Analysis of Z $\rightarrow \tau\,\tau \rightarrow$ e + μ in run 2

CMS experiment

Yiwen Wen

DESY

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eμ

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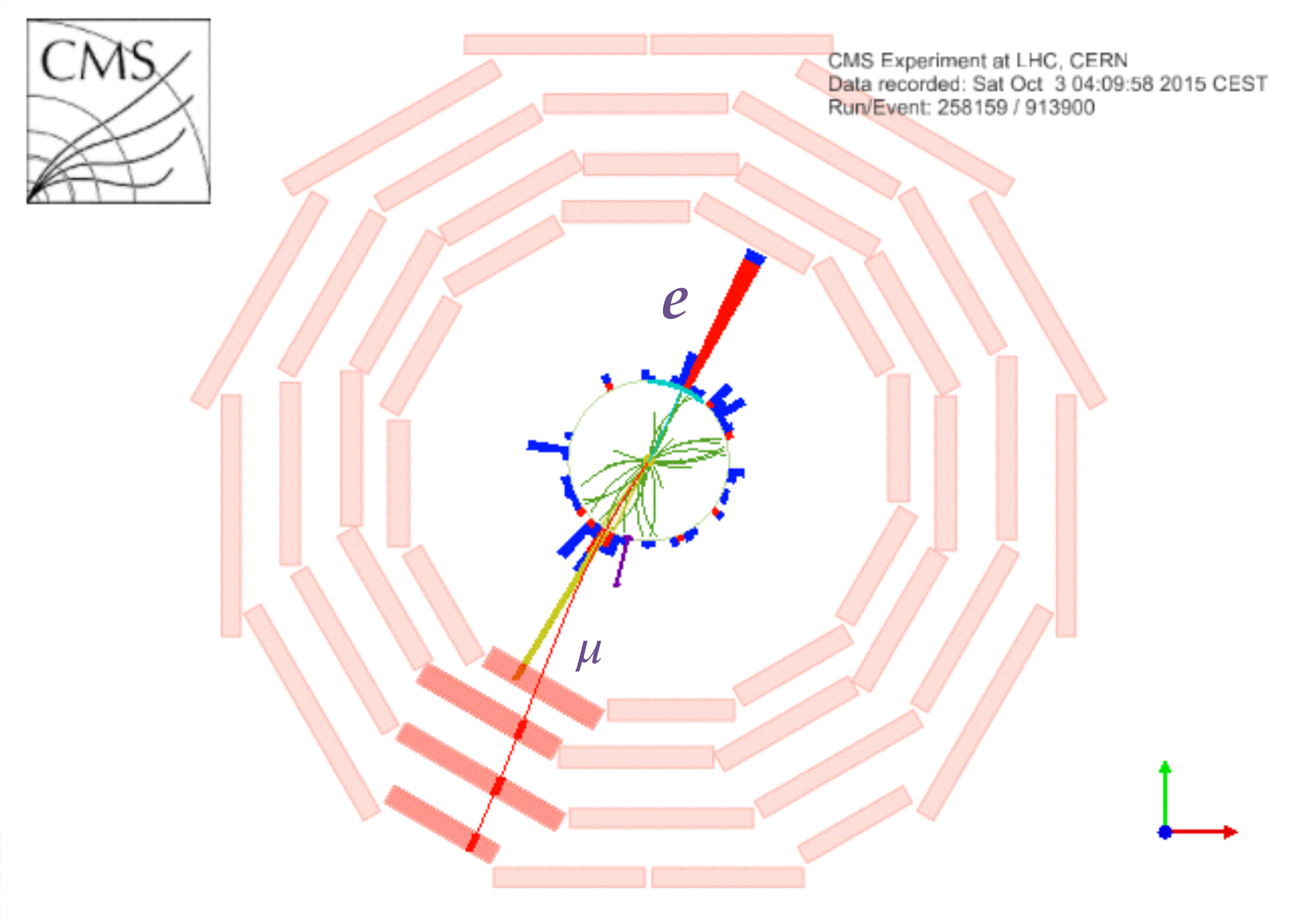
1.Introduction

motivations

- in LHC run 1, CMS and ATLAS combined searches for SM $H \to \tau\tau$ results, **5.4 sigma** reached(CMS-PAS-HIG-15-002)
- the Z $\to \tau\tau$ as **standard candle** for commissioning of (SM or BSM) $H \to \tau\tau$ analysis
- e + μ make up **6% of $\tau\tau$** decays
- small branching faction counter-balanced by **higher lepton reco. efficiency** and **lower fake rate** in comparison to the reco. of hadronic τ decay
- also benefits from **absence of large Z $\to$ ee or Z $\to$ $\mu\mu$ background** which dominate $\tau\tau \to$ ee and $\tau\tau \to \mu\mu$

1.Introduction

a typical $e + \mu$ event in CMS



2.Event selections

Samples

1. **data**

   2.3 fb^{-1} 13 TeV collected by CMS in 2015

2. **Monte-Carlo simulation**

DY+JetsToLL

Top pair

single Top:

Single top tW channel

Single top t channel

diboson:

WWTo1L1Nu2Q

ZZTo2L2Q

ZZTo4L

WZTo2L2Q

WZJets

WZTo1L3Nu

WZTo1L1Nu2Q

VVTo2L2Nu

W+Jets

2. Event selections

Selections

- major backgrounds:
  - **top pair production** modeling in MC simulation
  - QCD multi-Jet modeling in data-driven method
- dilepton selection:
  - **trigger**

    e + μ cross trigger: Muon pt > 17 GeV Electron pt > 12 GeV or Muon pt > 8 GeV Electron pt > 17 GeV

    leptons and trigger object matched in cone $\Delta R<0.3$

    data-MC trigger efficiency correction applied
  - **electron** and **muon**

    electron p_T > 13(18) GeV, muon p_T > 18(10) GeV

    electron and muon passing identification criteria

    relative isolation < 0.15

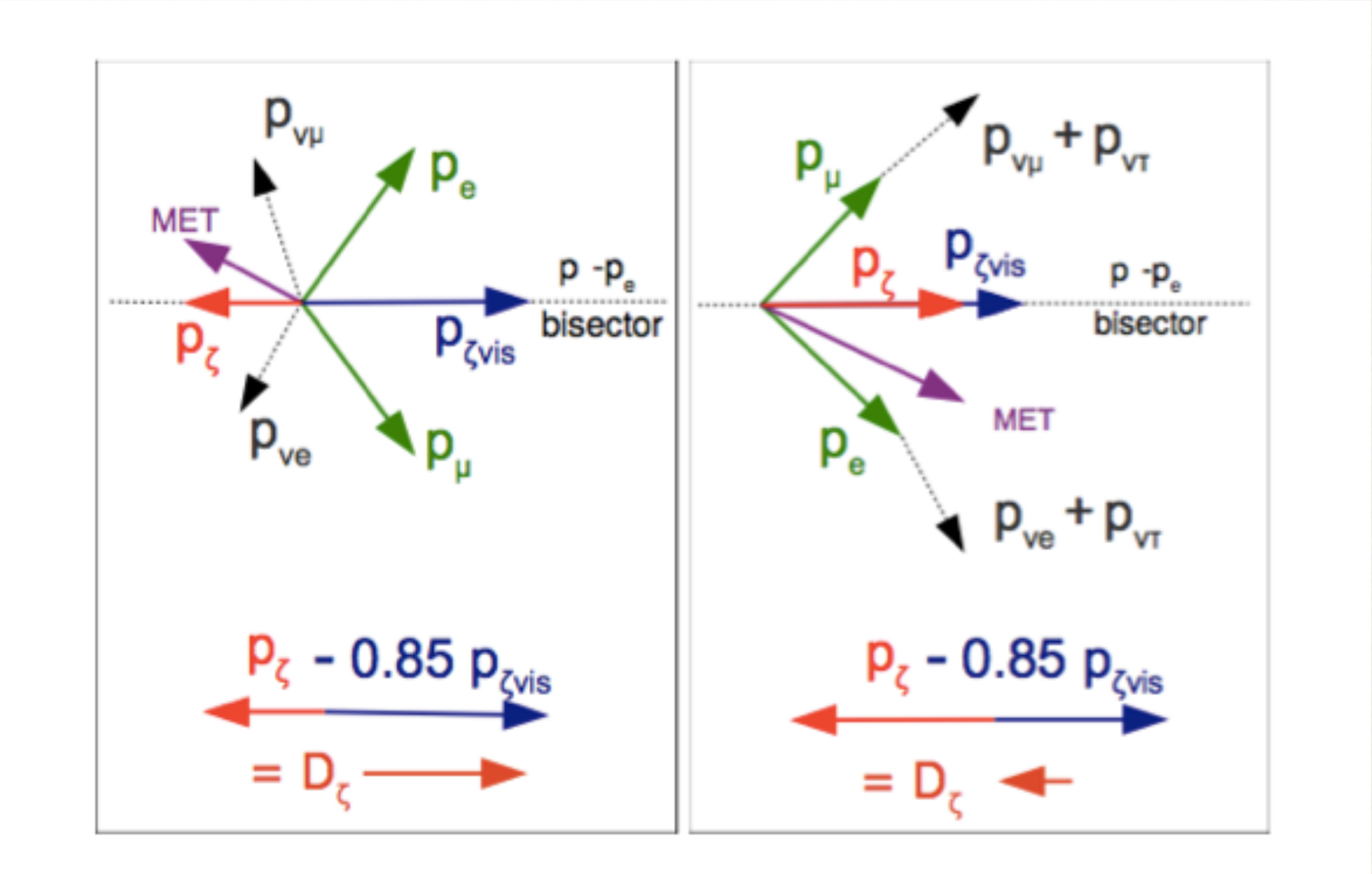
    data/MC isolation efficiency correction applied
- inclusive selection:
  - no extra lepton, D_ζ > -20 GeV (definition see next slide)

