# Searches for supersymmetric particles with **macroscopic or stable lifetimes** using the ATLAS detector

Hidetoshi Otono (Kyushu University)
on behalf of ATLAS collaboration


27th International Conference on
Supersymmetry and Unification
of Fundamental Interactions
(SUSY2019)

23th May, 2019

KYUSHU
UNIVERSITY

# We haven't found BSM yet, though

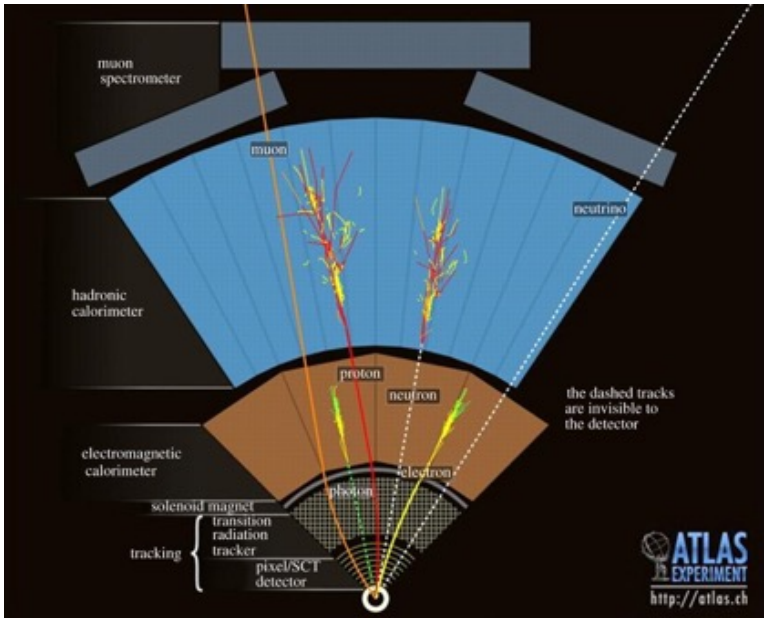
LHC gives us a great potential to find BSM.

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

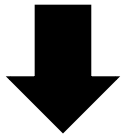
- Generating and decaying at interaction point of two beams,

**AND**

- Going through the detectors with speed of light ( $\beta = 1$ ).



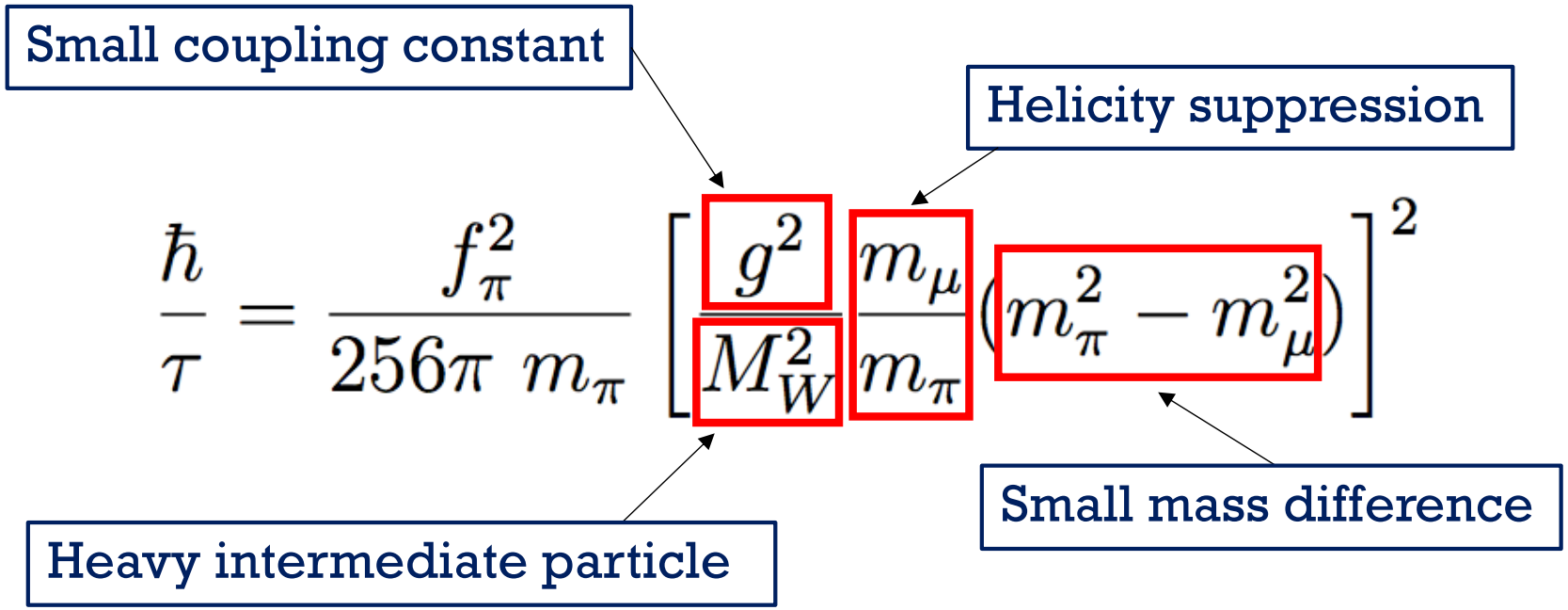

However, this strategy could miss **Long-lived particles**.



