Quirks and their Unusual LHC Signals

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past and ongoing works with
G. Burdman, Z. Chacko, H.S. Goh
and T. Wizansky.
+
Advertising ongoing work by Luty et al.

Outline

* Quirks:
  - What are they?
  - Why think about them?
* Signals in two cases:
  - Very long strings - anomalous muon tracks.
  - Short strings and Folded SUSY
    - resonances and anomalous UE's.

Quirks

* Consider a new strong force

$$SU(3)_c \times SU(2)_L \times U(1)_Y \times SU(N)$$

QCD'

* Matter:

$$q' = (\text{SM quantum numbers}, \mathrm{N})$$

If $\Lambda_{\mathrm{QCD'}} \ll m_{q'}$

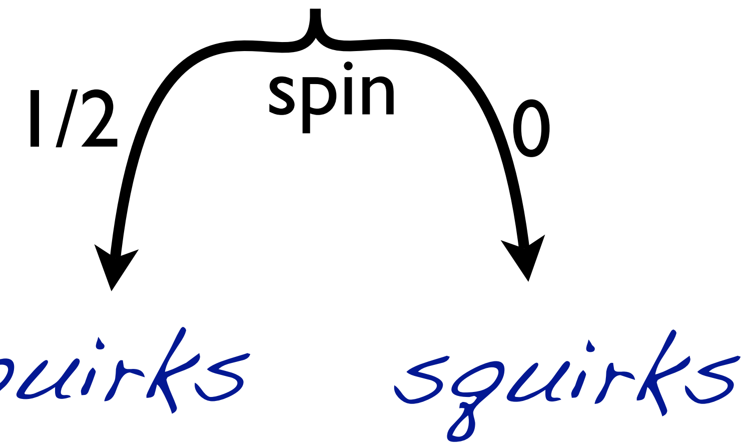
⇓

q' is a **Quirk**

Types of Quirks

* We can categorize quirks

$$q' = \left(\text{SM quantum numbers}, \mathrm{N} \right)$$

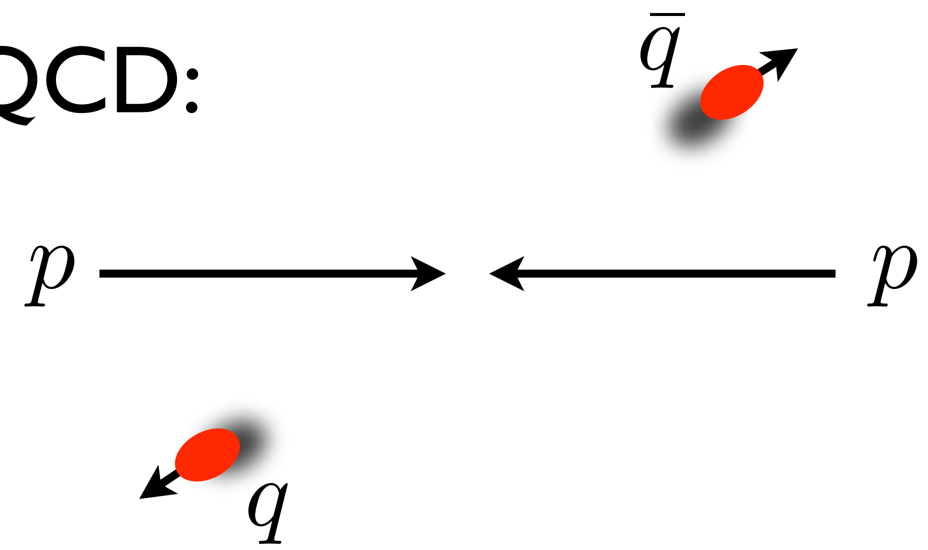


Colored or **Non-colored**
(under our QCD)

important for production, etc.

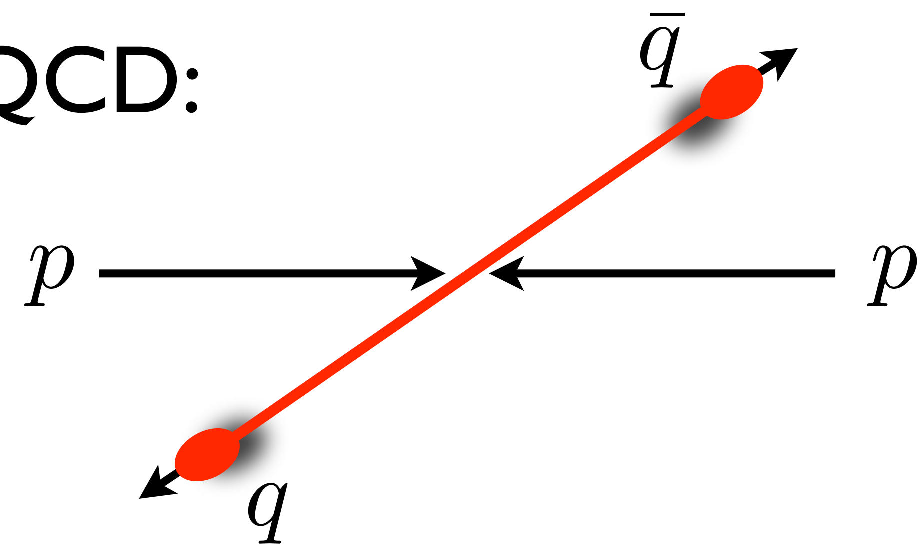
Quirky Dynamics

* In regular QCD:



Quirky Dynamics

* In regular QCD:



Quirky Dynamics

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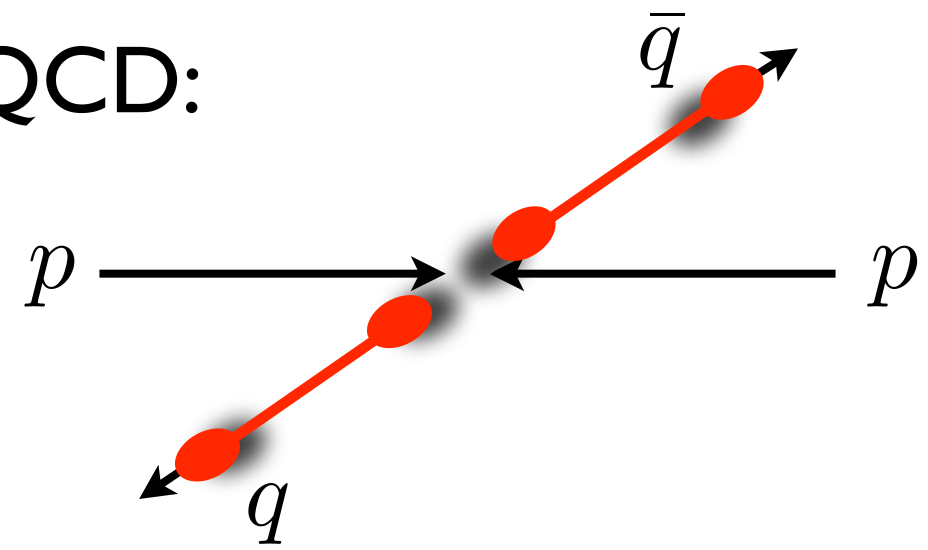
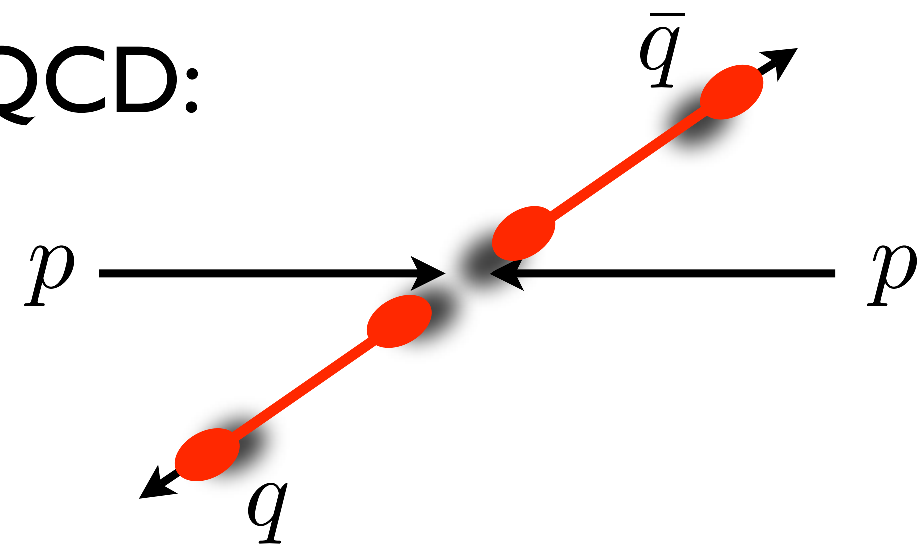
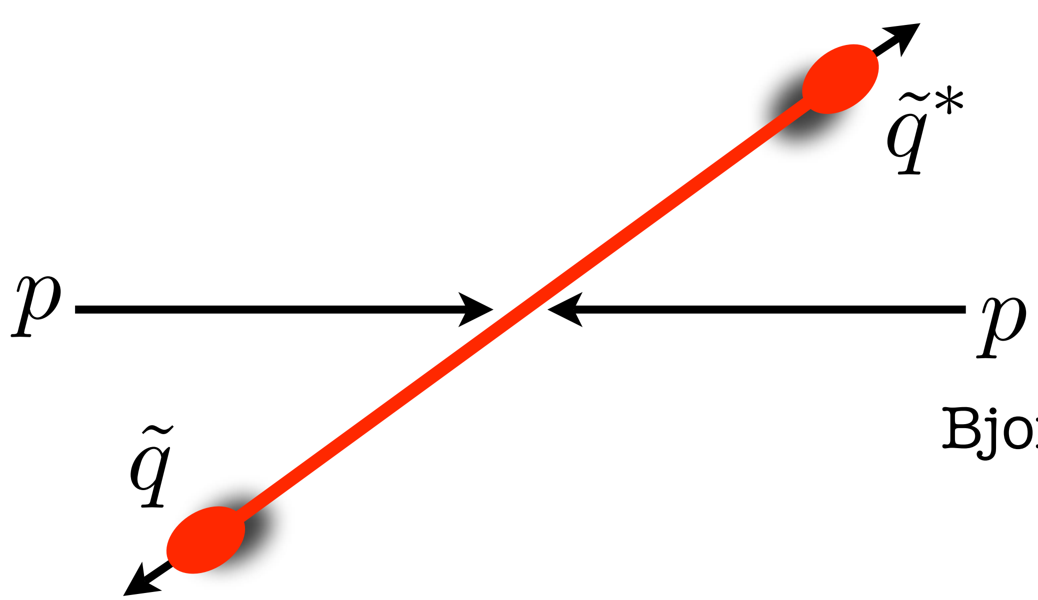


Quirky Dynamics

- In regular QCD:



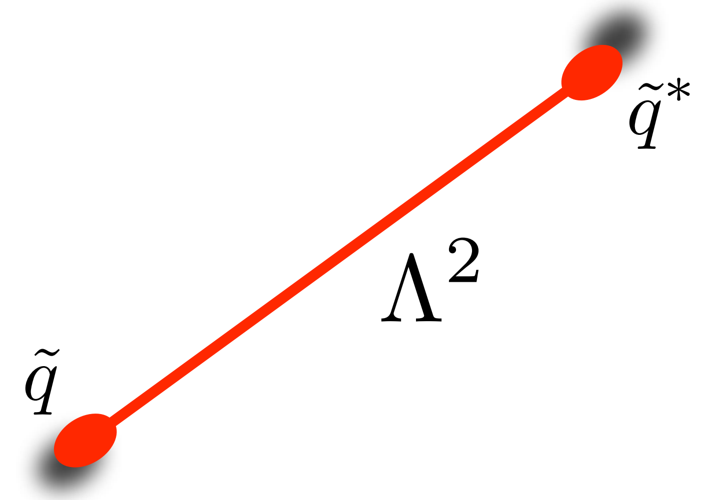
- In “quirky QCD” this costs too much energy. squarks’ are produced and **remain bound**!



