FEEBLY-INTERACTING PARTICLE SEARCHES

ICHEP 2026, Natal, Brazil

Jonathan Feng, UC Irvine, 3 August 2026

INTRODUCTION

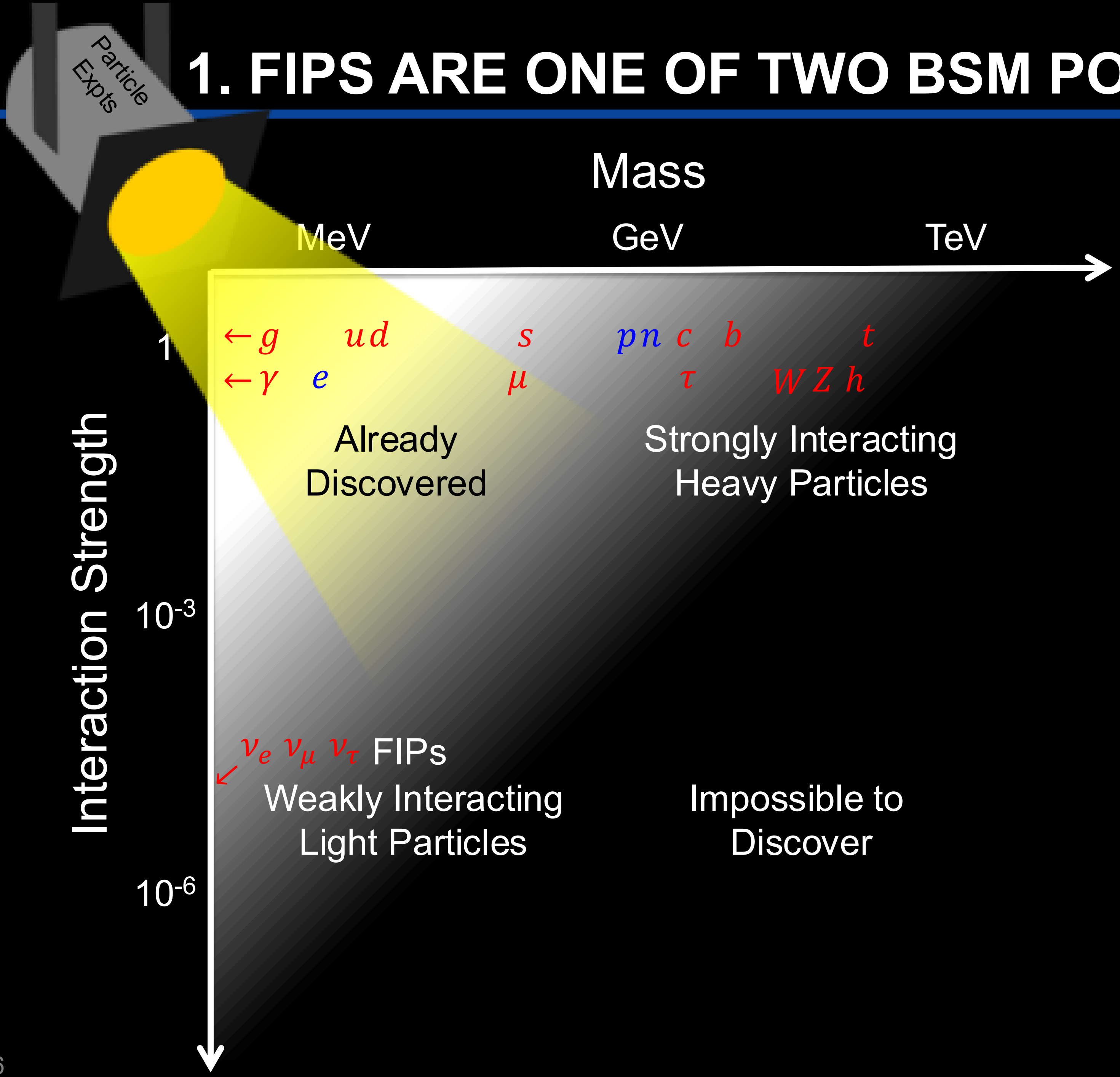
- In the last several years, FIPs have moved from “exotica” to the mainstream of particle physics.

- FIP searches featured in ICHEP 2026 parallel talks:
  - Belle II, BESIII, ATLAS, CMS, LHCb, NA62, NA64, FASER, PADME, MEG II, SBND, SHiP/NA67, DarkShine, ATUCHA II, LDMX, MATHUSLA, …
  - Far too many to summarize in this talk.

- And, of course, there were also more theory- and cosmologically-oriented FIP talks, and there is a lot of activity that is not represented at ICHEP.

