CODEX-b and the Search for Longevity

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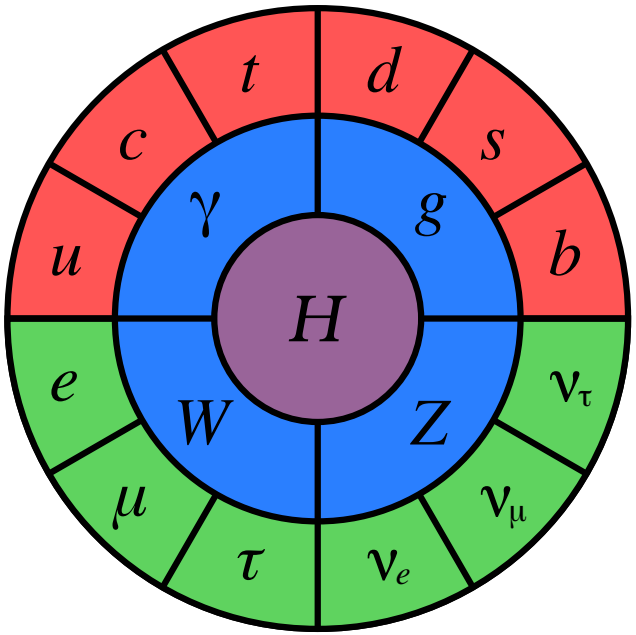
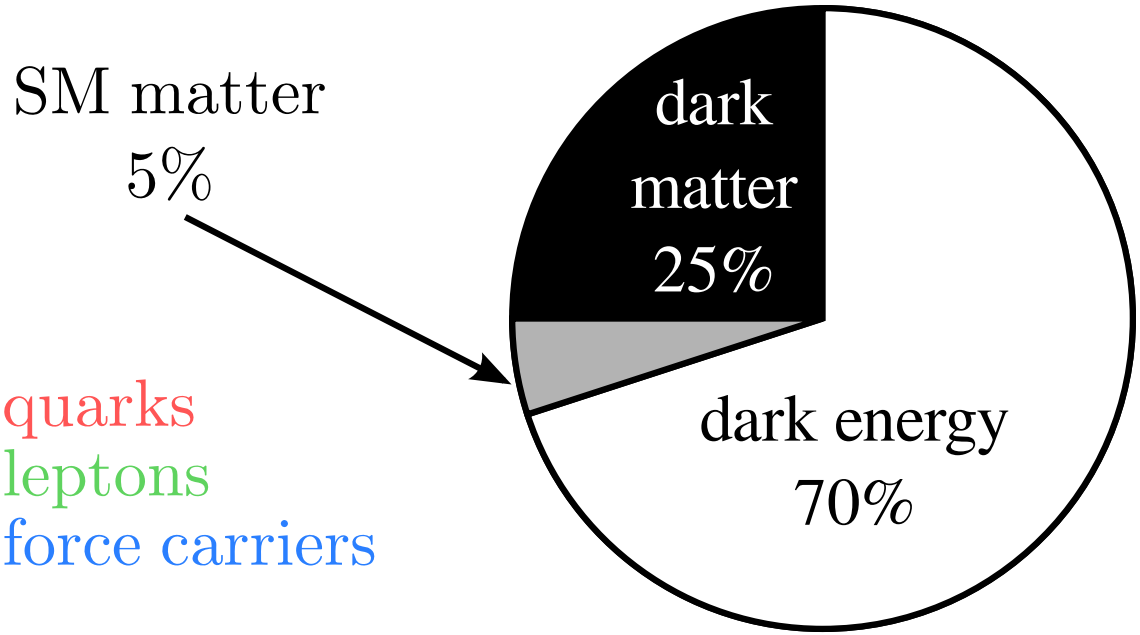
July 1, 2020

Liverpool Seminar

Dark Matter

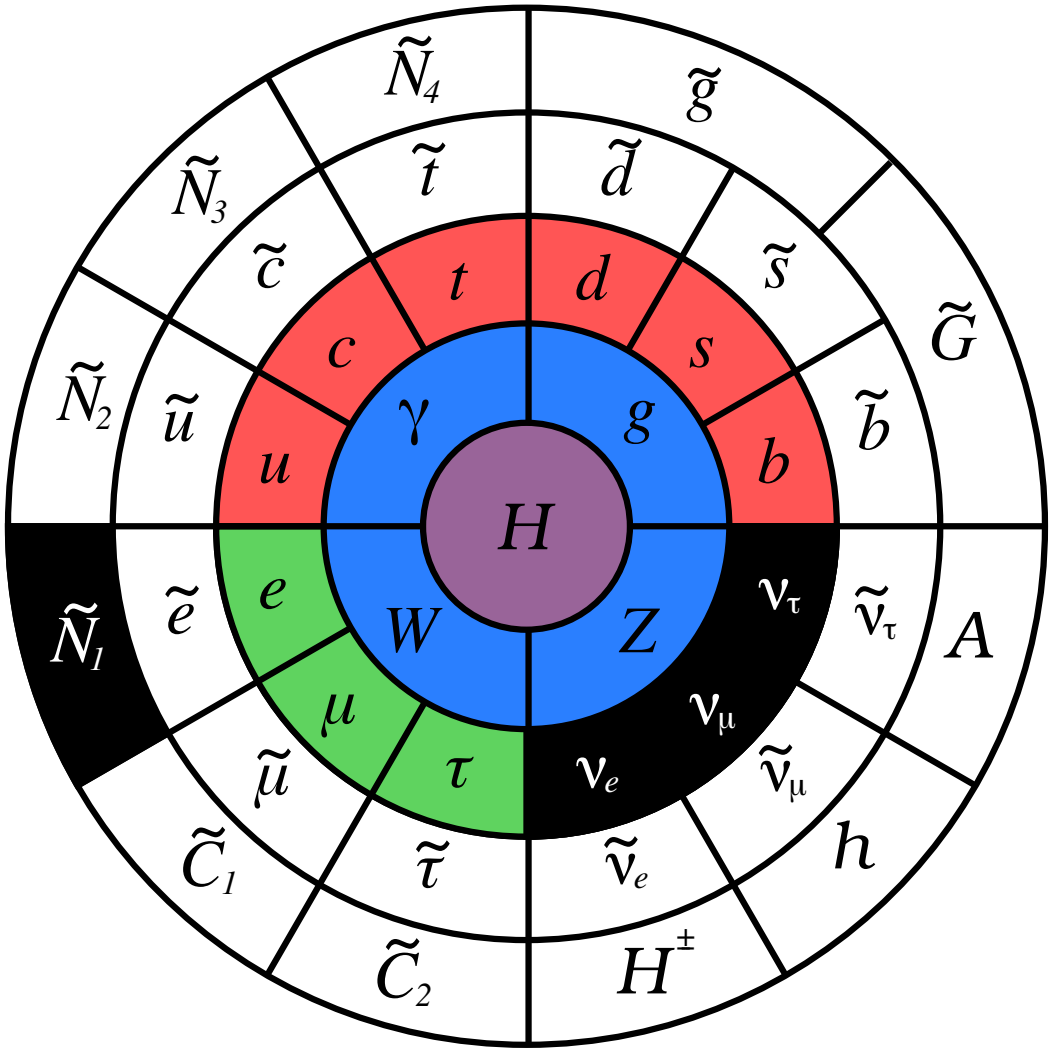


quarks
leptons
force carriers

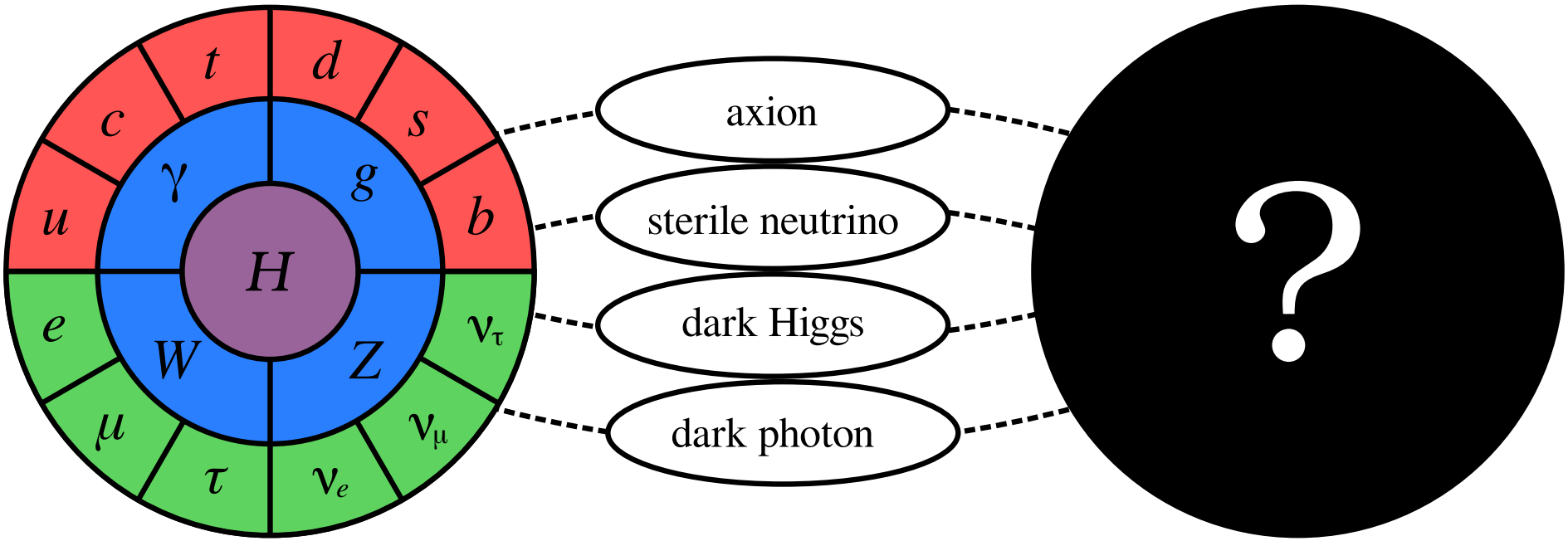


1. interacts through gravity
2. does not interact through the electromagnetic or strong forces
3. interacts weakly (or not at all) with itself

SM or Embedded Theory



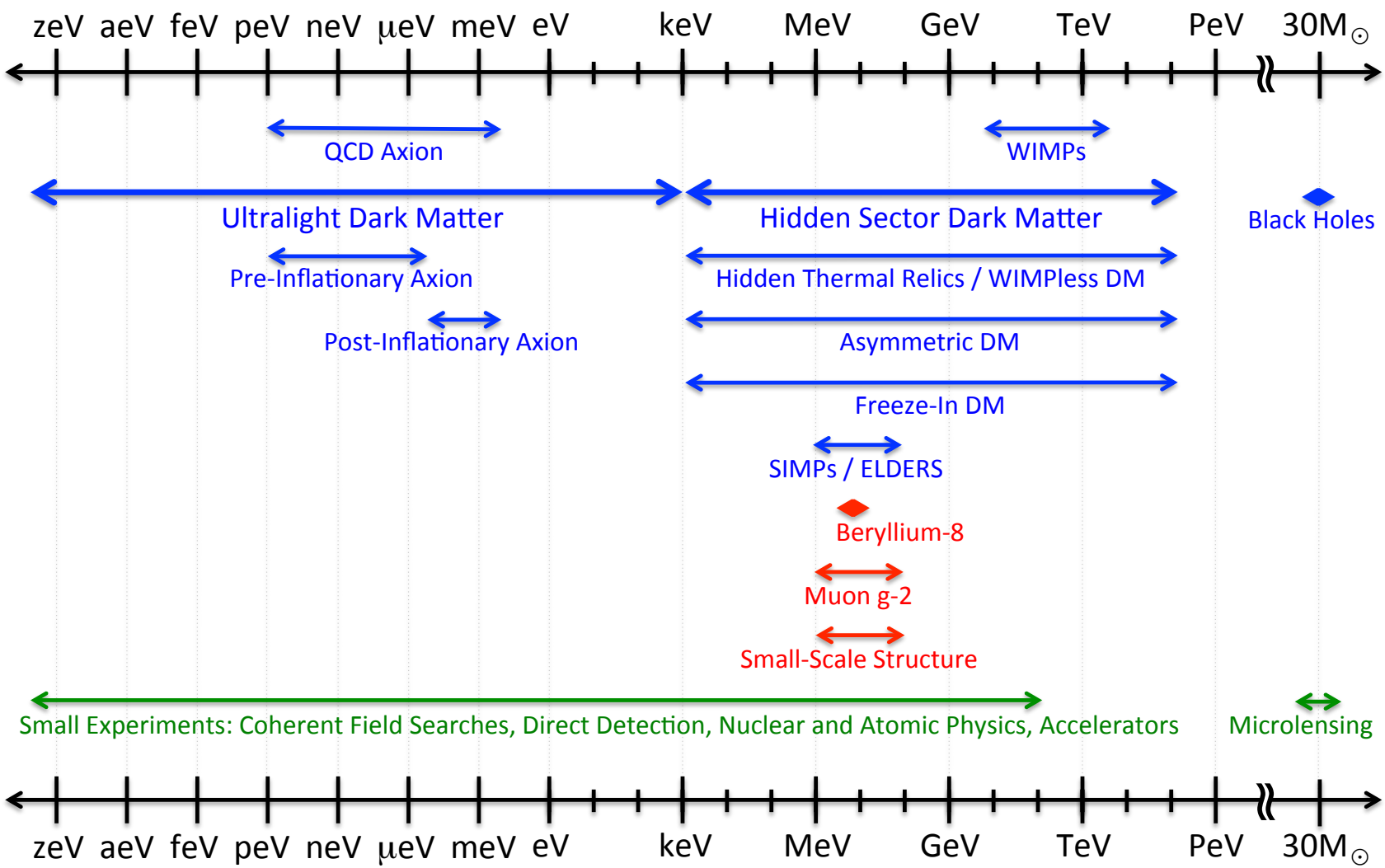
Hidden Sector



Widening the Net

arXiv:1707.04591 [hep-ph]

Dark Sector Candidates, Anomalies, and Search Techniques



It's Complicated

arXiv:1903.04497 [hep-ex]