Bjorken (79), Quinn and Gupta (81),...
Strassler and Zurek(06)
Luty et al. (08+)

Quirky Dynamics

* Now what?
  Quirks will loose kinetic energy to string tension.



* Energy conservation:

production $\quad E_k = \sqrt{\hat{s}} - 2m_{q'} \sim m_{q'}$

turning point $\quad E = \Lambda^2 l_{max}$

$$l_{max} \sim \frac{m_{q'}}{\Lambda^2}$$

can be very long!

Examples:

* Lets consider two extreme choices for Λ

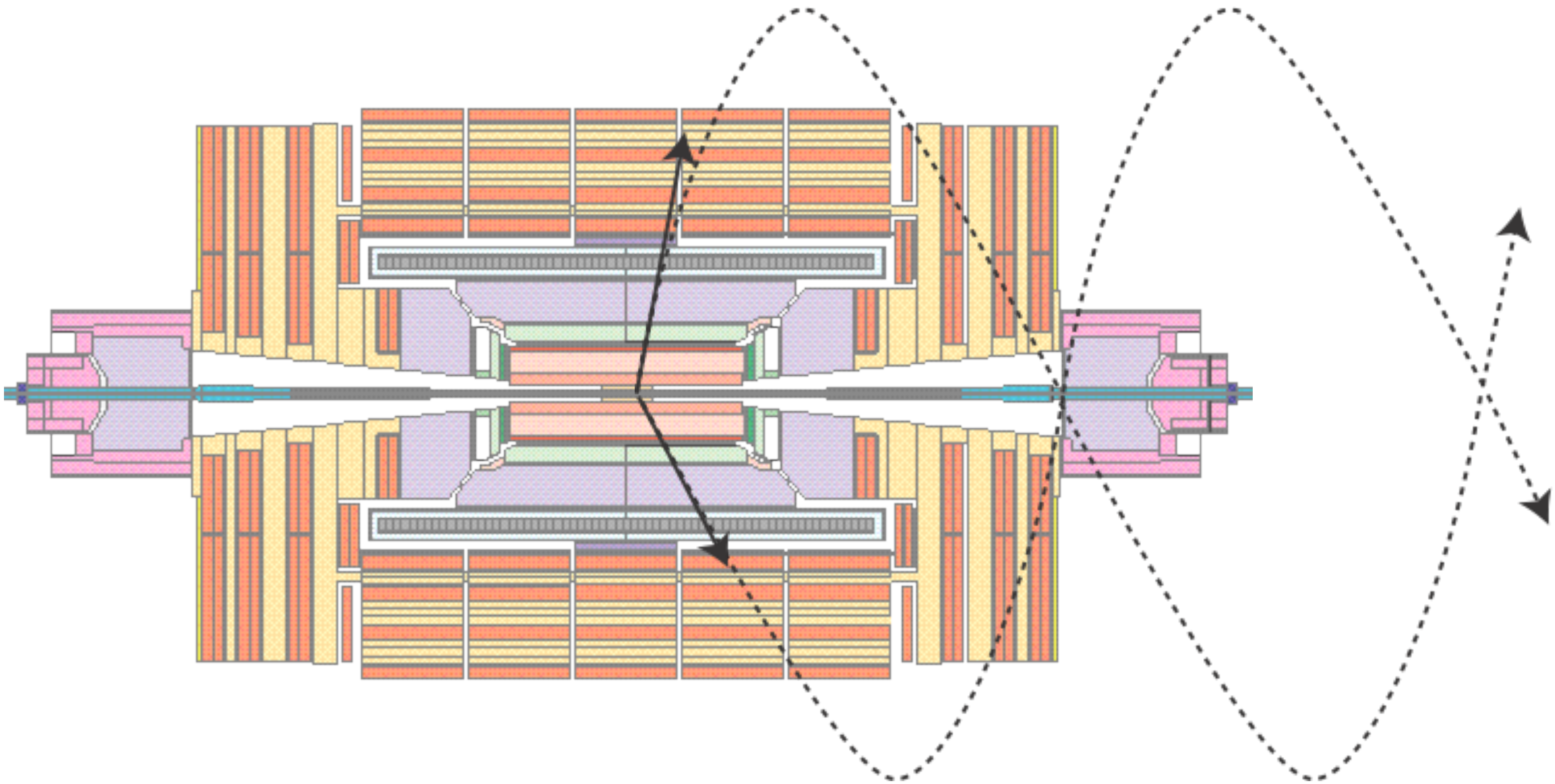
$\Lambda \sim \text{few eV}$	$\Lambda \sim \text{few GeV}$
$l_{max} \sim \text{meters}$	$l_{max} \sim \text{few fermi}$
Loooong strings	Excited bound state
Weird muon tracks.	Resonance. Soft radiation.

motivated by a model for hierarchy

Looooong Strings.

Long Strings

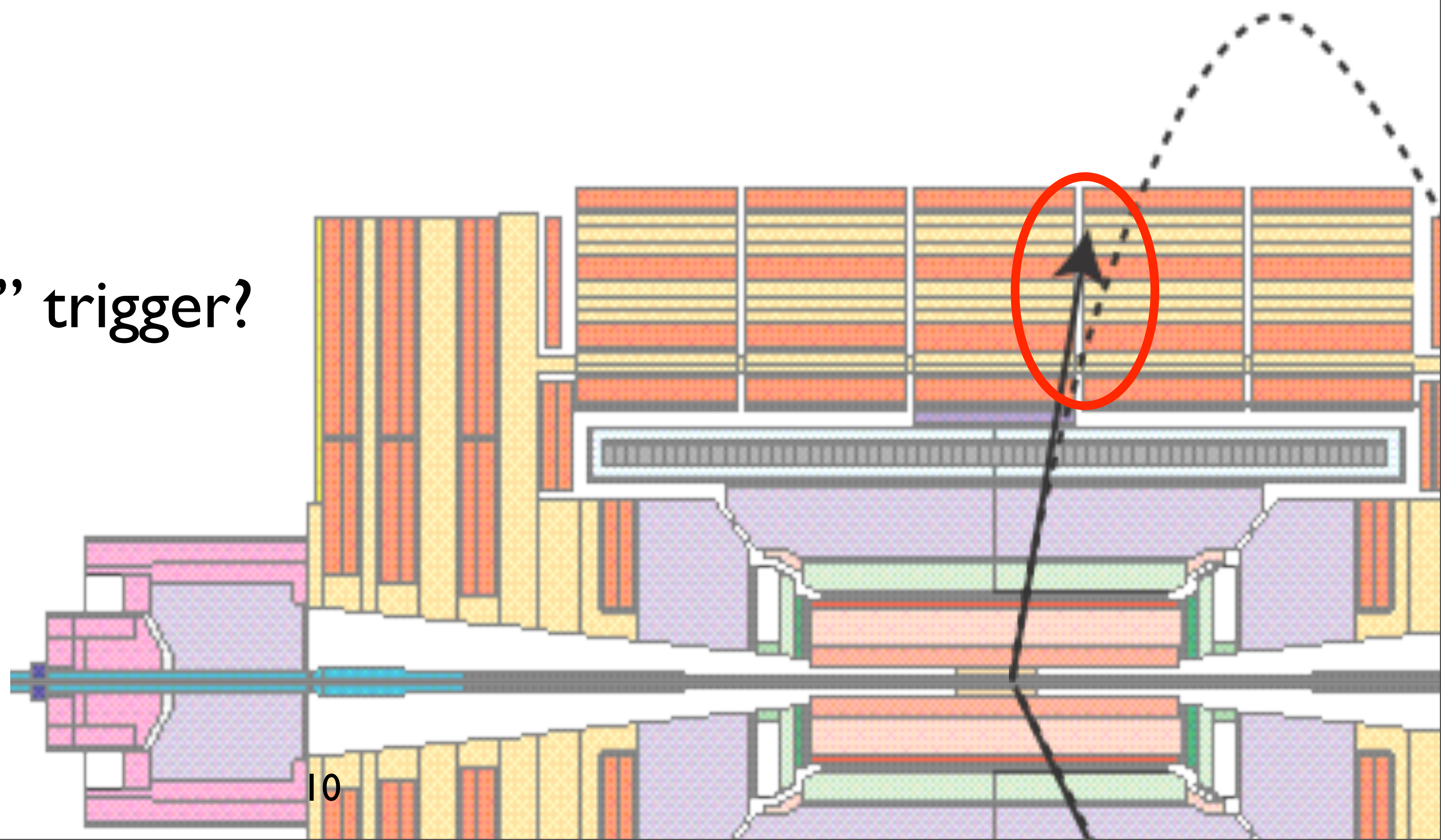
* Each end hadronizes separately.
  Assume a charged hadron.



A striking sginal:
Two “connected muons”.

