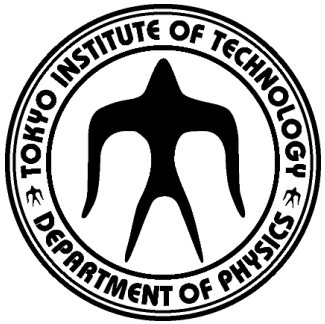


ATLAS searches for non-minimal and long-lived SUSY scenarios

Risa Ushioda (Tokyo Tech)

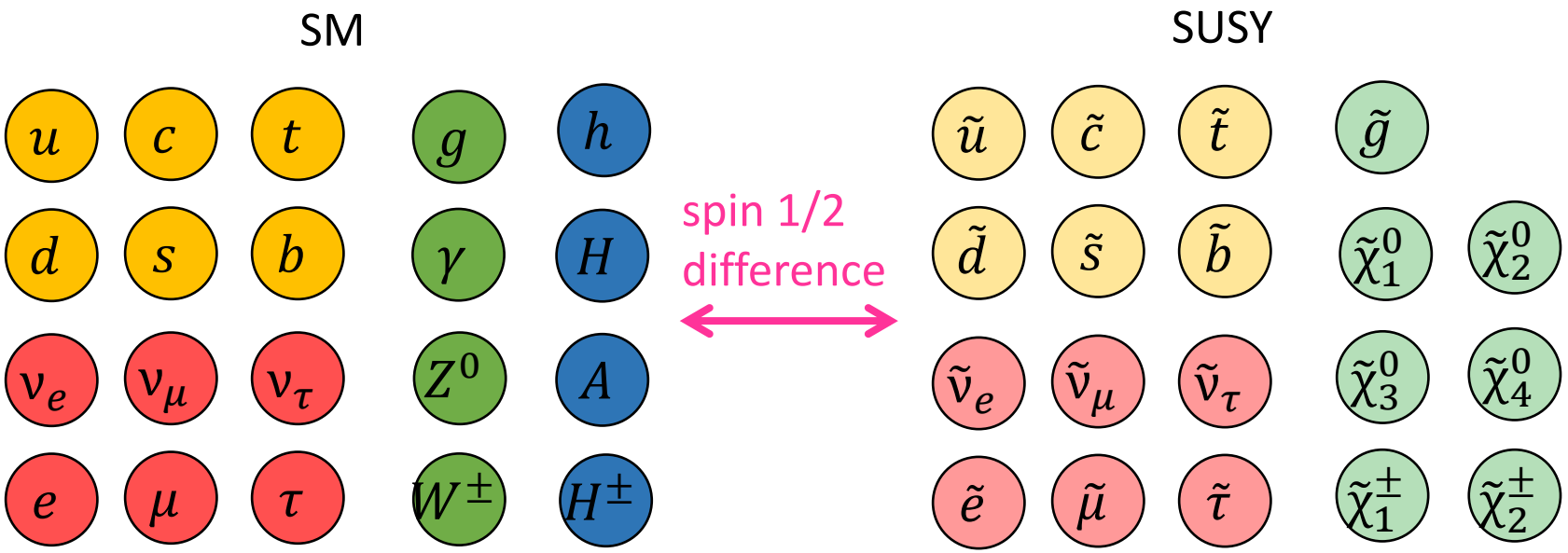
on behalf of the ATLAS Collaboration

XIII International Conference on New Frontiers in Physics

August 28th, 2024

Supersymmetry

- The Standard Model (SM) predictions agree with the measurements thought orders of magnitude
- Several problems: Fine-tuning problem in the Higgs boson mass, dark matter, neutrino mass, etc.
- Supersymmetry (SUSY) is one of the elegant solutions to them



ATLAS SUSY Searches

- Major SUSY models searched in ATLAS:
  - Simplified models (i.e. few free parameters, production/decay modes)
  - R-parity conservation

    → The lightest SUSY particle (LSP) is stable.
  - Minimal flavour violation
  - SUSY particles other than LSP decay promptly
- A variety of other unconventional models have also been searched using full Run 2 and partial Run 3 data

Long-lived SUSY

SUSY models with long-lived particles (LLPs):

- Gauge-Mediated SUSY breaking (GMSB)
- Mini-Split SUSY
- Mass degenerate
- R-parity violation (RPV)

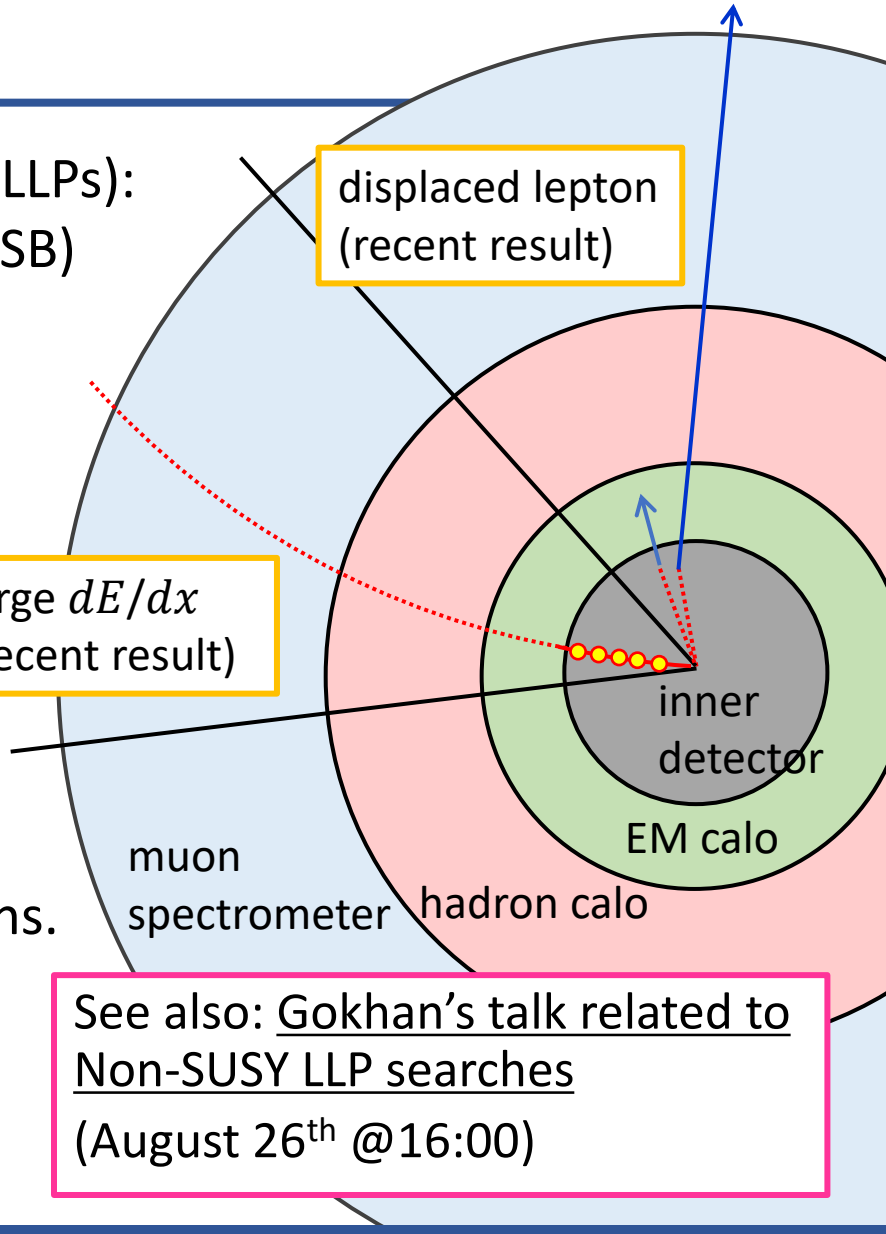
etc.

LLP signature depends on:

- Lifetime
- Charged or neutral
- Decay mode

→ Needs various special reconstructions.

Experimental background events (BGs) are dominant.
→ Data-driven estimation.



