Forward Physics Facility at CERN: Neutrino Interactions Physics

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U.S. DEPARTMENT OF ENERGY | Office of Science

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Forward Physics Facility

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

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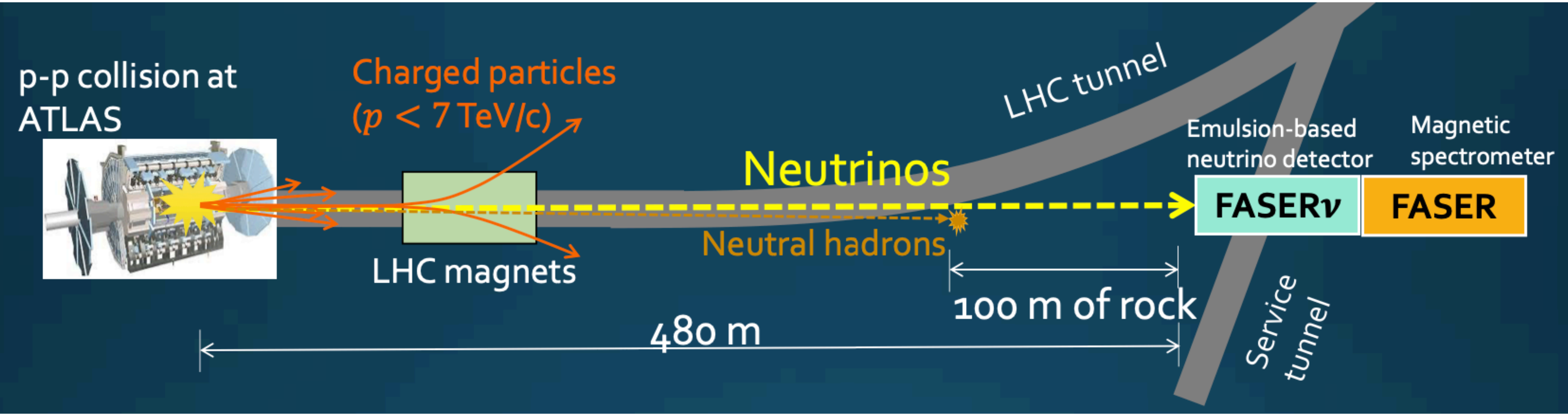
Neutrinos at the Forward Physics Facility

- The Forward Physics Facility (FPF) is a proposal to create a infrastructure to support a suite of experiments at the far-forward region at the LHC. To explore a rich BSM and SM physics program in the far-forward region during High Luminosity-LHC (HL-LHC) era.

- ATLAS provides an intense and strongly collimated beam of highly energetic neutrinos of all three flavors in the far-forward region around the beam collision axis.

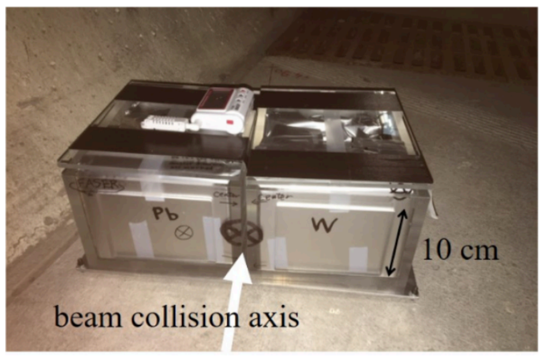
- The neutrinos at the FPF originate from weak decay of forward-going hadrons, in particular pions, kaons, hyperons, and charmed hadrons.

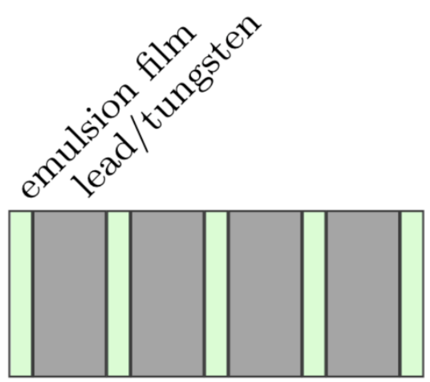


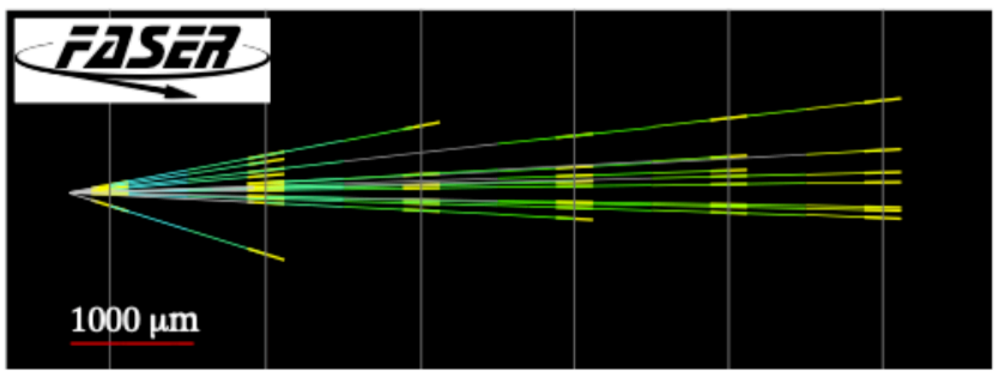
First Neutrino Interaction Candidates at the LHC

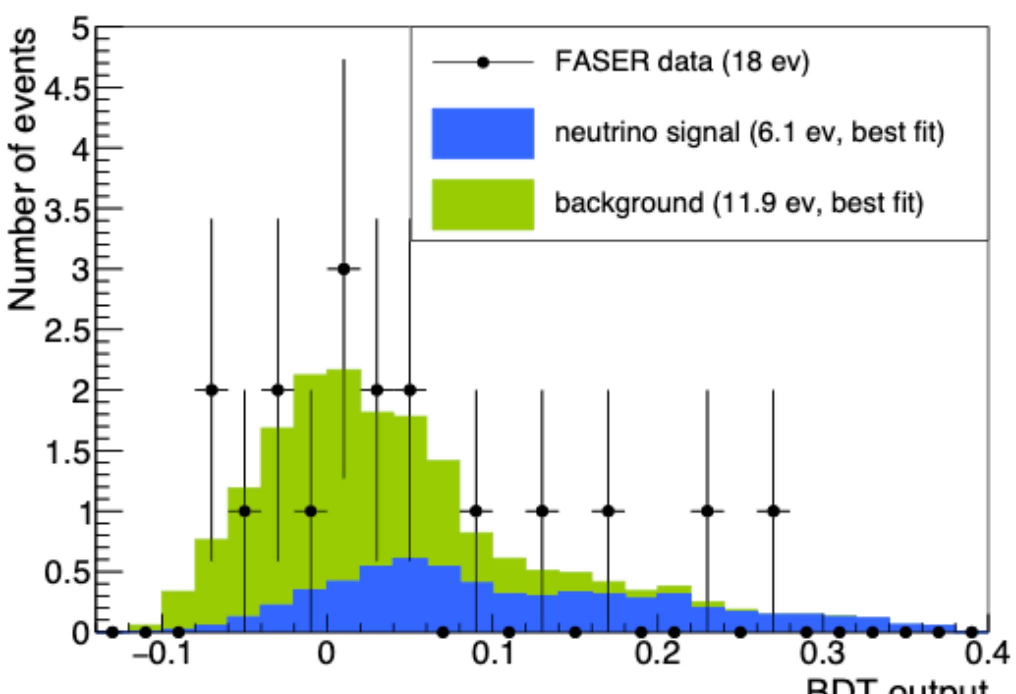
- In 2018, the FASERν collaboration placed a ~30 kg pilot emulsion detector in TI18 for a few weeks. They reported first ever neutrino interaction candidate events at the LHC. Marking the beginning of a new era of neutrino measurements in the LHC forward region.

