Quirky Signals: From Strings to the Underlying Event

Roni Harnik, SLAC/Stanford

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

But, before we begin:

A Brief Commercial

Aspen's great. But isn't it a bit....

Come to Aspen this summer!

Aspen Summer 2008

LHC: BSM signals in a QCD Environment

July 20th - August 17th

A workshop devoted to all aspects of the discovery of new physics at the LHC.

Organizers: Paddy Fox, Roni Harnik, Tilman Plehn

Outline

- Quirks:
  - What are they?
  - Why think about them?
- Signals in two cases:
  - Very long strings - anomalous muon tracks.
  - Short strings - 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:

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

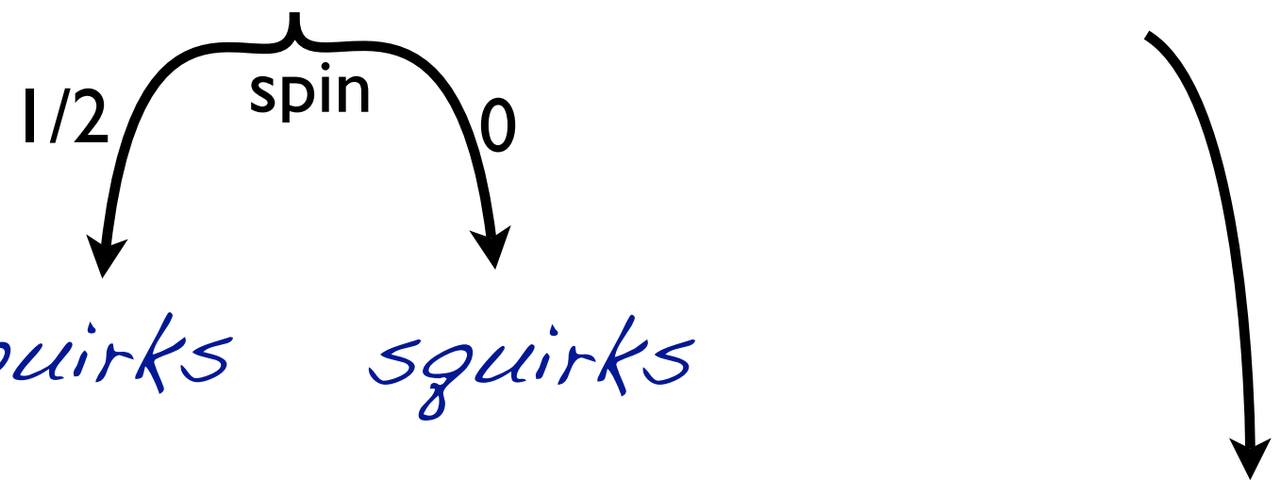
If $\Lambda_{\mathrm{QCD}'} \ll m_{q'}$

q' is a **Quirk**

Types of Quirks

* We can categorize quirks

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



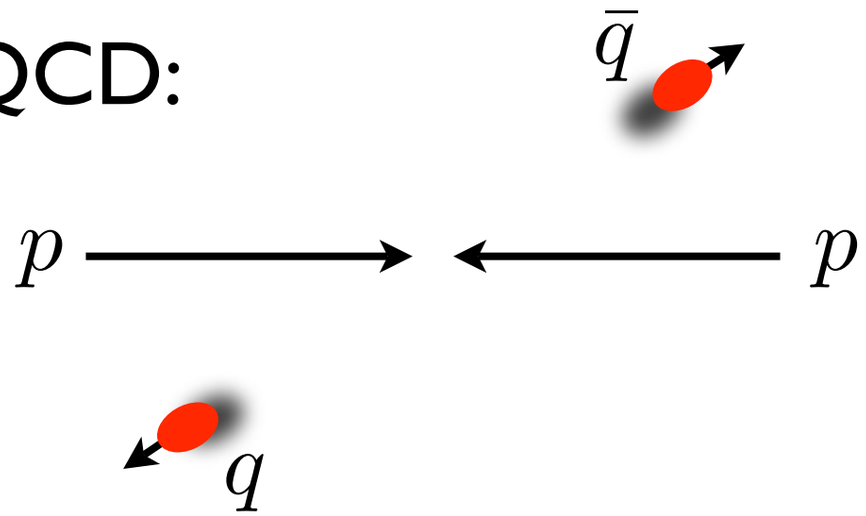
Colored or **Non-colored**

(under our QCD)

important for production, etc.

Quirky Dynamics

* In regular QCD:



Quirky Dynamics

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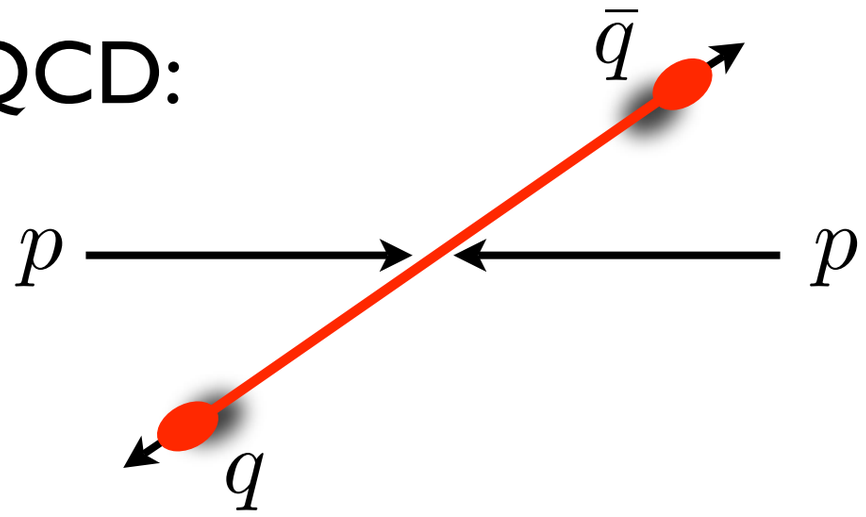

Quirky Dynamics

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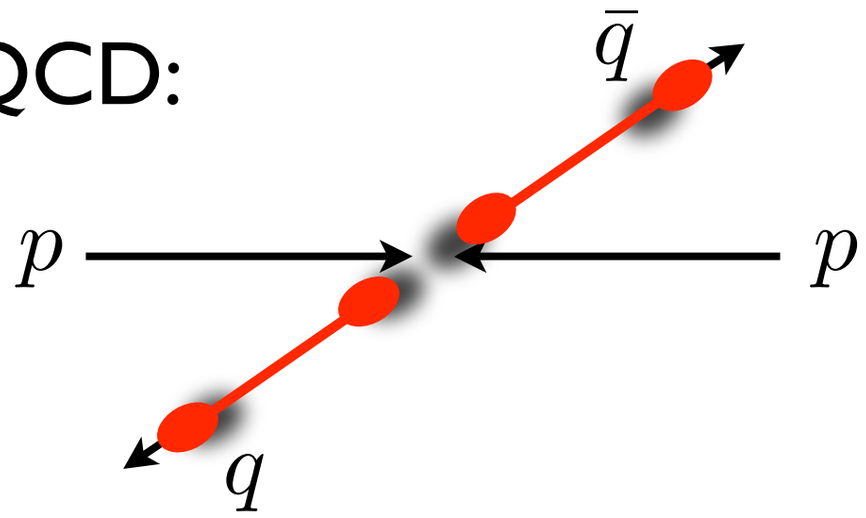

Quirky Dynamics

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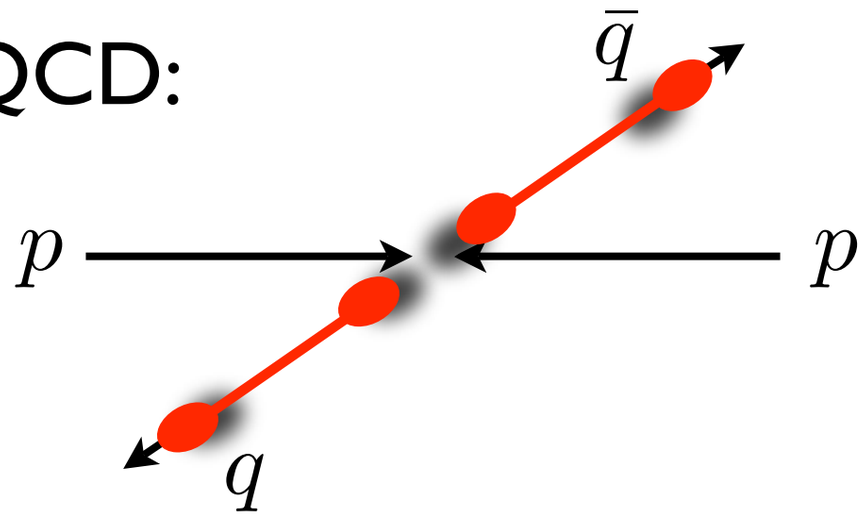
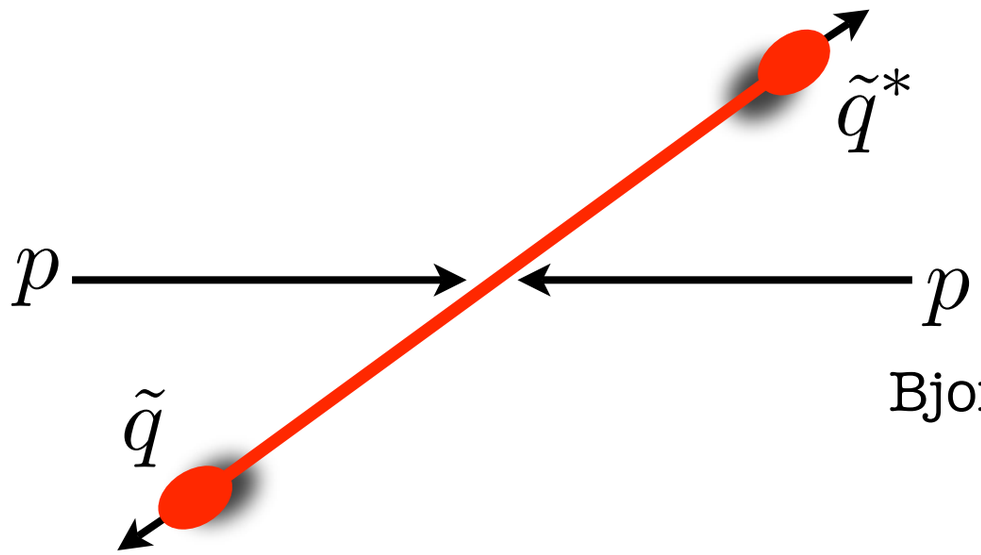


