Search for Z' with dilepton final state using full Run2 data in CMS

Li Yuan

Beihang University

Dalian, Liaoning Province

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Outline

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- Overview
- Analysis Strategy
  - Event selection
  - Efficiencies and resolution
  - Backgrounds estimation
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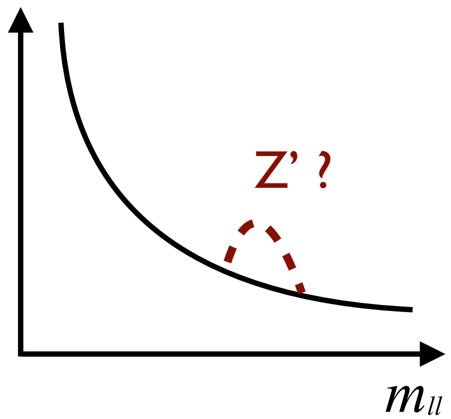
  - Results
- Conclusion

Introduction

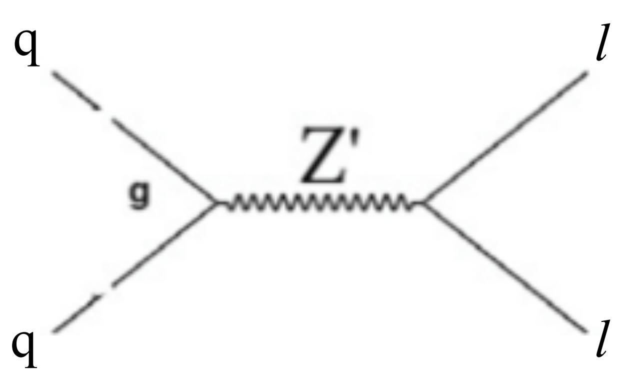
- **SM is not perfect, could not explain many phenomena in the universe.**
- **Many BSM theories predict new heavy resonances decay to dilepton (Z')**
  - extension of SM in Grand Unification predict spin-1 resonance (e.g Z'_{ψ})
  - sequential SM predict Z'_{SSM} (same coupling structure as Z in SM)
  - some SUSY models predict new spin-0 resonance
- **Bump hunt technique to look for narrow resonance above smooth decaying background**



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

Signal and backgrounds

signal



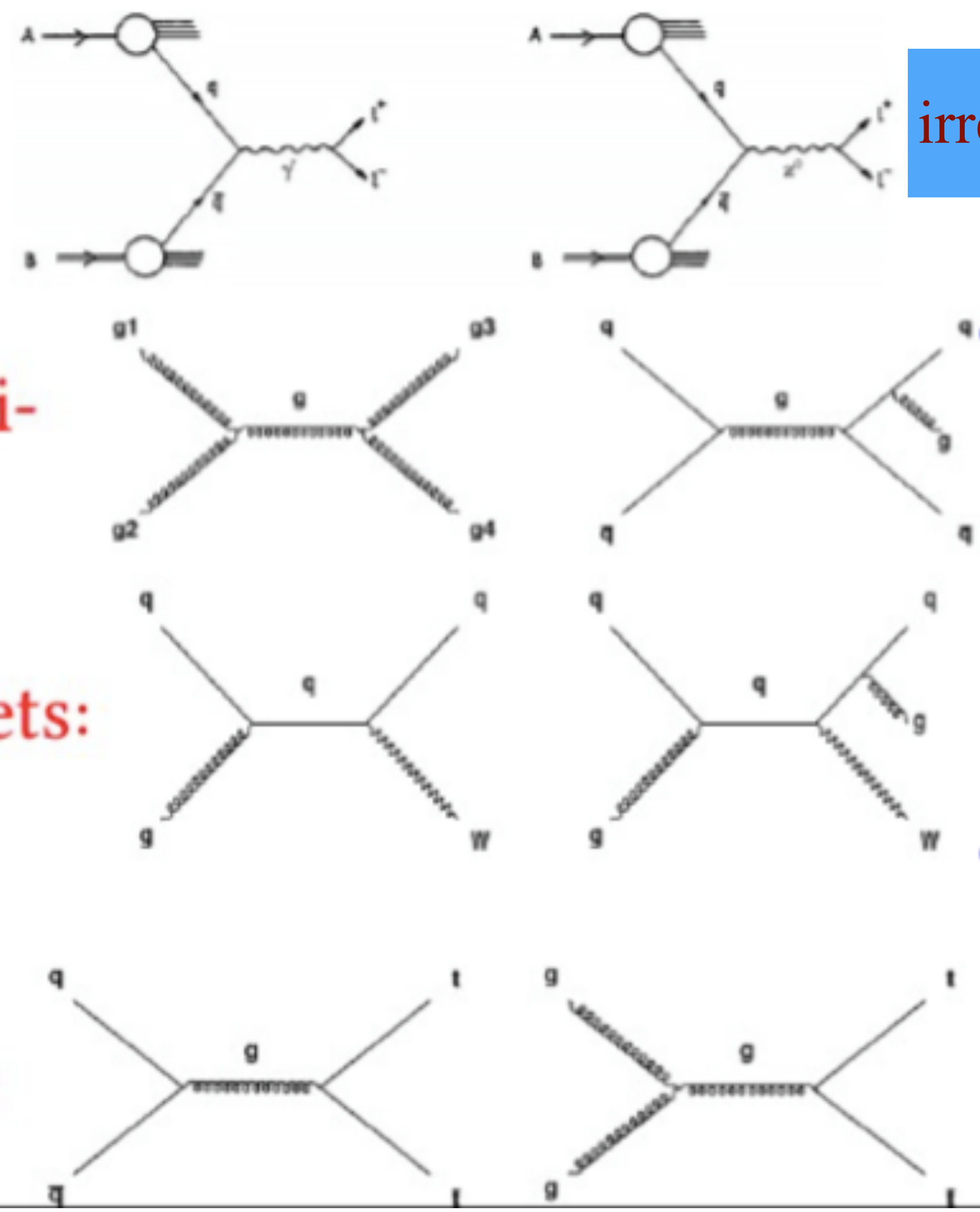
backgrounds

DY:

multi-jets:

W+jets:

ttbar:



irreducible background

jet(s) mis-identified as leptons

non-resonant background

tW, WW, ττ …

Object and Event selection

di-electron

- **Trigger:** di-electron trigger with $E_T > 33(25)$ GeV for 2016, 2017 (2018) data
- **Offline selection:**
  - $p_T > 35$ GeV
  - $|\eta| < 2.5$, crack region removal
  - electron ID based on shower shape variables
  - track isolation and calo-isolation
- **At least one electron in the barrel region**
- **No charge requirement**
- **Events are classified into two categories based on electrons η position: BB, BE**

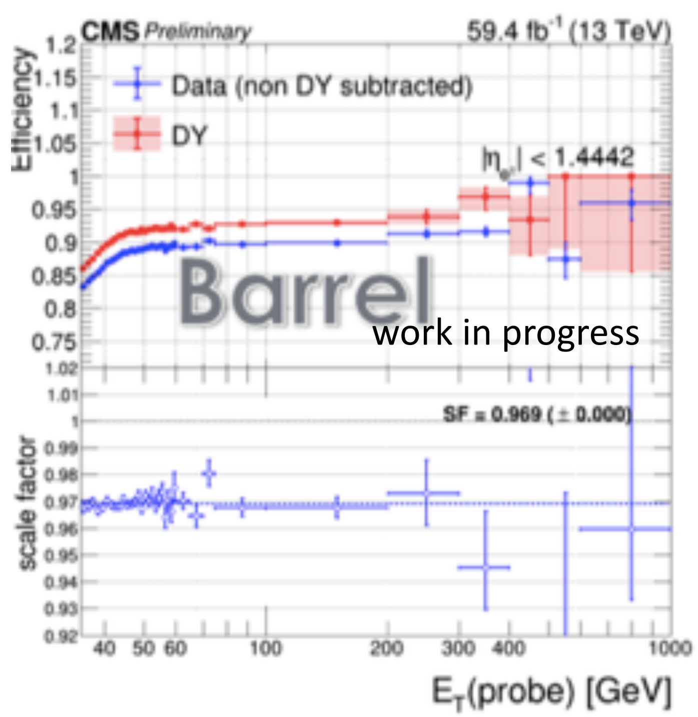
di-muon

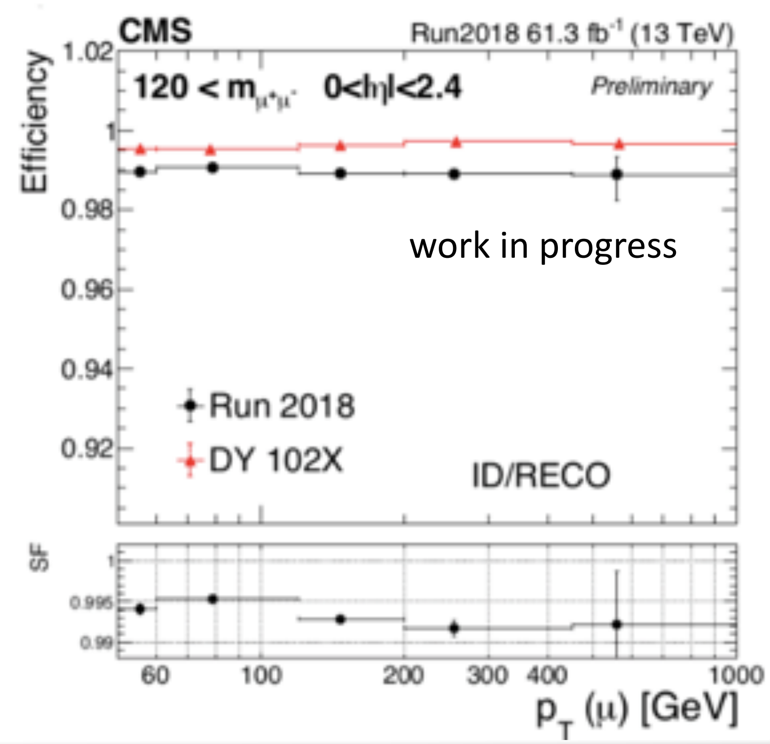
- **Trigger:** single-mu trigger with $E_T > 50$ GeV
- **Offline selection:**
  - $p_T > 53$ GeV
  - $|\eta| < 2.4$
  - high pT muon ID
  - isolation
- **Two opposite charged muons.**
- **3D angle between the muon pair < π-0.02 to reject cosmic muons**
- **vertex fit $\chi^2/N_{dof} < 20$**
- **Events are classified into two categories: BB, BE+EE**

