NEW LONG-LIVED PARTICLES AT THE LHC

Carleton University

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EPS July 7, 2017

KEYS TO LONGEVITY

Warning: Formulas ahead (sort of).

There are (at least) 3 ways for particles to live a long time $(\Gamma/M \ll 1)$:

1. Heavy scales: $\Gamma \sim (M/M_*)^{\#},\ M_* \gg M$

SM Example: Muon, heavy scale is m_W

BSM Example: Proton decay in GUT

KEYS TO LONGEVITY

Warning: Formulas ahead (sort of).

There are (at least) 3 ways for particles to live a long time $(\Gamma/M \ll 1)$:

2. Small couplings: $\Gamma \sim \lambda^2 M,\ \lambda \ll 1$

SM Example: B-mesons, small coupling is V_{cb}

BSM Example: Small couplings in RPV SUSY

KEYS TO LONGEVITY

Warning: Formulas ahead (sort of).

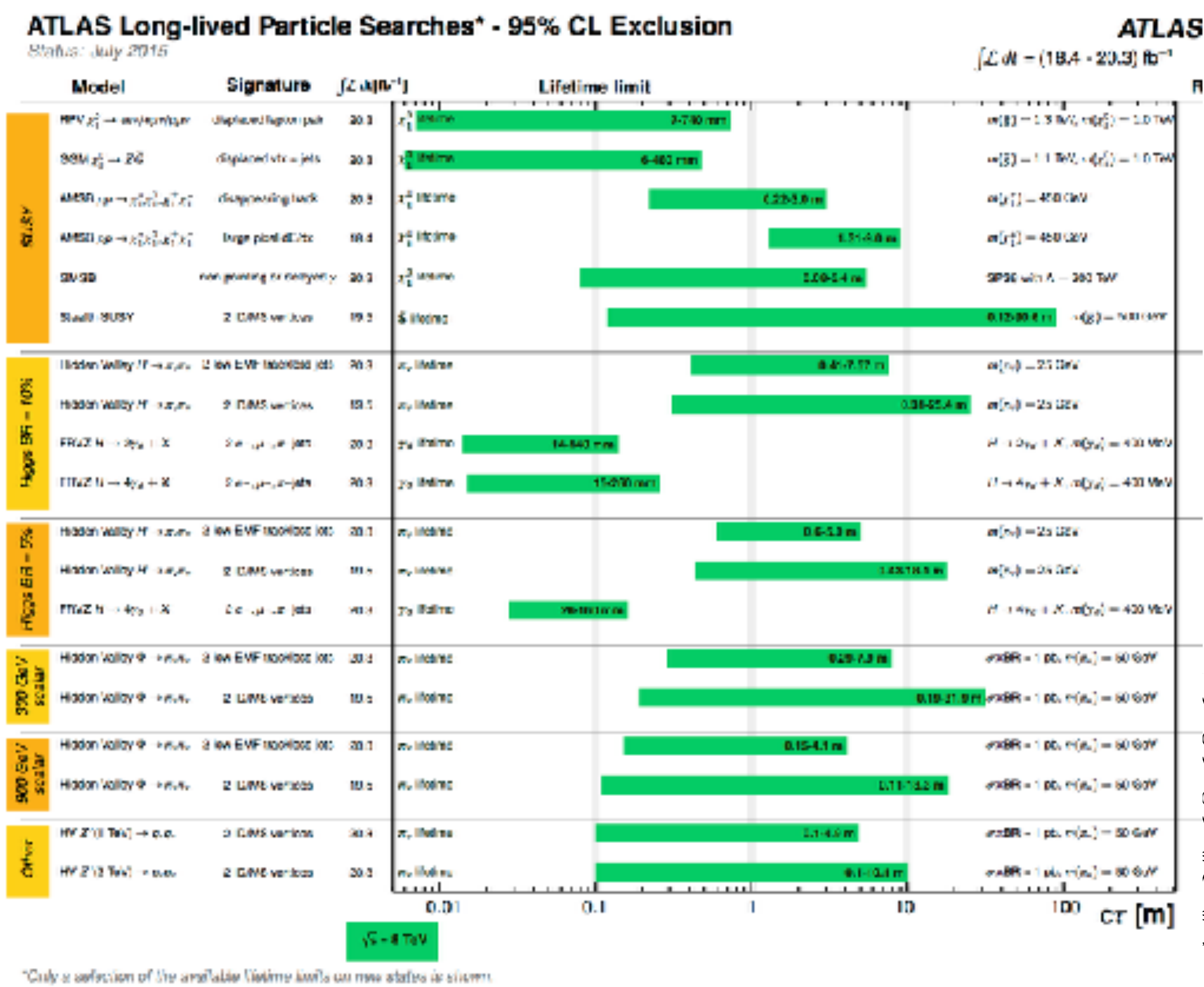
There are (at least) 3 ways for particles to live a long time $(\Gamma/M \ll 1)$:

3. Kinematic squeezing: $\Gamma \sim (Q/M)^{\#}, Q \ll M$

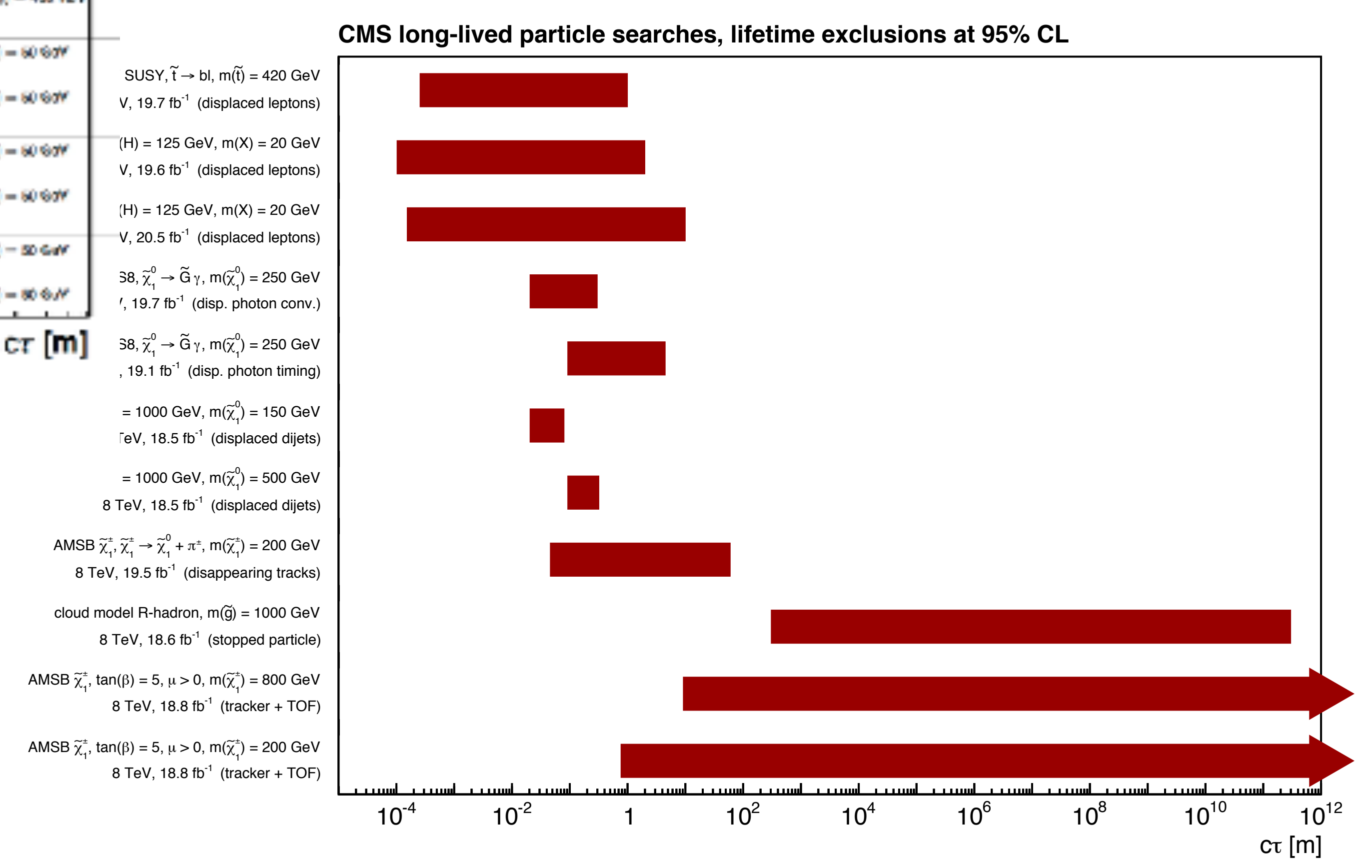
SM Example: Neutron, $m_N - m_p - m_e \ll m_N$

BSM Example: Charged and neutral Higgsino

CURRENT SEARCHES



See talks by Mauri, Lusiani, Adams, Petterson, Lutz, Saito, and Otono.

