Search for new heavy neutral gauge boson using dilepton channels with CMS experiment

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Outline

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- Overview
- Analysis Strategy [Focus on di-electron channel]
  - Event selection
  - Mass scale and resolution
  - Backgrounds estimation
  - Statistical framework
  - Results
- Conclusion

Introduction

- **Generally, all new particles that can decay to dilepton called Z'**

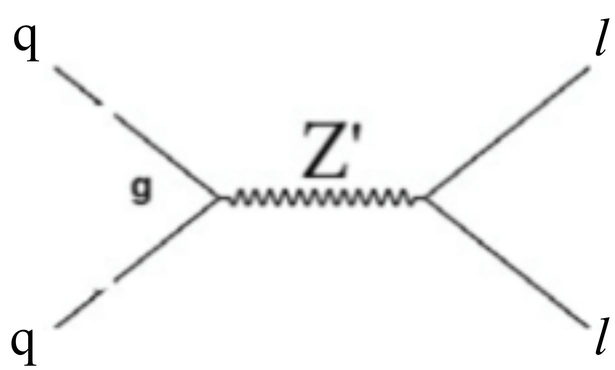
- **Many BSM theories predict new heavy resonances decay to dilepton**
    - extension of SM in Grand Unification predict spin-1 resonance (e.g Z'_{ψ})
    - some SUSY models predict new spin-0 resonance
    - sequential SM predict Z'_{SSM} (same coupling structure as Z in SM)

- **New physics manifest itself in a change of the dilepton mass spectrum**

- **Dilepton search channel — a promising channel for heavy resonance search:**
    - low background at high mass region
    - high accuracy of lepton reconstruction
    - good mass peak above background

Signal and backgrounds

signal



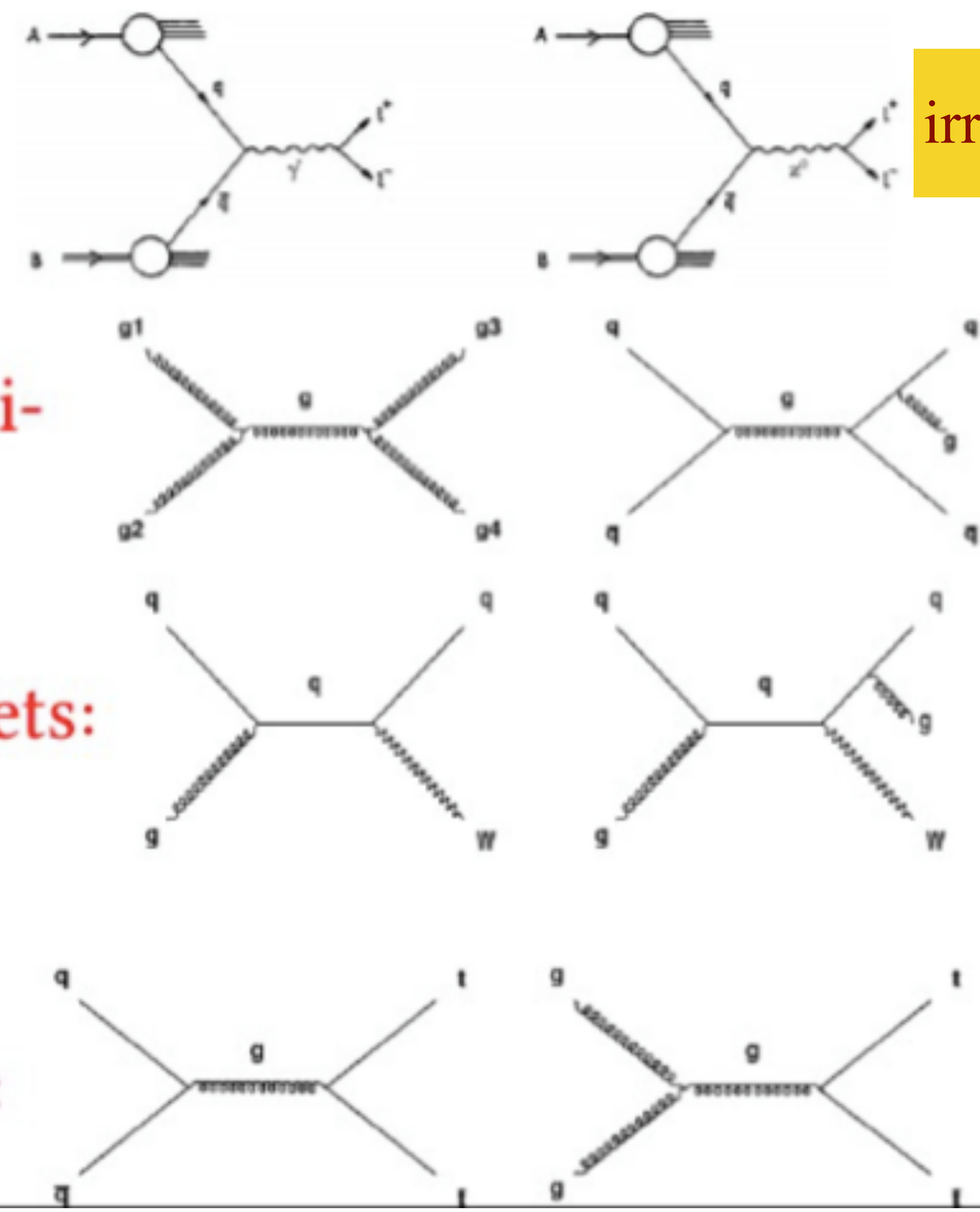
backgrounds

DY:

multi-jets:

W+jets:

ttbar:



tW, WW, ττ …

irreducible background

jet(s) mis-identified as leptons

non-resonant background

Object and Event selection

- **Trigger: di-electron trigger with E_T > 33 GeV**
- **Offline Electron selection:**
    - p_T > 35 GeV
    - $|\eta| < 2.5$, crack region removal: $1.444 < |\eta| < 1.566$
    - electron ID based on shower shape variables
    - track isolation and calo-isolation
- **At least one electron in the barrel region: $|\eta| < 1.444$**
- **Select two opposite charged electrons. If more than one di-electron candidate found, only the pair with the two largest E_T is retained.**
- **Events are classified into two categories based on electrons η position: BB, BE**

Mass Scale and Resolution

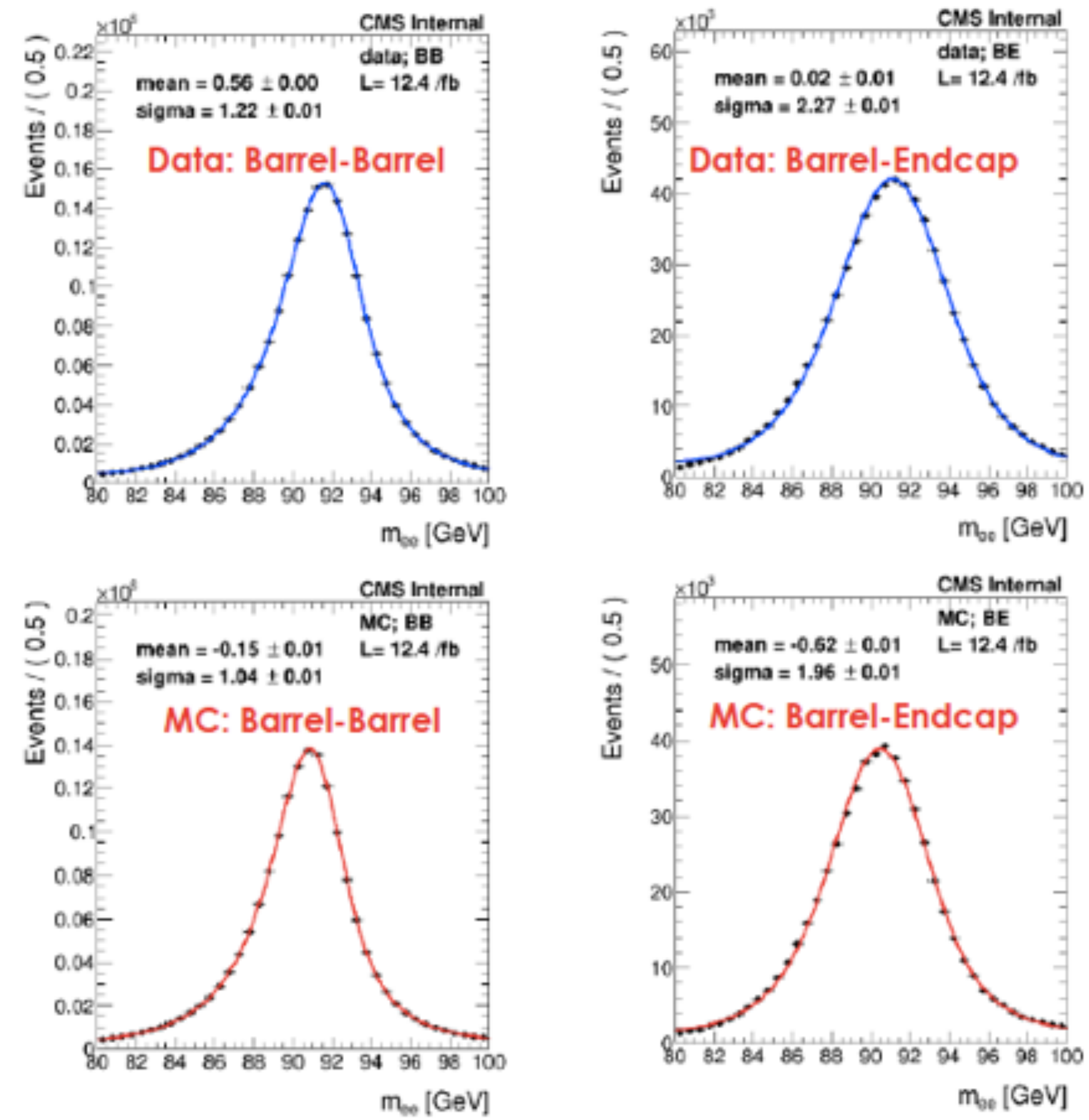
Defined in two steps:

- **Step 1)** data vs MC at the Z peak

At the Z peak [80, 100] GeV, distributions are fitted with Breit-Wigner convoluted with Double-sided Crystal Ball (dCB)

- Mean and sigma of gaussian part in dCB are quoted.
- Compute the resolution discrepancy between data and MC, $\sigma^2_{extra} = \sigma^2_{data} - \sigma^2_{MC}$
- The values in the table are expressed in percentage [%] w.r.t M_Z (PDG value: 91.1876 GeV)

Category	$\Delta M/M$ [%]	σ_{data} [%]	σ_{MC} [%]	σ_{extra} [%]
BB	0.79± 0.01	1.34± 0.01	1.14± 0.01	0.71± 0.03
BE	0.70± 0.01	2.49± 0.01	2.15± 0.01	1.26± 0.03