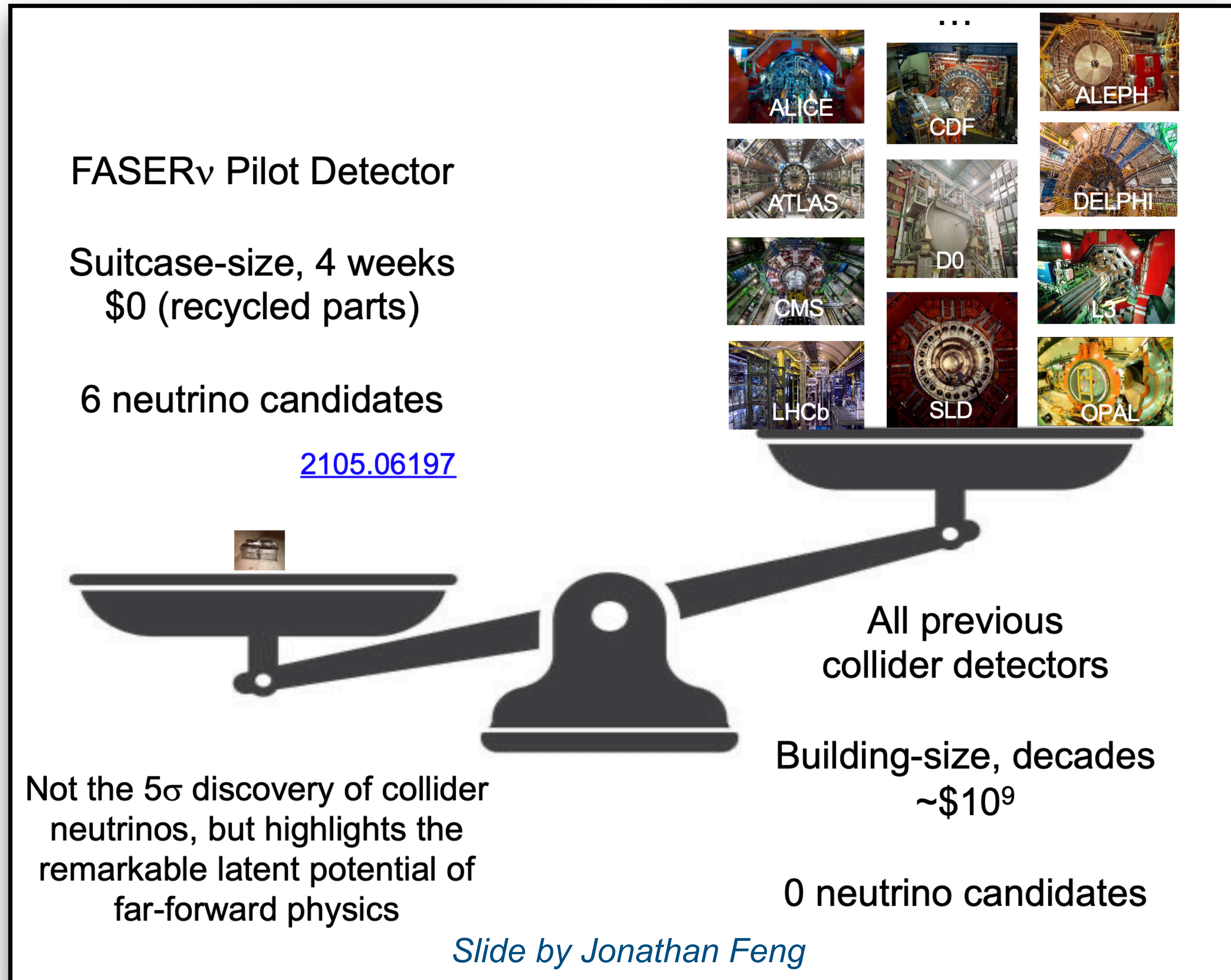
FASER collaboration: [arXiv:2105.06917 [hep-ex]]





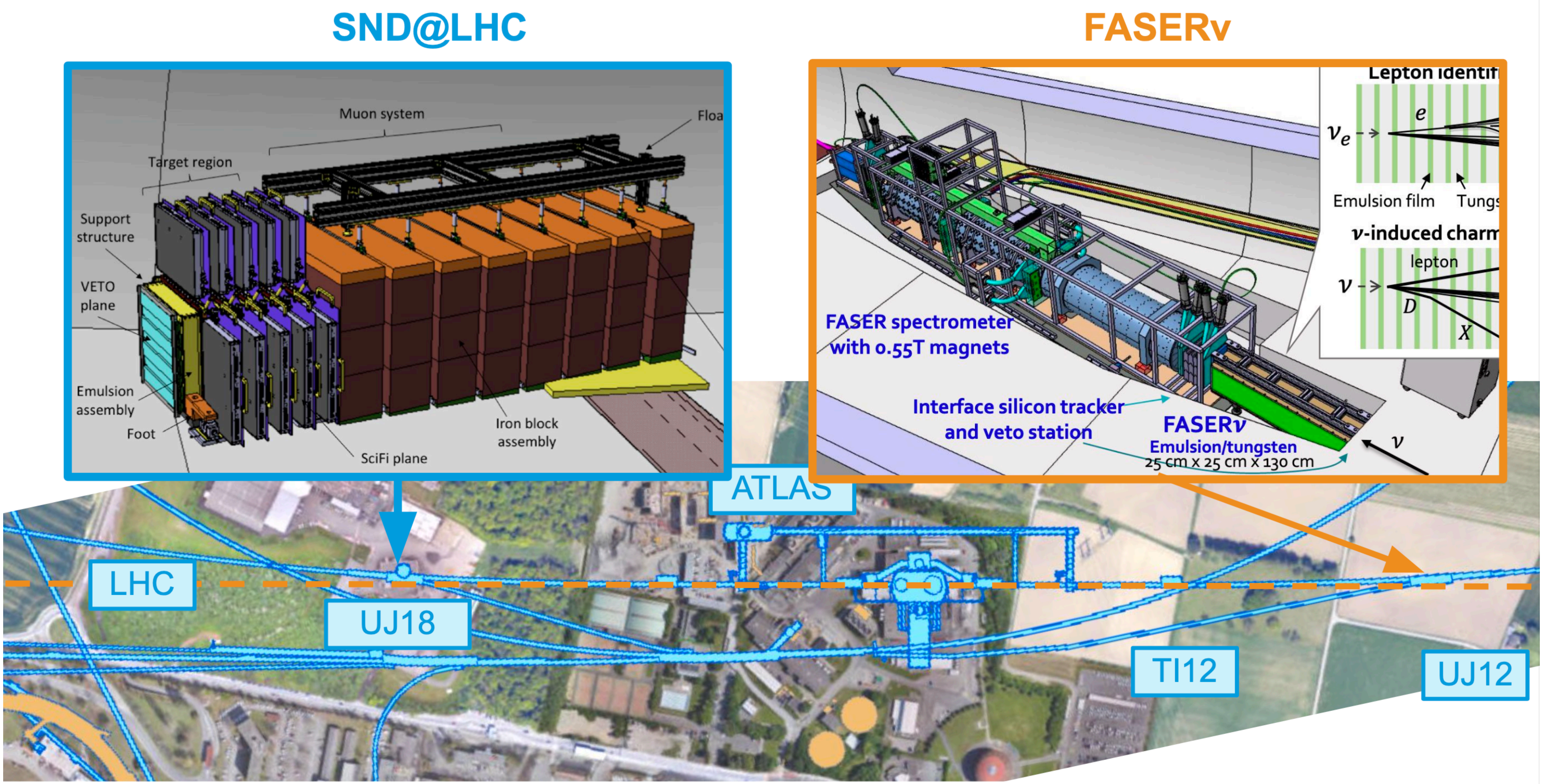






Experiments during LHC Run 3

- During the upcoming LHC Run 3, from 2022-24, two detectors are underway to exploit this far-forward potential.

