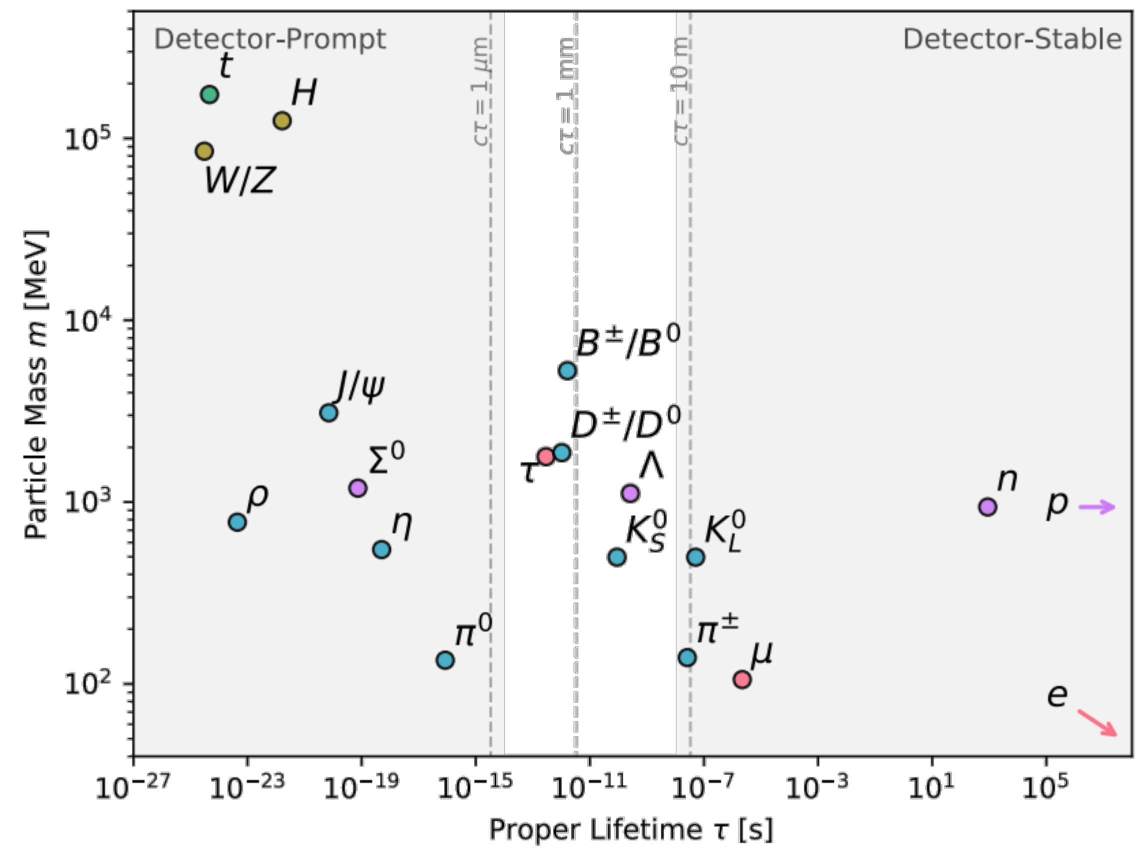
Why so many dedicated detectors?

Matthew Citron

Why should new physics be long-lived?

- Look to the standard model - particles have **wide range of lifetimes**!
- Properties of SM LLPs deeply connected to fundamental **hierarchies/symmetries** of underlying model
- BSM LLP would provide deep insights into properties of BSM physics
- Two ways to search: LLP decay to SM or direct detection of LLP interactions



https://doi.org/10.1016/j.ppnp.2019.02.006

e.g. $\pi^\pm \rightarrow \mu^\pm \nu_\mu$ ($c\tau_0 \sim 7.8$m)

small coupling

$$\frac{1}{\tau} = \frac{f_\pi^2 |V_{ud}|^2}{256 \pi m_\pi} \left[\frac{g^2}{M_W^2} \frac{m_\mu}{m_\pi} (m_\pi^2 - m_\mu^2) \right]^2$$

heavy mediator

compressed spectra

General purpose detectors: **advantages**

Neutral LLPs → SM

$$d = c\tau\beta\gamma$$

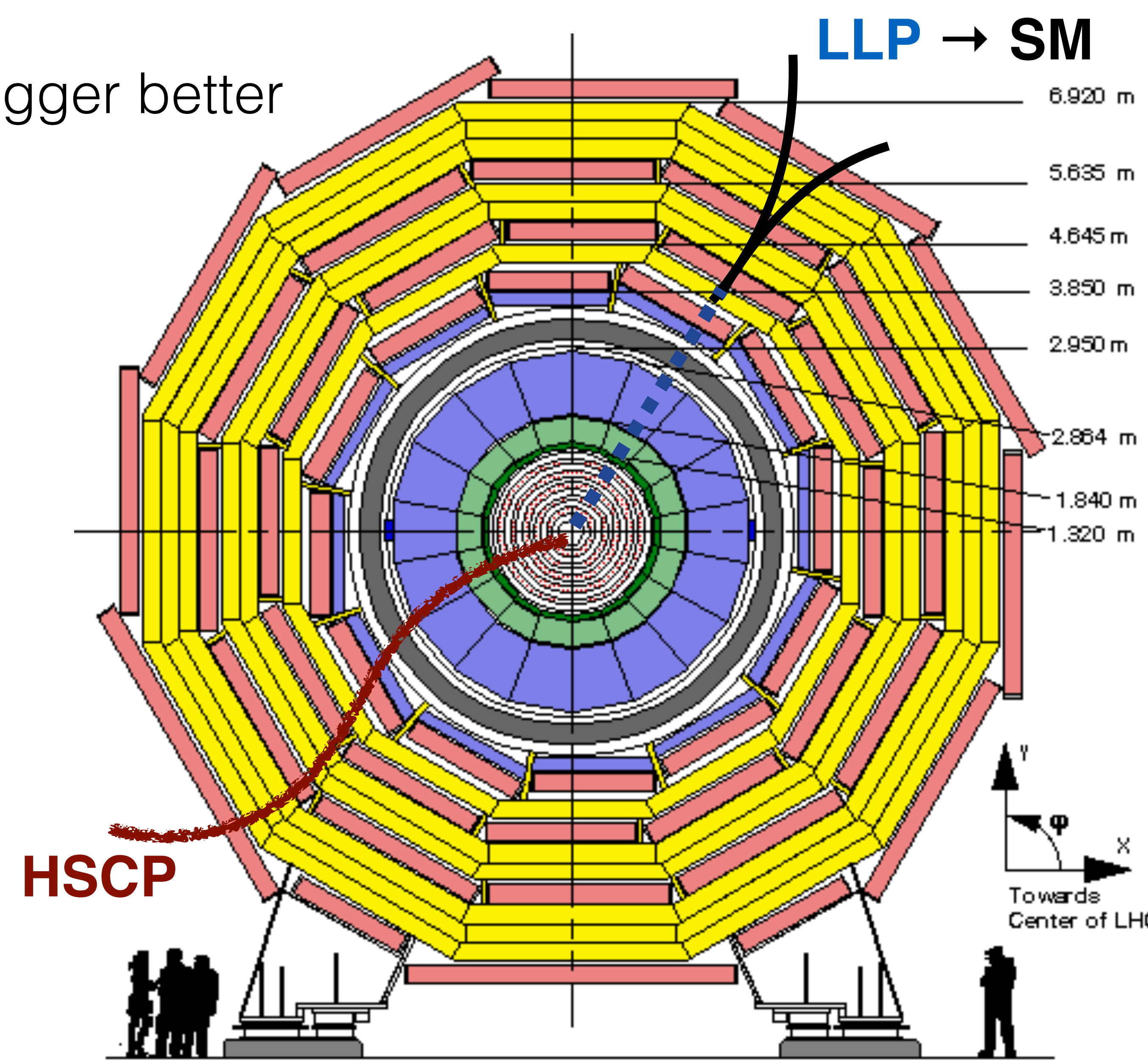
$$P_{\text{in}} = \frac{1}{4\pi}\int_{\Delta\Omega} d\Omega \int_{L_1}^{L_2} dL \frac{1}{d} e^{-L/d}$$

