connection with high-pT searches for specific models that explain the B anomalies – so far nothing found

Q&A

- Xin Q. asks about a possible systematic issue in the Kee fit and how it relates to R_K. Vladimir G. says the channel is complicated by mis-ID'd brem photons, especially to the right of the peak, so its not straightforward to connect it back to R_K.
- Milind D asks b->s nu nu result is swamped by backgrounds so what hope is there? Vladimir G. says Belle 2 has lot more data coming in + their use of ML techniques can improve things. Milind D also points out Mu2e could help as well for interpreting B anomalies

Yuval lepton flavor violation – theory overview

Connection between neutrino oscillations (observed LFV) and CLFV at colliders (only bounds)?

BSM ~ beyond SM + neutrino oscillations

- Global neutrino oscillation data usually interpreted with sterile neutrinos
- Oscillations at experimental level ~ NSI, PMNS non unitarity (hard to separate the two)
- CLFV : mu -> e gamma etc (O(10^-50) at SM level, so observation => new physics)

NSI

- new dim 6 operators for LFV give rise to linear effects in epsilon after interference with standard oscillations
- Tau CLFV bounded at O(10^-8) from colliders, mu ~ O(10^-12). Effects scale as epsilon^2
- CLFV
  - If we see it, we expect NSI. NSI => CLFV, not the other way around.
  - Bounds on CLFV => Bounds on NSI

    - Symmetry between neutrinos and charged leptons for NSI at dim-6, can break at higher dims but suppressed at that scale. (Irina M. points out this can go both ways : no CLFV effects but NSI or the converse)

Differences in LNU (non universality) and LFV?

- Can we look at LNU in neutrino sector?
- LNU tested at colliders

Q&A

- LNU in neutrinos. Andre d.G says that already happens in oscillations. Yuval G says he meant something stronger, like the ones probed at colliders, i.e flavor conserving but not universal Andre d. G says this is hard to test at neutrino oscillation expts. Yuval G: maybe by probing matter effects?
- Unitarity violation vs NSI :
    - Difference between NSI in propagation [unitarity violation] vs production/detection
    - Depends on where you see it, different experiments have different sensitivities to these effects

Peter White Paper Discussion

Purpose is to inform neutrino frontier reports -> Snowmass -> P5 and so on -> determines funding for ~next decade

Suggests not to lean too heavily on reproducing existing work because there will be a brief "history of tau neutrinos" section

John K suggests separation between VHE and UHE sections

Milind D./Sanjib K. suggest adding content about future directions for detector R&D and how it relates to nutau physics. Mary B. points out scope shouldn't be at the level of CDR, but appendices with relevant info can be added where appropriate

Wednesday September 29th

Production and detection of tau neutrinos from accelerator sources in DUNE¶20m

Speaker: Pedro Machado (Fermilab)

Peak of the flux from the CP optimized beam in DUNE is below the the tau production threshold of 3.4 GeV. Tau decay length at the energies of DUNE is of order 100 micron. DUNE position resolution is a few mm.

Interfaced GIBUU with TAUOLA to get Tau polarization accurately.

Cut and count analysis based on particle detection thresholds (no detector simulation)

Can get S/sqrt(B) > 3 even in CP optimized beam – much higher in tau optimized beam – s/sqrt(B) > 10 with 1 yr 40 kton 1.2 MW beam

New idea currently under study is looking into energy dependent mixing due to quantum effects at low energies - in addition to the unitarity and other 3-flavor mixing tests for numu->nutau

John K.: do you have the list of the processes that contribute to tau->e backgrounds

Answer: its mostly nue CC

Jason: Can you comment about what you mean by high energies for the running of the neutrino mixing matrix

Answer: When you produce neutrinos in a lower scale and detect in a higher scale like DUNE you would more likely to see larger differences. At very high energies like IceCUBE you are not doing a precision measurement. Because you don't know the source composition it is more difficult to do it.

Jason: I am talking about atmospheric – compare DUNE/Opera and say IceCUBE atmospherics.

Answer: I think yes this would be a very powerful to probe this mode

Experimental Detection and Studies of Atmospheric Tau Neutrinos in DUNE¶

Speaker: Adam Aurisano (University of Cinncinati)

Transverse kinematic approach ML trained on ND beam neutrinos which does know the incoming beam direction. Can achieve 80% accuracy for space point classification

DUNE data alone can constrain unitarity to 5% using numu->nutau with tau beam

For atmospheric neutrinos start with HONDA for flux simulation + GENIE for cross-section expect 1 nu-tau/kton.yr . In atmospheric sample you can see the 1st oscillation maxima, which you cant in the beam sample (below nutau CC threshold)

Performed a MC study of energy and angular resolution using visible particles for atmos nutau CC and NC events. 17% resolution in calorimetric energy for nutau CC and 5degrees angular resolution

Atmospheric does even better at constraining mixing paramters from oscillations to nutau because you can see oscillation maxima/minima compared to beam. Coupled with excellent angular resolution and calorimetric energy resolution

Q&A

Alberto: Do you have energy distribution for reconstructed taus? Efficiency vs energy for nutau? Can you reconstruct nutau of 100 GeV?

Answer: 1st oscillation maxima is around 25 GeV – very challenging to bin reco energy with small statistics – the L/E was more efficient in terms of binning. We havent studied high energies because of the containment. At the 10's of GeV the particles are mostly contained. But upward going 100 GeV there is less detector to contain

John: How is the atmospheric analysis sensitive to the nu/anti-nu content assumed? The energy is allocated differently between the tau and the neutrino in nu vs anti-nu

Answer: We havent explicitly studied this dependency yet. In the beam analysis from de Gouvea's paper the nu/anti-nu was explicitly separated but we havent done it for the atmospheric study

Sanjib: Comment – when we are looking for numu->nutau oscillation – only upward going neutrinos – have you checked the angular resolution what is the leakage that you can misidentify downward going for upward going?

Answer: It looks like we can get 5degree resolution of zenith angle – from the tau neutrino – all the activity from the neutrino and reconstruct the angle of visible particles. Because the nutau has a large charged track multiplicity the vertex is well identified from both the neutrino and tau decays. This helps separate upward and downward going well. There is more leakage in the events near the horizon.

Experimental techniques: Tau Neutrino Searches at Super-Kamiokande and Hyper-Kamiokande¶

Speaker: Roger Wendell

Neural network to search for tau neutrinos at SK to tag multiple rings in the event (bigger challenge for cherenkov to differentiate higher multiplicity events). Searches in all hadronic and leptonic decays. Instead of counting individual rings several more discriminatory variables are chosen

-measure sphericity – the background tends to be less spherical.

- count ring pieces instead of try to construct full rings since tau hadronic decay produces more pions above the cherenkov threshold than background.

-Fraction of momentum in leading ring

NN Efficiency is 76% for nutau and 28% for background. Purity is 4.7% for nutau. Rate is 422 nutau per Mton.year. Does better for hadronic tau modes.

Combine upward and downward going to constrain backgrounds (downward is mostly background)

Future prospects for improvements using neutron detection is ungoing. Improved ring reco from SK is also feeding into improving the relative charge ratio and ring fragment discriminants.

Q&A

Sanjib: What is the efficiency at higher energies for the tau events?

Answer: Don't have it as a function of energy – the energy range is up to 20-25 GeV in total visible energy in the detector.

Experimental techniques: IceCube atmospherics¶20m

Speaker: Jason Koskinen (NBIA)

At lower energies you get punched from the small cross-section with large uncertainties. With IC and moving up to larger energies the cross-sections are larger and this is the advantage over water cherenkov.

Detector noise is a large issue for IC atmospherics, but with a combination of cuts and BDT was able to improve S/B significantly.

Nutau appearance in DeepCore you can see both the first and 2nd oscillation band. But we cant separate out individual species – for the analysis so far we only had two morphologies: muon track line and non-muon track like. We do have information from angle and zenith that allows us to pick out tau neutrinos.

There is a significant signal but over a very large background in L/E. 3 yr sample 60K total events and of them 1.8K are nutau. Upcoming sample has 250K events including 10.8k nutau CC (prediction)

Previous analysis had managed to get 17K nutau but with lower purity so couldn't extract an oscillation signal. The 10.8k nutau are higher in purity and thus higher sensitivity to oscillation. So its not just about counts.

The DeepCore 3-year result has a tau normalization of 0.73 +0.3 -0.24. But still consitent with 1. The goal is to get to a precision to confirm normalization of 1.0 or a significant deviation from 1.0.

The expectation is that with 8 yr with DeepCore we get to 1 sigma sensitivity to 1.0

In cascade reconstruction (nutau) future analysis and IceCUBE upgrade (not just DOMS pointing downwards) coupled with CNN, graph NN using backwords light propagation from the DOMs to the neutrino interaction instead of the reverse (neutrino light to forward DOM propagation)

IC has examined over 64 systematics but is now starting to focus improving some of these uncertainties. The focus is in

-flux uncertainties – improve modeling of correlations.

-Cross-section uncertainties with a focus on the uncertainties specific to nutau. For example lepton mass dependancy uncertainty is higher for the nutau but some of the form factor uncertainties are found to have much smaller impact

IC upgrade enables much better cascade event reconstruction. Angular resolution for example improves by a factor of 3. Comparison of 1yr with IC upgrade comparing very conservatively to DeepCore 3yr – we can get to 10% resolution on nutau normalization – factor of 3 better than DeepCore.

Q&Q

Peter: On slide 8 you mention 60K muon neutrinos is this only in the tau neutrino range:

Answer: 48K of the 60K are numuCC - the selection shown on slide 8 is optimized for atmospheric event selection so it is optimized for both numu and nutau not specifiic to nutau.

