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Study of Z boson events in the decay to a tau lepton pair in the semileptonic channels with the CMS experiment at 13 TeV

DPG Spring Meeting
Hamburg, 29.02.2016

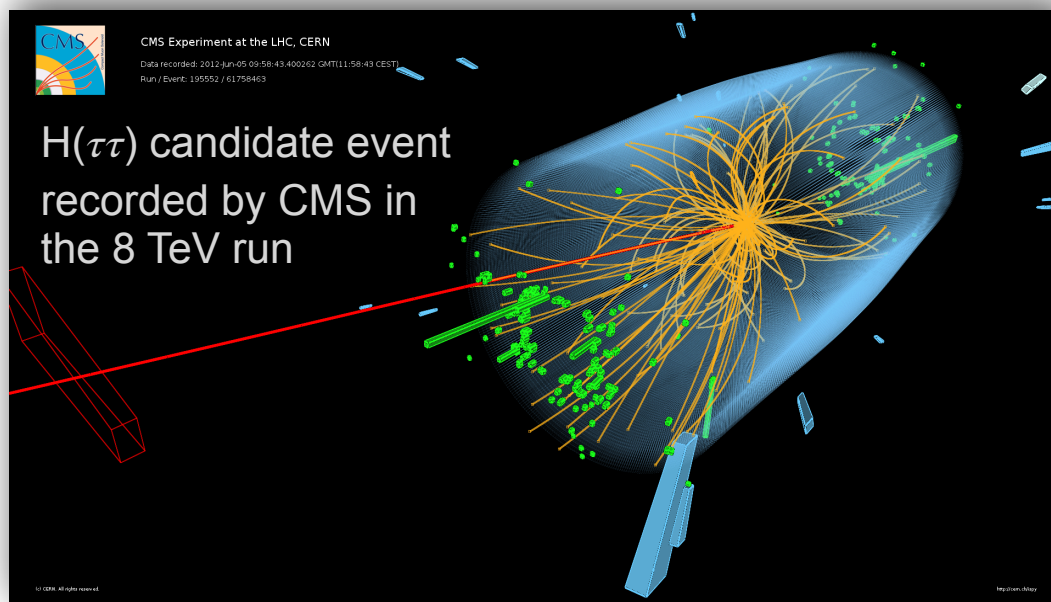
> Introduction

- > Results of $H(\tau\tau)$ in Run1
- > Moving to Run 2 with the $Z(\tau\tau)$ standard candle

> Description of the analysis

- > Topology
- > Tau reconstruction
- > Backgrounds
- > Event Selection
- > Corrections to MC

> Results



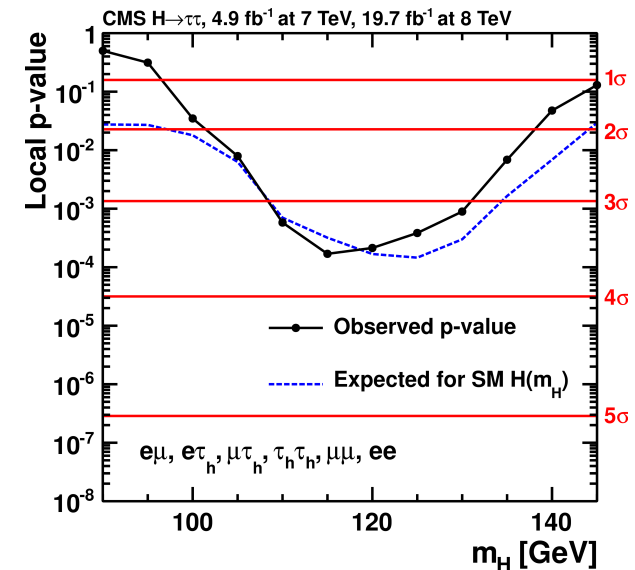
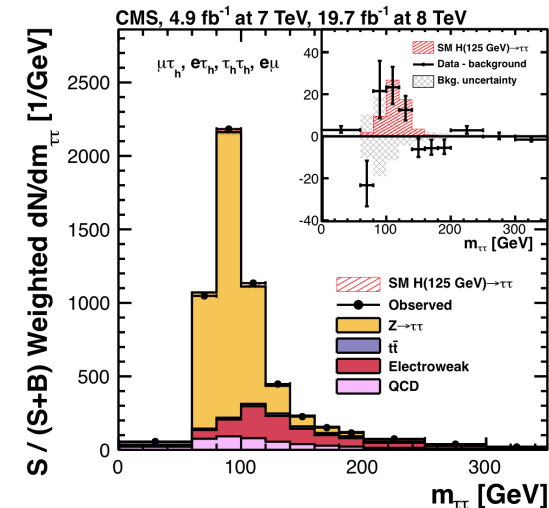
> Motivation for $H(\tau\tau)$ search

Detail study of **Yukawa couplings** - decay in two tau leptons is the most promising to measure the Higgs boson direct coupling to leptons and to fermions

Crucial test of electroweak symmetry breaking mechanism and probe of new physics

> With the LHC data taking in 2011-2012 a **5σ evidence** of $H(\tau\tau)$ decays reached only combining **ATLAS and CMS** data.

> But the second LHC run has just started...



- > Increase of the center-of-mass energy

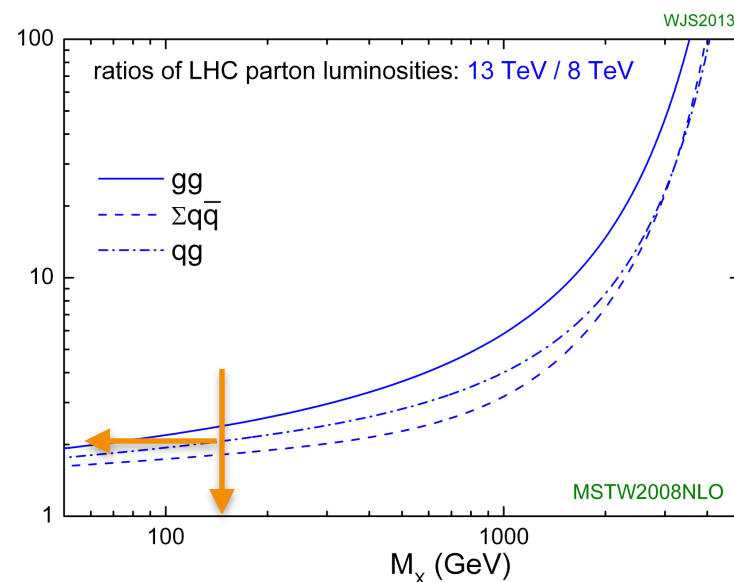
From 8 to 13 TeV, expected increase in the Higgs production cross section of a factor ~ 2

- > First of all, we must make sure that we understand the physics observables, backgrounds, tau reconstruction, ...

- > We can exploit the Z boson decays to a tau pair

Well known electroweak process, with the same final state and the same mass scale of ~ 100 GeV

Moreover, it is the main background for the $H(\tau\tau)$ search



Before searching for $H(\tau\tau)$ we are looking to $Z(\tau\tau)$ decays

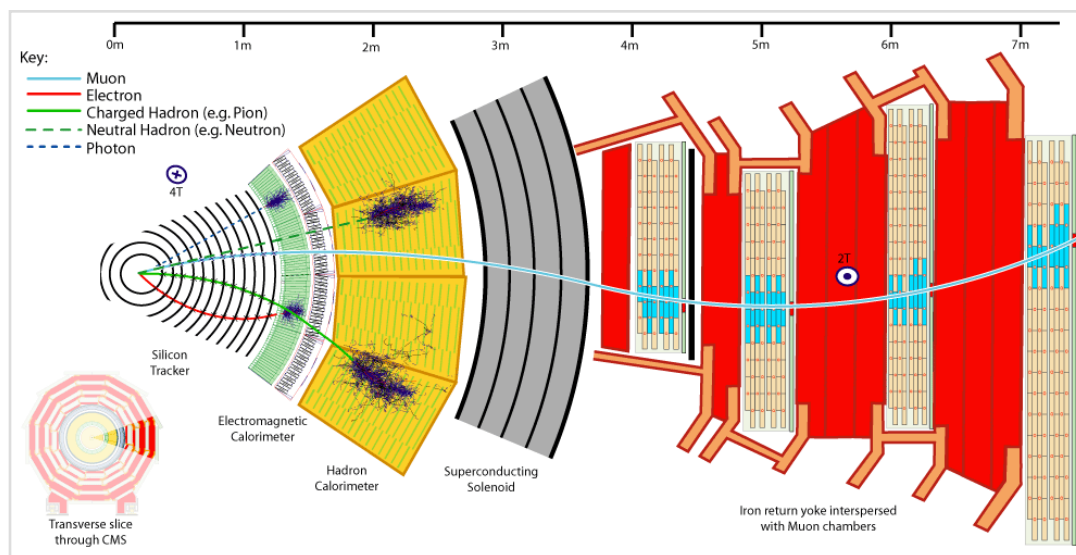
- > The **tau lepton** (1.777 GeV) decays to hadrons or to leptons (e, μ) and neutrinos.

