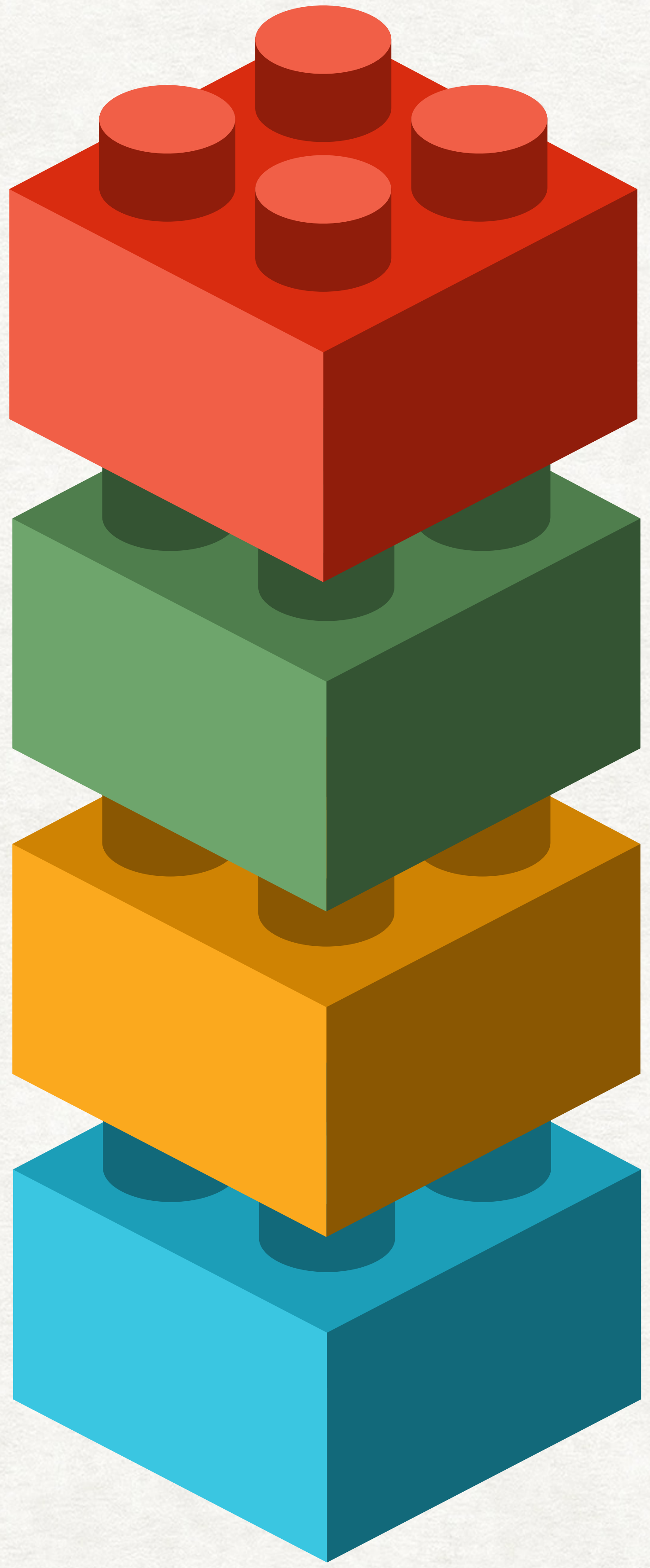
ATLAS
EXPERIMENT

BRINGING TAU TO IOP...

IOP EDINBURGH, 7TH-9TH APRIL

SUDEV PRADHAN
University of Sheffield

WHAT ARE WE SEEING TODAY?



General Overview

- What is Tau?
- Overview
- Decay Modes

Tau-identification

- TauID
- Decay Processes
- Reco

Sneak Peak to Future

- τ_{p_T} , τ_η & r_{QCD} CR Distributions
- Fitting Strategy
- Scale Factor

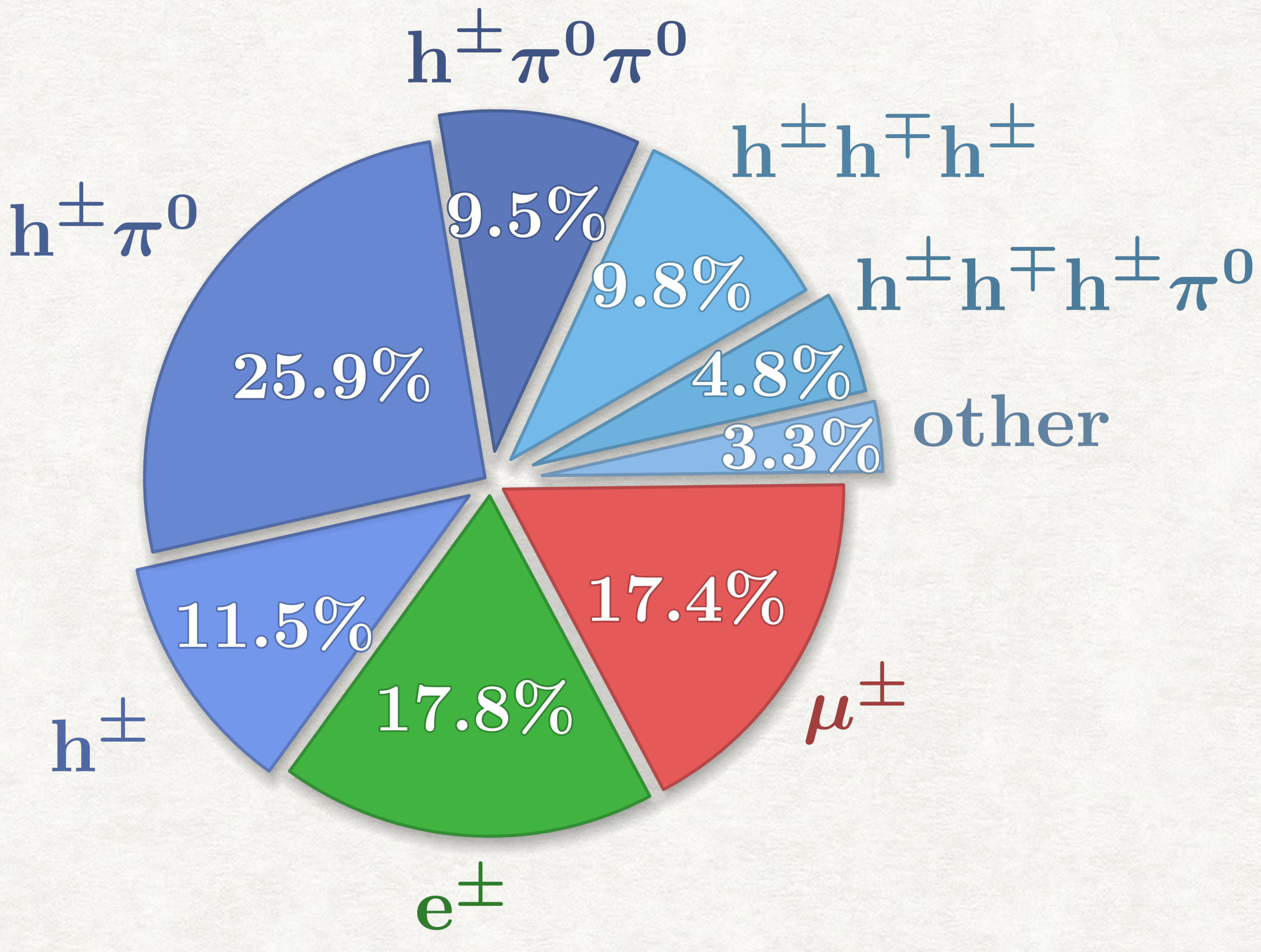
Future Plans

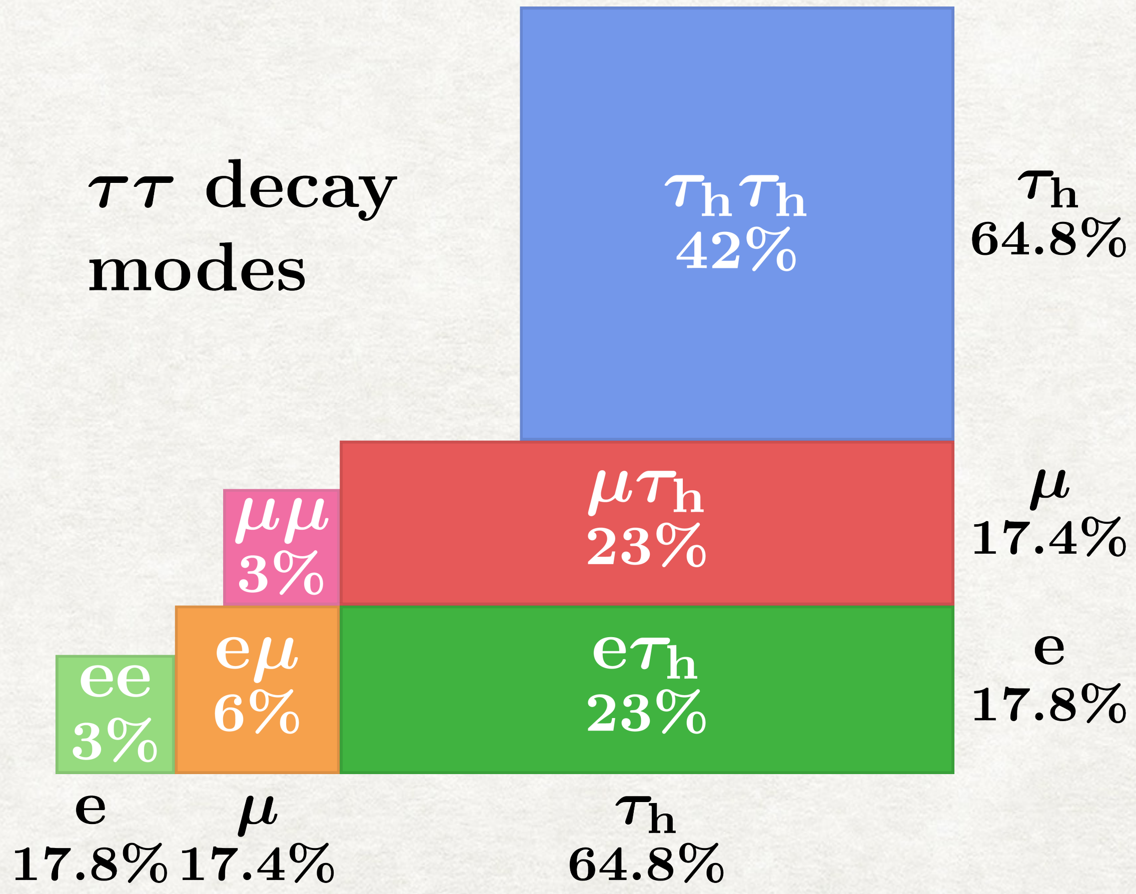
WHAT IS A TAU LEPTON?

IN PHYSICS

The tau is the 3rd generation charged lepton:

- Mass of 1777 MeV
- Lifetime of 0.29 ps
- Will decay into 1 e/μ+ 2ν (33%) or pions + 1ν (67%)
- Ideal for Higgs measurements due to largeHiggs branching fraction of Higgs to taus
- Abundant search program of BSM physics that is enhanced to 3rd generation fermions (eg. taus)





Credit: I. Neutelings

IN ATLAS

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

Signature Is 1 or 3 Charged Pions + Neutral Pions

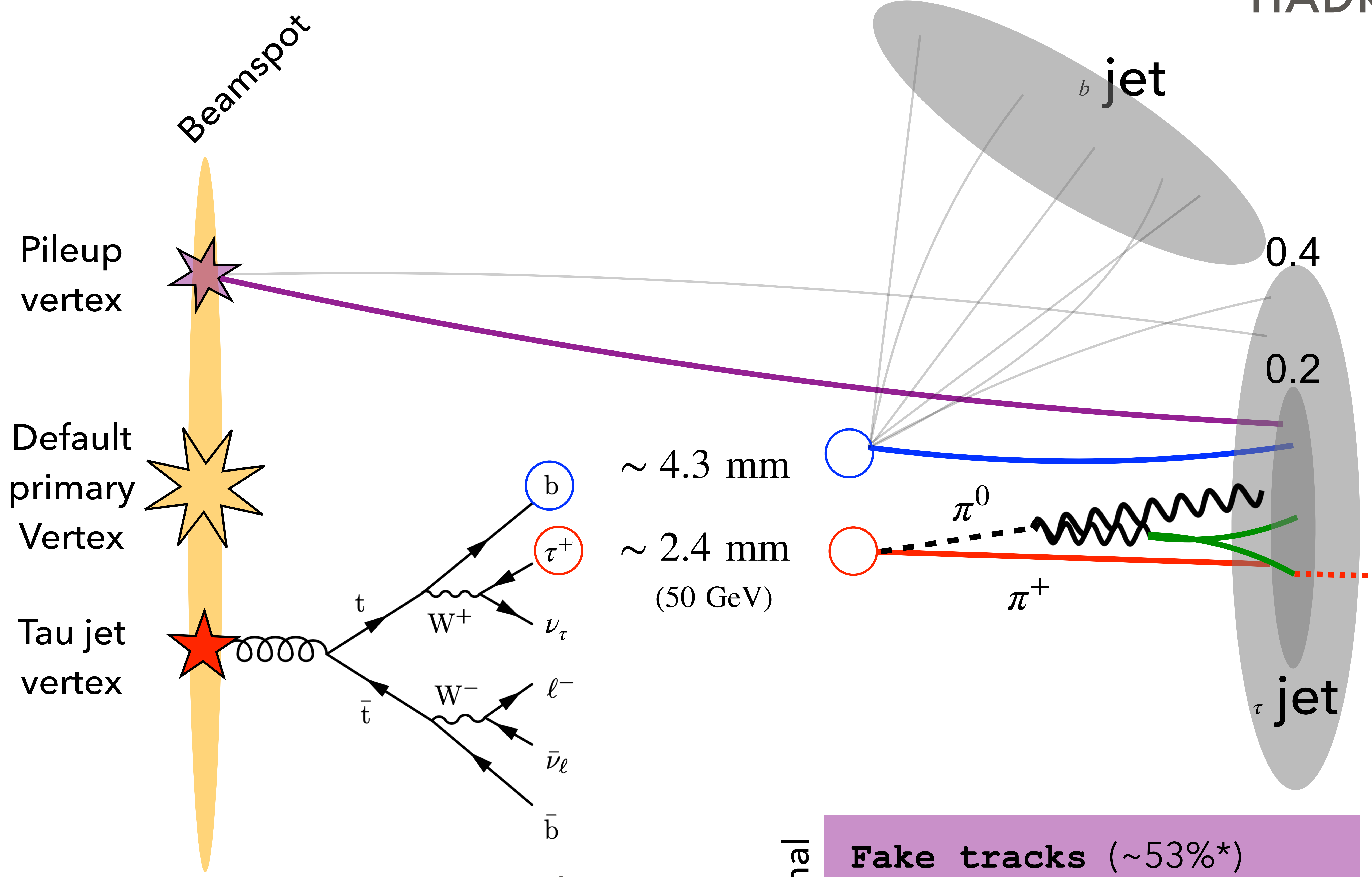
- Charged Pions Leave Tracks in Detector + Calorimeter Deposits
- Neutral Pions Decay Into Photons Leaving Entries in ECAL
- Need To Combine Track and Calorimeter Info
- Results in a Narrow Jet With Few Tracks
- Charge of Tracks Inside of Jet Required To Be ±1

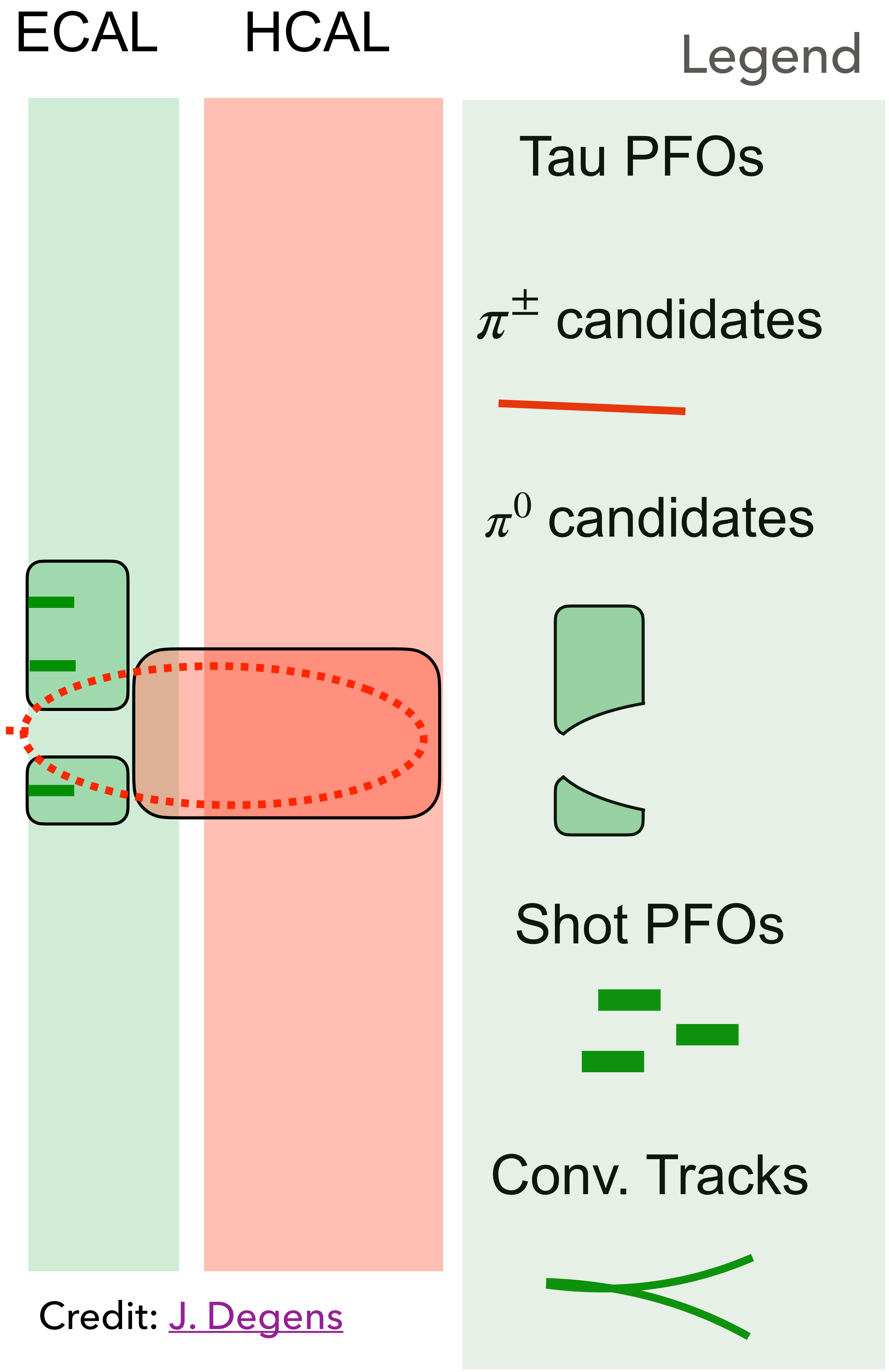
Rule of thumb:

- 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: J. Degens

HADRONIC TAU RECONSTRUCTION





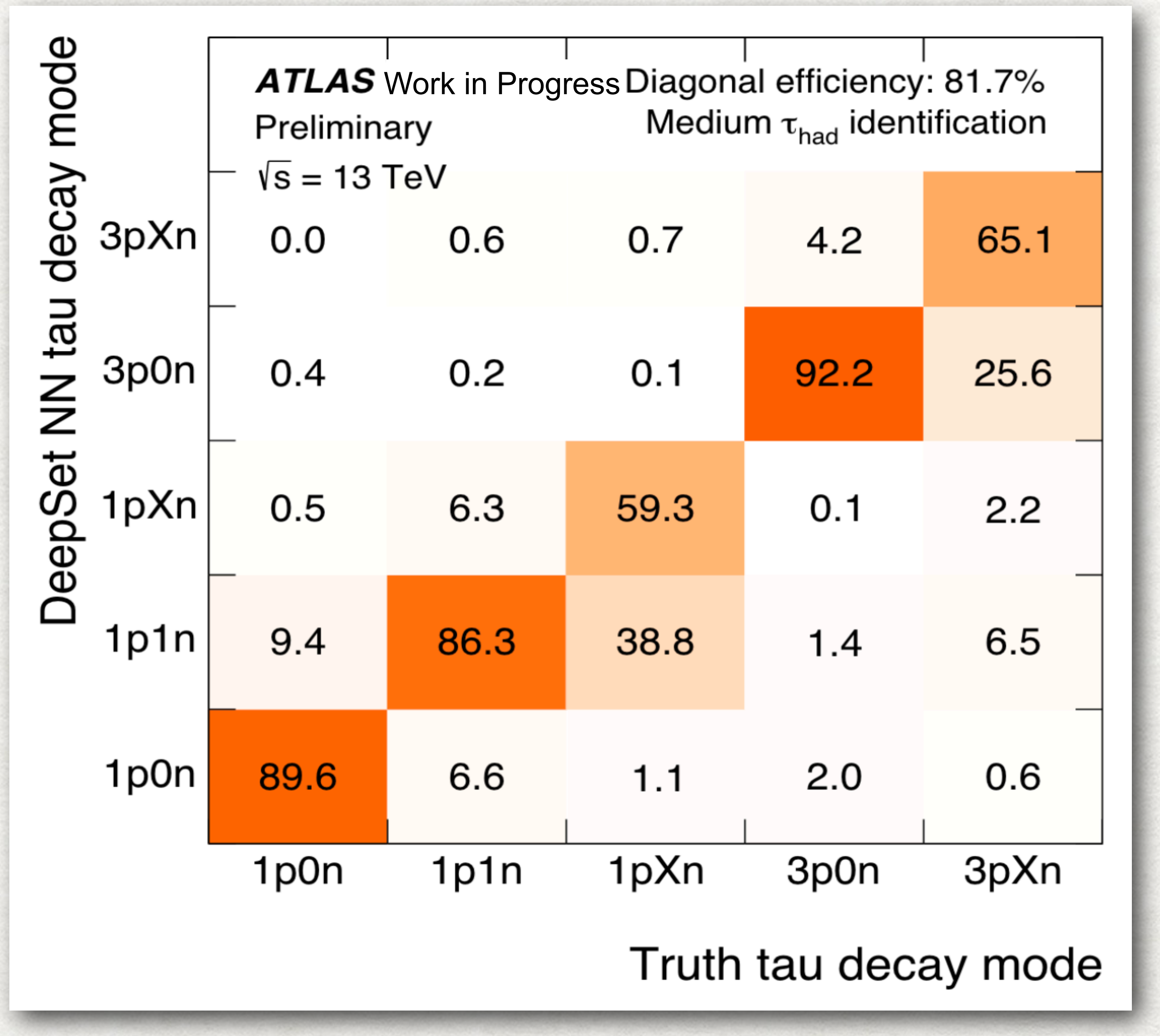
Credit: J. Degens

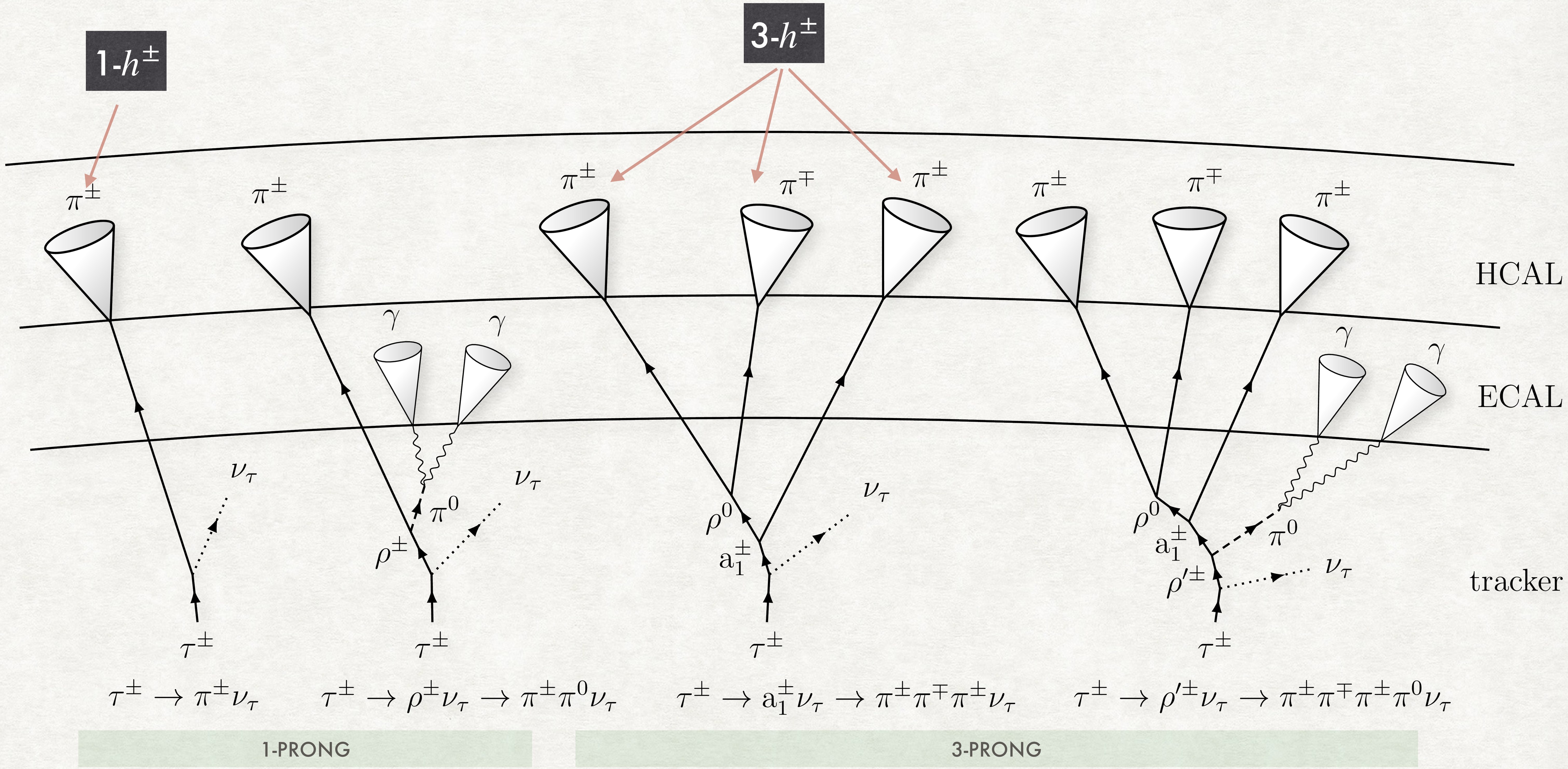
External	**Fake tracks**	(~53%*)
External	**Isol. tracks**	(~3%)
Internal	**Conv. tracks**	(~4%)
Internal	**Tau tracks**	(~40%)

- Hadronic tau candidates are reconstructed from charged tracks and neutral-energy deposits using particle-flow (PFO) objects.
- The main visible categories are 1-prong and 3-prong decays, with/without neutral pions (π0).
- This reconstruction output is the input to GNtau identification and the Run-3 calibration shown in later slides.

