FASER

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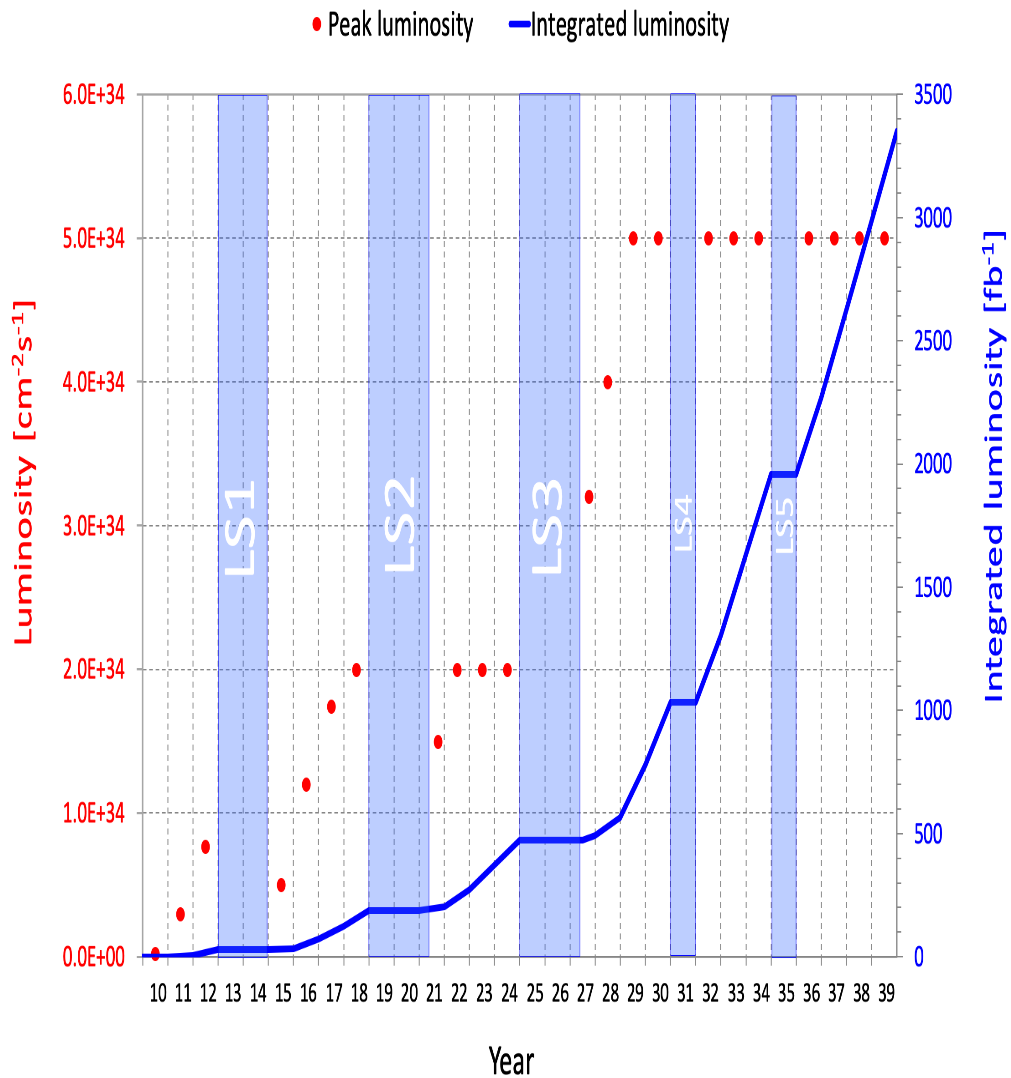
Ting Mini-Symposium, 22 February 2023

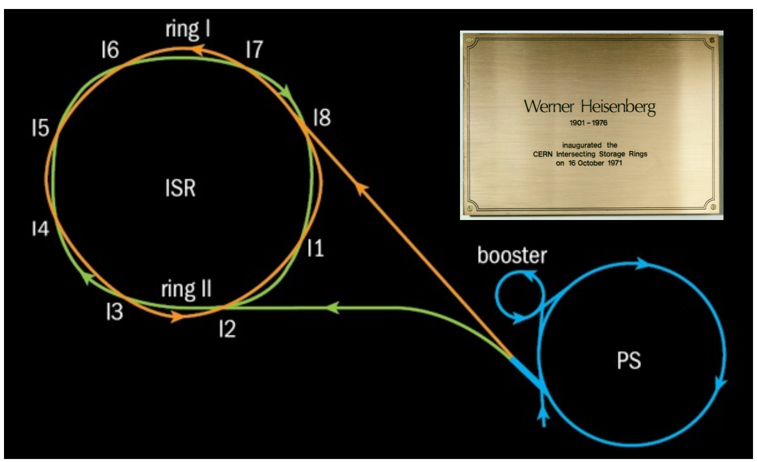
PARTICLE PHYSICS NOW

- This is a critical time in particle physics: many outstanding problems (neutrino masses, dark matter, …)
- At the energy frontier, the Large Hadron Collider at CERN started running again in 2022 and will run until ~2040.
- What can we do to enhance the LHC's prospects for discovering new particles and shedding light on the many outstanding problems?



SOME HISTORY

- Sometimes to look forward, it pays to first look back.
- 2021 was the 50th anniversary of the birth of hadron colliders.
- In 1971, CERN's Intersecting Storage Rings (ISR), with a circumference of ~1 km, collided protons with protons at center-of-mass energy 30 GeV.



ISR'S LEGACY

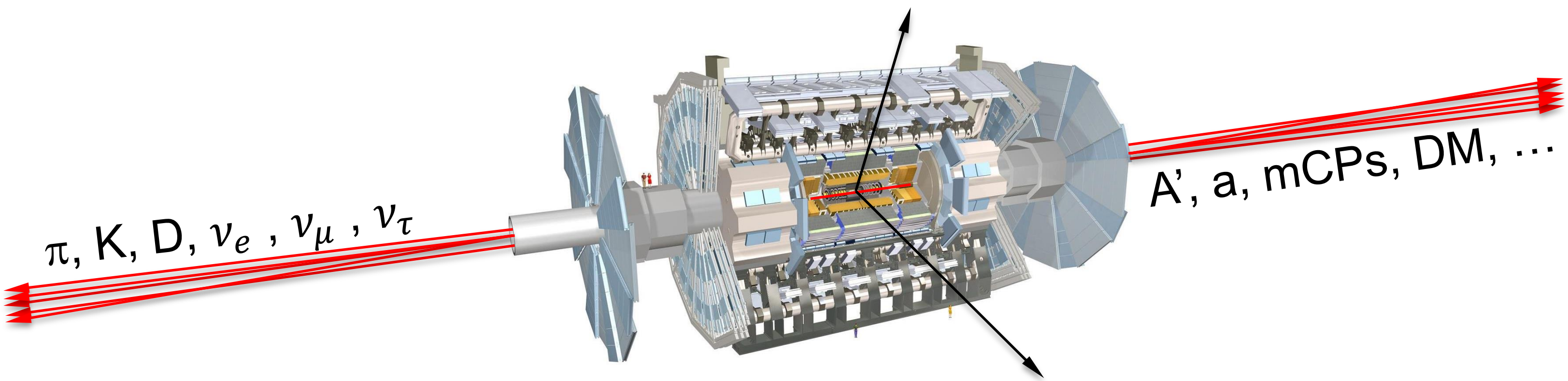
- During ISR's 50th anniversary, there were many fascinating articles and talks by eminent physicists looking back on the ISR's legacy.
  - "Enormous impact on accelerator physics, but sadly little effect on particle physics." – Steve Myers, talk at "The 50th Anniversary of Hadron Colliders at CERN," October 2021.
  - "There was initially a broad belief that physics action would be in the forward directions at a hadron collider…. It is easy to say after the fact, still with regrets, that with an earlier availability of more complete… experiments at the ISR, CERN would not have been left as a spectator during the famous November revolution of 1974 with the J/ψ discoveries at Brookhaven and SLAC ." – Lyn Evans and Peter Jenni, "Discovery Machines," CERN Courier (2021).
- Bottom line: They seem to be saying that the collider was creating new forms of matter (charm), but the detectors focused on the forward region (along the beamline) and so missed them.

