ICHEP 2022 BOLOGNA

Searches for BSM physics using challenging and long-lived signatures with the ATLAS detector

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on behalf of the ATLAS collaboration

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ATLAS EXPERIMENT

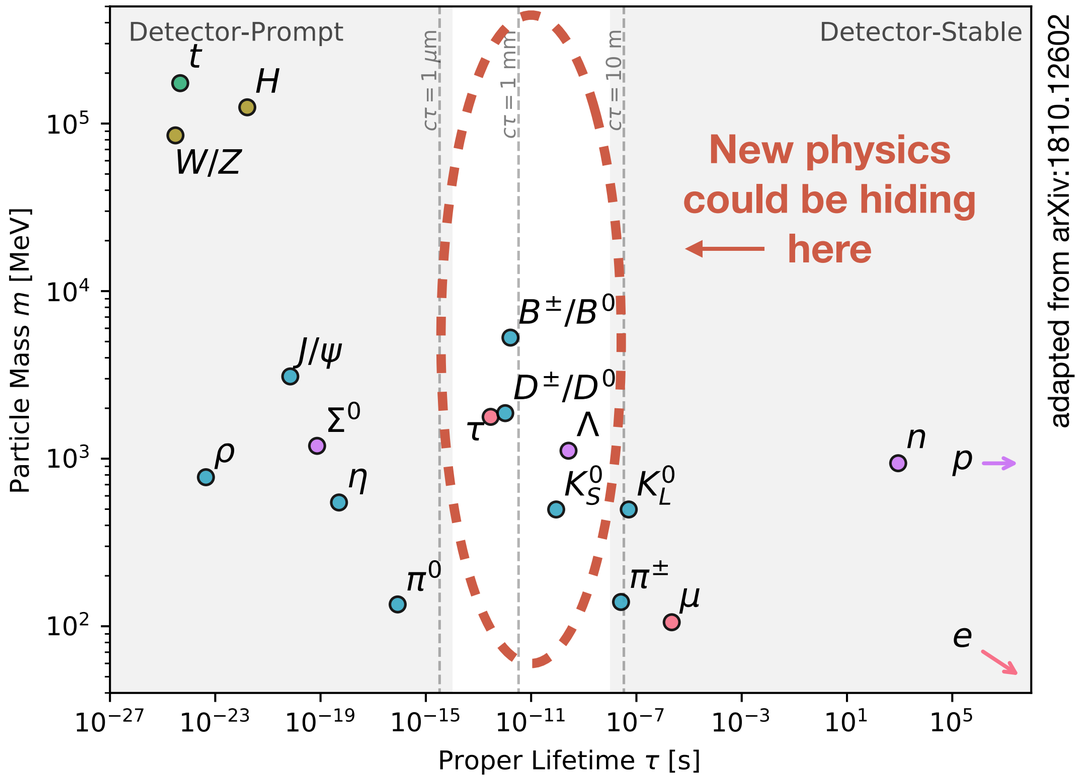
New Physics? Where?

- Do we need m*ore data? More energy?*
  Are we looking in the right place?

- New Physics could be rich in either charged or neutral **Long-Lived Particles (LLPs)**
  - Unusual energy deposits
  - Displaced vertices
  - Long time-of-flight

- **Exotic searches → unconventional backgrounds!**
  - Detector noise & Machine-induced background
  - Fluctuations in energy deposits
  - Data-driven approaches

The majority of the work of HEP experimentalists



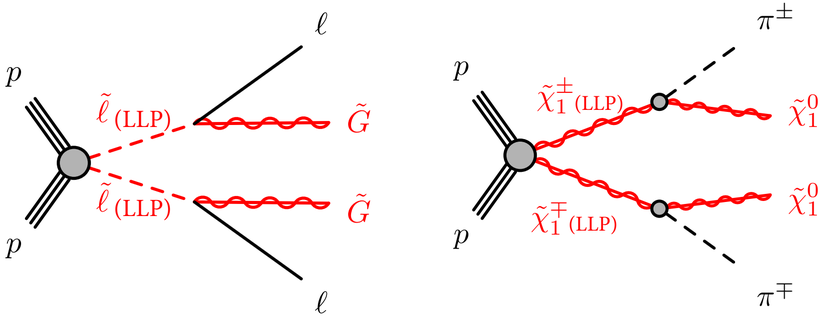
adapted from arXiv:1810.12602

arXiv:2205.06013

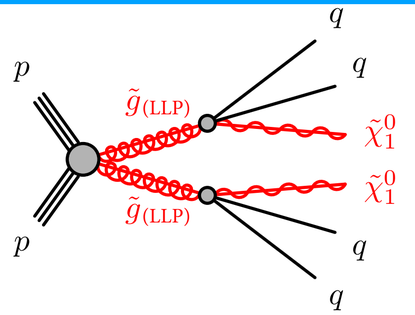
Pixel dE/dx

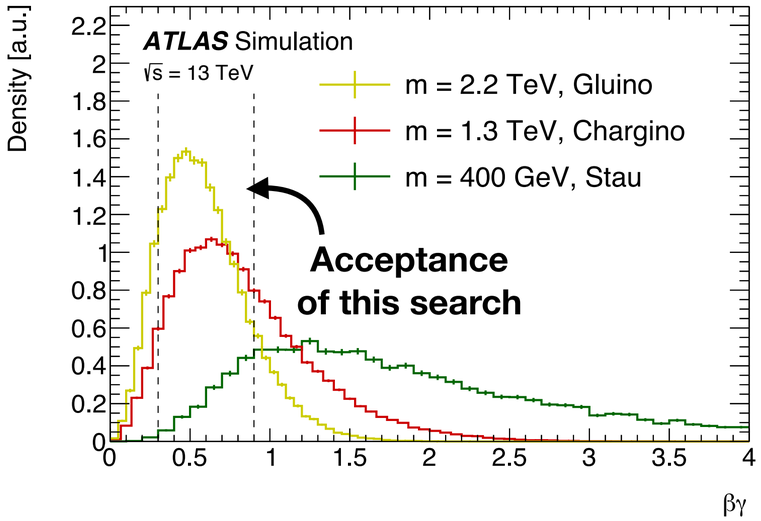
- Target: massive charged LLPs → Low β
- Pixel dE/dx information → Bethe-Bloch → βγ
- Mass estimate from βγ and momentum
- Selection exploiting missing E^T and tracks with large dE/dx
- 8 signal regions targeting different LLP masses and lifetime regimes

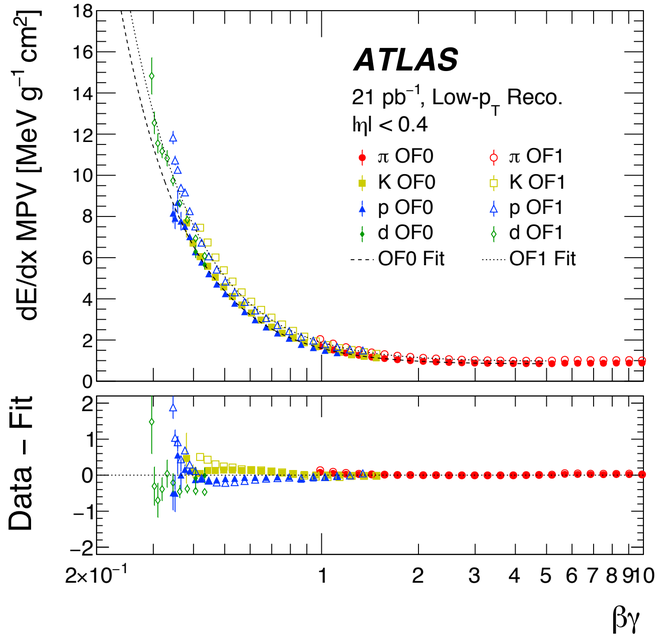
$$m = \frac{p}{\mathrm{d}E/\mathrm{d}x}$$

