

Hidden Valleys

and where to find them

01/16/2018 @ PCTS

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LBL & UC Berkeley

Based on discussions with

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D. Curtin

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M. Freytsis

M. Lisanti*

T. Lou

M. Low

S.Pagan Griso

M. Papucci

D. Robinson

J. Scholtz

J. Shelton*

B. Shuve

D. Stolarski*

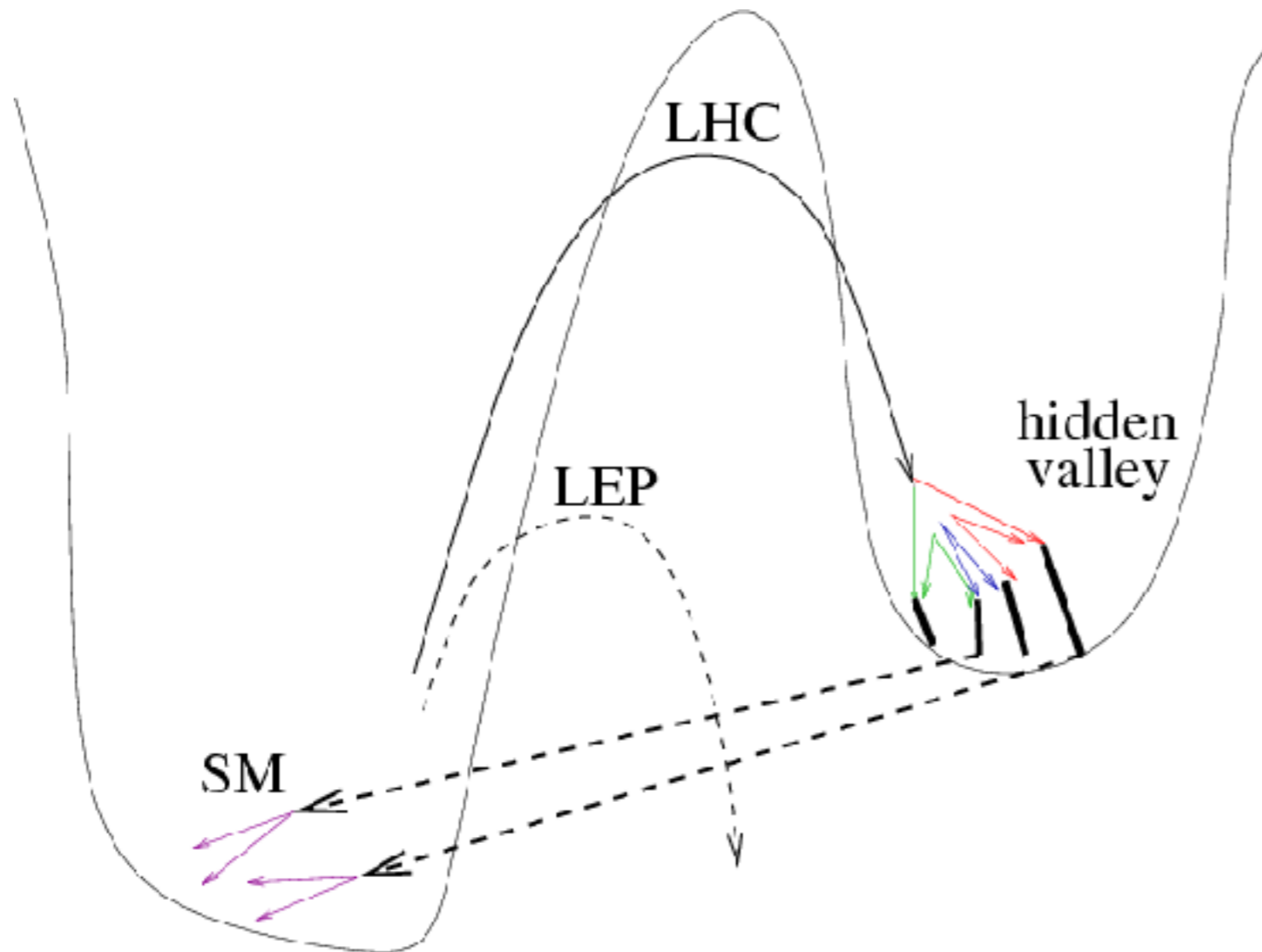
M. Strassler

Y. Tsai*

+ dark showers working group

* attending today

What is a hidden valley?

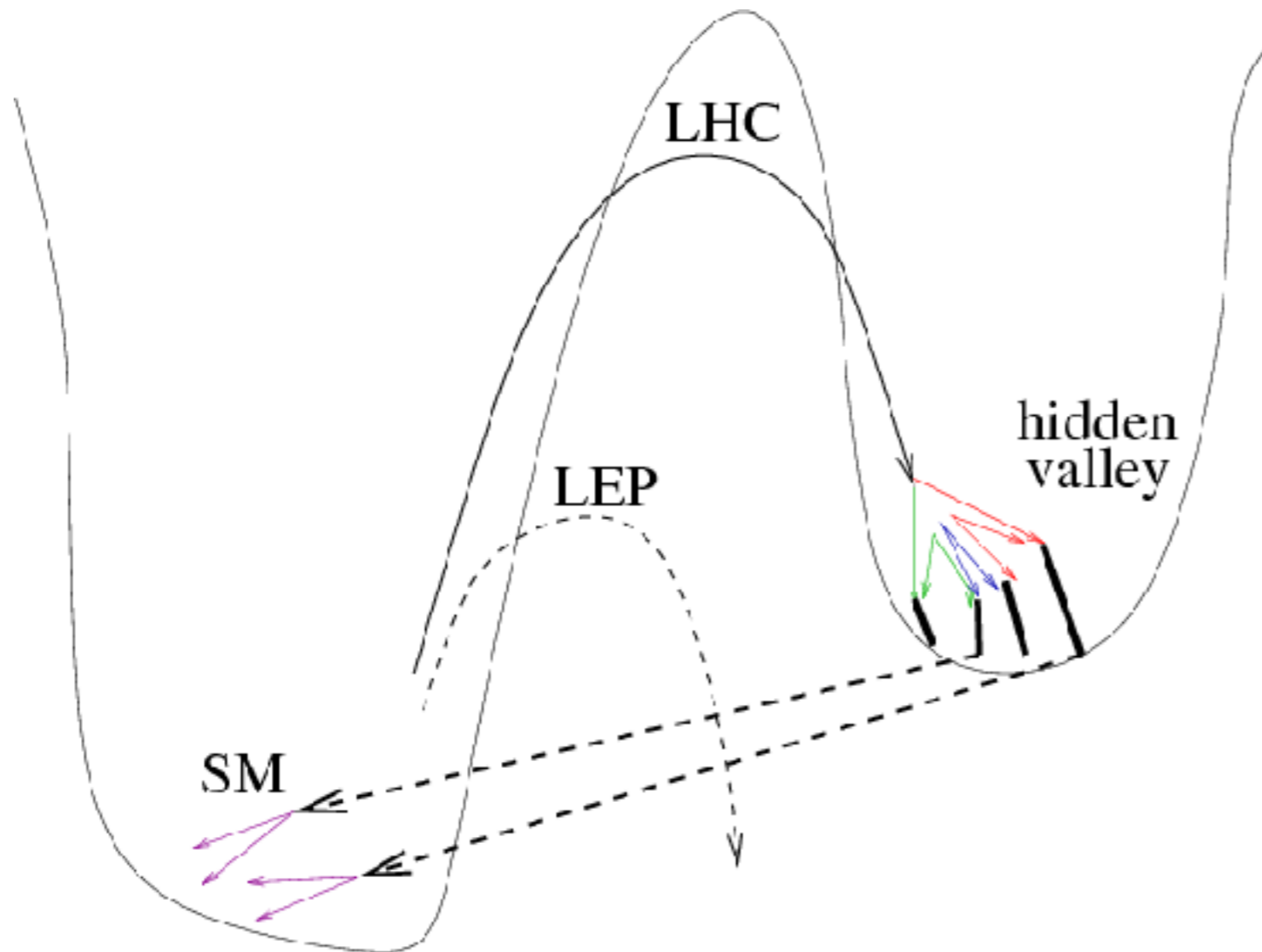


Broad definition:

Any cascade decay where low energy states are not produced directly (e.g. SUSY etc)

M. Strassler, K. Zurek: arXiv: 0604261, 0605193

What is a hidden valley?



M. Strassler, K. Zurek: arXiv: 0604261, 0605193

Broad definition:

Any cascade decay where low energy states are not produced directly (e.g. SUSY etc)

My definition today:

(Strong) hidden sector dynamics leading to large (>10) hidden sector final states with short to medium lifetimes

+ a few other comments at the end of the talk

Why hidden valleys?

Theory:

Show up in

- Neutral Naturalness
- Composite/asymmetric dark matter
- Standard Model*

Experiment:

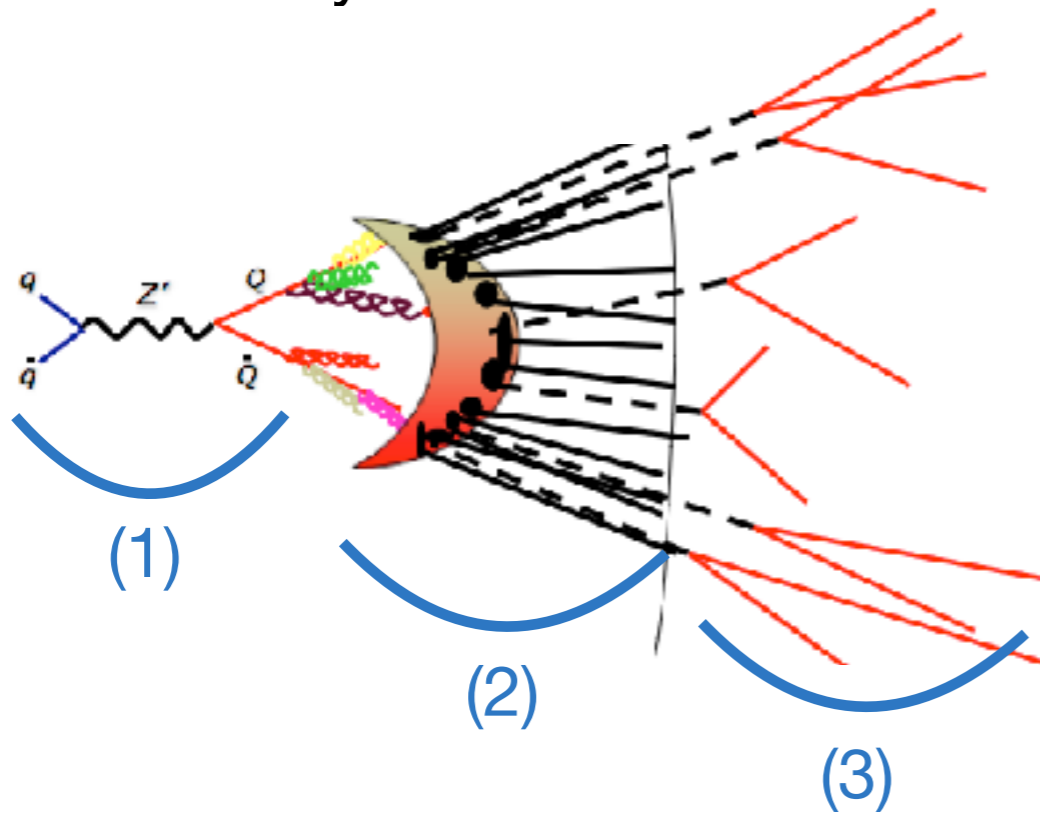
Hidden Valleys are “designed” to expose holes in trigger strategies

→ Testing ground for HL-LHC trigger strategies

* if the photon was massive

Anatomy of a hidden valley

Hidden valley “event”



Three “modules”:

(1) Production mode

- Higgs, Z' , something colored, ...

(2) Hidden shower & hadronization

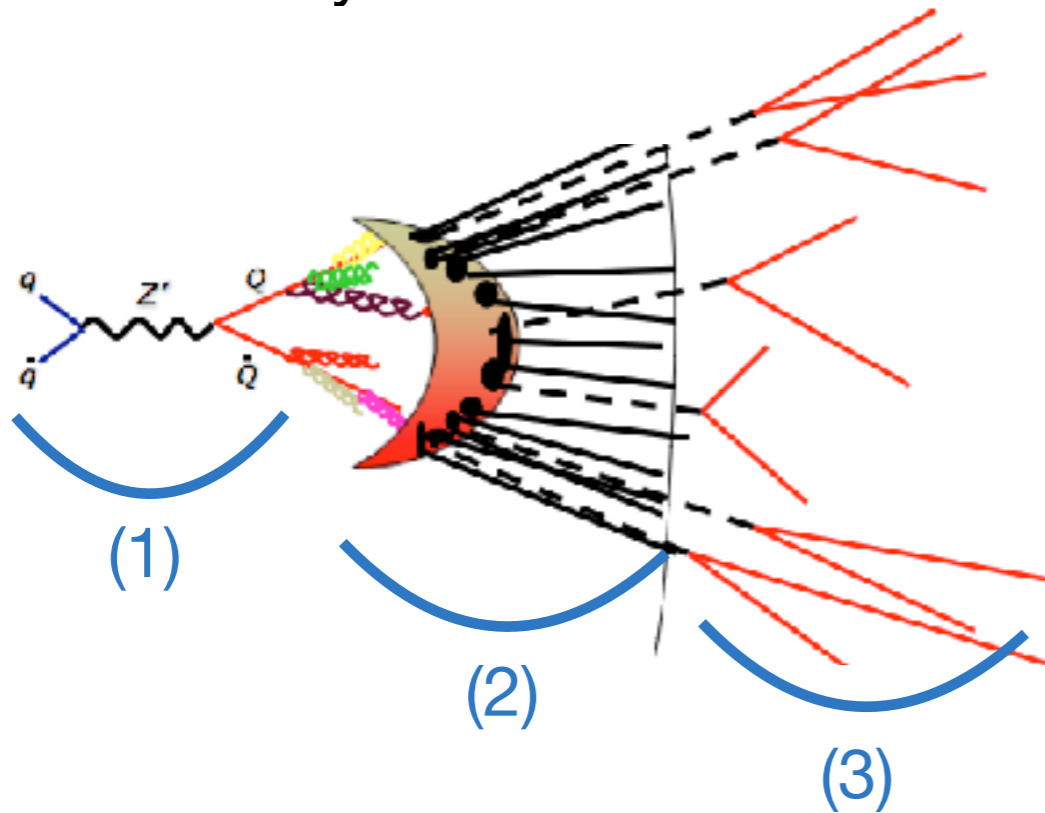
- p_T spectrum, sphericity, multiplicity

(3) Decay

- MET fraction, lepton fraction, lifetime

Anatomy of a hidden valley

Hidden valley “event”



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- MET fraction, lepton fraction, lifetime

Modules can be swapped in and out, greatly affecting the phenomenology

→ Daunting number of options... 🤔

Comprehensively coverage is tricky
(There are ideas, but more work needed)

A simpler problem

What to trigger on and how to prioritize?

Start here because

- Bandwidth is precious
- There will be time to worry about the offline stuff
- Organizing the trigger strategy will inform the offline strategies

Are there one or two triggers which cover all HV?

