Dielectron resonance search at $\sqrt{s} = 13$ TeV pp collisions

$(Z' \to ee)$

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On behalf of the HEEP group

2015/12/17

IIHE CMS meeting: Jamboree

CMS Compact Muon Solenoid
ULB
Science & Technology Facilities Council
Rutherford Appleton Laboratory
BUE The British University In Egypt
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北京航空航天大學 BEIHANG UNIVERSITY 1952
ΔΗΜΟΚΡΙΤΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΡΑΚΗΣ

outline

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- Analysis overview
- Data and standard model backgrounds
- Event selection and trigger studies
- High energy electron identification efficiencies
- Mass scale and resolution
- Background estimation
- Mass spectra
- Systematic uncertainties and statistical analysis
- Results

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- Diphoton searches

Physics Motivations

- A common signature of many physics model beyond the standard model (SM) is a new massive neutral spin 1 particle which can decay to lepton pairs (refer to Z').

- Using approximately 20 fb^{-1} of 8 TeV data, Z' with couplings to fermions the same as the SM Z boson (Z'_{SSM}) and a superstring-inspired Z' (Z'_{ψ}) are excluded with a mass less than **2.9** and **2.57** TeV respectively.

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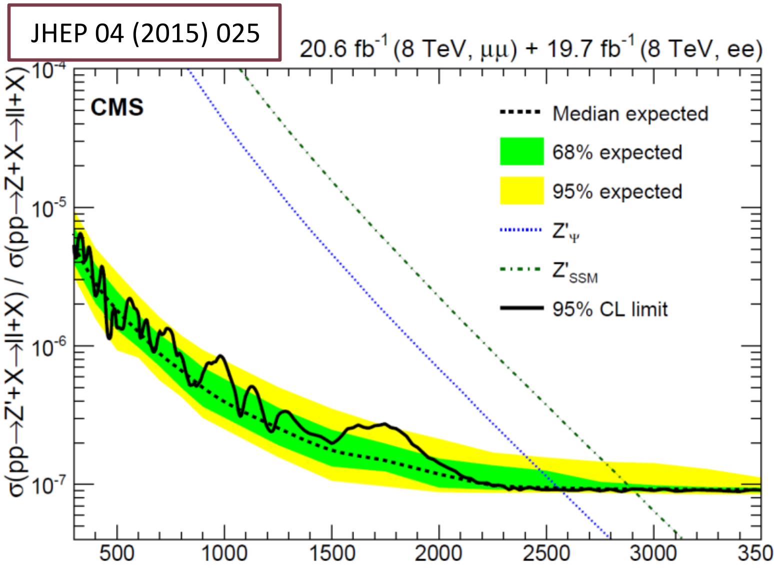
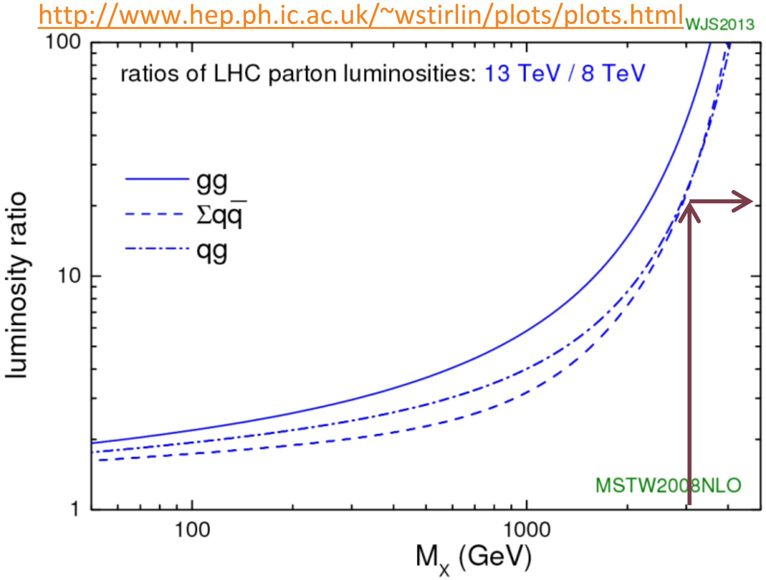


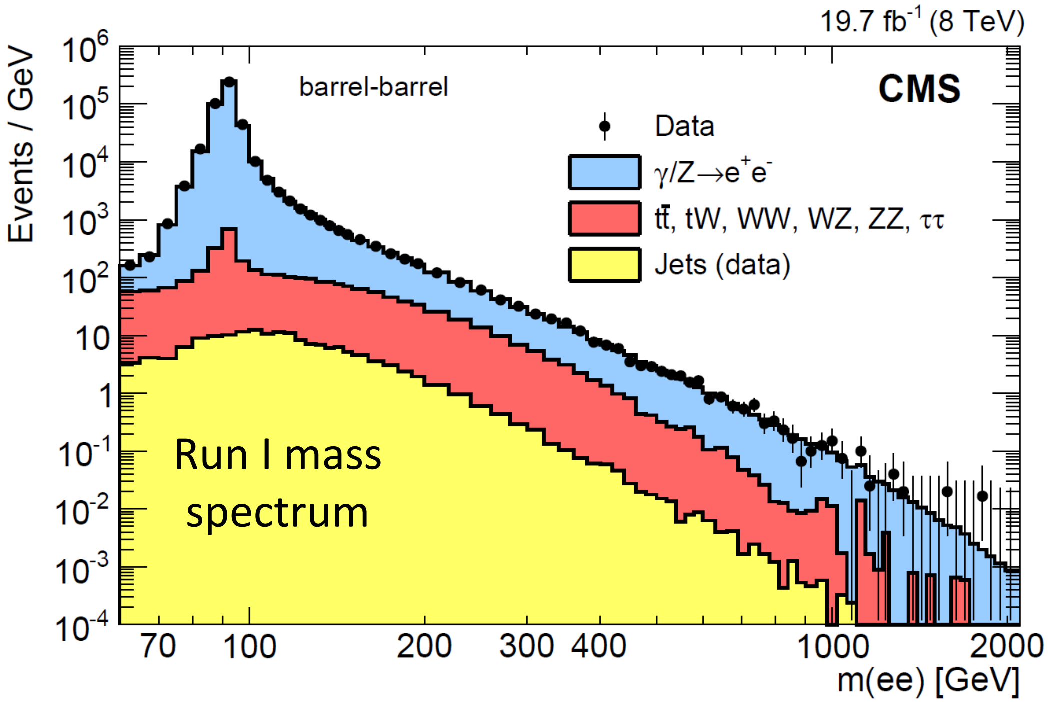
http://www.hep.ph.ic.ac.uk/~wstirlin/plots/plots.html



- The effect of the increase of $\sqrt{s}$ from 8 to 13 TeV is mass dependent.
- Cross section at higher masses getting more from the $\sqrt{s}$ increase.
- 1 fb^{-1} of 13 TeV data is equivalent to 20 fb^{-1} of data for a Z' mass of approximately 2.5 TeV.

Analysis overview

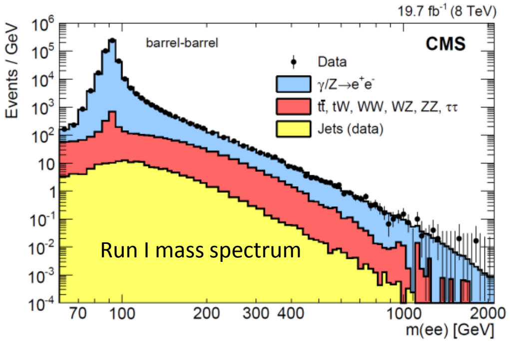
- The analysis follows the long-established approach of a shape-based search for a resonance in the dielectron mass spectrum.
- In this analysis we tried to
  - Develop a simple, robust high energy electron identification.
  - Maintain a robust trigger.
  - Profit from the maximum amount of statistics available at the Z peak.
  - Understand ID efficiencies from Z peak to high E_T.
  - Understand mass scale and resolution.
  - Measure and understand SM backgrounds.



Run I mass spectrum

Data and standard model backgrounds

- Run2015 B, C, and D DoubleElectron dataset (25 ns and 50 ns).
- **Silver JSON** (for 25 ns) used for main results, yielding 2.6 fb^{-1} of data.
- SM backgrounds can be divided into three categories;



Run I mass spectrum

$Z/\gamma^* \to e^+e^-$

Dominant background
Estimated using MC

$t\bar{t}, tW, WW, WZ, ZZ, \tau\tau$

Estimated using MC
Validated using $e-\mu$ events

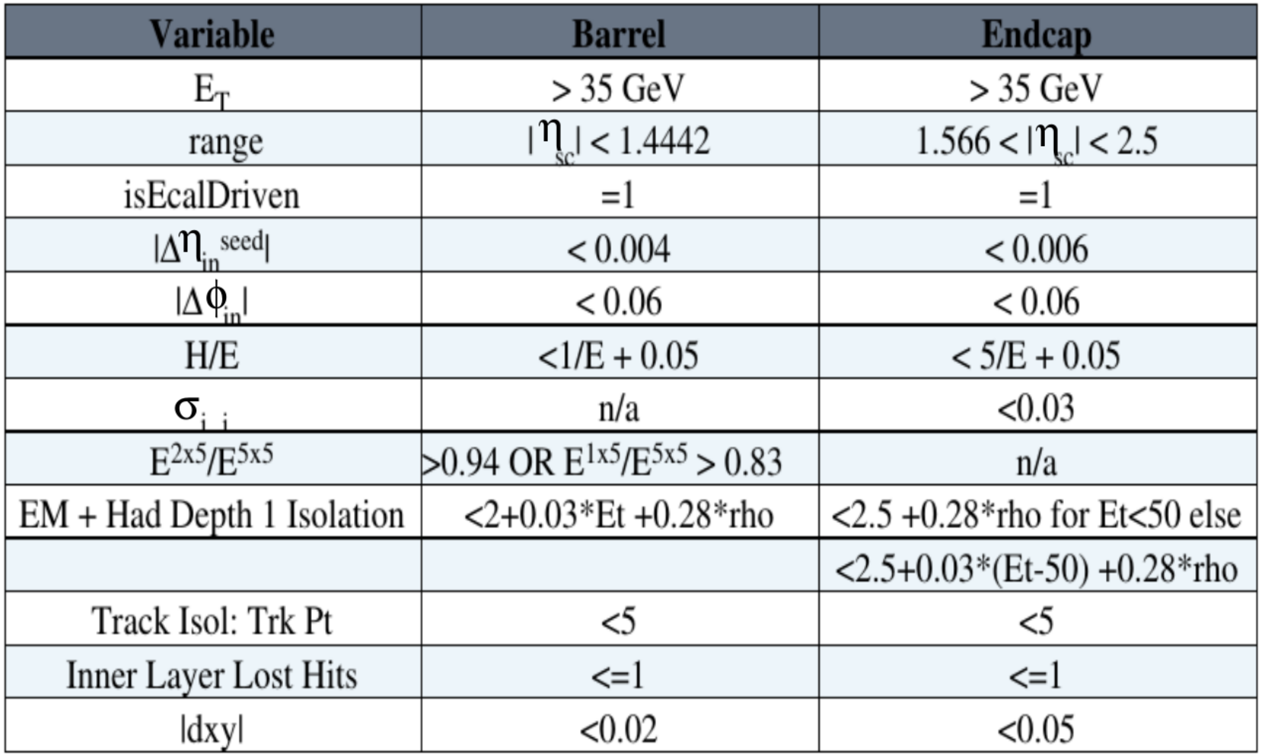
$W + jets, \gamma + jets, dijets$

With nonprompt and
misidentified object
Estimated using data

- MC samples from the RunIISpring15DR74 campaign.
- MC samples pile-up reweighted using the official recipe (minimum bias x-sec 69000 mb)

Object and event selection

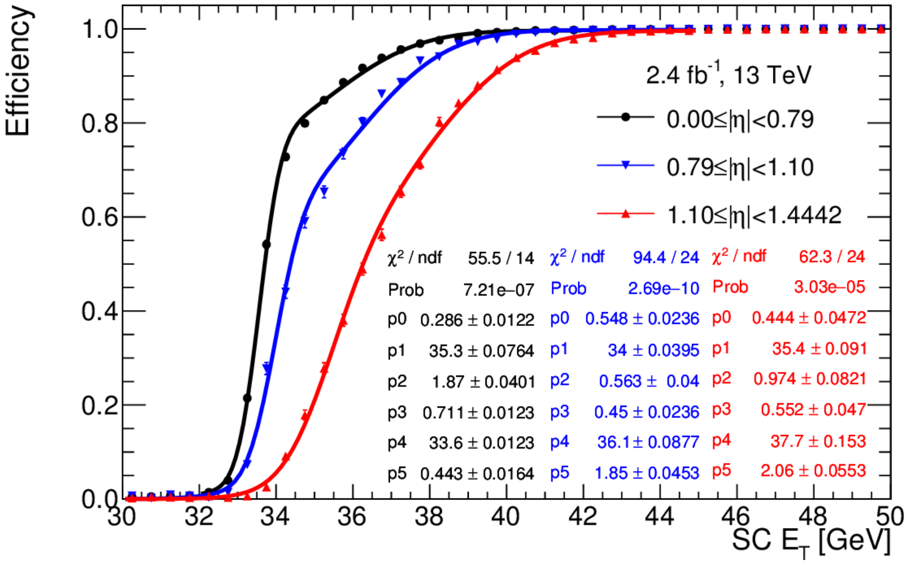
- High energy electron pairs (HEEP) selection v 6.0 used (official recommendation fro high energy electron selection).
- Cut-based selection designed to be highly efficient at high ET.
- Events categories: **Barrel-Barrel (BB)** or **Barrel-Endcap (BE)**.
- The highest mass ee pair is selected.