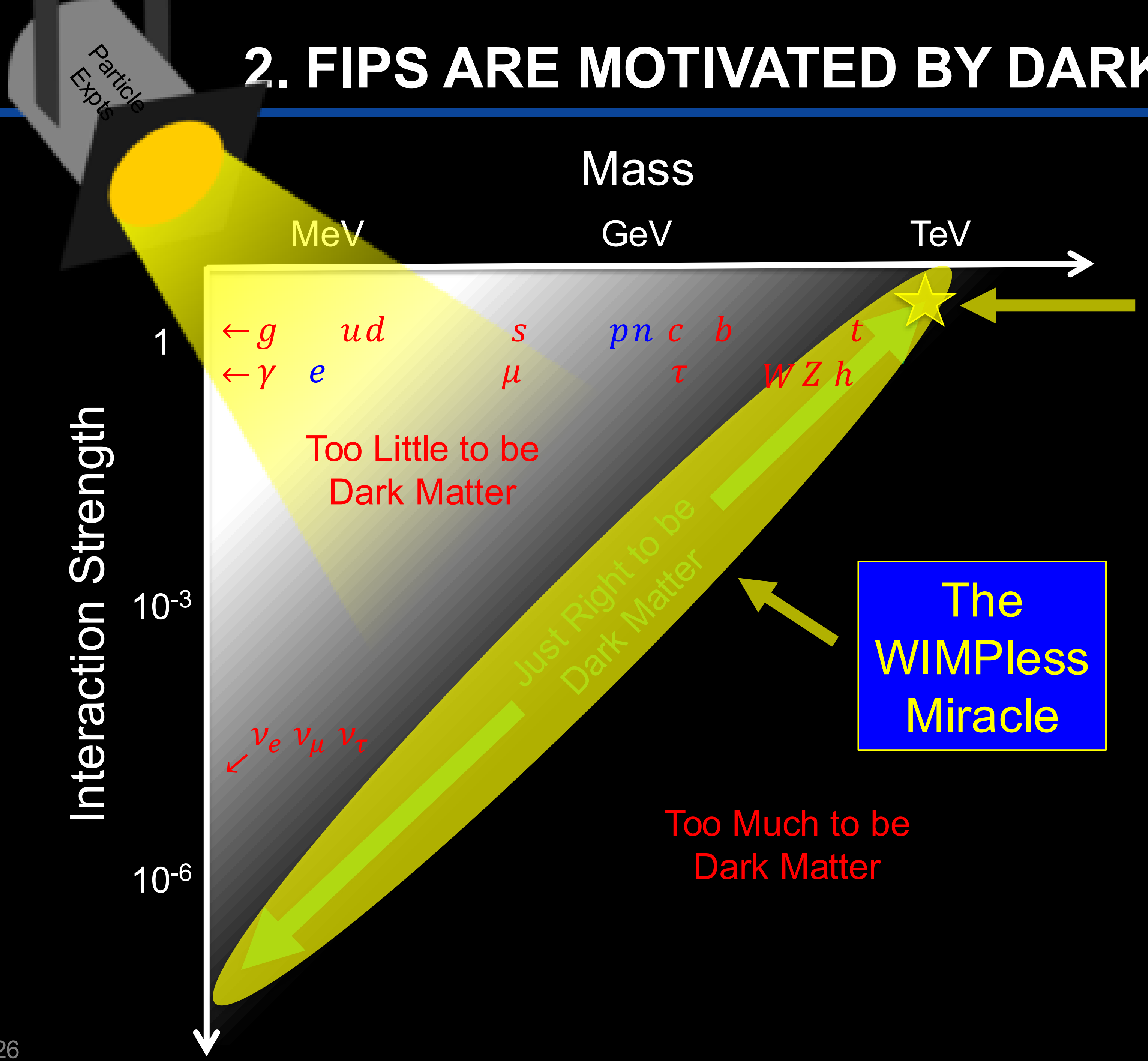
- Why all this interest? At least 3 good motivations.

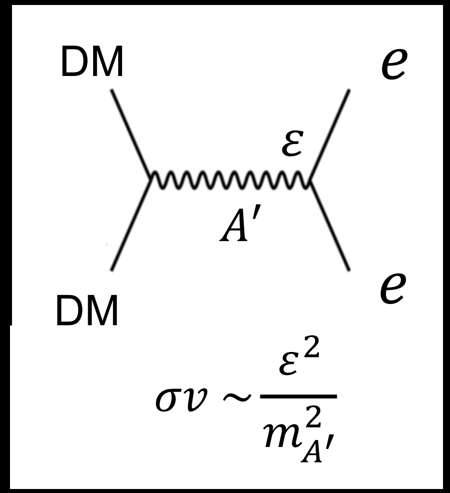
1. FIPS ARE ONE OF TWO BSM POSSIBILITIES



- For BSM particle discovery, FIPs are 1 of only 2 broad possibilities.
- FIPs can be discovered at an enormous variety of experiments and facilities, and they challenge us to use them to their full potential.

2. FIPS ARE MOTIVATED BY DARK MATTER





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

Cosmologically, FIPs are as well-motivated as WIMPs

3. FIPS ARE CONNECTED TO IMPORTANT PROBLEMS

- THE BIG 4: Axion-Like Particles and the 3 Portal Particles from models in which a dark sector interacts with the SM through renormalizable interactions.

Axion-Like Particle (ALP)

$$g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} + g_{aWW} a W_{\mu\nu} \widetilde{W}^{\mu\nu} + g_{agg} a G_{\mu\nu} \tilde{G}^{\mu\nu} + \cdots$$

Dark Photon

$$F_{\mu\nu} F_D^{\mu\nu}$$

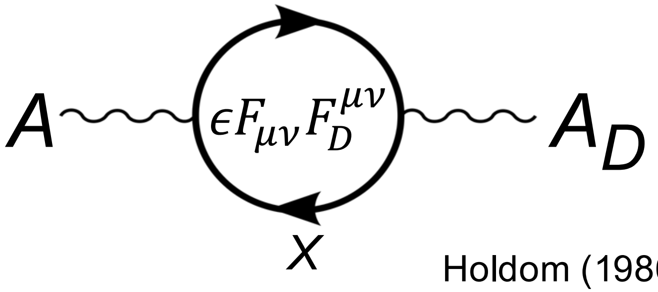
Heavy Neutral Lepton (HNL)

$$h L \psi_D$$

Dark Scalar

$$h^\dagger h \phi_D^\dagger \phi_D$$

- The renormalizable interactions are not suppressed by a large mass scale, and so are expected to be both relatively large and generic (mediated by arbitrarily heavy particles X – non-decoupling, probes the Planck scale!).

