Displaced tau jets: An exercise in unconventional signatures at the ATLAS experiment

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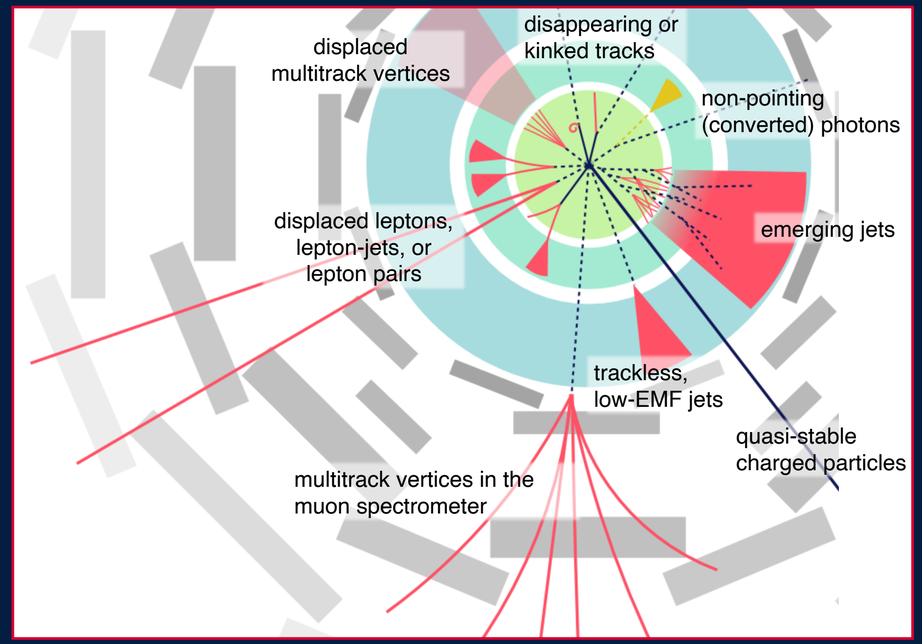
Long-Lived Particles and Displaced Signatures

- ATLAS has a wide BSM searches program that typically targets models with prompt signatures
- What if new particles had a large lifetime?
  - Small $|\mathscr{M}_{a\to XY}|^2$
  - High mass particles
- Result: New strange experimental signatures from LLPs at ATLAS!
  - Displaced jets [1]
  - Displaced leptons [1, 2]
  - Semi-visible/Emerging jets [1,2]
  - Ionisation in tracker [1]
- Dedicated effort to make these measurements possible → This talk about displaced taus

$$\Gamma_{a\to XY} = \frac{\vec{k}}{32\pi^2 m_a^2}\int |\mathscr{M}_{a\to XY}|^2 d\Omega$$

