

ATLAS results on searches for long-lived particles



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on behalf of ATLAS collaboration

ASPEN 2018 – The Particle Frontier



KYUSHU
UNIVERSITY

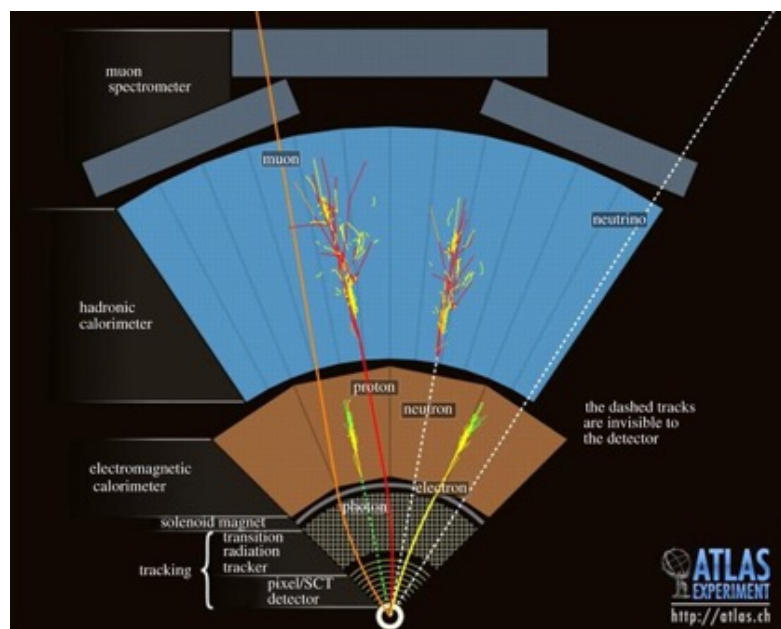
26th March, 2018

We haven't found BSM yet..

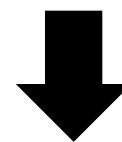
LHC-Run2 data gives us a great potential to find BSM.

Most of analyses focus on the particles (e.g., Higgs):

- Generating and decaying at interaction point of two beams, **AND**
- Going through the detectors with speed of light ($\beta = 1$).



However, this strategy could miss **Long-lived particles**.



We need to develop dedicated techniques to exploit full potential of the ATLAS detector!!

Physics making long-lived particles

Taking an example from π^\pm decay ($c\tau \sim 7.8$ m) :

Small coupling constant

Helicity suppression

$$\frac{\hbar}{\tau} = \frac{f_\pi^2}{256\pi m_\pi} \left[\frac{g^2}{M_W^2} \frac{m_\mu}{m_\pi} (m_\pi^2 - m_\mu^2) \right]^2$$

Heavy intermediate particle

Small mass difference

Effects shown above appear in various physics.

Physics behind long-lived particles

Caveat : These are just examples.

SUSY

- Long-lived \tilde{g} : Heavy squark, \tilde{g} -Bino co-annihilation
- Long-lived $\tilde{\chi}^{\pm}$: Wino/Higgsino Lightest Stable Particle (LSP)
- Long-lived $\tilde{\chi}^0$: Gravitino LSP, R-parity violation, Wino-Bino co-annihilation

Hidden/dark sector scenario

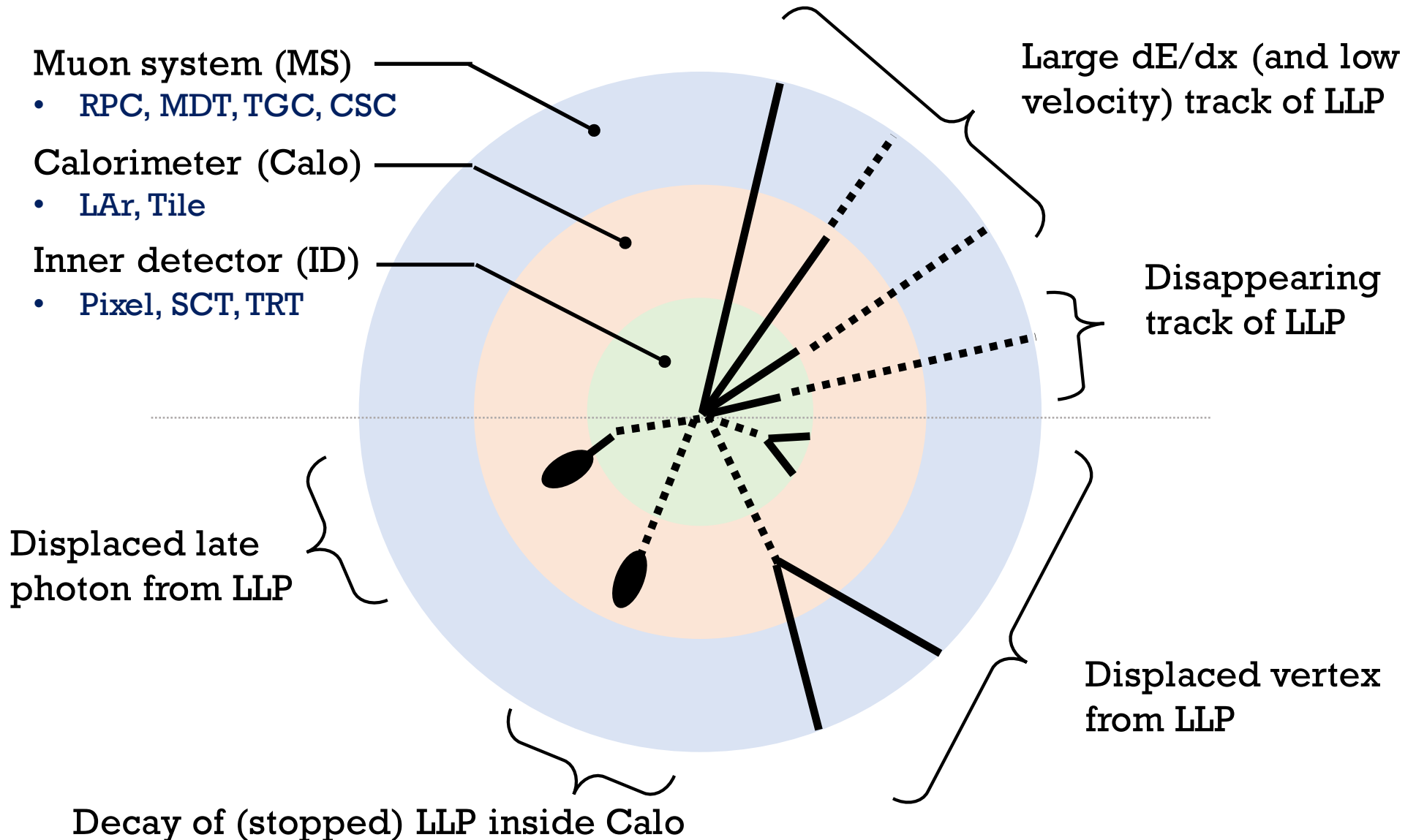
- Long-lived dark photon : Higgs portal model
- Long-lived neutral scalar : Heavy neutral boson portal model

Others

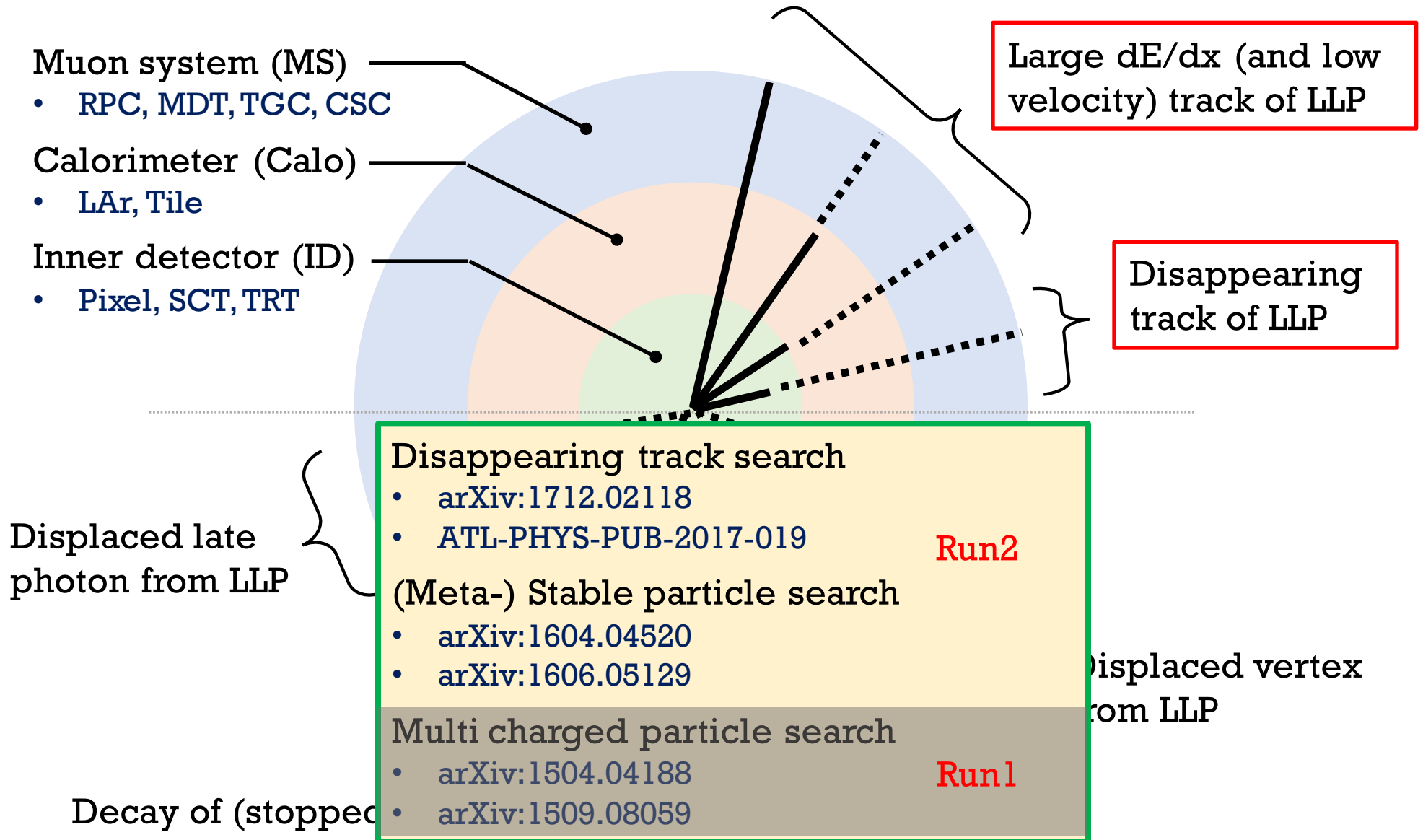
- Long-lived right-handed neutrino : Left-right symmetry extension of SM
- Long-lived multi-charged particle : Monopole, Micro black hole, Q-ball

And many more !!