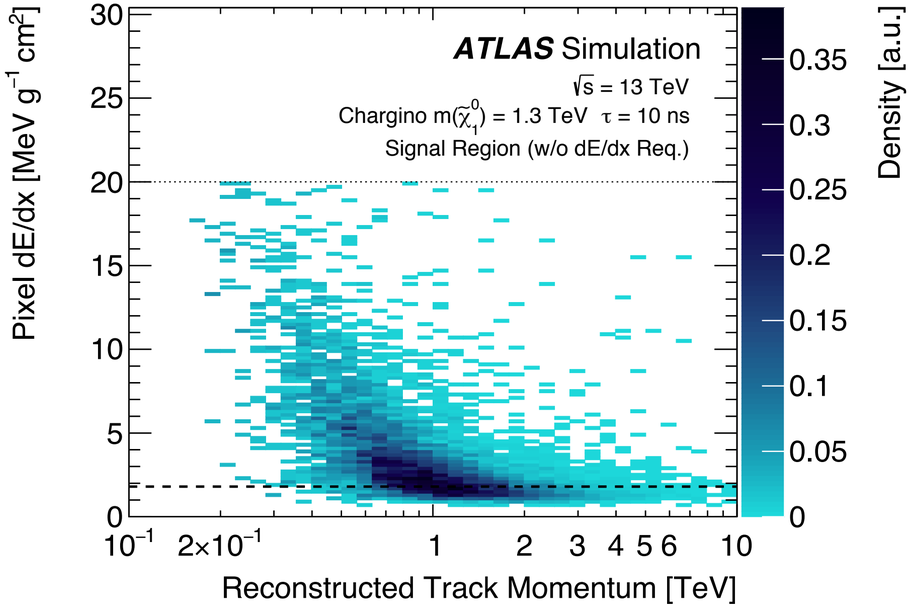


SUSY Benchmark models







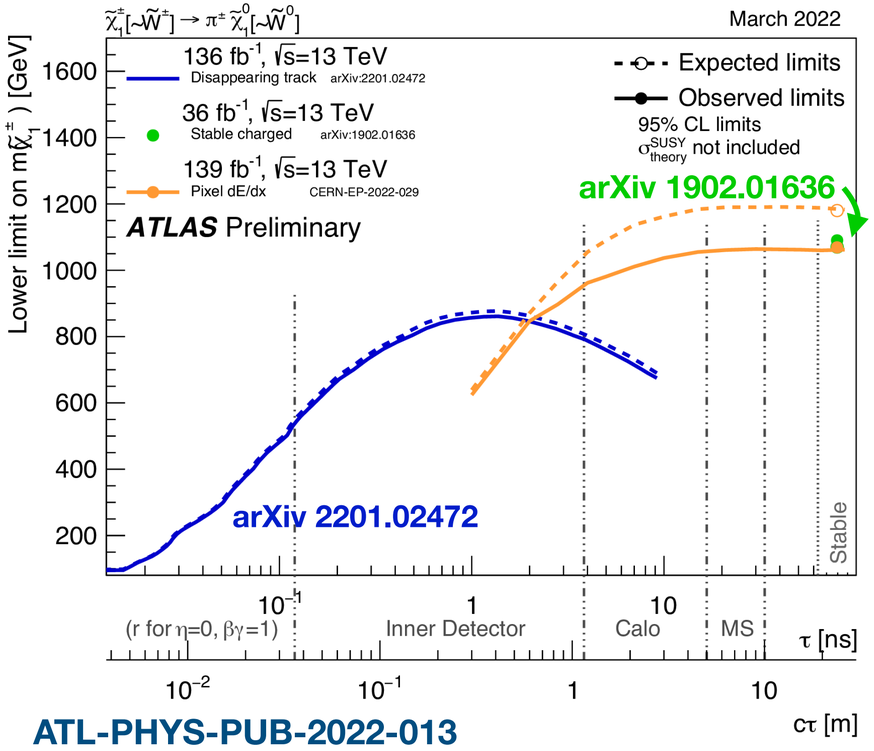


arXiv:2205.06013

Pixel dE/dx

- Background due to dE/dx fluctuations
- Fully data-driven background estimation (based on pseudo-data generation from CRs)
- Agreement with SM predictions in all-except-one SR

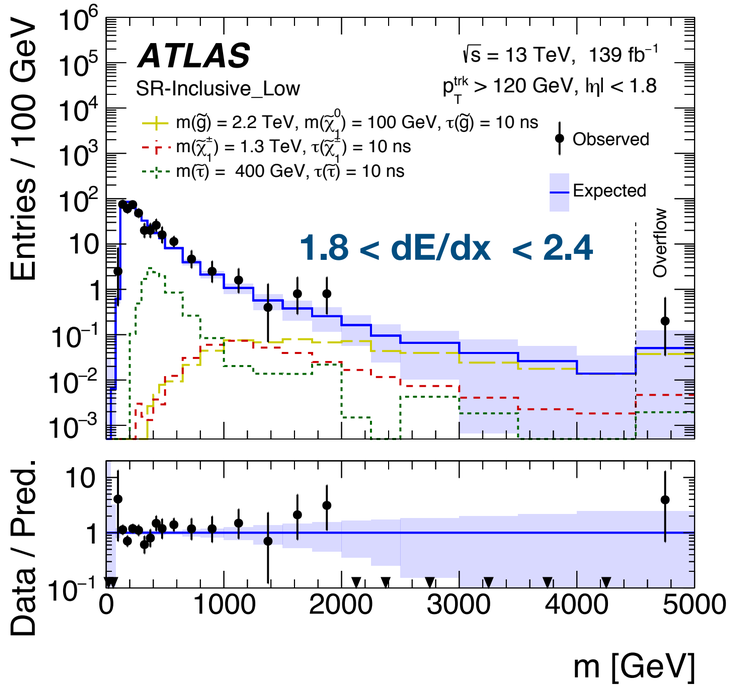
Complementarity with other ATLAS LLP searches

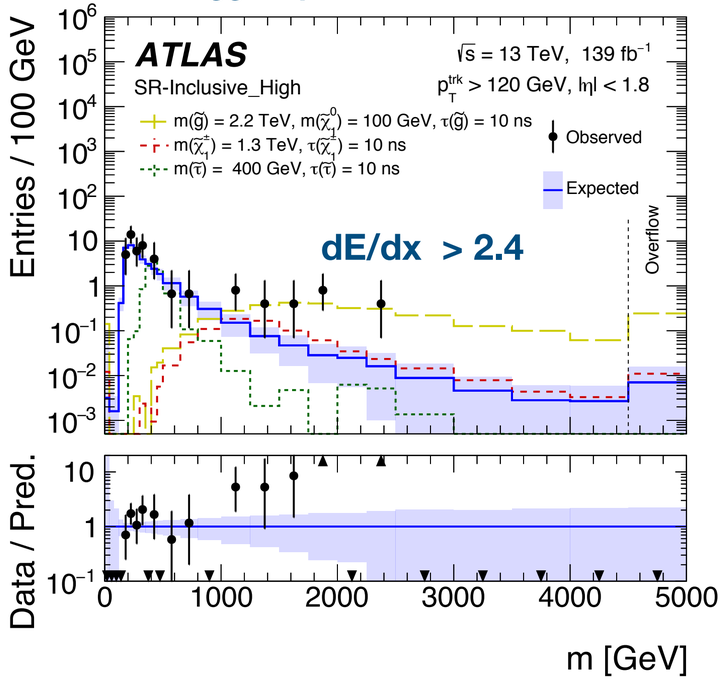


ATL-PHYS-PUB-2022-013

3.6σ local deviation from SM for m=1.4 TeV (3.3σ global significance)

Cross-checks with other subdetectors suggest β~1 for these tracks

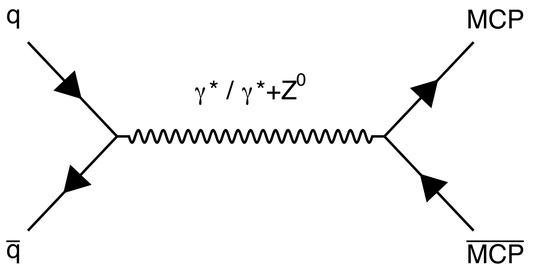


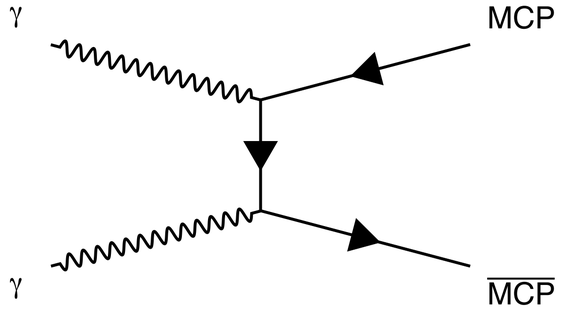


ATLAS-CONF-2022-034

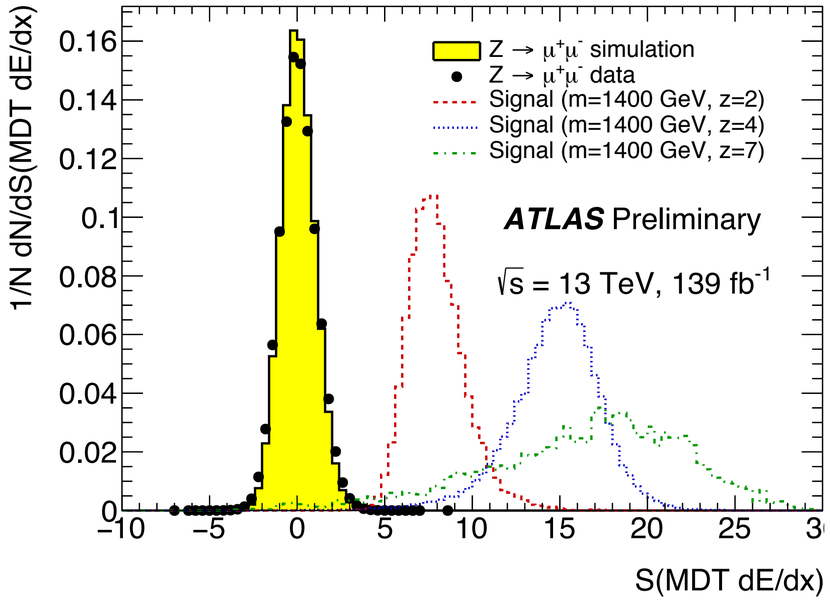
Multi-Charged particles

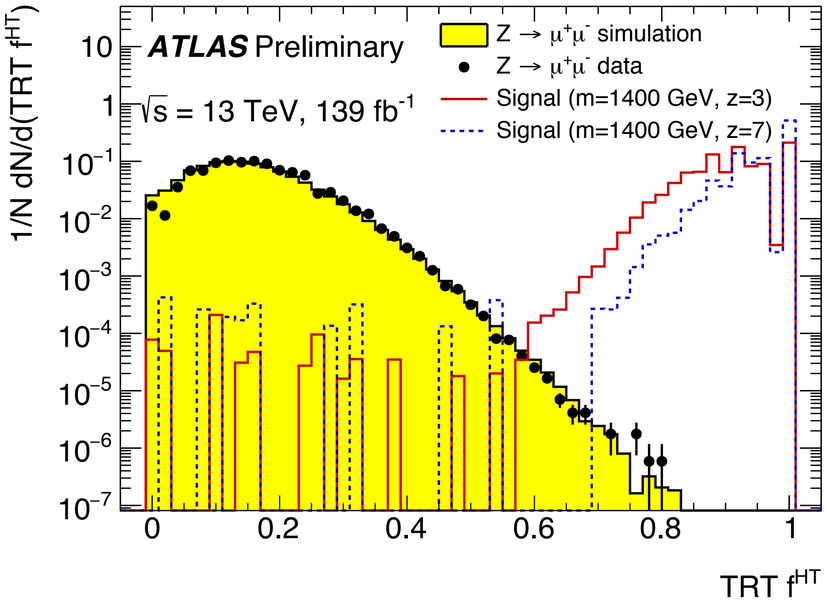
- Exotic heavy fermions with high electric charge (up to z=7)
- Long-lived → hits in the ID + MS → reconstructed as muons
- Missing E^T, single muon and late-muon triggers for maximum signal acceptance
- Two signal regions defined on dE/dx significance and/or fraction of high-threshold TRT hits

