DARK SHOWERS: MOTIVATION, SIMULATION, AND TRIGGERING

P. Schwaller

DANIEL STOLARSKI

Carleton University

PCTS “Triggering on New Physics at the HL-LHC”

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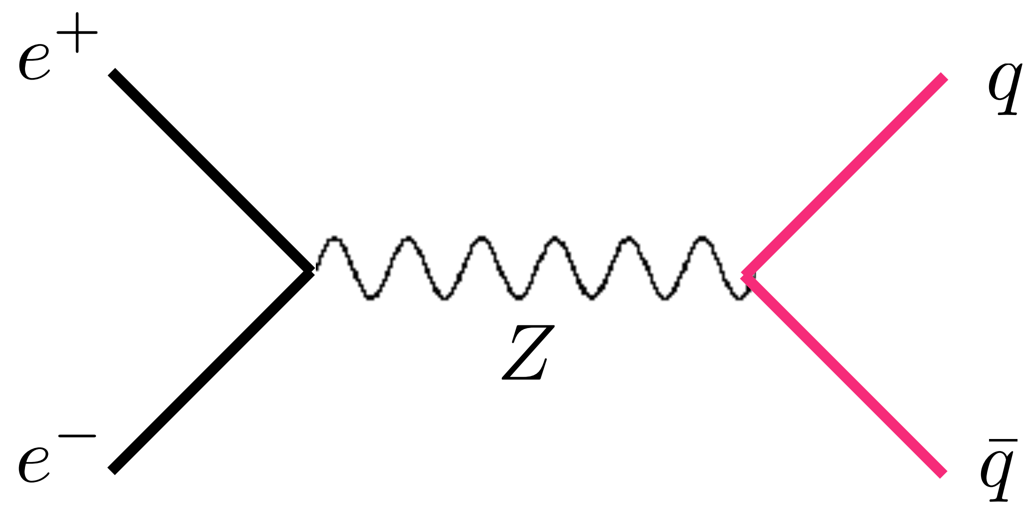
QCD SHOWERING



Quarks produced at a lepton collider will shower in a calculable way in QCD.

$$\frac{\mathrm{d}}{\mathrm{d}\log(t/\mu^2)} f_q(x,t) = \int_x^1 \frac{\mathrm{d}z}{z} \frac{\alpha_s}{2\pi} P_{qq}(z)\, f_q(x/z,t) + \int_x^1 \frac{\mathrm{d}z}{z} \frac{\alpha_s}{2\pi} P_{gq}(z)\, f_g(x/z,t)$$

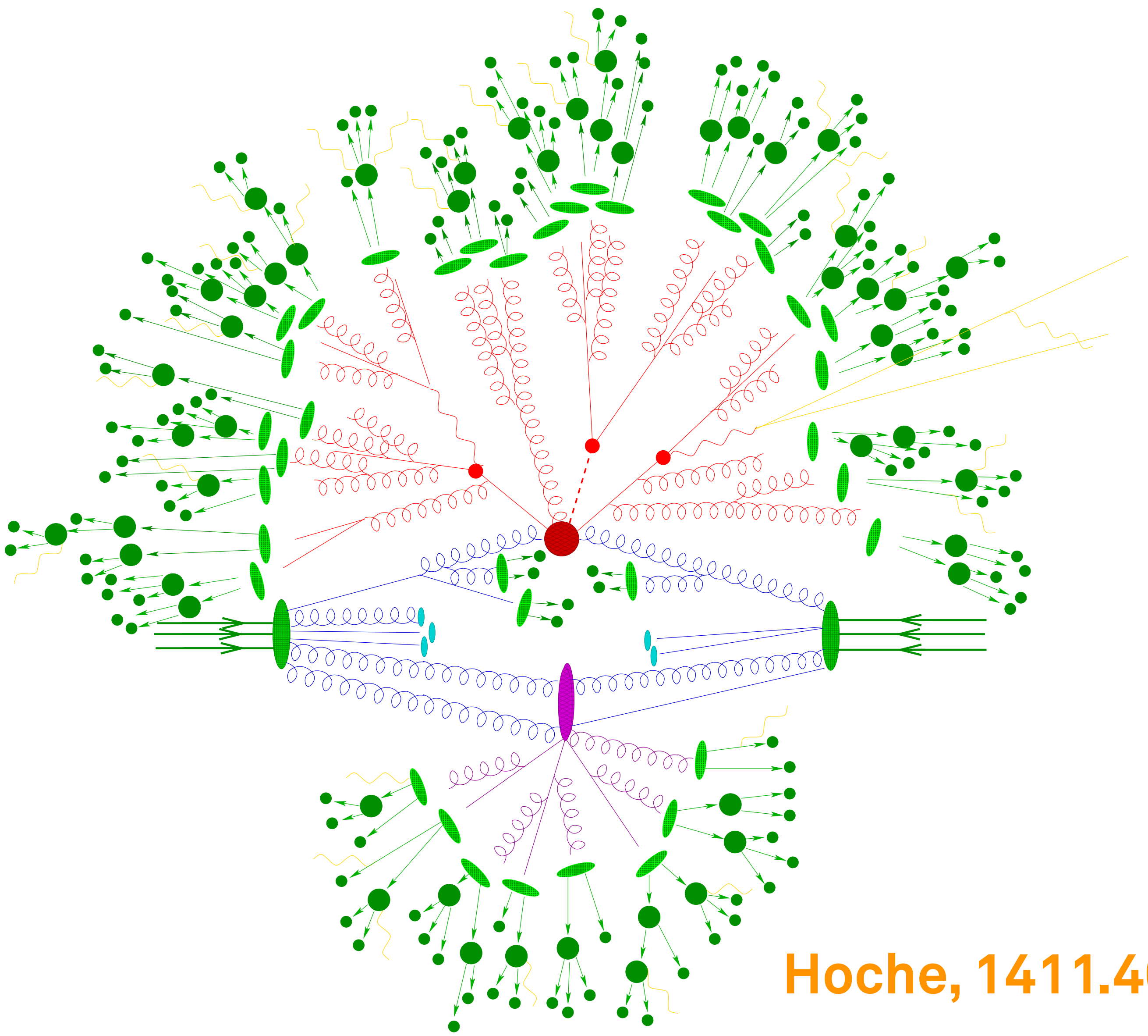
$$\frac{\mathrm{d}}{\mathrm{d}\log(t/\mu^2)} f_g(x,t) = \sum_{i=1}^{2n_f} \int_x^1 \frac{\mathrm{d}z}{z} \frac{\alpha_s}{2\pi} P_{qg}(z)\, f_q(x/z,t) + \int_x^1 \frac{\mathrm{d}z}{z} \frac{\alpha_s}{2\pi} P_{gg}(z)\, f_g(x/z,t)$$

Hoche, 1411.4085.

They will then form hadrons.

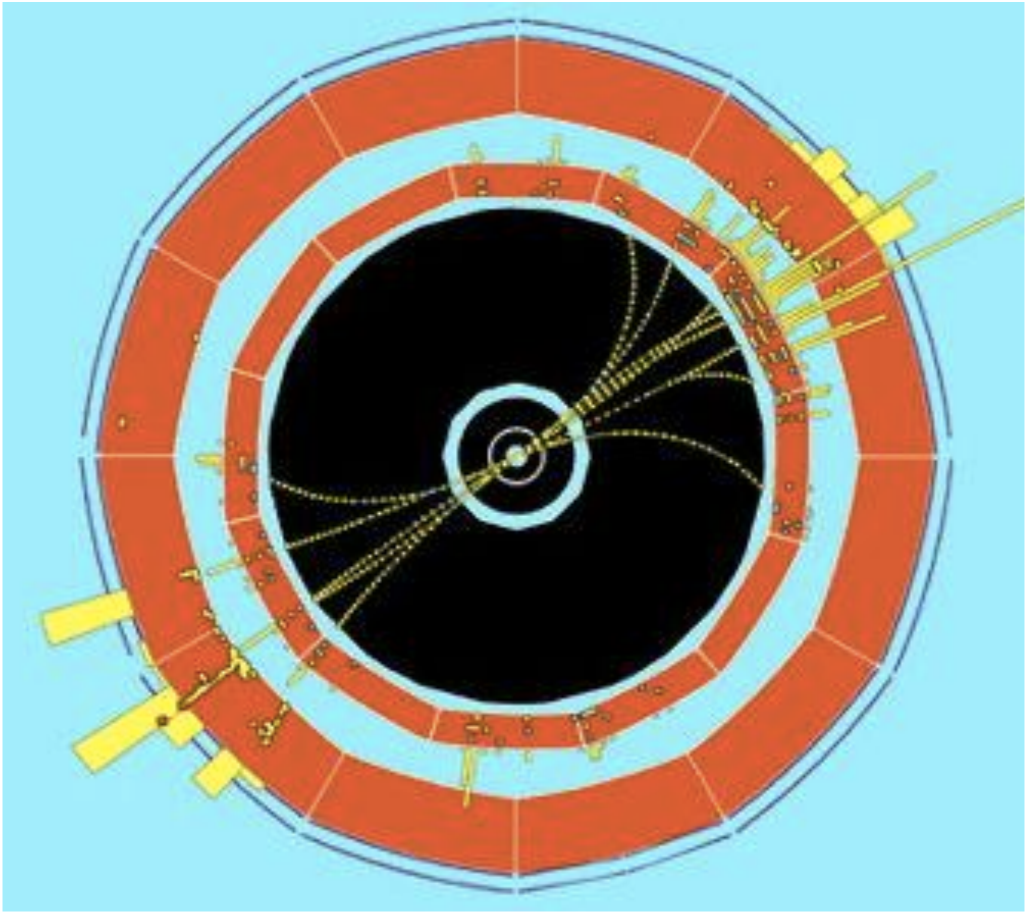
QCD SHOWERING

Cartoon picture



Hoche, 1411.4085.

