IMPLICATIONS OF LOW SCALE STRONG DYNAMICS AT LHCb

DANIEL STOLARSKI

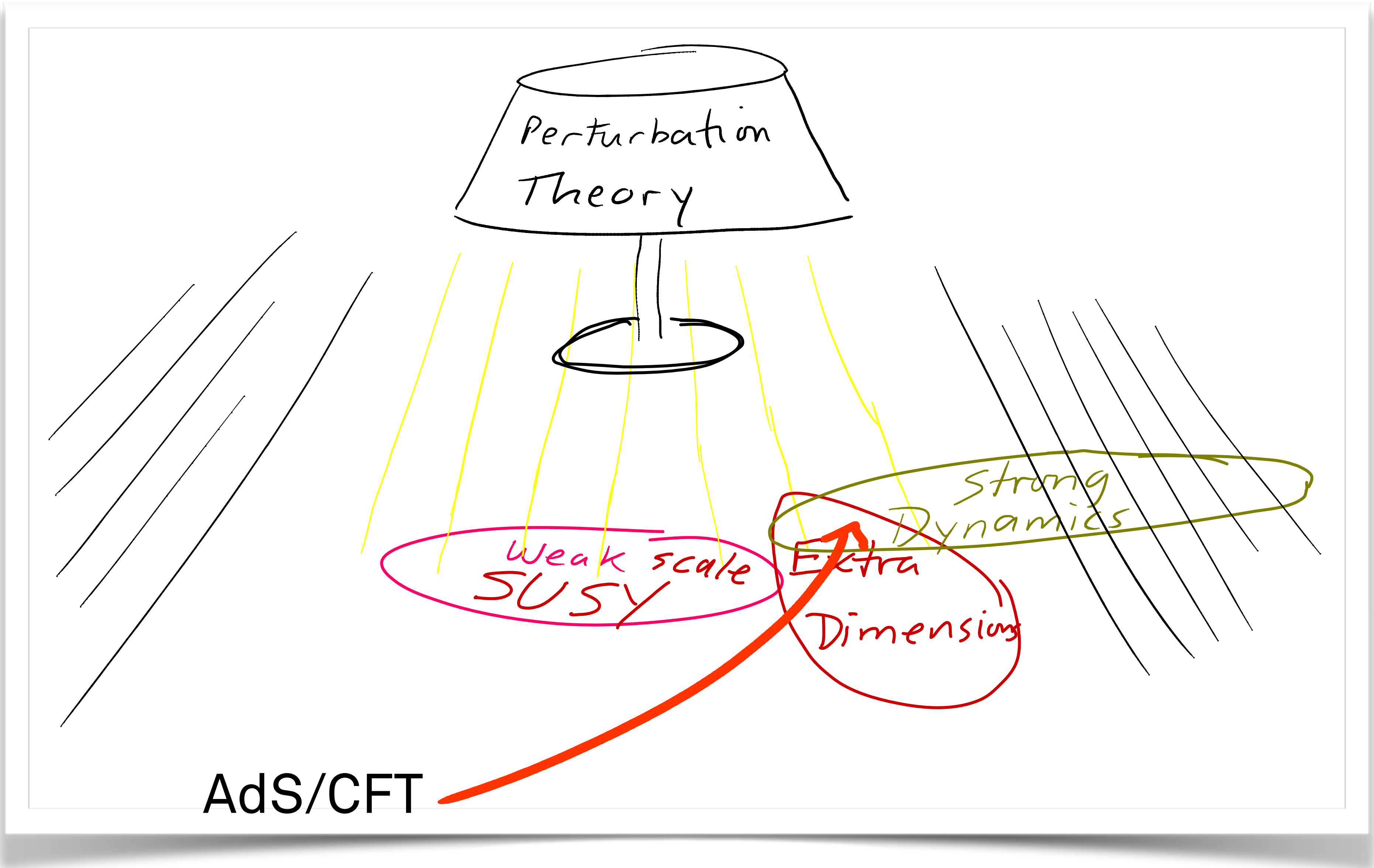
LHCb Workshop November 3, 2015

OUTLINE

- Three motivations for low scale strong dynamics.
- LHCb advantages in production.
- LHCb advantages in decay.
- Complementarity with other experiments.

MOTIVATION 1

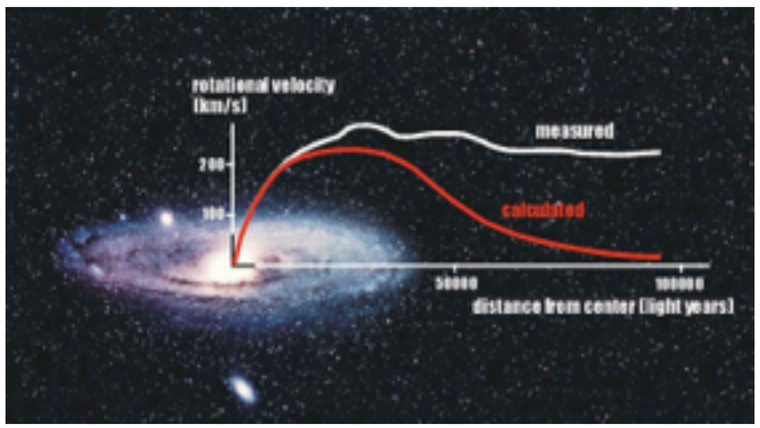
Getting away from the lamp post

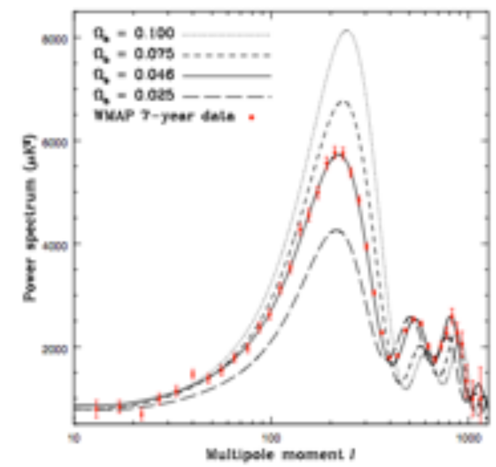


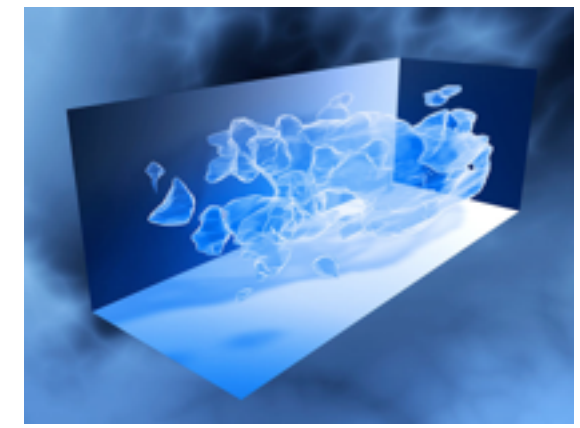
R. Sundrum

MOTIVATION 2

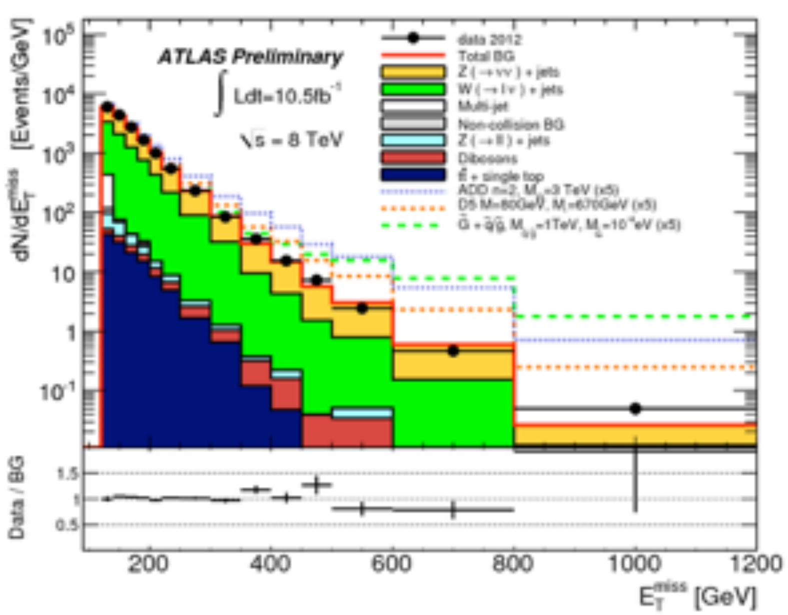
We have seen dark matter in the sky.

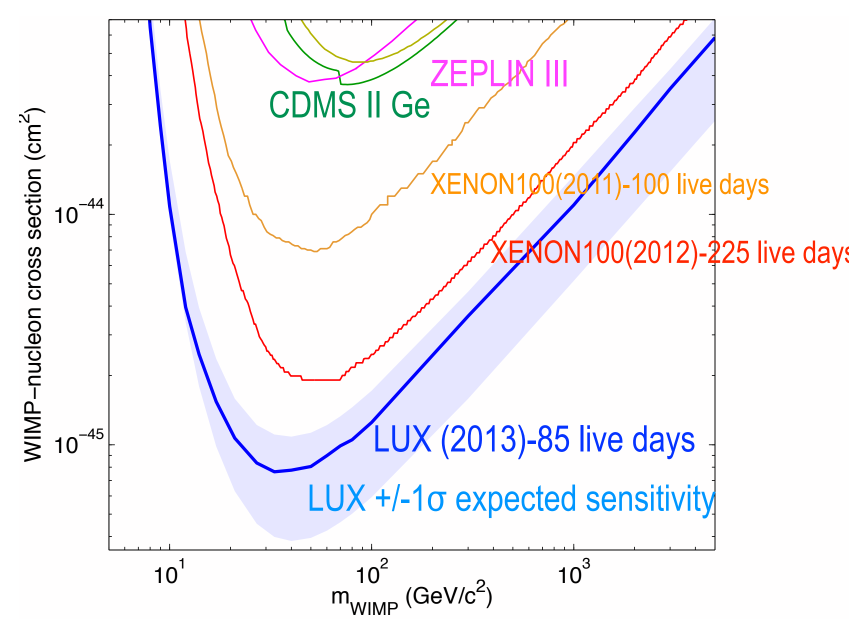






But not in the lab.





