ATLAS
EXPERIMENT

"ADVANCES IN HADRONIC TAU IDENTIFICATION IN ATLAS USING GRAPH TRANSFORMER NETWORKS"

On behalf of the ATLAS Collaboration

HIGGS HUNTING, 2026
PARIS

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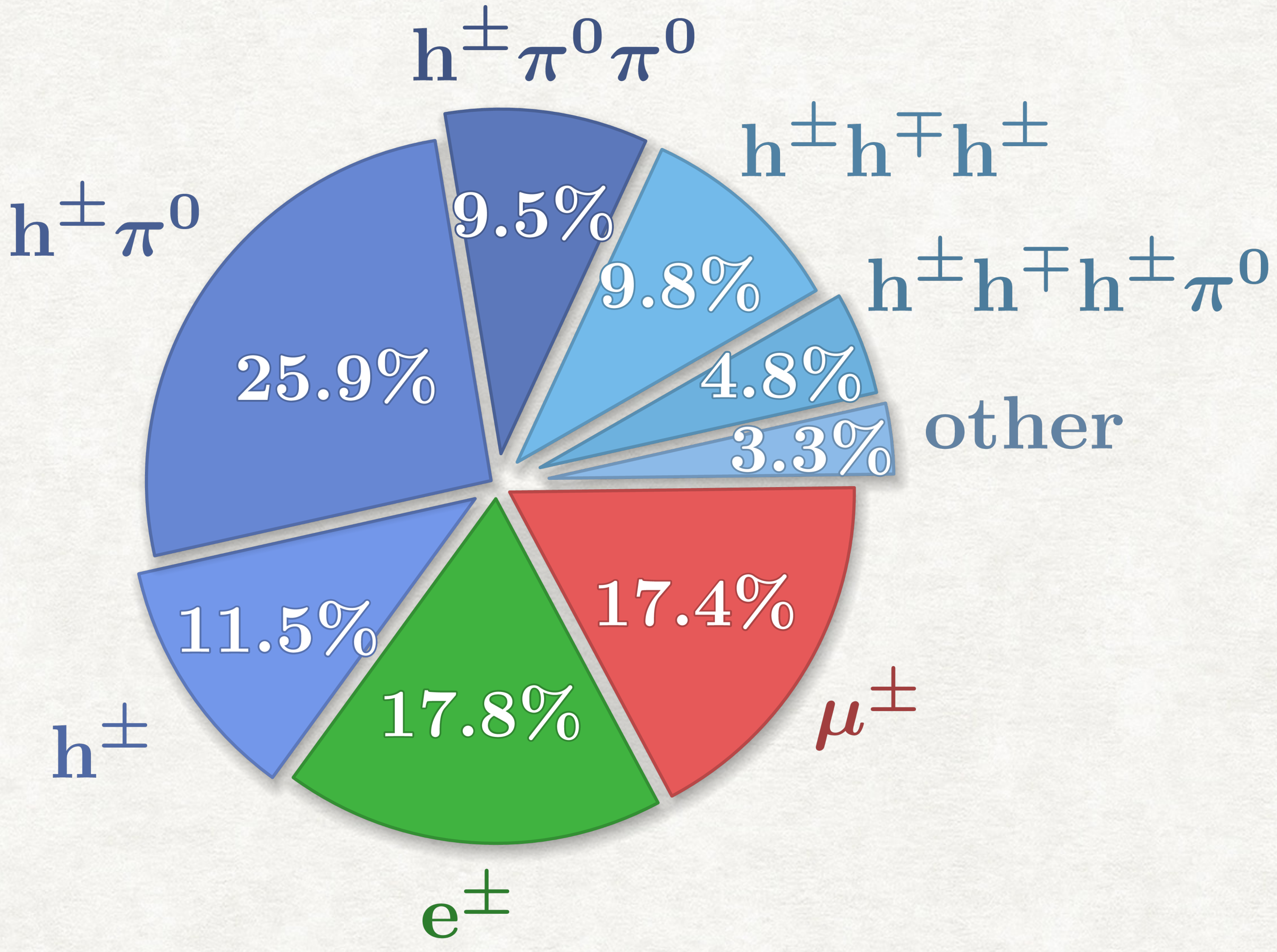
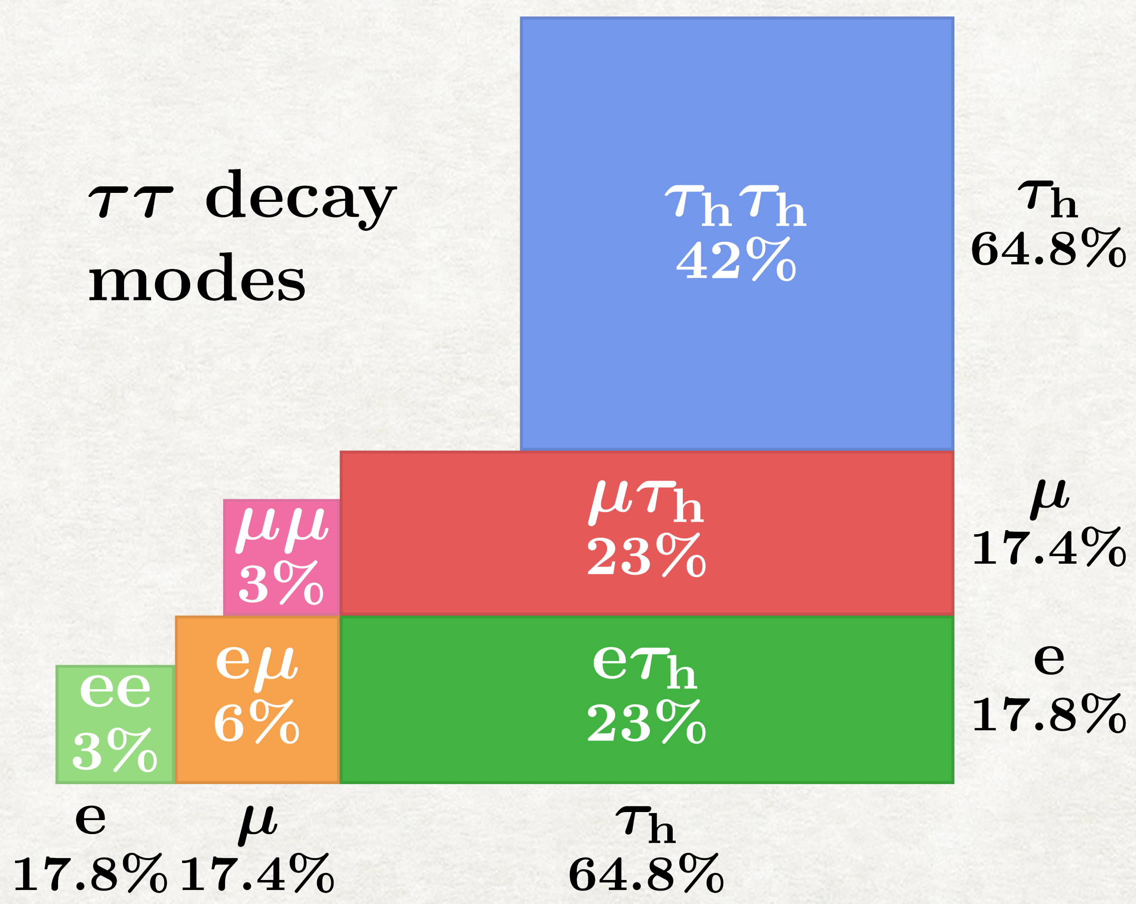
WHAT IS A TAU LEPTON?

IN PHYSICS

The tau is the 3rd generation charged lepton:

- Mass of 1777 MeV
- Lifetime: $\tau = 0.29$ ps, corresponding to $c\tau \approx 87$ µm
- Decays leptonically about 35% of the time and hadronically about 65% of the time.
- Important for Higgs measurements due to the large $H \rightarrow \tau\tau$ branching ratio, about 6.3% in the SM for mH = 125 GeV.
- Rich search program of BSM physics that is enhanced by coupling to third generation fermion (eg. taus)





IN ATLAS

For detector signatures we refer to taus only for hadronically decaying taus

Signature is 1 or 3 charged hadrons, mostly pions, plus possible neutral pions

- Charged pions leave tracks in the inner detector + calorimeter deposits
- Neutral pions decay to photons, leaving energy deposits in the electromagnetic calorimeter
- Need to combine track and calorimeter info
- Results in a narrow jet with few tracks
- Total charge of tracks associated with the tau candidate is required to be ± 1

Rule of thumb:

- When we talk about a physics process, taus refer to the 3rd generation lepton
- When we talk about detector signatures we mean hadronically decaying taus

Credit: I. Neutelings

TAUS IN HIGGS PHYSICS

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$HH \to b\bar{b}\tau^+\tau^-$

Di-Higgs searches

$H \to \tau\tau$

Higgs Yukawa coupling

τ_{had} Identification (ID)

Real tau eff vs jet fake rejection

$H/A \to \tau\tau$

BSM heavy-Higgs searches

Higgs CP

CP-sensitive tau decay information

Common object-level challenge

Keep real τ_{had} candidates while suppressing quark and gluon initiated jets

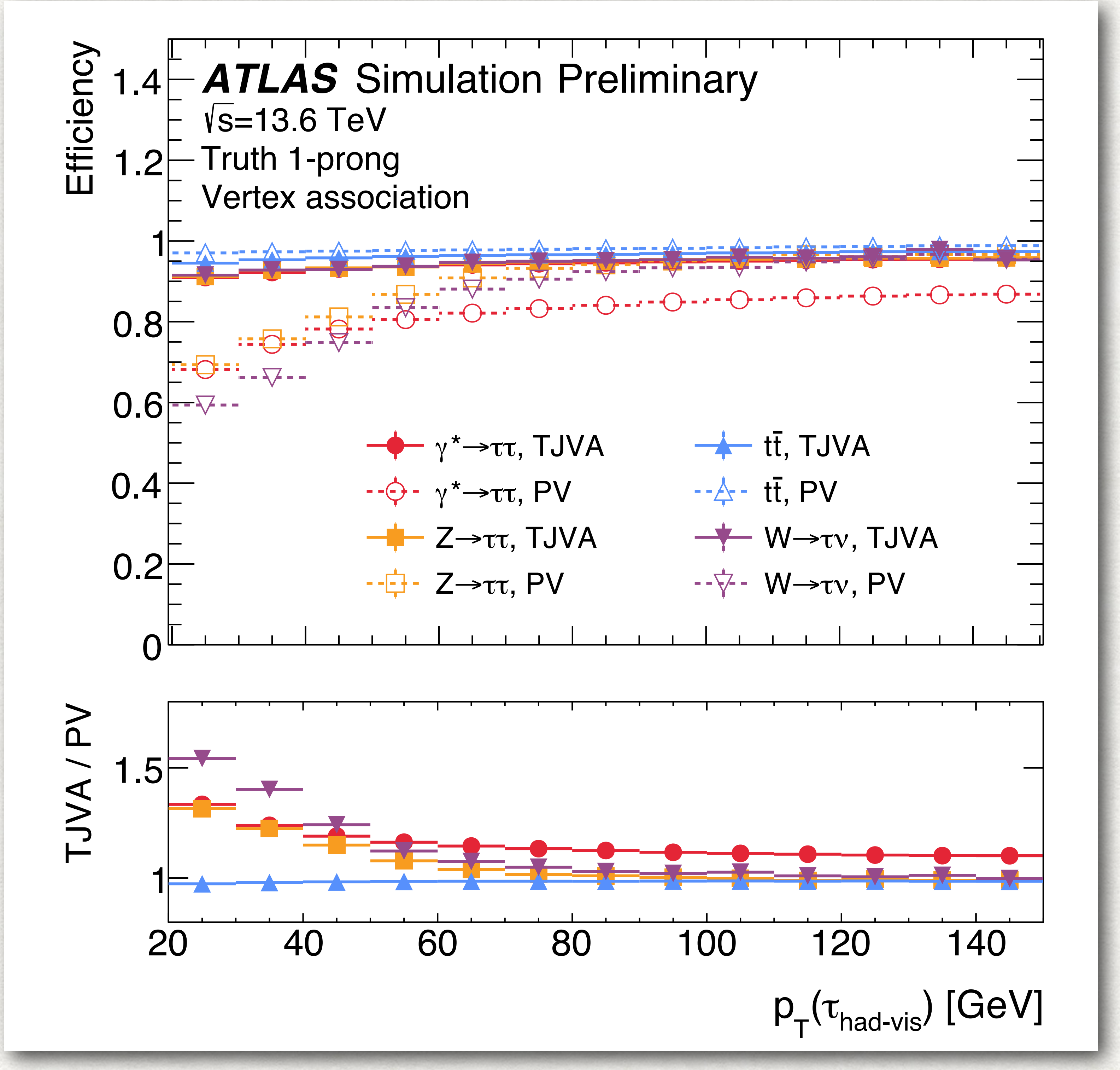
$HH \to b\bar{b}\tau^+\tau^-$	arXiv:2607.26879
boosted H → $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	arXiv:2607.22193
ttH/tH, H → $\tau\tau$	arXiv:2607.27276
VBF H → $\tau\tau$ CP	arXiv:2506.19395