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

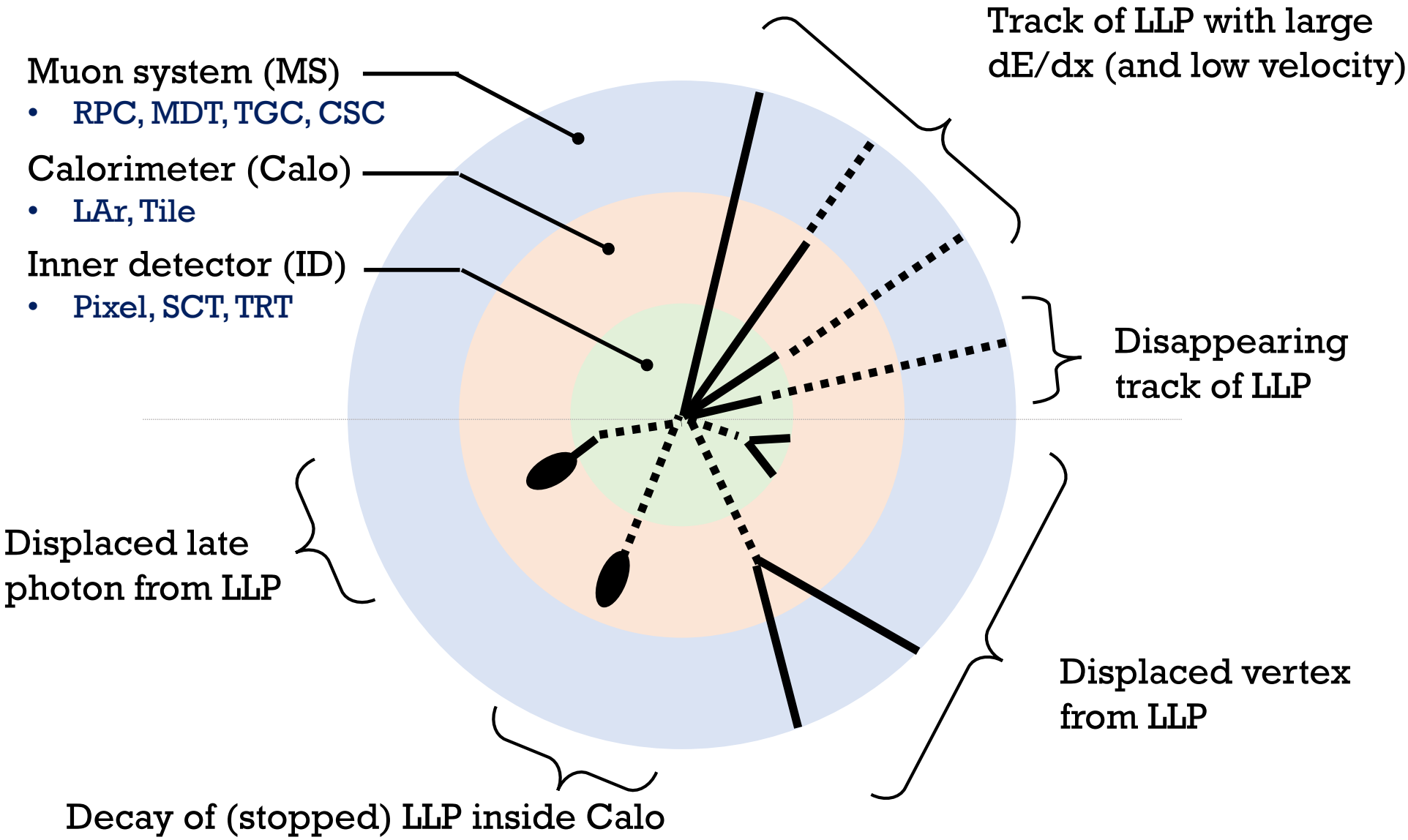
# Physics making long-lived particles

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

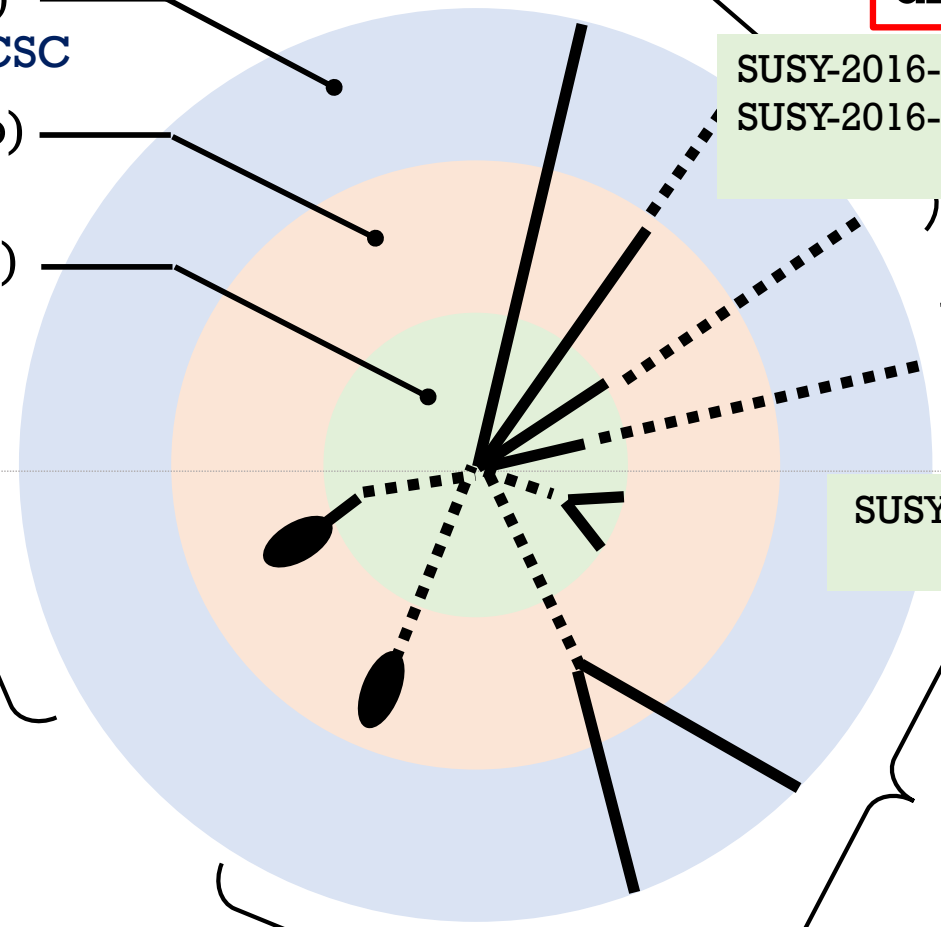



Effects shown above could appear
in various new physics.

# Signatures of long-lived particles



# Recent searches in ATLAS experiment



Muon system (MS)
- RPC, MDT, TGC, CSC

Calorimeter (Calo)
- LAr, Tile

Inner detector (ID)
- Pixel, SCT, TRT

Track of LLP with large dE/dx (and low velocity)

SUSY-2016-31 – Phys. Lett. B 788 (2019) 96
SUSY-2016-32 – Accepted by PRD
13 TeV, 36 fb$^{-1}$

Disappearing track of LLP

SUSY-2016-06 – JHEP 06 (2018) 022
13 TeV, 36 fb$^{-1}$

Displaced late photon from LLP

Displaced vertex from LLP

NEW

ATLAS-CONF-2019-006
13 TeV, 136 fb$^{-1}$

Decay of (stopped) LLP inside Calo

# Search for long-lived $\tilde{\chi}^{\pm}$

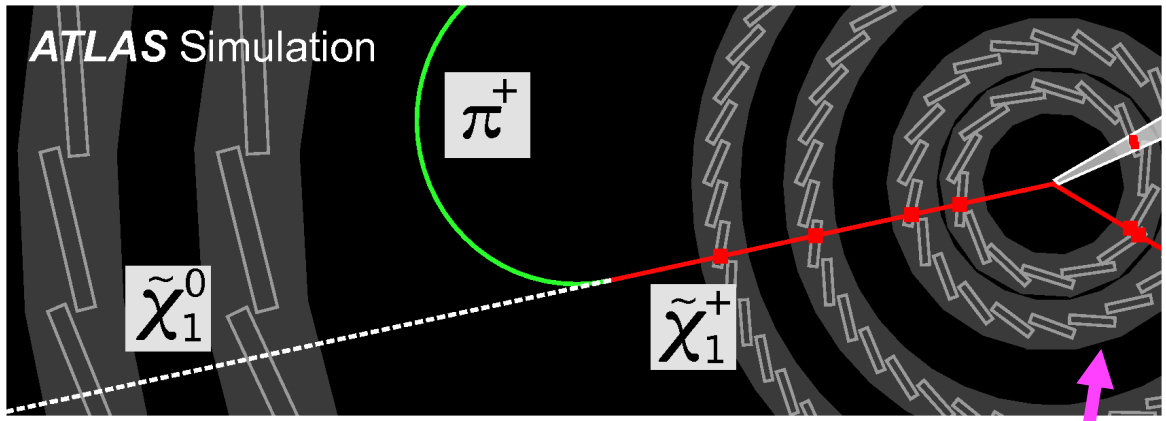
SUSY-2016-06 – JHEP 06 (2018) 022 13 TeV, 36 fb$^{-1}$ in 2015 + 2016 data

**$\tilde{W}^0/\tilde{H}^0$ 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.
- $\tilde{W}^{\pm}/\tilde{H}^{\pm}$ with small mass splitting makes its lifetime long:
  - $\tilde{W}^{\pm}$ : $\Delta M \sim 160$ MeV → $c\tau \sim 6$ cm
  - $\tilde{H}^{\pm}$ : $\Delta M \sim 350$ MeV → $c\tau \sim 1$ cm

→ Disappearing track !

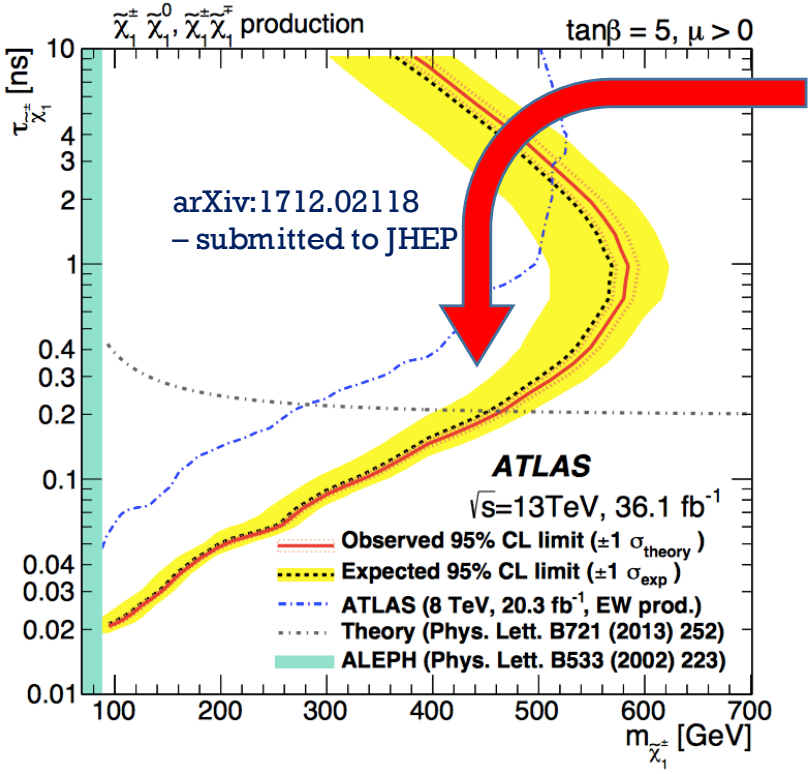
**Use "short" isolated high $p_T$ tracks requiring 4 silicon hits:**



