# NEUTRINOS AND FAR-FORWARD PHYSICS AT THE LHC

*Physics/Theory Colloquium, Los Alamos National Laboratory*

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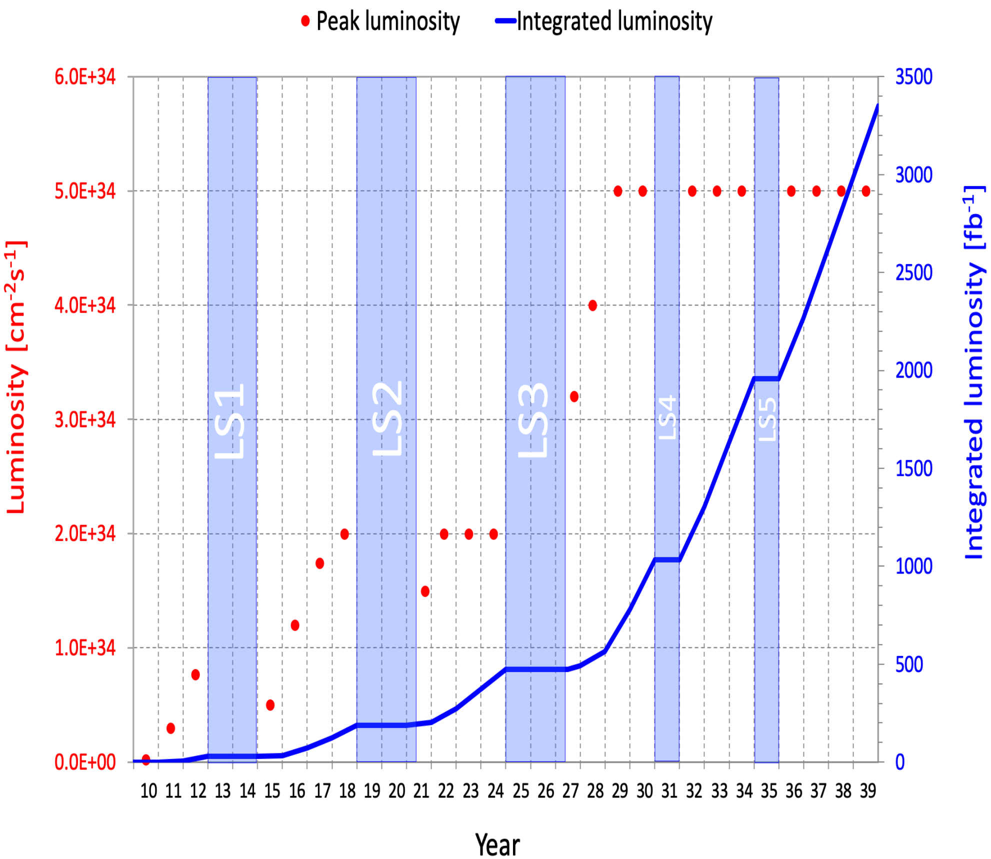
# PARTICLE PHYSICS: CURRENT STATUS

- This is a critical time in particle physics: the Higgs boson was discovered in 2012, but we have not discovered any other evidence of new particles, and many fascinating problems remain (neutrino masses, dark matter, gauge and flavor hierarchy problems, …).

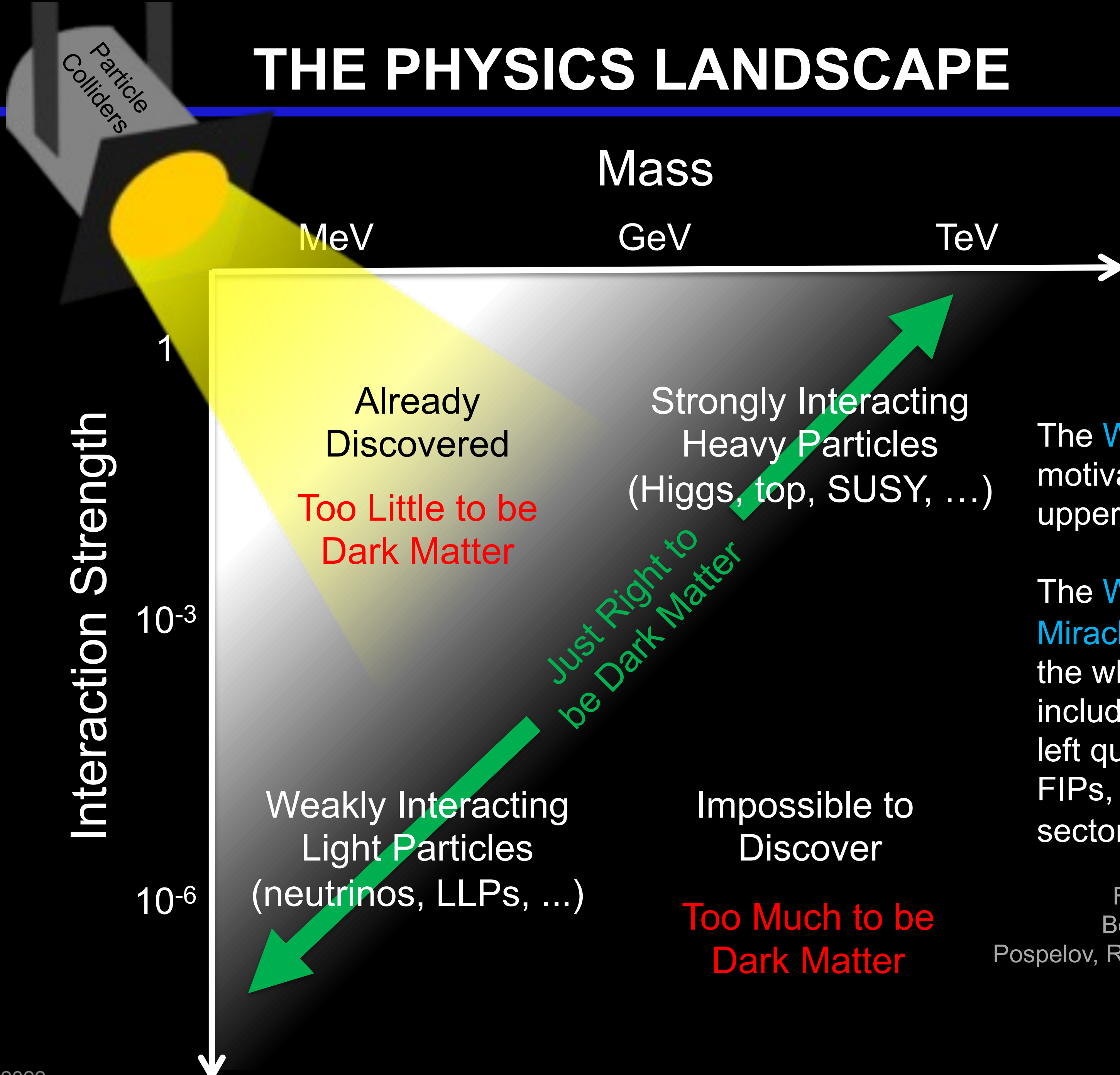
- At the energy frontier, the LHC has just emerged from Long Shutdown 2.