2.Event selections

D_ζ discriminant between $Z \to \tau\tau$ and top pair

- D_ζ - built from momenta of leptons and missing transverse energy
- for **Z** $\to \tau\tau$, decay products contained inside a narrow cone around the τ trajectory, missing transverse energy highly correlated with the two leptons
- for **top pair**, the leptons from a top can have trajectories far from associated neutrinos, missing transverse energy less correlated with the two leptons

top pair decay **$Z \to \tau\tau$ decay**

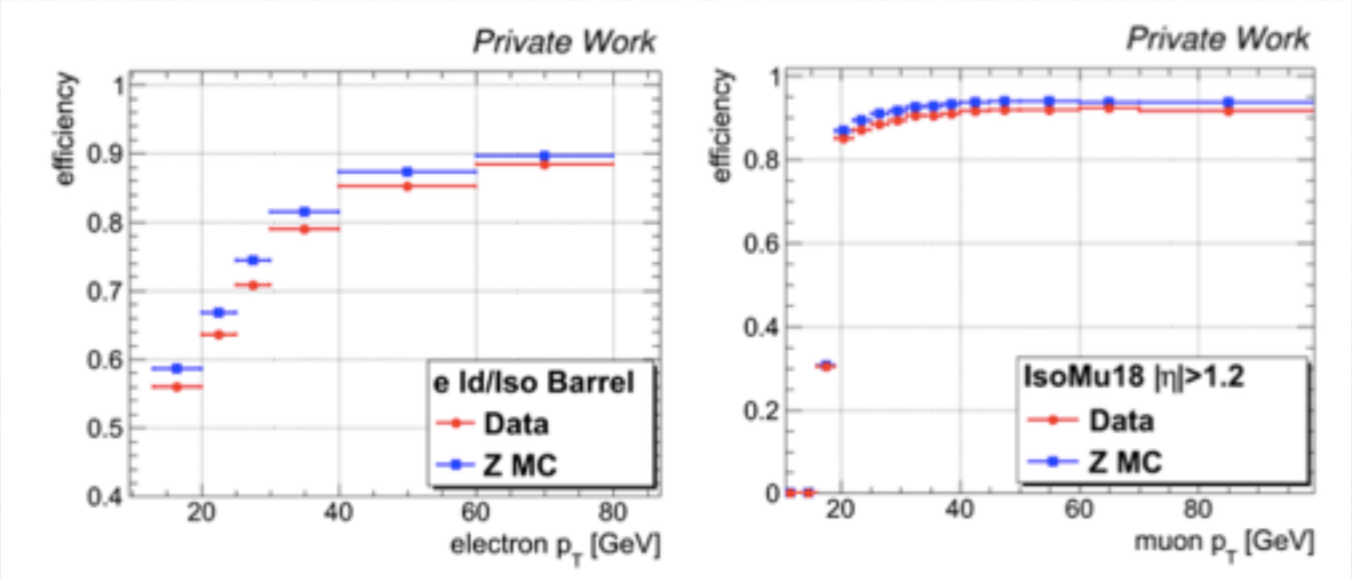


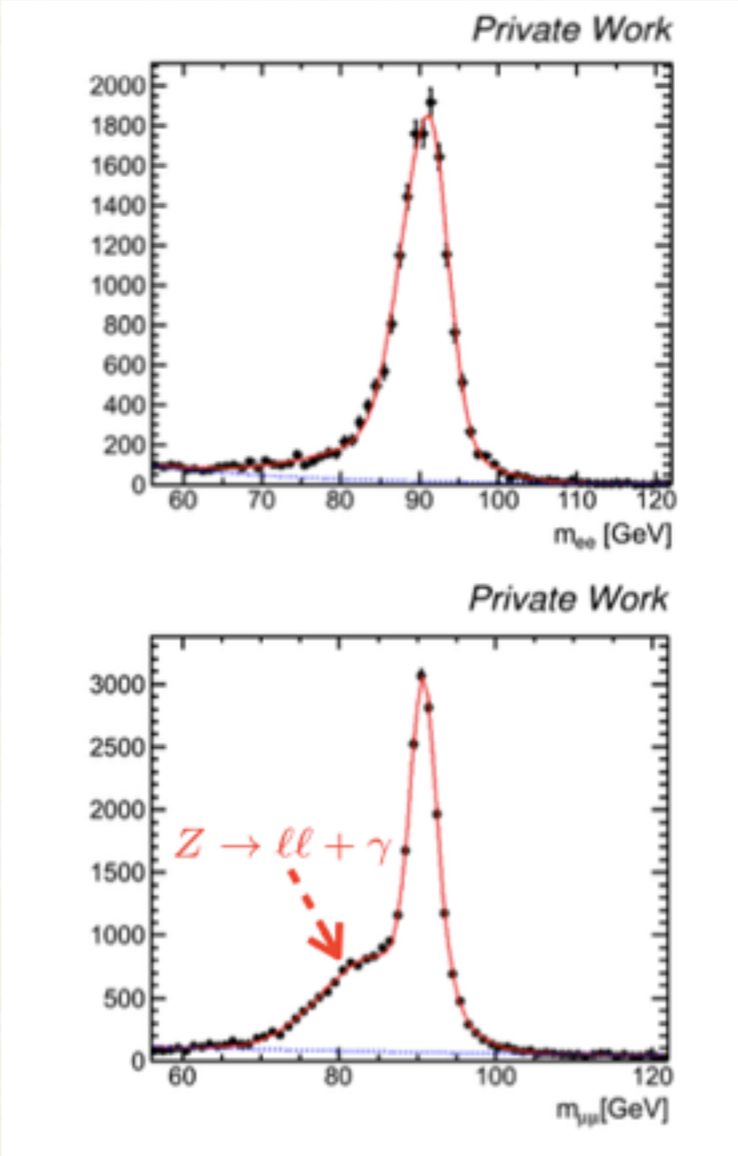
$$D_\zeta = \hat{\zeta} \cdot \vec{E}_T^{mis} - \alpha\hat{\zeta} \cdot (\vec{p}_{T,e} + \vec{p}_{T,\mu}) = P_\zeta - \alpha P_{\zeta vis}$$

2.Event selections

data/MC correction: Lepton scale factor

- 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 **ε** = #passing/#total probes in [80-102] GeV



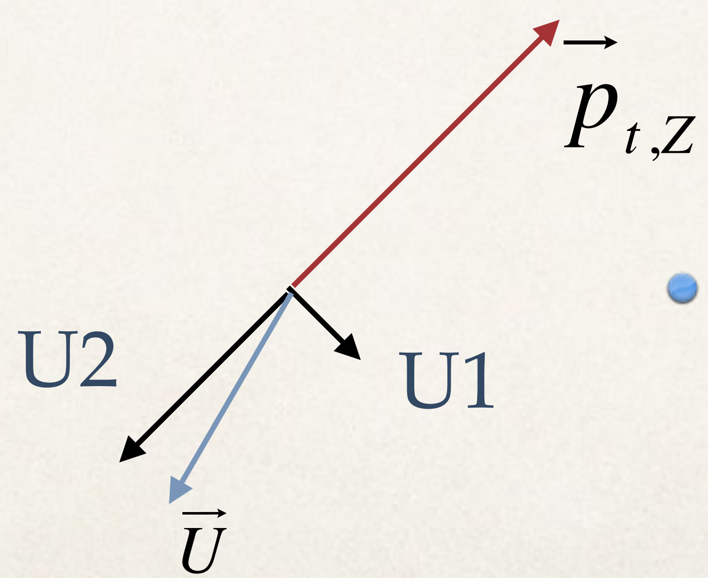


- Efficiency curves **ε (pT)** in different eta regions
  - scale factor~95%

2.Event selection

hadronic recoil correction

- avoid mis-modeling of MET in events with no genuine MET
- determination of the recoil effects and obtain correction from $Z \rightarrow \mu\mu$ events
- definition: in Z+Jets, $Z \rightarrow \mu\mu$ events: $\vec{U} = \vec{E}_T^{miss} = -\vec{H}_T - \vec{p}_{T,\mu\mu}$

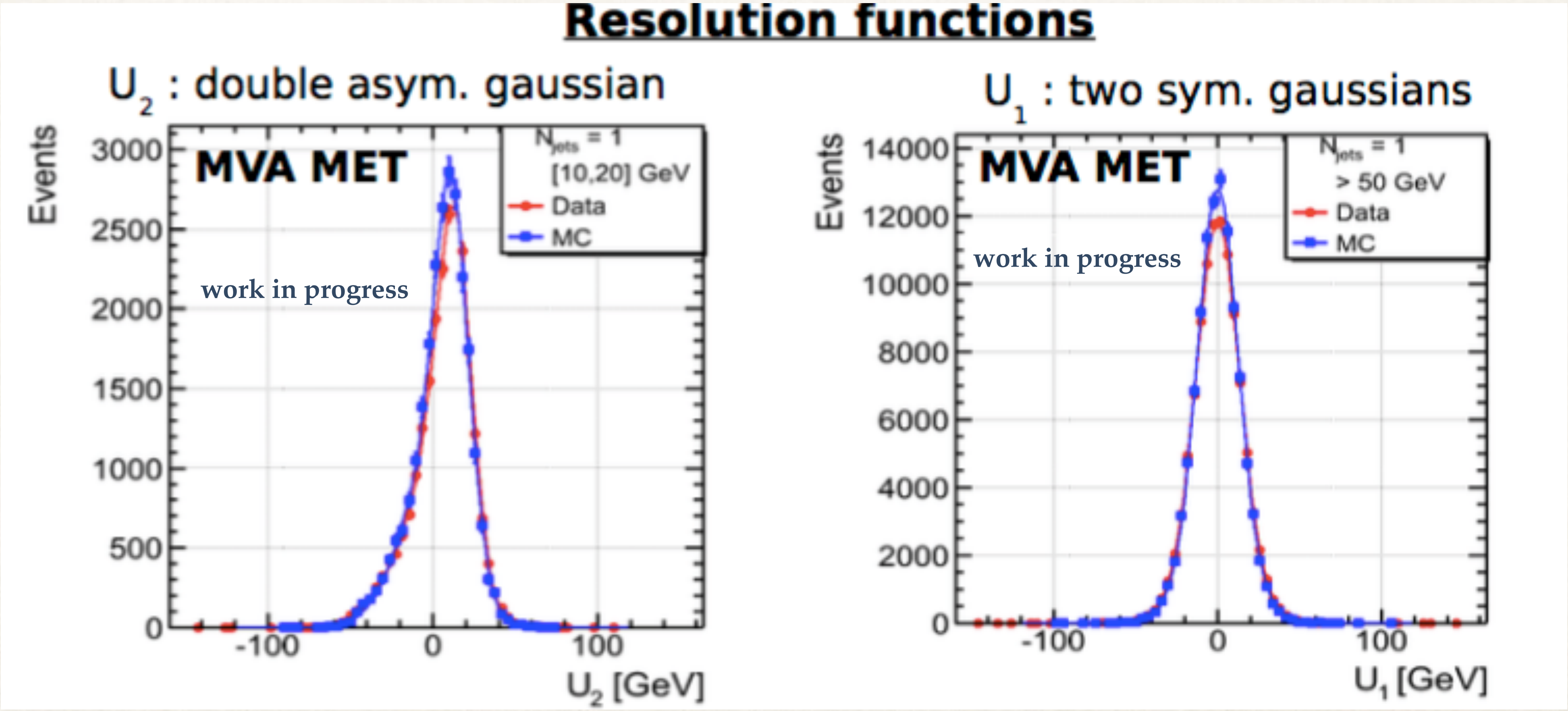


- project U on axis
  - parallel to the Z pT: U2
  - perpendicular to the Z pT:U1

