Kruger : Discovery Physics at the LHC

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

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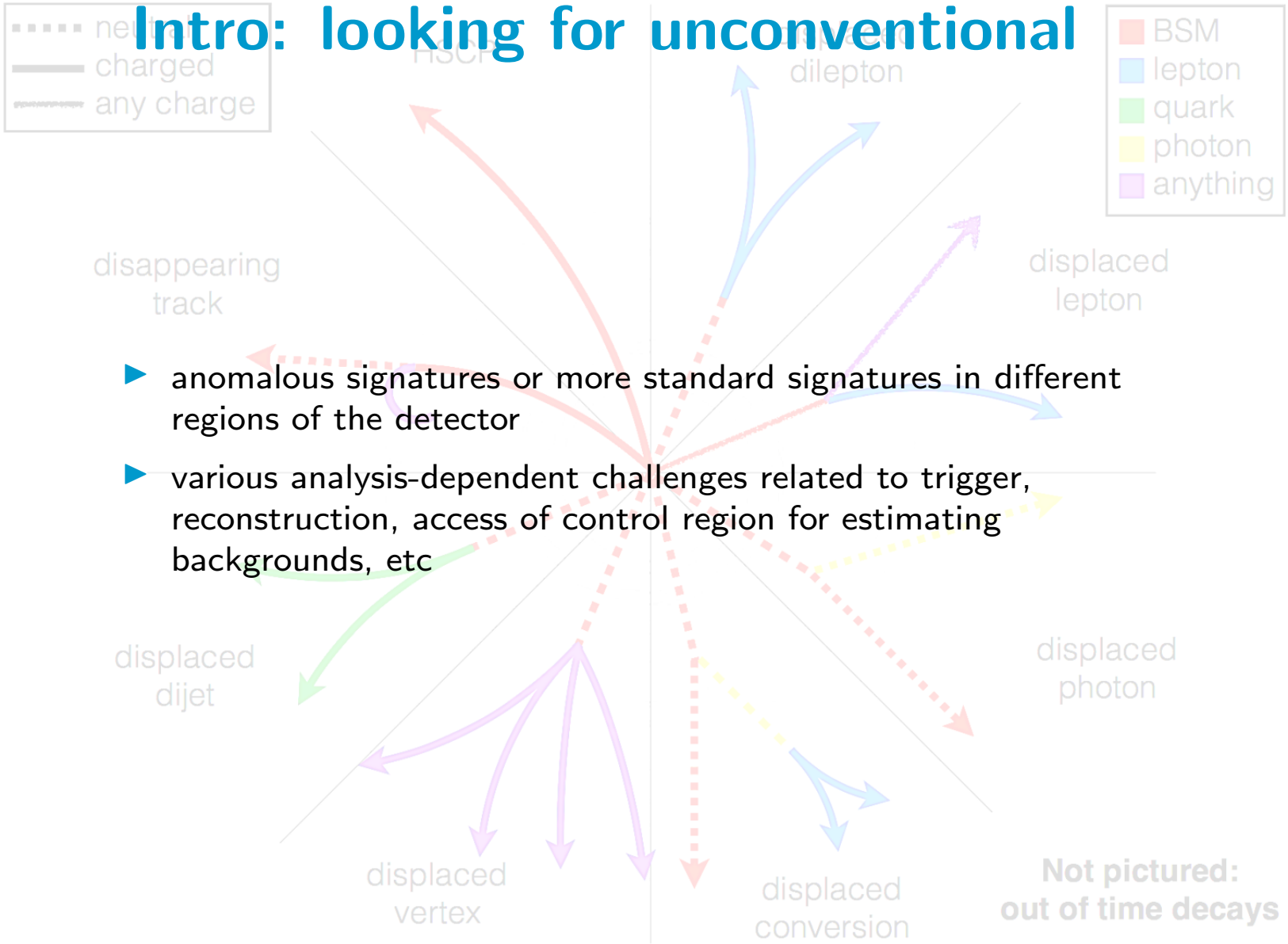
Intro: looking for unconventional



- anomalous signatures or more standard signatures in different regions of the detector
- various analysis-dependent challenges related to trigger, reconstruction, access of control region for estimating backgrounds, etc

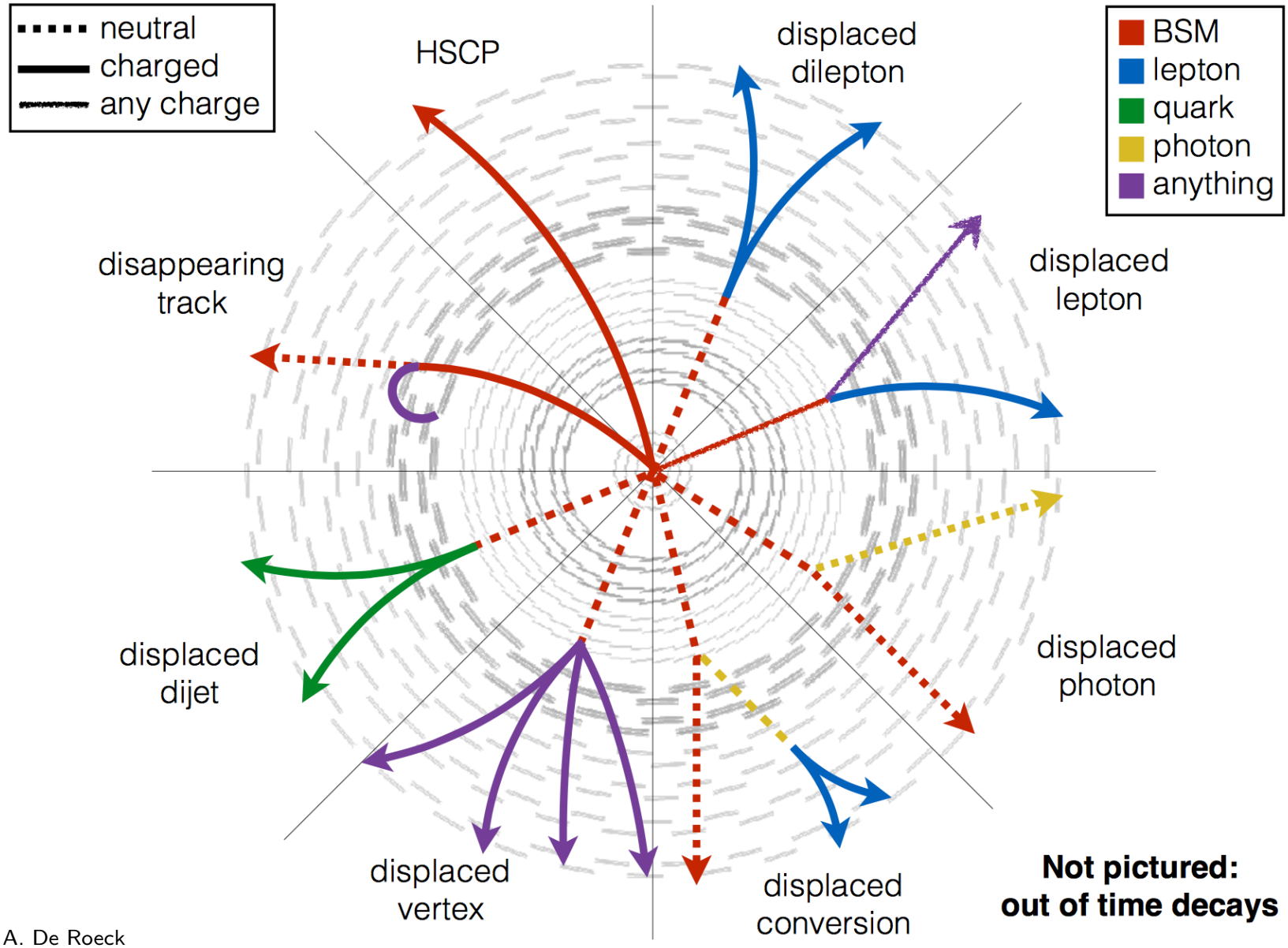


Image credit: A. De Roeck

Outline

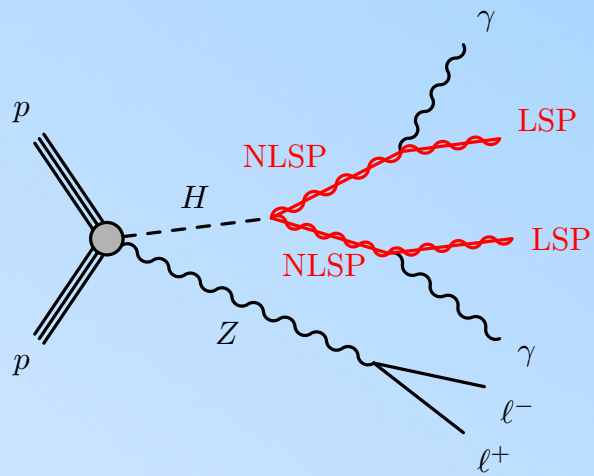
1. Displaced photons in exotic Higgs decays [arXiv:2209.01029]
2. Displaced Higgs or Z bosons into di-photon and di-electron [ATLAS-CONF-2022-051]
3. Neutral LLP into displaced hadronic jets in the calorimeter [JHEP 06 (2022) 005]
4. Neutral LLP into displaced hadronic jets in the MS [Phys. Rev. D 106, (2022) 032005]
5. Di-lepton displaced vertex in W-boson decays [arXiv:2204.11988]
6. Multi-charged LLP [ATLAS-CONF-2022-034]
7. Charged LLP with large ionisation energy loss [arXiv:2205.06013]
8. Displaced vertices with multiple jets [ATLAS-CONF-2022-054]

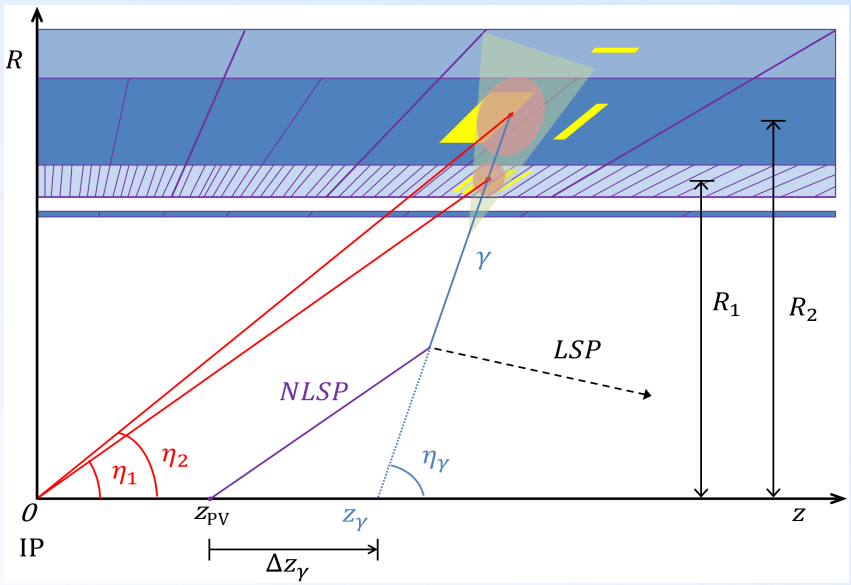
Displaced photons in exotic Higgs decays