DECAY MODES

- Classify hadronic tau decays by charged/neutral hadron multiplicity (1-prong, 3-prong, with/without π^0).
- Improve separation of true hadronic taus from jets, electrons, and muons.
- Use calorimeter clusters, tracking, and π^0 substructure reconstruction.



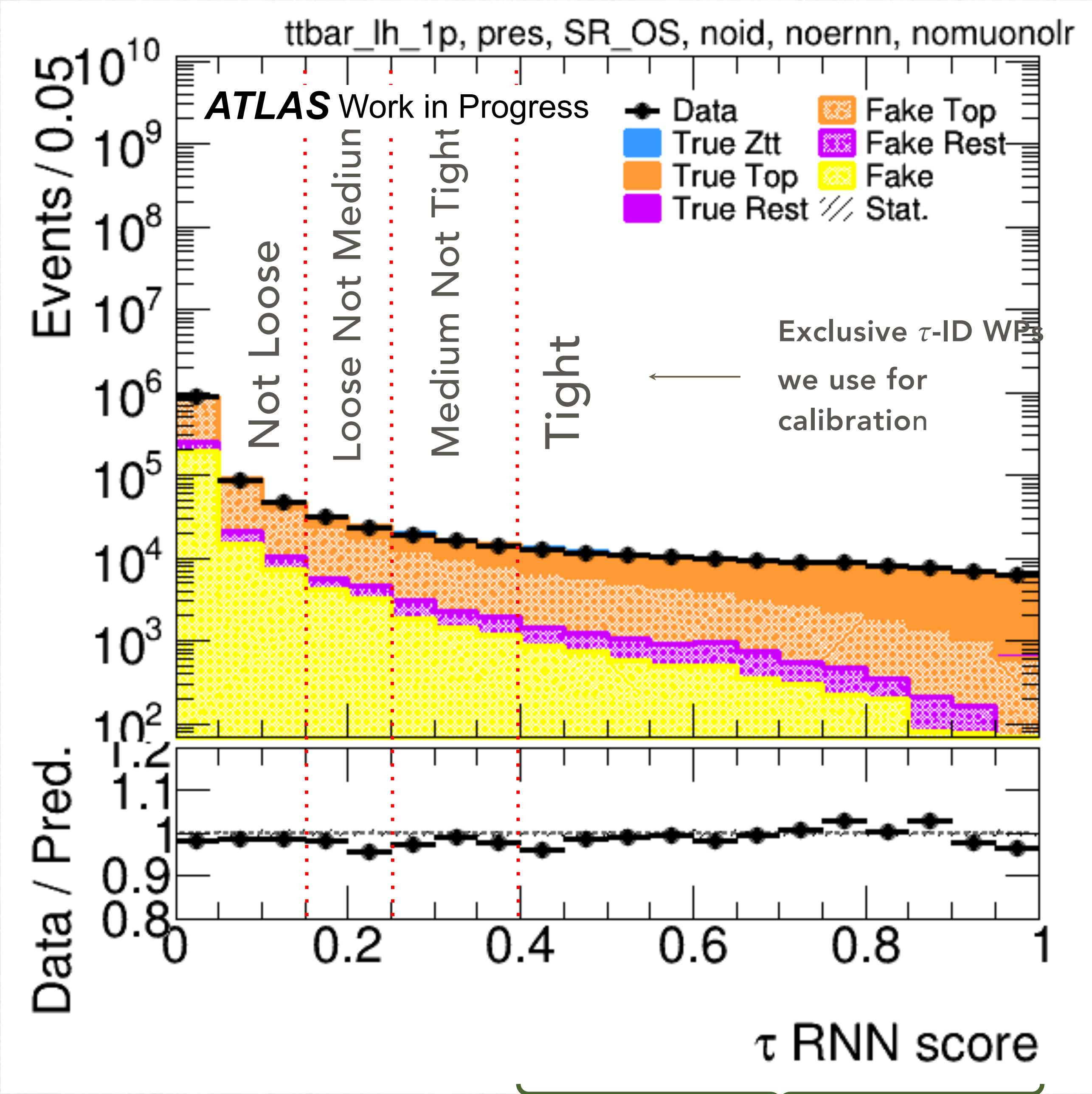


Credit: I. Neutelings

- 1-prong and 3-prong categories are used explicitly in calibration
- Decay-mode splitting improves both CP-sensitive analyses and 4-vector modelling
- Calibration is performed separately in 1-prong and 3-prong categories (i.e. category-dependent scale factors)

TAU IDENTIFICATION (TAUID)

Credit: Tau CP conveners



Working Point

TIGHT

MEDIUM

LOOSE

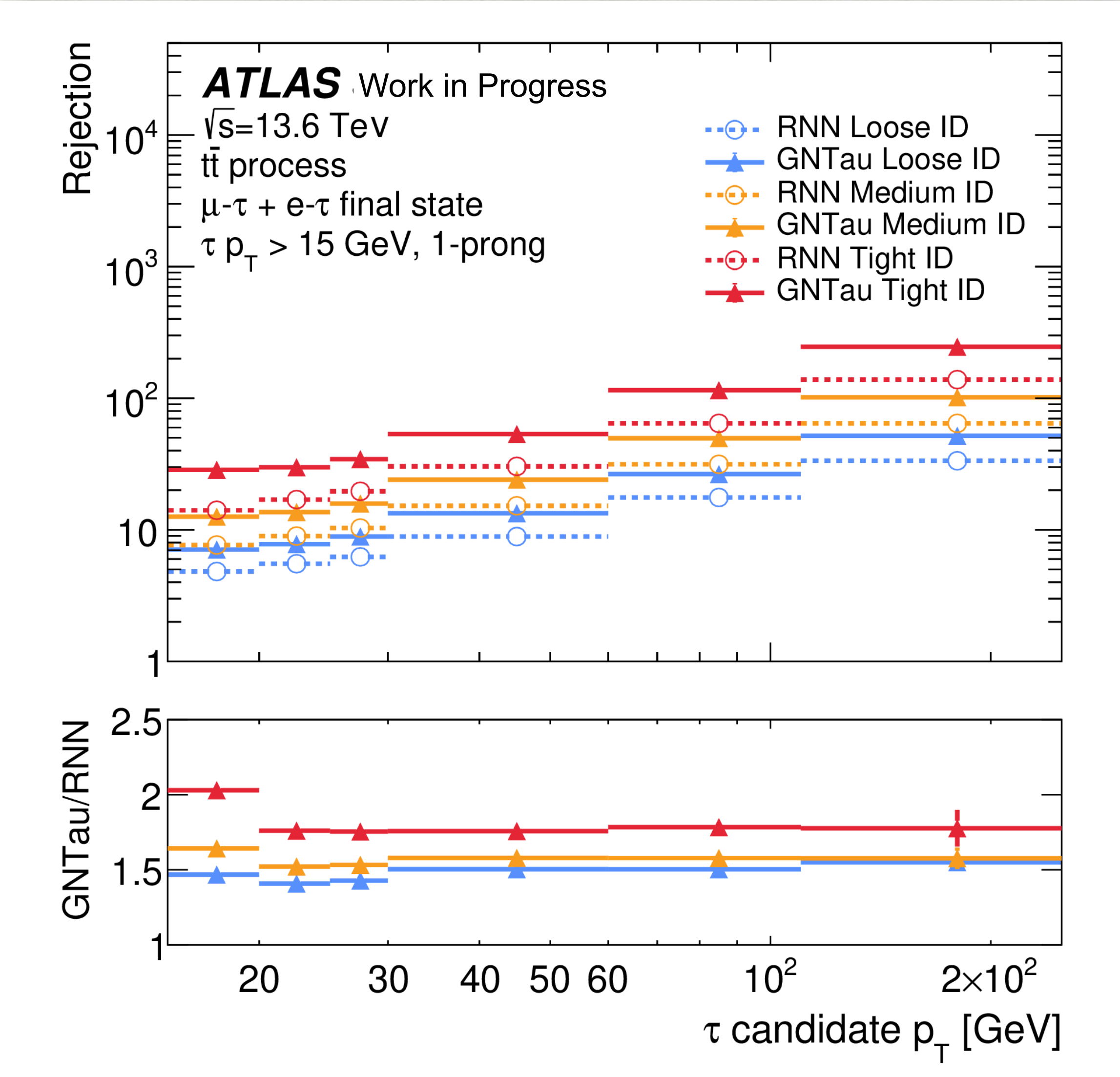
NO ID

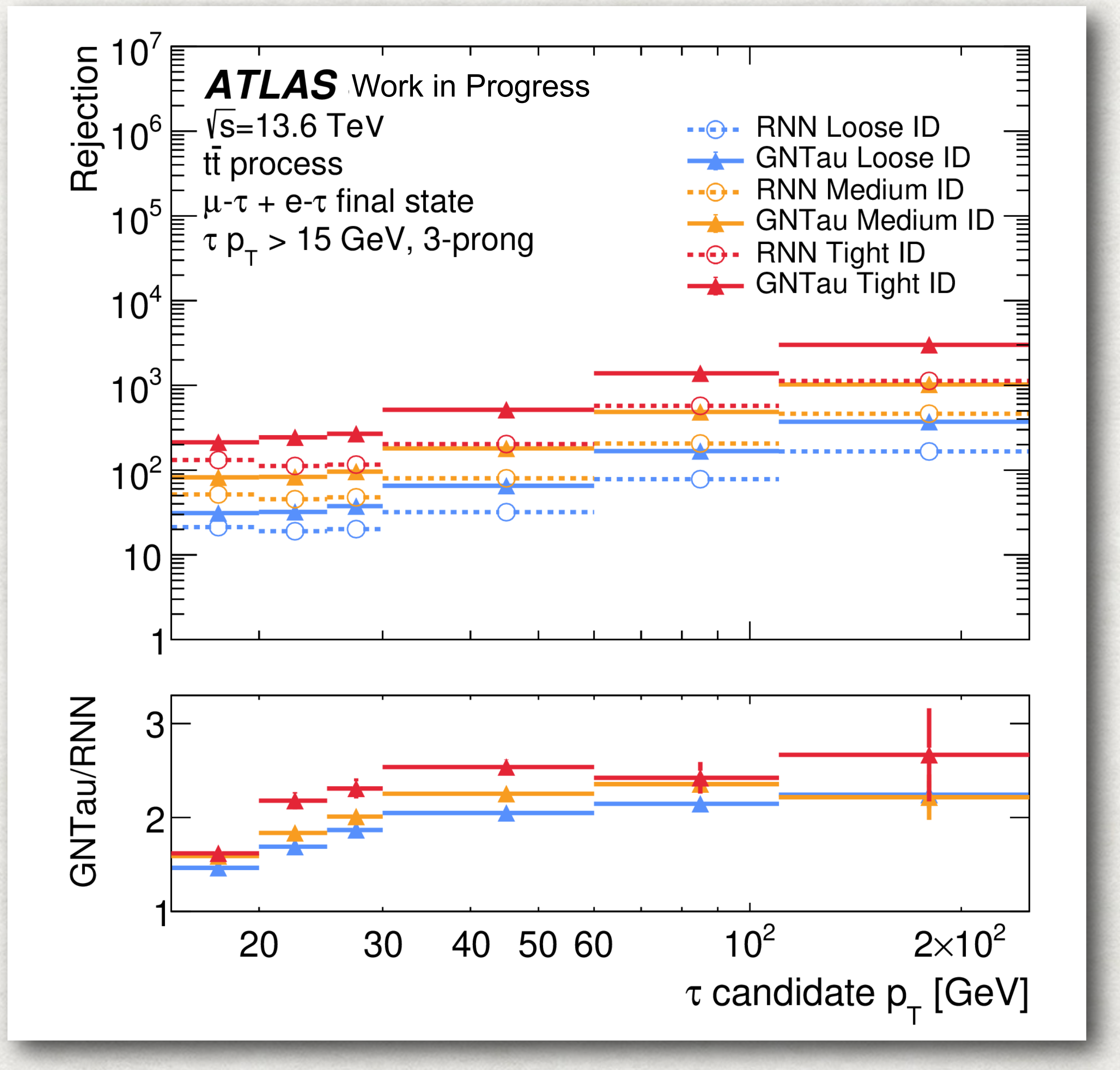
GNTau is a hybrid graph transformer-based neural network algorithm for the identification of the visible decay products of hadronic taus, used by the ATLAS experiment in Run 3 of the LHC.

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%

- **During Run 2, RNNs were used** to identify true hadronic taus and reject jets.
- **For Run 3, a new GNN based algorithm** has been developed (GNTau). Currently being calibrated for 2022, 2023 and 2024.

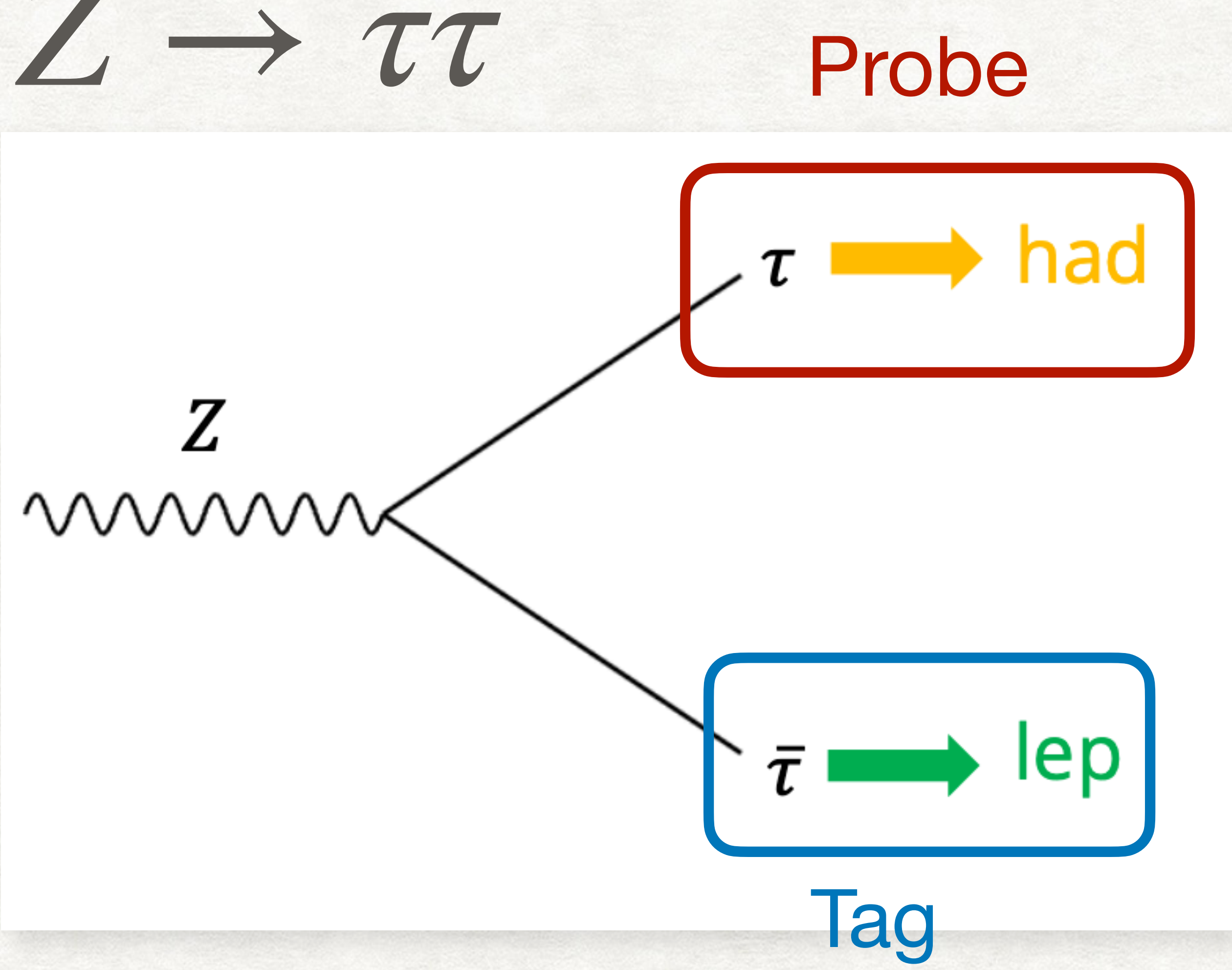
- ID trained to reject jets faking τ_h .
- Using artificial neural networks taking low level (tracks/clusters) and high level information from τ_h candidate
- Comparison of the inverse of the efficiency (rejection) of the RNN and GNTau identification algorithms for misidentified reconstructed τ candidates from $t\bar{t}$ events as a function of the τ pT
- The performance plots (right) compare Run-2 RNN and Run-3 GNtau at equal efficiency, showing higher rejection of fake taus with GNtau.



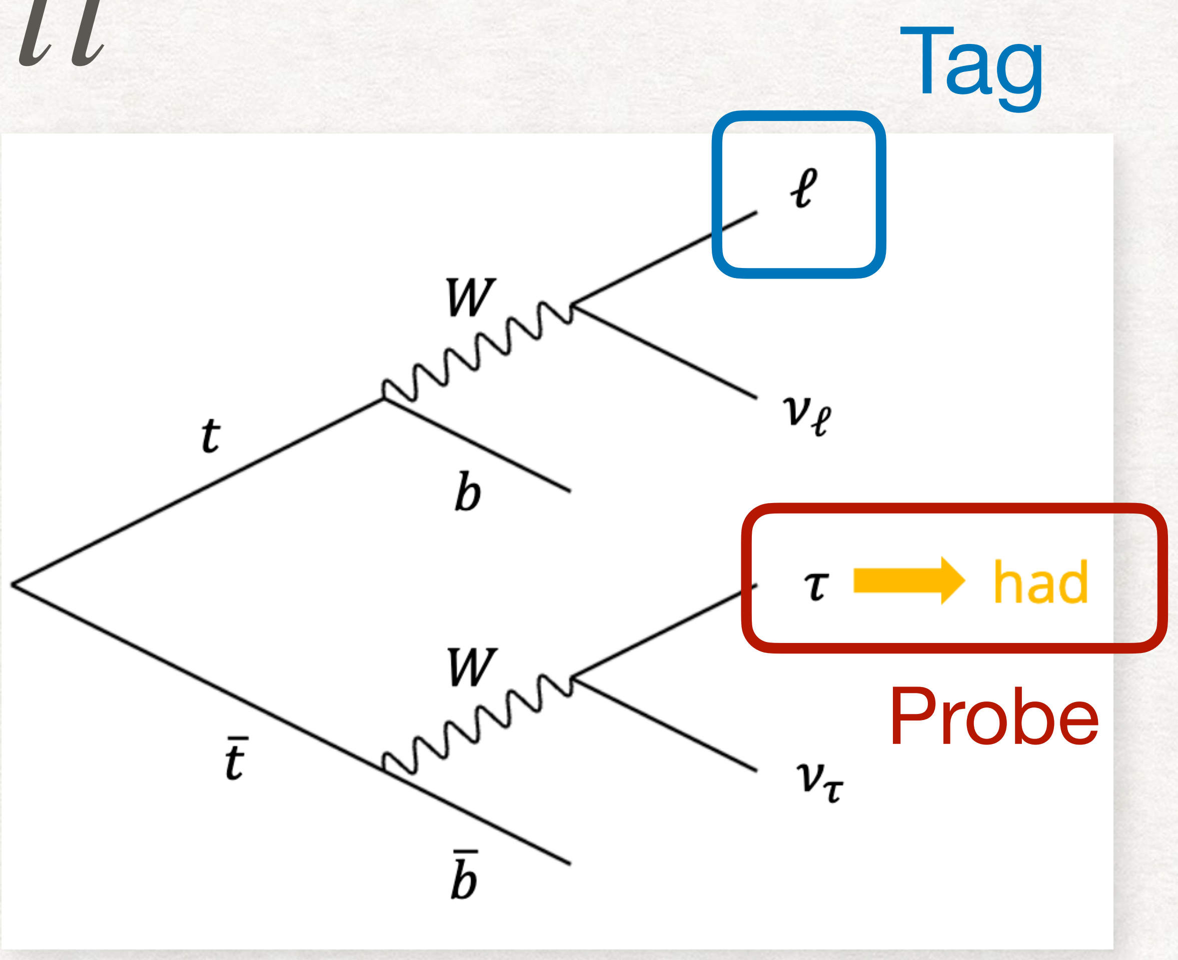


PROCESSES

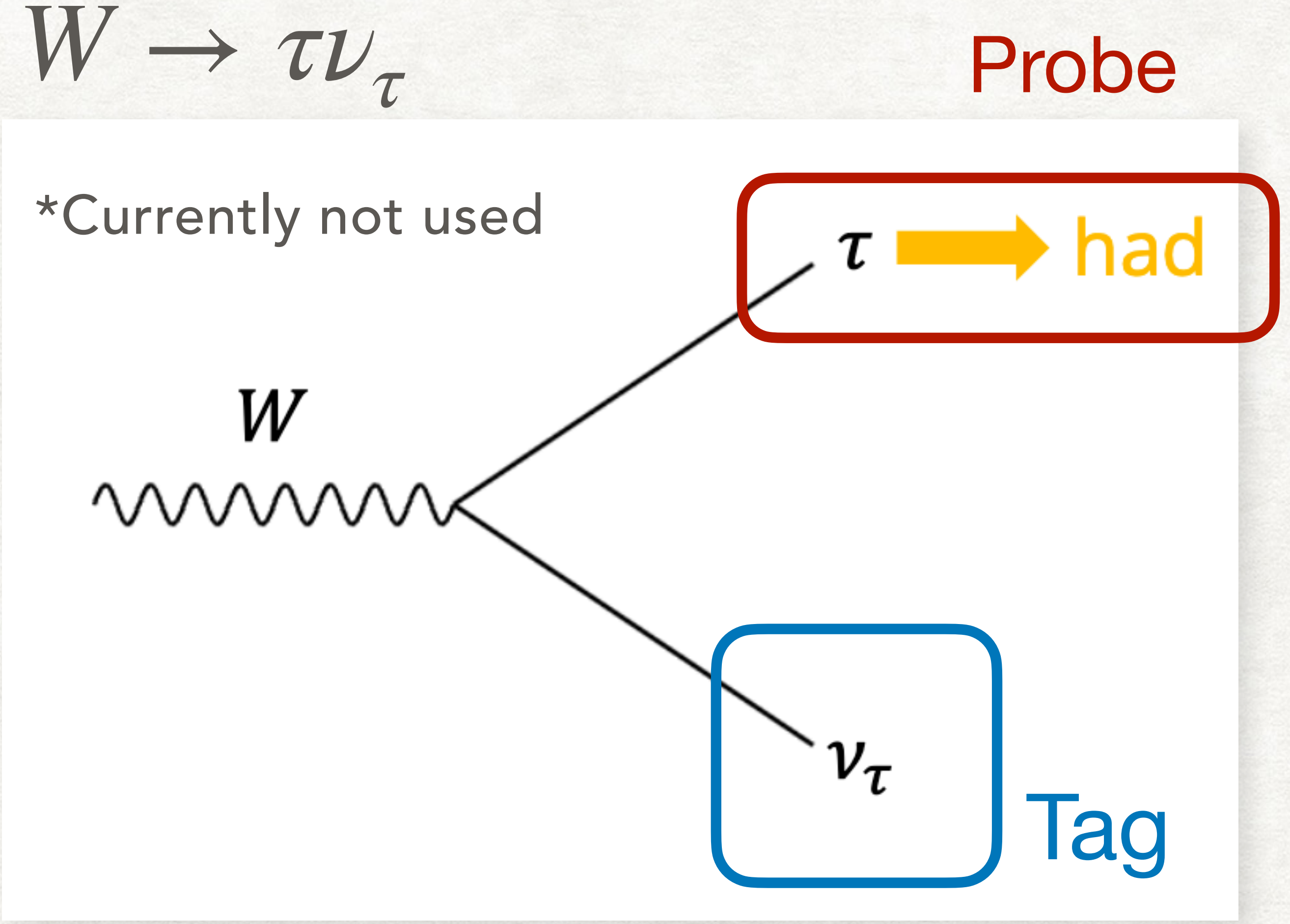
$Z \to \tau\tau$



$t\bar{t}$



$W \to \tau\nu_\tau$



- Correct Tau ID efficiencies on Tau ID scores, Scale factors are measured in pT bins, separately for 1-prong and 3-prong taus.

$$SF = \frac{\epsilon_{\text{Data}}}{\epsilon_{\text{MC}}} \qquad \epsilon = \frac{\text{N(true taus pass a certain ID)}}{\text{N(all truth taus)}}$$

- ϵ_{MC} is derived with pre-fit yields, ϵ_{data} is with post-fit yields.
- The fitted variable is the TauID score
- In total four measurements for three processes ($Z \to \tau_h\tau_l$, $t\bar{t} \to l\tau_h$, $W \to \tau_h\nu$) to provide SFs for pT ranging 15 GeV to over 200 GeV.