displaced multitrack vertices

disappearing or kinked tracks

non-pointing (converted) photons

displaced leptons, lepton-jets, or lepton pairs

emerging jets

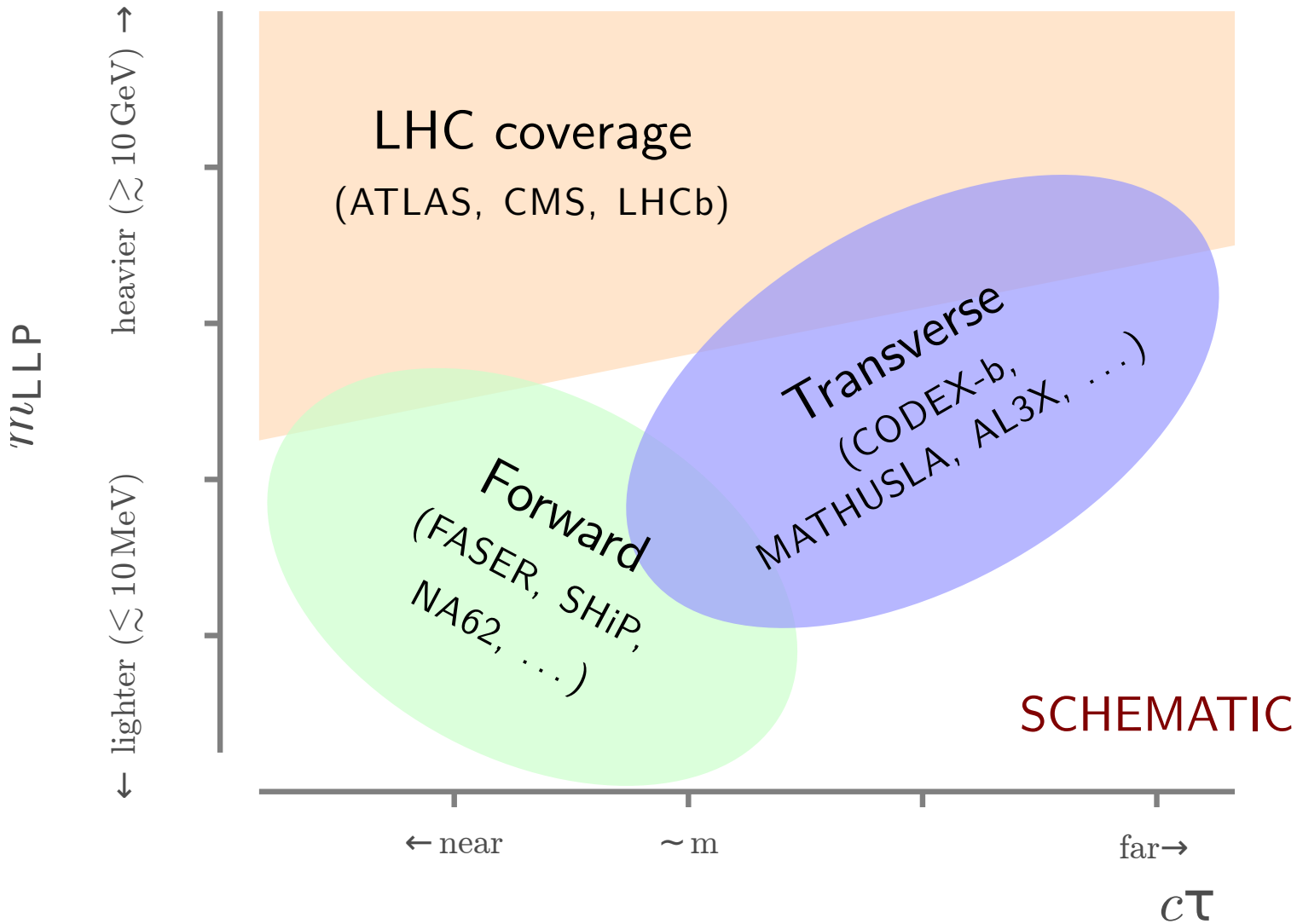
trackless, low-EMF jets

quasi-stable charged particles

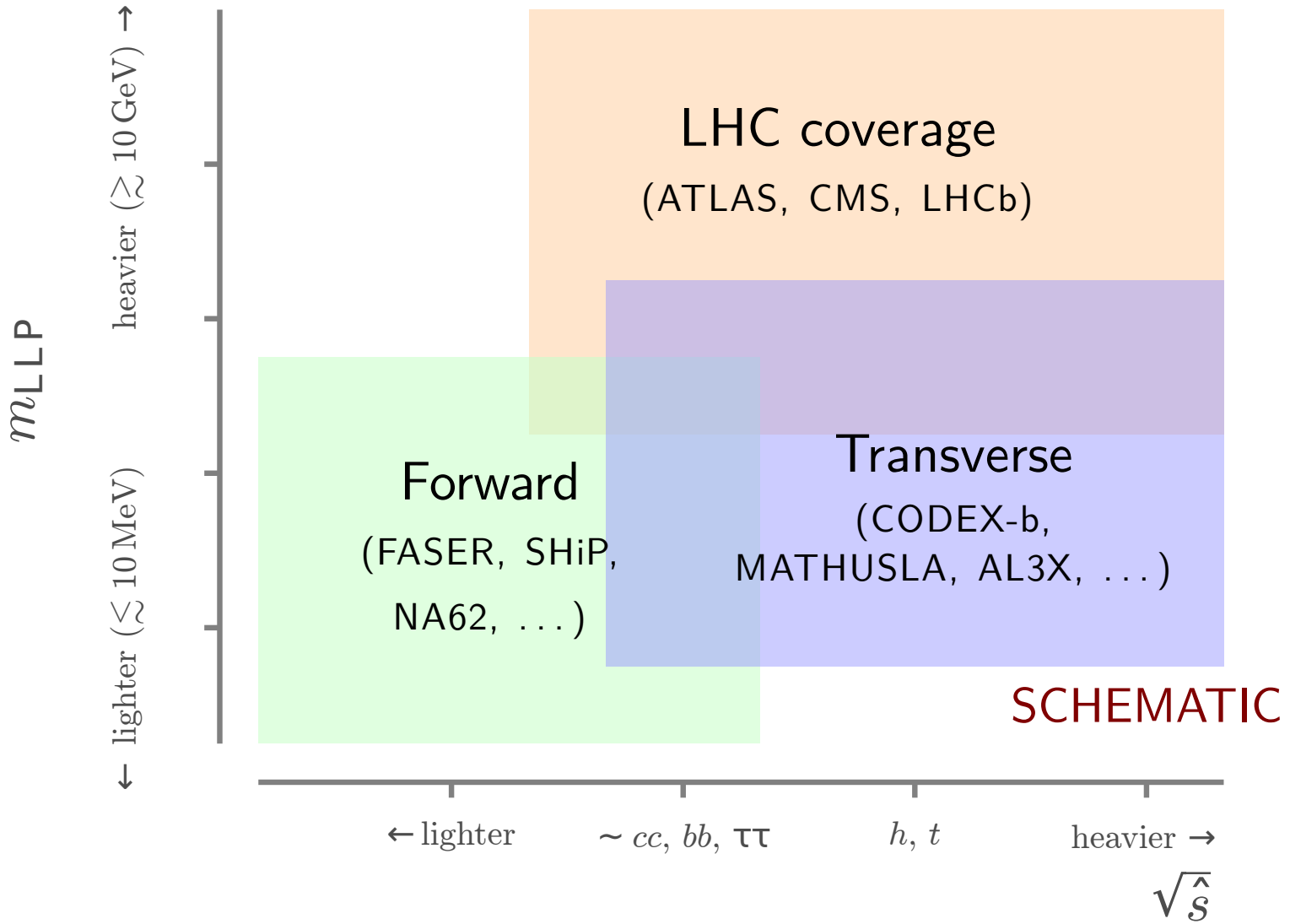
multitrack vertices in the muon spectrometer

Experimental Landscape

A Picture is Worth . . .

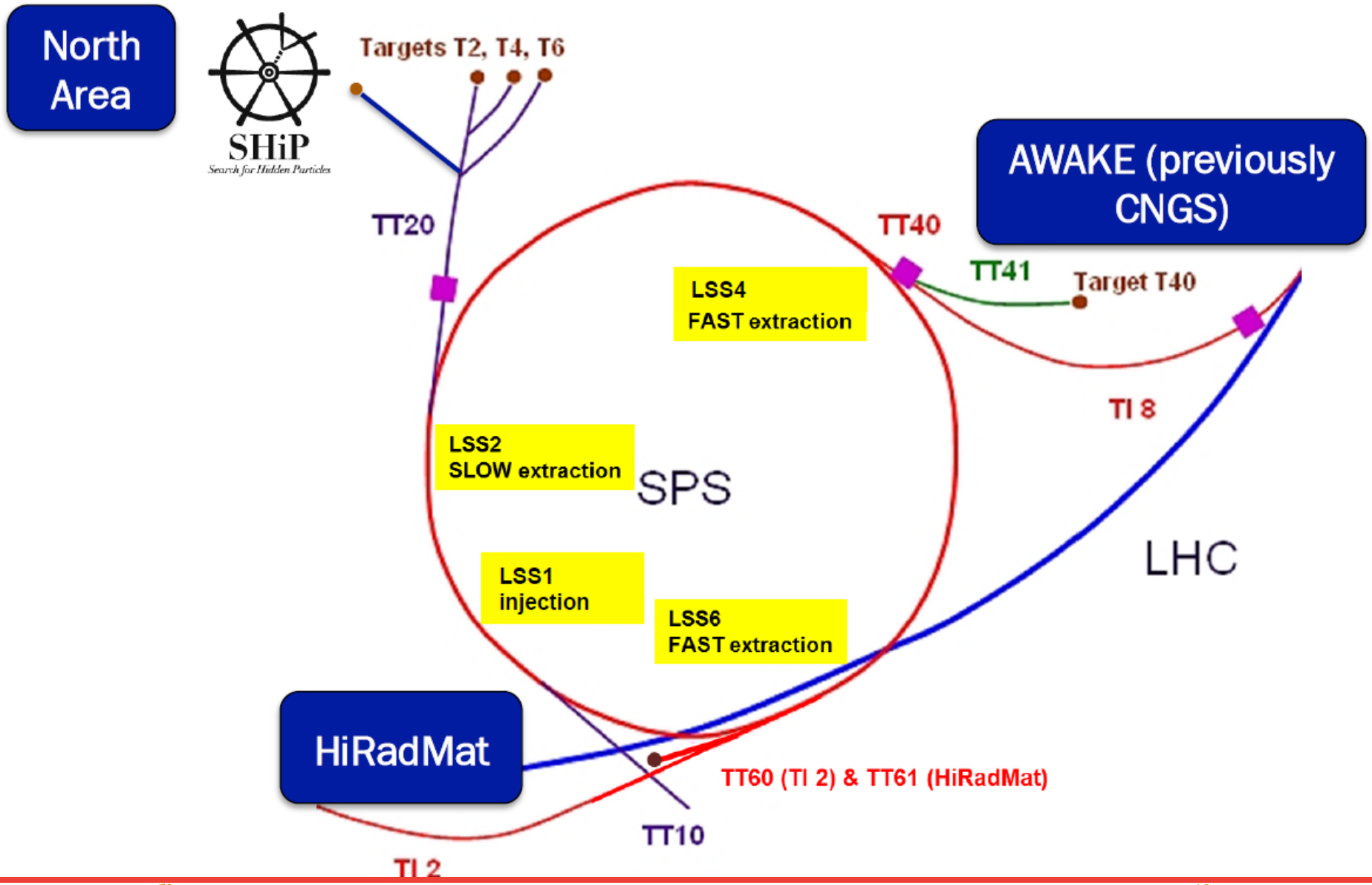


A Picture is Worth . . .



SHiP

arXiv:1310.1762



SHiP

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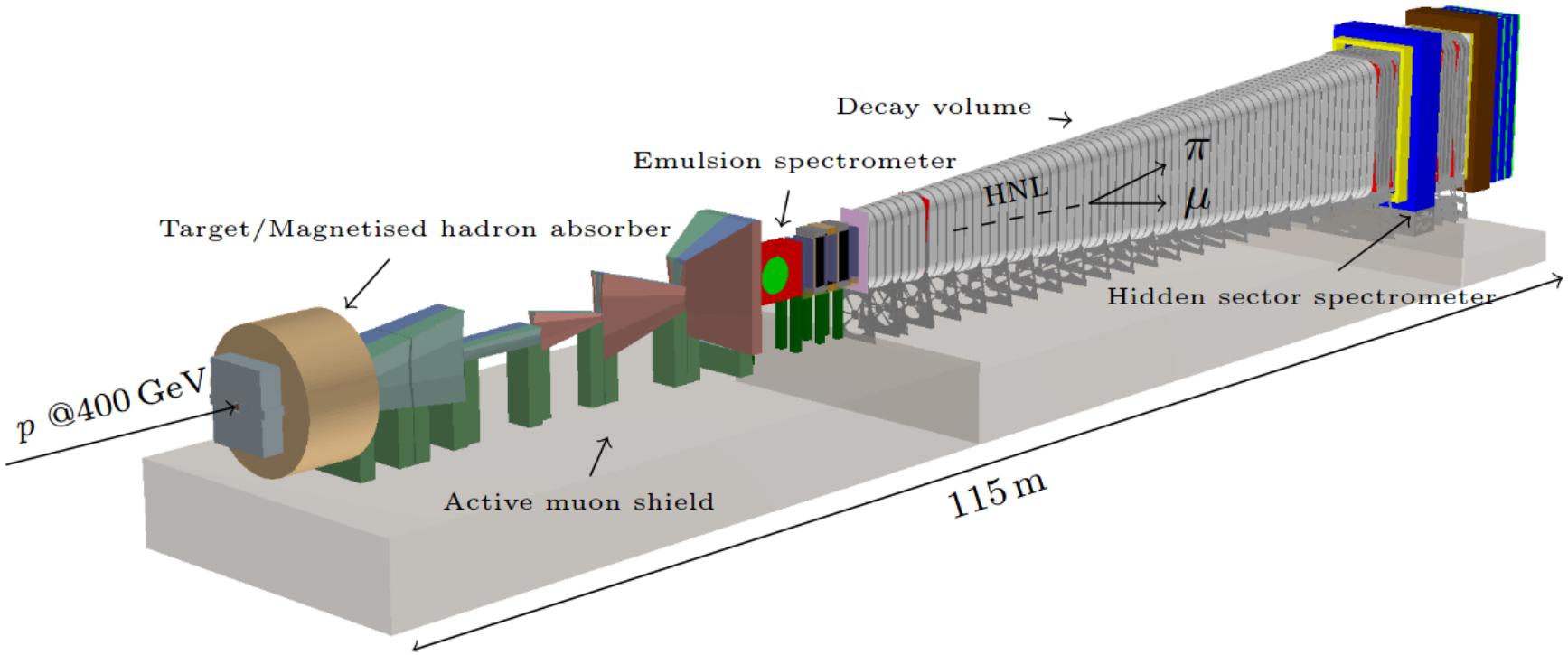
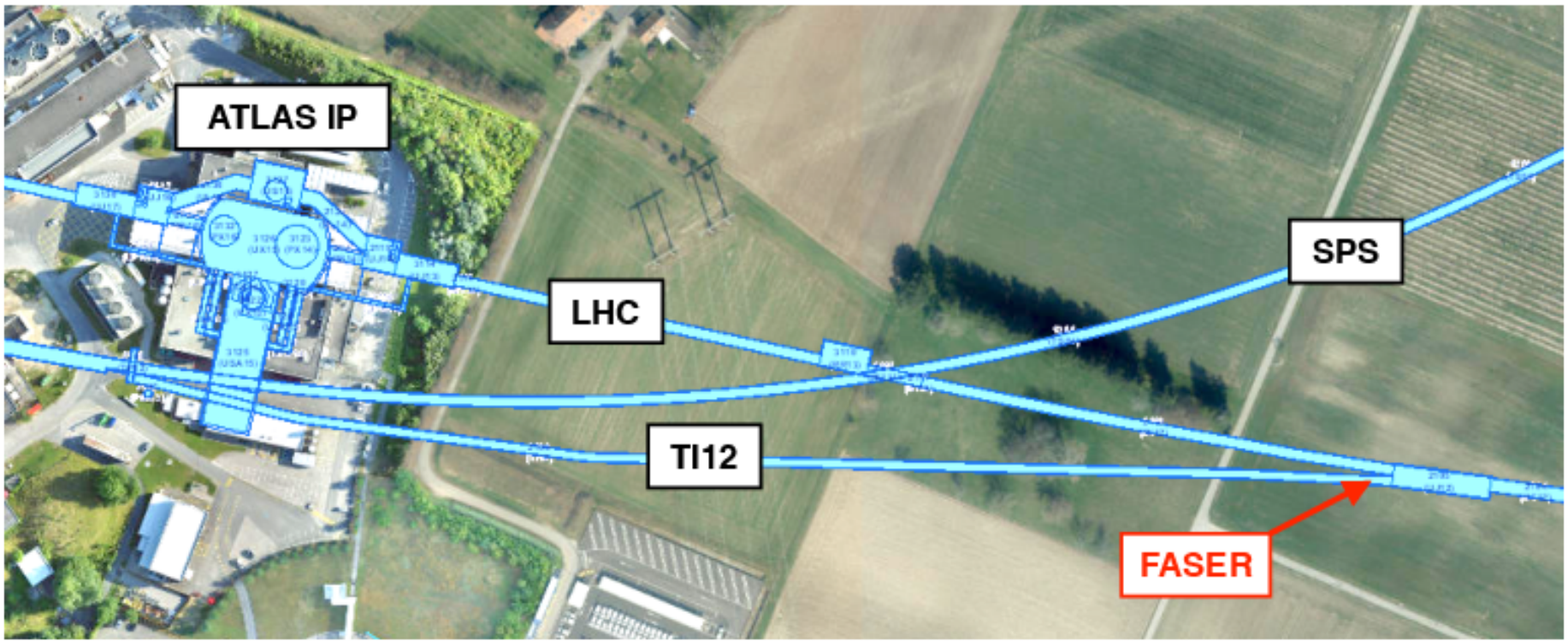