A simpler problem

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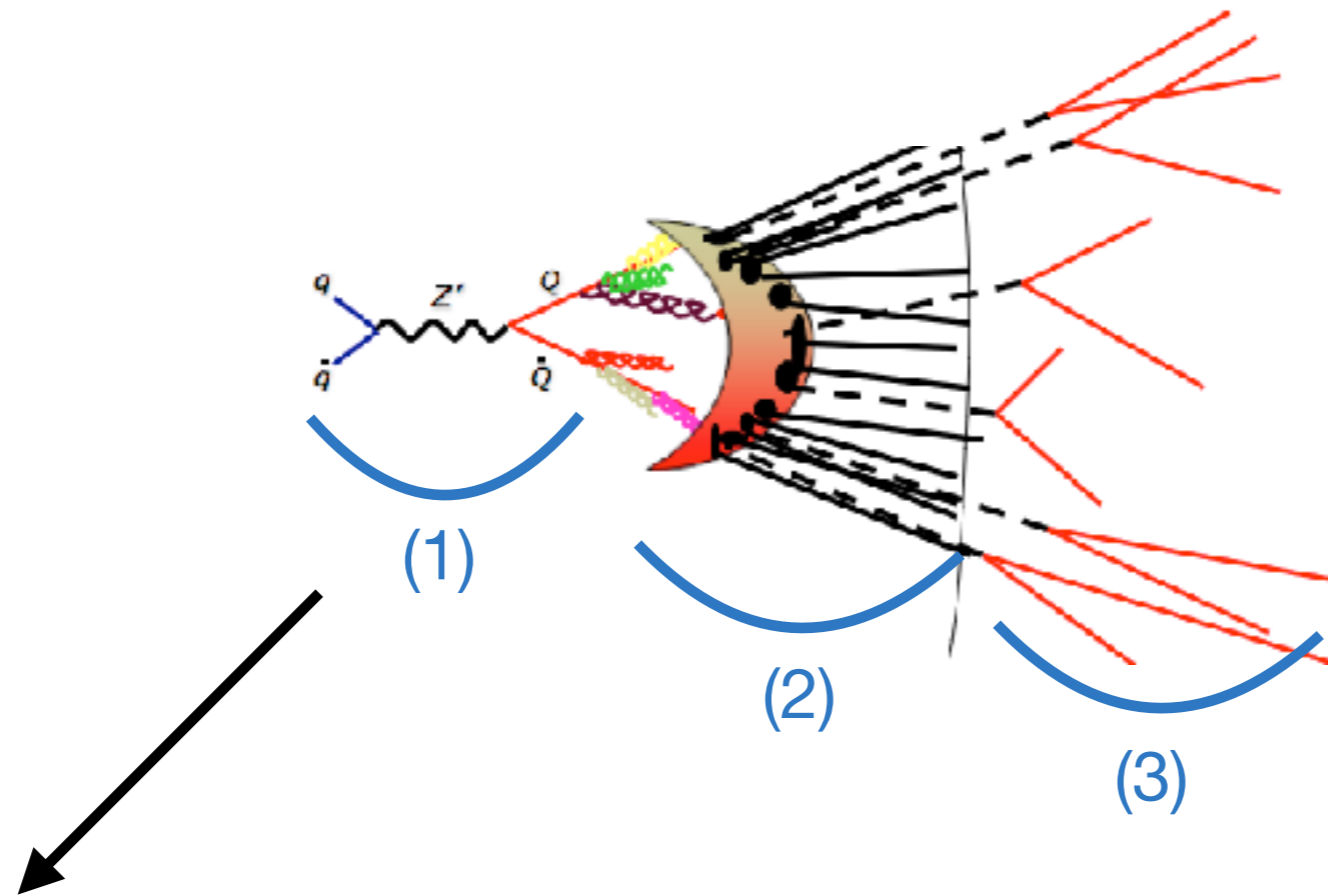
Nope, too many options...

Proposal: Insert theory prior*

* but proceed with caution



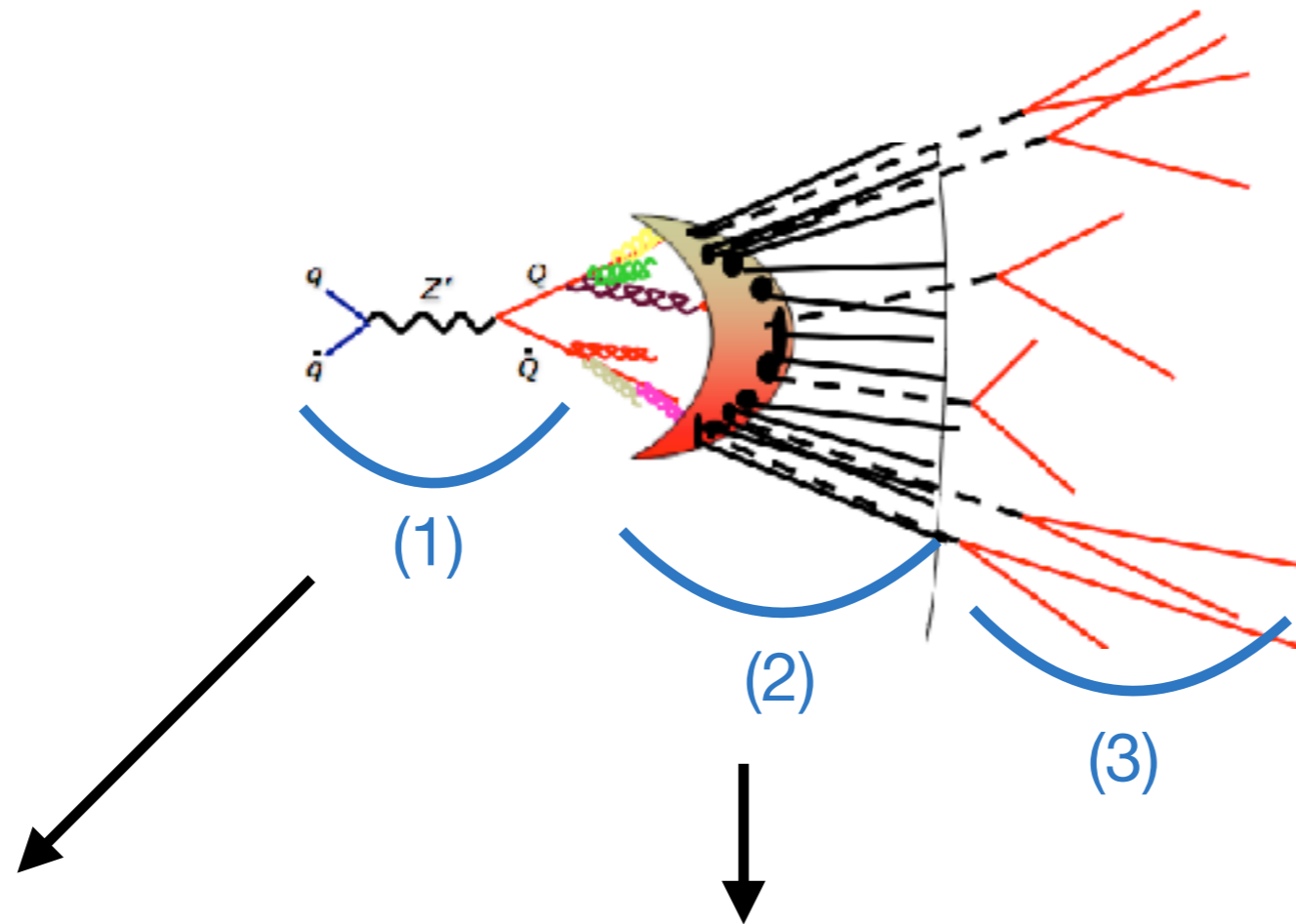
Where to inject theory prior?



e.g. Higgs VH production
For some cases we are
already triggering on this!

(see talks by Daniel and Yuhsin)

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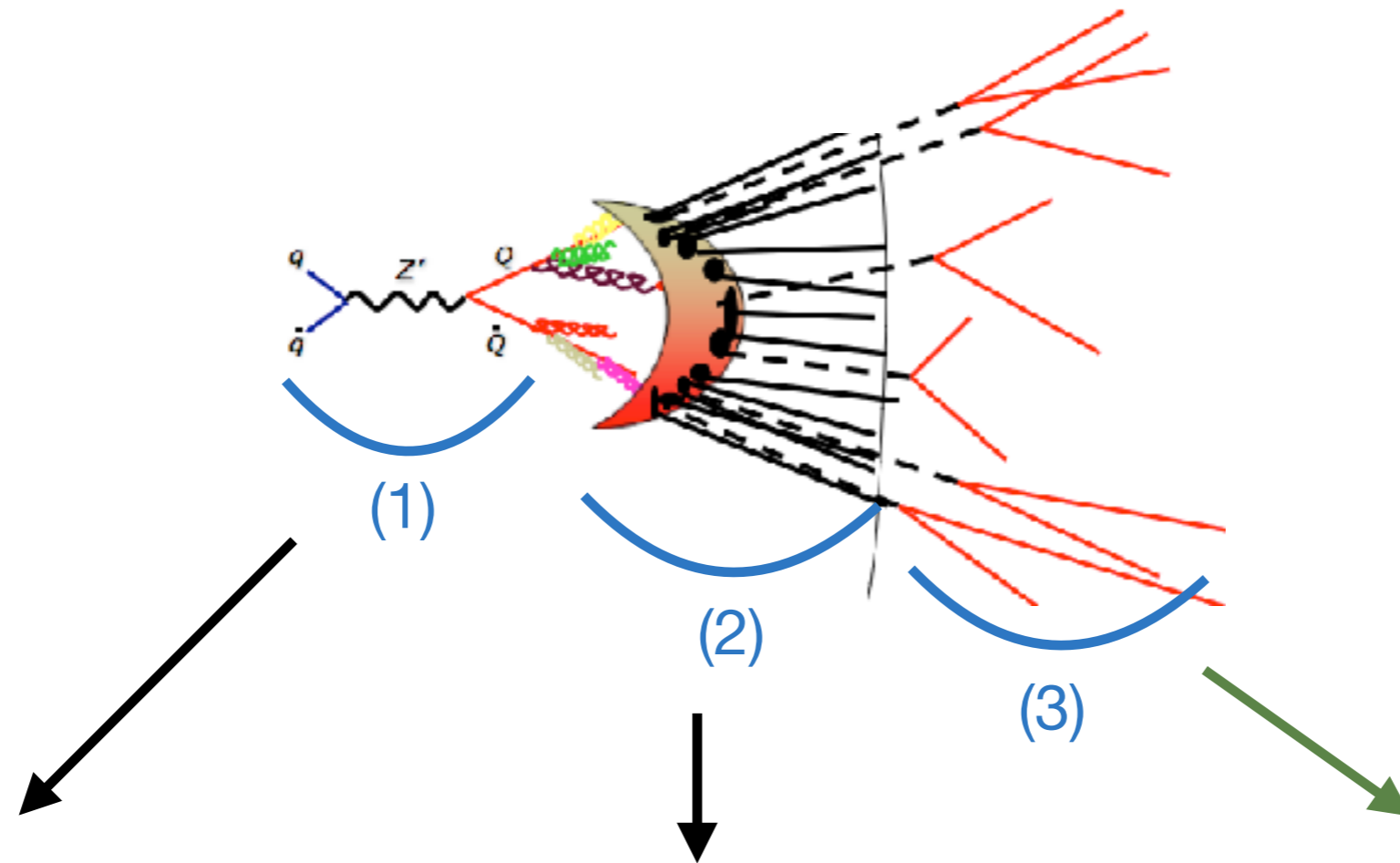
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We don't actually
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(see dark showers working group)

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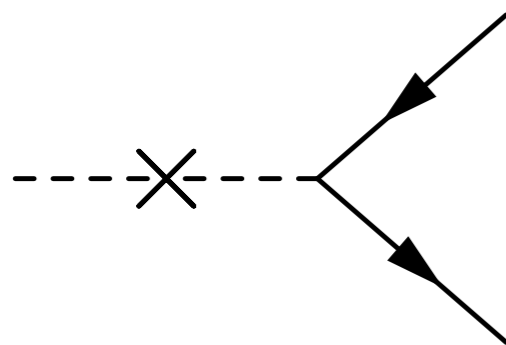
(see dark showers working group)

“Low” energy physics,
fairly constrained,
especially for shorter
lifetimes

Decaying a hidden sector meson

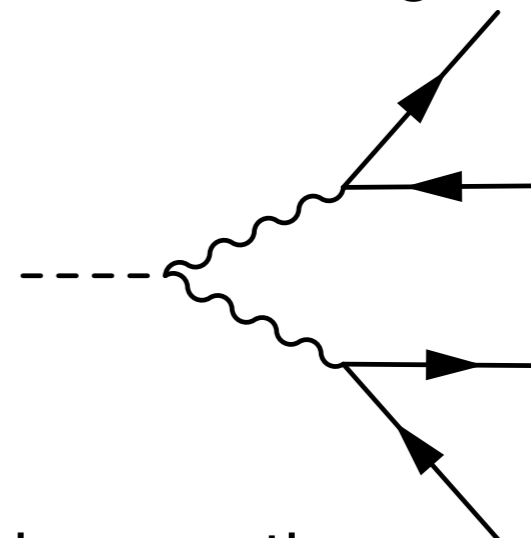
Two UV-complete operators:

Higgs mixing



b and τ rich

Photon mixing



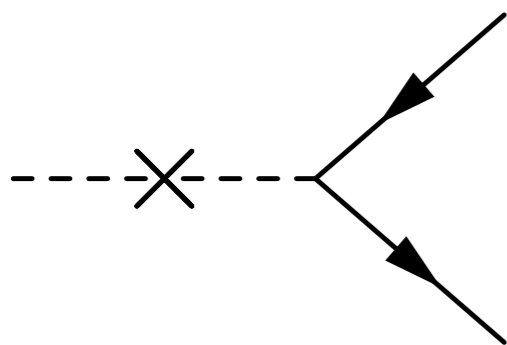
democratic

In both cases, likely to have leptons

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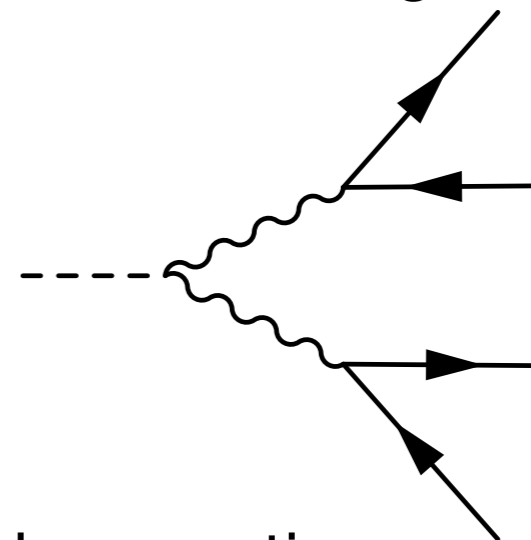
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Can I still have a leptophobic, non-flavor universal Z' portal, etc?

Sure....

