Searches for Unconventional and Long-Lived Signatures (beyond the SM)

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Long-Lived Particles

Searches for long-lived particles (LLPs) are well motivated (at least one type of LL BSM particle must exist) as LLPs arise naturally in many BSM scenarii.

Why long lived? (Could be any or all of these.)

amplitude suppressed

$$\Gamma \propto g^2 |\mathcal{A}|^2 \frac{\Phi}{M}$$

minimal phase space available

small coupling

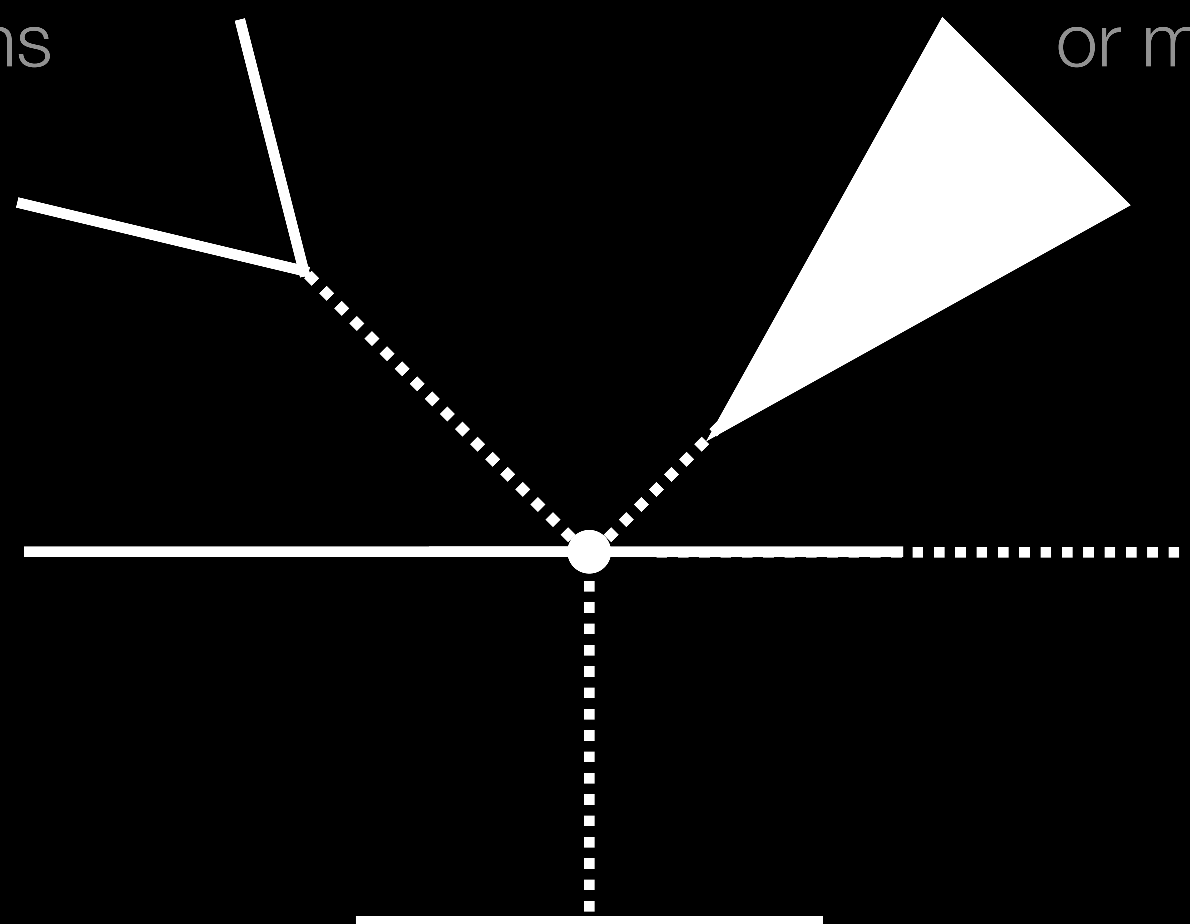
Too many results from the LHC to cover in 20 minutes, so I'll focus on results made public since the previous LHCP (also try to summarize the previous work).

Signatures of LLPs

LLP signatures depend on the model (often also include associated activity).

Displaced Vertex
from pp collision or HF decay,
2+ charged particles,
often with leptons

Displaced/Emerging Jet
jets (possibly lepton jets),
from a DV, or containing DVs,
or many displaced tracks



Abnormal Track
dE/dx, time of flight,
RICH rings,…

Disappearing Track
decay to invisible LLP
plus lost soft
particle(s)

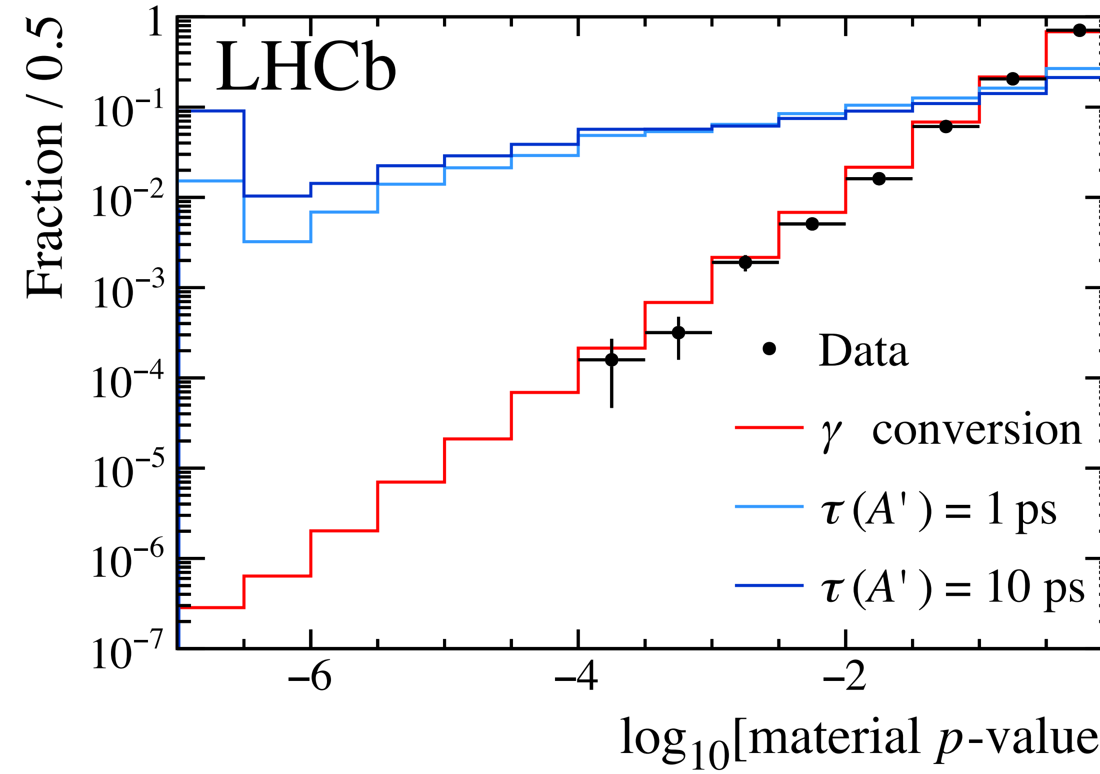
Stopped Particles
out-of-time decays to
neutrals or leptons

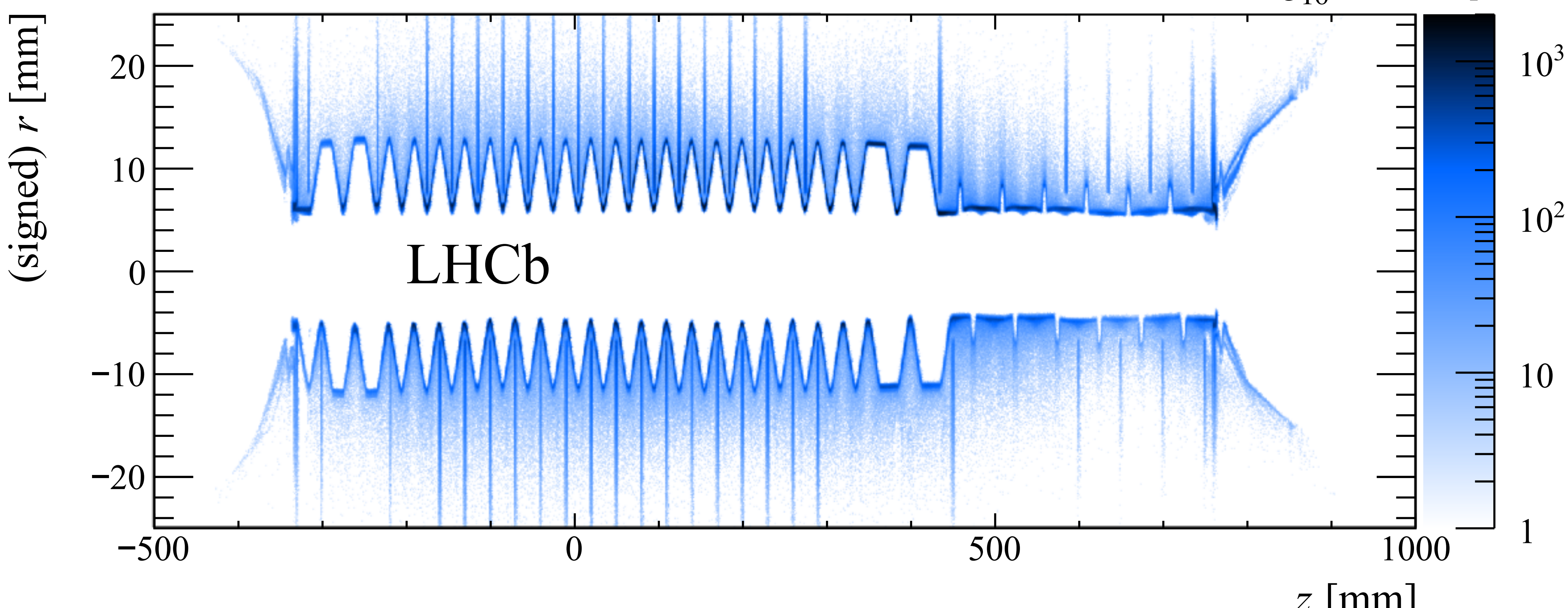
Other potential signatures exist, but only these have been employed thus far @ the LHC.

LHCb Material

LHCb-DP-2018-002
[1803.07466]

New high-precision map of the VELO material and a data-driven method for determining a p-value for the SV-from-material hypothesis (allows blind BKGD-free selections).

