Searches for long lived SUSY particles

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On behalf of the ATLAS Collaboration

Outline

- Motivations
- Models and long lived particle signatures
- ATLAS 8 TeV Searches

  (Meta-) Stable Massive Particles
  Disappearing Tracks
  Displaced Vertices

- Status after Run 1
- Summary

Motivations

Test Naturalness

The discovery of a light SM-like Higgs sharpens the hierarchy problem : we haven't found any particles protecting its mass.

So, where is natural SUSY hidden?

With no signs of prompt SUSY, natural physics could still be present, but hidden in exotic and non-standard signatures.

Long lived particles (LLP) are predicted by many BSM theories

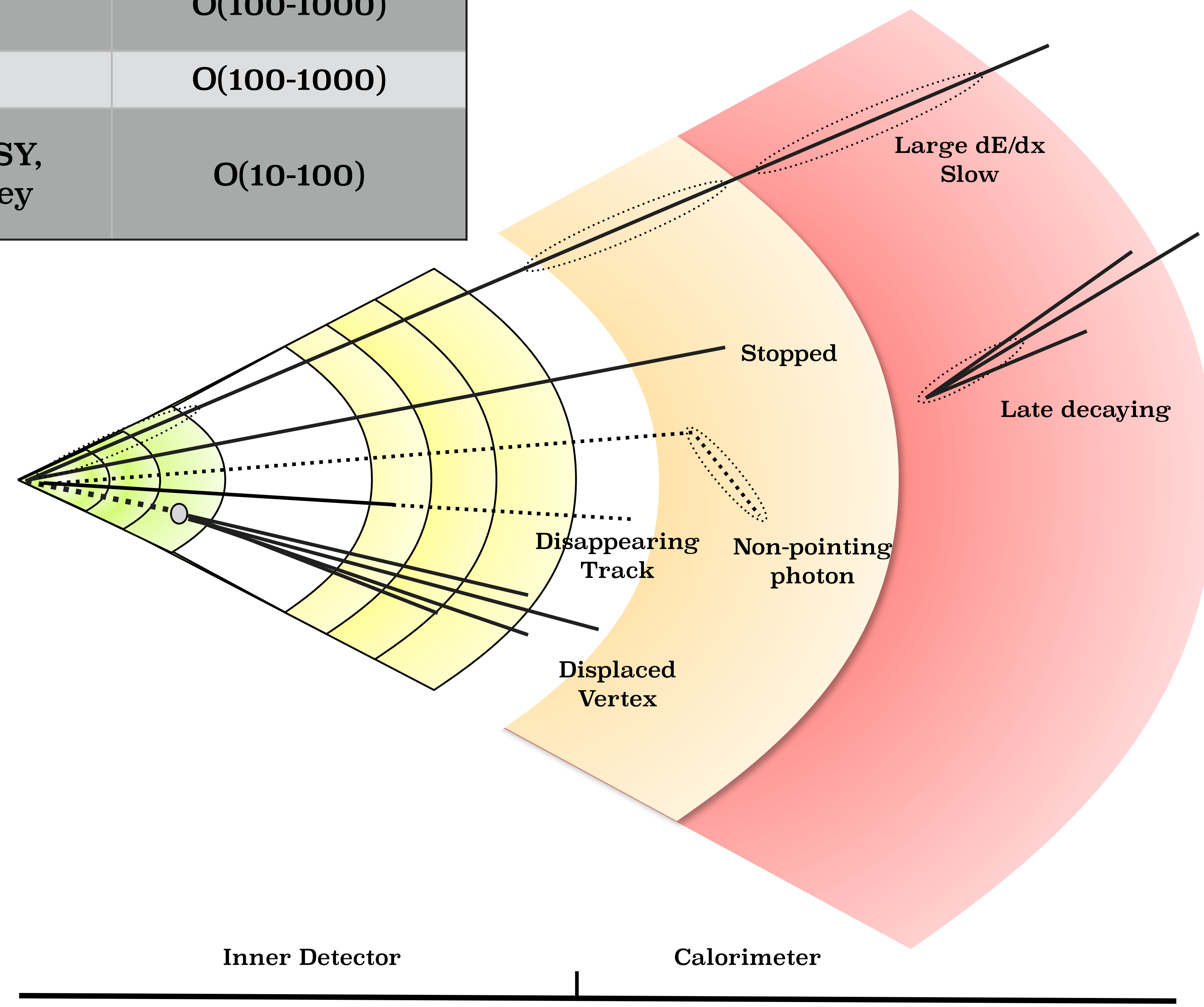
that include heavy particles with large enough lifetimes to allow them to travel measurable distances before decaying. Some of these are Heavy Ionising Particles (HIPs), Hidden Sectors, R-Parity violating decays, Split-SUSY, AMSB, GMSB.

In such models, the LLP have suppressed decays due to:

Small couplings, highly off-shell virtual propagators, very small mass differences in the decay chain or approximately conserved quantum numbers.

Models And Long Lived Particle Signatures

Signature	Model	Decay length [mm]
Late decaying	Split-SUSY, Hidden Valley	-
low β, large dE/dx	Split-SUSY, GMSB, Stealth SUSY, HIPs, AMSB	> 1000
Disappearing Tracks	AMSB	O(100-1000)
Non-pointing γ	GMSB	O(100-1000)
Displaced Vertex	Split-SUSY, RPV SUSY, GMSB, Hidden Valley	O(10-100)



Different lifetimes/charge/velocity/decays give rise to different detector signatures that require special triggers, reconstruction and/or simulation.

New!

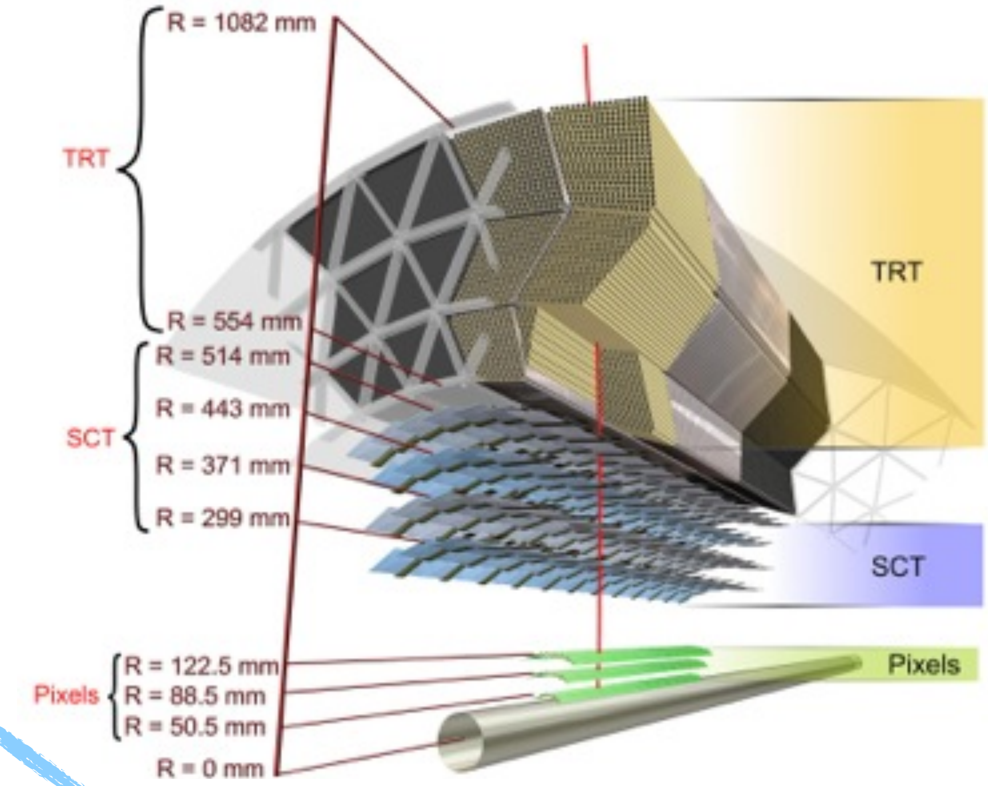
Metastable heavy charged particles

arXiv:1506.05332 , submitted to EPJ C

Searches for heavy, slow (β<1) highly ionising charged particles.

dE/dx on the Pixel as only discriminating variable, extending sensitivity to low lifetimes O(~ns).

Interpretations in the context of SUSY models with gluino R-hadrons and charginos in AMSB.

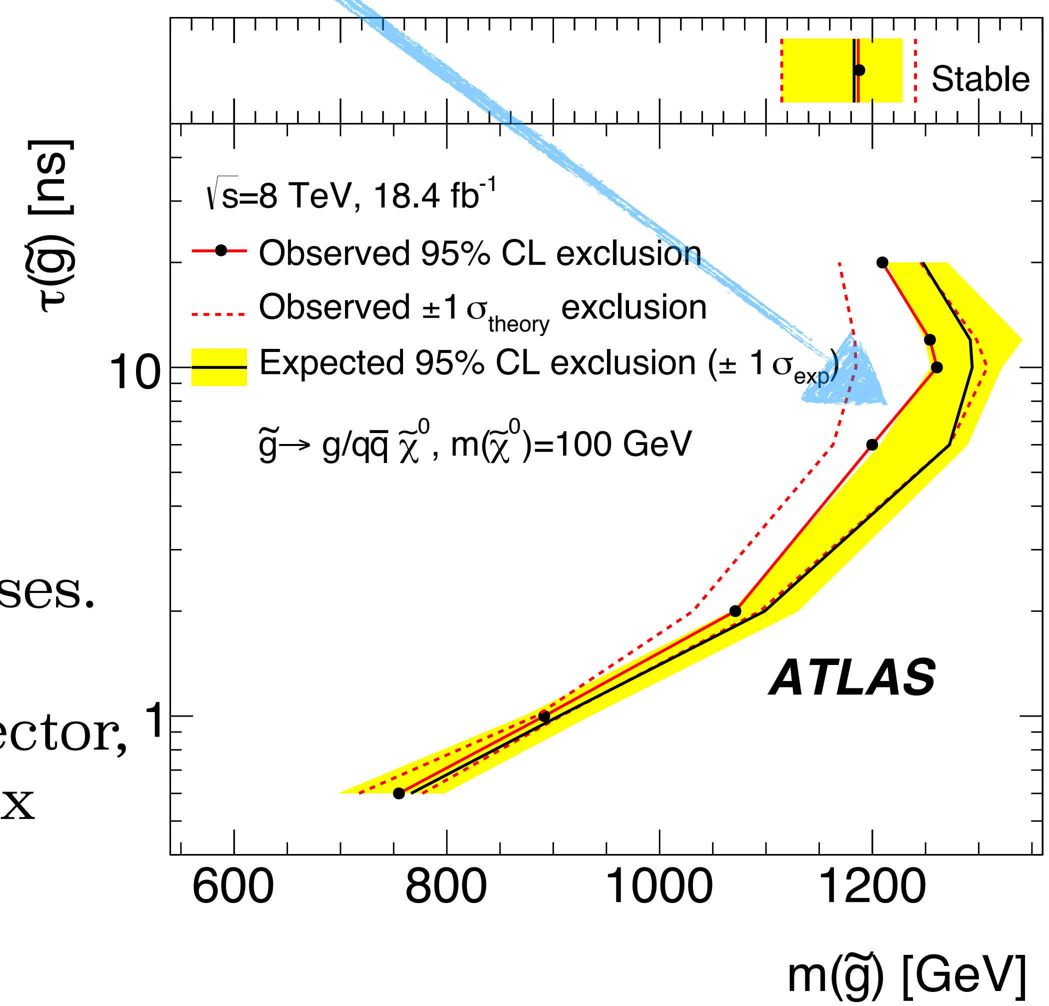


Analysis strategy

- Analysis triggers on MET only
- Mass measurement made with the Pixel detector, where particles are identified by fitting dE/dx to a Bethe-Bloch distribution.