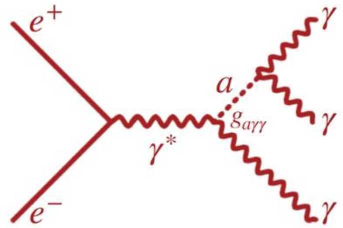


Holdom (1986)

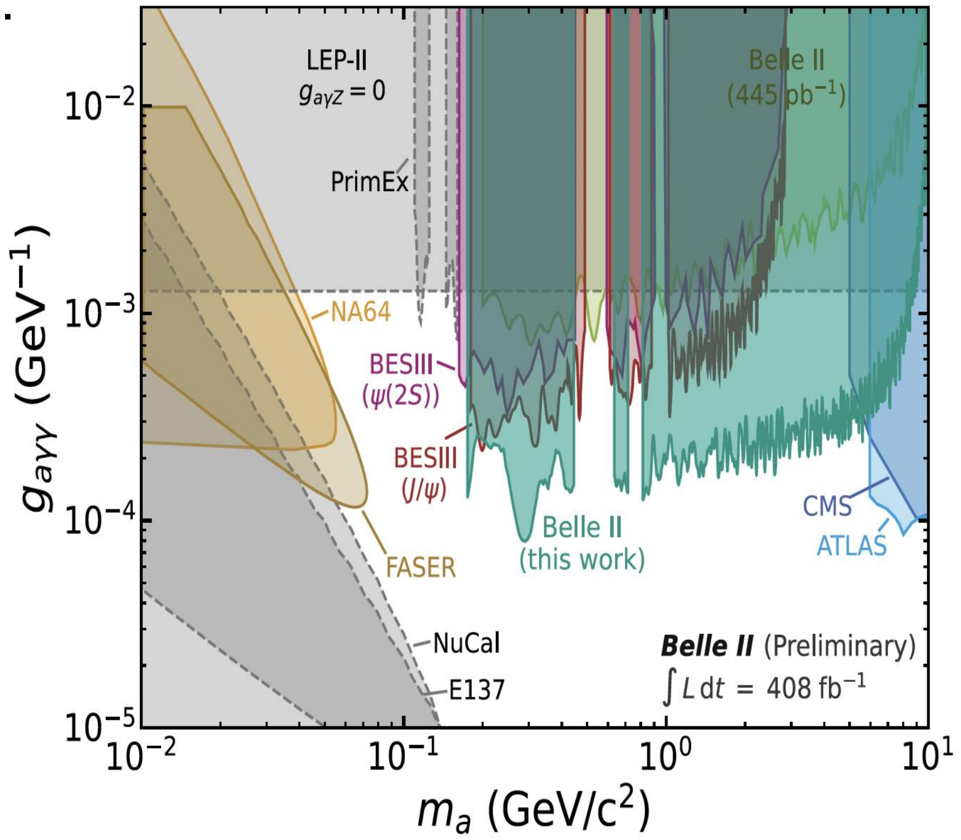
- These particles are connected to central problems of our field: the strong CP problem, dark matter, neutrino masses, electroweak symmetry breaking.

AXION-LIKE PARTICLES

- Many varieties of ALPs: γ, W, gluon, fermion couplings.
- Belle II: search for ALPγ in 3γ final state with bump in $m_{\gamma\gamma}$. Belle II (2607.07800); Heidelbach talk



See also results on ALPγ, ALPW, ALPg, ALPf from NA64 (Marini talk), FASER (Welch talk), BESIII (Jiao talk), LHCb (Merli talk), and NA62 (Martellotti talk).



- Interesting features
  - Gray regions are reinterpretations of ancient data; colored regions are more recent results from experimental collaborations (in this case NA64, FASER, BESIII, CMS, ATLAS, all since 2019).
  - Significant improvement: signals typically proportional to (coupling)^2 or (coupling)^4; depending on background, improvements of an order of magnitude in coupling → could have seen ~100 or 10^4 events.
  - The new experimental efforts are highly complementary.

VISIBLE DARK PHOTONS

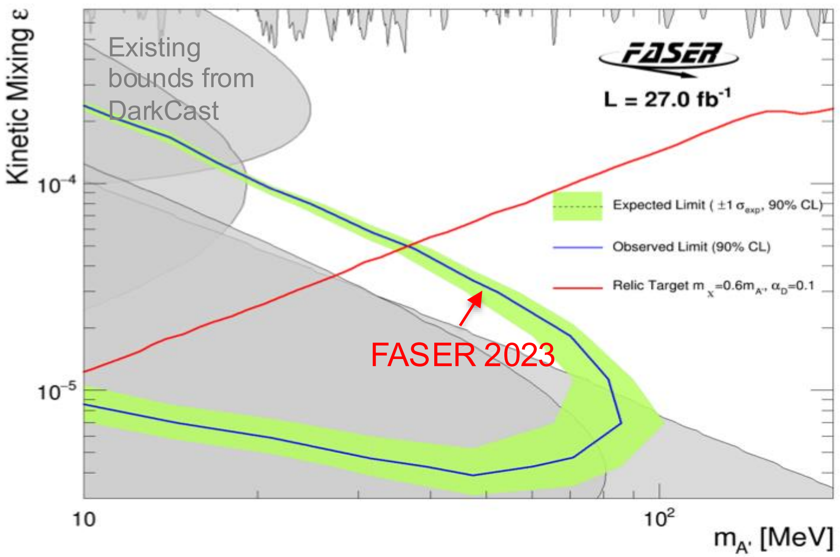
- Dark photons can be seen in fixed target experiments and at the LHC through $\pi/\eta \to A'\gamma$, followed by $A' \to e^+e^-, \mu^+\mu^-$.
- In 2023, FASER and NA62 set the first new limits on parameter space from low coupling since the 1990's.