FORWARD PHYSICS

- Are we now making a similar mistake at the LHC? Yes! We are now so focused on the transverse direction, that we are missing opportunities in the forward direction.

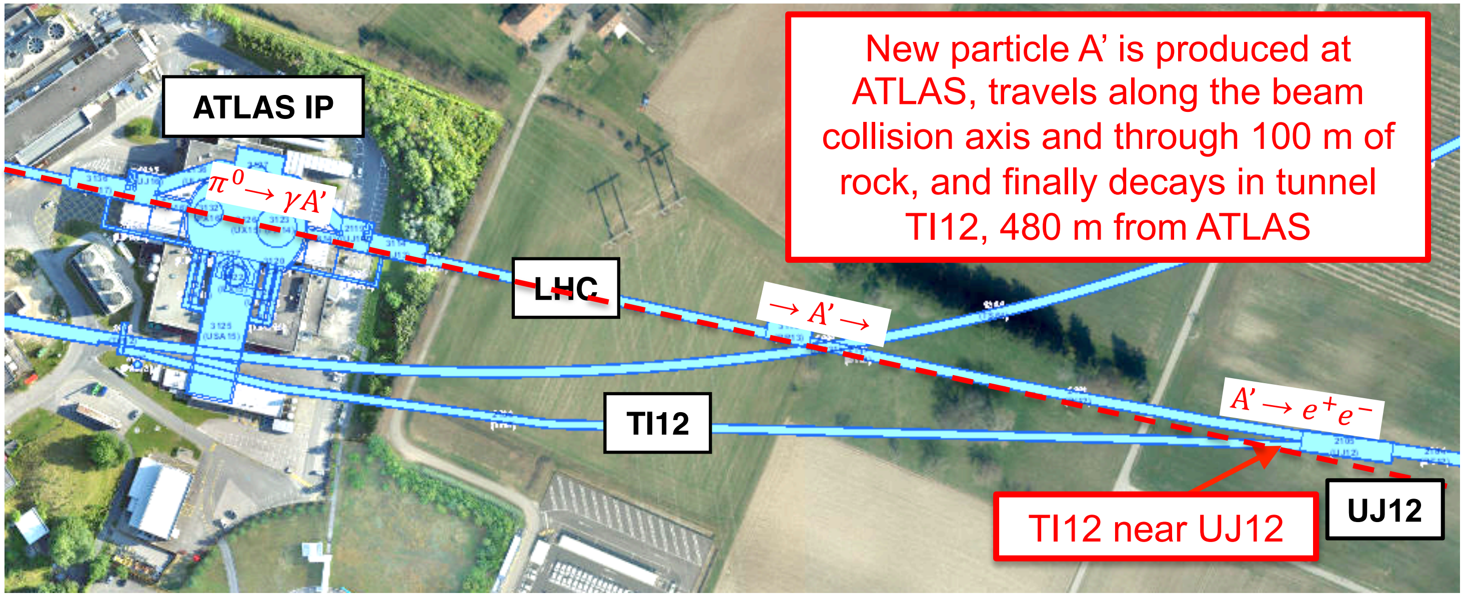
- Existing detectors are designed to find new heavy particles. These particles are produced at low velocities and decay roughly isotropically.

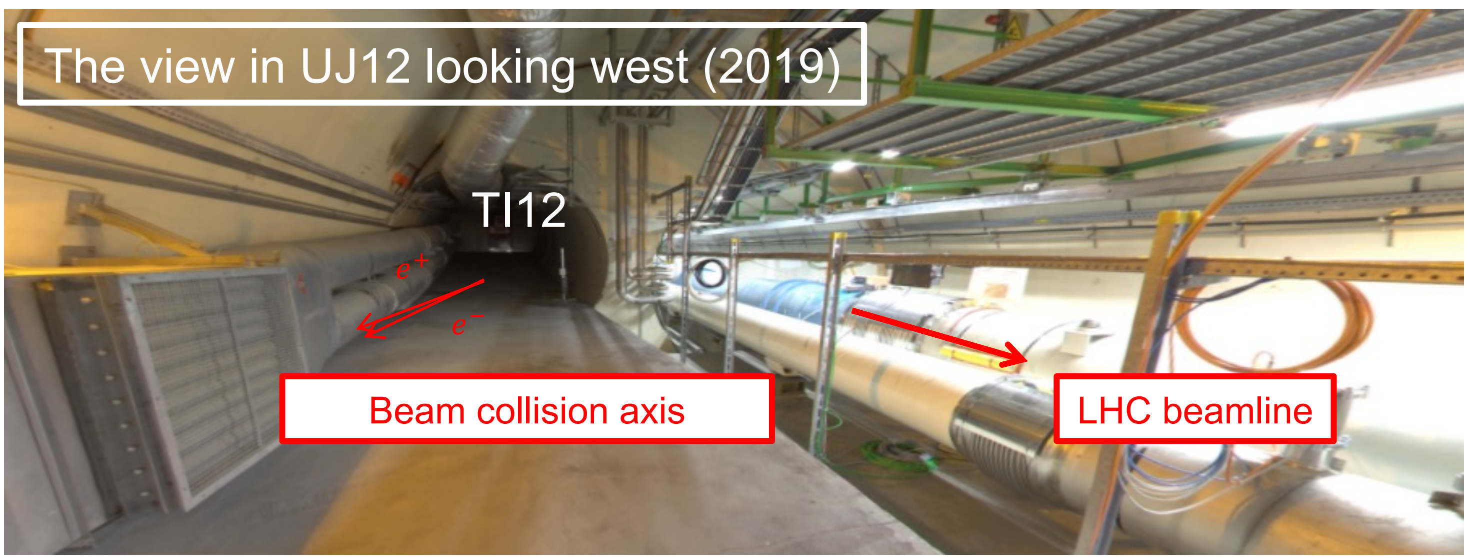
- But if new particles are light and weakly interacting, they are dominantly produced along the beam axis, and the existing big LHC detectors are perfectly designed NOT to see them.



- We are missing both SM and BSM opportunities: we need a detector to exploit the "wasted" $\sigma_{inelastic}$ ~ 100 mb and cover these "blind spots" in the far-forward region.

THE FAR-FORWARD REGION





FASER TIMELINE

- September 2017: Initial proposal (Feng, Galon, Kling, Trojanowski)
- July 2018: Submitted LOI to CERN LHCC
- October 2018: Approval from ATLAS SCT and LHCb Collaborations for use of spare detector modules
- November 2018: Submitted Technical Proposal to LHCC
- November 2018 – January 2019: Experiment funded by the Heising-Simons and Simons Foundations
- March 2019: FASER approved as 8^{th} LHC detector by CERN
- December 2019: FASERν approved as 9^{th} LHC detector by CERN
- March 2021: FASER fully installed, commissioning of the detector begins
- May 2021: FASERν announces first candidate collider neutrinos
- June 2022: FASER and FASERν collected data in Run 3
- March 2023: First physics results presented at Moriond (expected!)

