

A search for displaced tau production
from long-lived particles at the
ATLAS experiment

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European Research Council

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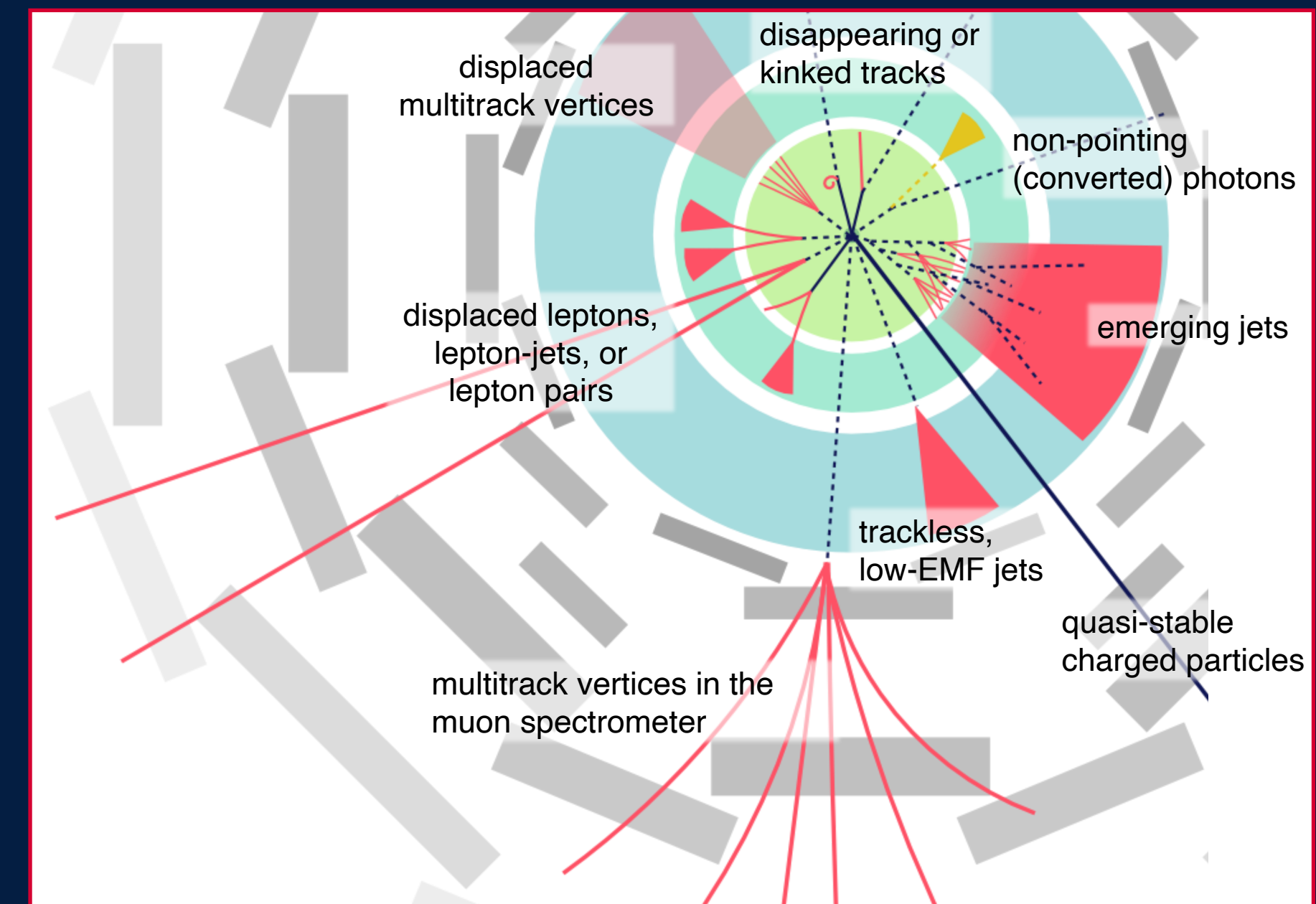
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2027/04/10

Long-Lived Particles and Displaced Signatures

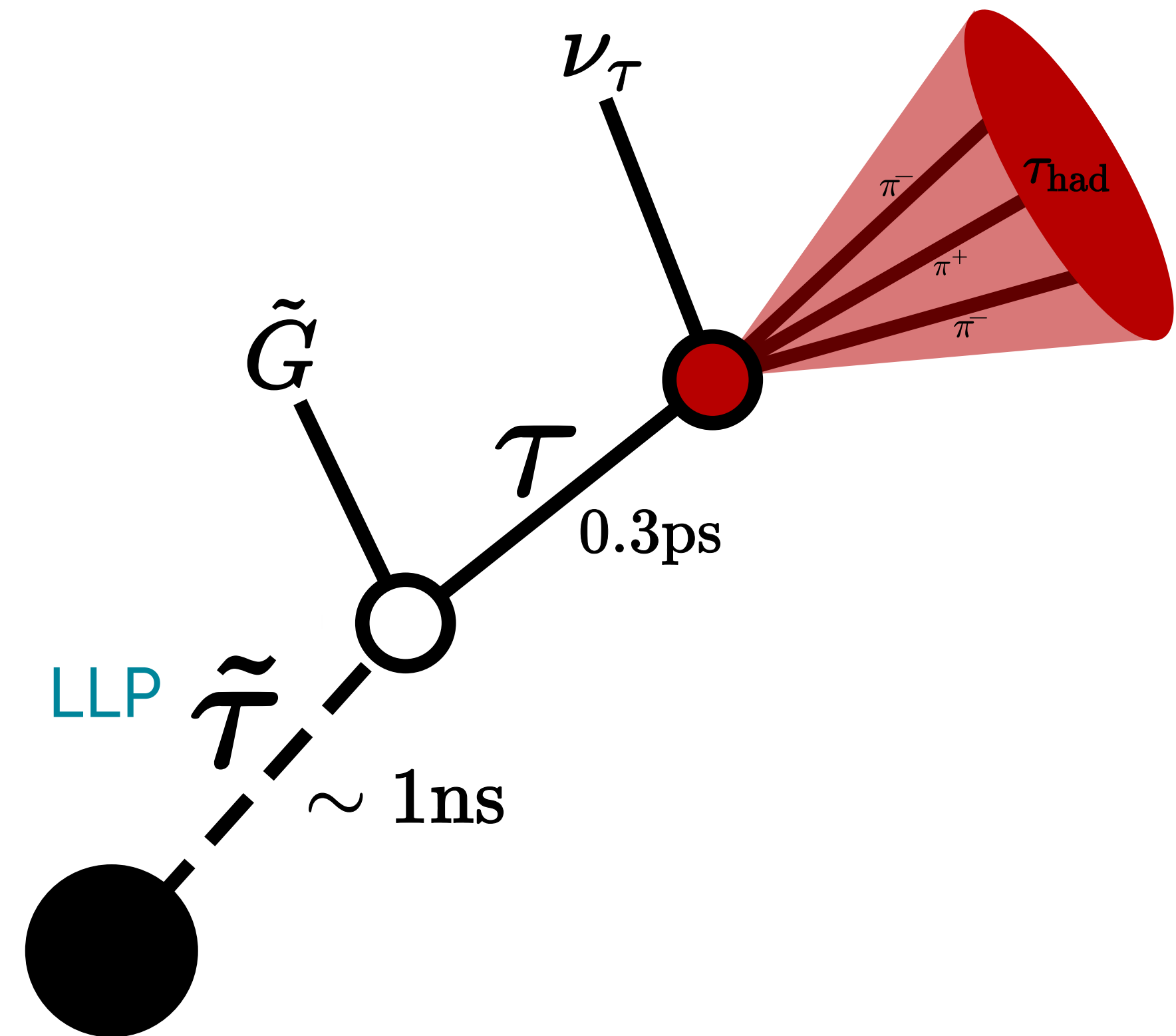
- ATLAS has a wide BSM searches program that typically targets models with prompt signatures
- What if new particles had a large lifetime?
 - Small $|\mathcal{M}_{a \rightarrow XY}|^2$
 - High mass particles
- Result: New unconventional experimental signatures from LLPs at ATLAS!
 - This talk about **displaced τ_{had} signatures**

$$\Gamma_{a \rightarrow XY} = \frac{\vec{k}}{32\pi^2 m_a^2} \int |\mathcal{M}_{a \rightarrow XY}|^2 d\Omega$$
$$\tau_a = \frac{\hbar}{\Gamma_a}$$



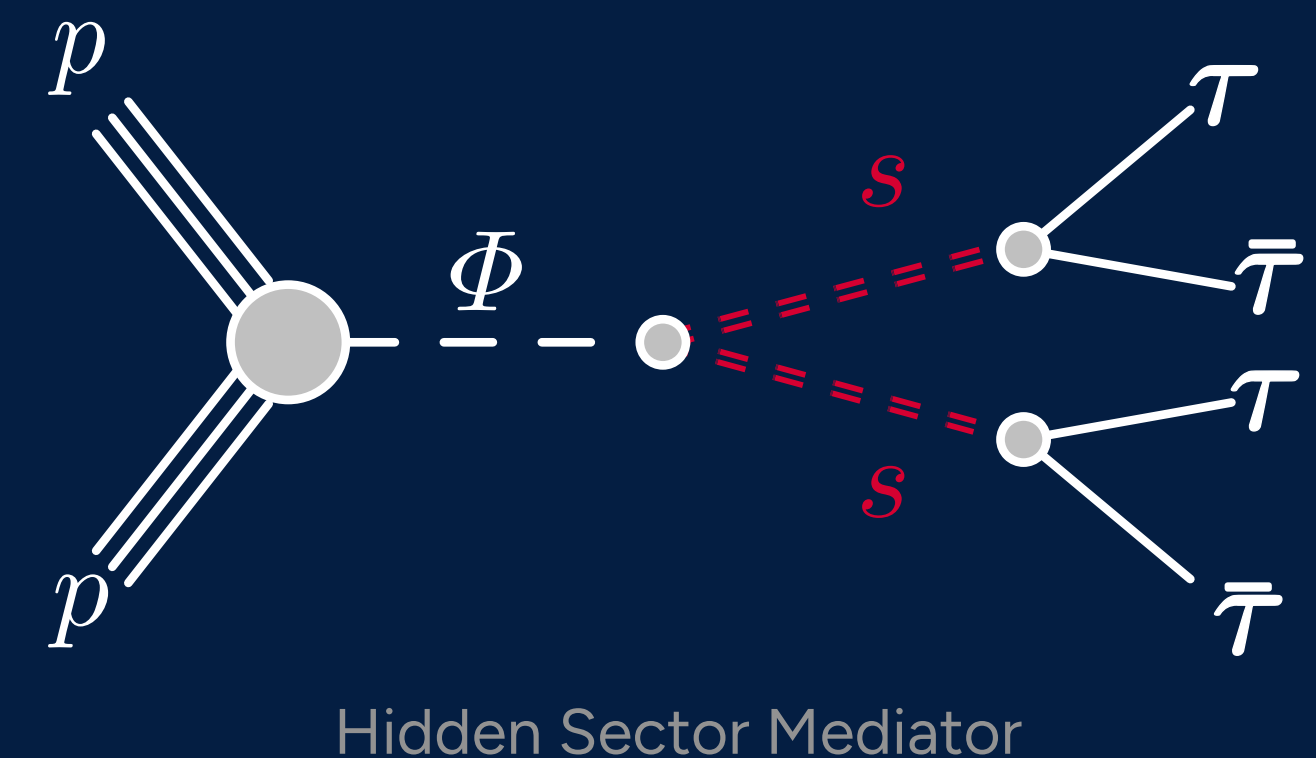
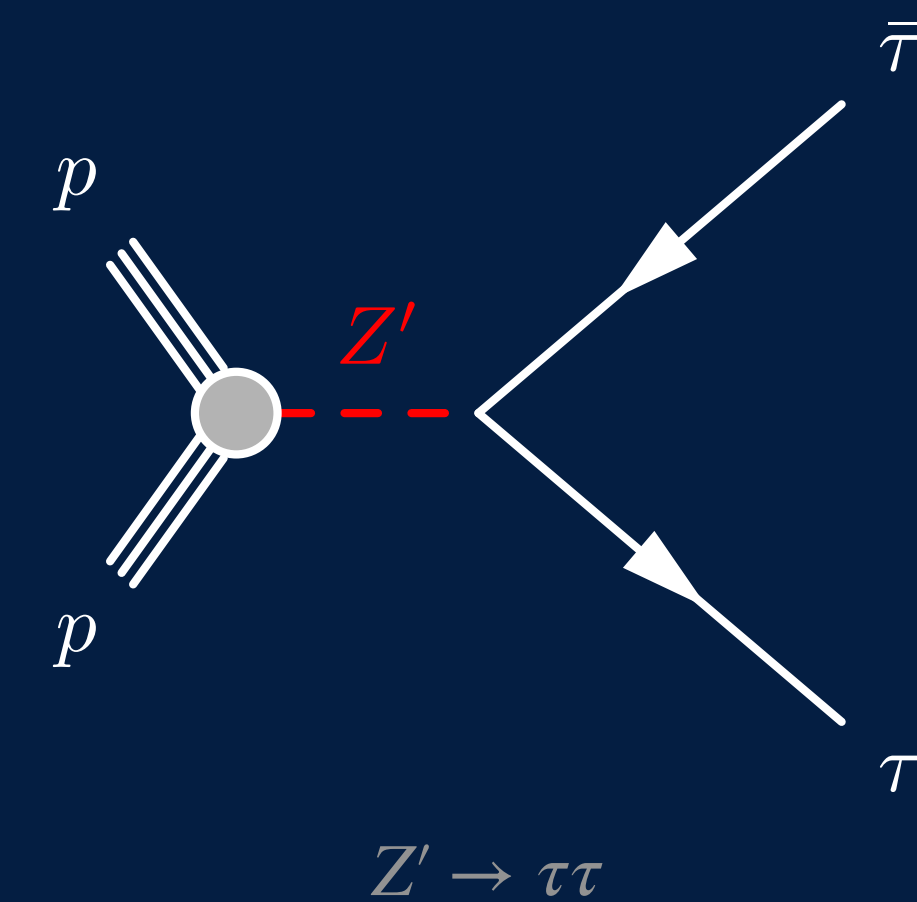
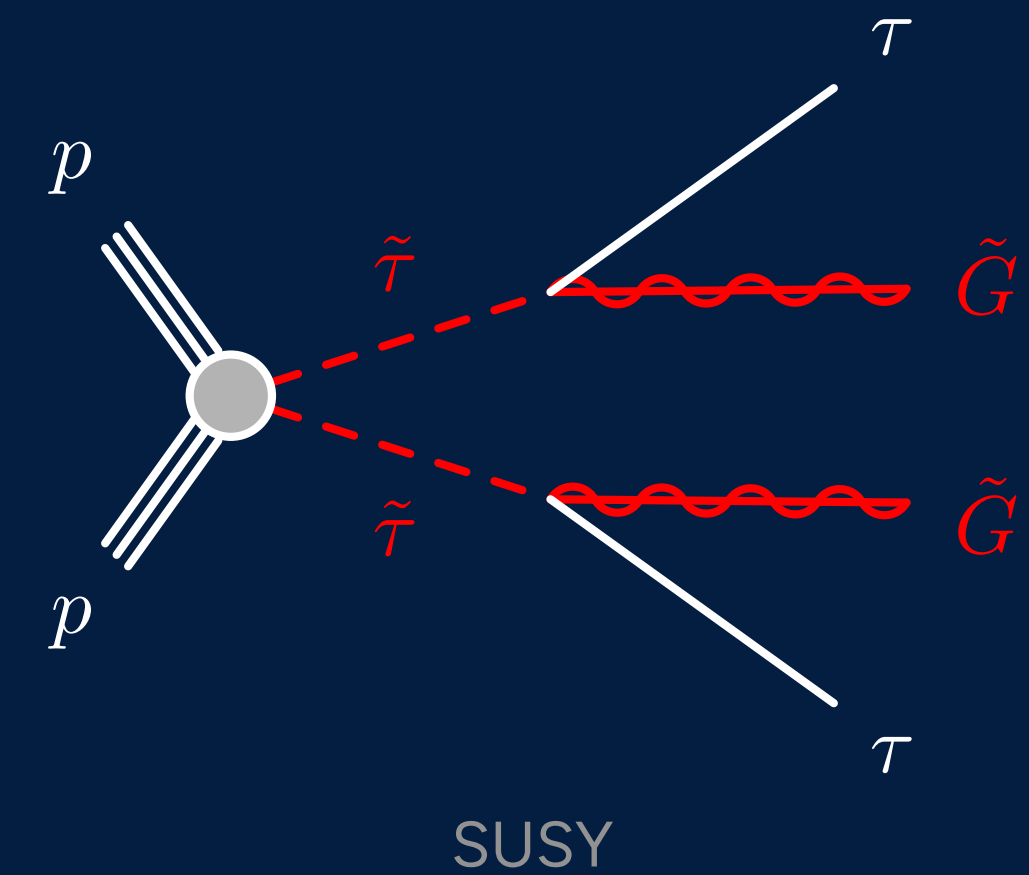
Displaced Tau Signature

