Searches with a Disappearing-Track Signature

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LHC Searches for Long-Lived BSM Particles
U. Mass, Amherst
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http://www.physics.umass.edu/acfi/seminars-and-workshops/lhc-searches-for-long-lived-bsm-particles-theory-meets-experiment

AMHERST CENTER FOR FUNDAMENTAL INTERACTIONS
Physics at the interface: Energy, Intensity, and Cosmic frontiers
University of Massachusetts Amherst

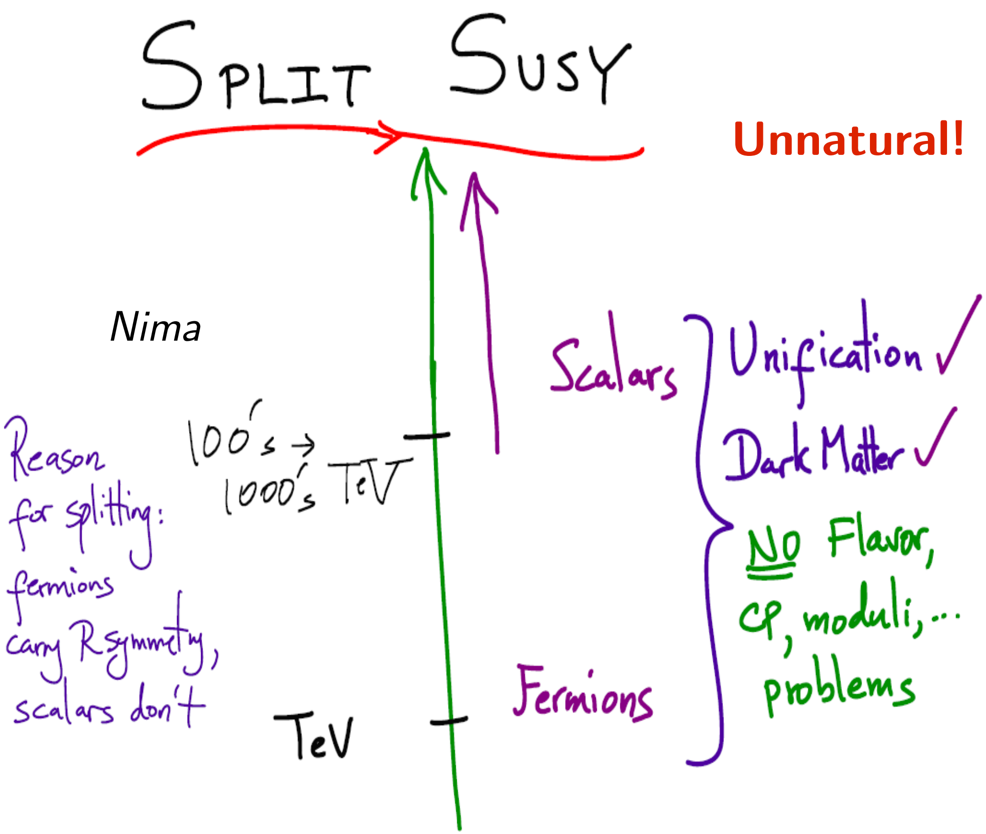
NEW YORK UNIVERSITY

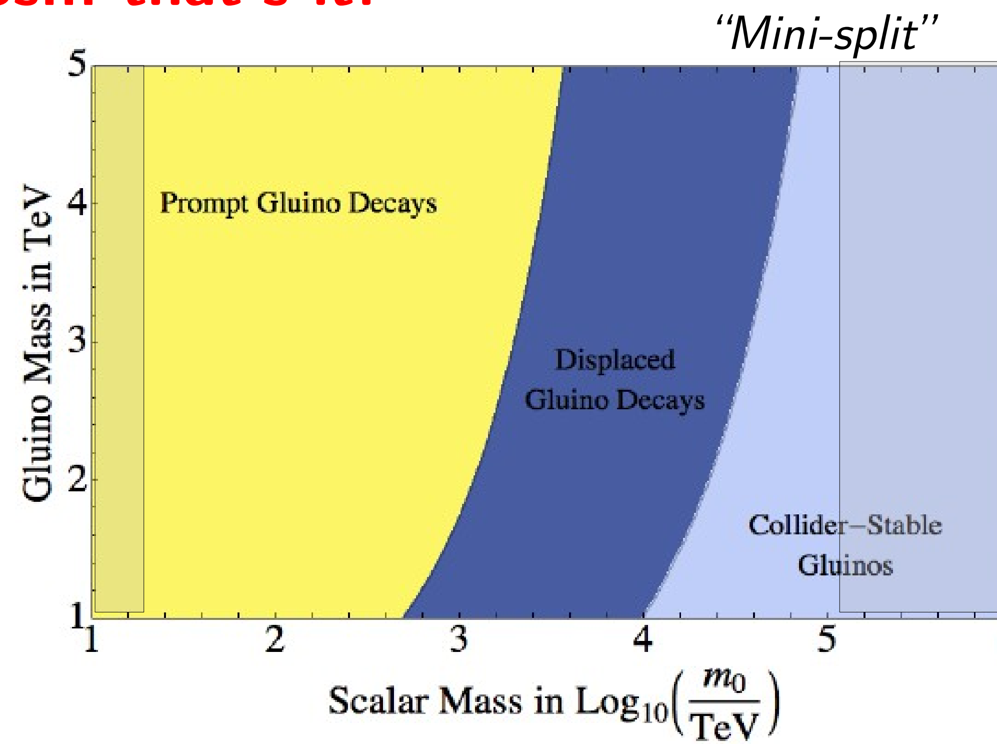
ATLAS

Introduction / motivations

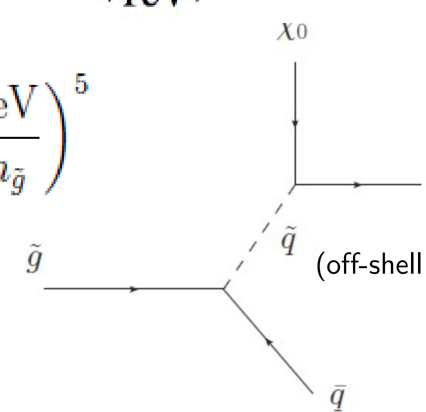
- **Only sfermions (Gauginos and Higgsinos) are within LHC reach**
- **Can go after gluinos or EW-inos... that's it!**

- ***Gluino lifetime depends on m_0***





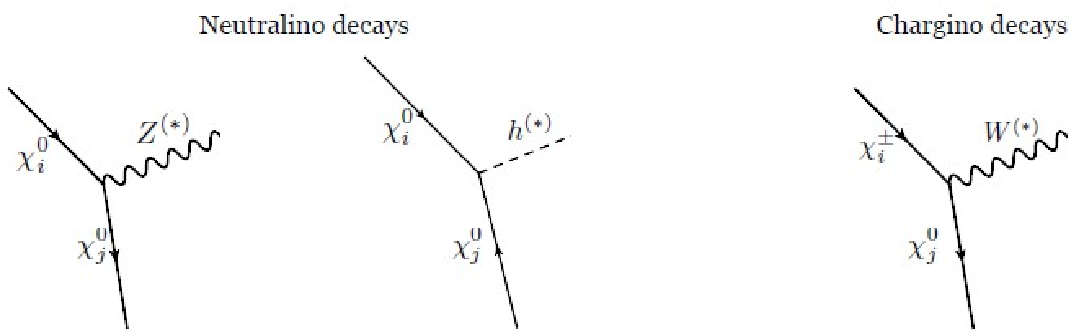
$$c\tau \approx 10^{-5}\mathrm{m}\left(\frac{m_{\tilde{q}}}{\mathrm{PeV}}\right)^4 \left(\frac{\mathrm{TeV}}{m_{\tilde{g}}}\right)^5$$



Introduction / motivations

- **EW-ino phenomenology depends on SUSY spectrum**

- Light Bino only: pp $\rightarrow$ invisible!
  - mono-jet+MET?
  - Out of luck?
  - ILC? μ-collider?