Selection Efficiencies

	Di-electron		Di-muon	
	Barrel electron	Endcap electron	Barrel muon	Endcap muon
Trigger	~98%		> 99%	
Reco+ID	85%-87%	83%-87%	98%	97%
	BB	BE	BB	BE+EE
Evt Eff for 1TeV	69%	65%	92%	

identification efficiency

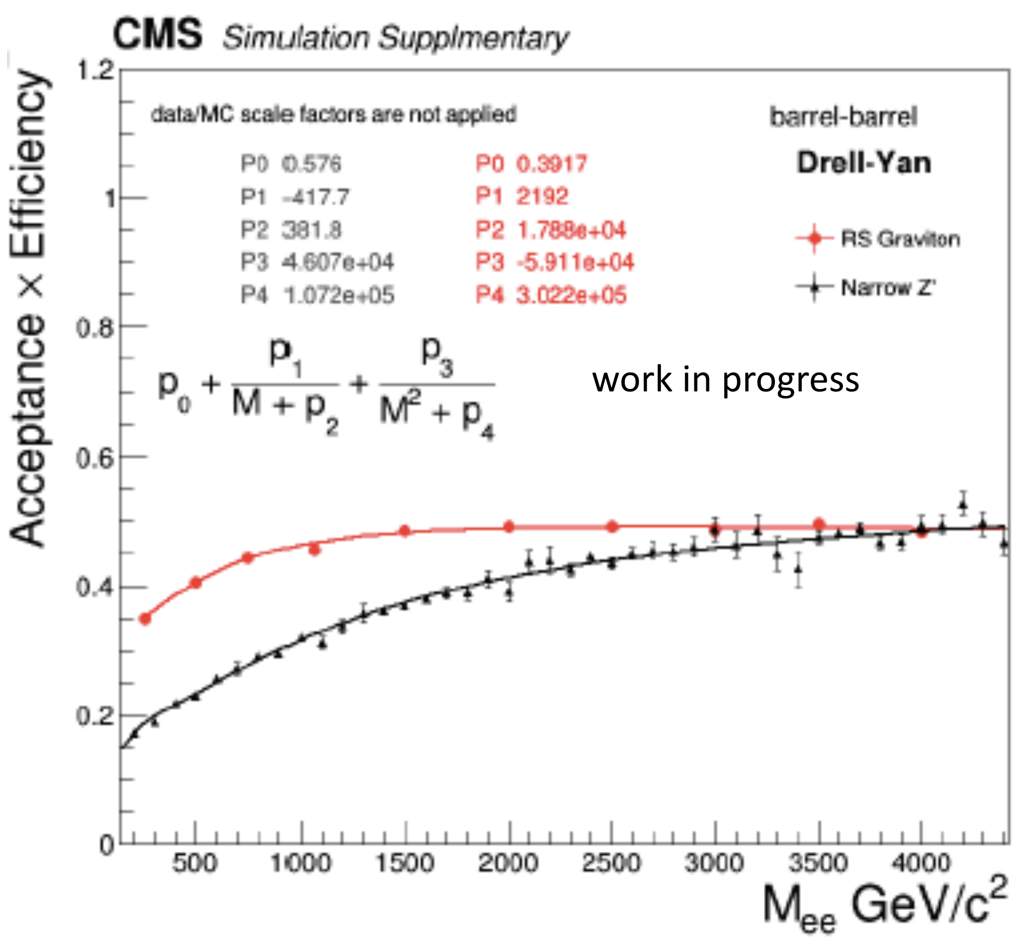




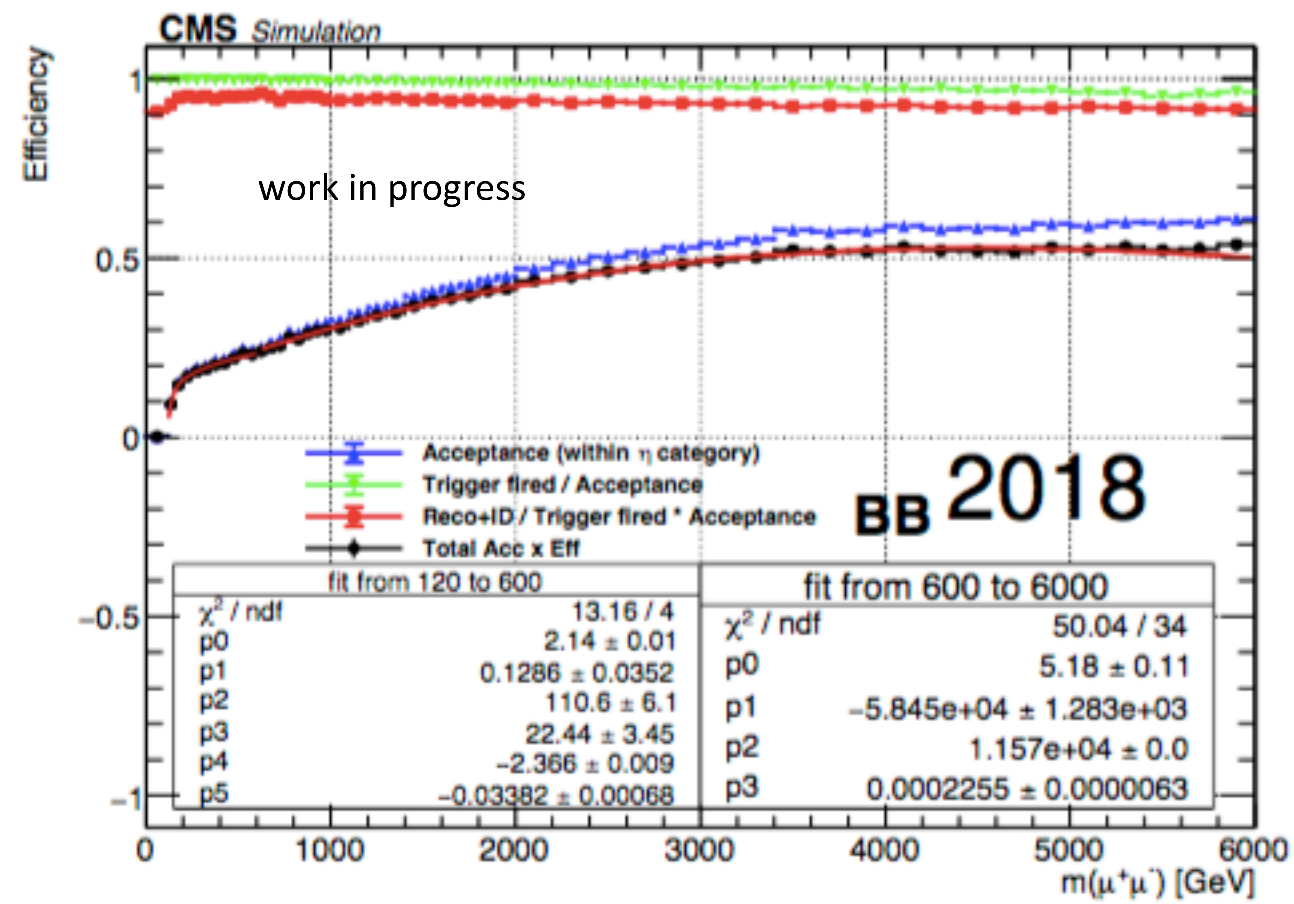
electron

muon

Acceptance×efficiency parameterisation



di-electron: BB

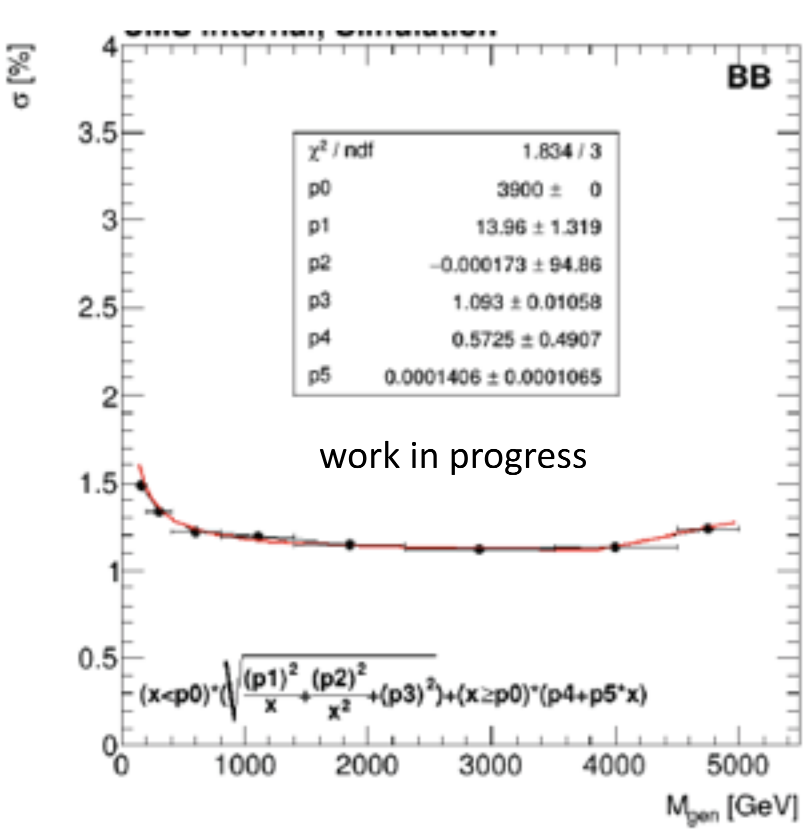


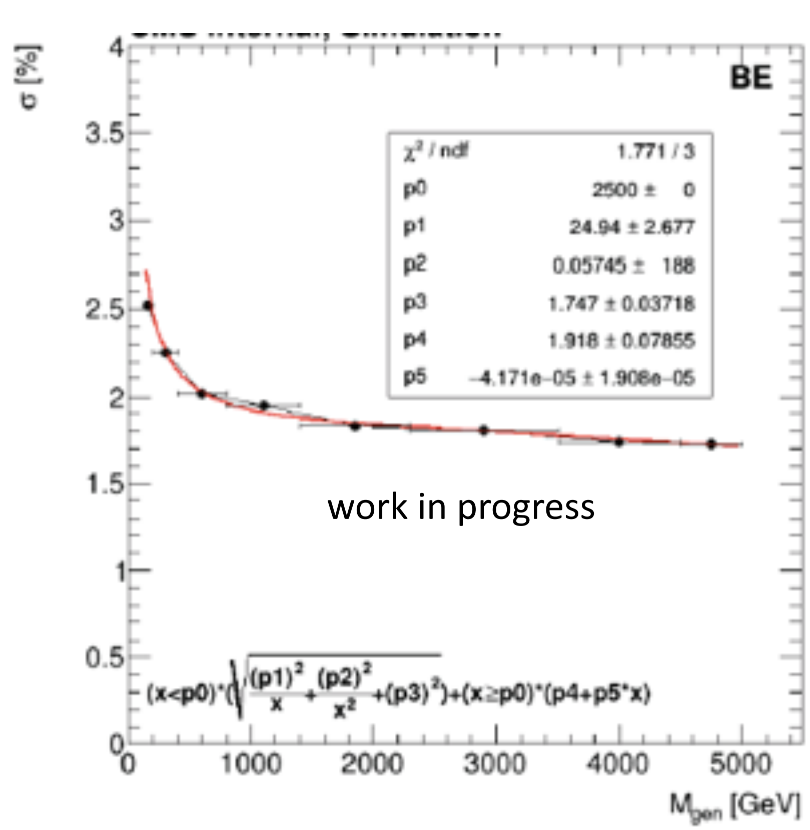
di-muon: BB

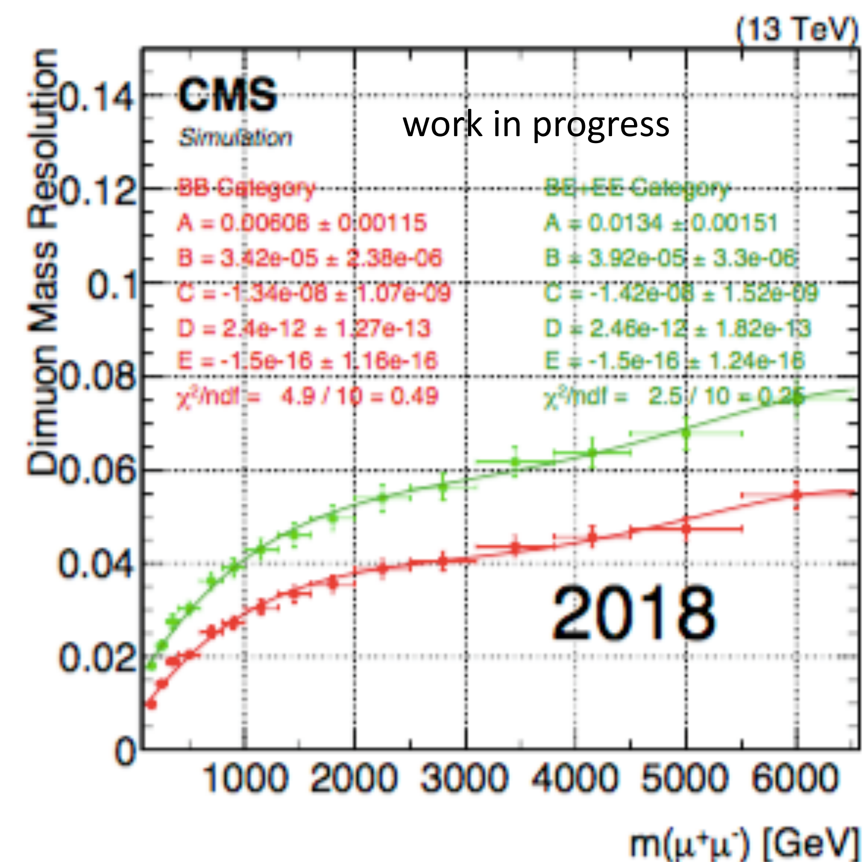
- **acceptance×efficiency parameterisation as a function of mass from DY MC**
- **extrapolate the parameterisation for Z' signals**