2.Event selection

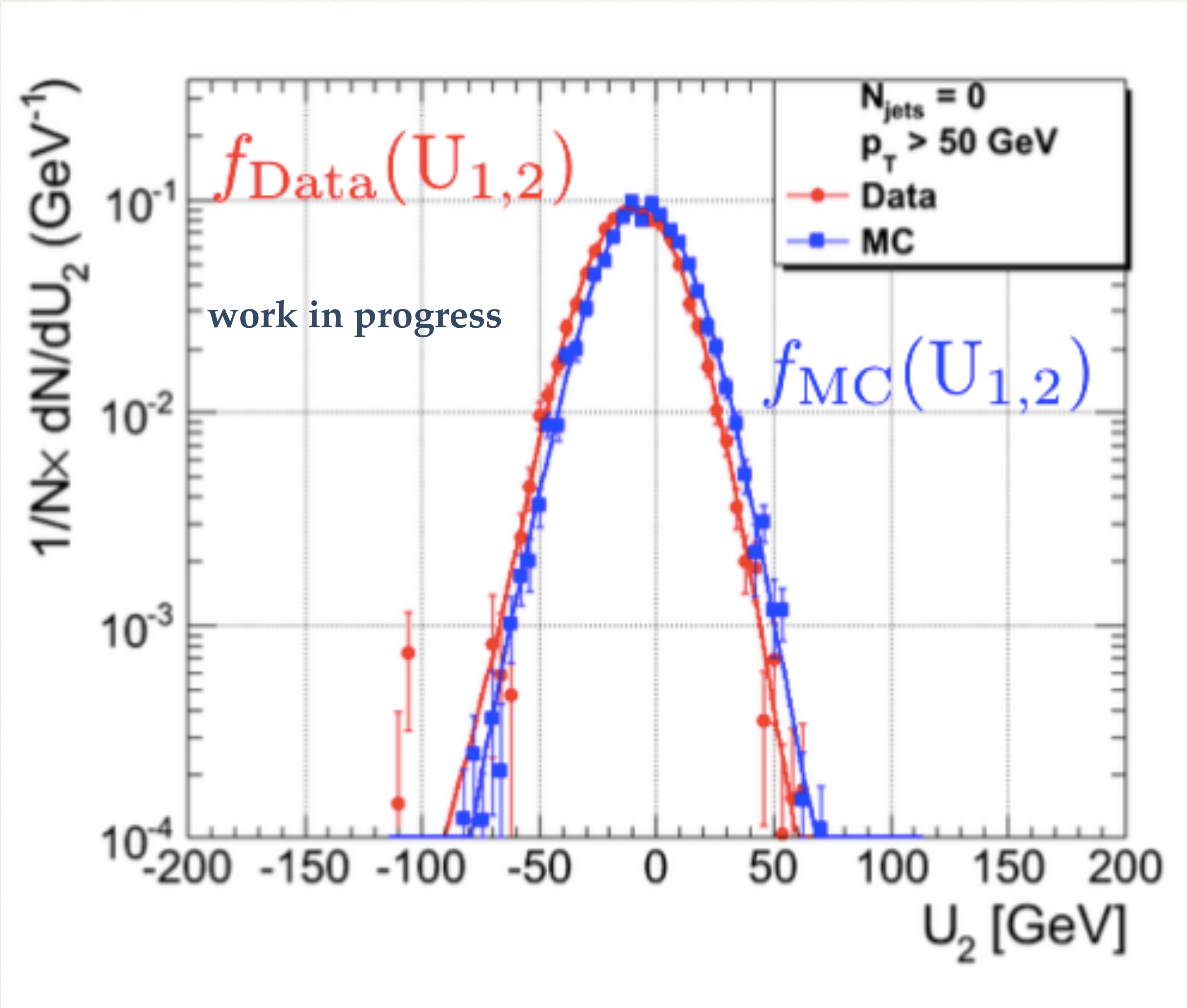
Recoil correction: fits of U1 and U2

- U1 and U2 are studied in dependence of Z pT and jet multiplicity
  - Z pT bins : [0,10] , [10,20] , [20,30] , [30,50] , [50,Inf] GeV
  - Njets bins : Njets=0 , Njets=1 , Njets ≥ 2
- $Z \rightarrow \mu\mu$ events from Z peak (70-110 GeV) are used
- backgrounds (dibosons, ttbar, single-top, QCD) are subtracted before fit in data



2.Event selection

Recoil correction: rescaling



- shift mean and rescale resolution
- Define offset w.r.t. mean value in MC:

$$w = U_{1,2} - \langle x \rangle_{MC}$$

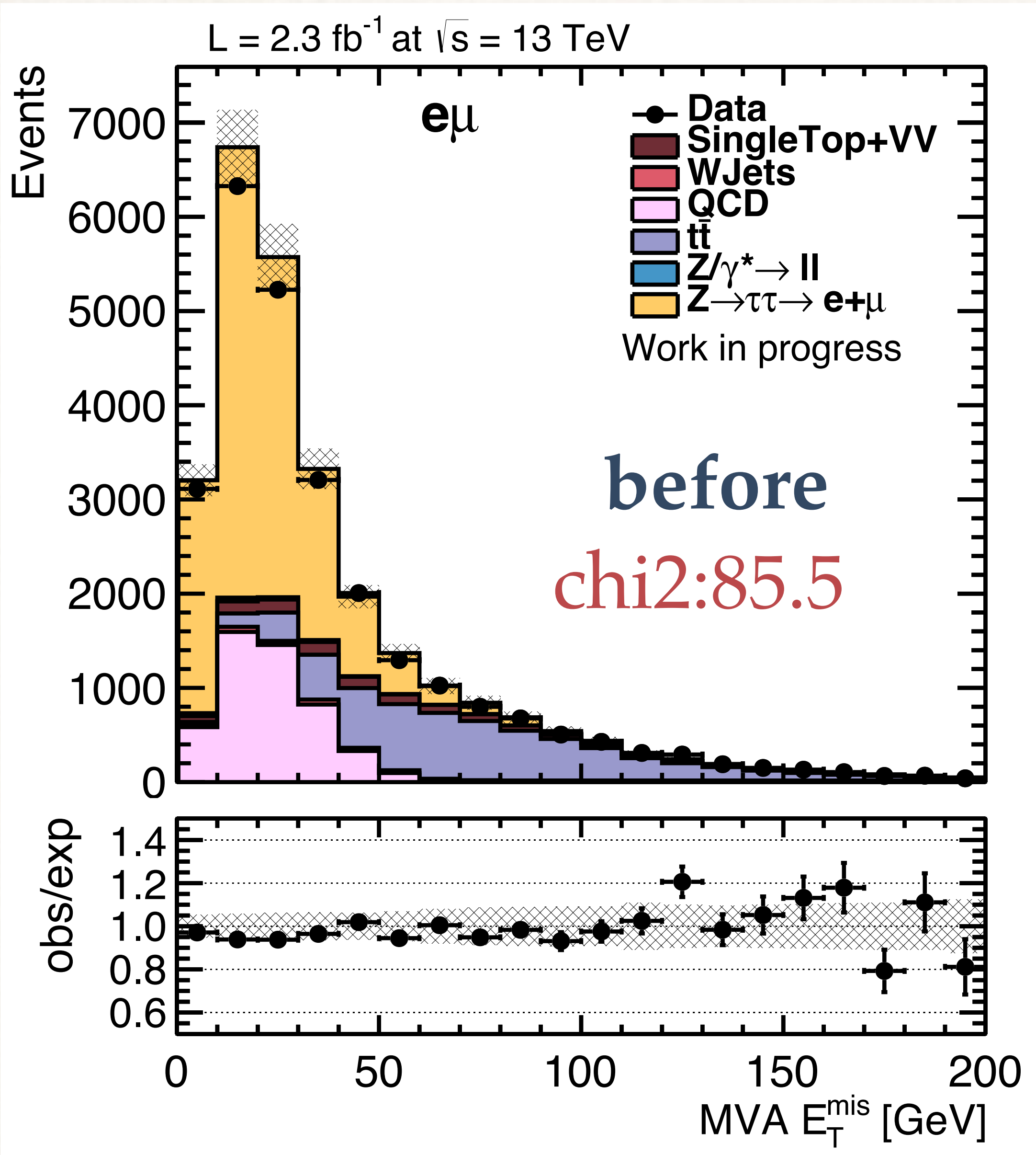
- Rescale resolution and shift w.r.t. mean value in data

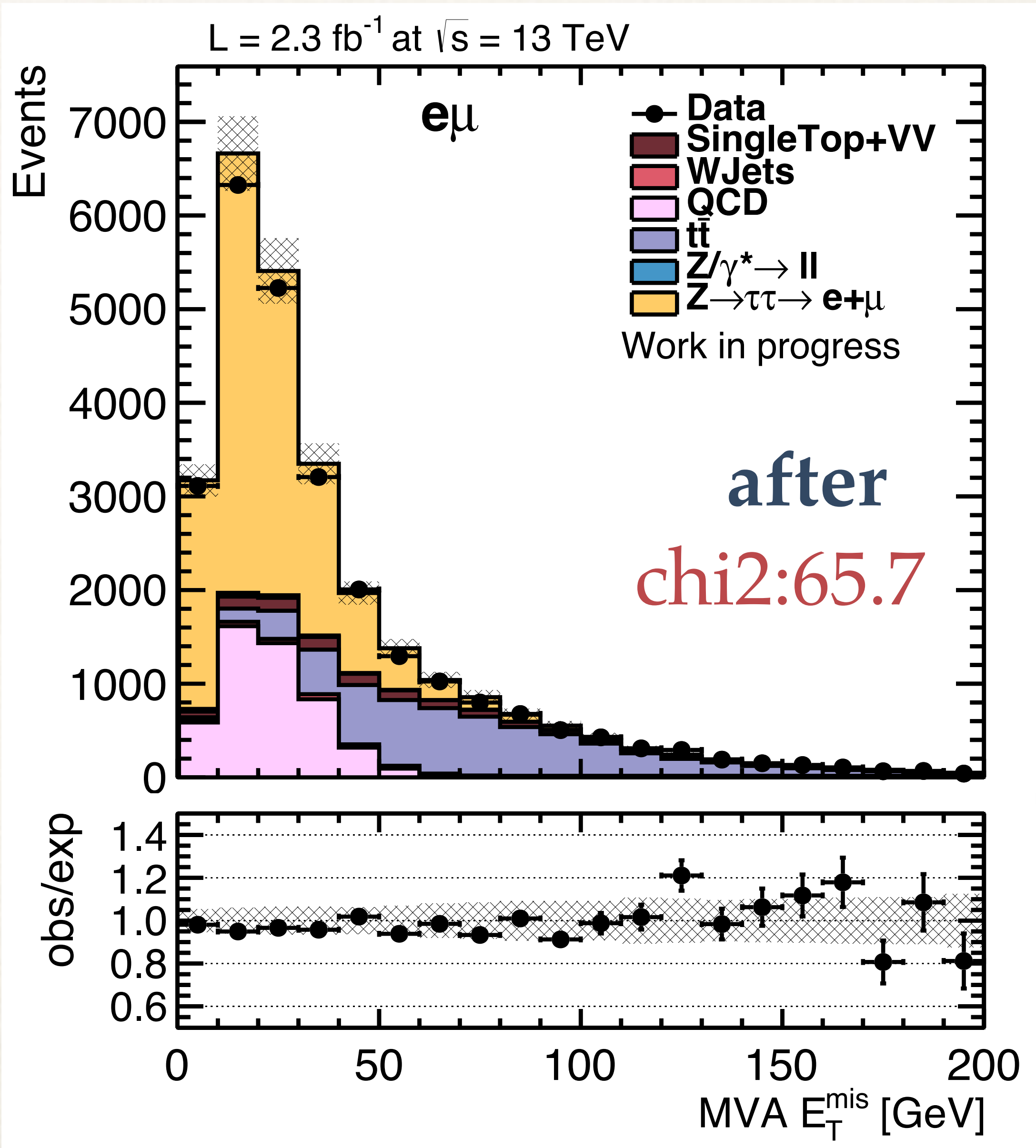
$$U'_{1,2} = \langle x \rangle_{data} + w \frac{\sigma_{data}}{\sigma_{MC}}$$

