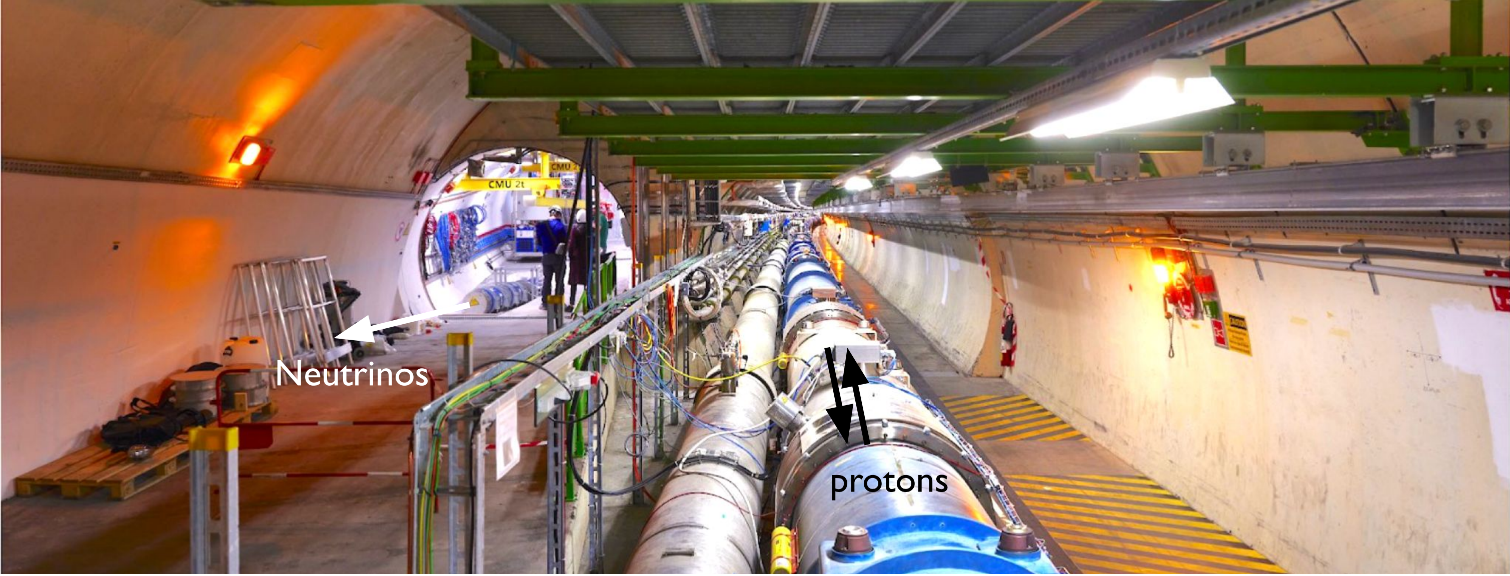
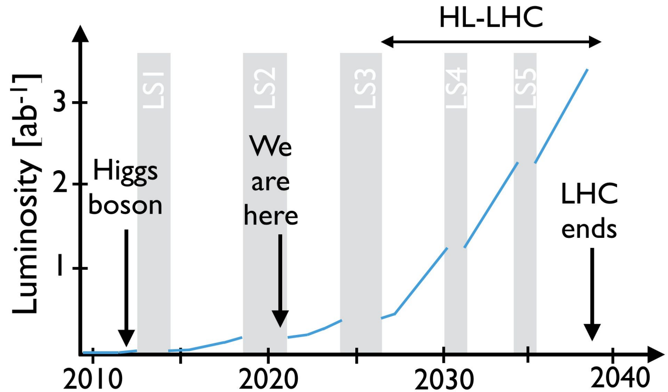


Looking Forward to Tau Neutrinos at the LHC.

Felix Kling
NuTau 2021

Motivation.



The LHC will soon start to prepare for its high-luminosity phase.

Can we do something to enhance its physics potential?
If yes, we need to do it now or lose them for many decades.

Explore a rich BSM and SM physics program in the far forward region that greatly expands the LHC physics potential with relatively little additional investment

In particular, use the LHC as a tau neutrino source.