Mass Resolution

- **Mass resolution extracted from DY MC simulation samples**
  - Z peak modelled with Breit-Wigner + dCB functions
  - higher mass region resolution (M > 110GeV) by fitting of $(m_{reco}-m_{gen})/m_{gen}$ with dCB
- **Apply the mass resolutions to mimic Z' signals: Breit-Wigner + dCB**



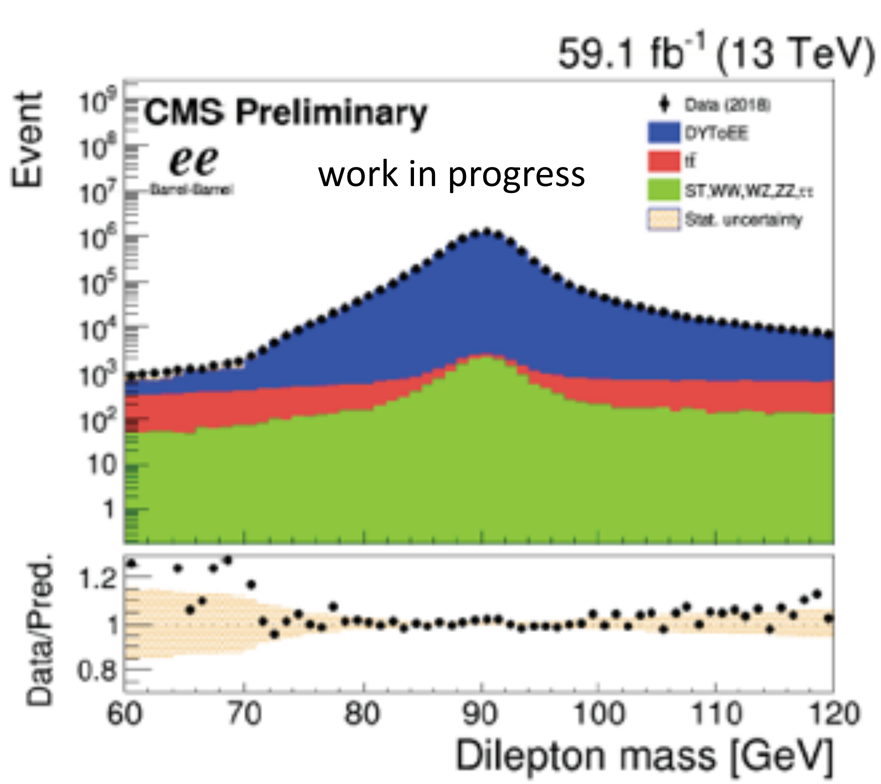


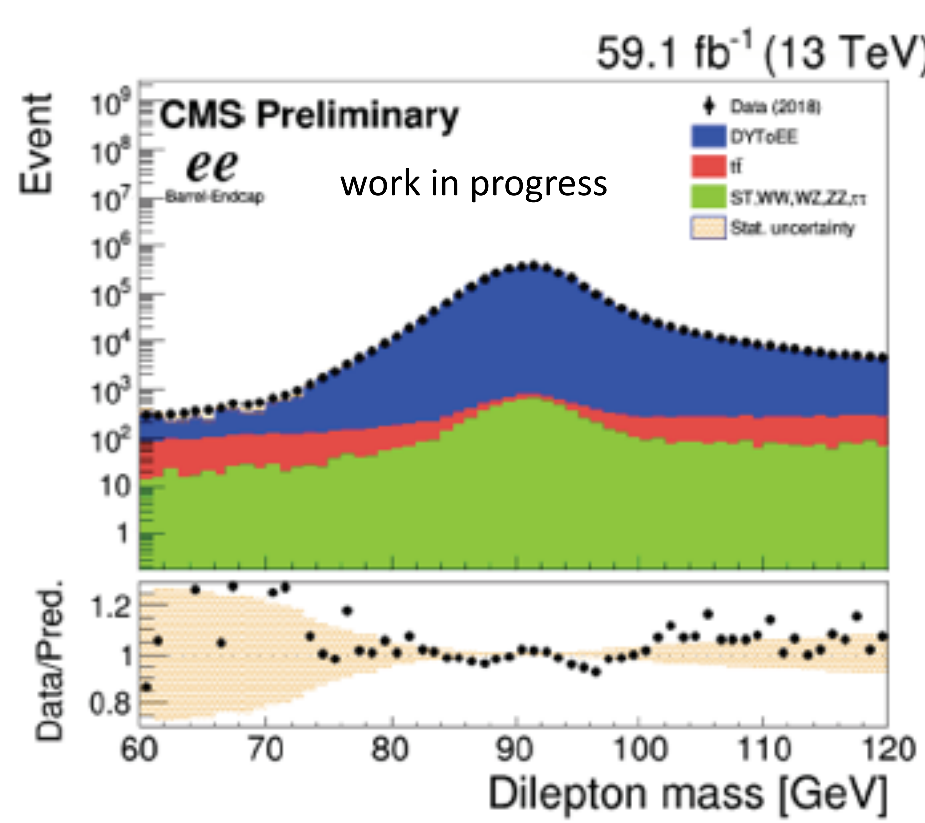


di-electron **di-muon**

Main background: Drell-Yan process

- **Mass spectrum of DY background from MC simulation**
  - Powheg sample reweighted to FEWZ prediction
- **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**