$$\approx \frac{\Delta\Omega}{4\pi}\, e^{-L_1/d}\, \frac{L_2 - L_1}{d}$$

Bigger better

Closer better

Transverse (CMS)



What are the advantages?

- Hermetic detector close to beam spot gives high acceptance
- For decaying LLPs: large detectors at beam spot gives sensitivity to wide range of lifetimes
- Multiple detector subsystems sensitive to range of signatures

L_1 ~ 0.1 mm
L_2 ~ 7m (ATLAS ~10m)

General purpose detectors: **limitations**

Neutral LLPs → SM

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$$P_{\text{in}} = \frac{1}{4\pi}\int_{\Delta\Omega} d\Omega \int_{L_1}^{L_2} dL \frac{1}{d} e^{-L/d}$$

$$\approx \frac{\Delta\Omega}{4\pi} \quad e^{-L_1/d} \quad \frac{L_2 - L_1}{d}$$

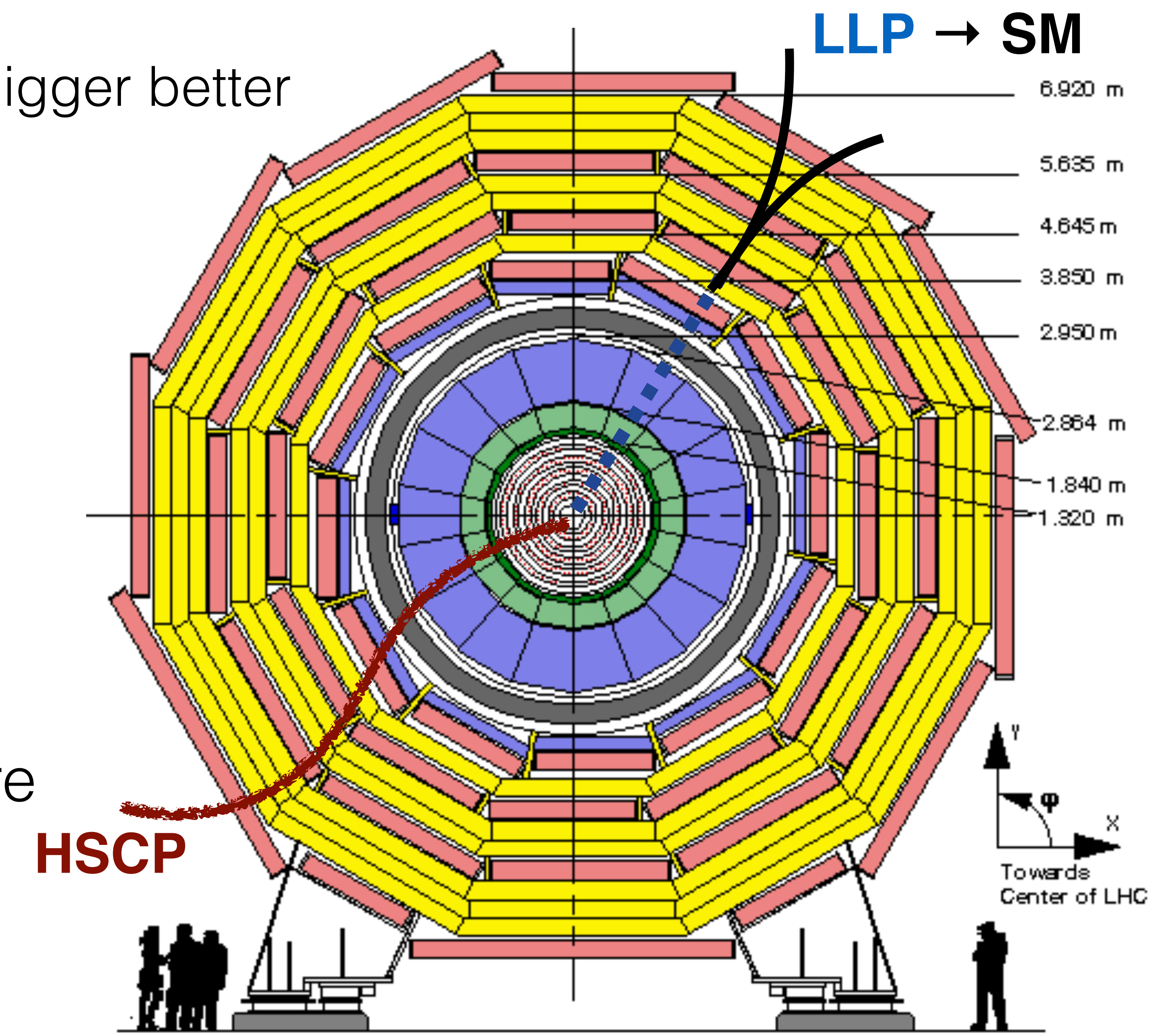
Bigger better

Closer better

What are the limitations?