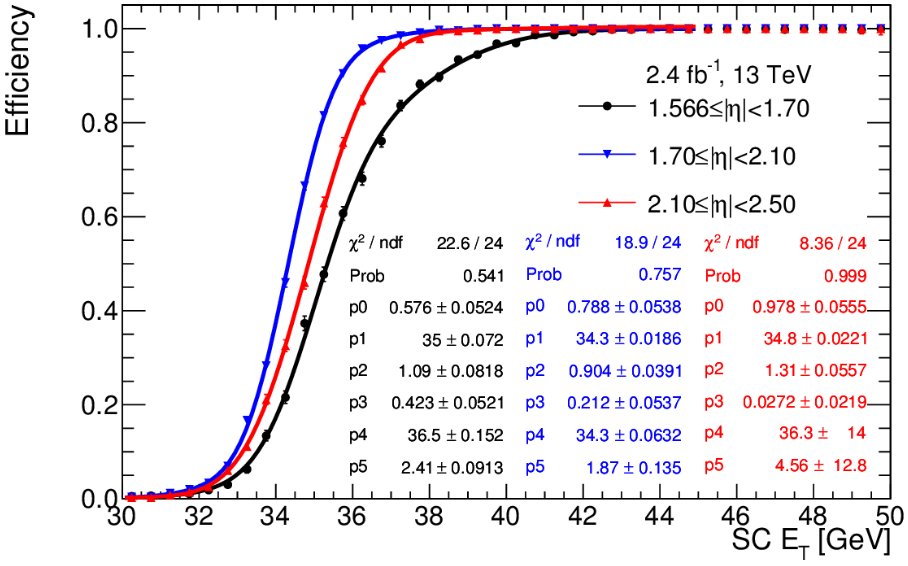


Variable	Barrel	Endcap
E_T	> 35 GeV	> 35 GeV
range	$\lvert\eta_{sc}\rvert < 1.4442$	$1.566 < \lvert\eta_{sc}\rvert < 2.5$
isEcalDriven	=1	=1
$\lvert\Delta\eta_{in}^{seed}\rvert$	< 0.004	< 0.006
$\lvert\Delta\phi_{in}\rvert$	< 0.06	< 0.06
H/E	<1/E + 0.05	< 5/E + 0.05
$\sigma_{i\,i}$	n/a	<0.03
E^{2x5}/E^{5x5}	>0.94 OR $E^{1x5}/E^{5x5} > 0.83$	n/a
EM + Had Depth 1 Isolation	<2+0.03*Et +0.28*rho	<2.5 +0.28*rho for Et<50 else
		<2.5+0.03*(Et-50) +0.28*rho
Track Isol: Trk Pt	<5	<5
Inner Layer Lost Hits	<=1	<=1
|dxy|	<0.02	<0.05

Trigger studies

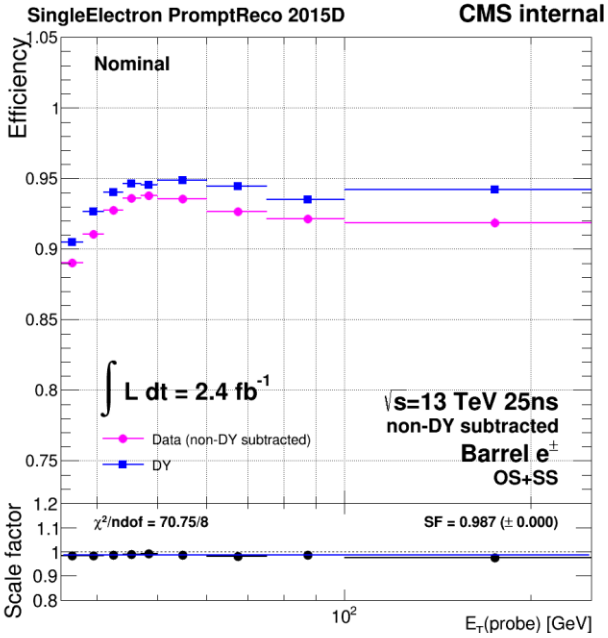
- HLT_DoubleEle33_CaloIdL_GsfTrkIdVL is used (data).
- Efficiency in the plateau is ~ 99%.
- In MC, no trigger applied.
- Weight MC by the turn-on measured in data.

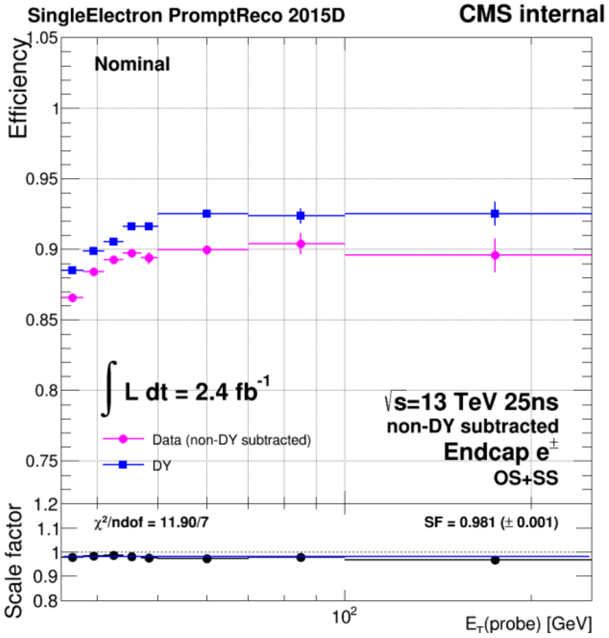




High energy electron identification efficiencies

- Scale factors for data and MC are studied using tag and probe method (as functions of Et, η, Φ of the probe and number of vertices in the event).
- The tag:
  - is required to pass the HEEP ID v6.0
  - It must be a barrel electron
  - Matched to the HLT_Ele27_eta2p1_WPLoose trigger
- MC are reweighted w.r.t the pileup and the trigger efficiency curves.
- Main strategy: Cut and count around the Z peak [60 GeV, 120 GeV].
- Non-DY processes either subtracted from data or included in MC.

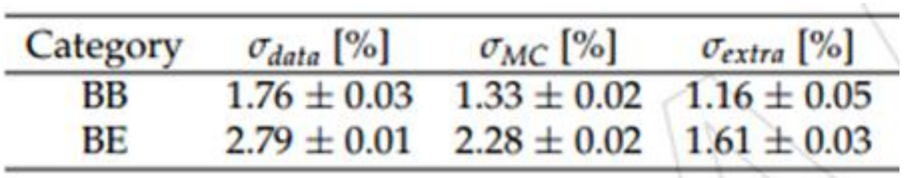




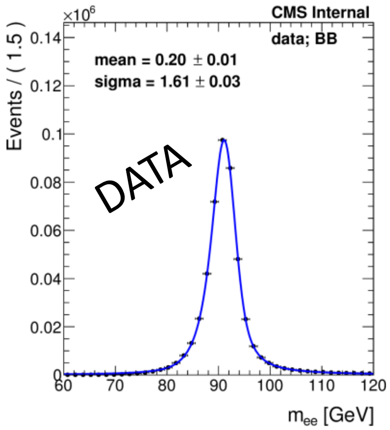
Mass scale and resolution

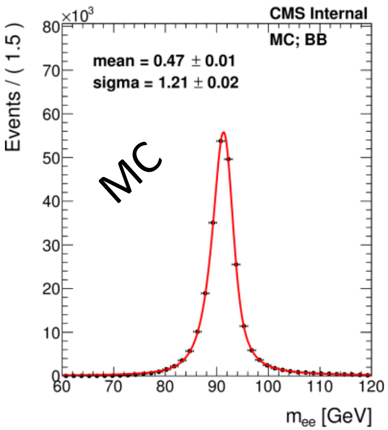
- At the Z peak (60-120 GeV) compute the discrepancy in the broadness of the distribution between data and MC →σ_{extra}.

$$\boxed{\sigma_{extra} = \sqrt{\sigma_{DATA}^2 - \sigma_{MC}^2}}$$

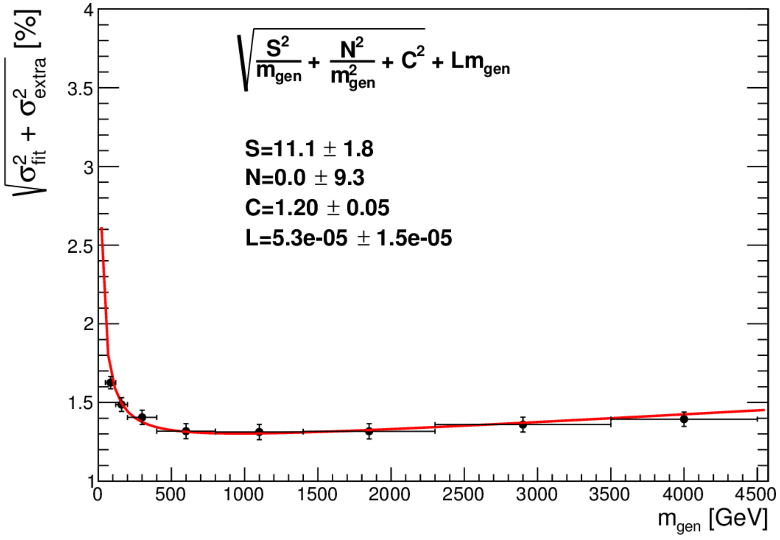


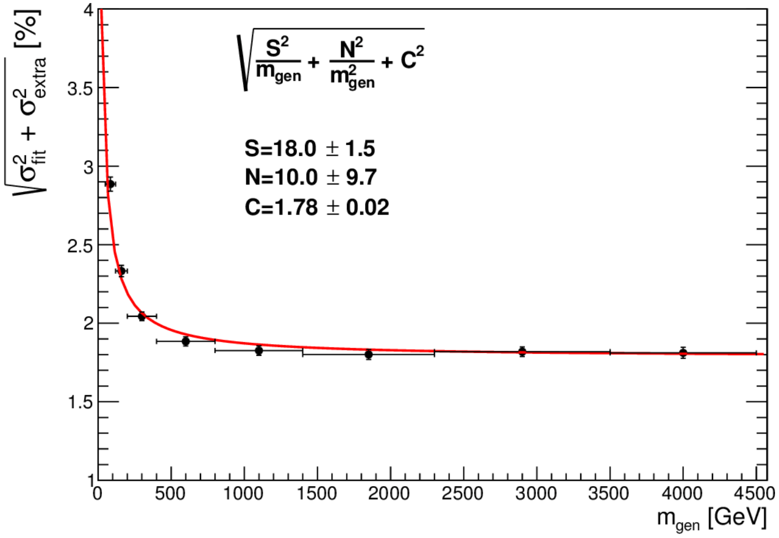
Category	σ_{data} [%]	σ_{MC} [%]	σ_{extra} [%]
BB	1.76 ± 0.03	1.33 ± 0.02	1.16 ± 0.05
BE	2.79 ± 0.01	2.28 ± 0.02	1.61 ± 0.03



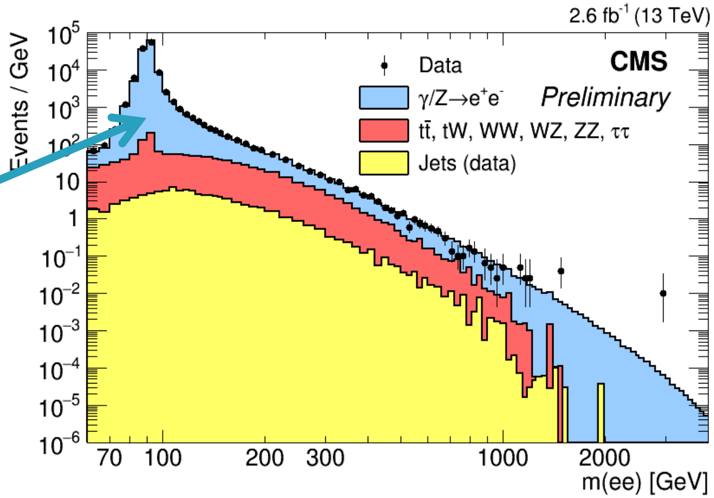


- At fixed bin of M_{ee} the histo $(M_{reco} - M_{gen})/M_{gen}$ is fitted with a crystal ball.
- The sigma parameter of crystal ball function is taken as mass esolution.





Background estimation



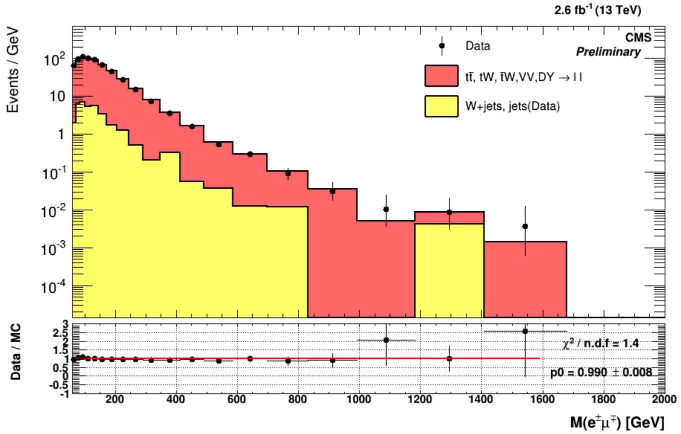
- The **SM Drell-Yan** background is estimated using POWHEG interfaced with PYTHIA8.
- The MC sample normalized to the data in Z peak region [60-120] GeV.
- The theory NNLO cross section is 1928 pb.

variable	barrel-barrel	barrel-endcap
nr data events	418872	133544
nr expect bkg	2805 ± 196	1027±93
MC acc×eff	0.0910±0.0020	0.0302±0.0007
MC acc×eff (E Corr)	0.0904±0.0021	0.0290±0.0007
trigger ID eff	0.977 ± 0.001	0.982 ± 0.001
data/MC Eff SF	0.982±0.001	0.978±0.003
cross-sec	1948 ± 3 (stat) ±233 (lumi) pb	1868 ± 5 (stat) ±224 (lumi) pb
cross-sec (E corr)	1961 ± 3 (stat) ±235 (lumi) pb	1945 ± 5 (stat) ±233 (lumi) pb

- The main uncertainty on the DY background comes from PDF.

mass range (GeV)	200-300	400-500	900-1000	1400-1500	1900-2000	2400-2500	2900-3000
relative uncert	6%	5%	8%	10%	13%	15%	19%