ALEPH event



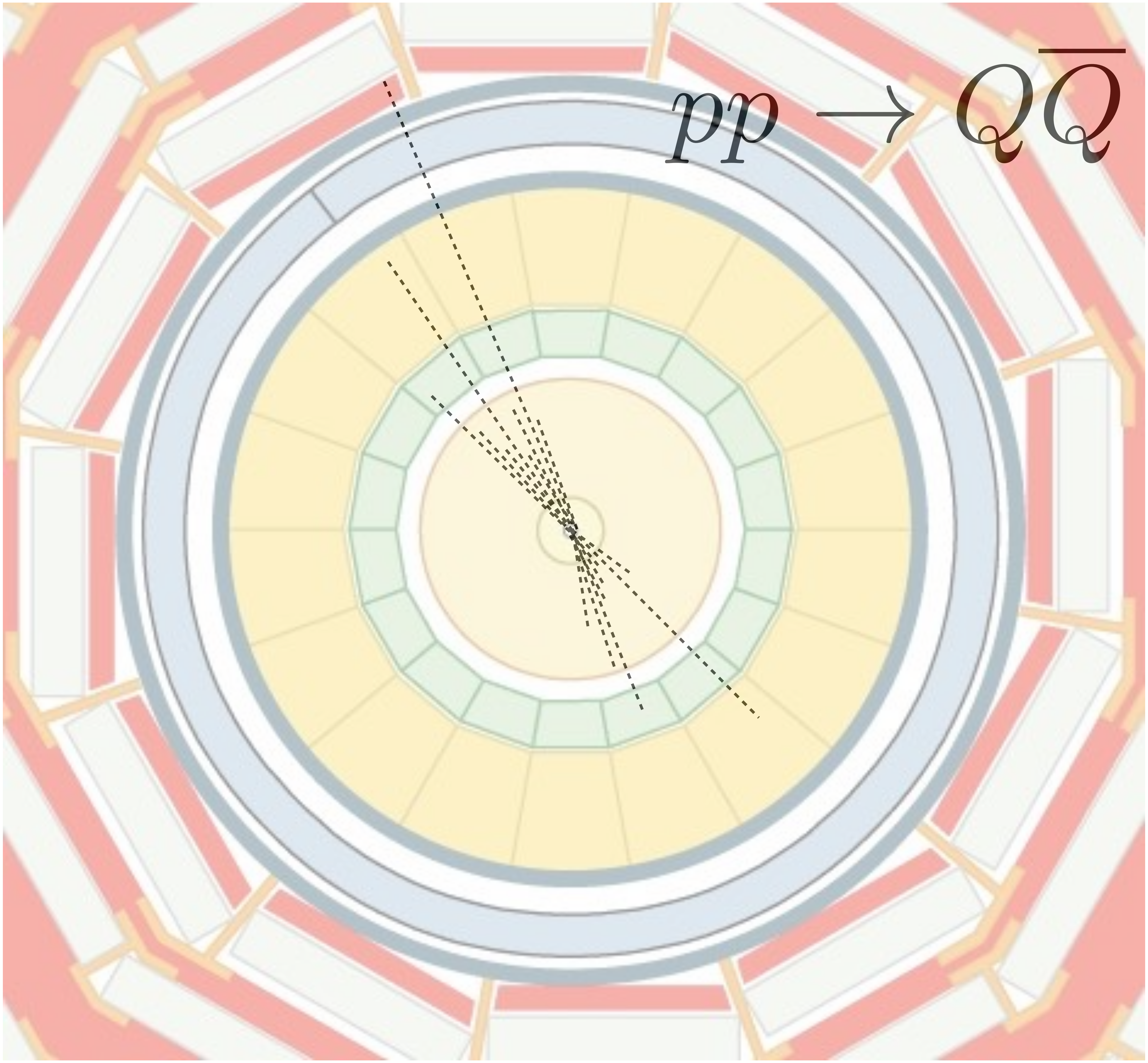
DARK SHOWERS

A new confining sector (possibly QCD-like) that:

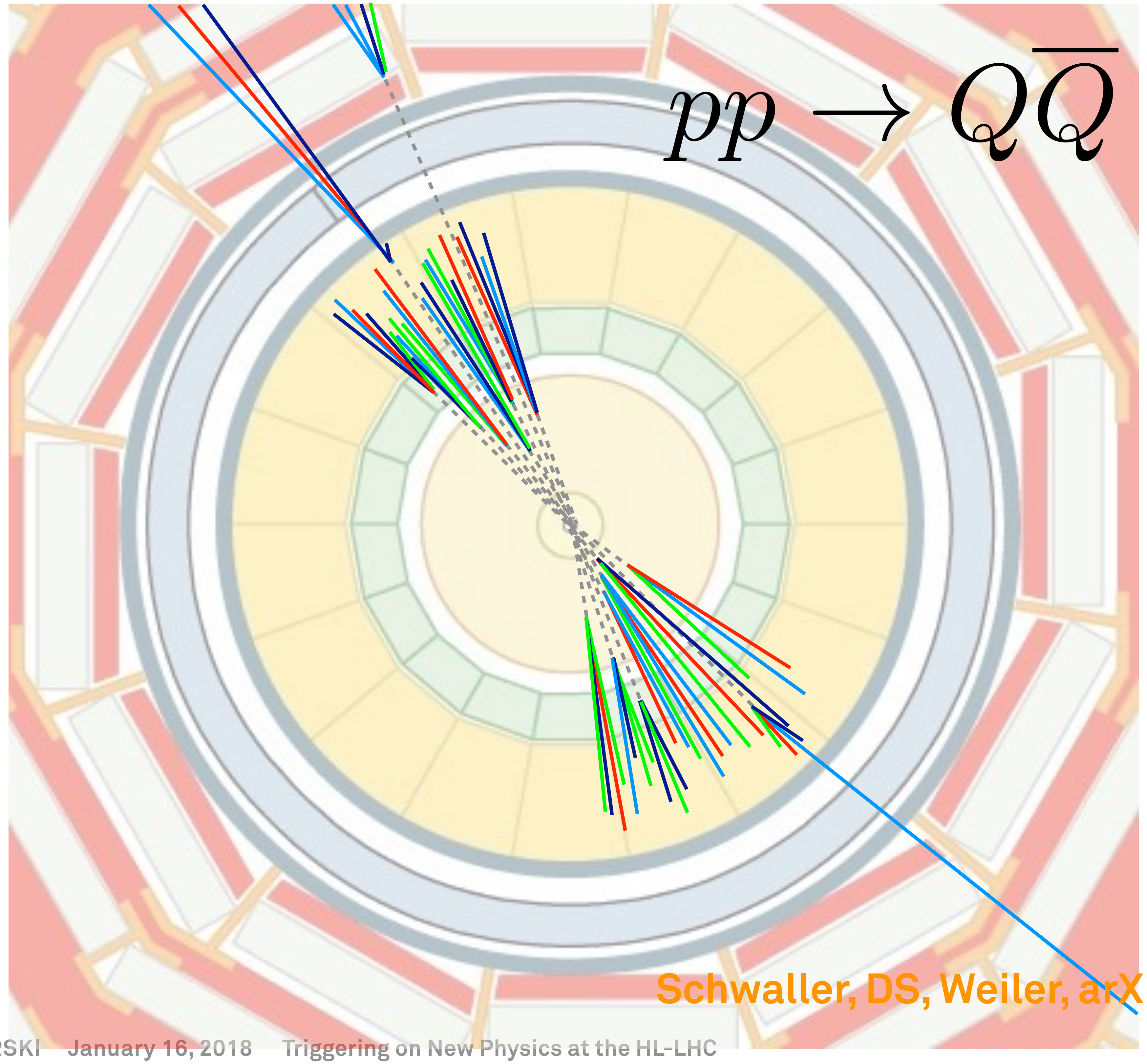
- Has a relatively low (~ GeV) confining scale.
- All SM particles are neutral under new force.
- All light particles that feel the force are neutral under the SM.

If there is a heavy mediator, then have large multiplicity of BSM particles at LHC.

Strassler and Zurek, arXiv:0604261.


$pp \to Q\overline{Q}$

EMERGING JETS



Schwaller, DS, Weiler, arXiv:1502.05409.

DIFFERENT DARK SHOWERS

Emerging Jets: QCD like, displaced vertices.

Schwaller, DS, Weiler, arXiv:1502.05409.

Semivisible jets: missing energy in the jet.

Cohen, Lisanti, Lou, arXiv:1503.00009. Cohen, et. al. arXiv:1707.05326.

Soft bombs or SUEP (Soft Unclustered Energy Patterns): spherical distribution of particles.

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

...

???

See also talk by D'Agnolo yesterday.

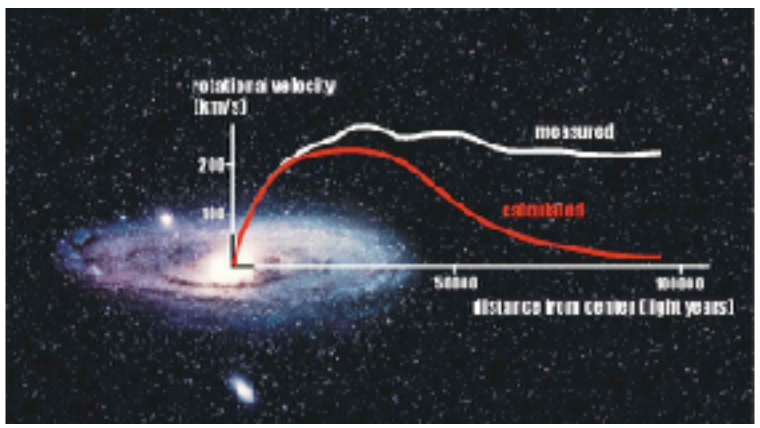
MOTIVATION

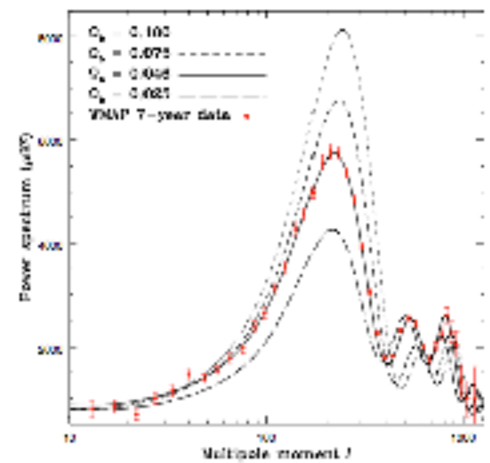
MOTIVATION

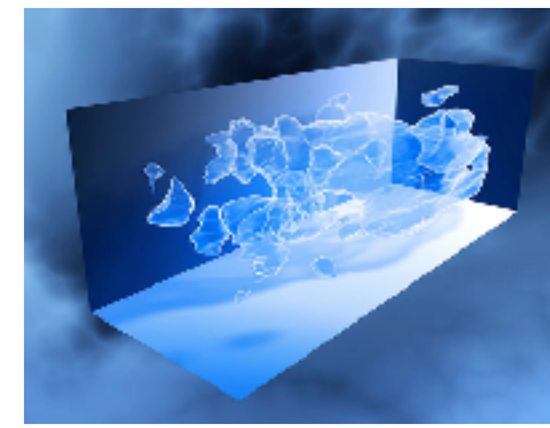
H. Murayama

DARK MATTER

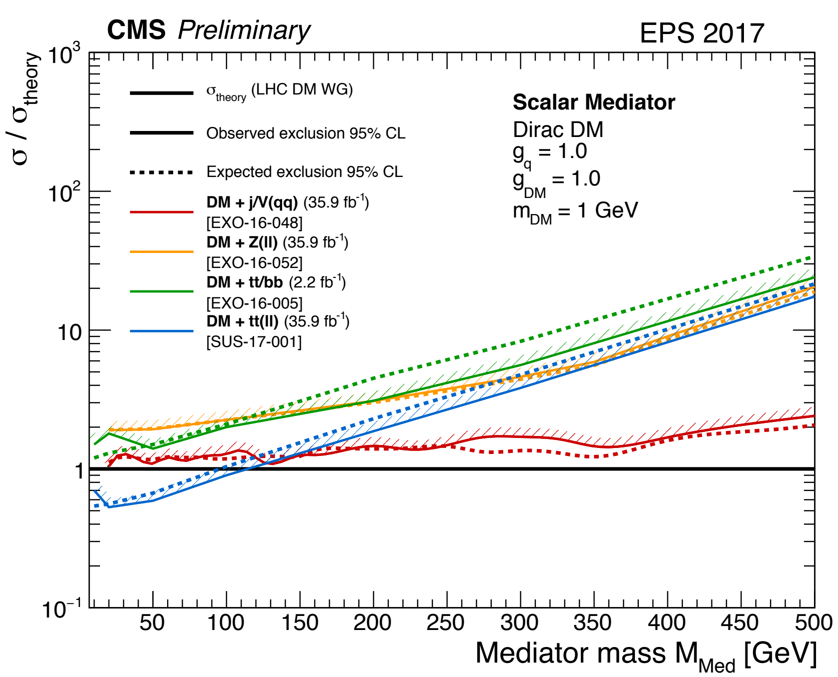
We have seen dark matter in the sky.