Discussion

Mary: I don't understand for the DUNE numu->nutau analysis how you could get such a good S/sqrt(B) for tau –e, the nutau appearance is for neutrino energies from 5-10 GeV, about 30% of it is nutau QE which results in lower multiplicity – how is that discriminated from the nueCC from the beam contamination?

Pedro: We depend on the DNN and so we can only speculate [Mary grumbles - don't like blind DNNs one bit – I am taking notes so I can add my own editorials ;)]. For the tau hadronic, its easier to understand since the lead pion is always high in energy compared to say neutirno NC pions which are softer and where the energy is distributed more evenly among the hadrons.

Jeremy: For the DNN you can try to understand what it is doing by taking variables in and out and other such tricks to try and understand what is going on.

Pedro: we can try some of these techniques to understand the DNN.

Looking forward to Tau Neutrinos at the LHC - Ideas and Physics Potential¶

Speaker: Felix Kling (SLAC)

Faser and Faser nu used limited space in old LEP tunnels. Future facilities are being considered to expand that space particularly to build a Forward Physics Facility (with HL-LHC) that is designed specifically to fit the needs of neutrinos at the LHC. The FPF would include Faser, Fasernu2 (emulsion based detector on-axis), FORMOSA plastic scintillator for milli charge particle searches and FLAre a big LAr based neutrino detector with dark matter scattering as well.

Tau neutrino fluxes at the LHC peaks in the 100 GeV – few TeV energies – neutrino flux also peaks on-axis if you go more than 1m away the tau neutrino flux starts to drop quickly.

Physics with tau neutrinos at the LHC inclused tau neutrinos as a probe of QCD which is relevant for astroparticle searches – for example constrain the prompt atmospheric neutrino background to astrophysical signals where the cross-sections are large.

For tau neutrino physics with interactions, we can measure tau neutrino DIS at TeV energies and in particular study separate neutirnos and anti-neutrinos via charge of the muon (in magnetized detectors) - also tests lepton universality in the high energy range

You can also study nuclear PDFs in a complemintary way to the EIC at BNL.

Potential for BSM with tau neutrinos: sterile oscillations, light tau-neutrinophillic mediators, tau neutrino magnetic dipole moments

Q&A

Alex: Slide 13 – are these numbers for the whole HL-LHC
Answer: around 10 yrs 2027-2038

Alex: Slide 19
Answer: The L/E is 10-3 so very large delta m2 – can you do sensitivity of dm2 vs mixing angle – how does it compare?

Peter: I ran it for all channels, the only channel that is competitive with the atmospheric neutrinos and NOMAD is only the muon neutrino channel.

Looking Forward to Tau Neutrinos at CERN - Experiments¶

Speaker: Albert De Roeck (CERN)

Interesting current experiment at CERN:

NA65 experiment taking data (or just ending) studies decays Ds->Tau to try and reduce the systematics on Tau (and nutau) from Ds. The current uncertainty is 50% and feeds into the uncertainty on nutau production. Also emulsion based.

Future experiment: SHiP – 400 GeV beam from SPS

Total detectable interactions/5yr is 6200/4700 nutau/anti-nutau – so 1000 events in the lepton channels and several 1000s in hadronic modes. In the last European Strategy was unfortunately not encouraged to build the beam facility but R&D is still encouraged. Complete design study in 2024 for next Strategy report.

FASERnu is an additional emulsion/tungsten detector. The test setup with target mass of 11kg collected 12pb-1 of data and observed first neutrinos at the LHC. This is on-axis, magnetized

SND&LHC (Scattering and Neutrino detector) - installation in T118 location in November of 2021. SND is slightly off-axis to enhance charm production, non-magnetized

Q&A

Alex: Is there a competition between SHiP and FPF

Albert: They are not at the same scale of discussion. SHiP is costed and with a CDR. FPF is still very much earlier than that. Only about a yr old idea.

Discussion

Mary: I have two topics to cast our for general discussion at this workshop

1) What is the overlap between the far forward neutrinos – in particular tau neutrinos at CERN and providing needed constraints on cross-sections for example at the high energy atmospheric neutrino physics like in Ice Cube? The energy range is similar to that probed by Deep Core but with much better detectors for studying the kinematics of neutrino interactions.

2) We heard about the potential for some very good physics on numu->nutau and atmospheric nutaus at DUNE this morning. Can we brainstorm about DUNE detectors optimized for nutau? Is LAr the best option? Massive tungsten emulsion [everybody runs away screaming] – although I note the tau decay length on order 100 micron is too small even for emulsion?

Albert: Emulsion detectors are difficult to produce, expensive – even with 3 small detectors at CERN we struggled.

Alberto: I see a similarity between NOMAD and DUNE – the radiation length is similar and also similar to GARGAMELLE. NOMAD design may be a good option for DUNE nutaus. For the far forward detectors at LHC, we need to come up with new technologies other than emulsions for the forward detectors at LHC.

John K: What are the requirements for the LHC detectors on spatial and angular resolution?

Jason: We need data on the low x region for neutrino scattering at the TeV scale for astrophysics which could be an interest for the astrophysics experiments like IC. So far we depend on data from HERA which is limited in the very low x region.

Maria: We can probe even lower x than HERA in the forward facility. The kinematical regions being probed by IC and Far forward physics are not exactly the same – we will have another presentation on Friday. We do better for cosmic ray physics with the data from far forward LHC than for IC neutrinos although we can certainly help improve over HERA limits.

On the reliability of present predictions for tau neutrino fluxes

Speaker: Maria Vittoria Garzelli (University of Hamburg)

Introduction: IceCube measures convolution of fluxes and cross sections.
Predictions are done separately for fluxes and cross-section in order to be consistent.
Since charm and bottom are massive, we are able to apply pQCD model.

Calculation of nu tau and anti nu tau: IN the forward region, the main contribution come from the meson production in decay. The direct decay and the chain decay contribute to the total energy regions.

Nominal uncertainties: Experimental data is more precise than the prediction. LHCb should work to lessen the uncertainties.

Slide 10: uncertainty due to scaling variation. The uncertaininty is constant with vary wide range of energy.

PDF related uncertainties: with different PDF fits and see the effect of it on prediction. The uncertainty in large energies is similar to that of the uncertainties from PDFs.

Example of event rate calculation: Central prediction is 12.1 which is a very big prediction with very large uncertainties.

Improvements: Thinking to new models for non-pQCD. This will improve the new tunes and find the way to account for uncertainties. This will improve not only the LHC community but also for Ilumi and HEP communities.

Q&A:

Tim Hobbs: missing higher order uncertainties in the perturbative sector. Have you considered heavy quark masses for perturbative uncertainties?

Maria: We are going very forward, so we neglect the charm mass doesn't make sense. Must pay attention to low pT because this is the region that matters most.

John Krizmanic: Accounting – B and D mesons. How do other lepton created from mesons fit into the energy distribution of forward nu tau and anti nu tau.

Maria: nu tau comes from reduced number of objects. We would see nu tau best with emulsion detectors. The uncertainty we have from B and D meson is much smaller than any other interactions. Lambda b production is much smaller than the production of lamdba C.

Alberto Marchionni: LHC forward – one can use to understand the cross section?

Maria: A little bit – but LHC forward doesn't measure anything in charm. When you are at very low pT, you need to put togethe rnumber 2 perturbative effects. So use MC generators and use this data to better tune pT. Better tune will help better understand #2 perturbative QCD.

Appearance of tau neutrinos in the near detectors due to the oscillations involving sterile neutrinos

Speaker: Katarzyna Grzelak (University of Warsaw)

Slide 1 - 5

- In particular want to learn lessons from MINOS+ because DUNE is very similar.
- In the 3+1 Model, the probability at short distance depends on theta mu tau and delta m squared 41.
- If theta 24 were very small, then theta 34 access would be very limited

Slide 6

- MINOS+ was in a very good position to see tau production in the ND.
- Compare the left and right plot, we are scaled close to the threshold. In the right plot, there are two blue arrows that mark the position of the DUNE energy area.
- MINOW+ was not optimal in low spatial resolution of the detector.

Slide 7

- Selection is similar to nu mu disappearance analysis. There is additional systematics with nu tau cross section. The plot shows the ratio of the nu tau and nu mu cross section by energy. The comparison of different generators show the differences are not large.

Slide 8

- 4 input variables: selected one track with possible proton events, kinematic variables, different angles, etc

Slide 9 - 10

- Expected events and main background
- Main background came from CC nu mu and NC events

Slide 11

- Impact of different factors on statistics only sensitivities.

Slide 12

- MINOS+ sensitivities doesn't look bad compared to other experiments such as NOMAD and OPERA but with more systematics added, sensitivities worsen.

Slide 14

- Large CC nu mu background can be reduced with protons can be reconstructed.

Q&A:
Mary: advantage of DUNE is tau to e but because of the shorter baseline of DUNE, we may lose some sensitivities there.

Constraining tau neutrino transition magnetic moments at DUNE

Speaker: Jingyu Zhu (Karlsruhe Institute of Technology)

Slide 2

- There are many constraints on dT. The dashed ones represent future experiments while solid lines represent previous experiments. The red band is from the DUNE detector. We are able to project much bigger region for dT and compeitive to other future experiments.

Slide 5

- Tau neutrinos up scatters outside of the detector while there are tau neutrinos that occur inside the detector. They have two different geometries because the ones that scatter outside of the detector must consider the space spent outside into the calculation.