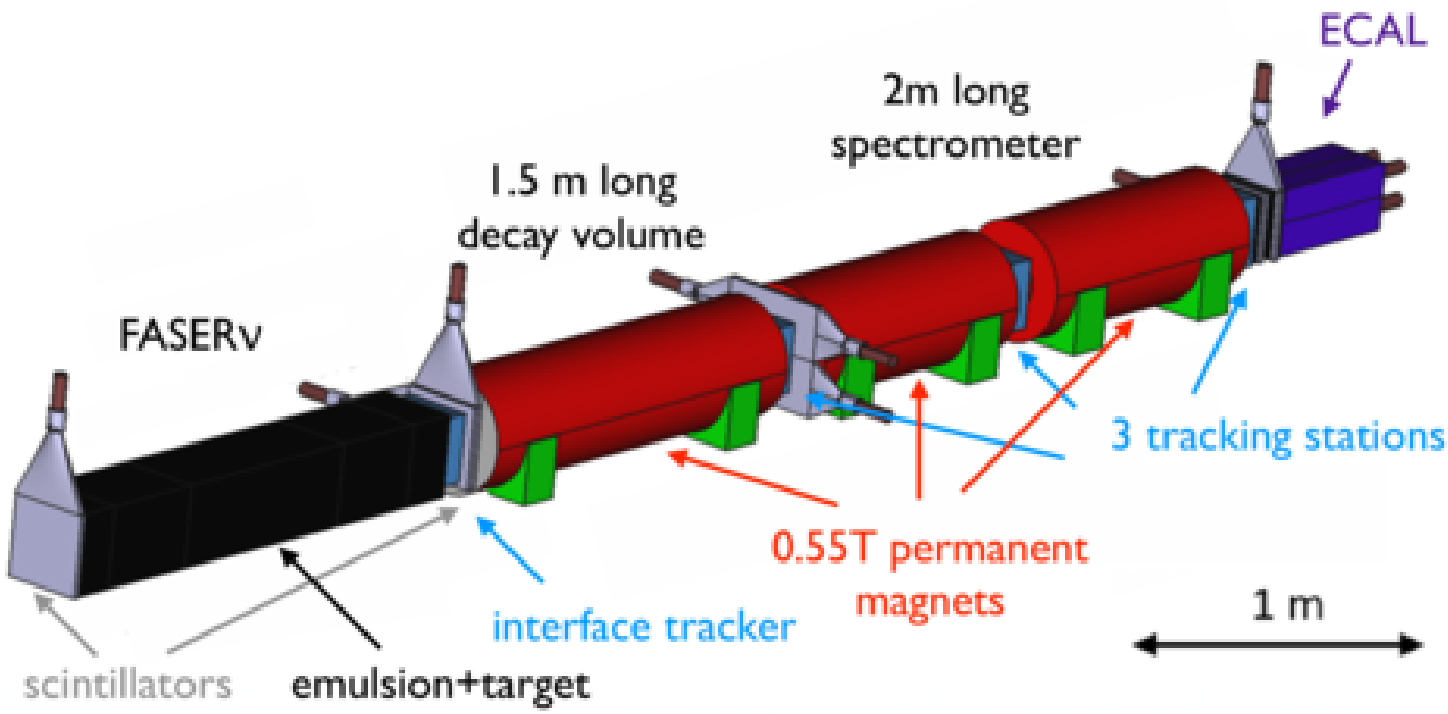
FASER

arXiv:1811.10243



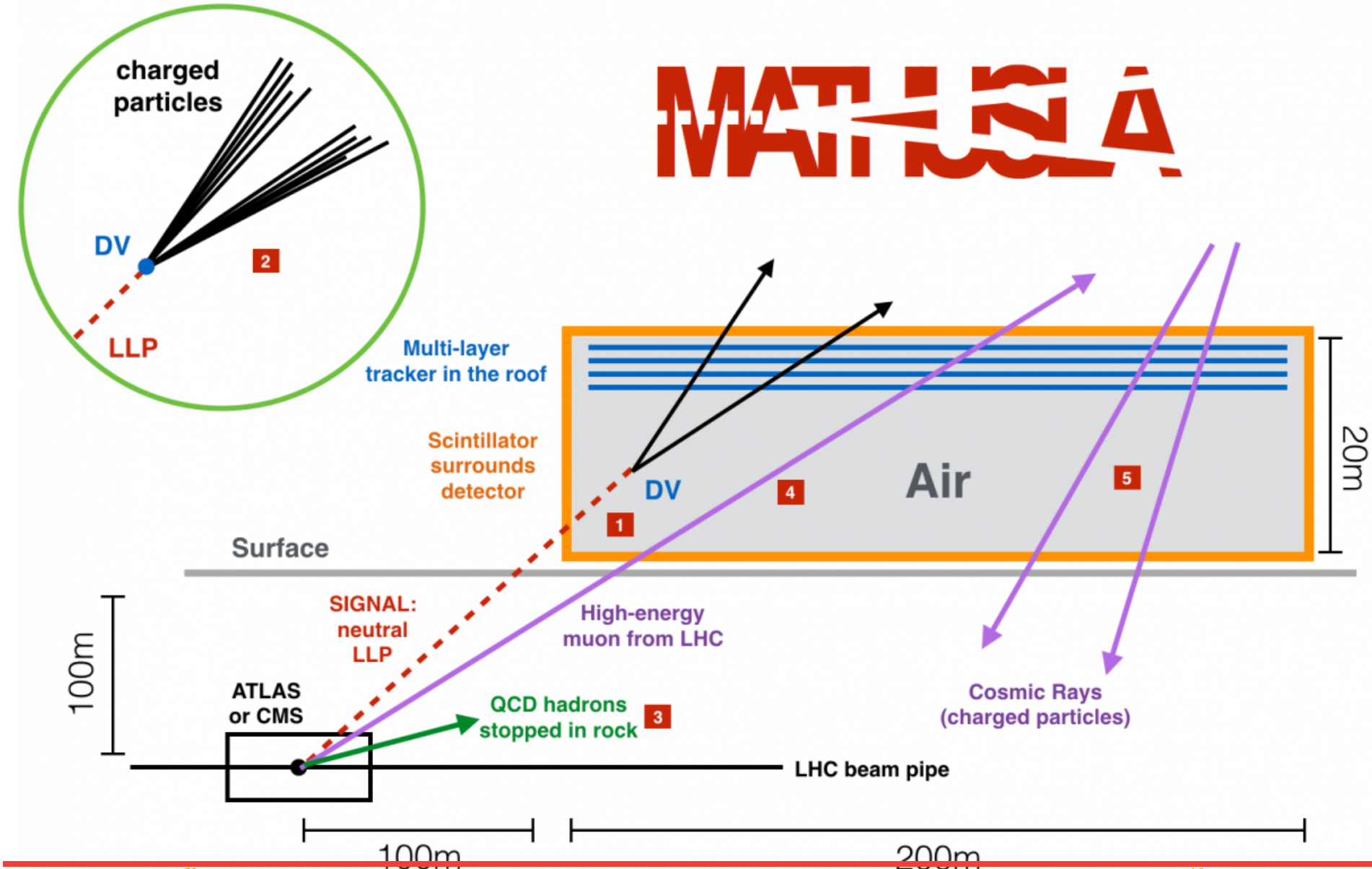
FASER

arXiv:1811.10243



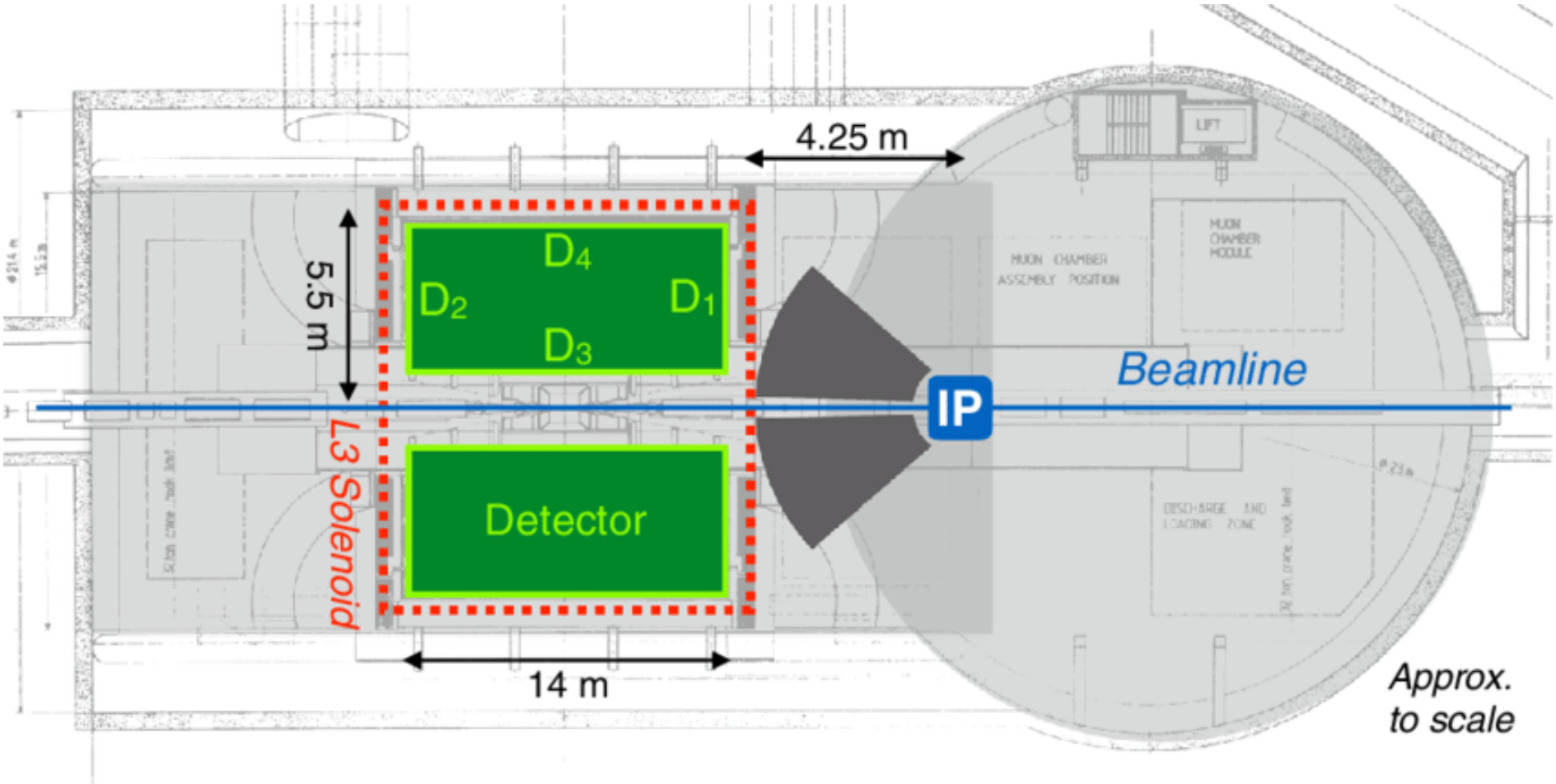
MATHSULA

arXiv:1606.06298



AL3X

arXiv:1810.03636



CODEX-b

Expression of Interest

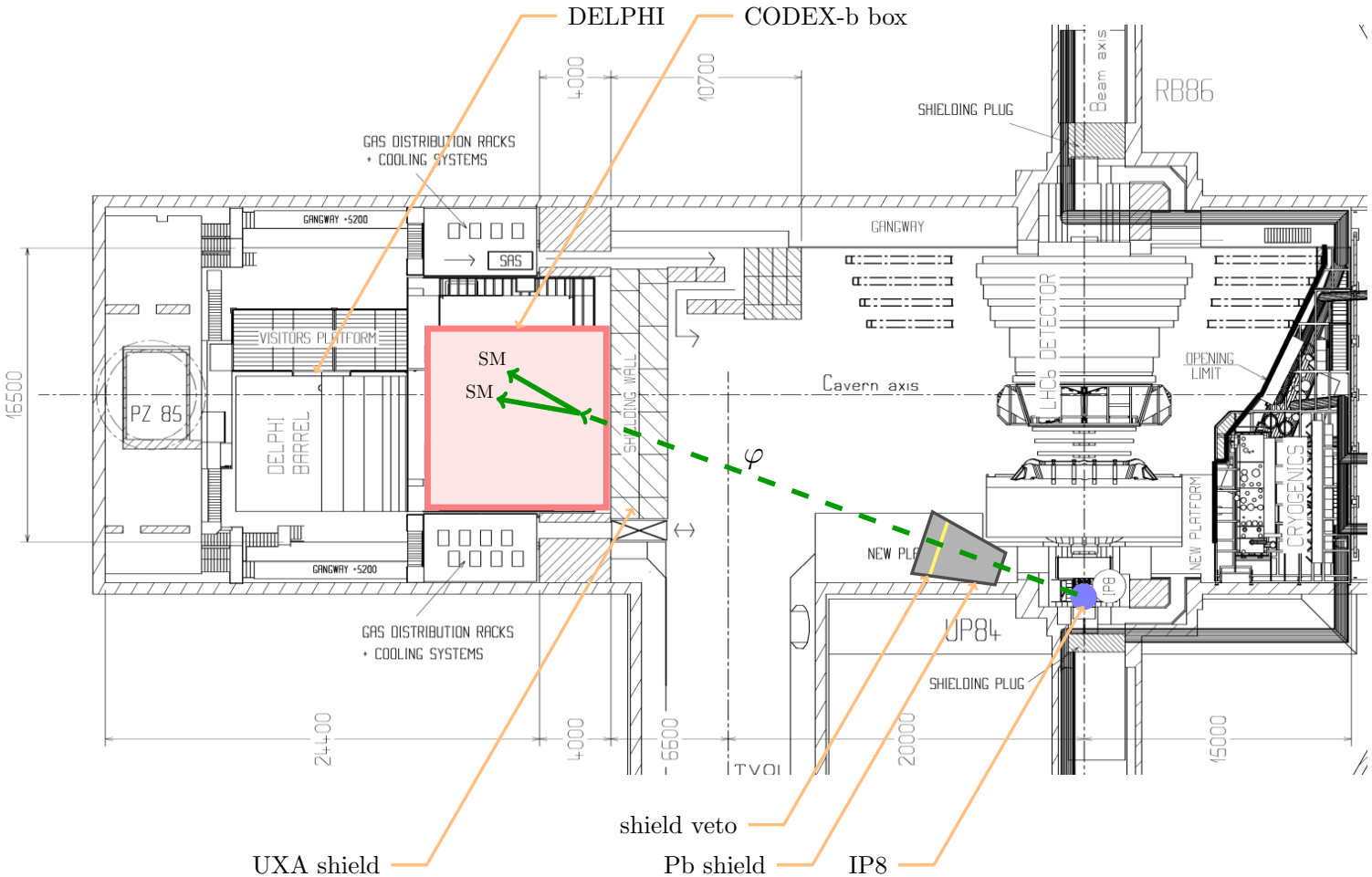
arXiv:1911.00481 [hep-ex]

Expression of Interest for the CODEX-b Detector

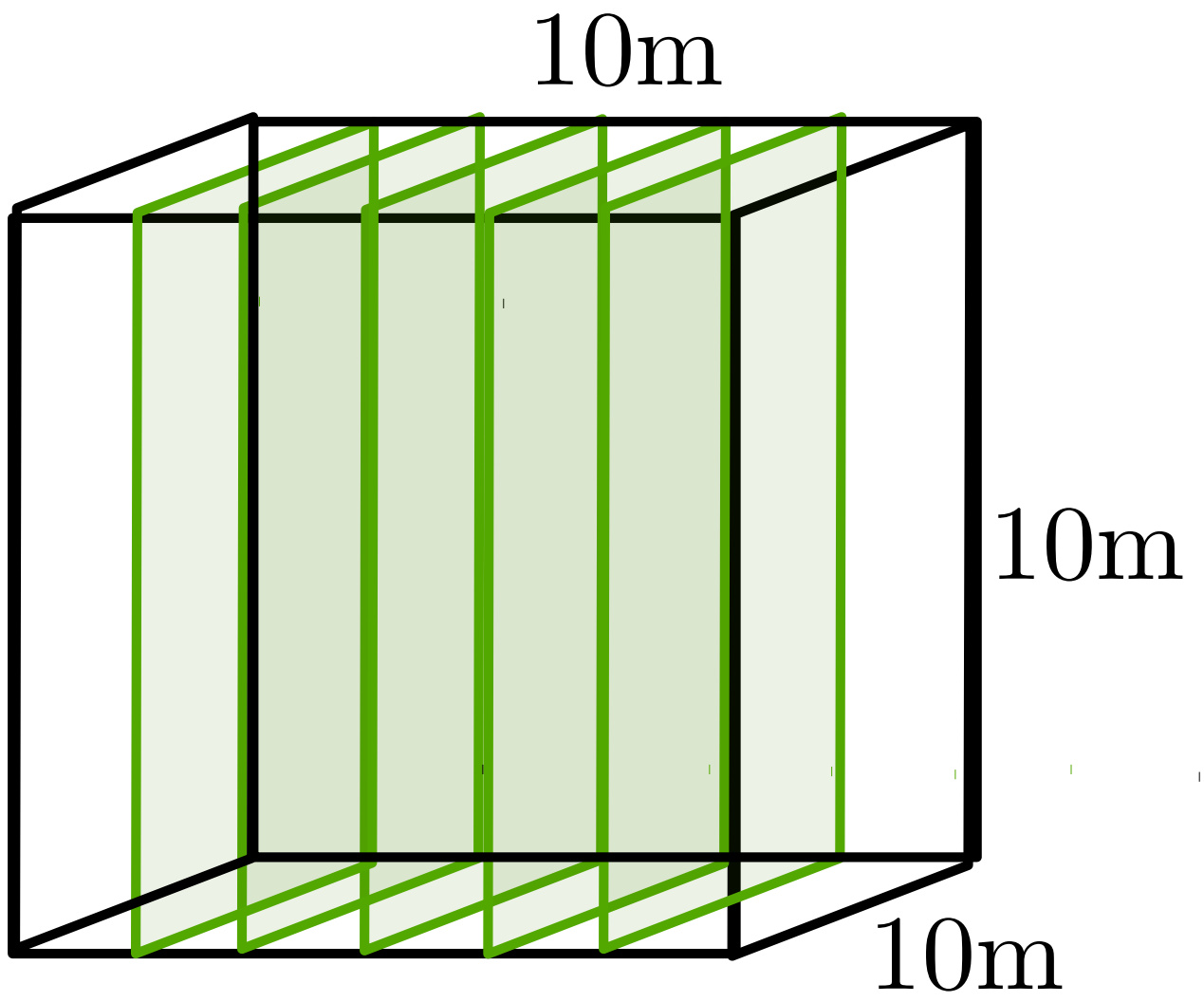
Giulio Aielli,[1] Roberto Cardarelli,[2] Matthew John Charles,[3] Xabier Cid Vidal,[4] Victor Coco,[5] Biplab Dey,[6] Raphael Dumps,[5] Jared A. Evans,[7] George Gibbons,[8] Olivier Le Dortz,[3] Vladimir V. Gligorov,[3] Eli Ben Haim,[3] Philip Ilten,[8] Simon Knapen,[9] Jongho Lee,[5,10] Saul López Soliño,[4] Benjamin Nachman,[11] Michele Papucci,[11,12] Francesco Polci,[3] Robin Quessard,[13] Harikrishnan Ramani,[11,14] Dean J. Robinson,[11] Heinrich Schindler,[5] Michael D. Sokoloff,[7] Paul Swallow,[8] Riccardo Vari,[15] Nigel Watson,[8] and Mike Williams[16]

