Long-lived particle results in ATLAS and CMS

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on behalf of the ATLAS and CMS collaborations

24 March 2023
57th Rencontres de Moriond
Electroweak interactions and unified theories

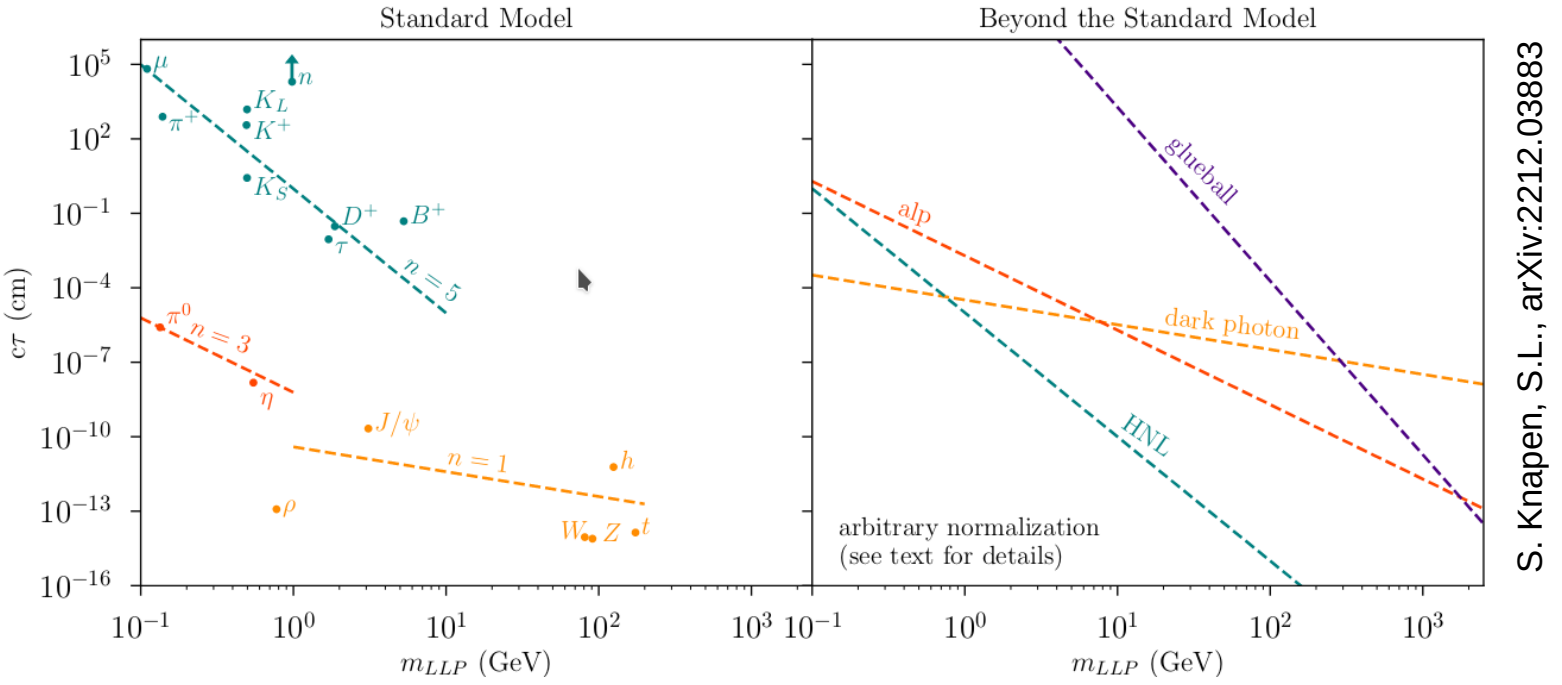
Why long-lived particles?

small coupling

suppressed phase space

$$\Gamma \sim \frac{\epsilon^2}{(8\pi)^{a-1}} \frac{m^n}{M^{n-1}}$$

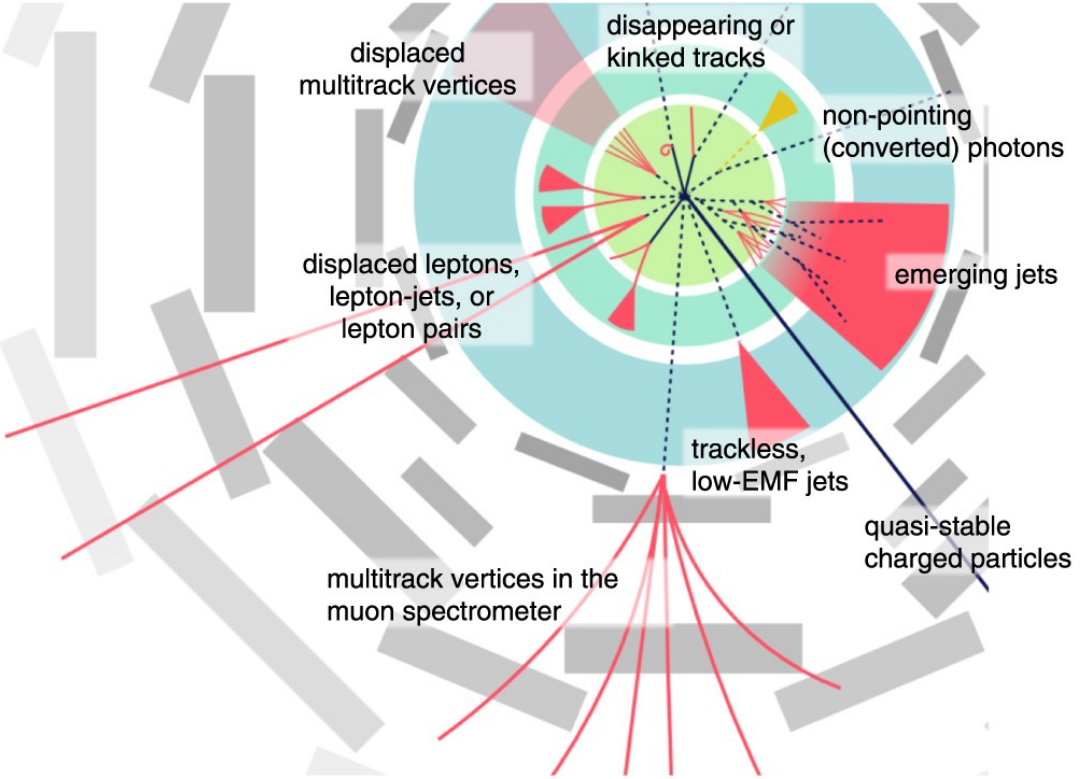
heavy off-shell mediator



S. Knapen, S.L., arXiv:2212.03883

Why long-lived particles?

- experimentally interesting
  - may need dedicated triggers
  - may require special reconstruction algorithms
  - unusual backgrounds
  - simulation can be challenging



Heather Russell; 1903.04497

- exciting times!
  - a rich set of searches have been performed using LHC Run-2 data
  - still new incoming LHC Run-2 results
  - Run-3 has started!

- a discovery may already be waiting in our data

Recent ATLAS and CMS LLP results

ATLAS

- NEW Mar '23: pairs of muons with small displacements [ATLAS-CONF-2023-018]
- Jul '22: massive LLPs in events with displaced vertices and multiple jets [2301.13866]
- Jul '22: diphotons and dielectrons from displaced H or Z bosons [ATLAS-CONF-2022-051]
- May '22: heavy long-lived multi-charged particles [CERN-EP-2023-017]
- Mar '22: displaced photons from exotic Higgs decays [2209.01029]
- Mar '22: charged LLPs in final states with high pixel ionization loss [2205.06013]
- Mar '22: displaced heavy neutral leptons [2204.11988]
- Jan '22: displaced Lepton Jet Search (ggF+WH) [2206.12181]

CMS

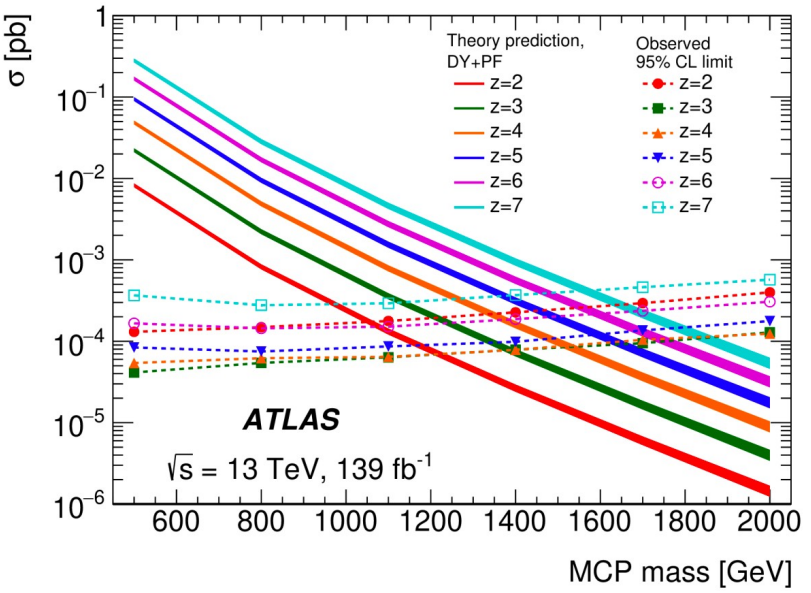
- NEW Mar '23: long-lived HNLs decaying to a displaced jet and e, mu or tau [CMS-PAS-EXO-21-013]
- NEW Mar '23: inelastic dark matter [CMS-PAS-EXO-20-010]
- Oct '22: LLPs using out-of-time trackless jets [2212.06695]
- Jul '22: fractionally charged particles [CMS-PAS-EXO-19-006]
- Jan '22: LLPs decaying to a pair of muons [2205.08582]

Anomalous charges: updates

CERN-EP-2023-017

- ATLAS: heavy long-lived multi-charged particles
  - DY and γγ t-channel production
  - muon-like, but high charge and mass

    high ionization ~ Q^2, slow and slowing down
  - trigger: single muon, "late" muon, or E_T^{miss}
  - use dE/dx in pixels, TRT, and MDT detectors