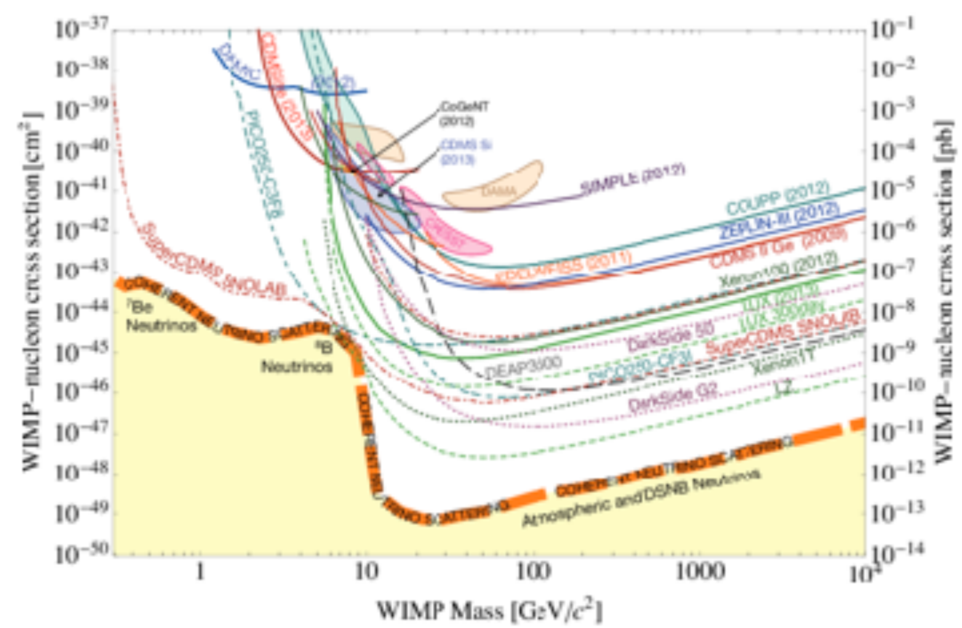






But not in the lab.





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

Nussinov, '85.
Kaplan '92.
Kaplan, Luty, Zurek, '09.
Bai and Schwaller, '13.
...

ASYMMETRIC DARK MATTER

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

QCD like

?

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

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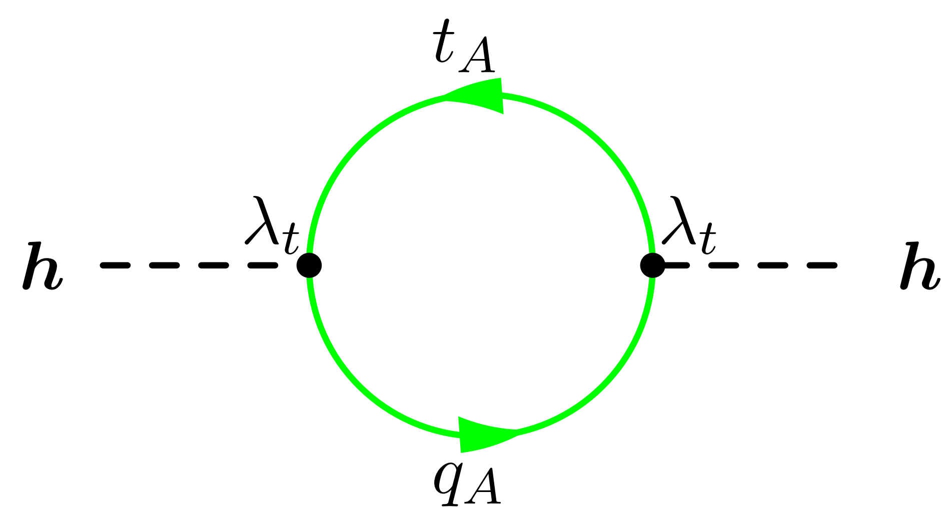
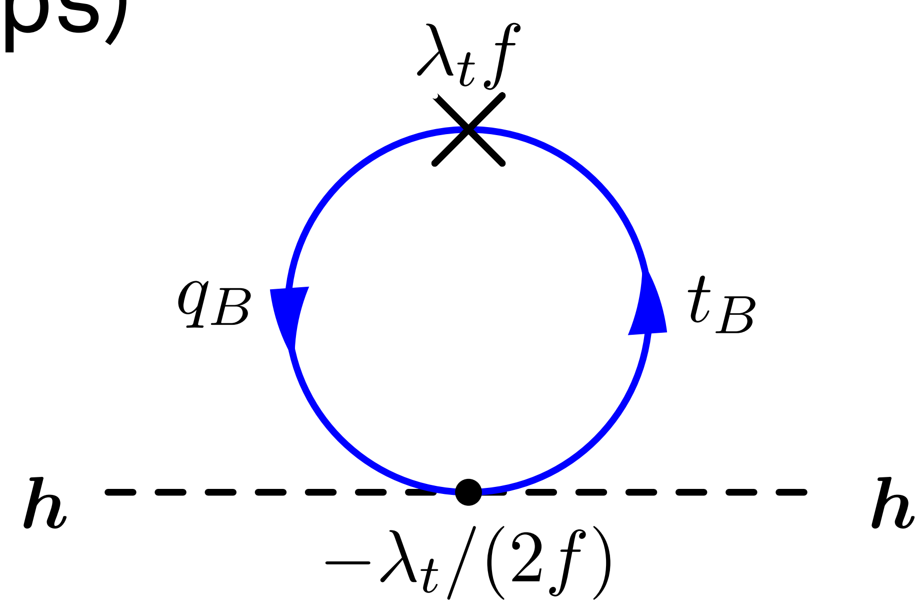
TWIN HIGGS/FOLDED SUSY

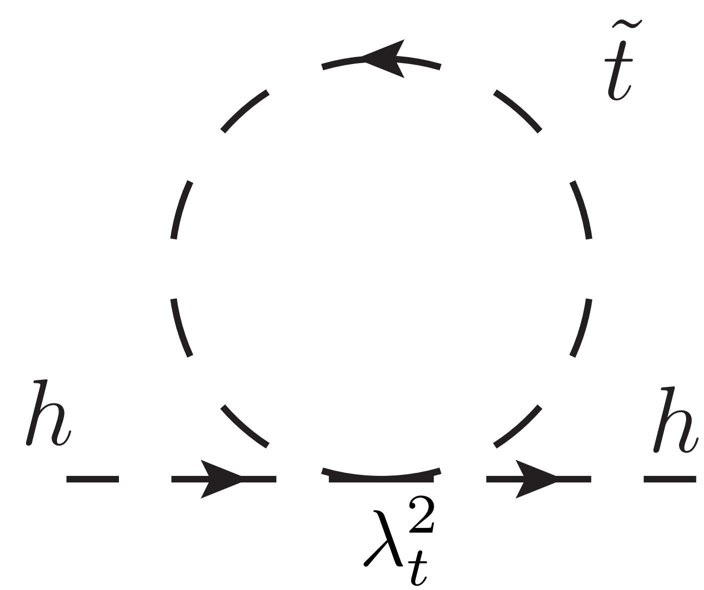
Gauge hierarchy problem:



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



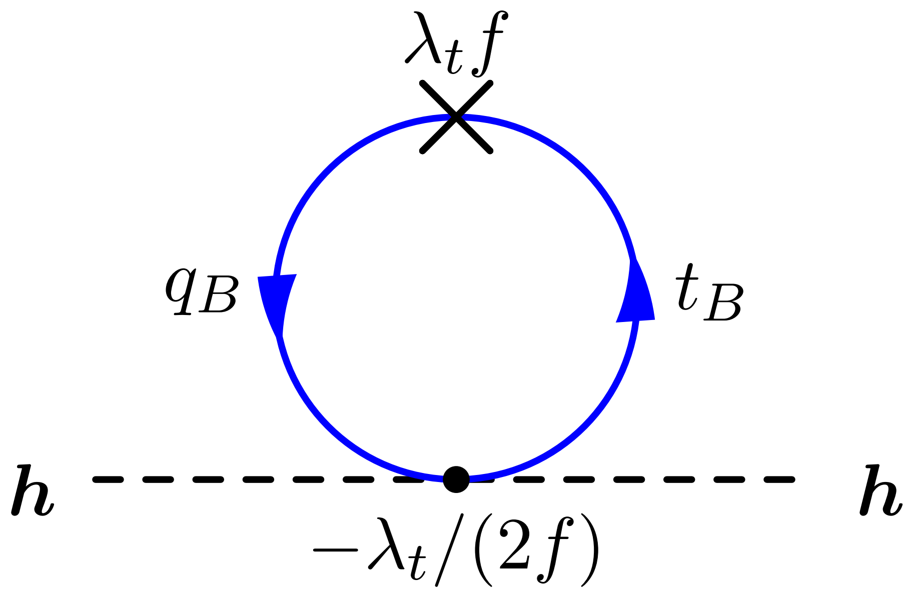
or

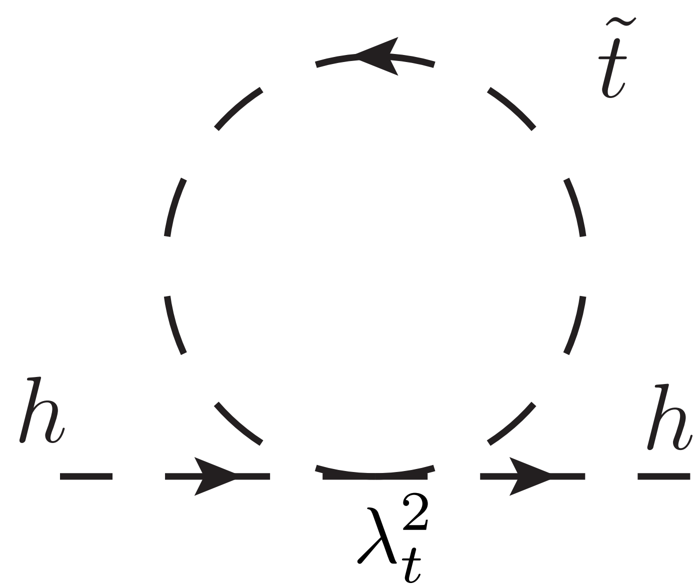


Do these partners need to be coloured?