- A **Co**mpact **D**etector for **Ex**otics at LHC**b**
- letter of interest released last November, arXiv:1911.00481 [hep-ex]
- letter of intent submitted
- collaboration growing: 28 contributors and 16 institutes

CODEX-b in a Nutshell



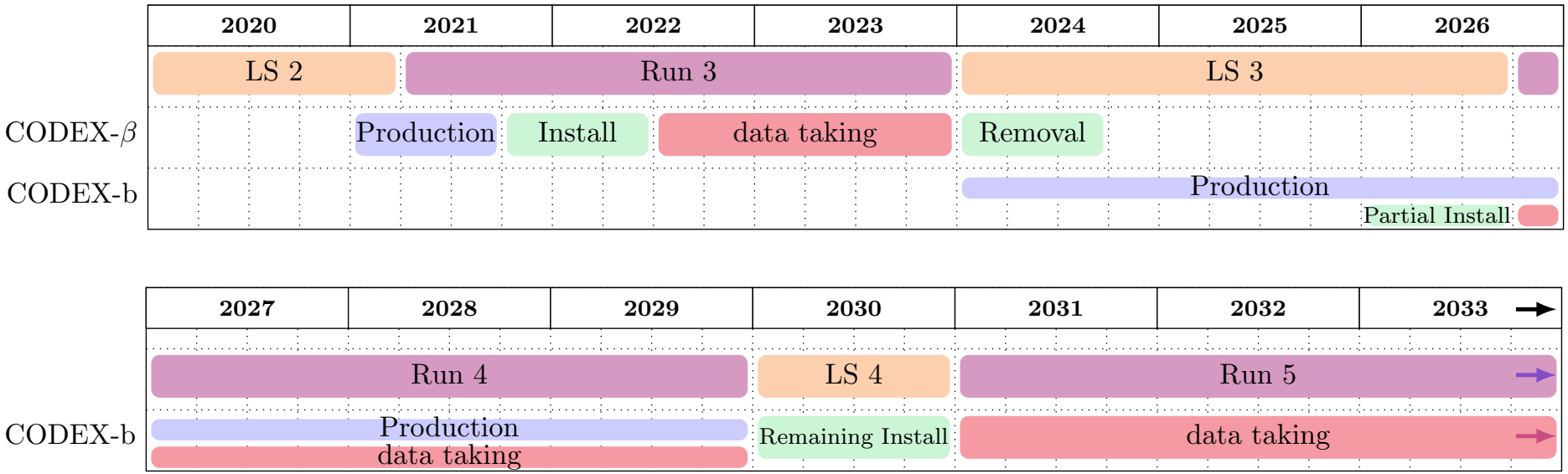
Zooming In



Why CODEX-b?

1. we need a transverse detector at the LHC
2. competitively probes a wide range of LLP models
3. zero background location with necessary services
4. integration with LHCb trigger-less readout
5. compact size and modest cost with ability to extend

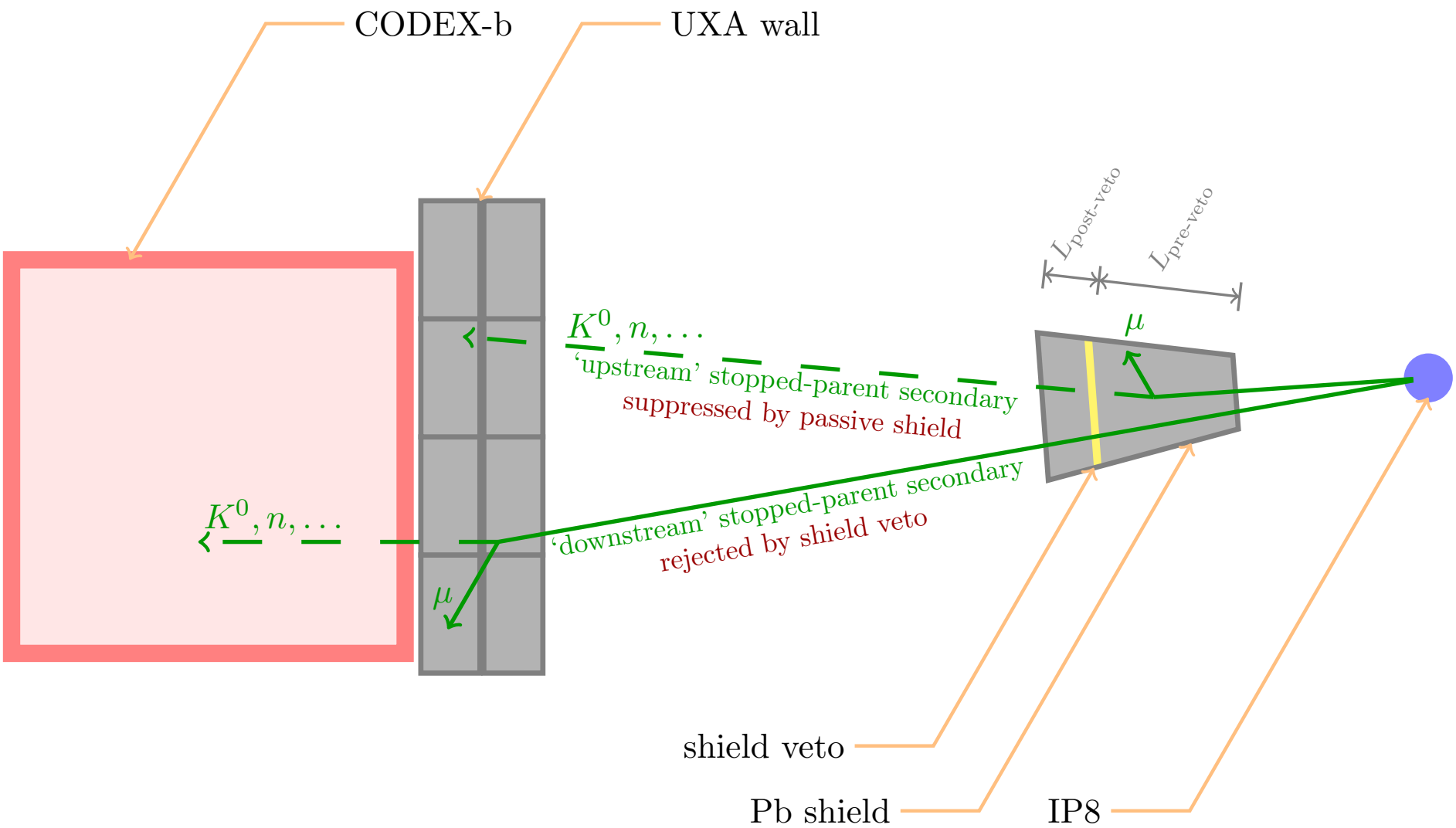
Timing is Key (pre COVID-19)



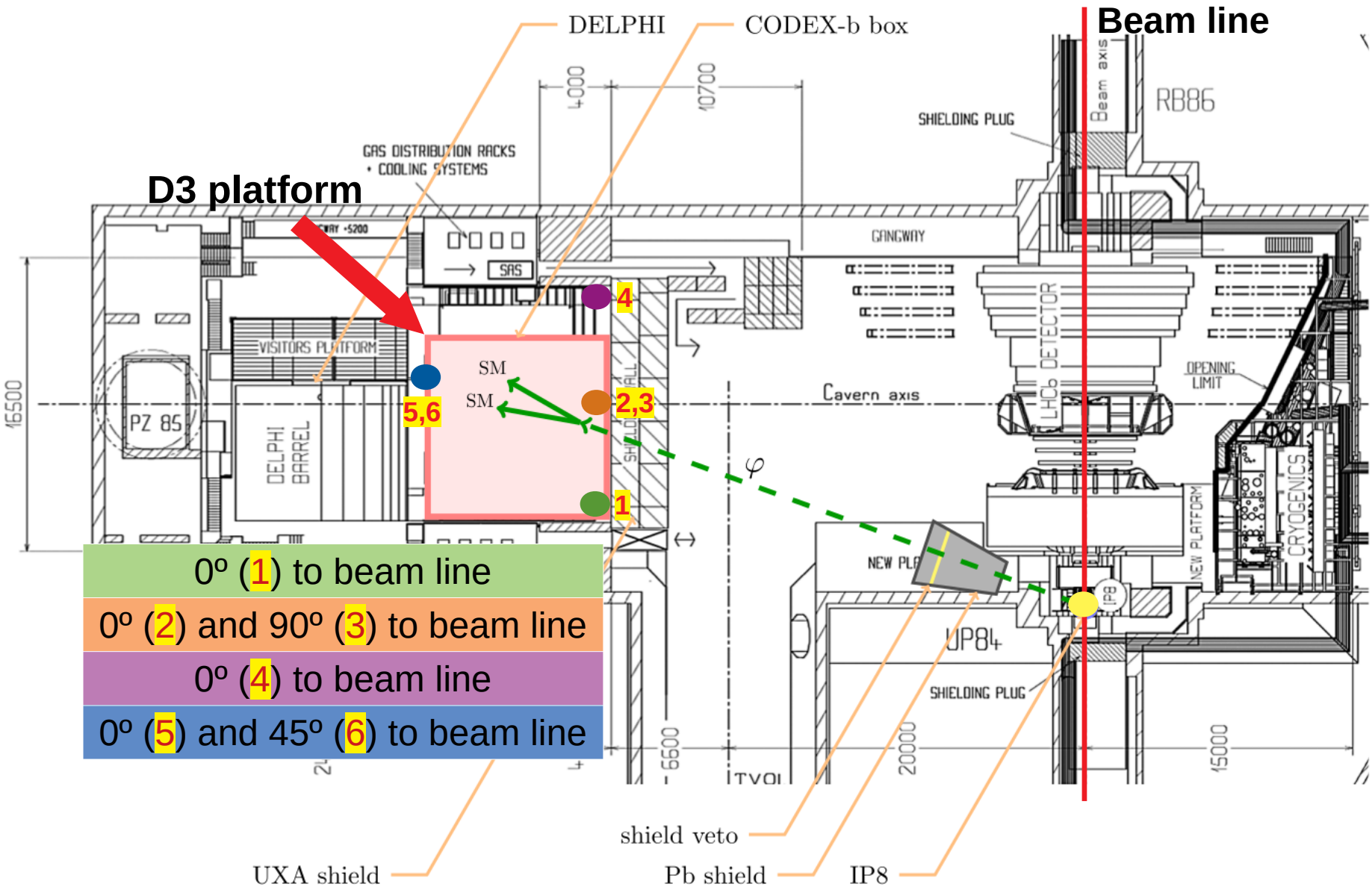
- priority is finalising CODEX-β design and plans
- Birmingham working on technical drawings
- more detailed design informed from CODEX-β

Building CODEX-b

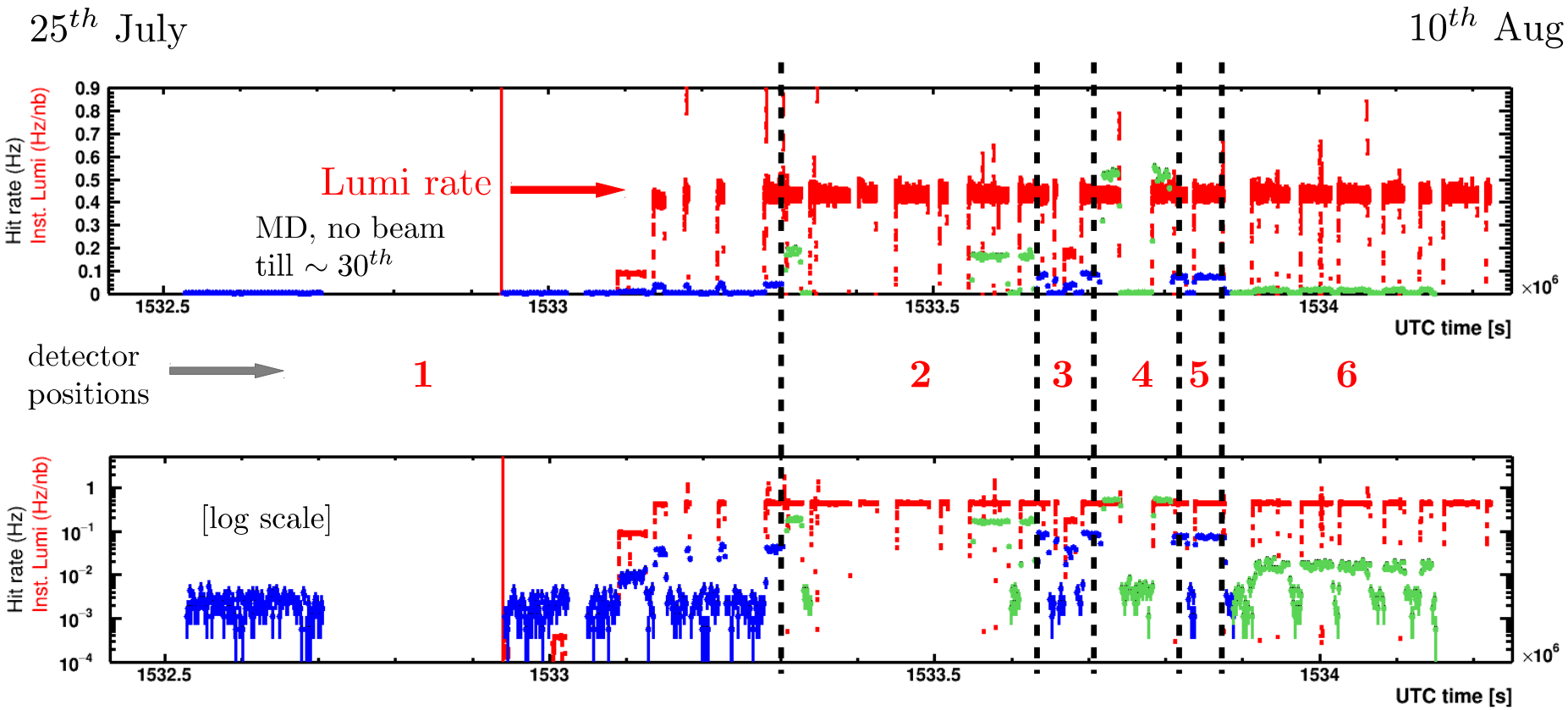
Shielding


CODEX-b
UXA wall
$L_{\text{post-veto}}$
$L_{\text{pre-veto}}$
$K^0, n, \ldots$
'upstream' stopped-parent secondary
suppressed by passive shield
μ
$K^0, n, \ldots$
'downstream' stopped-parent secondary
rejected by shield veto
μ
shield veto
Pb shield
IP8