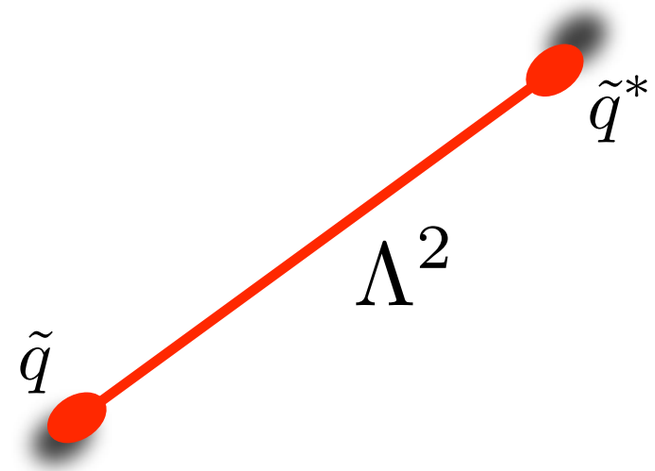
* In "quirky QCD" this costs too much energy. squarks' are produced and **remain bound**!



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

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

can be very long!

Examples:

* Lets consider two extreme choices for Λ

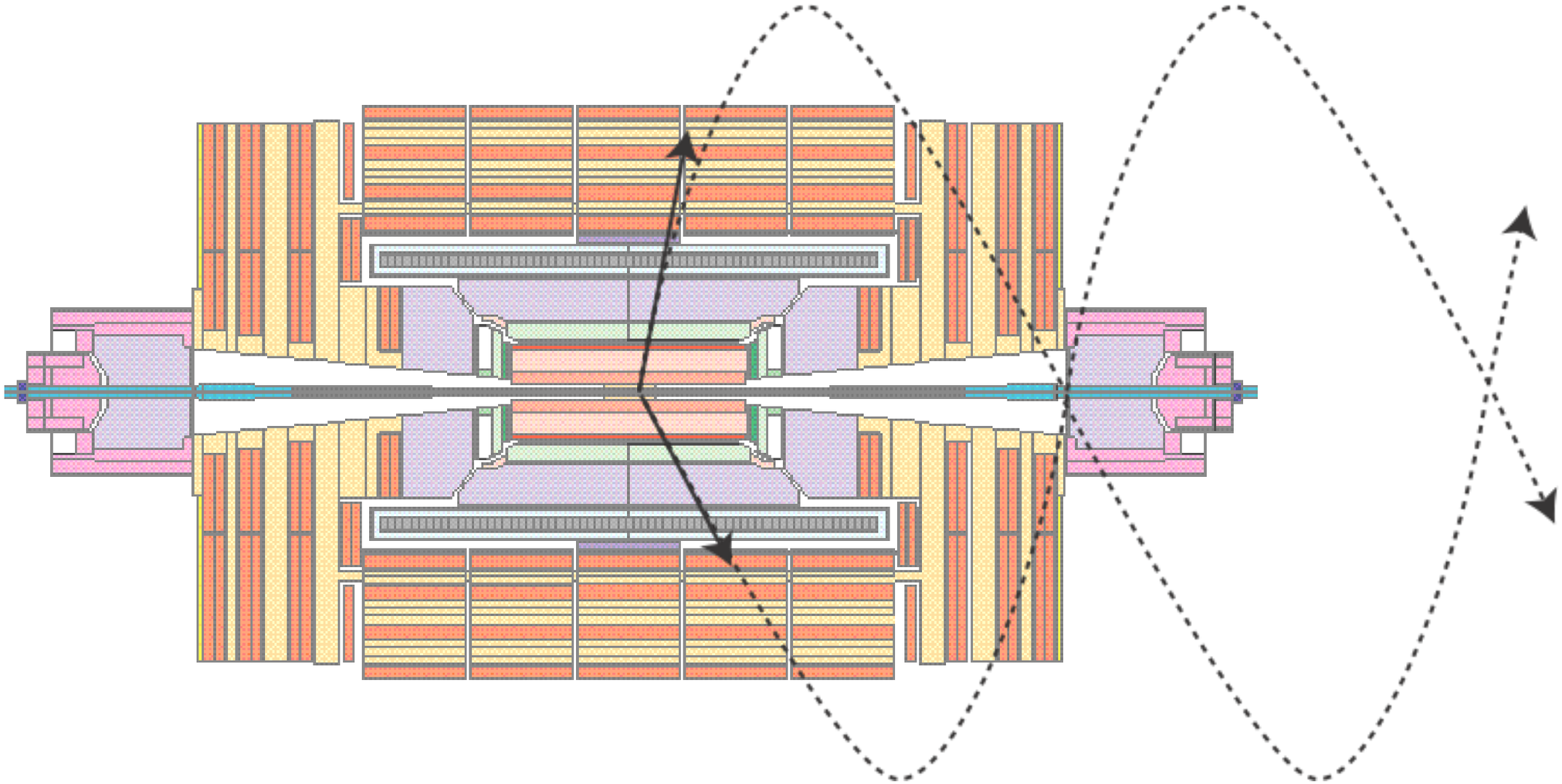
$\Lambda \sim$ few eV	$\Lambda \sim$ few GeV
$l_{max} \sim$ meters	$l_{max} \sim$ few fermi
Loooong strings	Excited bound state
Weird muon tracks.	Resonance. Soft radiation.

motivated by a model for hierarchy

Looooong Strings.

Long Strings

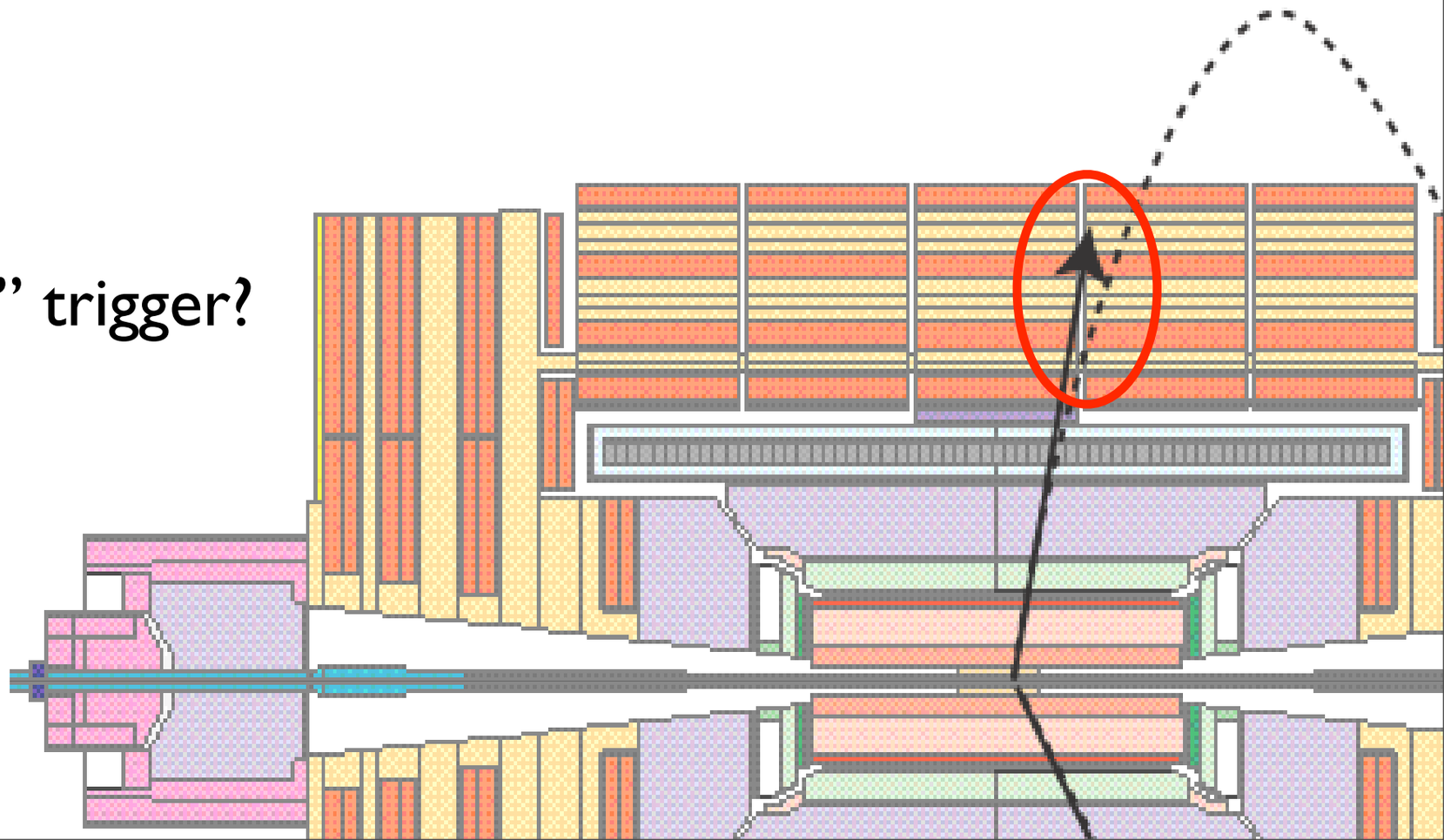
* Each end hadronizes separately.
  Assume a charged hadron.