Signatures of long-lived particles



Searches with direct detection of LLP



Search for disappearing track in ID

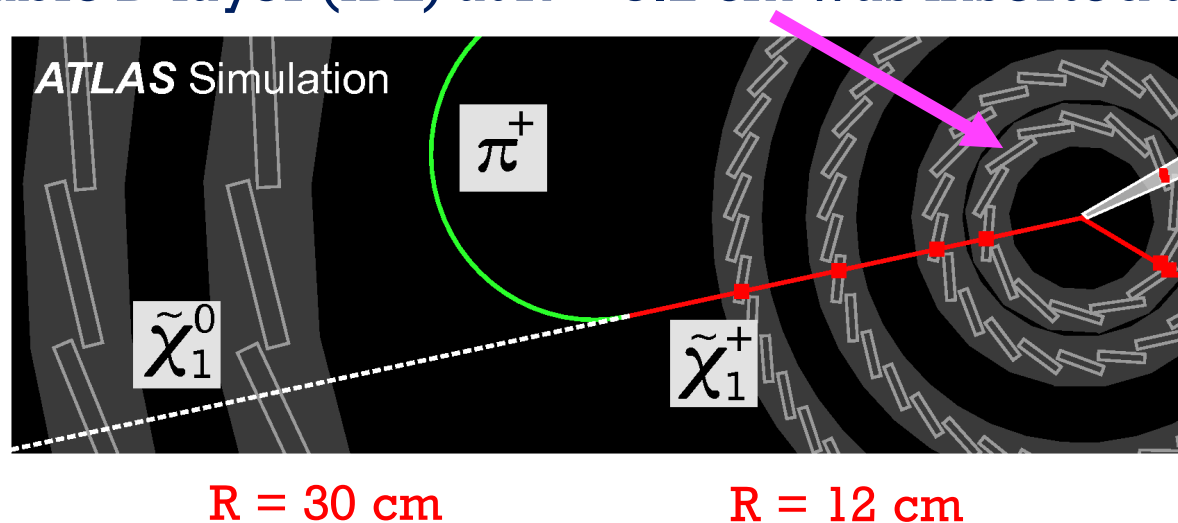
arXiv:1712.02118 – submitted to JHEP 36.1 fb⁻¹ in 2015 + 2016 data (Inner detector)

Pure \tilde{W}^0/\tilde{H}^0 LSP in SUSY are strong candidates for DM.

- Thermal relic implicates $M_{\tilde{W}} \sim 2.7$ TeV, or $M_{\tilde{H}} \sim 1.1$ TeV.
- Small mass splitting with Charginos, making $\tilde{W}^\pm/\tilde{H}^\pm$ long-lived.
 - \tilde{W}^\pm : $\Delta M \sim 160$ MeV $\rightarrow c\tau \sim 6$ cm
 - \tilde{H}^\pm : $\Delta M \sim 350$ MeV $\rightarrow c\tau \sim 1$ cm

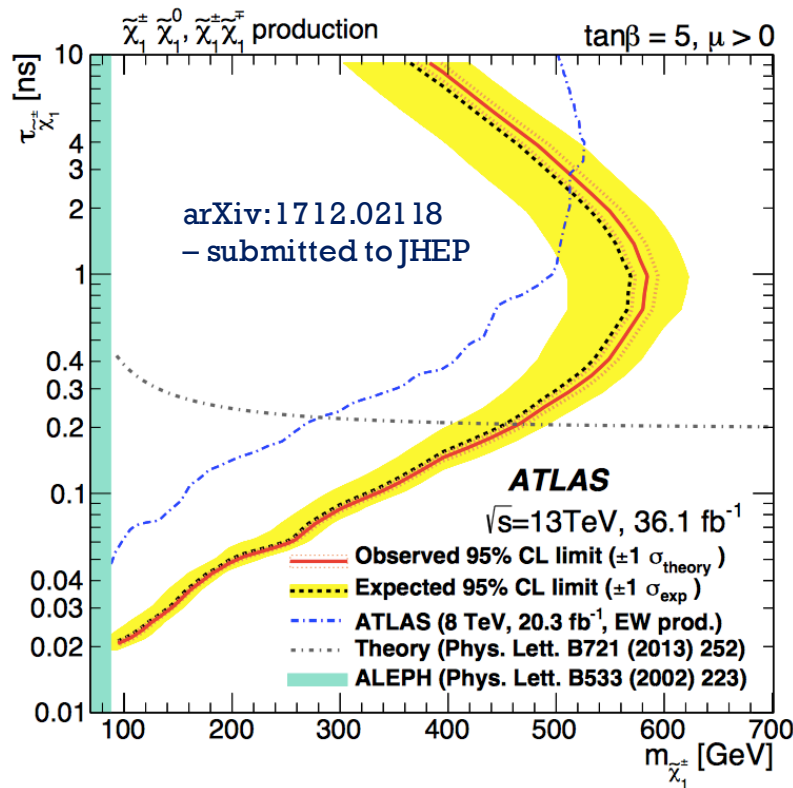
Use “short” isolated high p_T tracks requiring 4 silicon hits:

- Insertable B-layer (IBL) at $R = 3.2$ cm was inserted after Run 1.

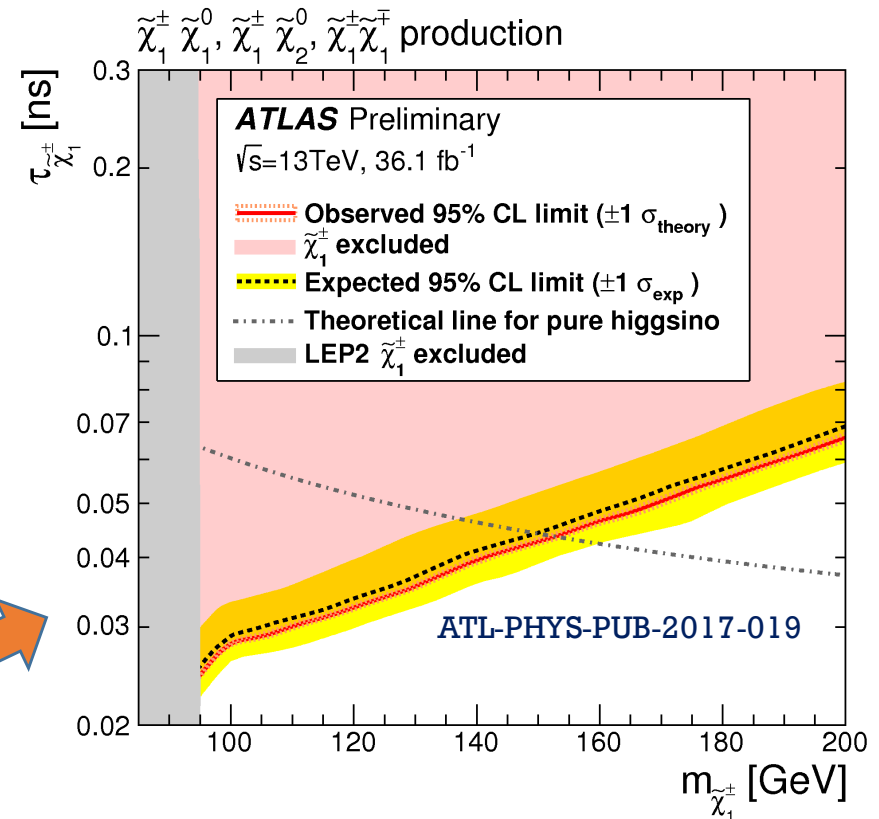


Result of disappearing track search

arXiv:1712.02118 – submitted to JHEP 36.1 fb⁻¹ in 2015 + 2016 data



In pure-Wino LSP model,
Chargino masses up to 460 GeV are excluded.



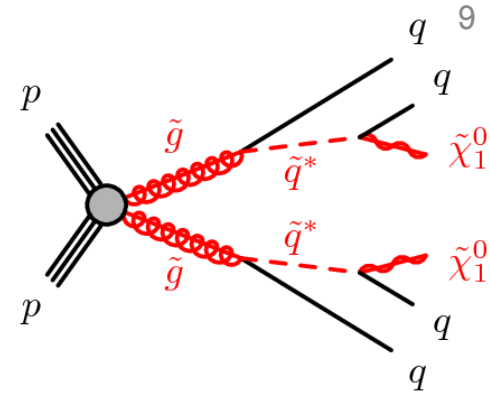
In pure-Higgsino LSP model,
Chargino masses up to 152 GeV are excluded.

While these search focus on O(1) cm long-lived particle,
longer lifetime is also quite interesting → Next topic !!

3.2 fb⁻¹ in 2015 data

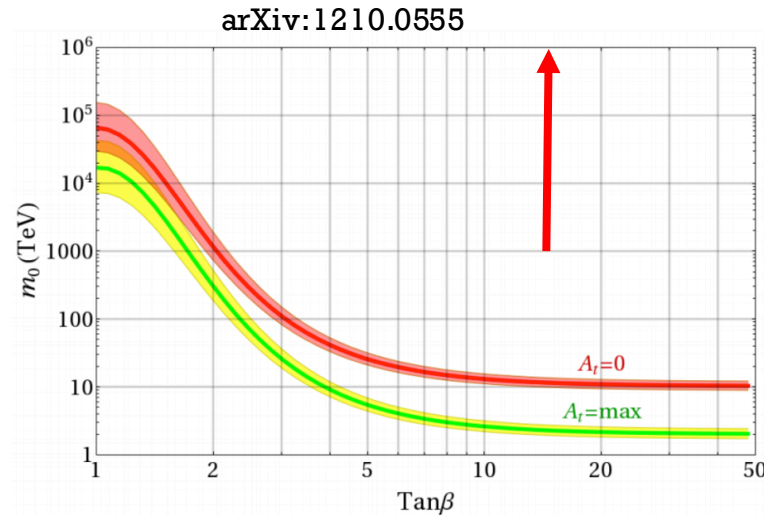
Meta-stable particle search

arXiv:1604.04520 – Phys.Rev. D 93, 112015 (2016)



Another target besides Chargino – Long-lived Gluino

- In minimal SUSY models, 125 GeV Higgs implies heavy squarks.
 - Higgs mass at tree level should be lighter than Z mass

 $c\tau \sim 10 \text{ m}$ $c\tau \sim 0.1 \text{ mm}$

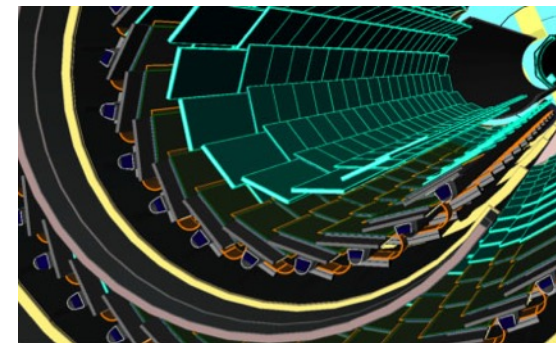
- If squark is heavier than $\sim 1000 \text{ TeV}$, Gluino becomes long-lived.