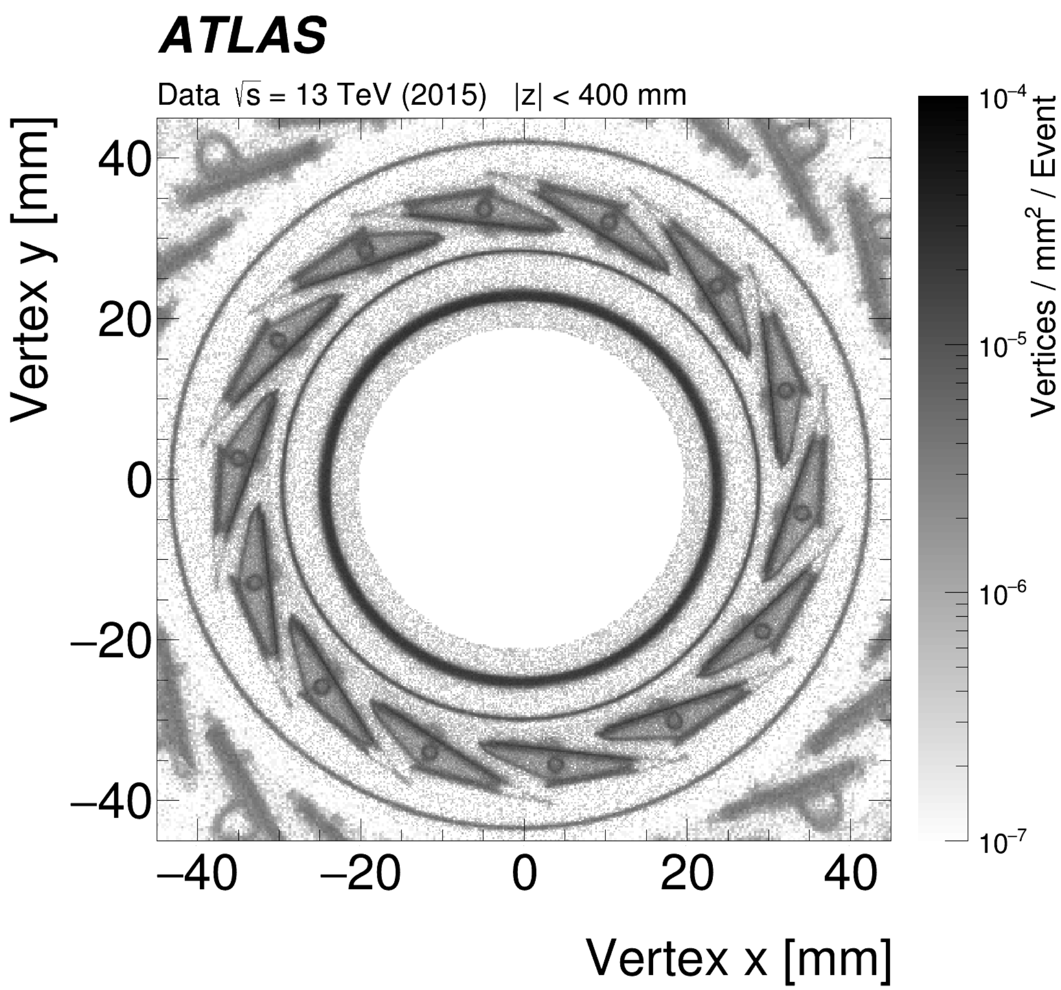


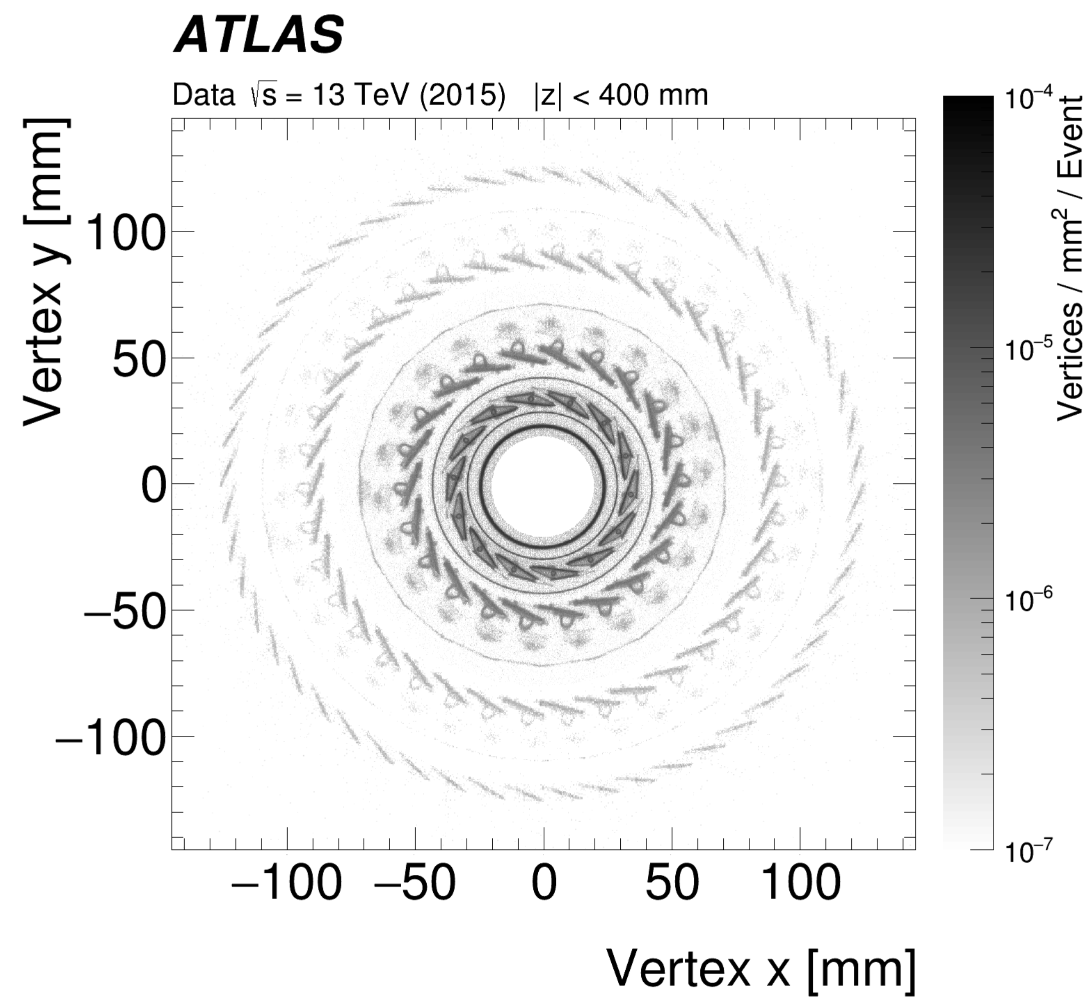


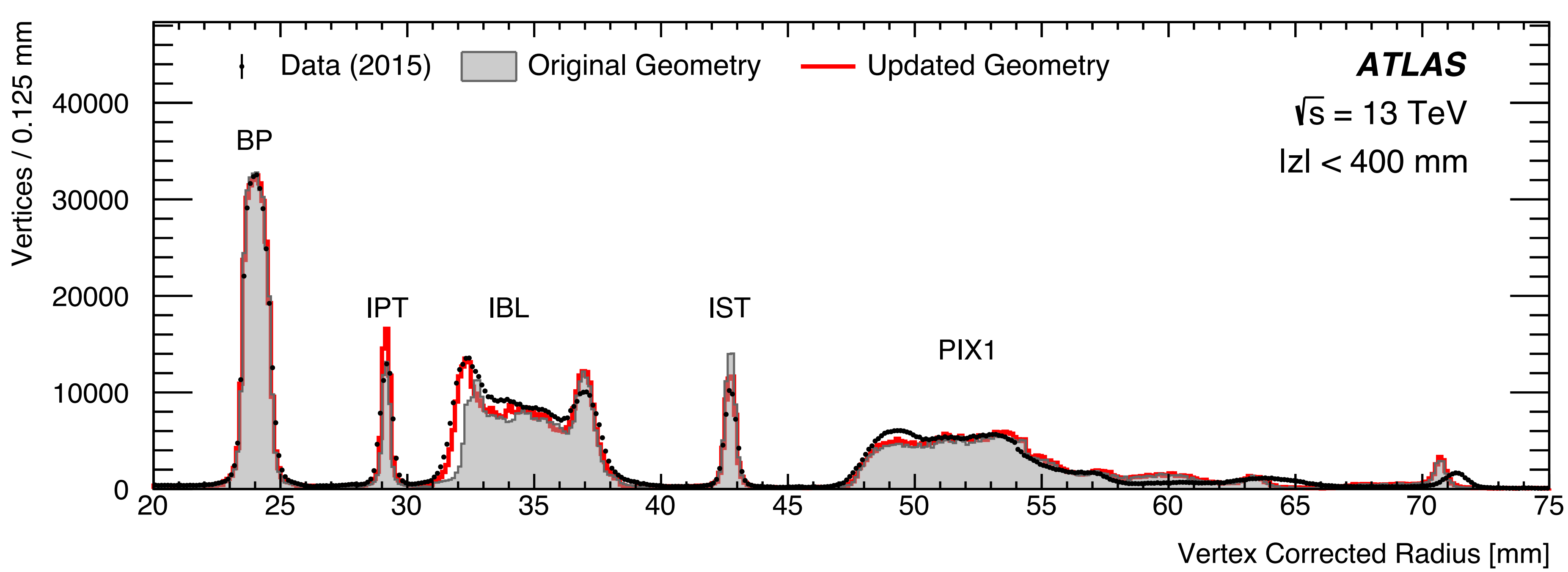
ATLAS Material

[1707.02826]

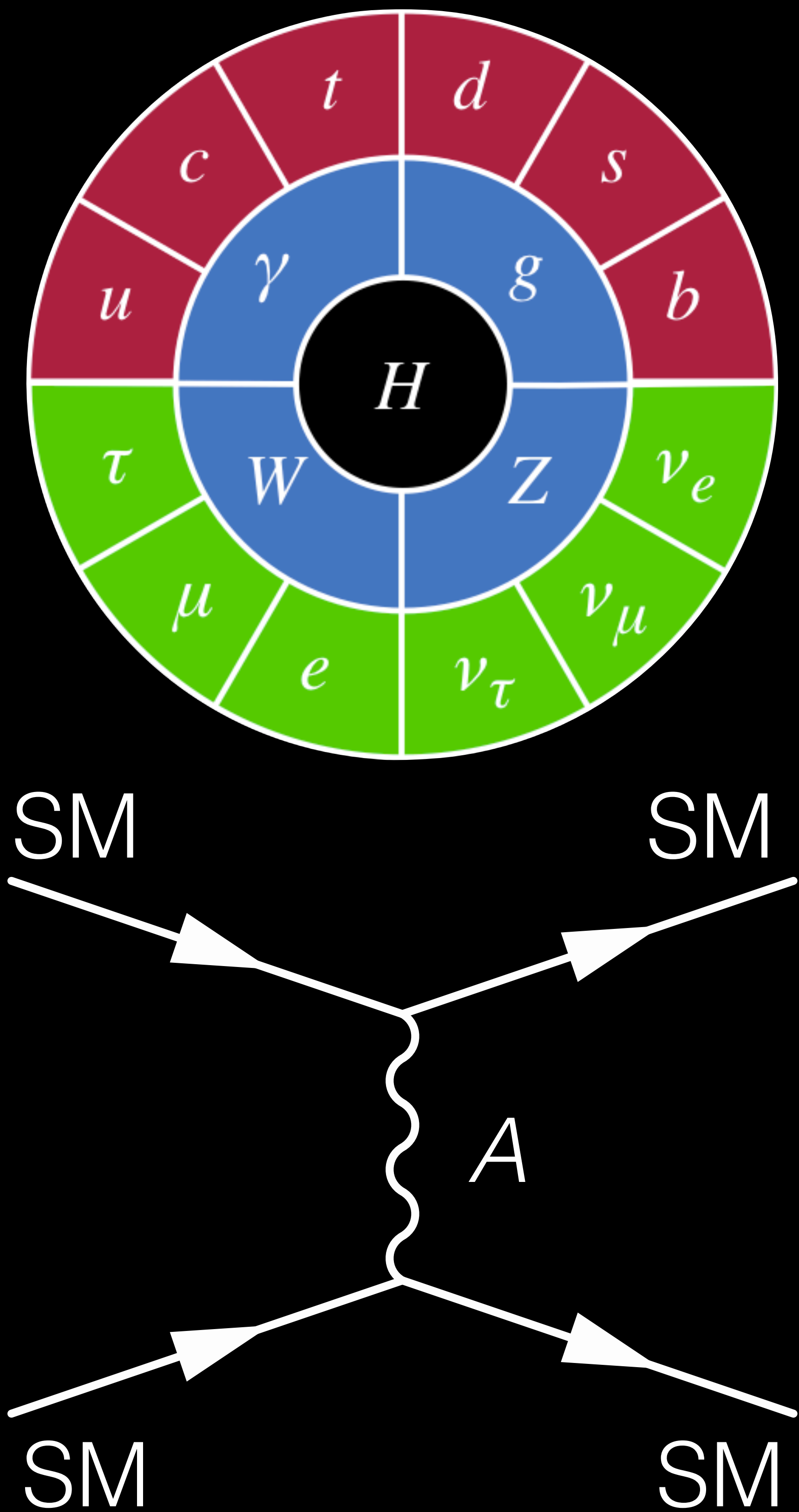
New (incredibly detailed) study of the ATLAS inner detector material (including the IBL) using Run 2 data, and an improved material description in the ATLAS MC.

