UPDATES AND THOUGHTS ON SCHEDULE FOR THE FORWARD PHYSICS FACILITY

BNL Discussion
8 July2021

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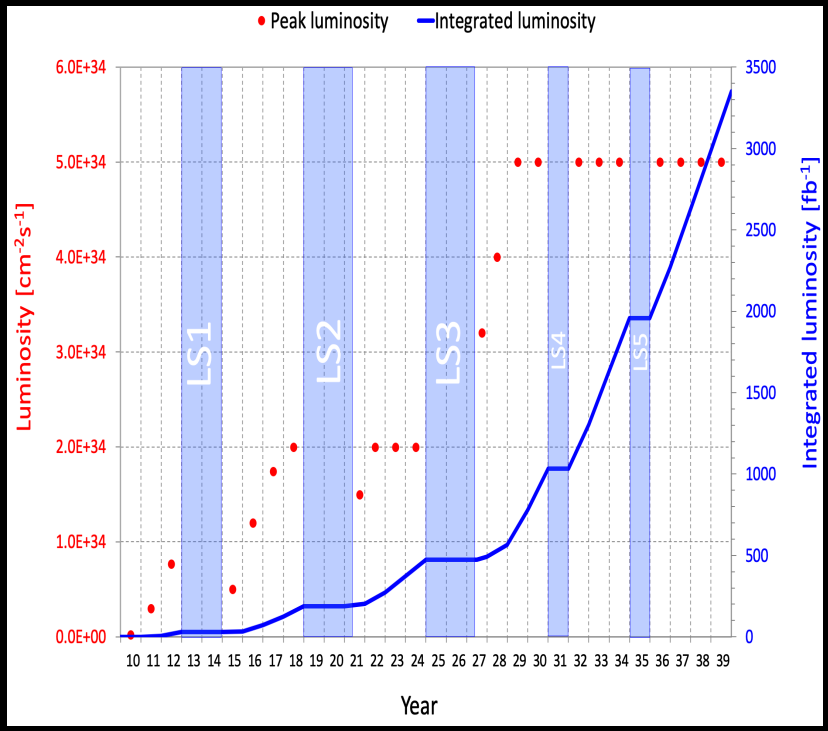
FORWARD PHYSICS FACILITY

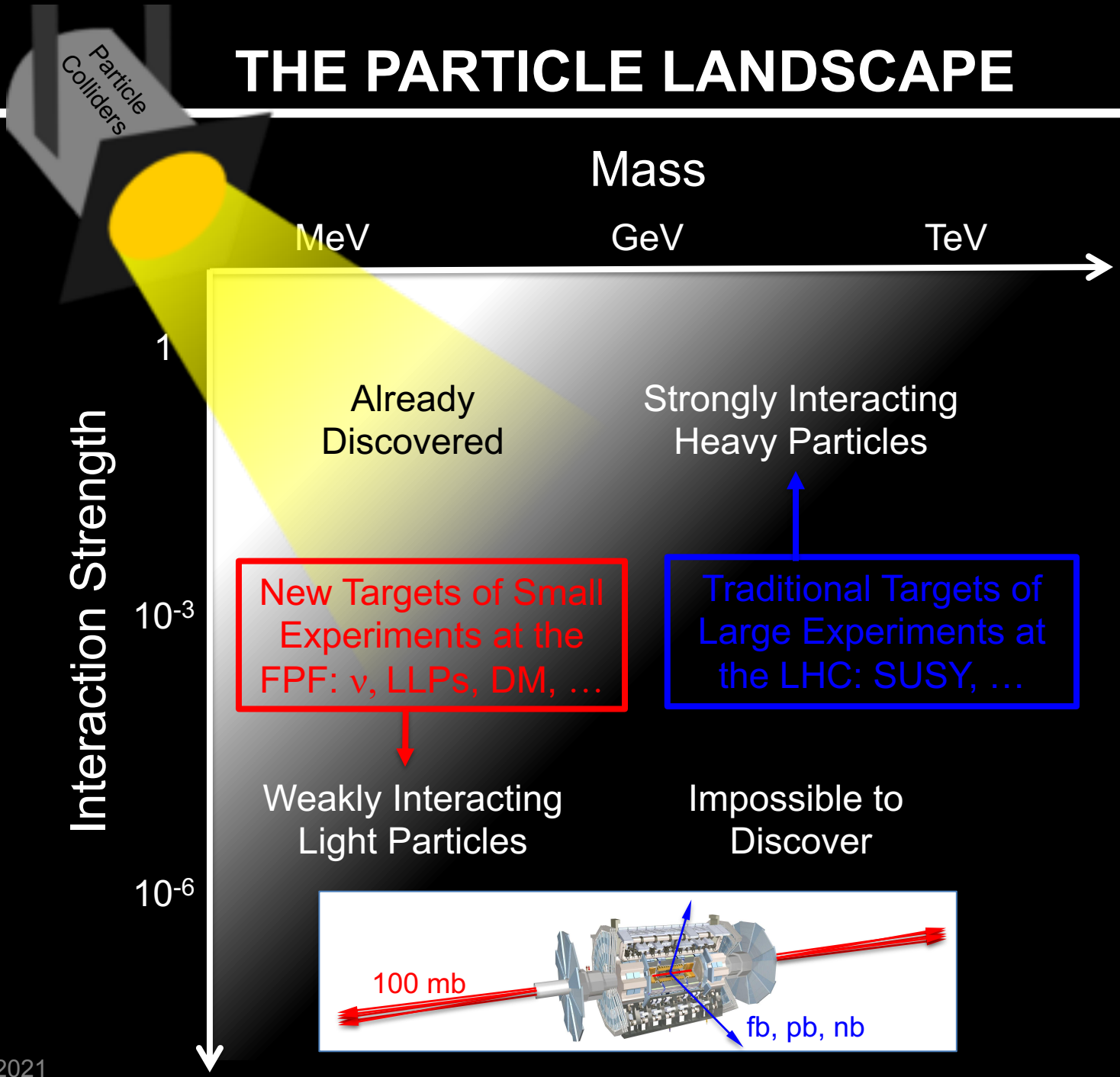
- A fact that should be better appreciated: we are in a critical period.

