DY Differential Cross Section Measurement at 13 TeV with the CMS Detector

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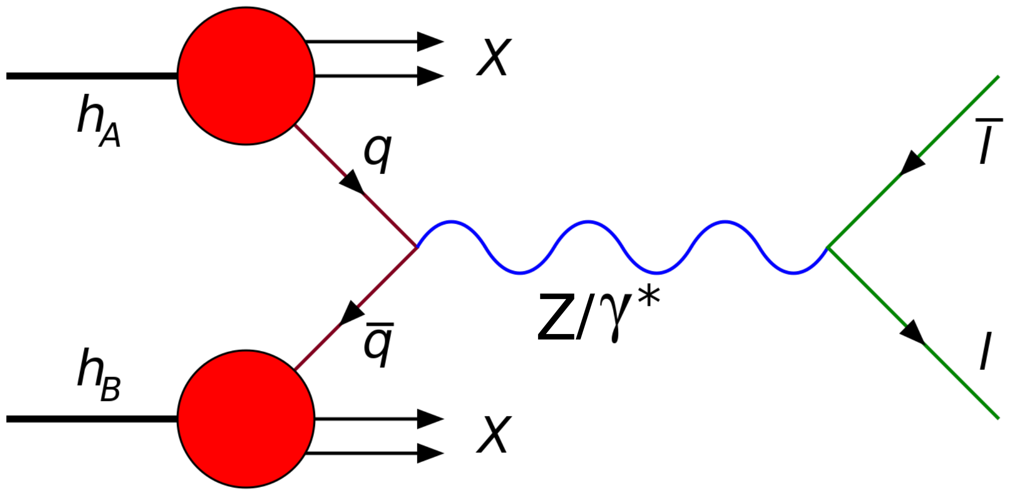
2nd BRL Workshop

Introduction: Drell-Yan Process and Cross Sections

Drell-Yan (DY) process

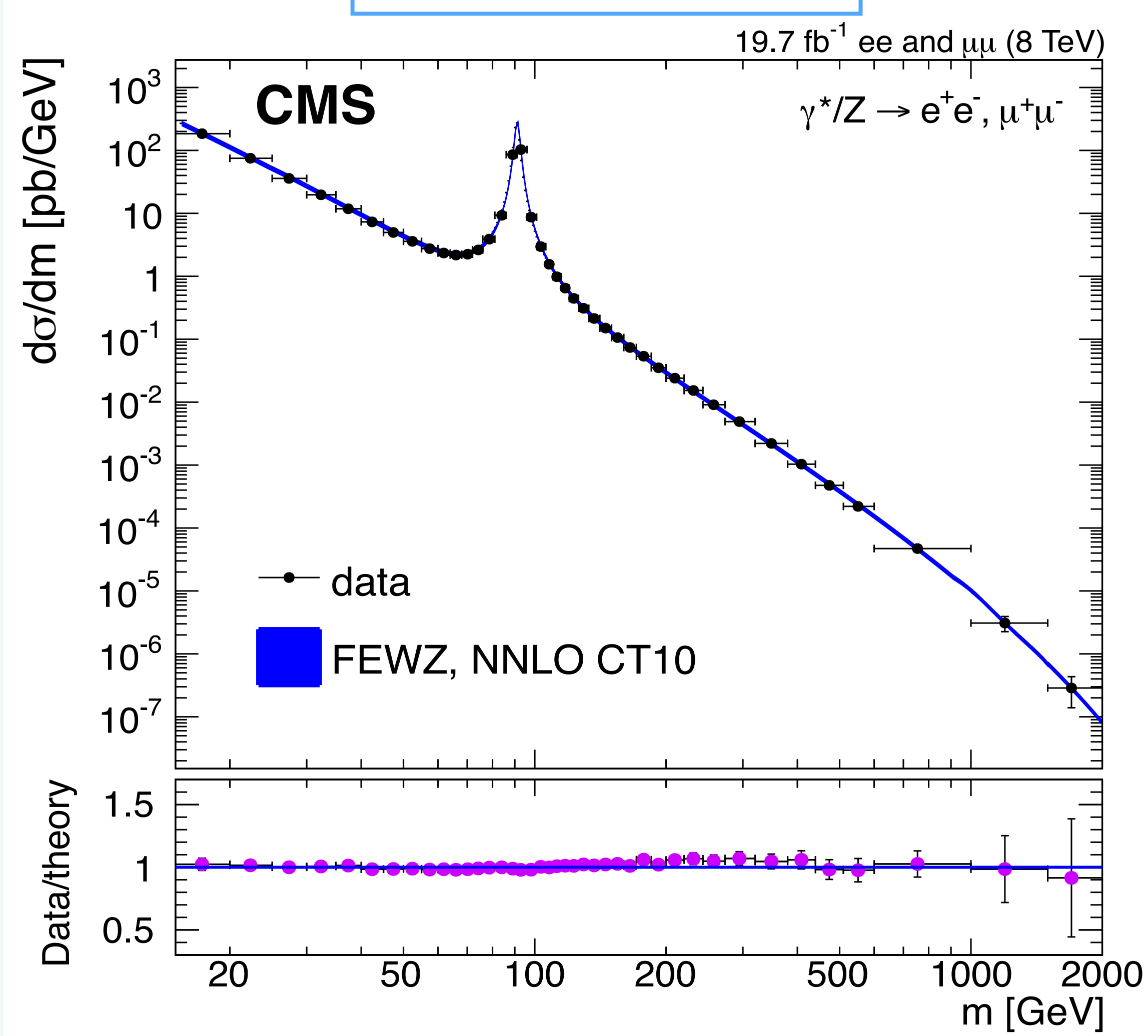
- process in which lepton pairs are produced via γ^*/Z exchange



Motivation to measure DY differential cross section

- Effective input for PDF constraints
  - $m_{\ell\ell}$ & $y_{\ell\ell}$: sensitive to parton distribution functions (PDFs)
  - achievable experimental precision < PDF uncertainty
- Important for various LHC physics analyses
  - a major source of background for many processes (ex> Z')

8TeV dσ/dm result



DY differential cross section is continuously measured in CMS

- JHEP10(2011)007 (7 TeV, early data: 36 pb^{-1})
- JHEP12(2013)030 (7 TeV)
- Eur. Phys. J. C (2015) 75:147 (8 TeV)
- CMS-PAS-SMP-16-009 (13 TeV, μμ only)

This is the first measurement using 13TeV data

Introduction: Analysis Overview

Goal of the analysis

- Measure the **differential cross section dσ/dm of Drell-Yan process**
  - Dilepton channel
  - 15 < M < 3000 GeV, 43 bins
  - Cut & count method

Cross section of i-th mass bin

$$\sigma_i = \frac{N_i^u}{A_i \ \varepsilon_i \ L}$$

Observed yield with
- momentum scale correction
- background subtraction
- unfolding correction

Integrated luminosity

Acceptance *Efficiency*

Analysis steps

Event selection → **Background subtraction** → **Corrections** → **Estimation on systematic uncertainties** → **Results**

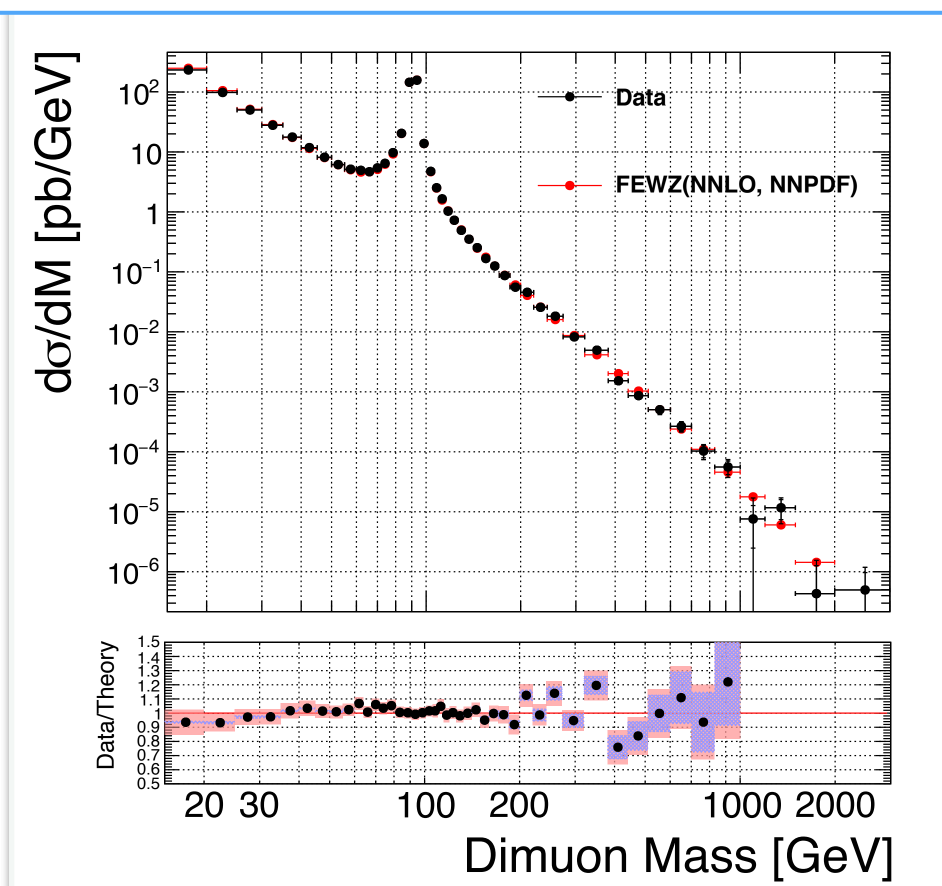
- Correction for the detector resolution based on MC
- Acceptance and efficiency estimation
- Efficiency correction using Tag&Probe method
- Correction for the FSR effects based on MC

Progress from Previous Workshop

1st Workshop (25-27 March, 2016: link)

- Preliminary result of diff. cross section in μ channel
  - Central value & most of uncertainties were available
  - A couple of uncertainties were missing (ex. theoretical unc.) & need to be finalized