Background Measurement



Background Measurement



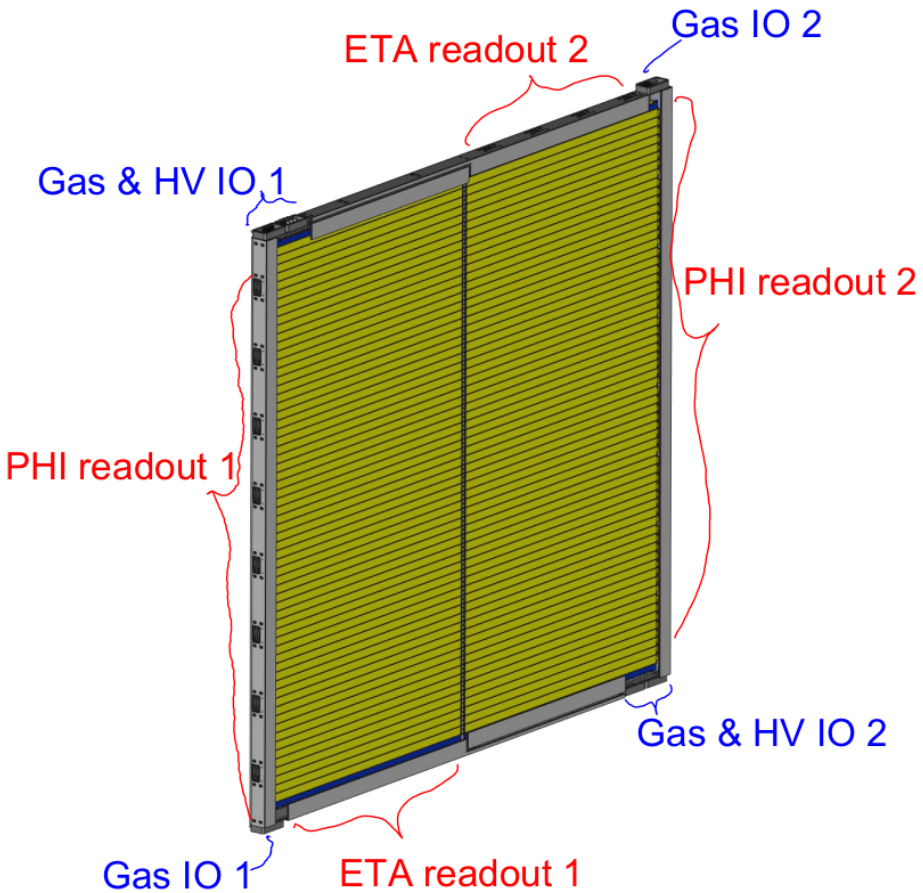
- 0.2 Hz hit rate at point 2 indicates GEANT4 prediction of 10 Hz is conservative

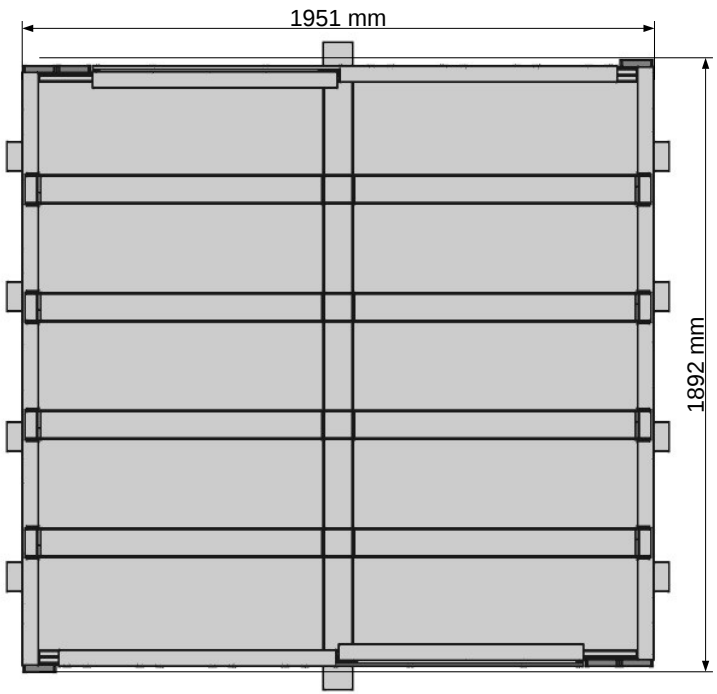
CODEX-β

- $2 \times 2 \times 2$ m^3 with central layer, each layer with triplet of RPCs
- each layer made of 2×1 m^2 RPC block, 42 such layers
- expected hardware cost of 150k EUR

1. *reconstruct charged particles*
2. *reconstruct an expected rate of neutral particles*
3. *demonstrate CODEX-b integration into the LHCb DAQ*

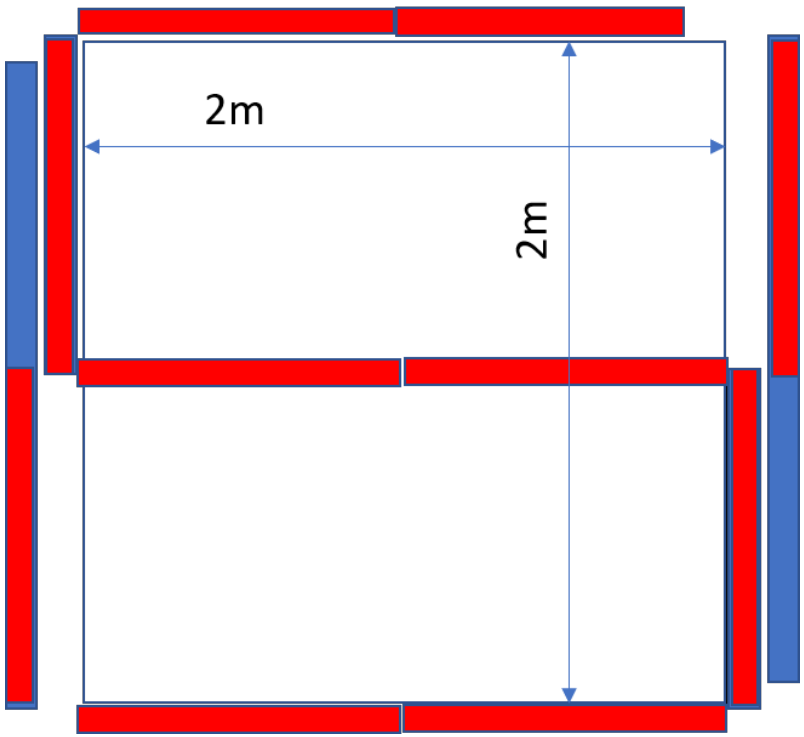
Triplet Support

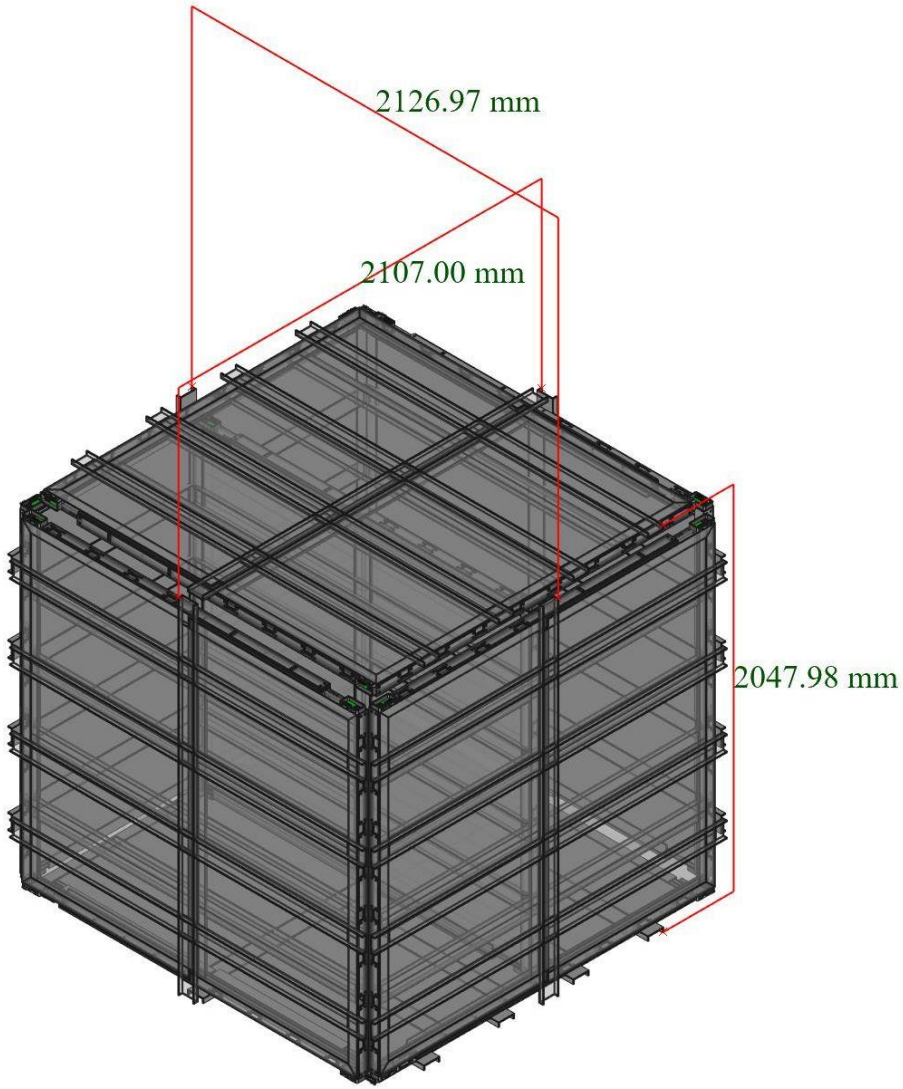




courtesy of James Glover

Cube Design





courtesy of James Glover

Outlook

Some Thoughts

- forward/beam-dump experiments $\implies \downarrow m, \quad \leftrightarrow c\tau, \quad \downarrow \sqrt{\hat{s}}$
- LHC detectors $\implies \uparrow m, \quad \uparrow c\tau, \uparrow \sqrt{\hat{s}}$
- transverse detectors $\implies \downarrow m, \quad \uparrow c\tau, \uparrow \sqrt{\hat{s}}$
- *we need a transverse detector at LHC*

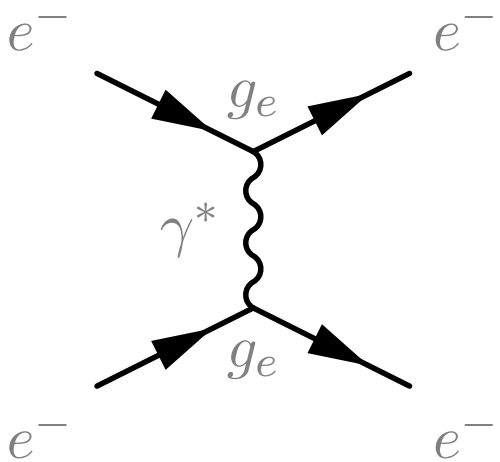
- CODEX-b covers does not have world-leading reach ...
- covers significant portions of parameter space
- *low cost with decent coverage compared to other proposals*

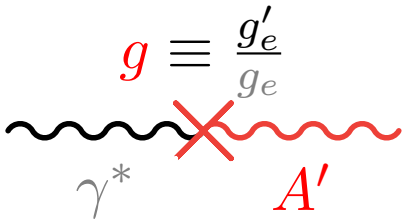
- clear plan forward for building CODEX-b
- first steps taken, CODEX-β plans underway
- *what else should we be thinking about?*

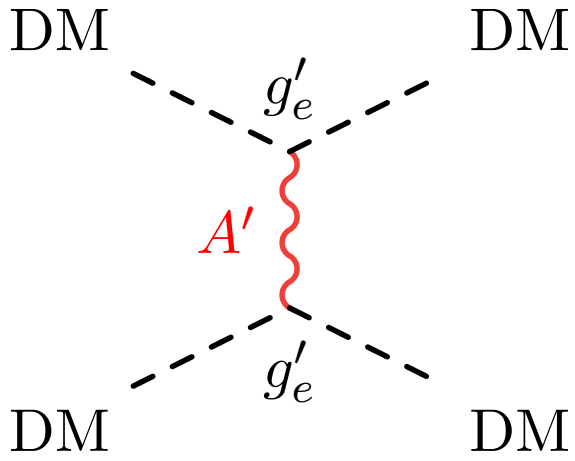
- *looking for new collaborators*

Appendix

An Example



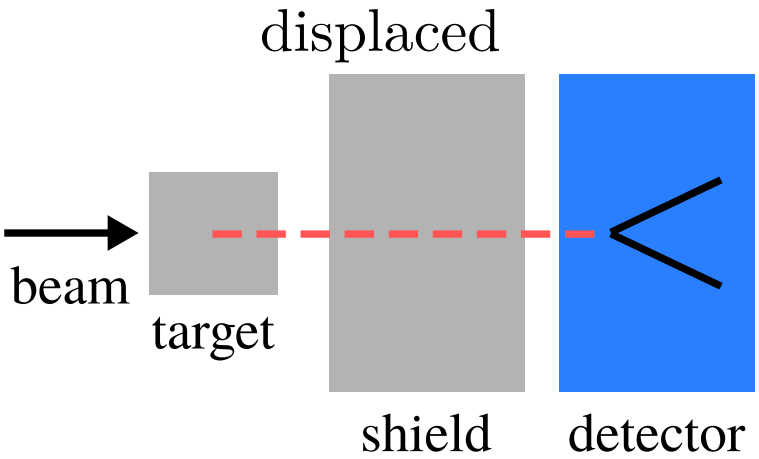


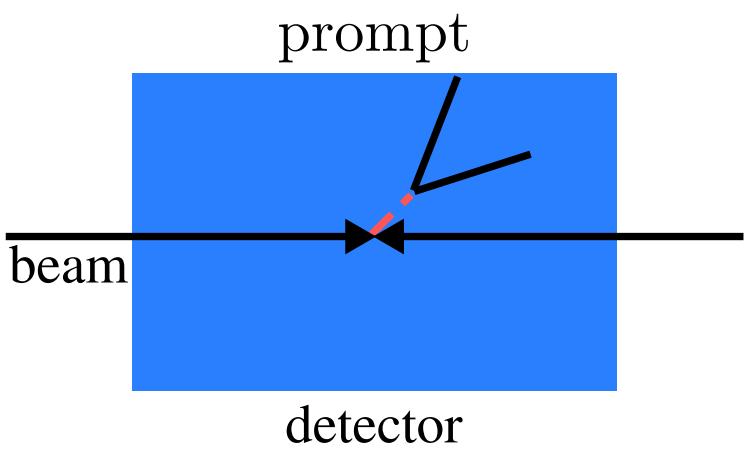


1. broken $U(1)$ gauge symmetry in dark sector
2. allow mixing between dark and SM hypercharge fields

$$\mathcal{L} \supset -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{{m_{A'}}^2}{2}A'_\mu A'^\mu + g_e J^\mu A_\mu + \varepsilon g_e J^\mu A'_\mu$$