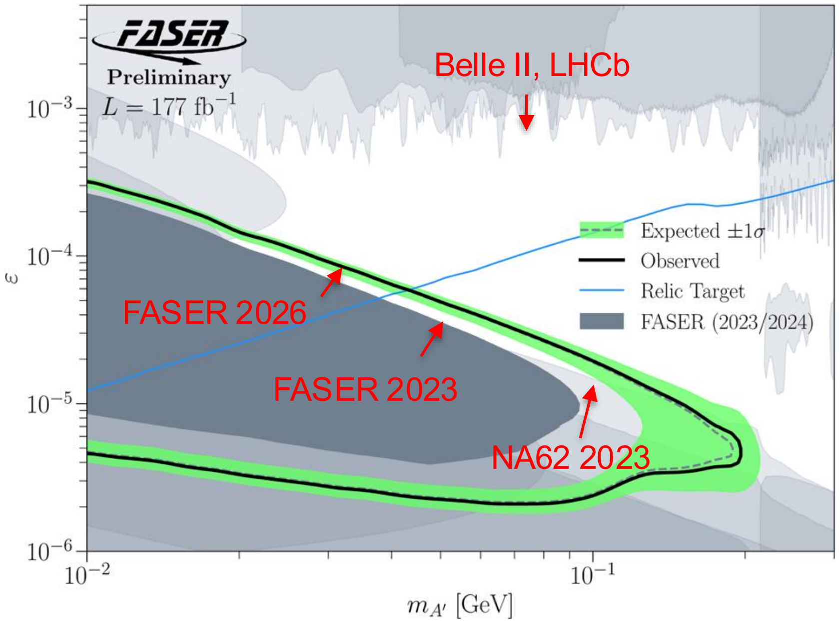
FASER (2308.05587), NA62 (2312,12055)

- In March 2026, FASER reported improved constraints using 2022-24 data and a more powerful analysis; still bkgd-free.

FASER (CERN-FASER-CONF-2026-001); Welch talk

- Prospects for the future
  - From high coupling: Belle II and LHCb should push down from the top by a factor of ~3 in coupling.
  - From low coupling: FASER will continue to improve in HL-LHC, and SHiP at the SPS is projected to extend the reach further.
  - Results from other experiments are also expected. This formerly enormous parameter space is still large, but is being squeezed from both sides.

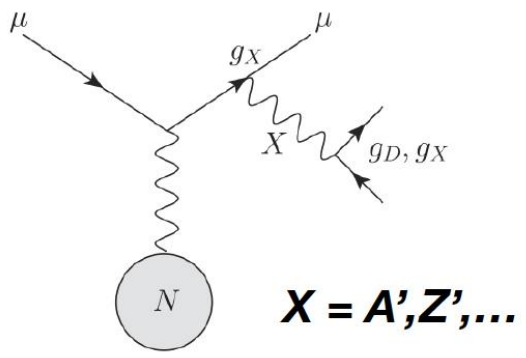




OTHER GAUGE BOSONS

- Many other possible gauge bosons to search for.

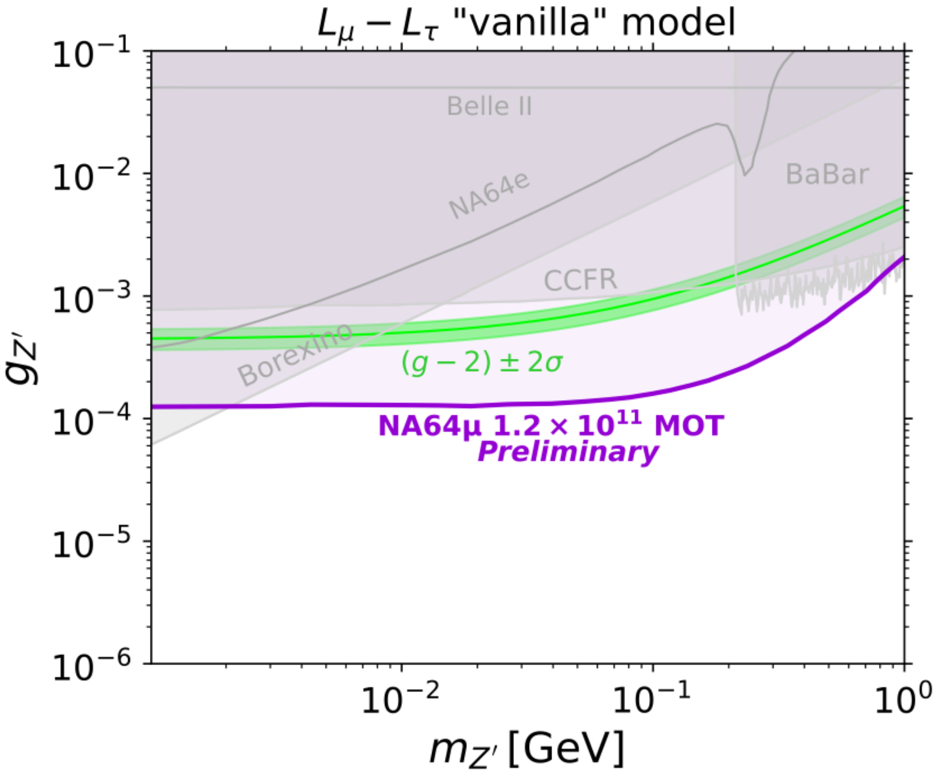
- Consider a seemingly difficult case: an $L_\mu - L_\tau$ gauge boson that decays invisibly to the dark sector.
  - Motivated by the desire to reduce the muon g-2 discrepancy
  - Make anomaly-free by adding tau coupling
  - No coupling to the first generation
  - No visible decay products



