UPDATES ON THE FORWARD PHYSICS FACILITY FOR THE HL-LHC

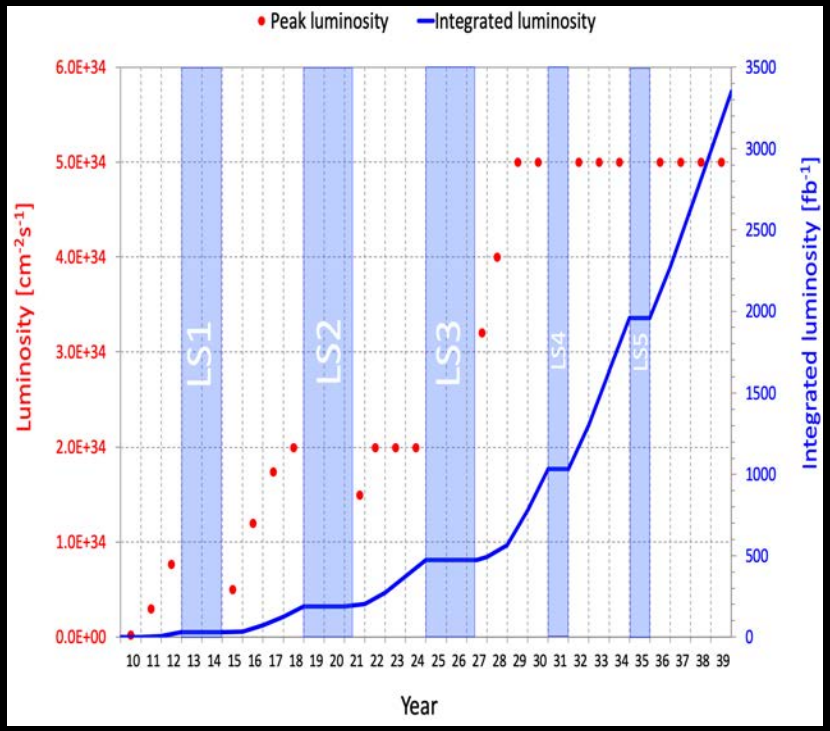
Snowmass EF09 (BSM General) Informal Gathering
30 April 2021

Jonathan Feng, UC Irvine

FORWARD PHYSICS FACILITY

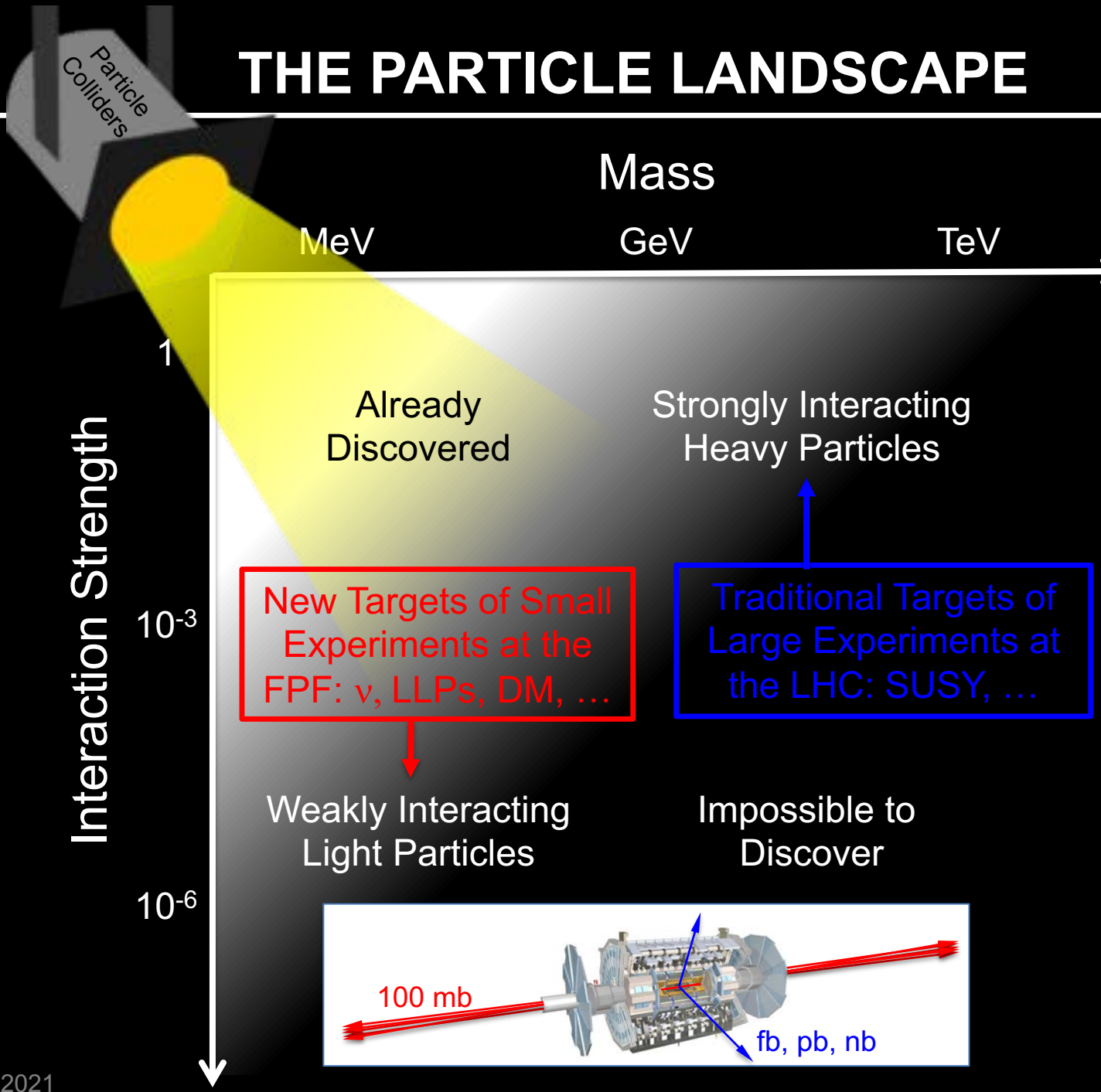
- A fact that should be better appreciated: we are in a critical period.