→ Leave distinct feature, e.g, large dE/dx and low velocity.

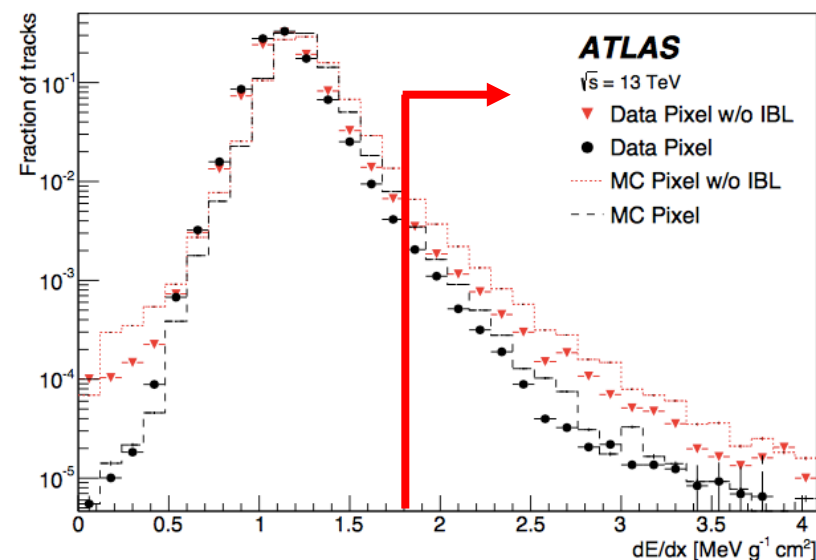
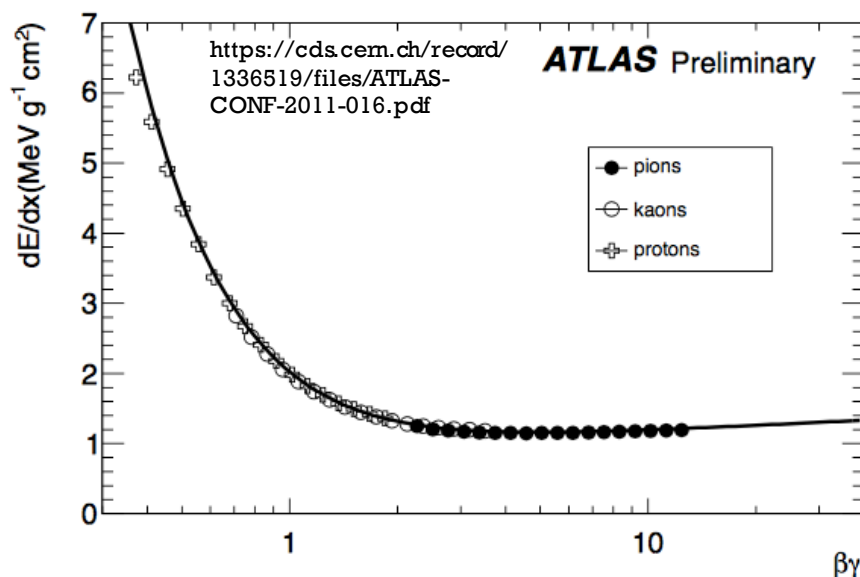
3.2 fb⁻¹ in 2015 data

Search using dE/dx in ID

arXiv:1604.04520 – Phys.Rev. D 93, 112015 (2016)



Pixel detector in ID can provide dE/dx information.



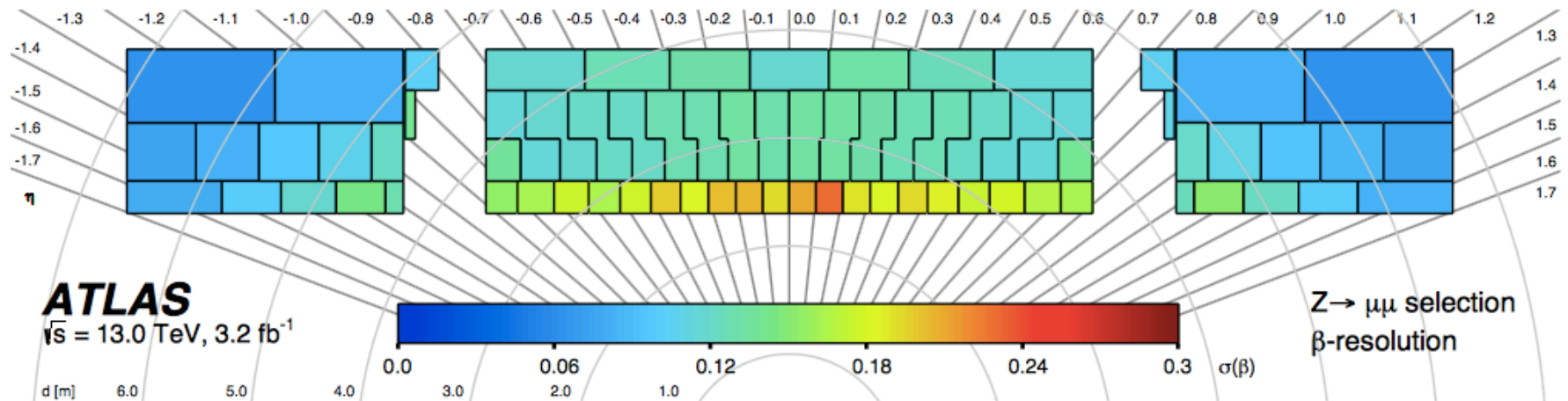
Require 7 silicon hits (> 37 cm) with high dE/dx.

- Sensitive to longer lifetime than the disappearing track search.
- Look for isolated and high-momentum track.
- Insertable B-layer in the Pixel improves the sensitivity from Run 1.
- Mass of long-lived particles can be calculated by $p/\beta\gamma$.

3.2 fb⁻¹ in 2015 data

Search using timing in Calorimeter

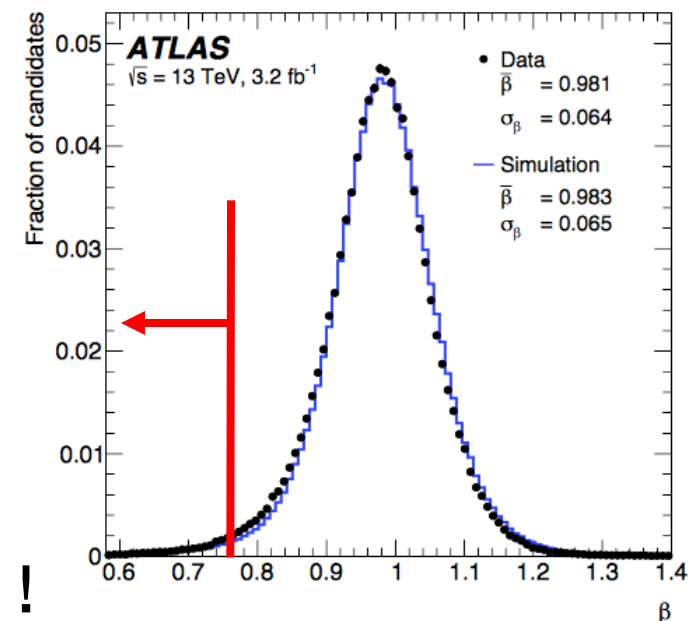
arXiv:1606.05129 – Physics Letters B (2016), pp. 647-665



Hadron Calo covers $2.3 \text{ m} < R < 3.9 \text{ m}$

- Provide good timing resolution.
→ $\beta < 0.75$ is required.
- Use dE/dx information in Pixel as well.
- Does not use Muon system at all.

The best sensitivity for stable particle !



3.2 fb⁻¹ in 2015 data

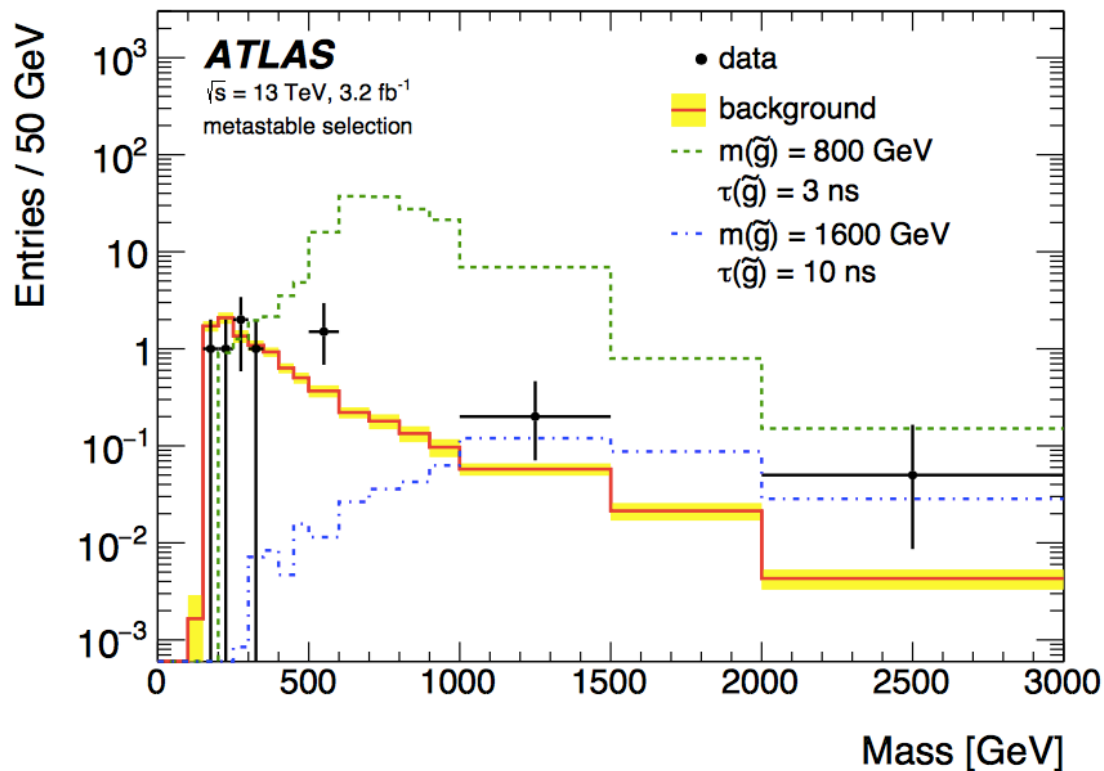
Results of dE/dx based searches

arXiv:1604.04520 – Phys.Rev. D 93, 112015 (2016)