FASER COLLABORATION TODAY

80 collaborators, 22 institutions, 9 countries

CERN

Université de Genève

Kyushu University

UC Irvine

Universität Bern

Technion
Israel Institute of Technology

Nagoya University

University of Washington

Johannes Gutenberg Universität Mainz
JG|U

מכון ויצמן למדע
Weizmann Institute of Science

KEK

University of Oregon

Universität Bonn

INFN

清華大學
Tsinghua University

Manchester 1824
The University of Manchester

Royal Holloway University of London

University of Liverpool

Chiba University

University of Sussex

DESY.

JINR

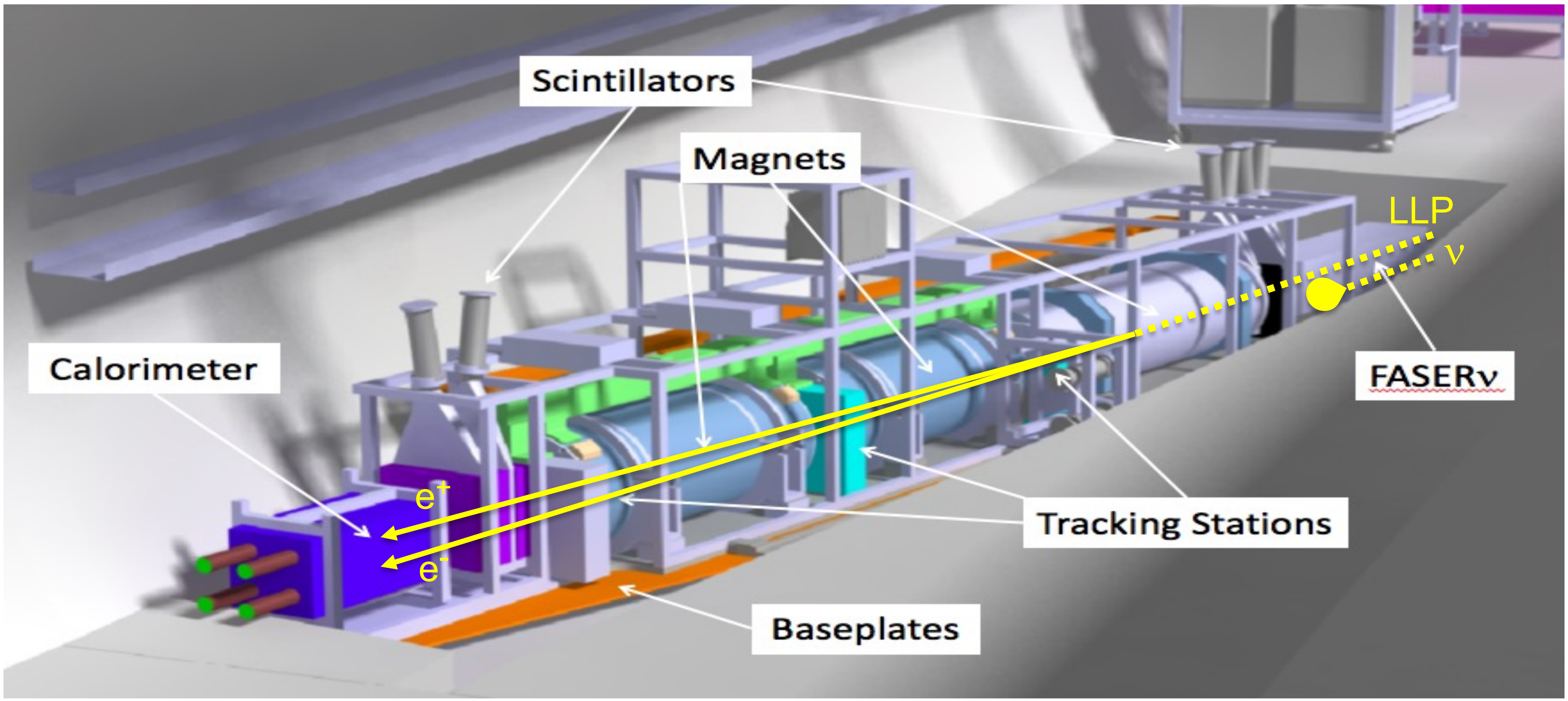
VIP TOUR OF FASER, JANUARY 2023

Left to Right:
Jamie Boyd FASER Co-Spokesperson
Mike Lamont CERN Director of Accelerators and Technology
Mark Heising, Heising-Simons Foundation
Joachim Mnich, CERN Director of Research and Computing
Jim Simons, Simons Foundation
Jonathan Feng, FASER Co-Spokesperson
Greg Gabadadze, Associate Director, Simons Foundation

Left to Right:
Mark Heising, Heising-Simons Foundation
Fabiola Gianotti, CERN Director General
Jim Simons, Simons Foundation

THE FASER DETECTOR

- Neutrino signal: nothing incoming, detect CC or NC interaction.
- BSM signal: nothing incoming, and 2 ~TeV, opposite-sign charged tracks pointing back to the ATLAS IP: a "light shining through (100 m-thick) wall" experiment.
- Scintillators veto incoming charged tracks (muons), magnets split the charged tracks, which are detected by tracking stations and a calorimeter.