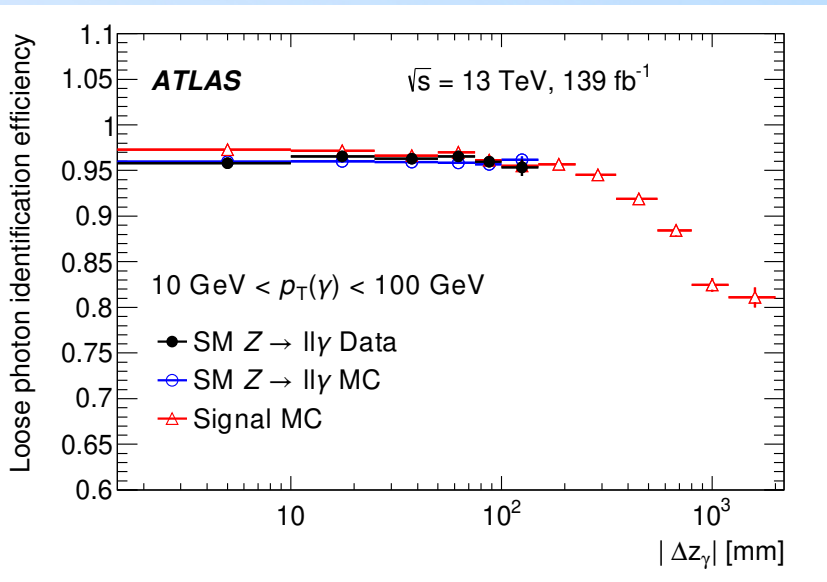
[arXiv:2209.01029]

Displaced photons in exotic Higgs decays

- LAr calorimeter for measuring the timing and trajectories of photons
- $Z \rightarrow ee$ events for measuring the time resolution with different gain readout scales
- loose photon-identification not imposing requirements on the EM shower shape

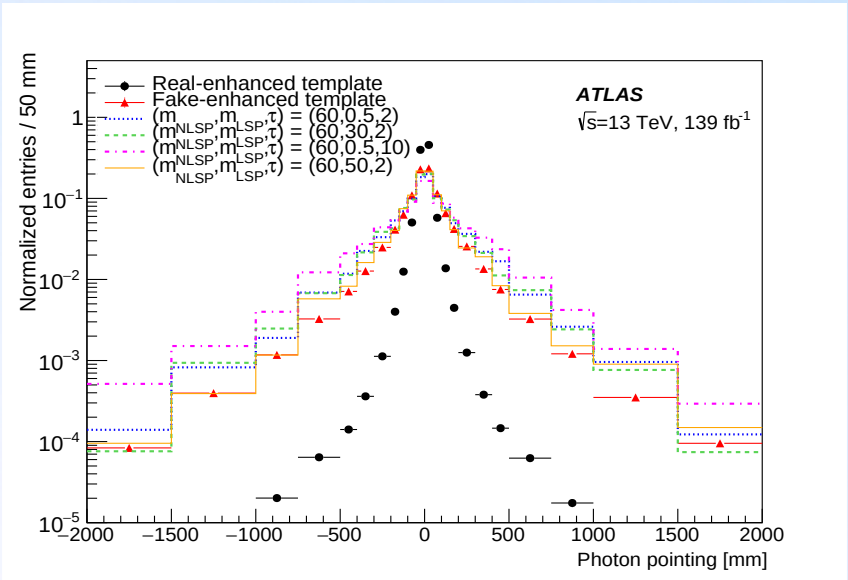


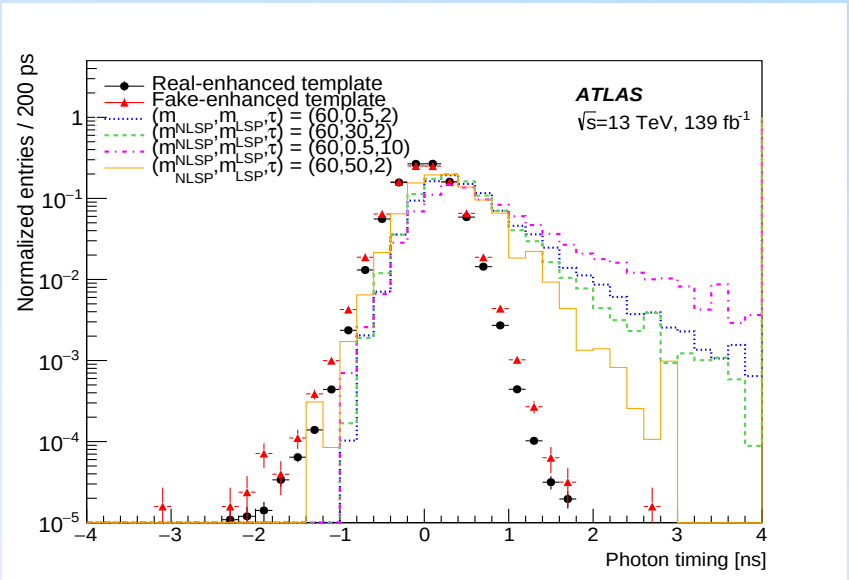




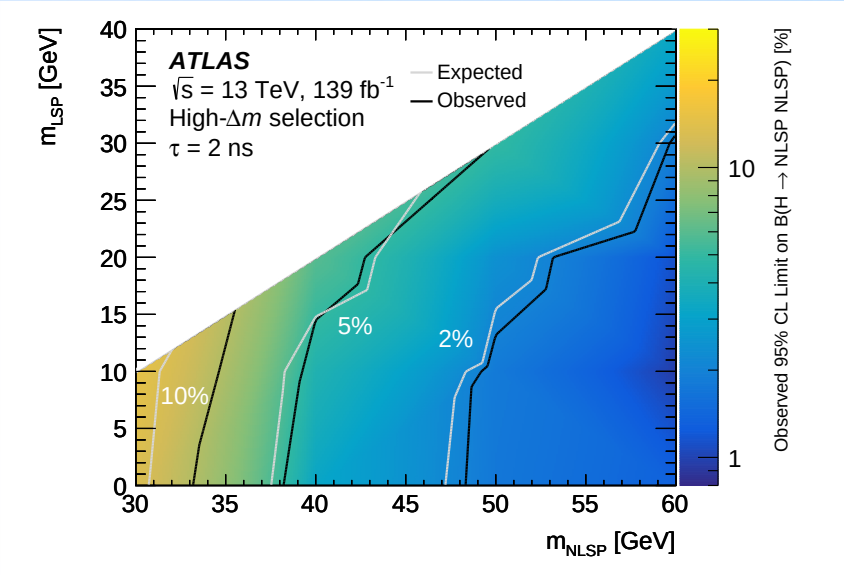
Displaced photons in exotic Higgs decays

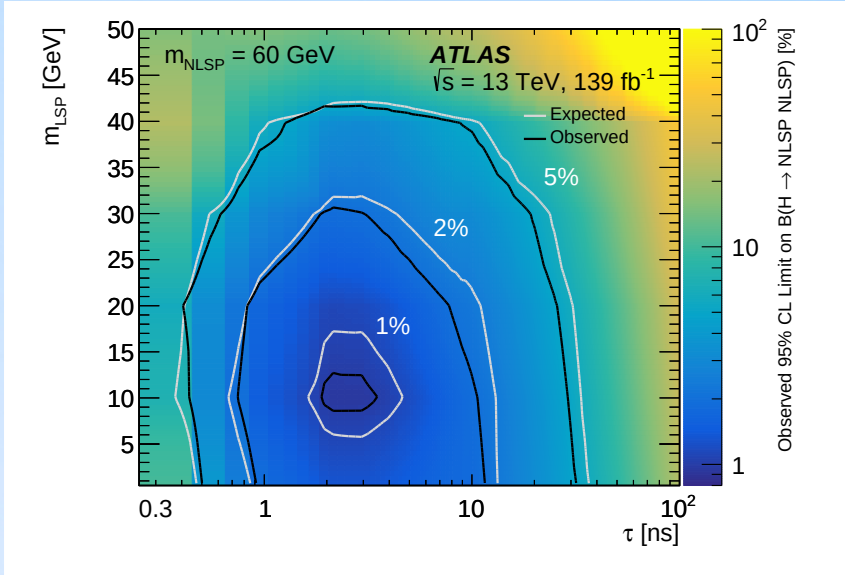
- data-driven background estimates using a low-E_T^{miss} CR
- two VRs with intermediate E_T^{miss} and by requiring $t_\gamma < 0$
- $|\Delta z_\gamma|$ to separate events into independent categories with unconstrained nuisance parameters in the fit model





Displaced photons in exotic Higgs decays





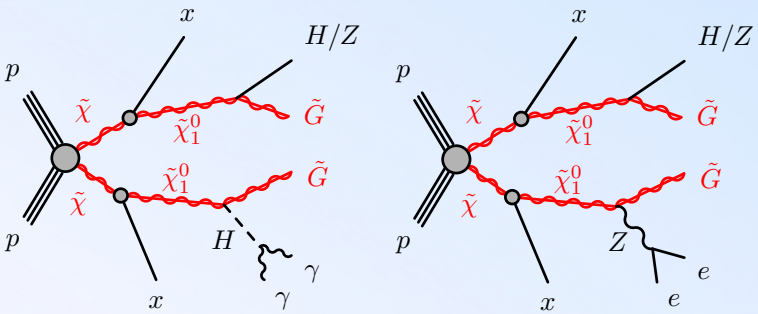
- set limits at 95% CL on LLP pair-production in exotic Higgs decays
- most stringent constraints on the BR are $\mathcal{O}(\%)$

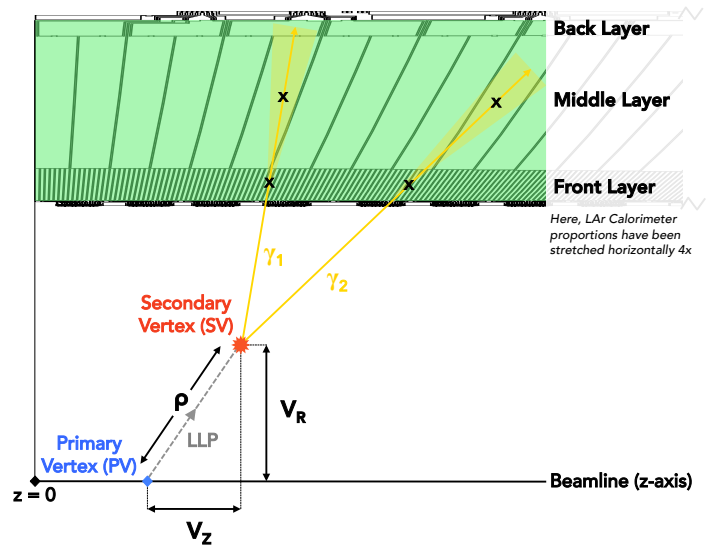
Displaced Higgs or Z bosons into di-photon and di-electron