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 colour which confines around GeV scale (or slightly higher).

SIMULATION

SIMULATION

Dark QCD is in Pythia. Can vary number of dark colours and flavours as well as mass scales.

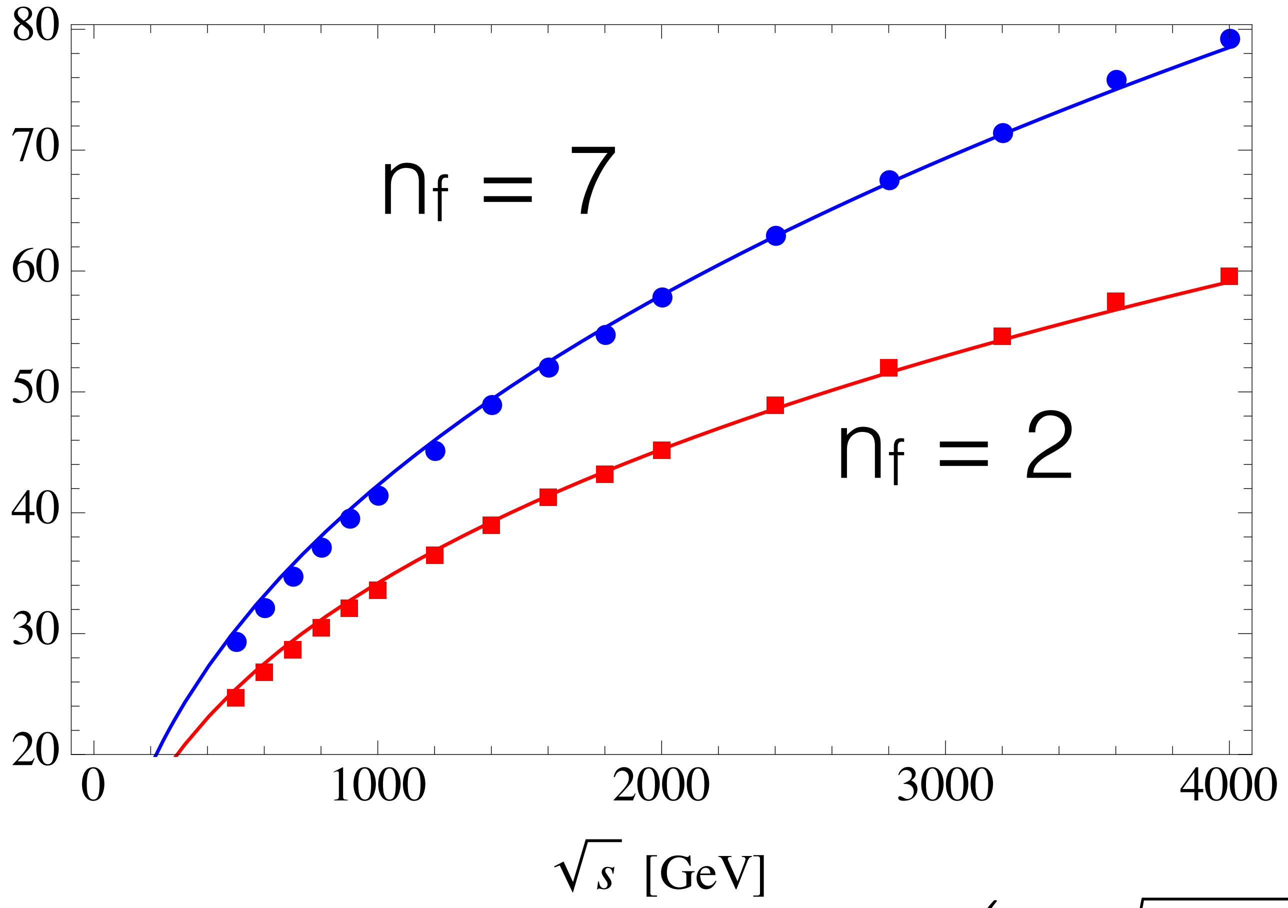
Carloni, Sjorstrand, 2010.
Carloni, Rathsman, Sjorstrand, 2011.
Further updates in versions > 8.2.

Two mediators also implemented.

- Scalar $pp \to \Phi\Phi^\dagger \to \bar{q}\, Q_d\, \overline{Q}_d\, q$
- Vector $pp \to Z_d \to Q_d\, \overline{Q}_d$

VALIDATION

Check to see if simulation makes sense by looking at average particle multiplicity.

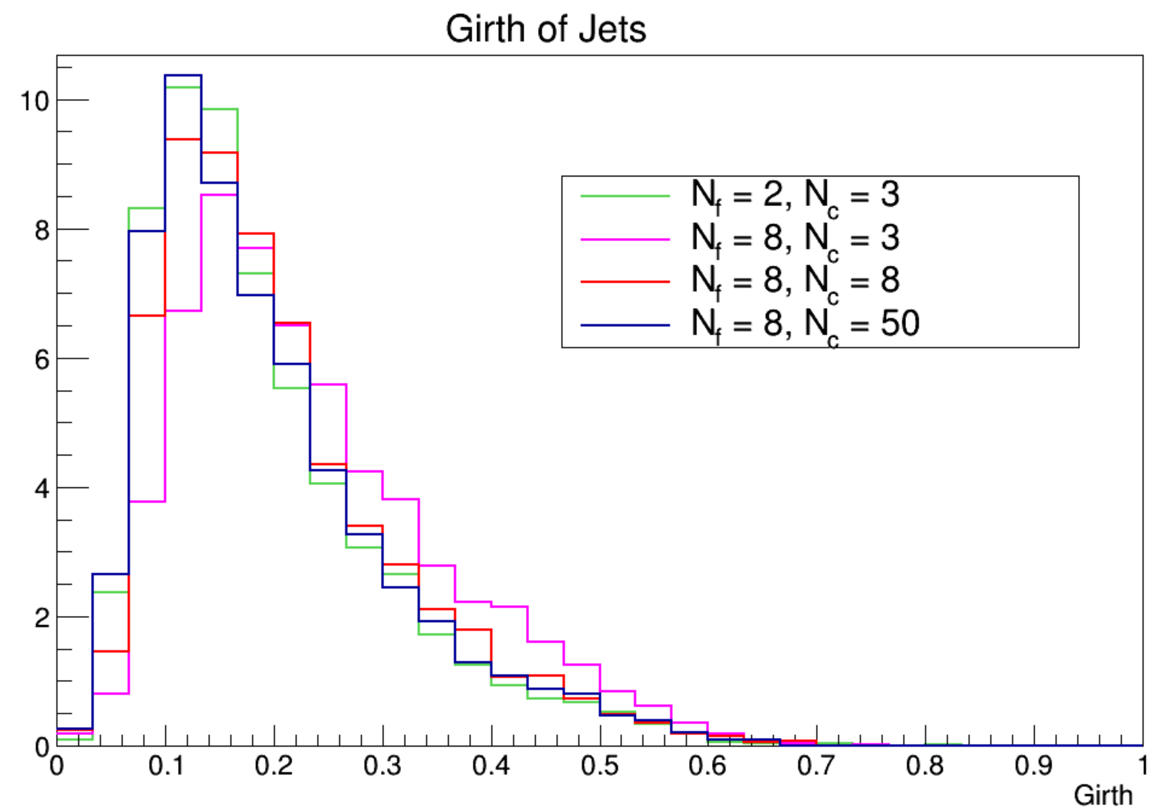


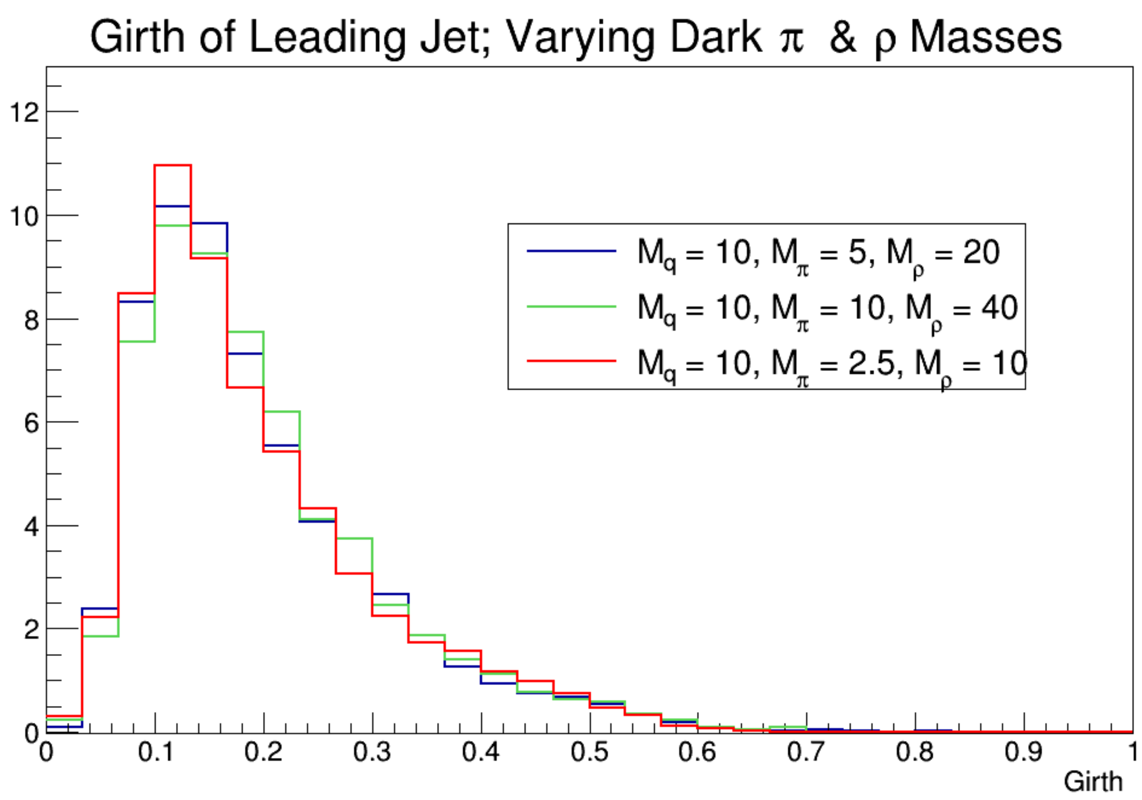
Ellis, Stirling, and Weber, 1996.

$$\langle N(\hat{s})\rangle \propto \exp\left(\frac{1}{b_1}\sqrt{\frac{6}{\pi\alpha_s(\hat{s})}} + \left(\frac{1}{4} + \frac{5n_f}{54\pi b_1}\right)\log\alpha_s(\hat{s})\right)$$

DARK JET SHAPES

Dark shapes do not change much varying parameters in Pythia.





$$girth = \frac{1}{P_T^j} \sum_i p_T^i \Delta R_i .$$

Work in progress with Dylan Linthorne and the dark showers working group.

