$Z \rightarrow \tau\tau$ Embedding in CMS

$m_{\tau\tau}$ Workshop Würzburg

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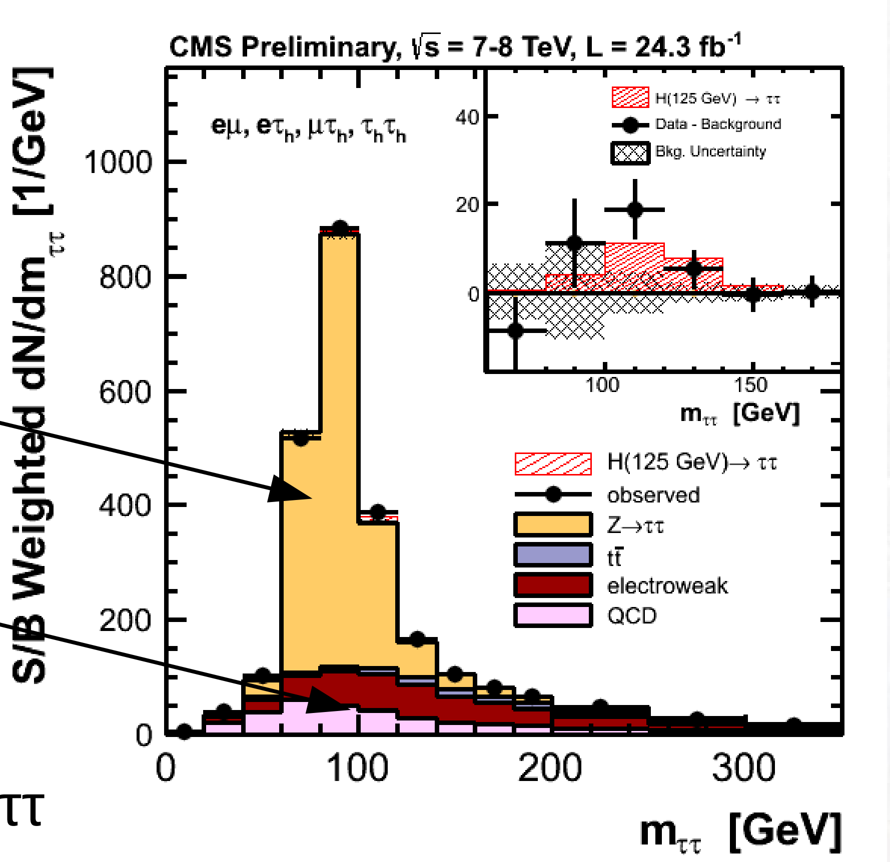
Higgs to Taus in CMS

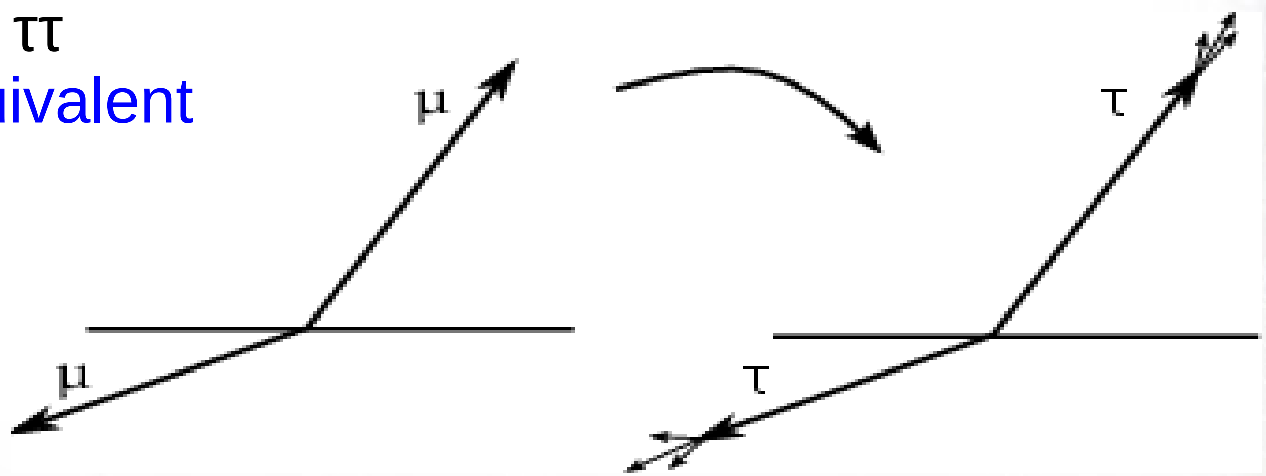
- $Z \rightarrow \tau\tau$ largest background in $H \rightarrow \tau\tau$ search
- Other backgrounds can be obtained from sidebands
- $Z \rightarrow \tau\tau$ is irreducible:
  - Same final state as $H \rightarrow \tau\tau$
  - Di-Tau mass resolution too low to separate
  - Data-driven estimation is crucial



CMS-HIG-13-004

The Embedding Method

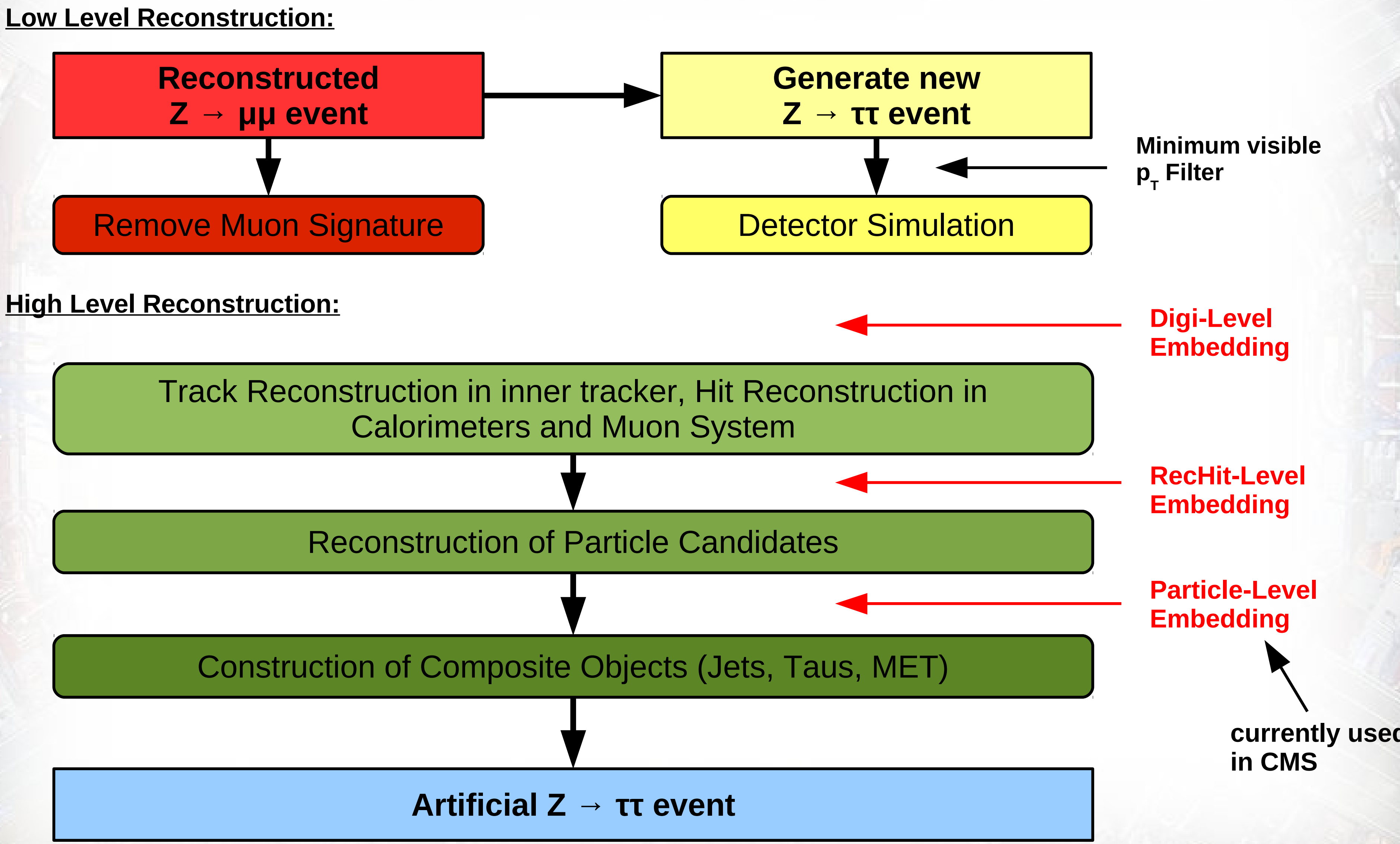
- Data-driven way to estimate the $Z \rightarrow \tau\tau$ background desired
- Select di-muon events from Z decays in data
- Replace measured muons by simulated generator level tau leptons
- Other event content (Underlying event, Pile-Up) taken from data
- $Z \rightarrow \mu\mu$ and $Z \rightarrow \tau\tau$ kinematically equivalent