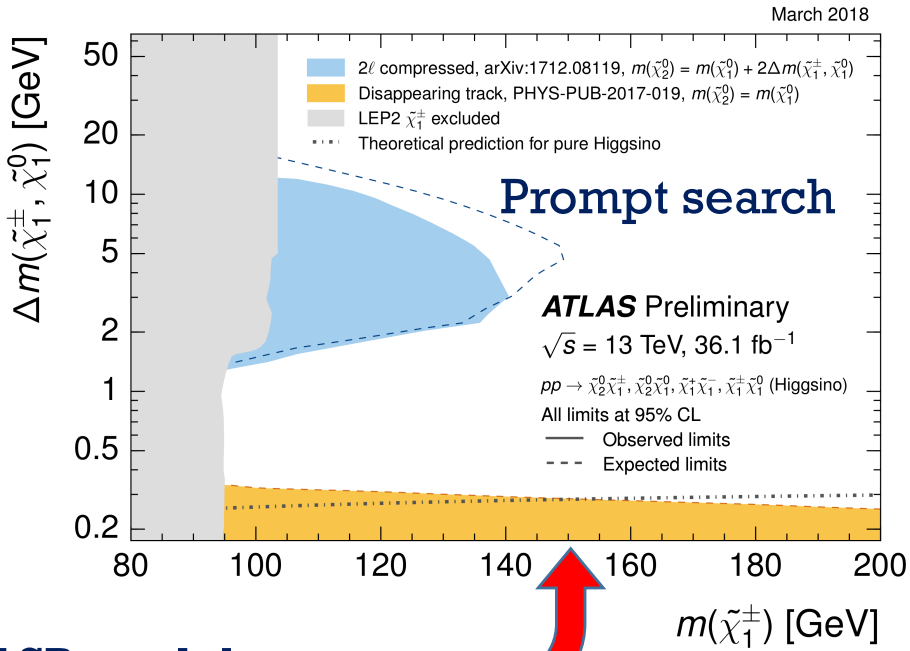

- After Run2, Insertable B-layer (IBL) at R = 3.2 cm improves sensitivity.

# Search for long-lived $\tilde{\chi}^{\pm}$

SUSY-2016-06 – JHEP 06 (2018) 022 13 TeV, 36 fb$^{-1}$ in 2015 + 2016 data



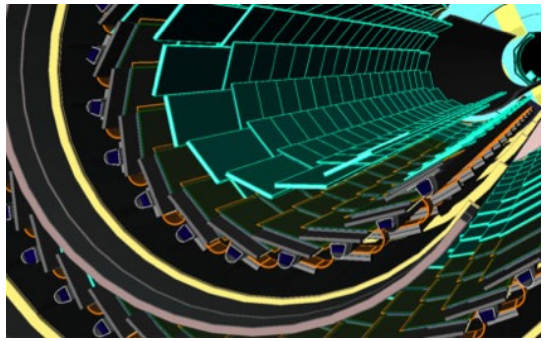

In pure-Wino LSP model,
Chargino masses up to 460 GeV are excluded.




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

13 TeV, 36 fb$^{-1}$ in 2015 + 2016 data

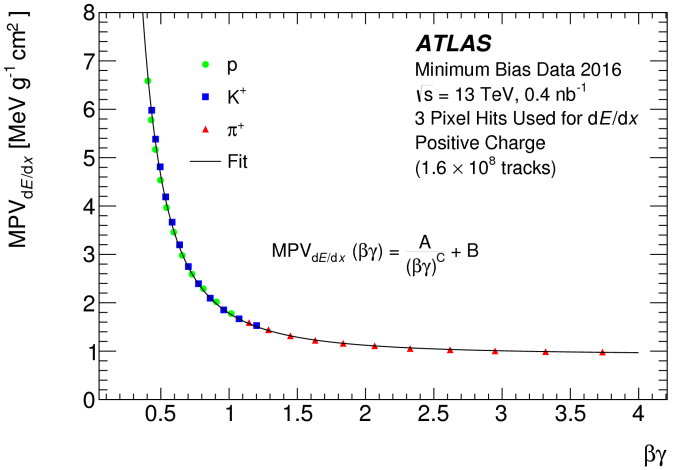
# Search using Pixel dE/dx

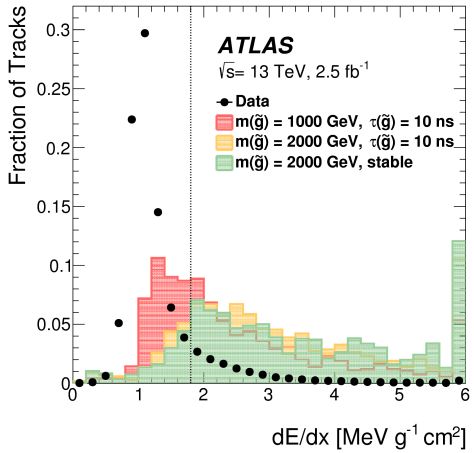


SUSY-2016-31 – Phys. Lett. B 788 (2019) 96

Heavy squark in Split SUSY could make $\tilde{g}$ long-lived.

- Massive $\tilde{g}$ leaves large dE/dx in ATLAS detector
- Pixel detector 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.
- Mass of long-lived particles can be calculated by p/βγ.

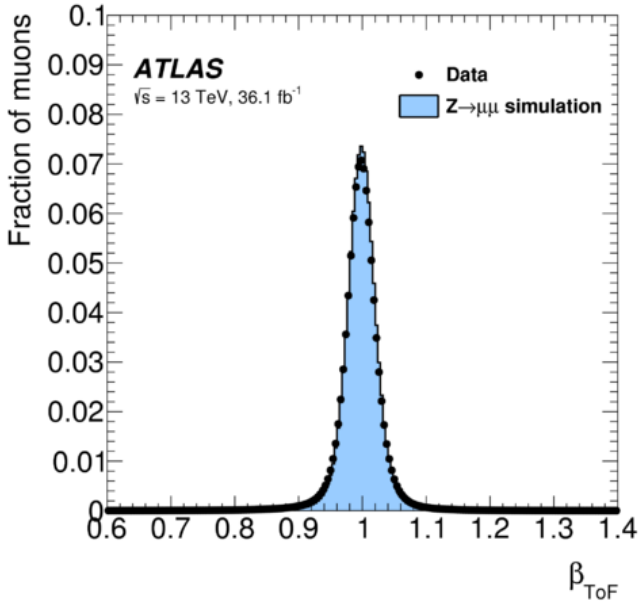
13 TeV, 36 $fb^{-1}$ in 2015 + 2016 data

# Search using timing in Calo + Muon

SUSY-2016-32 – Accepted by PRD

## Hadron Calo and Muon detectors

- Provide good timing resolution as a result of challenging calibration




→ $\beta < 0.75$ is required

- Use dE/dx information in Pixel as well.