- A new result for this gauge boson was reported by NA64μ, a fixed target experiment at the SPS with a high-energy (up to 250 GeV) and high-intensity muo beam.

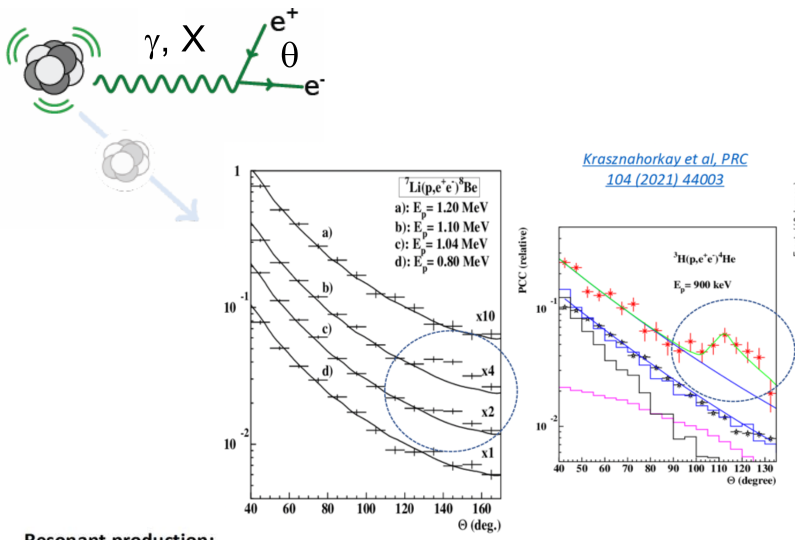
- Measure the incoming and outgoing muon momentum and look for missing energy + missing momentum.

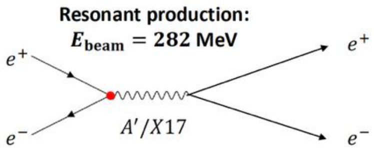
Molina-Bueno talk

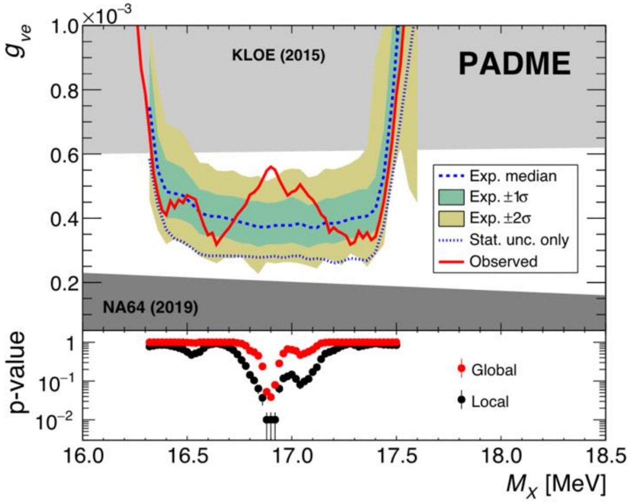


X17 AND THE ATOMKI ANOMALIES

- In 2015, the ATOMKI group reported a 7σ excess in ^{8}Be (18.15) → ^{8}Be e^+e^- decays at $\theta_{e^+e^-} \approx 140°$. Krasznahorkay et al., 1504.01527
- This can be explained by a FIP: 17 MeV protophobic gauge boson. Feng, Fornal, Galon, Gardner, Smolinsky, Tanedo, Tait (2016)
- In 2019, the ATOMKI group reported a new 7σ excess in the decays of excited ^{4}He (20.49) nuclei at $\theta_{e^+e^-} \approx 115°$. Remarkably, this can also be explained by the same 17 MeV gauge boson.
  Krasznahorkay et al., 1910.10459; Fieg, Makela, Tait, Toman, 2602.11263
- There has since been a ~2σ exclusion by MEG II, but also a ~2σ excess seen at 17 MeV by PADME. Frankenthal talk
  MEG II Collaboration, 2411.07994; PADME Collaboration, 2505.24797
- This is among the most tantalizing anomalies in the field. More data from PADME expected, and other experiments are finally poised to weigh in – stay tuned!