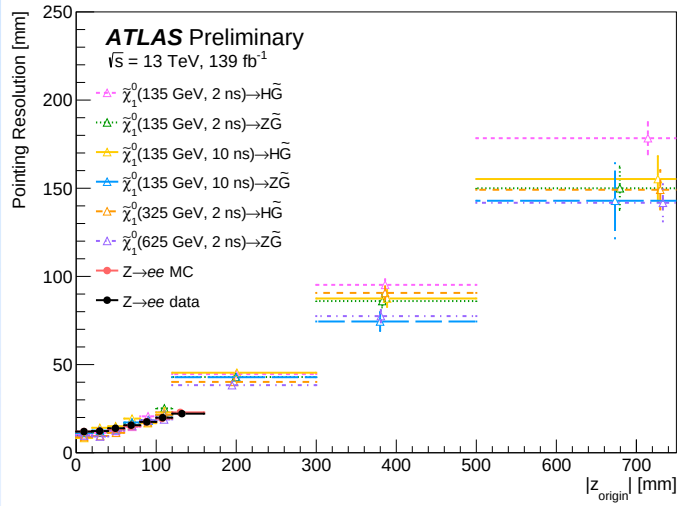
[ATLAS-CONF-2022-051]

Displaced di-photon and di-electron vertices

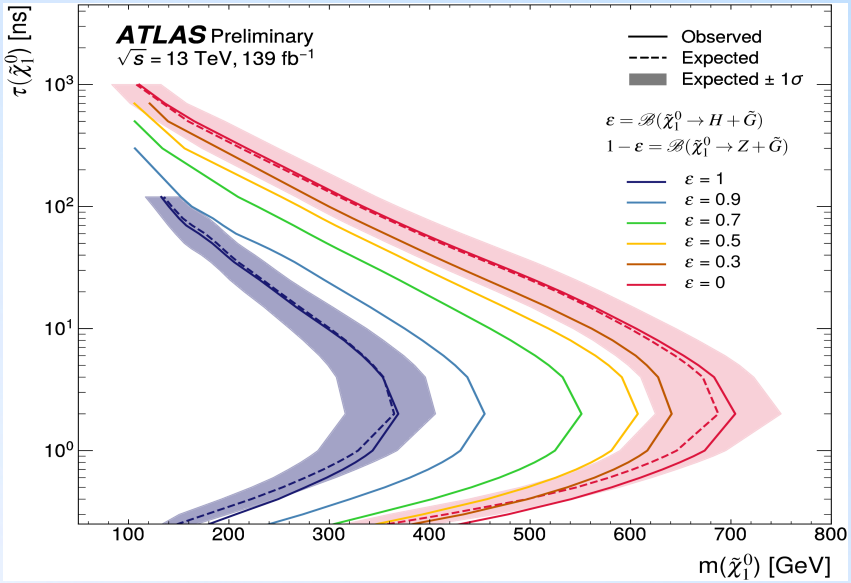
- displaced production of Higgs and Z bosons
- signature of pairs of photons and electrons arising from a common displaced vertex arriving with some delay in the LAr calorimeter
- pointing resolution validated against $Z \to ee$ events

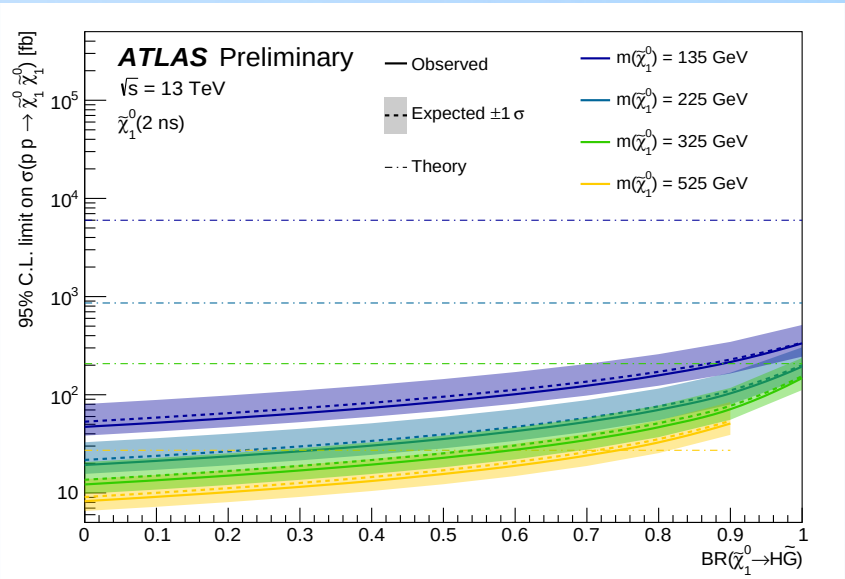






Results





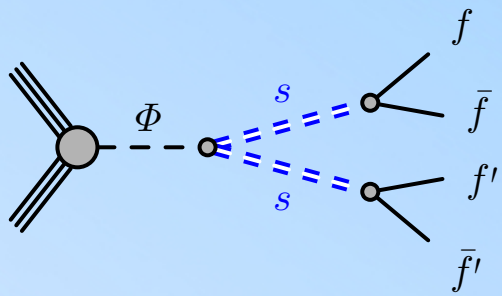
- set limits at 95% CL on the target signal hypothesis with different BR options
- and on cross section for LLP pair-production, with $100 < m < 705$ GeV and $0.25 < \tau < 1000$ ns

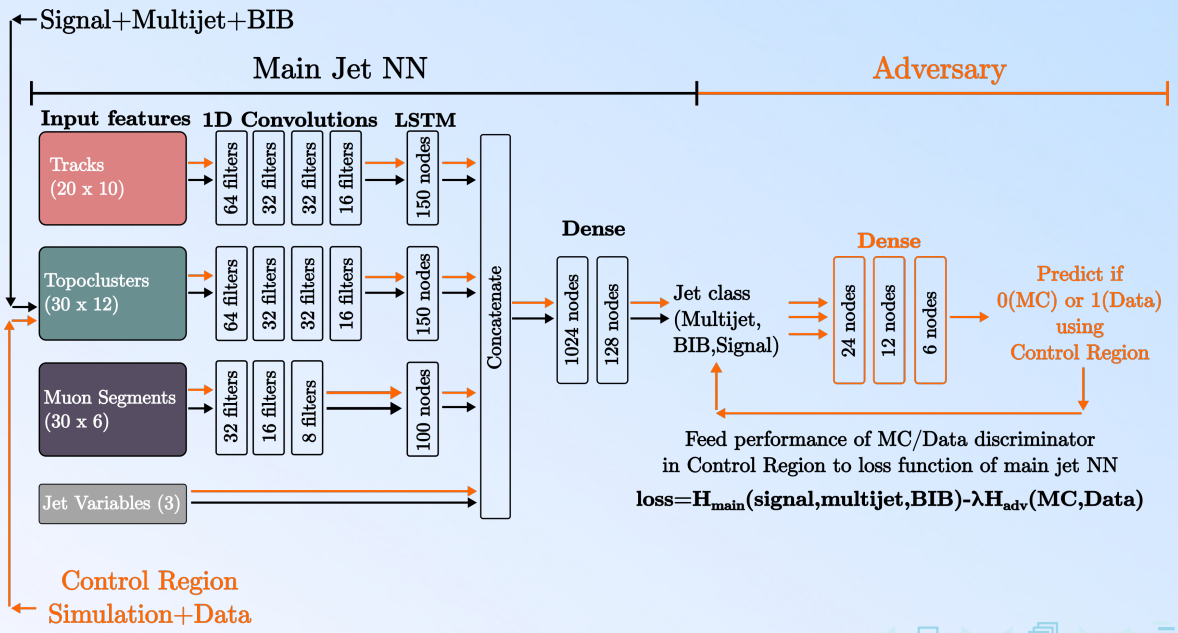
Neutral LLP into displaced hadronic jets in the calorimeter

[JHEP 06 (2022) 005]

Displaced hadronic jets in the calorimeter

- dedicated trigger looking for narrow jets with imbalanced energy deposits and track isolation
- two displaced hadronic jets to suppress the QCD multi-jet background
- displaced-jet tagger NN with adversarial technique for mis-modelled variables
- per-event BDT to discriminate BIB from signal events





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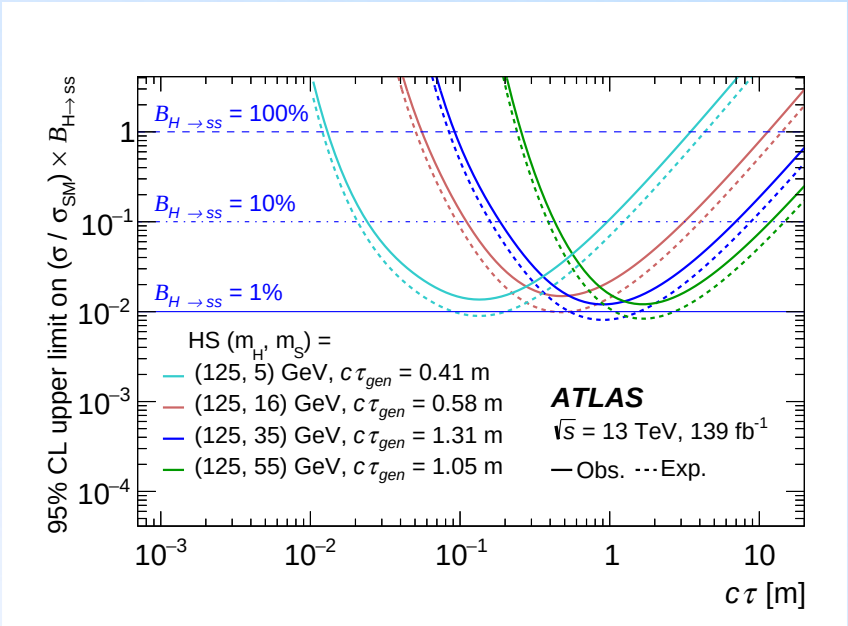
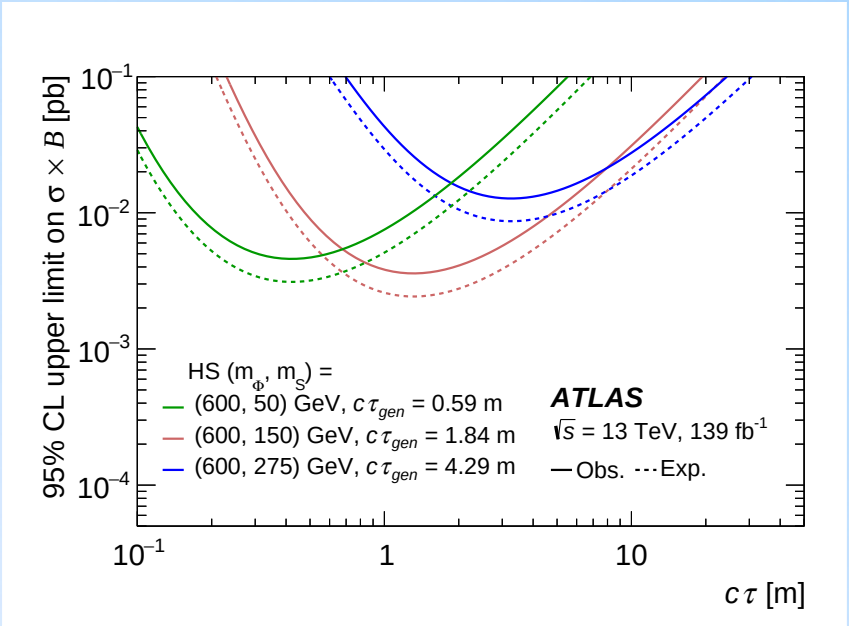