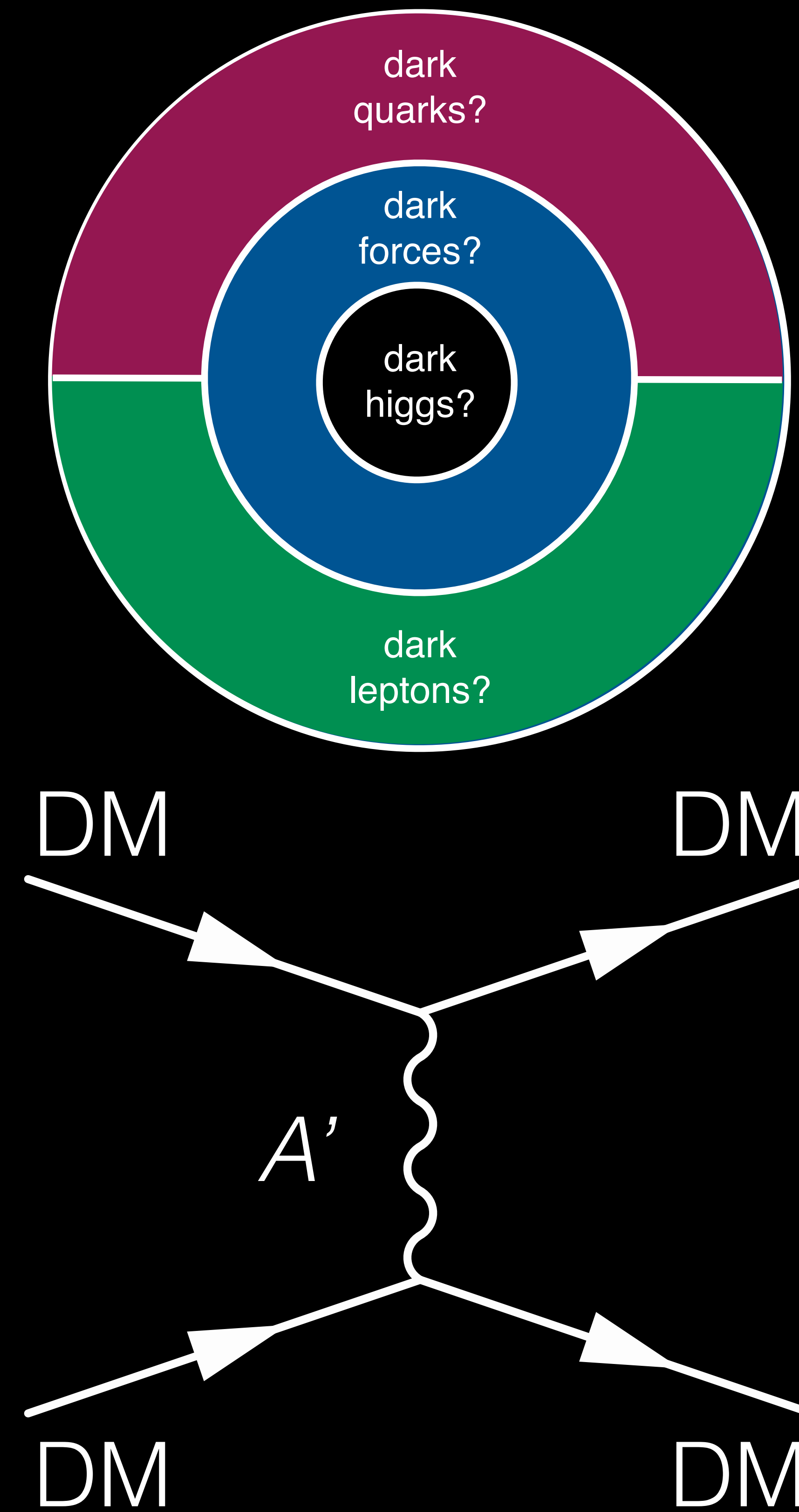




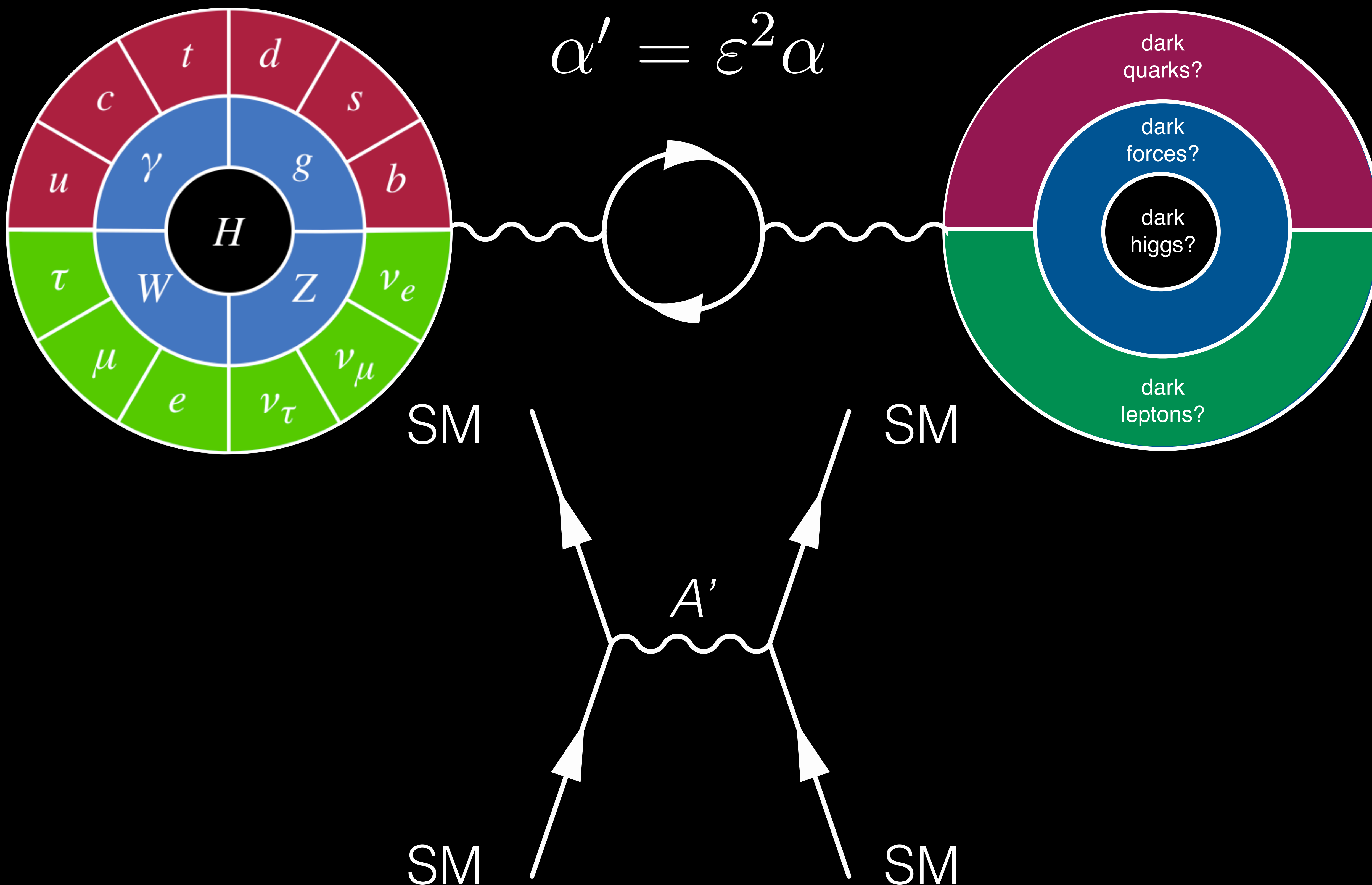


Dark Photons





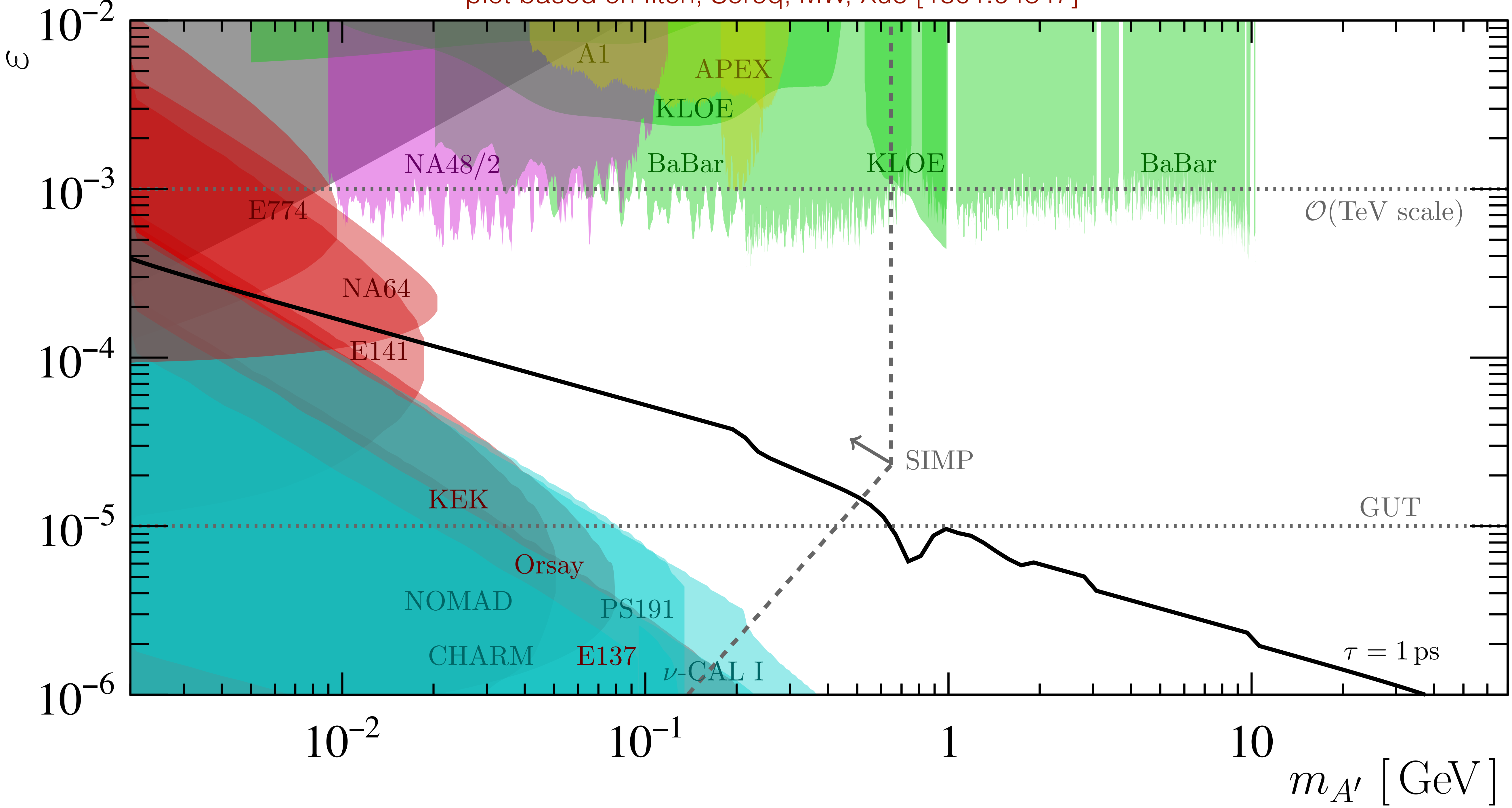
Dark Photons



Visible A' Decays

Existing bounds on visible A' decays.

plot based on Ilten, Soreq, MW, Xue [1801.04847]