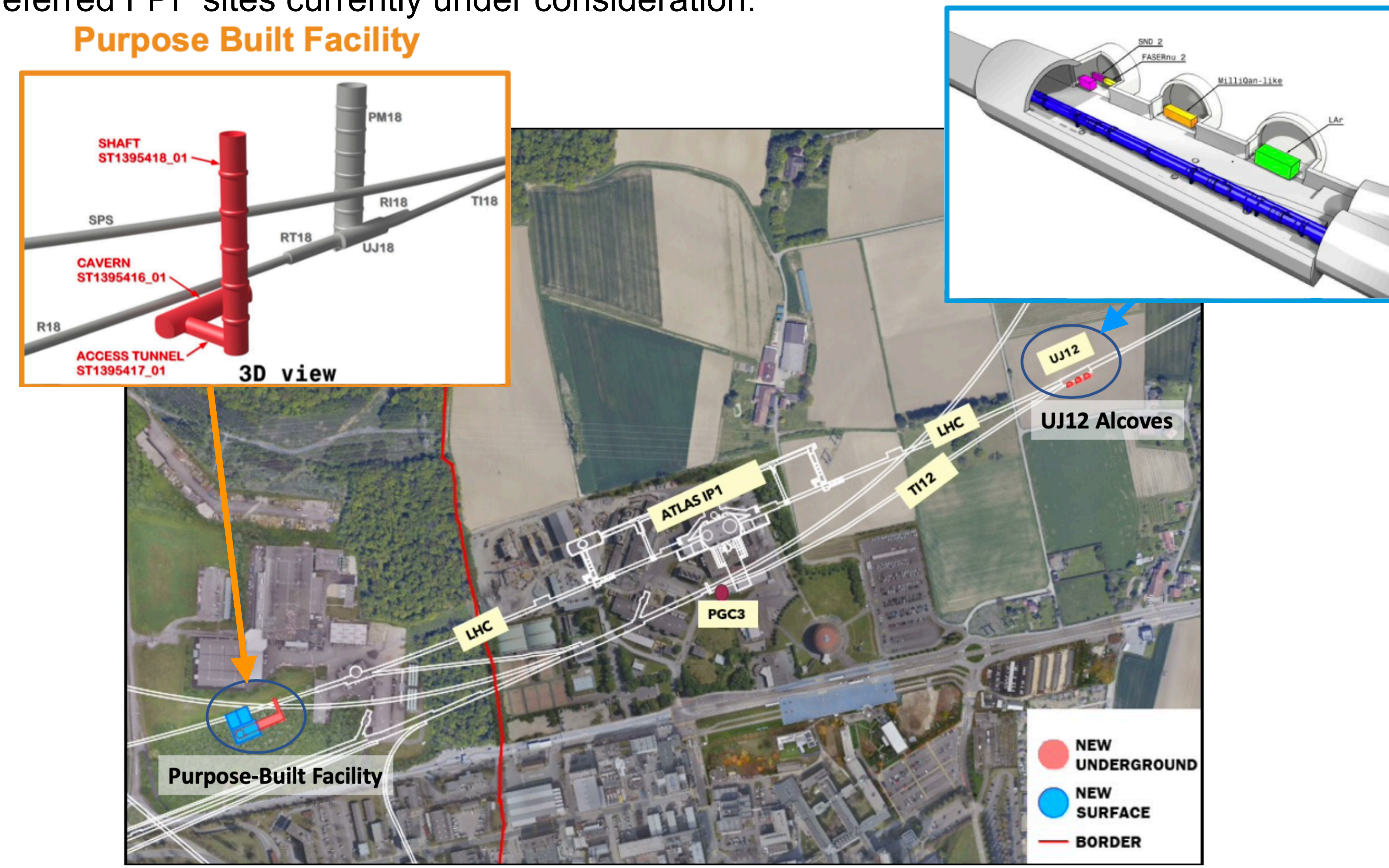


Forward Physics Facility Proposal

- The FPF is a proposal to extend this program into the High Luminosity LHC (HL-LHC) era, expected from 2027-37. 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.
- Two preferred FPF sites currently under consideration.

UJ12 Alcove Extension

Purpose Built Facility



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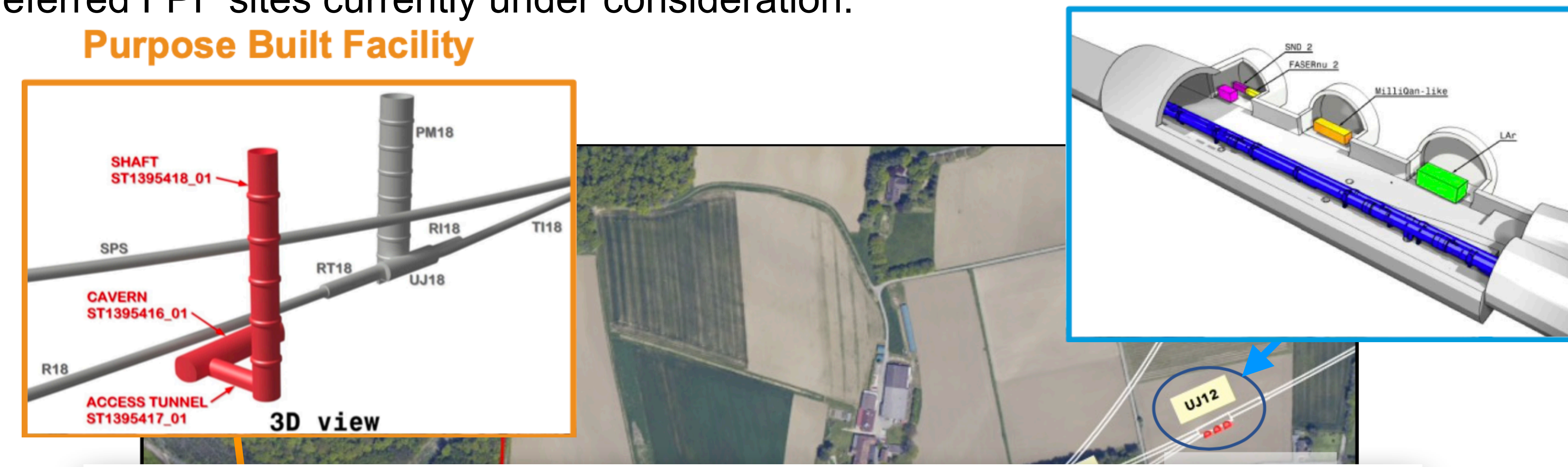