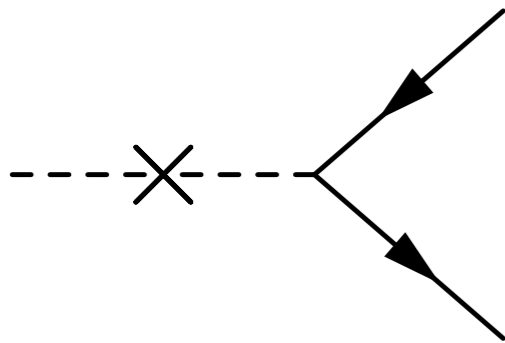
....but anomaly cancellation, flavor constraints etc etc...*



* except perhaps if production channel and decay portal are the same

Back-of-the-envelope estimate

Higgs mixing



mass	at least one μ / meson	at least 4 μ / event
15 GeV	35%	49%
5 GeV	20%	12%

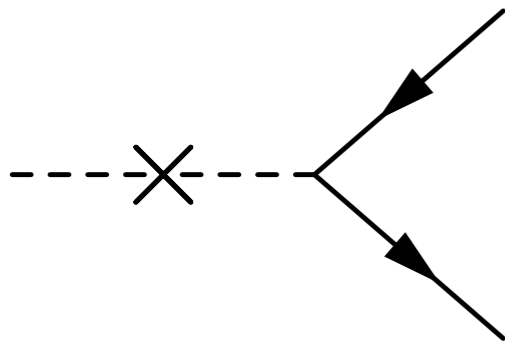
(Pythia 8)

Assuming 10 hidden mesons

See also M. Strassler, 0806.2385

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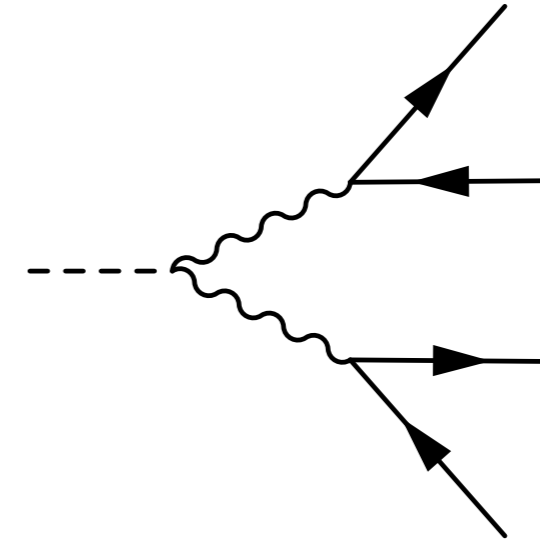
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8 GeV	30%	85%
1.2 GeV	55%	99%

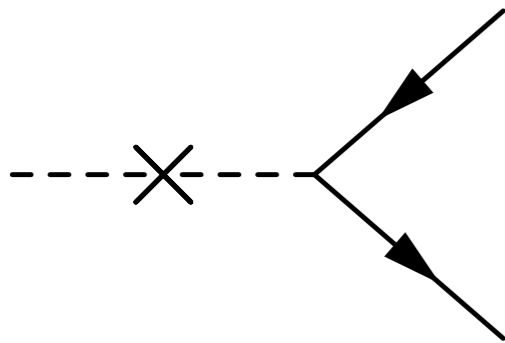
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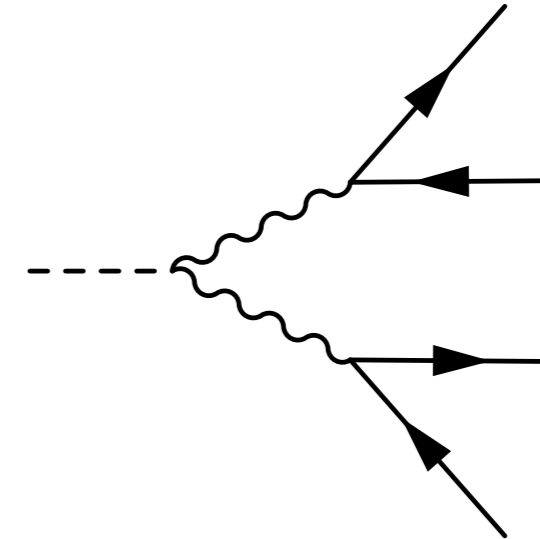
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Assuming 10 hidden mesons

get 4 muons fairly often, even in worst case scenarios

See also M. Strassler, 0806.2385

Combo lepton triggers

Multi-muons are generic but:

- could be soft
- generally not isolated

		L1	HLT	L1 rate (kHz)	HLT rate (Hz)
Three leptons	Three loose e 's, $p_T > 18, 11, 11$ GeV	15, 2×8	17, 2×10	15	< 0.1
	Three μ 's, each $p_T > 7$ GeV	3×6	3×6	0.1	3
	Three μ 's, $p_T > 21, 2 \times 5$ GeV	20	20, 2×4	13	4
	Two μ 's & one loose e , $p_T > 2 \times 11, 13$ GeV	2×10 (μ 's)	$2 \times 10, 12$	1.5	0.2
	Two loose e 's & one μ , $p_T > 2 \times 13, 11$ GeV	$2 \times 8, 10$	$2 \times 12, 10$	1.1	0.1

From ATL-DAQ-PUB-2017-001

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Thresholds are not too bad, but may need to relax online isolation

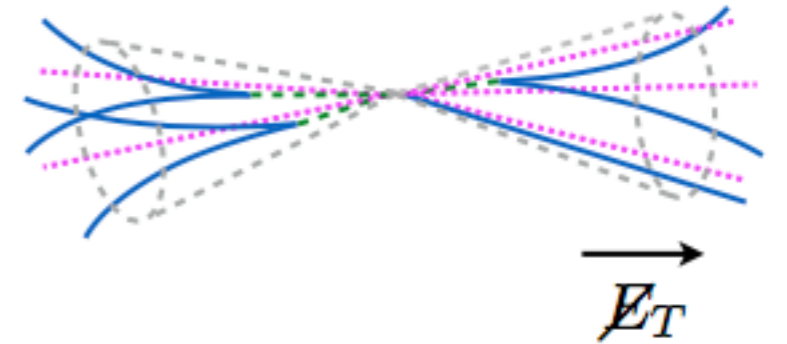
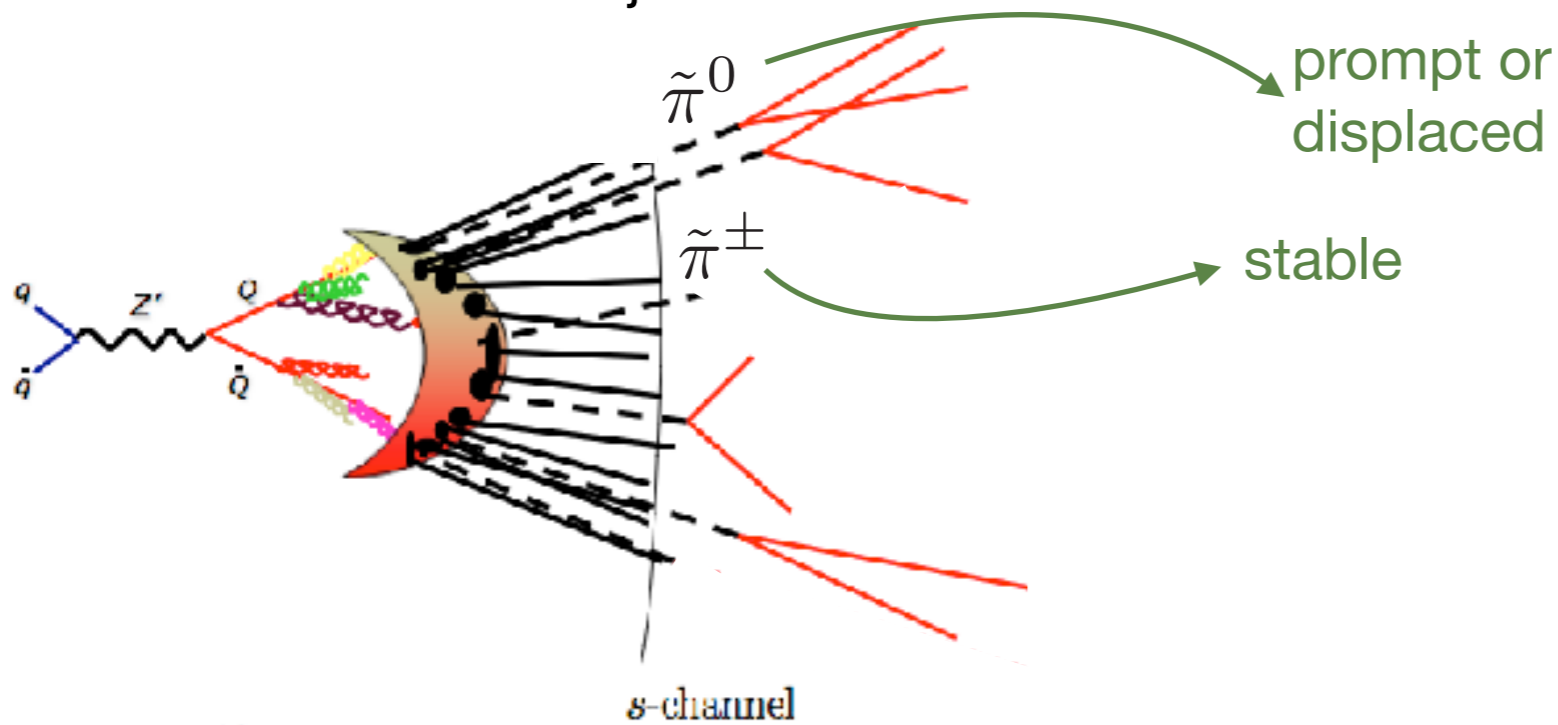
Recover bandwidth by adding:

- more muons
- MET
- H_T

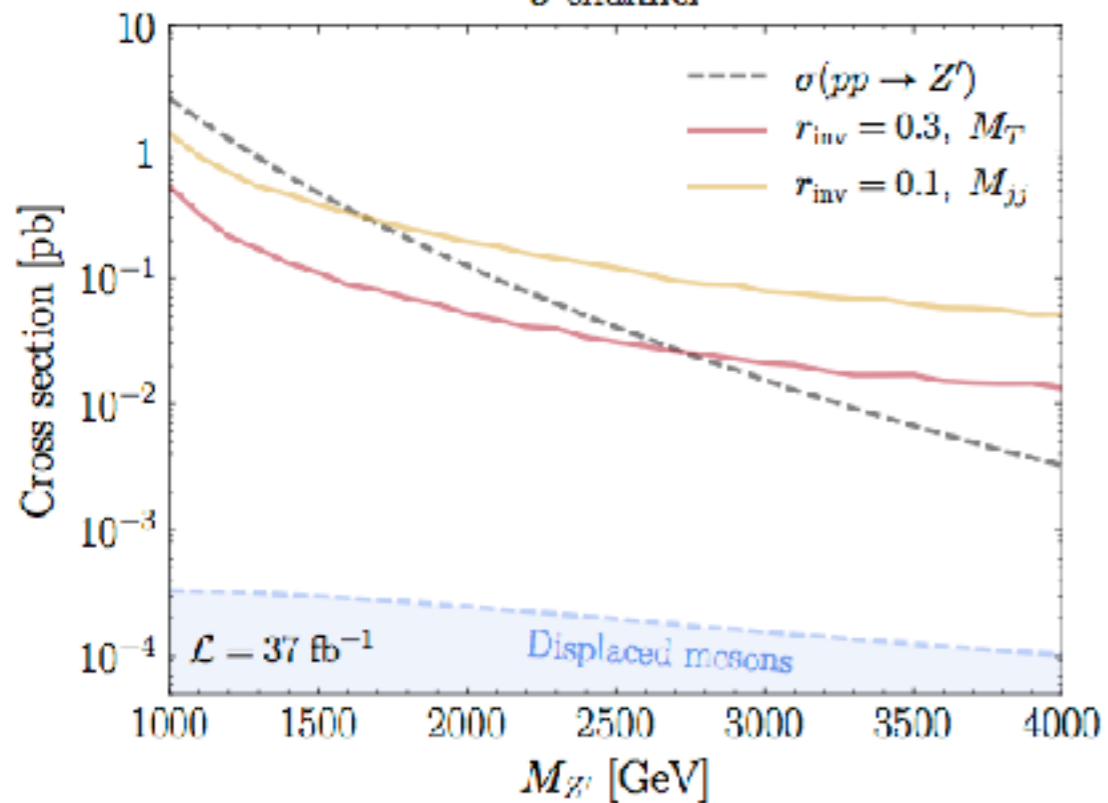
A theory study probably needed to optimize combo's

Example: Two flavor dark QCD (aka SM minus leptons)

This is a “semi-visible” jet



MET is aligned with one of the jets



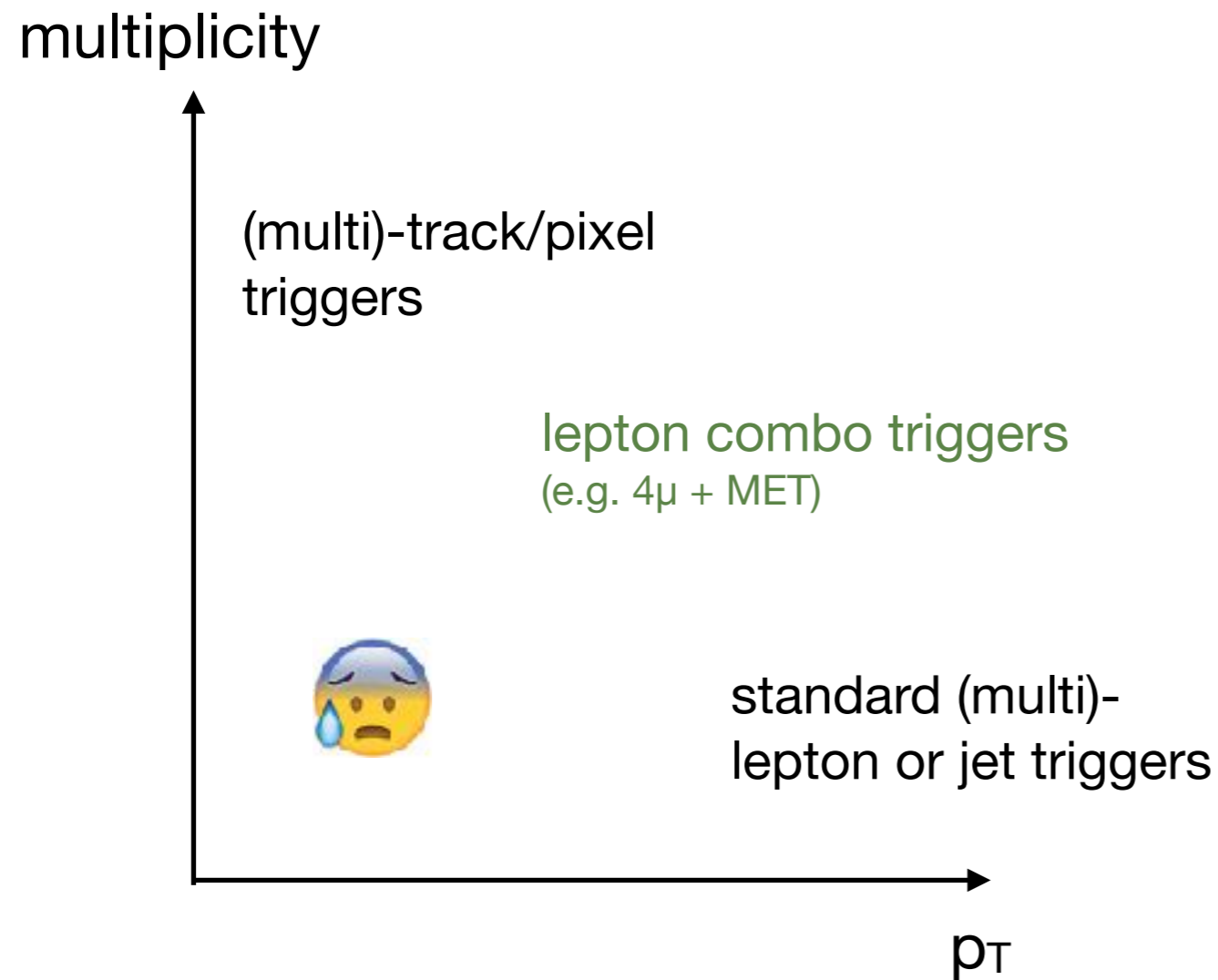
- hard 800 GeV MET cut
- require MET aligned with jet
- M_T bump hunt or cut & count