ASYMMETRIC DARK MATTER

$$\Omega_{DM} \simeq 5\Omega_B$$

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Controlled by complicated (known) QCD dynamics

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Unknown dynamics of baryogenesis

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?

Unknown dynamics of baryogenesis

ASYMMETRIC DARK MATTER

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QCD like

?

Controlled by complicated (known) QCD dynamics

$$\Omega_{DM} = m_{DM} n_{DM}$$

$$\Omega_B = m_p n_B$$

?

Unknown dynamics of baryogenesis

MANY PAPERS

S. Nussinov, Phys.Lett.B.165 (1985) 55.

D. B. Kaplan, Phys.Rev.Lett.B.68 (1992) 741-3.

...

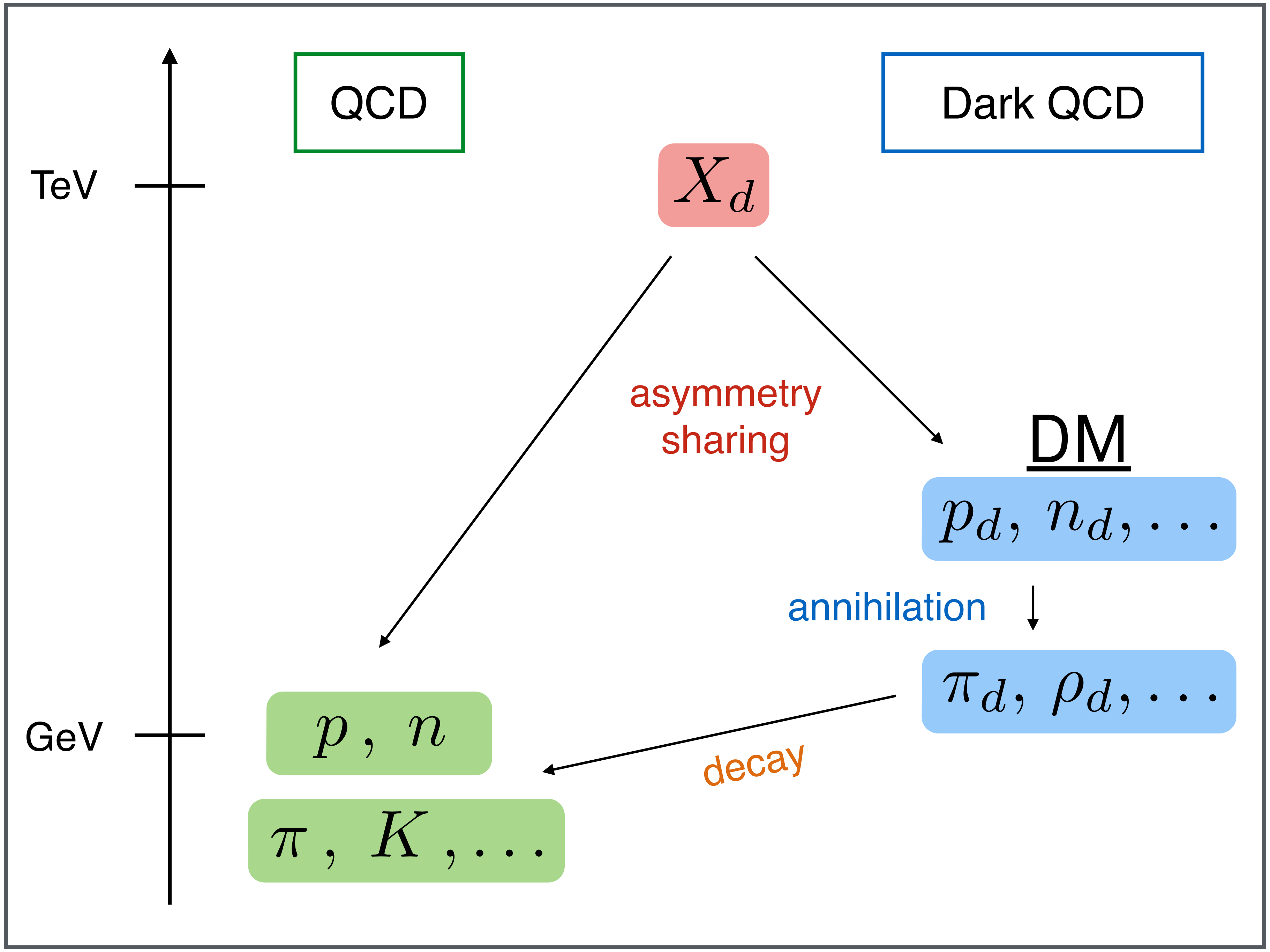
D. E. Kaplan, M. A. Luty, K. M. Zurek, arXiv:0901.4117.

Bai and Schwaller, arXiv:1306.4676.

K. K. Boddy, et.al. arXiv:1402.362.

For a review see K. Petraki and R. R. Volkas, Int.J.Mod.Phys.A 28, 1330028 (2013) [arXiv:1305.4939 [hep-ph]].

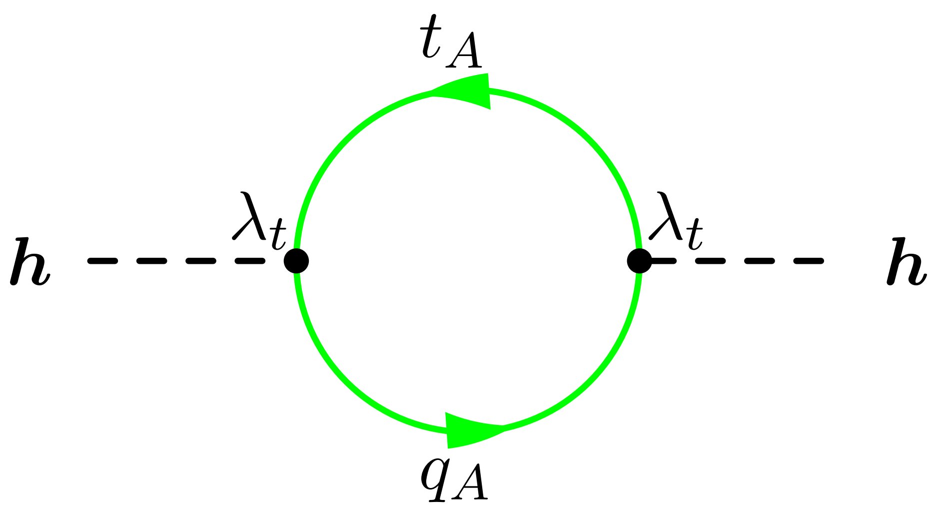
GENERAL PICTURE



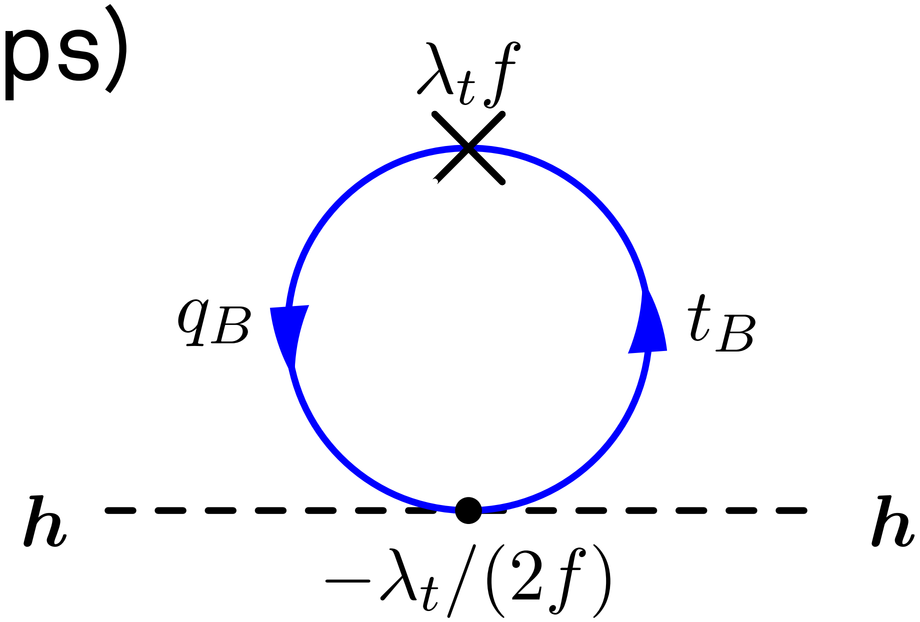
Emerging Jets: JHEP 1505, **059 (2015) [arXiv:1502.0409].**

MOTIVATION 3

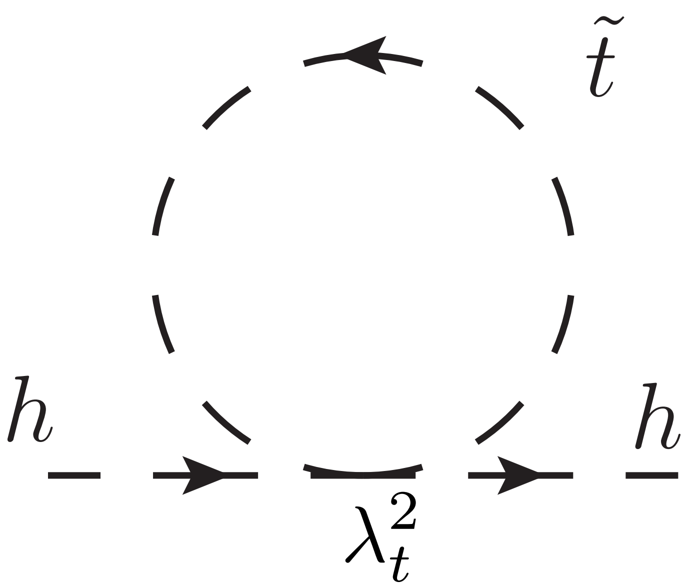
Gauge hierarchy problem:



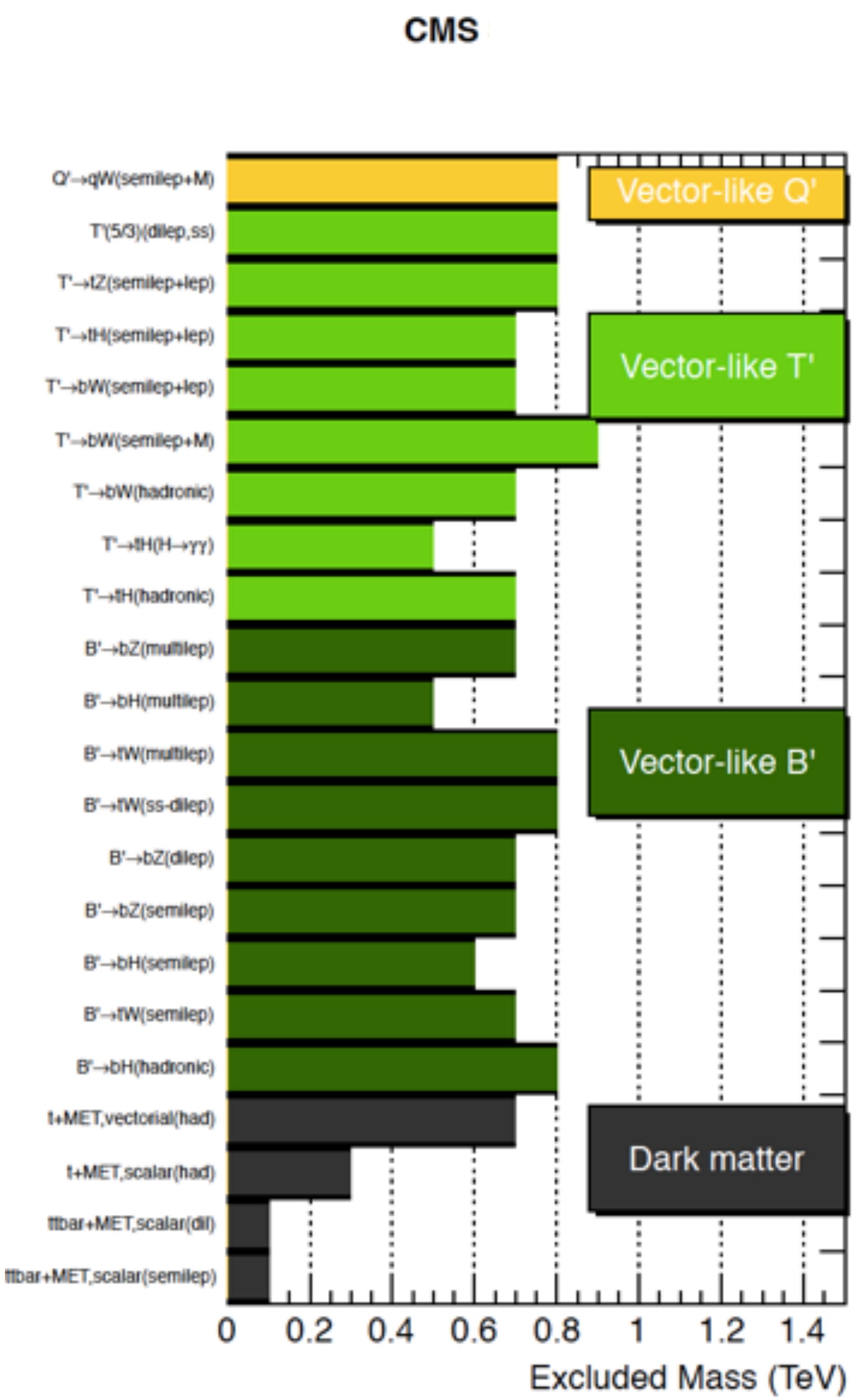
Solved in composite Higgs (SUSY) with top-partners (stops)

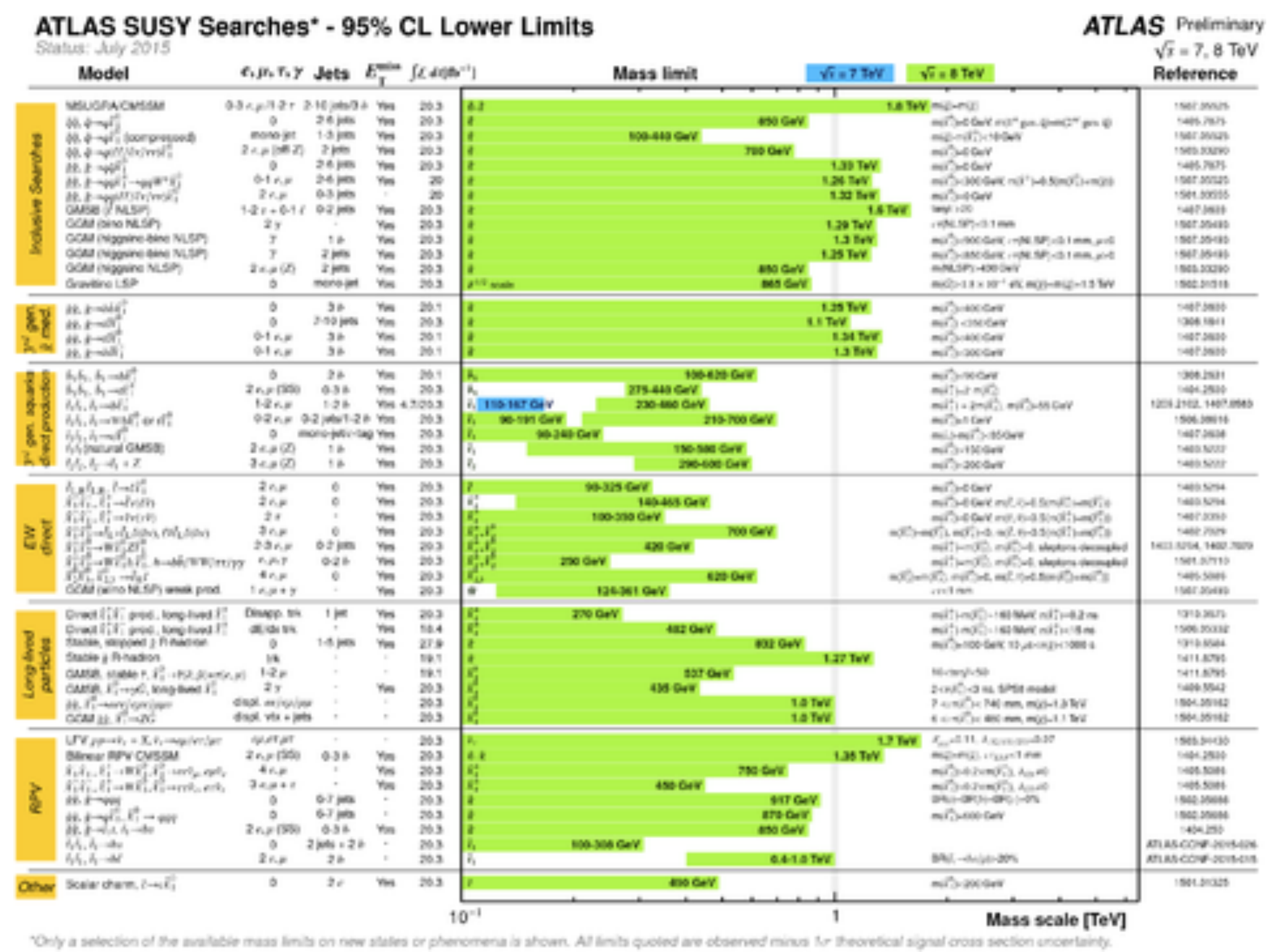


or



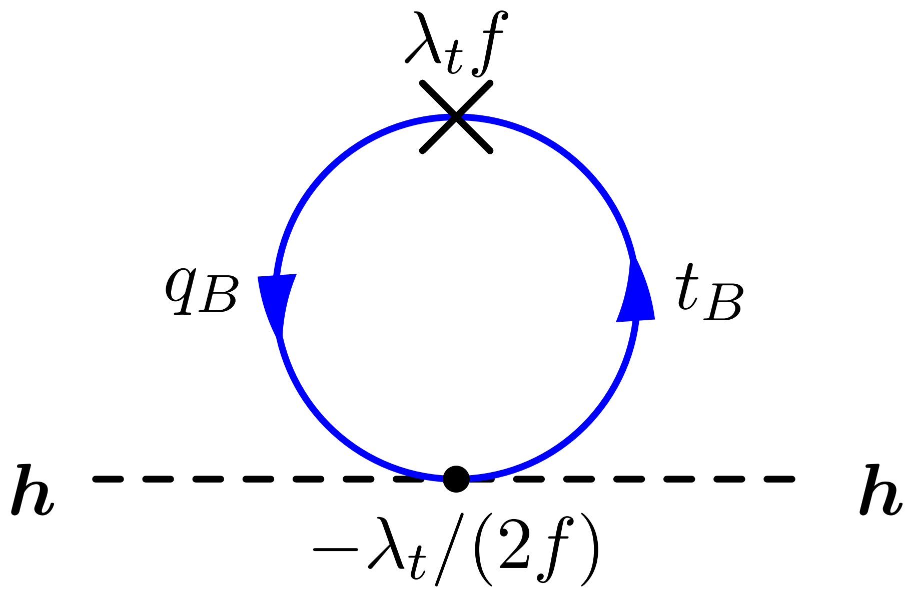
MOTIVATION 3

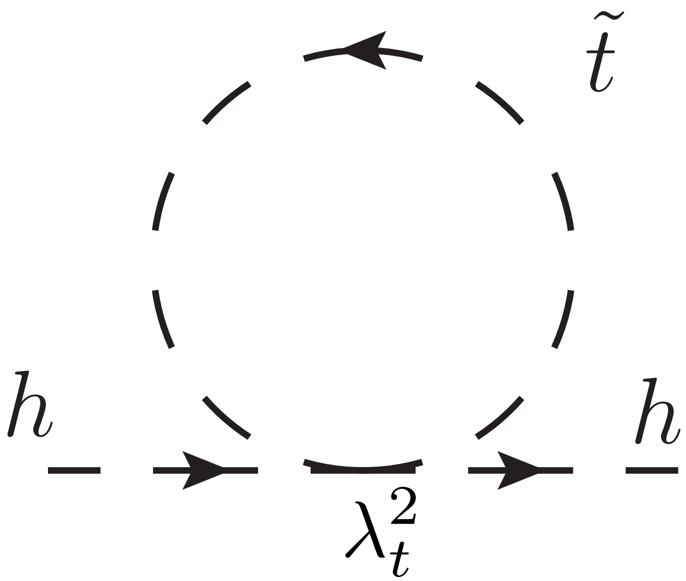




TWIN HIGGS/FOLDED SUSY

Partners need not be coloured (still need 3):