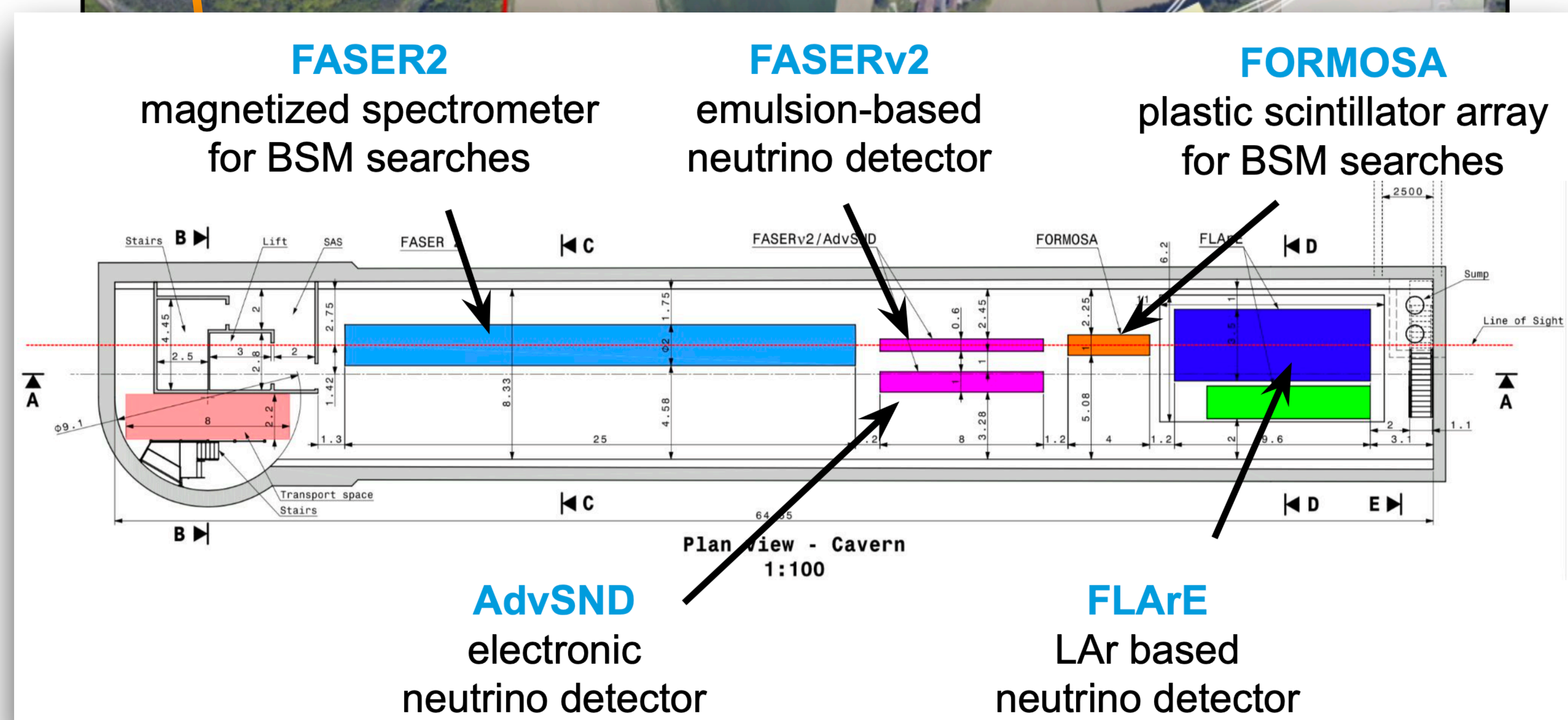

FPF Progress and Plans

- We had three dedicated FPF workshops so far:

  - FPF Kickoff Meeting, November 2020: https://indico.cern.ch/event/955956/
  - FPF2 Meeting, May 2021: https://indico.cern.ch/event/1022352/
  - FPF3 Meeting, October 2021: https://indico.cern.ch/event/1076733
  - 4th FPF workshop planned in February 2022

- We have completed a first short paper: arXiv:2109.10905 [hep-ph]: "The Forward Physics Facility: Sites, Experiments, and Physics Potential"
  A significant effort by ~80 authors distilling key progress on the FPF so far.

- We are now preparing a Snowmass FPF White Paper, a ~200 page document to be submitted to Snowmass in February-March 2022.
  We are currently soliciting contributions.

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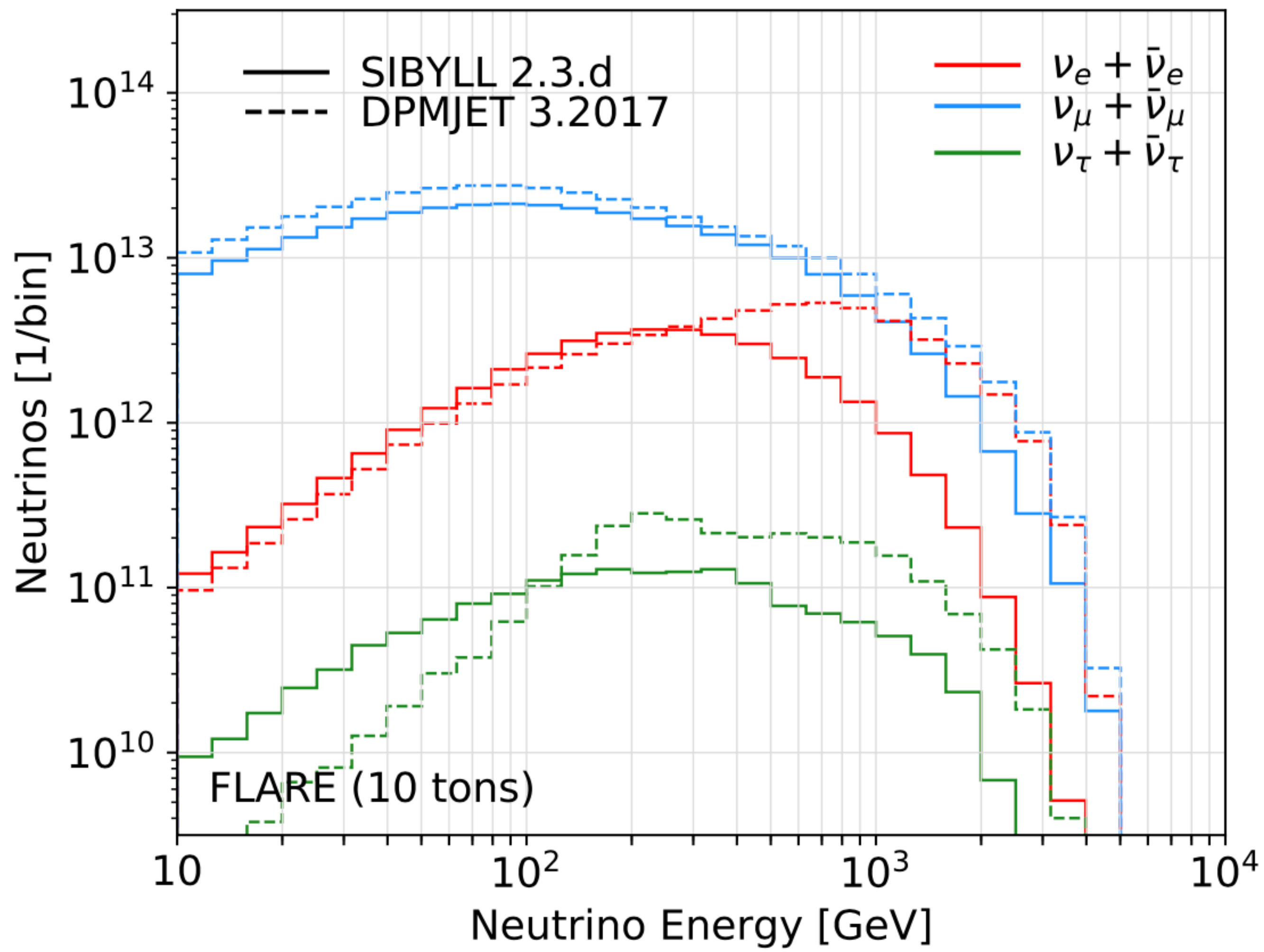
Neutrino Fluxes and Interactions

- Energy spectrum of neutrinos passing through a 1 m x 1 m cross-sectional area, corresponding to the FLArE detector.
- Neutrinos energy distributions peaks between 100 GeV - few TeV energies.
- Large statistics of neutrino events, of all neutrino flavors, expected during HL-LHC era.