Go lower in mass by requiring muons in the jet, at the expense of some model dependence

T. Cohen, M. Lisanti, H. Lou: 1503.00009

T. Cohen, M. Lisanti, H. Lou, S. Mishra-Sharma: 1707.05326 (but slightly different model)

Overview



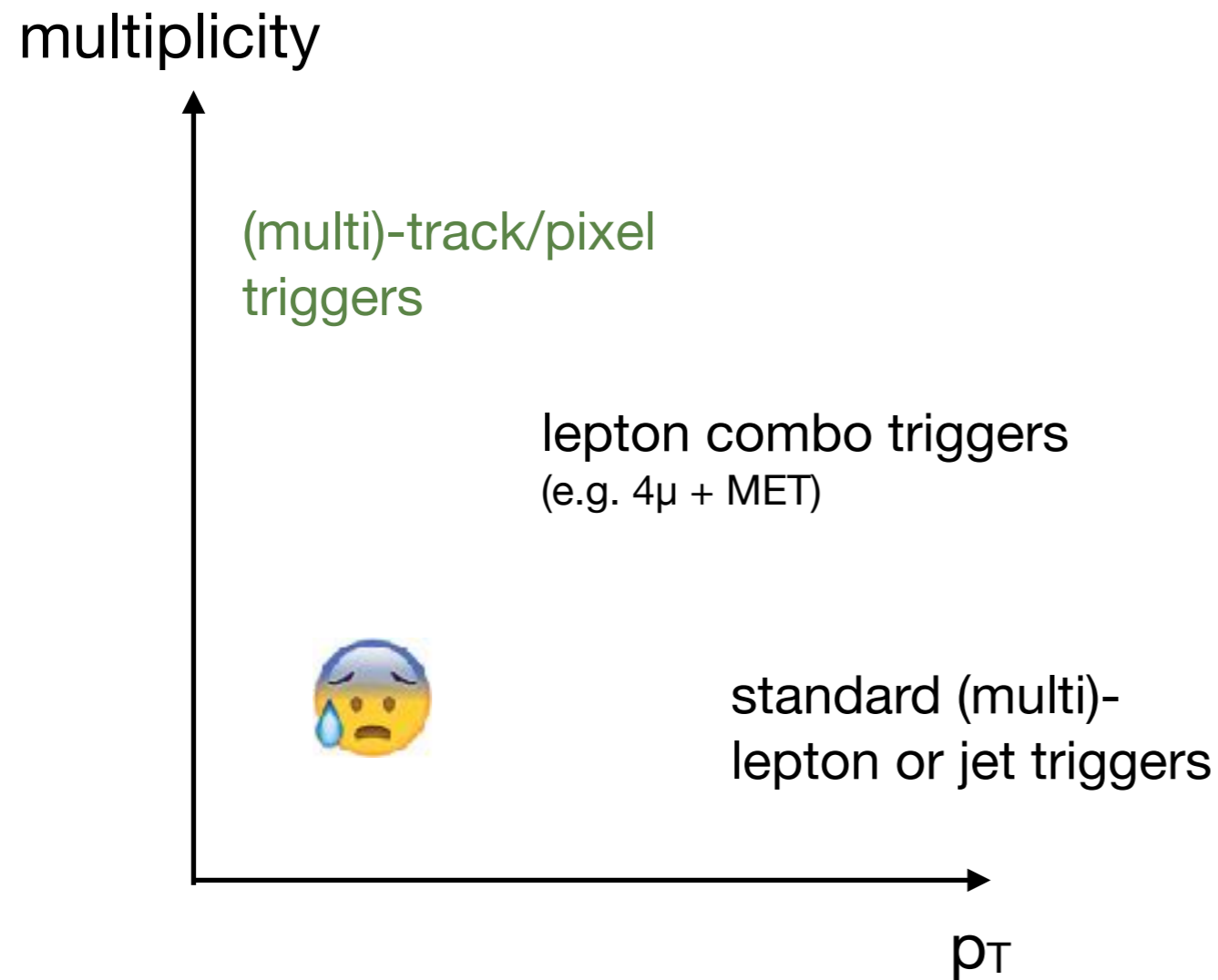
+ some miscellaneous things :

- photon jets
- quirks

Cover the most (motivated) cases with

- lepton combo triggers
- pixel/track triggers
- existing triggers for associated objects

Overview



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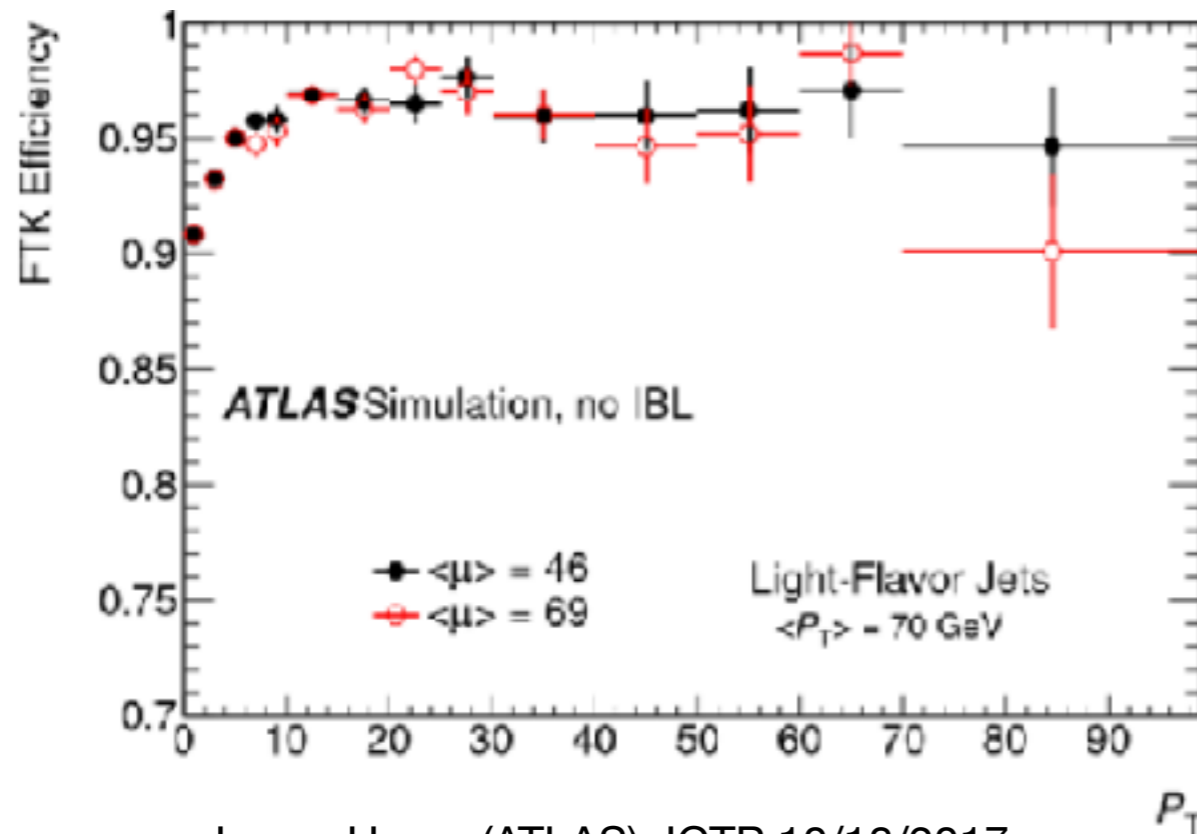
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ATLAS Fast Tracker (FTK)

At the moment: HLT tracking seeded by 0.4×0.4 ROI \longrightarrow

A lot of info lost, especially for fat hidden jets

With FTK: candidate tracks input in HLT, down to ~ 1 GeV



FTK may also find displaced tracks, if loaded in the pattern bank

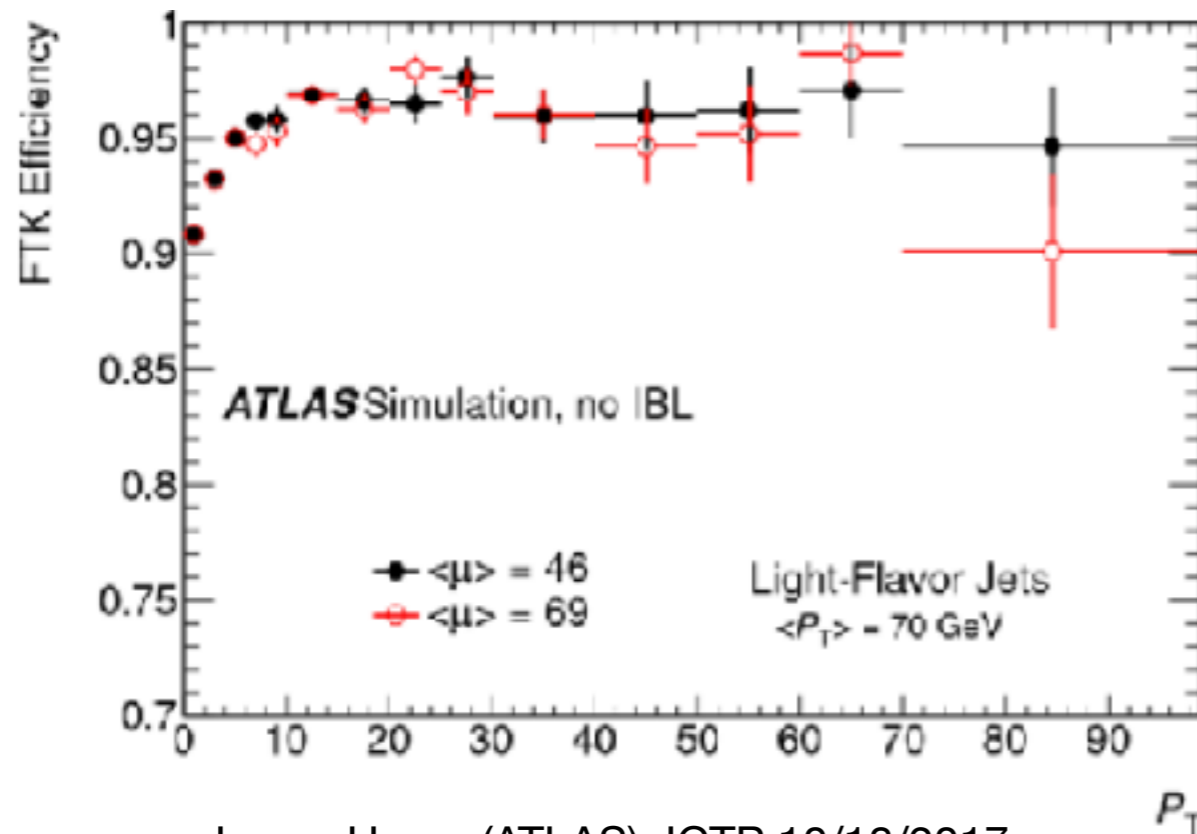
Lesya Horyn (ATLAS), ICTP 10/18/2017

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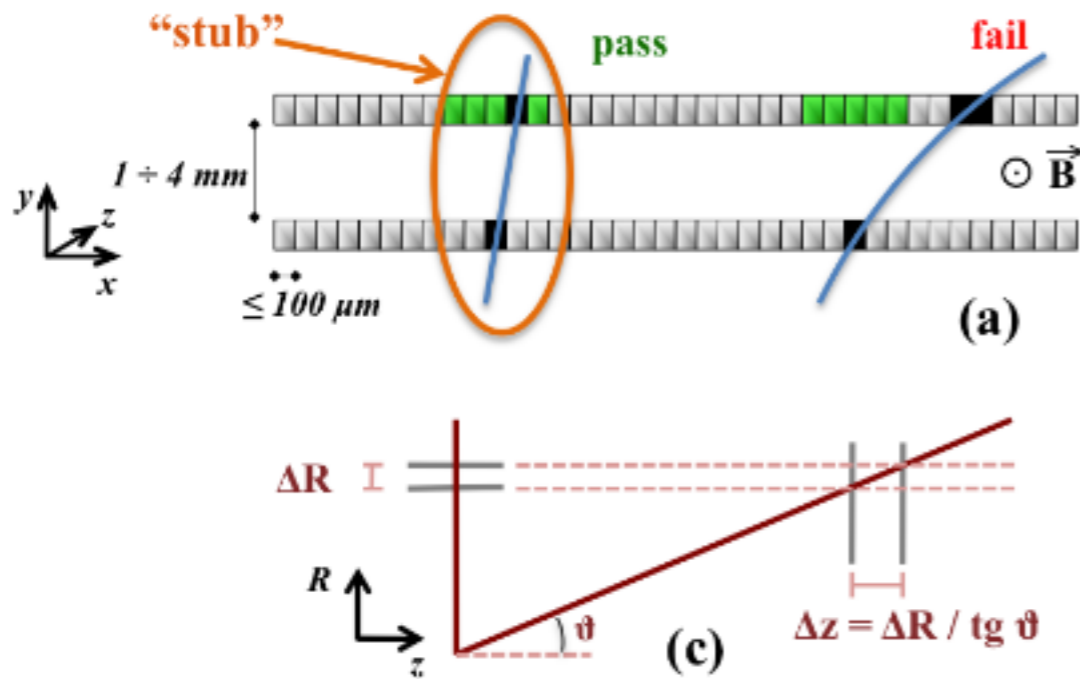
Lesya Horyn (ATLAS), ICTP 10/18/2017

With FTK, can HLT fire on anomalously large number of

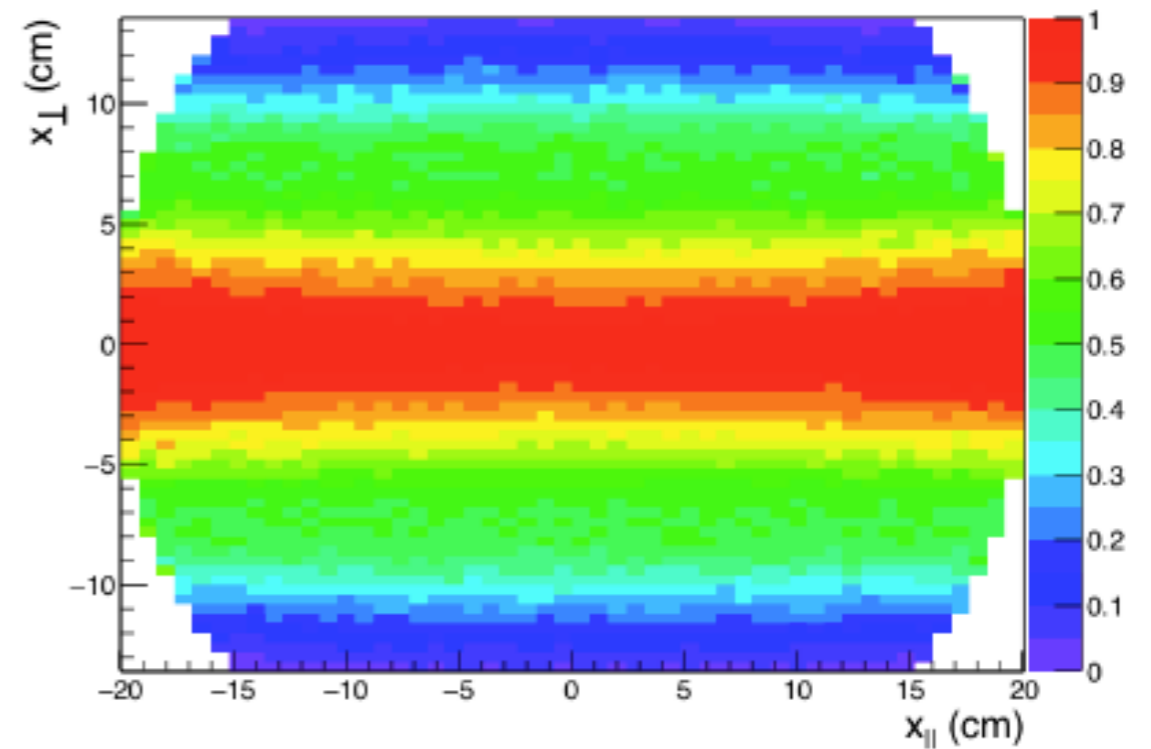
- prompt tracks at primary vertex?
- displaced tracks?