- Light Wino and Bino
  - Heavy Higgsinos
    - Bino LSP : $x_1^+ x_1^- \rightarrow W^+W^-$ (+MET), $x_1^+ x_2^0 \rightarrow W^+h$ (+MET)
    - **Wino LSP : Disappearing track (~10 cm, Δm~165 MeV)**
  - Light Higgsinos: W^+W^- (+MET), W^+h (+MET) and Zh (or Z*) and hh (or h*)
- Higgino LSP
  - **Only light Higgsinos: Disappearing track (~1 cm, Δm~355 MeV)**
  - Light Gravitino: hh (+MET), possibly displaced?

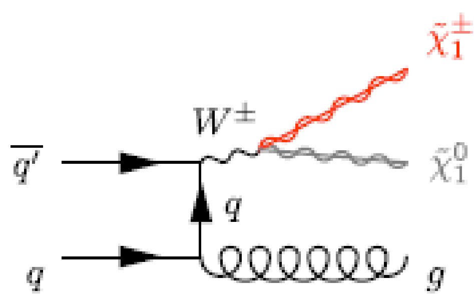
Long-lived Chargino

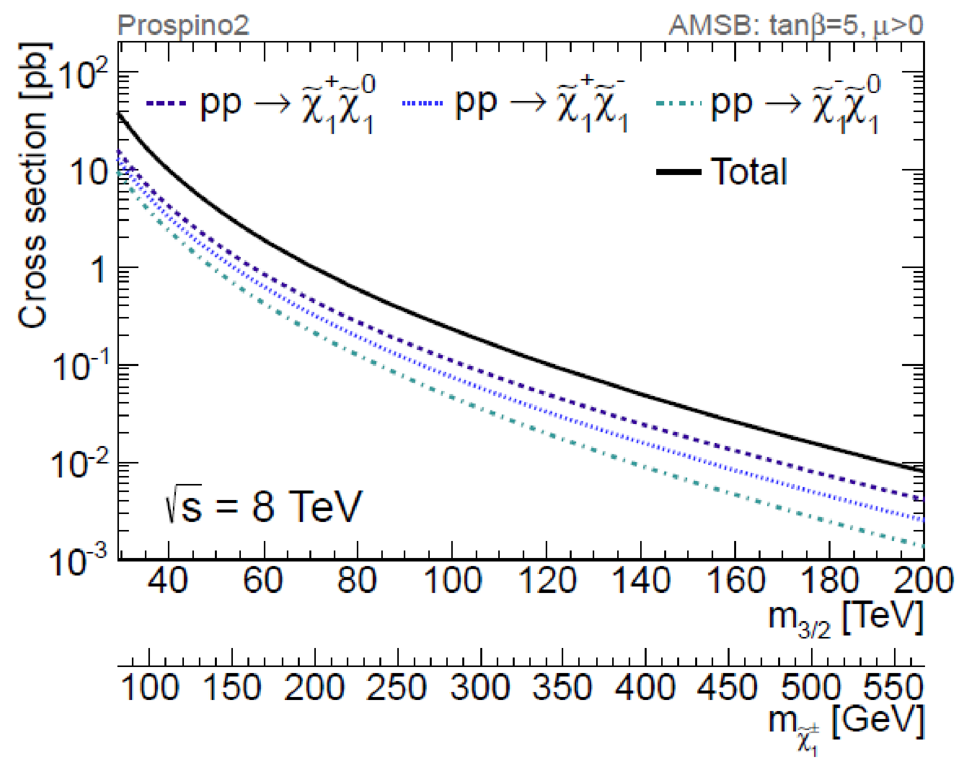
- Chargino becomes long-lived when nearly-degenerate with the LSP
- Phenomenology identical to Anomaloy-Mediated SUSY Breaking (AMSB)

- Light Wino and Bino, heavy Higgsinos, Wino LSP
  - Lifetime ~50 mm, Δm~165 MeV from EW contribution
- Higgsino LSP, only light Higgsinos
  - Lifetime ~5 mm, $\Delta m = \frac{1}{2}\, \alpha\, m_Z$ = ~355 MeV

$$pp \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{0} + \text{jet}\ ,\ pp \rightarrow \tilde{\chi}_1^{+}\tilde{\chi}_1^{-} + \text{jet}$$

Need pT>90 GeV ISR for MET trigger:
~15% of cross-section



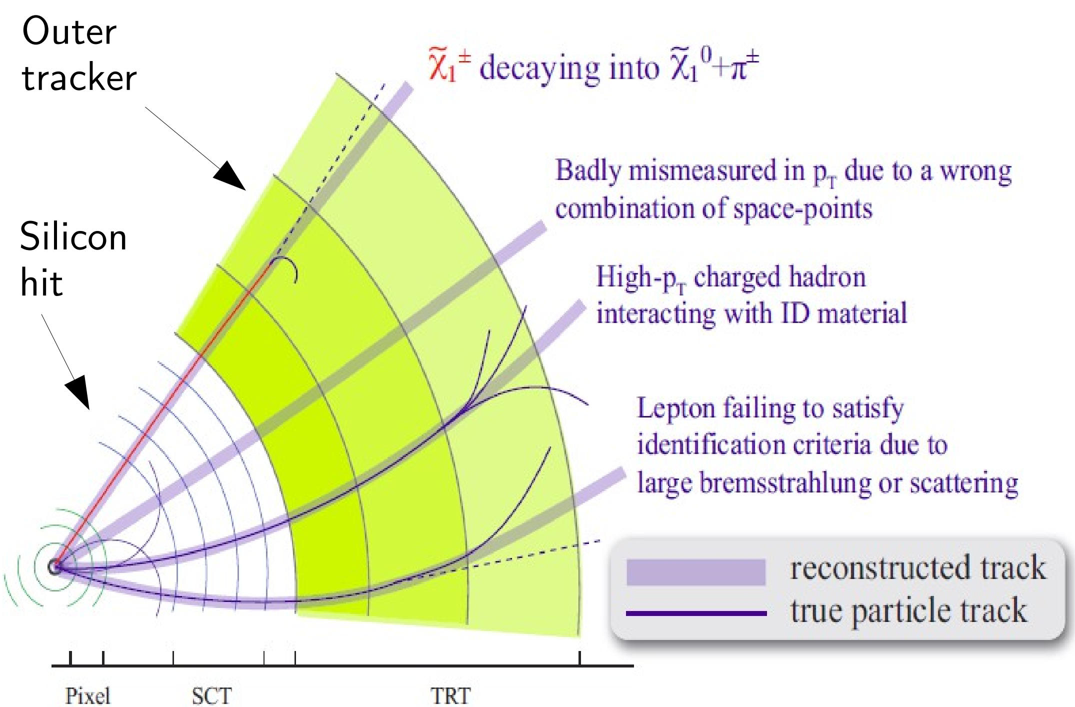


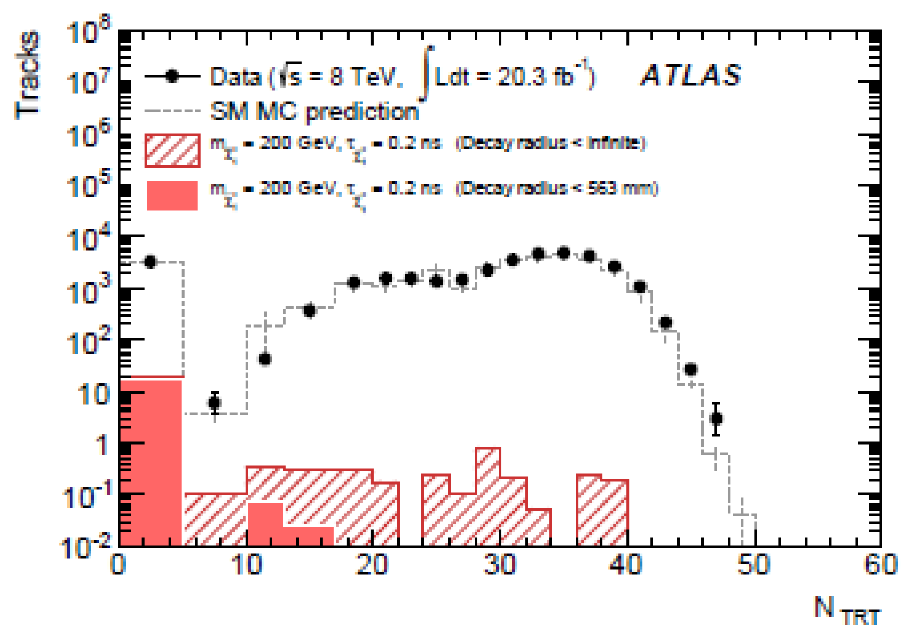
ATLAS Disappearing track search

arxiv:1310.3675

- Chargino travels through some layers
  then decays to a soft pion (not reconstructed) + MET