arXiv:1606.05129 – Physics Letters B (2016), pp. 647-665

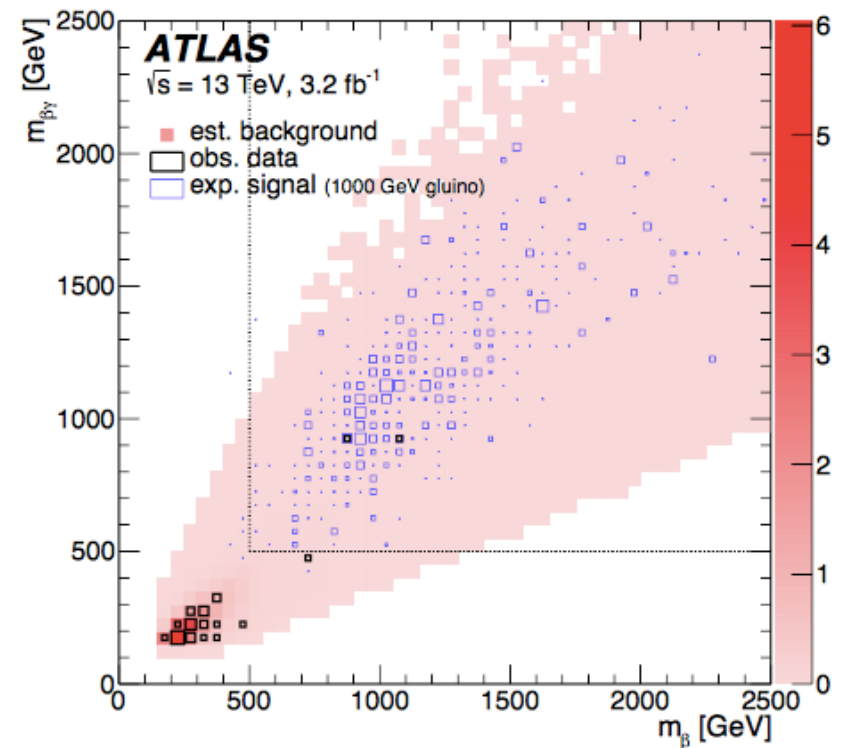
No excess observed for both searches.

Pixel dE/dx only



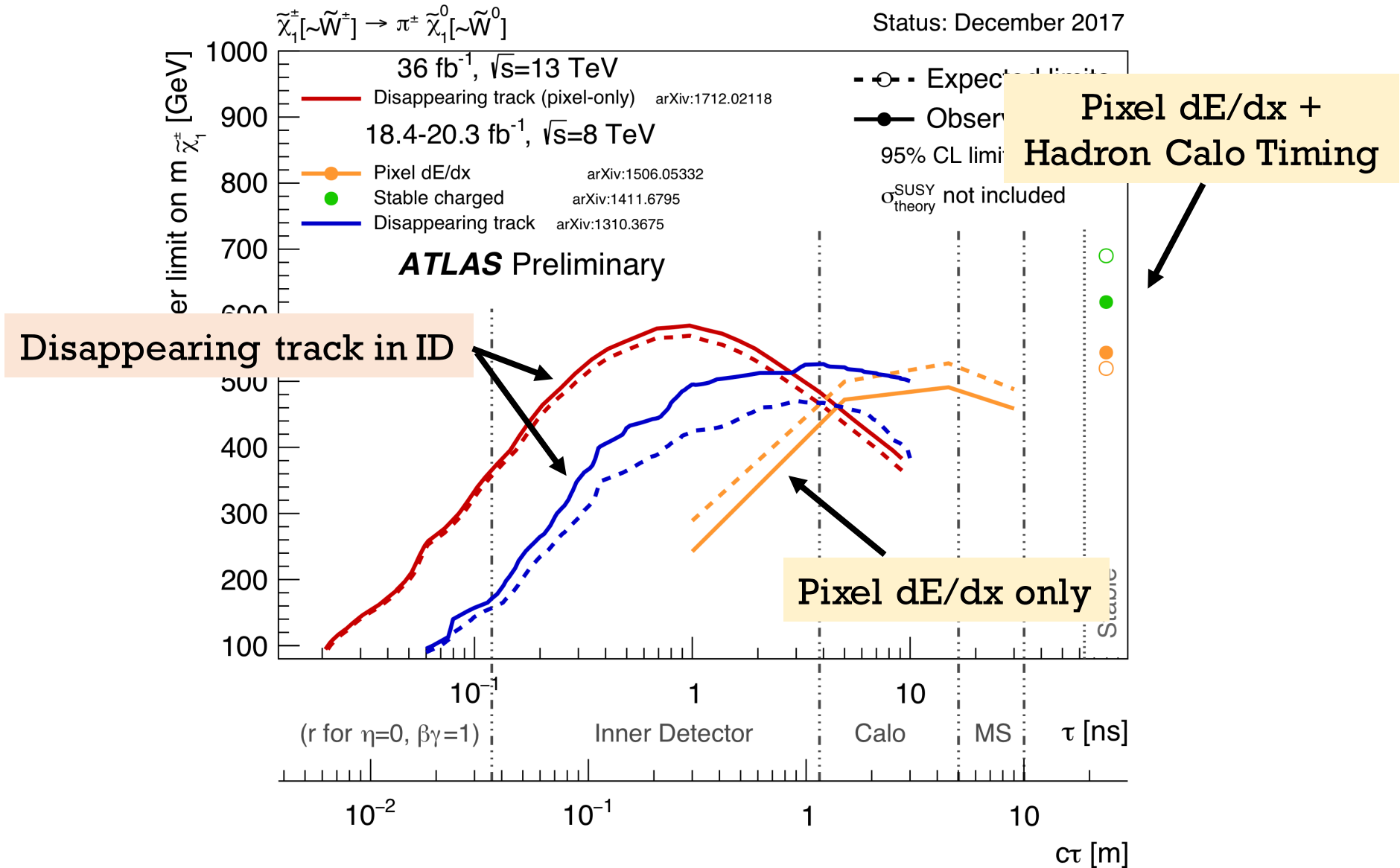
Glauino with 10 nsec lifetime
 excluded up to 1571 GeV

