

Collider Neutrinos: Opportunities and Perspectives.

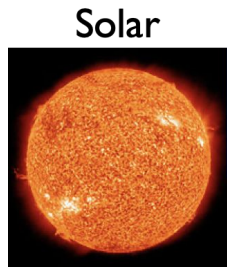
Felix Kling (DESY)
Neutrinos at CERN
24.01.2025



Motivation.

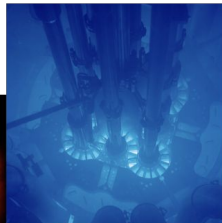
We have detected neutrinos a variety of source across a large energy range.

Each detection led to profound insights across the fields of particle physics, nuclear physics, and astrophysics.



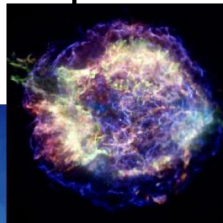
Solar

~MeV



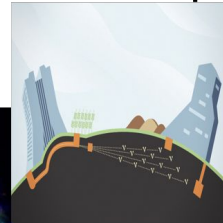
Reactor

~MeV



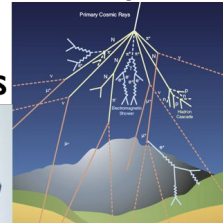
Supernova

~MeV



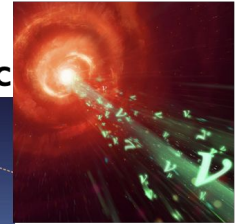
Beam Dumps

GeV-subTeV



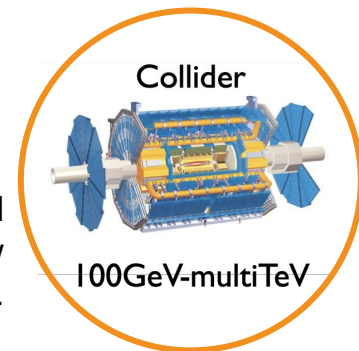
Atmospheric

subGeV-PeV



Cosmic

TeV-EeV



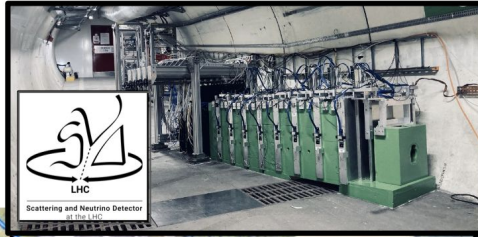
Collider

100GeV-multiTeV

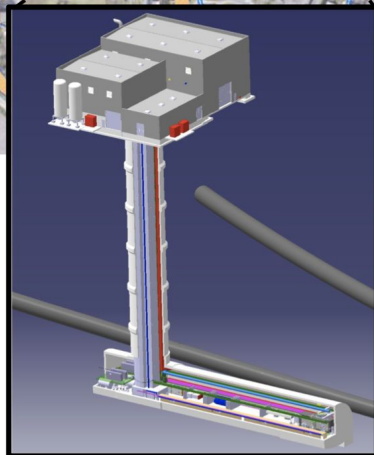
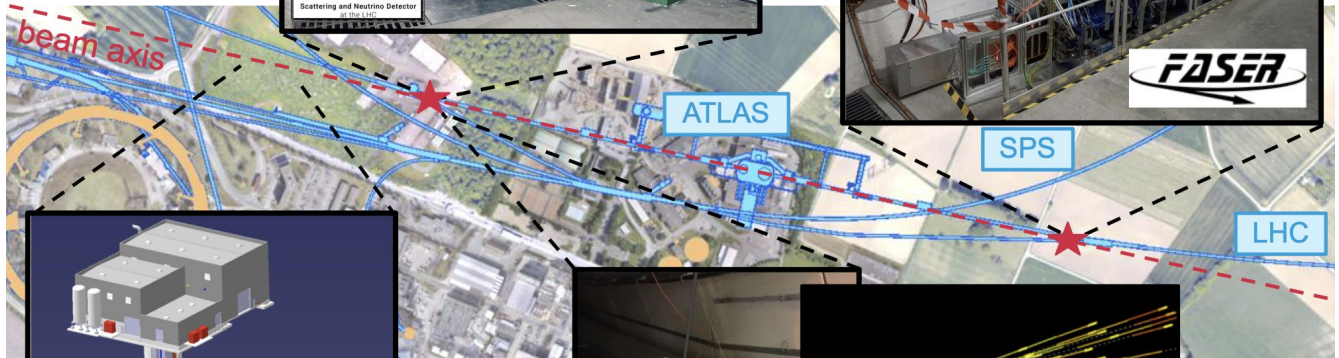
Only recently we observed the first neutrinos from a new source: particle colliders.

Collider Neutrino Experiments.

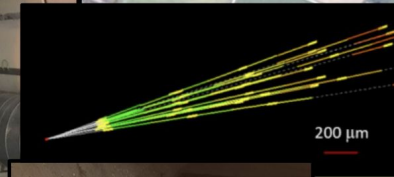
SND@LHC



FASER



FPF

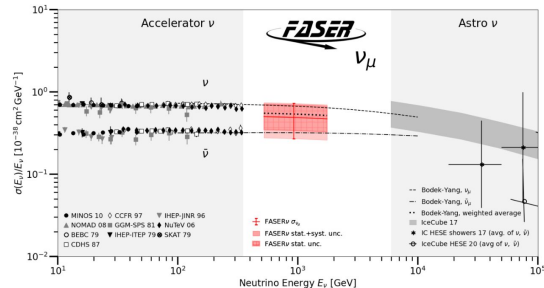
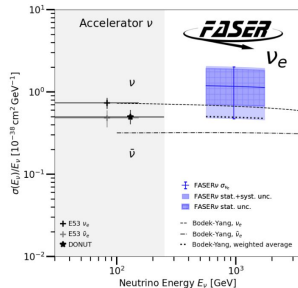
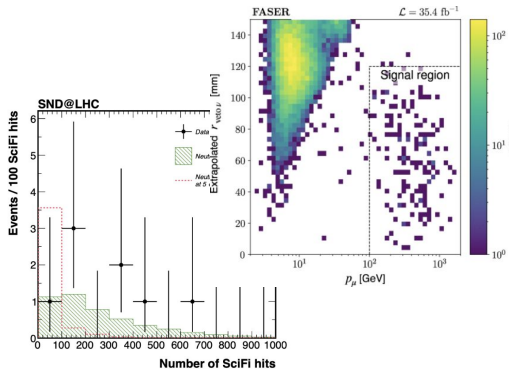


Pilot
Emulsion
Detector

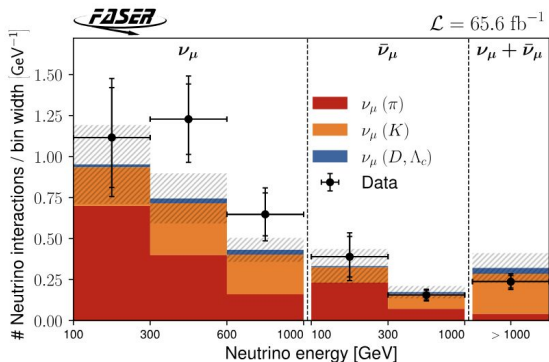
LOS

First Experimental Results.

First observation of collider neutrinos:
 153 events (FASER) + 8 events (SND@LHC)
 [FASER, [2303.14185](#)] [SND@LHC, [2305.09383](#)]



first cross sections measurement
 [FASER, [2403.12520](#)]



first flux measurement
 [FASER, [2412.03186](#)]

The Dawn of Collider Neutrino Physics.