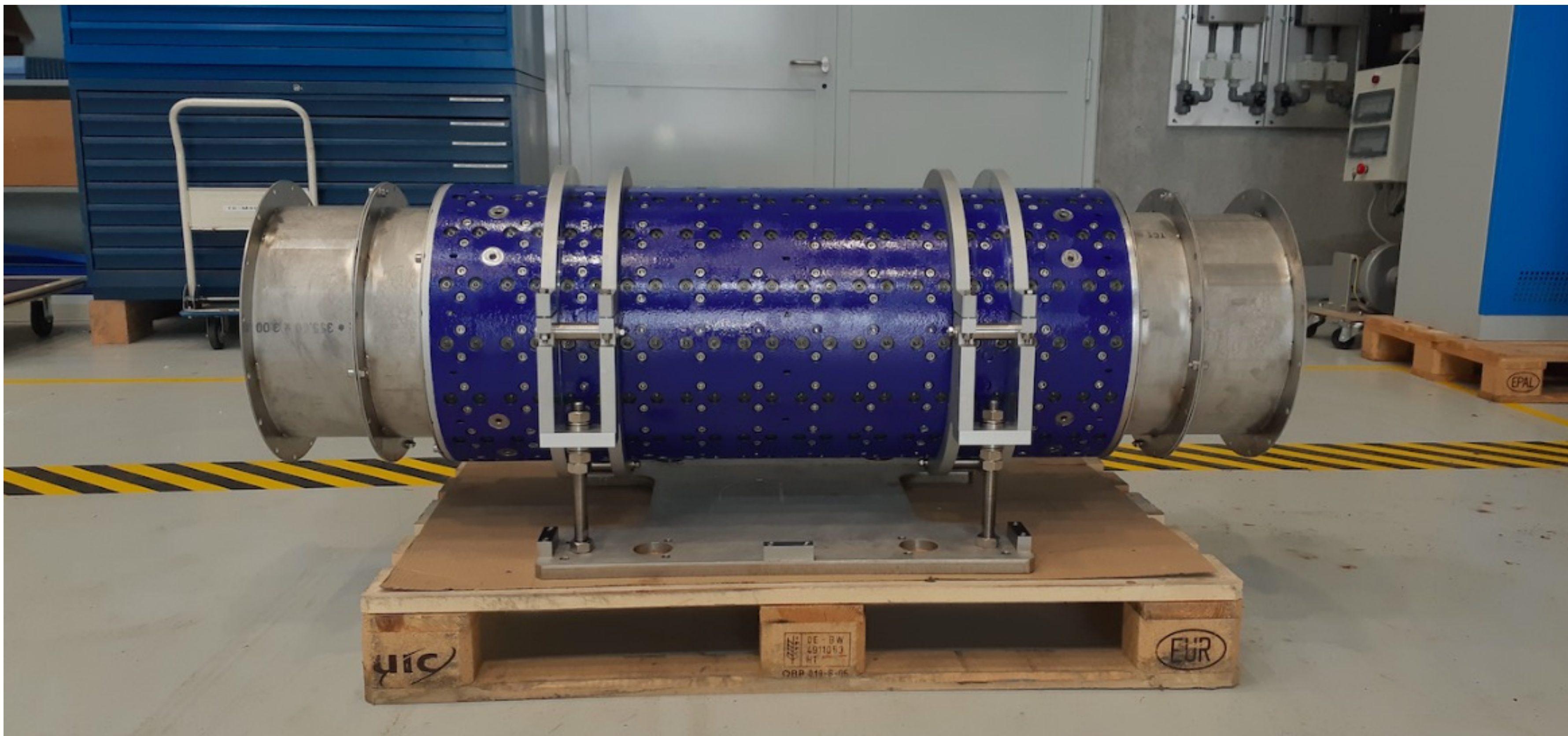
FASER IN TUNNEL TI12

- The beam collision axis was located to mm accuracy by the CERN survey department. To place FASER on this axis, a trench was required to lower the floor by 46 cm.

- The trench was completed by an Italian firm just hours before COVID shut down CERN in Spring 2020.

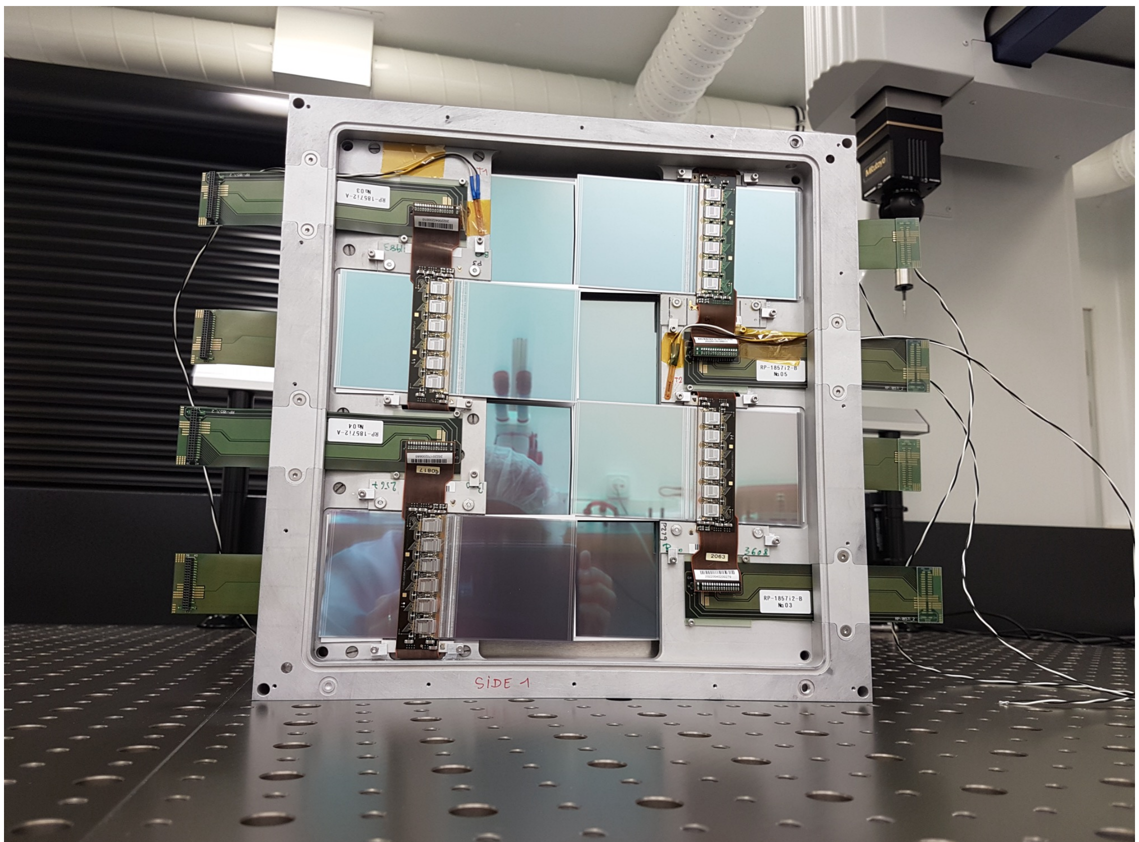
MAGNETS

- FASER includes 3 magnets: 1.5 m, 1 m, and 1m long.
- 0.57 T permanent dipoles with an inner diameter of 20 cm, require little maintenance.
- Constructed by the CERN magnet group.