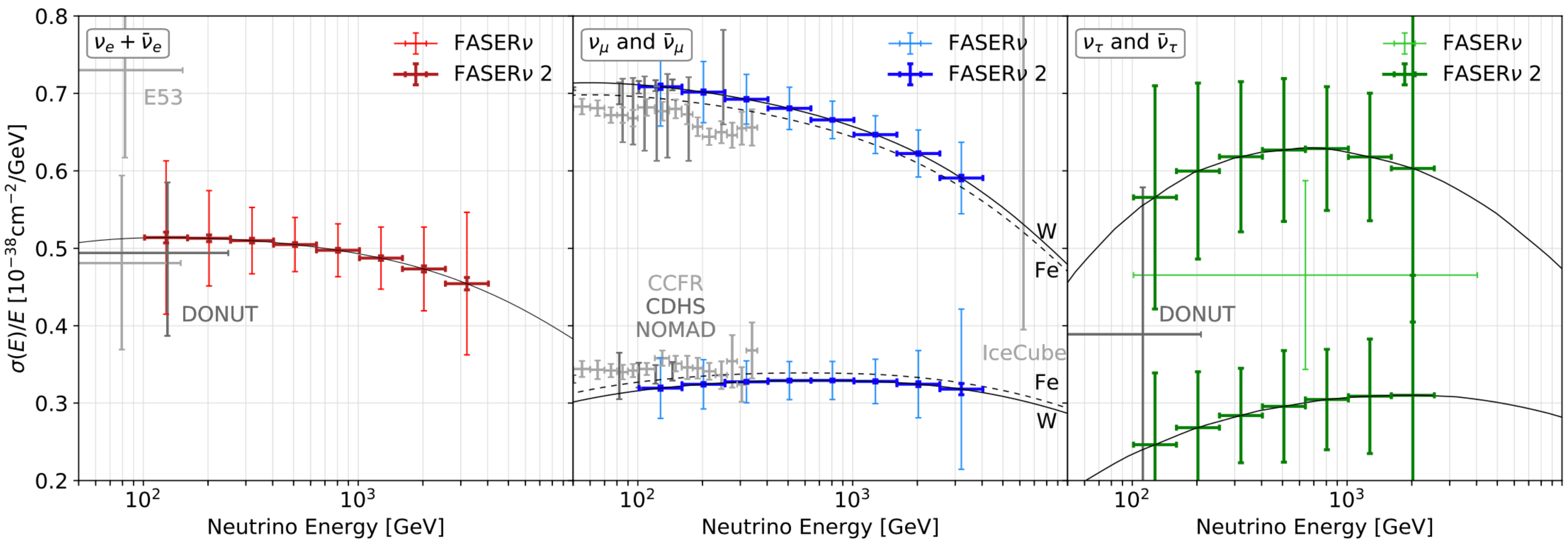


Detector			Interactions at FPF			
Name	Mass	Coverage	CC $\nu_e+\bar{\nu}_e$	CC $\nu_\mu+\bar{\nu}_\mu$	CC $\nu_\tau+\bar{\nu}_\tau$	NC
FASERν2	20 tonnes	$\eta \gtrsim 8.5$	178k / 668k	943k / 1.4M	2.3k / 20k	408k / 857k
FLArE	10 tonnes	$\eta \gtrsim 7.5$	36k / 113k	203k / 268k	1.5k / 4k	89k / 157k
AdvSND1	2 tonnes	$7.2 \lesssim \eta \lesssim 9.2$	6.5k / 20k	41k / 53k	190 / 754	17k / 29k
AdvSND2	2 tonnes	$\eta \sim 5$	29 / 14	48 / 29	2.6 / 0.9	32 / 17

TABLE III. The estimated number of neutrino interactions as obtained using two different event generators, `Sibyll 2.3d` and `DPMJET 3.2017`, for FPF experiments located 620 m downstream of the ATLAS IP at the HL-LHC with 14 TeV pp collisions and an integrated luminosity of $\mathcal{L} = 3\ \text{ab}^{-1}$.

Neutrino Interaction Cross Section

- High statistics CC and NC neutrino interaction cross sections on a variety of nuclear targets. Cross section measurements cover uncharted energy region between the accelerator and IceCube neutrino energies.
  - **DIS cross section:** Large statistics at completely unexplored energy region.



- FASERν at the Run-3 LHC

- FASERν2 at the HL-LHC

QCD physics: nuclear parton distributions, higher-order QCD corrections, …

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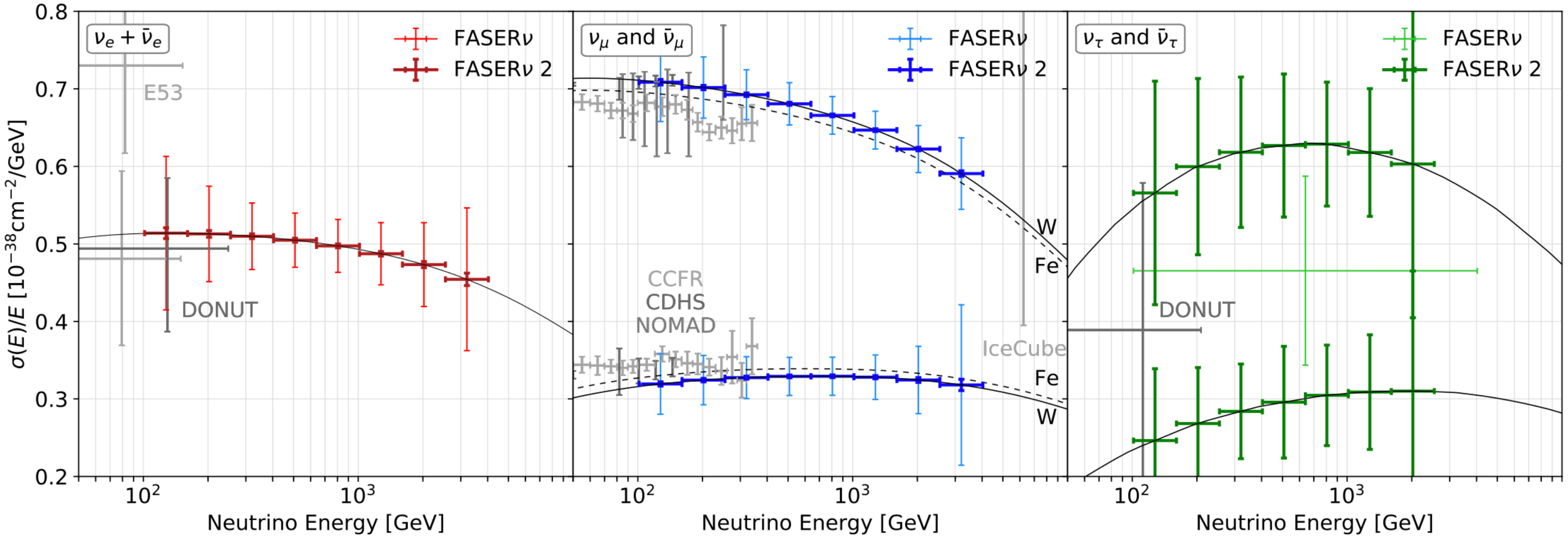