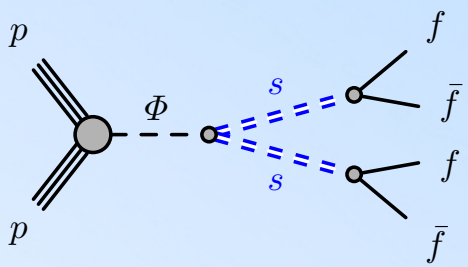


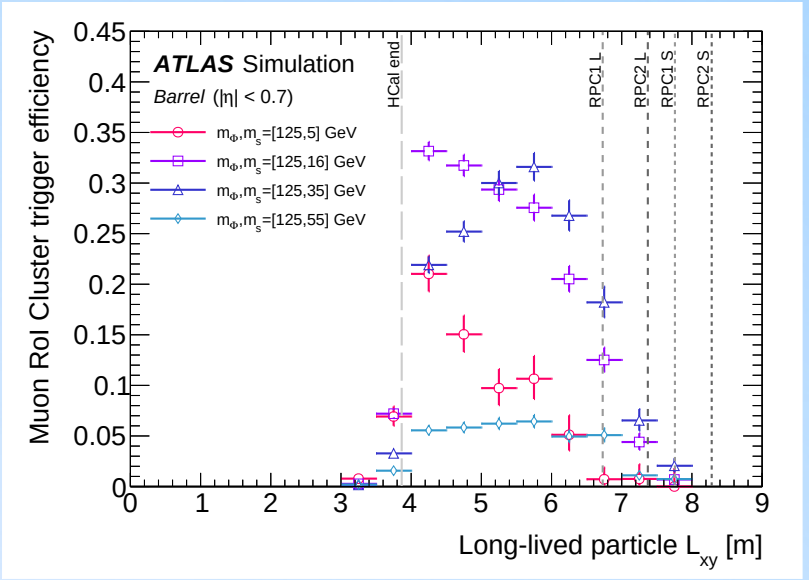
- set limits at 95% CL on the BR of SM Higgs bosons to pairs of neutral LLPs
- and on hidden sector models with $60 < m < 1000$ GeV

Neutral LLP into displaced hadronic jets in the MS

[Phys. Rev. D 106, (2022) 032005]

Displaced hadronic jets in the MS

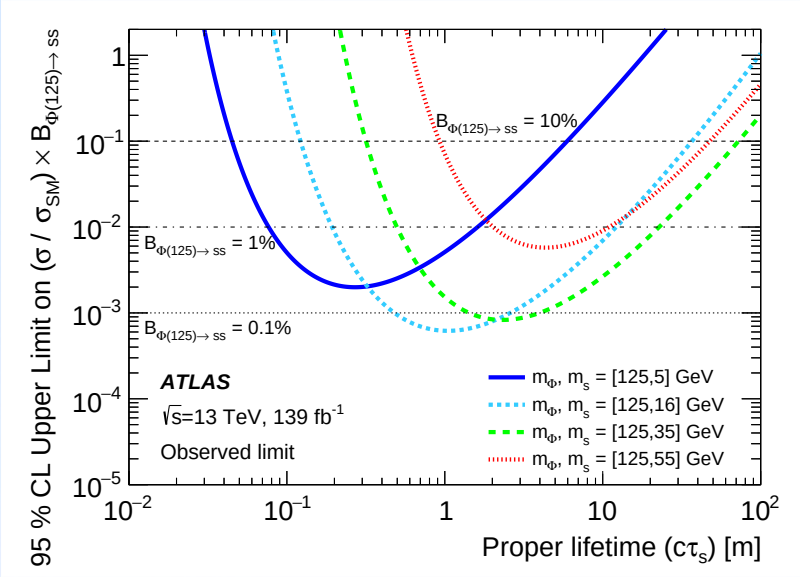


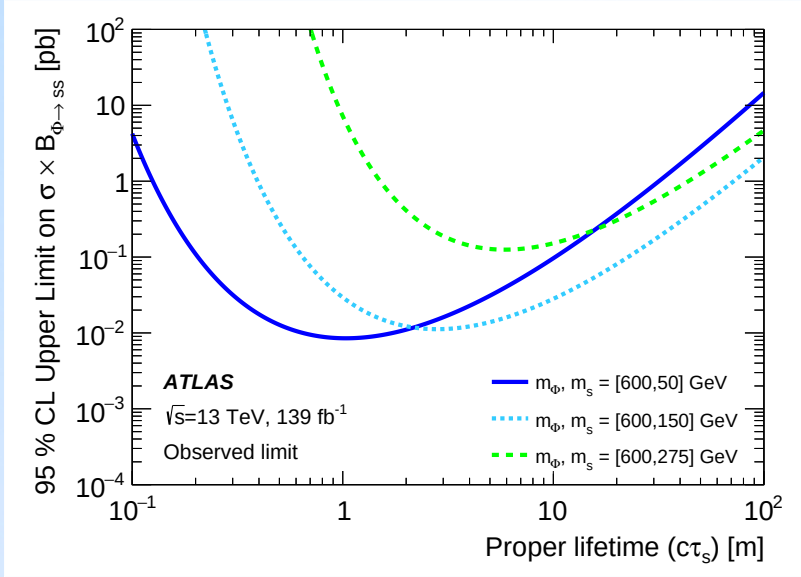


- neutral long-lived particles decaying to jets in the muon spectrometer
- dedicated trigger (JINST 8 (2013) P07015) and vertex reconstruction (JINST 9 (2014) P02001) techniques
- two displaced vertices per event to suppress the background, composed by punch-through jets, non-collision background and cosmic rays

Isolation requirements	Barrel	Endcaps
Isolation from high-p_T tracks ($p_T > 5$ GeV)	$\Delta R > 0.3$	$\Delta R > 0.6$
Isolation from low-p_T tracks ($\Sigma p_T(\Delta R < 0.2)$)	$\Sigma p_T < 10$ GeV	$\Sigma p_T < 10$ GeV
Isolation from jets	$\Delta R > 0.3$	$\Delta R > 0.6$

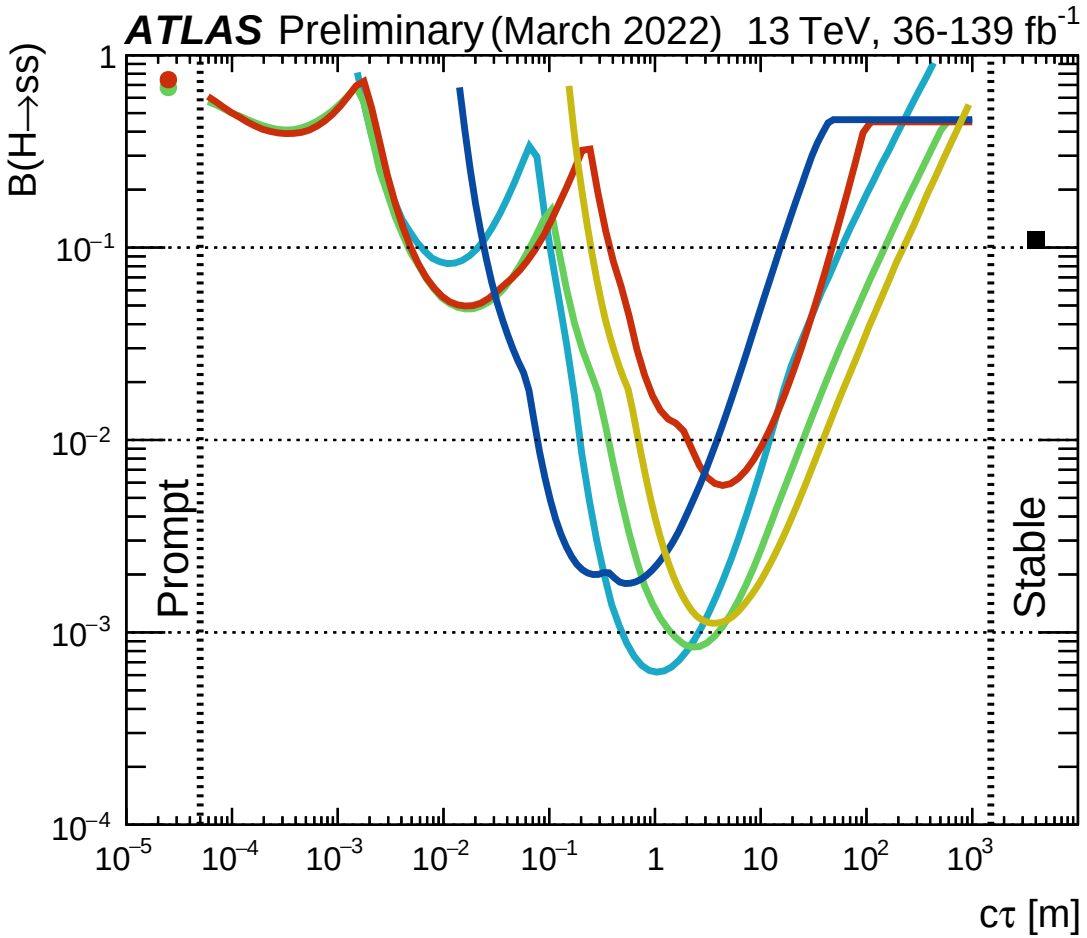
Results





- interpretation considering exotic Higgs decay and Hidden Abelian Higgs model
- toy MC to extrapolate number of signal events as a function of different proper lifetimes
- Higgs boson BR to neutral LLP excluded down to 0.1%

Results



Hidden Sector, m_H = 125 GeV
Selected **ATLAS** results
95% CL observed limits

Contributing searches:

- **Muon System (2 Vtx Only), 139 fb^{-1}**
  arXiv:2203.00587
- **Muon System (1 Vtx + 2 Vtx), 36 fb^{-1}**
  Phys. Rev. D 99 (2019) 052005
- **Calorimeter, 139 fb^{-1}**
  arXiv:2203.01009
- **Tracker+Muon System, 36 fb^{-1}**
  Phys. Rev. D 101 (2020) 052013
- **Tracker (LRT), 139 fb^{-1}**
  JHEP 11 (2021) 229
- ● **Tracker (b-tag), 36 fb^{-1}**
  JHEP 10 (2018) 031
- **Monojet, 139 fb^{-1}**
  ATL-PHYS-PUB-2021-020
- ■ **H→ inv, 7-8-13 TeV combination**
  ATLAS-CONF-2020-052

LLP masses:

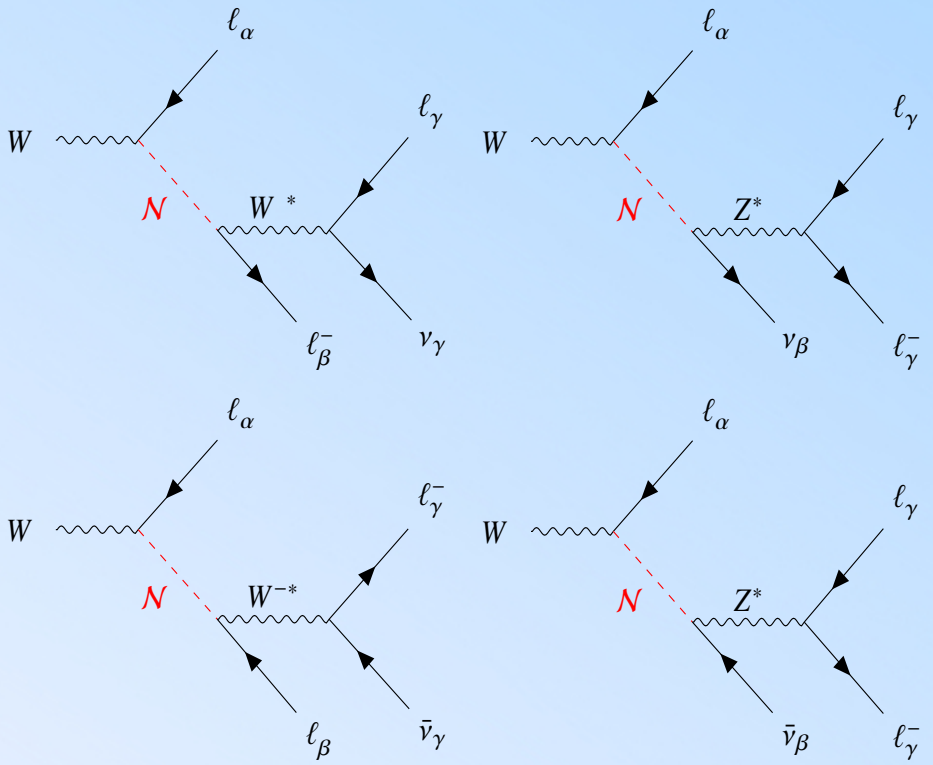
5-8 GeV | 15-20 GeV | 25-35 GeV
40 GeV | 45-60 GeV | Any

Di-lepton displaced vertex in W-boson decays

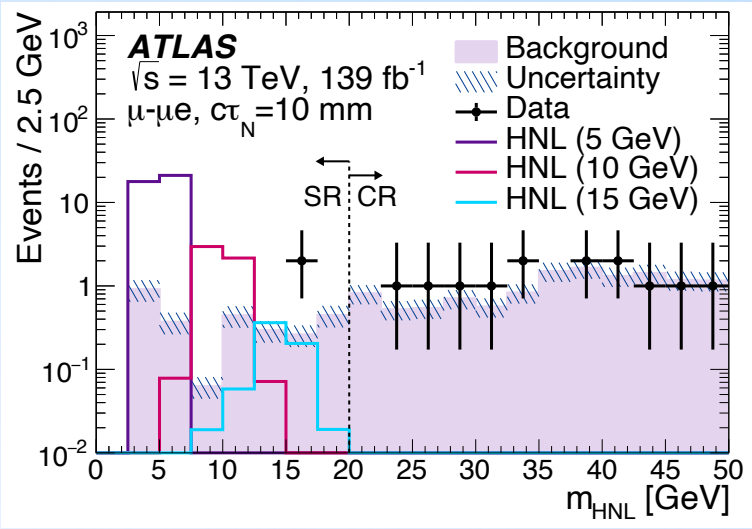
[arXiv:2204.11988]

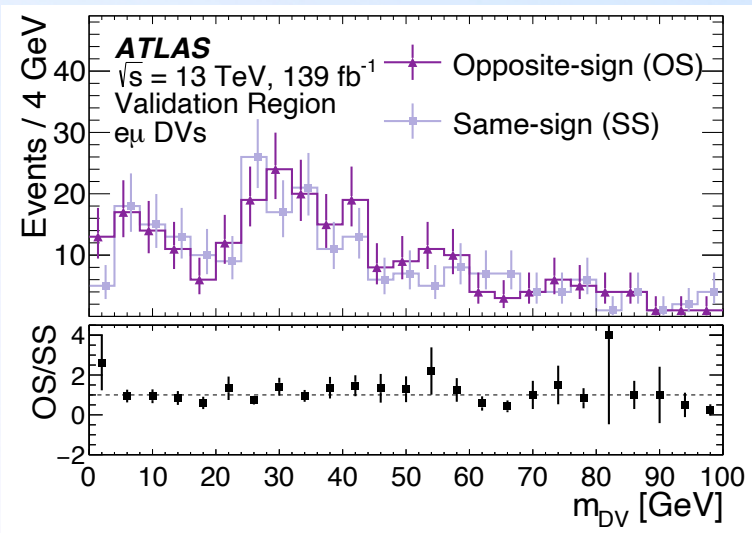
Di-lepton displaced vertex in W-boson decays

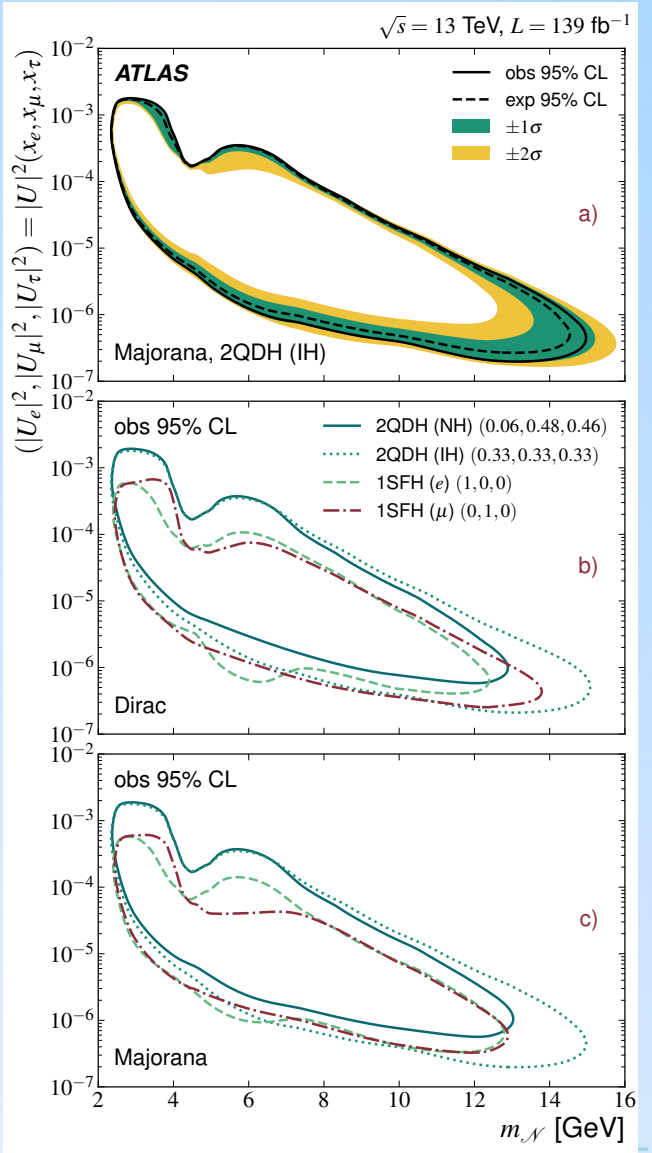
- heavy neutral lepton (HLN) $\mathcal{N}$ in W decays
- events triggered with standard isolated single-lepton triggers
- one displaced vertex per event, using second-pass tracking with relaxed cuts
- selected displaced vertices required to have two OS leptons and no additional tracks
- limits are set on the squared mixing parameters of the $\mathcal{N}$ with the left-handed neutrino and considering the two quasi-degenerate HNL model



Results


ATLAS
√s = 13 TeV, 139 fb-1
μ-μe, cτN=10 mm
Background
Uncertainty
Data
HNL (5 GeV)
HNL (10 GeV)
HNL (15 GeV)
SR
CR
Events / 2.5 GeV
mHNL [GeV]


ATLAS
√s = 13 TeV, 139 fb-1
Validation Region
eμ DVs
Opposite-sign (OS)
Same-sign (SS)
Events / 4 GeV
OS/SS
mDV [GeV]

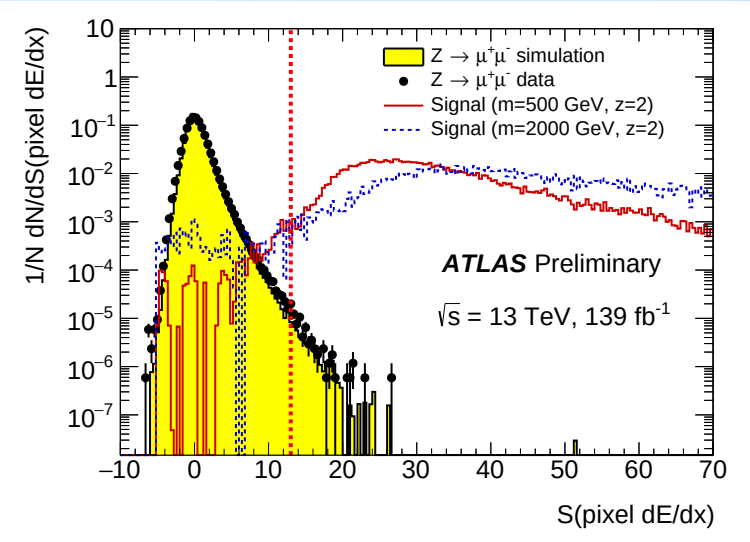

√s = 13 TeV, L = 139 fb−1
ATLAS
obs 95% CL
exp 95% CL
±1σ
±2σ
a)
Majorana, 2QDH (IH)
obs 95% CL
2QDH (NH) (0.06, 0.48, 0.46)
2QDH (IH) (0.33, 0.33, 0.33)
1SFH (e) (1, 0, 0)
1SFH (μ) (0, 1, 0)
b)
Dirac
obs 95% CL
c)
Majorana
mN [GeV]

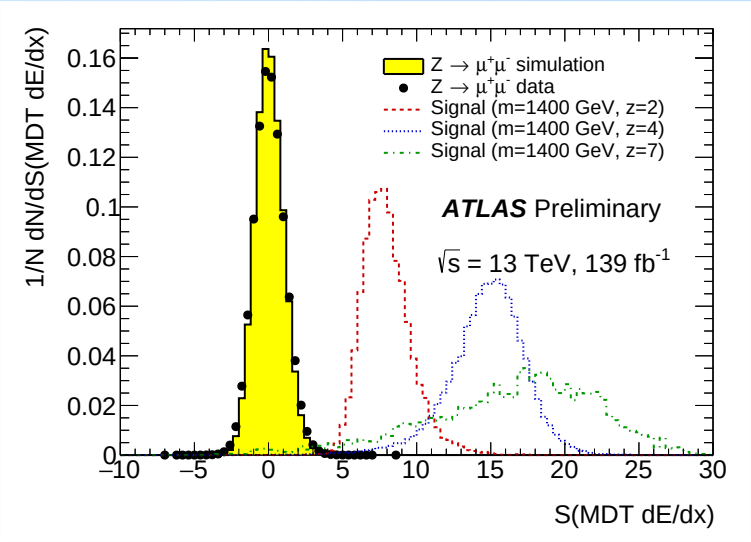
Multi-charged LLP

[ATLAS-CONF-2022-034]