Two taus in the final state, I will focus on semileptonic channels

Decay Mode	Resonance	Mass(MeV/c^2)	Branching Fraction (%)
$\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$	Leptonic decays BR ~ 1/3		17.8
$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$			17.4
$\tau^- \rightarrow h^- \nu_\tau$	Hadronic decays BR ~ 2/3		11.6
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$			25.9
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$			9.5
$\tau^- \rightarrow h^- h^- h^+ \nu_\tau$			9.8
$\tau^- \rightarrow h^- h^- h^+ \pi^0 \nu_\tau$			4.8
Other hadronic decays			3.2

- > **Electrons** and **muons** are well reconstructed with the CMS detector

- > Experimental signature for neutrino is **missing energy** in the transverse plane



The visible decay products of a τ_h are

> Charged hadrons

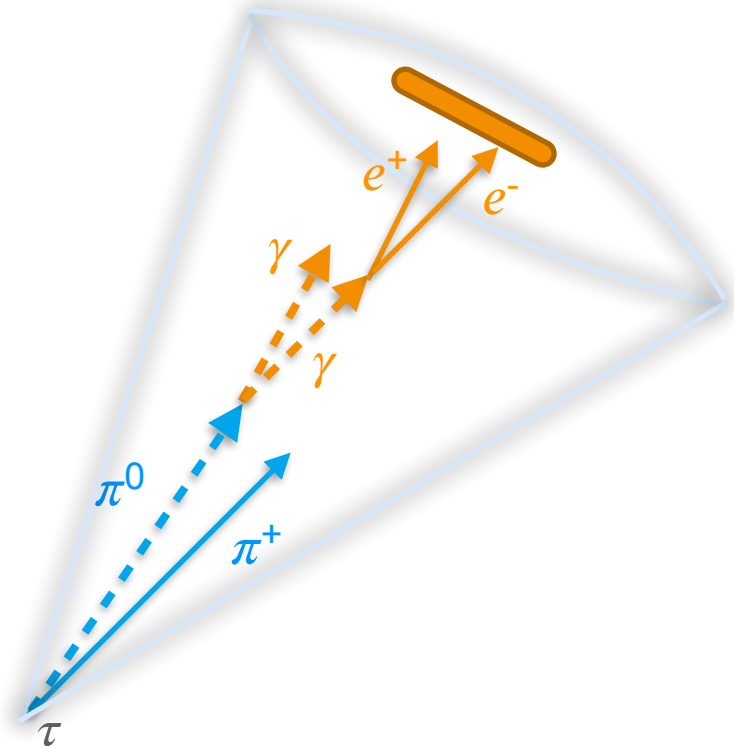
- > Jets anti- k_T ($R=0.5$)

> Neutral hadrons

- > Two photons from the π^0 , eventually convert to e^+e^-
- > Cluster e/γ (typical shape)

> Tau candidate

- > Matching of hadrons and e/γ in a cone of $R = 3.0/p_T$
- > Apply mass cuts



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> Charged hadrons

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> Neutral hadrons

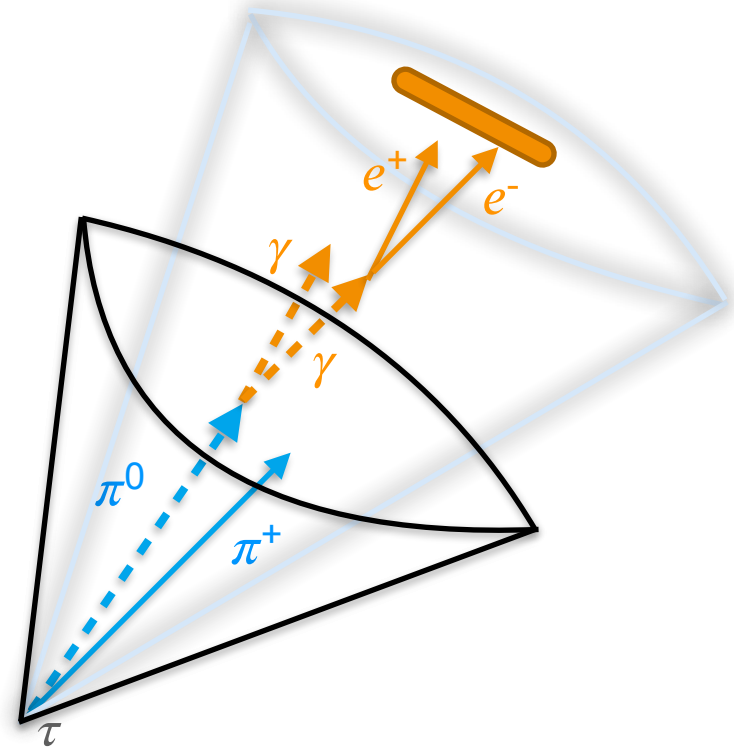
- > Two photons from the π^0 , eventually convert to e^+e^-
- > Cluster e/γ (typical shape)

> Tau candidate reconstruction

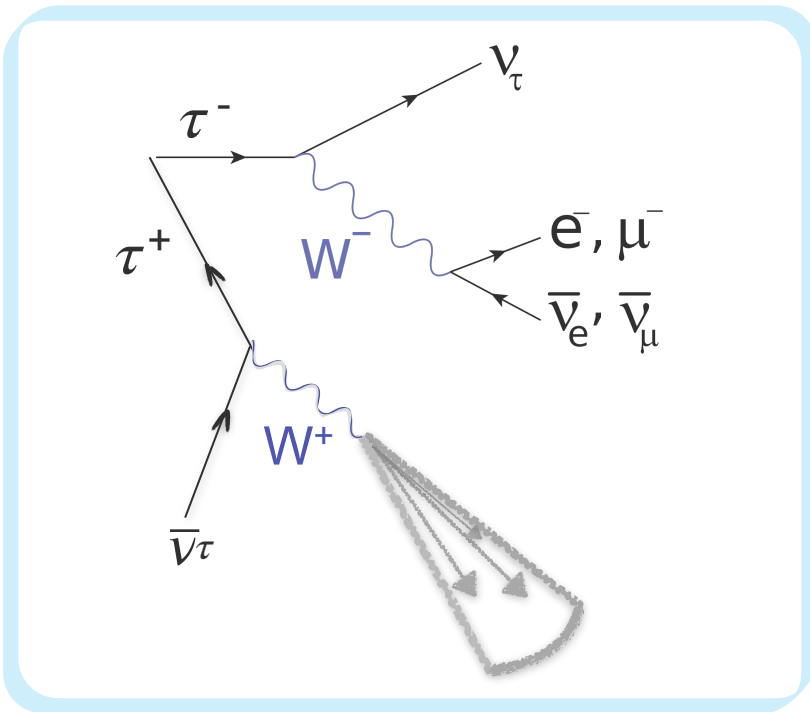
- > Matching of hadrons and e/γ in a cone of $R = 3.0/p_T$
- > Apply mass cuts

> Require **isolation** in a cone of $R = 0.5$ around the tau candidate

The isolation requirements define the working point of the algorithm



- > Final states considered here
- one τ decays to e or μ + neutrinos
- one τ decays to hadrons + neutrinos



The main backgrounds are

- > Drell-Yan production ($\mu\mu$ or ee)
where a lepton is mis-identified as a tau
- > W+jets events
where $W(\ell\nu)$ and the jet fakes a tau
- > QCD events
where one jet fakes a tau and another jet fakes a lepton
- > Very small contributions from diboson and top production

Corrections to MC - Lepton scale factors



- > Measure **efficiency** in data and simulation, for **lepton identification criteria and triggers**

Derive a correction to apply on simulation with Tag&Probe method

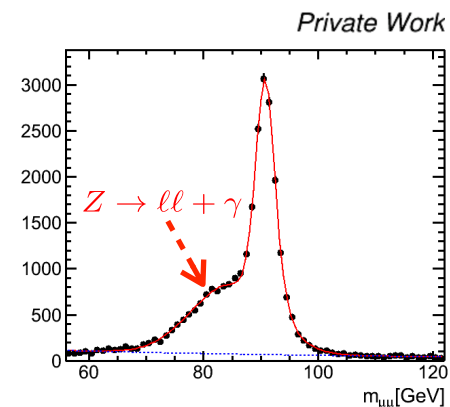
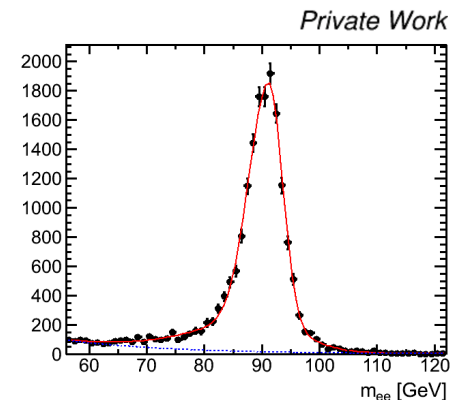
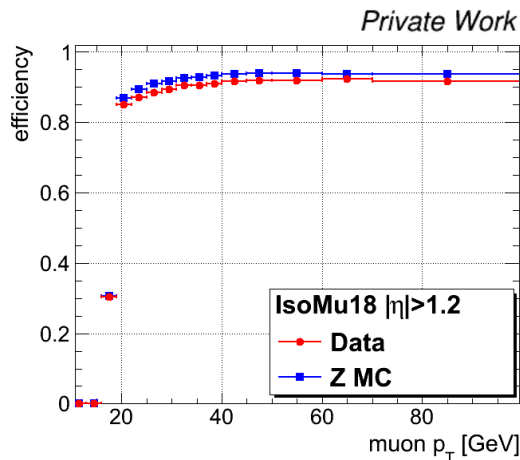
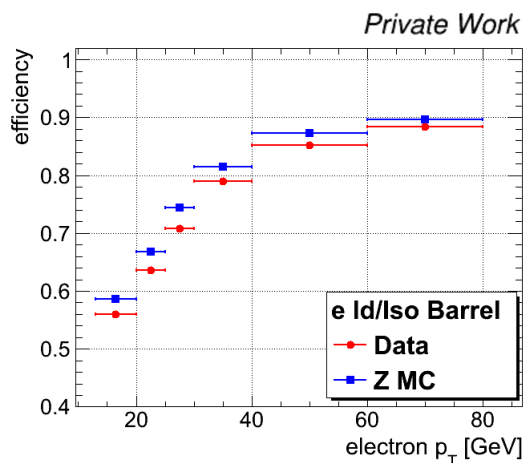
- > **Selection**