See also: Gokhan's talk related to Non-SUSY LLP searches
(August 26th @16:00)

Long-lived SUSY

Recent Results on
Searches for Long-lived SUSY

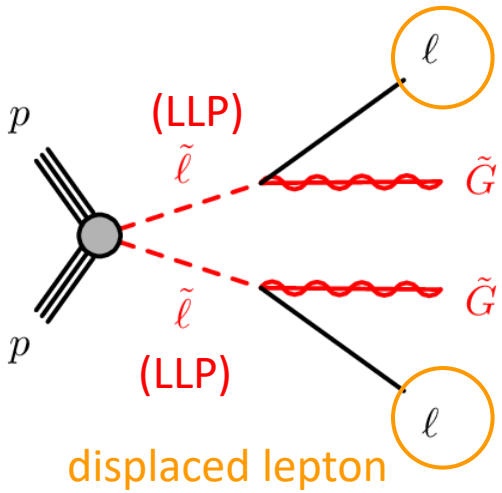
Displaced Leptons

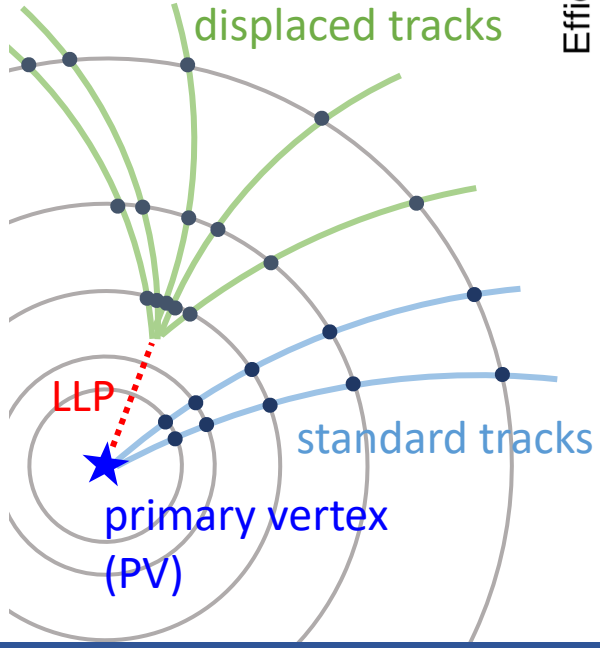
- Motivation: GMSB
- Full Run 2 + partial Run 3 data analysis

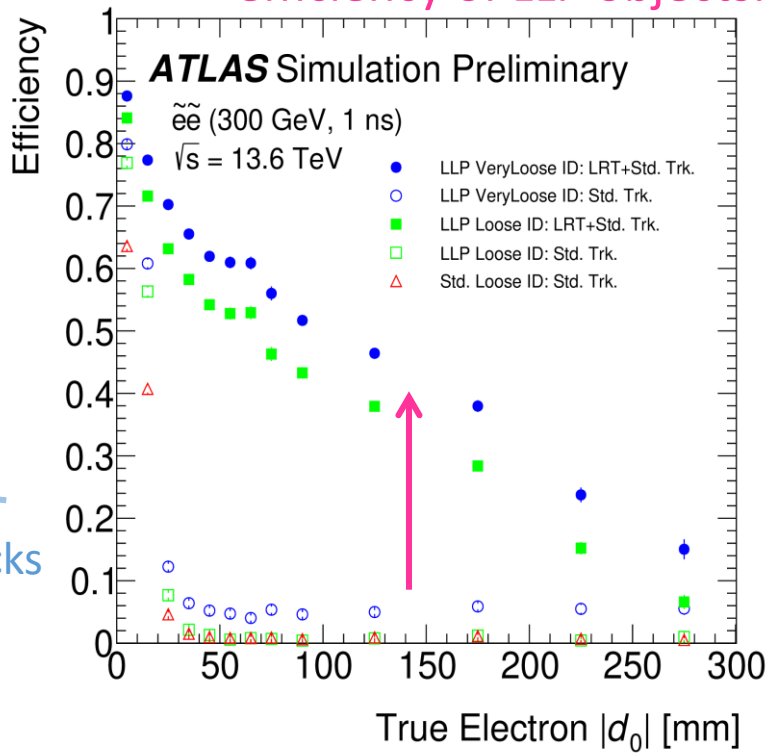
Large radius tracking (LRT)

- Reconstruct tracks with large impact parameters using unused hits after standard tracking
- Available at trigger-level in Run 3

Improve reconstruction efficiency of LLP objects.



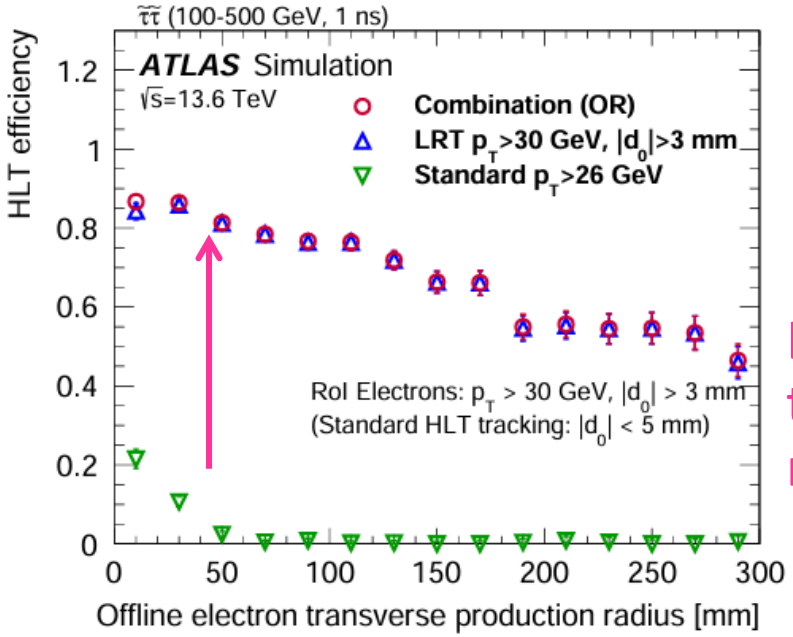




Displaced Leptons

Strategy 1: Displaced leptons

- Photon, muon, or LRT lepton triggers (Run 3 only)



LRT lepton triggers enable to save events with low momentum leptons.

- LRT and looser lepton identification requirements
- Signal region (SR): Displaced $ee/e\mu/\mu\mu$
- BGs: Fake leptons, leptons from heavy flavour decay, cosmic muons
  → Estimate using ABCD method.

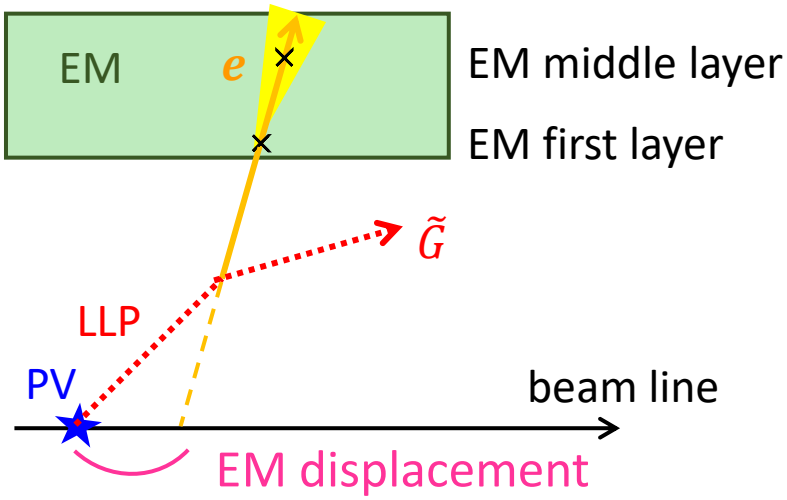
Displaced Leptons

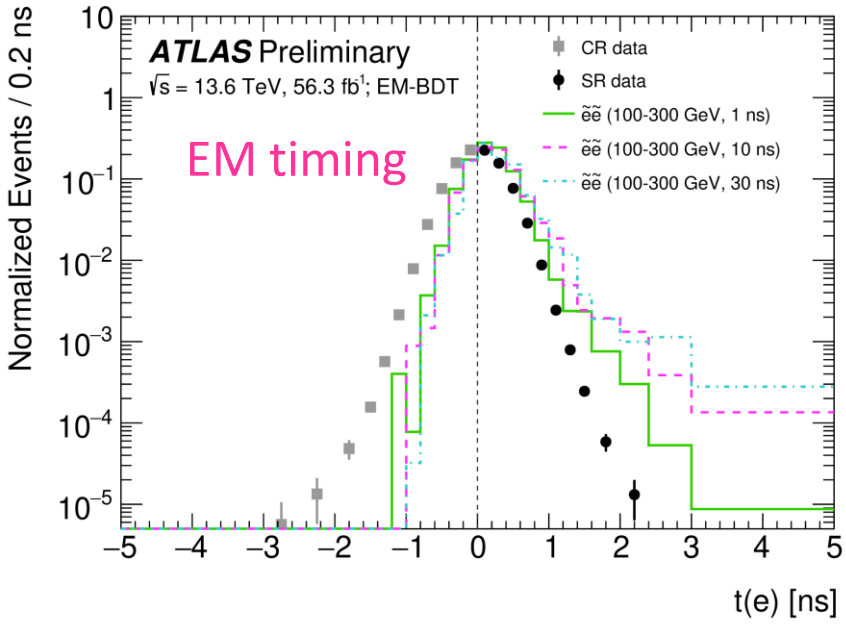
Displaced electrons which decay too late to leave a track are reconstructed as photons.