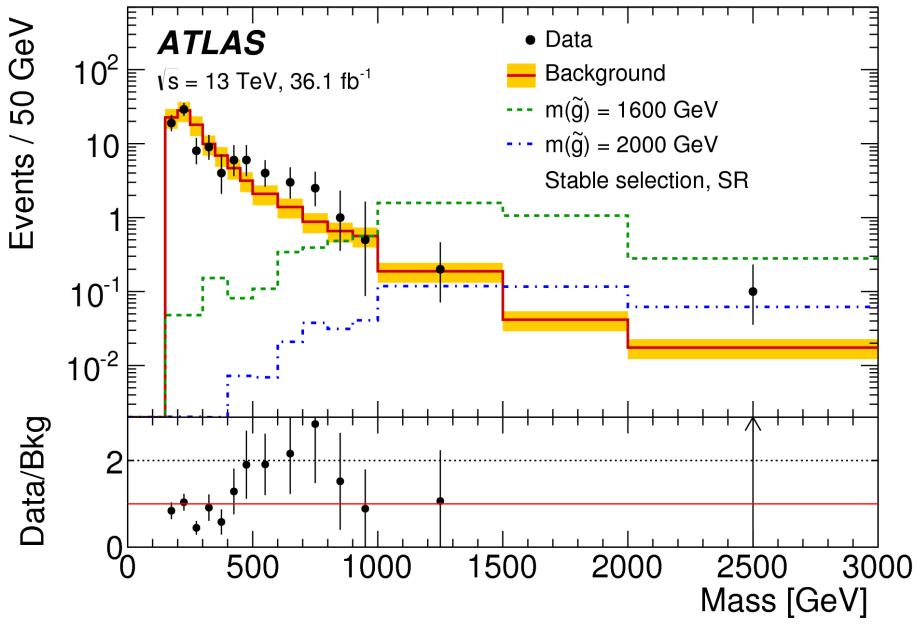
The best sensitivity for stable particle !

13 TeV, 36 fb$^{-1}$ in 2015 + 2016 data

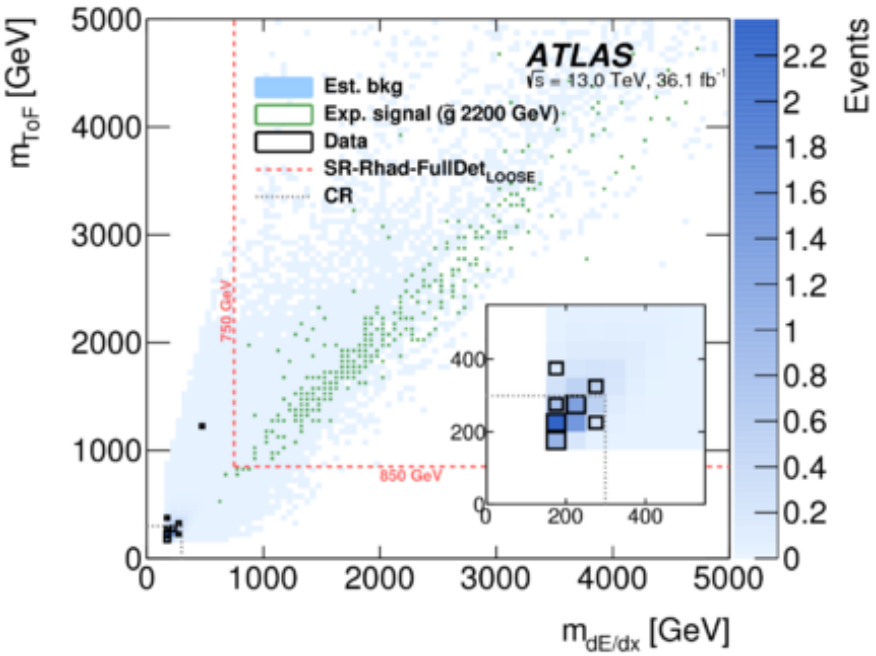
# Results of dE/dx based searches

SUSY-2016-31 – Phys. Lett. B 788 (2019) 96
SUSY-2016-32 – Accepted by PRD

Pixel dE/dx only




Pixel dE/dx and
Timing in Calo + Muon

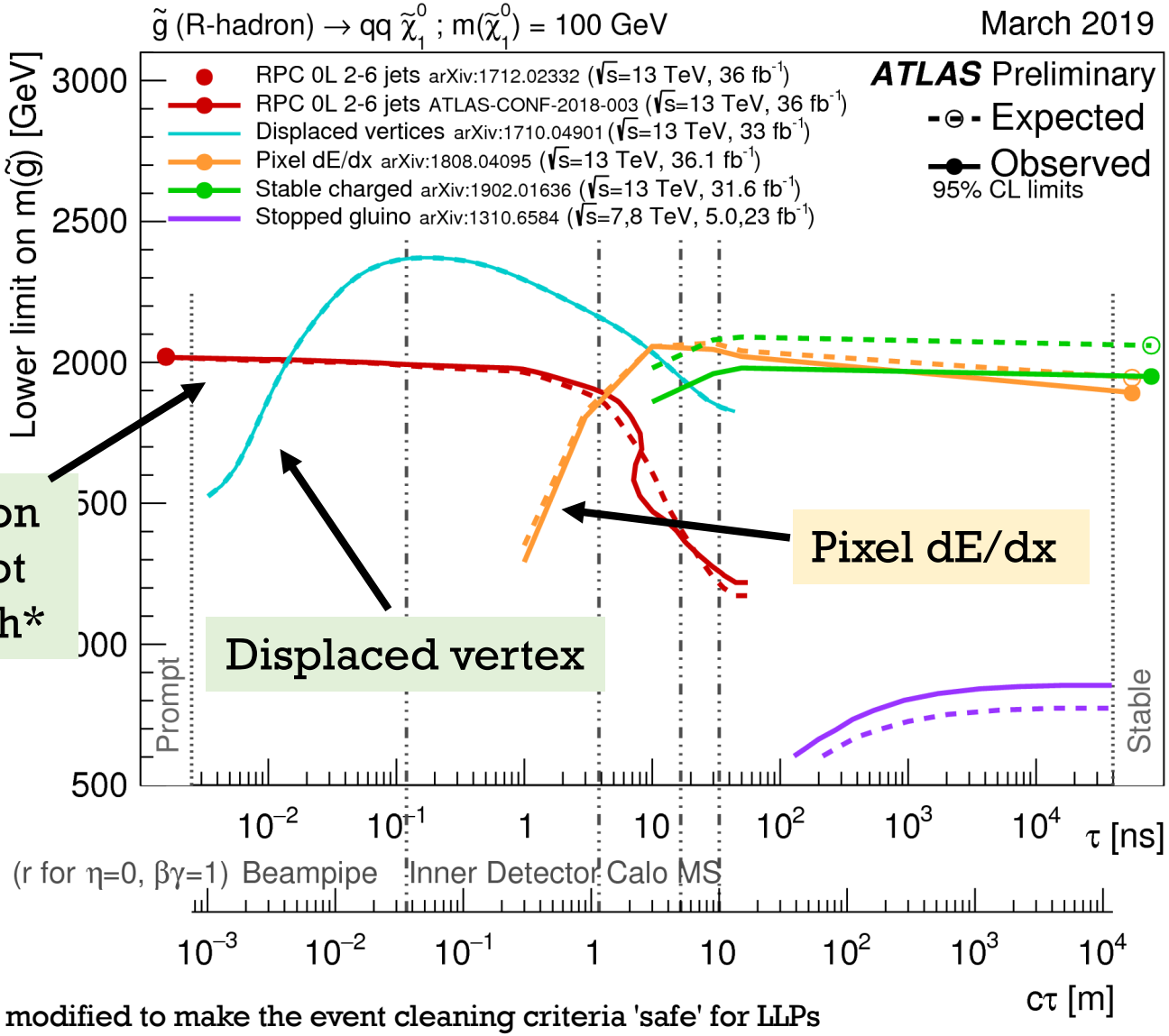



Gluino with 10 ns lifetime excluded up to 2 TeV

Mild excess: 2.4$\sigma$ local in stable selection.

Stable Gluino excluded
up to 2 TeV

# Status of long-lived $\tilde{g}$ search




Pixel dE/dx + Calo + Muon

Interpretation from prompt decay search*

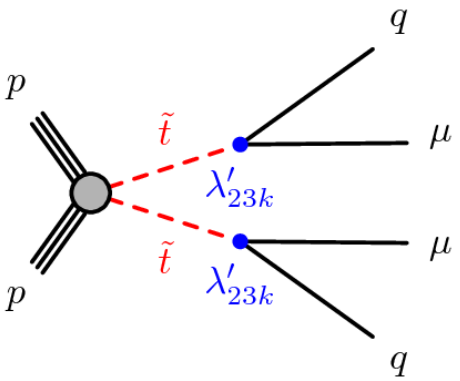
Displaced vertex

Pixel dE/dx

* Note that gently modified to make the event cleaning criteria 'safe' for LLPs

NEW

# Displaced vertex with muon



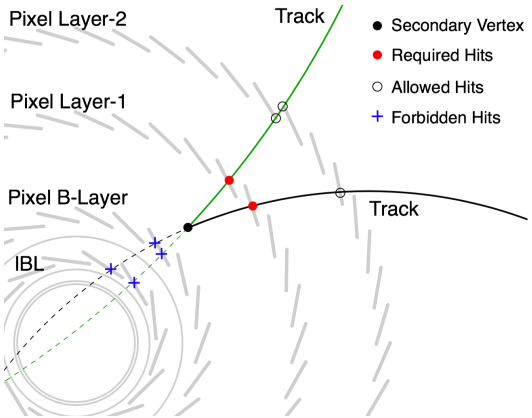

ATLAS-CONF-2019-006 13 TeV, 136 fb$^{-1}$

R-parity violation would make LSP long-lived.