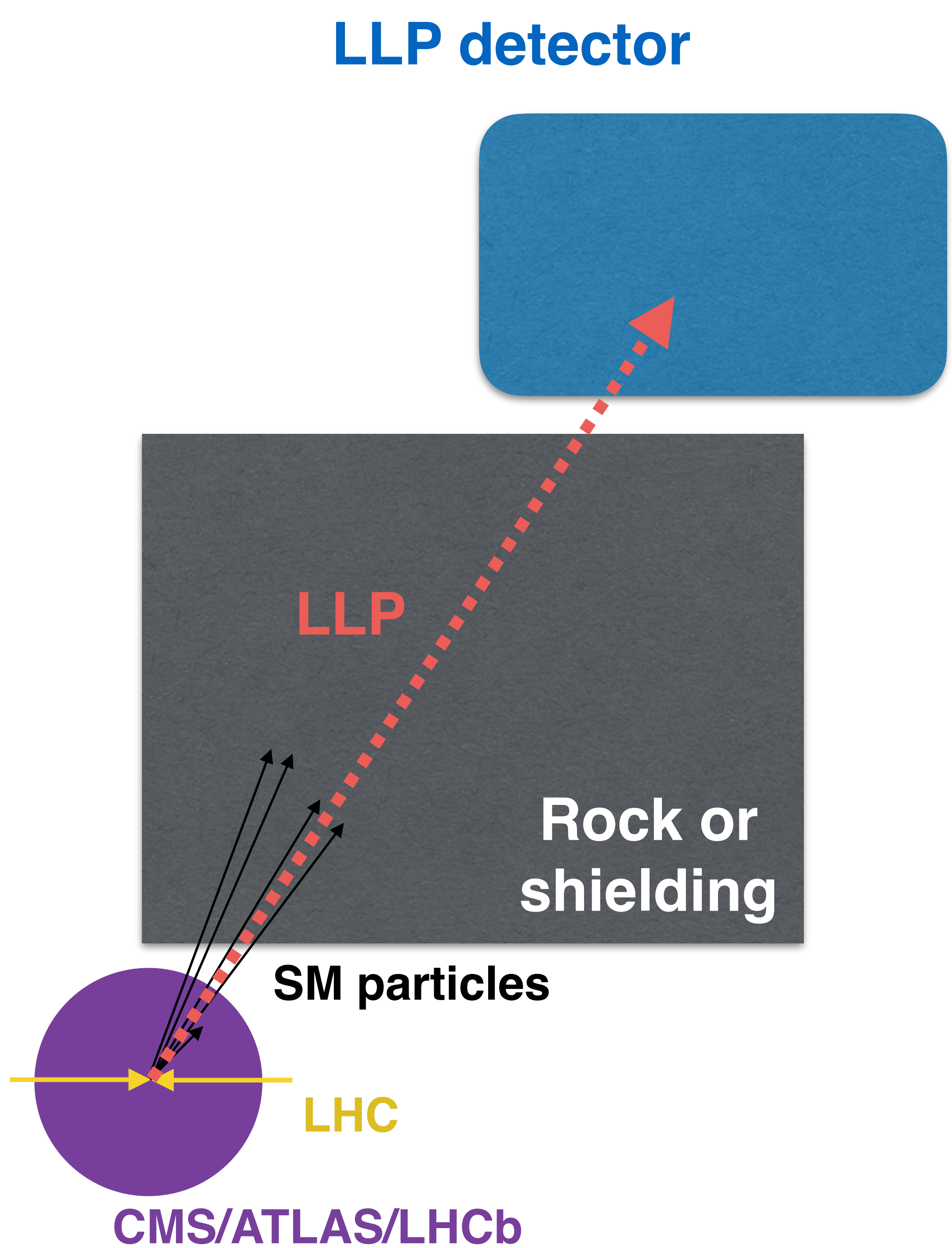
- Huge prompt and long-lived SM backgrounds
- Triggering (especially with hardware triggers) can be highly challenging
- Highly non-standard signatures produced by LLPs can be difficult to reconstruct efficiently

Transverse (CMS)



L_1 ~ 0.1 mm
L_2 ~ 7m (ATLAS ~10m)

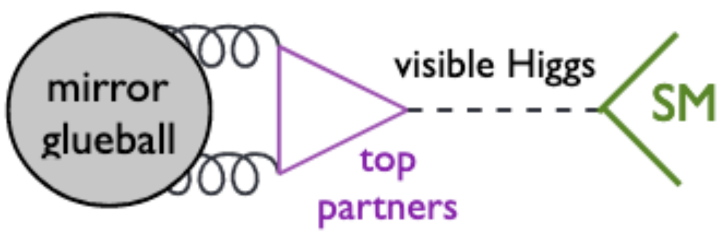
Why dedicated detectors?



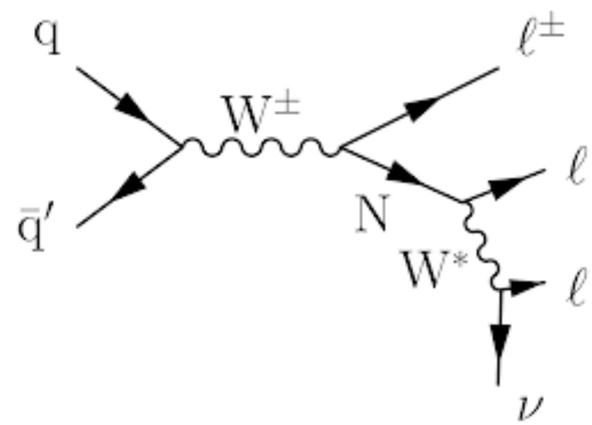
- **Backgrounds mitigated** by rock or dedicated shielding (or removing detector for readout)
- **Triggering simple** (or don't need trigger)
- Reconstruction **designed** for targeted LLP signature(s)
- Optimal **detector design** and **position** depend strongly on targeted signature: we need range of different detectors!

