

**Performance of tau and muon leptons
reconstruction and identification in the ATLAS
experiment using pp collisions at $\sqrt{s}=13$ TeV
and their prospects for the HL-LHC**

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on behalf of the ATLAS collaboration
ICHEP2018 Seoul
07 July 2018

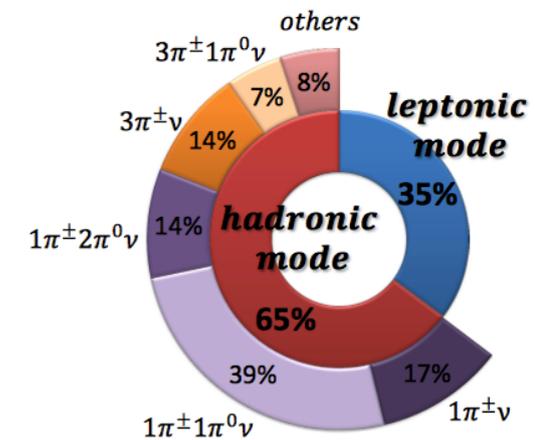
Challenges for Tau And Muon Reconstruction

Muon Reconstruction

- Achieve calibration sufficient for high precision measurements
- Optimize performance at very high- p_T vs. linear degrading of resolution with p_T
- Purity at very low p_T vs. energy loss in calorimeter
- Maintain good performance in high pile-up conditions vs. prompt muon selection and isolation criteria

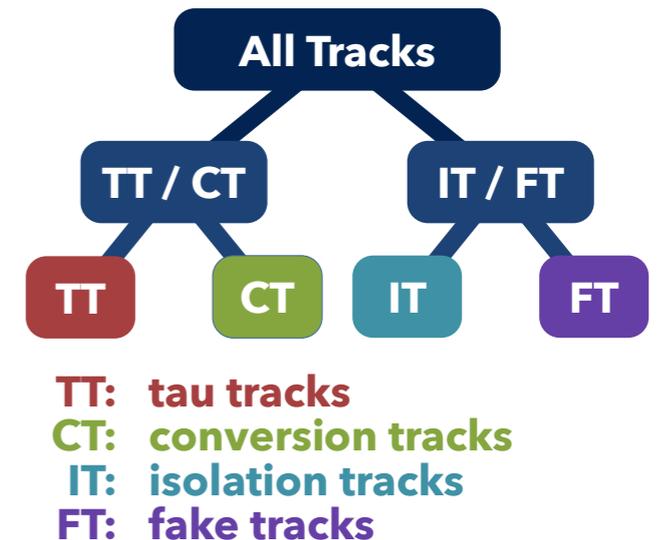
Tau Reconstruction

- Reconstruction of hadronic decay products
- Requires high background separation power against large quark and gluon jet background
- Tau energy calibration for precision measurements
- Maintain good performance in high pile-up conditions



Tau Reconstruction

- Reconstruction of hadronic tau decays is seeded by anti- k_T jets
- Association of tau production and decay vertices
- Multivariate track selection to maximize efficiency for correct track assignment and counting
- Decay mode classification by reconstructing individual charged and neutral hadrons in tau decays



ATLAS Simulation $Z/\gamma^* \rightarrow \tau\tau$

Tau Particle Flow Diagonal fraction: 74.7%

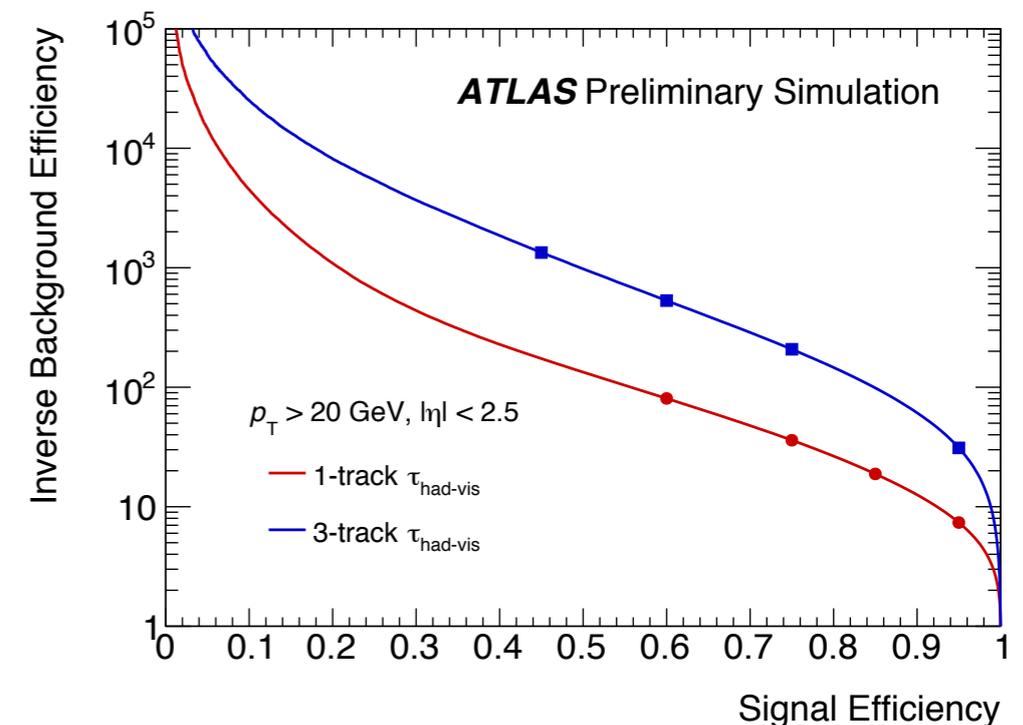
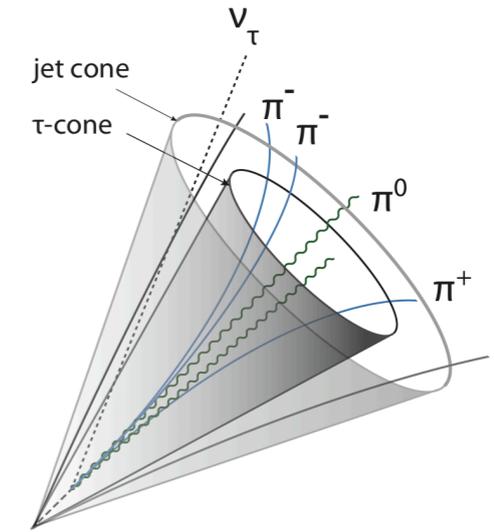
Reconstructed decay mode	h^\pm	$h^\pm \pi^0$	$h^\pm \geq 2\pi^0$	$3h^\pm$	$3h^\pm \geq 1\pi^0$
$3h^\pm \geq 1\pi^0$	0.2	2.5	3.6	5.3	56.6
$3h^\pm$	0.2	0.6	0.3	92.5	40.2
$h^\pm \geq 2\pi^0$	0.4	6.0	35.4	0.1	0.4
$h^\pm \pi^0$	9.4	74.8	56.3	0.9	2.5
h^\pm	89.7	16.0	4.3	1.2	0.3

Generated decay mode

[Eur. Phys. J C 76(5), 1-26 (2016)]