- Benchmark : semi-leptonic decay of $\tilde{t}$

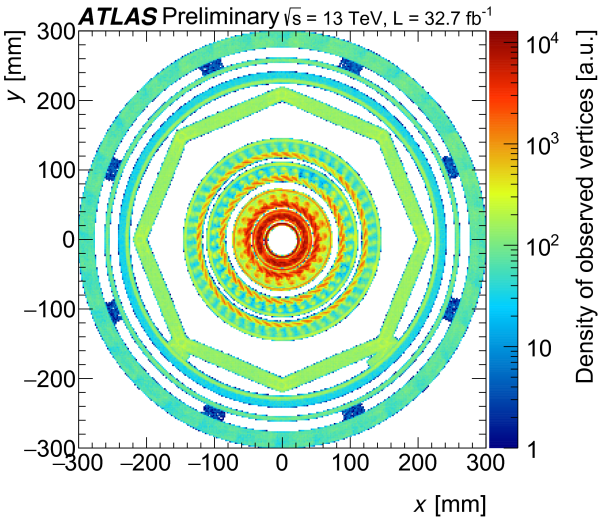
Trigger:

- Muon reconstructed in MS or Missing $E_T$



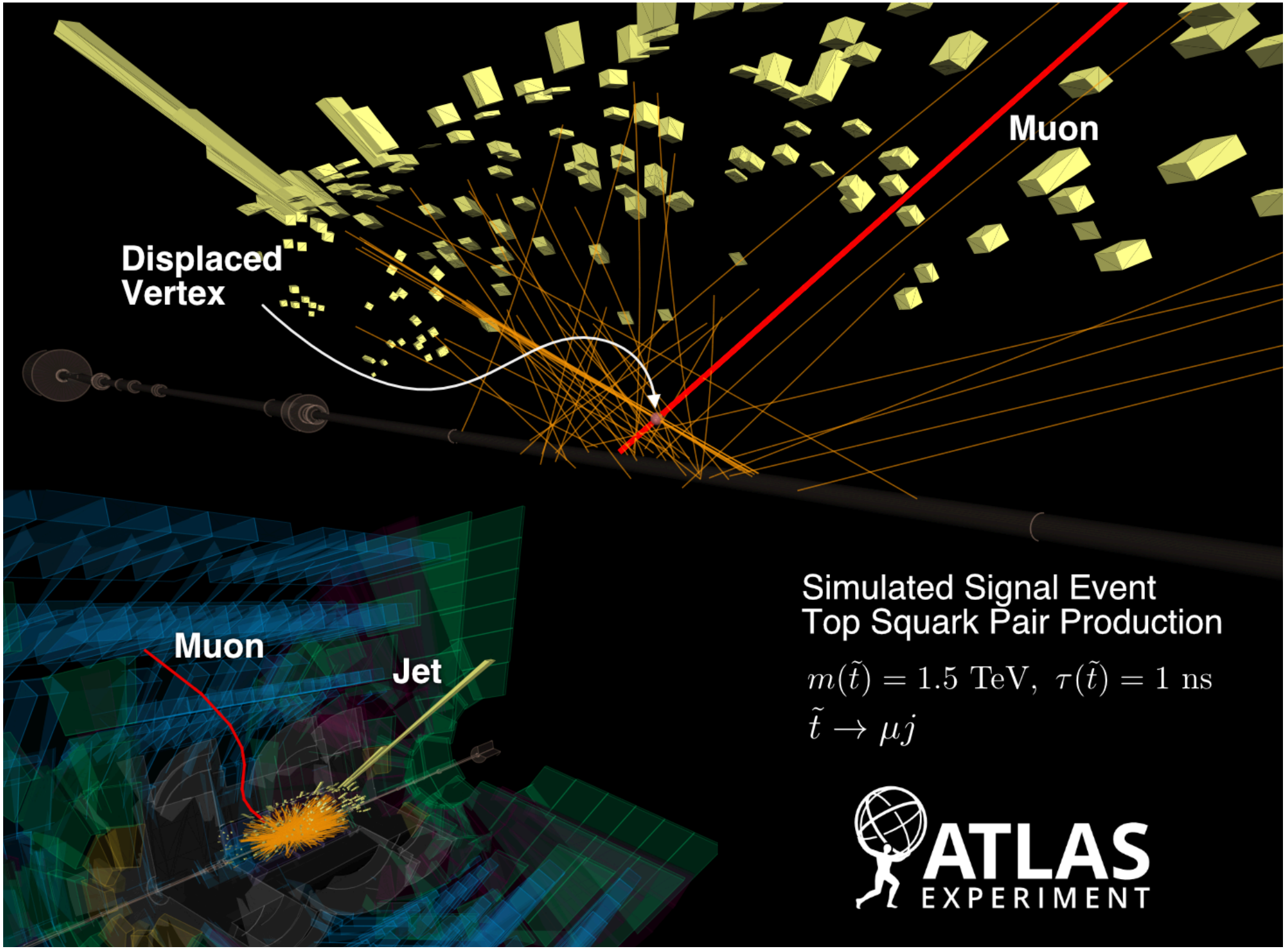

Signal selections:

- Veto material region using hadronic interaction
- DV with at least 3 tracks, and $M_{DV} > 20$ GeV
- Isolated non-prompt muon



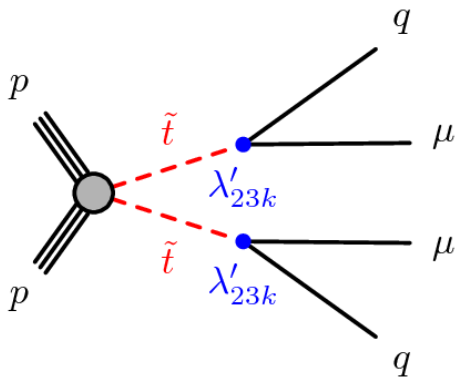

Data-driven background estimation

- Cosmic-ray
- Heavy flavor decay
- Instrumental fakes

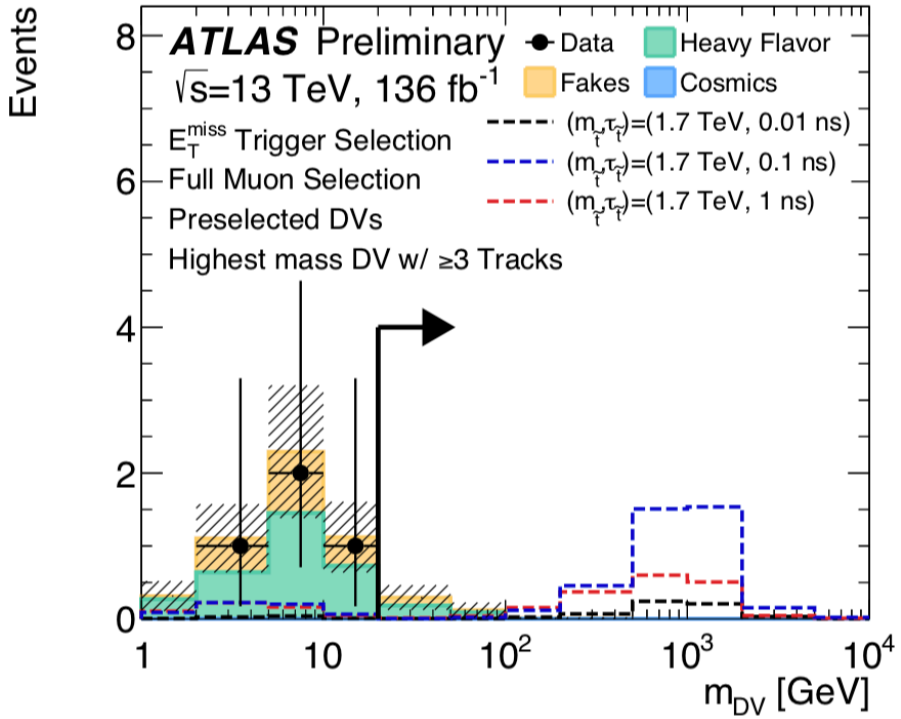

Displaced
Vertex
Muon
Muon
Jet
Simulated Signal Event
Top Squark Pair Production
$m(\tilde{t}) = 1.5$ TeV, $\tau(\tilde{t}) = 1$ ns
$\tilde{t} \rightarrow \mu j$
ATLAS
EXPERIMENT