- In the next year or two, we will either make plans to exploit new opportunities at the HL-LHC, or lose them until 2045, 2060, 2075, …, long after many of us are (professionally) dead.



- The Forward Physics Facility is such an opportunity: an opportunity to explore a rich BSM and SM physics program in the far forward region with relatively little additional investment.

THE PARTICLE LANDSCAPE



UPDATES:

CIVIL ENGINEERING

BSM PHYSICS

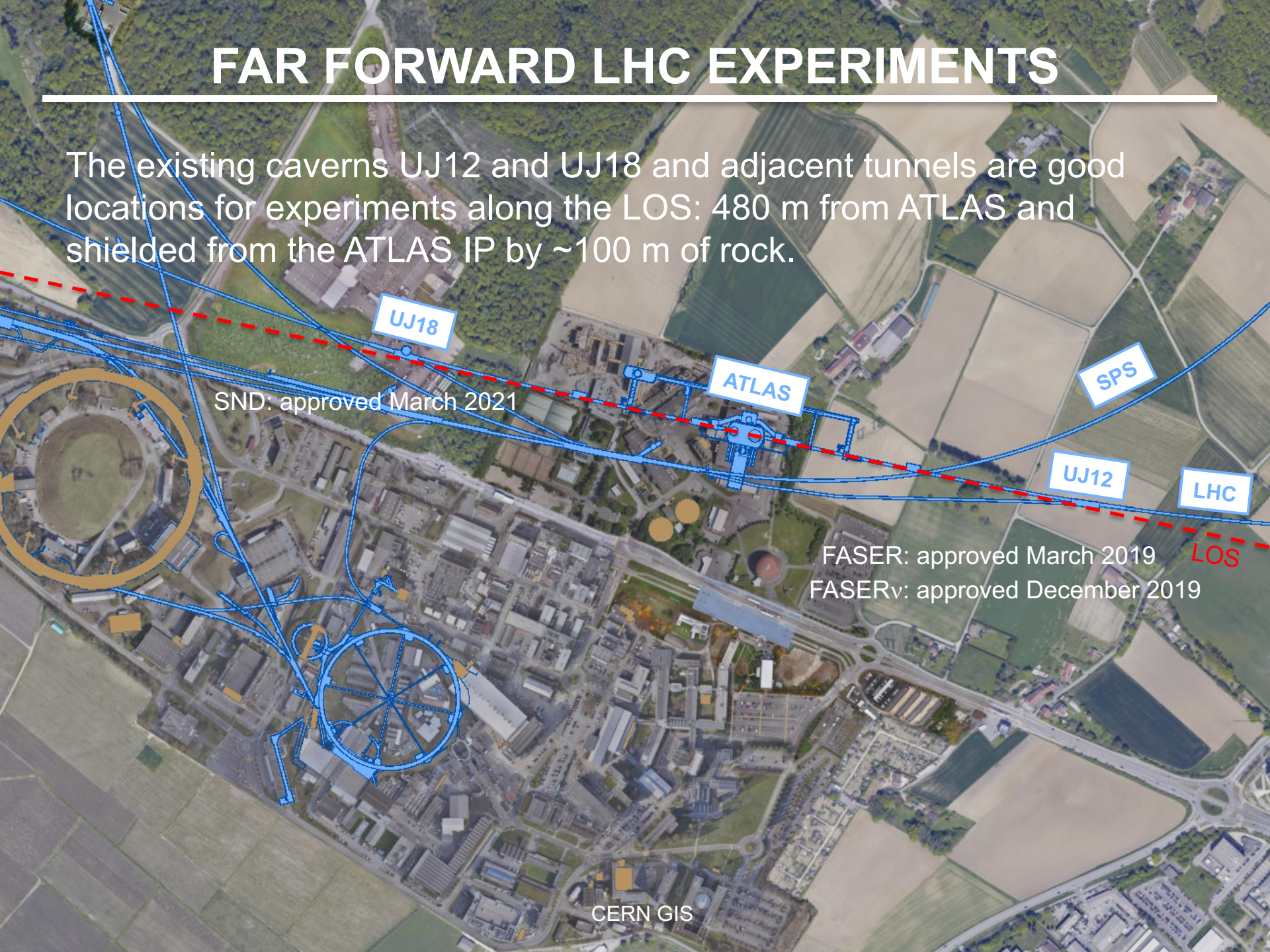
SM PHYSICS

NEXT STEPS

CIVIL ENGINEERING

FAR FORWARD LHC EXPERIMENTS

The existing caverns UJ12 and UJ18 and adjacent tunnels are good locations for experiments along the LOS: 480 m from ATLAS and shielded from the ATLAS IP by ~100 m of rock.



RECENT NEWS

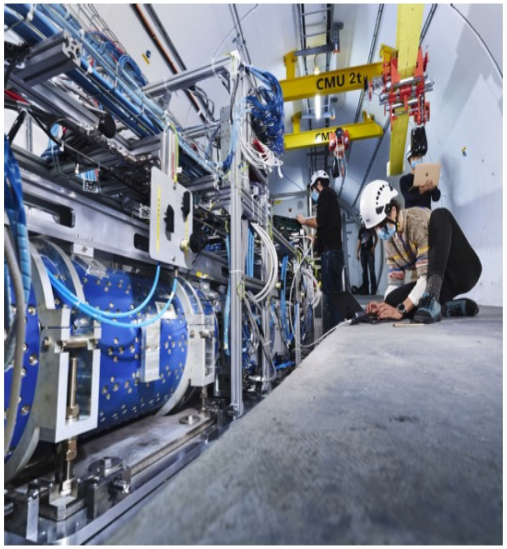
25 March 2021

CERN Bulletin

Issue No. 12-13/2021-Thursday 25 March 2021
More articles at http://home.cern/cern-people

LS2 REPORT: FASER IS BORN

FASER, the Forward Search Experiment, has been installed in the LHC tunnel during Long Shutdown 2. It is currently being tested and will start taking data next year



The final elements of FASER were put into place this month. (Image: CERN)

A WORD FROM CHARLOTTE LINDBERG WARAKAULLE

EXCELLENCE IN SCIENCE THRIVES ON GLOBAL INTERACTION

A year ago, it seemed that the world closed around us. From one day to the next, travel and movement became restricted. The usual in-person exchanges with colleagues from across the world suddenly became a rare occurrence.