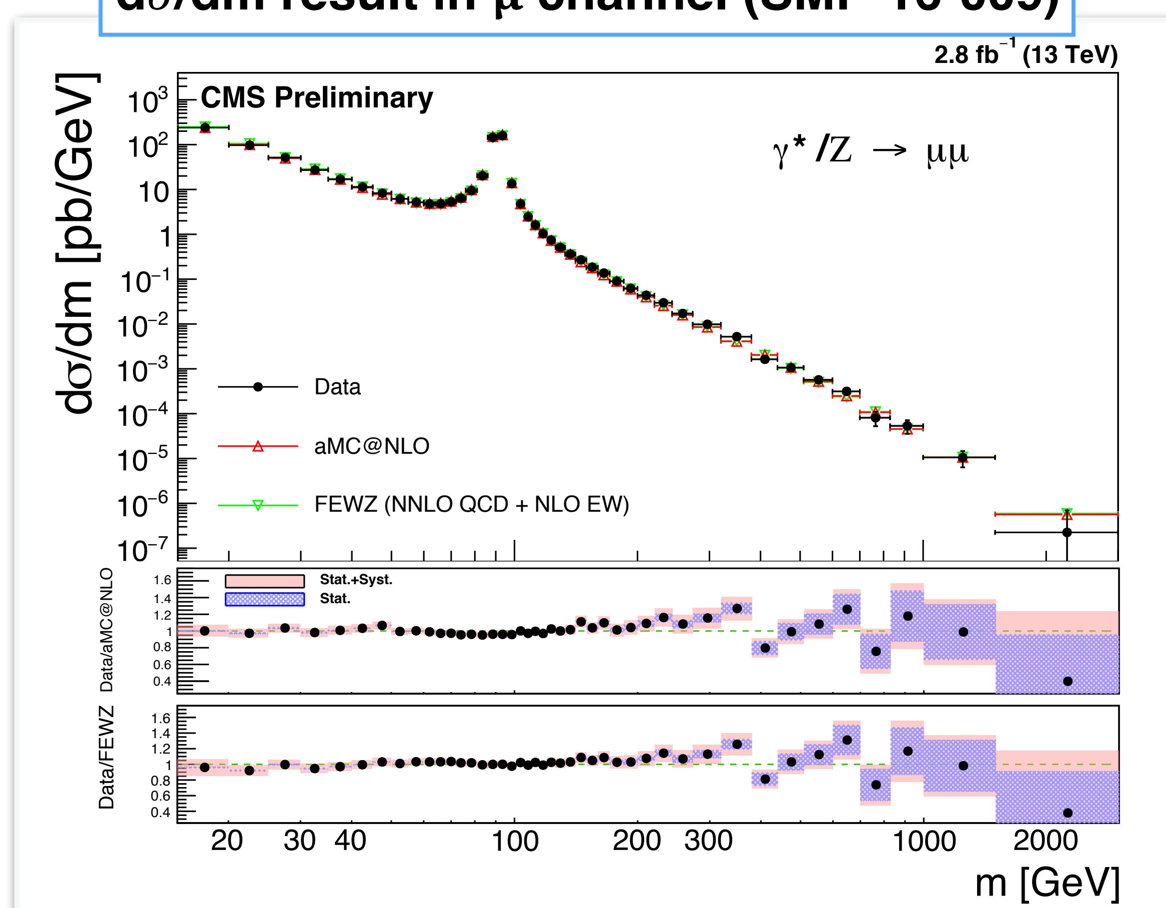
dσ/dm result in μ channel (@ 1st workshop)



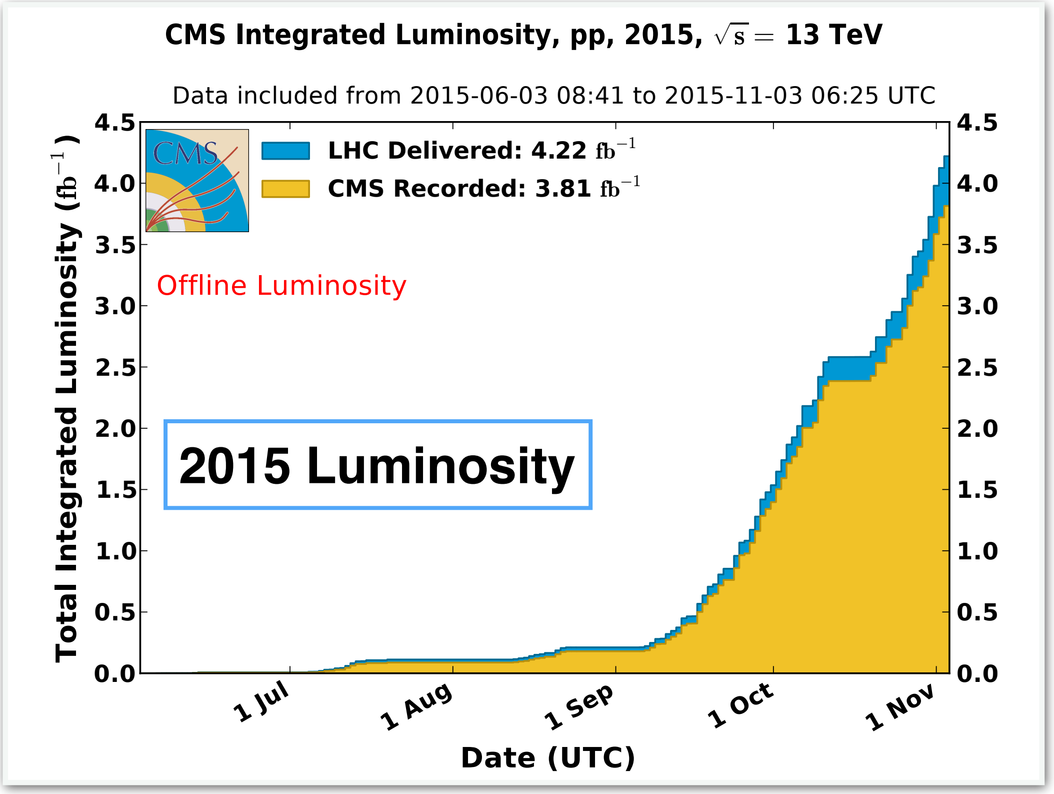
2nd Workshop (16-18 June, 2017)

- Diff. cross section in μ channel became **public** & was presented in ICHEP2016
  - **CMS-PAS-SMP-16-009** (link)
- Working on **e** channel & combination of two channels
  - Under review process in CMS now

dσ/dm result in μ channel (SMP-16-009)



Samples and Event Selection



Data: 2015 full CMS dataset

- proton-proton collision data with $\sqrt{s}$=13 TeV
  - Muon channel: **2.8 fb^{-1}**
  - Electron channel: **2.3 fb^{-1}**

Monte-Carlo (MC) samples

- Signal: $Z/\gamma^* \rightarrow \ell^+\ell^-$ simulated using **aMC@NLO**
- backgrounds: $t\bar{t}$, tW+$\bar{t}$W, diboson, W+Jets and QCD

Event Selection: Select 2 prompt and isolated leptons

- Isolated **single lepton trigger** with $P_T > 20$ (23) GeV for **μ** (**e**) channel
- $P_T^{lead} >$ **22 (30)** GeV, $P_T^{sub} >$ **10** GeV, $|\eta| < 2.4$ (2.5) for **μ** (**e**) channel
- Follow the CMS standard selection

Corrections

- Pileup reweighting on MC
  - To have same pileup distribution with the data
- Muon momentum scale correction & Electron energy scale correction
  - Better agreement between MC and data in dilepton mass distribution