- Look for high-pt isolated track with few hits in outer tracking layer
  - Track needs at least 3 inner pixel hits and 1 silicon strip hit
  - Require <5 outer-tracker (TRT) hits

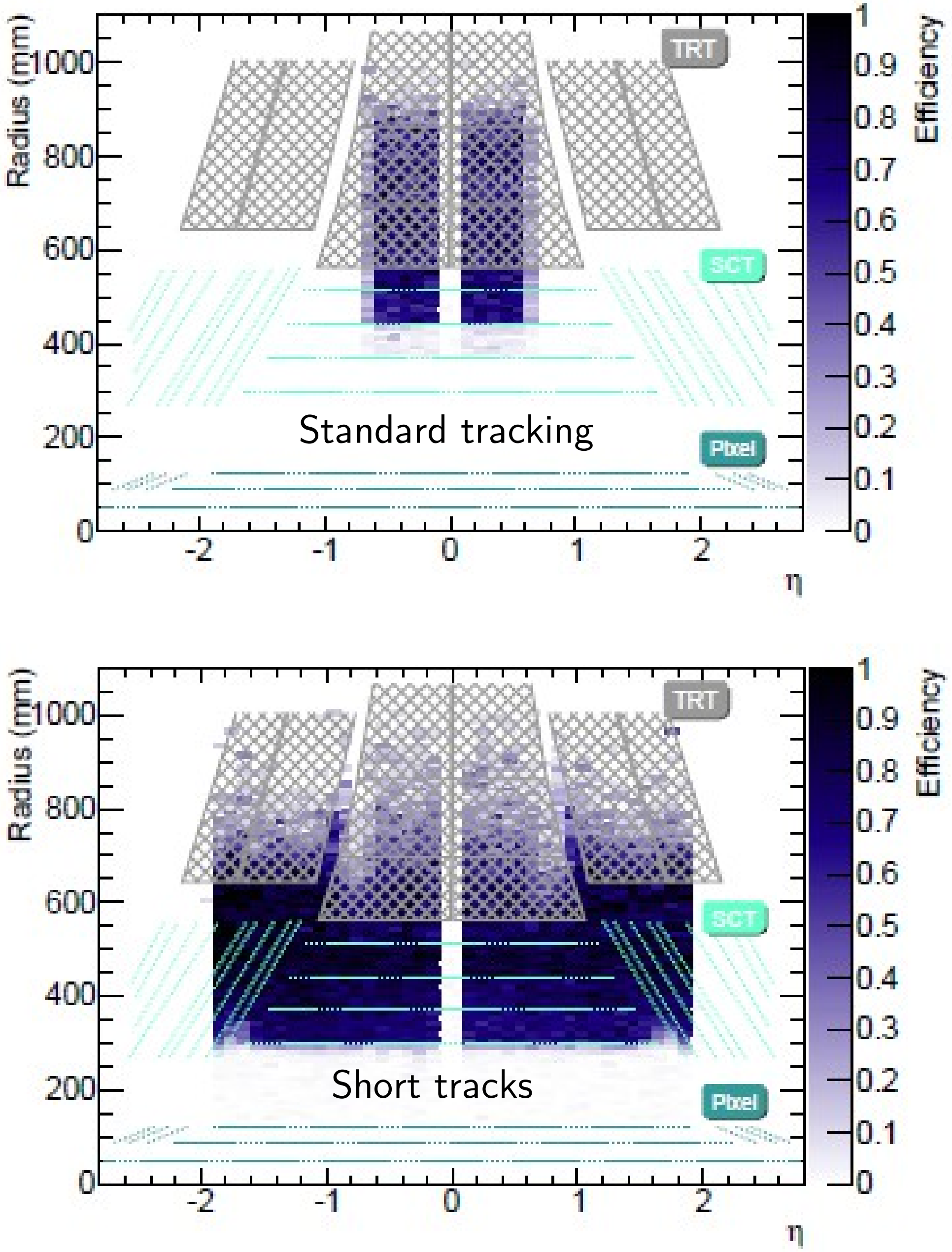




Improved ATLAS disappearing track search

- Large improvement from customized track reconstruction
  - *(Needs access to data with all tracker hits saved…)*

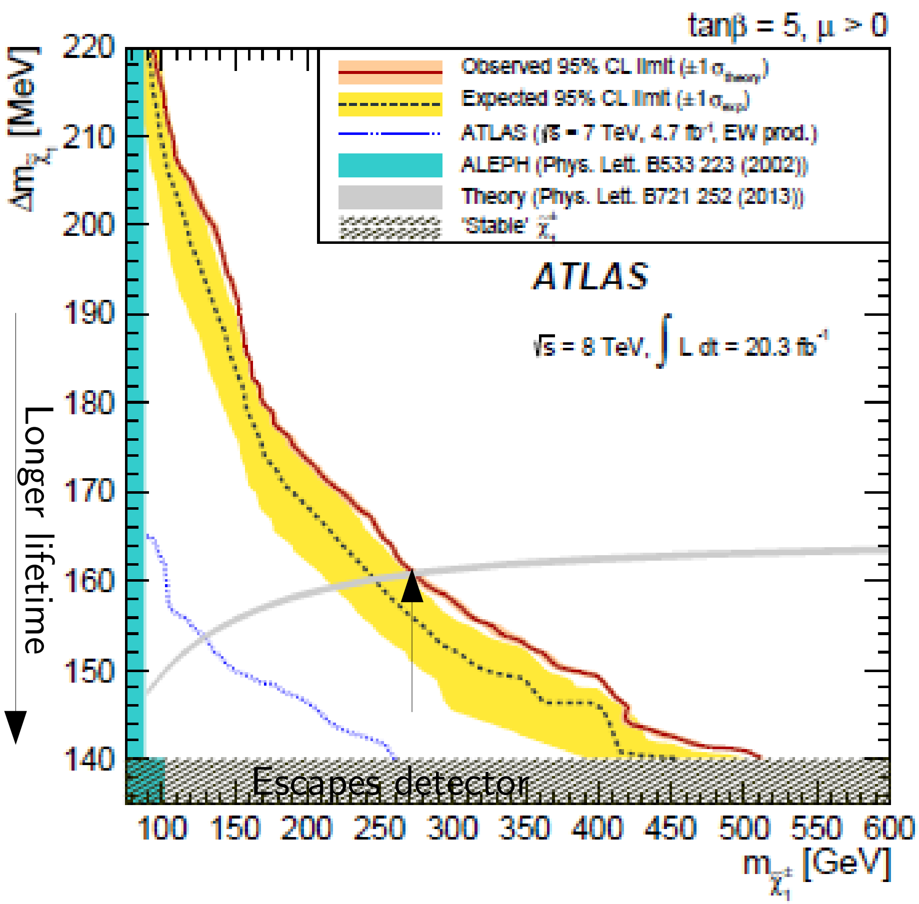
- Require just 1 Si strip layer (instead of 3) and no TRT
  - Decay volume moves to r>~300 mm and widens
  - Efficiency 100x larger for cτ=50mm (165 MeV)