CMS hardware track trigger

Same goal, different approach



$\sim 10 \text{ cm}$ displaced tracks possible

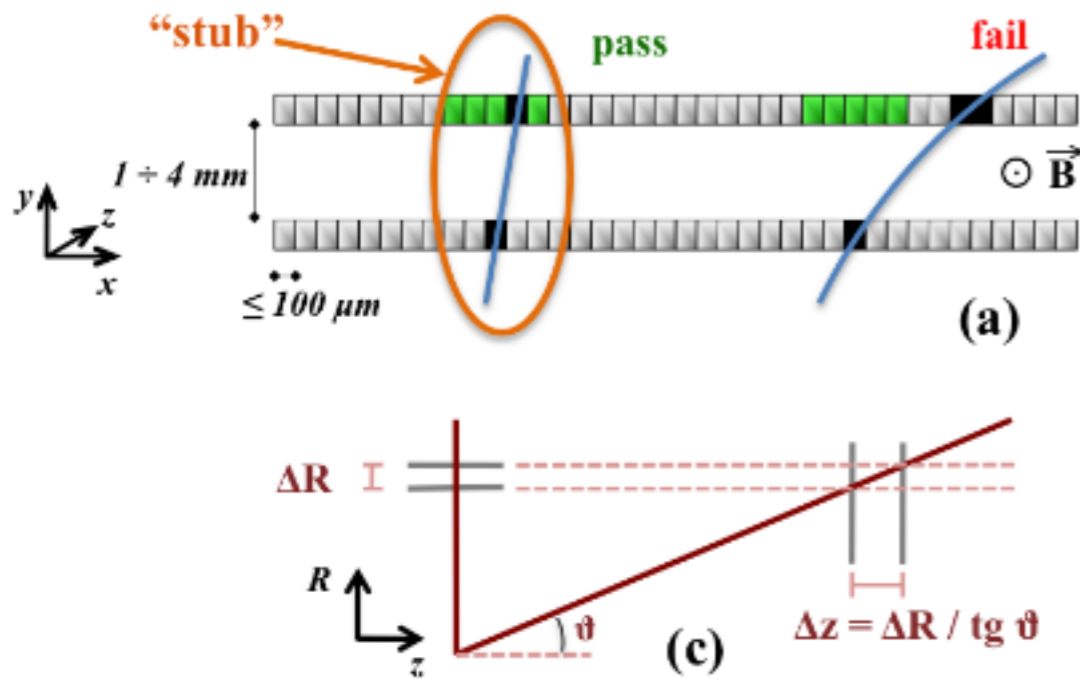


Finds tracks with $p_{\text{T}} > 2 \text{ GeV}$ at L1

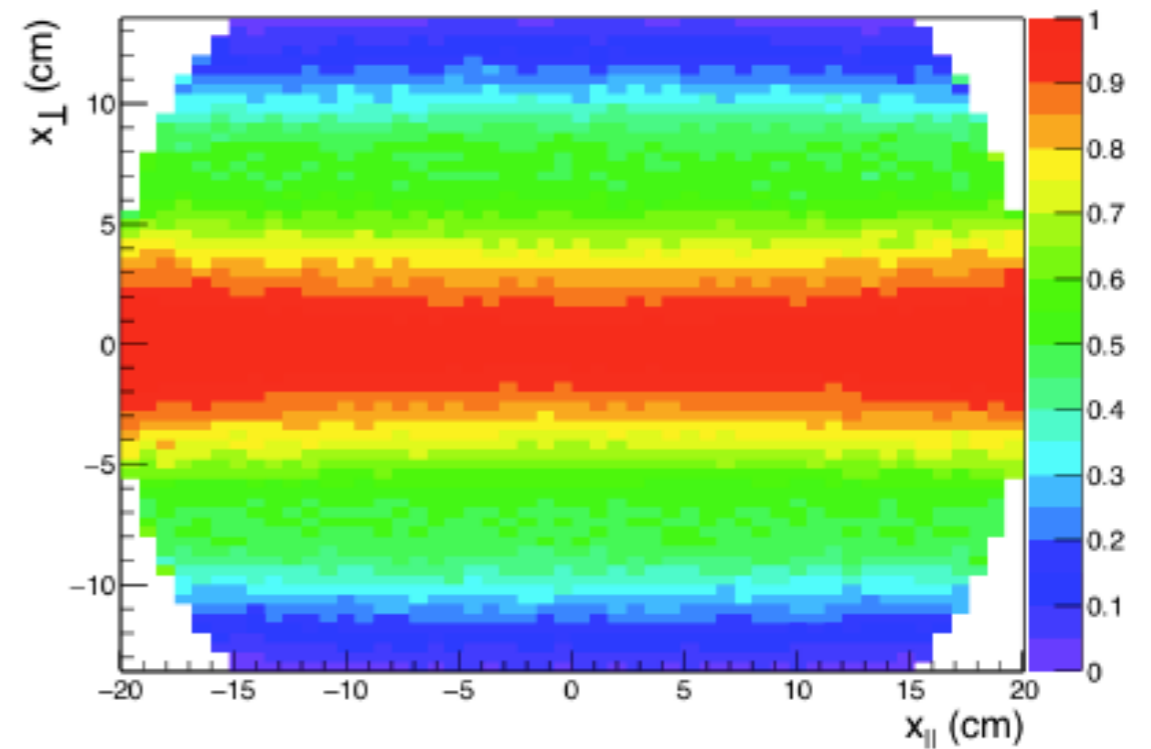
See Yuri's talk & Y. Gershtein 1705.04321

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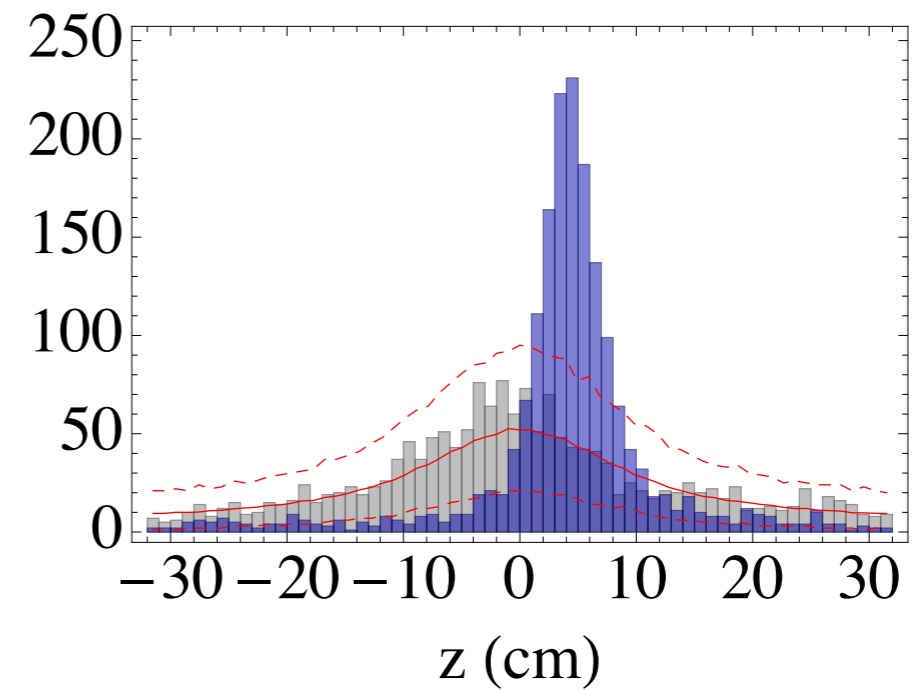
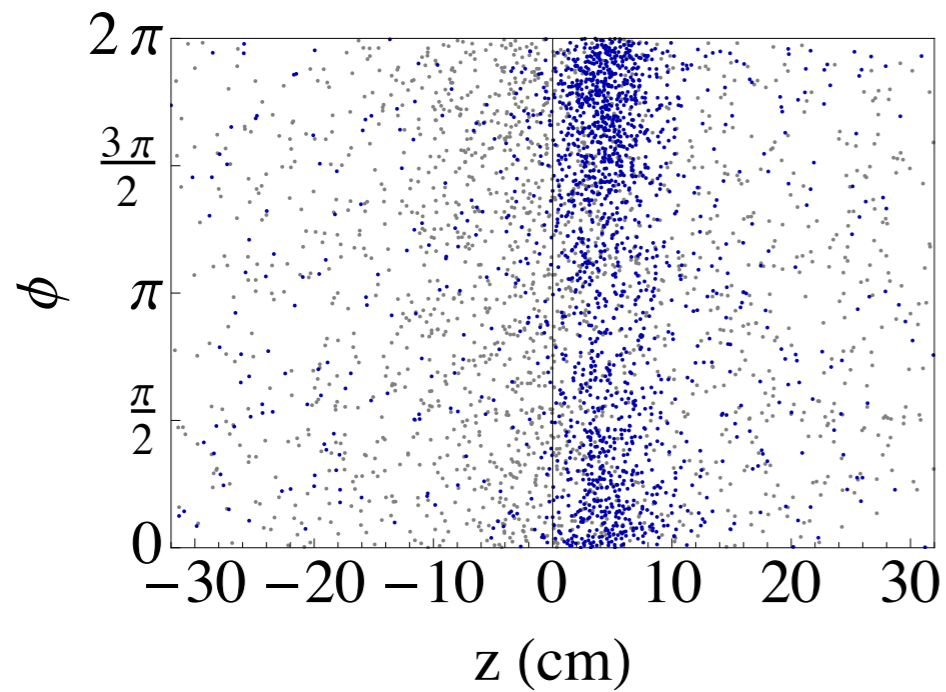
Finds tracks with $p_{\text{T}} > 2 \text{ GeV}$ at L1

Again, can HLT fire on a anomalously busy primary vertex or a large number of displaced tracks?

See Yuri's talk & Y. Gershtein 1705.04321

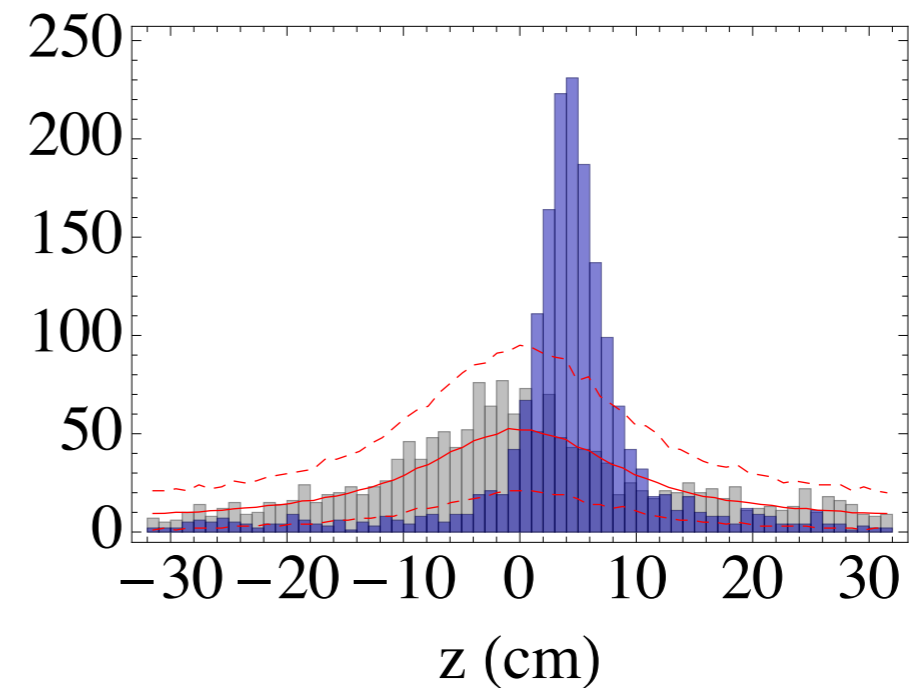
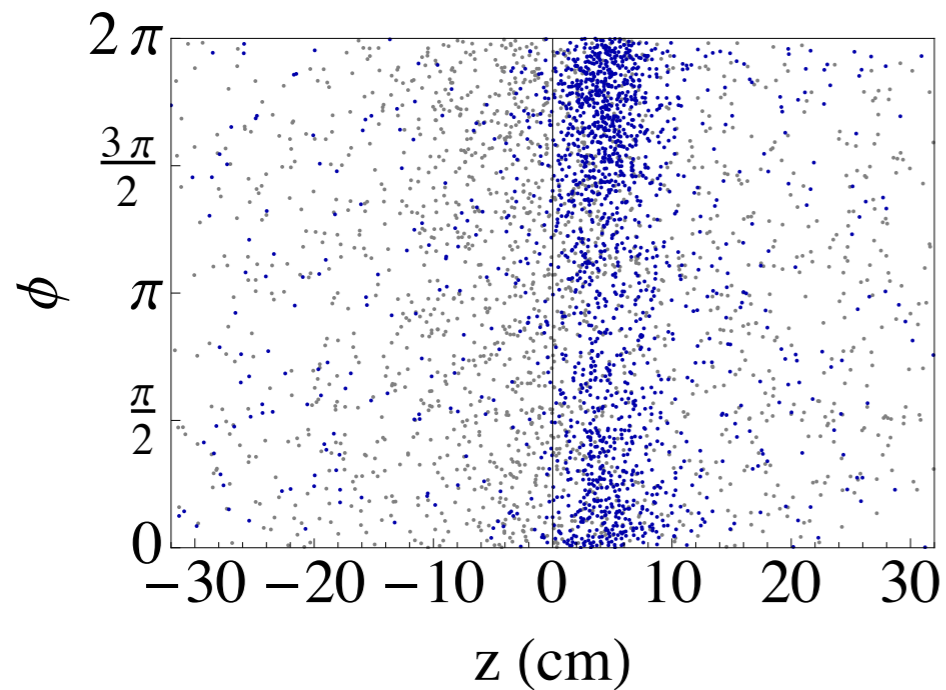
SUEP/soft bomb pixel trigger