∴ $\tau_{\mathrm{had-vis}}$ *denotes the visible decay products, excluding the neutrino.*

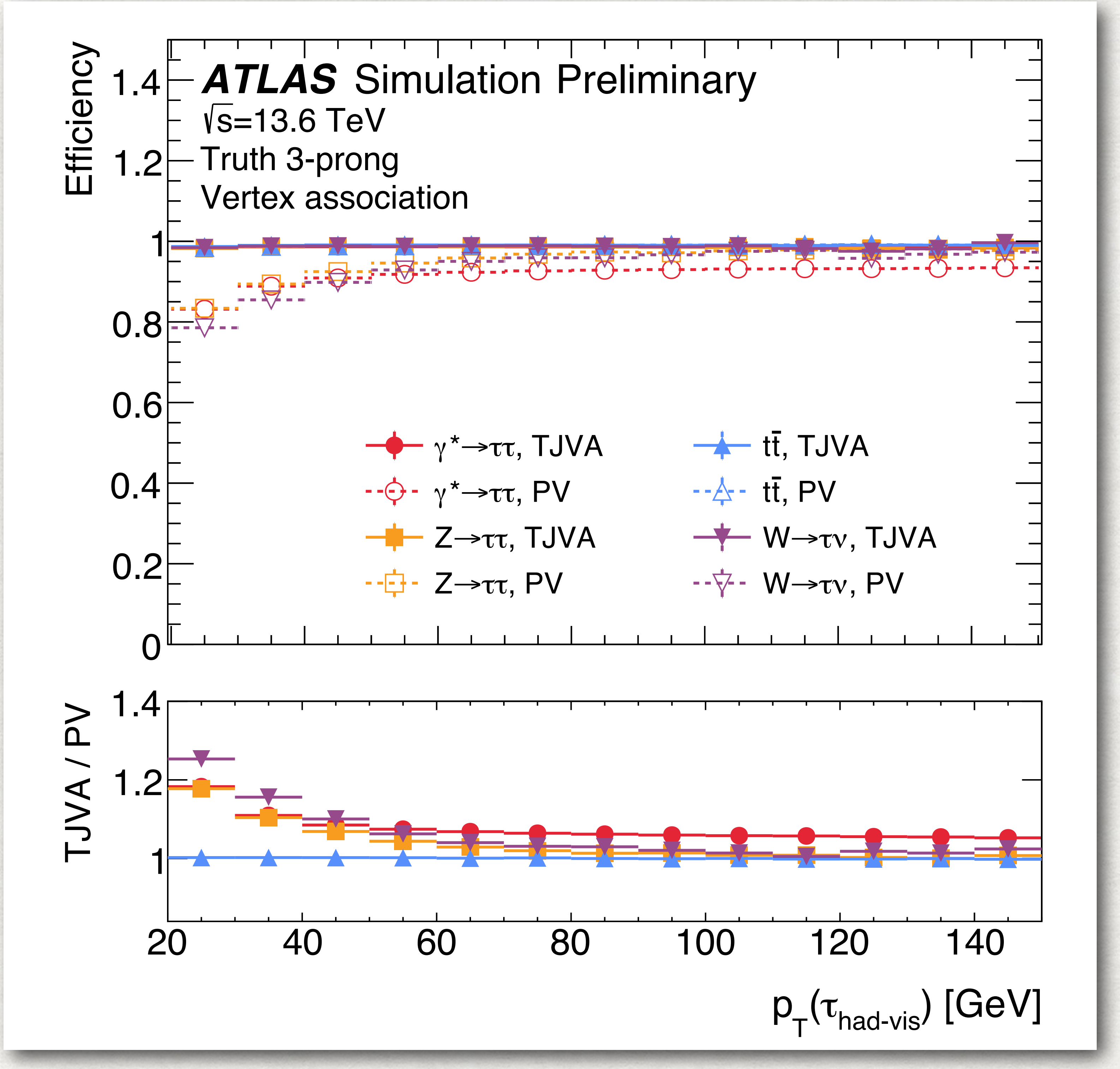
BEFORE ID: BUILDING A STABLE TAU OBJECT

- Tau candidates need reliable production-vertex association.
- ATLAS uses Tau Jet Vertex Association (TJVA) to associate tau candidates with the correct production vertex.
- The plots compare TJVA with default primary-vertex choice.
- Shown for 1-prong and 3-prong tau decays.
- TJVA improves the probability of selecting the correct tau production vertex, with the largest gains shown for low-p_T, 1-prong candidates.

1-prong



3-prong



Correct tau production-vertex selection efficiency using TJVA compared with the default PV choice, shown for truth 1-prong and 3-prong tau decays. The horizontal axis shows the transverse momentum of the visible tau decay products. The neutrino escapes detection, so this is not the full momentum of the original tau.

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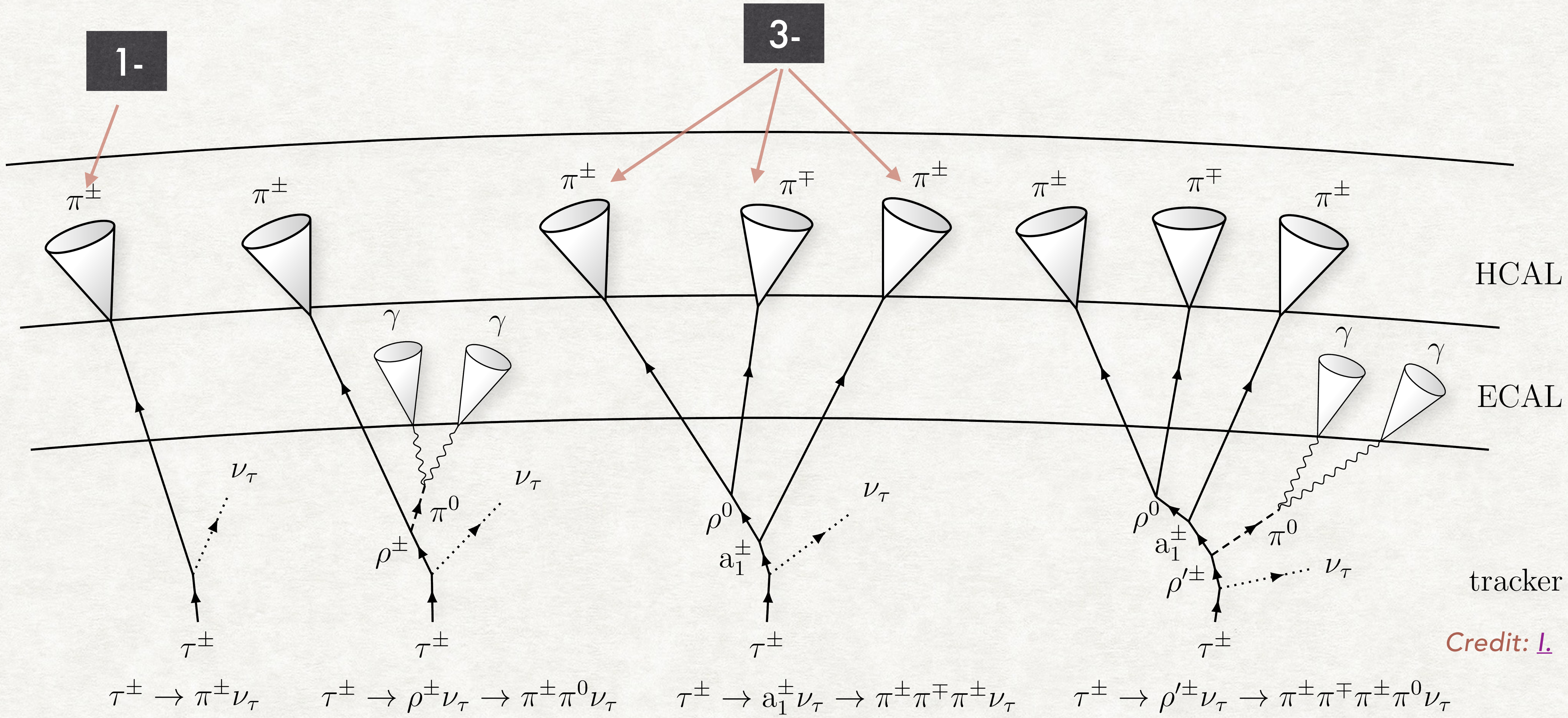
DECAY MODES

- τ_{had} decays are classified by charged/neutral hadron multiplicity: 1-prong or 3-prong, with/without π^0).
- Different decay modes leave different track and calorimeter signatures.
- This helps distinguish genuine hadronic taus from jets, electrons, and muons.

ATLAS Simulation Preliminary
$\sqrt{s}$ = 13 TeV
Diagonal efficiency: 81.7%
Medium τ_{had} identification

DeepSet NN tau decay mode \ Truth tau decay mode	1p0n	1p1n	1pXn	3p0n	3pXn
3pXn	0.0	0.6	0.7	4.2	65.1
3p0n	0.4	0.2	0.1	92.2	25.6
1pXn	0.5	6.3	59.3	0.1	2.2
1p1n	9.4	86.3	38.8	1.4	6.5
1p0n	89.6	6.6	1.1	2.0	0.6

Truth versus reconstructed $\tau_{had-vis}$ decay-mode efficiency matrix for candidates passing Medium τ_{had} identification



1-PRONG

3-PRONG

- 1-prong and 3-prong categories are used in tau reconstruction and performance studies.
- Decay-mode splitting helps describe different detector signatures. Reconstructed decay modes *: 1p0n, 1p1n, 1pXn, 3p0n, 3pXn.
- This motivates showing tau performance separately by prong category.