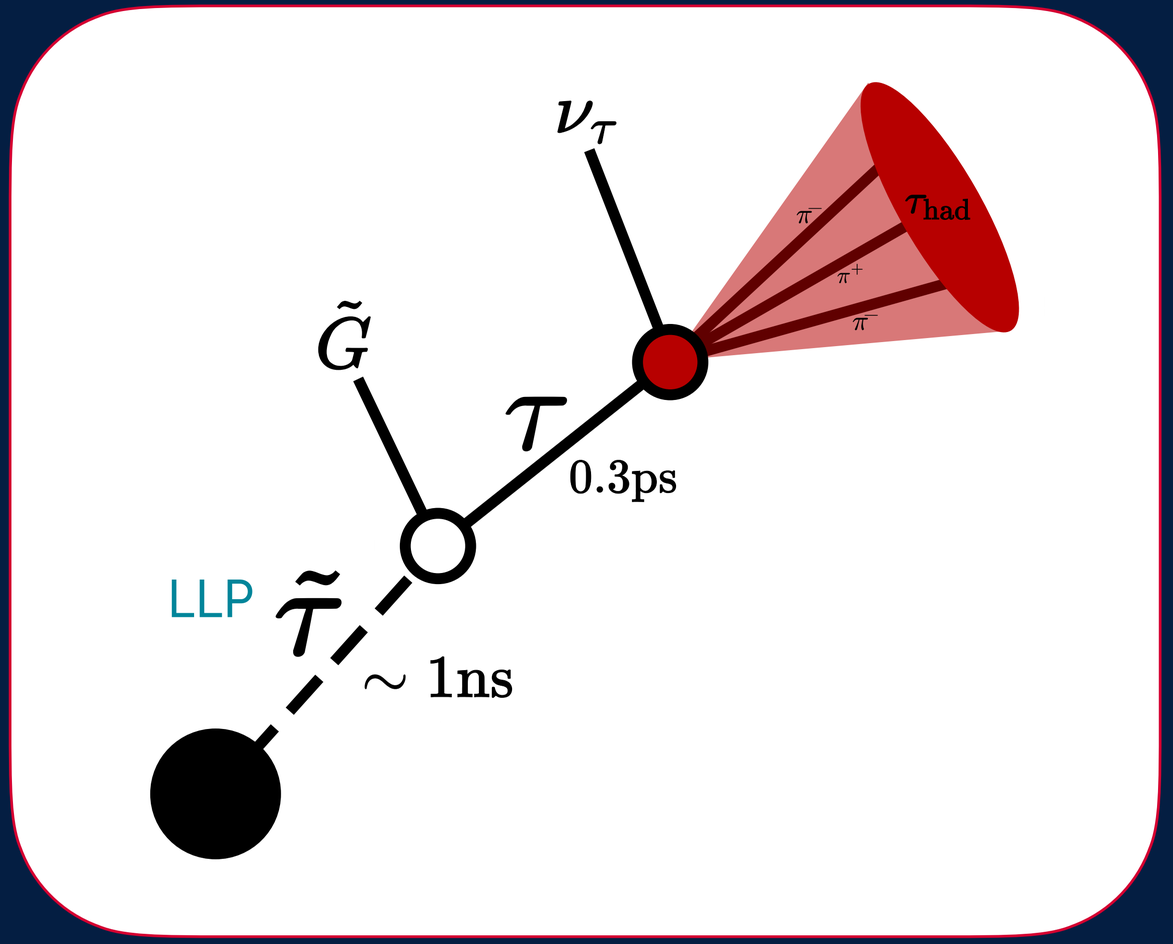
$$\tau_a = \frac{\hbar}{\Gamma_a}$$



(LLP White Paper, 2020)

Displaced Tau Signature

- What is a displaced tau?
  - SM tau decaying at a highly displaced vertex
  - Preferably in the tracking system of general particle detectors
- Kicked off with a workshop in 2019
- Many possible sources of displaced taus
  - SUSY with stau as NLSP
  - Long-lived HNLs
  - Higgs-like hidden sector mediators
  - Long-lived Z' particle



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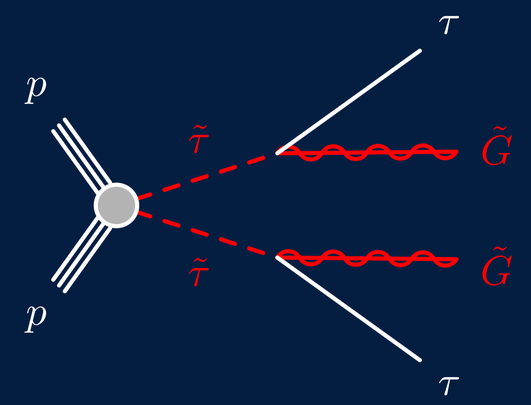
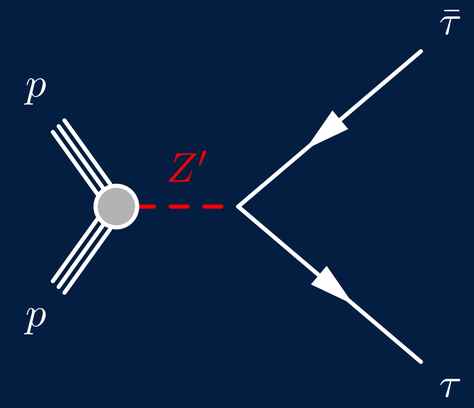


$\tilde{\tau} \to \tau\tilde{G}$



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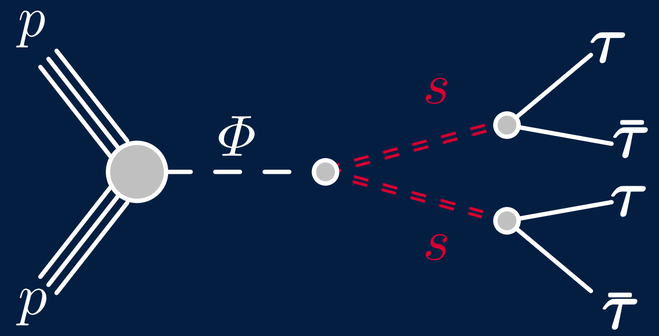

Hidden Sector Mediator

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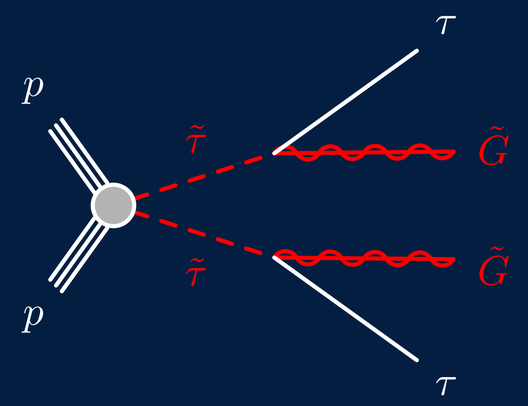
But what does it look like in the detector?
Depends on the tau decay mode



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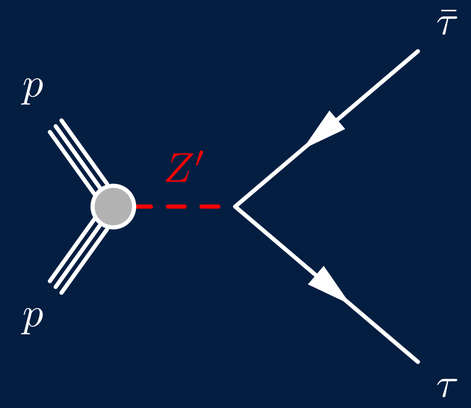