LATEST RECOMMENDATION FROM THE ATLAS-TAU GROUP

1. Tau Identification

- RNN-based ID scale factors & uncertainties available for Run2 (documented in CDS link) and **Run2 dataset** (documented in slides and slides).
- Provided via **TauEfficiencyCorrectionTool** for Loose/Medium/Tight WPs.
- From ABR 25.2.57: SFs also for 15–20 GeV (Medium/Tight WPs).

2. eVeto:

- Scale factors for electrons mis-ID as tau, available for **Run2** (documented in **CDS link**) and **Run3 2022 dataset** (documented in **CDS link**).
- Provided via **TauEfficiencyCorrectionTool** for combinations of Tau RNN ID/eVeto WPs.
- Matching to true electrons handled internally → no extra matching needed.

3. TauEnergyScale (TES):

- New in-situ TES from $Z\to\tau\tau$ (Run3), covering low-pt spectrum documented in **Slides** and **JIRA** .
- High-pt: old uncertainties (TestBeam & MC comparison) still valid until updates.
- TES and uncertainties provided via **TauSmearingTool**.

AND WHERE TO FIND IT (ALL THE LINKS ATTACHED)

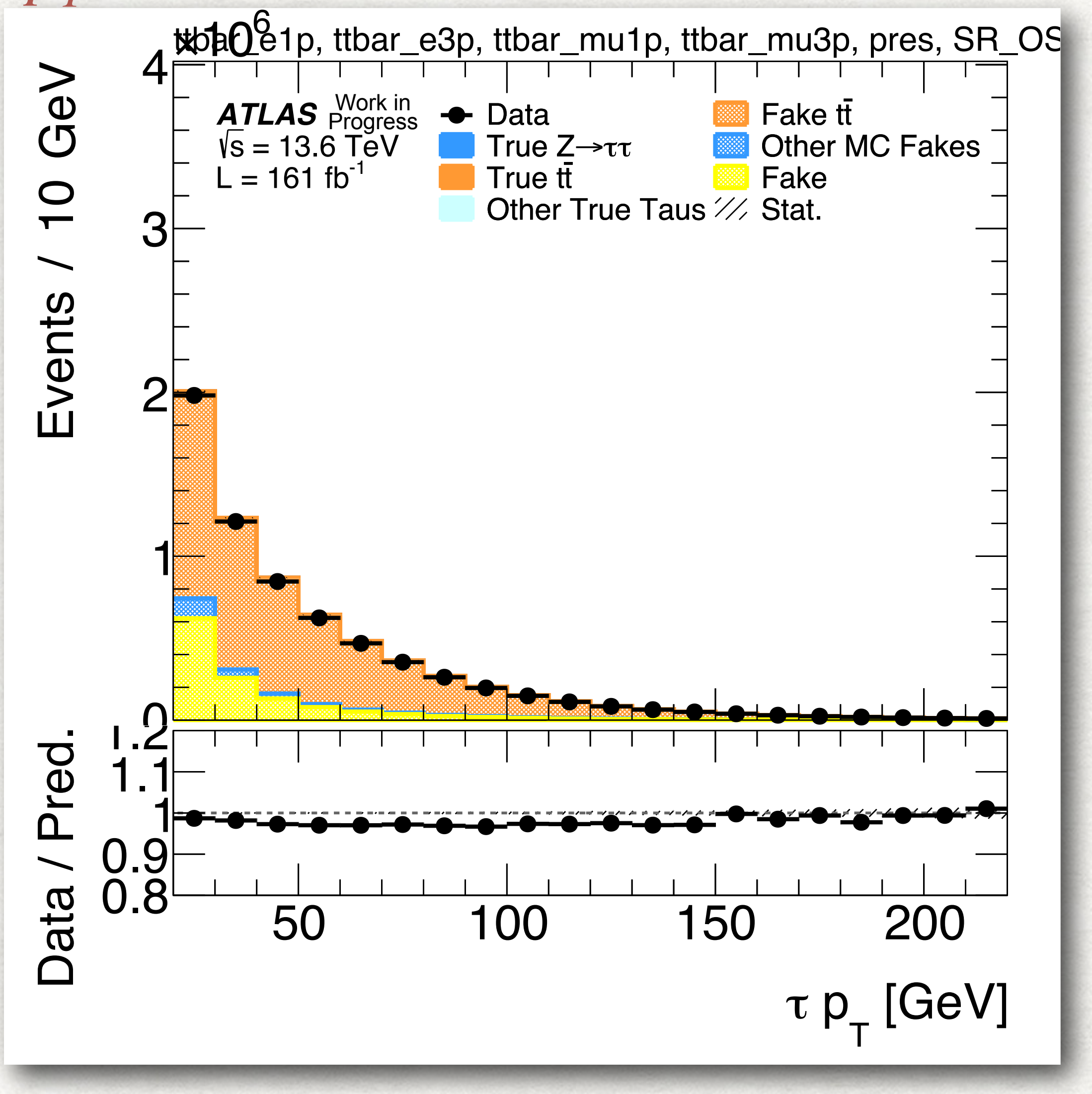
COMBINED RUN-3 GNTAU CALIBRATION RESULTS

— Run:3 (Year 2022+2023+2024) with GNTau

— Latest V07 nTuples

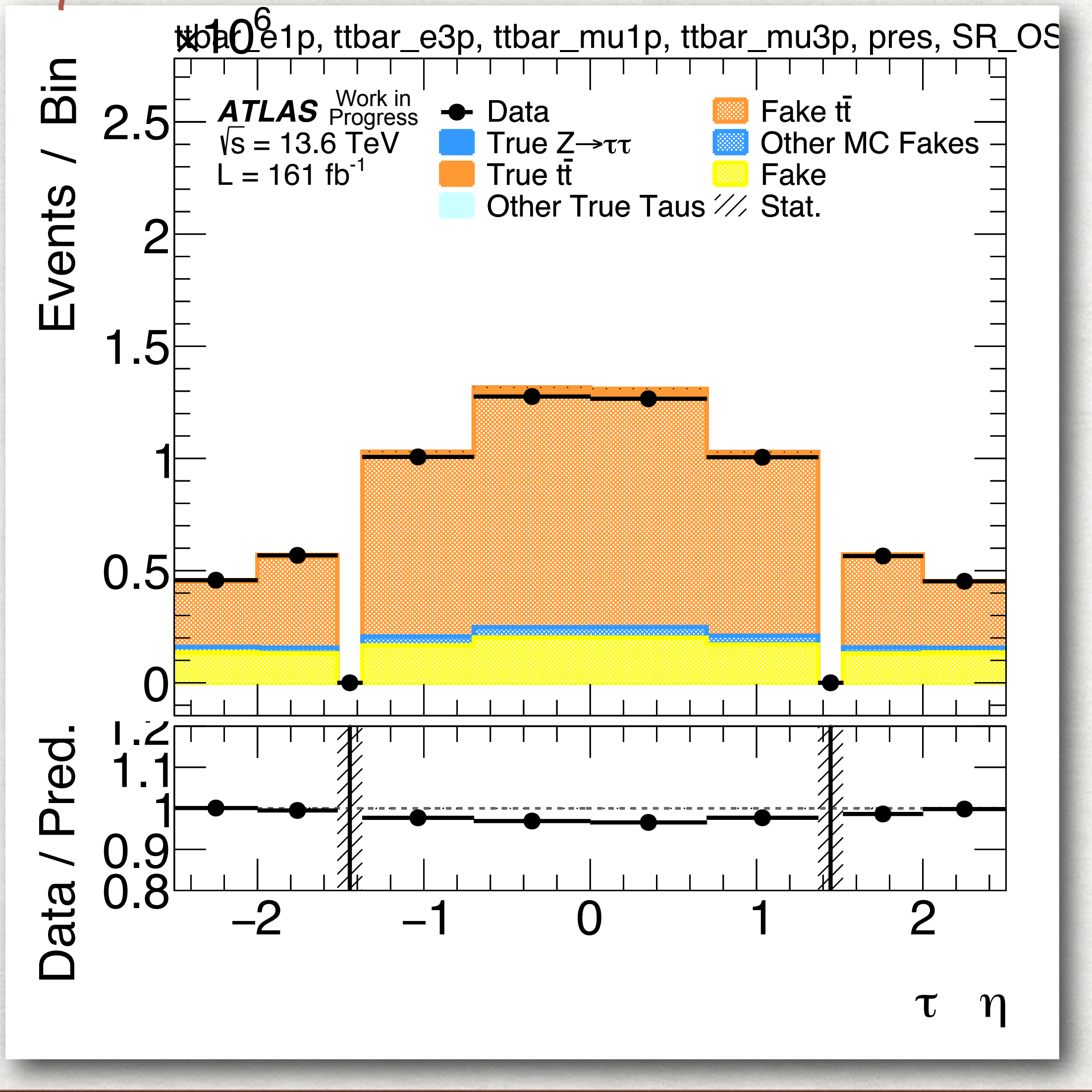
τ_{p_T} , τ_η AND r_{QCD} CR DISTRIBUTIONS

τ_{p_T} Distribution



τ_η Distribution

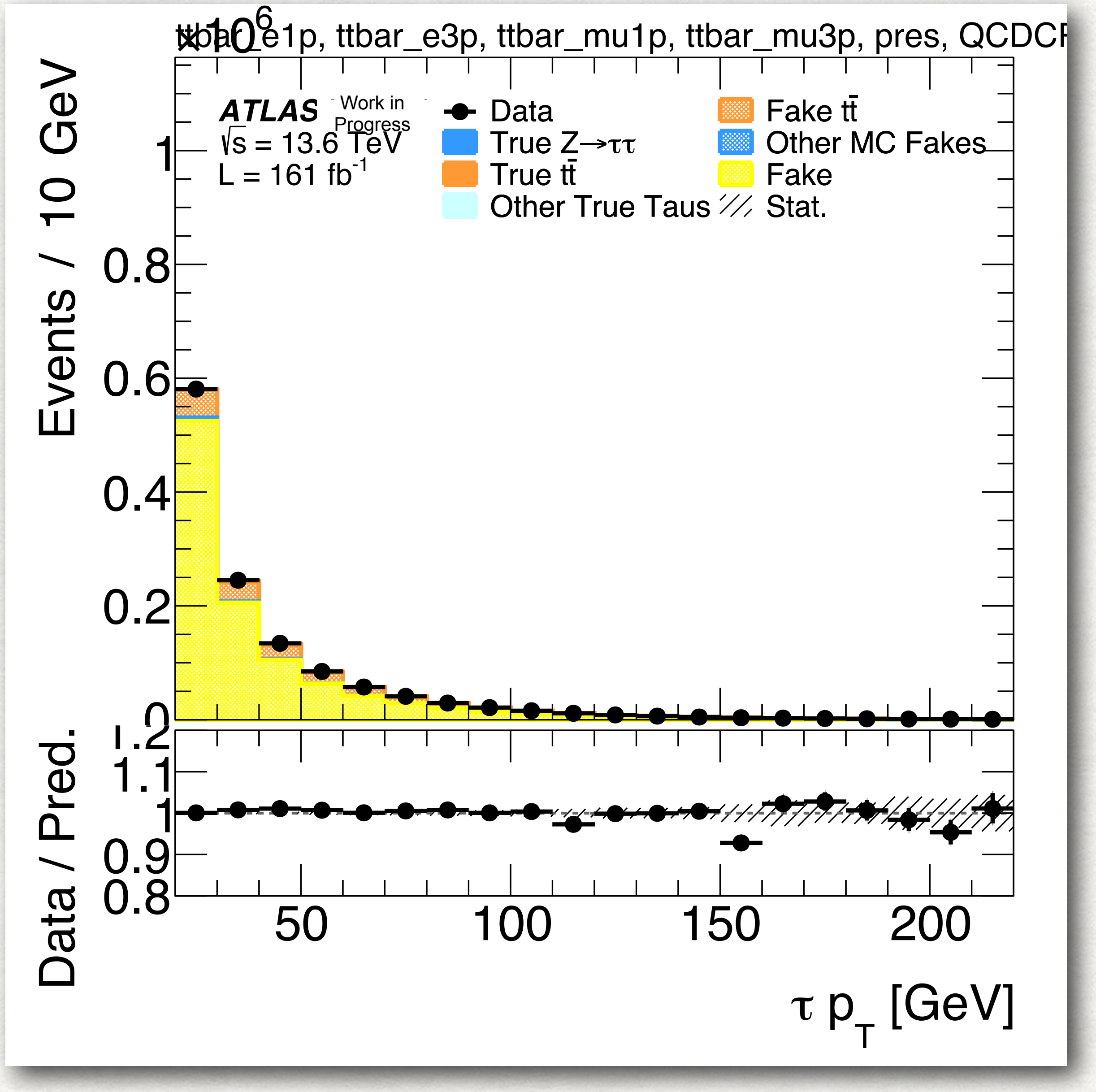
Not Loose



- We validate the core tau-lepton kinematics using transverse momentum and pseudorapidity in all the 4 working point (plots showing- “Not Loose” (NL) category).
- Data and simulation are in good agreement in the populated regions, with residual differences covered by uncertainties.
- This confirms that the event kinematics are well modelled before extracting calibration factors.
- Equivalent checks for other tau-identification categories are consistent and kept in backup.

r_{QCD} CR Distribution

Not Loose



- The same-sign control region is used to derive the misidentified-jet background distribution for the signal region.
- In the NL category, the control-region shape is well described within uncertainties.
- This supports a stable transfer of the misidentified-jet estimate from control to signal regions.

— *More info at the backup*

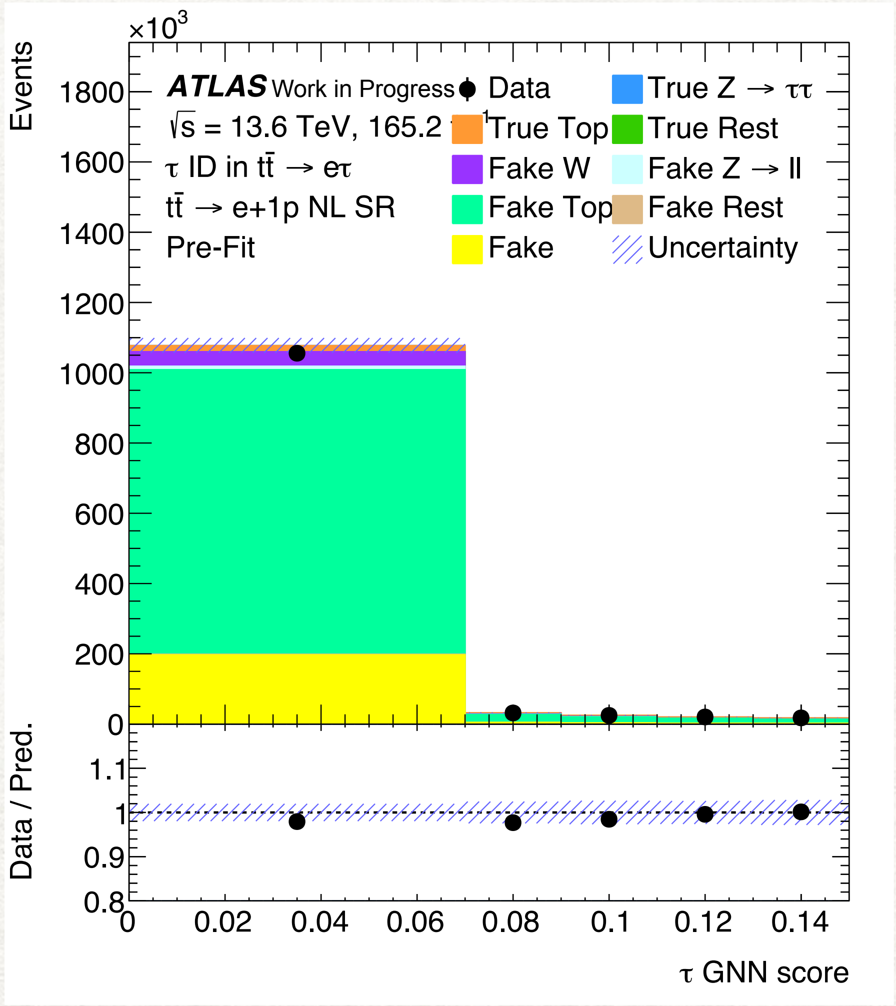
FITTING STRATEGY

- We use a simultaneous template likelihood fit across channels and tau-ID categories.
- Signal and fake components are constrained together using SR and CR information.
- POIs are tau-ID efficiency scale factors, extracted by prongness and working point.
- Detector and theory systematics are profiled consistently in one global fit.
- Prefit-to-postfit comparison is used to verify closure and fit stability.
- Final output is a coherent set of Run-3 SFs with full uncertainties and correlations.

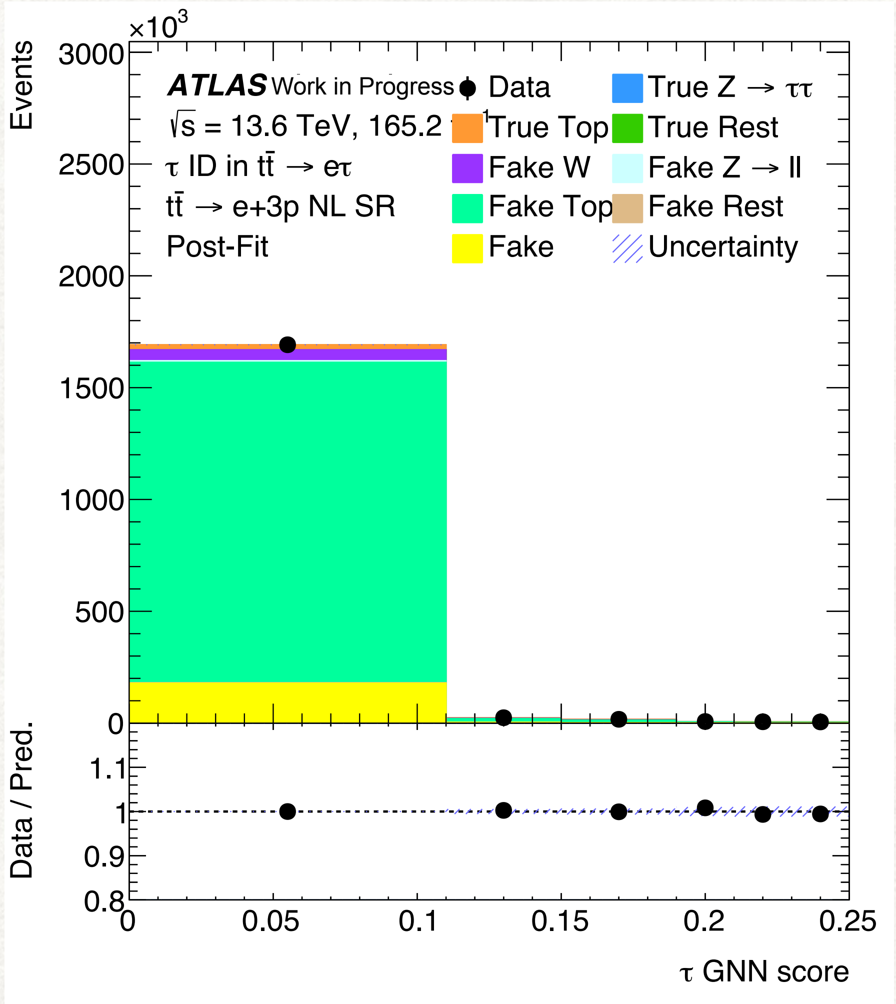
Credit: TRExFitter

E-1/3P PREFIT POSTFIT DISTRIBUTION

e1p Prefit



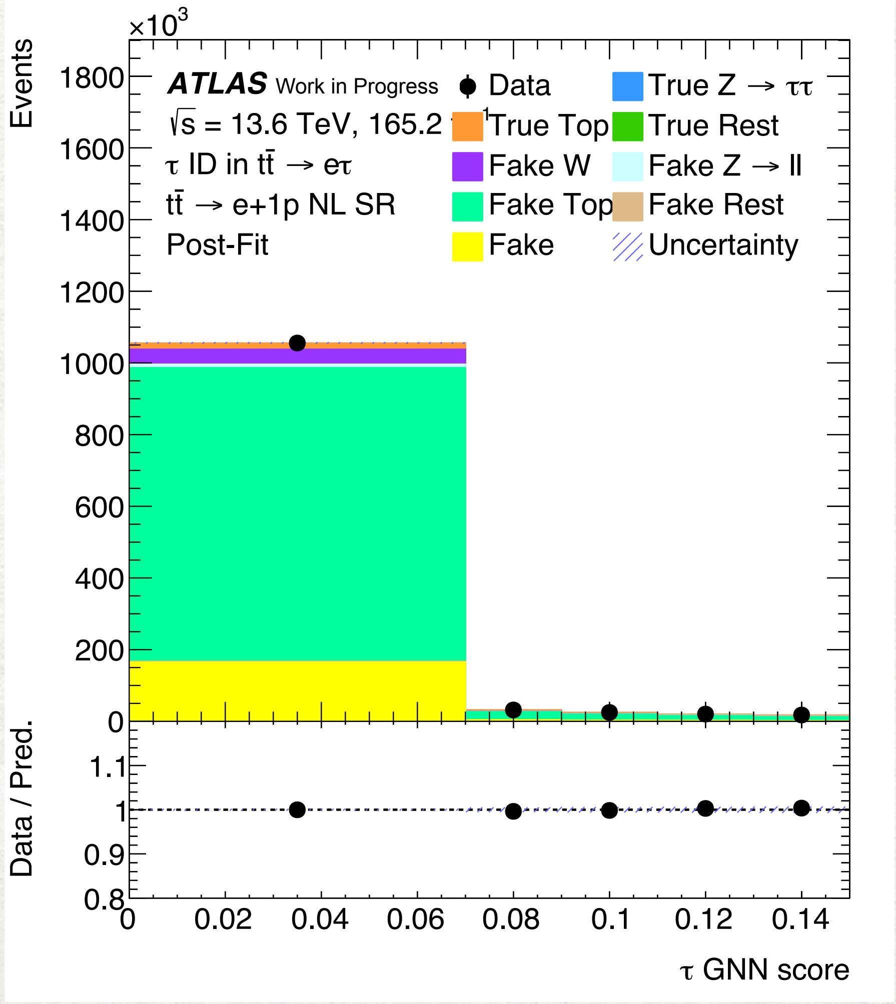
e3p Prefit

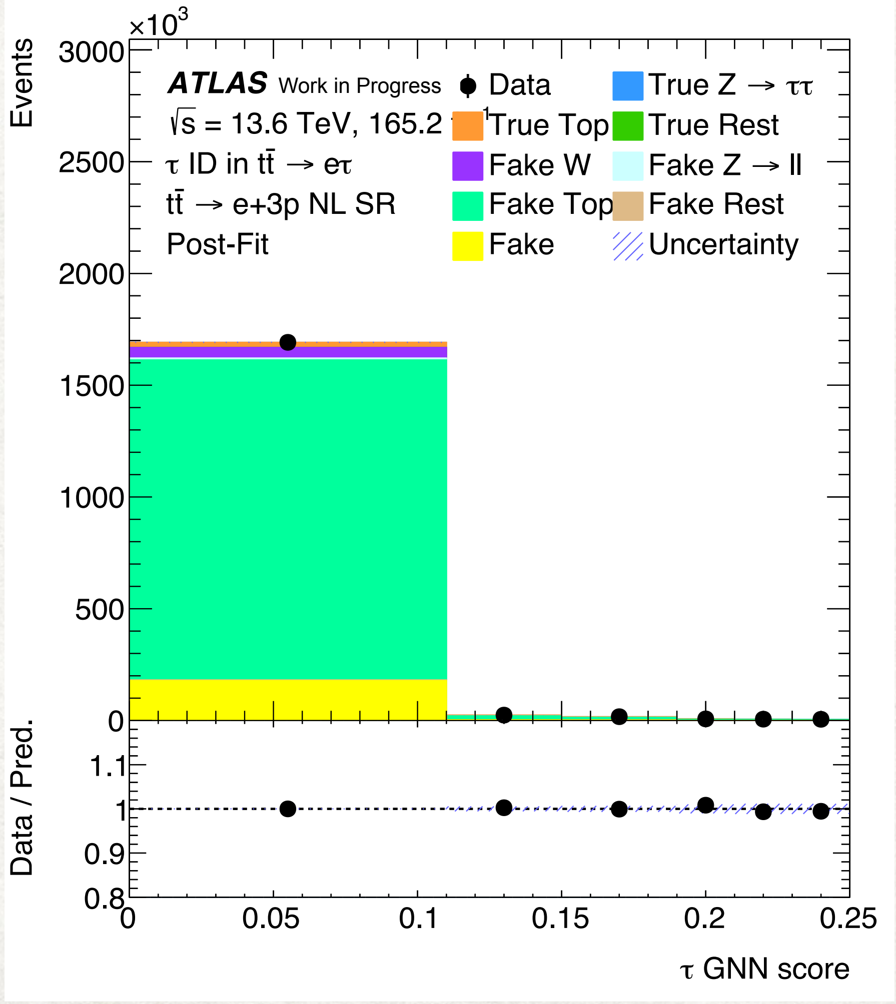


e1p Postfit

Not Loose

e3p Postfit





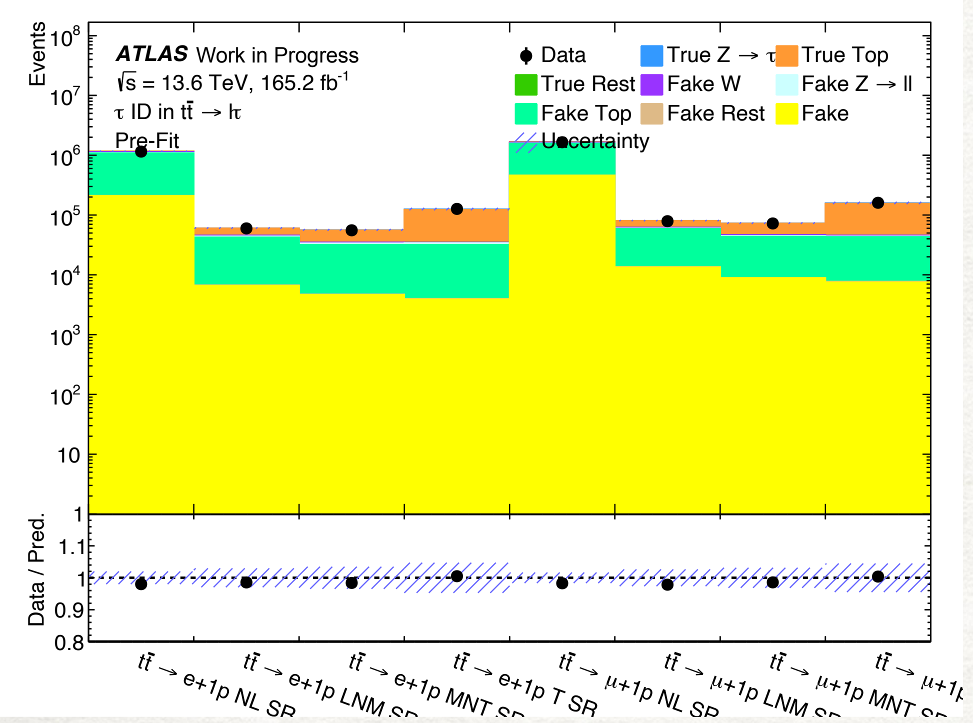
- These panels compare before-fit and after-fit distributions for the electron + tau channel in the 1-prong and 3-prong categories for NL working point.
- Before the fit, small data-to-simulation differences are visible in some tau-identification regions, as expected.
- After the simultaneous fit, agreement improves across the distributions and the ratio panels move closer to unity.
- The improvement is seen in both 1-prong and 3-prong, showing that the fit handles different tau topologies consistently.
- No large residual structure remains after the fit, indicating a stable and well-constrained model.
- This validates the fitting strategy used to extract the final tau-identification calibration factors.