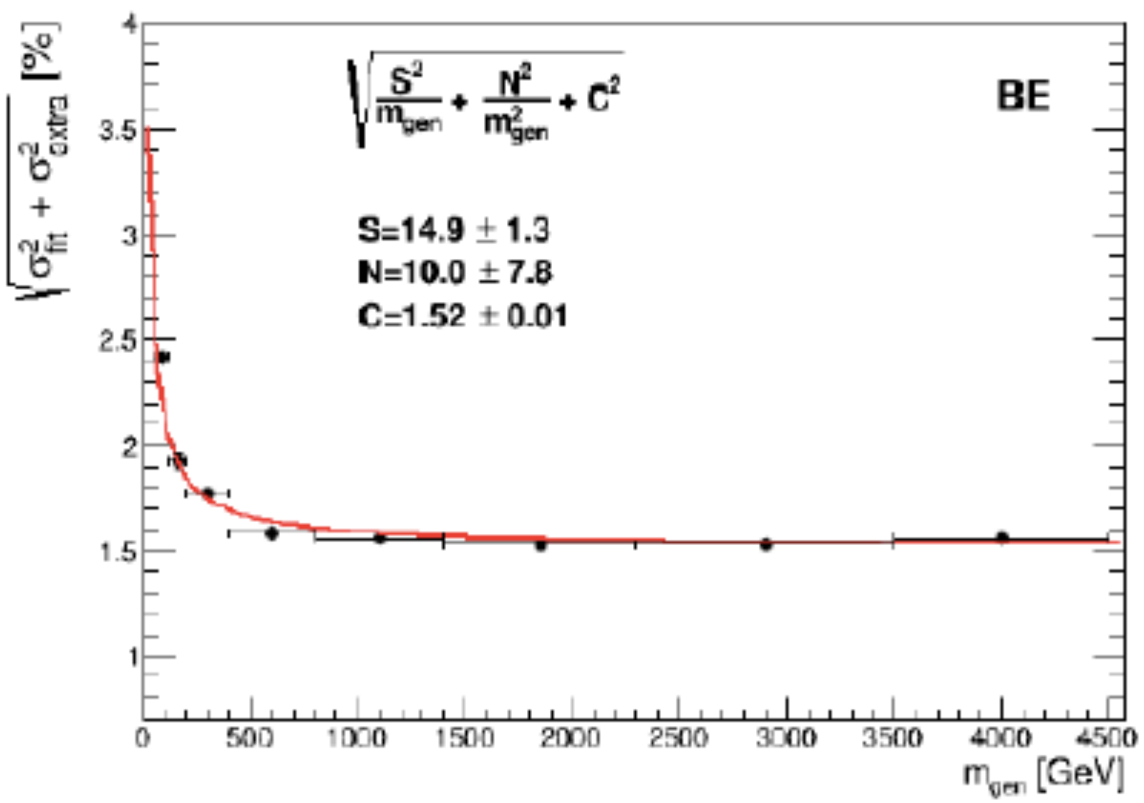


Mass Scale and Resolution

Defined in two steps:

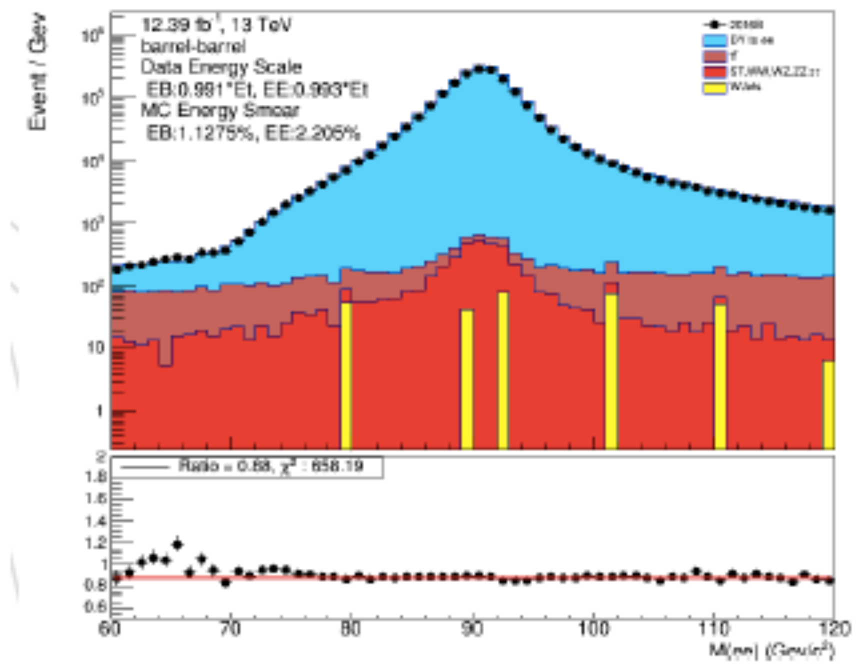
- **Step 1)** data vs MC at the Z peak
- **Step 2)** MC for high mass signal sample, gen vs reco

- For each mass points of high mass Z', get the distribution of $(M_{reco} - M_{gen}) / M_{gen}$
- Distributions are fitted with a Crystal Ball (CB) function
- σ_{extra} (obtained in Step 1) added in quadrature to the sigma of CB to get the mass resolution of high mass region for data
- $\sigma^2_{high\ mass} = \sigma^2_{CB} + \sigma^2_{extra}$

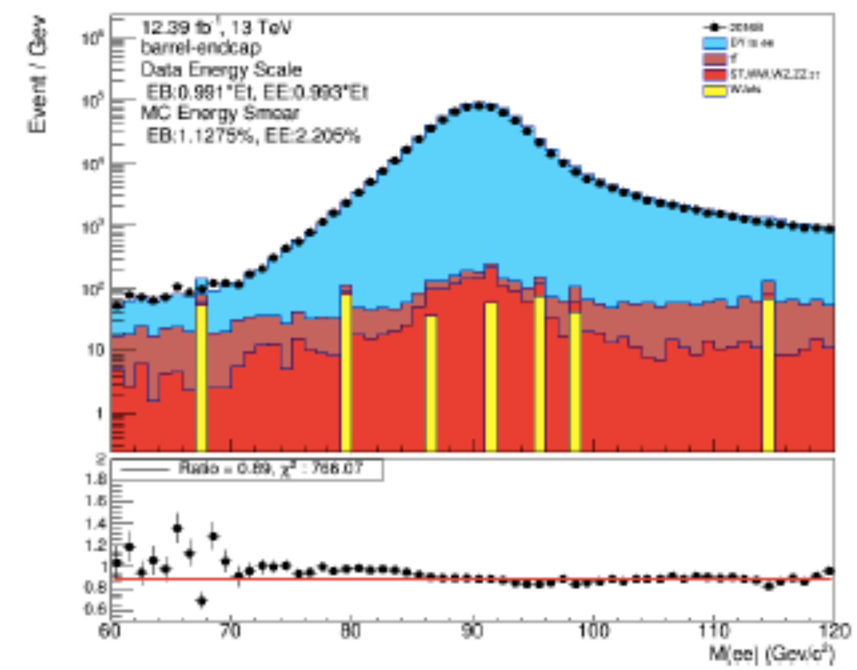


Main background: Drell-Yan process

- **Mass spectrum of DY background from MC simulated events**
- **Measure the cross section at the Z peak [60, 120] GeV**
- **Compare with theoretical prediction**
  - theoretical prediction: 1928 pb (NNLO)
- **Obtain a global Normalisation Factor for DY**



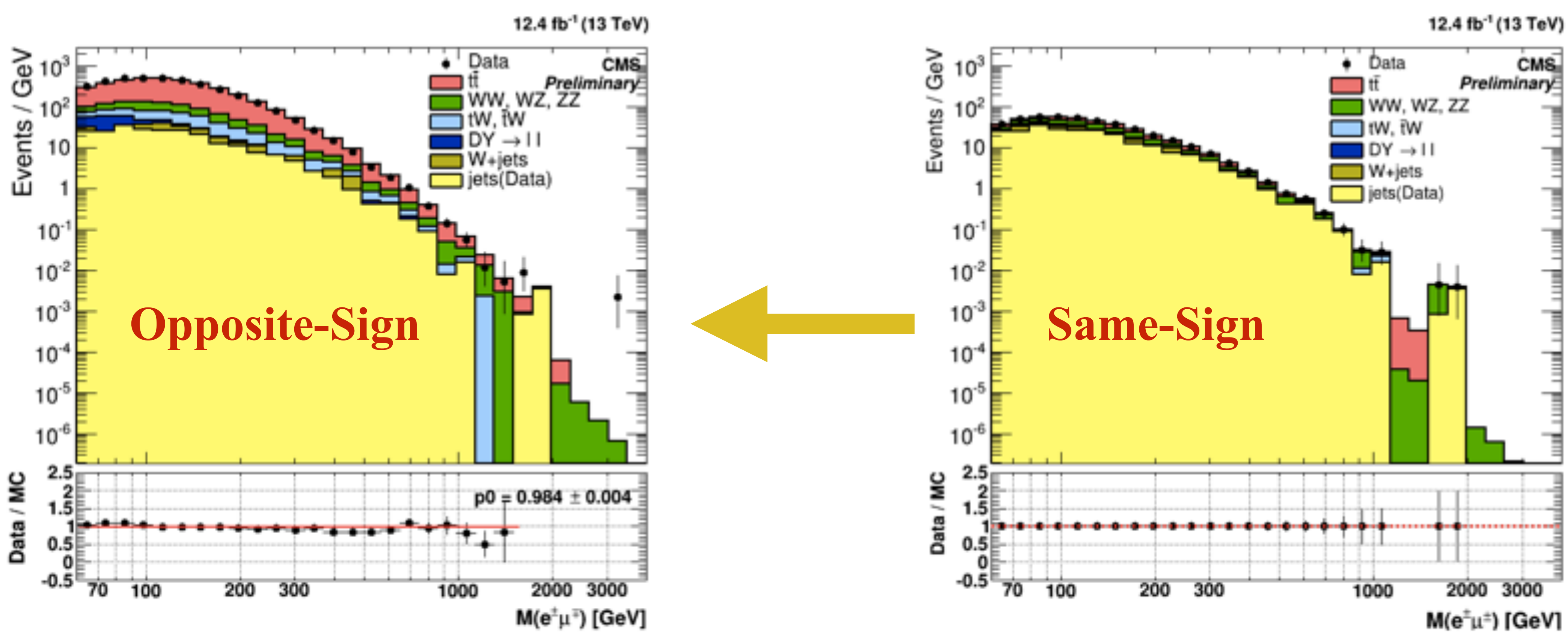
variable	barrel-barrel	barrel-endcap
nr data events (E corr)	1899912±1378	688938±830
nr expect bkg	11334	4133
MC acc×eff	0.0901±0.001	0.0324±0.001
data/MC Eff SF	0.923±0.001	0.927±0.001
cross-sec (E corr)	1831 ± 3 (stat) ± 109(lumi) pb	1841 ± 4 (stat) ±110 (lumi) pb



Measured DY cross section is ~5% lower than theoretical prediction.