Recent Developments

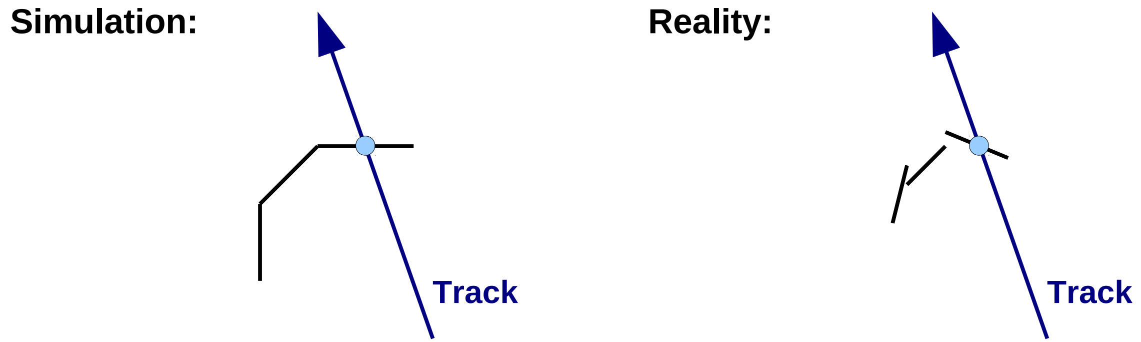
- Several improvements to the method have been developed and studied recently in CMS:
  - Embedding on RecHit level
  - Rotation of embedded leptons around Z boson axis
  - Use TauSpinner to model spin effects
  - Subtraction of $t\bar{t}$ contamination in embedded samples

Embedding Technique



RecHit-based Embedding

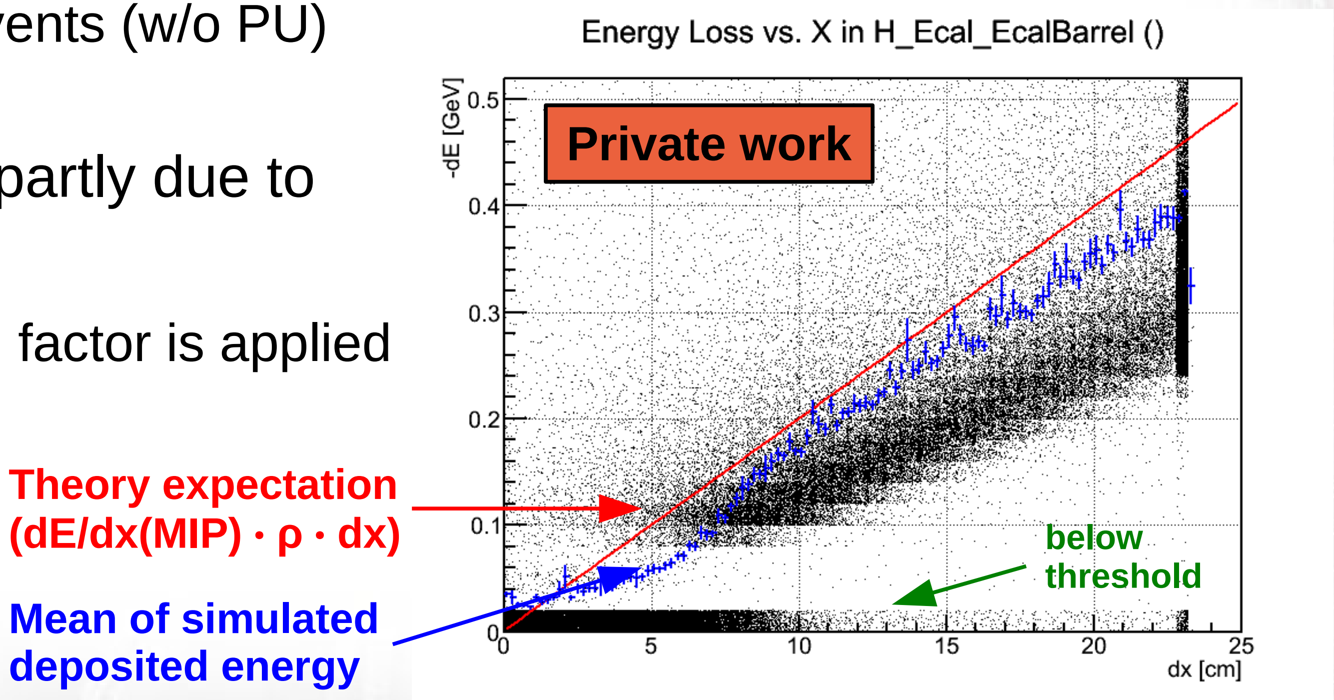
- It is preferable to run the mixing at the lowest possible level
- However, there are technical limitations
  - Different geometry in simulation and reality
    - e.g. Simulation runs with ideal tracker geometry



- Compromise: RecHit-based embedding
  - Merge reconstructed inner tracks and calorimeter hits