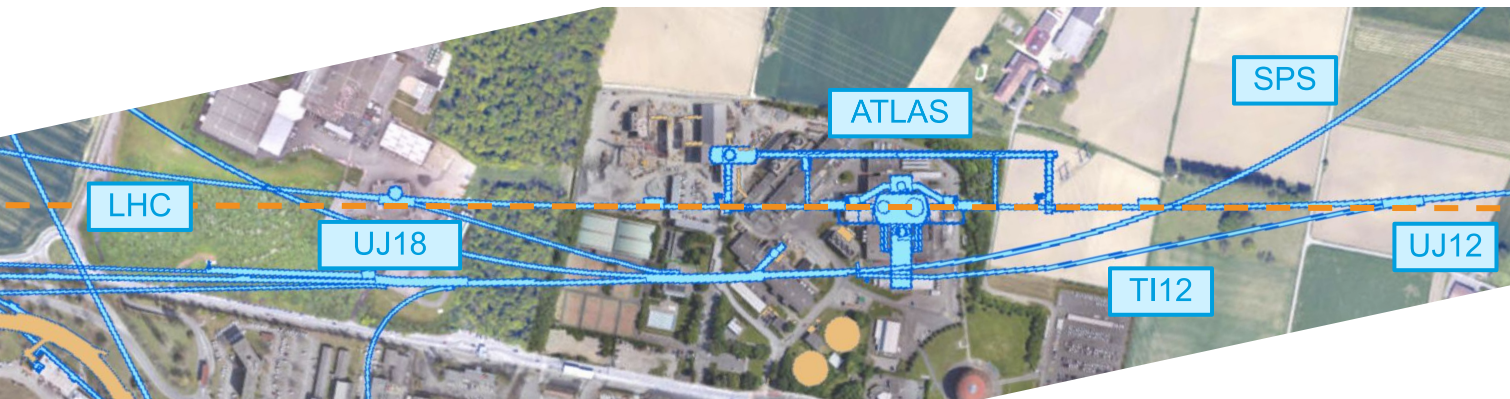
Neutrinos at the LHC.

1984 — 2018 — 2022 — 2028

Neutrinos detected from many sources, but not from colliders.

But there is a huge flux of neutrinos in the forward direction, mainly from π, K and D meson decay. [De Rujula et al. (1984)]

ATLAS provides an intense and strongly collimated beam of TeV-energy neutrinos of all flavours along beam collision axis.



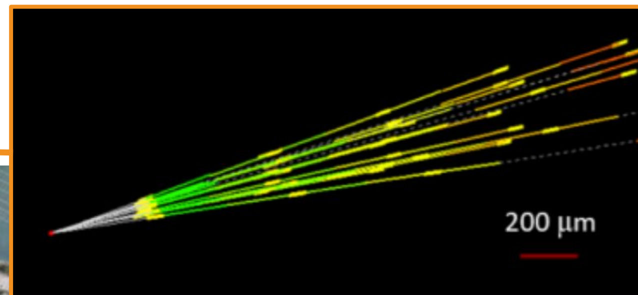
Neutrinos at the LHC.

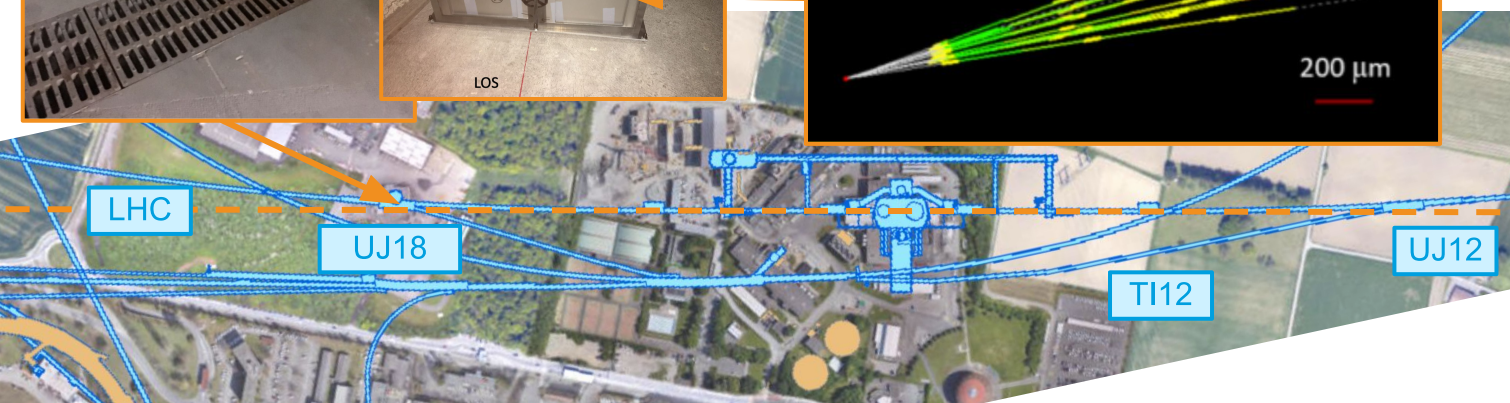
1984 — 2018 — 2022 — 2028

In 2018, the FASER collaboration placed ~30 kg pilot emulsion detectors in TI18 for a few weeks. O(10) neutrino interactions expected

First neutrino interaction candidates were recently reported.

[FASER, 2105.06197]





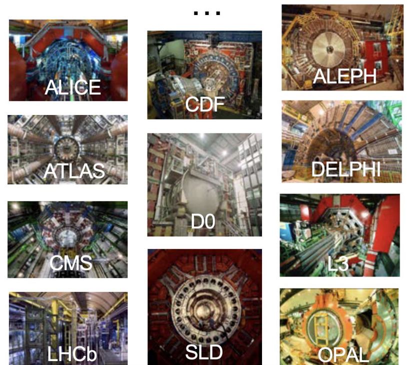
Neutrinos at the LHC.