— More info at the backup

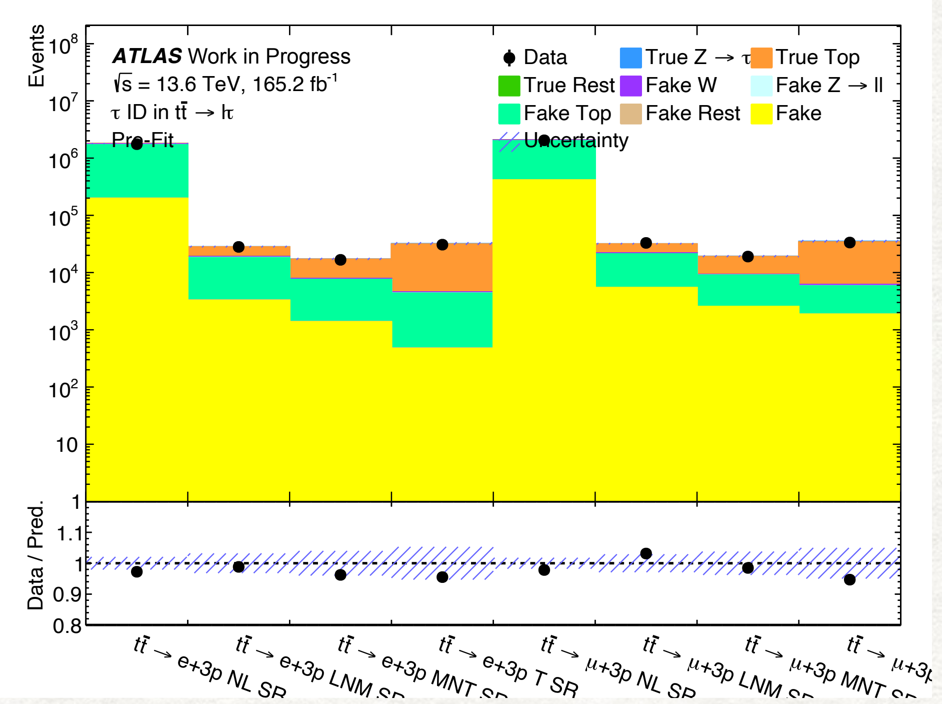
GNTAU TTBAR RUN-3

Summary Plots

Prefit

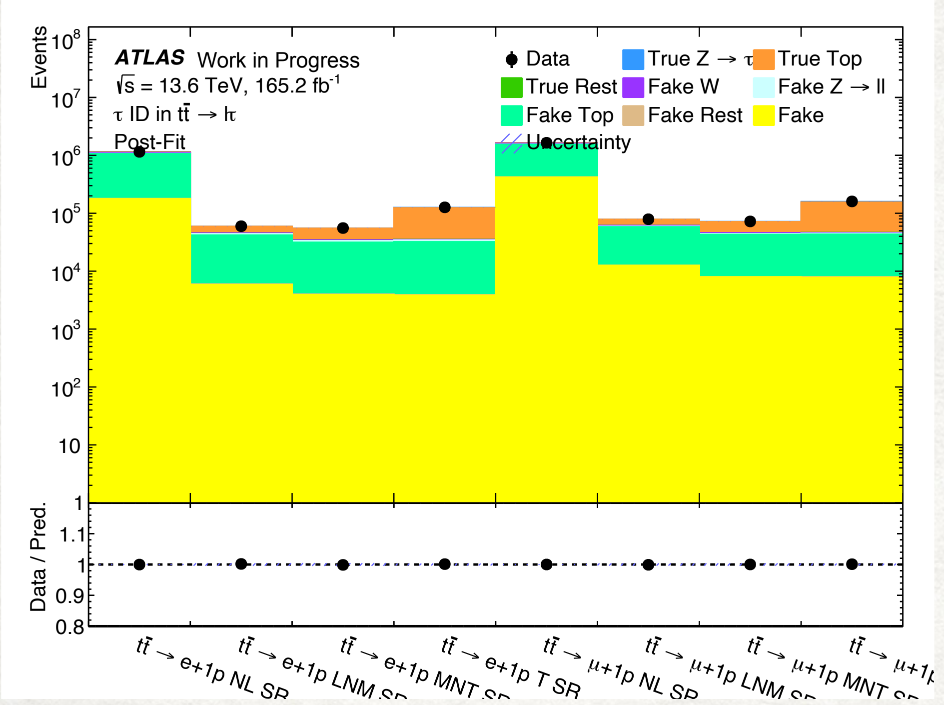


Emu1p

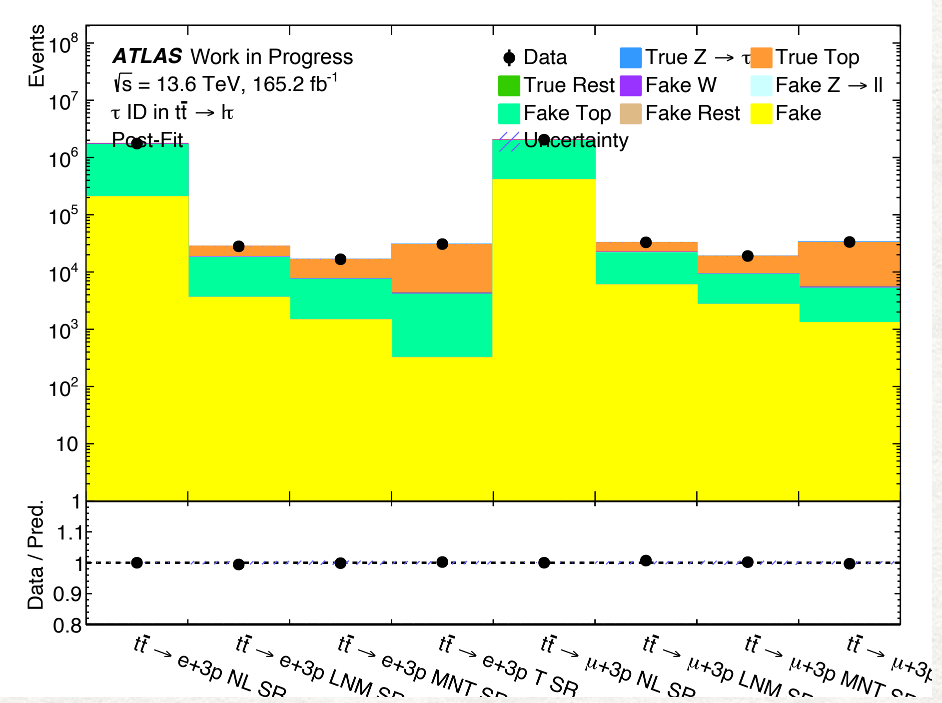


Emu3p

Postfit

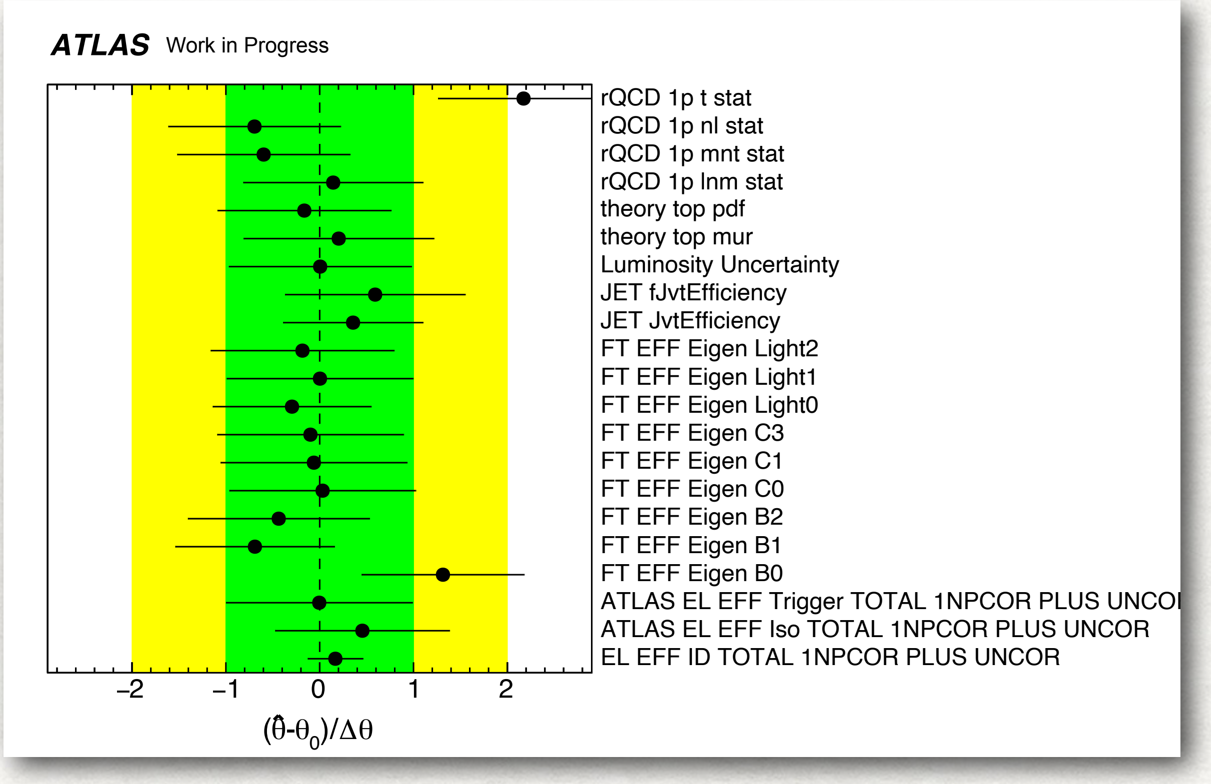


Emu1p

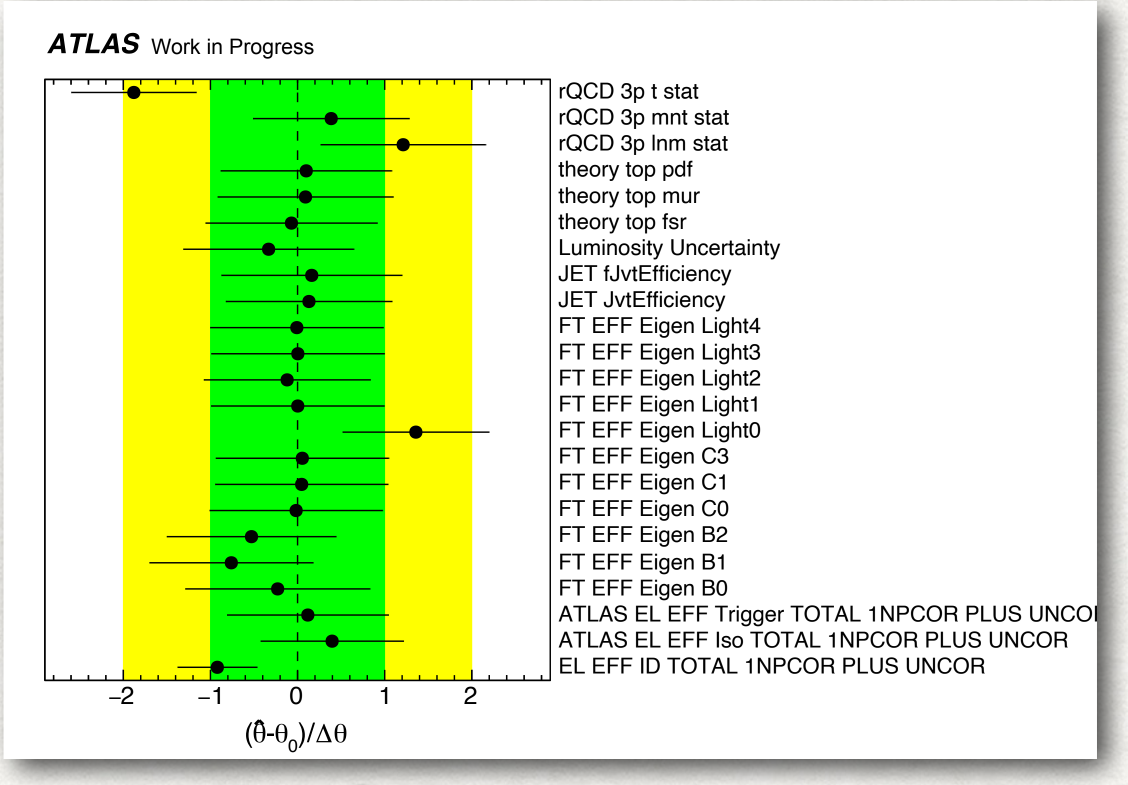


Emu3p

Nuisance parameter



Emu1p

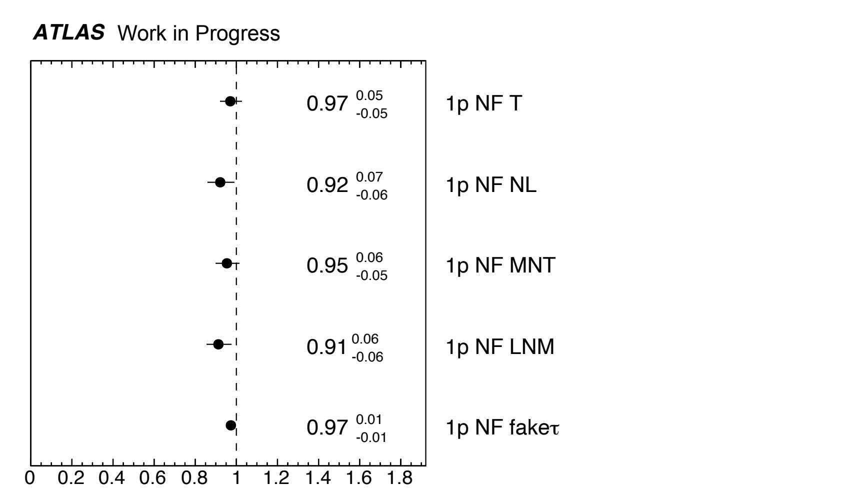


Emu3p

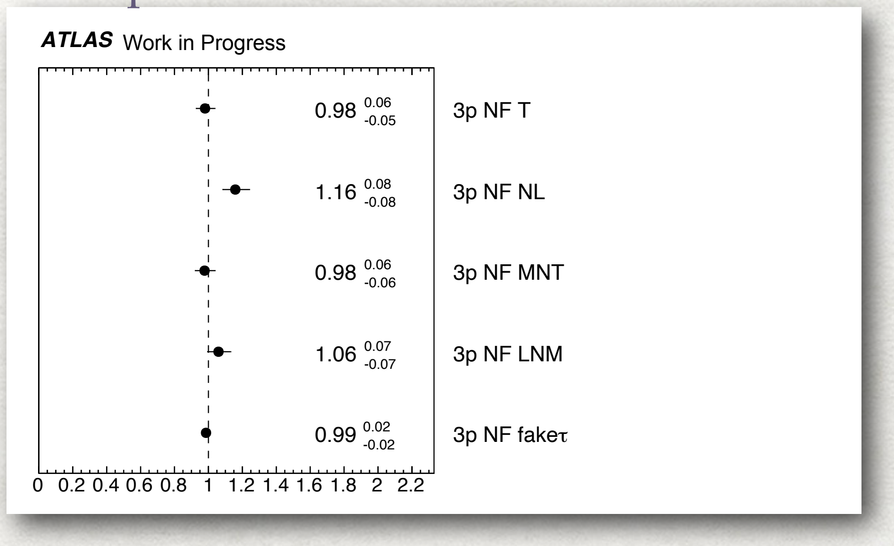
- NP (nuisance parameter) pulls: most are within expected ranges, with no broad over-constraining pattern.
- Largest pulls are in known sensitive components and remain physically interpretable.
- No single NP dominates the fit in a pathological way across channels.
- NF (normalisation factors): fitted values stay close to unity in most categories.
- NF shifts are moderate and consistent with prefit data/MC trends.
- Together, NP and NF behaviour confirms fit stability and supports the robustness of the final SFs.

Norm Factors

Emu1p



Emu3p



- This slide shows the summary prefit/postfit distributions across all l+1p categories.
- It gives one global view of closure quality before showing final SF numbers.
- Prefit shows the expected spread around unity across categories.
- Postfit pulls the distributions into better data/MC agreement consistently.

SCALE FACTOR RUN-3

Year–22+23+24

e+tau	Loose	Medium	Tight
1p	0.99 ± 0.02	1.00 ± 0.02	1.00 ± 0.03
3p	0.93 ± 0.03	0.92 ± 0.04	0.92 ± 0.05

mu+tau	Loose	Medium	Tight
1p	1.01 ± 0.02	1.02 ± 0.02	1.02 ± 0.03
3p	0.95 ± 0.03	0.92 ± 0.04	0.92 ± 0.04

l+tau	Loose	Medium	Tight
1p	1.01 ± 0.01	1.01 ± 0.01	1.01 ± 0.02
3p	0.94 ± 0.02	0.93 ± 0.02	0.93 ± 0.03

Run-3 ptBin 1/3-prong

- Final Run-3 SFs are extracted for e+tau, mu+tau, and combined l+tau, split by prongness and WP.
- 1-prong SFs are near unity; 3-prong SFs are slightly below unity but stable across Loose/Medium/Tight.
- Results are consistent across channels and provide the recommendation-ready calibration for analyses.

— More info at the backup

FUTURE PLANS FOR TAU

NEXT ROUND

Aiming at Summer 2026

- Nominally will only cover 2022+2023+2024 and GNTau case:
  - With help from PA teams, run2 GNTau recommendations are also covered quite well
  - Will cover ttbar Run-3 reco

- Extension to MC23d with MC-MC comparison
- Missing:
  - TauID: W->tauv Run2&3, Combination studies for Run2, pseudo-continuous recommendations for Run2&3
  - In-situ TES in ttbar channel

RECOMMENDATION

Credit: Tau CP conveners

SUMMARY

- This work delivers a combined Run-3 GNTau tau-ID calibration in semileptonic ttbar events (2022+2023+2024, 13.6 TeV).
- Core kinematic and control validations (tau pT, tau eta, rQCD CR) show consistent modelling in the fitted phase space.
- A simultaneous SR+CR template likelihood fit is used to constrain signal and fake components in situ.
- Prefit/postfit comparisons in representative channels show clear closure improvement and NP pulls remain within expected ranges overall.
- Final SFs are stable across e+tau, mu+tau, and combined l+tau, with 1p near unity and 3p slightly below unity.
- These results provide recommendation-ready Run-3 calibration inputs for ATLAS analyses using hadronic taus.

Credits-OpenAI

BACK UP

Scale Factor Run-3

1prong | Year–22+23+24

e+tau	Loose	Medium	Tight
[20,25]	0.99 ± 0.04	0.99 ± 0.04	0.99 ± 0.05
[25,30]	0.97 ± 0.03	0.98 ± 0.03	0.98 ± 0.04
[30,40]	1.00 ± 0.02	1.00 ± 0.03	1.00 ± 0.04
[40,60]	0.98 ± 0.02	0.99 ± 0.02	0.98 ± 0.03
[60,80]	1.00 ± 0.02	1.01 ± 0.03	1.02 ± 0.04
[80,120]	1.02 ± 0.02	1.03 ± 0.03	1.06 ± 0.04
[>120]	1.03 ± 0.03	1.05 ± 0.04	1.06 ± 0.05

mu+tau	Loose	Medium	Tight
[20,25]	1.05 ± 0.04	1.03 ± 0.04	1.04 ± 0.05
[25,30]	1.01 ± 0.03	0.99 ± 0.03	1.00 ± 0.04
[30,40]	1.00 ± 0.02	1.01 ± 0.03	1.00 ± 0.03
[40,60]	1.02 ± 0.02	1.03 ± 0.02	1.04 ± 0.03
[60,80]	1.01 ± 0.02	1.02 ± 0.03	1.03 ± 0.03
[80,120]	1.03 ± 0.02	1.05 ± 0.03	1.07 ± 0.04
[>120]	1.01 ± 0.04	1.03 ± 0.04	1.03 ± 0.05

l+tau	Loose	Medium	Tight
[20,25]	1.02 ± 0.02	1.02 ± 0.02	1.02 ± 0.03
[25,30]	0.99 ± 0.02	0.99 ± 0.02	0.99 ± 0.02
[30,40]	1.01 ± 0.01	1.01 ± 0.02	1.00 ± 0.02
[40,60]	1.00 ± 0.01	1.01 ± 0.02	1.01 ± 0.02
[60,80]	1.01 ± 0.01	1.02 ± 0.02	1.02 ± 0.02
[80,120]	1.03 ± 0.01	1.04 ± 0.02	1.07 ± 0.02
[>120]	1.02 ± 0.02	1.04 ± 0.02	1.05 ± 0.03

Run-3 ptBin 1-prong

Scale Factor Run-3

3prong | Year-22+23+24

e+tau	Loose	Medium	Tight
[20,30]	0.84 ± 0.05	0.79 ± 0.05	0.79 ± 0.06
[30,40]	0.93 ± 0.04	0.91 ± 0.04	0.91 ± 0.05
[40,60]	0.95 ± 0.04	0.95 ± 0.04	0.96 ± 0.05
[60,80]	1.00 ± 0.04	0.99 ± 0.05	0.99 ± 0.06
[80,120]	1.01 ± 0.05	1.04 ± 0.05	1.03 ± 0.06
[>120]	1.08 ± 0.06	1.09 ± 0.06	1.10 ± 0.07

mu+tau	Loose	Medium	Tight
[20,30]	0.88 ± 0.05	0.84 ± 0.06	0.81 ± 0.06
[30,40]	0.95 ± 0.04	0.92 ± 0.04	0.91 ± 0.05
[40,60]	0.99 ± 0.04	0.98 ± 0.04	0.97 ± 0.05
[60,80]	1.00 ± 0.04	0.97 ± 0.04	0.98 ± 0.05
[80,120]	1.04 ± 0.04	1.04 ± 0.05	1.05 ± 0.06
[>120]	1.07 ± 0.07	1.05 ± 0.07	1.06 ± 0.08

l+tau	Loose	Medium	Tight
[20,30]	0.86 ± 0.03	0.82 ± 0.03	0.82 ± 0.03
[30,40]	0.94 ± 0.02	0.92 ± 0.03	0.91 ± 0.03
[40,60]	0.97 ± 0.02	0.96 ± 0.03	0.96 ± 0.03
[60,80]	1.00 ± 0.02	0.98 ± 0.03	0.98 ± 0.03
[80,120]	1.03 ± 0.03	1.04 ± 0.03	1.04 ± 0.04
[>120]	1.08 ± 0.02	1.08 ± 0.03	1.08 ± 0.04

Run-3 ptBin 3-prong

STRUCTURE OF THE ATLAS TAU GROUP

WORKING GROUP

Tau Reco and ID

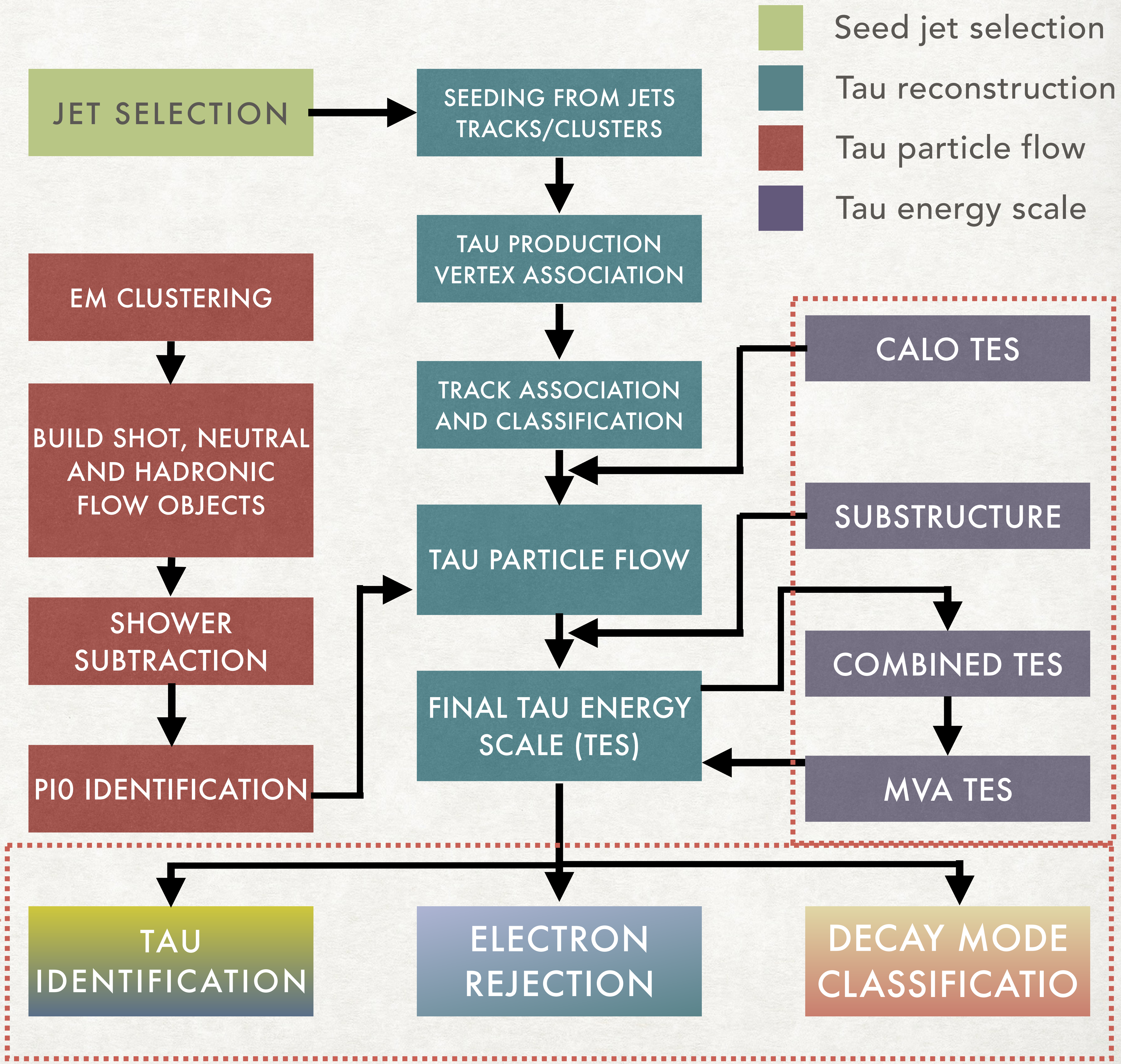
- Maintain & Develop ATLAS Tau Reconstruction Software and Mis-ID Rejection Algorithms
- Improve Tau Reconstruction Algorithms & Event Data Model
- Liaise With Central Computing & Reconstruction Developments
- Develop Tau Validation Software & Follow Up PhysicsValidation Issues
- Build Frameworks for MC-Based Tuning of Tau Algorithms

Fake Tau Task Force (FFTF).