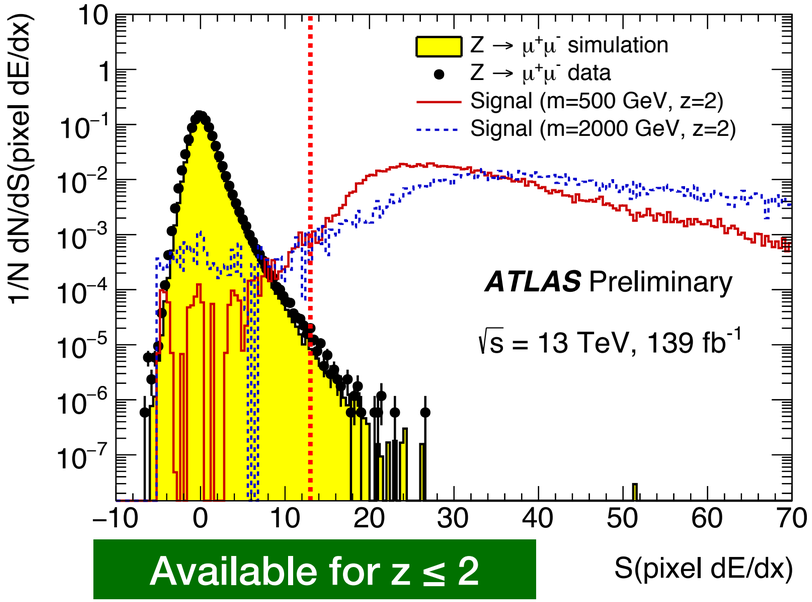




$$S(dE/dx) = \frac{dE/dx_{candidate} - \langle dE/dx_{muon} \rangle}{\sigma(dE/dx_{muon})}$$



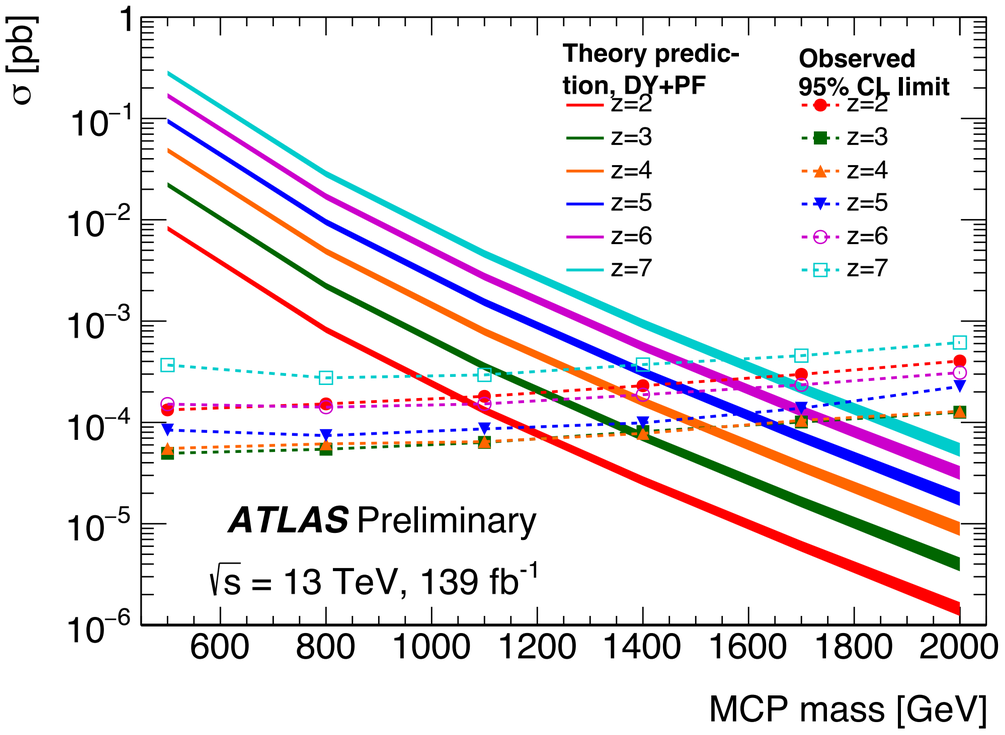


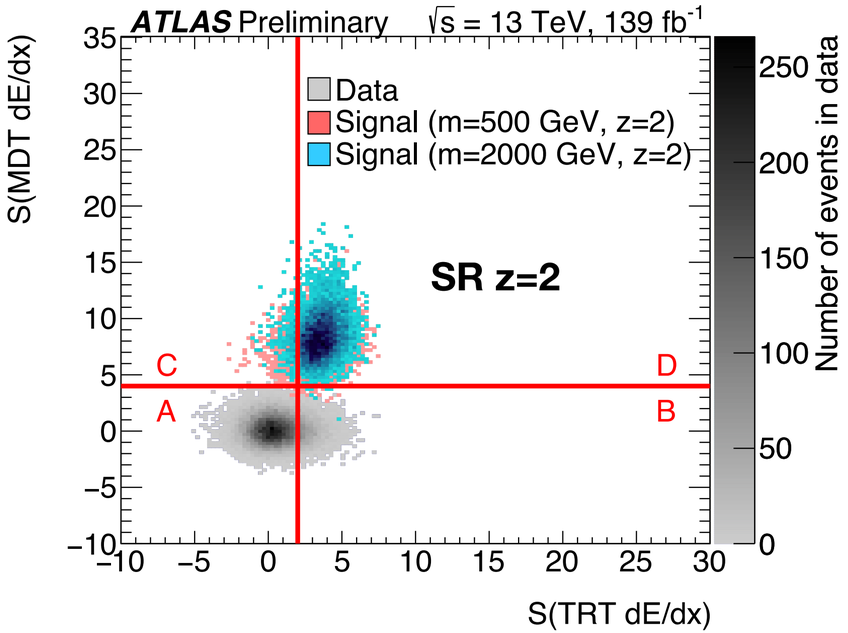


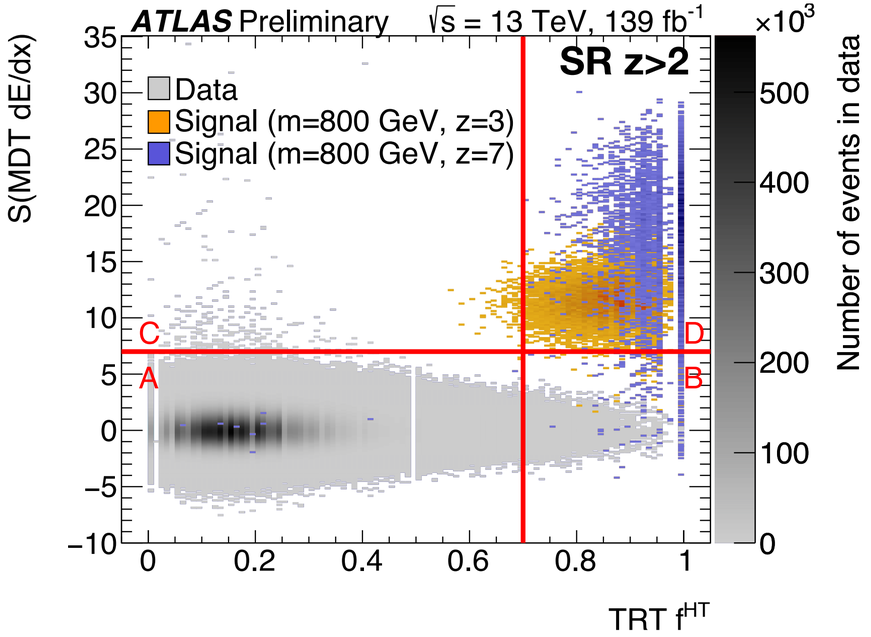
Available for z ≤ 2

Multi-Charged particles

- Background due to random fluctuations of the energy loss
- Data driven (ABCD) background estimation
- No excess! → Limits set on MCP production cross section for MCP mass up to ~1.7 TeV





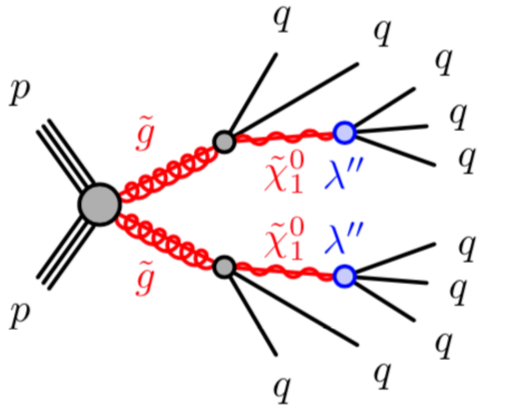


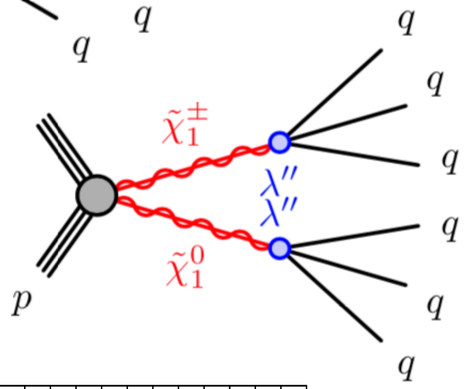
NEW!