Strategy 2: BDT-based selection (Run 3 only)

- Photon or LRT lepton triggers
- BDT using $ee/\gamma\gamma$ information
- SR: High BDT score
  + leading e/γ with $t > 0$
- BGs: Prompt objects
  → Estimate using events with e/γ with $t < 0$.

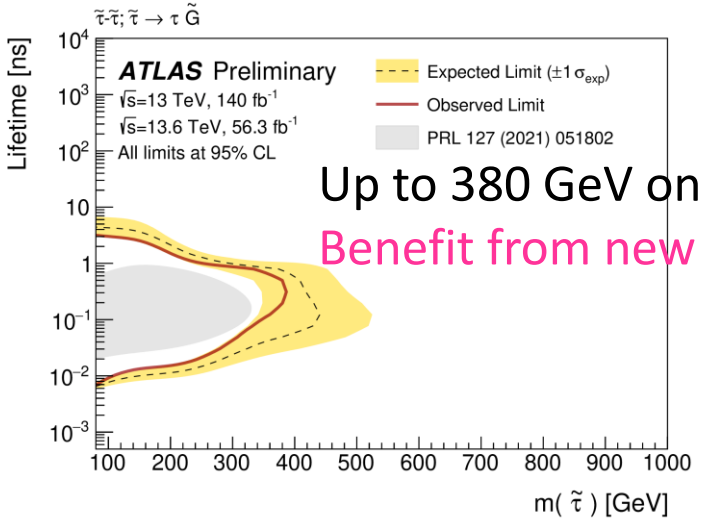
- eBDT: Leading e's track info, EM timing and displacement, etc.
- γBDT: Two γs' EM timing and displacement, etc.





Displaced Leptons

Results: Exclusion limits are set on $m(\tilde{e})/m(\tilde{\mu})/m(\tilde{\tau})$ as a function of lifetime.

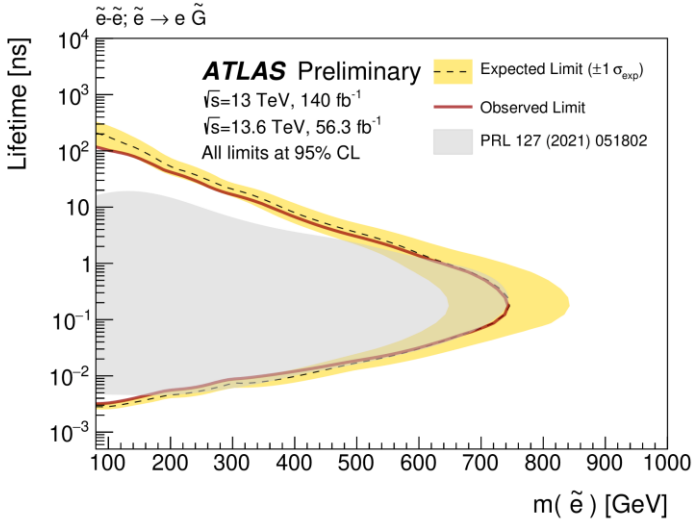


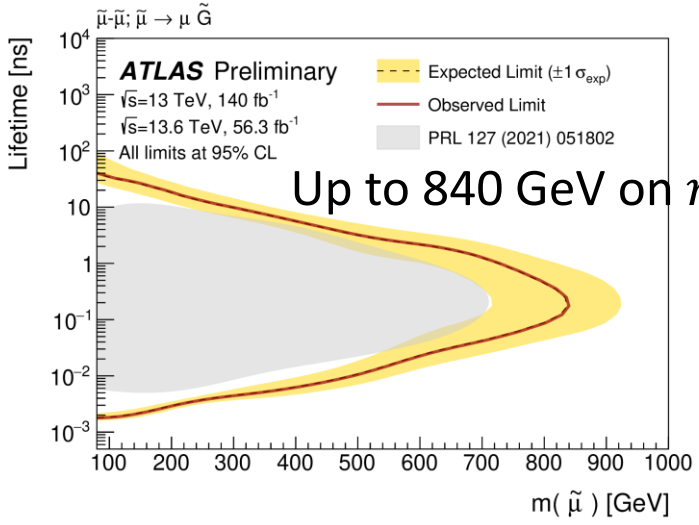
Up to 380 GeV on $m(\tilde{\tau})$.

Benefit from new triggers.

Up to 740 GeV on $m(\tilde{e})$.

The BDT-based analysis improved the sensitivity in the long lifetime region.





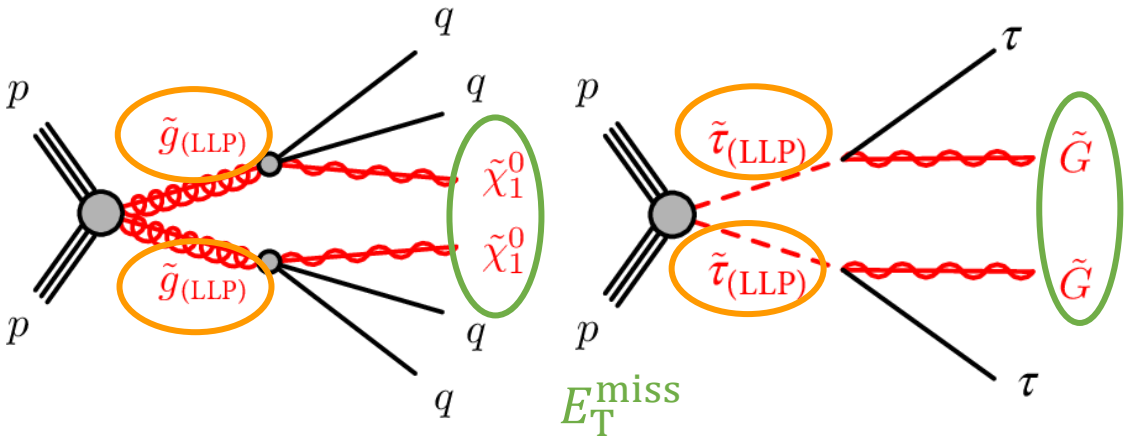
Up to 840 GeV on $m(\tilde{\mu})$.