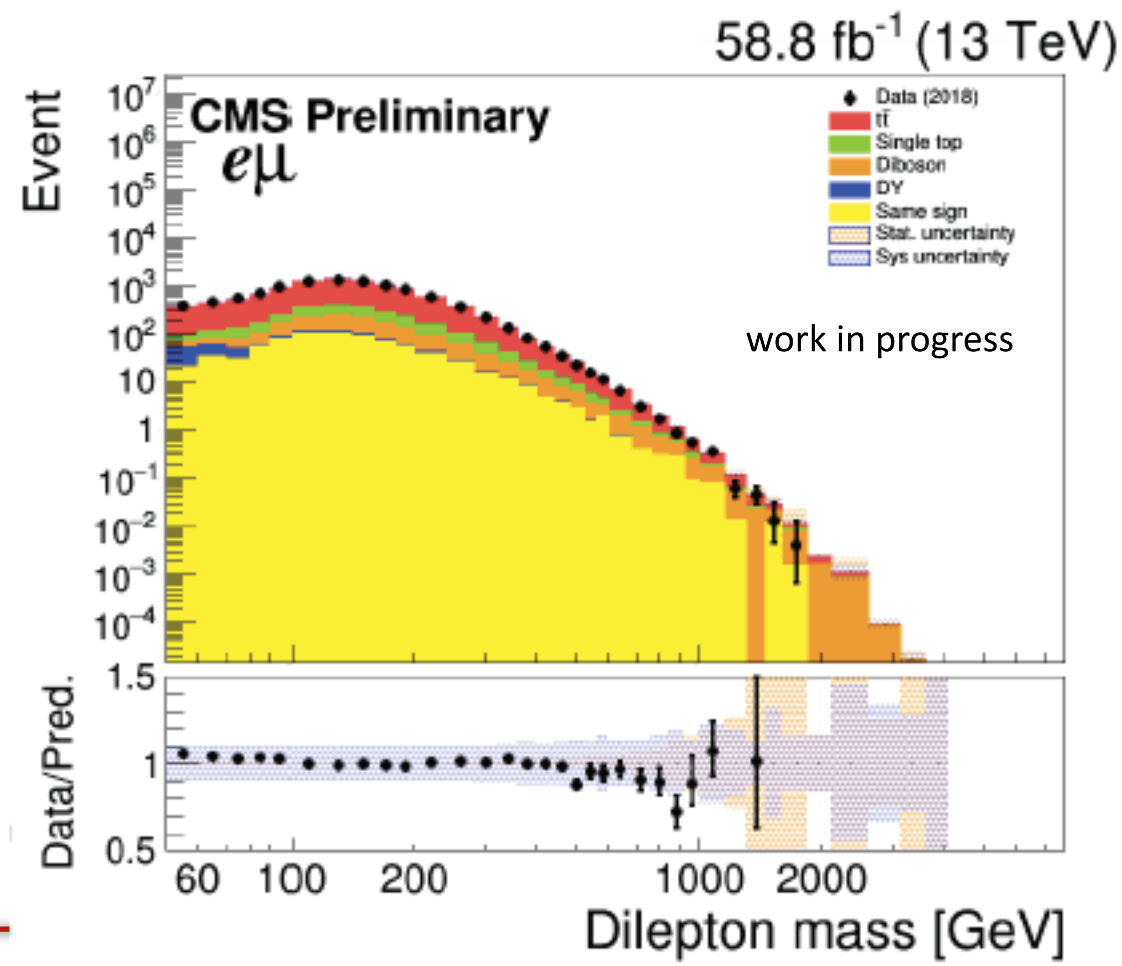


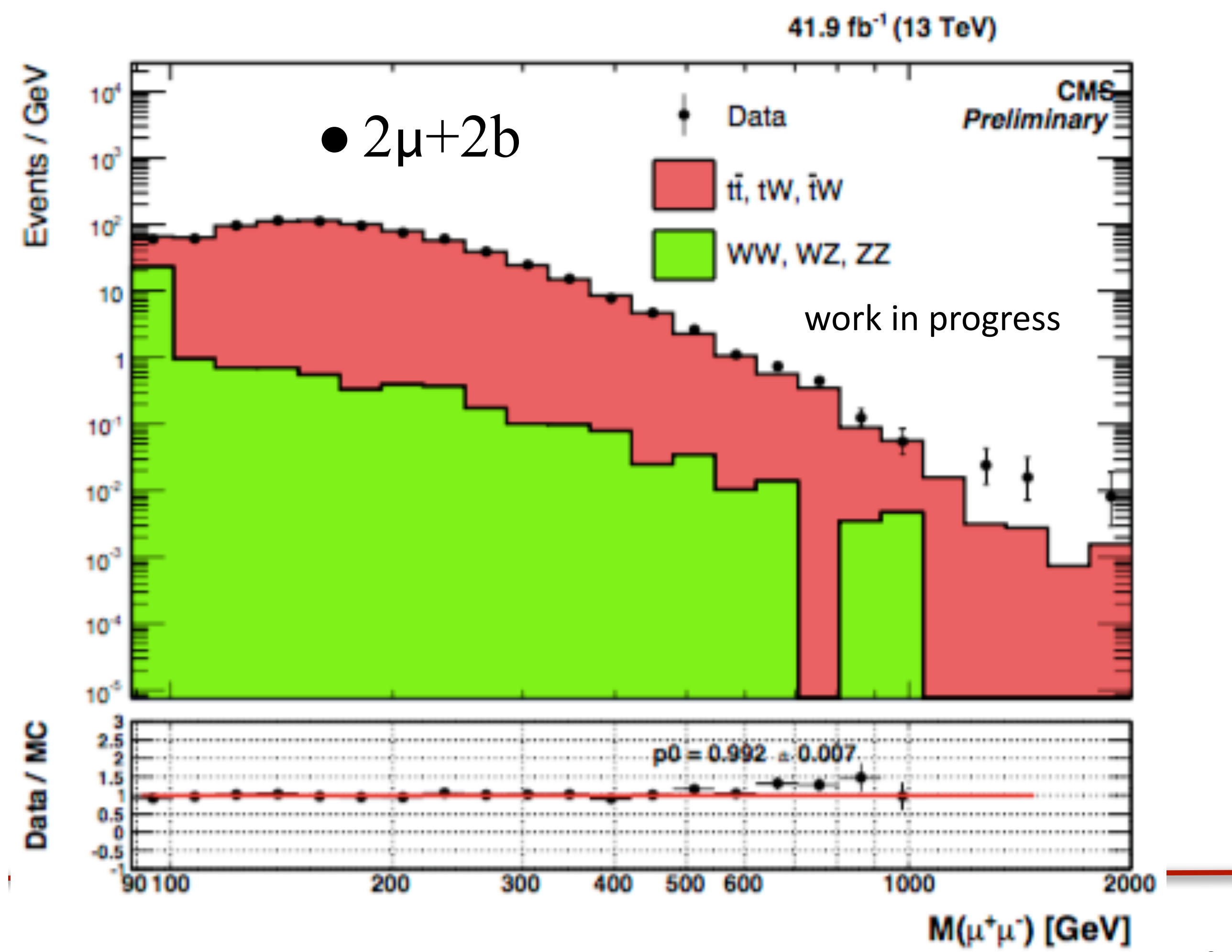


BB **BE**

Flavour symmetric backgrounds

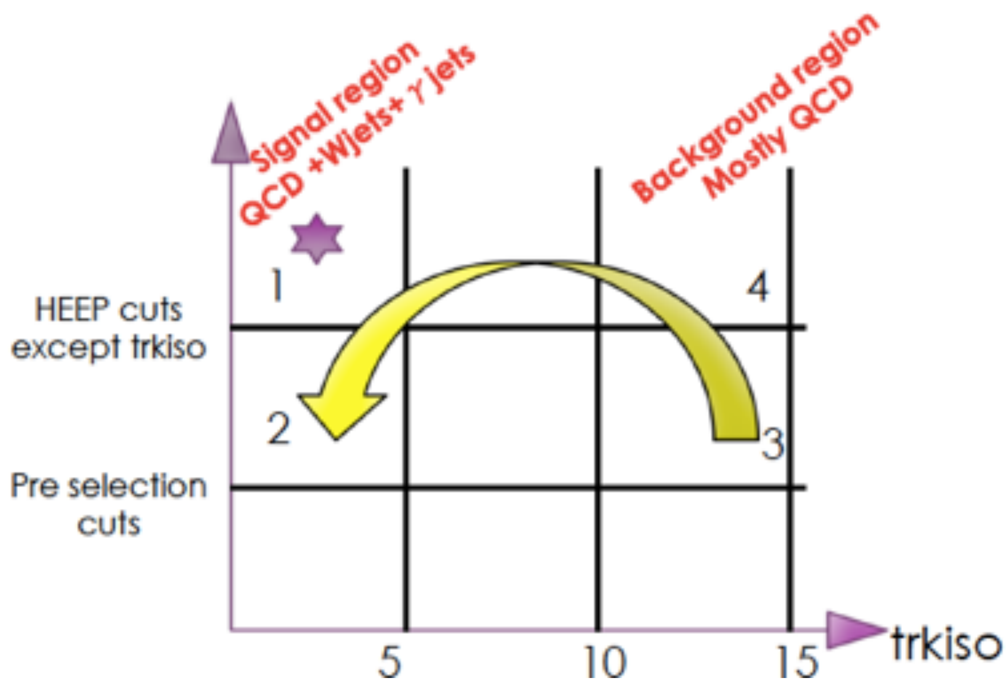
- Flavour symmetric backgrounds (ttbar, tW, WW, WZ, ZZ, ττ) are from MC prediction
- **Validation study is performed for the MC prediction for those backgrounds**
  - use different flavour control region: $e^+\mu^-$ or $e^-\mu^+$ (opposite sign)
  - use 2μ+2b events
- **Good agreement between data/MC in the validation plots**