Slide 6

- There are three types of events: outside events, inside coherent events, and inside incoherent events.
- The figure shows the reconstruction of events in momentum versus efficiency.

Slide 7

- Inside spectra changes heavily with different neutrino masses.

Results

- DUNE FD plot shows the sensitivities for different DUNE events per year.
- Because of the strong flux in the detector, we can constrain the parameter space better.

Kinematic Tau neutrino search at DUNE far detectors

Speaker: Thomas Kosc (Institut de Physique des 1 Infinis (Lyon, France))

Slide 4:

- Plot on the right: Tau and anti tau cross section shows that for DUNE there is a critical region.

Slide 5:

- The method is a fast MC analysis.

Slide 6:

- The first decay mode to look at is tau to e analysis.
- In the background you have both nu my to nu e and nu e to nu e. The additional nu e to nu e will bring some fraction of background.
- The plot on the right shows the kinematic distributions of the transverse missing momentum with and without background.
- The plot on the left shows the distribution for the likelihood ratio.
- Used neural network machine learning to improve it but it di the same thing.

Slide 7

- Nu tau statistics would be boosted by time 6 while the other statistics are constant.
- The asimov significance is boosted but for the CP flux is not as much.

Slide 8

- Tau decaying into rho has a very large branching ratio and exploit the fact that there is resonance with invariant masses.

Slide 9

- Sensitivity for nu tau appearance was significantly 9 or 10 asimov sensitivity.

Slide 10

- Both tau decay modes show possibility of 40% selection efficiency with 90% of background rejection.
- Since machine learning techniques did not improve anything, it shows that the original method was already doing a good job of rejection background and selecting efficiently.
- With combined sensitivities of three different modes, there is a significant improvement in tau optimized beam.

Q&A:

Mary: Clarification question - # of tau optimized beam is also in 3.5 years?

Thomas: It is with 3.5 year, but in terms of MW times + Q times, it is 120 MW times. But it doesn't include the 2.5 MW upgrade plan. It is the same exposure.
Mary: Comment – looked at 3 flav oscillation with sensitivity with 1 year and tau optimized ¾ years with regular beam. The nu tau mode improves and also improves CP sensitivities.

Pedro Machado: is there a distribution from tau to e signal?
Thomas: (Showing back up slides with different transverse plane kinematics)

Jason Koskinen: Asimov test for sensitivity significance – expectation of what quasi realistic sensitivity might be?
Thomas: No data on that. For the statistical sensitivity error that I have is in the discussion page. No clue on the systematics.

Learning from Tau Neutrino Appearance at Long Baselines

Speaker: Kevin J Kelly (Fermilab)

Discussing the three-neutrino mixing paradigm, and then moving beyond it. Point out that any experiment optimised to study numu -> nue appearance will also have a large nutau appearance probability. DUNE expects to see considerable nutau appearance, but much of that is below the charged tau production threshold, which rules out interesting physics in the solar mixing region.

Discuss three-neutrino mixing first. Assume 30% signal ID and 0.5% background contribution from NCs, and assume three years each in forward & reverse horn current, plus one year in nutau enhanced beam running mode. Use these assumptions to show sensitivities in terms of the sin^2 {θ_μe, θμτ, θ_μμ} angles, and also check the angles sum to unitarity. Also show constraints on each of the oscillation channels independently – nutau channel has weaker sensitivity than numu and nue channels, but can still produce contours with nutau channel alone.

Move onto light sterile neutrinos. Tau neutrino appearance channel provides insight into one of the new 3+1 mixing angles not probed by the numu disappearance or nue appearance channels. Also show constraints on the tau mixing matrix elements with and without the assumption of unitarity – if the unitarity assumption is abandoned, both DUNE and IceCube Gen2 can provide strong constraints.

Q (Peter Denton): Are atmospheric neutrinos included in matrix element plots?
A: Includes Super-K and IceCube constraints, although the latter is not as strong.
Peter: IceCube don't reconstruct individual tau neutrino events.
Jason (IceCube): IceCube just scales the template of the nutau events up and down.
Kevin: Will revisit how IceCube constraints are handled w.r.t. DUNE sensitivities.

Q (Jacobo Lopez-Pavon): Expecting unitarity bound from Super-K to be stronger (ie. 10^-1)
A: This analysis did not make assumption that the PMNS matrix is a submatrix of a larger unitary matrix.

Prospects for anomalous tau neutrino appearance searches at the DUNE Near Detector

Speaker: Miriama Rajaoalisa (University of Cincinnati)

Brief DUNE overview: 1300 km baseline, 40 kT LArTPC far detector, 147 ton ND-LAr near detector at 574m baseline. Under 3f oscillations, no nutaus should be seen in ND-LAr. Searching for tau neutrinos allows probing of short-baseline oscillations.

Summary of tau decay channels: e channel (~18%), μ channel (~17%), ρ channel (~26%). Use kinematic variables to select these interactions and distinguish them from background processes. Use MVA techniques for signal v background disambiguation.

Momentum balance is different for nutau interactions vs background – nutau events tend to have more missing transverse momentum. BDT does a good job of separating signal and background events in the e channel, and also for the μ channel, which utilises a recurrent neural network (RNN) for μ/π separation. Use two BDTs for ρ channel – one to disambiguate NC events from ρ events, which feeds into another that actually selects nutau -> ρ events.

Smear final state particles, accounting for thresholds, energy resolution and angular resolution. Above 10 eV^2 in Δm_41^2, achieve sensitivity to sin^2 (2θ_μτ) of ~3 x 10^-4 for the e and μ channels, and ~2 x 10^-3 for the ρ channel. Overall, achieve sensitivity of ~10^-4 when combining channels.

Q (Pedro Machado): Why compare different tau decayers (ie. TAUOLA)? This may already have been done by the developers. Difference between GENIE & GiBUU probably much larger.
A: Future versions of GENIE will be using a different tau decayer, so want to check these as a GENIE cross-check. Talking to Robert Hatcher (GENIE developer) about their work to make GENIE handle the tau polarisation correctly.

New tau neutrino oscillation constraints on unitarity violation

Speaker: Julia Gehrlein (Brookhaven National Laboratory)

Studying unitarity in terms of tau appearance – how can we constrain leptonic mixing without assuming unitarity? Phenomenology of sterile neutrinos at oscillation experiments depends on mass scale. At 10eV – 15 MeV, sterile oscillations are too rapid to be resolved, and average to a normalisation shift. Above 40 MeV, beams cannot produce sterile neutrinos. Focus on intermediate regime.

Discuss how unitarity affects oscillation probabilities. Deviations from unitary well-constrained for e and μ, but τ constraints are weak. Move beyond numu disappearance and nue appearance, and draw on tau neutrino datasets from literature to improve constraint. Use DOnuT, atmospheric & astrophysical nutau appearance from IceCube, NC data from SNO and CEνNS. Show constraints on tau matrix elements with and without unitarity assumption – atmospheric and long baseline data has largest impact. NC, DOnuT, astrophysical data less impactful.

Also consider impact of future results: nutau CC scattering from FASERnu, atmospheric & astrophysical nutau appearance from KM3NeT/ORCA, HyperK, IceCube-Gen2, 5x NC dataset from CEνNS. Again find atmospheric and LBL data is most impactful, and also NC data from CEνNS becomes more impactful. Current and future sensitivities to tau row normalisation are shown – prospects to constrain to few-percent level when incorporating future data.

This study can place a flat limit on |U_τ4|^2 at a much lower range of m_4 than direct searches (down to 10^-5 MeV, compared to lower threshold of ~10 MeV for direct searches).

Q (Pedro Machado): What constraints do you place on the sum of the tau matrix elements?
A: Unitarity not required, but the sum is not allowed to exceed 1.

Q (Alberto Marchionni): What's more important for DUNE – beam nutaus or atmospheric nutaus?
A: This study did not consider atmospheric oscillations in DUNE.

Q (Mary Bishai): If we could combine DUNE nutau appearance with atmospherics, get cancellation of cross-section uncertainties. How much does that cancellation help?
A: If one uses a measured cross-section (from a near detector, for instance) instead of lifting them from theory, that helps constrain uncertainties. DUNE-specific details beyond that are outside the scope of this work.
Peter Denton: Not much exploration of fitting samples with correlated uncertainties, but that is potentially a very powerful technique.

Constraining neutrino magnetic moments at the LHC

Speaker: Roshan Mammen Abraham (Oklahoma State University)

Electromagnetic properties of neutrinos can be used to probe new physics. Extending SM with right-handed neutrinos gives them a magnetic moment proportional to their mass. Look for electron recoil from a neutrino interacting with a nucleus and scattering, either elastically or quasielastically from an active to sterile state. Can look for enhancement of signal cross-section at low recoil energies resulting from neutrino magnetic moment – with neutrino source and low-threshold detector, can probe neutrino magnetic moment.

Consider elastic ν scattering first. Dominant backgrounds are μ -> brem -> pair production (vetoed by μ coincidence) and NC + CC numu neutrino backgrounds. Search in FASERν2 (10t tungsten detector) and FLArE (100t LArTPC) – the latter is more sensitive due to lower thresholds. SM background rate is flat in energy, but NMM contribution enhances at lower energies. Simple event selection just identifies events with an energy above threshold and less than 1 GeV. FLArE can improve on μ_{ν_α} limits from DONUT by an order of magnitude.