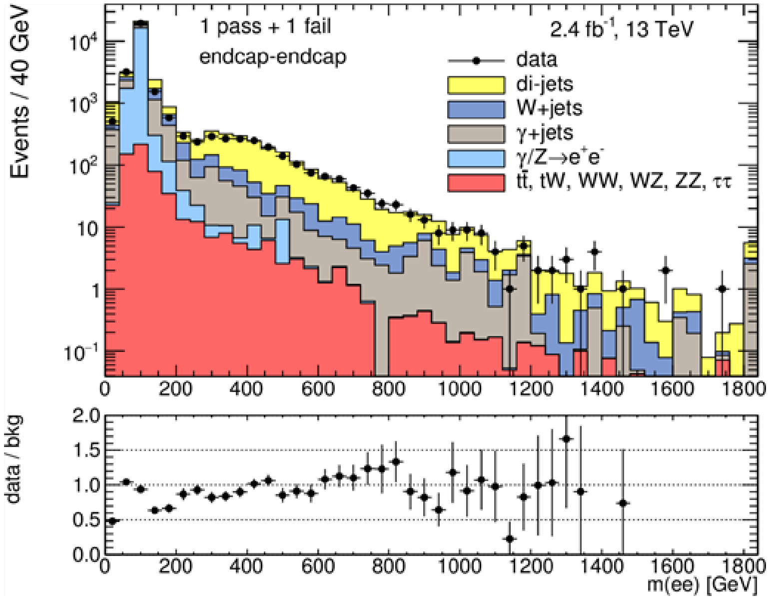
Background estimation



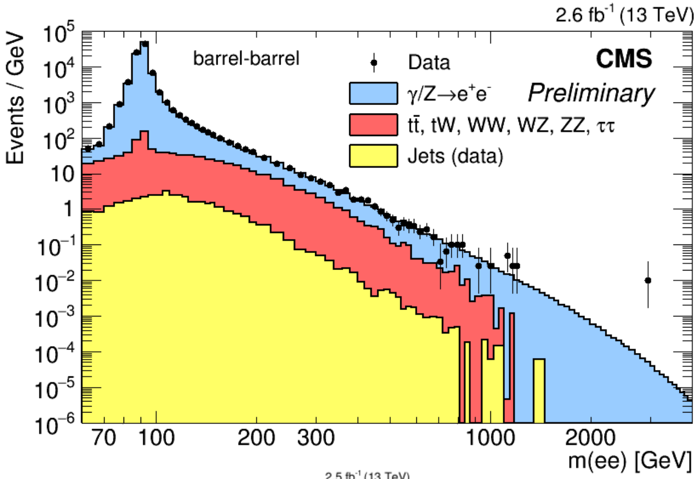
- Flavor symmetric backgrounds are estimated from MC samples.
- $t\bar{t}, tW$ samples are generated using POWHEG and WW, WZ, ZZ are generated by PYTHIA 8.
- $Z/\gamma^* \rightarrow \tau^+\tau^-$ is also in this category generated by MadGraph5aMC@NLO.

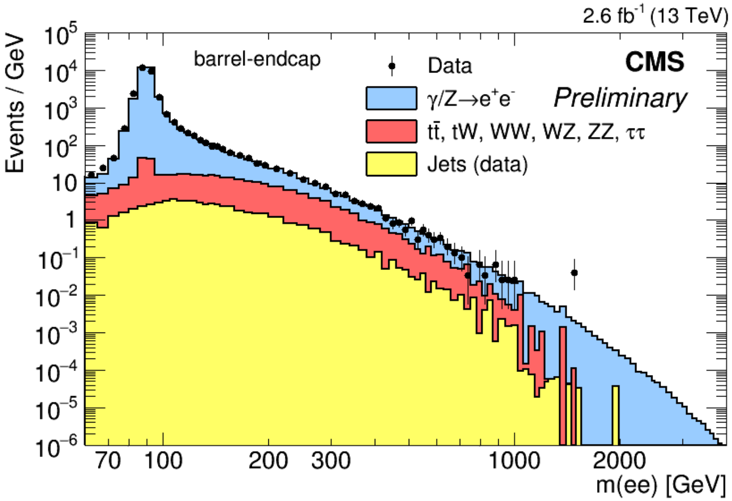
- In these processes the branching fration to a pair of leptons of different flavour, $e\mu$, is twice as large as the branching ratio to e^+e^-.
- Good agreement is seen in $e\mu$ channel between data and the predicted background.

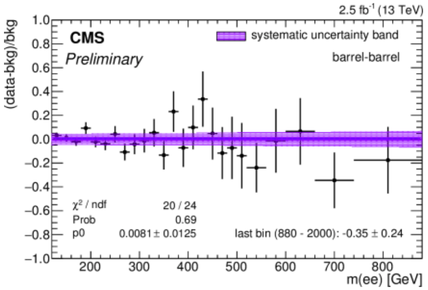
- Backgrounds with misidentified object are estimated from data using fake rate method ($W + jets, \gamma + jets, dijets$).
- This category of background is small, representing less than 3% of the background above masses of 500 GeV.

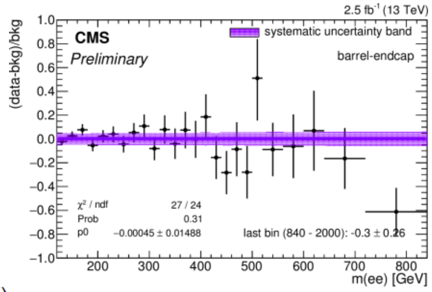


Mass spectra

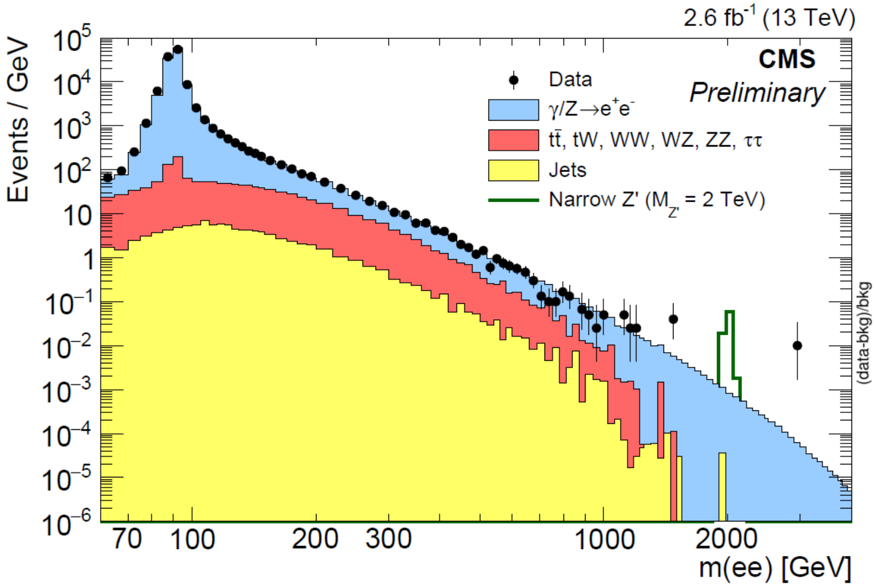


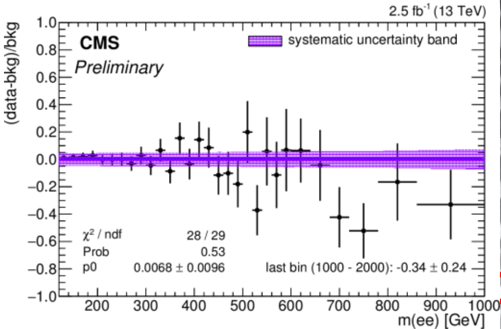






Data consistent with SM





Highest mass event:
2.9 TeV
Expected enevts:
M(ee)>2 TeV -> **0.31**
M(ee)>2.5 TeV -> **0.08**
M(ee)=[2.8,3] TeV -> **0.013**

Systematic uncertainties and statistical analysis

- Results are presented as a ratio of cross sections at high mass to those at the Z.
  - all pt independent effects cancel (both known and unknown)
  - we are not affected by changes in luminosity uncertainty.

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

- The main sources of systematic uncertainty are:
  - Electron ID at high energy (assign 4%(Barrel) -6%(Endcap) per lepton).
  - PDF uncertainties (mass dependent) from 6% to 20% up to 3 TeV.
  - Energy scale uncertainties (values @ RUN1 are 1-2%).
  - The jet background uncertainty is 50% and the non DY BG is 7%.
  - Normalization at the Z peak ~ 2%
- Using Bayesian unbinned likelihood .

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

Signal Model;

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

Background Model;

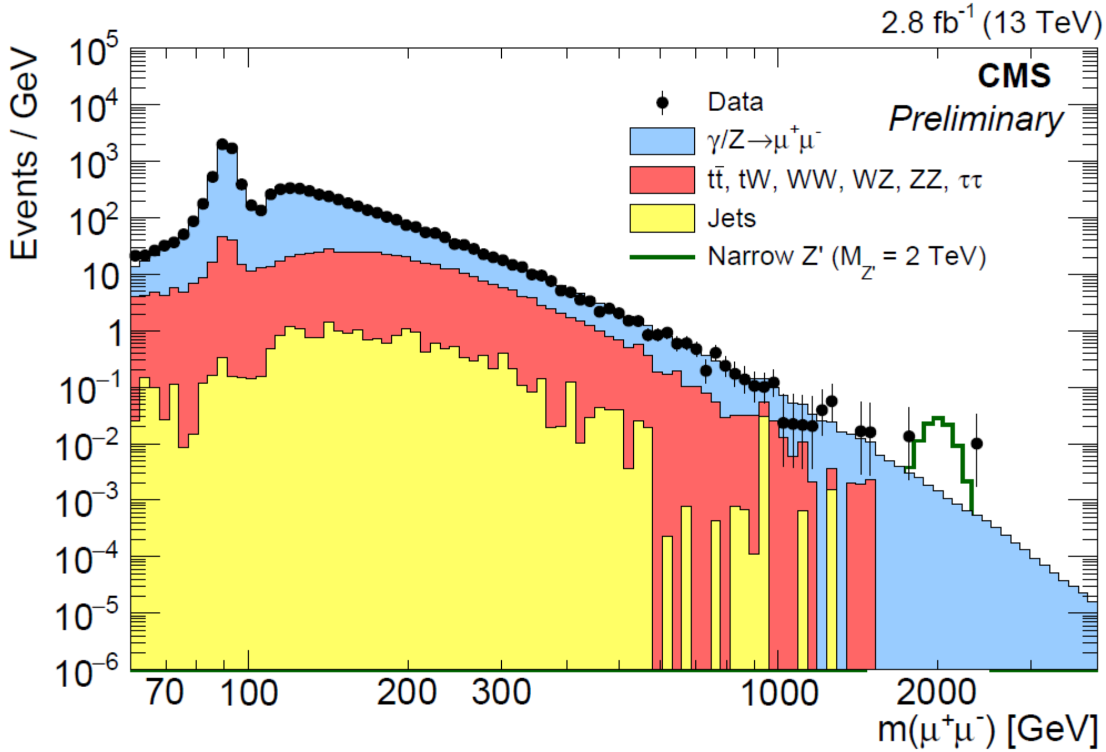
$$f_{BG}(m|\theta,\nu) = e^{am+bm^2+cm^3} m^d$$

Dimuon analysis

- Using Run2015 B, C, and D SingleMuon dataset: 2.8 fb^{-1} MuonPhys.
- Main trigger for analysis: HLT_Mu50
- Offline cut: pT > 53 GeV

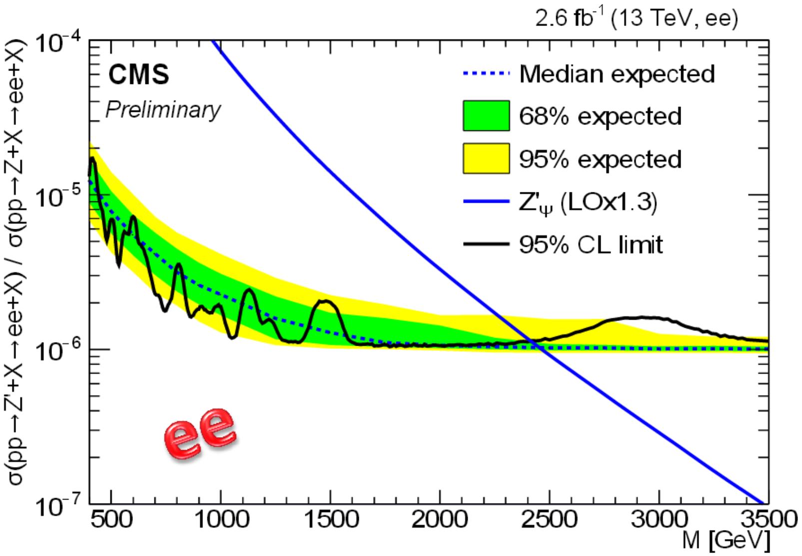
Data consistent with SM

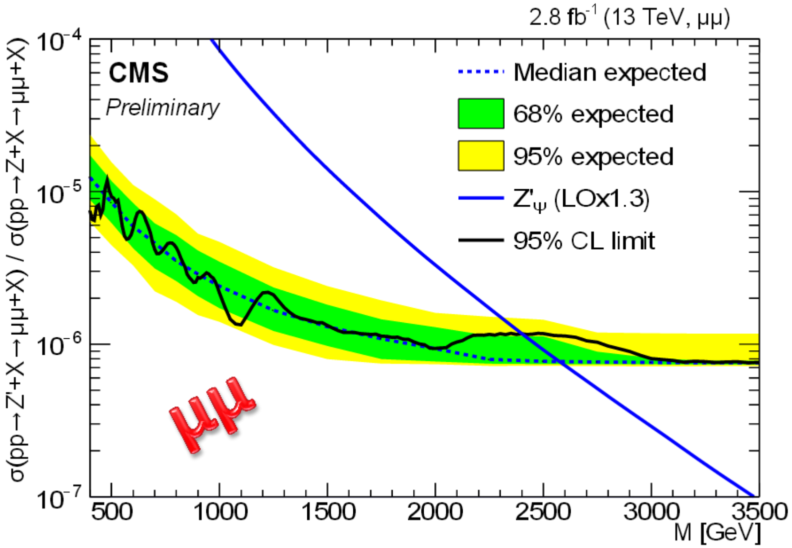
Two highest mass events;
2.4 TeV
1.8 TeV

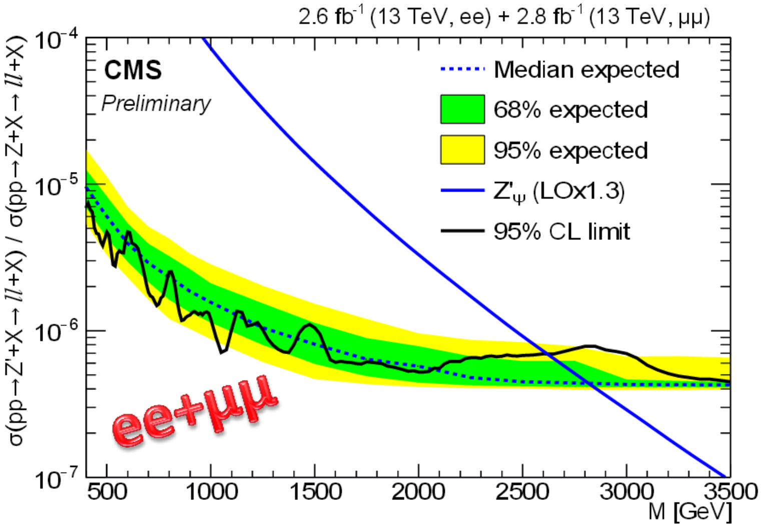


Results

- Limit plots for an input of 0.6% of the mass peak for the signal width.
    - Due to the presence of the 2.9 TeV event, assumed width is important in limit setting.