- What is a displaced hadronically decaying tau?
 - SM tau decaying at a highly displaced vertex
 - Preferably in the tracking system of general particle detectors
- Kicked off with a 2019 [workshop](#) in Edinburgh
- Many possible sources of displaced taus
 - SUSY with stau $\tilde{\tau}$ as NLSP
 - Long-lived Z' particle
 - Higgs-like hidden sector mediators
 - Long-lived heavy neutral leptons



Displaced Tau Signature

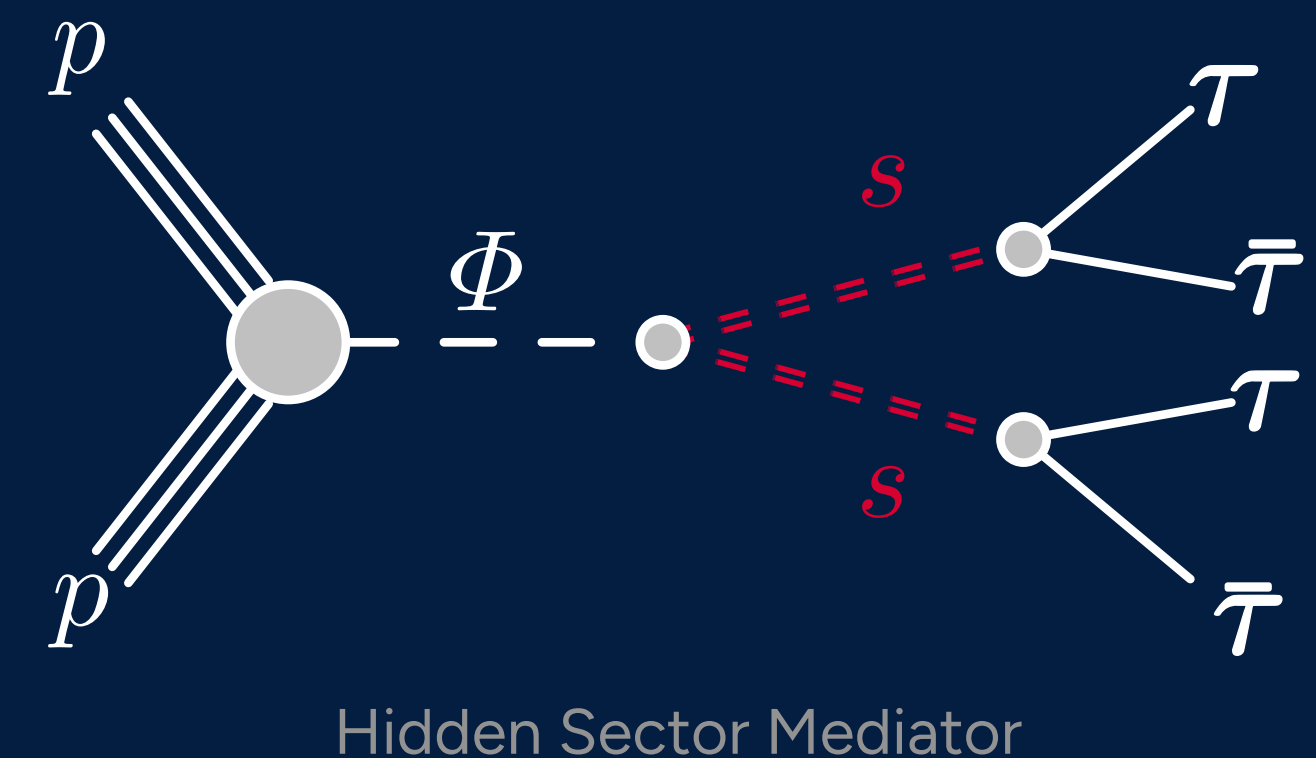
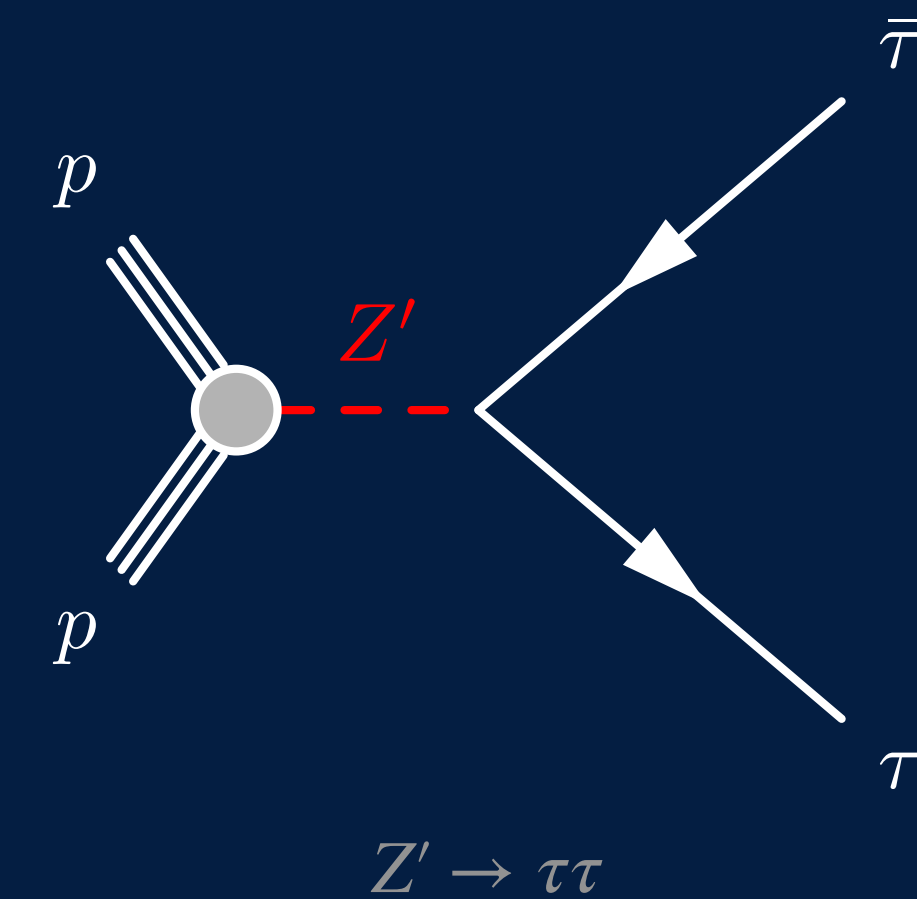
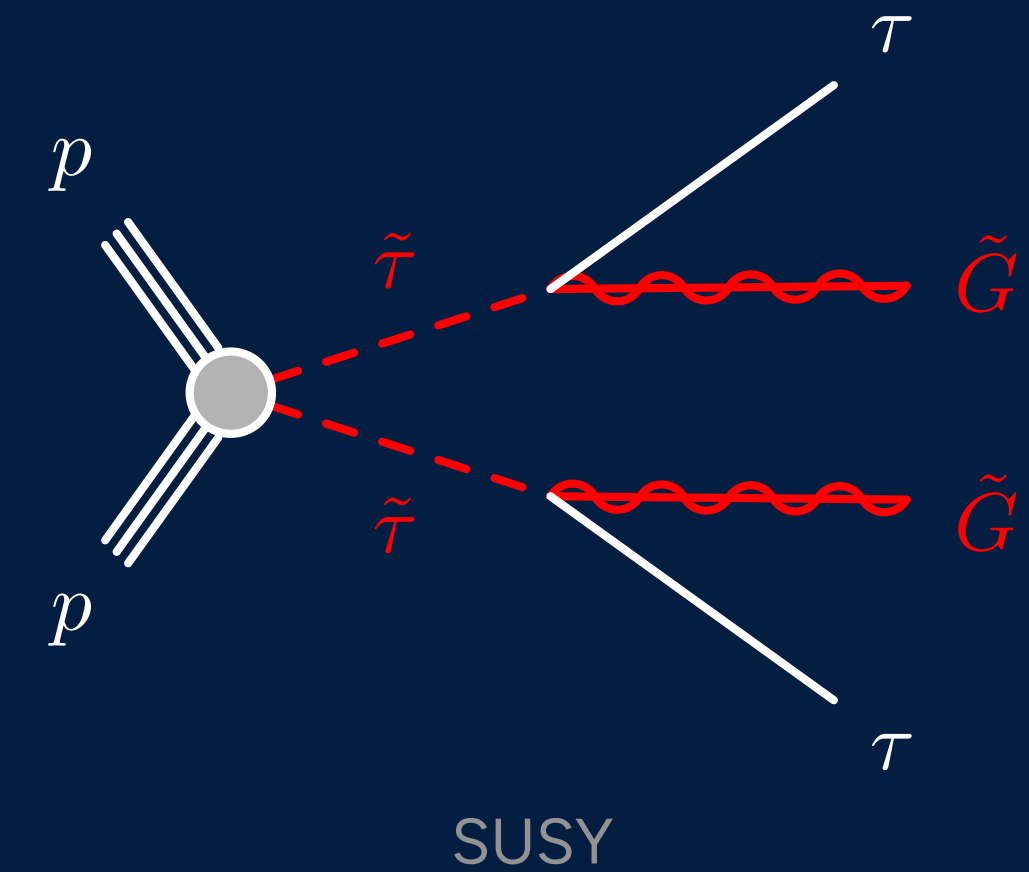
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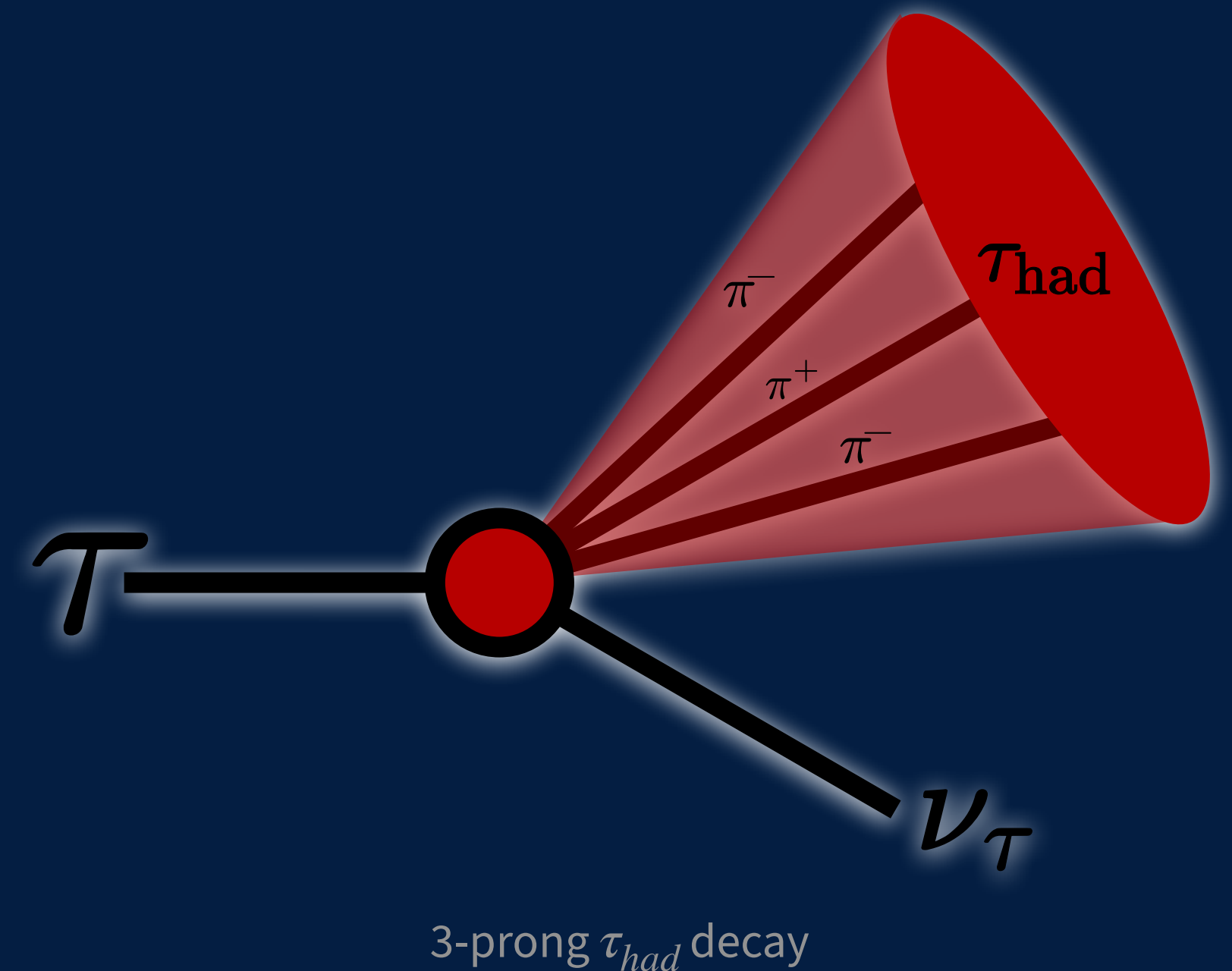
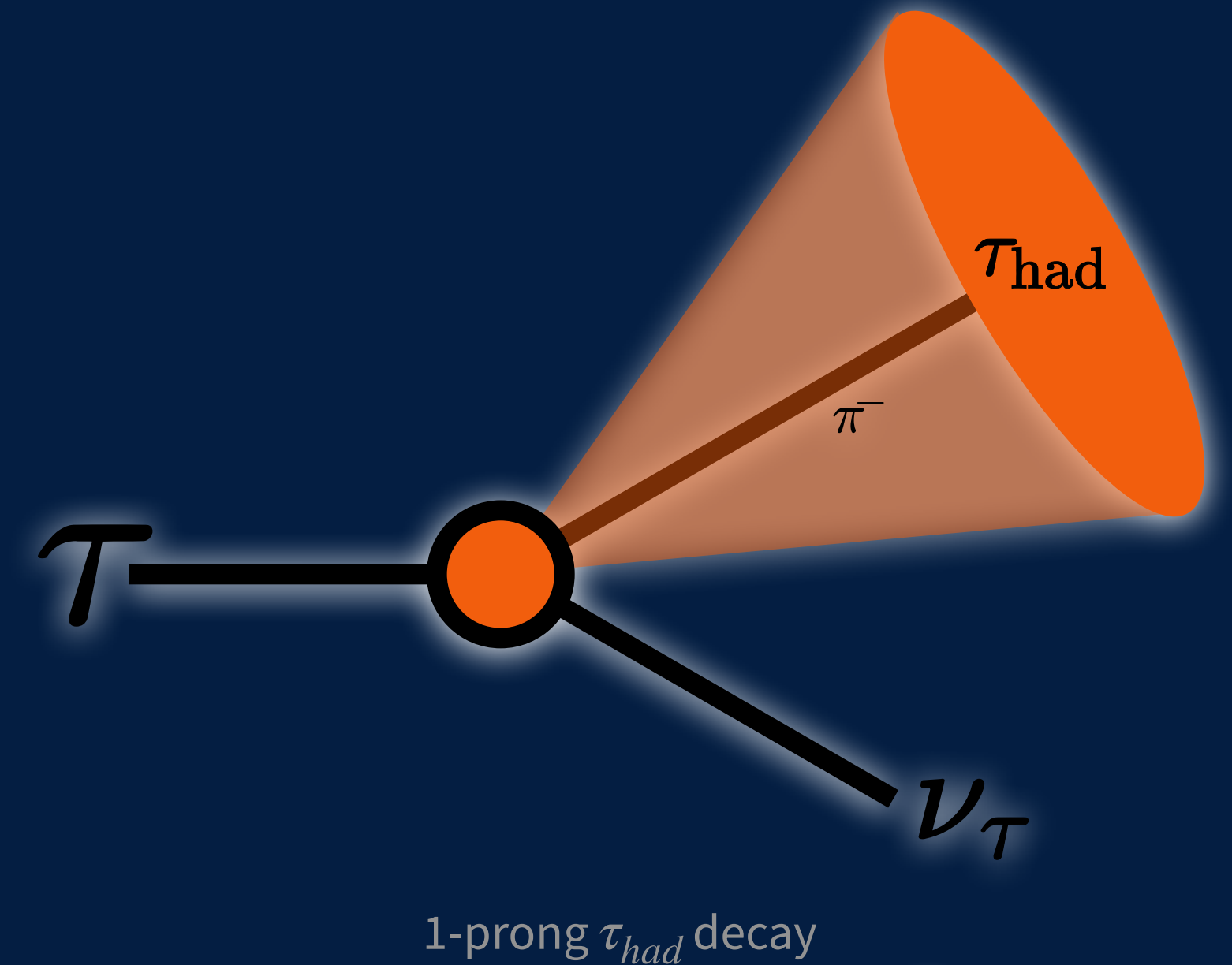
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But what does a τ_{had} decay look like in the ATLAS detector?



