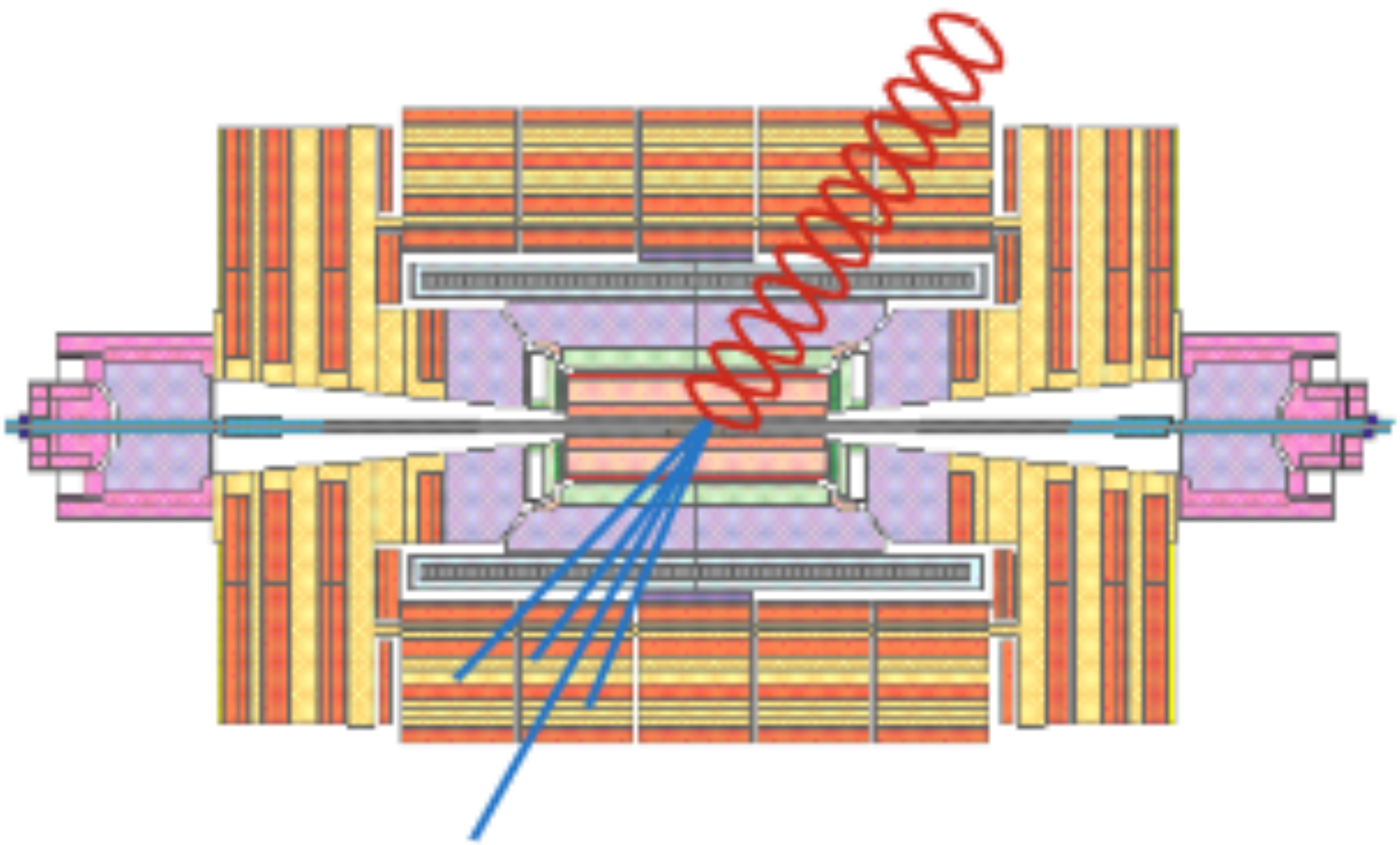
Tracking down quirks at the LHC

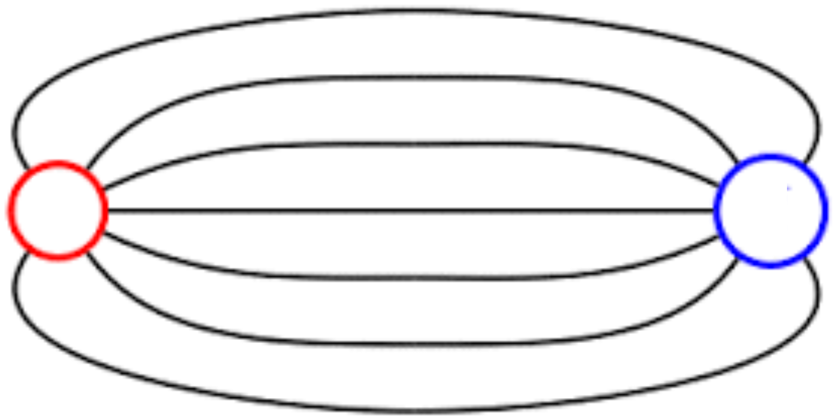
Simon Knapen, Tim Lou, Michele Papucci, Jack Setford
1708.02243