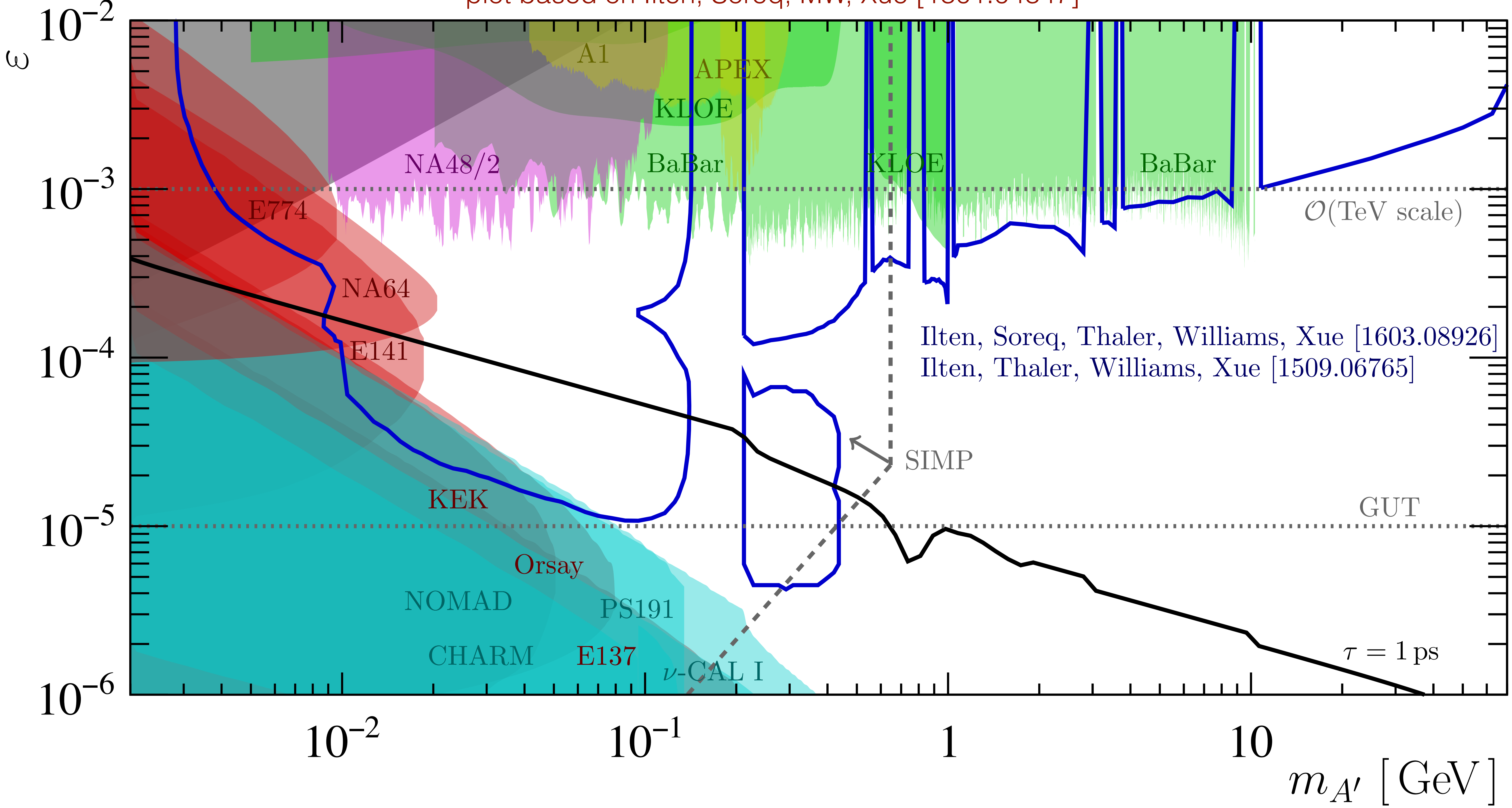
Well defined target range in epsilon—that is almost unexplored above 20 MeV (thermal DM requires ε > 10^{-8}). Lower masses are preferred by SIMP models.

Thermal: see Evans, Gori, Shelton [1712.03974]; SIMP: see Choi et al [1707.01434]

Visible A' Decays

Leverage LHCb's excellent **τ** resolution and move to triggerless readout in Run 3.

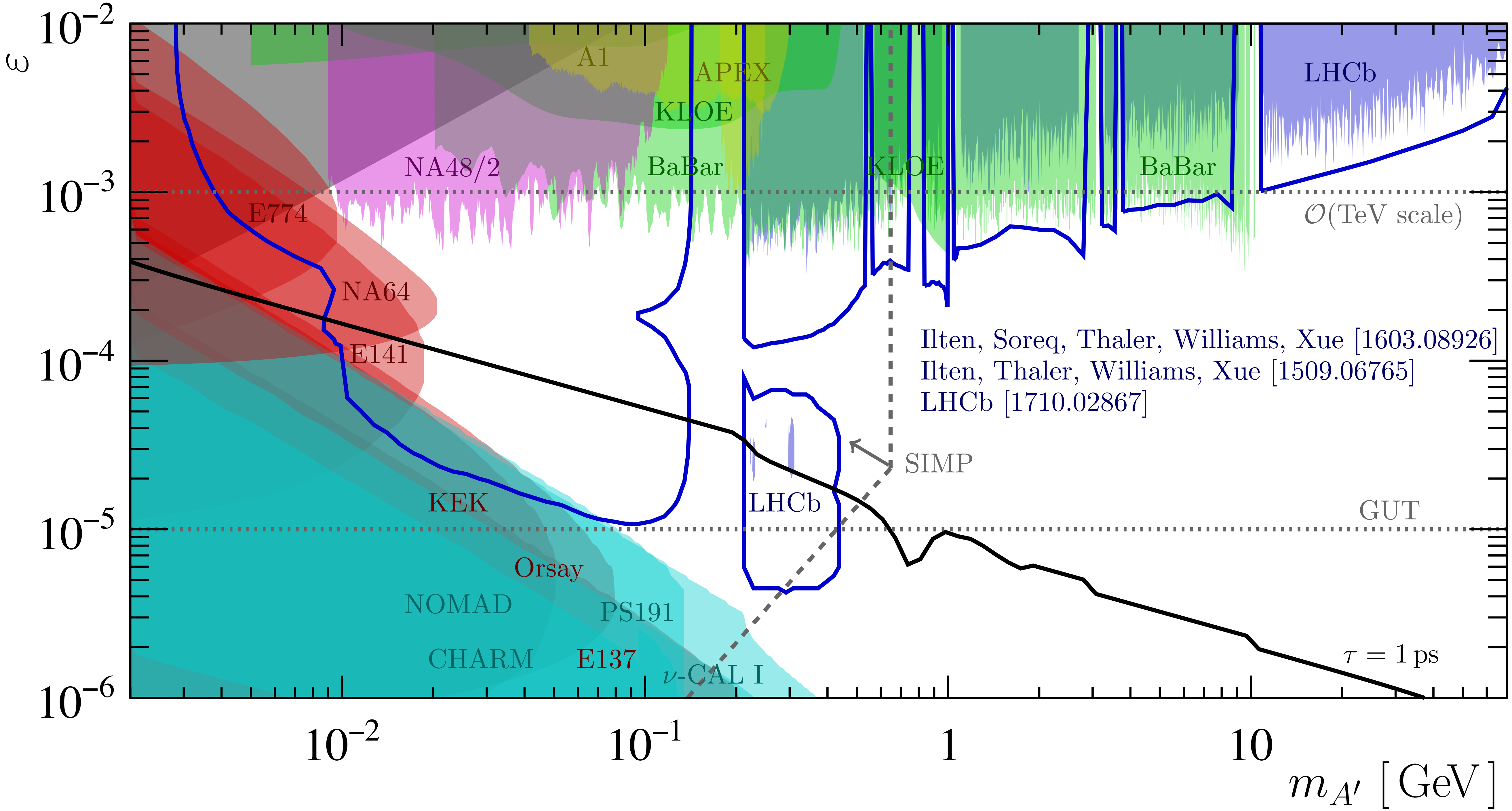
plot based on Ilten, Soreq, MW, Xue [1801.04847]



But why wait for Run 3? Triggers written in 2016 taking advantage of LHCb's move to real-time calibration and the introduction of a reduced-event-size data stream.

Visible A' Decays

2016 μ⁺μ⁻ results are consistent with our predictions rescaled to this sample. Huge improvements implemented in the 2017 triggers, plan quick update 2017 dimuon search — then onto e⁺e⁻ and non-standard decay topologies.

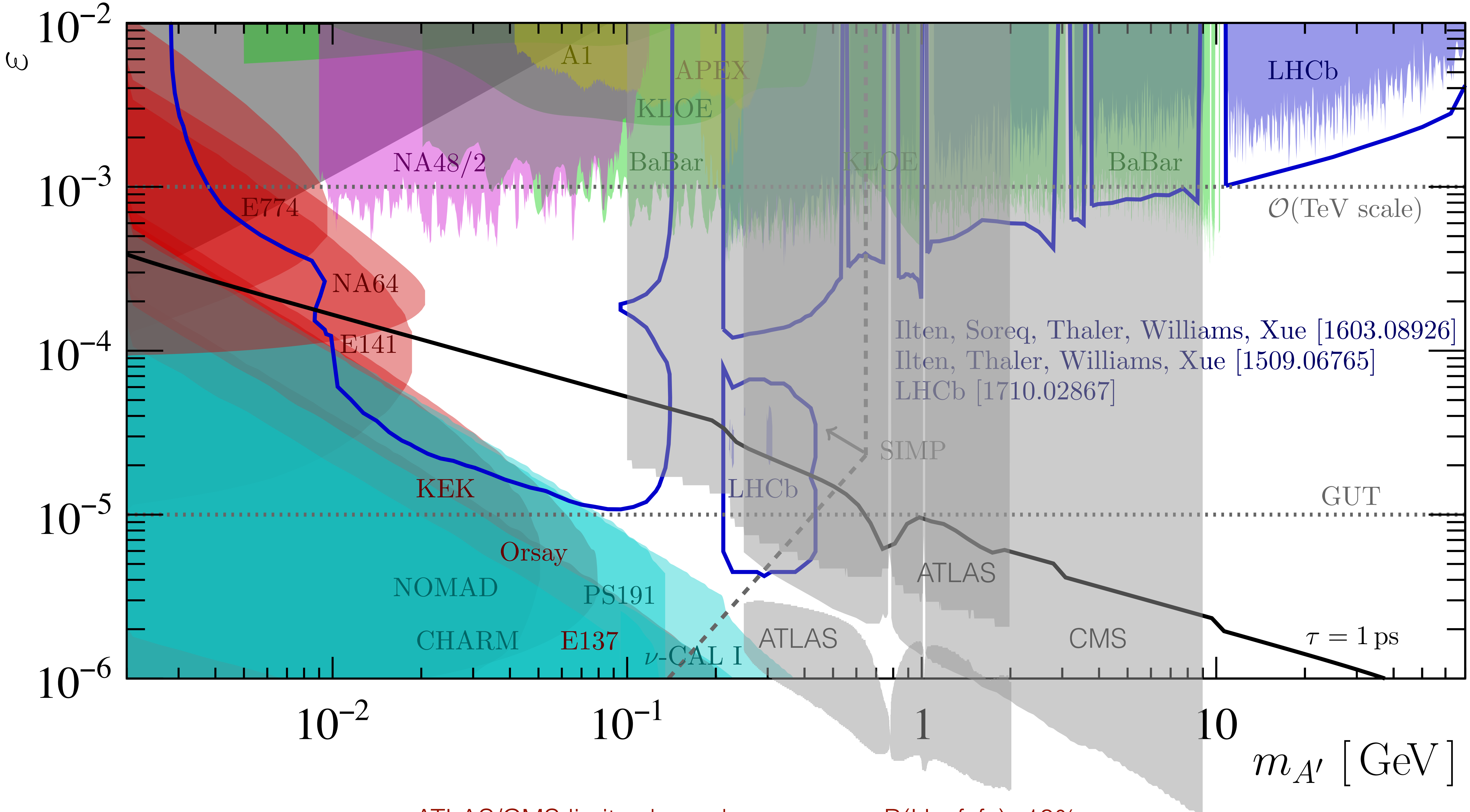


see for [1801.04847] and gitlab.com/philten/darkcast for recasting to any other vector model

LHCb also has limits for prompt A' near the Υ resonances [1805.09820].

Visible A' Decays

Dark photon sensitivity can be very different in non-minimal models, e.g., if dark-sector fermions also couple to our Higgs boson allowing $H \to f_D f_D \to A'A' + X$ decays to occur.

