Physics Opportunities in the Near DUNE Detector hall (POND^2) Review

Peter B. Denton

BNL's HET Lunch Seminar

December 14, 2018

Discussion Outline

- What is the DUNE Near Detector?
- What does the ND need to do?
- What kind of physics can it probe?

Lots of discussion!

http://indico.fnal.gov/e/PONDD2018

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- What kind of physics can it probe?

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"Not building the near detector correctly is like buying a Lamborghini and instead of putting high octane fuel in, putting in diesel." - Stephen Parke

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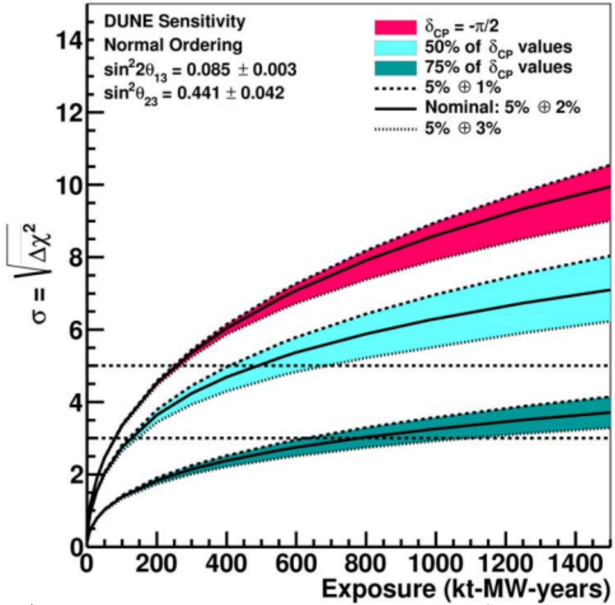
Near Detector Physics Program

1. **Aid DUNE FD in measuring δ_{CP}**
   - θ_{23} octant
   - Mass ordering
   - BSM oscillation physics
2. Measure beam properties
3. Measure ν-Ar cross sections
4. DM? MiniBooNE's anomaly? New physics? Other things?

CPV Sensitivity

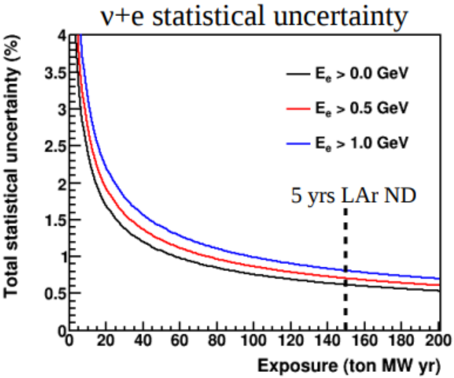


A. Bross

Direct flux measurement: ν+e elastic scattering

- Pure EW process with known* cross section:

$$\frac{d\sigma(\nu_\mu e^- \to \nu_\mu e^-)}{dy} = \frac{G_F^2 m_e E_\nu}{2\pi}\left[\left(\frac{1}{2}-\sin^2\theta_W\right)^2 + \sin^4\theta_W (1-y)^2\right]$$



- Even with conservative reconstruction assumptions, DUNE LAr ND can select over 3,000 ν+e events per year at initial intensity
- <1% statistical uncertainty
- Very powerful *in situ* constraint on absolute flux normalization

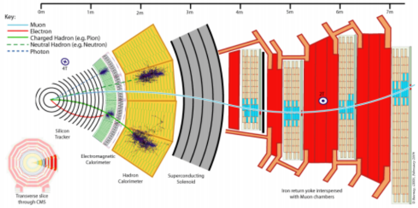
C. Marshall

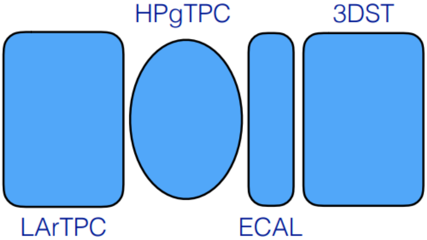
ND design timeline

- LBNE era: Reference ND conceptual design (fine-grained tracker)
- 2016-2017: Near Detector Task Force to study FGT, LAr near detector, high-pressure gas TPC
- 2017-2018: Near Detector Concept study
- August 2018: concept study recommendations accepted
- 2018-present: Near Detector Design Group
- Spring 2019: Conceptual design report
- 2020: Technical design report