- Much more to come:
  Run 3, 2022-25, 300 $fb^{-1}$
  HL-LHC, 2029-42, 3-4 $ab^{-1}$

- What can we do to enhance the physics potential of the (HL-)LHC?



# THE PHYSICS LANDSCAPE

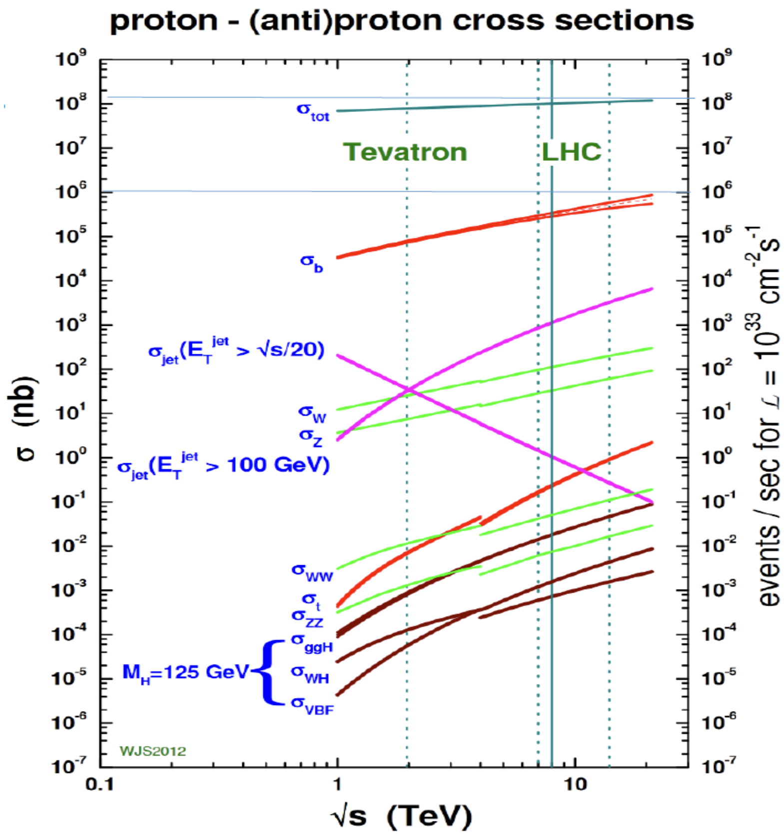


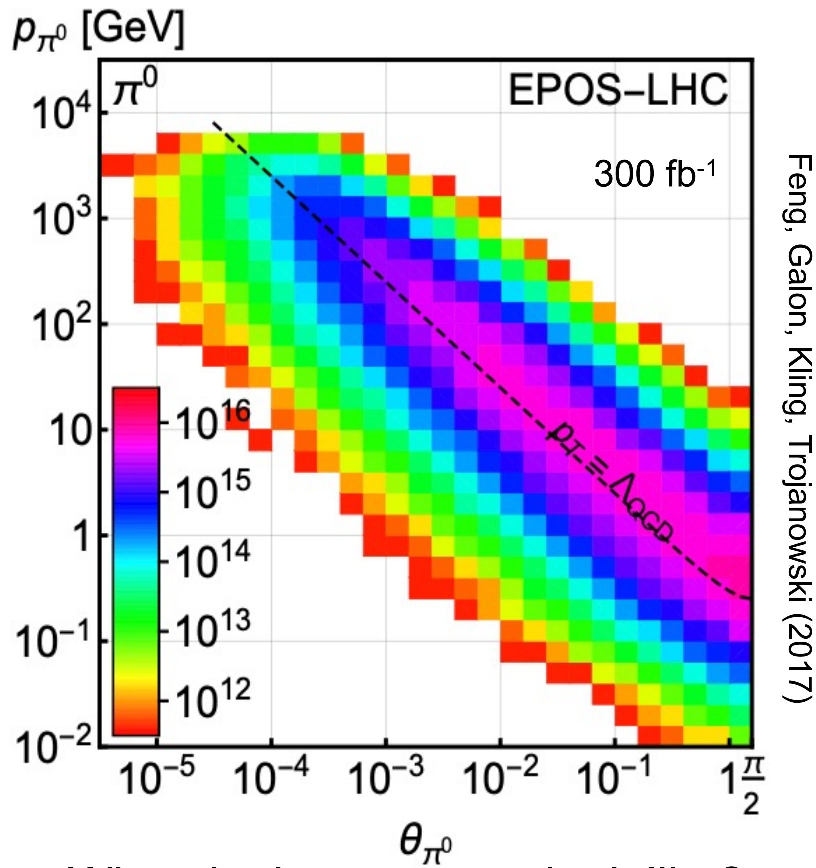

The WIMP Miracle motivates the upper right corner.