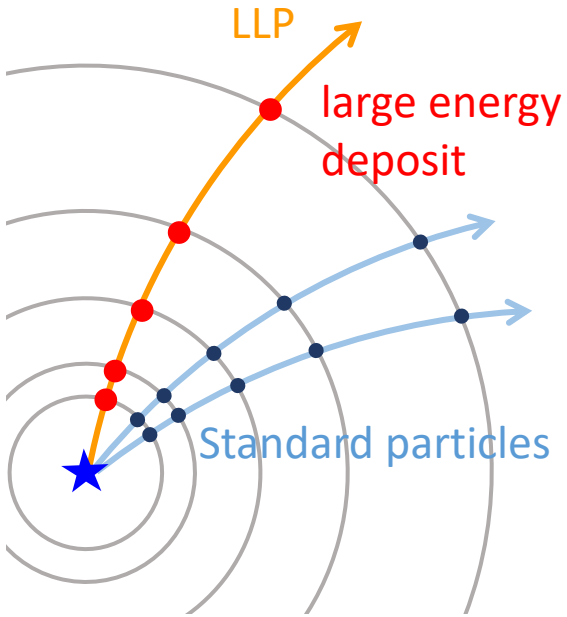
CONF-SUSY-2022-12
PUB-SUSY-2024-11

Meta-stable Charged Particles

Motivation: Mini-split SUSY, GMSB

high p_{T} track with large dE/dx





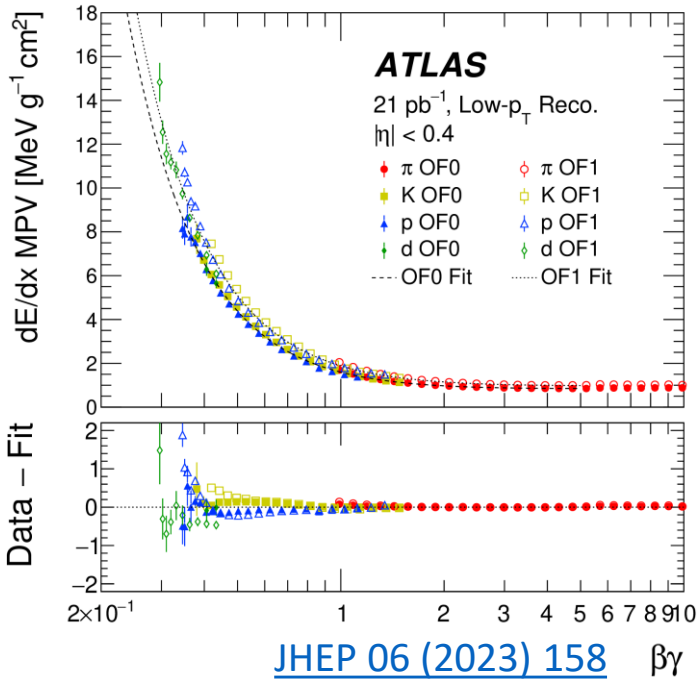
- Missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) from LSPs
- Tracks with high transverse momentum (p_{T}) and large energy deposit (dE/dx) by a non-relativistic LLP

  → 3.3σ excess in the previous analysis
- If it comes from an LLP, the time of flight (ToF) at the calorimeter should be consistent ← New !

Meta-stable Charged Particle

dE/dx-$\beta\gamma$ calibration

- Most provable value (MPV) of the dE/dx is corrected based on the period and η
- Calibrate dE/dx-$\beta\gamma$ relation using low-momentum SM particles



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β measurement in the calorimeter (β_{ToF})

- Measurements in i-th calorimeter cell:

  $\beta_i = 1/(1+\frac{ct_i}{l_i})$

  (t_i: measured timing, l_i: distance from the PV)
- β_{ToF}: Weighted average of β_i in calorimeter cells

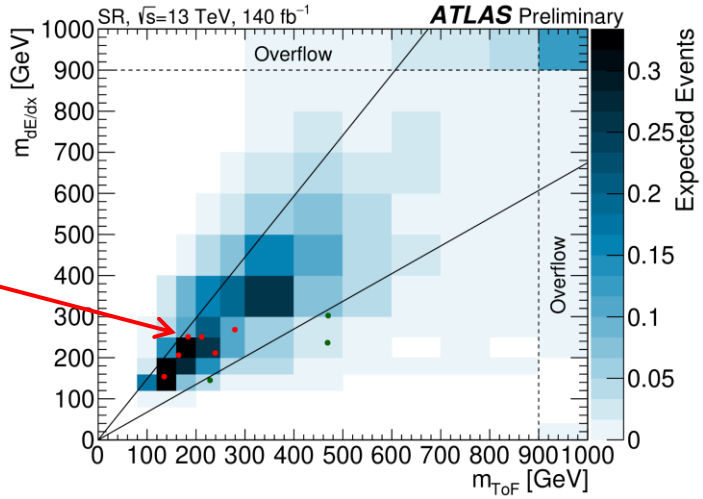
Strategy

- SR: $E_{\mathrm{T}}^{\mathrm{miss}}$ > 170 GeV + $\beta_{\mathrm{ToF}} < 1 - 2\sigma_{\mathrm{ToF}}$
  + Track with dE/dx > 1.8 MeV/g^{-1} cm^2 and p_{T} > 120 GeV
- BGs: Estimate using toys sampled from a control region

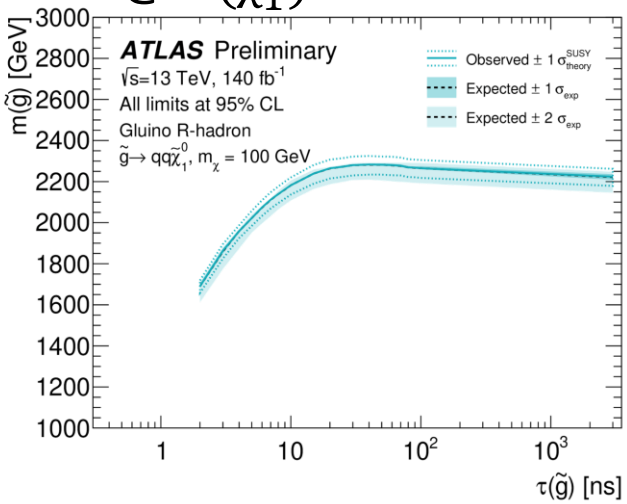
Meta-stable Charged Particles

Results

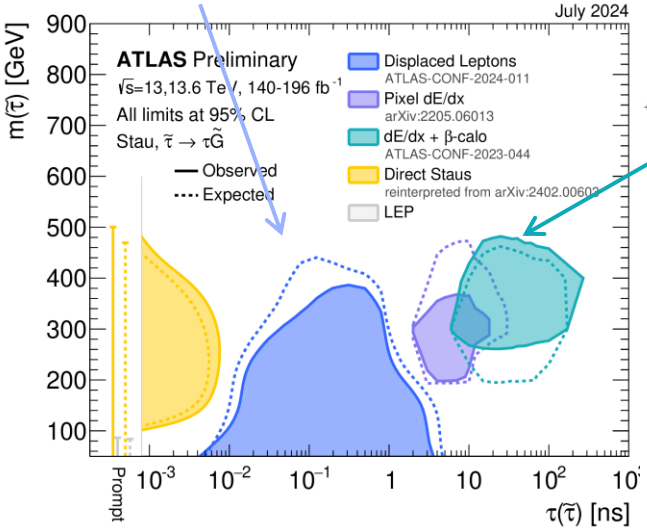
- 9 events in SR (est. 5.1 ± 0.5)
- 6 of them have compatible $m_{dE/dx}$-$m_{\beta_{\mathrm{ToF}}}$ (est. 3.7 ± 0.4)
  → 1.8σ excess in 200 GeV mass window.
- Exclusion limits on each target model:



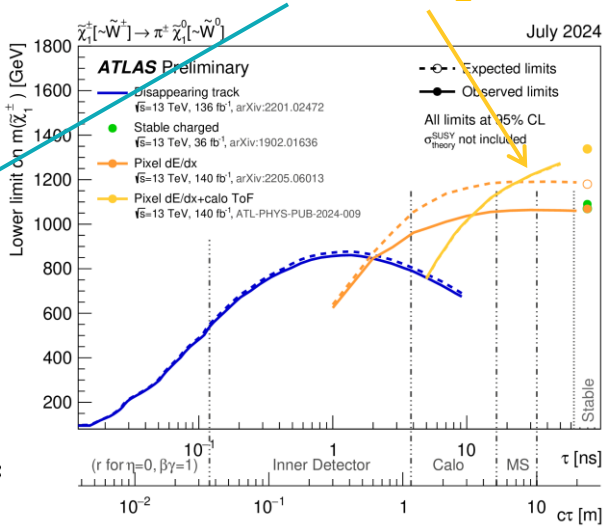
$m(\tilde{g})$ up to 2.3 TeV
$@m(\tilde{\chi}_1^0)$ = 100 GeV



displaced leptons



Unique sensitivity on $\tilde{\tau}$ and $\tilde{\chi}_1^{\pm}$.