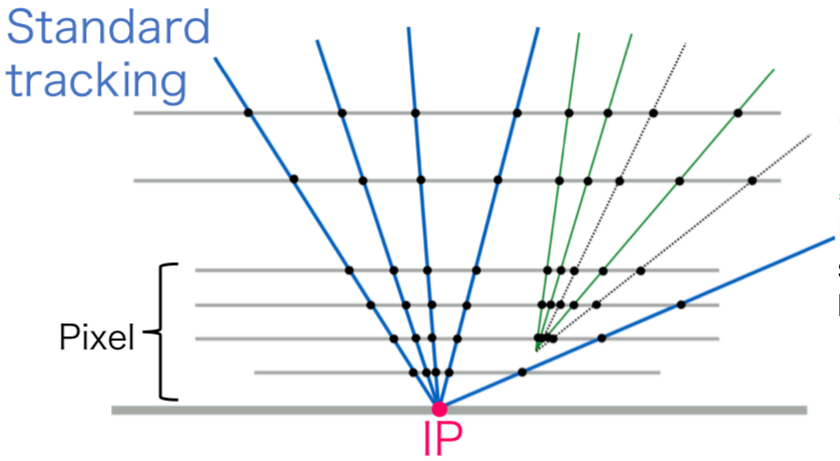
ATLAS-CONF-2022-054

Jets + Displaced Vertices

- General search for heavy LLPs decaying in hadrons
- Looking for an excess in multi-jet events with reconstructed Displaced Vertices
- DV reconstruction possible up to 300 mm thanks to Large Radius Tracking
- Two cut-and-count SR targeting different jet p_T regimes



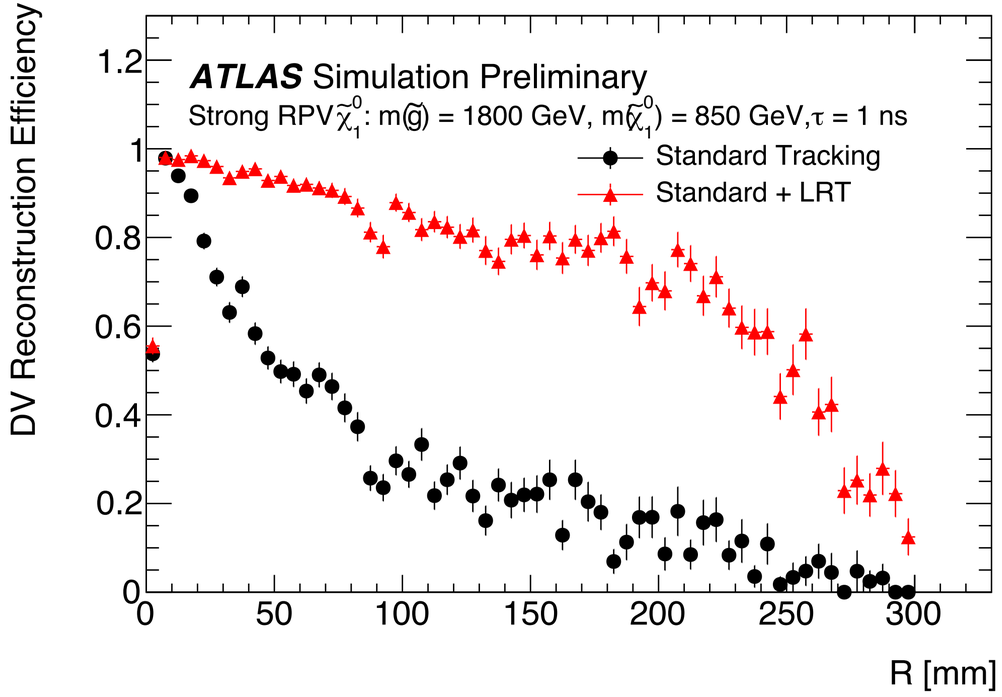




Large radius tracking

ATL-PHYS-PUB-2017-014

Left-over hits after the standard tracking with looser IP constraints



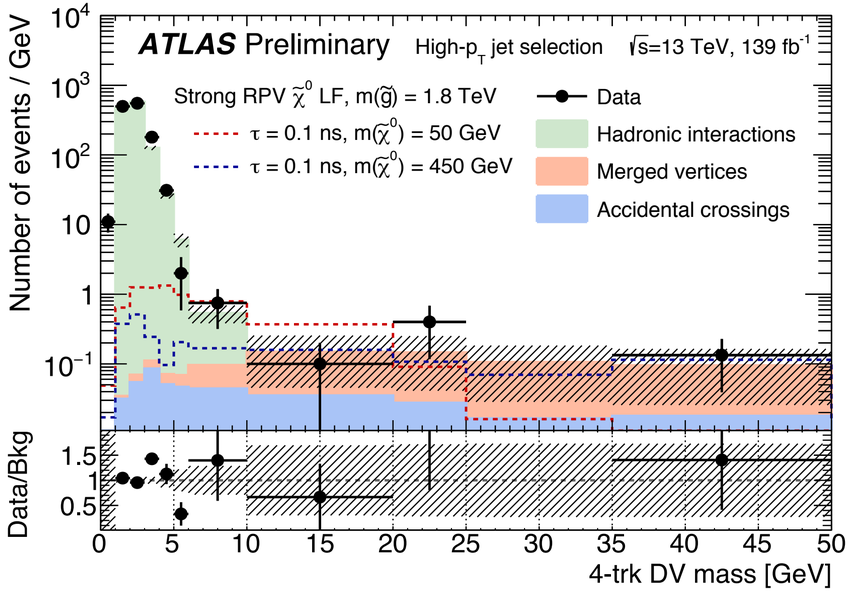
NEW!

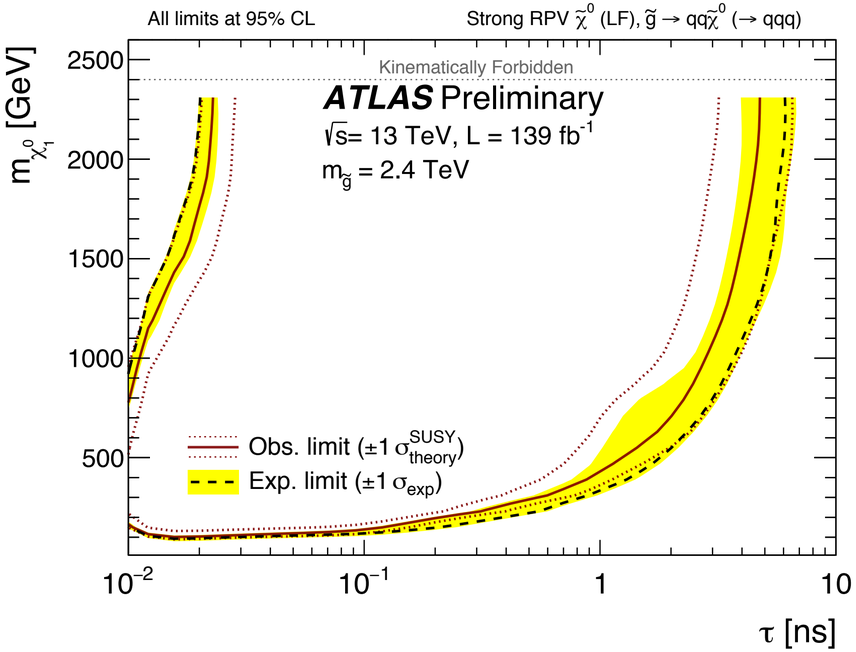
ATLAS-CONF-2022-054

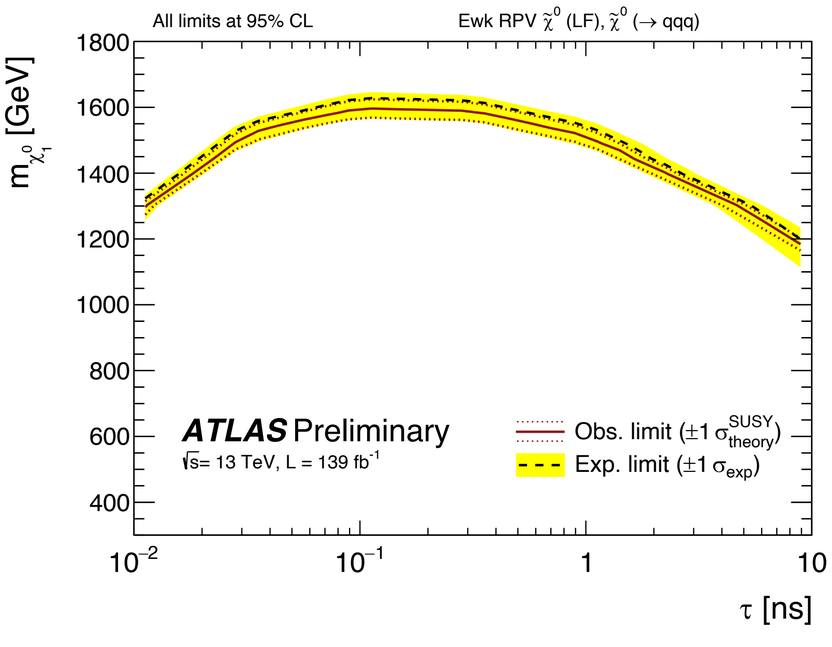
Jets + Displaced Vertices

- Background: rare hadronic events, accidental track-crossing and close-by secondary vertices
- Jet-DV correlation is measured in a signal-free CR and used to estimate the background in the SR
- No excess → limits are set on the SUSY benchmark models