Triggering

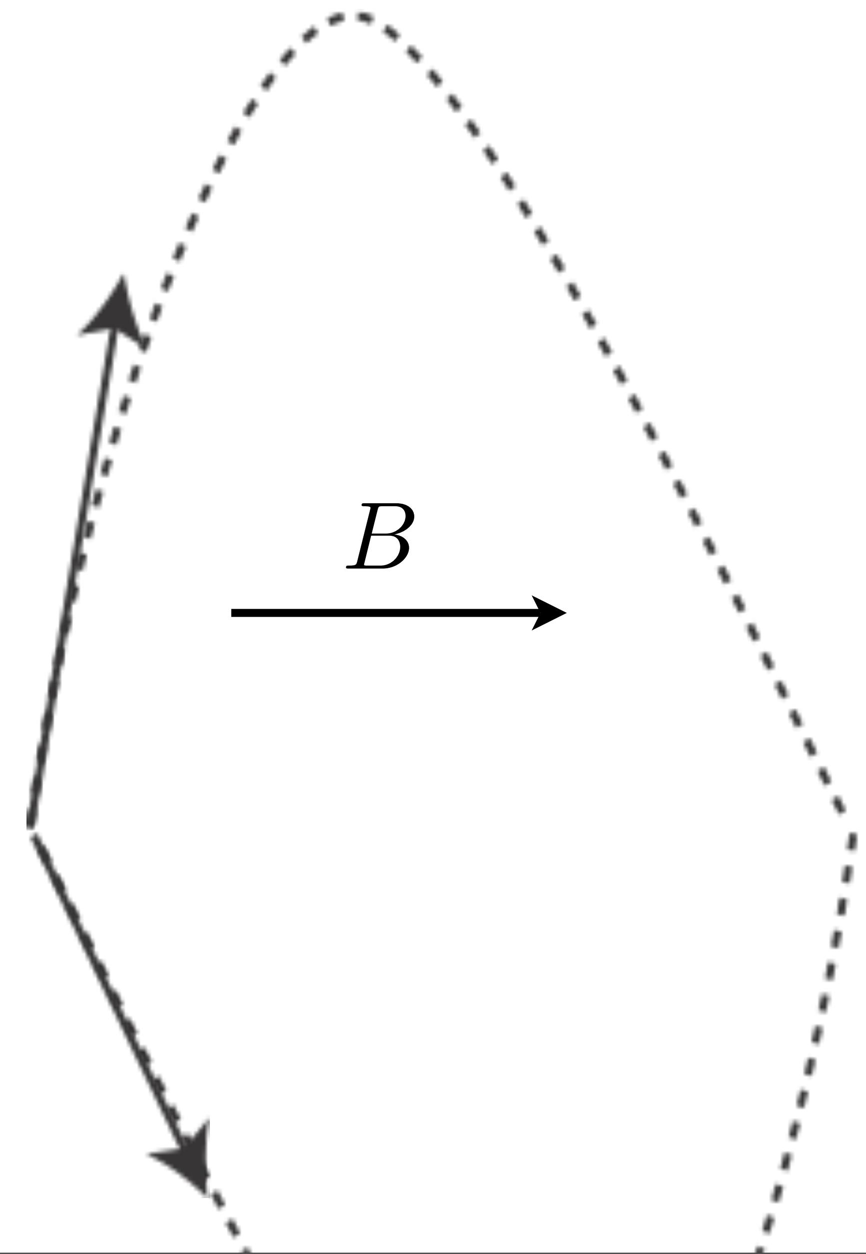
* Naively, this will pass a muon trigger.
* But, track curvature and direction is not consistent with a muon coming from the interaction point. **May fail LVL2**.
* Possibilities:
  - Slow muon?
  - "Stable stau" trigger?
  - Timing?



Triggering

* An interestin possibility:
  Trigger events with tracks curving **along** the magnetic field.

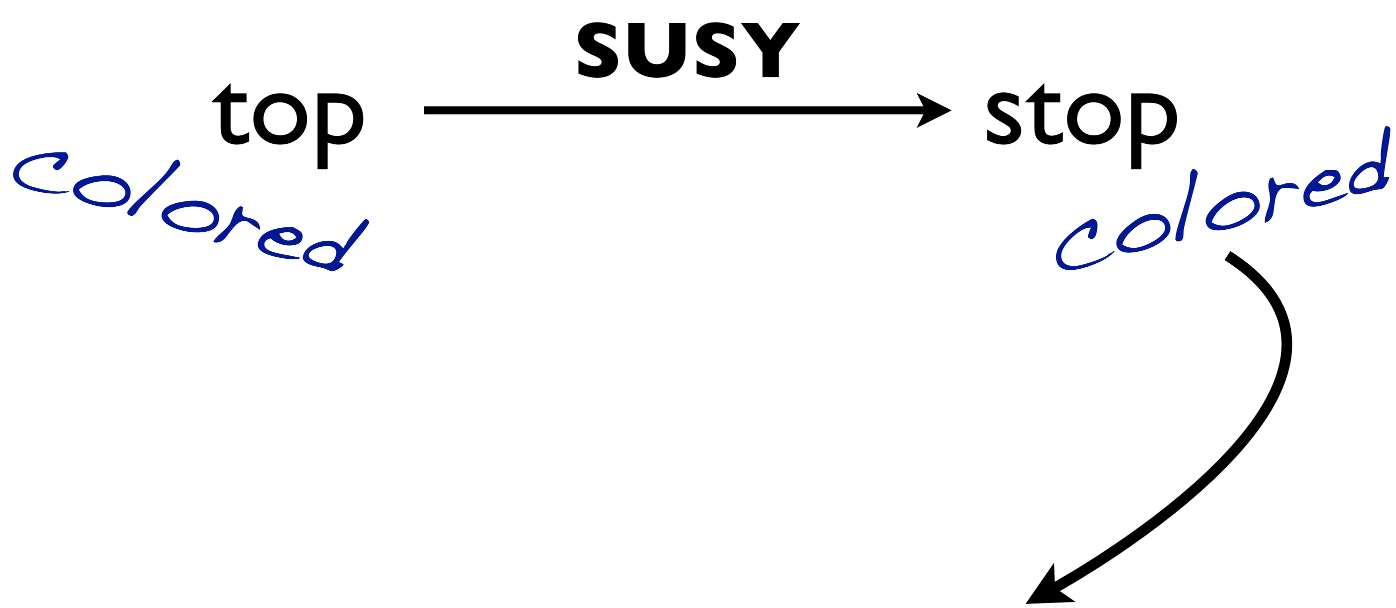
Anything that does this is exotic and worth keeping. (Unless its noise?)



Microscopic Strings.

Model Building

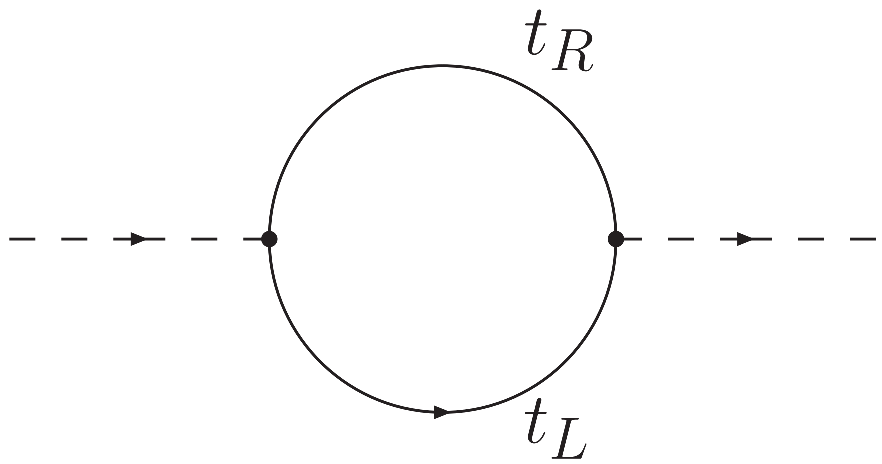
* The hierarchy problem suggests a new symmetry.



A huge impact on
collider phenomenology!

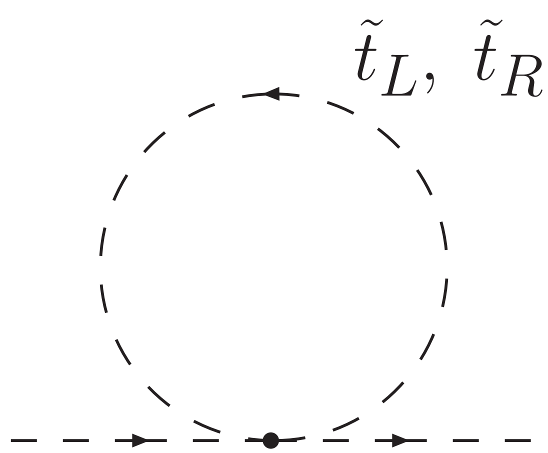
Can squarks be uncolored?

Just a Factor of 3



Standard Model

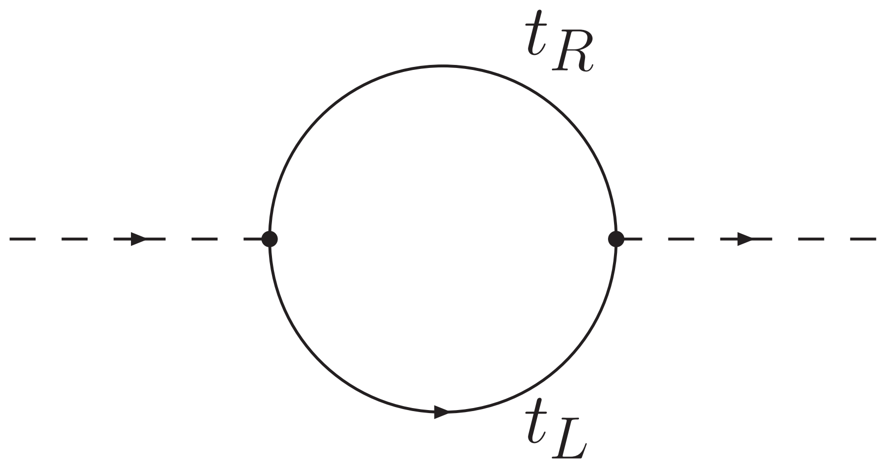
$\times 3$



Supersymmetry

$\times 3$

Just a Factor of 3



Standard Model

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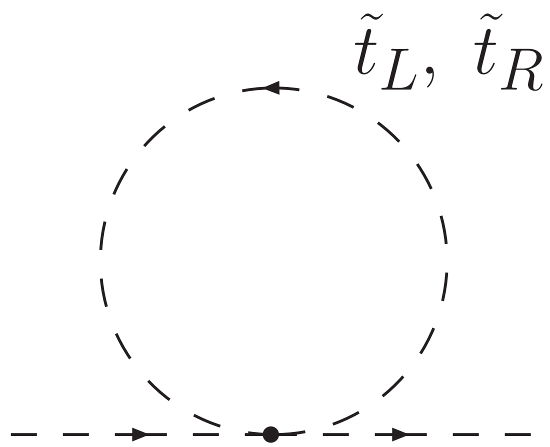