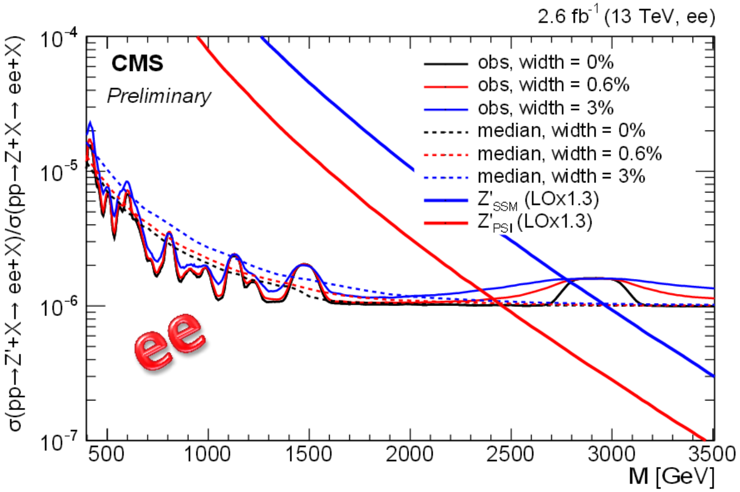


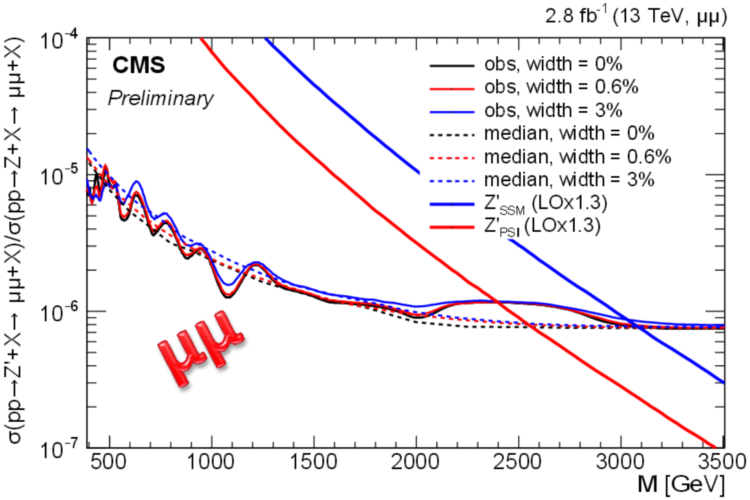


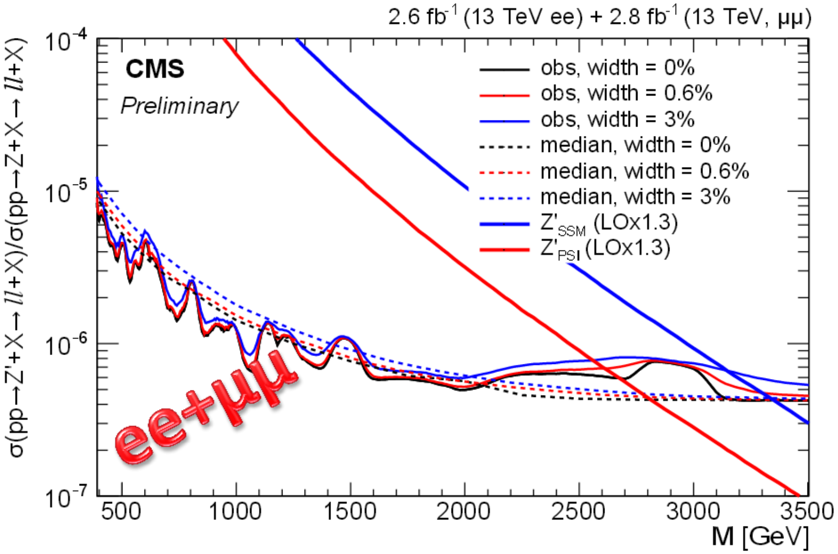
Results

Γ = 0.6% M ↓ Γ=3% M ↓

channel	Z'_{ψ}		Z'_{SSM}	
	obs (TeV)	expected (TeV)	obs (TeV)	expected (TeV)
ee	2.40	2.45	2.75	2.95
$\mu^+\mu^-$	2.40	2.55	3.00	3.05
$ee+\mu^+\mu^-$	2.60	2.80	3.15	3.35







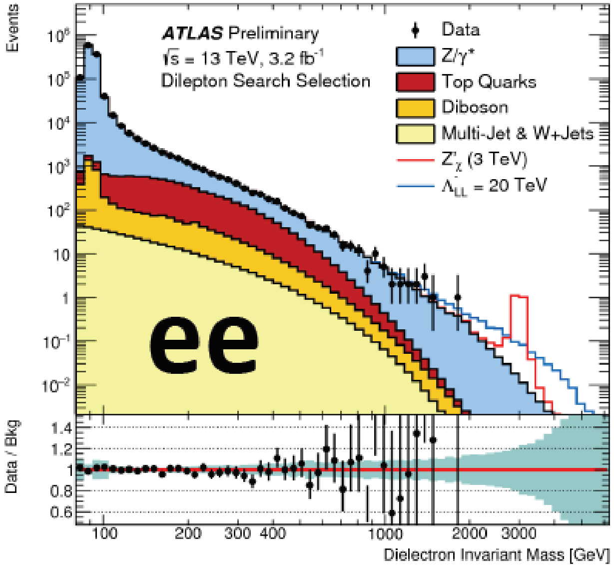
ATLAS results

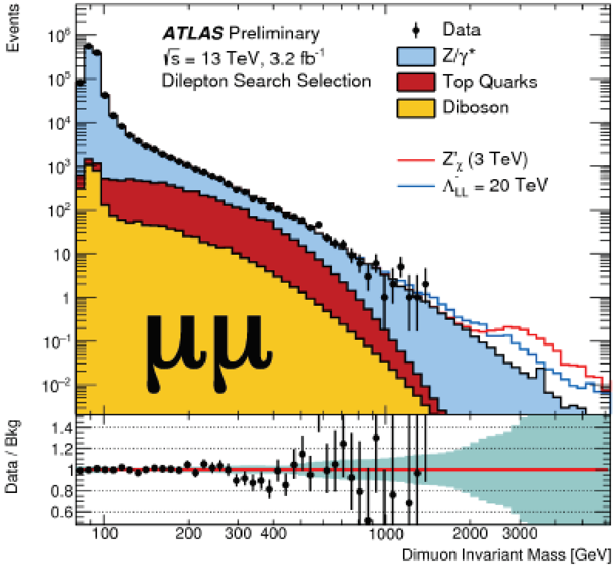
Search for Z' in dilepton (LFC) and (LFV) *(in eμ decays)*

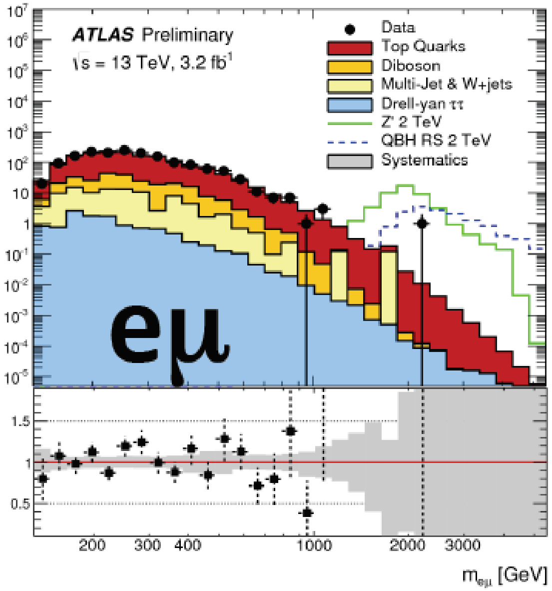
ATLAS-CONF-2015-070

ATLAS-CONF-2015-072

- Main background DY is taken from MC
- Top and diboson extrapolated at very high masses using a functional form
- Background from MC except for MJ in dielectron uses Matrix method (based on electron ID)







Highest di-electron mass event at 1.8 TeV

Highest di-muon mass event at 1.4 TeV

Highest eμ mass event at 2.1 TeV

CMS: 2.9 TeV

CMS: 2.4 TeV

No Excess found !

95% CL Limit on SSM Z' at 3.4 TeV (2.9 TeV from Run-1)

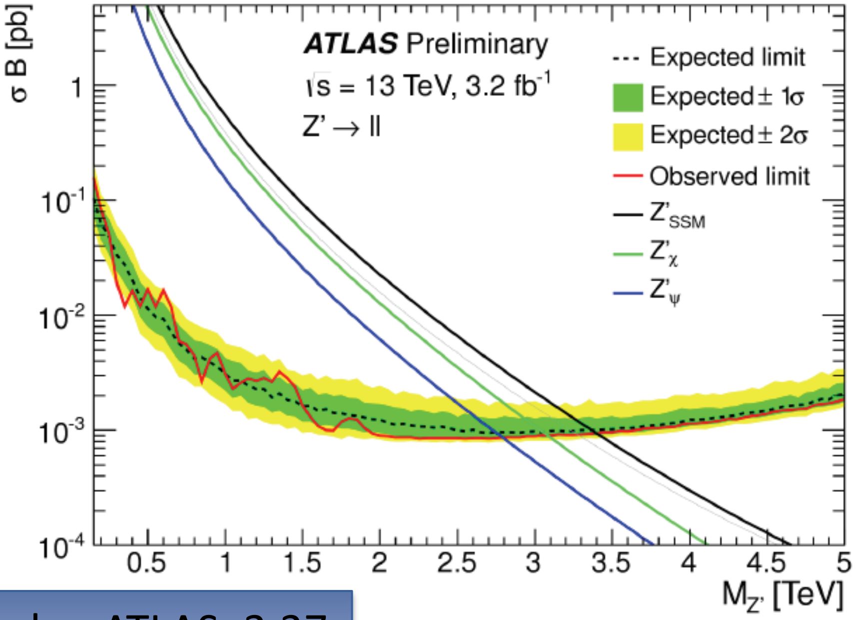
95% CL Limit on SSM LFV Z' at 3.0 TeV (2.5 TeV from Run-1)

ATLAS results

Searches for **Dilepton Resonances (LFC** and **LFV)** (I)

Search for Z’ in dilepton (LFC) and (LFV) *(in eμ decays)*

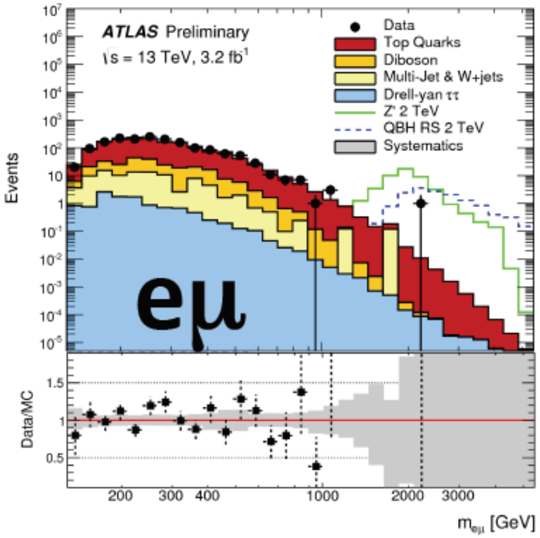
- Main background DY is taken from MC
- Top and diboson extrapolated at very high masses using a functional form
- Background from MC except for MJ in dielectron uses Matrix method (based on electron ID)



Expected -> ATLAS: 3.37
Expected ->CMS: 3.35

No Excess found !

