Searches for FIPs at accelerators: status and prospects

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30th anniversary of the Rencontres du Vietnam

10/08/23

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Office of Science

What is a **F**eebly **I**nteracting **P**article?

Standard model

We are here

"Feeble" portal

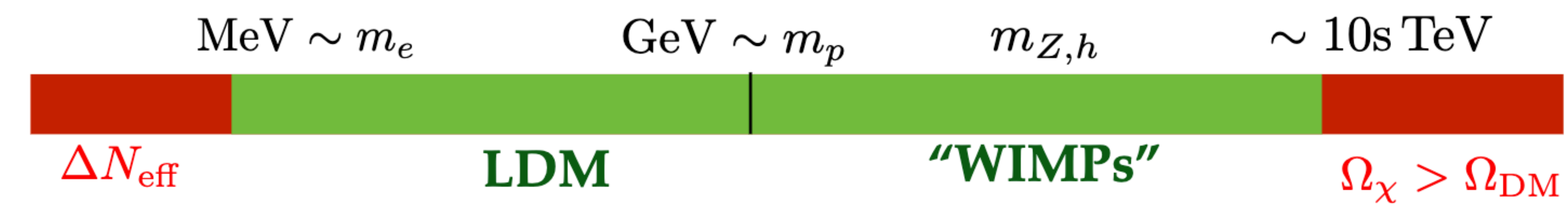
New physics

DM (maybe) here

- Common feature of "hidden sectors" in which dark matter is part of a **hidden universe** with **no SM gauge interactions**
- Hidden universe can have **complex structure** and provide solutions to mysteries beyond DM
- SM and new physics connected by a **"feebly interacting"** portal

FIPs in the MeV - GeV mass range

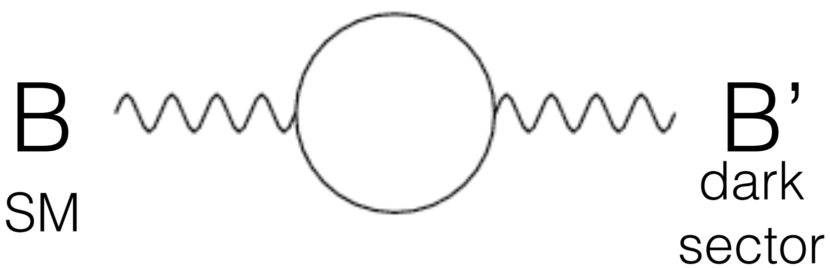
Light dark matter



conflicts with BBN

allowed mass range for thermalization

violates unitarity

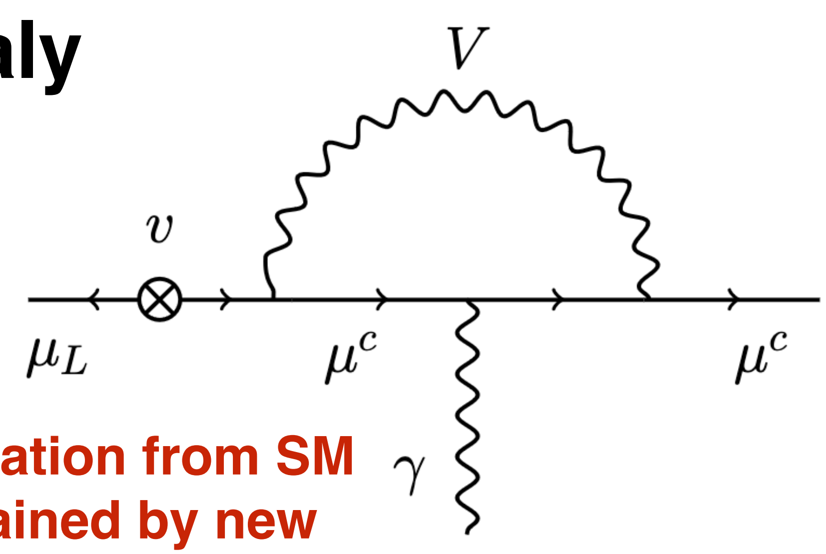


e.g. dark photon via kinetic mixing

+ scalar, neutrino and axion portals

1808.05219

g_μ-2 anomaly



~4.2 sigma deviation from SM could be explained by new light gauge boson!

2101.10334

See talks by Andrew and Boris for ultralight FIPs (axions, …)!

FIPs may be **copiously produced** at **high energy/intensity** accelerators

LHC

Future HE colliders

SPS beam dumps at CERN

Neutrino facilities (FNAL, J-PARC)

B factories

e^-/e^+ beam facilities (JLAB, SLAC,…)

Highest energy (access to Higgs etc…)

Highest intensity - optimal for m < ~O(GeV) sensitivity

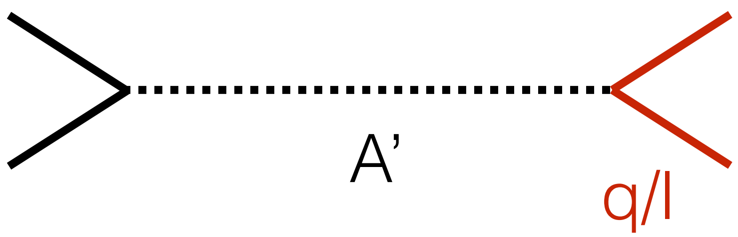
> TeV

~100-400 GeV

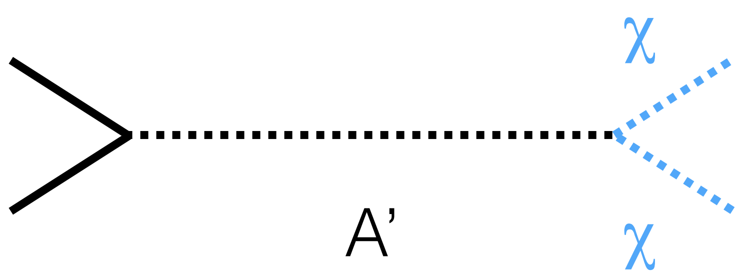
O(1-100 GeV)

Searching for FIPs

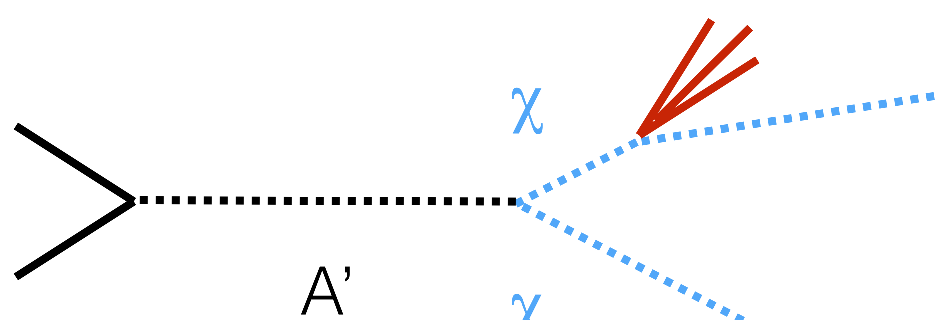
Three generic signatures:



“Displaced” decay to visible



Decay to invisible



Scattering/ionisation

NB: dark photon example (similar for other models)

Discuss detectors using **wide range of technologies** to achieve sensitivity

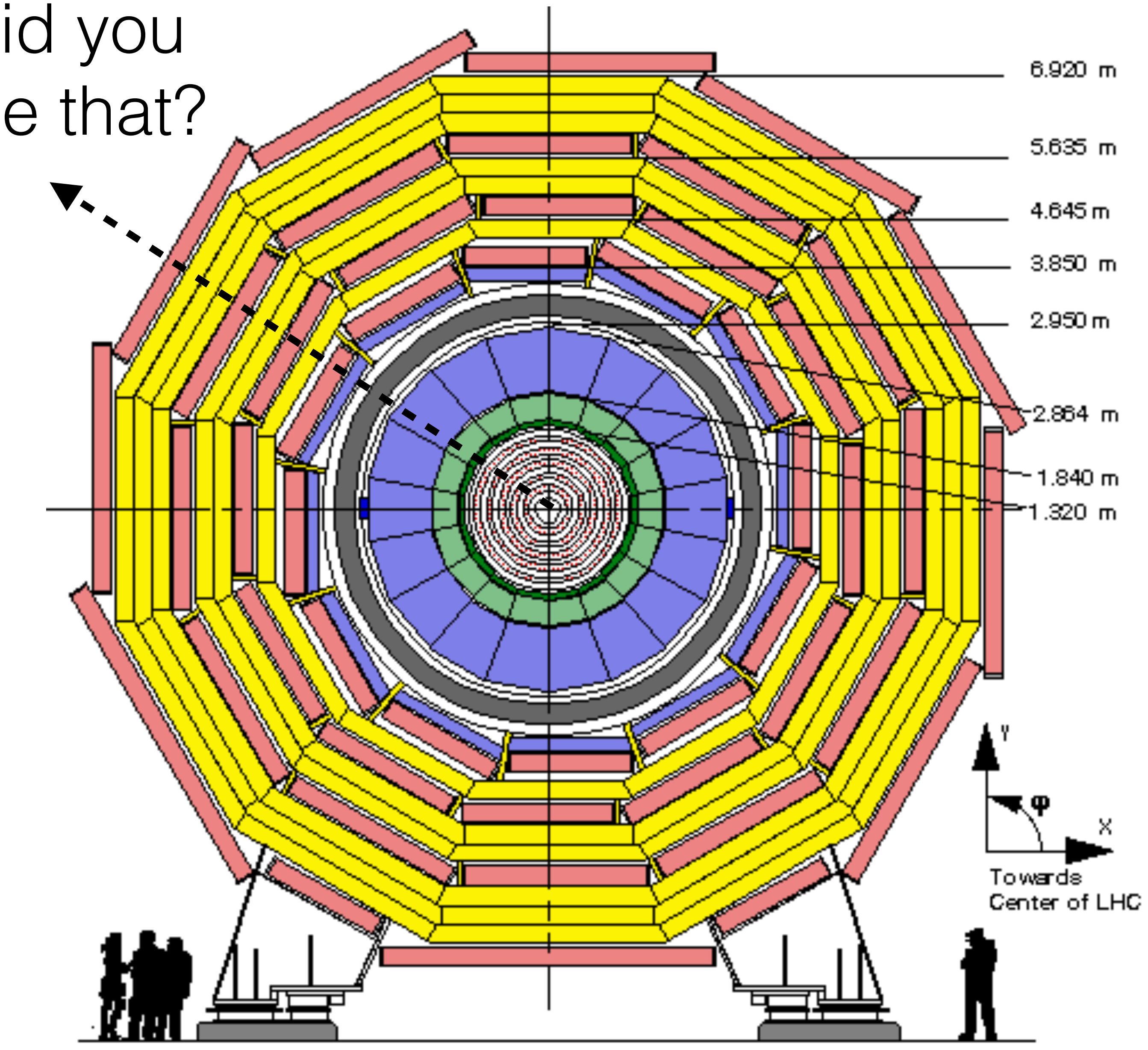
FIPs at the LHC

General purpose detectors do excellent job for wide range of signatures!

but…

Low energy signatures from FIPs face **huge backgrounds**, are **very difficult to trigger** and require **highly non-standard reconstruction**

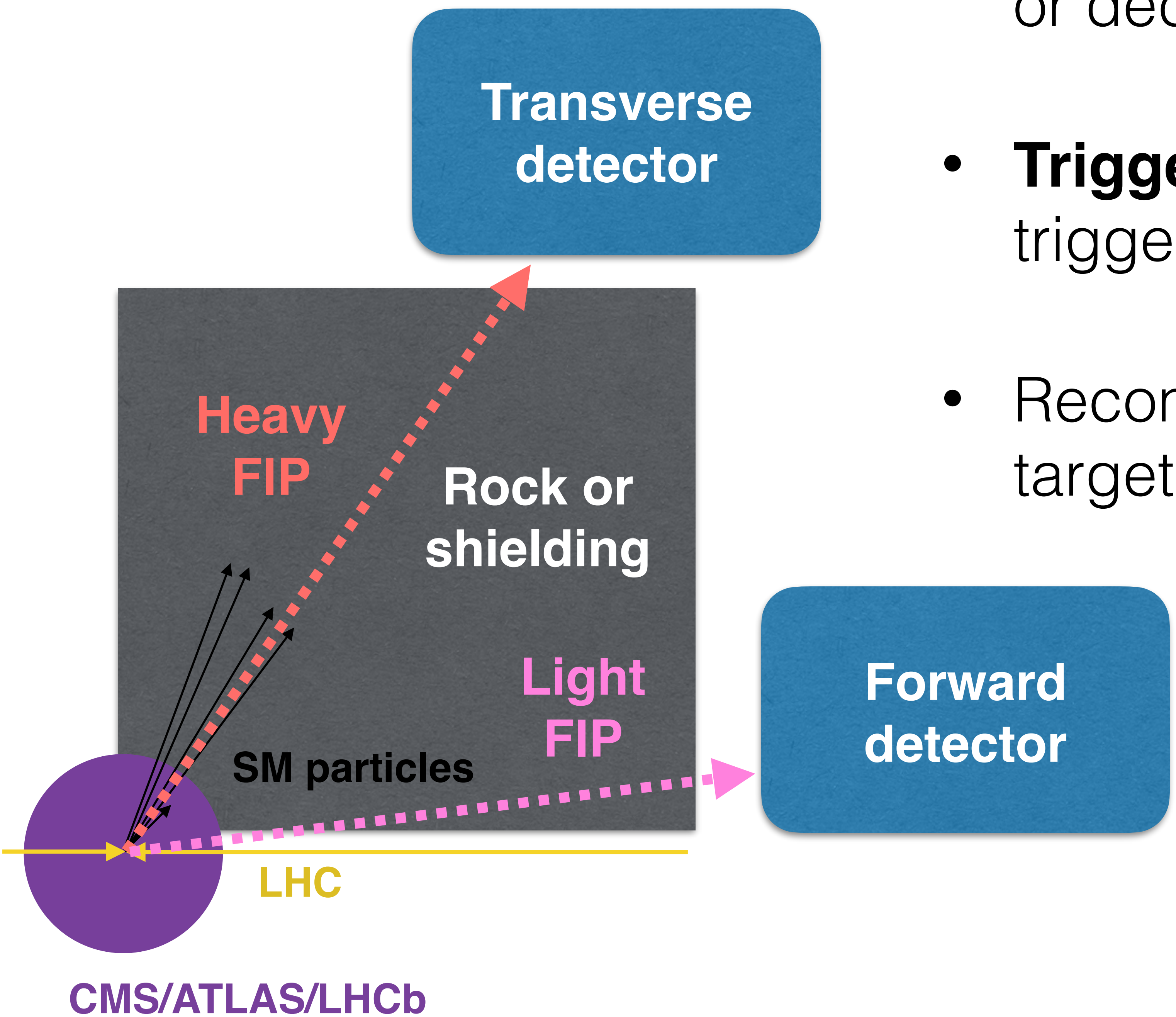
Did you see that?



Nope

NB: **New trigger selections** for **Run 3** (started July 2022) and **detector upgrades** for the **HL-LHC** will greatly expand sensitivity (see backup)!