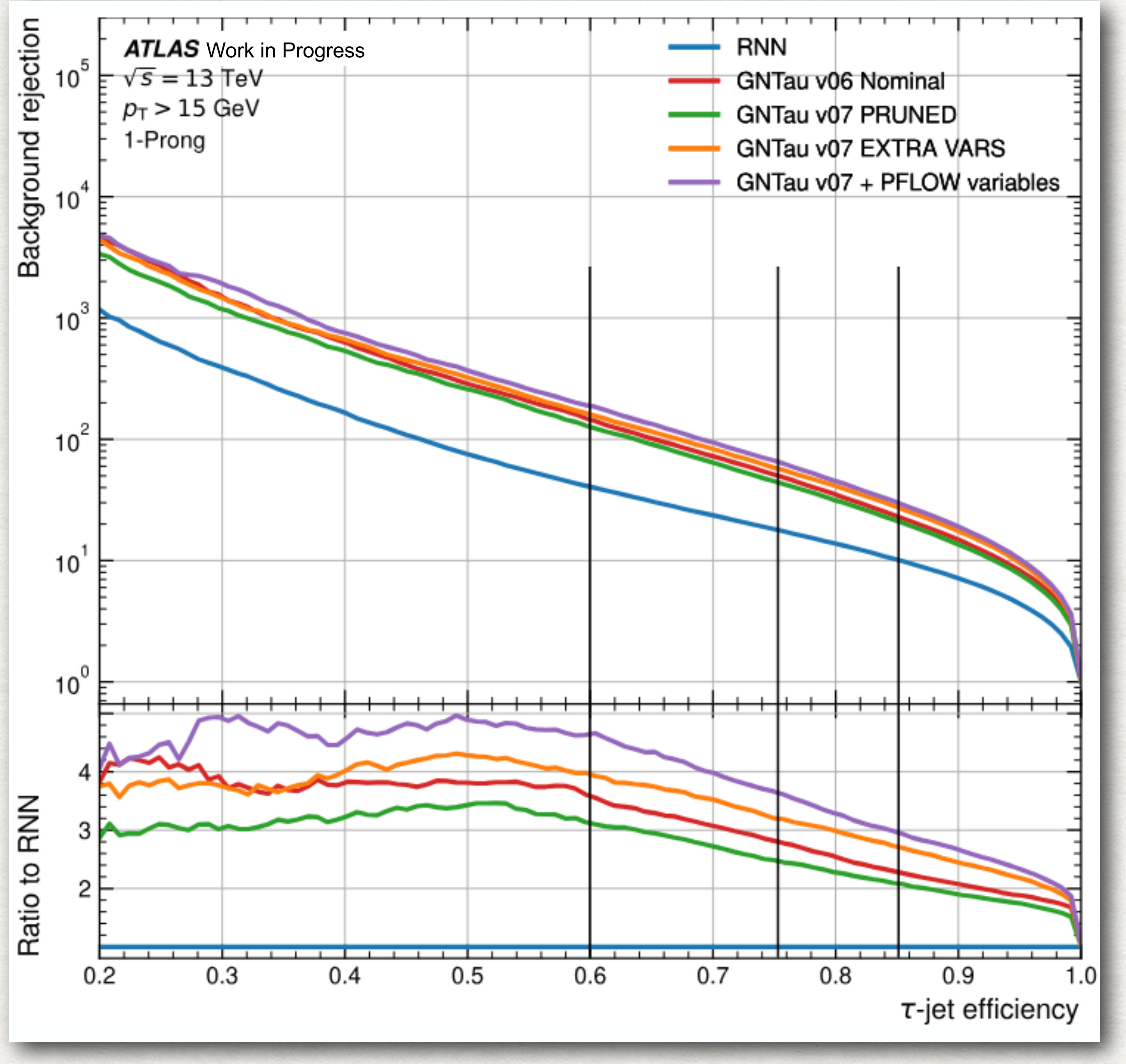
- Assist Analysis Teams To Implement Fake-Tau Backgound Estimations Using the Universal Fake Factor (UFF) Method.
- Liase With the Analysis Teams To Understand and Support Their Fake-Tau Background Estimations Using Other Methodologies.
- Develop Primitive Fake-Factor and Templates To Implement the UFF Method With the New Run3 Dataset.

Tau Measurement & Calibration (M&C) Provides Corrections for the Different Tau Algorithms To Cover the Difference Between Data and MC

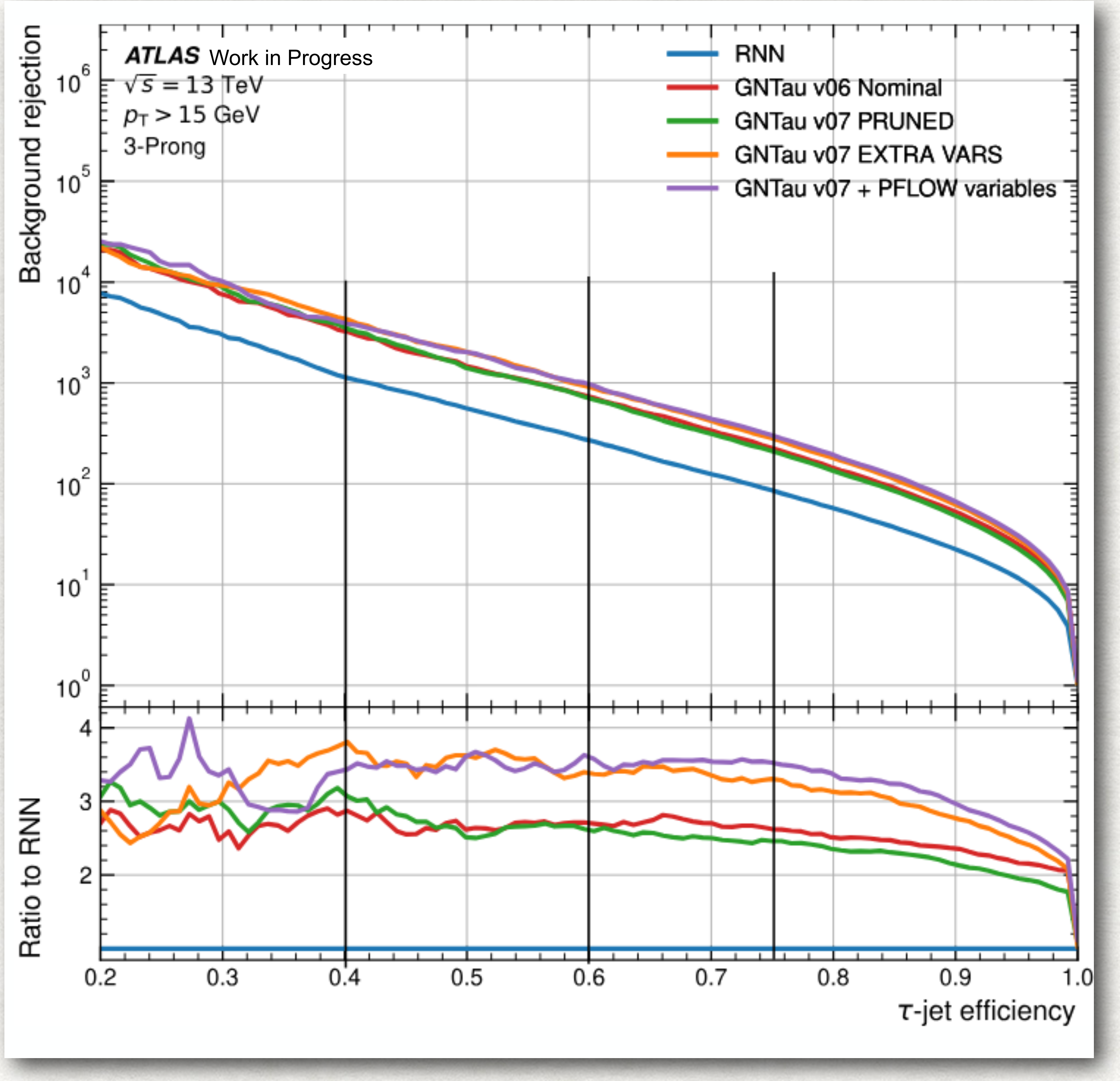
- Correction to **Tau ID Efficiency** (Jet Rejection).
- Correction to **Electron Rejection Efficiency** (eVeto).
- Correction to **Tau Decay Mode Classification Efficiency**.
- Correction to **Tau Energy Scale** (TES).



PERFORMANCE OF GNTAU



1-prong ROC



3-prong ROC

1-PRONG:

- All GNTau v07 variants outperform the RNN baseline across efficiency range.
- PFLOW and Extra Variables models give the highest background rejection (×3–4 vs RNN).
- Consistent gain over v06 nominal, especially at loose and medium WPs.

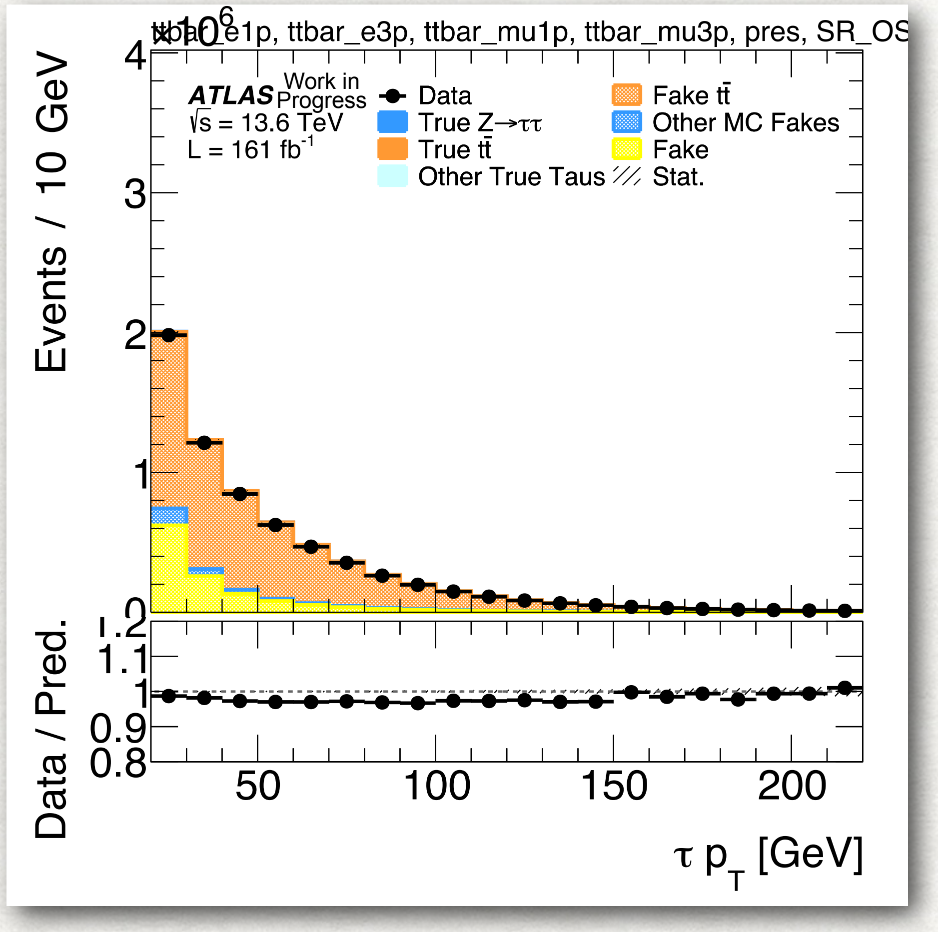
3-PRONG:

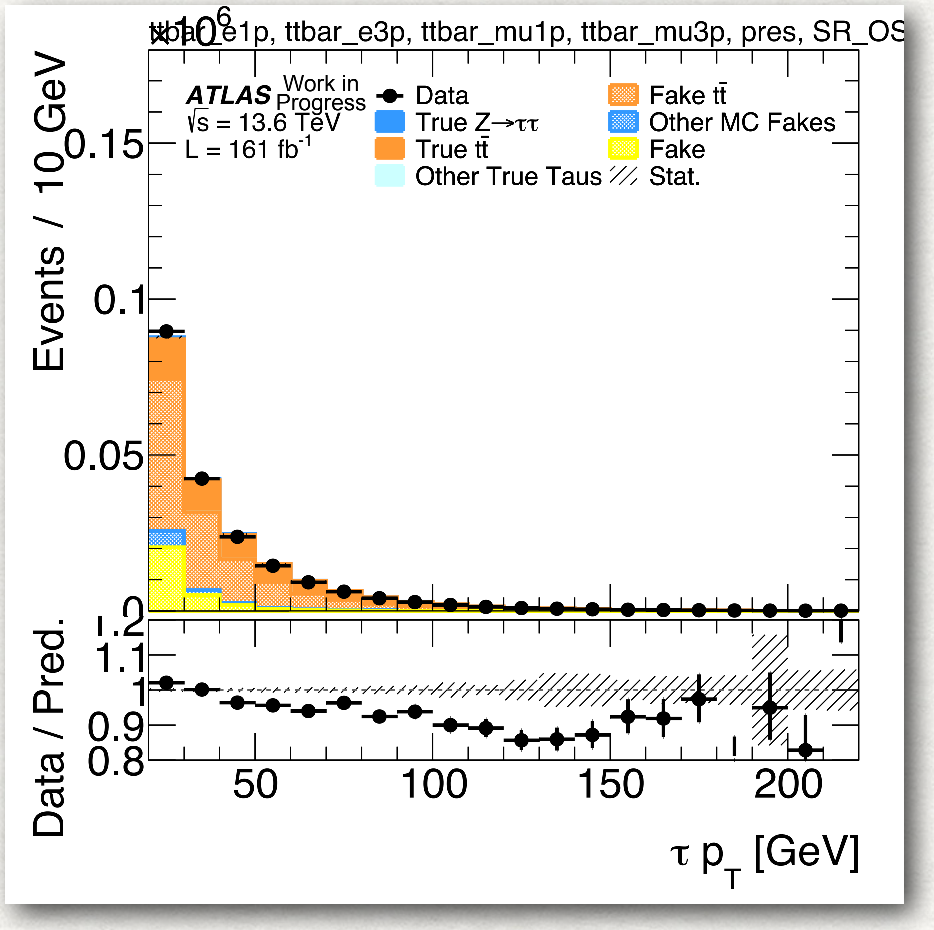
- Similar trend: v07 variants significantly better than RNN.
- Improvement mainly below 100 GeV; 20–30% gain at loose/medium WPs.
- PFLOW provides additional benefit, but stability at high-pt still under study.