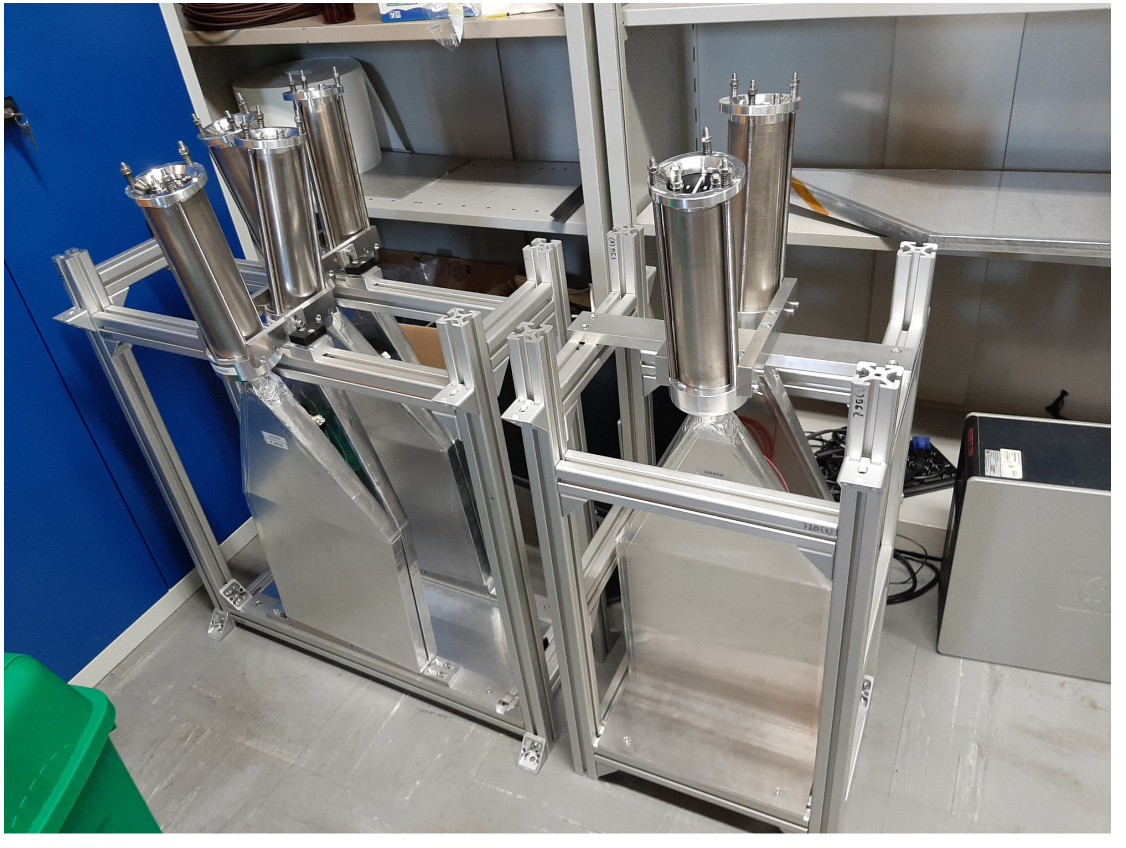
TRACKERS

- ATLAS tracker consists of ~3000 SCT modules.
- ~300 spares were never used. ~100 of these were generously donated to FASER: 8 modules x 3 tracking planes x 4 tracking stations at FASER.



SCINTILLATORS

- 4 veto scintillators, each 2cm x 30cm x 30cm. Efficiency of each one is > 99.99%, reduces muon background by $(10^{-4})^4$, makes negligible.
- Additional beam backgrounds, simulated with FLUKA and validated with pilot detectors in 2018, are also expected to be negligible.



FASER CURRENT STATUS

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FASER collected data during LHC Run 3 from July – November 2022.

FASER performed well, collected enough data to detect 100s of TeV neutrinos and probe new regions of parameter space in many BSM models. Analyses are currently underway.

FPF

Forward Physics Facility

FORWARD PHYSICS FACILITY

- FASER, FASERν, and other proposed far-forward detectors are currently highly constrained by 1980's infrastructure (LEP!) that was never intended to support experiments.

- The rich physics program in the far-forward region therefore strongly motivates creating a dedicated Forward Physics Facility to house far-forward experiments for the HL-LHC era from 2029-40.

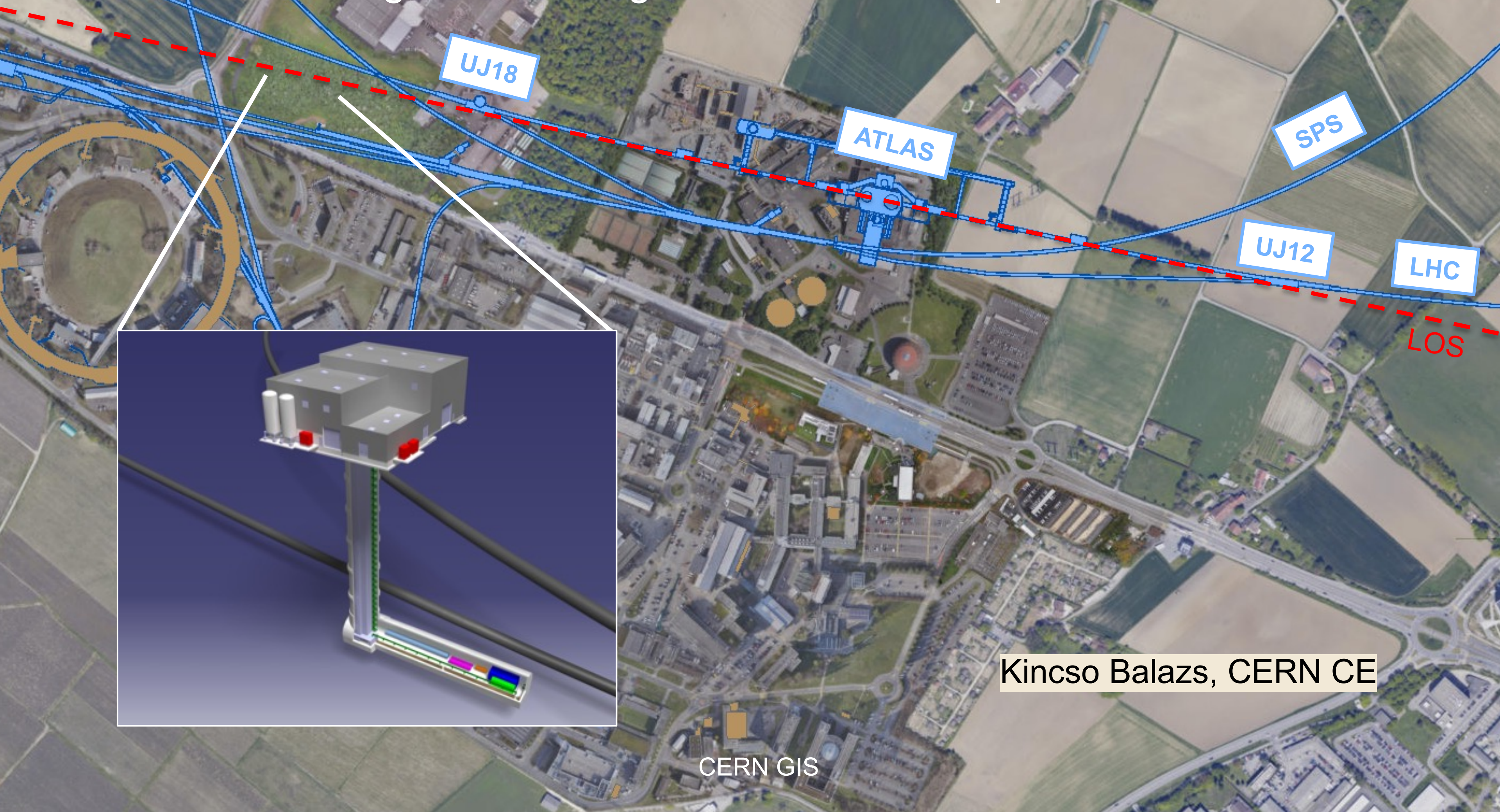
- FPF Meetings
  - FPF Kickoff Meeting, 9-10 Nov 2020, https://indico.cern.ch/event/955956
  - FPF2 Meeting, 27-28 May 2021, https://indico.cern.ch/event/1022352
  - FPF3 Meeting, 25-26 Oct 2021, https://indico.cern.ch/event/1076733
  - FPF4 Meeting, 31 Jan-1 Feb 2022, https://indico.cern.ch/event/1110746
  - FPF5 Meeting, 15-16 Nov 2022, https://indico.cern.ch/event/1196506

- FPF Papers
  - "Short" Paper: 75 pages, 80 authors (2109.10905, Phys. Rept. 968, 1 (2022)).
  - White Paper: 429 pages, 392-authors+endorsers (2203.05090, J. Phys. G).

FPF LOCATION

Site selected: ~612 m to the west of ATLAS on CERN land in France.

Cavern: 65m long, 8m wide/high. Shaft: 88m-deep, 9.1m-diameter.