95% CL Limit on SSM Z’ at 3.4 TeV (2.9 TeV from Run-1)



Highest eμ mass event at 2.1 TeV

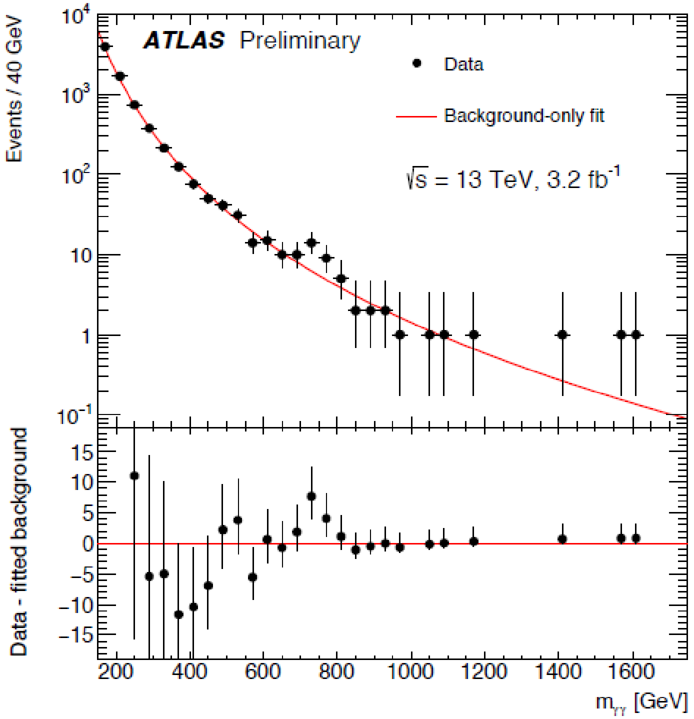
95% CL Limit on SSM LFV Z’ at 3.0 TeV (2.5 TeV from Run-1) 40

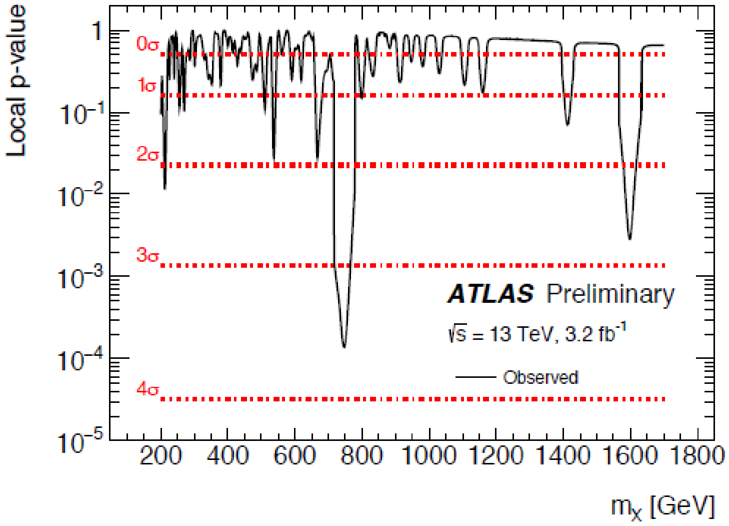
CMS -> 95% CL limit on SSM Z' at 3.15 TeV (2.9 TeV from Run-1)

Diphoton searches (ATLAS)

Search for a **Two Photons Resonance** (II)

Results: Events with mass in excess of 200 GeV are included in **unbinned fit**





- **In the NWA search**, an excess of **3.6σ** (local) is observed at a mass hypothesis of minimal p_0 of 750 GeV
- Taking a LEE in a mass range (fixed before unblinding) **of 200 GeV to 2.0 TeV** the global significance of the excess is **2.0σ**

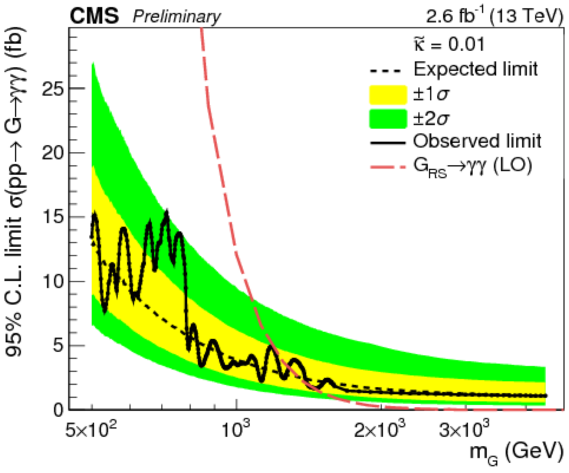
In the NWA fit the resolution uncertainty is profiled in the NWA fit and is pulled by 1.5σ

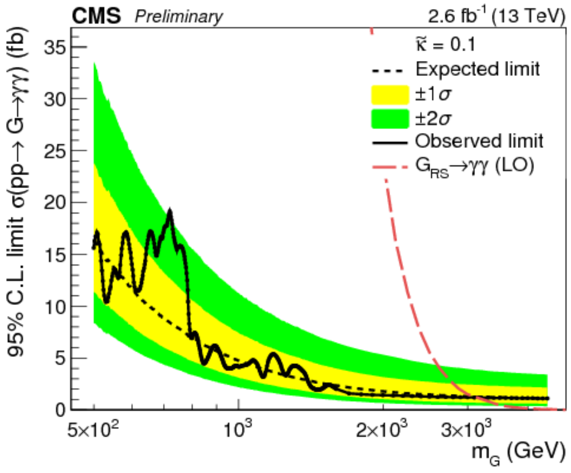
The data was then fit under a **LW hypothesis** yielding a width of approximately 45 GeV (Approx. 6% of the best fit mass of approximately 750 GeV)

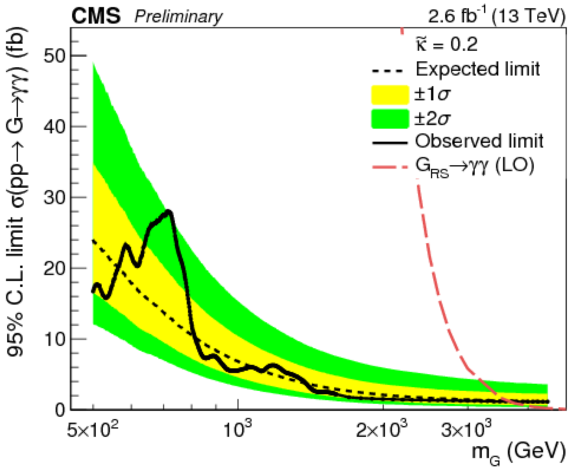
- As expected the local significance increases to **3.9σ**
- Taking into account a LEE in mass and width of up to **10%** of the mass hypothesis of **2.3σ** (Note: upper range in resolution fixed after unblinding)

Diphoton searches (CMS)

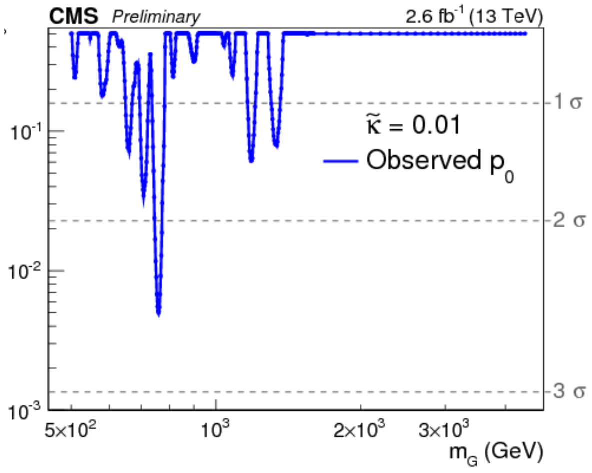
ULB HEEP team contributed to calculate mass resolution and scale in diphoton analysis

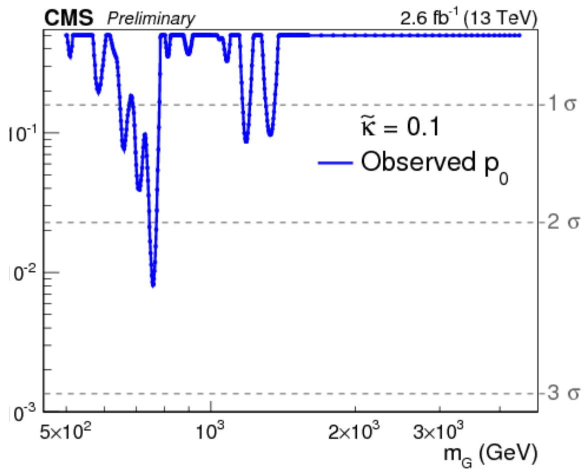


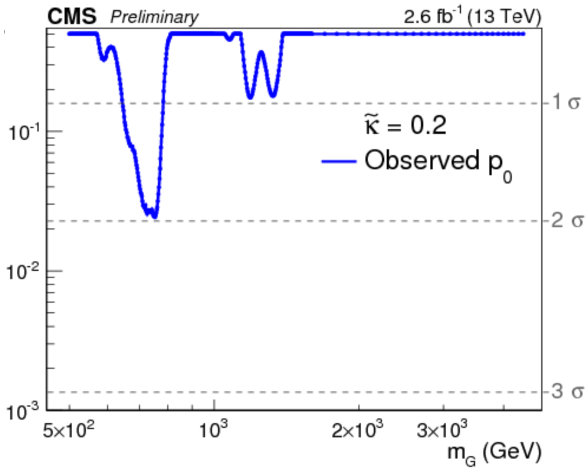




Narrow Width → **Wide (6%) Width**



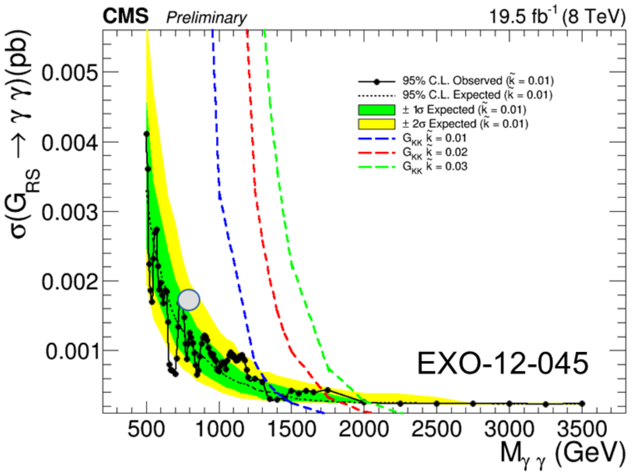


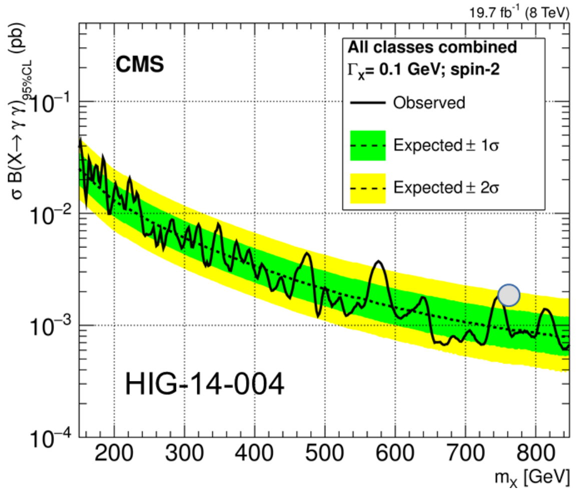


Including LEE (0.5 - 4.5 TeV; narrow width), global p-value < 1.2σ

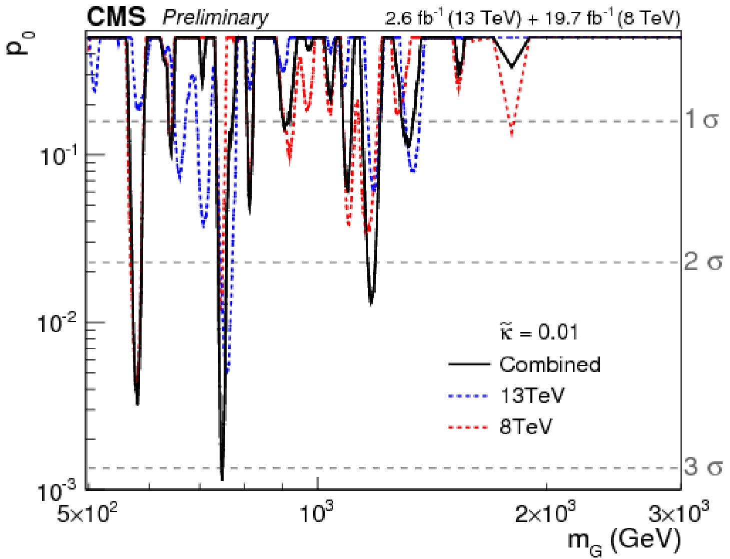
Diphoton searches (CMS)

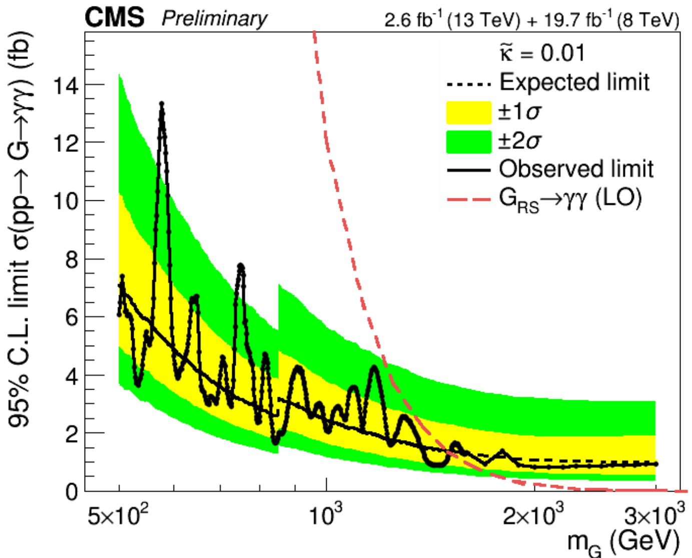
Compatibility with Run 1





- Combined limit improves single analyses sensitivity by 20-30%.
  - Largest excess: MG=750GeV, local significance 3σ
  - global significance < 1.7σ





Summary

- The entire 2015 data are analyzed to search for dilepton resonance.
- No significance excess observed w.r.t expected backgrounds.
- Lower limits are set on Z' mass assuming different width.
- With ~2.5 fb^{-1} of data in Run-II, limits are improve compared to Run-I.
- New (small) excess in diphoton spectrum is observed.

