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Light Dark Matter and Long-Lived particles at accelerators

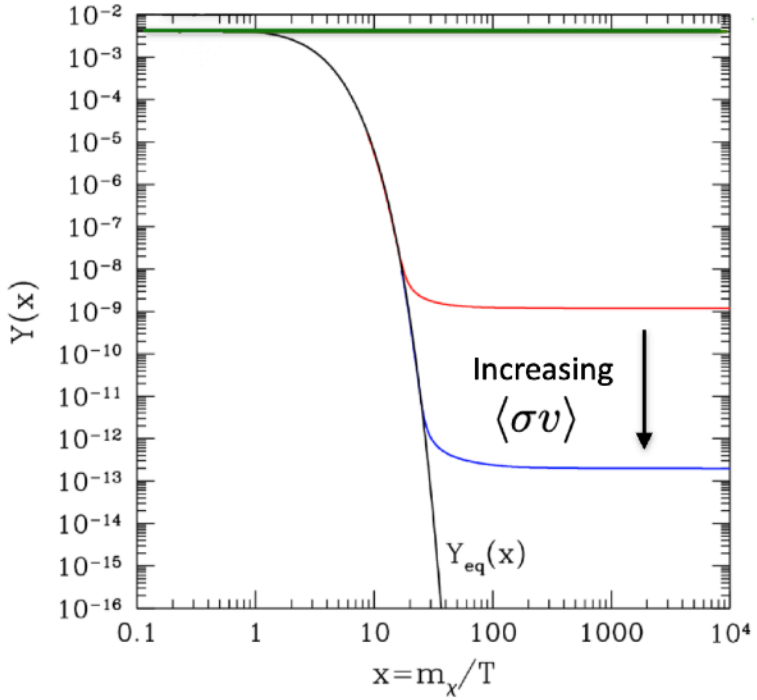
Beyond the Standard Models:
Particle Physics Meets Cosmology

IFT UAM/CSIC Madrid
3-28 October 2022

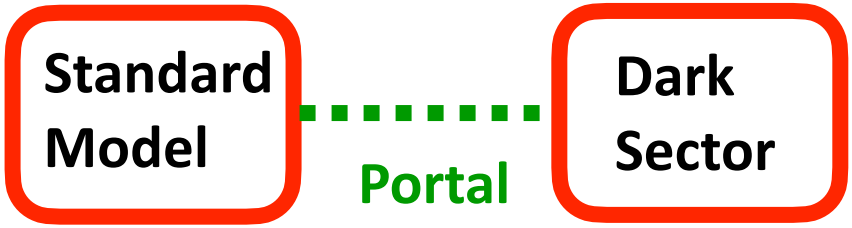
Light dark matter

- Thermal freeze-out: DM abundance controlled by $\langle \sigma v \rangle \sim \frac{\alpha}{M^2}$
- "Standard" WIMPs have $\alpha \simeq \alpha_{\rm EW} \quad M \simeq M_{\rm EW}$
- **Light dark matter**: extends parameter space below the Lee-Weinberg bound

  Boehm, Fayet; Pospelov Ritz Voloshin; Feng, Kumar
- Light mediators are needed for a sizeable annihilation cross-section



Dark sectors



Minimal **renormalizable portals** to connect the dark sector with the SM

$\frac{\epsilon}{2} F'_{\mu\nu} B_{\mu\nu}$ Vector portal

$H^\dagger H(\mu S + \lambda S^2)$ Scalar portal

$yLHN$ Neutrino portal

Other options:

Gauge anomaly-free global symmetries (B-L, …)

Higher dimensional operators portals (e.g. ALPs…)

More complex dark sectors, e.g. dark strongly interacting confining sectors

Could lead to unconventional cosmology, e.g. **Hochberg, Kuflik, Murayama**

Light dark sectors

- Light dark matter might be difficult to probe with conventional strategies.

  E.g. direct detection experiments loose sensitivity at low masses

- Many new ideas/concepts to explore sub-GeV DM

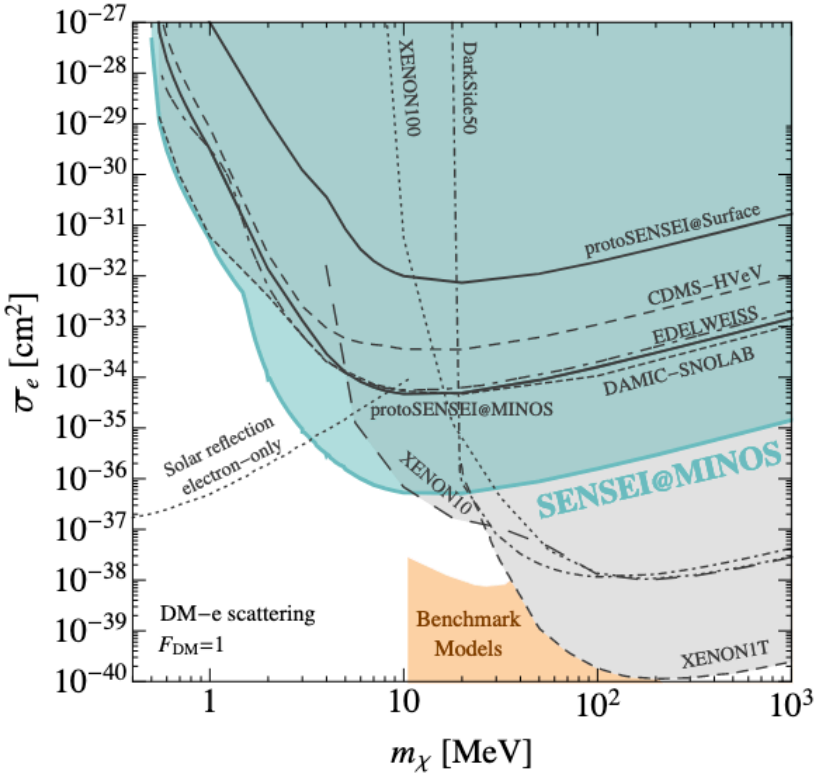
- Light DM good target for

  high intensity fixed target accelerator experiments

  Pros: large luminosities, large volume detectors,

  good reconstruction capabilities

SENSEI Coll. PRL 125 (2020) 17



Long-lived particles

- Dark sectors often contain **Long-Lived Particles (LLPs)**.

- **Example 1**

  Mediators can be long-lived when they can only decay into SM through suppressed interactions, e.g. dark photon, light scalar…

  A dark photon produced at an energy E has a decay length:

$$L = \beta\gamma c\tau \simeq 100\,\mathrm{m}\,\frac{10^{-5}}{\epsilon}\,\frac{E}{\mathrm{TeV}}\left(\frac{100\mathrm{MeV}}{m_{A'}}\right)^2$$

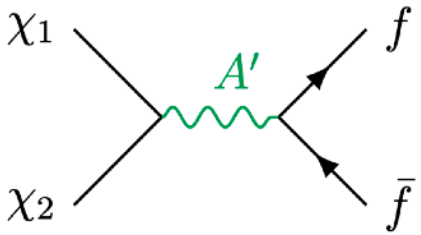
- **Example 2**

  Heavy Neutral Leptons $yLHN$

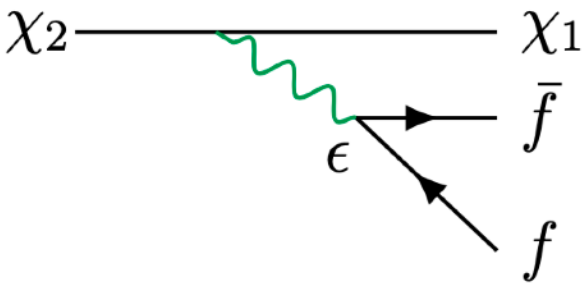
  Neutrino portal

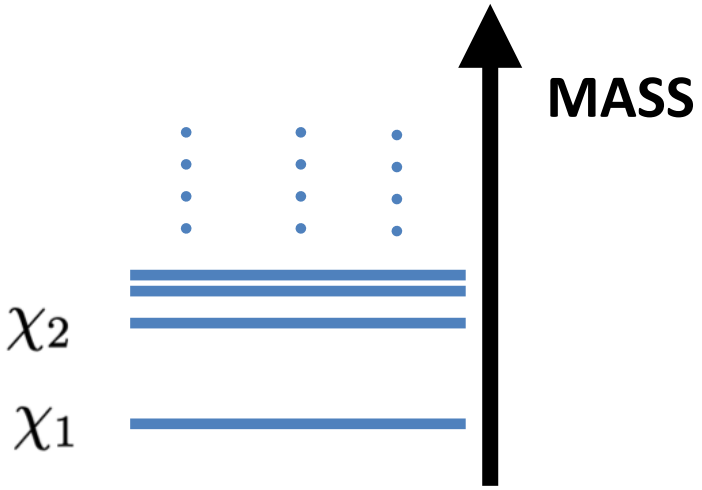
Long-lived particles

- **Example 3: Inelastic DM**



- Pair of dark states with a small mass splitting
- Coannihilation processes lead to thermal DM abundance
- Almost degenerate dark states -> evade strong bounds from CMB, indirect detection and direct detection
- Heaviest state can be a **LLP**



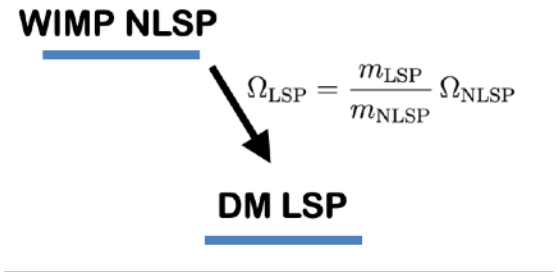


Long-lived particles

- Other examples motivated by the DM production

Freeze-in production of DM involves small couplings: long-lived particles are easily found in these scenarios