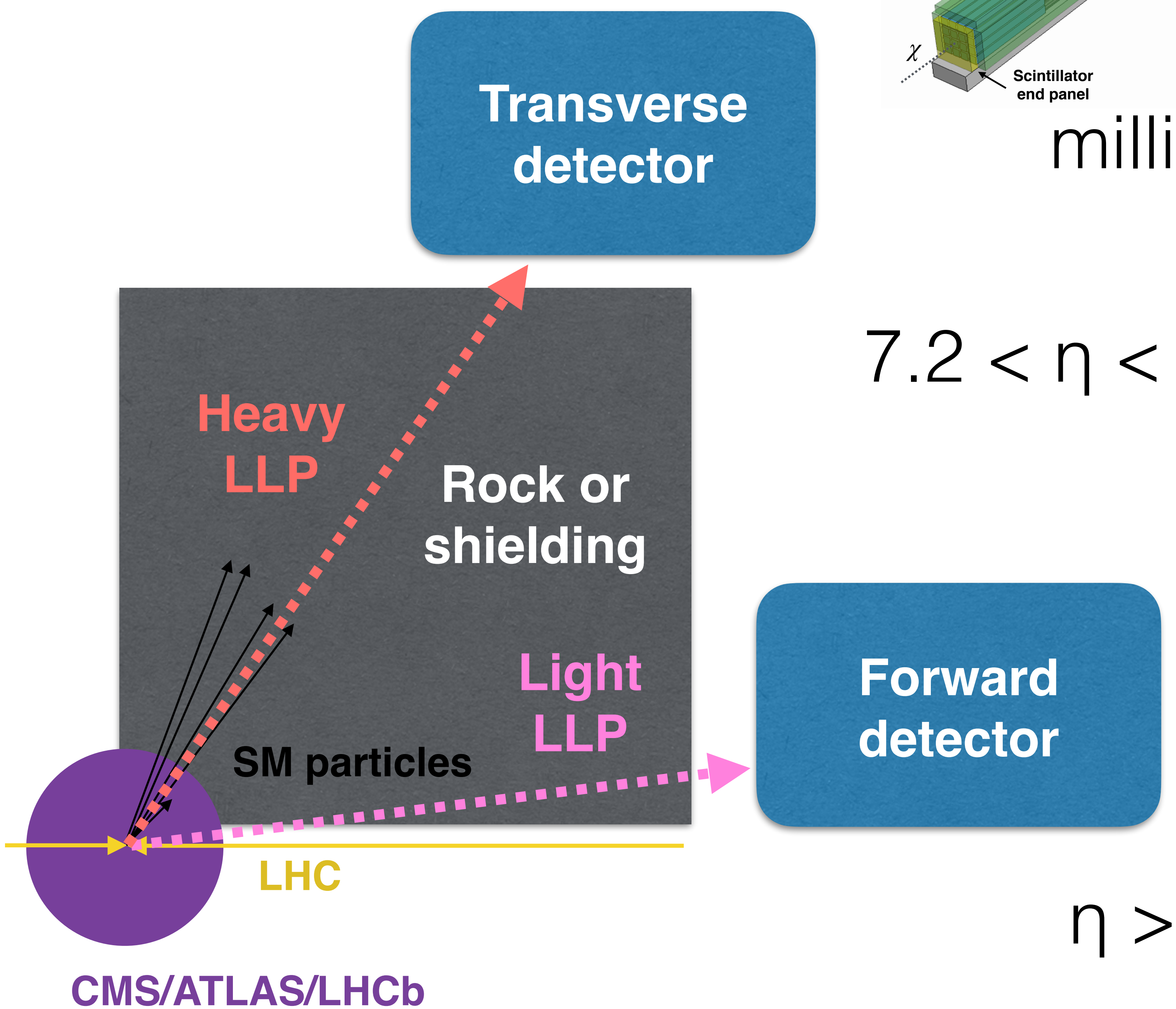
Dedicated detectors at the LHC

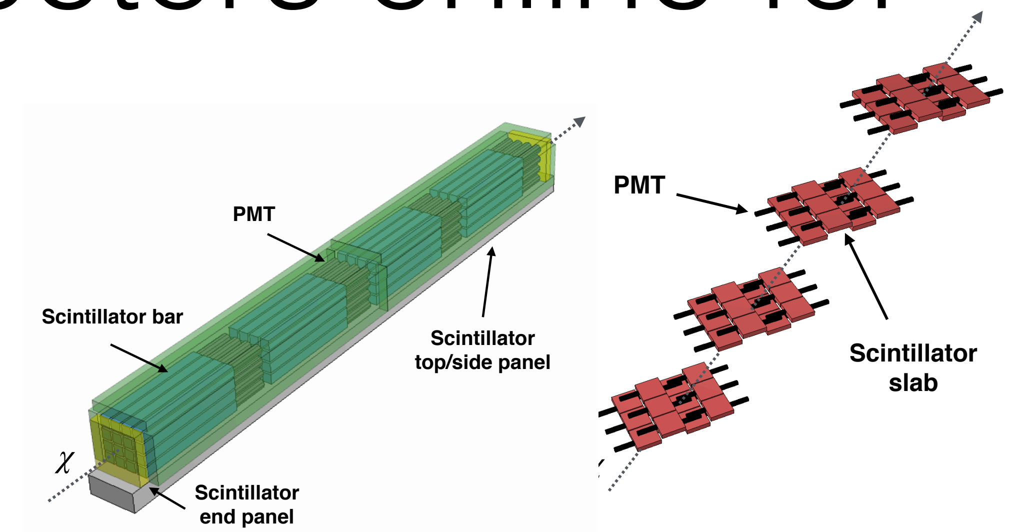


- **Backgrounds mitigated** by rock or dedicated shielding
- **Triggering simple** (or don't need trigger)
- Reconstruction **designed** for targeted signature(s)
- Optimal **detector design** and **position** depend strongly on targeted signature: need **range** of different detectors!

Range of new detectors online for LHC Run 3!

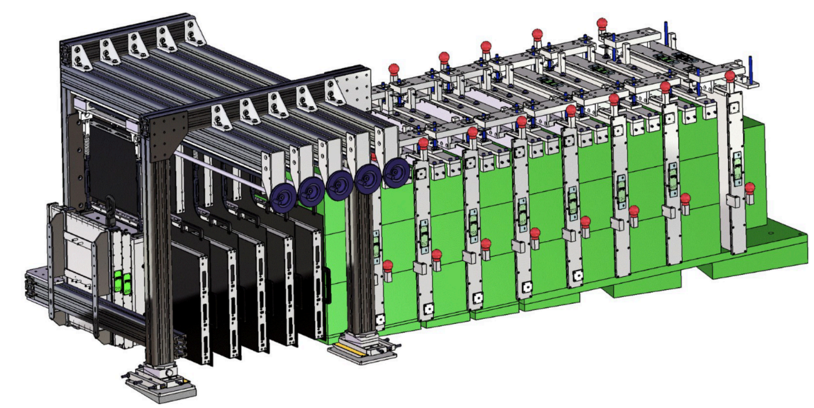
η ~ 0



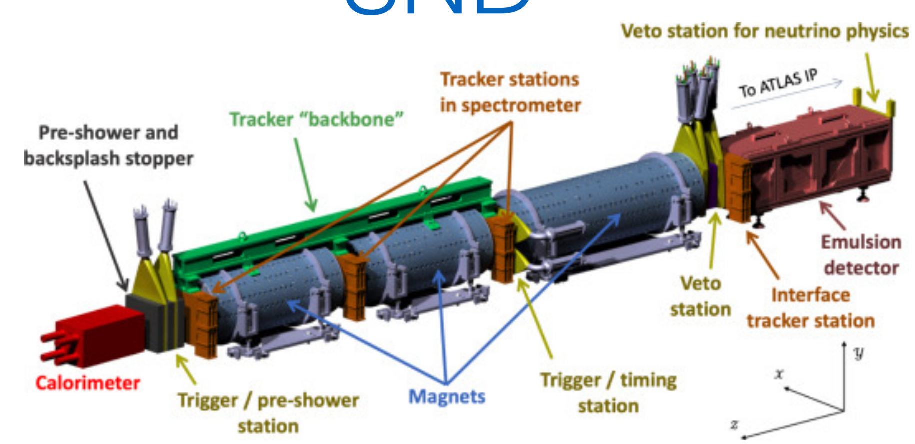


milliQan

7.2 < η < 8.6



SND



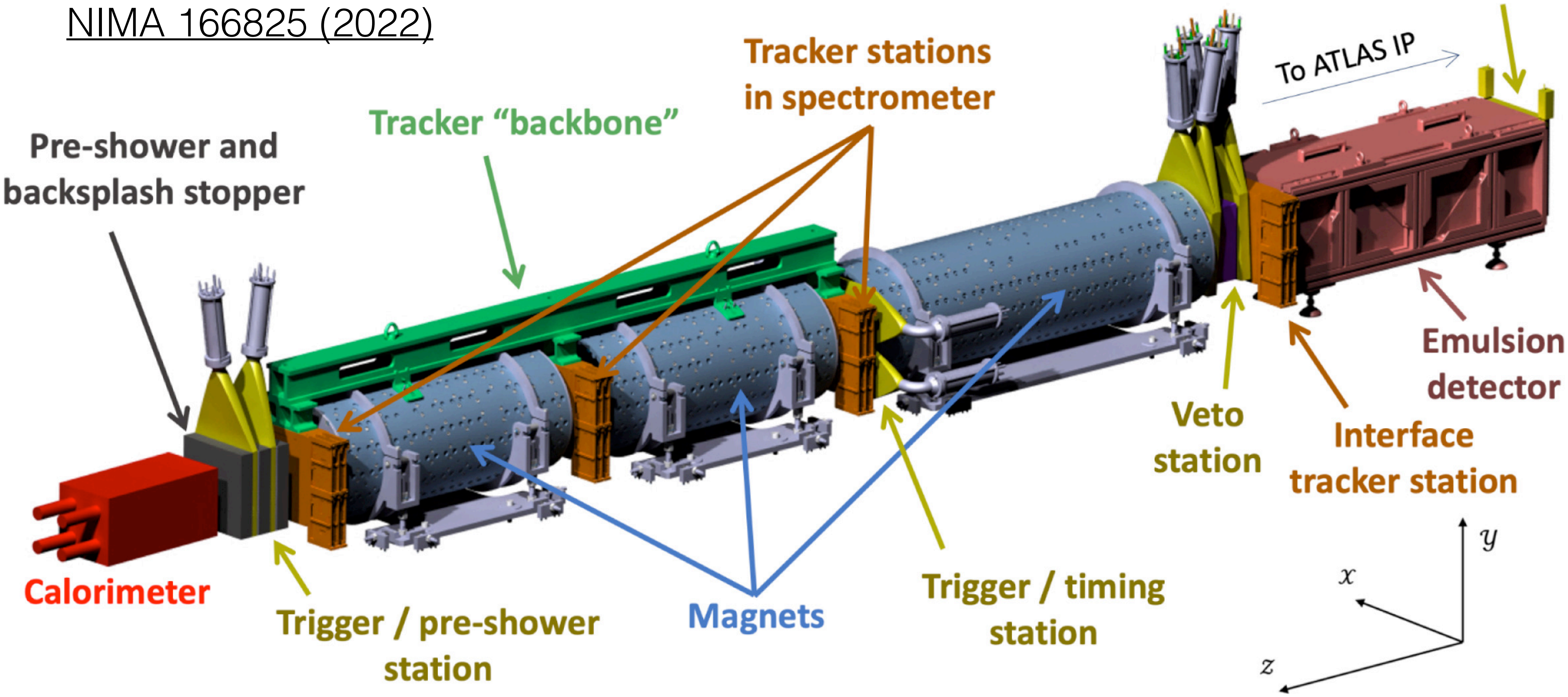
η > 9

FASER/FASERν

See next talk!

FASER detector

NIMA 166825 (2022)

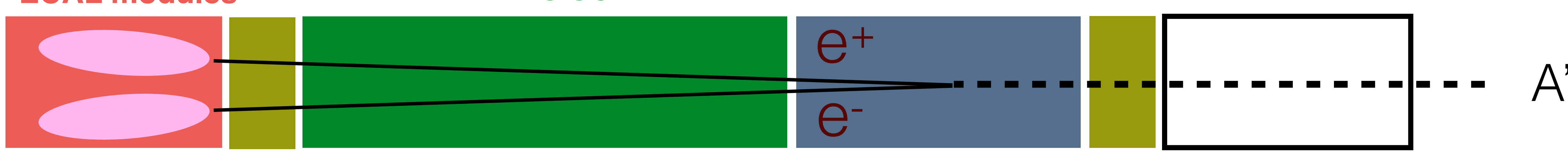


~500m to ATLAS IP

Radius = 10cm
Length = 7m

Spare LHCb outer ECAL modules

Tracker uses ATLAS SCT



Calorimeter | Trigger | Tracking spectrometer | Decay volume | Veto | FASERν

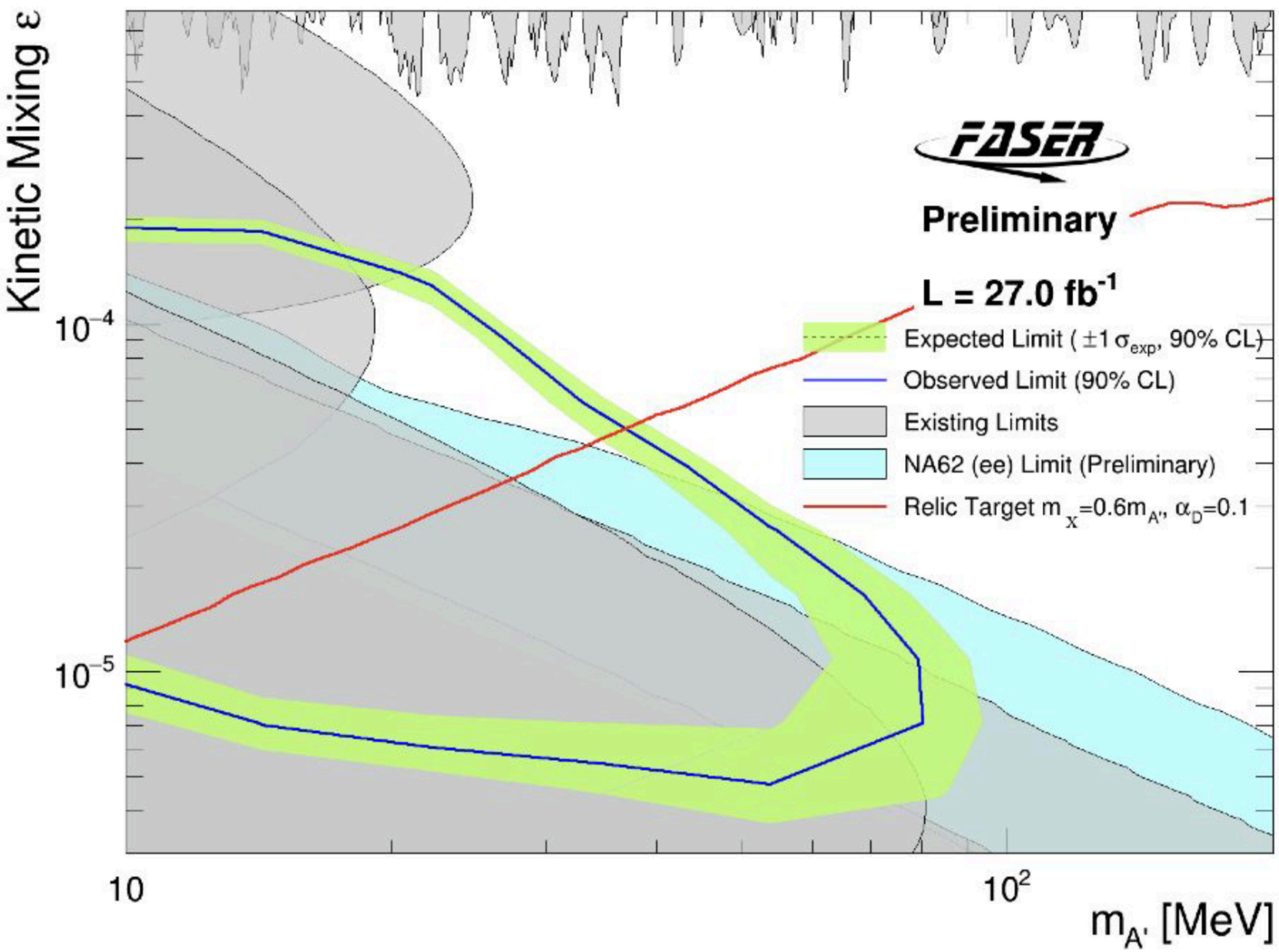
~ TeV scale momentum

~1% energy resolution

Resolution ~20 μrad

FASER first search with Run 3 data!

New sensitivity to dark photons!