** p = charged prongs; n = neutral-pion candidates; Xn = additional neutral-pion activity.*

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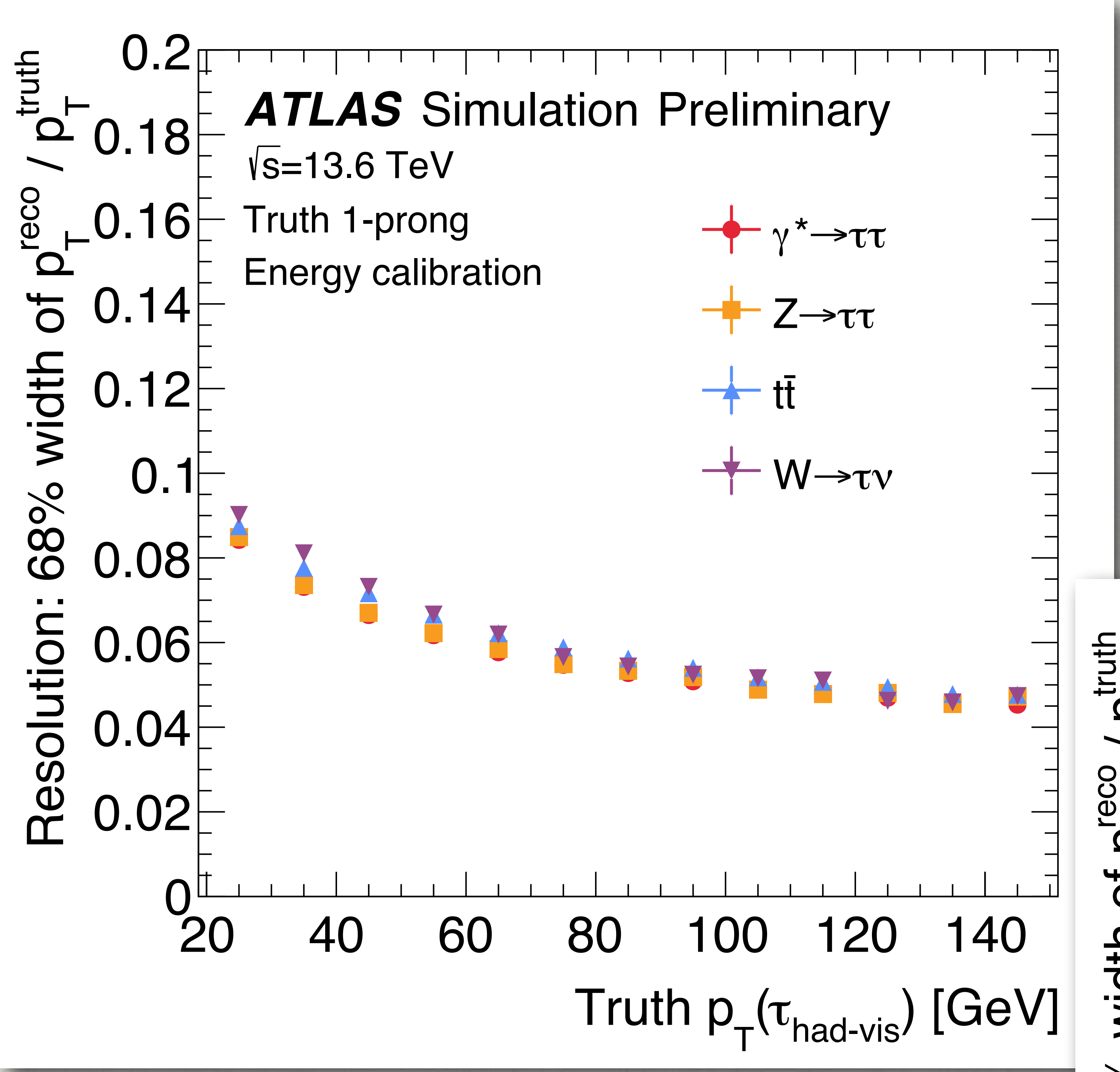
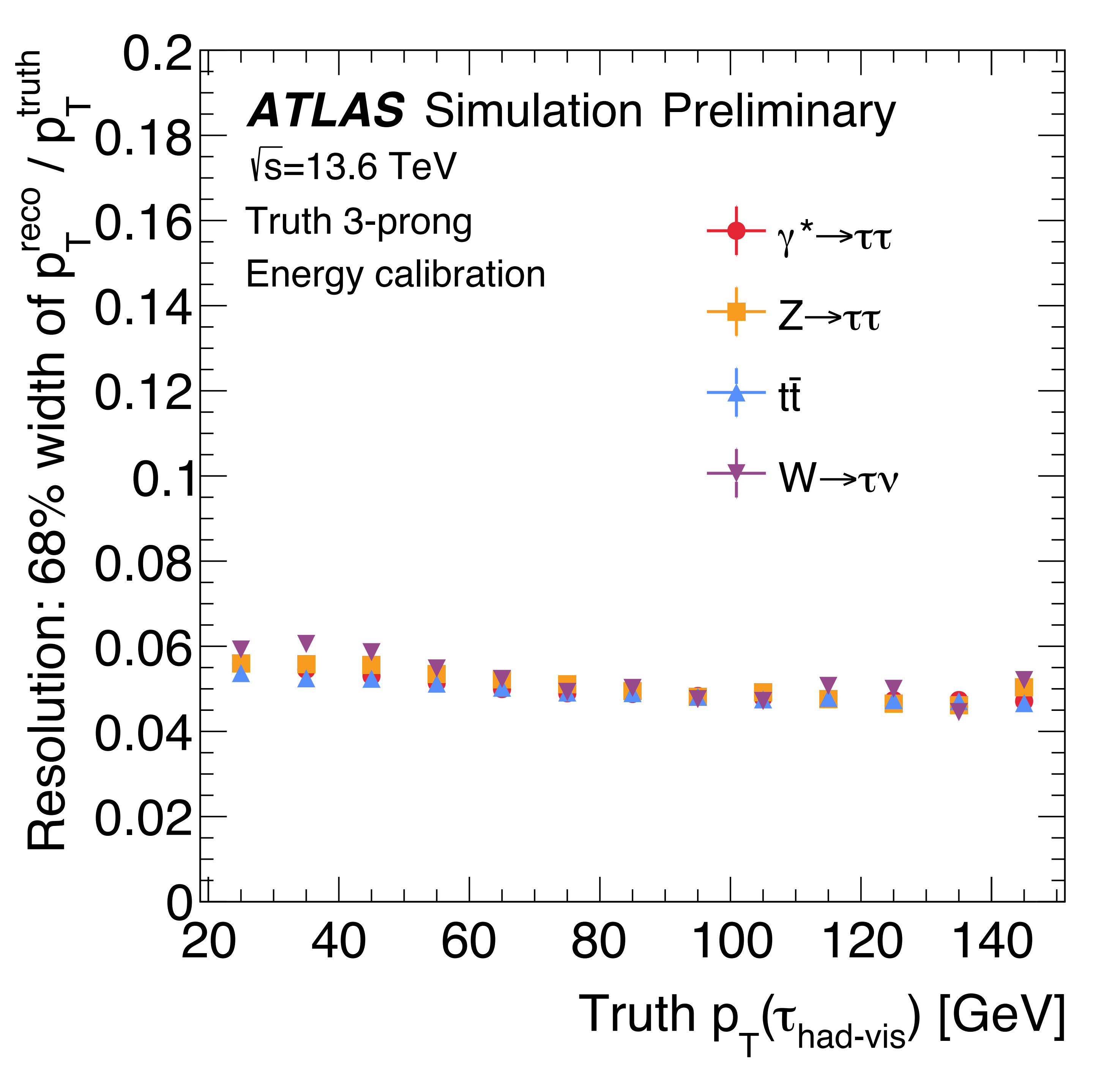
BEFORE ID: TAU ENERGY RECONSTRUCTION

- Reconstructed $\tau_{\text{had-vis}}$ candidates need a well-measured energy.
- Tau energy resolution affects kinematic reconstruction in Higgs final states.
- The plots study the resolution versus generator-level tau p_T.
- Results are shown separately for truth 1-prong and 3-prong tau decays.
- Before asking whether a candidate is a real tau, ATLAS first needs to reconstruct a stable tau object.



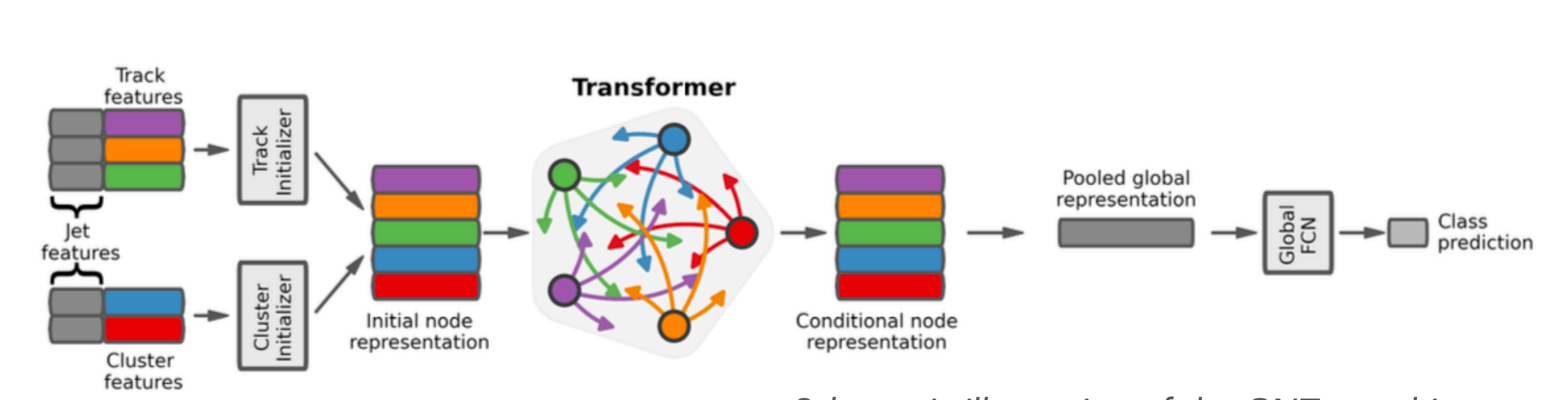
ATLAS Collaboration, ATL-PHYS-PUB-2026-012, Fig. 04a-04b