A striking sginal:
Two “connected muons”.

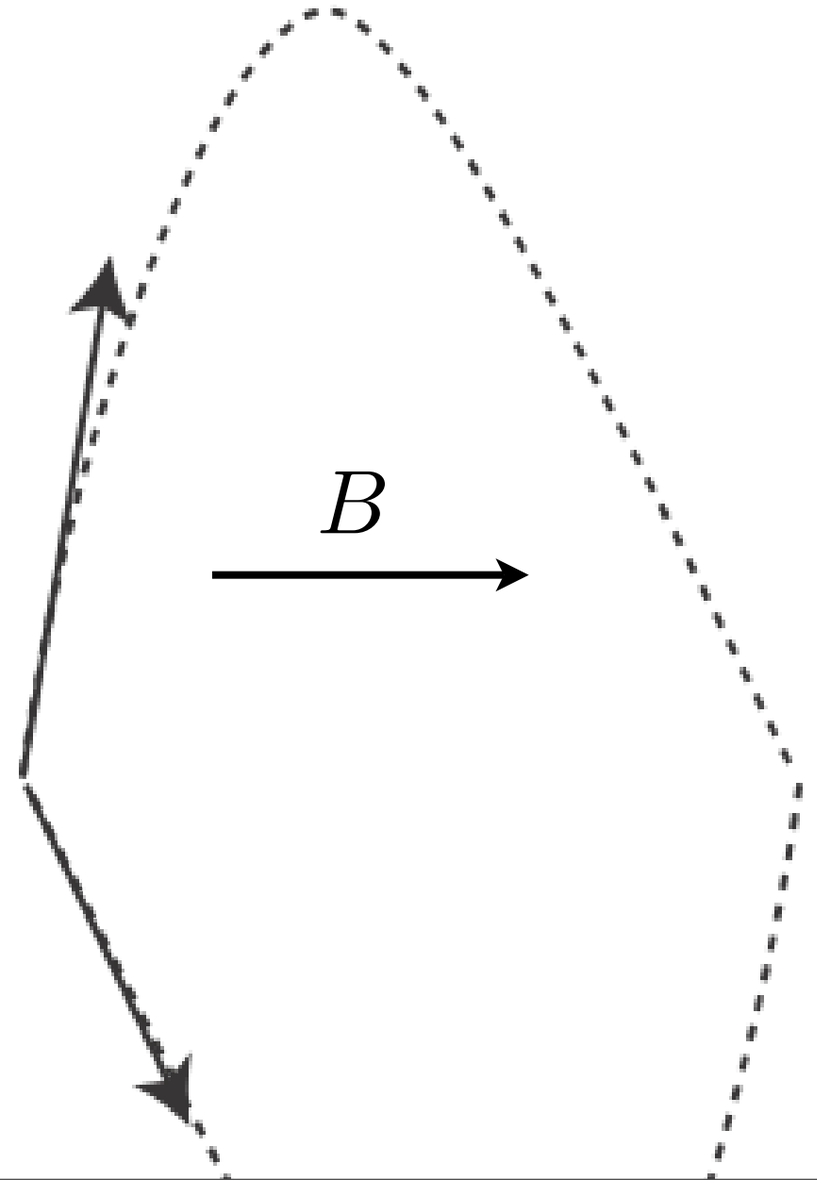
Triggering

* 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.

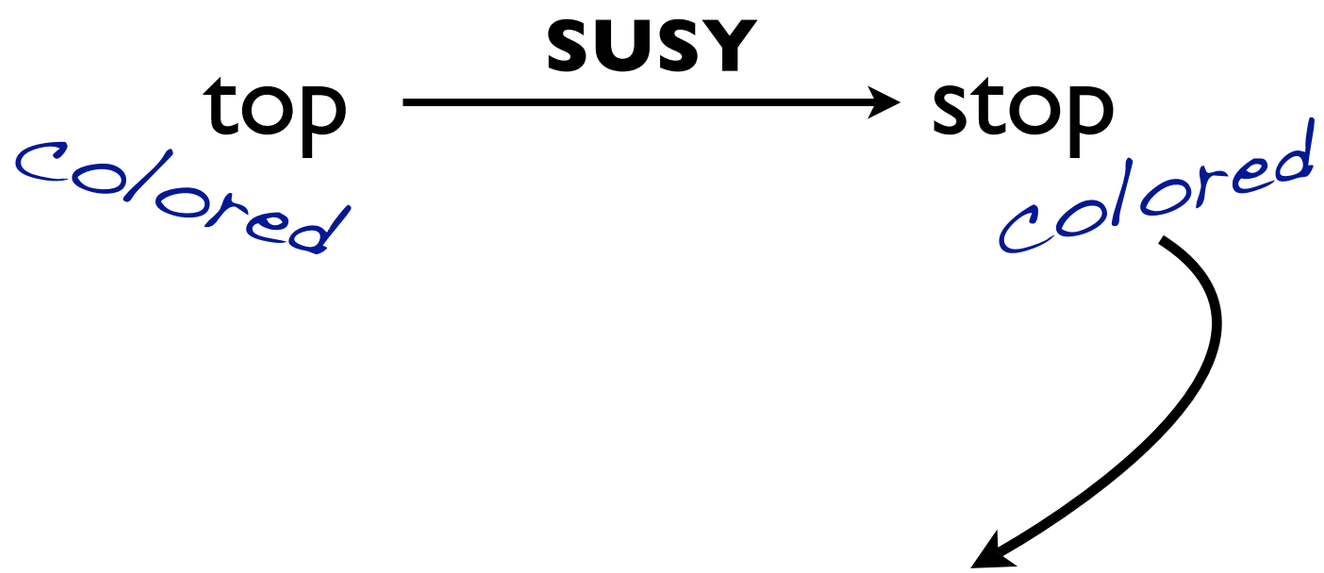


Anything that does this is exotic and worth keeping. (Unless its noise?)

Microscopic Strings.

Model Building

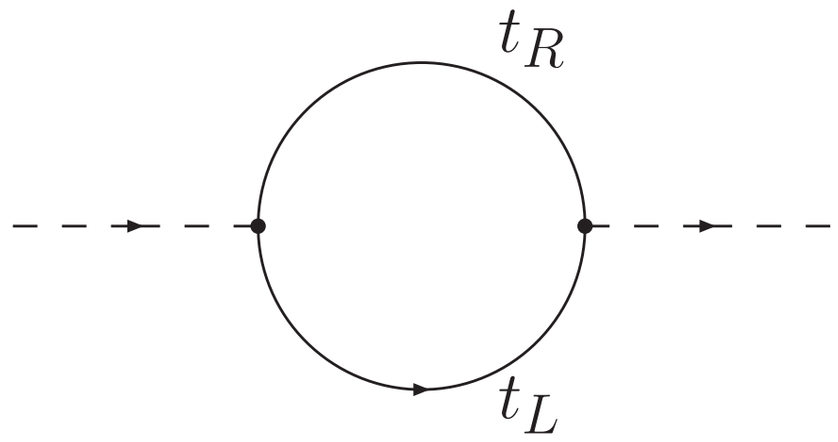
* The hierarchy problem suggests a new symmetry.



A huge impact on
collider phenomenology!

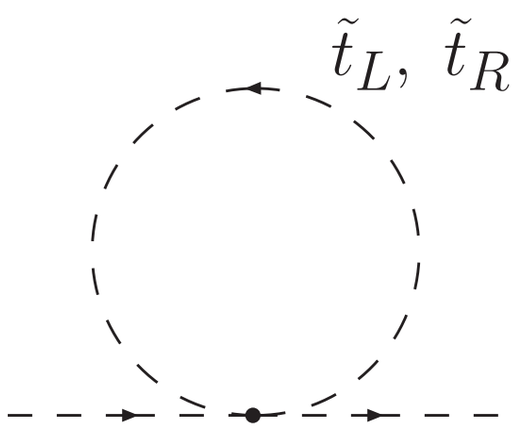
Can squarks be uncolored?