The WIMPless Miracle motivates the whole diagonal, including the lower left quadrant (LLPs, FIPs, portals, dark sectors…)

Feng, Kumar (2008)
Boehm, Fayet (2003)
Pospelov, Ritz, Voloshin (2007)

# LHC PARTICLE PRODUCTION



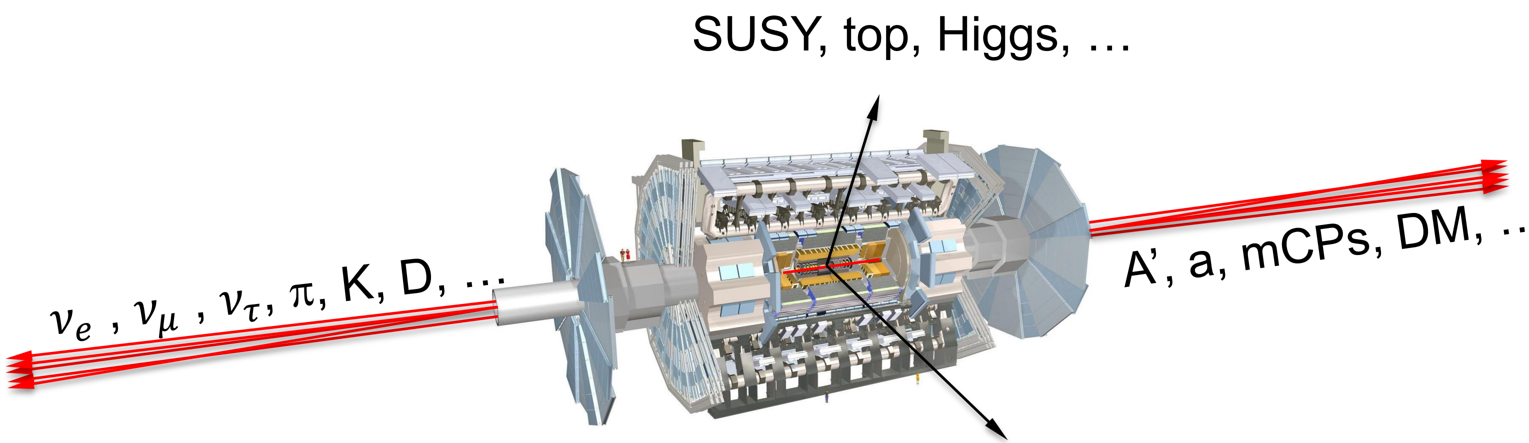




- The existing large LHC detectors have focused on heavy particles and processes with σ ~ fb, pb.
- But light particles can be produced with $\sigma_{\mathrm{tot}}$ ~100 mb.

- What do these events look like? Consider pions ($\pi^{\pm} \to \nu$ , $\pi^0 \to A'$, ... )
- Typical $p_T$ ~ 250 MeV, but many with $p$ ~ TeV within 1 mrad (η > 7.6) of the beamline.

# THE PROMISE OF FAR-FORWARD PHYSICS

- Particles that close to the beamline are not seen by existing large LHC detectors. They were designed to find strongly-interacting heavy particles.



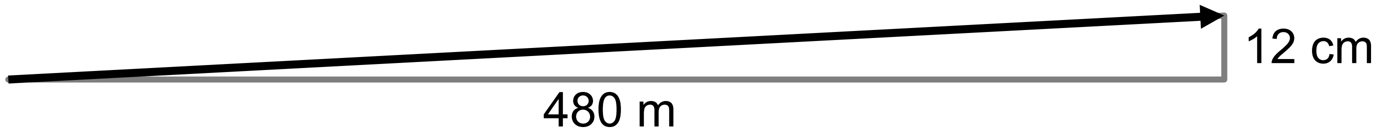

- But weakly-interacting light particles are dominantly produced in the rare decays of light particles (π, η, K, D, B, …) along the forward direction, and so escape through the blind spots down the beamline.

- There are both SM and BSM motivations to explore the "wasted" $\sigma_{tot}$ ~ 100 mb and cover these blind spots in the far forward region.

# HOW BIG DO THE DETECTORS HAVE TO BE?

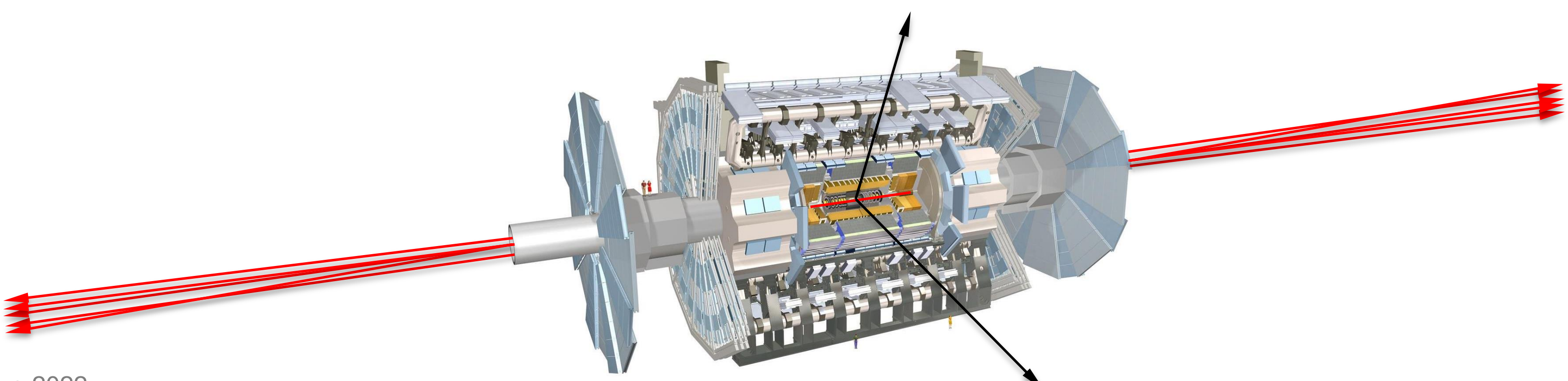
- Momentum:


- Space:



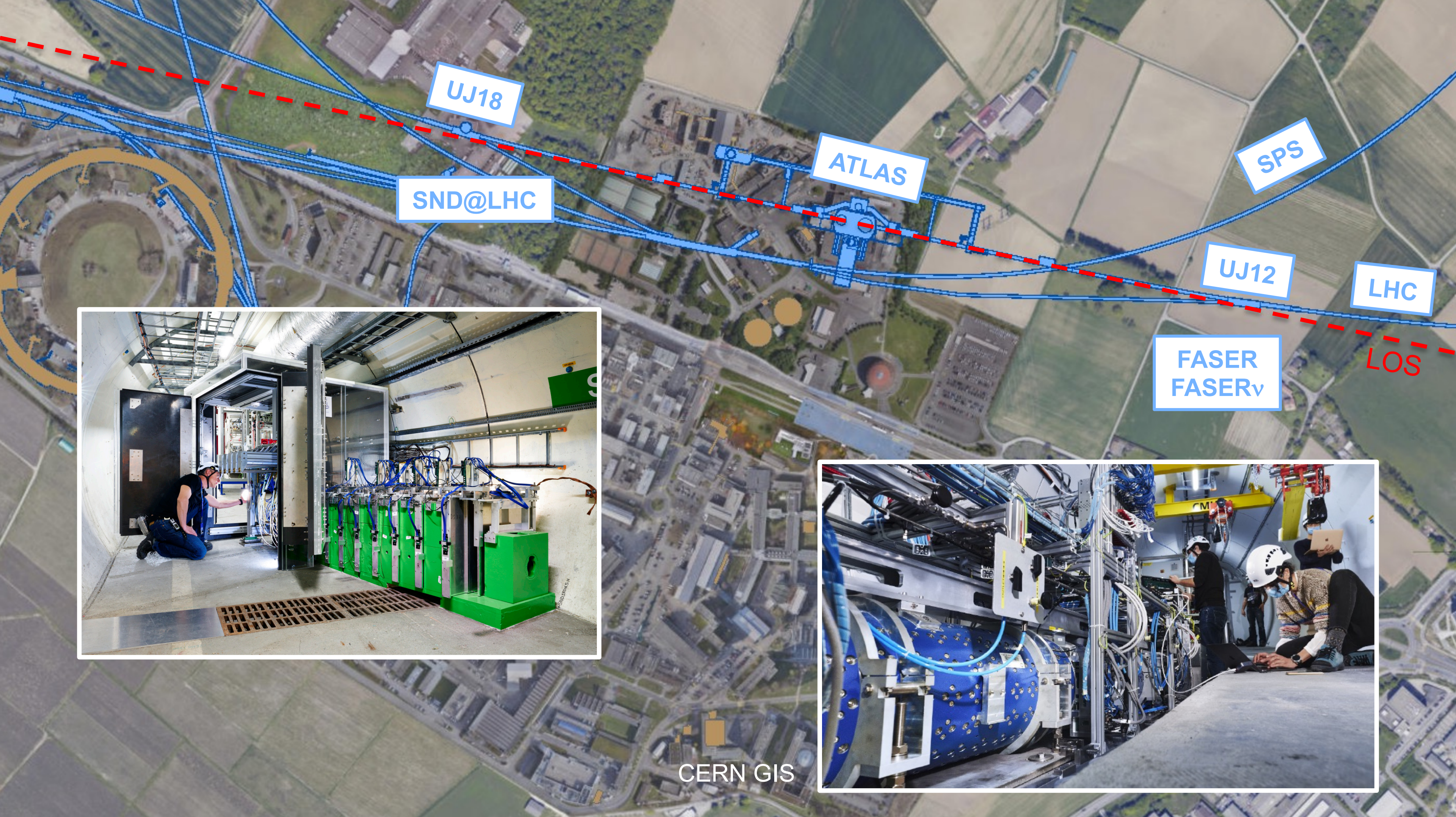

- Particles produced in pion decays have $\theta \sim 0.2$ mrad ($\eta \sim 9$); cf. the moon (7 mrad).

- Particles produced in $\pi$, $\eta$, K, D, B decay are therefore far more collimated than shown below, motivating new, small, fast, and cheap experiments at the LHC.