$Z(ee)$ and $Z(\mu\mu)$ events (from data and Drell-Yan simulated sample)

- > **Fit** the dilepton invariant mass distribution

Exponential bkg, asymmetric gaussian for the signal

Efficiency $\varepsilon = \text{\#passing}/\text{\#total probes in [80-102] GeV}$



- > Efficiency curves $\varepsilon(p_T)$ in different eta regions
- Scale factors ~ 95%



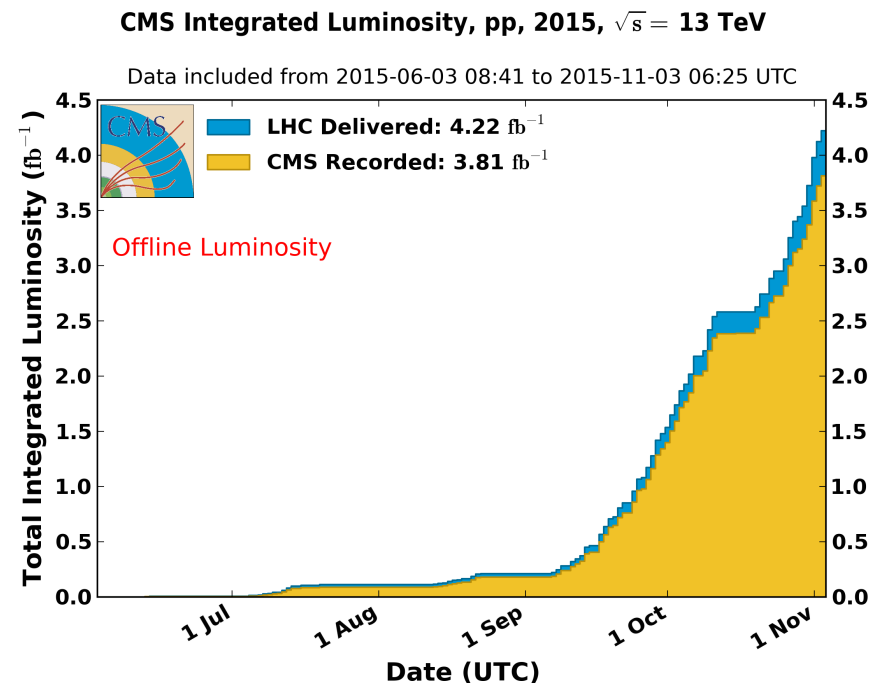
> Amount of collected “good” **data** in the 25 ns runs is $\sim 2.2 \text{ fb}^{-1}$

> Trigger

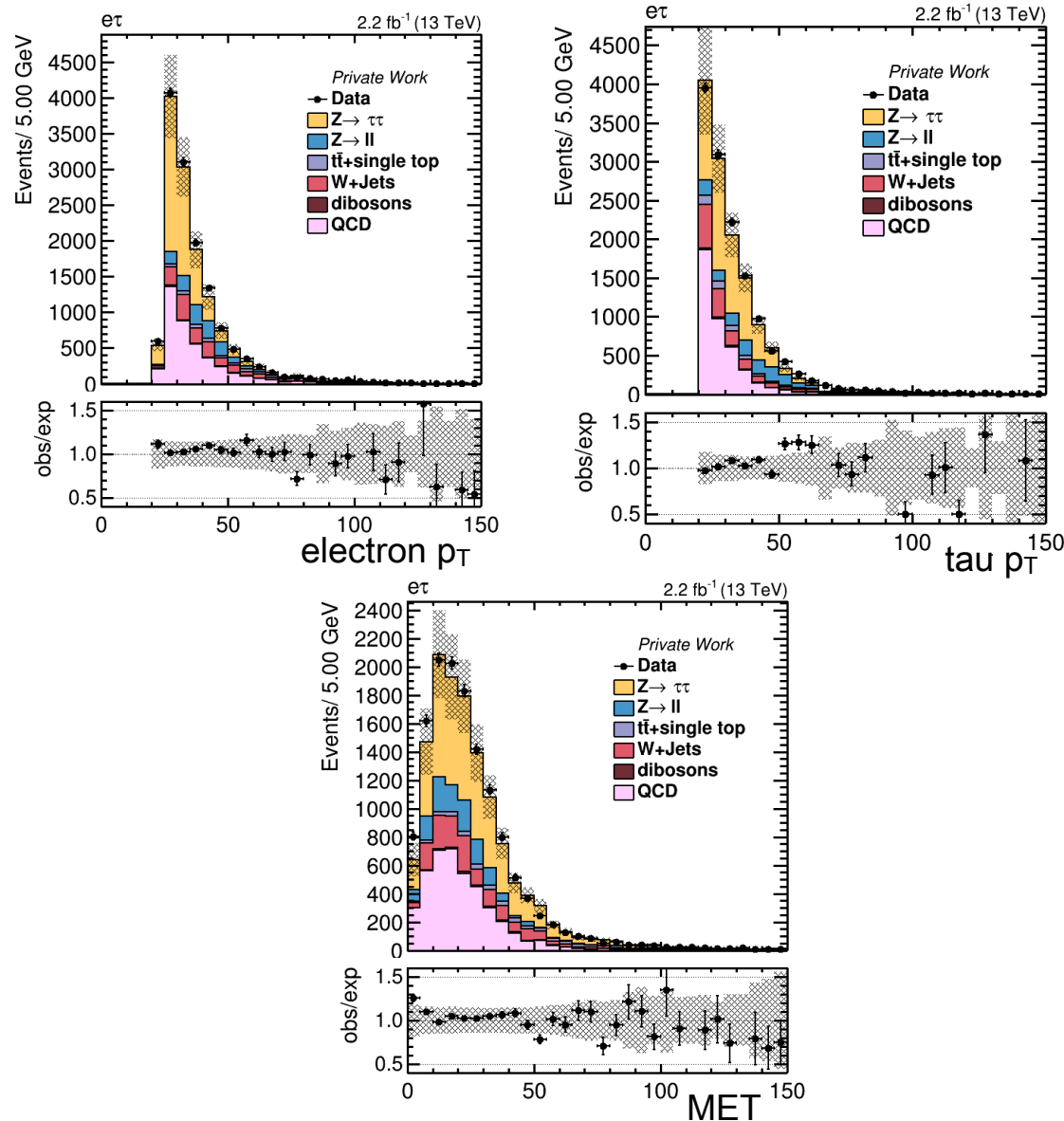
- Muon with $p_T > 18 \text{ GeV}$
- Electron with $p_T > 23 \text{ GeV}$

> Selection

- Identification and isolation criteria for leptons
- Tau $p_T > 20 \text{ GeV}$
- Prefer most isolated tau-lepton pair
- No additional leptons in the event

