FASER, FASERν, AND THE FORWARD PHYSICS FACILITY

Synergy of Astroparticle Physics and Collider Physics

Snowmass Community Planning Meeting

Jonathan Feng, UC Irvine, 7 October 2020

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ASTROPARTICLE PHYSICS AND COLLIDERS

- There are many topics of great interest at the astroparticle/collider interface.

- Here focus on the synergy of collider physics with cosmic rays and cosmic/atmospheric neutrinos. In particular, there are important and interesting puzzles related to forward hadron production and the resulting fluxes of muons and neutrinos.

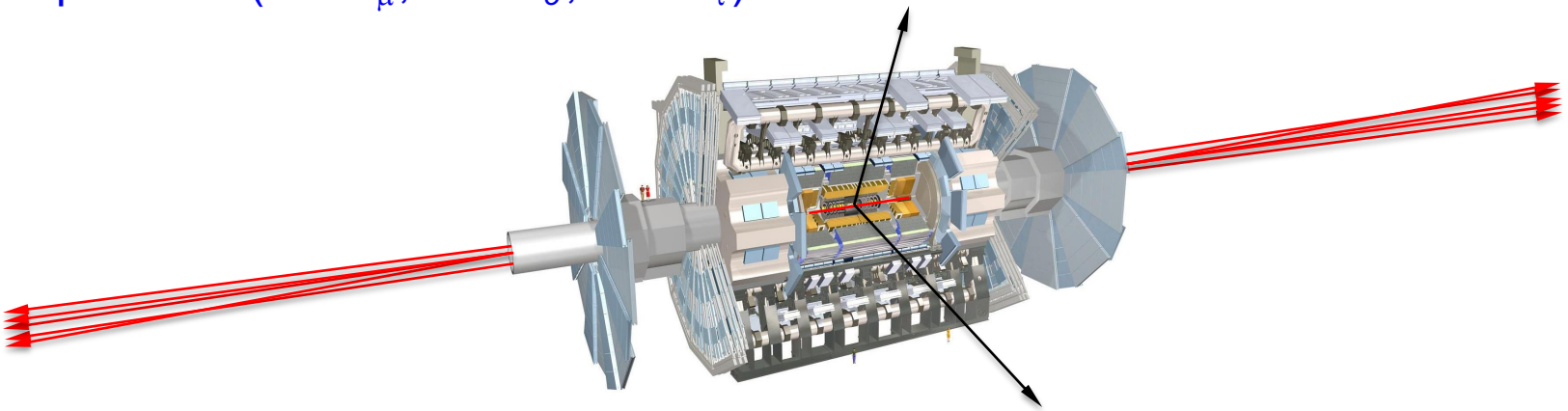
  See talks of Engel, Reno, Albrow

- What can collider experiments tell us? At the LHC, in addition to longstanding experiments in the forward region (HF, CASTOR, TOTEM, PPS, LUCID, ZDC, LHCf, AFP, ALFA, …), there are new initiatives of a qualitatively different nature.

- Here will discuss
  - Current experiments: FASER and FASERν are under construction, will begin installation next week, collect data in LHC Run 3 from 2022-24.
  - Future initiative: the Forward Physics Facility is a proposed facility to house a suite of far-forward experiments for the HL-LHC from 2027-36.