2.Event selection

Recoil correction

- apply recoil correction on DYJets and WJets samples



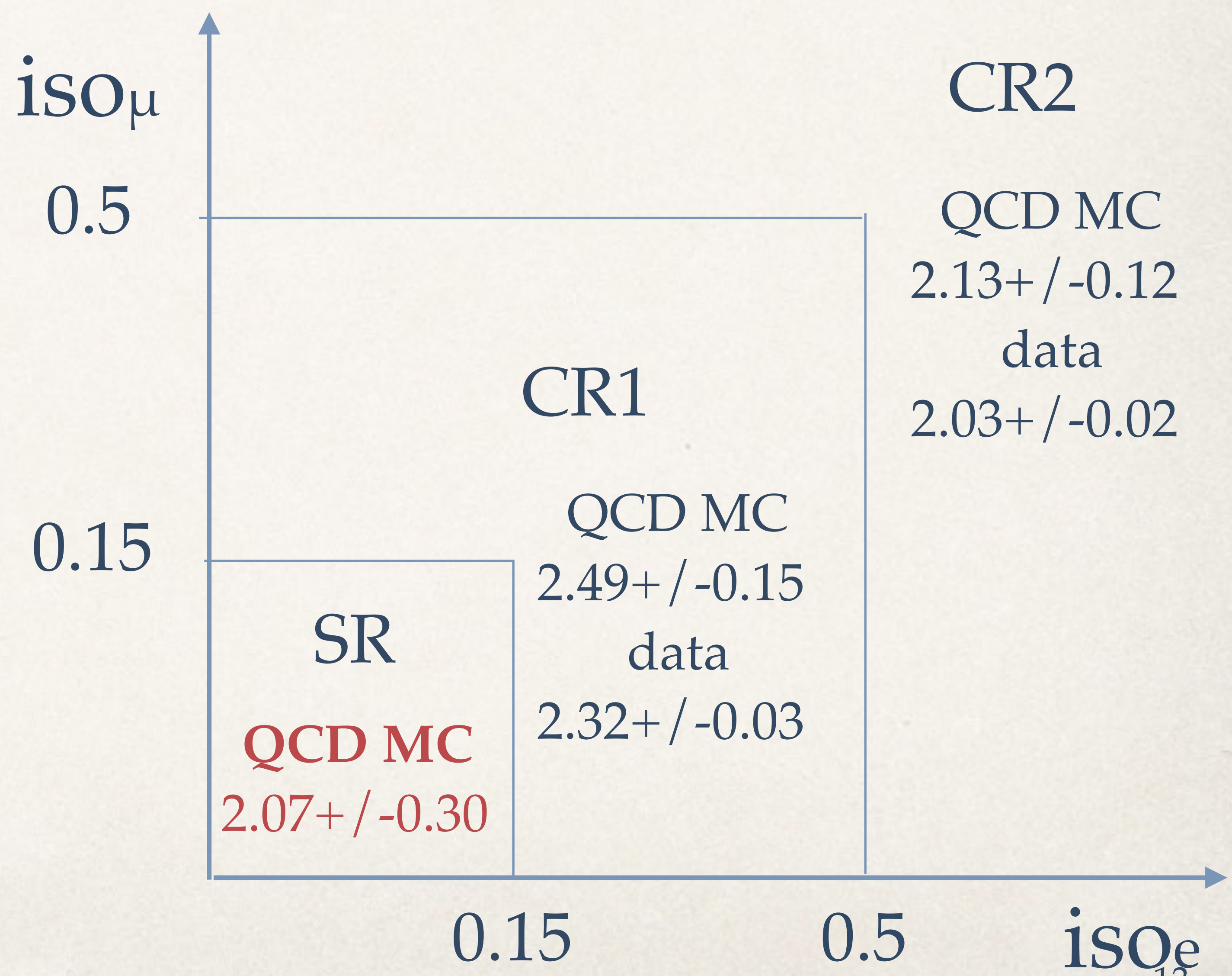


3.Background estimates

introducing refined QCD modeling

- reminder: we used ABCD method:obtained the OS/SS ratio in the inverted-lepton isolation control region and then weight the shape of SS dilepton isolation control region
- refined QCD modeling method introduced
- define control regions:
  - CR1 : ($iso_{\mu} > 0.15$ || $iso_{e} > 0.15$) && ($iso_{\mu} < 0.5$ && $iso_{e} < 0.5$)
  - CR2 : $iso_{\mu} \geq 0.5$ || $iso_{e} \geq 0.5$(for uncertainty estimation)

Compare MC prediction with data
data/MC extrapolation factors

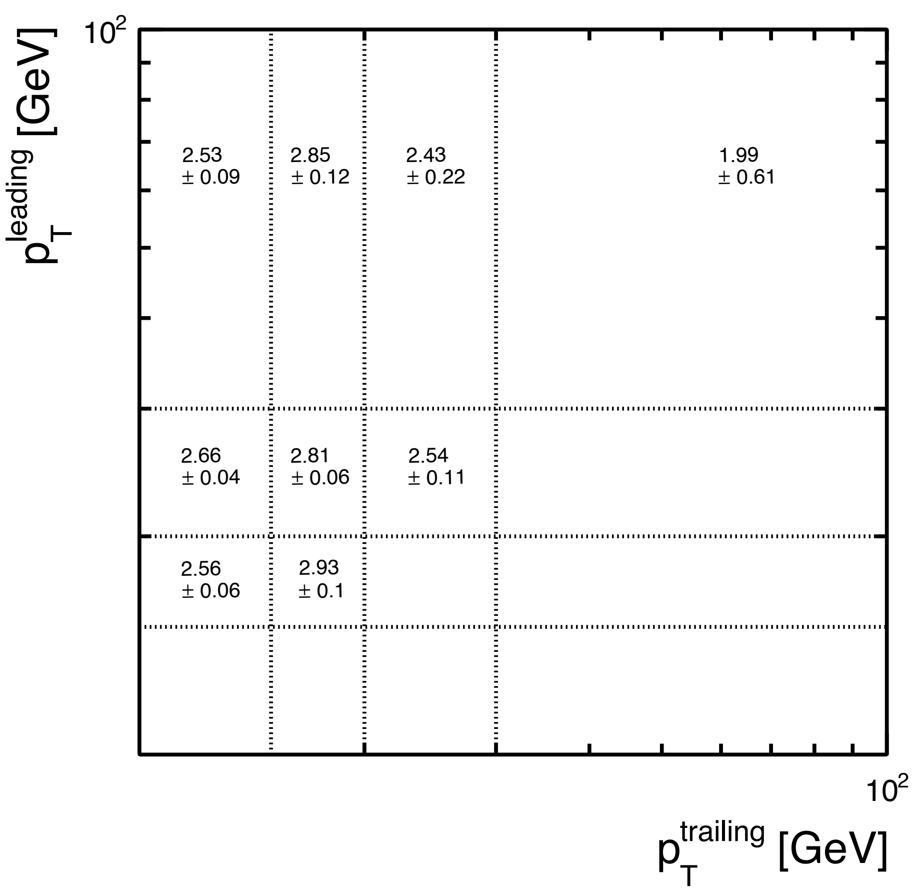


3.Background estimates

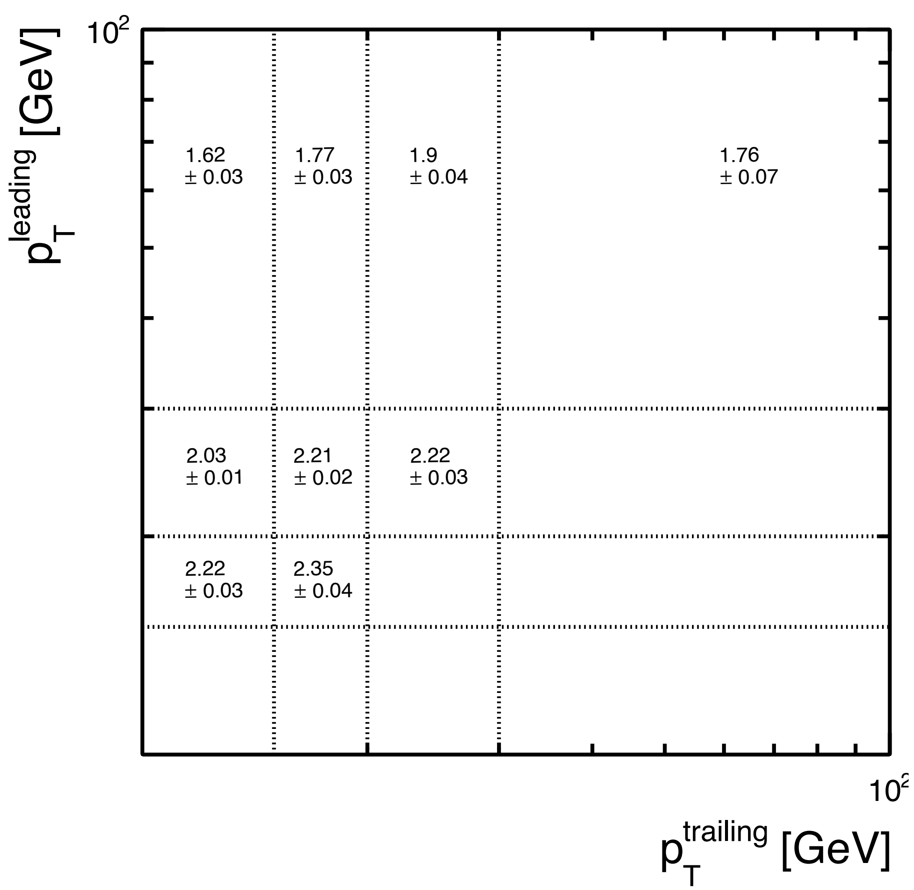
refined QCD modeling method

- shape from the SS dilepton control region
- Normalization factor: $N_{QCD} = (N_{data}^{SS} - N_{nonQCDMC}^{MC}) \times 2.07$
- OS/SS ratio as function of leading Pt, trailing Pt and $\Delta R(e,\mu)$