What does a displaced τ_{had} look like

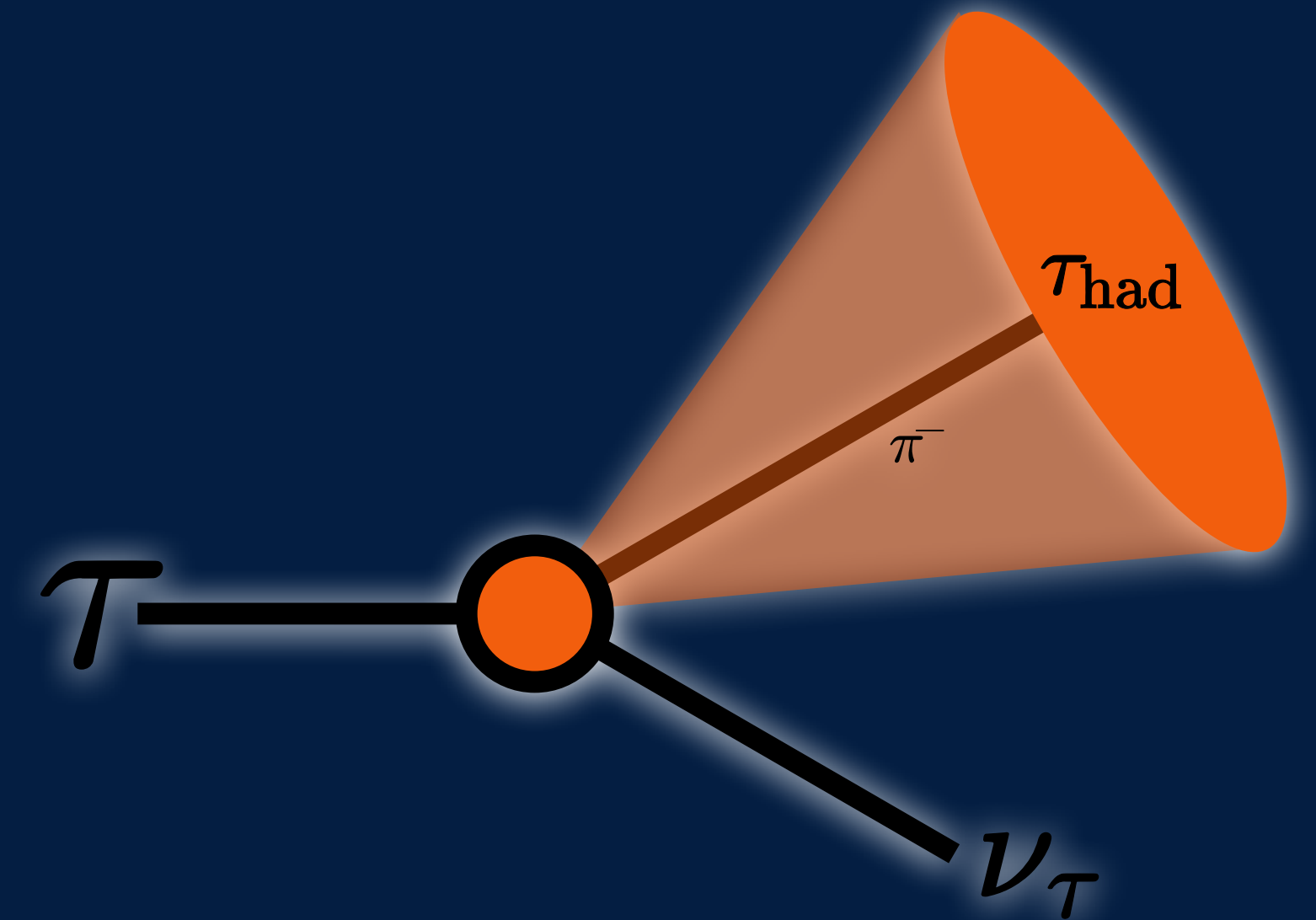
- Collimated jet in the calorimeter
- Displaced tracks (or prongs) from π/K in the tracking system
 - Need to reconstruct **displaced track**
 - Also need to **classify tracks** as either from tau or not
- These provide a distinct signature
 - Can discriminate **displaced tau jets** from **QCD-induced jets**



