Search for new massive resonances decaying to two charged leptons at CMS

Young Scientists Forum

28e Rencontres de Physique de la Vallée d'Aoste
La Thuile

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for the CMS Collaboration

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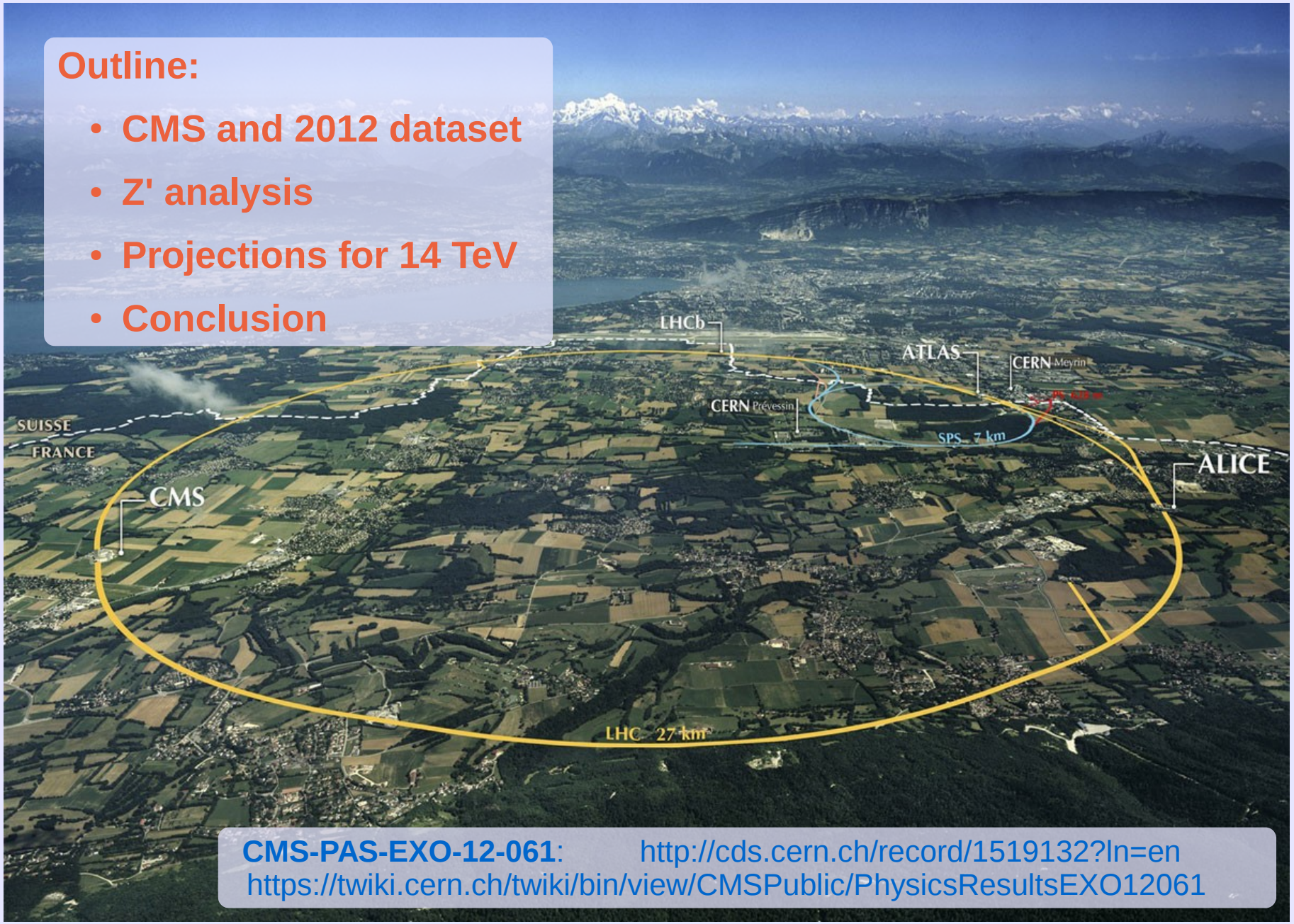
28th February 2014