For high multiplicity (strong coupling), trigger on ring of pixels in inner layer of tracker



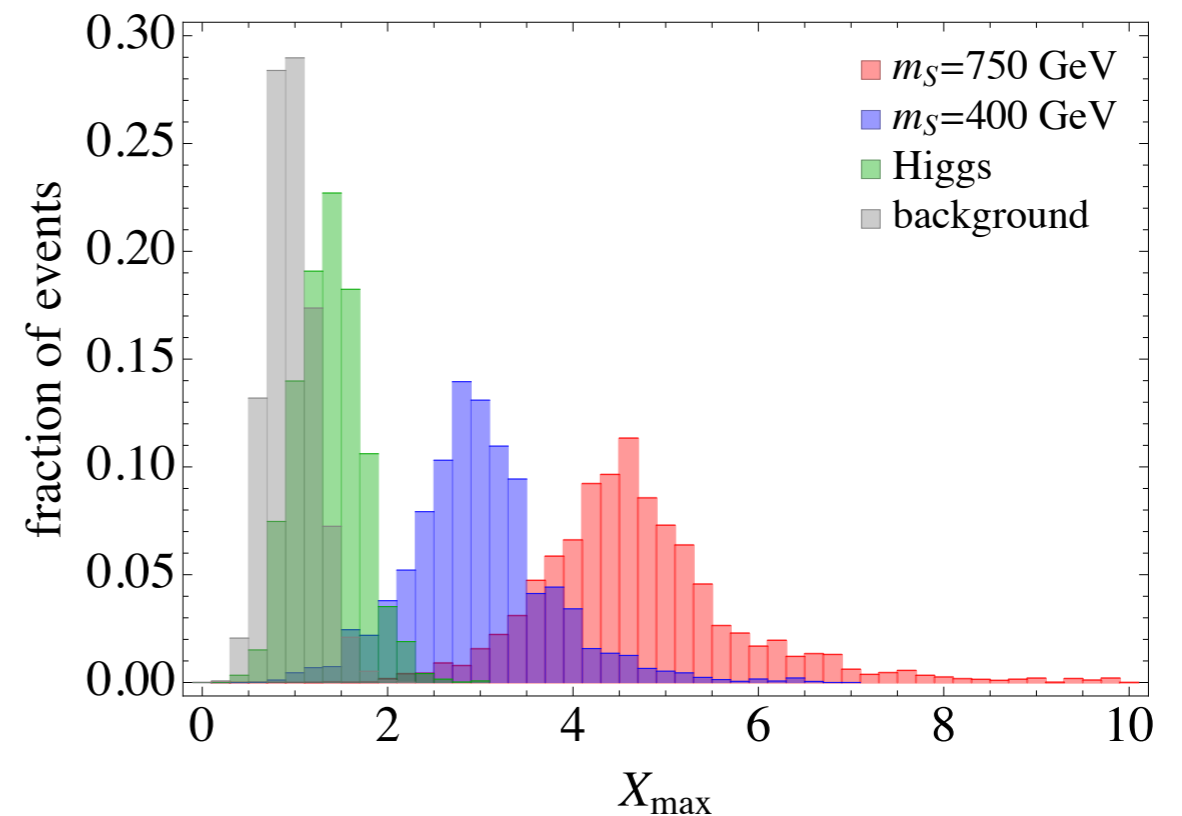
SUEP/soft bomb pixel trigger

For high multiplicity (strong coupling), trigger on ring of pixels in inner layer of tracker



- Need ISR for L1 trigger
- can get 10^{-4} discrimination at HLT

(Study done for $\langle \mu \rangle \sim 50$, may not work at HL-LHC)

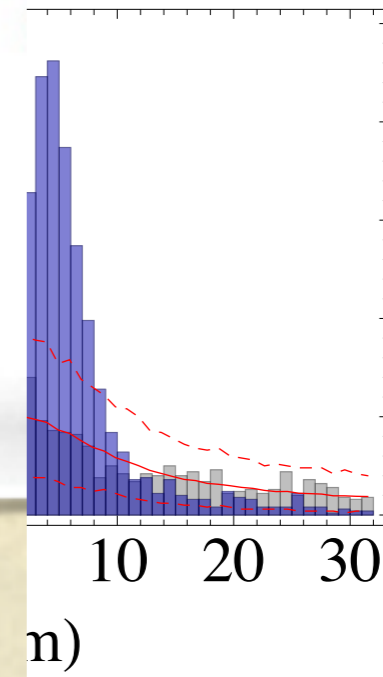
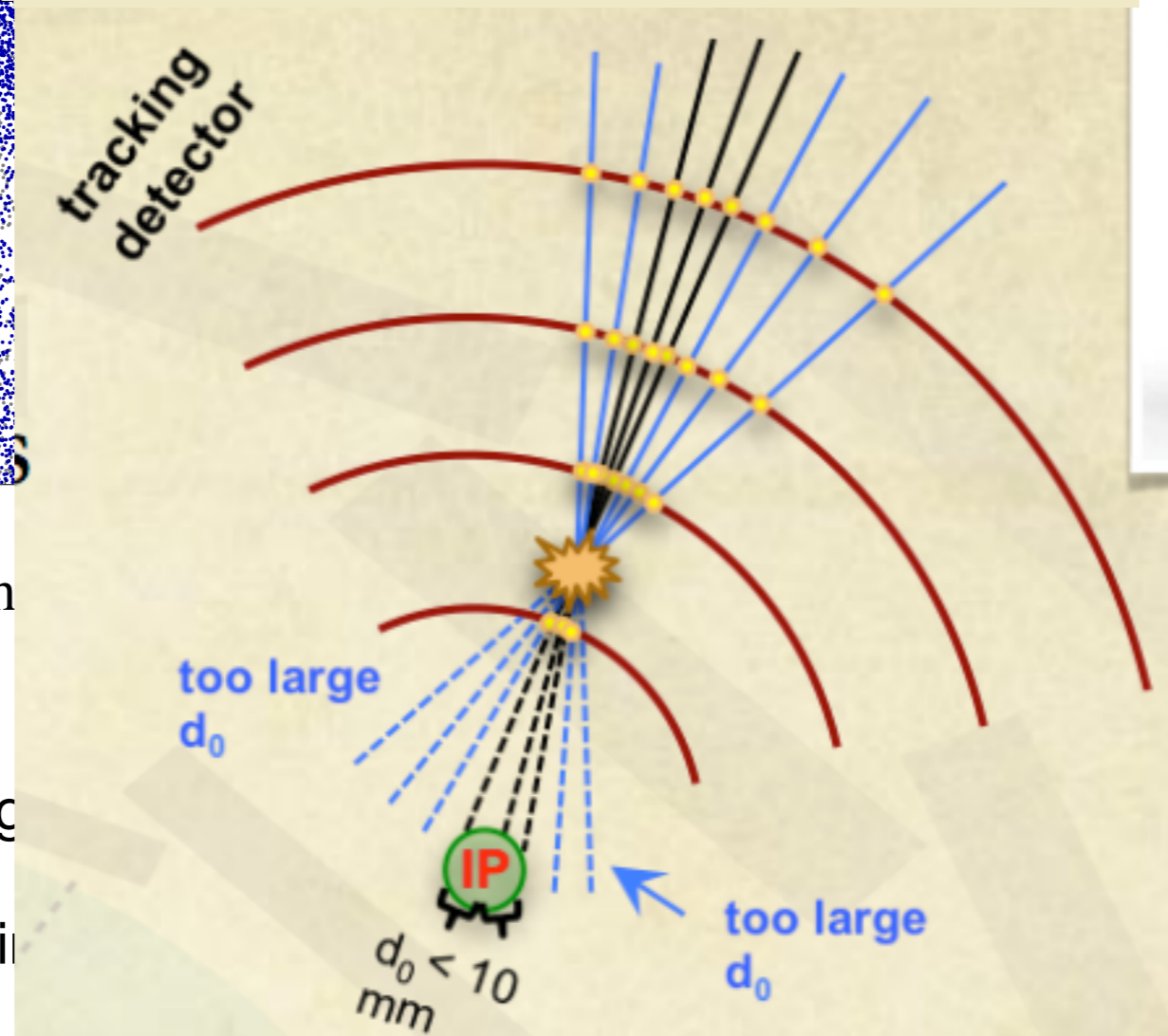
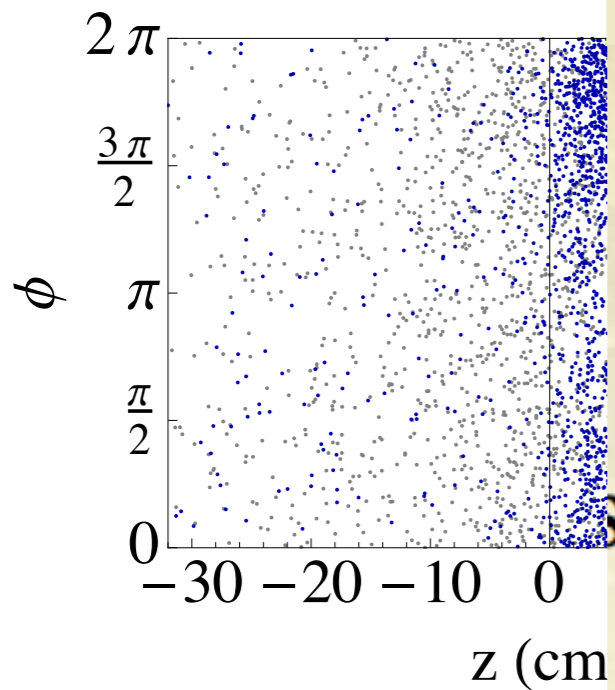


S. Pagan Griso, SK, M. Papucci, D. Robinson:1612.00850

SUEP/soft bomb pixel trigger

For high multiplicity (stamps) trigger in inner layer of tracker

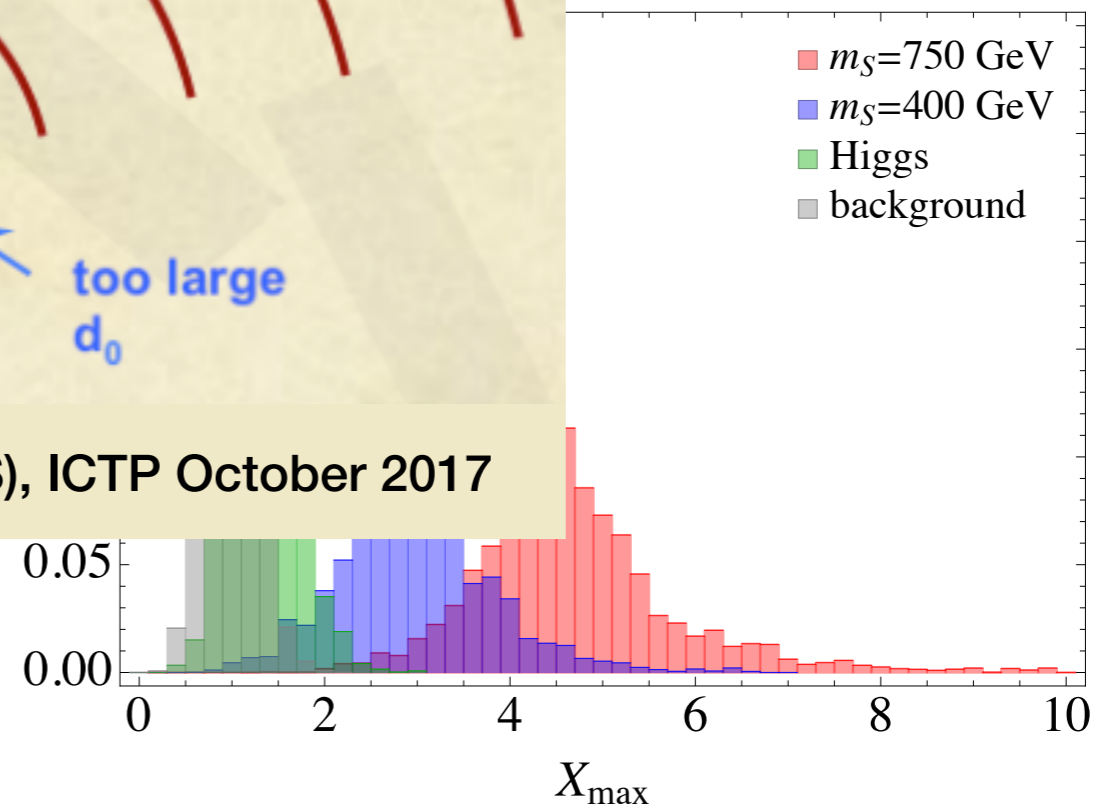
Maybe also useful for displaced vertices?