Just a Factor of 3



Standard Model

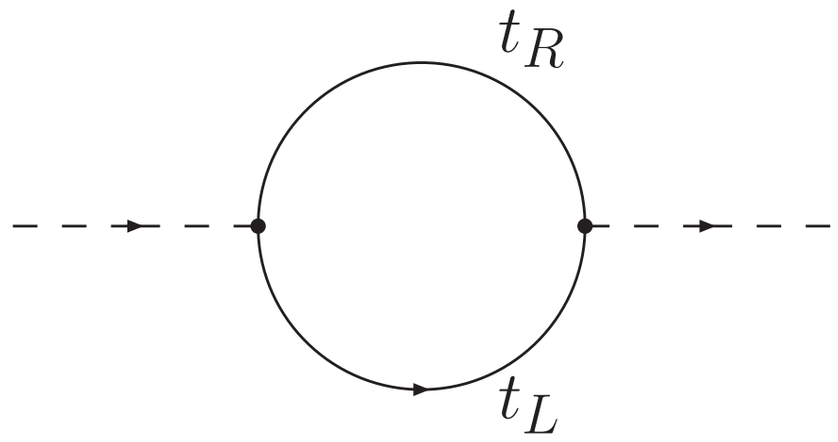
$\times 3$



Supersymmetry

$\times 3$

Just a Factor of 3



Standard Model

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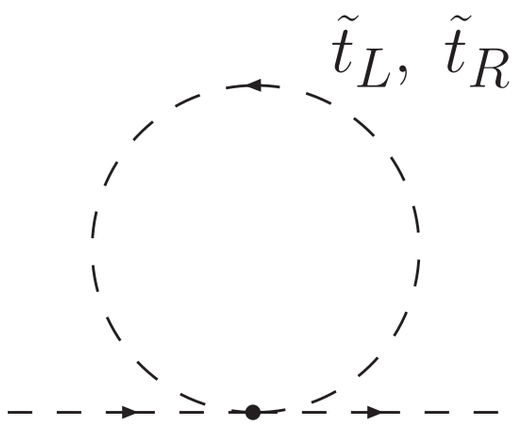
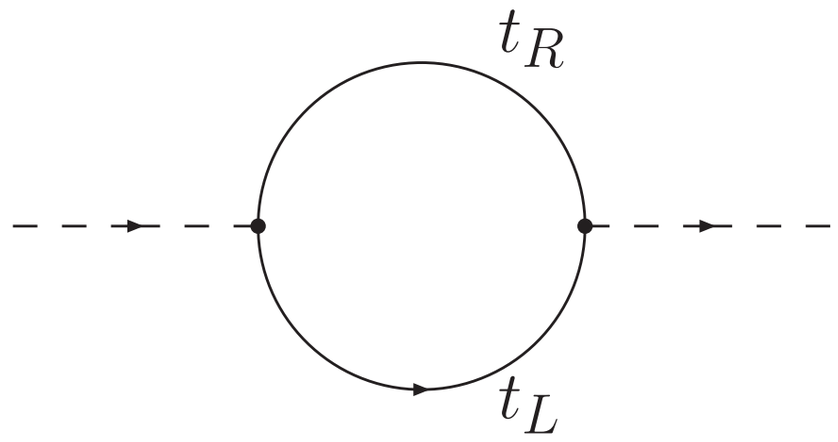


Supersymmetry

$\times 3$

3'

Just a Factor of 3



Standard Model

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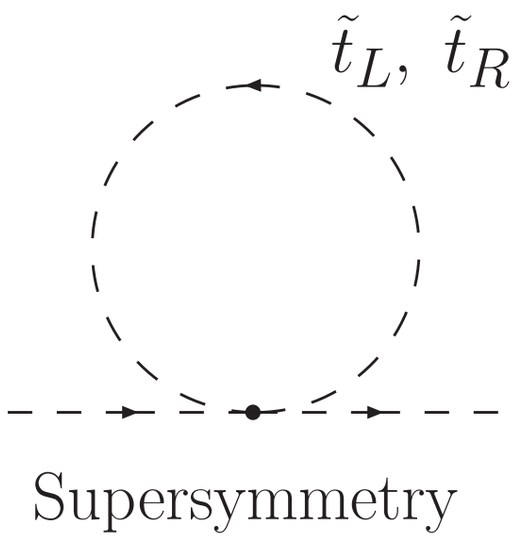


Supersymmetry

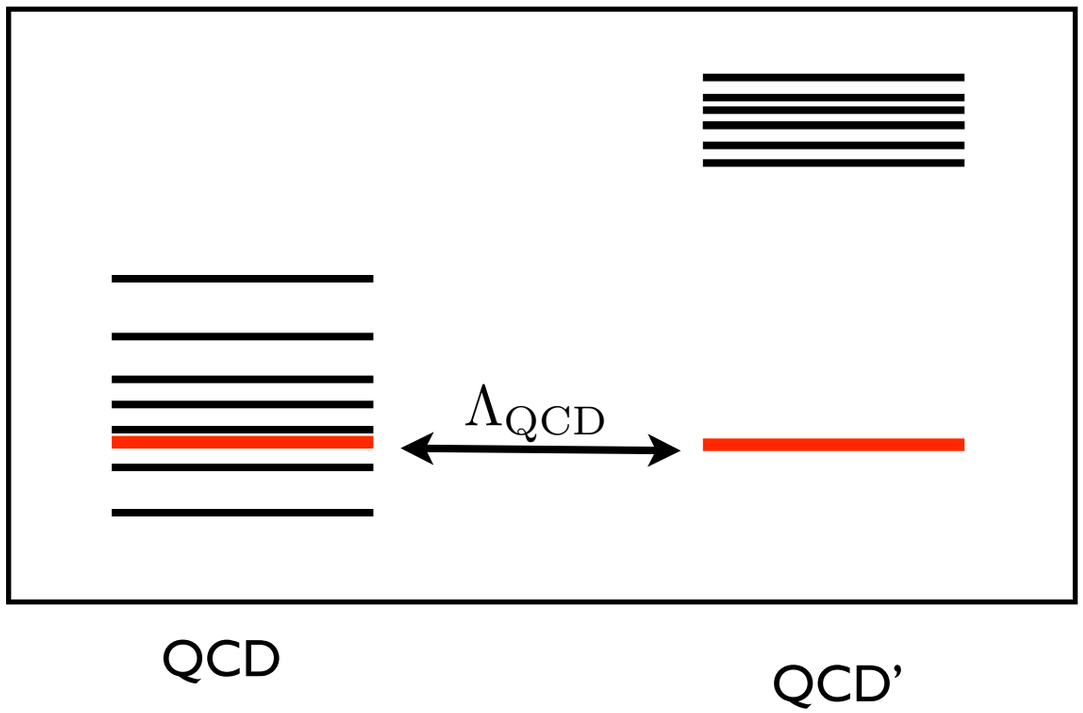
~~$\times 3$~~ 3'

Folded SUSY

(Burdman, Chacko, Goh, RH)

Hierarchy solved by squirks!

Folded SUSY



LEP bounds

QCD scales are related by a Z_2.

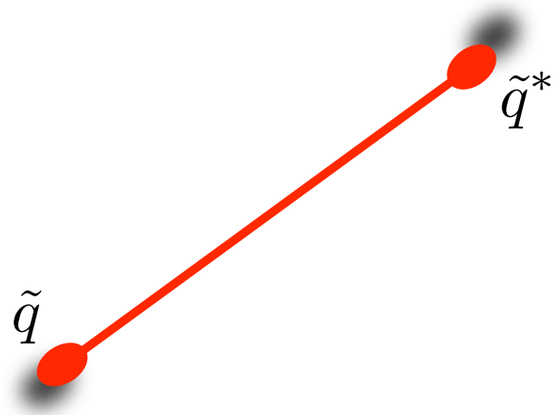
- Motivates both colored and non-colored (s)quirks. e.g.

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

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

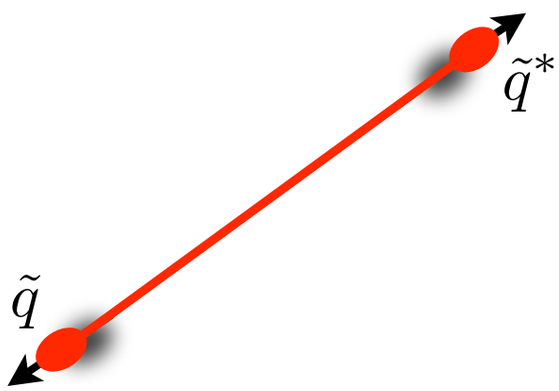
Quirky Dynamics

* The squirks eventually stop.
  come back.
  oscillate.

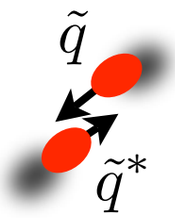


* This system will loose energy by radiation.

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



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: $m_\gamma \sim m_{\rm glue}$

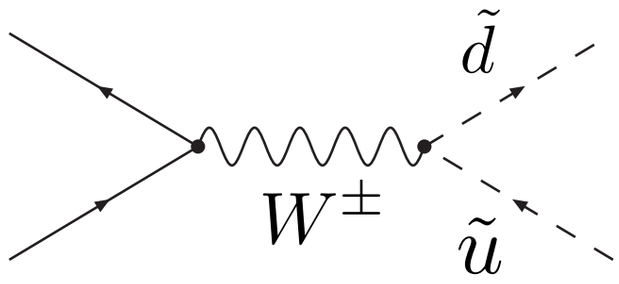
    We'd expect $$\frac{E_\gamma}{E_{\rm glue}} \sim \frac{\alpha(m_\gamma)}{\alpha_{s'}(m_{\rm glue})} \sim \frac{1}{20} \ .$$

  - **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:



Ongoing work w/ Wizansky.

Ongoing work w/ Burdman et al

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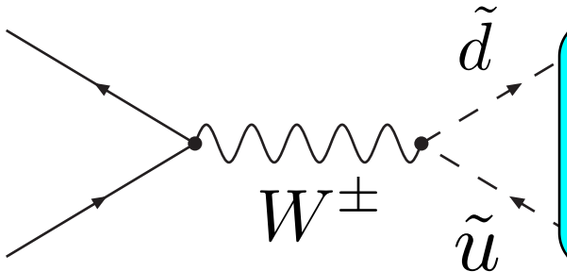

"squirkonium"

Ongoing work w/ Wizansky.