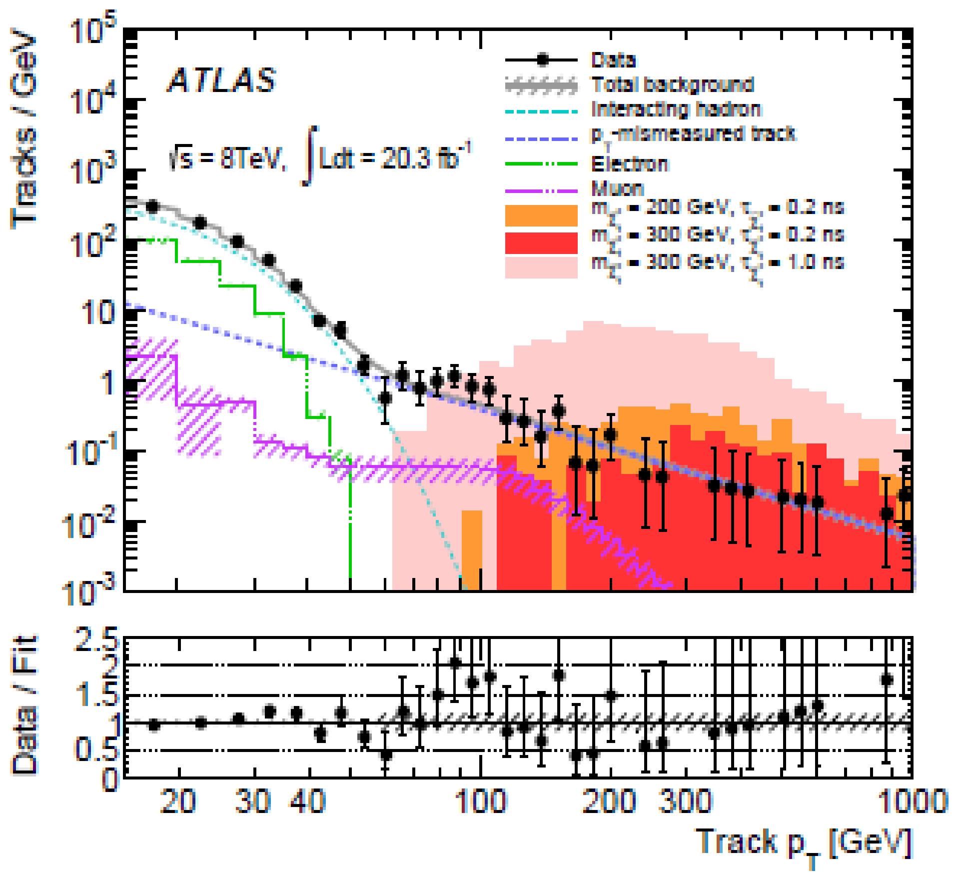


Improved ATLAS disappearing track search

- Background track pT shapes fit to data
  - No excess seen at high pT :(

- Exclude chargino <270 GeV in AMSB with Δm~165 MeV

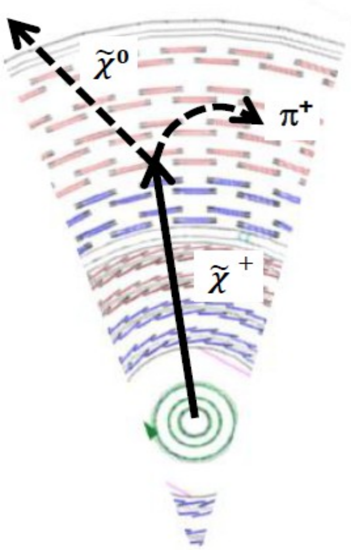


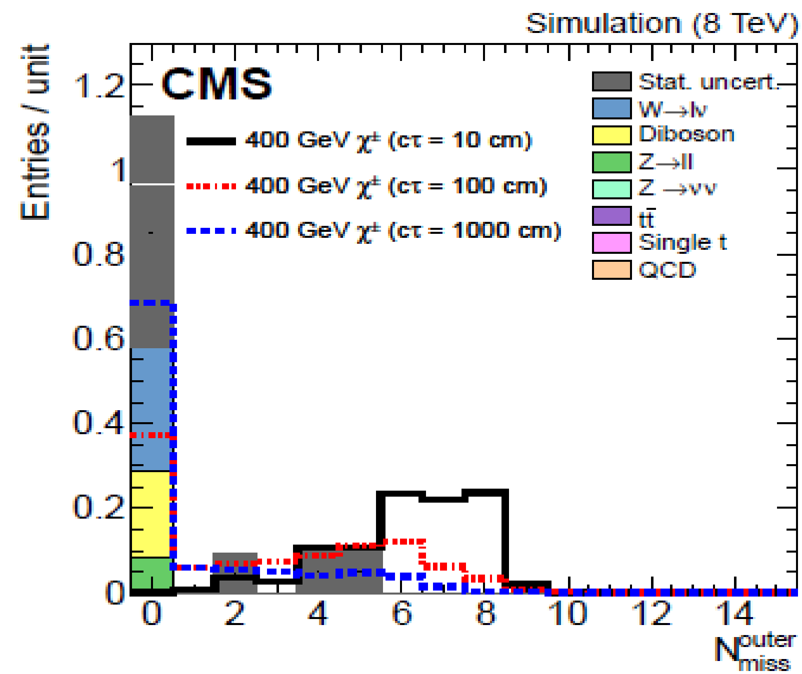


CMS Run1 search for disappearing tracks

- CMS has recently published a very similar search with very similar sensitivity and results
- Takes advantage of more tracking layers to reduce fake-track background
- Additional pattern-recognition issues (outer hits can form an alternate track)

Event source	Yield
Electrons	<0.49 (stat) <0.50 (stat+syst)
Muons	$0.64^{+1.47}_{-0.53}$ (stat) ± 0.32 (syst)
Taus	<0.55 (stat) <0.57 (stat+syst)
Fake tracks	$0.36^{+0.47}_{-0.23}$ (stat) ± 0.13 (syst)
Data	2