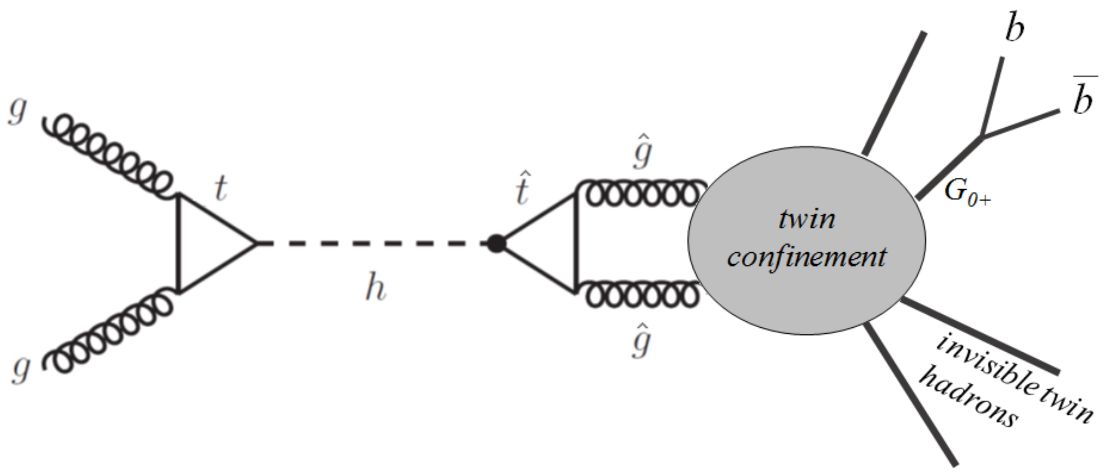




Chacko, Goh, Harnik, hep-ph/0506256.
Burdman, Chacko, Goh, Harnik, hep-ph/0609152.

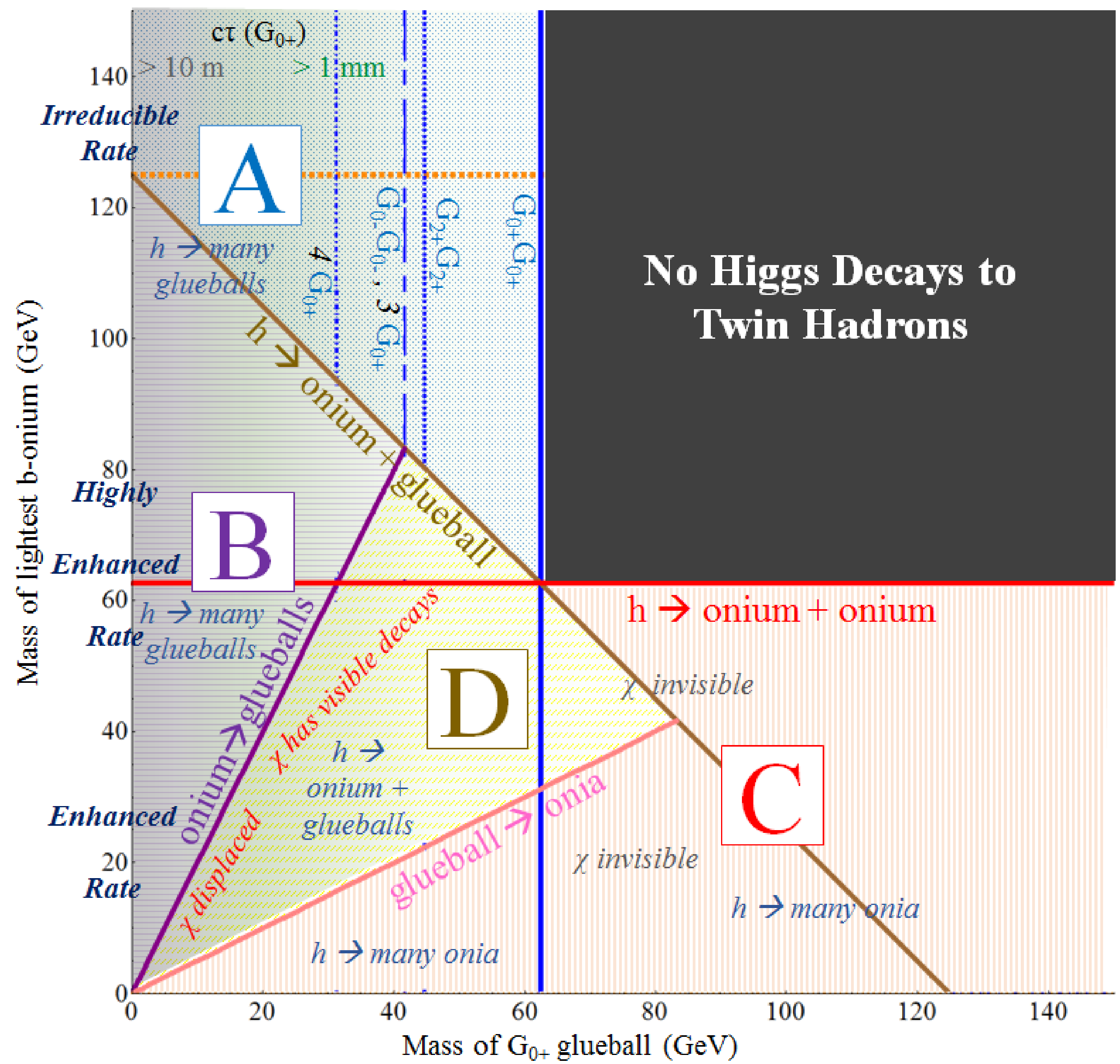
Most models have twin colour which confines around GeV scale (or slightly higher).

HIGGS DECAYS



Craig, Katz, Strassler, Sundrum, arXiv:1501.05310.

See also Curtin, Verhaaren, arXiv:1506.06141.



DARK QCD

Confining SU(N_c) gauge group with N_f flavours.

$$Q_i \quad \overline{Q}_j \quad G_d^{\mu\nu}$$

This sector is QCD like, and it confines at a scale.

$$\Lambda_d \sim 1 - 10 \text{ GeV}$$

At the confining scale we have all the usual states.

$$p_d \qquad \pi_d \qquad \text{Zoo}_d$$

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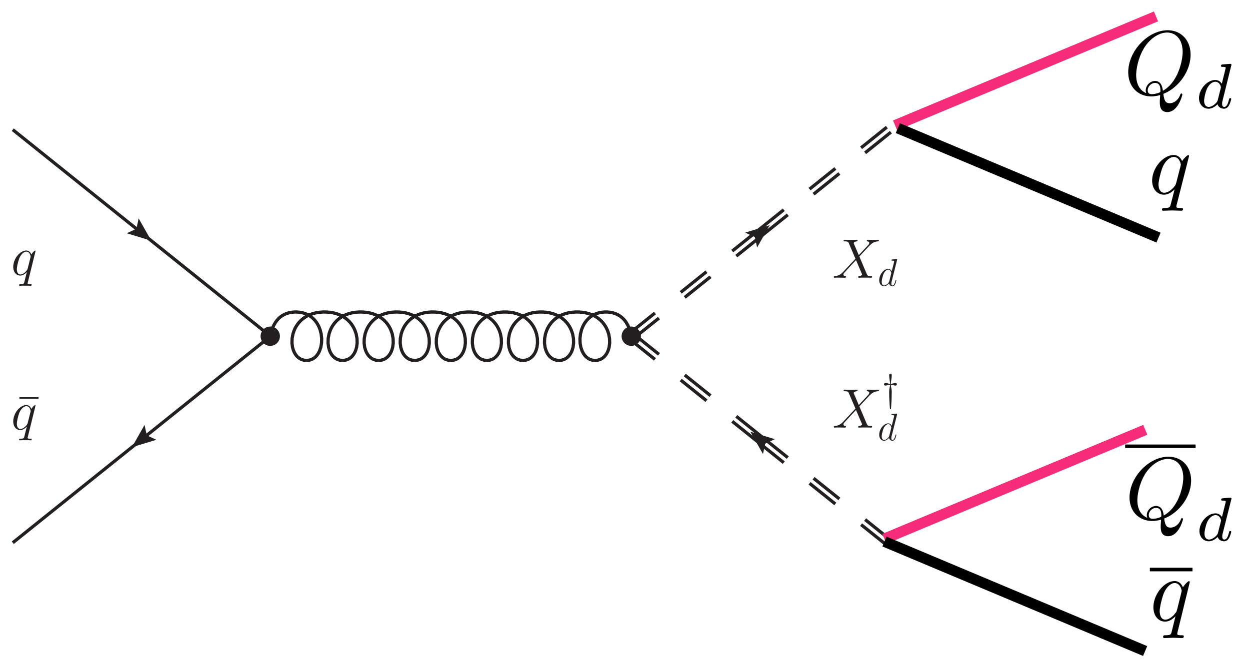
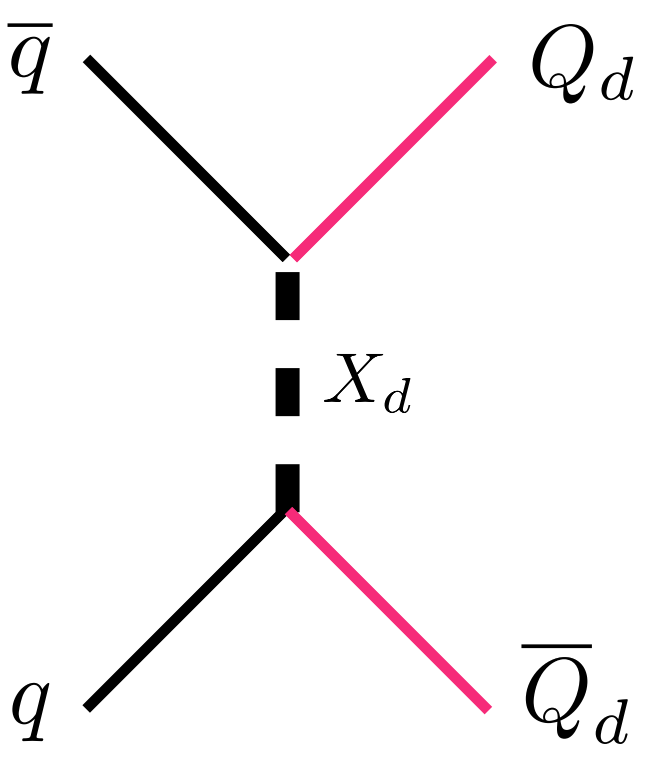
Stable

Decays to SM

DARK QUARK PRODUCTION

Two ways to produce dark quarks:





CMS/ATLAS sensitive to left, LHCb can do both.