- Need ISR for L1 trigger
- can get 10^{-4} discrimination

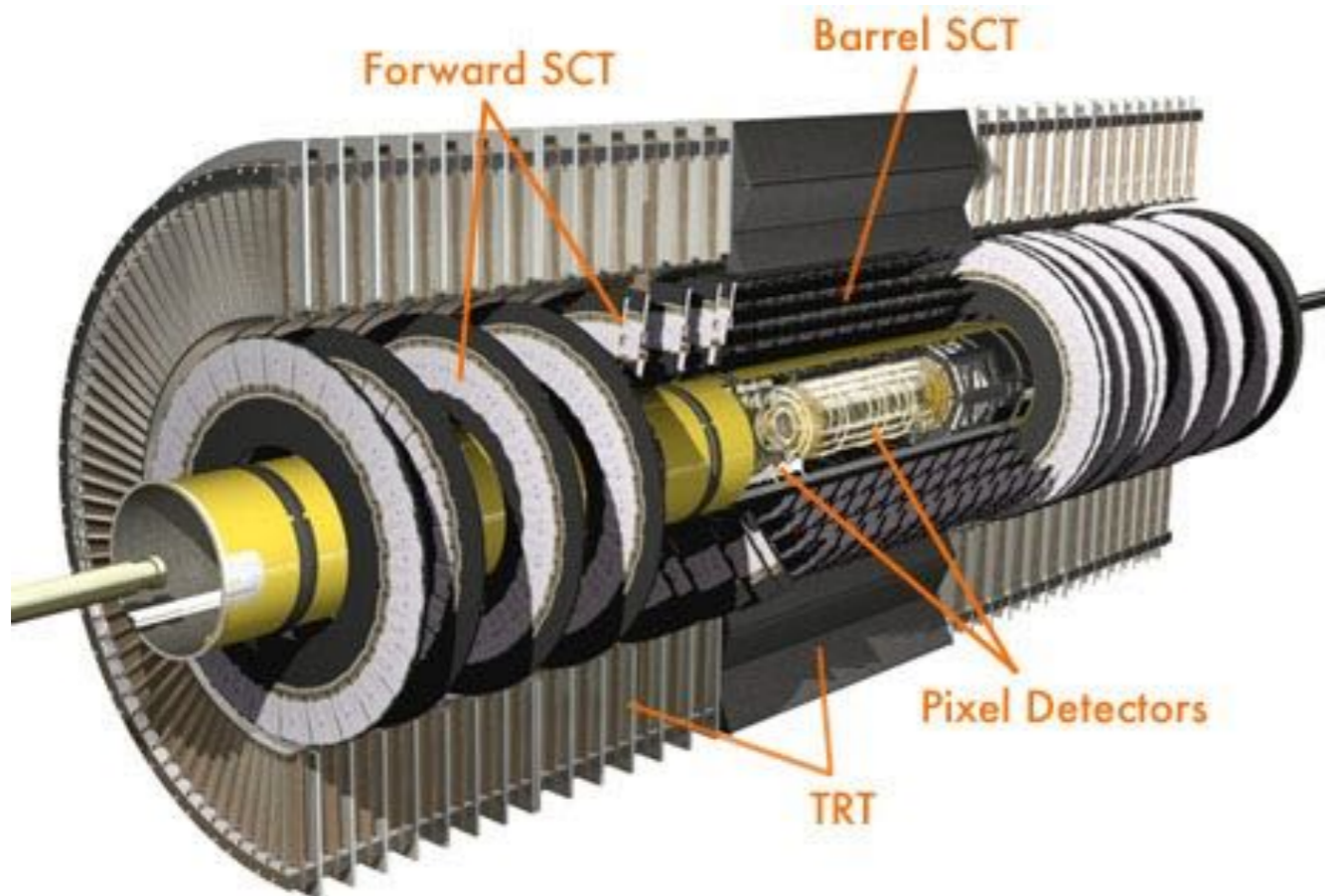
(Study done for $\langle \mu \rangle \sim 50$, may not be optimal)

Cristiano Alpigiani (ATLAS), ICTP October 2017



Theorist-level detector simulation

python-based simplified simulation of ATLAS ID
(can be adapted for CMS)



components included in simulation

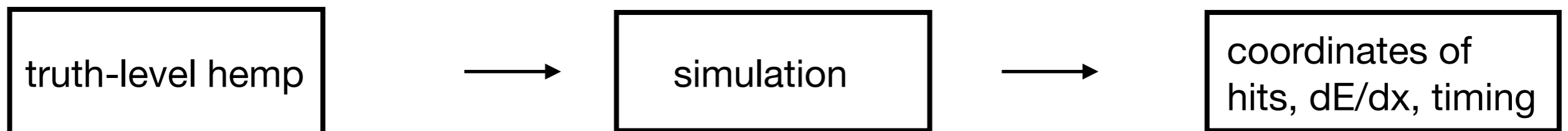
- | | |
|--------------------|-----------------|
| 1. Beam pipe | 7. SCT wheels |
| 2. IBL | 8. TRT barrel |
| 3. pixel barrel | 9. TRT wheels |
| 4. pixel wheels | 10. ECAL barrel |
| 5. services layers | 11. ECAL wheels |
| 6. SCT barrel | |

included:

- Brehmstrahlung
- dE/dx
- handles displaced decays

neglected:

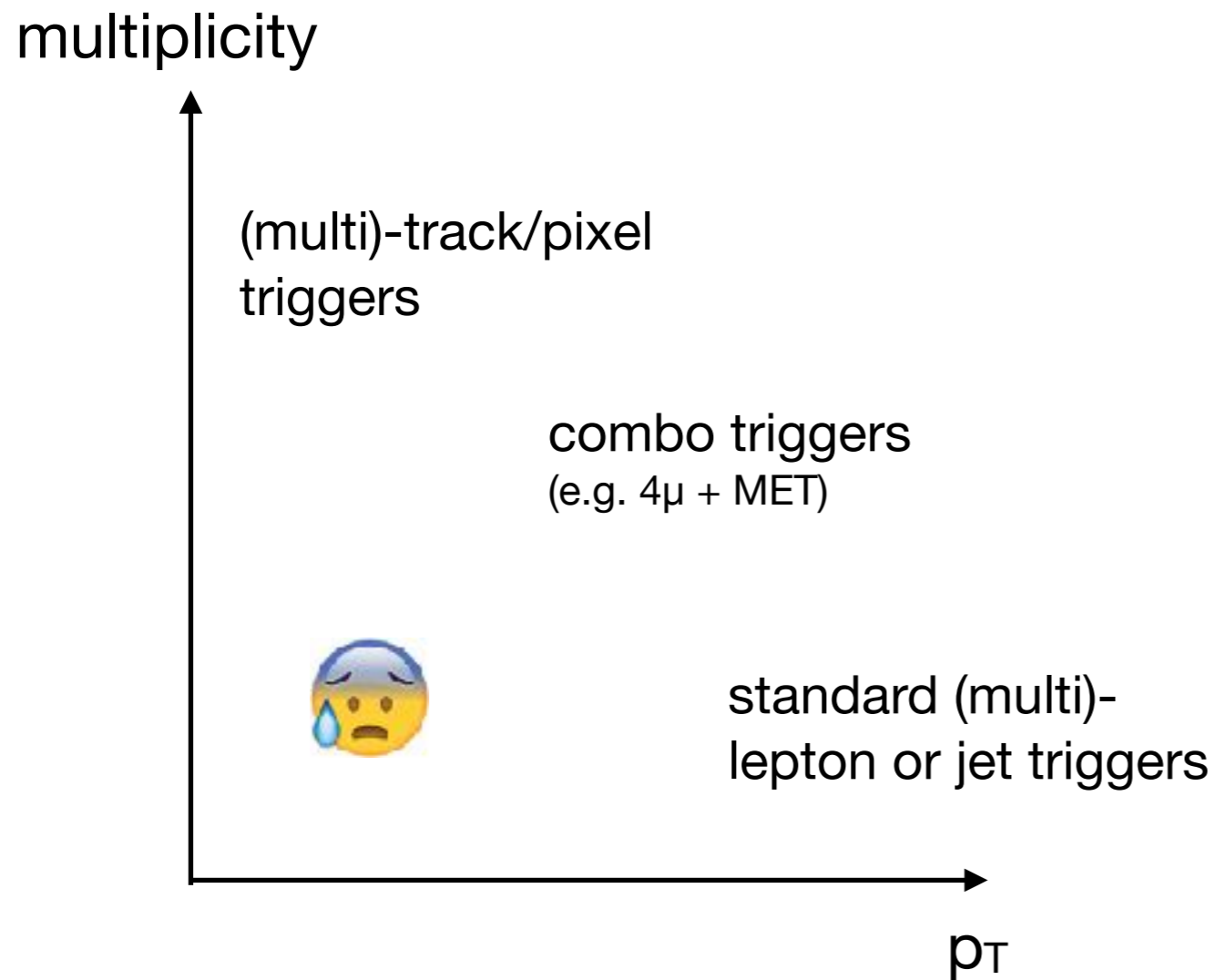
- hadronic secondaries



Happy to provide code and/or collaborate if this is useful for something

S. Pagan Griso, SK, M. Papucci, D. Robinson:1612.00850

Overview



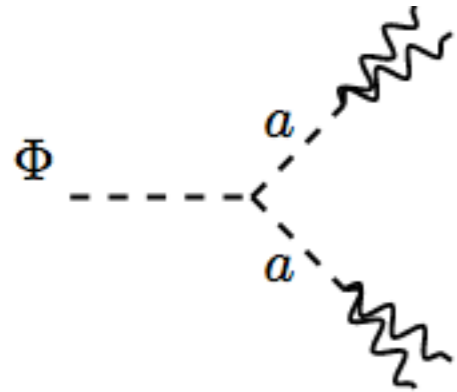
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Photon jets



e.g. exotic Higgs decay

B. Dobrescu, G. Landsberg, K. Matchev: 0005308

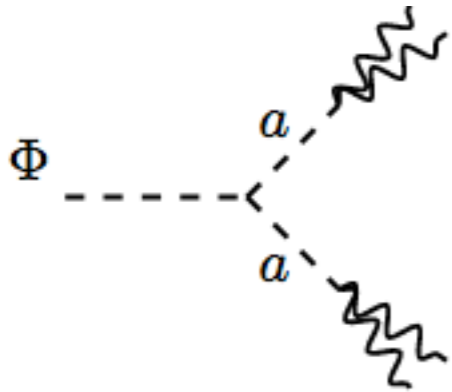
current thresholds

	L1	HLT
1γ	> 22 GeV	> 140 GeV
2γ	>2x15 GeV	>35,25 GeV

from ATL-DAQ-PUB-2017-001

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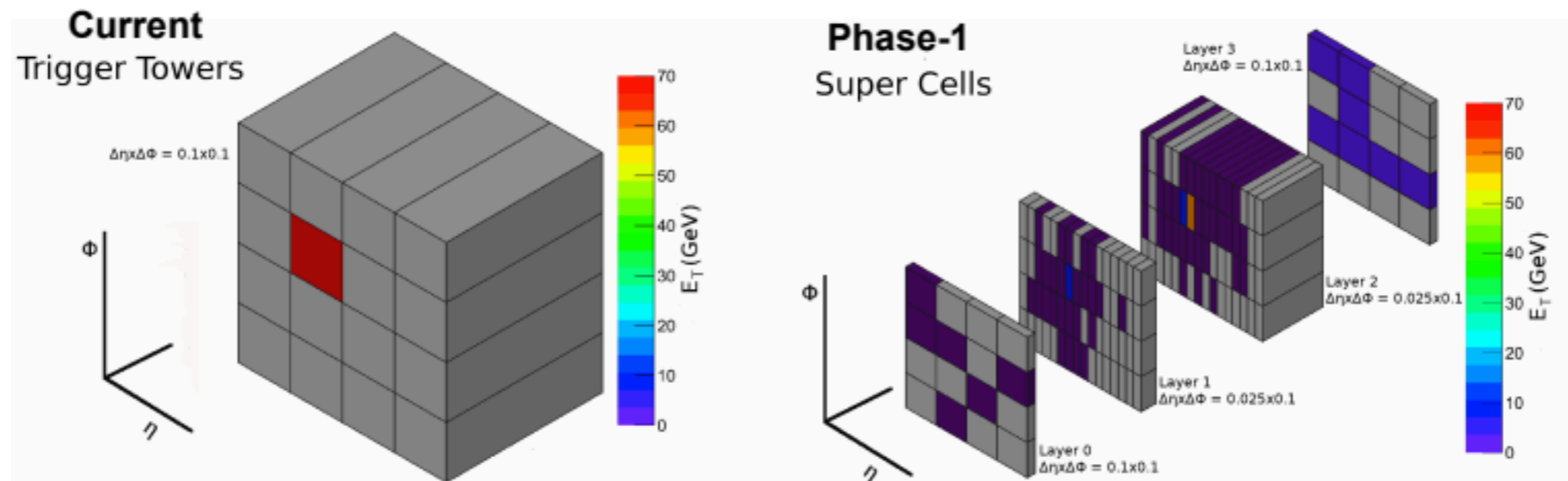


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from ATL-DAQ-PUB-2017-001



from Simon Viel (ATLAS) LBNL 06/08/2017

With more ECAL granularity at trigger level, could one build a photon jet trigger?

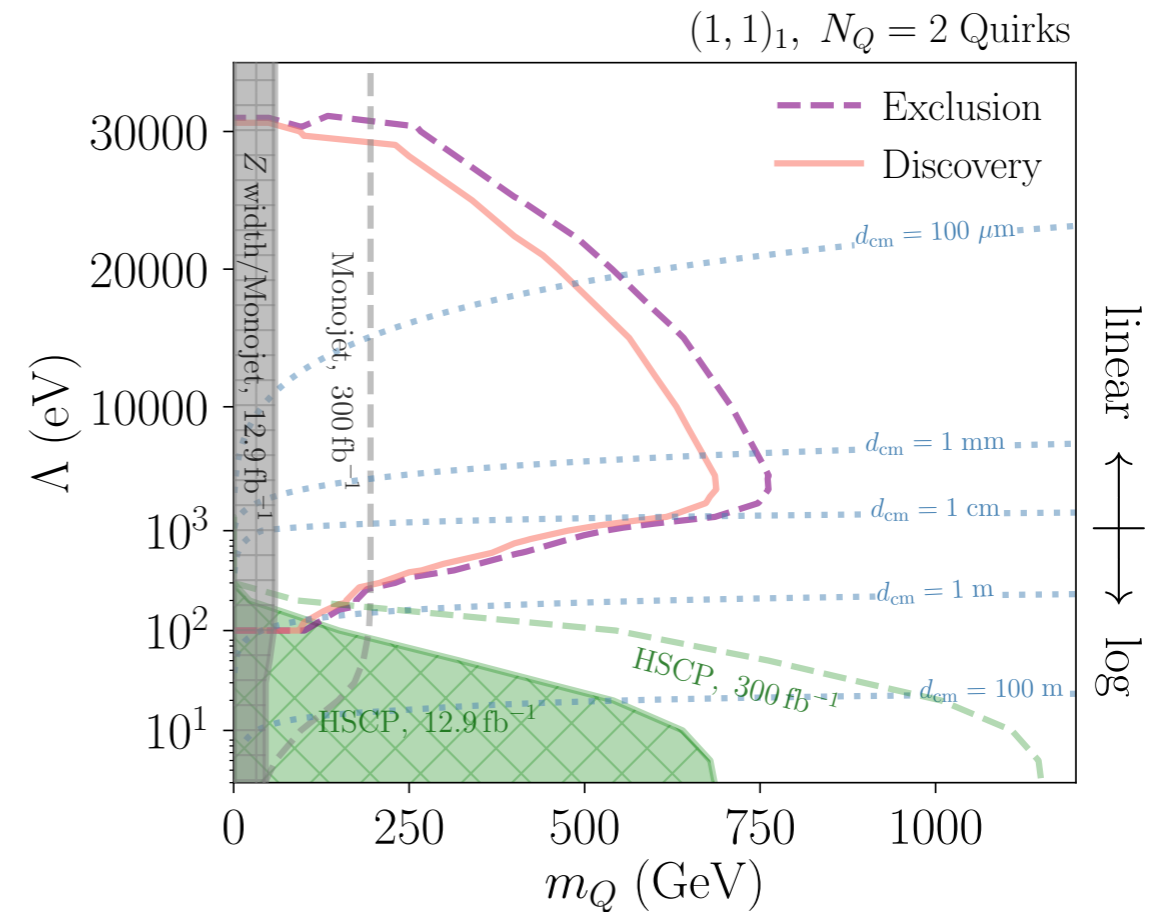
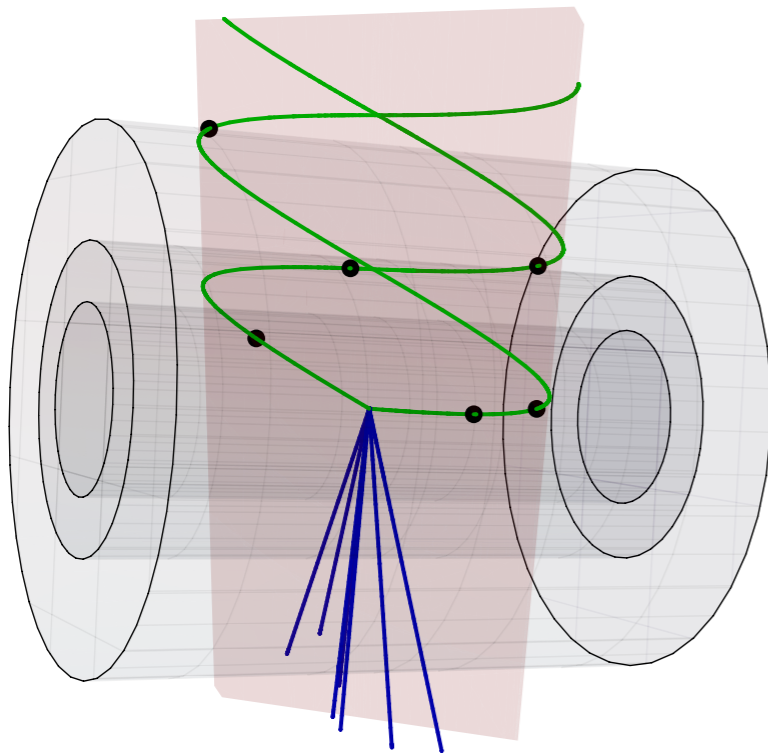
CMS could do this too, but maybe not needed?