Tau Identification

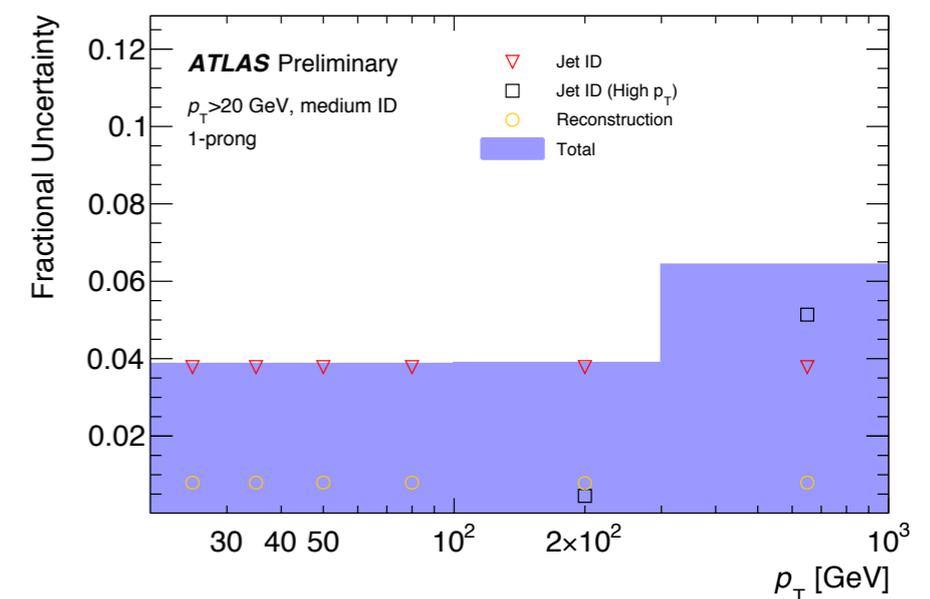
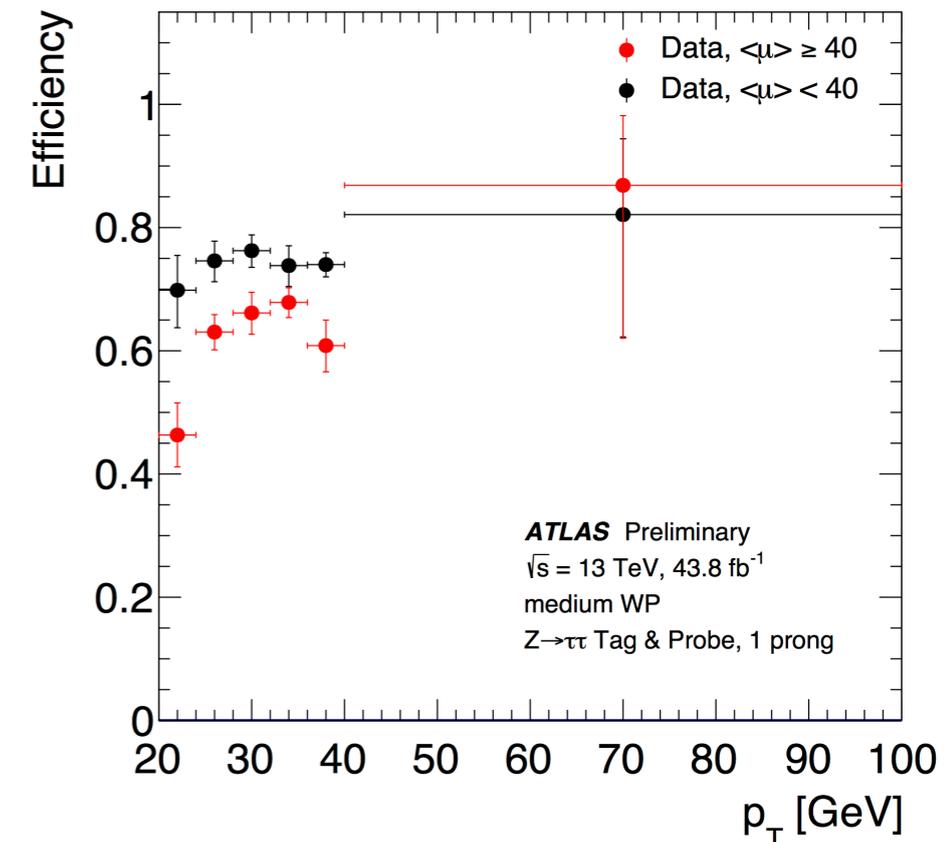
- Multivariate techniques for efficient discrimination against quark and gluon jets
- Boosted Decision Trees (BDT) in use, Recurrent Neural Networks under investigation
- Transformed BDT score to achieve constant signal efficiency with respect to p_T and pile-up



[Tau Public Results]

Tau Identification

- Identification efficiency evaluated in $Z \rightarrow \tau_\mu \tau_{\text{had}}$ tag-and-probe measurement
 - Monte Carlo samples (MC) for real taus and lepton fake background
 - Data driven estimate of multi-jet and W +jets background
 - Maximum likelihood fit for all identification working points and 1-prong and 3-prong taus
- Scale factors and their uncertainties evaluated from data/MC ratio
- Additional reconstruction uncertainties estimated from simulations
- High- p_T uncertainties estimated using a sample enriched in dijet events
- For details also see [poster about tau performance measurements](#) by Samuel Dysch

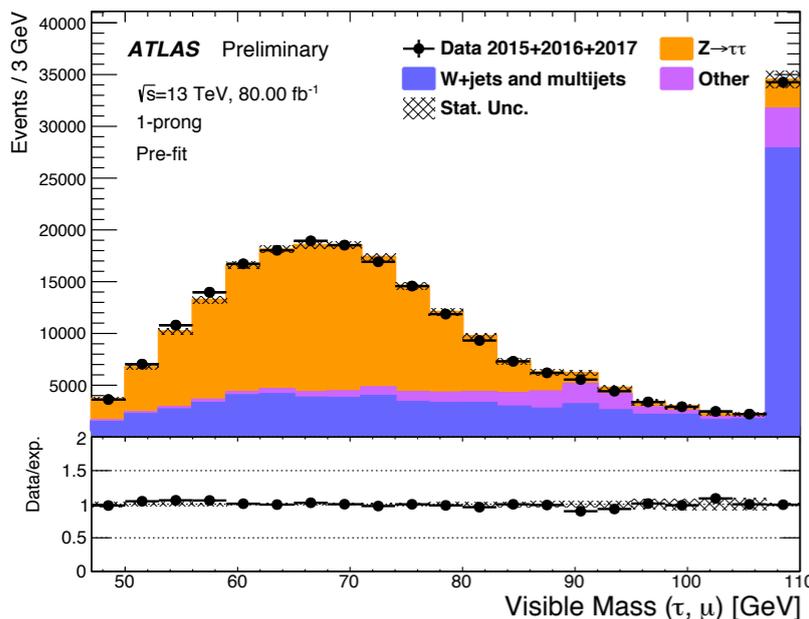


[Tau Public Results]

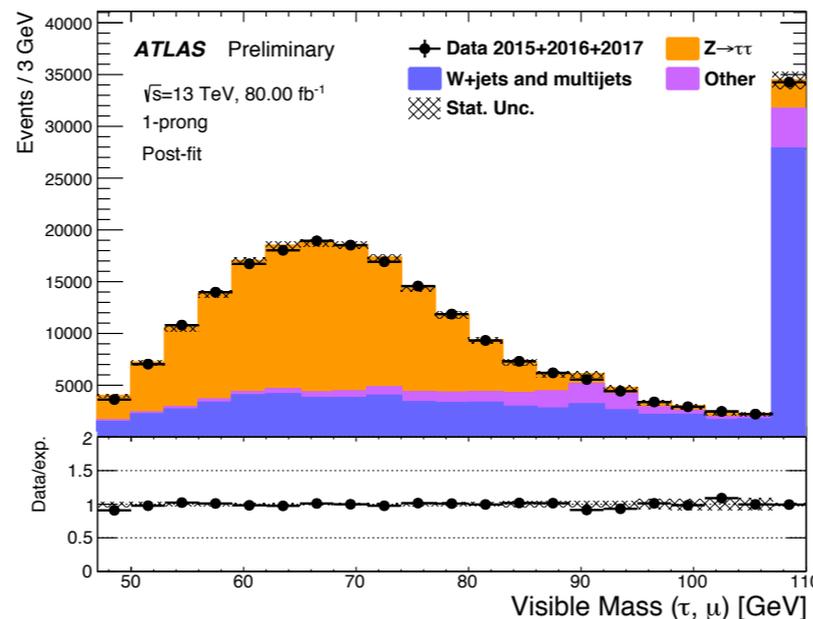
Tau Energy Scale

- Energy calibration based on multivariate regression
- Evaluate momentum shifting factor $p_{\tau}^{\text{fit}} = (1 + \alpha) \times p_{\tau}$ by comparing $m_{\text{vis}}(\mu, \tau)$ between data and simulations in different η regions
- Uncertainties evaluated from in-situ data
- Single hadrons data is used to derive uncertainties for high p_{τ}
- Additional modelling uncertainty from MC

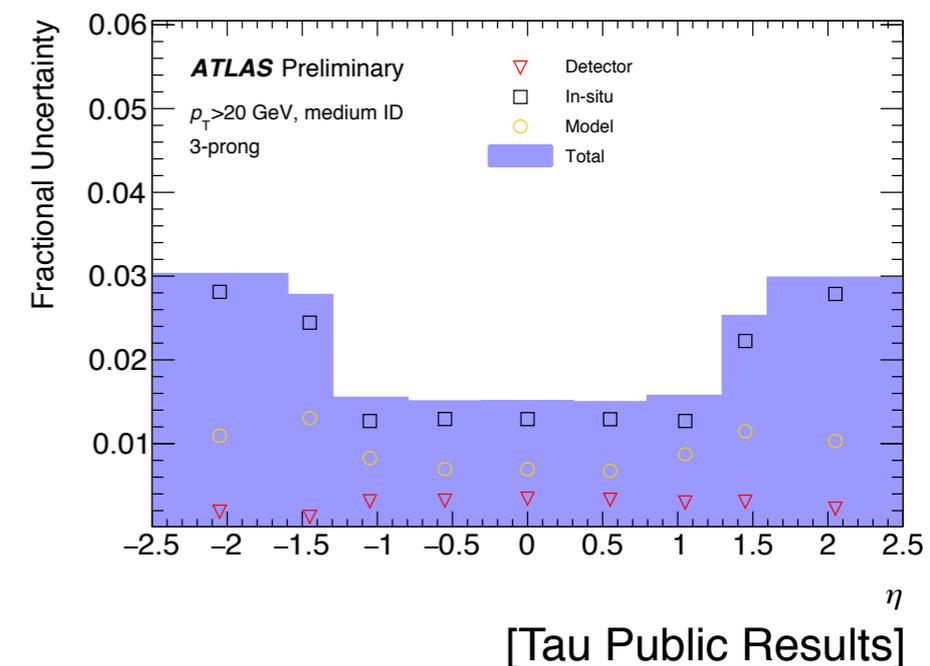
Pre-fit Visible Mass



Post-fit Visible Mass



Fractional Uncertainties



Muon Reconstruction and Identification

Reconstruction

- Independent track based reconstruction in Inner Detector (ID) and Muon Spectrometer (MS)

