Overview of collider neutrinos

active neutrinos at the LHC

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中国广东珠海

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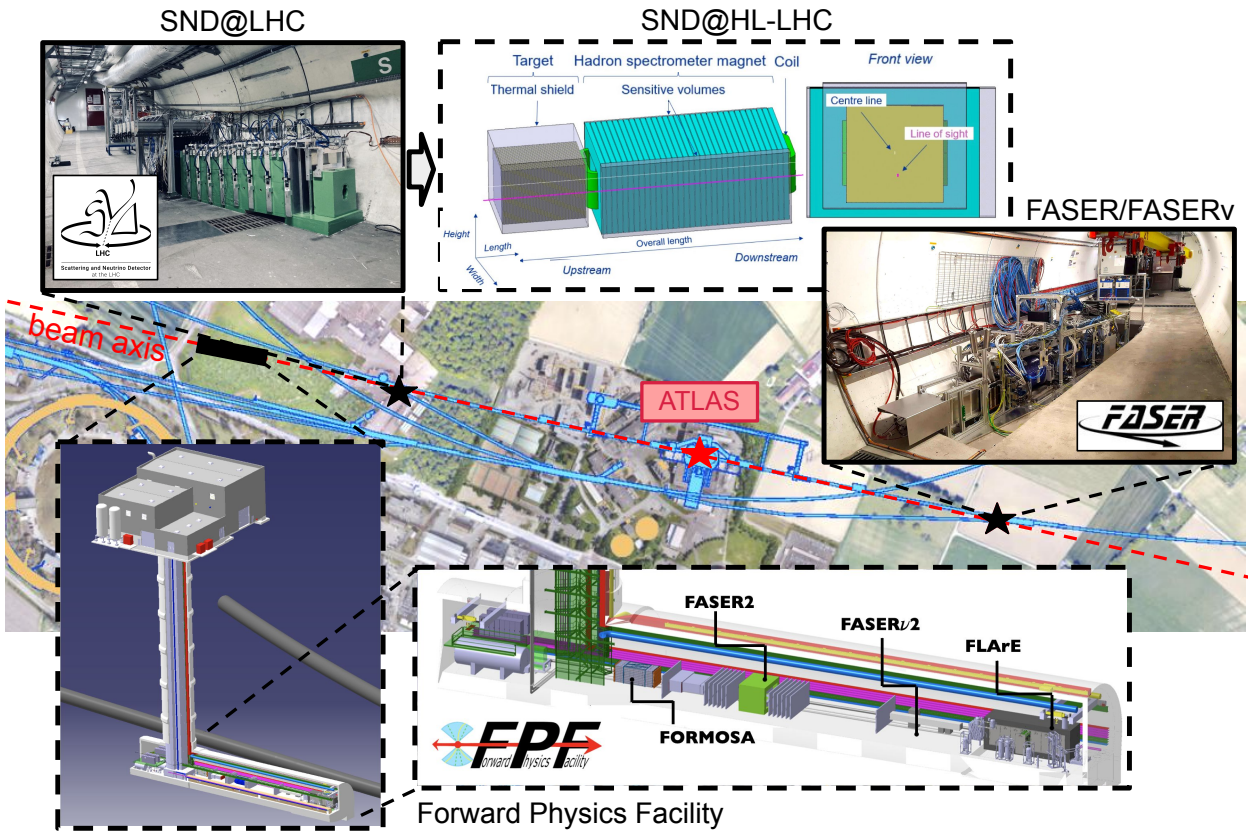
Motivation – collider neutrinos

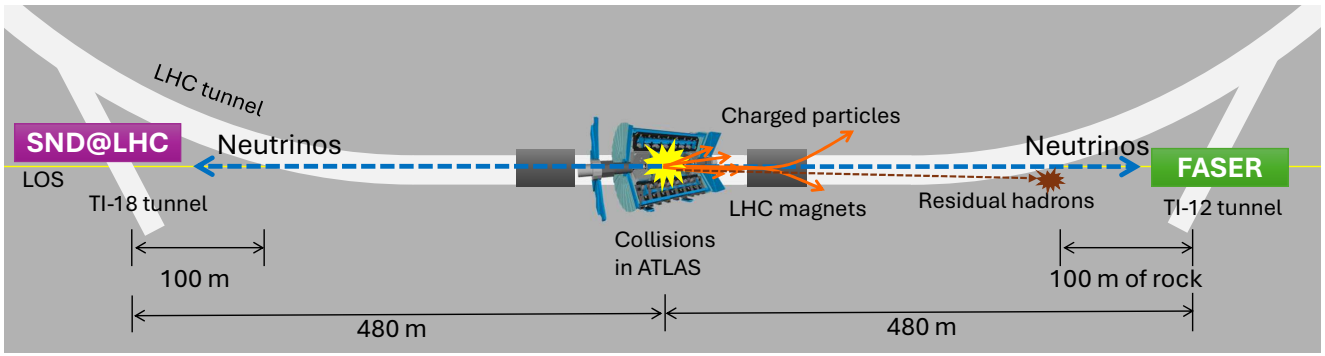
- $m_\nu = 0$ in the SM
- $\nu_\alpha \leftrightarrow \nu_\beta \Rightarrow m_\nu \neq 0$ and very light:
- Observed $\Delta m^2_{\text{sol.}} \& \Delta m^2_{\text{atmo.}} \Rightarrow \geq 2$ neut. mass eigenstates have $m \neq 0$
- Concrete evidence of BSM physics
- Detected neutrinos from various sources over a wide energy range:

Solor	Reactor	Supernova	Beam Dumps	Atmospheric	Cosmic
$\sim$ MeV	$\sim$ MeV	$\sim$ MeV	GeV – subTeV	subGeV – PeV	TeV – EeV

- See Zhenjie Wang's talk for an overview of high-energy neutrinos
- Recently observed *collider neutrinos* for the first time: highest-energy ever human-made neutrinos (100 GeV – multi TeV), complementary to the other sources
- Sources: decays of π, K, Λ, D, Λ_c, W, Z, ...
- Dominantly forward flying at the LHC

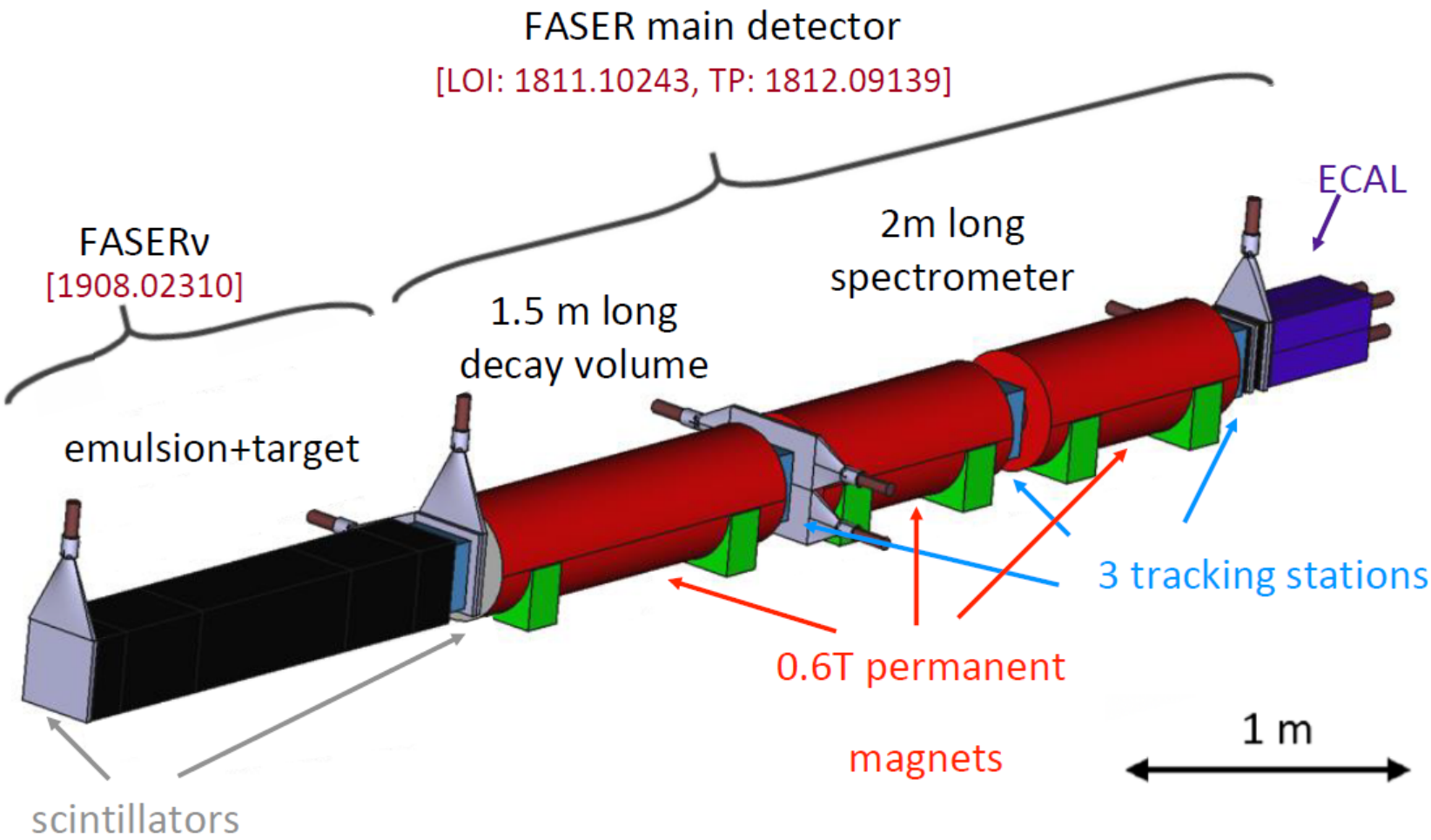
LHC neutrino experiments





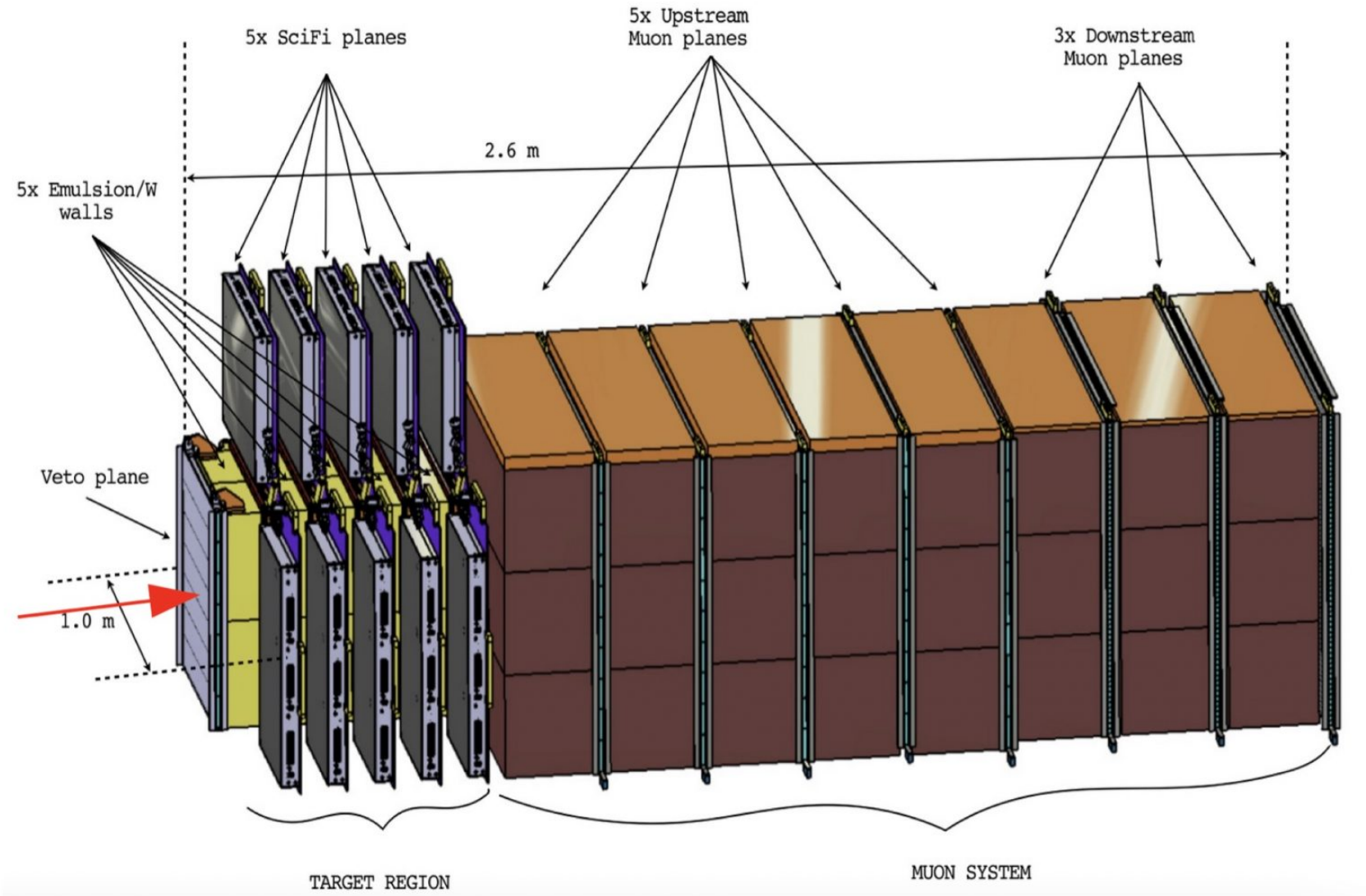
Ariga et al. 2501.10078

FASER



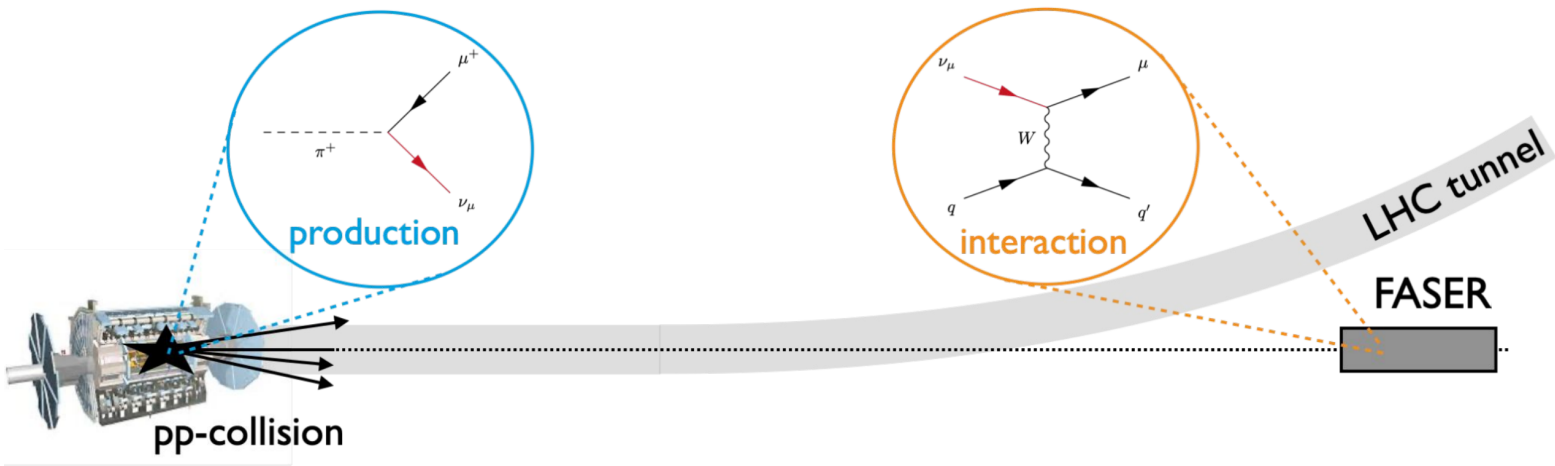
- FASERν: LOI 1908.02310 and TP 2001.03073
- FASER: LOI 1811.10243 and TP 1812.09139