Supersymmetry

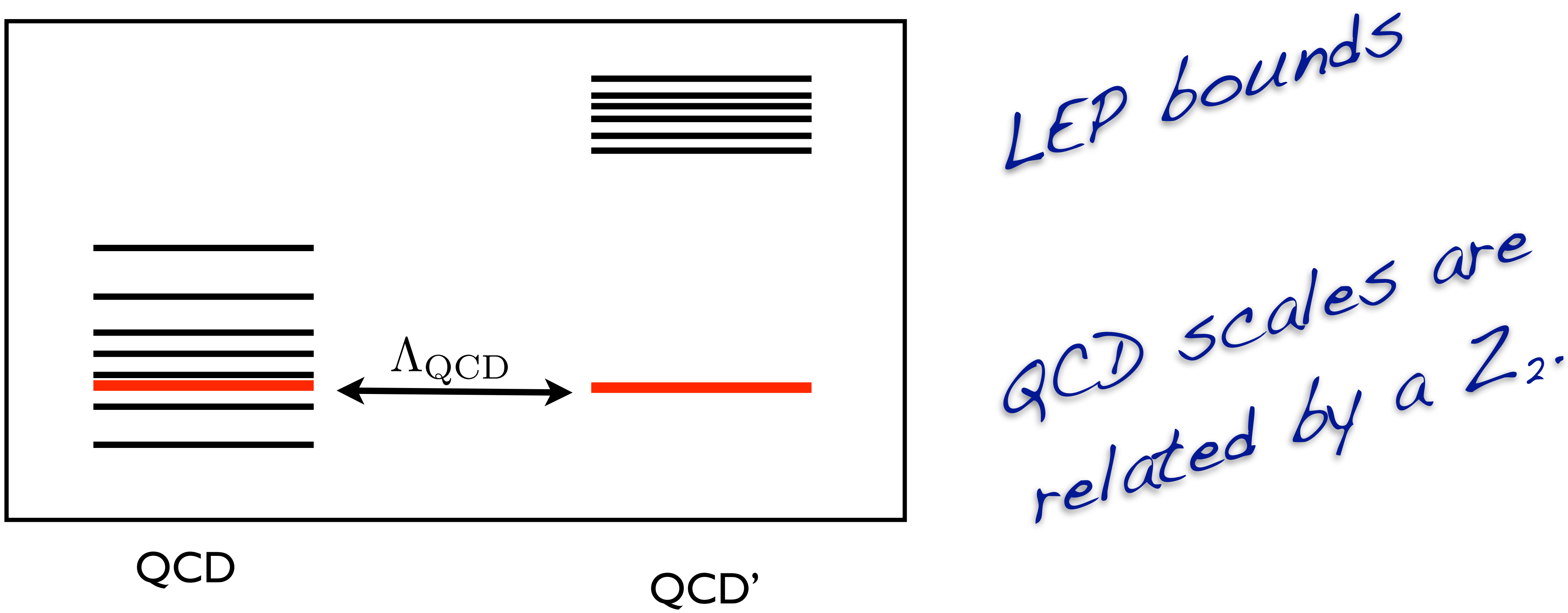
$\times$ ~~3~~ 3'

Folded SUSY

(Burdman, Chacko, Goh, RH)

Hierarchy solved by squirks!

Folded SUSY



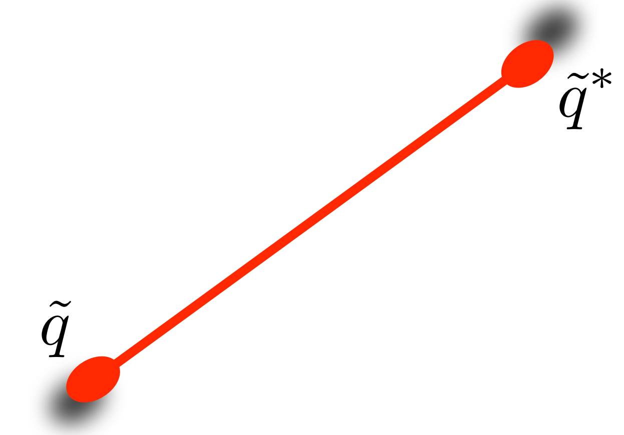
* Motivates both colored and non-colored (s)quirks. e.g.

$$\tilde{q}_L = (1, 2, 3)_{1/6}$$

under $SU(3)_c \times SU(2)_L \times U(1)_Y \times SU(N)$

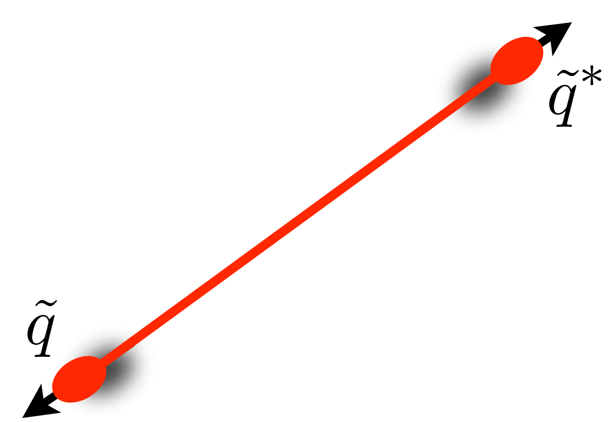
Quirky Dynamics

* The squirks eventually stop.
  come back.
  oscillate.

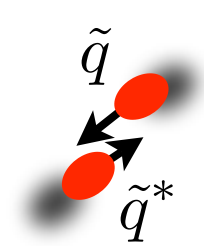


* This system will loose energy by radiation.

$$\omega \sim \frac{\Lambda^2}{m_{\tilde{q}}} \ll \Lambda \sim m_{\text{glue}}$$



Soft:
photon dominated



Hard:
glueball dominated.

(decreases with impact parameter!)

Photons vs. Glue

* Can we guesstimate $E_\gamma / E_{\rm glue}$?
  - Suppose the photon was massive: $m_\gamma \sim m_{\rm glue}$

    We'd expect $\dfrac{E_\gamma}{E_{\rm glue}} \sim \dfrac{\alpha(m_\gamma)}{\alpha_{s'}(m_{\rm glue})} \sim \dfrac{1}{20}$.

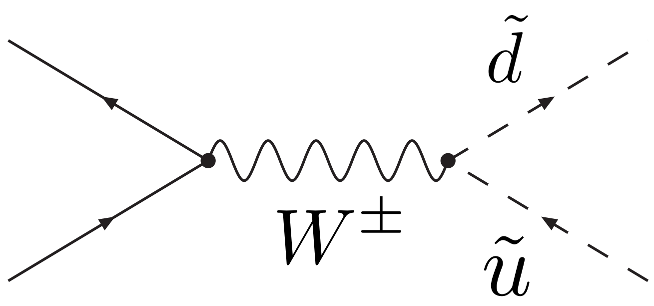
  - **But** photon does not have a mass!
    The kinematic suppression due to the mass depends on impact parameter and energy. May easily be a factor few

$$\frac{E_{\rm soft}}{E_{\rm hard}} \sim \frac{m_{\tilde{q}} \Lambda^2 b^3}{\alpha_{s'}^2}$$

Settle for 10%

An Event

* Consider squirk production via a W:



An Event

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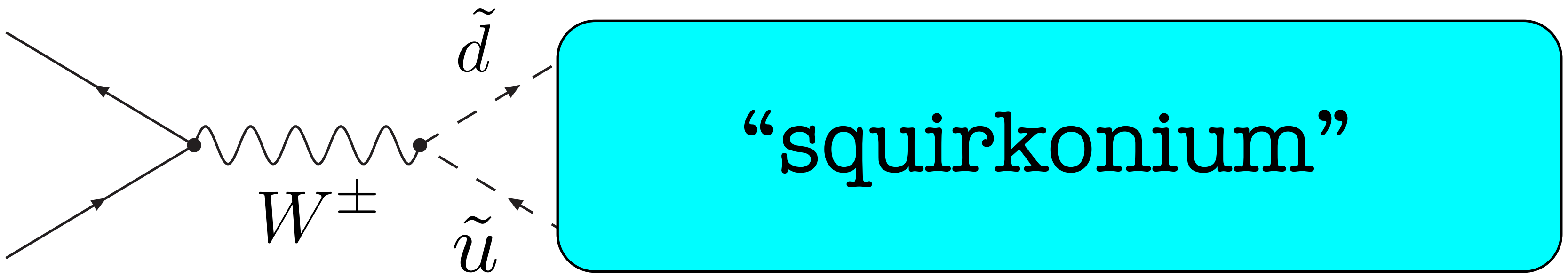
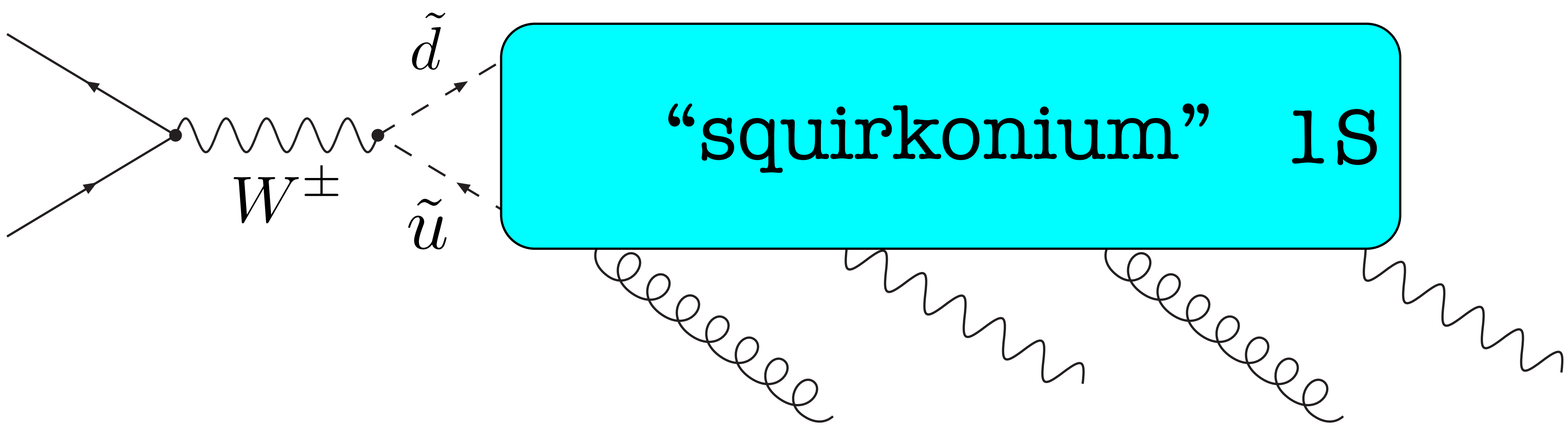


An Event

* Consider squirk production via a W:



An Event

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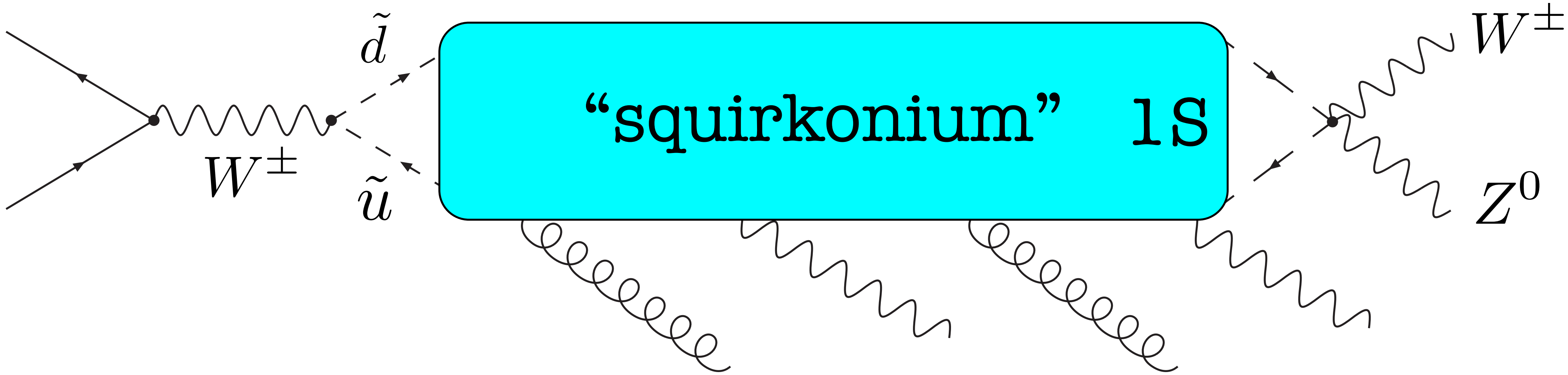