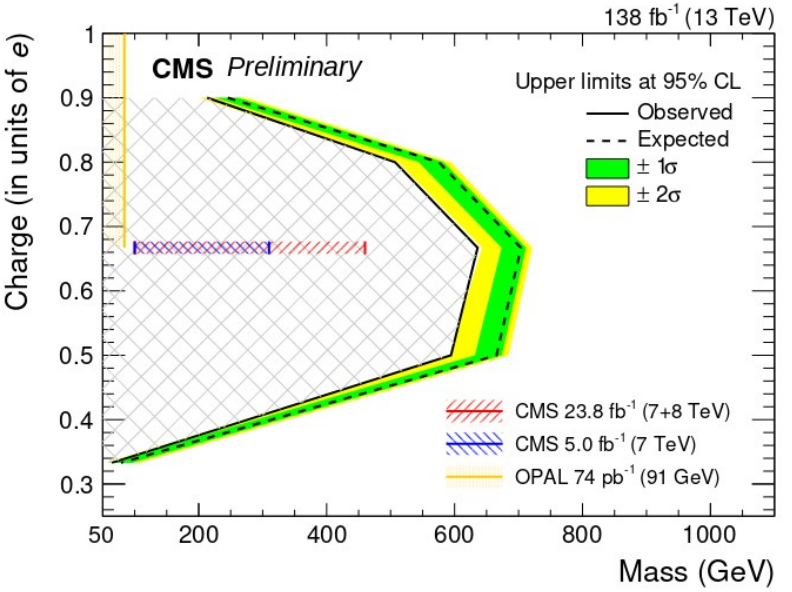
CMS-PAS-EXO-19-006

- CMS: fractionally charged particles
  - search for tracks with large number of low-ionization tracker hits
  - Summer 2022: charge down to Q = e/2
  - now additional extension at Q = e/3

    [50,65] GeV excluded at 95%CL
  - new look into muon simulation revealed previously unaccounted inefficiency

    previous results at Q = e/3 superseded

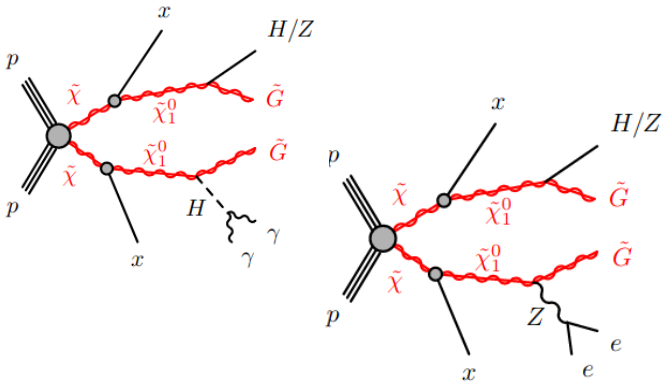
NEW

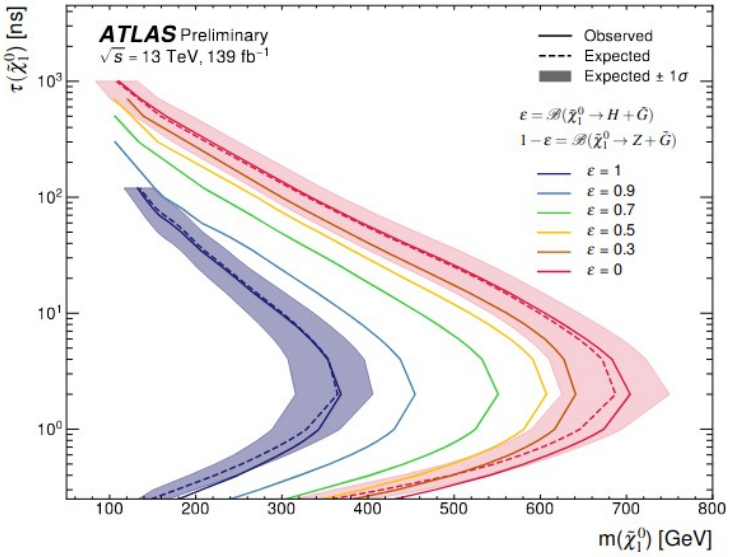


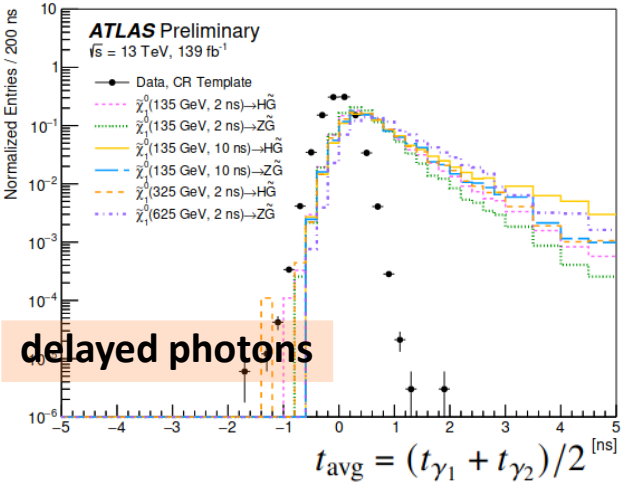
yy/ee from displaced H/Z

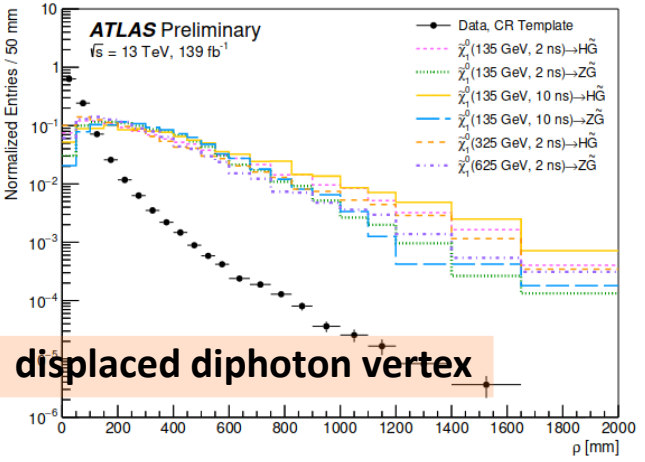
ATLAS-CONF-2022-051

- heavy particles yielding displaced H→yy or Z→ee
  - benchmark model with GMSB long-lived neutralino
- LAr calorimeter provides precise timing and direction
  - key observables: photon t_{avg} and position vertex ϱ
  - other selections on m(yy), Δϕ(yy), E_T^{miss}
- nearly background-free for t_{avg} above 0.9 ns
  - data matches background estimated in low-E_T^{miss} CR
- signal extracted from fit on t_{avg} and ϱ



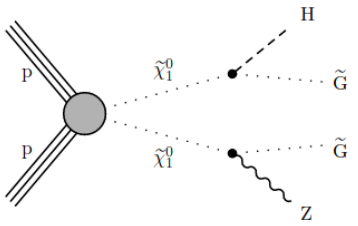




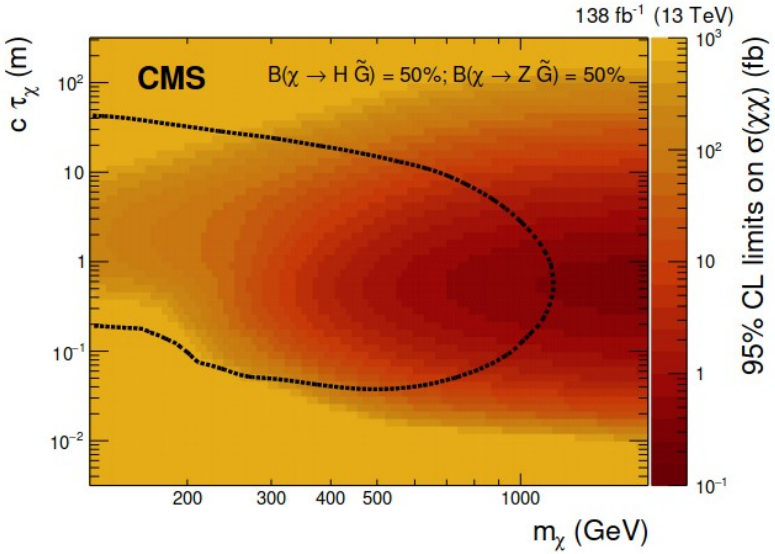


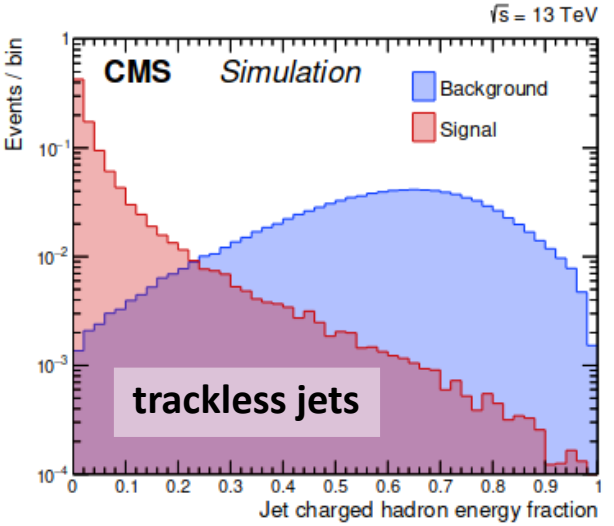
Out-of-time trackless jets

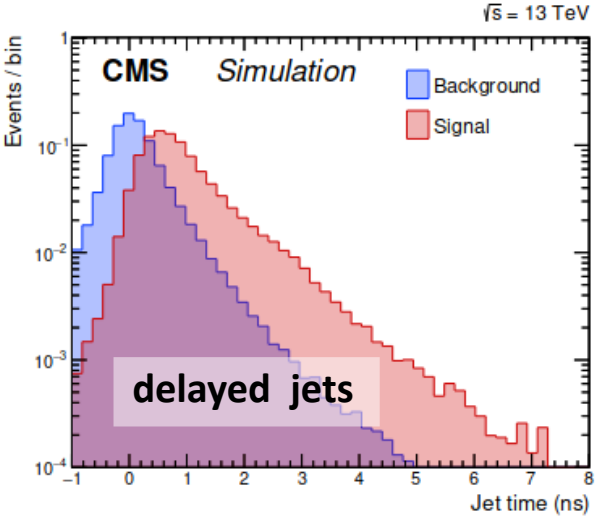
arXiv:2212.06695



- heavy long-lived neutralino decaying in calorimeter or outer tracker regions
  - missing transverse momentum (trigger)
  - jets without tracks, delay in calorimeter
    → combined in DNN jet tagger
- background predicted from mistag rates measured in lepton+jets region
  - no data in 2 tags, matching prediction