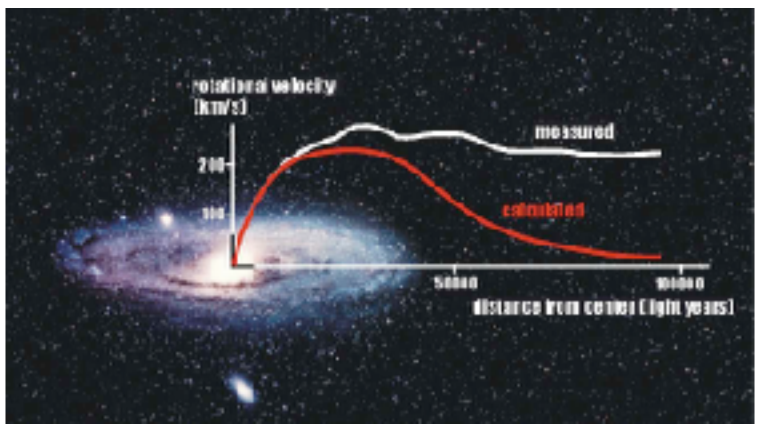


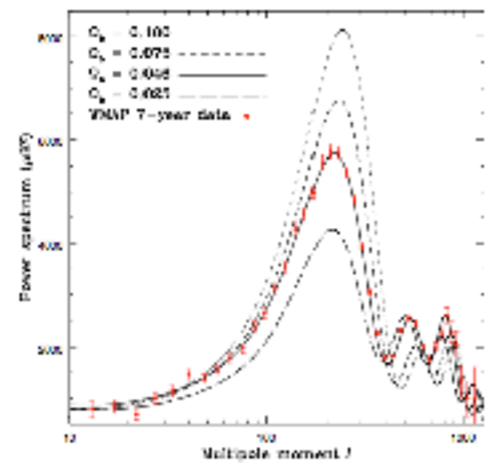
MOTIVATION

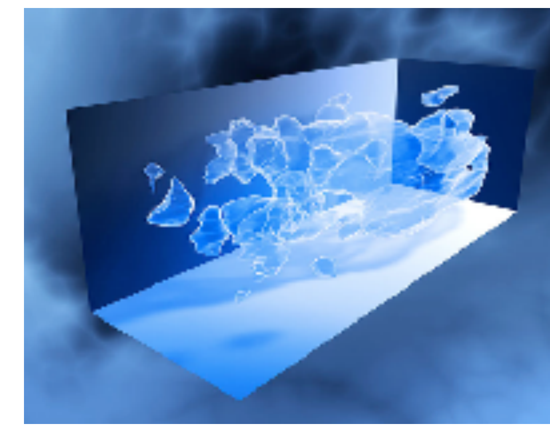
H. Murayama

DARK MATTER

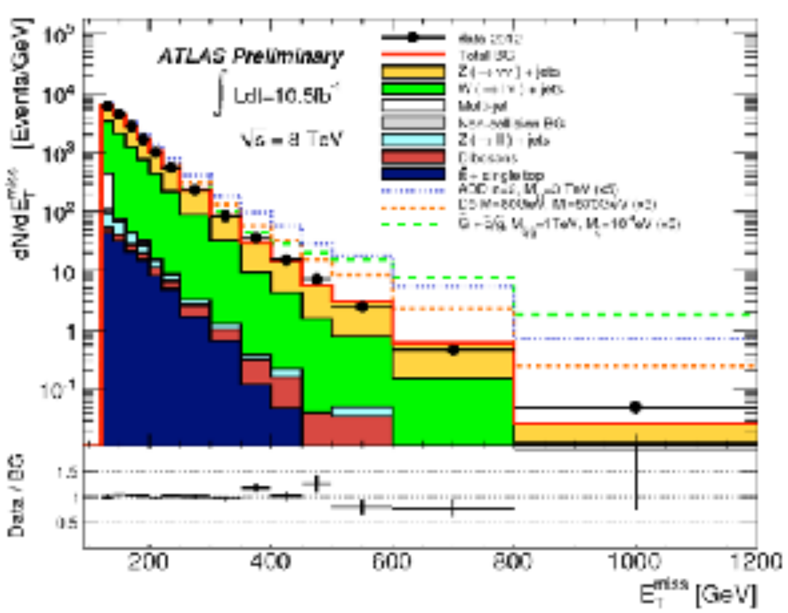
We have seen dark matter in the sky.

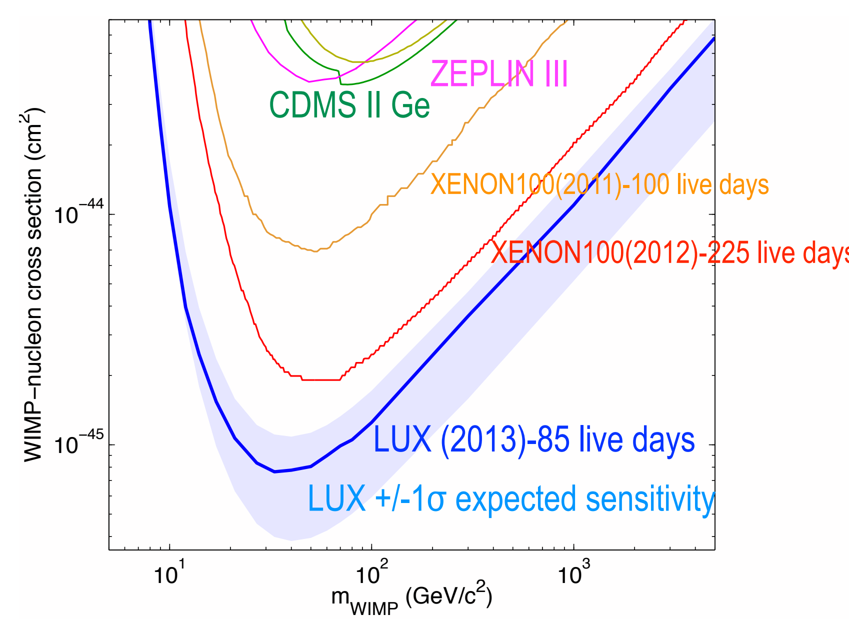






But not in the lab.



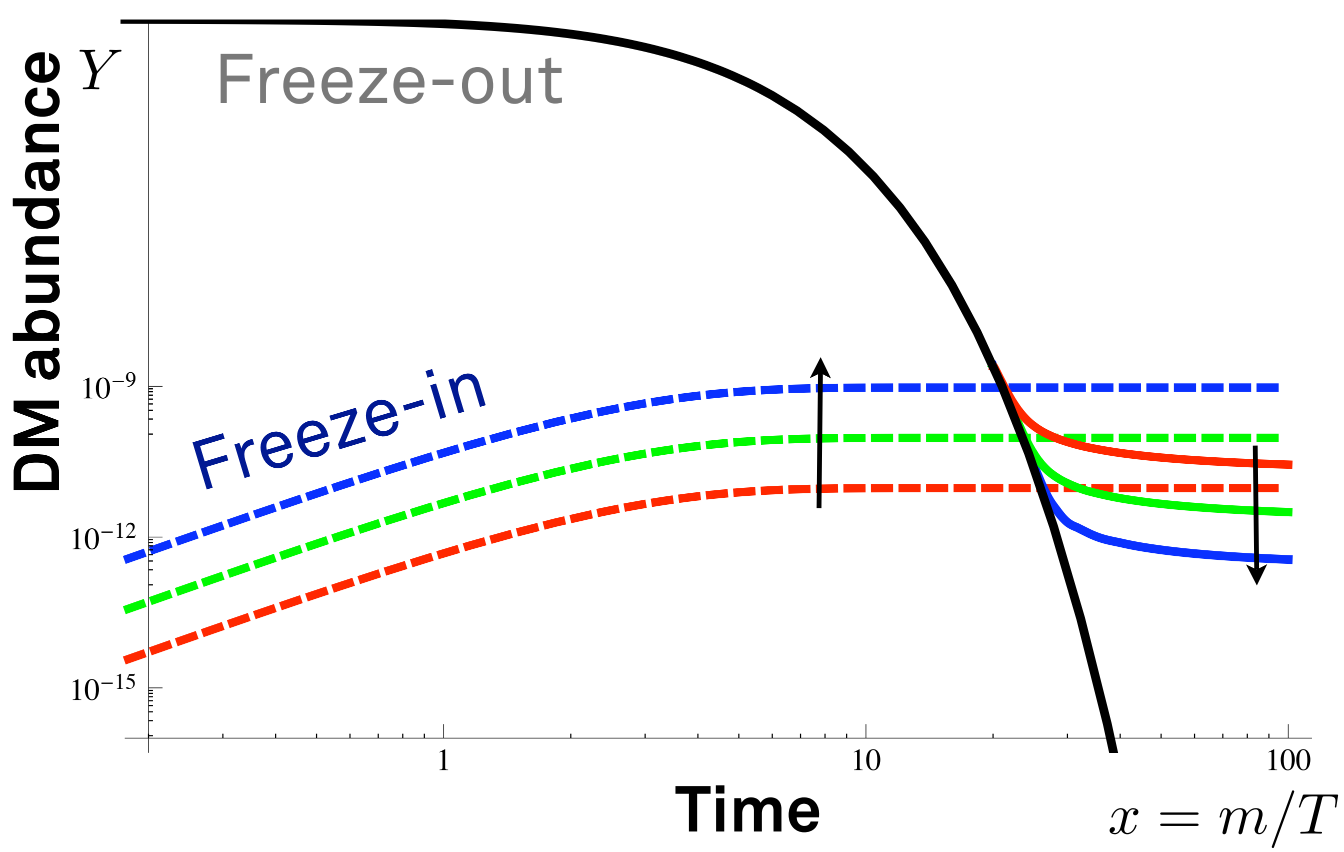


FREEZE-IN

Weak coupling of DM to thermal bath.