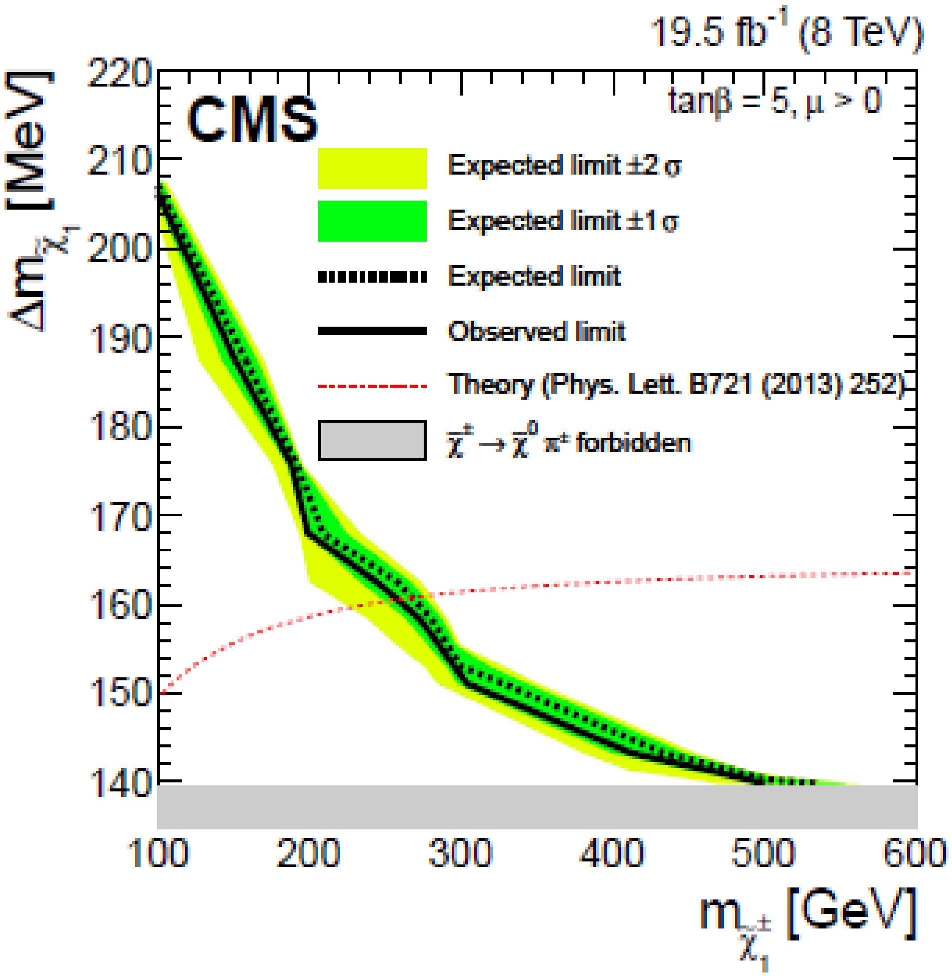


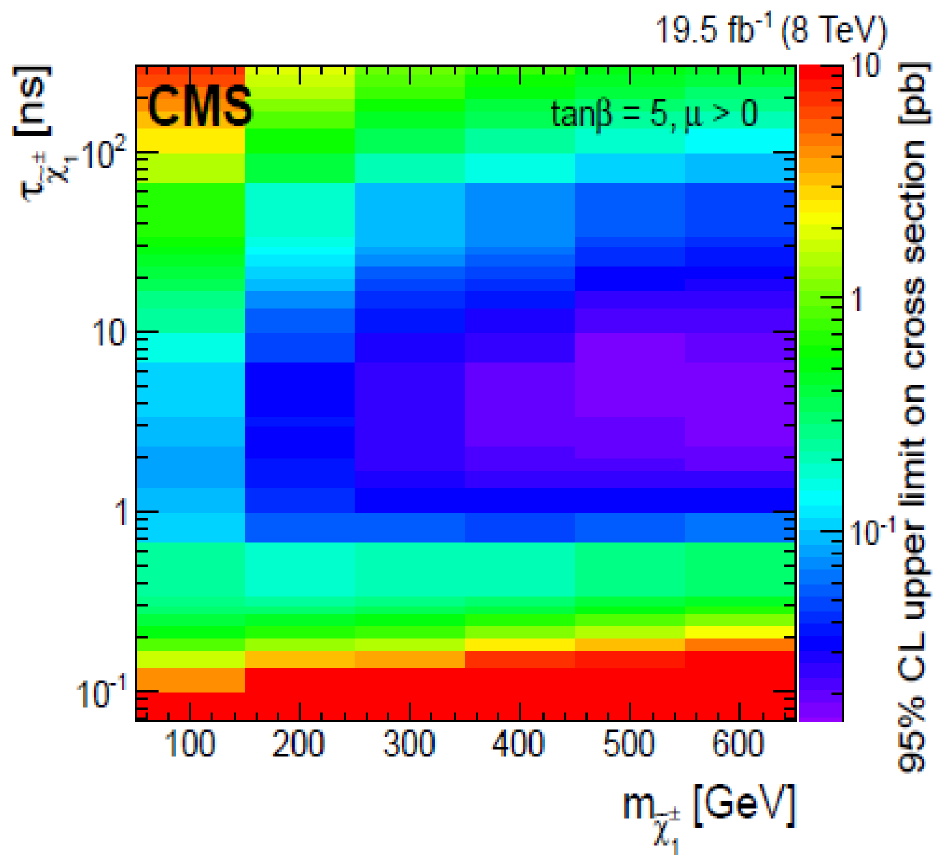


- Have Pt > 50 GeV.
- Be isolated.
- Deposit < 10 GeV in calorimeter.
- Not be identified e, μ or τ.

CMS Run1 search for disappearing tracks

- Slightly better (expected) mass reach,
  slightly worse (expected) small-lifetime reach
- Nice "model-independent" plot of cross-section exclusion





Lots of room for gains!

- **As opposed to most other BSM searches, selection efficiency for disappearing tracks is *tiny* ! (At ATLAS too!)**

- Need ISR for triggering
  - Are there other production channels we could use? VBF?

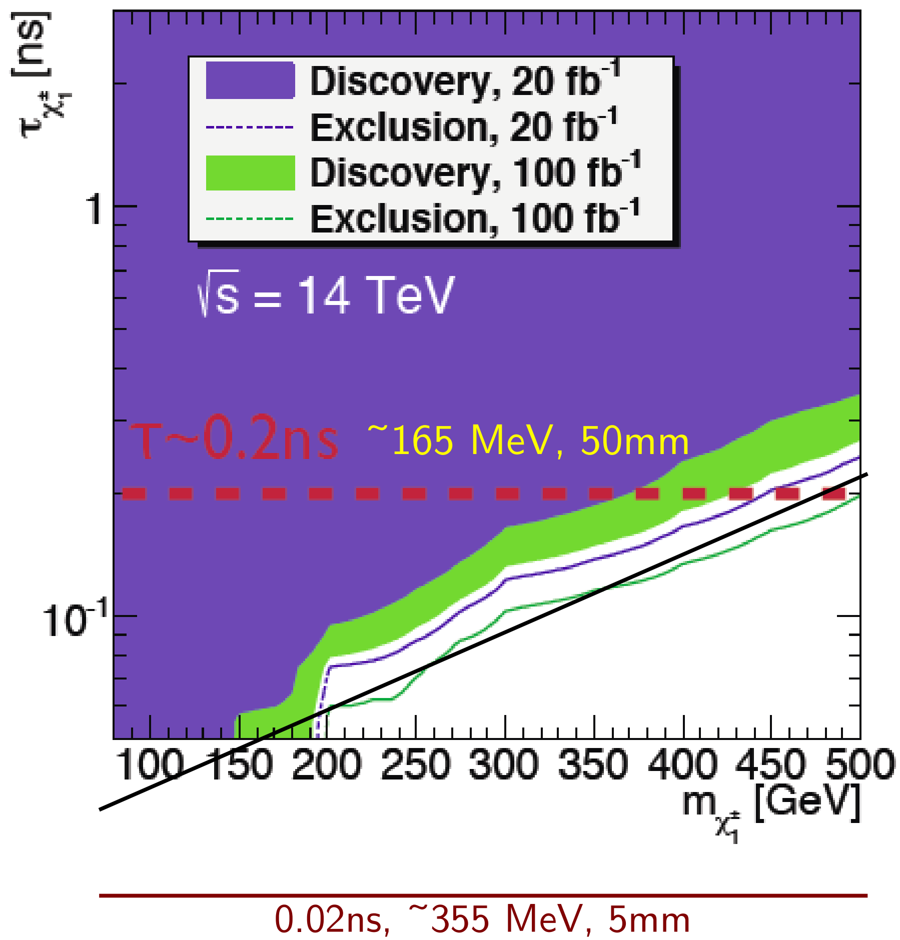
- Need to be very boosted / tail of exponential lifetime
  - Can we reconstruct shorter tracks?
  - Can we boost the chargino more?

Chargino mass [GeV]	500	500
Chargino $c\tau$ [cm]	10	100
Trigger	13%	13%
Basic selection	8.9%	9.0%
High-p_T isolated track	0.14%	4.4%
Candidate track	0.10%	2.9%
Disappearing track	0.095%	1.4%

(CMS efficiencies from Run 1)