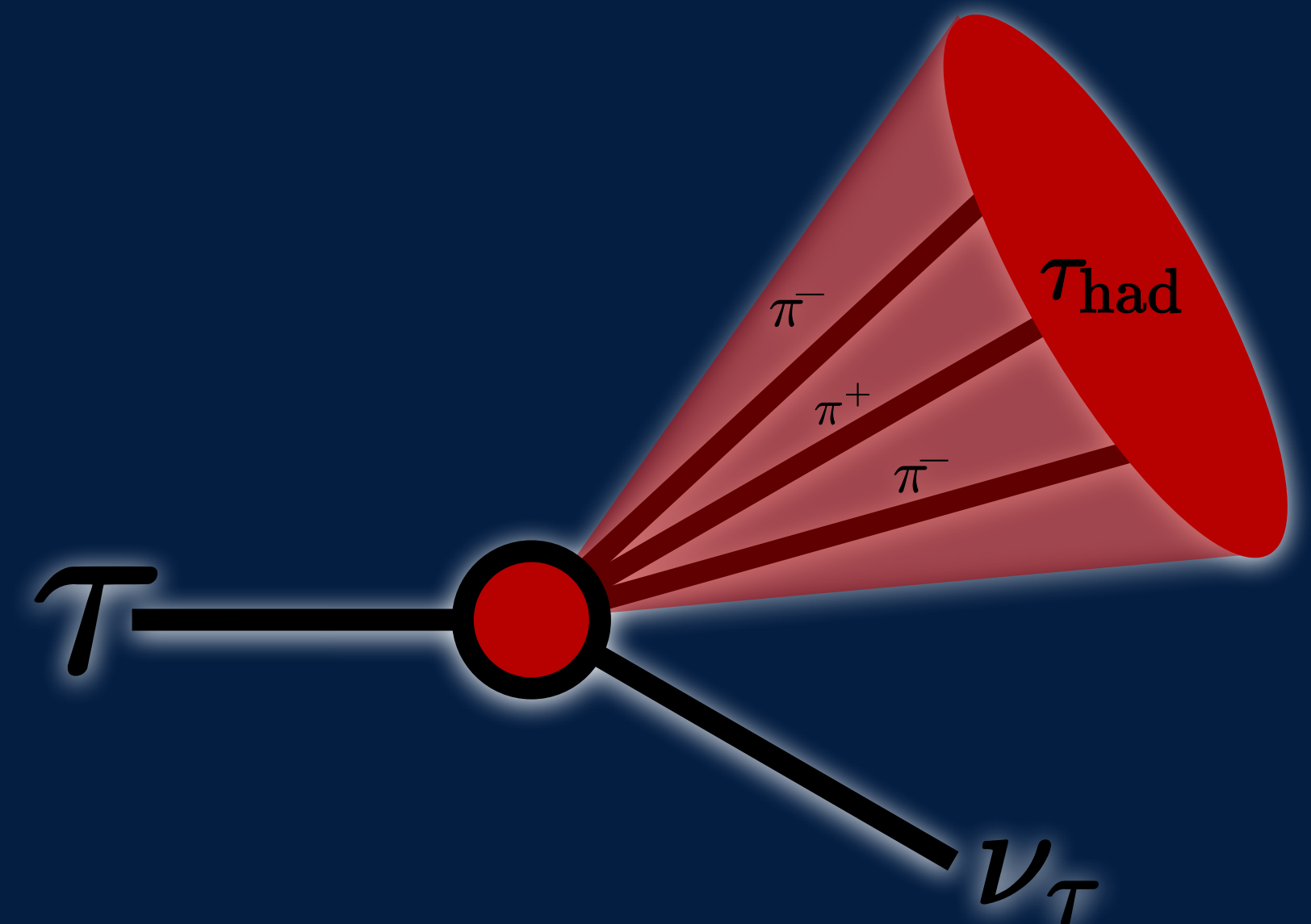
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Issue: ATLAS tracking was not designed for reconstructing highly displaced tracks...



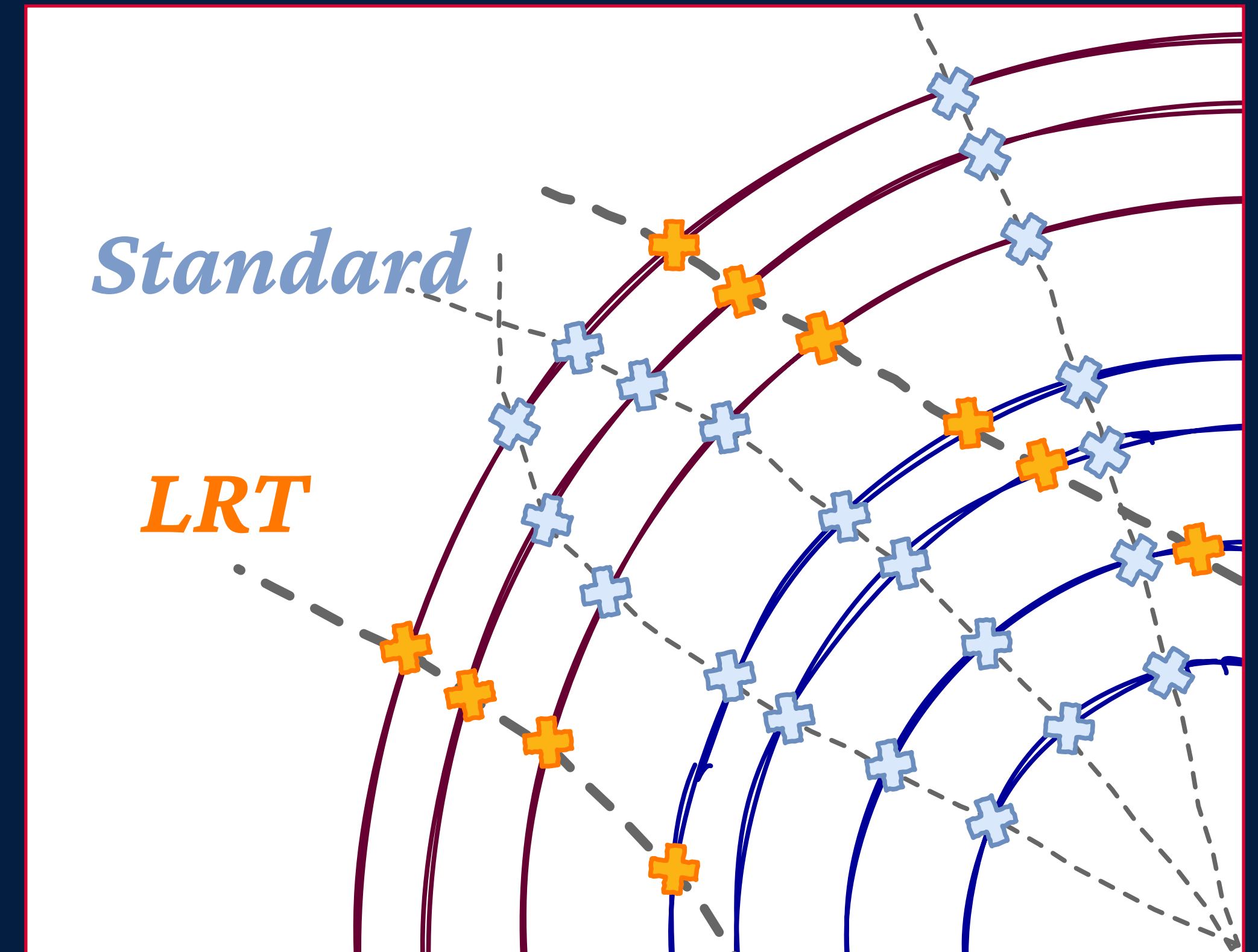
1-prong τ_{had} decay



3-prong τ_{had} decay

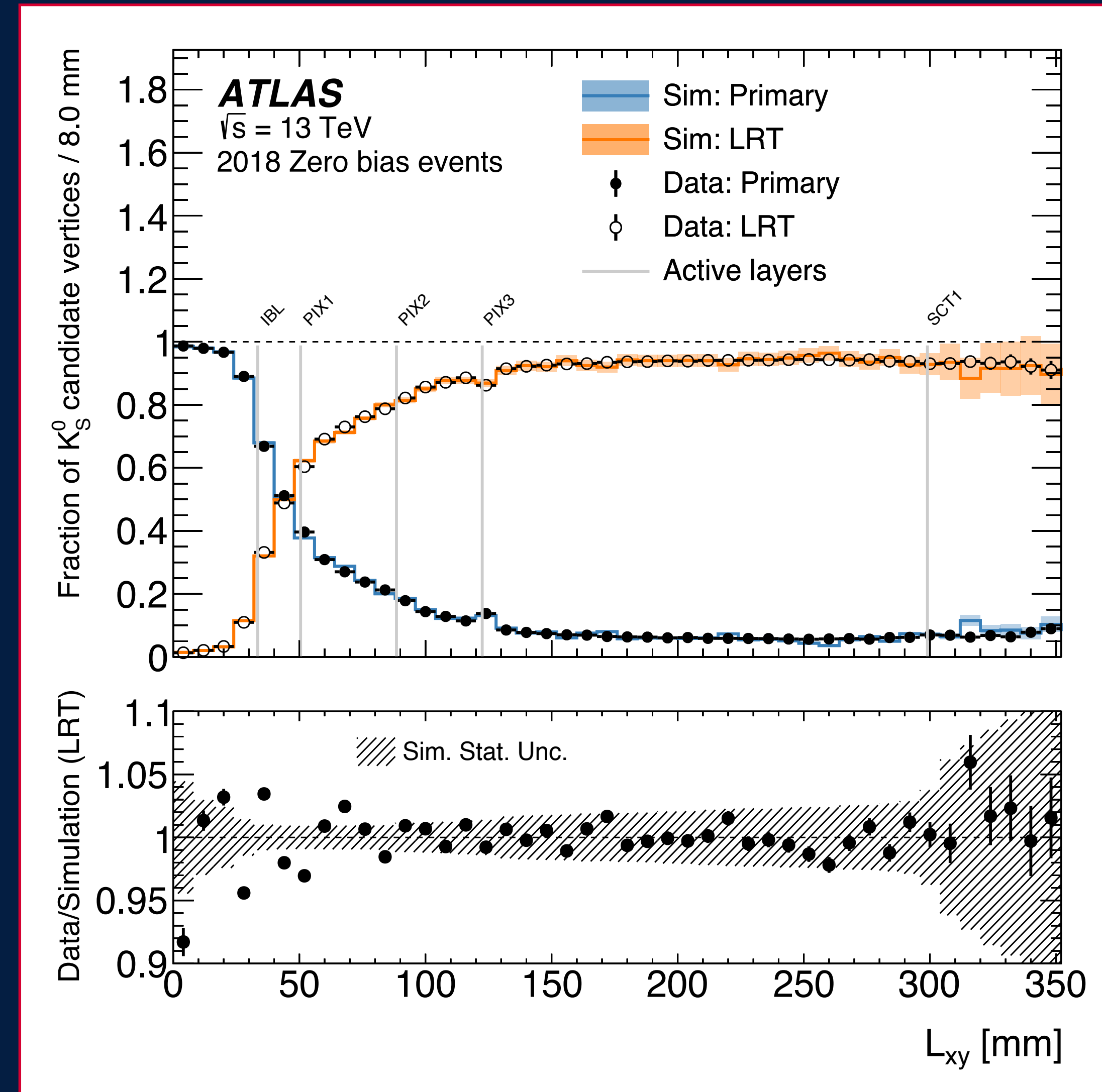
Large Radius Tracking

- Large Radius Tracking (LRT) algorithm [Eur. Phys. J. C 83 (2023) 1081] allows for the reconstruction of highly displaced tracks
 - $IP_{trans.} < 5\text{mm} \rightarrow IP_{trans.} < 300\text{mm}$ (beginning of SCT)
 - $IP_{long.} < 200\text{mm} \rightarrow IP_{long.} < 500\text{mm}$
- 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)