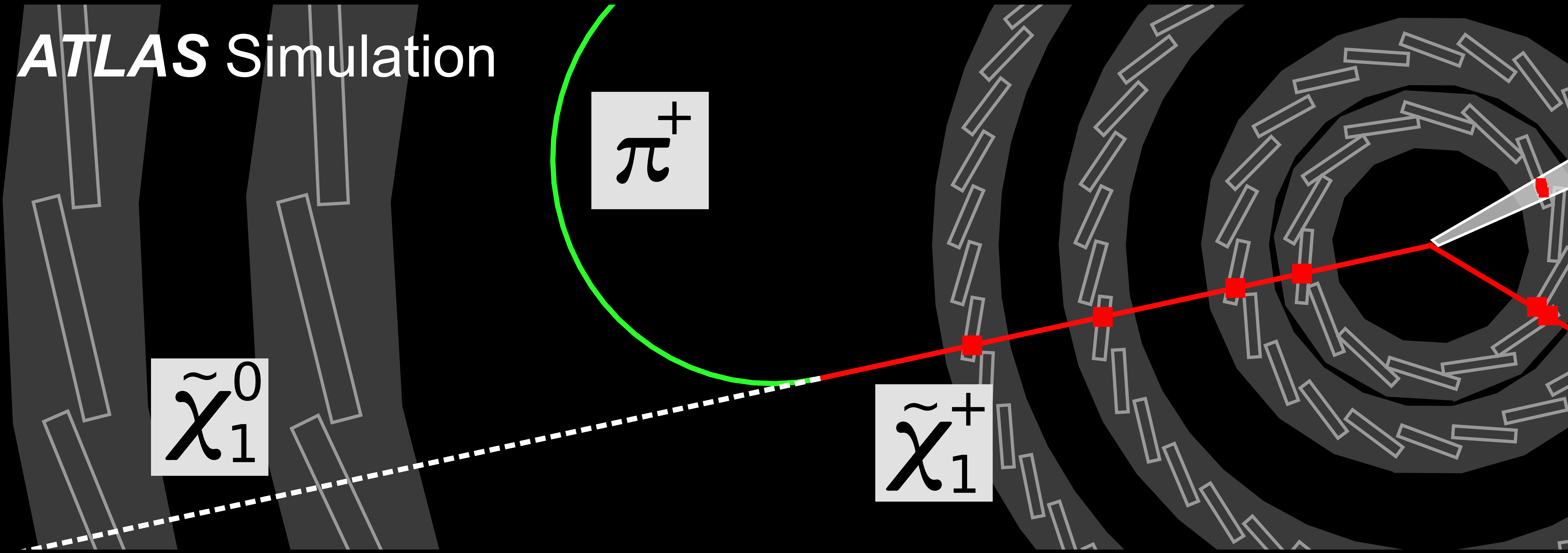


ATLAS/CMS limits shown here assume $B(H \to f_D f_D)$=10%.

ATLAS [1511.05542] (see also 1505.07645,CONF-2016-042), CMS [PAS-HIG-16-035].

Disappearing Tracks

Many models (e.g. AMSB SUSY) predict nearly degenerate EW-scale states, where the neutral state is lighter (typically the DM) with ΔM ~ O(100 MeV).

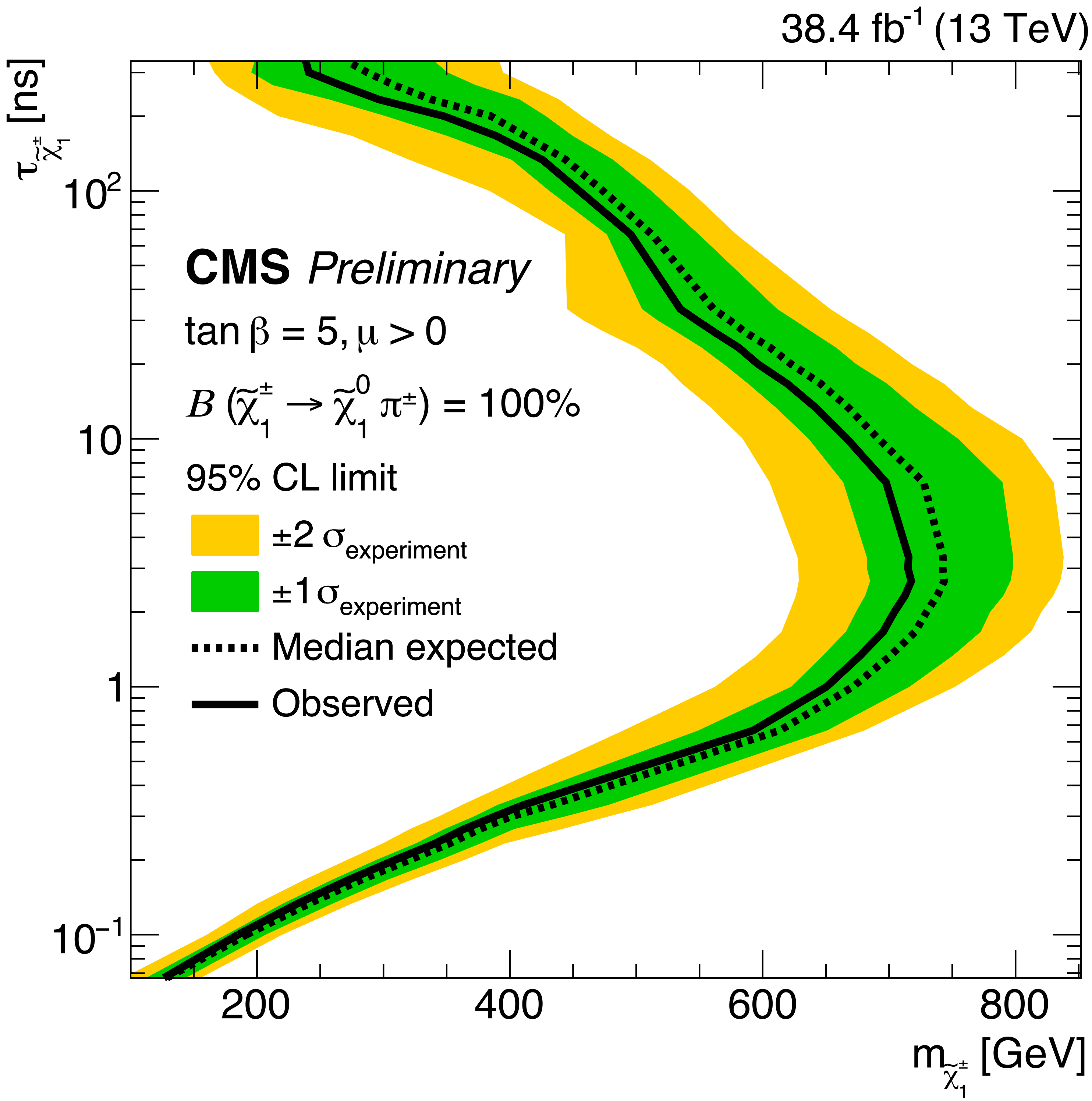


Signature is a short (cτ~O(cm) in benchmark models) and isolated high-p_T track in an event with a large amount of missing transverse energy.

Disappearing Tracks @ CMS

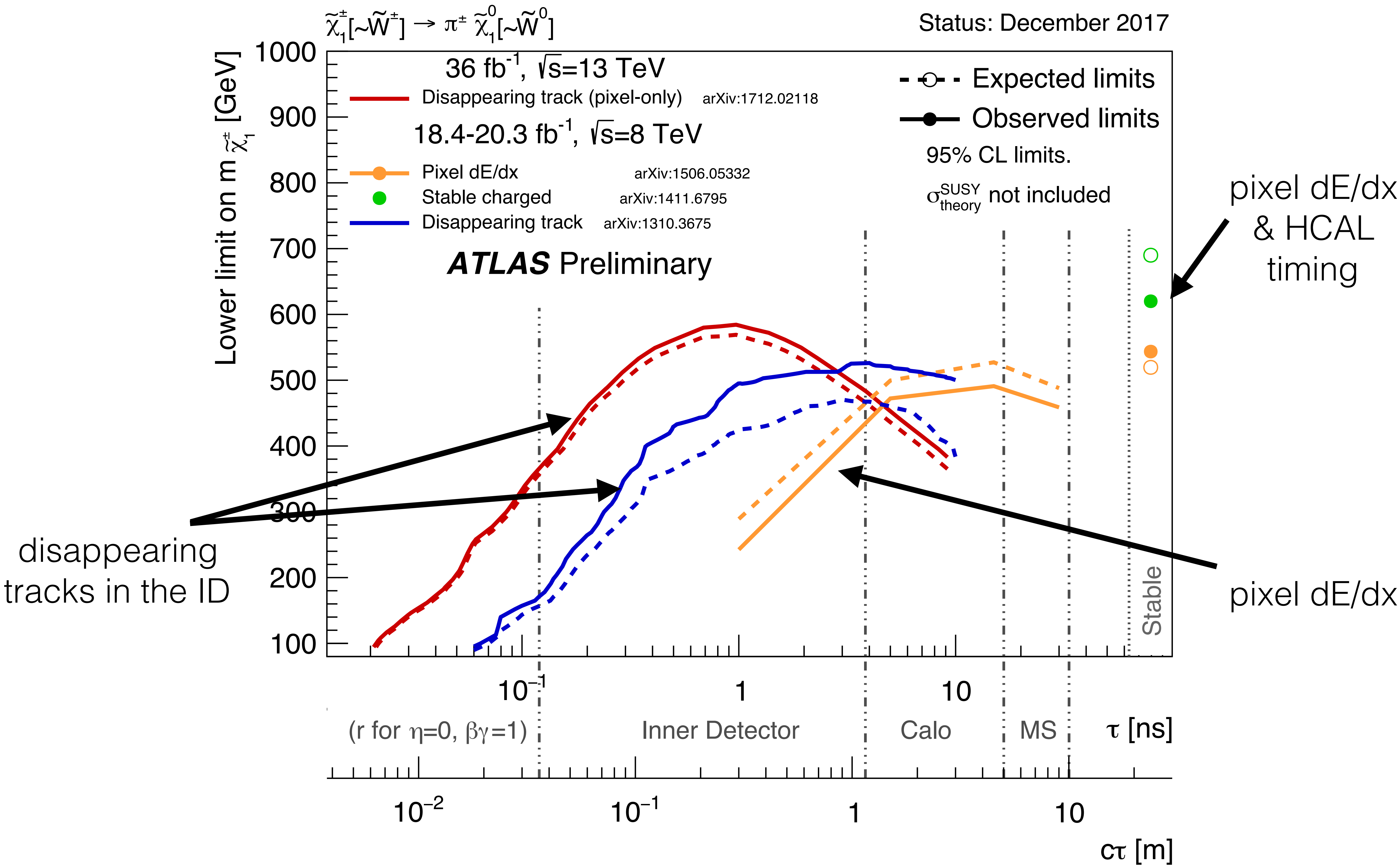
CMS-EXO-16-044
[1804.07321]

In principle, this is a striking BSM signature; however, in practice, backgrounds from pattern-reco failures, material interactions, etc, make this a difficult search.



- trigger requires MET > 75 GeV and an isolated track with $p_T > 50$ GeV;
- at least 7 (3) track (pixel) hits and NO missing inner hits;
- transverse impact parameter must be consistent with the pp collision;
- background mostly from real leptons (estimated using a Z-decay tag-and-probe sample) and fake tracks (estimated using a pure Z sample with additional large-IP tracks);
- 7 candidates observed consistent with the 6.5±1.3 background events expected.