- FASERν at the Run-3 LHC

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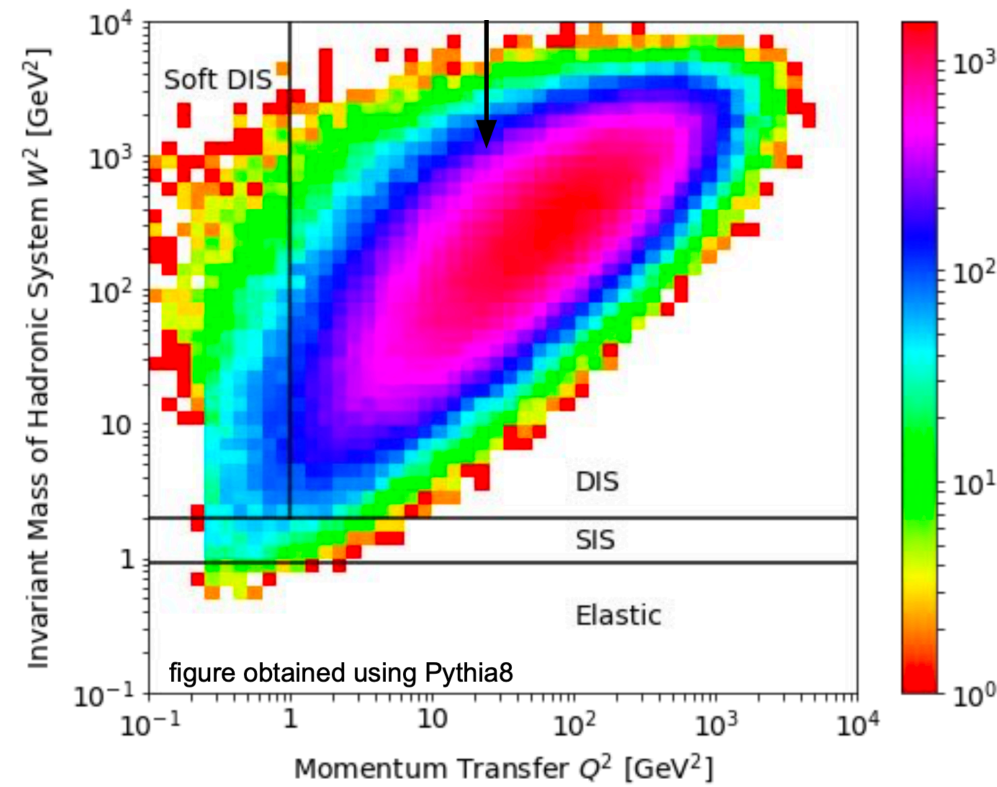
QCD physics: nuclear parton distributions, higher-order QCD corrections, …

- **SIS/DIS cross section:** Phase space covers 1000s of expected events in the SIS/DIS transition region.

- **QE/RES cross section:** Significant expected events in the QE & RES region.

>10^3 expected quasi-elastic and resonant events (estimated with GENIE)

at FLArE	CCQE				CCRES				NCEL	NCRES
	ν_e	ν_μ	$\bar{\nu}_e$	$\bar{\nu}_\mu$	ν_e	ν_μ	$\bar{\nu}_e$	$\bar{\nu}_\mu$	all	all
Event Rate	58	590	47	366	167	1673	184	1219	175	1206



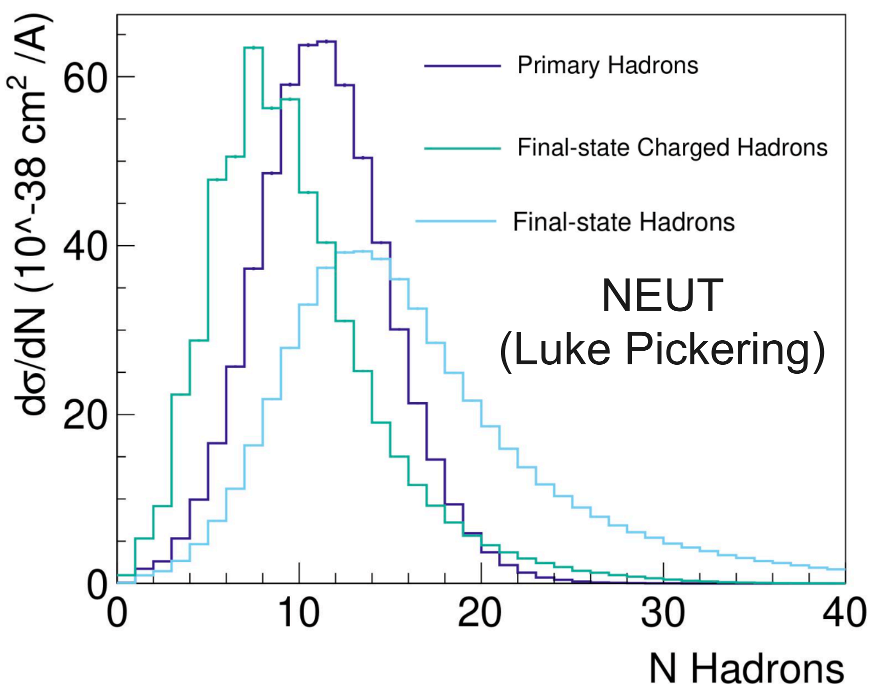
- **Test of lepton universality:** Intense beam of neutrinos of all three flavors allows unique opportunity to test lepton universality in neutrino scattering.

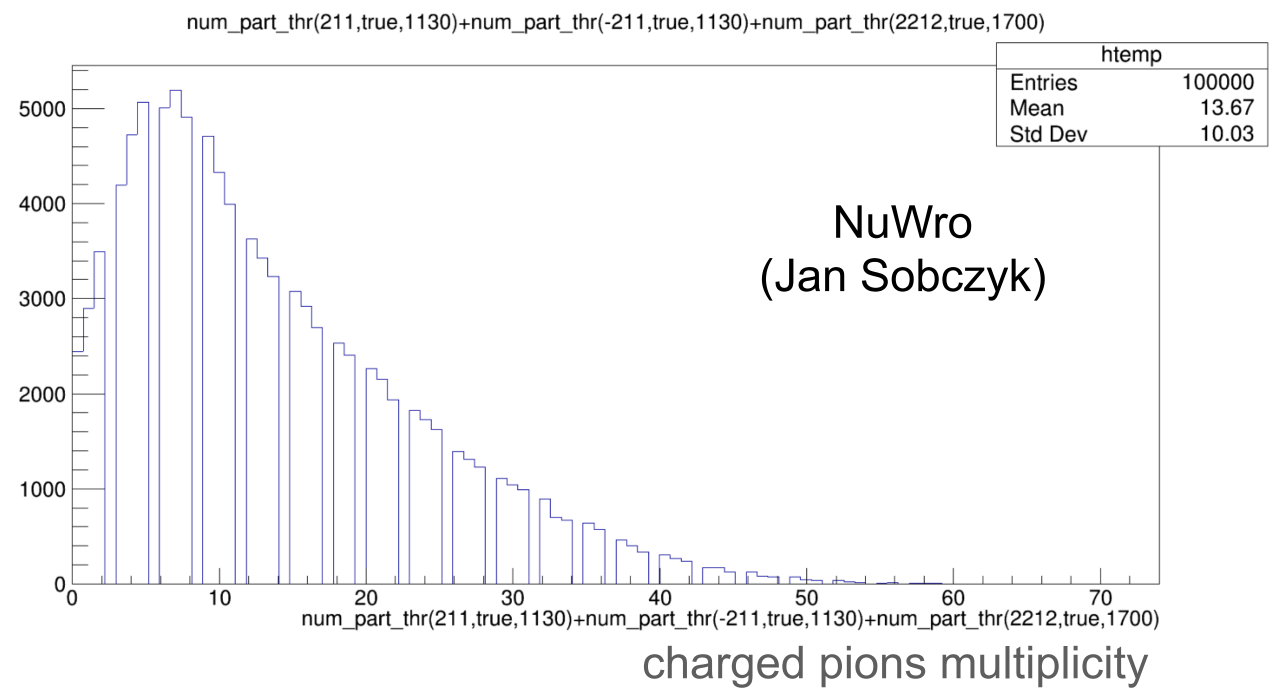
Neutrino Interaction Cross Section: Generators