C. Marshall

Multi-purpose detector design, akin to CMS

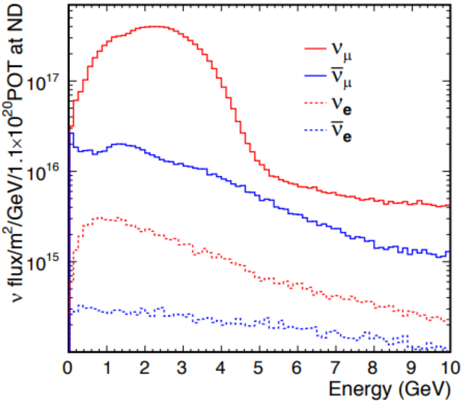




R. Harnik

$\sim$ 75t fiducial LAr ND

Optimized CPV tune

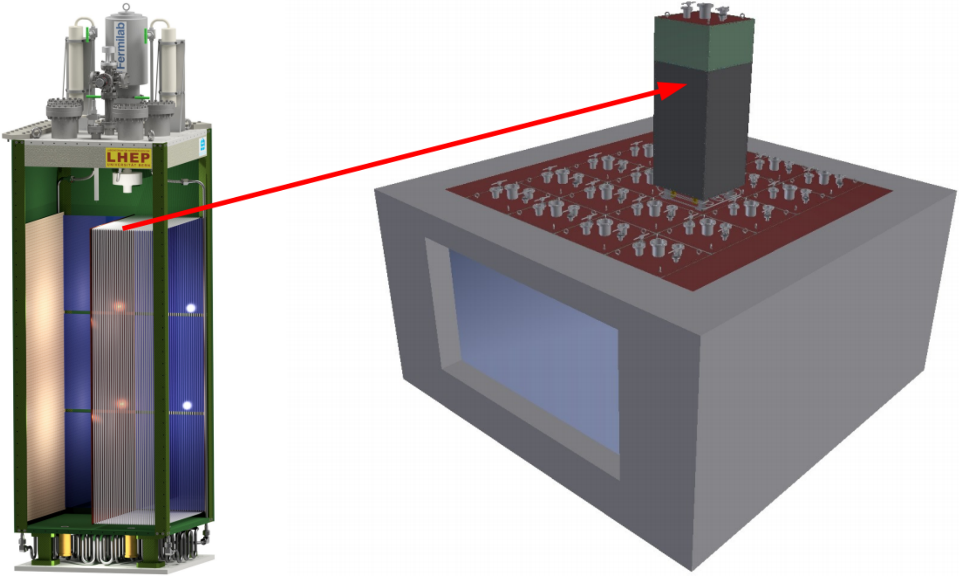


FHC, Events/ton_Ar-year

Event class	Number of events per ton-year
ν_μ CC Total	1.64×10^6
ν_μ NC Total	5.17×10^5
ν_μ CC Coherent	8.35×10^3
ν_μ NC Coherent	4.8×10^3
ν_μ - electron elastic	135
ν_μ CC π^0 inclusive	4.47×10^5
ν_μ NC π^0 inclusive	1.96×10^5
ν_μ Low ν (250 MeV)	2.16×10^5
ν_μ Low ν (100 MeV)	7.93×10^4
$\bar{\nu}_\mu$ CC Coherent ($\bar{\nu}$ mode)	6.90×10^3
ν_e CC Total	1.89×10^4
ν_e NC Total	5.98×10^3
ν_e CC Coherent	93
ν_e NC Coherent	52

