Karlsruher Institut für Technologie

Institute of Experimental Particle Physics

Tau Embedding at CMS

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KSETA Workshop

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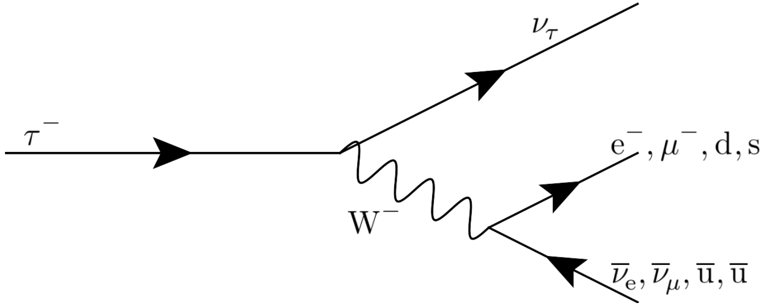
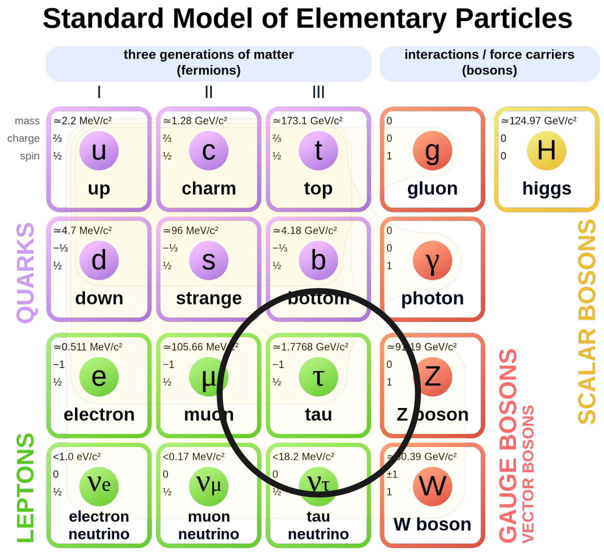
The Tau lepton

The only lepton heavy enough (1.7 GeV) to decay into hadrons

- ➢ 65% - Pions and Kaons (hadronic decay, τ_h)
- ➢ 35% - Electrons or Muons

+ neutrino(s)





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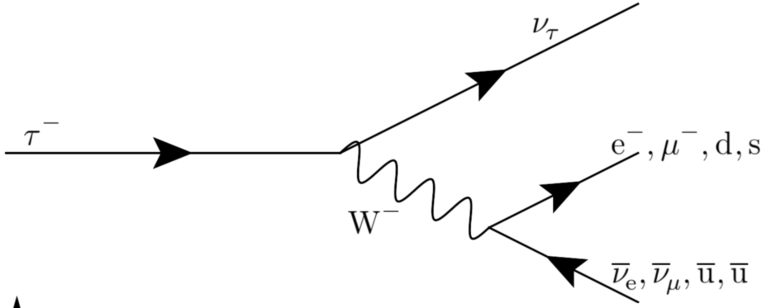
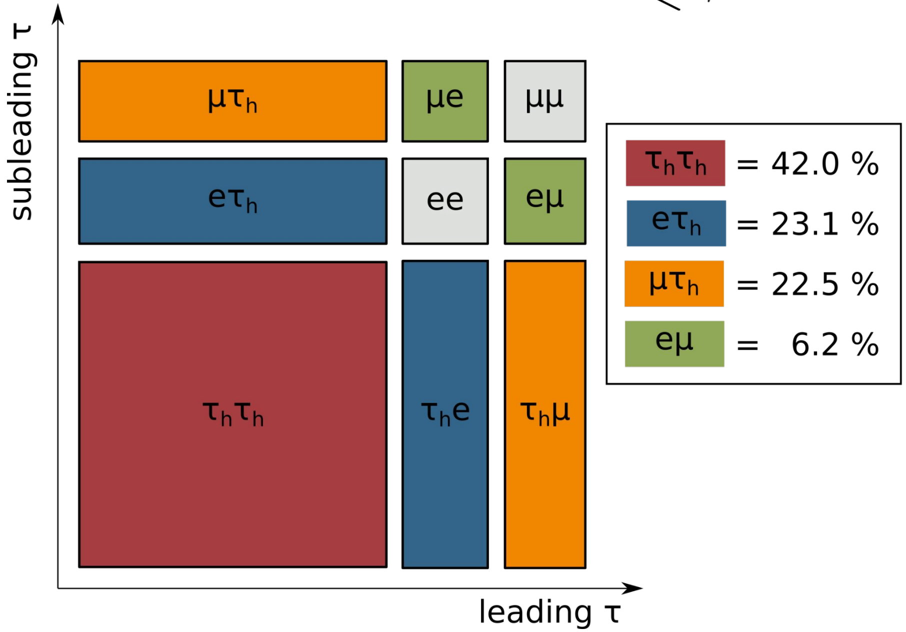
In **di-tau** analyses, this results in **six** final states, of which **four** are used in the analysis



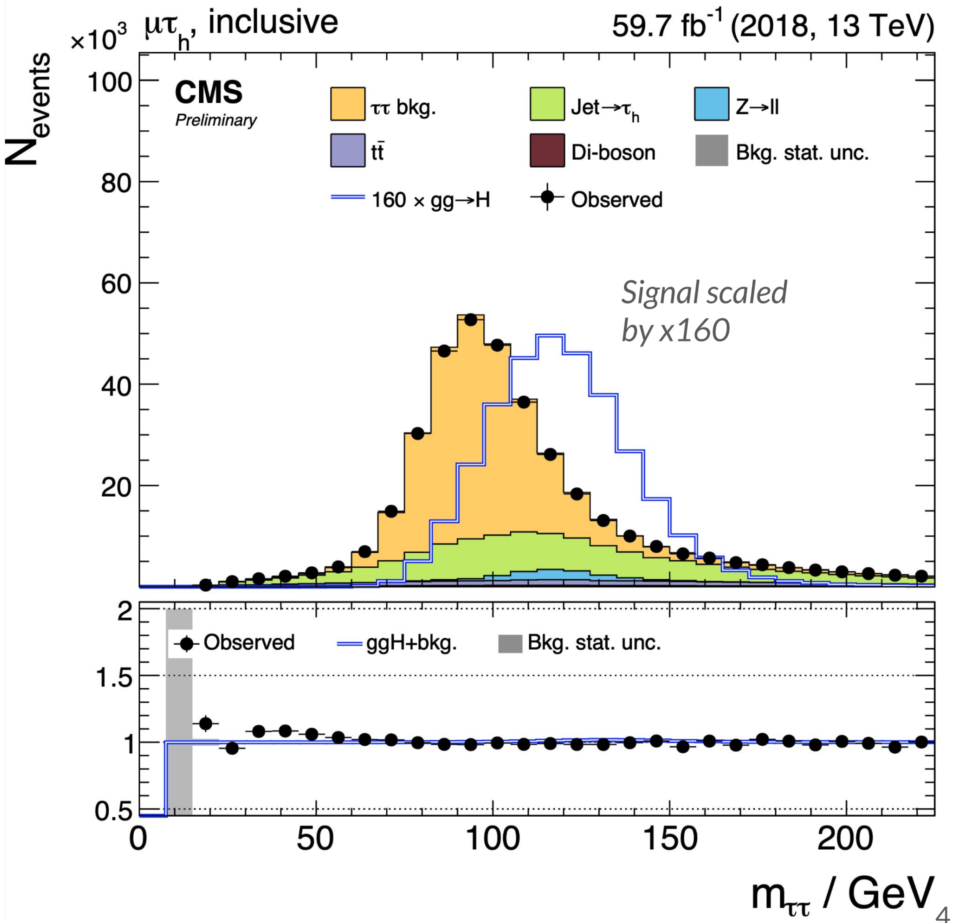


Analysis with ττ final states

Many analyses have final states with two τ leptons

Example: H→ττ

Overlap of Z-boson mass peak and Higgs mass peak due to finite detector resolution