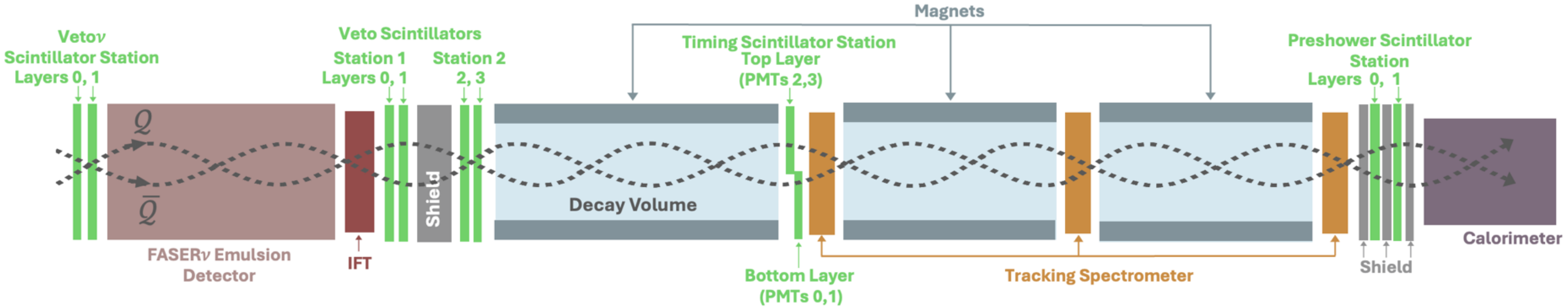


FIRST DEDICATED LHC SEARCH FOR QUIRKS

- What if the dark sector has particles bound together by a strong force, “dark QCD”? A generic possibility (cf. neutral naturalness), but leads to particles with bizarre new signatures.

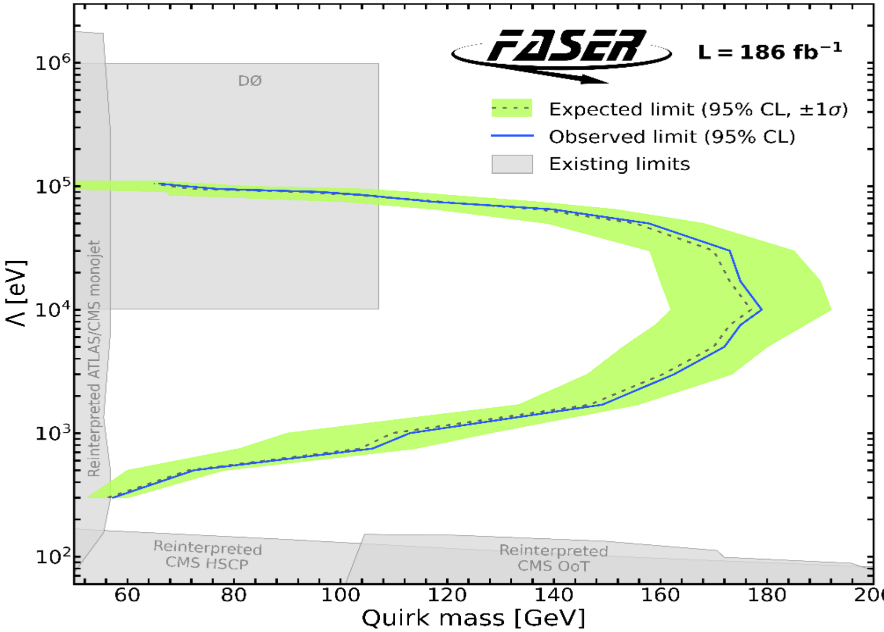
Kang, Luty (2008)

- Quirks are particles with dark QCD interactions and
  - Mass $m \sim$ O(100) GeV.
  - Confining scale $\Lambda_{\text{QCD}}^{\text{dark}} \ll m$.



- If quirks have SM electric charge, they are produced at colliders, but cannot dark hadronize by quirk pair production. Instead, they appear as 2 heavy, stable charged particles, oscillating around their center of mass and propagating slowly in the forward direction.

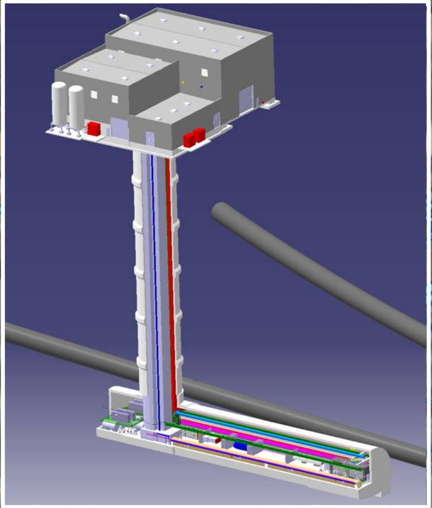
- FASER searched for 2 charged tracks, slow and out of time with bunch crossings. For 300 eV < $\Lambda_{\text{QCD}}^{\text{dark}}$ < 100 keV, excluded quirks as heavy as 180 GeV, well above the embarrassingly weak previous bounds. Welch talk



FASER Collaboration (2607.26195)

FUTURE PLANS

- SHiP/NA67: approved fixed target experiment at the SPS, planned to start operation c. 2033.
  Cristinziani talk
- Forward Physics Facility: proposed underground detector hall at the LHC.