DARK QUARK PRODUCTION

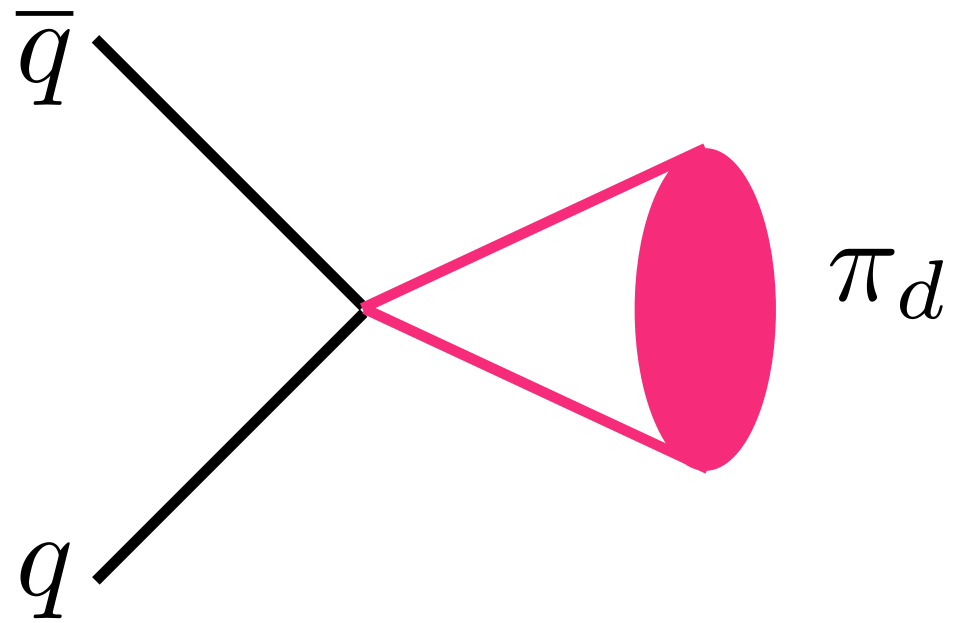
Second production method can have very large production cross section.

$$\mathcal{L} \supset \frac{1}{\Lambda^2}(\bar{q}\Gamma_q q)(\bar{Q}_d \Gamma_d Q_d)$$

$$\sigma(pp \to \bar{Q}_d Q_d) \approx (8.2 \text{ pb}) \times N_d \times n_f \times \left(\frac{\text{TeV}}{\Lambda}\right)^4$$

Limited coverage of event can be overcome by large multiplicity and looser triggers.

PION DECAY



$$\frac{1}{M_X^2}\overline{Q}\gamma_\mu Q\,\bar{d}_R\gamma^\mu d_R$$

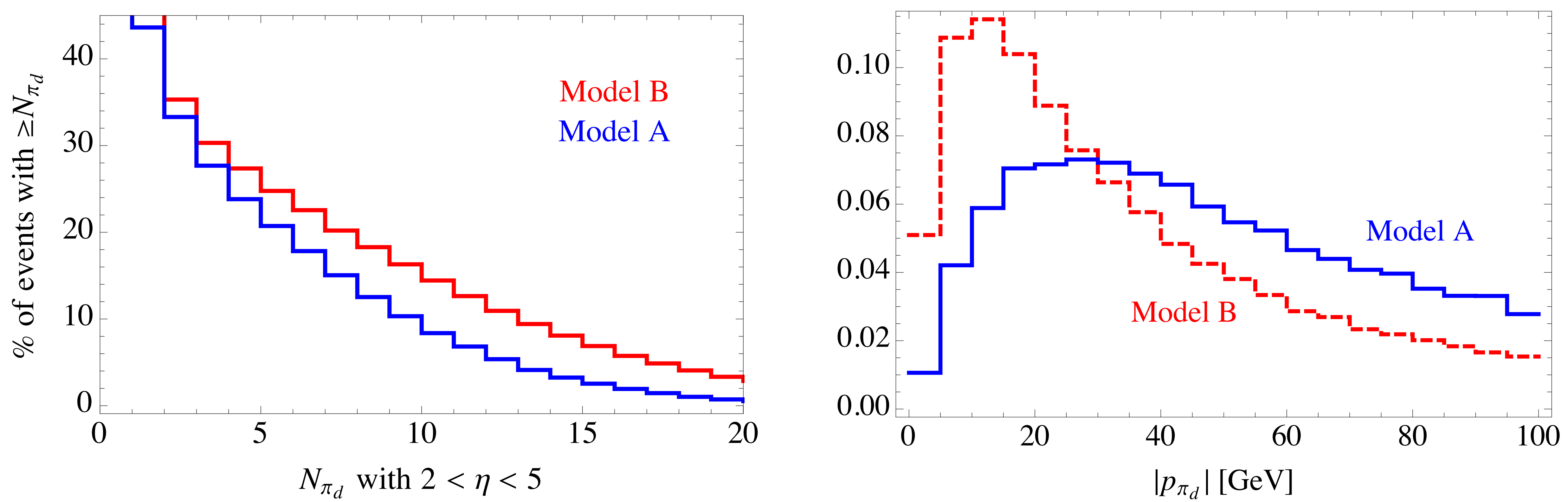
Can use (dark) chiral Lagrangian to estimate:

$$\Gamma(\pi_d \to \bar{d}d) \approx \frac{f_{\pi_d}^2 m_{\rm d}^2}{32\pi M_{X_d}^4} m_{\pi_d}$$

$$c\tau_0 \approx 10\,{\rm cm} \times \left(\frac{2\ {\rm GeV}}{f_{\pi_d}}\right)^2 \left(\frac{100\ {\rm MeV}}{m_{\rm down}}\right)^2 \left(\frac{2\ {\rm GeV}}{m_{\pi_d}}\right) \left(\frac{M_{X_d}}{1\ {\rm TeV}}\right)^4$$

LHCb SENSITIVITY

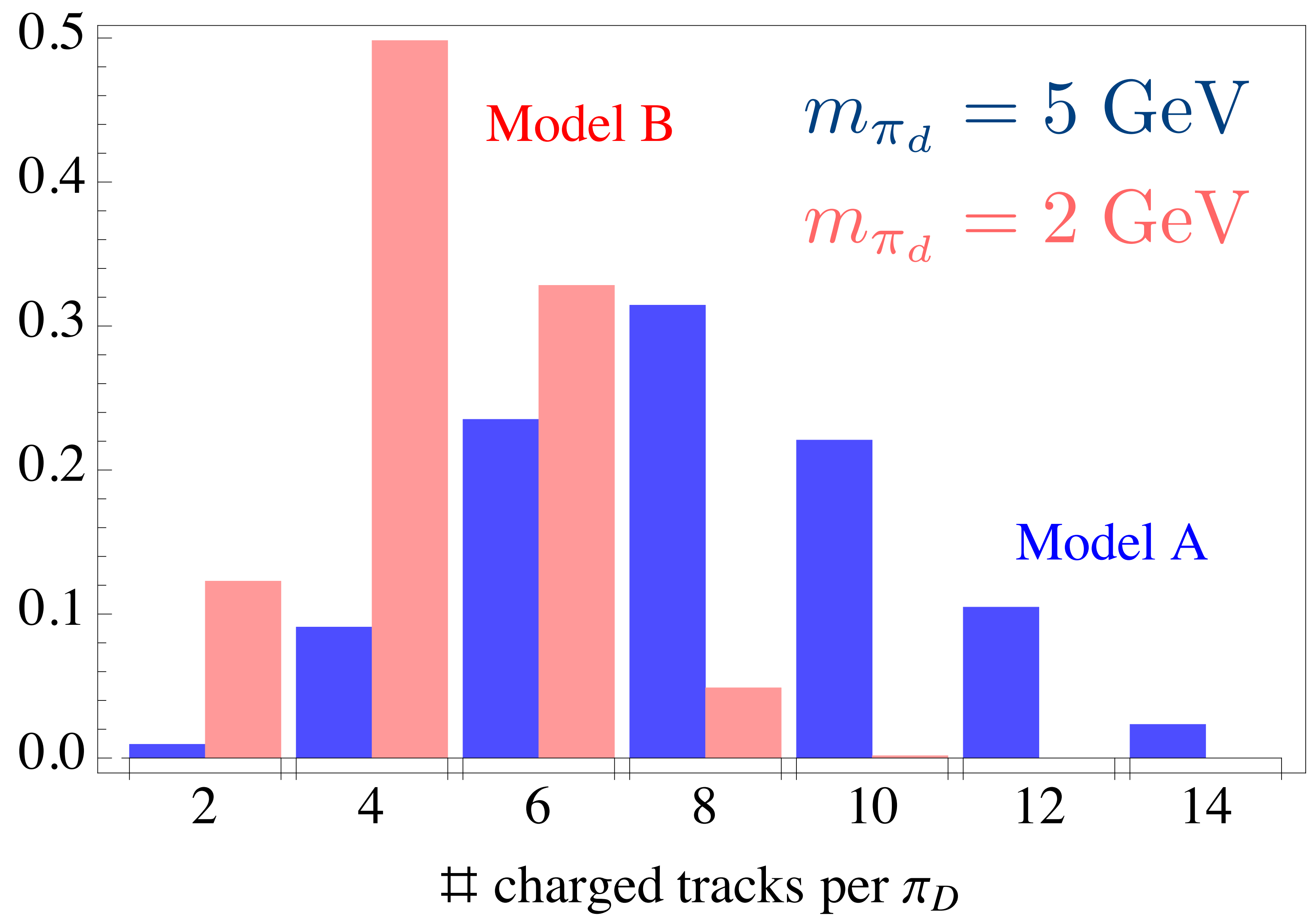
LHCb can use excellent tracking and mass resolution to measure individual dark pions.