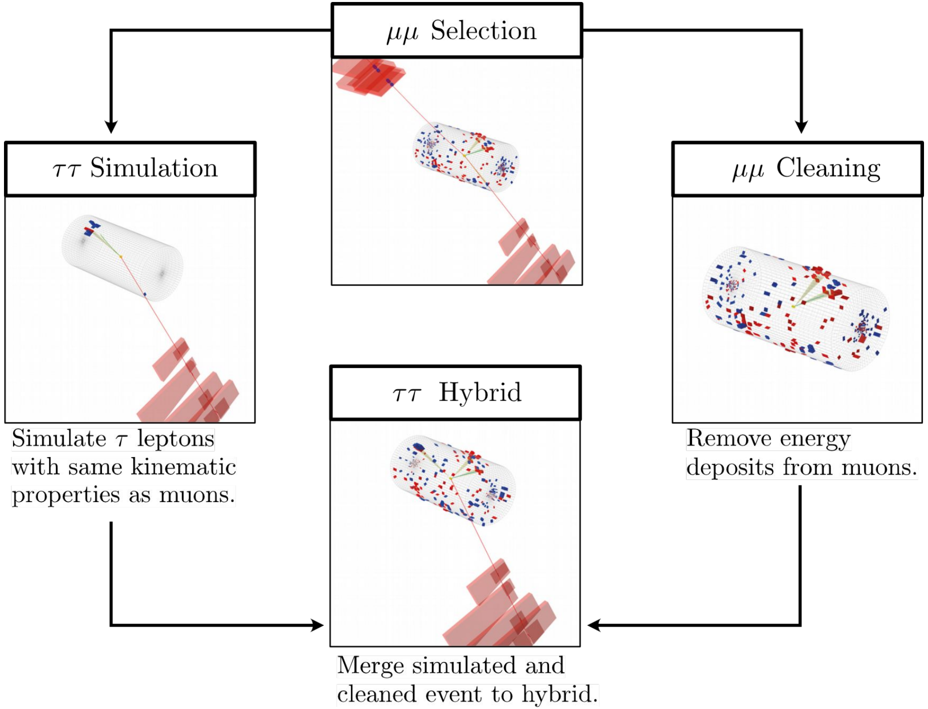


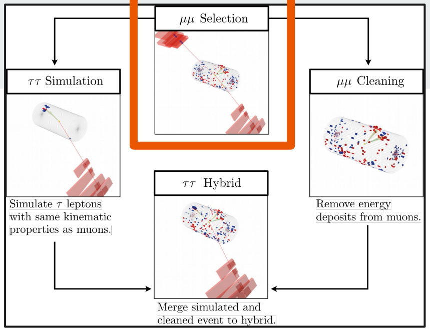
Good description of ττ backgrounds is crucial for measurements of small signals

Tau Embedding

Estimate from data of genuine ττ events. This is done by replacing two muons in a data event with simulated τ lepton decays on and **event by event basis**

Requires a detector which can select muon decays with a high purity and efficiency



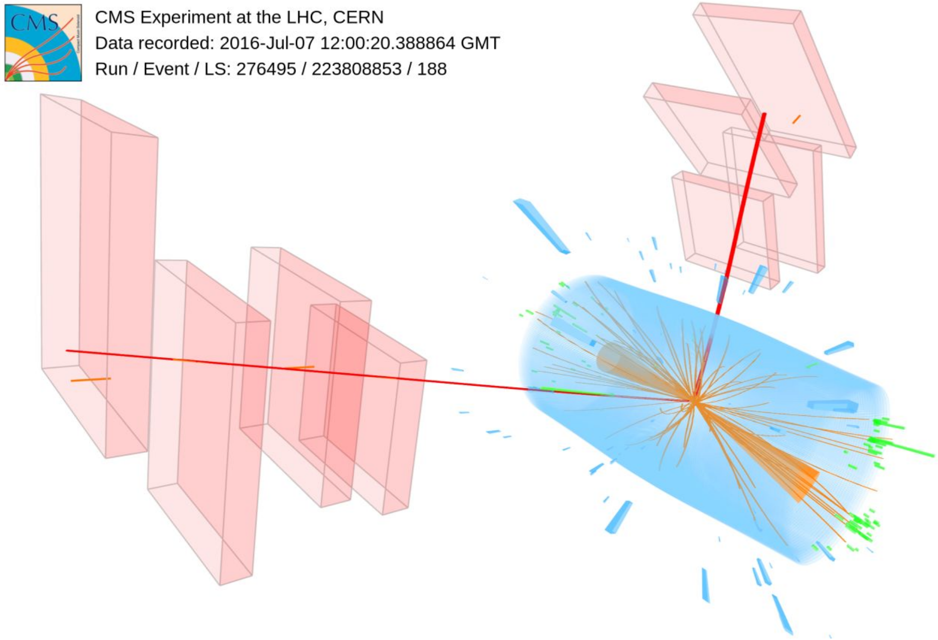


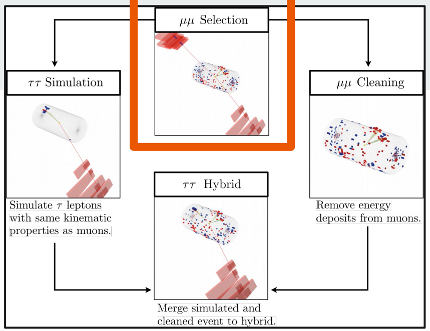
1. Selection

Select **events with at least two muons**

- $p_{T,1} > 17$ GeV
- $p_{T,2} > 8$ GeV
- Opposite charged muons
- Tracks in the muon system
- $m_{\mu\mu} > 20$ GeV

Two muons with the largest $m_{\mu\mu}$ are selected





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Select **events with at least two muons**