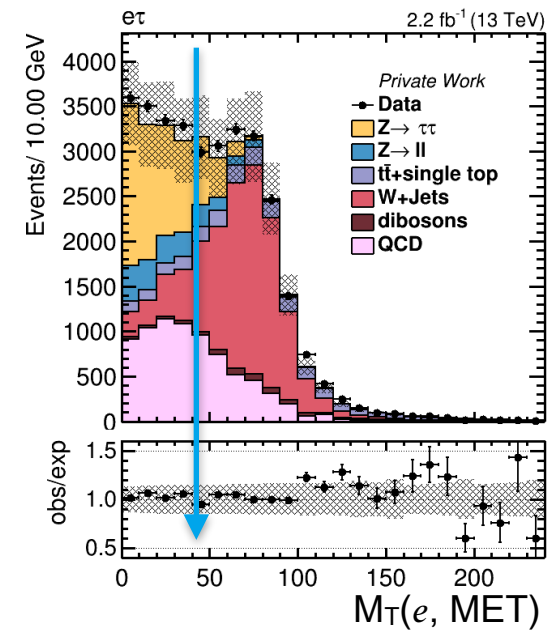


Kinematic distributions - $e\tau$ channel

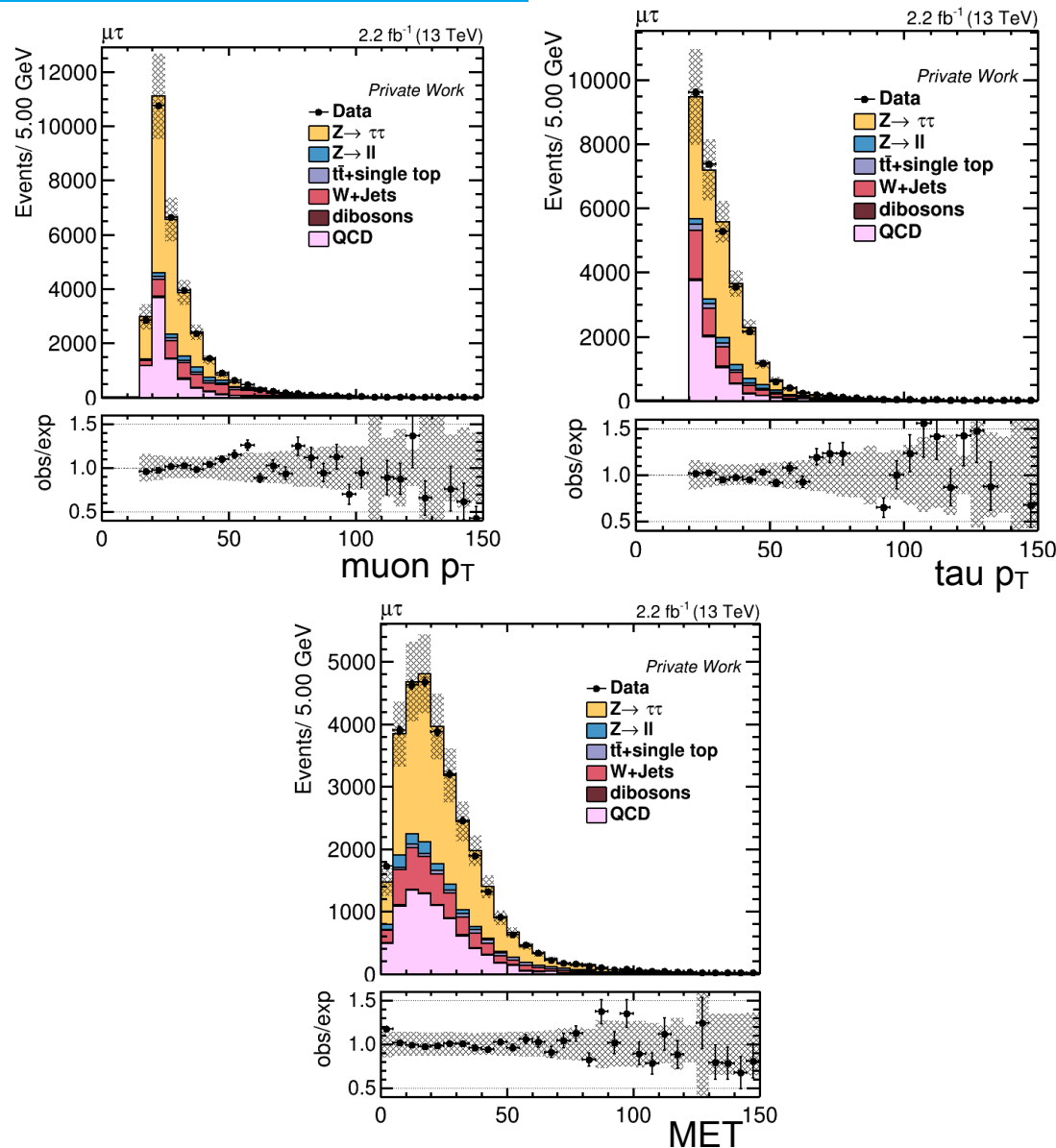


Use of transverse mass of the electron+MET system to reject W+jets events

$$M_T(e, MET) = \sqrt{2p_T^e MET (1 - \cos\Delta\phi)}$$

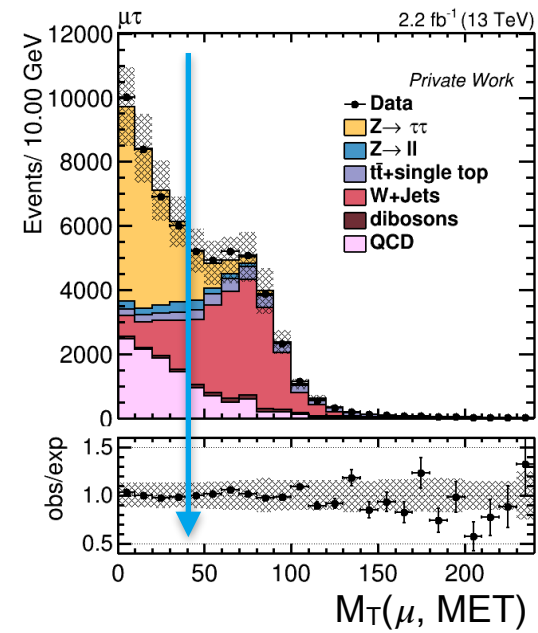


Kinematic distributions - $\mu\tau$ channel

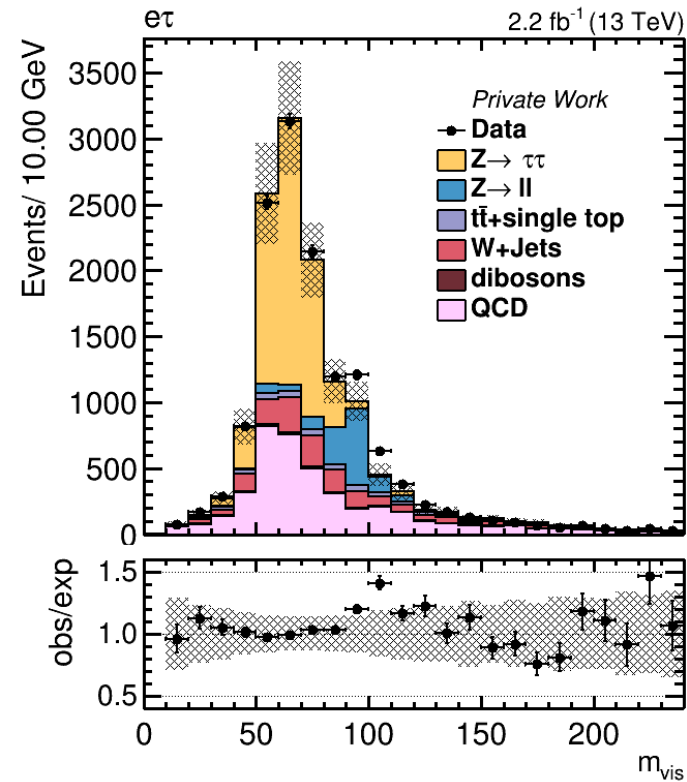
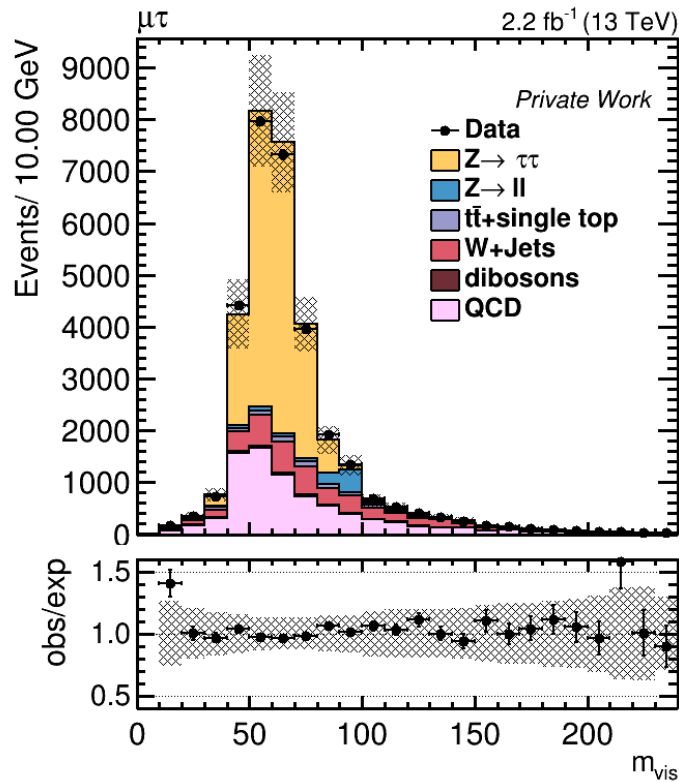


Use of transverse mass of the muon+MET system to reject W+jets events

$$M_T(\mu, MET) = \sqrt{2p_T^\mu MET (1 - \cos\Delta\phi)}$$



Visible mass distribution



Systematic uncertainties included so far

- background normalization (QCD:30%, VV:20%, W:15%, $t\bar{t}$:10%, Z($\ell\ell$):10%)
- luminosity (4.6%)
- tau ID (8%)



> **Theoretical value** $\sigma^{\text{theo}}(Z \rightarrow \tau\tau) = 2008.4 \pm 75.7 \text{ pb}$

> **Measured cross section**

Counting events in the mass region [40-90] GeV

$$\sigma^{\text{meas}}(Z \rightarrow \tau\tau) = \frac{\text{Data} - \text{MC}(bkg)}{\text{MC}(Z \rightarrow \tau\tau)} \sigma^{\text{theo}}(Z \rightarrow \tau\tau)$$

> from the $e\tau$ channel

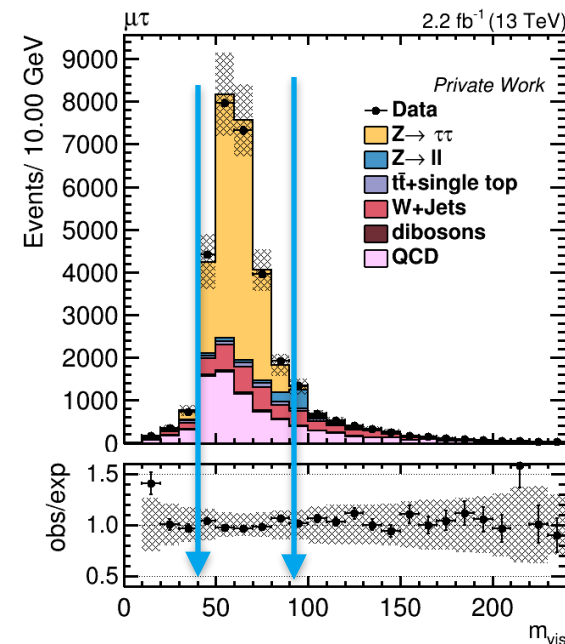
Private Work

$$\sigma^{\text{meas}}(Z \rightarrow \tau\tau) = 2010 \pm 180 \text{ (lumi)} \pm 20 \text{ (stat)} \pm 350 \text{ (sys)} \text{ pb}$$