~45% of events have > 0 pions in LHCb.

~30% have > 2.

TRACK MULTIPLICTY



LHCb SEARCH

Search for long-lived particles decaying to jet pairs

The LHCb collaboration[†]

Abstract

A search is presented for long-lived particles with a mass between 25 and 50 GeV/c^2 and a lifetime between 1 and 200 ps in a sample of proton-proton collisions at a centre-of-mass energy of $\sqrt{s} = 7$ TeV, corresponding to an integrated luminosity of 0.62 fb^{-1}, collected by the LHCb detector. The particles are assumed to be pair-produced by the decay of a Standard Model-like Higgs boson. The experimental signature of the long-lived particle is a displaced vertex with two associated jets. No excess above the background is observed and limits are set on the production cross-section as a function of the long-lived particle mass and lifetime.

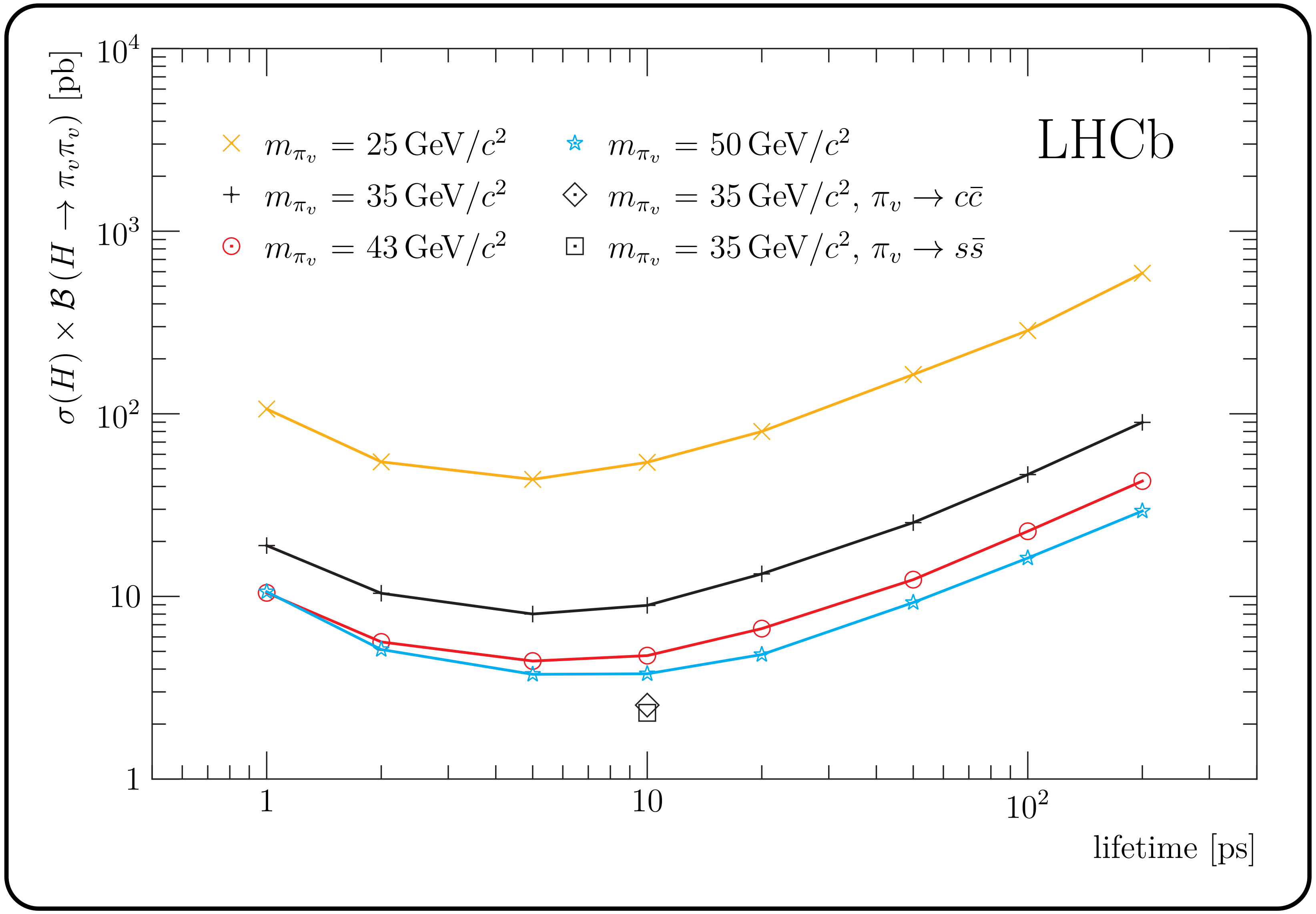
arXiv:1412.3021v1

Similar model to CMS search.

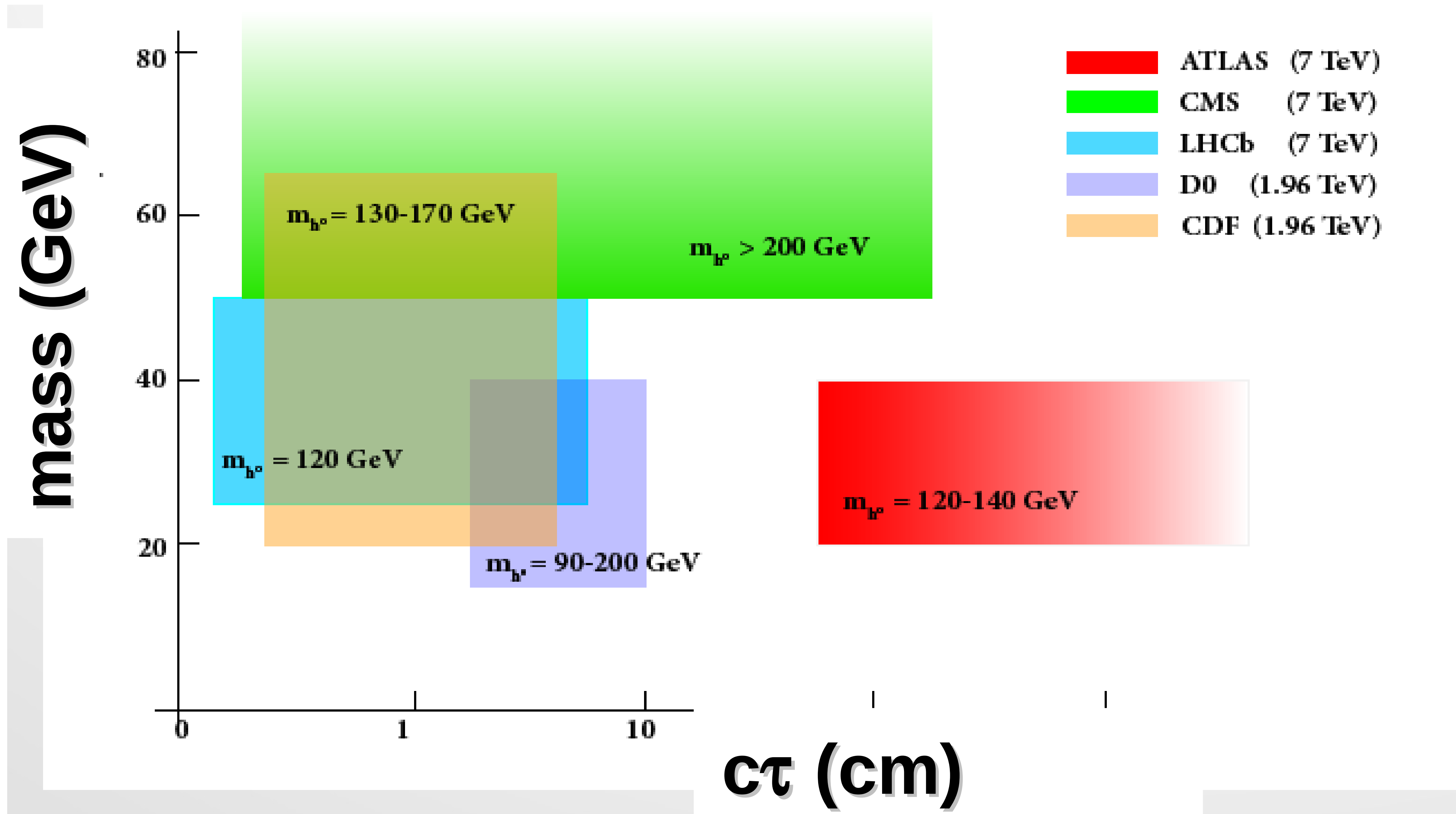
LHCb SEARCH

Not sensitive to strong interaction phenomenology.

Important proof of principle.



COMPLEMENTARITY



Talk by A. Hicheur, SILAFAE 2014

CONCLUSIONS

- Important to explore different ways LHC can search for NP.
- Dark matter and twin Higgs/folded SUSY give interesting and motivated models with new GeV scale strong interactions.
- Signatures at ATLAS, CMS, and LHCb can be quite spectacular, but few current searches are sensitive.
- LHCb's excellent tracking and loose triggering make it excellent for these kinds of models.
- Opportunities to discover new physics abound!