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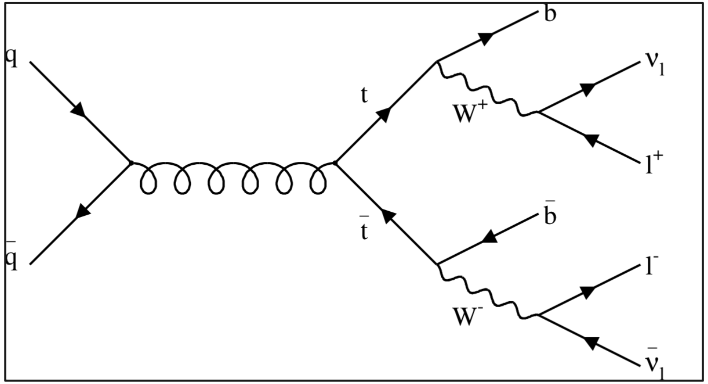
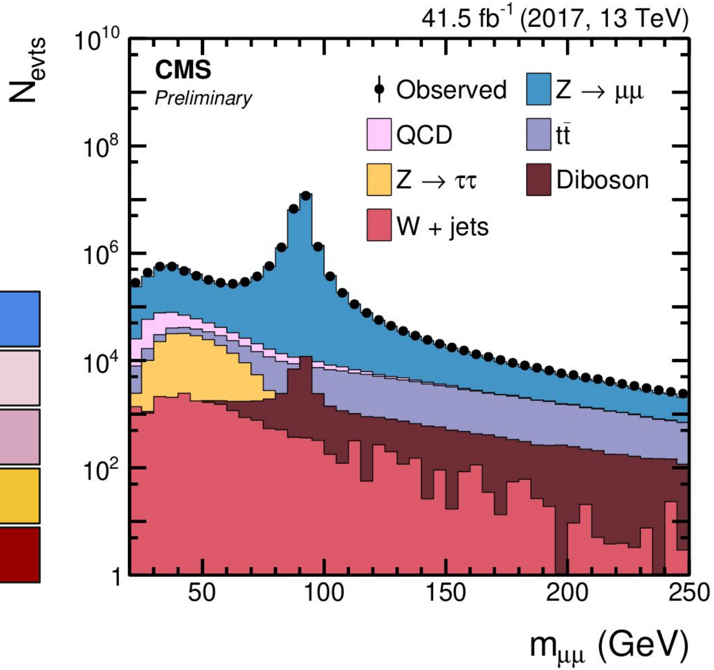
$p_{T,2}$ > 8 GeV
Opposite Charge Muons
Tracks in the muon system
$m_{\mu\mu}$ > 20 GeV

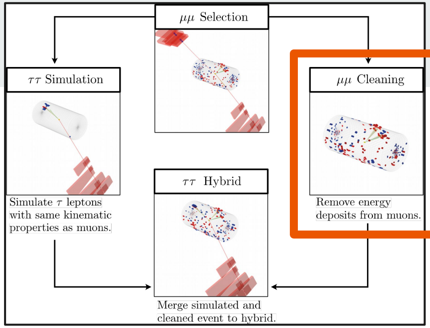


Event Composition

$Z \rightarrow \mu\mu$	97.36 %
QCD	0.84 %
ttbar	0.78 %
$Z \rightarrow \tau\tau$	0.74 %
Diboson	0.20 %



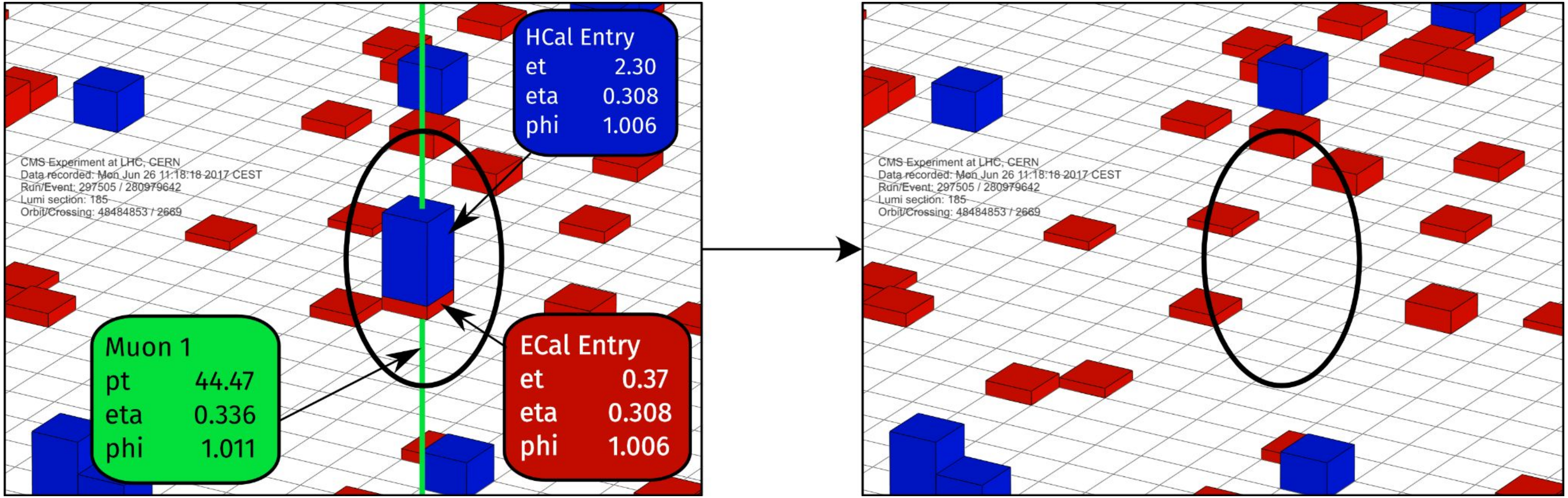
2. Cleaning



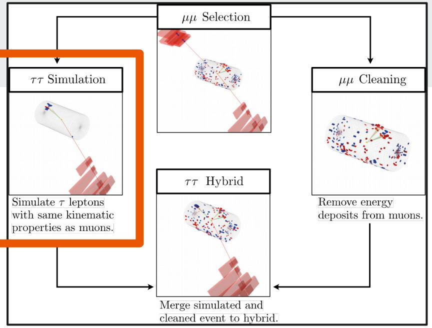
Remove energy deposits of the two selected muons from the event