	Expected	Observed
High-p_{T} SR	$0.46^{+0.27}_{-0.30}$	1
Trackless-jets SR	$0.83^{+0.51}_{-0.53}$	0





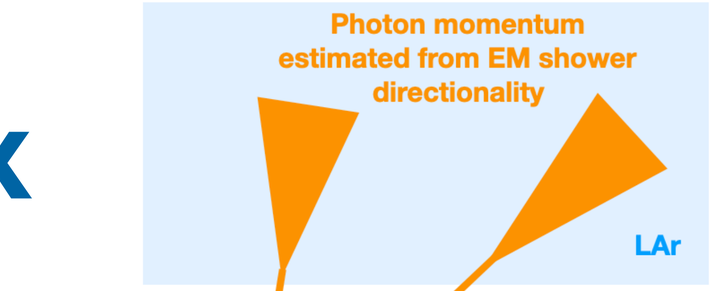


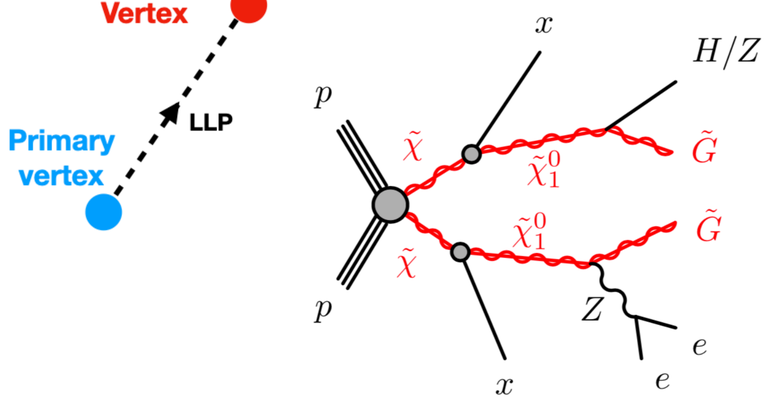
NEW!

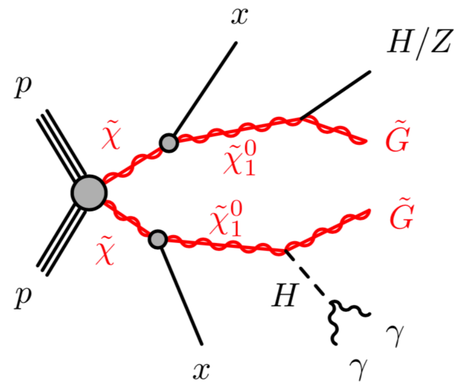
ATLAS-CONF-2022-051

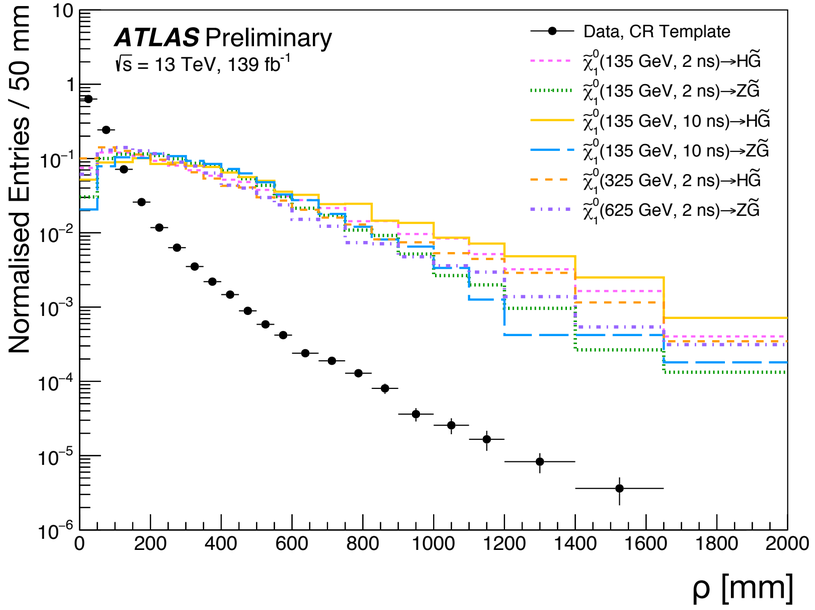
Displaced di-photon vertex

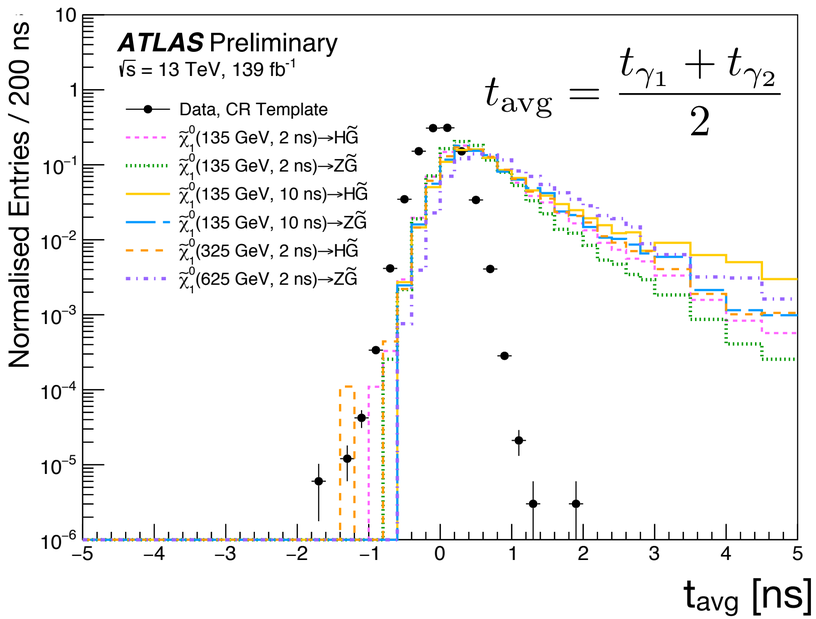
- Target: heavy particles originating displaced H→γγ or Z→ee decays
- Benchmark model: gauge-mediated SUSY breaking with long-lived NLSP
- Exploit LAr timing (t_{avg}), 2D position (ρ) of the DV and combined mass of the γ pair