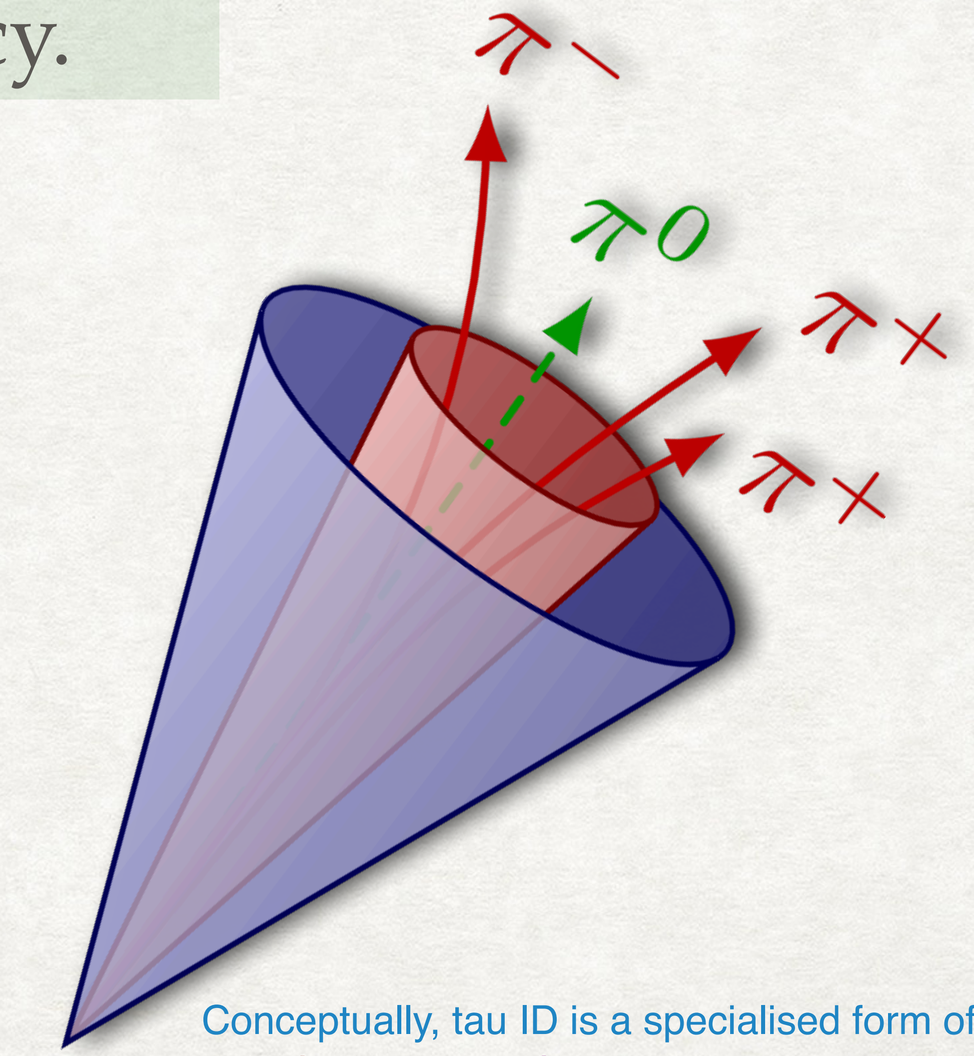
Tau energy resolution versus generator-level tau pT for truth 1-prong and 3-prong tau decays.

GNTau: A GRAPH TRANSFORMER FOR TAU ID

- Run-3 ATLAS algorithm for identifying visible hadronic tau decays.
- Hybrid graph transformer-based neural network. Hybrid: combines constituent-level information from tracks and calorimeter clusters with high-level tau variables.
- Treats tau-associated tracks and clusters as variable-size input collections.
- Uses attention to learn relations among tau-associated constituents.
- Output score defines Loose, Medium, and Tight tau-ID working points.
- Goal: reject quark- and gluon-initiated jets while keeping fixed genuine-τhad efficiency.



Schematic illustration of the GNTau architecture



Conceptually, tau ID is a specialised form of jet tagging.
Credit: I. Neutelings

FROM RNN TAU ID TO GNTau

- Previous ATLAS tau-ID benchmark.
- Uses reconstructed tau-candidate information.
- Treats low-level inputs with a sequential architecture.
- Strong Run-2/early Run-3 performance, but less natural for unordered constituents.
- Used as the benchmark in TAUP-2026-01.

Same inputs
modern architecture

- Hybrid graph-transformer architecture.
- Designed for variable-size collections of tau-associated tracks and clusters.
- Better suited to set-like inputs without imposing a fixed sequence.
- Uses attention to model relations among tau-associated constituents.
- Goal: higher jet rejection at the same real-tau efficiency.

ATLAS Collaboration, TAUP-2026-01

A FAIR COMPARISON: FIXED TAU EFFICIENCY

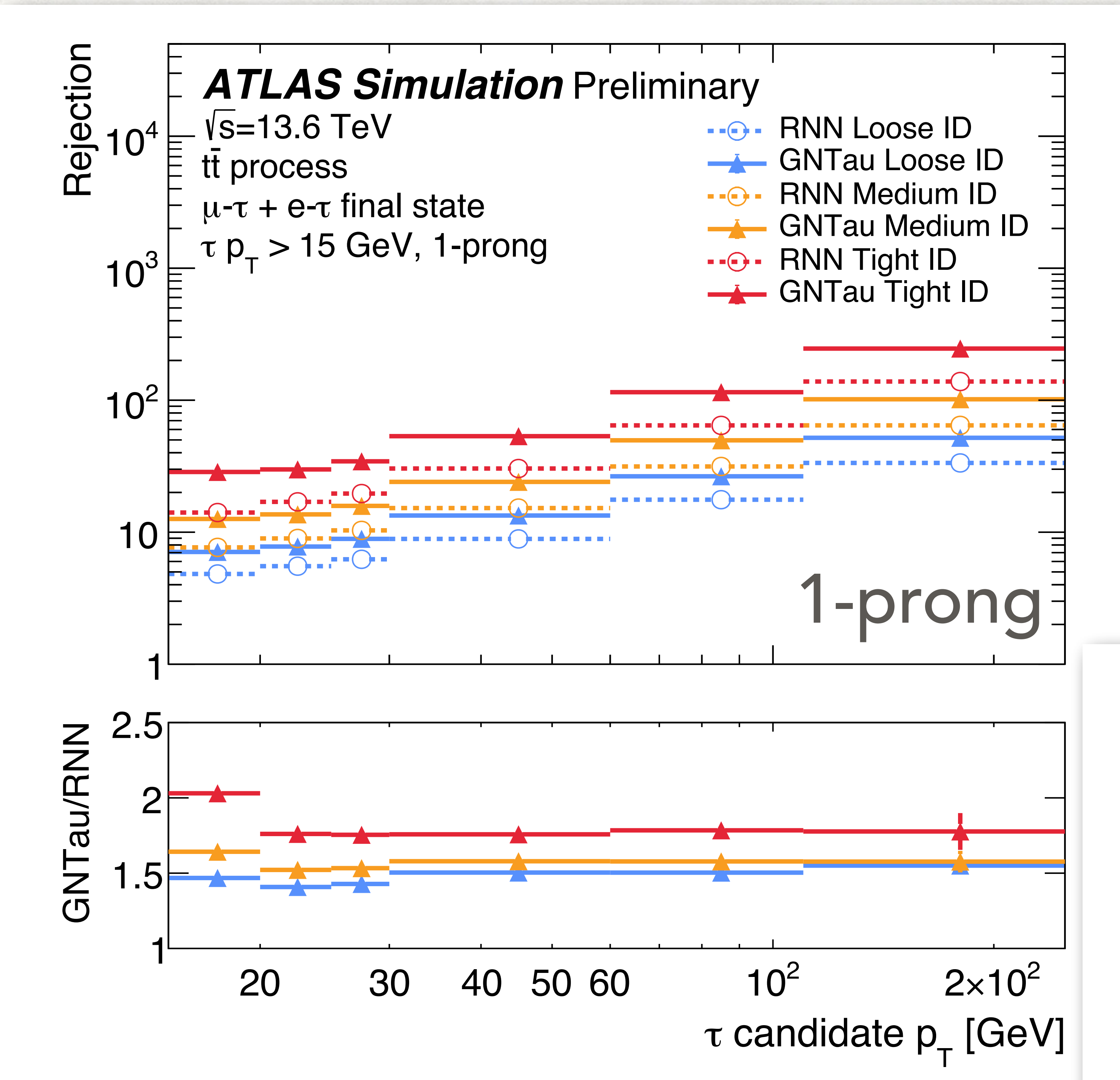
- GNTau and RNN are compared at the same genuine-tau identification efficiency.
- Performance is evaluated using genuine hadronic taus and jet backgrounds in simulated $t\bar{t}$ events.
- Jet rejection = $1/\epsilon_{\text{fake}}$ higher rejection means fewer jets pass tau identification.
- The following plots would compare Loose, Medium, and Tight working points for 1-prong and 3-prong candidates.

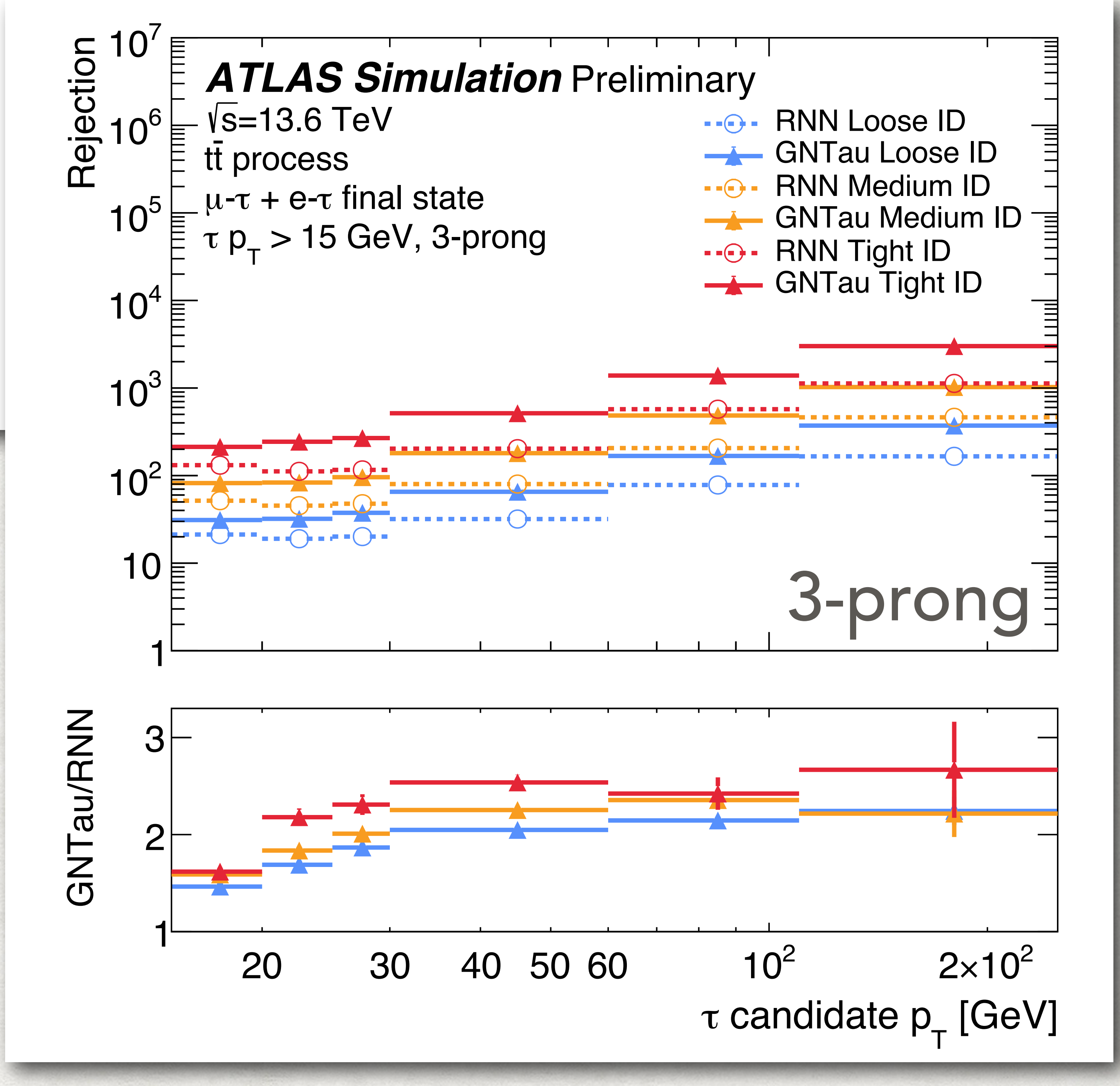
Working Point	Signal efficiency
Very Loose	95%
Loose 1-prong	85%
Loose 3-prong	75%
Medium 1-prong	75%
Medium 3-prong	60%
Tight 1-prong	60%
Tight 3-prong	45%

ATLAS Collaboration, TAUP-2026-01

GNTAU IMPROVES JET REJECTION AT FIXED TAU EFFICIENCY

- Studies done with $t\bar{t}$ events simulated with 2022 data-taking conditions.
- Compares GNTau with the previous RNN tau-ID algorithm.
- Shown as background rejection versus reconstructed tau p_T.
- Working points are fixed to the same signal efficiencies.
- GNTau gives higher jet rejection than RNN across the displayed p_T range.
- Improvement is visible for both 1-prong and 3-prong tau candidates





ATLAS Collaboration, TAUP-2026-01, Fig. 01-02

Jet rejection versus reconstructed tau p_T for 1-prong and 3-prong tau candidates, comparing GNTau with the previous RNN tau-ID algorithm at fixed signal efficiency.