Large Radius Tracking

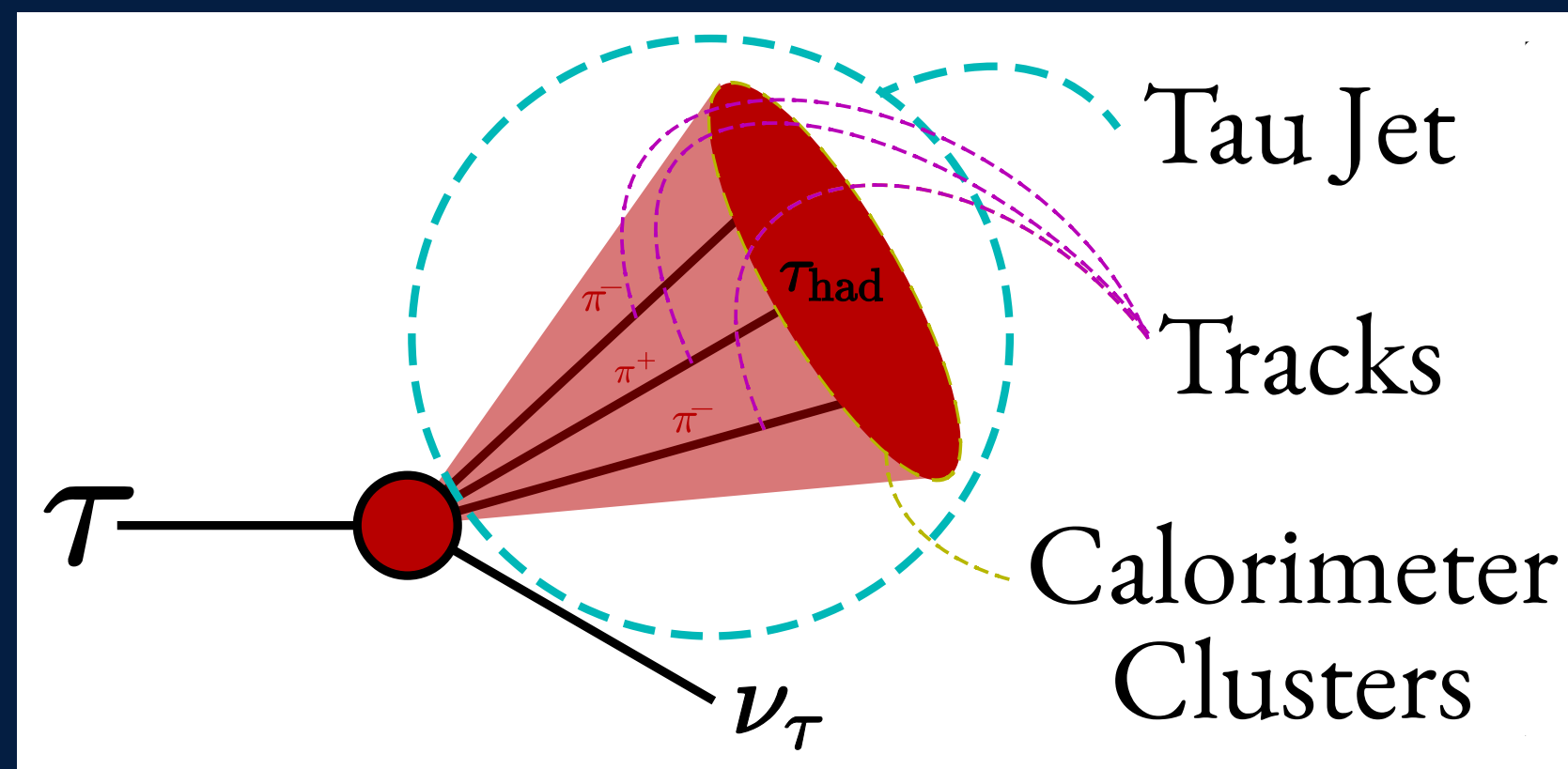
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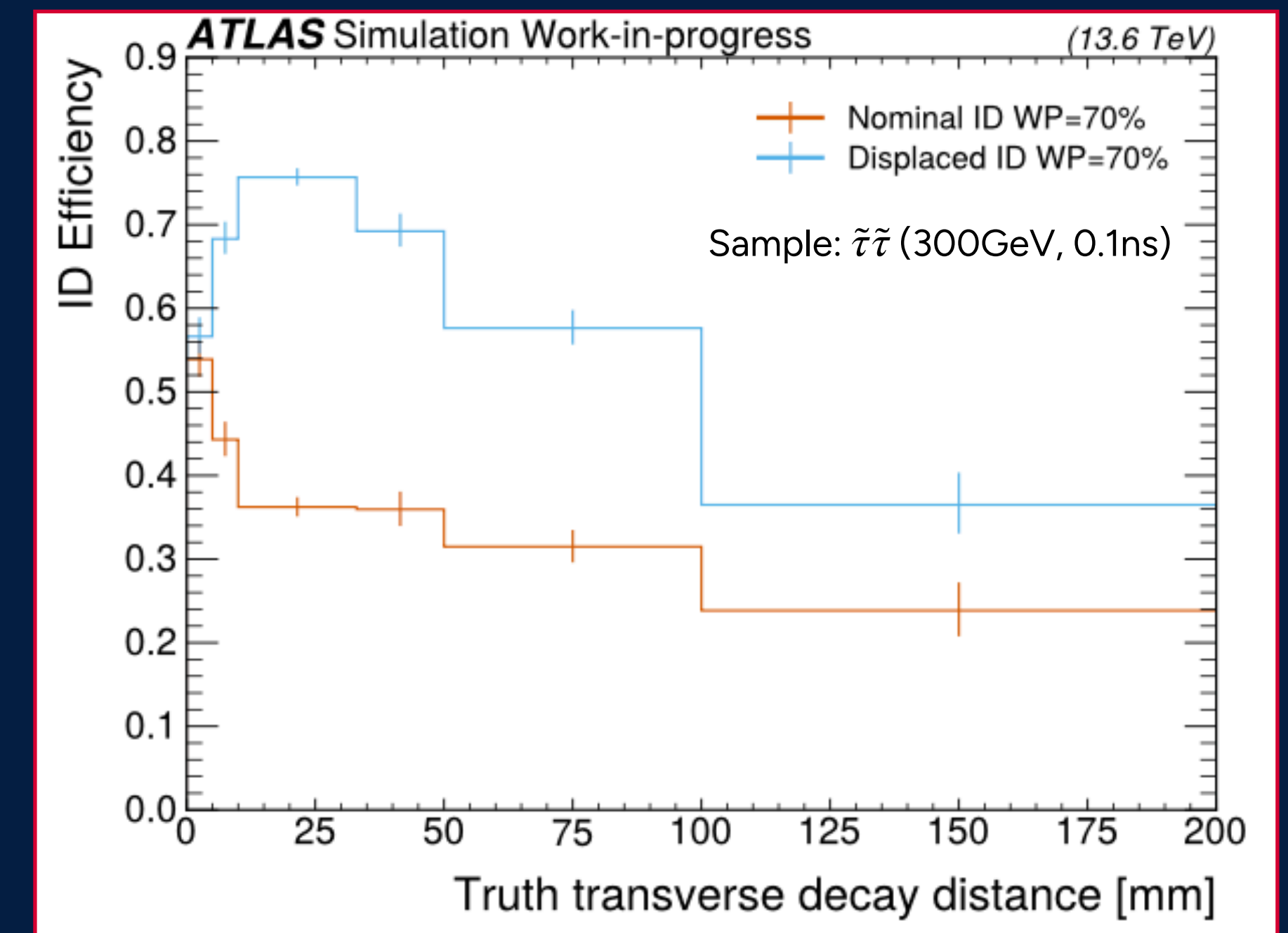
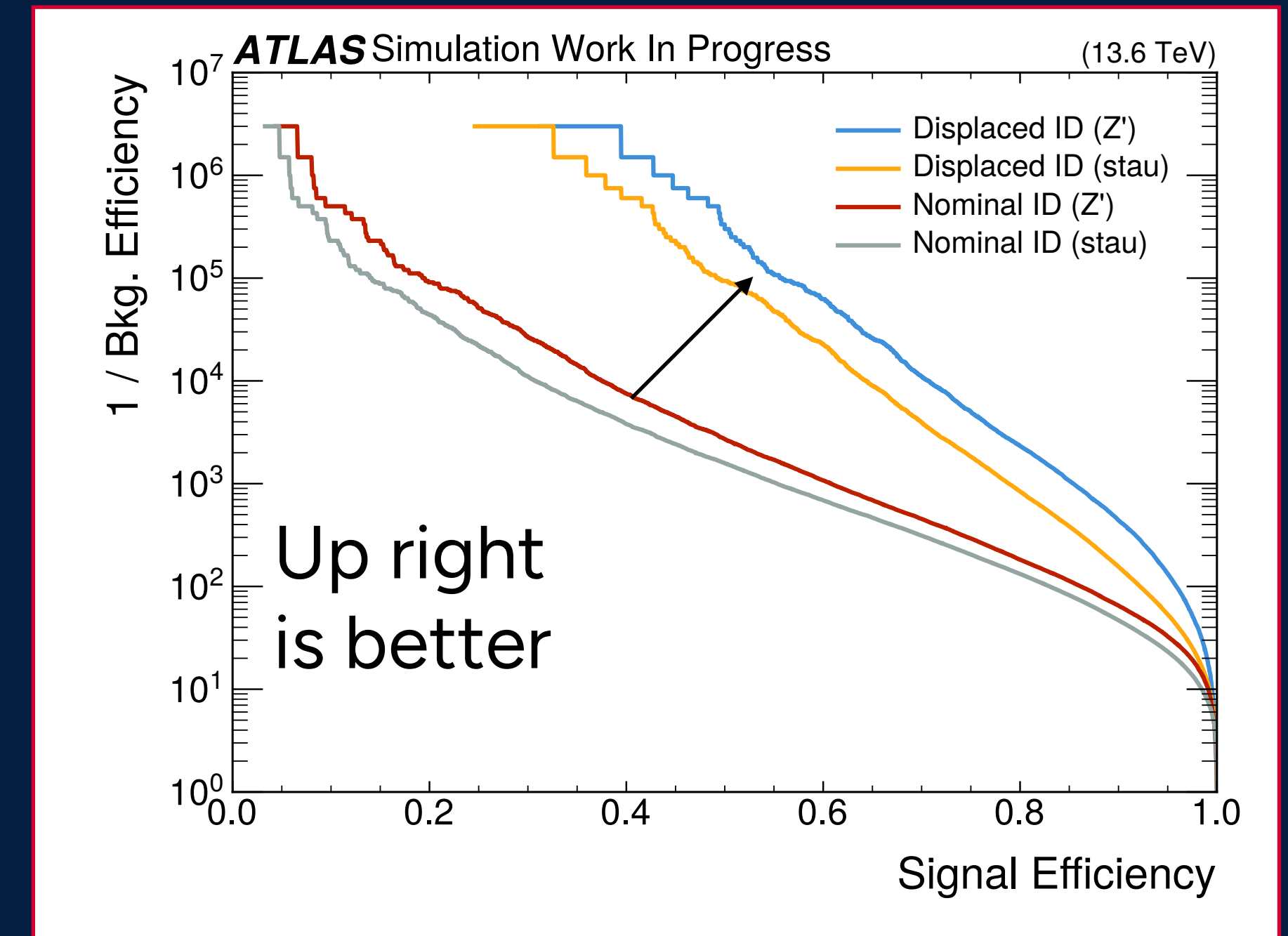
Vertex reconstruction performance w.r.t transverse decay distance
[Eur. Phys. J. C 83 (2023) 1081]

Identification algorithm

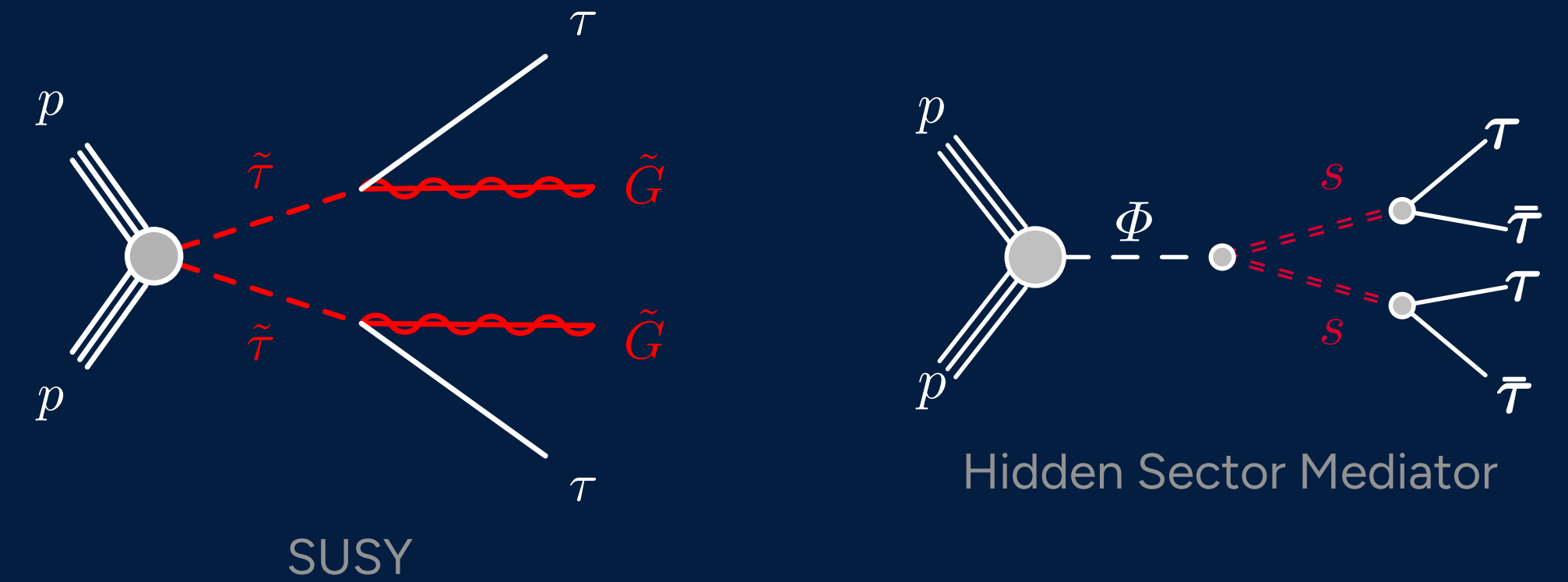
- Major background when reconstructing tau jets are QCD-induced jets
- Need procedure for deciding tau jet vs QCD jet → tau ID
 - Retrained ATLAS tau ID with simulated displaced tau jets and QCD jets
- Algorithm inputs