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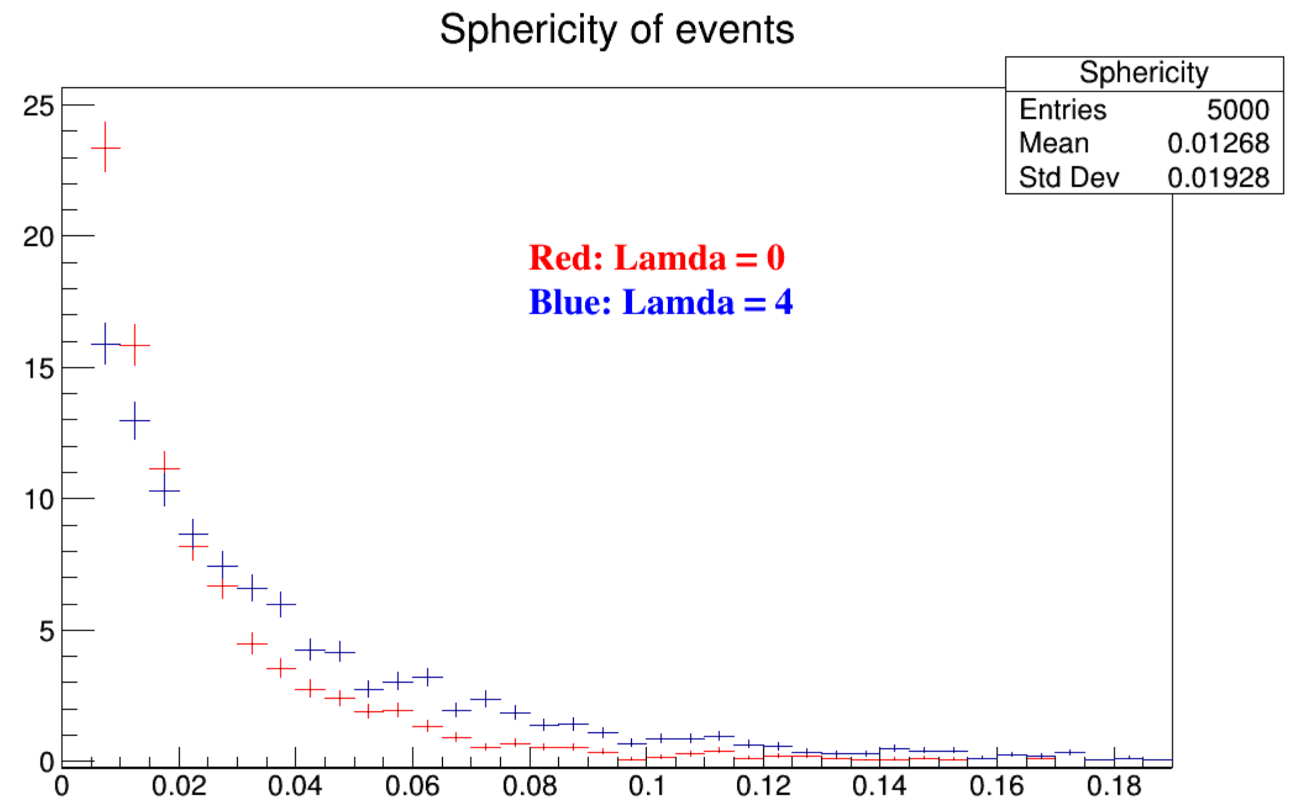
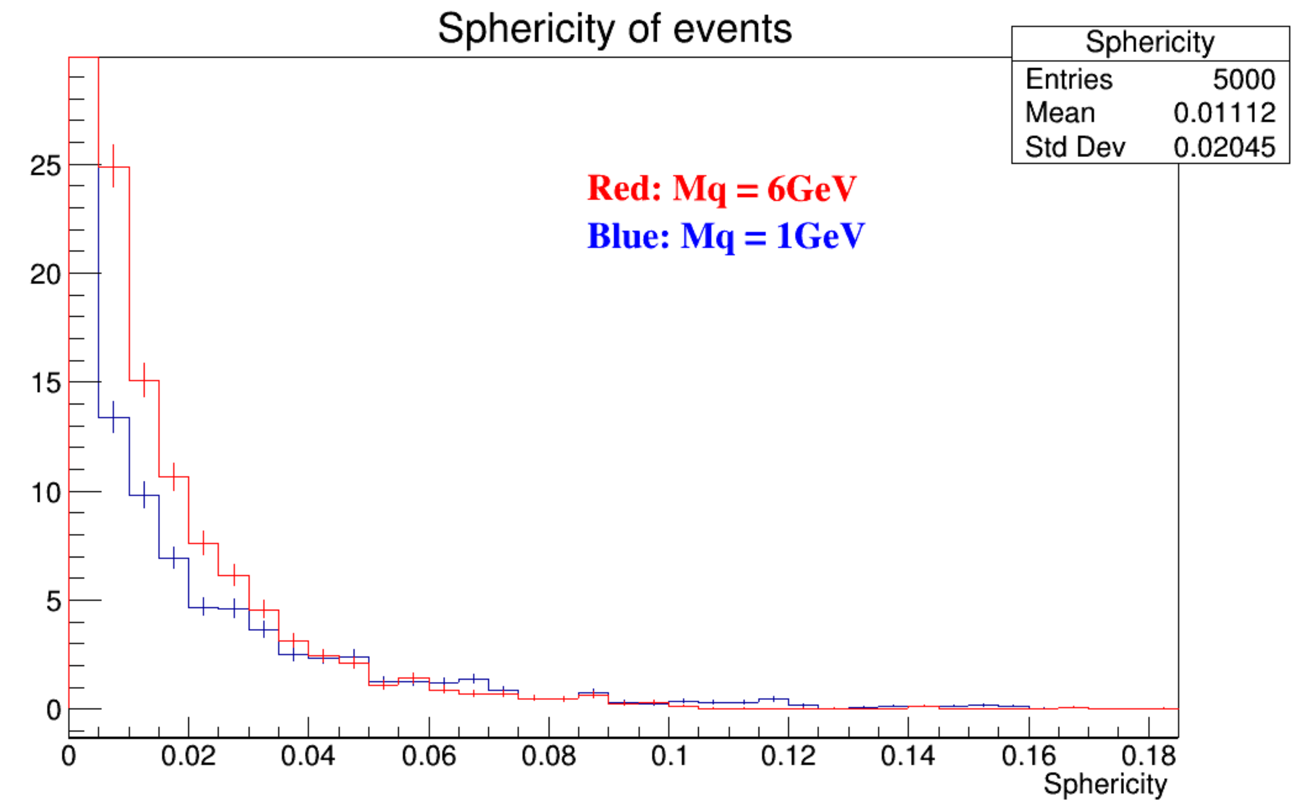




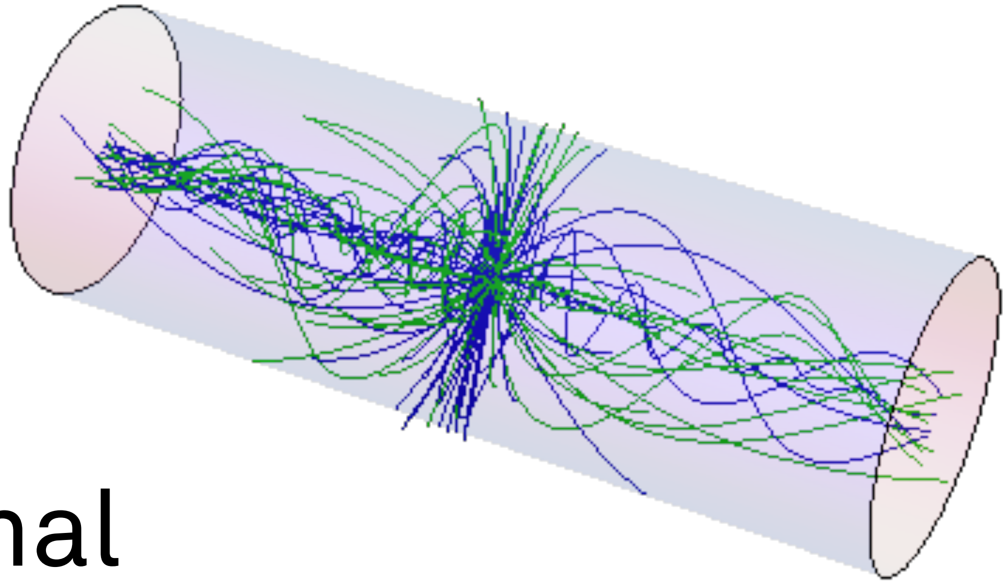
Sphericity

Work in progress with Dylan Linthorne and the dark showers working group.

SOFT BOMBS

Soft bombs have approximately isotropic particle distribution.