> from the $\mu\tau$ channel

Private Work

$$\sigma^{\text{meas}}(Z \rightarrow \tau\tau) = 1980 \pm 150 \text{ (lumi)} \pm 12 \text{ (stat)} \pm 260 \text{ (sys)} \text{ pb}$$



- > I have presented the first look at **$Z(\tau\tau)$ events with the 13 TeV data**
- > **Fairly good agreement** between data and simulation
 - > After correcting for different pileup and lepton efficiencies wrt data
 - > This is reflected in the good agreement in the $Z(\tau\tau)$ cross section estimate
- > Currently working on improving estimate of the most difficult **backgrounds** and fake rates and evaluating **systematic uncertainties**
- > This is an important step for **commissioning** the Higgs to $\tau\tau$ search
- > Working for having public **$H(\tau\tau)$ results** with the 13 TeV data
- > Looking forward for **more data** to come!



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Thanks for your attention!

Are there any questions?

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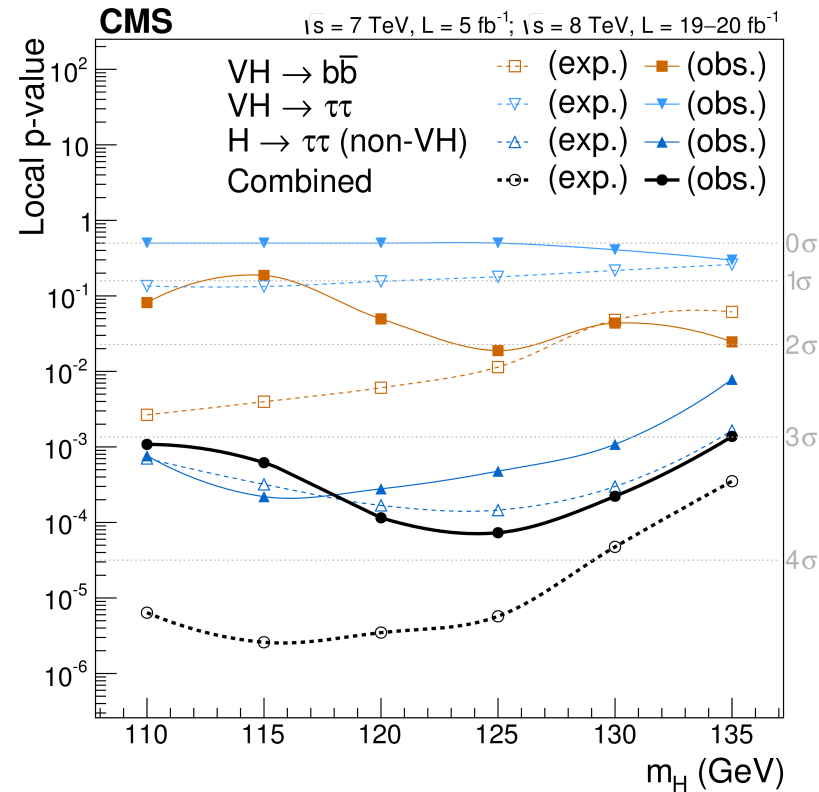
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BACKUP

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Evidence for Higgs to fermions decays



CMS Collaboration, Evidence for the direct decay of the 125 GeV Higgs boson to fermions, Nature Phys. 10 (2014)



Tag & Probe Selection

- **Trigger**

Muons

- HLT_IsoMu20

- **Tag Muon**

- passes baseline Id/Iso selection
- matched to the respective HLT filter

- **Probe Muons**

- $p_T > 10 \text{ GeV}$, $|\eta| < 2.4$
- loose cut on IPs $|dxy| < 2 \text{ mm}$, $|dz| < 5 \text{ mm}$

- **Trigger**

Electrons

- Data: HLT_Ele23_WPLoose_Gsf
- MC: HLT_Ele22_eta2p1_WP75_Gsf + online $p_T > 23 \text{ GeV}$

- **Tag Electron**

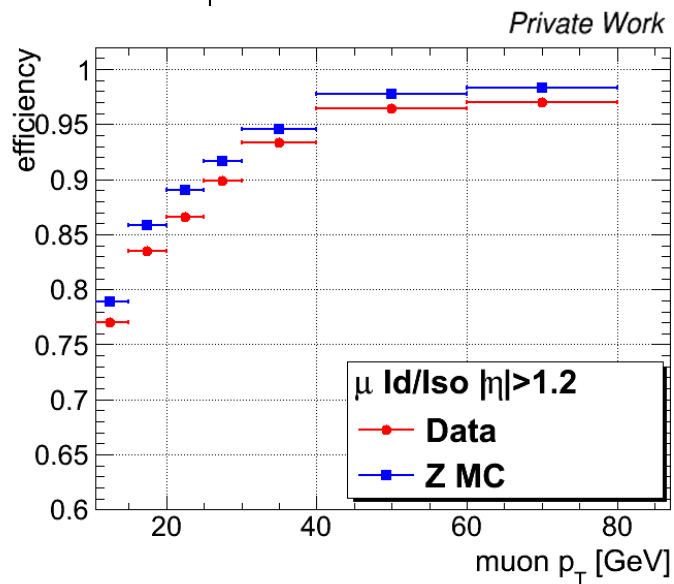
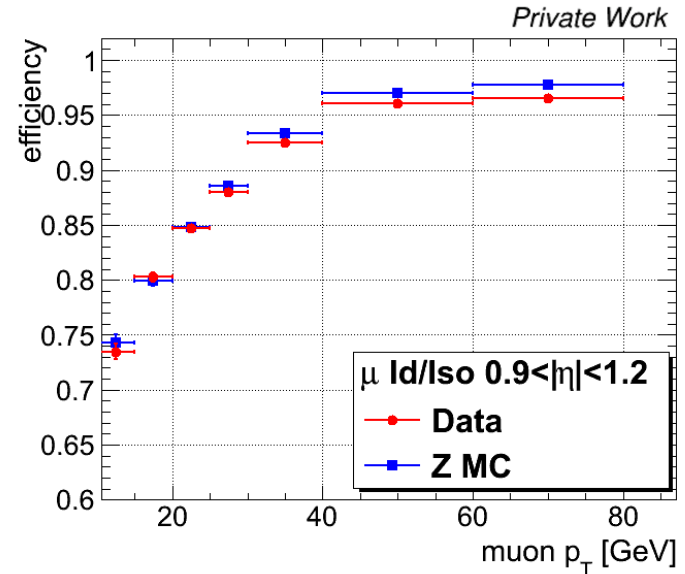
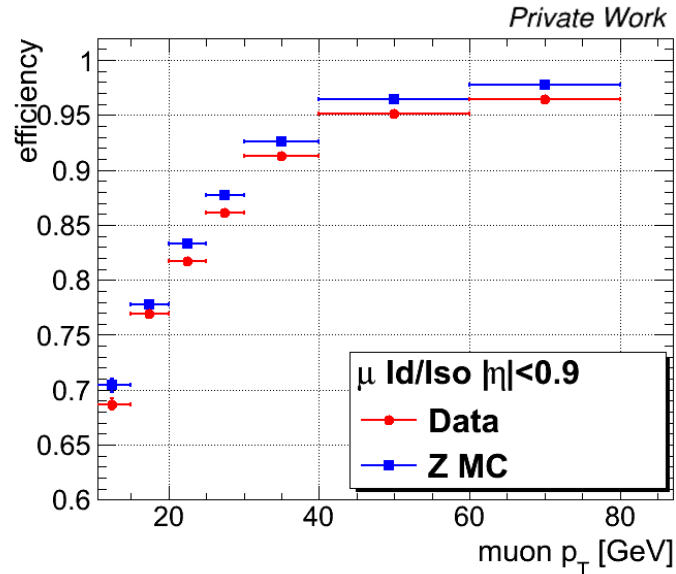
- passes baseline Id/Iso selection
- matched to the respective HLT filter