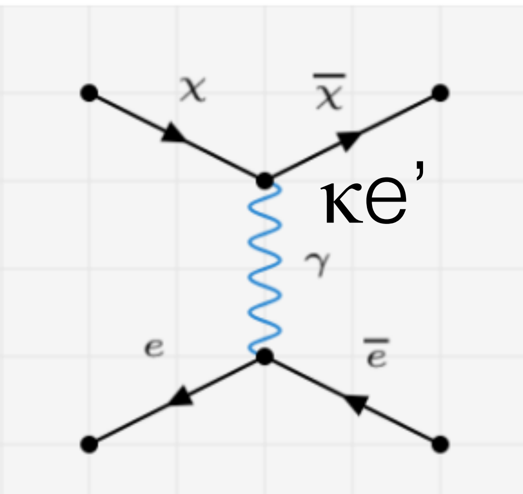
Very low background after selections: 2.4x10^{-3}

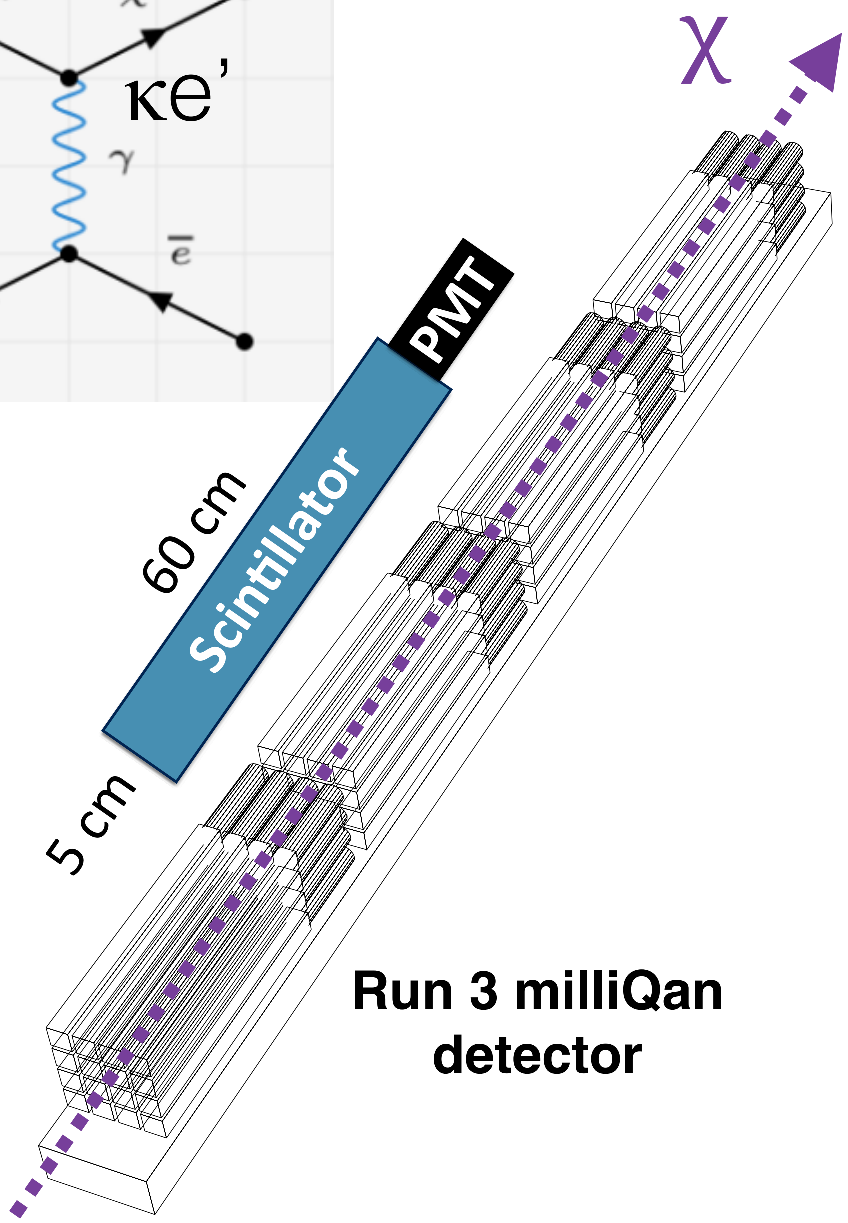
Signal eff ~ 50%

Expect improvements in **tracking/alignment**, **x10 more data** and **additional final state searches** (HNLs, ALPs,…)

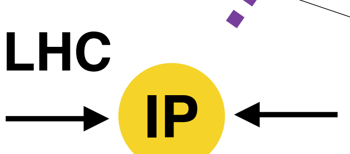
milliQan search for millicharged particles

mcps appear in case of **massless** dark photon (charge proportional to kinetic mixing)

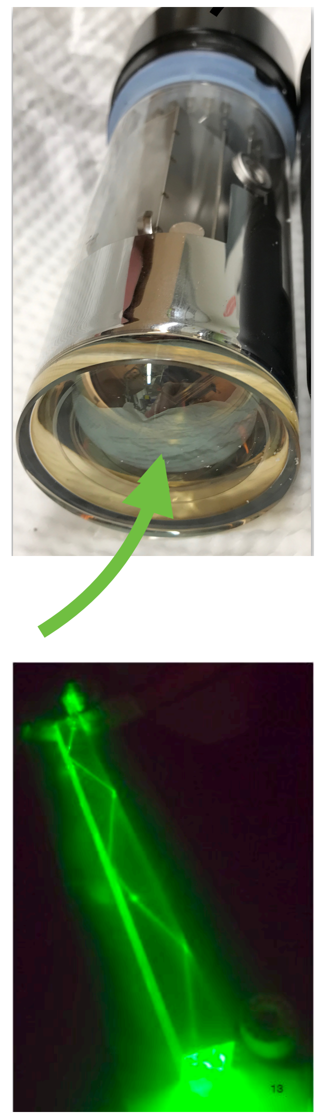




Run 3 milliQan detector



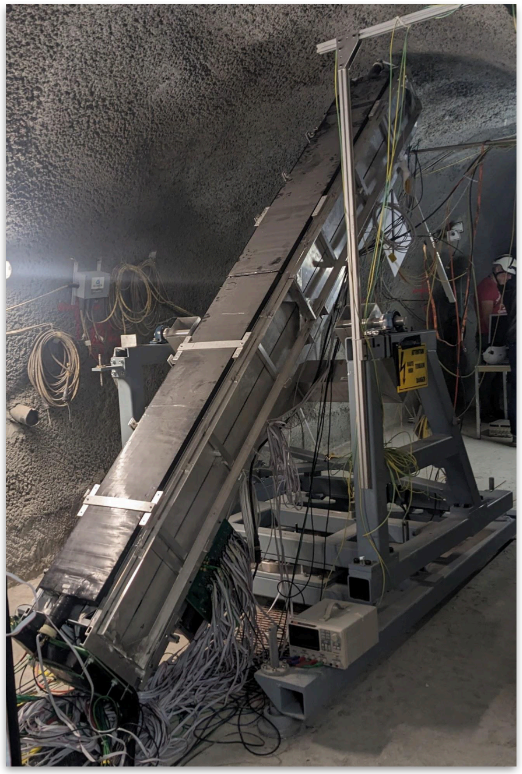
30m from IP (17m of rock blocks beam particles)

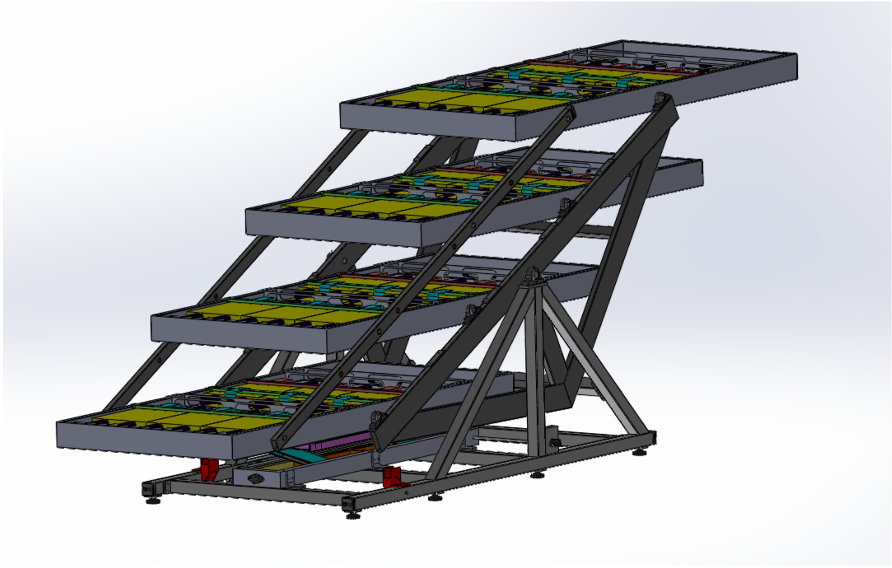


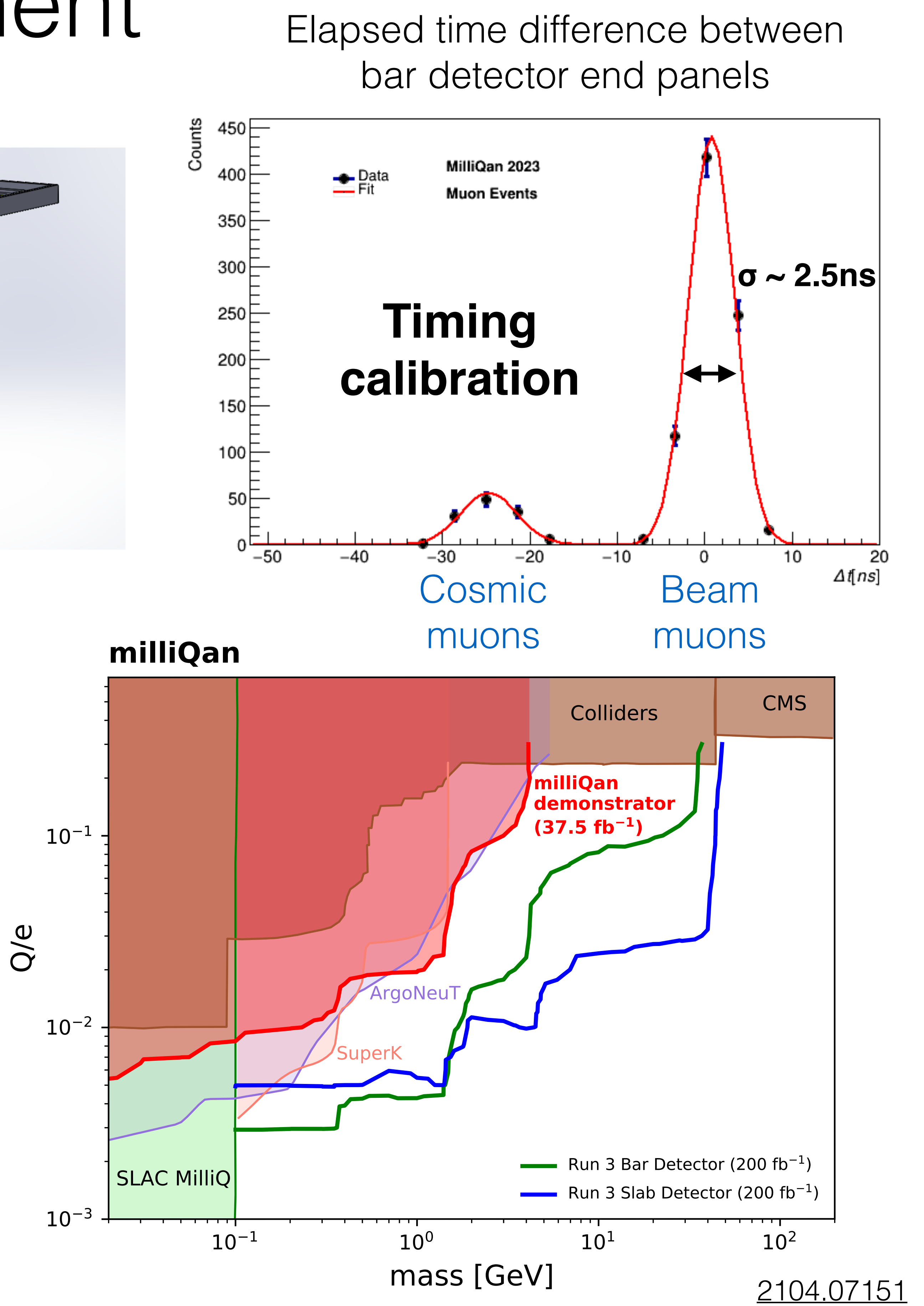
Scintillator bar

- Use long scintillator bar array to detect **(very) small ionisation** from low charged particles
- Expected signal: few scintillation photons in multiple layers → each bar + PMT must be capable of detecting **a single scintillation photon**
- Require hits in multiple layers within a **small time window** for stringent background rejection
- Modular design is easy to scale and adapt: proposals around the world include **milliQan**, FORMOSA (LHC), FerMINI (FNAL), **SUBMET** (JPARC)

Run 3 milliQan experiment





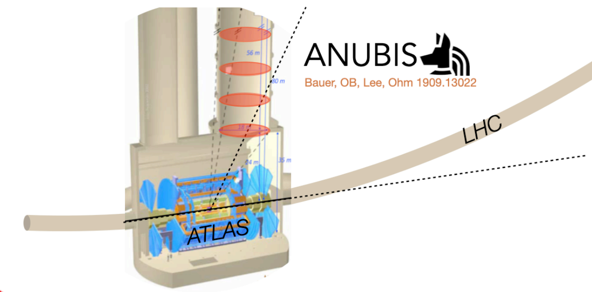


- Combination of two **scintillator-based** detectors will provide excellent sensitivity to **millicharged particles**
- Installed and taking physics data now!
- Search will follow example of Run 2 demonstrator

What could come next?

CODEX-b

MATHUSLA



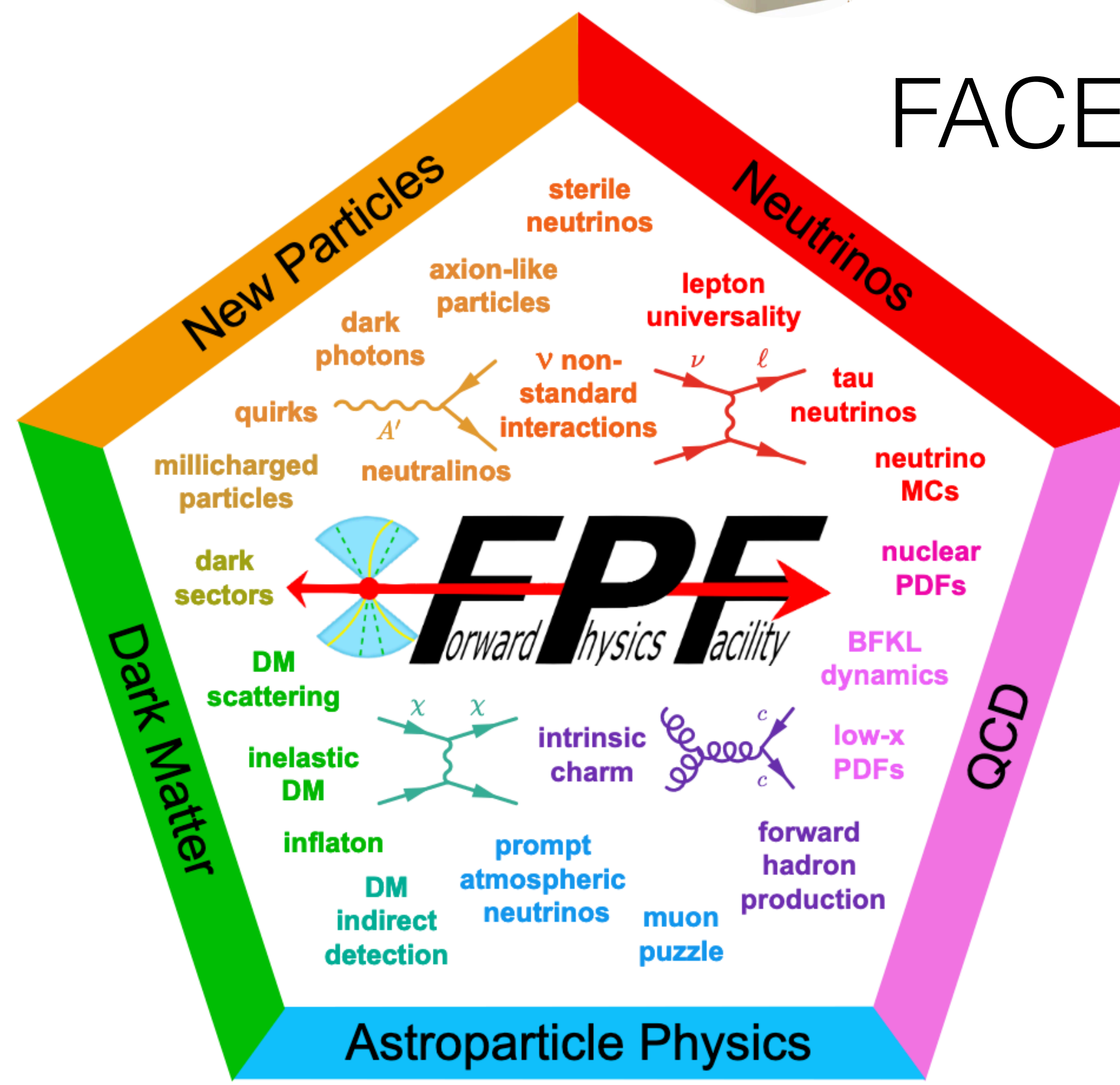
FACET

- The HL-LHC will provide over **3000 fb^{-1}** of p-p collisions

- Many proposals for dedicated detectors (summary in backup)!