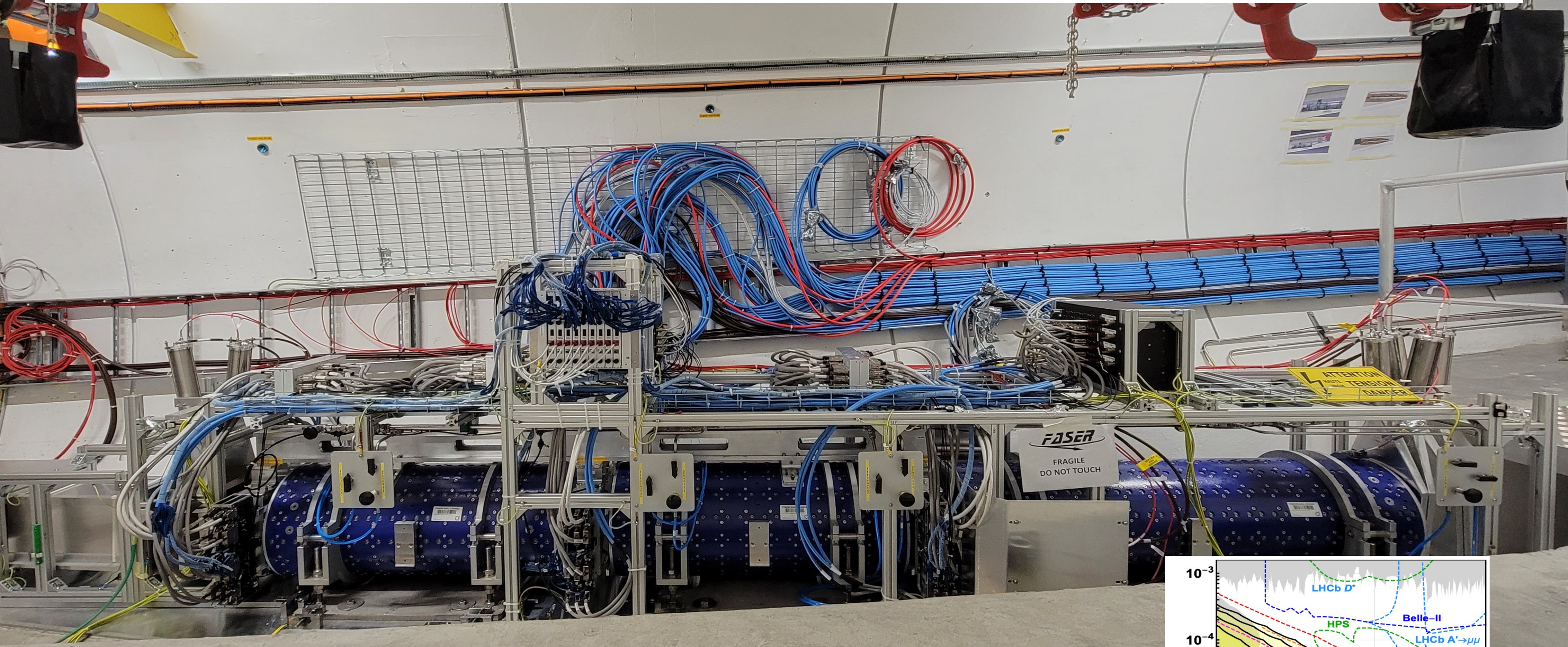
# CURRENT FAR FORWARD DETECTORS

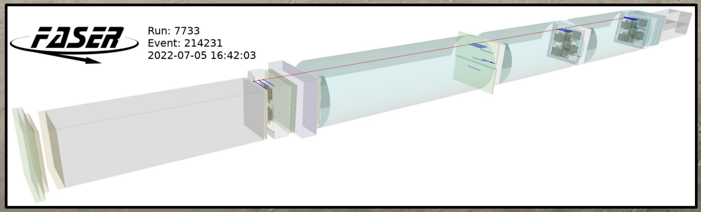
3 far forward detectors have been constructed and installed and are currently taking data in LHC Run 3: FASER, FASERν, and SND@LHC.

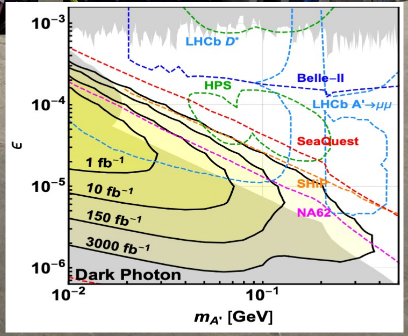


# FASER CURRENT STATUS

LHC Run 3 started (officially) on 5 July 2022. Muon backgrounds are within ~30% of expectations (i.e., negligible), and FASER already has enough data to exclude or discover proposed LLPs in new regions parameter space.

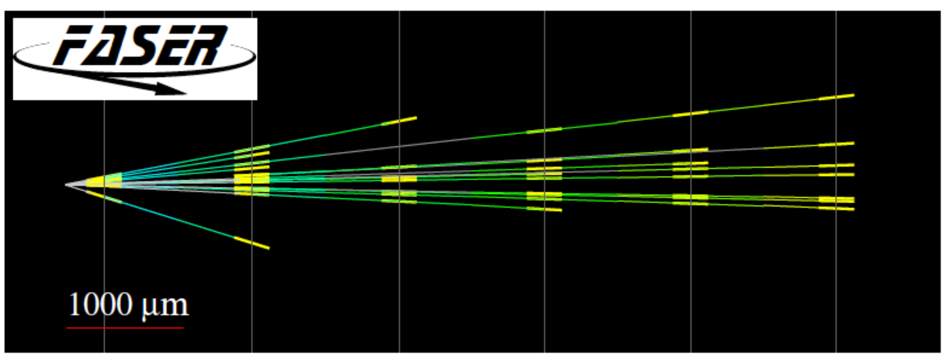


# FASERν CURRENT STATUS

- In 2018 a FASER pilot emulsion detector with 11 kg fiducial mass collected 12.2 $fb^{-1}$ on the beam collision axis (installed and removed during Technical Stops).
- In May 2021, the FASER Collaboration announced the direct detection of 6 candidate neutrinos above 12 expected neutral hadron background events (2.7σ).
- In LHC Run 3, FASERν will observe ~10,000 TeV-neutrino interactions.