Heavy(ish) decaying LLPs

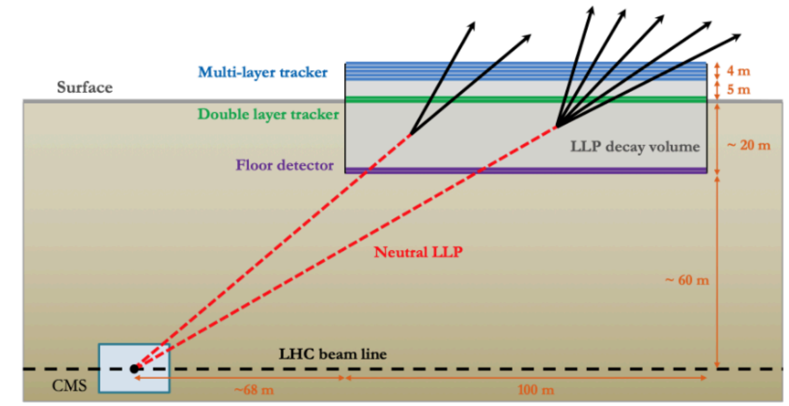
e.g. Twin Higgs



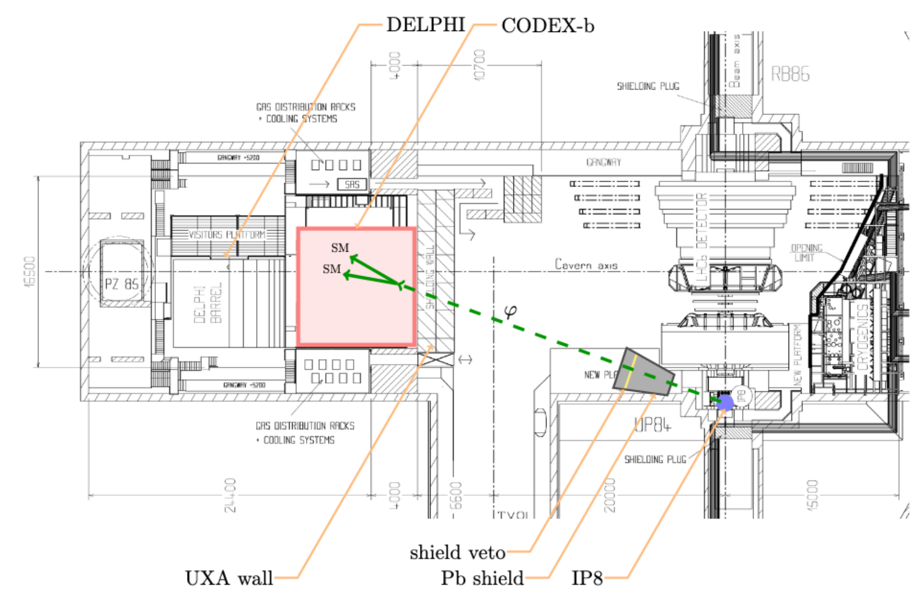
e.g. HNL



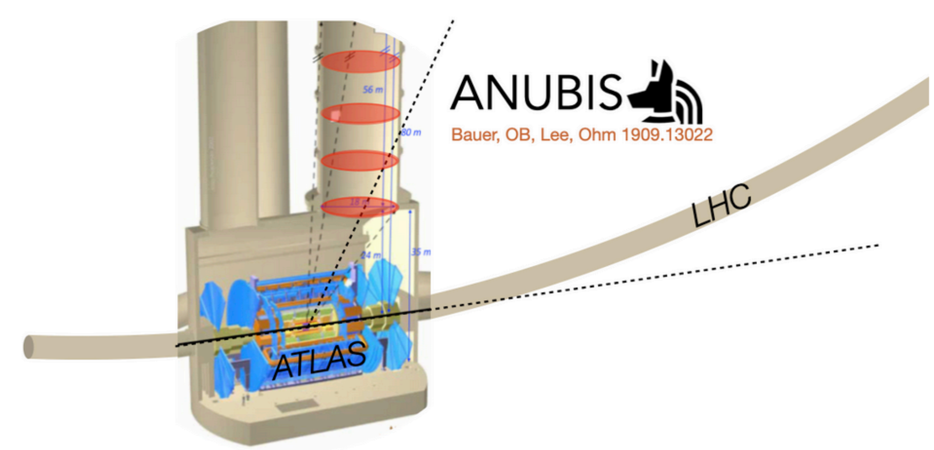
- **Centrally produced** LLPs arise in wide range of well motivated models: Twin Higgs, HNL, SUSY, …
- Wide mass range: from ~ GeV to ~TeV
- Range of detectors proposed: optimal lifetime coverage ~ distance from detector to IP



MATHUSLA: ~ IKEA at CMS IP surface



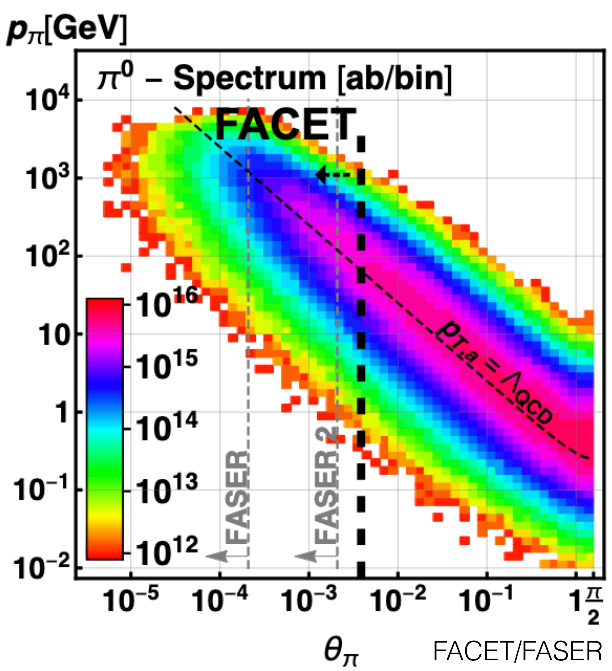
CODEX-b: detector + Pb shield at LHCb IP



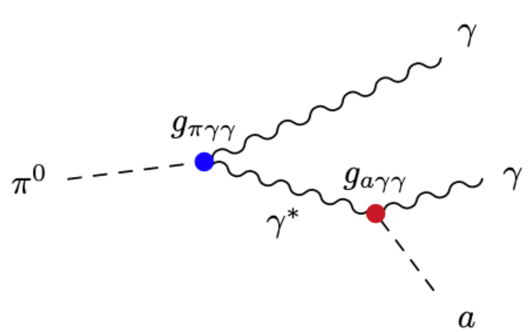
ANUBIS: instrument ATLAS shaft

Disclaimer: not comprehensive summary of physics reach!