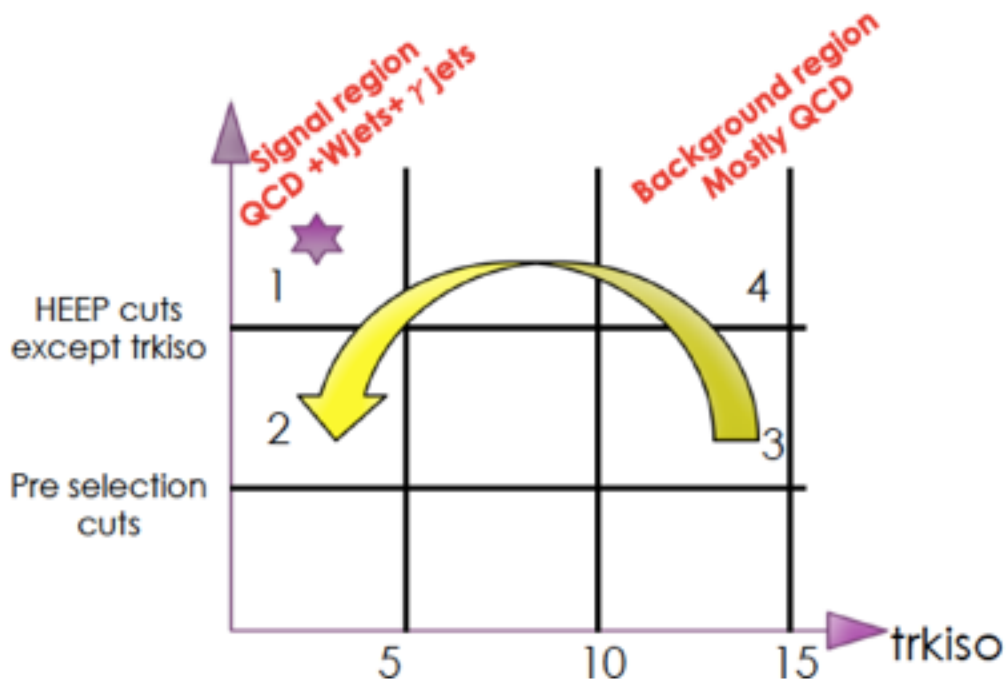
Flavour symmetric backgrounds

- **Flavour symmetric backgrounds (ttbar, tW, WW, WZ, ZZ, ττ) are from MC prediction**
- **Validation study is performed for the MC prediction for those backgrounds**
  - use different flavour control region: $e^{+}\mu^{-}$ or $e^{-}\mu^{+}$ (opposite sign)
  - jet(s) background (W+jets and dijets) estimated from same-sign CR
- **Good agreement between data/MC in the opposite sign CR**



Jet(s) background

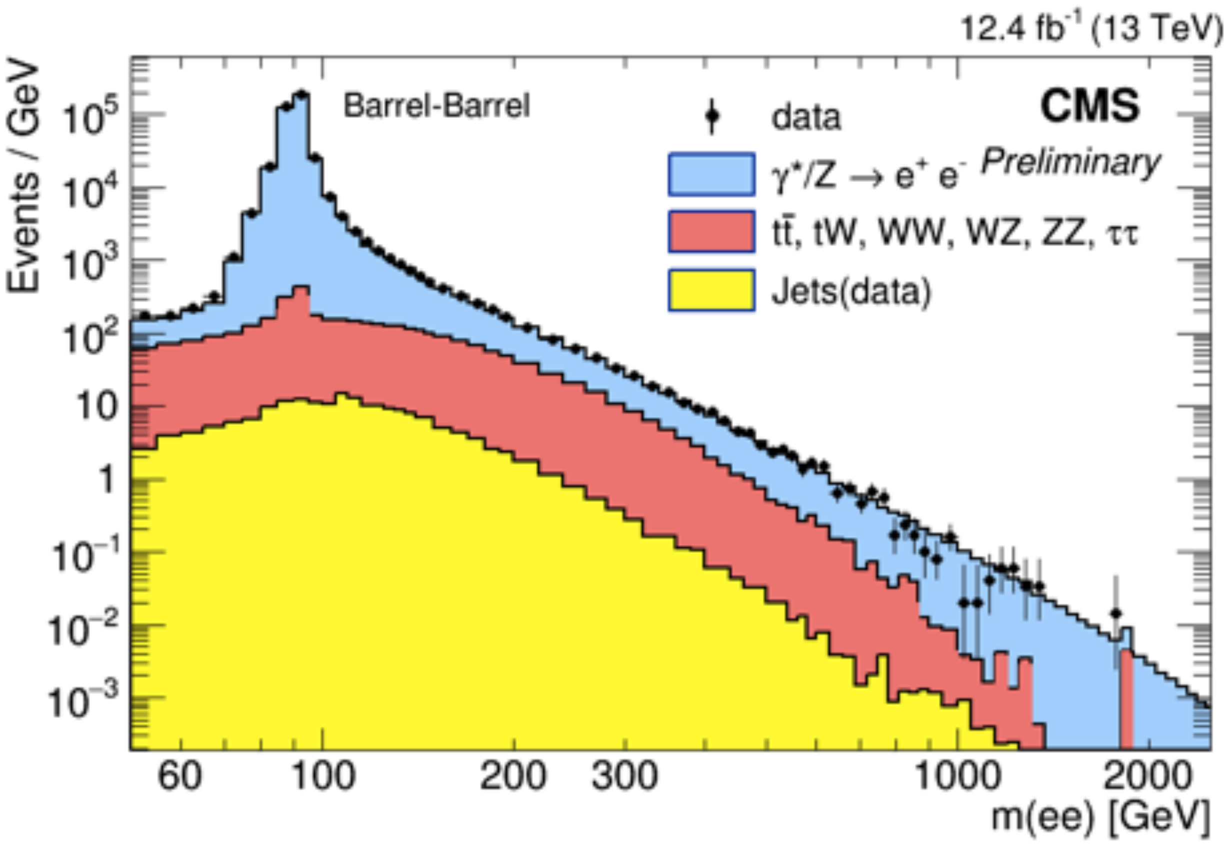
- **Jet(s) background estimated with Fake Rate Method from data**
- **Firstly measure the Fake Rate (FR) with real data**
  - use data events triggered by single photon trigger
  - events with more than one electron ($E_T > 10$) is vetoed to suppress DY
  - use track isolation template to calculate FR



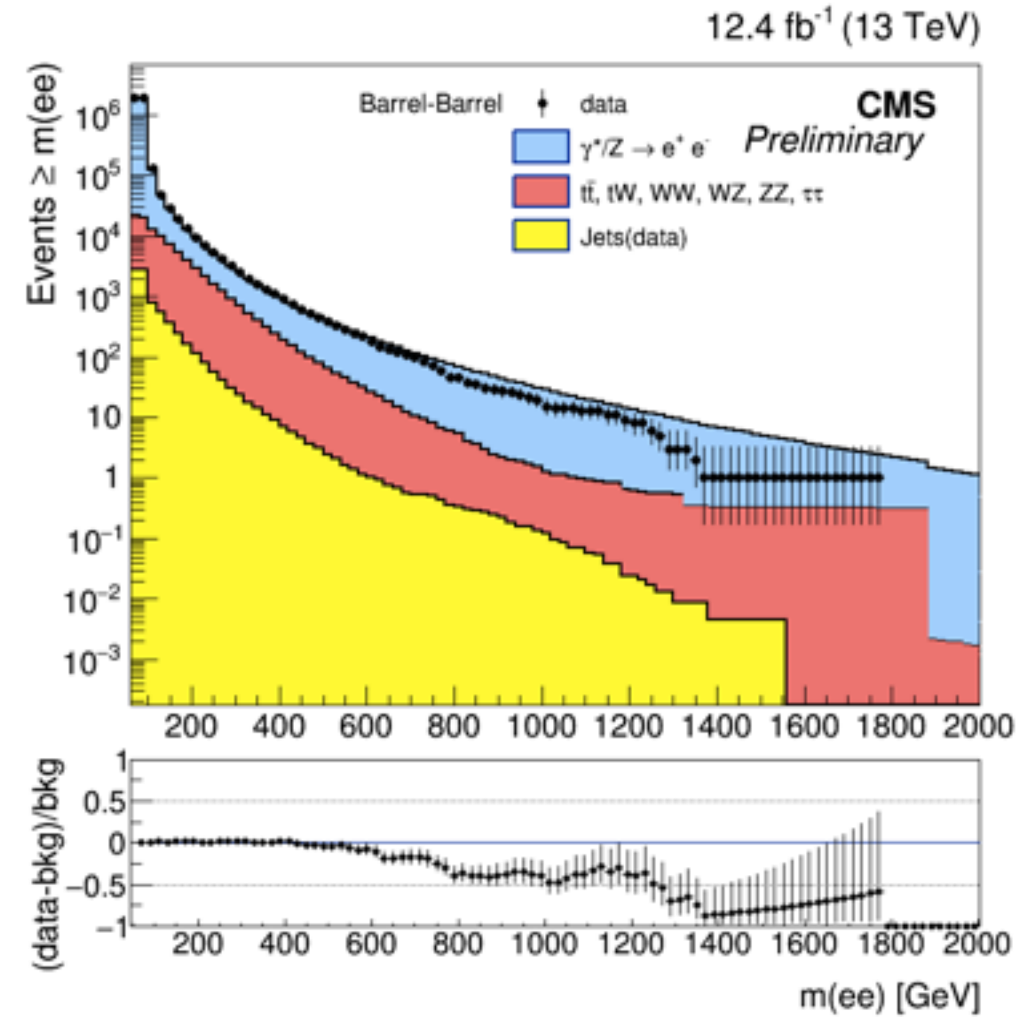
$$FR = N^4 / N^3$$

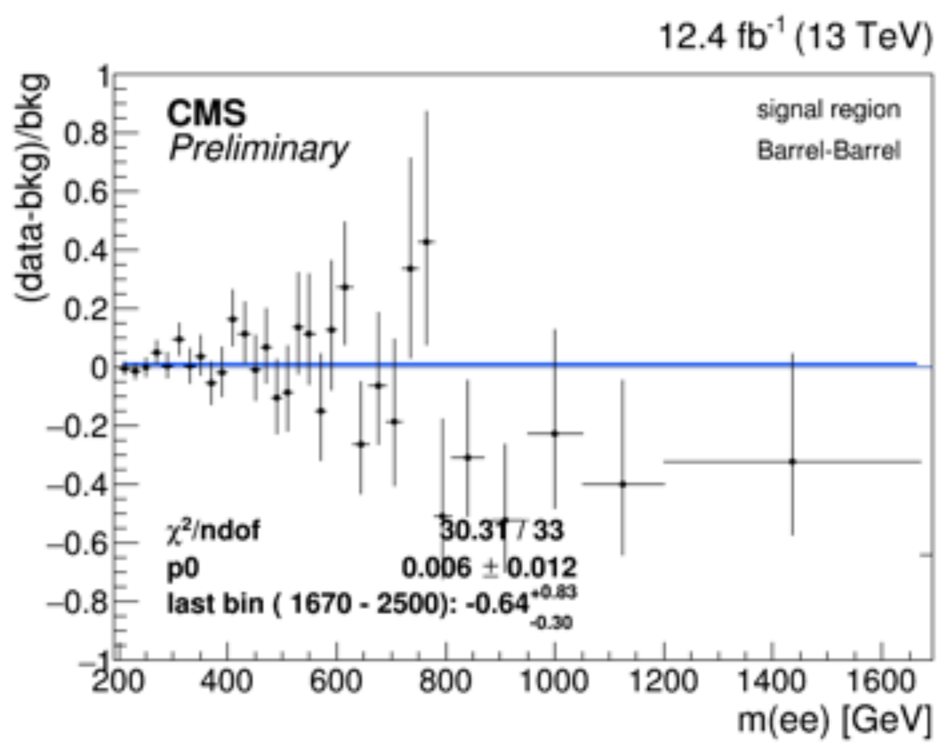
- **Select di-jet CR (2Fail) and W+jets CR (1Pass + 1Fail) from data**
  - apply FR once to W+jet CR to obtain 1F estimate
  - apply FR twice to di-jet CR to obtain 2F estimate
  - **Final jet(s) background = 1F estimate - 2F estimate**