1984 — 2018 — 2022 — 2028

FASER Pilot Detector

suitcase-size, 4 weeks
$0 (recycled parts)

6 neutrino candidates



all previous collider detectors

building-size, decades ~$1B

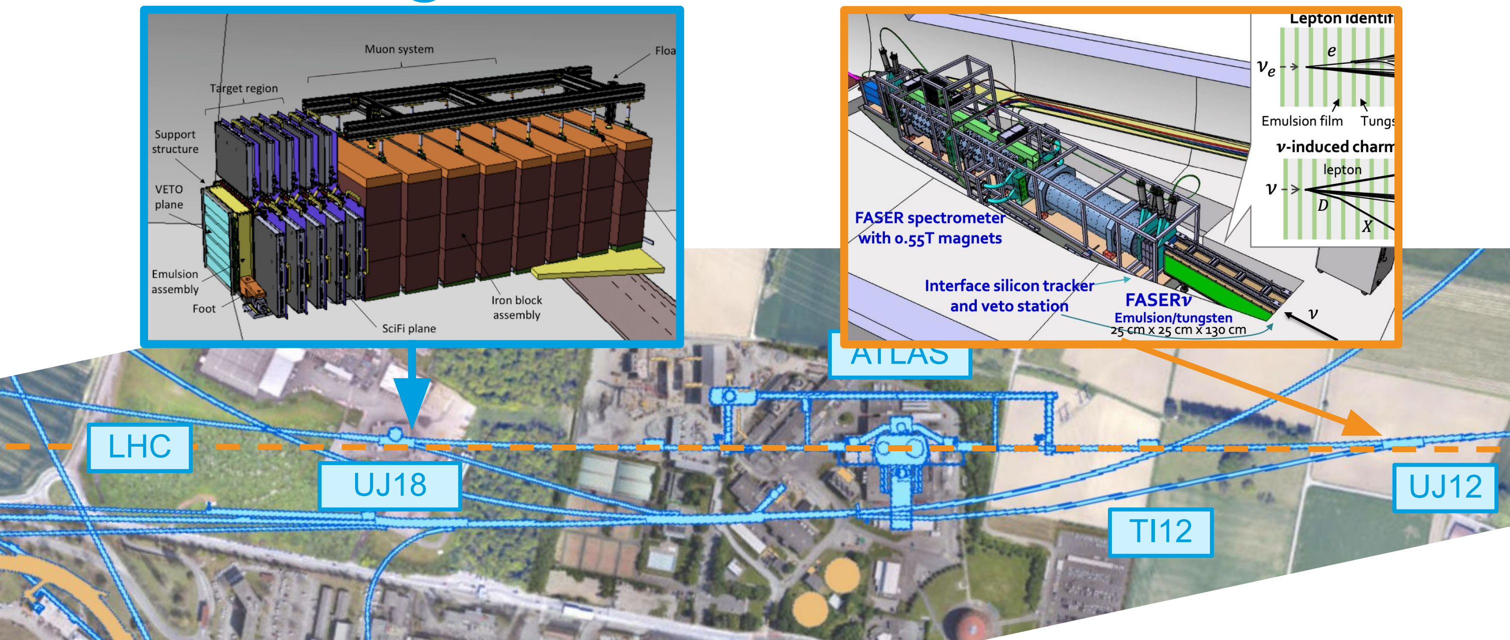
0 neutrino candidates

Neutrinos at the LHC.

1984 — 2018 — 2022 — 2028

During Run 3 of the LHC, two new experiments will detect LHC neutrinos.
FASERv: O(1k) nu_e, O(10k) nu_mu and O(10) nu_tau.

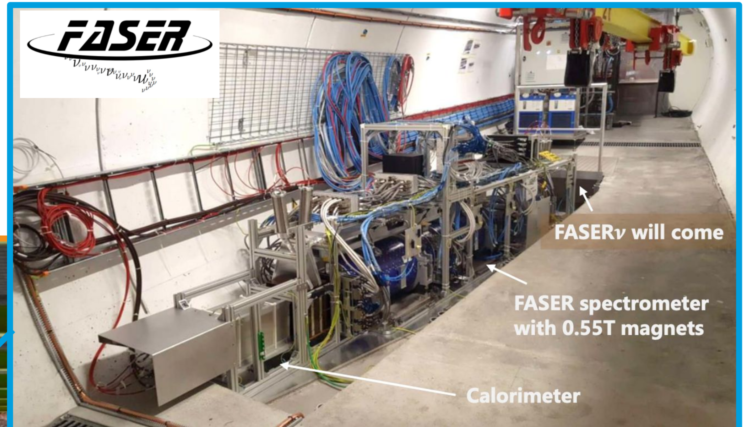
SND@LHC **FASERν**



Neutrinos at the LHC.