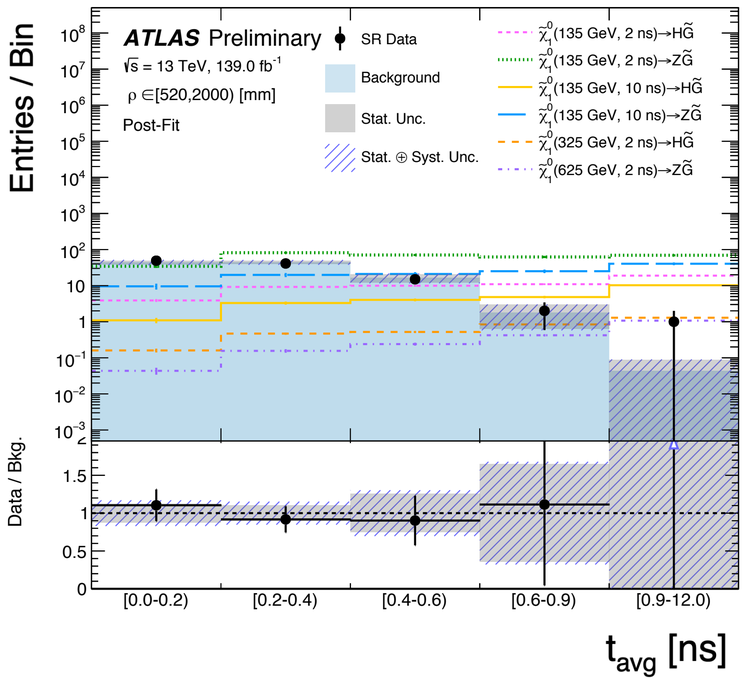


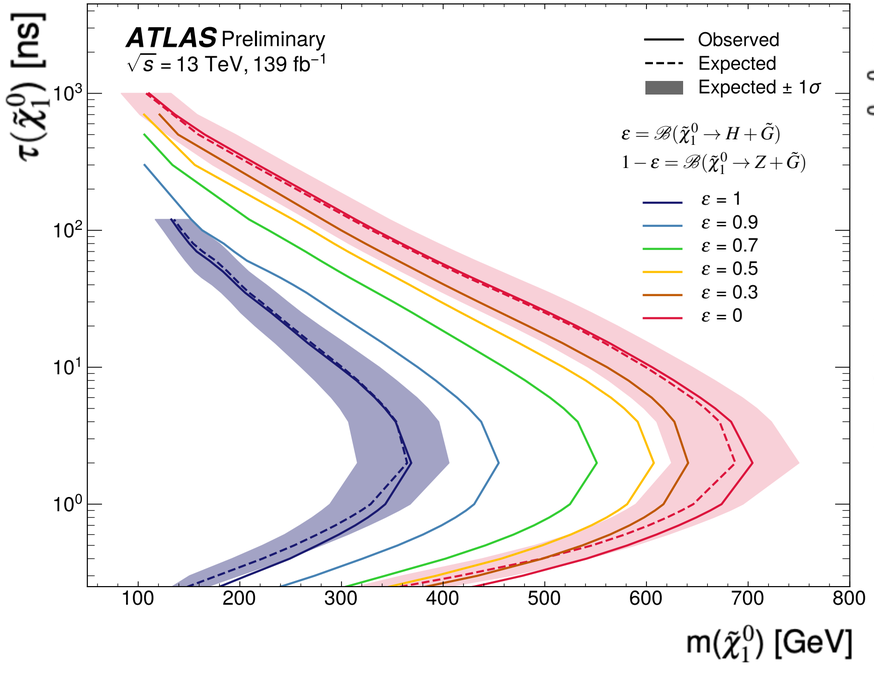
NEW!

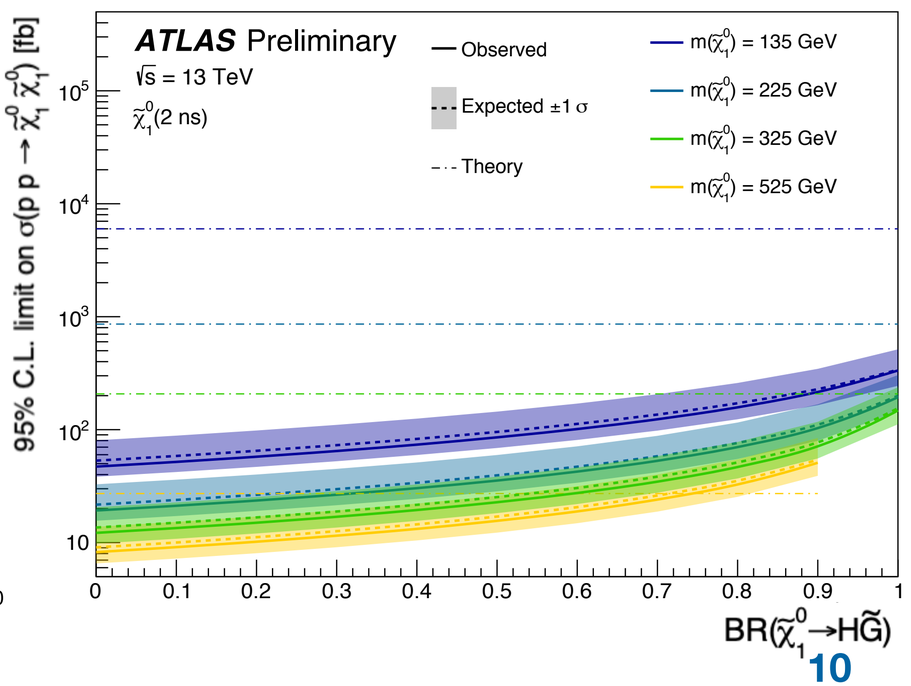
ATLAS-CONF-2022-051

Displaced di-photon vertex

- Background due to fake and mis-measured photons
- Likelihood fit of t_{avg} in different bins of ρ, background estimated from t_{avg} templates from CR
- No disagreement with SM observed → strong limits on neutralino masses and lifetimes