M_{ee} Distribution in data (Barrel-Barrel)



Highest mass: 1769 GeV

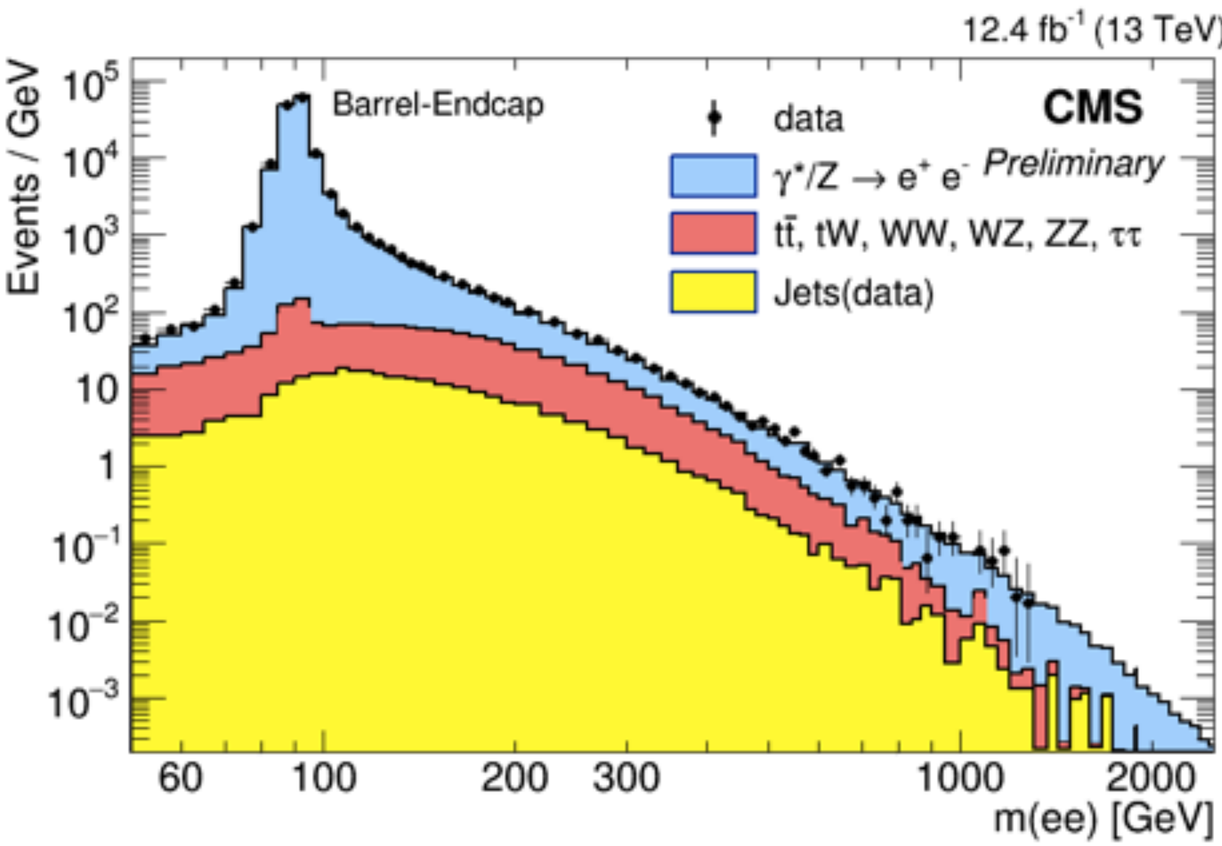


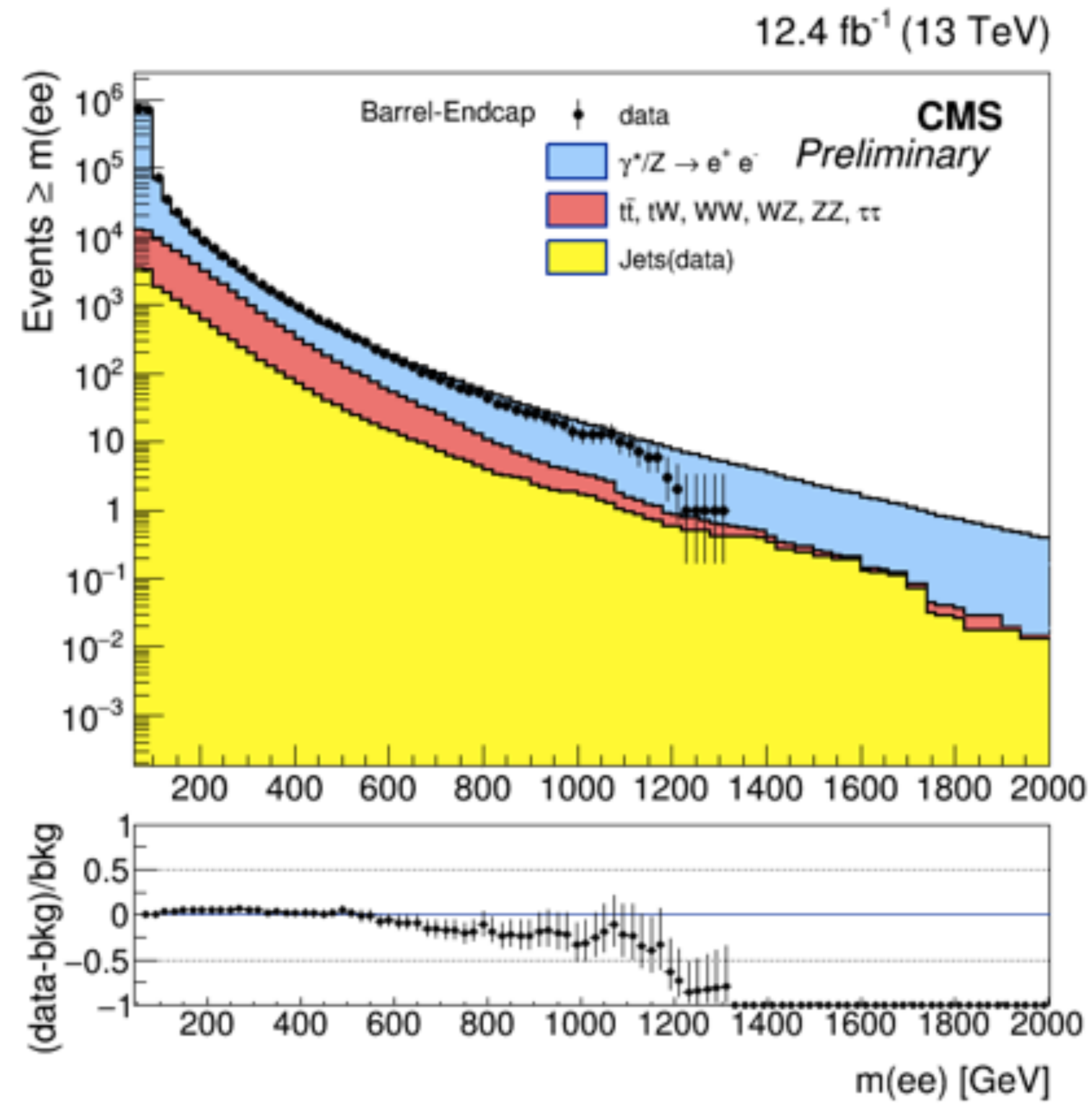


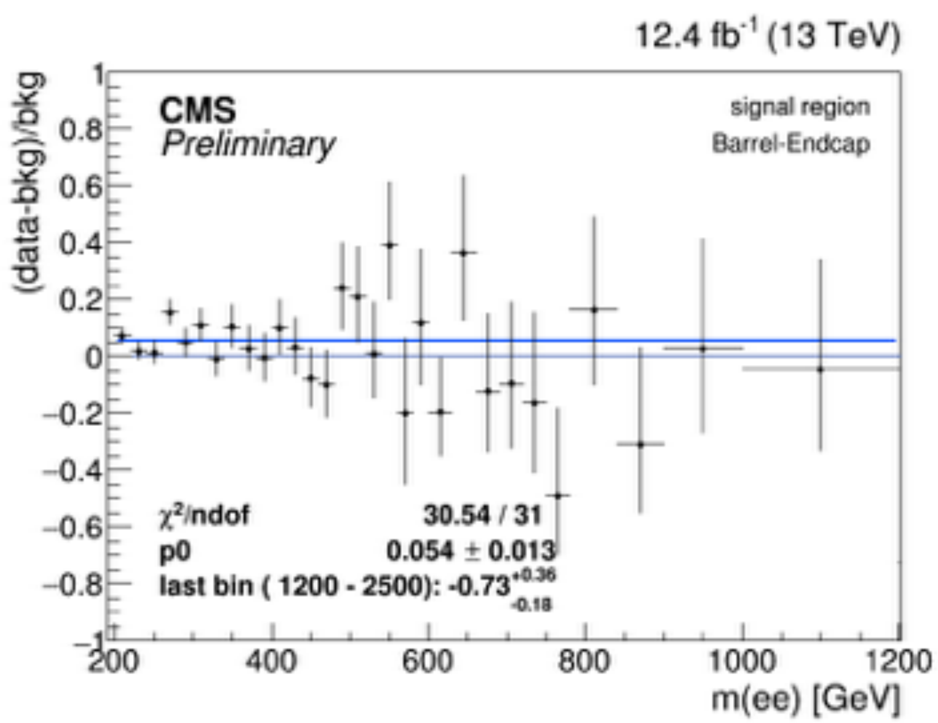
Integral distribution: in each bin, fill events number with M_{ee} > bin lower edge.

Deficit in the high mass region!