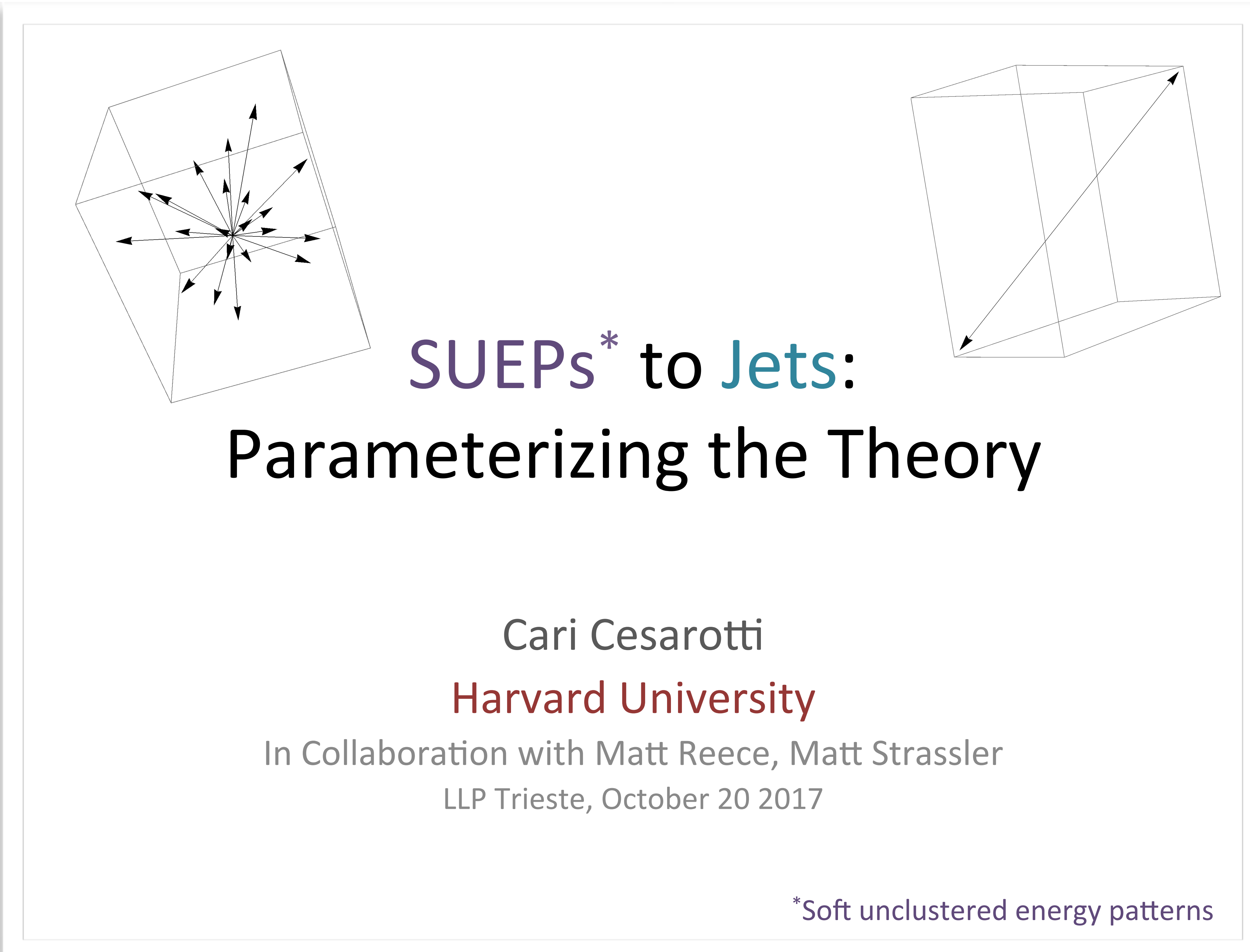
Knapen, Griso, Papucci, Robinson, arXiv:1612.00850.
Possibly more in talk by Simon next.



Can be simulated with a thermal distribution.

$$\frac{dN}{d^3\mathbf{p}} \sim \exp\left\{-\sqrt{\boldsymbol{p}^2 + m^2}/T\right\}$$

INTERPOLATION?



INTERPOLATION?

Seems that you can simulate the interpolation using an extra dimensional model and the AdS/CFT correspondence.

See talk by Cesarotti at Trieste workshop for more details.

https://indico.cern.ch/event/649760/

TRIGGERING

EASY WAYS TO TRIGGER

Easy ways to trigger on dark showers:

- Lots of energy: use H_T or multi jet trigger.
- Missing energy.

Will almost always get one of these if mediator mass is large (SUEP is an interesting exception).

- Isolated leptons (difficult if multiplicity is large).

SIMPLE STUDY

Can do simple trigger study using known trigger thresholds.

Pythia hidden valley.

Current thresholds, not high-lumi.

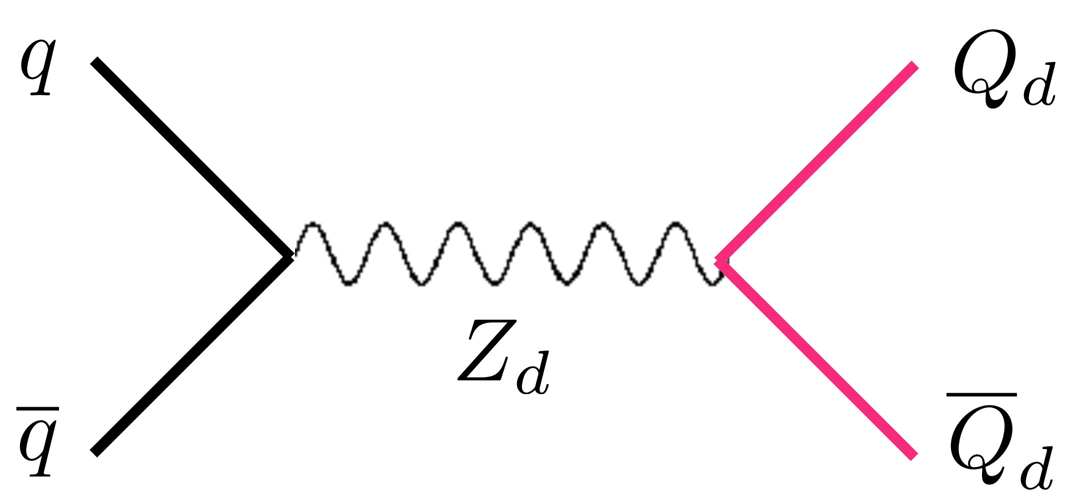
ATLAS not CMS. 🇨🇦

Performance of the ATLAS Trigger System in 2015

The ATLAS Collaboration

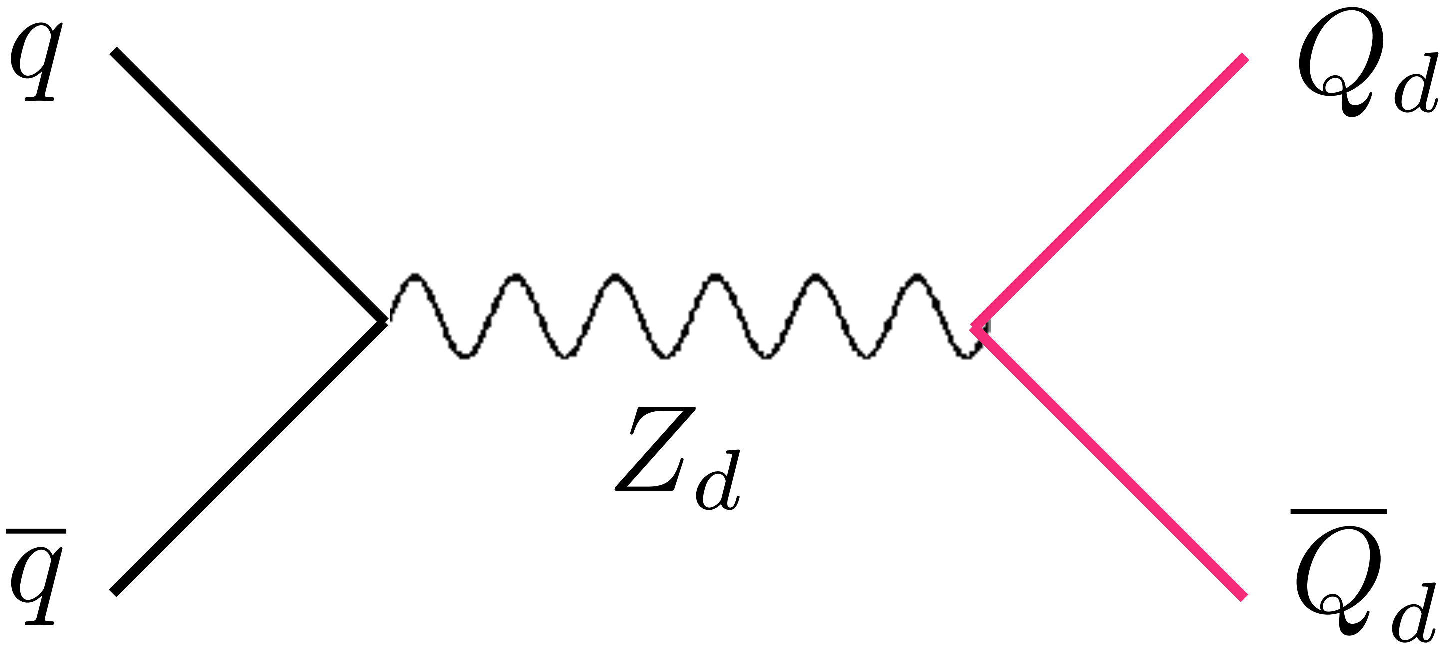
During 2015 the ATLAS experiment recorded 3.8 fb^{-1} of proton–proton collision data at a centre-of-mass energy of 13 TeV. The ATLAS trigger system is a crucial component of the experiment, responsible for selecting events of interest at a recording rate of approximately 1 kHz from up to 40 MHz of collisions. This paper presents a short overview of the changes to the trigger and data acquisition systems during the first long shutdown of the LHC and shows the performance of the trigger system and its components based on the 2015 proton–proton collision data.

arXiv:1611.09661



ISR FOR TRIGGERING

For any dark shower, ISR is always there.



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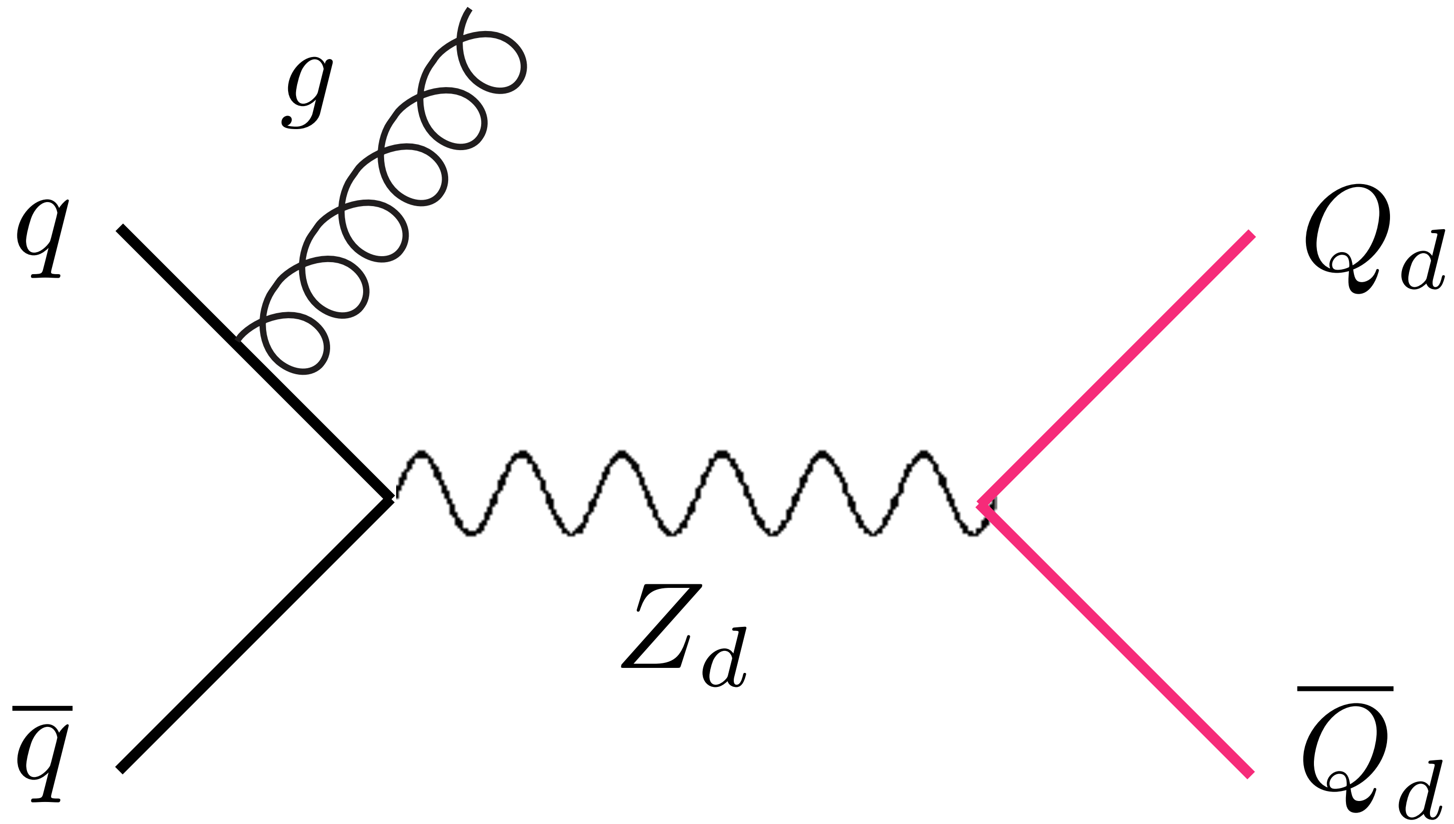