- 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 dead (either professionally or actually).



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

THE PARTICLE LANDSCAPE



UPDATES:

CIVIL ENGINEERING

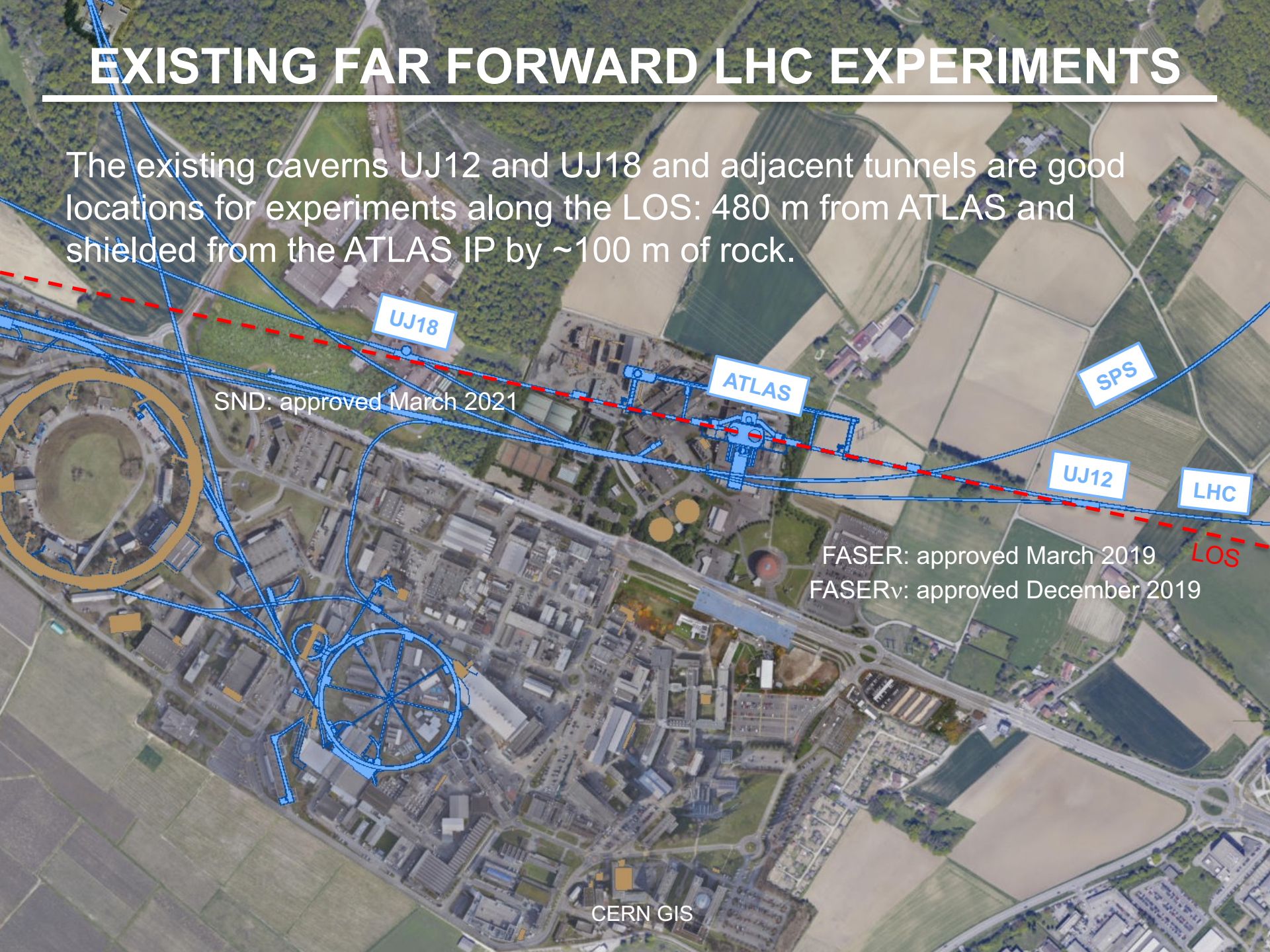
BSM PHYSICS

SM PHYSICS

CIVIL ENGINEERING

EXISTING 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.