Muon Energy Subtraction

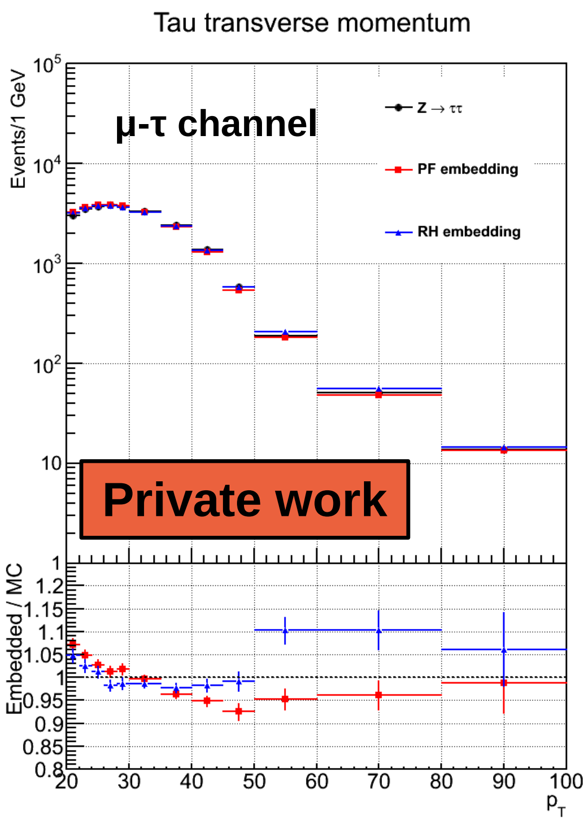
- Energy deposited in calorimeter by muons needs to be subtracted
  - Extrapolate muon track into calorimeter
  - Calculate mean deposited energy in absorber material
  - Compare with actual calorimeter deposits in simulated $Z \to \mu\mu$ events (w/o PU)
- Small Deviation, partly due to threshold effects
  - Correction factor is applied

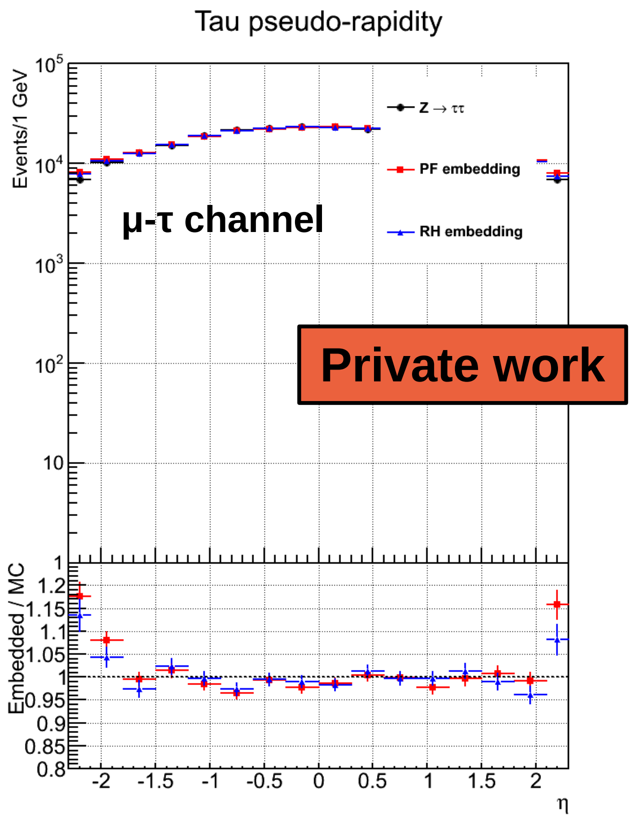


Validation Procedure

- Run Embedding procedure on Z → μμ simulation
  - Evaluate the performance of Particle-based and RecHit-based embedding techniques
  - Compare to Z → ττ simulation to study possible biases
- Select events in mu-τ_h and e-τ_h final states
  - Simple analysis cuts, not 100% identical to official CMS H → ττ analysis
  - Does not use any correction on top of embedded samples