Deutsches Elektronen-Synchrotron DESY
A Research Centre of the Helmholtz Association

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News

News from the DESY research centre

2023/03/21

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Research team detects first neutrinos made by a particle collider

The discovery promises to help physicists understand the nature of the elusive particle

An international research team at the FASER experiment at the LHC near Hadron Collider 1M in Geneva has for the first time to deepen its understanding of the particle in its measurements. Rencontres at a collider phenomena.

Download [1] The FASER

UNIVERSITÄT BONNEN

UNIVERSITÄT STUDIUM FORSCHUNG UND LEHRE

20. März 2023

Erstmals Neutrinos aus einem Teilchenbeschleuniger beobachtet

Internationale Studie hilft, die Natur des fast masselosen Elementarteilchens besser zu verstehen

Neutrinos gehören zu den am häufigsten vorkommenden Teilchen im Kosmos, geben Forschenden jedoch nach wie vor viele Rätsel auf. Ein internationales Team unter Beteiligung der Universität Bonn hat jetzt zum ersten Mal Neutrinos direkt beobachtet, die in einem Teilchenbeschleuniger erzeugt wurden. Die Physikerinnen und Physiker erhoffen sich, durch ihre neue Entdeckung die Natur dieser fast masselosen Elementarteilchens besser verstehen zu können. Die Ergebnisse wurden am vergangenen Wochenende bei der 57. Moriond-Konferenz in Italien vorgestellt und werden demnächst in der Fachzeitschrift Physical Review Letters zur wissenschaftlichen Begutachtung eingereicht.

Physics ABOUT BROWSE PRESS COLLECTIONS

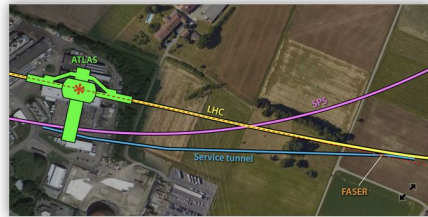
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VIEWPOINT

The Dawn of Collider Neutrino Physics

Elizabeth Worcester
Brookhaven National Laboratory, Upton, New York, US
July 19, 2023 • Physics 16, 113

The first observation of neutrinos produced at a particle collider opens a new field of study and offers ways to test the limits of the standard model.



Google Earth, imagery ©2023 Maxar Technologies, map data ©2023; CERN; adapted by APS/Alan Stonebraker

Figure 1: The Forward Search Experiment (FASER) is installed in a service tunnel that connects the Large Hadron Collider (LHC) and the Super Proton Synchrotron (SPS). Proton collisions at the ATLAS experiment's interaction point (red star) generate beams of neutrinos (dashed red lines) that escape along a tangent to the LHC.

YouTube

Suchen

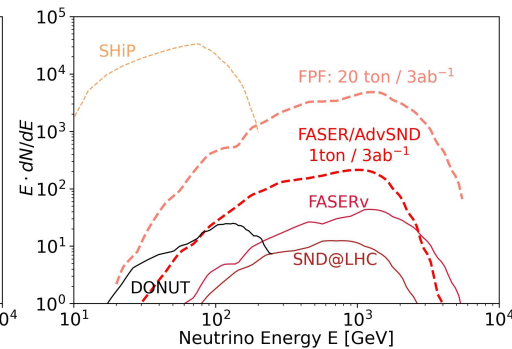
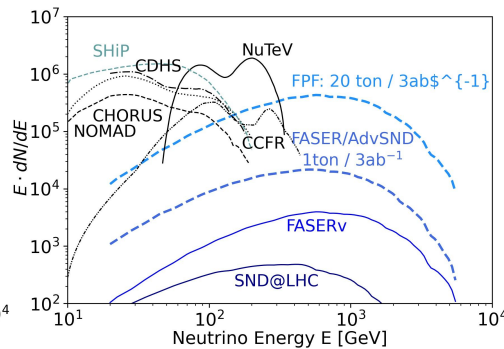
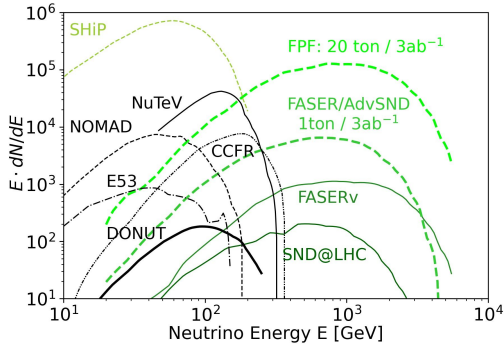
FASER observes first collider neutrinos

Physics • CERN

0:00 / 2:54

Neutrino Fluxes.

LHC is source of most energetic human made neutrinos.

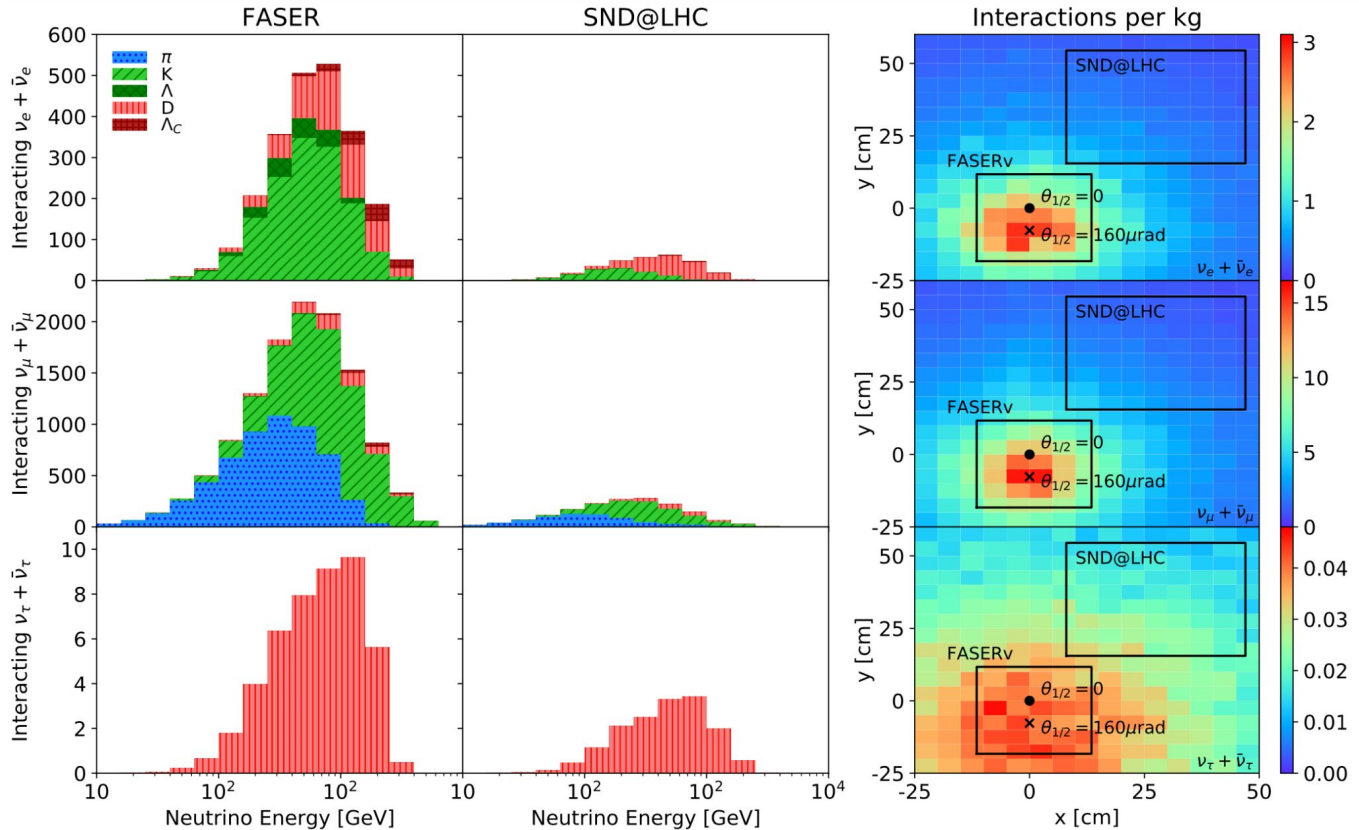


Current LHC experiments will detect **thousands** of neutrinos
The FPF experiments will detect **millions** of neutrinos.