A. Bross

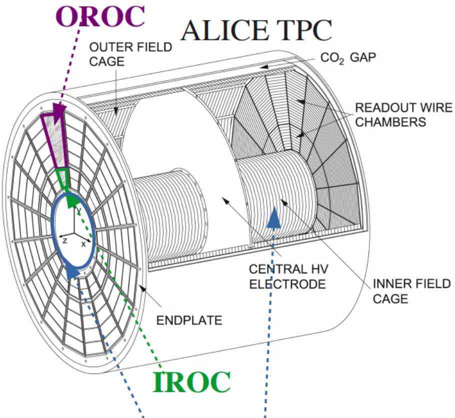
LAr: 3m (tall) x 5m (beam) x 4(7?)m (wide)



J. Sinclair

High Pressure gas Time Projection Chamber (HPgTPC): Properties

1. High pressure gaseous Ar
    - Possibly others, maybe H^2?
2. Clear PID: μ, π, e, K, p, D, ...
3. Magnetic field
4. Charge identification
5. Surrounded by ECAL, μ tagger
6. Hardware is from ALICE
7. Prototype exists at FNAL: Gaseous-Argon Operation of the ALICE TPC



Not provided by ALICE: **central readout chambers** (do not exist in ALICE), **field cages,** front-end electronics

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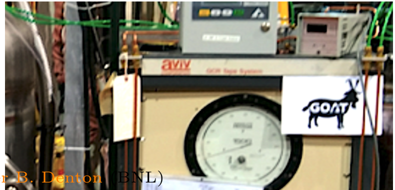

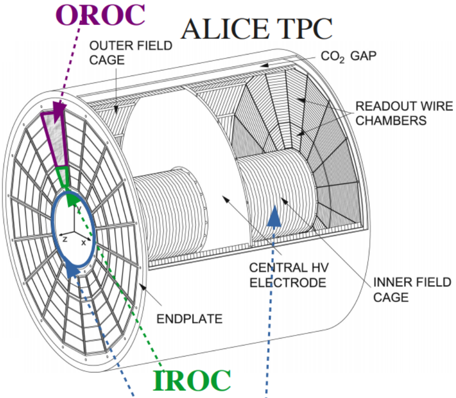

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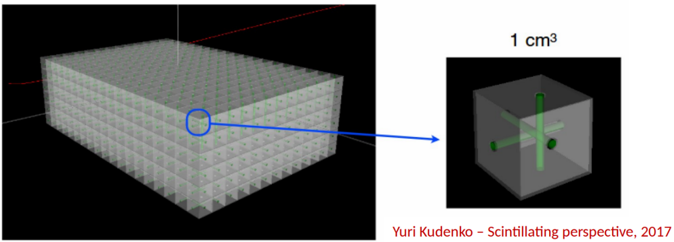
3DST

What it is

- 3D Scintillator Tracker
- Connect with other scintillators (**T2K**, NOvA, MINERvA, ...)
- Charge identification (B-field)
- External tracking and ECAL