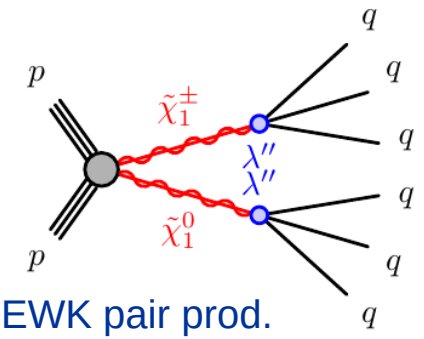


- sensitivity beyond 1 TeV for proper lifetimes of ~1m

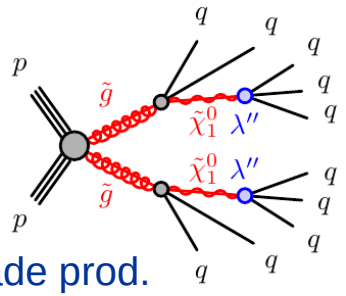
Displaced vertices

arXiv:2301.13866

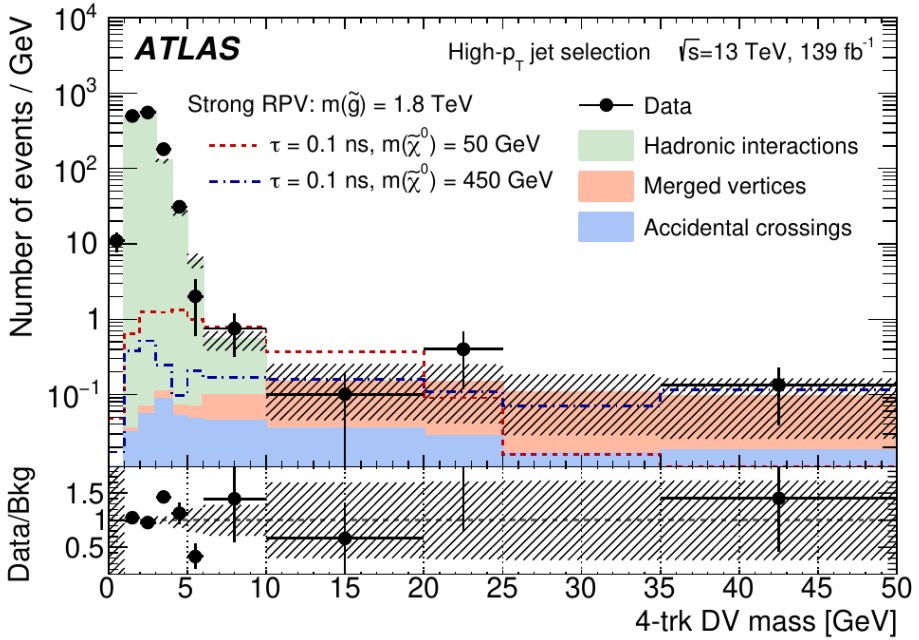
- simpl. model: RPV SUSY neutralino/chargino
  - lifetime from small coupling
- many jets → multijet triggers
- key observable: Displaced Vertex (DV)
- backgrounds
  - hadronic interactions → material map veto
  - accidental crossings
  - merged vertices

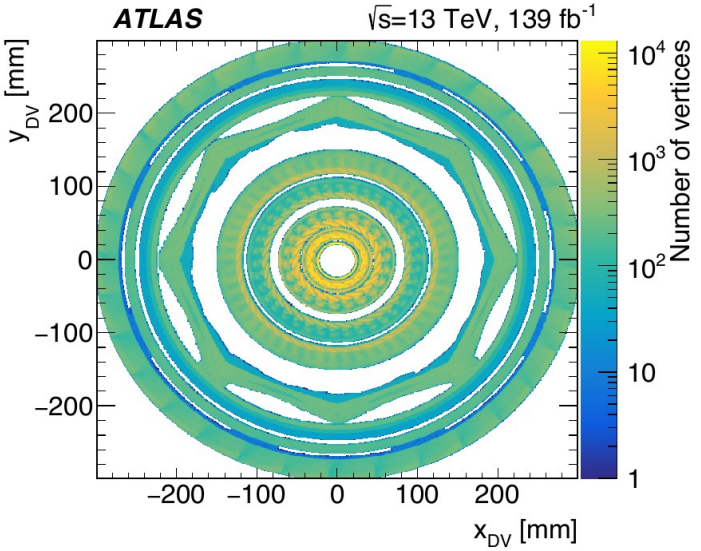


EWK pair prod.



strong cascade prod.





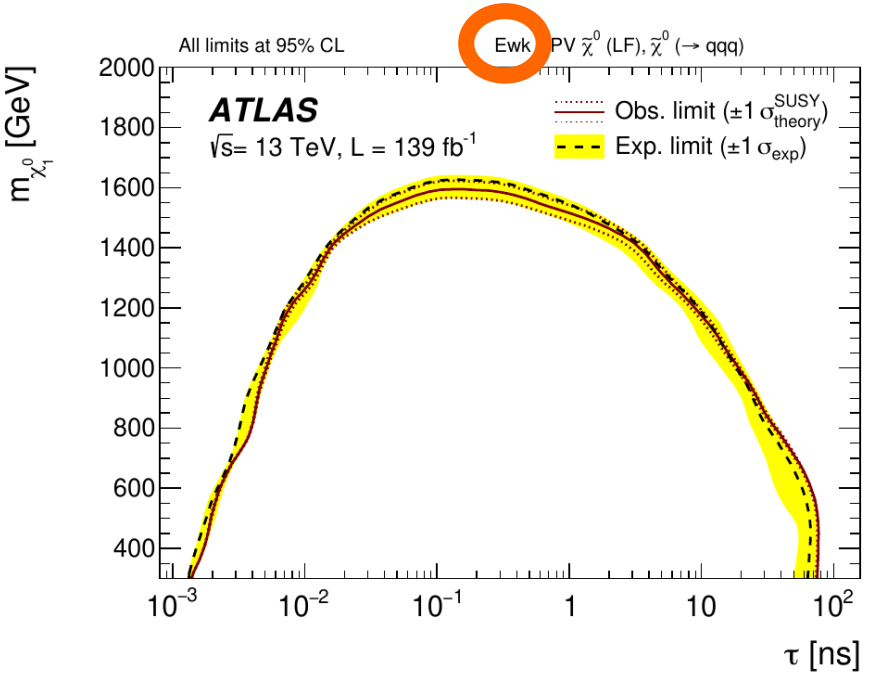
- predict inclusive background using correlation between trackjets and DV
- also piecewise predictions

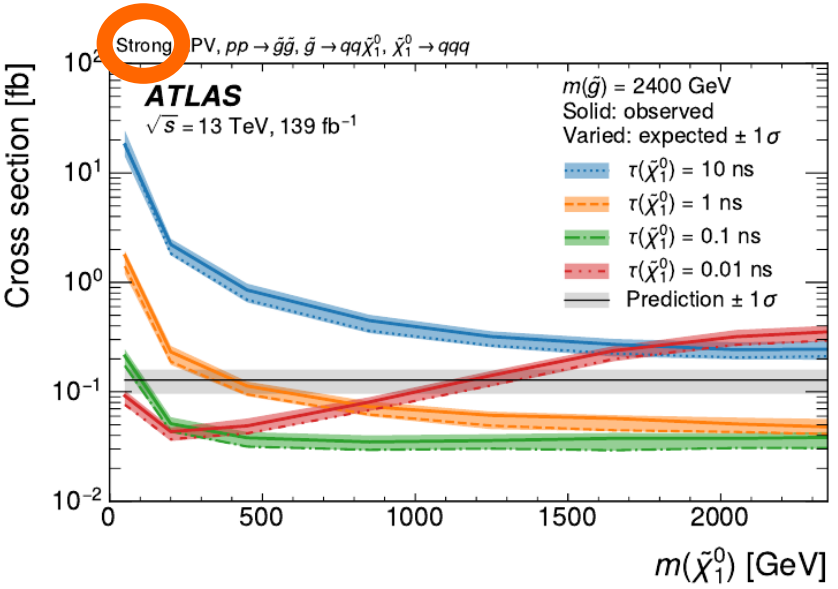
Displaced vertices

- data matches nearly-zero background expectation

Region	Merged vertices	Hadronic interactions	Accidental crossings	Combined	Inclusive	Observed
High-p_T jet SR	0.79 ± 0.66	0.006 ± 0.018	0.28 ± 0.21	1.08 ± 0.69	$0.46^{+0.27}_{-0.30}$	1
Trackless jet SR	1.5 ± 1.1	0.248 ± 0.077	0.32 ± 0.24	2.1 ± 1.1	$0.83^{+0.51}_{-0.53}$	0

- broad proper lifetime sensitivity





visible cross sections excluded as low as 0.02 fb

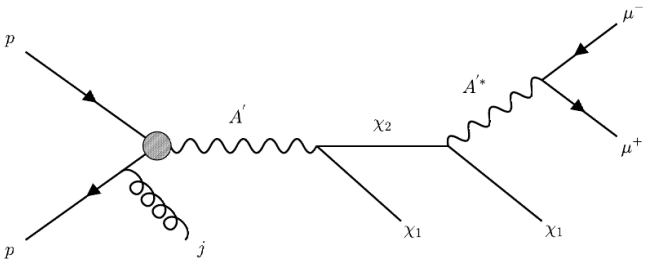
Inelastic dark matter

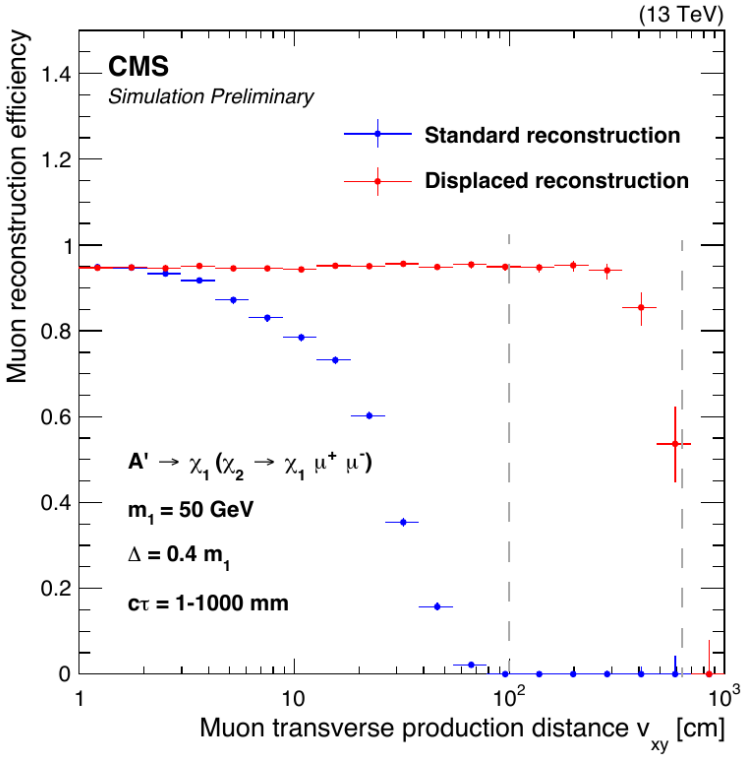
NEW

CMS-PAS-EXO-20-010

- first search for inelastic dark matter at a collider
  - 2 inelastically-coupled dark sector states; χ_1 stable (DM)
  - kinetically mixed massive dark photon ($m_{A'}=3m_1$)
  - lifetime from coupling and compressed phase space
- p_T^{miss} aligned with collimated muon pair
  - p_T^{miss} trigger; ask recoiling ISR jet
- dedicated displaced muon algorithm (dSA)
  - standalone muons or matched to regular muons with tracker track