Before cleaning

After cleaning

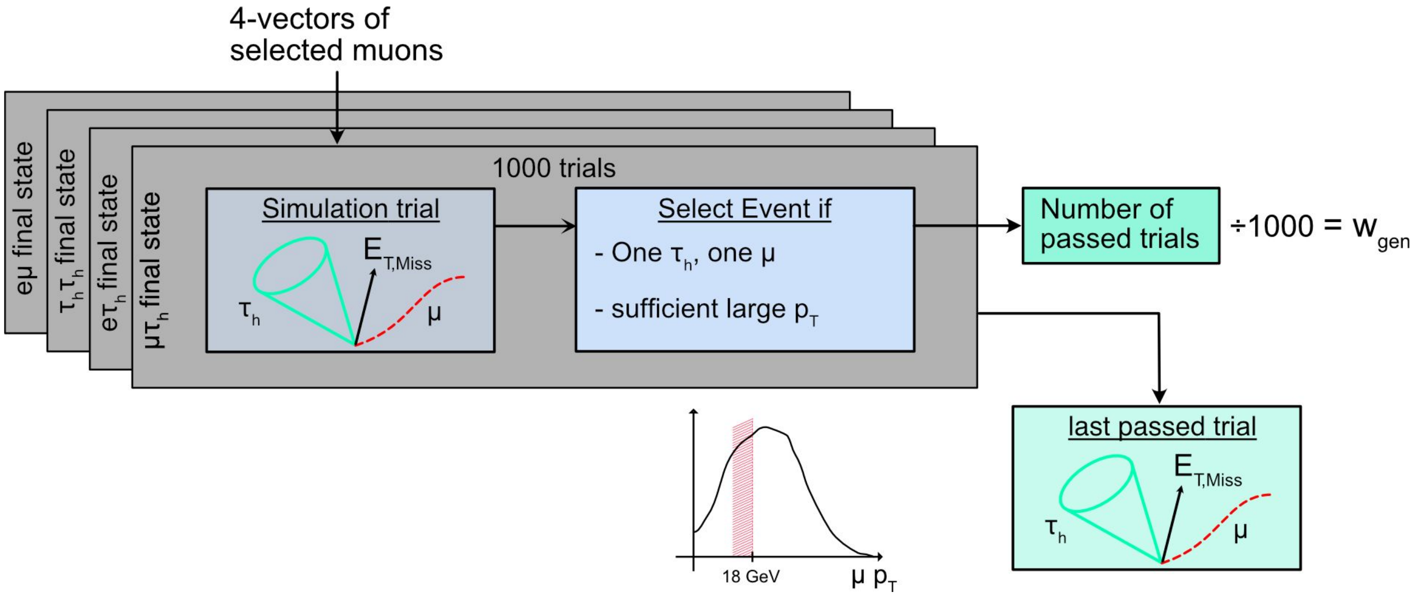


3. Simulation



Simulate decay of two τ leptons using the kinematic properties of the muons and apply **selection requirements on the visible τ lepton decay products** to enrich the sample

→ Dedicated sample for each of the four final states



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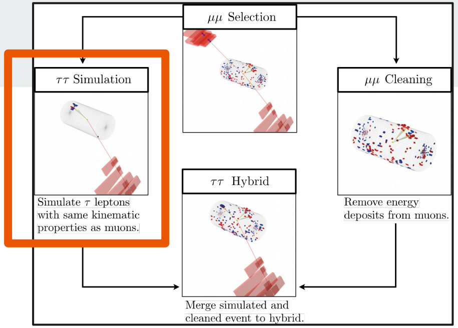
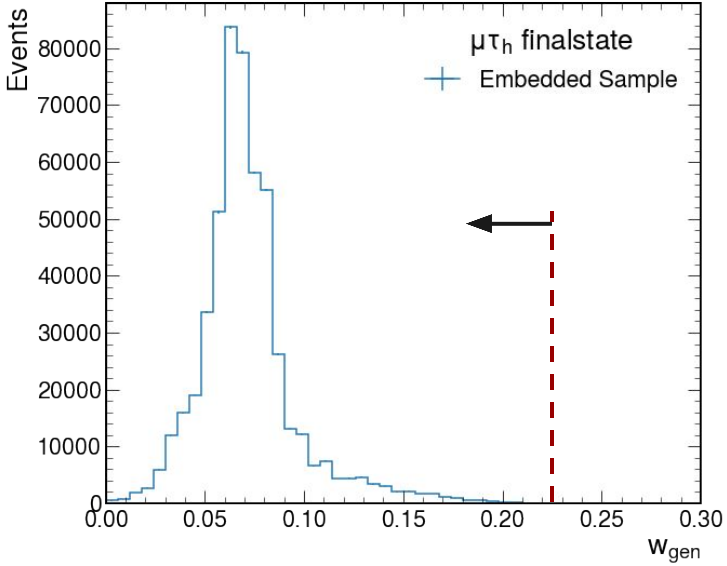
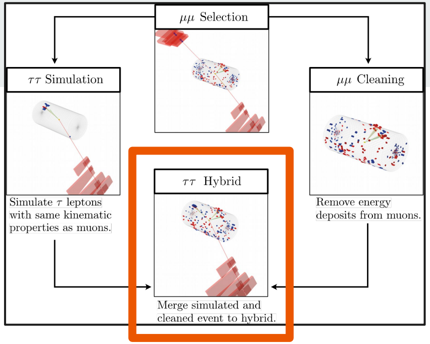


Simulate decay of two τ leptons using the kinematic properties of the muons and apply **selection requirements on the visible τ lepton decay products** to enrich the sample
→ **Filters** ensure, that only decays that have a chance to end up in analyses fully propagated through all steps of the technique

Final State	1st Decay Product	2nd Decay Product
$\tau_h\tau_h$	$p_T^\tau > 33$ GeV $\eta^\tau < 2.2$	$p_T^\tau > 33$ GeV $\eta^\tau < 2.2$
→ $\mu\tau_h$	$p_T^\mu > 18$ GeV $\eta^\mu < 2.2$	$p_T^\tau > 18$ GeV $\eta^\tau < 2.4$
$e\tau_h$	$p_T^e > 22$ GeV $\eta^e < 2.2$	$p_T^\tau > 18$ GeV $\eta^\tau < 2.4$
$e\mu$	$p_T^e > 10$ GeV $p_T^e > 21$ GeV	$p_T^\mu > 21$ GeV $p_T^\mu > 10$ GeV





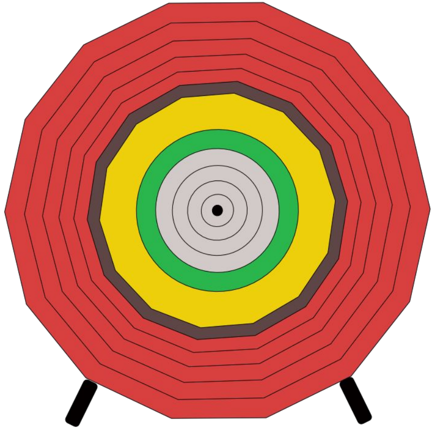
4. Merging

Combine the **cleaned event with the simulated τ decays** to form a hybrid event

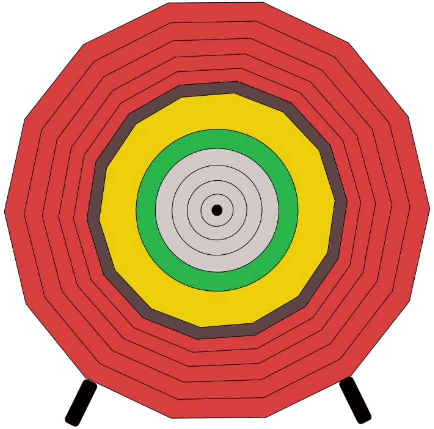
Combine on the level of simulated & measured detector signals