An Event

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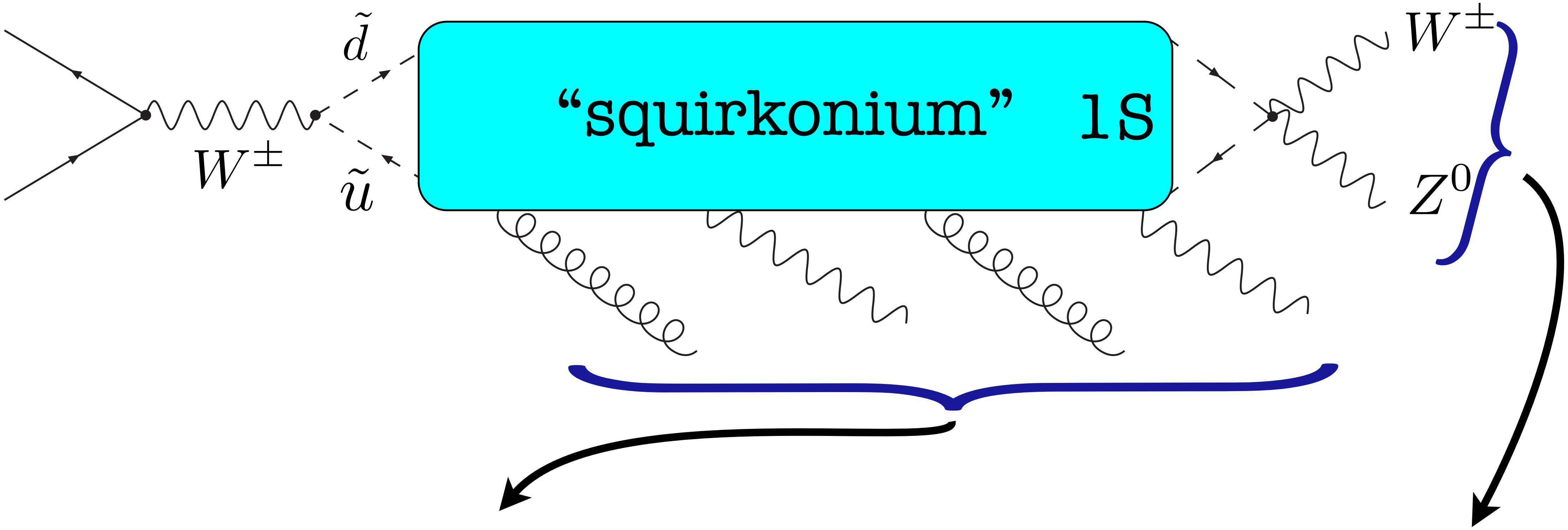


Soft radiation of **photons** and (hidden) glueballs

A **peak** in the invariant mass of W+Z

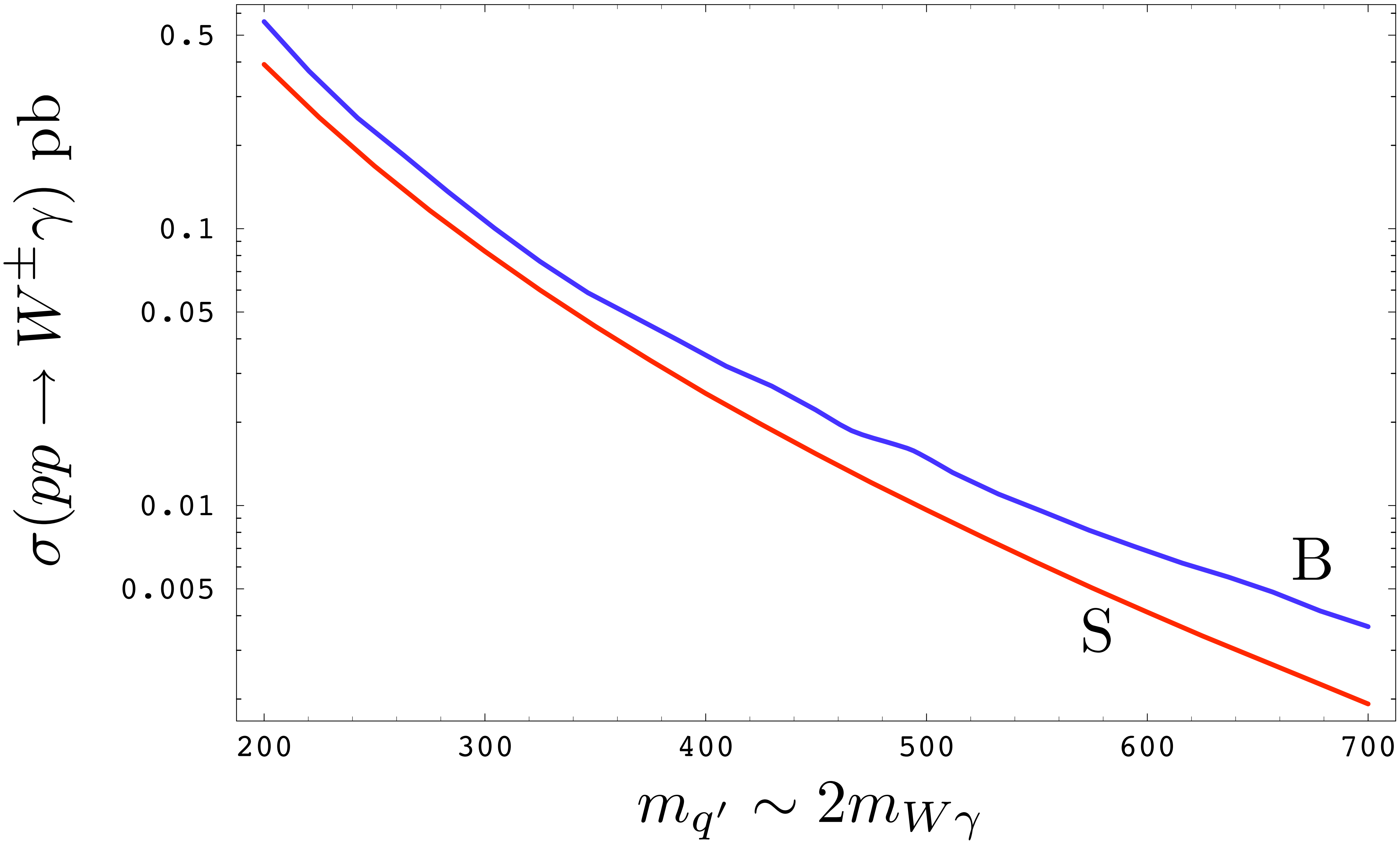
$$m_{WZ}^2 = m_{1S}^2 \sim 4m_{\tilde{q}}^2$$

Ongoing work w/ Wizansky.

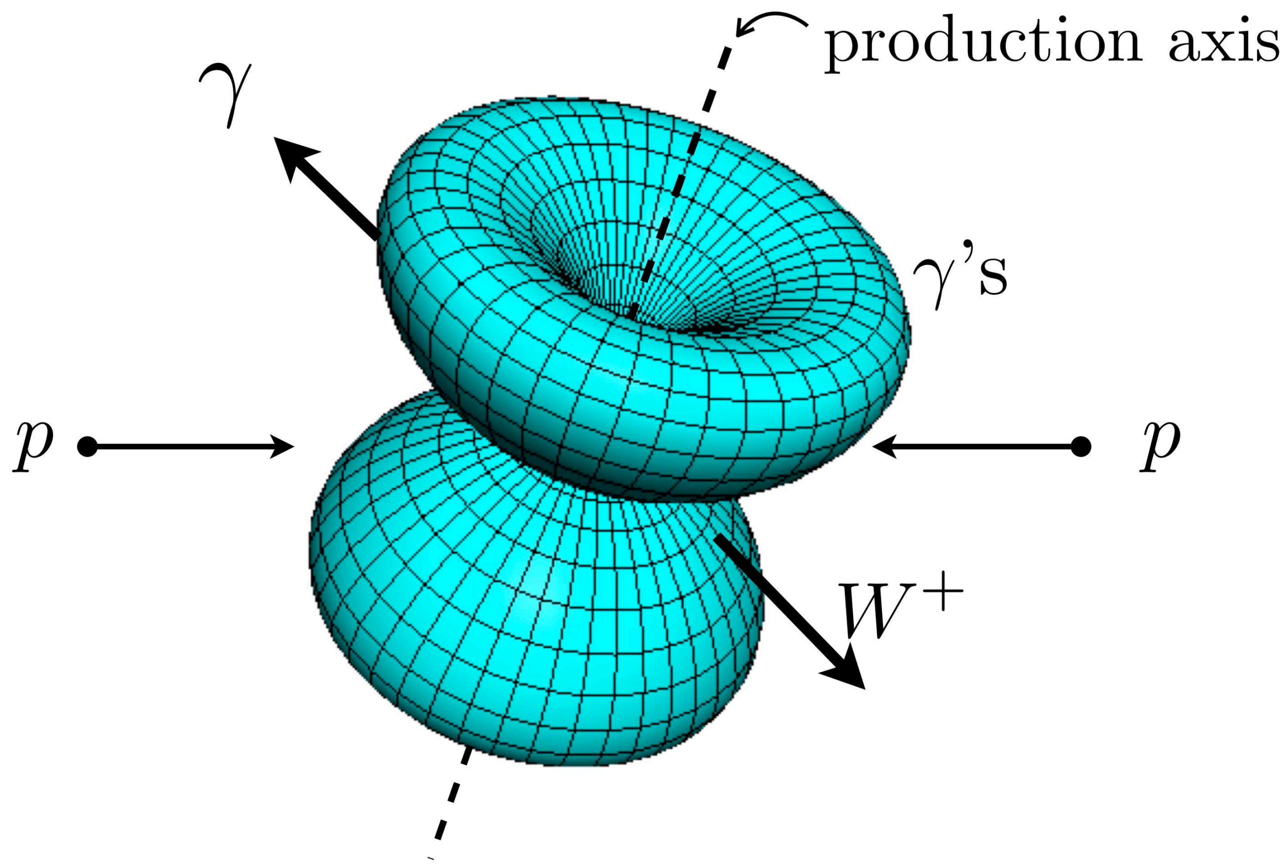
Ongoing work w/ Burdman et al

Annihilation

* Annihilation to W+photon: S/B~1 (before η-cut)