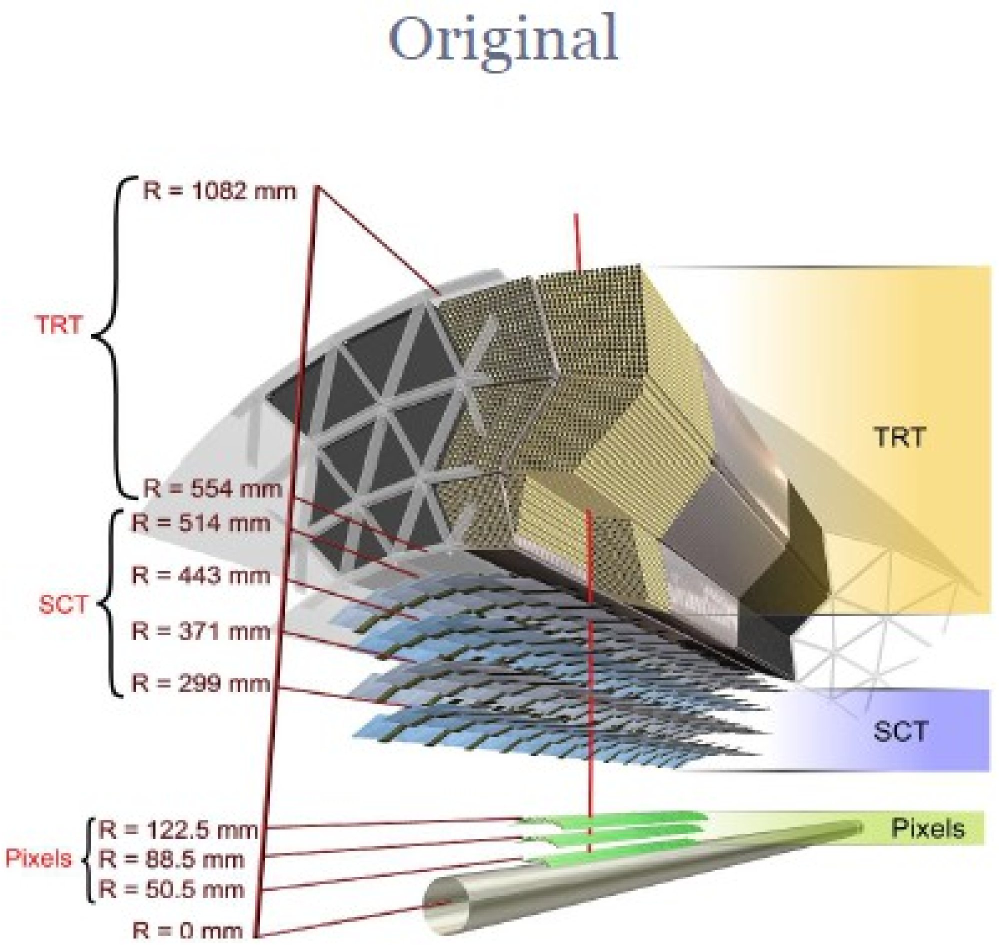
Improved disappearing track search

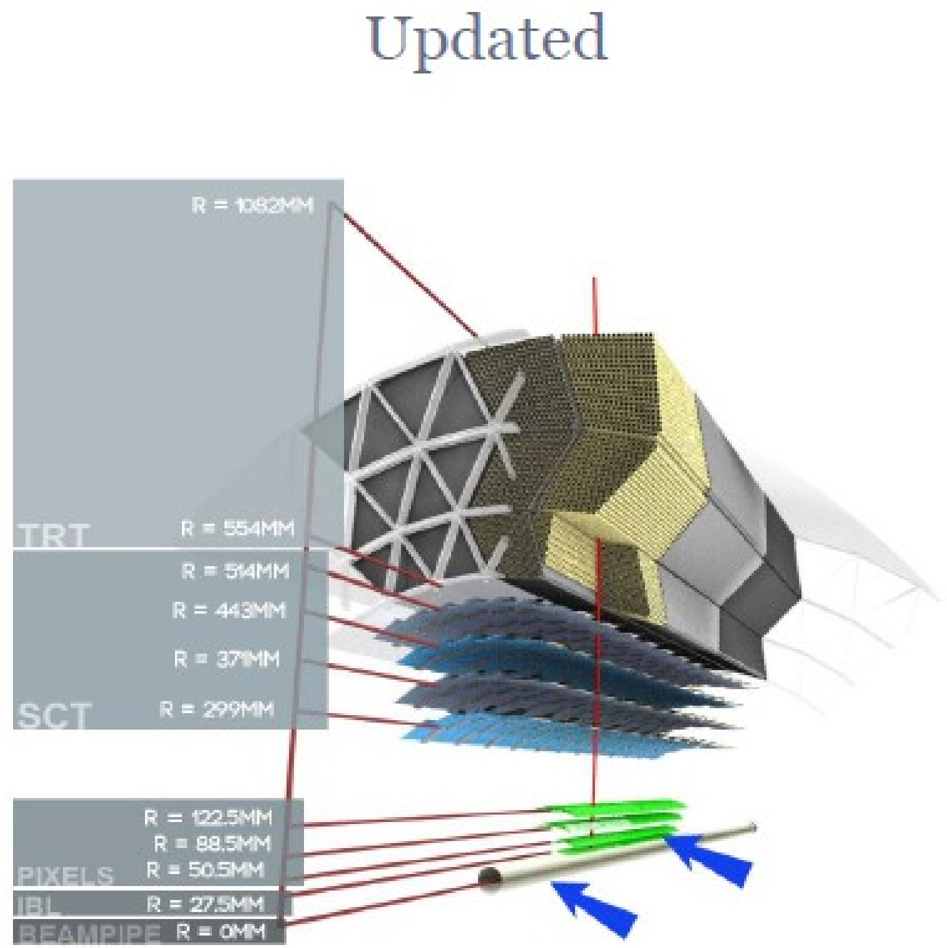
- Eventual sensitivity with 14 TeV and *same short-track analysis* ~500 GeV for Δm~165 MeV
- Going to need even shorter tracks to reach the ~5 mm lifetime case…



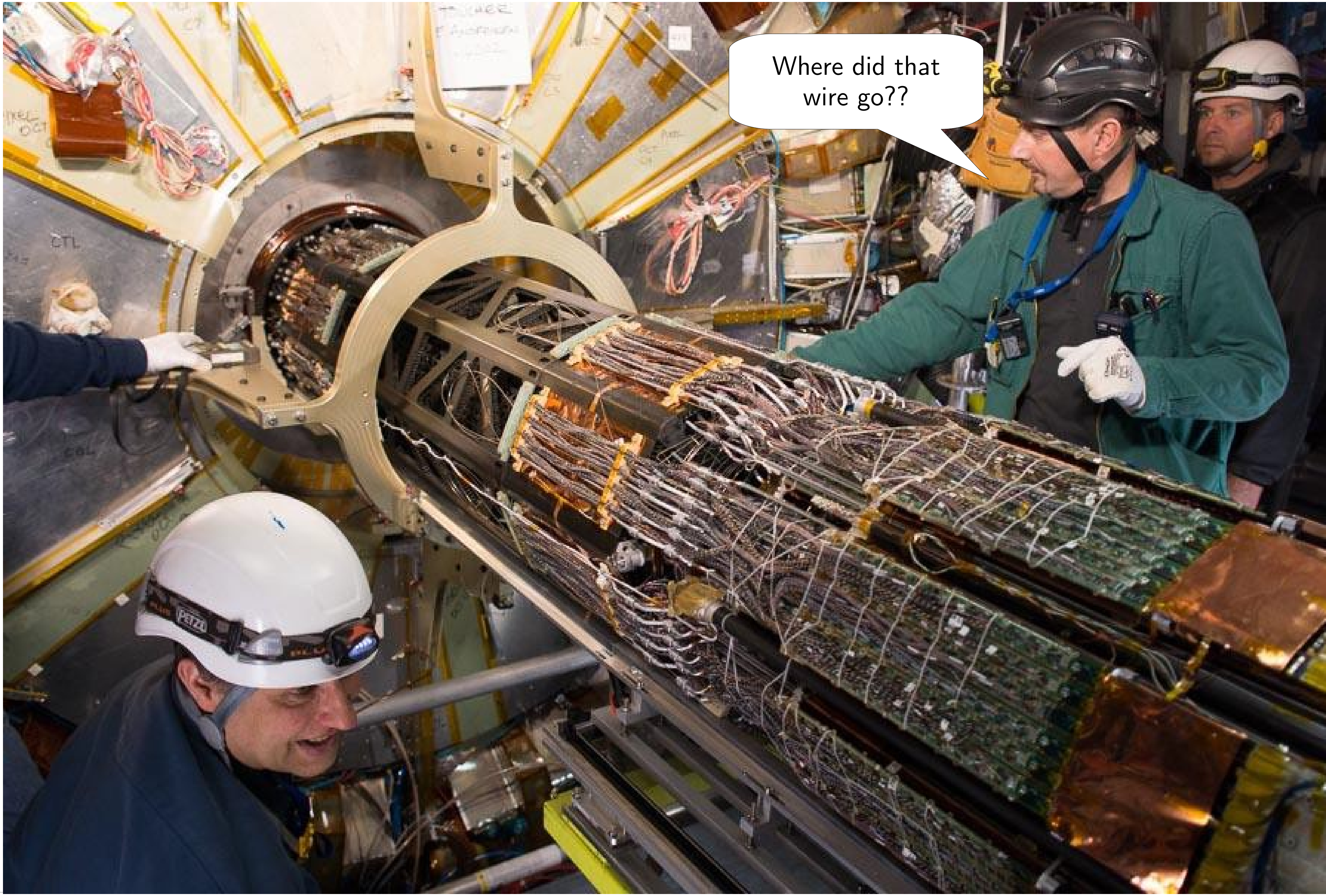
Detector Upgrades

- New silicon layer installed!
- Many trigger upgrades also installed... (including L1 VBF trigger)
- ...