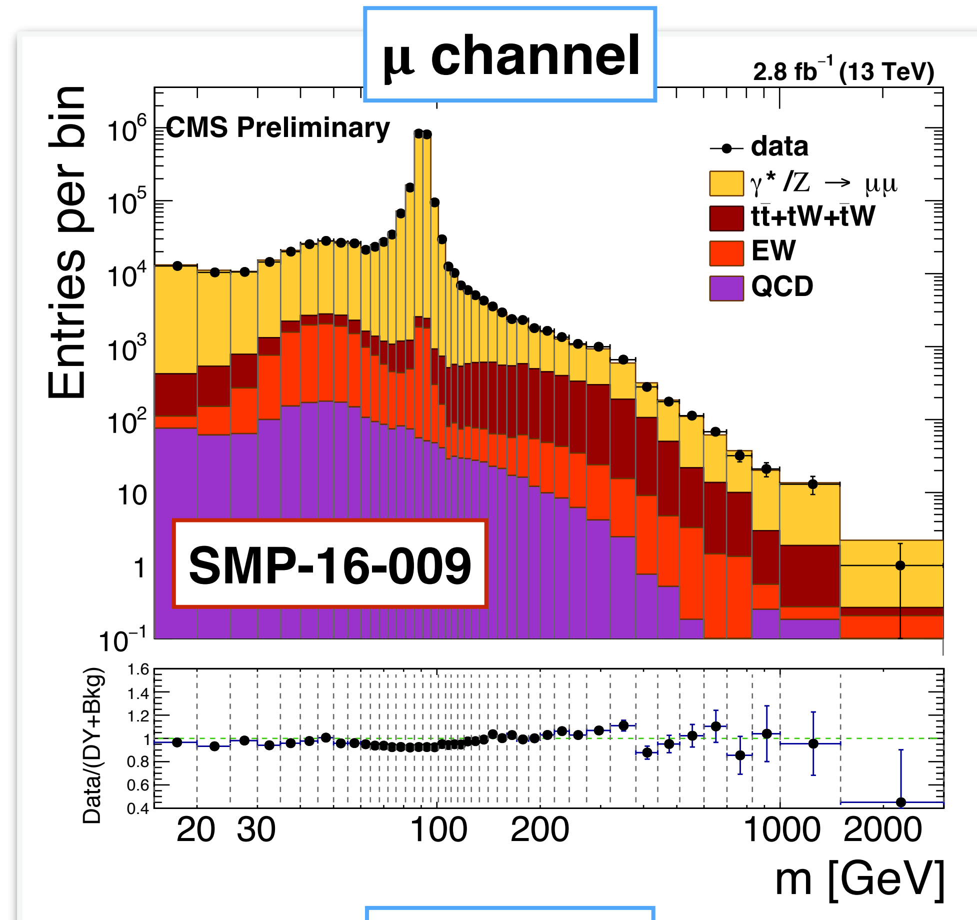
Background Estimation

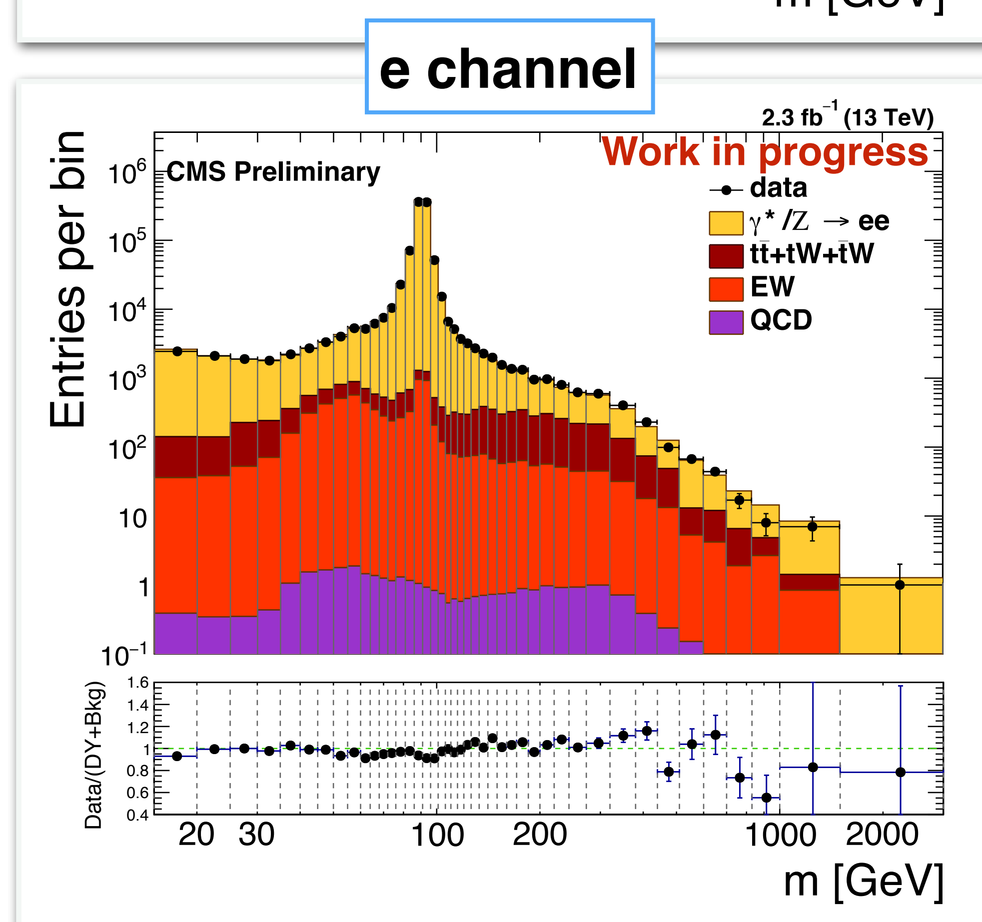
How to estimate backgrounds

- **Data-driven** method
  - Fake rate method: **QCD** and **W+jets**
    - Estimate the probability that a fake muon is identified as a signal using a fake-dominant sample
  - **eμ** method: **$t\bar{t}$, $tW+\bar{t}W$, WW** and **$Z/\gamma^* \rightarrow \tau\tau$**
    - Estimate **μμ** events based on the number of **eμ** data events and the ratio of **eμ** to **μμ** events
- **MC**-based backgrounds
  - **WZ** and **ZZ**

Dominant backgrounds: top-quark processes

- Other backgrounds
  - Low mass region: **QCD** and **W+jets**
  - Z-peak region: **Diboson, $Z/\gamma^* \rightarrow \tau\tau$**





Correction 1: Unfolding for the Detector Resolution

Motivation

- Detector resolution → Migration of events **from true bin to the other bin** in reconstruction level
- **Bin migration should be corrected** to measure precise differential cross section in each mass bin

Method: Unfolding technique

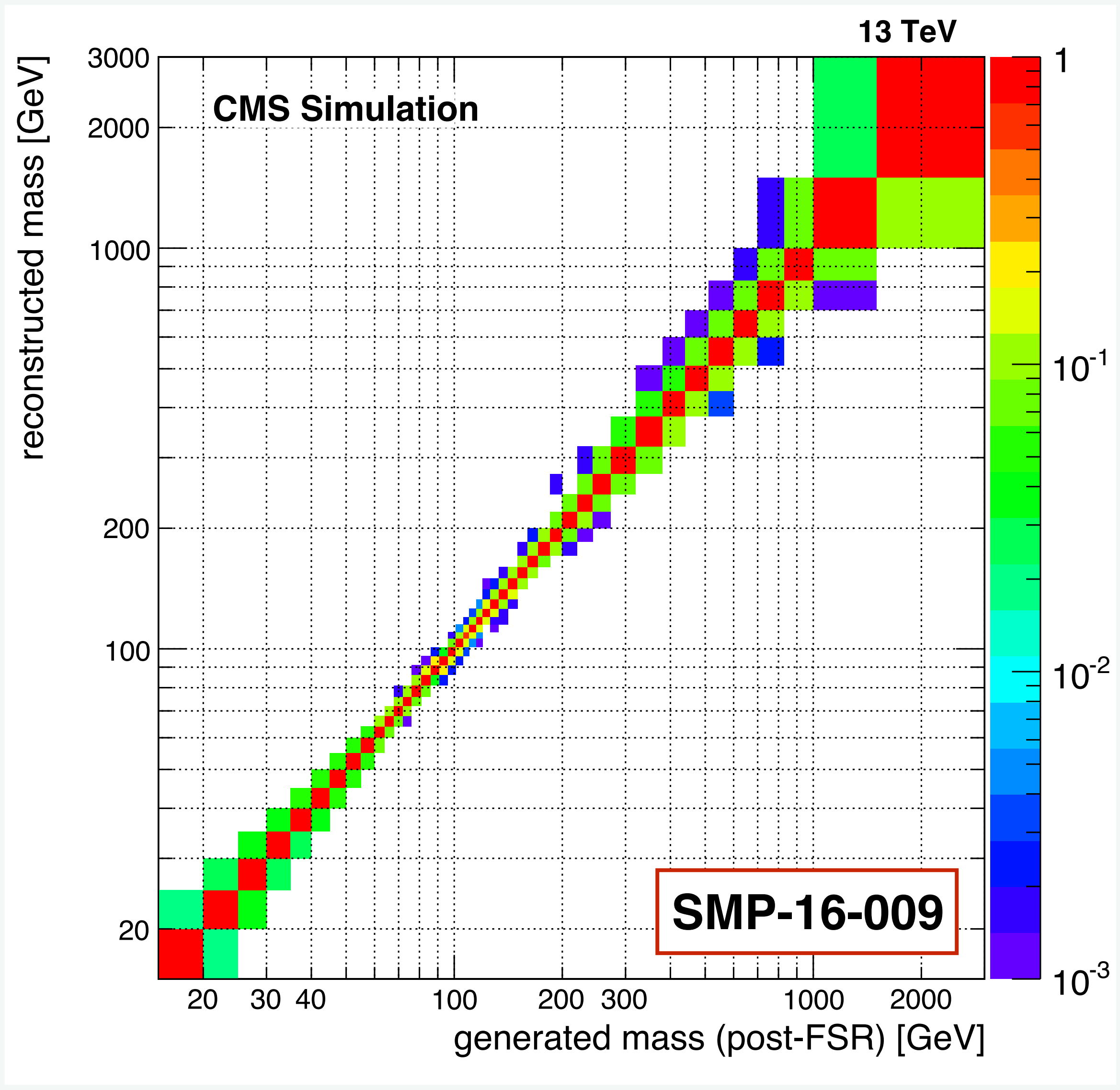
- Response matrix $\mathbf{T_{ik}}$ = the fraction of events of **k-th bin in true** distribution → **i-th bin in reconstructed** distribution

$$N_i^{obs} = \sum_k T_{ik} N_k^{true} \longrightarrow N_i^{true} = \sum_k (T^{-1})_{ik} N_k^{obs}$$

◎ Estimated by MC

- D'Agostini's iteration method (Nucl. Instrum. Meth. A 362 (1995) 487)

Response matrix: μ channel



Acceptance & Efficiency

- To compensate for the lost signal events due to
  - detector's geometrical/kinematical limit (**acceptance**)
  - identification procedure and event selection (**efficiency**)

Definition

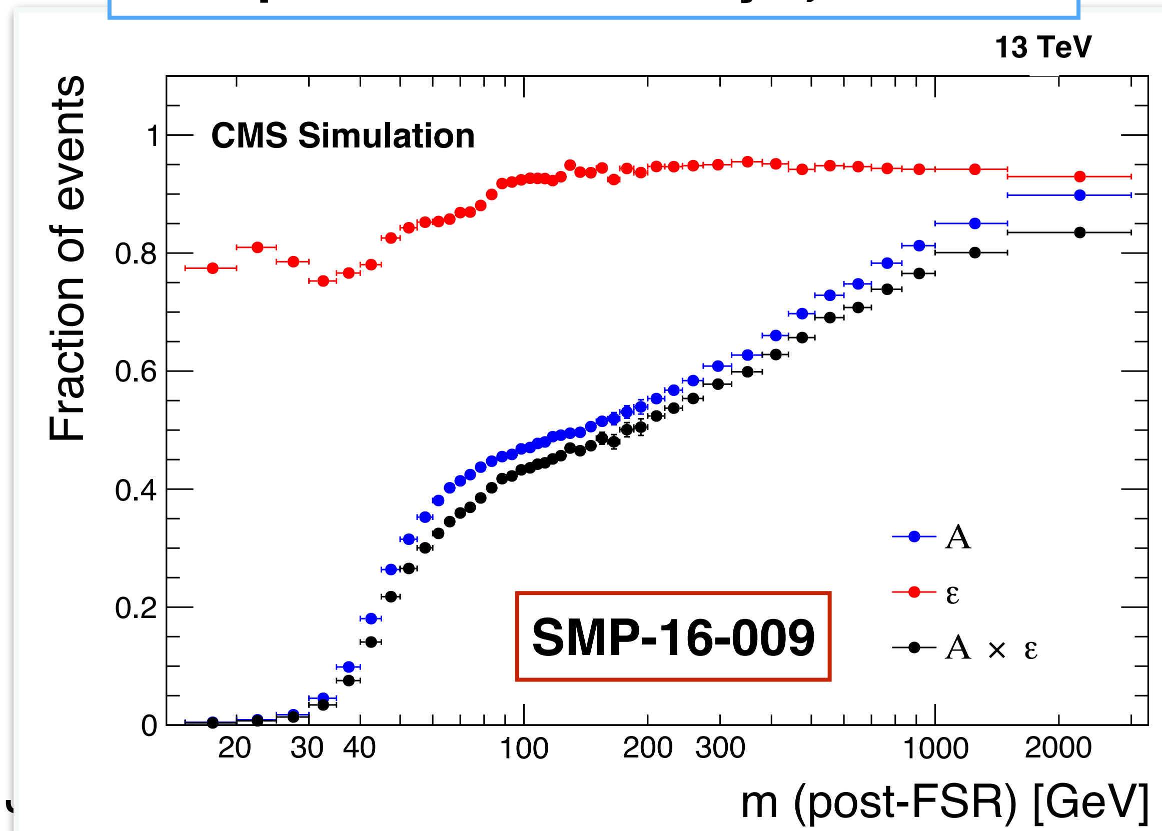
$$A \times \varepsilon = \frac{N_{acc}}{N_{gen}} \times \frac{N_{sel}}{N_{acc}} = \frac{N_{sel}}{N_{gen}}$$