Search Strategies





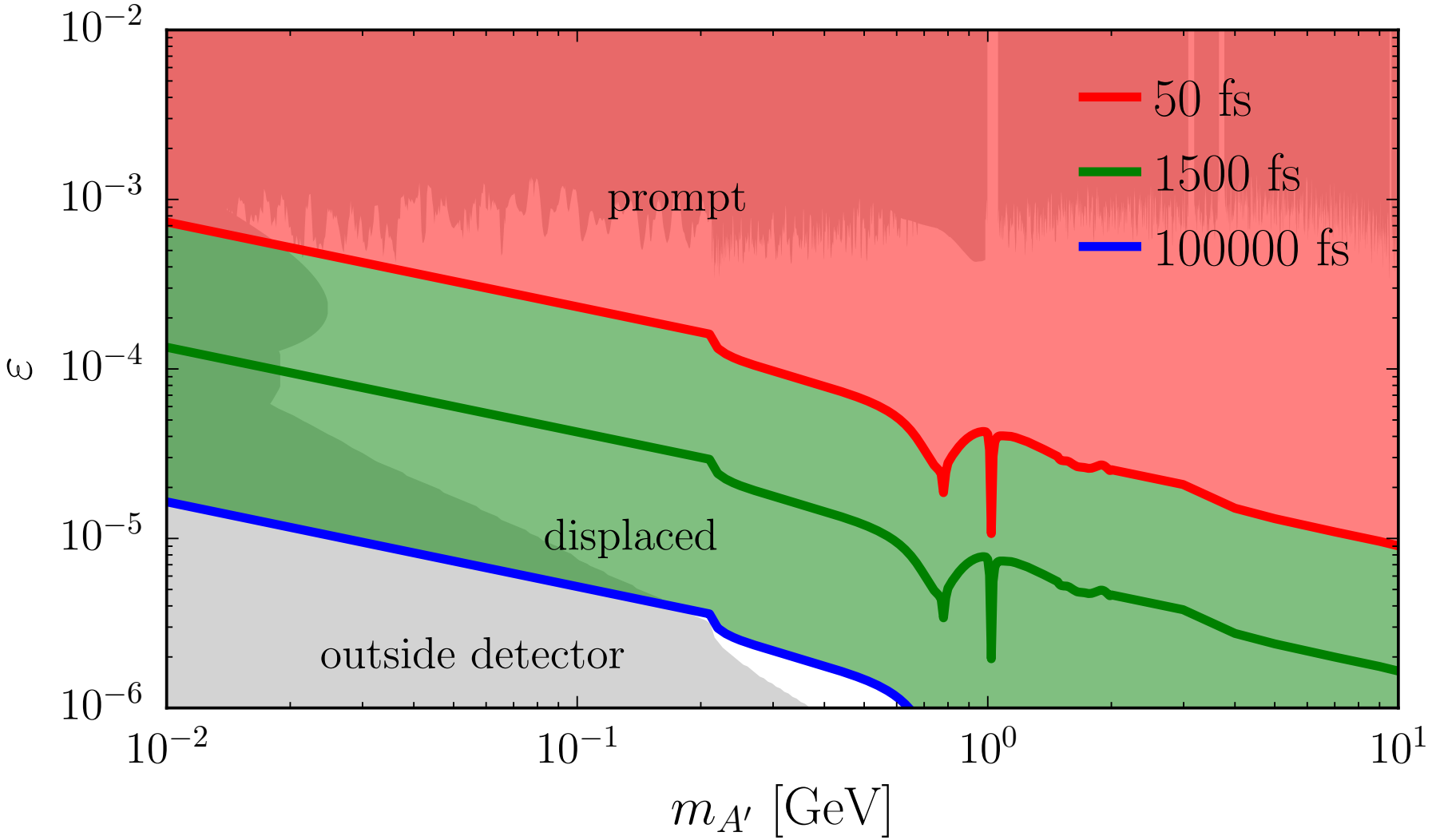
- sensitive to long lifetimes
- EM background free
- difficult to normalise

- sensitive to shorter lifetimes
- bump hunt on large EM background
- normalised from sidebands

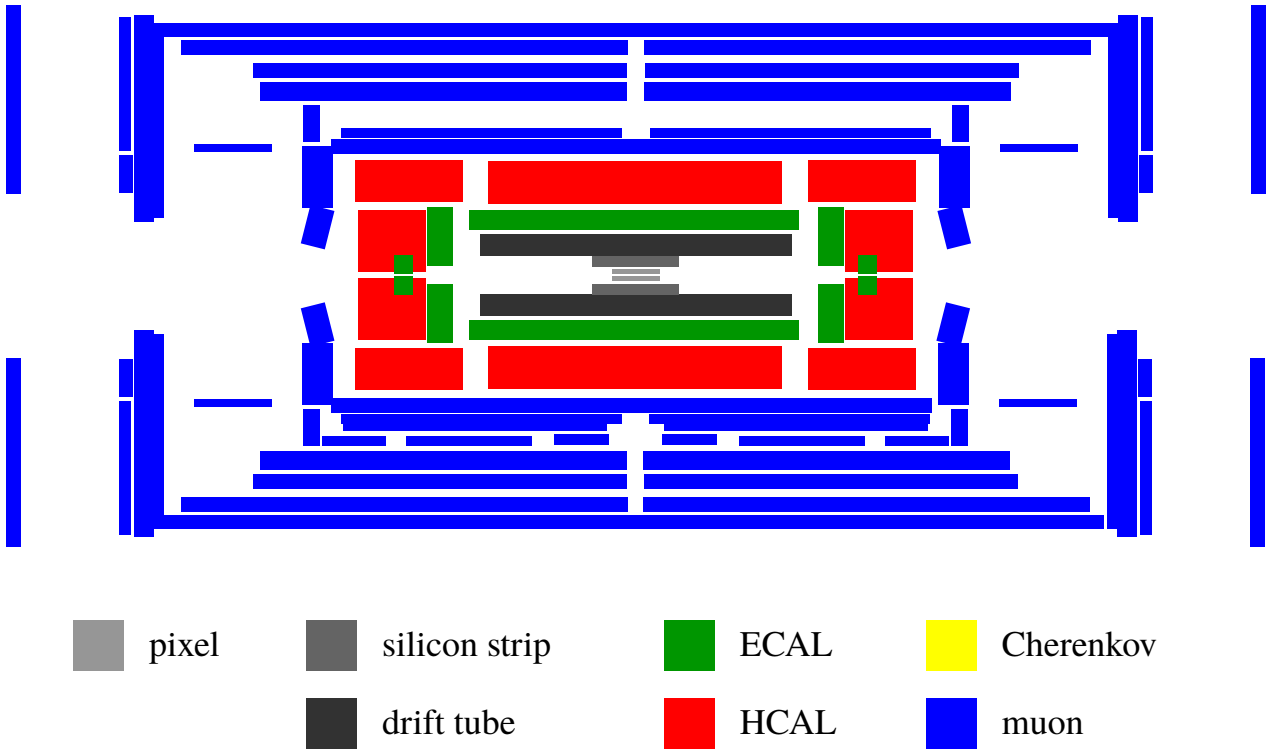
- do both simultaneously for best of both worlds

Parameter Space

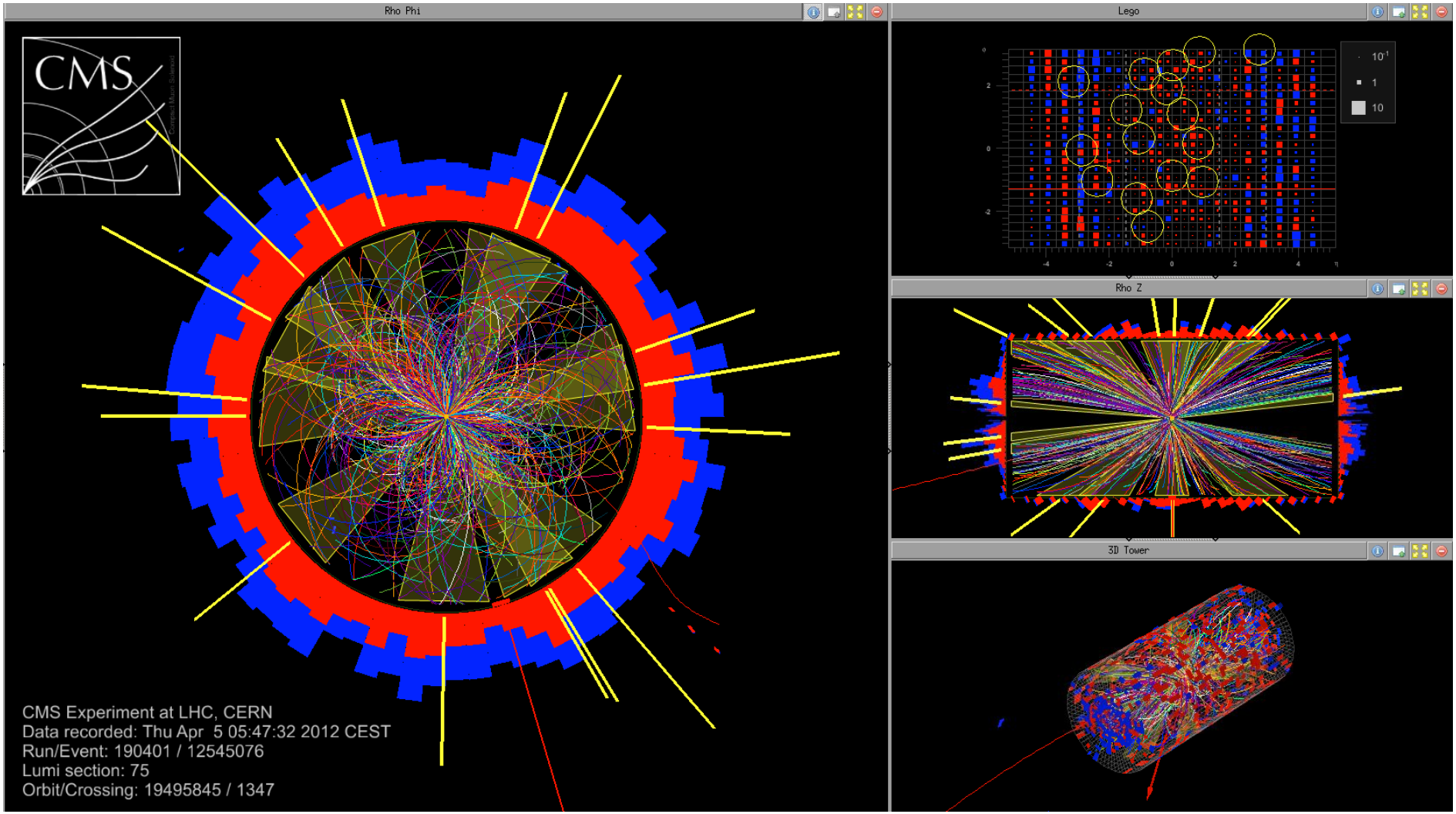
JHEP 06 (2018)



LHC Detectors

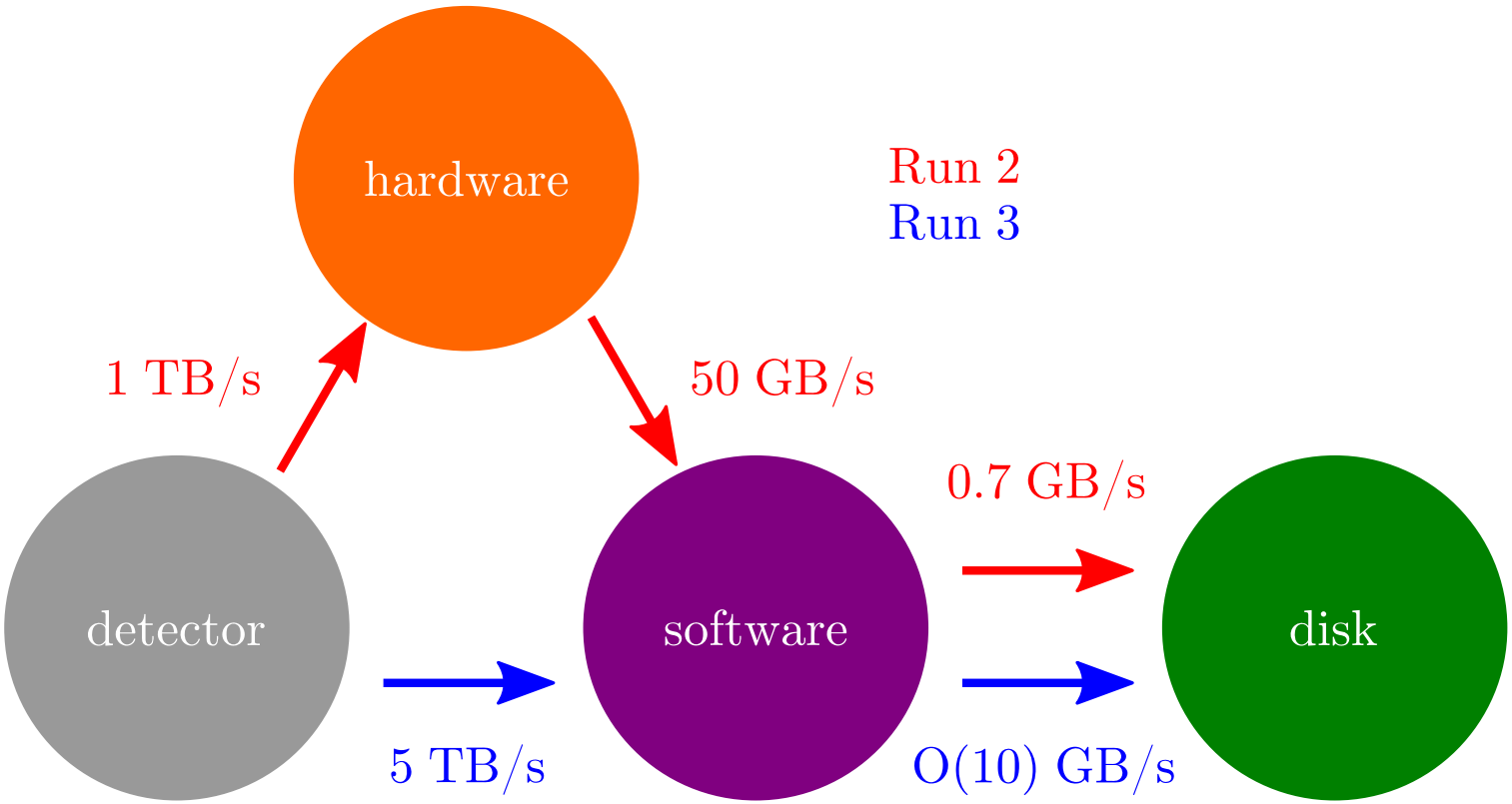


Seeing a Signal



LHCb Trigger

LHCb, JINST 8 (2013)



- real-time calibration and full event reconstruction in Run 2
- inclusive dimuon from threshold and jet triggers in Run 2
- full detector readout in Run 3

Model Overview

Vector (A')	$hA'A'$	$F'F$
$F'F$	yes	no reach

Scalar (S)	$SH^\dagger H$	$S^2H^\dagger H$
$SH^\dagger H$	yes	yes

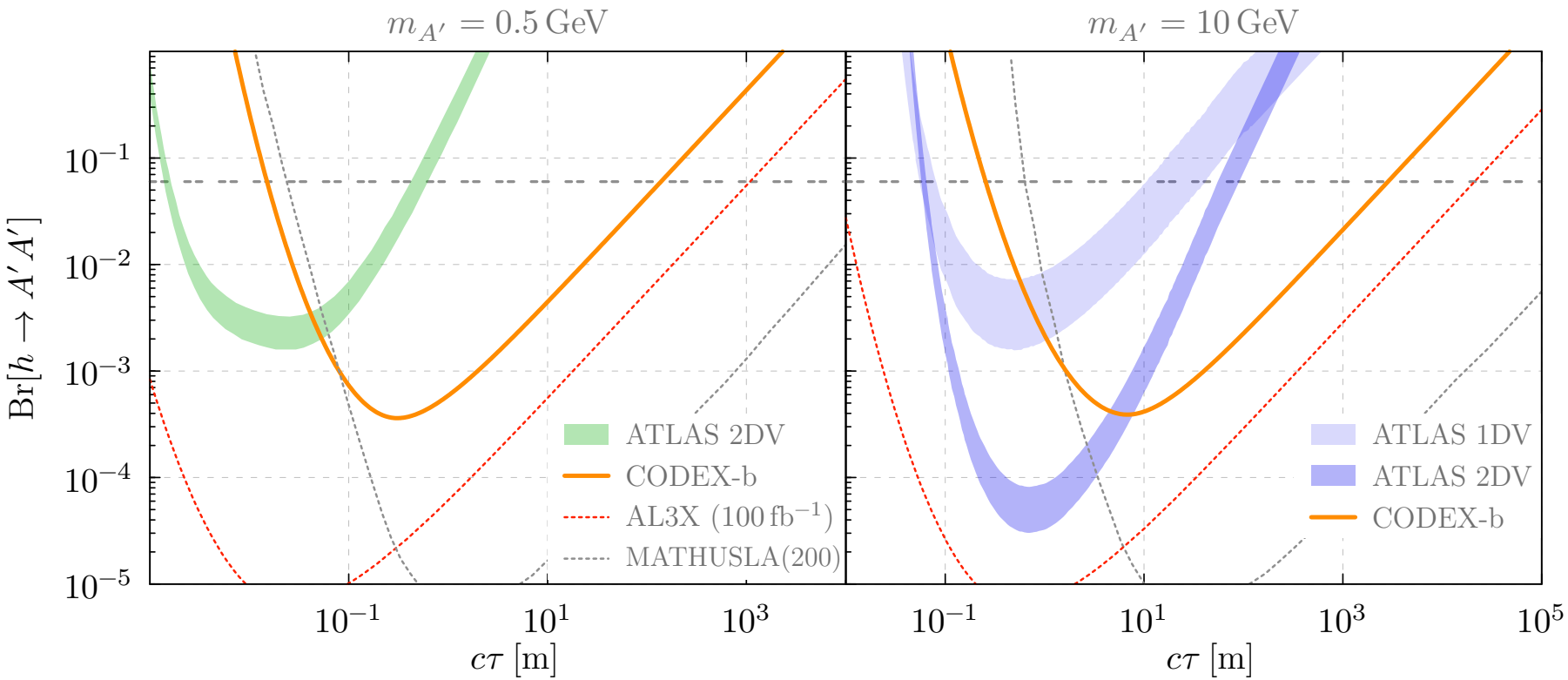
HNL (N)	HLN
HLN	yes

ALP (a)	$\partial_\mu a\bar{q}\gamma^\mu\gamma^5 q$	$a\tilde{G}G$	$a\tilde{F}F$	$a(W\tilde{W}-B\tilde{B})$
	yes	yes	pending	pending