Jet(s) background

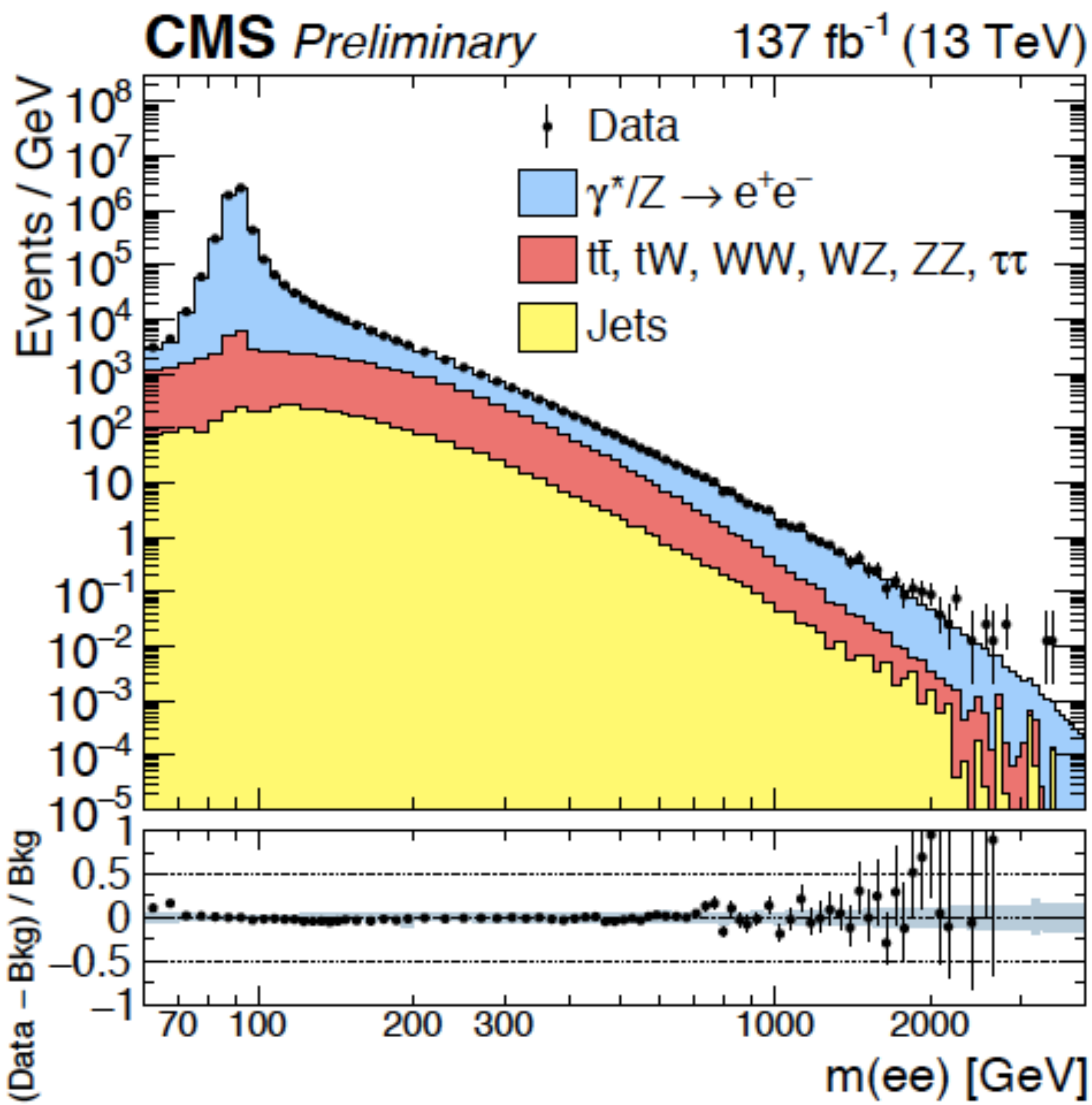
- **Jet(s) background estimated with Fake Rate Method from data**
- **Firstly measure the Fake Rate (FR) with real data**
  - use data events triggered by single photon trigger
  - events with more than one electron ($E_T > 10$) is vetoed to suppress DY
  - use track isolation template to calculate FR

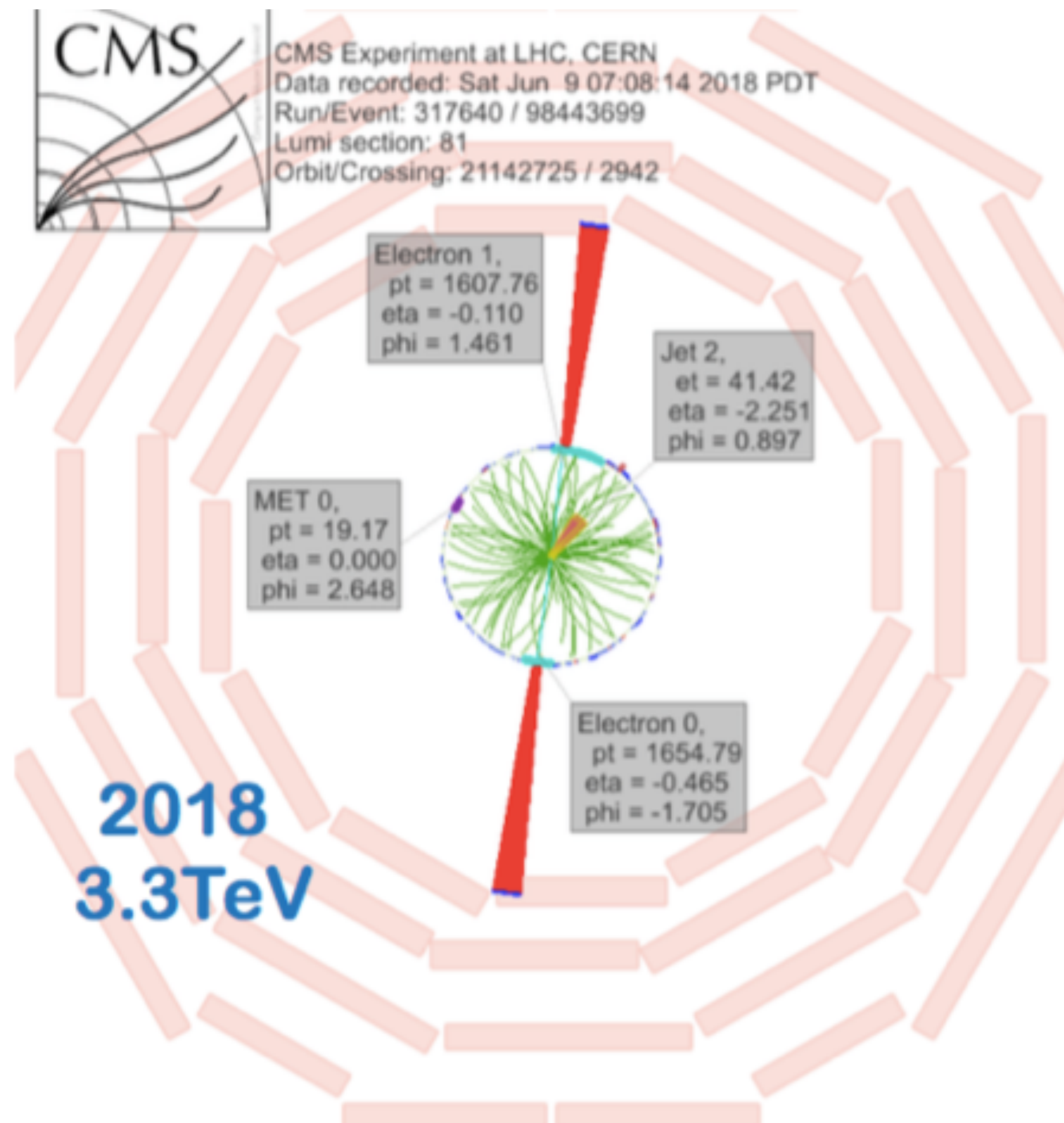


$$FR = N^4 / N^3$$

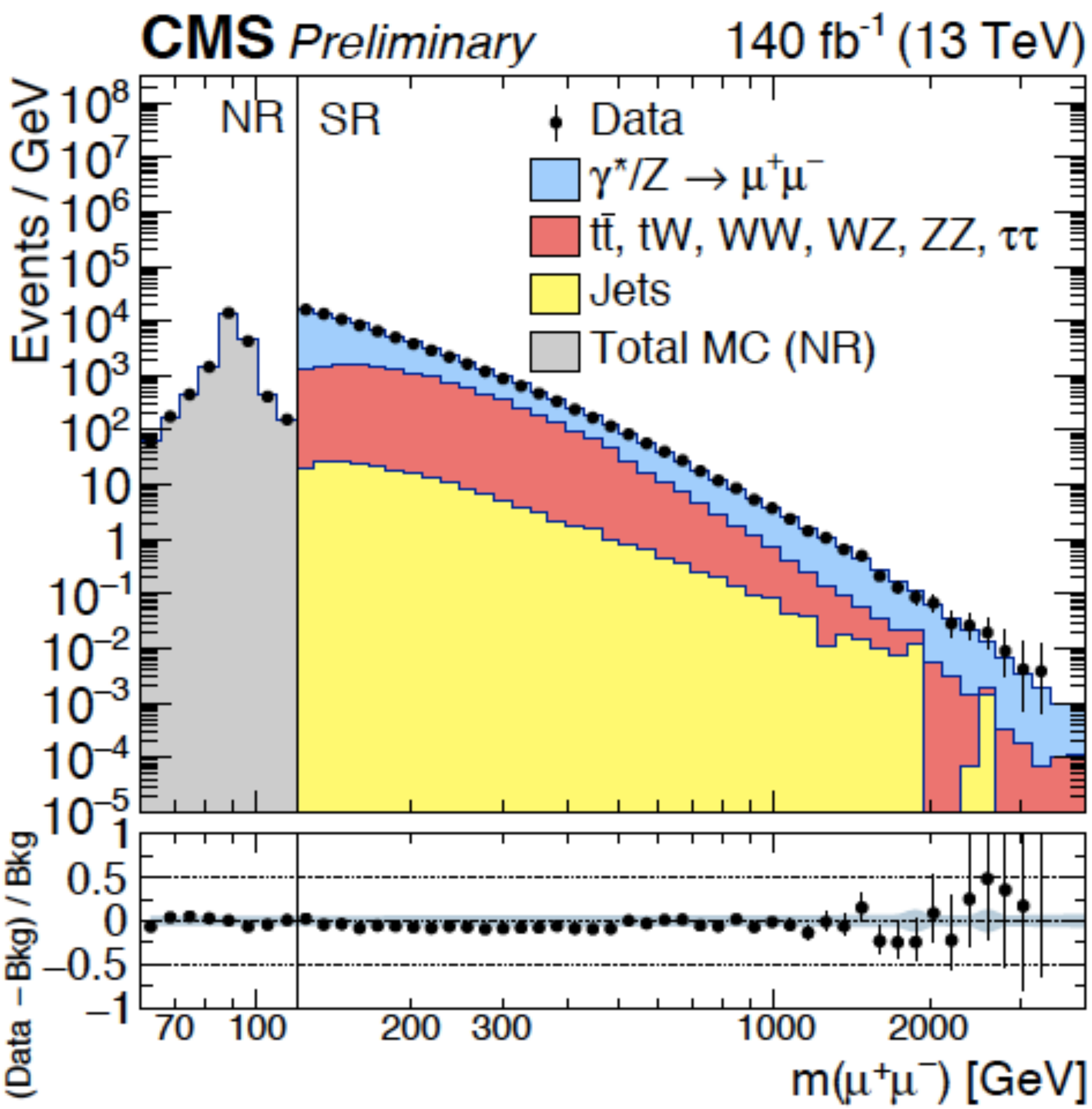
- **Select di-jet CR (2Fail) and W+jets CR (1Pass + 1Fail) from data**
  - apply FR once to W+jet CR to obtain 1F estimate
  - apply FR twice to di-jet CR to obtain 2F estimate
  - **Final jet(s) background = 1F estimate - 2F estimate**