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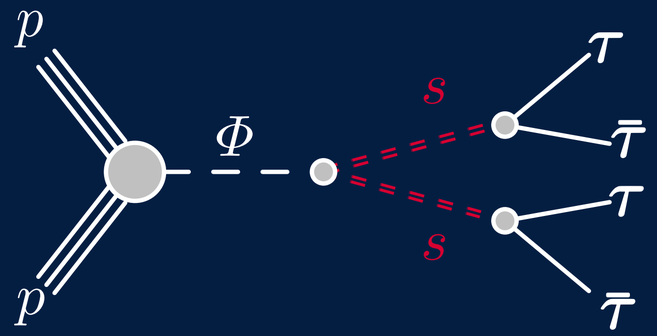
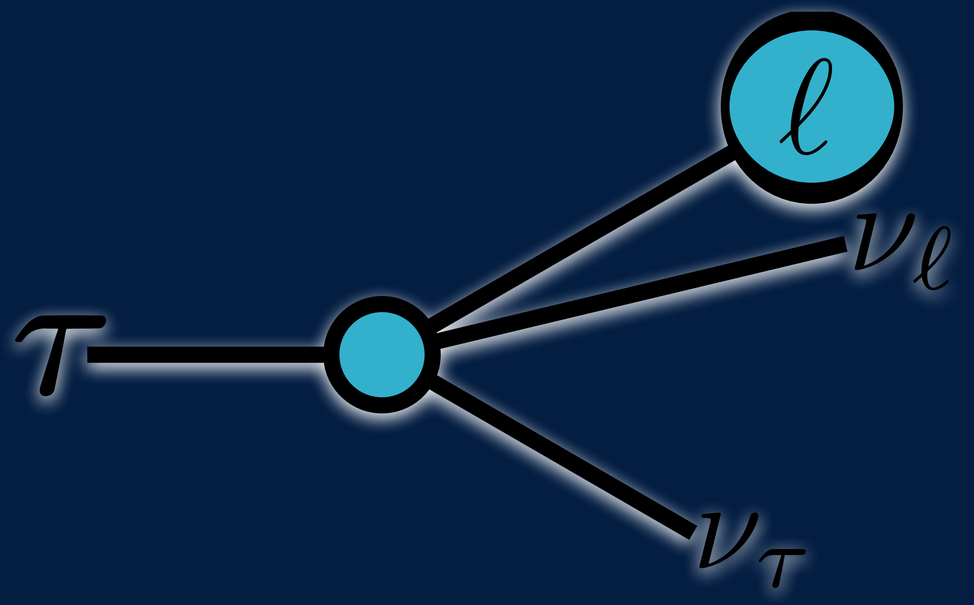