No excess of events, lower limits on particle masses.

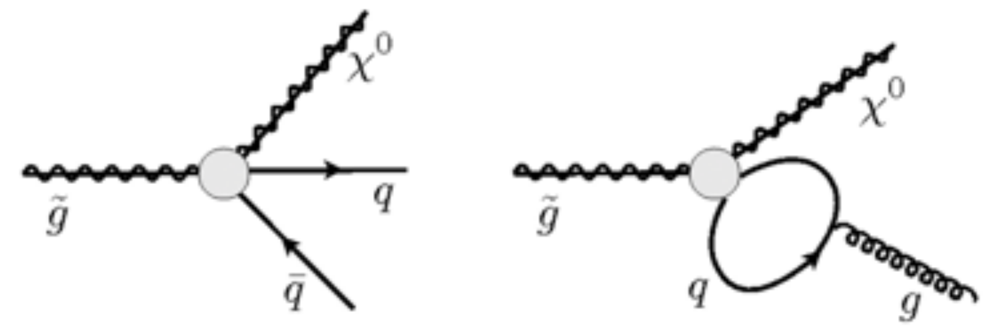
For Run 2, the Pixel transforms in a 4-layer detector, so a potentially significant improvement in dE/dx discriminating power is expected.



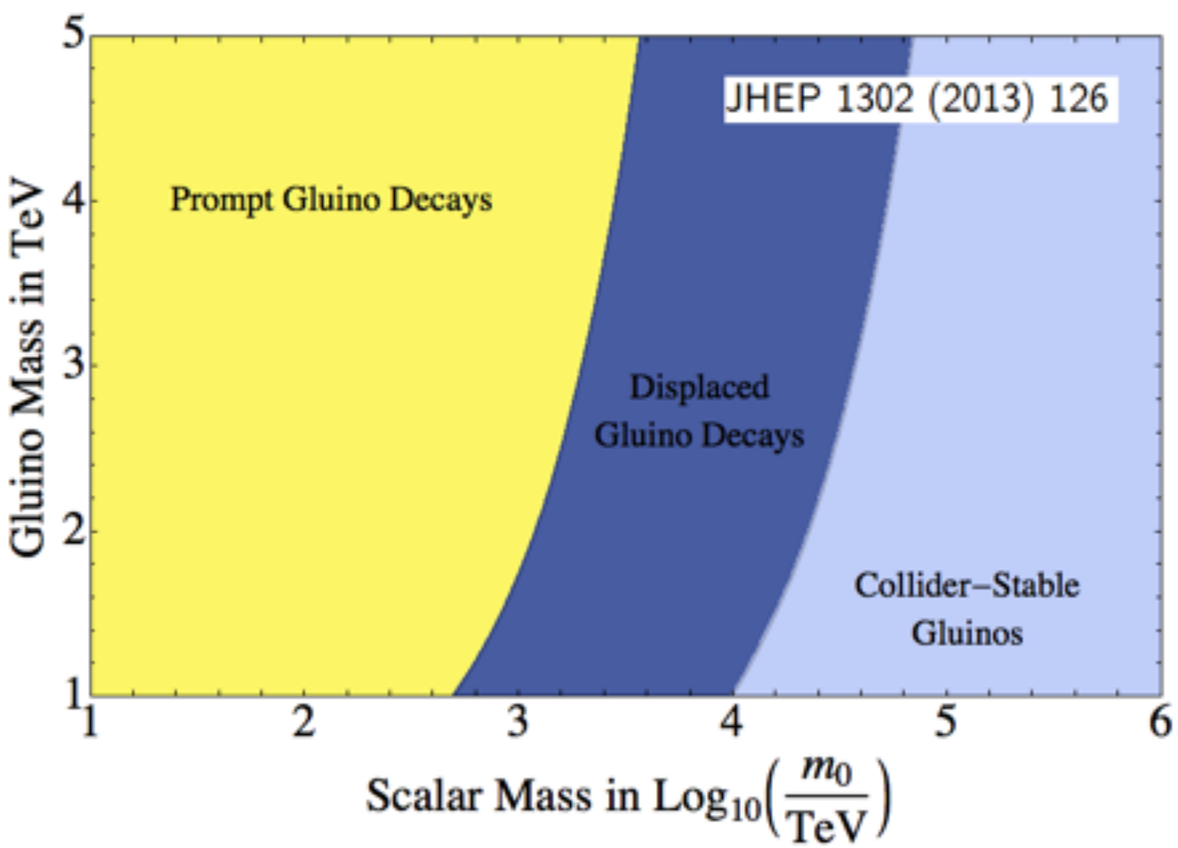
Metastable Gluinos

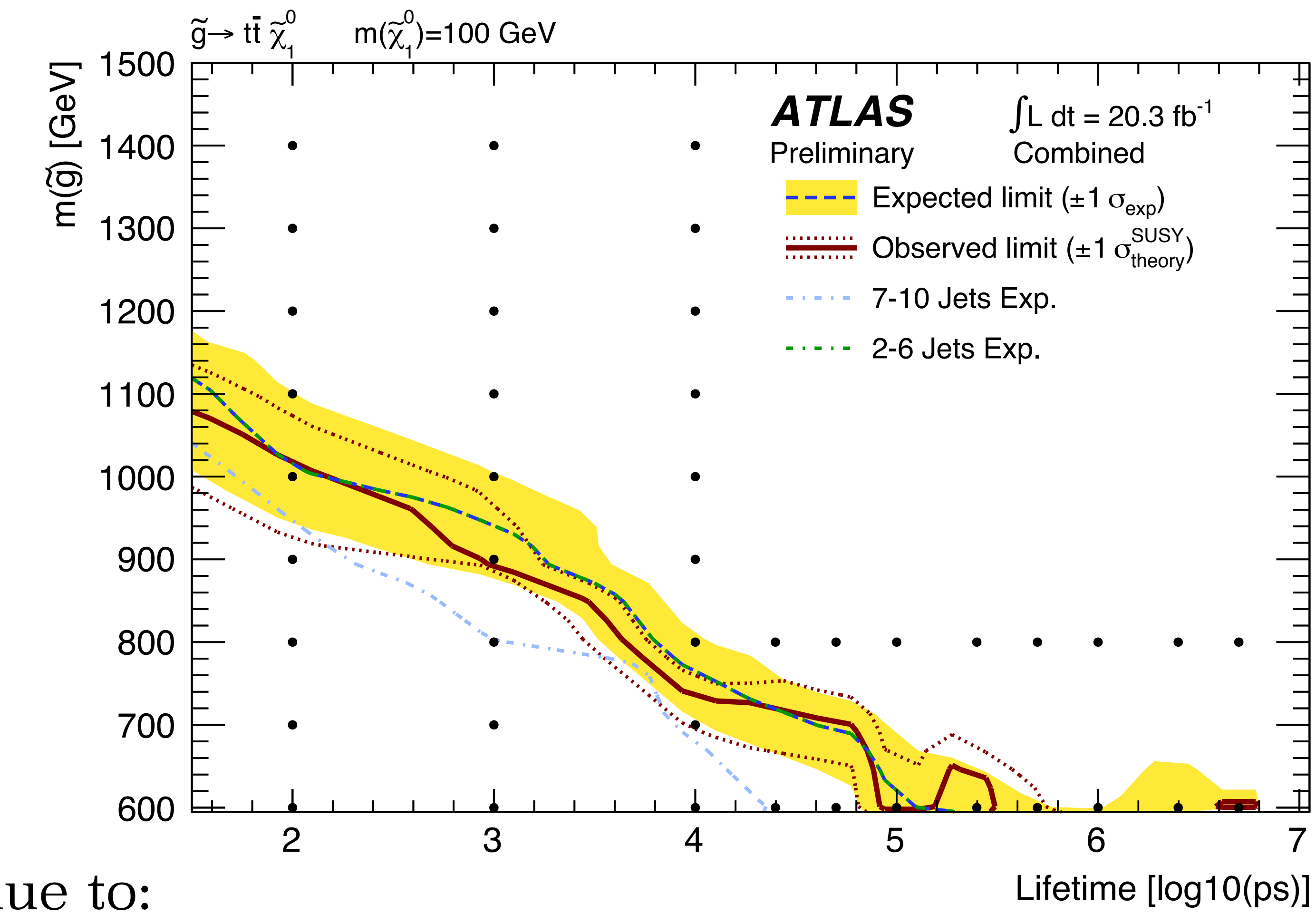
ATLAS-CONF-2014-037

First search for gluinos with intermediate lifetimes O(~ps-ns). ATLAS reinterpretation of prompt searches.



Motivated in the context of (mini) Split-SUSY





Decreased sensitivity for long lifetimes due to:

- decrease in jet multiplicity for lifetimes longer than O(10 ns) (as gluino decays in or outside the calorimeter)
- decrease in signal acceptance as lifetime increases (prompt searches had standard quality cuts rejecting non-prompt jets)

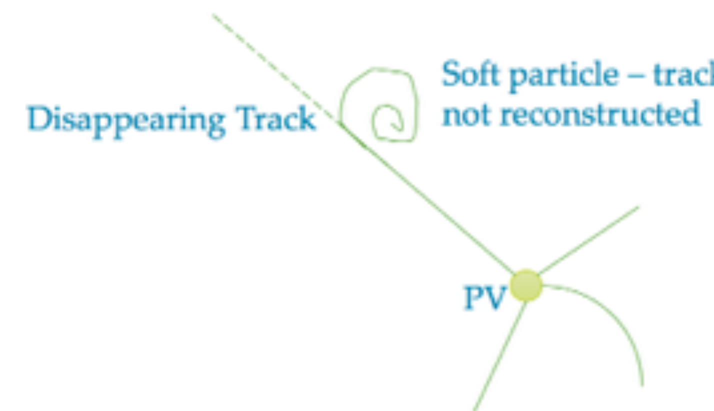
Disappearing Tracks

Phys. Rev. D 88, 112006 (2013)

Long-lived chargino (~0.2ns) decays to a neutralino and soft pion in AMSB.