Now focus on quasielastic ν_a -> ν_s case. Qualitatively similar to elastic case, so same selection applied, but sterile neutrinos can decay through channels inaccessible to active neutrinos. Define additional cuts to constrain this – focus on events with a single electron track emerging from the vertex, and use timing information to ignore events where the heavy sterile neutrino would decay promptly, and focus on “double bang” events where the decay vertex is displaced from the production vertex. Define “loose” and “strong” versions of cut, which correspond to a maximum reconstructed energy of 10 and 1 GeV, respectively.

Demonstrate that FLArE is sensitive down to $\sim 2 \times 10^{-8}\ \mu_B$ for the neutrino magnetic moment below 0.1 GeV in heavy neutrino mass, almost an order of magnitude more sensitive than current limits from LEP.

Pedro Machado: Very large nutau magnetic moment would have been noticed elsewhere, ie. Solar/atmospheric searches, Borexino.

John Krizmanic: From an astrophysical context, you can depopulate the active neutrinos via transition to steriles. How are these processes constrained by astrophysical searches?
A: Constraints exist from astrophysics, but place limits in a comparatively much lower regime of sterile neutrino energy compared to this search.

Follow-up question for Julia Gehrlein:

Q: How can nutau matrix elements be constrained by atmospheric numu disappearance data?
A: When the neutrino travels through the earth, indirect constraints can be placed on nutau normalisation using numus if the sterile neutrino is kinematically available, since the oscillation probabilities are modified. If the sterile neutrino is not kinematically available, this constraint disappears.

Cross Section Measurement of Tau Neutrinos from GeV to TeV in Ar_{40}

Speaker: Barbara Yaeggy

Why cross sectional knowledge is important: Cross sections are the major contributor to systematic uncertainties in oscillation measurements. Similarly, reconstruction techniques rely on good knowledge of the cross sections and interaction models, as well as extraction of the oscillation parameter

At a few GeV, there is an overlap between DIS and resonance. New accelerators allow for more precise interaction models. For example: the oscillation of nu_tau in long-baseline experiments. Nuclear models rely on different approximations, valid in different regimes: can nu_tau help us to better understand these processes?

Can use deep inelastic scattering (DIS) to probe the structure of hadrons by extracting information from the leptopn scattering cross sections to measure structure functions of the target.

Because the tau is much heavier than the other charged leptons, the F5 structure function becomes more important due to a squared mass dependence. The phase space in (x,y) is also reduced for nu_taus. At low energies, the tau neutrino has lower interaction cross section than the other flavors, and has a significant amount of uncertainty. By probing DIS regime, can check the cross section of nu_tau in argon, and check to see if it follows the standard model or other models (F4=F5=0, for example).

As described yesterday, the detection of taus is of low statistics due to being very heavy, having a high energy threshold, and short lifetime. Considering the hadronic decay channel (specifically tau->nu_tau+rho, where rho->pi- + pi0). Background signal is the NC nu_tau interaction. Use a boosted decision tree (BDT) to check for rho decay products.

Signal and background separation over the kinematic variables is acceptable, and could potentially be improved by using tools other than BDTs.

Discussion:

Alberto: Can you say more about F4? Is it really zero? Do you know what GENIE is using?
Barbara: F4 holds when the nucleon target is replaced by a lepton target. GENIE is using both F4 and F5

Cross Sections Across All Energies-Theory

Speaker: Hallsie Reno

For interest in this workshop: GeV to EeV (and above), specifically focusing on nucleon targets. At low energies, pion contributions, and quasi-elastic collisions. Sigma/E is constant from ~10-100GeV but begins to fall above this.

Considering quasi-elastic cross sections, resonant productions, and deep inelastic scattering. Many monte carlo generators which model these interactions. NuSTEC: recent collaboration which has combined theory and experiment.

For quasi eleastic scattering with nucleons, energy threshold of 3.5GeV. Polarization asymmetries for target, recoil, and tau. Polarization of the tau affects the decay distributions—can be measured.

For deep inelastic scattering, two more structure functions F4=0 and F5 (related to F2) contribute to cross section. As before, F5 is more important for the tau flavor due to mass dependence. F5 is also more prominant for tau anti neutrinos. Several comparable mass scales in this range: nucleon, tau, charm quark. Low Q needs to be treated—many different methods.

Looking at the allowed DIS kinematic regions, there exist limitations (compared to other neutrino flavors) in x and Q (or x and y) phase space due to the heavy tau mass. Specifically, pushed to higher x values. Making the transition from RES to DIS without double counting is an issue. Significant suppression of the tau neutrino cross section until mid range energies (1000GeV)

At the highest energies, the x ranges are beyond probed measurements so small x extrapolations are required. In this regime, there exist gluon and sea uncertainties. Extrapolation leads to increasing UHE cross section uncertainties. At UHE energies, cross sections for nu_mu and nu_tau are equal.

Sub-leading effects: example: real W boson production. Hadronic coupling to virtual photons to produce W's. This effect is important in several regimes, and gives a non-negligble change to the neutrino cross section.

At UHE: nu_tau regeneration is an important effect for propagation through the Earth. Several different monte carlo simulations for Earth propagation which will be compared in the white paper. Different assumptions on cross sections, energy losses, decays, etc.

Summary: At low energies, kinematics are the primary difference between muon and tau neutrinos, but not the only difference; access to Fp and F5. At high energies, common uncertainties in extrapolating the cross sections (DIS).

Discussion:
Q: Looking at tau cross section, DIS doesn't take off until 10GeV. Does that mean that the DUNE rate is QE?
A: There has been a huge amount of work on QE. DUNE high energy beam between 6 and 10GeV. 30% is QE compared to DIS

Q: What sort of angular resolution would be needed to map the tau flux to say something about high energy cross sections?
A: Good question, but no answer. Follow up studies would be very interesting. John K. says in optical Cherenkov, angular resolution is about 1 degree. If huge fluxes of UHE neutrinos, this would be helpful.

Neutrino cross-sections from GeV to ZeV energies – experiment

Speaker: Spencer Klein

Different classes of experiment based on the neutrino cross section. Can look at direct detection, or neutrino absorption studies (look at the neutrinos you don't see). The first case requires a good knowledge of the neutrino flux, whereas the latter case, mostly the angular distribution needs to be known.

As before, the low energy differences between the neutrino cross sections disappear at high energy, with nuclear effects becoming critical at higher energies. Historically, neutrino energies up to 400GeV, with 5 -10% precision. Current focus is on low energy neutrinos, which are better for oscillation.

Example: MINERvA is a Fermilab experiment to study neutrino interactions on a variety of nuclear targets. Useful for tuning models such as GENIE.

Future experiments: DUNE and FASERv. FASERv will measure neutrino cross sections for all 3 flavors up to 5TeV. Have already seen neutrino events in a 2018 pilot run, and full detector installation currently ongoing.

IceCube intermediate energy measurement. Need to know the atmospheric neutrino flux (predicted uncertainties of ~10%).

For higher energies, Earth absorption measurements. A chord going halfway through the Earth, 15TeV corresponds to one absorption length. For higher enegies, the Earth becomes more opaque, and measurement moves closer to the horizon. IceCube has performed nu_mu absorption measurement; NC events cause a spectral dependence that affects the results. Assume sigma is a multiple R of the standard model. Make a best fit, assuming the astrophysical flux and spectral index (and isotropy) to yield the neutrino cross section as a function of energy. IceCube plans to make the same measurement with 8 years of data (1-10TeV, 10TeV-1PeV, >1PeV) with improved systematic errors. Using high energy starting events, can make the same measurement with excellent energy precision at the expense of low statistics.

Future: Radio detection. Radio detection should become important above 100PeV energies. Will see more neutrinos if UHE cosmic rays are mostly protons. The neutrinos which are important for radio detection are very near the Earth limb due to cross sectional arguments.

Additional discrimination: inelasticity. Inelasticity probes the different types of neutrino interactions. Specifically, nu_tau interactions have higher inelasticity than nu_mu interactions. IceCube has measure the inelasticity in thousands of track events, and provides an additional discriminator to the corss section.

Nu_tau cross sections difficult to measure at low energies due to the low flux and small cross section. Most nu_tau are from oscillations. At high energies, astrophysical nu_taus are assumed to be fully oscillated and well known. However, at high energies, nu_tau identification is hard.

Discussion:
Q: Mountain top experiments should have good angular resolution (measure the neutrino cross section to ~20%)

High Energy Tau Neutrino Detection

Speaker: Dawn Williams

PeV – EeV tau neutrinos are interesting because they are astrophysical in origin and not produced at the source. Energy ranged covered are in the cosmogenic region and cosmic accelerators. Particles which are cosmic accelerated have high energy with magnetic field. (note: Neutrinos and antineutrinos are both referred to as neutrinos in this talk). The plot is an active galactic event which creates cosmic accelerators which points at the Earth. Another possible source of cosmic accelerator is merge of two black holes. Slide 7 right plot, Example of predicted neutrino flux from neutrino star merger.

Cosmic neutrinos fluxes above 100TeV requires a giga ton detector, which is quite large. Ice and water are both used in the detectors. Pros and cons to both environments. Ongoing experiments on both environments to test. Slide 9 figure, charged current interactions and their simulated IceCube events correspondingly. Muon tracks, cascade – electron shower length is shorter, double cascade – from tau particle which also decays into another tau neutrino. NC interactions also seen as cascade.

Detectors: IceCube is the first detector to reach 1 km^3. ANTARES ongoing long standing detector of 0.01 km^3. Slide 11, the shaded bands show the coverage of the sky from the detectors. Greater sensitivity comes with more detectors covering the sky.