Hidden Sector Mediator

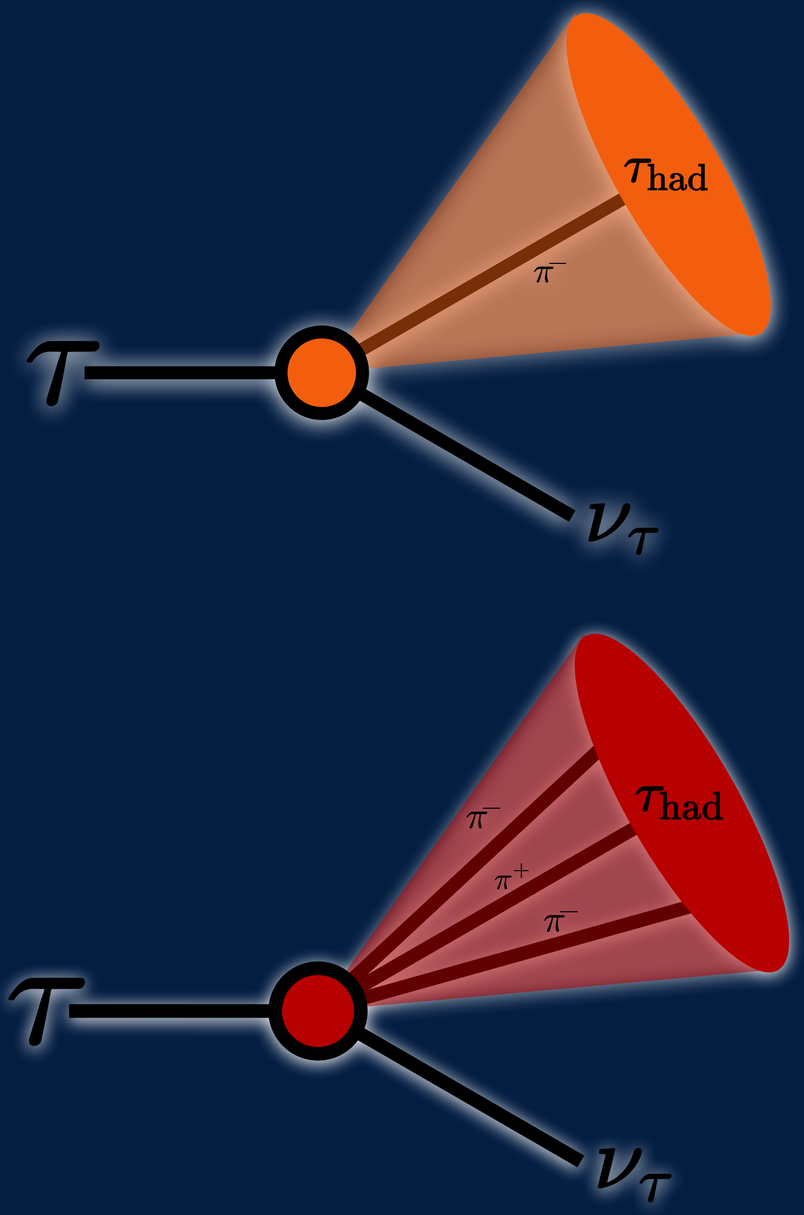
What does it look like

- Leptonic tau decay
  - Produces e or μ
  - Has a highly displaced track ($IP_{trans.}$ > 5mm)
  - Reconstructing displaced e/μ is similar to prompt, requires some loosening of track requirements



What does it look like

- Hadronic decay
  - Displaced decay vertex
  - Highly displaced charged tracks (or prongs) from π/K
  - Jet in the calorimeter



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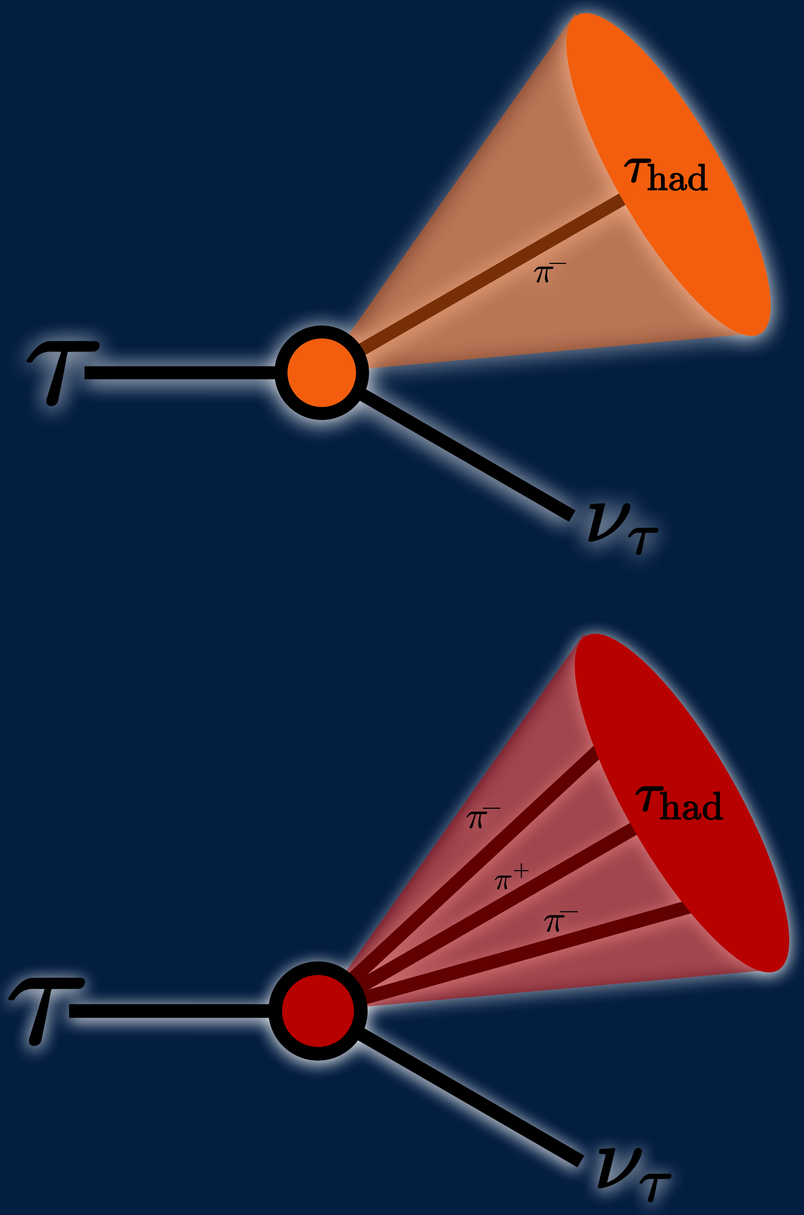
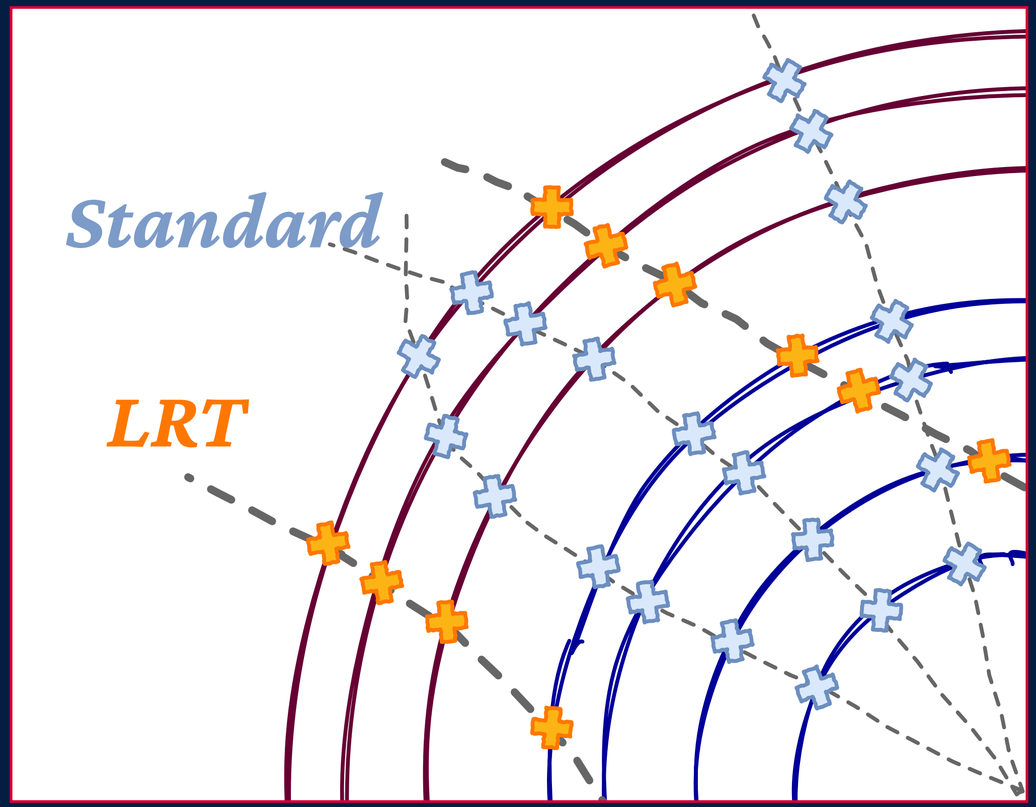