SND@LHC



SND@LHC in 2025 and Beyond

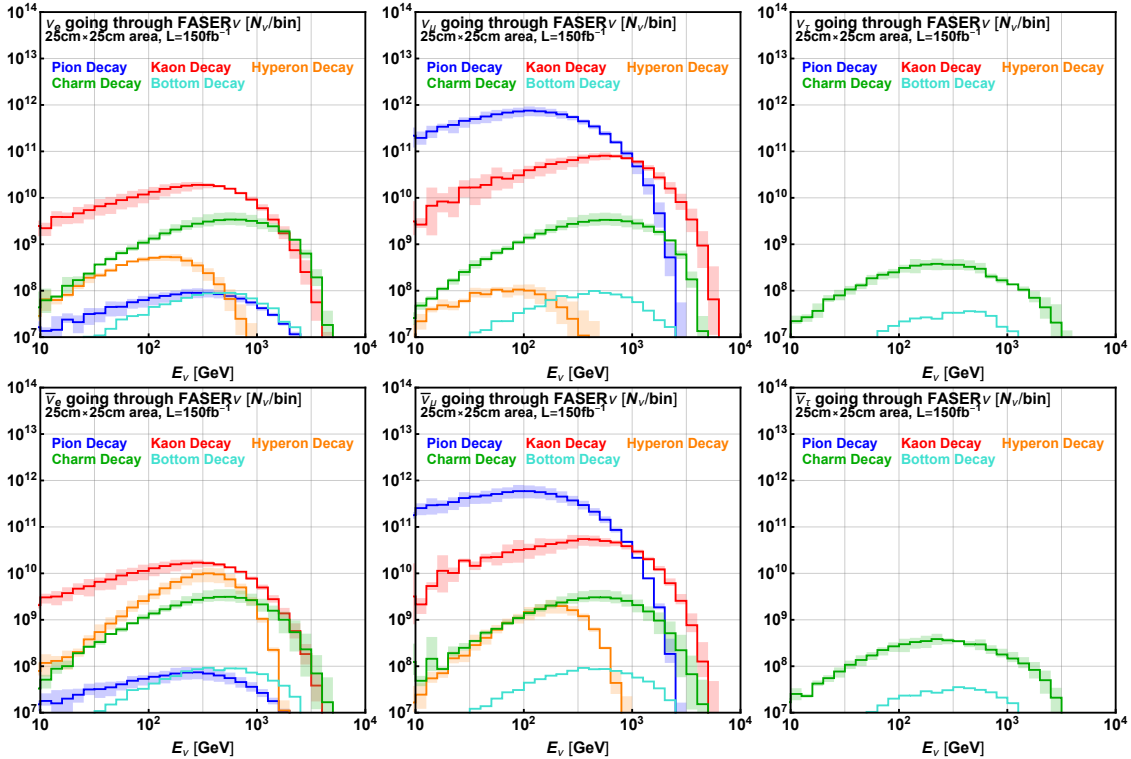
Production and Detection

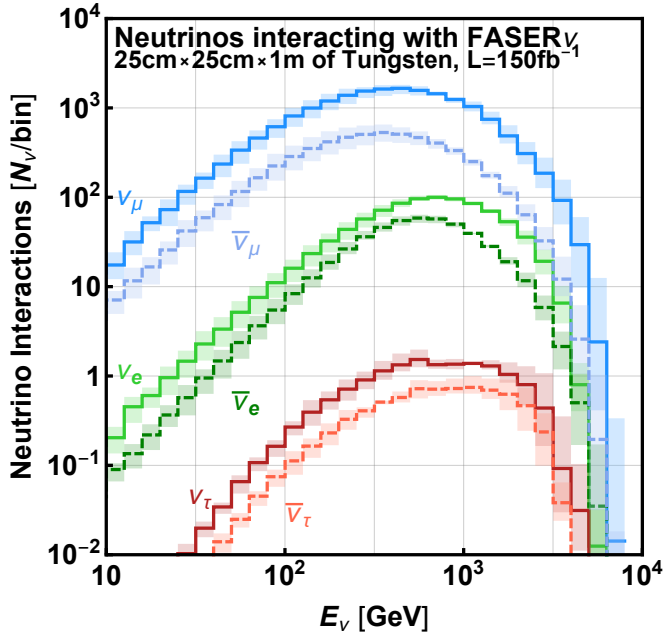


Extracted from F. Kling's talk

- Production dominantly from light and charm hadrons
- Detection via CC interactions, with TeV-energy neutrino interactions