    → 0, 1, 2-match categories
- ask at least 1 muon pair fitted to a good vertex
- main backgrounds from QCD and W/Z+jets



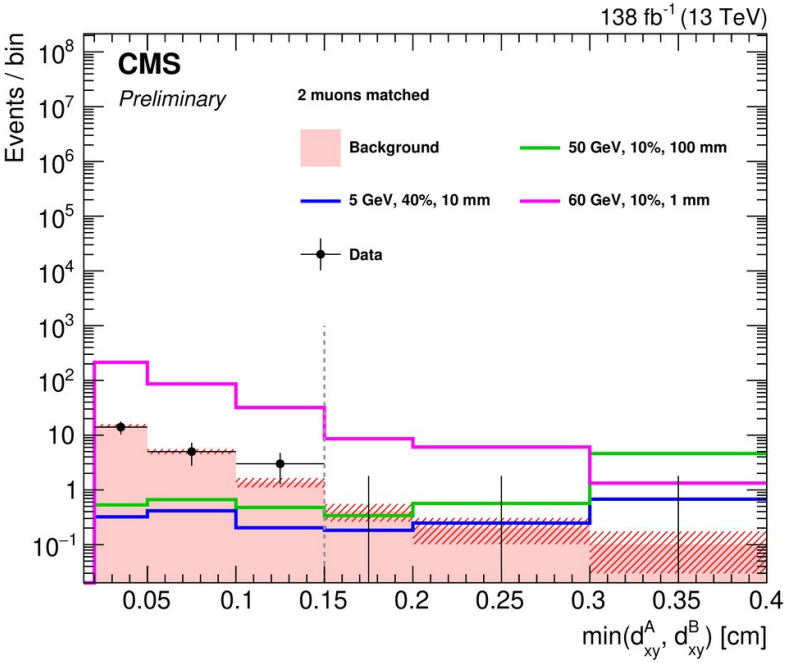


Inelastic dark matter

NEW

CMS-PAS-EXO-20-010

- background+signal fitted on ABCD regions:
  - 0-match: min-d_{xy} versus $\Delta\phi(\mu\mu,\text{MET})$
  - 1 or 2-match: min-d_{xy} versus relative isolation
- B prediction matches observation

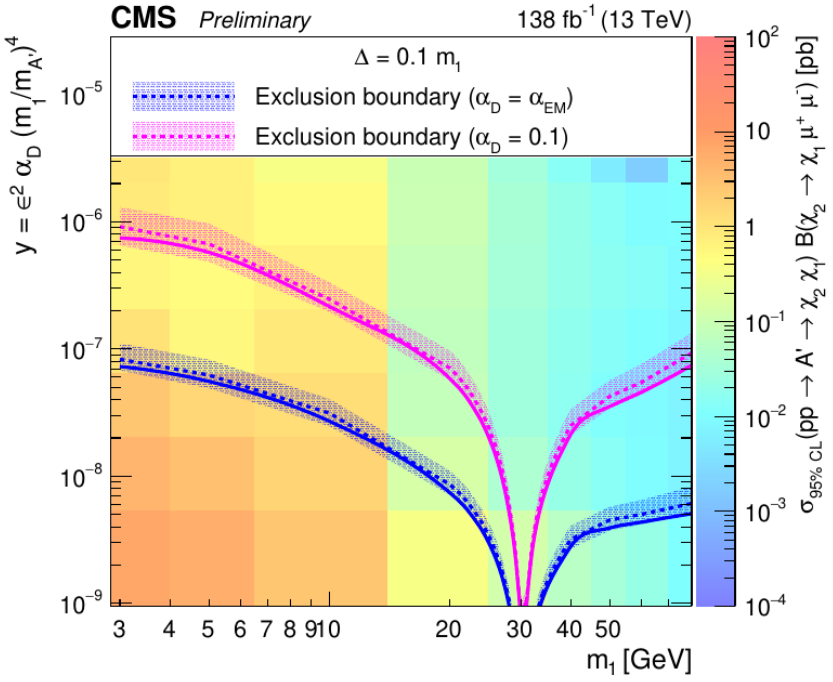


- limits expressed in (m_1 , y) plane
  - with "interaction strength" y:

$$\sigma v \propto \epsilon^2 \alpha_D \left(\frac{m_1}{m_{A'}}\right)^4 \equiv y$$

arXiv:1903.04497

- DM annihilation rate largely depends on just m_1 and y
  - simple thermal relic abundance scaling

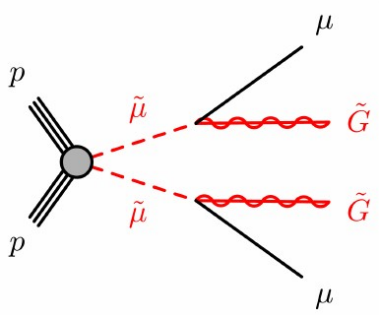


Muon pairs with small lifetime

NEW

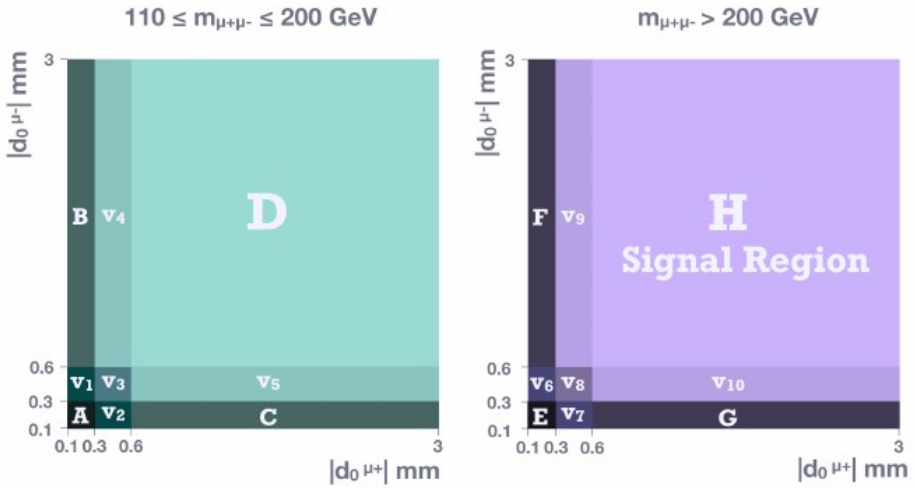
ATLAS-CONF-2023-018

- smuon pair production simplified GMSB SUSY model
  - lifetime from small coupling NLSP-LSP
- aiming for lifetime gap between prompt and O(100-1000) ps
  - key observable: tranverse impact parameter d_0
  - $|d_0|$ probed down to 0.6mm



- search, control, and validation regions in 3 overlapping sets
  - $110 < m_{\mu^+\mu^-} < x$ GeV

Set of Regions	$\lvert d_0\rvert^{\text{low}}$ [mm]	$\lvert d_0\rvert^{\text{low}}$ [mm]	$\lvert d_0\rvert^{\text{high}}$ [mm]	$\lvert d_0\rvert^{\text{high}}$ [mm]	$m_{\mu^+\mu^-}$ [GeV]	Additional cut
1	≥ 0.1	< 0.3	≥ 0.6	< 3	200	-
2	≥ 0.1	< 0.3	≥ 0.6	< 3	140	-
3	≥ 0.1	< 0.3	≥ 0.6	< 1.3	125	$\Delta R_{\mu^+\mu^-} > 3$ rad.

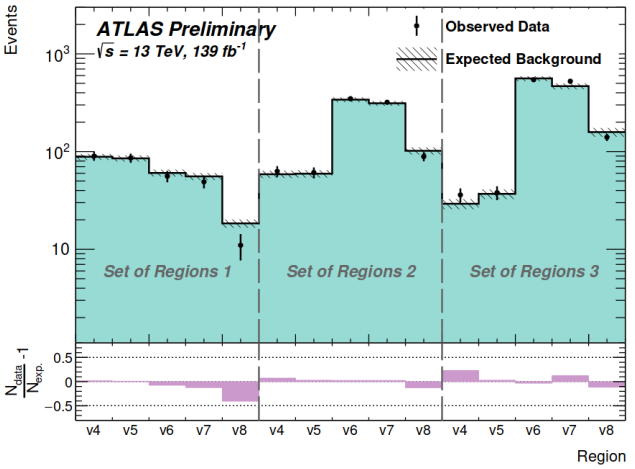


Muon pairs with small lifetime

NEW

ATLAS-CONF-2023-018

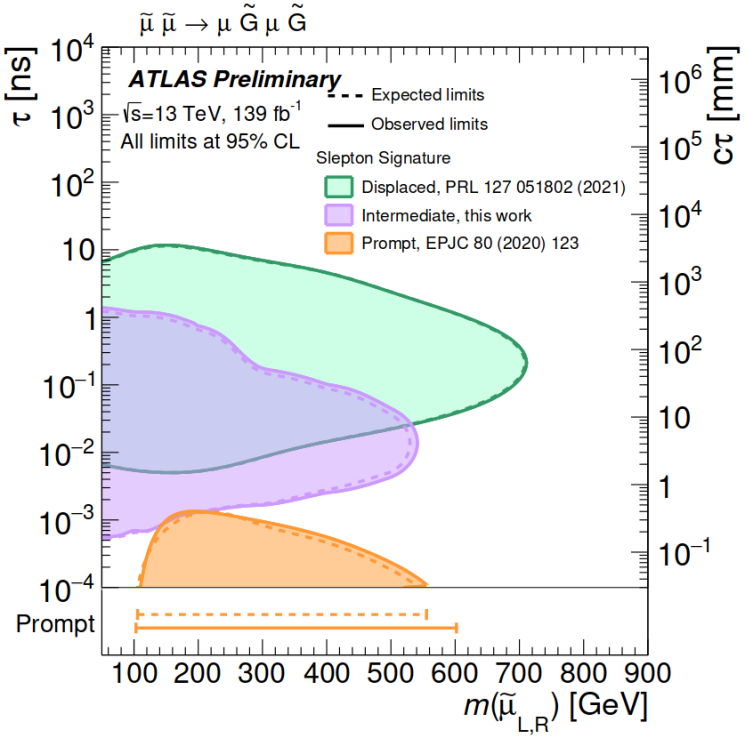
- dominant background from $b\bar{b} \rightarrow \mu^+\mu^-$
- prediction from data using 3 uncorrelated variables:
  - d_{0,μ^+} , d_{0,μ^-} , $m(\mu^+\mu^-)$
  - prediction tested in validation regions



- observation matches background prediction
- model-independent limits on visible cross section in 3 sets of regions

Set of Regions	Expected N_H^{bkg}	Observed N_H^{data}	$\langle A\epsilon\sigma \rangle_{obs}^{95}$ [fb]
1	2.1 ± 0.8	1	0.02
2	12.5 ± 5.2	7	0.04
3	17.2 ± 7.4	14	0.06