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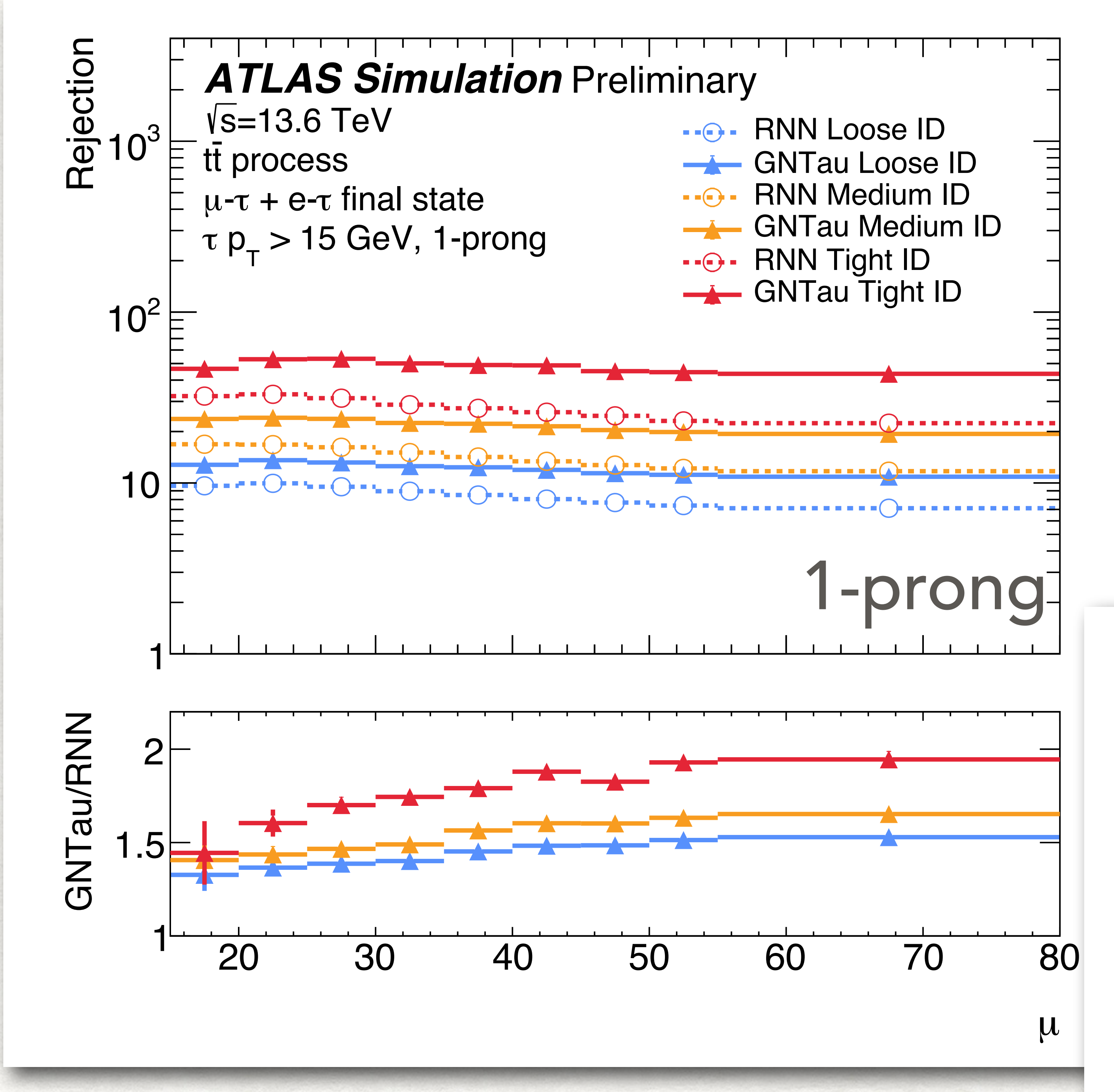
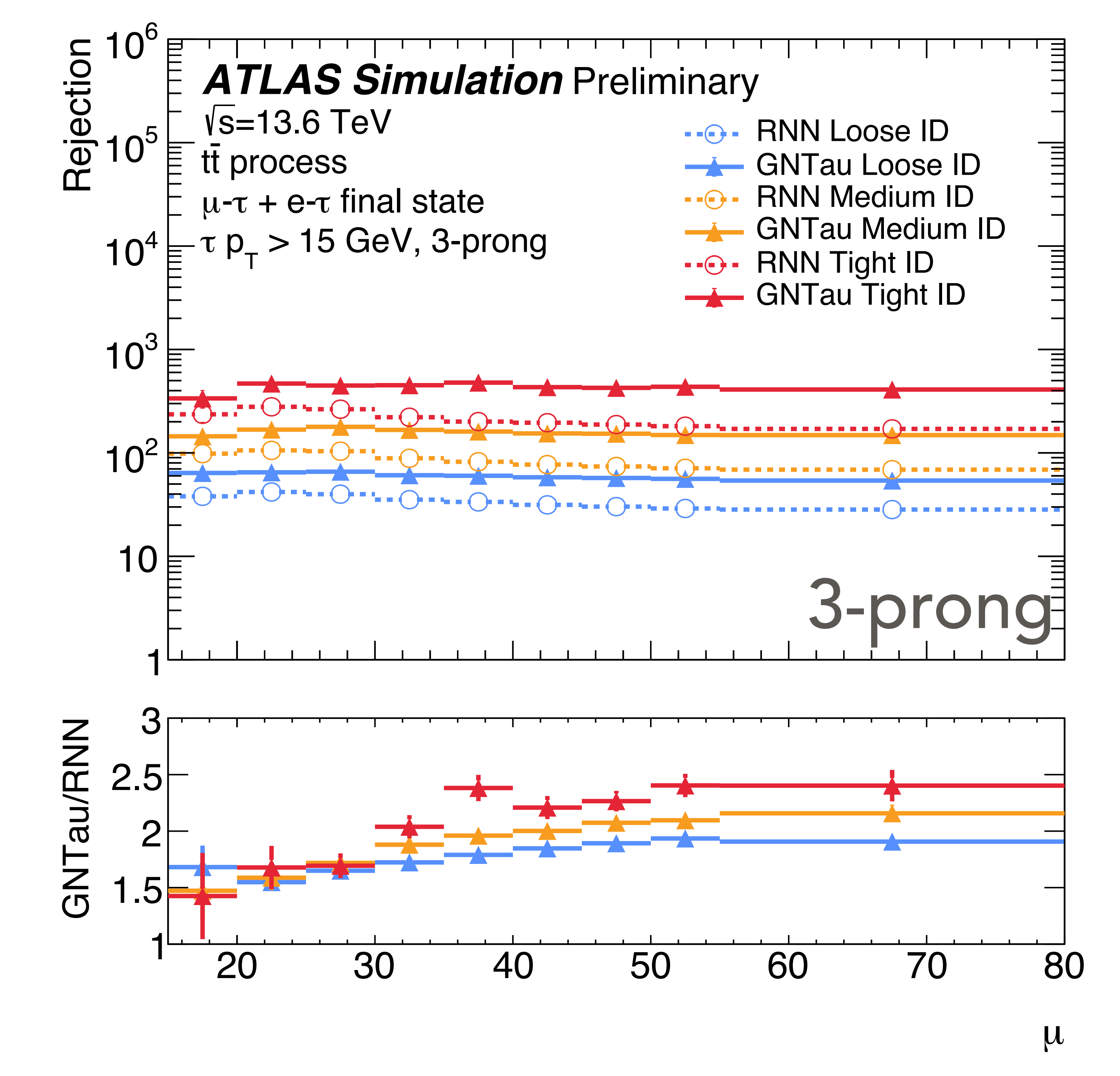
HIGHER REJECTION ACROSS PILEUP

- Run-3 tau ID must remain stable in busy collision environments.
- The plots compare GNTau and RNN as a function of average pileup.
- Working points are fixed to the same genuine-τ_{had} signal efficiencies.
- GNTau maintains higher jet rejection across the displayed pileup range.
- The GNTau/RNN rejection ratio increases with pileup, especially for 3-prong candidates.
- This indicates that GNTau degrades less with pileup than the RNN benchmark.