Estimated neutrino numbers at FASERν



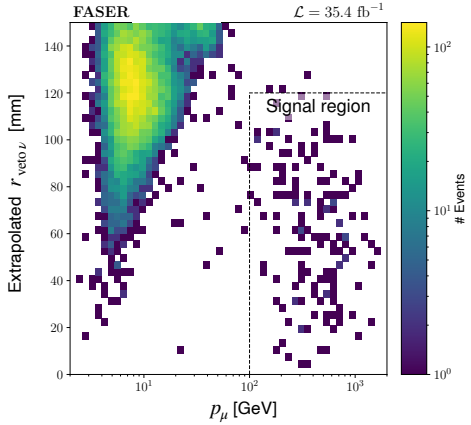


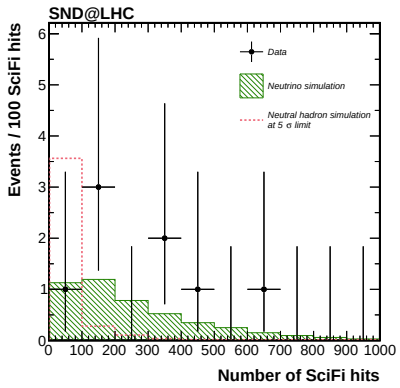
FASER

- ν_μ's from decays of charged pions and kaons
- ν_e's from decays of kaons and charm baryons
- ν_τ's from $D_s \to \tau$ and τ decays

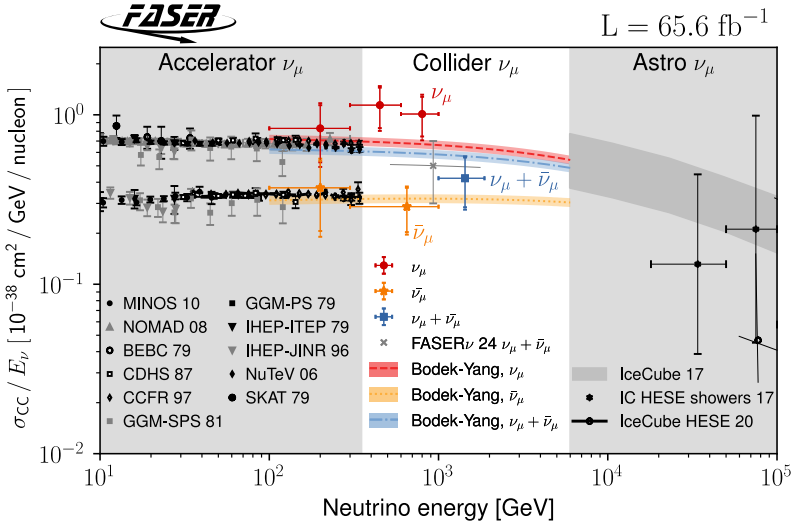
First experimental results

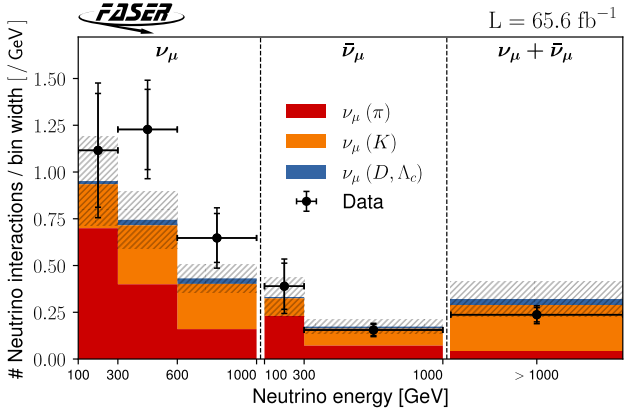
- First observations of collider neutrinos:
  153 events (FASER) & 8 events (SND@LHC)