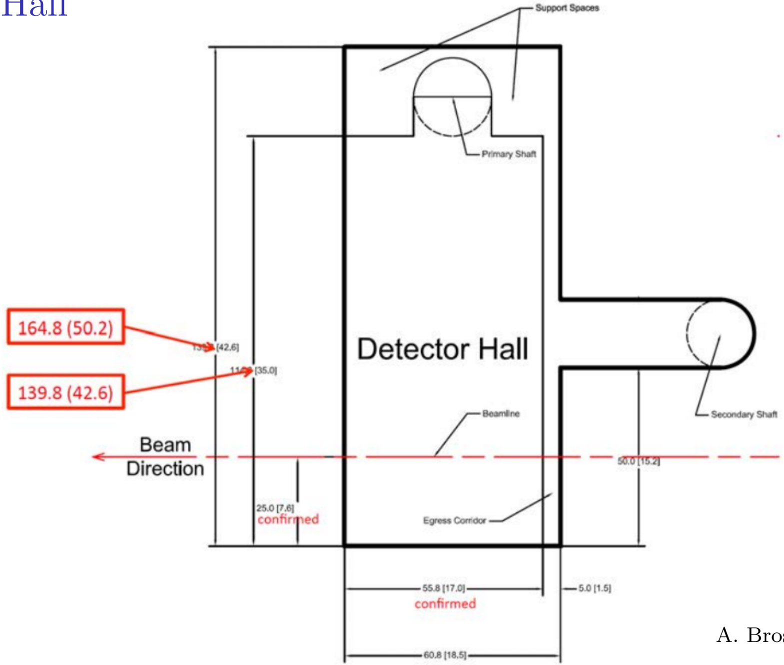
What it is good for

- Multi-nucleon interactions
- 4π angular coverage
- Neutrons
- ν-e^- scattering



C. McGrew

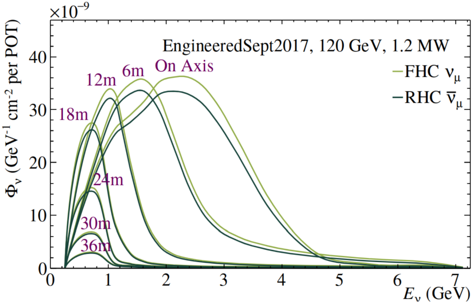
ND Hall



A. Bross

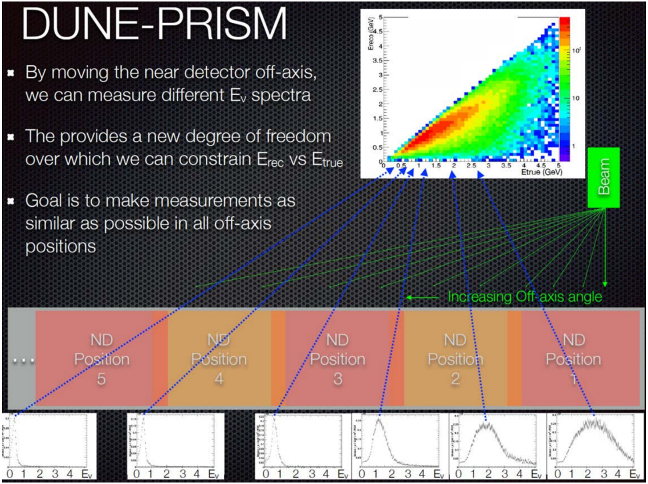
DUNE PRISM

Move the LAr detector horizontally on rails



C. Vilela

DUNE PRISM



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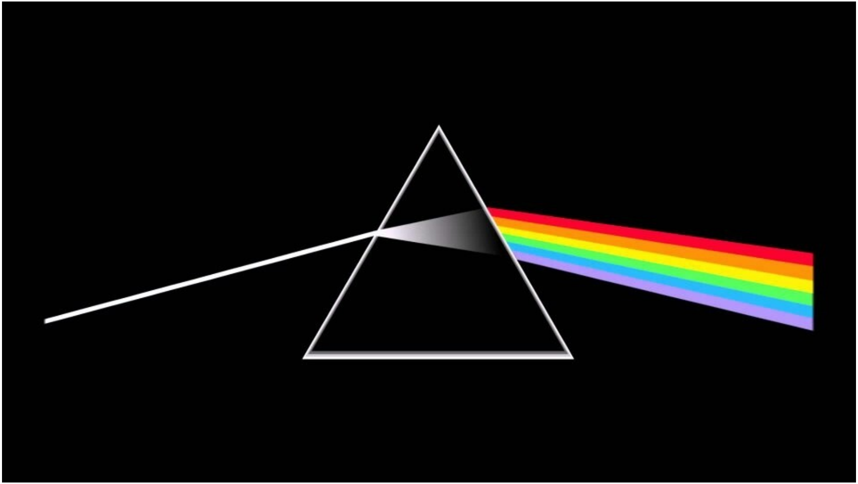
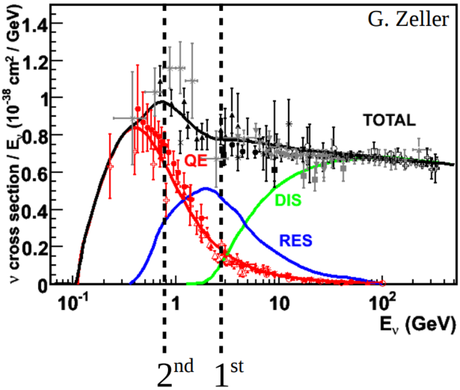
DUNE PRISM



Cross sections:
2.5 GeV is a challenging energy



DUNE oscillation peaks where 0π, 1π, DIS reactions are all relevant!