$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 \pi^{\pm}$$

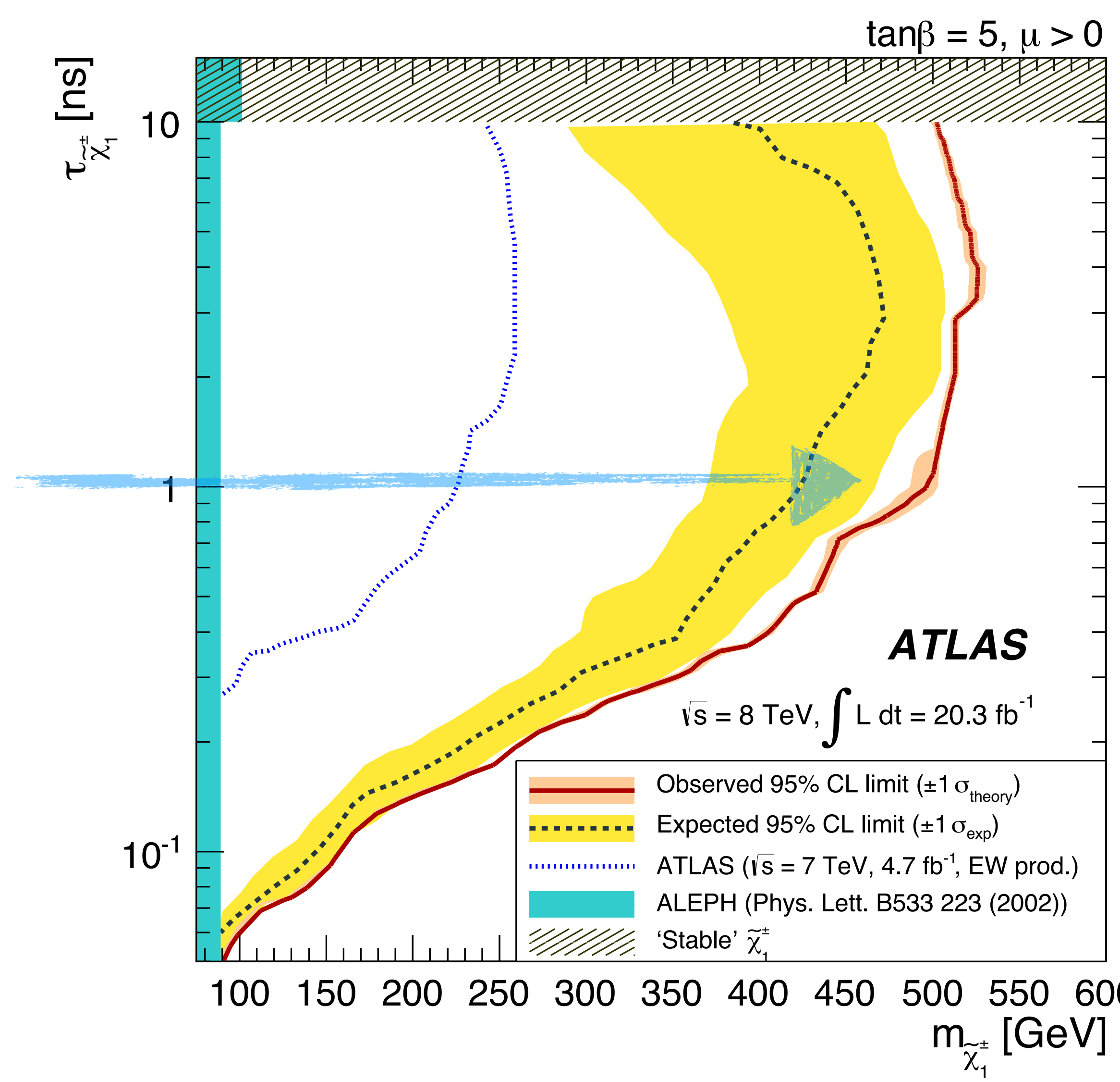
Chargino is reconstructed as a high pT disappearing track. The pion is not reconstructed, since is emitted softly.



Analysis strategy

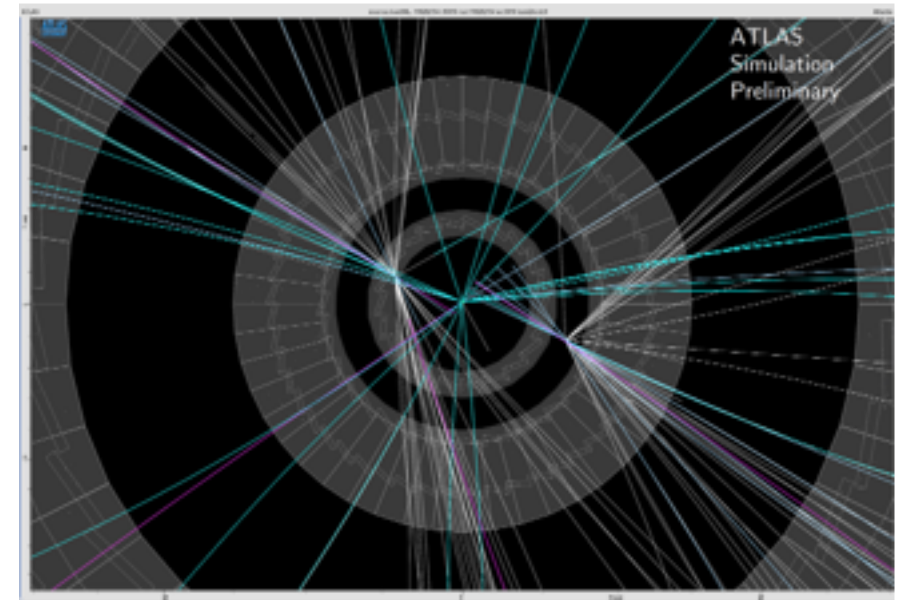
- Disappearing track pT as discriminant variable.
- Look for high pT isolated tracks having few associated hits in the outermost part of the inner detector (TRT).
- Dedicated tracking reconstruction that uses seeds only from the Pixel to improve efficiency for short tracks.

No excess observed, so we can place limits on chargino lifetime.