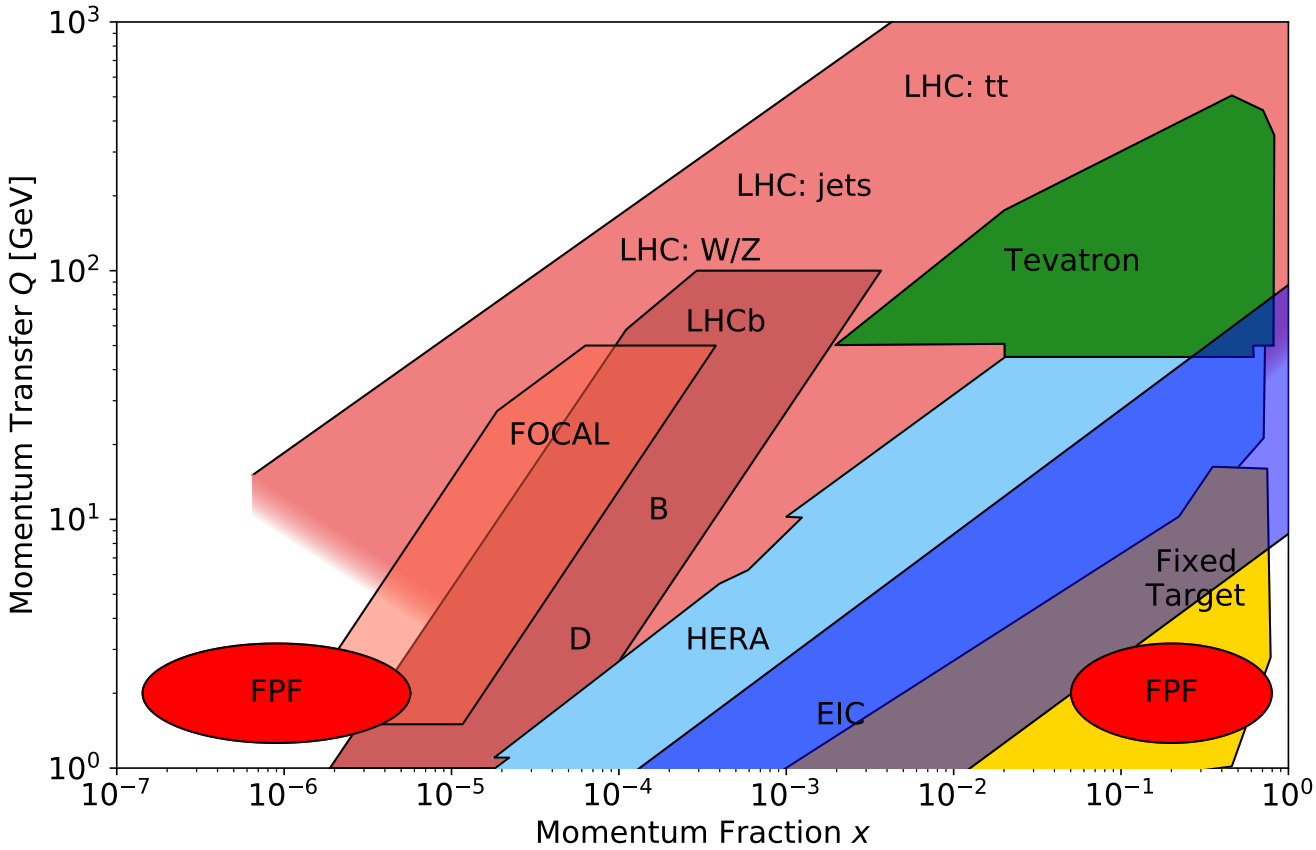
- First cross-section measurement (FASER, FASER)





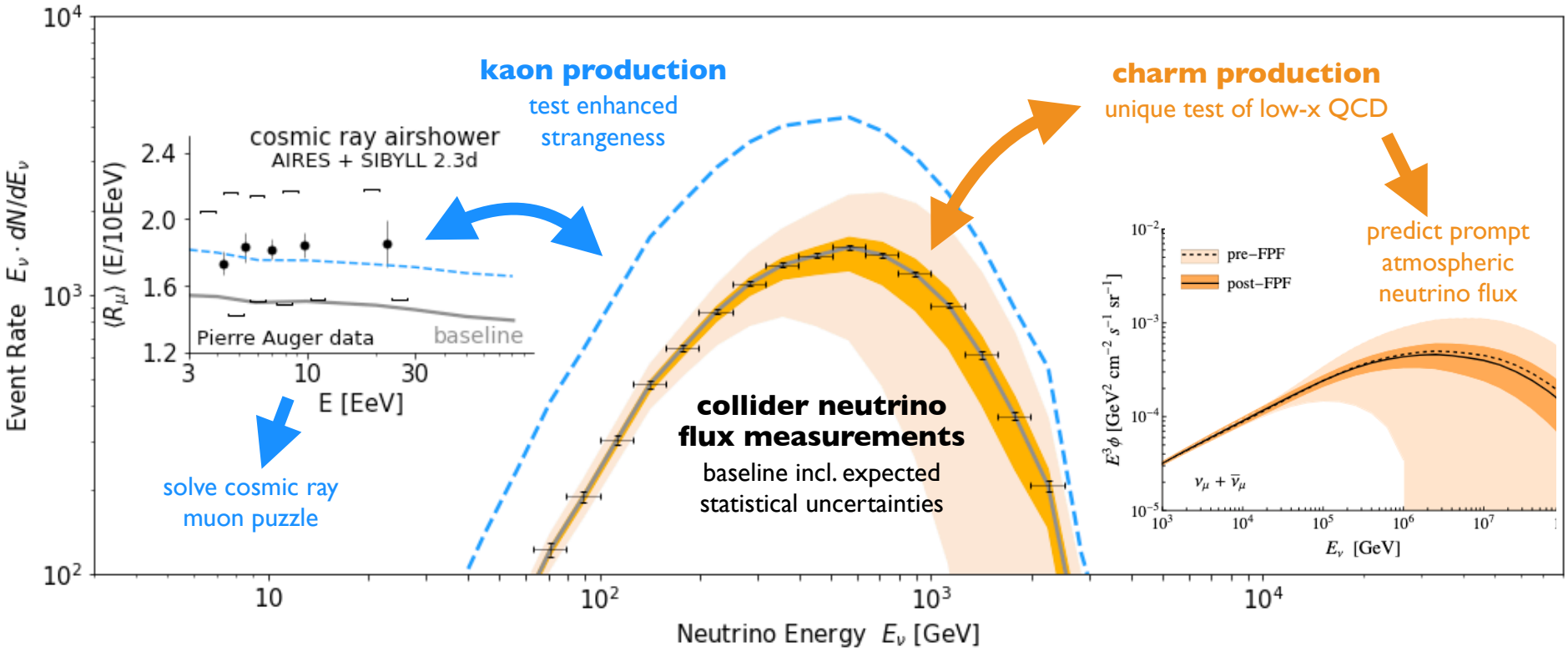
- First flux measurements FASER

Probing QCD from charmed-hadron decays



- Uncharted kinematic regimes in QCD probed with neutrinos from forward charm production FPF 2022
- Constraining gluon PDF at $x \sim 10^{-7}$ FPF 2024