- Due to oscillations, the fluxes are different at ND and FD
- Sensitive to different mix of neutrino cross sections
- Different reactions give different relationship between E_ν and detector observable, $E_\nu \to E_{rec}$

C. Marshall

Cross section modeling is complicated: possible degeneracies

MaCCQE
VecFFCCQEshape
MaNCEL
EtaNCEL
MaCCRES
MvCCRES
MaNCRES
MvNCRES
RDecBR1gamma
RDecBR1eta
Theta_Delta2Npi
AhtBY
BhtBY
CV1uBY
CV2uBY
FormZone
MFP_pi
FrCEx_pi
FrElas_pi
FrInel_pi
FrAbs_pi
FrPiProd_pi
MFP_N
FrCEx_N
FrElas_N
FrInel_N
FrAbs_N
FrPiProd_N
CCQEPauliSupViaKF
Mnv2p2hGaussEnhancement
MKSPP_ReWeight
E2p2h_A_nu
E2p2h_B_nu
E2p2h_A_nubar
E2p2h_B_nubar

NR_nu_n_CC_2Pi
NR_nu_n_CC_3Pi
NR_nu_p_CC_2Pi
NR_nu_p_CC_3Pi
NR_nu_np_CC_1Pi
NR_nu_n_NC_1Pi
NR_nu_n_NC_2Pi
NR_nu_n_NC_3Pi
NR_nu_p_NC_1Pi
NR_nu_p_NC_2Pi
NR_nu_p_NC_3Pi
NR_nubar_n_CC_1Pi
NR_nubar_n_CC_2Pi
NR_nubar_n_CC_3Pi
NR_nubar_p_CC_1Pi
NR_nubar_p_CC_2Pi
NR_nubar_p_CC_3Pi
NR_nubar_n_NC_1Pi
NR_nubar_n_NC_2Pi
NR_nubar_n_NC_3Pi
NR_nubar_p_NC_1Pi
NR_nubar_p_NC_2Pi
NR_nubar_p_NC_3Pi
BeRPA_A
BeRPA_B
BeRPA_D
BeRPA_E
C12ToAr40_2p2hScaling_nu
C12ToAr40_2p2hScaling_nubar
nuenuebar_xsec_ratio
nuenumu_xsec_ratio
SPPLowQ2Suppression

- At left is an *partial* list of cross section parameters in the current DUNE oscillation analysis
- There are a lot of moving parts
- We may be able to adjust these parameters to fit our ND data, but how do we know we've made the *right* adjustment?

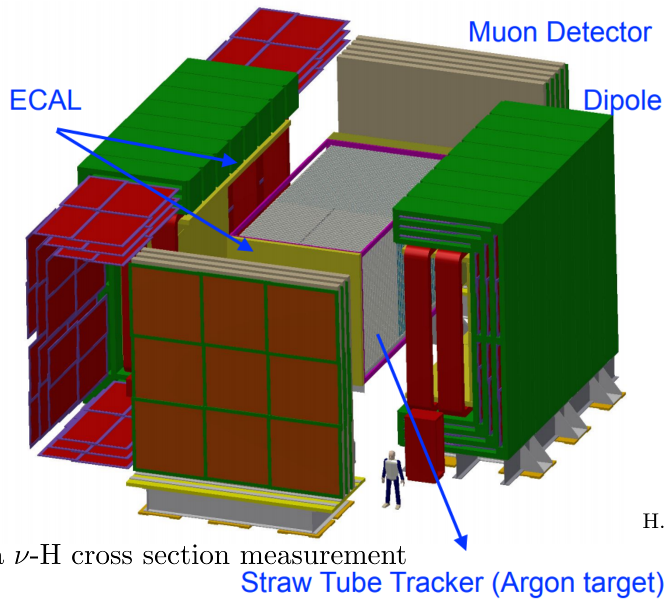
C. Marshall

Generators

- GENIE is widely used at FNAL
  - It is wrong in many ways
  - Knobs and dials that are not internally consistent
- GiBUU is an alternative
  - Less wrong
  - More physics
  - Fewer free parameters