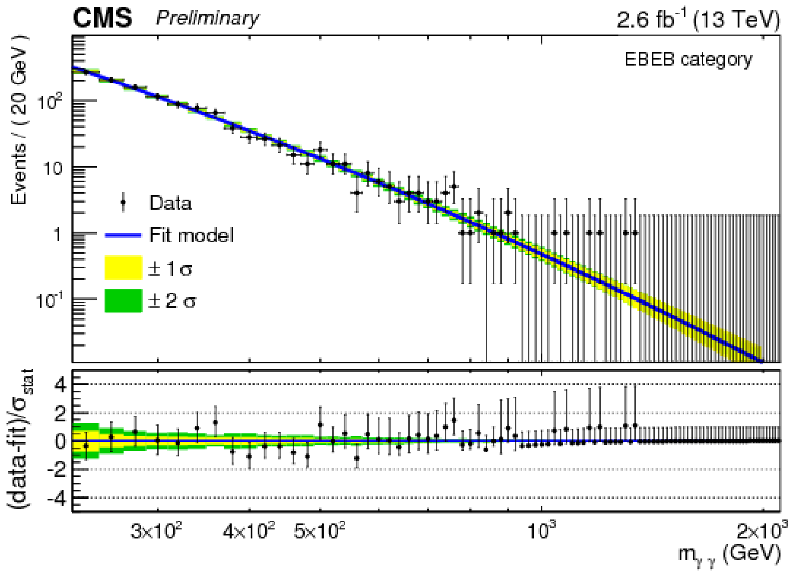
THANKS FOR YOUR ATTENTION

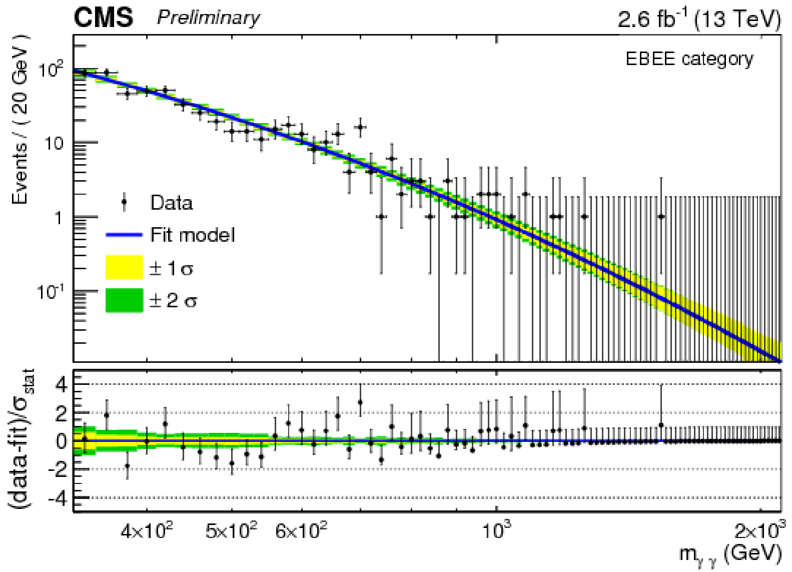
Backup

Search for diphoton resonances

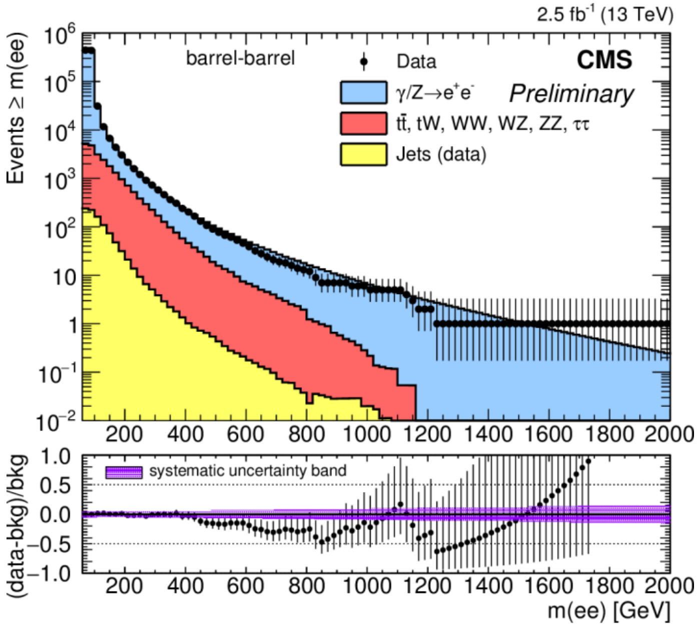
EXO-15-004

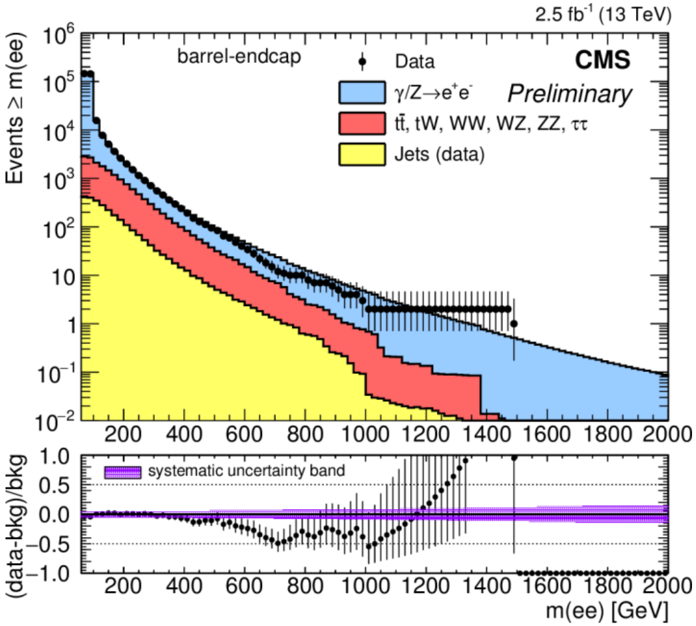
- Two categories: barrel-barrel (EBEB), barrel-endcap (EBEE)
- pT(g) > 75 GeV, Ich < 5 GeV (in 0.3 cone around photon direction)
- Efficiency, scale and resolution calibrated on $Z \to ee$ and high-mass DY events
- Search for RS graviton with three assumptions on coupling: $\tilde{k} = 0.01$ (narrow), 0.1, 0.2 (wide)
- Blind analysis, no changes have been made to the analysis since unblinding data in the signal region

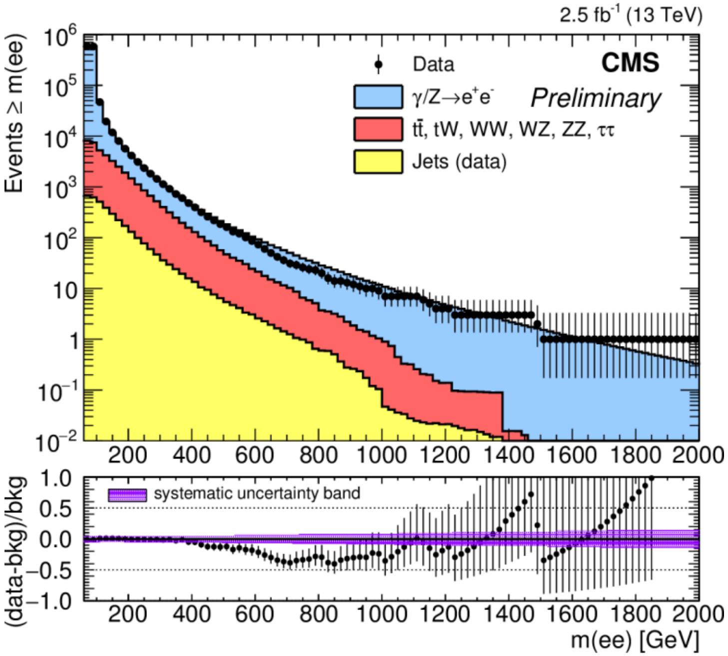




Mass spectra

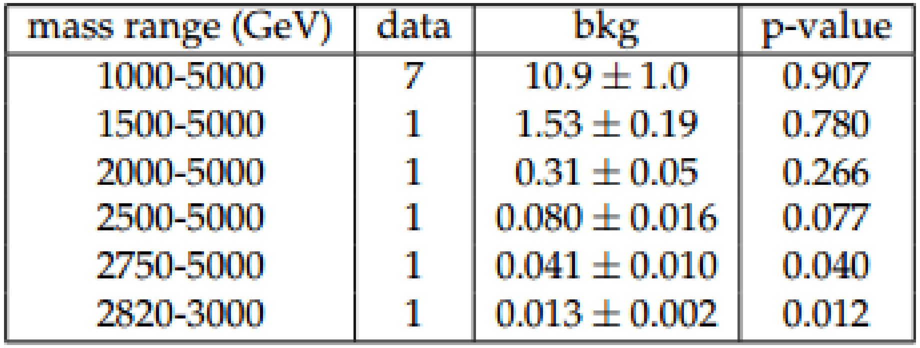






Significance of the 2.9 TeV event

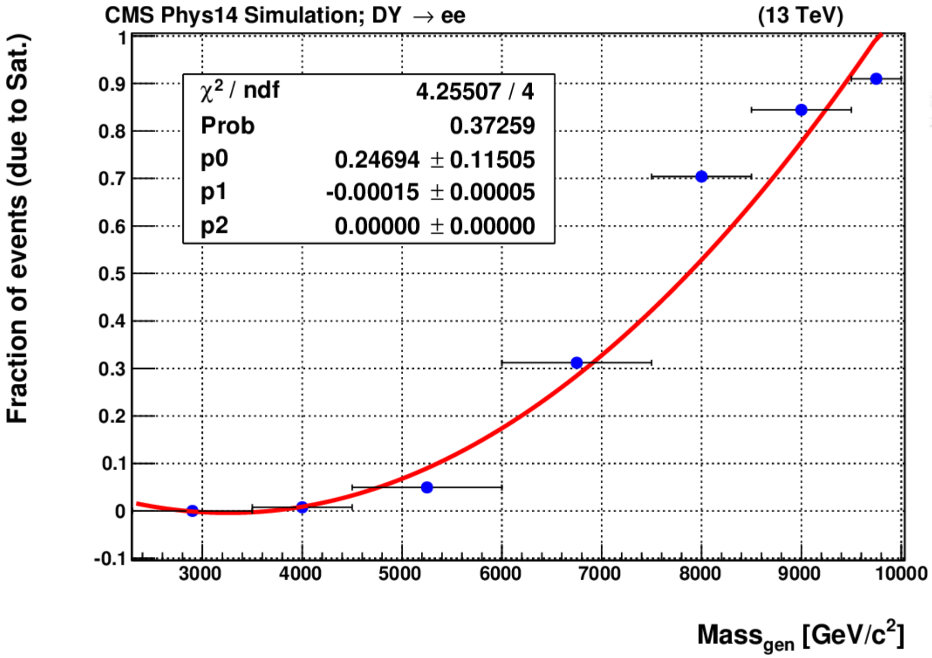
- An event was observed with a mass of 2.9 TeV
- This event has been scrutinised: the p-value (without LEE effect) never drops below 0.01

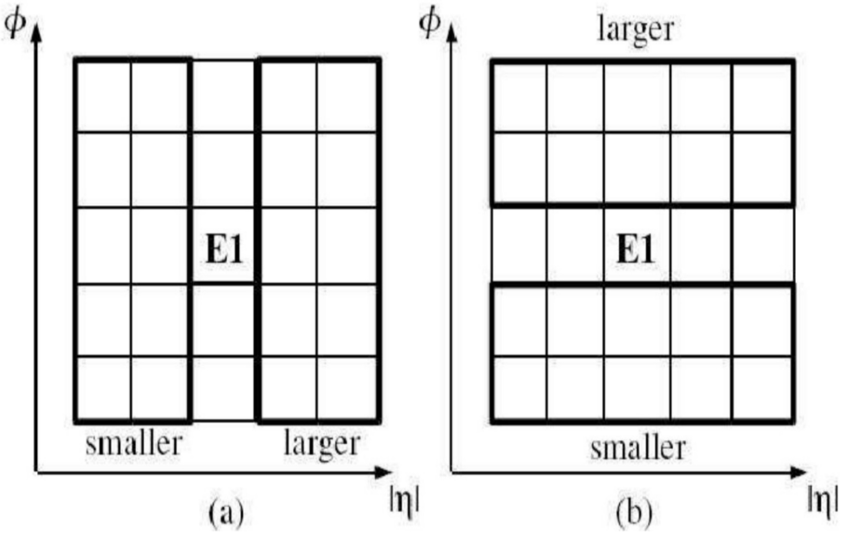


mass range (GeV)	data	bkg	p-value
1000-5000	7	10.9 ± 1.0	0.907
1500-5000	1	1.53 ± 0.19	0.780
2000-5000	1	0.31 ± 0.05	0.266
2500-5000	1	0.080 ± 0.016	0.077
2750-5000	1	0.041 ± 0.010	0.040
2820-3000	1	0.013 ± 0.002	0.012