Ongoing work w/ Burdman et al

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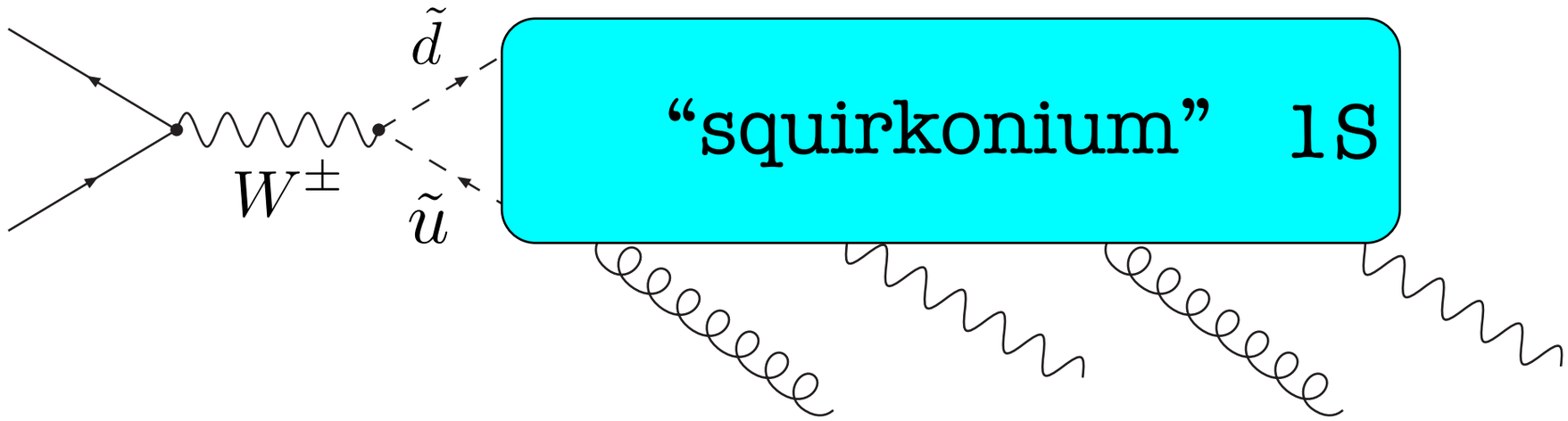

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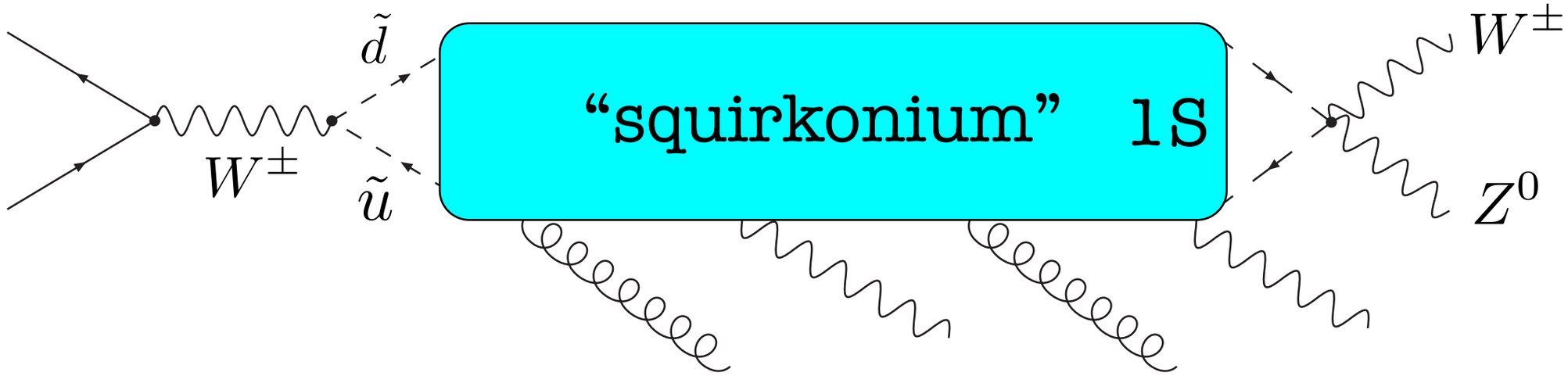

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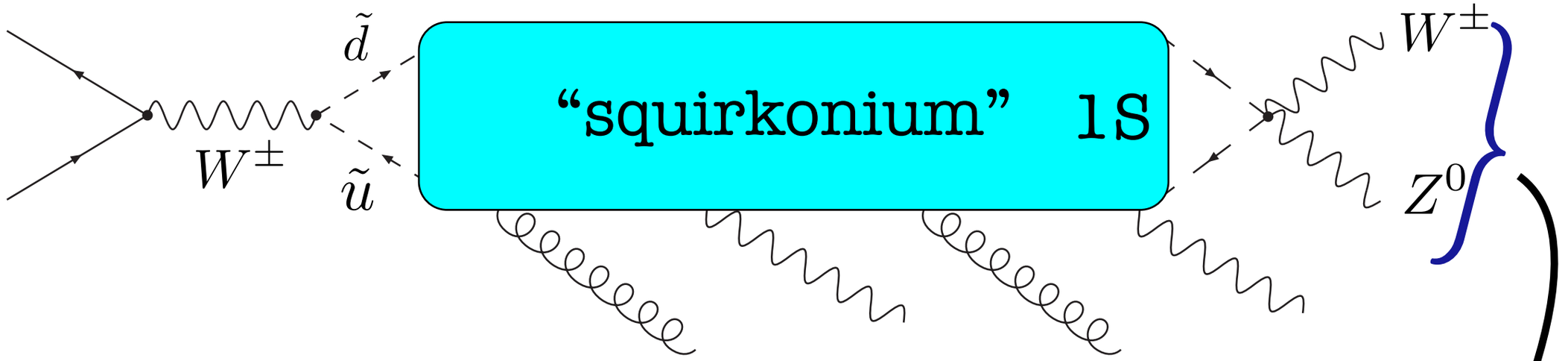

A **peak** in the invariant mass of W+Z

$$m^2_{WZ} = m^2_{1\mathrm{S}} \sim 4m^2_{\tilde{q}}$$

Ongoing work w/ Wizansky.

Ongoing work w/ Burdman et al

An Event

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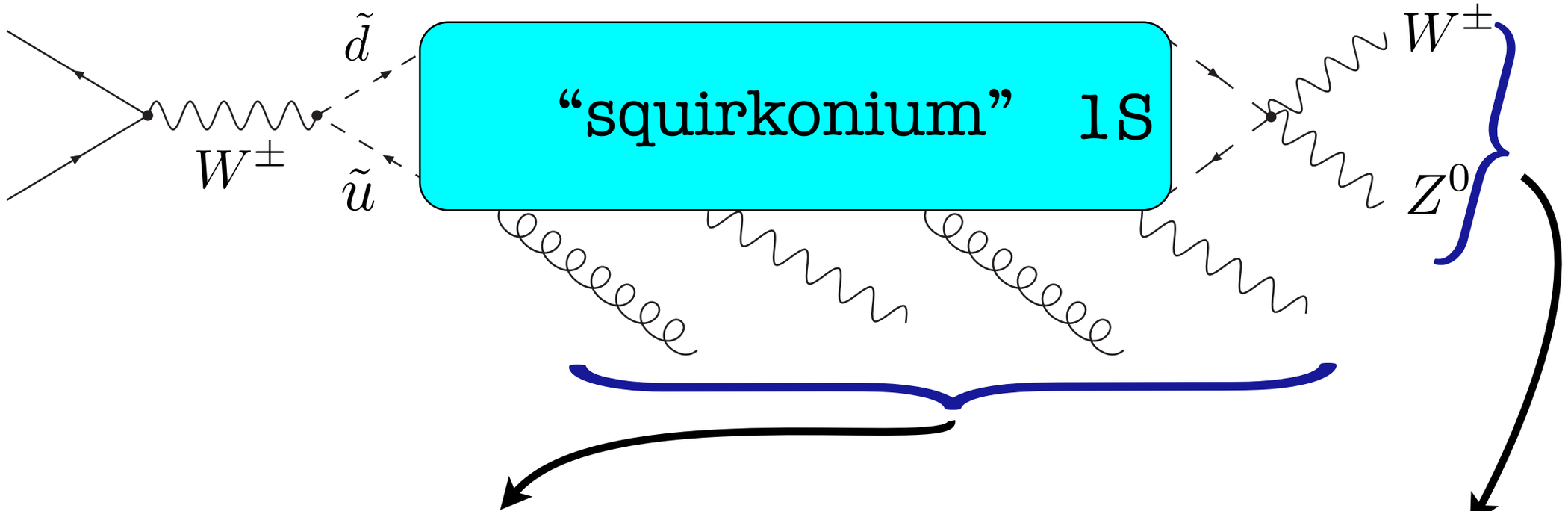