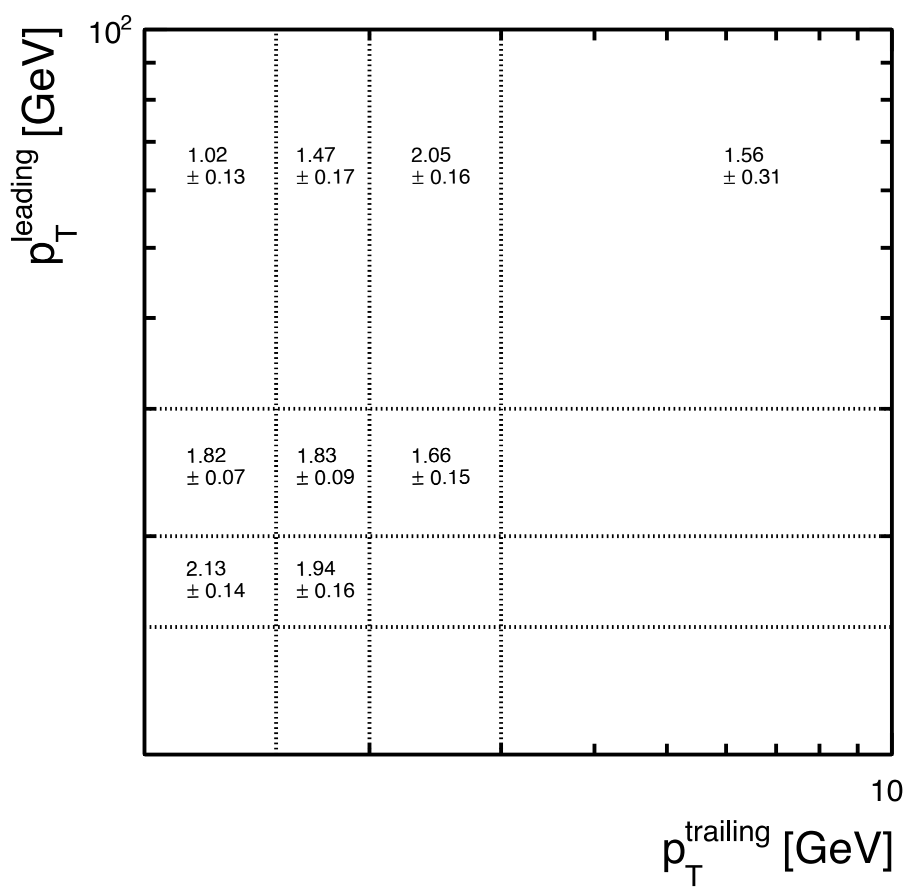
CR1 $\Delta R(e,\mu)<2$



CR1 $2<\Delta R(e,\mu)<4$

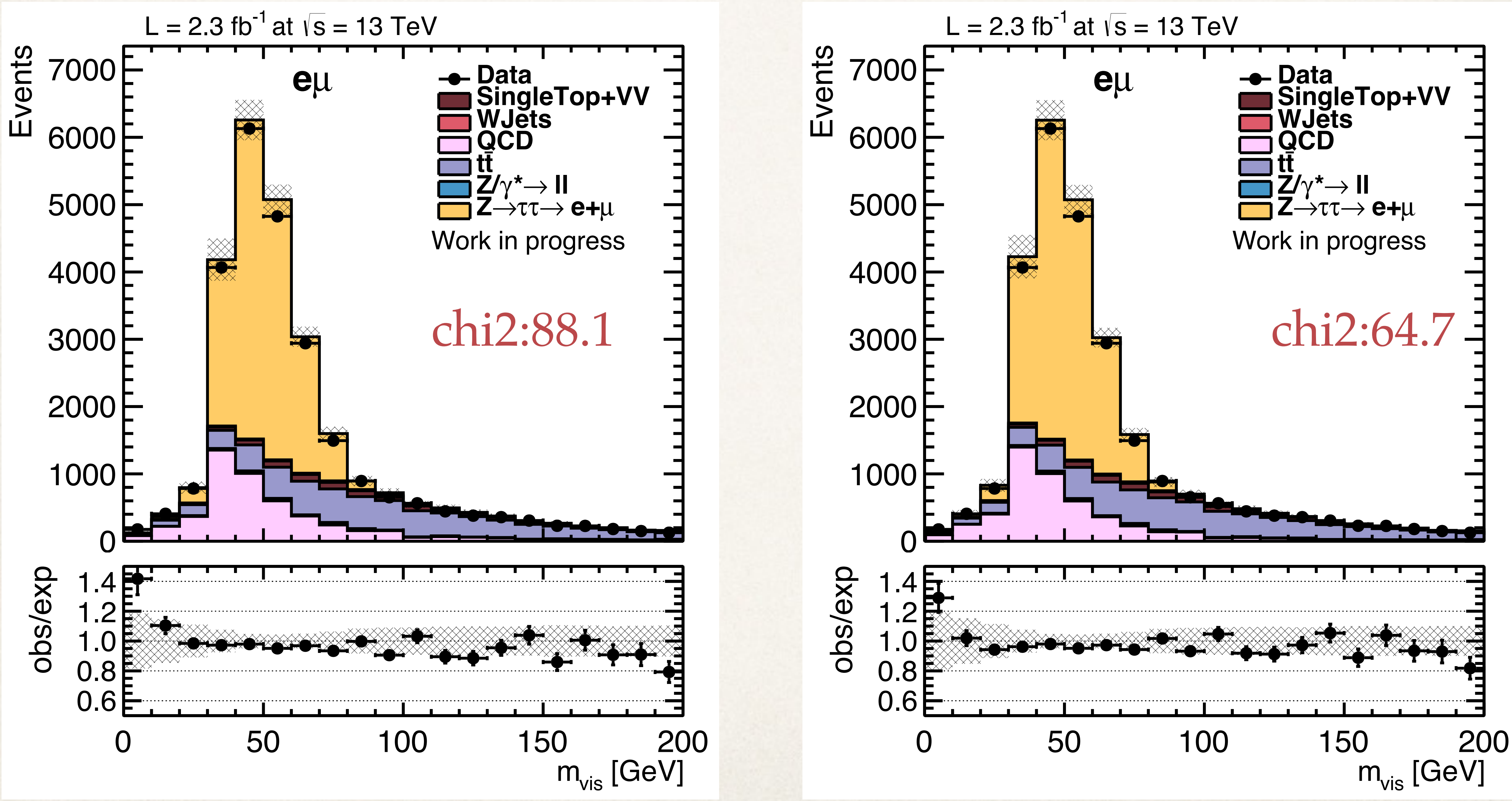


CR1 $\Delta R(e,\mu)>4$



3.Background estimates

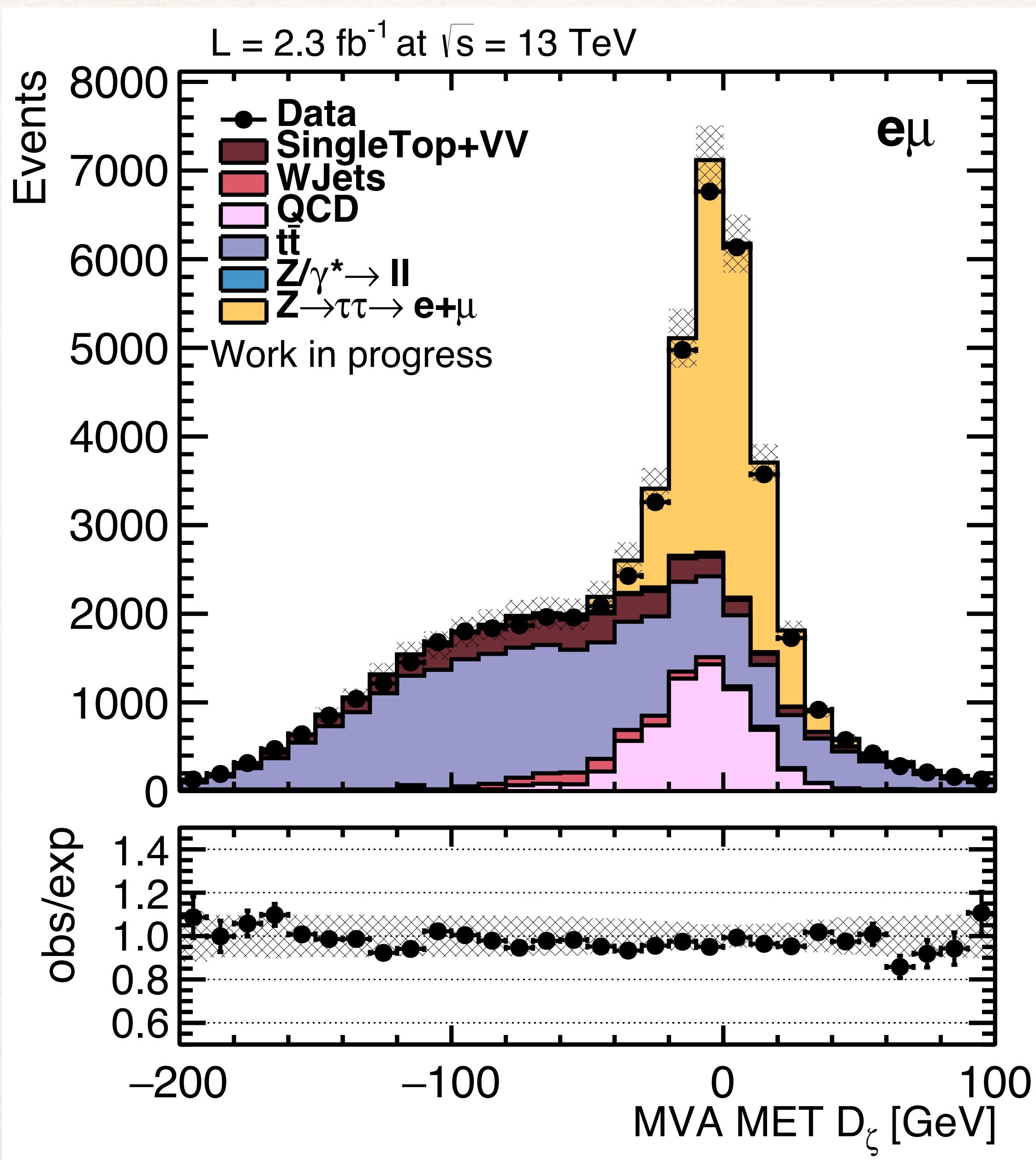
flat extrapolation factor vs. refined method