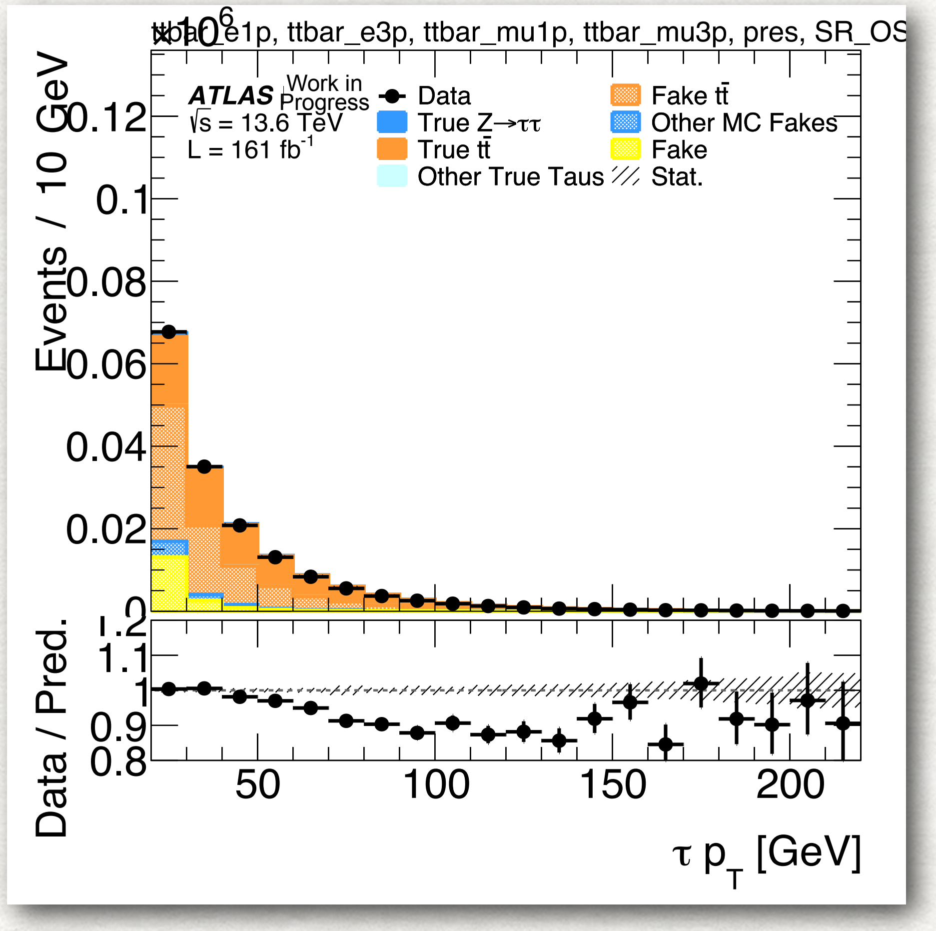
GNTAU- JORDY & MEHUL

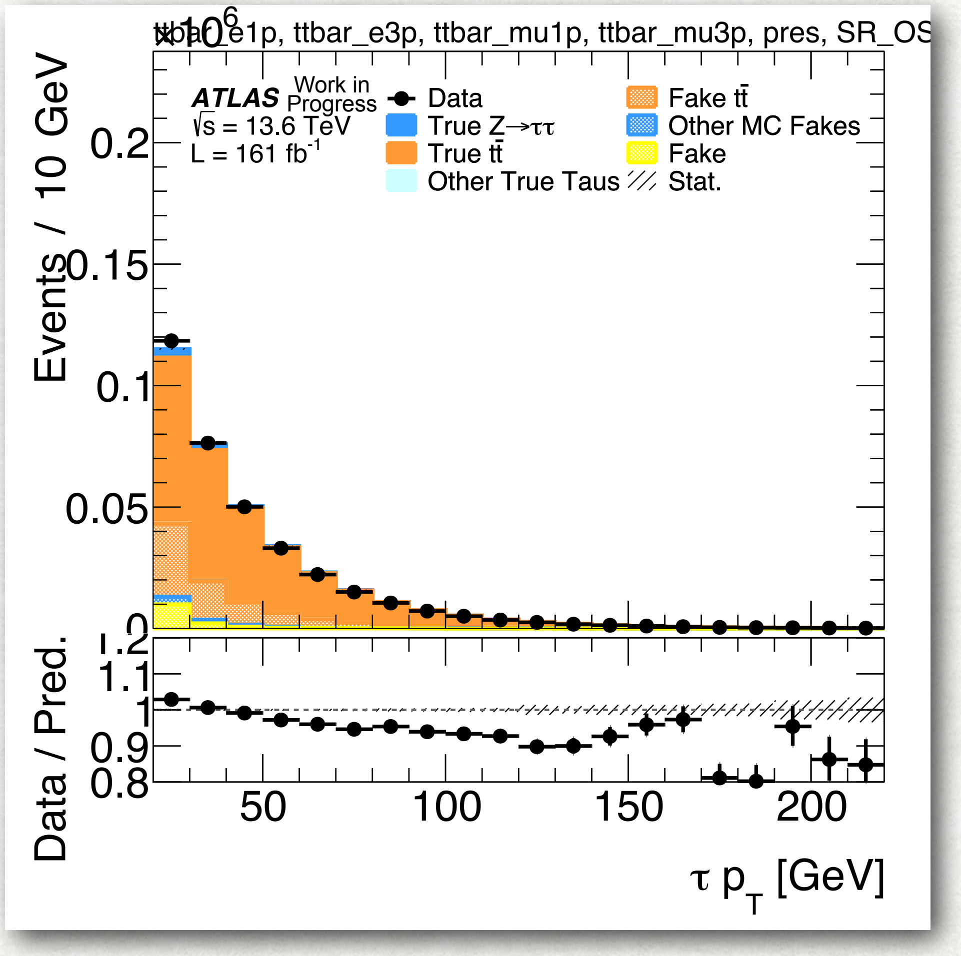
τ_{p_T} AND τ_η DISTRIBUTIONS

τ_{p_T} Distribution

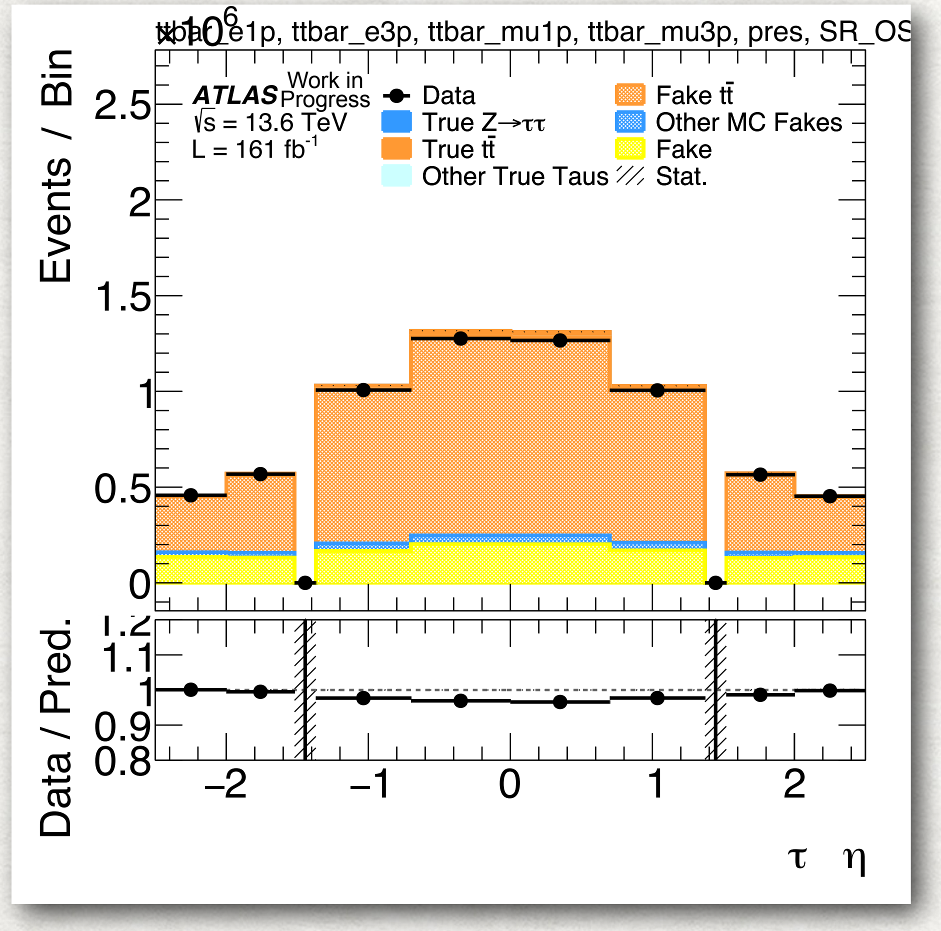


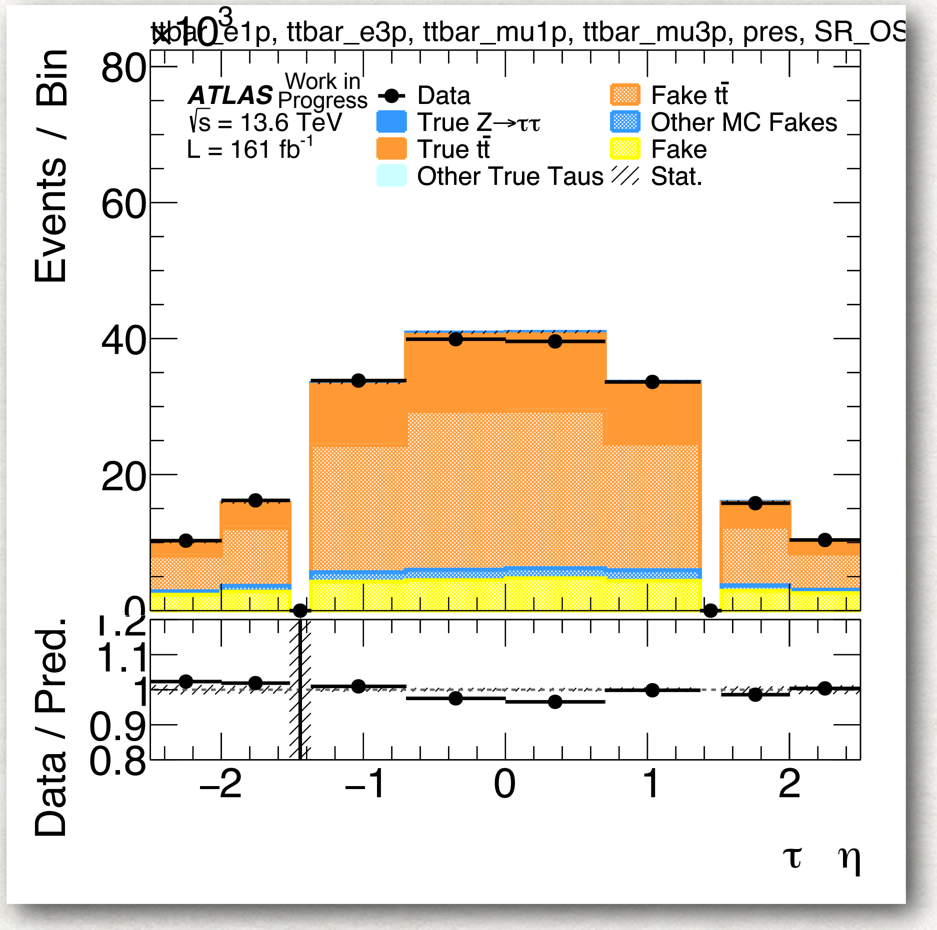


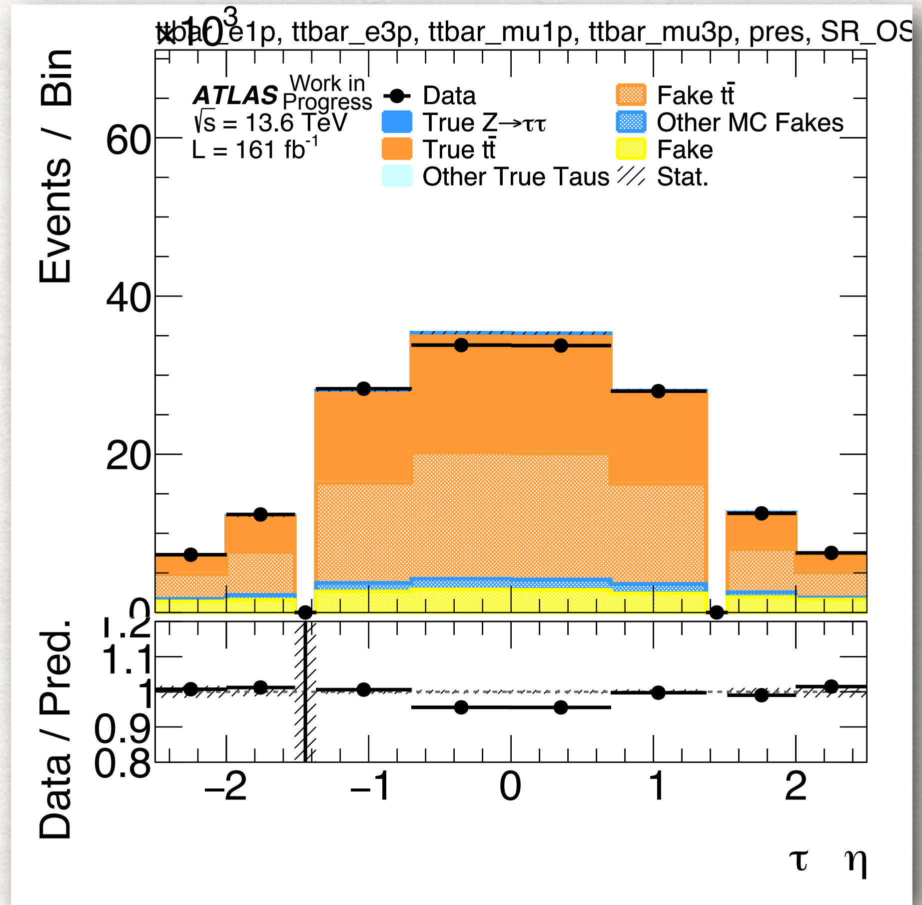


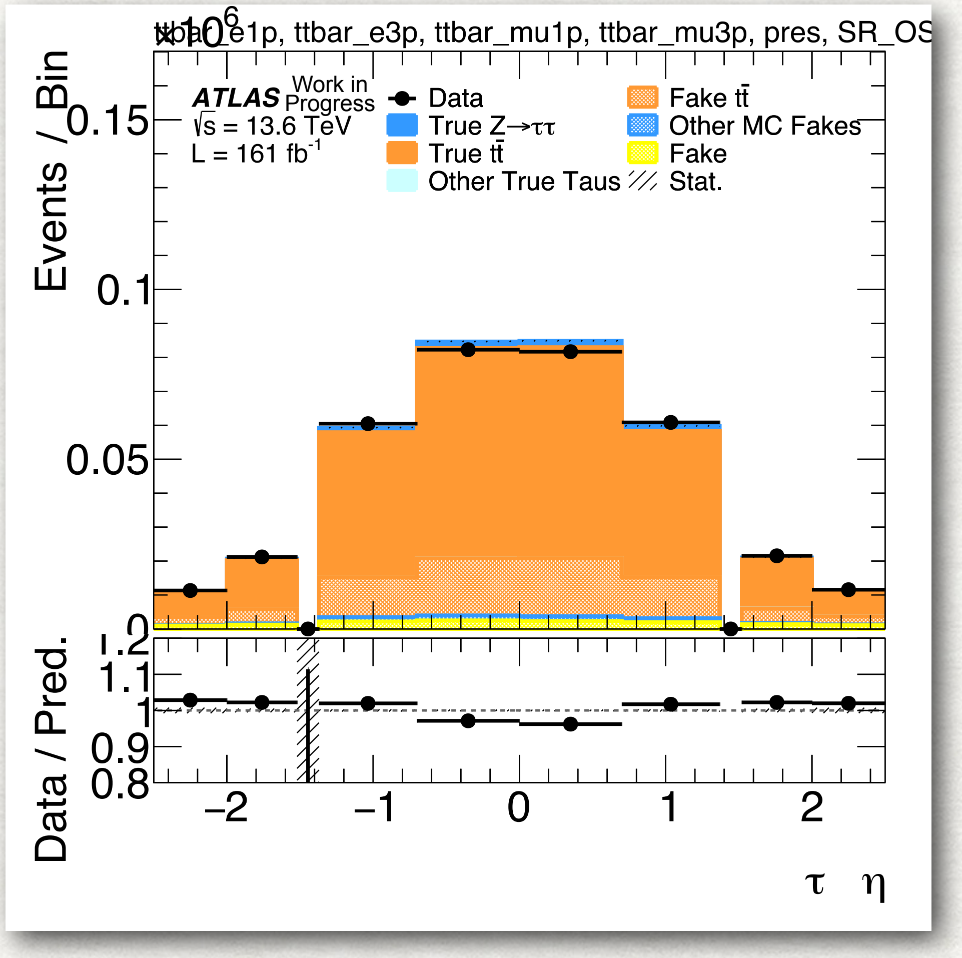


Not Loose | Loose Not Medium | Medium Not Tight | Tight



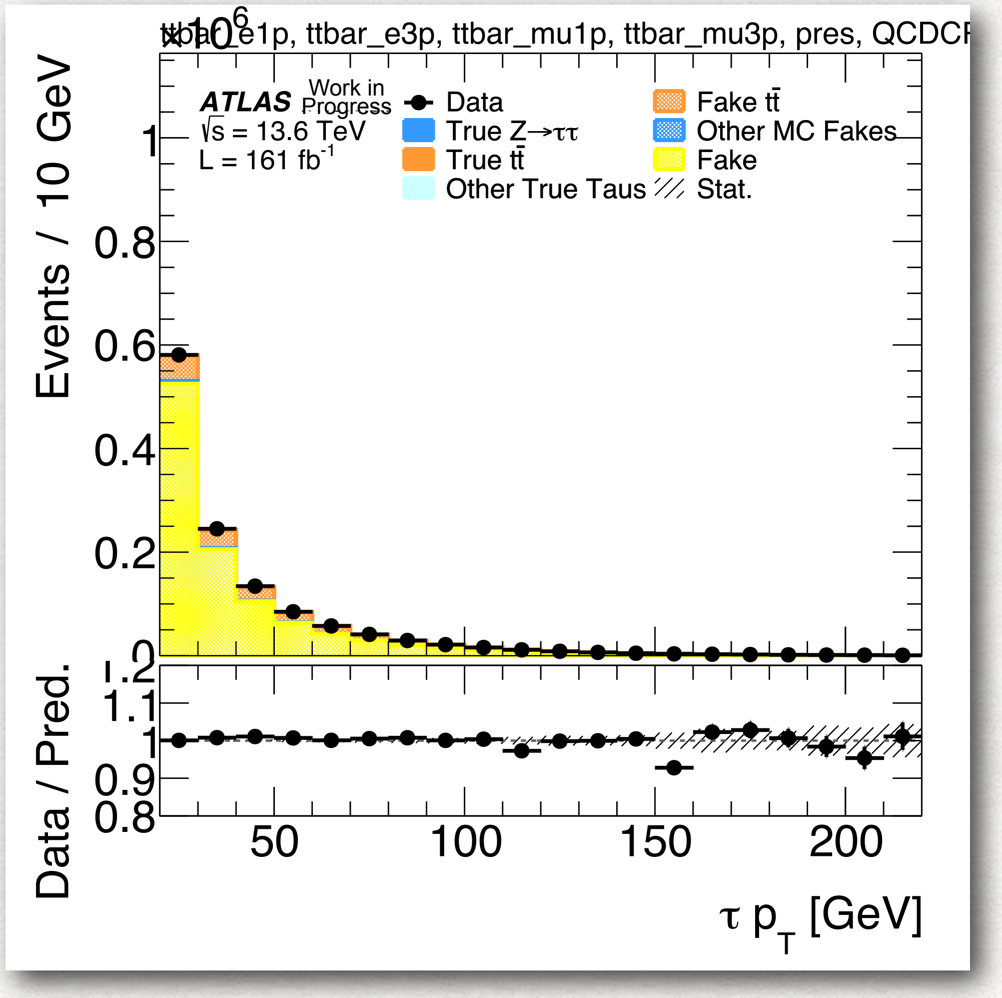




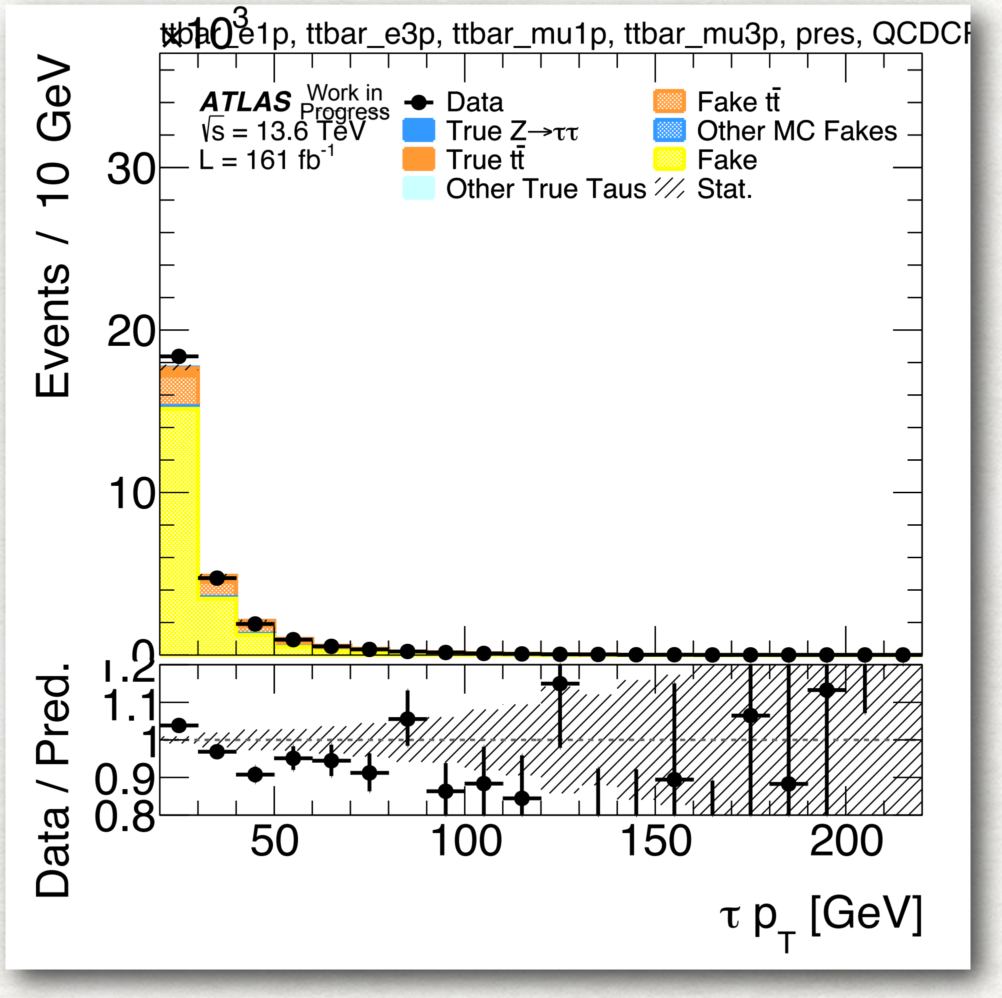


τ_η Distribution

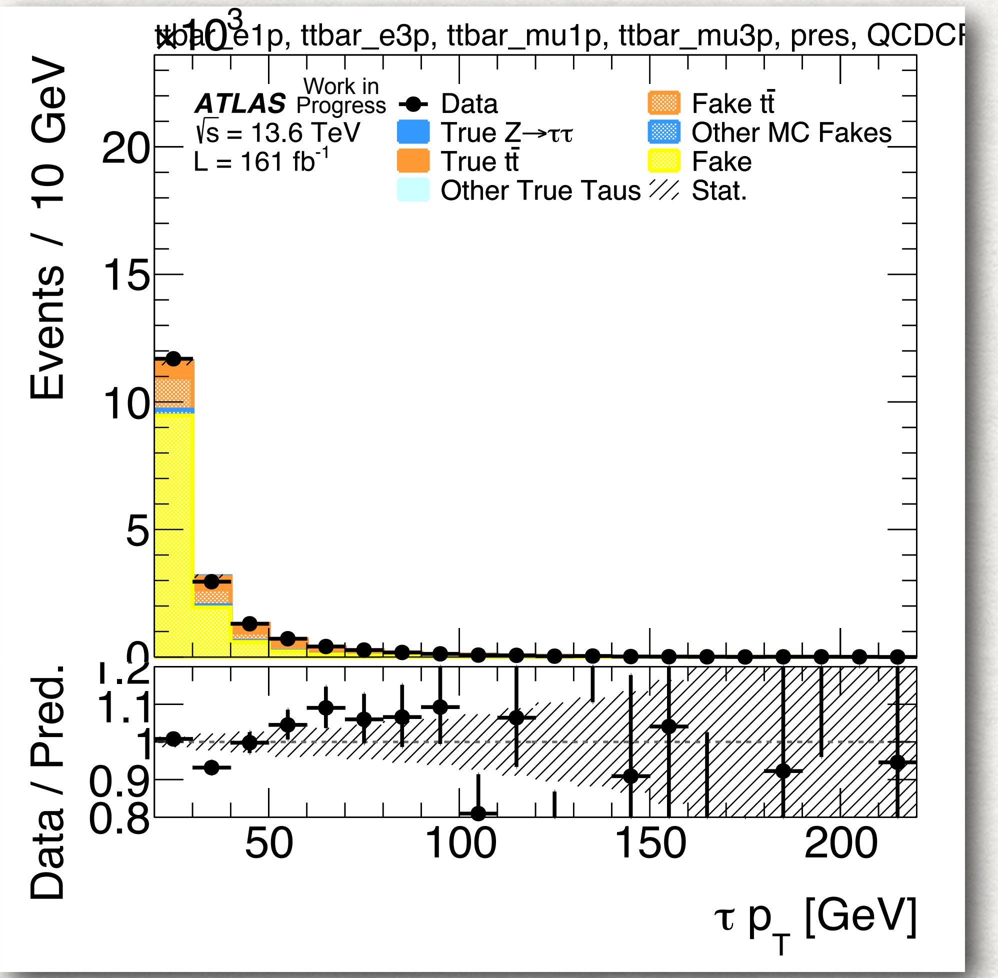
r_{QCD} CR DISTRIBUTIONS



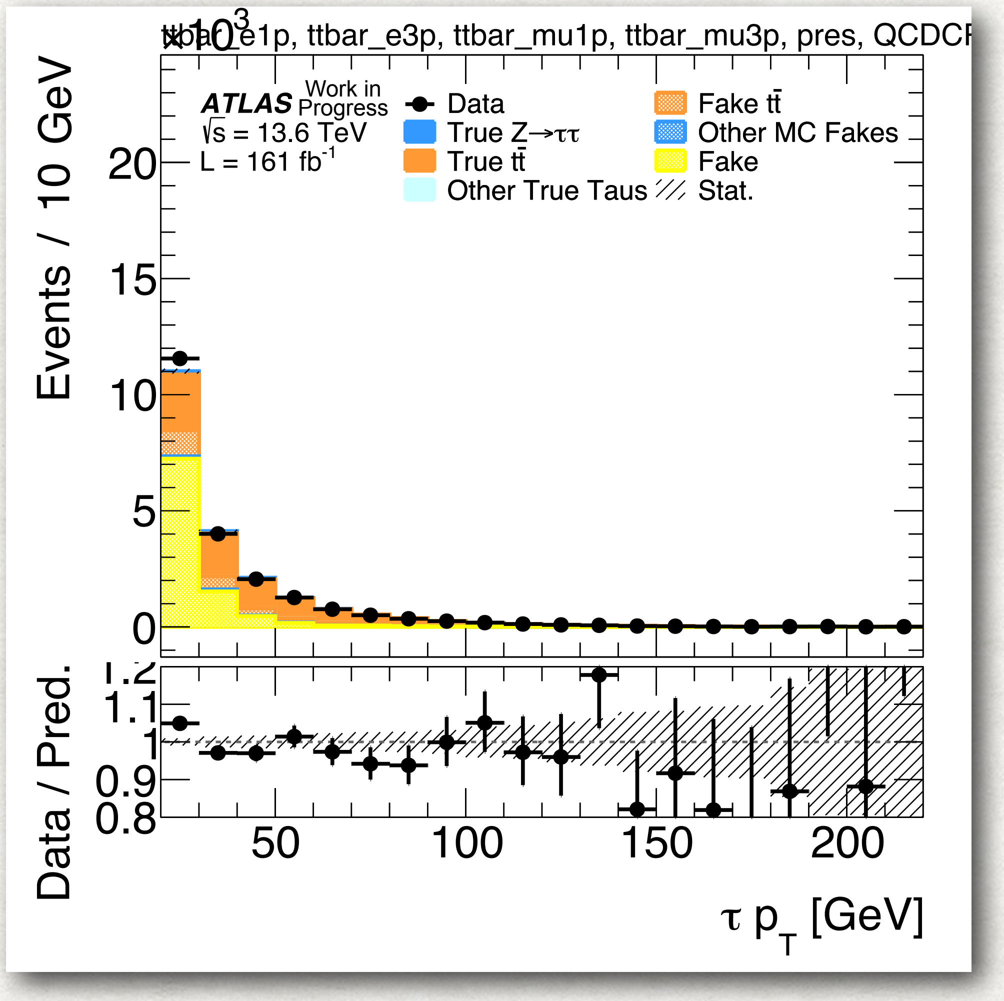
Not Loose



Loose Not Medium



Medium Not Tight

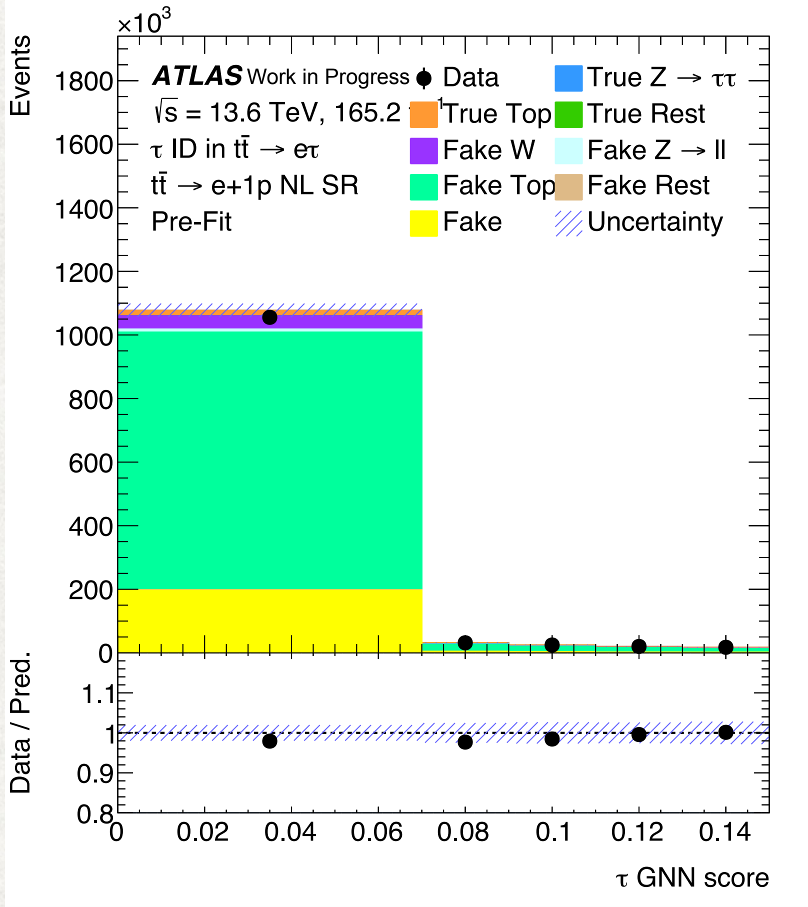


Tight

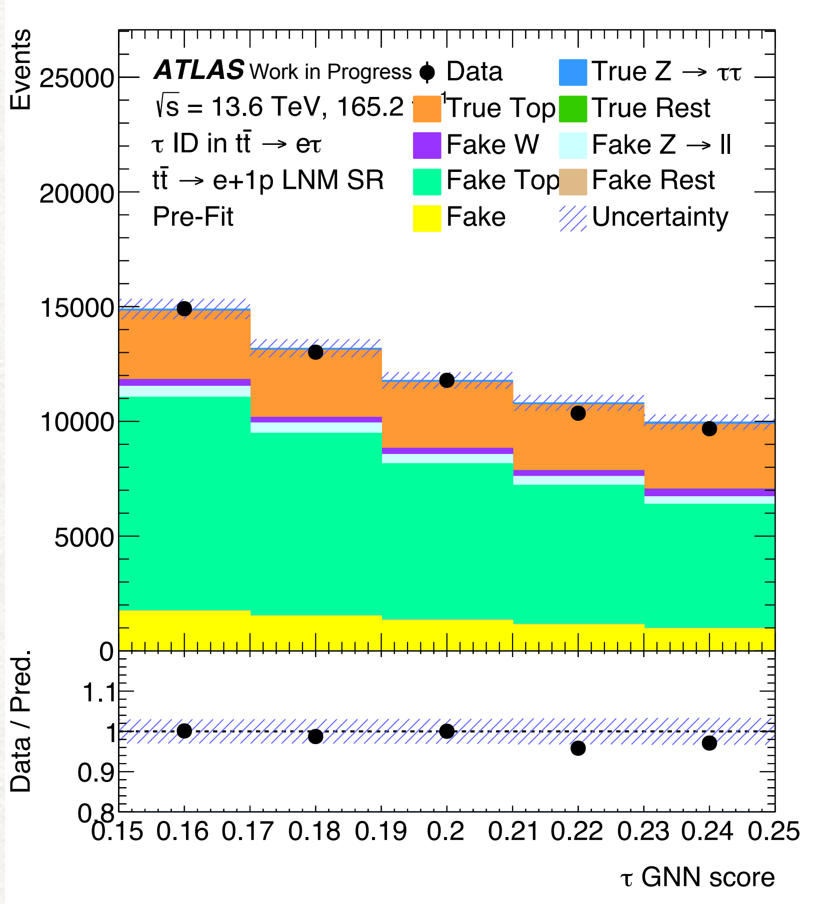
- The SS control region is used to define the fake-template shape.
- Fake yield in a region is computed as (Data - non-fake MC).
- rQCD is the OS/SS transfer factor for this fake component.
- Definition: rQCD = [(Data-MC)_OS] / [(Data-MC)_SS].
- SR fake prediction is built as Fake_SR = rQCD × (Data-MC)_SS.
- This method uses SS data shape and normalises to OS expectation.
- rQCD is evaluated per tau-ID category and prongness.
- rQCD binning is optimised (bin merging when needed) to keep transfer factors stable.
- Stability is assessed from fit behaviour and uncertainty propagation, not visual inspection alone.
- The final SR fake model is therefore data-driven in both shape (SS) and normalisation (rQCD transfer).