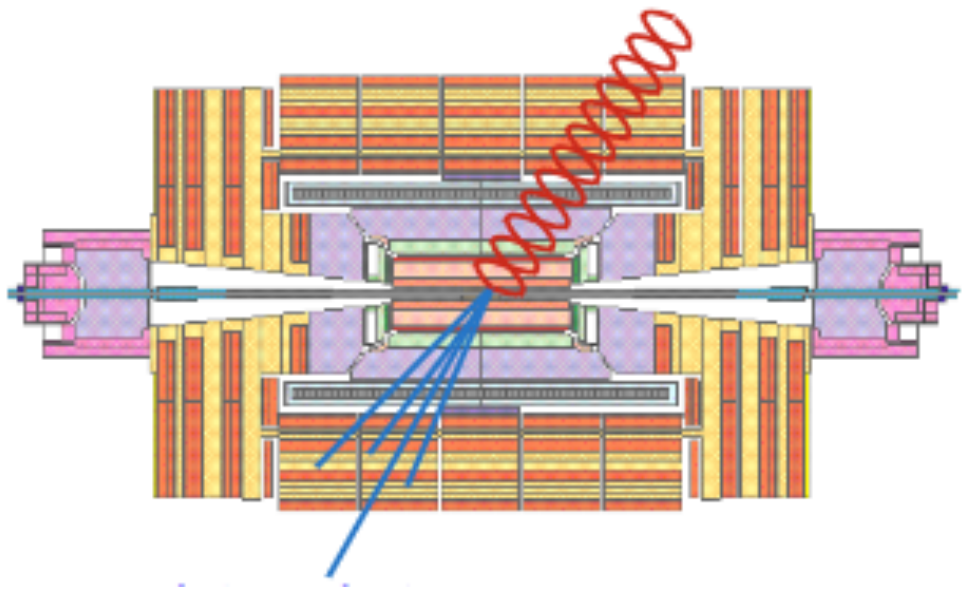


@ Searches for long-lived particles at the LHC in Trieste

Quirks

Quirks: $\Lambda_c \ll m_Q$





Oscillates, eventually annihilates

Quirk-antiquirk pairs cannot be created, flux tube never breaks

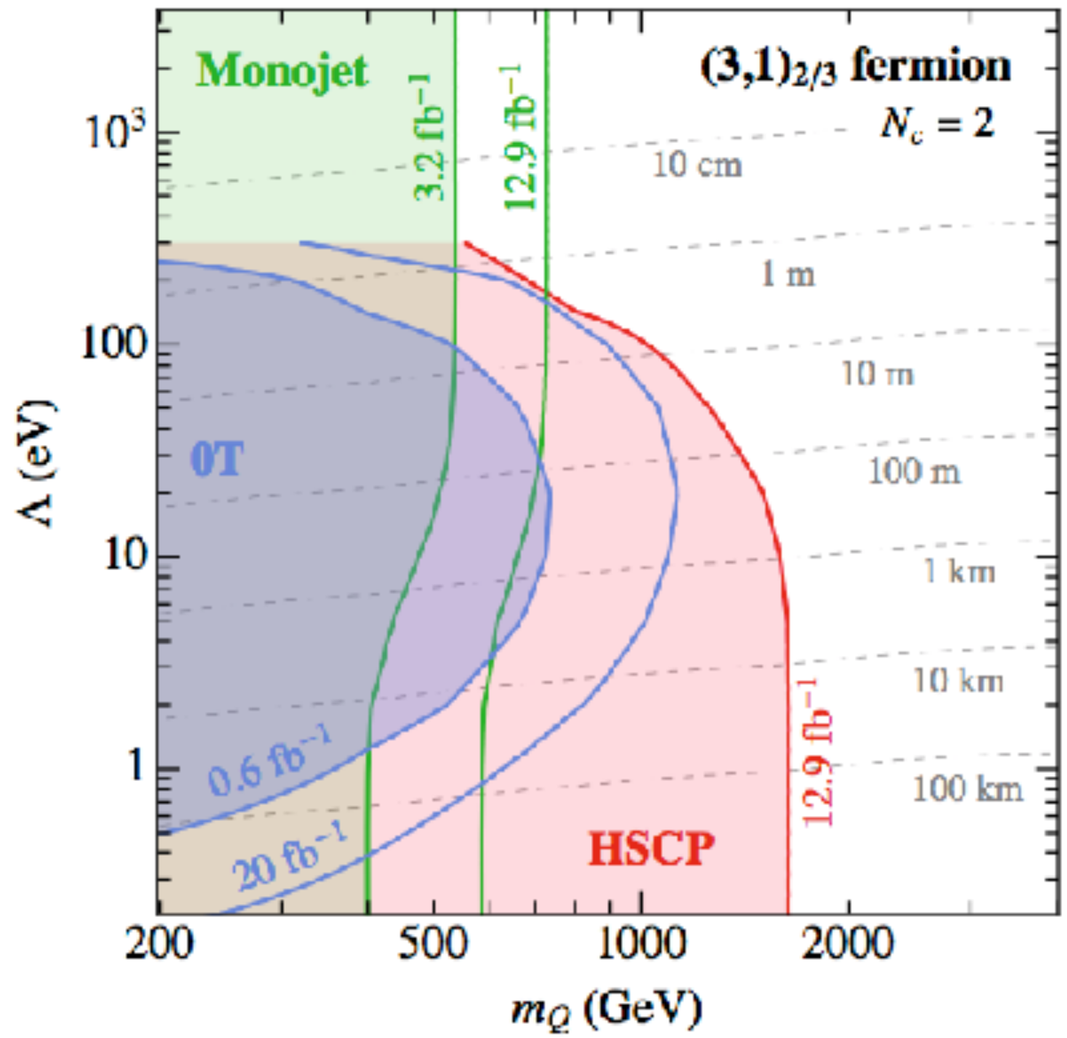
Spectacular, but…

… unknown how to reconstruct it

J. Kang, M. Luty: arXiv: 0805.4642

Existing limits

In the long string-length limit, the HSCP searches are sensitive



M. Farina, M. Low: 1703.00912

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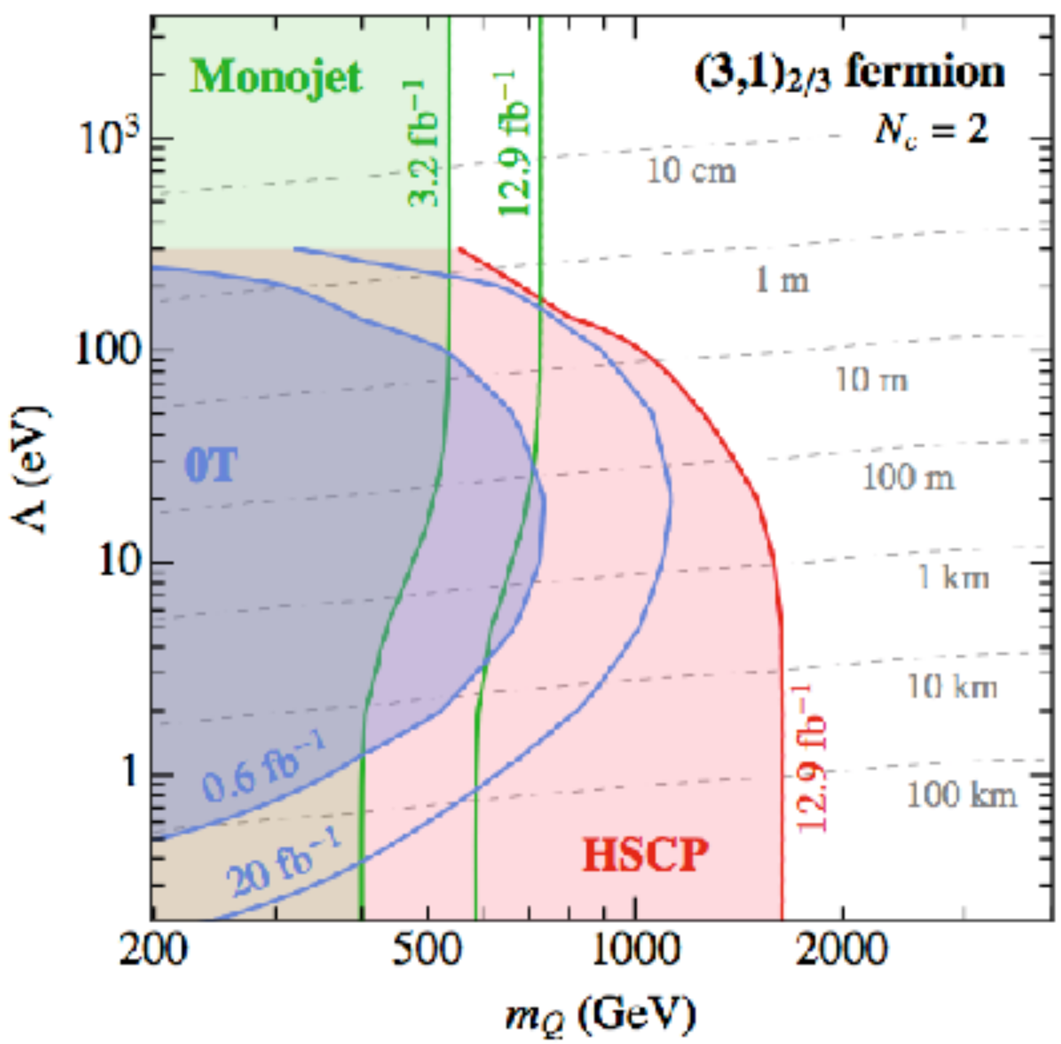

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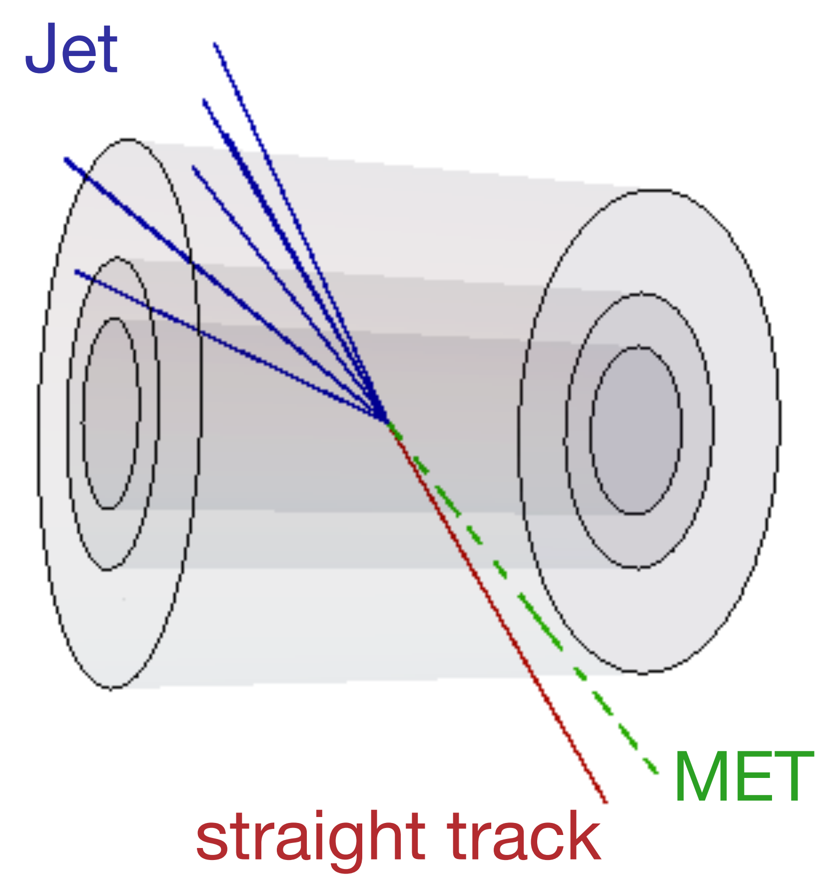
In the short string-length limit, the hits merge in the detector



Exclude $m_Q > 110$ GeV for $\Lambda > 10$ keV
(Drell-Yan production)