(Continued on page 2)

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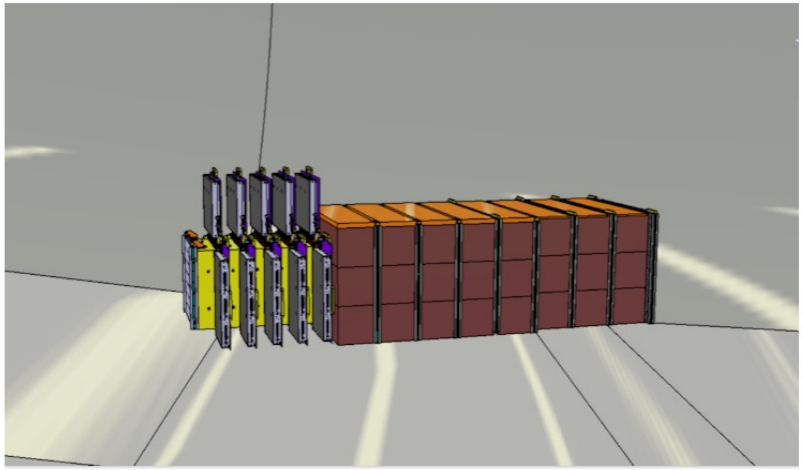
Aligning the ATLAS muon spectrometer 5
Tackling tomorrow's computing

27 April 2021

CERN approves new LHC experiment

SND@LHC, or Scattering and Neutrino Detector at the LHC, will be the facility's ninth experiment

27 APRIL, 2021 | By Ana Lopes



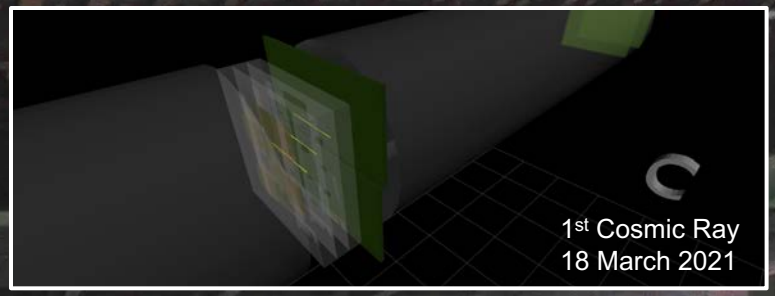
The SND@LHC experiment consists of an emulsion/tungsten target for neutrinos (yellow) interleaved with electronic tracking devices (grey), followed downstream by a detector (brown) to identify muons and measure the energy of the neutrinos. (Image: Antonio Crupano/SND@LHC)

The world's largest and most powerful particle accelerator is getting a new experiment. In March 2021, the CERN Research Board approved the ninth experiment at the Large Hadron Collider: SND@LHC, or Scattering and Neutrino Detector at the LHC. Designed to detect and study neutrinos, particles similar to the electron but with no electric charge and very low mass, the experiment will complement and extend the physics reach of the other LHC experiments.

SND@LHC is especially complementary to FASERν, a neutrino subdetector of the FASER experiment, which has just recently been installed in the LHC tunnel. Neutrinos have been detected from many sources, but they remain the most enigmatic fundamental particles in the universe. FASERν and SND@LHC will make measurements of neutrinos produced at a particle collider for the first time, and could thus open a new frontier in neutrino physics.

FASER CURRENT STATUS

- Installation completed in March 2021
- Commissioning with cosmics ongoing
- No room for more experiments along the LOS in the existing tunnel



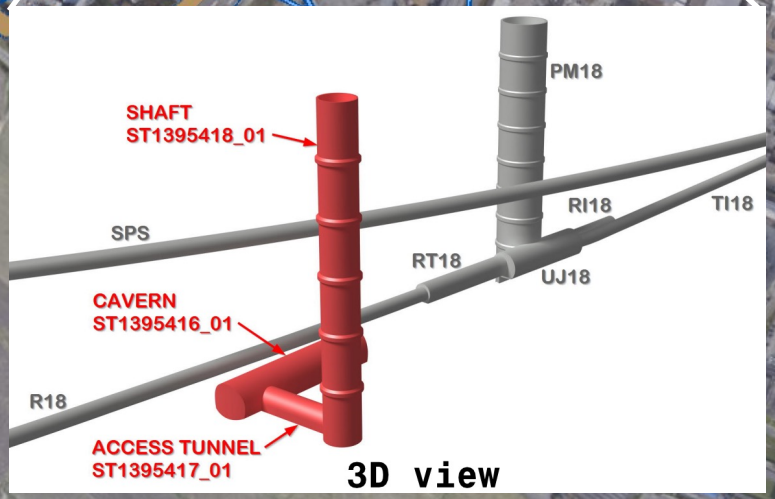
1st Cosmic Ray
18 March 2021

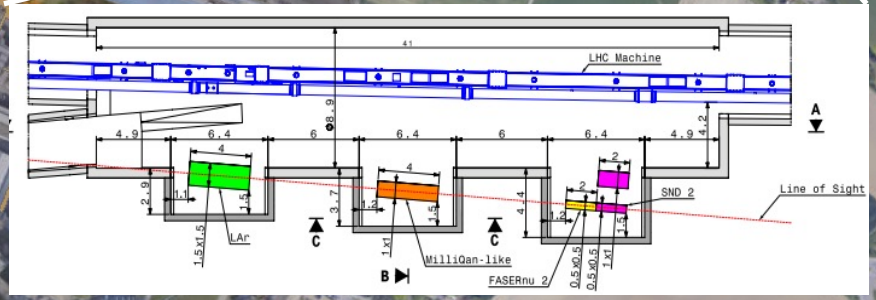
FPF LOCATION

Possibilities under active investigation:

(1) enlarge existing cavern UJ12 with alcoves for each experiment

(2) create a new shaft and cavern ~612 m from ATLAS past UJ18





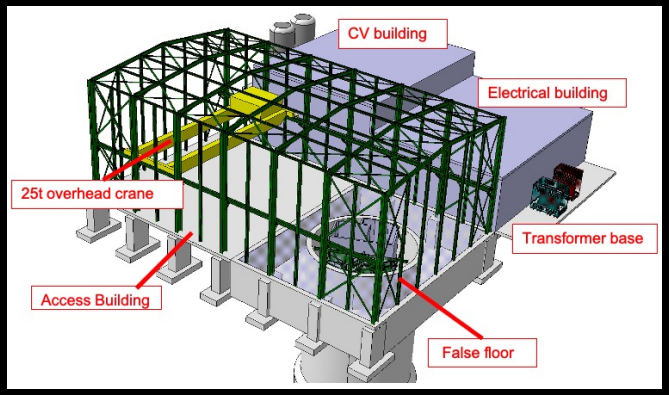
John Osborne, Kincso Balazs, Jonathan Gall

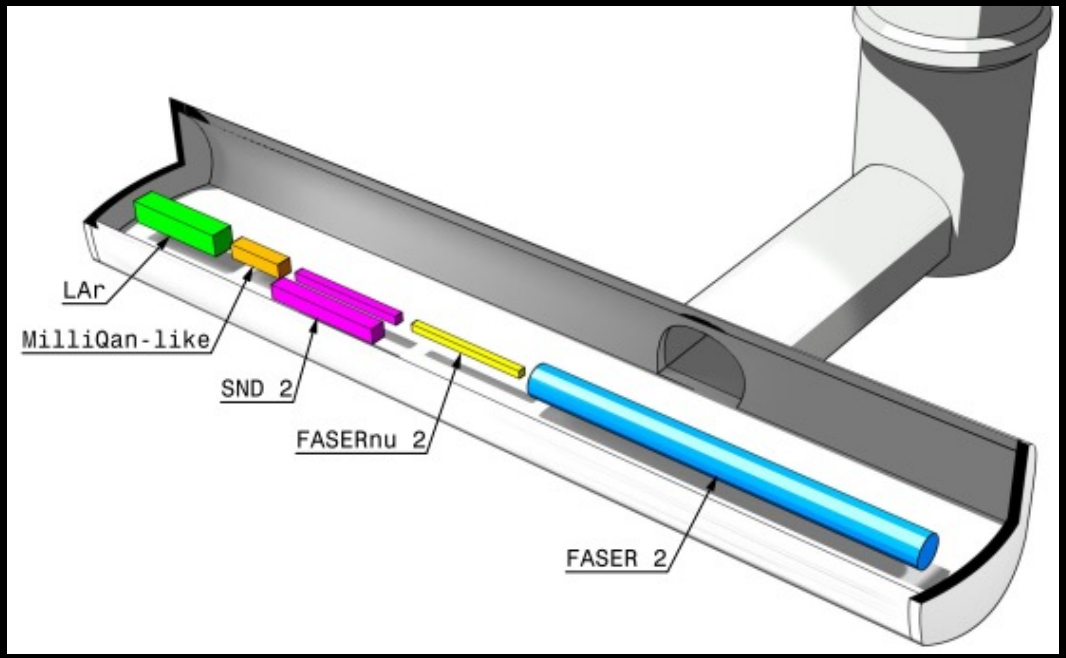
see John Osborne's talk, PBC Workshop 3/3/21

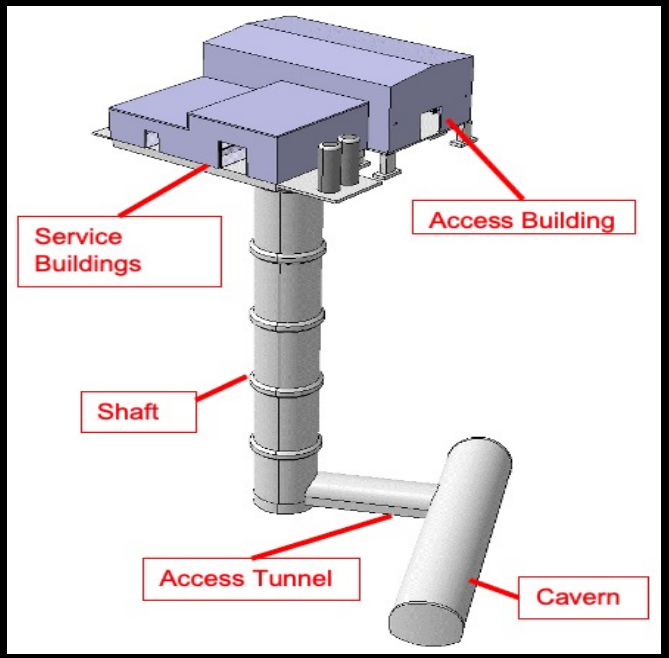
CERN GIS

NEW SHAFT AND CAVERN

- Many advantages
  - Construction access far easier
  - Access possible during LHC operations
  - Flexible size and length of cavern (> 60 m)
  - Designed around needs of the experiments