E1P PREFIT POSTFIT DISTRIBUTION

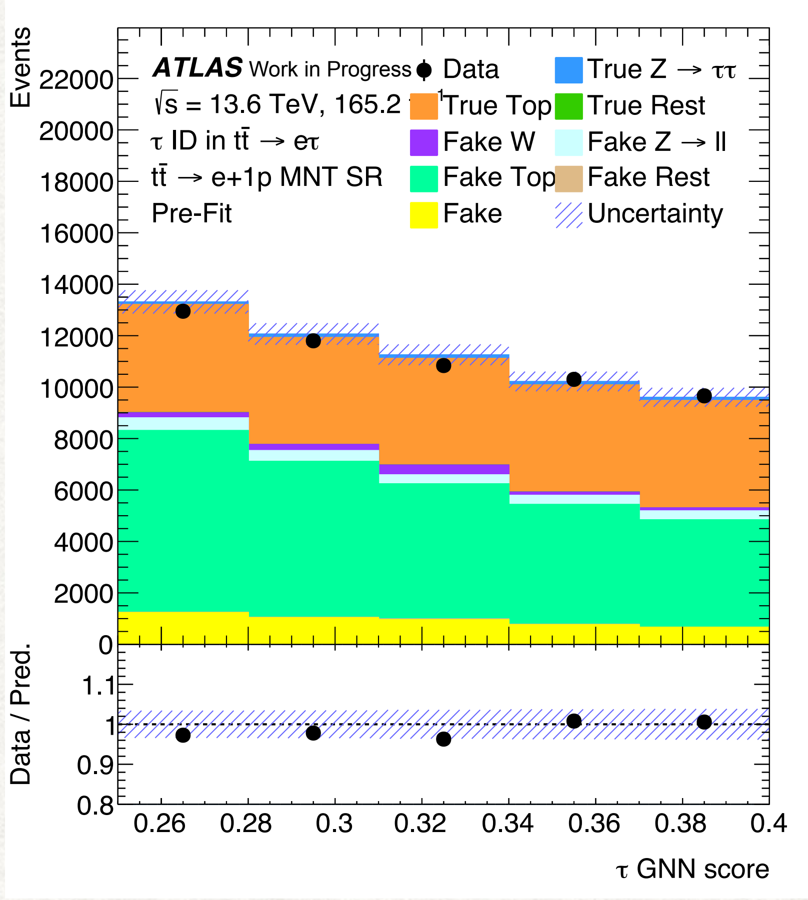
e1p Prefit Distribution



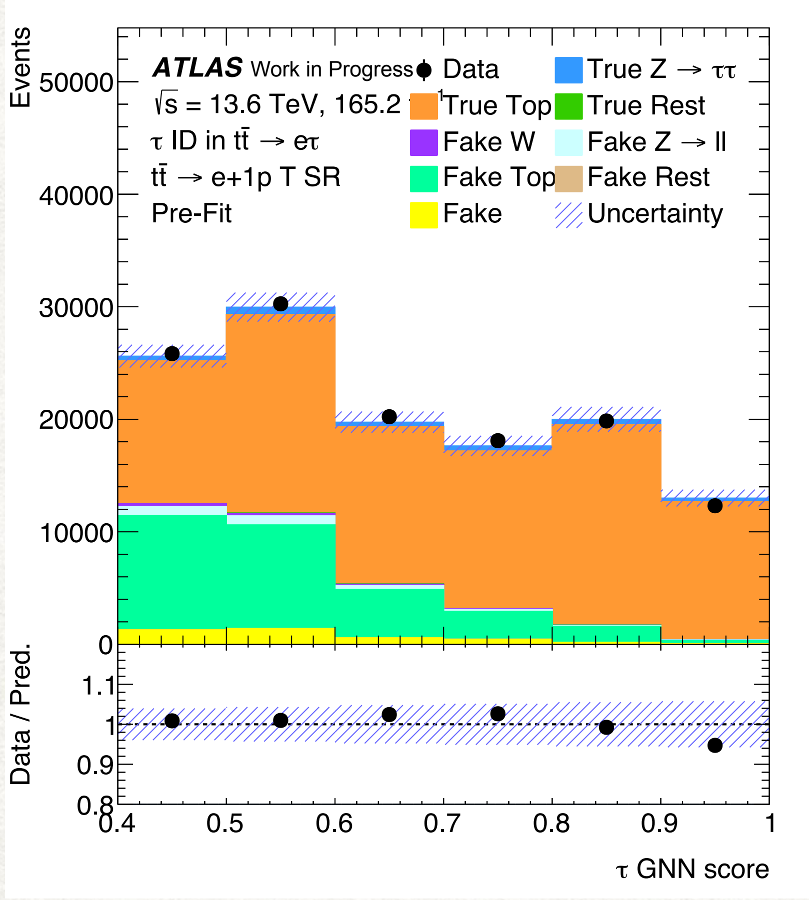
Not Loose



Loose Not Medium

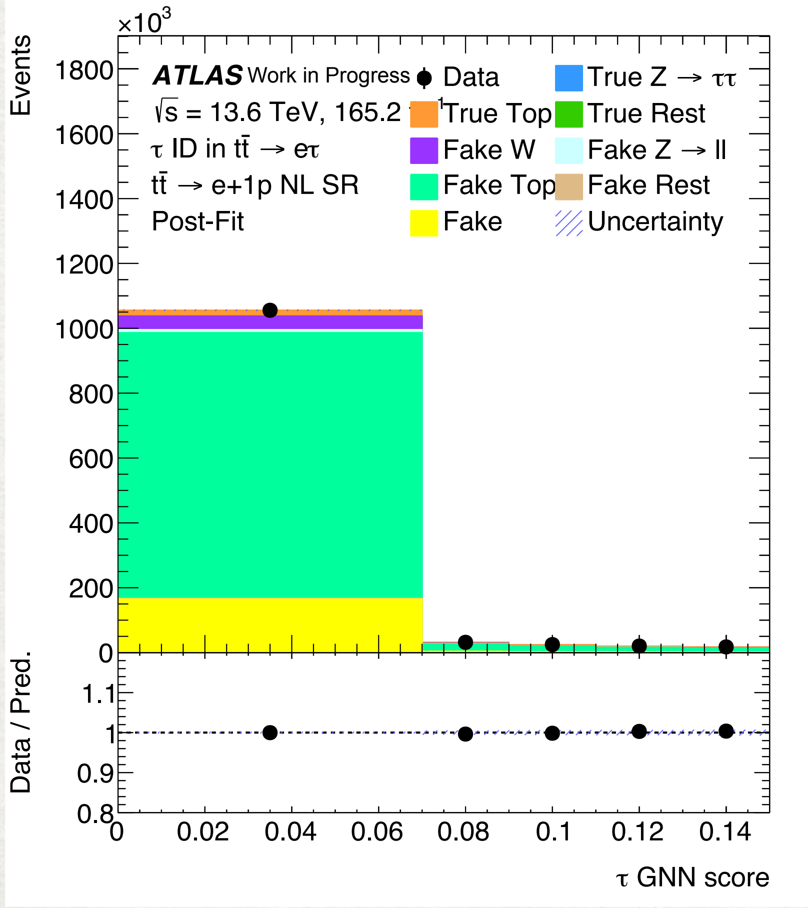


Medium Not Tight

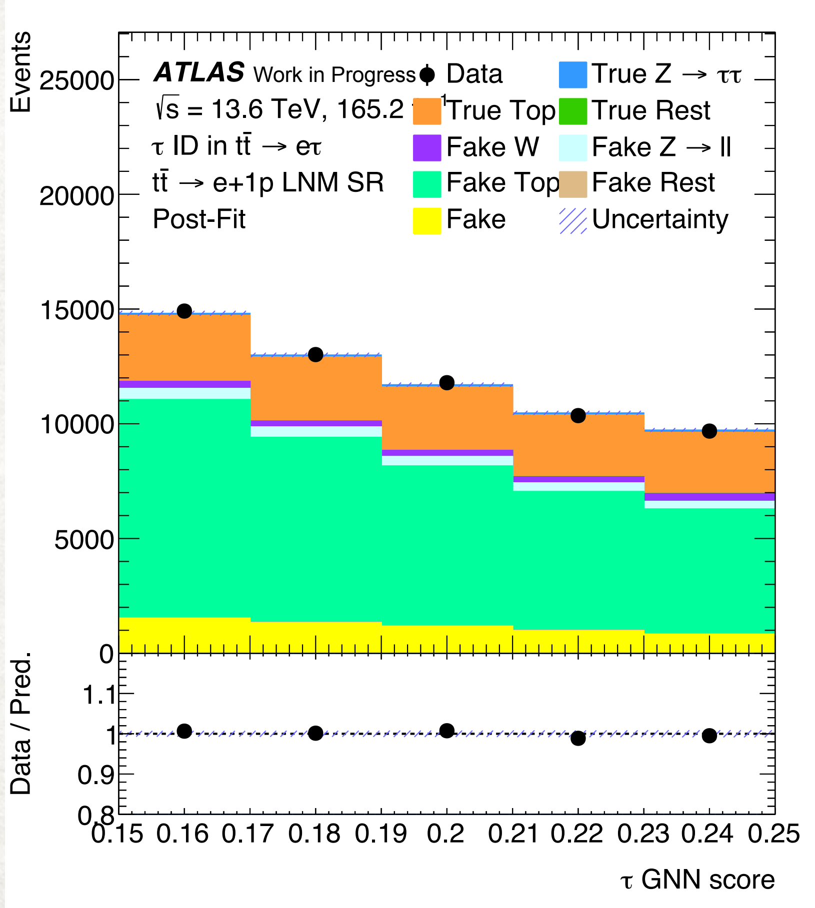


Tight

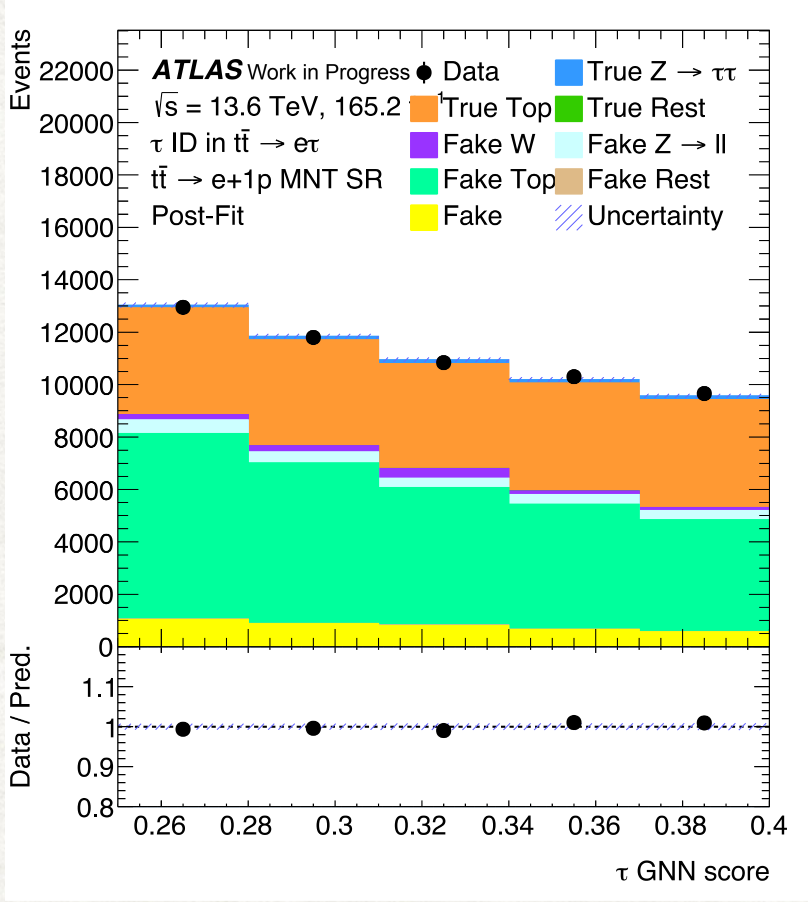
e1p Postfit Distribution



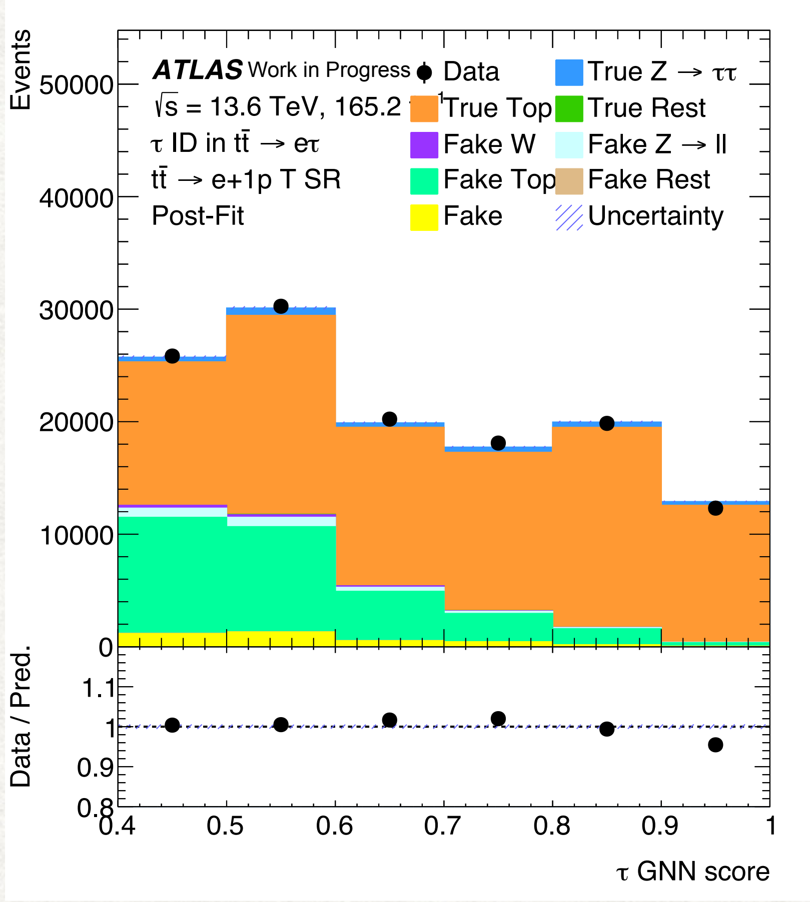
Not Loose



Loose Not Medium



Medium Not Tight



Tight

Prefit

Pre-fit data/MC trends: Prefit shows expected normalization/shape residuals across some WP bins.

Data/MC differences are moderate and consistent with prefit systematic envelope.

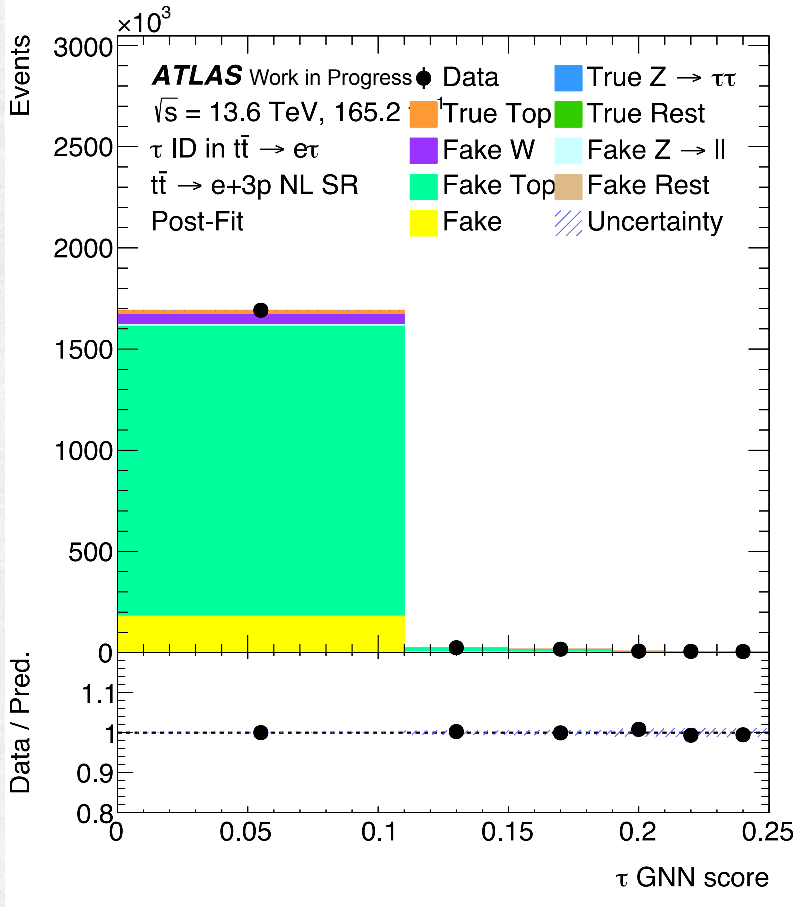
Postfit

Improves data/MC: Postfit improves closure across NL, LNM, MNT, & T categories.

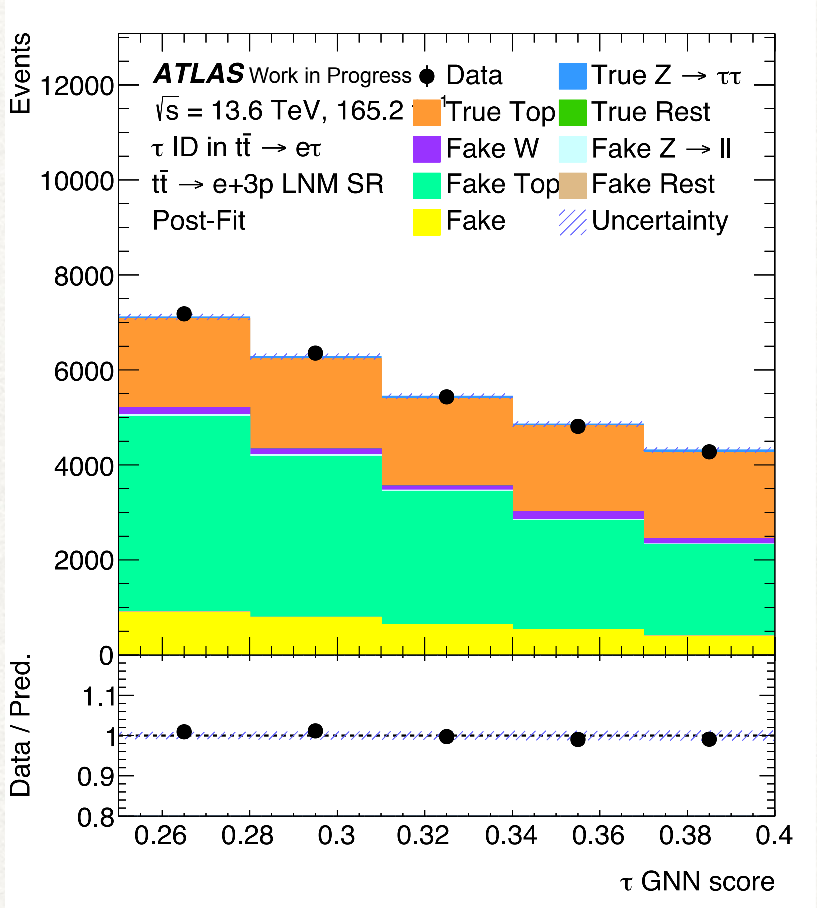
Ratio is flatter and closer to unity, supporting stable E1p SF extraction.