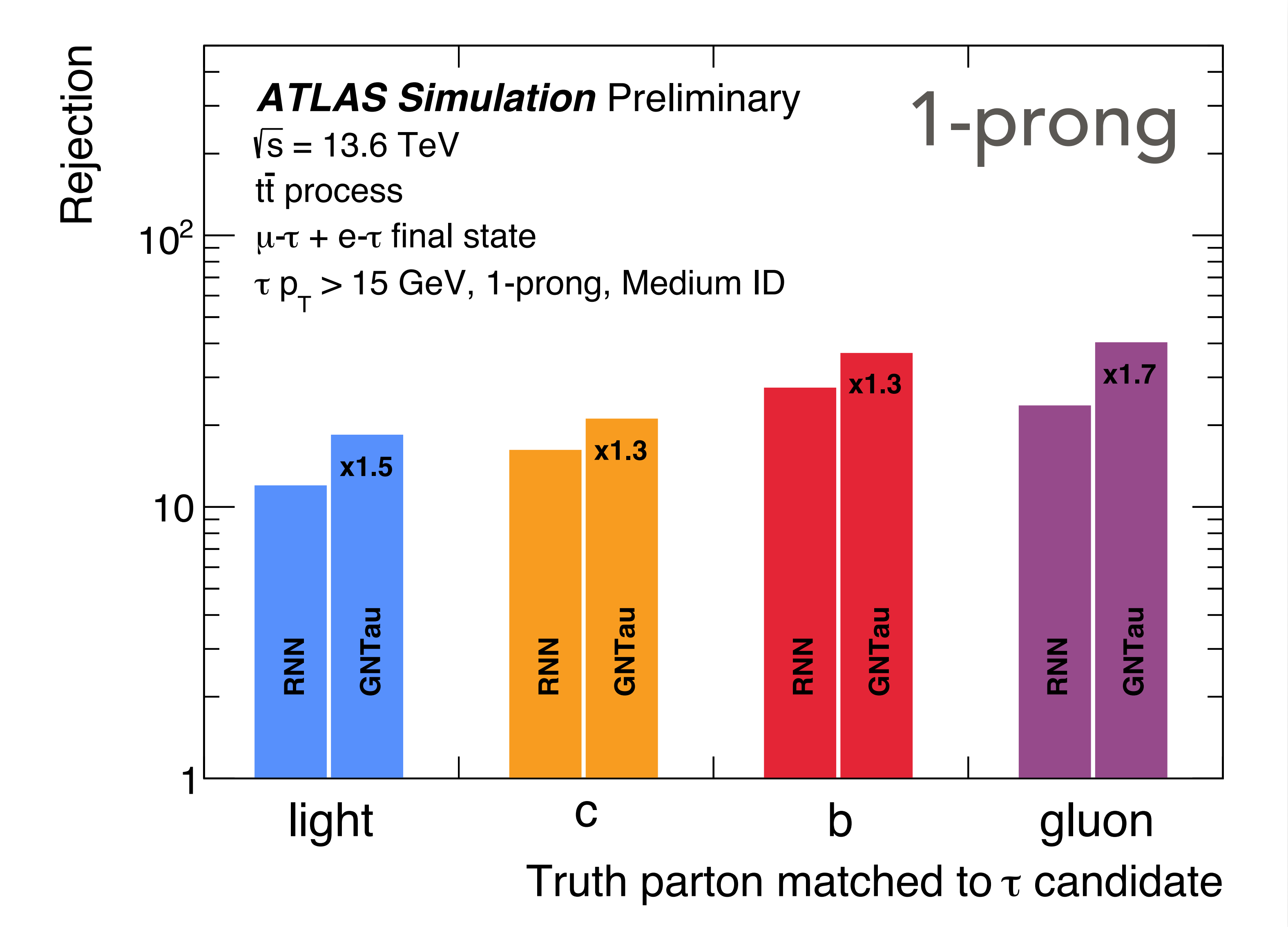


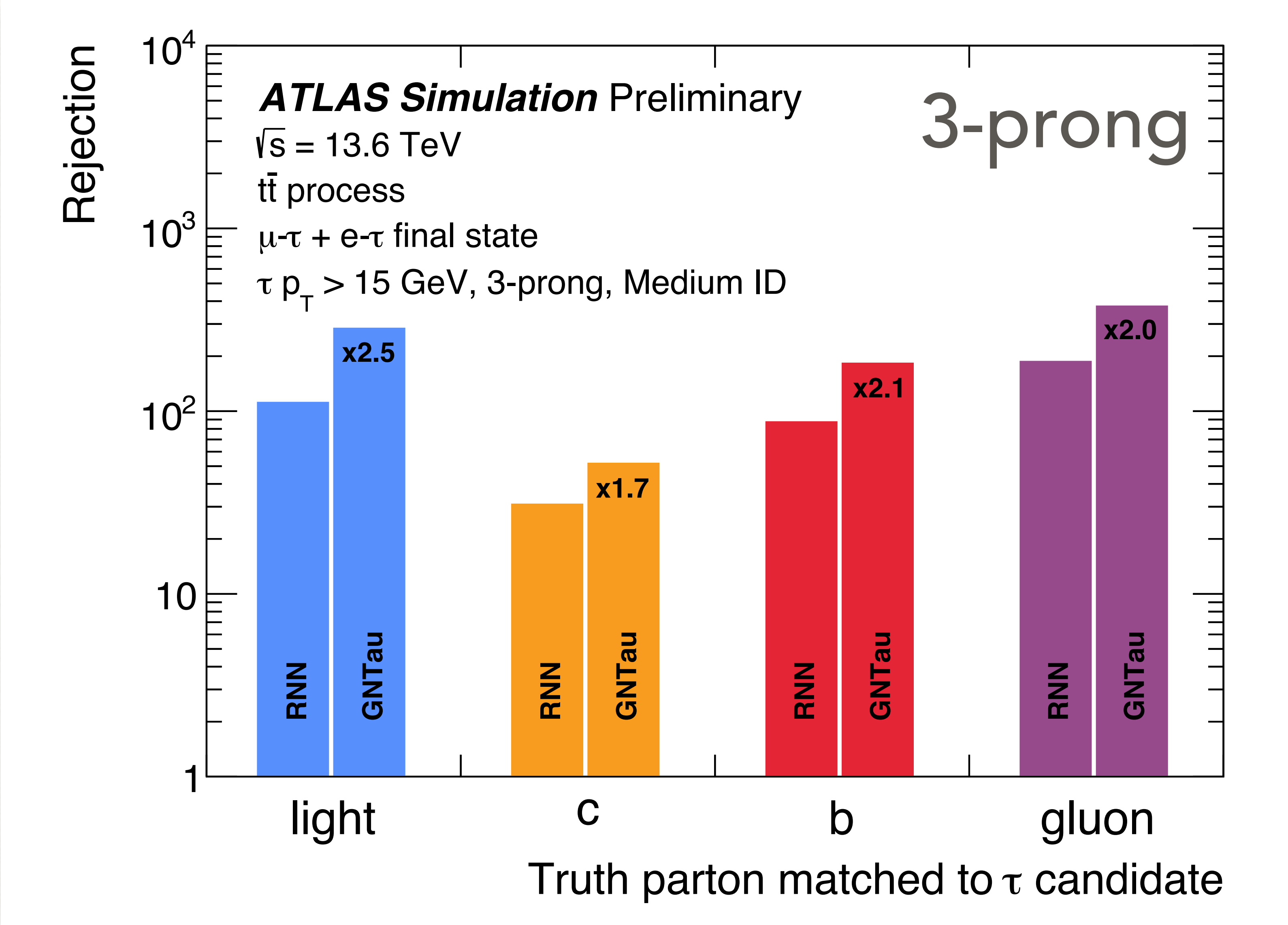
Jet rejection versus average number of interactions per bunch crossing for 1-prong and 3-prong tau candidates.

ATLAS Collaboration, TAUP-2026-01, Fig. 05-06



REJECTION AS A FUNCTION OF FAKE SOURCE





Jet rejection for fake tau candidates matched to light quark, c quarks, b quarks and gluons shown for the Medium ID working point.

- Fake $\tau_{\text{had-vis}}$ candidates are matched to: light quarks, c quarks, b quarks, and gluons.
- RNN and GNTau are compared at the Medium ID working point.
- This Medium WP signal efficiency: 75% for 1-prong, 60% for 3-prong.

- GNTau improves jet rejection for all fake sources shown.
- **The largest relative gains are seen for gluon fakes in 1-prong and light-quark fakes in 3-prong candidates.**
- This matters because Higgs analyses have different fake compositions: top-associated channels receive fakes from $t\bar{t}$-like environments, while VBF-like selections can be affected by multijet and W+jets backgrounds.

ATLAS Collaboration, TAUP-2026-01, Fig. 11-12

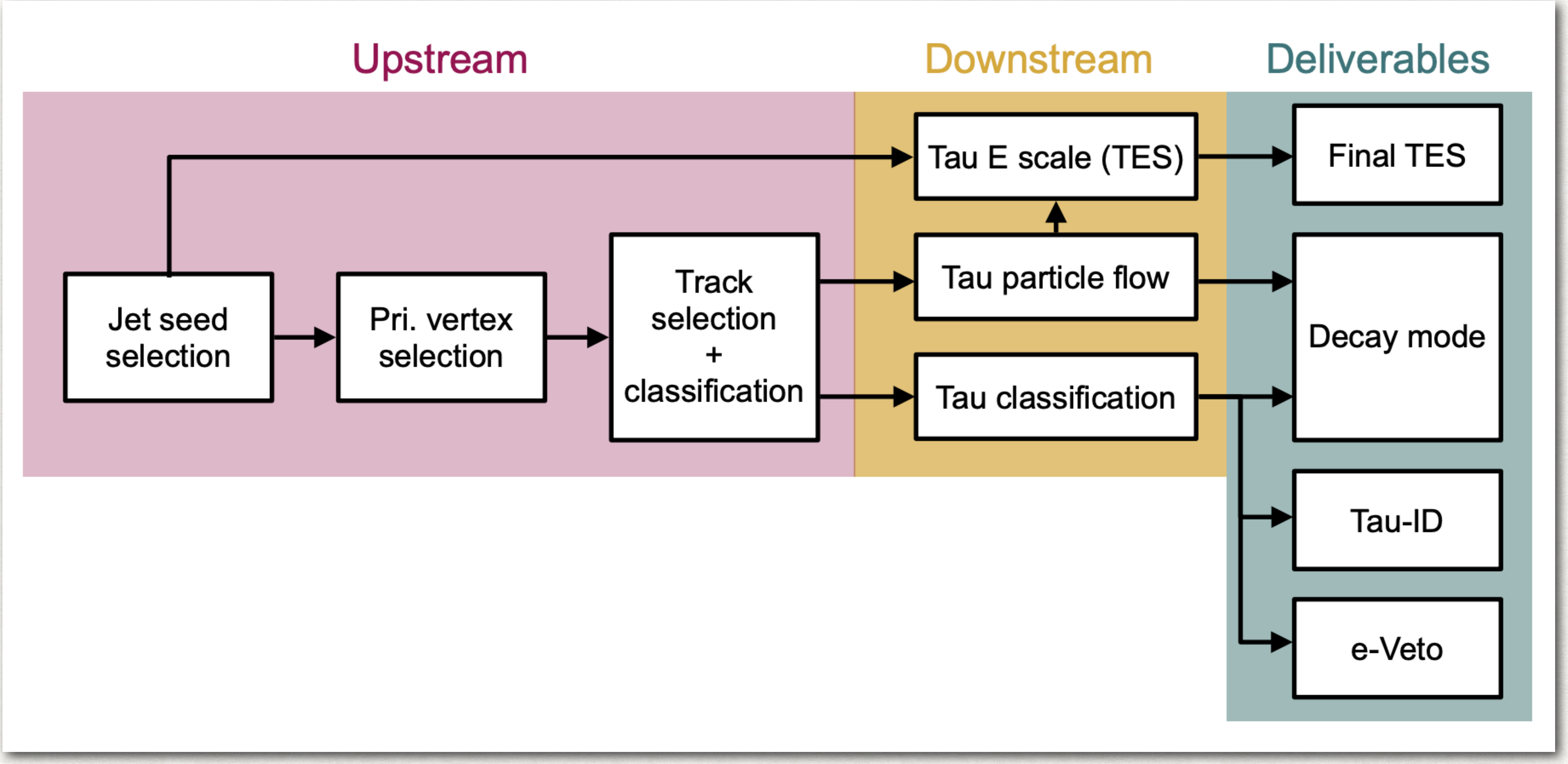
SUMMARY

- Hadronic taus are key signatures in Higgs and BSM Higgs final states.
- The main experimental challenge is separating genuine $\tau_{\mathrm{had-vis}}$ decays from quark/gluon jet fakes.
- ATLAS Run-3 tau performance relies on both robust reconstruction and powerful identification.
- GNTau is a hybrid graph transformer-based tau-ID algorithm using tracks, calorimeter clusters, and high-level tau variables.
- Recent studies show improved jet rejection over the previous RNN benchmark at fixed signal efficiency.
- These advances strengthen the Run-3 tau-performance toolkit for Higgs analyses.
- GNTau is being studied in $H \to \tau\tau$ and $HH \to b\bar{b}\tau^+\tau^-$ analyses to improve sensitivity to single- and double-Higgs production.