What physics can we probe with them?

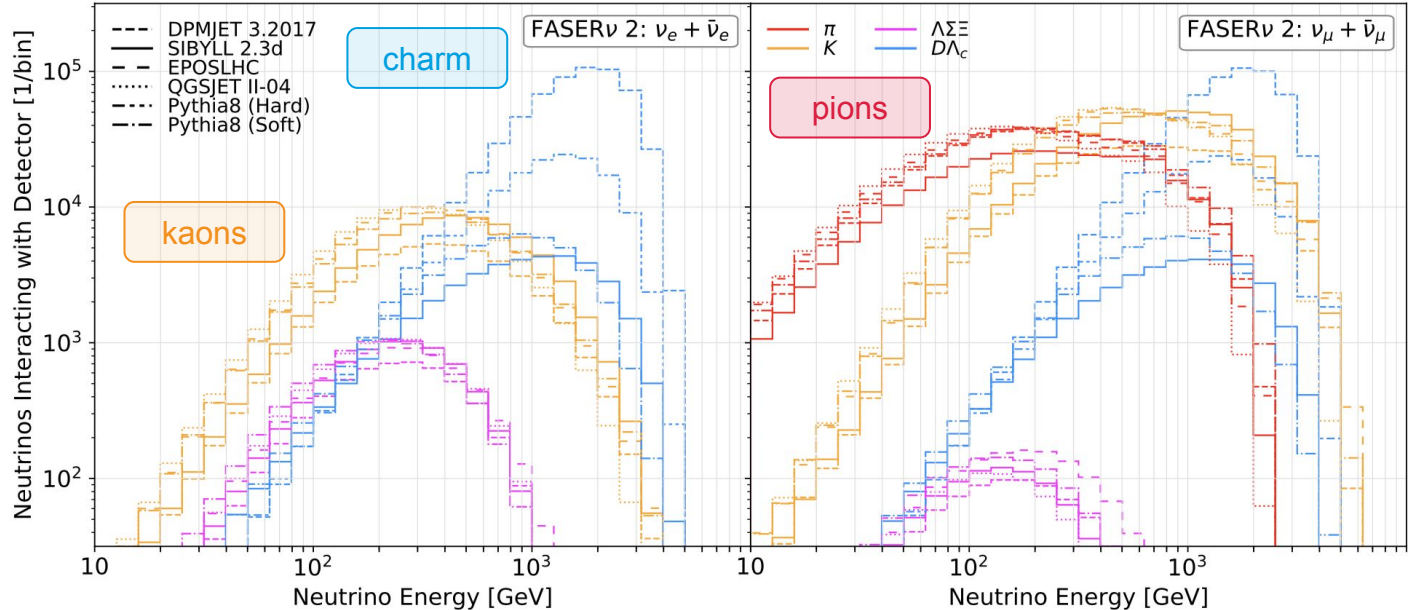
Neutrino Production.

Neutrino Fluxes.



Collider neutrinos are a novel probe of forward particle production.

Neutrino Fluxes.



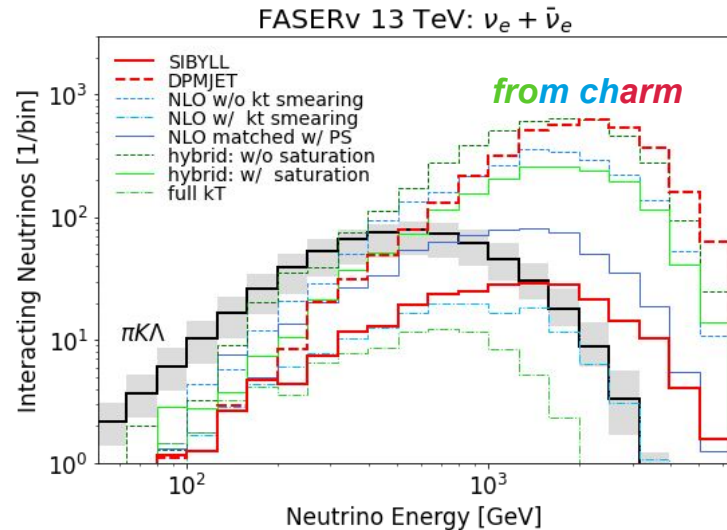
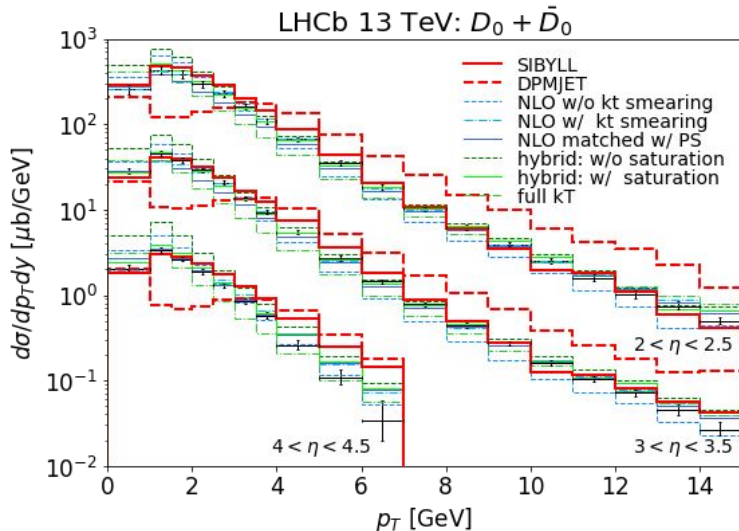
Collider neutrinos are a novel probe of forward particle production.

Neutrinos from Charm Hadrons.

forward charm hadron production can be calculated using perturbative QCD

several predictions for FPF based on **hadronic interaction models**, **NLO collinear factorization** and **kT factorization**: guided by LHCb data

[Bai, Diwan, Garzelli, Jeong, Reno, [2002.03012](#)] [Maciula, Szczurek, [2210.08890](#)] [Bhattacharya, FK, Sarcevic, Stasto, [2306.01578](#)] [Buonocore, FK, Rottoli, Sominka, [2309.12793](#)]