N_{acc}: # events passing acceptance cut

N_{sel}: # events passing event selection

N_{gen}: # total events

Acceptance & efficiency: μ channel



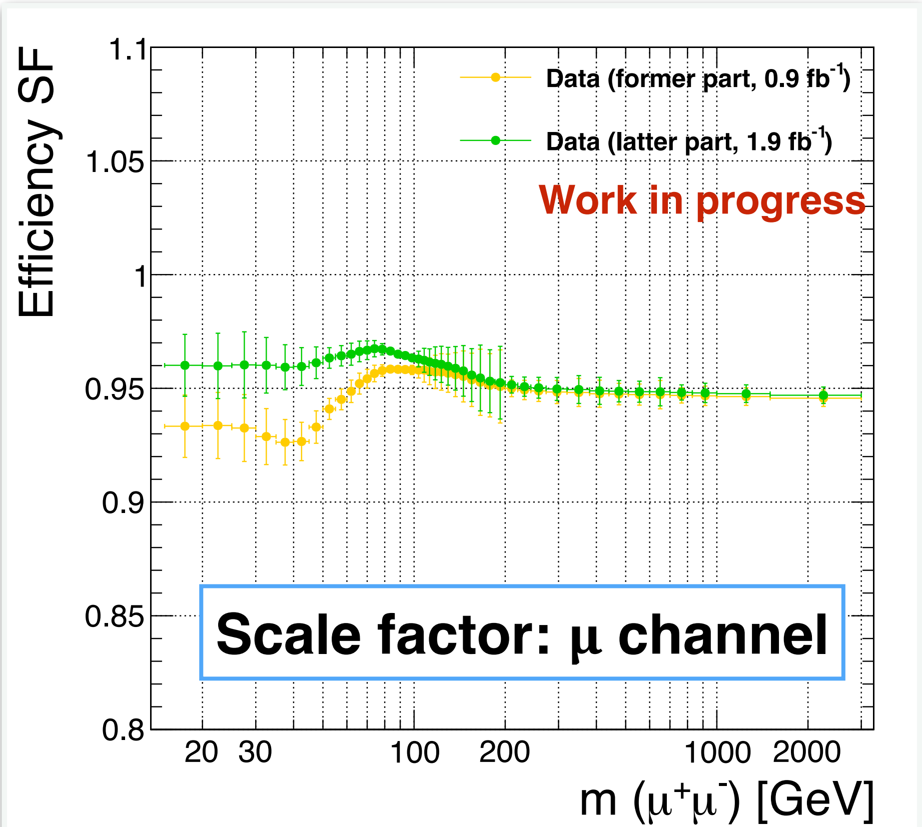
Efficiency Scale factor

- Signal efficiency is based on MC

→ **The difference of the efficiency between data and MC** should be taken into account

Efficiency measurement: Tag&Probe method

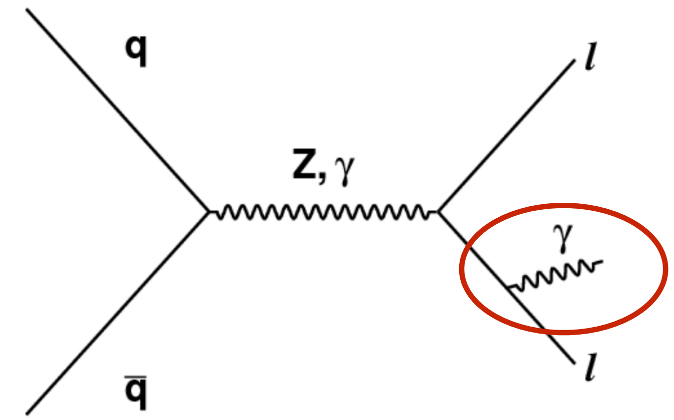
- Extract efficiencies from data by exploiting Z resonances
- Scale factor $\rho = \rho(P_T, \eta) = \varepsilon_{data}(P_T, \eta) / \varepsilon_{MC}(P_T, \eta)$



Correction 3: Unfolding for the FSR effects

Motivation

- Leptons: can emit photons via FSR effect
  → **observed $M_{\ell\ell}$ < original $M_{\ell\ell}$**
- Apply the correction to obtain the mass before FSR effect



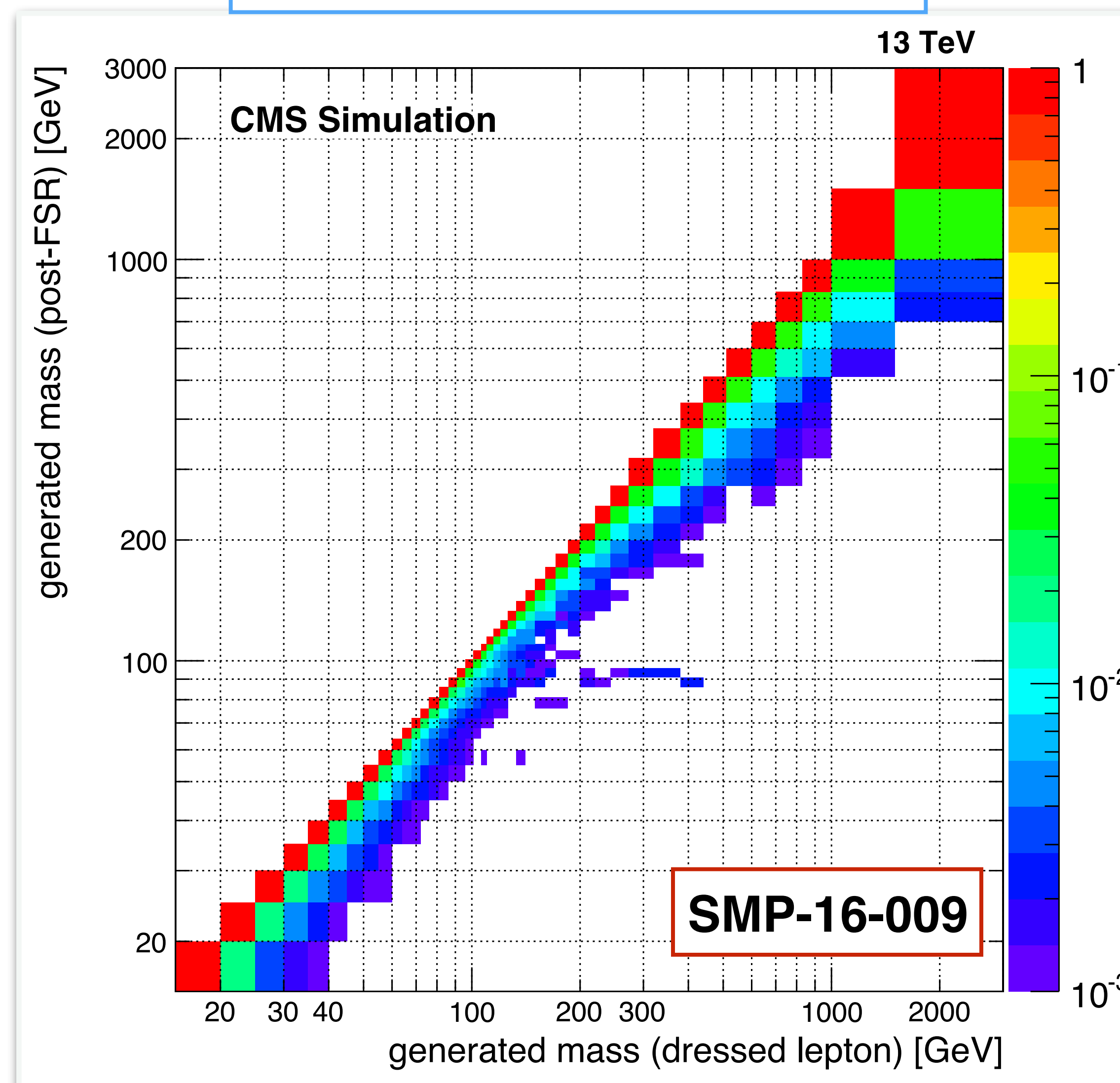
Method: Unfolding technique (dressed vs. post-FSR)

- Dressed lepton
  - Compensate the momentum lost by FSR effect

$$\vec{P}^{\mu}_{dressed} = \vec{P}^{\mu}_{post-FSR} + \sum_{\Delta R(\mu,\gamma)<0.1} \vec{P}^{\gamma}$$

- Matrix inversion method (**μ** channel) & D'Agostini's iteration method (**e** channel)