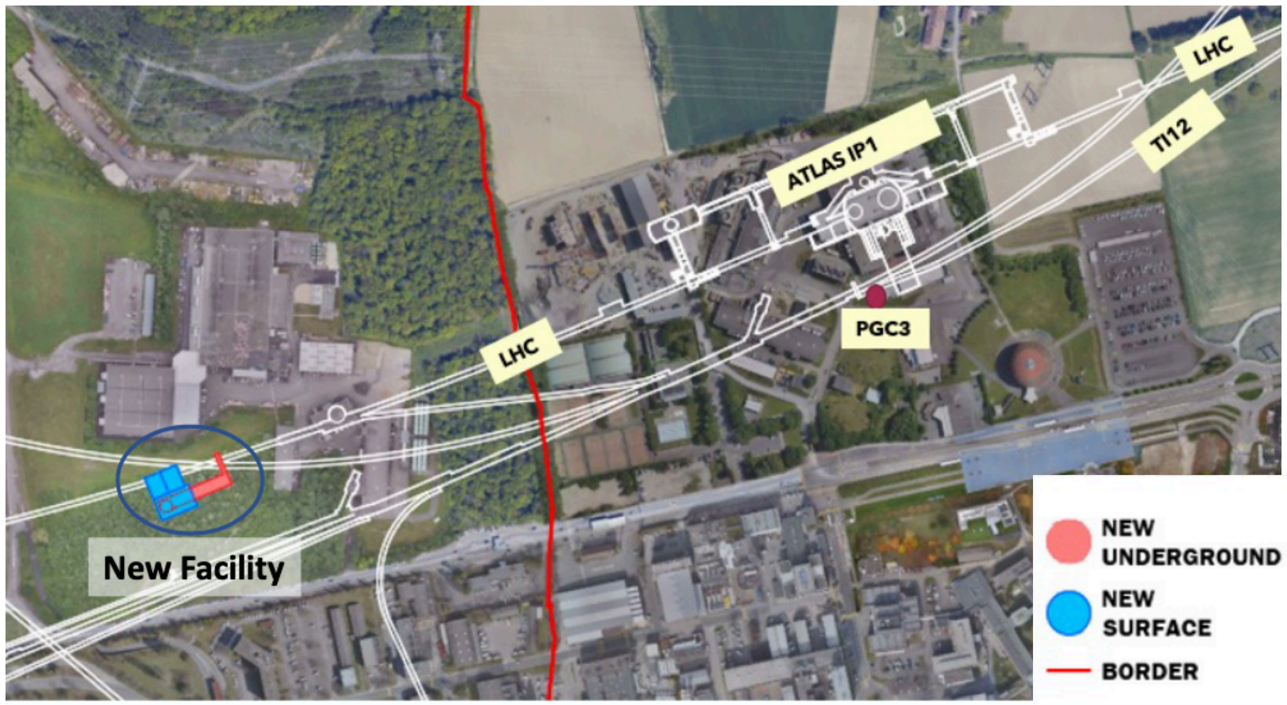
- Focus on FPF: dedicated **forward physics facility** provides extensive probe of wide range of FIP-like signatures to **fully exploit** physics potential of the LHC!

- Facility allows **longer**, **wider** and **new** detectors for optimal sensitivity!



Detailed white paper with > 200 authors released in March 2022

Forward Physics Facility



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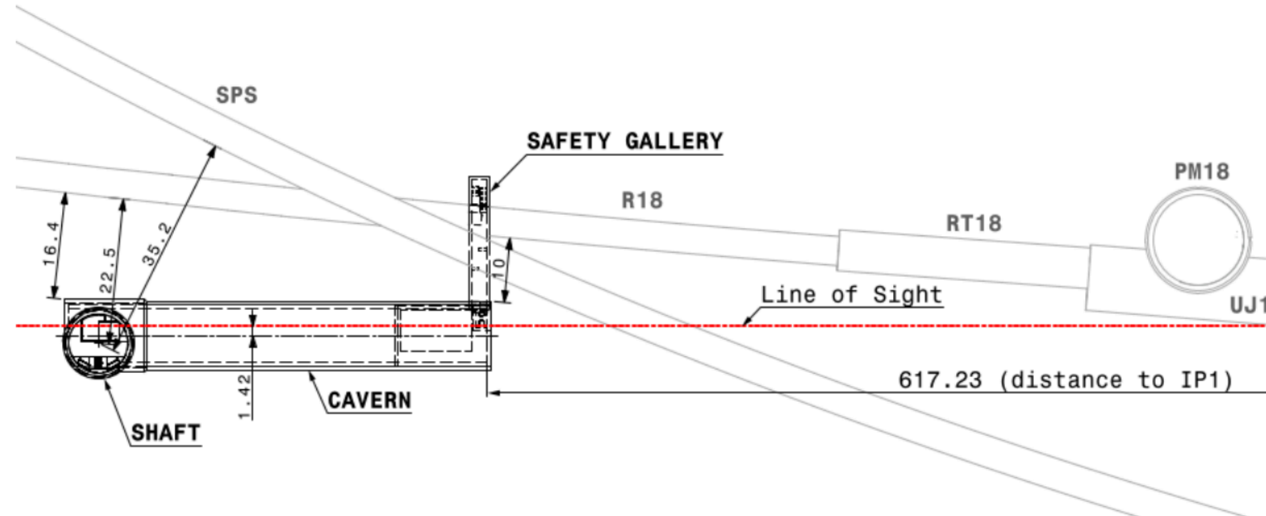
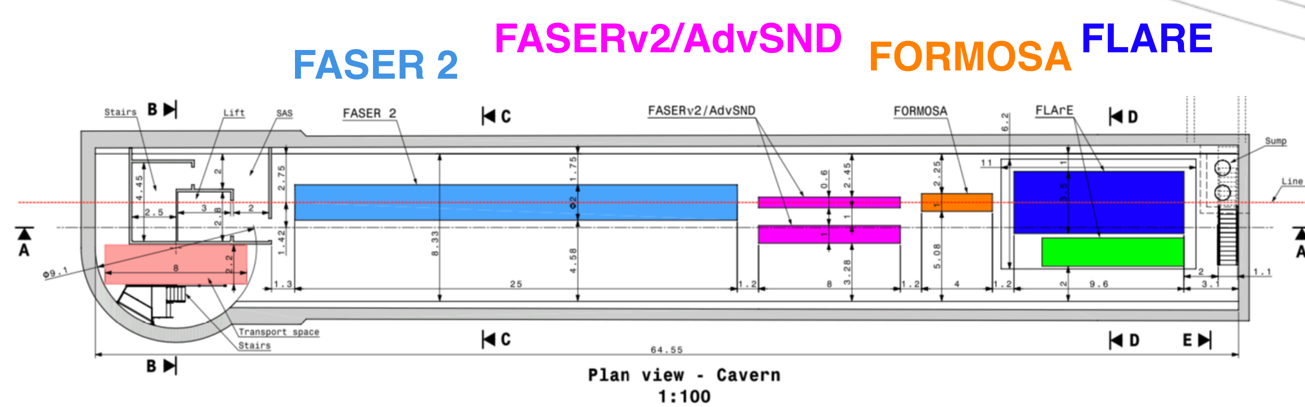
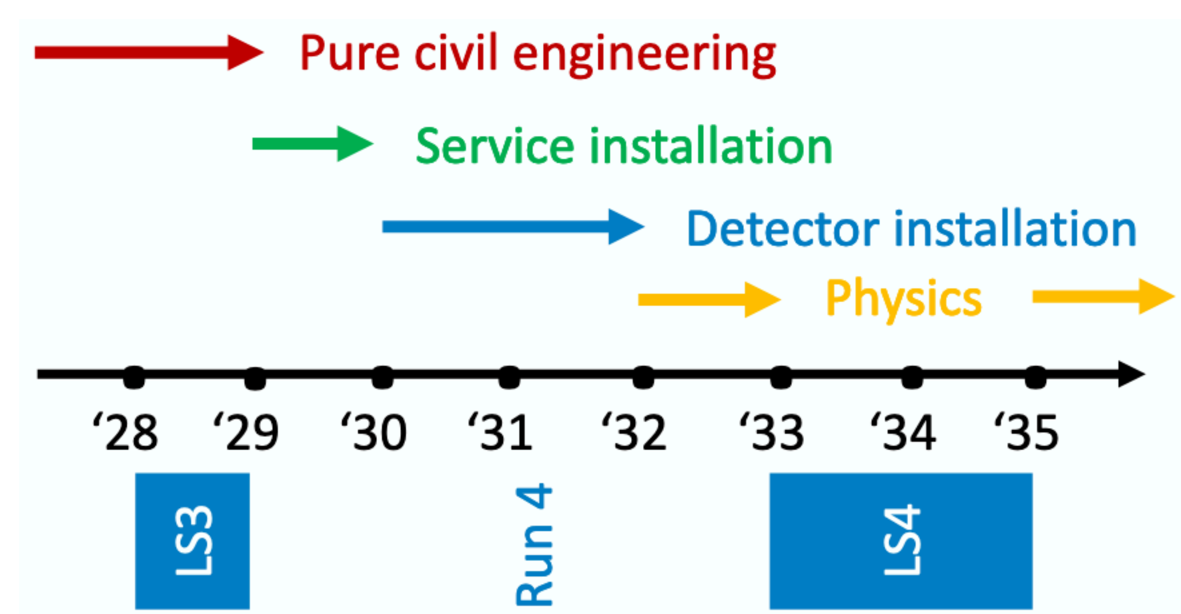




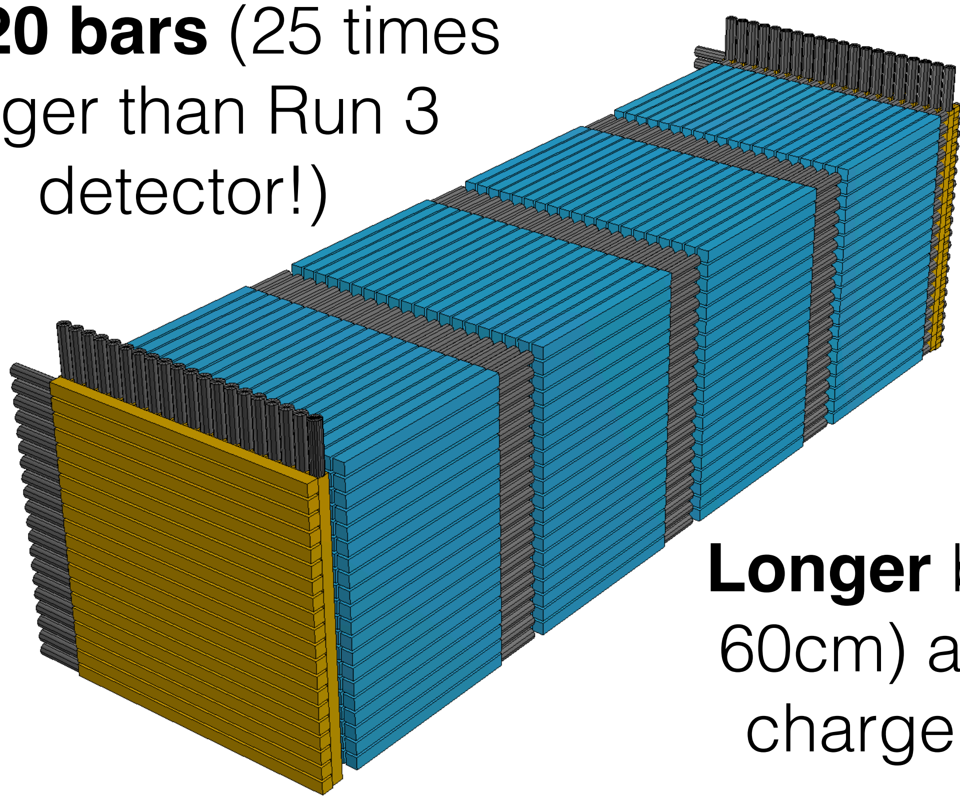
- Purpose built cavern ~600m in front of ATLAS IP
- Five detectors provide **comprehensive coverage** of forward BSM and SM physics

Timeline

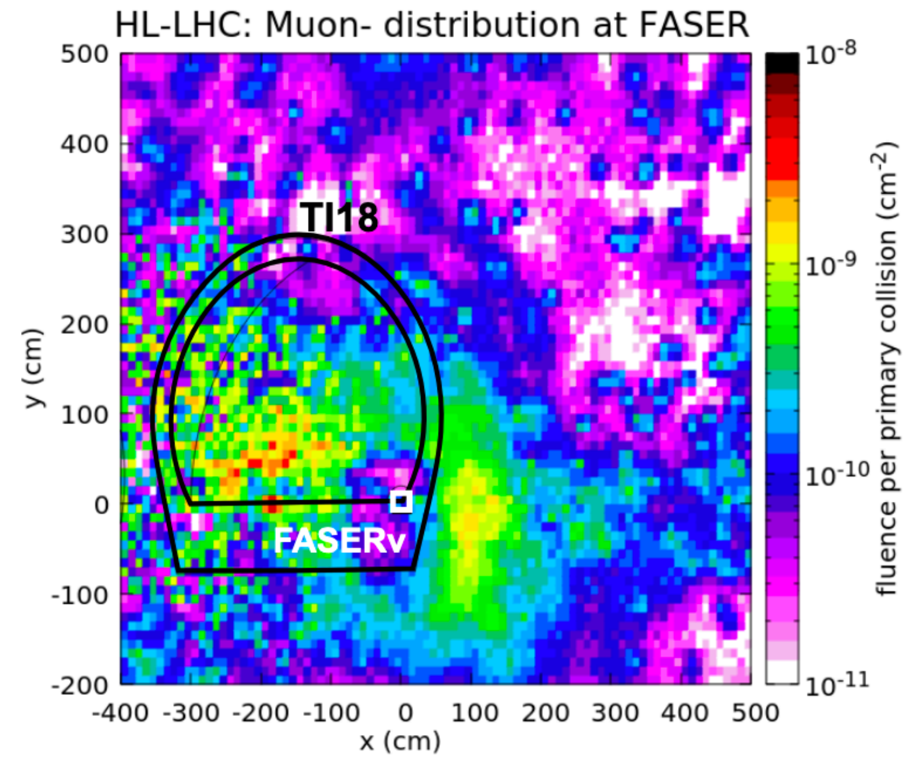


FPF detectors: FORMOSA

20x20 bars (25 times larger than Run 3 detector!)