Super-WIMP



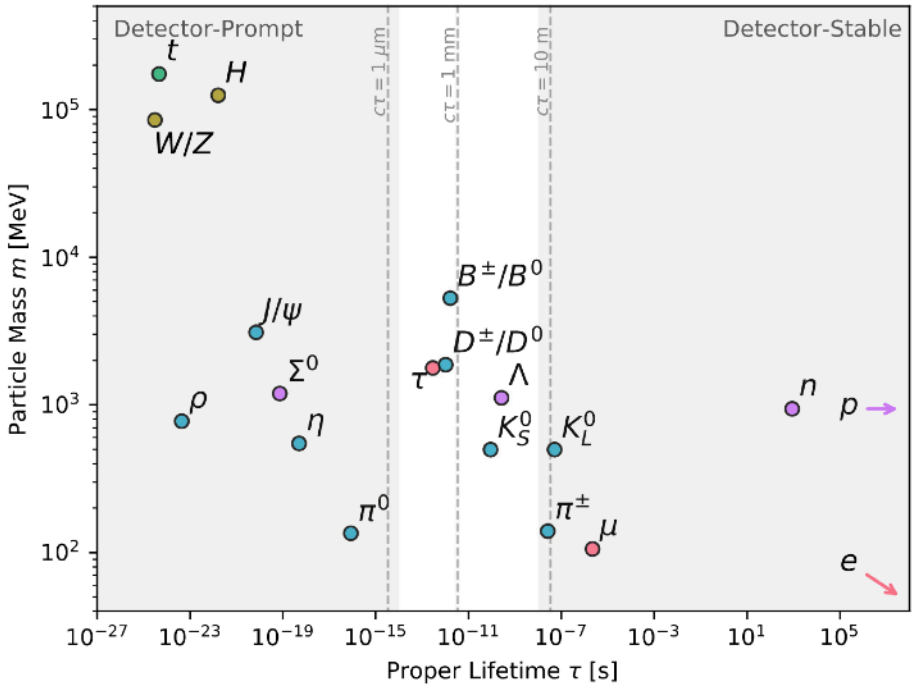
- Metastable particles already in the SM

- Surveys of models -theory motivations for LLPs

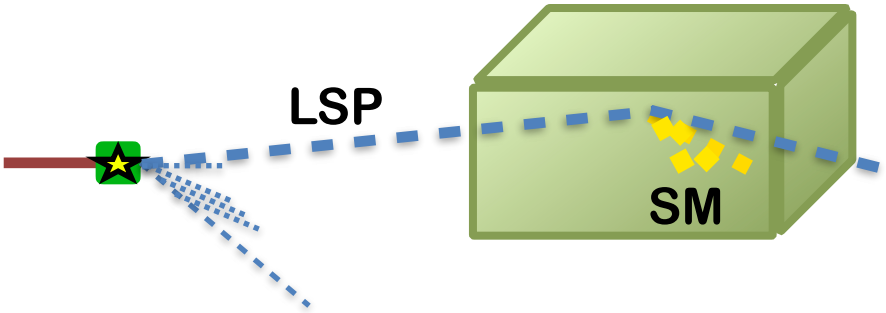
Feng et al. 2022 Snowmass Summer Study, 2203.05090

Curtin et al. Rept.Prog.Phys. 82 (2019) 11

Lee, Ohm, Soffer, Yu, Prog.Part.Nucl.Phys 106 (2019) 210



Proposed LLPs experiments @ LHC



- Backgrounds strongly reduced
- Designed and optimised for LLPs signatures

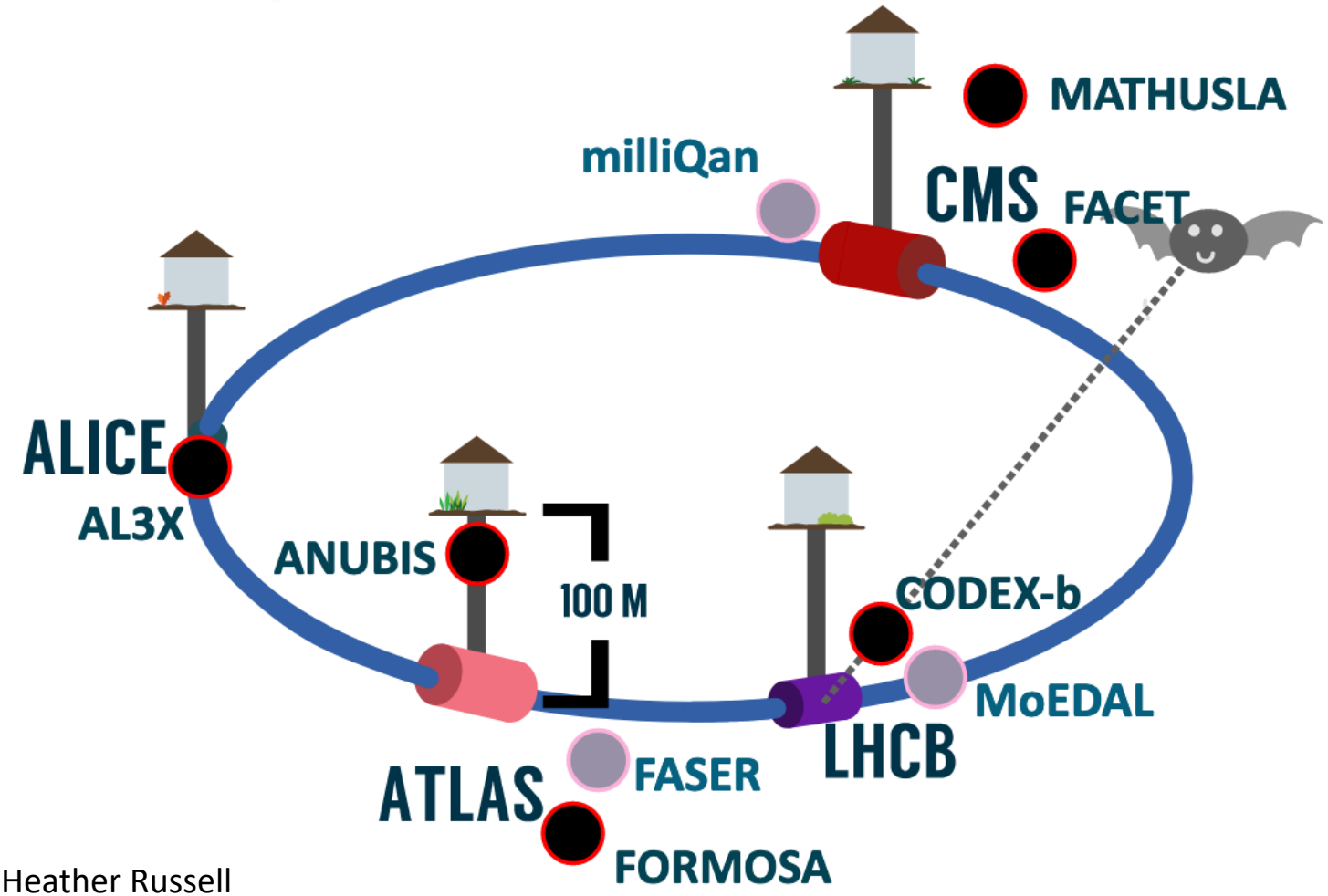
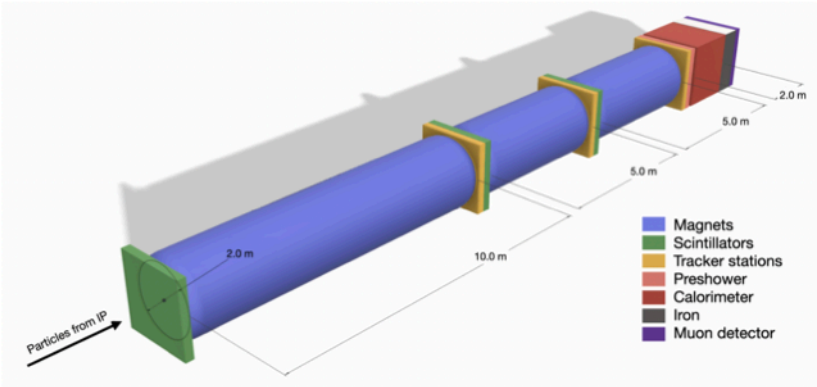


Image credit: Heather Russell

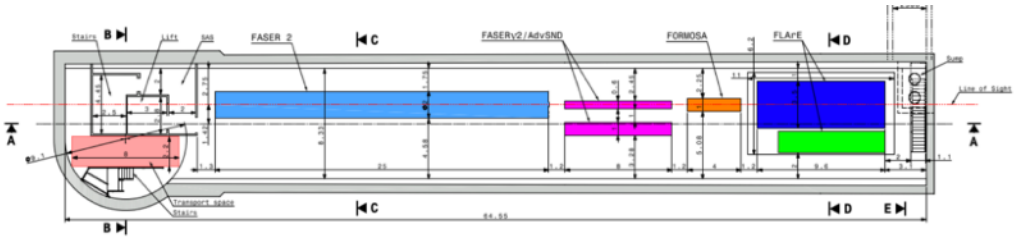
Forward detectors

FASER Feng et al. 2022 Snowmass Summer Study, 2203.05090

Detect LLPs produced in the forward region
Backgrounds mitigated by rock + veto shielding