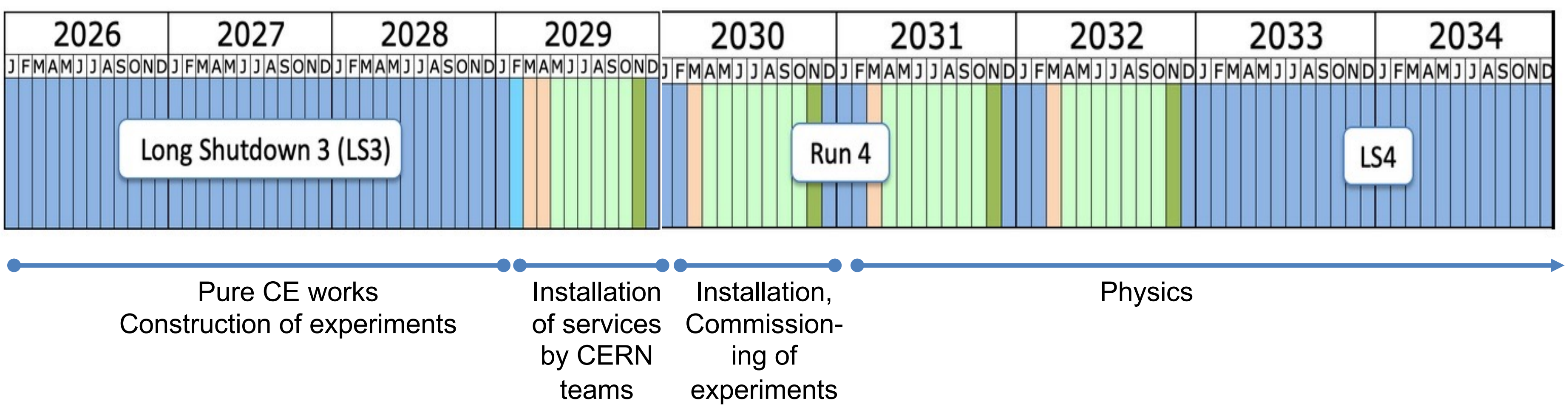
Kincso Balazs, CERN CE

CERN GIS

COST AND TIMELINE

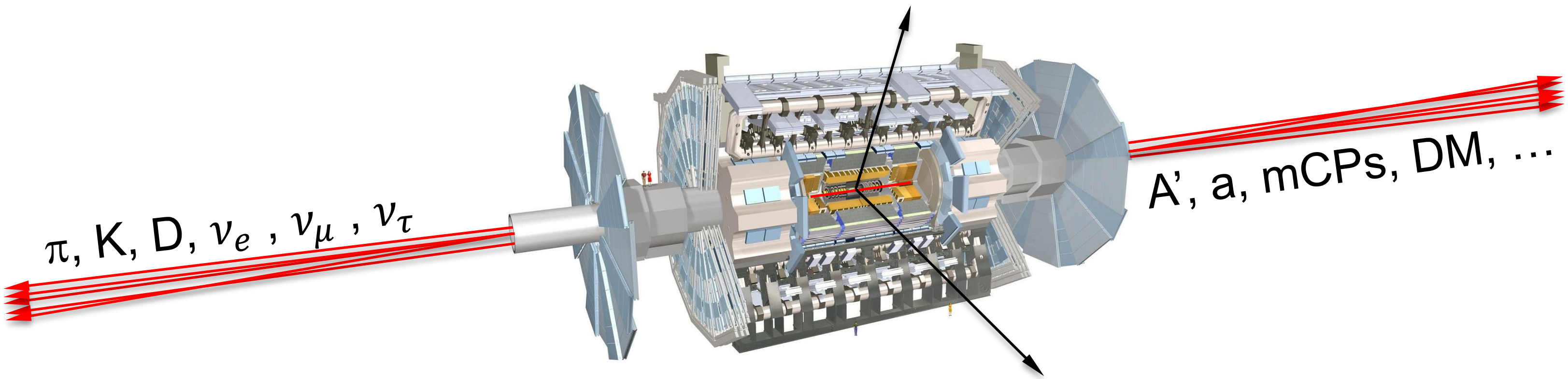
- Very preliminary (class 4) cost estimate: 23 MCHF (CE) + 15 MCHF (services) ≈ 40 MCHF (+50%/-30%). Experiments will be another ~50 MCHF, so total cost is ~100 MCHF.

- Timeline considerations
  - Can construct and service the FPF and its experiments while the LHC is running.
  - Timeline set by the HL-LHC.
  - Possible timeline presented at Chamonix (Jan 2022) allowing physics from 2031-42:



SUMMARY

- SM and new physics opportunities are currently being missed in the far-forward region at the LHC.

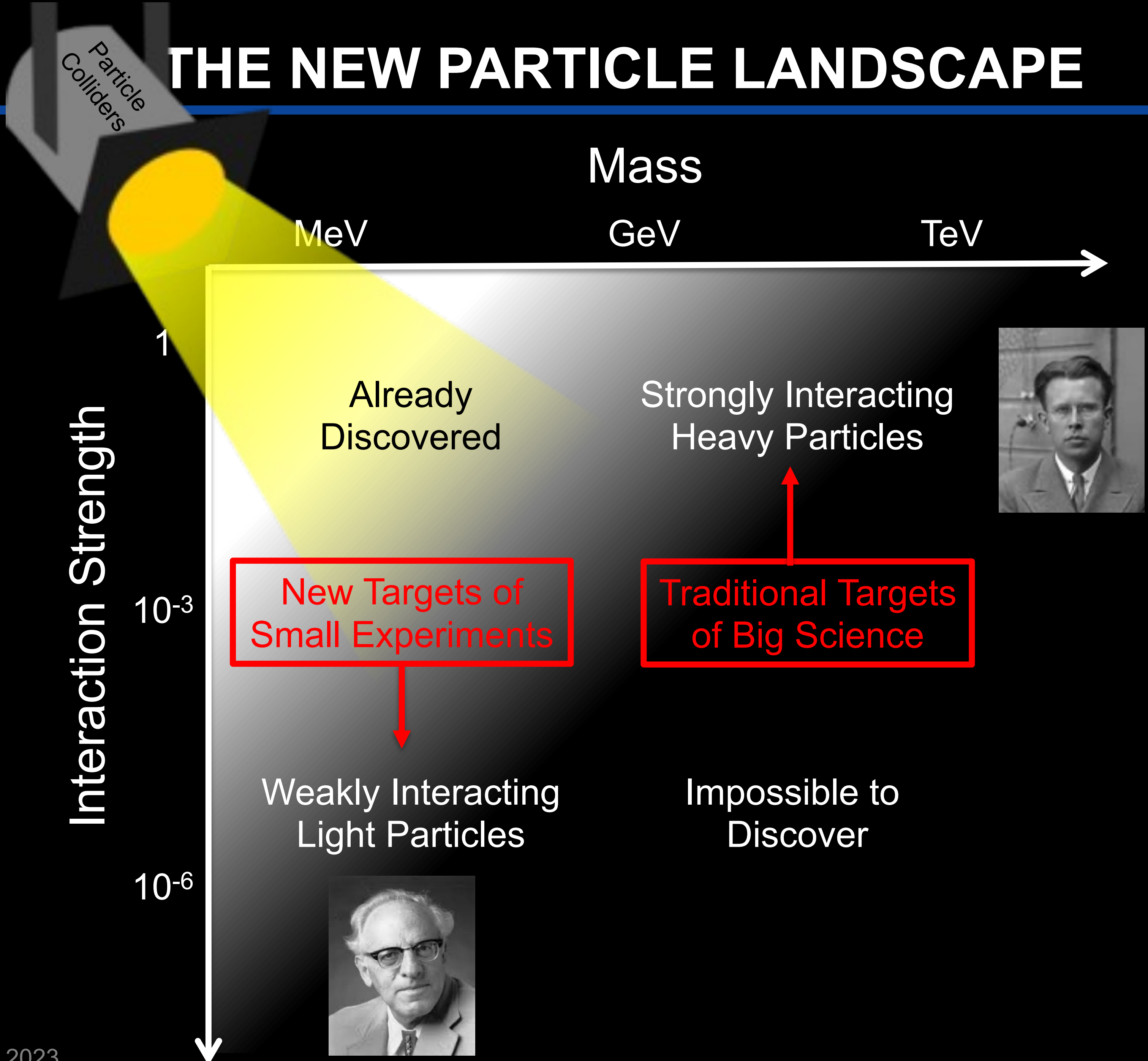


- Modest investment in a few small experiments can solve this problem.