Response matrix: μ channel



Estimation of the Systematic Uncertainties

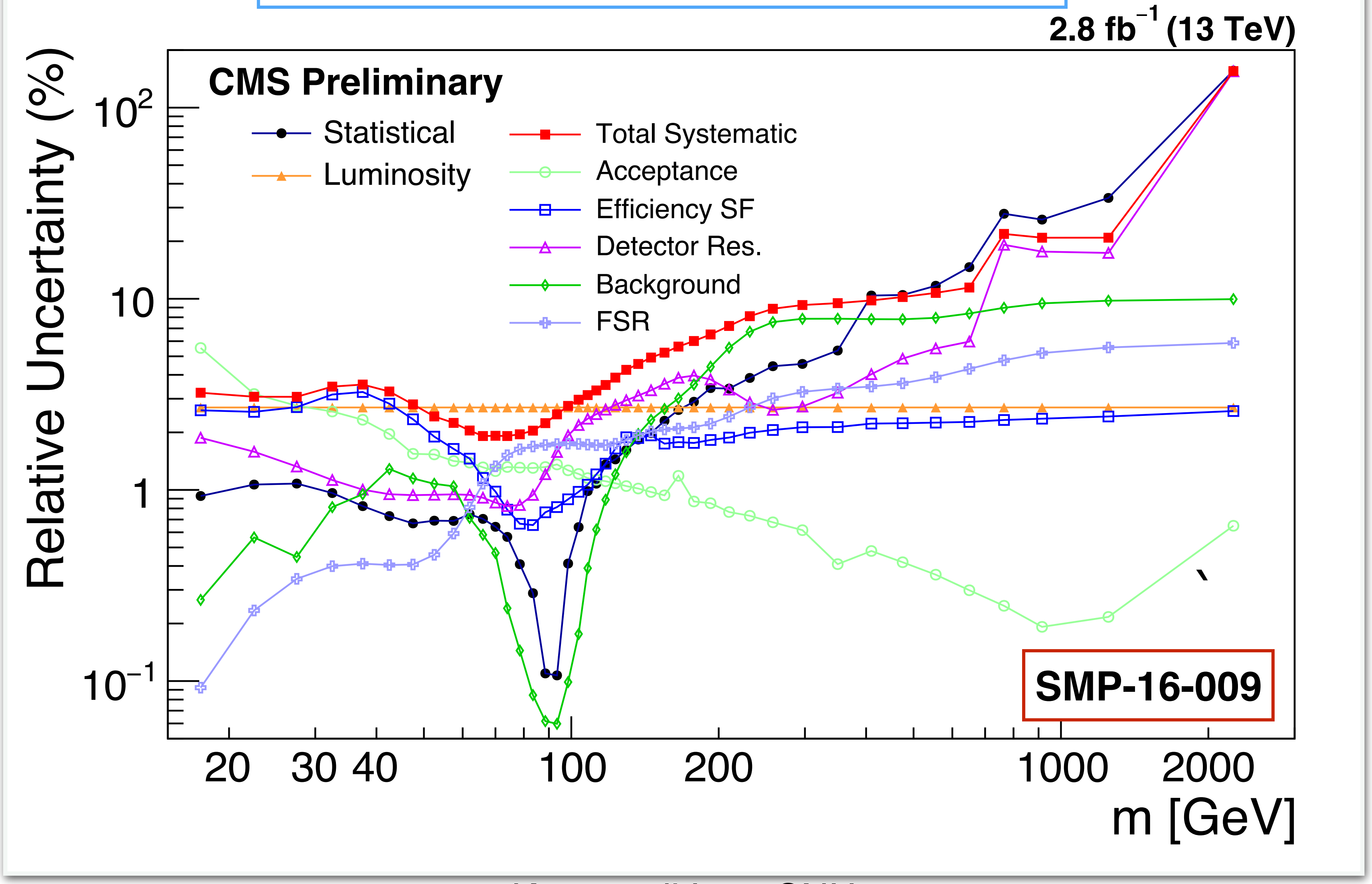
Uncertainty in each mass bin

- Total systematic uncertainty:
  < 10 % level precision in most of the regions
- Uncertainty goes up in high mass region:
  because of lack of statistics

Dominant uncertainties

Region	Source
Low mass	Efficiency SF
Z-peak	FSR
High-mass	Background estimation

Summary of uncertainties: μ channel



Result: Drell-Yan Differential Cross Section

Combination of μ and e channel

- Differential cross section of each channel is generally in agreement in entire mass range

→ **The results of two channels are combined for greater precision**

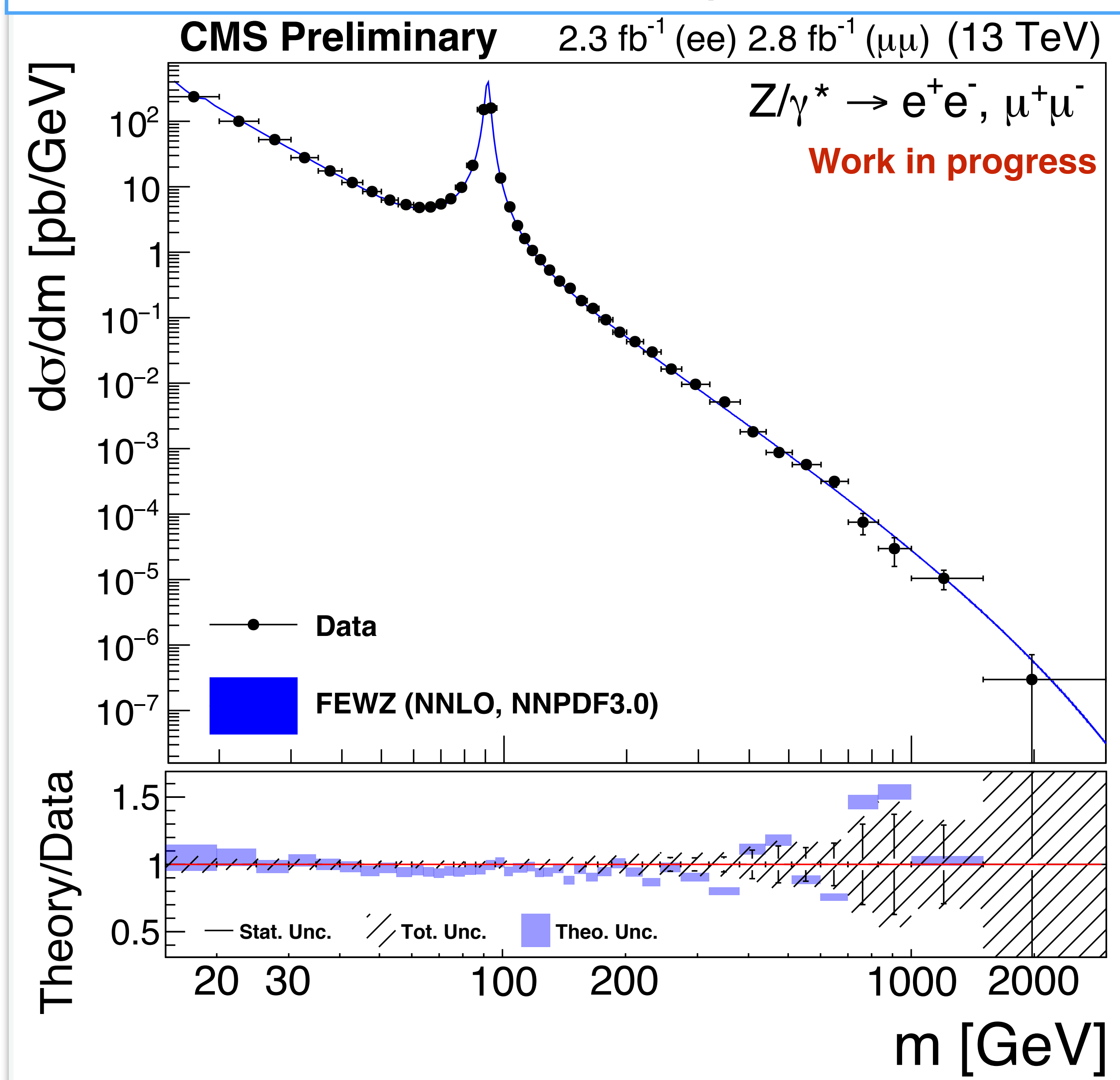
- Best Linear Unbiased Estimator (BLUE) method is used for the combination

Comparison with the theoretical prediction

- Theory prediction: calculated by FEWZ (QCD@NNLO & EWK@NLO)
  - PDF set: **NNPDF 3.0**

- **Generally experimental result shows good agreement with the theory prediction**

DY differential cross section (after combination)



Summary

Drell-Yan differential cross section at 13 TeV is measured in dilepton channel

- Full 2015 dataset collected by the CMS detector
  (2.8 fb^{-1} for **μ**, 2.3 fb^{-1} for **e** channel)
- 15 < M < 3000 GeV with 43 bins
- Combination of two channel is performed:
  Generally shows **good agreement** with the theoretical prediction @ NNLO