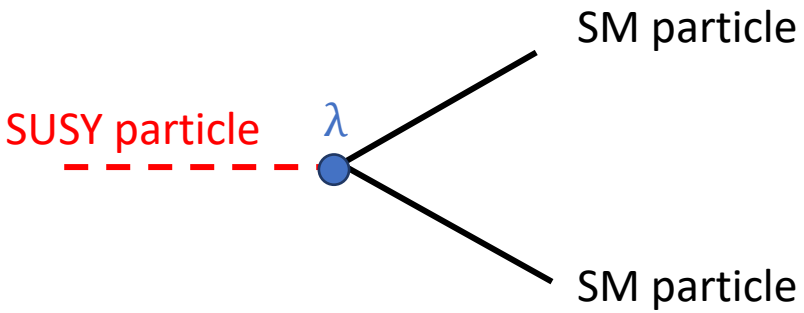


Non-minimal SUSY (Prompt)

Several non-minimal SUSY models with prompt SUSY particles have been searched in the ATLAS.

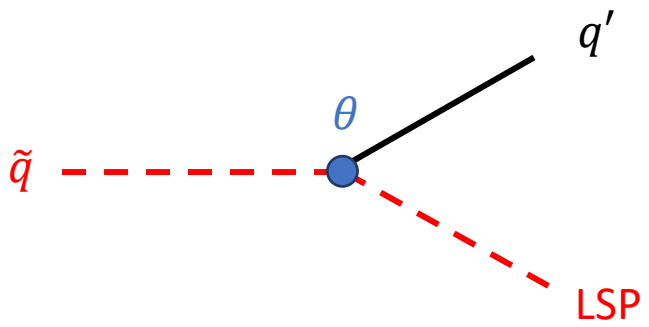
< RPV* >

*Often includes LLP.



The LSP decays to the SM particles with RPV coupling constant λ.
→ No significant $E_{\mathrm{T}}^{\mathrm{miss}}$.

< Flavour mixing >



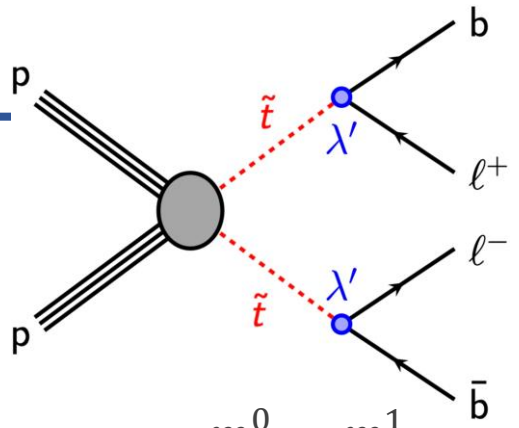
The SUSY particle decays to the SM particle in different generation through mixing angle θ.

Non-minimal SUSY (Prompt)

Recent Results on
Searches for Non-minimal SUSY

$B - L$ RPV Stop

arXiv:2406.18367



- Motivation: Local $B - L$ symmetry with RPV
- Full Run 2 data analysis

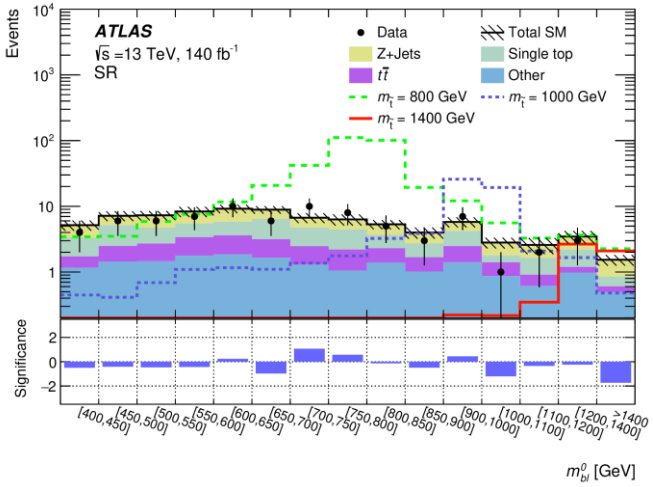
Strategy

- 2 opposite charge leptons + 2 jets (≥ 1 b-tagged)
- Pair lepton-jet, minimizing m_{bl}^{asym}
- SR binned by m_{bl}^{0} ($m_{bl}^{\mathrm{asym}} < 0.2$ is required)

BGs: $t\bar{t}$, single t, Z+jets

$$m_{bl}^{\mathrm{asym}} = \frac{m_{bl}^{0} - m_{bl}^{1}}{m_{bl}^{0} + m_{bl}^{1}}$$

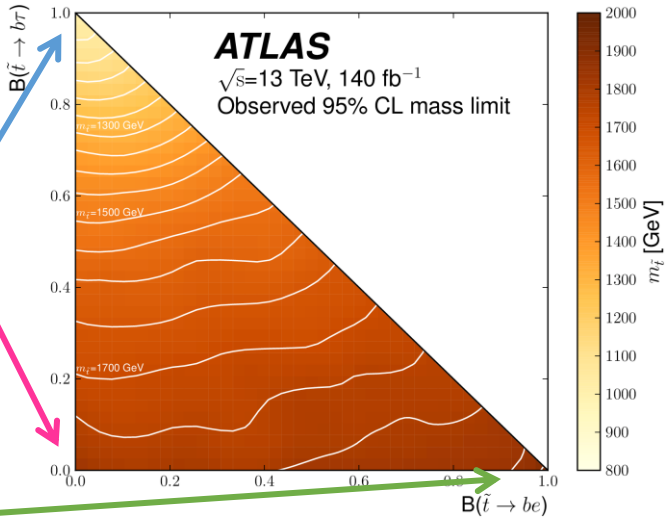
Results: Limits on $m(\tilde{t})$ as a function of branching ratio.



800 GeV
@Br($\tilde{t} \rightarrow b\tau$) = 100%

1.8 TeV
@Br($\tilde{t} \rightarrow b\mu$) = 100%

1.9 TeV
@Br($\tilde{t} \rightarrow be$) = 100%



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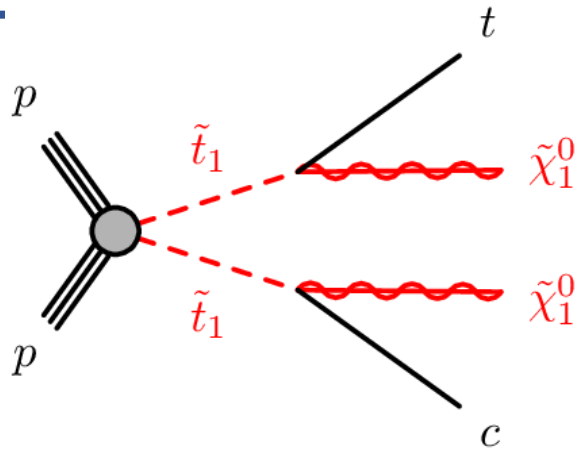
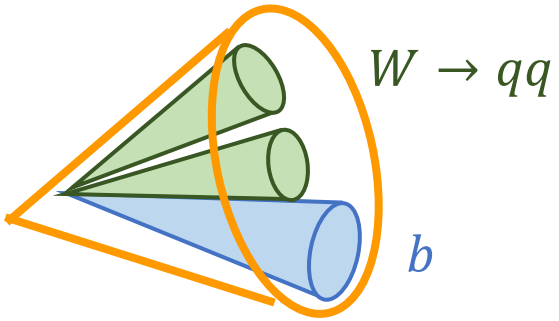
Stop to Top or Charm

- Motivation: Flavour mixing of 2nd and 3rd generation squarks
- Br($\tilde{t} \to t\tilde{\chi}_1^0$) = Br($\tilde{t} \to c\tilde{\chi}_1^0$) = 50% when the mixing is maximal
- Use hadronically decaying top quark
- Full Run 2 data analysis



Boosted top-tagging

- A top quark decays to a b-quark and a W-boson
- DNN top-tagger identifies a large-R jets with multi boosted and collimated small-R jets by looking at jet substructure



large-R jet from top

Strategy

- High $E_{\mathrm{T}}^{\mathrm{miss}}$ + multi-jets (≥ 1 b-tagged & ≥ 1 c-tagged)
- Use top-tagger and analysis-specific c-tagger