Astroparticle physics

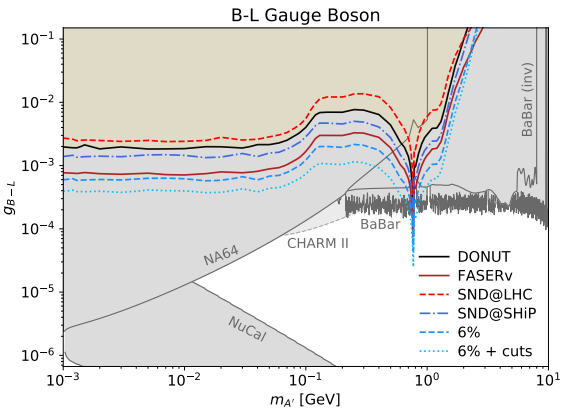


FPF 2024

- Cosmic-ray muon puzzle: observed 8σ excess of muons compared to predictions from hadronic interaction models; need strangeness enhancement
- Forward charm production at the LHC places constraints on PDF and thus prompt atmospheric neutrino flux at IceCube

BSM physics

1. Kling 2020: constraint dark gauge bosons with ν_τ production rates
2. Ismail, Abraham, Kling 2020: measure NC ($\nu N \to \nu N$) cross sections and place limits on NSIs
3. Cheung, Ouseph, Wang 2021: NSI and Z' modify XS predictions
4. Cheung, Ouseph 2022: $\nu \to N$ transitional magnetic dipole moments with a Z', and displaced decays of N inside FASERν or FASER
5. Cheung, Nguyen, Ouseph 2023: a vector leptoquark modifies XS predictions
6. Abraham, Abari, Kling, Tsai 2023, Kelly, Kling, Tuckler, Zhang 2021, Francener, Goncalves, Gratieri 2024. . . . . .



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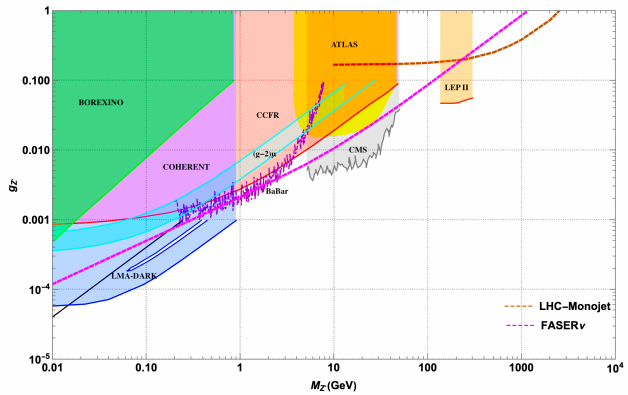

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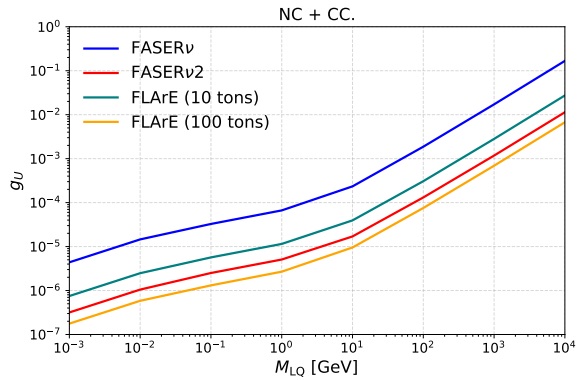