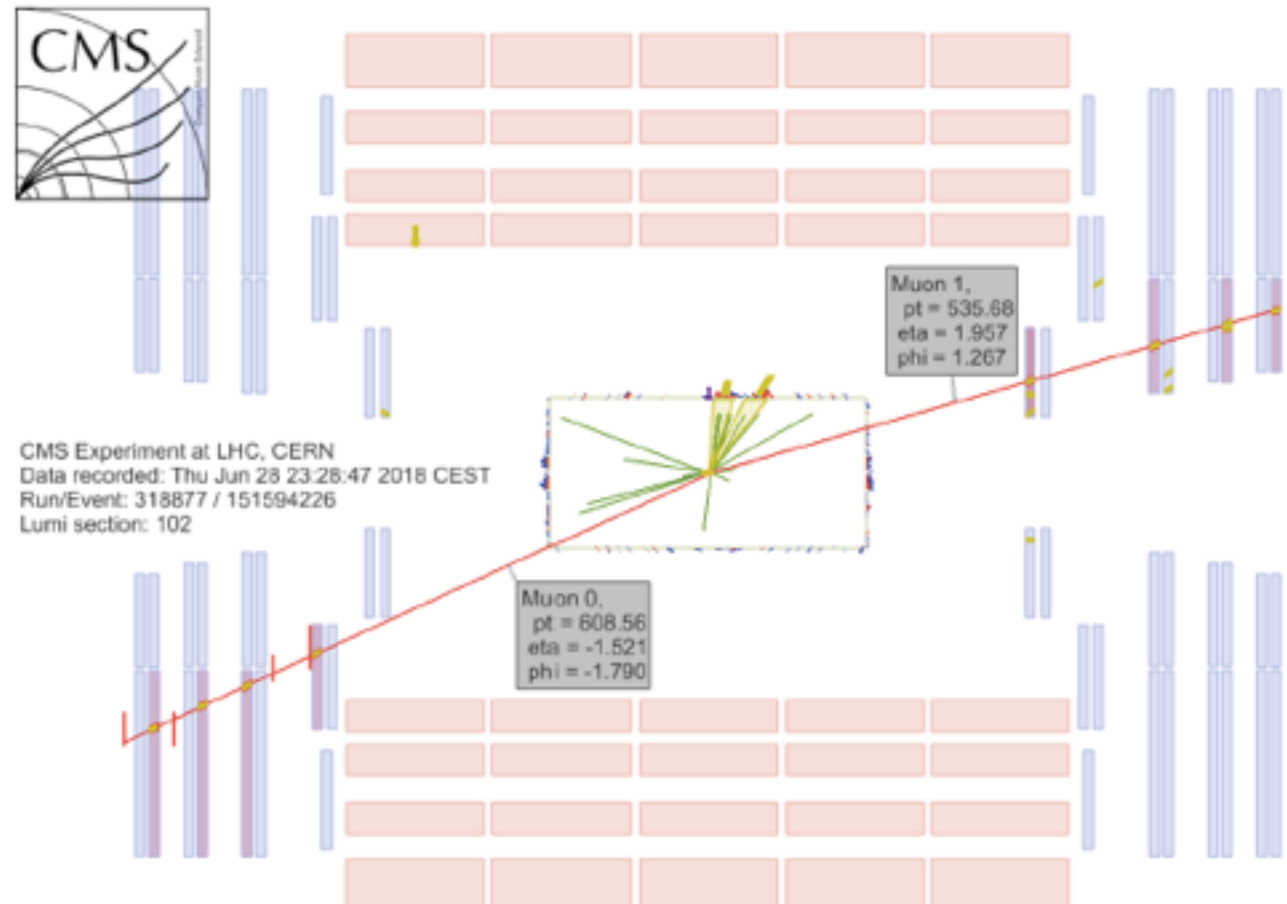
M_{ee} Distribution in data





$M_{\mu\mu}$ Distribution in data





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:

$$f_{BG}(m|\theta,\ \nu) = \begin{cases} m^{\kappa} \exp\left(\sum_{i=0}^{3} \alpha_i m^i\right), & \text{if } m \le 600\,\text{GeV} \\ m^{\lambda} \exp\left(\sum_{i=0}^{3} \beta_i m^i\right), & \text{if } m > 600\,\text{GeV}, \end{cases}$$

di-electron

$$\begin{cases} m^{\mu} \exp\left(\sum_{i=0}^{2} \gamma_i m^i\right), & \text{if } m \le 500\,\text{GeV} \\ m^{\nu} \exp\left(\sum_{i=0}^{3} \delta_i m^i\right), & \text{if } m > 500\,\text{GeV}. \end{cases}$$

di-muon

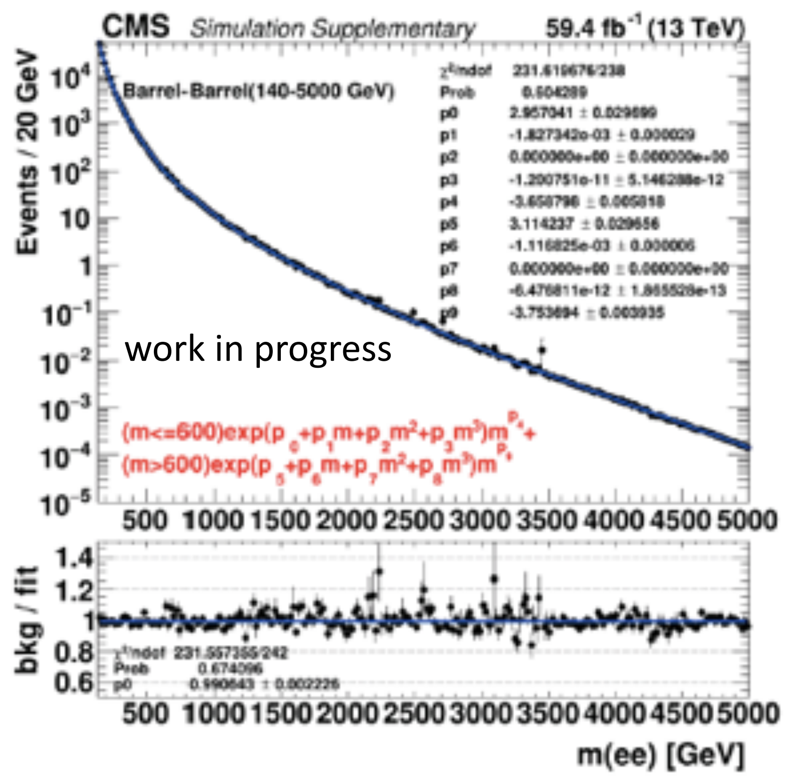
- **Build likelihood (summing up signal and background) based on M_{ll}**
- **Systematic uncertainties also included with lognormal function**
- **Fit on M_{ll}, background amplitude information from sidebands automatically included in the Likelihood.**
- **Results are presented as a ratio of high mass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

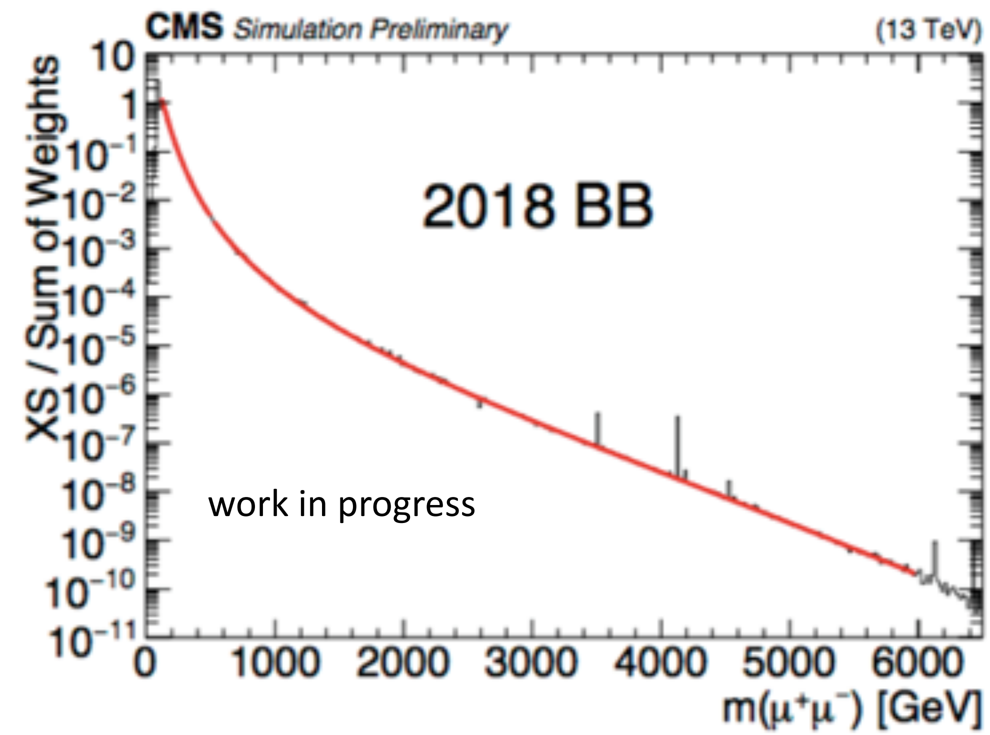
$$R_\sigma = \frac{\sigma(pp \to Z' + X \to e^+e^- + X)}{\sigma(pp \to Z + X \to e^+e^- + X)} = \frac{N(Z' \to e^+e^-)}{N(Z \to e^+e^-)} \times \frac{A(Z \to e^+e^-)}{A(Z' \to e^+e^-)} \times \frac{\varepsilon(Z \to e^+e^-)}{\varepsilon(Z' \to e^+e^-)}$$