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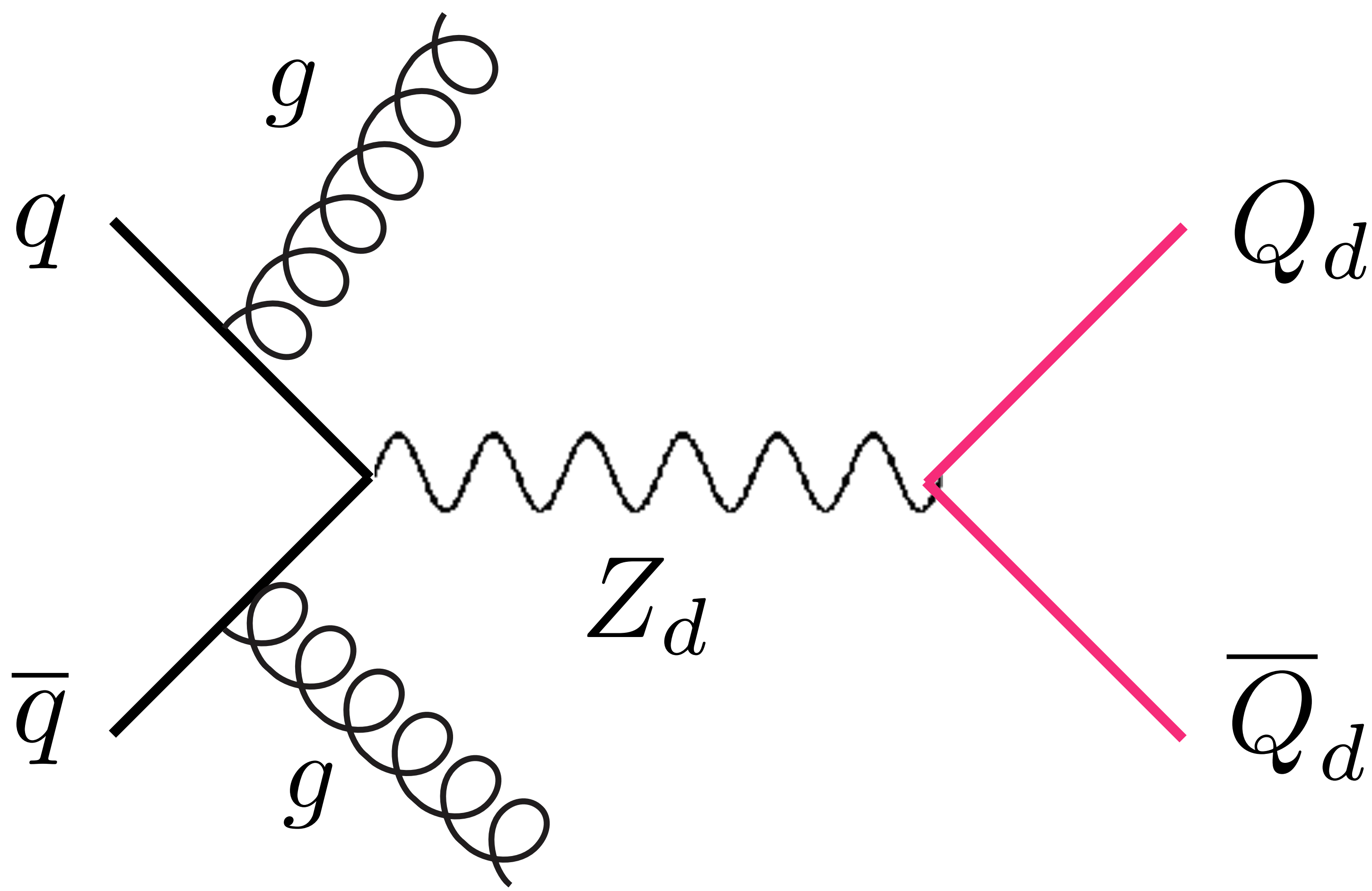

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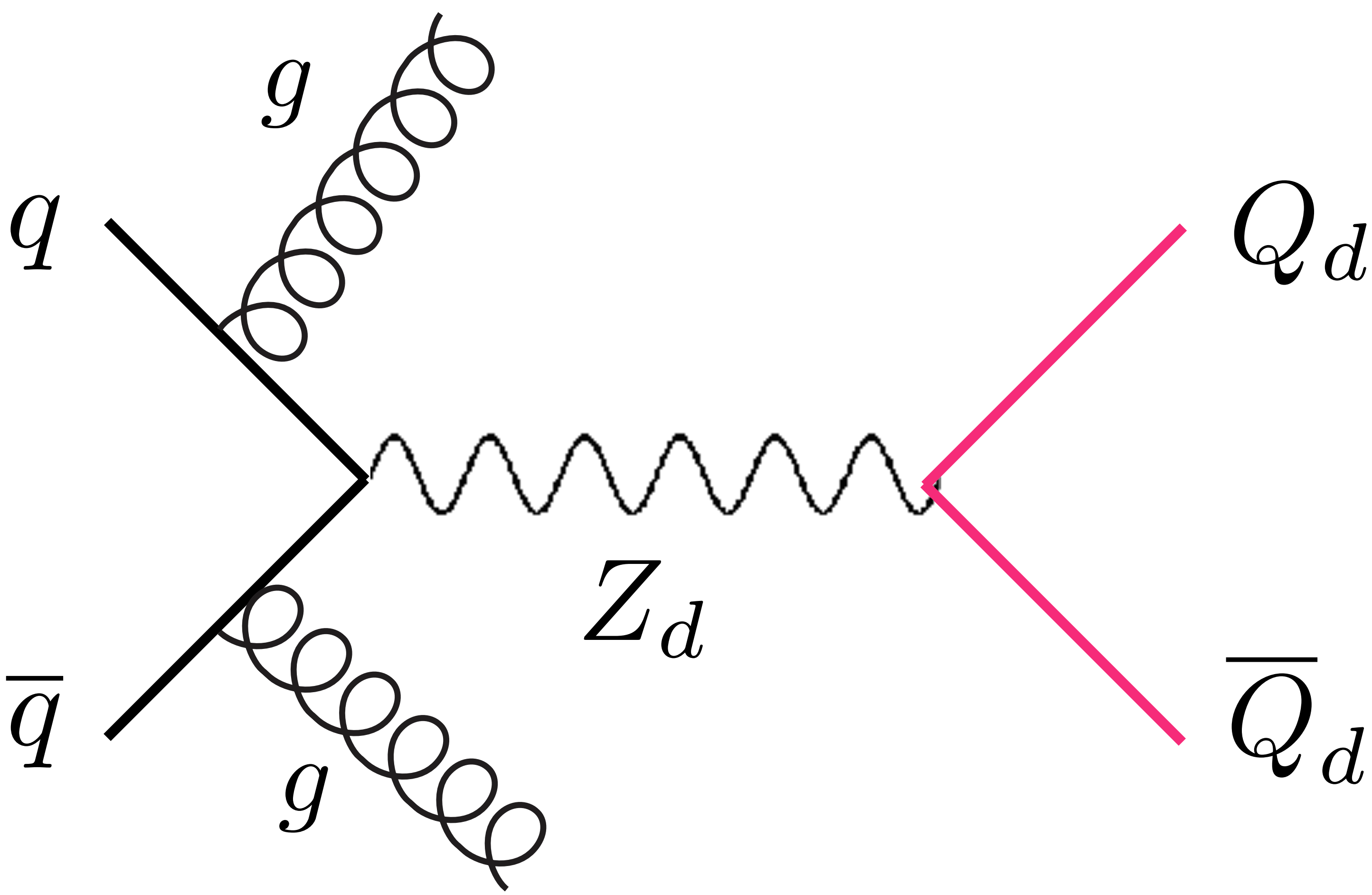

Strategy of mono-X searches.