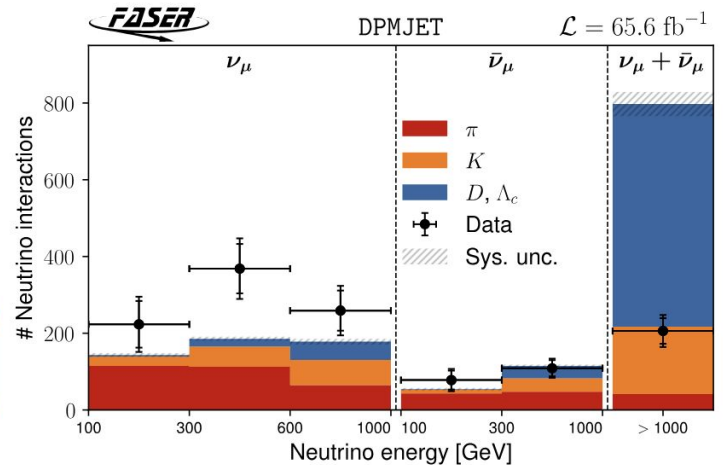
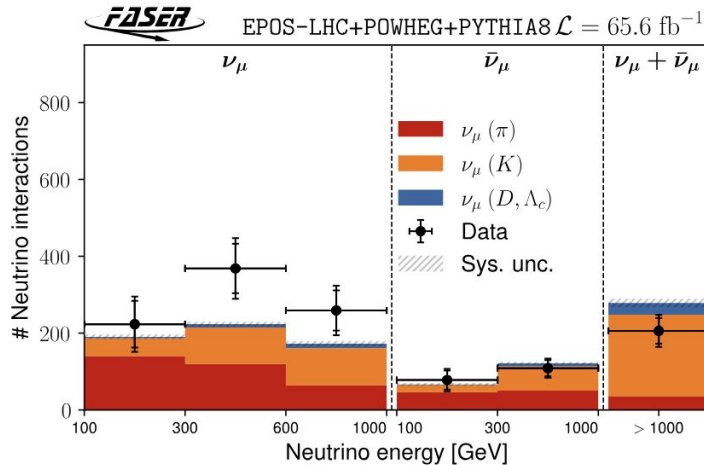


Collider neutrinos will be able to distinguish predictions that LHCb cannot.

Neutrinos from Charm Hadrons.

FASEER data already ruled out some models.

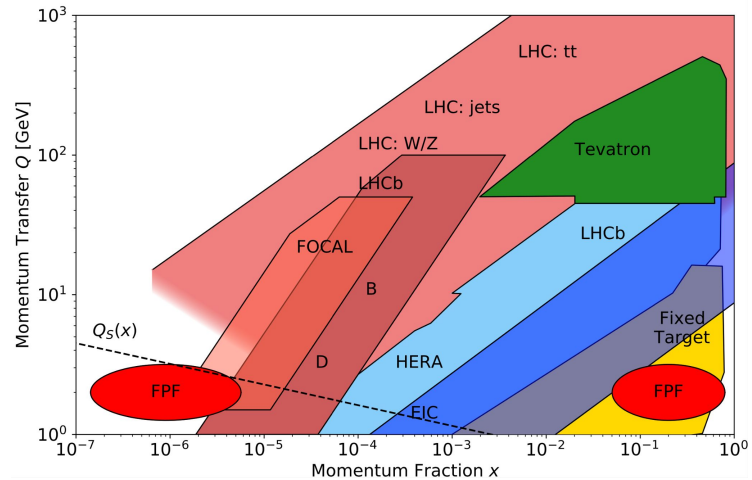
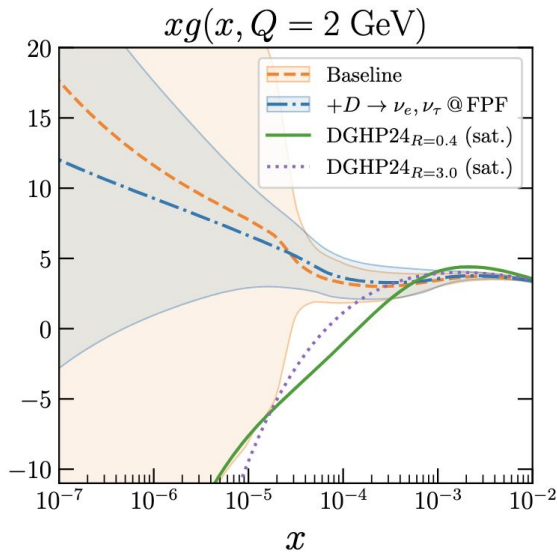
[FASEER, [2412.03186](#)]



Neutrinos from Charm Hadrons.

Neutrinos from forward charm production
 probe uncharted kinematic regimes in
 QCD. [FPF 2203.05090]

$$Q \sim 2m_c, \quad x_1 \sim 1, \quad x_2 \sim 4m_c^2/s \sim 10^{-6}$$



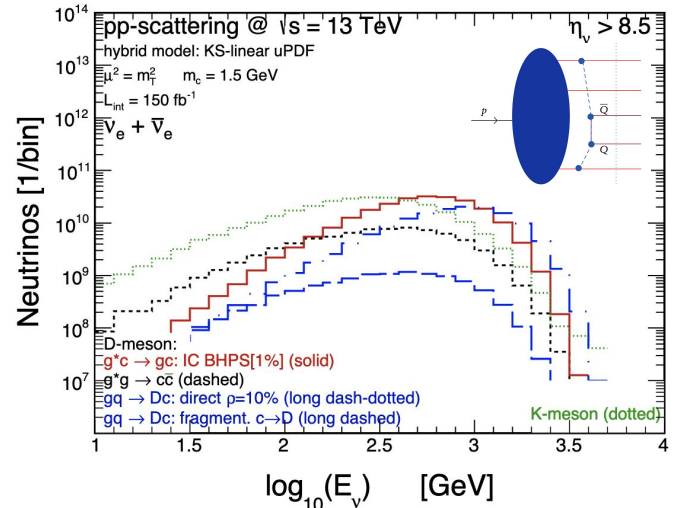
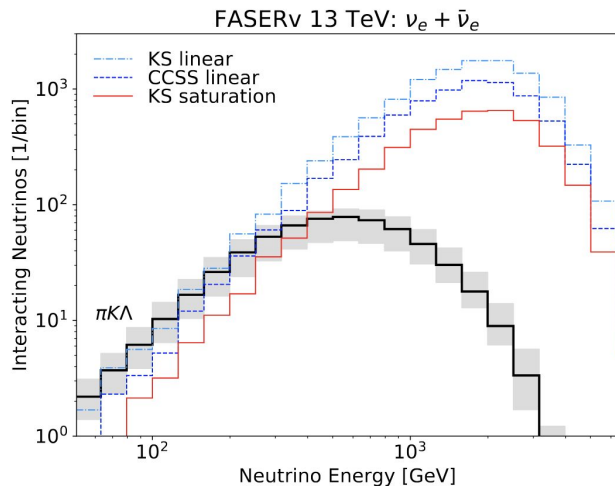
Unique ability to constrain
 gluon PDF at $x \sim 10^{-7}$

[FPF 2411.04175]

Neutrinos from Charm Hadrons.

probe of **intrinsic charm** at high-x

[Maciula, Szczurek [2210.08890](#)]