- interpretation in GMSB model
  - exclusion up to 520GeV and down to 1ps
  - compared to prior large-d_0 analysis (>3mm)
  - compared to reinterpretation of prompt search using RECAST

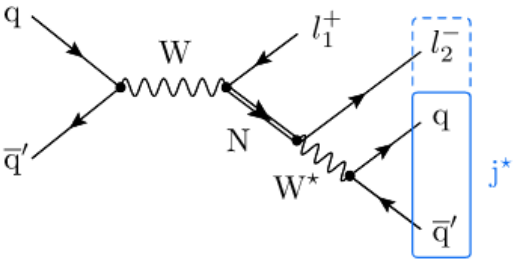


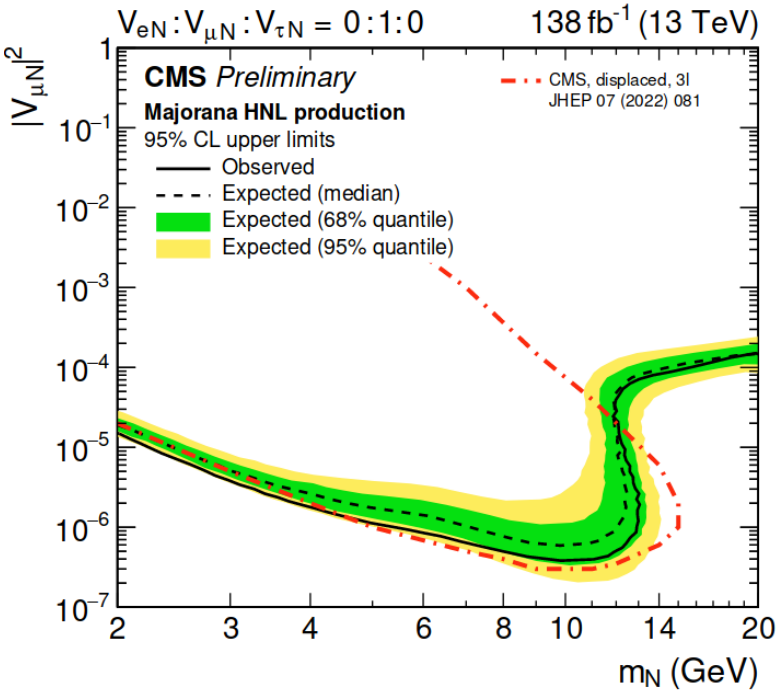
HNLs in displaced e/μ/τ+jet

NEW

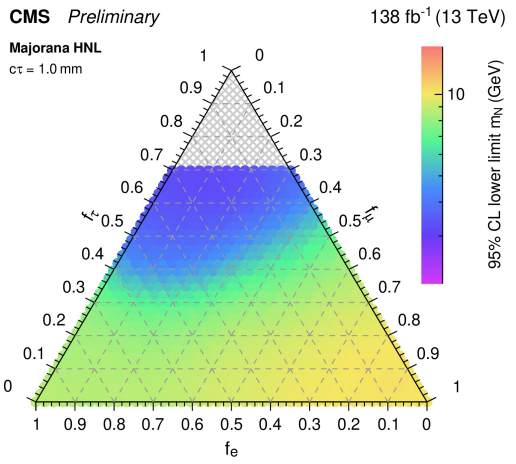
CMS-PAS-EXO-21-013

- HNLs from W decays, displaced at low mass/coupling
- key feature: displaced jet tagging
  - based off parametrized DNN from arXiv:1912.12238,
  - extended to include leptons
- W mass signal region: $70 < m_{lljj} < 90$ GeV
  - backgrounds from sidebands
- diversity of categories
  - μμ/ee/μe/eμ, SS and OS → LFC/V & LNC/V
  - boosted and resolved (2nd lepton in/out jet)
  - prompt, medium, and displaced (2nd lepton)





- sensitivity to mixed scenarios
  - including taus!

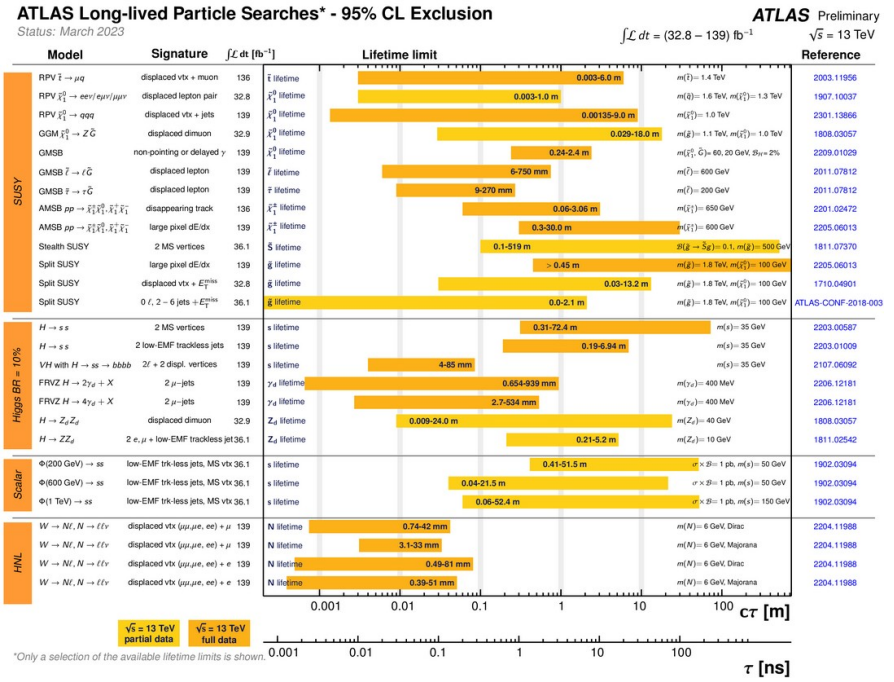


More details in Haifa Sfar's talk on Monday!

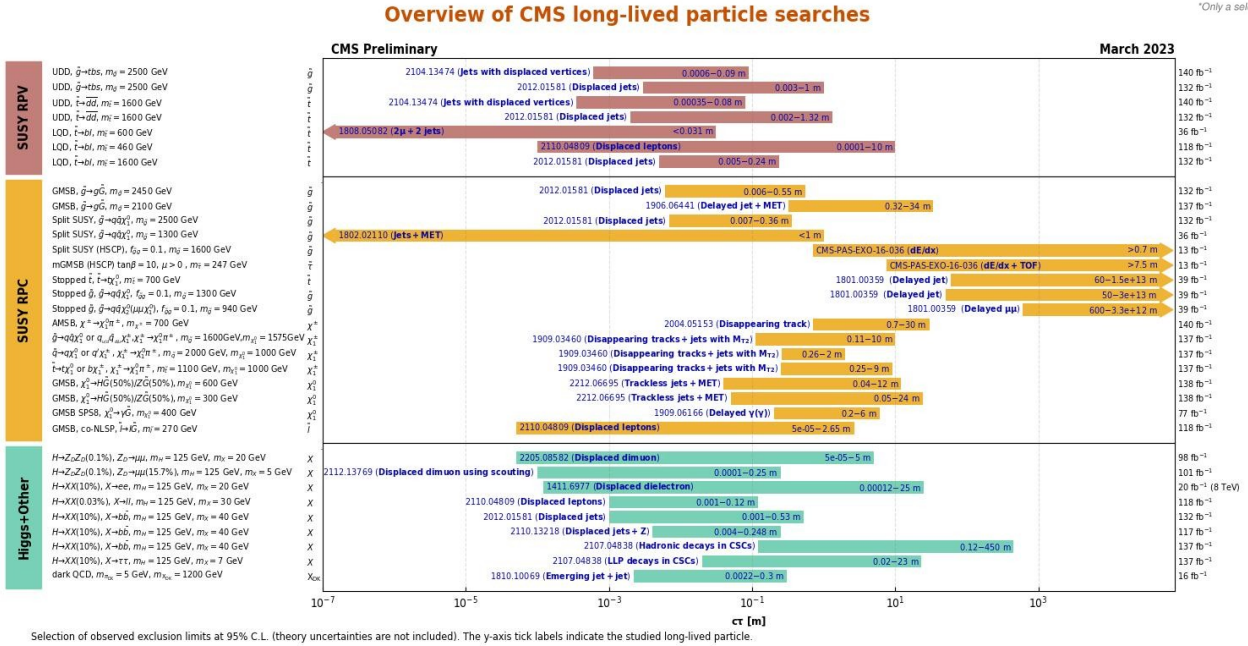
Outlook

- LLPs are theoretically motivated, and experimentally motivating
- Going to great lengths to mine LHC Run-2 data for signs of LLPs
  - impressive list of results, still new ones coming in
  - large diversity in signatures and approaches
  - formidable ingenuity in analyses
  - several recent new results from both ATLAS and CMS presented
- LHC Run-3 has taken off swiftly
  - detector improvements in LHC LS2
  - new and improved triggers and data taking strategies
  - other experiments weighing in as well
- Also HL-LHC will bring a big boost to LLPs
  - only started to scratch the surface of new detector capabilities
  - still other detectors being planned

LLP results in ATLAS and CMS



[link]



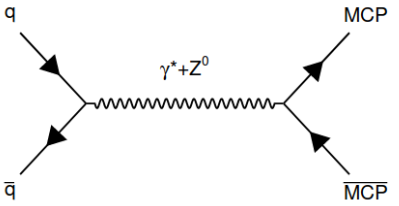
[link]

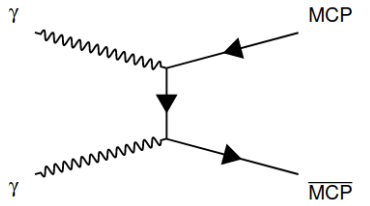
Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