Issue: ATLAS tracking was not designed for reconstructing highly displaced tracks...

Large Radius Tracking

- The Large Radius Tracking (LRT) algorithm [paper] allows for the reconstruction of highly displaced tracks
  - $IP_{trans.} < 5 \rightarrow IP_{trans.} < 300$ (beginning of SCT)
  - $IP_{long.} < 200 \rightarrow IP_{long.} < 500$
- Additional step after standard ATLAS tracking
  - Constructs new tracks from leftover tracker hits
  - Looser track requirements
- Used by analyses targeting LLPs decaying before or within the Inner Detector (< 300 mm)



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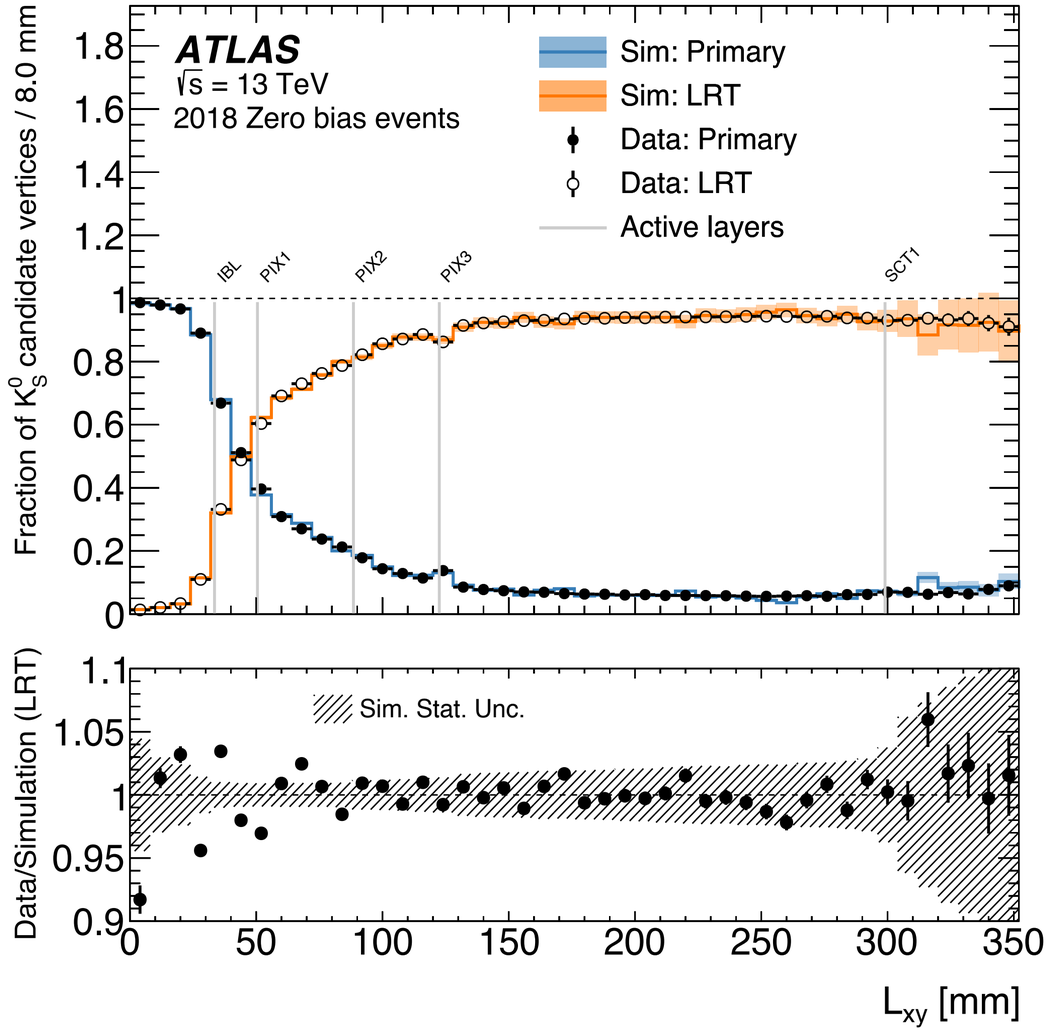
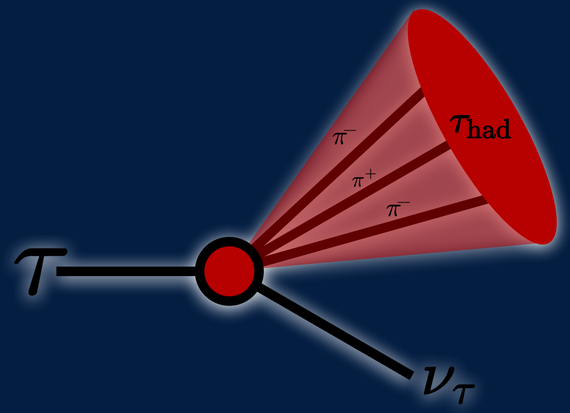