IceCube: Located in Antarctica, in the south pole station. Surface detectors are for cosmic ray detection. Have been operating for 10 years at full volume. The DOM – has a single 10 inch PMT for each detector. Digitizers takes the signals from the PMT to the computers for reconstruction of wave forms. Has succeeded in detecting cosmic ray flux and seeing relation with sources. Slide 14 - blue line - measurement of the diffused cosmic ray flux. Still in to answer where do these cosmic neutrinos come from and how far does this flux extend are some questions we need to answer. Recently seeing the sources of the diffused cosmic neutrino events. Tau neutrinos in IceCube – there is a double pulse event that they have been studying. Identified the first tau neutrino candidates in IceCube. The likelihood prefers the double cascade hypothesis over the one cascade hypothesis. We can start to set limits for the flavors of the neutrinos. The one sigma countour is quite large so want to increase sensitivity.

Next step – IceCube gen2: order of magnitude increase in sensitivity. Includes a radio detector. Multi PMT concept. Increase improvements in cosmic neutrino flux capability of IceCube – gen2. Plot on the rigth show s improvement to sensitivity for blazars sch as neutrino flares. Hight statistic sample of tau neutrinos can help learning about the environment of the astrophsyical neutrinos. The plot (slide 19) on the right shows different variety of sensitivity of BSM parameter space.

KM3NET: Located in the Mediterranean. Also uses multi PMT concept pointing at multiple directions. Active construction going to start working in spring of 2022. Based on simulation, starting to see separation between double cascade above 10 meters.

Baikal-GVD: Located in lake Baikal, has the advantage of ice. Looking at both double pulse and double cascade but they do not look like tau neutrinos yet. It might be a muon that might have stuck through.

P-ONE: RND phase off the coast of Canada in the Pacific ocean. Also a site using ICeCUbe upgrade, using it to test detection modules which will be used in IceCube.

Air showers: we can see Cherenkov interactions with upgoing, earth-skimming neutrino events. There can be tau neutrino events with regeneration interaction.

Pierre Auger Observatory: looks at particles from the showers in the surface detector. Setting limits – dashed lines are for earth skimming technique while solid lines are from earth going through neutrinos.

GW170817: neutron star merger happened to be located where Auger was most sensitive. Therefore, it was able to set limits at the higher energy.

Earth Skimming technique dedicated experiments such as The Trinity Tau Neutrino Observatory uses Earth Cherenkov detector design. Camera will be made of silicon PMT. Trinity demo will not be as sensitive as IceCube sensitivity since it's meant to demonstrate its technology. Trinity expects to 6 neutrinos in ten years with smaller POT. POEMMA – probes earth skimming technique out in space. Two telescopes sharing information in the atmosphere detecting florescence to see Cherenkov events. 10^10 giga ton detector. POEMMA has ability to slew and change direction rapidly. It can target events for neutron start mergers or other events of interest.

Q&A:
Peter Denton: What kind of suggestion/recommendations for other water Cherenkov detectors? What different advantages do different detectors have?
Dawn: Water detectors have longer scattering events which ice detectors cannot do. Advice – double pulse technique is very interesting so record full waveforms is suggested. Water gives better resolutions especially angular resolutions. IceCube has the advantage of having built first in ice. Deploying in water can be complicated in construction.
Juliana Stachurska: One advantage of ice is that it is fixed so you can add calibration and add more data. Can study in more detail. Water has bio luminescence, tides and time variable studies that needs to be included.
Milind Diwan: Page 16 – time scale of these plots?
Dawn: The waveforms – each square is 100 ns for each signals in the digitizers.

The Radio Techniques and UHE tau neutrino searches

Speaker: Enrique Zas

Neutrino detection: The showers give different particle identification for each interaction. There are different ratio of particles in the decay process.

Earth Skimming technique: The air shower sometimes escapes the air and there is no shower. There is a strong theta dependence such as attenuation. The regeneration effect also has to do with the scale with the zenith angle. The earth skimming is not great for high eneries but it's good for EeV energies. Directional - Auger is a very sensitive detector with the earth skimming technique. That's why you want more detectors in order to cover more of the sky.

Slide 18 plot - In very high frequency at 56 degrees, you get rich interference pattersn. With reduced frequencies you can have wider angle distribution.

Length – If you look at angles greater than the Cherenkov angle, then there would be a diffraction minimum from the path difference. This explains the diffraction pattern depending on the silt.

Diameter – a lot smaller than the legnth of the shower, but there is a path difference between the edges of the shower. THis is what exactly happens at the cherenkov angle with the width of the shower.

Unidimensional current time domain: Due to the vector potential being dependent on the zeta parameters, we get an electric field.

Coherence: electron showers which produce electrons has LPM showers and creates another showers. Therefore, it creates a double bang which you can use to measure the changed length of the shower and can reconstruct and identify the particle. Slide 34 – neutrino electron producing electron shower which produces another pulse in the radio detection.

Atmosphere: The transverse currents in the shower front which is perpendicular to the shower front which moves at a speed of light. Big surprise from ANITA is that they discovered cosmic rays in the GHz since the showers were so much bigger. This happened because the cherenkov angle is so small that the width of the shower front is blew up. Showers within 30 m of shower axis have very little time delays within 70 degrees.

Radio technique: ARRIANA has advantages of putting it on the surfaces with the antennas, ANITA - has a balloon or satellite concept in the air. It is flown around antarctica with number of cycles that last about a month. They have the best limits above 30 EeV. ARA in the ice. RNO-G constructed in Greenland is very similar to that of ARRIANA. It can also remove radio interference with antennas underground and on the surface. There are 35 of theses stations. Also uses faced array combining several antennas for energy detection. IceCube Gen2 – phased stations are used to reduce noise and combines surface and deep stations to remove interference noises.

ANITA's mysterious events: has seen horizontally polarized pulses from air showers where certain pulses suggest certain angles. However, there are anomalous events with direct event angles has the opposite polarity. They could be explained as a tau neutrino because it is emitting directly emerging from the earth.

PUEO: improved but same concept as ANITA. The improvements are due to the reduced horns which are used for high frequency measurements and now start at 3400 MHz which makes them smaller with many more antennas.

Q&A:
John Krizmanic: slide 18 – when designing a radio how does one optimize for increasing the observation angle at the cost of increasing frequency in antennas?
Enrique: in a single place, you want to measure frequencies with a broad angle. Wider angles may be harder to reconstruct the events. If you don't get a wider angle distribution, you can still have good reconstructed events.
Stephanie Wissel: PUEO has a low frequency array which is meant to cover up to high frequency arrays which you can cross calibrate.
Christian Glaser: @John: We did this optimisation study for the in-ice detector ARIANNA where we checked which bandwidth gives us the most neutrino effective volume: https://arxiv.org/abs/2011.12997 It turned out that 80-200MHz is the optimum. But for reconstruction, a larger bandwidth is of course better, so we only trigger on the small bandwidth but then record the signal at higher bandwidth

Discussion:
Milind Diwan to Enrique: any advantage to being stationed at an escarpment such as the South African escarpment where there's a step drop of 6000 ft of 100 km.
Enrique: You need to have right amount of neutrino to go through, then right amount of tau neutrinos to come through. This can be done in a mountain if you look into the ground. It can be advantageous.
John Krizmanic to Enrique: any potential for earth skimming neutrinos for other detectors?
Enrique: yes, any experiment looking for cosmic rays can look for earth skimming neutrinos.
Carlos to Enrique: ANITA has anomalous events seem to be explained by tau neutrinos, but is a standard model background or noise that could be making those events or prevent those events in the future?
Enrique: Some theories are bags of ice or air within ice that could explain the anamolies. My favorite interpretation is that it could be due to cosmic rays that could be impacting the ice and create a transition relation while they hit. CR can have high energies and therefore could be creating these unexplained events. The background cosmic events have not been explained enough.
Frances Halzen: What about the paper by Prohira and deVries? They claim that the events are due to the reflection of transition radiation of cosmic ray showers hitting the surface.
Stephanie Wissel: @Francis I think that's what Enrique was referring to as a possible standard model explanation
Carlos: More ice or more water?
Dawn: Should be less than water because scatters can be resolved better in ice than in water.

Enrique: Yes, I think that is a possible explanation, not necessarily reflected though, it can just be transition radiation, but there is not a detailed simulation made yet.
Frances: But they cannot come through the Earth
Enrique: It is semantic, I mean from the interface.
Peter: How many tau neutrinos do we need to detec in order to calculate the flux?
John: In air showers, the parameters that can change with the assumption of the Earth. We can at least simulate what's happning in the atmosphere.
Peter: The difference between the earth skimming neutirnos between the crust and the ocean is drastic. How big of an effect is the anticipated uncertainties?
Enrique: Auger definitely gives siginificance of the uncertainties.
Peter: IceCube can measure some parameter with some uncertainty. But if it is competitive with Auger and other detectors can provide more improvements in the parameters with different energy ranges.

Tau neutrino reconstruction techniques

Reconstruction of multi-GeV tau neutrinos in tracking detectors¶

By Dario Auterio

In this talk, there was a discussion/overview about the reconstruction techniques used in the past experiments which performed nutau appearance searches and what we can learn from those. Starting in the 90s with the Gallex results, which confirm the solar neutrino deficit and how a controlled observation of neutrino oscillations with an accelerator neutrino beam would have been a great discovery. CERN nutau appearance experiments appear (WANF, NOMAD). The tau decay can be identified using two different methods, 1) tau decay kink (DONUT/OPERA), main channel: muon tau decay. 2) Kinematics of the tau decay (NOMAD/ICARUS/DUNE), presence of neutrinos in the FSI, visible decay daughters, tracking & calorimetry, main channel: electronic tau decay.