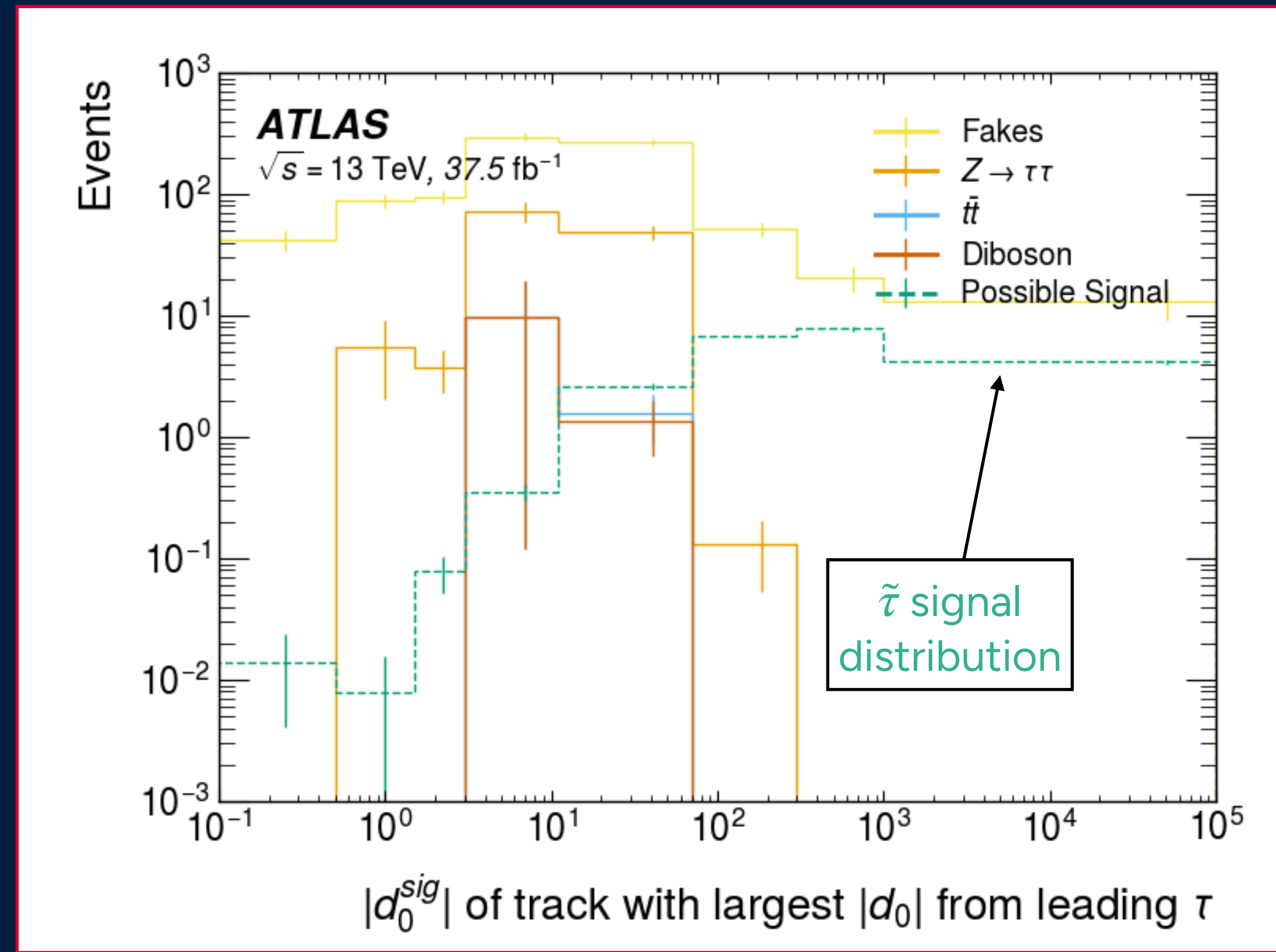
- Improved signal/background discrimination compared to nominal
- RNN-based model in Run 2, Transformer-based in Run 3
 - Run 3 version results shown on slide



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)
- Only using 37.5 fb^{-1} in had-had, 58.8 fb^{-1} in lep-had of 2018 data
 - Limited by trigger choice
- Designed for **model independence**, leveraging ID algorithm
 - Plus model-dependent limits
 - Gauge-Mediated Symmetry Breaking SUSY [Expected limits shown today]
 - Higgs-like hidden sector mediator [planned]
- Major background is fake taus from QCD-jets
 - Hard to model with MC → Data-driven approach



Displacement-dependent variables provide great discrimination against SM bkg. **Data not shown**

Channel Selections

- Defined by trigger choice and number of displaced objects
 - Trigger strategy avoids tracking requirements
 - Displaced tau τ_{displ} defined by displaced tau ID scores
 - Displaced light leptons e_{displ} and μ_{displ} must have $|IP_{trans.}| > 3\text{mm}$

mu-had

Single muon in Muon Spectrometer trigger

$$\mu_{displ} = 1 \text{ AND } \tau_{displ} \geq 1$$

e-had

Trigger: Single photon trigger

$$e_{displ} = 1 \text{ AND } \tau_{displ} \geq 1$$

had-had

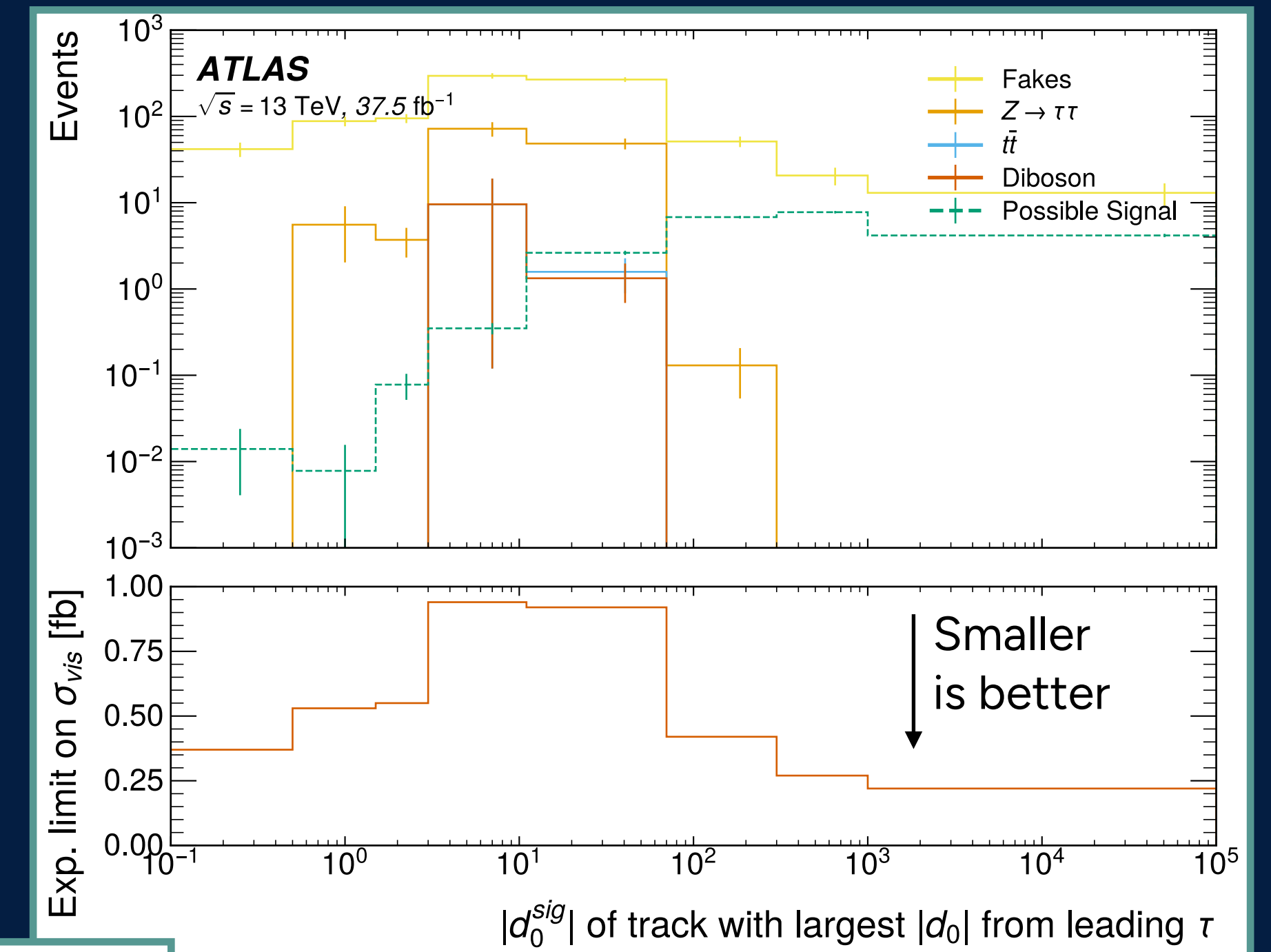
RNN-based tau trigger (only available in 2018)

$$\tau_{displ} \geq 2 \text{ AND } \ell_{displ} = 0$$

Preliminary model independent expected limits

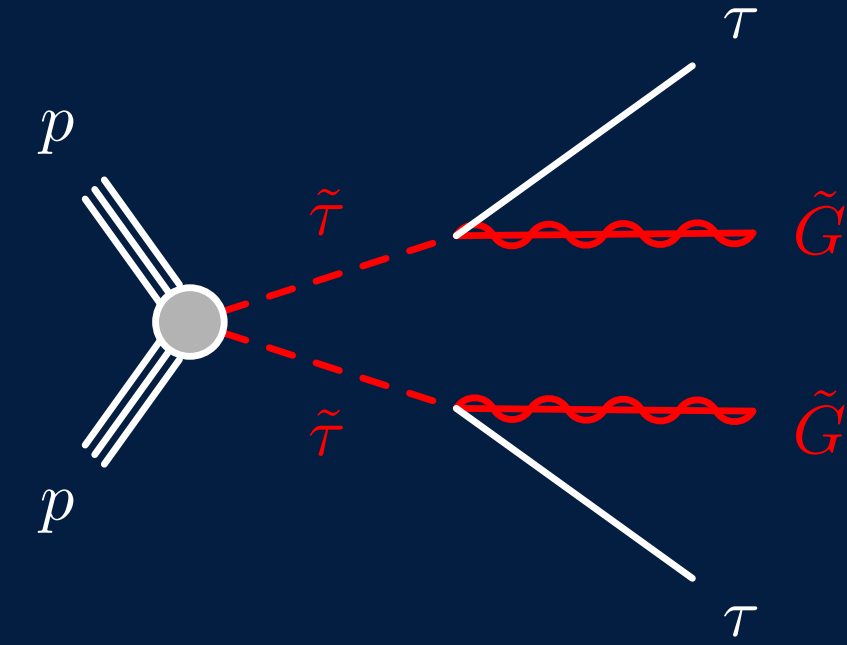
- Many possible models can produce displaced taus
 - Model independent limits can be compared to any new model
- Different discovery fit strategies in each region
 - $\tau_\mu \tau_{had}$ and $\tau_e \tau_{had}$ are independent single bin fits
 - $\tau_{had} \tau_{had}$ is done in independent per-bin fits in displacement-dependent variable
- Shown results are for an **Asimov** dataset