Longer bars (1m vs 60cm) allows lower charge sensitivity



- FORMOSA: forward detector sees up to **factor ~ 250 higher** mcp rate compared to central location
- Challenging location → prove feasibility with **FORMOSA demonstrator** in Run 3!
- Considering upgrades including **high performance scintillator (CeBr3)**

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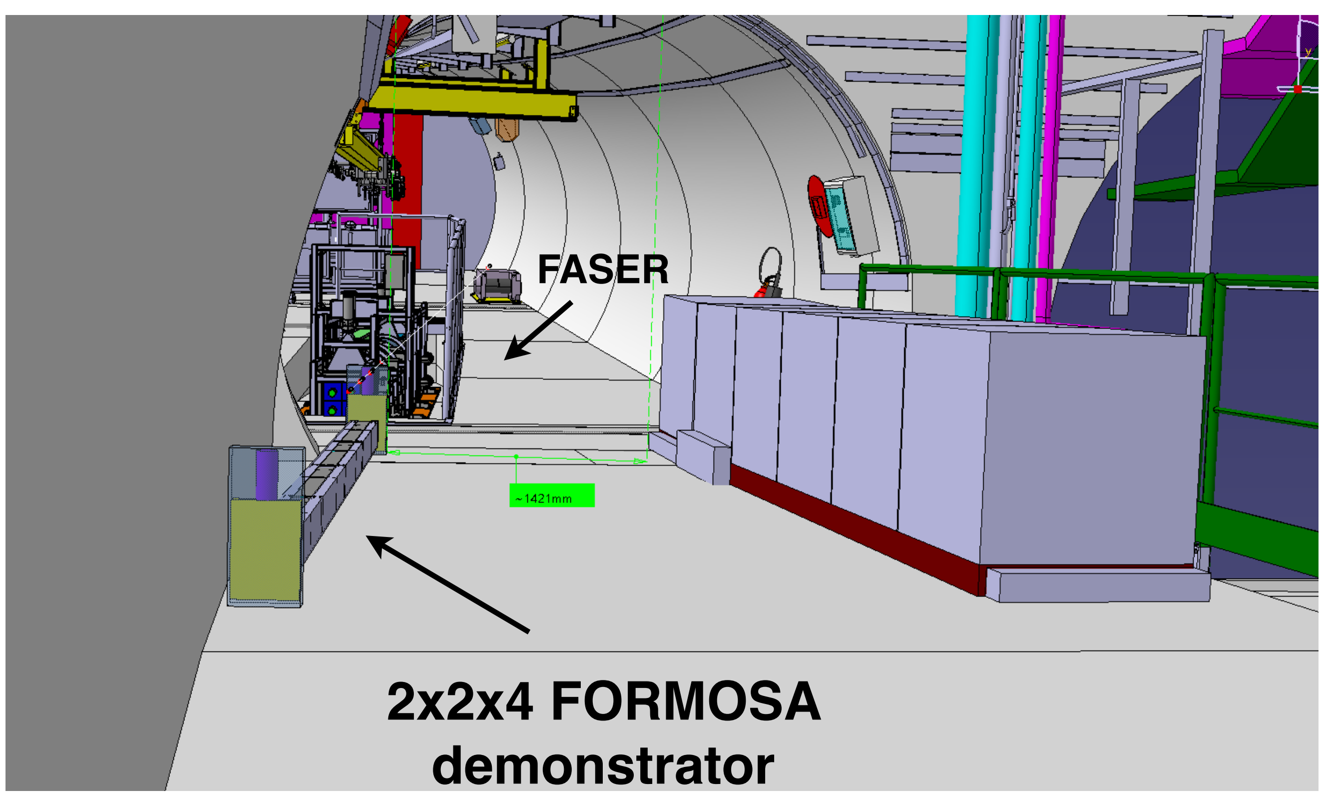
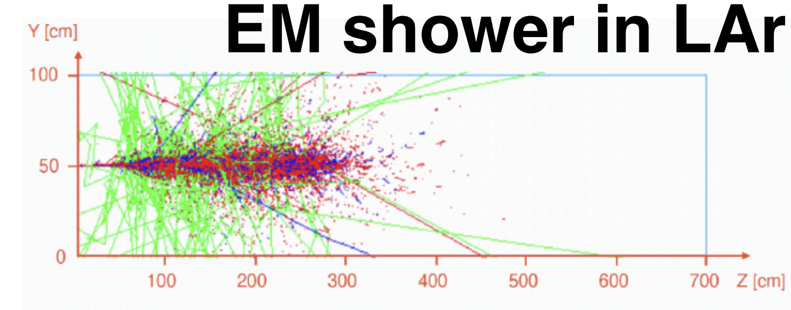
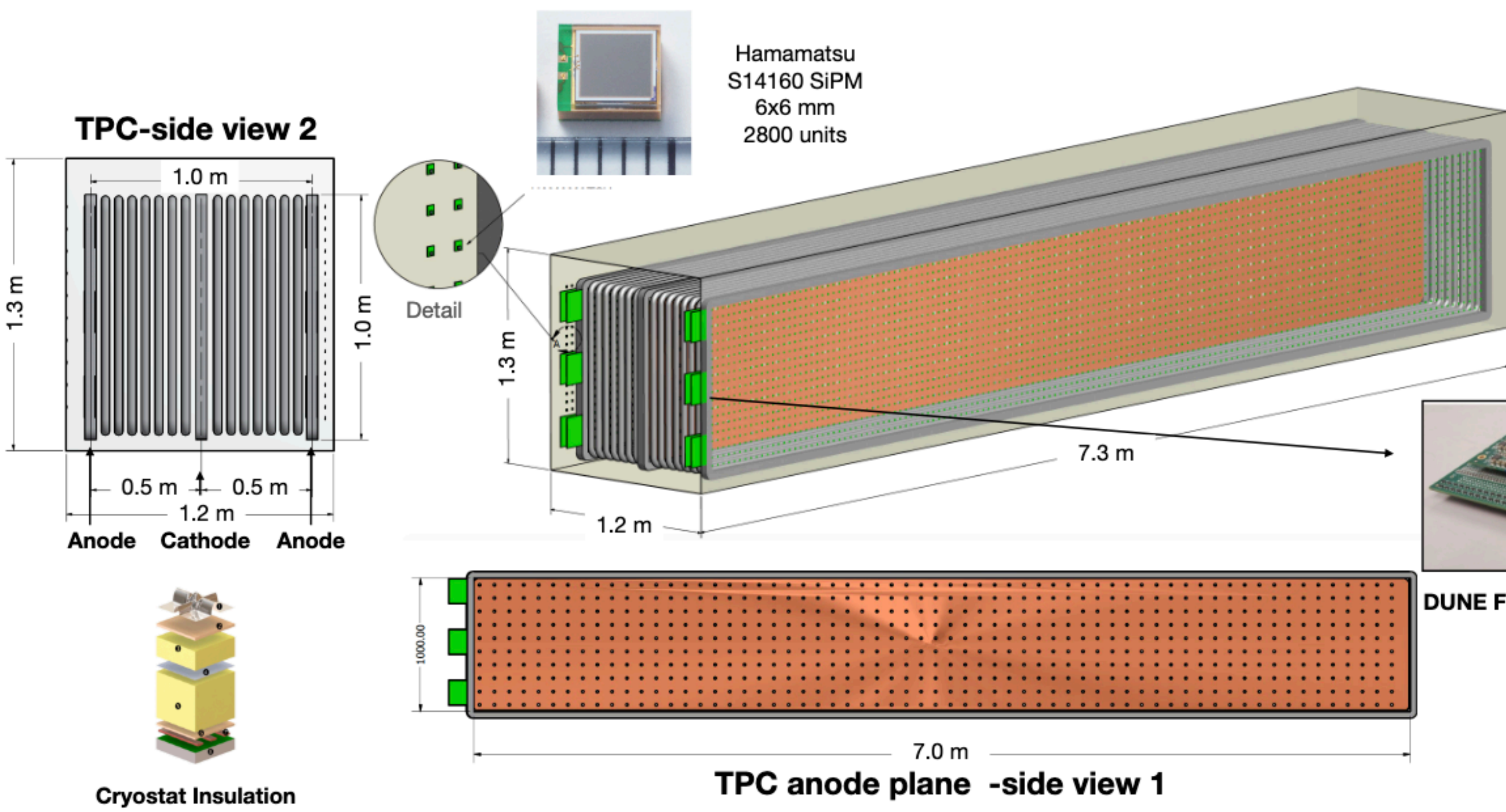


FPF detectors: FLArE

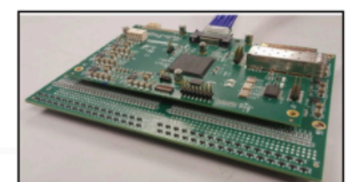


Brookhaven National Laboratory

FLArE Detector Preliminary Sketch

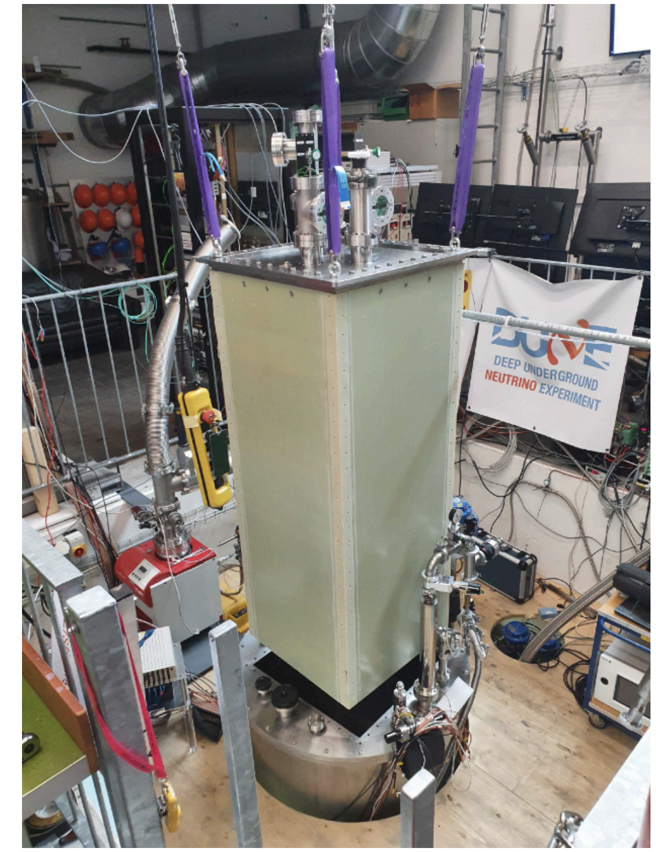


Volume	11.5 m^3
LAr	16 ton
LKr	27.5 ton
menbran	0.5 m
heat loss	290 W

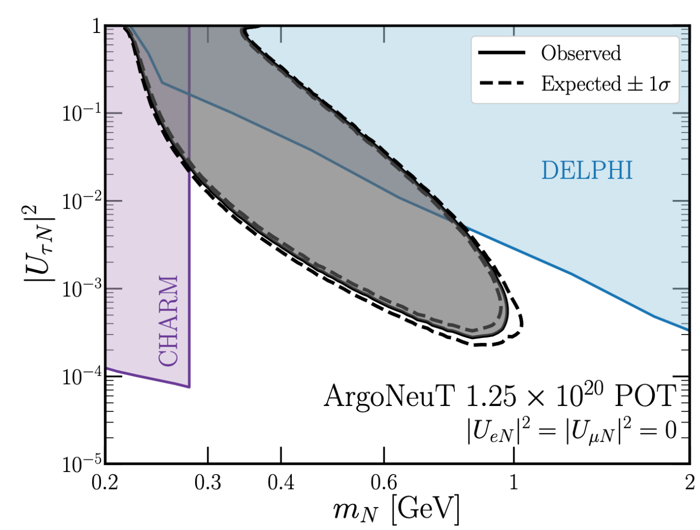


DUNE Front End Motherboard

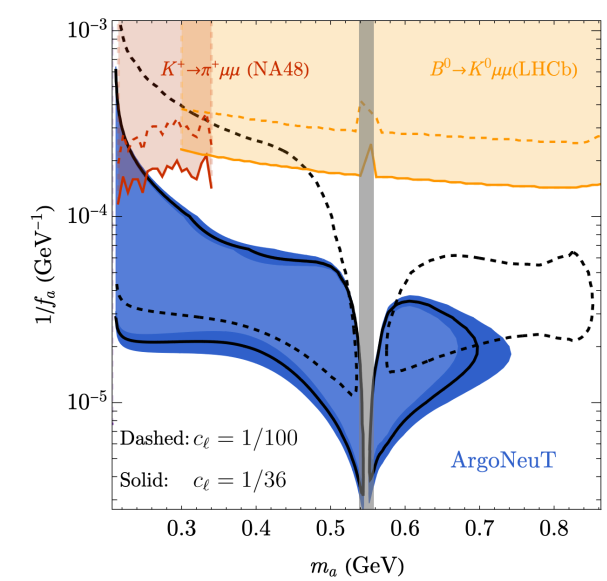
M. Diwan



- Measure showers from neutrinos or FIPs scattering/decay with ~16 ton LArTPC
- Big advantage compared to emulsion for DM scattering: real-time readout!
- ArgoNeuT shown feasibility of LArTPC for FIP searches!