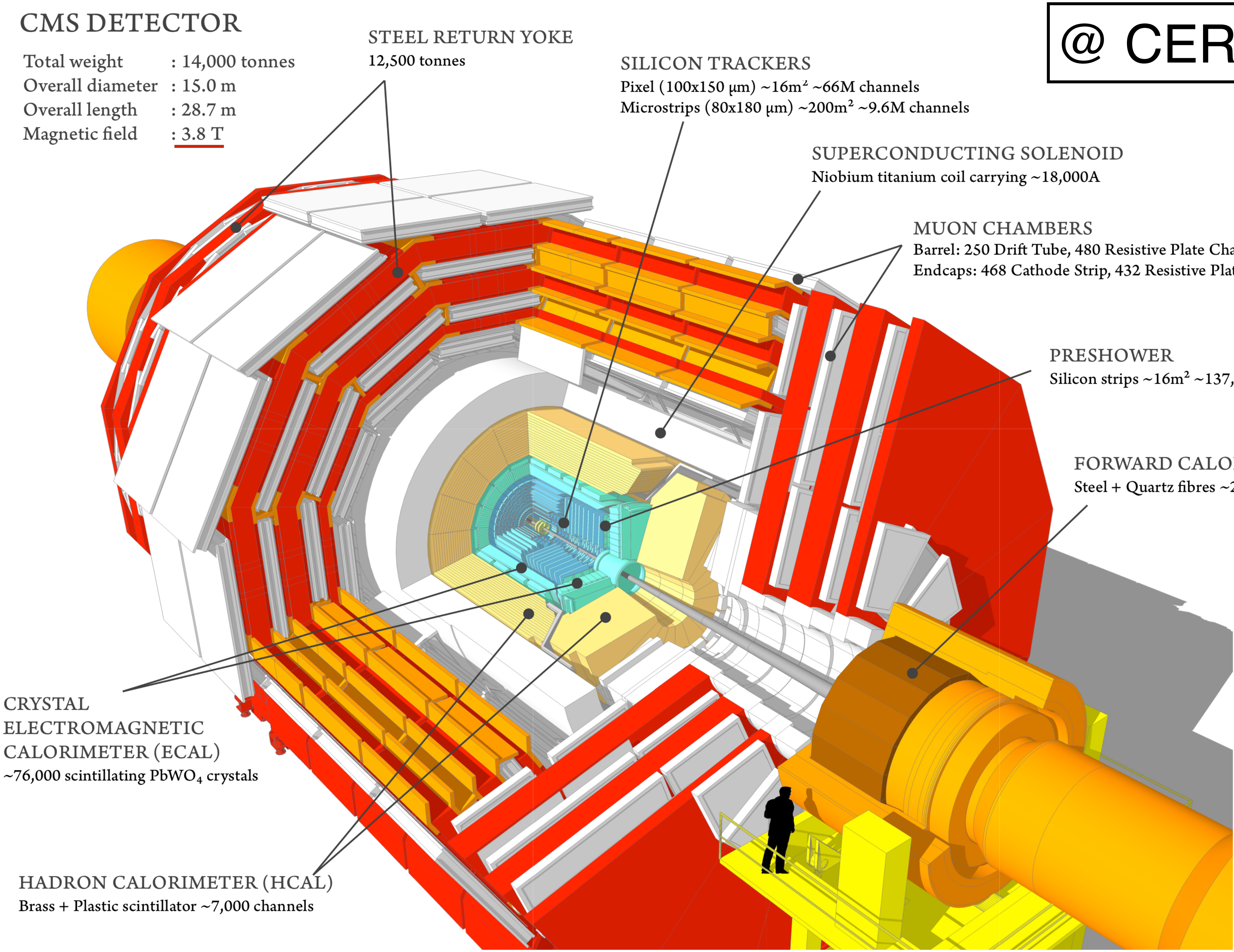
Future plan

- Aim to present full results in incoming summer conferences
  - Will publish this result in journal publication afterward
- Start same analysis using 2016 data (see Dalmin's talk)
  - Double-diff. cross section as well as diff. cross section
  - Target to obtain much higher precision than 2015 (< 10% @ TeV scale)

Backup

CMS Detector

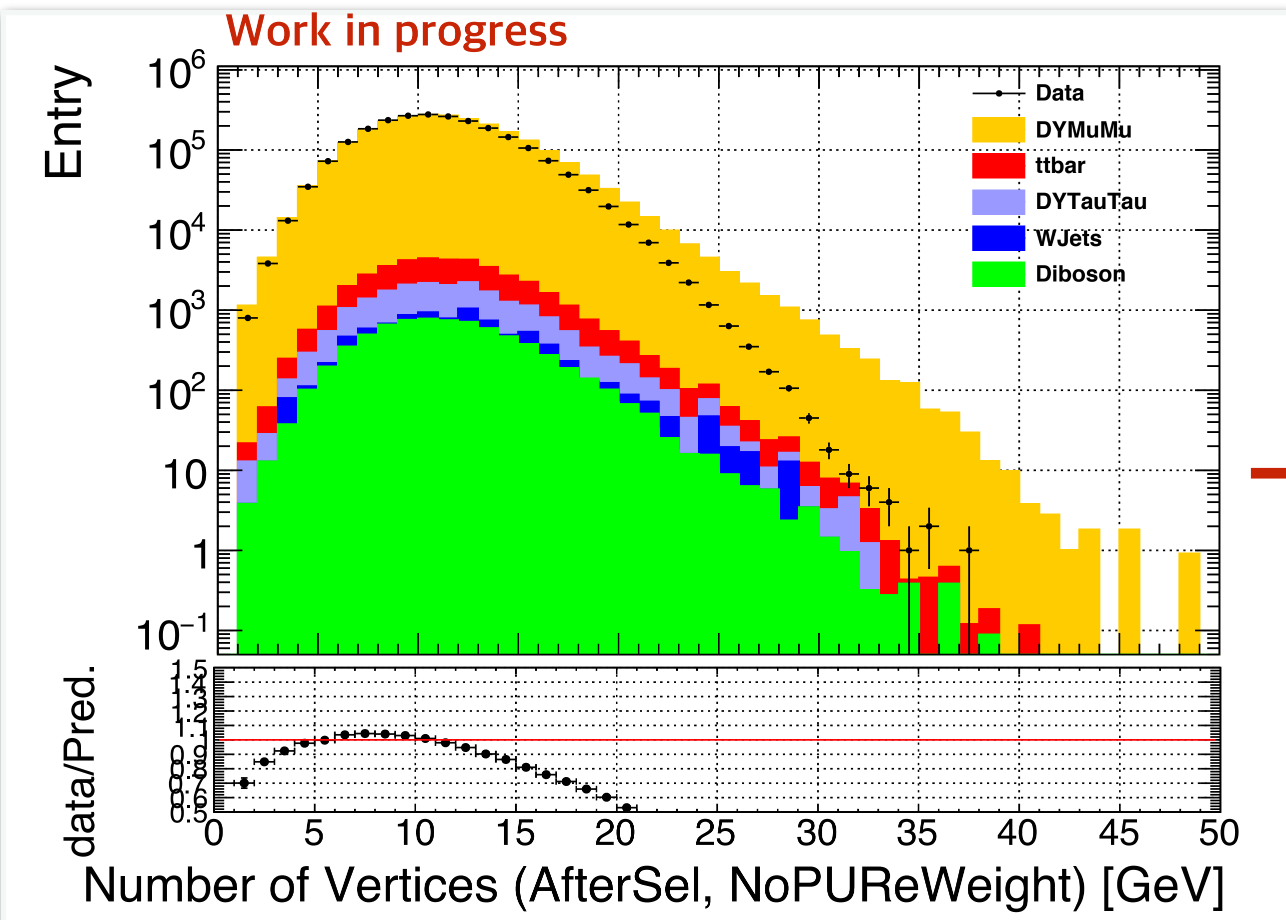
@ CERN LHC



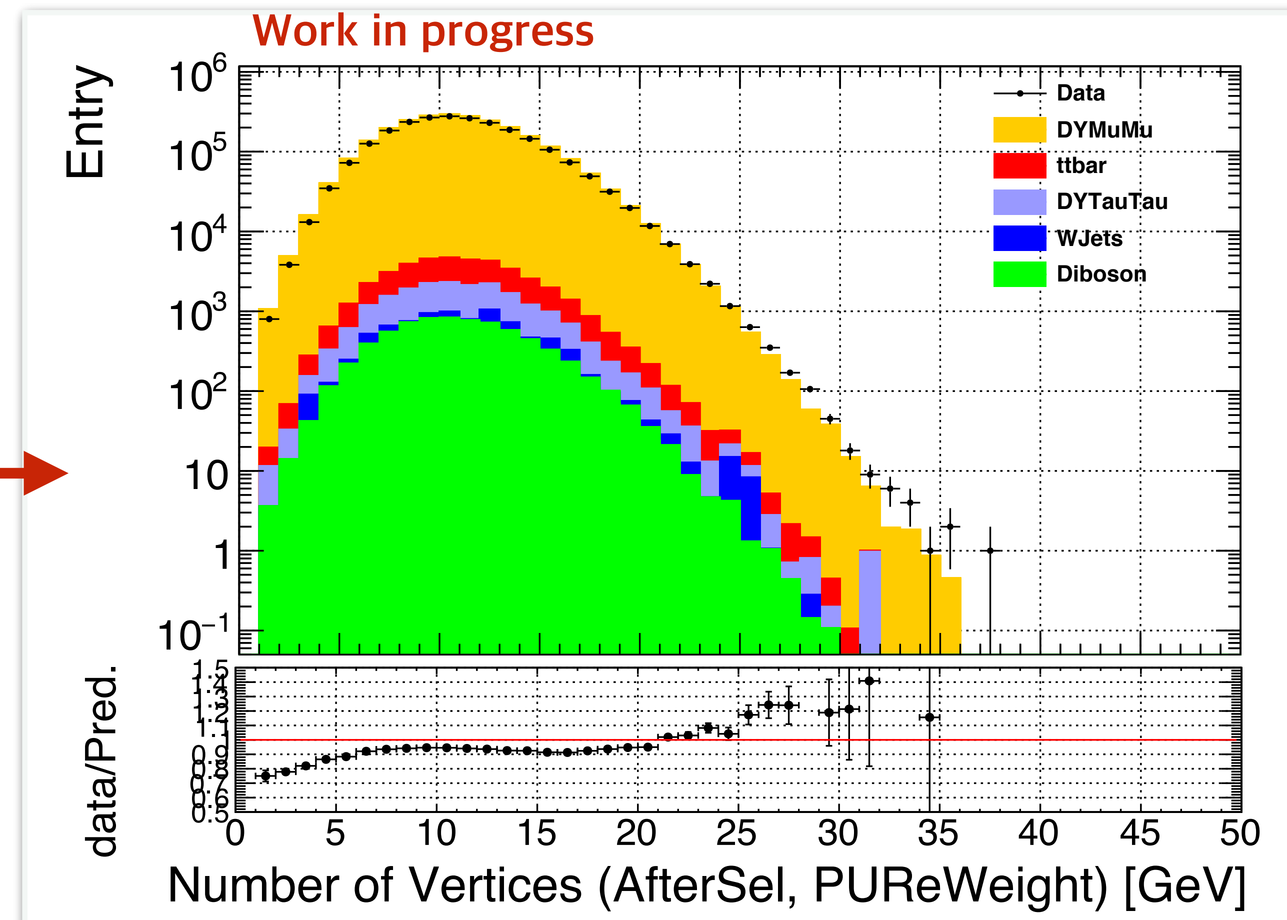
Pile-up Reweighting

- Pileup Reweighting is performed following the CMS standard recommendation
  - Min-bias cross section for data PU distribution: 71 mb