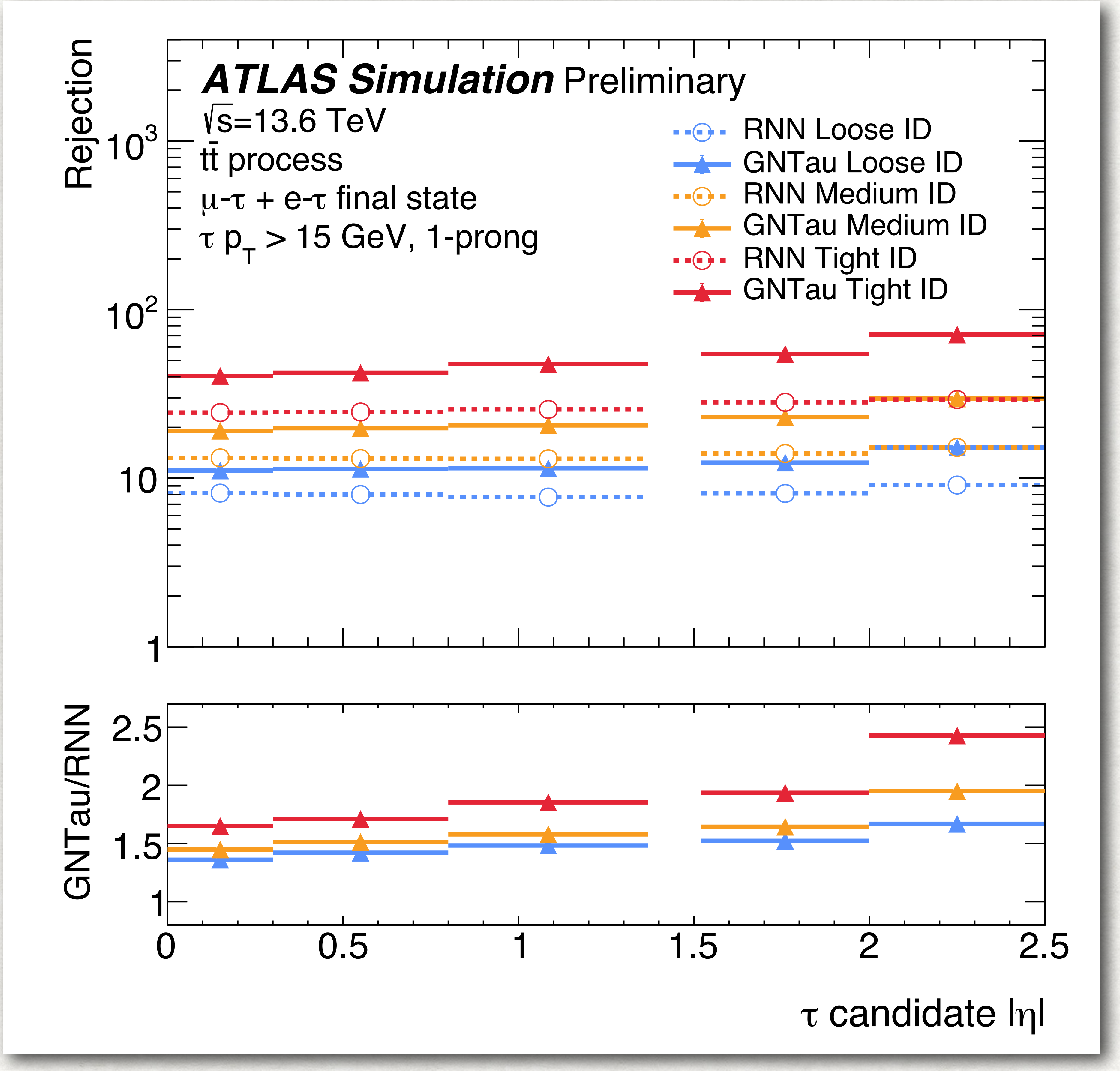
Credits-OpenAI

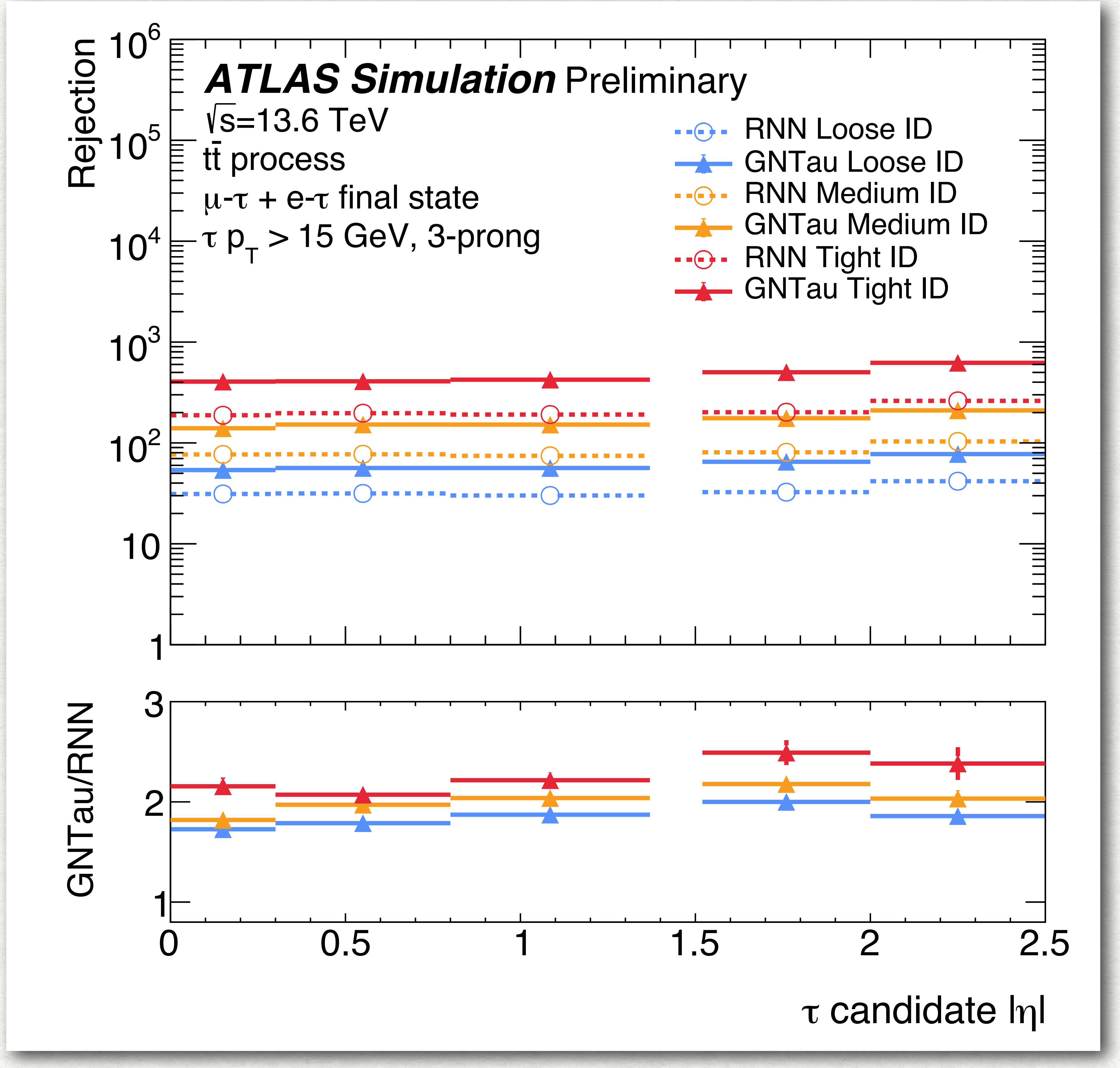
Credits-OpenAI

TAU RECO AND ID WORKFLOW



η DEPENDENCE





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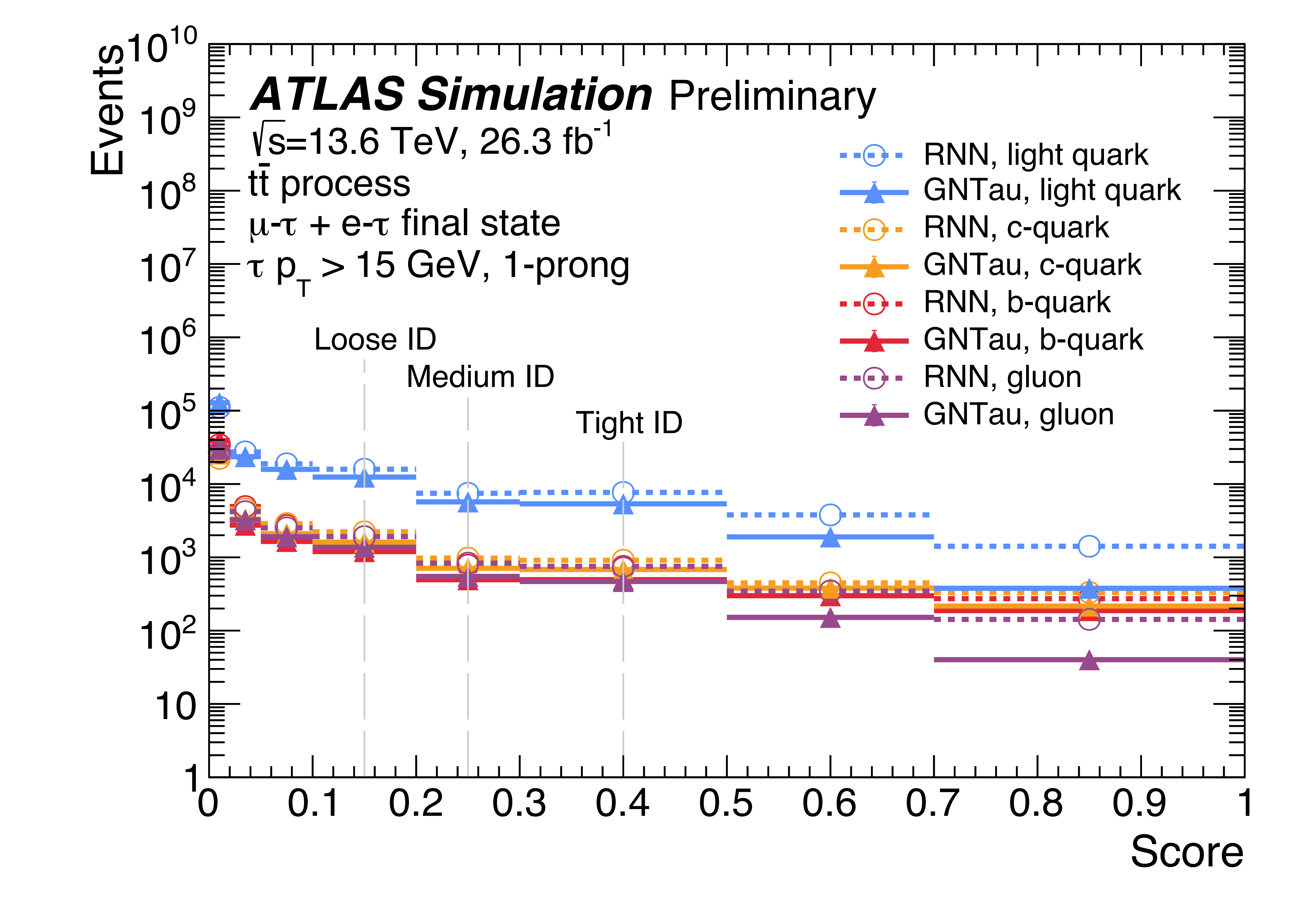
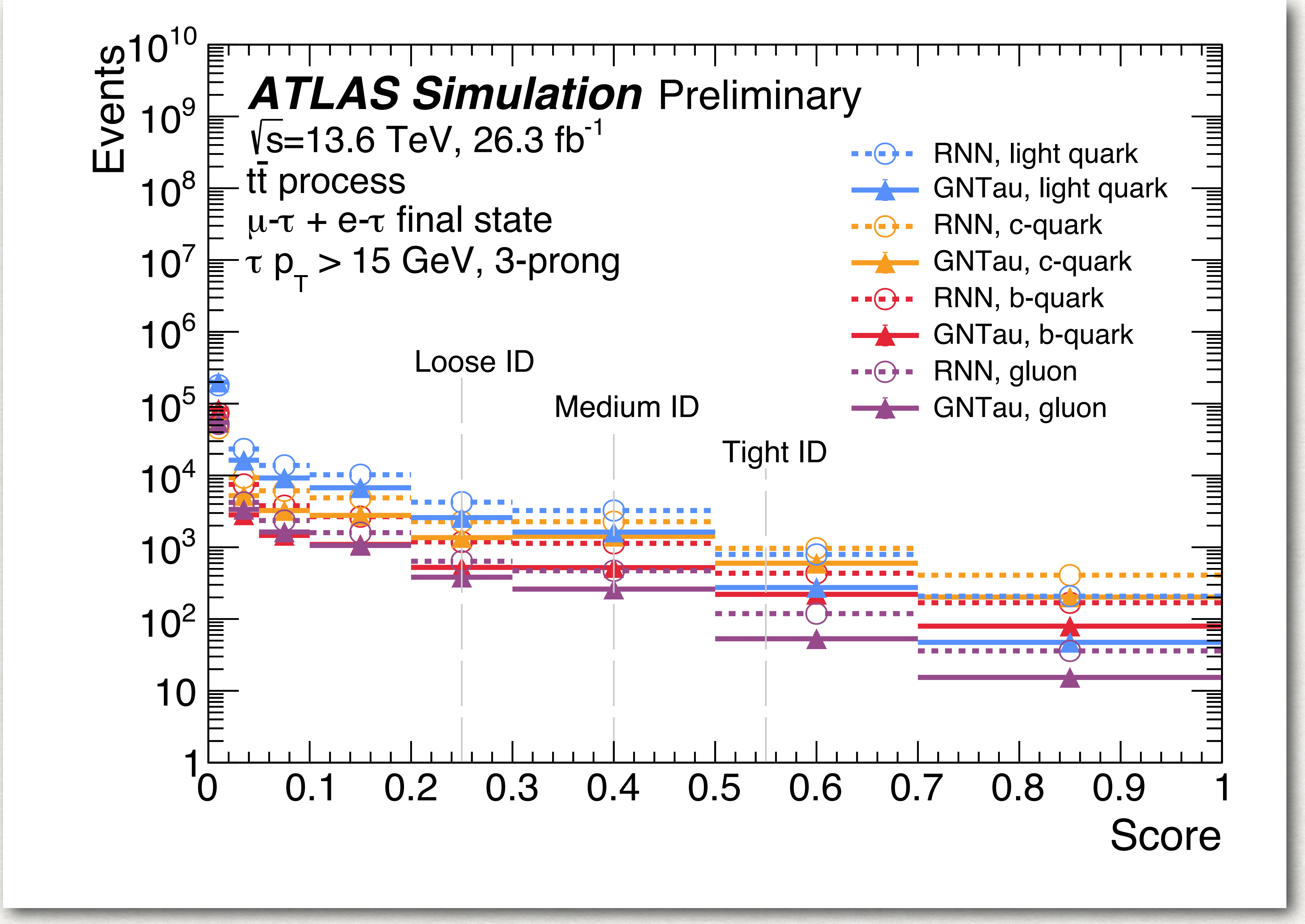
SCORE DISTRIBUTIONS