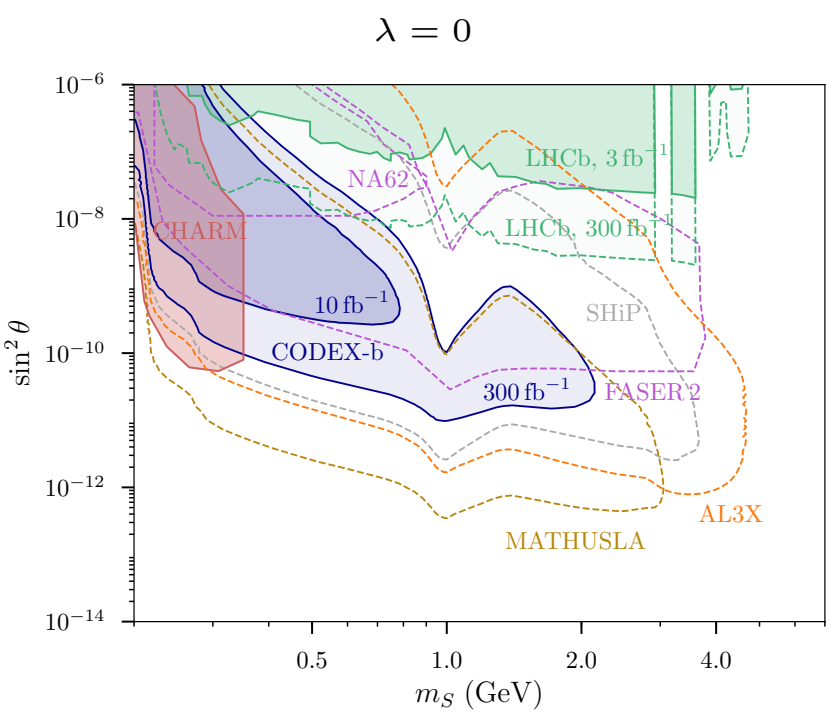
Production portal
Decay portal
UV operator

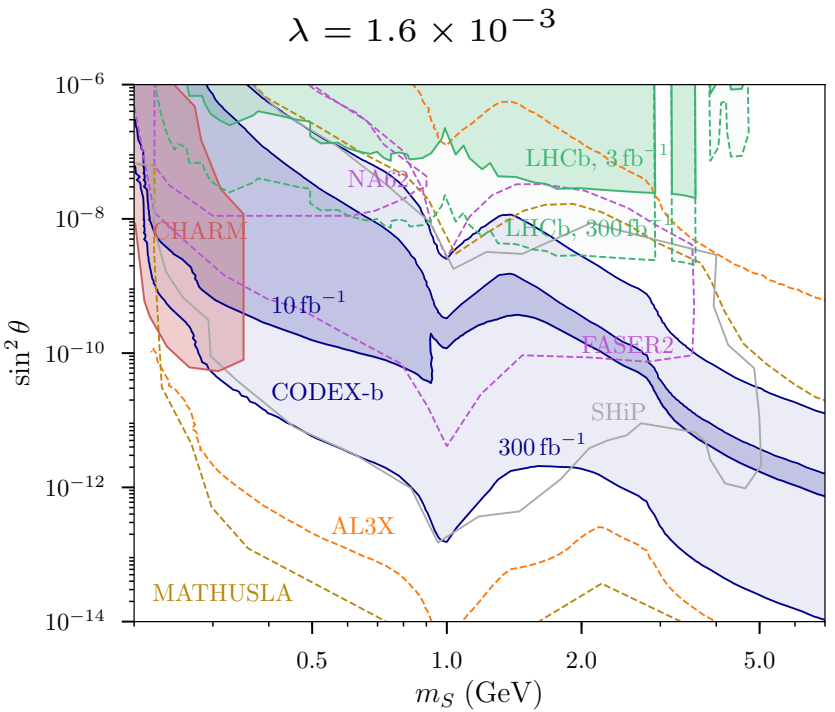
Dark Photon

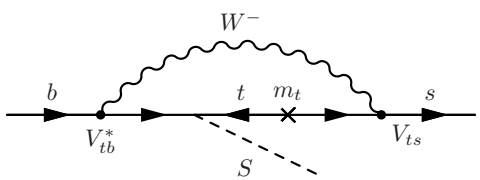
- no sensitivity to inclusive production from EM currents
- sensitive to production from $H \to A'A'$ decays