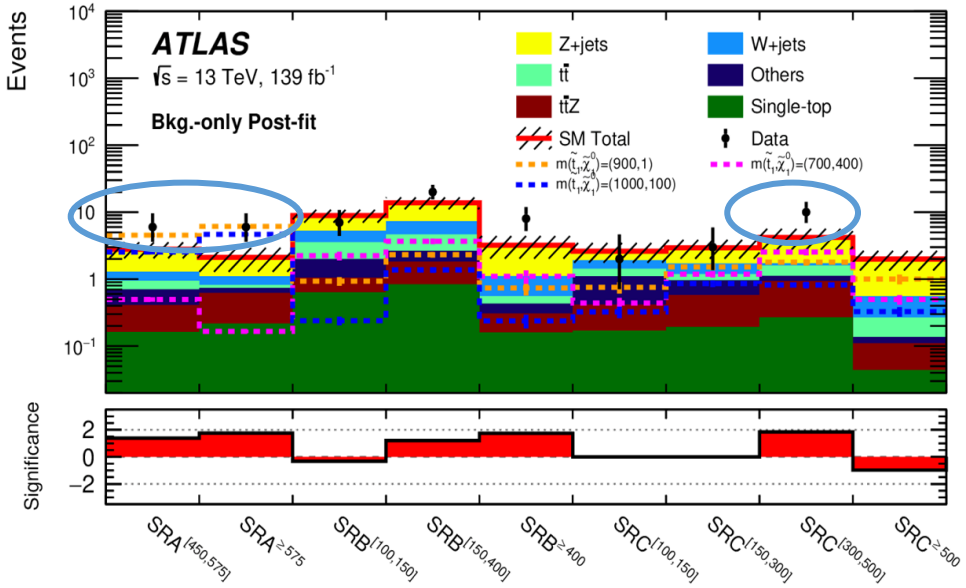
Stop to Top or Charm

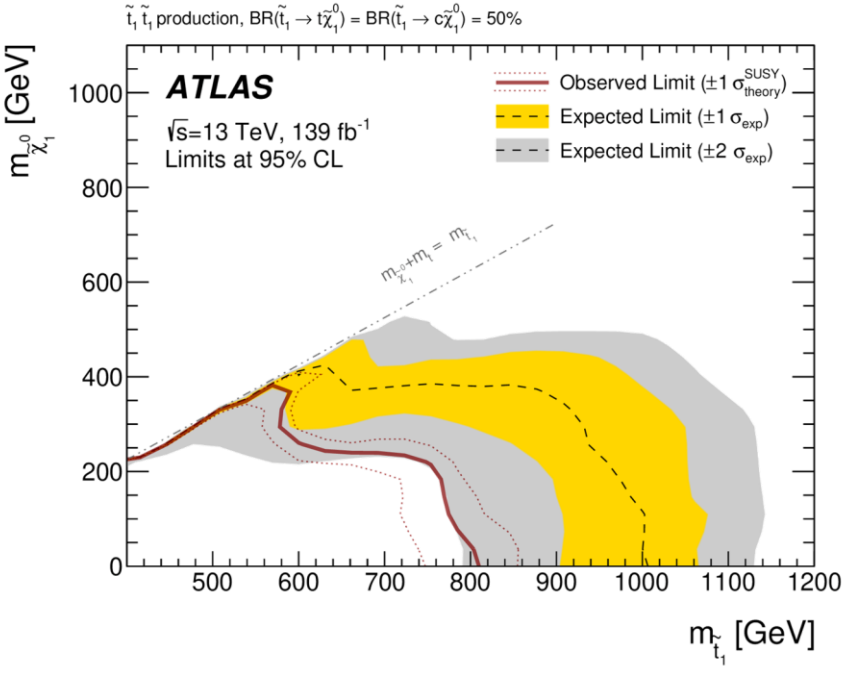
SR: Multiple SRs are defined depending on target model:

- Small $\Delta m(\tilde{t}, \tilde{\chi}_1^0)$: Initial radiation state jet + high NN score to distinguish signal and BG
- Large & intermediate $\Delta m(\tilde{t}, \tilde{\chi}_1^0)$: Top-tagged large-$R$ jet

BGs: Z/W+jets, single- t, $t\bar{t}$

Result: Mild excess in SRs for large & intermediate Δm.
Exclusion limits on $m(\tilde{t})$ are set.





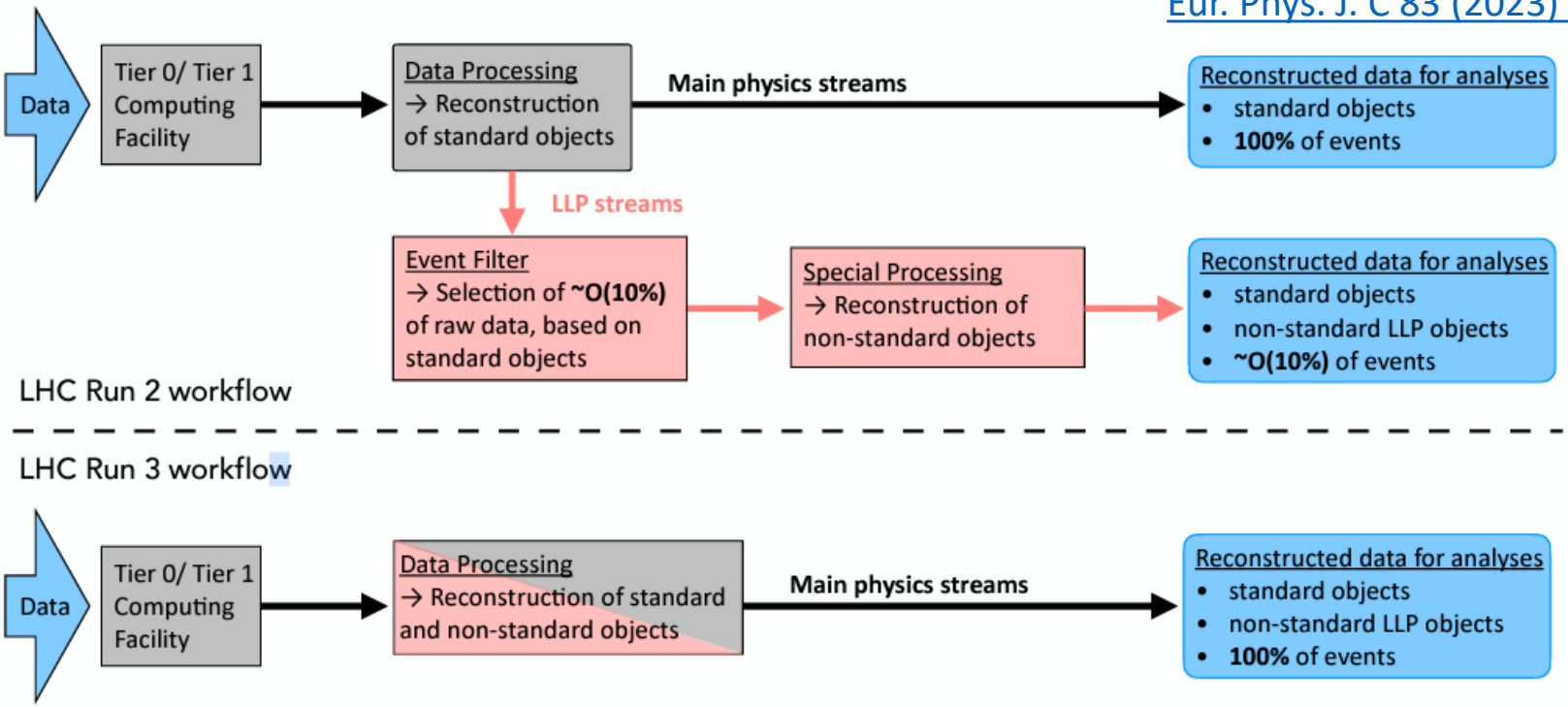
Summary

- Various searches targeting SUSY models including LLP or non-minimal assumptions have been performed in the ATLAS.
- Special reconstructions and analysis methods are used for each target model to capture unconventional signals.
- No evidence of new physics was found so far, but those results gives the constraints to the parameter space.
- Several full Run 2 analyses are in preparation for new results, and many partial Run 3 analyses are also progressing.
- Run 3 is on-going and will improve sensitivity thanks to more statistics and new techniques.