Pixel dE/dx + Hadron Calo Timing

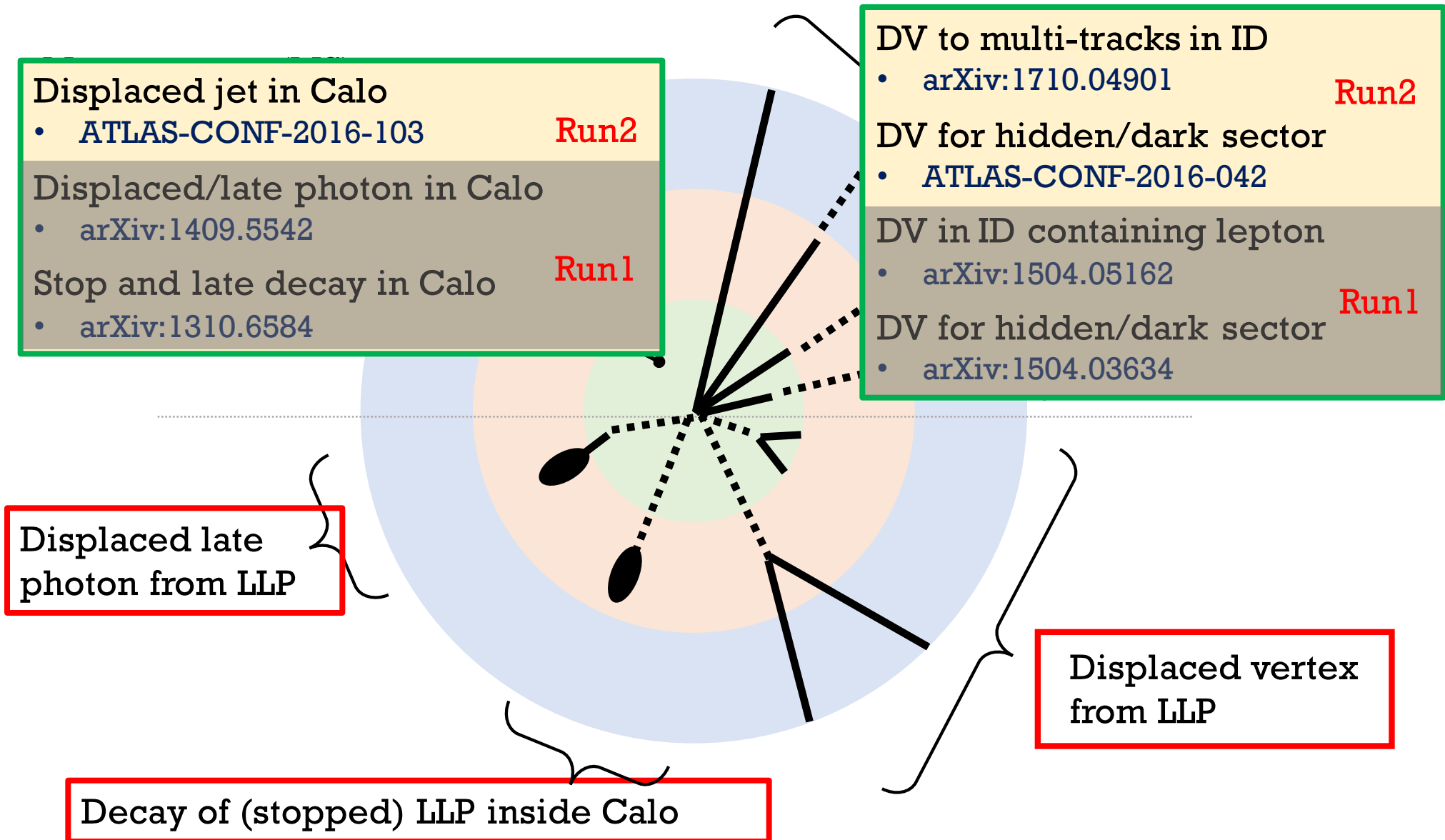


Stable Glauino excluded
 up to 1580 GeV

Summary of direct searches for LLP

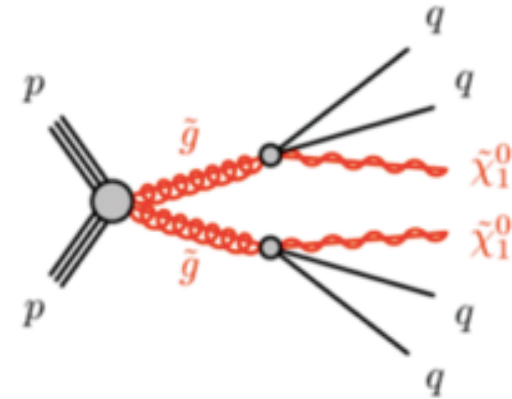


Searches for decay of LLP



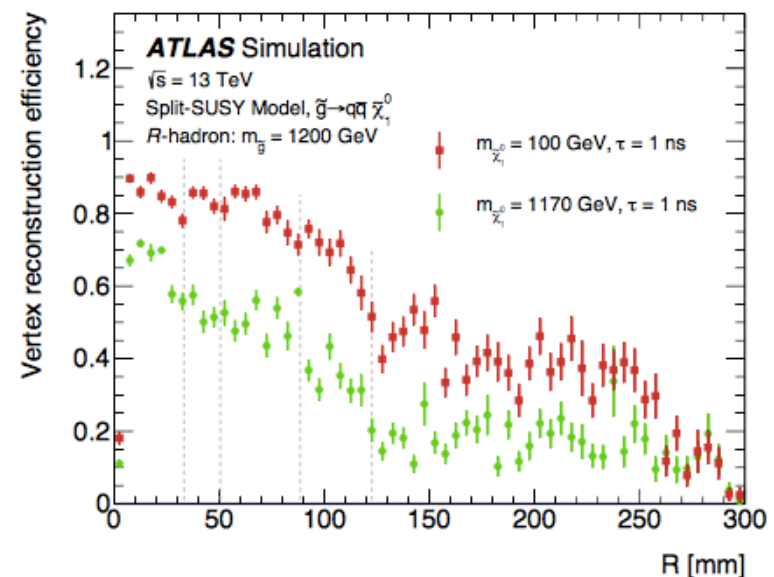
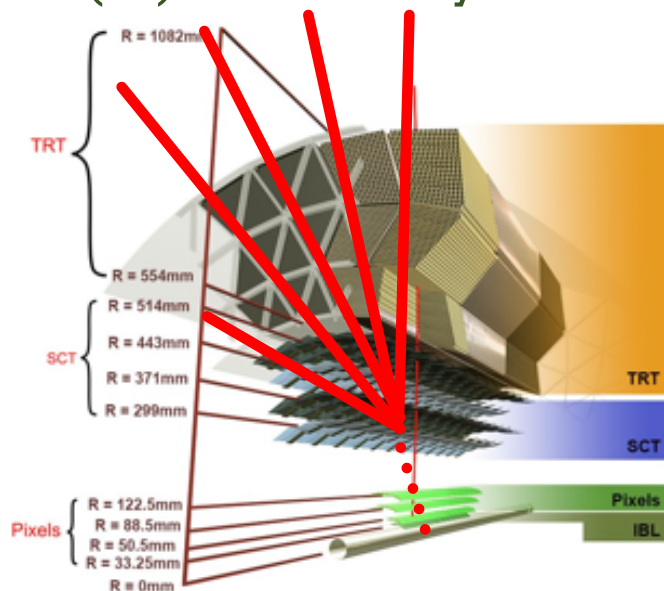
Search for LLP decay in ID

arXiv:1710.04901 – Submitted to PRD 32.8 fb⁻¹ in 2016 data



Target : Long-lived \tilde{g} decays to multi-tracks

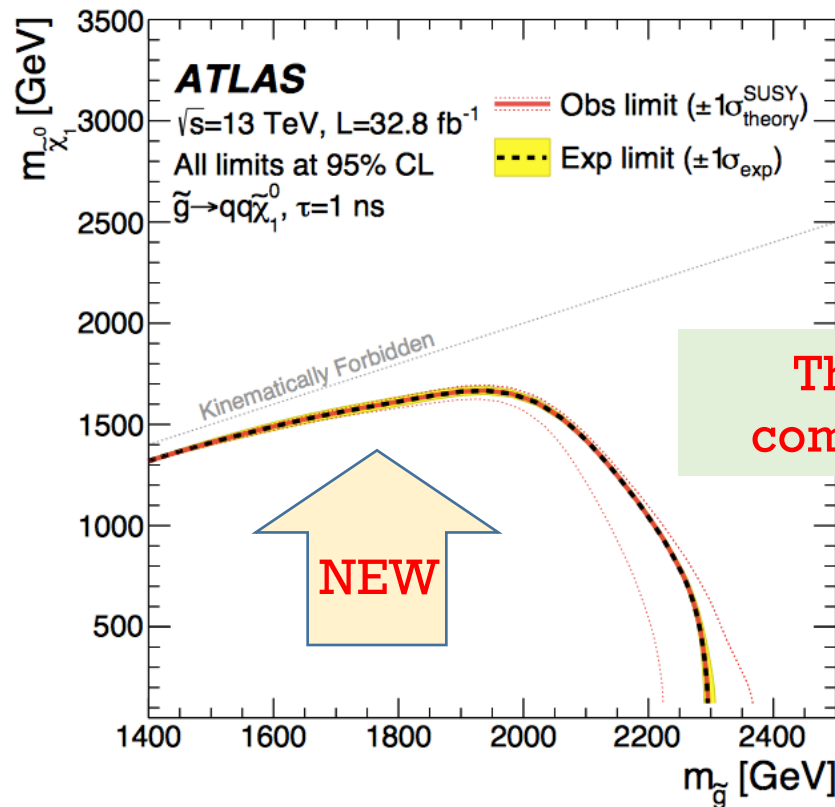
- Reconstruction of displaced vertex has been developed.
- The number of tracks is related to mass difference of \tilde{g} and $\tilde{\chi}_1^0$
- For Run2, compressed region between \tilde{g} and $\tilde{\chi}_1^0$ is also explored.
 - Inspired by Gluino-Bino co-annihilation (arXiv:1504.00504)
 - O(10)% efficiency is achieved even for $\Delta M=30$ GeV.



Results of search for LLP decay in ID

arXiv:1710.04901 – Submitted to PRD 32.8 fb⁻¹ in 2016 data

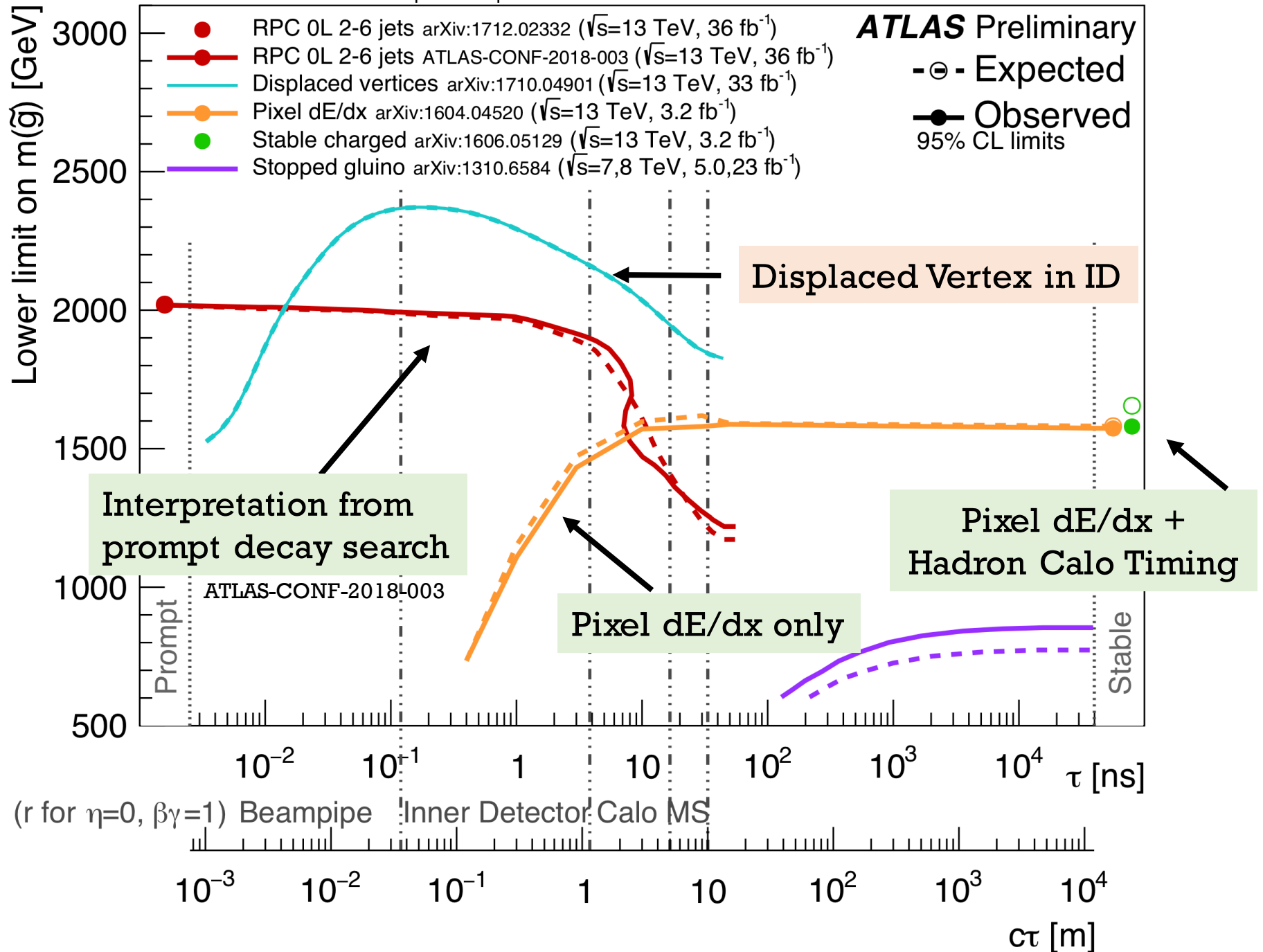
No excess observed ..