PhysRevLett.105.211803: D0 collaboration

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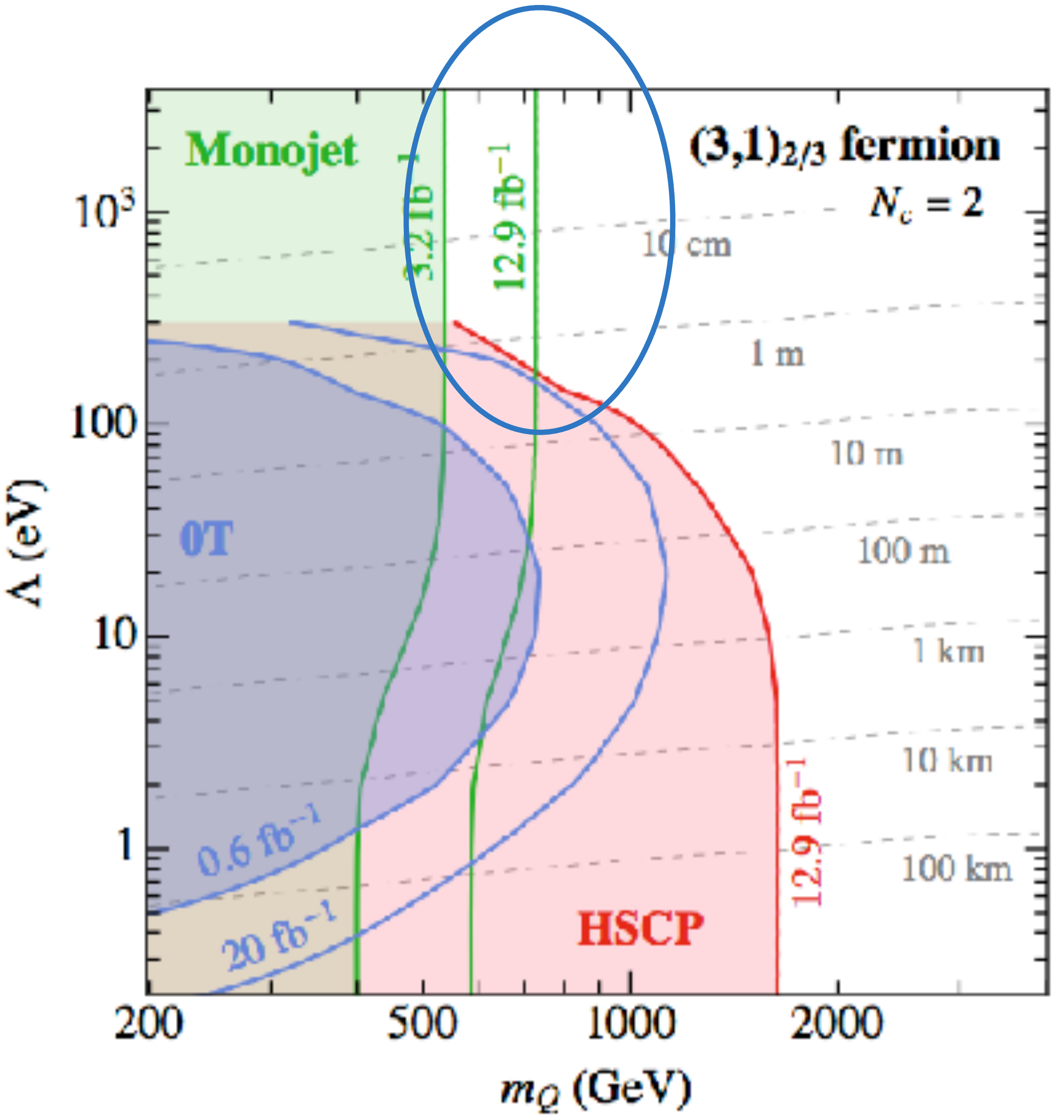

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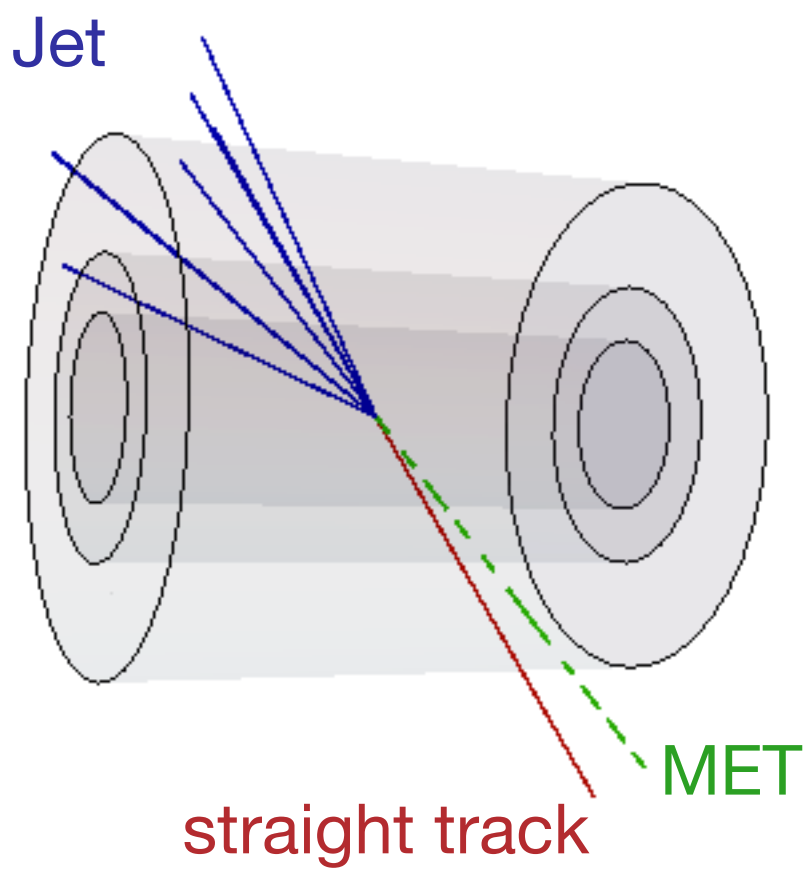
In the short string-length limit, the hits merge in the detector



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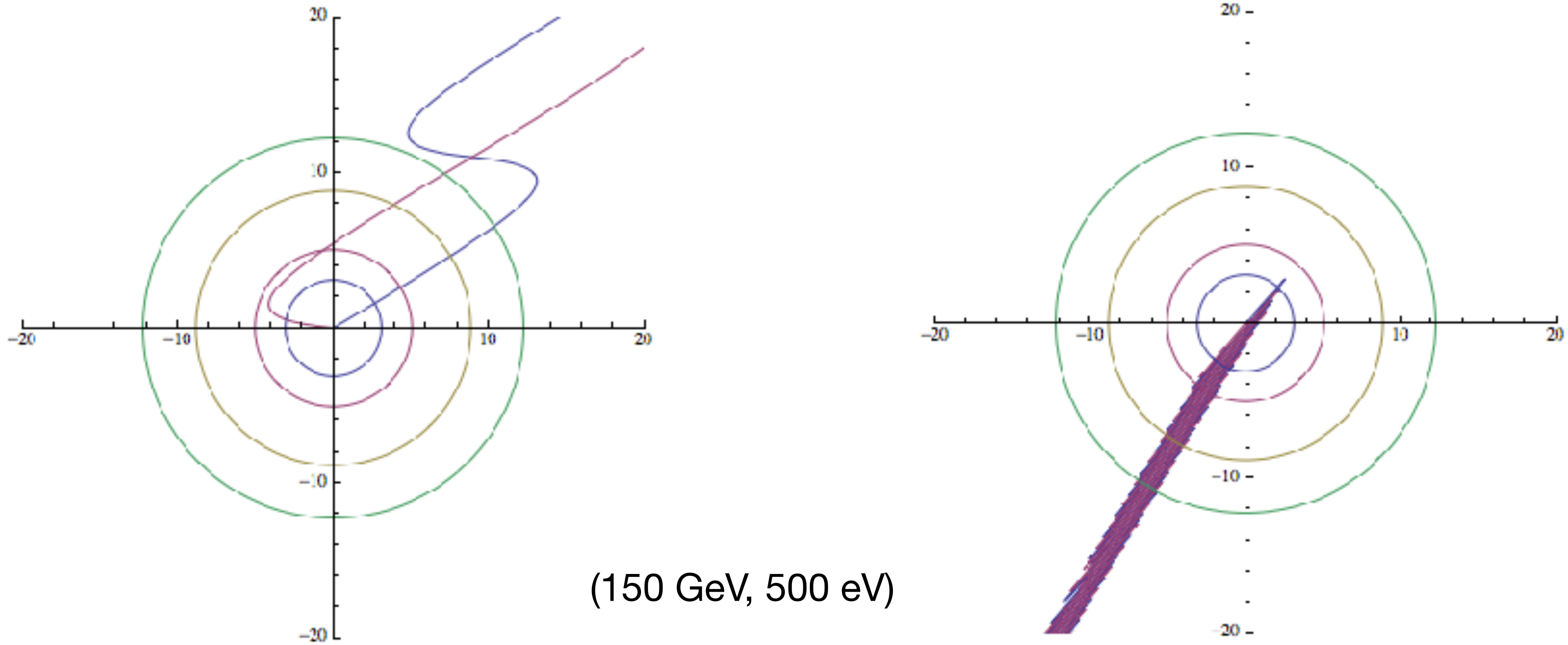
m to mm size oscillations are unconstrained

Why is this hard?

- Signature depends strongly on m_Q and Λ
- Even for same model point (m_Q, Λ), strong dependence on ISR



Both trajectories must be fit together, in total 8 degrees of freedom in the fit!