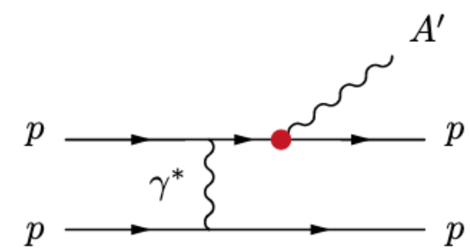
Low mass decaying LLPs

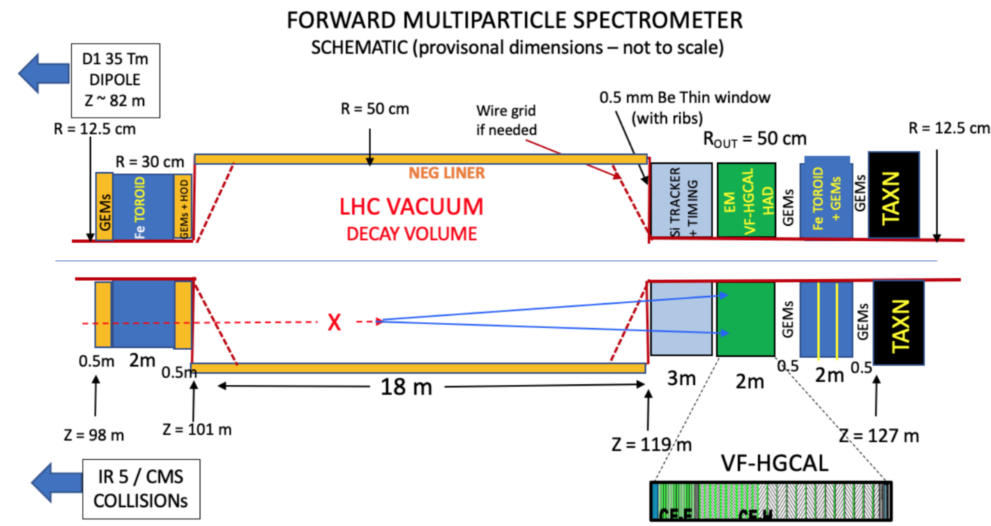


e.g. ALP from pion decay



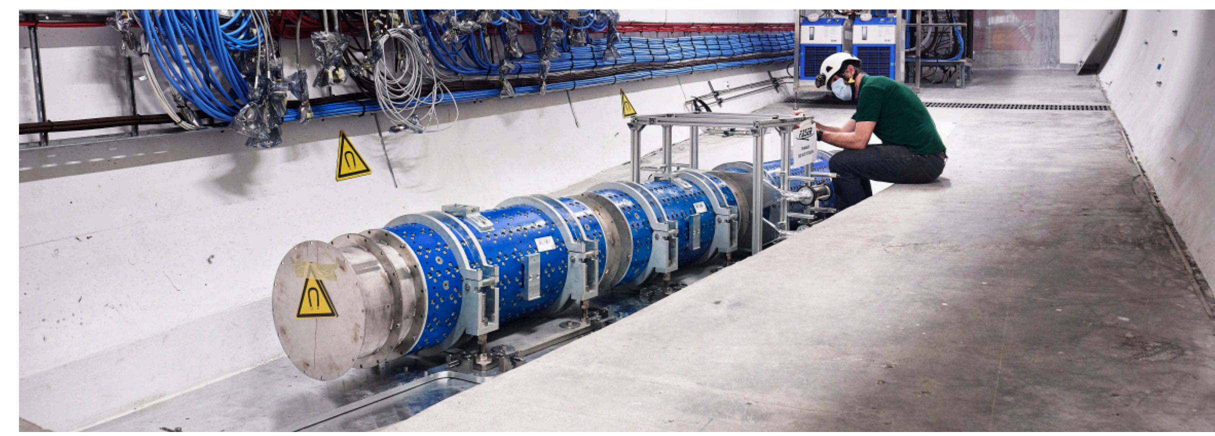
e.g. dark bremsstrahlung



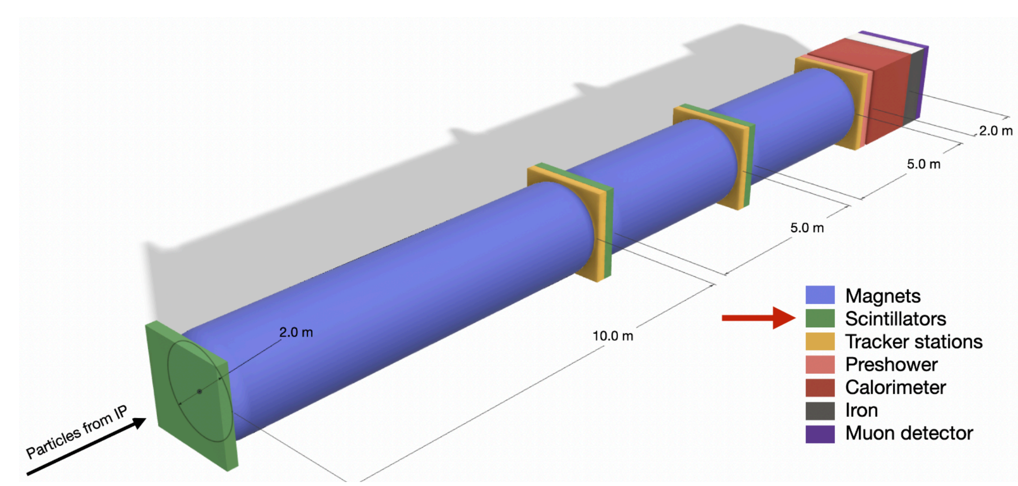


FACET: ~100m in front of CMS

- The lower the mass of the LLP (typically) the higher the **forward** production
- Far forward detectors target m_{LLP} < ~GeV to provide sensitivity to e.g. ALPs, dark photons, dark higgs, …
- Forward physics facility (FPF) designed to **comprehensively cover** forward BSM/SM signatures



FASER: installed ~400m from ATLAS IP



FASER2: larger detector proposed for FPF

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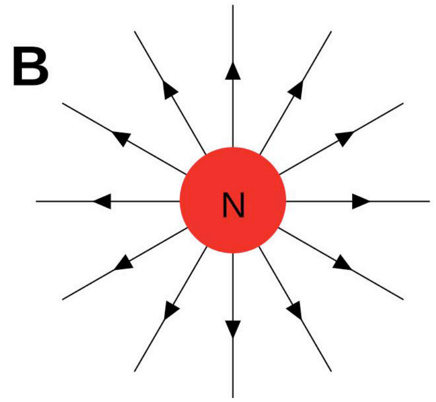
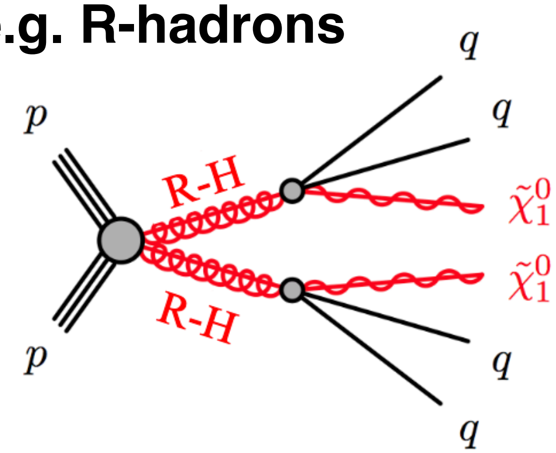
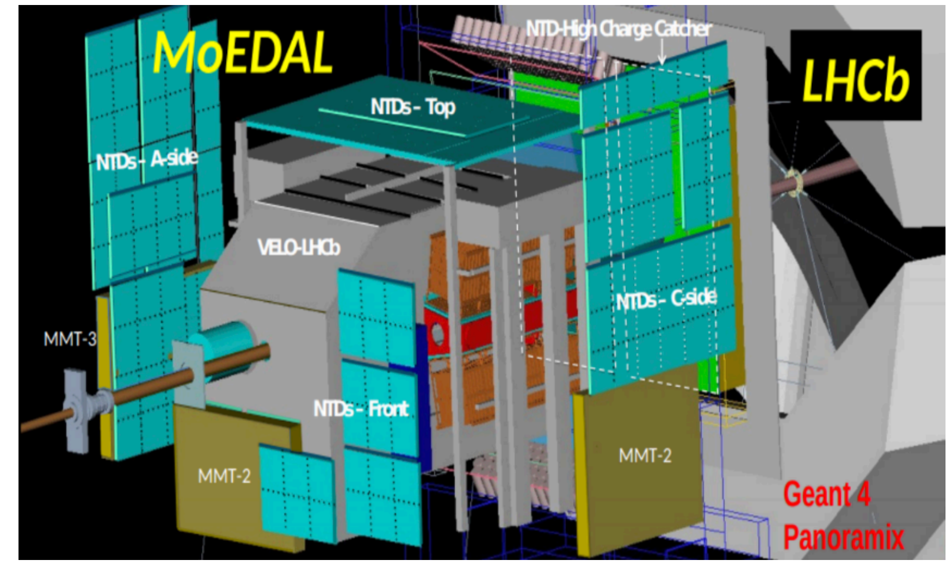
Direct detection: highly interacting LLPs