An Event

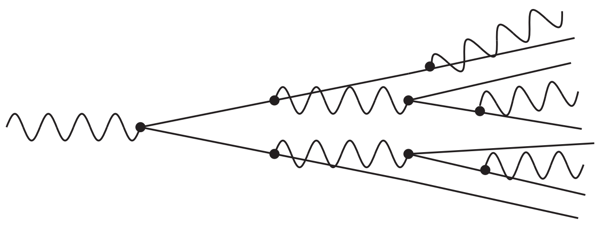


$$E_\gamma \sim \frac{\Lambda^2}{\sqrt{\hat{s}}} \sim \frac{\Lambda^2}{m_{\tilde{q}}}$$

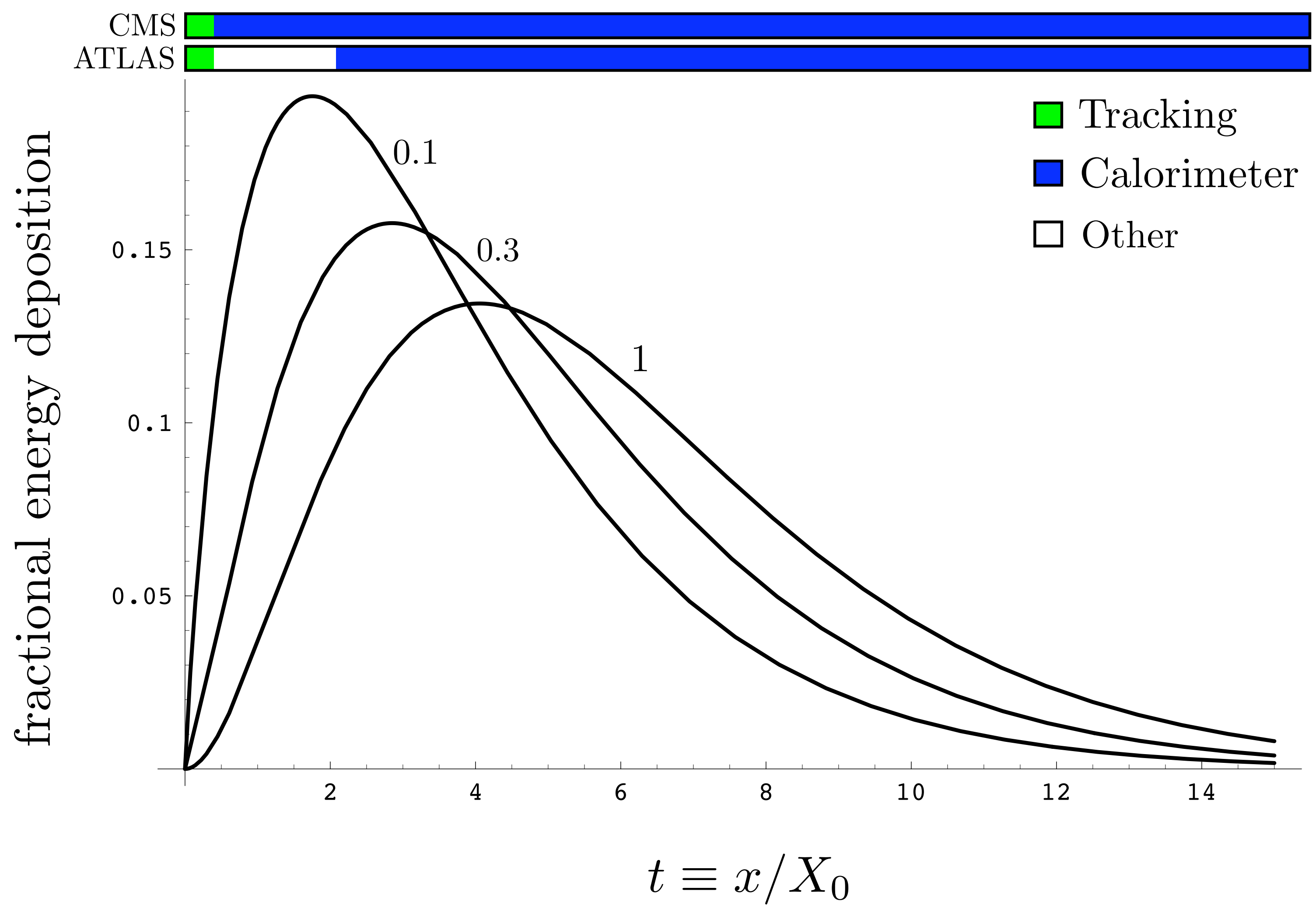
$$\sim 0.1 \text{ - } 1 \text{ GeV}$$

Can we see such soft photons?
Can it compete with the Underlying Event?
Is the "antenna pattern" visible?
(This is not what the detectors were designed for!)

EM Showers

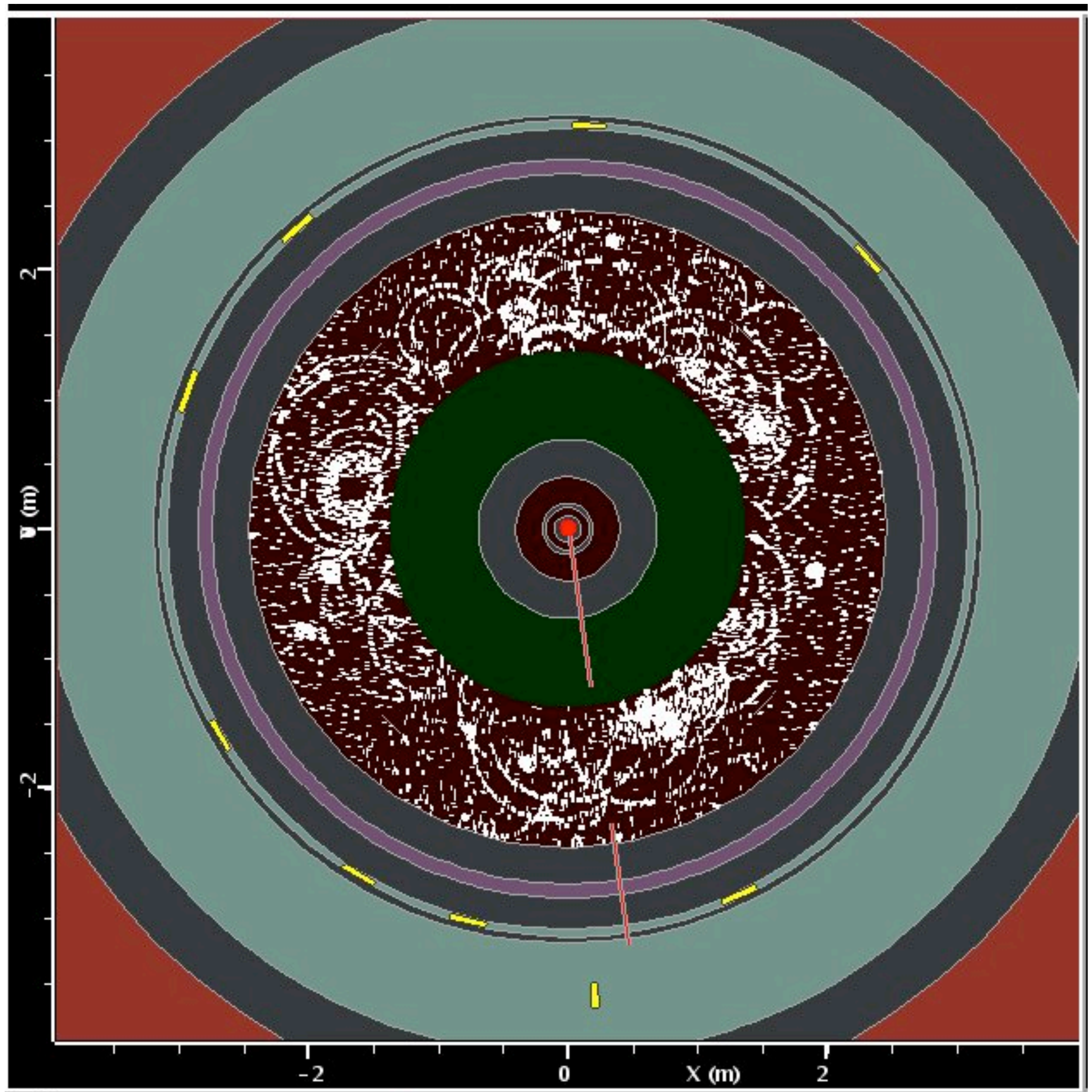


- Estimate:
  - ~30% of photons convert to electron-positron pairs in tracking system.
  - ~50% of energy reaches Ecal.



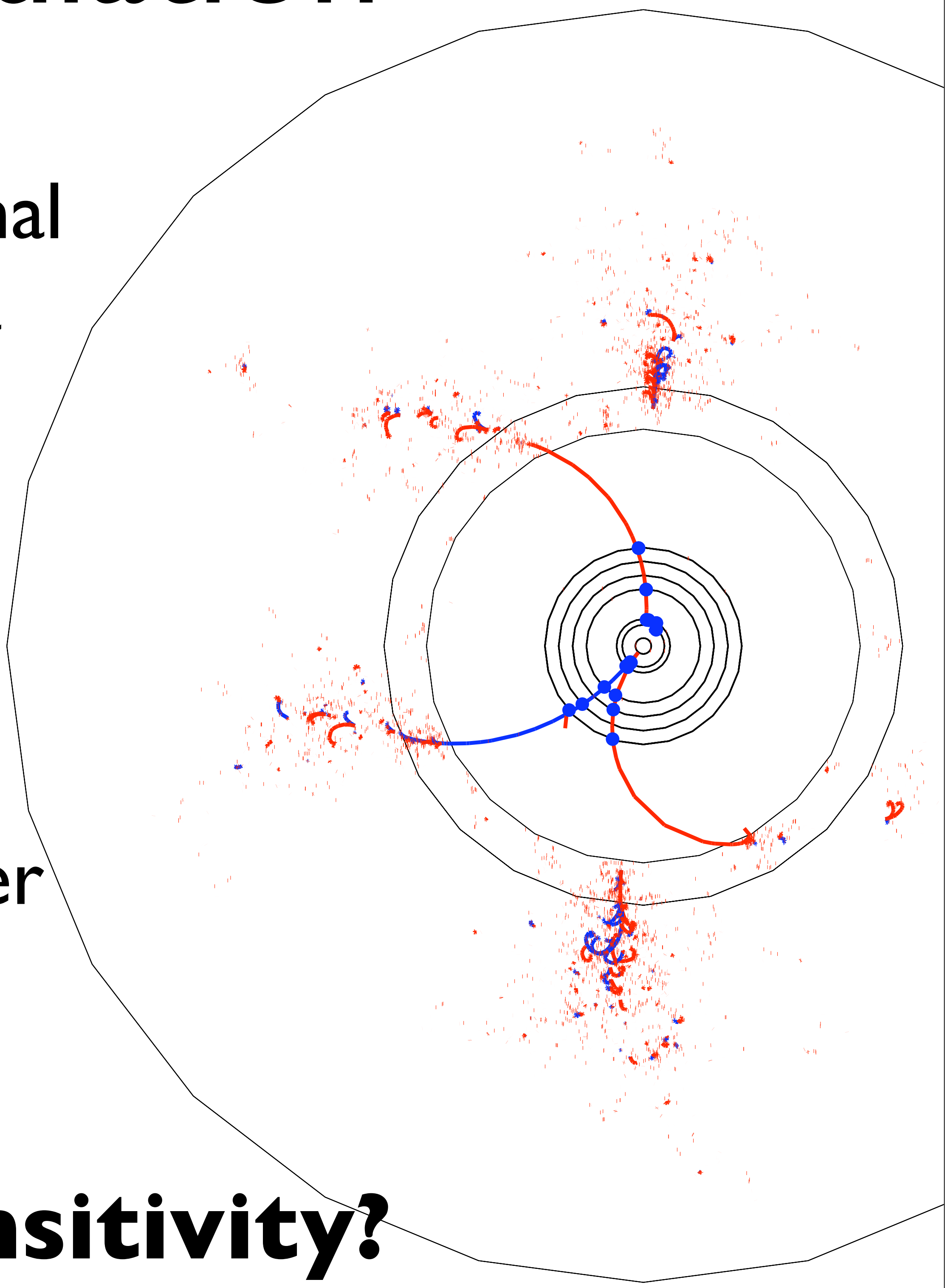
Possible Signals:
1. High charge track multiplicity
2. Calorimetric Signal