Ideal

Detector Geometry of τ decay simulation



Detector Geometry of data taking



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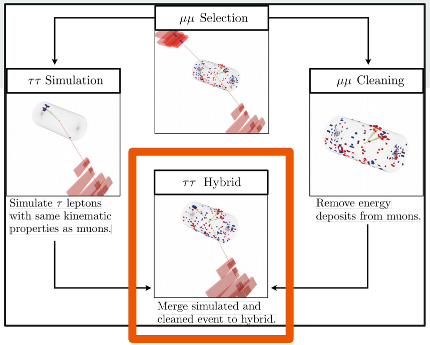
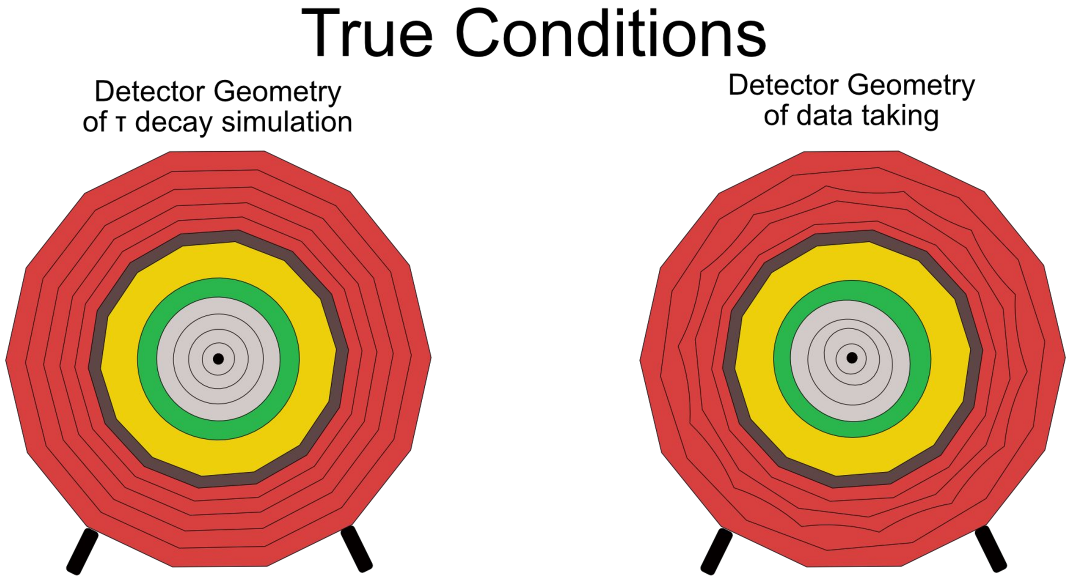


For the simulation, an ideal model of the detector is used



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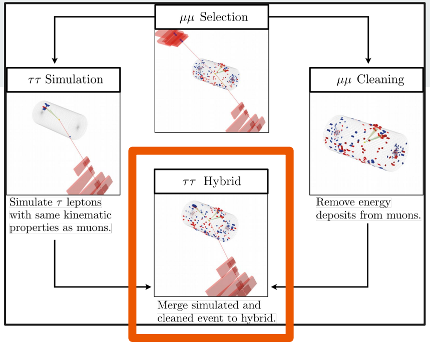

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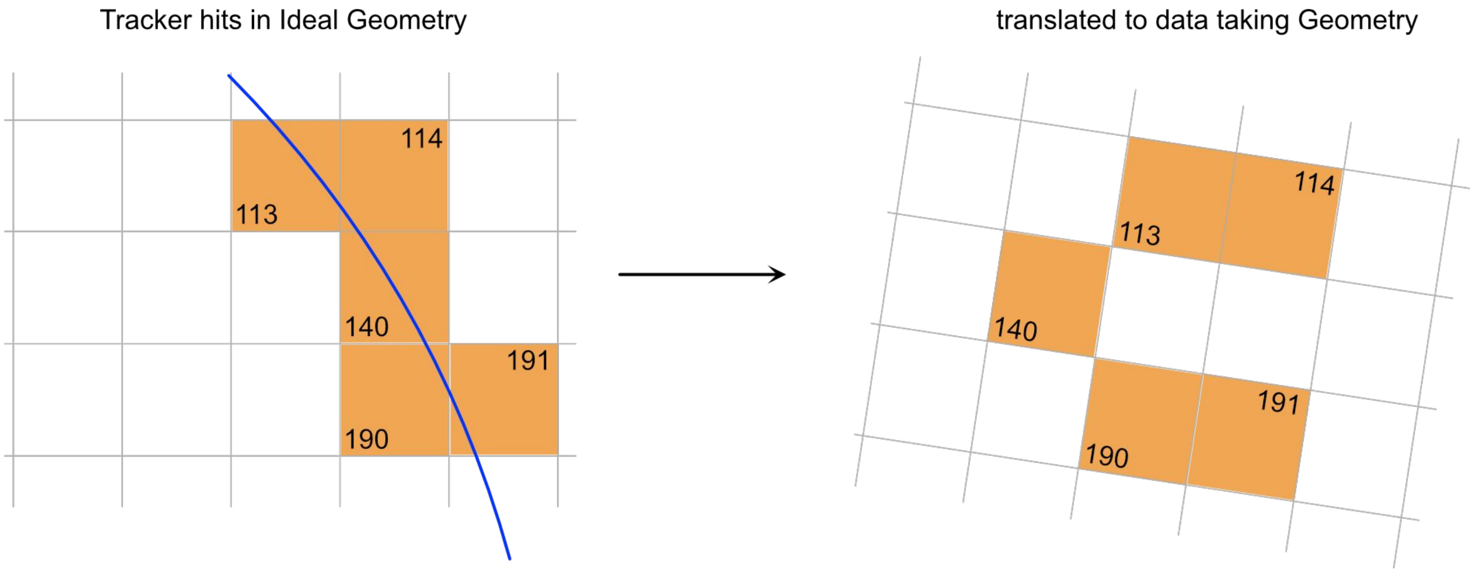

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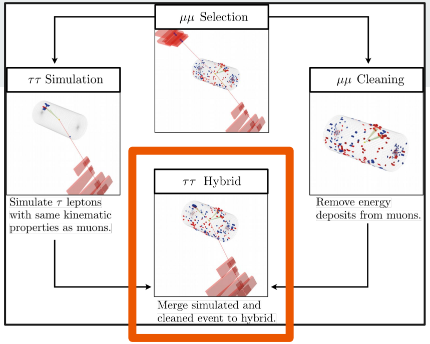
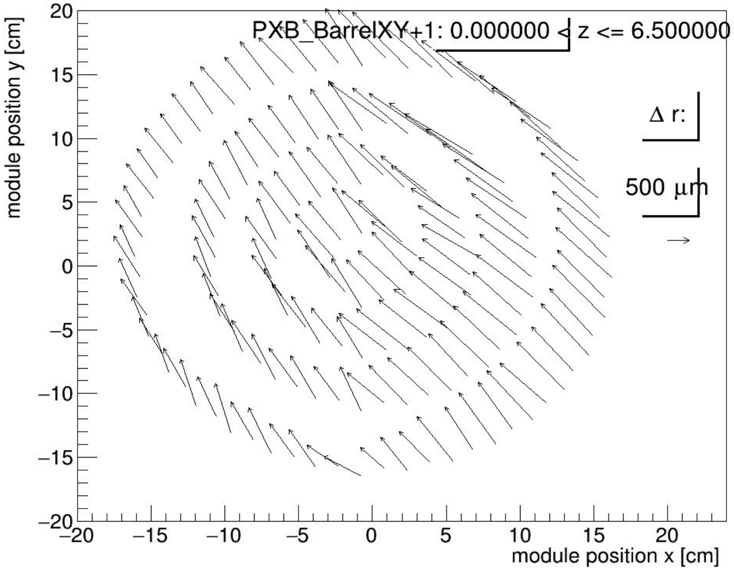