Assuming 100 GeV $\tilde{\chi}^0$, Gluino with 1 nsec lifetime excluded up to 2.3 TeV.
 Strong limit for broad range of lifetime → See next page

\tilde{g} (R-hadron) \rightarrow qq $\tilde{\chi}_1^0$; $m(\tilde{\chi}_1^0) = 100$ GeV

March 2018



Search for neutral LLP decaying in Calo

ATLAS-CONF-2016-103

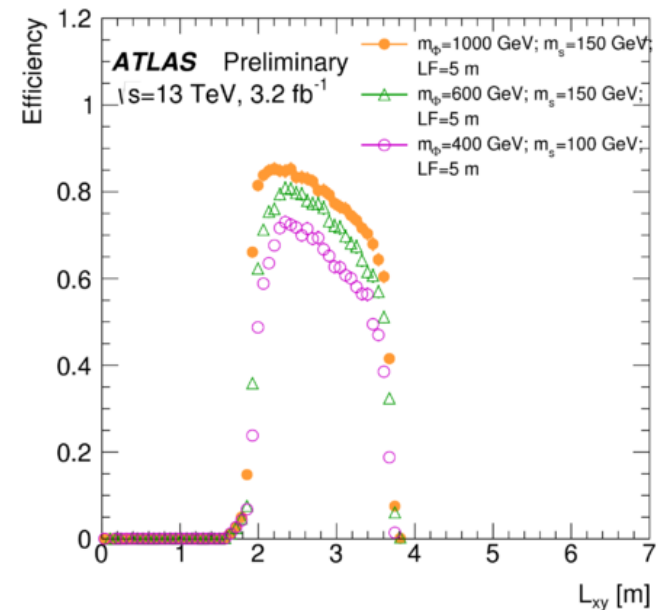
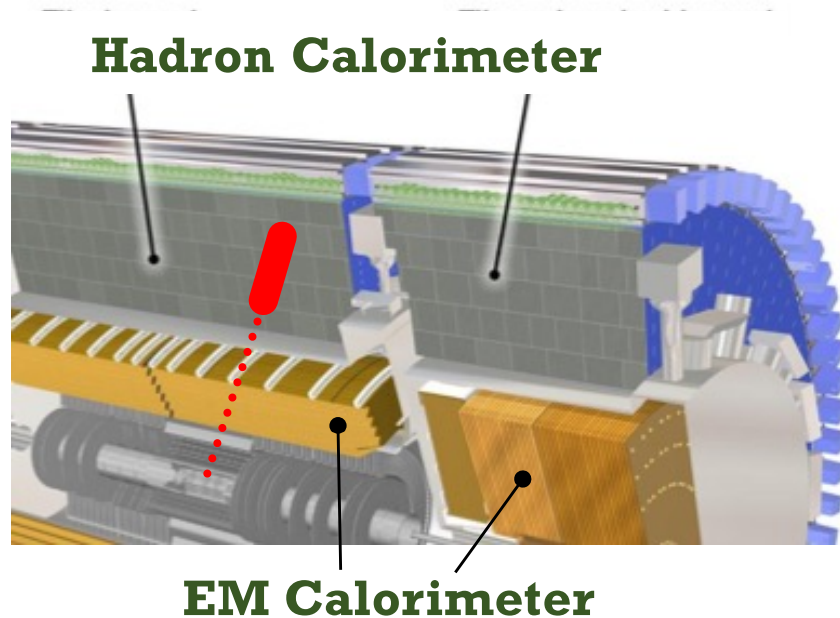
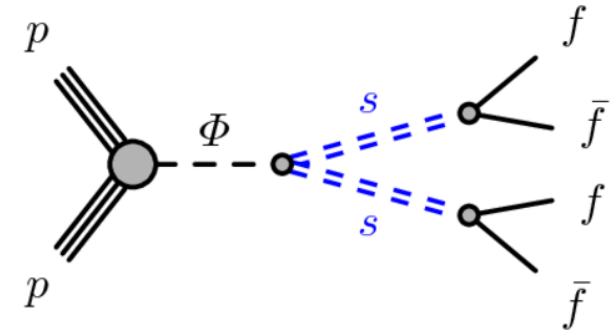
3.2 fb⁻¹ in 2015 data

Target : Hidden sector models

- Communicator particle may produce neutral LLP

Look for displaced jets that have low energy in EM calo.

- Calo-ratio trigger compares the energy deposit in Had/EM calo.
→ Could achieve reconstruction efficiency of O(10)%.

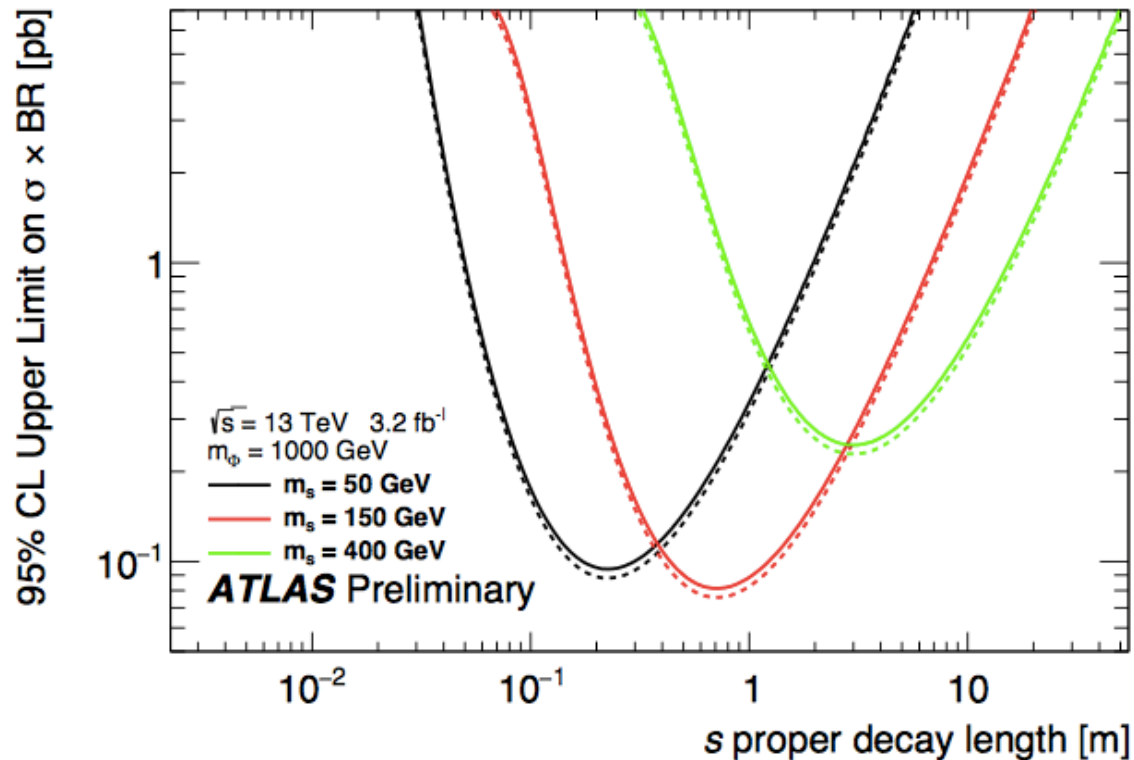
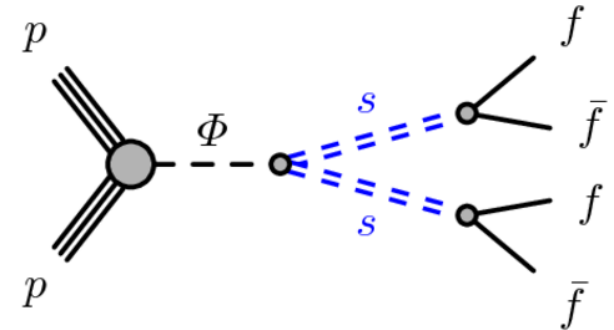


Result of search for neutral LLP decaying in Calo

ATLAS-CONF-2016-103

3.2 fb⁻¹ in 2015 data

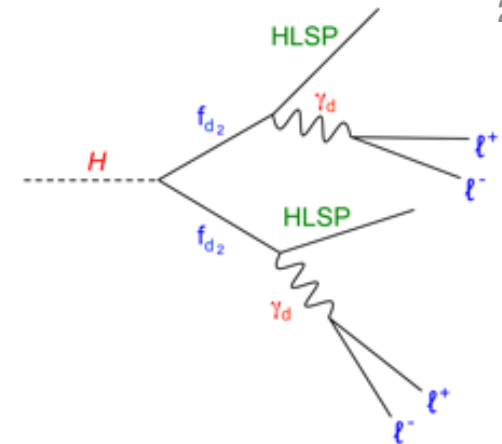
No excess observed...



Upper limits on $\sigma \times \text{Br}$ are set for $400 \text{ GeV} < m_\Phi < 1 \text{ TeV}$ and
 $50 \text{ GeV} < m_s < 400 \text{ GeV}$

Search for neutral LLP decaying to lepton-jets

ATLAS-CONF-2016-042 3.2 fb⁻¹ in 2015 data



Higgs might be a portal for Hidden sector.

- Dark photon decays to collimated objects such as $ee/\pi\pi/\mu\mu$.

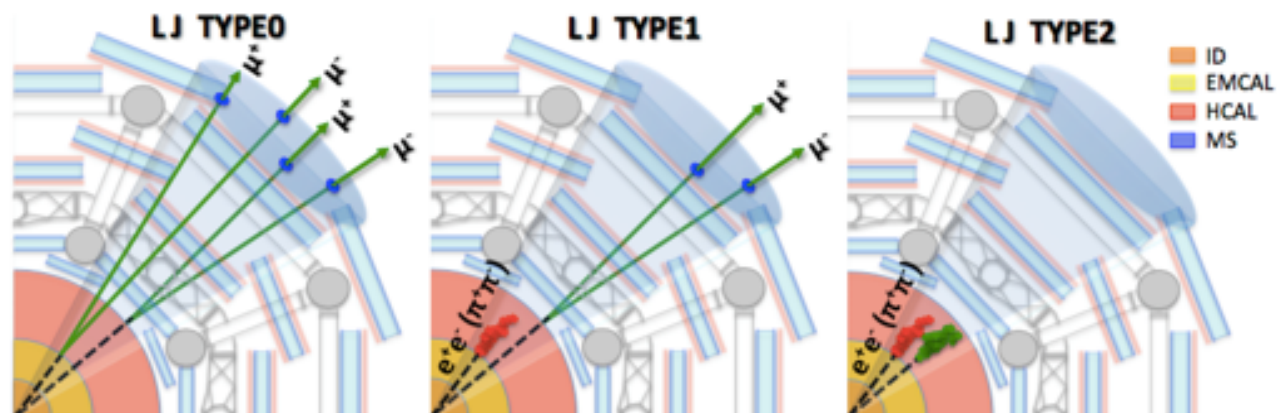
Two types of signature:

Same as the search in the previous pages.