Displaced Vertices

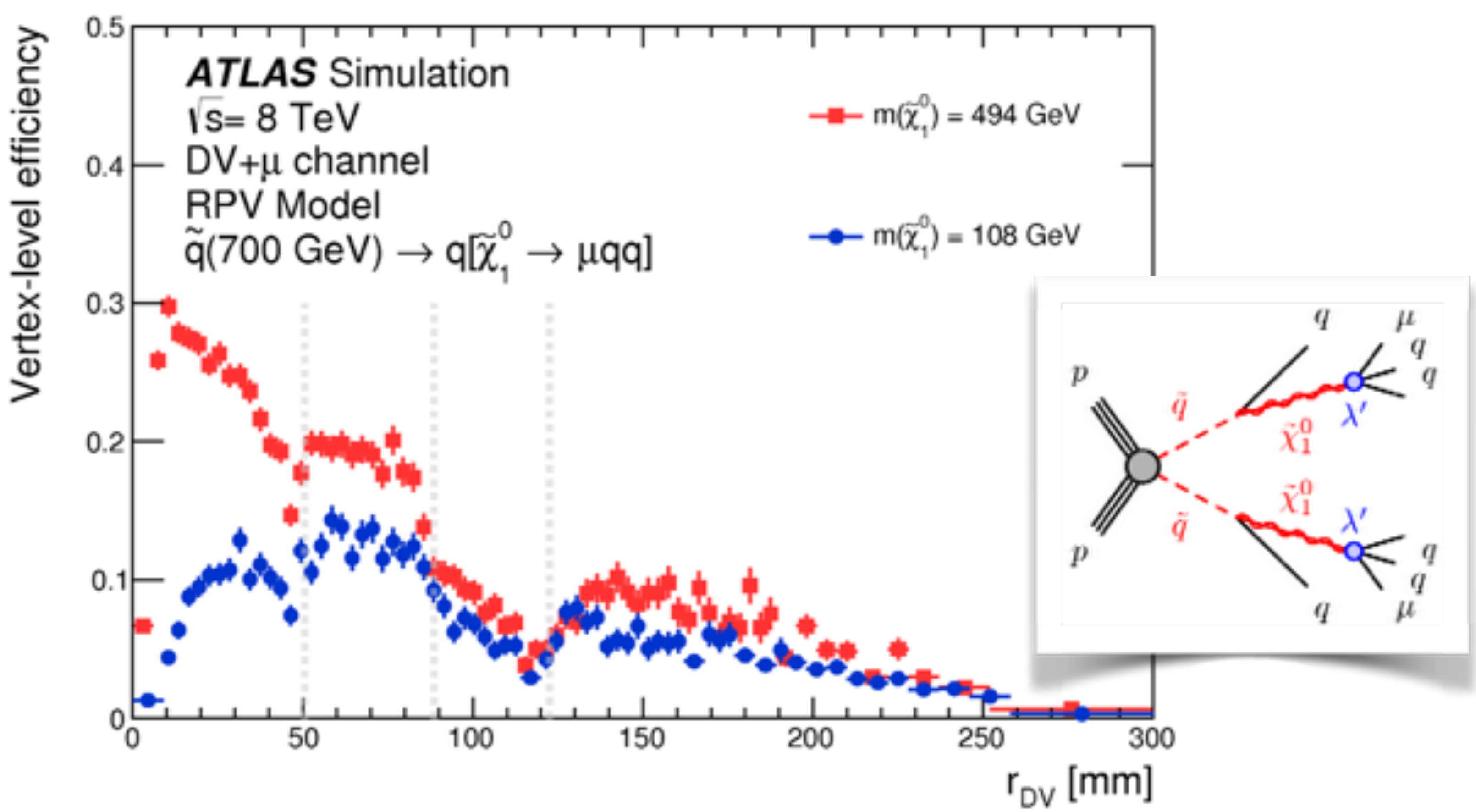
arXiv:1504.05162 , submitted to PRD

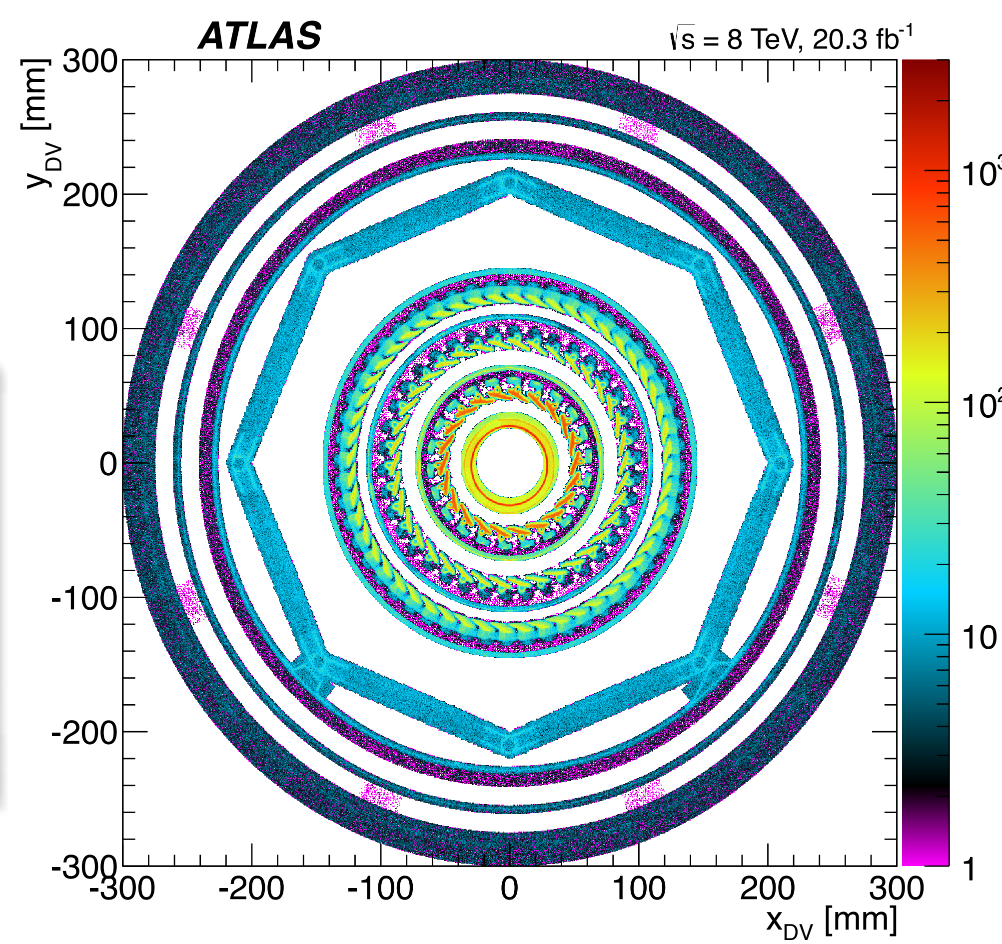


We look for long-lived particles decaying inside the Inner Detector.

Physics model interpretations include Split-SUSY, GMSB, different RPV couplings.

- Multi-track DV+μ, DV+e, DV+jets and DV+ETmiss
- Displaced dileptons: ee,eμ,μμ
- First displaced dileptons search in ATLAS.