Background fit and Main systematics

background fit

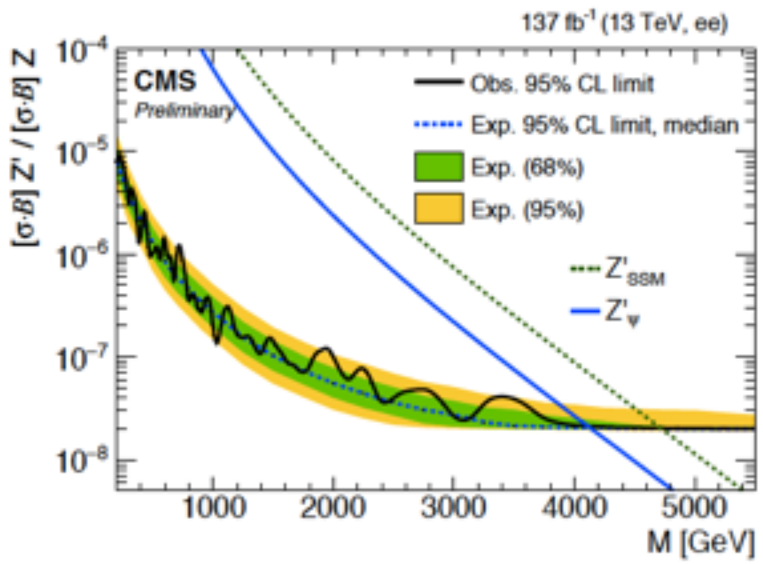
$$f_{BG}(m\,|\,\theta,\ \nu) = m^{\kappa}\exp\Big(\sum_{i=0}^{2\,or\,3}\alpha_i m^i\Big)$$

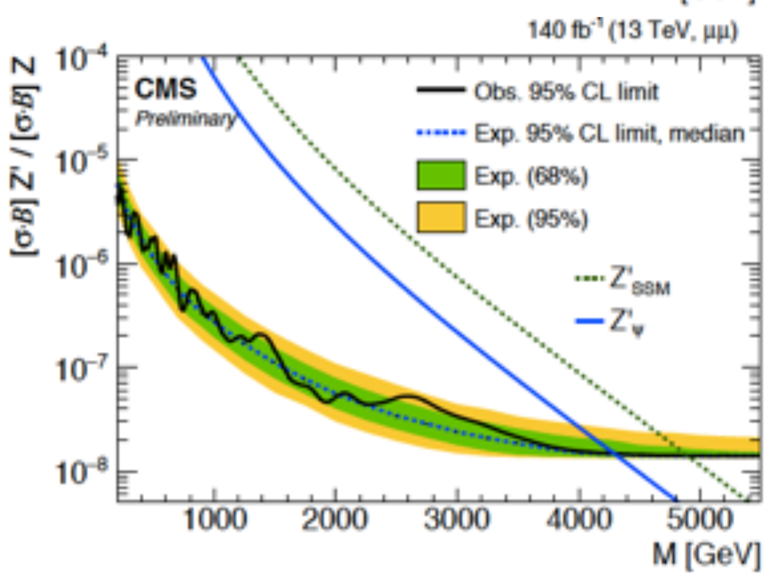


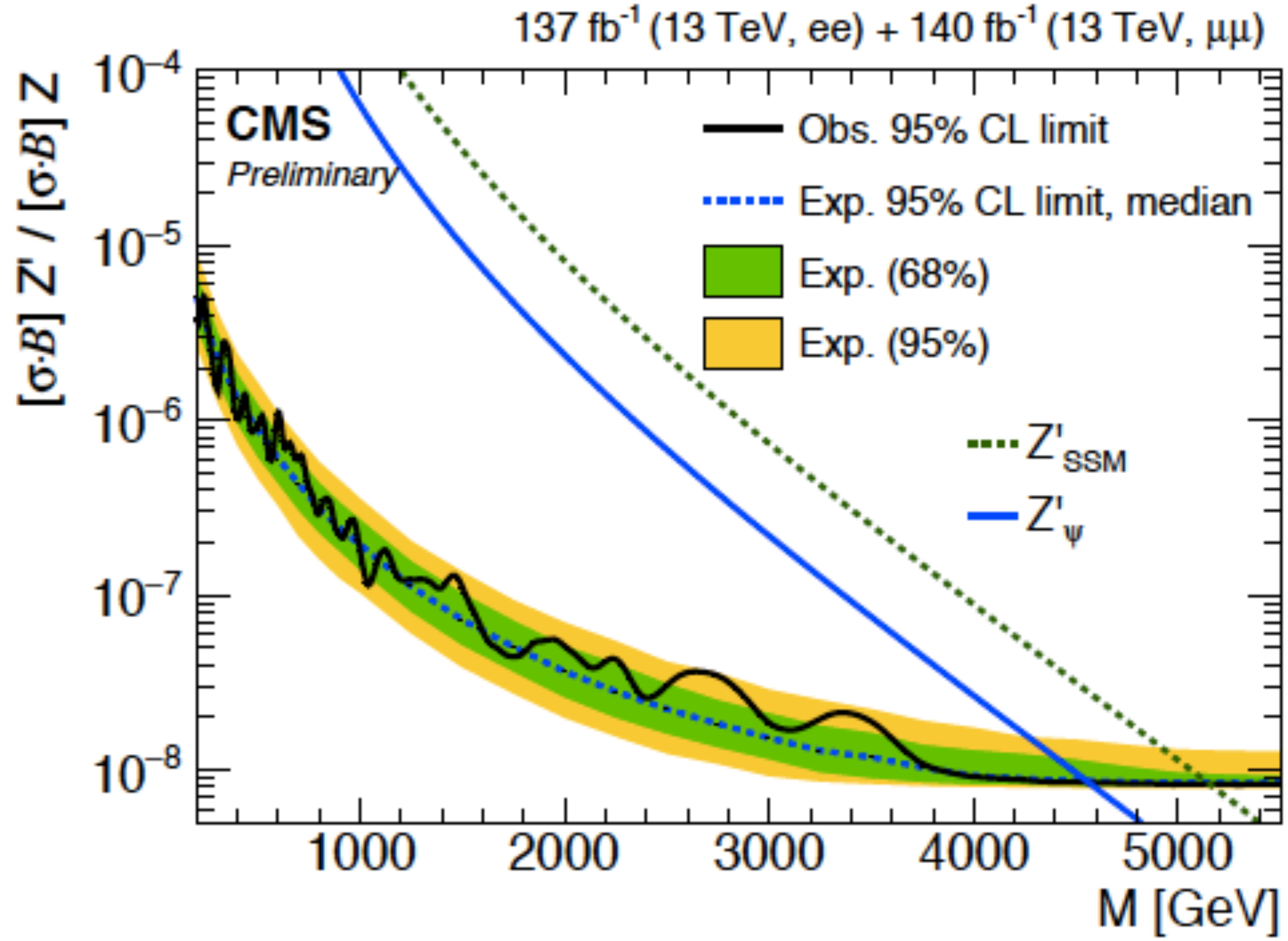


- **Background shape (from estimation) is used to perform the background fit**
- **The absolute background yields is obtained through fit on data**
- **Main systematic uncertainties:**
  - Lepton selection efficiency: 1-5%
  - Mass scale: 1-3%, Mass resolution: 0-15%
  - DY bkg: 0-20%, jet(s) bkg: 50-100%, top etc. bkg: ~7%
  - Normalisation at the Z peak: 1-5%
  - Luminosity: 2.3-2.5%

Results







obs(exp) limit	ee	μμ	ee+μμ	ATLAS (ee+μμ)
Z'$_{SSM}$	4.72TeV (4.72TeV)	4.89TeV (4.90TeV)	5.15TeV (5.14TeV)	5.1TeV (5.1TeV)
Z'$_{\psi}$	4.11TeV (4.13TeV)	4.29TeV (4.30TeV)	4.56TeV (4.55TeV)	4.5TeV (4.5TeV)

Conclusion

- Z' search with di-lepton final states was updated with full Run 2 data. Results presented at EPS 2019.
- No excess found! Most stringent limits set on the Z' mass:
    - 4.56TeV for Z'_{ψ} and 5.15TeV for Z'_{SSM}
- Beihang University made significant contribution to this analysis:
    - Status Reports
    - Editor for analysis note
    - pre-Approval talk for 2016, 2017 analyses
- A paper is in preparation!