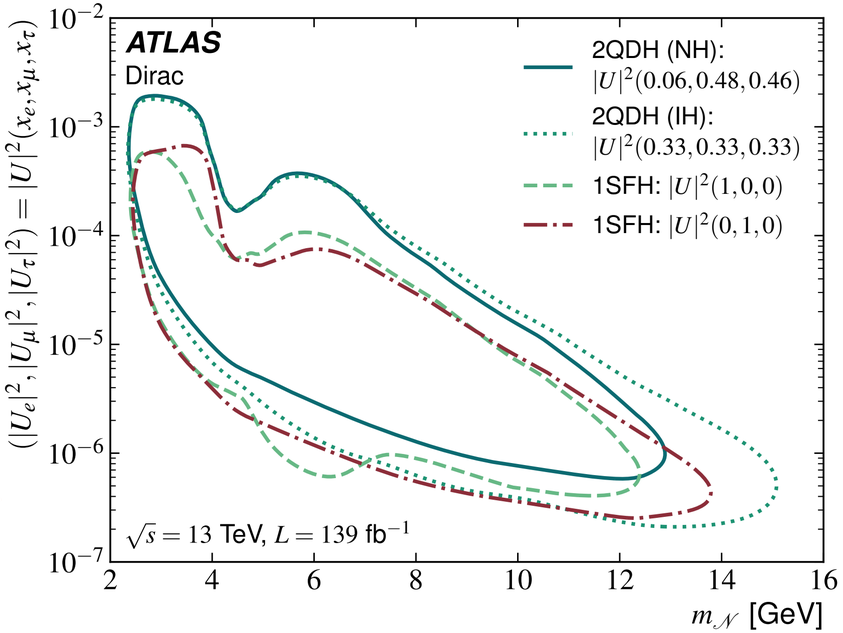




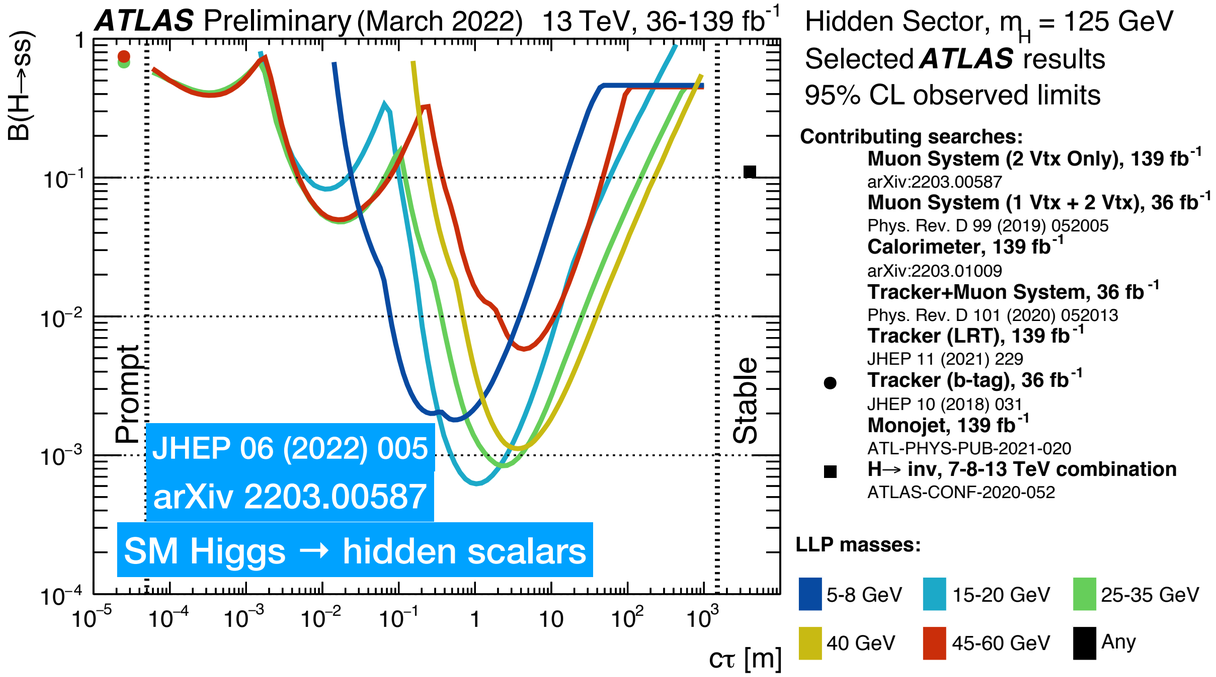


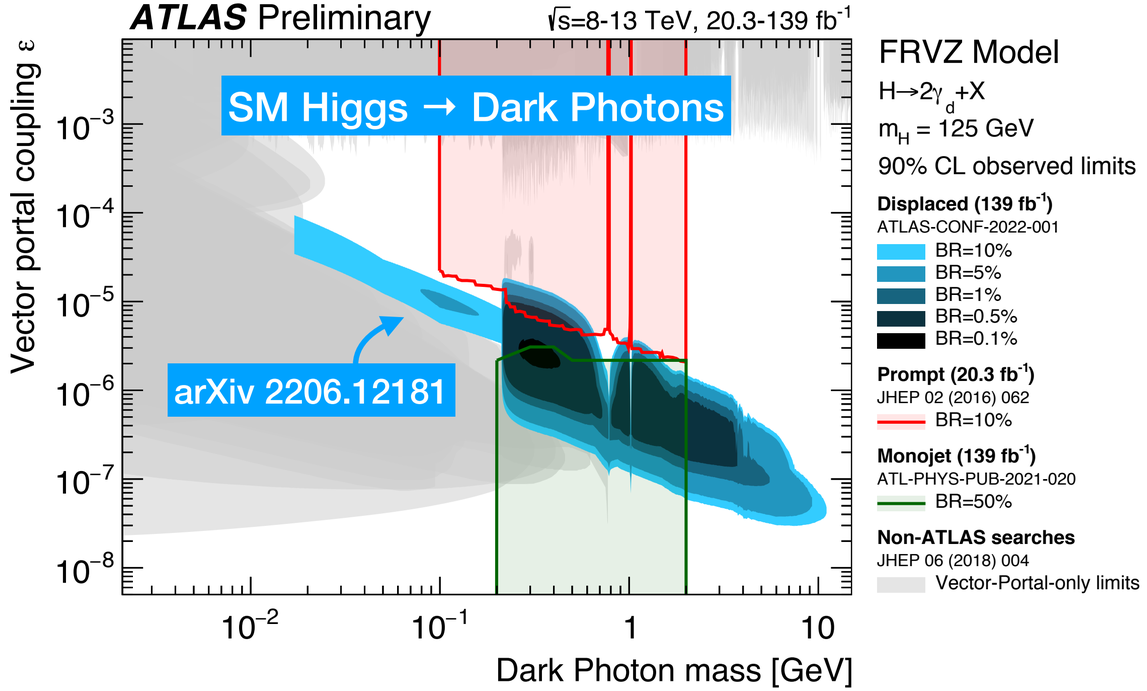
Other recent ATLAS LLP results

Displaced Heavy Neutral Leptons
arXiv:2204.11988



Nice complementarity between many different ATLAS searches (ATL-PHYS-PUB-2022-007)





All ATLAS public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/

Summary

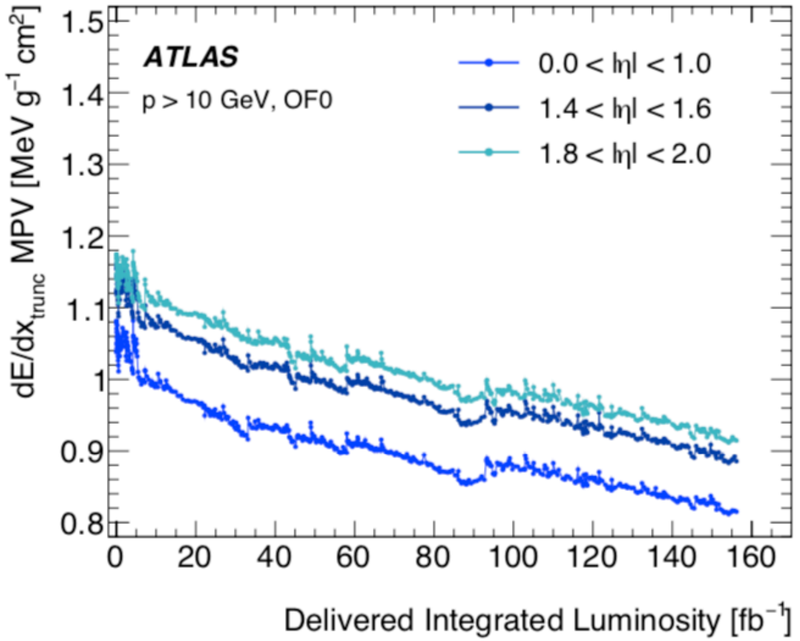
- **ATLAS is a powerful probe for LLP models giving unconventional signatures**
- Many analyses looking for it, but no new physics have been found ***yet***!
- **Run-3 just started**, many new ideas to extend the ATLAS reach:
  - Large-radius tracking now available for all events
  - New triggers
  - Trigger-level analysis
  - New ideas for combination & reinterpretation

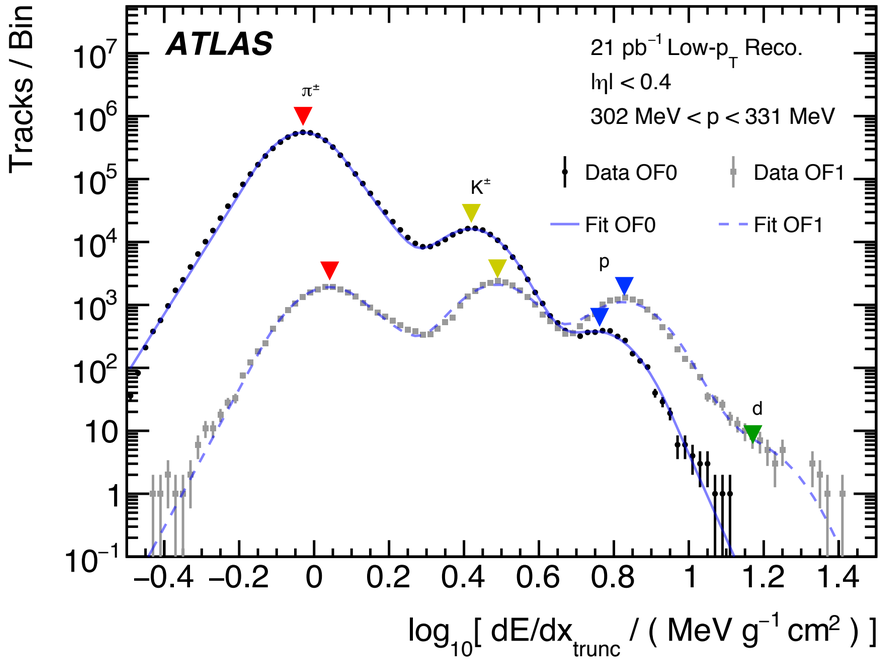
Stay tuned!

Backup

Pixel dE/dx calibration

- Time-over-threshold from pixel sensors → charge measurement
- Overflow (OF1) bit information available to identify pixels where the released ionisation is too large
- Average dE/dx is evaluated from all the sub-leading pixel clusters
- dE/dx corrected to account for radiation damage and η dependence



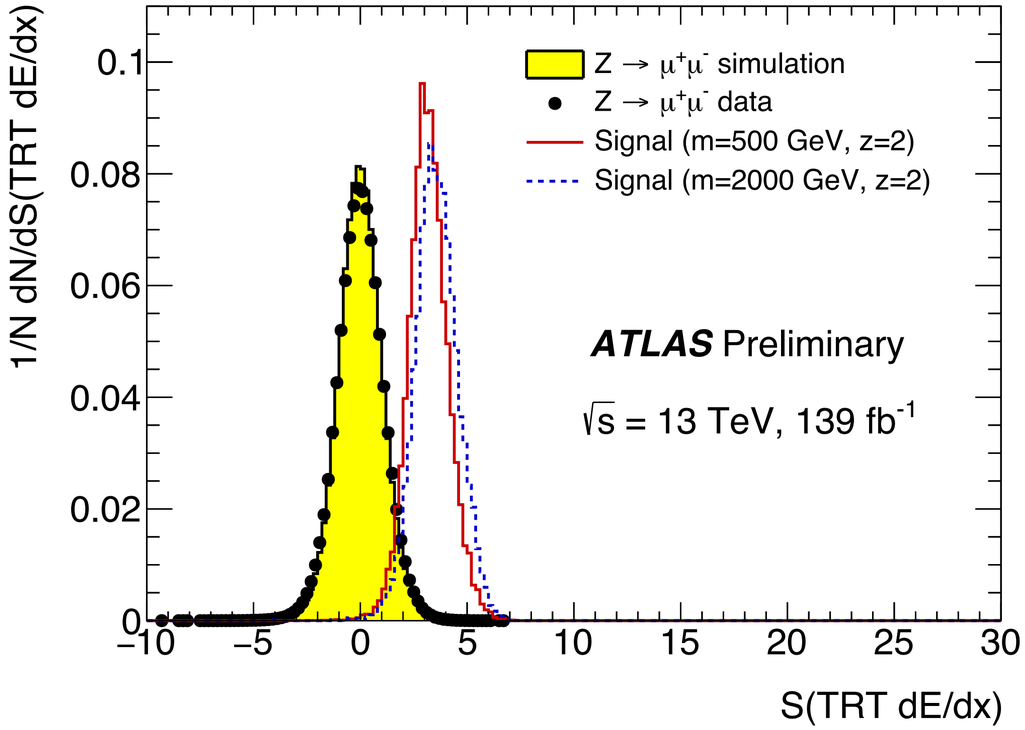


- Calibration performed in a special dataset with low-p_T tracks
- Fitted MPV of dE/dx for known particle species
  → Calibrated MPV-βγ relation

$$\mathrm{MPV}_{dE/dx}(\beta\gamma) = \frac{1+(\beta\gamma)^2}{(\beta\gamma)^2}\left(c_0 + c_1 \log_{10}(\beta\gamma) + c_2\left[\log_{10}(\beta\gamma)\right]^2\right)$$

MCP - Calibration

- Pixel dE/dx is calibrated following the process of the dedicated analysis
- TRT dE/dx and f_{HT} are corrected for detector occupancy, geometrical effects
- MDT dE/dx measurement is corrected taking into account the different response of the detector in different regions