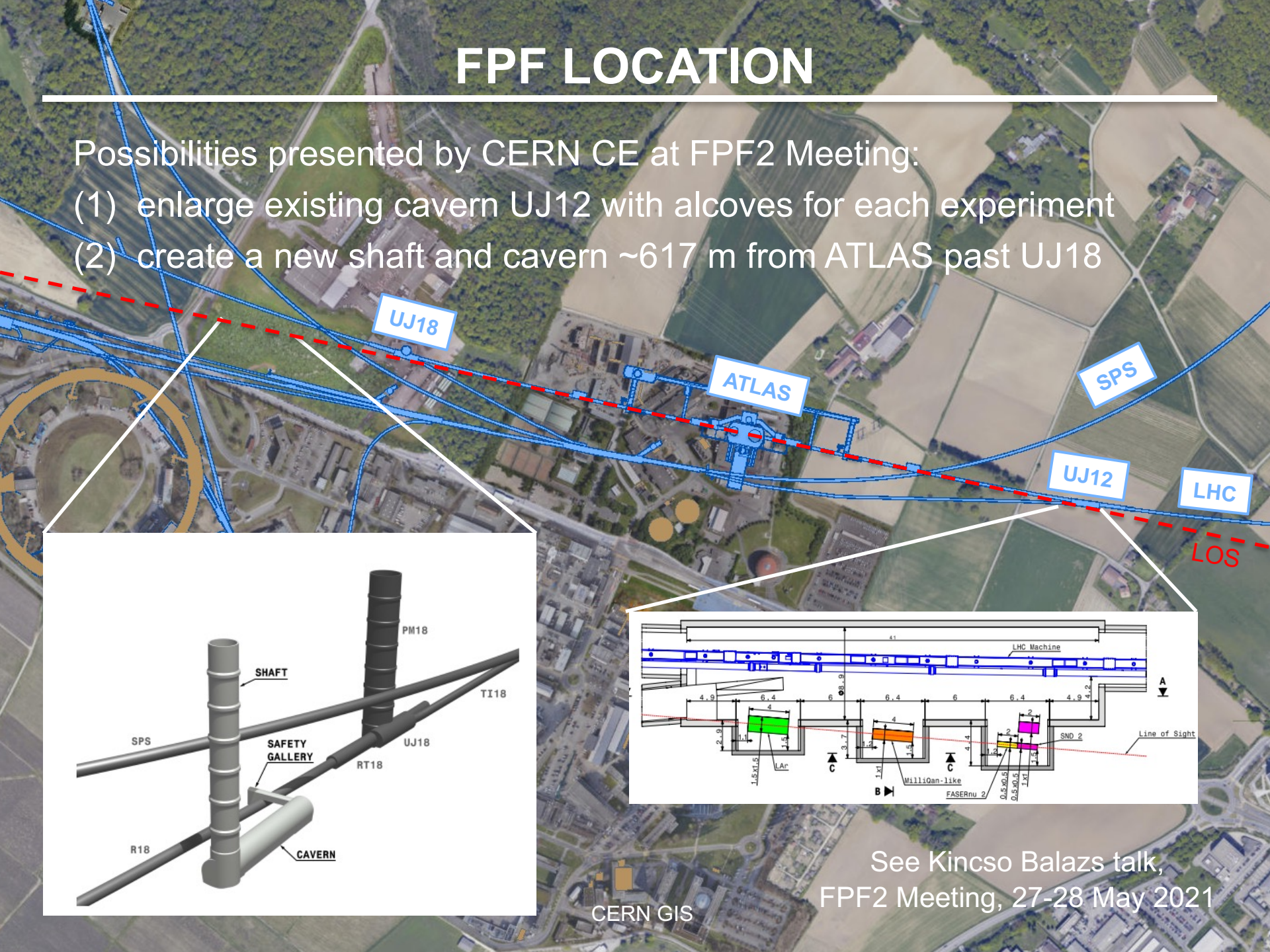


FPF LOCATION

Possibilities presented by CERN CE at FPF2 Meeting:

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

(2) create a new shaft and cavern ~617 m from ATLAS past UJ18

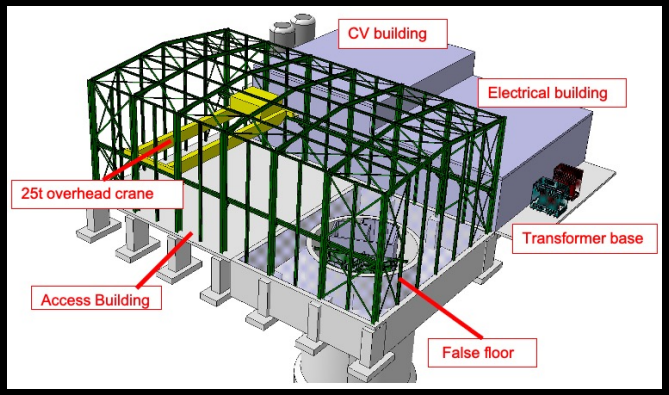


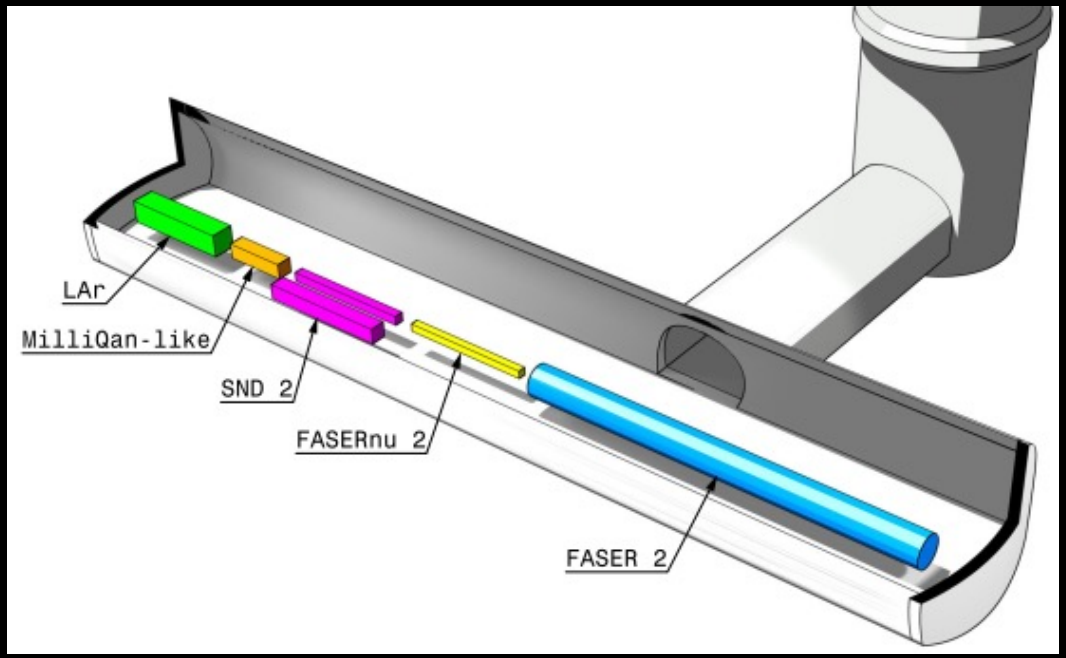
CERN GIS

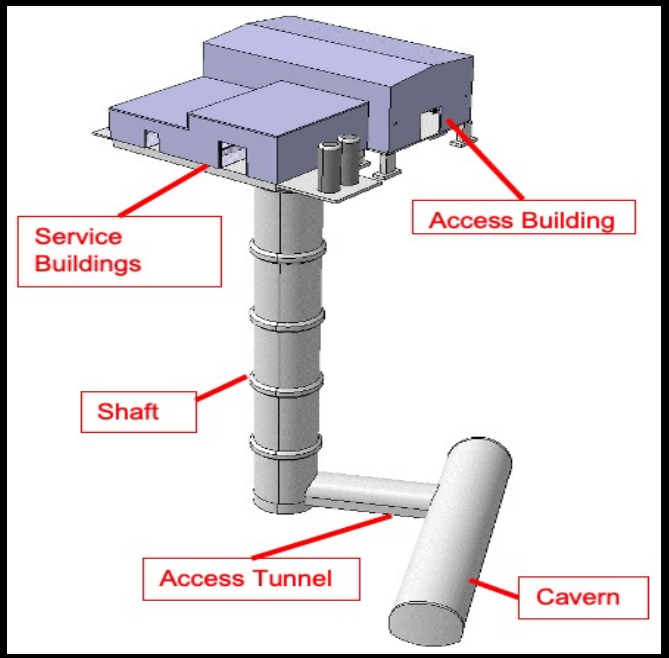
See Kincso Balazs talk,
FPF2 Meeting, 27-28 May 2021

NEW SHAFT AND CAVERN

- Many advantages
  - Construction access far easier
  - Flexible size and length of cavern (> 60 m)
  - Designed around needs of the experiments
- Very preliminary (class 4) cost estimate: ~$23 MCHF, not including services. See Balazs talk for the many significant caveats.