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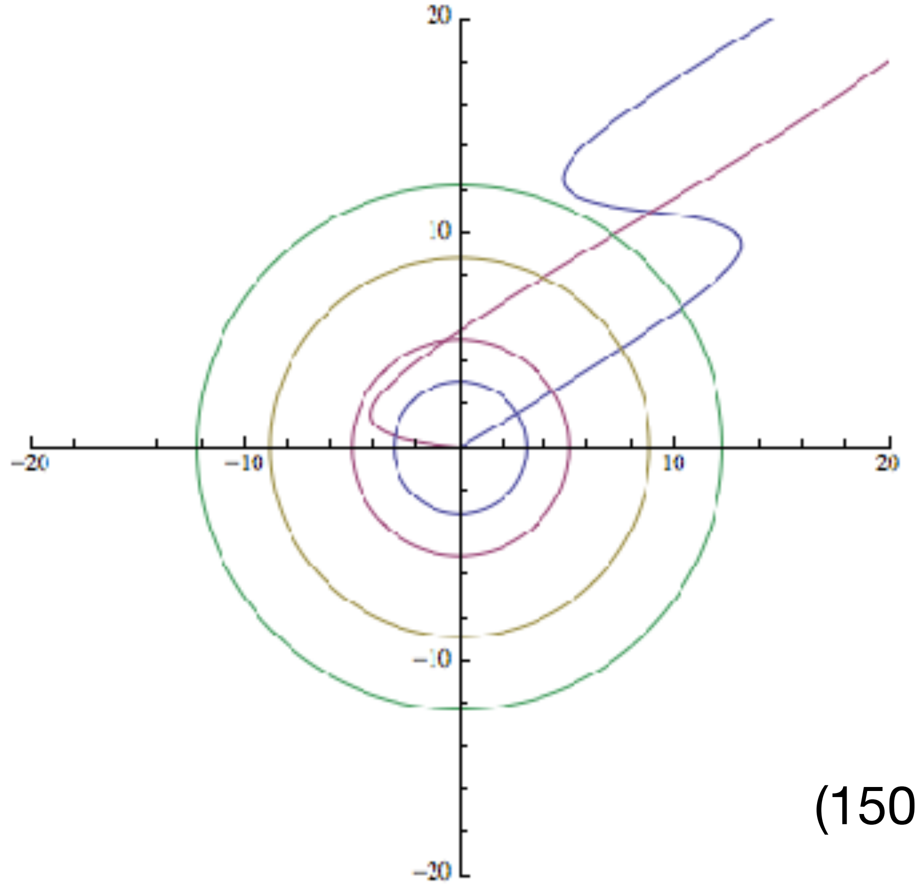
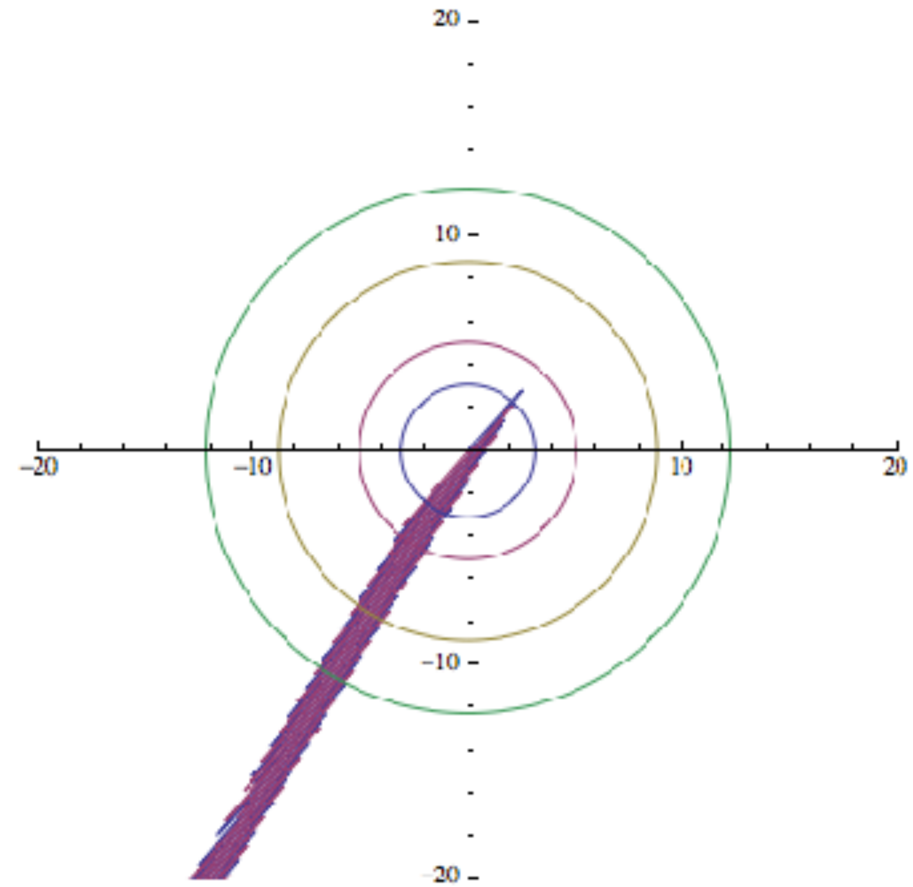


(150 GeV, 500 eV)



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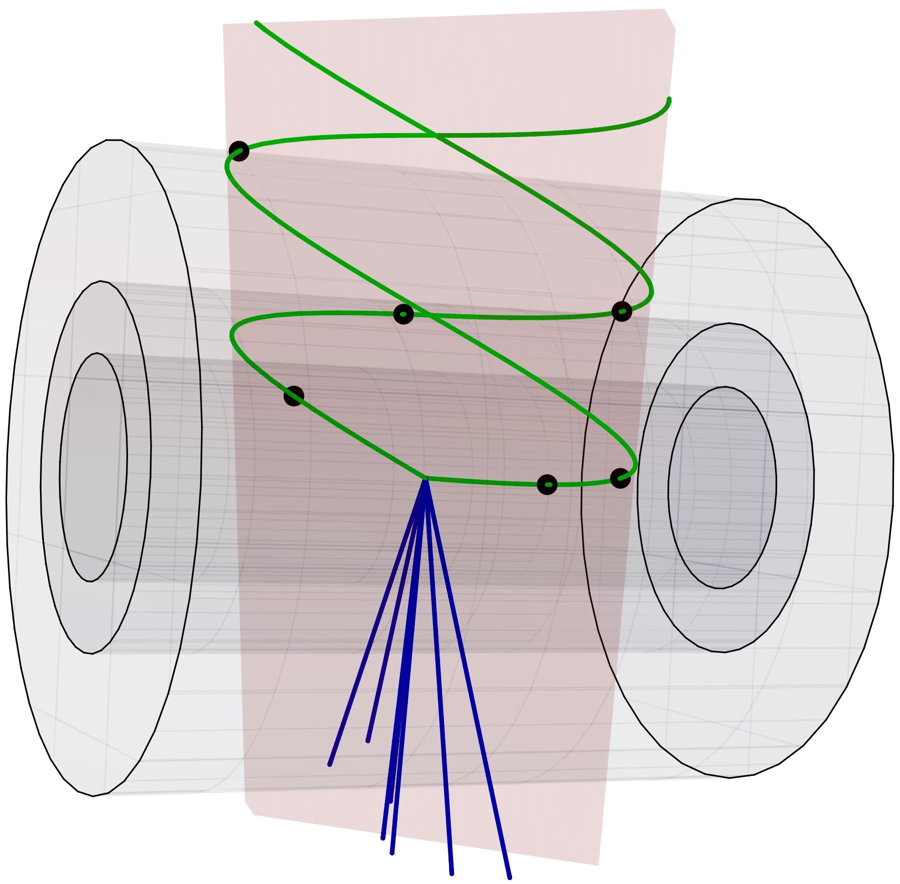
- Tons of unassociated hits from pile-up

Need a model-independent way to reject pile-up background to 10^{-9}, while maintaining signal efficiency

General idea

All hits lay in a plane



Dimensional analysis:

oscillation amplitude and period

$$d \sim \Delta t \sim \frac{m_Q}{\Lambda^2}$$

torque

$$\tau \sim 2d \times eB$$

angular rotation

$$\Delta\phi \sim \frac{\tau \Delta t^2}{I} \sim e\frac{B}{\Lambda^2}$$

As long as the string tension >> Lorentz force, the trajectories will be planar

(valid for any central force)

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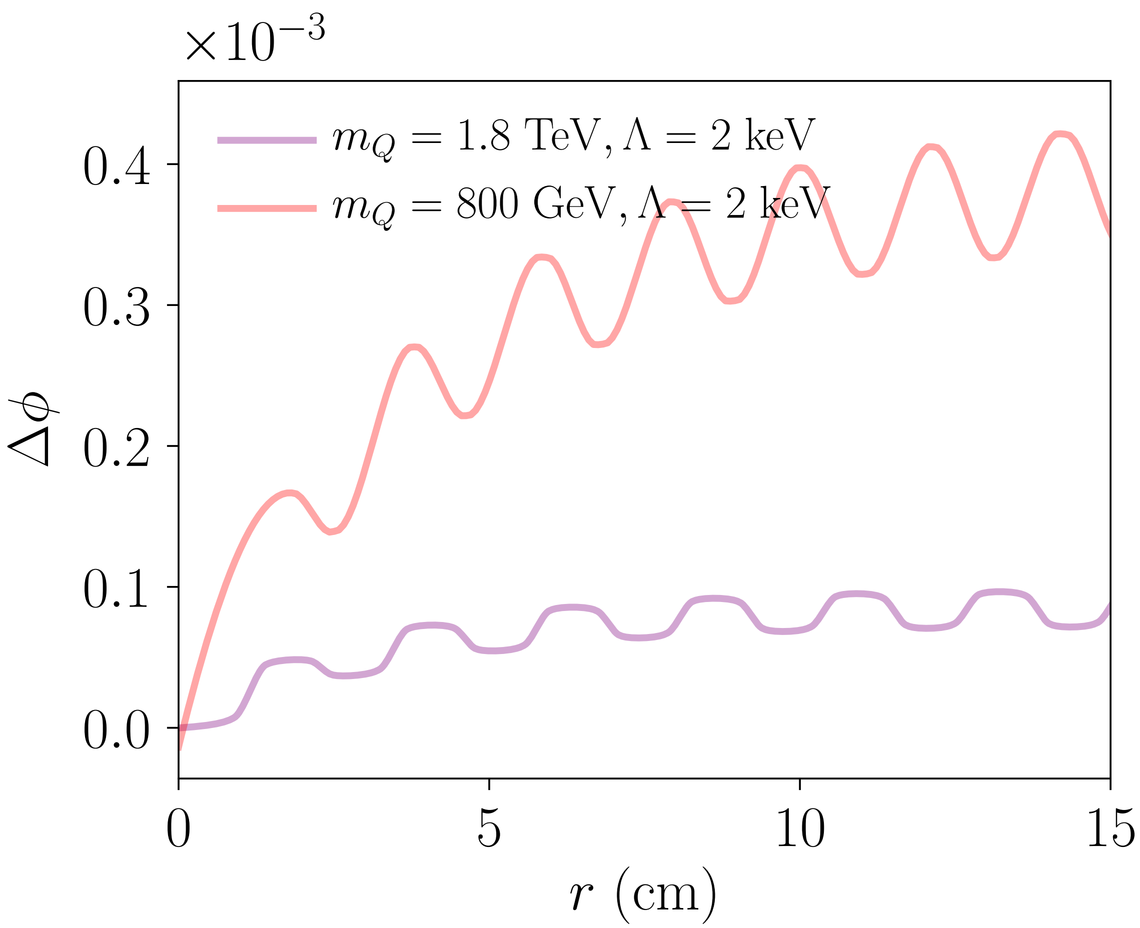