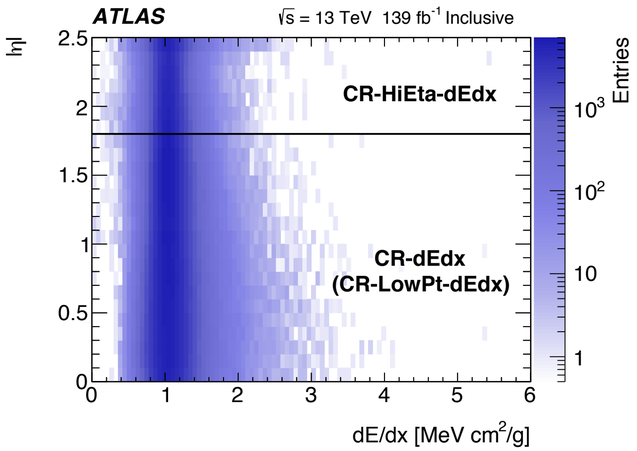


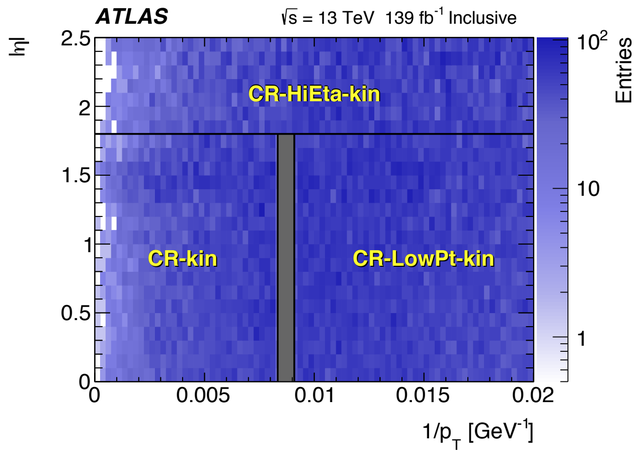
Pixel dE/dx - Background

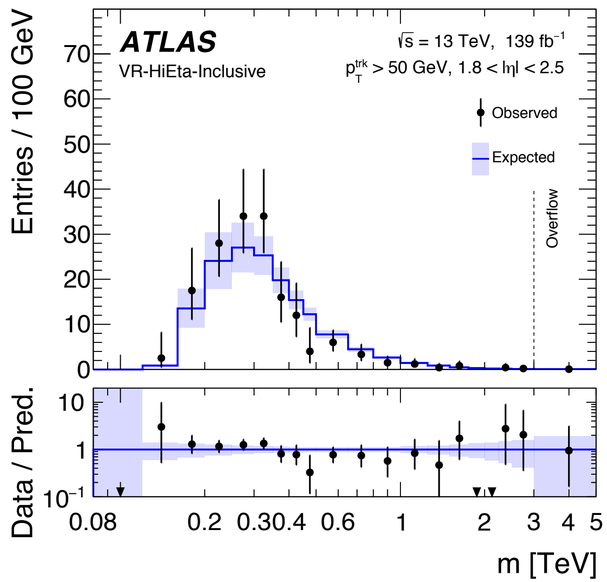
- dE/dx - and $1/p_T$ sampled from CR to generate toy values of m
- Toy mass distribution normalised to data in a signal-free region

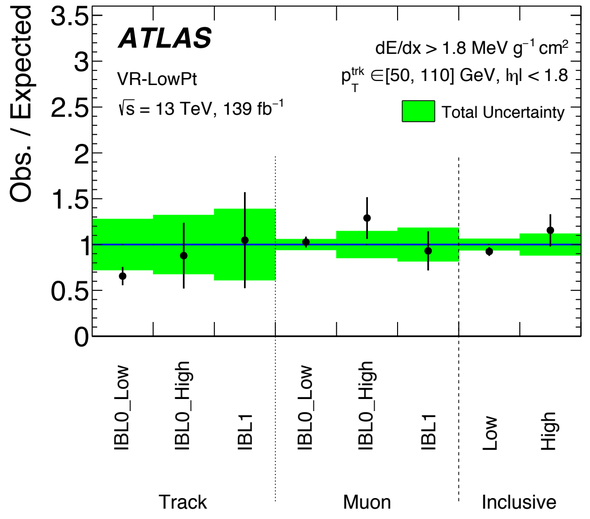
Control/Validation regions defined inverting SR cuts

Region	p_T [GeV]	$\|\eta\|$	E_T^{miss} [GeV]	dE/dx [MeV g^{-1}cm^2]
SR			> 170	> 1.8
CR-kin	> 120	< 1.8	> 170	< 1.8
CR-dEdx			< 170	> 0
VR-LowPt			> 170	> 1.8
CR-LowPt-kin	[50, 110]	< 1.8	> 170	< 1.8
CR-LowPt-dEdx			< 170	> 0
VR-HiEta			> 170	> 1.6
CR-HiEta-kin	> 50	[1.8, 2.5]	> 170	< 1.6
CR-HiEta-dEdx			< 170	> 0



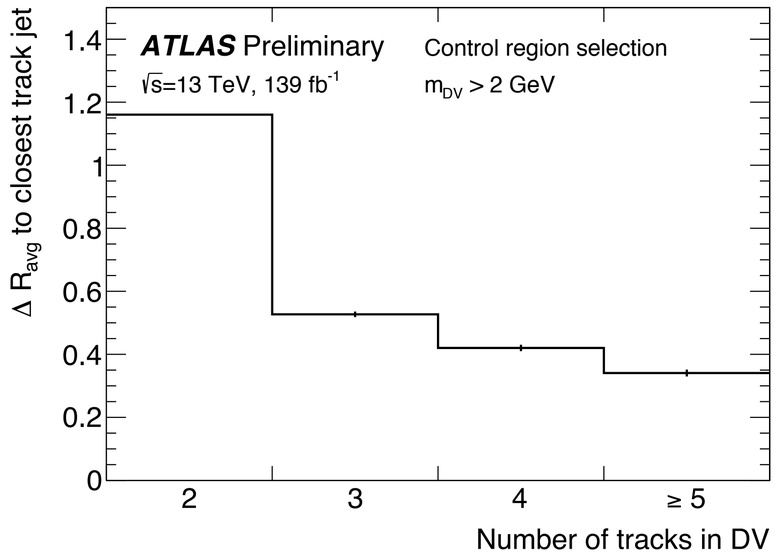


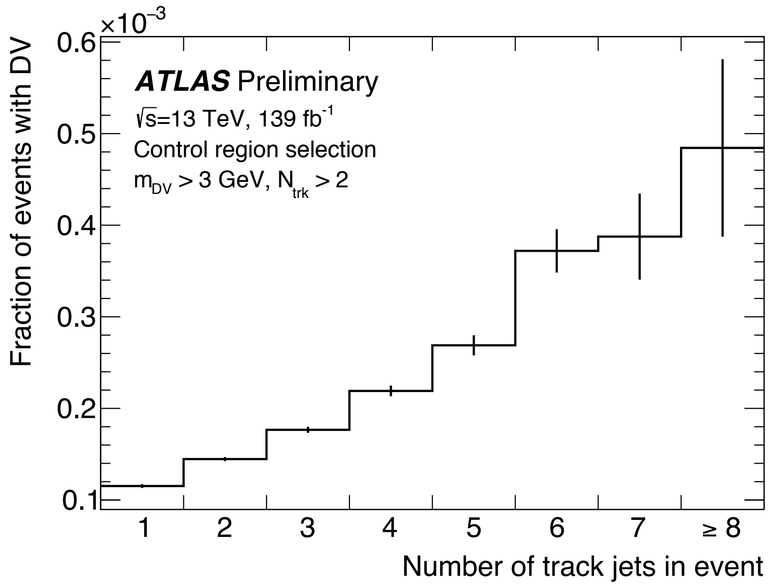
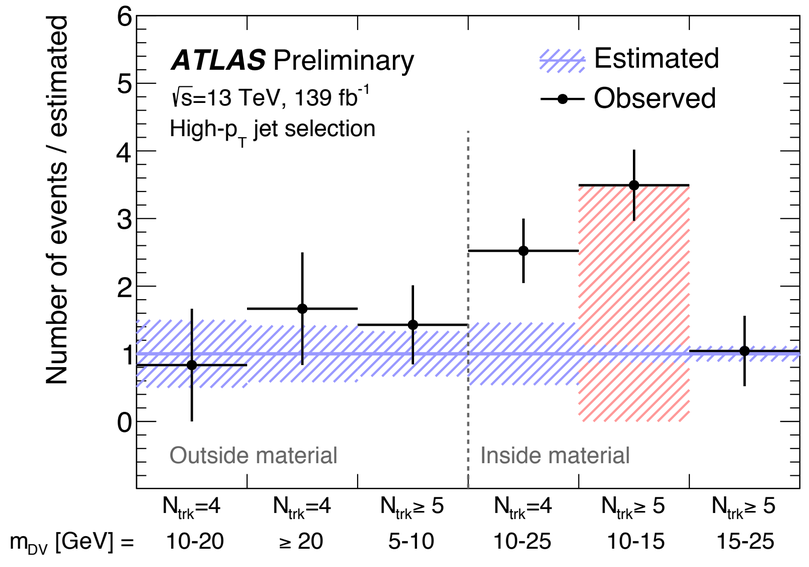




Jet + DV - background

- DV are more likely to be found when many jets are present
- CR defined with inverted jet-p_T requirements w.r.t. SR and requiring ≥3 track-jets in the event
- DV identification probability (p_{DV}) obtained from CR
- p_{DV} ~ #jets with matched DV in CR / # number of track-jets in CR
- p_{DV} is then applied to SR jets → estimate of background DV





Closure test performed in multiple VR