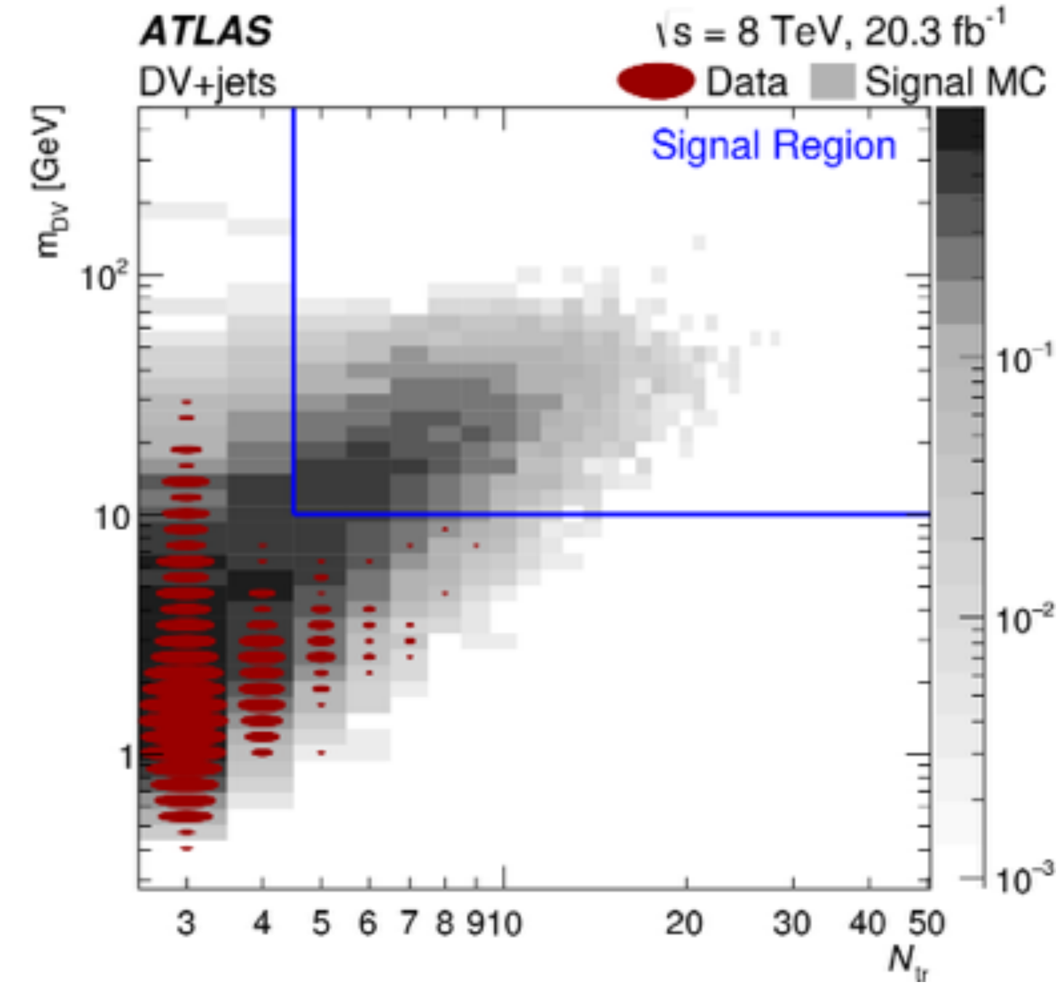


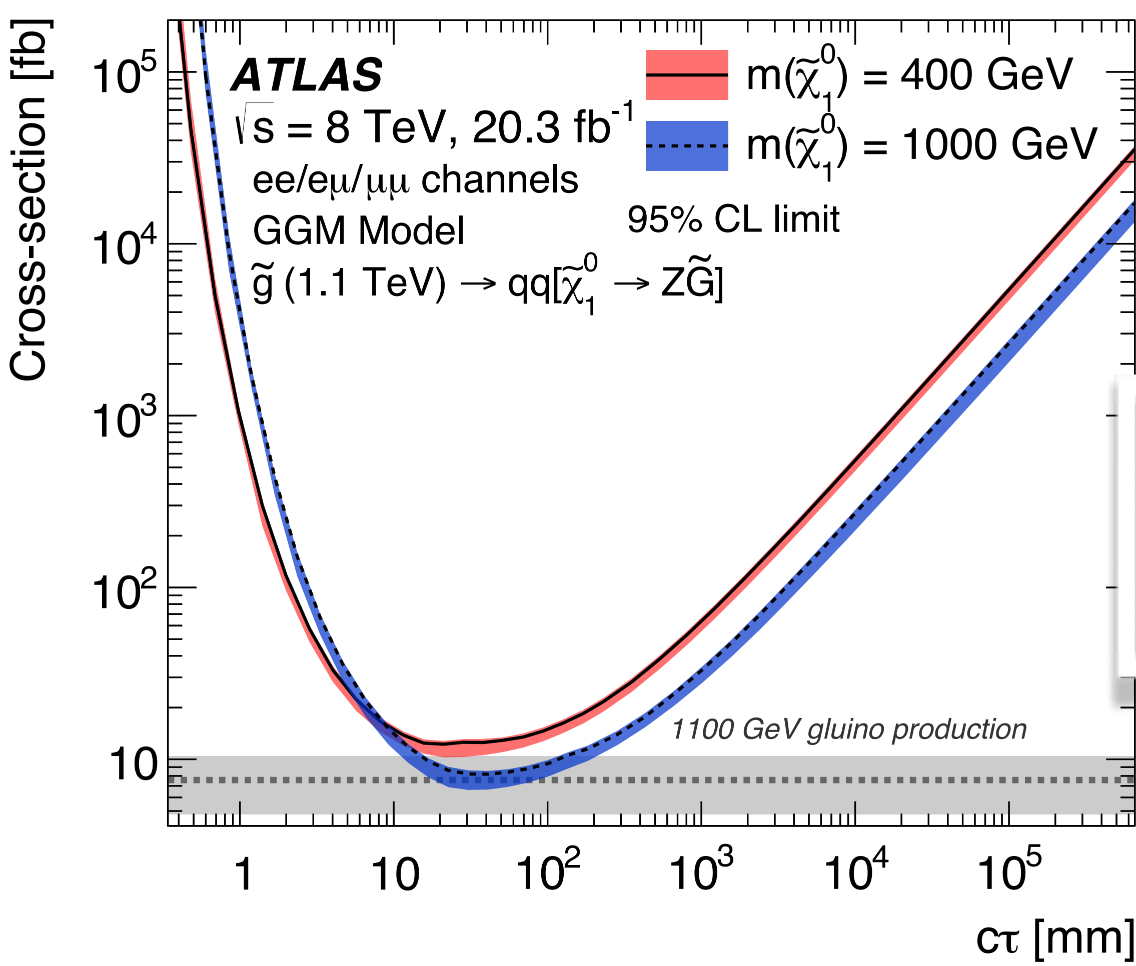


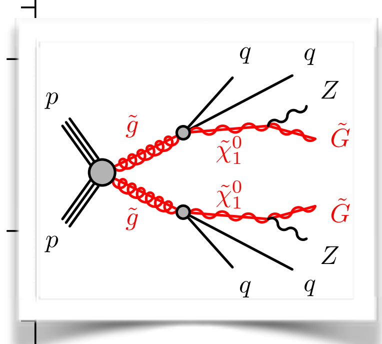
Analysis strategy

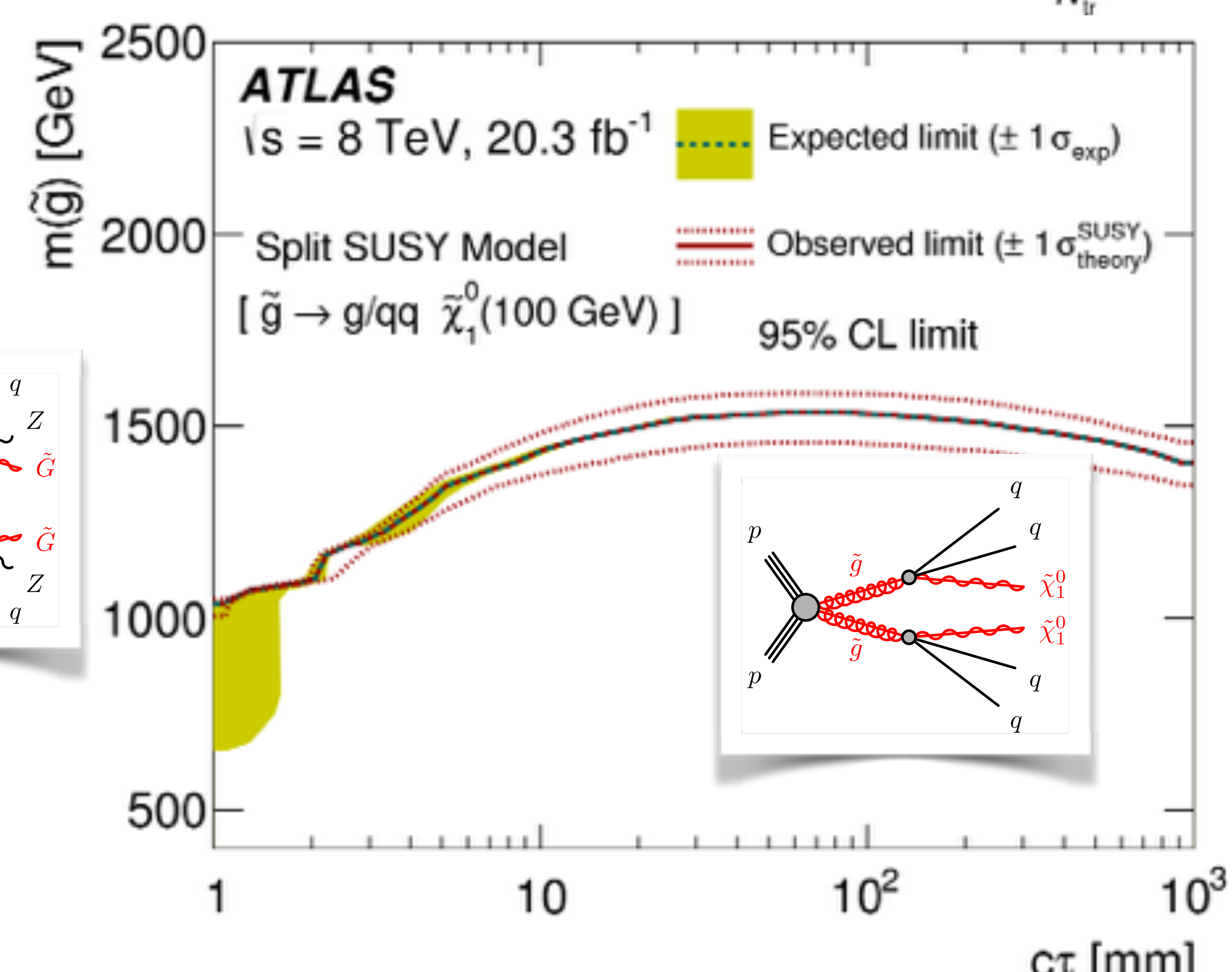
- Standard ATLAS tracking algorithms are re-run with looser cuts to gain efficiency for high-d0 tracks.
- Veto vertices in material layers (dominantly background vertices) with a 3D material map.
- High-mass, high-track multiplicity vertices with mass>10 GeV and at least 5 tracks (or at least 2 leptons).

No events observed in any signal region.
Limits on Split-SUSY, RPV and GGM models.



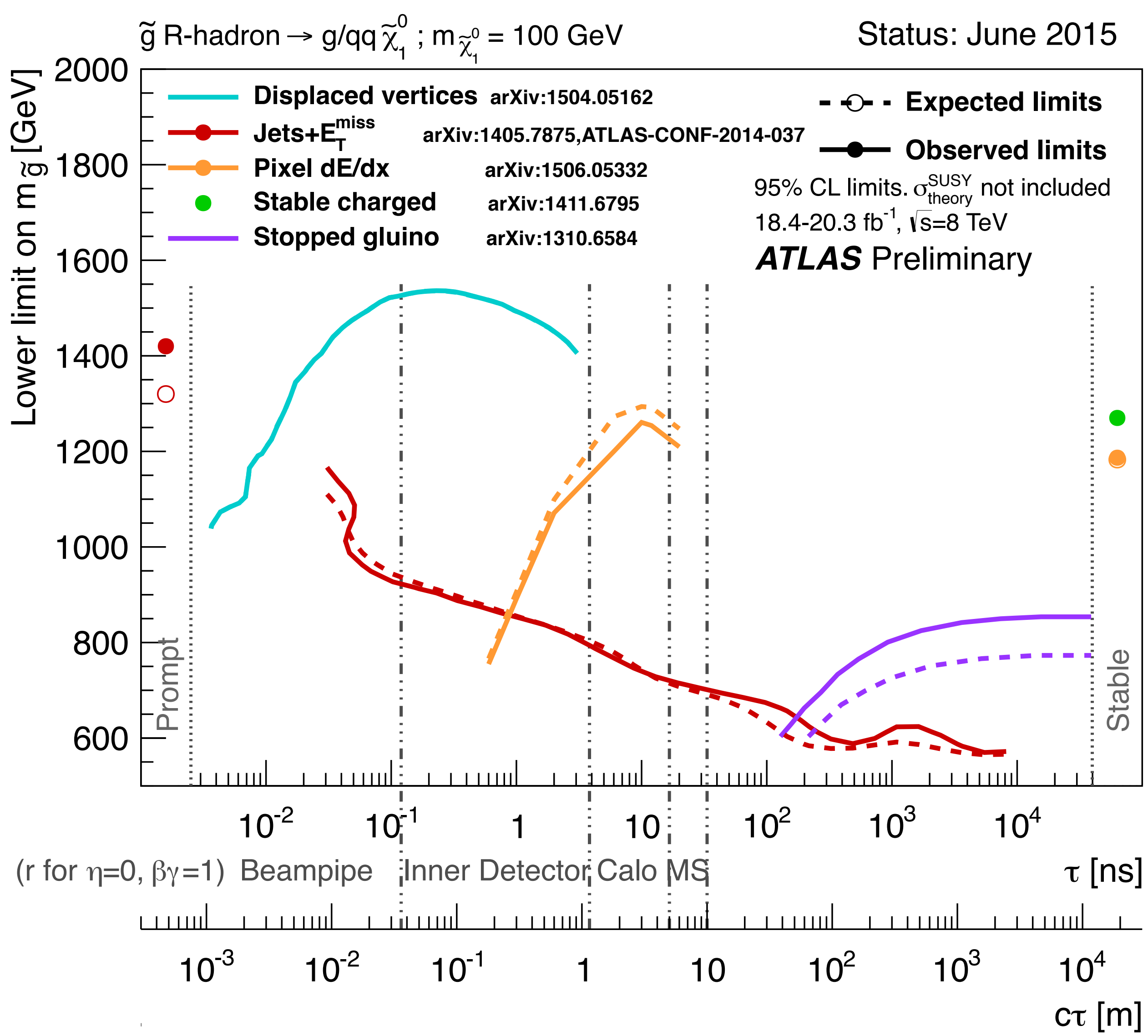


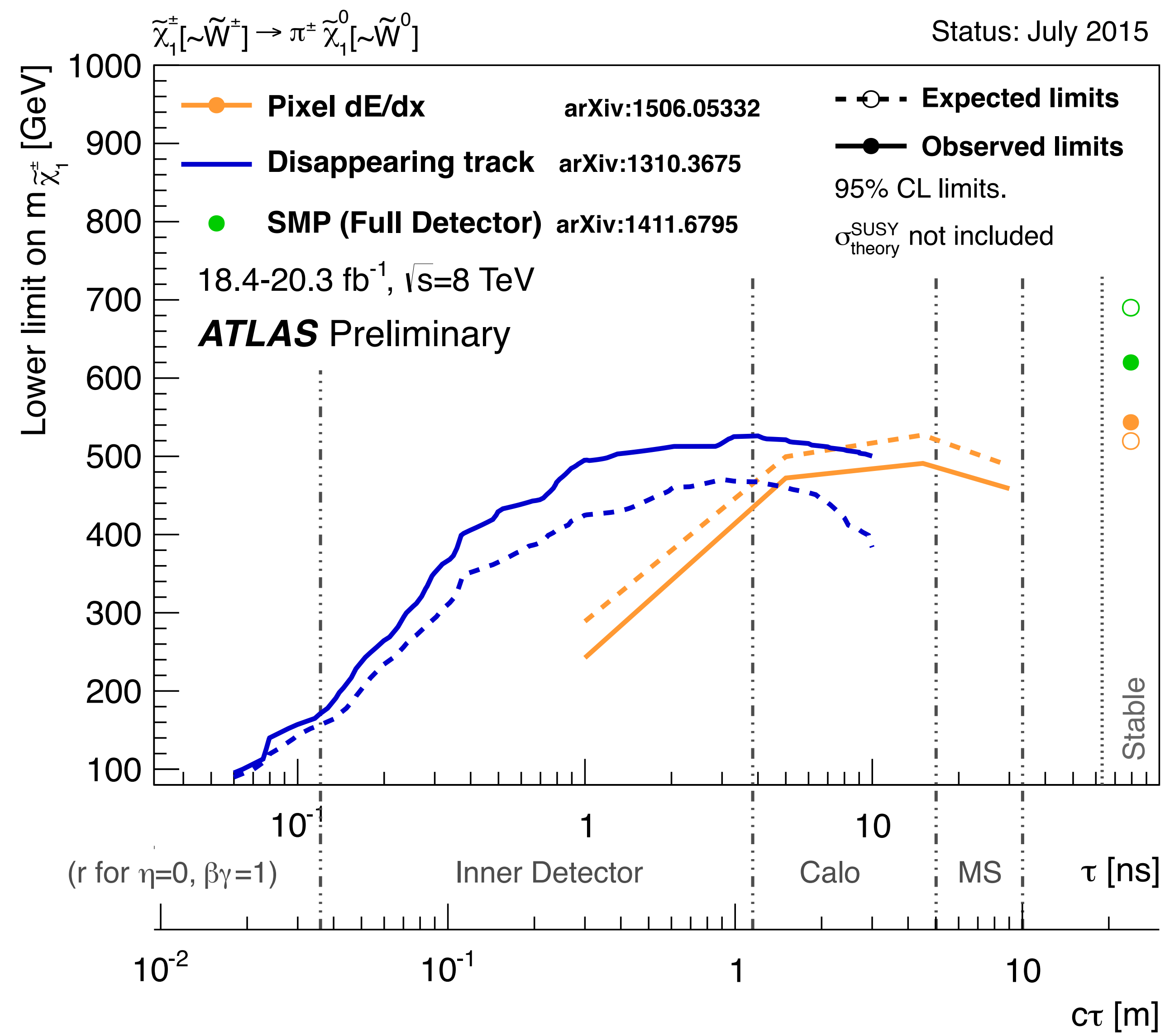




Status after Run 1

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults





Good coverage of different lifetimes achieved by complementary analysis.