Backup

LRT

Eur. Phys. J. C 83 (2023) 1081



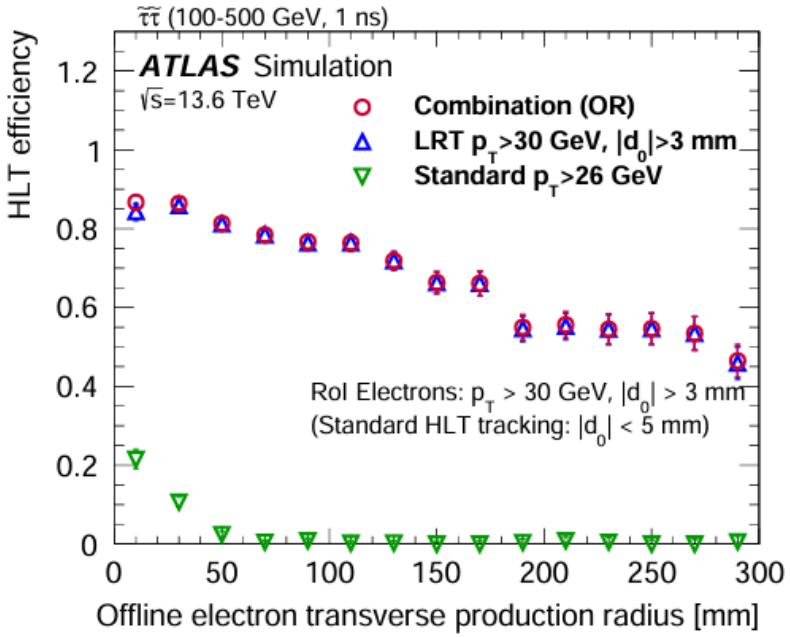
Standard tracking
- $|d_0|$ < 10 mm
- $|z_0|$ < 250 mm
- p_{T} > 500 MeV

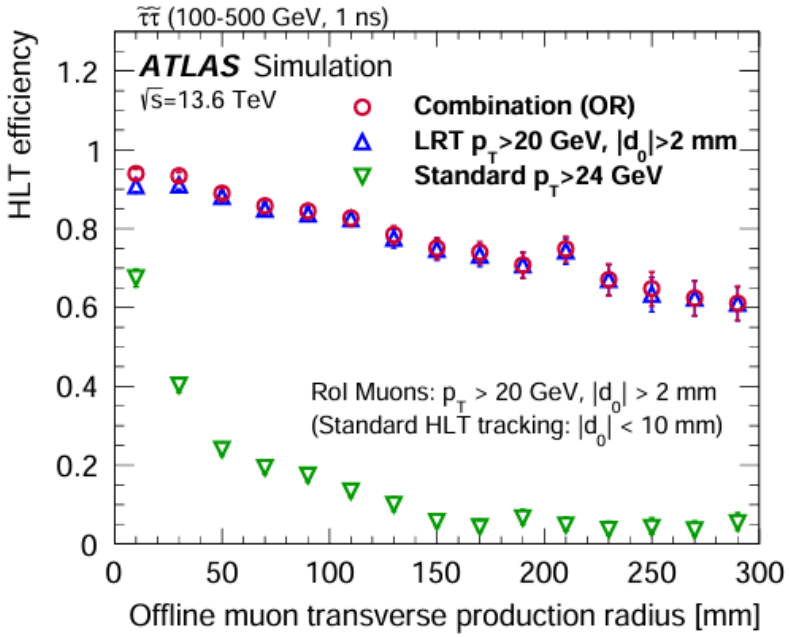
Large radius tracking
- $|d_0|$ < 300 mm
- $|z_0|$ < 1500 mm
- p_{T} > 1 GeV
- Relaxed hit conditions

ATLAS Data

	Full Run 2 (2015-2018)	Partial Run 3 (2022-2023)
Center of mass energy	13 TeV	13.6 TeV
Integrated luminosity	140 fb^{-1}	56.3 fb^{-1}

LRT Lepton Trigger

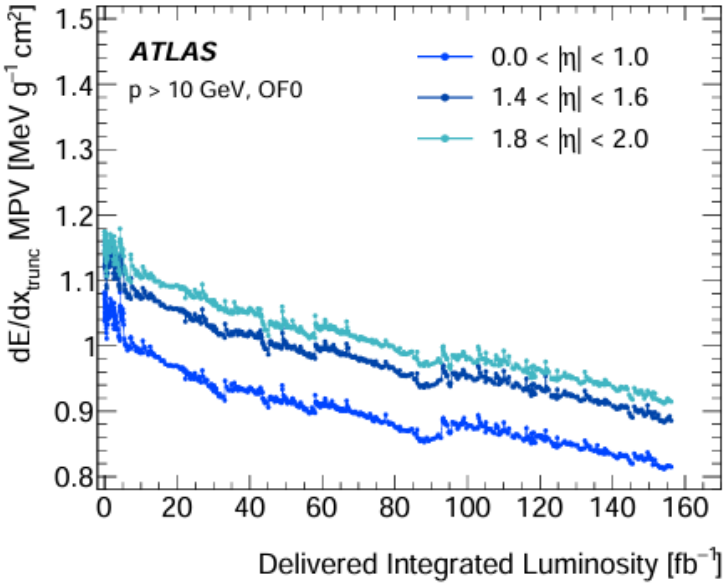




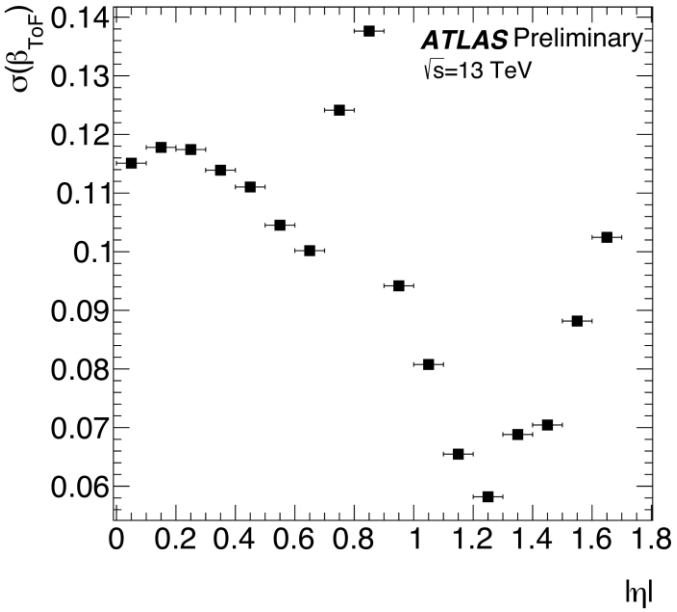
JINST 19 (2024) P06029

Meta-Stable Charged Particle

- dE/dx_{trunc}: Remove the highest, or 2 highest clusters to reduce the effect of the tails of the Landau distribution and exclude IBL overflow clusters
  - Average number of clusters used in dE/dx_{trunc} is 2.7 per track
- dE/dx_{corr}: Corrected dE/dx_{trunc} for variations of Pixel conditions during the data-taking period and for $|\eta|$