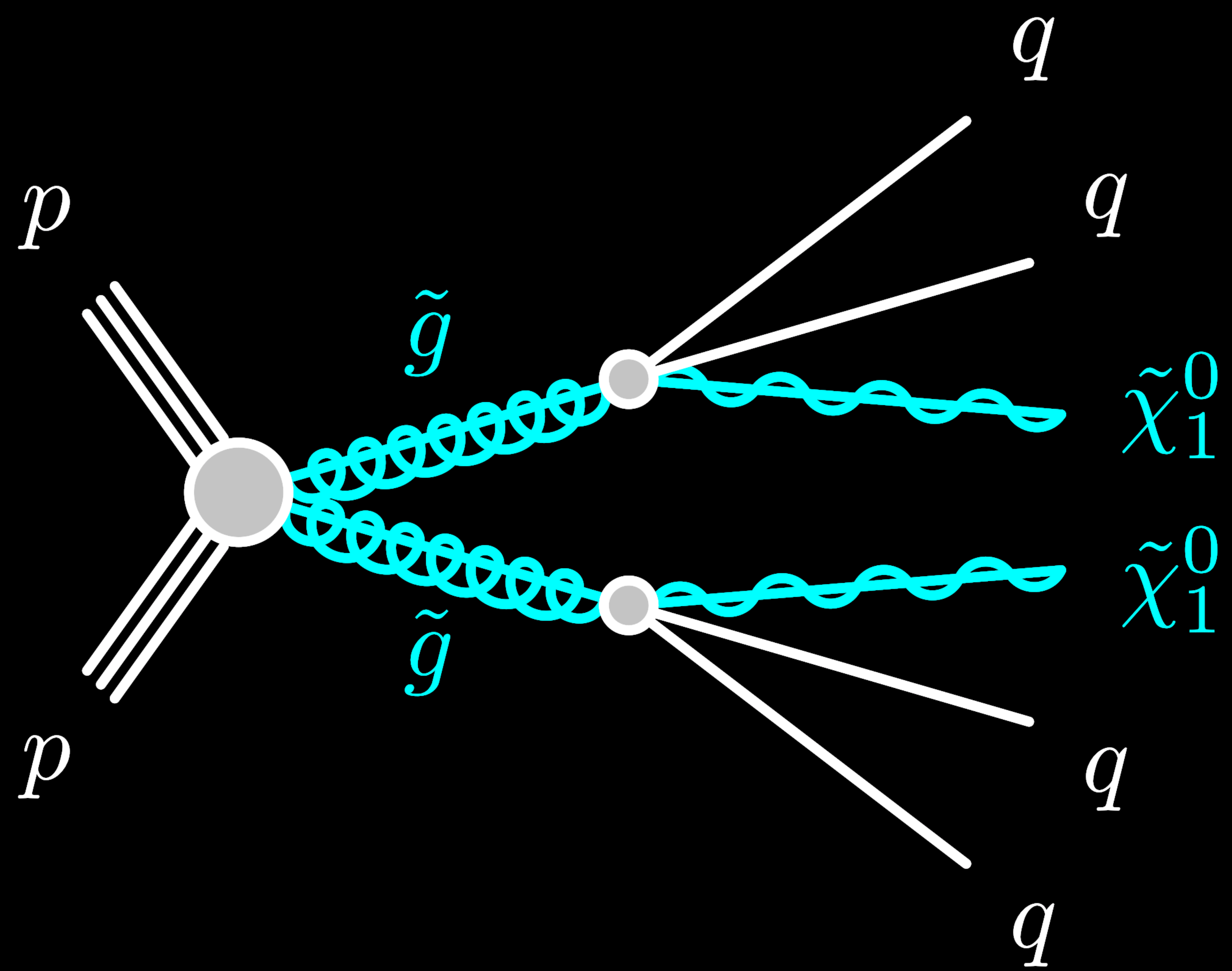
Summary of Direct LLP Searches @ ATLAS



Excluded: a pure Wino LSP with m(χ^+) < 460 GeV [1712.02118] and a pure Higgsino LSP with m(χ^+) < 152 GeV [ATLAS-PHYS-PUB-2017-019].

R-Hadron Models

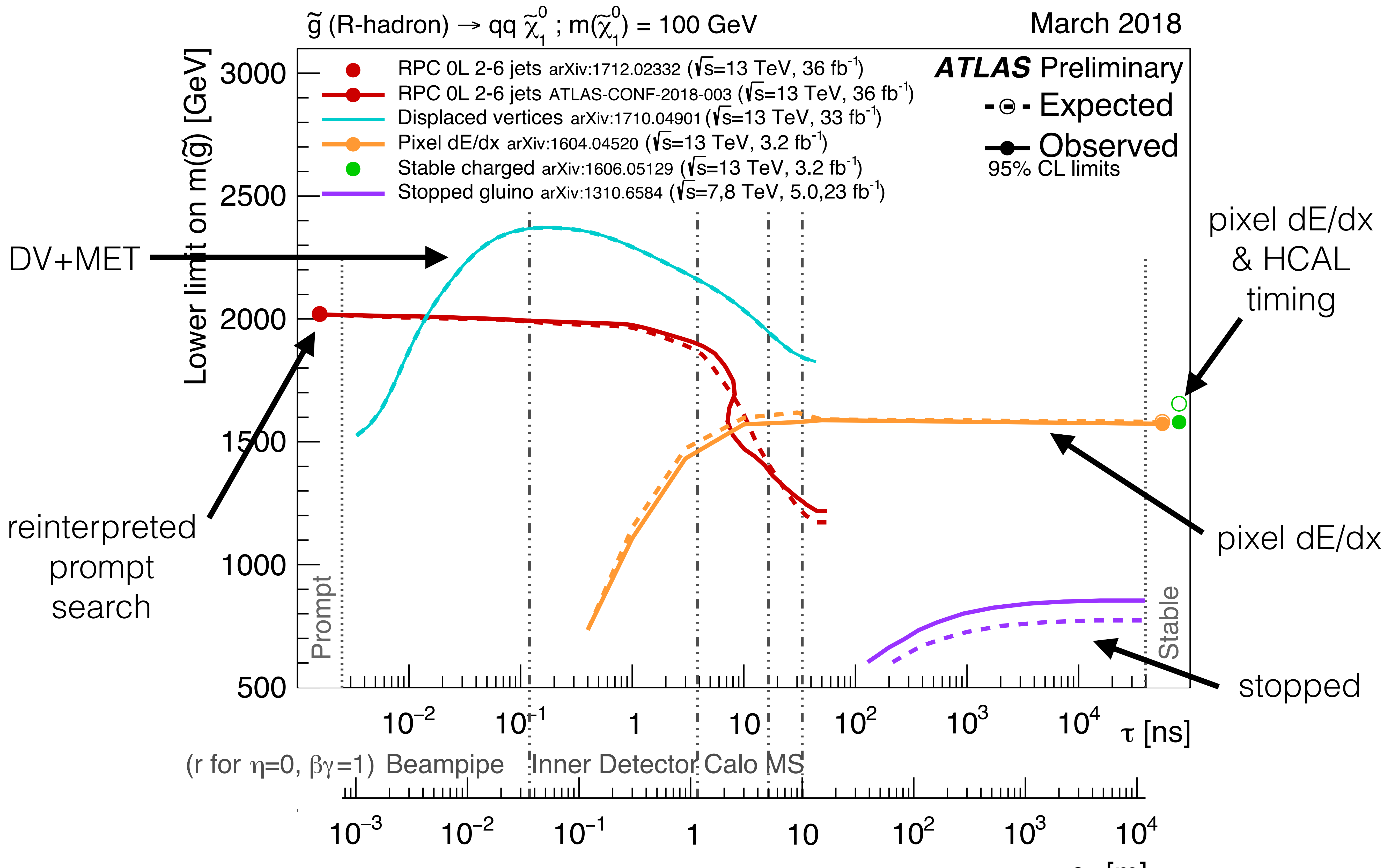
The gluino can form an R-hadron if its lifetime is larger than the QCD hadronization time scale (e.g. R-parity conserving split SUSY).



Signature changes as the gluino lifetime increases: prompt-like jets → b-like jets → jets with a multi-track displaced vertex → direct detection or stopped decay.

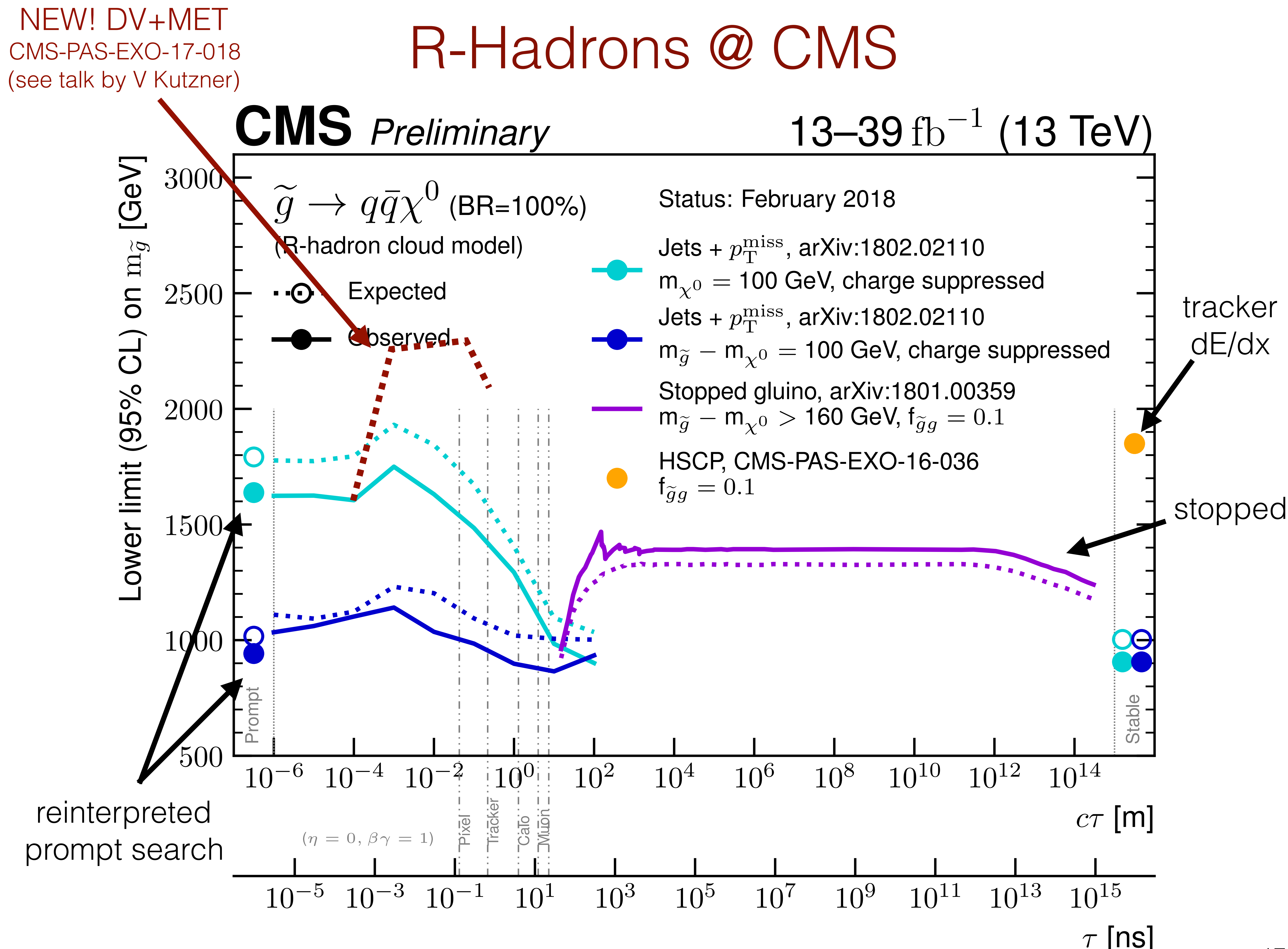
R-Hadrons @ ATLAS

ATLAS-CONF-2018-003

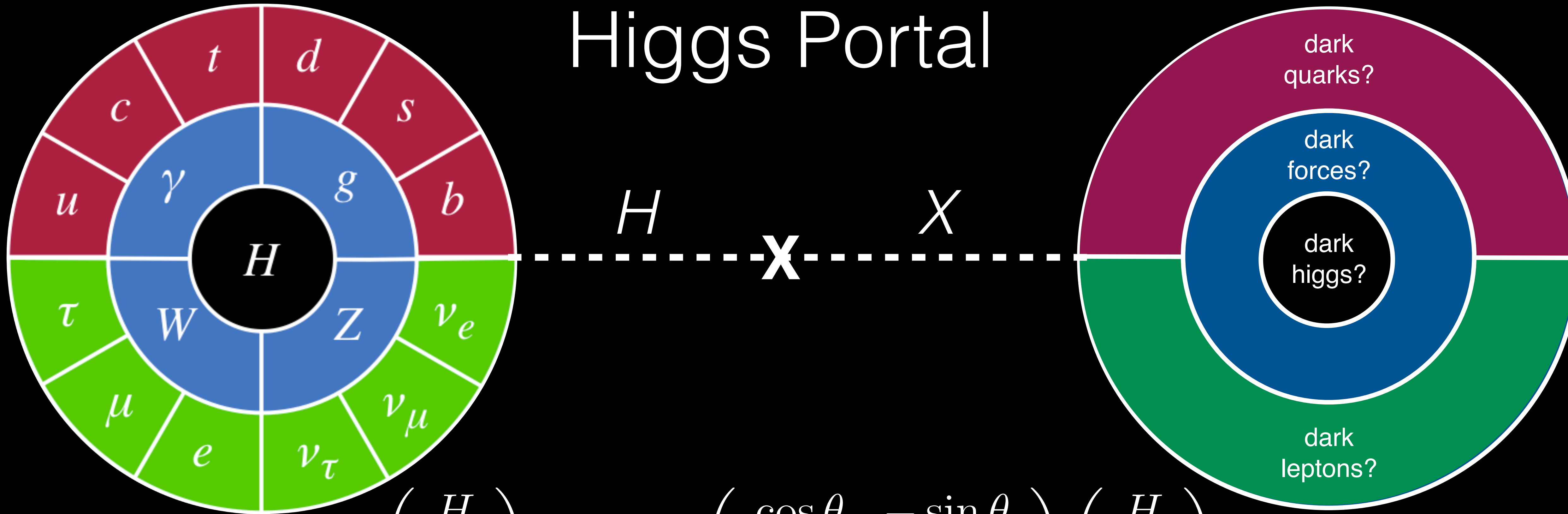


See ATLAS-CONF-2018-003 for additional limits for RPV models.