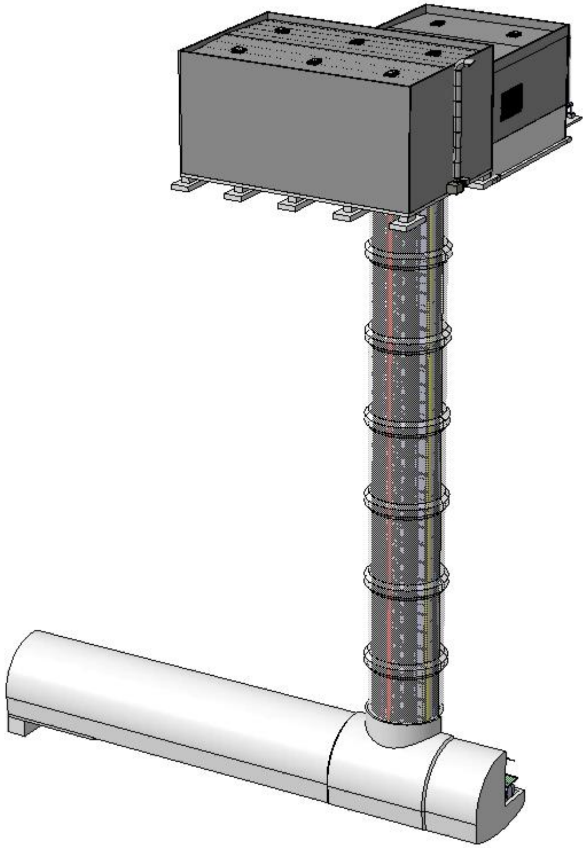


https://cds.cern.ch/record/2851822

FPF site selection and core studies have identified an ideal site in France just outside the CERN main gate