e.g. magnetic monopoles



e.g. R-hadrons

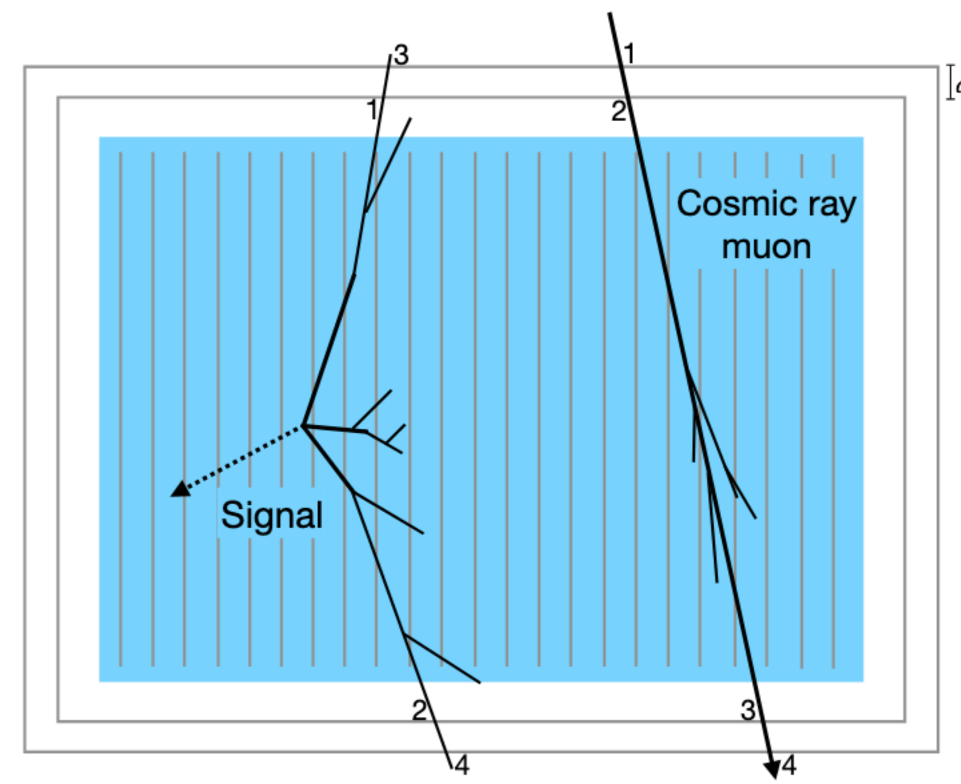




MoEDAL/MoEDAL-MALL: search for magnetic monopoles, dyons and charged particles

- Highly interacting LLPs can produce highly ionising tracks and/or get trapped in detector material: e.g. magnetic monopoles, dyons, R-hadrons, …

- Scan detector material for evidence of LLPs or place material in detector and wait for decays



Trapped particle detector: embed within CMS

New!

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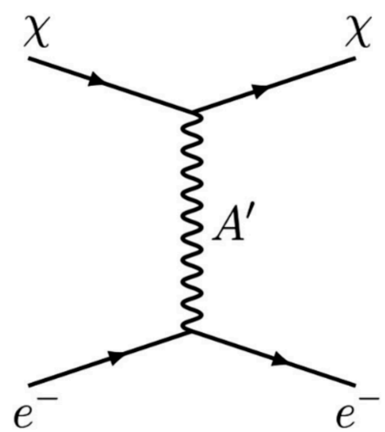
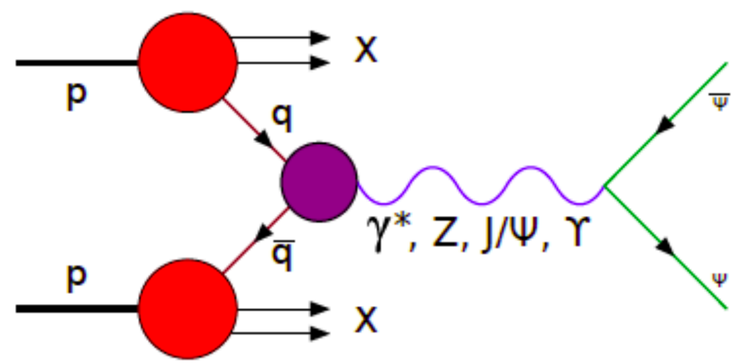
Direct detection: stable FIPs