DM never in equilibrium, bath slowly leaks energy into DM sector.

Thermal abundance set by small coupling.



Hall, Jadamzik, March-Russel, West, arXiv:0911.1120.

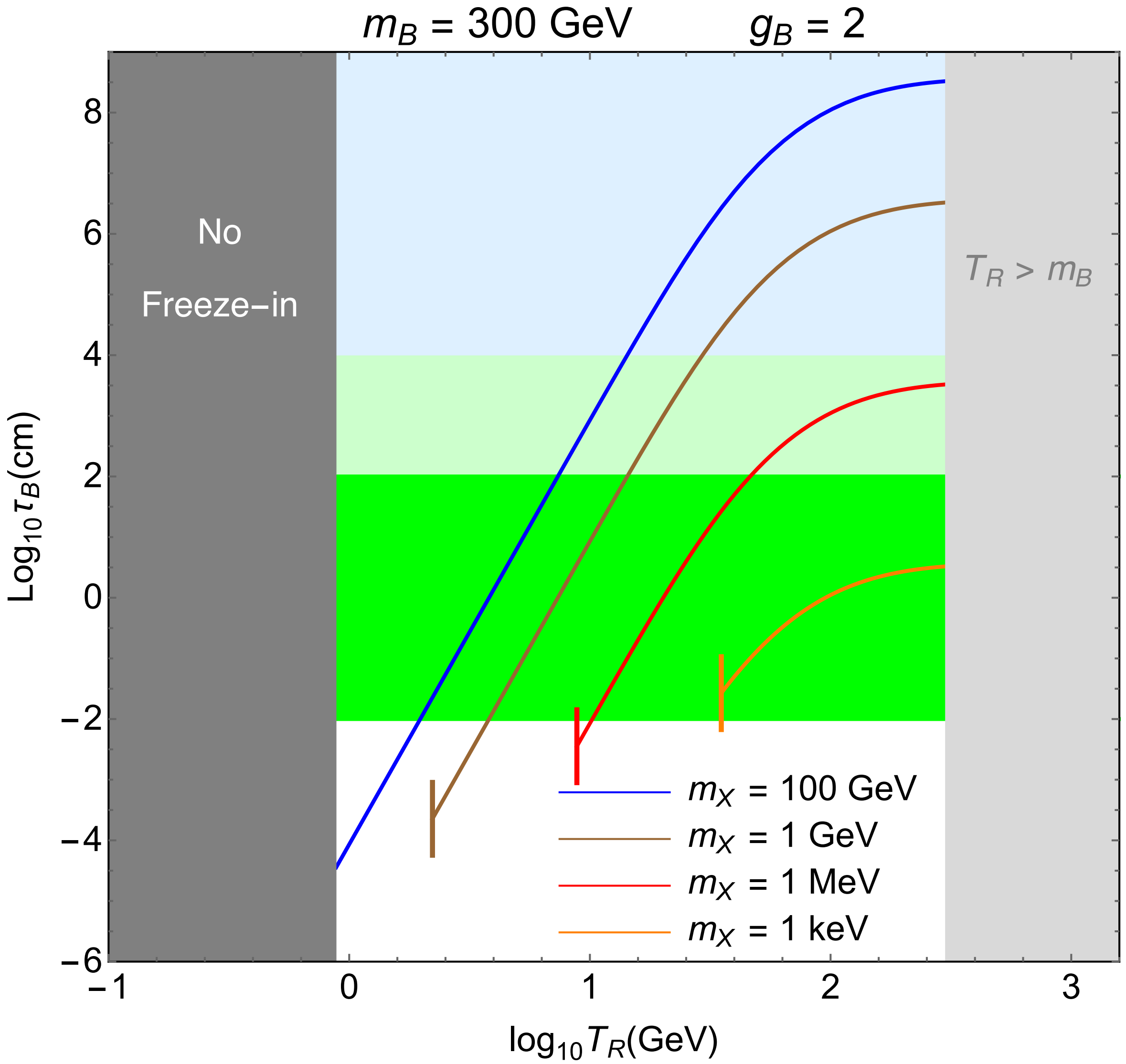
FREEZE-IN

$$B \to A_{\rm SM} X$$

DM

Big coupling to SM,
small coupling to DM.
(Type 1 longevity)

Co, D'Eramo, Hall, Pappadopulo, arXiv: 1506.07532.



Shaded region	Decay length	Signature from LOSP	Neutral	Charged
Dark green	$10^{-2}\mathrm{cm} < \tau_B < 10^{2}\mathrm{cm}$	Displaced vertices	✓	✓
Light green	$10^{2}\mathrm{cm} < \tau_B < 10^{4}\mathrm{cm}$	Displaced jets/leptons	✓	✓
Light blue	$10^{4}\mathrm{cm} < \tau_B$	Stopped particle decays	X	✓

FREEZE-IN

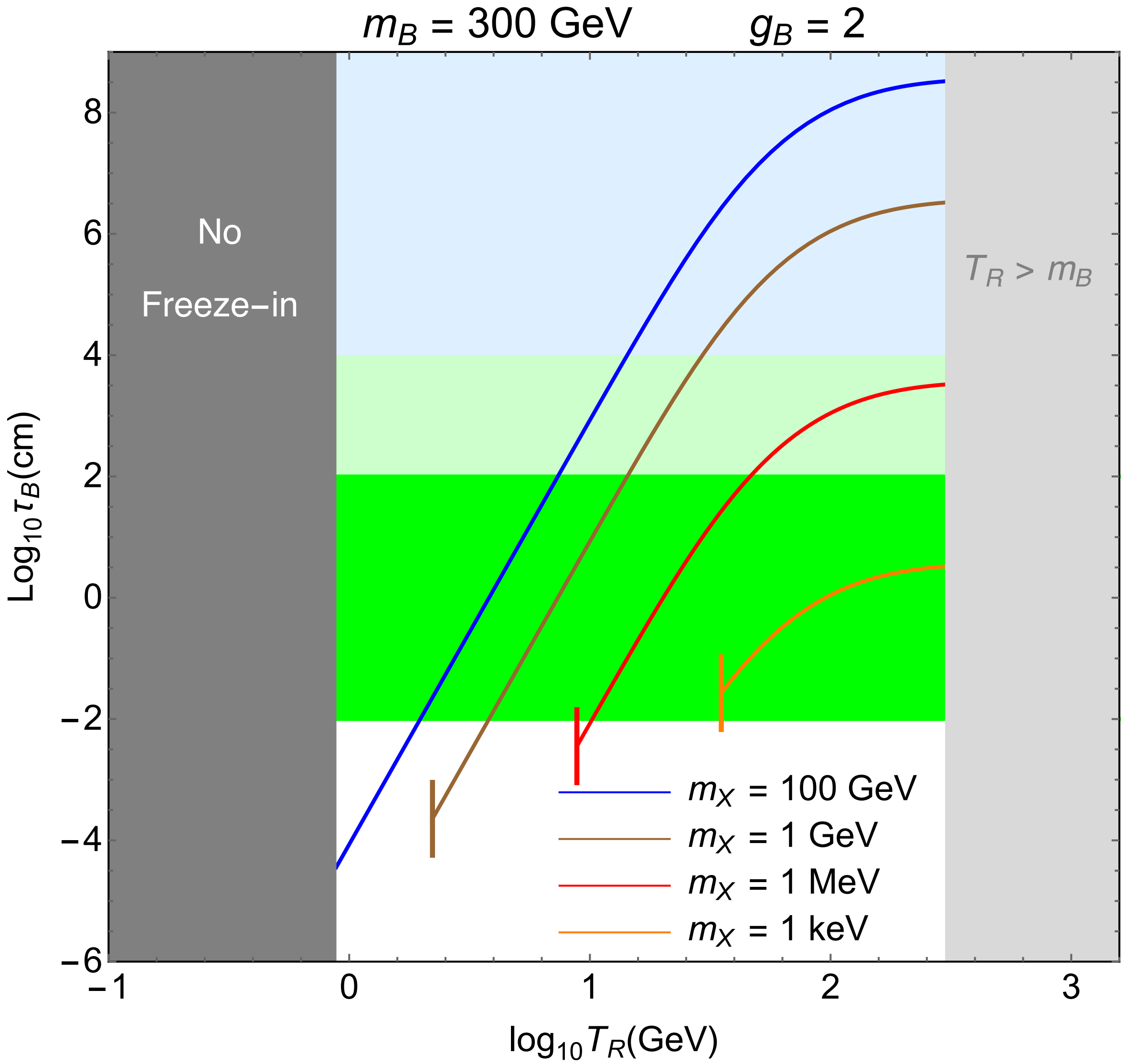
$$B \to A_{\rm SM} X$$

$$\downarrow$$

Any SM state:

$h,\ Z,\ \ell^+\ell^-,\ q\bar{q},\ \gamma$, ...

Co, D'Eramo, Hall, Pappadopulo, arXiv: 1506.07532.



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ASYMMETRIC DARK MATTER

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

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

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ASYMMETRIC DARK MATTER

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Controlled by complicated (known) QCD dynamics

$$\Omega_{DM} = m_{DM} n_{DM} \qquad \Omega_B = m_p n_B$$

ASYMMETRIC DARK MATTER

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

Controlled by complicated (known) QCD dynamics

$$\Omega_{DM} = m_{DM} n_{DM} \qquad \Omega_B = m_p n_B$$

Unknown dynamics of baryogenesis

ASYMMETRIC DARK MATTER

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

Controlled by complicated (known) QCD dynamics

$$\Omega_{DM} = m_{DM} n_{DM} \qquad \Omega_B = m_p n_B$$

?