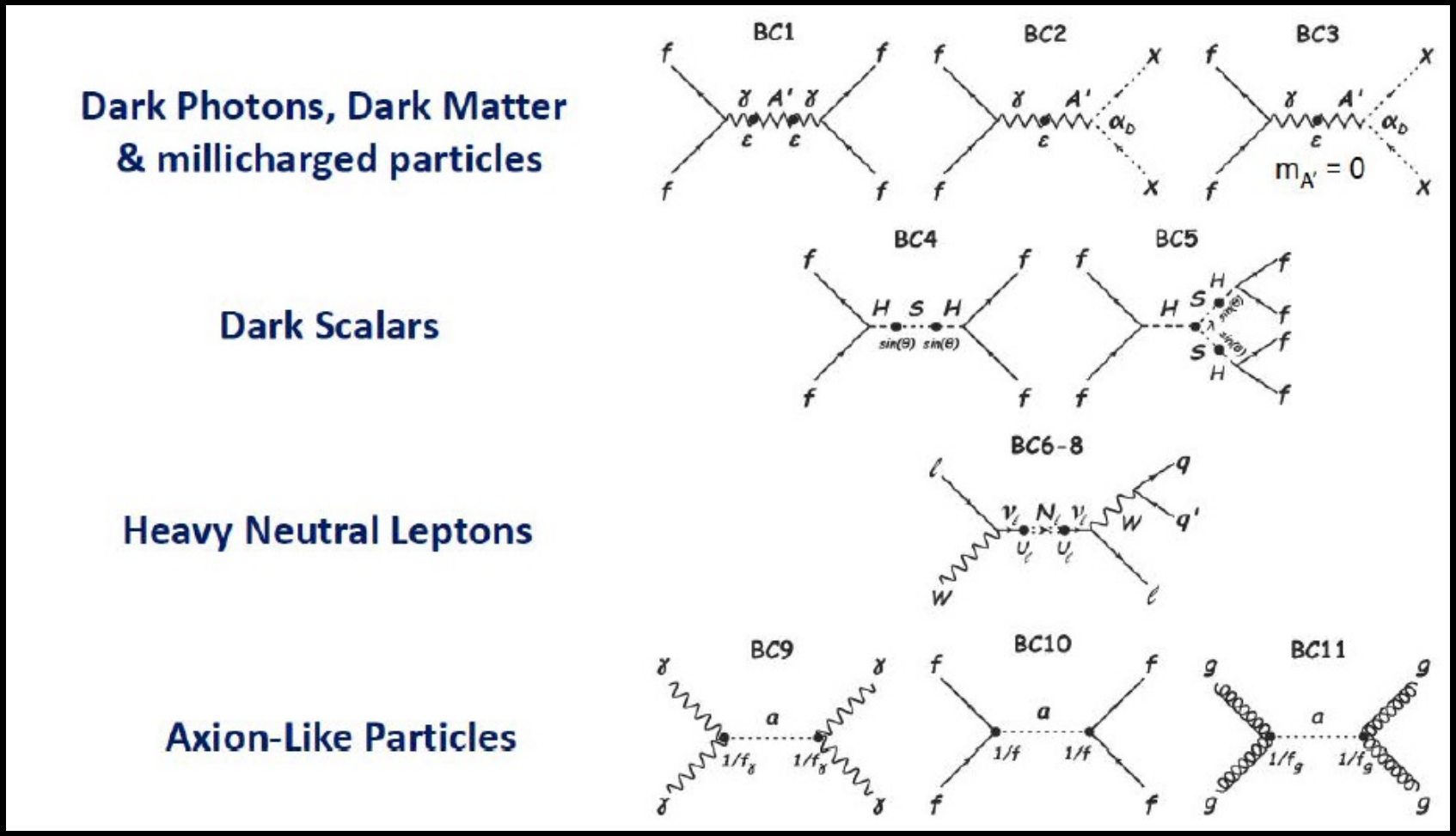


Design by Liam Dougherty (EN-ACE-INT)

BSM PHYSICS

PBC BSM BENCHMARK CASES

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



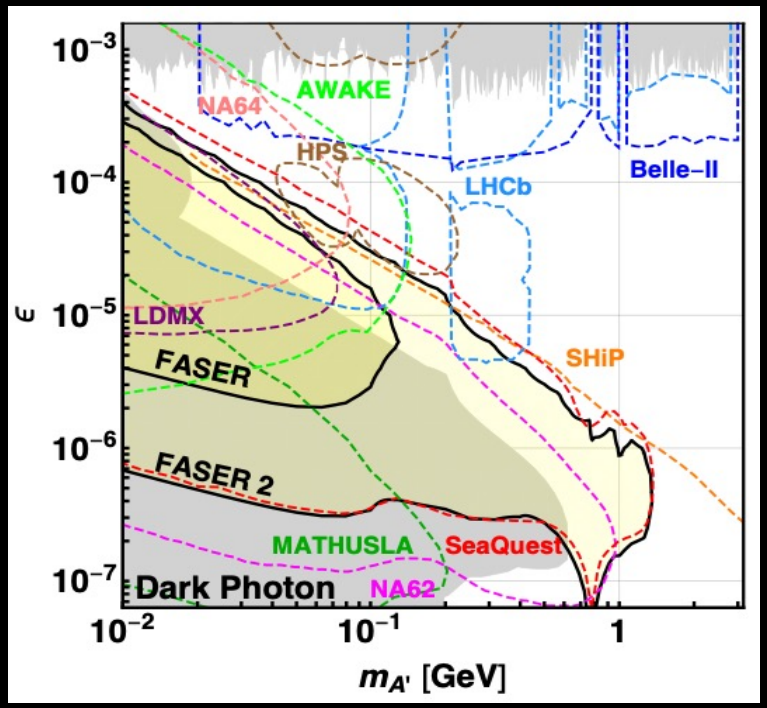
BSM SUMMARY

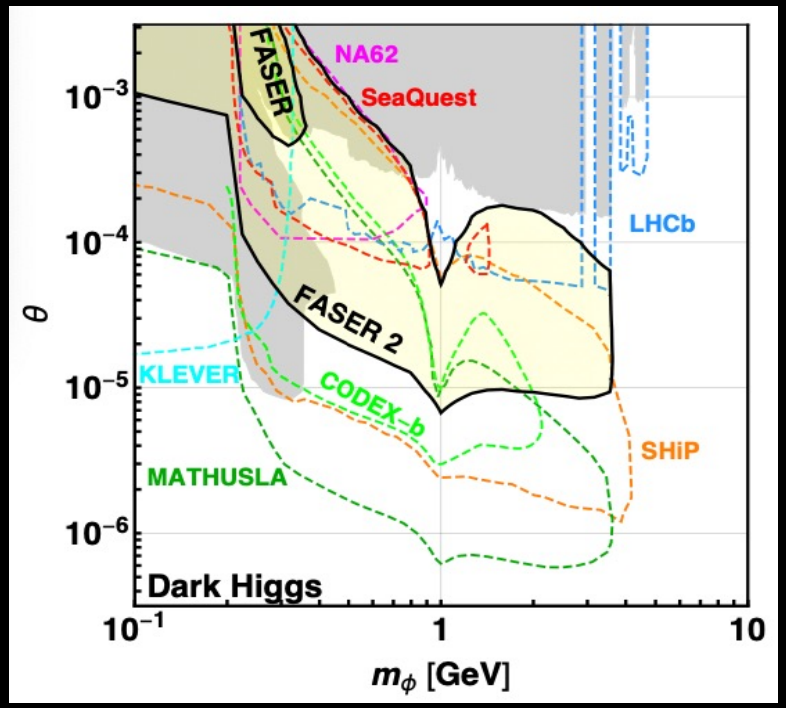
- FASER and FASER2 are well-known to cover many, but not all, of the benchmarks.
- Recent studies have shown that FPF experiments can discover new physics in the remaining two PBC benchmark cases (BC2 and BC3).

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 Batell, Feng, Kling, Ismail, Mammen, Trojanowski 2107.00666
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.