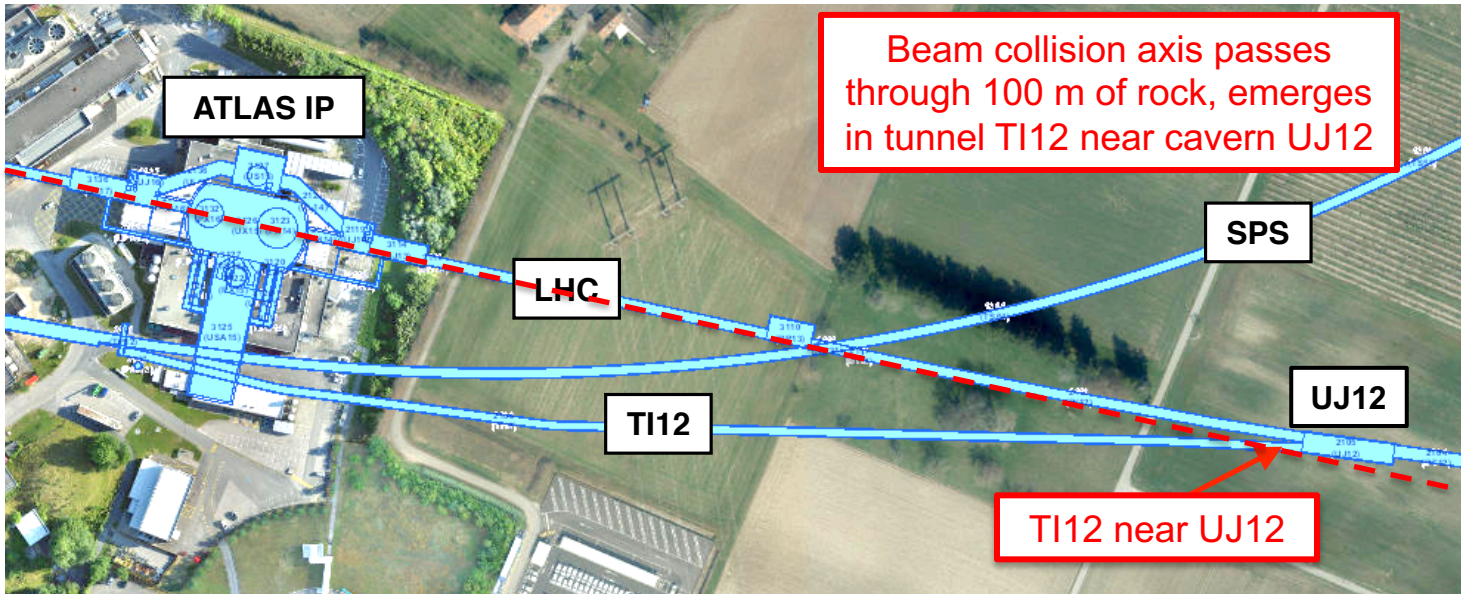
MOTIVATIONS FOR FAR FORWARD EXPERIMENTS

- SM: There is a large flux of TeV neutrinos at the LHC.
  - But these are overwhelmingly produced in the far forward direction, travel down the beampipe, and escape all existing detectors. **No collider neutrino has ever been detected.**
  - If they can be detected, there is a rich SM physics program: all flavors are produced($\pi \to \nu_\mu$, $K \to \nu_e$, $D \to \nu_\tau$) and both neutrinos and anti-neutrinos.



- BSM: Dark matter and dark sectors motivate weakly-interacting particles with MeV-GeV masses. These are also preferentially produced along the beam axis.
  - They escape the detector, may also decay far away (LLPs).
  - Rich BSM physics program: $\pi \to$ dark photon, $B \to$ dark Higgs, $\gamma \to$ ALP, etc.