THANK YOU

CMS SEARCH

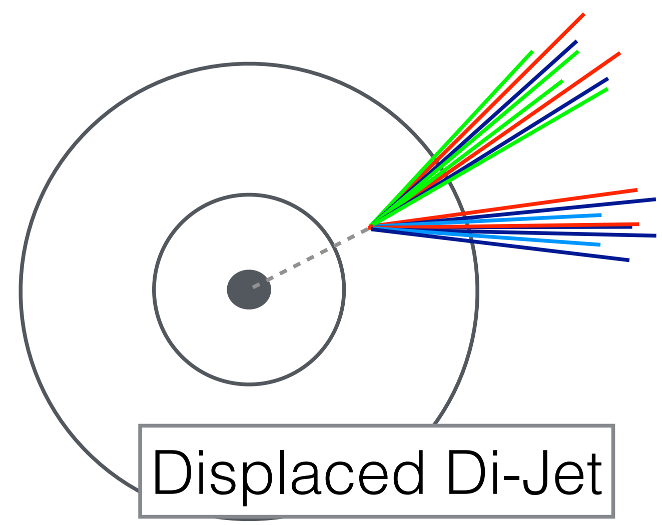
Search for long-lived neutral particles decaying to dijets

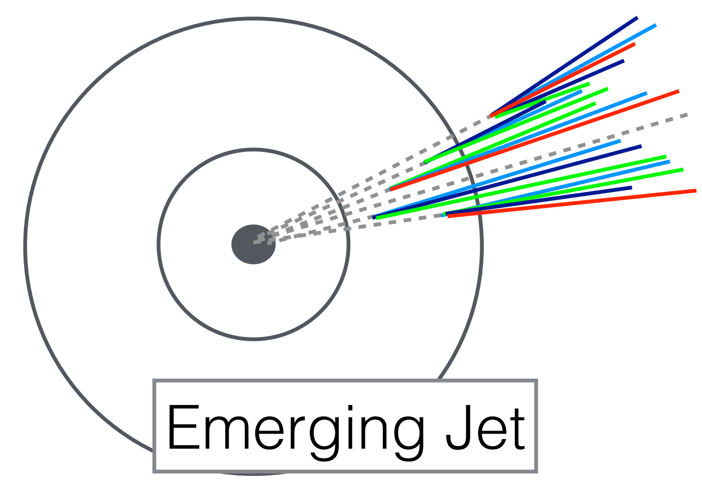
The CMS Collaboration

Abstract

A search is performed for long-lived massive neutral particles decaying to quark-antiquark pairs. The experimental signature is a distinctive topology of a pair of jets originating at a secondary vertex. Events were collected by the CMS detector at the LHC during pp collisions at $\sqrt{s} = 8$ TeV, and selected from data samples corresponding to 18.6 fb^{-1} of integrated luminosity. No significant excess is observed above standard model expectations and an upper limit is set with 95% confidence level on the production cross section of a heavy scalar particle, H^0, in the mass range 200 to 1000 GeV, decaying into a pair of long-lived neutral X^0 particles in the mass range 50 to 350 GeV, which each decay to quark-antiquark pairs. For X^0 mean proper lifetimes of 0.1 to 200 cm the upper limits are typically 0.3−300 fb.

CMS Collaboration, Phys.Rev.D.91, 012017 (2015) [arXiv:1411.6530].





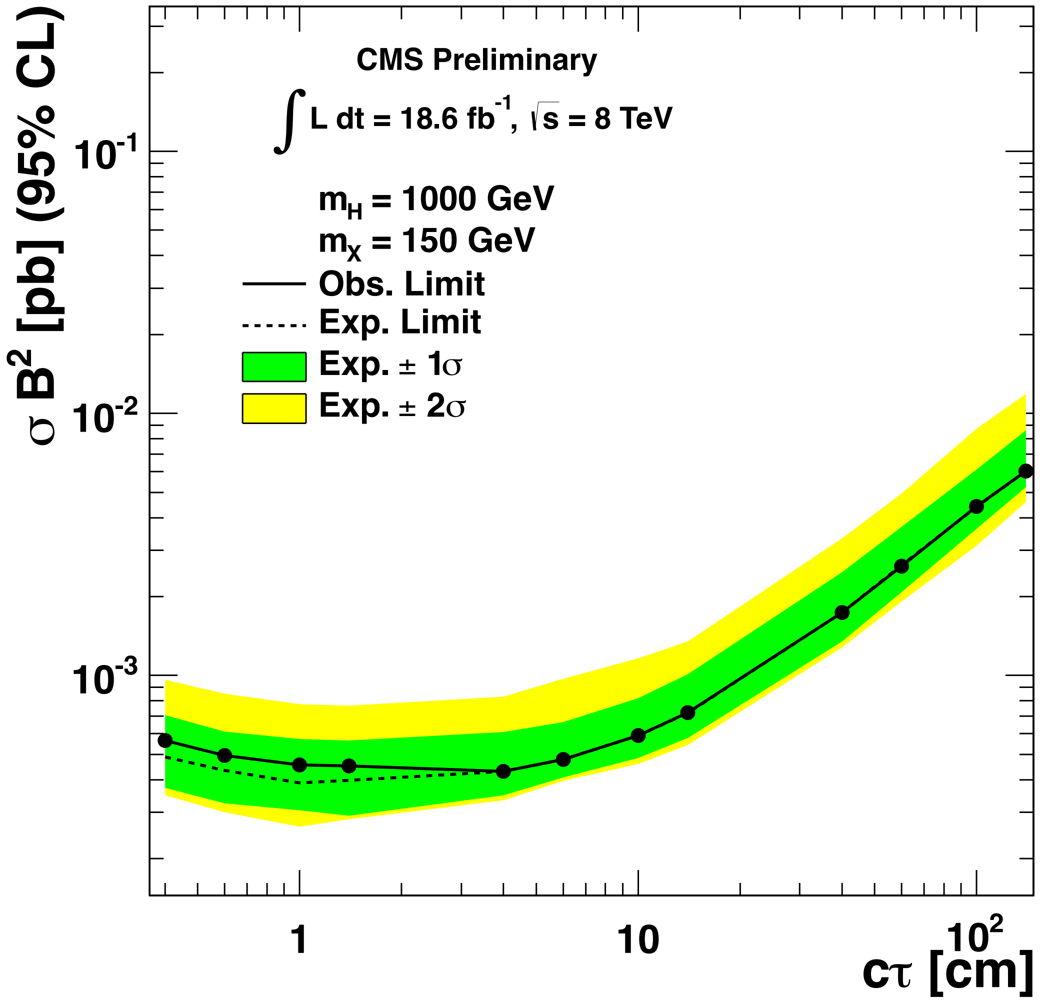
CMS SEARCH

CMS PAS EXO-12-038

Require di-jets all coming from a single displaced vertex.

Throw away energy of tracks not reconstructed from vertex.

Unlikely to be sensitive to emerging phenomenology.



ATLAS SEARCH 1

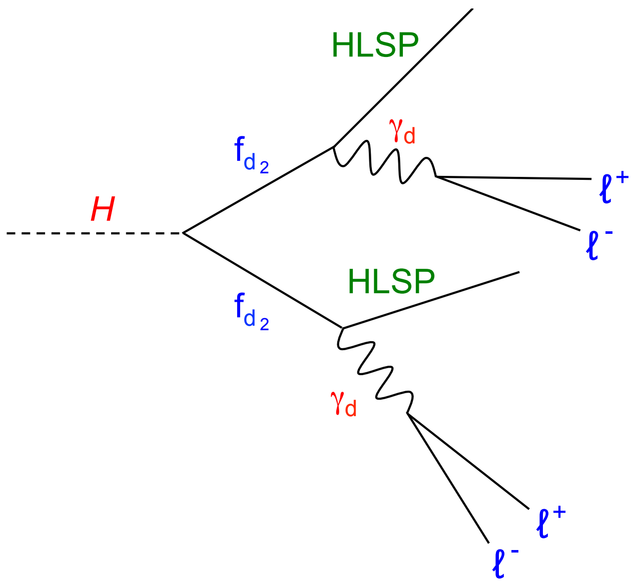
Search for long-lived neutral particles decaying into lepton jets in proton–proton collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector

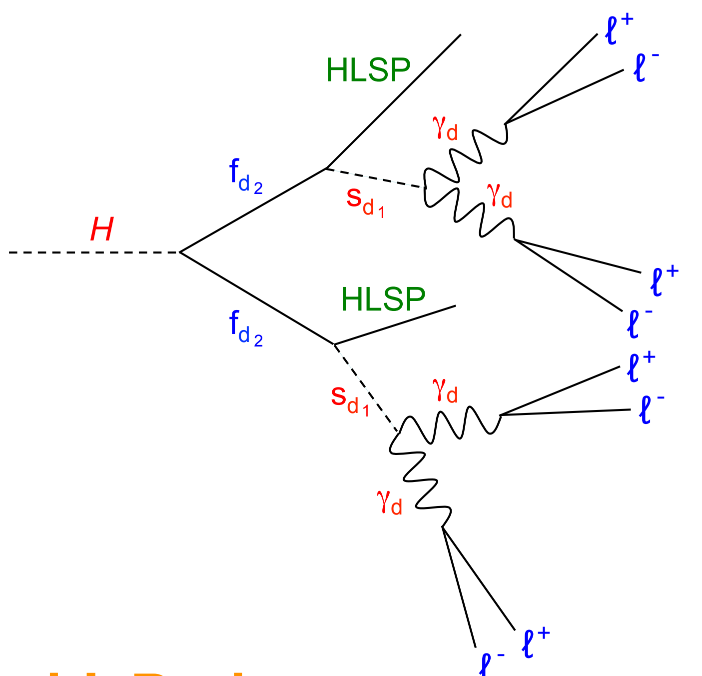
The ATLAS Collaboration

Abstract

Several models of physics beyond the Standard Model predict neutral particles that decay into final states consisting of collimated jets of light leptons and hadrons (so-called "lepton jets"). These particles can also be long-lived with decay length comparable to, or even larger than, the LHC detectors' linear dimensions. This paper presents the results of a search for lepton jets in proton–proton collisions at the centre-of-mass energy of $\sqrt{s}$ = 8 TeV in a sample of 20.3 fb^{-1} collected during 2012 with the ATLAS detector at the LHC. Limits on models predicting Higgs boson decays to neutral long-lived lepton jets are derived as a function of the particle's proper decay length.

ATLAS Collaboration, JHEP.1411,88 (2014) [arXiv:1409.0746].
ATLAS Collaboration, [arXiv:1501.04020].