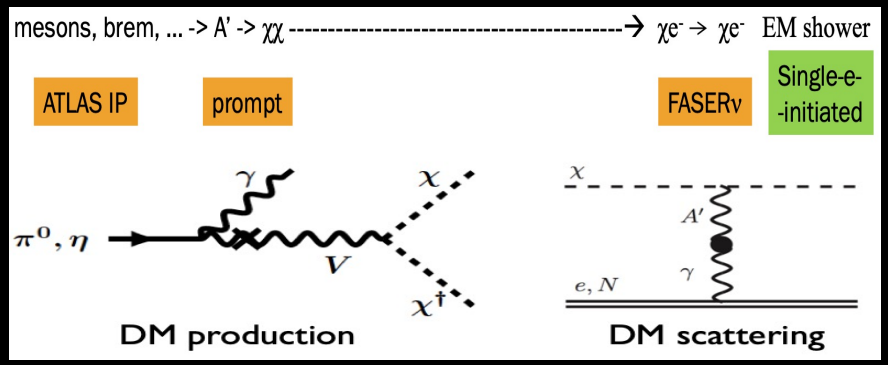




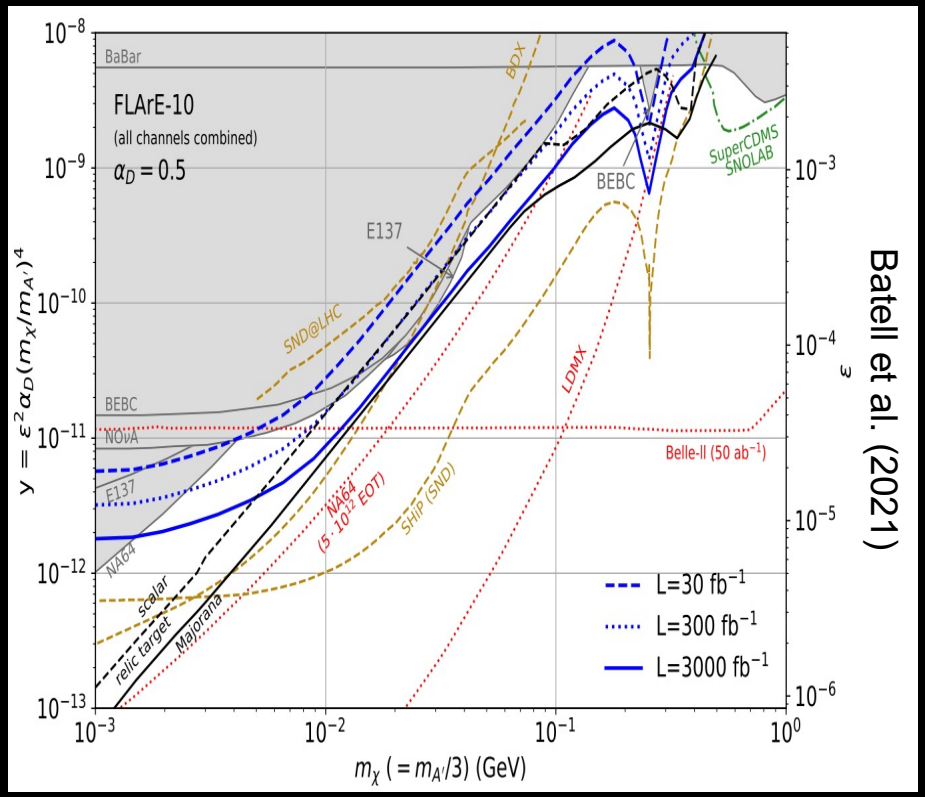
FASER Collaboration, 1811.12522 (2018)

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 and nuclei at FLArE, Forward Liquid Argon Experiment, a proposed 10-100 tonne LArTPC.



- FLArE probes most of parameter space that is not excluded by DM overclosing the universe.
- Direct detection, not missing energy.



SM PHYSICS

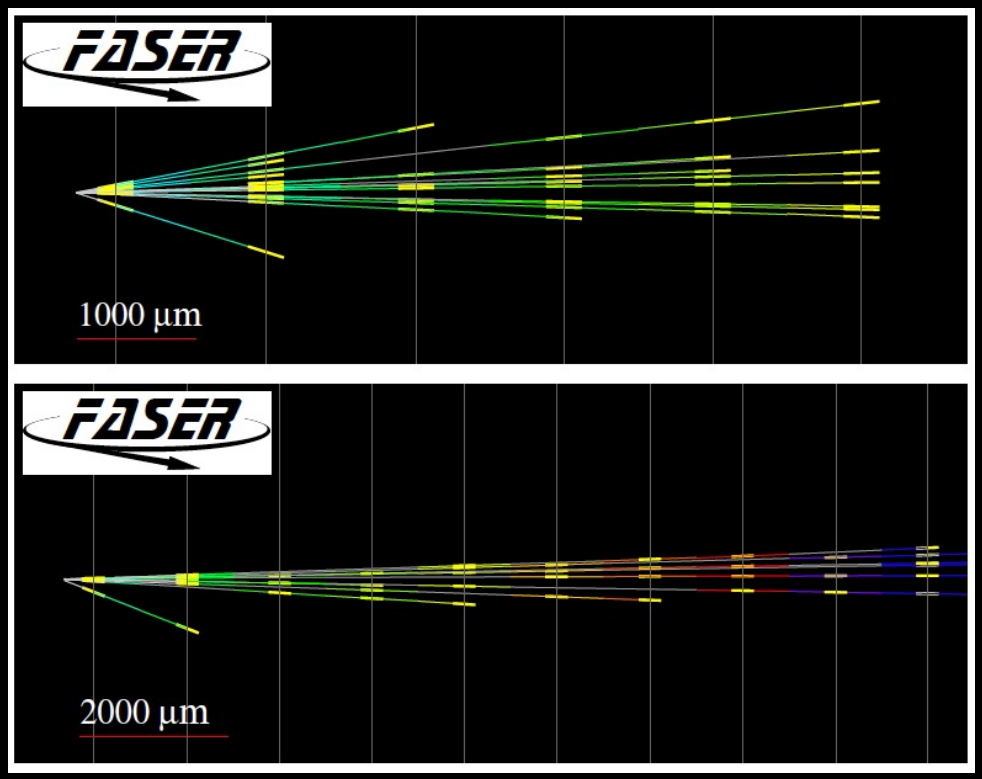
FIRST COLLIDER NEUTRINOS

- No collider neutrino was previously detected, but there is a huge flux of TeV neutrinos in the far forward direction

  De Rujula, Ruckl (1984); Winter (1990)

- In 2018 a 29 kg FASER pilot emulsion detector collected 12.2 fb^{-1} on the beam collision axis (installed and removed during Technical Stops).