Tracking Signal



Cheu and Parnell-Lampen (ATLAS)

“Detector Simulation”

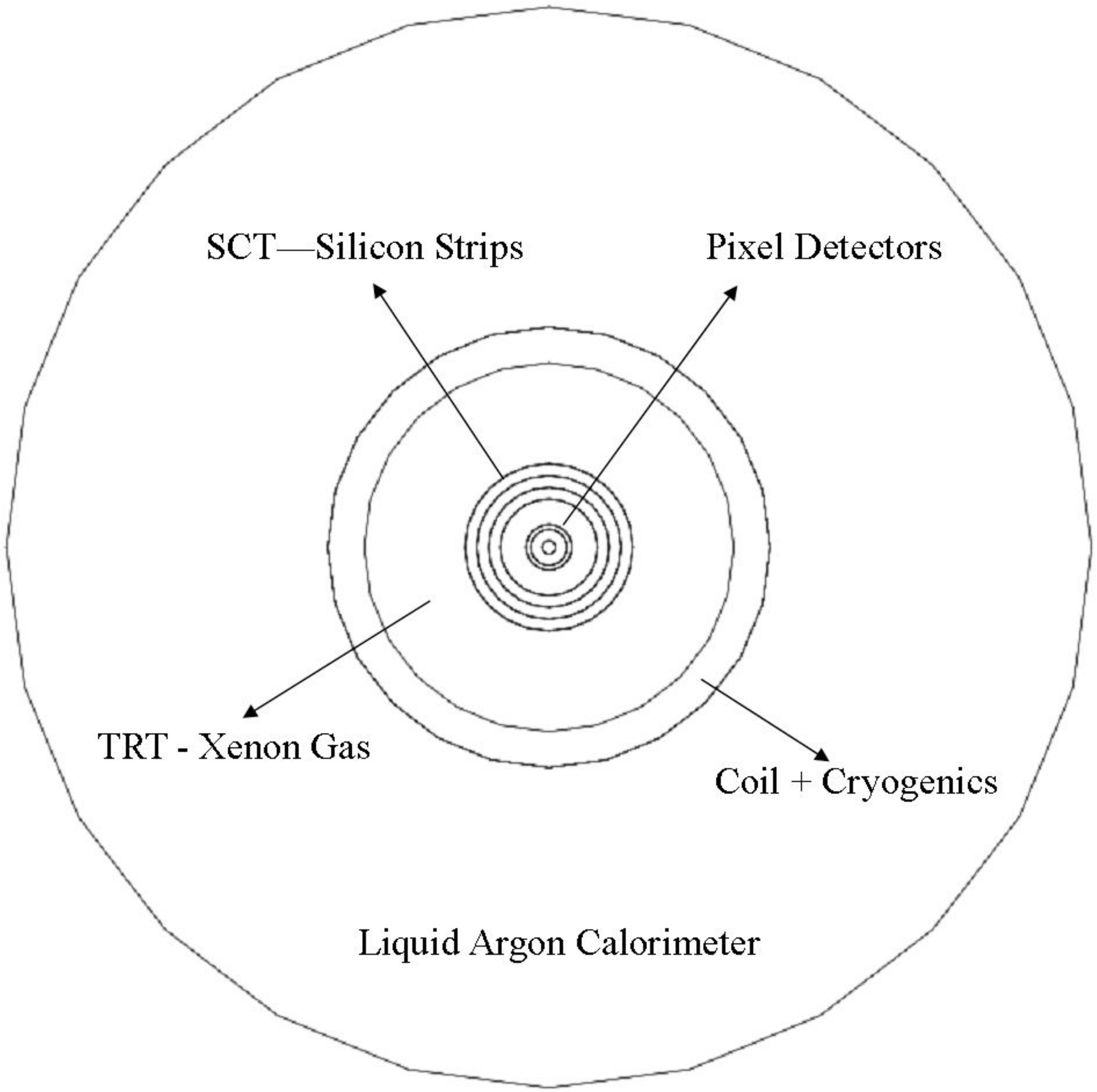


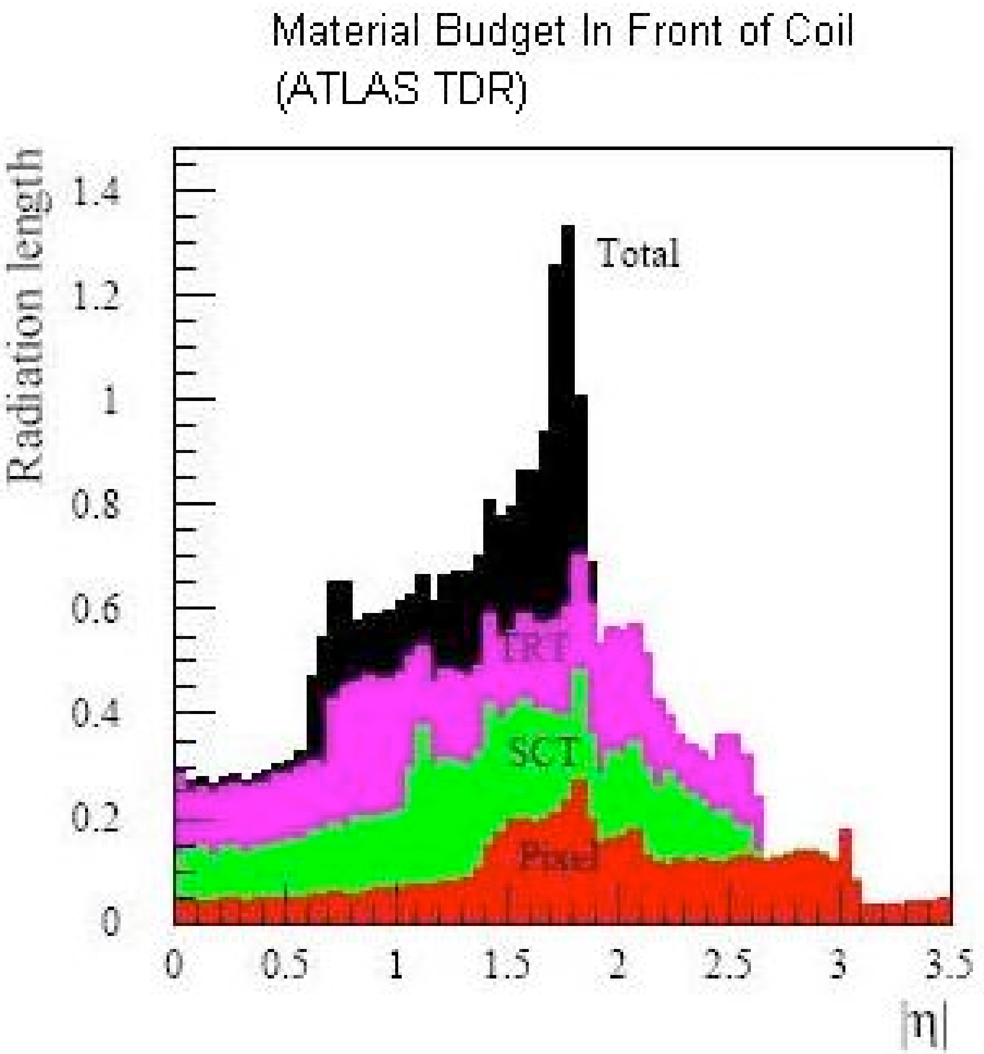
* We simulated the photon signal according to a simple antenna model.
* Analyze soft photons with a dedicated simulation of a “toy detector” (using GEANT4).
* Take $E_\gamma/E_{\rm glue}$ as a parameter (can change event by event).

what is the sensitivity?

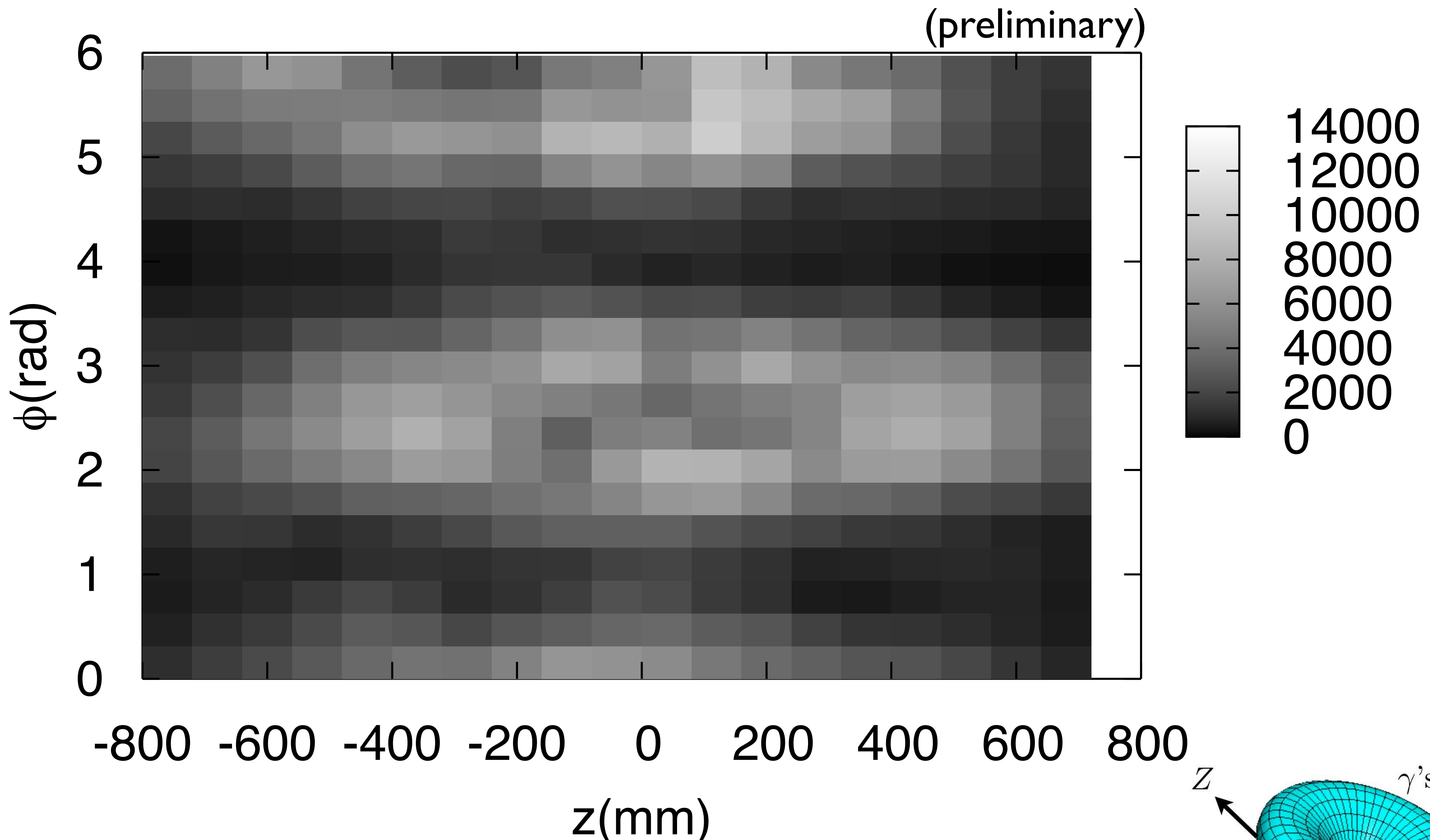
what are the backgrounds? min-bias? pile-up? etc.