Saturation

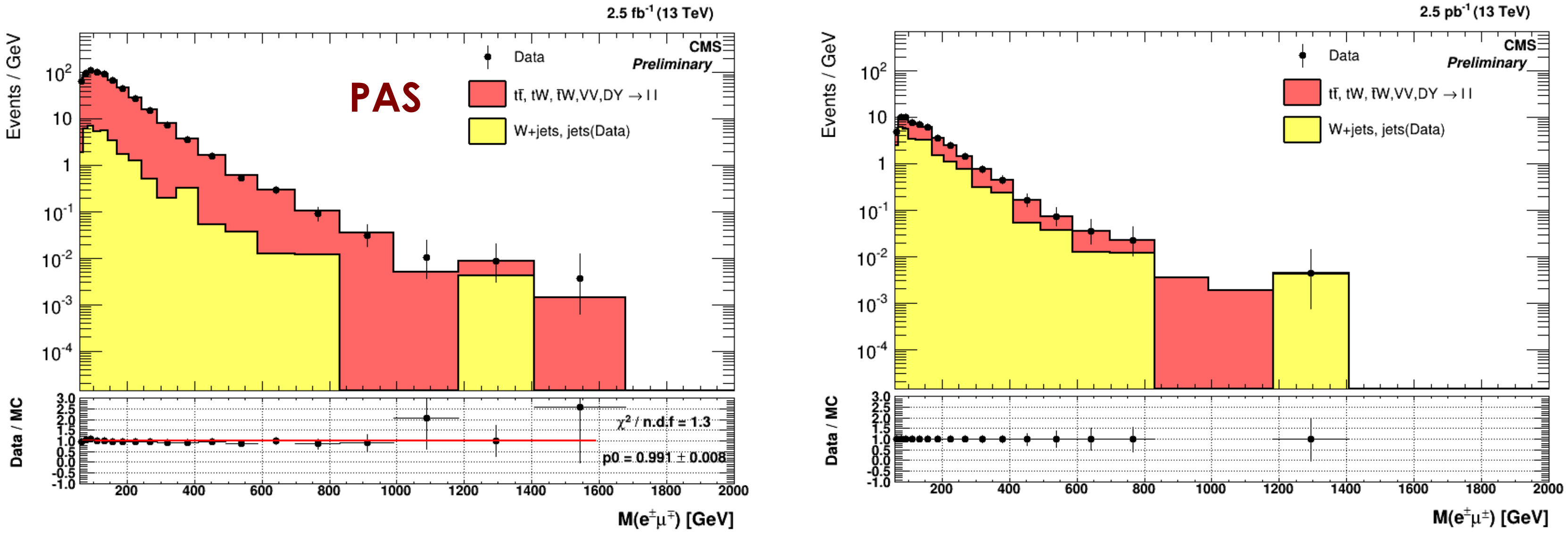
- Due to the limited range of its Multi Gain Amplifiers, the front end electronics of ECAL will saturate for energy deposits > 2 TeV (in barrel) and > 3 TeV (in endcap)
- It is possible to look at the energy deposit around the saturated crystal and “guess” its true energy (E1) with Multivariate Techniquess (TMVA)
- No saturated events in data
- Mature study ready for 2016

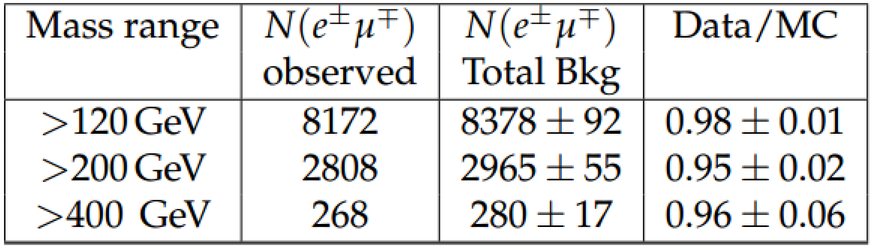




e-μ method

- Flavour symmetric backgrounds (tt, tW, WW, WZ, ZZ, Z → ττ)
- are cross-checked using the e-μ invariant mass spectrum
- BGs containing jets estimated using the same sign (SS) sample
- Good Data/MC agreement in a wide mass range

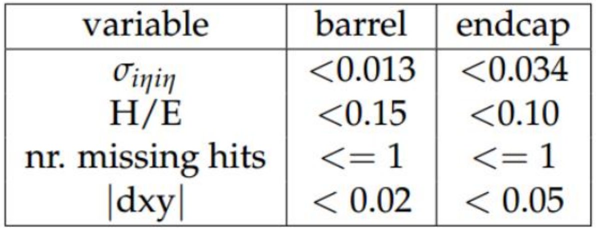




Mass range	$N(e^{\pm}\mu^{\mp})$ observed	$N(e^{\pm}\mu^{\mp})$ Total Bkg	Data/MC
>120 GeV	8172	8378 ± 92	0.98 ± 0.01
>200 GeV	2808	2965 ± 55	0.95 ± 0.02
>400 GeV	268	280 ± 17	0.96 ± 0.06

Jet background estimates

- Primary components: di-jet events (both jets passing ele ID criteria), W + jets, γ + jets
- “Fake Rate” (FR) method is used
- FR = # jets passing HEEP 6.0/ # jets passing FR preselection
- Derived vs ET in bin of |η| (<1.4442, 1.566-2.0, 2.0-2.5)

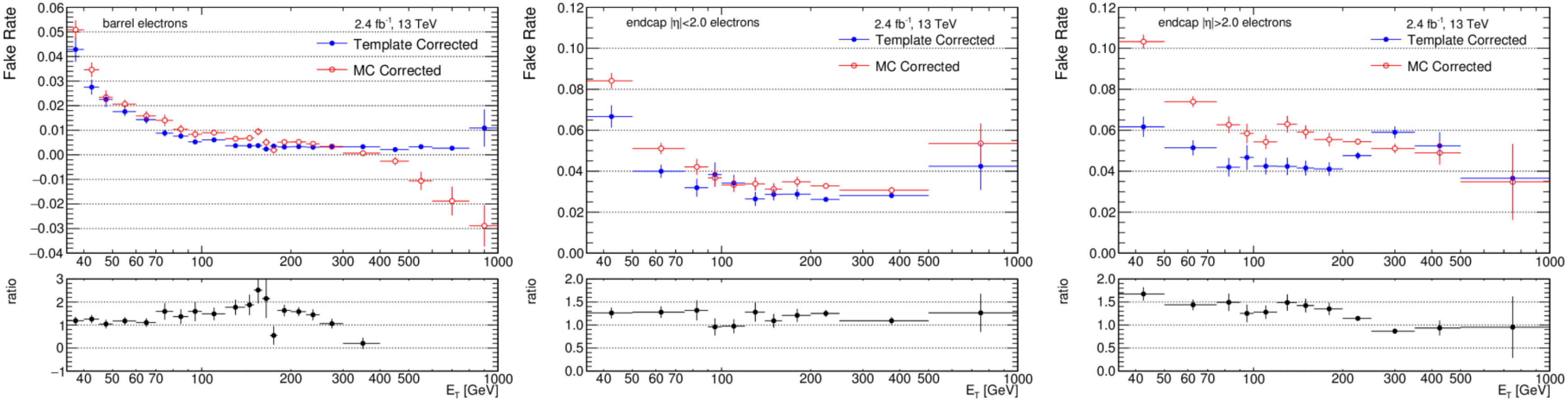


variable	barrel	endcap
$\sigma_{i\eta i\eta}$	<0.013	<0.034
H/E	<0.15	<0.10
nr. missing hits	$<= 1$	$<= 1$
$\lvert\text{dxy}\rvert$	< 0.02	< 0.05

- Require at most 1 EcalDriven gsf electron to reduce Z → ee events
- Numerator has large real electron contamination from W+jets/γ+jets estimated either by MC or via tracker isolation template
- MC method is straightforward (direct subtraction after applying NLO corrections)
- The template method uses a template fo fit te relative contributions of real and fake electrons in the signal region →Tracker isolation chosen (weak dependance on electron energy and pileup) in 2 bins: signal region (< 5 GeV) and BG region (10-15 GeV)
- Tweak w.r.t pre-approval: required to pass the calorimeter isolation and H/E cut but failing another cut (improves the template at large ET values)

Jet background estimates

- With the MC approach: direct subtraction from numerator
- With the template approach:
- Nsigjets = Nbkg * Rjetssig/bkg
- Nsigjets = number of jets passing the HEEP 6.0
- Nbkg = number of observed events in the bkg region
- Rjetssig/bkg = ratio of the # jets in signal and background region (measured in each ET bin)



- At high ET the MC method overestimates the real electron contributions
- Below ~300 GeV, the two estimates agree
- The template FR is the chosen one (applying a 50% uncertainty based on 1HEEP + 1Fail and EE-EE closure tests)

Jet mass spectrum estimates

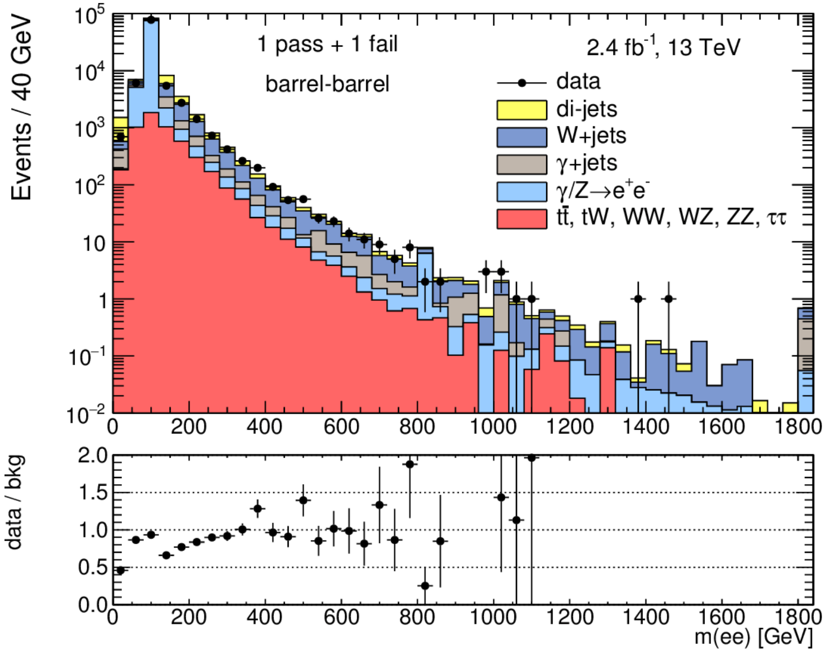
- 1FR estimate:
- Events are selected with electron pairs 1HEEP + 1Fail (passing FR preselection)
- These events are then weighted by FR/(1 – FR)
- It includes W+jets, gamma+jets, 2*di-jets

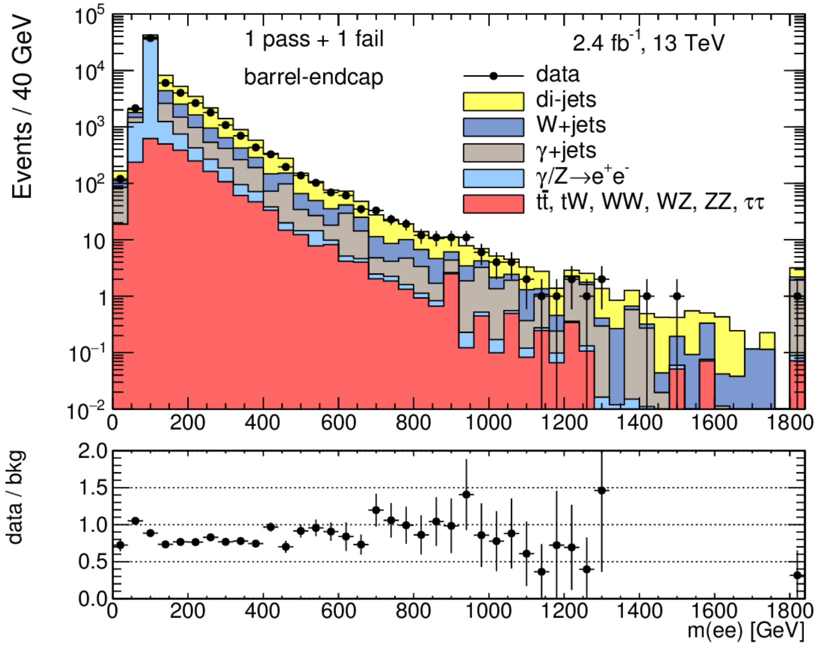
- 2 FR estimate:
- The di-jet component can be estimated by selecting electron pairs where both electrons pass the FR preselection but fail the HEEP
- These events are then weighted by FR1/ (1 – FR1) * FR2/ (1 – FR2)
- This estimate is then subtracted off the 1FR estimate to get the total jet bg

- The uncertainty on the estimated background is set to 50 %

Estimates in jet rich regions

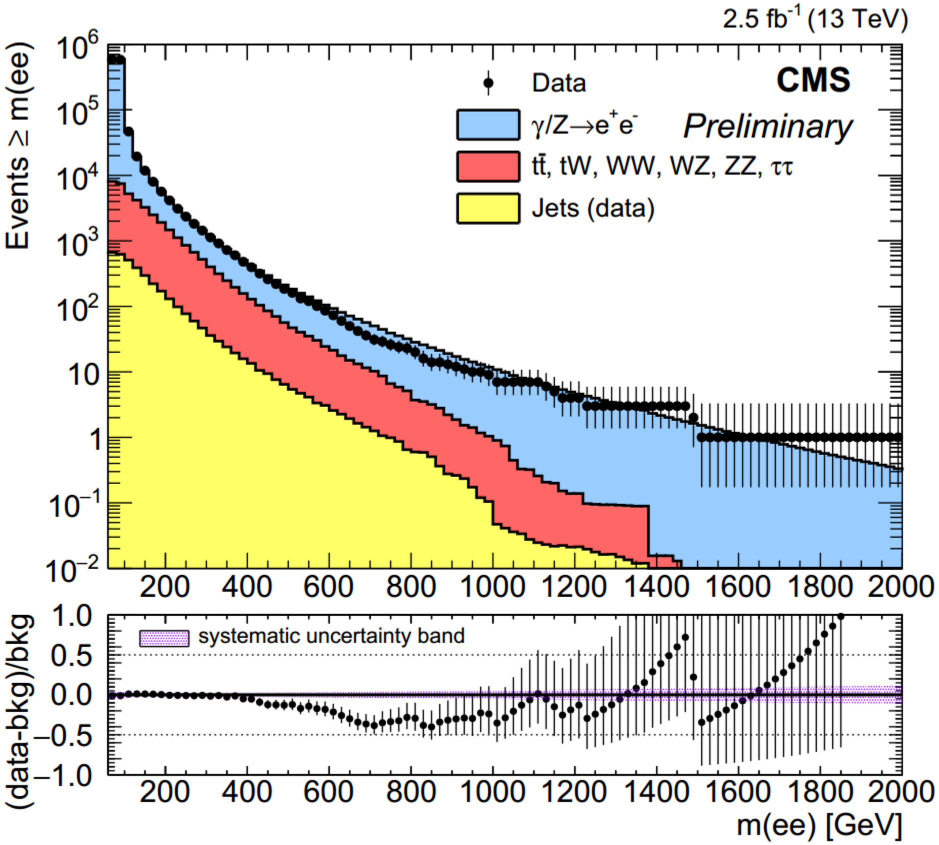
- The FR method is used to estimate the jet bg in jet rich regions
- 1 HEEP + 1 Fail region:
- W + jets taken from MC
- Gamma + jets taken from MC
- The di-jet background is estimated weighting the 2 Fails events by FR1/ (1 – FR1) + FR2/ (1 – FR2)
- Agreement ~ 20-40 % (BB and BE)
- Agreement within 50 % (EE)