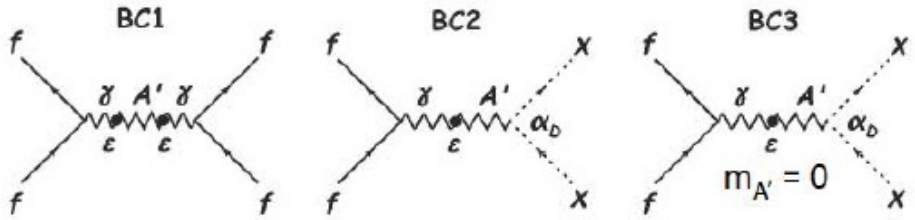
Design by Liam Dougherty (EN-ACE-INT)

BSM PHYSICS

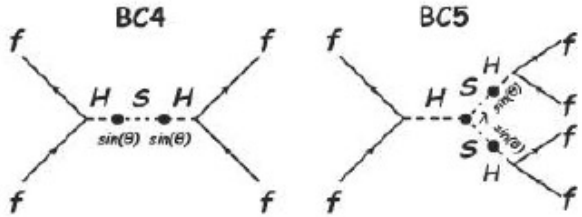
PBC BSM BENCHMARK CASES

- 11 models of light, weakly-interacting particles (LLPs, FIPs)

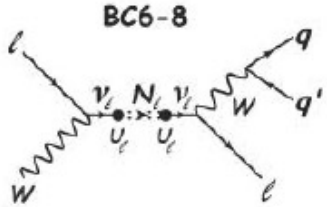
Dark Photons, Dark Matter & millicharged particles



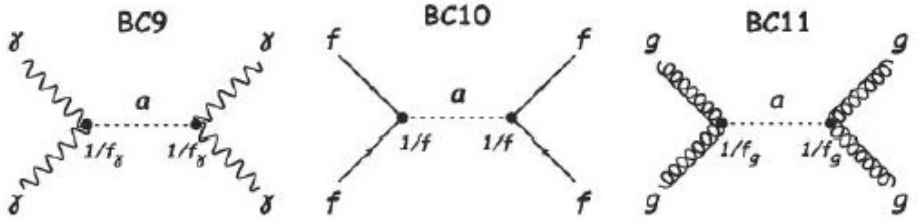
Dark Scalars



Heavy Neutral Leptons



Axion-Like Particles



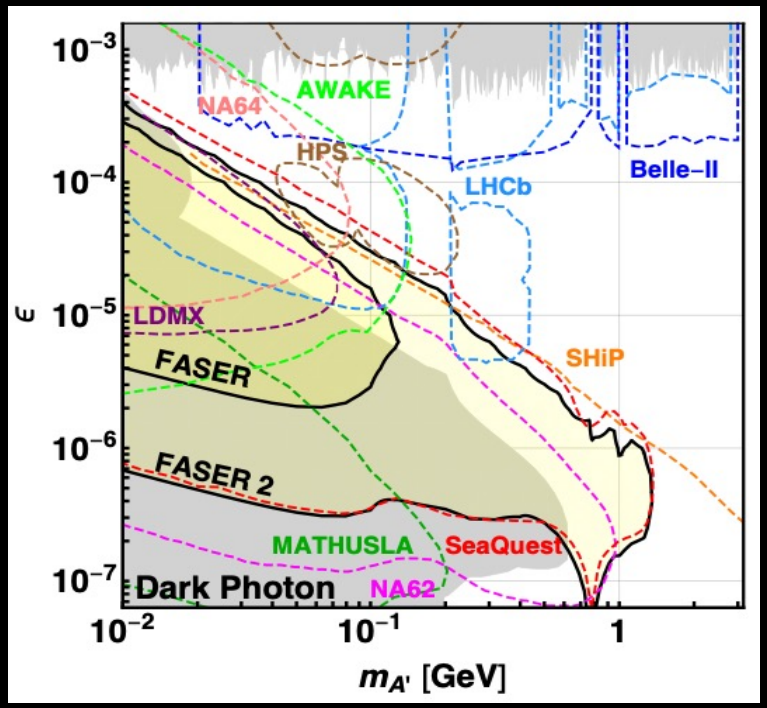
BSM SUMMARY

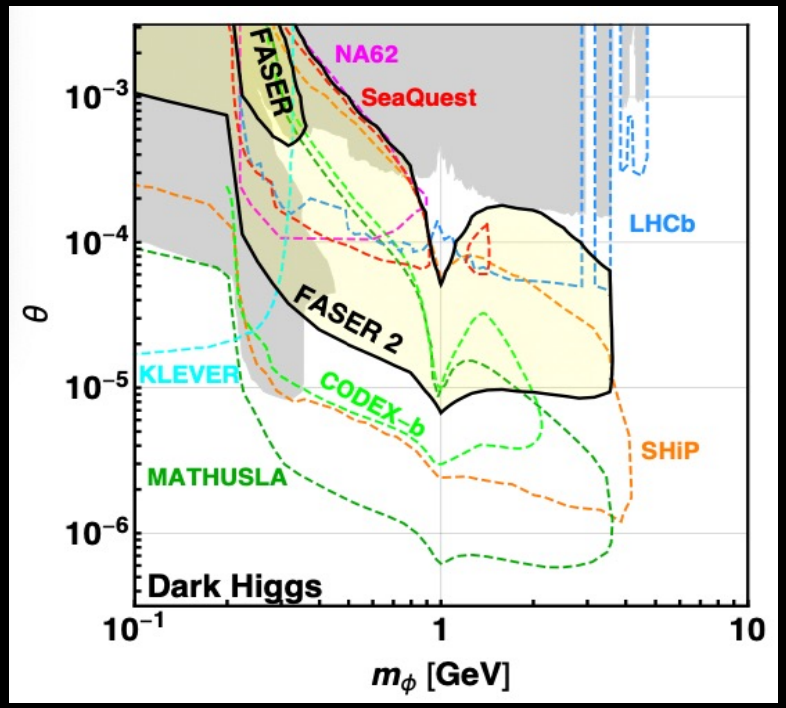
- FASER and FASER2 are well-known to cover many, but not all, of the benchmarks.
- Recent studies have shown that FPF experiments can discover new physics in the remaining two PBC benchmark cases (BC2 and BC3).