N_{vtx} distribution (before PU-reweighting)



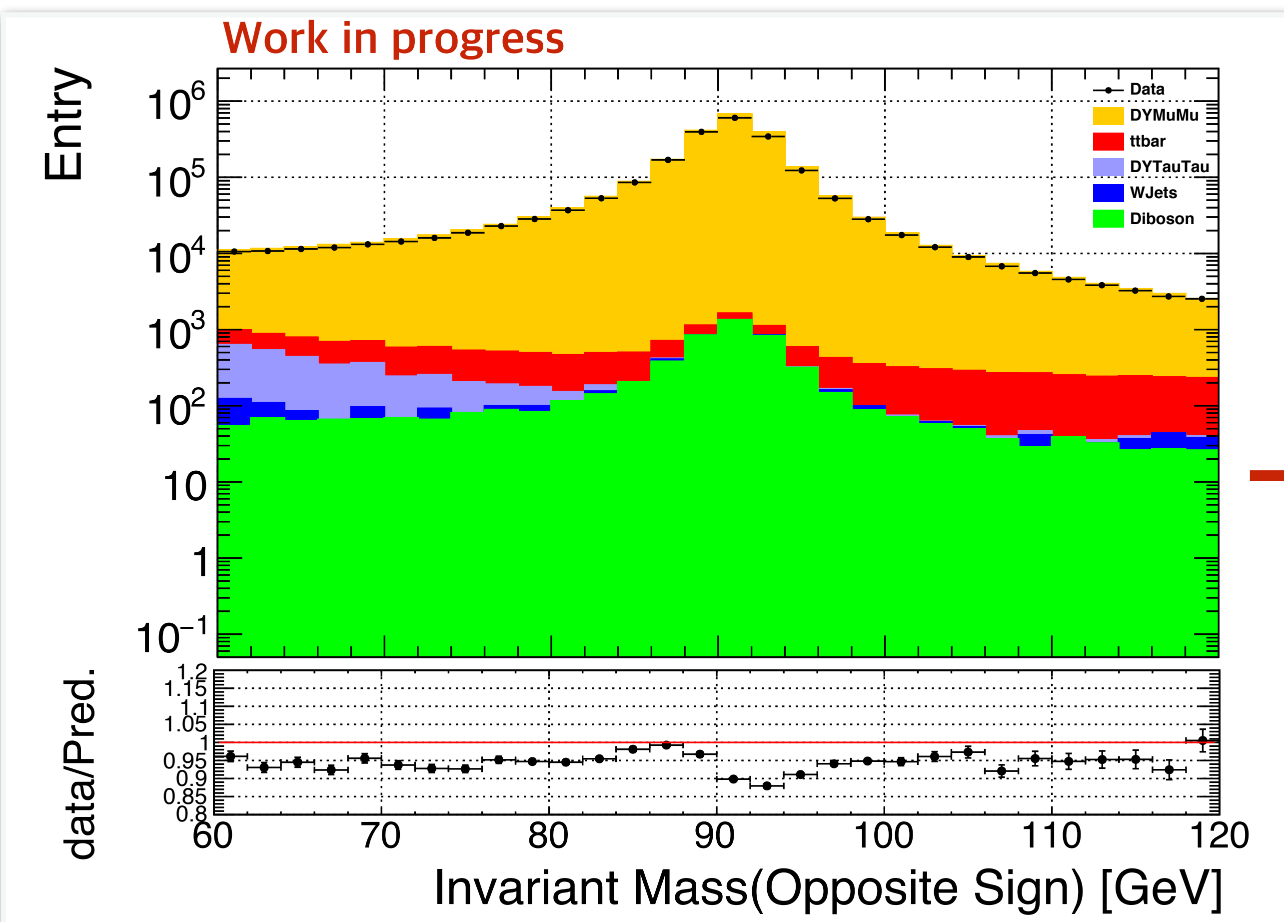
N_{vtx} distribution (after PU-reweighting)



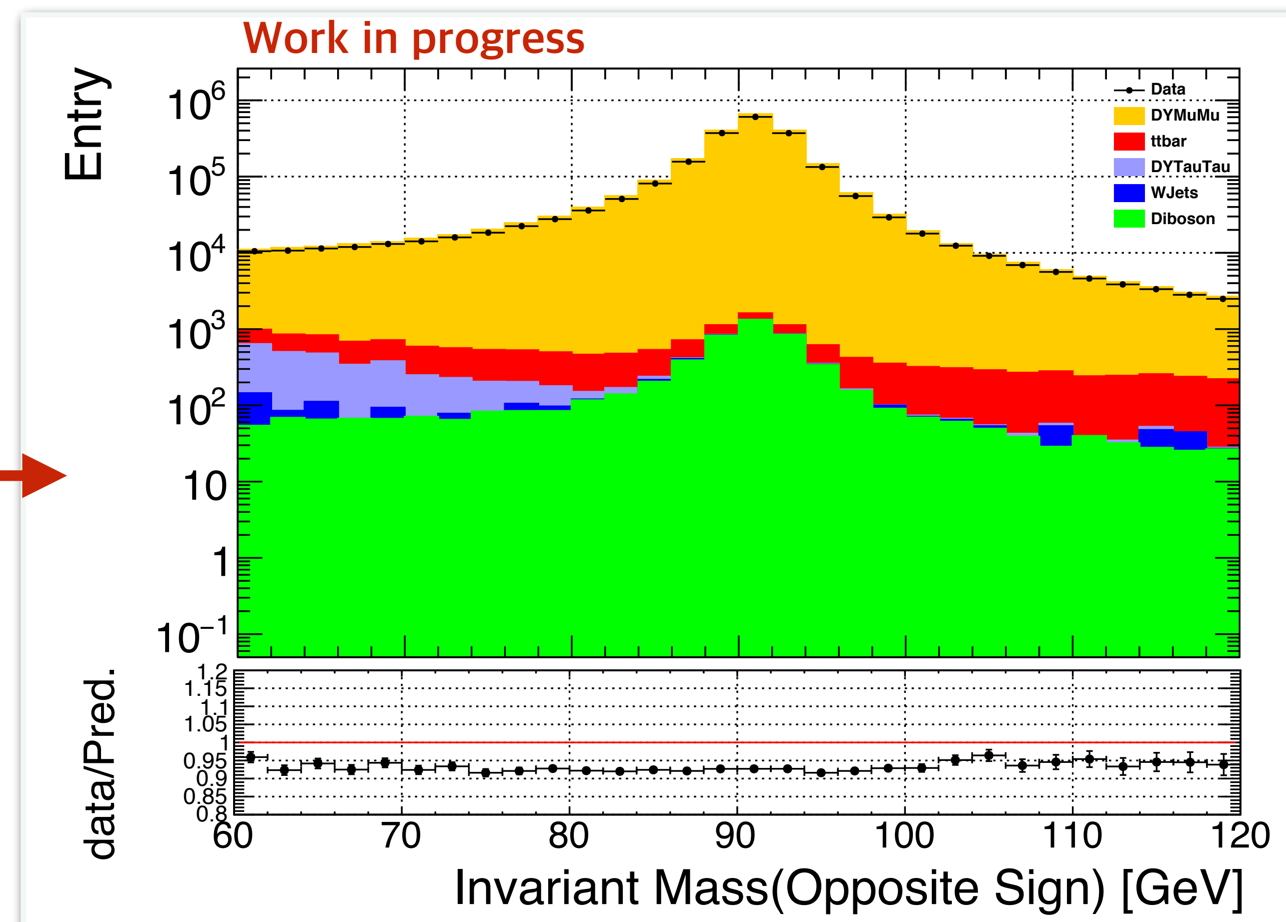
Muon Momentum Scale Correction

- Rochester muon momentum correction is applied
  - Remove the bias on (η,ϕ,Q) dependence of mass & momentum distribution
    - Correction is derived from <1/P_T> in (η,ϕ,Q)
  - Agreement between MC and data has been improved especially in Z-peak region (up to 10%)

Z-peak region (before correction)

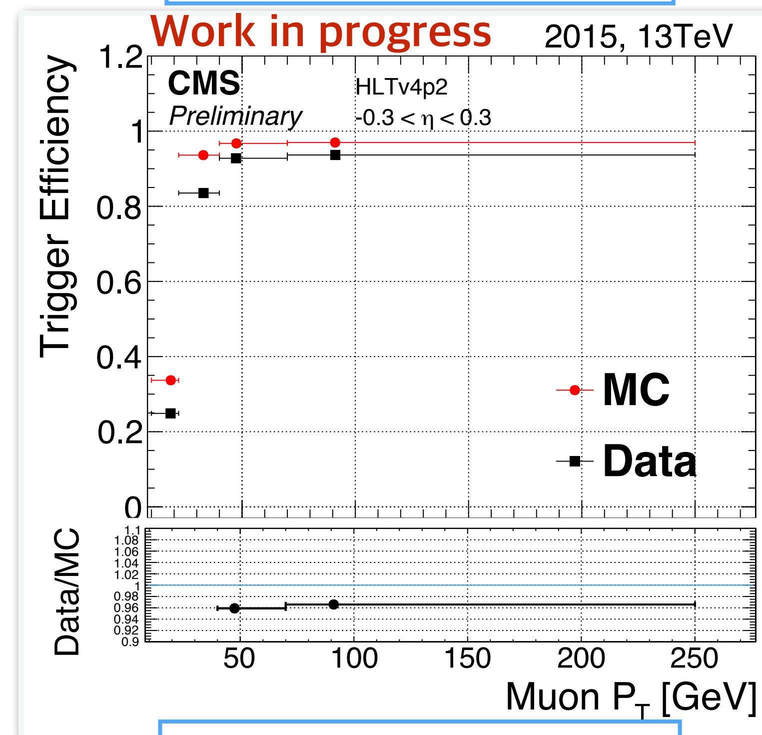


Z-peak region (after correction)