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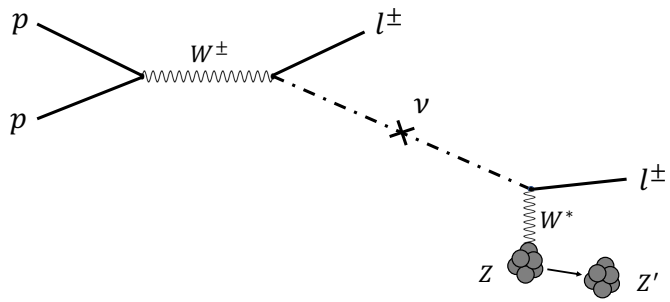
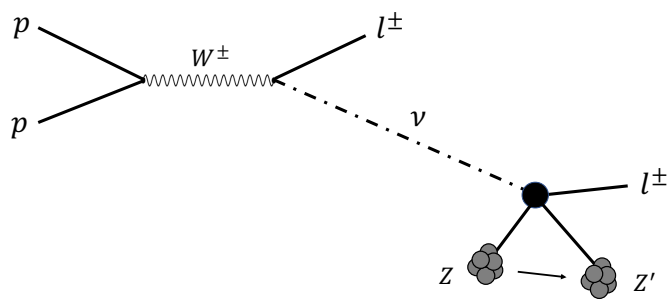
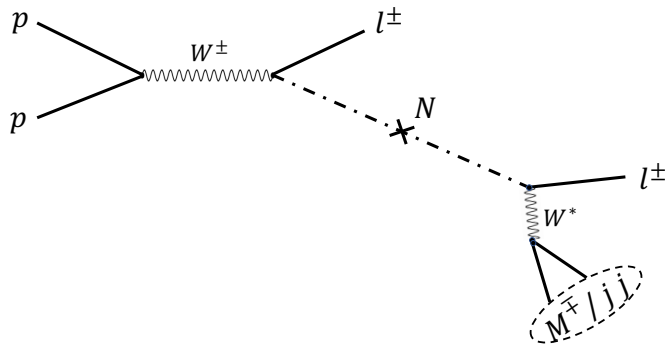
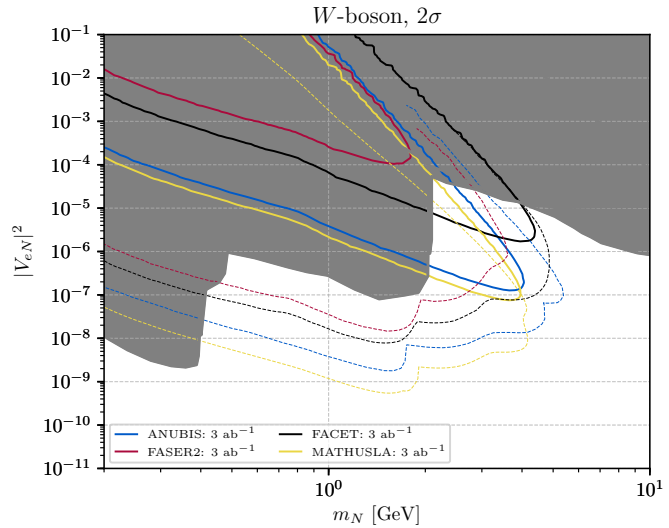
Probing lepton number violation





- Small CC interaction rates & strong helicity-flip suppression: no $\mathcal{O}(1)$ results, even with EFT Mao, Wang, ZSW 2023



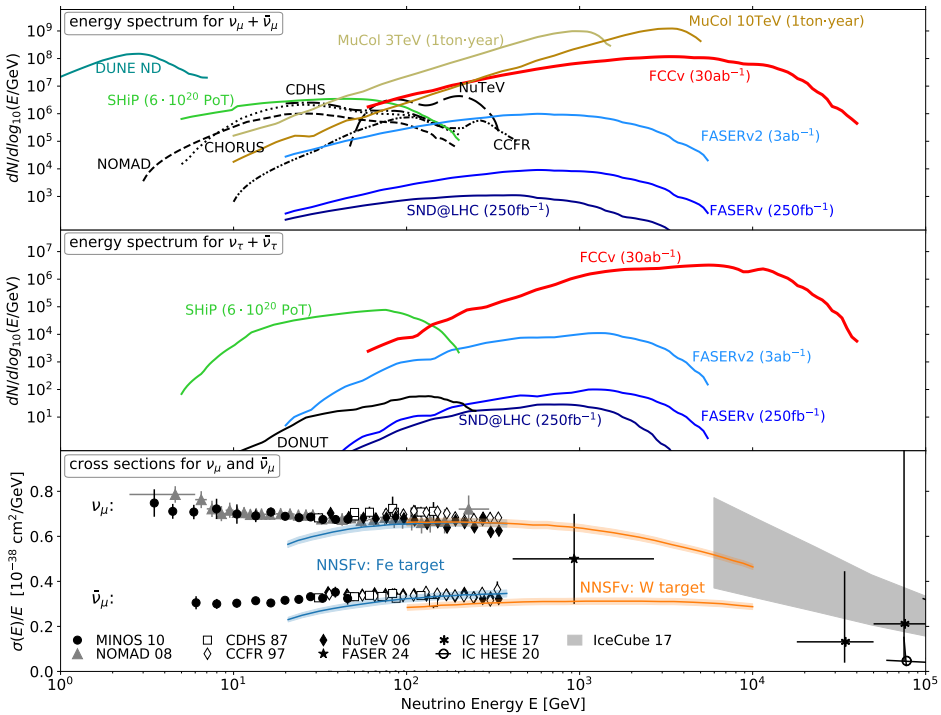


- Displaced search for long-lived N with LNV: meaningful results

Mao, Wang, ZSW 2023 See the talk of Ramsey-Musolf for discussions on LNV

Collider neutrinos at future colliders

- Larger forward neutrino fluxes at future Muon colliders and FCC-hh



Detector	$N_{\nu_e} + N_{\bar{\nu}_e}$	$N_{\nu_\mu} + N_{\bar{\nu}_\mu}$	$N_{\nu_\tau} + N_{\bar{\nu}_\tau}$
FASERν2	220k	1.1M	4.3k
FCCν	62M	130M	3.2M
FCCν(d)	620M	1.3B	32M
FCCν(w)	170M	370M	11M

Up to $\mathcal{O}(10^9)$ neutrinos

Summary

- Lots of neutrinos esp. from decays of π, K, D, Λ_c, ...
- Current experiments: FASERν and SND@LHC, detection with CC int.
- First observations of collider neutrinos (FASERν and SND@LHC)
- Cross-section and flux measurements (FASERν)
- Physics applications:
  - Reducing uncertainties of proton and nuclear PDFs
  - BSM physics
  - ...
- Orders of magnitude more collider neutrinos expected at future muon colliders and FCC-hh

Thank You! 感谢垂听!