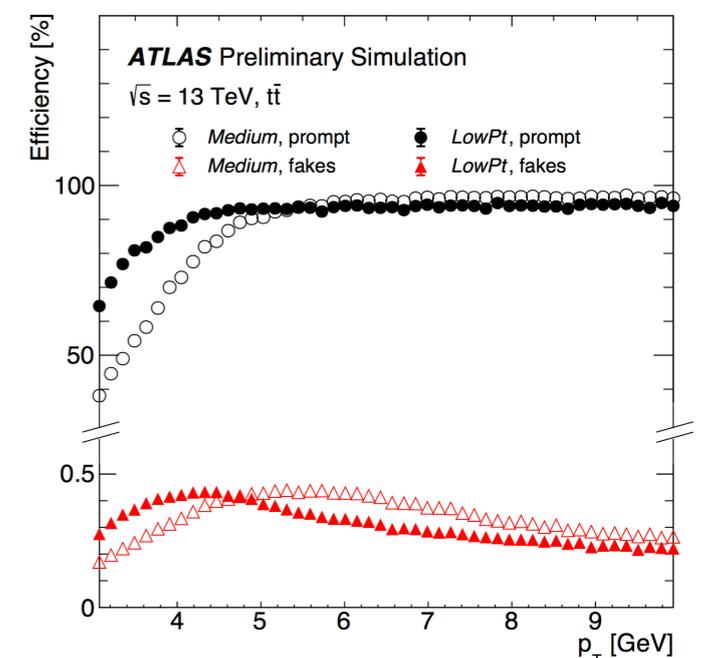
Reconstruction Types	Involved Sub-Detectors
combined	reconstructed tracks in MS and associated to ID tracks
segment-tagged	ID track extrapolated to MS
calo-tagged	ID track associated with energy deposit in calorimeter
stand-alone	track only reconstructed in MS

Identification

- Different muon identification selections for specific needs

ID Working Point	Specification
loose	maximizes identification efficiency
medium	minimizes systematic uncertainties
tight	maximizes purity
low- (high-) p_T	optimized for $p_T < 5$ GeV (>100 GeV)

- Details about low- p_T working point in [this poster by Zhi Zheng](#)

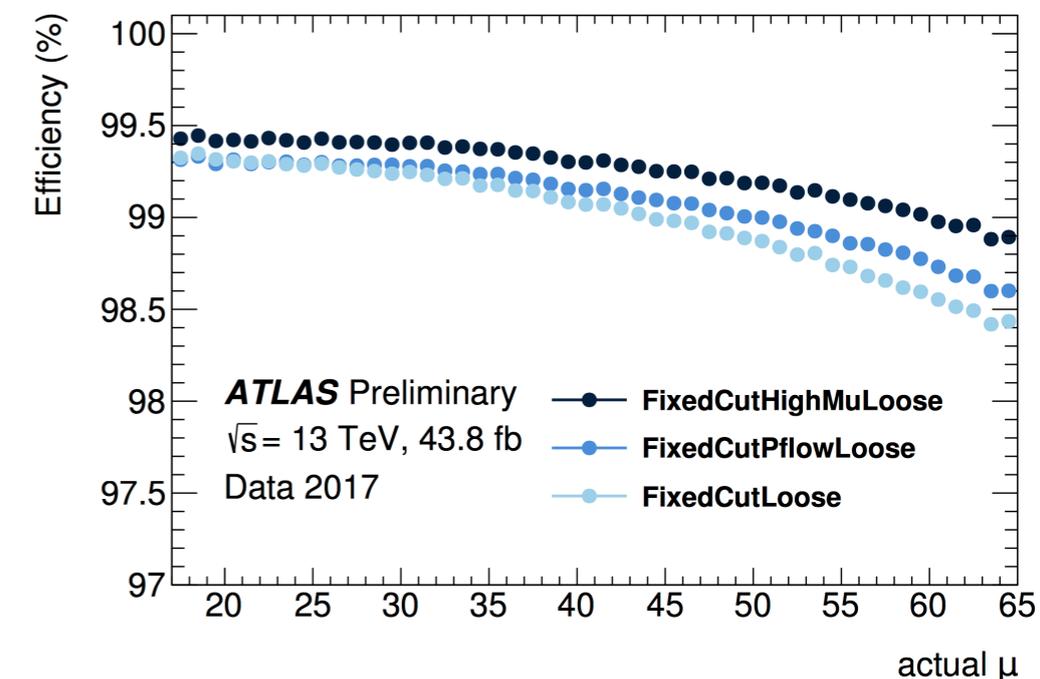
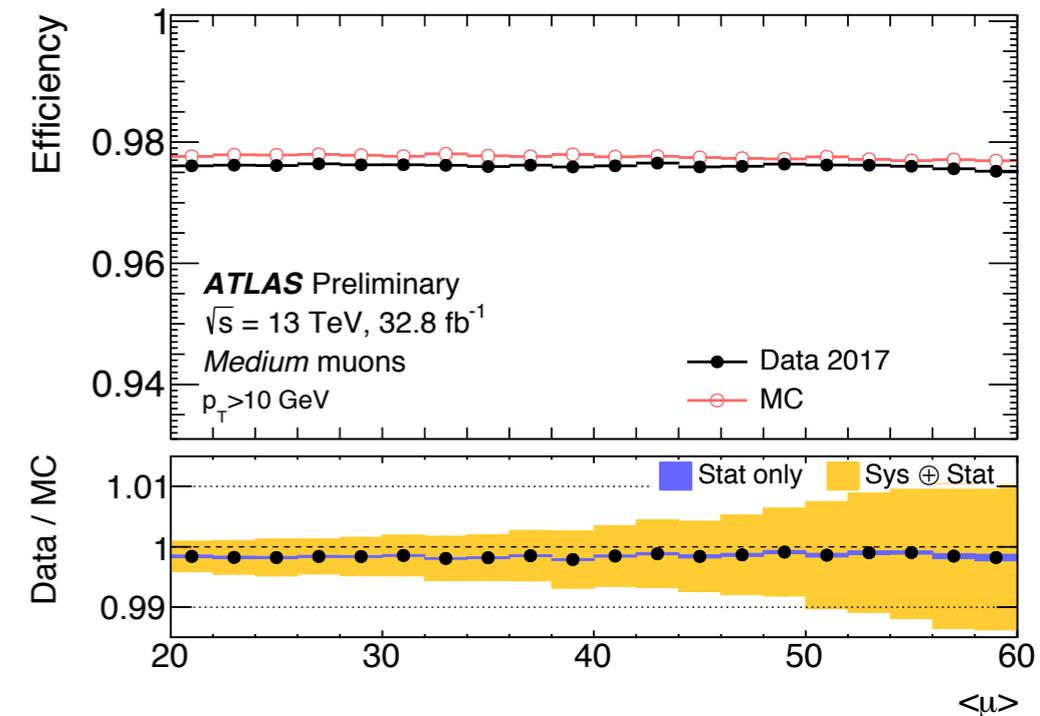


[Very low- p_T Muon Identification Poster]

[Eur.Phys.J. C76 (2016) no.5, 292]

Muon Efficiency Measurements

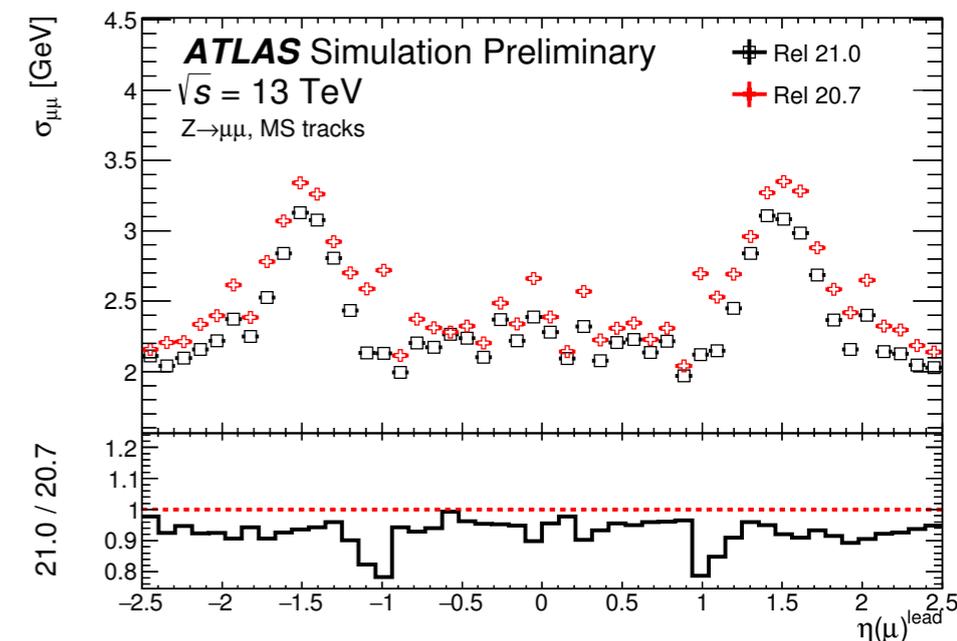
- Combined-muon identification efficiency evaluated in two tag-and-probe measurements:
 - $Z \rightarrow \mu\mu$ decays for $p_T > 15$ GeV region
 - $J/\Psi \rightarrow \mu\mu$ decays for $2.5 \text{ GeV} < p_T < 20 \text{ GeV}$
- Scale factor evaluated as data/MC ratio is close to unity
- Pile-up dependencies tested in $Z \rightarrow \mu\mu$ data events with up to 65 collisions per bunch crossing
- Enhancing isolation working points for higher pile-up robustness



[Muon Public Plots - High- μ]
[Muon Public Plots - Isolation]