- **Probe Electrons**

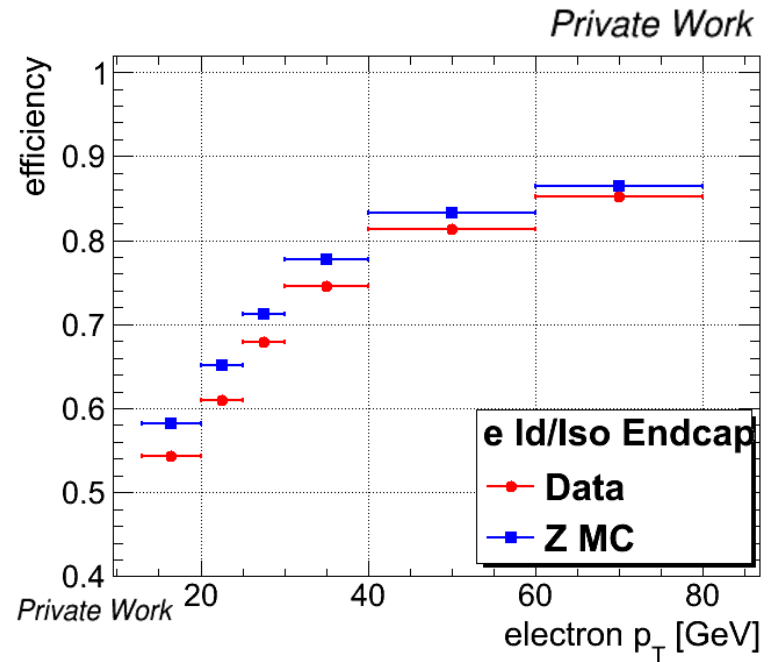
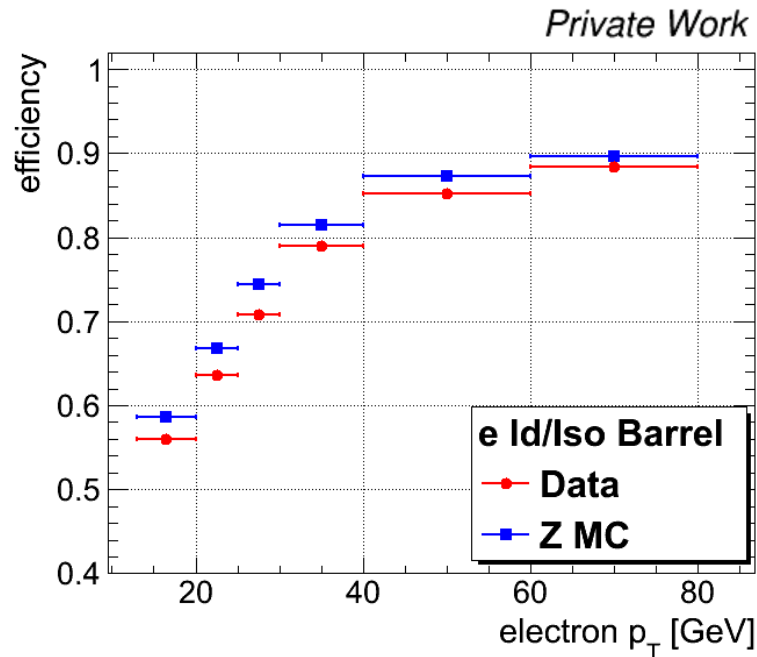
- $p_T > 13 \text{ GeV}$, $|\eta| < 2.5$
- loose cut on IPs $|dxy| < 2 \text{ mm}$, $|dz| < 5 \text{ mm}$

- **Tag&Probe pair: opposite sign, well separated ($\Delta R > 0.5$), $m_{\ell\ell} > 50 \text{ GeV}$**
If the probe lepton satisfies the tag selection, the pair is considered twice

Muon Identification efficiencies



Electron Identification efficiencies



➤ Scale factors between 92 and 98 %

Single lepton trigger efficiencies

Triggers to collect the T&P samples (must be matched by the tag lepton)

Muons : HLT_IsoMu20

Electrons : HLT_Ele23_WPLoose_Gsf in data and
HLT_Ele22_eta2p1_WP75_Gsf + online $p_T > 23$ GeV in MC

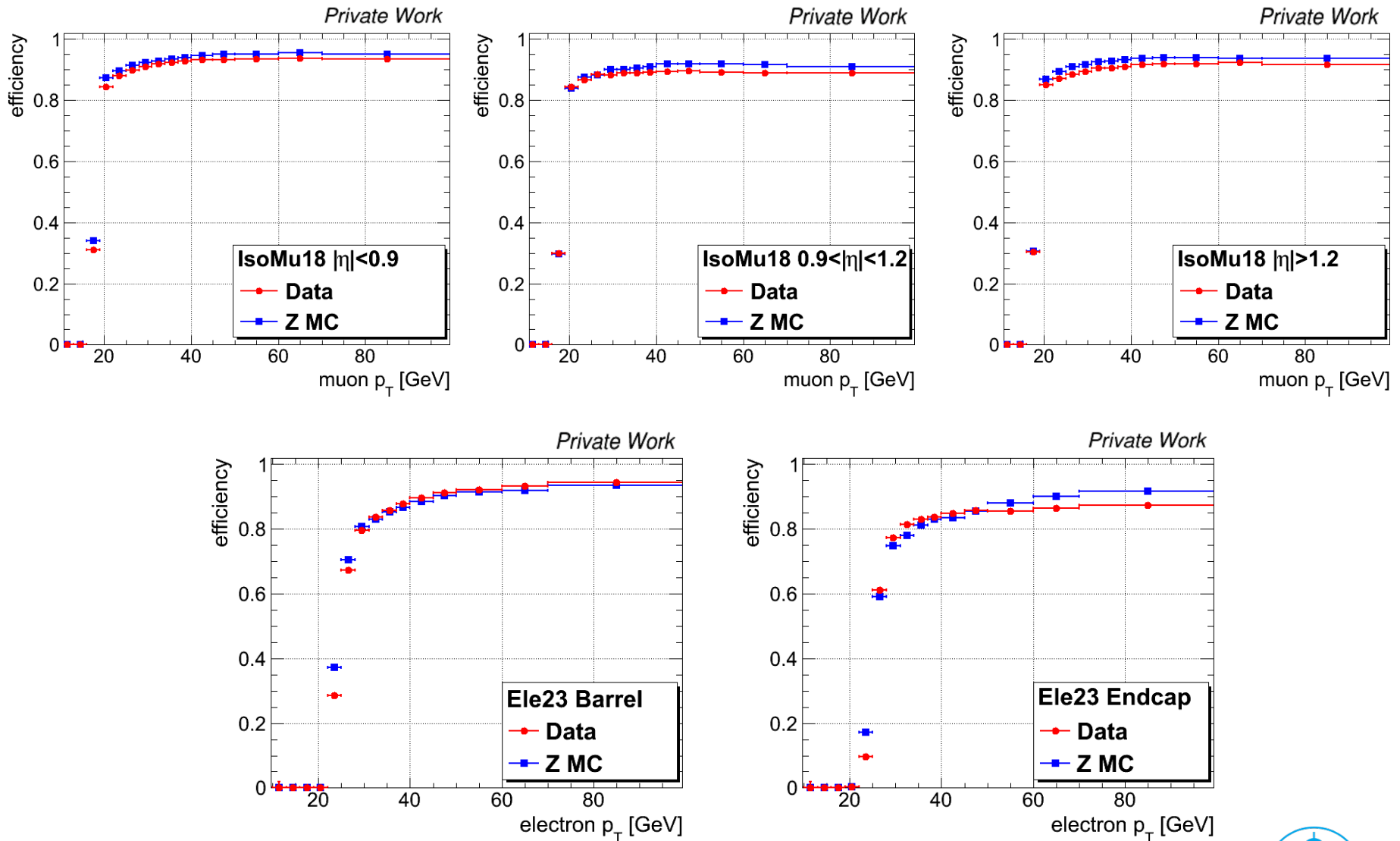
Trigger efficiency is measured **relative to the offline selection**

Tag lepton must match the **T&P triggers** (above) and pass **offline selection**

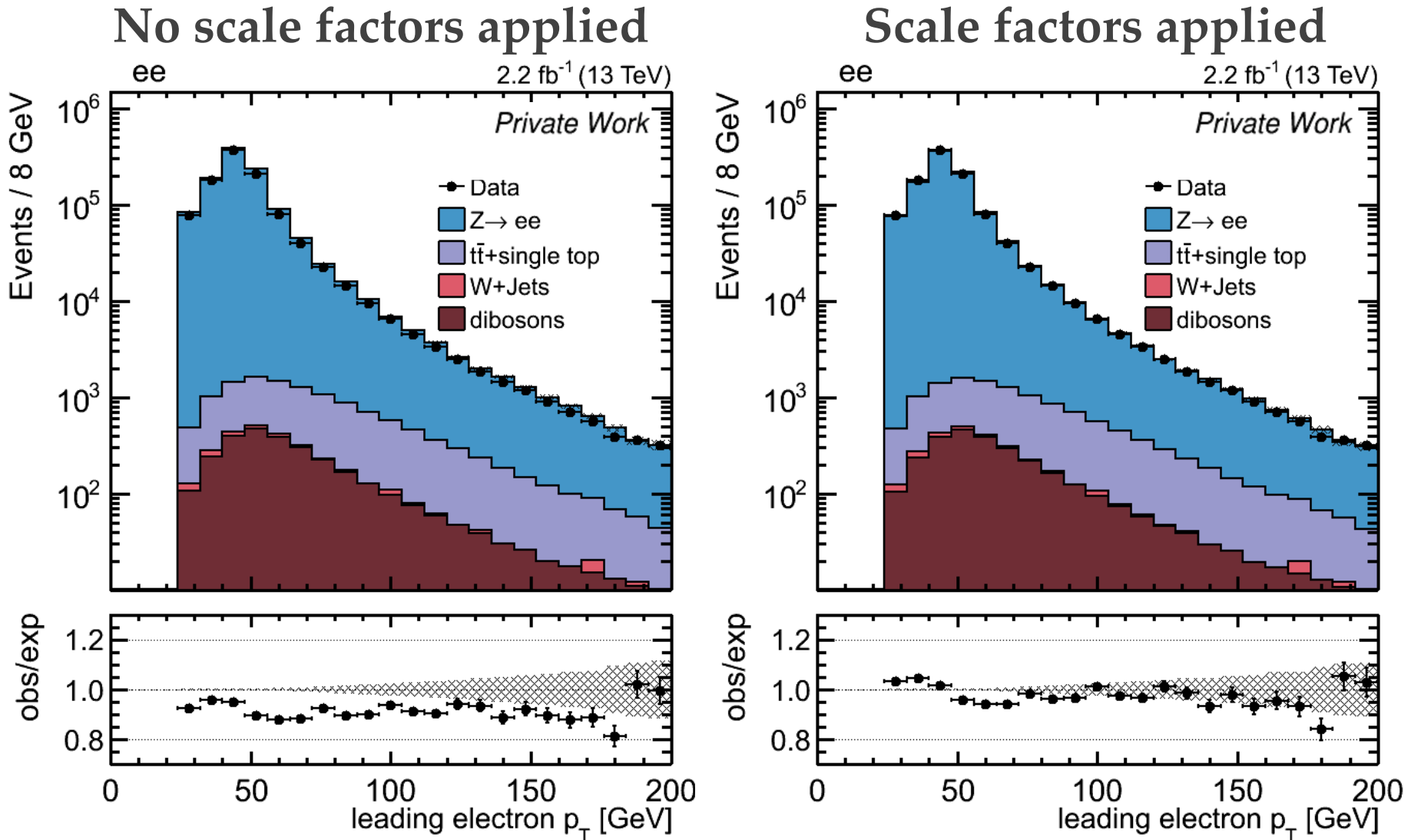
Probes are all leptons **passing Id&Iso** cut