Discovery Region	Expected Limit on vis. xsec [fb]
mu-had	0.06
e-had	0.12

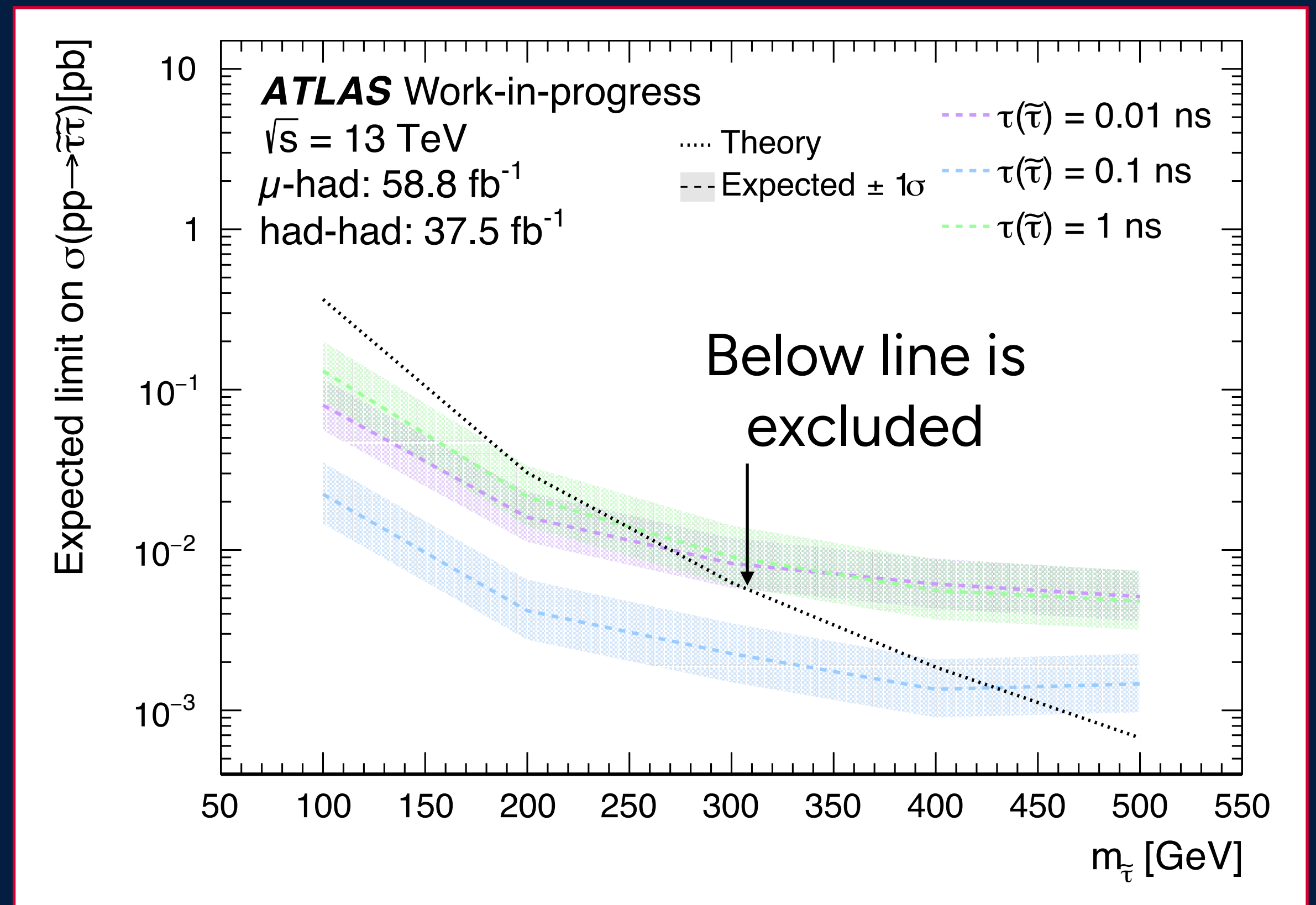


$$d_0^{sig} = d_0 / \sigma(d_0)$$

Preliminary $\tilde{\tau}\tilde{\tau}$ exclusion limits



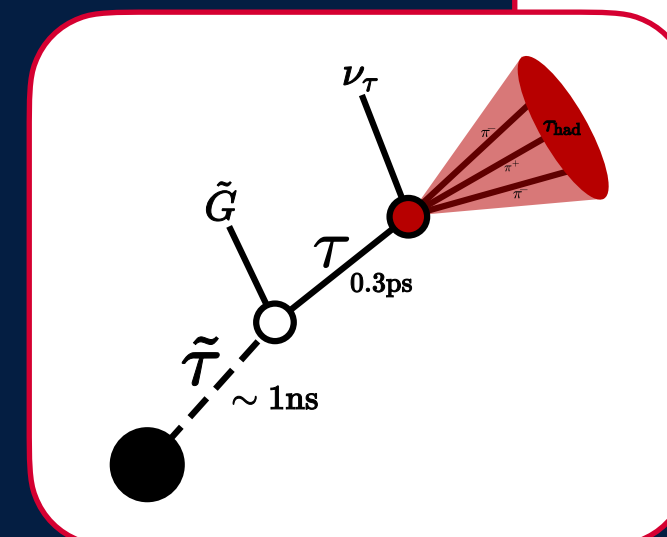
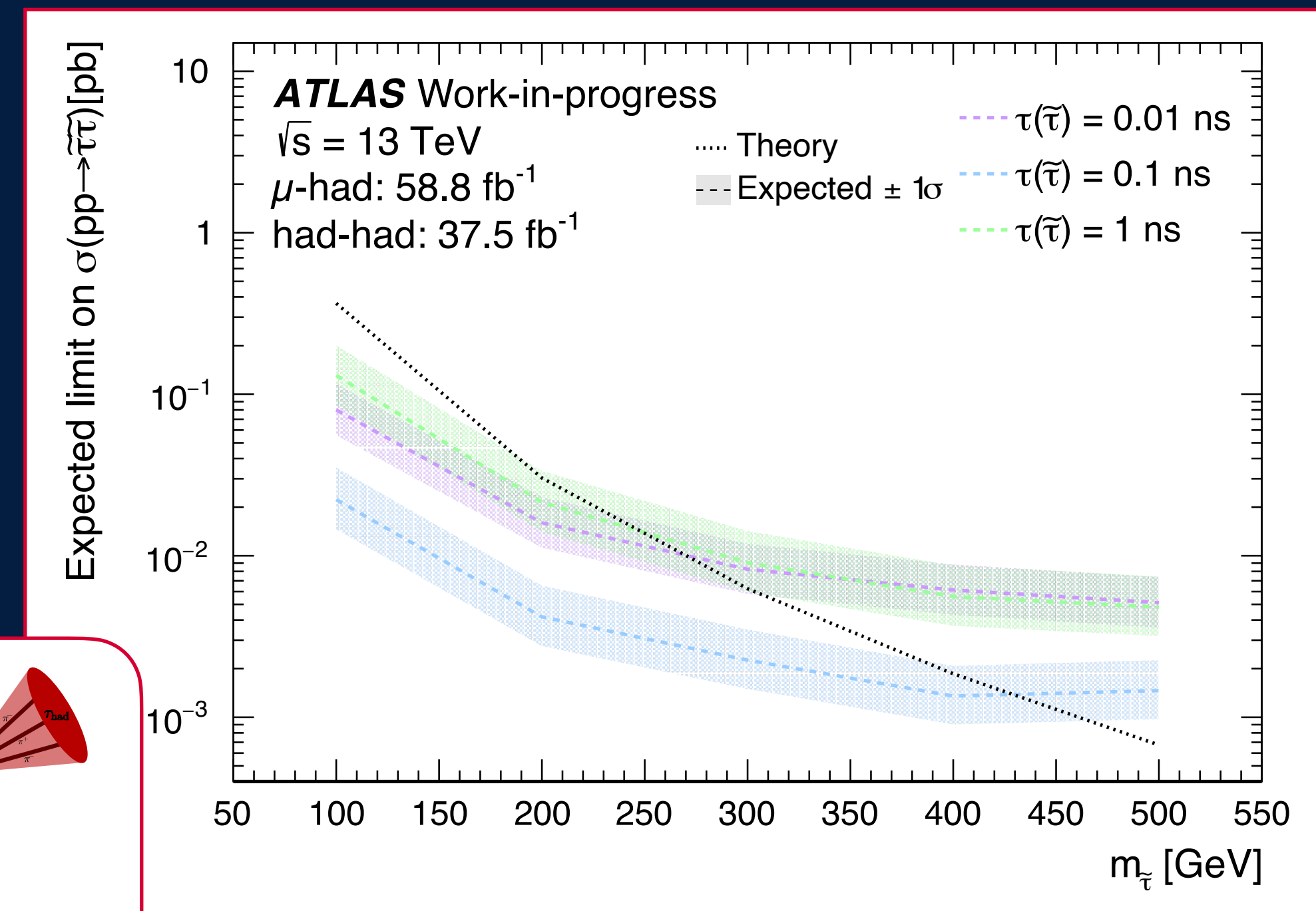
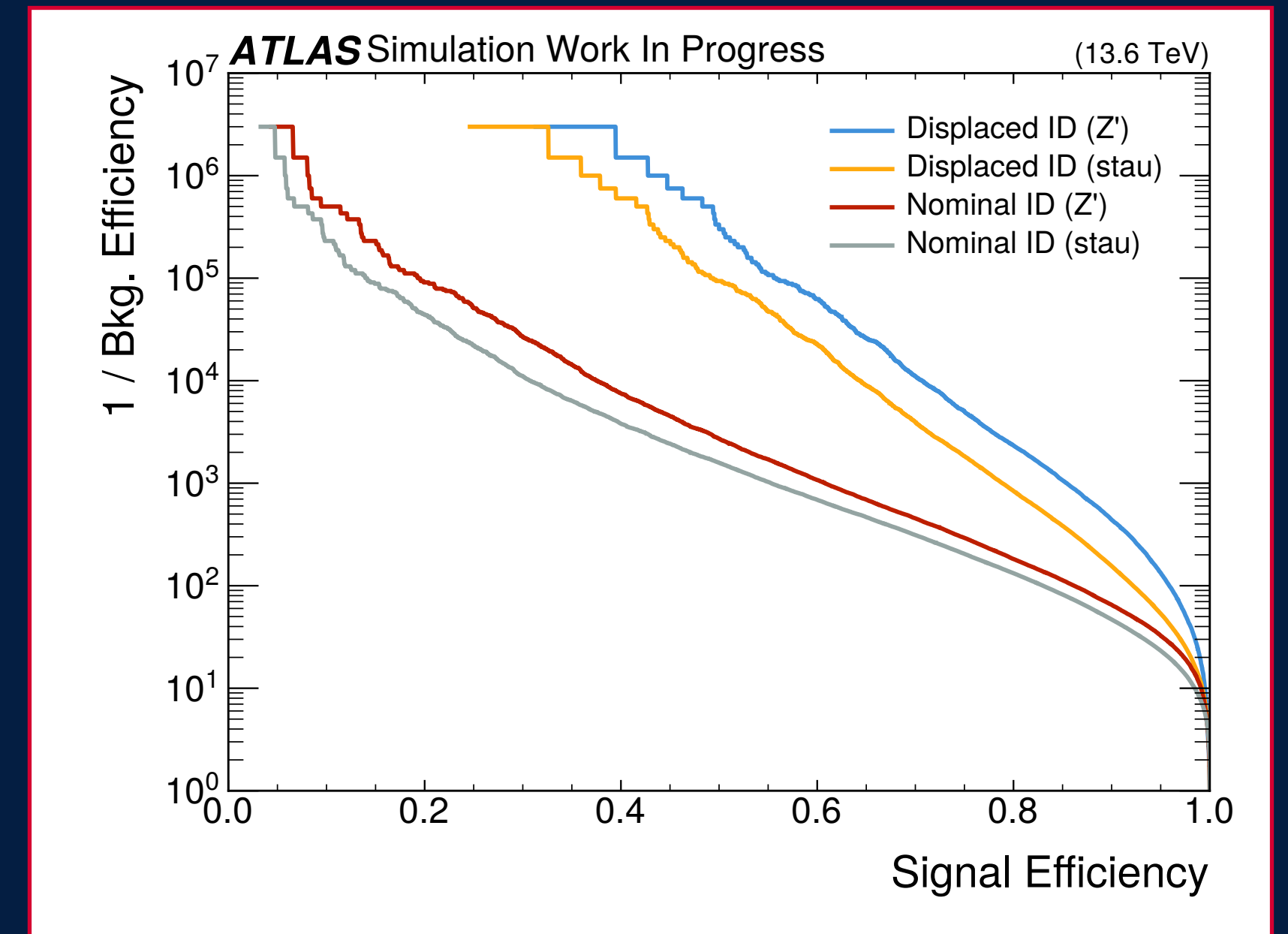
- Preliminary expected limits as still WIP
 - Missing some experimental systematics
 - Expected to be statistically limited
- Combined fit of mu-had and had-had
- Highest sensitivity to $\tau_0=0.1\text{ns}$
 - Avoids SM bkg's but still has decent track reconstruction efficiency
- Limit is mostly driven by $\tau_\mu\tau_{had}$
 - Muon Spectrometer trigger allows for a larger τ_{had} energies to be accepted



Combined expected sensitivity on an Asimov dataset

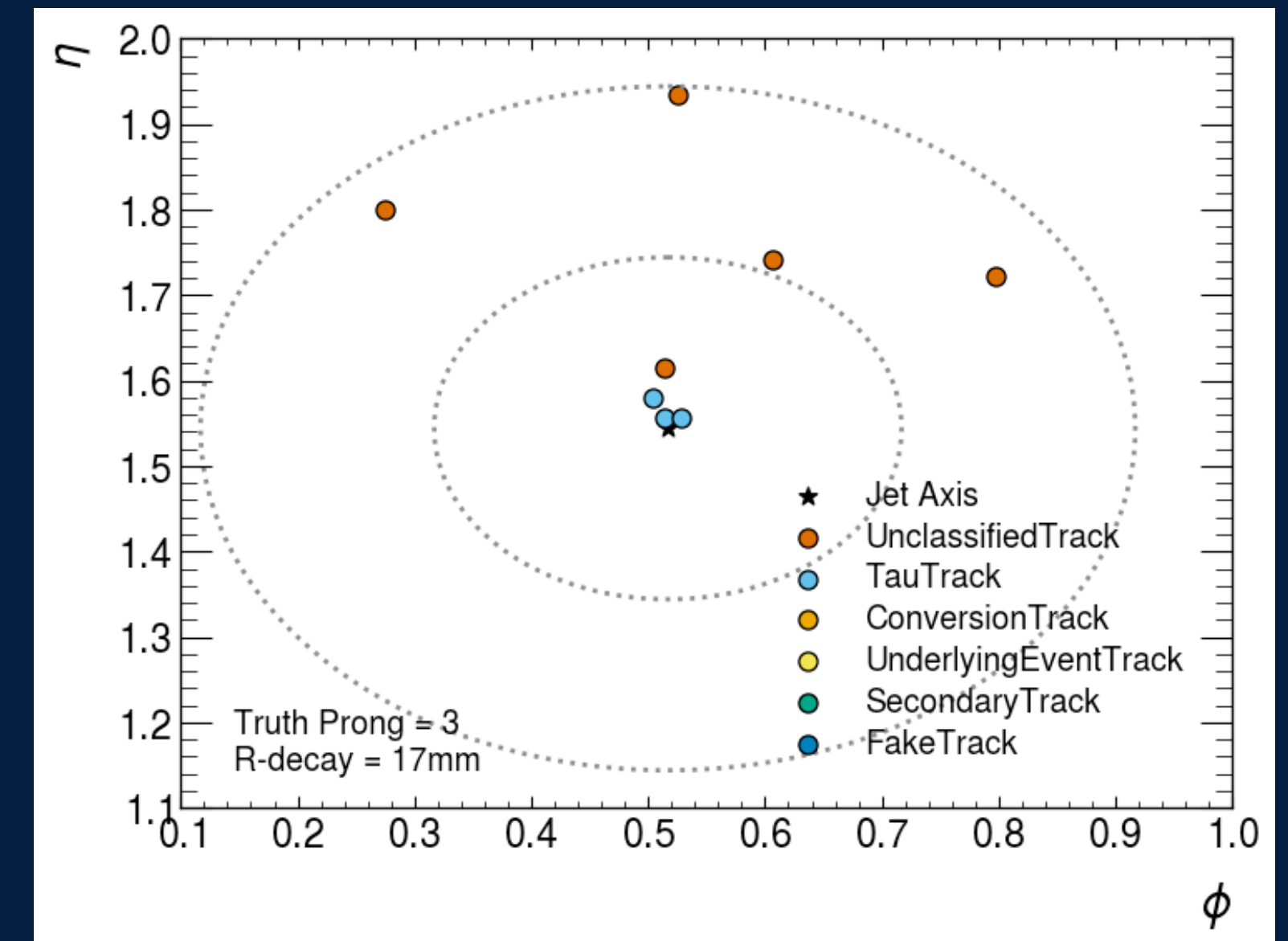
Conclusion

- Displaced taus could be produced by BSM models with long-lived particles
- A dedicated search for this signature is underway
 - Displaced tau reconstruction with highly displaced tracks
 - Displaced tau identification
- Analysis is setting both model independent and dependent limits
- Run 3 analysis is planned
 - More data
 - Dedicated LLP tau triggers
 - Better displaced tracking performance