FASERν: emulsion detector for neutrino physics and DM scattering

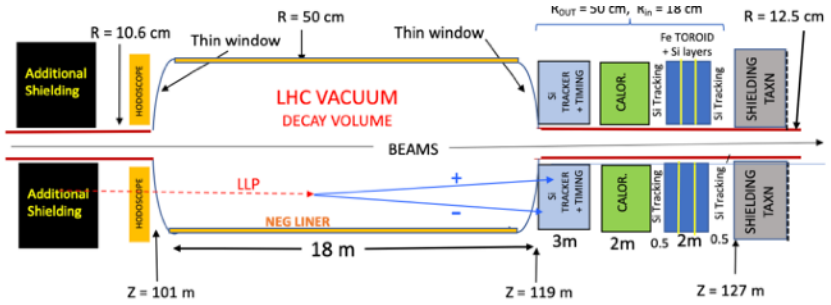


Already installed. Plan for
Forward Physics Facility with 5 detectors

FASER 2, FASERν 2, FORMOSA, SND, FLAeE

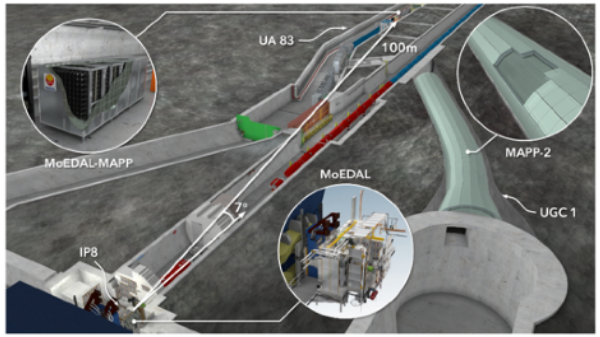
FACET: forward detector close to CMS

Cerci et al. JHEP (2022) 06 110



MoEDAL - MAPP

Acharya et al. 2022 Snowmass Summer Study

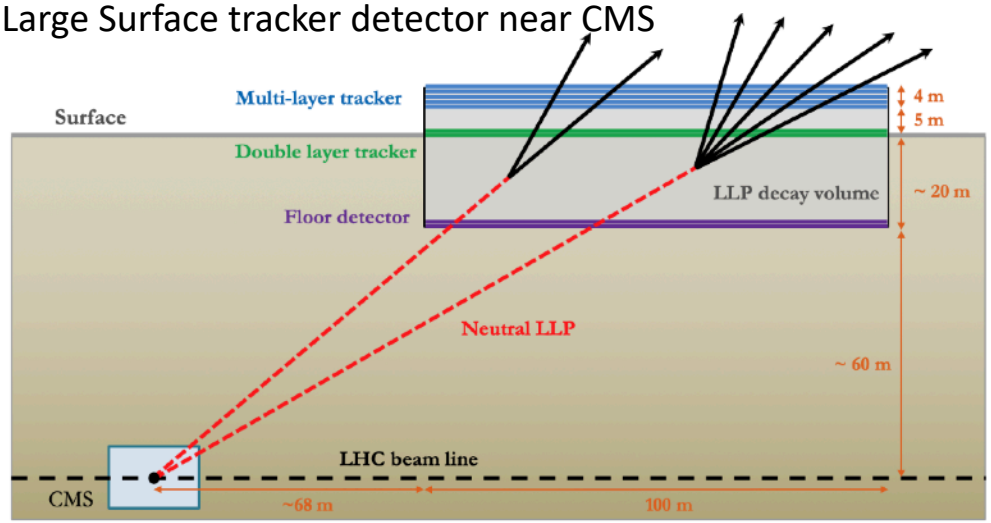


Transverse detectors

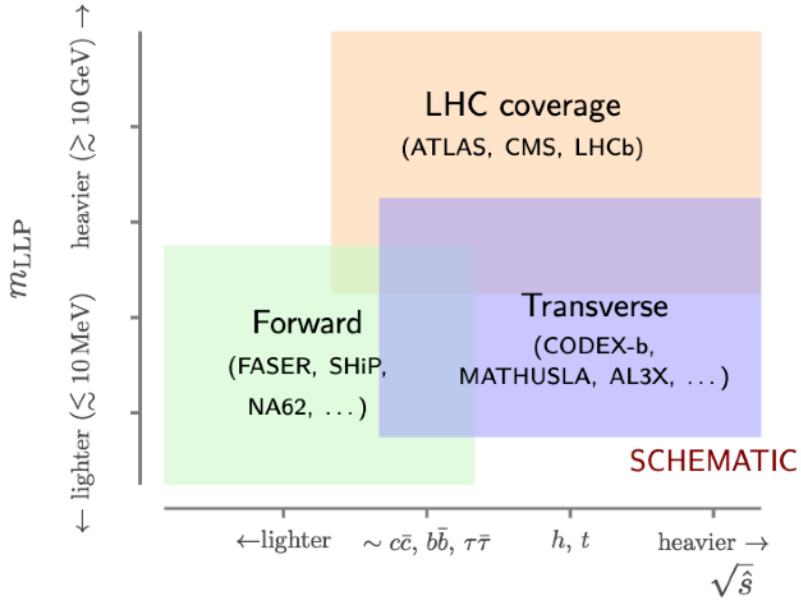
Complementary to forward detectors

MATHUSLA

Large Surface tracker detector near CMS

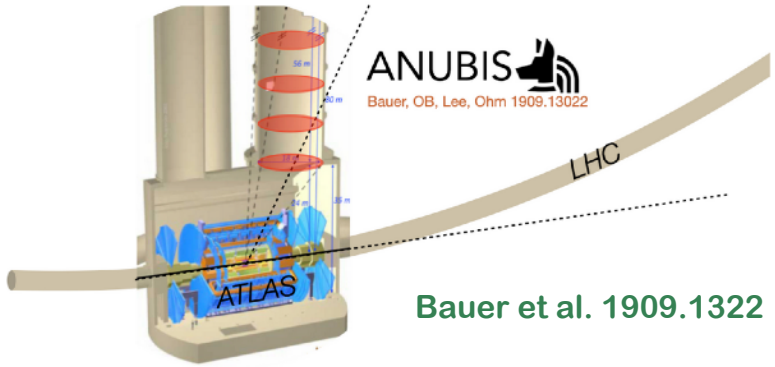


Alpigiani et al. 2009.01693



ANUBIS

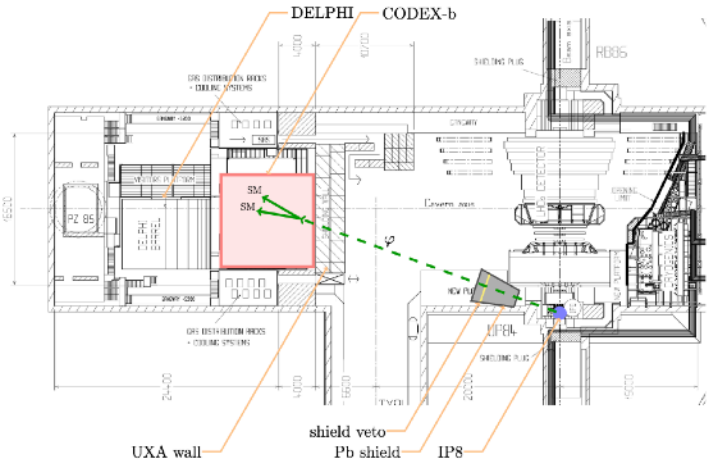
Tracker detector in ATLAS access shaft



Bauer et al. 1909.1322

CODEX-b

Tracker + calorimeter near LHC-b



Aielli et al. Eur.Phys.J.C 80 (2020) 12

AL3X

Gligorov et al. PRD 99 (2019) 1

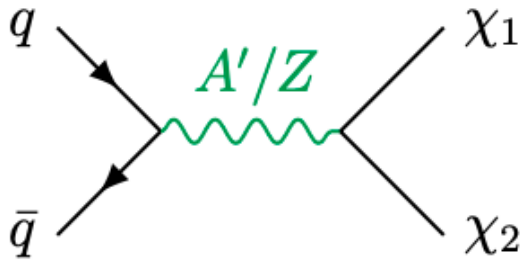
Use ALICE cavern

Would imply ALICE is removed!

Inelastic DM

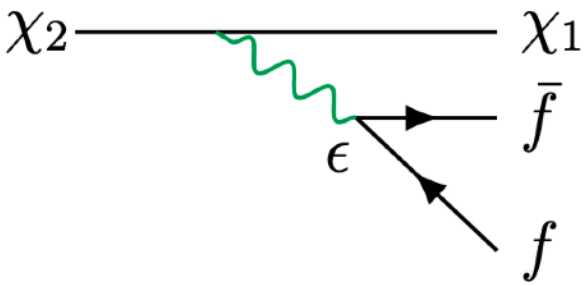
$$\mathcal{L}_{int} = \frac{\epsilon}{2\cos\theta_w} A'_{\mu\nu} B^{\mu\nu}.$$

- **Production**
- Drell-Yann processes: dominant production channels for masses > O(GeV)