In particular, it was presented a good overview of the roots of the kinematic method and what it implies from the point of view of the detector and of its responsibility for the reconstruction of the hadronic system, which implies a good understanding of simulations. TPCs are ideal detectors for the massive scaling up of these techniques. Looking forward to seeing how these technique can be applied to data in DUNE.

Q (Alberto Marchionni): I see that in OPERA there are no taus decaying to electrons, it could be due to statistics since obviously there is a limit on the number of event but there is a problem in the notion on how to identify the electron.

Dario: Interesting, as you said It's statistical compatible because you would expect 0.8 events or so, however, to follow back an electron in the motion is a lot complicate task than to go and look a muon because you have to go backward in the development of the shower, so maybe the efficiency was optimistic however OPERA also did a nue oscillation search where the electrons were compatible with the expectations. [Followup from Alberto: See https://arxiv.org/pdf/1803.11400.pdf, and the efficiency in fig 1. You also see that for tau to e OPERA expects 3 evts and see 6, again compatible with statistics. The background there might be higher due to had scattering. Opera measured that background carefully following many pion tracks.]

Q (Alberto Marchionni): can you give an idea of the time that it took to scan on average one event? And how this would be extrapolated to HE ?
Dario: there was an evolution of the scanning system but I don't see the technique that can be applied to a larger scale than the one running in OPERA.

Q(Mary Bishai): what of the interesting things for me is traying to reconstruct just the nuta QE in DUNE, if that means long hadronic multiplicity since you want to exclude that?, so, Can we also do this in the hadronic mode? because if we can do that, then we would have a very clean numu nutau signal and maybe beat the atmospherics in term of universality.

Dario: If you check Thomas K. talk going in this kind of details, indeed, the QE are an important component of the sample, he tried to restrict to QE and exclusive samples but it didn't bring to sensitives. Mary: there is more that we could do to pull that sample out, if there are any future ideas?, Dario: this is a very promising aspect and it should be part of discussions in the future.

(notes by Roshan Mammen Abraham)

Friday October 1st

Tau neutrinos and BSM

Tau neutrinos and BSM

By Carlos Arguelles

Tau nu and what lies beyond....
Outline
1) Odyssey of HNL searches
2) 3,4, or more nus
3) Search for misbehaving nus (skipped due to time limitations)

1) Odyssey of HNL searches
m4 vs V_tau,4 mixing plane...constraints from NOMAD , CHARM, DELPHI cover a large region. Tau mixing least constrained.

300MeV < M < 3 GeV -> Triangle of opportunity, vanishing constraints
Use atmospheric nus, high intensity tau nus from atmospheric nus oscillating, allows for production of HNLs.

Nu_tau, HNL, Z vertex is the production vertex. HNL then decays after some distance-> low energy double bang events, signature also produced via TMM.

IceCube (deep core only) proposed constraints sort of can fill this triangle of opportunity. Assumed small backgrounds as there is no SM process with similar signature.

Not unique to above experiment, also for DUNE, SuperK, HyperK (slide 8), complementarity between anthropogenic and natural nu sources to cover this triangle. Only considering double bang signatures. But can also look at HNL decaying in another dedicated decay volume, but more backgrounds here.

What about backgrounds?

Signature in IceCube: Slide 10, double bang event simulation at IceCube
NC interactions that produces HNL and decay of HNL later causes energy deposition into detector. Decay length ~ 200m

Slide 11: True dist vs Best fit distance between the two bangs. 25% correlation.
Also energy reconstruction, E_true vs Best fit E, 17% correlation
Black line is the median

Sometimes second bang is on periphery of detector, so second loss is not reconstructed properly, and hence the black line flattens.
Signal vs bgrnd: using classifier n/w.
S/sqrt(B)~ 1e-6 at BDT=-0.2 for mixing = 1e-1

Slide 13: signal strength vs HNL mass: improves at higher masses (~ 3e-1 GeV)
IceCube upgrades: 10X efficiency

ArgoNeuT constraints at Fermilab: slide 16

Slide 18: Why does charm constraints stop abruptly? First bump from Ds-> tau N, second bump is unphysical. This is corrected for in slide 19, this mostly rules out the triangle of opportunity.

2) 3,4, or more nus
Searches for non unitarity in short baseline experiments. HNL produces not via oscillatins but kinematically
Tau constrained weakly. Need to study tau row more.
But if tau appearance from atm nus measurements are included then can improve the result considerably.

How can IcecCube tau appearance test unitarity?
Difficult to distinguish from low energy e nus.
But can use the following to help
energy distribution of cascades produced by taus are shifted to lower energies, XS is known for both processes, tau induced event rate affected by XS thresholds

Q&A:
Q: (Peter Denton Slide 11) can we cut out bad region in top left? will this improve the reconstructed median?
A: Being looked into. Single bang vs double bang is being looked into with a classifier n/w.

Q: (Ahmed Ismail): Can a global cut on the energy dumped into the detector be imposed?
A: We know the other params so we look only at DB like events using energy reconstruction.

BSM searches with Atmospheric Tau-neutrinos

By Sanjib Agarwalla

Physics with atmospheric tau nus at ICAL-INO
Focusing on multi-GeV energies. Detection of atmospheric nus at this energy range is a challenge due to low flux and detector constraints. Statistics is a serious bottleneck, also the small size of detectors.

ICAL-INO: iron calorimeter detector by INO collaboration

Nu_tau CC XS falls at low energies due to phase space suppression. This is the first bottle neck. But as E increases XS increases, but flux decreases sharply.
Normal 3 flavor oscillations decrease at large energies, but now NP effects improve in significance.
So before BSM we should think about the standard 3 flavor paradigm, particularly nutau – numu oscillations.

Tau lepton decay:
Leptonic mode ~ 35% (17.5 via e, 17.8 via mu)
Lots of muons are already in the detector with large XS, so muon from tau leptons needs higher exposure to stand out, also very good energy and direction resolution in detectors. Challenging
Hadronic modes: 65% (within this, 77% - 1 prong , 23% - 3 prong channel)
Hadronic showers deposit energy in the iron calorimeter. Can be calibrated by counting the number of hits.

50KT magnetized iron calorimeter. 3 modules: each module has a 5.6cm iron plate (target), with a 4cm air gap in between where the active element, glass resistive plates, go. Cannot detect electrons due to the size of Iron plates. But muon can be detected.
Upward vs downward hadrons can be distinguished, we expect more tau leptons going upwards due to more path length for oscillations.
Charge distinction for leptons possible with statistics.

Basics of nutatu Detection at ICAL-INO
plot1: flux vs energy, sharply decreasing with energy
Plot2: XS, increases with e
Plot3: flux X XS: peaks at ~< 10GeV for L-8000km, and std. Oscilations params give the dashed black curve.

Hadronic channel:
CC
nutau + N => tau + X(hadrons), tau-> sum_i H_i + nuta
Counting the hits can give the energy deposited
NC
Nualpha + N -> nualphs + X

Can we see excess tau over this NC background?

Simulation details:

NUANCE event generator with Honda-3D flux
PREM profile for earth
Reconstruction eff taken from same collaboration.
Efficiency improves with energy and direction; > 90% if energy>2GeV.
Directional eff: up vs down classification (2 bins) ~ 80% for vertical events, ~0 for near horizontal events.

Energy resolution~ 40-60% in 2-4GeV ENERGY range, >60% at higher energies
Most of the events are up-going.
Considering all the systematics with E_cut of 3GeV to remove soft muons can get Delta Chi2 = 14.6

NSI params:
Nu_mu -> nutau via the NSI eps_mutau.

Contributes to P(numu-> nutau)
Eps_mutau comes in linearly, so sign can be distinguished. Not for eps_mumu – eps_tautau

Tau induced muon events vs eps_mutau: different for mu, mubar. Needs sufficient stats.

Eps_mutau prospects are better for this channel.

Before looking at BSM we need more than 5 sigma in the SM tau events. Need to improve reconstruction, long exposure, and better detector resolution.

Tau event direct probes of theta_23, osc. params, helpful in mass ordering.

Q&A:
Q: (Peter Denton) Can you briefly comment on status of INO.
A: R&D for the magnetized detector is over. Project fully funded. Mini ICAL already running, cant see nutau events but can see bending of cosmic ray events, students working on this. Next goal is an engineering model ~ 700Ton, and then the full scale detector.
Physics is ready, pending some approval from state government etc.

High-energy and ultra-high-energy tau neutrinos and BSM

By Mauricio Bustamante

CR nus have high energies, and travel cosmological distances, so tiny effects can accumulate.
At the highest energies (>10^15 eV) new experiments are planned.
HE (TeV-PeV): detected
UHE (> 100PeV): predicted but not detected, testable next decade

NP grow as ~ kn * E^n * L

4 HE nus observables: energy, arrival direction, arrival times, flavor composition
Can test XS, nu self interactions etc.

Cartoon of nu production in universe at different energies and arriving at earth.

Cartoon showing circle of opportunity with 4 “corners” being the observables, and within the circle various physics scenarios that can be tested.

Today Tev-Pev
Data driven tests for BSM predictions.
Needs bigger detectors, better reconstruction, etc.

Next decade > 100PeV
Make predictions.
Need new detection techniques, better UHE nu flux prediction.
Need to make these robust in the white paper.

What is unique about BSM with HE and UHE nutau?
From experimental side: makes up 1/3rd of the flux

From theory.
Tau sector least constrained, test 3 flavor oscillation paradigm, flavor universality in nu-N interactions upto sqrt(100 TeV).