Status after Run 1 (2)

Many new long lived results came out in 2015. Wide interest from the community in recasting long lived results! Some examples are,

Desai, Ellis et al http://arxiv.org/abs/1404.5061 → *"Closing in on the Tip of the CMSSM Stau Coannihilation Strip"*
Disappearing track analysis reinterpretation.

Liu and Tweedie http://arxiv.org/abs/1503.05923 → *"The Fate of Long-Lived Superparticles with Hadronic Decays after LHC Run 1"*
ATLAS and CMS reinterpretations of various long-lived/displaced analysis.

Cui ans Shuve http://arxiv.org/abs/1409.6729 → *"Probing Baryogenesis with Displaced Vertices at the LHC"*
ATLAS DV+muon and CMS displaced dijets reinterpretation.

Csaki et al http://arxiv.org/abs/1505.00784 → *"Phenomenology of a Long-Lived LSP with R-Parity Violation"*
ATLAS and CMS reinterpretations of various long-lived/displaced analysis, including full recast of ATLAS DV+jets.

… and more to come !

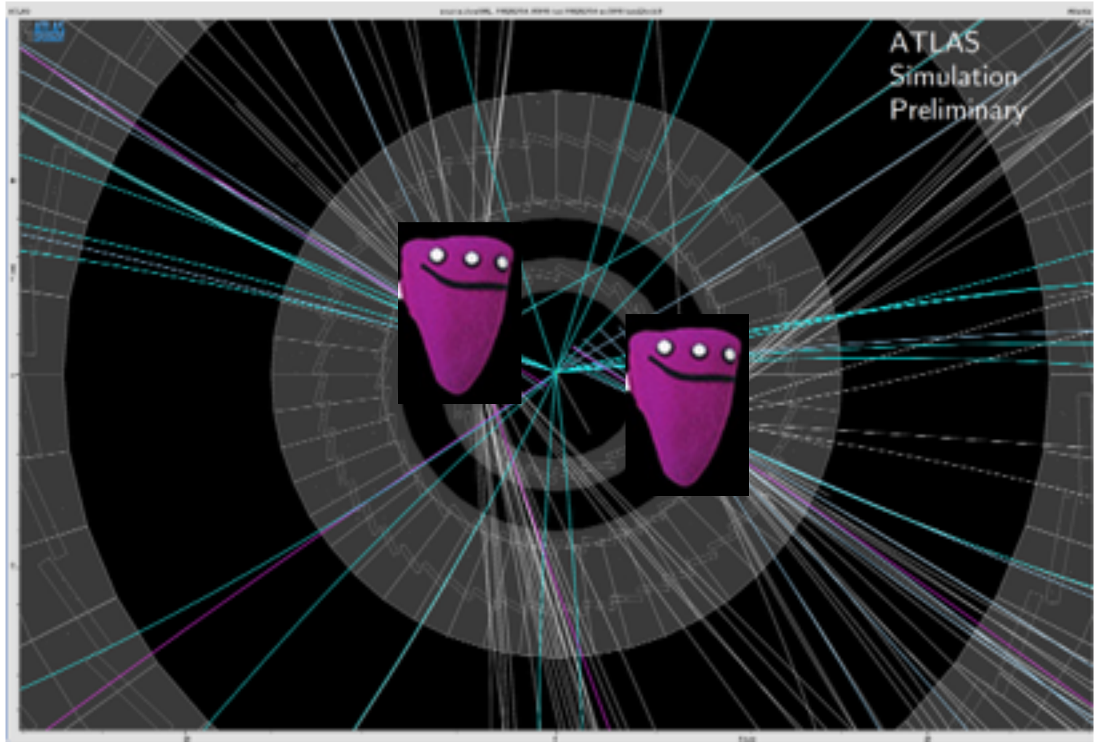
There is rich phenomenology for these searches !!

Naturalness ?
Interplay between collider physics and dark matter/cosmology ?

Summary

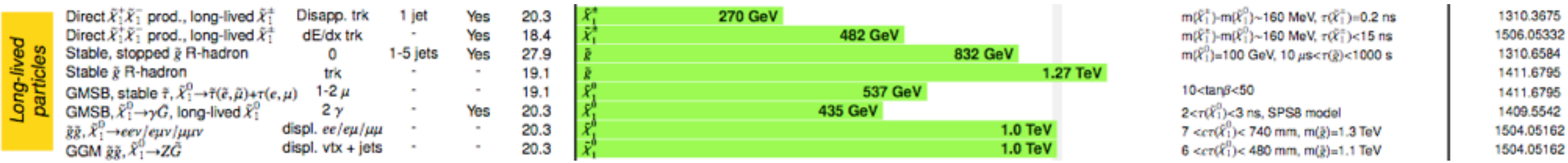
- Searches for massive, long lived particles are an important part of the ATLAS program of searches for new physics.
- Long lived analysis are non standard and very challenging, even more for Run 2. There is good coverage of different lifetimes and models by complementary analyses at the LHC.
- With no sign of prompt SUSY, long lived analysis become VERY relevant and complementary to constrain new models and testing new theories !

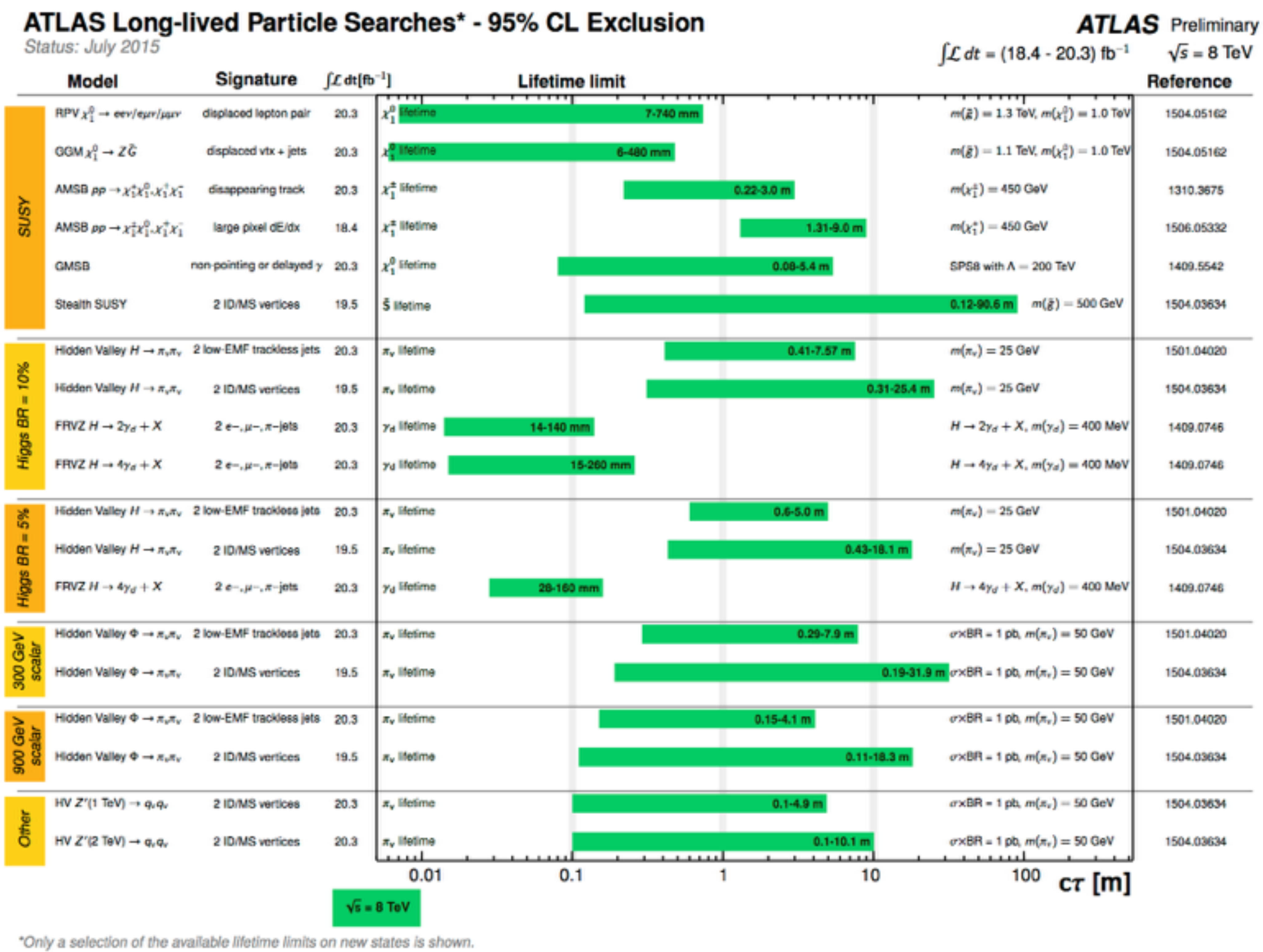
Looking forward to the increased discovery potential in Run 2!



Backup Slides

Status after Run 1 (3)





Why Long-Lived Particles?

- LLPs are predicted by a wide variety of models : Hidden Sectors, RPV violating decays, Split-SUSY, AMSB, GMSB, etc.

Why Long-Lived Particles in Run 2?