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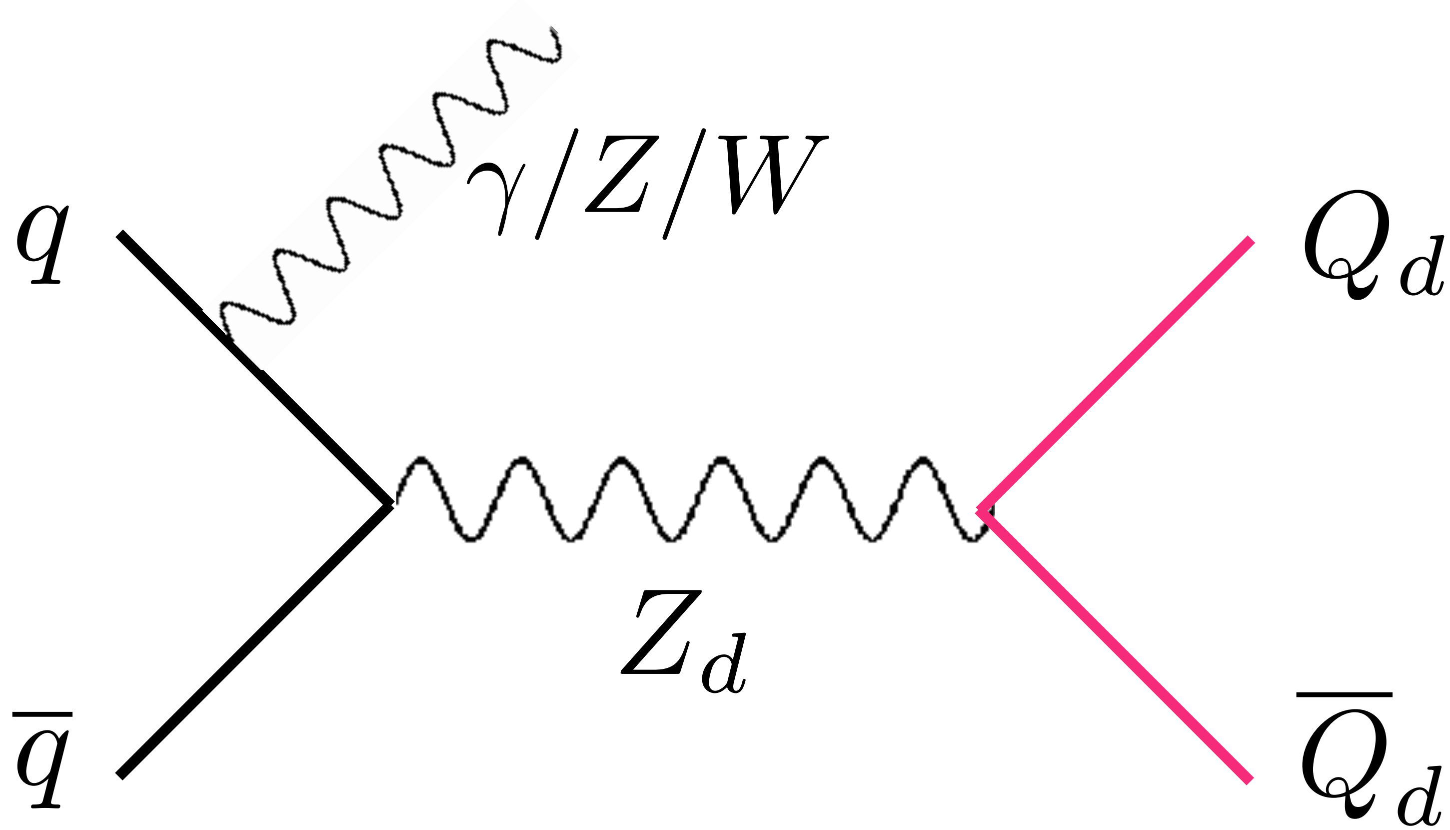
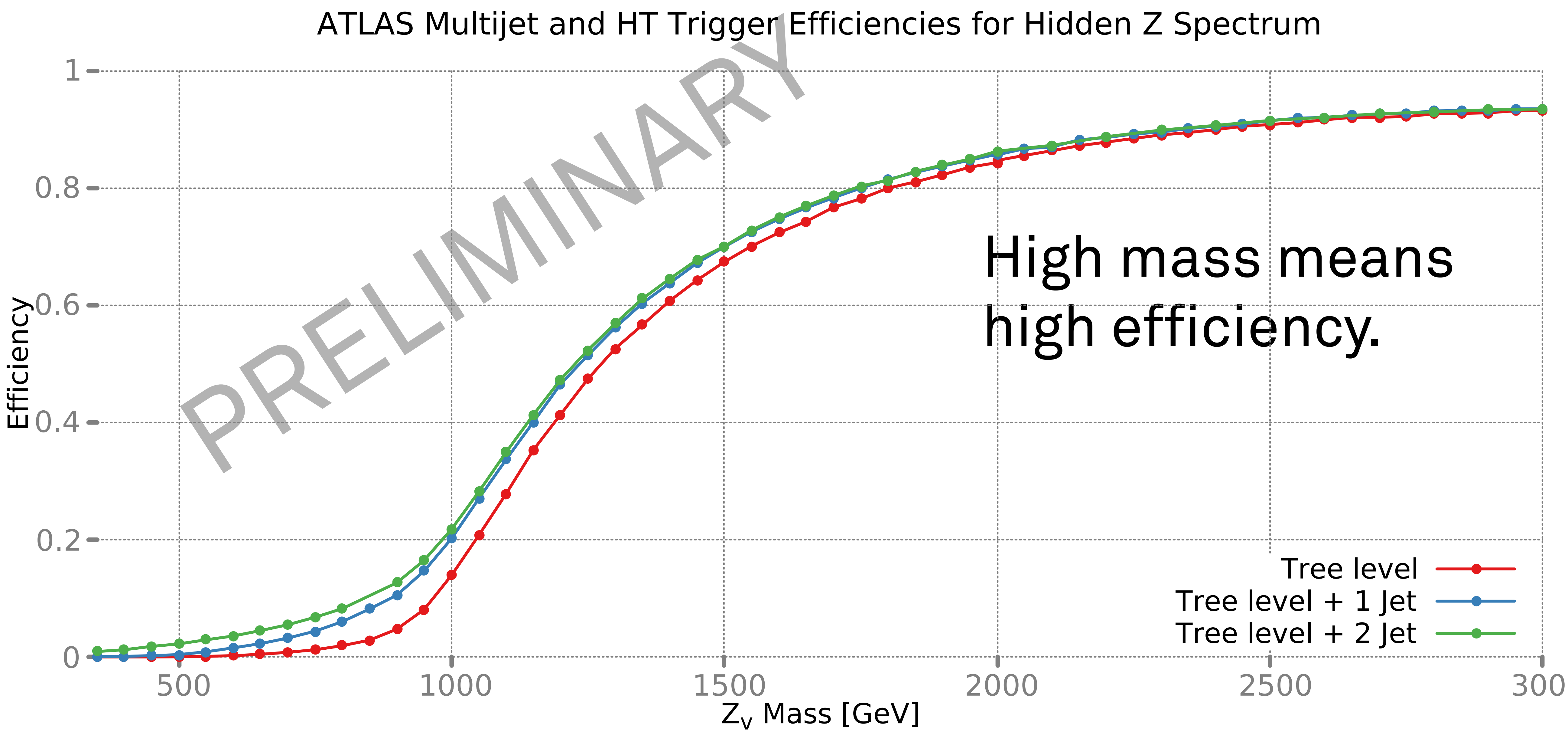


Strategy of mono-X searches.

TRIGGER EFFICIENCY

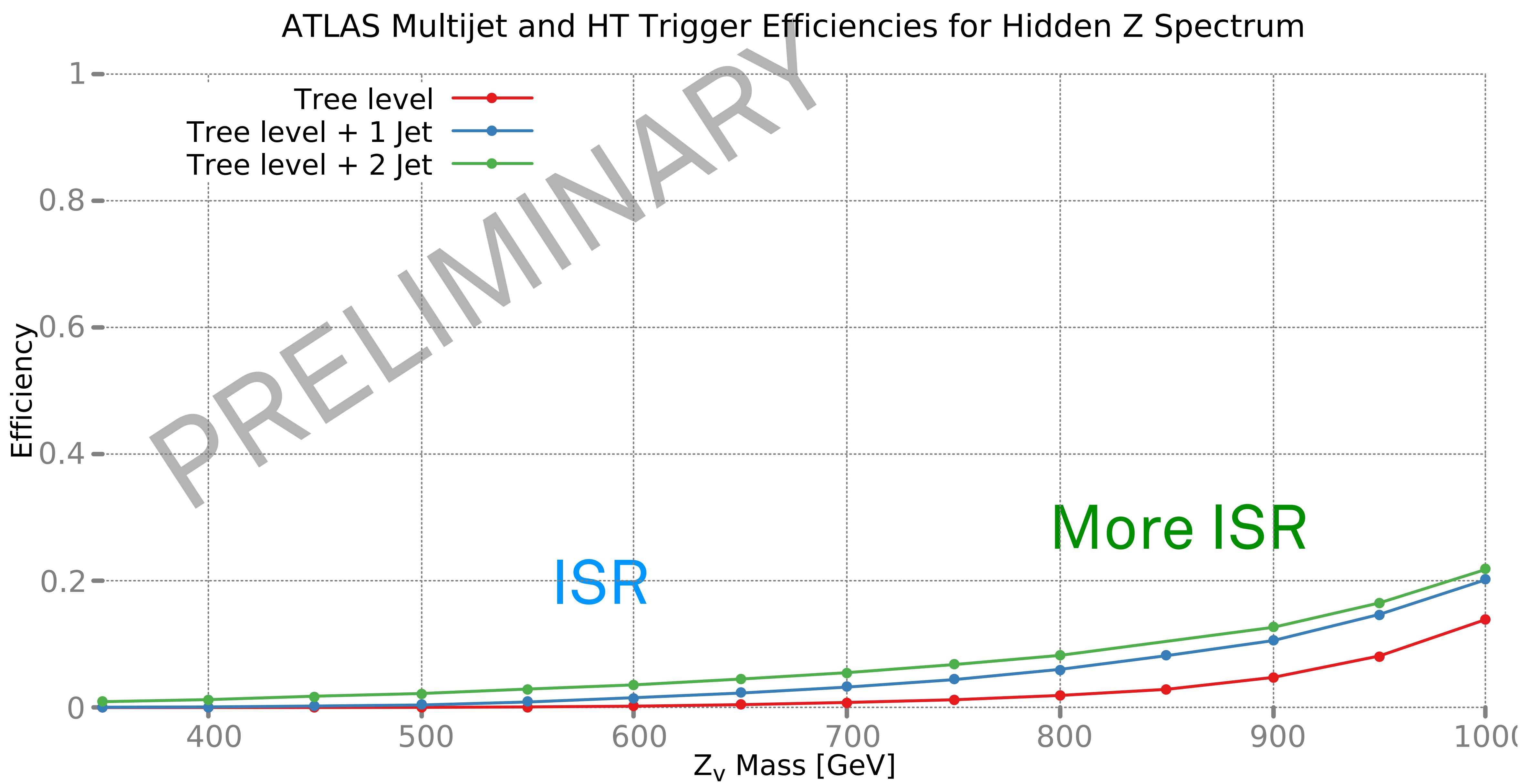


High mass means high efficiency.

Work in progress with D. Linthorne.

HLT H_T trigger (850 GeV) dominates.

TRIGGER EFFICIENCY



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HLT HT trigger (850 GeV) dominates.

LESSONS

Some showering models can naively be impossible to trigger.

Even for worst case model, can get a few percent trigger efficiency with ISR jet.

Worthwhile to simulate ISR (using usual matching procedure) to can get more coverage.

ONGOING WORK

To do:

- See if you can do better with multiple (vanilla) triggers.
- Check electroweak ISR.
- Compare to dedicated triggers.
- Interplay between L1 and HLT.

Stay tuned!

THANK YOU

DETAILS

	Model **A**
Λ_d	10 GeV
m_V	20 GeV
m_{π_d}	5 GeV
$c\,\tau_{\pi_d}$	150 mm

Trigger menu (or):

- HT > 850 (pT > 50)
- 3 jets > 175
- 4 jets > 85
- 5 jets > 60
- 6 jets > 45

Delta function detector