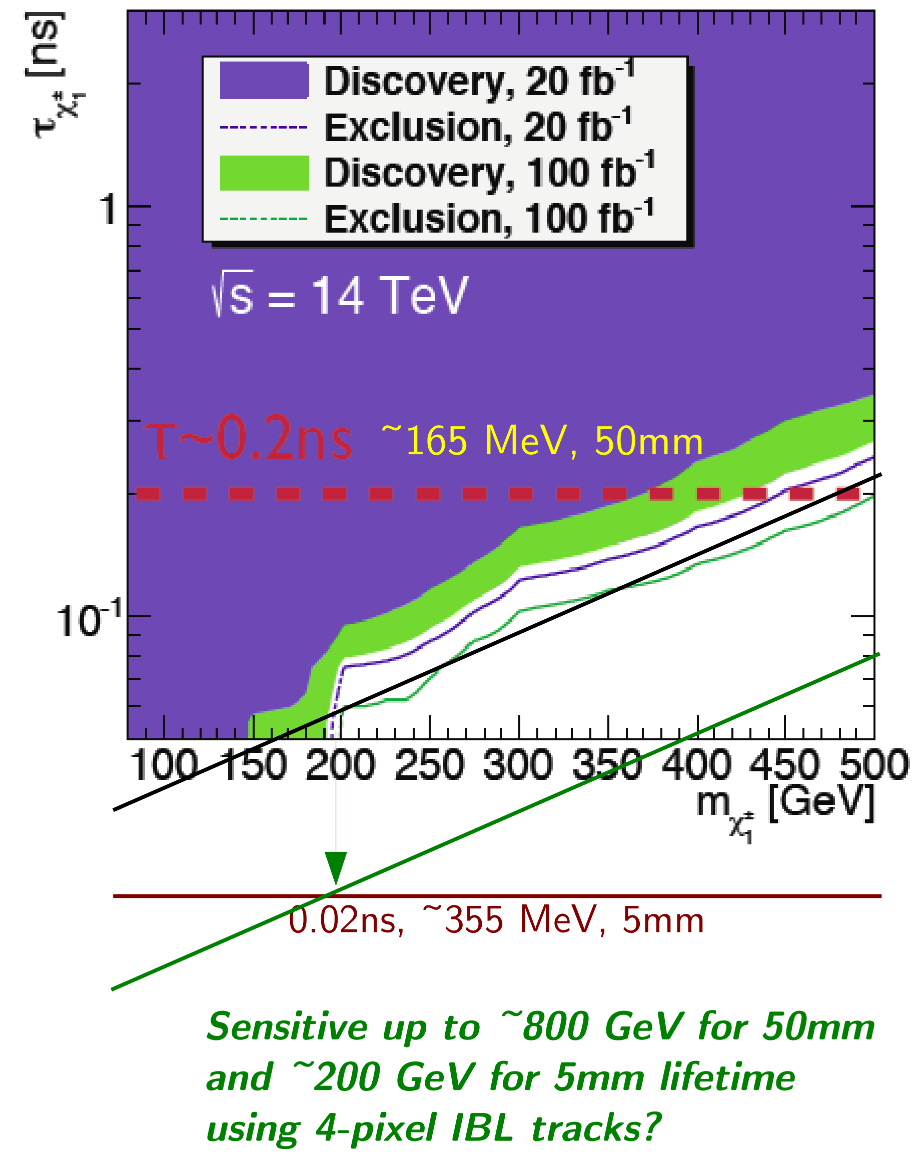
IBL installation!

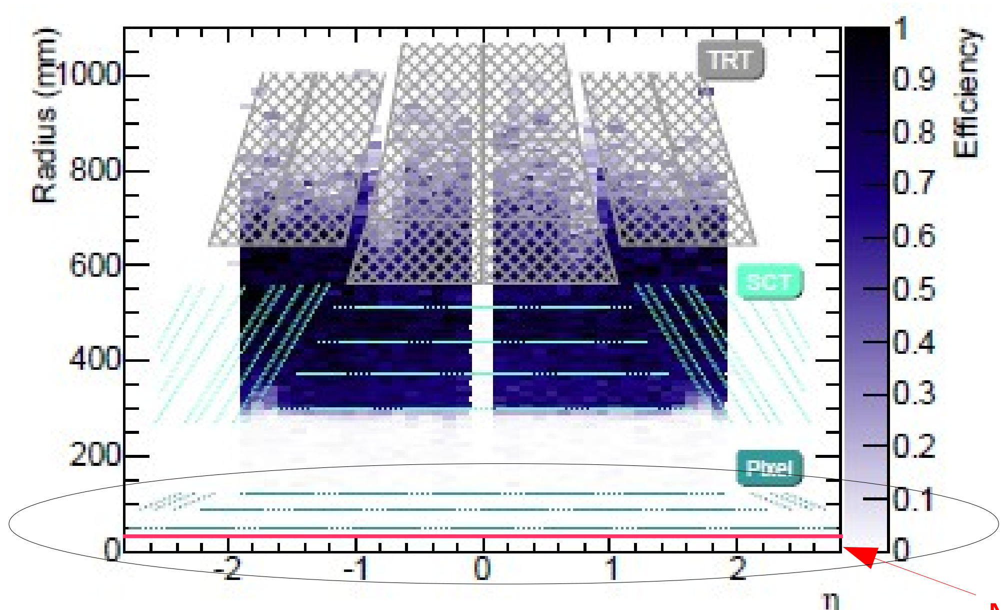


IBL installation!

Improved disappearing track search

- Eventual sensitivity with 14 TeV and *same short-track analysis* ~500 GeV for Δm~165 MeV
- Going to need even shorter tracks to reach the ~5 mm lifetime case
  - Insertable B-Layer (IBL) added
  - Could have r>150 mm tracks using just 4 pixel hits?!