τ HNL

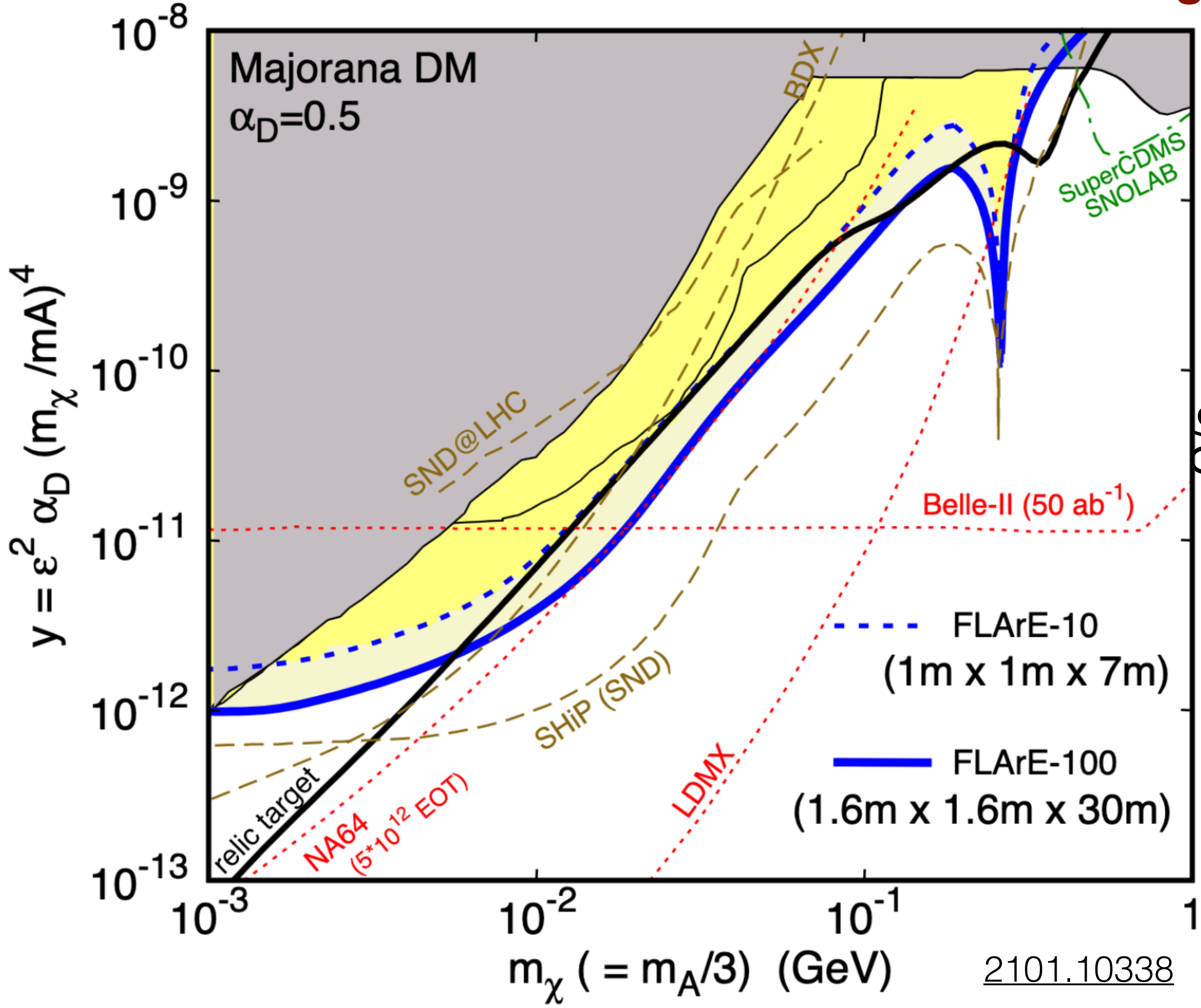


Axion

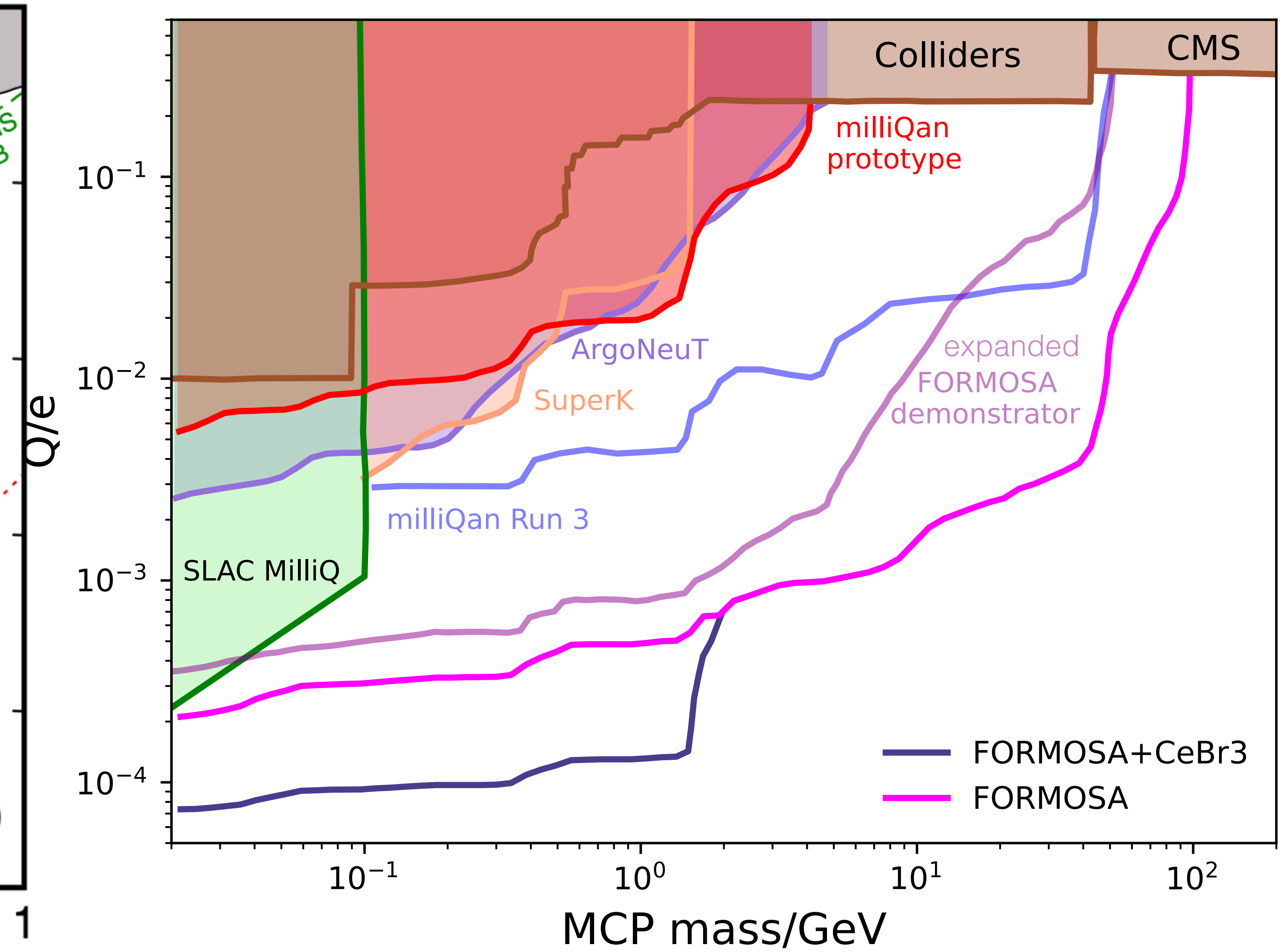
Recent results from ArgoNeuT

FIP sensitivity at the FPF

Dark matter scattering



millicharged particle



See later for A’ → visible!

NB: just two examples of many!

CERN beam dumps

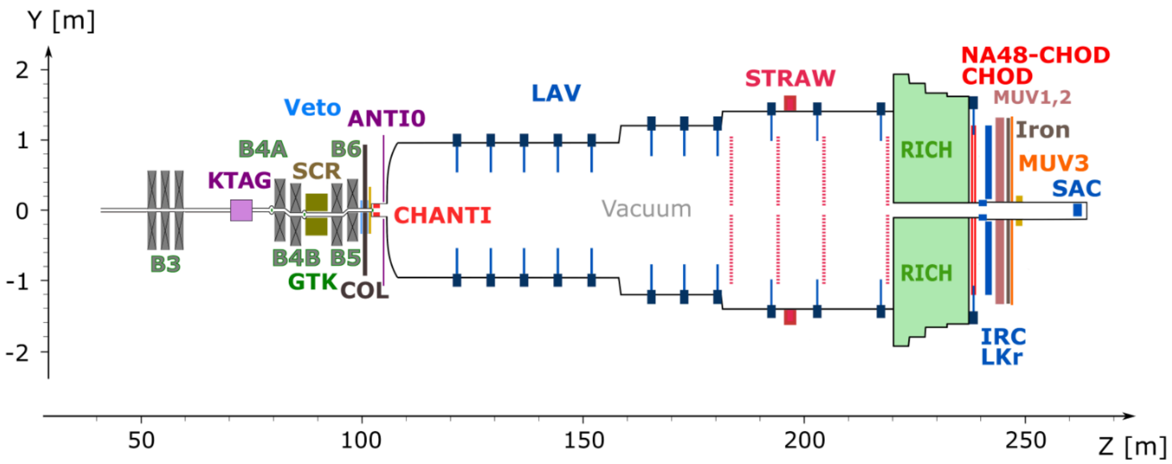
SPS provides multiple high intensity beams - ideal for FIP production!

- **400 GeV p beam** (up to 3×10^{18} pot/year could be upgraded to ~10^{19} pot/year)
- **100-150 GeV e^- beam** (up to 5×10^{12} eot/year)
- **~160 GeV μ^- beam** (currently ~10^{11} mot/year and up to 10^{13} mot/year after LS3)

Current experiments

NA62 (ECN3)

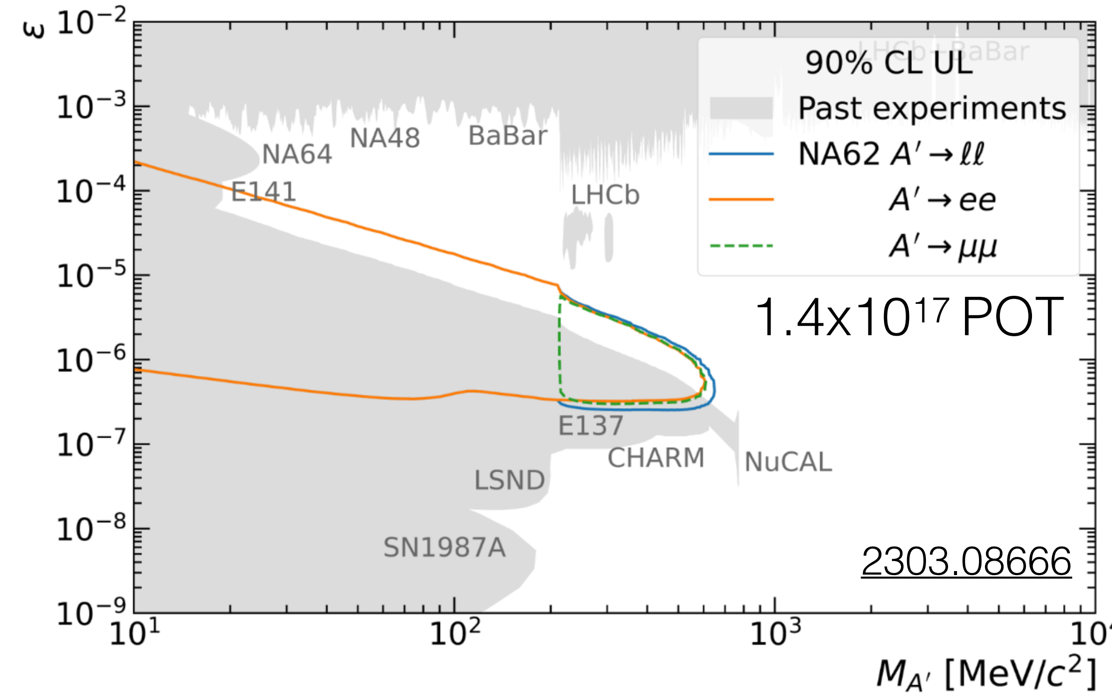
400 GeV protons



Focus is kaon physics but can achieve dark sector sensitivity

Dedicated talks Wed (Artur, Alina)!

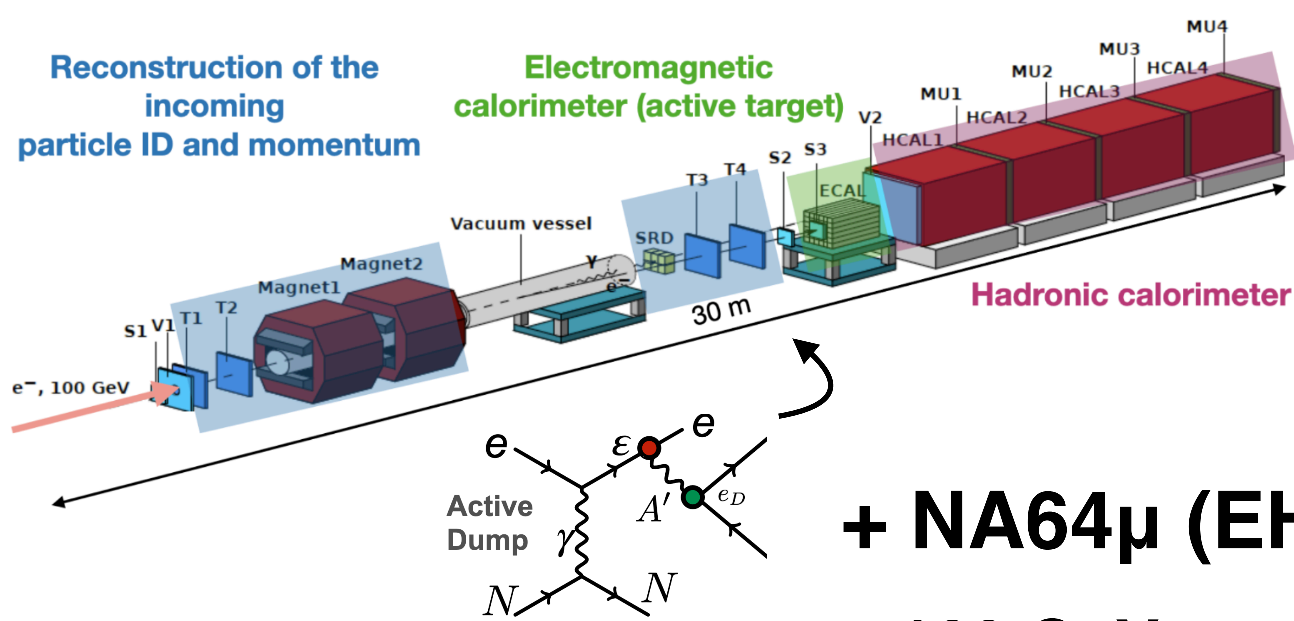
Running in proton dump mode (target removed)

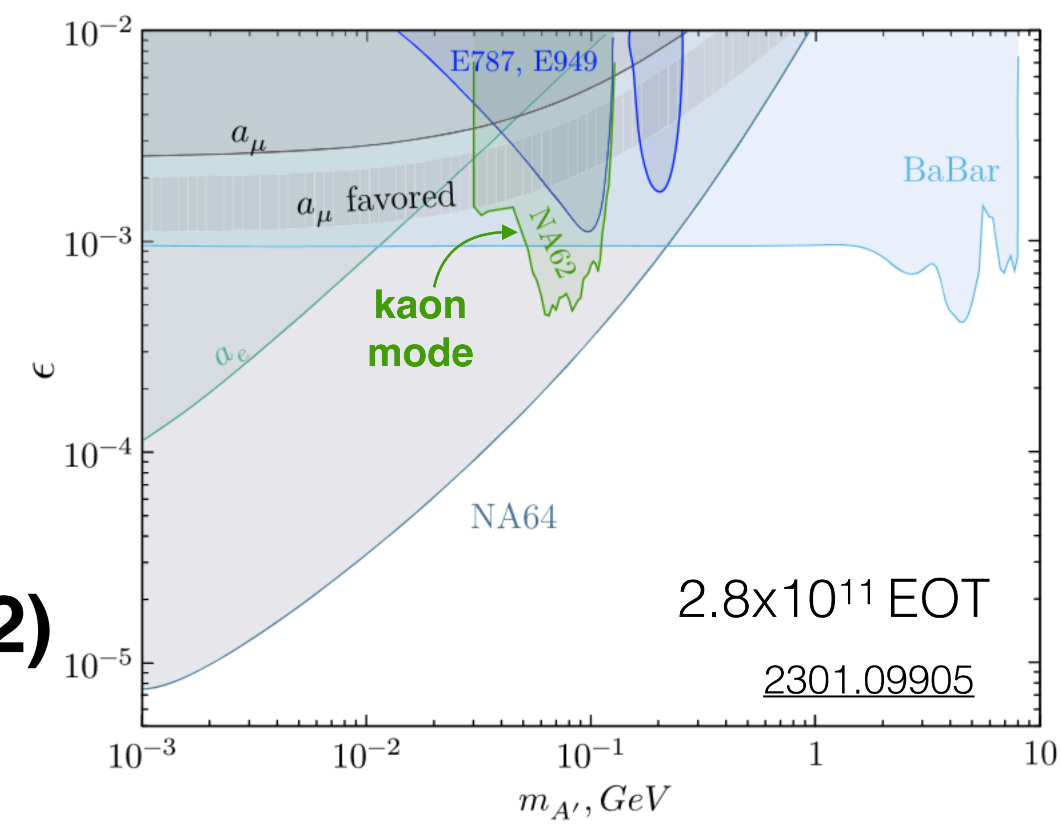


New dark photon → **visible** search

NA64e (EHN1)

100 GeV electrons





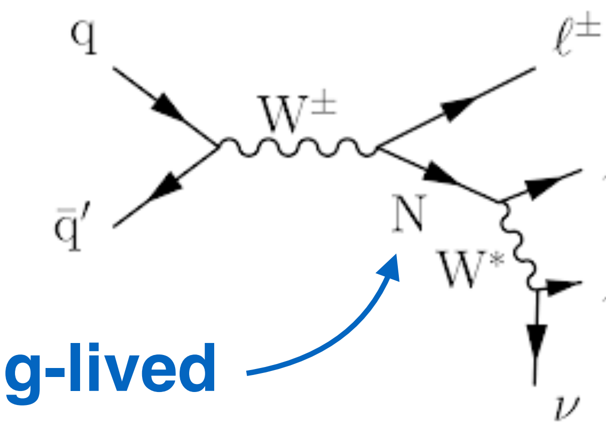
+ NA64μ (EHN2)

160 GeV muons

Designed for dark sector searches: invisible, visible

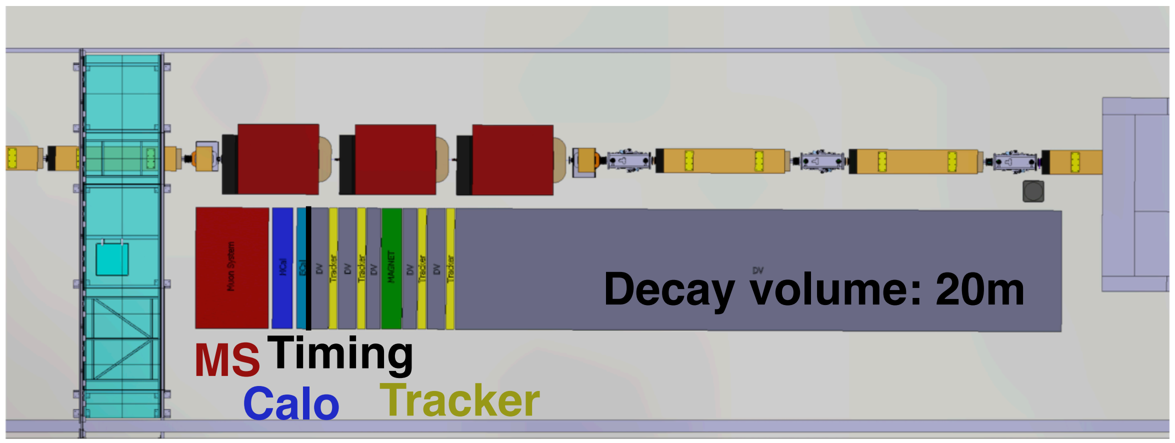
Dark photon → **DM** search

What could come next in ECN3?