Tau Kinematics

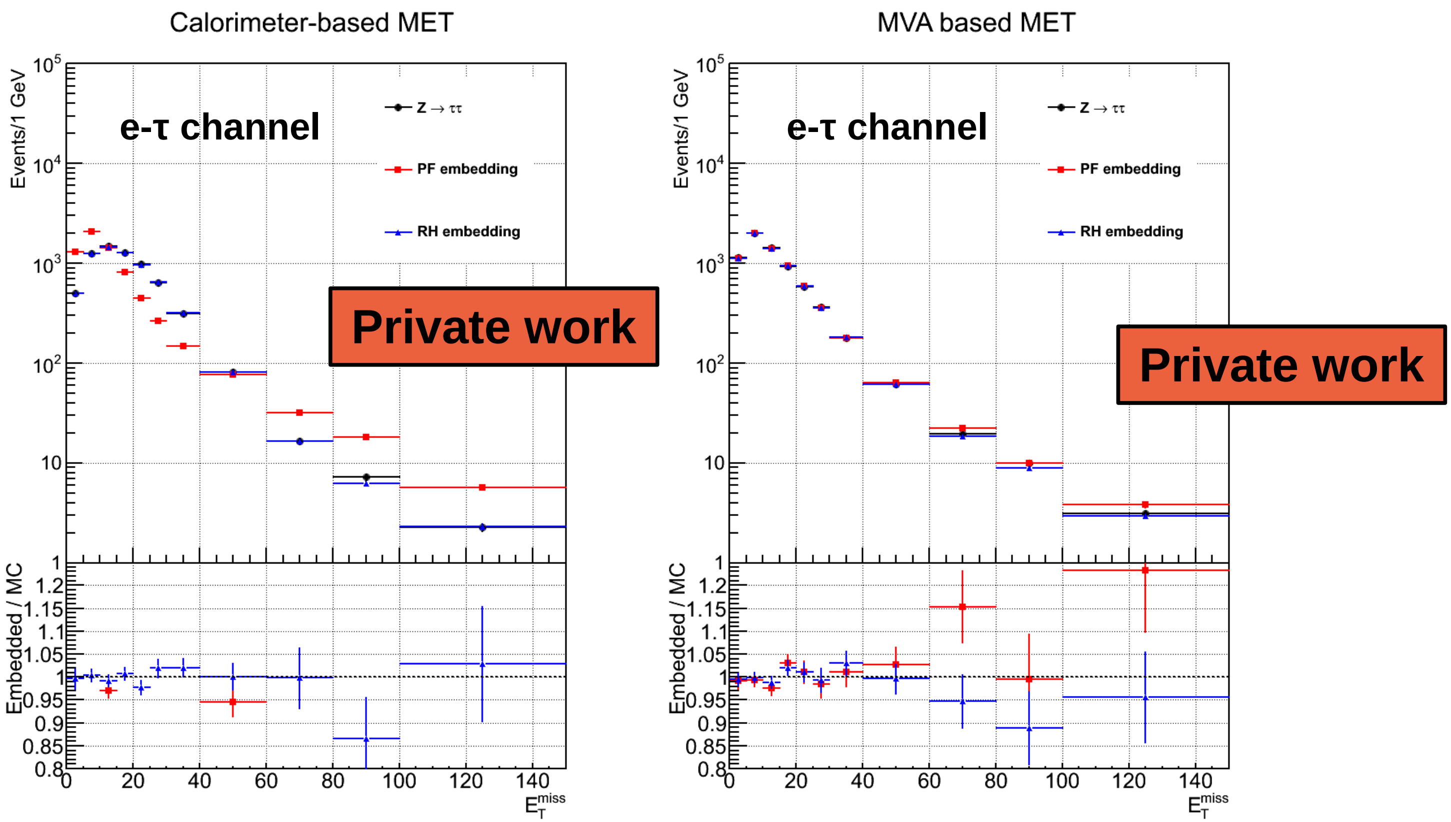




Basic kinematic variables fairly well modelled

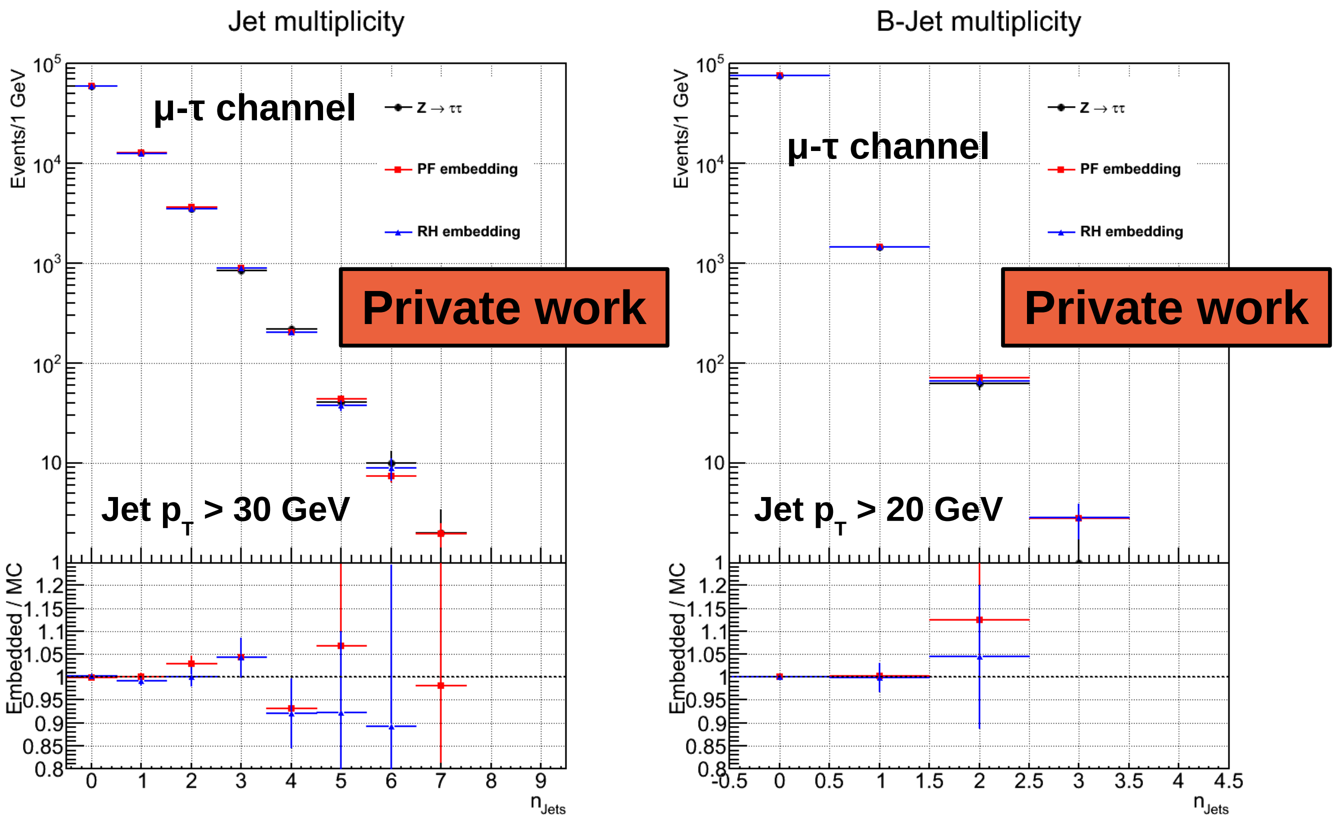
Tau ID efficiency slightly higher at high eta

Missing transverse Energy



Good description of calorimeter-based E_T^{miss} by RH method → Essential for "soft lepton" analysis which uses Lepton+tau+MET trigger