study of **gluon saturation** at low-x

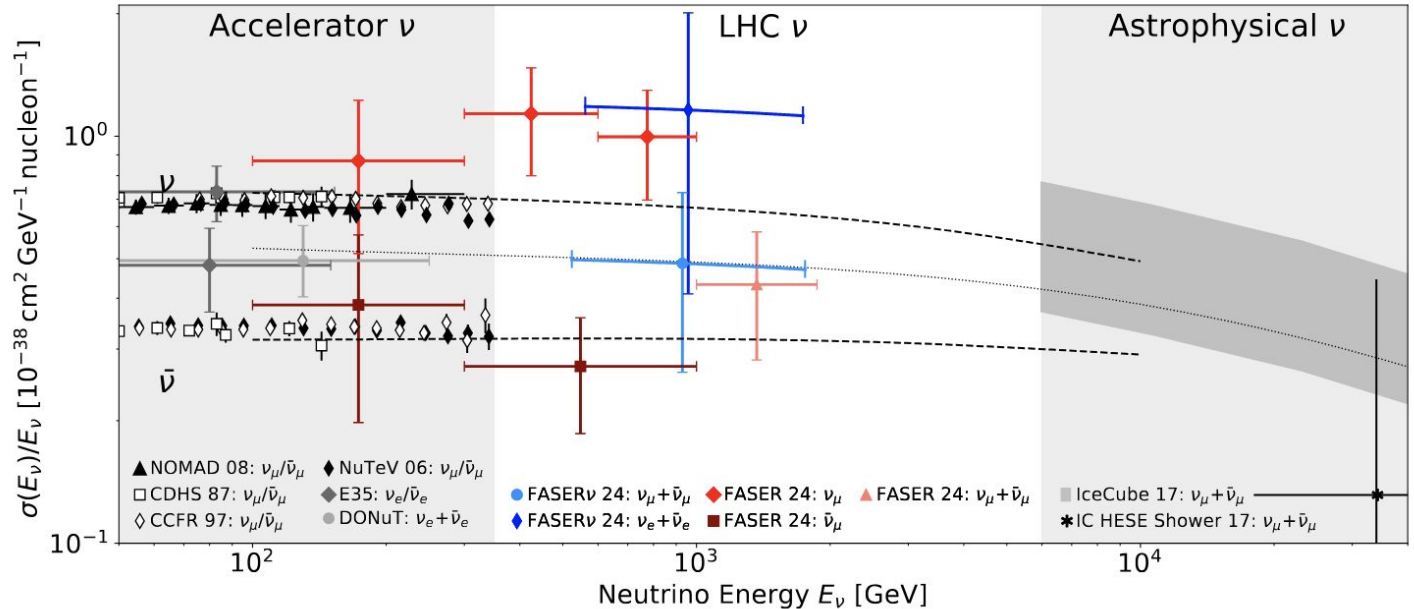
[Bhattacharya, FK, Stato, Sarcevic: [2306.01578](#)]

Neutrino Interaction.

Neutrino Interactions.

first measurements of the neutrino interaction cross section

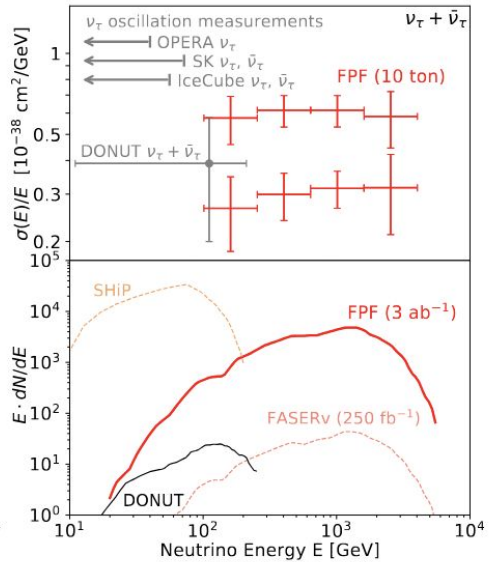
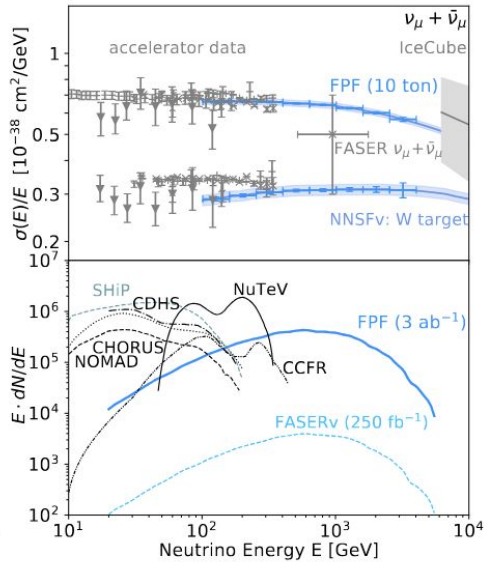
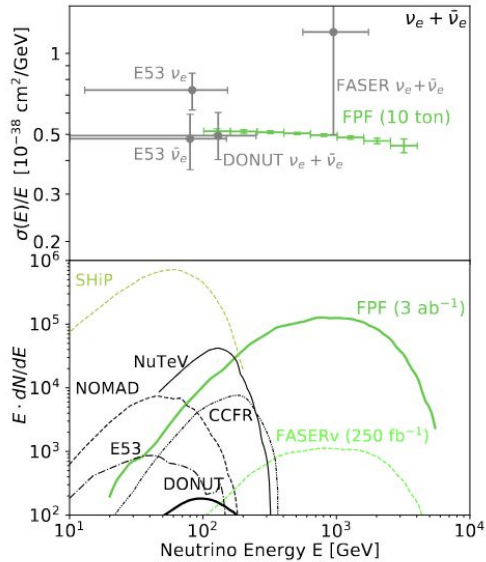
[FASER, [2412.03186](#)], [FASER, [2403.12520](#)]



Neutrino Interactions.

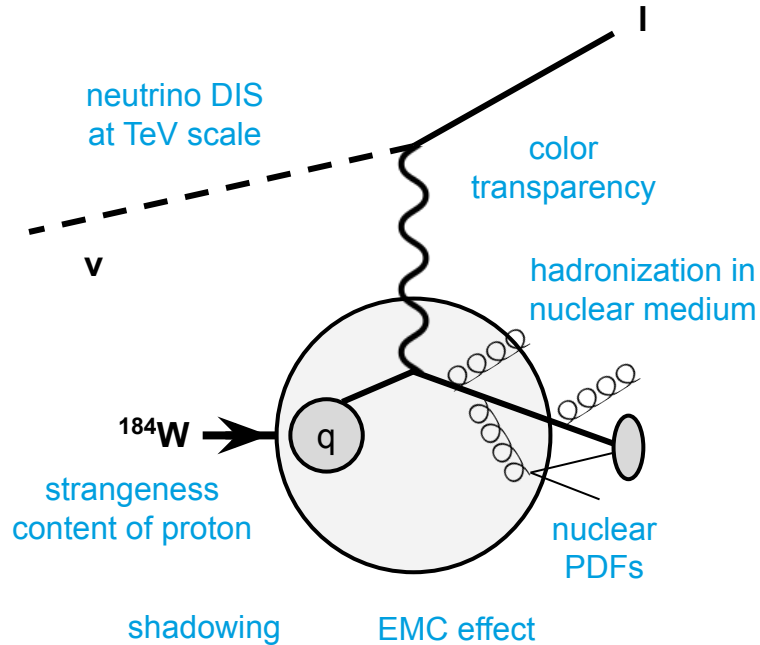
more precise measurements possible at FPF

[FPF, [2411.04175](#)]



Neutrino Interactions.