Long-lived

SHADOWS + HIKE (maintain kaon program)



MIB (deflects muons)

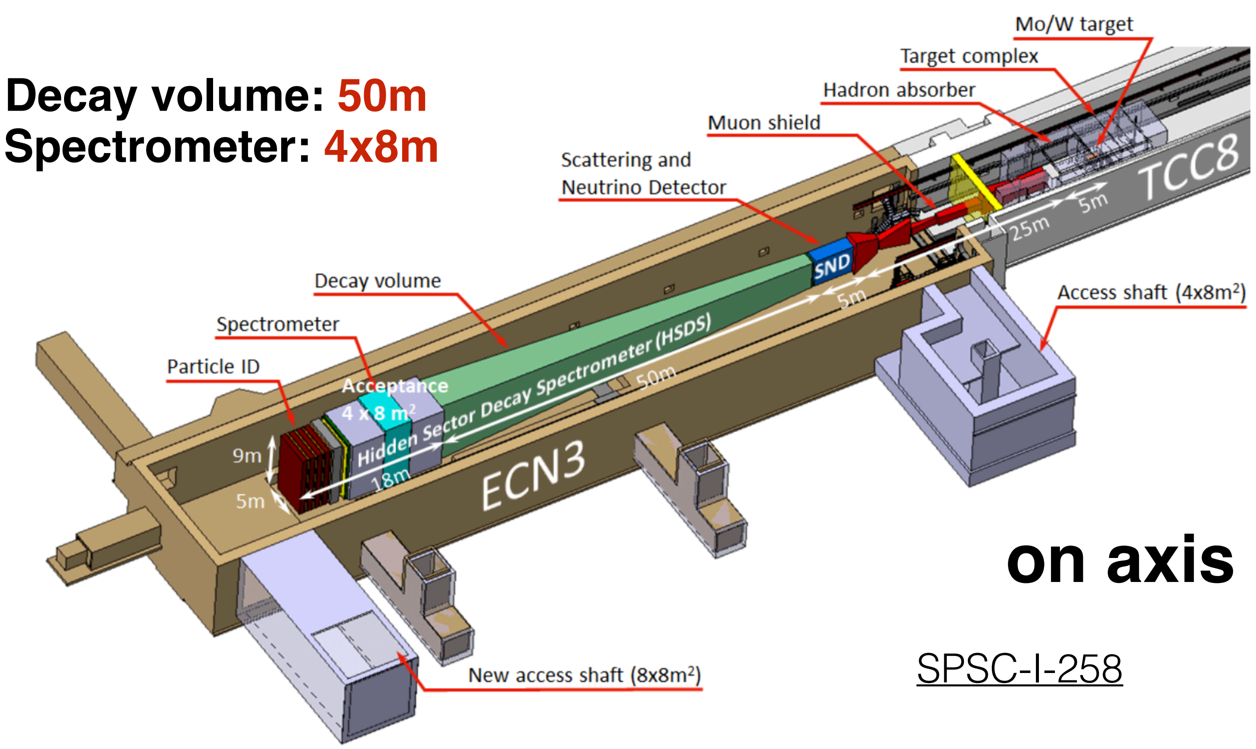
Decay volume: 20m
Spectrometer: 2.5x2.5m

off axis

SPSC-EOI-022

SHIP + space for other ideas (LArTPC, TauFV, …)

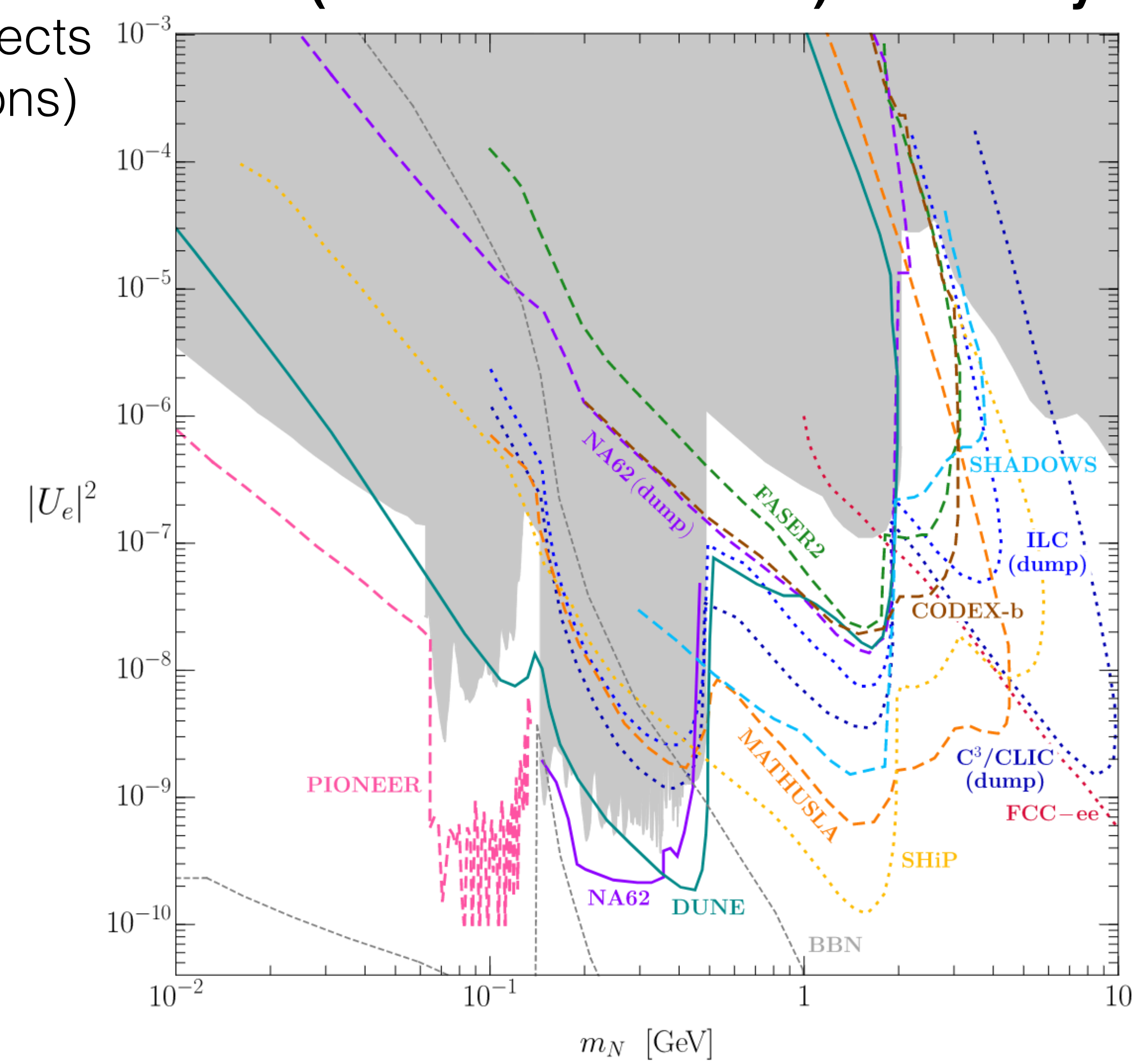
Decay volume: 50m
Spectrometer: 4x8m



on axis

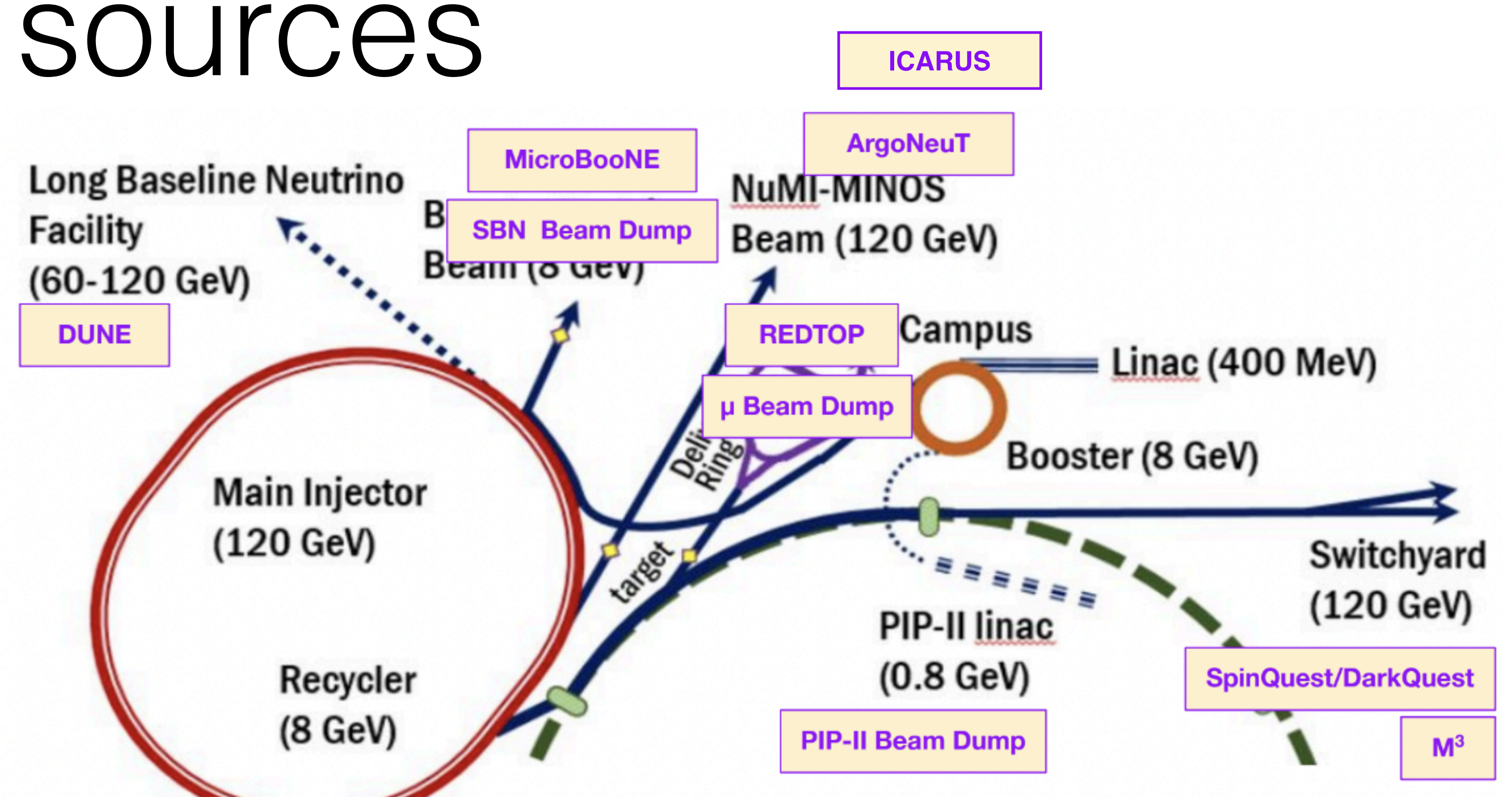
SPSC-I-258

HNL (electron dominance) sensitivity



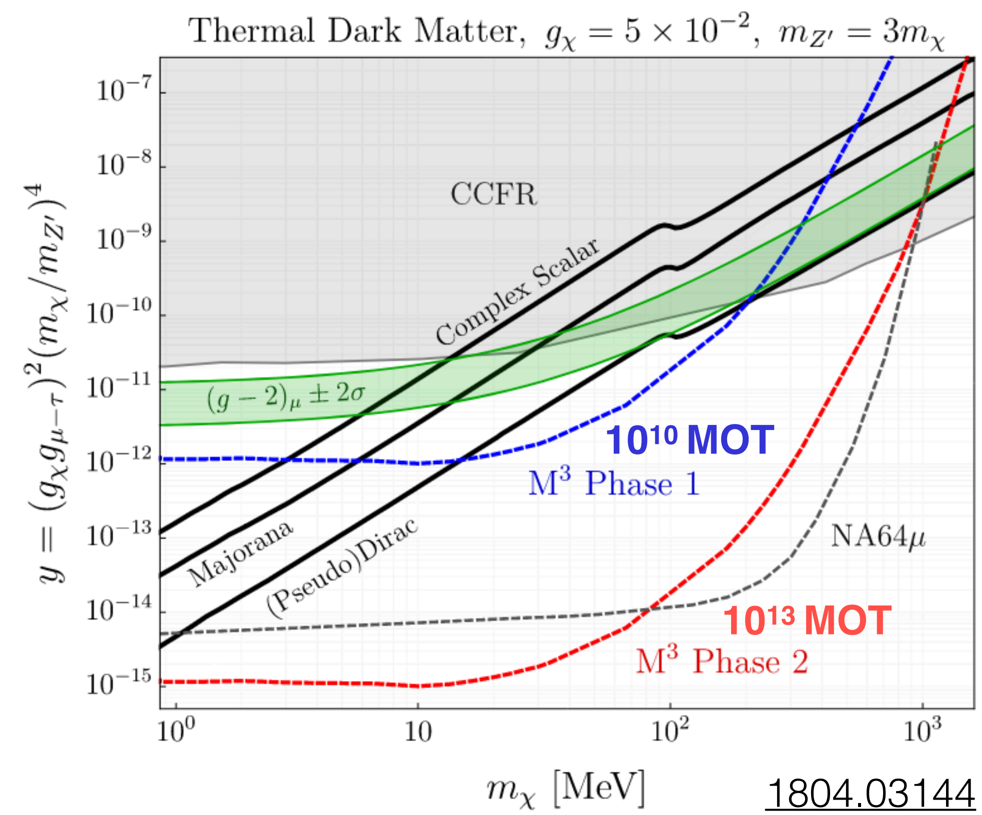
Decision coming ~ end of 2023!

Facilities across the world: neutrino sources

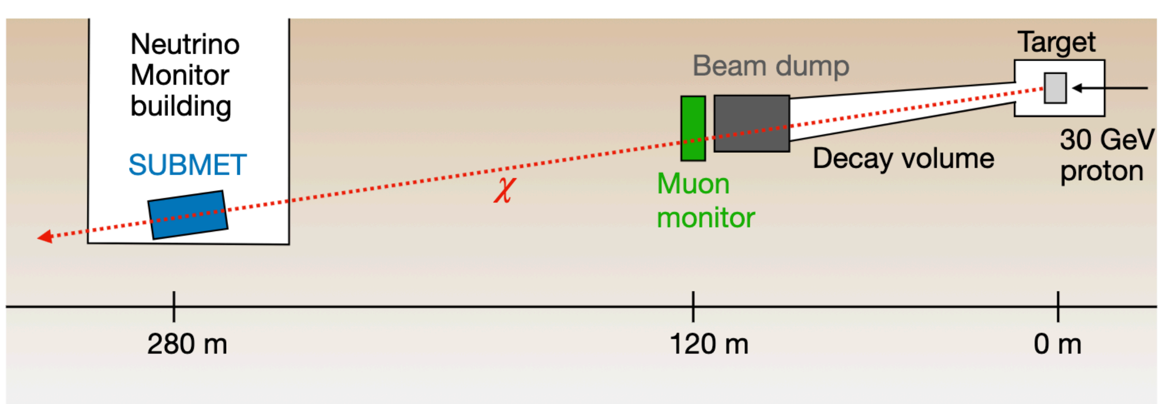


N. Tran

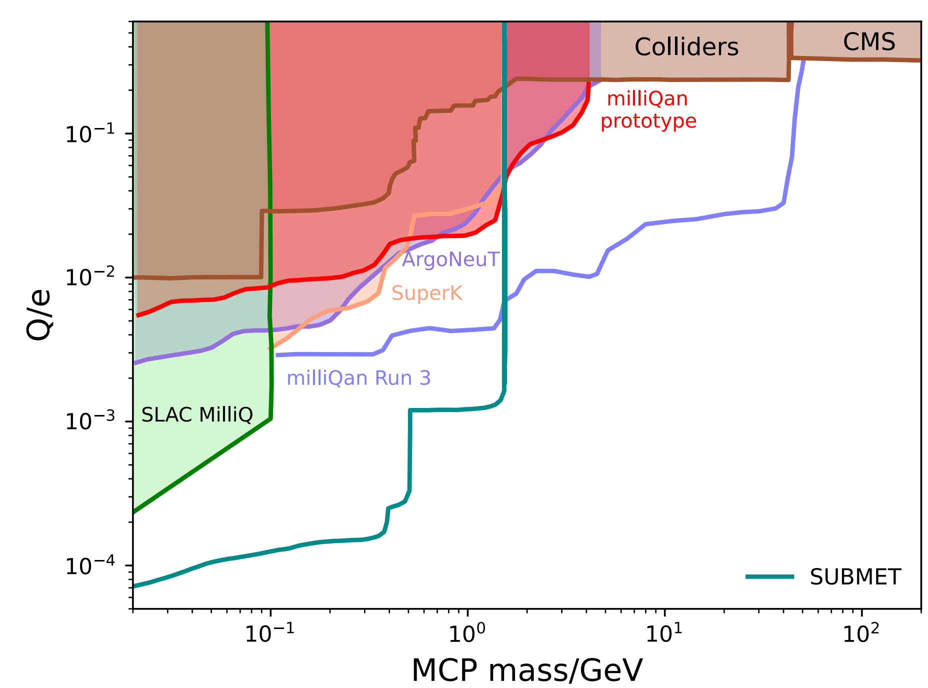
FNAL will provide wide range of dark sector sensitivity (see Nhan's talk!)