Benchmark Model	Underway	FPF	References
BC1: Dark Photon	FASER	FASER 2	Feng, Galon, Kling, Trojanowski, 1708.09389
BC1': $U(1)_{B-L}$ Gauge Boson	FASER	FASER 2	Bauer, Foldenauer, Jaeckel, 1803.05466 FASER Collaboration, 1811.12522
BC2: Dark Matter	–	FLArE	Batell, Feng, Trojanowski, 2101.10338
BC3: Milli-Charged Particle	–	FORMOSA	Foroughi-Bari, Kling, Tsai, 2010.07941
BC4: Dark Higgs Boson	–	FASER 2	Feng, Galon, Kling, Trojanowski, 1710.09387 Batell, Freitas, Ismail, McKeen, 1712.10022
BC5: Dark Higgs with hSS	–	FASER 2	Feng, Galon, Kling, Trojanowski, 1710.09387
BC6: HNL with e	–	FASER 2	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
BC7: HNL with μ	–	FASER 2	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
BC8: HNL with τ	FASER	FASER 2	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
BC9: ALP with photon	FASER	FASER 2	Feng, Galon, Kling, Trojanowski, 1806.02348
BC10: ALP with fermion	FASER	FASER 2	FASER Collaboration, 1811.12522
BC11: ALP with gluon	FASER	FASER 2	FASER Collaboration, 1811.12522

BCs 1, 4-11: LLPS AT FASER AND FASER 2

- FASER can discover new physics in some of these models with 1 fb^{-1}.
- The Forward Physics Facility will provide space to upgrade FASER (R=10cm, L=1.5m, Run 3) → FASER 2 (R=1m, L=5m, HL-LHC), either extending sensitivity greatly (e.g., dark photon), or providing new discovery prospects (e.g., dark Higgs) complementary to other expts.

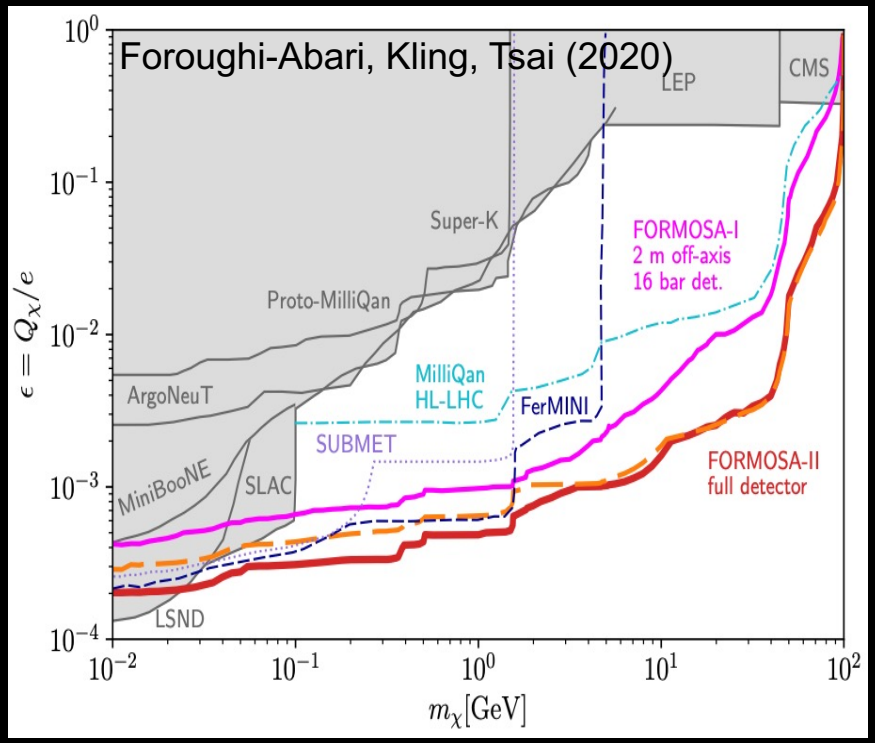




FASER Collaboration, 1811.12522 (2018)

BC2: MILLI-CHARGED PARTICLES

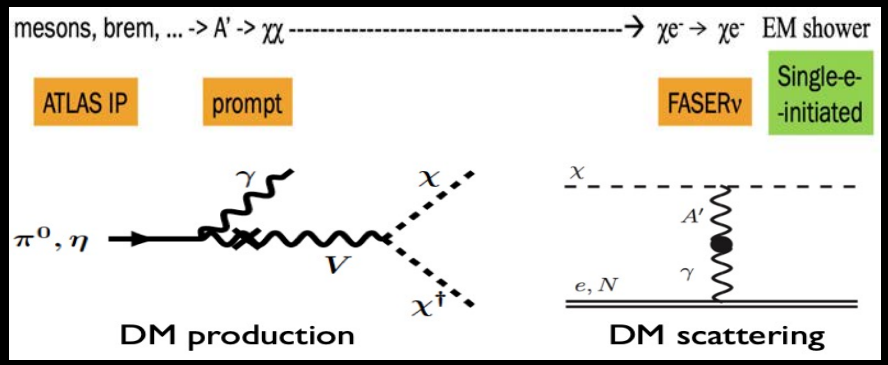
- Currently the target of the MilliQan experiment near the CMS IP.
- MilliQan Demonstrator (Proto-MilliQan) already probes new region. Full MilliQan planned to run in this location at HL-LHC, but the sensitivity can be improved significantly by moving it to the FPF (FORMOSA).