1984 — 2018 — 2022 — 2028

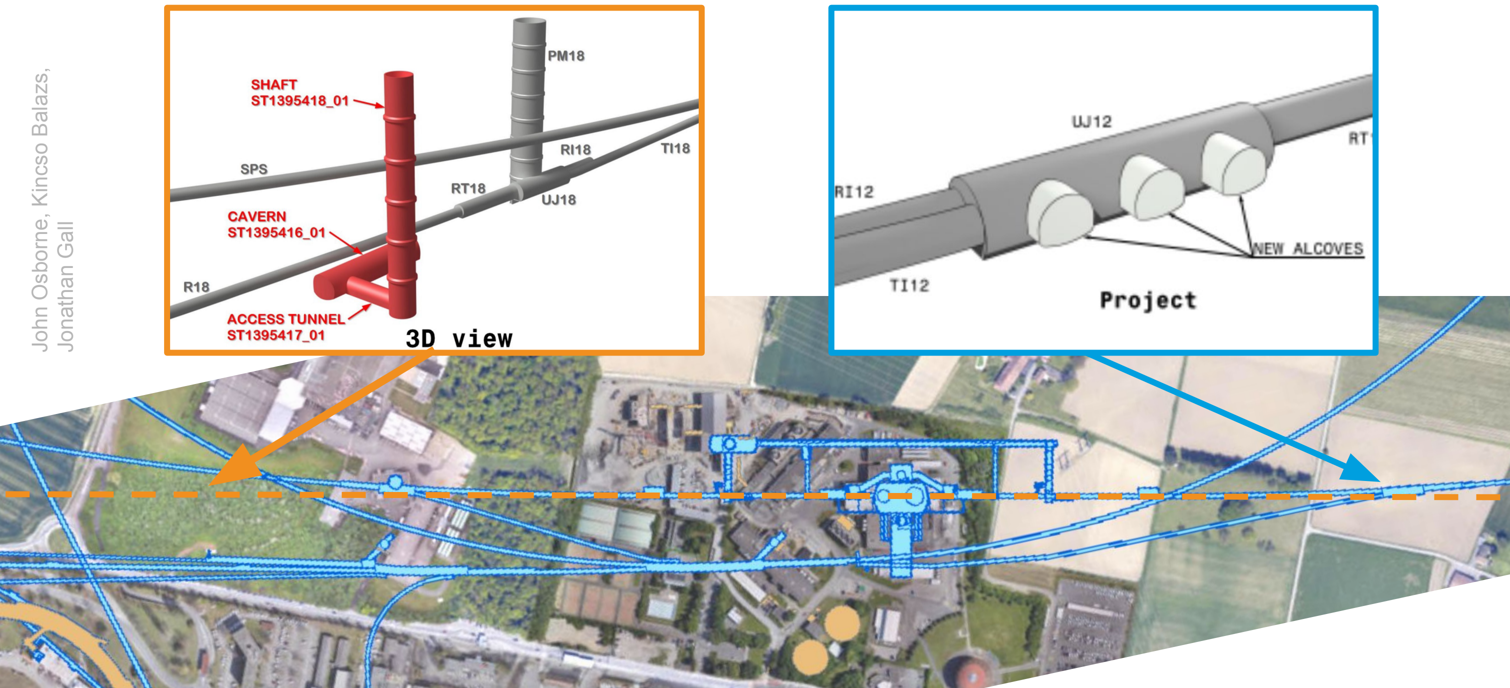
FASER detector was successfully installed into the TI12 tunnel in March 2021



Forward Physics Facility.

1984 — 2018 — 2022 — 2028

The proposal: create a Forward Physics Facility (FPF) for the HL-LHC to house a suite of experiments. Two promising locations were identified.



John Osborne, Kincso Balazs, Jonathan Gall

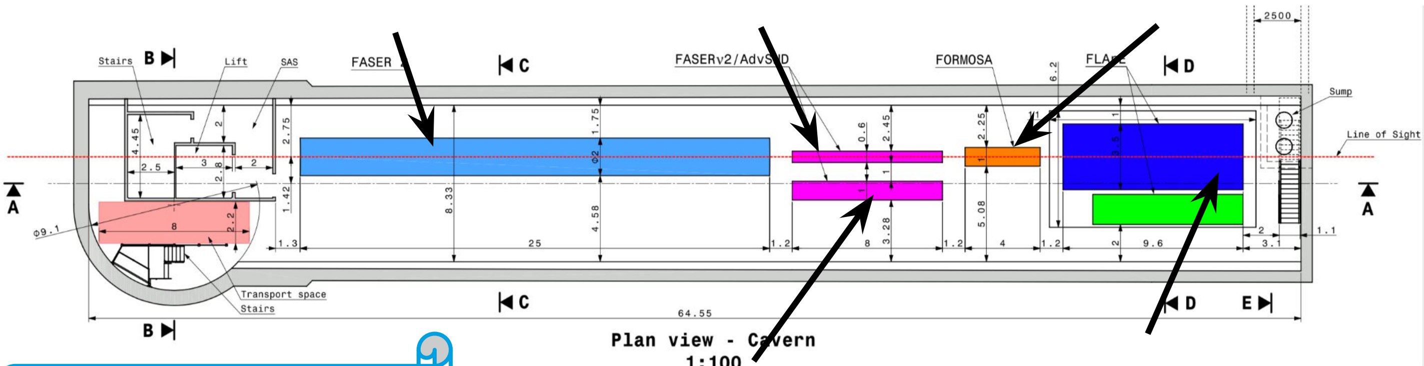
Forward Physics Facility.