R-Hadrons @ CMS

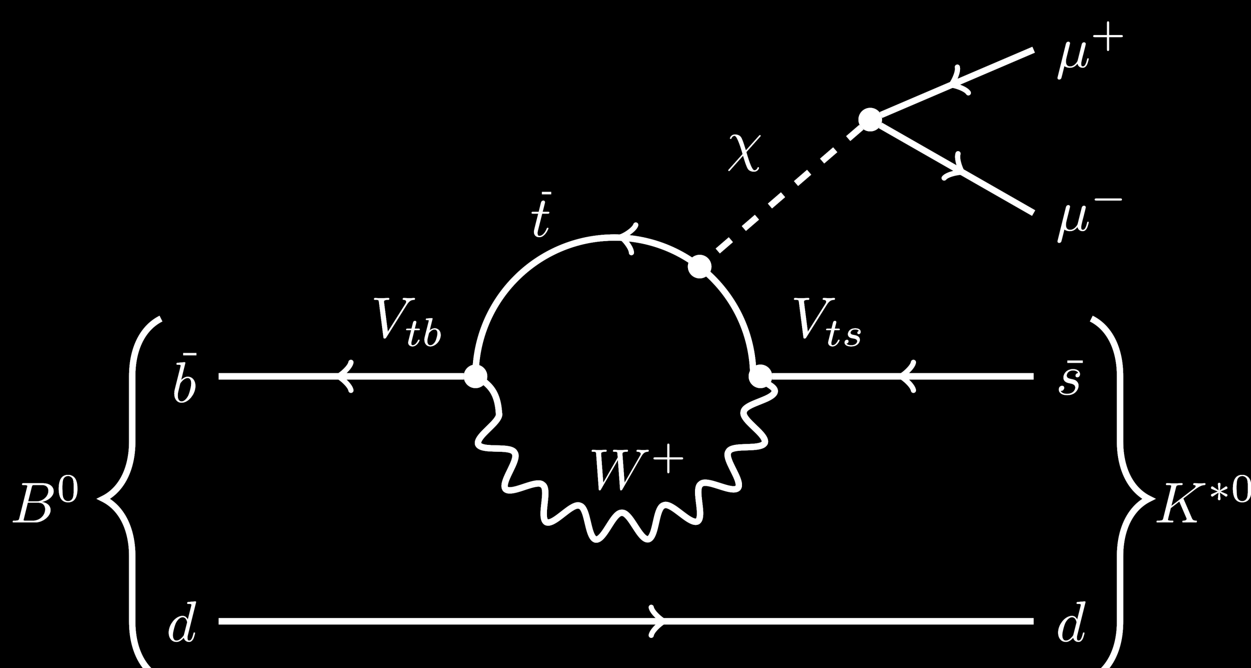


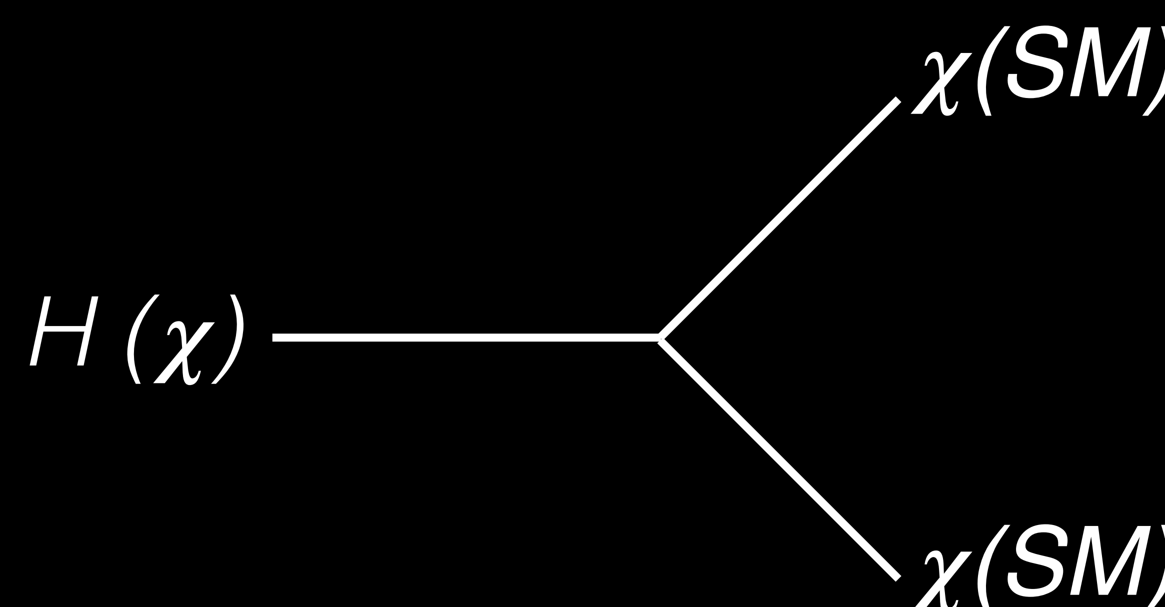
Higgs Portal



$$\begin{pmatrix} H \\ \chi \end{pmatrix}_{\text{physical}} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} H \\ \chi \end{pmatrix}_{\text{ideal}}$$

LHC signatures (which is best depends on mass)

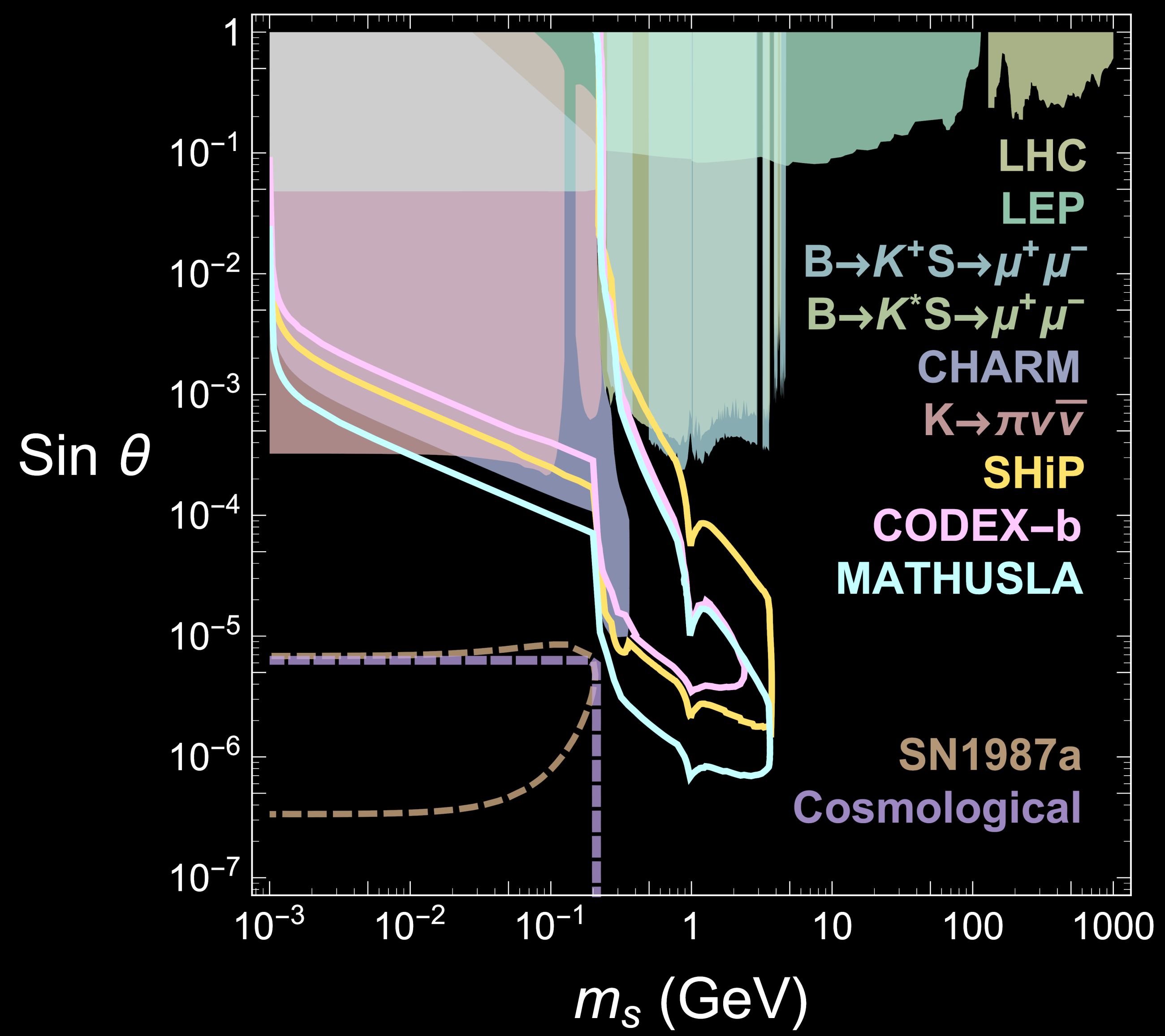


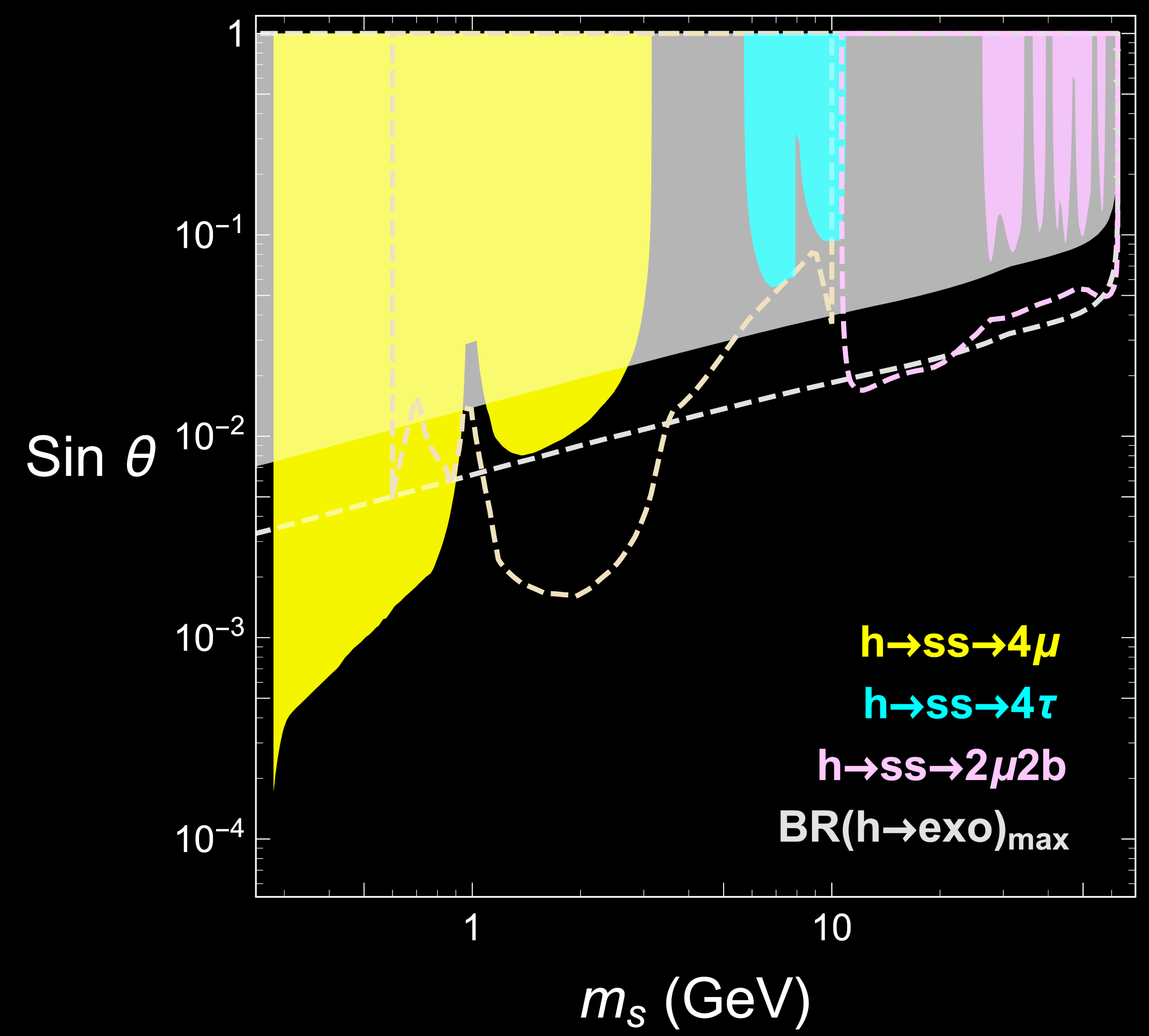


Higgs Portal

The strongest constraints on minimal Higgs portal models come from beam dumps, kaon decays, b→s penguin decays @ LHCb, LEP Higgs searches, and the UL on exotic Higgs decays from ATLAS/CMS.