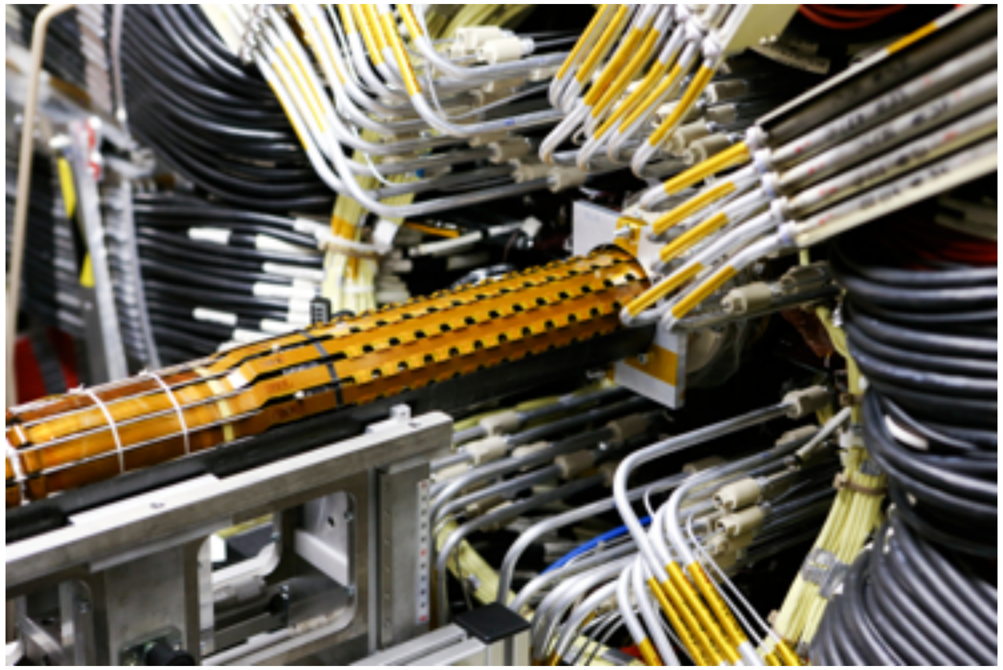
- LLP have interesting and non-standard decay signatures. These may have been overlooked or misidentified by searches not dedicated to LLPs.

- All our signatures can come from strong production (biggest gain from higher energies).

- We should keep looking for new physics everywhere and every way we can!

Priorities for Run 2

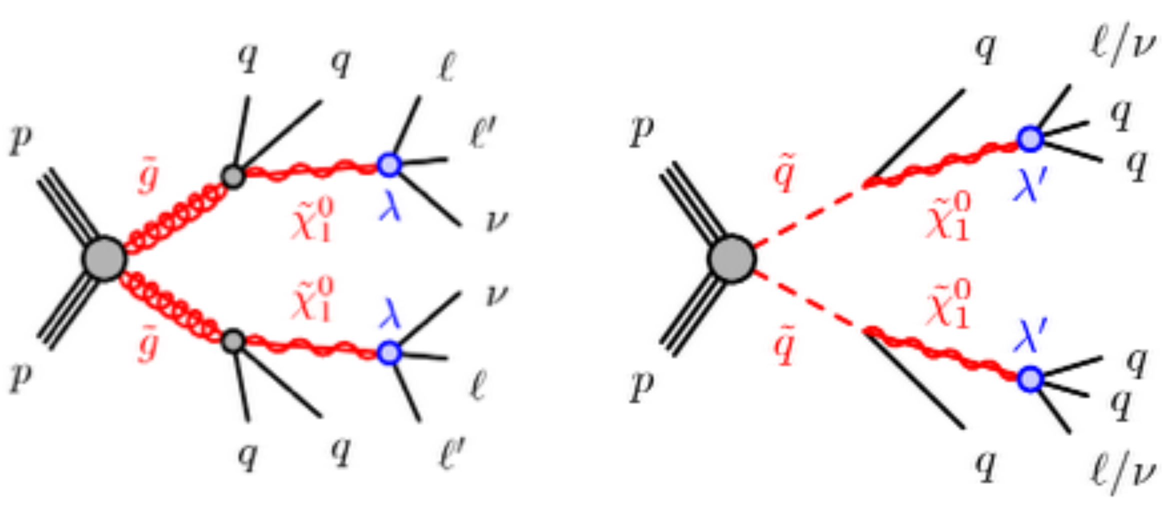
- Extend Run 1 analysis with new methods and using new capabilities of the detector!
- Make sure triggers are in place for our signals.
- Make sure we have software selections in place (DESD) for our Run2 analyses.
- Make sure we can use new data formats (xAOD).



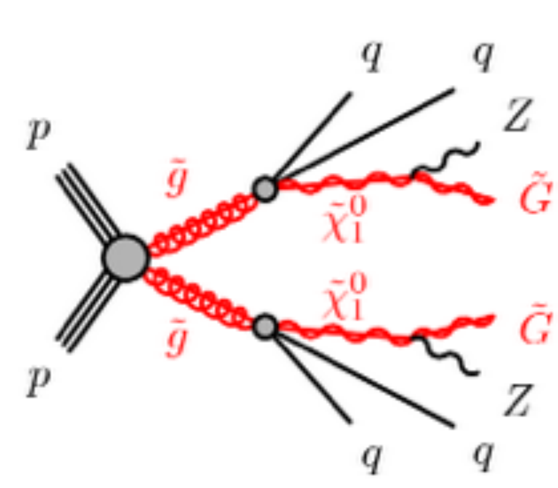
Displaced Vertices

arXiv:1504.05162 , submitted to PRD

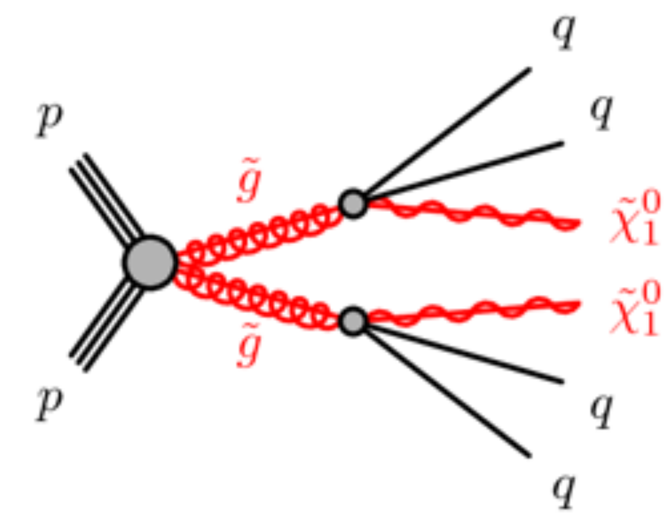
Signatures



R-parity violation allows for the decay of the neutralino through different lambda and lambda' couplings.



Neutralino decay in a GMSB scenario where the Gravitino is the LSP.



Split SUSY model with heavy scalars. The gluino is long-lived and forms an R-hadron before decaying.

$$\varepsilon_{ij}[\lambda'_{abc}\hat{L}^i_a\hat{Q}^j_b\hat{D}_c + \lambda_{abc}\hat{L}^i_a\hat{L}^j_b\hat{R}_c$$

$$c\tau_{\tilde{f}} = 10^{-2}\left(\frac{100\ \text{GeV}}{m_{\tilde{f}}}\right)^5\left(\frac{\sqrt{\langle F\rangle}}{100\ \text{TeV}}\right)^4\ \text{cm}\qquad c\tau_{\tilde{g}} = 10^{11}\left(\frac{1\ \text{TeV}}{m_{\tilde{g}}}\right)^5\left(\frac{m_{\tilde{q}}}{10^9\ \text{GeV}}\right)^4\ \text{cm.}$$

- $\tau \propto 1/\lambda^2$

lifetimes of ~ picoseconds to a nanosecond

Backgrounds

Main sources of backgrounds (after material veto):

- Multitrack: Low mass DV's (from hadronic interactions with gas molecules) that are crossed by an unrelated high-pT track at a large angle, making their reconstructed mass seem high.
- Di-lepton: Two unrelated leptons crossing close enough for the vertexing method to combine.

Backgrounds are really small !

Channel	No. of background vertices ($\times 10^{-3}$)
DV+jet	$410 \pm 7 \pm 60$
DV+E_T^{miss}	$10.9 \pm 0.2 \pm 1.5$
DV+muon	$1.5 \pm 0.1 \pm 0.2$
DV+electron	$207 \pm 9 \pm 29$

Channel	No. of background vertices ($\times 10^{-3}$)
e^+e^-	$1.0 \pm 0.2\ ^{+0.3}_{-0.6}$
$e^\pm\mu^\mp$	$2.4 \pm 0.9\ ^{+0.8}_{-1.5}$
$\mu^+\mu^-$	$2.0 \pm 0.5\ ^{+0.3}_{-1.4}$

Displaced Vertices

arXiv:1504.05162 , submitted to PRD

Run 2 Plans

- Dedicated DV trigger studies. Maybe use FTK. Otherwise, we will keep using multi-jet, met and lepton triggers.
- Improvement in vertexing: Expand fiducial volume, study of other selections.
- New material map.
- Re-tracking including IBL, higher pileup.
- More physics models!

Stable Massive Particles

JHEP 01 (2015) 068

arXiv:1506.05332 , submitted to EPJ C

Particles with lifetimes >~ns could traverse the detector. Candidate particles include long-lived slelptons in GMSB models and R-hadrons.

If massive, then they will be produced with $\beta<1$

Mass measurements ($m=\frac{p}{\beta\gamma}$) depends on the interaction with ID, calorimeters and muon spectrometer (where we can measure time of flight and p).

Can also measure energy loss $\frac{dE}{dx}$, related to $\beta\gamma$ -> **Pixel Only search**

Signal models: Stable and metastable (10-0.001 ns) squarks and gluino R-hadrons. Stable and metastable (1-0.3 ns) charginos.

R-hadrons can interact with material and even flip charge. If they are too slow, they may be associated with the following bunch crossing by the time it gets to the muon spectrometer. Muon trigger efficiency can be low.