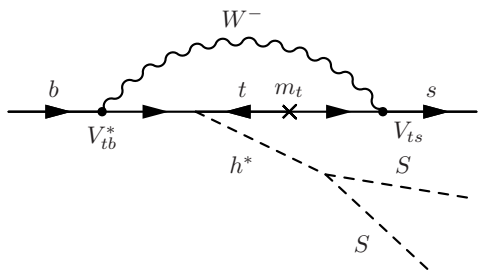


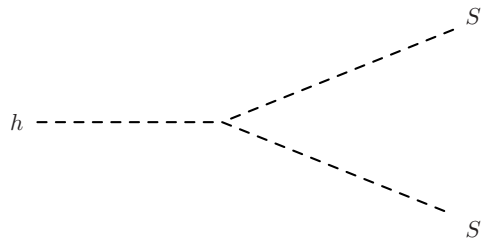
Higgs Portal



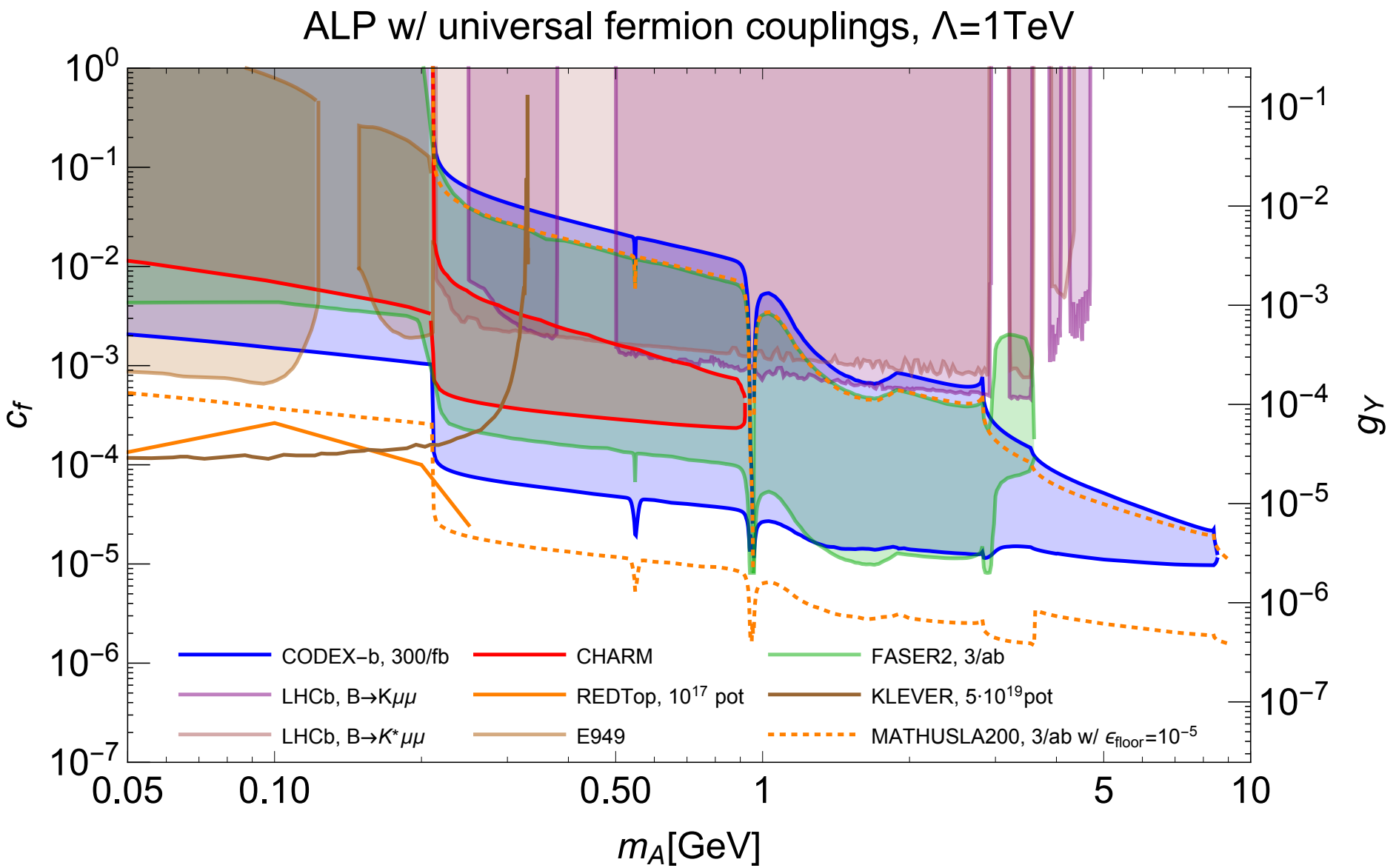




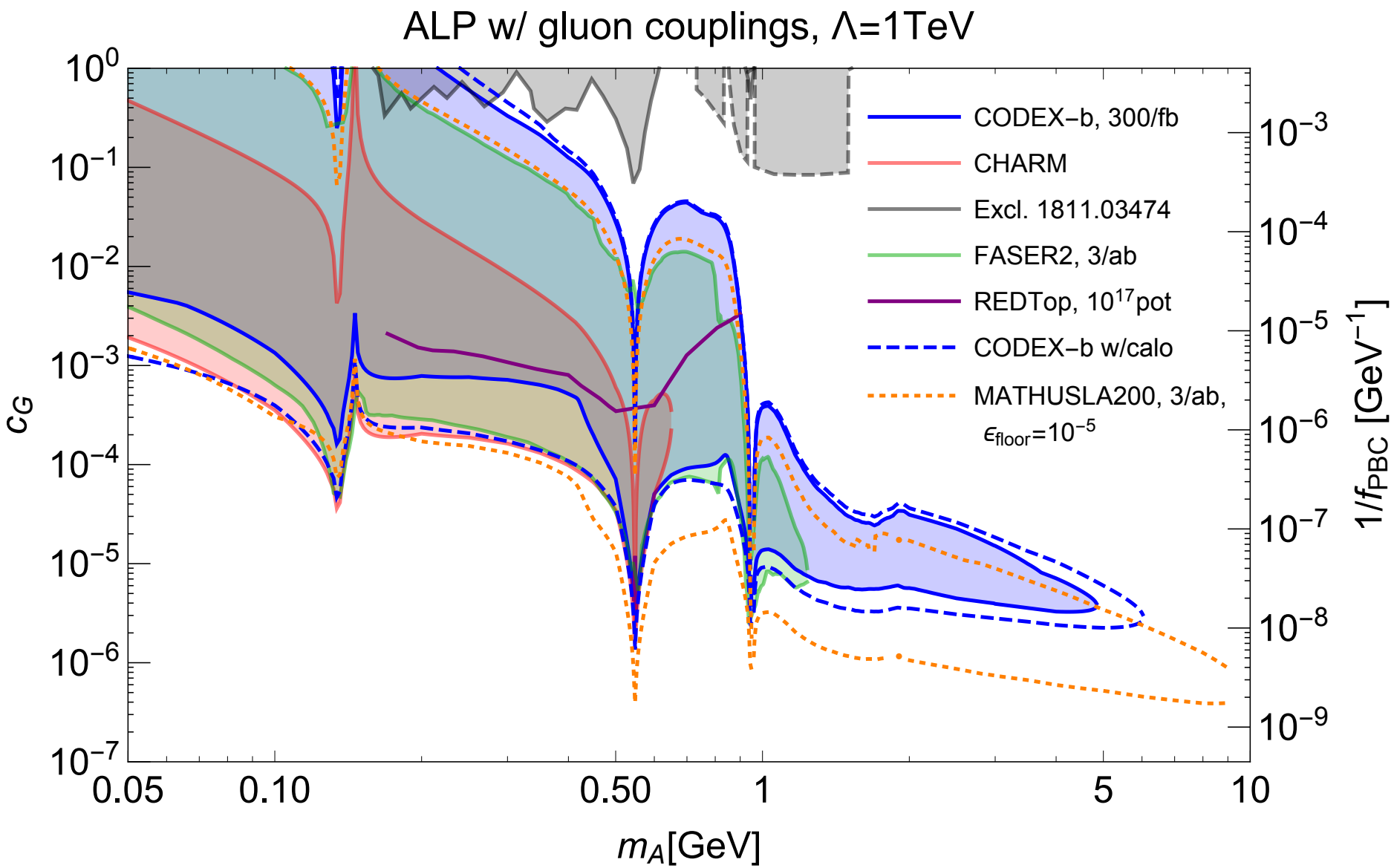




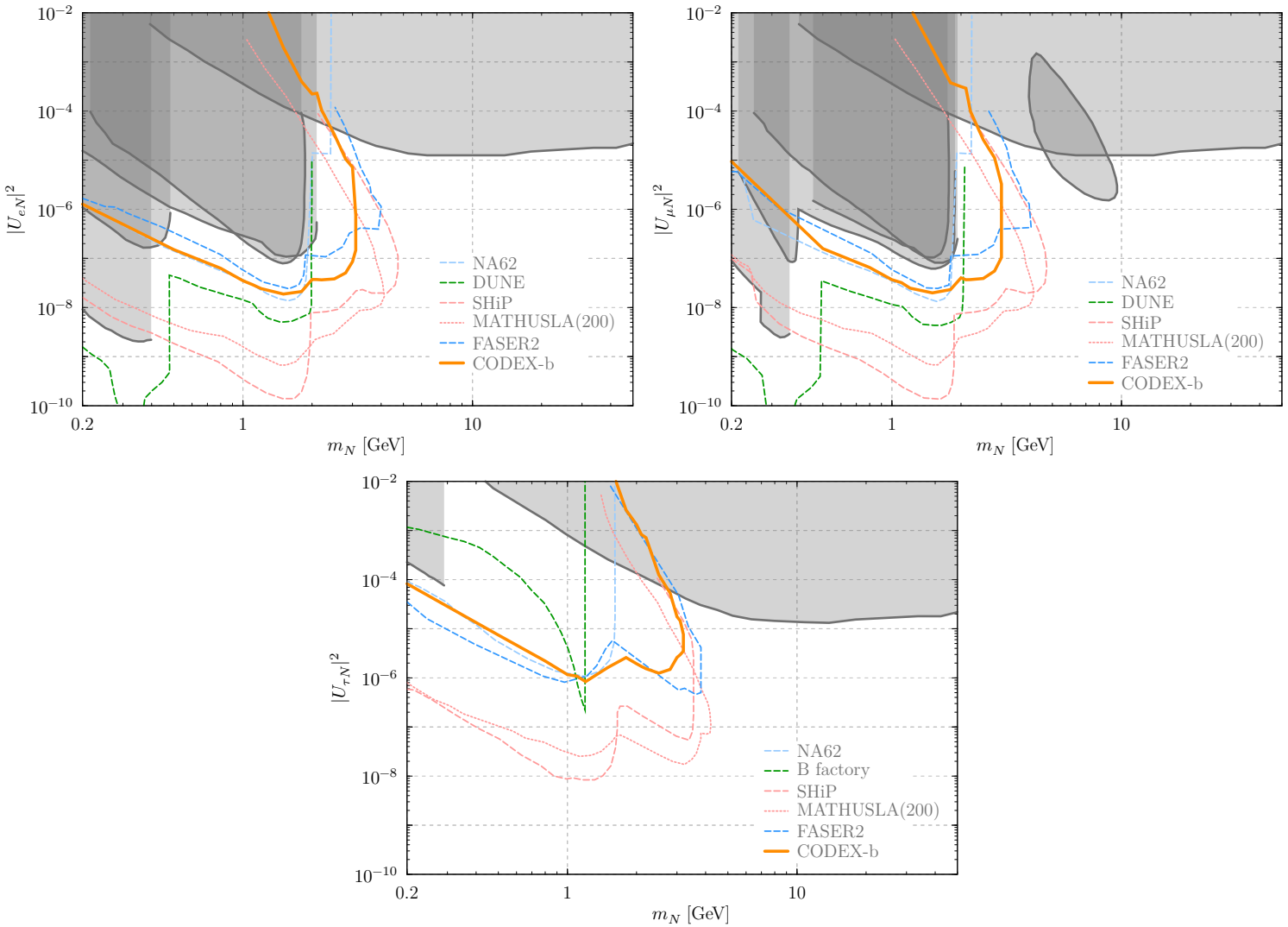
Fermion Coupled ALPs



Gluon Coupled ALPs



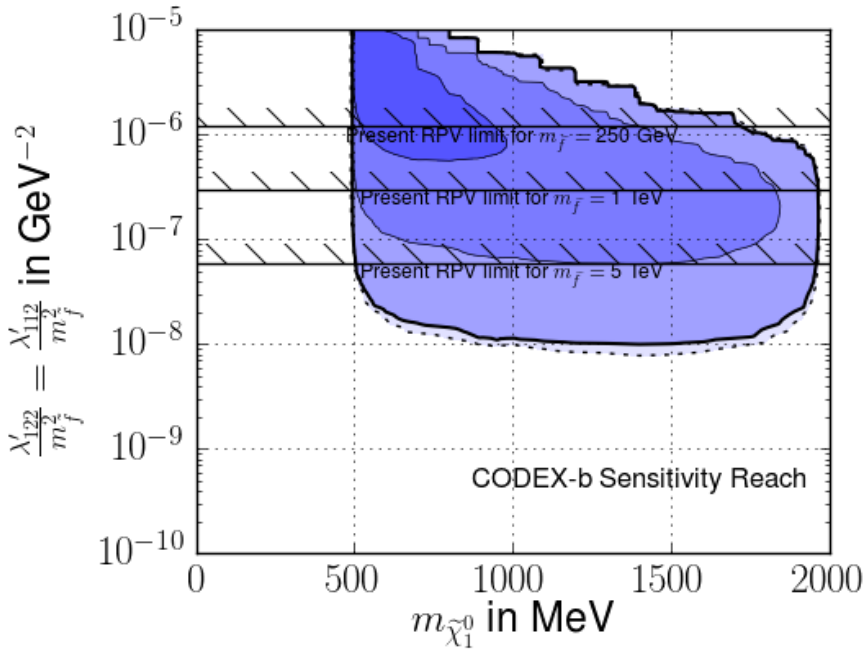
Heavy Neutral Leptons

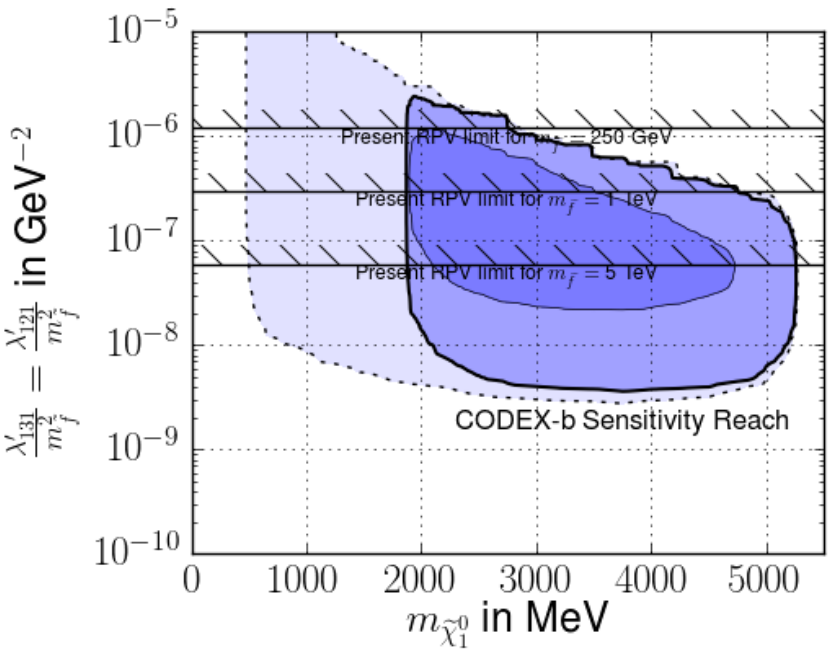


R-parity Violating Supersymmetry

- study from Dercks, Vries, Dreiner, and Wang in PRD 99 055039 (2019)

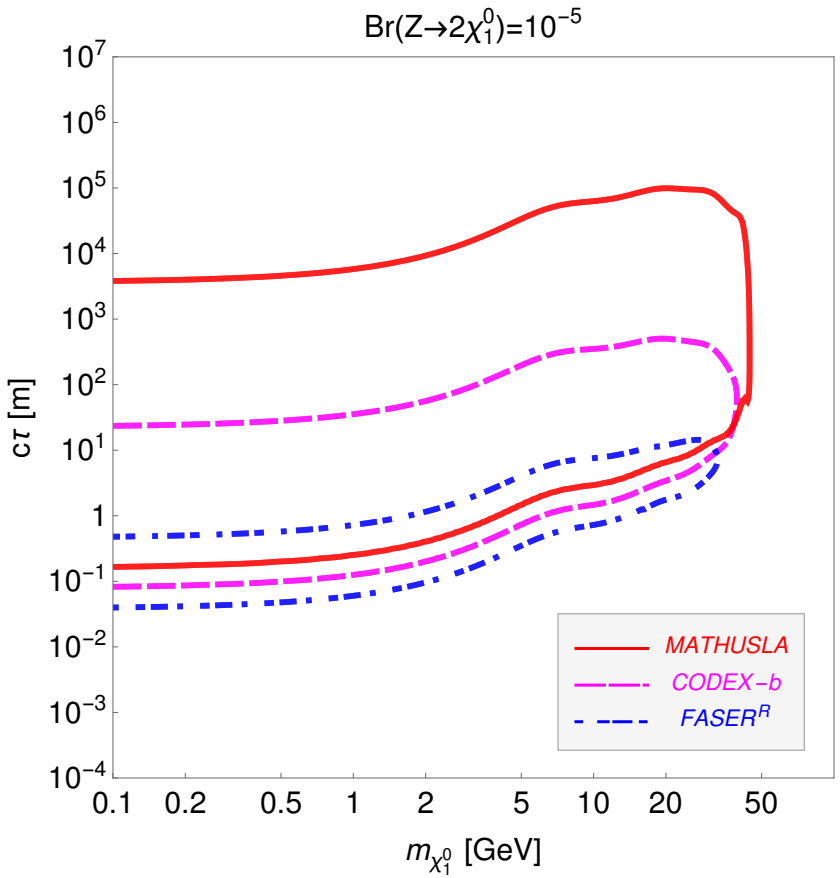
benchmark	coupling	production	decay products
1	$\lambda'_{122},\ \lambda'_{112}$	$D_s^{\pm} \to \tilde{\chi}_1^0 + e^{\pm}$	$\eta, \eta', \phi, K^{0,\pm} + \nu_e,\ e^{\mp}$
4	$\lambda'_{131},\ \lambda'_{121}$	$B^{0,\pm} \to \tilde{\chi}_1^0 + X^{0,\pm}$	$D^{\pm}, D^{*\pm} + e^{\mp}$

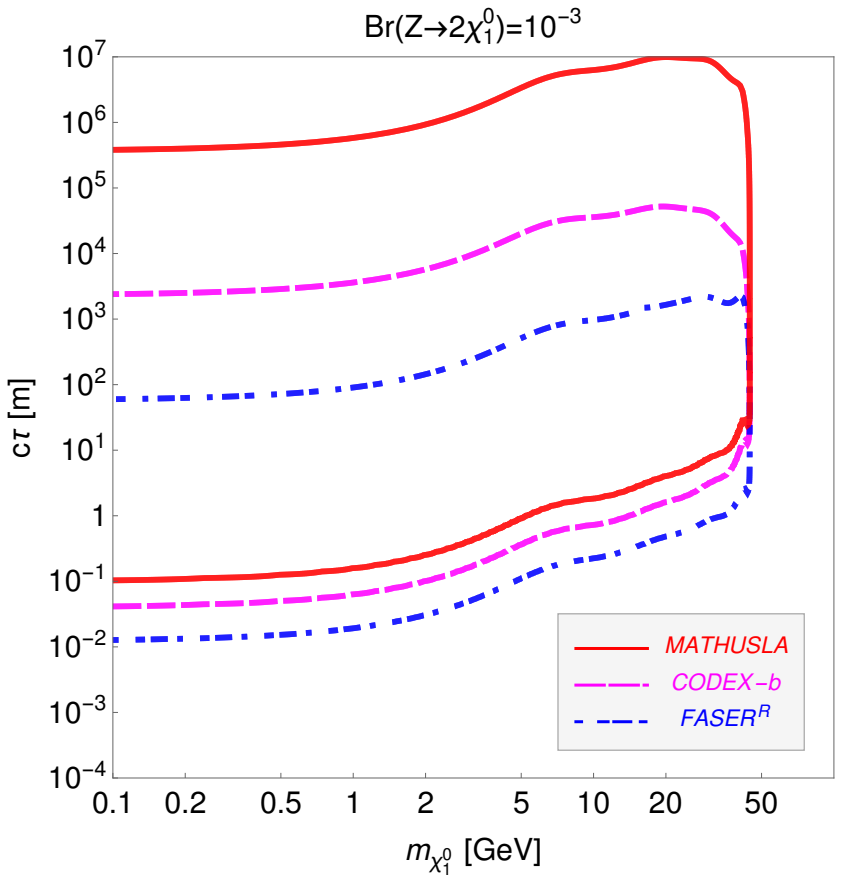




R-parity Violating Supersymmetry

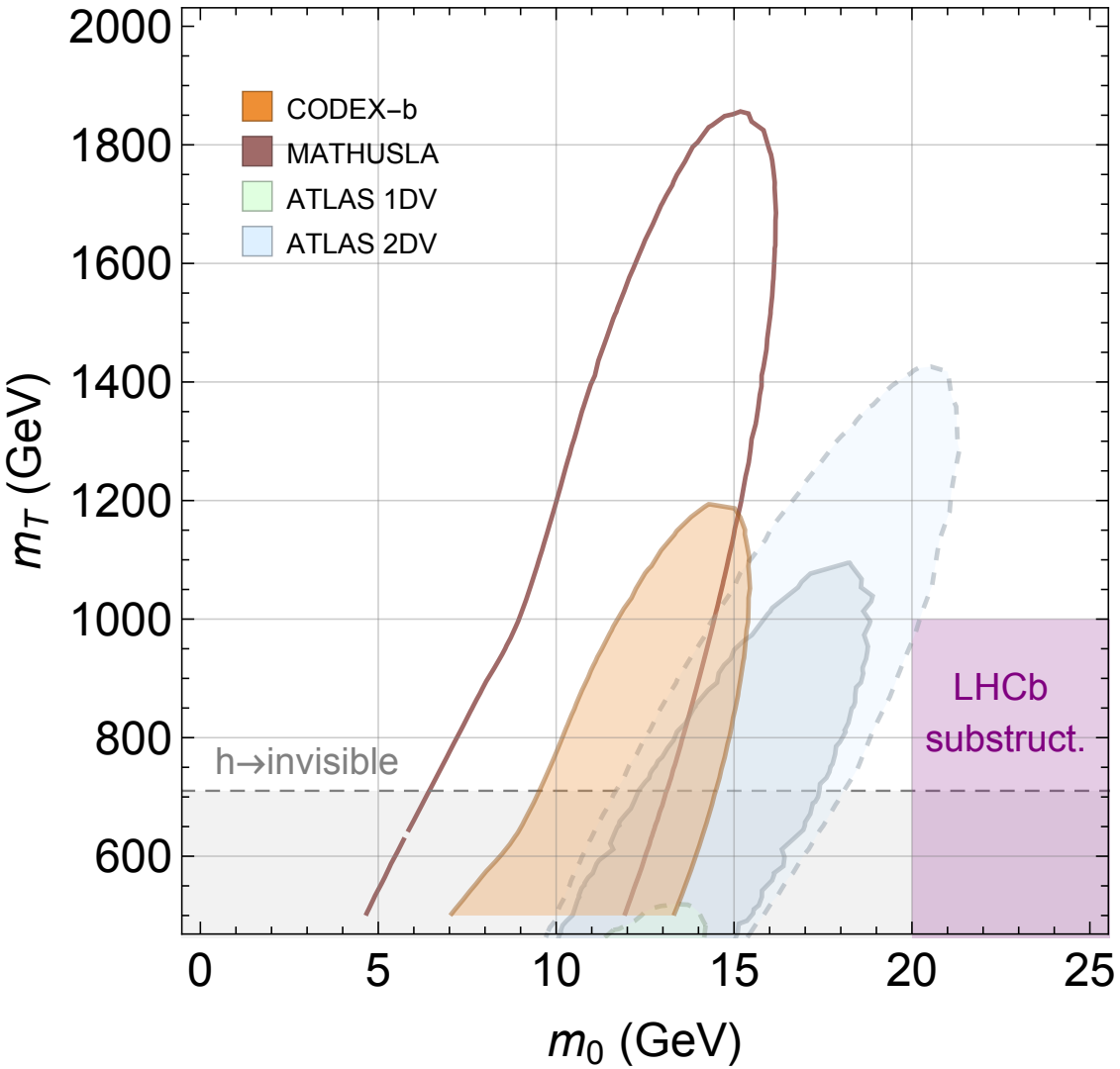
- study from Helo, Hirsch, and Wang in JHEP 07 056 (2018)





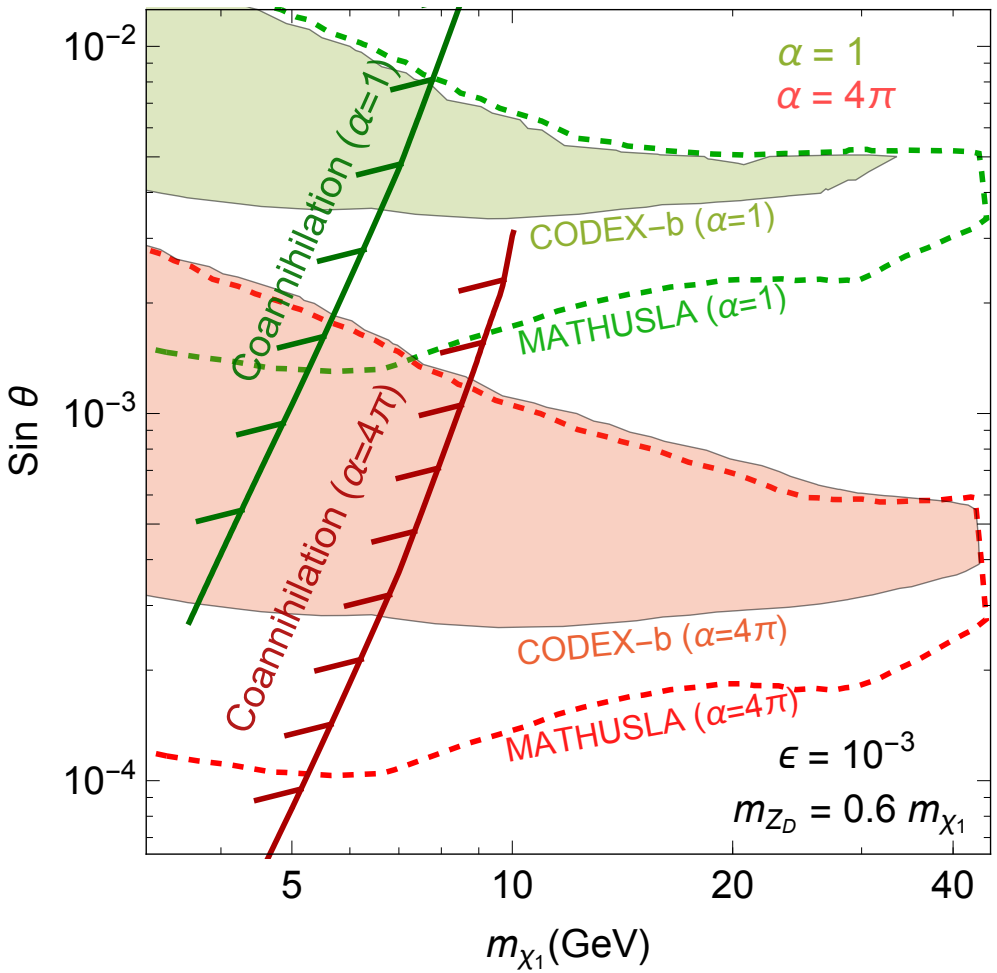
Neutral Naturalness

- consider fraternal twin Higgs model and search for glueball



Dark Matter Models

- a number of models considered including inelastic, co-scattering, co-annihilation, *etc.*



Backgrounds

- 10^{14} neutrons and K_L^0 per 300 fb^{-1}
- this requires 32λ of shielding
- 7λ from UXA wall, 25λ from lead shield
- expect $\approx 10^9$ muons per 300 fb^{-1} which can produce secondaries
- 10^3 K_L^0 per 300 fb^{-1} pass through the shield
- need active layer in shield for vetoing
- update of previous studies with detailed GEANT4 study

Background Simulation