Unknown dynamics of baryogenesis

ASYMMETRIC DARK MATTER

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

QCD like

?

Controlled by complicated (known) QCD dynamics

$$\Omega_{DM} = m_{DM} n_{DM} \qquad \Omega_B = m_p n_B$$

?

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.

...

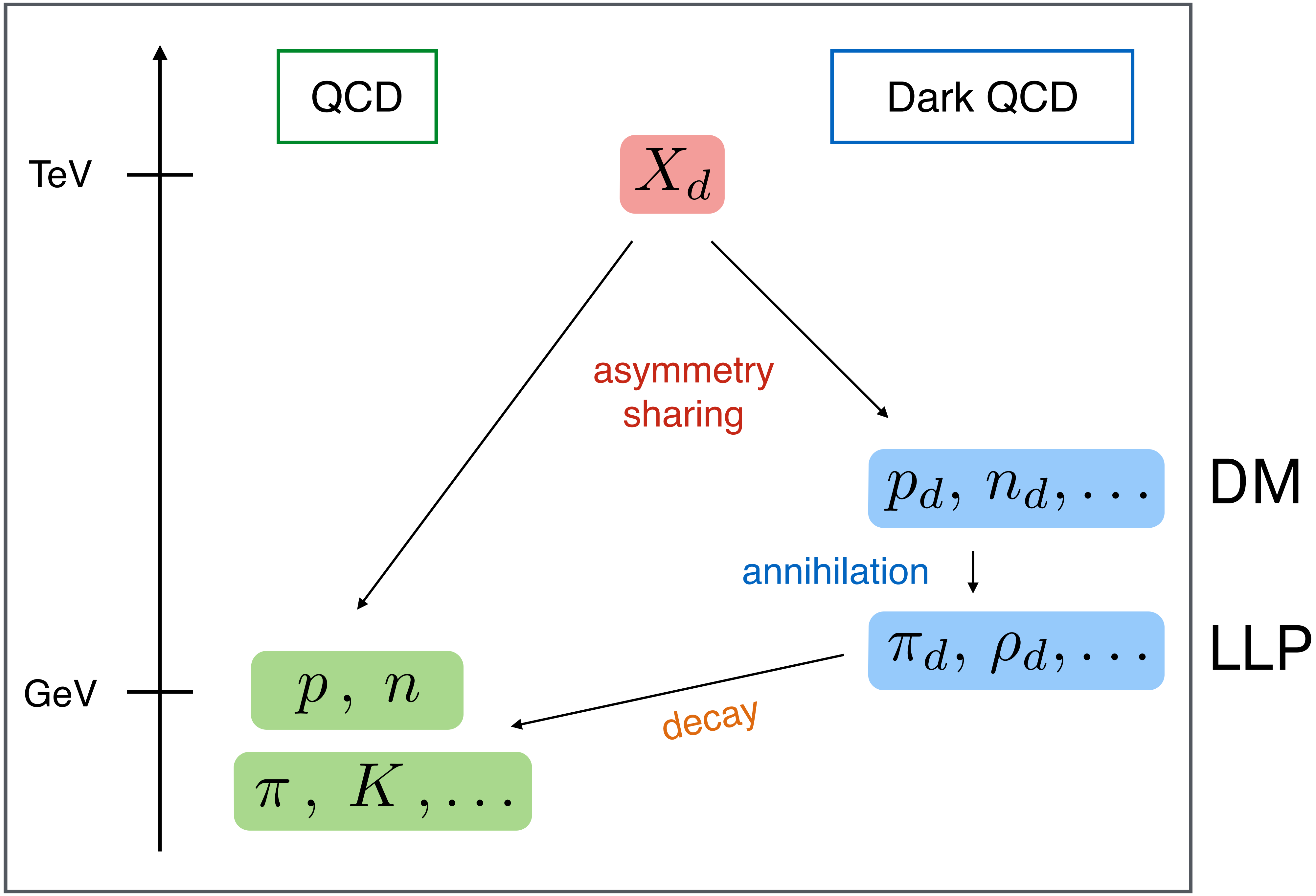
D. E. Kaplan, M. A. Luty, K. M. Zurek, arXiv:0901.4117.

Bai and Schwaller, arXiv:1306.4676.

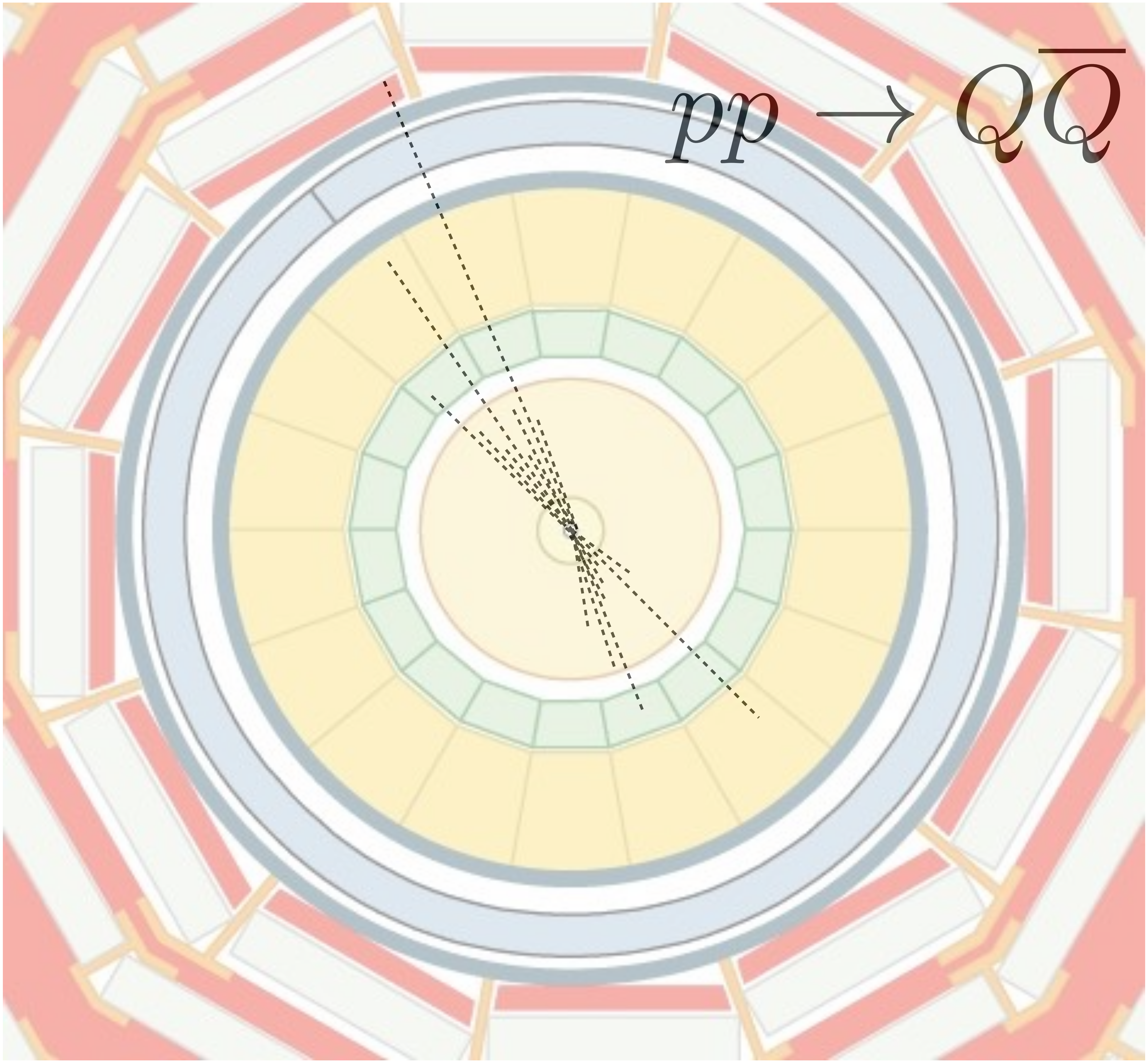
K. K. Boddy, et.al. arXiv:1402.362.