- Meson decays and proton bremsstrahlung

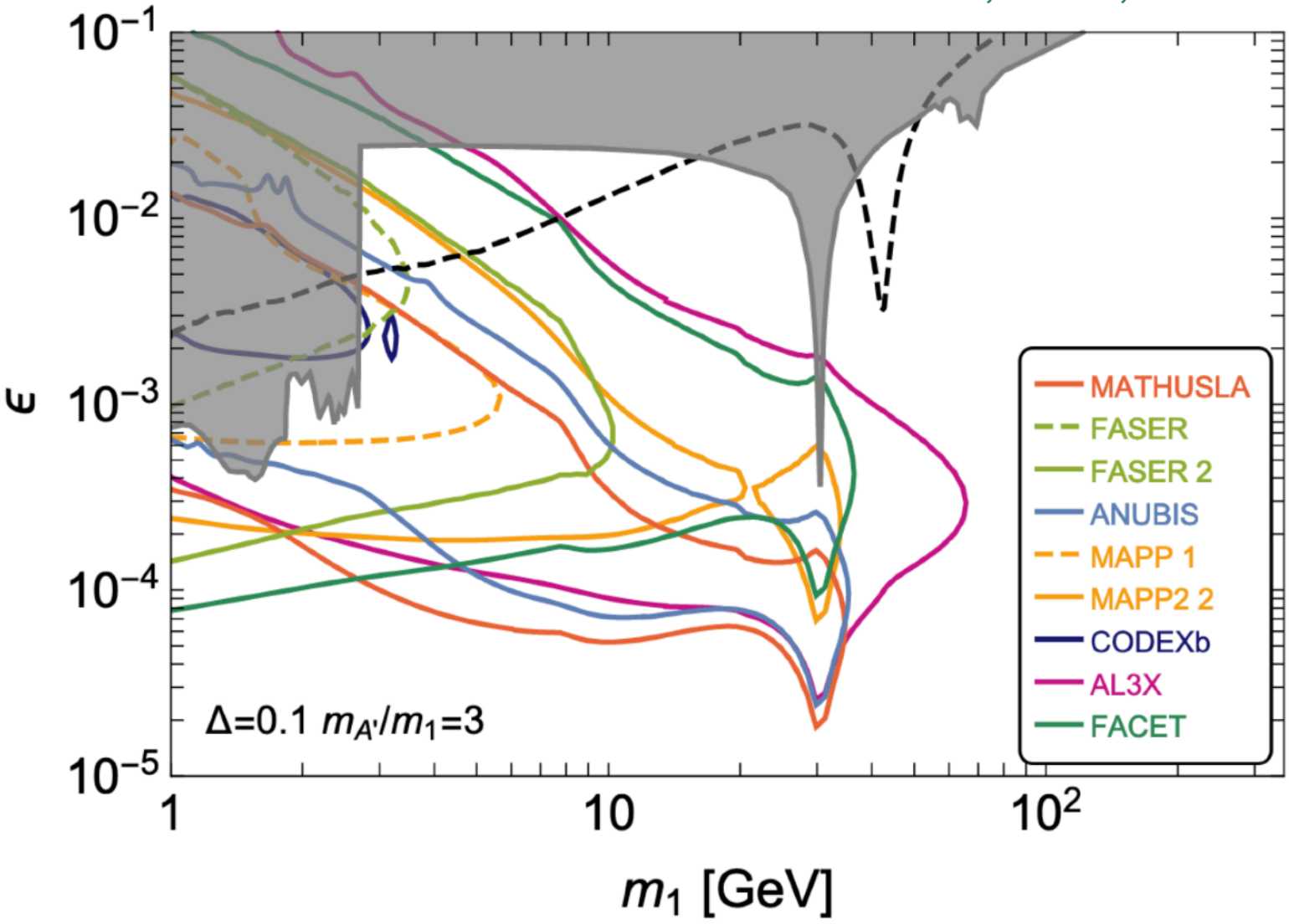
- **Detection**



$$\Delta = \frac{m_2 - m_1}{m_1}$$

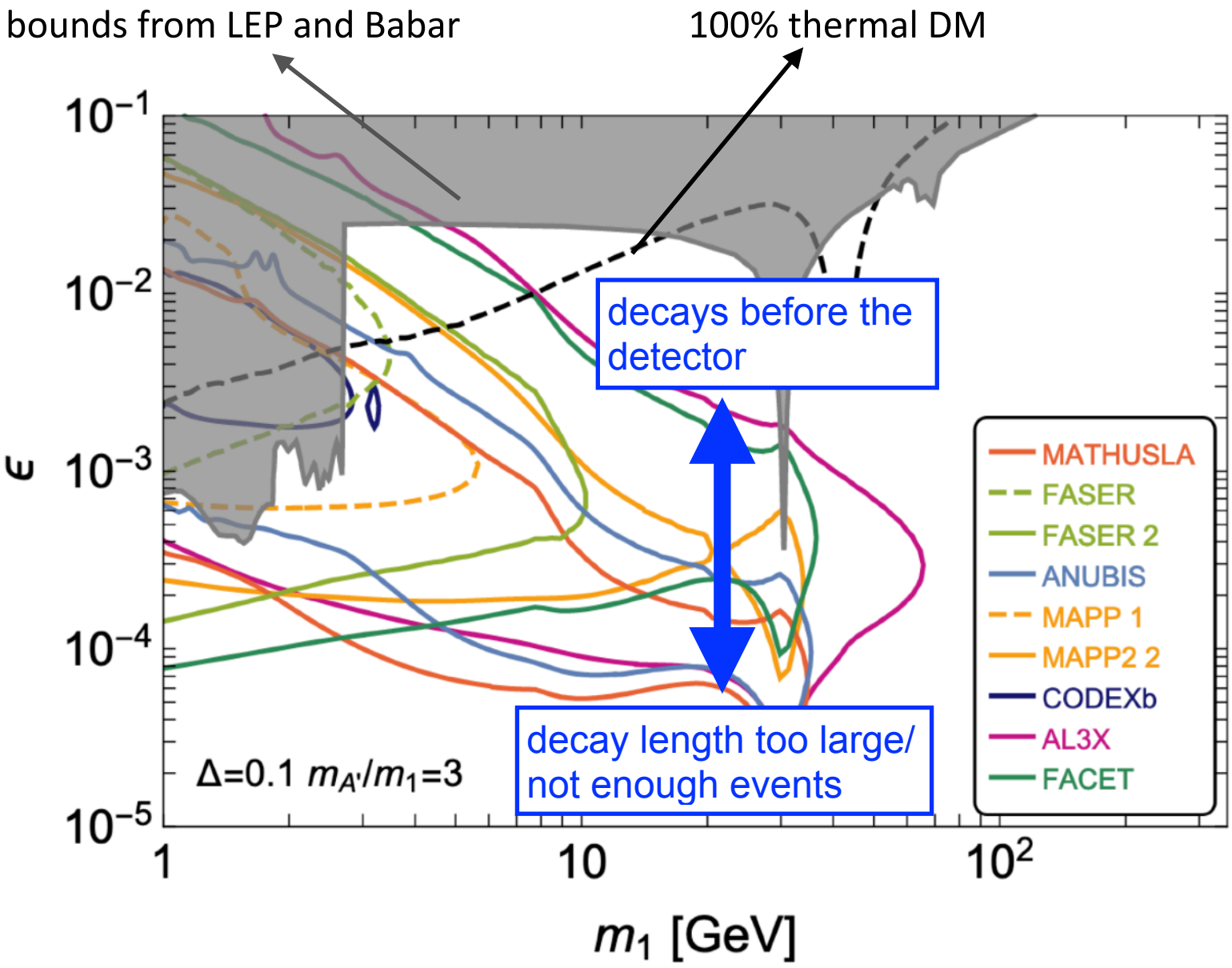
Sensitivities

Bertuzzo, Scaffidi, M.T. JHEP 08 (2022) 100



See also Berlin, Kling PRD 99 (2019) 1

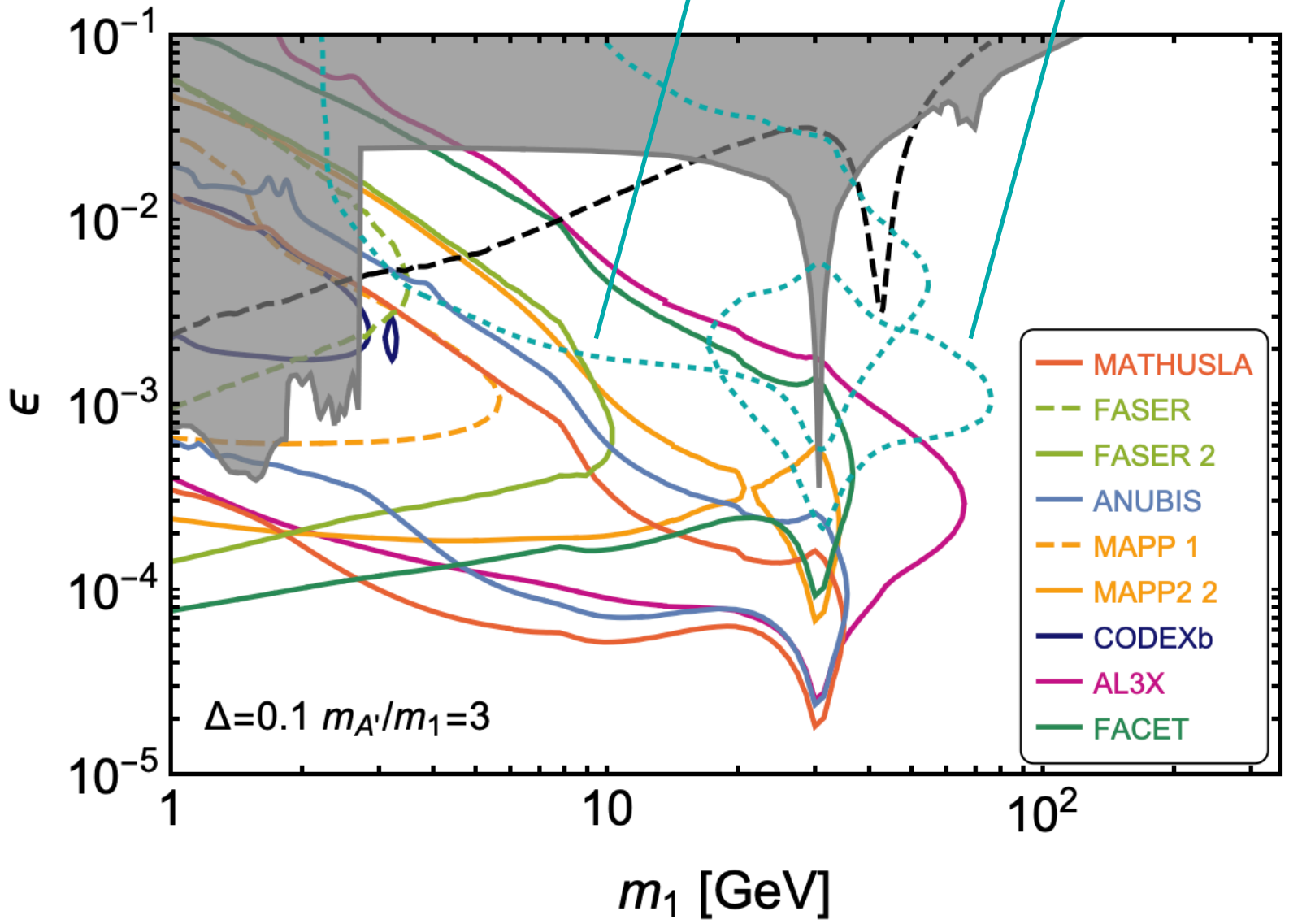
Forecasting sensitivities



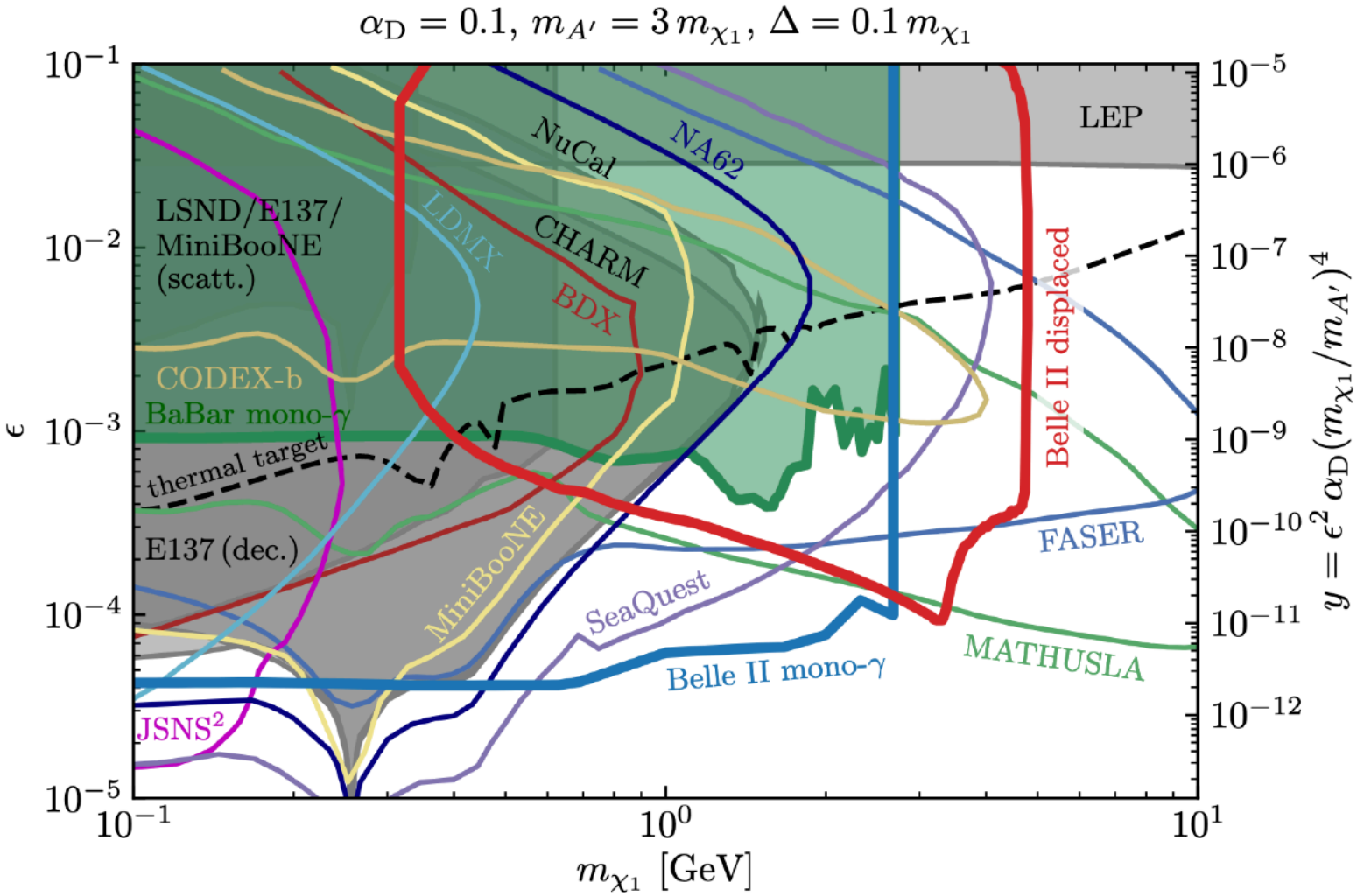