- backup

Mass Scale and Resolution

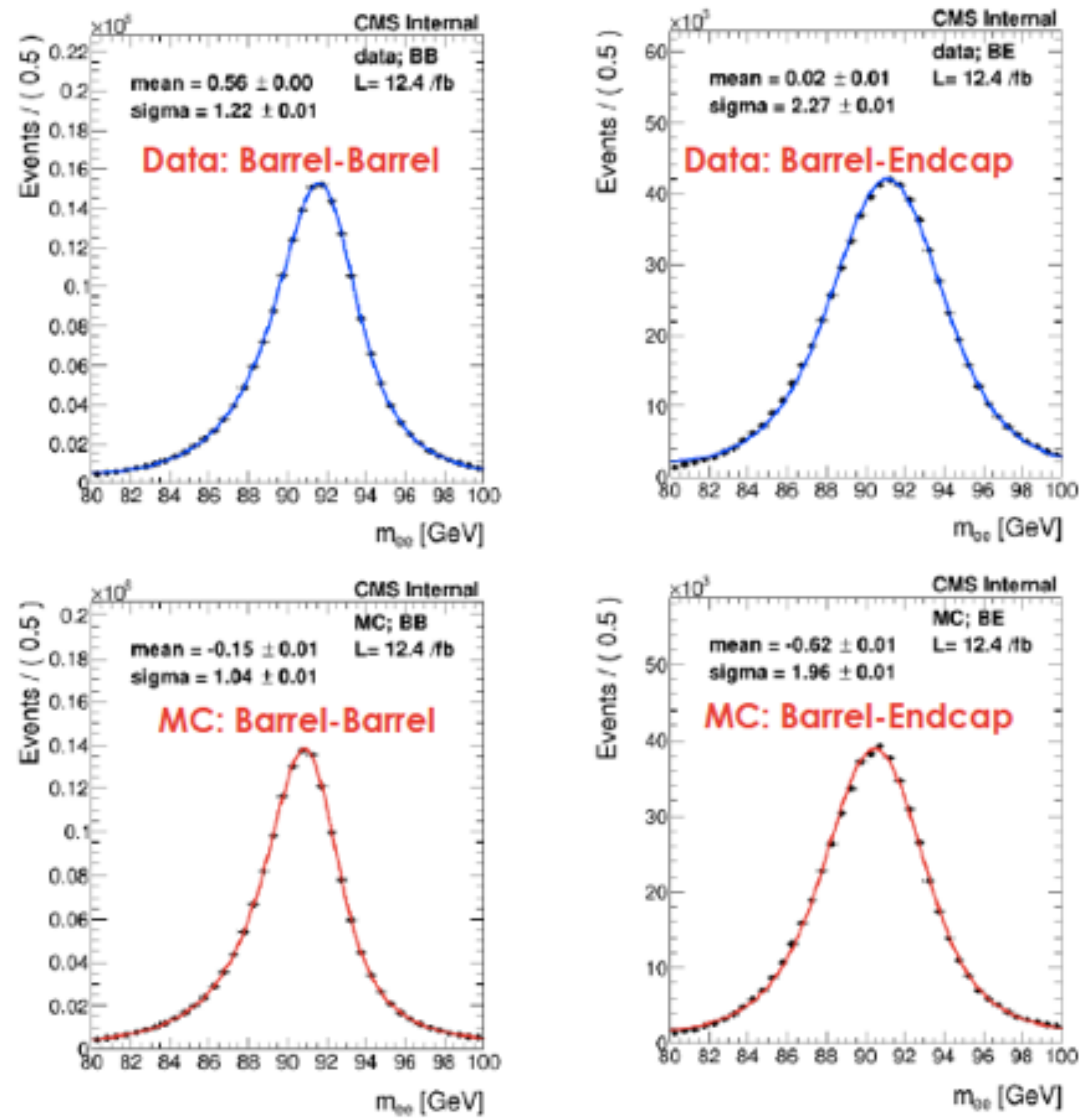
Defined in two steps:

- **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

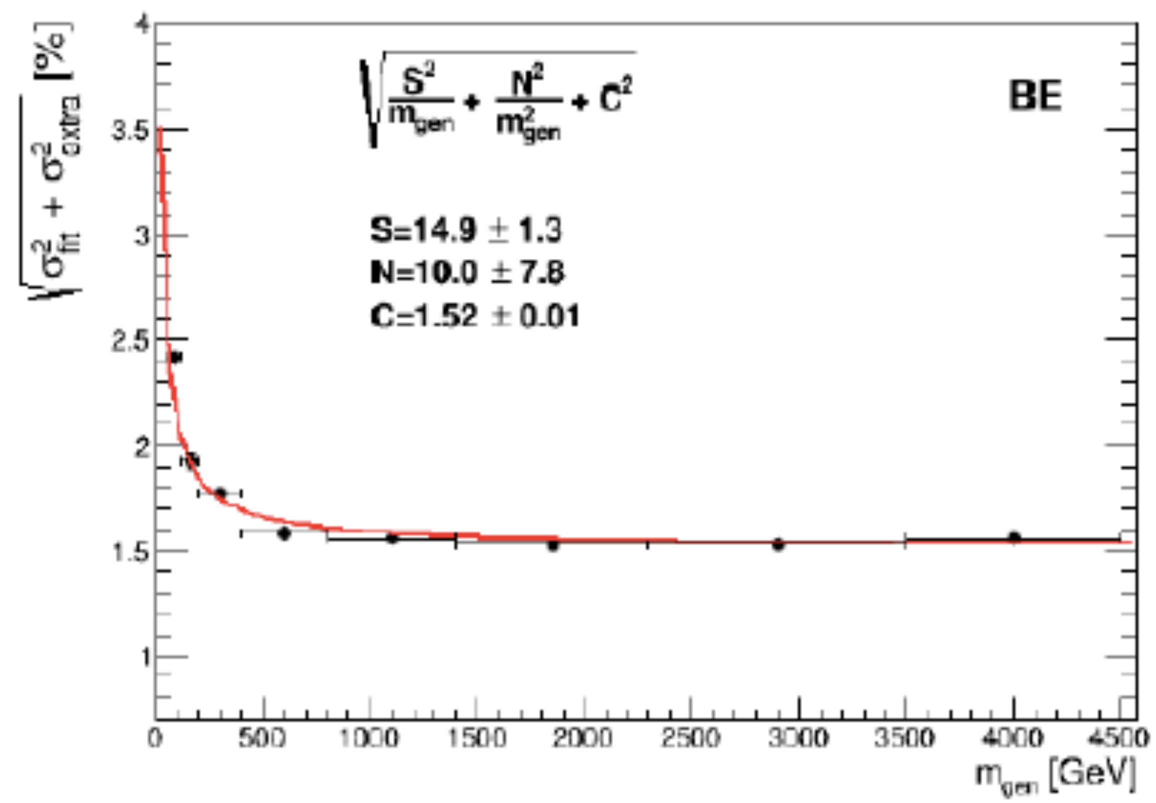


Mass Scale and Resolution

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
- $\sigma^2_{high\ mass} = \sigma^2_{CB} + \sigma^2_{extra}$

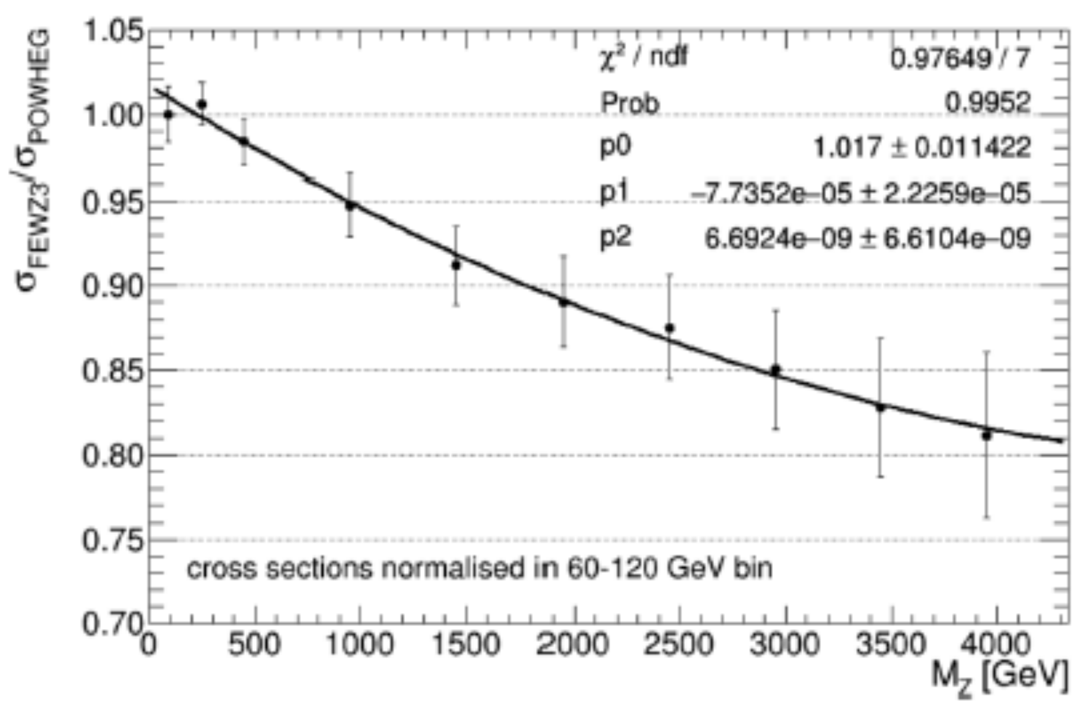


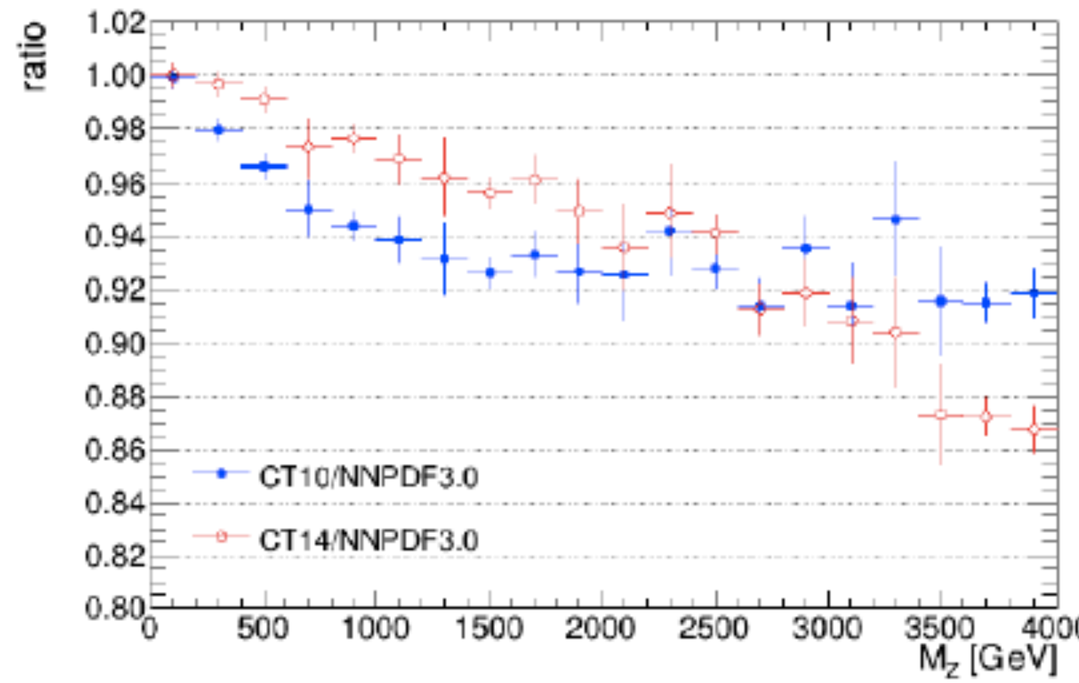
Uncertainties on the DY Background

- 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-16-056





- 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