M_{ee} Distribution in data (Barrel-Endcap)



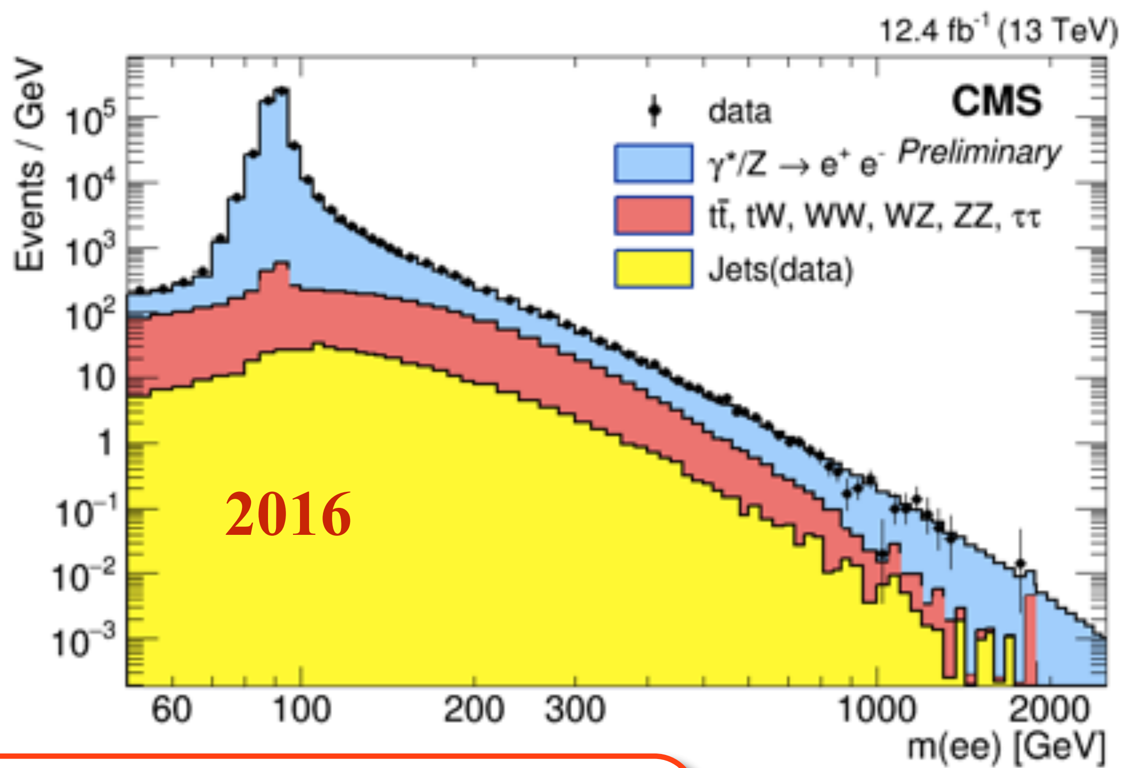


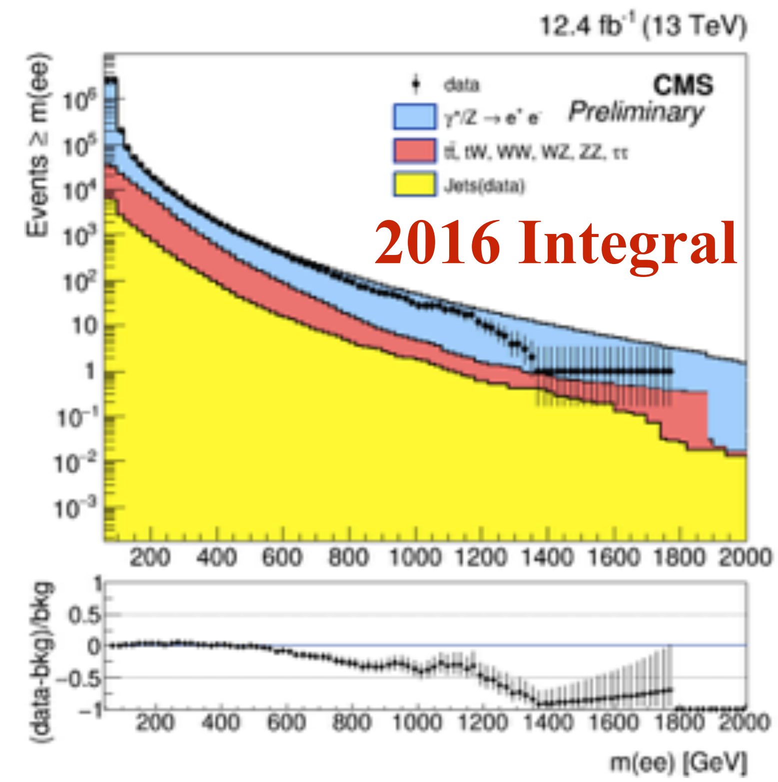


Integral distribution: in each bin, fill events number with M_{ee} > bin lower edge.

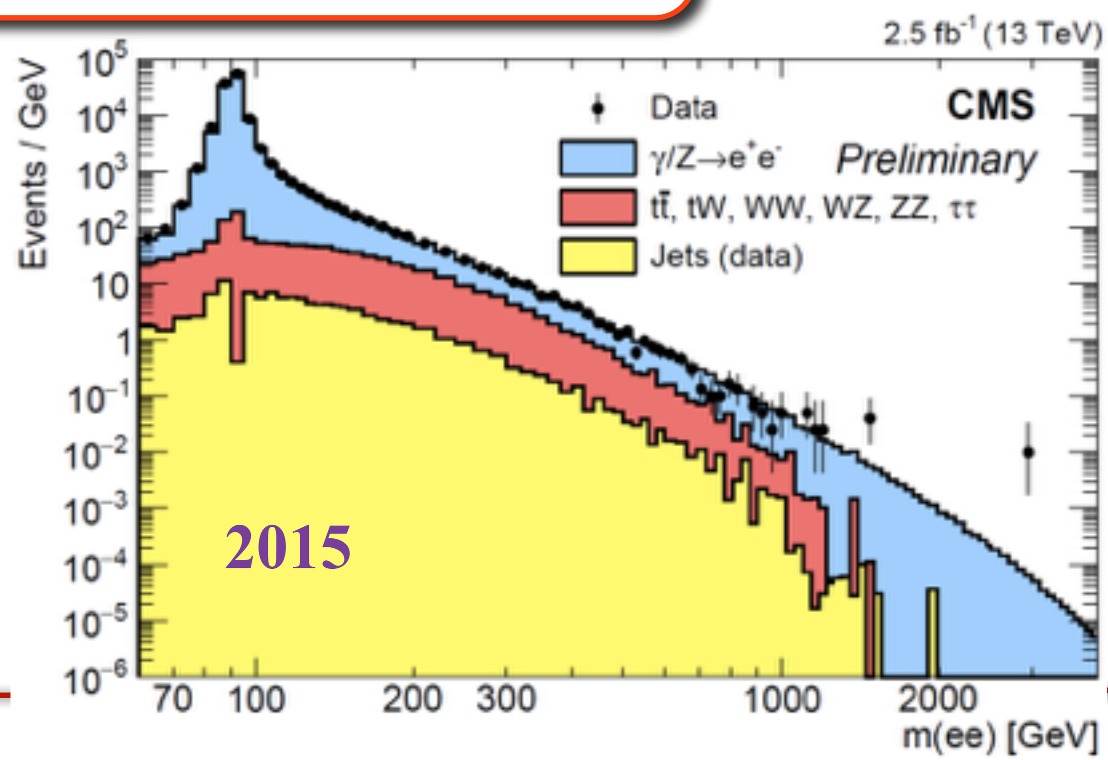
Deficit in the high mass region!

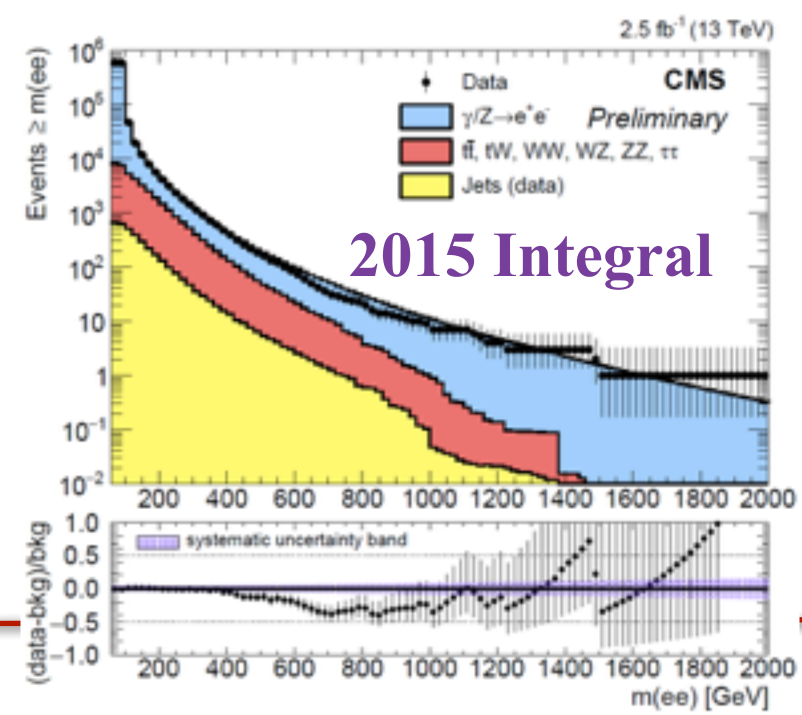
M_{ee} Distribution in data (BB, BE Combined)





Compared with 2015





Limit setting

$$\mathcal{L}(m|\theta,\nu) = \frac{\mu^N e^{-\mu}}{N!} \cdot \prod_{i=1}^{N} \left(\frac{\mu_{SIG}(\theta,\nu)}{\mu} f_{SIG}(m|\theta,\nu) + \frac{\mu_{BG}(\theta,\nu)}{\mu} f_{BG}(m|\theta,\nu) \right)$$

Signal Model;

$$f_{SIG}(m|\theta,\nu) = BW(m|\Gamma) \otimes Gauss(m|\sigma)$$

Background Model;

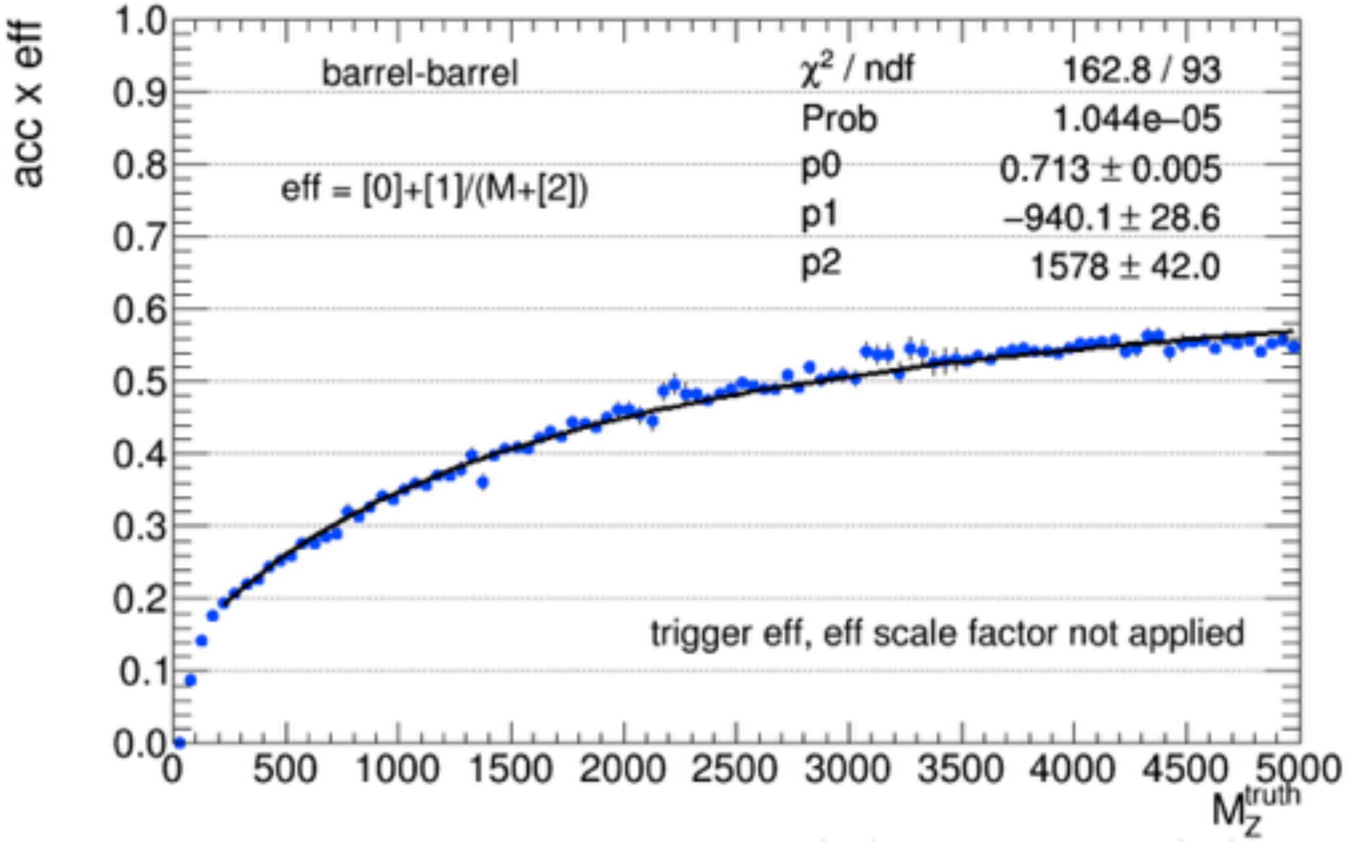
$$f_{BG}(m|\theta,\nu) = e^{am+bm^2+cm^3}\, m^d$$