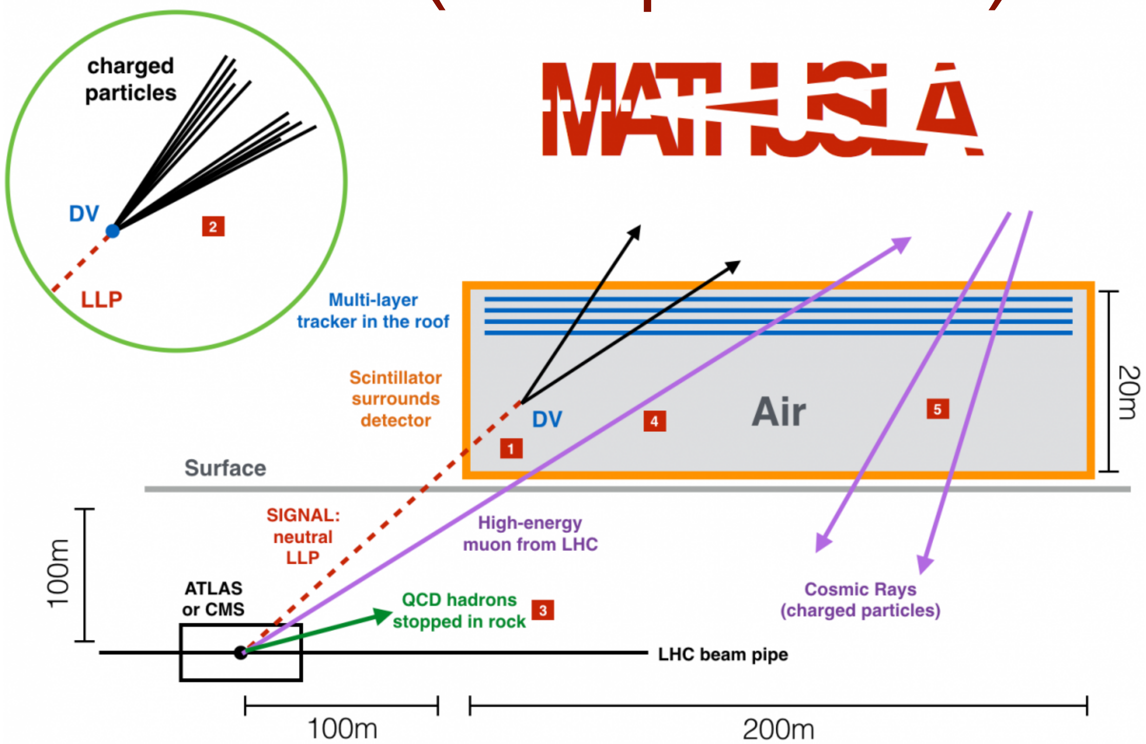
plots from Evans, Gori, Shelton [1712.03974]

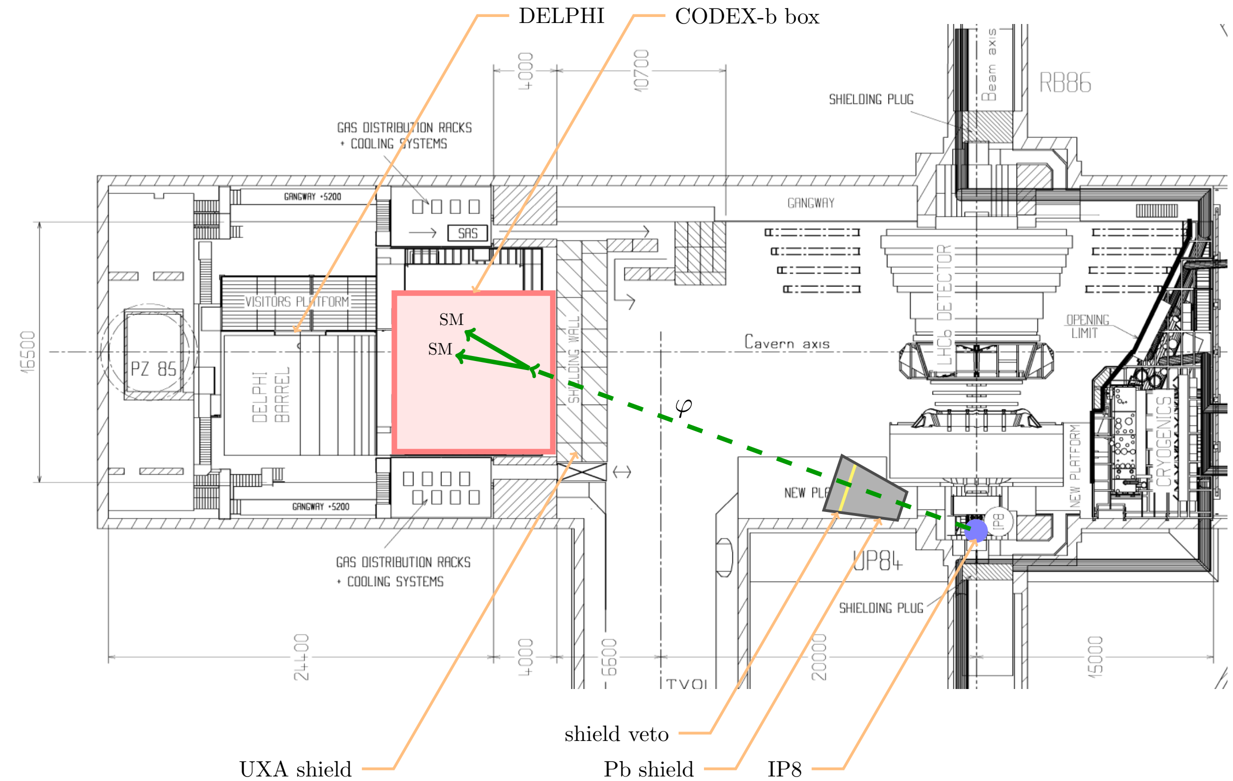


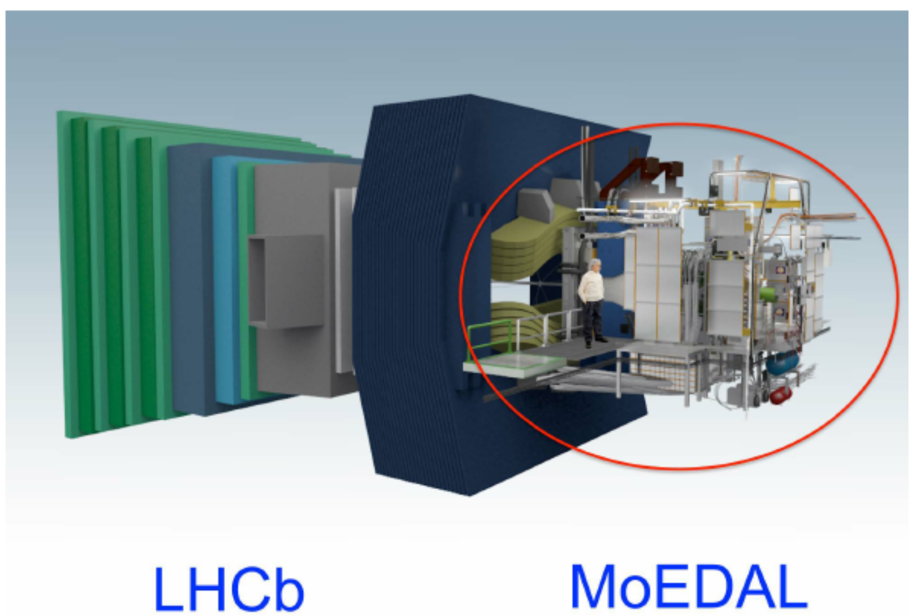


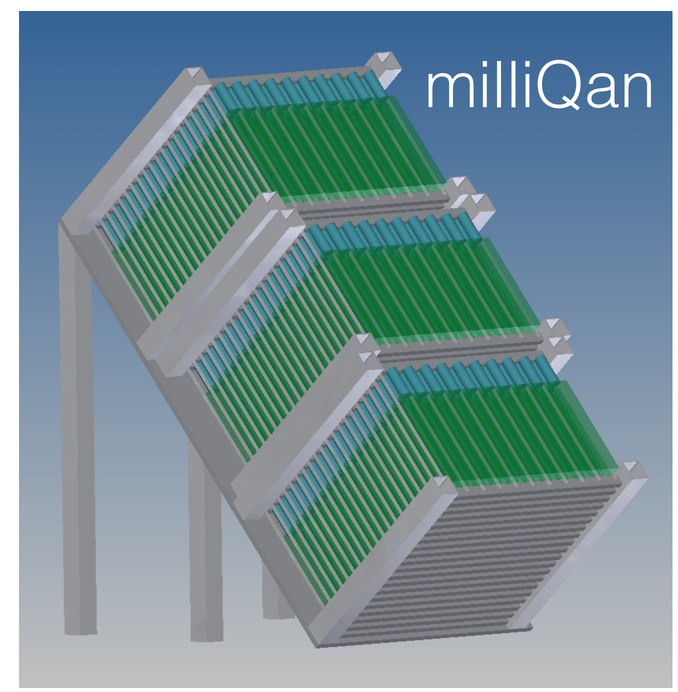
Searches at low mass suffer from the *curse of longevity*, as vertex detectors are optimally sized for mixing angles O(0.01 rad).

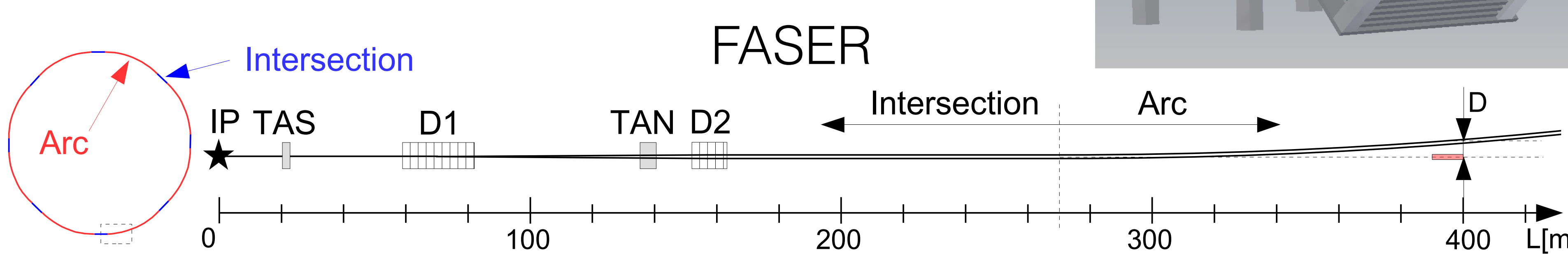
(Proposed) LHC LLP Detectors











Additionally, many non-LHC experiments have been proposed, including SHiP, BDX, …

Summary

- Searches for LLPs are well motivated (at least one type of LLP must exist to explain DM) as long-lived particles arise naturally in many BSM scenarii.
- The LHC experiments each have active and vibrant LLP programs performing a diverse set of LLP searches. For many BSM models, the LHC limits are the most stringent.
- I only had time to cover a small fraction of the searches that have been performed thus far at the LHC (this talk focused on the most recent results). (See LLP snapshots from ATLAS, CMS, LHCb at [this indico page] for more complete lists of existing searches.)
- Many dedicated LLP experiments have been proposed to target parameter space that is (probably) not accessible at the LHC.
- Looking forward to discovery(ies) soon!