Muon Momentum Scale Measurement

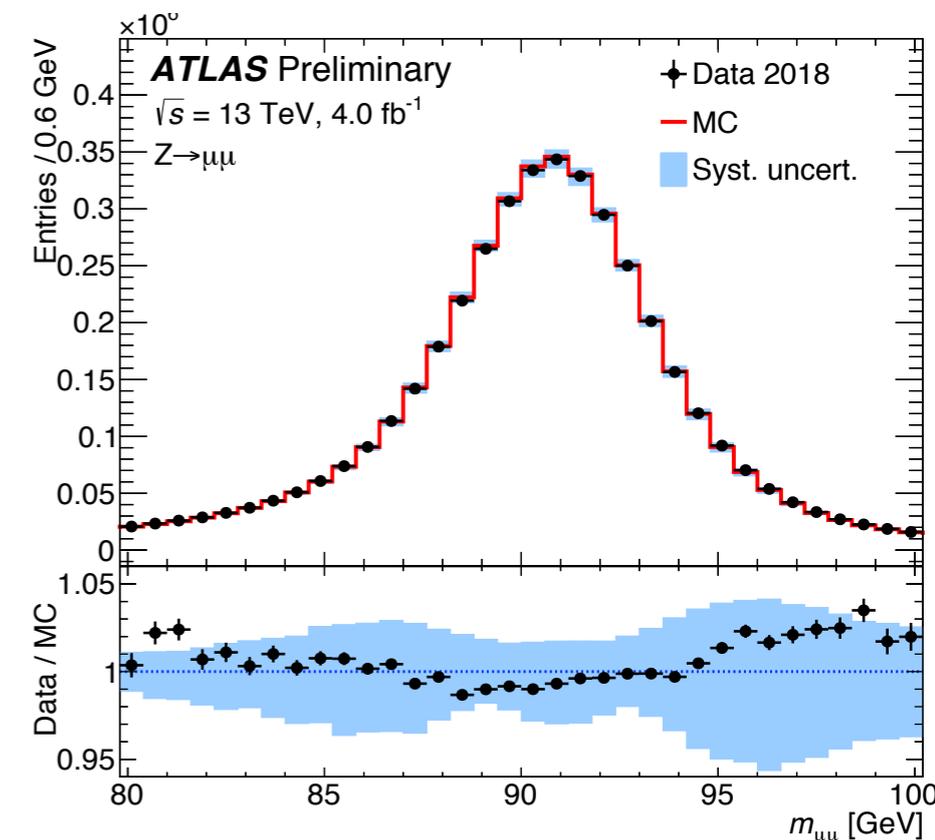
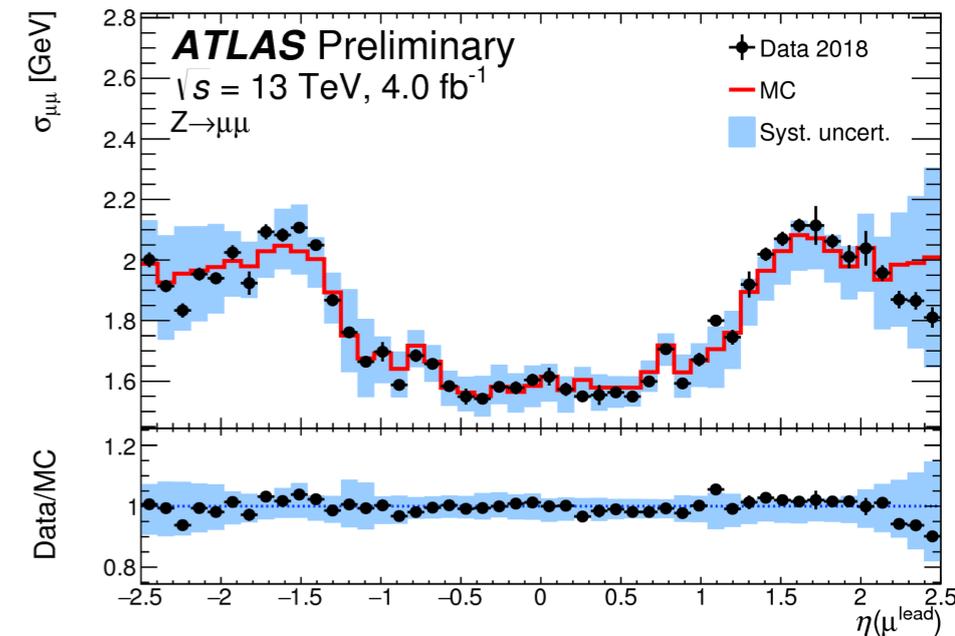
- Obtained $\sim 10\%$ resolution improvements due to better reconstruction
- Data-driven calibration of simulated muon momentum resolution and scale
- Derived using simultaneous template fit of Z and J/ Ψ lineshapes
- Di-muon mass resolution is compared between 2018 data and p_T calibrated Z $\rightarrow \mu\mu$ simulation
- p_T calibration was derived from 2016 dataset



[Muon Public Plots - Muon Resolution]

Muon Momentum Scale Measurement

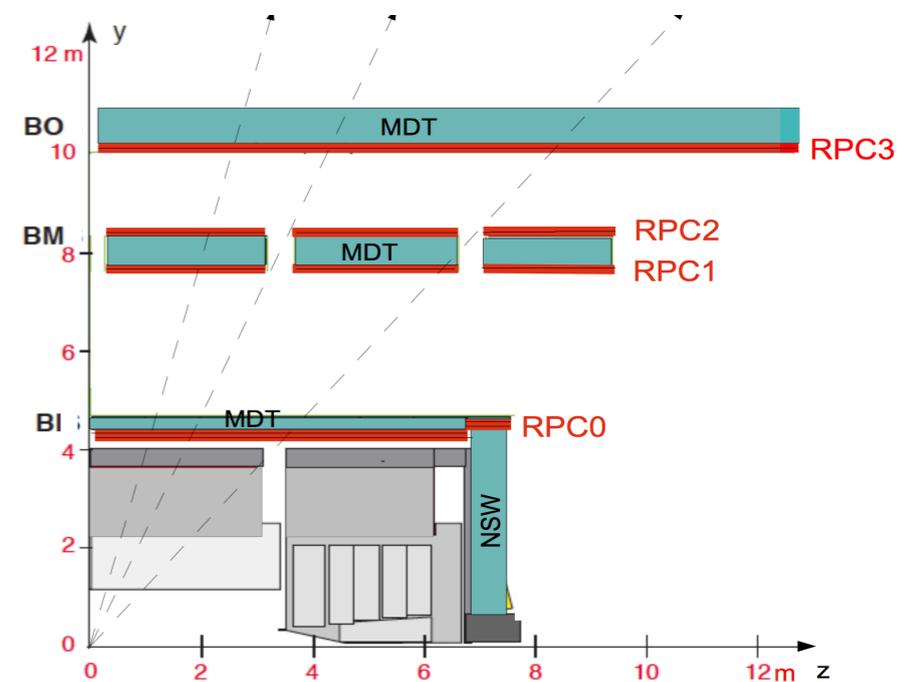
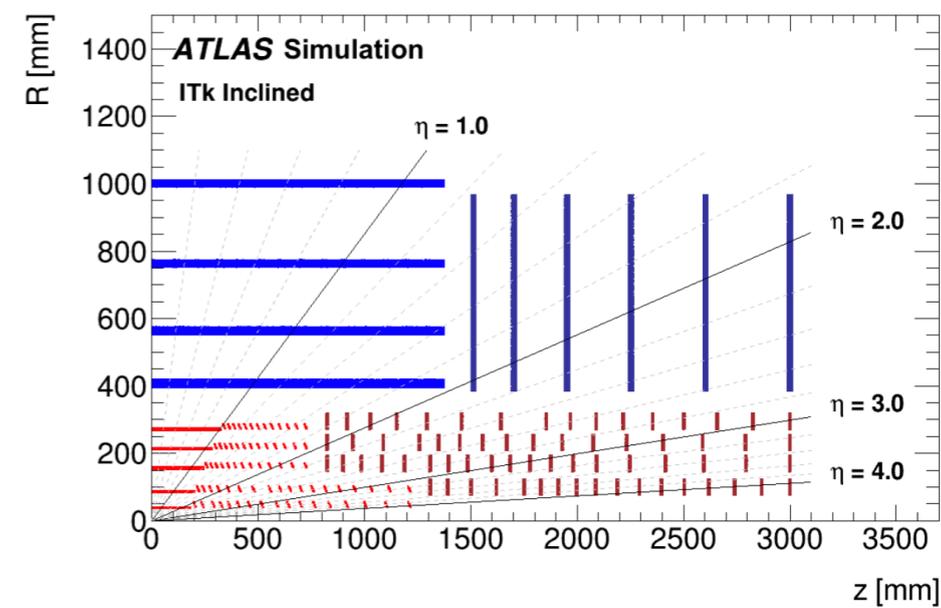
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[Muon Public Plots - first 2018 data]