Searches at the main LHC detectors

Berlin, Kling PRD 99 (2019) 1

Searches of displaced events at the main LHC detectors

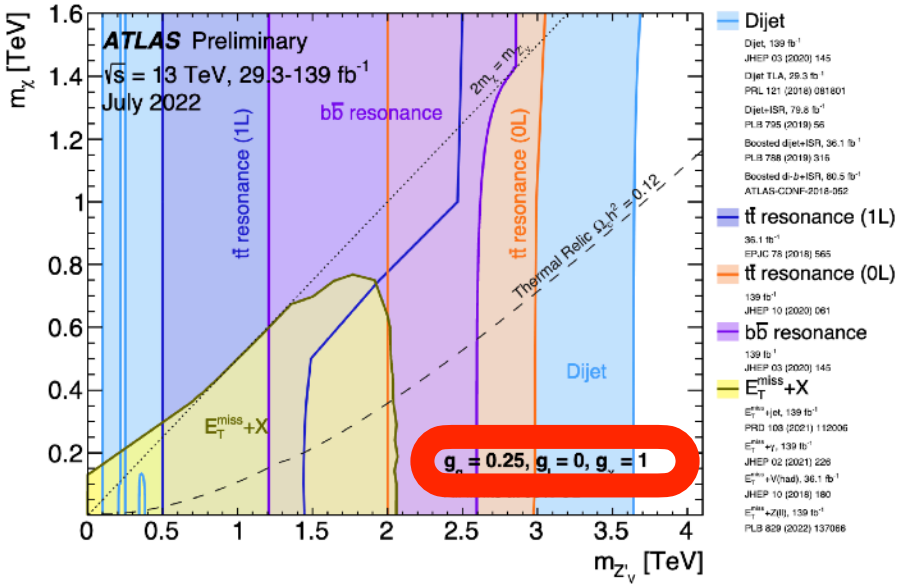


Belle II sensitivity



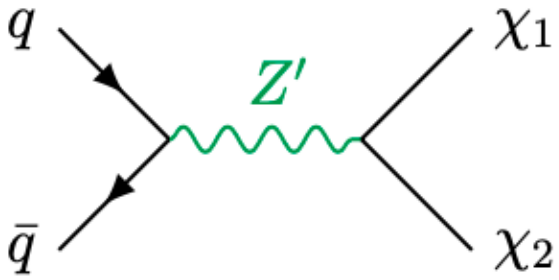
Duerr et al. JHEP 02 (2020) 039

The case of heavy mediators



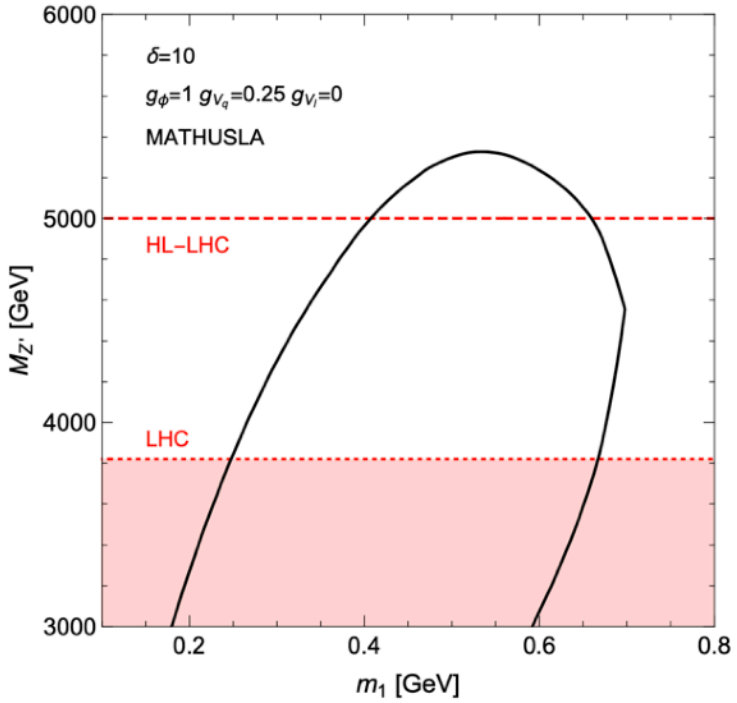
ATLAS Coll.
"Dark matter summary plots for s-channel, 2HDM+a and Dark Higgs models",