Jet Multiplicity

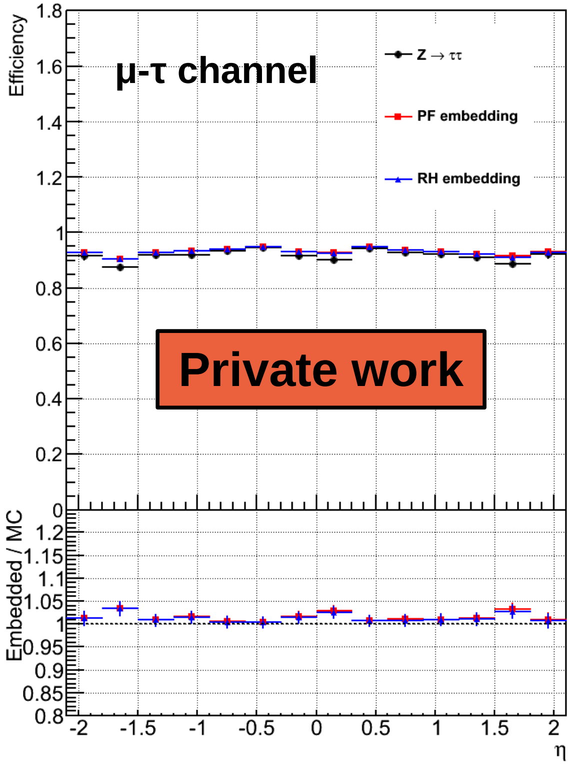


Jet Multiplicity well described

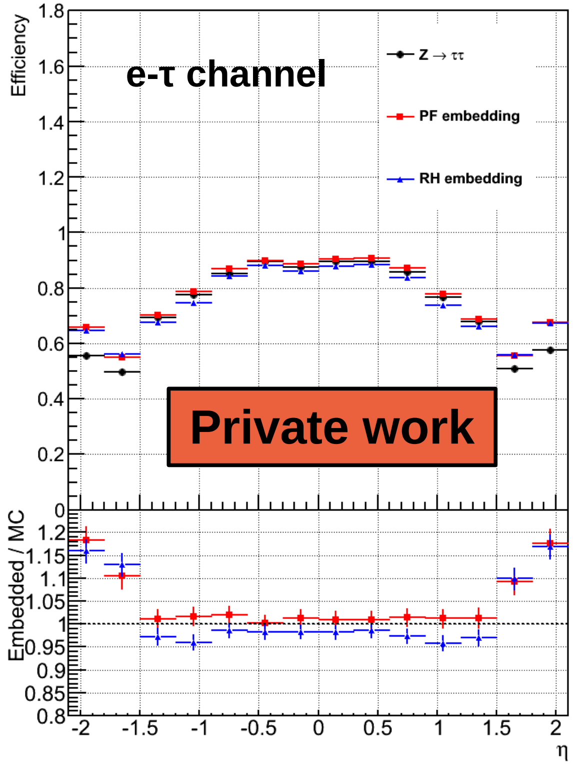
Important for Event Categorization

Lepton ID Efficiency

Muon ID efficiency vs. eta



Electron ID efficiency vs. eta

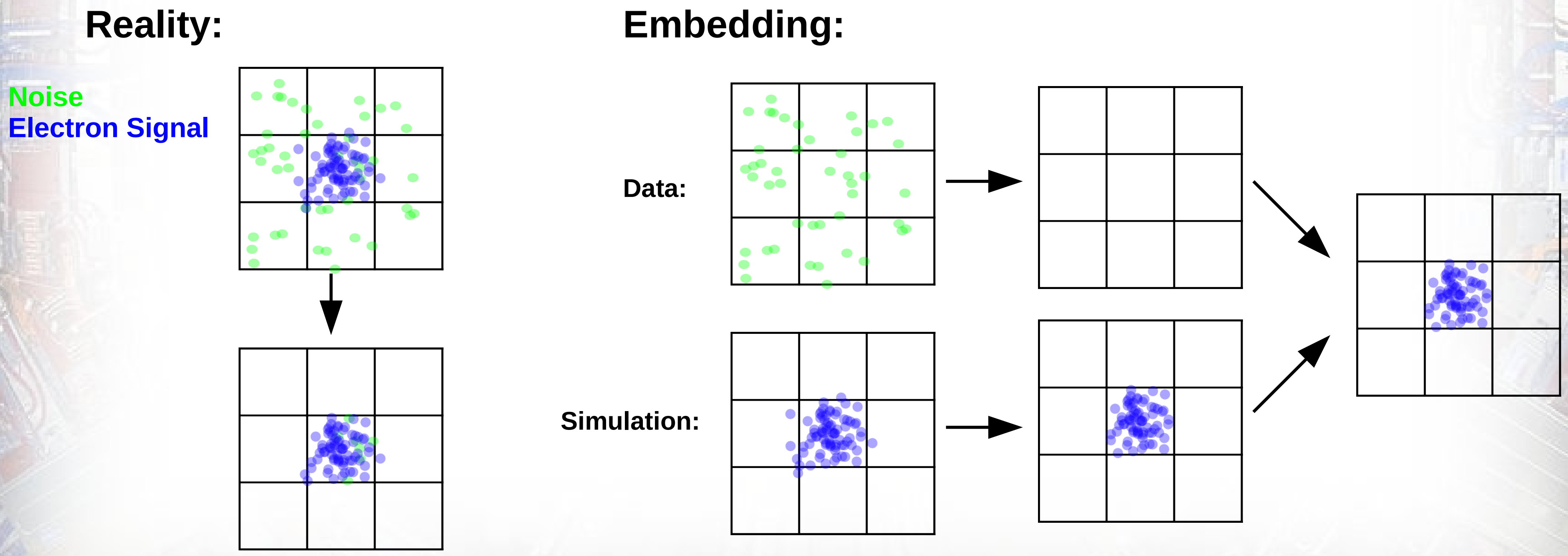


Muon ID Efficiency higher in crack region

Electron ID Efficiency too high at high eta

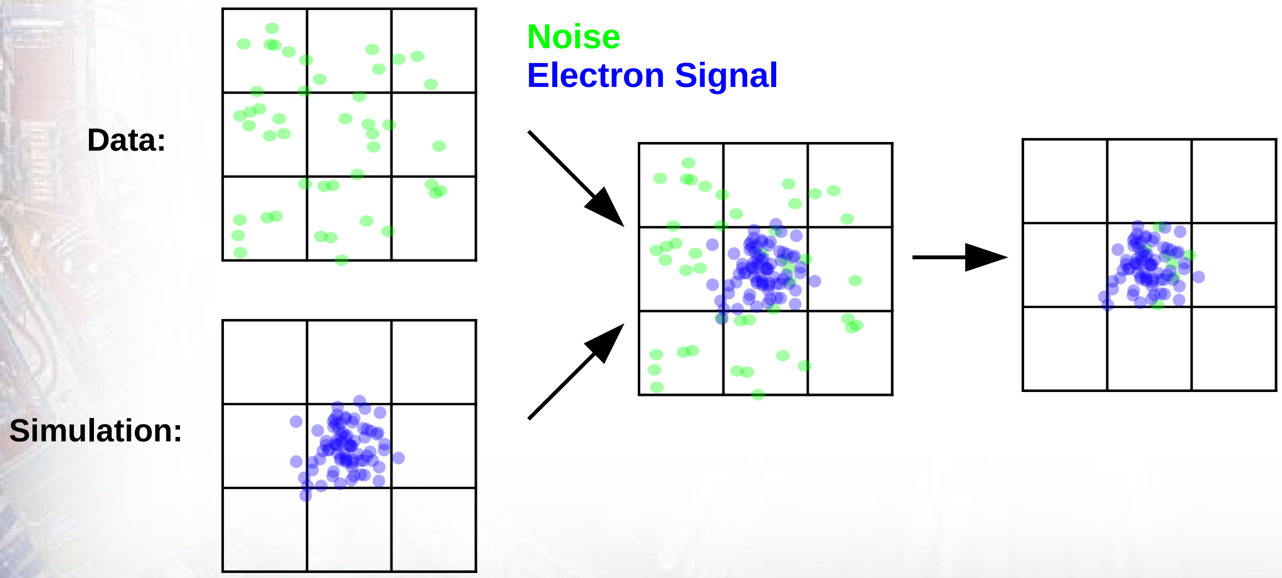
Electron ID Efficiency

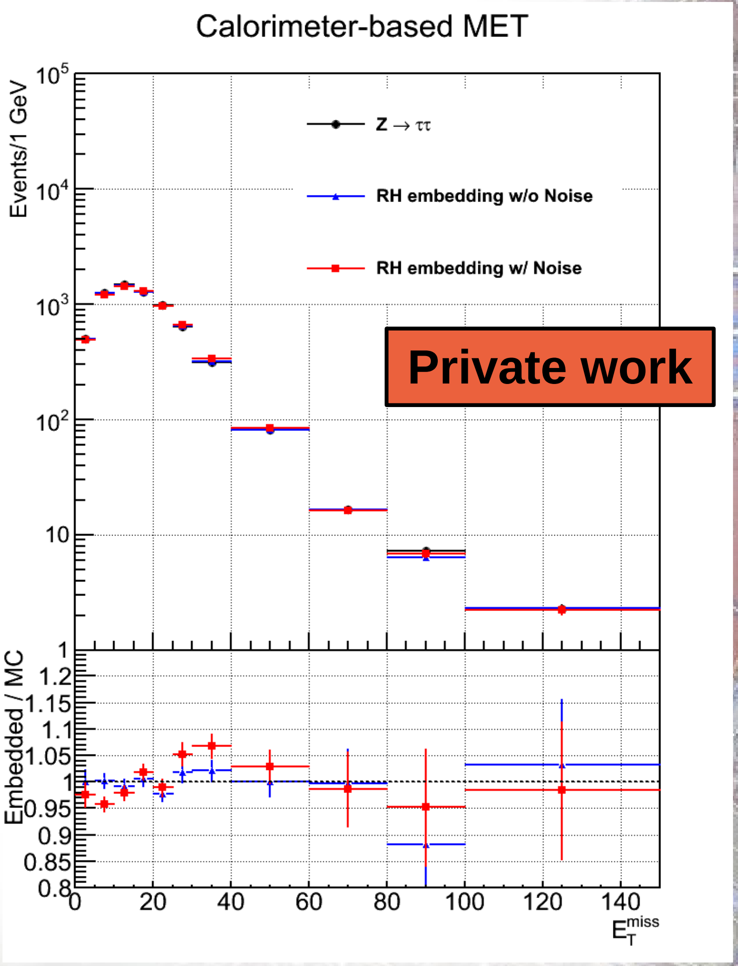
- Calorimeter noise simulation is disabled for embedded event
- Electron ID Efficiency is a noise and threshold effect
  - ECAL Threshold is higher in endcap than in barrel



Electron ID Efficiency (2)