E3P PREFIT POSTFIT DISTRIBUTION

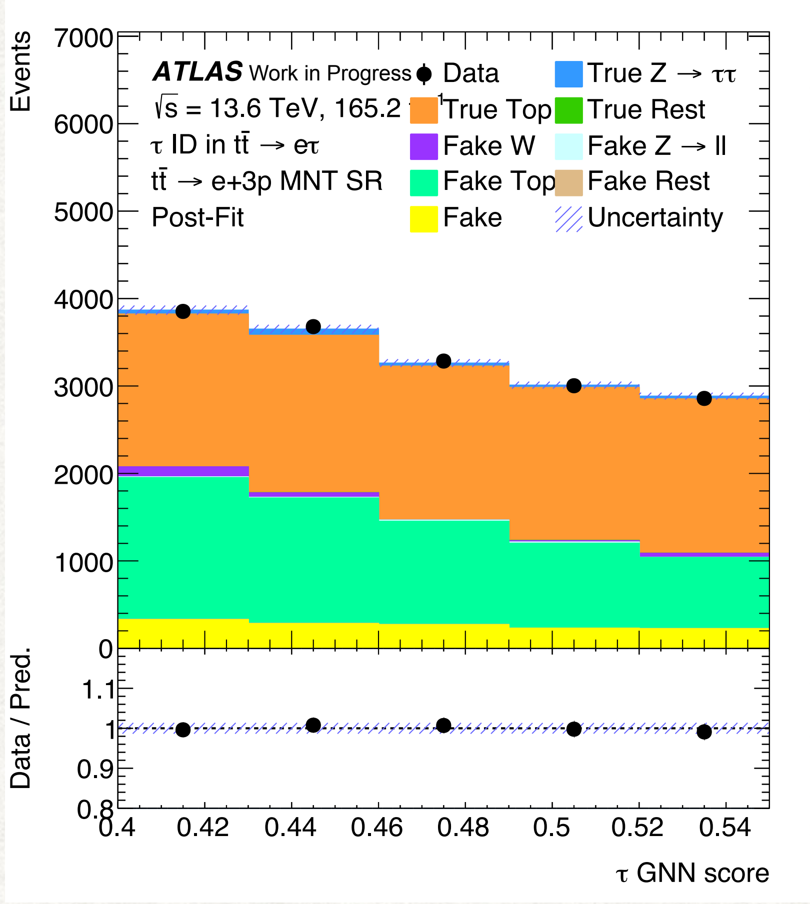
e3p Prefit Distribution



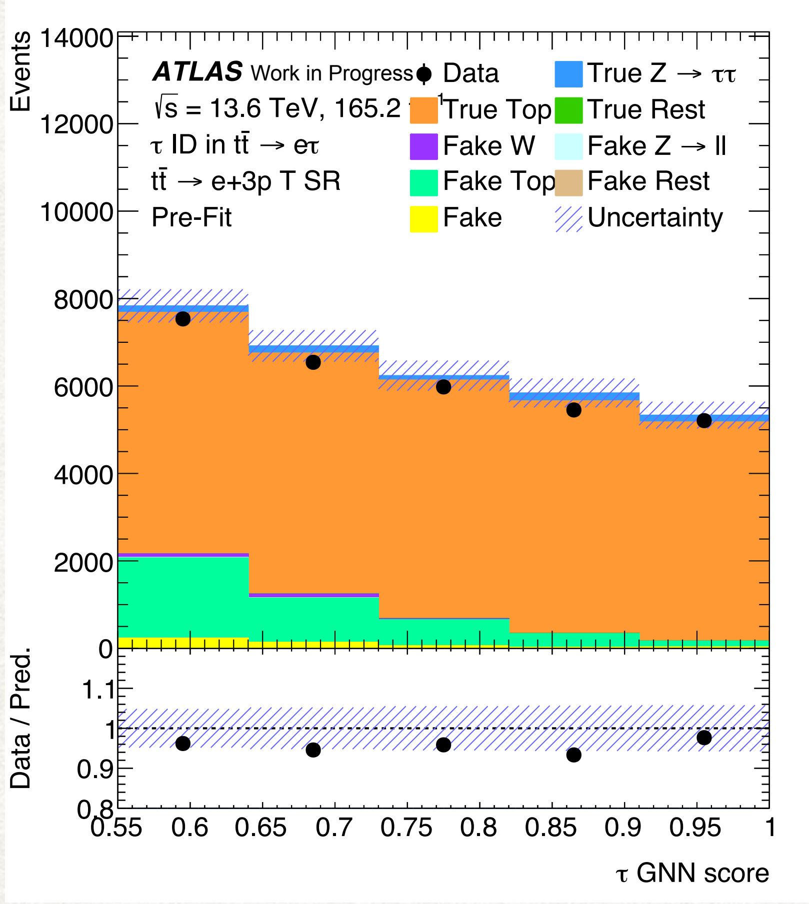
Not Loose



Loose Not Medium

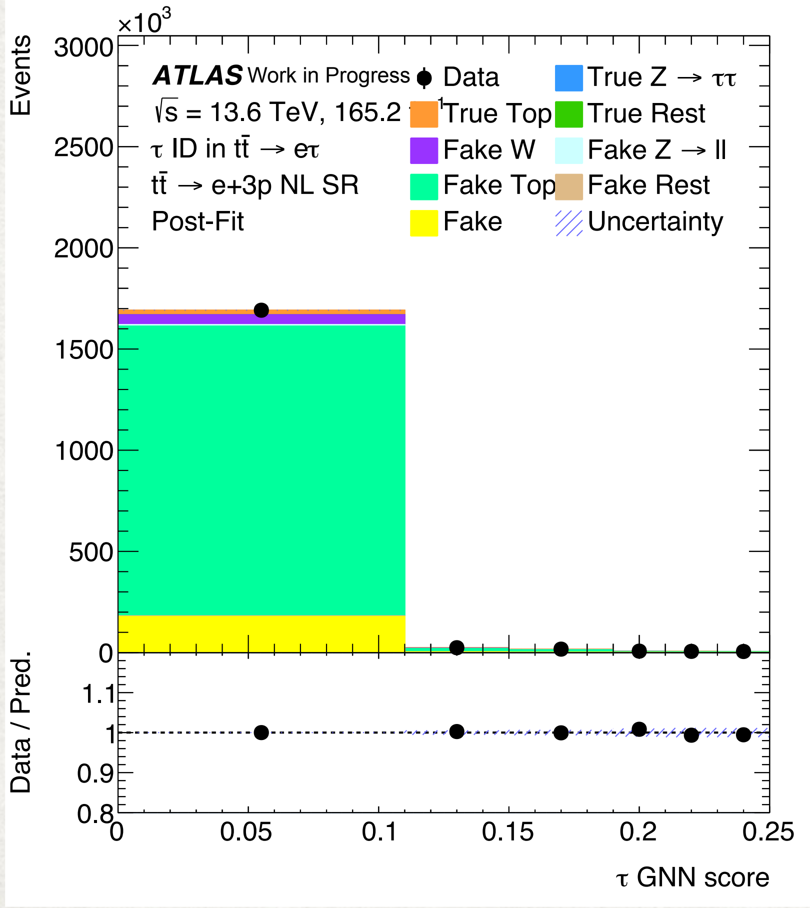


Medium Not Tight

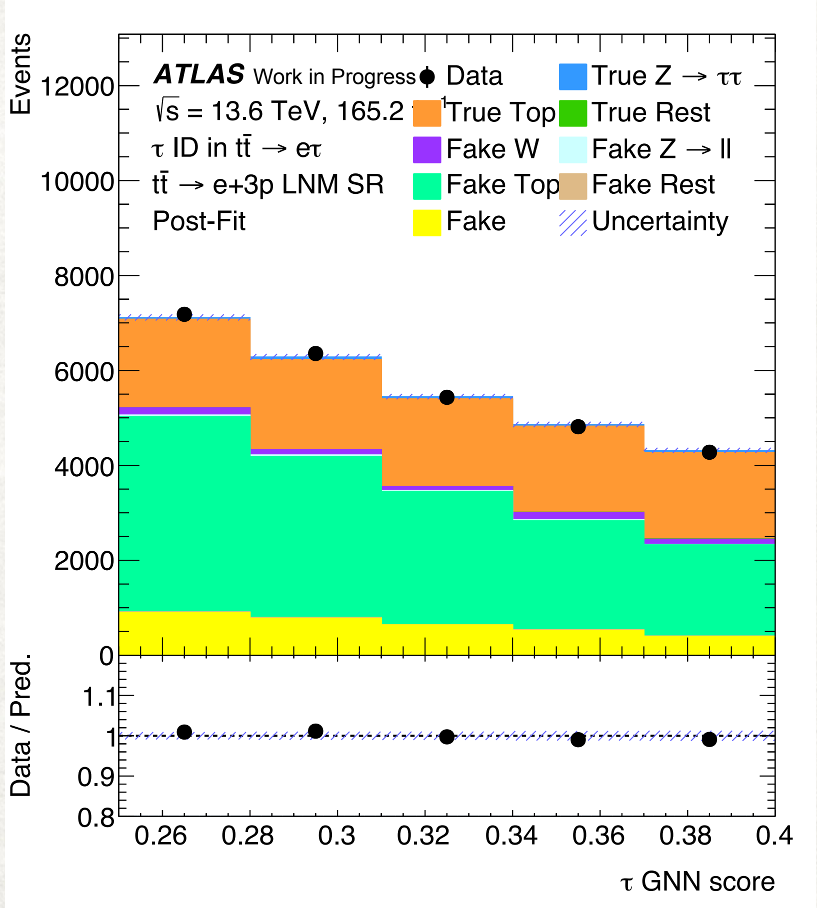


Tight

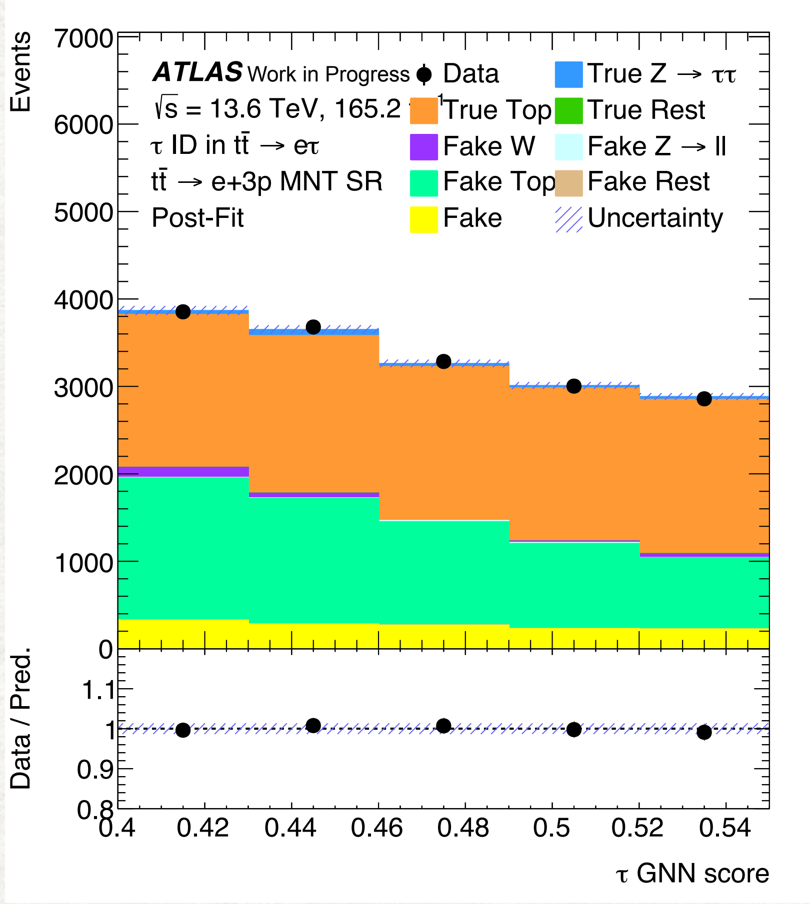
e3p Postfit Distribution



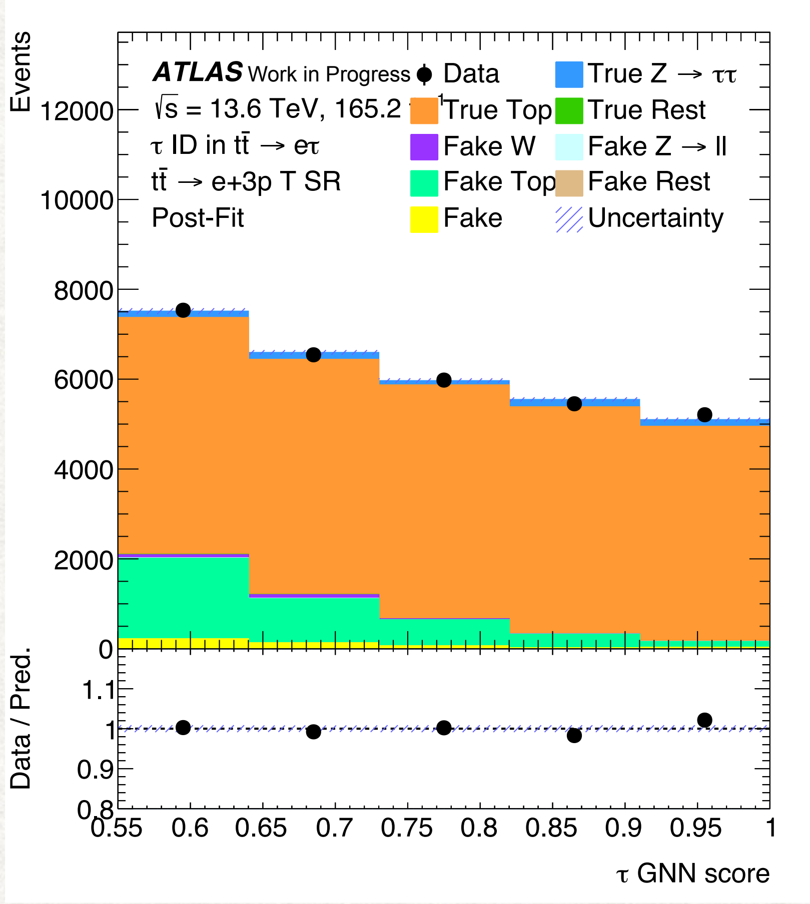
Not Loose



Loose Not Medium



Medium Not Tight



Tight

Prefit

Pre-fit data/MC trends: E3p prefit is more statistically sensitive and shows larger residual structure than 1p.

The main differences appear in WP-dependent normalization/shape composition.

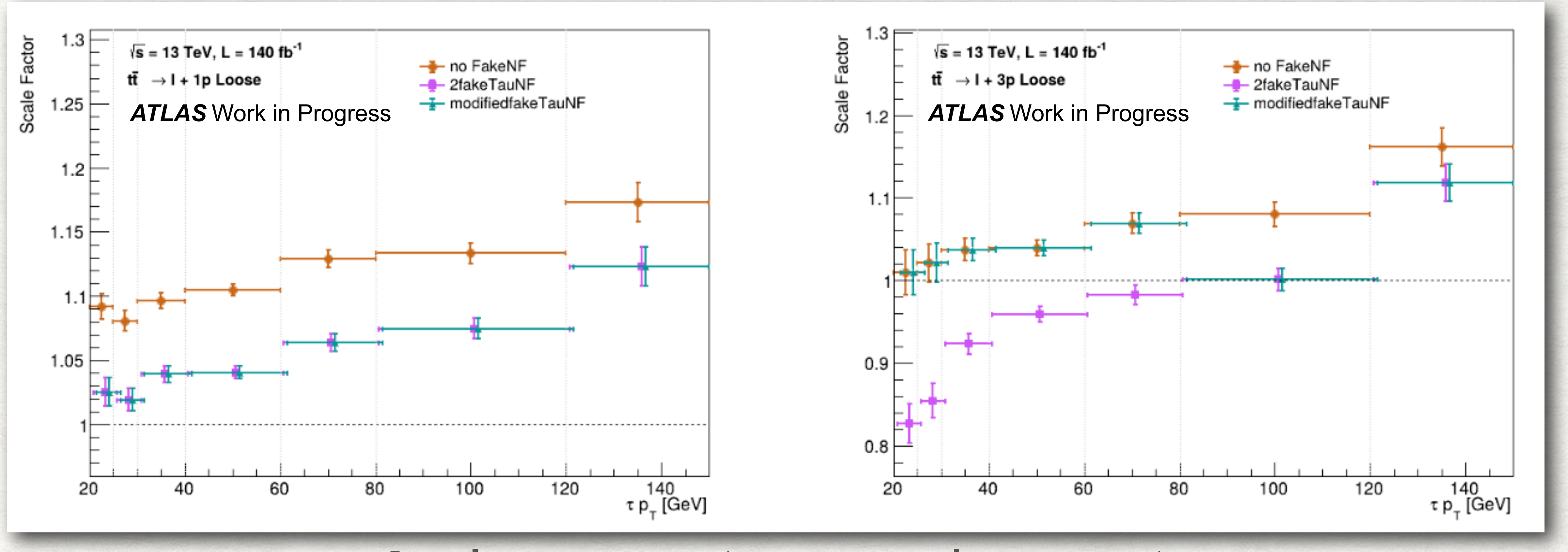
Postfit

Improves data/MC: Postfit reduces prefit residuals and gives consistent Data/MC within uncertainties.

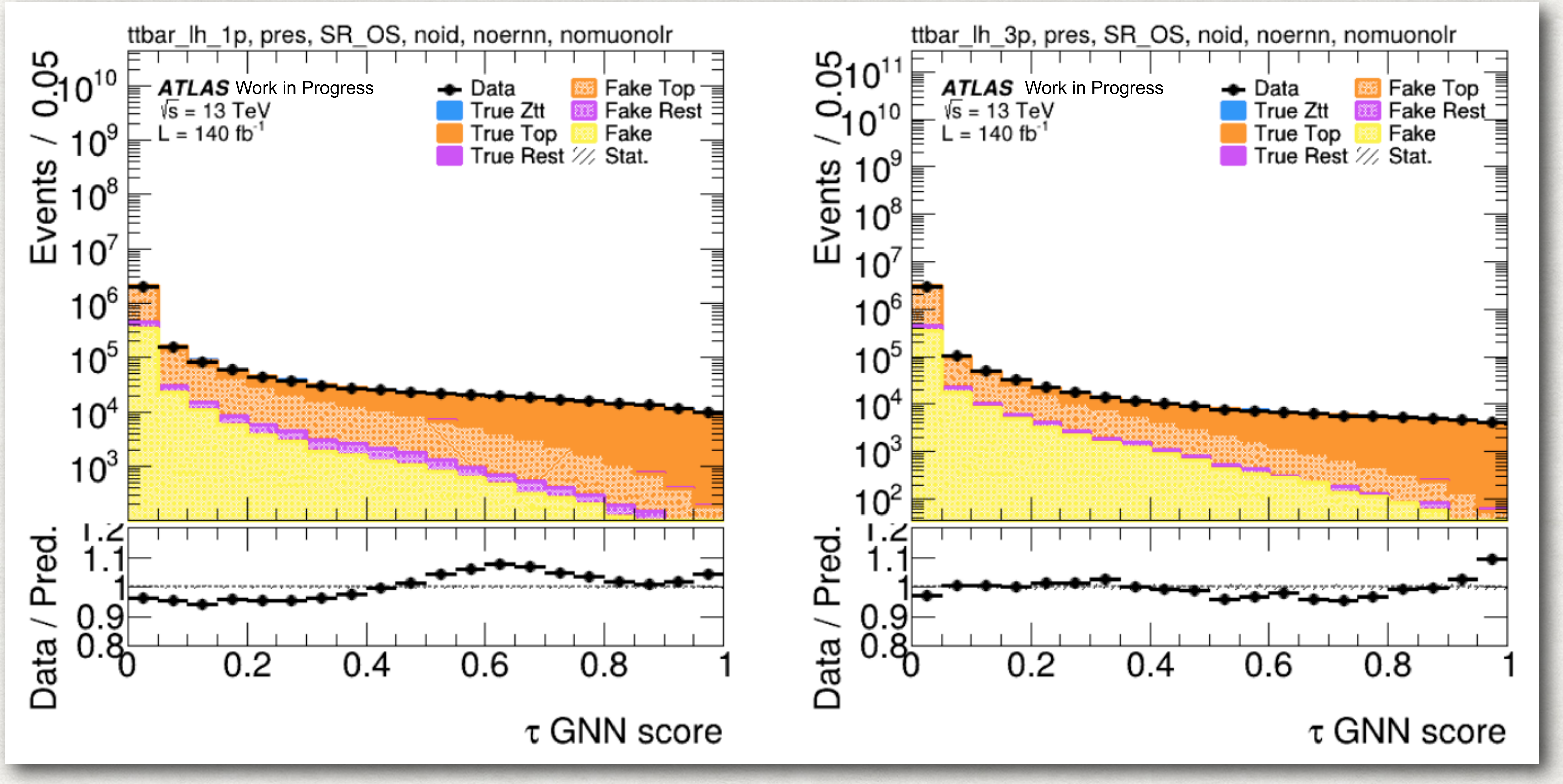
Stable closure in E3p confirms robust 3-prong SF extraction in combined Run-3.

GNTAU TTBAR RUN-2

- Scale factors measured for **different p_T bins.**
- All available systematics.
- **Smaller uncertainties** than previous scale factor recommendations.
- **Optimisations to decrease uncertainties:**
  - Rebinning.
  - Floating normalization for fakes.
  - Additional cuts to reduce fakes.
- **Currently switching to GNTau.**
- A comparison of SFs from three fits where with 3 different options for background treatment:
  - no FakeNF - no floating normalization for background
  - 2 fakeTauNF - a norm factor is assigned for 1 prong and 3 prong in the fit
  - modifiedfakeTauNF - assigning a norm factor based on tau pT



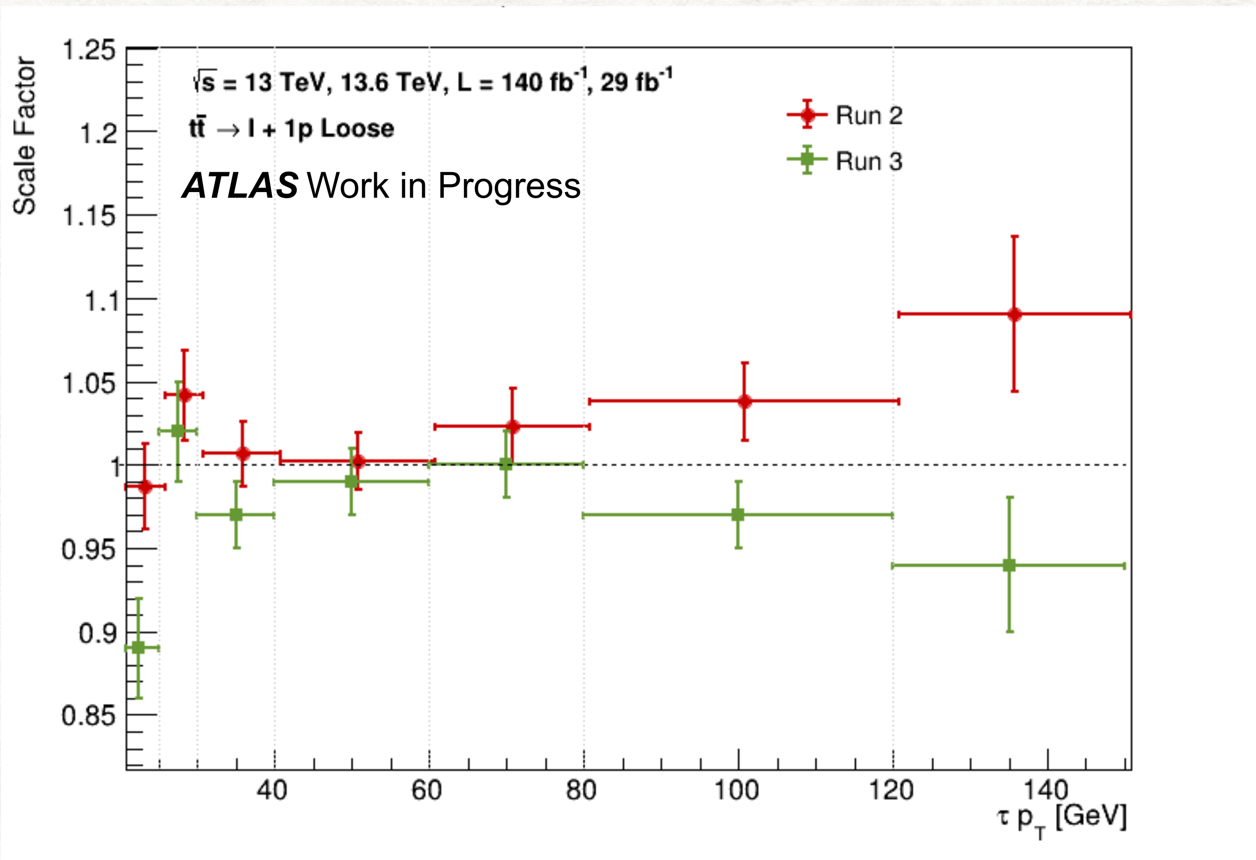
Scale Factor (very preliminary)

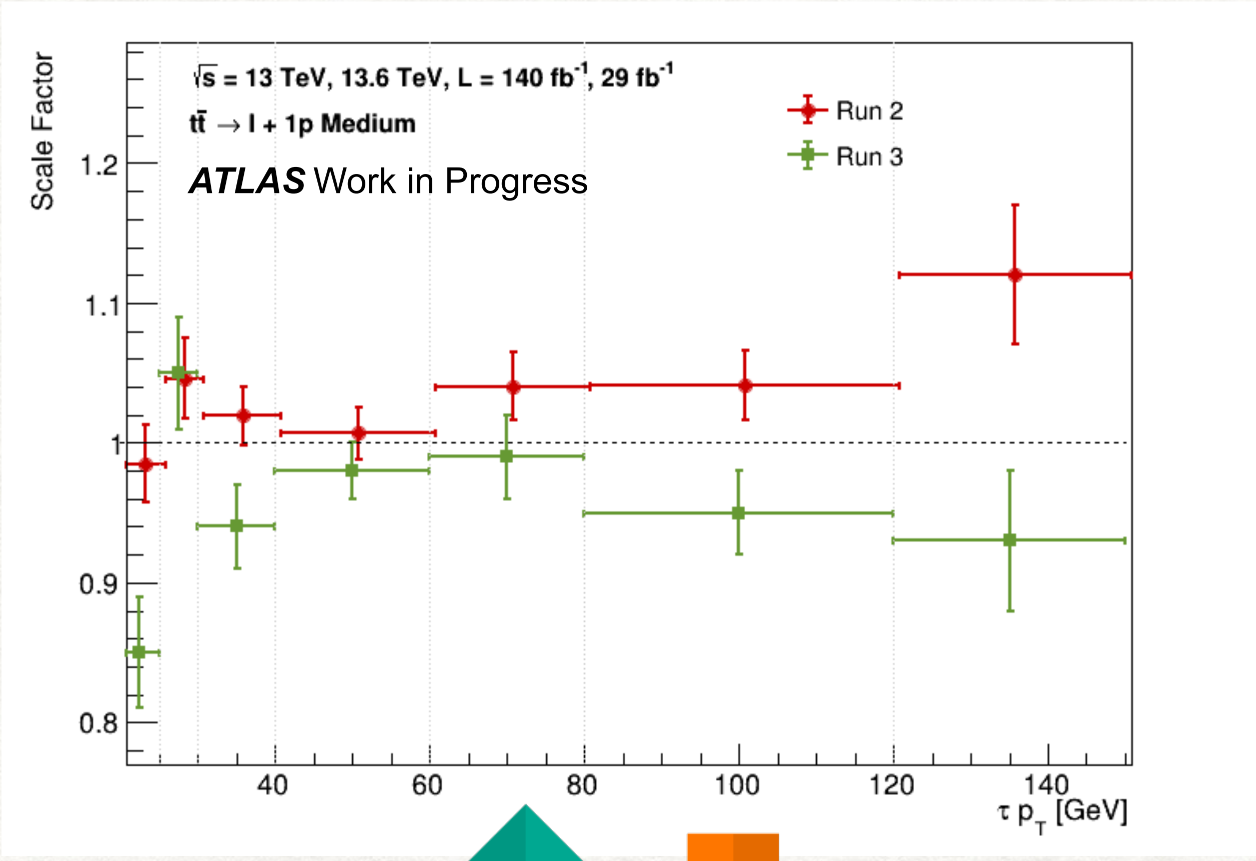


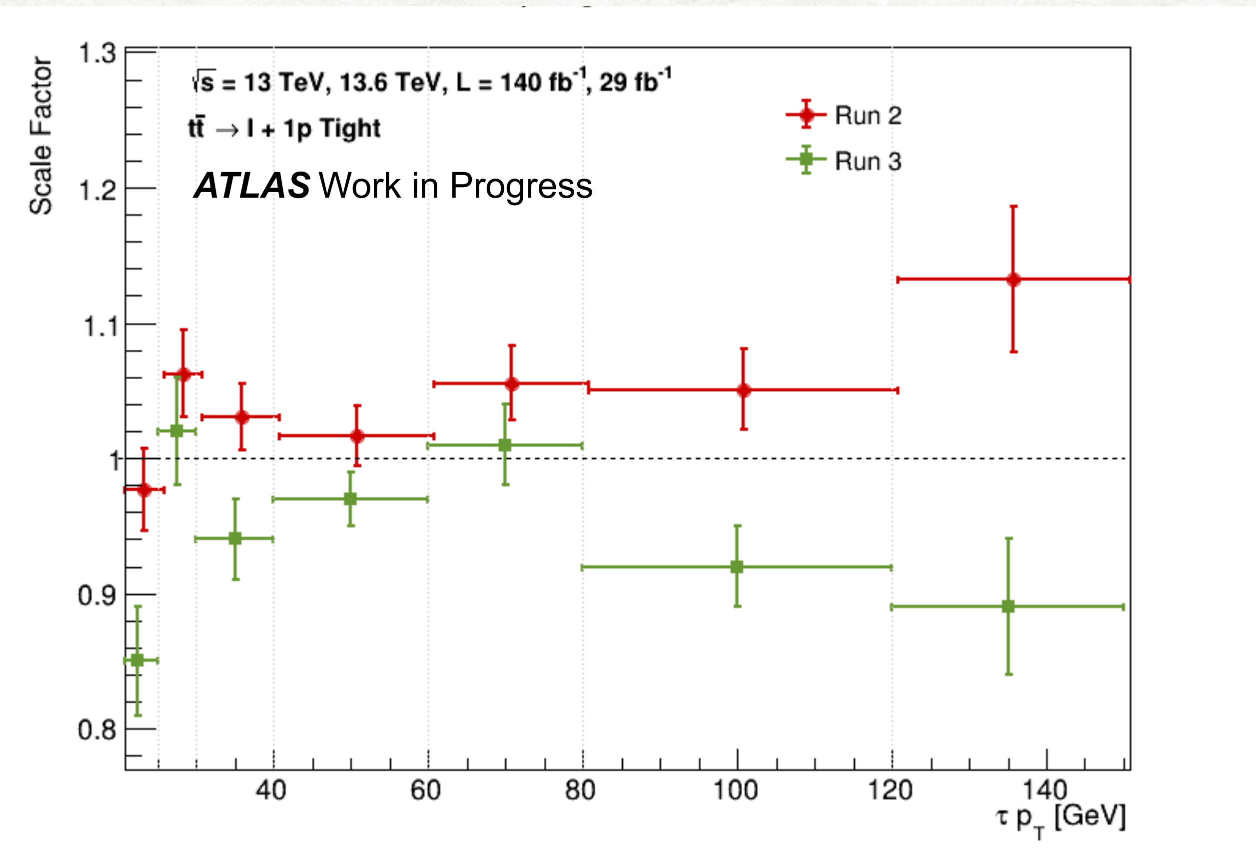
Data/MC of tau GNN score

SLIDES- CHAMATHKA

COMPARISON OF RUN-2 AND RUN-3







LH 1-PRONG

LH 3-PRONG