Most crucial in the silicon tracker

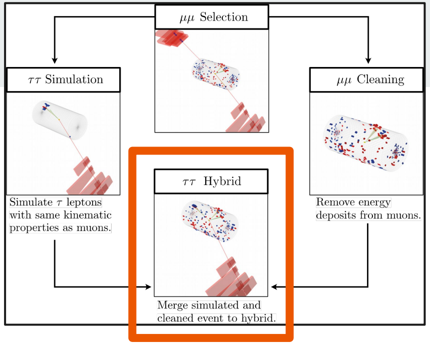
local positions of tracker modules are shifted **in O(cm)**

Full reconstruction after combination of detector signals not possible



Comparison of geometry used for simulation and for data taking

4. Merging



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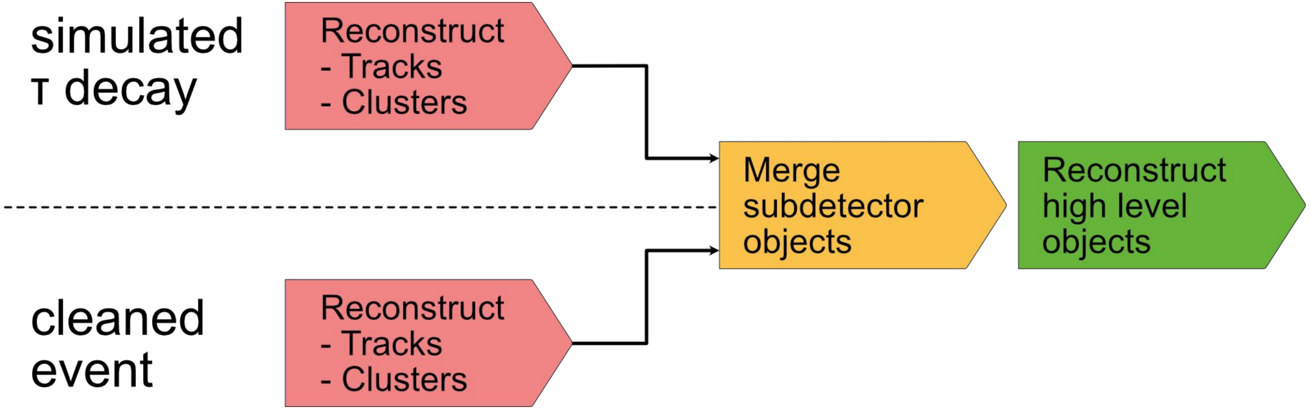
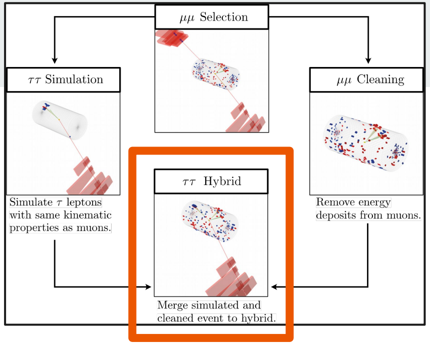
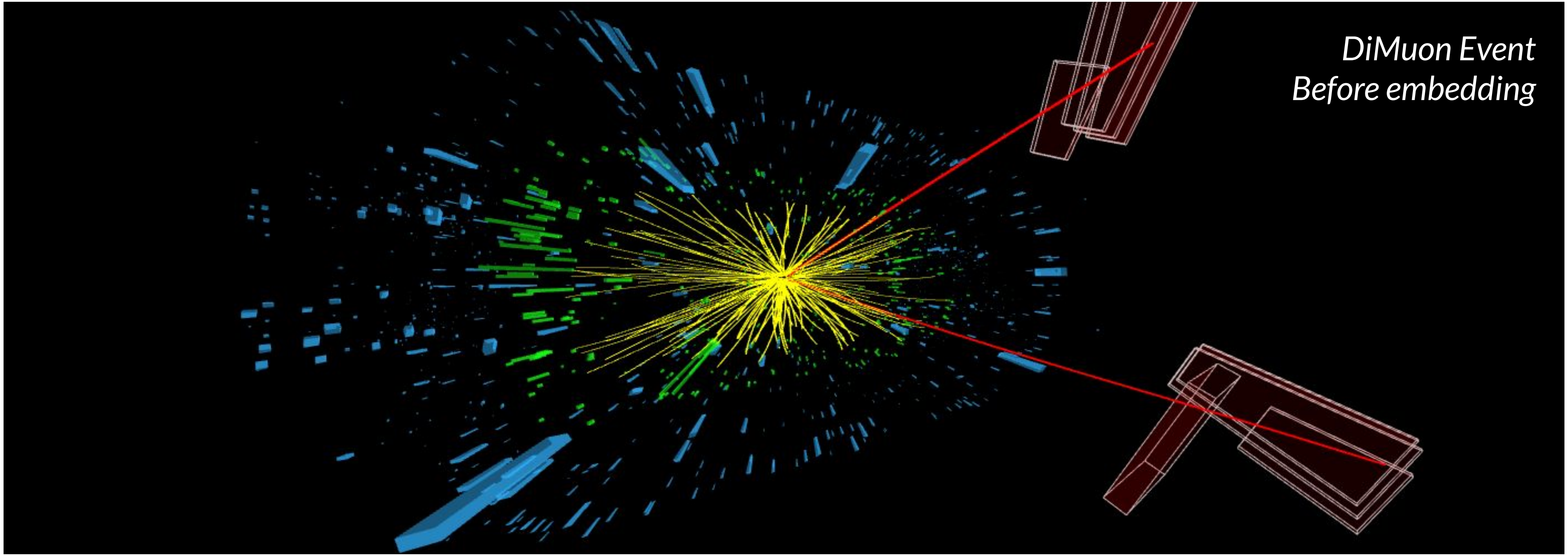


Solution: Merge on the level of reconstructed subdetector objects

4. Merging



Combine the **cleaned event with the simulated τ decays** to form a hybrid event, where only the decay of the **two τ leptons is simulated**



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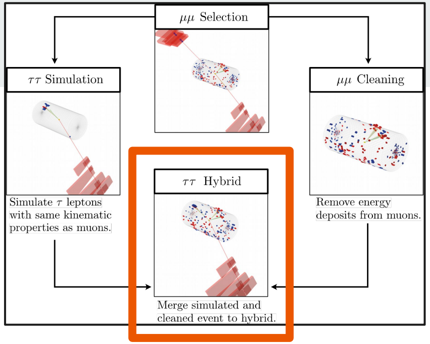