What BSM can we focus on?
1) Flavor stuff
2) XS
3) energy spectrum

1) Flavor: Towards precision.
Nu telescope, flavor measurements will become better with more events.
New oscillation experiments will better measure oscillation parameters.
Test non-unitarity

One liekly Tev-Pev nu production scenario:
P + gamma => pi plus -> mu plus + numu
Mu plus -> e plus nue numubar

Triangle (fraction of nu_alpha forming each side of triangle)

Measuring flavor composition:
Larger detectors coming up

Ice Cube constraints on the triangle in slide 19

Prediction of flavor composition at detectors require some flavor composition at source, and oscillation parameters.

Use NuFit golbal fit to constrain oscillation parameters.
Better mixing params can constrain the flavor composition triangle better.
Slide 25: triangle in 2020 , 2030, 2040 (precision measurements start)
Repurpose flavor sensitivity to test NP.

Nu-N XS: not measured > 10PeV
GRAND and POEMMA can measure to 20% at 10^9 GeV
IceCube gen2: needs good flux measurements, propagate to earth, and detector response.
The contribution of nutau is significant. So from this infer the nu-N XS, then we have some measurements of XS at > 10^7 GeV in 2040 to within few times theory uncertainty.

Food for thought:
1) UHE BSM nu program is under developed. Act now to inform the design ad funding of detector currently planned.

Q&A:

Q: (Ahmed Ismail) Do the future detector have any prospect on distinguishing nus and anit-nus?
A: In principle, the inelasticity distribution could be used but thats mostly at low energies. So difficult. Maybe via Glashow resonance, but this is a low energies.

Q: (Samjib Agarwalla) At DUNE without magnets but with inelasticity distribution, nu and nubar maybe can be distinguished but with good stats. Also at SuperK via michelle electron this has demonstrated.

Q (Juliane Stachurska): what assumption on flux, uncertainties etc.
A: We took the IceCube gen2 projection form white paper, assumes sensitivity to flavor is similar but scales up/dwn for other detectors.

Comment from audience: Maybe focus on systematic also for the white paper, the white paper assumes it's under control now.

Q(Jason Koskien): Use of full waveforms important at lower enegies. How much are you dependent on scaling for different detectors.

A: …..Needs to be looked into in the white paper.

Q (Peter Denton): On the XS, one thought is since there is a dramatic shift in XS at higher energies, may be of interest.

Q(John Krizmanic): E thresholds at TAMBO ?
A: Sees nutau at IceCube like energies. Not sure abt thresholds but ~ 1TeV.

Comment from John Krizmanic: At that energy num,u starts to dominate. Its interesting that this may give you a nutau type distinguishing factor.

Discussion:
Transcript from the chat box.

Yasaman Farzan: If the HNL is highly boosted, it seems to me that there should be destructive interference between Cherenkov emissions from its charged decay products. The sum of their charges is zero and they move almost in the same direction because of the high boost. It may look like propagation of a neutral particle with no Cherenkov emission. Is my naive intuition missing something? (In the case of HNL discussed by Carlos, probably the boost is too small for such destructive interference).

Carlos Arguelles Delgado: That's is an interesting point Yasaman. I don't think that cancellation happens at these energie, things are not so collinear

Dawn Williams: The TAMBO threshold is meant to be around 1 PeV

enrique zas: I think the TAMBO target for threshold is at about 1 PeV, with good overlap with IceCube

Carlos Arguelles Delgado: @John: see Dawn William's talk where the TAMBO effective area is given, that partiall answers your threshold

Austin Cummings: Her eis the paper John is talking about regarding muons being important: https://arxiv.org/abs/2011.09869

Carlos Arguelles Delgado: See https://arxiv.org/abs/2002.06475

Austin Cummings: One other important thing to note is that muon events are important for optical telescopes because they can begin their showers above atmospheric extinction. This may not be important for TAMBO.

Mauricio Bustamante: Thanks, Austin!
I believe Andrés looked at muon events and, like Dawn said, they should be 1 for every 20 nu_tau or so. Still, those were preliminary studies, and we will need to revisit that to get final numbers.

Stephanie Wissel: yeah. I don’t think Andres used NuMuonSim, so it might be worth revisiting, but I suspect that the geometry suppresses this

Mauricio Bustamante: Agreed

Tau neutrinos in astrophysics

Prompt atmospheric tau neutrino flux

By Yu Seon Jeong (CERN)

The prompt atmospheric tau neutrinos are only directly produced neutrinos from natural sources. The prompt atmospheric tau neutrinos can be important for the study of interaction and oscillation with

atmospheric and possibly astrophysical neutrinos at TeV energy range.

What are the main components for evaluating the prompt neutrino flux and its theoretical uncertainties?.

Prompt component of atmospheric neutrinos, which are from the heavy flavor hadron decays, focusing on tau neutrinos. For the energy above ~10 TeV, the flux of prompt atmospheric tau neutrinos dominates over the conventional tau neutrino flux, produced from the oscillation of conventional muon neutrinos, and at lower energies, it can be a background to the conventional tau neutrino flux. Unlike the conventional neutrinos, the prompt neutrino flux has large uncertainty.

Prompt tau neutrinos can play a role in the measure of a cross-section and therefore test lepton universality.
The evaluation of the prompt tau neutrinos relies on cosmic ray spectrum, Heavy quark production cross-section in pA collision, fragmentation functions of heavy quark to hadrons, decay rate and distribution, and atmosphere density (particle propagation in the atmosphere).

Theoretical uncertainty for the flux of prompt neutrinos is large and depends on many factors. The most prominent uncertainty for tau neutrinos is from the heavy quark production cross sections by QCD.

Q (Ivan J. Martinez): does the magnetic field has some impact on meson production and therefore into the prompt neutrino?
A: mesons decay very fast, so, no.
Sanjib Kumar: not soft pions would be affected by the magnetic field and therefore the flux
Yu Seon Jong:

Contributed talks II
nutau-nucleon/nucleus deep inelastic scattering in the multi-GeV energy region

By VANIYA ANSARI (ALIGARH MUSLIM UNIVERSITY)

An overview of the results for a study of some perturbative and nonperturbative effects on the evaluation of the nutau(nutaubar)-nucleon scattering cross-sections. The free nucleon structure functions have been obtained by using the evolution of parton distribution functions at the next-to leading order and taking the effects of kinematical and dynamical higher twists. These free nucleon structure functions are then convoluted with the nucleon spectral function in the nucleus to obtain the nuclear structure functions F_{iA} (x, Q^2); (i=1-5), by taking into account Fermi motion, binding energy, and nucleon correlations. We also include the contribution of pi and rho mesons and the corrections due to shadowing and obtain the results for F_{iA} (x, Q^2); (i=1-5) and the cross-sections. This is the first theoretical study, which includes nuclear medium effects in the evaluation of nutau(nutaubar)-nucleus differential and total scattering cross-sections

On the Tau flavor of the cosmic neutrino flux

By Yasaman Farzan (IPM)

Generalities on the different sources, flavor compositions, and detection are discussed. In specific the detection of Ultra-high energy cosmic neutrinos (tau events) by ICECUBE constrains the interaction of the neutrinos with ultralight dark matter and discusses the implications of this interaction for even higher energy cosmic neutrinos detectable by future radio telescopes such as ARA, ARIANNA and GRAND. We also revisit the 3+1 neutrino scheme and clarify a misconception about the evolution of high energy neutrinos in the matter within the 3+1 scheme with a possibility of scattering off nuclei.

RESULT: Rho DM(outside halo)~ 10^-5 ~Rho DM(inside halo)

Q: The ANITA acceptance is ~ 2 x 10 ^9 cm^2, is this a variable result, or its a test result?

A: This is for electron and muon neutrinos, for tau neutrinos probably is higher.

Q(Oleksandr Tomalak) : you talk about generate neutrinos from stop muons, could you clarify from where they go?
A: basically is because an energetic pion decays and produces an energetic muon neutrino and muon and then the muon gets stuck and eventually it decays in much less energy, below the threshold of the telescopes.

(notes by Mahdi Bagheri)

KM3NeT/ORCA sensitivity to atmospheric tau-neutrino appearance

Speaker: Steffen Hallmann (DESY)

Appearance of neutrino and anti-neutrino
Neutrino detection in oscillation band, using 6 out of 115 detectors

First oscillation measurement: muon neutrino disappearance mode
Event signatures: looking for shower-like event happening at higher energies

Tau neutrino CC interactions: 2 important things to consider: tau mass and tau decay
Event classification: using Random Decision Forest – 3 event classes for analysis: shower, intermediate and track
Sensitivity of ORCA to tau neutrino appearance: Possible reasons for the normalization not equal to 1
Notable difference between tau neutrino and other neutrinos (table)

Significance evaluation: Scaling CC-only or CC+NC contribution
Sensitivity of OCRA for 1-year and 3-yar: constraints at 3sigmal -> 30%after 1year and 20% after 3-year

ORCA is optimized in few-GeV energy with 3k events per year, tau neutrino events appear shower-like

Q/A:
Nepomuk: some difference between neutrino and antineutrino classification using random forest:
Yes. Antineutrino wider average energy distribution

The Giant Radio Array for Neutrino Detection - the experimental status and plans

Speaker: Lech W Piotrowski (University of Warsaw)

Idea behind the grant : find the source of UHECR, find a clear angle where they are coming from
Vertical shower : footprint is different from horizontal showers -> radio antennas better on the ground -> cheap, robust and ideal for giant array -- 200k antennas over 200,000 km^2