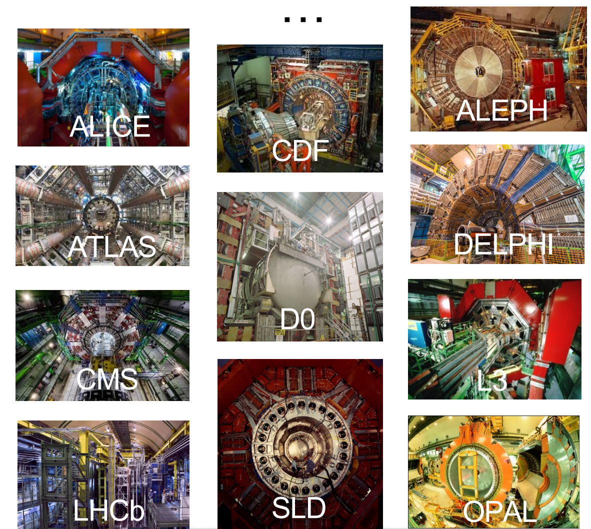



# LOCATION, LOCATION, LOCATION

FASER Pilot Detector

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

6 candidate neutrinos




All previous
collider detectors

Building-size, decades
~$$10^9$

0 candidate neutrinos

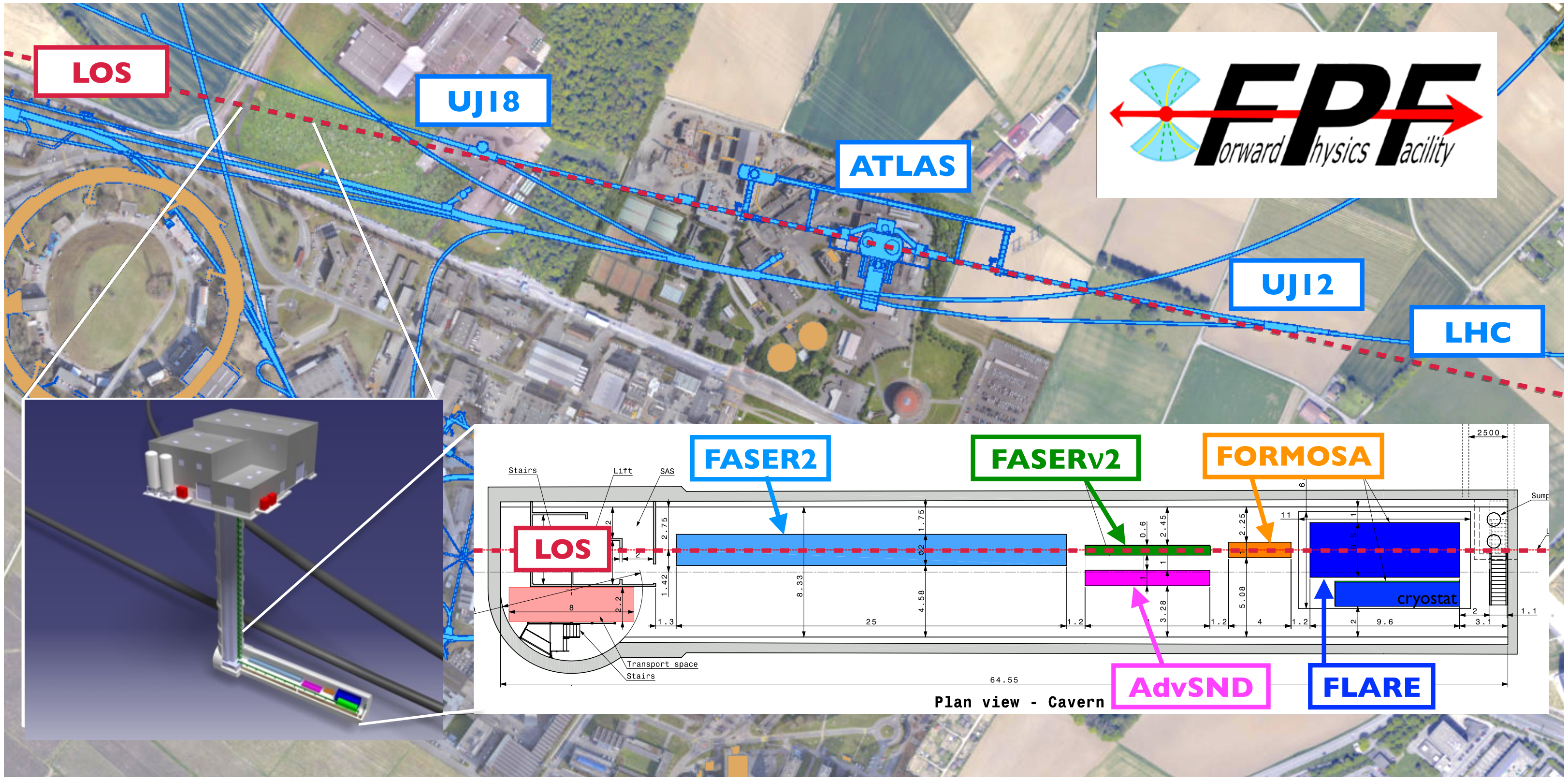
This opens up a new field:
neutrino physics at colliders

# FORWARD PHYSICS FACILITY

- FASER, FASER$\nu$, and SND@LHC are currently highly constrained by 1980's (LEP!) infrastructure that was never intended to support experiments.
- The rich physics program therefore strongly motivates creating a dedicated Facility to house far-forward experiments for the HL-LHC era from 2029-2042.
- FPF Meetings
  - FPF Kickoff Meeting, 9-10 Nov 2020, https://indico.cern.ch/event/955956
  - FPF2 Meeting, 27-28 May 2021, https://indico.cern.ch/event/1022352
  - FPF3 Meeting, 25-26 Oct 2021, https://indico.cern.ch/event/1076733
  - FPF4 Meeting, 31 Jan-1 Feb 2022, https://indico.cern.ch/event/1110746
- FPF Papers
  - "Short" Paper: 75 pages, 80 authors (2109.10905, Physics Reports 968, 1 (2022)).
  - Snowmass White Paper: 429 pages, 392-authors+endorsers (2203.05090, J. Phys. G).
- FPF-related talks at Snowmass
  - July 18: EF05-07, Hallsie Reno
  - July 20: EF09/RF06, Jonathan Feng
  - July 21: NF02, Felix Kling
  - July 22: EF/NF: Milind Diwan
  - July 24: NF04/CF07, Ina Sarcevic
  - July 26: Small- and Mid-Scale Experiments/Facilities, Jonathan Feng
  - Many summary discussions, talks, panels