Displaced τ_{had} Reconstruction



Tau Jet Reconstruction 101

1. Collect Jets in Calorimeter

Same as standard taus

2. Associate and classify tracks

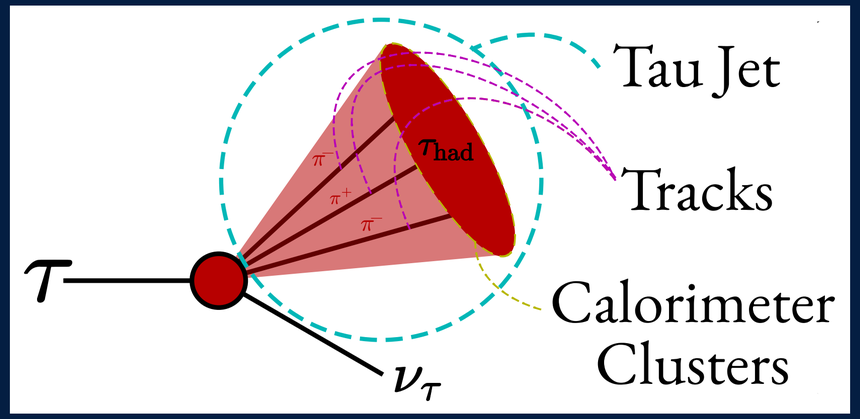
Need to modify track classification for displaced tracks

3. Perform tau identification

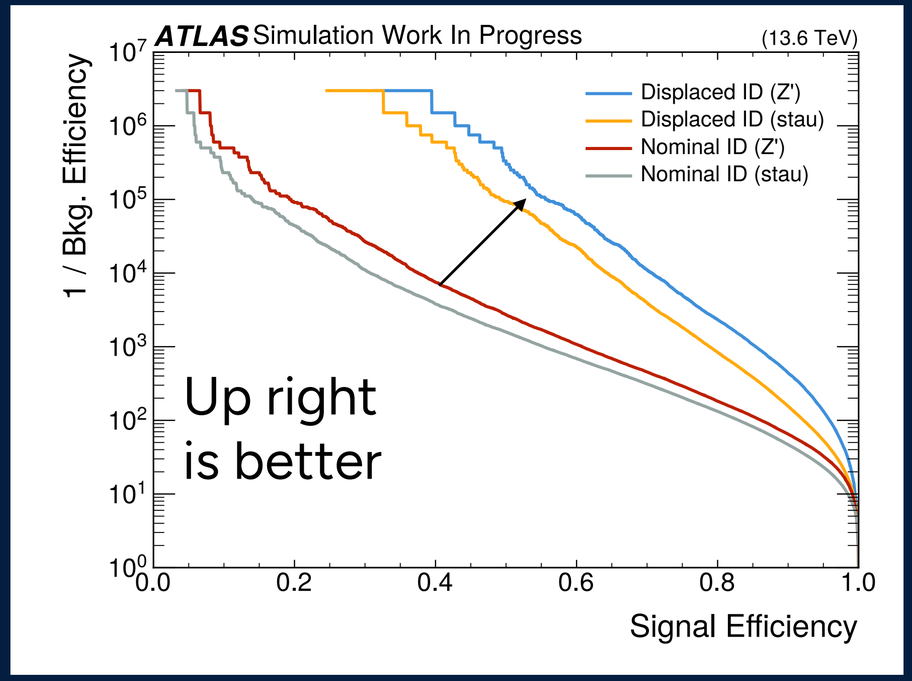
New ID algorithm for displaced taus (next slide)