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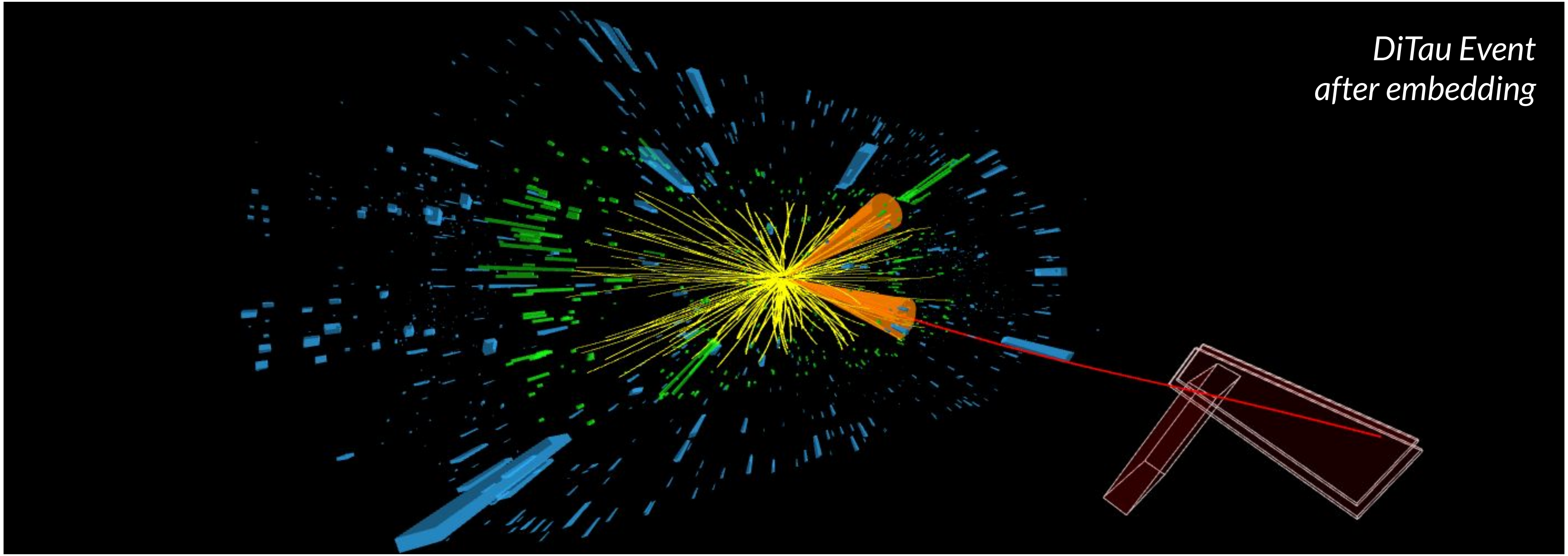
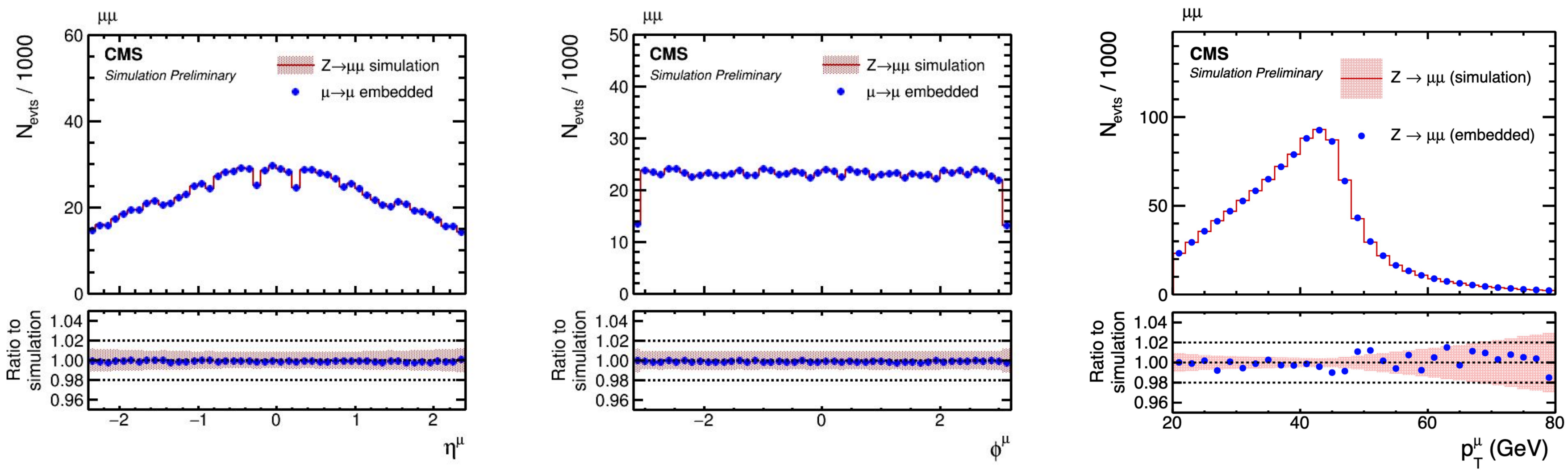