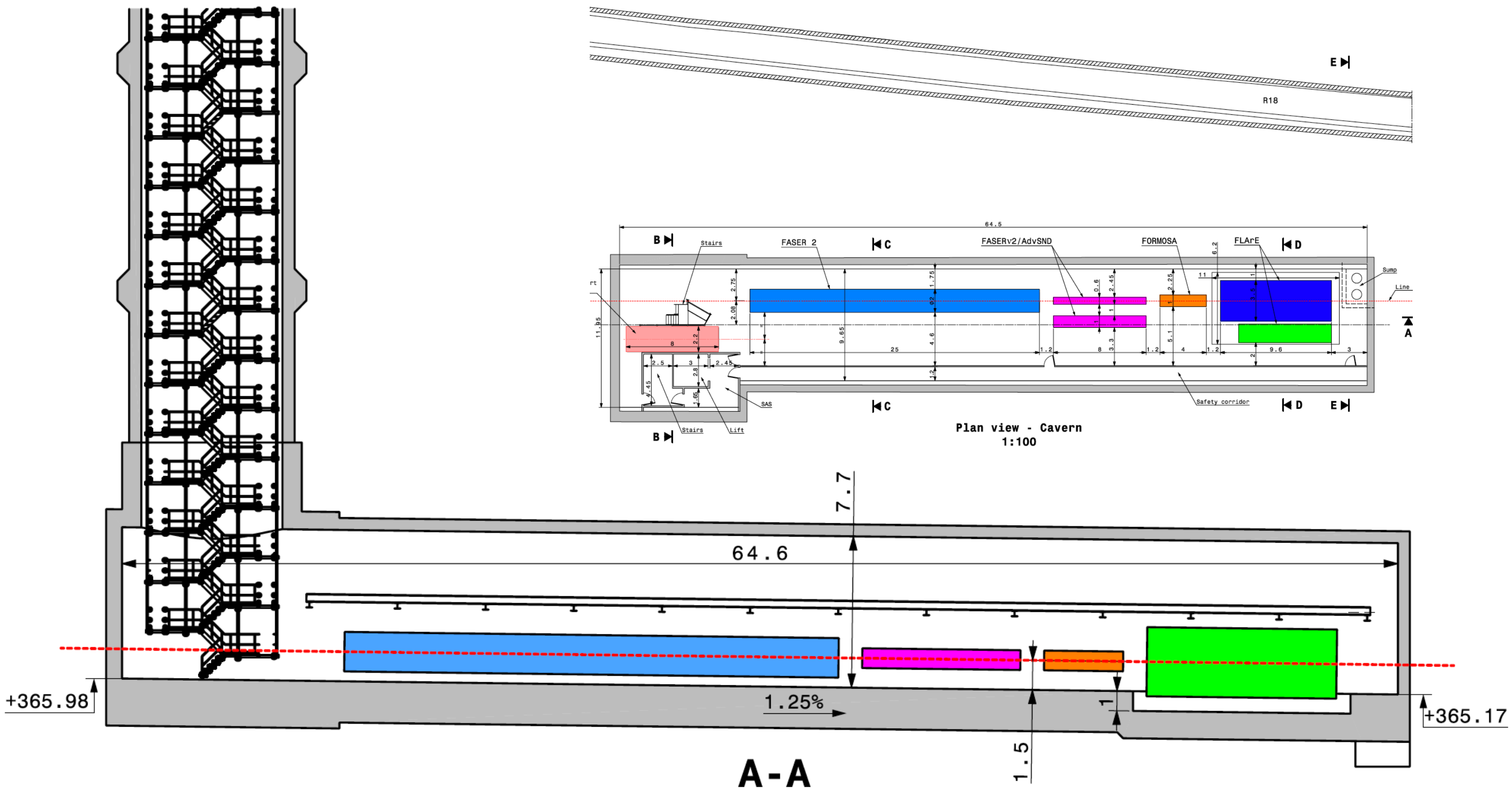
# THE FPF SITE

- Site selection has been completed: the CERN civil engineering team considered and documented promising sites and identified a preferred location on CERN land in France, 620-685 m west of the ATLAS IP, shielded by ~200 m of rock.

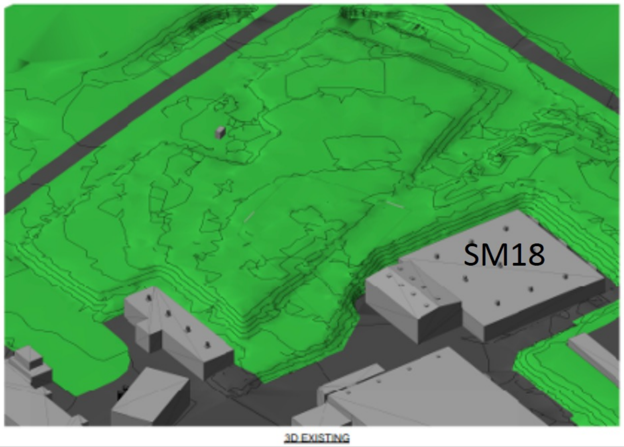


# CAVERN AND SHAFT

- Cavern: 65m long, 8m wide/high.  Shaft: 88m-deep, 9.1m-diameter.
- The FPF is completely decoupled from the LHC: no need for a safety corridor connecting the FPF to the LHC, preliminary RP and vibration studies indicate that FPF construction will have no significant impact on LHC operation.