- **Build likelihood (summing up signal and background) based on M_{ee}**
- **Systematic uncertainties also included with lognormal function**
- **Fit on M_{ee}, background amplitude information from sidebands automatically included in the Likelihood.**
- **Results are presented as a ratio of high mass to those at Z peak.**
- **Many uncertainties cancel out in the ratio, especially those independent of mass and luminosity uncertainty.**

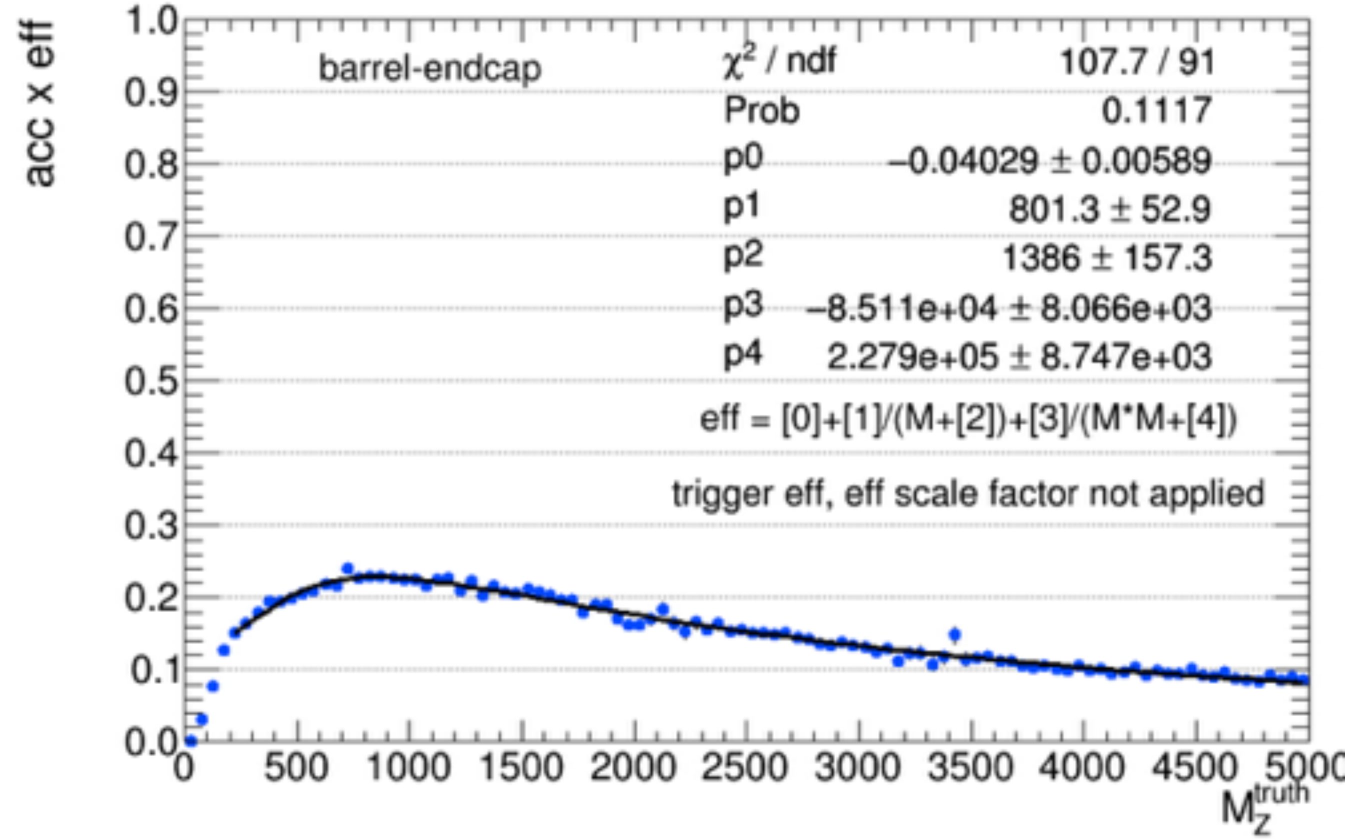
$$R_\sigma = \frac{\sigma(pp \to Z' + X \to e^+e^- + X)}{\sigma(pp \to Z + X \to e^+e^- + X)} = \frac{N(Z' \to e^+e^-)}{N(Z \to e^+e^-)} \times \frac{A(Z \to e^+e^-)}{A(Z' \to e^+e^-)} \times \frac{\varepsilon(Z \to e^+e^-)}{\varepsilon(Z' \to e^+e^-)}$$

Signal shape parameterisation

Barrel-Barrel



Barrel-Endcap



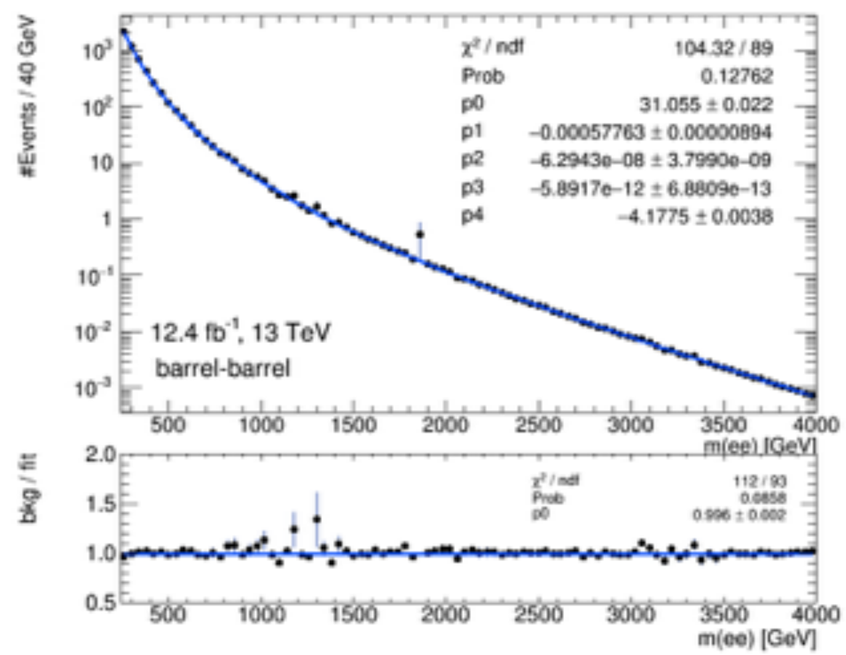
- **Mass resolution parameterisation already shown on page 6 and 7**
- **acceptance × efficiency parameterisation as a function of mass**

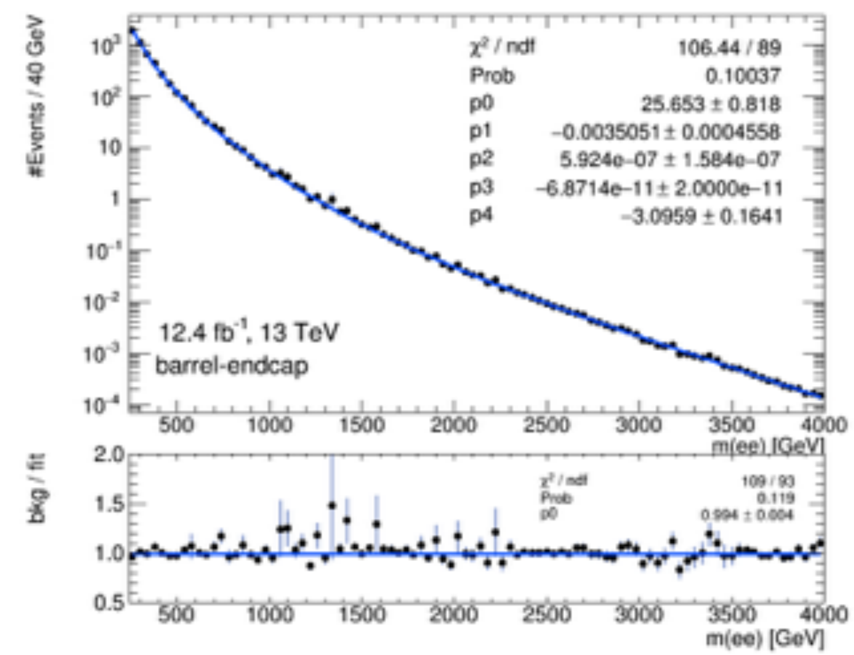
Background fit and Main systematics

background fit

Background Model;