Jakub Scholtz and James Beacham are looking at this

Quirks

See also M. Farina, M. Low: 1703.00912 & Jared's talk

Quirks trajectories lay in a plane

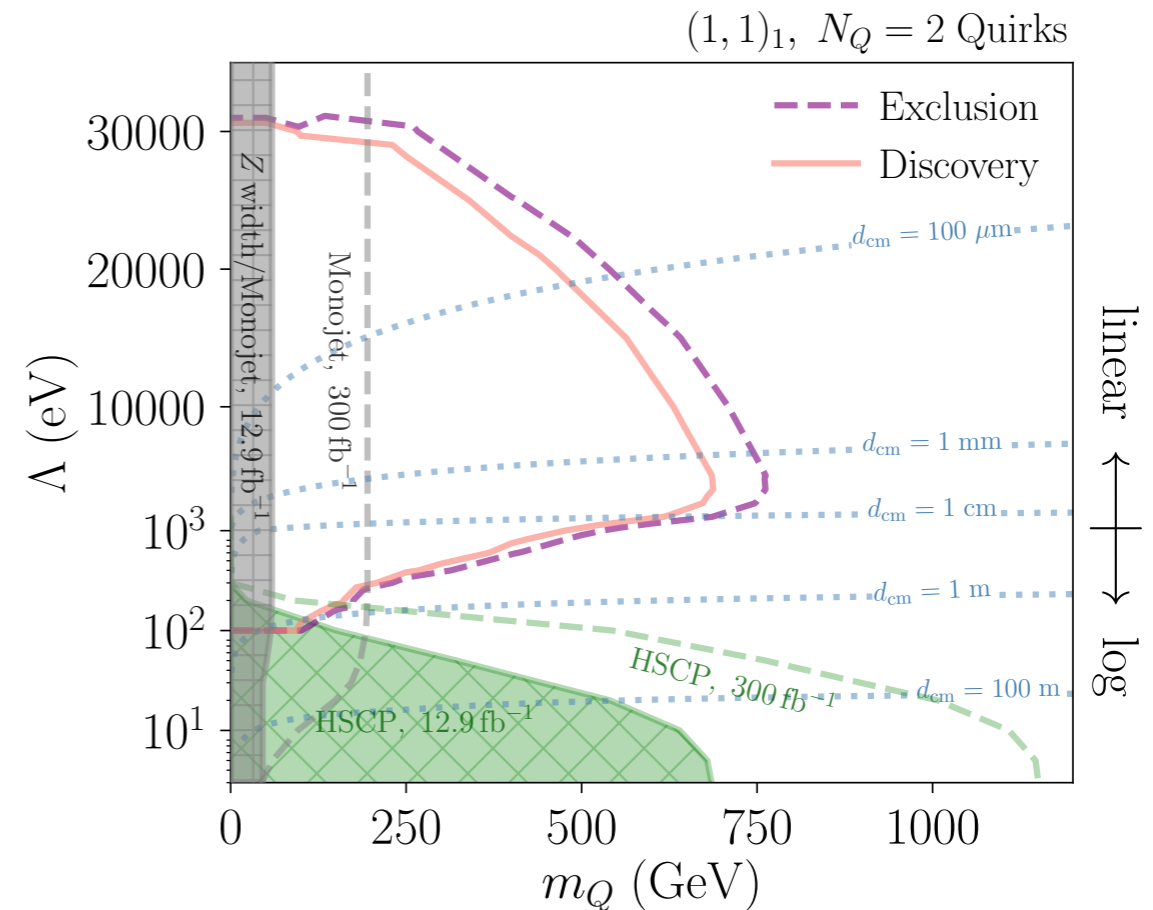
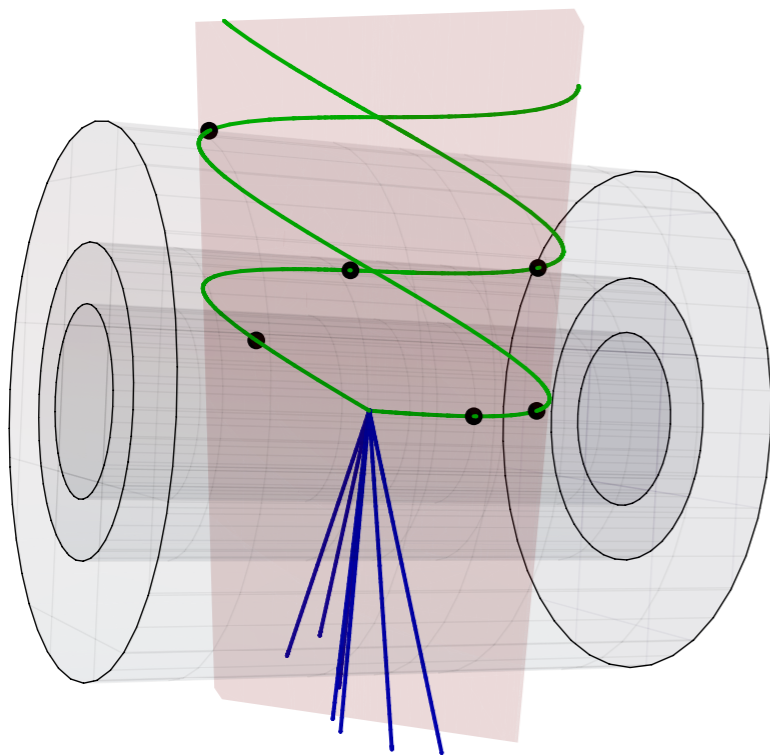


Trigger limitation: quirks too slow & not reconstructed as muons
 → rely on MET

Quirks

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Quirks trajectories lay in a plane



Trigger limitation: quirks too slow & not reconstructed as muons

→ rely on MET

Trigger on MET + μ in next bunch crossing (under study for slow HSCP's)

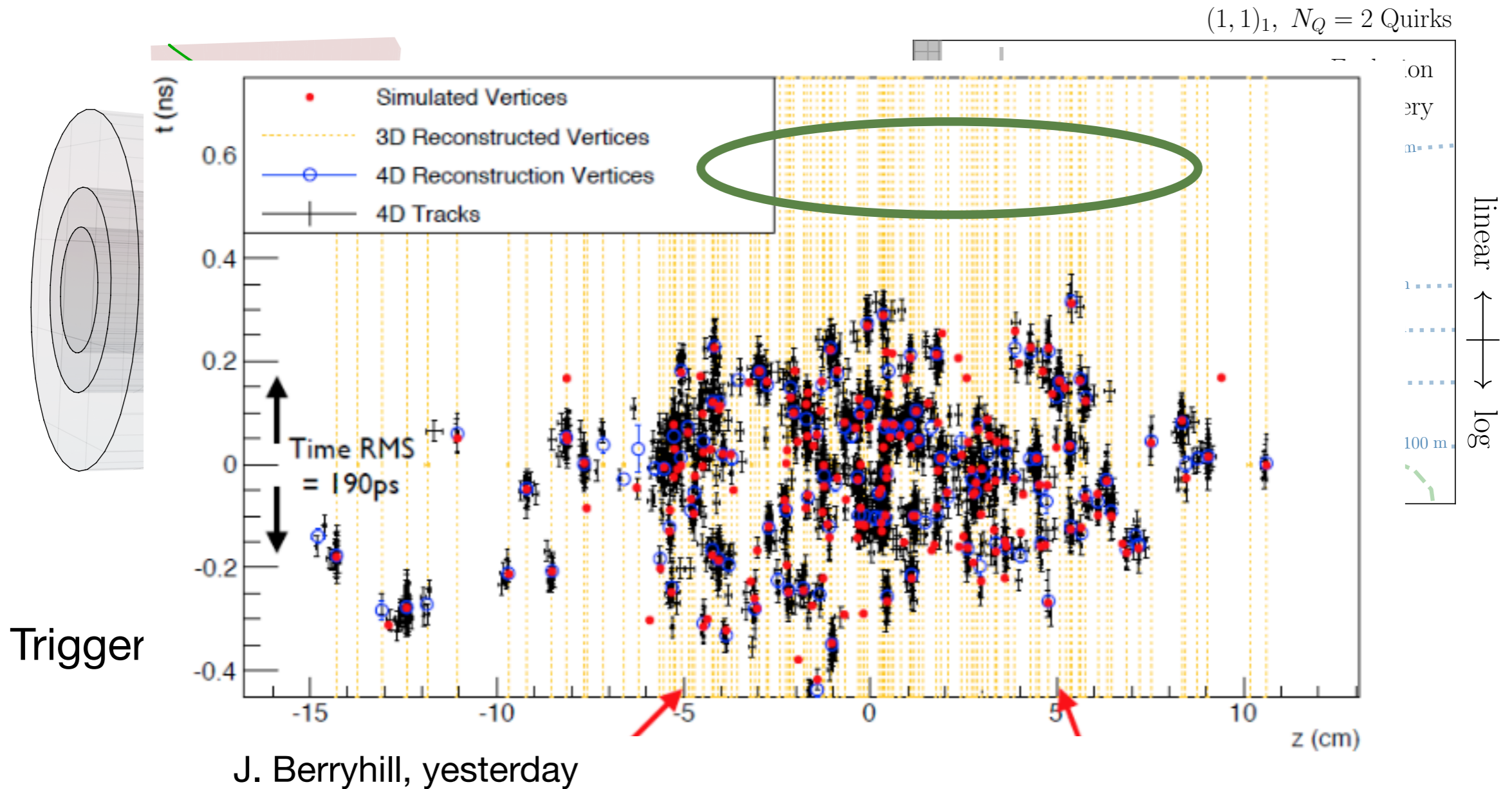
Mike Hance (ATLAS), LBNL 04/18/2017
CMS: 1609.02366

Can we avoid tight quality cuts on the “muon” tracks?

Quirks

See also M. Farina, M. Low: 1703.00912 & Jared's talk

Quirks trajectories lay in a plane



A useful role for the MIP timing layers?

Conclusions

Organizing trigger strategies for hidden valleys:

- **Associated objects** from production channel (leptons, jets)
- Higgs/photon mixing portals motivate **multi- μ + MET/H $_T$** combo triggers (but be careful with isolation conditions!)
- **ATLAS FTK, CMS HTT or pixel triggers** may make it possible to trigger on the softer, high multiplicity stuff

Probably provides good coverage, at the expense of some model dependence

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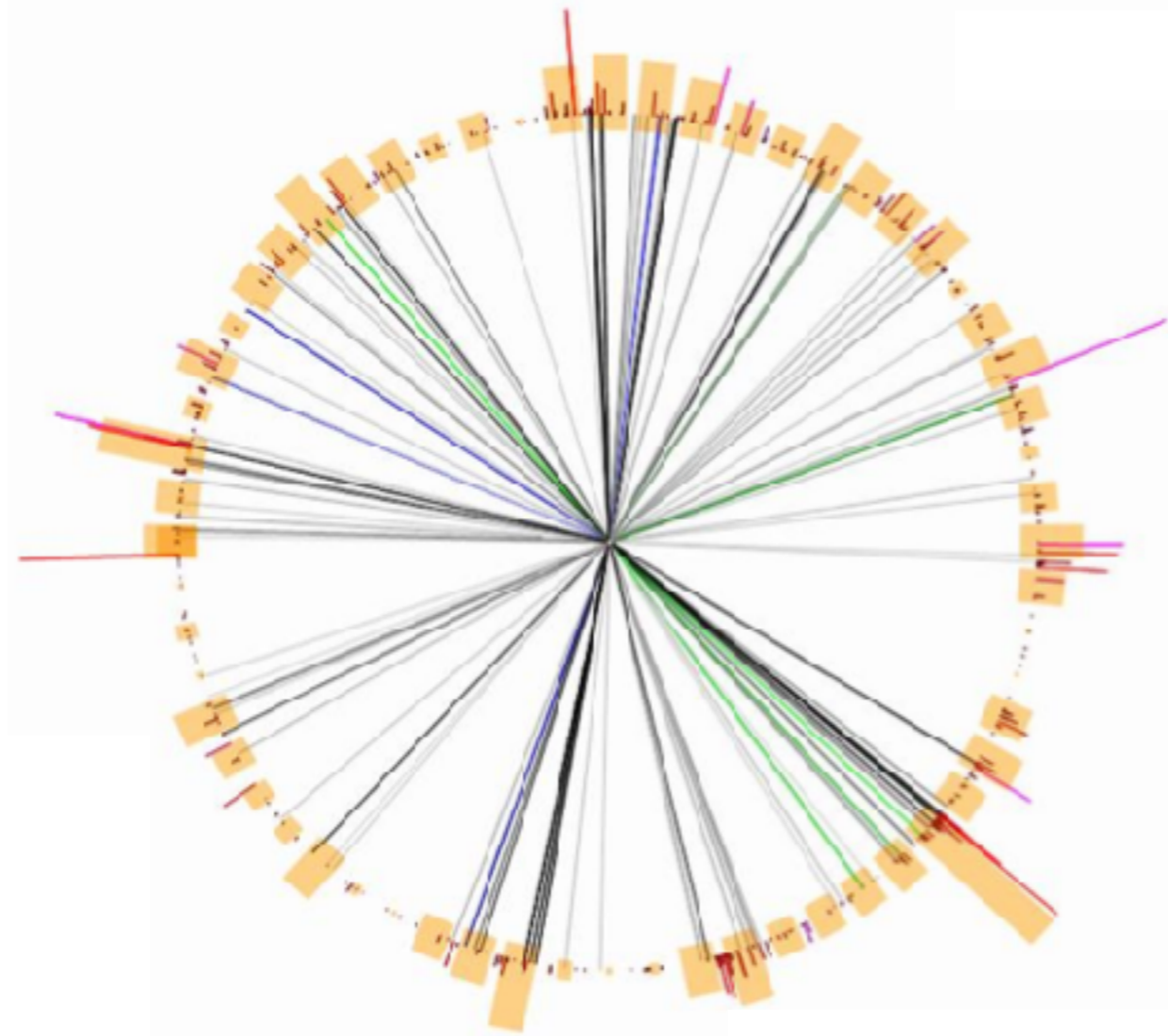
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To make quantitative proposals, theorists must estimate/guess trigger rates.

What are possible pitfalls, problems we should be aware off?

Thanks!



soft bomb/SUEP event, image by Matt Strassler