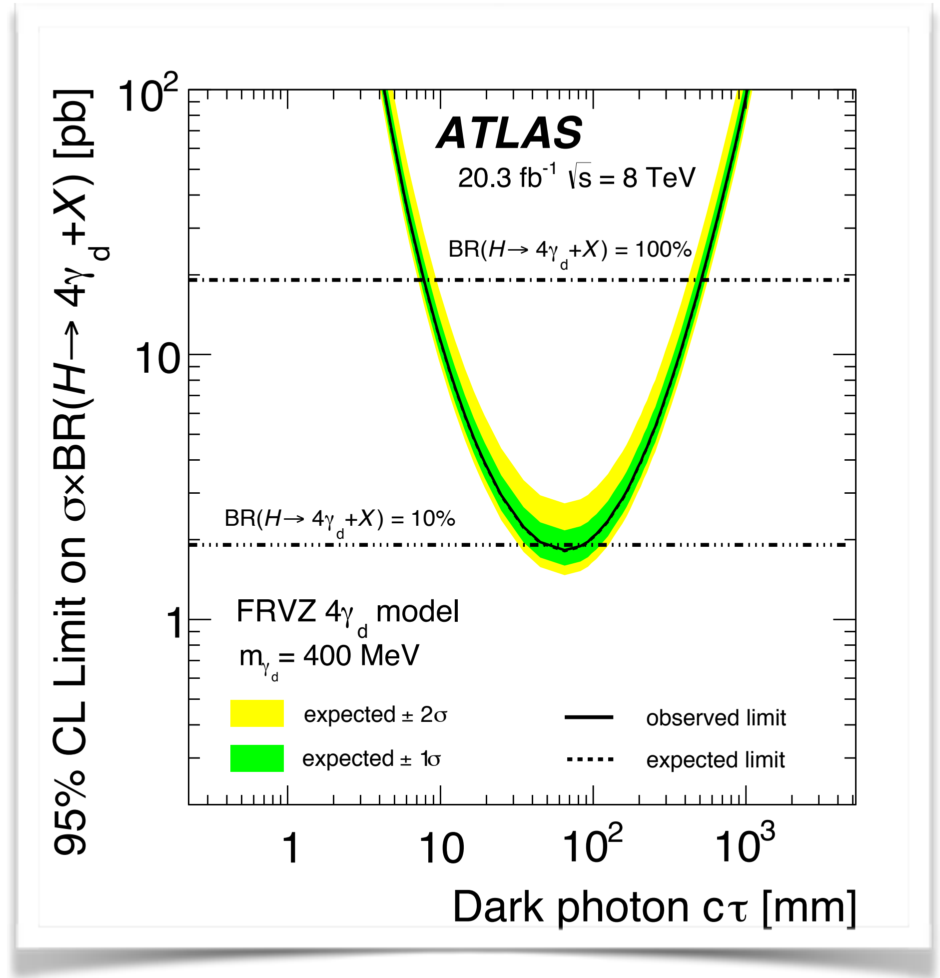
Falkowski, Ruderman, Volansky, Zupan '10

ATLAS SEARCH 1

arXiv:1409.0746v2 [hep-ex]

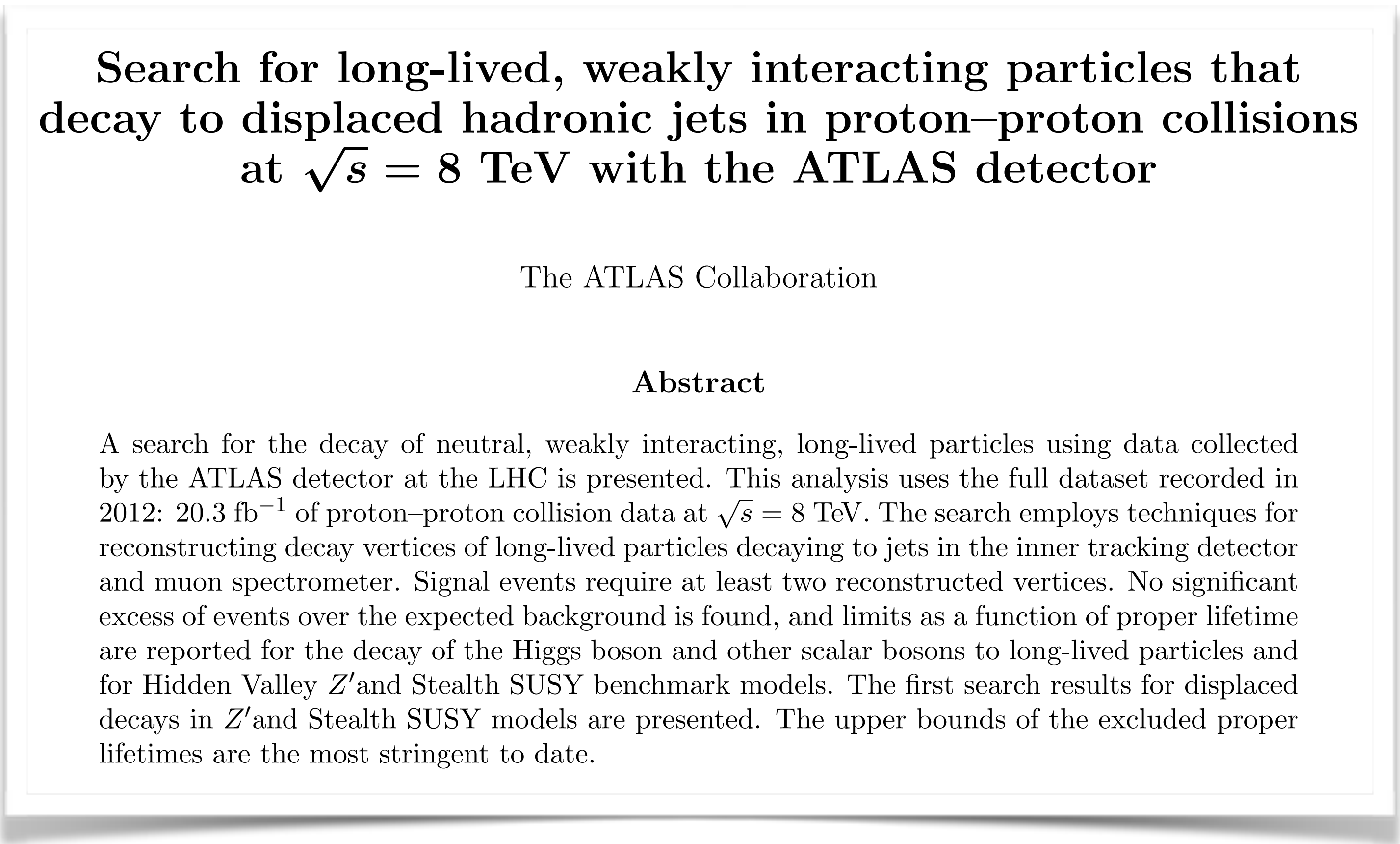
Requires ECAL/HCAL < 0.1.

Optimized for decays within HCAL, extremely low efficiency except possibly for long lifetimes.



See also ATLAS trigger paper: arXiv:1305.2204 [hep-ex].

ATLAS SEARCH 2

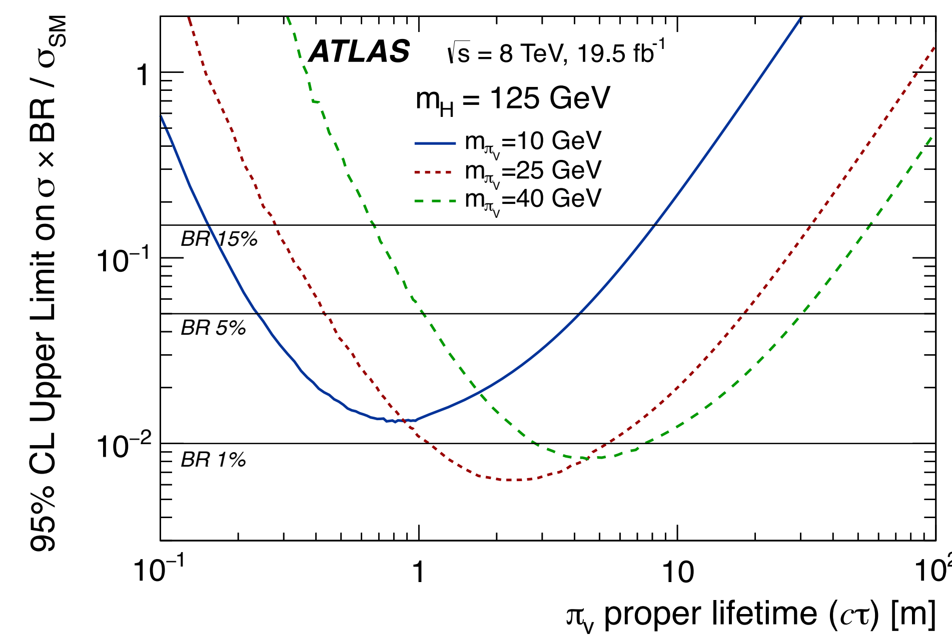


Search for long-lived, weakly interacting particles that decay to displaced hadronic jets in proton–proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

The ATLAS Collaboration

Abstract

A search for the decay of neutral, weakly interacting, long-lived particles using data collected by the ATLAS detector at the LHC is presented. This analysis uses the full dataset recorded in 2012: 20.3 fb^{-1} of proton–proton collision data at $\sqrt{s} = 8$ TeV. The search employs techniques for reconstructing decay vertices of long-lived particles decaying to jets in the inner tracking detector and muon spectrometer. Signal events require at least two reconstructed vertices. No significant excess of events over the expected background is found, and limits as a function of proper lifetime are reported for the decay of the Higgs boson and other scalar bosons to long-lived particles and for Hidden Valley Z' and Stealth SUSY benchmark models. The first search results for displaced decays in Z' and Stealth SUSY models are presented. The upper bounds of the excluded proper lifetimes are the most stringent to date.



ATLAS Collaboration, Phys.Rev.D.92 (2015) [arXiv:1504.03634].
See also ATLAS [arXiv:1501.04020].

Similar isolation requirements as CMS search.