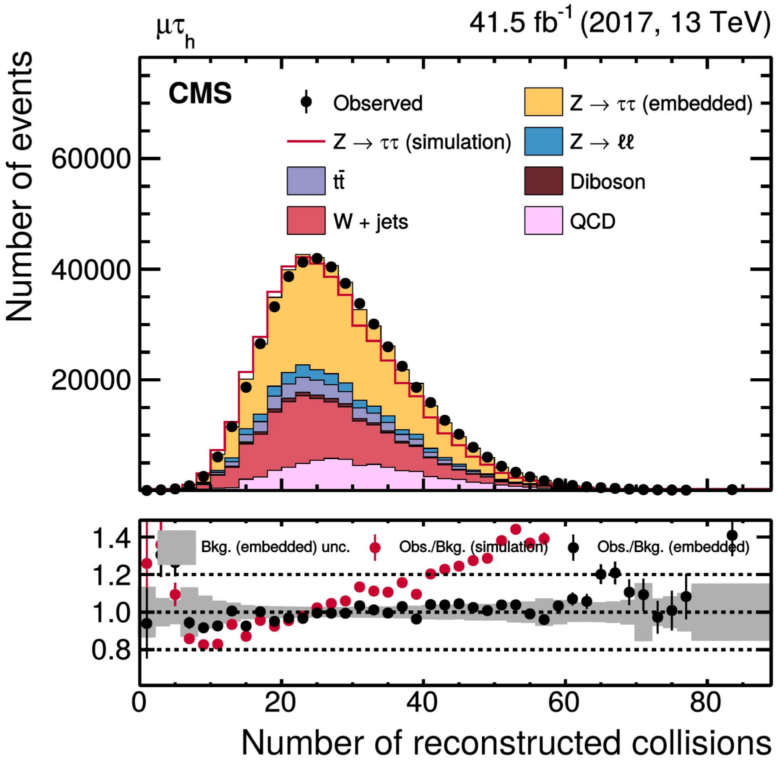
Validation of the technique

μ → μ embedding on simulated Z → μμ events



Benefits compared to full event simulation

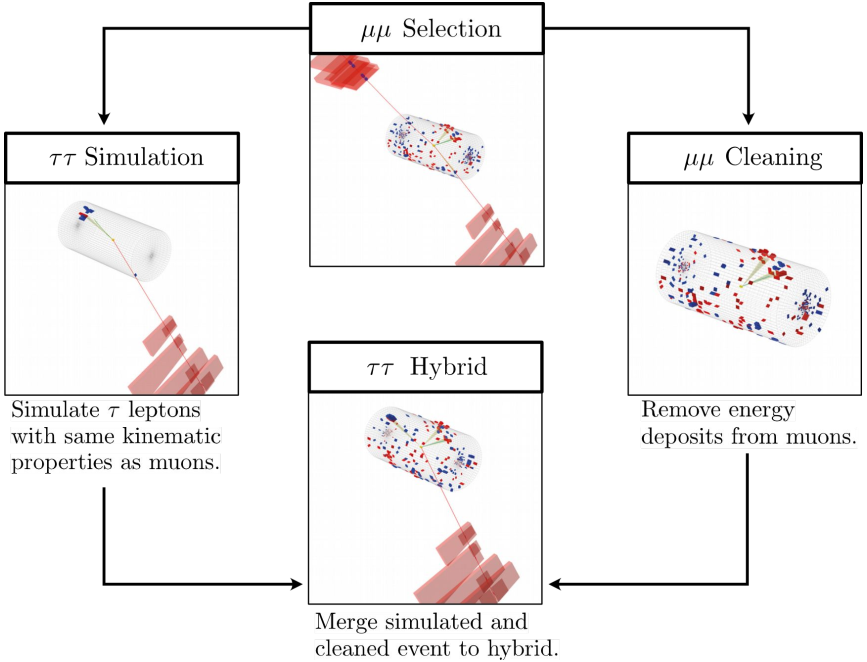
- ➢ Better description of pileup, jet related quantities
- ➢ Fewer corrections required
- ➢ Lower computational effort since only τ lepton decays have to be simulated
- ➢ Easily applicable also for more challenging conditions, e.g. as anticipated for HL-LHC



With HL-HLC and the anticipated high event pileup (140-200), background estimations like this one will become even more important

Conclusion

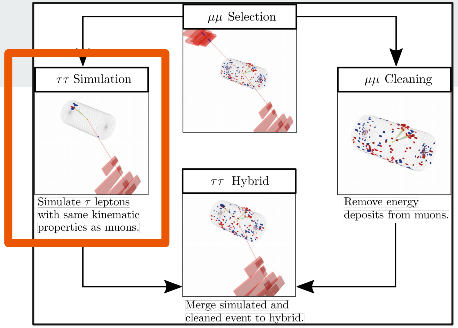
- The **τ-Embedding Method** is the default method of estimating genuine ττ backgrounds
- used in multiple publications of CMS over the last years
- Developed and maintained solely by ETP
- Reduced set of corrections (+ associated uncertainties) compared to full process simulation
- Embedding principle can be expanded to embed other simulated decays

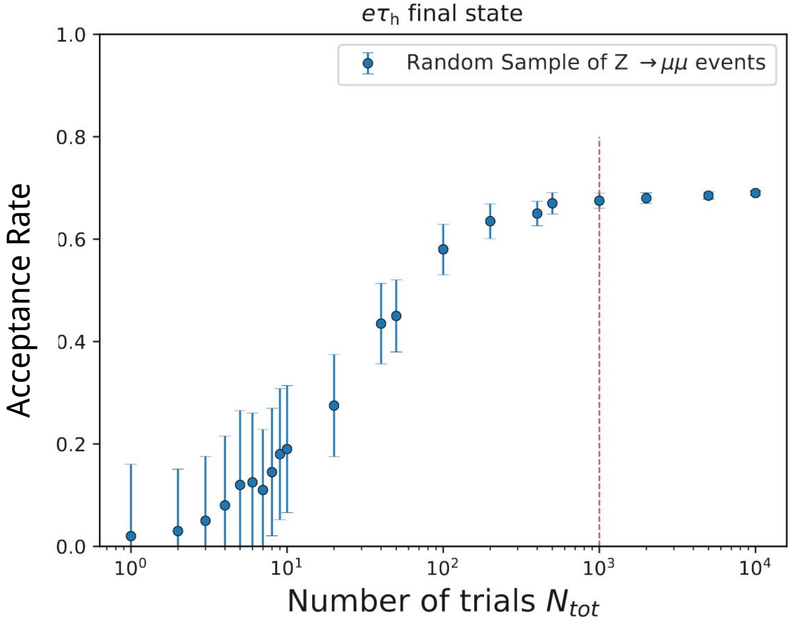


Backup

3. Simulation

Simulate decay of two τ leptons using the kinematic properties of the muons and apply **selection requirements on the visible τ lepton decay products** to enrich the sample
→ After **1000 trials,** the acceptance rate of the filter **does not increase** anymore





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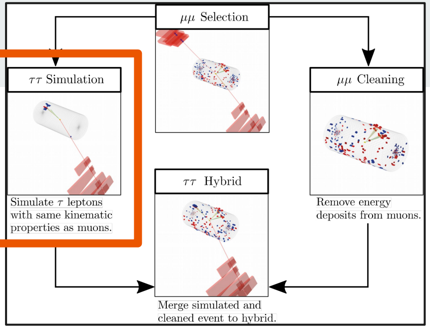
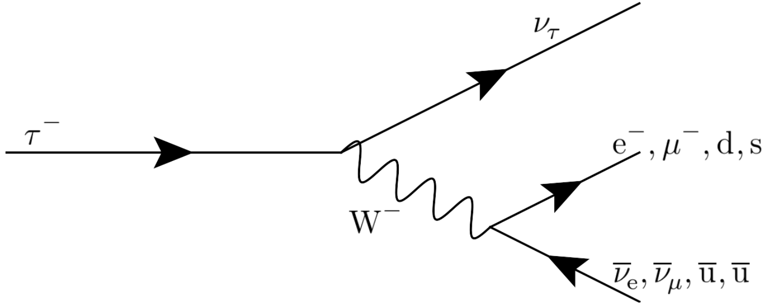
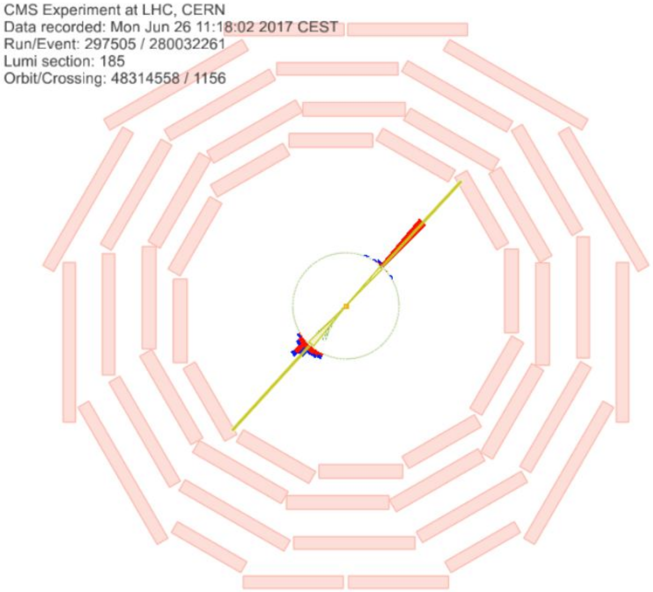


Simulate decay of two τ leptons using the kinematics of the muons and apply **cuts on the visible τ lepton decay products** to enrich the sample





Validation of the technique

Validate technique by

→ τ embedding on simulated Z → μμ events and compare with simulated Z → ττ events