LOCATION OF FASER AND FASERν

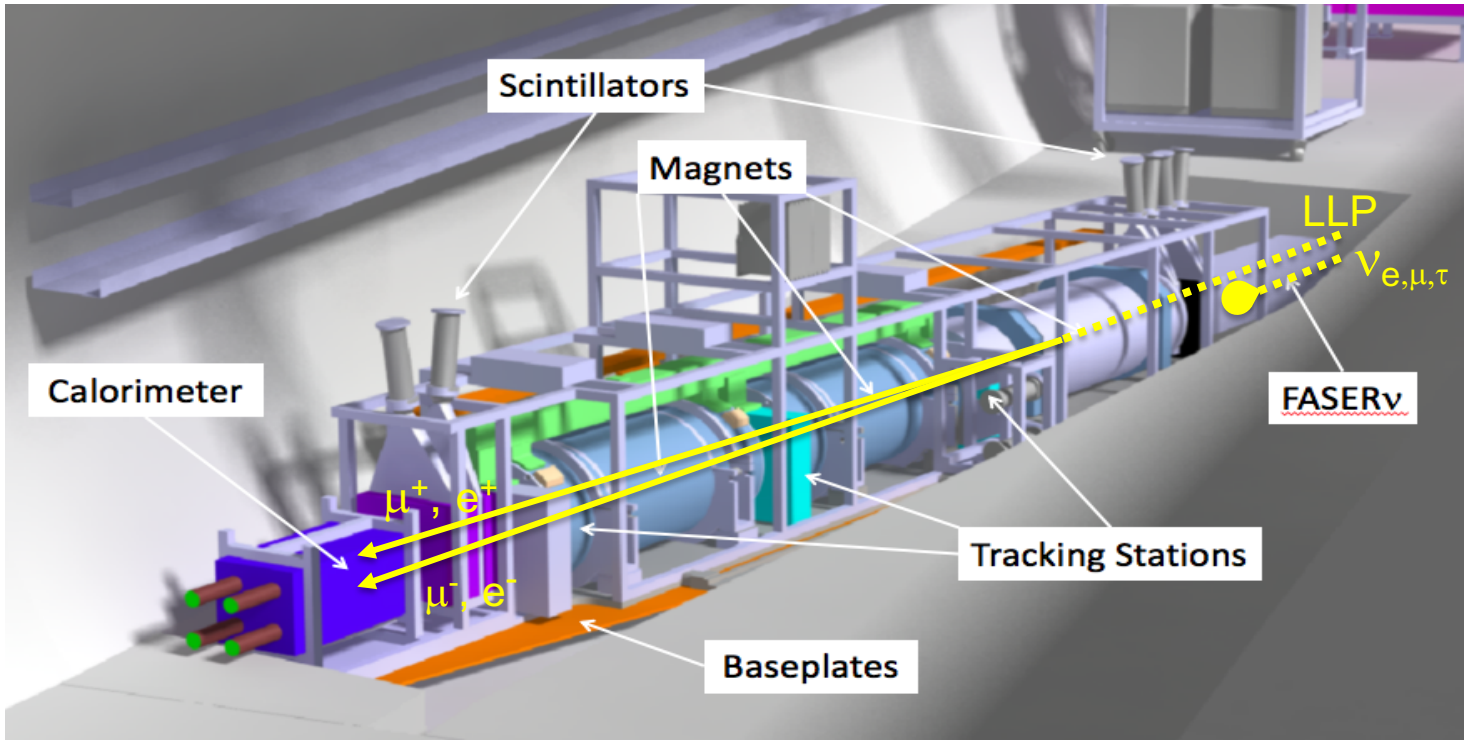


THE FASER AND FASERν DETECTORS

- FASER: 3 x 3 tracker planes, scintillators, calorimeter, and magnets. Designed to detect charged particles. Cylinder with R = 10 cm, $\eta > 9.2$.

  FASER 2: proposed upgrade to Cylinder with R = 1 m, $\eta > 6.9$.

- FASERν: 1.1 tonne emulsion/tungsten detector. Designed to detect CC and NC neutrino interactions, differentiate neutrino flavor and (with an interface detector) ν_μ vs. $\overline{\nu}_\mu$. Rectangular 25 cm x 30 cm plates, $\eta > 8.9$.



CURRENT STATUS

- FASER is being commissioned on the surface, and the tunnel location has been prepared for installation. Will be installed underground in two stages, beginning on October 19.