Soft radiation of **photons** and (hidden) glueballs

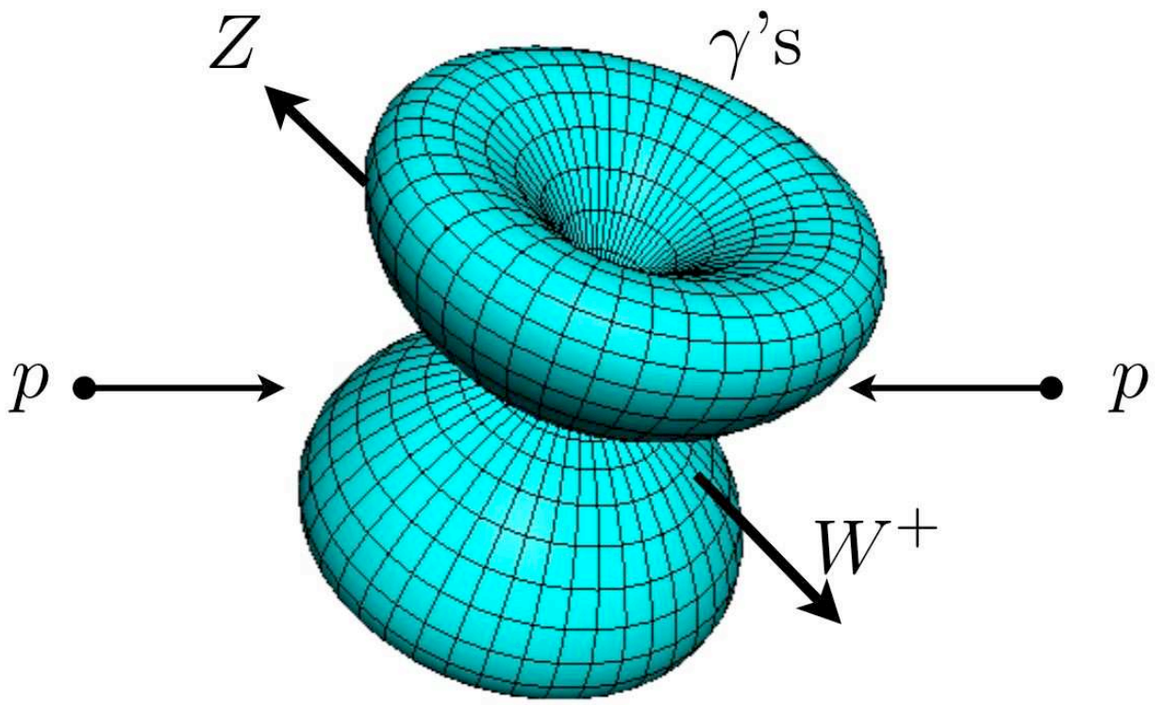
Ongoing work w/ Wizansky.

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

$$m^2_{WZ} = m^2_{1\mathrm{S}} \sim 4m^2_{\tilde{q}}$$

Ongoing work w/ Burdman et al

An Event



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

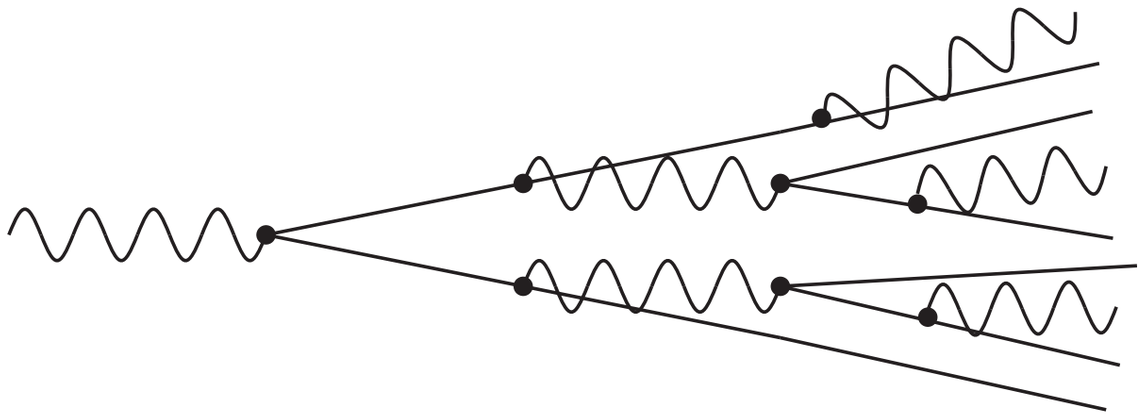
$$\sim 0.1 \text{ - } 1 \text{ GeV}$$

Can we see such soft photons?
Isn't there plenty of soft background?
Is the "antenna pattern" visible?

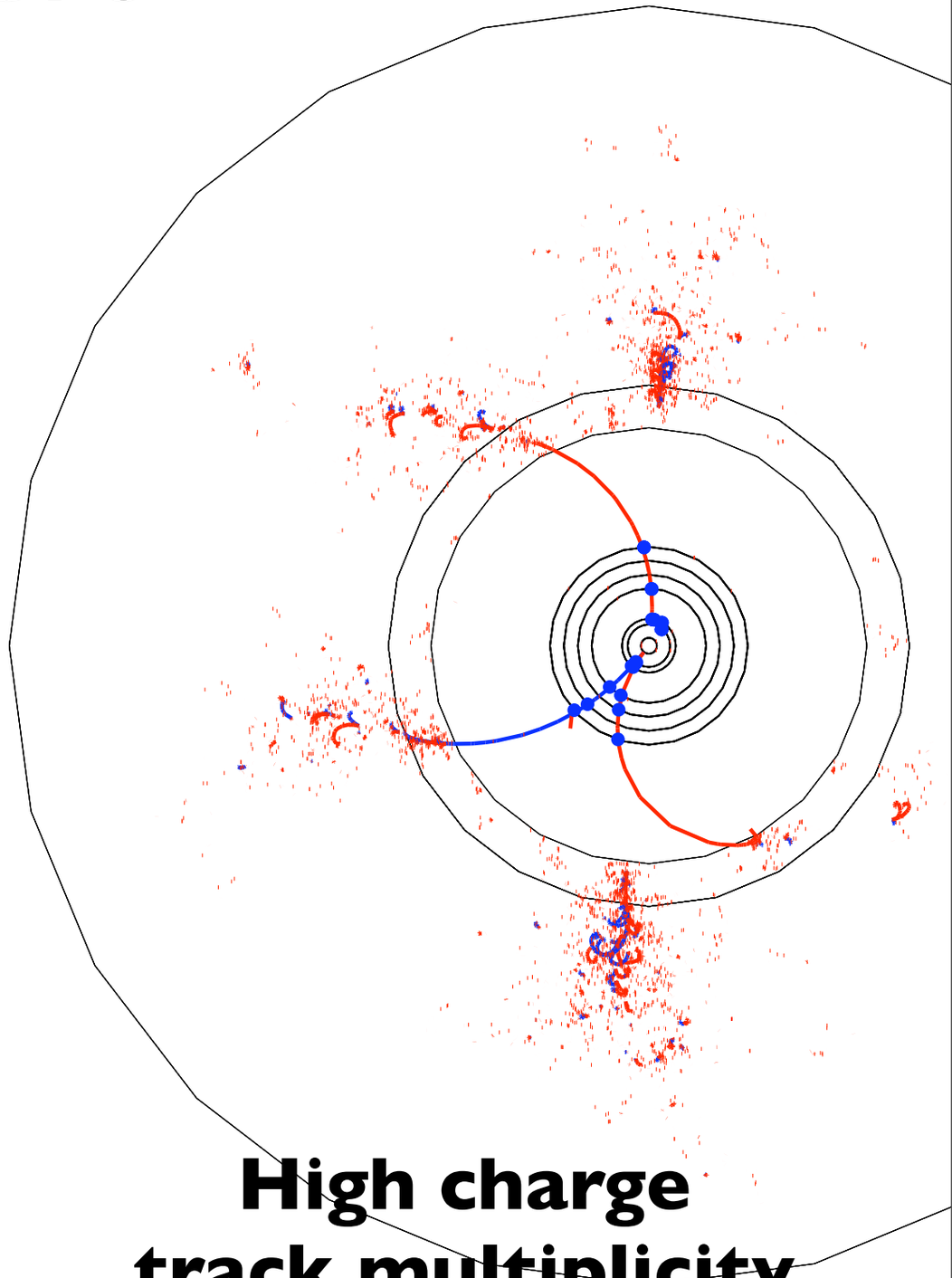
(This is not what the detectors were designed for!)

EM Showers

* Soft photons initiate EM showers in the detector.



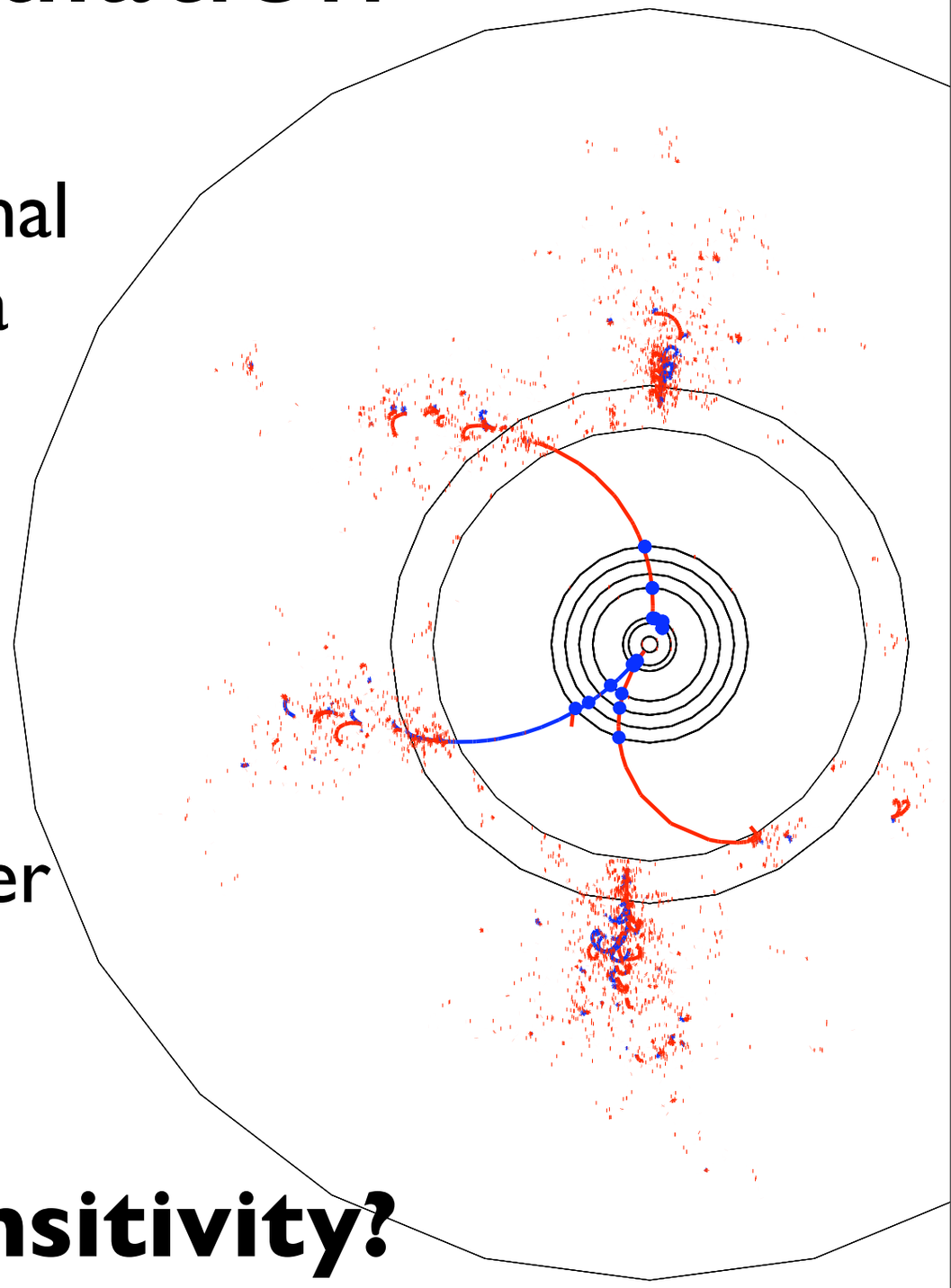
* A naive estimate:
  - ~30% of photons convert to electron-positron pair in tracking system.
  - ~50% of energy reaches Ecal.