U. Mosel

Other Ideas: Straw Tube Tracker

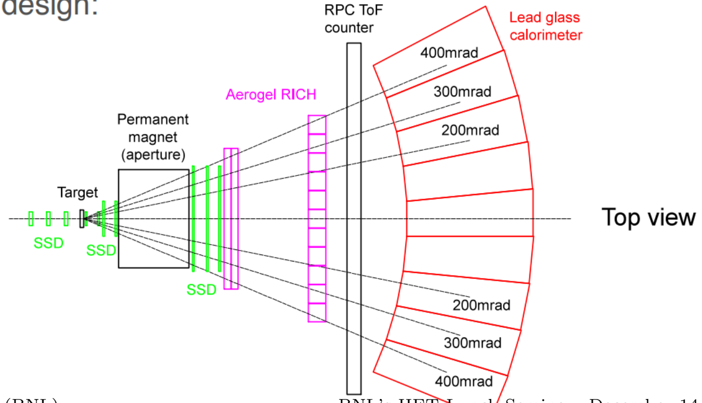


H. Duyang

Get a ν-H cross section measurement

Other Ideas: Flux Measurement: EMPHATIC

- **E**xperiment to **M**easure the **P**roduction of **H**adrons **A**t a **T**est beam **I**n **C**hicagoland
  - Uses the FNAL Test Beam Facility (FTBF), either MTest or MCenter
  - Table-top size experiment, focused on hadron production measureme with $p_{beam} < 15$ GeV/c, but will also measure 120 GeV/c p+C.
- Ultimate design:



New Physics at the Near Detector

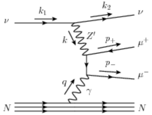
Neutrino Trident

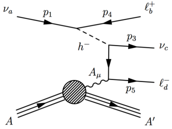
$$\nu + A \to \nu + \ell^+ + \ell^- + A$$

$\mu^+\mu^-$ measured by:

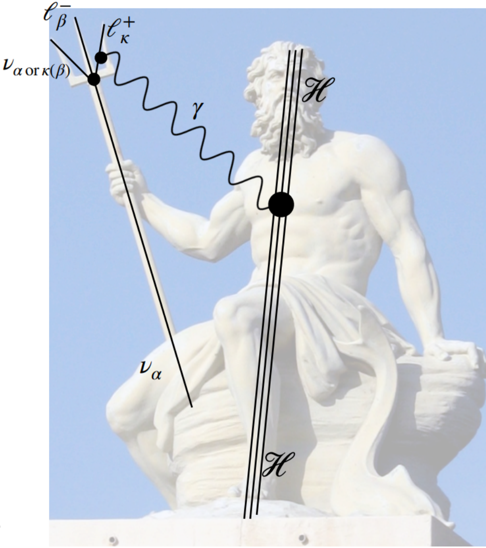
- CHARM II (1.58 ± 0.57)
- CCFR (0.82 ± 0.28)
- NuTeV (0.67 ± 0.27)

Constrains $Z', h^\pm, \ldots$ models:





M. Hostert



Y. Perez-Gonzalez

Trident Rates

Channel	SBND	μBooNE	ICARUS	DUNE ND	νSTORM ND
Total $e^{\pm}\mu^{\mp}$	10	0.7	1	2993 (2307)	191
	1	0.1	0.1	391 (299)	23
Total e^+e^-	6	0.4	0.7	1007 (800)	114
	0.2	0.0	0.02	64 (49)	6
Total $\mu^+\mu^-$	0.4	0.0	0.0	286 (210)	11
	0.3	0.0	0.0	143 (108)	6

Not seen yet ($e^{\pm}\mu^{\mp}$)

Not seen yet (e^+e^-)