Passing probes: leptons **matching trigger objects** (from the trigger we want to study, i.e. IsoMu18 and Ele23)

Trigger efficiencies

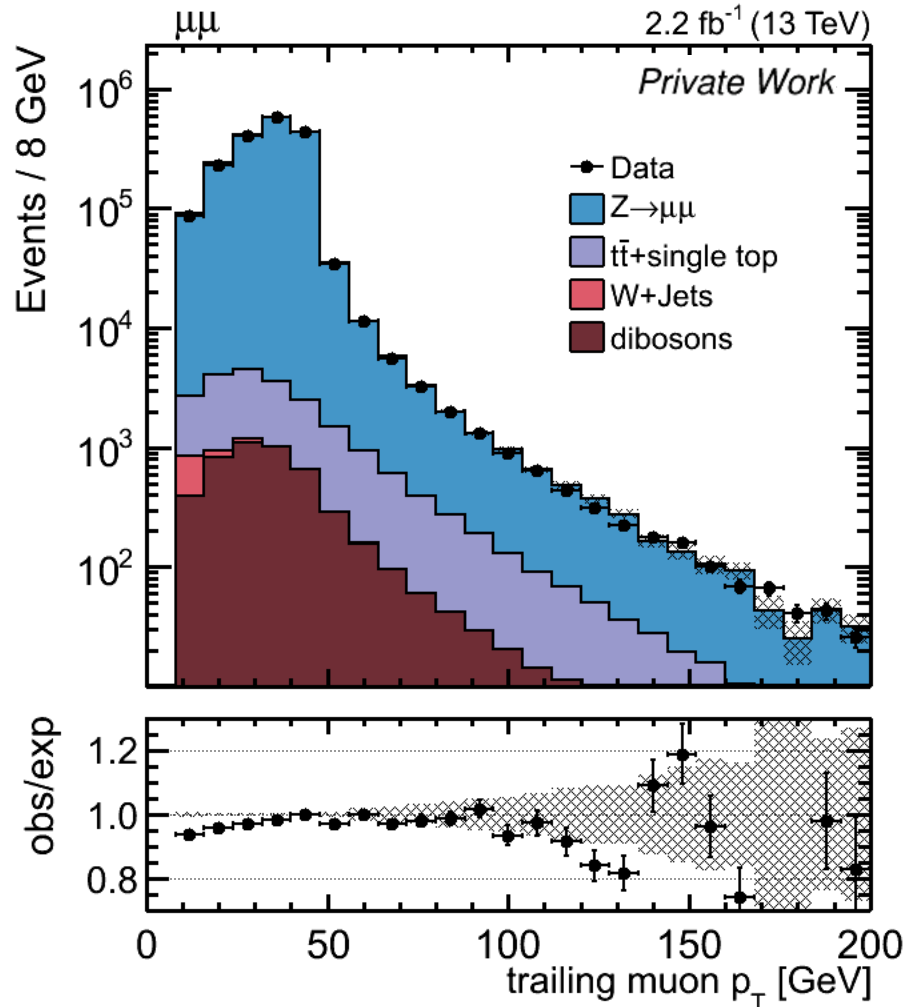


Validation of the electron scale factors on $Z(ee)$ events

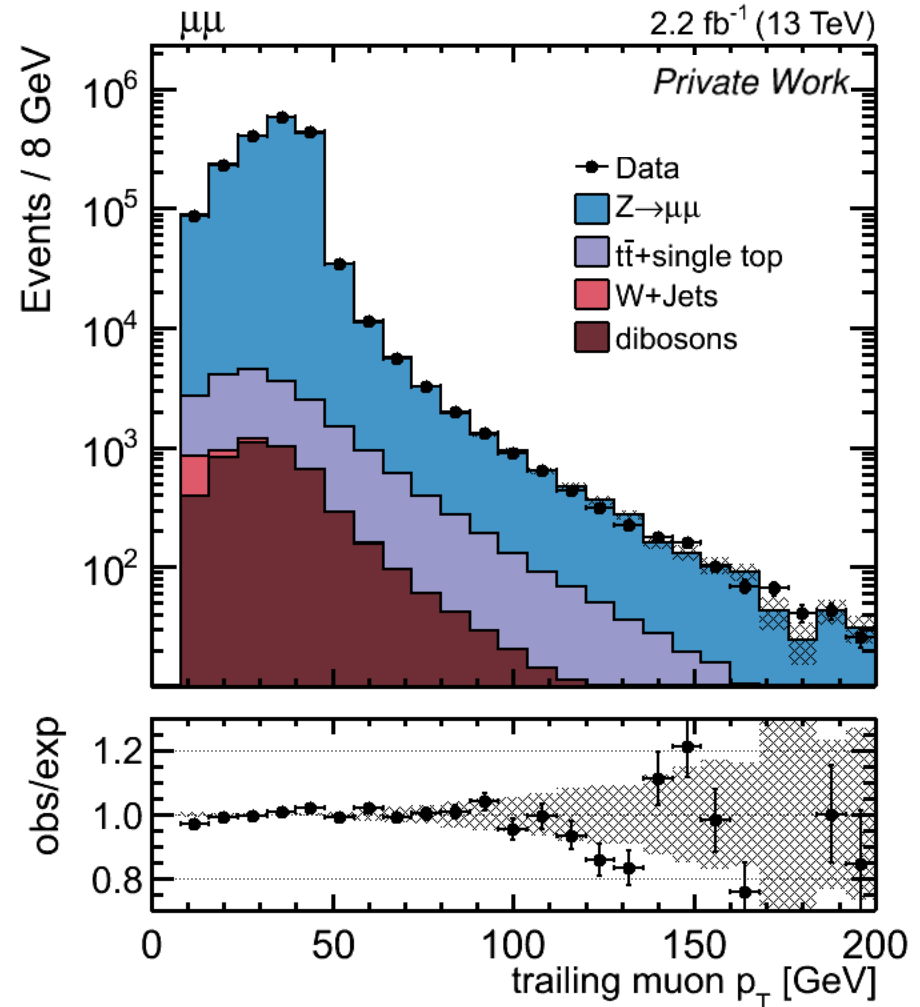


Validation of the electron scale factors on $Z(\mu\mu)$ events

No scale factors



Scale factors



Corrections to MC - Pile up reweighting



> Different number of pile up interactions in simulation and in data

$\langle \text{PU} \rangle \sim 11.5$ in data and $\langle \text{PU} \rangle \sim 16$ in simulation

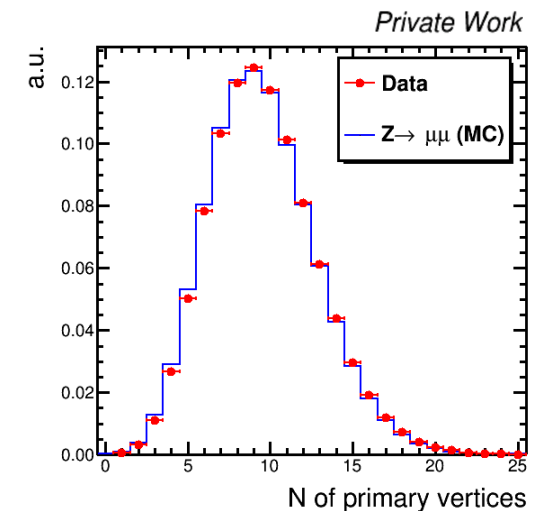
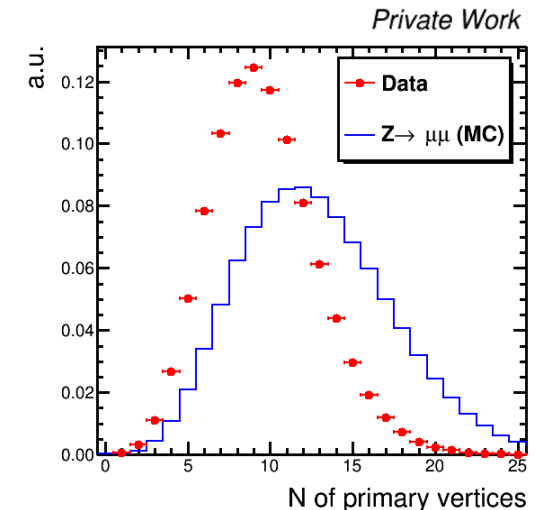
> Derive the pile up distribution in data