- Based on 11 kg fidiucial mass, expect ~3.3 ν interactions. In May 2021, announced the first direct detection of 6 collider neutrino candidates above 12 expected neutral hadron backgrounds (2.7σ).

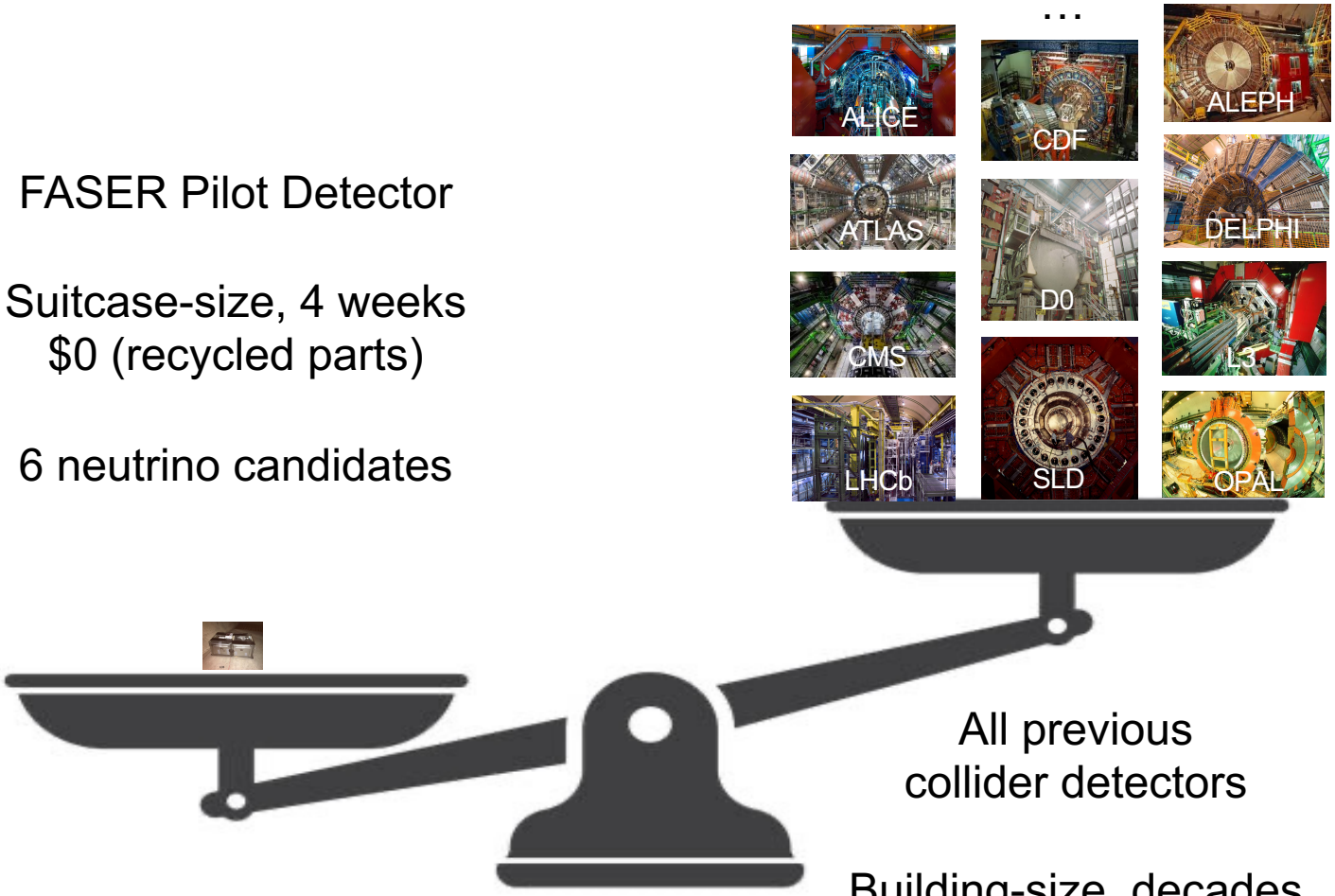


LOCATION, LOCATION, LOCATION

FASER Pilot Detector

Suitcase-size, 4 weeks
$0 (recycled parts)