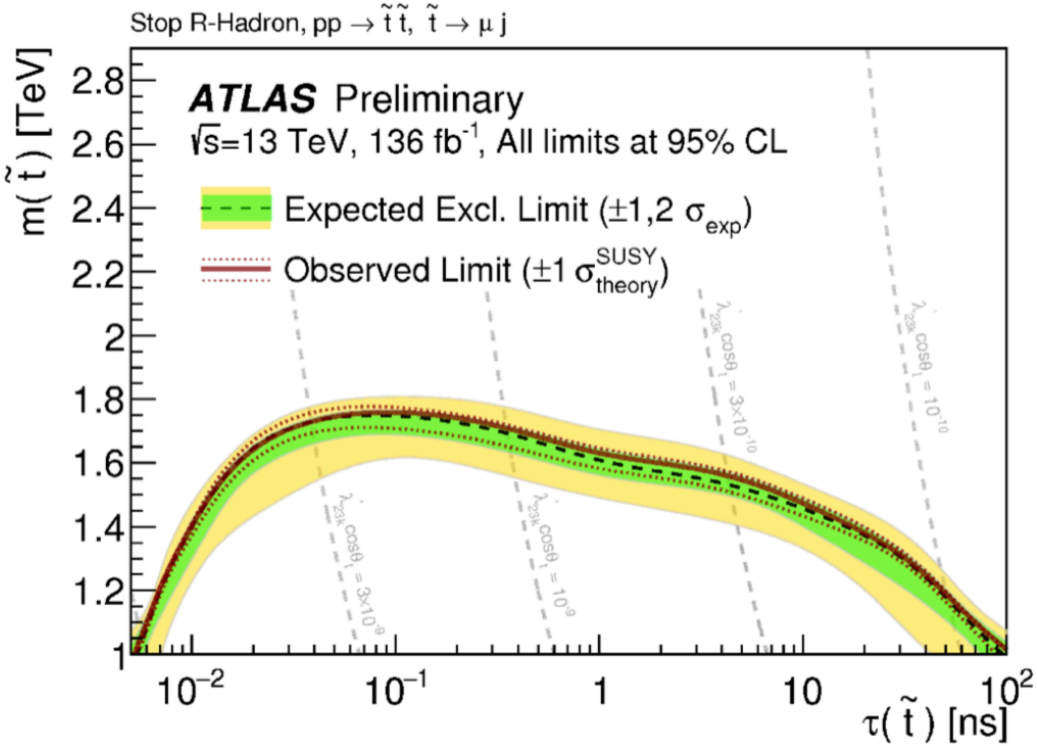
NEW

# Displaced vertex with muon




ATLAS-CONF-2019-006 13 TeV, 136 fb$^{-1}$




No excess observed neither in MET nor muon trigger selection.

Around ~0.1 ns lifetime, stop mass up to 1.75 TeV is excluded.

# Conclusion

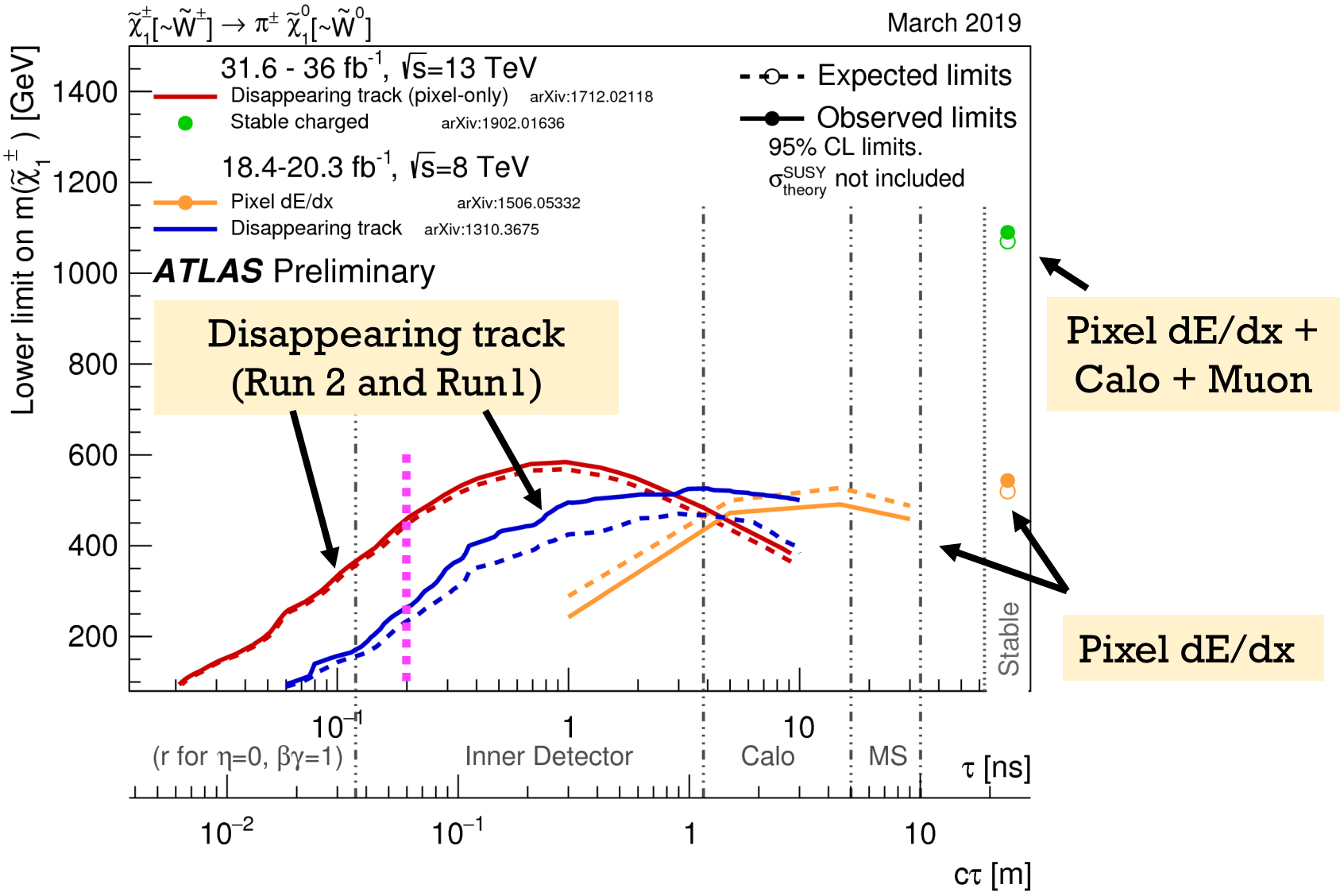
Long-lived particles appear in various physics models.

- Many types of unconventional signatures.
- Creative analysis techniques exploiting all aspects of our detector.
- Huge efforts done with LHC-Run2 data.

For long-lived particle search, the DV+muon analysis is the first result with LHC-Run2 full dataset.