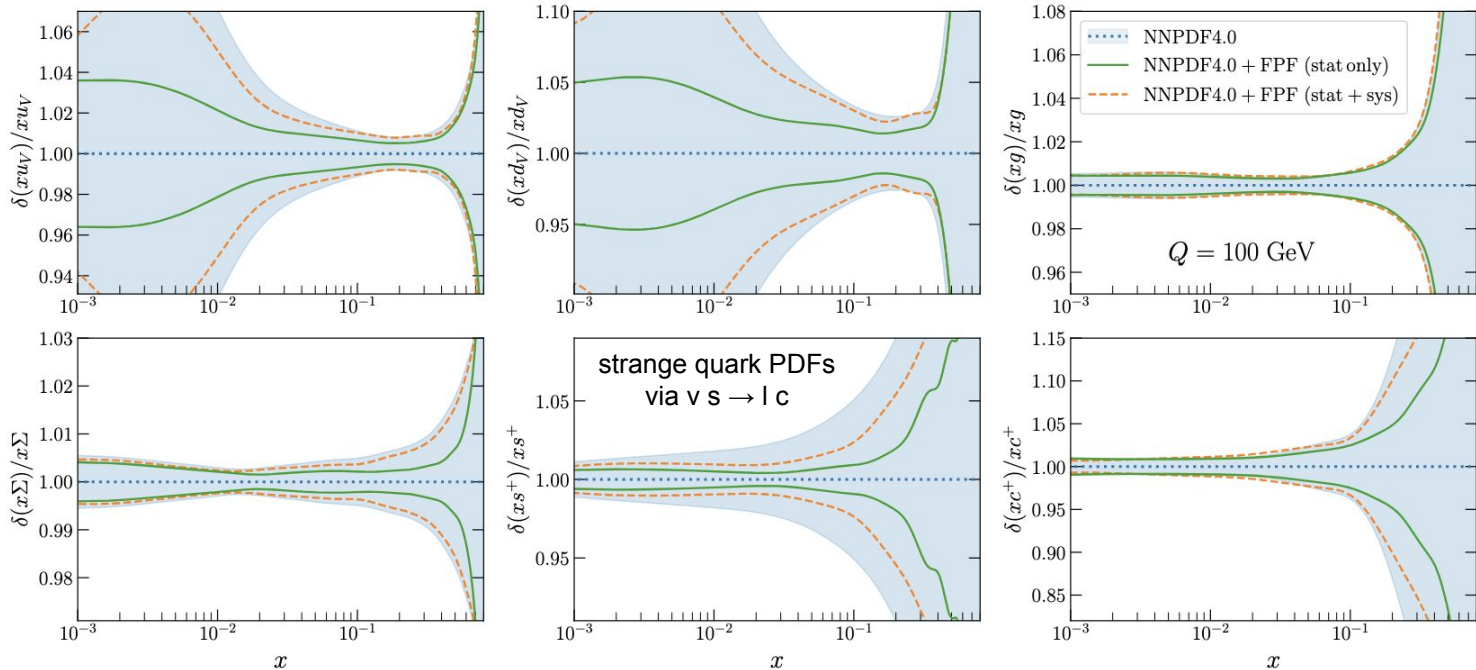
Collider Neutrino Experiments
are a **Neutrino-Ion Collider**
at **EIC** center of mass energies



Collider Neutrinos: Interactions.

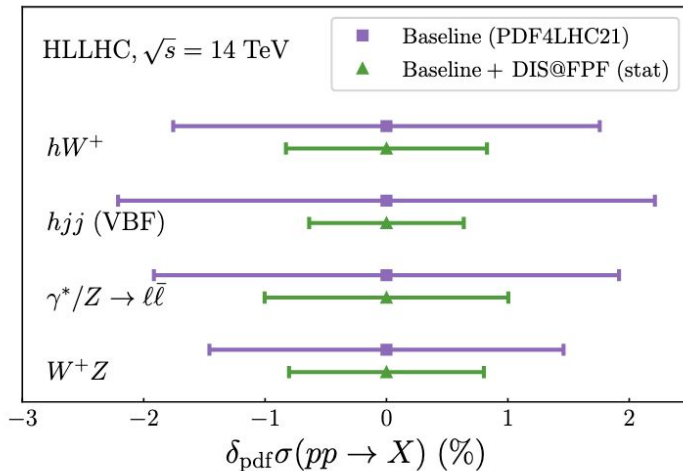
neutrino DIS data will improve PDFs

[FPF, P5 Input] [Cruz-Martinez et al. 2309.09581]

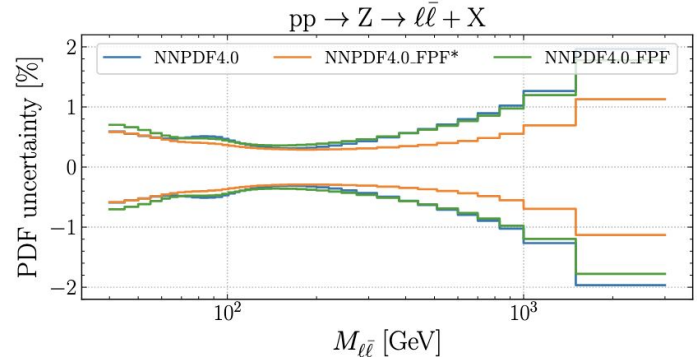


Collider Neutrinos: Interactions.

reduced PDF uncertainties for many key LHC processes



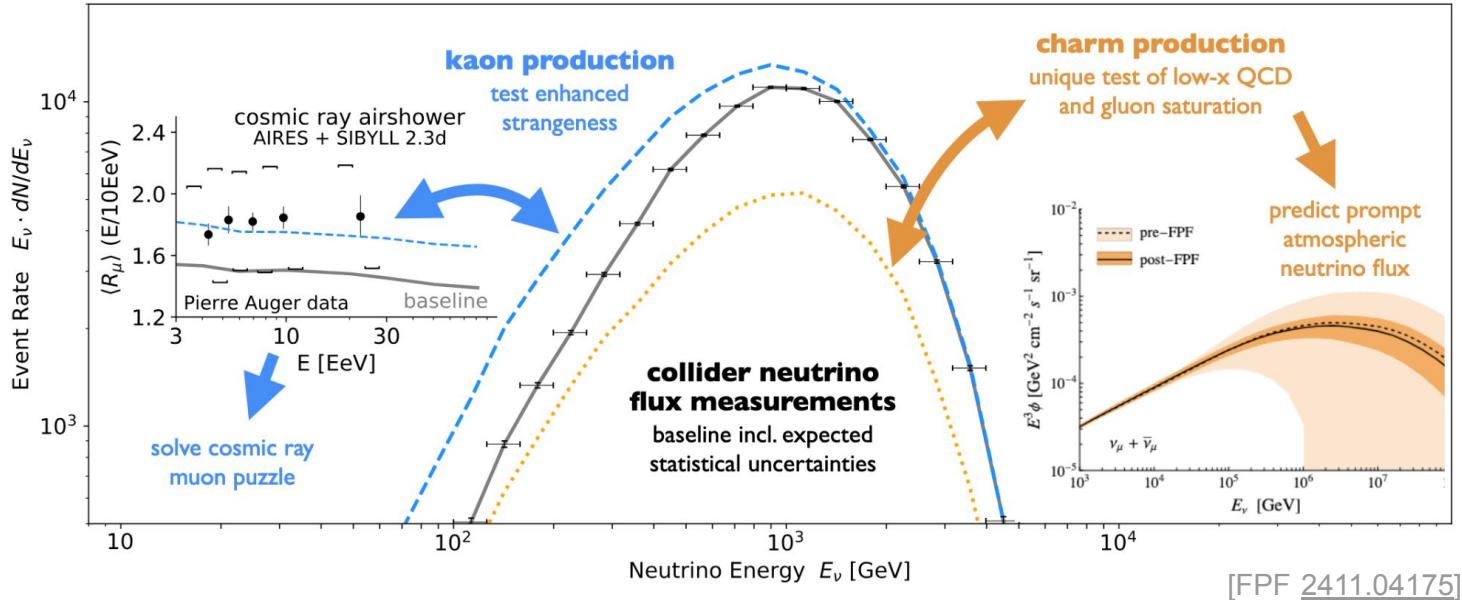
[FPF, [2411.04175](#)]



[Cruz-Martinez et al. [2309.09581](#)]

Astroparticle Physics

Input for Astroparticle Physics.