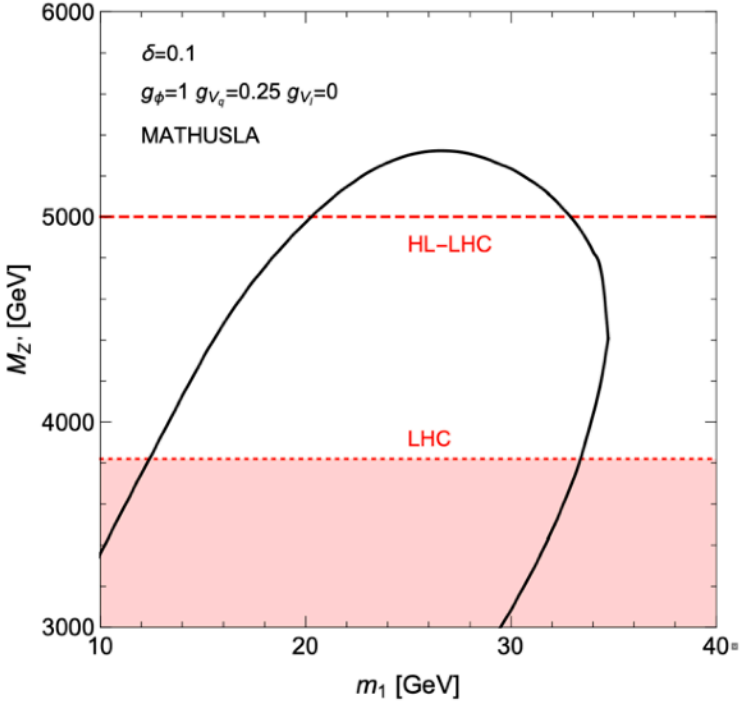
https://cds.cern.ch/record/2816368/files/ATL-PHYS-PUB-2022-036.pdf



Complementarity with main LHC detectors

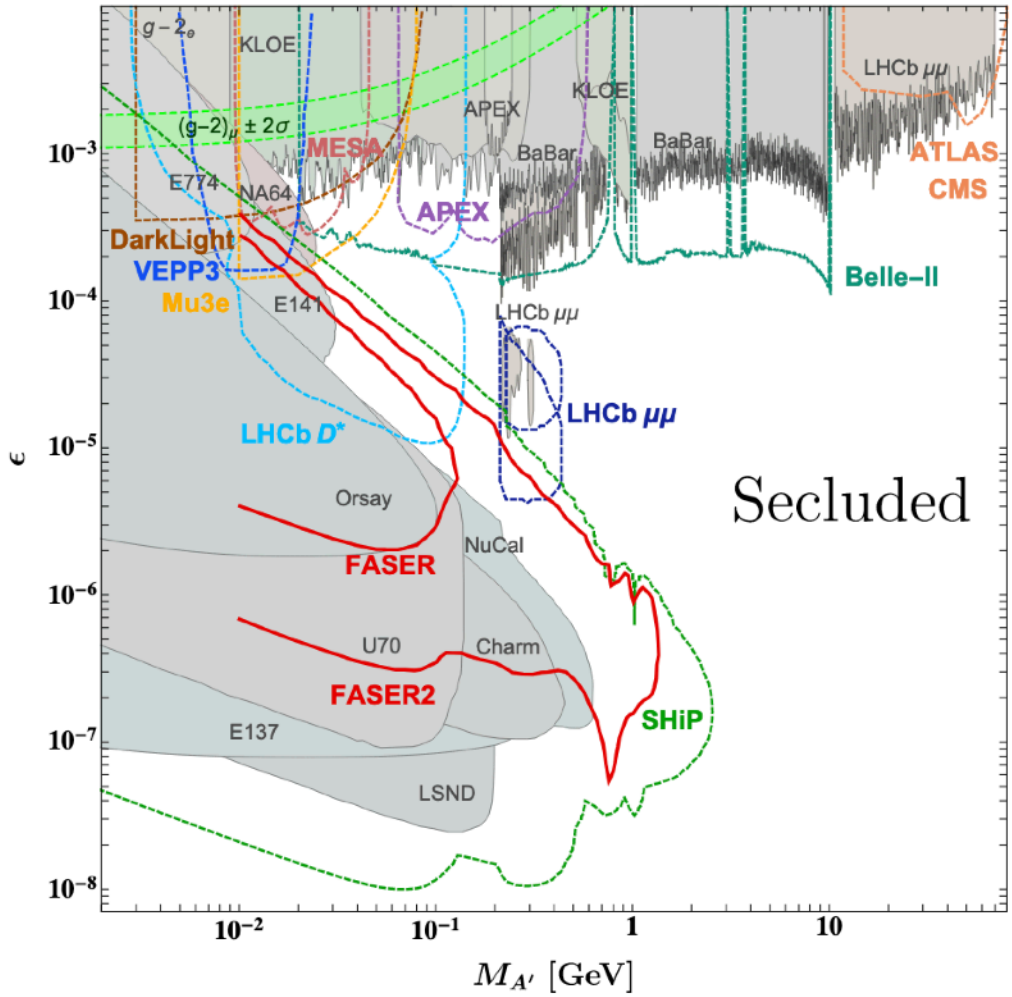
Bertuzzo, M.T. JHEP 03 (2021) 272

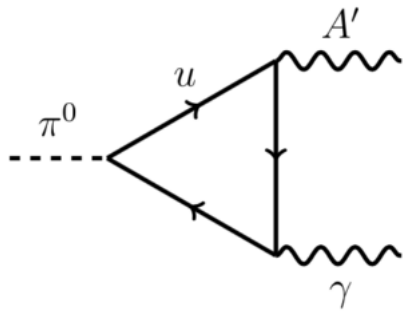


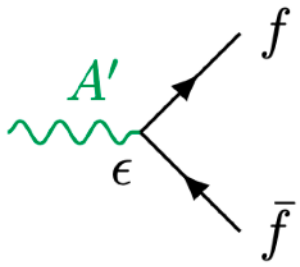


Secluded dark photon

Produced by decays of π, η, η' mesons: good target for forward detectors







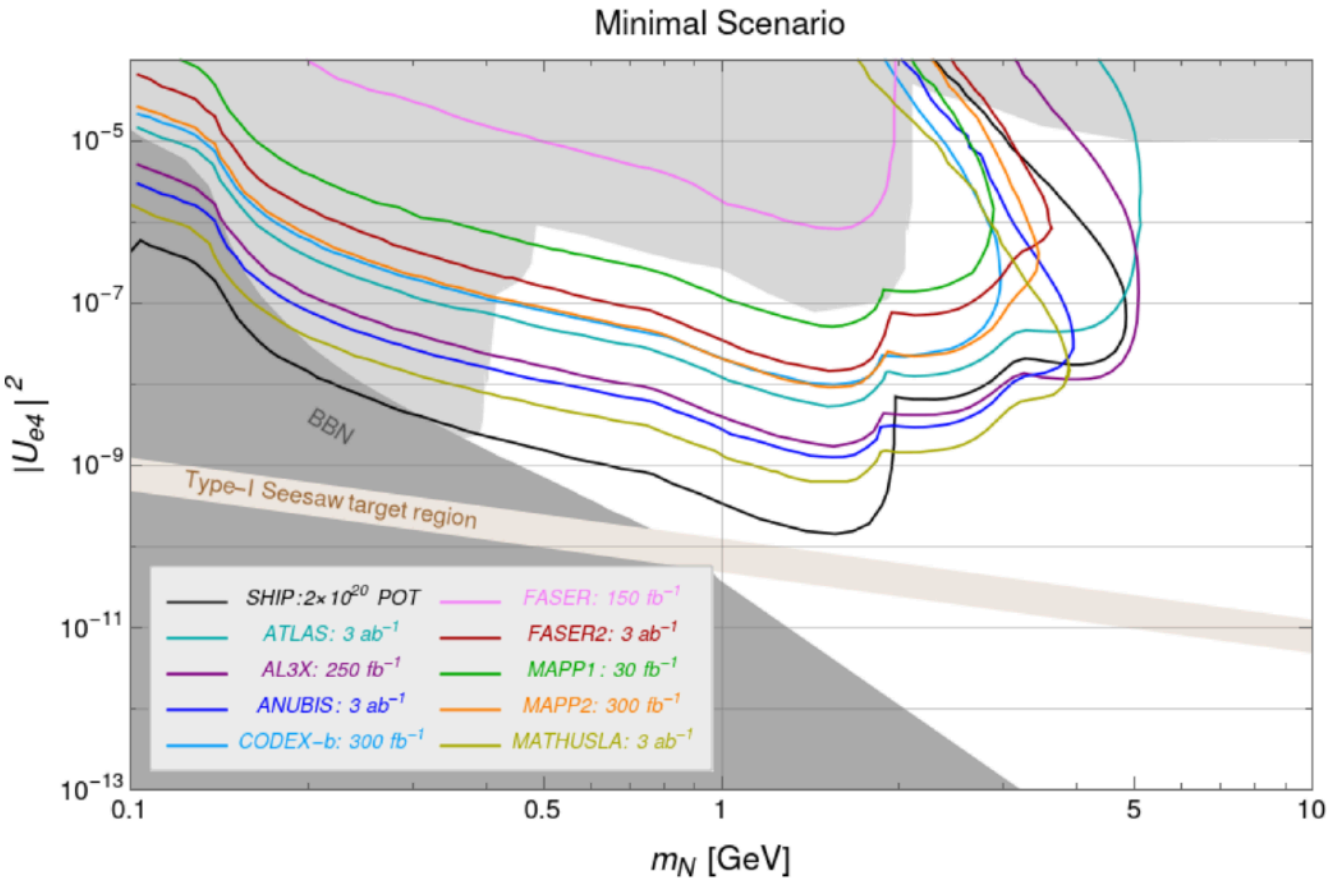
Feng et al. 2022 Snowmass Summer Study, 2203.05090