**No BSM yet, however we will come up with more searches with LHC Run-2 dataset soon !!**

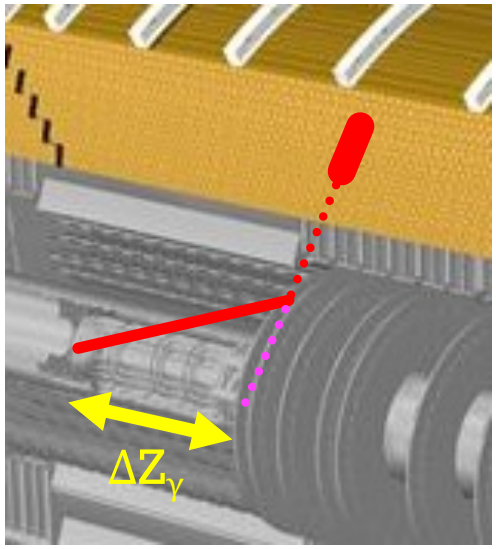
# Status of long-lived $\tilde{\chi}^{\pm}$ search



Run1

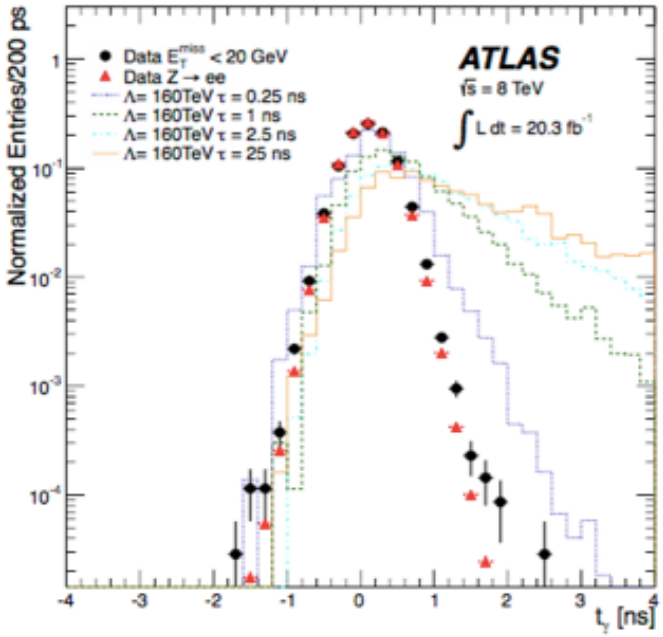
# Calorimeters : Displaced photon search

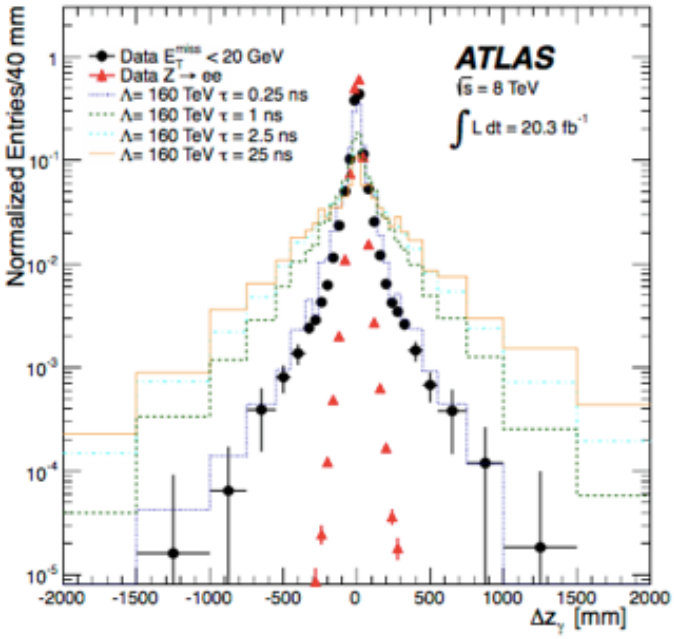
JHEP 11 (2014) 088 – arXiv:1409.5542



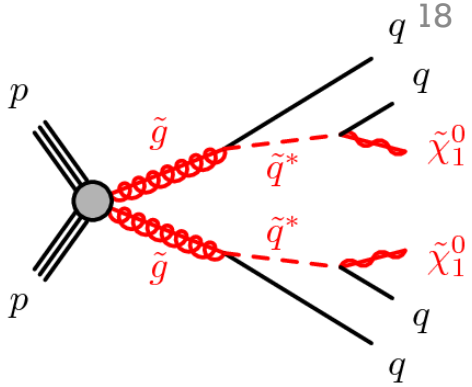

## Use Liquid Argon Calorimeter

- Timing information ($t_\gamma$)
- Displacement in z-coordinate ($\Delta Z_\gamma$)



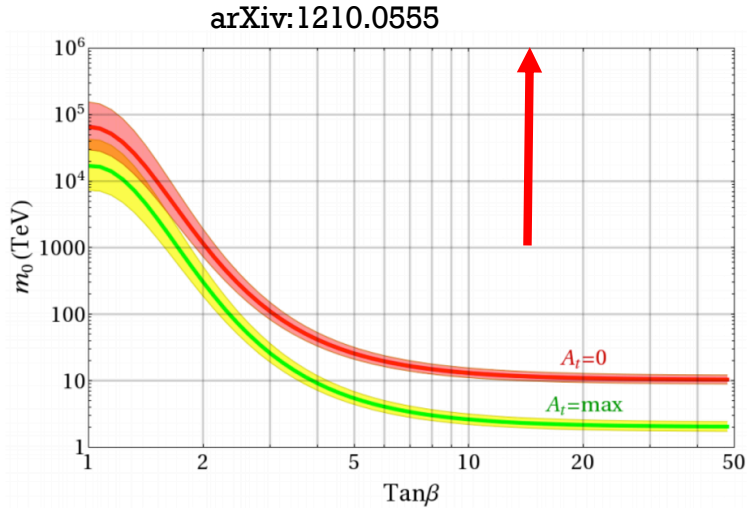



# Meta-stable particle search




## 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

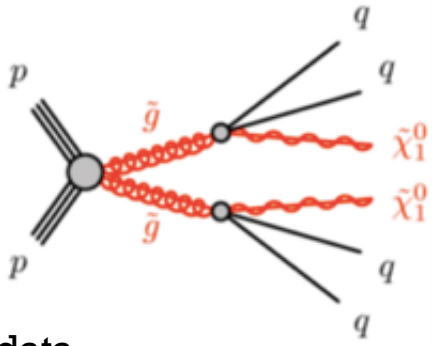



cτ ~ 10 m

cτ ~ 0.1 mm

- If squark is heavier than ~1000 TeV, Gluino becomes long-lived.

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

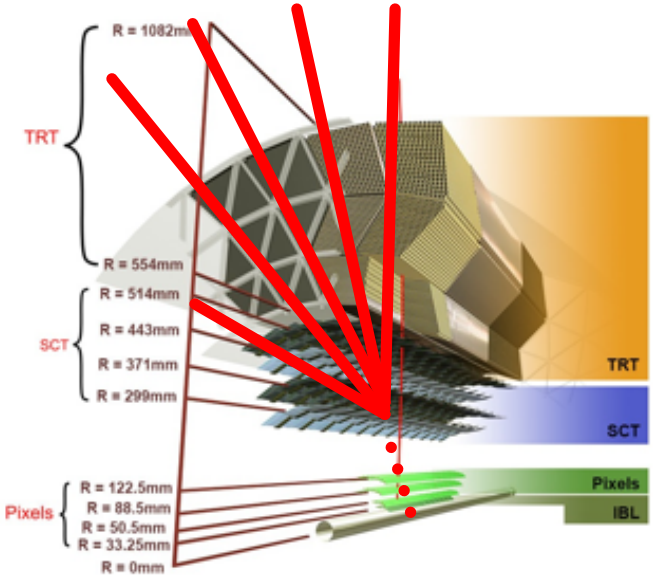


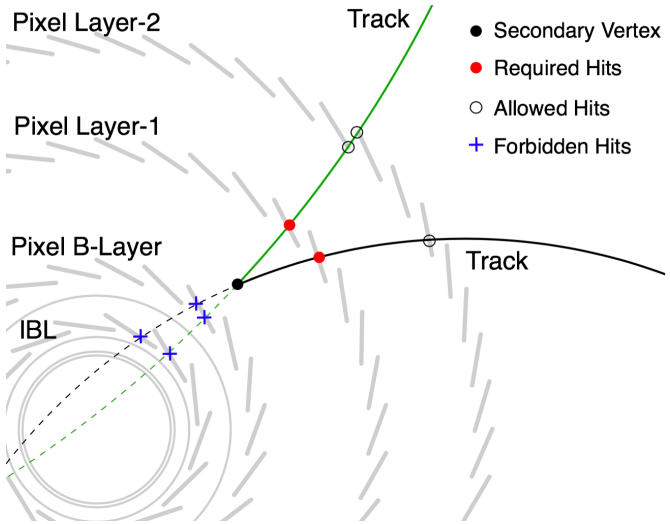

# Displaced vertex in ID

SUSY-2016-08 – Phys. Rev. D 97 (2018) 052012 33 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 $\tilde{\chi}^0$ is also explored.
  - Inspired by Gluino-Bino co-annihilation (arXiv:1504.00504)
  - $E_T^{\text{miss}} > 250$ GeV is used.