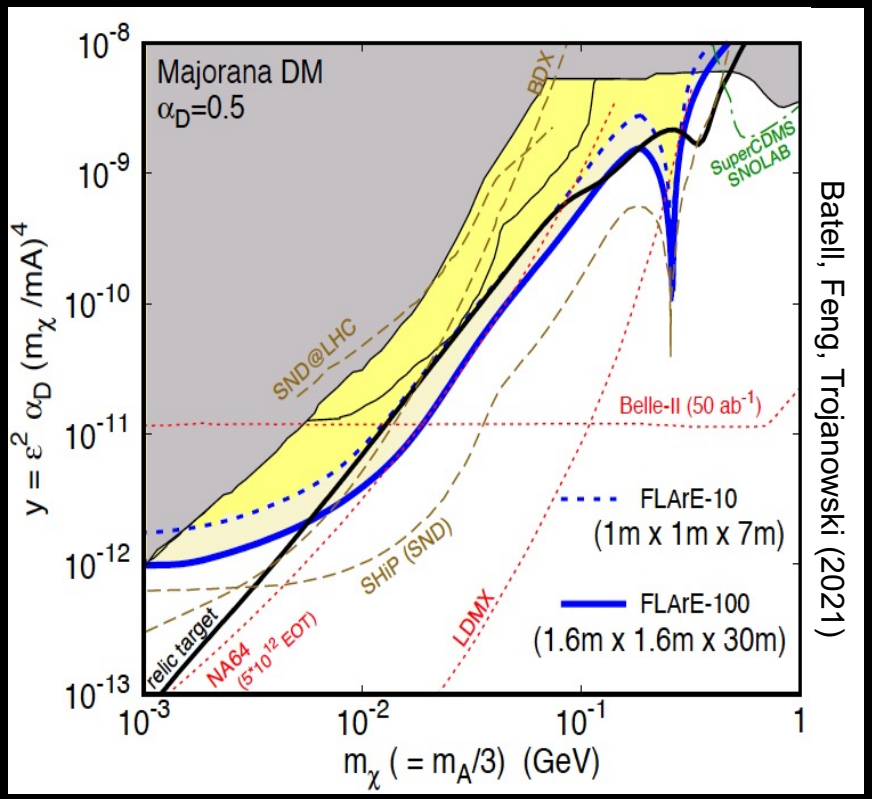
BC3: DARK MATTER

- If $m_{LLP} > 2m_{DM}$, the LLP will typically decay to dark matter, leading to a highly collimated beam of dark matter particles.

- Can look for the resulting DM to scatter off electrons at FLArE, Forward Liquid Argon Experiment, a proposed 10 to 100 tonne LArTPC.



- FLArE probes most of the favored/ allowed relic target region. Complementary to missing energy experiments that probe more of the "too large $\Omega_\chi h^2$" region, but don't detect DM scattering.

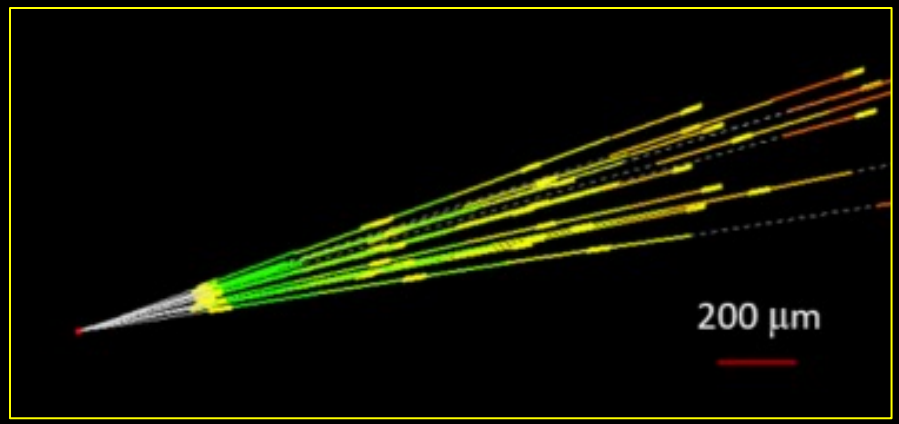


SM PHYSICS

FIRST COLLIDER NEUTRINOS

- No collider neutrino has ever been detected.
- But there is a huge flux of TeV neutrinos in the far forward direction.

  De Rujula, Ruckl (1984); Winter (1990)
- In 2018, the FASER Collaboration placed a 29 kg emulsion detector in the far forward region for 6 weeks (inserted and removed in TSs).
- Expect ~few neutrino interactions. Several neutral vertices have been identified, likely to be neutrinos. Paper expected soon.



LOCATION, LOCATION, LOCATION

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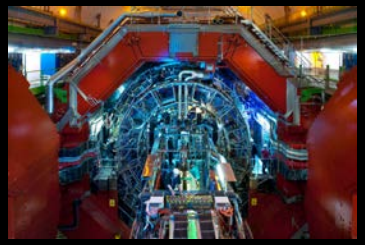
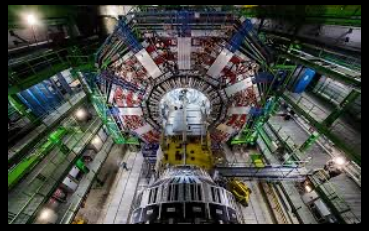
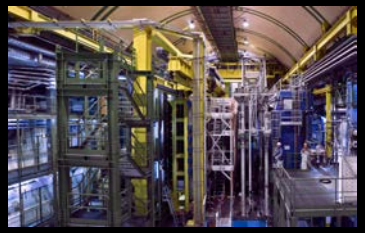
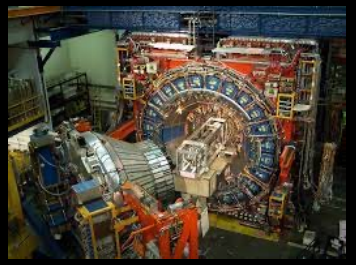
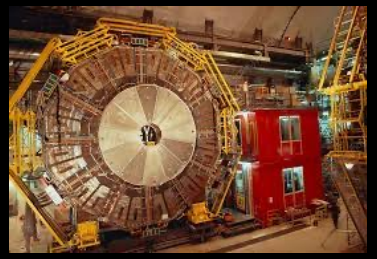