ATLAS Upgrades for HL-LHC

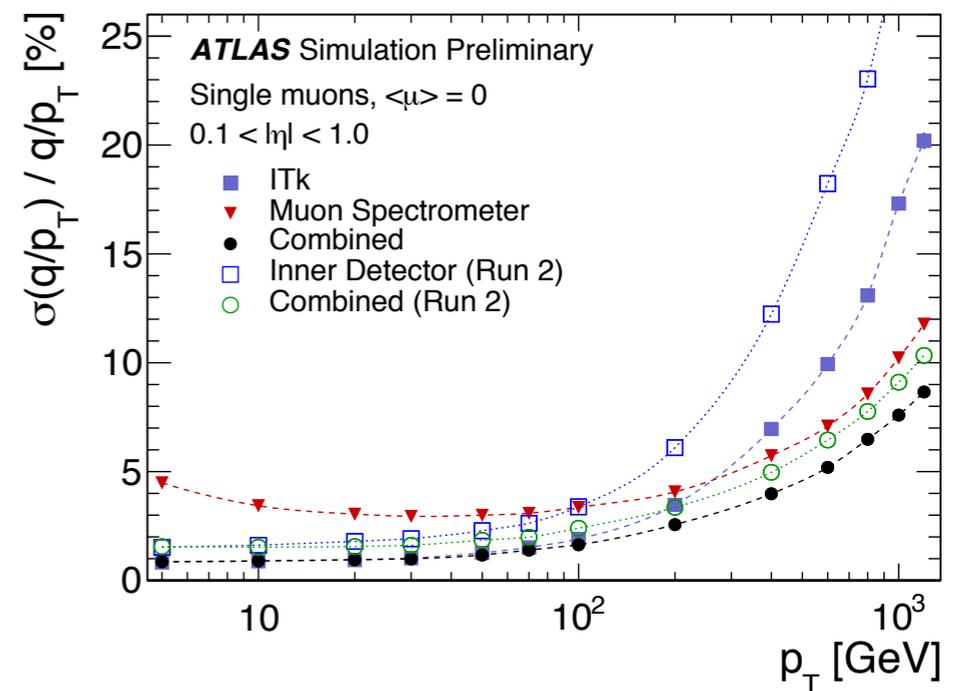
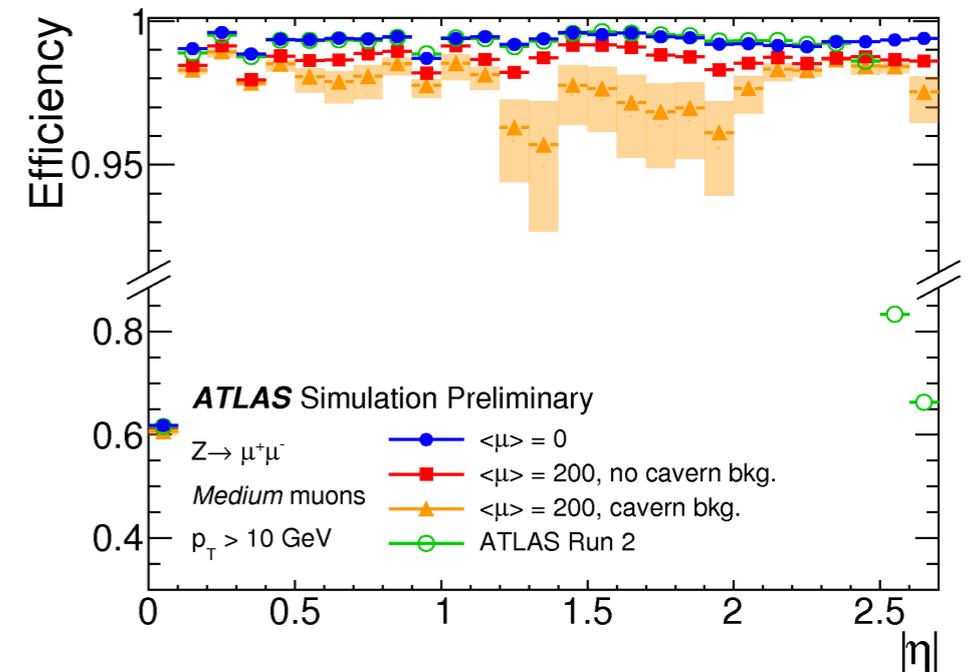
- New conditions at HL-LHC:
 $\sqrt{s}=14$ TeV
 $\mathcal{L}=7.5 \times 10^{34}$ cm⁻² s⁻¹
 $\mu \approx 200$
- Requires significant detector upgrades in terms of radiation hardness, granularity and bandwidth
- New all-silicon Inner Tracker (ITk) with higher granularity, η coverage and radiation resistance
- Replacement of readout electronics for all calorimeters
- New innermost barrel RPC layer for increased muon trigger coverage and robustness



[CERN-LHCC-2017-005, ATLAS-TDR-025]
[ATL-PHYS-PUB-2016-026]

Muon Performance at HL-LHC

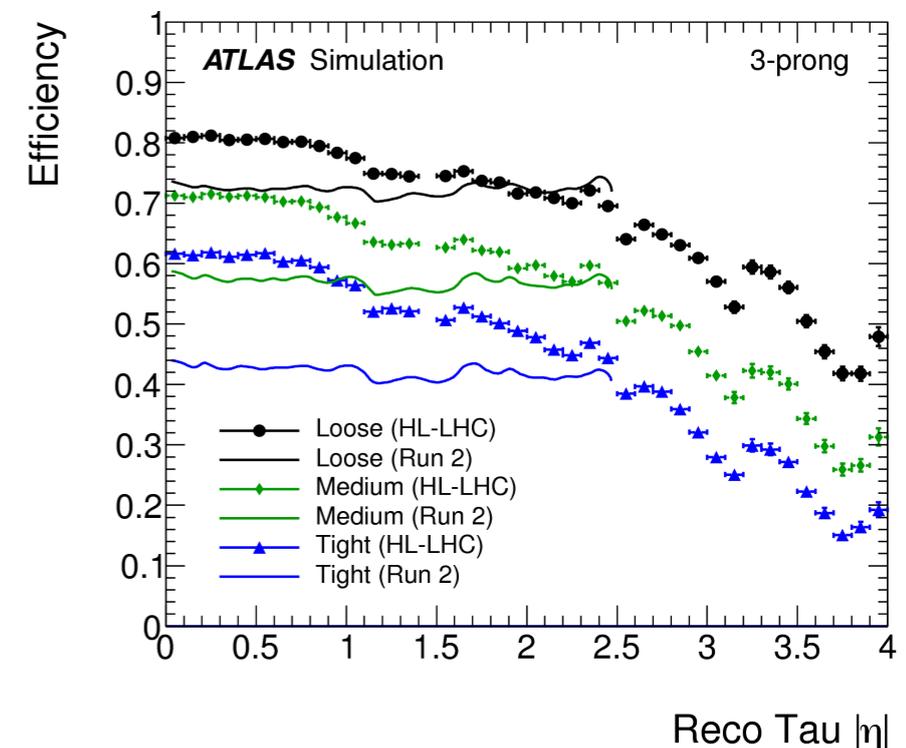
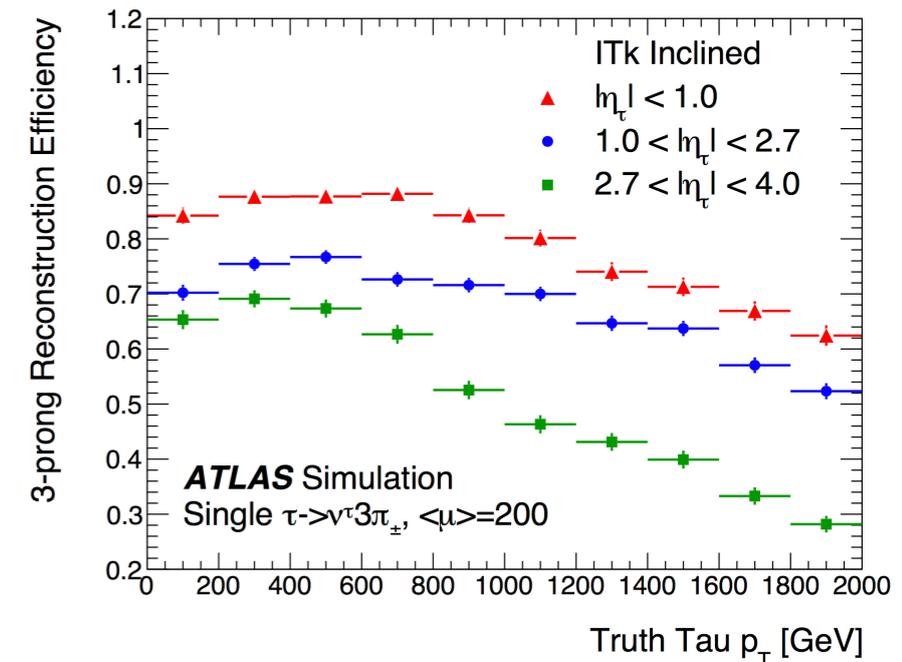
- Stronger pile-up conditions lead to percent level deficits in identification efficiency
- Improved efficiency at $|\eta| > 2.5$
- ITk dominates momentum measurement below $p_T = 100$ GeV
- Combined fit benefits from ITk resolution in the full p_T range compared to Run2
- New RPC chambers allow better coverage and efficiency for muon trigger



[Muon Public Plots - Phase II TDR]

Tau Performance at HL-LHC

- 3-prong taus with high p_T as test case for track reconstruction efficiency in dense environments
- Due to fine granularity of ITk significantly less track merges compared to Run2
- Tau ID at HL-LHC shows higher signal acceptance at same background rejection in $|\eta| < 2.5$ region
- New $2.5 < |\eta| < 4.0$ region accessible for tau reconstruction and identification



[CERN-LHCC-2017-005, ATLAS-TDR-025]
[Pixel TDR Plots]