$\# \text{PU} = \text{instantaneous luminosity} \times \sigma(\text{min bias})$

Compute instantaneous luminosity for each active bunch and take the weighted average according to the recorded luminosity per bunch

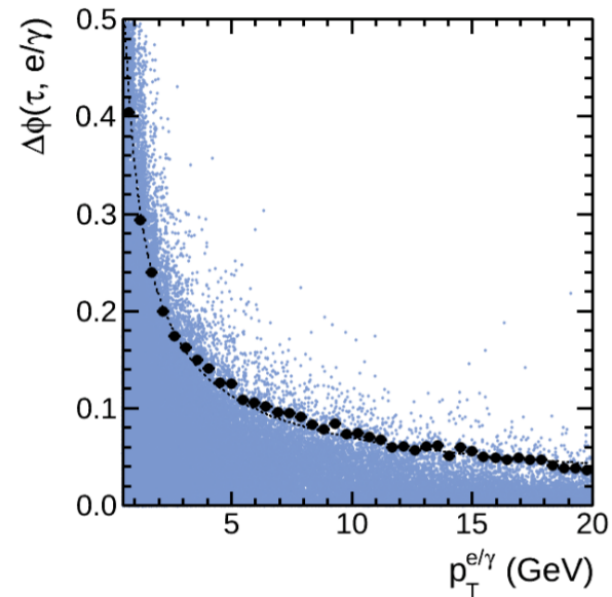
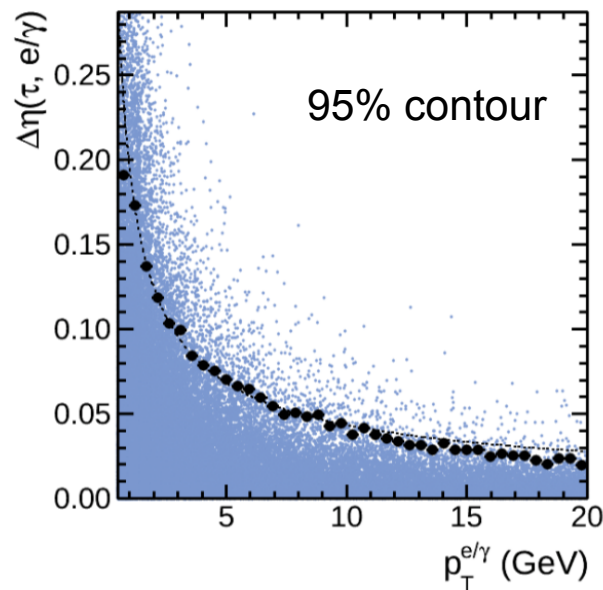
> Get the pile up distribution in simulated samples

> Assign a **weight** to each simulated event



Tau reconstruction - Dynamic strip reconstruction

- The dimension of the strip is allowed to vary depending on the p_T of the e/γ to be merged
- Low p_T electrons belonging to the tau decay can fall outside the fixed strip window and spoil the isolation of the tau candidate



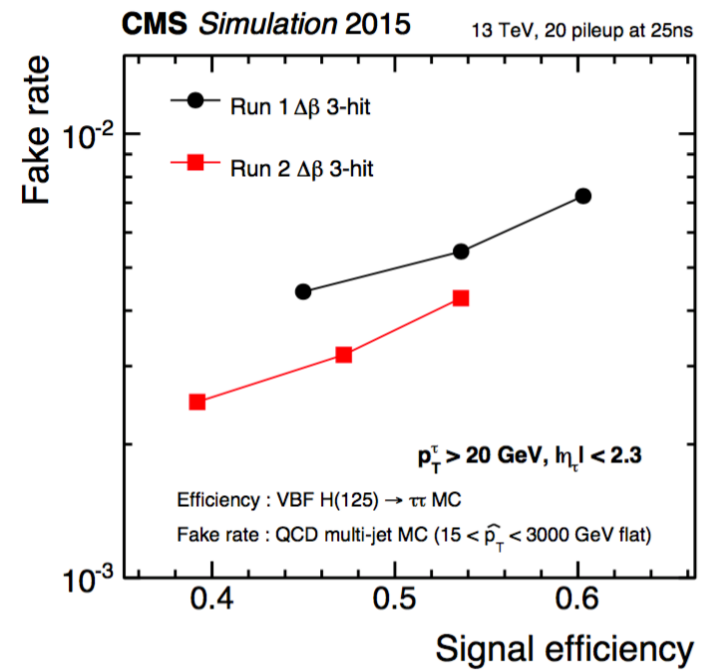
Tau reconstruction - Isolation

- Isolation is computed considering charged particles not assigned to the tau candidate, coming from the PV, in the isolation cone

$$\hat{I}_\tau = \sum p_T^{\text{charged}}(d_Z < 0.2 \text{ cm}) + \max(0, \sum p_T^\gamma - \Delta\beta)$$

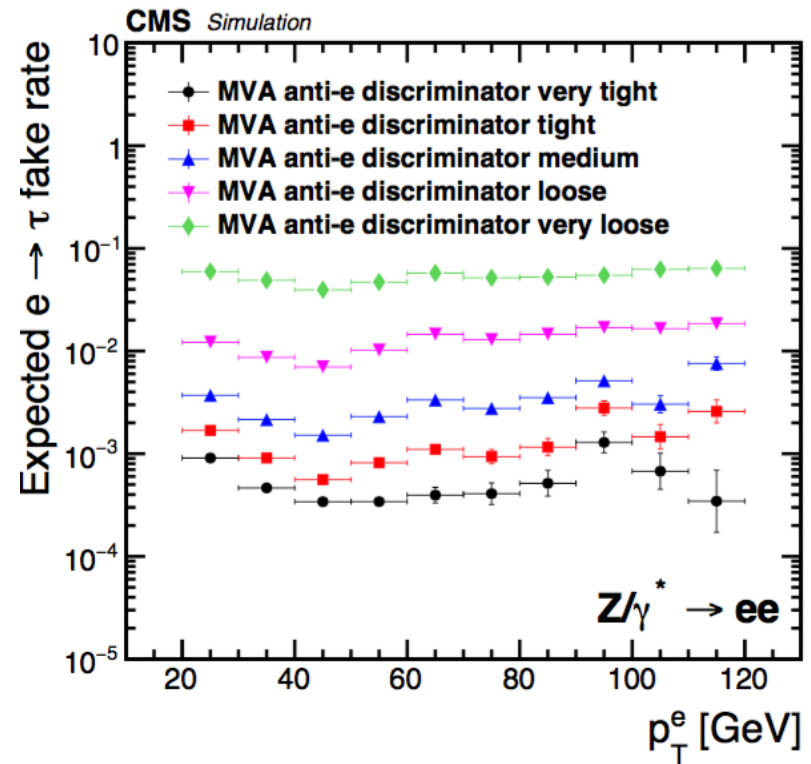
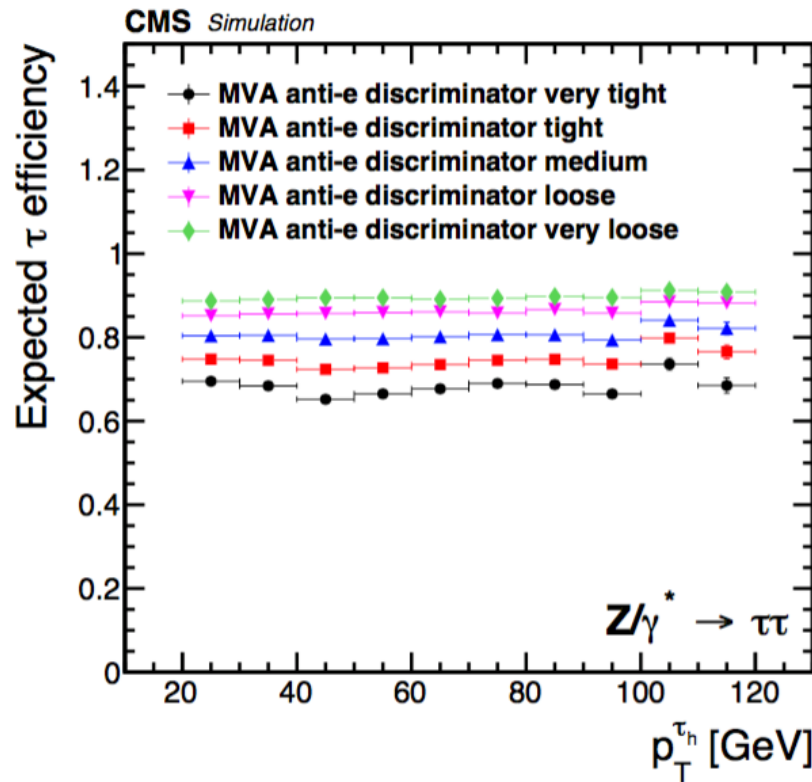
$$\Delta\beta = 0.2 \sum p_T^{\text{charged}}(d_Z > 0.2 \text{ cm})$$

- The beta factor corrects on a statistical basis for energy deposit due to pile up



Backup - Anti-electron discriminator

➤ Expected efficiency and fake rate



Kinematic distributions - Eta