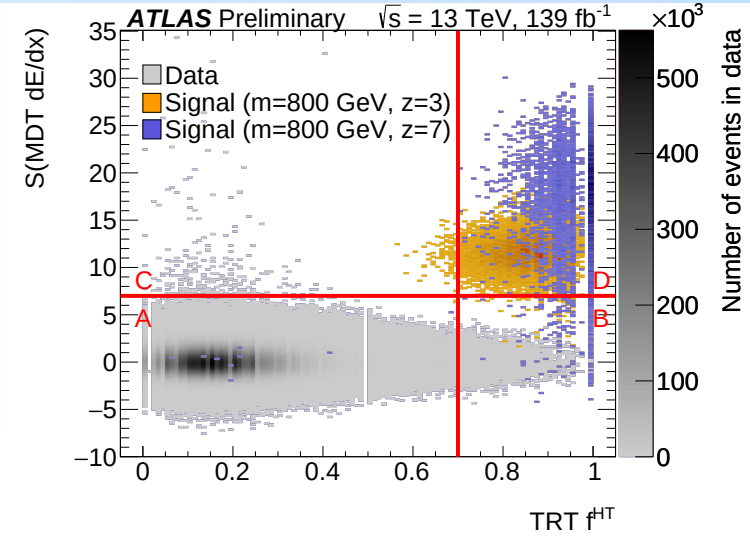
Stable multi-charged particles

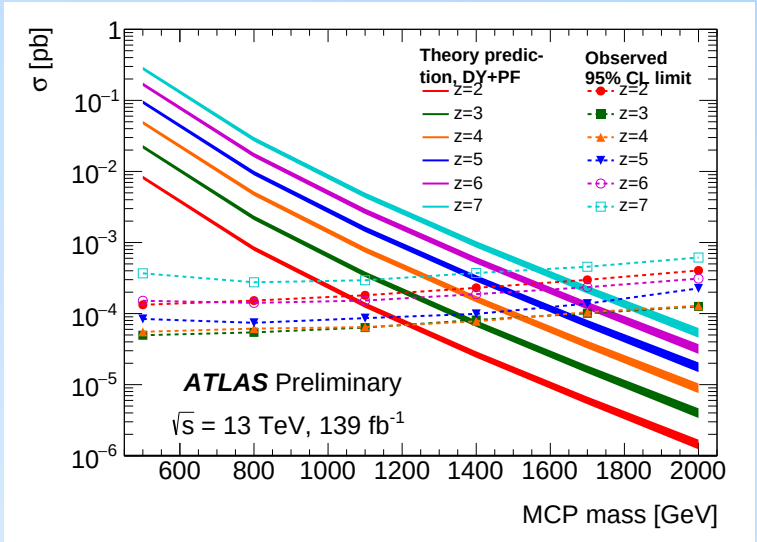
- muon and E_T^{miss} triggers plus a novel late-muon trigger combining information from two nearby bunch crossings
- looking at pixel TRT and MDT $S(dE/dx)$ plus the fraction of high-threshold TRT hits





Results





- heavy long-lived multi-charged particles with $0.5 < m < 2$ TeV and $|q| = ze$ with $2 \geq z \geq 7$ traversing the entire detector
- different selections for $z = 2$ and > 2 with ABCD background estimation
- limits at 95% CL on the lower mass for a Drell-Yann and photon-fusion production modes

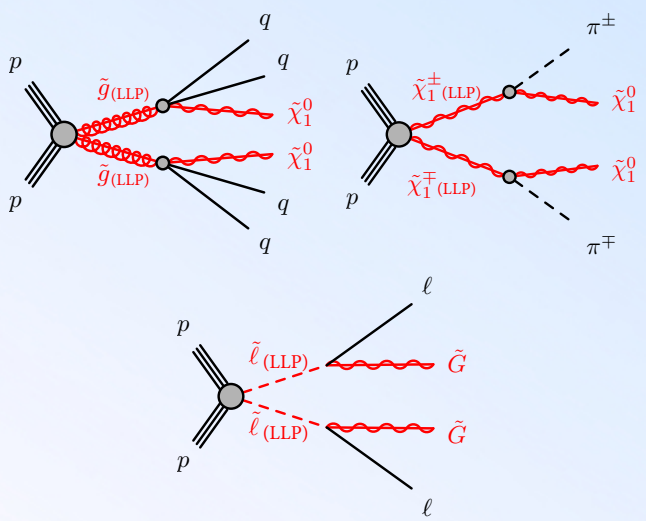
Charged LLP with large ionisation energy loss

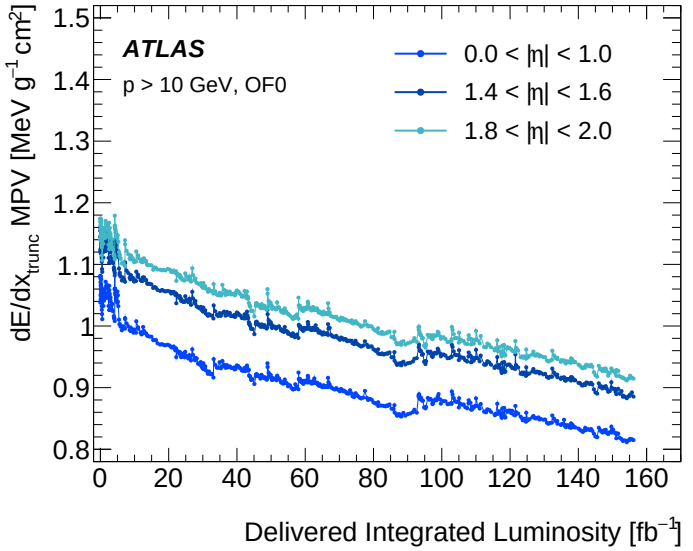
[arXiv:2205.06013]

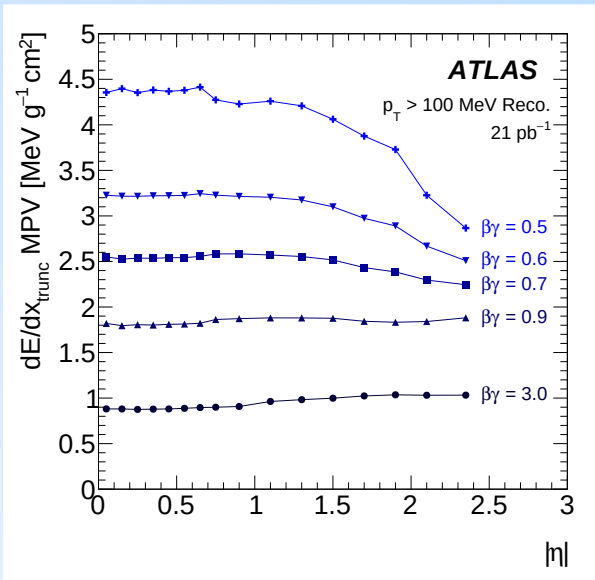
Charged LLP with dE/dx

Looking at large ionisation energy loss of charged particles in the pixel detectors

- measurement starts from the time-over-threshold of the pixel sensors
- only looking at the pixel detector to be sensitive to short lifetimes
- dE/dx calibration also taking into account detector aging effects