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

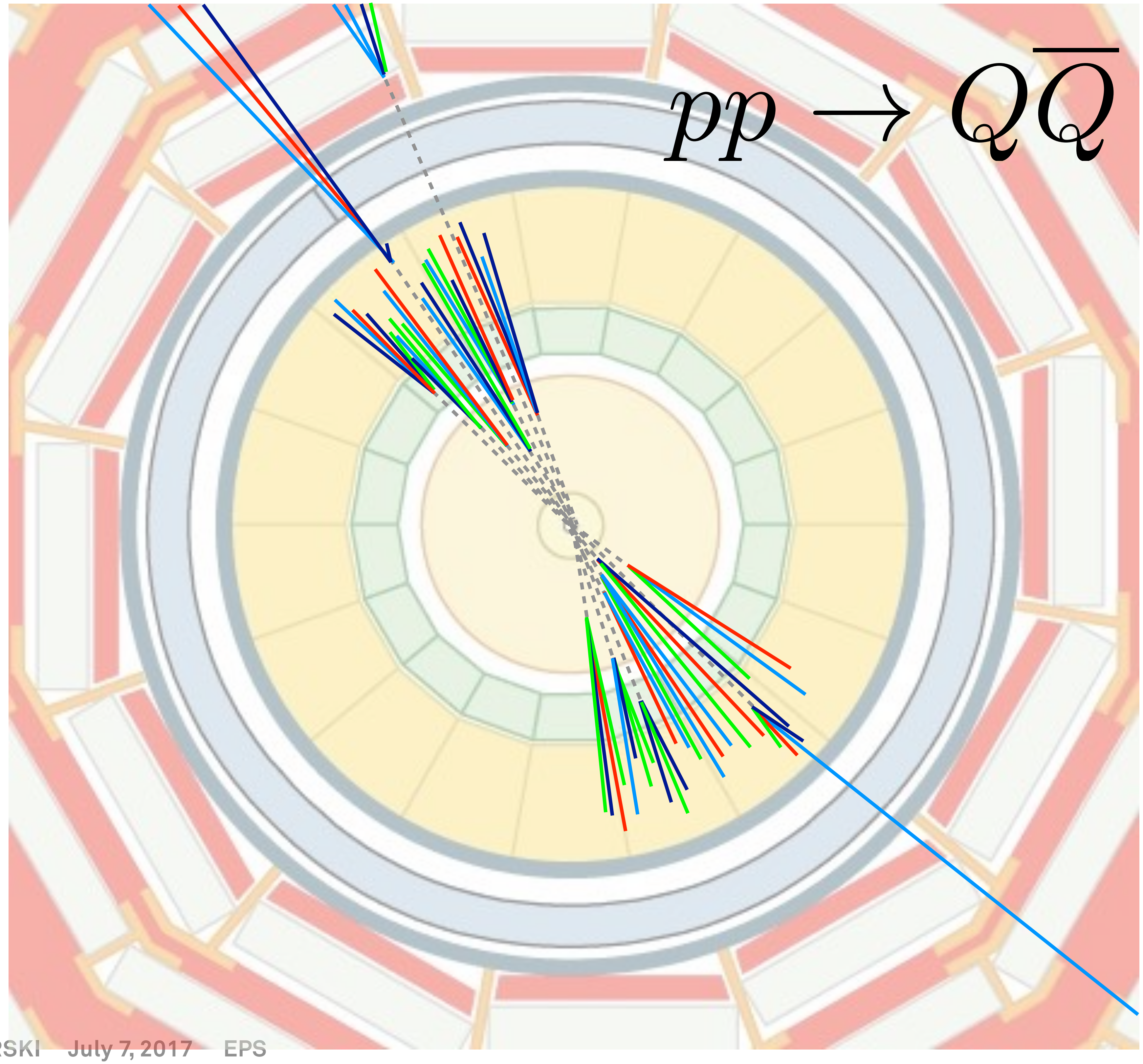
GENERAL PICTURE



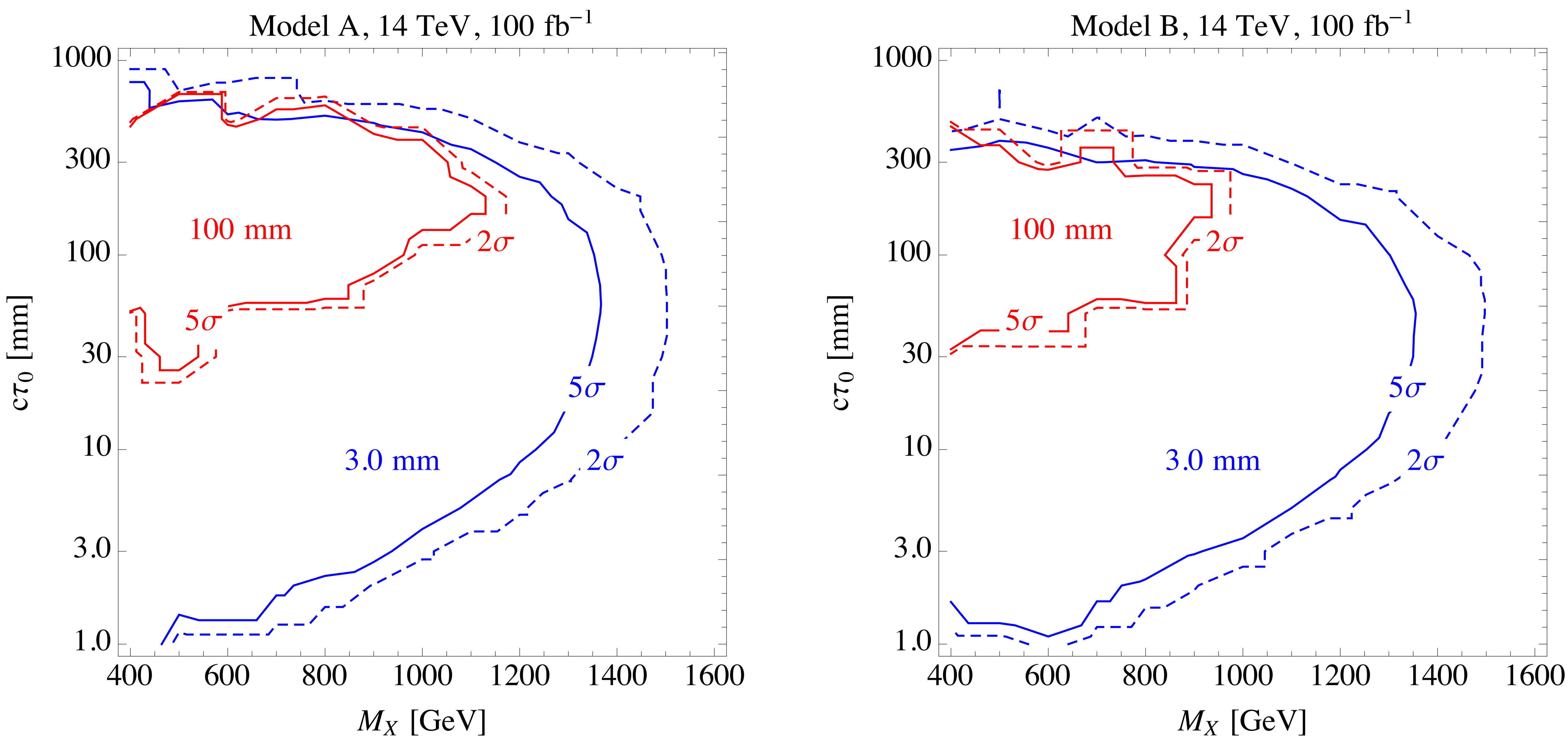
(Type 1 longevity)


$pp \to Q\overline{Q}$

EMERGING JETS



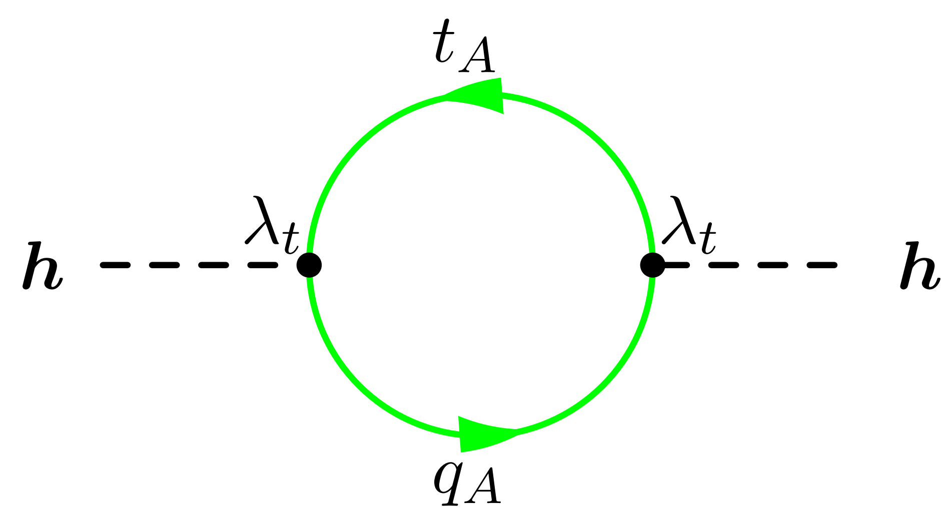
EMERGING JETS



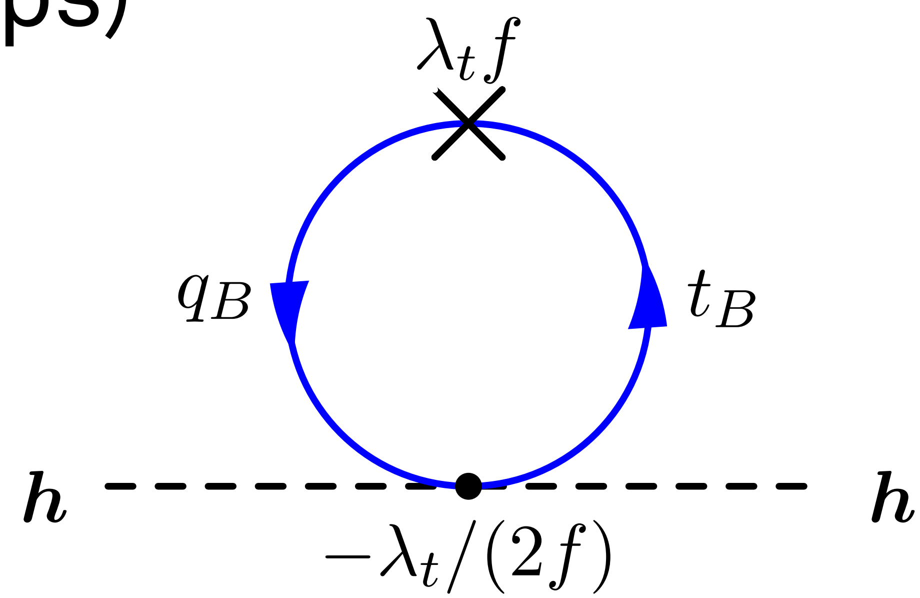
Schwaller, DS, Weiler, arXiv:1502.05409.