[FPF 2411.04175]

cosmic ray muon puzzle: observed 8σ excess of muons compared to predictions from hadronic interaction models

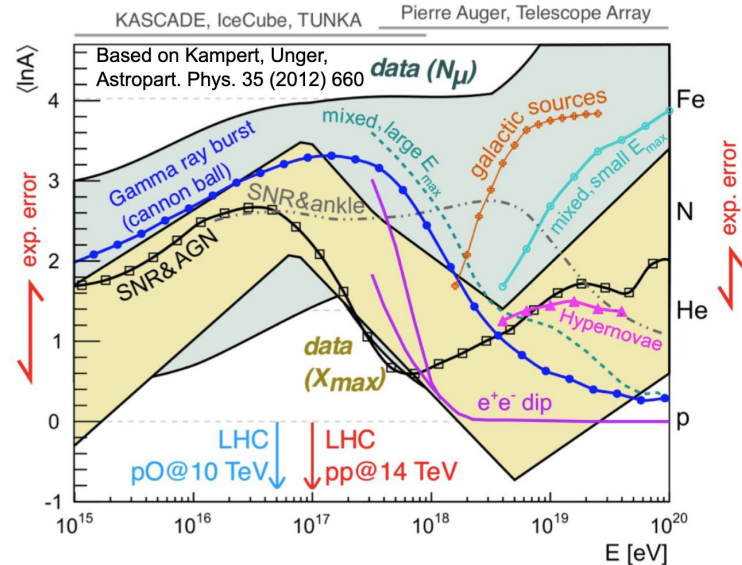
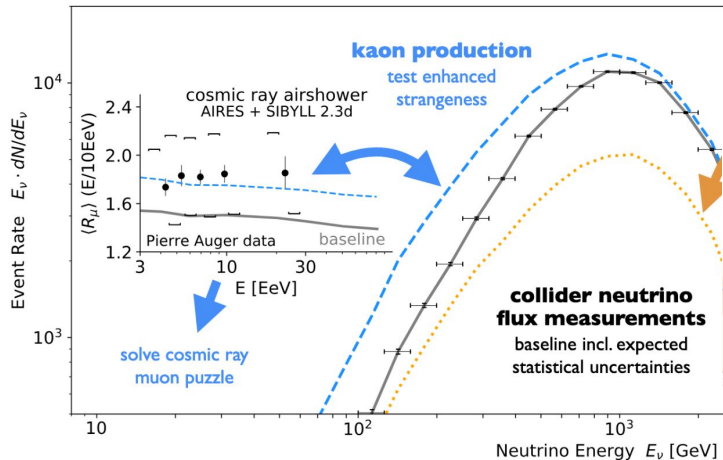
forward charm production at the LHC constraints on **prompt atmospheric neutrino flux** at IceCube

collider neutrino program is endorsed/supported by the astroparticle community

Light Hadrons and Muon Puzzle.

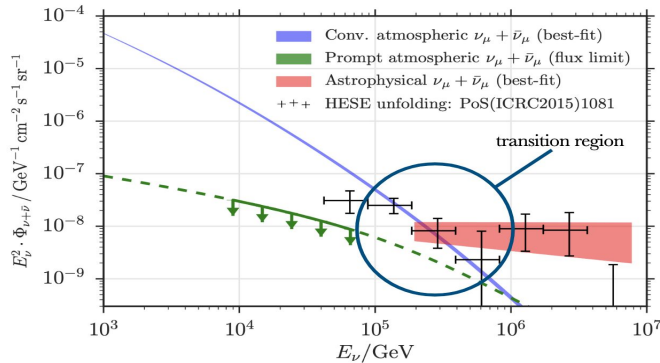
cosmic ray muon puzzle: observed 8 σ excess of muons compared to predictions from hadronic interaction models

prevents extracting flux composition and origin of cosmic rays



strangeness enhancement: solves puzzle and can lead to large differences at LHC

Charm Astroparticle Physics.

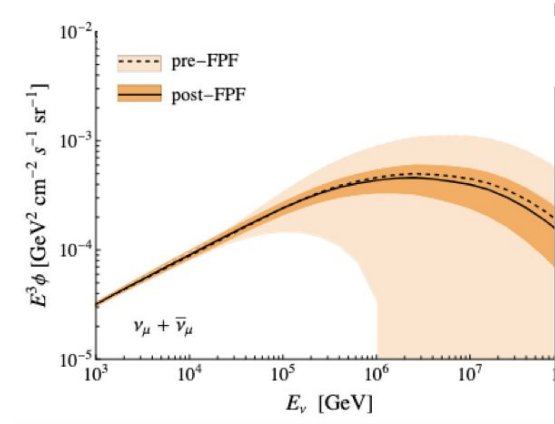


forward charm production at the LHC



constraints on prompt atmospheric
neutrino flux at IceCube

(currently very poorly
constrained/understood)

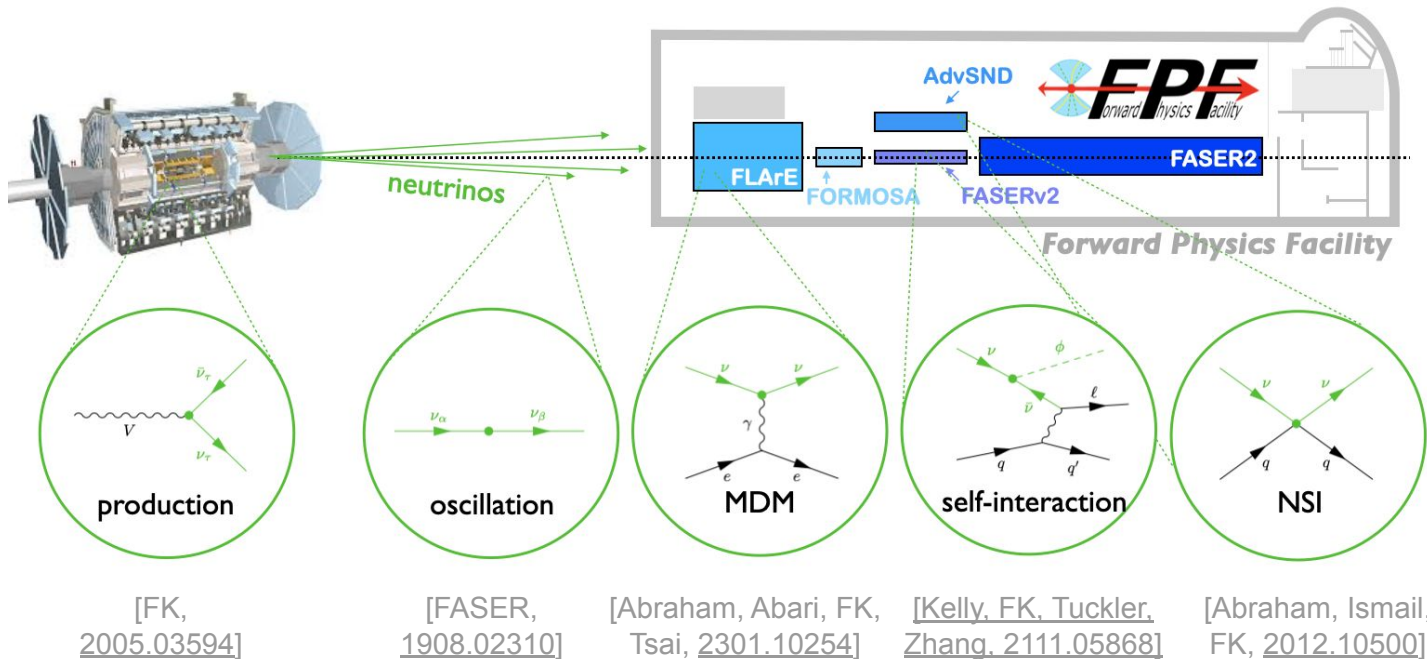


FPF data will improve flux predictions!