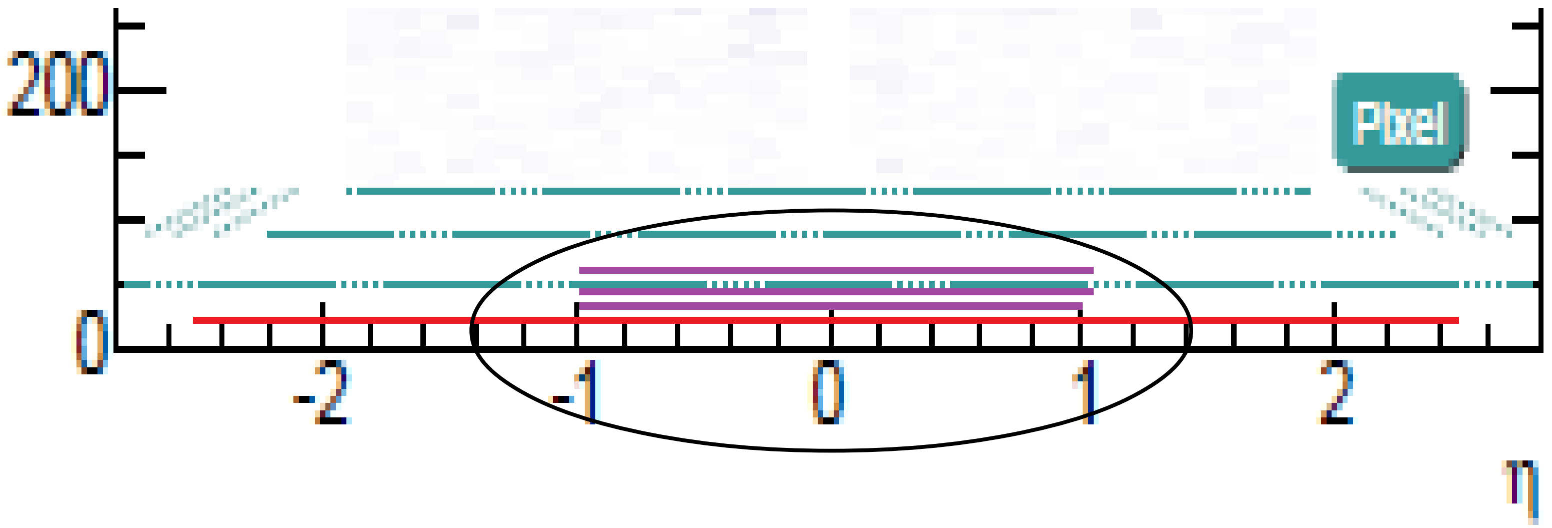




New IBL pixel layer at radius of ~26mm

Super improved disappearing track search

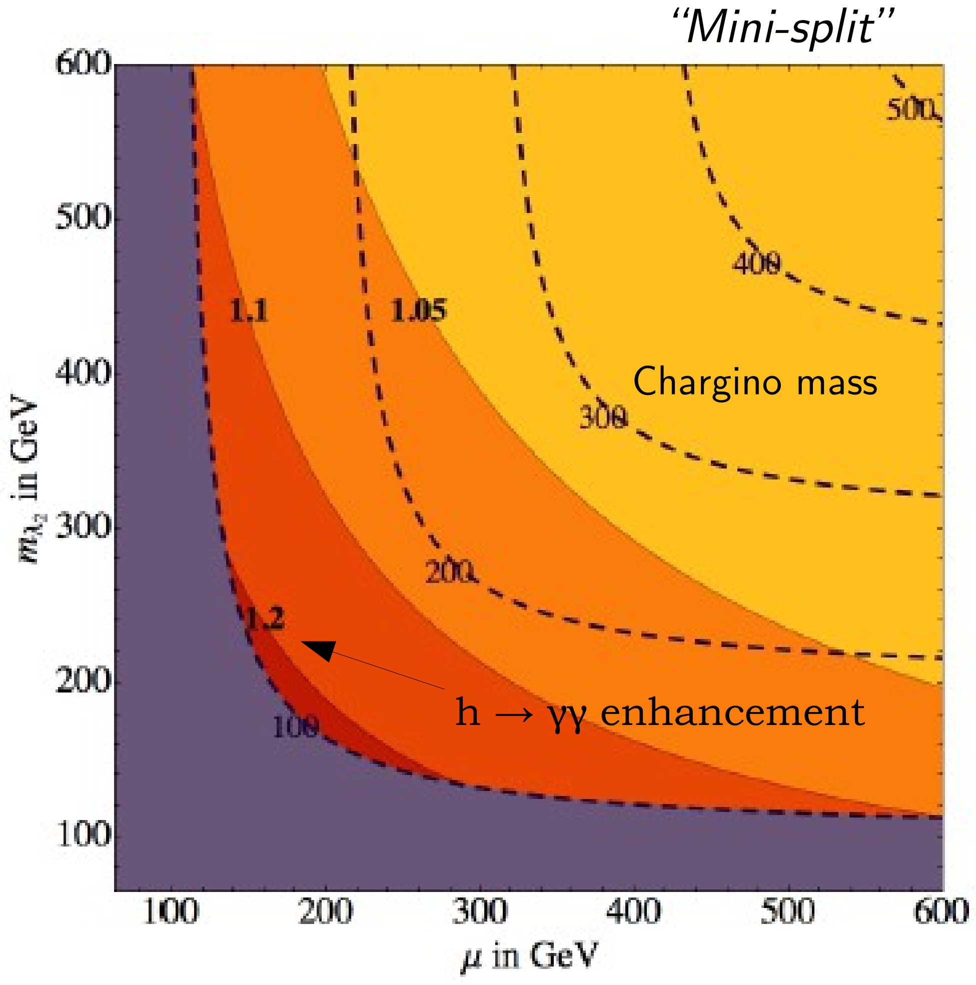
- **How to find even shorter tracks?**
- 150 mm → 50 mm tracks gives ~25 times larger Higgsino efficiency
  - Sensitivity for chargino of 5mm lifetime goes from ~200 to ~400 GeV
- New tracking layers at small radii?
  - Most important in central eta region
- Need to maintain ~30% 1/pT resolution at pT=~100 GeV ...
  - High resolution pixels (in r-phi), small scattering
- Any other ways? Boosted in forward direction? Pixel disks?
  - Asymmetric collisions ala BaBar?



Other effects of light charginos

- BR(h → γγ) can be enhanced ~20% (or suppressed ~40%) by light charginos

- Long-term LHC can measure BR(h → γγ) to +-5%
- Sensitive to Chargino masses up to ~200 GeV



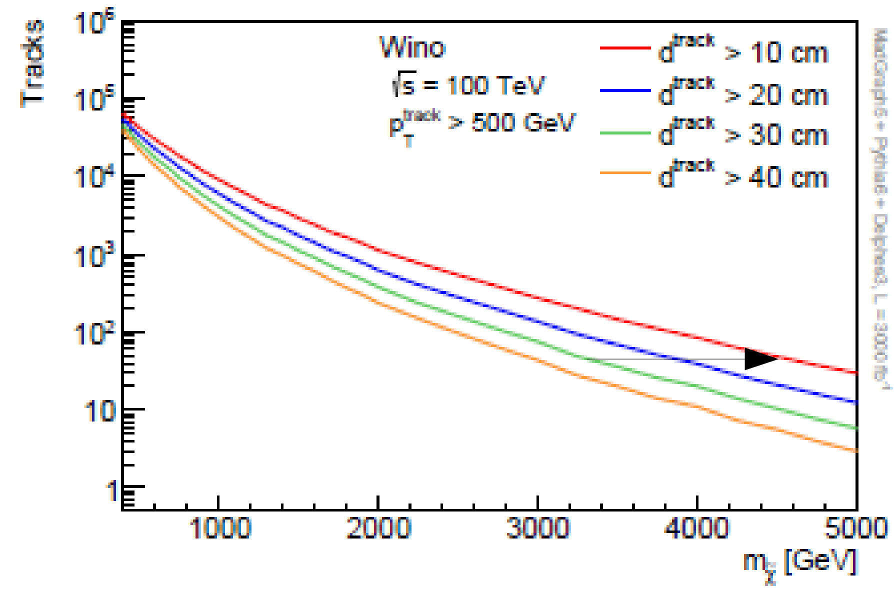
(Far-)Future of Disappearing Track Searches

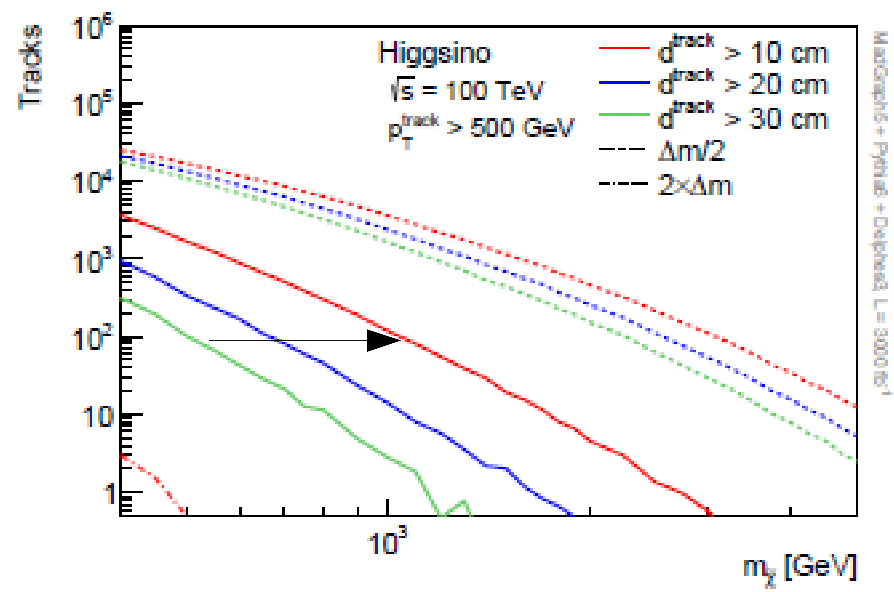
- Reconstructing very short tracks (with good momentum resolution!) is essential for mass reach
- 15 cm tracks seem possible at ATLAS

- If we could reconstruct 10 cm tracks at a 100 TeV detector:
  - Wino sensitivity from 3.5 $\rightarrow$ 4.5 TeV
  - Higgsino from ~600 GeV $\rightarrow$ 1 TeV !

- *Short tracks should perhaps be a design goal of future detectors (and accelerators?)*

M. Low and L.T. Wang
arXiv: 1404.0682





Exploring other possibilities: *milliQan@LHC*

- Milli-charged particles = new particles with electric charge ~10^{-3}
- Easy to add to SM: "dark U(1)" (with massless dark photon) mixing through kinetic term → dark fermion milli-charged under SM
- Currently weak direct limits for fermion mass > 100 MeV
- Would need new detector to see them at LHC... **arXiv:1410.6816**
- ~1 photo-electron in 1.4m long scintillator
- Require triple coincidence in time window