The FPF would house a suite of experiments that will greatly enhance the LHC's physics potential for BSM physics searches, neutrino physics and QCD.

FASER2
magnetized spectrometer
for BSM searches

FASERν2
emulsion-based
neutrino detector

FORMOSA
plastic scintillator array
for BSM searches



AdvSND
electronic
neutrino detector

FLArE
LAr based
neutrino detector

see talk by
Albert de Roeck
on experimental aspects

Forward Physics Facility.

Two dedicated FPF workshops in November 2020 (https://indico.cern.ch/event/955956) and May 2021 (https://indico.cern.ch/event/1022352)

Results summarized in paper discussing the facility, proposed experiments and physics potential for BSM Physics, Neutrinos, QCD and Astroparticle Physics.

~75 pages, written over last ~3month by ~80 authors

https://arxiv.org/abs/2109.10905

The Forward Physics Facility: Sites, Experiments, and Physics Potential

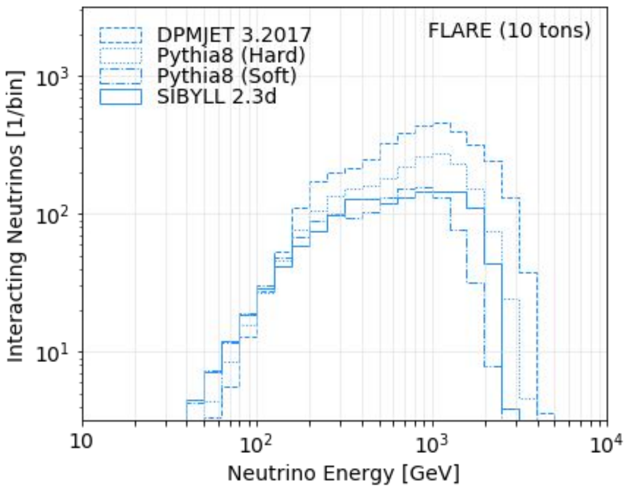
Luis A. Anchordoqui,[1,*] Akitaka Ariga,[2,3] Tomoko Ariga,[4] Weidong Bai,[5] Kincso Balazs,[6] Brian Batell,[7] Jamie Boyd,[6] Joseph Bramante,[8] Adrian Carmona,[9] Mario Campanelli,[10] Francesco G. Celiberto,[11,12,13] Grigorios Chachamis,[14] Matthew Citron,[15] Giovanni De Lellis,[16,17] Albert de Roeck,[6] Hans Dembinski,[18] Peter B. Denton,[19] Antonia Di Crecsenzo,[16,17,6] Milind V. Diwan,[20] Liam Dougherty,[21] Herbi K. Dreiner,[22] Yong Du,[23] Rikard Enberg,[24] Yasaman Farzan,[25] Jonathan L. Feng,[26,†] Max Fieg,[26] Patrick Foldenauer,[27] Saeid Foroughi-Abari,[28] Alexander Friedland,[29,*] Michael Fucilla,[30,31] Jonathan Gall,[32] Maria Vittoria Garzelli,[33,‡] Francesco Giuli,[34] Victor P. Goncalves,[35] Marco Guzzi,[36] Francis Halzen,[37] Juan Carlos Helo,[38,39] Christopher S. Hill,[40] Ahmed Ismail,[41,*] Ameen Ismail,[42] Sudip Jana,[43] Yu Seon Jeong,[44] Krzysztof Jodłowski,[45] Fnu Karan Kumar,[20] Kevin J. Kelly,[46] Felix Kling,[29,47,§] Rafał Maciuła,[48] Roshan Mammen Abraham,[41] Julien Manshanden,[33] Josh McFayden,[49] Mohammed M. A. Mohammed,[30,31] Pavel M. Nadolsky,[50,*] Nobuchika Okada,[51] John Osborne,[6] Hidetoshi Otono,[4] Vishvas Pandey,[52,46,*] Alessandro Papa,[30,31] Digesh Raut,[53] Mary Hall Reno,[54,*] Filippo Resnati,[6] Adam Ritz,[28] Juan Rojo,[55] Ina Sarcevic,[56,*] Christiane Scherb,[57] Pedro Schwaller,[58] Holger Schulz,[59] Dipan Sengupta,[60] Torbjörn Sjöstrand,[61,*] Tyler B. Smith,[26] Dennis Soldin,[53,*] Anna Stasto,[62] Antoni Szczurek,[48] Zahra Tabrizi,[63] Sebastian Trojanowski,[64,65] Yu-Dai Tsai,[26,46] Douglas Tuckler,[66] Martin W. Winkler,[67] Keping Xie,[7] and Yue Zhang[66]

The Forward Physics Facility (FPF) is a proposal to create a cavern with the space and infrastructure to support a suite of far-forward experiments at the Large Hadron Collider during the High Luminosity era. Located along the beam collision axis and shielded from the interaction point by at least 100 m of concrete and rock, the FPF will house experiments that will detect particles outside the acceptance of the existing large LHC experiments and will observe rare and exotic processes in an extremely low-background environment. In this work, we summarize the current status of plans for the FPF, including recent progress in civil engineering in identifying promising sites for the FPF; the FPF experiments currently envisioned to realize the FPF's physics potential; and the many Standard Model and new physics topics that will be advanced by the FPF, including searches for long-lived particles, probes of dark matter and dark sectors, high-statistics studies of TeV neutrinos of all three flavors, aspects of perturbative and non-perturbative QCD, and high-energy astroparticle physics.