Sterile Neutrinos

Heavy Neutral Leptons

Sterile neutrinos with masses of O(GeV) mixing with active neutrinos

$$\mathcal{L} = y_N \, L \, H \, N$$

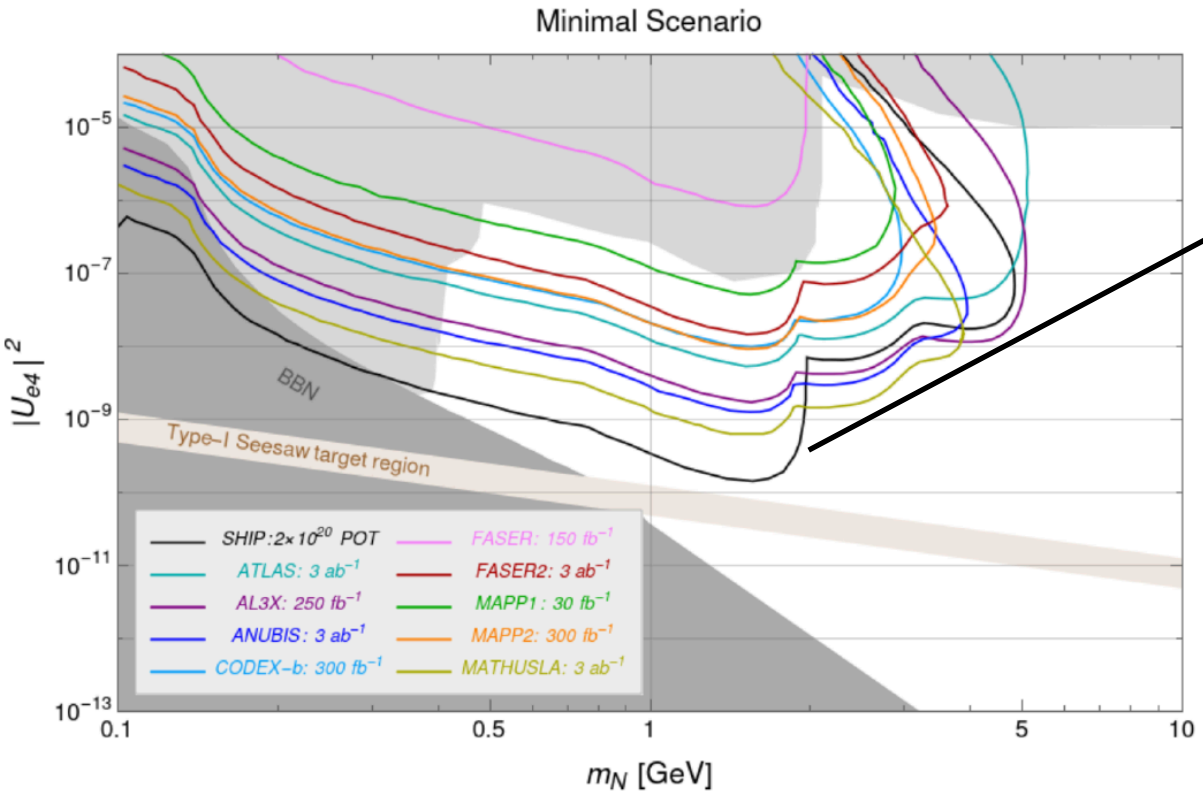


De Vries et al. JHEP 03 (2021) 148

Sterile Neutrinos

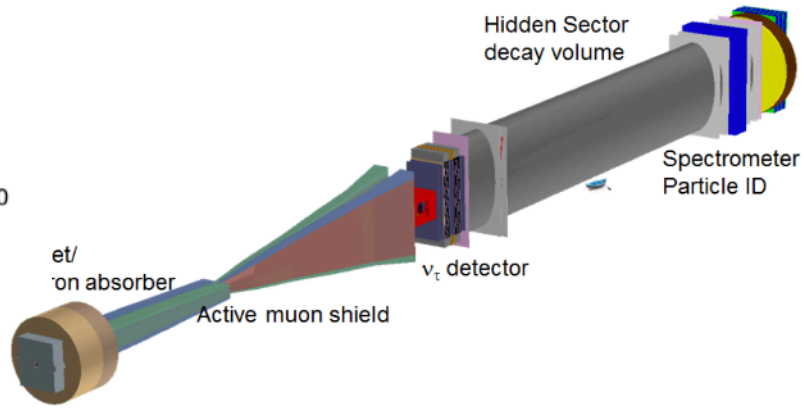
Heavy Neutral Leptons

Sterile neutrinos with masses of O(GeV) mixing with active neutrinos

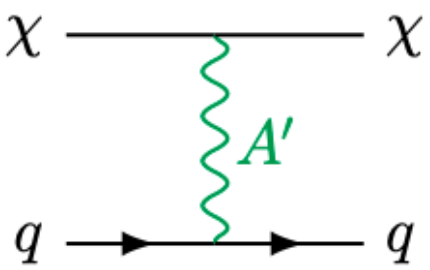


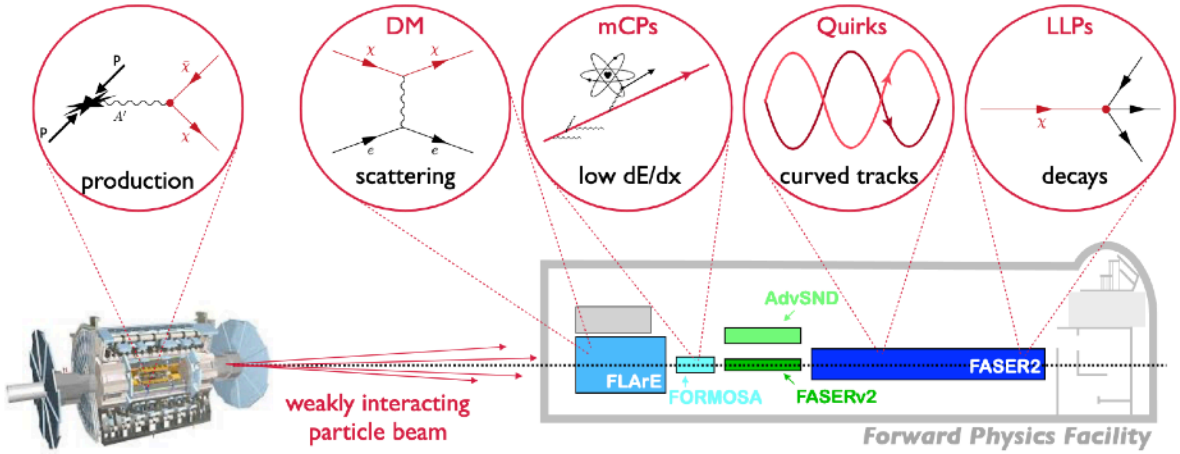
SHiP

Proposed proton beam-dump experiment at the CERN SPS



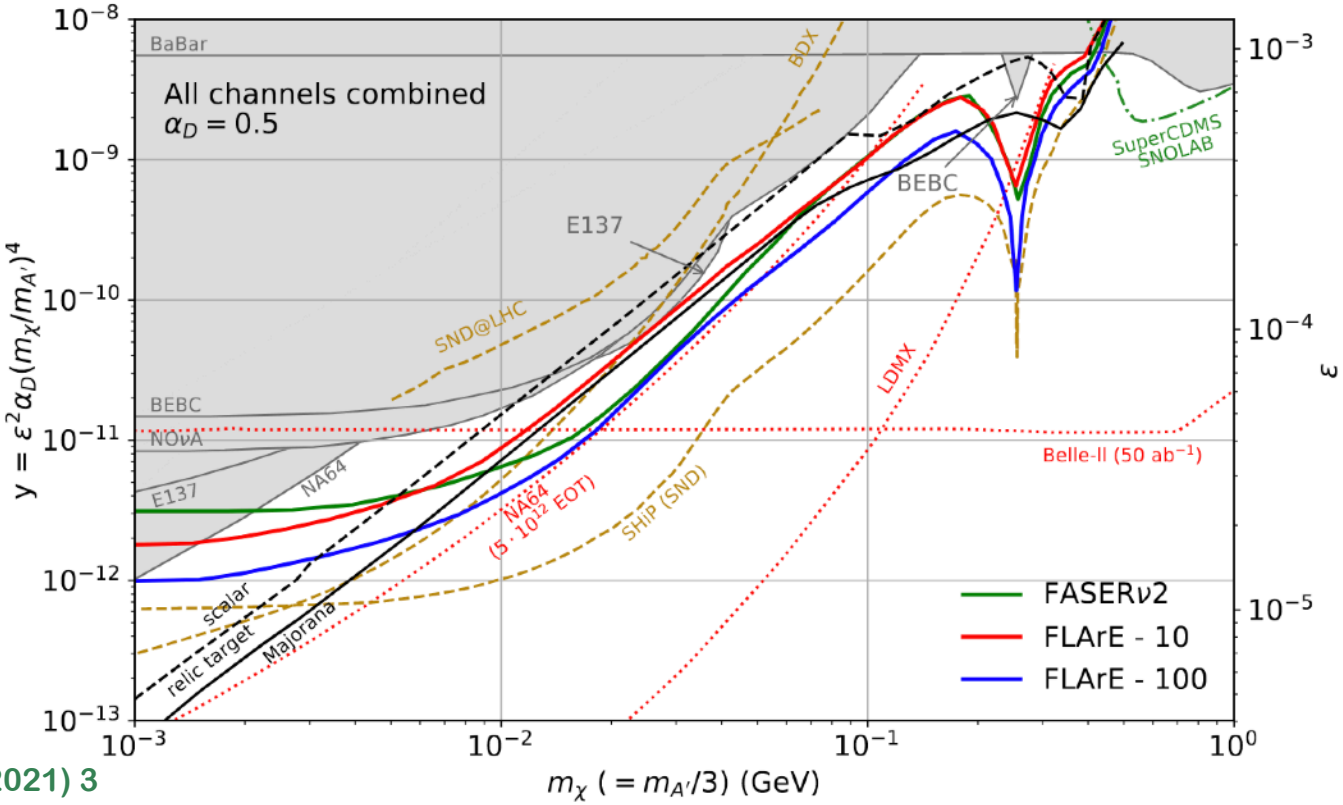
Dark matter scattering





Scattering of light dark matter

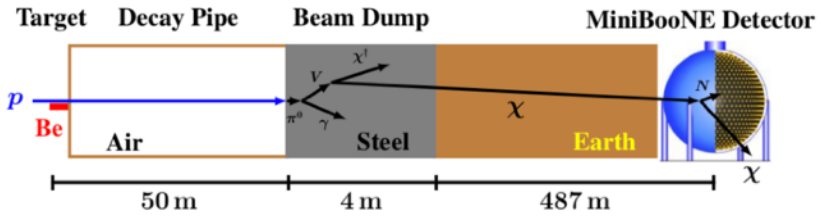
@ **FASER**ν and **FLArE**



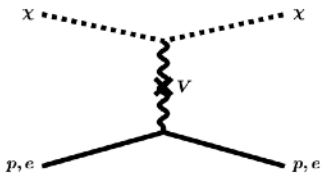
Batell, Feng, Ismail, Kling, Abraham PRD 104 (2021) 3