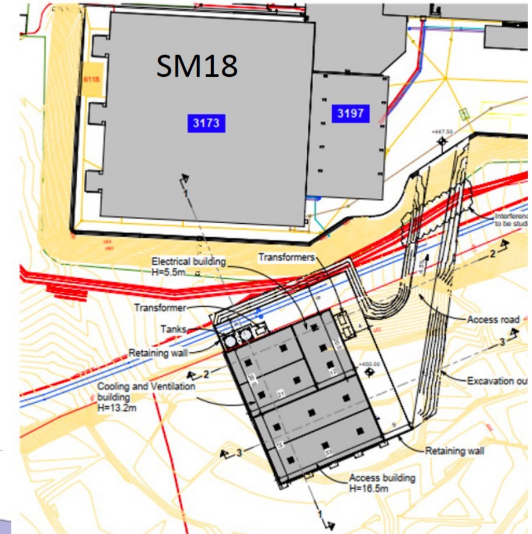


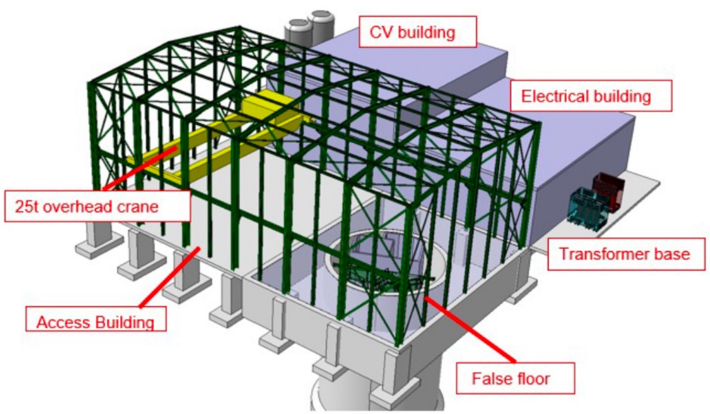
# SURFACE BUILDINGS

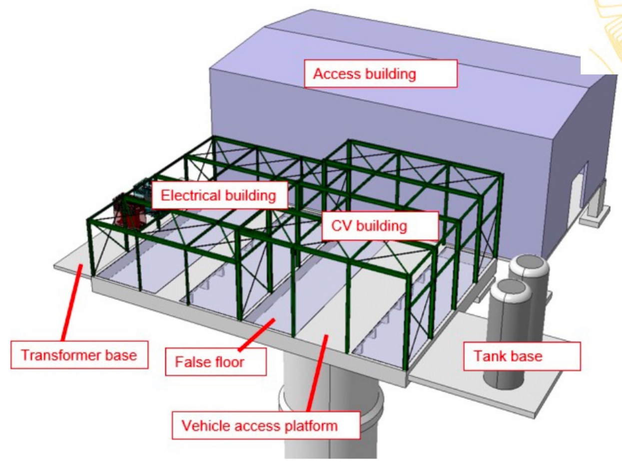


3D EXISTING

3D NEW




Kincso Balazs,
John Osborne,
CERN CE (2022)

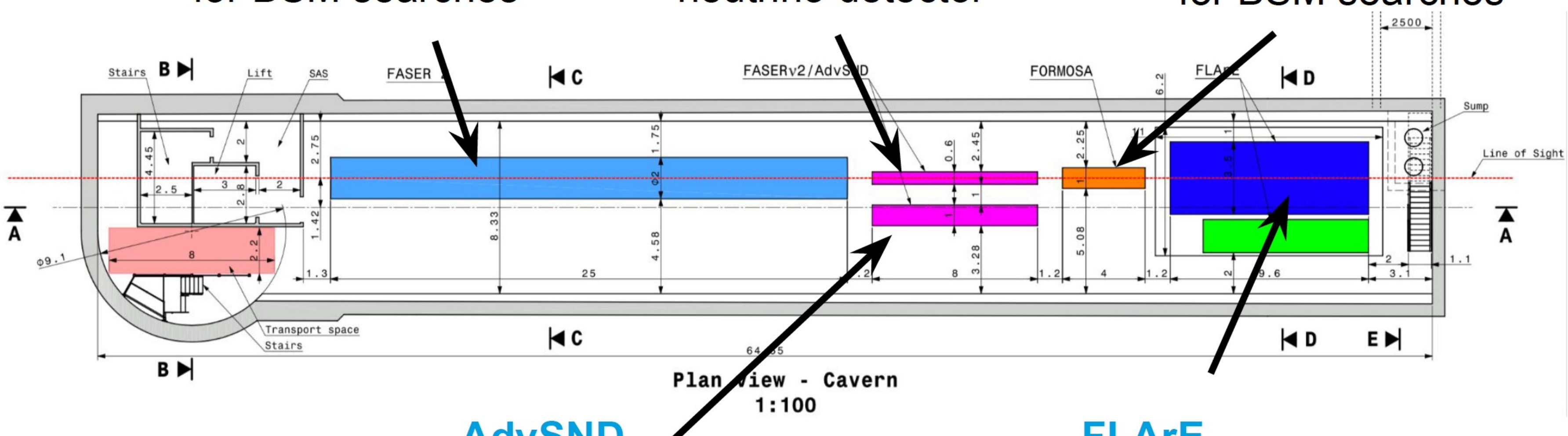
# FPF EXPERIMENTS

- At present there are 5 experiments being developed for the FPF.
- Pseudo-rapidity coverage in the FPF is $\eta > 5.5$, with most experiments on the LOS covering $\eta > 7$.

**FASER2**
magnetized spectrometer
for BSM searches

**FASERv2**
emulsion-based
neutrino detector

**FORMOSA**
plastic scintillator array
for BSM searches




**AdvSND**
electronic
neutrino detector

**FLArE**
LAr based
neutrino detector

Kling (2022)

# FPF PHYSICS

- The FPF is a general purpose facility with a broad SM and BSM physics program that expands on the physics of FASER and FASERν. For details, see the FPF White Paper.