FASER LOI 1811.10243 and TP 1812.09139

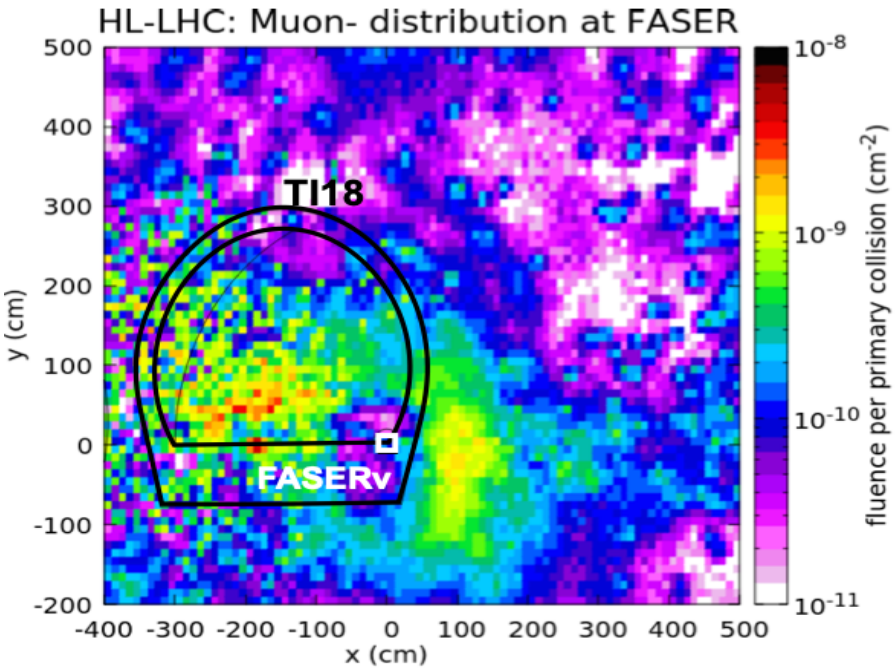
- FASERν approved, funded, will be installed in 2021.

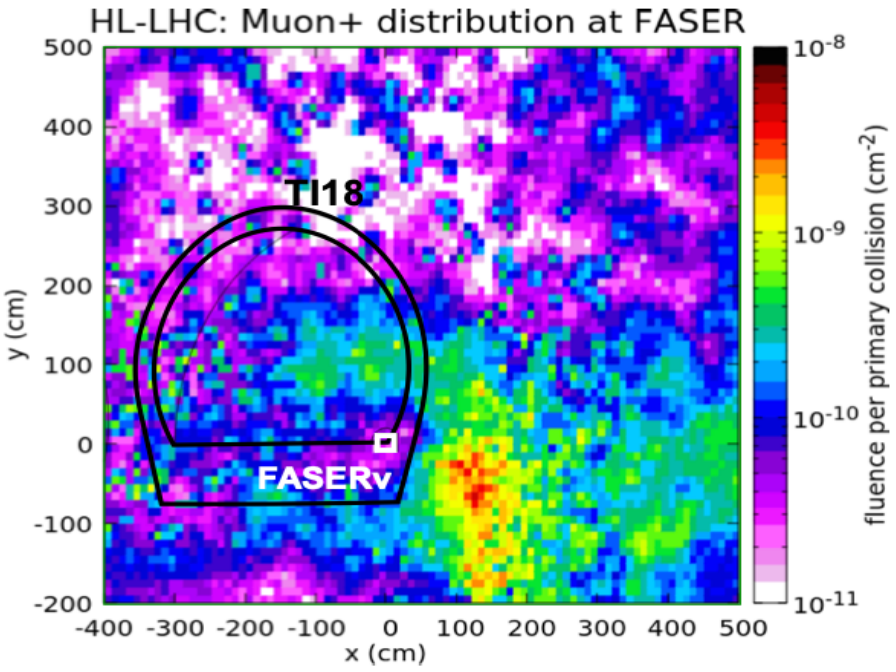
FASERν LOI 1908.02310 and TP 2001.03073

MUON FLUXES

- The only SM particles that can transport significant energy through 100m of rock to the FASER location are muons and neutrinos.