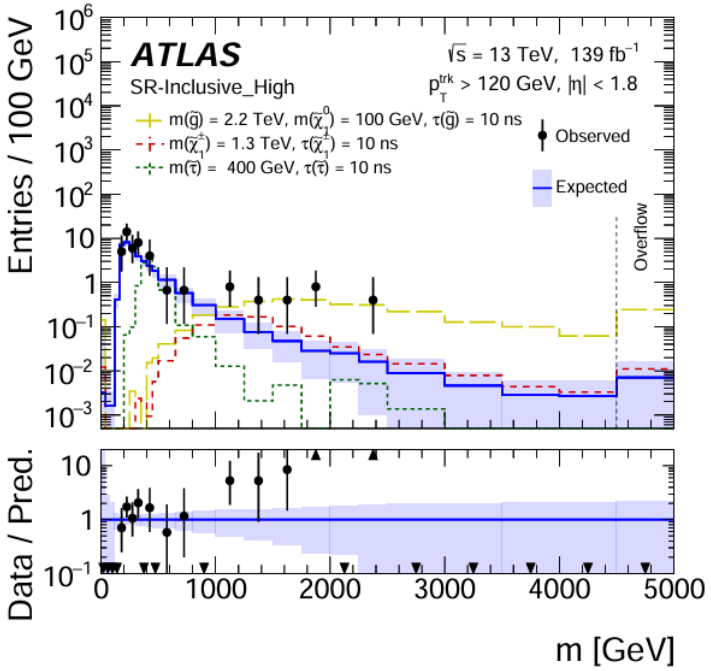


β_{ToF} resolution

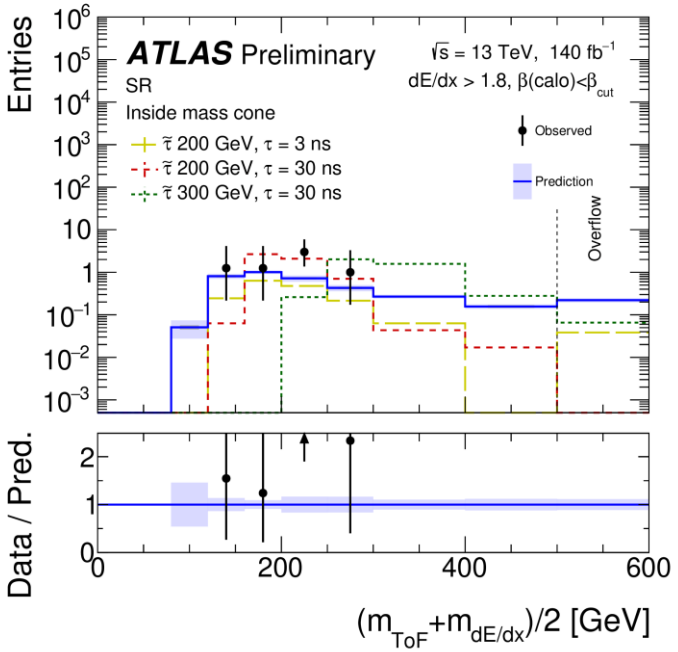


Meta-Stable Charged Particle

< Previous result >



< New result >



Meta-Stable Charged Particle

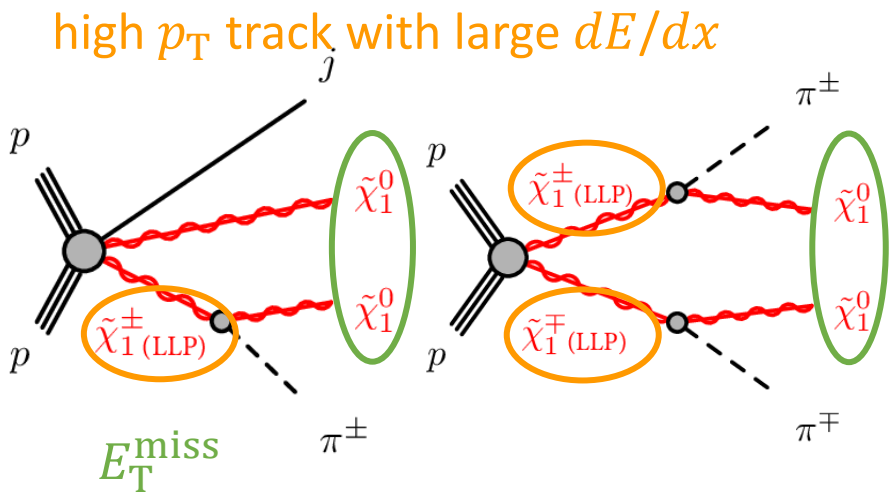
Region	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	$\mathrm{d}E/\mathrm{d}x$ [MeV g^{-1}cm^2]	β_{ToF}
SR	> 170	> 1.8	$< \beta_{cut}$
kin-CR		< 1.6	< 1.0
$\beta\gamma$-CR	< 150	-	< 1.0
Highβ_{ToF}-VR	> 170	> 1.8	$[\beta_{cut}, 1.0]$
Highβ_{ToF}-VR kin-CR		< 1.6	$[\beta_{cut}, 1.0]$
Highβ_{ToF}-VR $\beta\gamma$-CR	< 150	-	$[\beta_{cut}, 1.0]$
LowdEdx-VR	> 170	[1.05,1.6]	$< \beta_{cut}$
LowdEdx kin-CR		< 1.05	< 1.0
LowdEdx $\beta\gamma$-CR	< 150	< 1.6	< 1.0

→ Kinematic template
→ dE/dx and β_{ToF} template

Make mass distribution

Meta-Stable Charged Particle

Interpretation to long-lived chargino in mass degenerate $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$.



- Anomaly-mediated SUSY breaking models with a wino scenario
- Wino $\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0$

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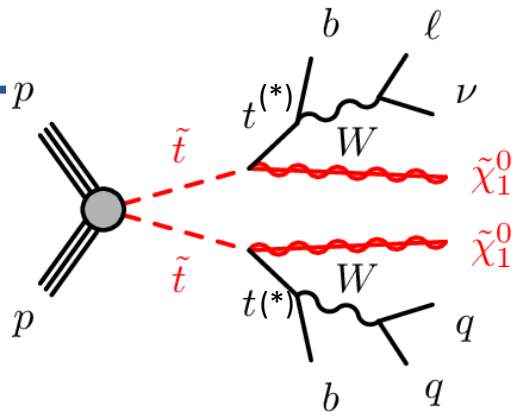
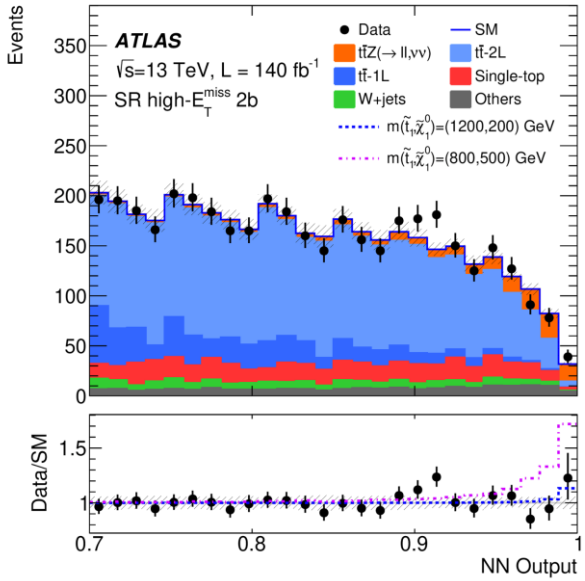
Top Pair + MET

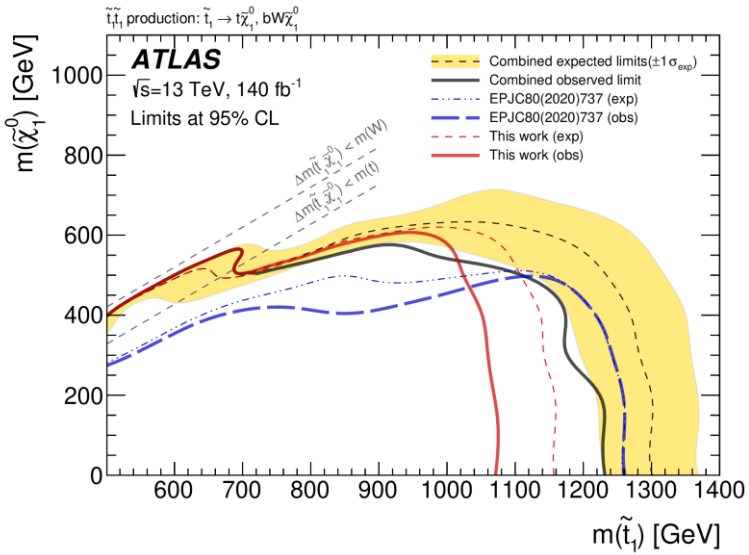


Strategy

- High MET + 1 lepton + jets
- Use event-level NN to distinguish signal and BGs
- Two SR categories:
  - High $E_{\mathrm{T}}^{\mathrm{miss}}$ SRs: MET > 230 GeV + 3 or more jets
  - Boosted SRs: Large-R jet

BGs: Z/W+jets, single-t, $t\bar{t}$





Results

- Mild excess in high $E_{\mathrm{T}}^{\mathrm{miss}}$ SRs
- Set exclusion limits