High charge track multiplicity

Detector Simulation

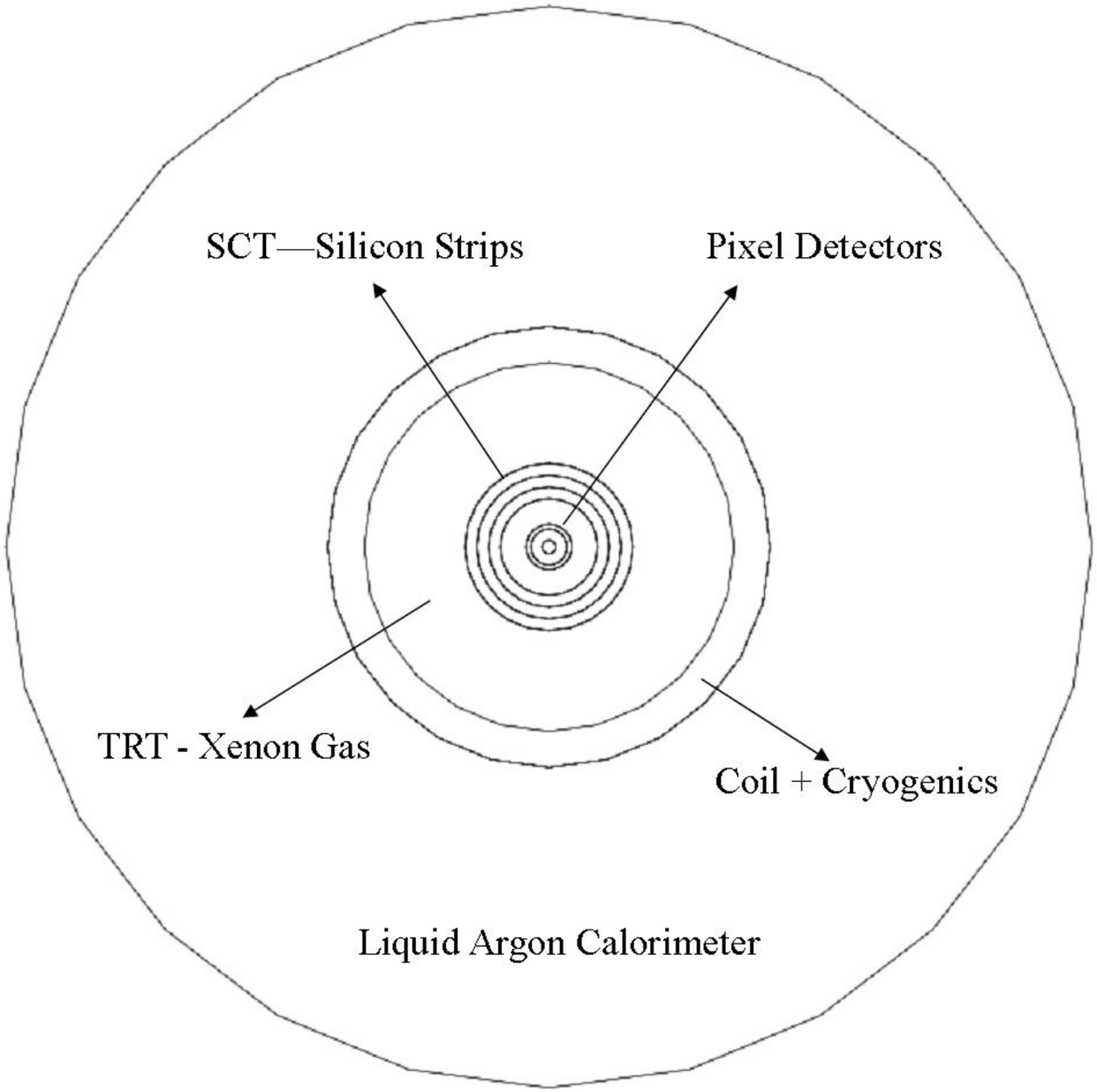
- We simulated the photon signal according to a simple antenna model.
- Analyze soft photons with a dedicated simulation of a "toy detector" (using GEANT4).
- Take $E_\gamma / E_{\mathrm{glue}}$ as a parameter (can change event by event).

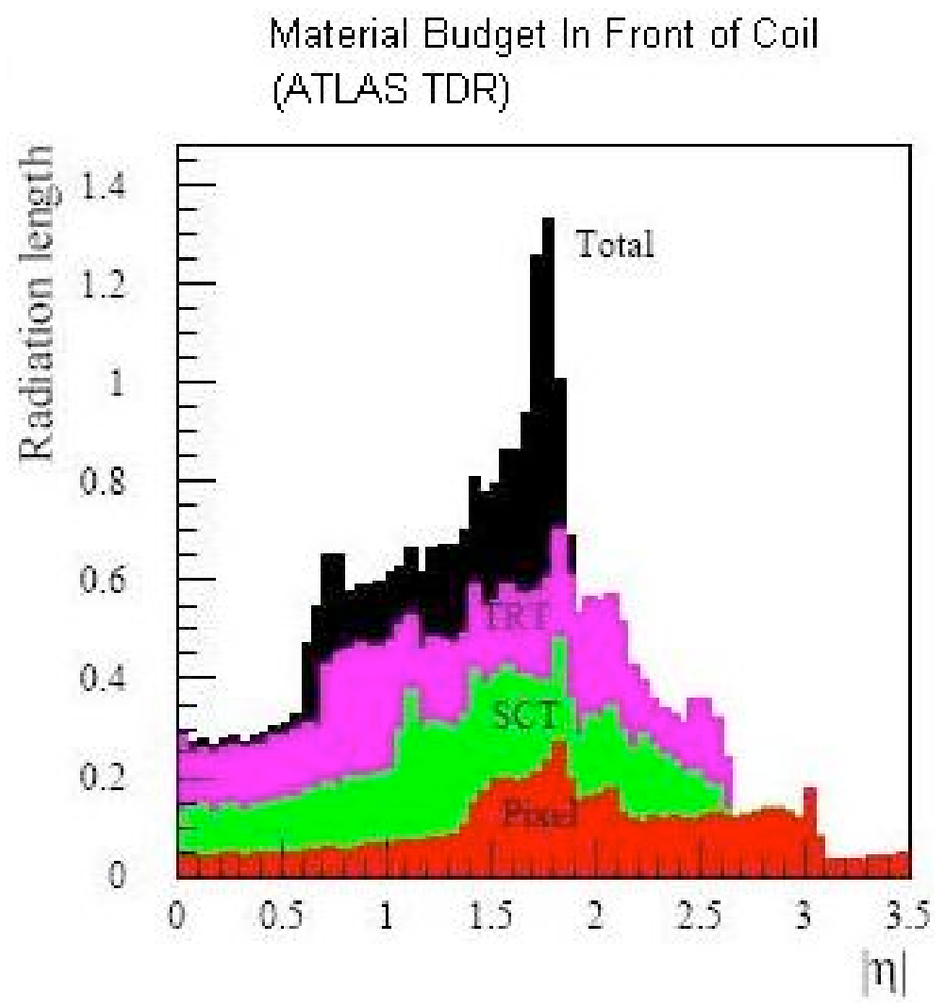


what is the sensitivity?