e.g. M³ sensitivity compared to NA64μ for L_μ-L_τ gauge boson

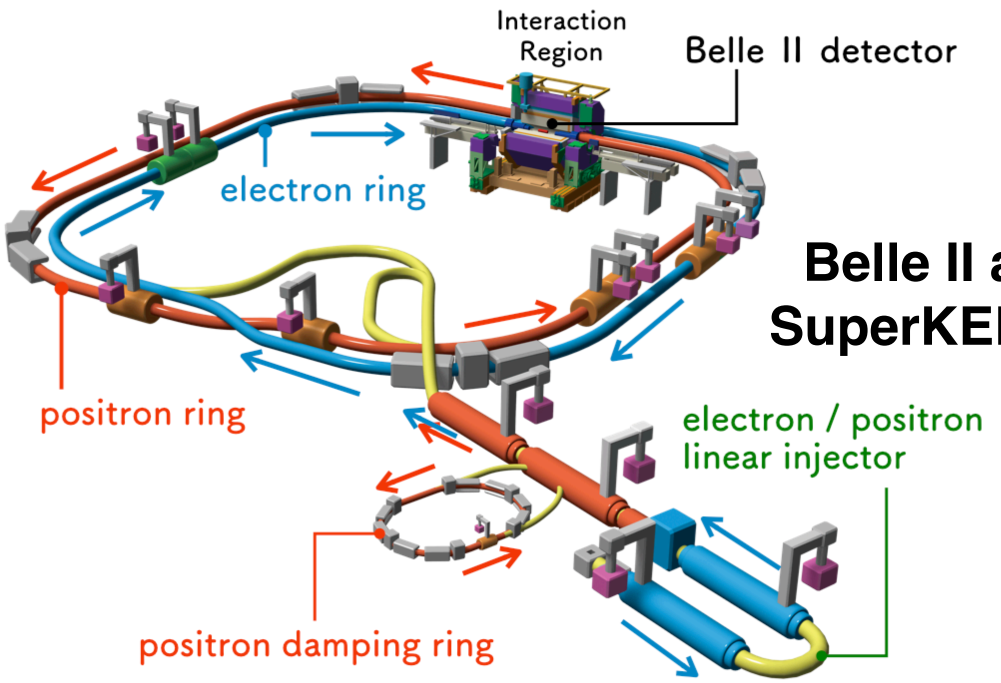


SUBMET millicharged particle detector at **J-PARC** (approved and under construction!)



Other facilities across the world

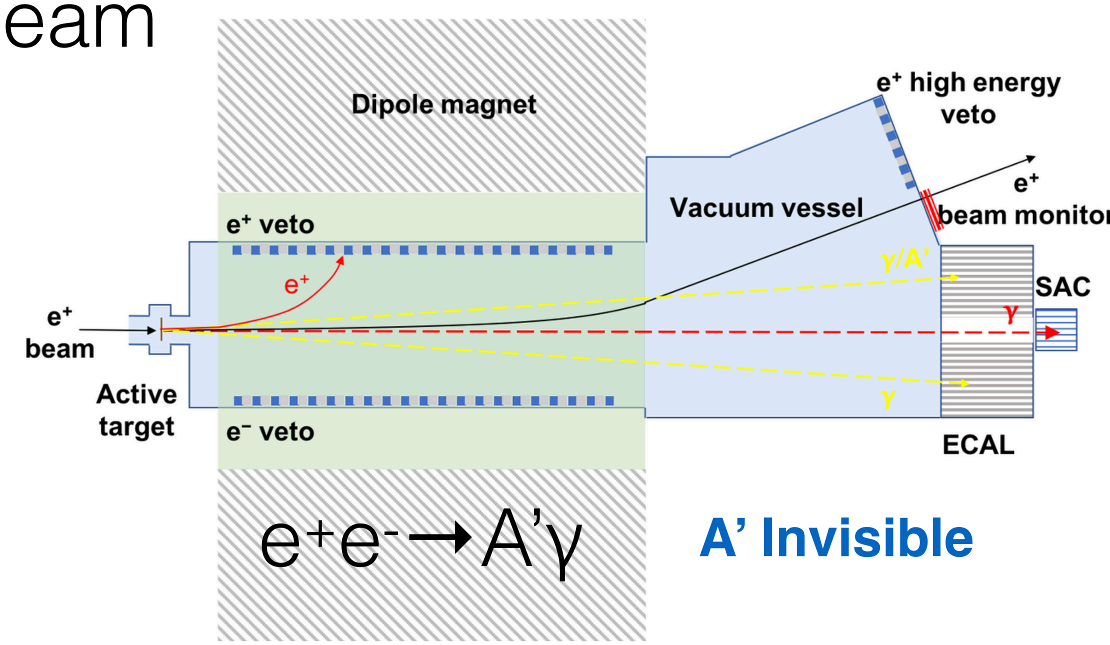
9.4 GeV e^+e^- collider



Belle II at SuperKEKB

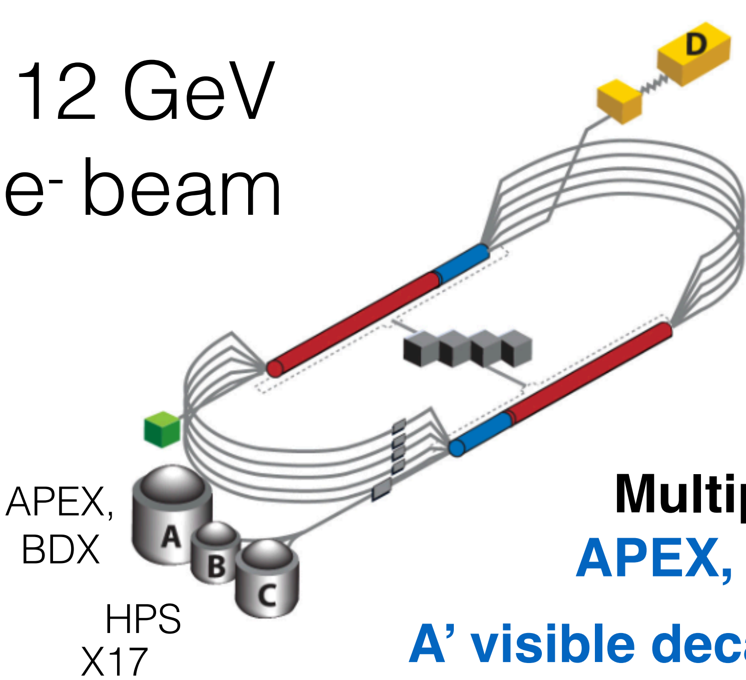
550 MeV e^+ beam

$m_{A'} < 23.7$ mEV



PADME at DAΦNE

12 GeV e^- beam



GlueX (9 GeV γ beam)

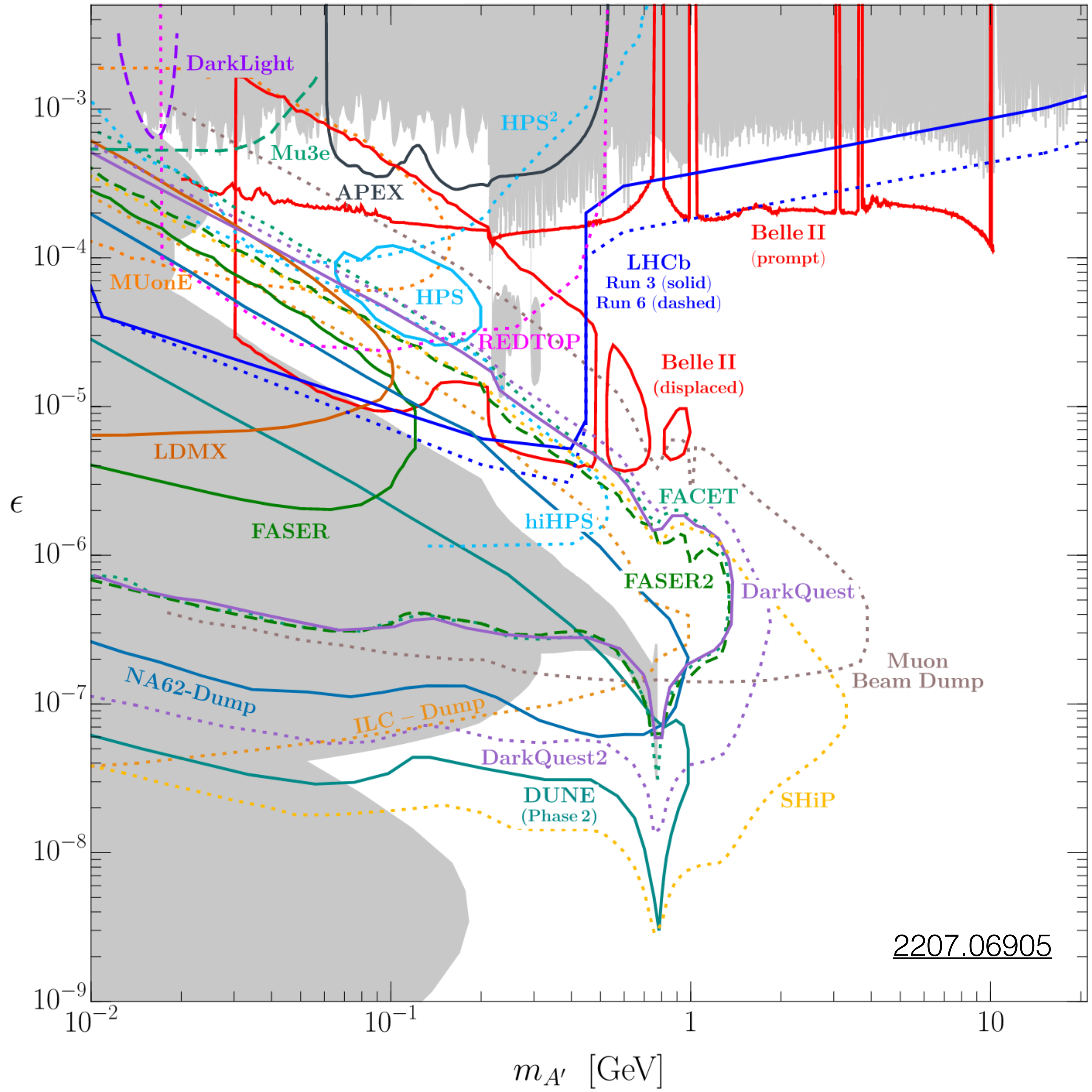
Multiple detectors:
APEX, HPS, X17, BDX

A' visible decays **A' scattering**

JLAB

- Experiments using range of facilities will provide complementary probes
- Huge number of experiments not shown here (see Nhan's talk for a summary)!

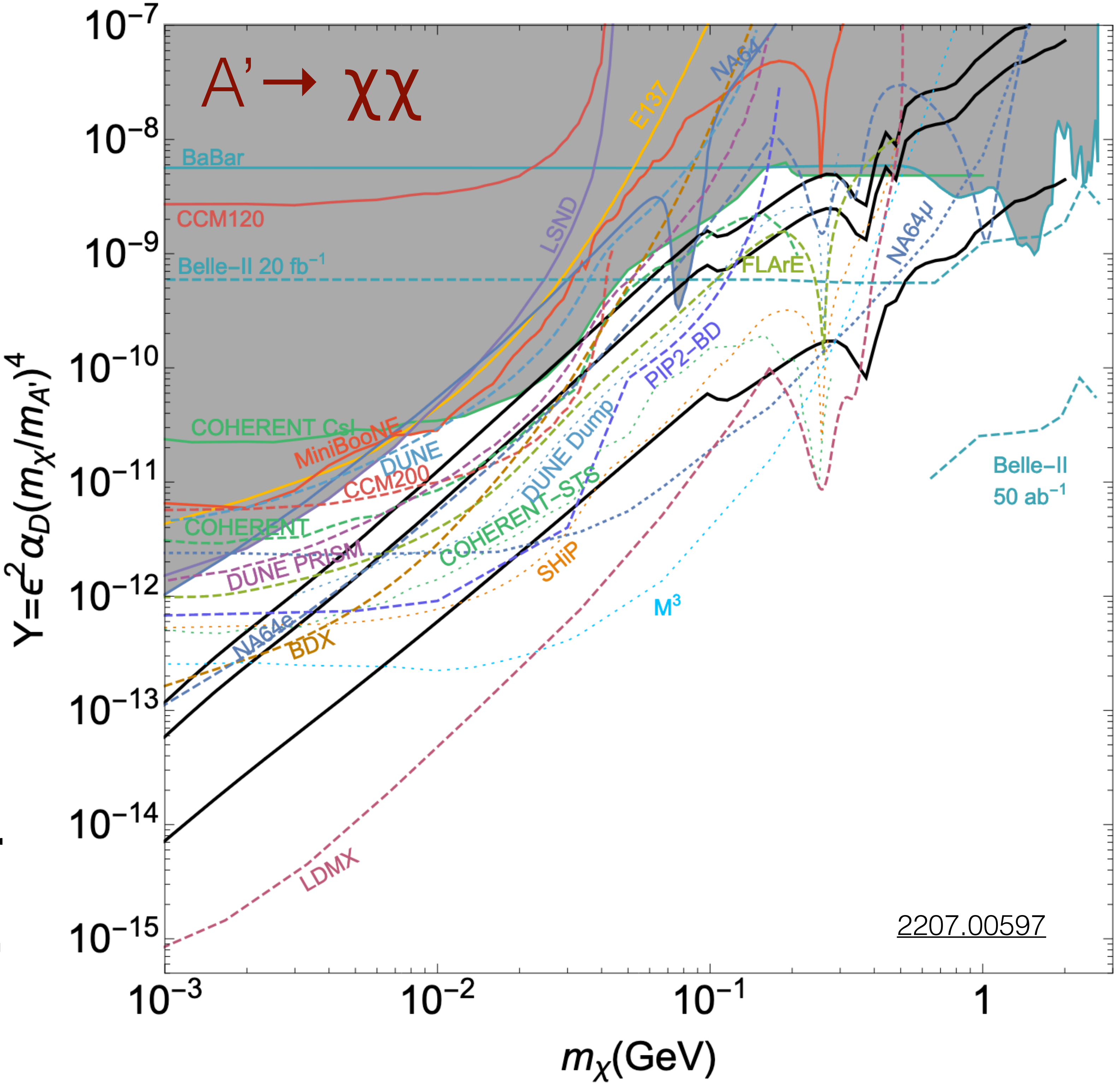
Sensitivities: A' → visible



NB: limits depend strongly on what A' couples to!

Limits extended by orders of magnitude in charge and mass

Sensitivities: A' → DM



NB: limits depend strongly on what A' couples to!

Widely cover DM thermal relic density!

Limits extended by orders of magnitude in charge and mass

Summary

- An **eco-system of dedicated experiments** will fully exploit the physics potential of the LHC and high intensity facilities!
- Range of beams/facilities and detector technologies crucial for comprehensive coverage
- Many detectors **taking data now** - excellent prospects for discovery
- Experiments at future facilities (DUNE, HL-LHC,…) cover much of the “interesting” phase space that **explain g_μ-2** and/or give **correct DM relic density**