PBS

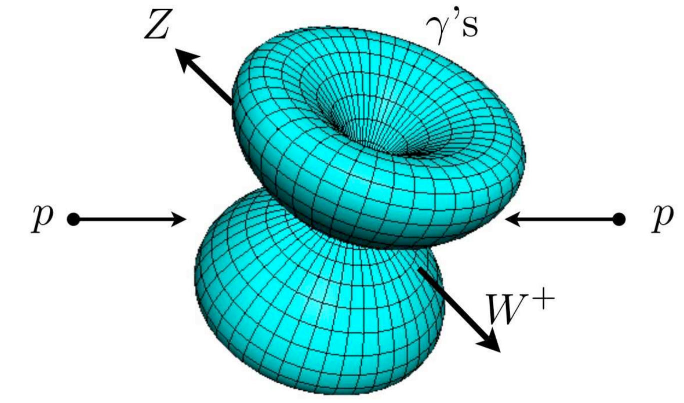

SCT—Silicon Strips
Pixel Detectors
TRT - Xenon Gas
Coil + Cryogenics
Liquid Argon Calorimeter


Material Budget In Front of Coil
(ATLAS TDR)
Radiation length
Total
TRT
SCT
Pixel
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
0.5
1
1.5
2
2.5
3
3.5
|η|

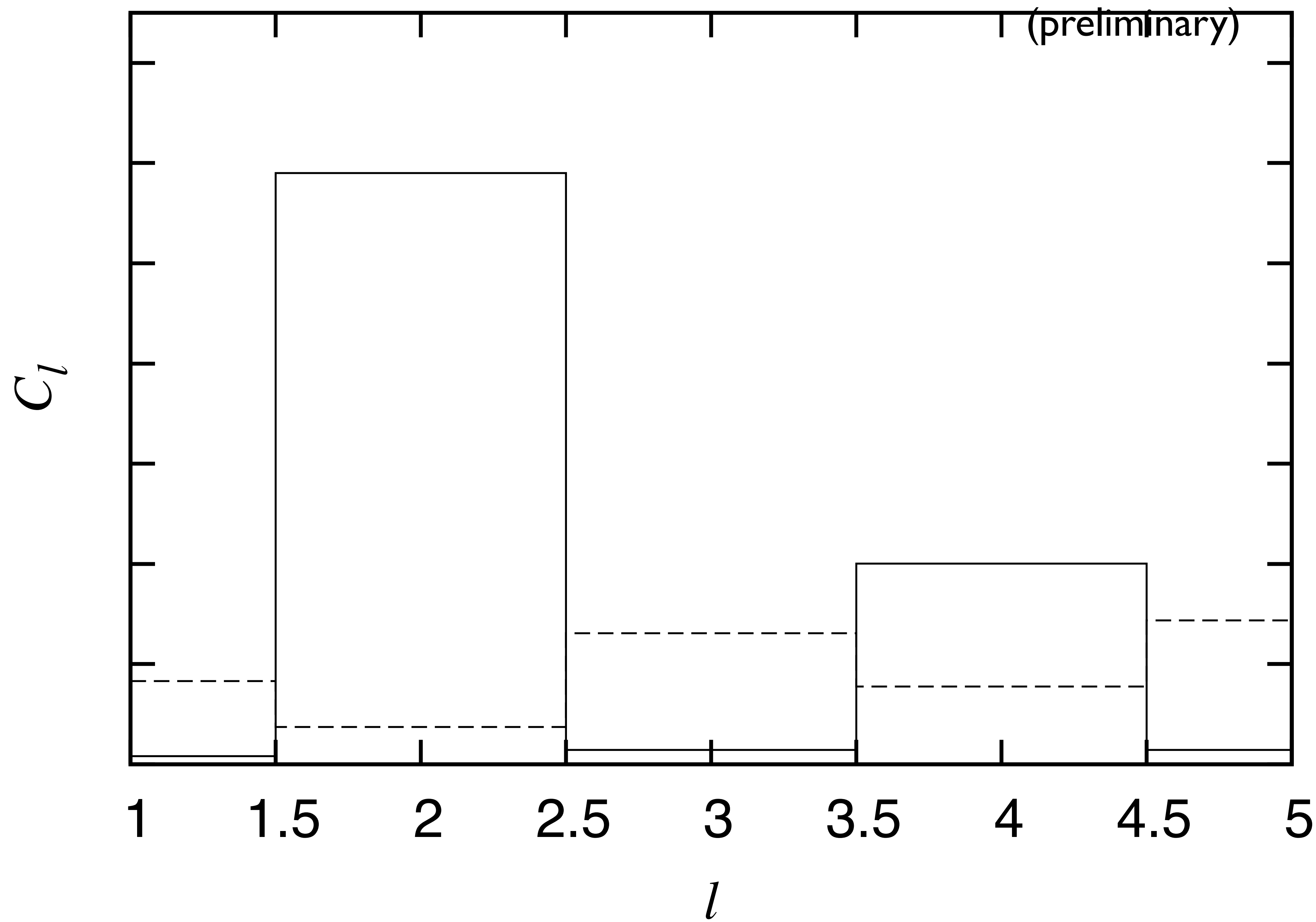
Pattern Recognition



The pattern is visible!



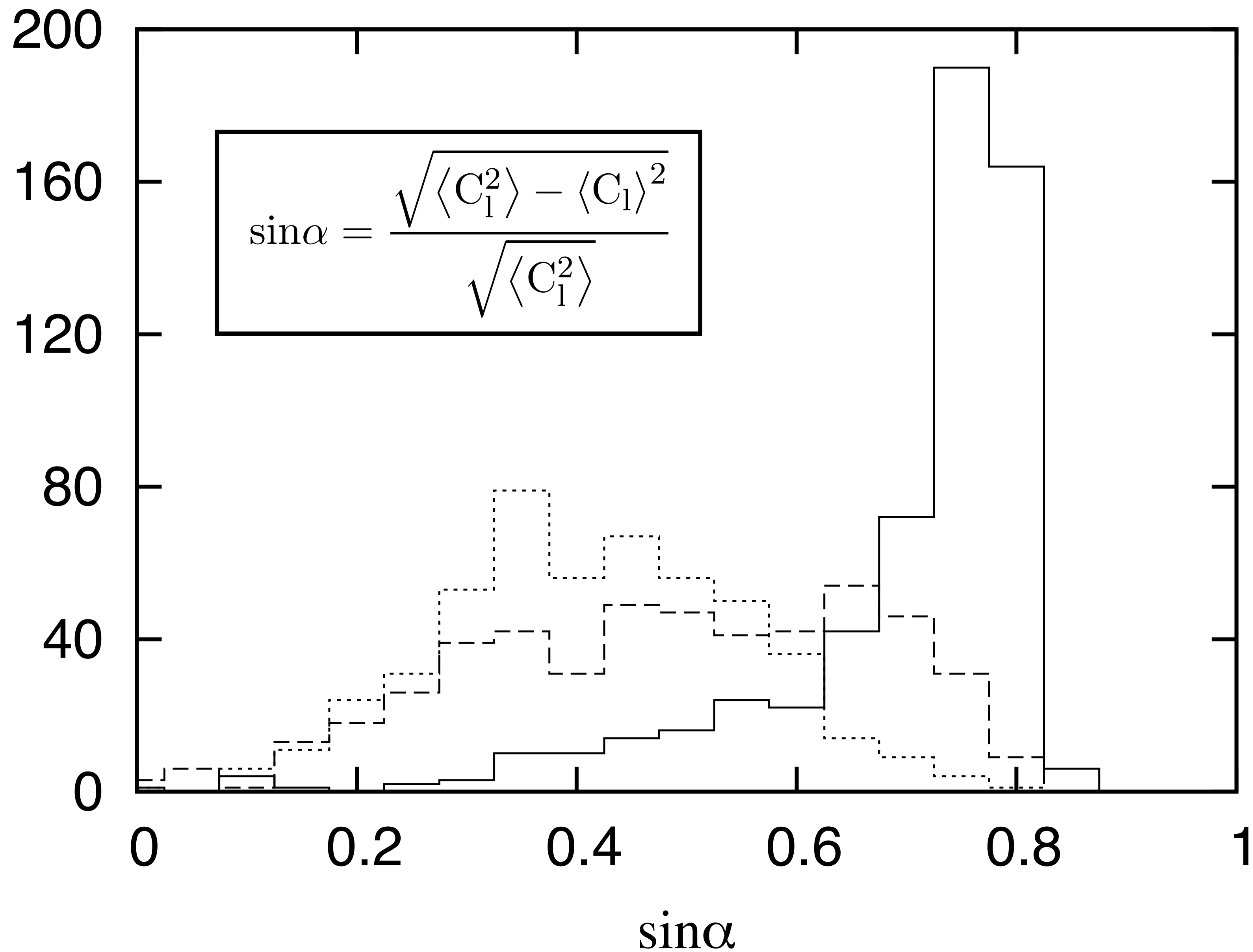
Pattern Recognition



Angular distribution distinct from the background.

Pattern Recognition

(preliminary)



Angular distribution distinct
from the background.

Summary of experimental issues

Quirks raise interesting challenges:

* Triggers for anomalous muon like tracks.
* Trigger for **curves along the B field**.
* Some NP searches, e.g. resonances, may be improved by an **accompanying underlying event study**.
* Possible observables:
  * Multipoles of soft energy deposition in Ecal.
  * Number of charged tracks in central region....