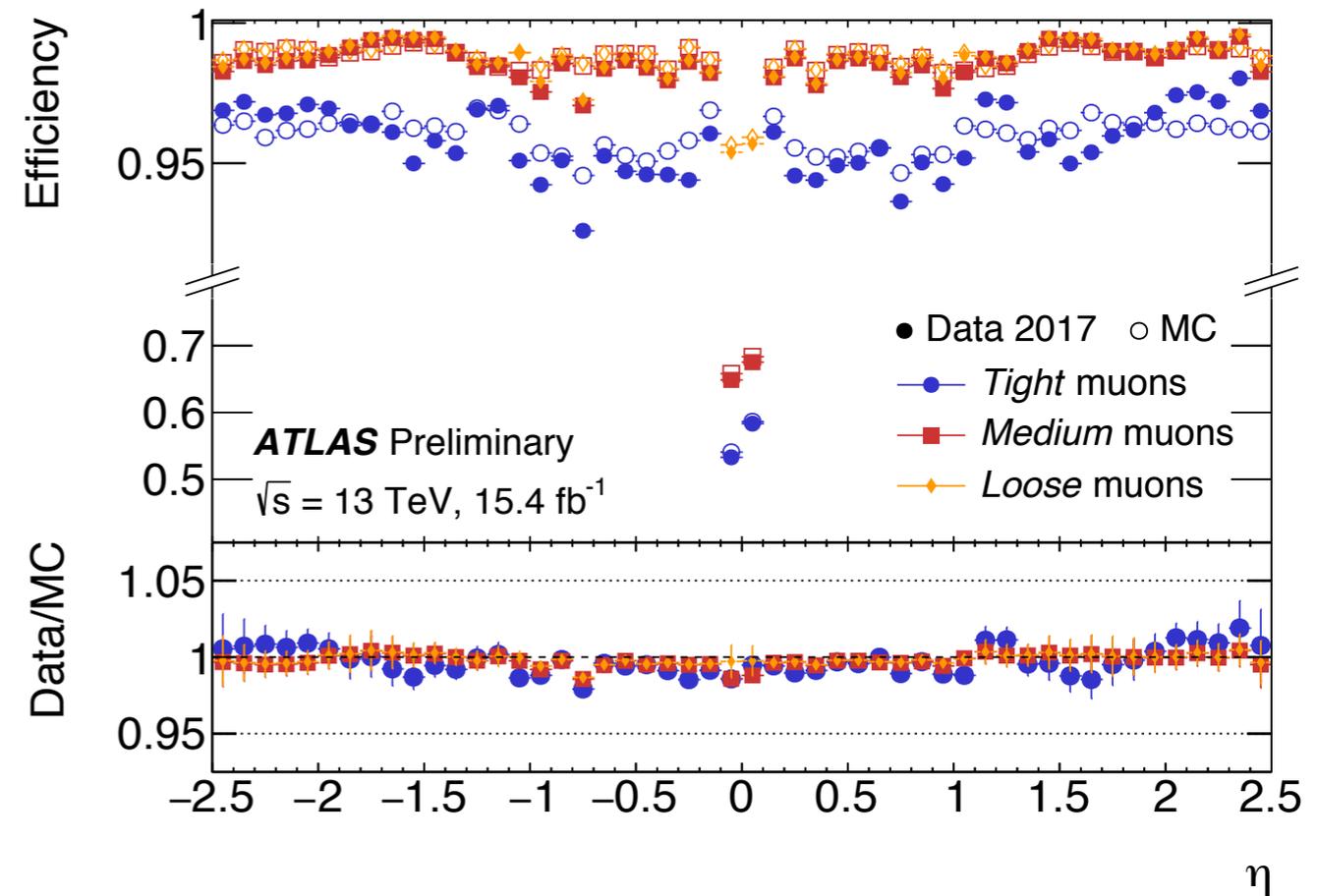
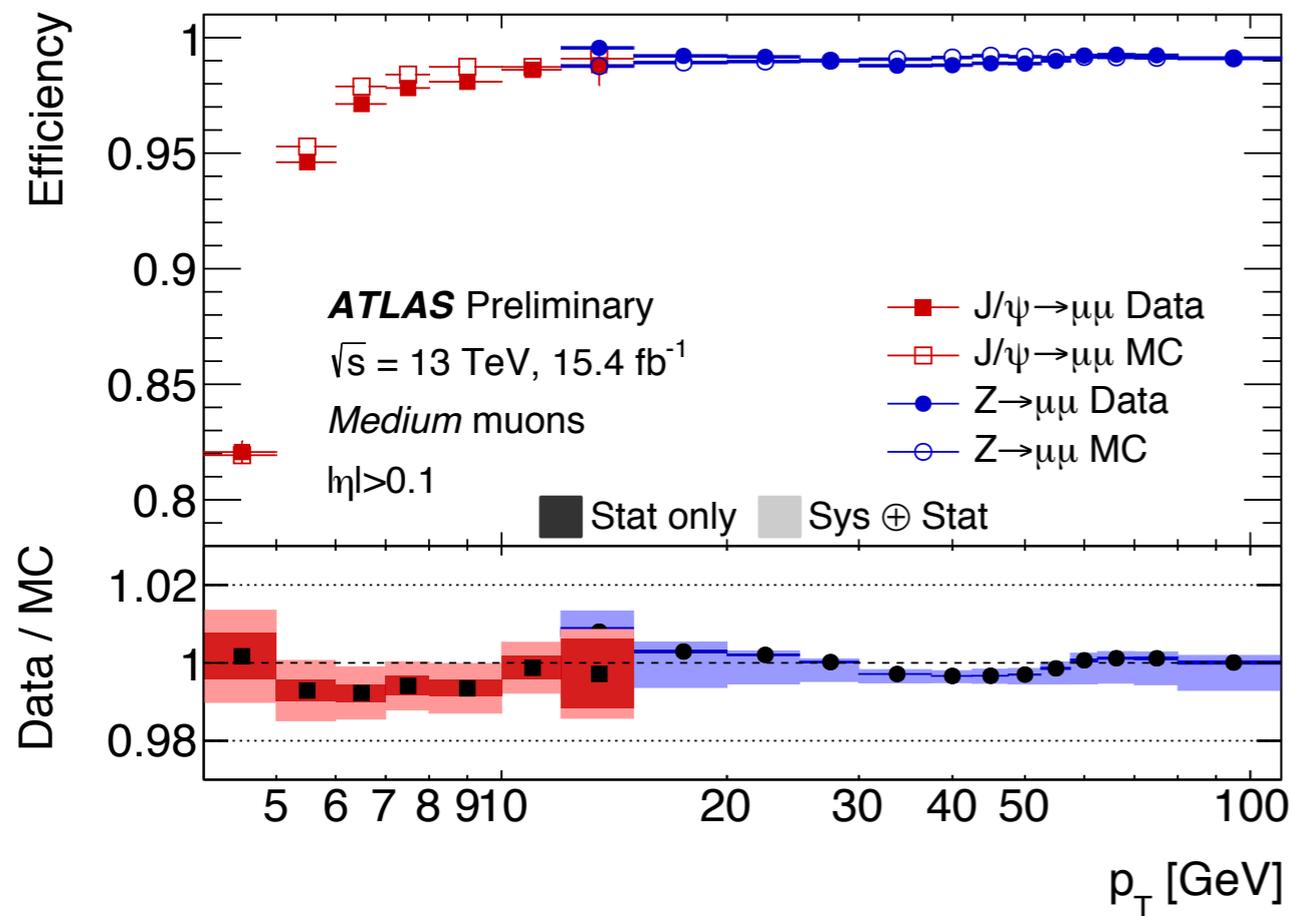
Summary

- Efficient muon and tau reconstruction is central for many ATLAS measurements and searches
- Hadronic tau decay reconstruction, identification and calibration validated in $Z \rightarrow \tau_\mu \tau_{\text{had}}$ tag-and-probe measurement
- Muon performance validated in $Z \rightarrow \mu\mu$ and $J/\Psi_{\mu\mu} \rightarrow \mu\mu$ tag-and-probe measurements
- First studies on 2018 data already performed
- Significant detector upgrades are planned towards HL-LHC, allowing to maintain efficient muon and tau reconstruction in ATLAS

An aerial photograph of a city at night, showing a dense grid of buildings and streets. The image is centered on a bright, multi-colored starburst light effect, with rays of light in red, orange, yellow, green, and blue emanating from the center. The word "Backup" is overlaid in white, bold, sans-serif font on the starburst.