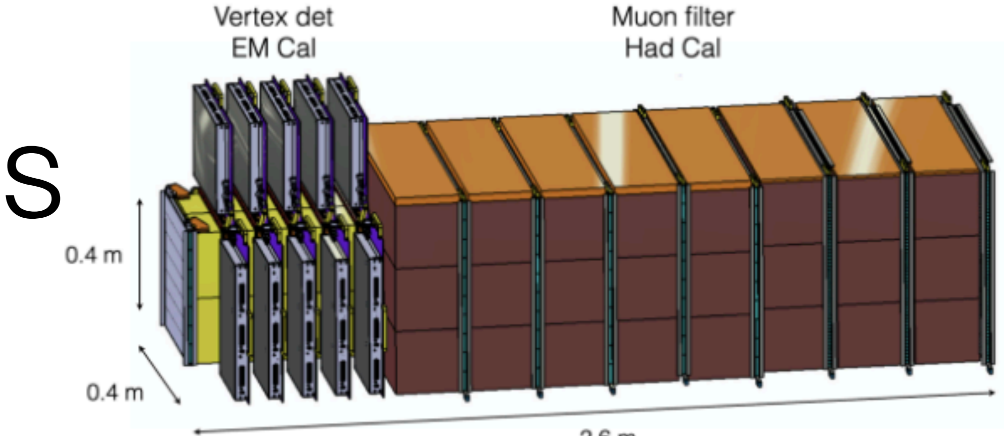
e.g. DM scattering



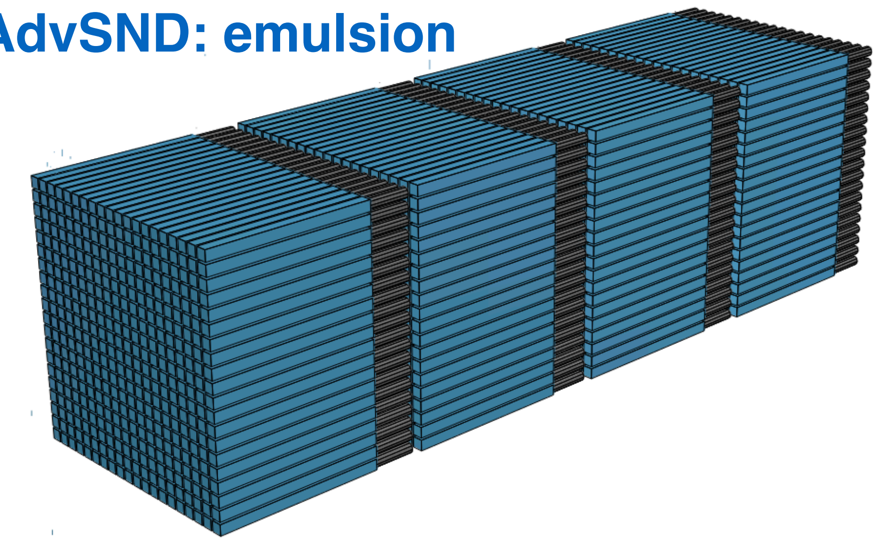
e.g. millicharged particles



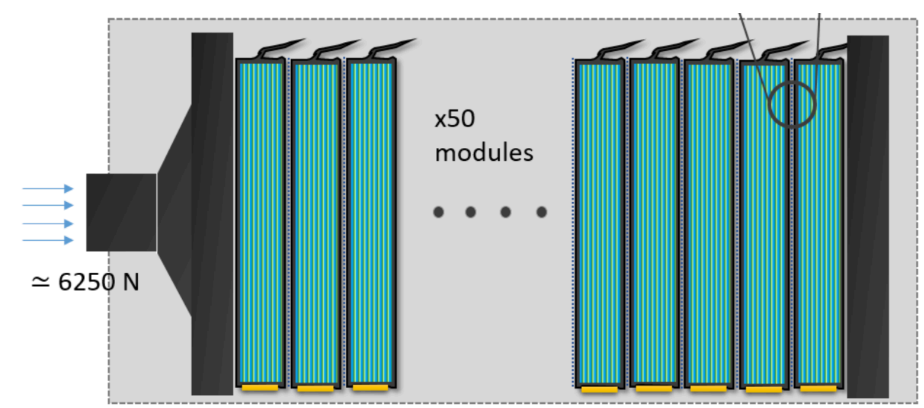
- Interactions of many LLPs **too weak** to observe with general purpose detectors: e.g. light DM, millicharged particles, …
- Require dedicated detectors with **large volume** of active material
- Range of detector designs provides comprehensive coverage (including several at FPF)



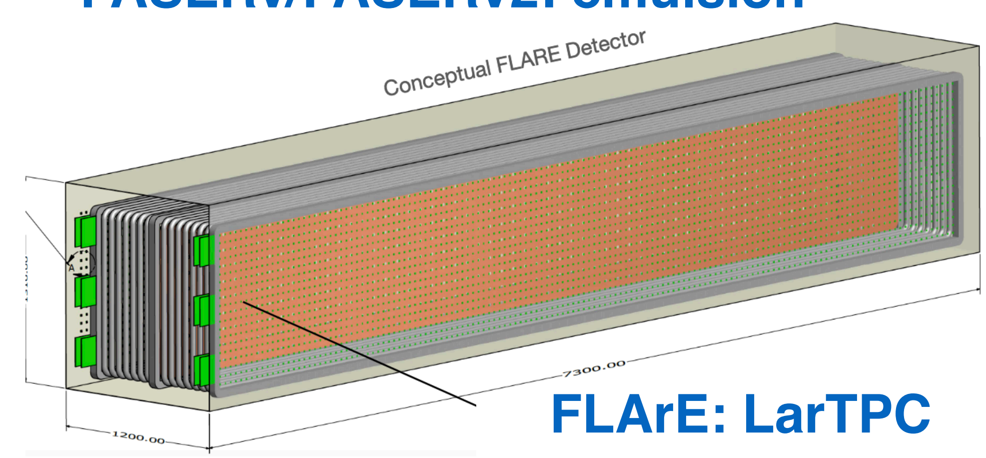
SND/AdvSND: emulsion



FORMOSA/milliQan/moedal-mQP: scintillator



FASERν/FASERν2: emulsion



FLArE: LarTPC

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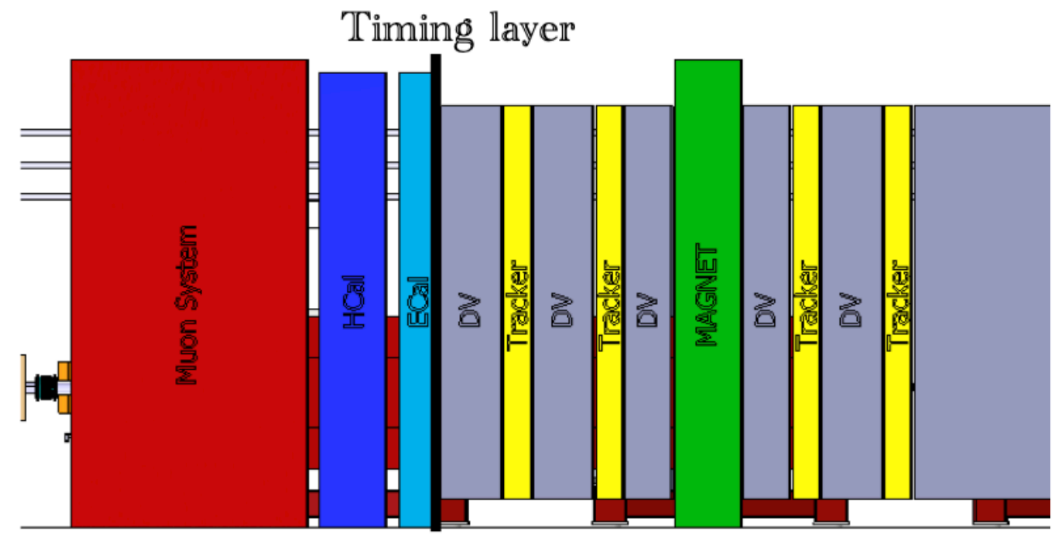
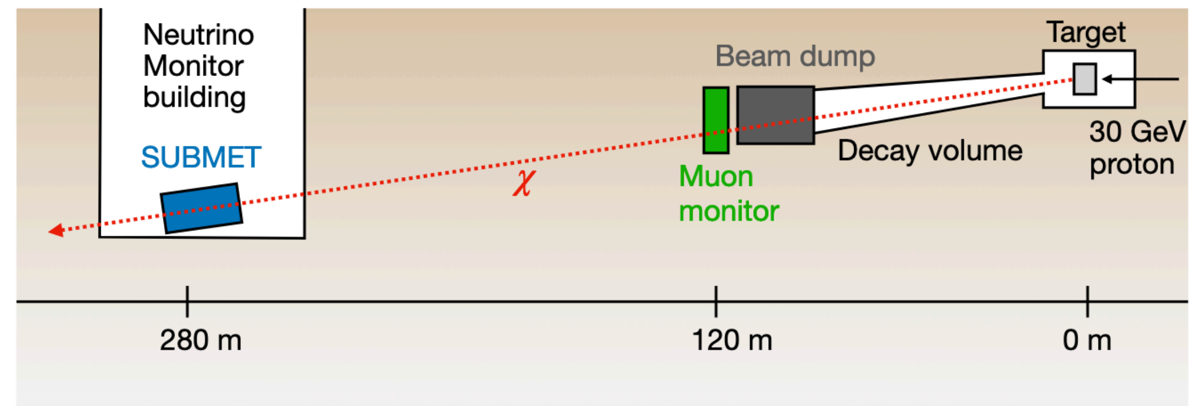
Beyond the LHC