Europe is empty due to requirements for quiet areas, topography -> mountains
Simulated Performance of GRADND -> full sensitivity to neutrino (E->10^17 eV) -> 4x10^-10

GRANDProto300-> pathfinder searching for inclined cosmic rays at 10^16.5 to 10^18 eV (no neutrino detection is expected, mostly for test bench)

Hardware of grandproto300: Horizon antenna is fully tested in 2018 -- layout will be different from grand200k for better optimization

Data format --> not HDF5 anymore , musing ROOT TTress
For simulation: ZHAires for big studies, CORSIKA for up-going air showers, Radio-morphing and MGMR3D

Timeline: 100 antennas are ready, mechanics and electronics are ready for deployment -> first data for GRAND expected by the od the year hopefully

GRANDProto300 ->2021, GRAND10K->2025 and GRAND200K-> ???
Can not pin point a specific source due to unphased instrument

Q/A:

Nepomuk: slide 8 – muon problem: what is meant by that
Lech: for very inclined shower muon content is negligible

Prospects for EeV tau-neutrino physics with in-ice radio detectors

Speaker: Christian Glaser (Uppsala University, Sweden)

Prospects for EeV tau neutrinos
Shower produces radio signal due to Askaryan effect
Current experimental landscape: ARIANNA, ARA (now), RNO-G and IceCube-Geb2 (future)

Comparison of the Sensitivity of radio detectors -> how many tau neutrino can we measure -> not possible to say due to uncertainty

Review of Neutrino interactions at EeV energies (NC and CC)
This talk is focused on CC mu, tau : displaced showers from loss and decay

Tau decay length in order of several kilometers above 10^17 eV
Simulated tau propagation using PROPOSAL and integrated into NuRadioMC only for > 1PeV -> several interaction channels

At different energy channels different interactions are dominant -- the higher the energy , the better chance of detection

Energy losses of high energy muon -> many low energy showers might interfere constructively
Tau neutrino effective volume: at low energies tau decay channel dominates
at high energies-> many first and secondary interaction detected at the same time

Signatures of golden events: clear signature of muon of tau cc interactions

Summary: radio emission from secondary lepton included into NuRadioMC
Taus and muons generated produce visible radio signals, provide flavor sensitivity

Q/A:
Nepomuk: what is the resolving power between interaction
A clear signatures is how close they are and how well we can resolve the vertex – by 20% resolution
Nepomuk -- Resolving power is dependent on the station density ??? And signal to noise ratio

POEMMA: Probe Of Extreme Multi-Messenger Astrophysics

Speaker: John F Krizmanic (UMBC/CRESST/NASA/GSFC)

POEMMA: UHECR for E>20 EeV
ToO neutrinos with E> 20 PeV

Scientific and experimental motivation: paper-> https://iopscience.iop.org/article/10.1088/1475-7516/2021/06/007/meta

Based on the OWL 2002, then EUSO, EUSO-SPB1 and …

We need good spectral measurement and full sky distribution
Primary: discover origin of UHECR and Observe neutrinos from transient and astrophysical events at energies above 20 PeV – secondary ->???

POEMMA acceptance compared to other instruments both at nadir and limb
Optical performance -> 45 degree overall FOV -- with 3mm pixels at 0.084 degree

Will use both Fluorescence and Cherenkov technique
Pointing resolution 0.1 degree with 8 mins slew rate for 90 degree

Two operation modes:
Stereo mode: for observing fluorescence light from UHECR and neutrinos
Limb mode: observe Cherenkov from cosmic neutrinos just below the limb of the Earth and fluorescence from UHECRs throughout the volume
We can bring the threshold by pointing both instruments at the Cherenkov cone

Significance exposure with all sky coverage
Very good angular and energy resolution -> composition
Uniform sky coverage to make sure the discovery of UHECR sources

For neutrinos-> excellent angular resolution – determining the slant depth of EAS starting point
Sensitivity is energy robust
Charged current -> 100% of energy will be seen in electron neutrino, 20% for muon and 20-40% for tau

Energy of tau lepton is used to determine the Cherenkov light distribution
Sensitivity of TiO neutrino : short bursts and long bursts
Number of neutrino events for differet configurations

Looking for the source of Cherenkov signal
Tau-lepton induced upward going air showers
Simulation architecture -> SpeceSim

Summary-> we are confident PEOMMA has a great performance for UHECR and neutrino

(Yuchieh start taking notes)

Axial and pseudoscalar form factor with tau neutrinos

Speaker: Oleksandr Tomalak (Los Alamos National Laboratory)

HyperK DUNE, ~GeV nu

Scattering on free nucleon. Axial and pseudoscalar form factors are important for calculation of cross section

Only few experiments directly measure the form factors (through deuterium bubble chamber), can be largely improved.

Slide 8 shows how tau_nu cross section is sensitive to the form factors.

Polarization observables is a way to access axial structure: Asymmetry.

Several observables:

Target transverse asymmetry: sensitive to pseudoscalar form factor.

Target longitudinal asymmetry: sensitive to both from factors.

Recoil transverse asymmetry: sensitive to pseudo form factor.

Recoil longitudinal asymmetry: sensitive to both

Lepton transverse/longitudinal asymmetry: sensitive to axial form factor.

Summary: asymmetry is a good way to probe nucleon structure, axial and pseudoscalar form factors.

Q/A:

John: how does the uncertainty (?) for the cross section from (one of the) previous talk fall in the oscillation experiment?

A: Can input the uncertainty to the model through formula in slide 2.

Looking for HNLs via Double Bang signals

Speaker: Ivan Martinez-Soler (Fermilab and Northwestern University)

SM neutrinos, massless, no RH , SM can be considered as low E effective model

Type-I Seesaw mechanism:
Right handed neutrinos,
Allow L number violation

Heavy sterile nu, flavor state is written as superposition of massive states.
Connection to experiments:
Nu_tau by atmosphere sources, MeV-PeV
DUNE (good event topology reconstruction)& IceCube (higher energy), GeV-PeV, cascade & tracks
Double bang signals can be used to search HNLs in DUNE and Icecube.

heavy nu travel long distance , decay length deps on M4& U_tau4.
Icecube, large volume, allow large decay length.

Other BSM can be explored through double bang: ex. transition magnetic moment. signals majorly from DIS.
Summary: Double bang events can probe BSM theory: 1 HNL via NC interaction 2. Transition magnetic moment.

Q/A:
Tom: what exactly the channel that produces double bang events.
A: Referring to the diagram on slide 7, similar to DIS to nuclei.
John: Can this (hadronic process) be produced in collider (???)
A: yes.

Tau neutrino propagation with NuPropEarth

Speaker: Alfonso Garcia (Harvard University)

Model for High energy tau neutrino propagation.
Physical process is the same for all experiments. Models can be applied to different experiments.
The procedure of modeling:
1.Nu flux before entering the Earth 2. Propagation through the earth. Oscillation/interaction, etc. 3. detection side.

Through the earth: medium, cross section , energy loss, tau decay
Medium: Interaction depends on Energy. For PeV nu, local feature are not relevant. EeV->Earth skimming, mountain/valley modeling is important.

Cross section: DIS CC/NC(E>PeV) , coherent/trident scattering,
Nuclear effect haven't been modeled properly in this model-> high Energy inconsistency in slide 6 figure.
Energy loss: Ein, Eout comparison after a 10 km ice.
Tau decay: high E, RH tau. Pythia 6 doesn't consider polarization of tau.
Comparison btw framework: Tau exit probability: nuproEarth/NutauSim: very consistent
Nu absorption and secondary yield.-> relevant to nu telescope. Consistent btw frame work

Summary: Table comparison btw framework on the market. Frameworks are not redundant, important to compare between them.
Q/A:
Pete: table in slide 11 should be in white paper.
Ivan Estaban: Slide 6: Cross section contribution. E~ 10^4 coherent dominant?
A: IT the ratio, so it's ~2%'
Tom: tau polarization, what's the energy of tau?
A: for high E, RH , low Energy, not 100% RH. Need further investigation.

Goulart Peres: Cross section in slide 6. what is Coherent?
A: nu interact with photon field of nuclei.
Peter: comments on the threshold of this process.

Probing Secret Interactions of Tau Neutrinos in the High-Statistics Era

Ivan Esteban (CCAPP, Ohio State University)

Motivation: Do nu have Sizable self-interaction? Lint ~ -g v_bar v φ
Constraint for nuSI almost doesn't exist for tau nu. (constraint exists for other flavor nutrinos.)
Motivation: Shed light to nu mass origin. NuSI can make nu tighlty-coupled fluid. Cosmology aspects, may affect how we infer cosmological parameters.
MInu solution
In nu_tau sector: For M_phi~1-MEV E_nu ~ 10^5 GeV->Icecuve detection range
Signature: a dip on E_nu spectrum
In both Nu mass ordering: close double dips signature. but spectrum is a bit different.

Nu spectrum: look for all flavor, double dips.
Current Icecube data doesn't provide enough statistics to constraint this interaction.
Icecube gen2 can test this theory by looking at the Nu spectrum.

Summary: Tau nuSI can affect our understanding to the early universe, can be tested by Icecube gen2 through nu spectrum.

Q/A:
Goulart Peres: ??? Plots of constraints for different flavors. … Fermi constant???

A: ???nunu scattering calculation, resonance contribution???

John: does this include radio part of Icecube-Gen2
A: not yet. can probe larger param space if included. ~10 PeV Energy range.

Tom& Ivan Esteban: Discuss the inconsistency between plots.