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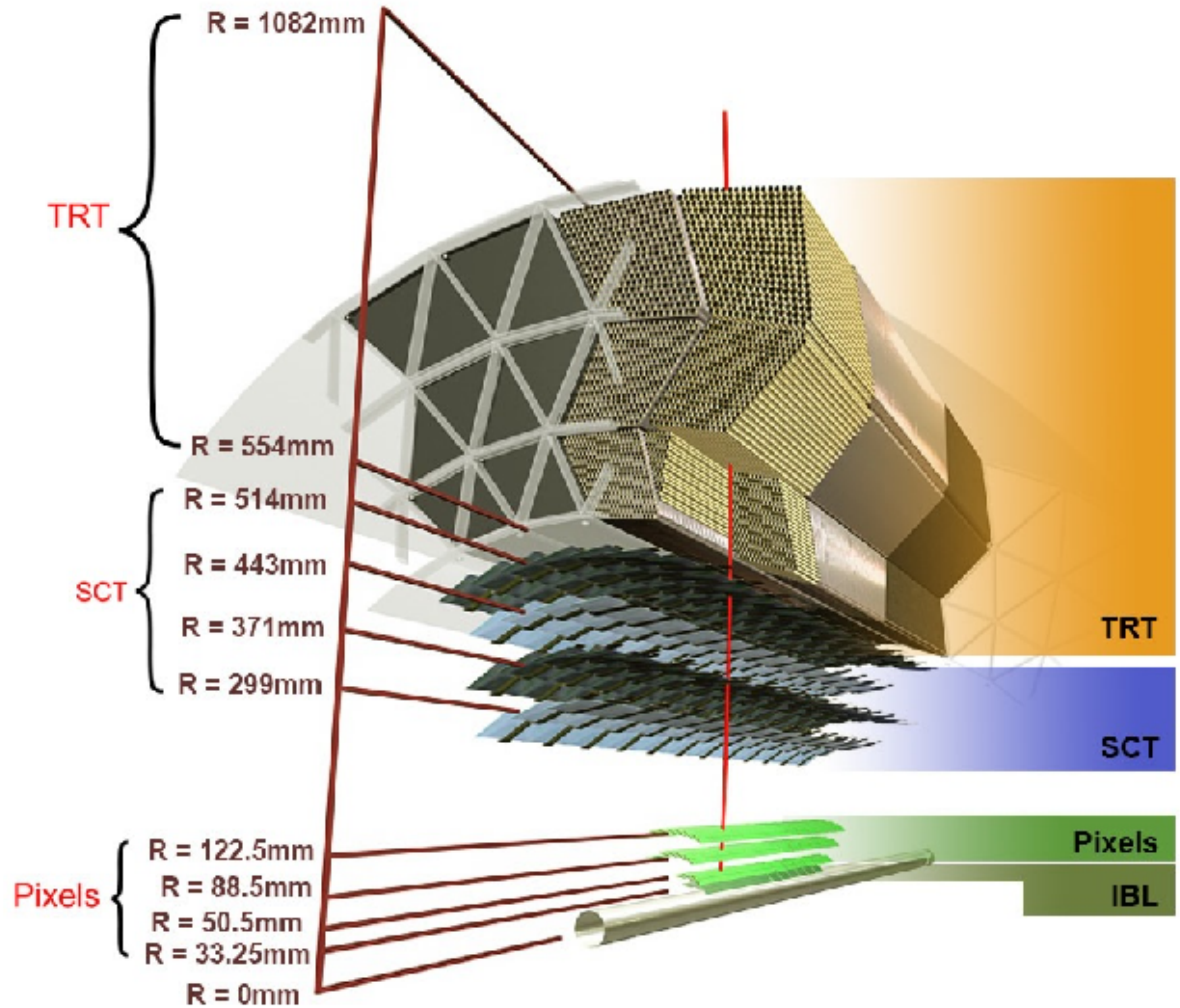
Analysis strategy

1. Trigger on MET (> 200 GeV)
   (muon trigger may also be possible)

2. Select planes with pairs of hits

3. Apply some selection cuts



For simplicity, only including the barrel of the pixel and SCT
(including more detector elements would of course enhance the sensitivity)

Simulation

Signal

- 0j+1j matched sample with Madgraph+Pythia 8
- Numerically solve quirk EOM, with B-field
- Propagate through theory model of ATLAS inner tracker
  (account for resolution, hit merging, finite beamspot, out-of-time hits etc)
- Overlay pile-up

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Pile-up

- Pythia 8 min bias, on average 50 pile-up interactions per crossing (~ twice current conditions)
- Propagate through theory model of ATLAS inner tracker
  (also account for bremstrahlung, dE/dx & service layers)

What is a ‘good’ plane?

We need a metric

$$\Delta = \sqrt{\mathbf{T}_{ij}\mathbf{n}_i\mathbf{n}_j}$$

minimize this

normal vector of plane

$$\mathbf{T}(\mathbf{x}_a)_{ij} \equiv \frac{1}{N-1}\sum_{a=1}^{N}\mathbf{x}_i^a\,\mathbf{x}_j^a$$

coordinates of hits

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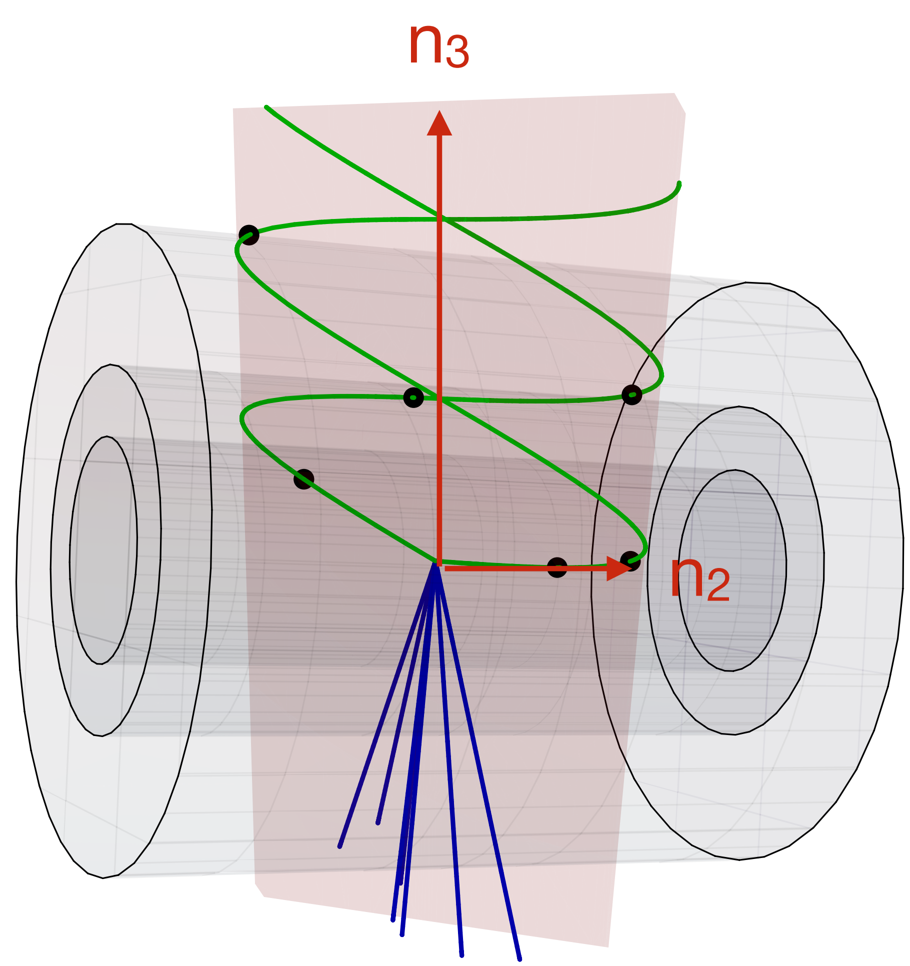
Eigenvectors:

n_1: “thickness” of the plane

n_2: “width” of the strip

n_3: direction of the center of mass frame



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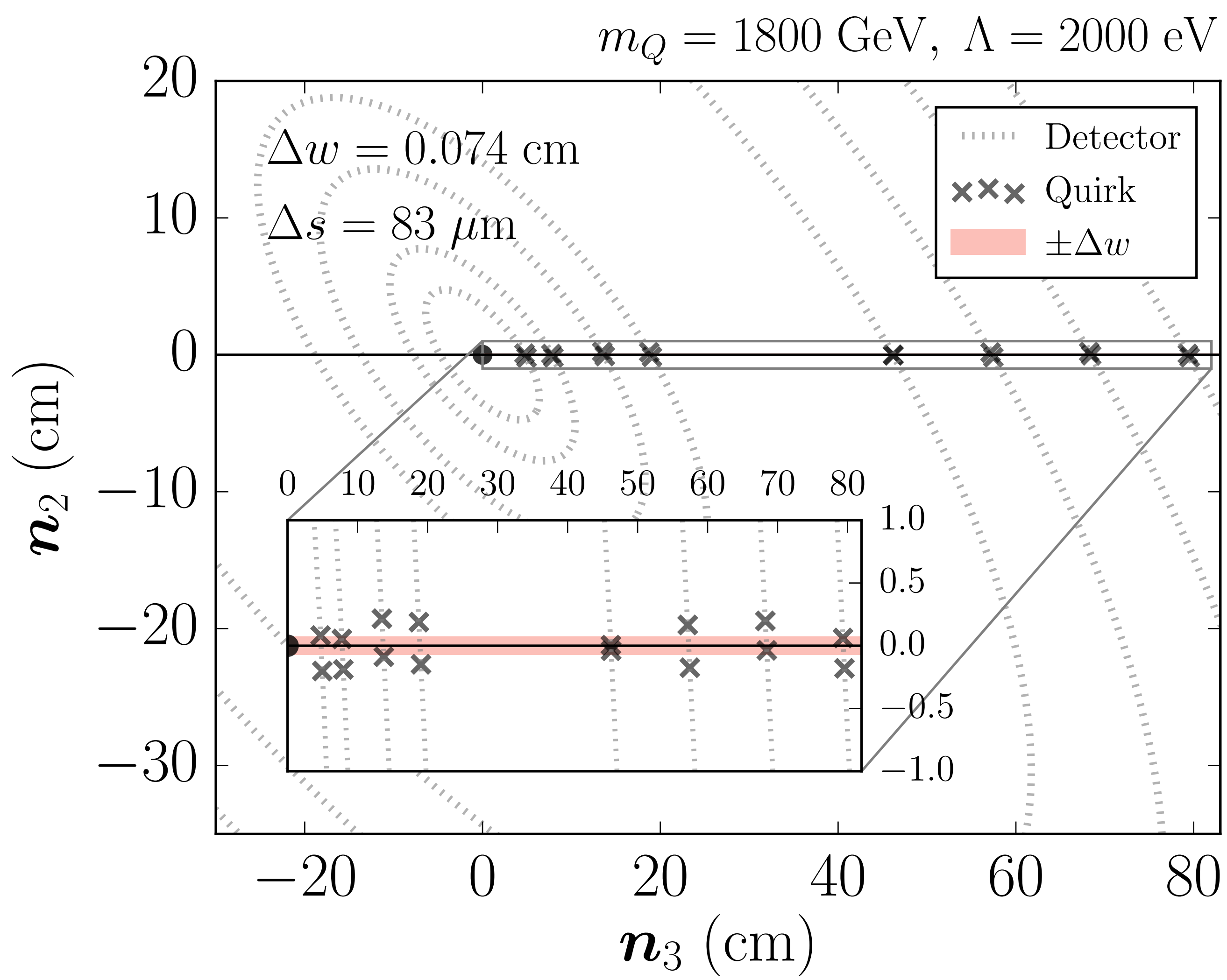

Fitting procedure

1. Seeding: starting with outer most layer 4th and 3rd layer of SCT
    - Select pairs of hits in each plane with $\Delta\phi < 0.1$ and $\Delta z < 2$ cm
    - 1 pair in 4^{th} layer + 1 pair in 3^{th} layer makes a seed

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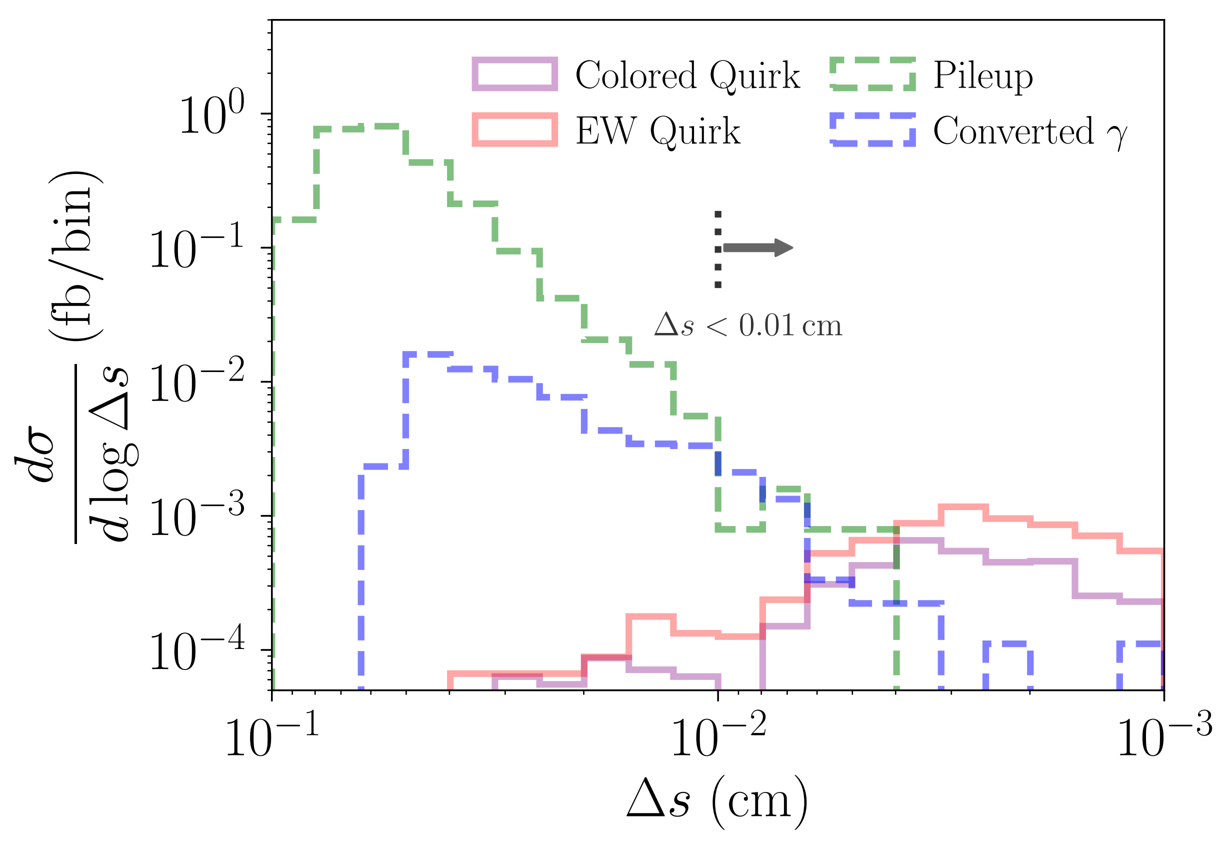
3. Plane selection: cut on
    - Δs
    - Δw
    - N_{miss}

Results

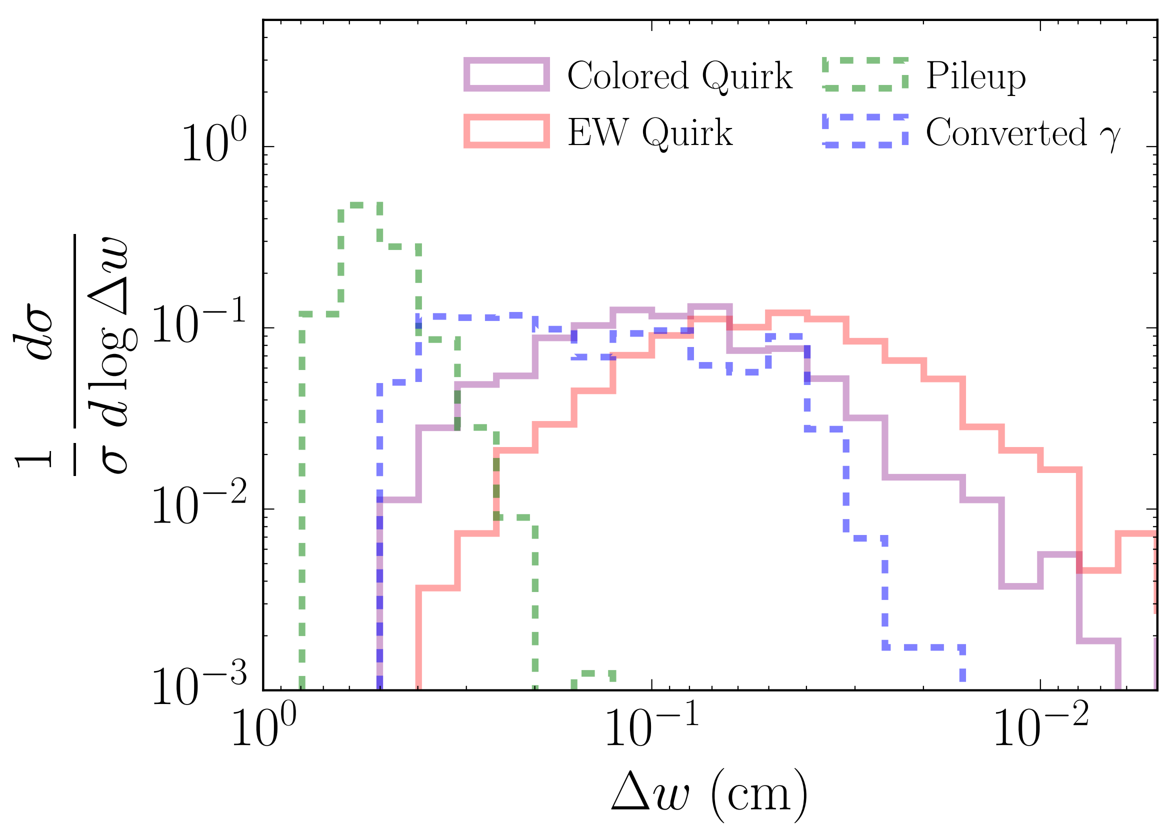
cuts:

- At most one missing hit
- Δs < 0.01 cm and Δw < 1 cm

“thickness”



“width”



For 300 fb^{-1}, only a handful of background events

Signal efficiency

$$\epsilon = \epsilon_{\rm trig} \times \epsilon_{\rm fid} \times \epsilon_{\rm reco}$$

ϵ_{trig} : pass MET trigger

ϵ_{fid} : 2 hits in each layer of pixel + SCT barrel

ϵ_{reco} : efficiency of identifying correct plane

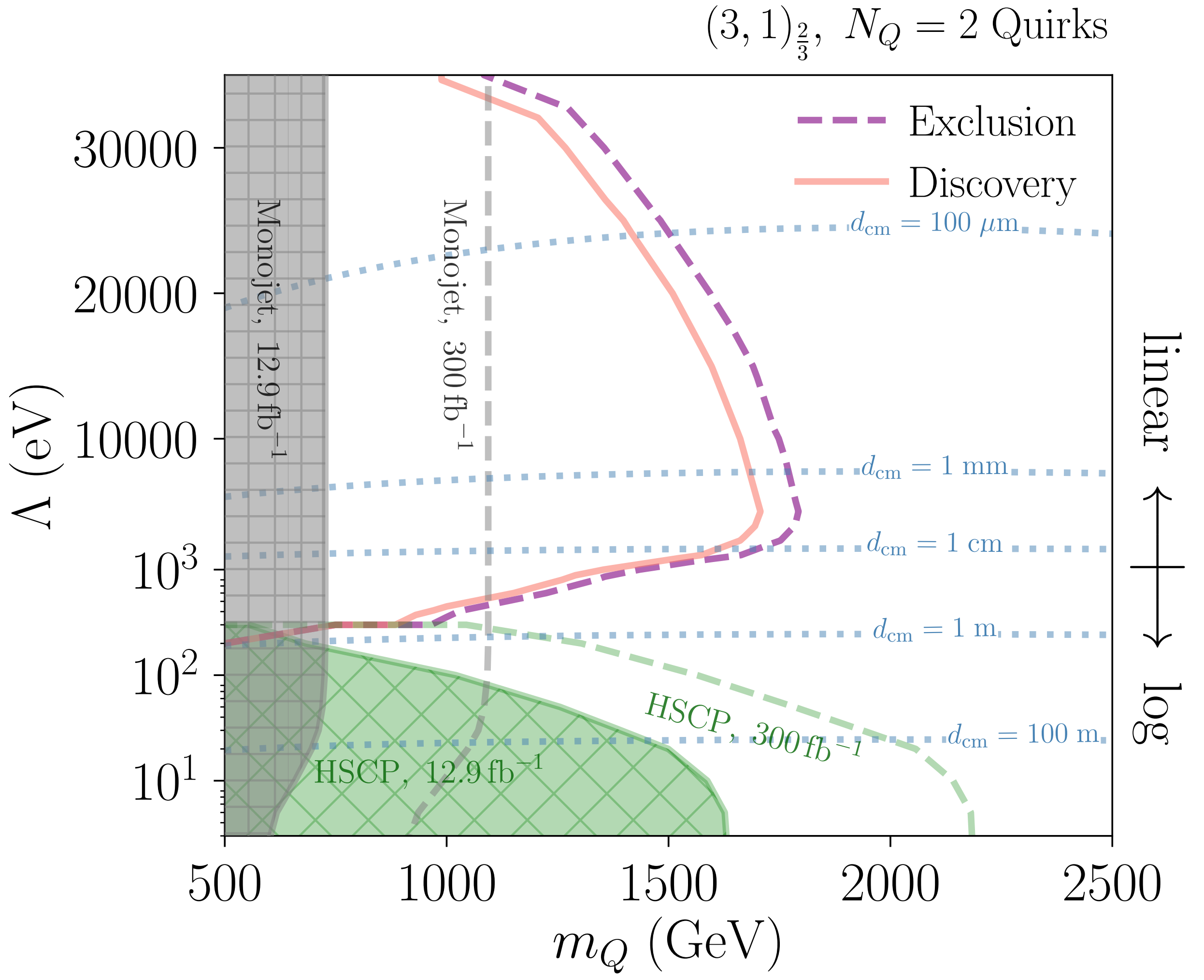
m_Q (GeV)	Λ (keV)	$\epsilon_{\rm trig}$	$\epsilon_{\rm fid}$	$\epsilon_{\rm reco}$
800 (DY)	1	0.10	0.28	0.11
	2			0.41
	3			0.65
	4			0.72
	5			0.74
1800 (QCD)	1	0.24	0.28	0.083
	2			0.35
	3			0.59
	5			0.74
	10			0.58

seeding fails, because hits too far apart

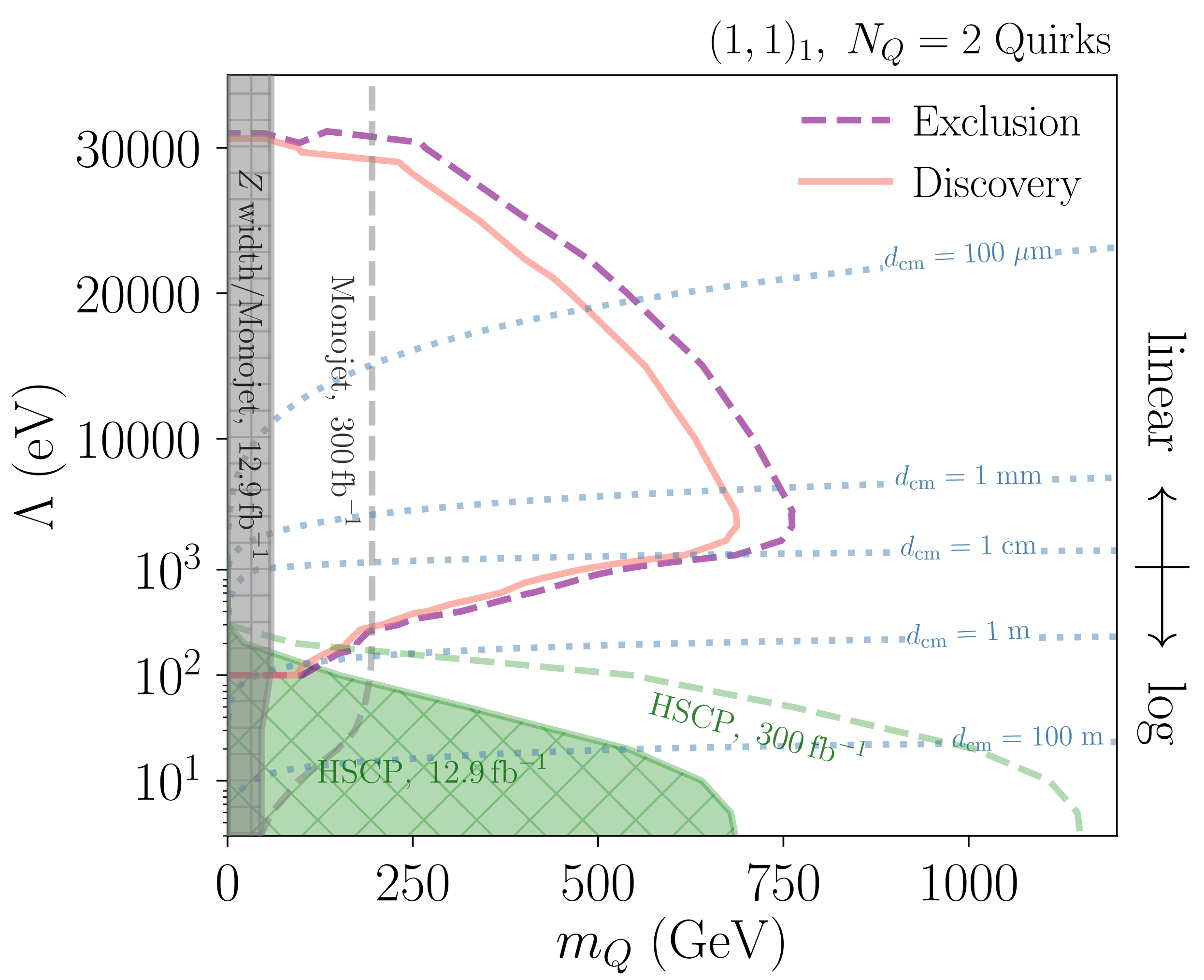
Hits start merging, only 1 hit per layer is found