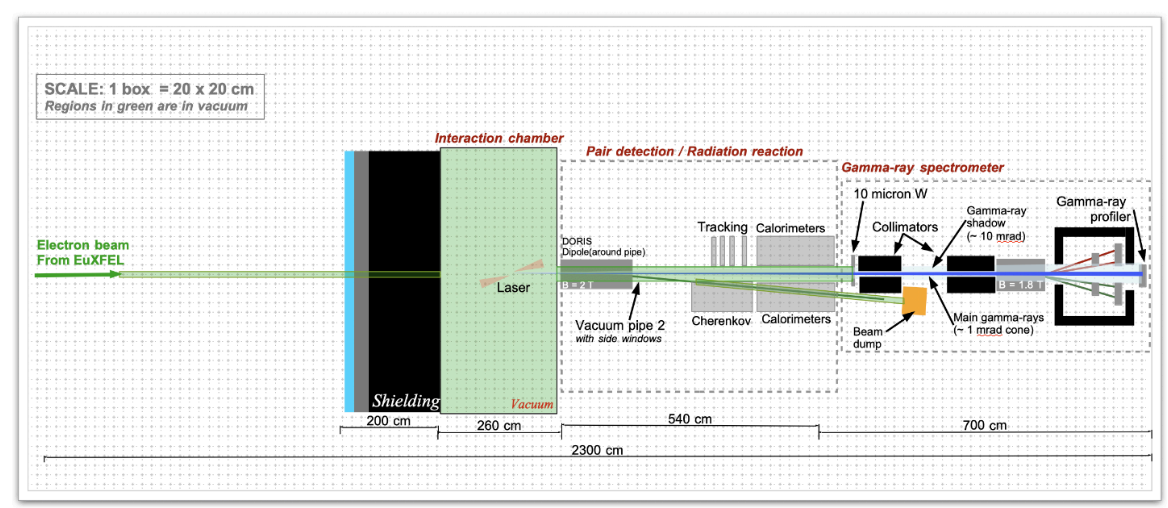
- LHC provides highest **energy** but not always highest **intensity**
- Dedicated detectors at other facilities provide excellent complementary sensitivity for low mass LLPs
- Also sensitivity from detectors such as Belle-2 (see session tomorrow!)
- Excellent opportunities for BSM discovery at multiple locations



SHADOWS at SPS beam-dump: low mass LLPs



SUBMET at J-PARC: millicharged particles



LUXE at DESY: LLPs coupling to photons

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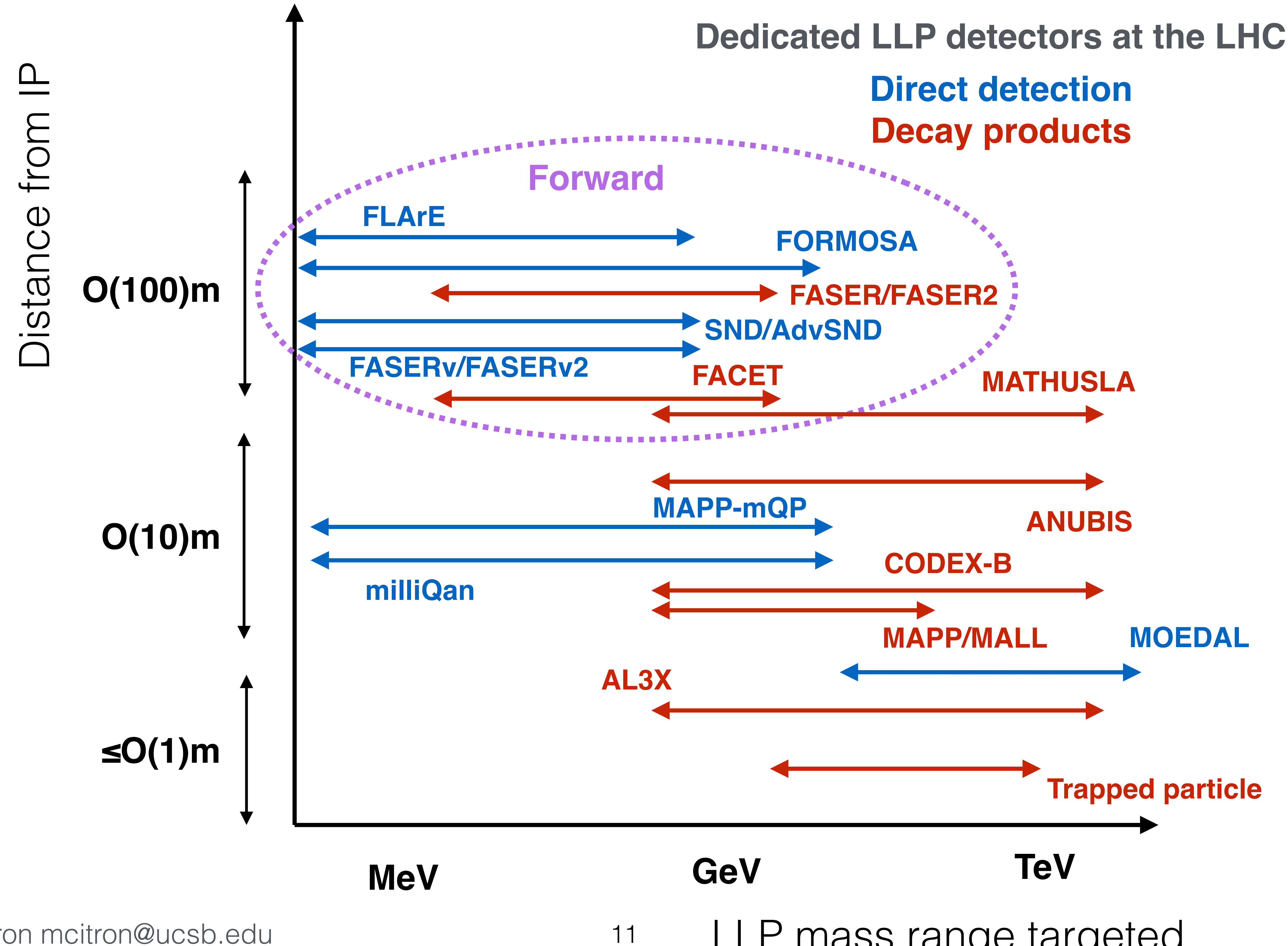
Qualitative summary



Let's hear more!