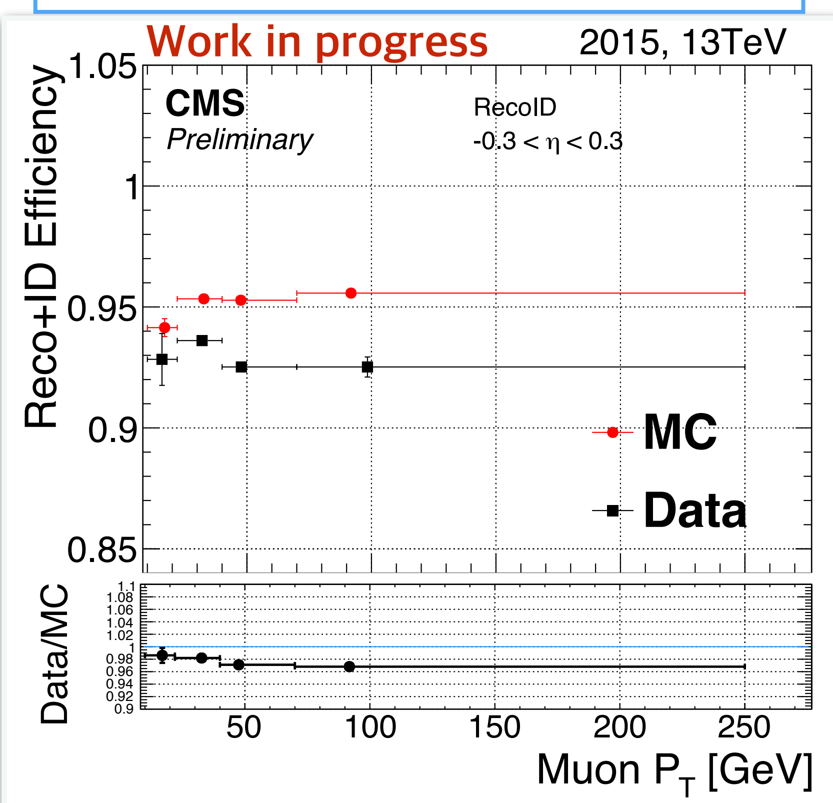


- Example of the efficiencies measured by Tag&Probe method (Barrel Region)
  - Take into account the run-dependency of the data efficiency
    - due to the change of trigger algorithm during data-taking period

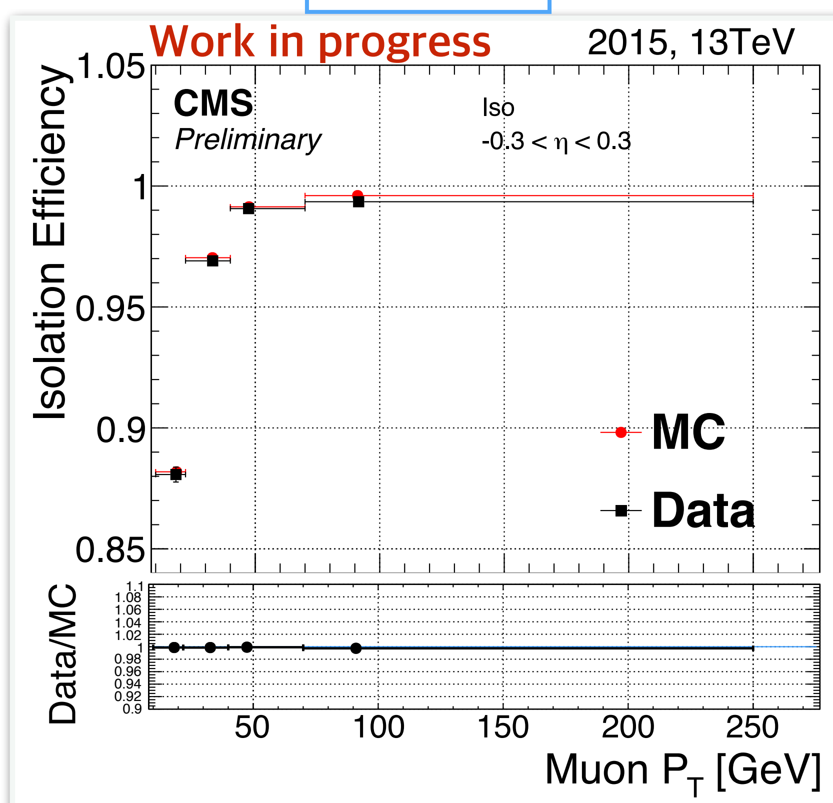
Trigger (early data)



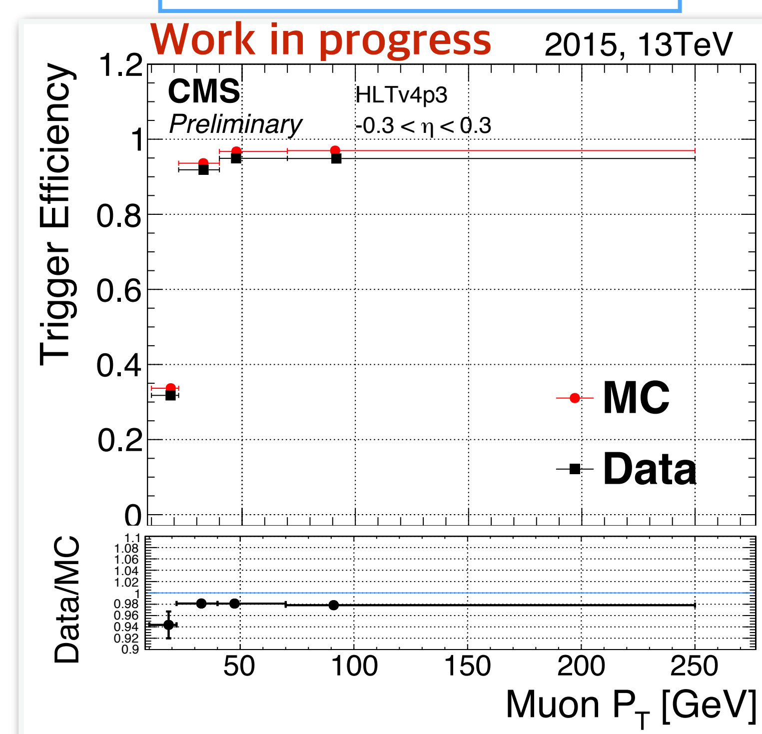
Reconstruction+Identification



Isolation



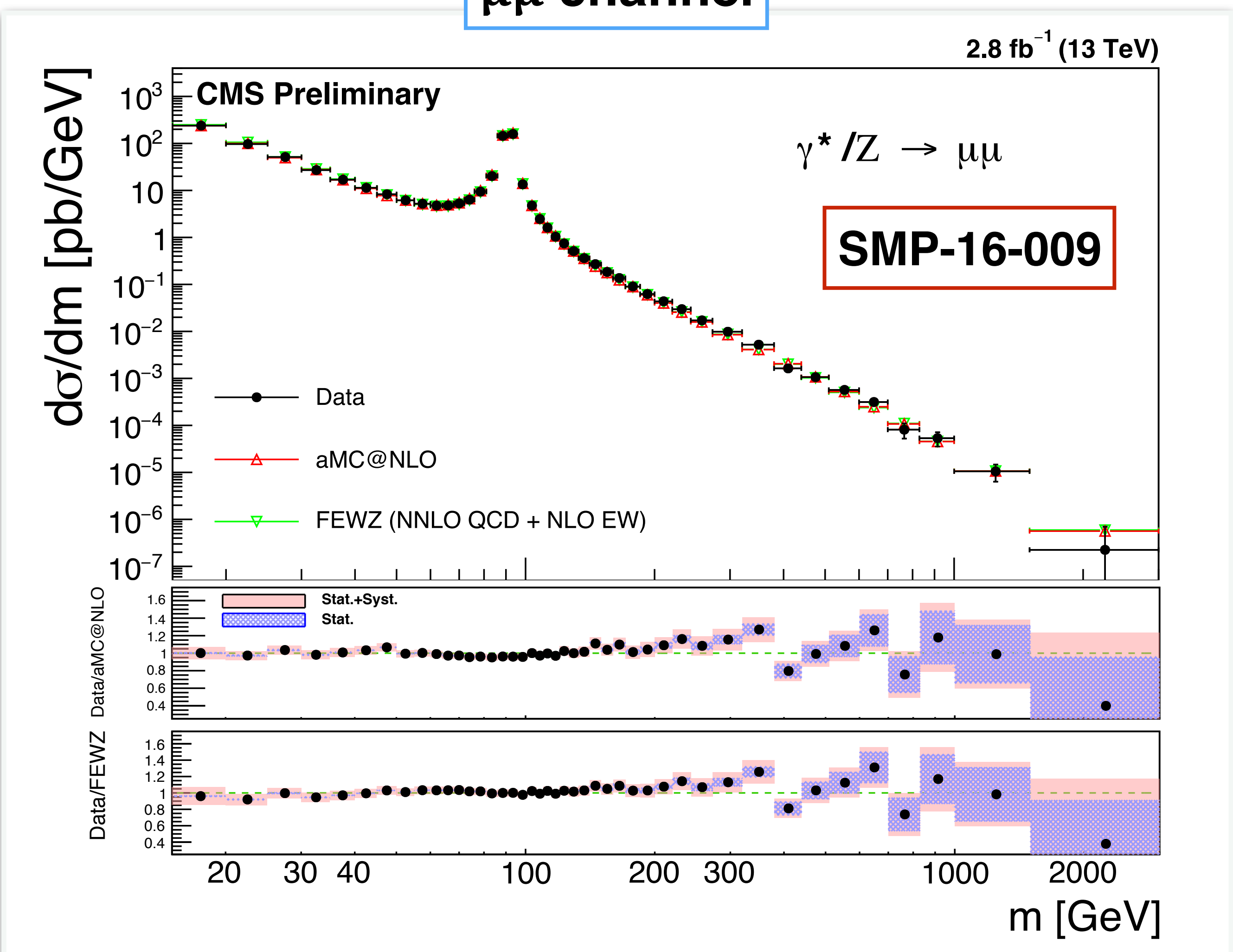
Trigger (latter data)



Drell-Yan Differential Cross Section in Each Channel

- Comparison with the theoretical prediction (FEWZ, aMC@NLO)

μμ channel



ee channel