- e/π pair : Requiring no activity preceding Hadron Calorimeter.
- μ pair : Reconstructed only by Muon system

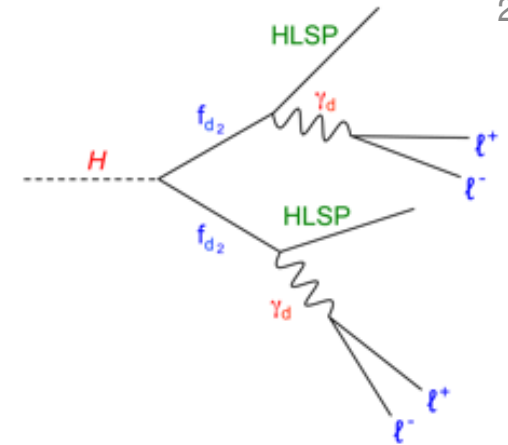
Collimated muon trigger is introduced for Run2.

- Calo-ratio trigger and MS-only Tri-muon trigger is also used as Run1.

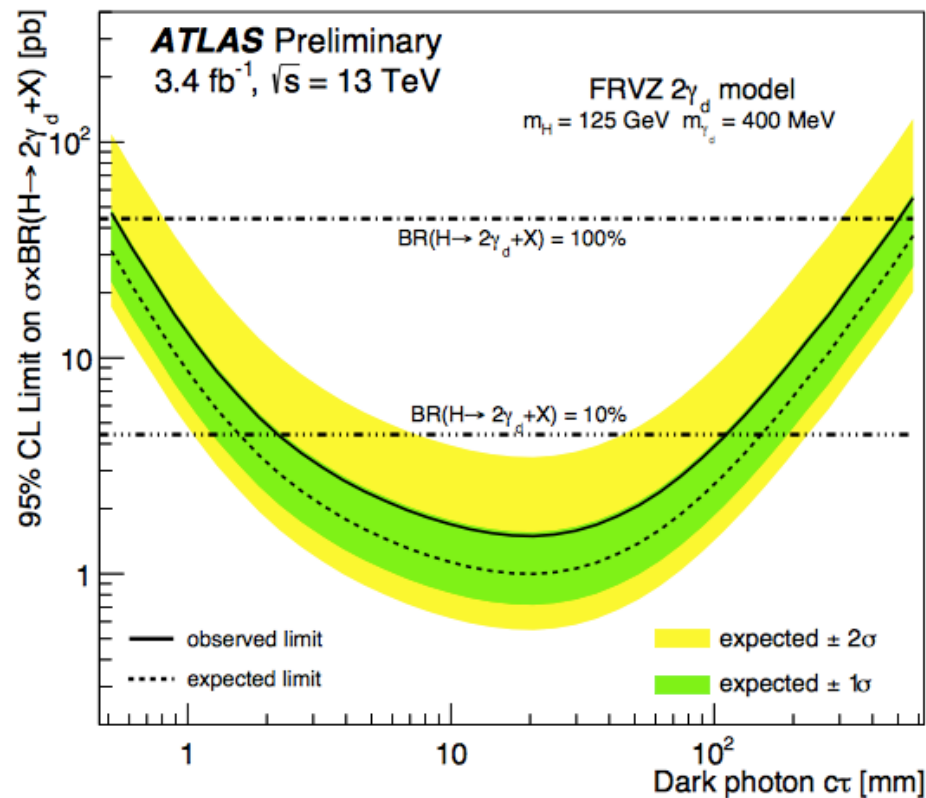


Result of search for neutral LLP decaying to lepton-jets

ATLAS-CONF-2016-042

3.2 fb⁻¹ in 2015 data

No excess observed...



Upper limits on $\sigma \times \text{BR}(H \rightarrow 2\gamma_d + X)$ as well as $\sigma \times \text{BR}(H \rightarrow 4\gamma_d + X)$, assuming the 125 GeV Higgs or 800 GeV Higgs-like scalar.

Conclusion

Long-lived particles appear in various physics models.

- Many types of unconventional signatures.
- Creative analysis techniques exploiting all aspects of our detector.
- Huge efforts done for LHC-Run 1.

We have intensively improved the analyses with Run2 data.

- Disappearing track and dE/dx search get benefits from the IBL insertion.
- Displaced vertex search explores more compressed region.
- Lepton-jet search introduce a new trigger, and many more...

No BSM yet, however we still have too many things to be done !!

Multiply-charged particle search

arXiv:1504.04188 – EPJ C75 (2015) 362

arXiv:1509.08059 – Phys. Rev. D 93, 052009 (2016)

Produce high ionization loss

- 2D plots for a particle with electric charge from 2 e to 6 e.
 - dE/dx in TRT in Inner detector
 - dE/dx in MDT in Muon system

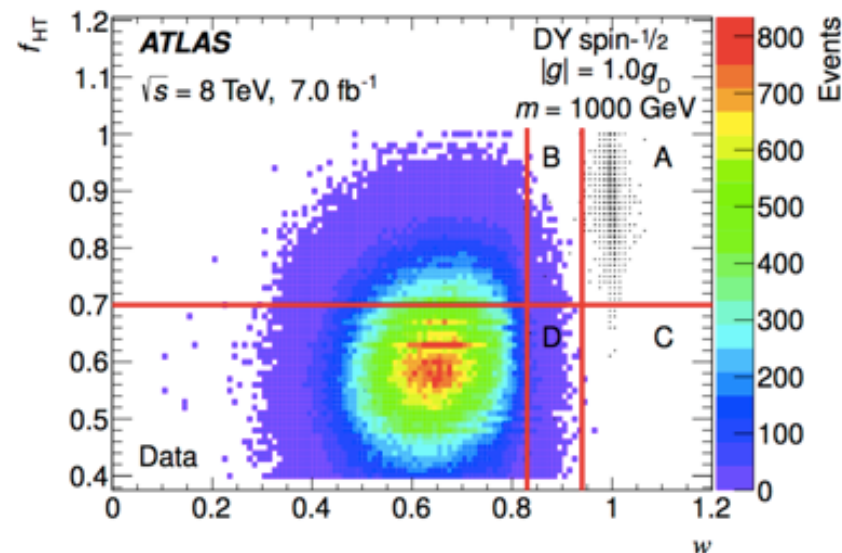
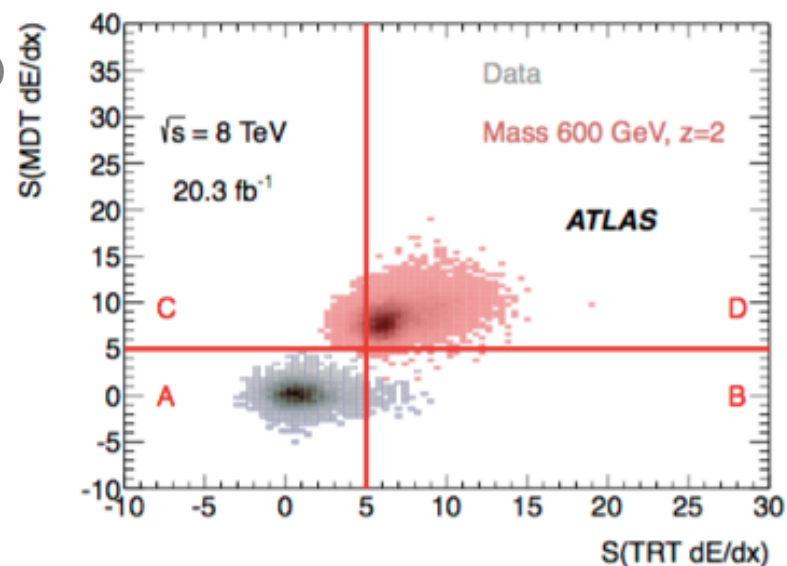
No event is observed.

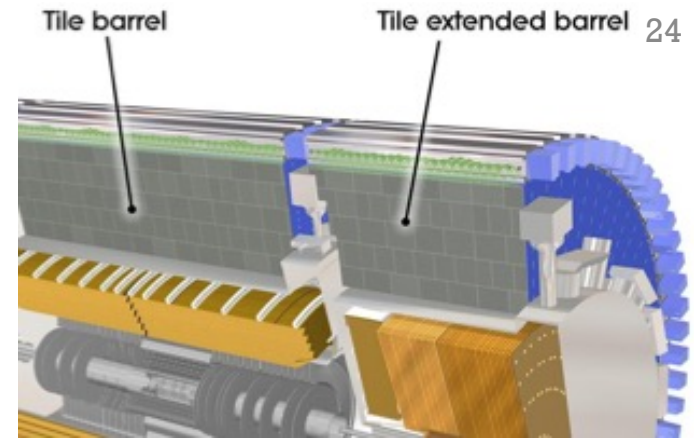
Set limit between 660 GeV and 785 GeV

- 2D plot for monopole with 68.5 e.
 - Energy dispersion in EM calo
 - Fraction of high-threshold hits in TRT

No event is observed.

Set limit in the mass range 200 – 2500 GeV



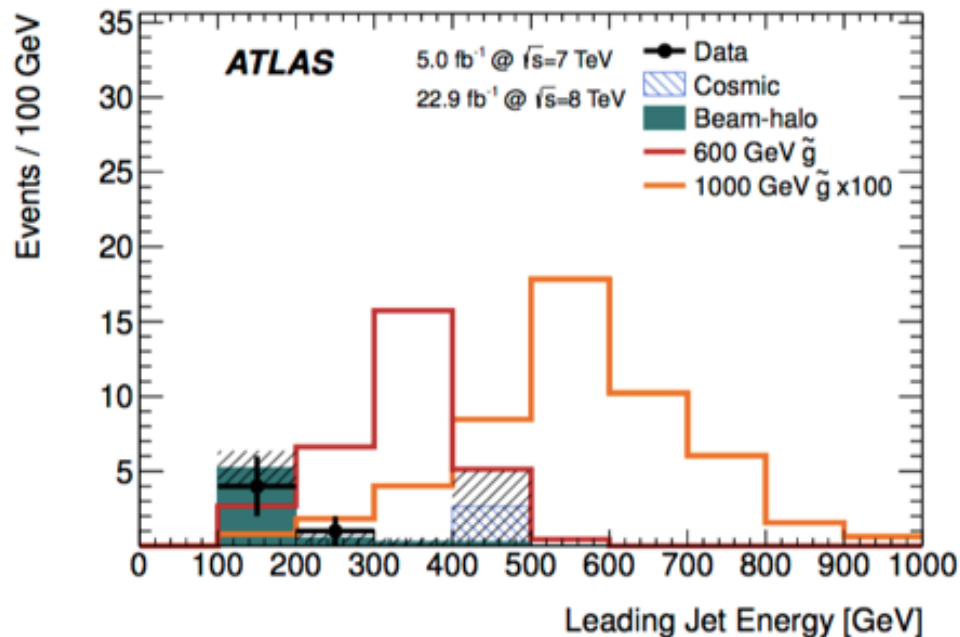


Calorimeters : Stop and Late decay search

Phys.Rev. D 88, 112003 (2013) – arXiv:1310.6584

Analyze events triggered in empty bunch crossing of the LHC.