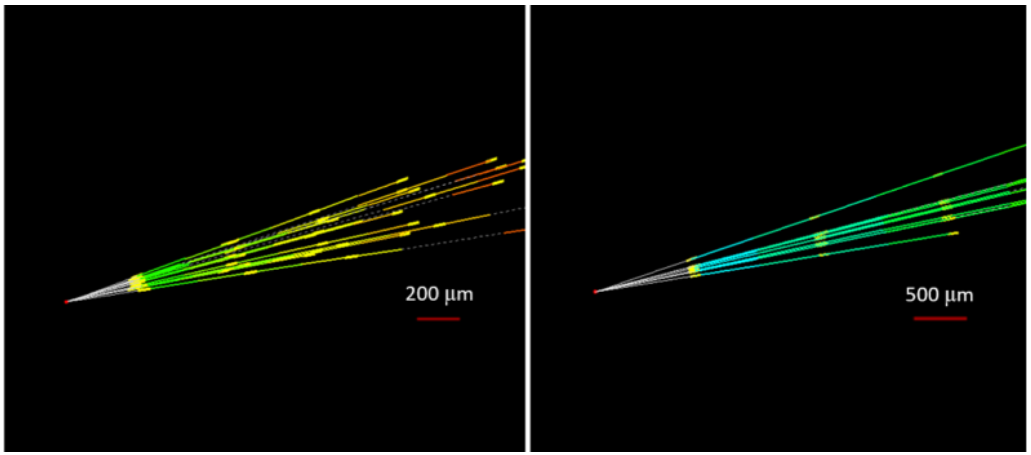
- Muon flux from FLUKA, validated by *in situ* measurements in 2018.
  - Expect 2 x10^9 muons with E_μ > 10 GeV detected in FASER in Run 3.
  - Muons originate at IP and also through collisions with downstream machine elements, and distributions for μ^- and μ^+ are impacted by bending in LHC magnets. Complicates comparison with CR experiments, work to be done!





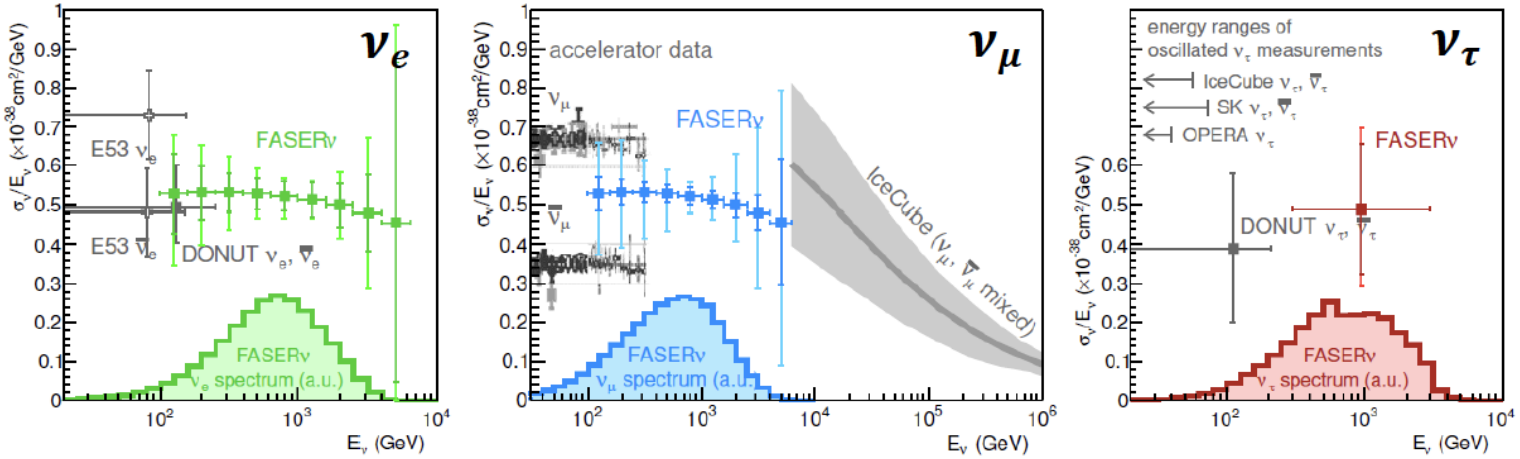
NEUTRINO FLUXES

- We have probably already seen our first TeV collider neutrino.
- 2018: FASER pilot ~30 kg emulsion detectors collected 12.5 fb^{-1} on the beam collision axis (installed and removed during Technical Stops).
- Expect ~10 neutrino interactions. Several neutral vertices identified, likely to be neutrinos. Analysis ongoing.