# Displaced vertex in ID

SUSY-2016-08 – Phys. Rev. D 97 (2018) 052012 33 $fb^{-1}$ in 2016 data

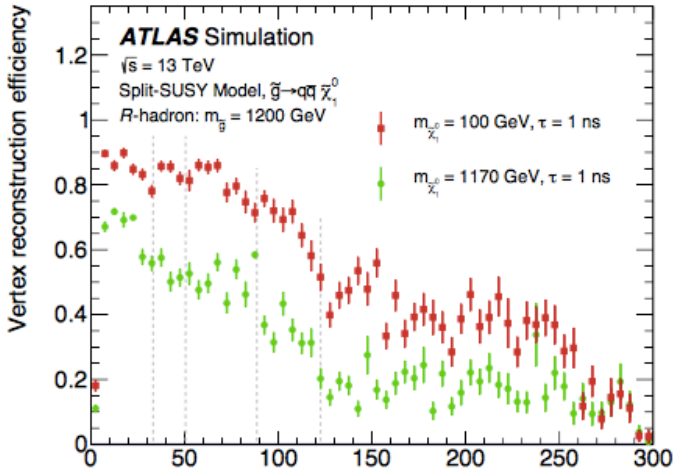
## Displaced vertex selection:

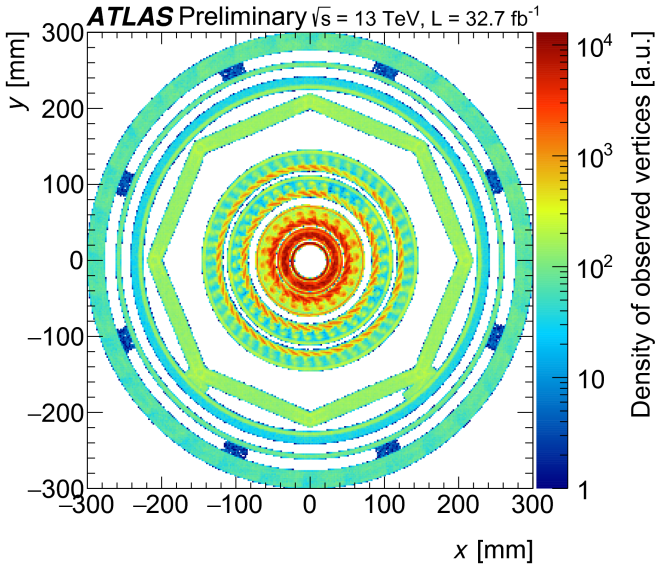
- $R_{DV} < 300$ mm and $|z_{DV}| < 300$ mm
- $chi^2/NDF < 5$
- $|R_{DV} - R_{PV}| > 4$ mm
- At least 5 tracks and $M_{DV} > 10$ GeV

➡ O(10)% efficiency is achieved even for ΔM=30 GeV.

## Background rejection:

- Veto non-collision background
- Veto material dominated regions
- Estimate random track crossing in data-driven method.

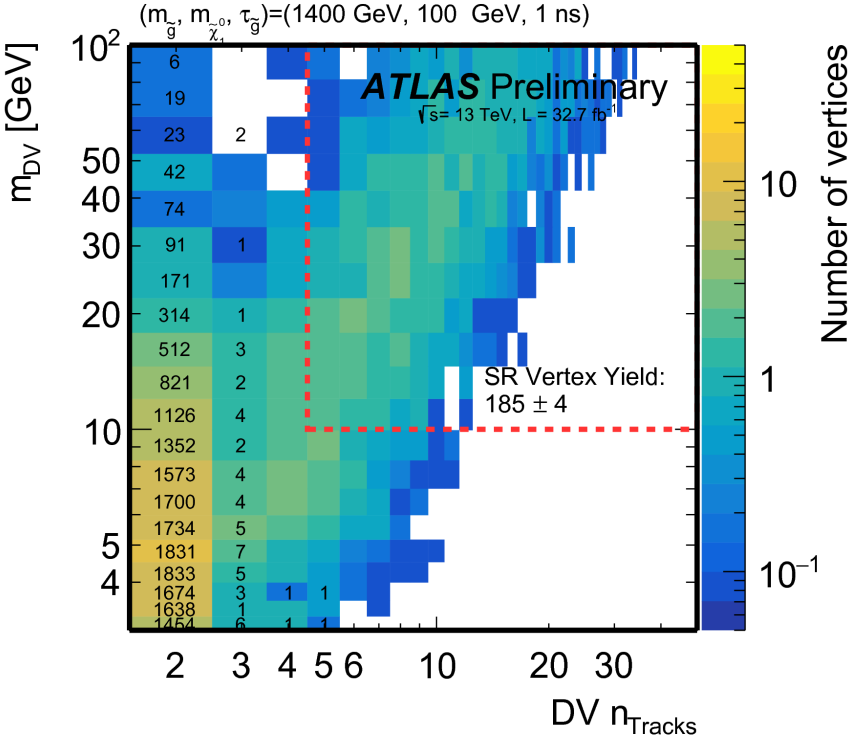


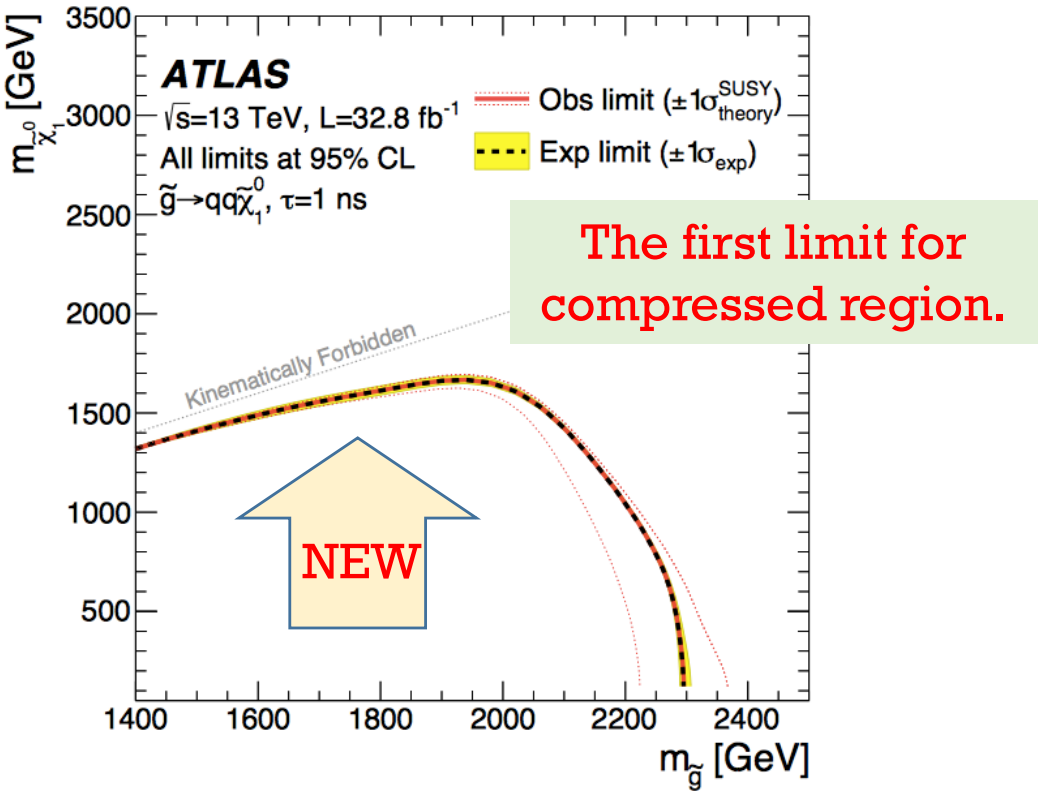



# Displaced vertex in ID

SUSY-2016-08 – Phys. Rev. D 97 (2018) 052012 33 fb$^{-1}$ in 2016 data

No excess observed ..




The first limit for compressed region.

Assuming 100 GeV $\chi^0$,Gluino with 1 nsec lifetime excluded up to 2.3 TeV.

Strong limit for broad range of lifetime.