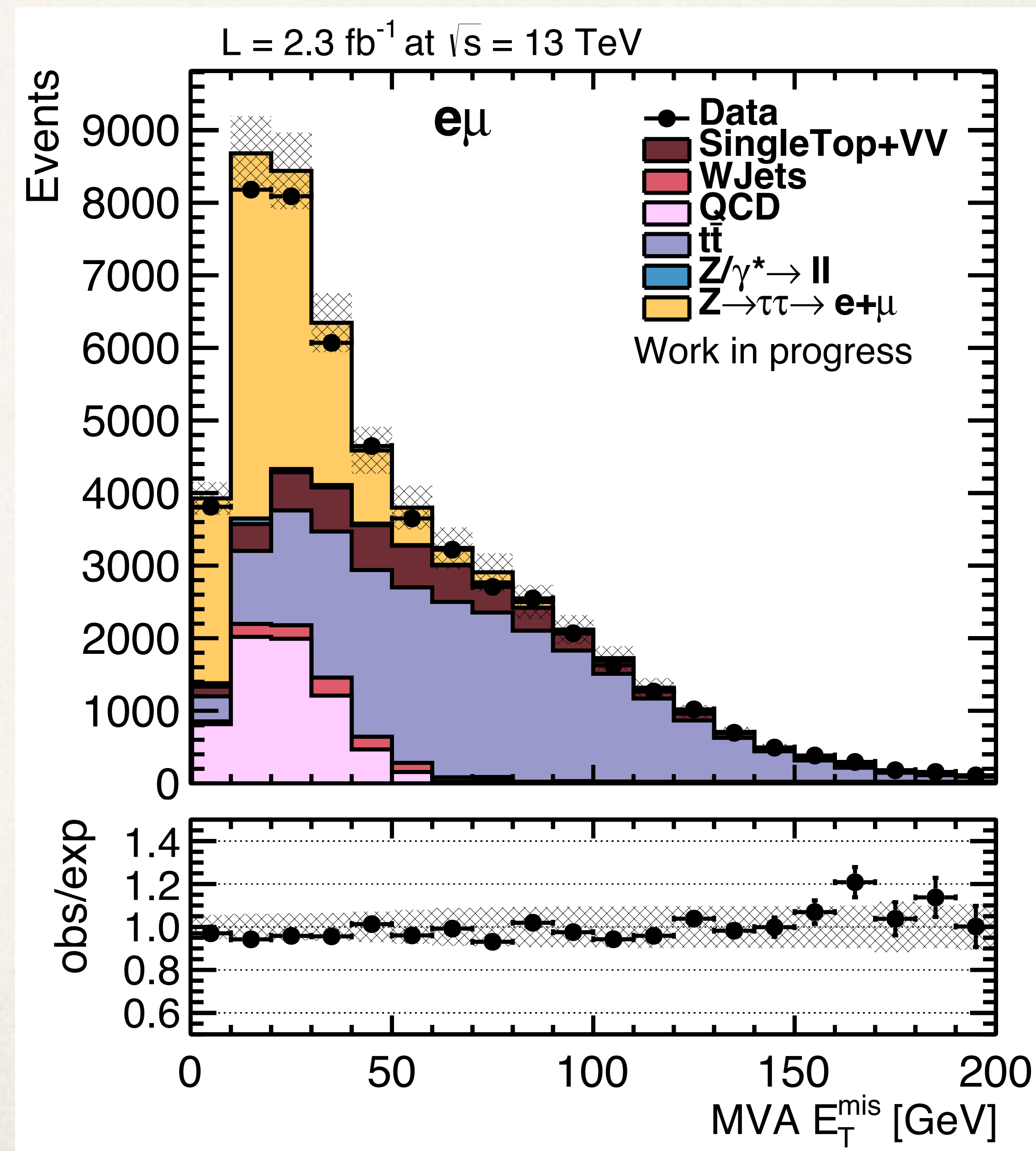


3.Background estimates

define top pair enriched region

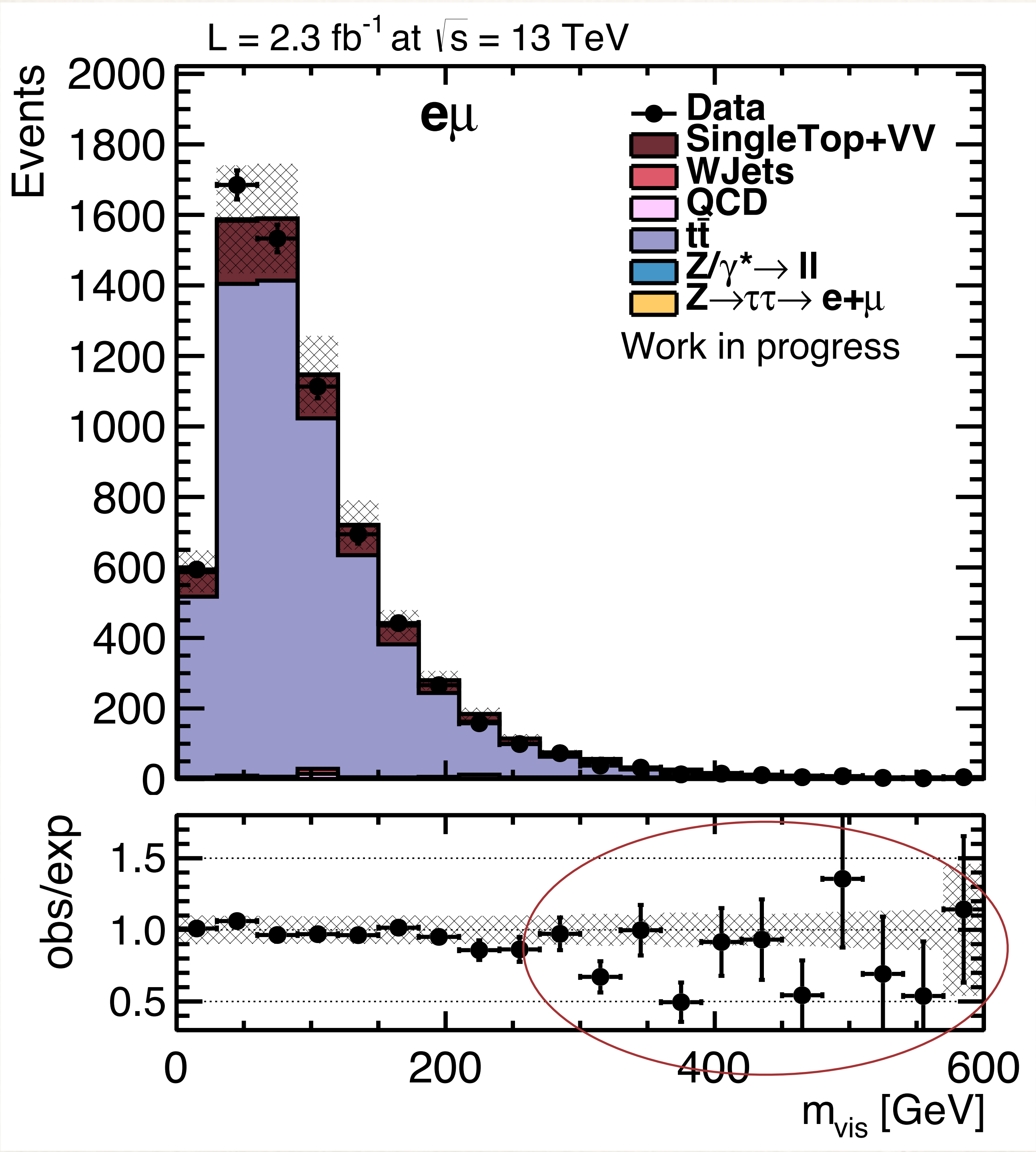
- D_ζ <-60 GeV, MET>80 GeV





3.Background estimates

visible mass distribution in control region



- Normalization consistent with unity(within uncertainty)
- Bias in shape observed

3.Background estimates

top pt reweighting

- in case TTbar is not the signal but a background, this could be improved data/MC agreement in TTbar-enriched control regions or in TTbar-enriched signal region

$$w_{\mathrm{event}} = \sqrt{w_t \cdot w_{\bar{t}}}$$

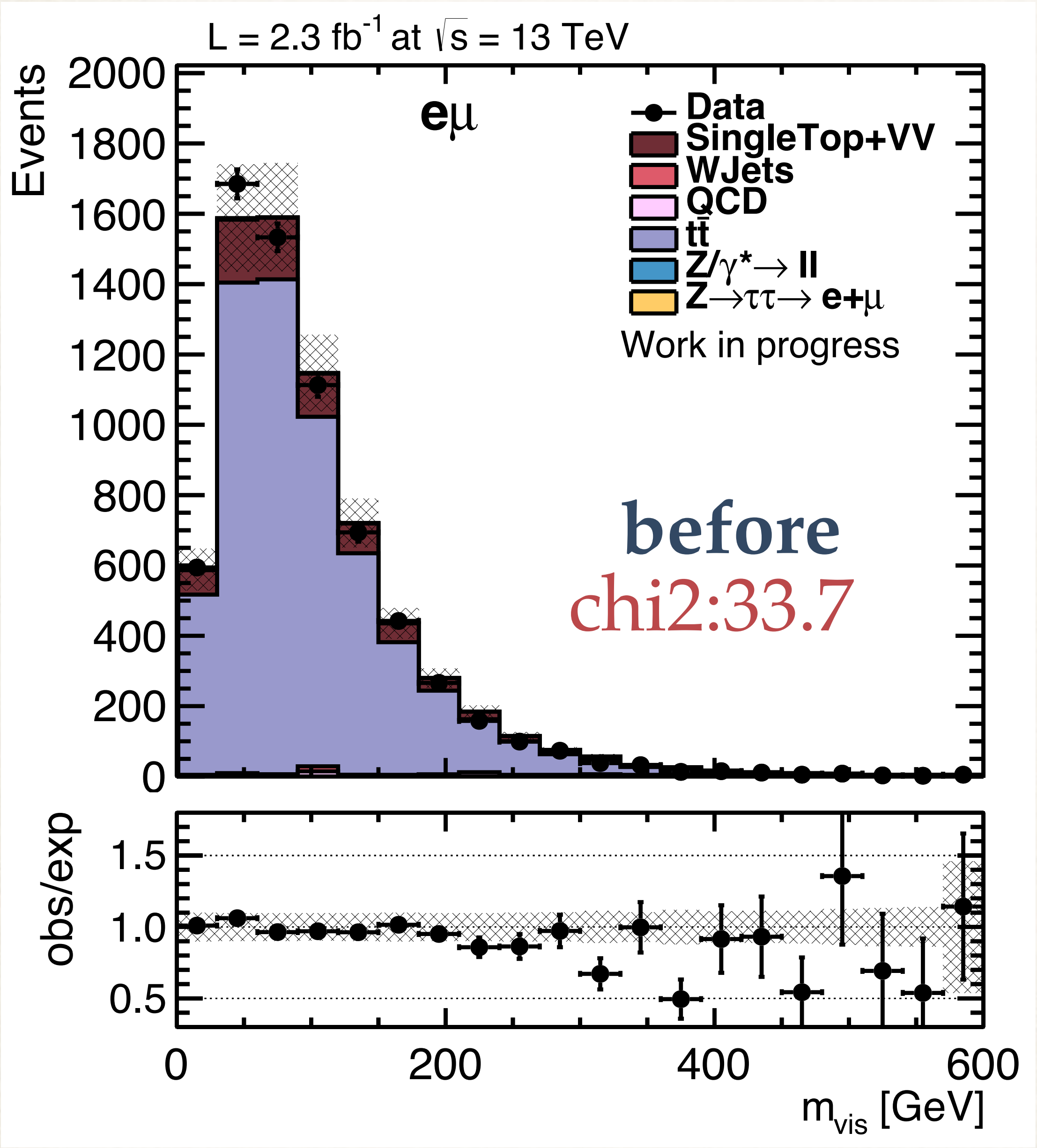
$$w_{t(\bar{t})} = \exp\left(a + b \cdot p_{\mathrm{T},t(\bar{t})}\right)$$