CERN GIS

FORWARD PHYSICS FACILITY

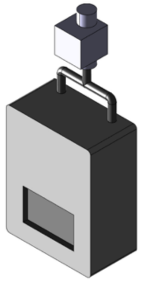


Anastasiya Magazinik, Julien Prosic, talk at FPF9, 5 March 2026

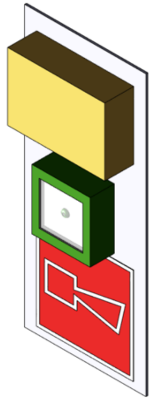
FPF SURFACE BUILDING

ENGINEERING DEPARTMENT

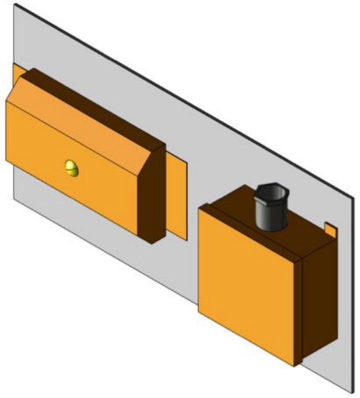
ACTEMIUM



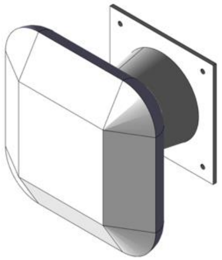
Fire detector



Evacuation panel

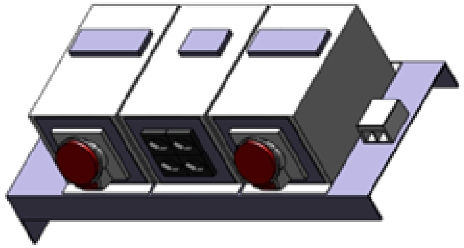


Anti Panic light

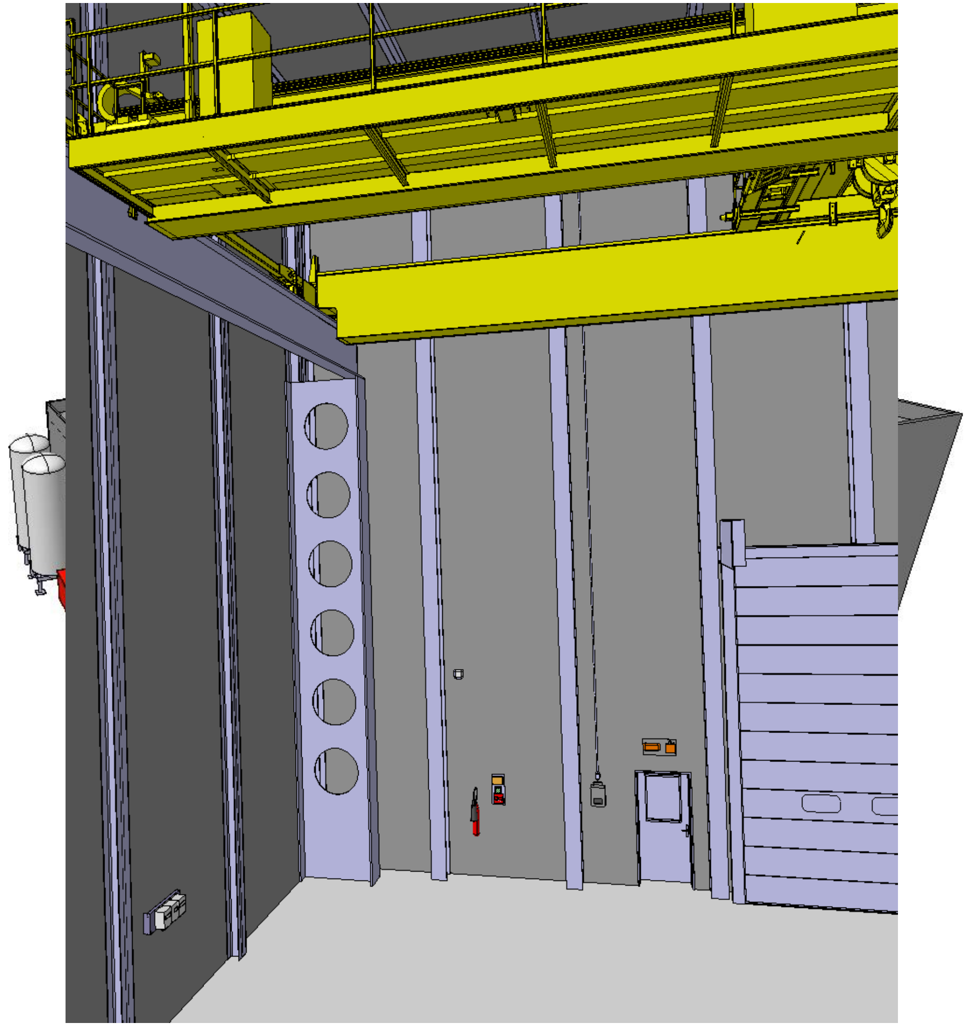


WIFI

Fire extinguisher



Electrical boxes



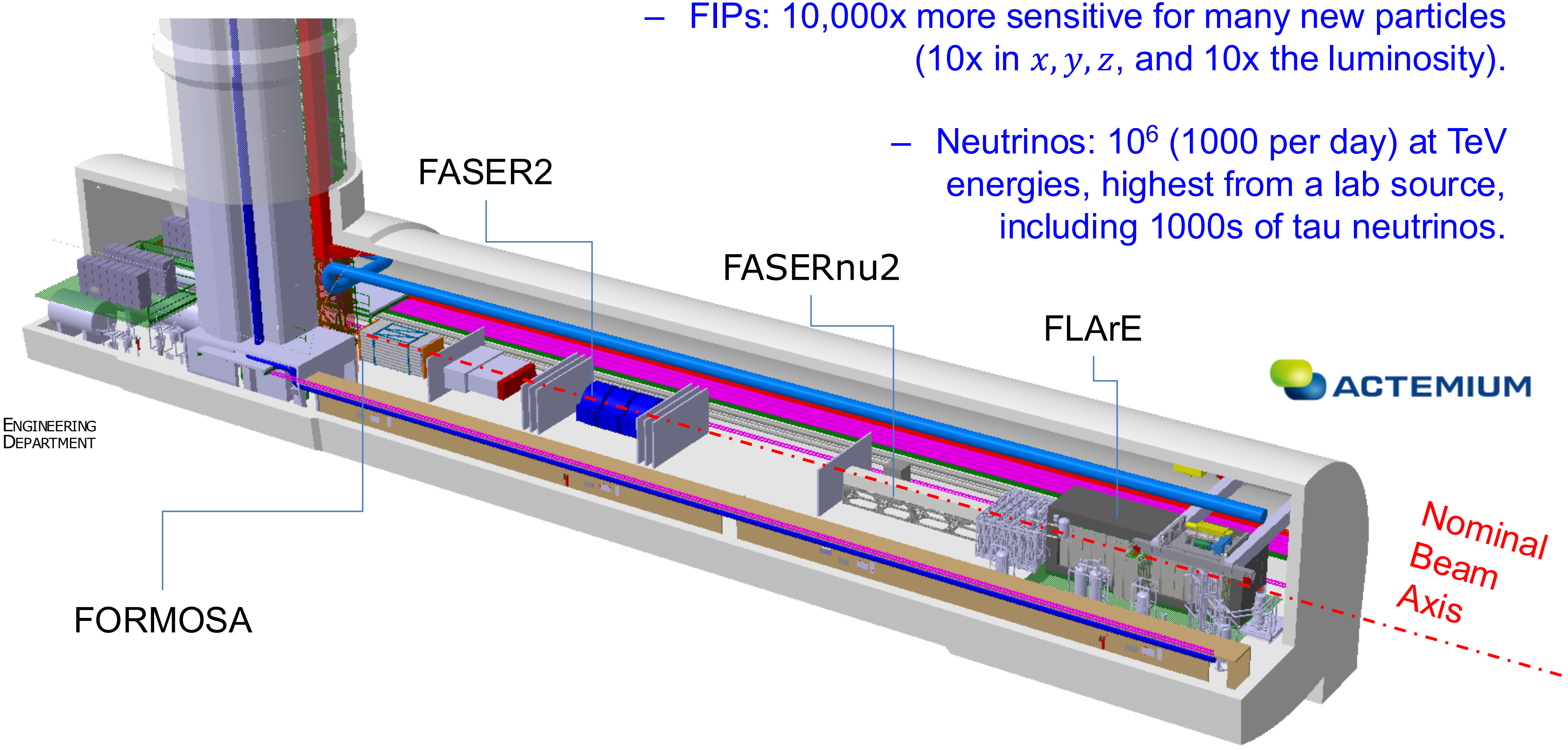
Anastasiya Magazinik, Julien Prosic, talk at FPF9, 5 March 2026

FPF EXPERIMENTS

4 experiments, all on the LOS to maximize the discovery potential of the LHC.

– FIPs: 10,000x more sensitive for many new particles (10x in x, y, z, and 10x the luminosity).

– Neutrinos: 10^6 (1000 per day) at TeV energies, highest from a lab source, including 1000s of tau neutrinos.



Anastasiya Magazinik, Julien Prosic, talk at FPF9, 5 March 2026

CONCLUSIONS

There are good reasons to think that the next breakthrough in particle physics will be the discovery of a FIP.

- 1 of 2 possibilities for BSM particles.
- Accessible parameter space is well-motivated by cosmology.
- Connected to important problems central to our field: strong CP, dark matter, neutrino mass, EWSB.
- Still in the "low-hanging fruit" era, with many opportunities for innovative, fast, small, and cheap experiments to make huge strides forward. We are already seeing impressive results, with much more to come.