- FASER and FASERν: 5 m long, ~$2M. Along with SND@LHC, will soon create the new field of LHC neutrino physics, and also look for many new particles.

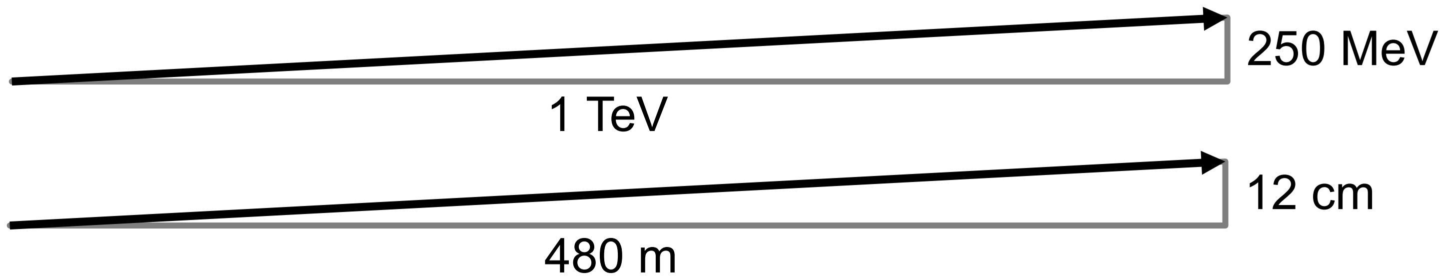
- In the future, the FPF and its experiments are being planned to carry this research program into the High Luminosity LHC era.

THE NEW PARTICLE LANDSCAPE



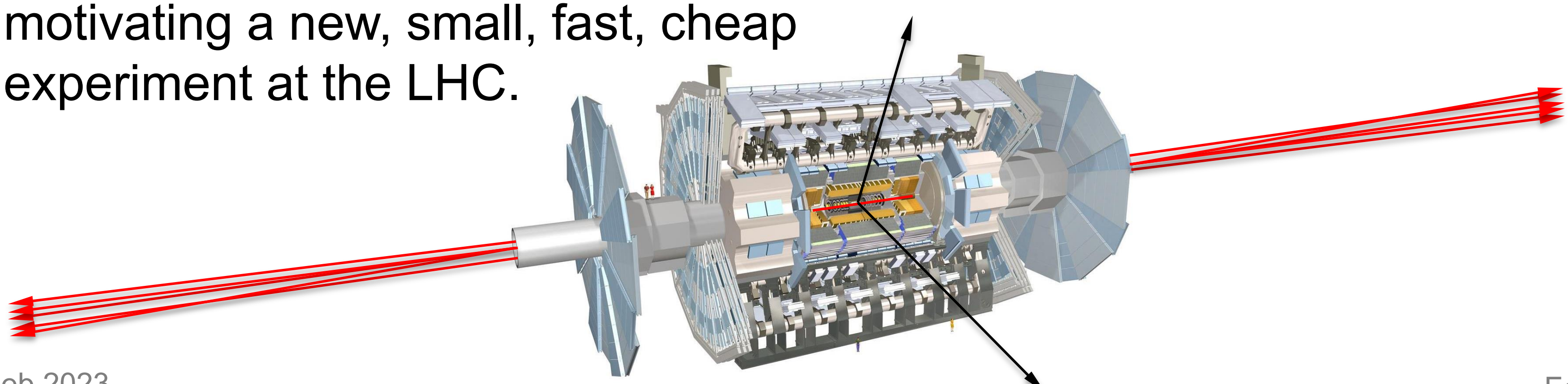
HOW BIG DOES THE DETECTOR HAVE TO BE?

- Momentum:
- Space:

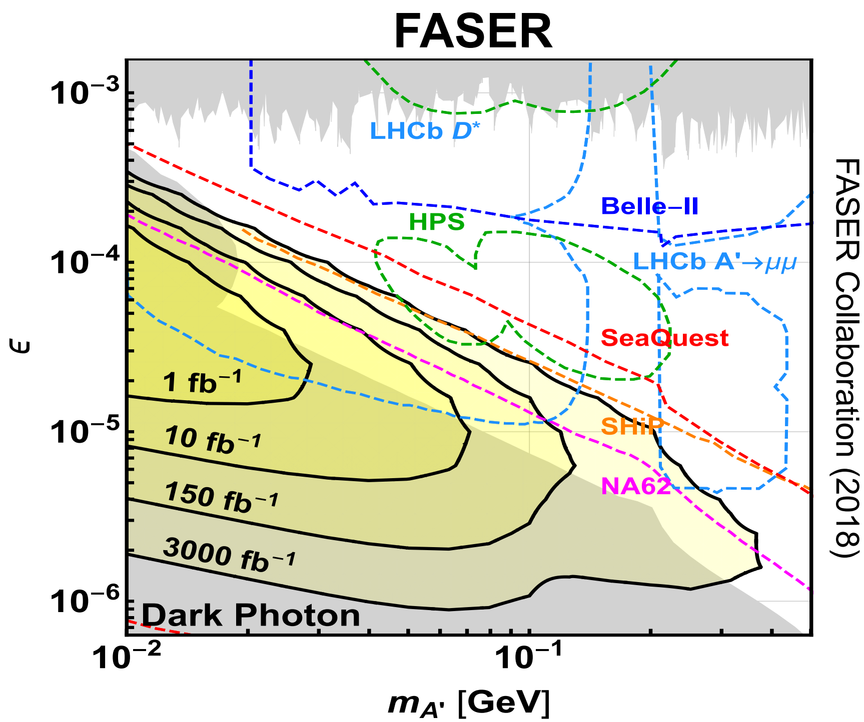


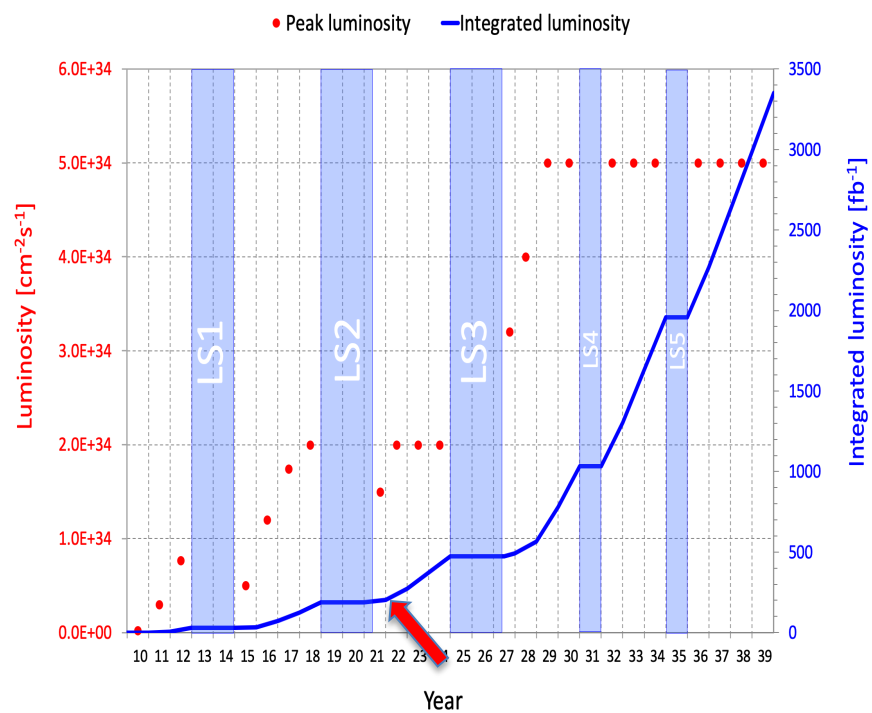
- The opening angle is 0.2 mrad ($\eta \sim 9$); cf. the moon (7 mrad). Most of the signal passes through 1 sheet of paper at 480 m.

- TeV dark photons (or any other new particles produced in π, η, K, D, B decay) are far more collimated than shown below, motivating a new, small, fast, cheap experiment at the LHC.



DARK PHOTON SENSITIVITY REACH





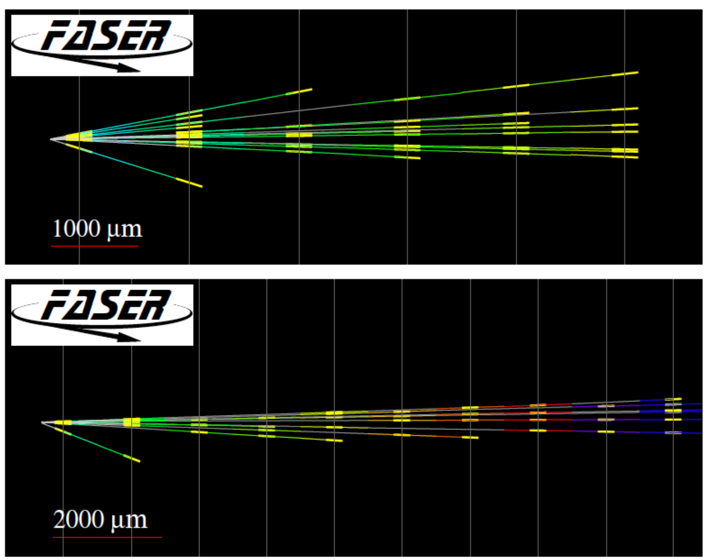
- FASER has collected 10 fb^{-1} and has started probing many new models.
- Without upgrade, HL-LHC extends (Luminosity*Vol) by factor of 3000 – could detect as many as 10,000 dark photons.
- Possible upgrade to FASER 2 (R=1m, L=20m) extends (Luminosity*Vol) by factor of ~10^6 – could detect as many as 3 x 10^6 dark photons.

FIRST COLLIDER NEUTRINOS

- 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).

- This opens up a new field: neutrino physics at colliders.

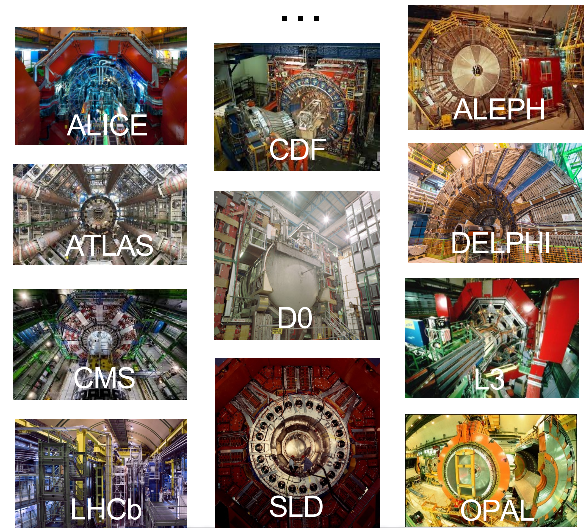


LOCATION, LOCATION, LOCATION

FASER Pilot Detector

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

6 candidate neutrinos



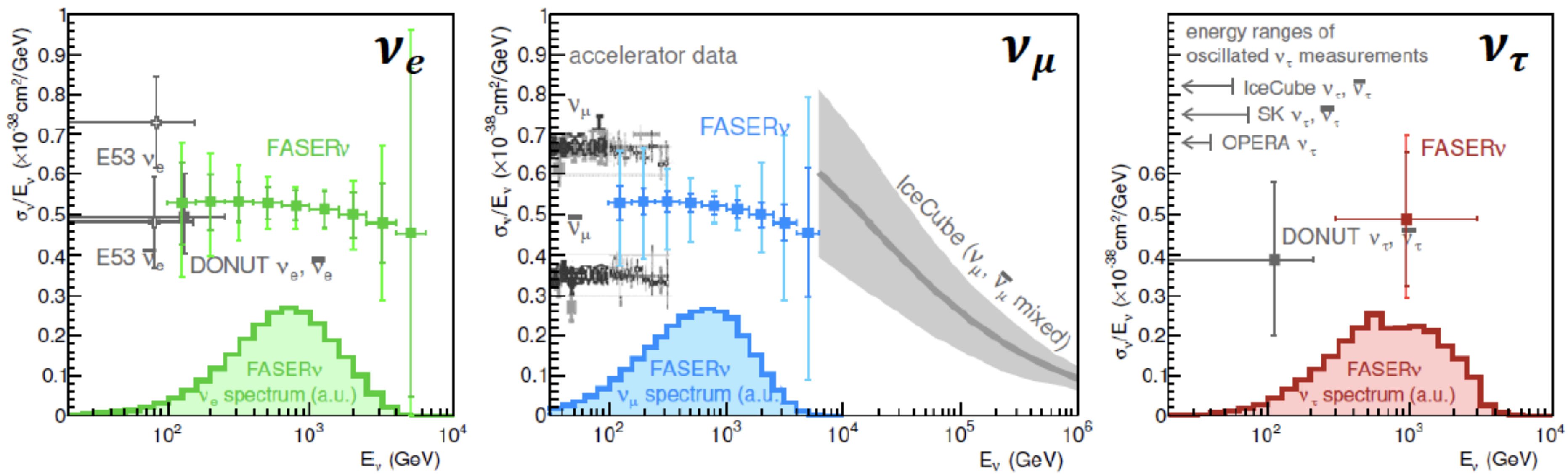
All previous
collider detectors

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

0 candidate neutrinos

NEUTRINO PHYSICS

- In Run 3 (2022-24), the goals of FASERν are to
  - Detect the first collider neutrino.
  - 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.
  - Distinguish muon neutrinos from anti-neutrinos by combining FASER and FASERν data, and so measure their cross sections independently.
  - Add significantly to the number of ν_τ and detect the first anti-ν_τ .



FASER Collaboration 1908.02310 (2019)

CAVERN AND SHAFT

- Cavern: 65m long, 8m wide/high. Shaft: 88m-deep, 9.1m-diameter.
- The FPF is completely decoupled from the LHC (as of today, no need for a safety corridor connecting FPF to the LHC).