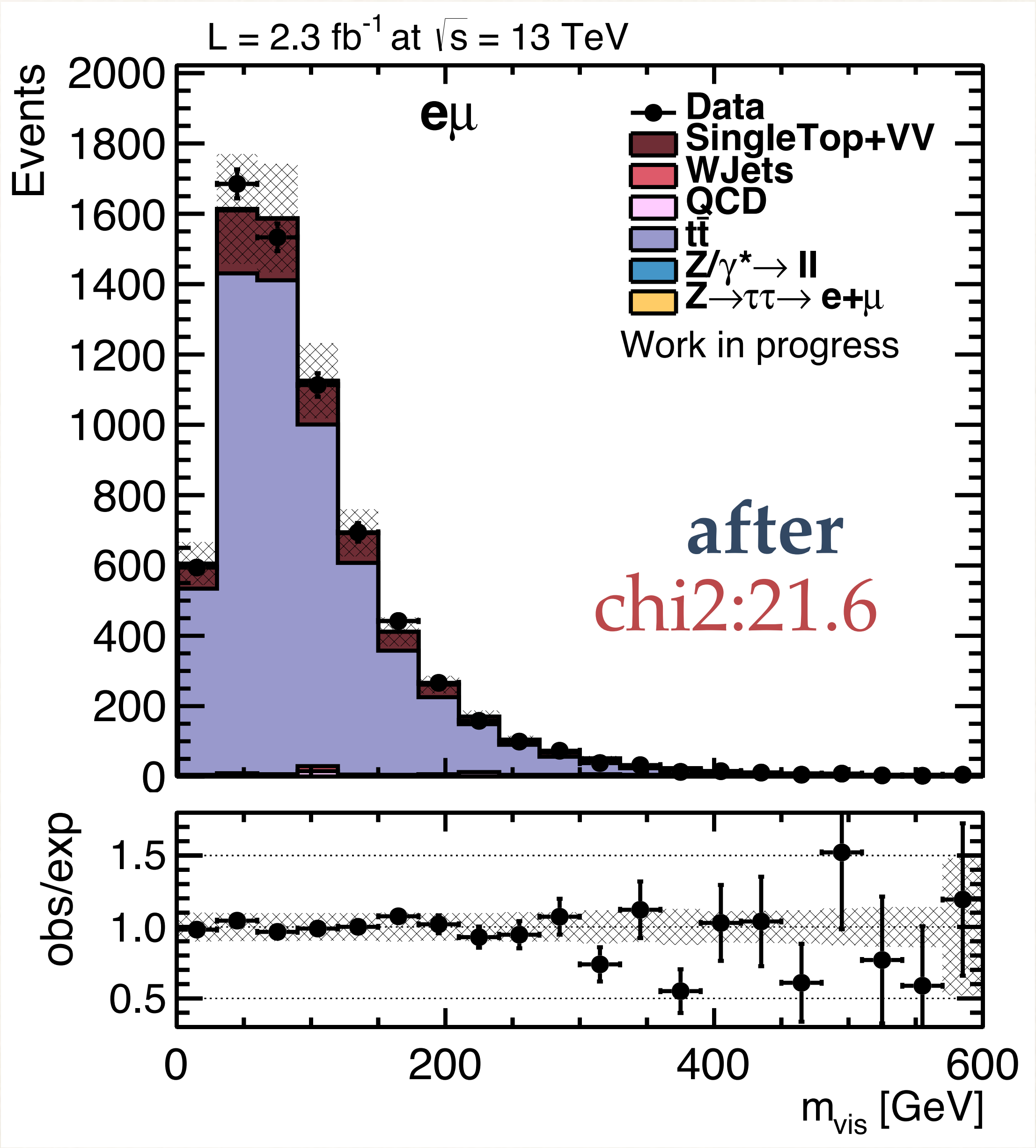
$$a = 0.156, \qquad b = -0.00137\ [\mathrm{GeV}^{-1}]$$