Tau Track Classifier for LRT tracks

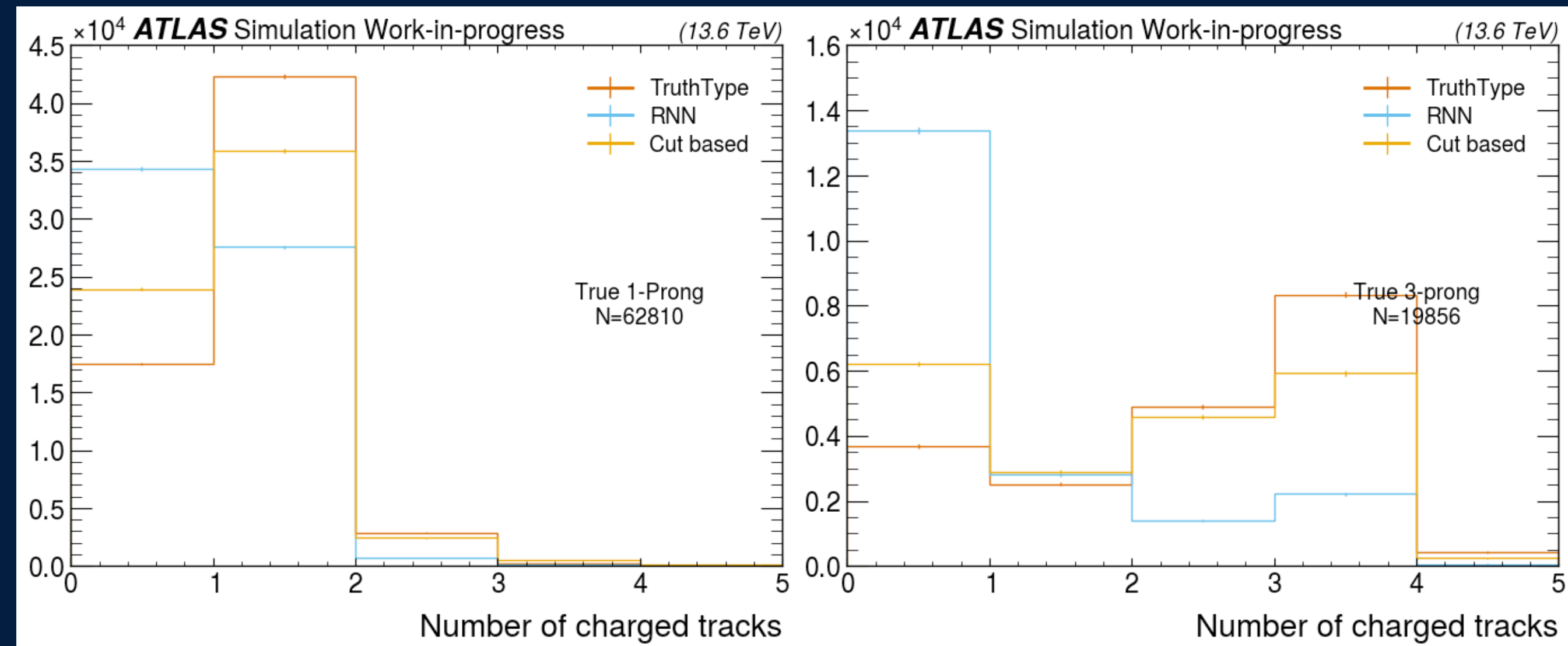
- Track classification step identifies charged tracks out of the associated tracks
 - Affects tau reconstruction, unlike ID
- Standard tau track classification uses a recurrent neural network trained on prompt taus
 - Displaced charged tracks are often misclassified as fake or conversion
- Dedicated classifier for LRT tracks provides discrimination against QCD jets



Example 3-prong tau

Performance gain is blue to yellow

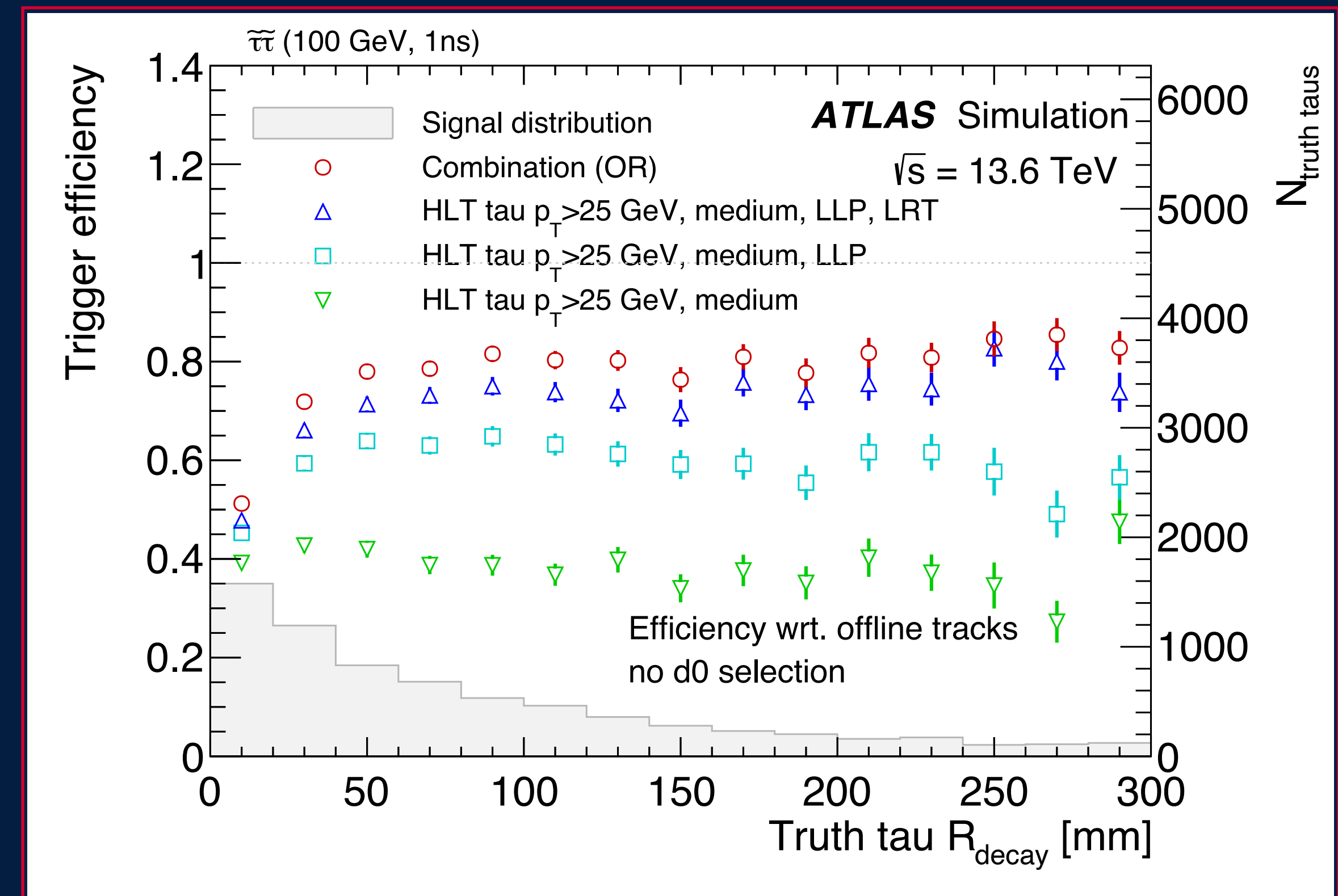
Sample: $Z' \rightarrow \tau\tau$ (500GeV, 1ns)



Signature based Triggers: Displaced τ_{had} trigger

Approx. 60% eff. gain at higher decay radii

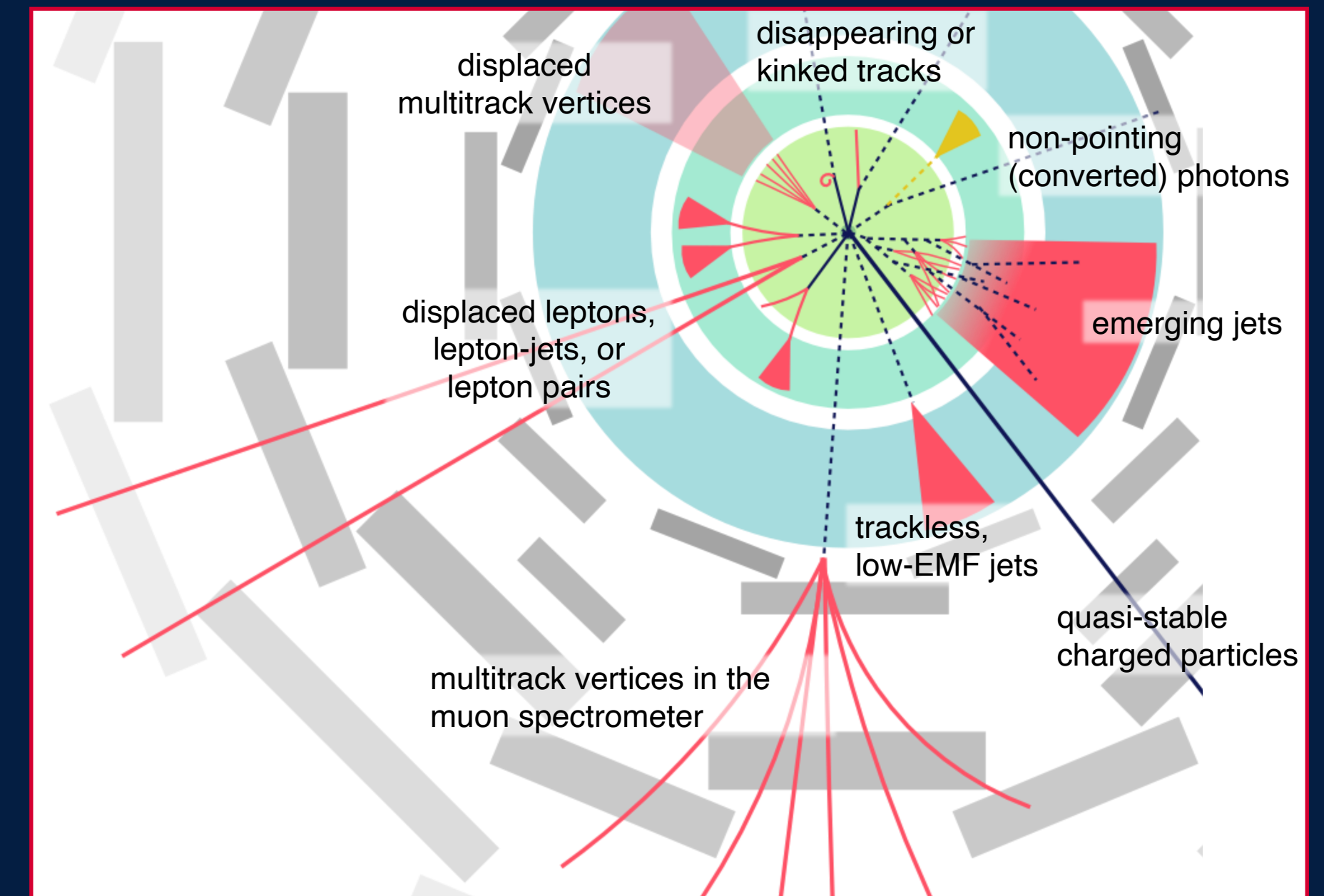
- Dedicated displaced tau trigger in Run 3
 - Online RNN τ ID trained on displaced samples
 - Compare **nominal** to **LLP** trigger in plot



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

Long-lived particles search in ATLAS

- Result: New unconventional experimental signatures from LLPs at ATLAS!
 - Displaced jets [[Phys. Rev. D 112 \(2025\) 092001](#)]
 - Displaced leptons [[Phys. Rev. D 112 \(2025\) 012016](#), [JHEP 07 \(2025\) 196](#)]
 - Semi-visible/Emerging jets [[Rep. Prog. Phys. 88 \(2025\) 097801](#), [arXiv:2510.12347](#)]
 - Ionisation in tracker [[JHEP 06 \(2023\) 158](#)]



LHC LLP White Paper [[J. Phys. G: Nucl. Part. Phys. 47 090501 \(2020\)](#)]