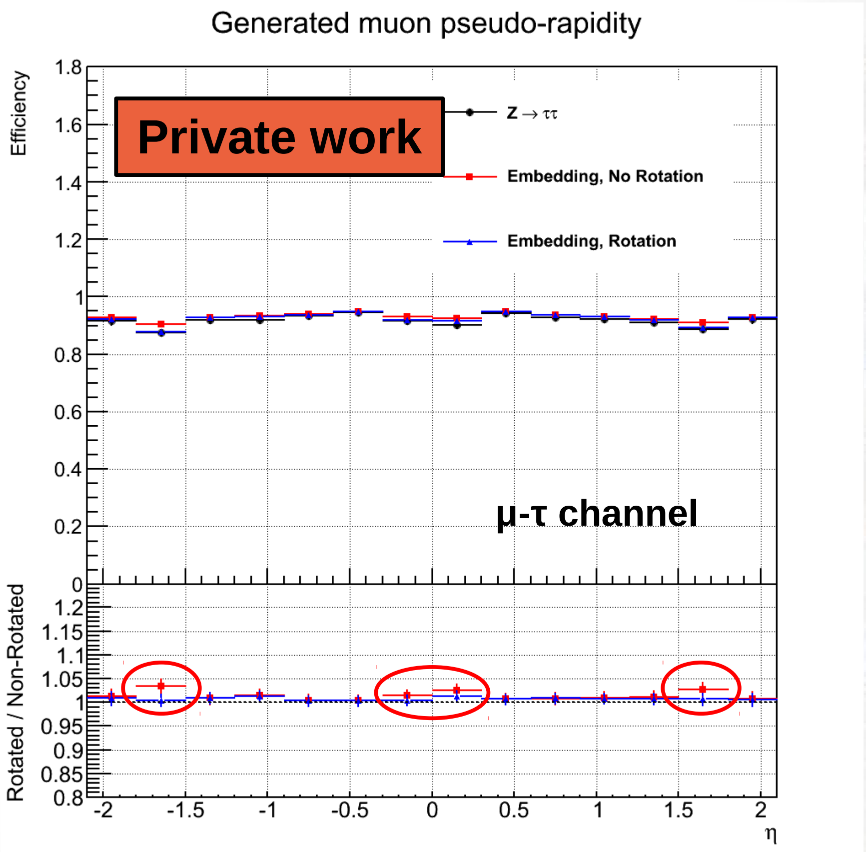
- Enabling the noise cuts would lead to mis-modelling E_T^{miss}
- Ideal would be to apply noise cuts only after mixing
  - Requires special Di-Muon trigger with no noise suppression





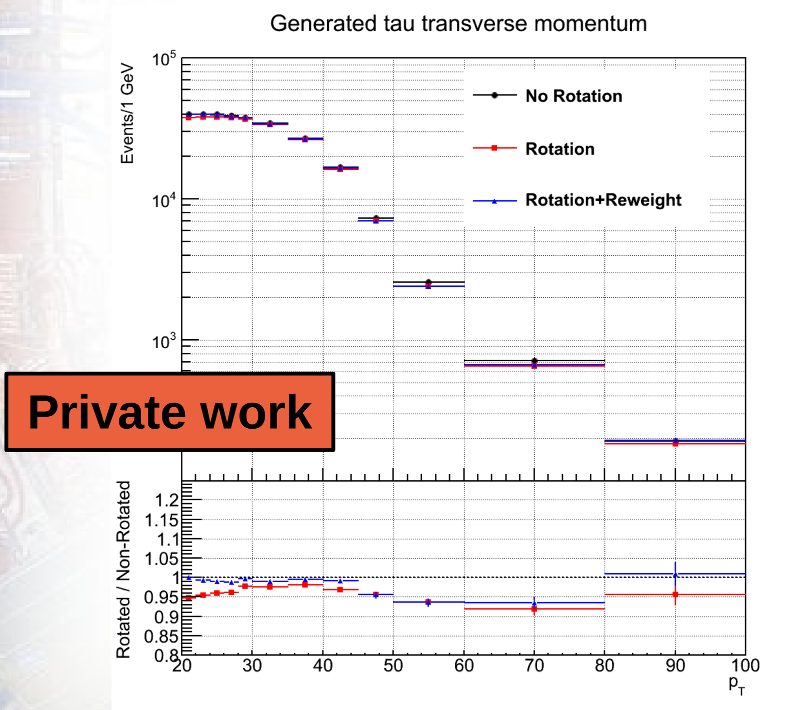
Muon ID Efficiency

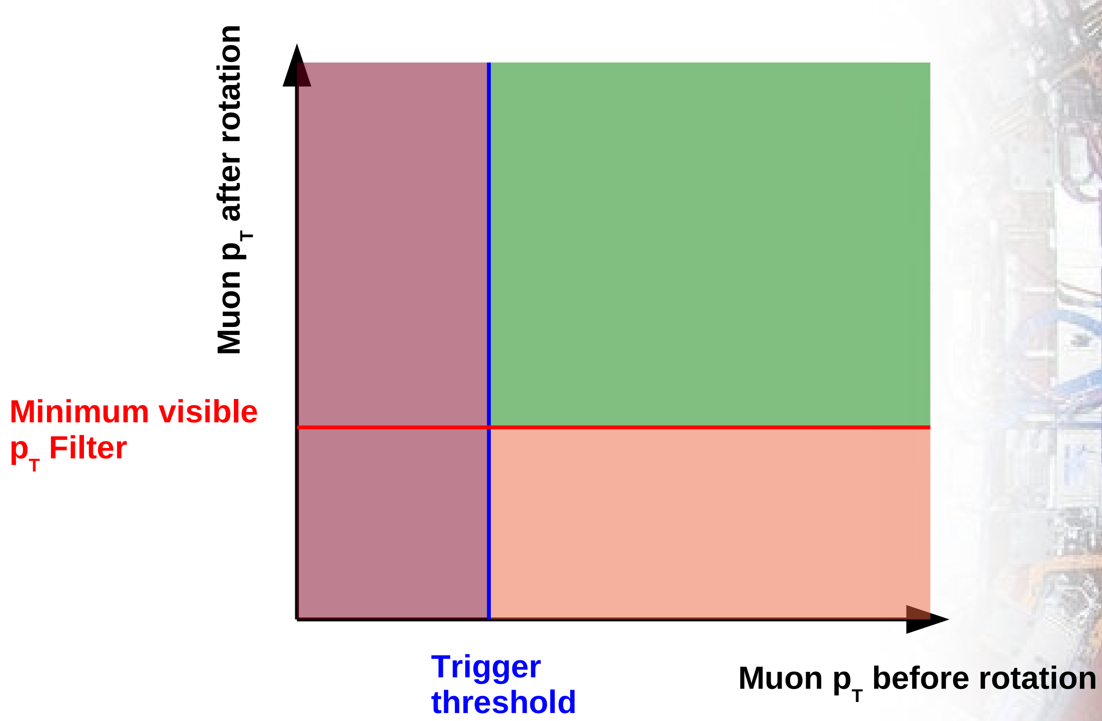
- Rotate Z decay products around Z axis in Z rest frame
  - Not sensitive to spin information
  - Decay products end up in different detector region than muons
    - reduces bias from muon selection



Muon ID Efficiency (2)

- Rotation decreases Z → μμ acceptance:
  - Effect is small
  - Corrected with event weights