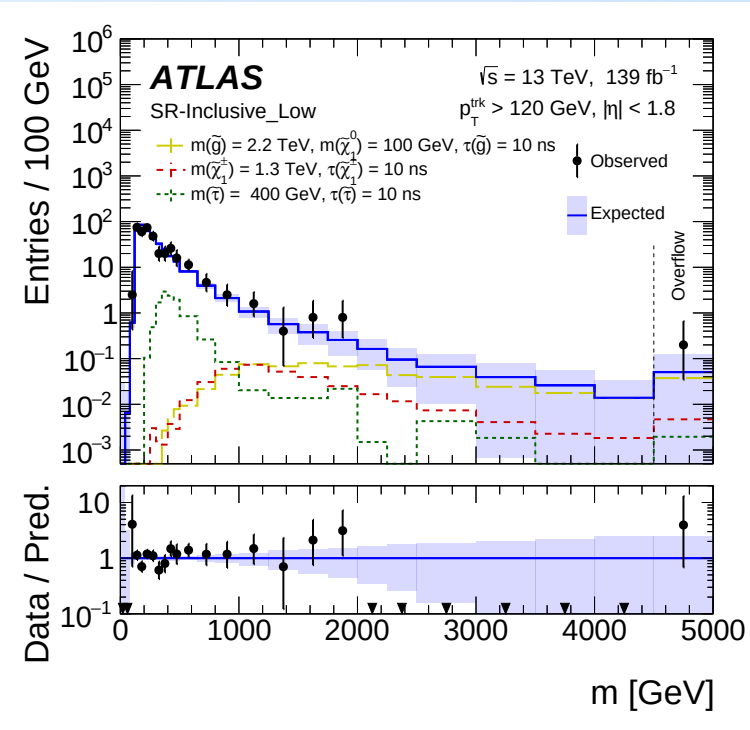


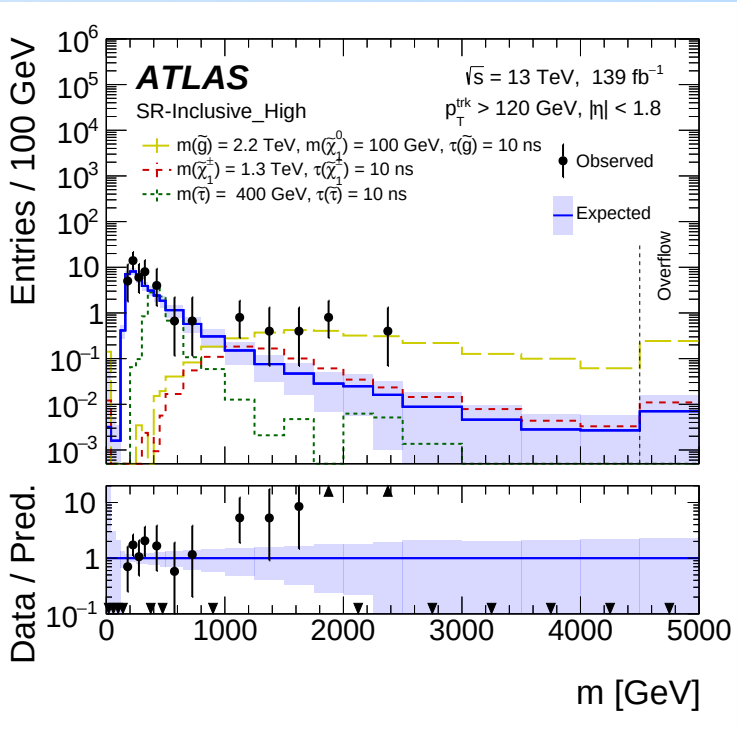




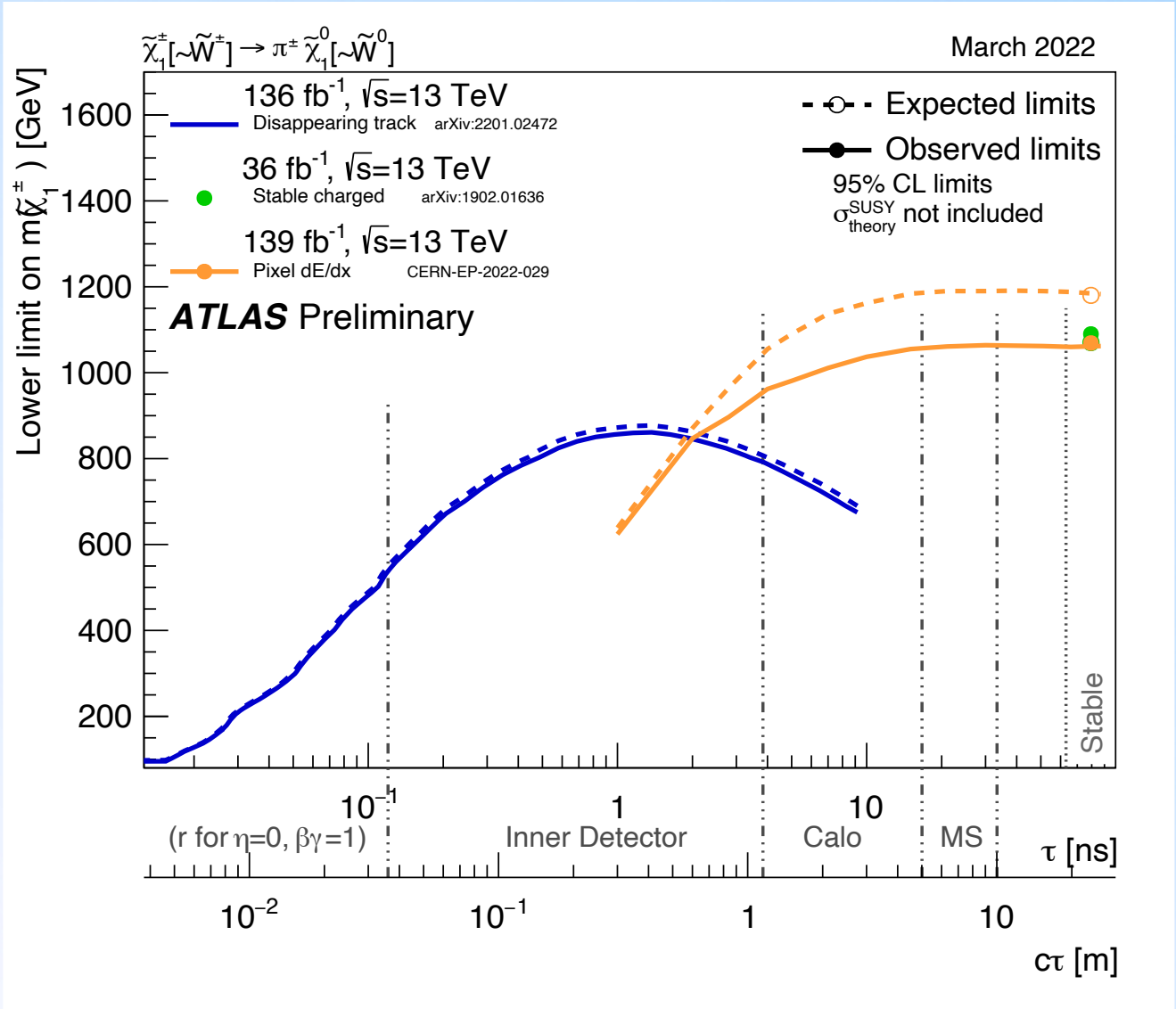
Charged LLP with dE/dx

- E_T^{miss} trigger
- background from SM processes and random overlapping tracks
- 3.6σ local (3.3σ global) excess not confirmed when looking at timing measurement from other detectors





Results

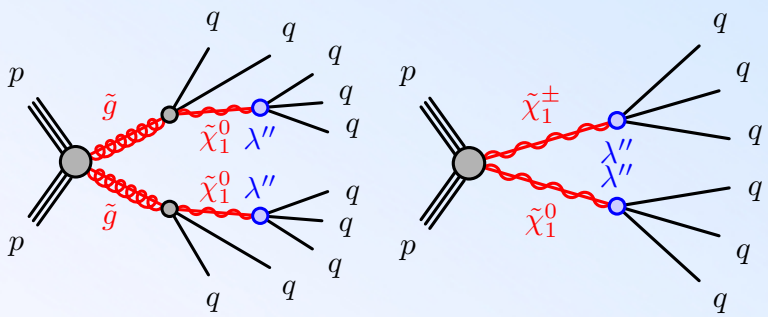

$\tilde{\chi}_1^{\pm}[\sim\tilde{W}^{\pm}] \rightarrow \pi^{\pm}\,\tilde{\chi}_1^0[\sim\tilde{W}^0]$
March 2022
136 fb^{-1}, $\sqrt{s}$=13 TeV
Disappearing track arXiv:2201.02472
36 fb^{-1}, $\sqrt{s}$=13 TeV
Stable charged arXiv:1902.01636
139 fb^{-1}, $\sqrt{s}$=13 TeV
Pixel dE/dx CERN-EP-2022-029
Expected limits
Observed limits
95% CL limits
σ^{SUSY}_{theory} not included
ATLAS Preliminary
Lower limit on $m(\tilde{\chi}_1^{\pm})$ [GeV]
1600
1400
1200
1000
800
600
400
200
Stable
10^{-1}
1
10
(r for η=0, $\beta\gamma$=1)
Inner Detector
Calo
MS
τ [ns]
10^{-2}
10^{-1}
1
10
$c\tau$ [m]

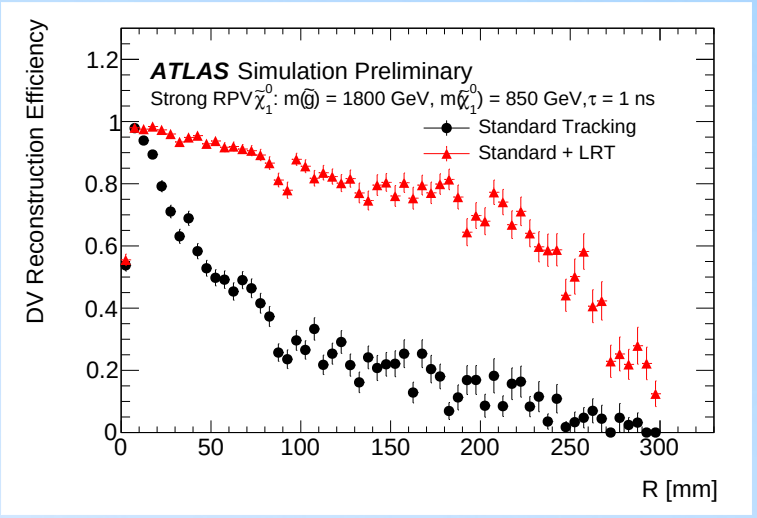
Displaced vertices with multiple jets

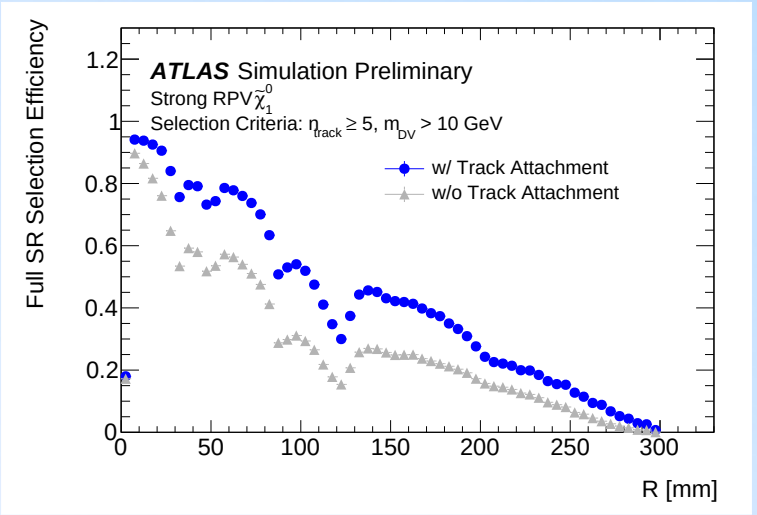
[ATLAS-CONF-2022-054]

Displaced vertices in multi-jets

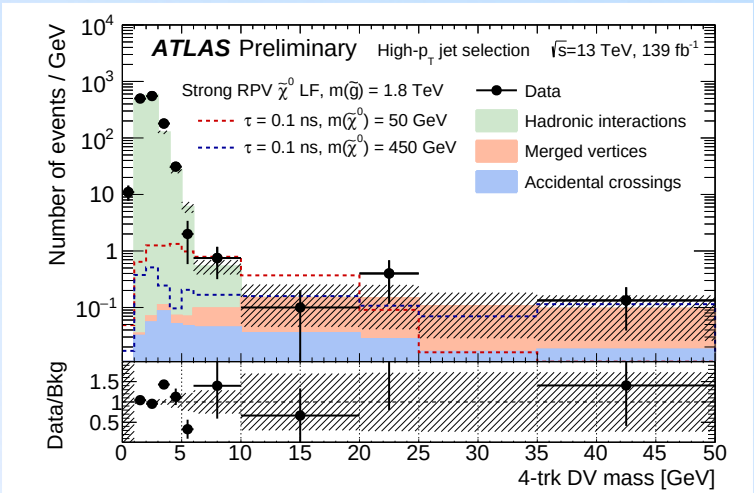
- displaced vertex signature using tracks in events with multi-jets
- optimised second-pass tracking using left-over hits with looser requirements on the impact parameters
- dedicated SV reconstruction with selected tracks for forming seeds and attached tracks compatible with SV seed and looser hit requirements