Projected reach

Colored production



Drell-Yan production

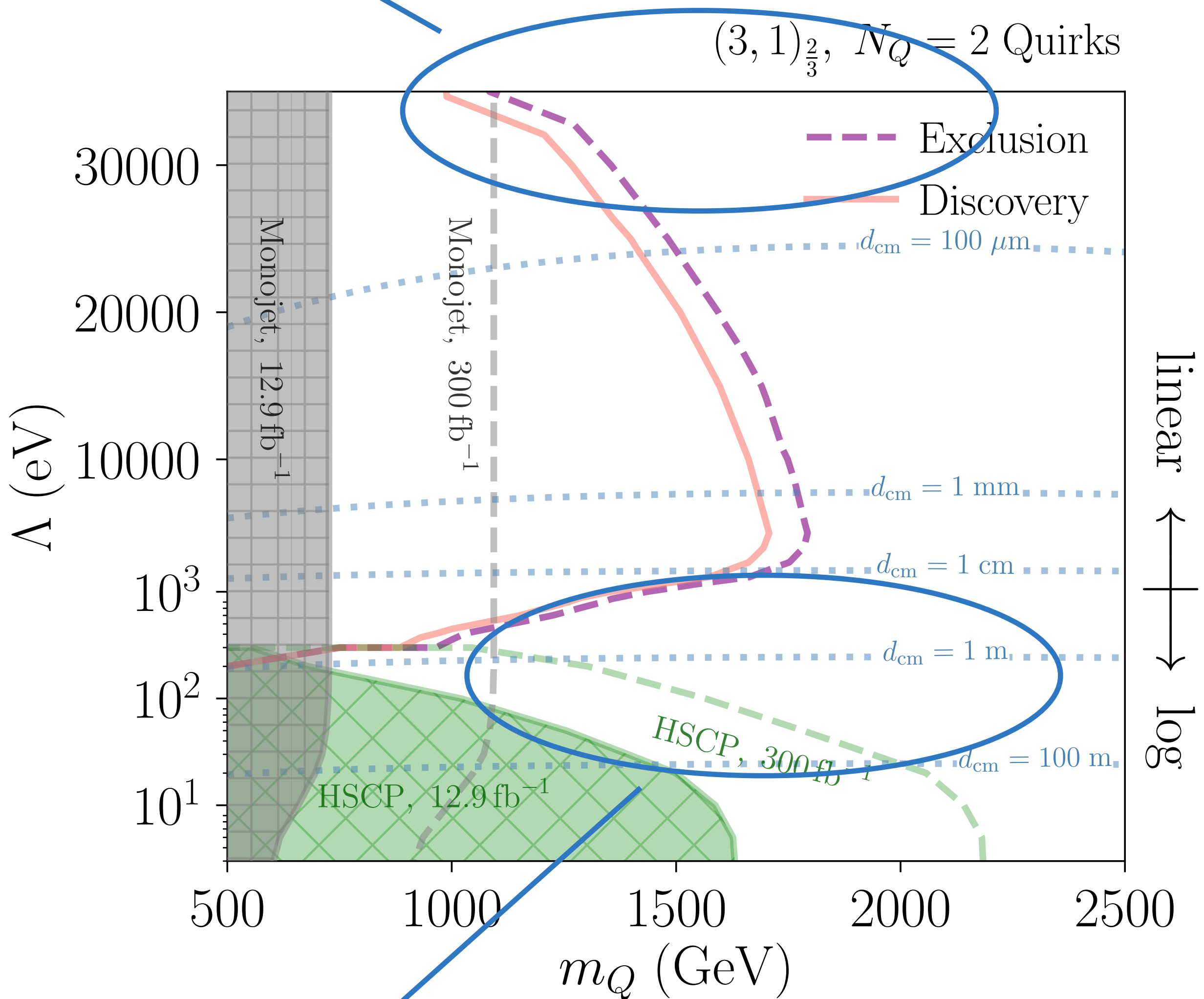


(Assuming negligible irreducible backgrounds)

Projected reach

Hits merge

Colored production



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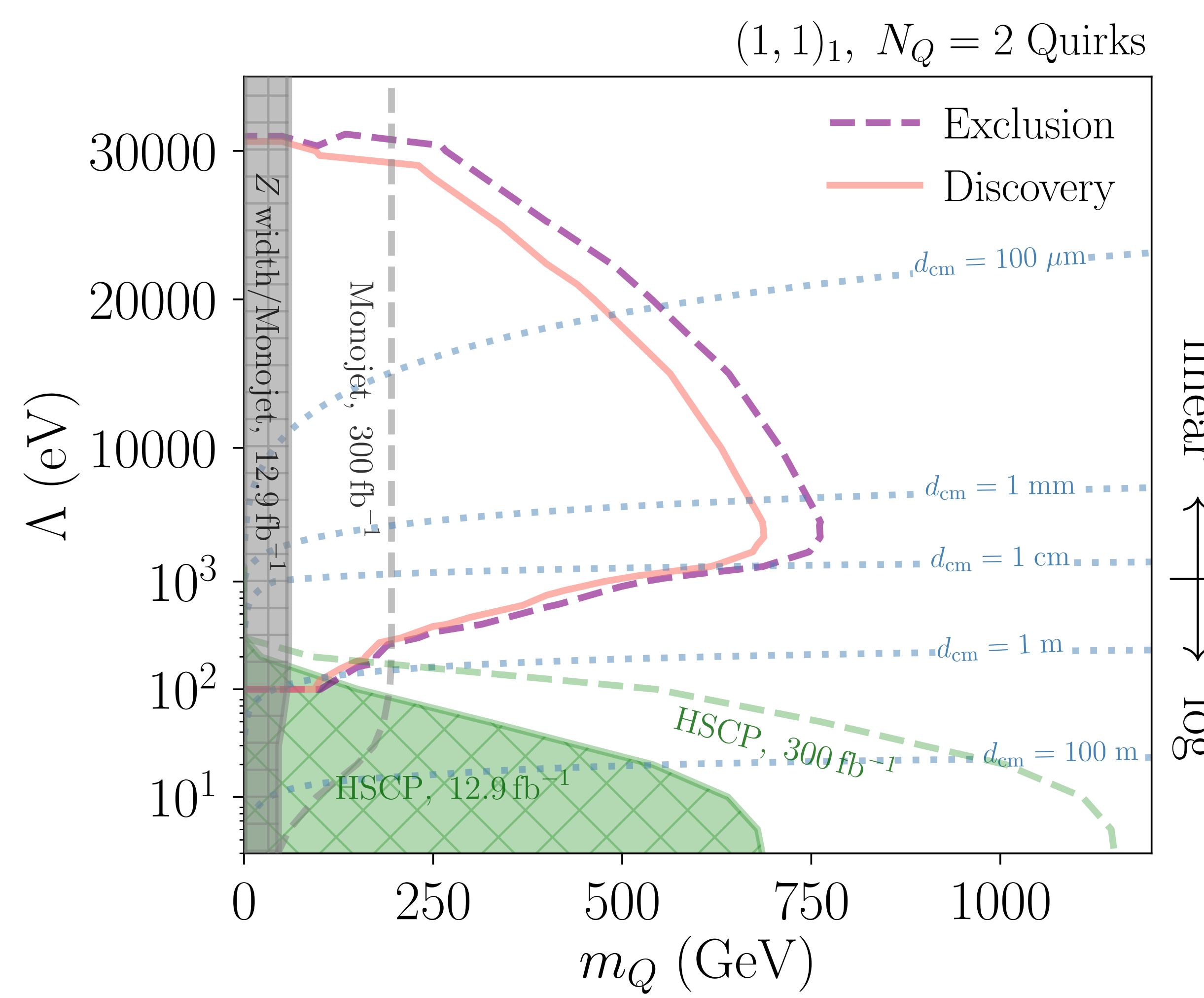
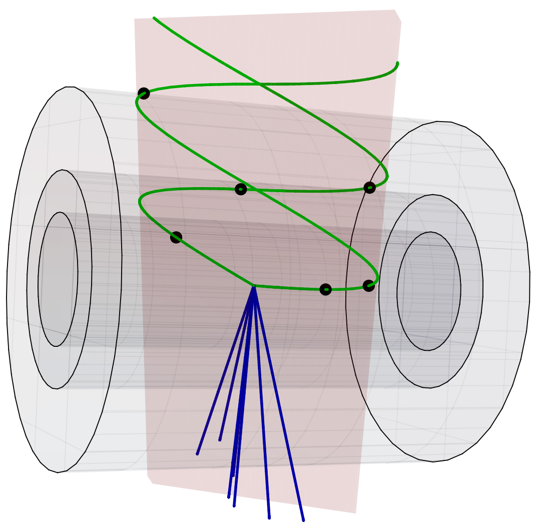


Δw cut, due to computational limitations

(Assuming negligible irreducible backgrounds)

Upshot



Quirks can be found by searching for hits forming planes, without developing a tracking algorithm for quirky tracks.

- So far only used barrel of pixel & SCT
- Works for any central force, provided that is stronger than the B-field
- Let’s not overlook the high string tension case!

Thanks!