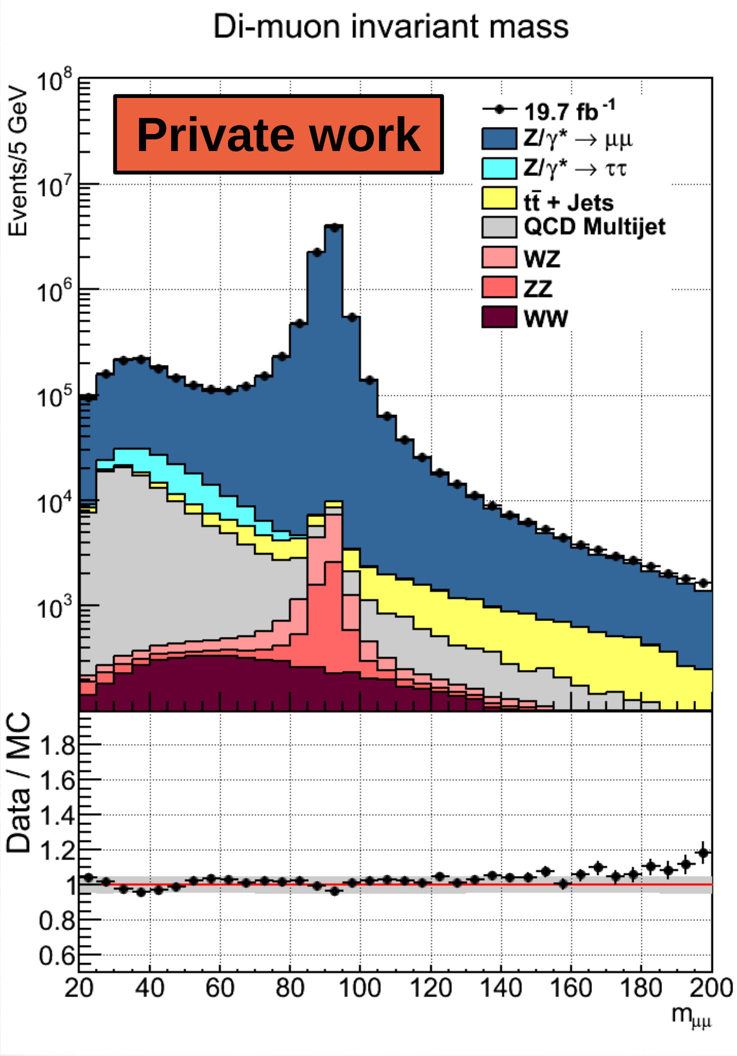




TauSpinner

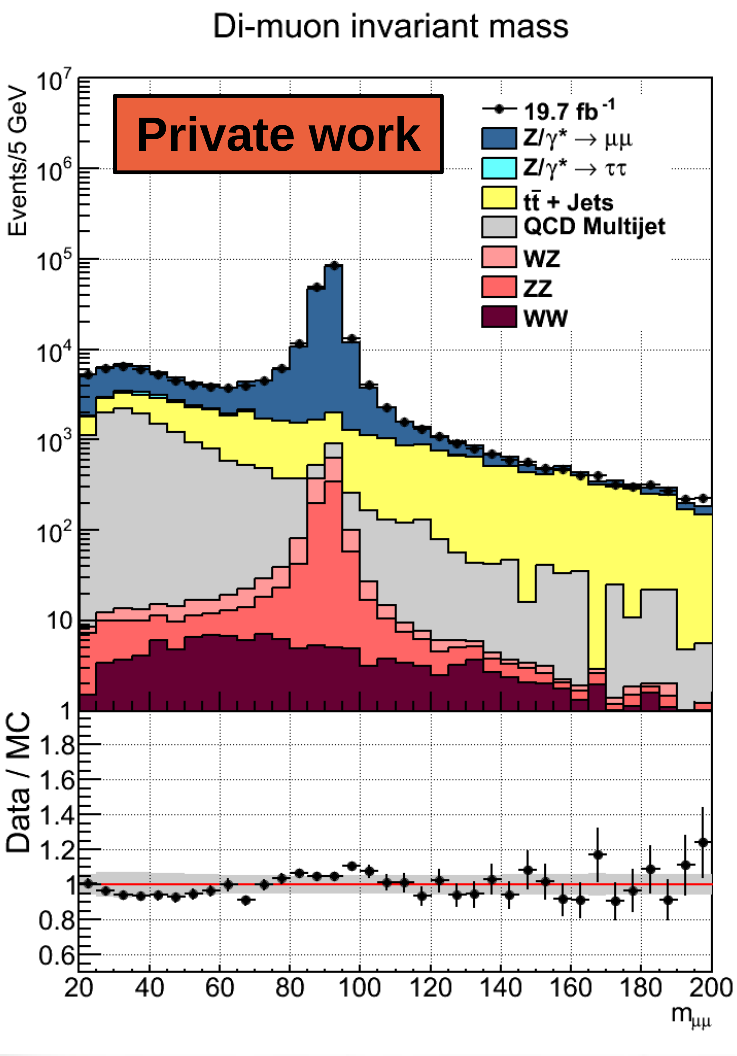
- Until recently, spin effects were simulated with TAUOLA
- Cannot be correct, because tau polarization depends on flavor of incoming parton and virtuality of the intermediate boson
  - Not available in embedded samples
- Solution: TauSpinner [arXiv:1201.0117]
  - Samples the proton PDF stochastically
  - Produces an event weight for each event, which can be applied to take spin effects into account

$t\bar{t}$ Contamination



- The Z → μμ selection procedure has some $t\bar{t}$ in it
- Small in general, but can be enhanced in events with
  - High jet multiplicity (VBF)
  - Events with b-tagged jets (MSSM bbH search)

$t\bar{t}$ Contamination in b-tagged events



- Look at Z → μμ events with at least one b-tagged jet
- $t\bar{t}$ → μμ dominates at high mass
- Run embedding on $t\bar{t}$ simulation
- Subtract from data embedding on histogram level

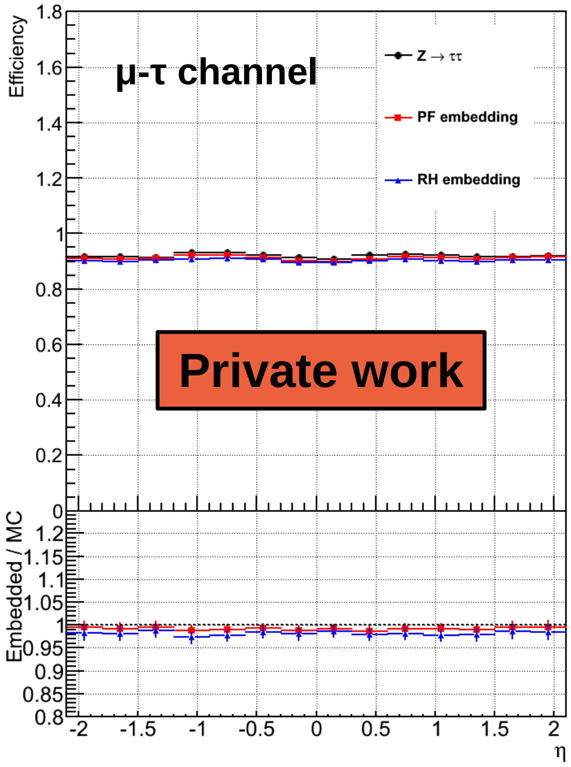
Conclusions

- Embedding Method is a data-driven way to estimate Z → ττ background in H → ττ Search
  - Validation shows good agreement in a large number of quantities
- Rotation around Z boson axis reduces bias from Z → μμ selection
- TauSpinner to model tau polarization effects correctly
- Particle-based embedding currently used in CMS
  - RecHit-based embedding provides more accurate modelling of hybrid event
    - Allows modelling of calorimeter-based quantities
    - Noise suppression a somewhat inherent problem