- coefficients obtained from run 1 analysis

3.Background estimates

top pt reweighting

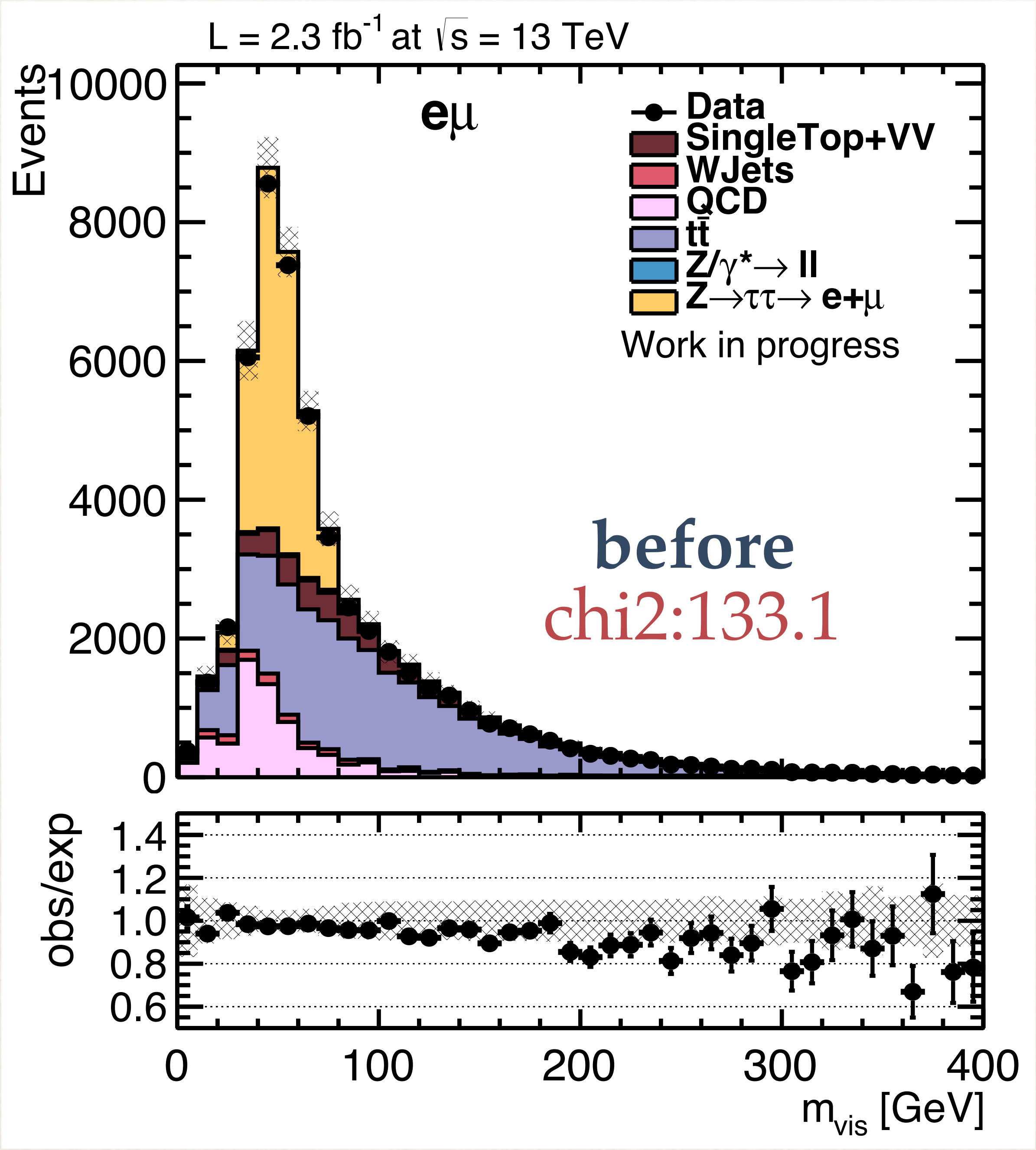


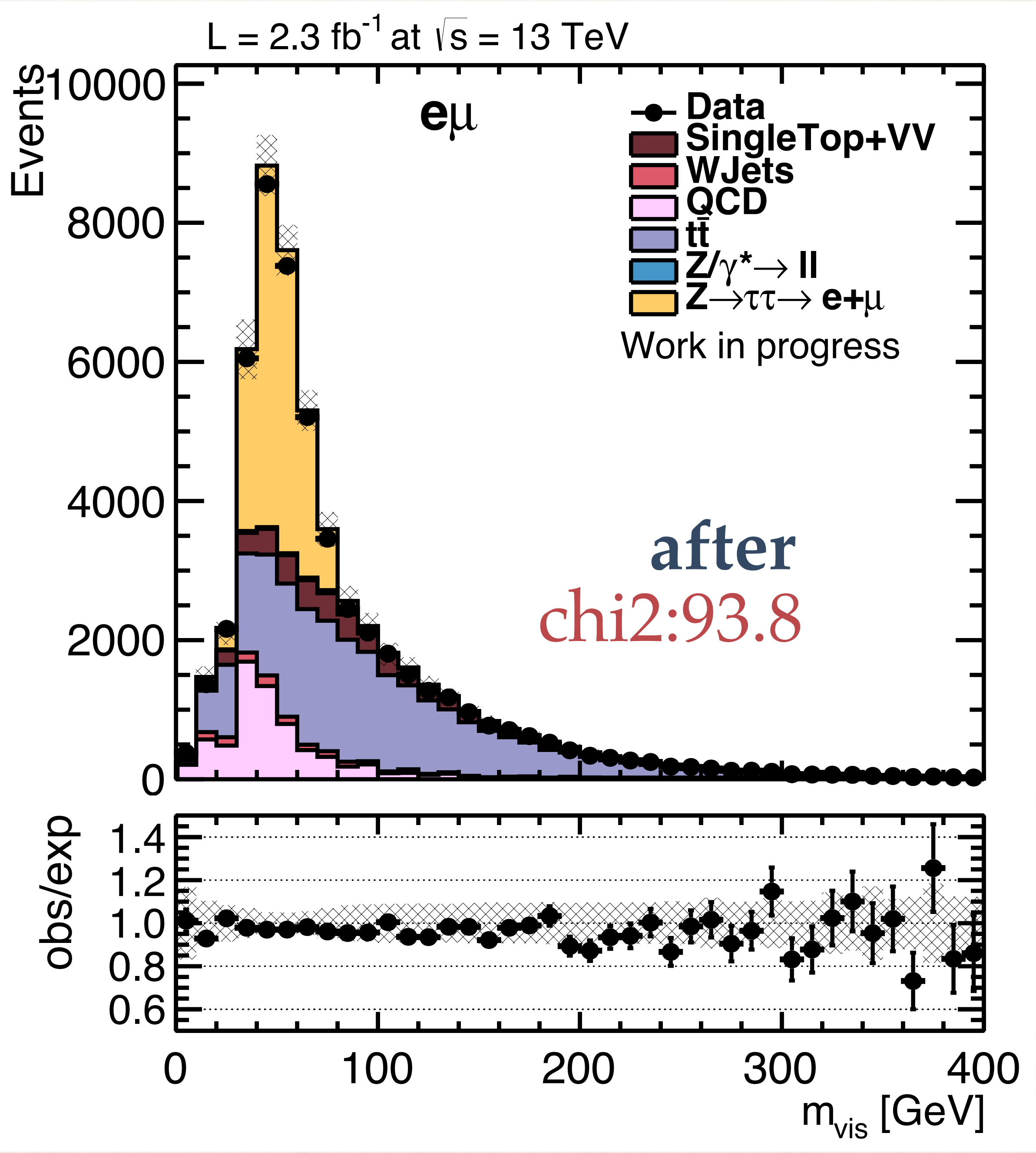


top pt reweighting improve data/MC agreement

3.Background estimates

top pt reweighting, no cut on D ζ





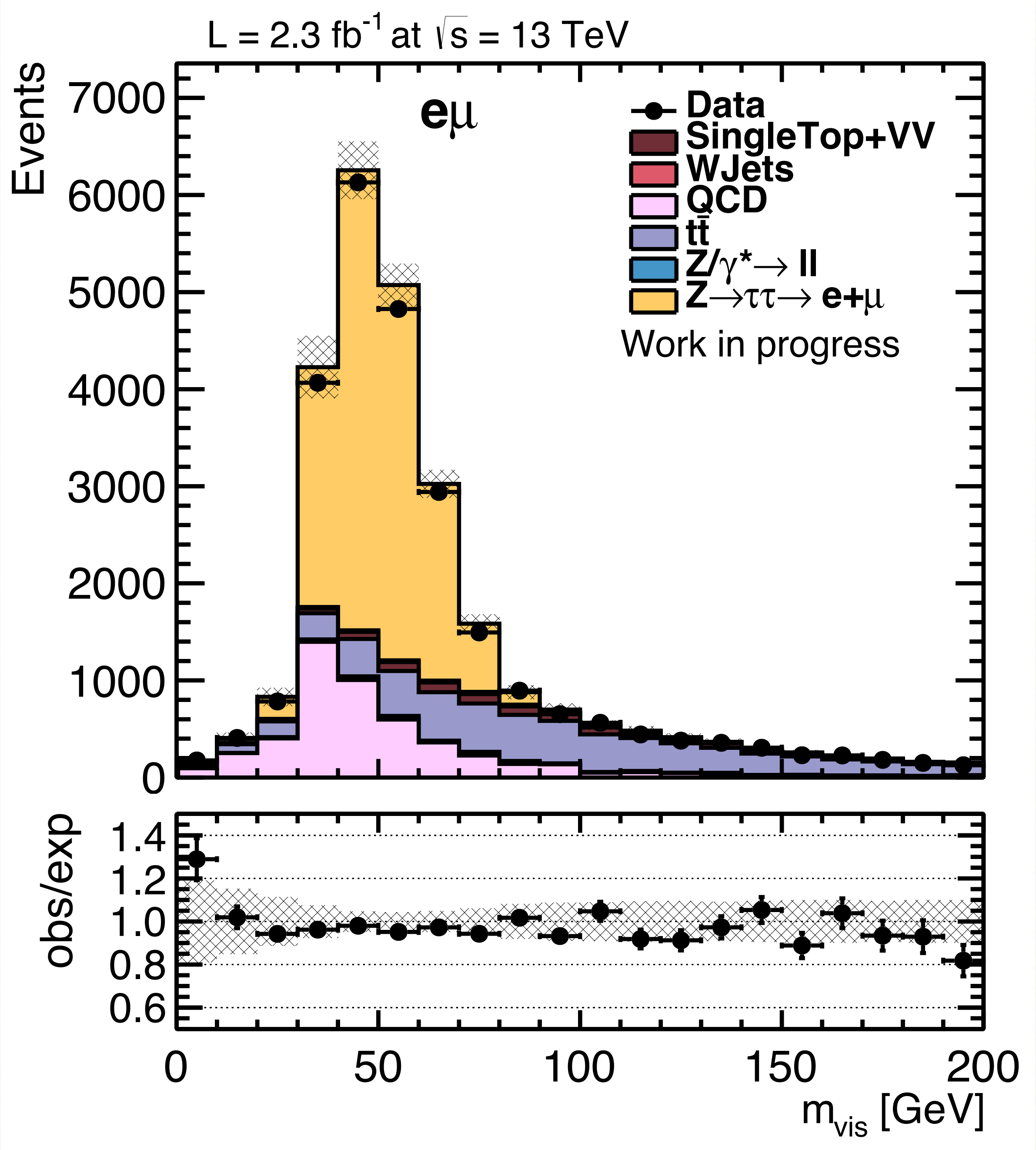
top pt reweighting improve data/MC agreement

Results

visible mass distribution

- applied topological cuts:
  - missing transverse energy < 80 GeV
  - D_{ζ} > -60 GeV
- good agreement between data and MC simulation
- cross-section could be estimated in the 30 - 90 GeV mass range

- Systematic include so far:
  - background normalization: (QCD: 20%, VV:20%, W:15%, ttbar:10%, Z(ll):10%)
  - luminosity:3%



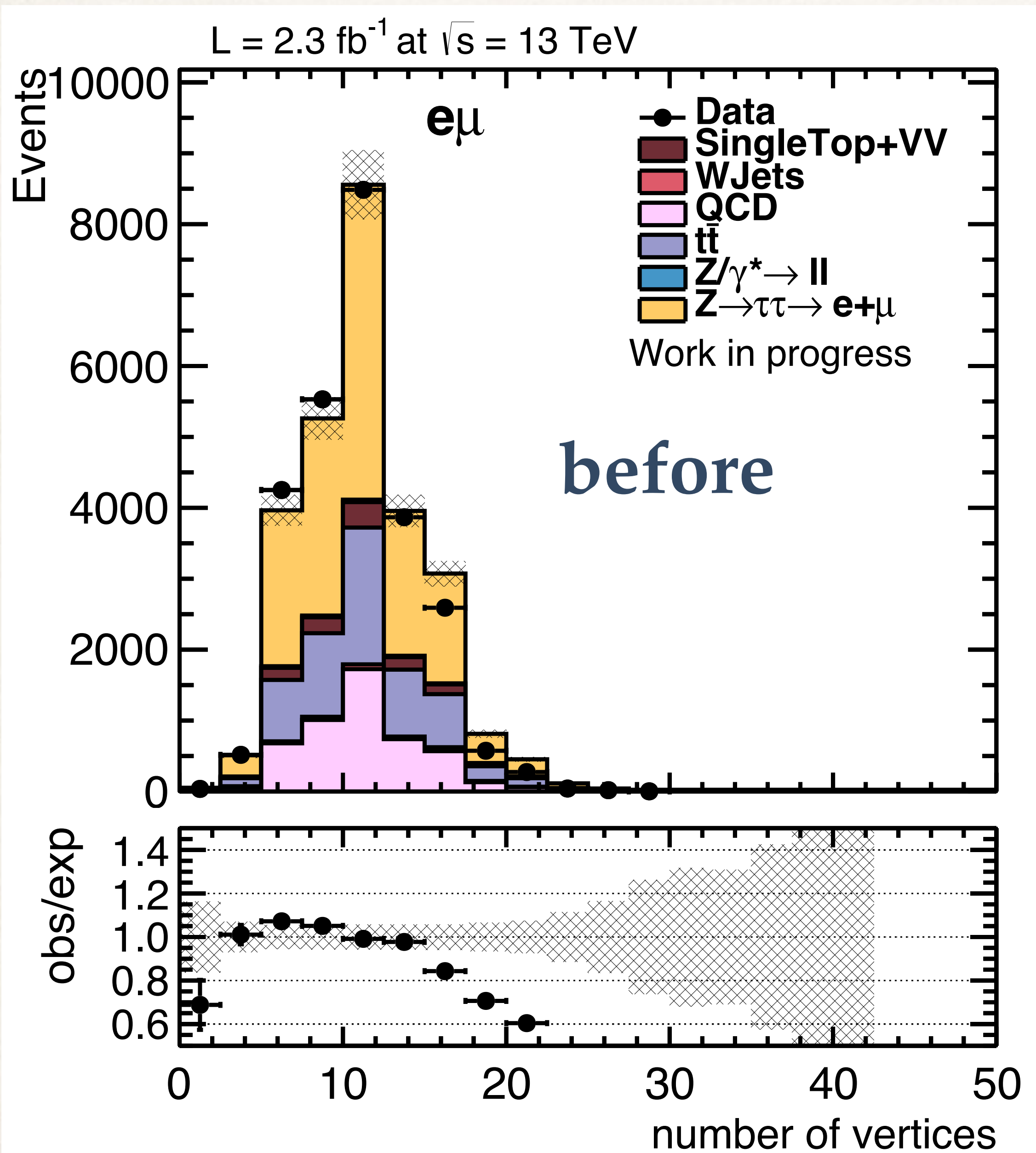
Summaries

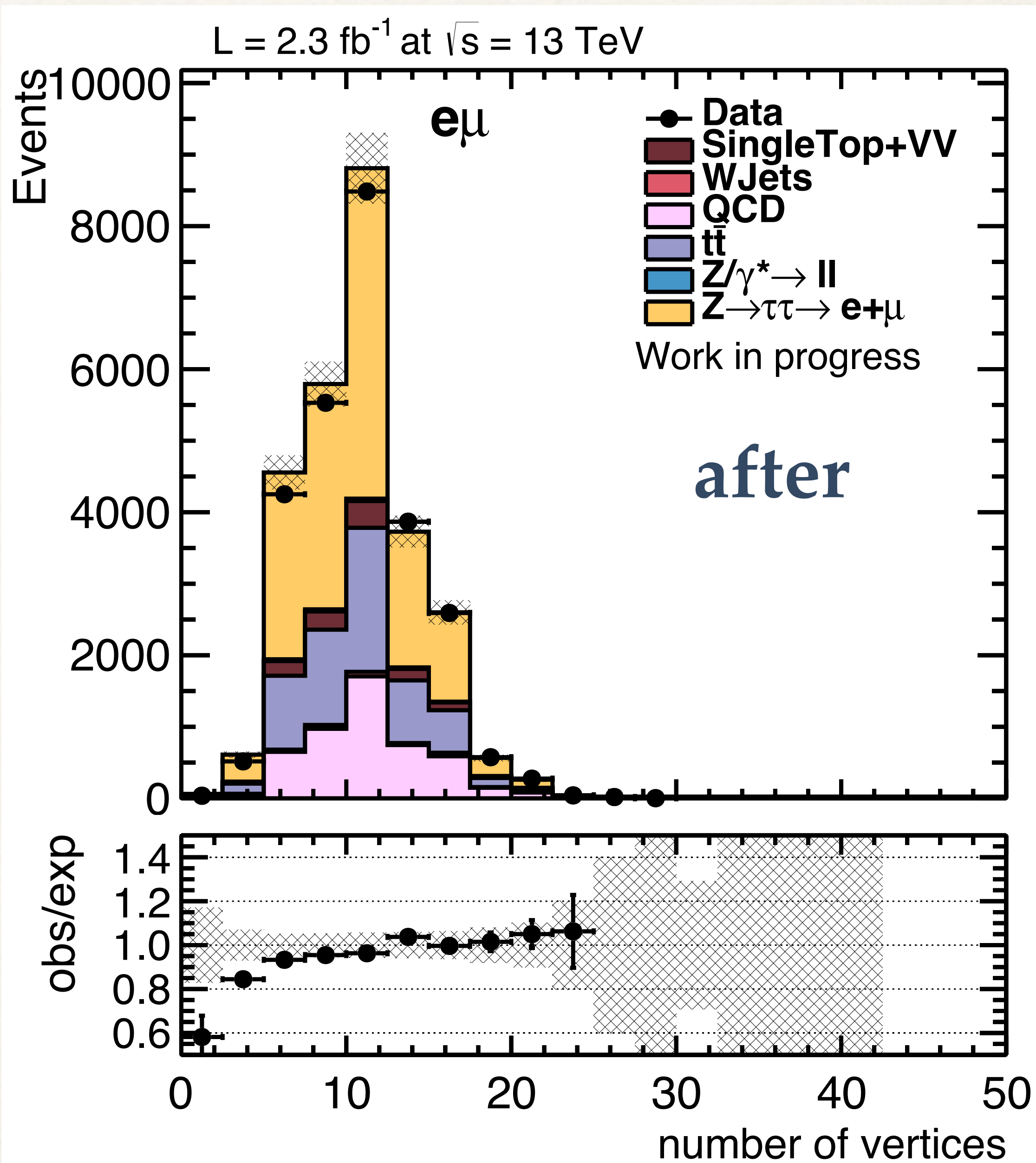
- $Z \rightarrow \tau\,\tau \rightarrow e + \mu$ studies
- implement different kinds of data/MC correction
- refining QCD modeling method shows improvement
- included top pt reweighting
- shows good data/MC agreement
- uncertainty studies are on-going and ready for cross-section measurement
- stay tuned!

Back up

2.Event selections

data/MC correction: Pileup





MC should be reweighted so that the pile up distribution matches with data

3.Background estimates

uncertainty estimates strategy on QCD modeling

- central template: using the CR1 OS/SS ratio
- up template: using the CR2 OS/SS ratio
- down template: $(CR1)^2/CR2$