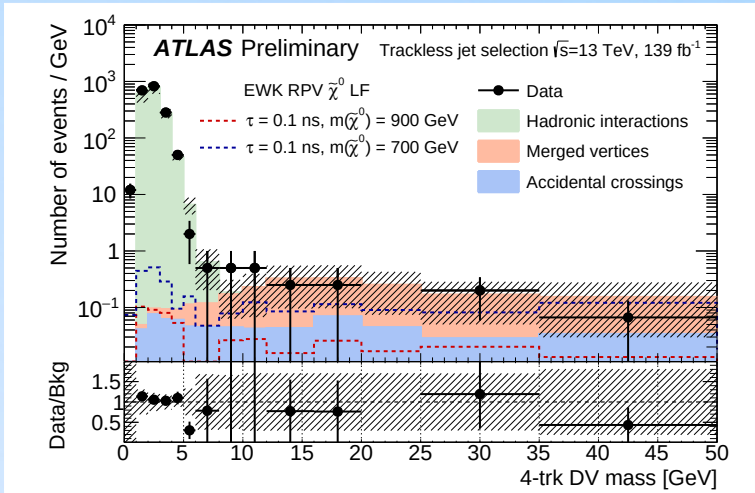


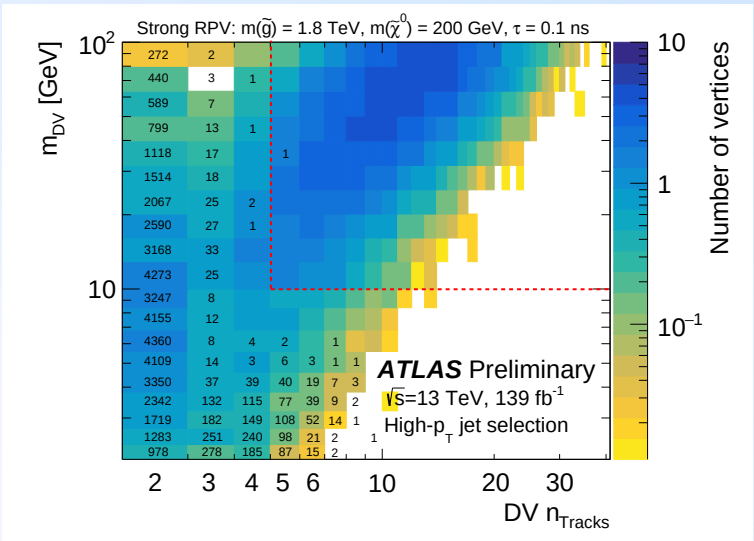


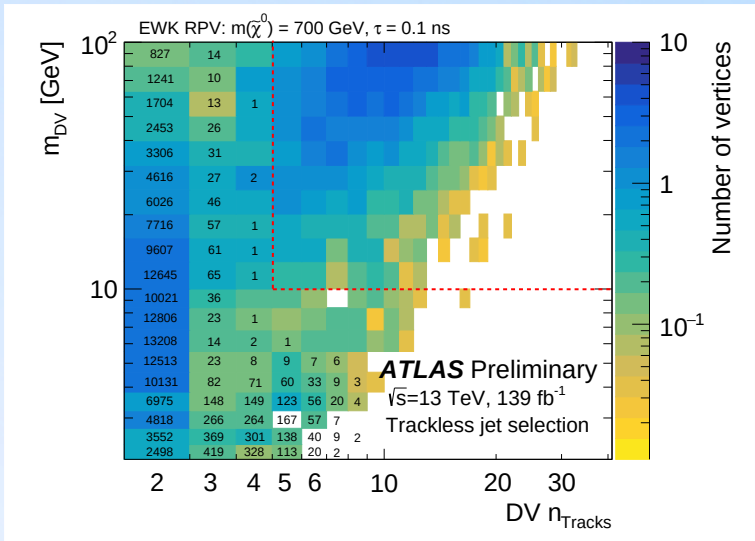


Displaced vertices in multi-jets

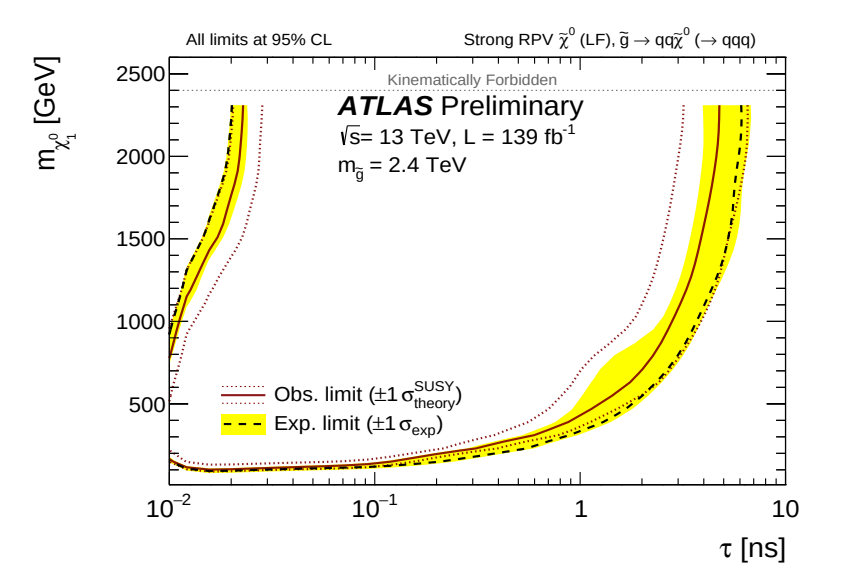


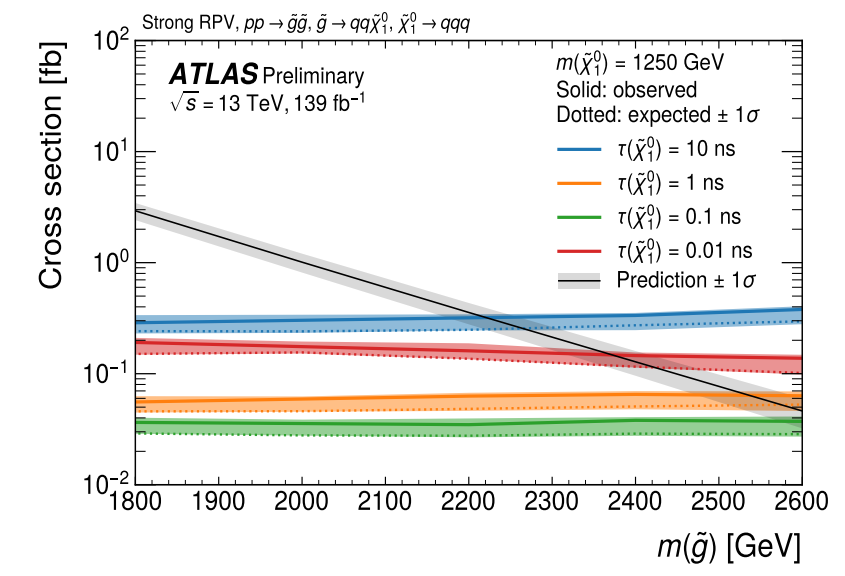






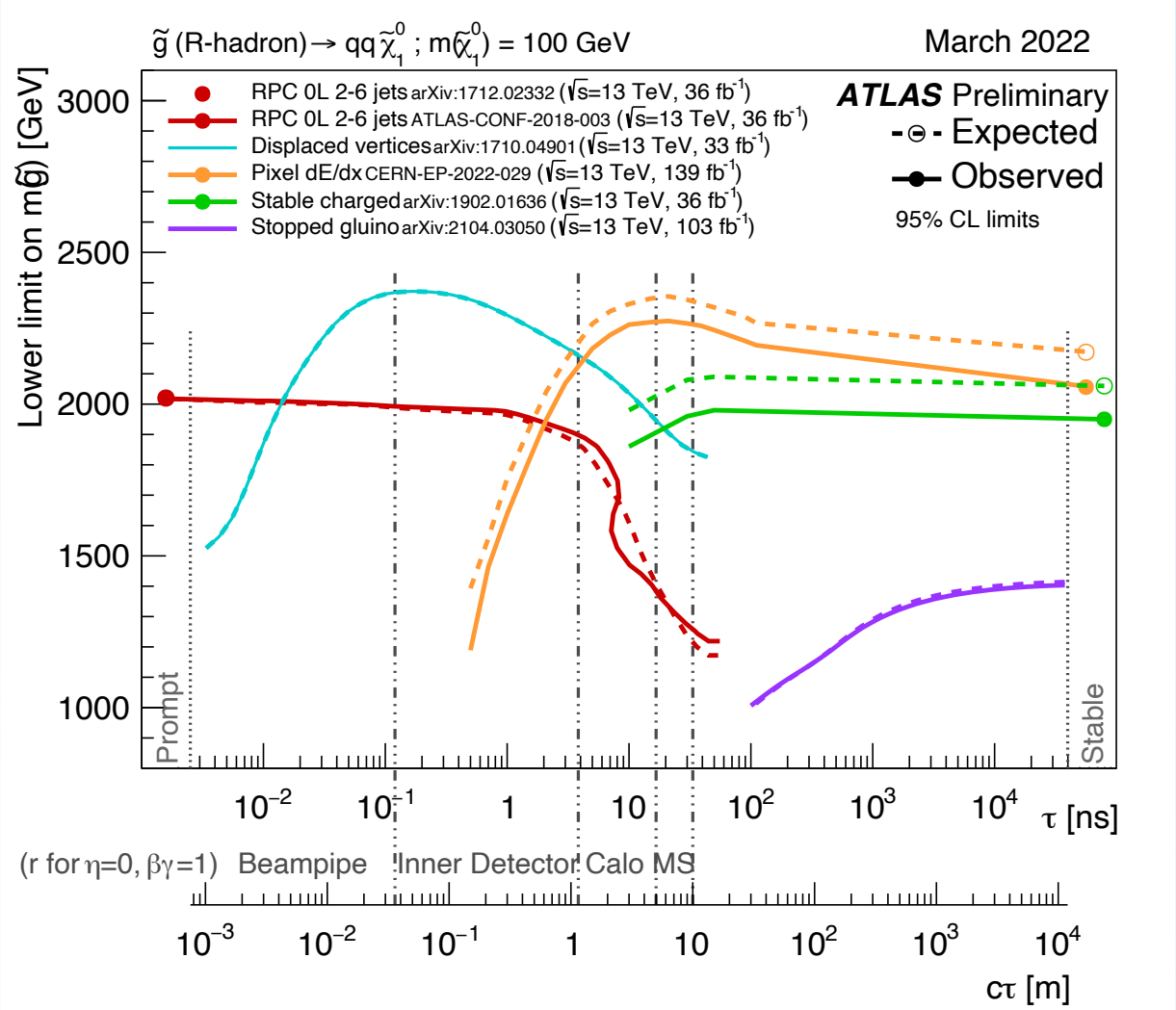
Results





- limits at 95% CL on model-independent BSM cross sections and on RPV long-lived model
- electroweakino masses below 1.5 TeV are excluded for $0.03 < \tau < 1$ ns

Results


g̃ (R-hadron) → qq χ̃₁⁰ ; m(χ̃₁⁰) = 100 GeV
March 2022
RPC 0L 2-6 jets arXiv:1712.02332 (√s=13 TeV, 36 fb⁻¹)
RPC 0L 2-6 jets ATLAS-CONF-2018-003 (√s=13 TeV, 36 fb⁻¹)
Displaced vertices arXiv:1710.04901 (√s=13 TeV, 33 fb⁻¹)
Pixel dE/dx CERN-EP-2022-029 (√s=13 TeV, 139 fb⁻¹)
Stable charged arXiv:1902.01636 (√s=13 TeV, 36 fb⁻¹)
Stopped gluino arXiv:2104.03050 (√s=13 TeV, 103 fb⁻¹)
ATLAS Preliminary
Expected
Observed
95% CL limits
Lower limit on mg̃ [GeV]
3000
2500
2000
1500
1000
Prompt
Stable
10⁻²
10⁻¹
1
10
10²
10³
10⁴
τ [ns]
(r for η=0, βγ=1)
Beampipe
Inner Detector
Calo
MS
10⁻³
10⁻²
10⁻¹
1
10
10²
10³
10⁴
cτ [m]

Conclusions

Wide experimental program targeting unconventional signatures

- number of considered signatures is growing over time
- challenging experimental techniques when triggering and reconstructing the events
- sensitive to subtle detector effects or non standard backgrounds
- looking at the entire Run-2 dataset

More Run-2 results in the pipeline and Run 3 data-taking in full swing

THANK YOU FOR YOUR ATTENTION !

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