Compare order of magnitudes

ν mode

$\bar{\nu}$ mode

NSI with Zero-Distance Effect

- NSIs provide a new matter-like effect
- Generally their effects grow with E and L
- Can be a CC component, affects production, detection
- Can lead to an effect at $L = 0 \Rightarrow$ ND
- In general DUNE FD can constrain many NSI models

B. Dev

Also generalized NSI's with S, P, V, A, T interactions

- Systematics crucial to disentangle new interactions from beam uncertainties

I. Bischer

Some DM Models

- Boosted DM:
  - Solar capture
  - Up scattered towards the Earth
  - Angular information in detector
  - Nuclear effects important

J. Berger

- Lepton Number Charged Scalar (LeNCS) for $B-L$
  - New scalar ϕ with $B-L=+2$
  - Neutrinos are Dirac
  - Leads to: Higgs/Z invisible, meson decays, $0\nu\beta\beta$
  - ND (statistics, charge) is sensitive to $m_\phi \sim 0.5-2$ GeV
  - Can add a DM candidate

J. Berryman

Lots of parameter space probed by the ND,
probably is much more to do!

Milicharged Particles

- Fractional charges allowed
- Even with integer charges can get mCP via 1-loop $\epsilon F_{\mu\nu}F'^{\mu\nu}$
- Production: from meson decays $\rightarrow$ very high rate
- Detection: think dE/dx but much slower $\Rightarrow$ soft hits
- If two soft hits line up, then mCP
- ArgoNeut analysis (with data) en route, DUNE ND next
- Good parameter space sensitivity improvement

Neutrino Theory Network (NTN)

- FNAL got leftover money ($\sim$\$300k) from the DOE
- Has been assigned for neutrino theory
- Initial struggles managing the money
- Awards go for things promoting the US neutrino effort
- Can be spent:
  - To go somewhere for a time $\mathcal{O}$(weeks to months)
  - To host a workshop
  - To pay a grad student for $\mathcal{O}$(months)
- Has been renewed
- Expect two calls per year, next should be in January
- http://ntn.fnal.gov

See also the NPC, IF, URA which provide for to travel to Fermilab
Please ask if you have questions[1]!

[1] Disclaimer: I am not affiliated with the NTN.

Zenodo

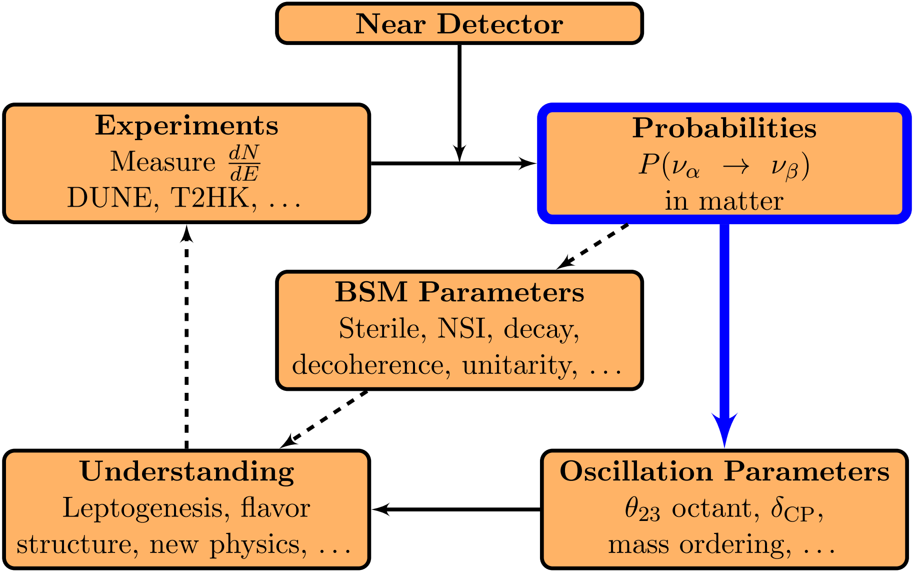
- Conference proceedings:
  - Time inefficient
  - Either aren't read (theory) or not representative of the conference (experiment)
  - Treated (roughly) the same as an article by inspire
- Alternative: upload slides to https://zenodo.org
  - Permanent record of what was discussed
  - Get a DOI so is citable
  - Working with inspire to track them
- This was done from Neutrino 2018 Heidelberg
- This is being done for PONDD
- Talk to Stephen Parke about how to do this for future conferences/workshops