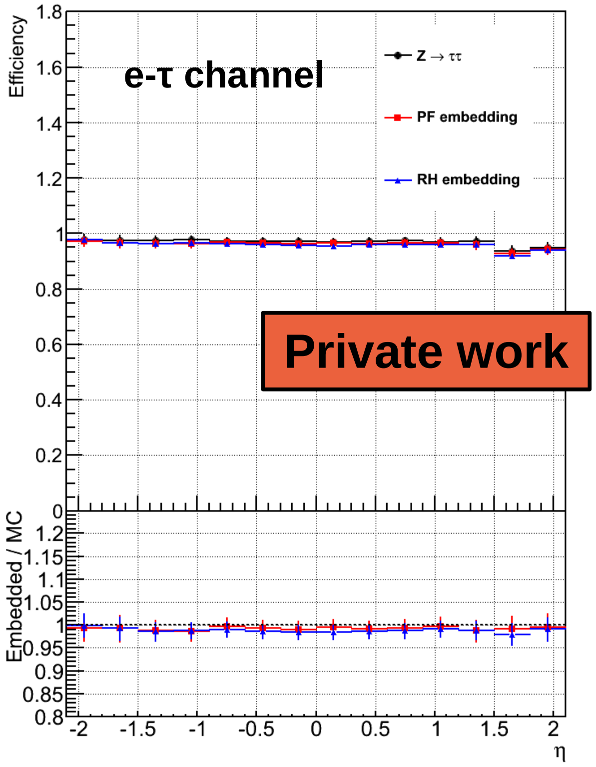
Backup

Lepton Isolation Efficiency

Muon Iso efficiency vs. eta

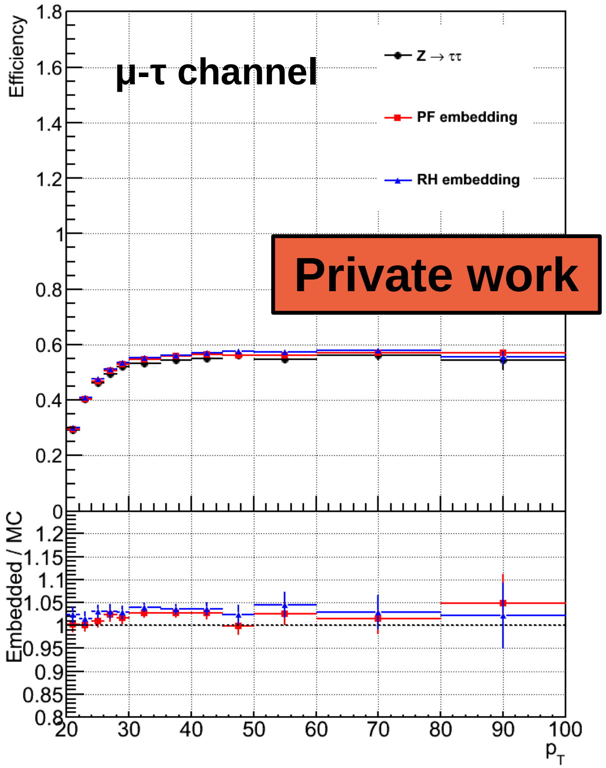


Electron Iso efficiency vs. eta

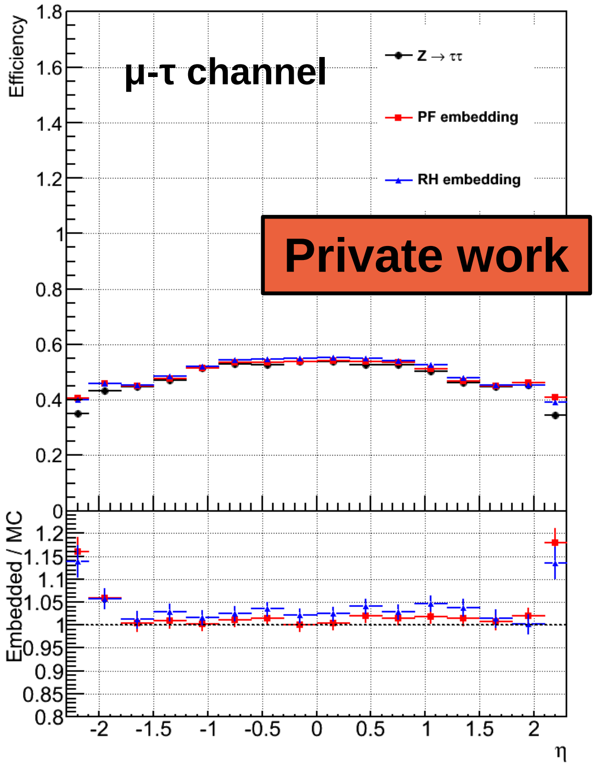


Tau ID Efficiency

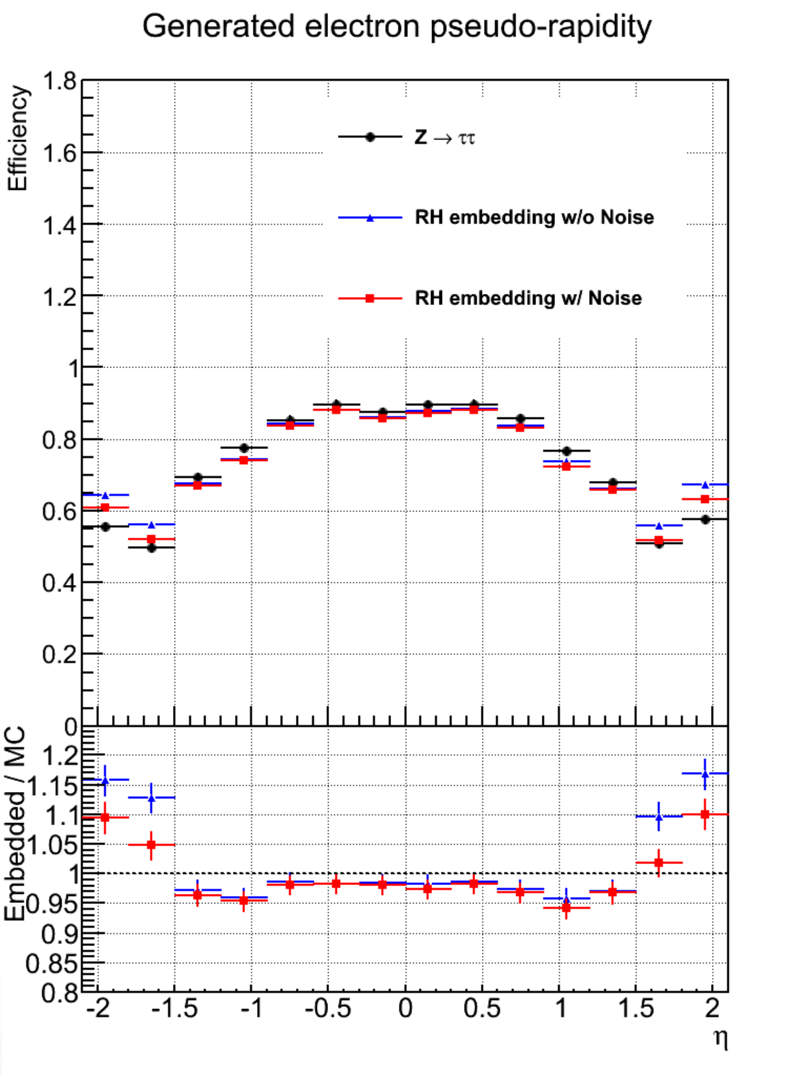
Tau ID efficiency vs. P_T



Taui ID efficiency vs. eta



Electron ID Efficiency with Calorimeter Noise



Improves the agreement in electron ID efficiency
Still a residual effect is left