Run 2 plans

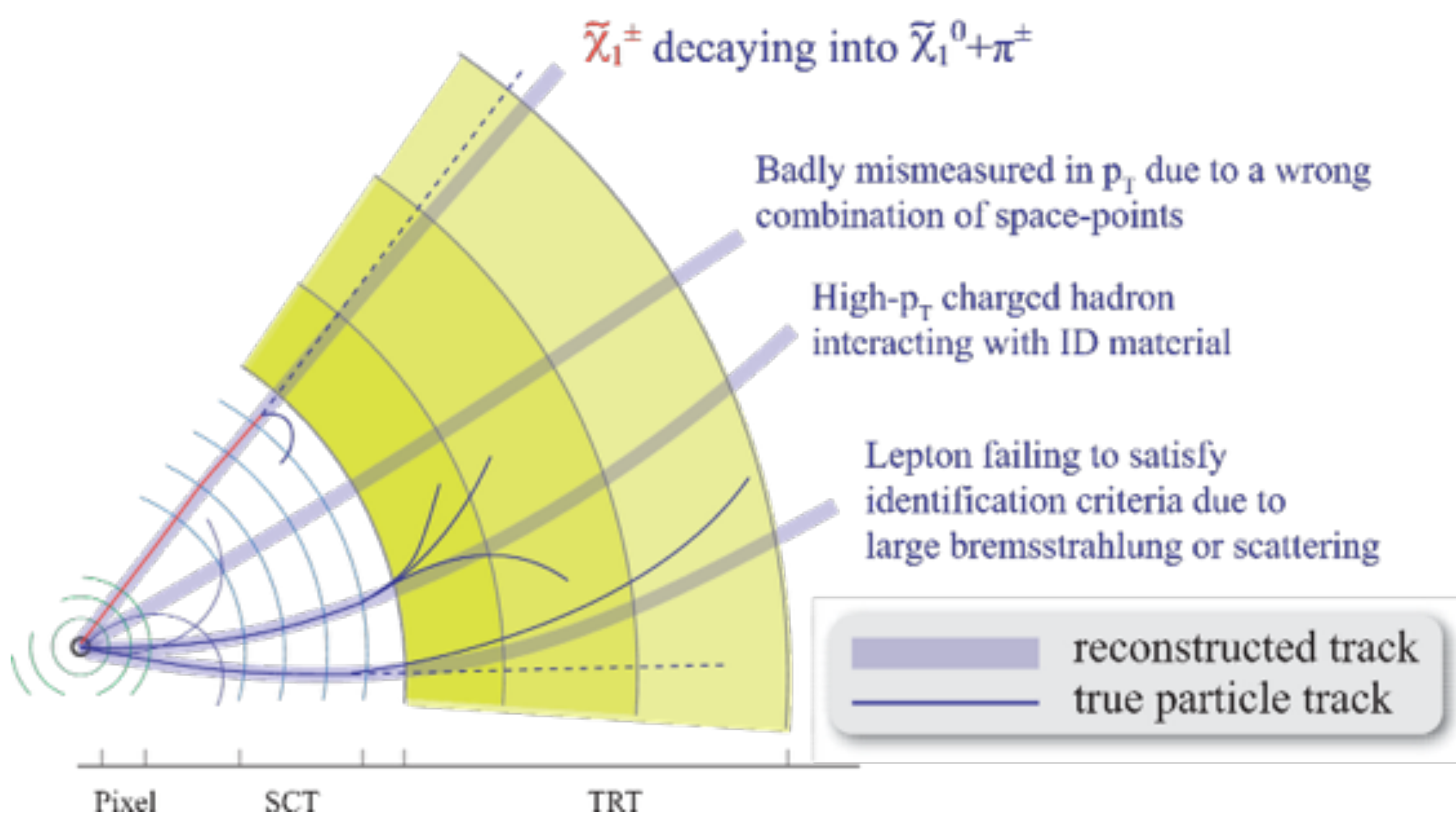
- Trigger strategy to look for met in one bunch crossing and a high pT muon in the next one.
- Improvement on observables: Time correction, include IBL in pixel $\frac{dE}{dx}$: New definition and calibration (Bethe-Bloch) needed.
- FTK trigger could select events with high pT isolation and tracks with $\frac{dE}{dx}$. Acceptance increases!

Disappearing Tracks

Phys. Rev. D 88, 112006 (2013)

Run 2 plans

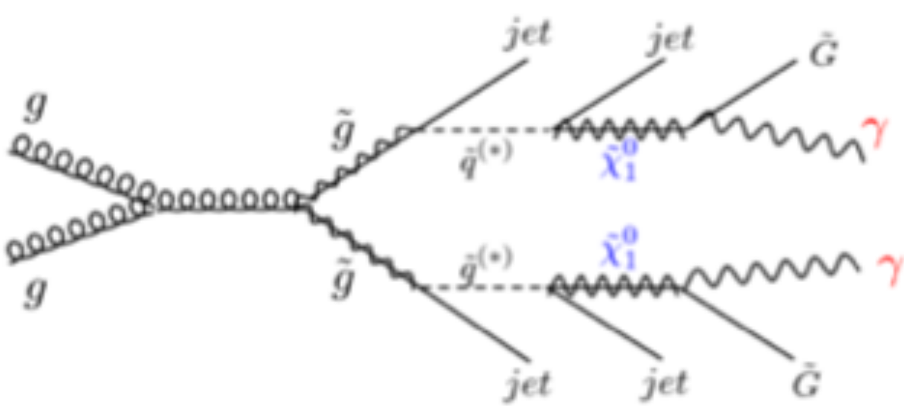
- Trigger on met back-to-back with high-pT jet
- Possibly use FTK in 2016.
- Tracking with IBL. Can use shorter tracks (charginos decaying within ~ 130 mm <R< 300 mm). Signal acceptance improves!

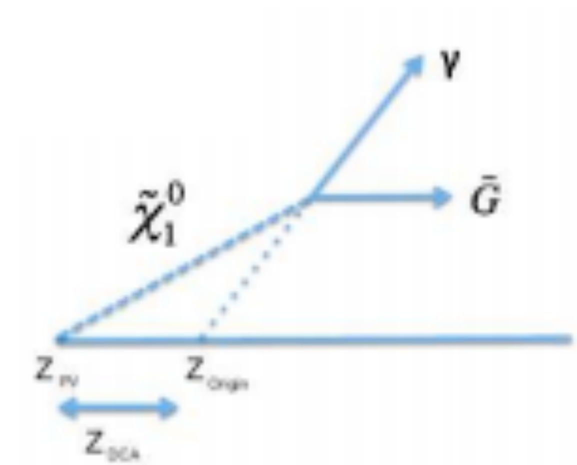


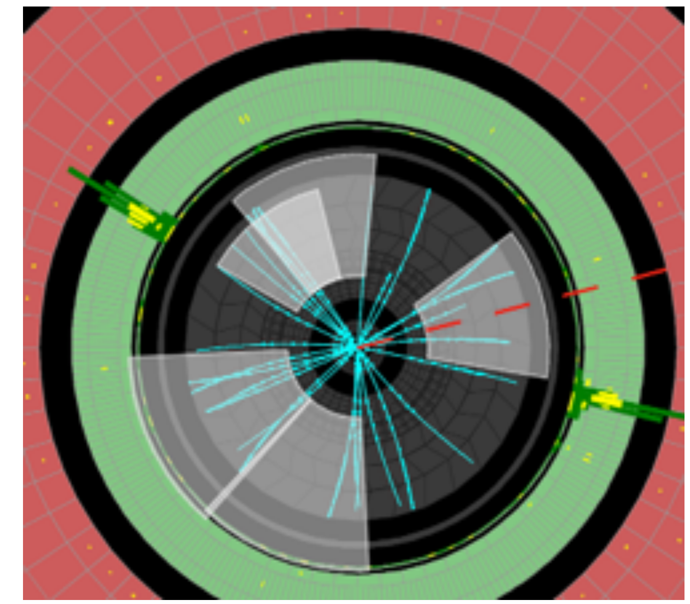
Delayed/Non-pointing Photons

Phys. Rev. D. 90, 112005 (2014)

Non-prompt photon search performed in the context of GMSB. Long-lived $\tilde{\chi}_1^0$ NLSP has finite lifetime (250 ps), producing distinctive signature.







Uses LAr pointing angle and timing as key variables.

Trigger choice for **Run 2** will affect the analysis!

- Continue with a “loose” diphoton trigger.
- Change analysis to single “photon+met” trigger
- Use a dedicated timing trigger : Will need rates study, timing selection. Perhaps not suitable.

Also need to do LAr timing calibration for the new data period.

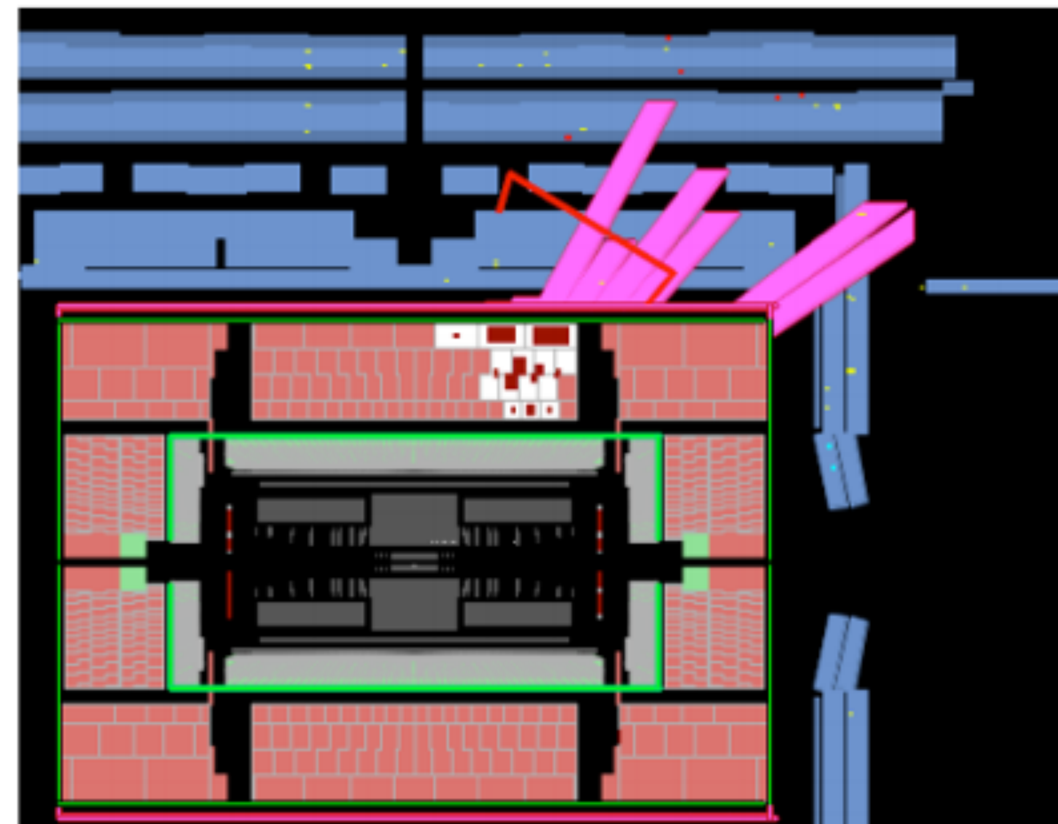
Results are interpreted in specific SPS8 benchmark model of GMSB. Possibility for a more general “displaced photon” search?

Stopped R-hadrons

Phys. Rev. D. 88, 112003 (2013)

Long-lived R-hadron stops in the calorimeter. Detect decay to jets in “empty” bunch crossing (many bunch crossings later)

Analysis sensitivity is really determined by “live-time" (how long to record data in absence of collisions). Could improve quickly in Run2! (just by occasionally taking data between LHC fills)



Run 2 plans

- Make sure all needed triggers are in place.
- Move to Pythia8 in Rhadron simulation.