Key Points

- Near detector design is coming along: 3+ detectors and PRISM
- Flux and cross section uncertainties are/will be always concerning
- The ND alone will be an excellent probe of SM and NP, more to do
- Lots of other good talks on:
  - MiniBooNE
  - Global fits
  - LAr backgrounds
  - Solar neutrinos with DUNE
  - HNL and long-lived particles
  - Machine learning
  - Many other topics

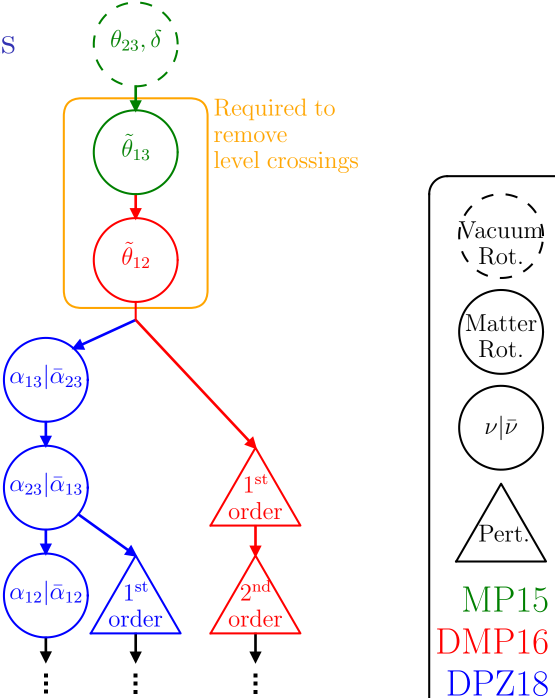
Backups

A Theorist's Long-Baseline Picture



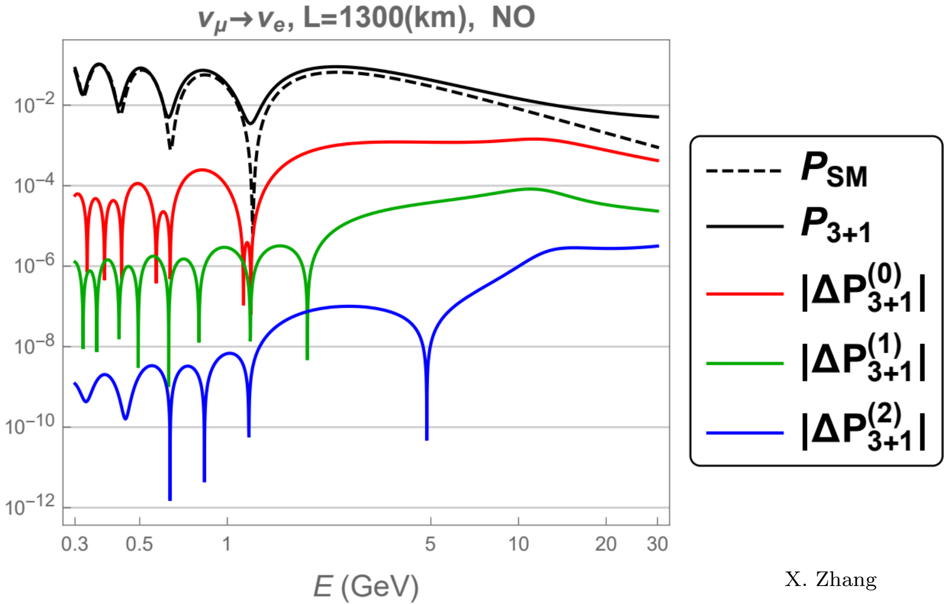
PBD

Rotations, Perturbations



PBD

Extend to new physics such as steriles



X. Zhang