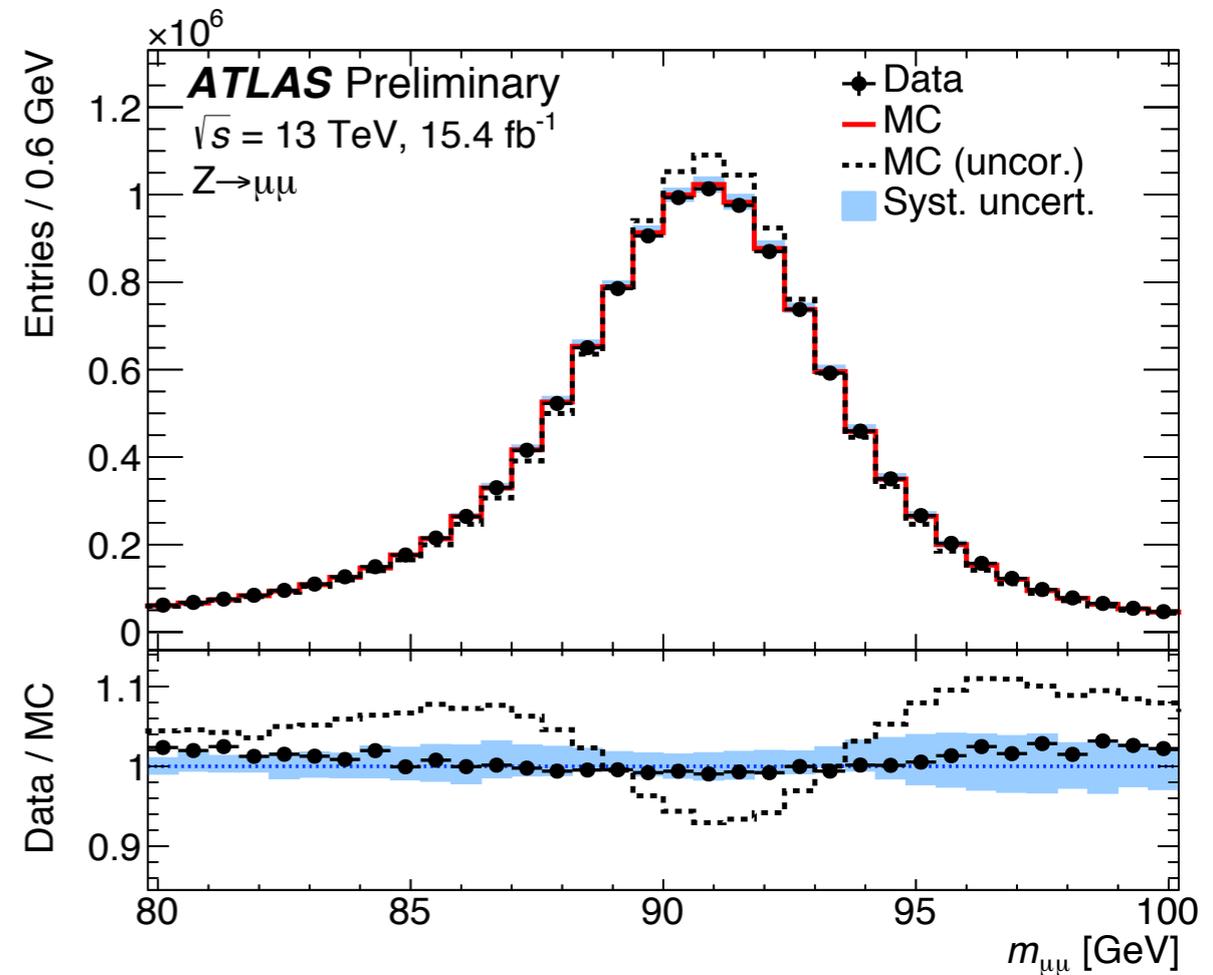
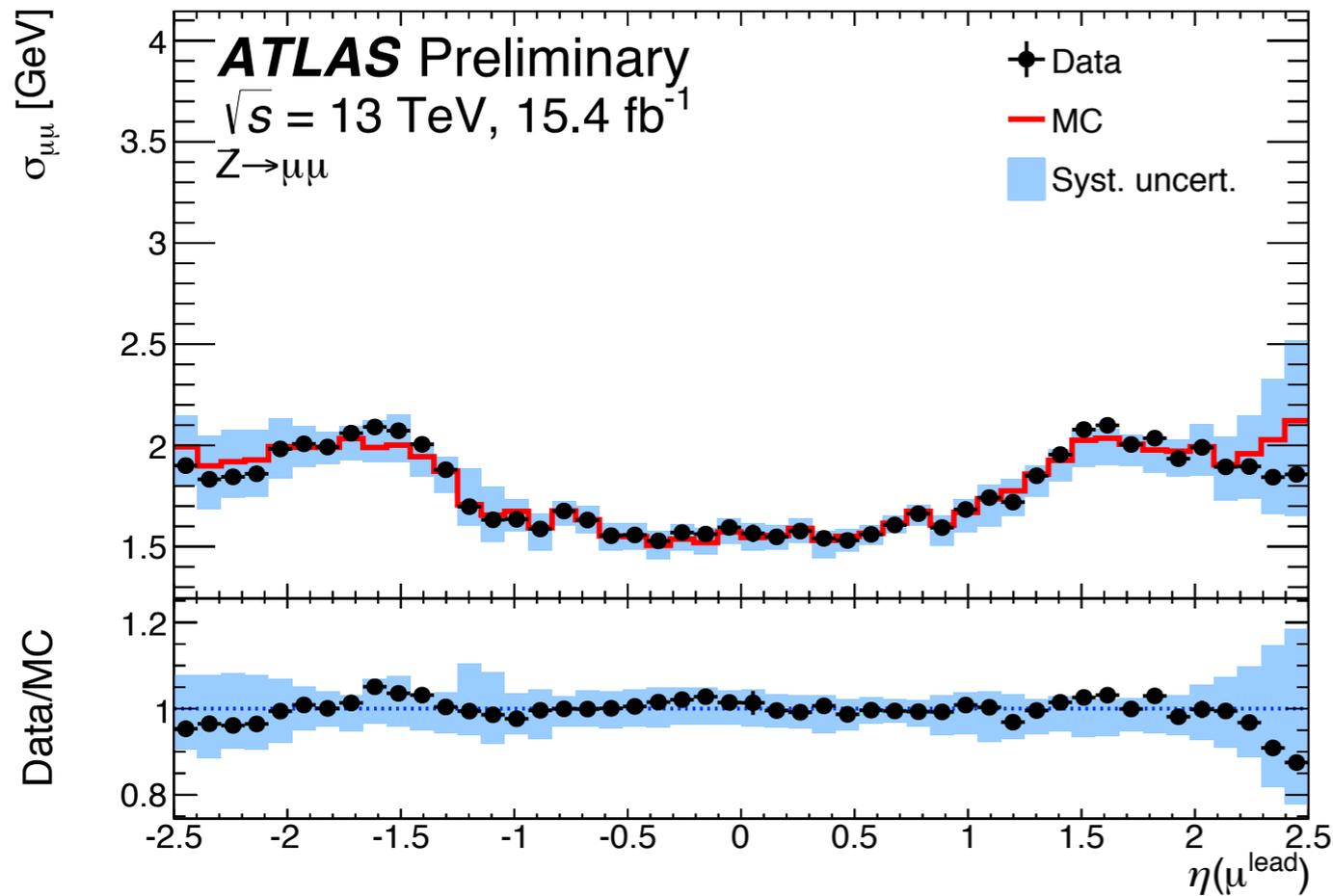
Backup

Muon reconstruction efficiency in 2017 data



[Muon Public Plots - 2017 and 2016 data]

Muon resolution in 2017 data



[Muon Public Plots - 2017 and 2016 data]