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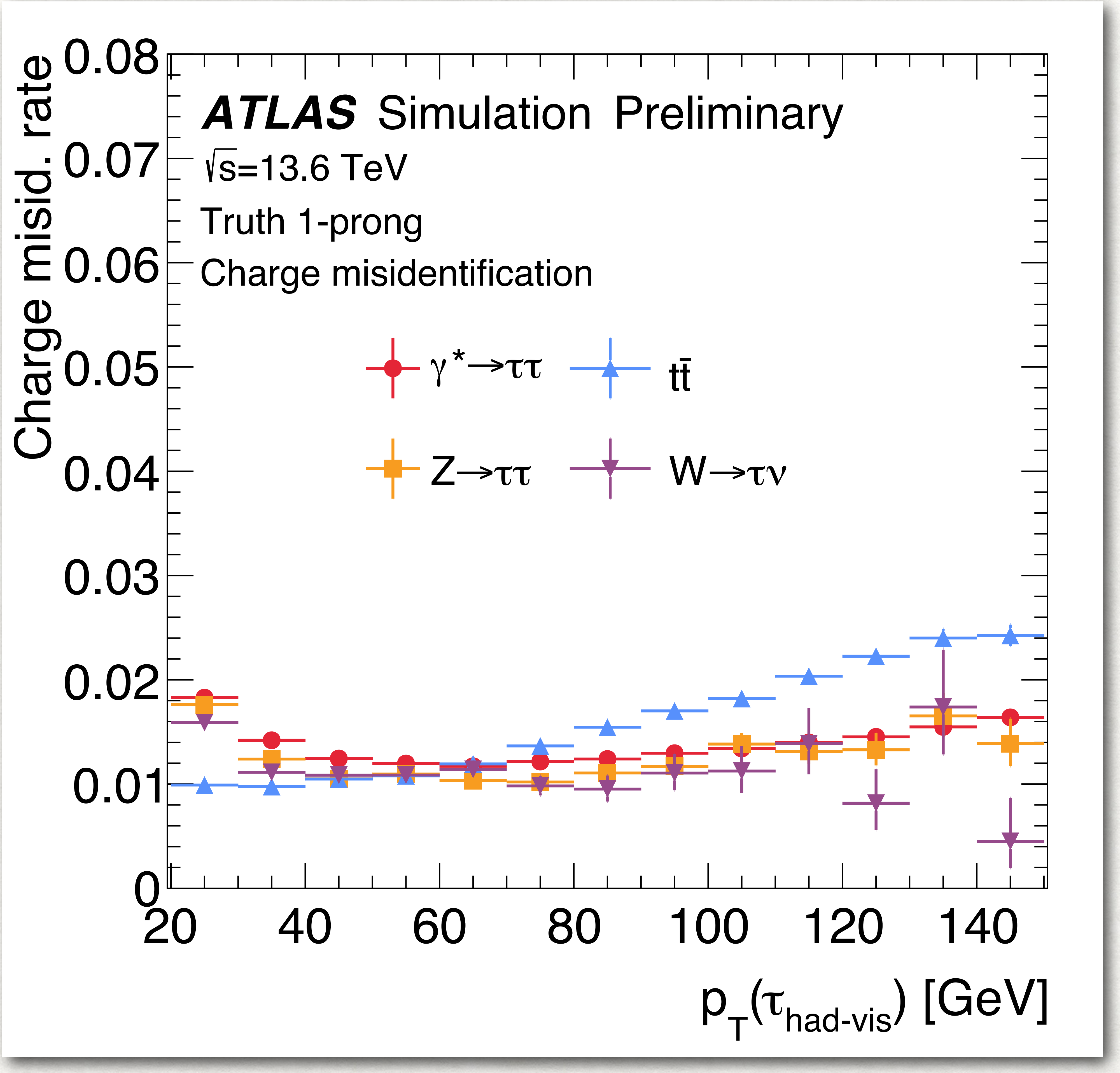
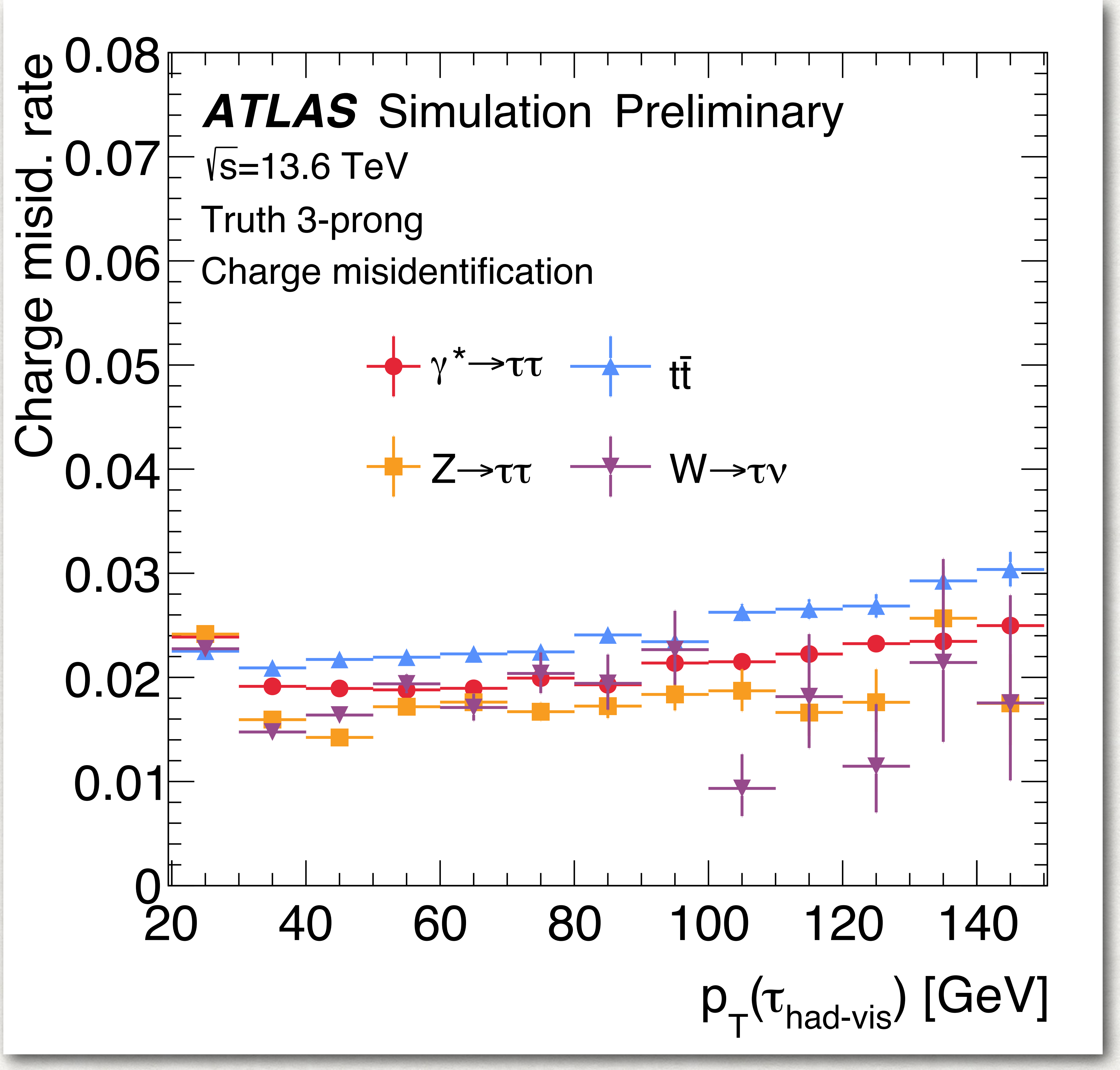
TRACK MULTIPLICITY OR CHARGE MIS-ID





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