NEUTRINO PHYSICS

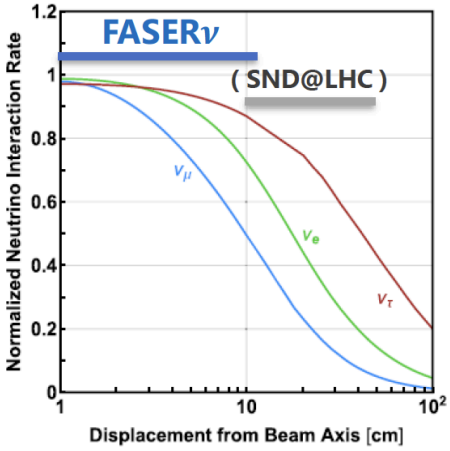
- 2022-24: FASERν will collect data with 1.1 tonne detector in Run 3
  - Detect ~1000 ν_e, ~10,000 ν_μ, and ~10 ν_τ. Probe neutrino properties at energies E_ν ~ TeV, first direct exploration of this energy range for all 3 flavors.



FASER Collaboration 1908.02310 (2019)

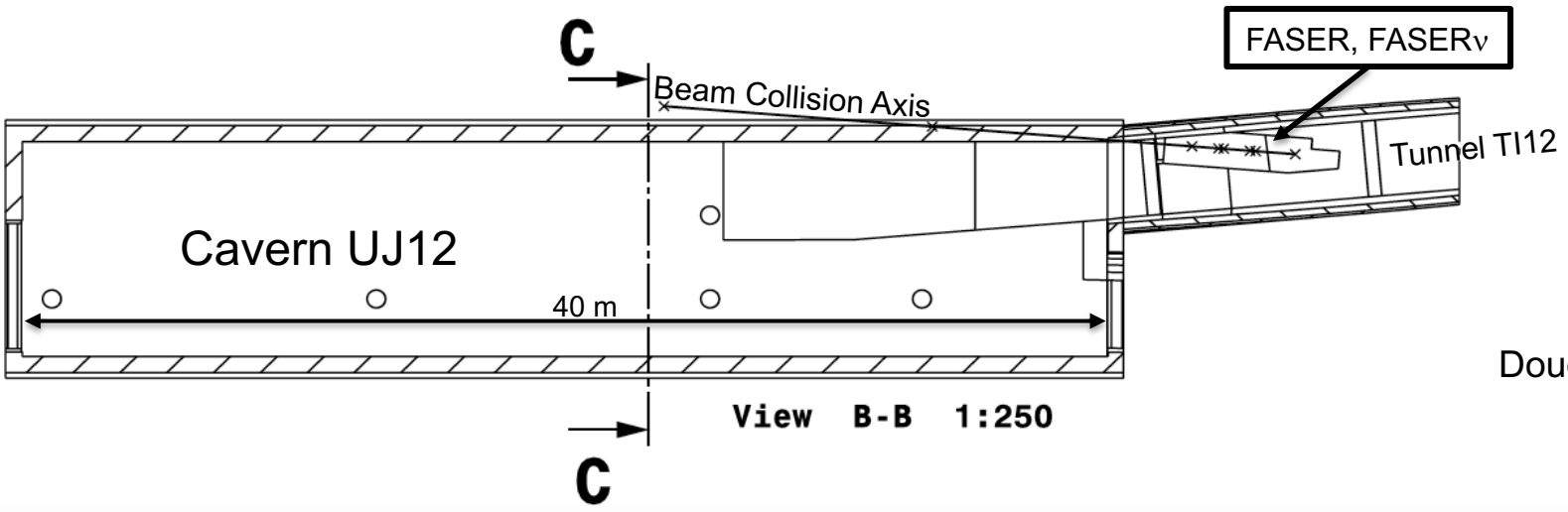
- 2027-36: FASERν upgrade to ~10 tonnes in HL-LHC
  - Detect ~100,000 ν_e, ~1,000,000 ν_μ, ~1000 ν_τ, each with its own radial distribution.

- FASERν will provide significant constraints on charm production, help differentiate cosmic neutrinos from atmospheric ν background at IceCube and elsewhere.



FORWARD PHYSICS FACILITY

- Current experiments in the far-forward region are severely limited by the tunnels and infrastructure that were created long ago (in the 1980's for LEP!) and long before the physics potential of this space was appreciated.