$$f_{BG}(m|\theta,\nu) = e^{am+bm^2+cm^3}\, m^d$$

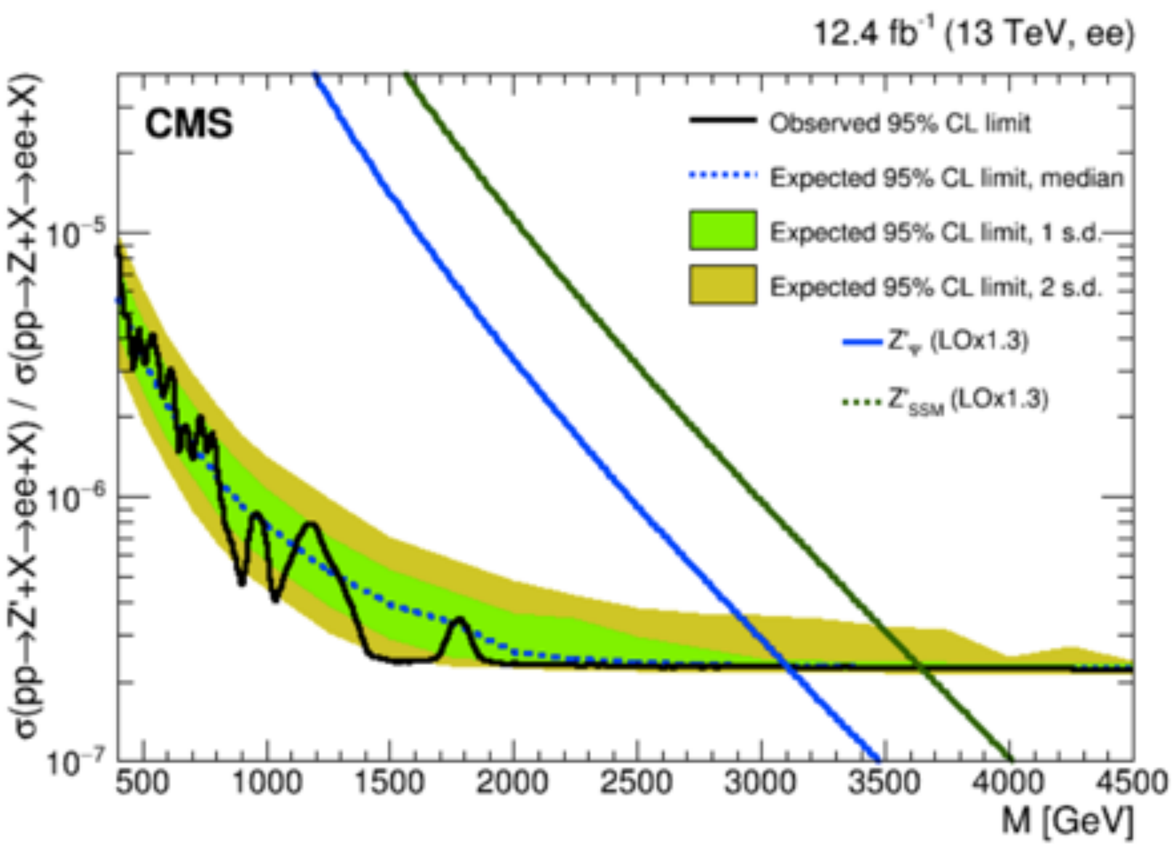




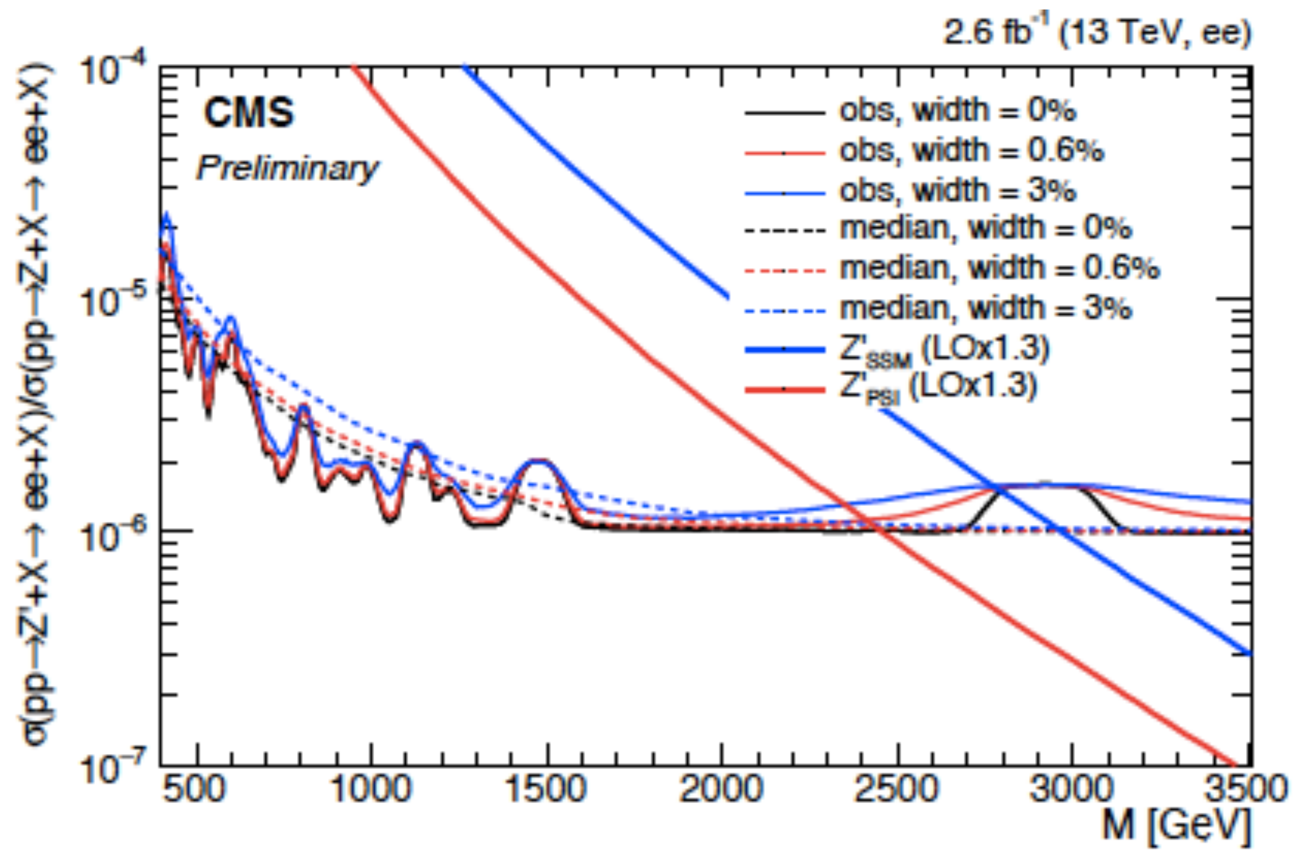
- **Background shape (from estimation) is used to perform the background fit**
- **The absolute background yields is obtained through fit on data**
- **Main systematic uncertainties:**
  - Electron ID at high energy: 4% for barrel and 6% for endcap per lepton
  - PDF uncertainty (mass dependent) ranging from 5% at 400 GeV to 19% at 3TeV
  - Energy scale uncertainty: 1-2%
  - jet(s) background uncertainty 50%, Flavour symmetric bkg ~7%
  - Normalisation at the Z peak: 2%

Results

2016 ee channel



2015 ee channel



obs(exp) limit	2016 data (ee)	2015 data (ee)	2016 data (ee+μμ)
Z'$_{SSM}$	3.65TeV (3.65TeV)	2.75TeV (2.95TeV)	4.0TeV (4.0TeV)
Z'$_\psi$	3.10TeV (3.10TeV)	2.40TeV (2.45TeV)	3.50TeV (3.50TeV)

Conclusion

- Z' search with di-lepton final states was updated with 12.4 fb^{-1} of 2016 data. Results presented at ICHEP 2016.
- No excess found! More stringent limits set on the Z' mass. (3.5TeV for Z'_{ψ} and 4.0TeV for Z'_{SSM})
- Beihang University (joined CMS last Sept.) made significant contribution to this analysis.
  - Editor for analysis note
  - Approval talk on behalf of the analysis group
- A paper (combine 8TeV and 13TeV data) is prepared, being reviewed in CMS Collaboration.
- Continue the search with more Run II data. Stay tuned!

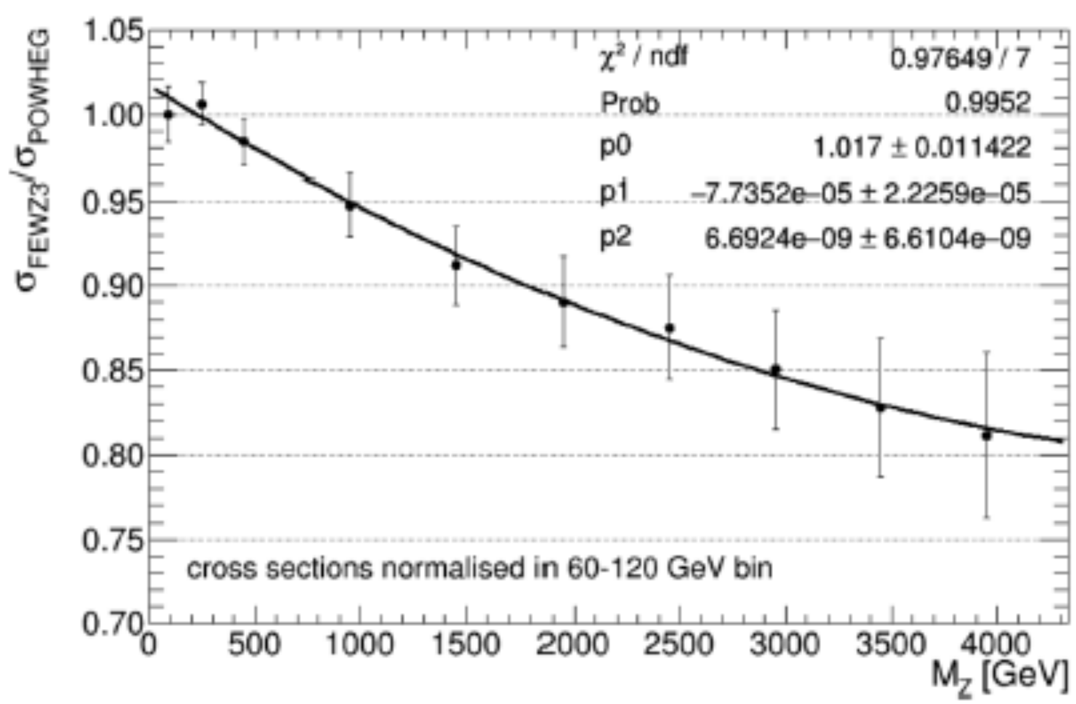
- backup

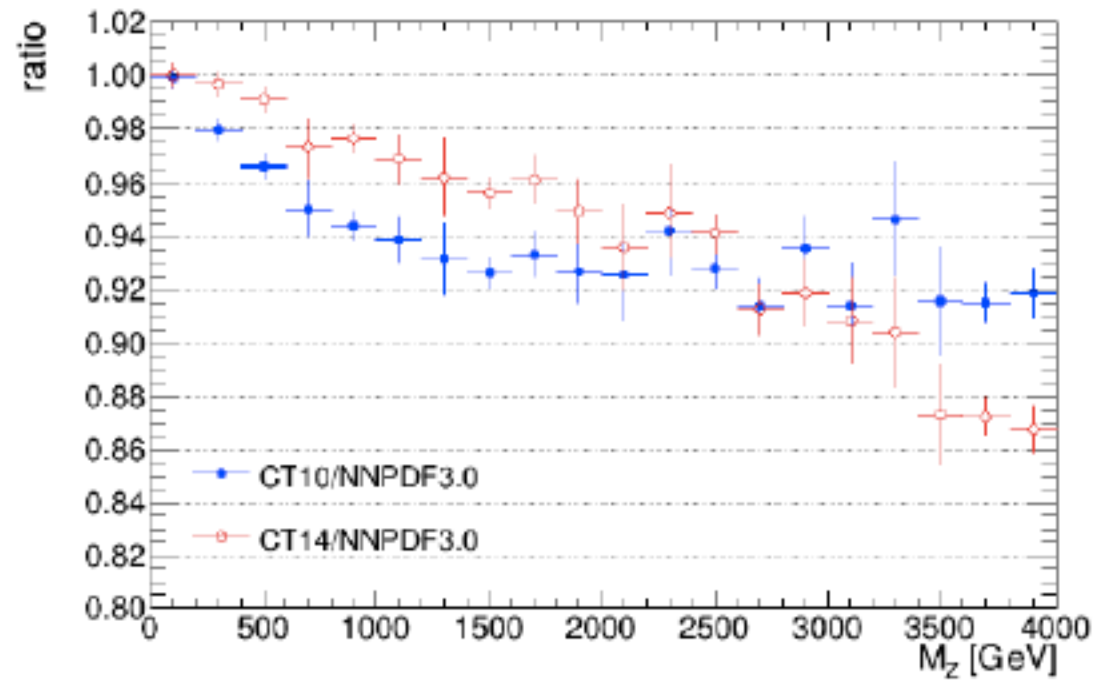
Uncertainties on the DY Background

- The main uncertainties on the Drell-Yan background come from PDF and NNLO effects.