6 neutrino candidates



All previous
collider detectors

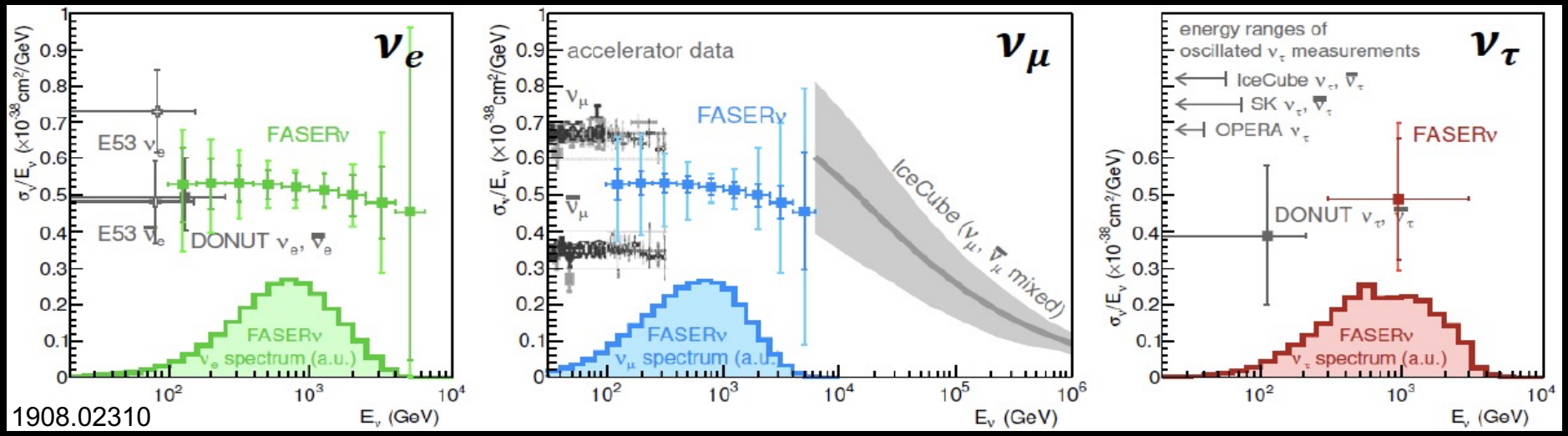
Building-size, decades
~10^9

0 neutrino candidates

A sign of things to come

NEUTRINO PHYSICS

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



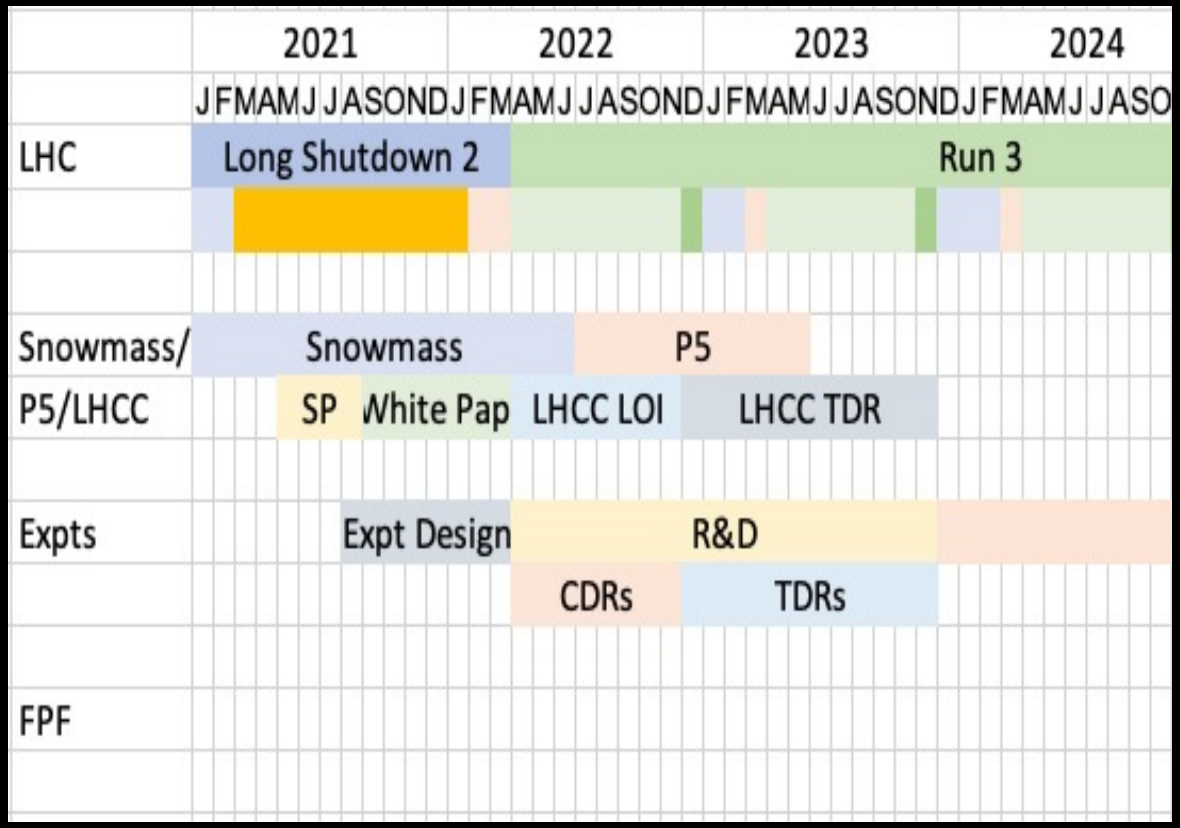
1908.02310

- HL-LHC: FPF will accommodate FASERν2 / SND2 (~10-tonne emulsion detectors), FLArE (10+ tonne LArTPC)
  - ~100,000 ν_e , ~1,000,000 ν_μ , and ~1000 ν_τ interactions at TeV energies

THOUGHTS ON SCHEDULE

EXAMPLE SCHEDULE

- Not even “very preliminary” !
- Assumes new cavern option for the FPF.



Shutdown / YETS
Proton physics
Ion physics
Commissioning with beam
Hardware commissioning / magnet training

- Starting when the HL-LHC starts is necessary to maximize physics. A long way to go, but experiment design in coming year is a crucial step.
- Would welcome lab help for designing FLArE, DOE reviews, etc.