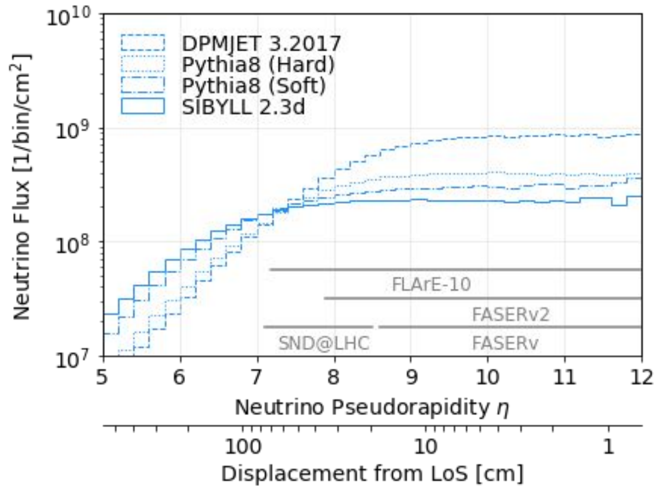
Tau Neutrino Fluxes and Rates.

Tau neutrinos at LHC are mainly produced in Ds meson and tau decays.

energy spectrum of interacting neutrinos



neutrino flux as function of displacement from LoS



100 GeV - few TeV energies

flux peaked around LoS, start to drop around 1m away from LoS

complementary coverage of FASERv and SND@LHC

Tau Neutrino Fluxes and Rates.

Event rates at LHC neutrino experiments:
estimated with two LO MC generators: SIBYLL / DPMJET

	Detector			Number of CC Interactions		
	Name	Mass	Coverage	$\nu_e+\bar{\nu}_e$	$\nu_\mu+\bar{\nu}_\mu$	$\nu_\tau+\bar{\nu}_\tau$
LHC Run3	FASERν	1 ton	$\eta \gtrsim 8.5$	1.3k / 4.6k	6.1k / 9.1k	21 / 131
	SND@LHC	800kg	$7 < \eta < 8.5$	180 / 500	1k / 1.3k	10 / 22
HL-LHC	FASERν2	20 tons	$\eta \gtrsim 8$	178k / 668k	943k / 1.4M	2.3k / 20k
	FLArE	10 tons	$\eta \gtrsim 7.5$	36k / 113k	203k / 268k	1.5k / 4k
	AdvSND	2 tons	$7.2 \lesssim \eta \lesssim 9.2$	6.5k / 20k	41k / 53k	190 / 754

O(10) tau neutrinos at FASERv and SND@LHC:
similar to event rate at DONuT and OPERA

thousands of tau neutrinos at FPF experiments:
use LHC as tau neutrino factory

Tau Neutrino Fluxes and Rates.

Event rates at LHC neutrino experiments:
estimated with two LO MC generators: SIBYLL / DPMJET

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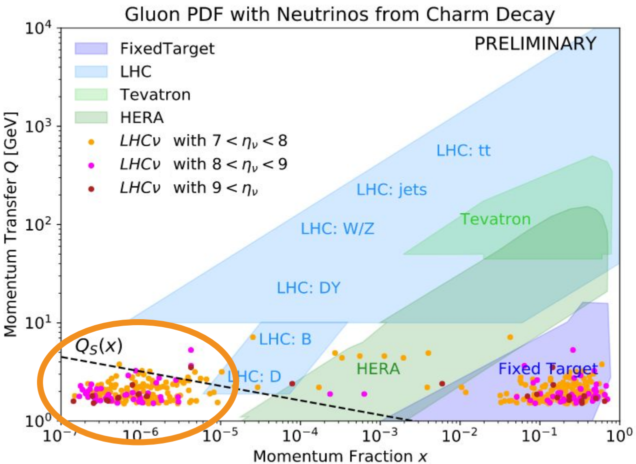
Large spread in generator predictions:
need to quantify and improve neutrino flux uncertainties.

$m_C > \Lambda_{QCD}$: charm production calculable in perturbative QCD

Define uncertainties associated with scale choice, PDFs and modeling of hadronization.

see talk by
Maria V. Garzelli on
theoretical
considerations and
better flux
predictions

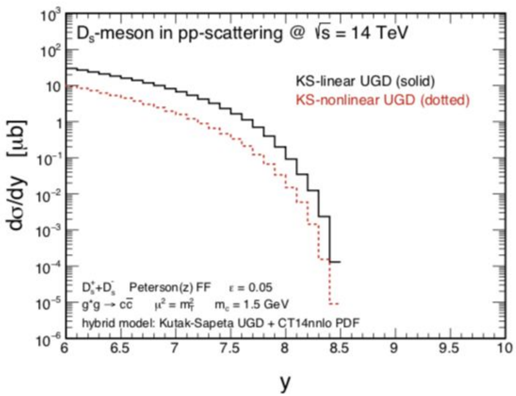
Physics with tau Neutrinos: Production.