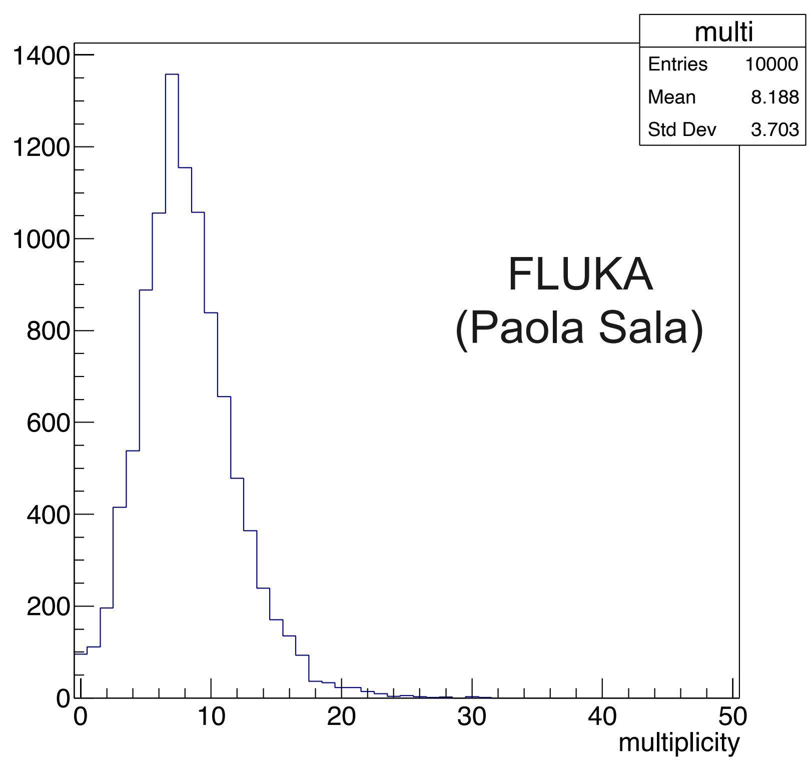
- We organized a dedicated session on Neutrino Monte-Carlo Generators at FPF3 Meeting in Oct 2021 (https://indico.cern.ch/event/1076733)