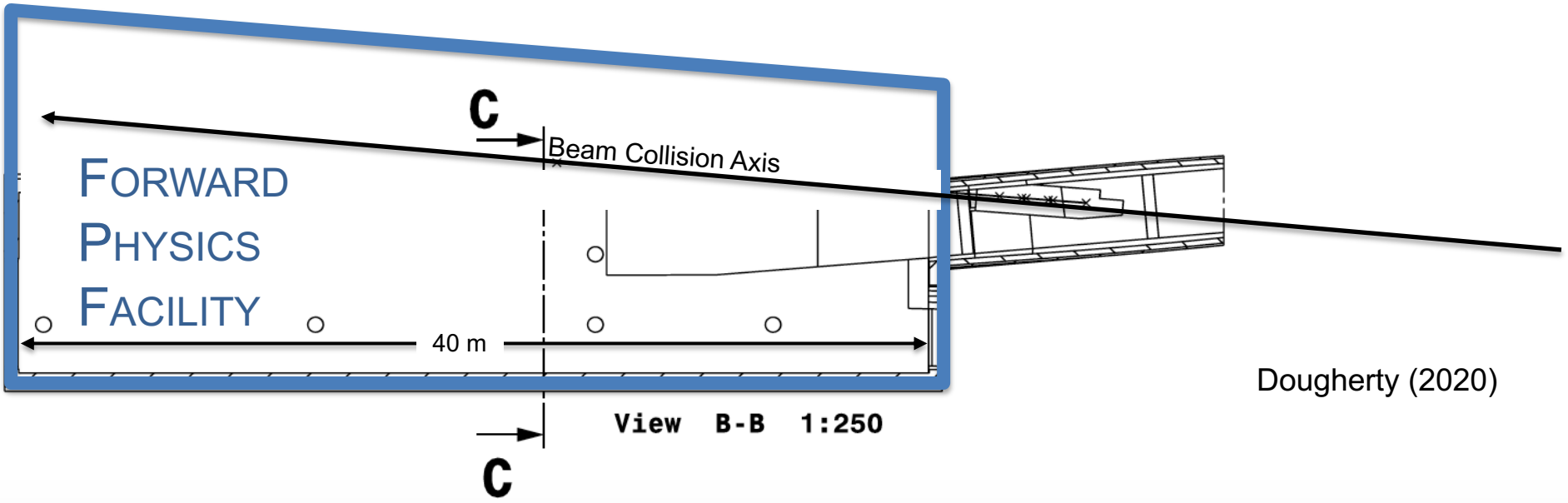


Dougherty (2020)

FORWARD PHYSICS FACILITY

- These and other “supplementary detectors” all require surveying, CE, and support services that are currently being developed piecemeal.

- These would all benefit from a facility dedicated to supporting far-forward experiments.



Dougherty (2020)

- The Forward Physics Facility would lead to a huge gain in power for new physics searches, neutrino studies, studies of hadronic physics, and implications for cosmic rays and cosmic neutrinos.

UJ12 AND UJ 18 CAVERNS

- The Forward Physics Facility would require widening a pre-existing cavern by a few meters (UJ12 shown, or UJ18 on the other side of ATLAS).

Snowmass LOI: SNOWMASS21-EF9_EF6_EF10_EF5-NF6_NF3_NF10-RF6_RF0-CF7_CF0-AF5_AF0-UF1_UF2_ForwardPhysicsFacility-193.pdf

FPF KICKOFF WORKSHOP

- We are organizing an FPF Kickoff Meeting on November 9-10.
- Goal is to bring together a diverse group for brief talks and significant discussion, work toward white paper, FPF proposal: Garzelli, Kling (co-organizers), Halzen, Ostapchenko, Soldin, Reno, Krauss, Sjostrand, Nadolsky, Gall, Ariga, deNiverville, Boyd, Hill, Balantekin, Ritz, Rizzo, Su, Kelly, Perez de los Heros, Foldenauer, Goncalves, Khoze, Bai, You, Iacobucci, and many others.
- All invited to join and contribute a talk (https://indico.cern.ch/event/955956).