- Left figure shows the ratio of FEWZ3 cross-sections to that predicted by our POWHEG samples generated with NNPDF3.0. It is noted that the POWHEG NNPDF3.0 prediction is increasingly higher than the FEWZ prediction when the mass increases. (see the mass spectrum after applying the reweighting on slides 25)(Note: QCD(NNLO) and EWK(NLO) corrections are include in FEWZ and this is without detector simulation and particle reconstruction in both cases)

- Right figure shows the ratio of the POWHEG cross-section predictions when using CT10 and CT14 over the prediction using NNPDF3.0. The ratio decrease when the mass increase. It should be noted that ATLAS in their 2015 result used CT10.
- More details in AN-16-050



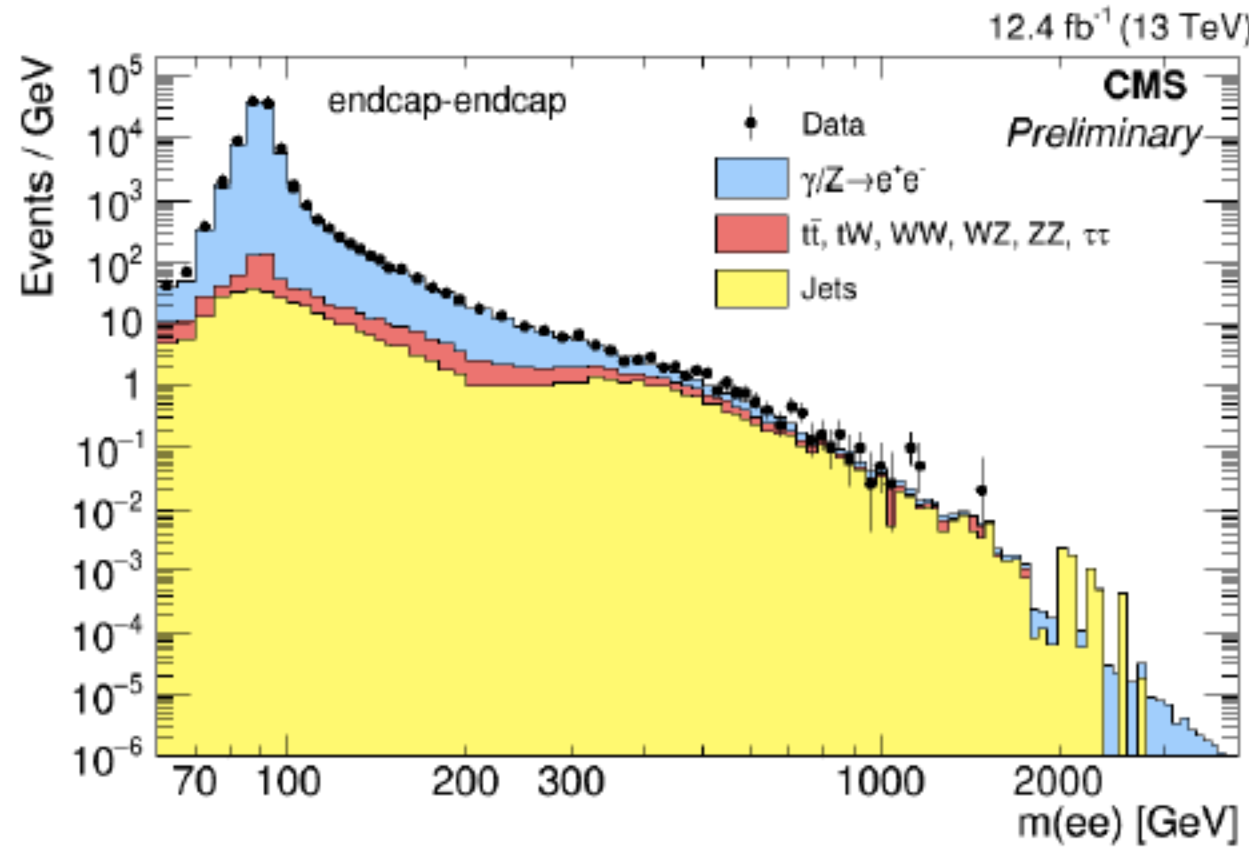


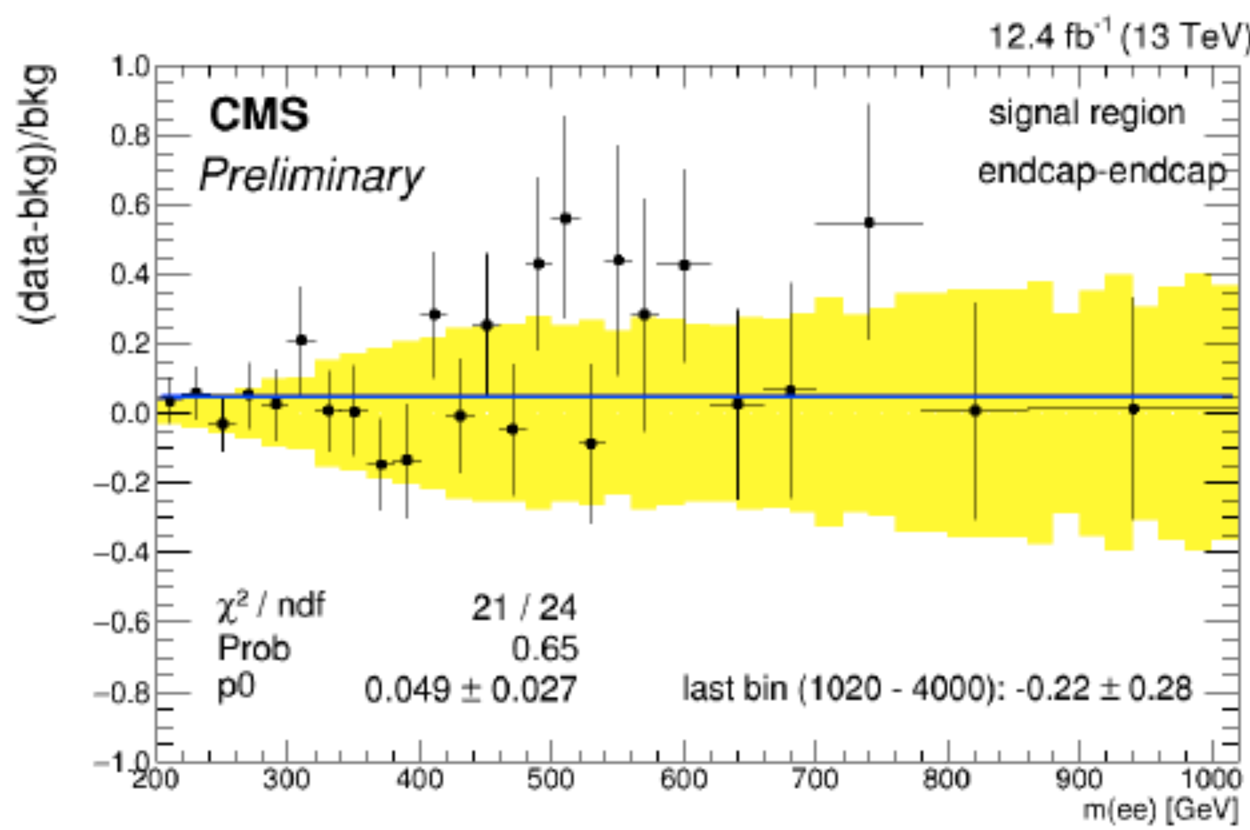
- The PDF uncertainties relative to Z peak region for FEWZ 3.1 at NNLO with the PDF4LHC15nnlo PDF set :

mass range (GeV)	200-300	400-500	900-1000	1400-1500	1900-2000	2400-2500	2900-3000	3400-3500	3900-4000
relative uncert	1.6%	1.9%	2.4%	2.9%	3.5%	4.0%	4.8%	5.1%	7.3%

Jet Background: W+jets, dijet

- smallest background
  - >500 GeV: 0.3% bkg (EB-EB)
  - >500 GeV: 5% bkg (EB-EE)
  - quote a 50% uncertainty
- estimated using fake-rate method, unchanged from last year
  - fully data driven
  - fake rates slightly higher this year but within 50%
- fake rate binned in E_T, eta
- validate in endcap-endcap channel which is mostly jets
  - excellent agreement





$\Delta M/M$ vs DPG scale corrections @ 12.9/fb

Given that: $M_{ee} = \sqrt{E_1 E_2(1 - cos(\theta))}$

- the Mass scale $\approx \sqrt{scale(1) \times scale(2)}$

Using DPG mean scale corrections (0.991 for EB and 0.993 for EE):

- $(Mass\ scale)_{EBEB} \approx mean\ scale\ EB\ per\ electron = 0.9\%$
- $(Mass\ scale)_{EBEE} \approx \sqrt{mean\ scale\ EB \times mean\ scale\ EE} = 0.7\%$

To be compared with $\frac{\Delta M}{M}$ of Table 5:

- $(Mass\ scale)_{EBEB} \approx 0.8\%$ (vs 0.9%)
- $(Mass\ scale)_{EBEE} \approx 0.7\%$ (vs 0.7%)

σ_{extra} vs DPG smearings @ 12.9/fb

Smearing coefficients ($smear$) can be thought as relative errors on the energy, so:

- $smear = \frac{\Delta E}{E}$

The σ_{extra} coefficient can be thought as the relative error on the mass:

- $\frac{\Delta M}{M} = \frac{1}{2}\sqrt{(\frac{\Delta E_1}{E_1})^2 + (\frac{\Delta E_2}{E_2})^2}$

Running the numbers:

$$(\frac{\Delta M}{M})_{EBEB} = \frac{1}{2}\sqrt{2 \times (mean\ smear\ in\ EB)^2} = \frac{(mean\ smear\ in\ EB)}{\sqrt{2}} \quad (1)$$

$$(\frac{\Delta M}{M})_{EBEE} = \frac{1}{2}\sqrt{(mean\ smear\ in\ EB)^2 + (mean\ smear\ in\ EE)^2} \quad (2)$$

mean smear in EB $\approx$ 1.127
mean smear in EE $\approx$ 2.205

$(\frac{\Delta M}{M})_{EBEB} \approx 0.79$ vs fitted value of 0.71 (see σ_{extra} Table 5)

$(\frac{\Delta M}{M})_{EBEE} \approx 1.24$ vs fitted value of 1.26 (see σ_{extra} Table 5)