Light dark matter @ nu-experiments

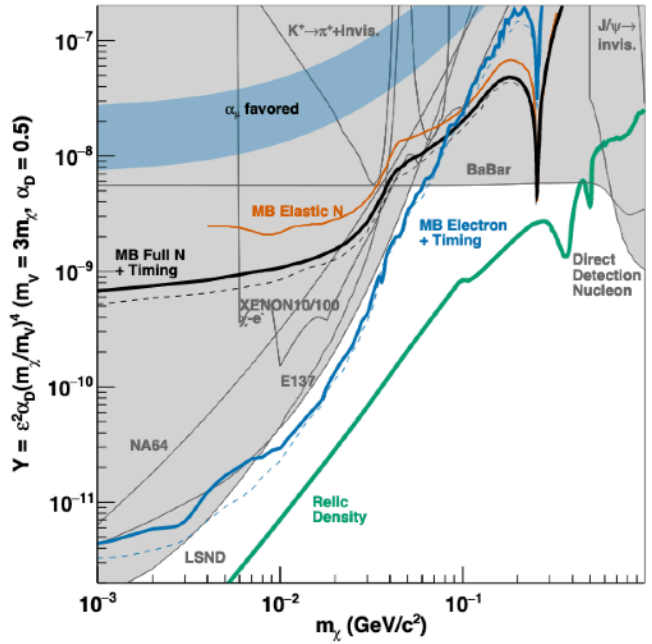
MiniBooNE



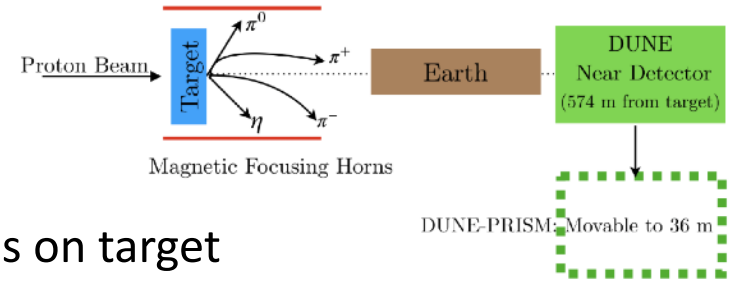
- 8 GeV protons on iron target
- 800 ton mineral oil detector
- Dedicated DM run in beam dump mode
- Bounds on DM scattering on p/e



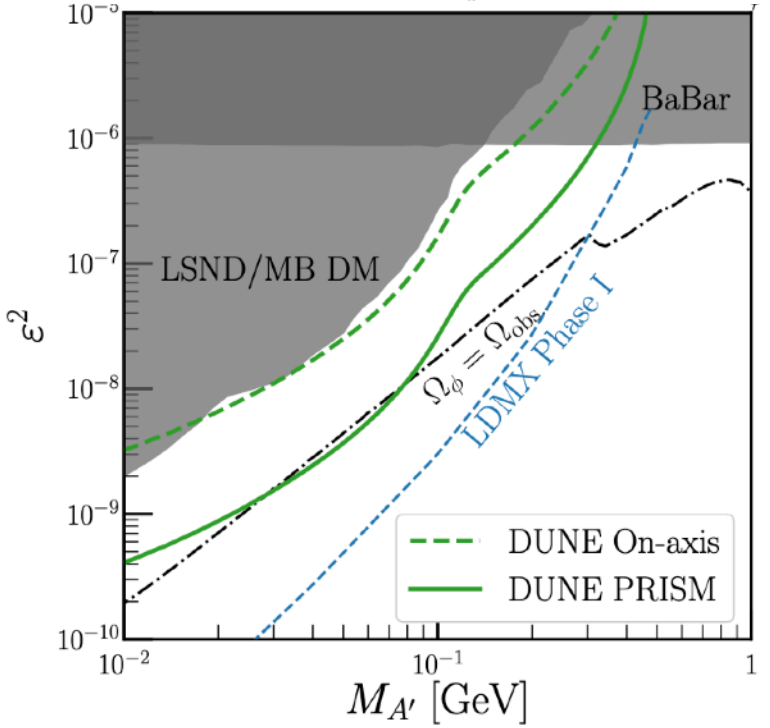
MiniBooNE Coll PRD 98 (2018) 11



DUNE-PRISM



- 120 GeV protons on target
- Good prospects with the near detector
- Possibility to move it off-axis



De Romeri, Kelly, Machado PRD 100 (2019) 9

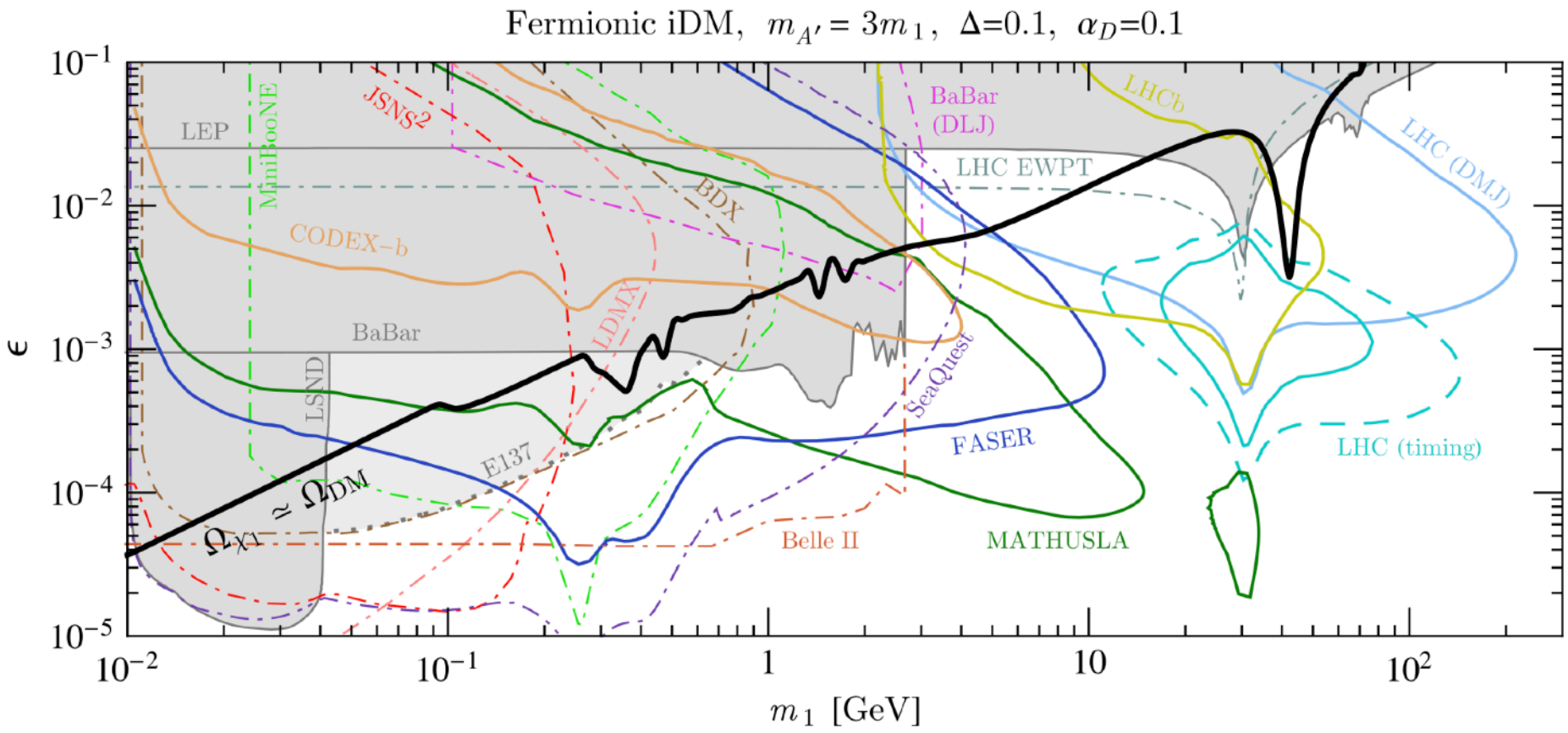
Breitbach et al. JHEP 01 (2022) 048

Conclusions

- Light dark matter and Long-lived particles are plausible and motivated scenarios
- Dedicated detectors at LHC and neutrino experiments can explore these scenarios

THANKS

Conclusions



Berlin, Kling PRD 99 (2019) 1