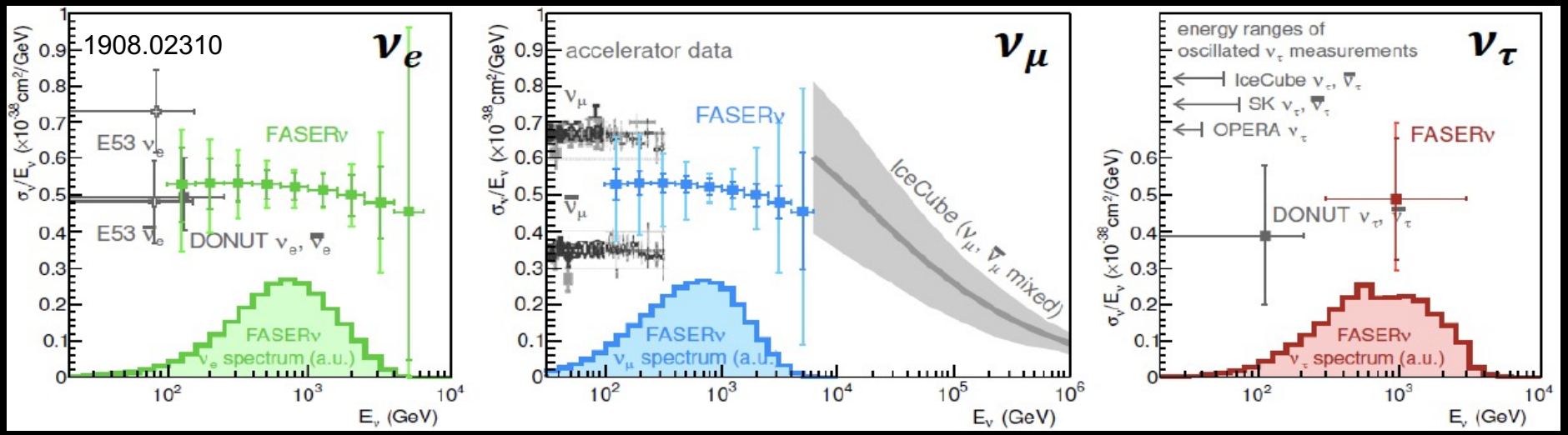




…

NEUTRINO PHYSICS

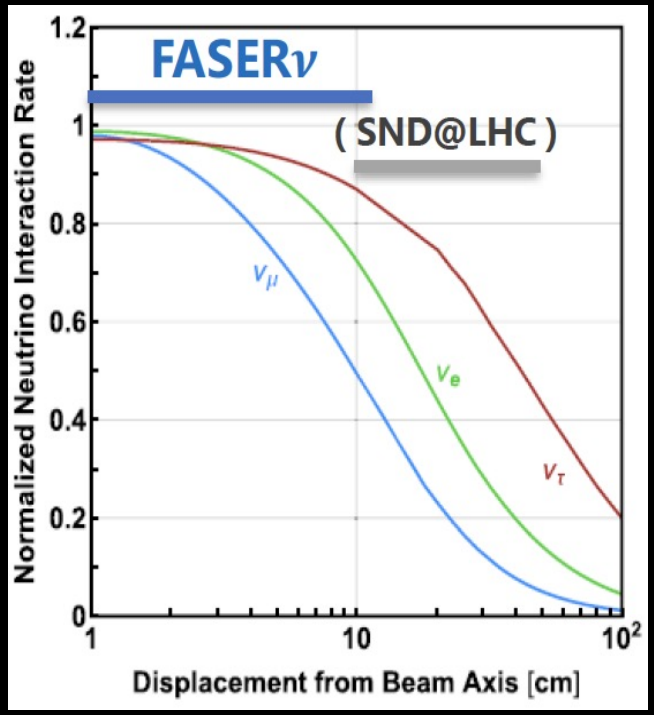
- Run 3: FASERν (on-axis) and SND (off-axis), ~1-tonne emulsion/tungsten detectors, will open the new field of neutrino physics at the LHC
  - Will record ~1000 ν_e, ~10,000 ν_μ, and ~10 ν_τ interactions at TeV energies, the first direct exploration of this energy range for all 3 flavors



- HL-LHC: FPF will accommodate FASERν2 / SND2 (~10-tonne emulsion detectors), FLArE (10+ tonne LArTPC), FORMOSA, …
  - Will record ~10^5 ν_e, ~10^6 ν_μ, and ~10^3 ν_τ interactions at TeV energies.
  - Identify 1st anti-ν_τ, probe neutrino properties (NSIs, ν_τ MDM), …

QCD PHYSICS

- The forward production of hadrons is currently subject to large uncertainties. FPF experiments would provide useful insights.
  - By accommodating both on-axis and off-axis neutrino detectors, could provide complementary information ($\pi \to \nu_\mu$, $K \to \nu_e$, $D \to \nu_\tau$).
  - Different target nuclei (lead, tungsten) to probe different nuclear pdfs
  - Strange quark pdf through $\nu s \to lc$
  - Forward charm production, intrinsic charm
  - Refine simulations that currently vary greatly (EPOS-LHC, QGSJET, DPMJET, SIBYLL, PYTHIA…)
  - Provide essential input to astroparticle experiments; e.g., distinguish galactic neutrino signal from atmospheric neutrino background at IceCube



NEXT STEPS

NEXT STEPS

- Explore the full physics potential of the Forward Physics Facility
- Identify the suite of experiments that will maximize the physics potential within the constraints of cost, schedule, safety, …. A fascinating and multi-faceted optimization problem!
- The FPF Kickoff Workshop was held 9-10 November 2020
  - 40 talks, fascinating discussions across a broad range of topics
  - For talk slides and recordings, see https://indico.cern.ch/event/955956
- Snowmass EF06 meeting on SM physics at the FPF will be 5 May 2021
- The 2nd FPF Workshop will be 27-28 May 2021
  - https://indico.cern.ch/event/1022352
  - Questions? Contact Jonathan Feng, Maria Vittoria Garzelli, Felix Kling