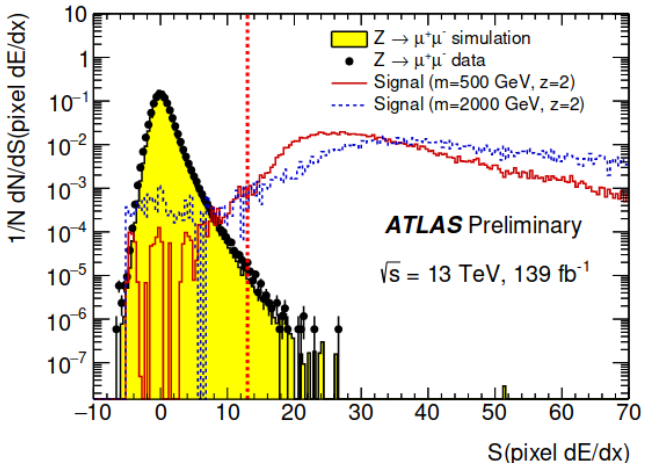
Backup

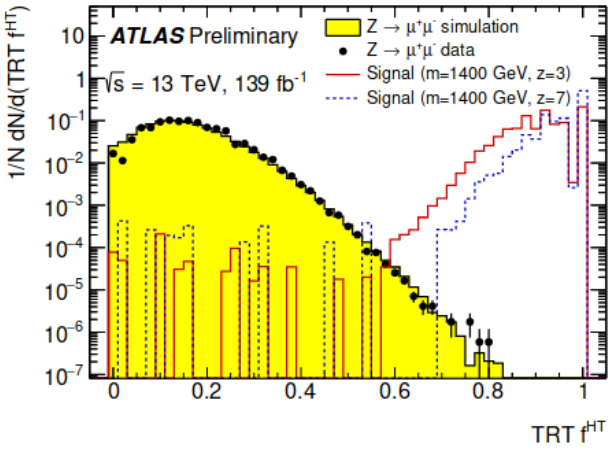
Backup

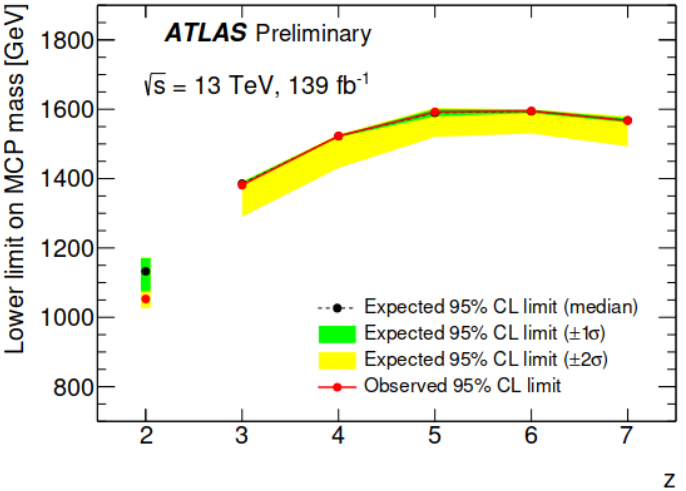
ATLAS-CONF-2022-034

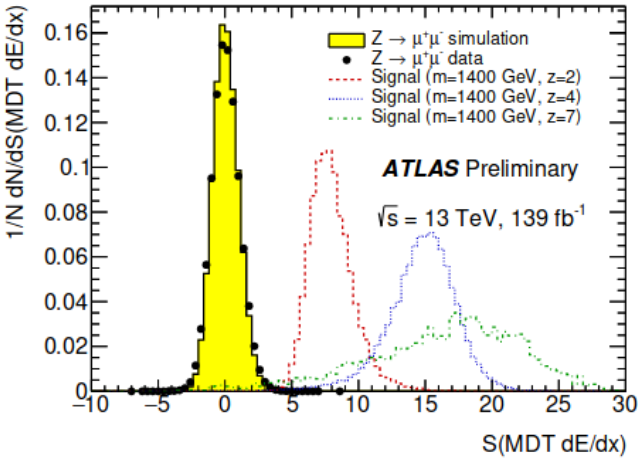


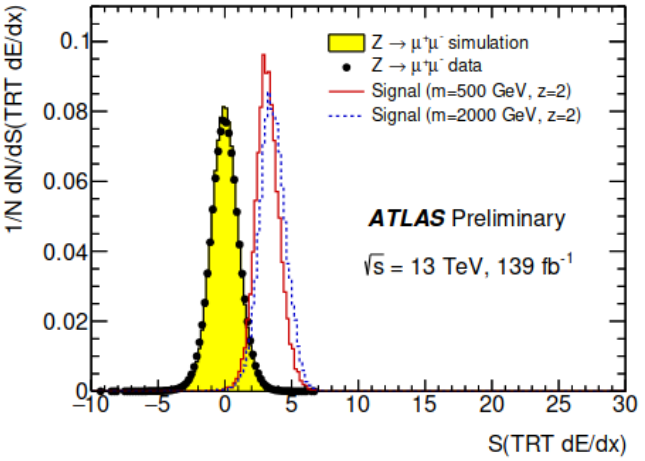










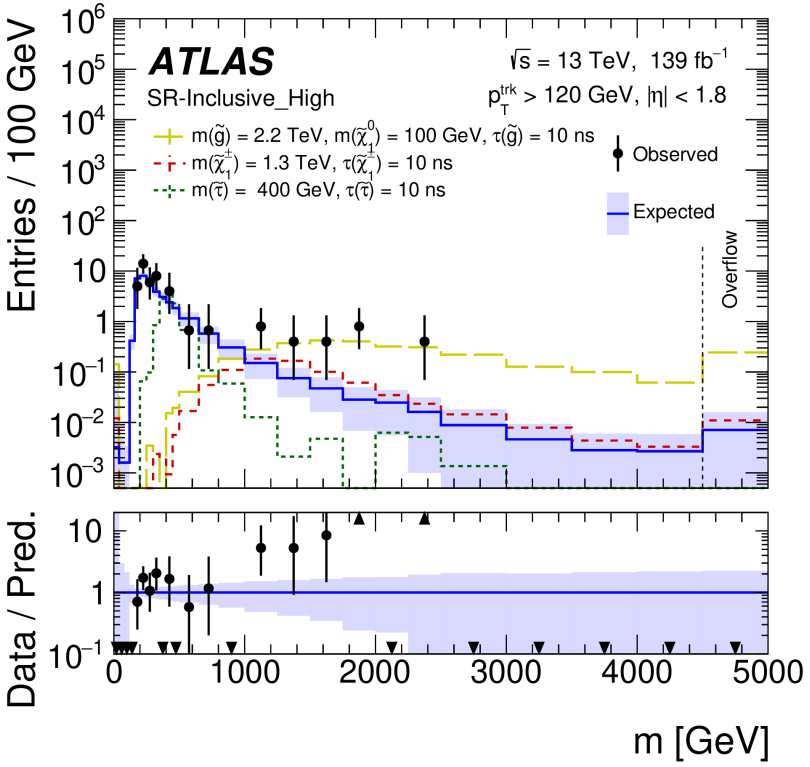


Backup

ATLAS-CONF-2022-034

Recently, an excess of events in a signal region in an ATLAS search [43] for heavy long-lived charged particles identifiable by their unusually large pixel dE/dx values was observed. Two of these observed events feature candidates with pixel dE/dx values compatible with those satisfying the $z = 2$ tight-selection requirement in the current analysis, but not ending up in the corresponding signal region. A dedicated check was performed to understand the reason for this. It was demonstrated that neither of the two candidates have high enough ionization loss in TRT or MDT to make it into the signal region – in fact, both of them belong to the A control region (see Figure 4(a)).

https://arxiv.org/abs/2205.06013



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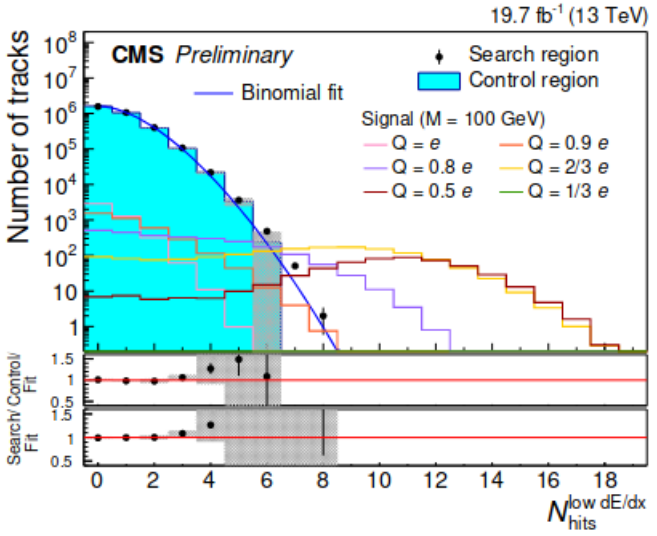