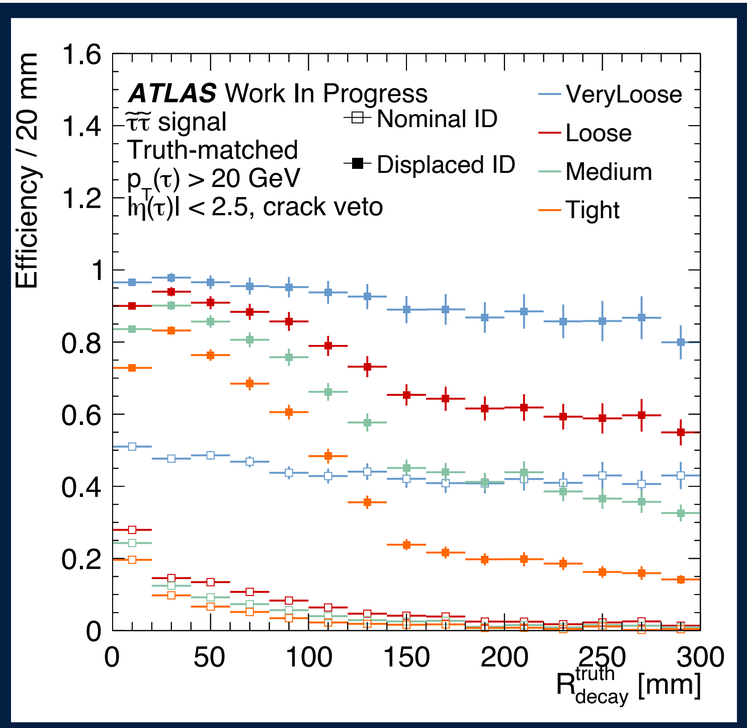
Identification algorithm

- Major background when reconstructing tau jets are QCD-induced jets
- Need procedure for deciding Tau jet vs QCD jet
  - ML-based algorithm trained on simulated jets
- Algorithm inputs



- For displaced taus, need dedicated ID
  - Retrained ATLAS tau ID with displaced taus
- Improved signal/background discrimination compared to nominal

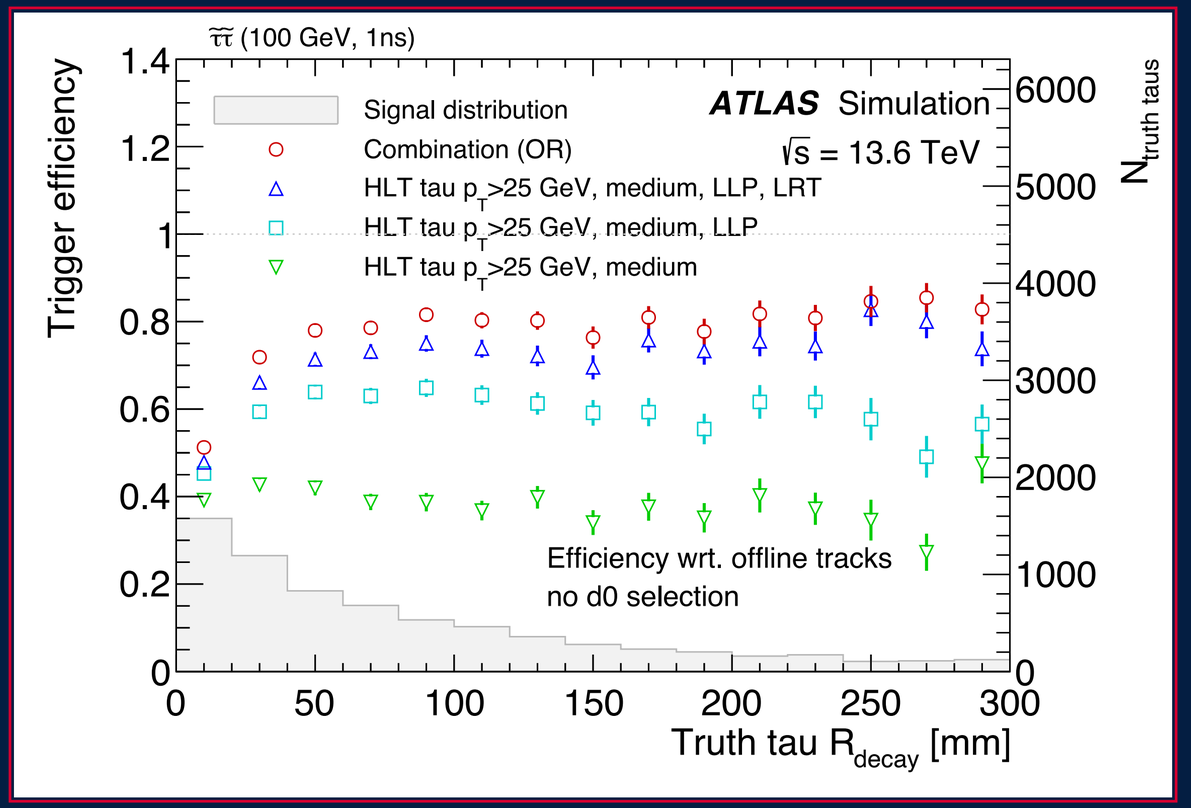




Signature based Triggers: Displaced τ_{had} trigger

- Dedicated displaced tau trigger in Run 3
  - Online RNN τ ID trained on displaced samples
  - Compare nominal to LLP trigger in plot
- More LLP Run 3 trigger menu
  - High ionisation
  - Disappearing track
  - Displaced e/μ