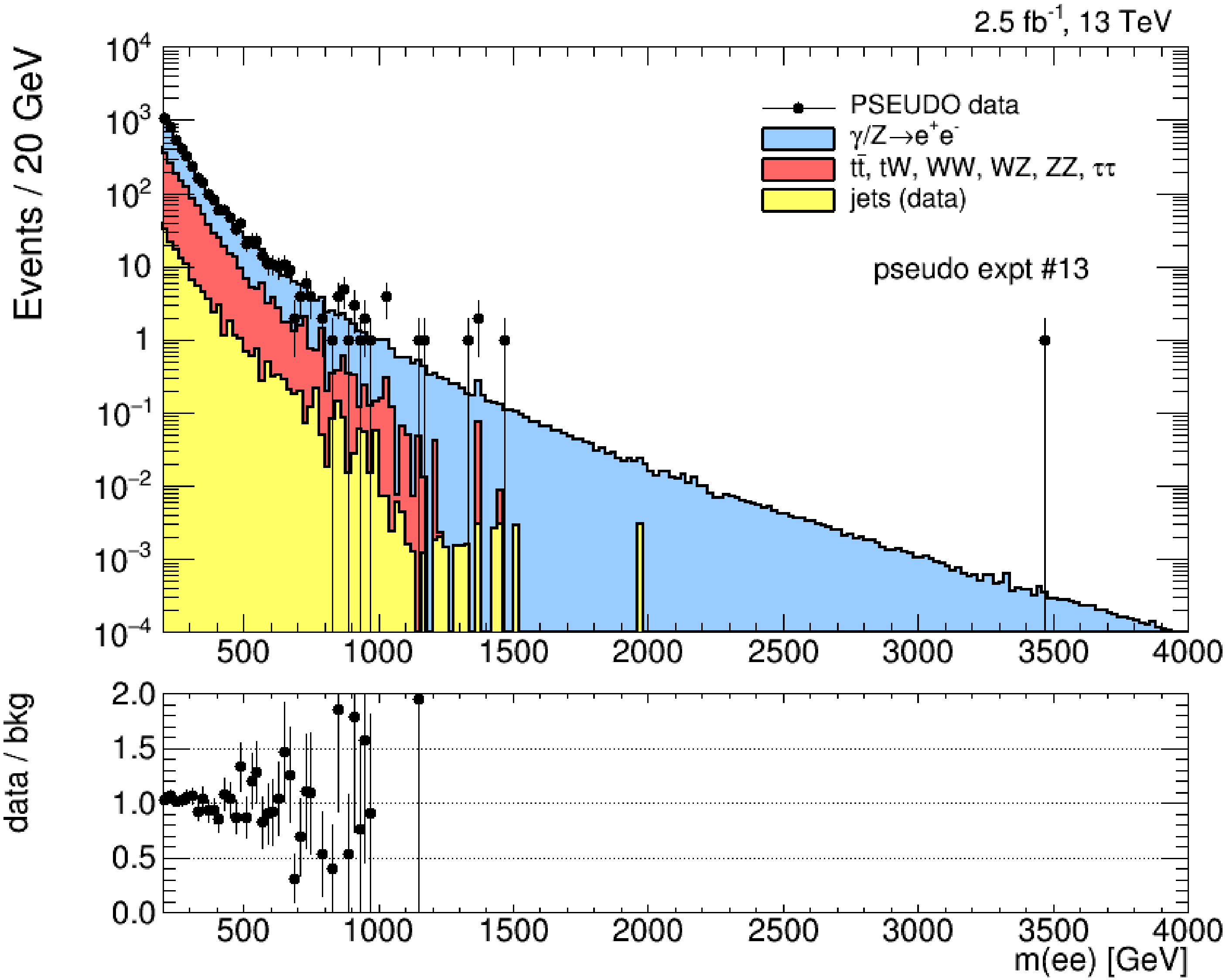


Pseudo Experiment Tests

- deficit ~ 700 GeV
- ran 100 toys to see if we saw something similar
- used fits for limit bkg as the input
- https://sharper.web.cern.ch/sharper/cms/heep/2015/Nov26_PseudoPlots/
- saw 4 similar deficits in 100 expects, this is a sub 2 sigma effect

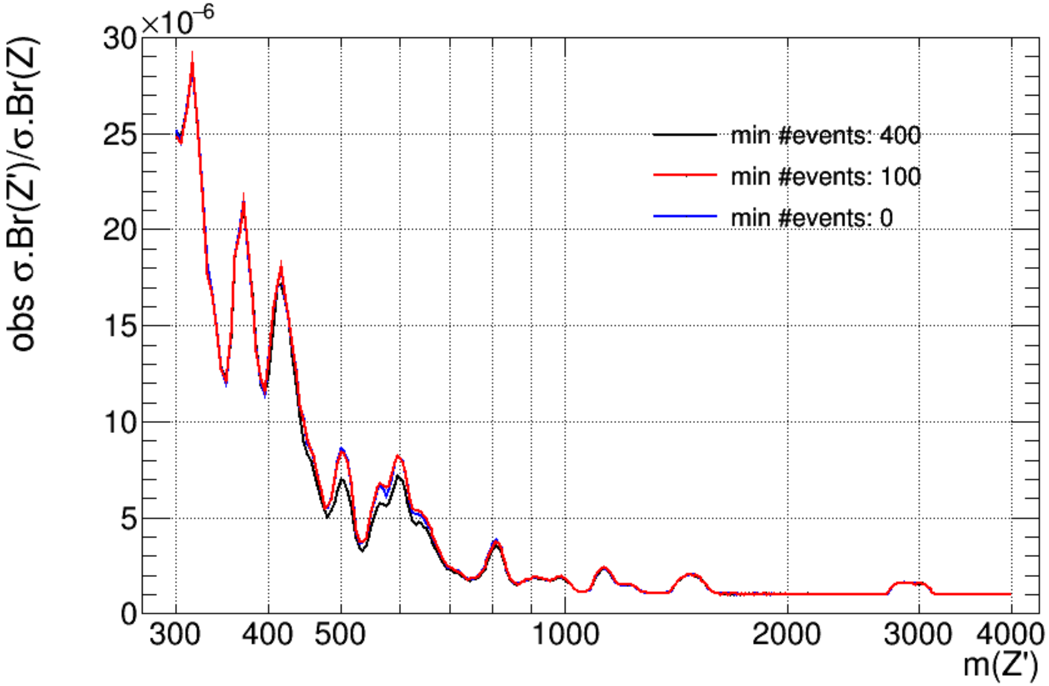


Pseudo Experiment Tests : Expt 13



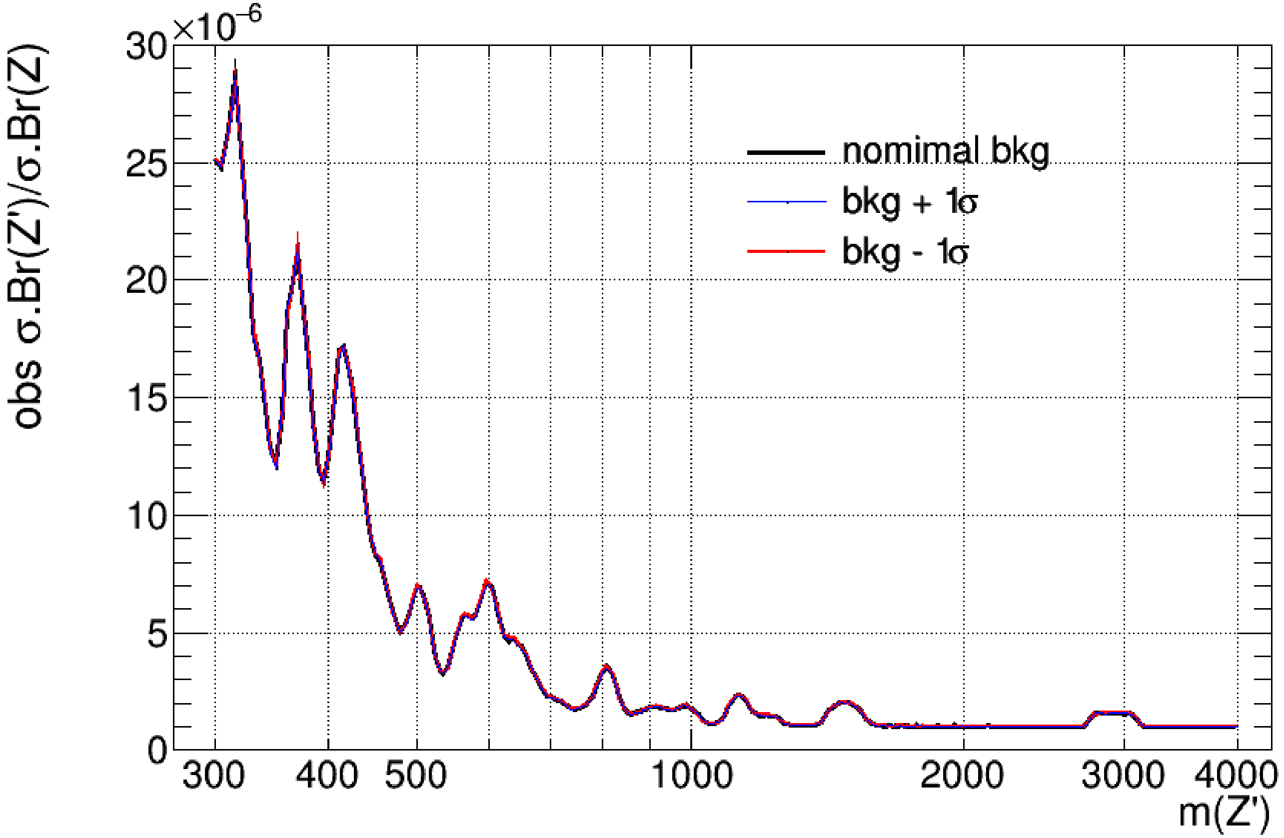
Robustness Tests : min number of events

- method uses a low bkg tail to effectively normalise the bkg PDF to data
- require a minimum of 400 events
- checked changing to zero and 100 and see little difference
- most sig change at 500 when limits go from 7E-6 to a bit over 8E-6



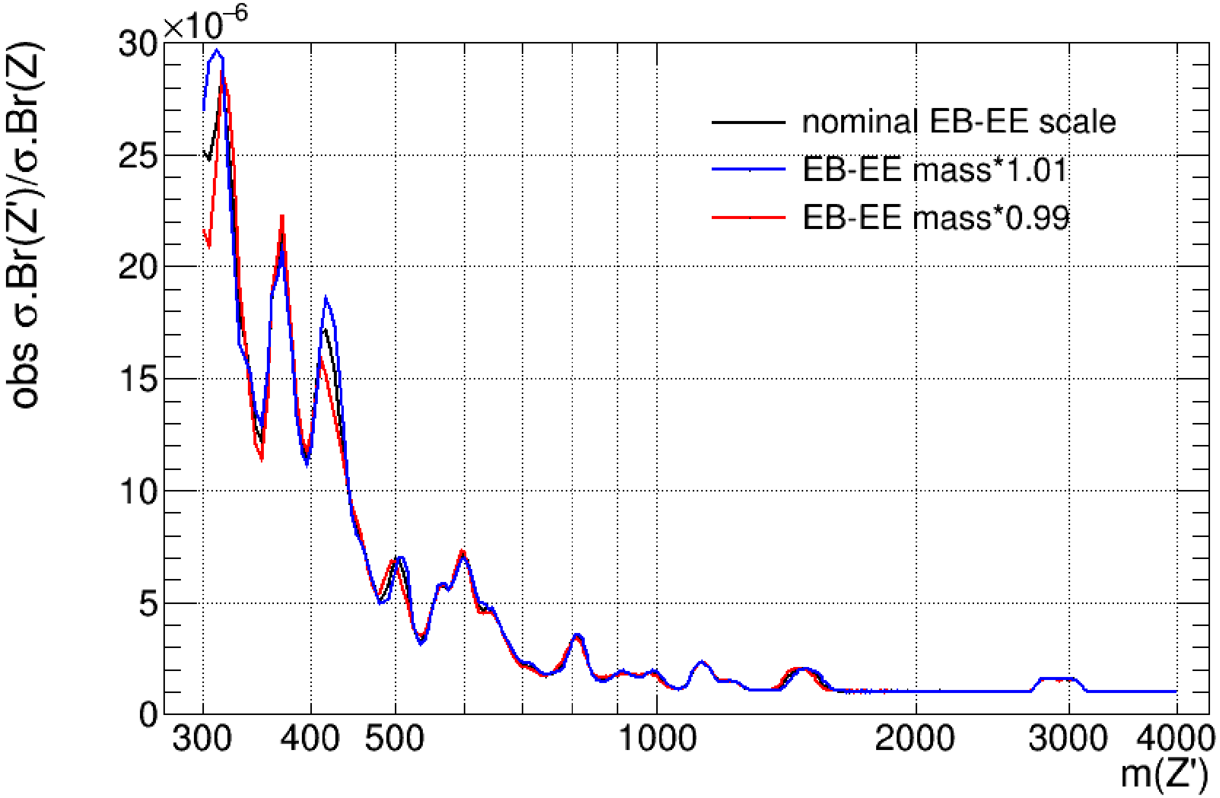
Robustness Tests : Bkg PDF

- manually changed the bkg pdf to go +/- 1 sigma of PDF uncertainty
- so 19% at 3 TeV, 6% at 500 GeV
- no difference observed
- this is expected given the previous results test



Robustness Tests : Endcap Energy Scale

- the EB-EE mass space is different from the barrel
- adjusted the EB-EE scale up and down 1%
- very little difference observed



Robustness Tests : Effect of Mass Scale Uncertainty

- currently apply a 1% uncertainty on the mass scale
- only makes sense when combining channels
- effect is not large