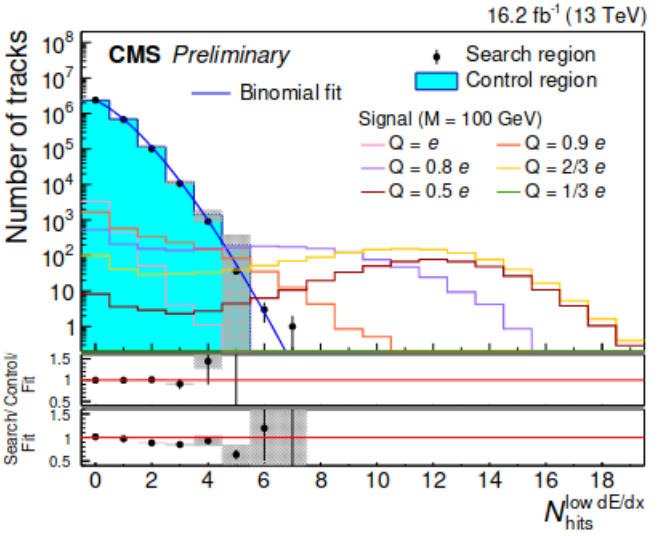

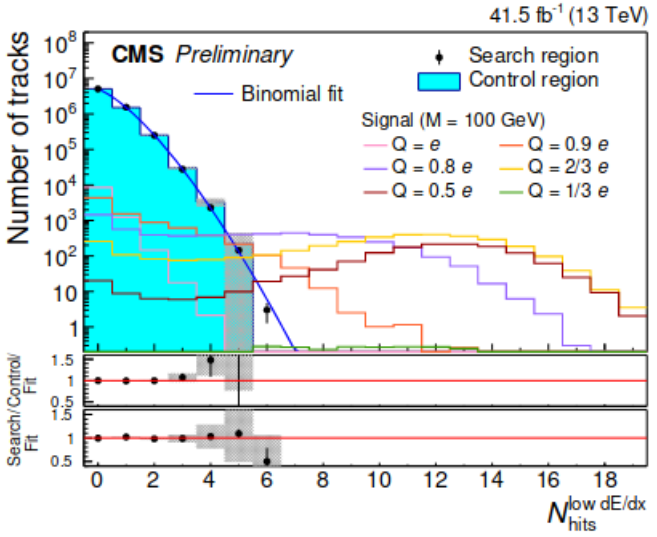

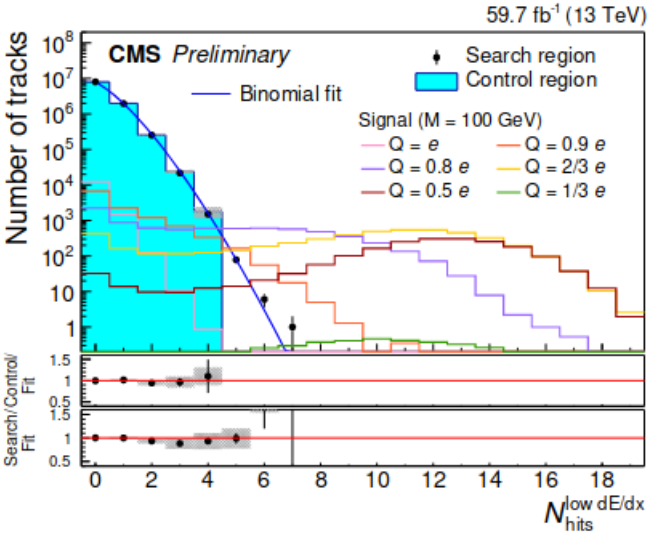

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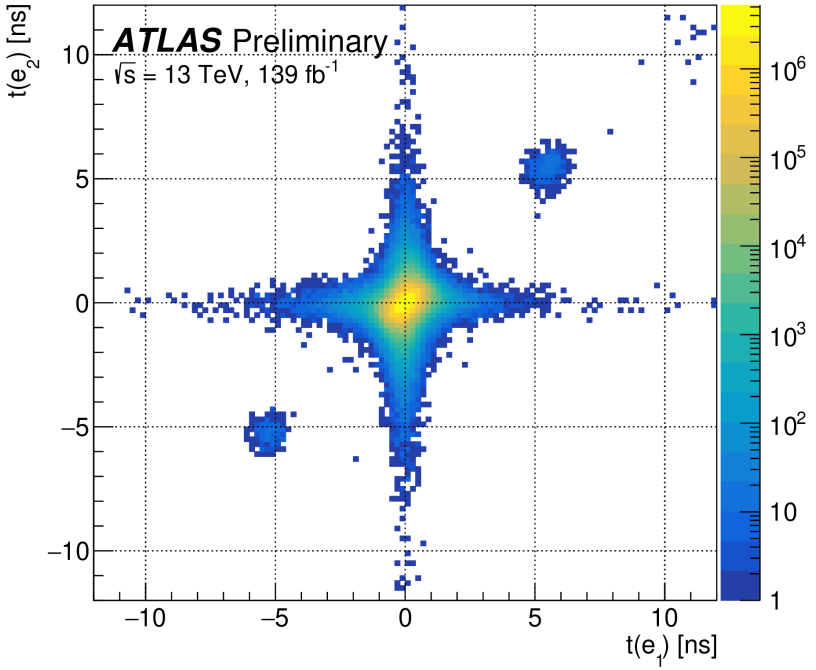

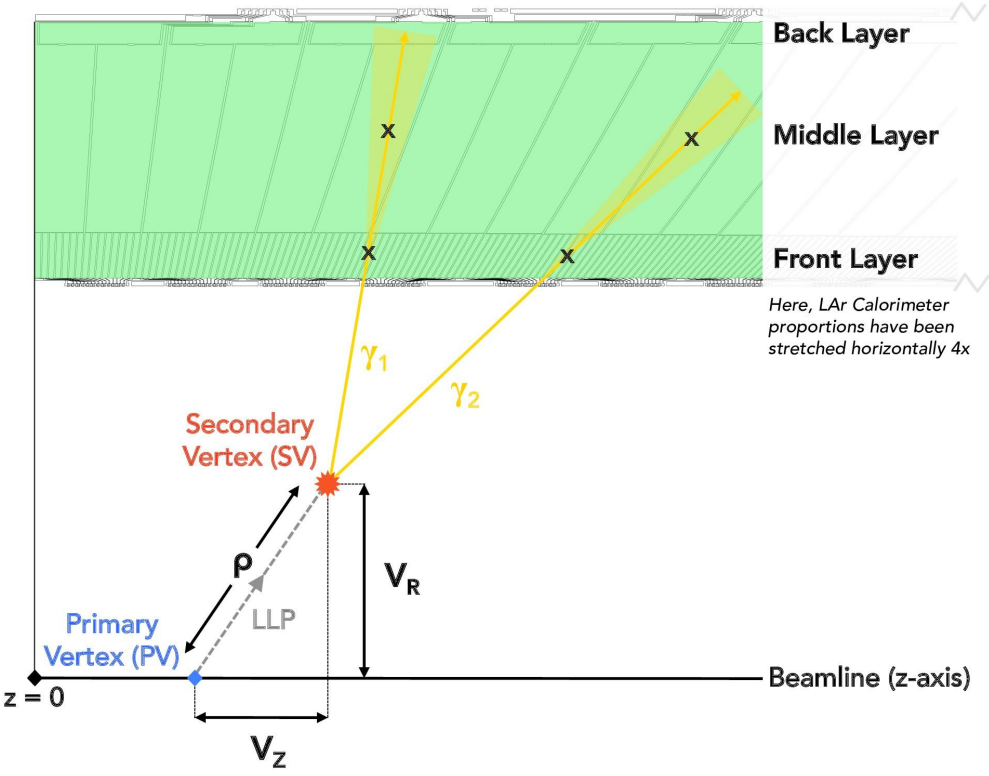

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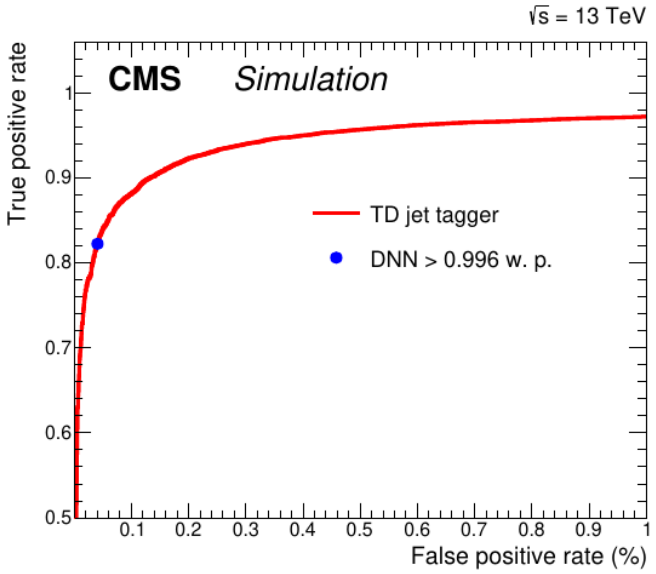

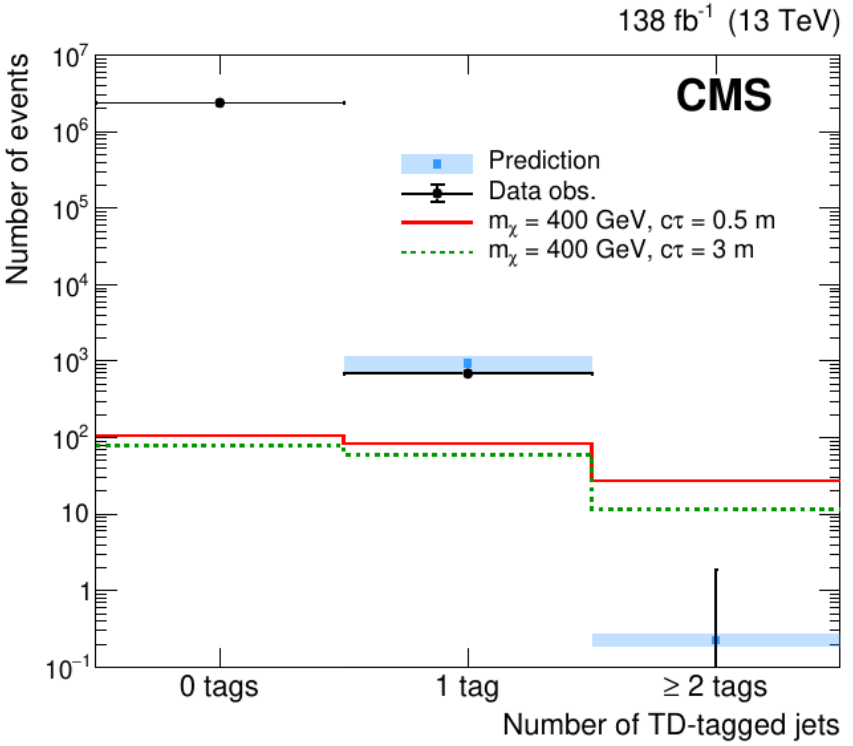

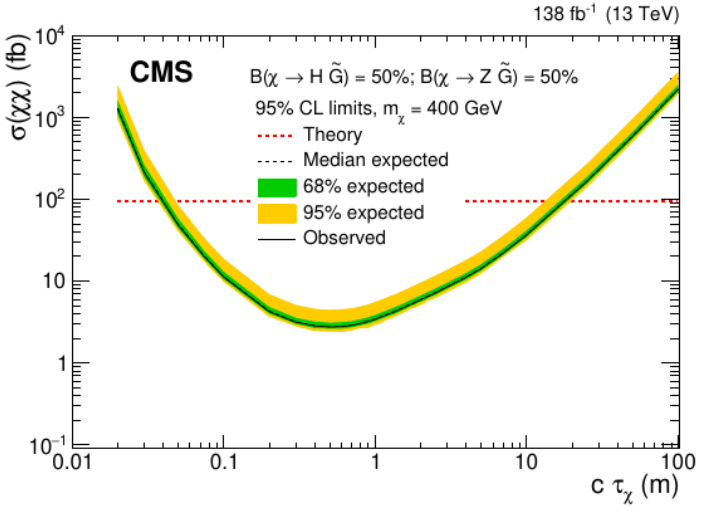

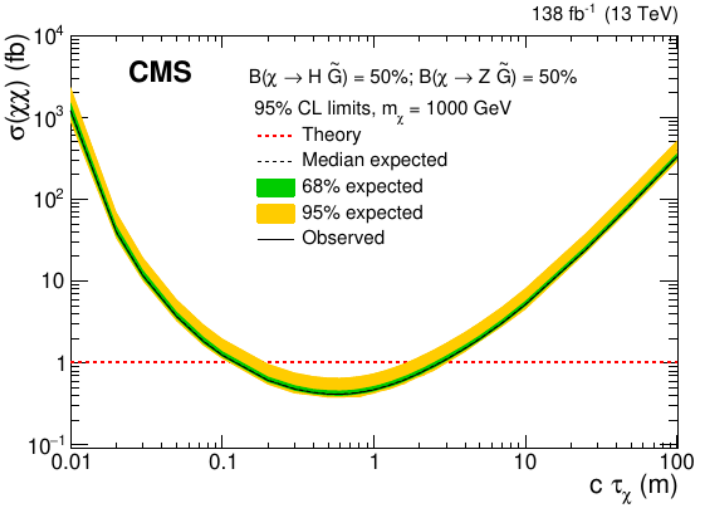

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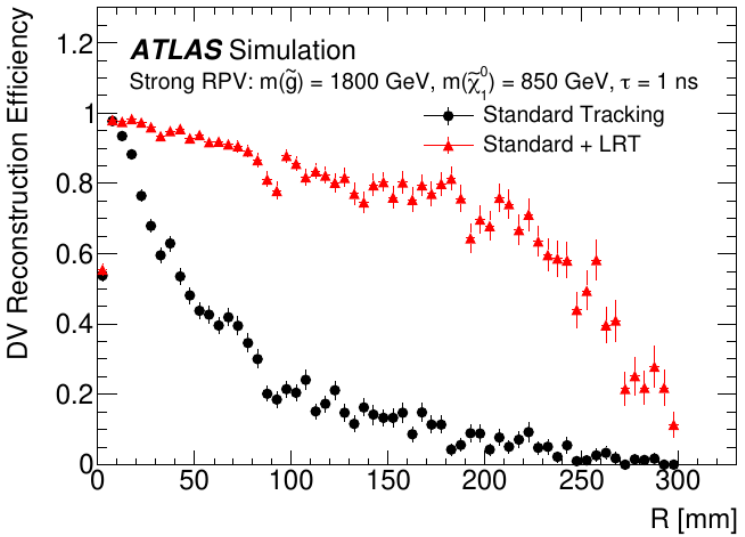