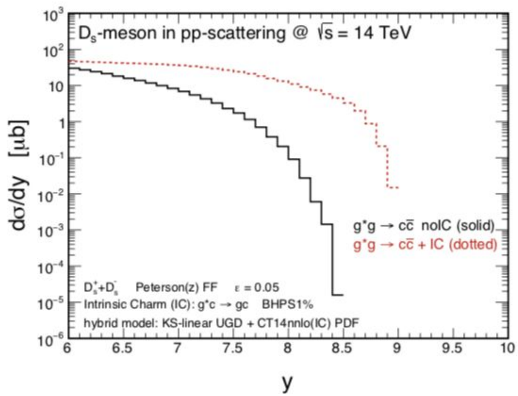
Tau Neutrinos as Probe of QCD:

Neutrinos from charm decay could allow to test transition to small-x factorization, constrain low-x gluon PDF, probe gluon saturation, and probe intrinsic charm.

saturation



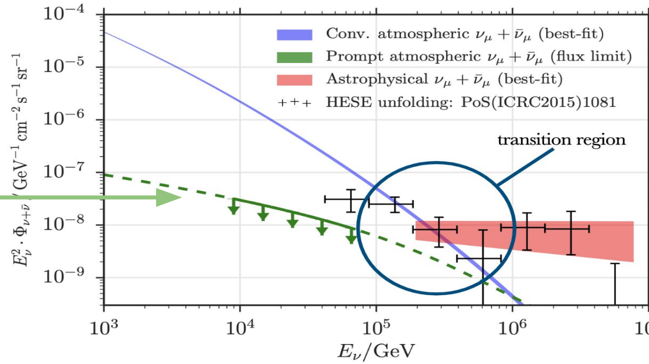
intrinsic charm

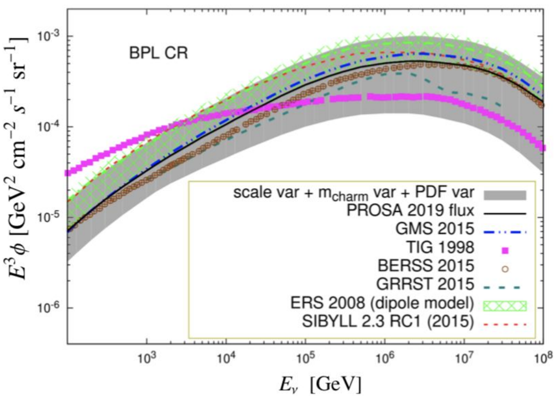


Physics with tau Neutrinos: Production.

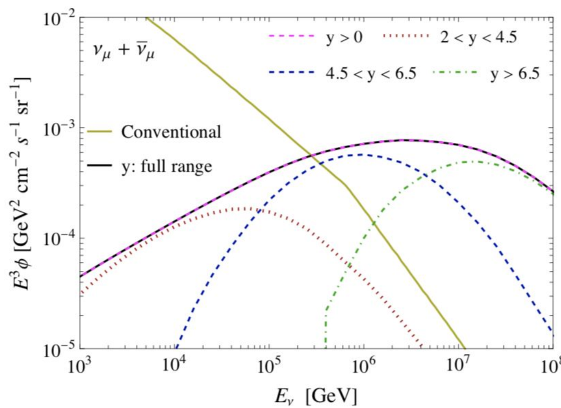
Relevant for Astroparticle Physics:

Measuring forward charm production at the LHC would help to constrain the (currently very poorly constrained) prompt atmospheric neutrino flux at IceCube.





Prompt atmospheric neutrino flux predictions



Prompt atmospheric neutrino fluxes from different collider rapidity ranges

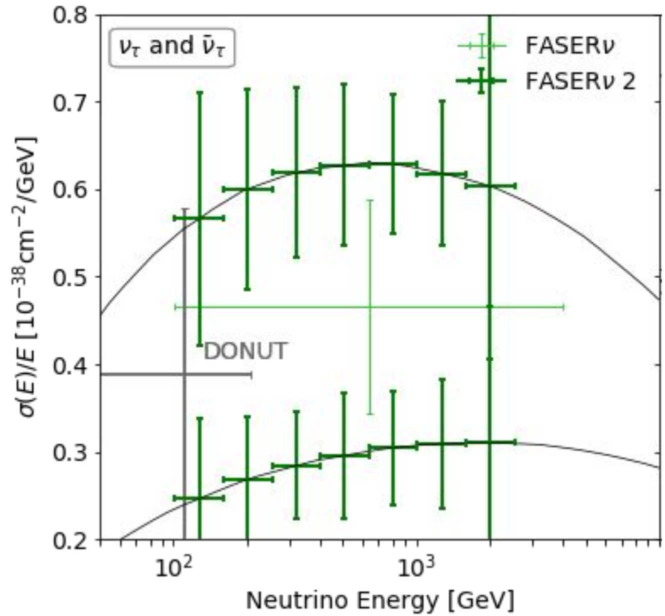
Physics with tau Neutrinos: Interactions.