Muon Trigger Coverage at HL-LHC

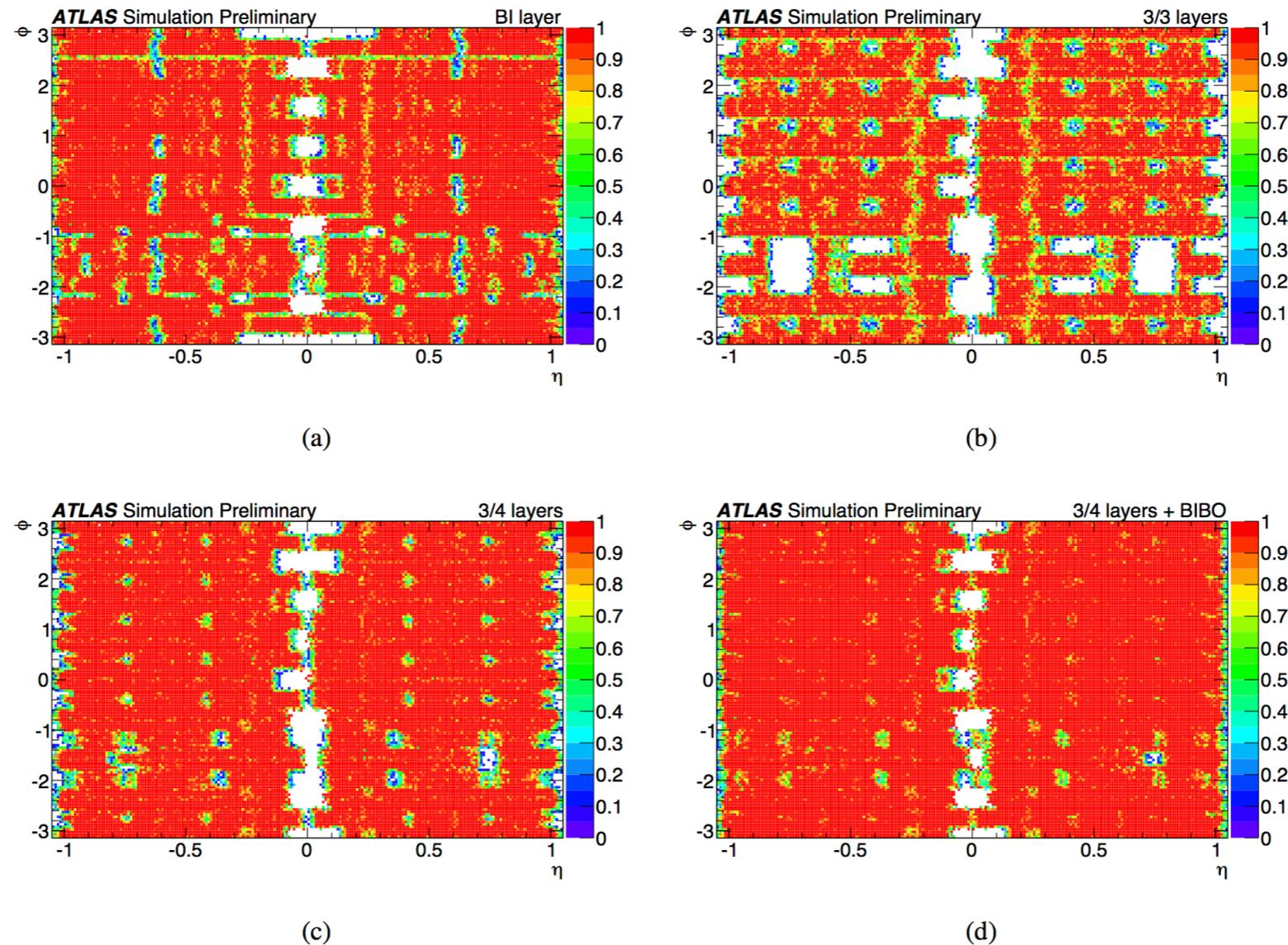
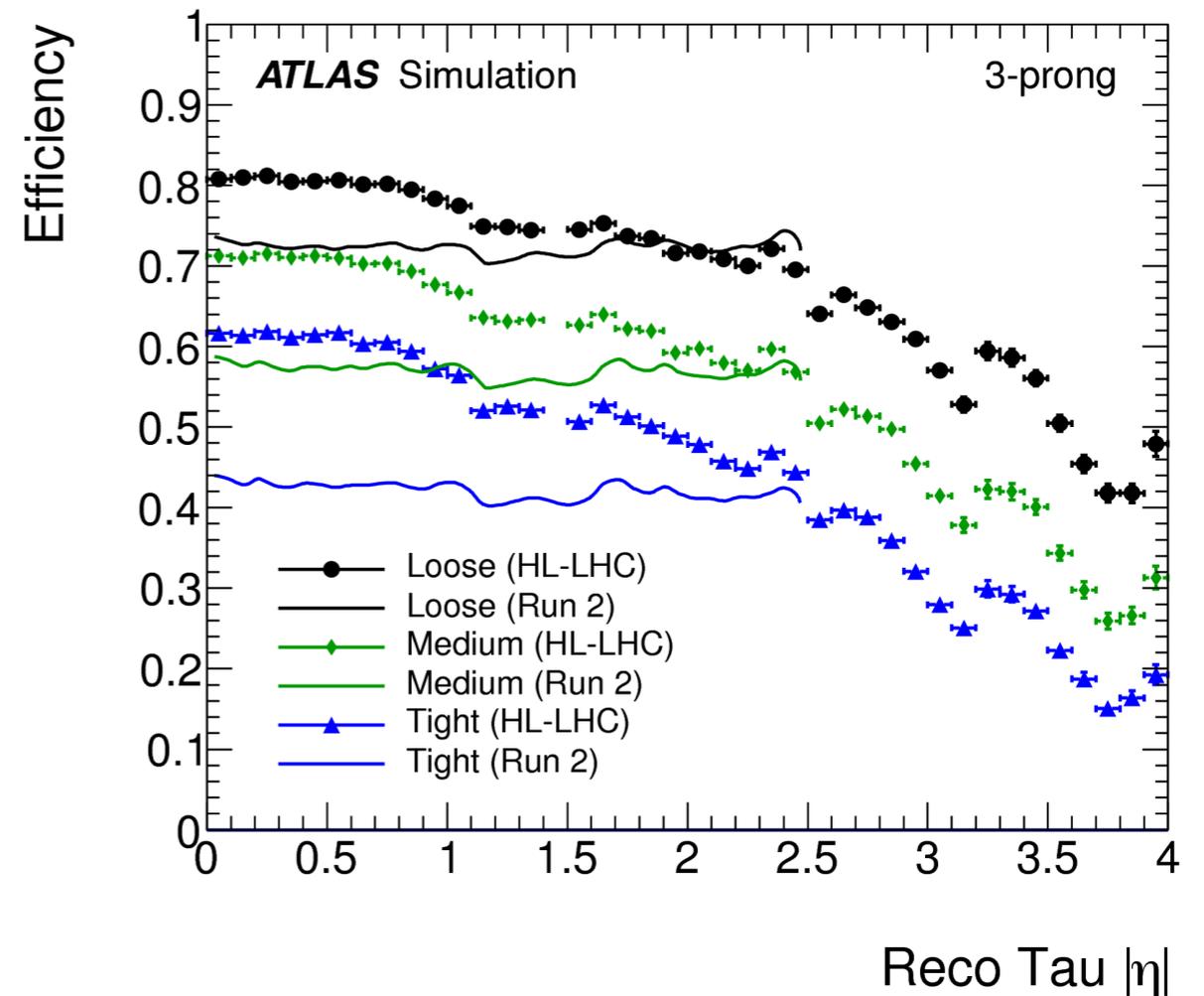
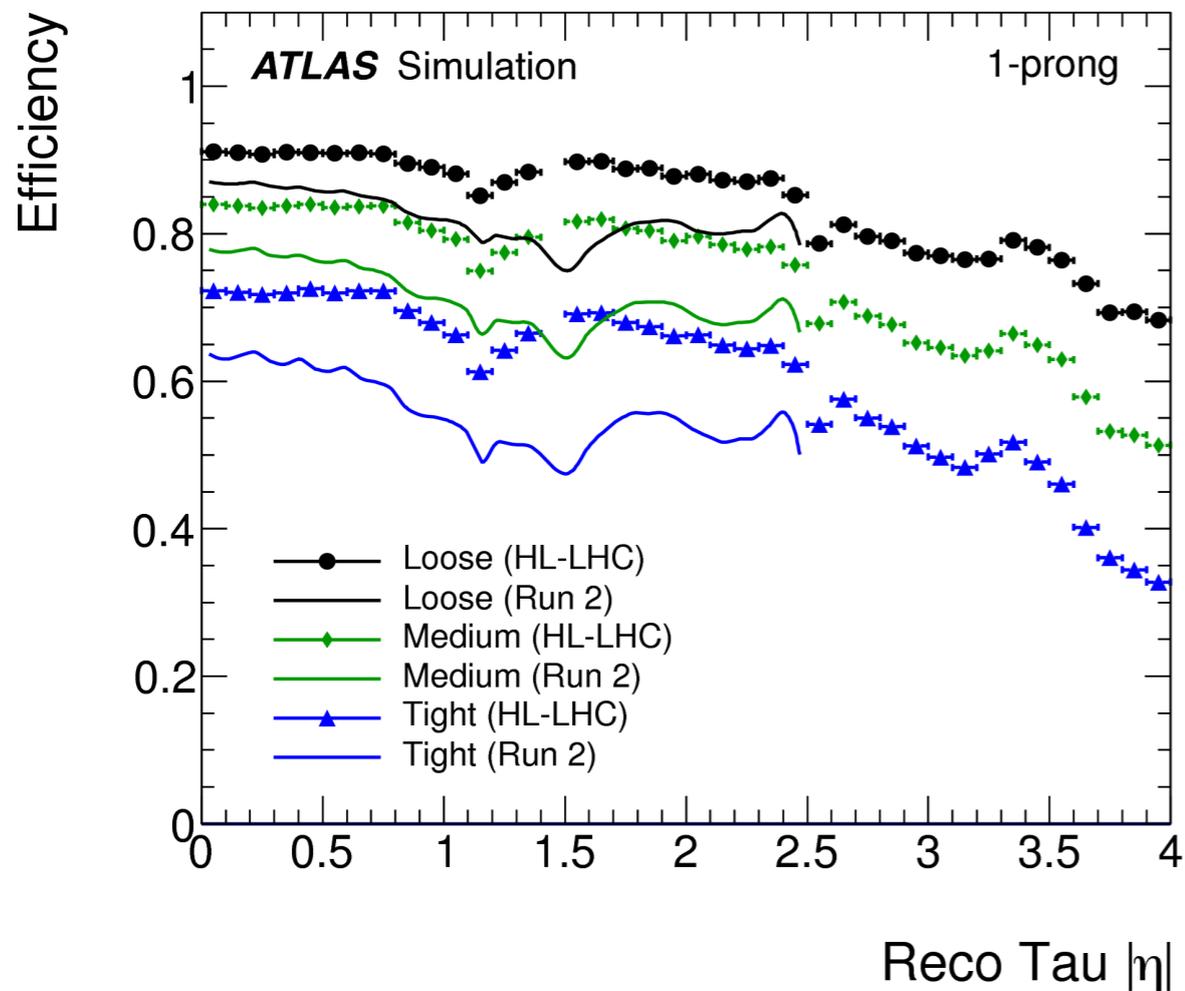


Figure 10: Acceptance of the L0 Barrel trigger with respect to reconstructed combined muons in the η - ϕ plane. Figure (a) shows the acceptance of the BI layer. Figures (b), (c) and (d) show the acceptance for the different trigger coincidence logics “3/3 layers”, “3/4 layers” and “3/4 layers + BI-BO”, respectively (see text). The white areas correspond to zero acceptance.

Tau Performance at HL-LHC



[Pixel TDR Plots]