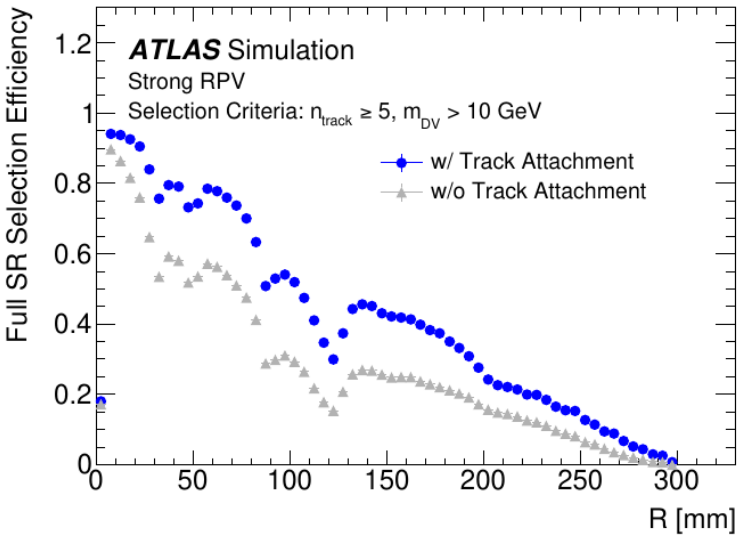

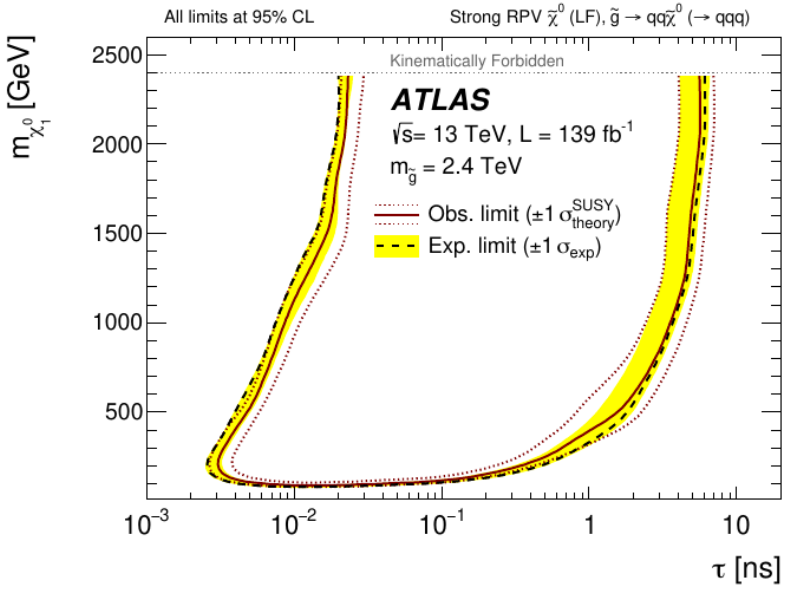

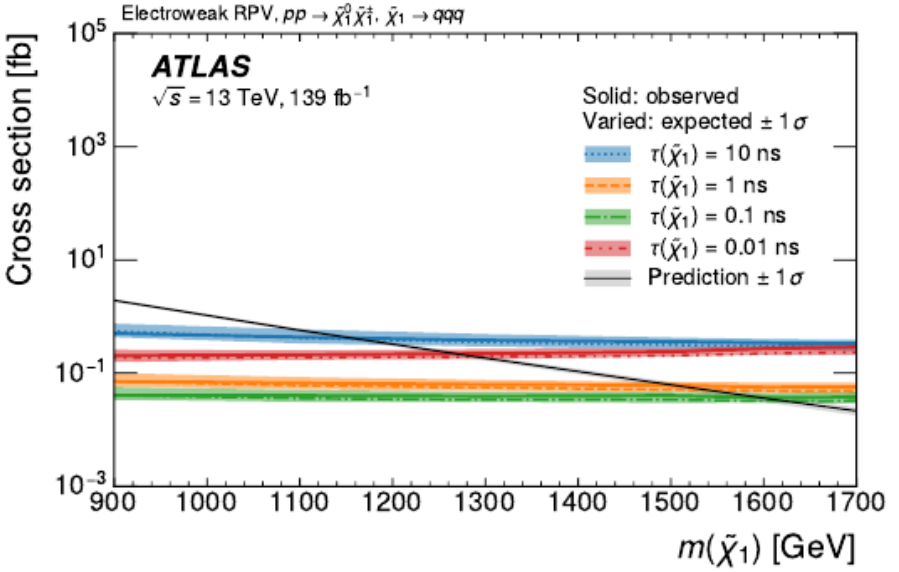

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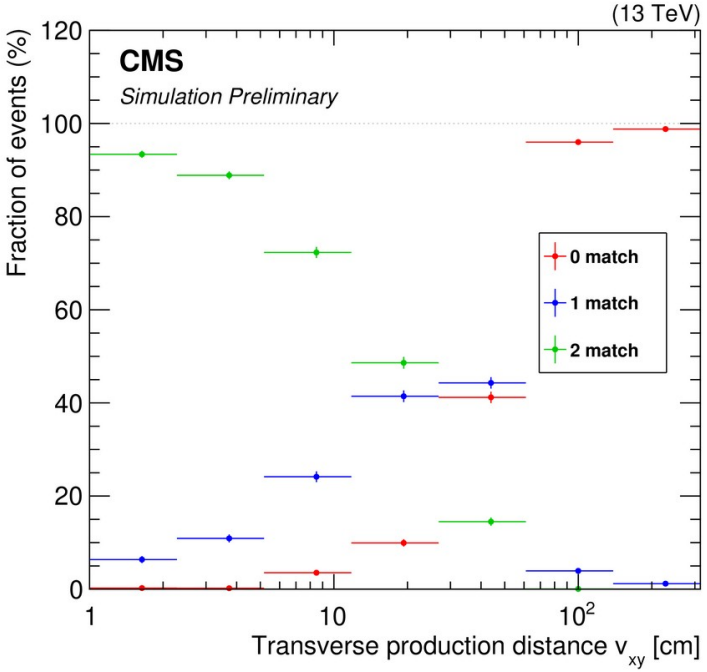

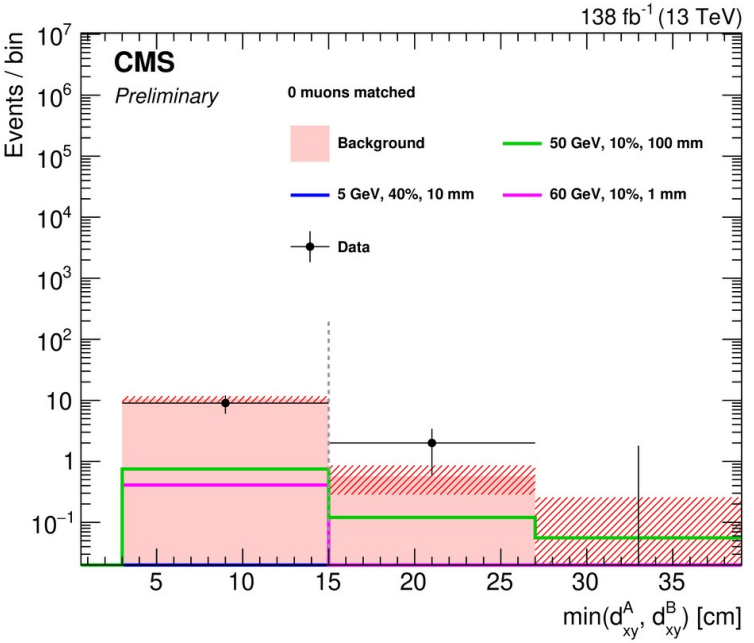

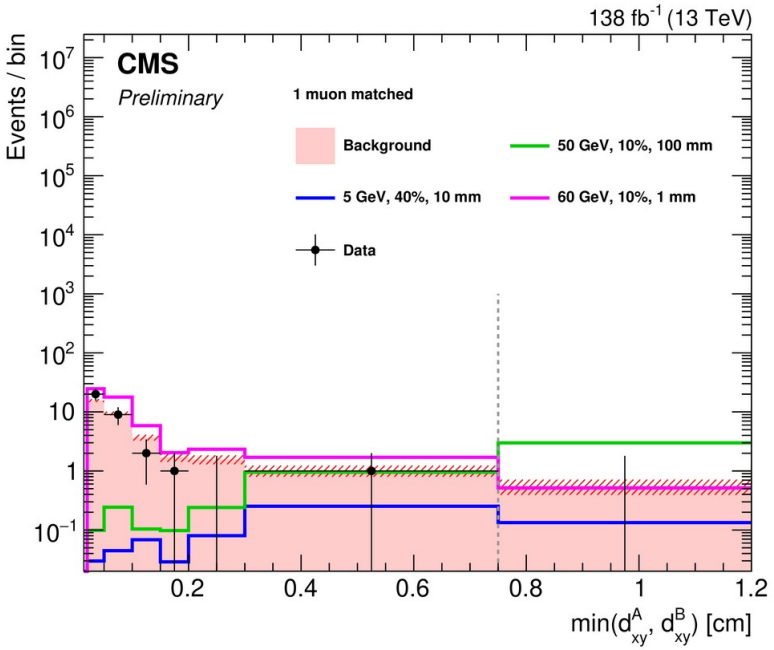

Additional Figure 11-a:
Fraction of events in each muon match category versus generated χ_2 decay transverse position v_{xy} for an inelastic dark matter model with $m_1 = 50$ GeV and $\Delta = 0.4\,m_1$. Left: $\chi_2|\eta| < 1.2$. Right:

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