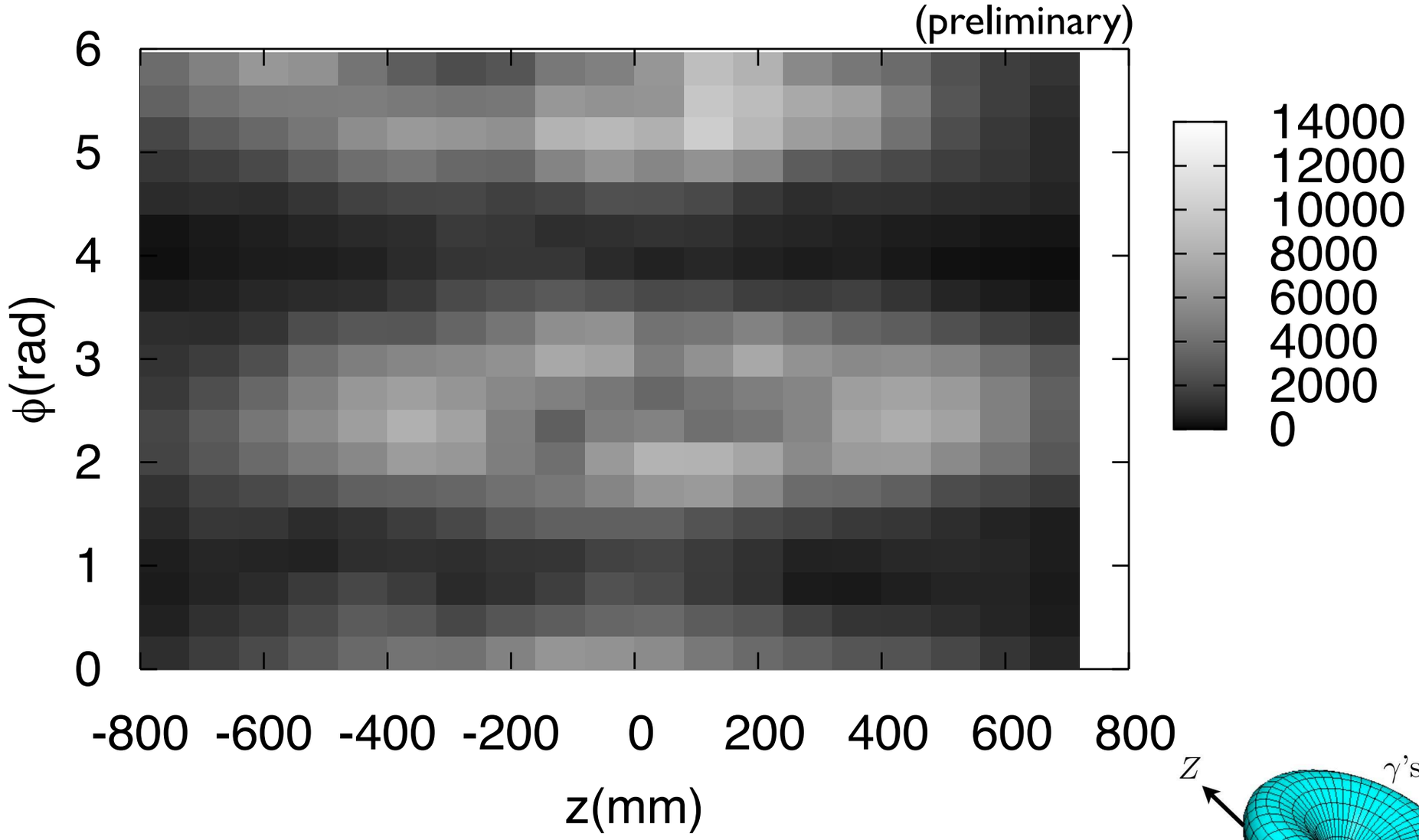
what are the backgrounds? min-bias? pile-up? etc.

PBS

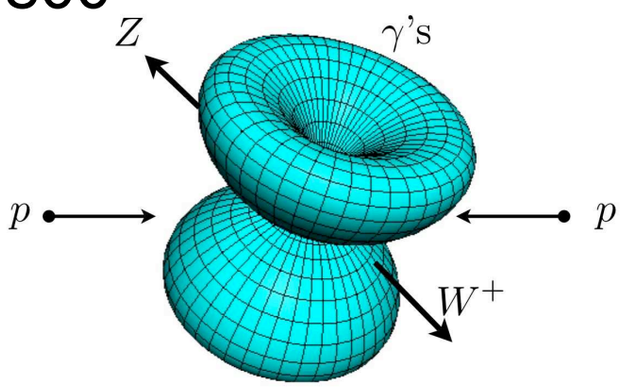

SCT—Silicon Strips
Pixel Detectors
TRT - Xenon Gas
Coil + Cryogenics
Liquid Argon Calorimeter


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

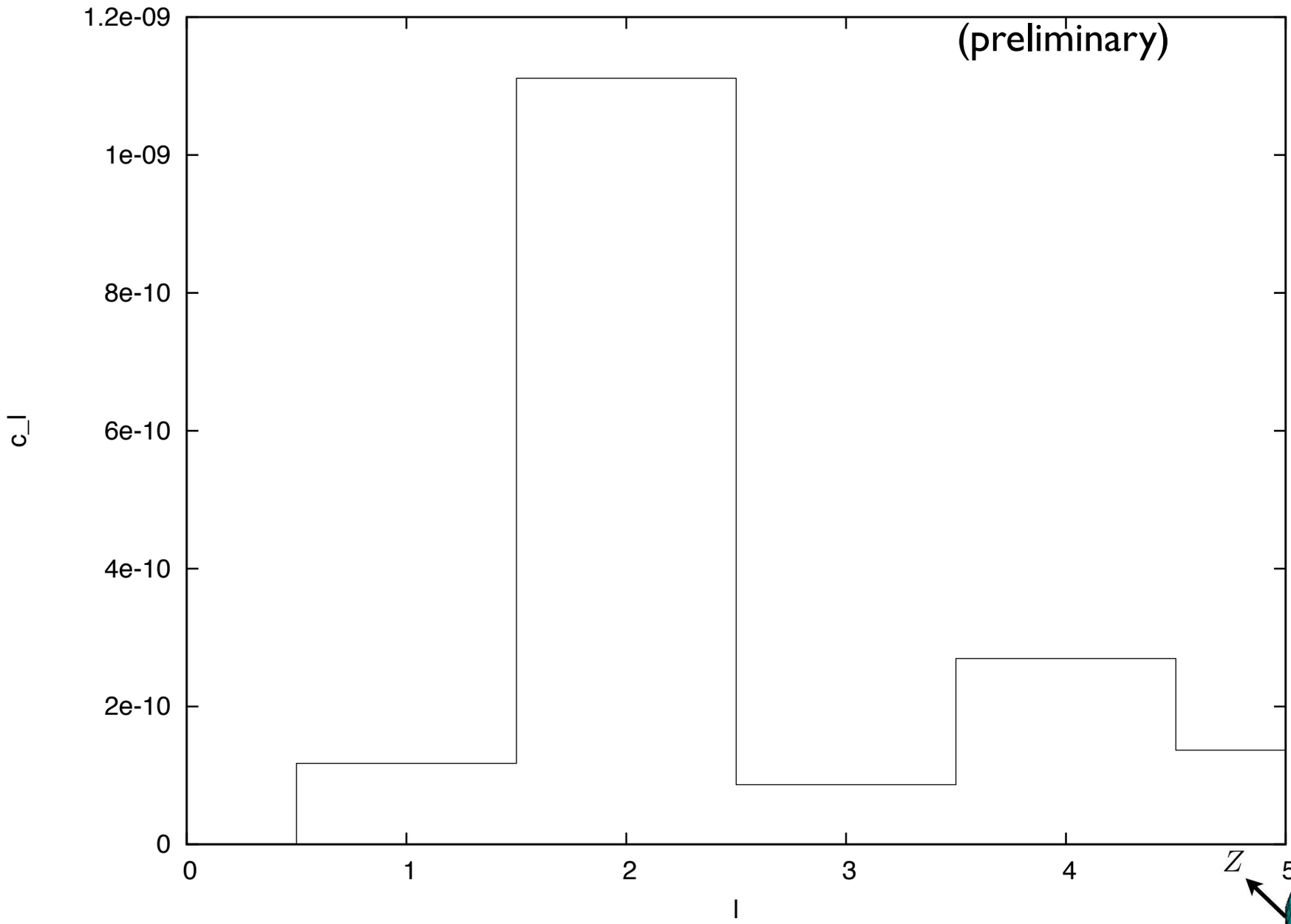
Pattern Recognition



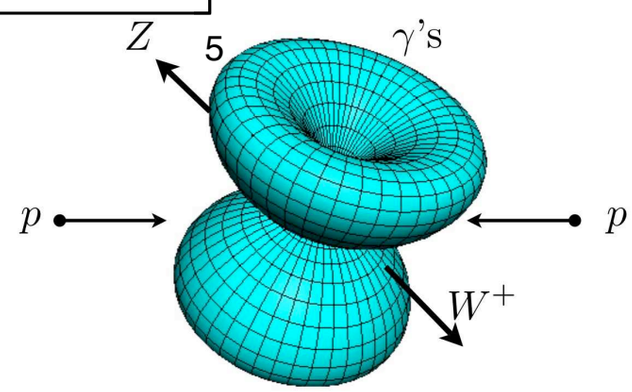
The pattern is visible!



Pattern Recognition



Angular distribution distinct from the background.



Conclusion - Theory

* Quirks are fun!
* Quirks may solve the hierarchy problem.
* Lead to quirky collider phenomenology.
  - Long strings
  - Excited quirkonium $\longrightarrow$ soft stuff

* Are there other models that give anomalous underlying events... (hidden unvalleys, ...)

Conclusion - Experiment

* Triggers for anomalous muon like tracks.
* Trigger for **curves along the B field**.

* Some NP searches, e.g. resonances, may be improved by an **acompanying underlying event study**.
* Possible observables:
  - Multipoles of soft energy deposition in Ecal.
  - Number of charged tracks at central region....

Work in Progress...

* Preliminary:

$$\frac{E_\gamma}{E_{\text{glue}}} \sim 10\%$$

may be enough to beat background