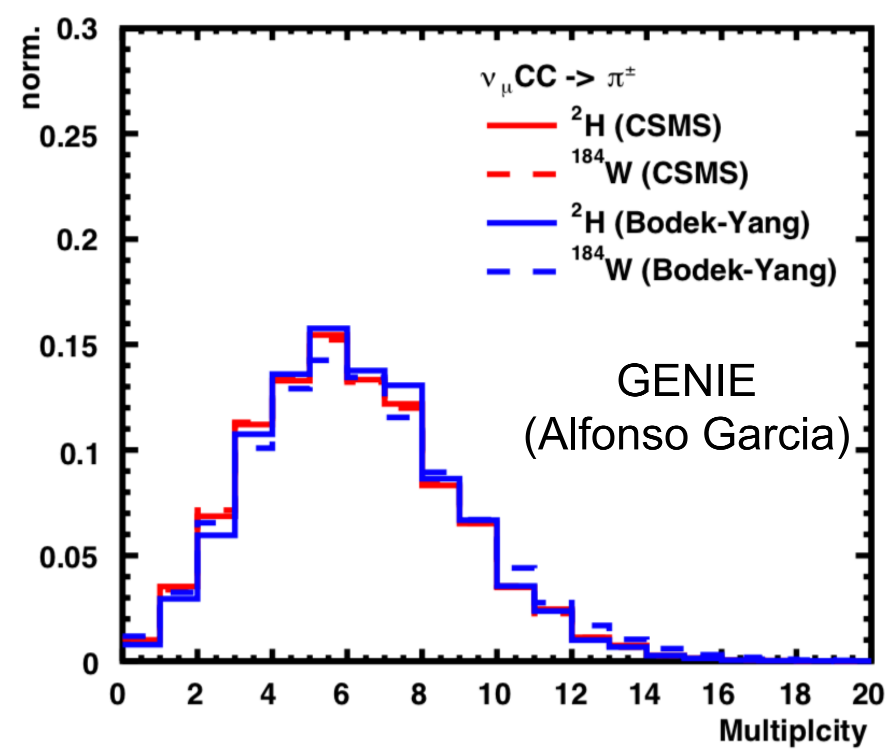
1 TeV ν_μ CC events on W

- **Hadron Multiplicity**









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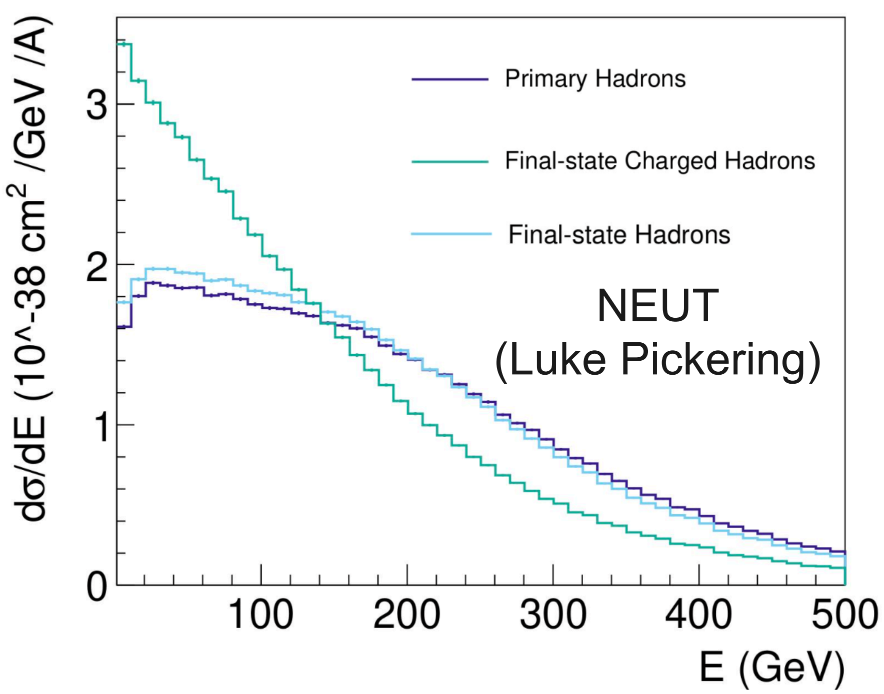
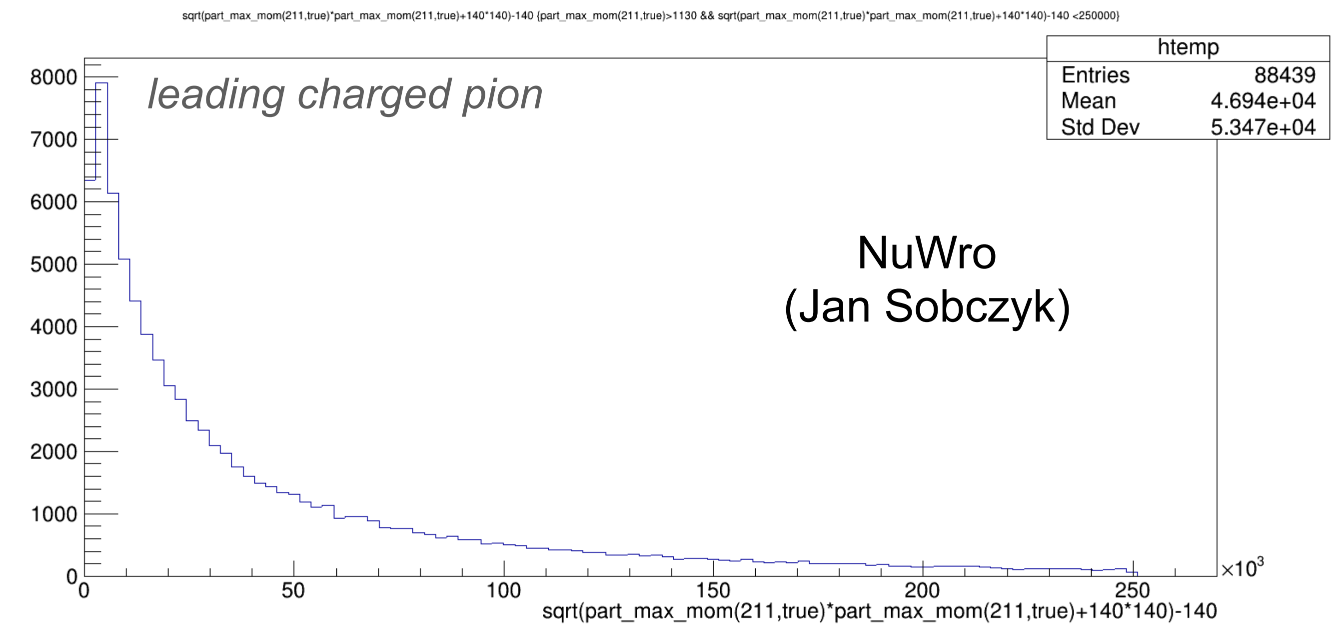
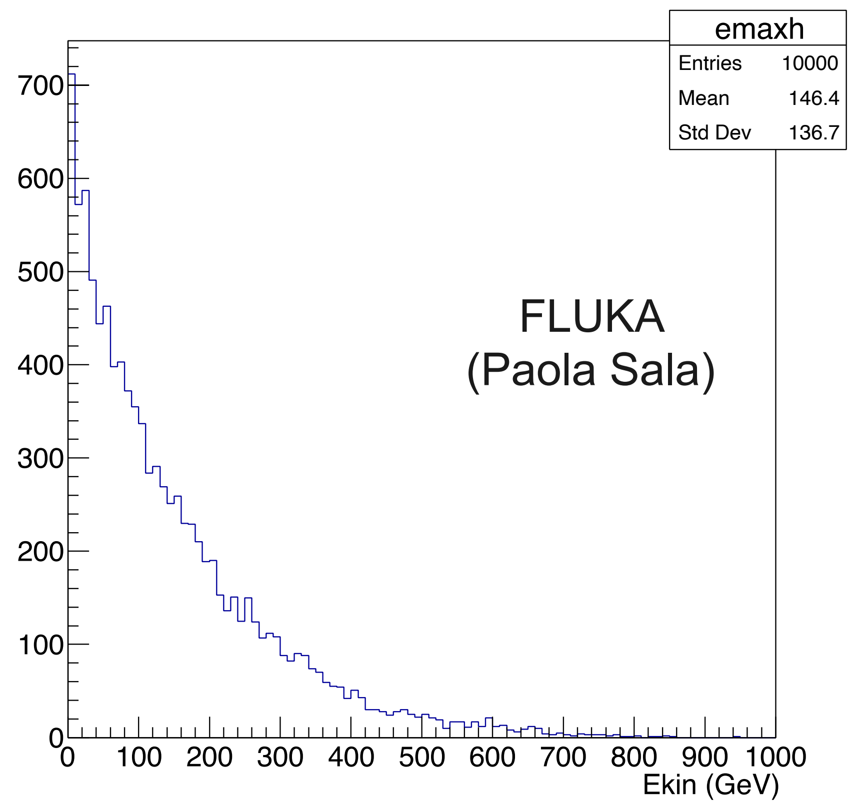
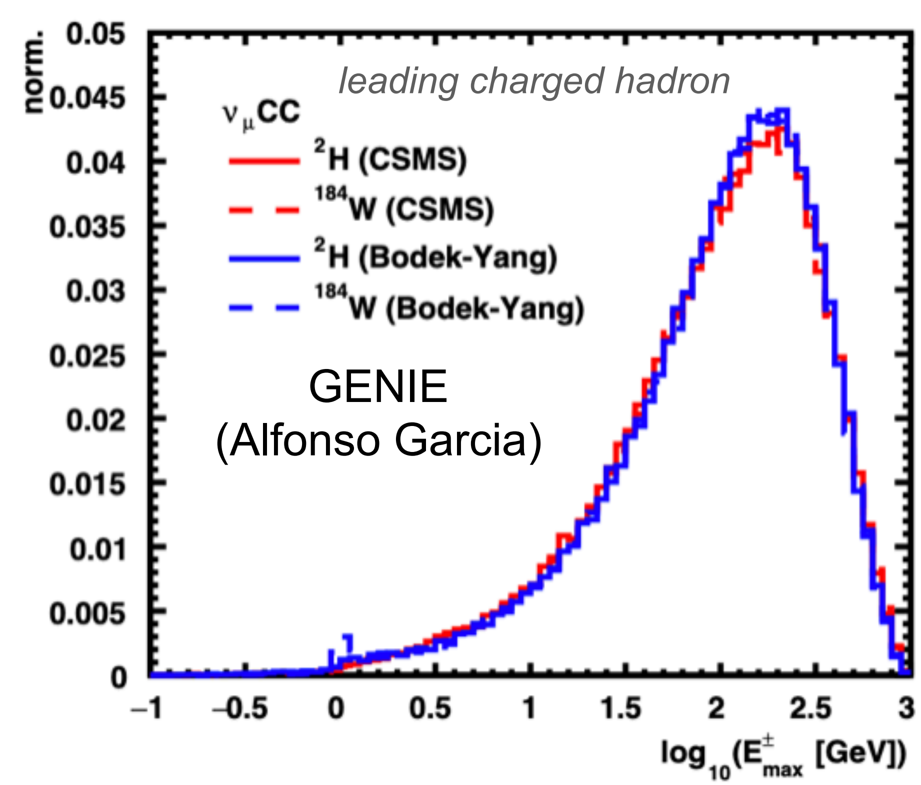
- **Leading Hadron Energy**









FPF Snowmass White Paper: In-preparation

- We are currently preparing a Snowmass FPF White Paper.

Forward Physics Facility Whitepaper

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- If you are interested in contributing to the neutrino parts, please get in touch with:

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  Vishvas Pandey (vpandey@fnal.gov)

- Snowmass Slack Channel: #fpf-whitepaper

- 4th FPF Workshop: Jan 31- Feb 1, 2022