TWIN HIGGS/FOLDED SUSY

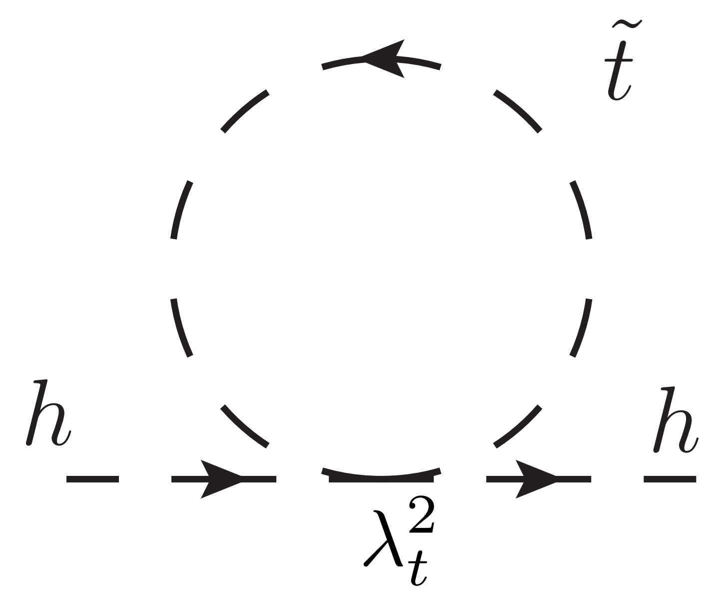
Gauge hierarchy problem:



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



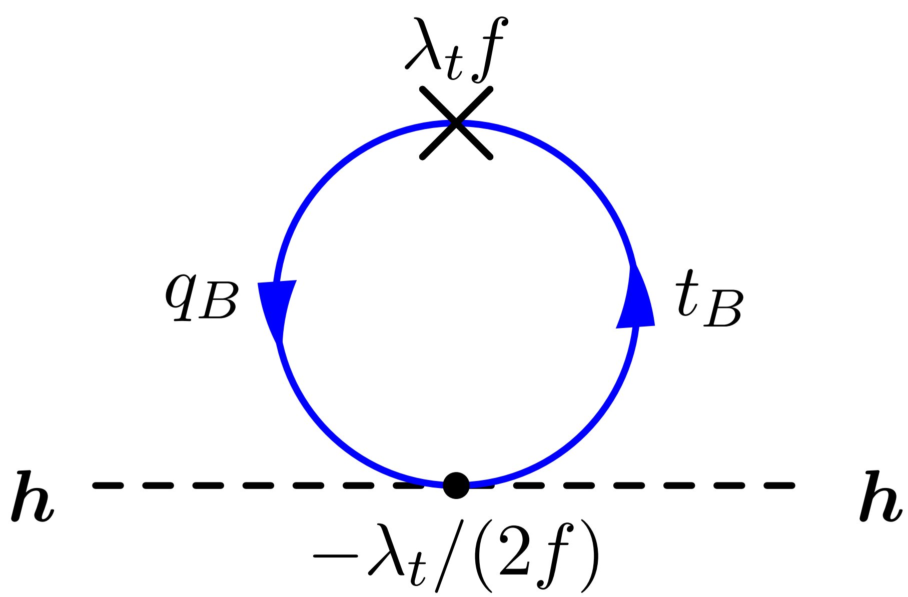
or

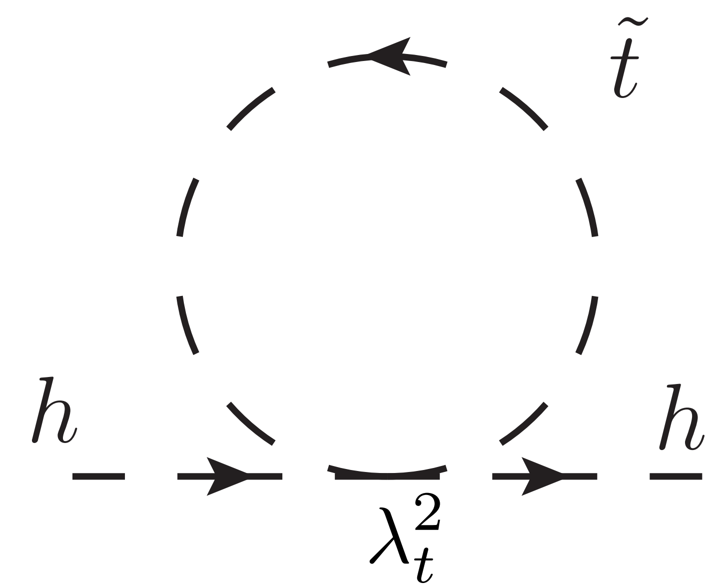


Do these partners need to be coloured?

TWIN HIGGS/FOLDED SUSY

No! But still need factor of 3.

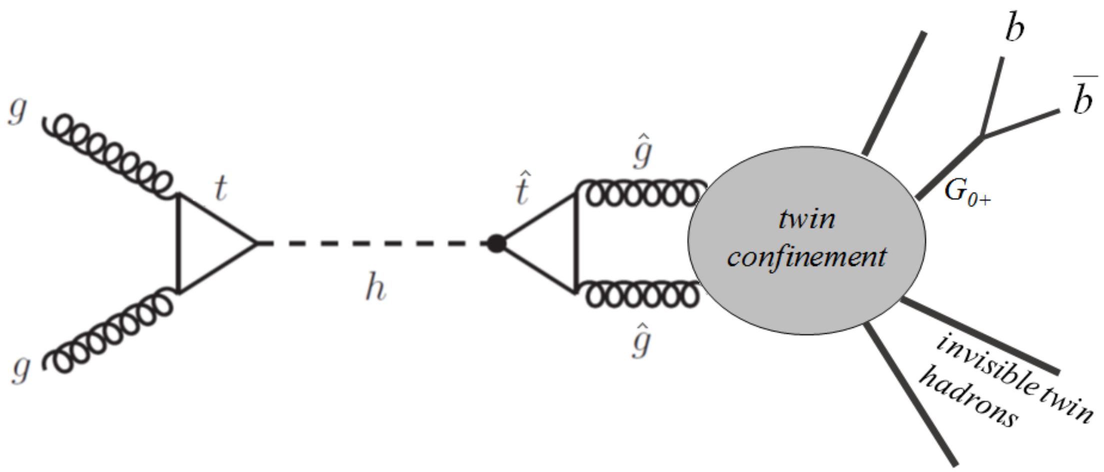




Chacko, Goh, Harnik, hep-ph/0506256.
Burdman, Chacko, Goh, Harnik, hep-ph/0609152.