[Reno, Jeong, FPF [2411.04175](#)]

BSM Physics

Collider Neutrinos: BSM Physics.

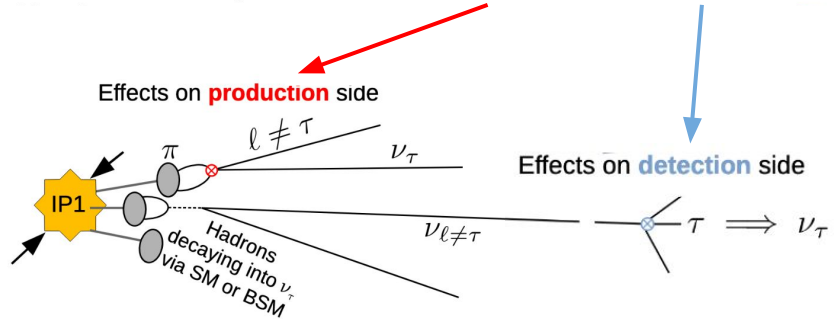


Collider Neutrinos: BSM Physics.

Non Standard Interactions associated can modify tau neutrino flux

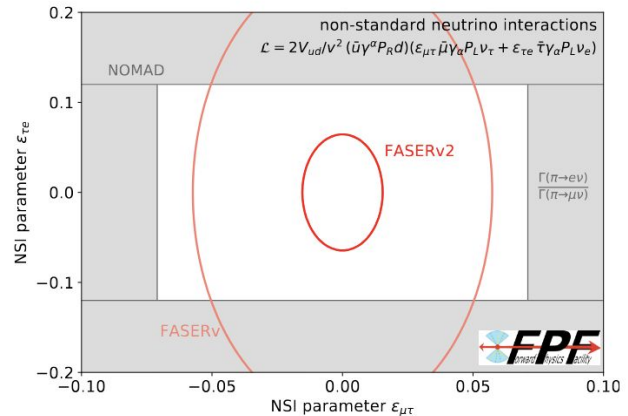
[Falkowski et al, [2105.12136](#)]

$$\mathcal{L} = \mathcal{L}_{\text{SM}} - \frac{2V_{ud}}{v^2} \times (\bar{u}\gamma^\kappa P_R d) \times [\epsilon_R^{\mu\tau} (\bar{\ell}_\mu \gamma_\kappa P_L \nu_\tau) + \epsilon_R^{\tau e} (\bar{\ell}_\tau \gamma_\kappa P_L \nu_e)]$$



Can be probed at FPF!

[FK, Mäkelä, Trojanowski, [2309.10417](#)]



Collider Neutrinos: BSM Physics.

new light weakly coupled particles could decay into tau neutrinos.

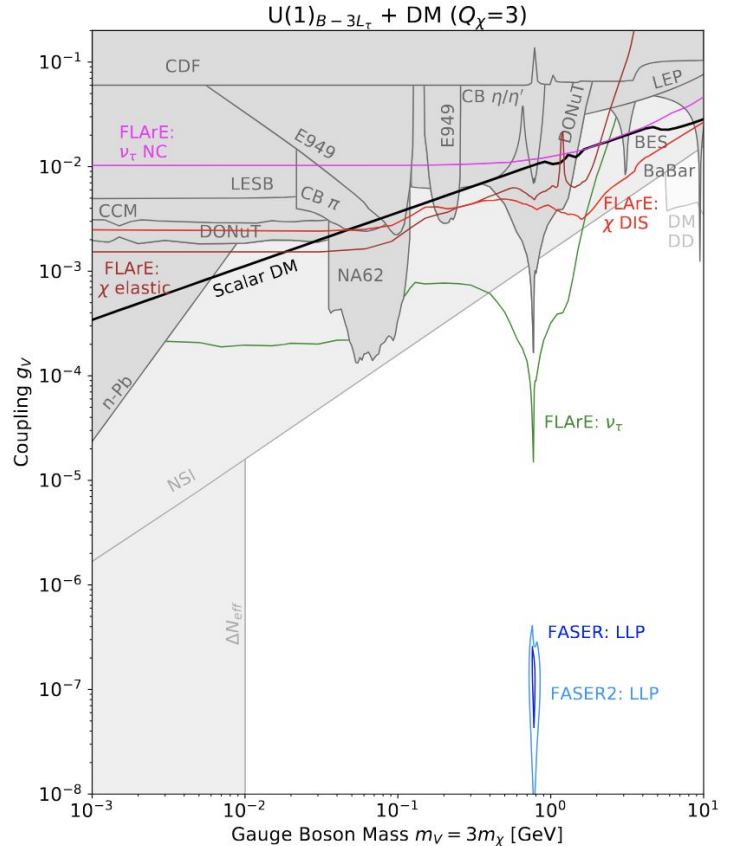
$$\pi^0 \rightarrow V\gamma, \quad V \rightarrow \nu_\tau \nu_\tau$$

Excess of tau neutrinos

[FK, [2005.03594](#)]

Can be probed at FPF!

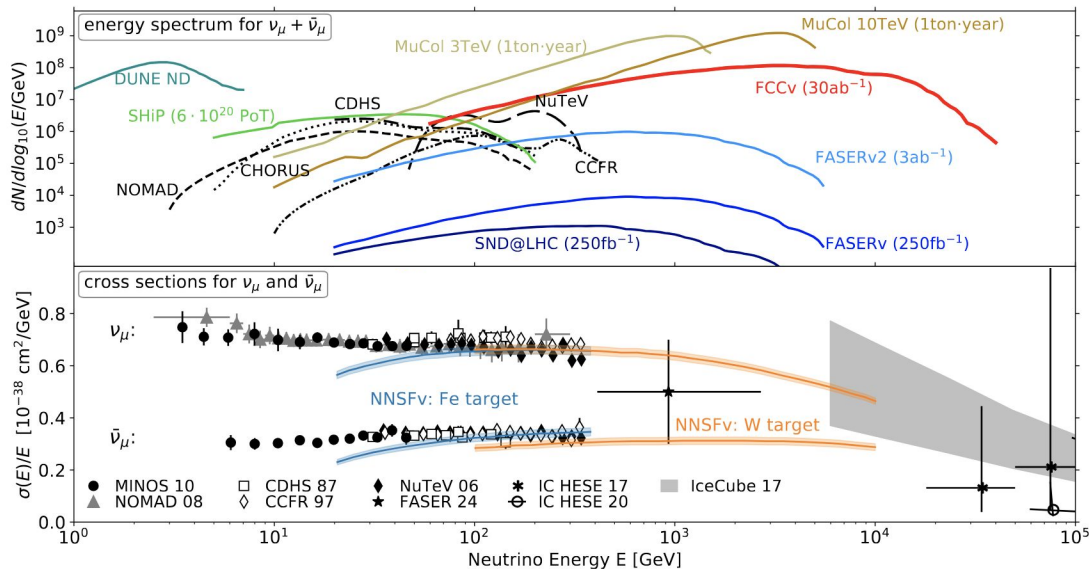
[Batell et al [2111.10343](#)]



Summary and Outlook

Future Colliders.

Great potential for forward neutrino measurements and searches also muon collider [IMCC, [2407.12450](#)] and FCC-hh [Abraham et al, [2409.02163](#)]



1B neutrinos will allow many precision studies:
PDFs at $x \sim 10^{-9}$, polarized PDFs, nuclear PDFs, neutrinos from heavy ions

Summary.

There is lots of interesting and unique physics that can be done with collider neutrinos.