Approx. 60% eff. gain at higher decay radii

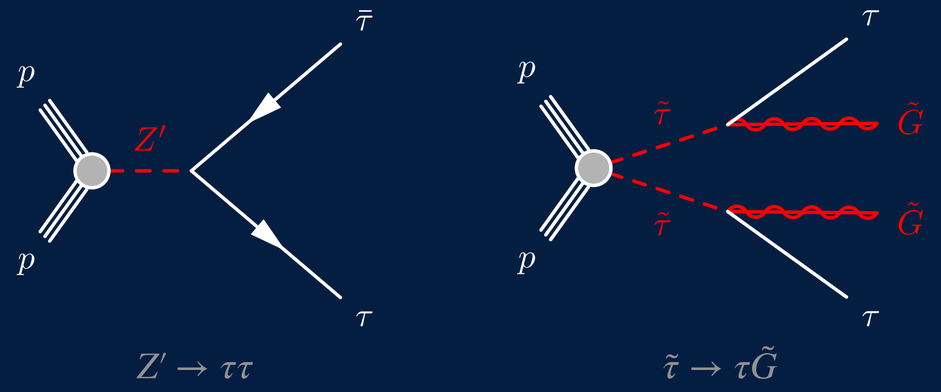


Trigger efficiency as a function of τ decay transverse radius [Paper]

Analysis Overview (Run 2)

- Target decays of LLPs to **2 displaced taus**
- Focussed on final states with **hadronically decaying taus**
  - Fully leptonic final states covered by ATLAS displaced lepton searches
  - Three final states considered
    - $\tau_{had}\tau_{had}$ (had-had), $\tau_e\tau_{had}$ (e-had), $\tau_\mu\tau_{had}$ (mu-had)
- Designed with **model independence,** leveraging ID algorithm
  - Plus model-dependent limits (GMSB SUSY)
- Hard to model major bkg of fake taus from QCD-jets with MC
  - Data-driven background estimations
- Run 3 planned with new developments

More at IOP!



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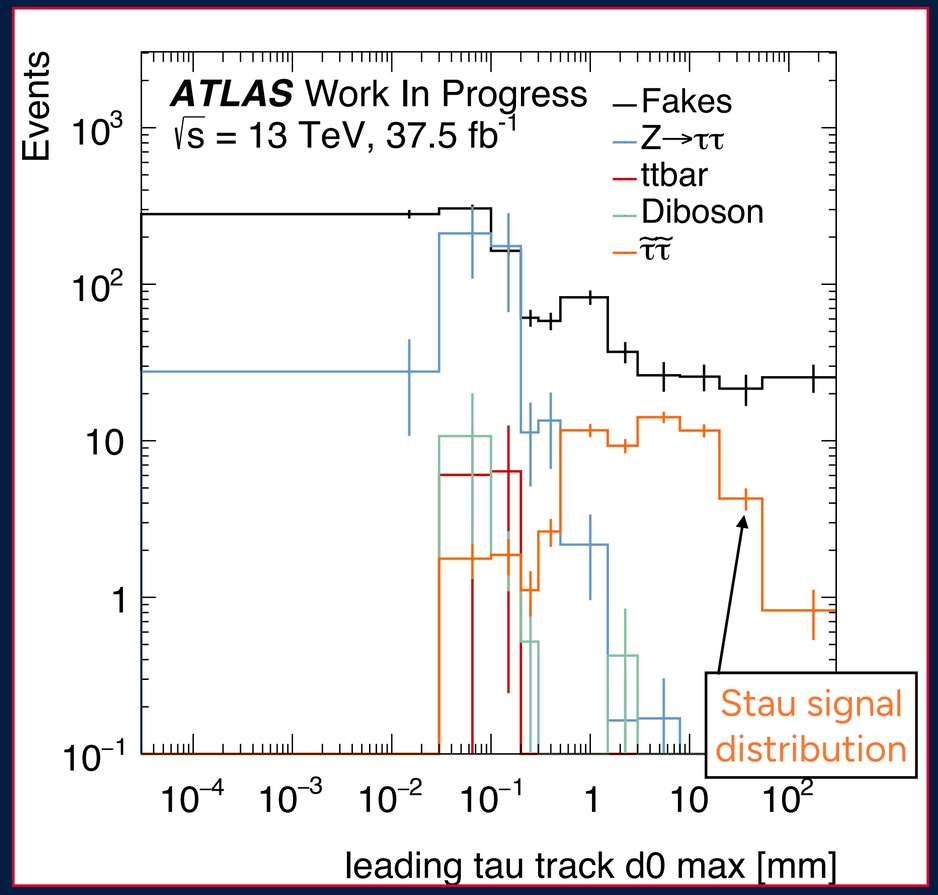

Displacement-dependent variables provide great discrimination against SM bkgs. **Asimov** dataset shown

Conclusion

- General particle detectors can be sensitive to new signatures with dedicated procedures
  - Unconventional approaches lead to interesting detector use
- Displaced taus produced from long-lived particles could be measured at ATLAS
  - Special handing of τ_{had} decays improves sensitivity
  - Dedicated reconstruction, identification and triggering deliver improvements
- Don’t shy away from strange signatures