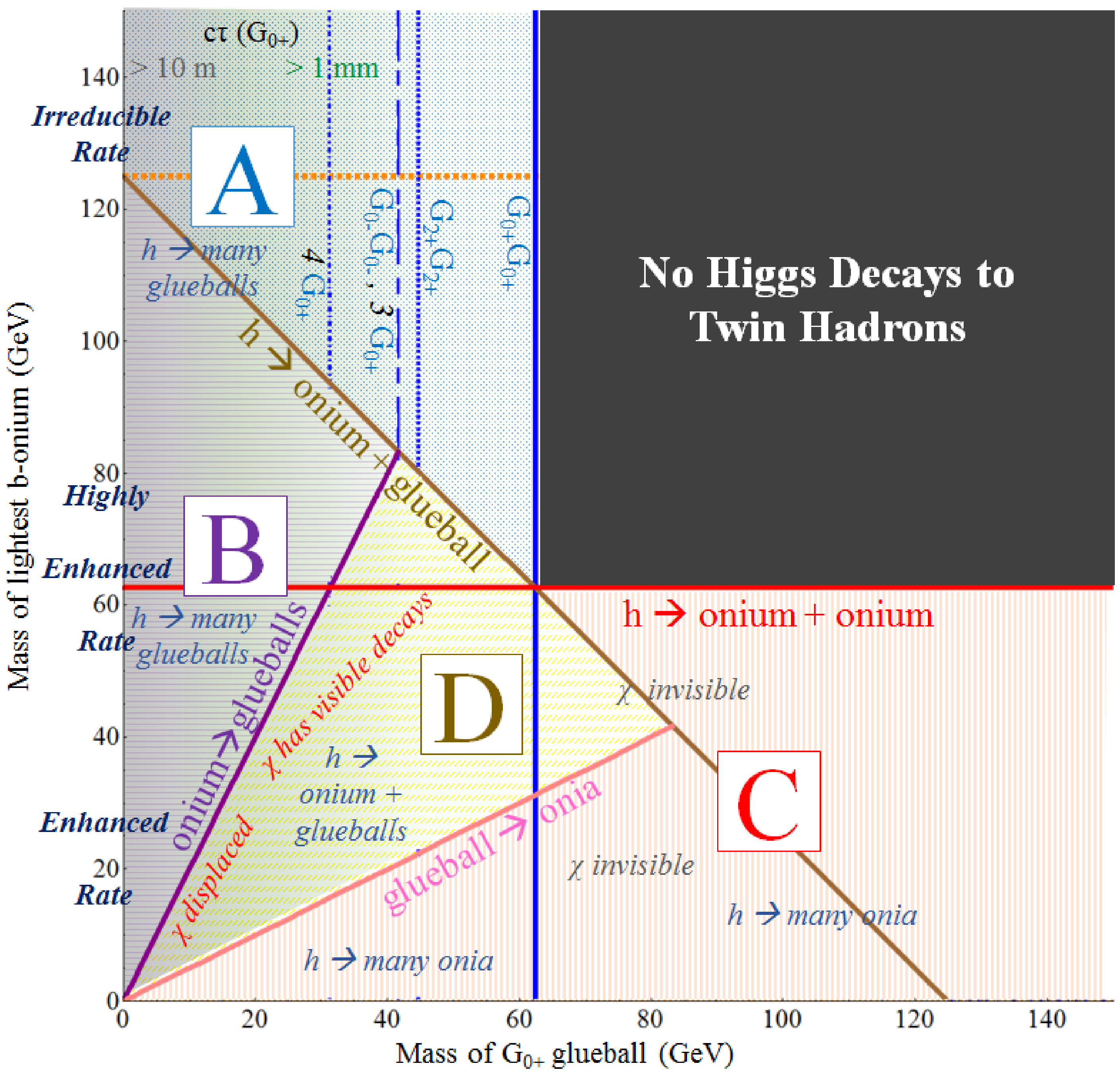
Most models have twin color which confines around GeV scale (or slightly higher).

HIGGS DECAYS



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

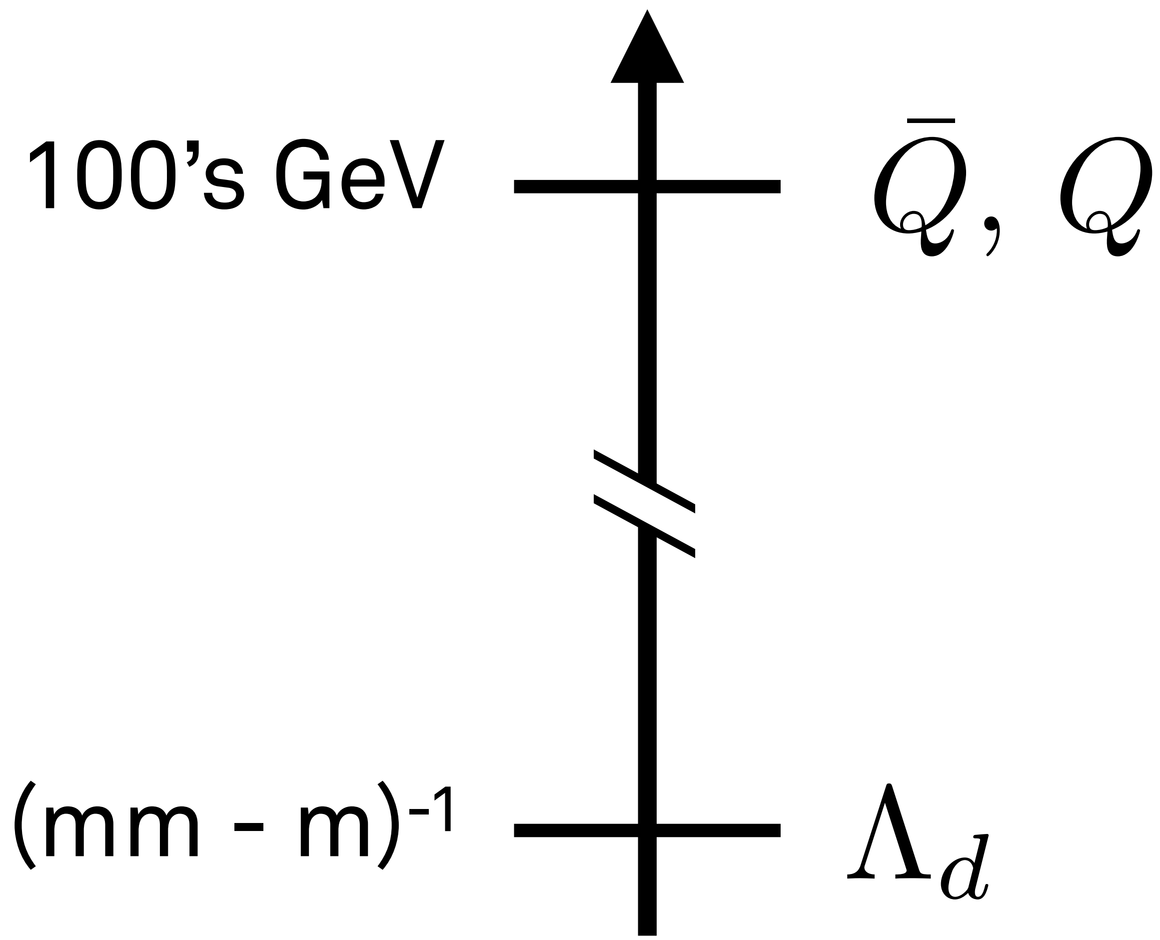
See also Curtin, Verhaaren, arXiv:1506.06141
for more detailed pheno and
Csaki, Kuflik, Lombardo, Slone, arXiv:1508.01522
for other displaced Higgs scenarios.



(Type 1 and 2 longevity)

QUIRKS!

Can imagine taking confinement scale of twin/dark QCD to be much lower.

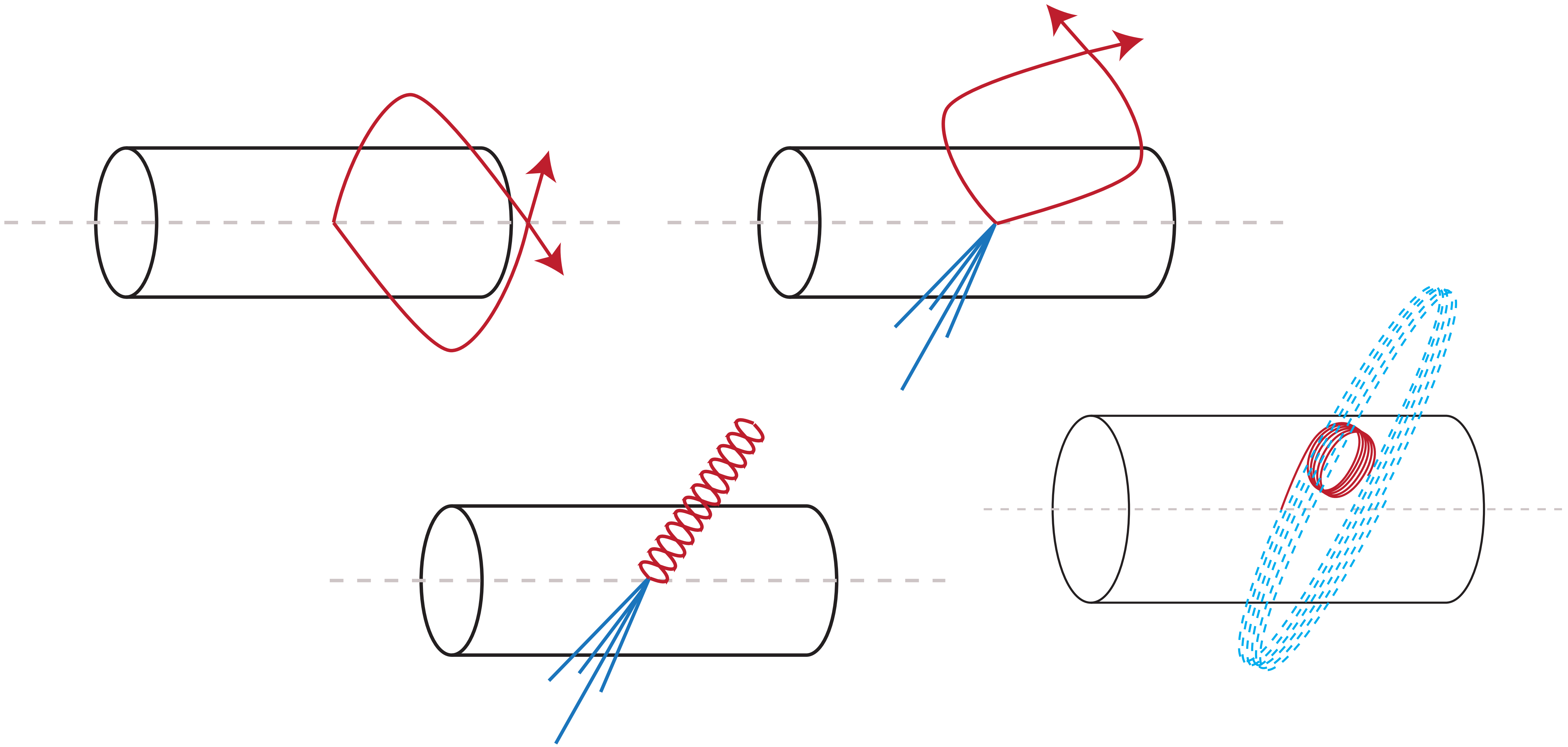


Quirks charged under SM and dark colour.