- Massive particle might be stopped in the Tile Calo
- Characteristic jet shape is used for signal selection.



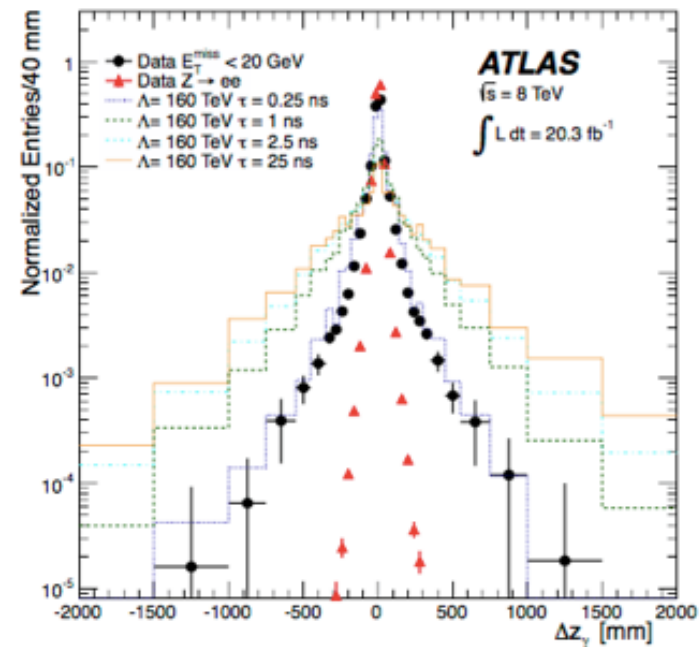
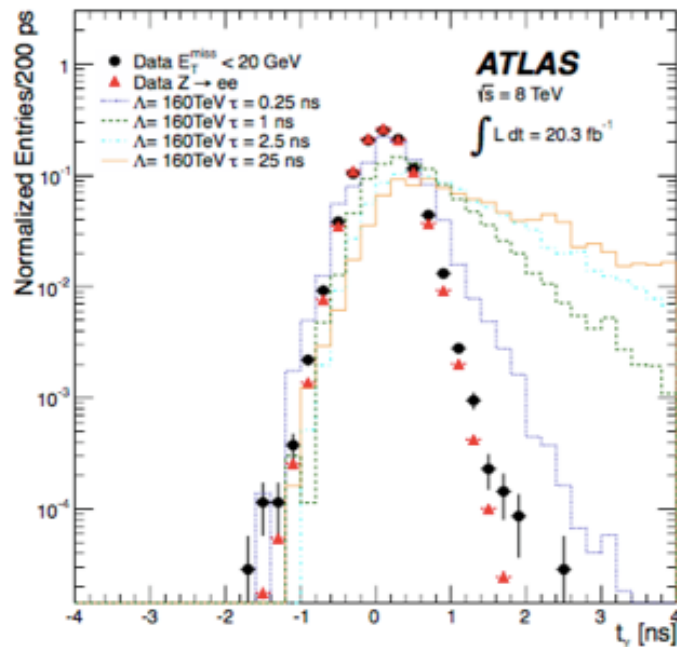
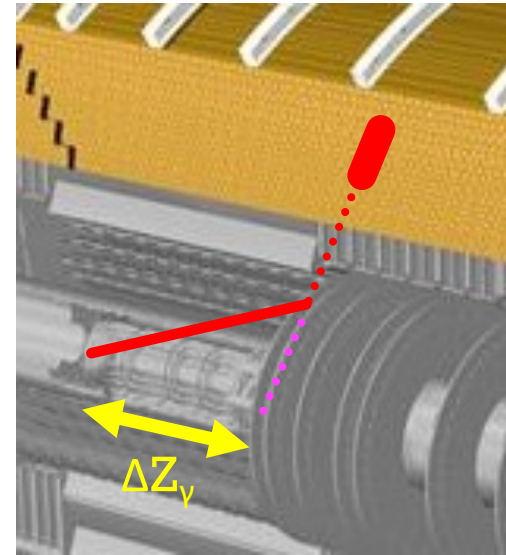
Run I

Calorimeters : Displaced photon search

JHEP 11 (2014) 088 – arXiv:1409.5542

Use Liquid Argon Calorimeter

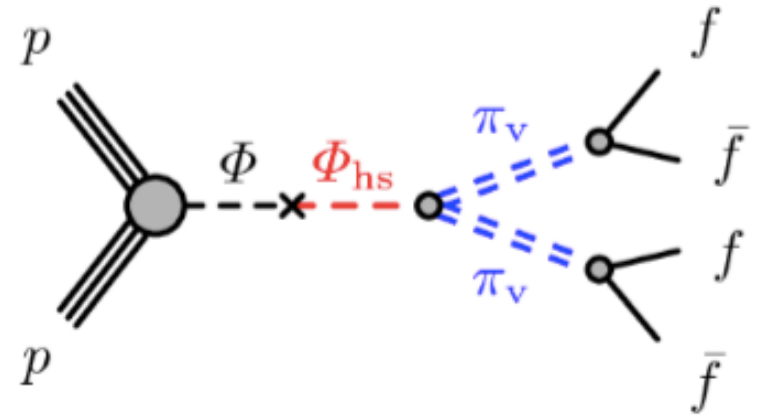
- Timing information (t_γ)
- Displacement in z-coordinate (ΔZ_γ)



Run 1

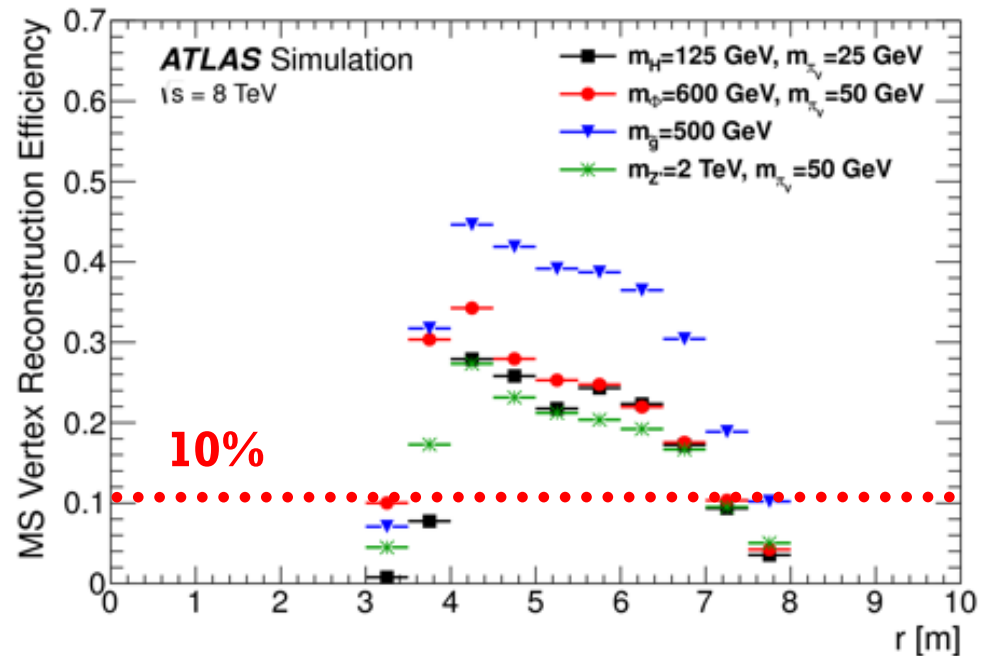
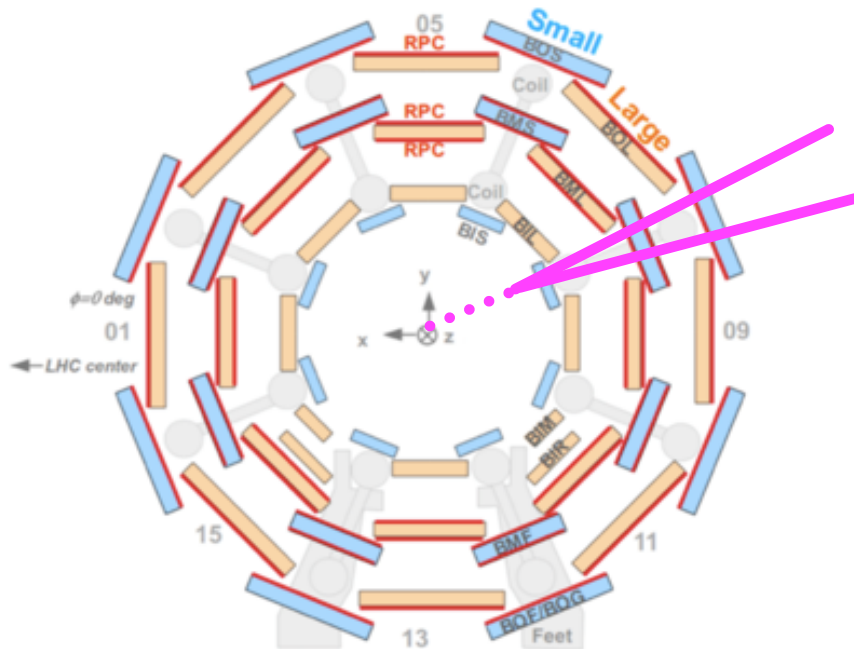
Muon system : Displaced vertex search

JINST 8 (2013) P07015 – arXiv:1305.2284
 JINST 9 (2014) P02001 – arXiv:1311.7070
 Phys.Rev. D 92, 012010 (2015) – arXiv:1504.03634



Special Muon RoI Cluster trigger:

- Use localized clusters in Muon System isolated from jets and tracks
- O(10)% reconstruction efficiency by Muon System standalone vertexing



Potentials for long-lived particle

ATLAS detector performance enable us to reconstruct unconventional sign