thousands of CC tau neutrino interactions expected at FPF
→ FPF allows tau neutrino precision measurements

measure tau neutrino DIS cross section at TeV energies

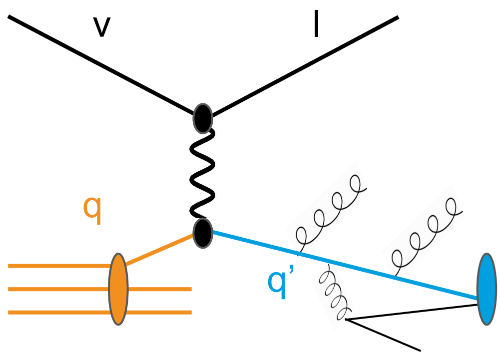
separate neutrinos and anti-neutrinos via charge of muon from tau decay

tests of lepton universality in neutrino scattering



Physics with tau Neutrinos: Interactions.

The FPF is essentially a Neutrino-Ion collider with sqrt(s)~50GeV



Final State

response of cold nuclear matter to fast moving quarks

medium-induced energy losses

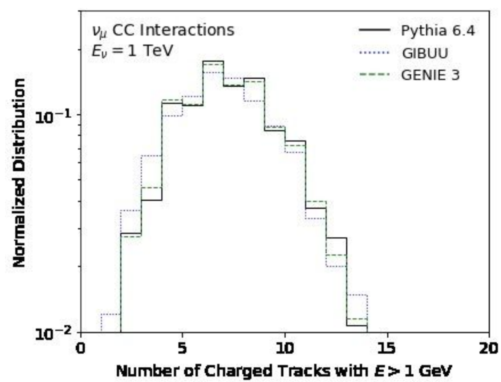
fragmentation functions

final state interactions

Initial State

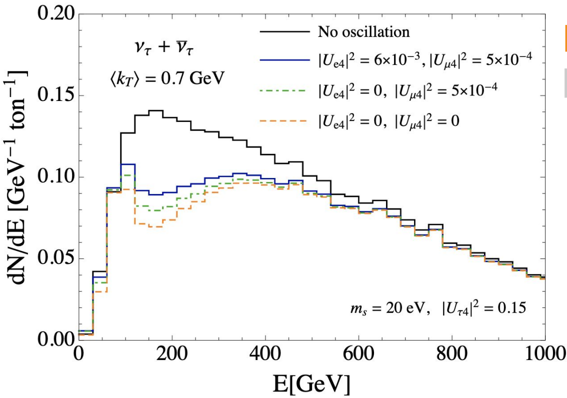
nuclear PDFs via measurements on different targets

strange quark PDFs via v s → l c



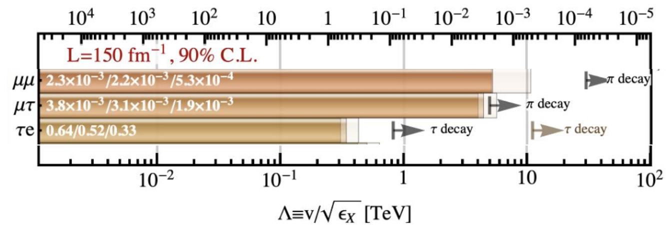
Physics with tau Neutrinos: BSM.

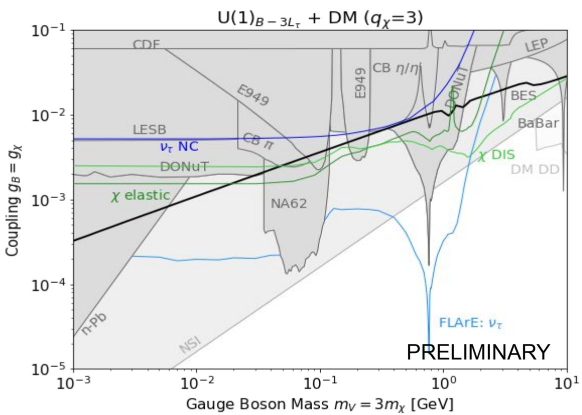
Use tau neutrinos as probe of new physics.



Probing Sterile Neutrino Oscillations
[Bai et al, 2002.03012]

Probing EFTs
[Falkowski et al, 2002.03012]





Probing Light Tau-Neutrinophilic Mediators
[Kling, 2005.03594, Batell et al, in progress]

also see talk by
Roshan Mammen Abraham on
Tau Neutrino MDMs

Summary.

With FASER and SND@LHC, two new experiment will soon start to perform tau neutrino measurements at the LHC.

They also pave the way for a forward neutrino program at the HL-LHC, opening up many many new opportunities for neutrino physics, QCD and BSM physics searches, significantly extending the LHC's physics program.

↓

We would like to invite the NuTau community to help us better understand the physics potential of this program and contribute the development of the experiments.

You are welcome to join!

For questions, ideas, comments and other feedback:
please contact me via: felix.kling@desy.de