Dark colour confinement scale.

QUIRKS!

Confinement string can have macroscopic length.



(Type 1 + spatial separation)

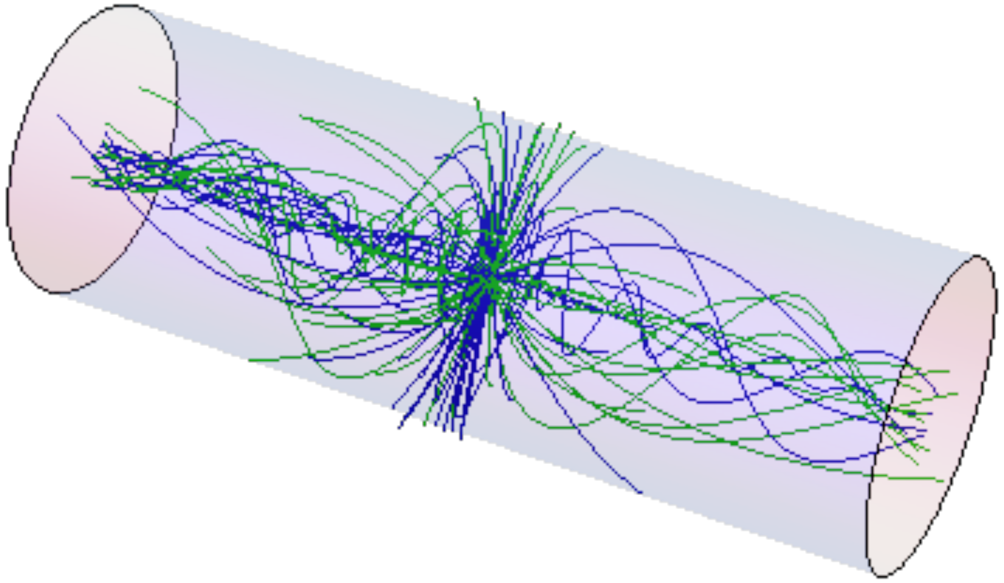
Luty, Kang, arXiv:0805.4642.

SOFT BOMBS

If dark sector is approximately conformal instead of QCD-like, hadrons will generate soft bombs instead of jets.

Knapen, Griso, Papucci, Robinson, arXiv:1612.00850.

Unclear what the best strategies are for this.



Also called Soft Unclustered Energy Patterns (SUEP).

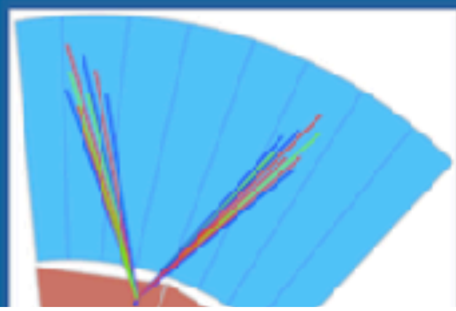
WORK IS ONGOING

Searches for long-lived particles at the LHC: Workshop of the LHC LLP Community

24-26 April 2017
CERN
Europe/Zurich timezone

Search...

WORK IS ONGOING



Searches for long-lived particles at the LHC: Workshop of the LHC LLP Community

WG 1: Simplified models / MC / RECASTing and reinterpretation for LLPs

- How do we make sure the published searches are optimally useful in the future? In addition to discussing simplified models for LLPs, this working group will include a hands-on, proof-of-concept recasting of some existing experimental searches that have been archived with the RECAST framework, for a few benchmark model scenarios.

WG 2: Backgrounds for LLP searches

- What are the challenges of low- or non-standard background searches? How these have been addressed in the past? What are the limitations of the current approaches? What new ideas for better estimates may exist?

WG 3: Triggering strategies and recommended studies for experiments for LLP searches

- What are the most important, high priority LLP signatures for which triggering strategies don't exist or are known to be sub-optimal? What recommendation can we as a community make to the experiments for studies that should be done over the summer in support of new triggers? New, blue-sky ideas mandatory.

WG 4: Dark showers

- As theorist and ad hoc coordinating committee member Jessie Shelton put it, "one of the major outstanding questions in designing a search program for displaced objects is how to design a simple and flexible basis of models for showering dark sectors." How do we address this in a more detailed and comprehensive way, and what does this mean for the current searches in the experimental collaborations for this class of models?

DARK SHOWERS

P. Schwaller

DARK SHOWERS

Tasks for the theorists

- Vary particle multiplicity in existing MCs and check effect
- Benchmark models <= can we populate the classifications we have outlined above
- What gives us wide jets? (Nf, Kinematics -- How to MC this?): (how to interpolate between Emergent Pencil jets and SUEP)
- Pedro and Dan add multiple lifetimes for dark pions
- Doodle a meeting for theorist discussion of these things

Tasks for the experimentalists

- Secondary vertex efficiency in ATLAS and CMS
- How Jet cleaning cuts (or a MET cut, if we were to do one) affect emerging jet efficiencies cuts
- Get SUEP lhe files from Simon Knapen, et al., and simulate, estimate efficiencies
- Investigate dedicated triggers (ATLAS: FTK, photon-jets, inner tracker hit multiplicity, etc.)

MORE WORK TO DO

Searches for long-lived particles at the LHC | (smr H534)

Starts 18 Oct 2017
Ends 20 Oct 2017
Central European Time

Trieste - Italy
Giambiagi Lecture Hall (AGH)
Strada Costiera, 11
I - 34151 Trieste (Italy)

Web Page

If you are interested in getting involved, there is lots of interesting work to do.

NOTE ON TRIGGERS

Exotic

Standard

Trigger	m_{π_v} (GeV)	$c\tau = 1$ mm				$c\tau = 10$ mm				$c\tau = 100$ mm			
		ϵ_{ggF}	ϵ_{VBF}	ϵ_{VH}	ϵ_{Total}	ϵ_{ggF}	ϵ_{VBF}	ϵ_{VH}	ϵ_{Total}	ϵ_{ggF}	ϵ_{VBF}	ϵ_{VH}	ϵ_{Total}
Displaced jet	10	0.01%	0.03%	0.03%	**0.01%**	0.3%	0.7%	0.6%	**0.3%**	5.5%	13.1%	10.8%	**6.3%**
	25	0%	0.02%	0.02%	**0.002%**	0.1%	0.3%	0.3%	**0.1%**	6.3%	16.5%	13.4%	**7.4%**
	40	0%	0.03%	0.03%	**0.004%**	0.2%	0.5%	0.5%	**0.2%**	6.6%	17.8%	14.2%	**7.8%**
Inclusive VBF	10	1.9%	15.5%	0.8%	**2.8%**	1.8%	15.5%	0.7%	**2.8%**	1.6%	15.1%	0.6%	**2.6%**
	25	1.7%	15.3%	0.7%	**2.7%**	1.7%	15.3%	0.7%	**2.7%**	1.6%	15.2%	0.6%	**2.6%**
	40	1.6%	15.2%	0.7%	**2.6%**	1.6%	15.2%	0.7%	**2.6%**	1.6%	15.2%	0.6%	**2.6%**
VBF, $h \to b\bar{b}$	10	5.8%	20.3%	13.1%	**7.2%**	5.8%	20.2%	13.0%	**7.2%**	3.5%	13.3%	8.1%	**4.4%**
	25	4.6%	16.6%	10.9%	**5.8%**	4.7%	16.7%	10.9%	**5.9%**	4.2%	15.2%	9.7%	**5.3%**
	40	4.0%	14.2%	9.2%	**5.0%**	4.0%	14.2%	9.2%	**5.0%**	3.8%	13.9%	8.9%	**4.8%**
Isolated Lepton	10	3.6%	3.7%	14.7%	**4.1%**	1.0%	1.0%	12.5%	**1.5%**	0.1%	0.2%	11.8%	**0.6%**
	25	1.0%	1.5%	13.0%	**1.6%**	0.3%	0.4%	11.9%	**0.8%**	0.05%	0.07%	11.7%	**0.6%**
	40	1.0%	1.4%	12.6%	**1.6%**	0.3%	0.4%	11.9%	**0.8%**	0.05%	0.07%	11.6%	**0.6%**
Trackless jet	10	0.02%	0.04%	0.04%	**0.02%**	0.8%	1.5%	1.3%	**0.9%**	2.0%	2.4%	2.2%	**2.0%**
	25	0.02%	0.04%	0.06%	**0.02%**	0.5%	1.0%	0.8%	**0.6%**	3.6%	5.9%	5.0%	**3.8%**
	40	0.01%	0.02%	0.03%	**0.01%**	0.1%	0.2%	0.2%	**0.1%**	2.1%	4.1%	3.3%	**2.3%**

Standard triggers can be very effective for exotic searches.

Csaki, Kuflik, Lombardo, Slone, arXiv:1508.01522.

WISHLIST

- More searches for distinct collider objects.
- Searches for different SM states originating in all different places in the detector.
- More general use of triggers, including multi-jet and VBF. Also, a published list of available triggers and thresholds.
- Keep searches as model-independent as possible.

THANK YOU