Overview

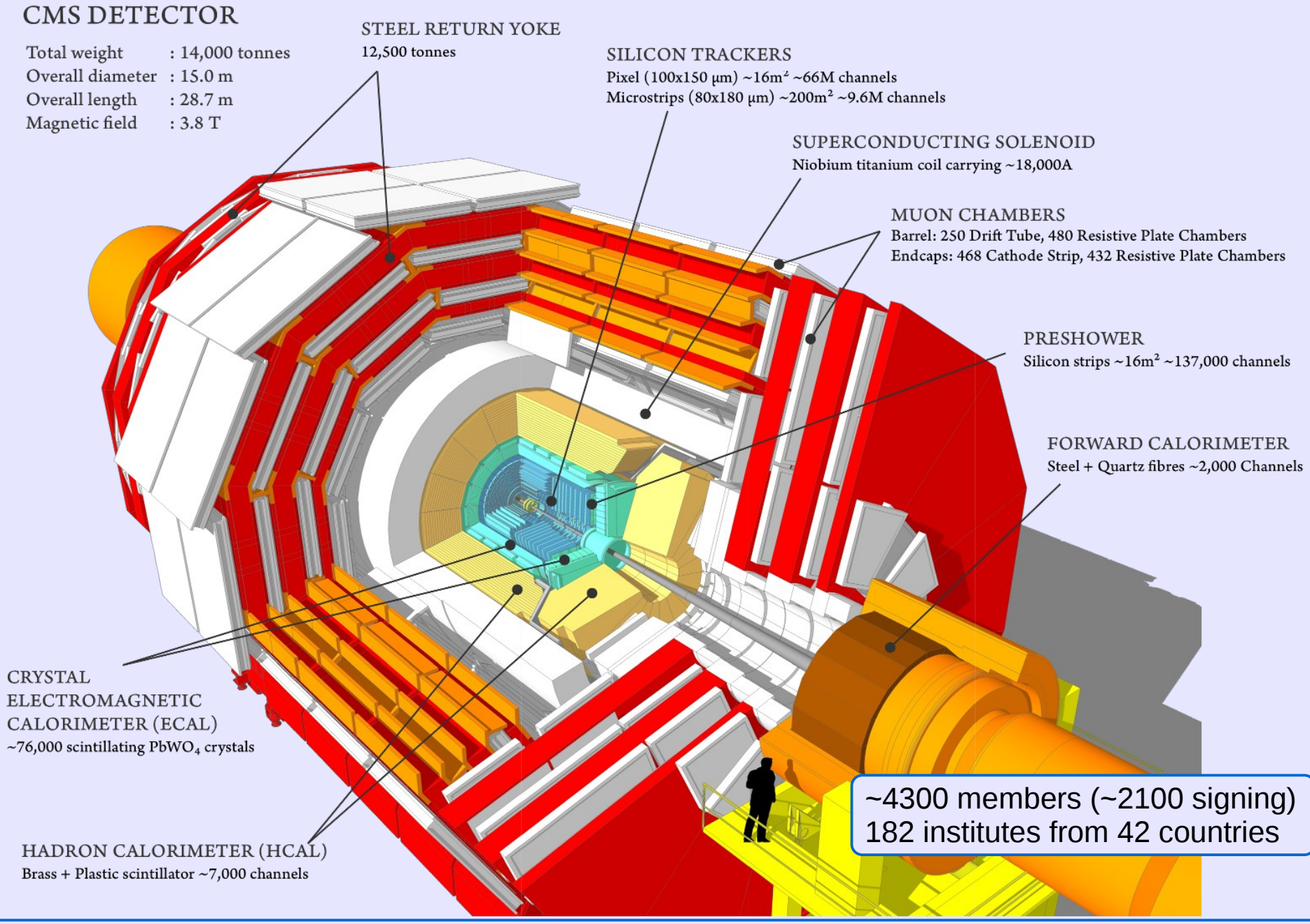
Outline:

- **CMS and 2012 dataset**
- **Z' analysis**
- **Projections for 14 TeV**
- **Conclusion**



CMS-PAS-EXO-12-061: http://cds.cern.ch/record/1519132?ln=en
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO12061

CMS Experiment

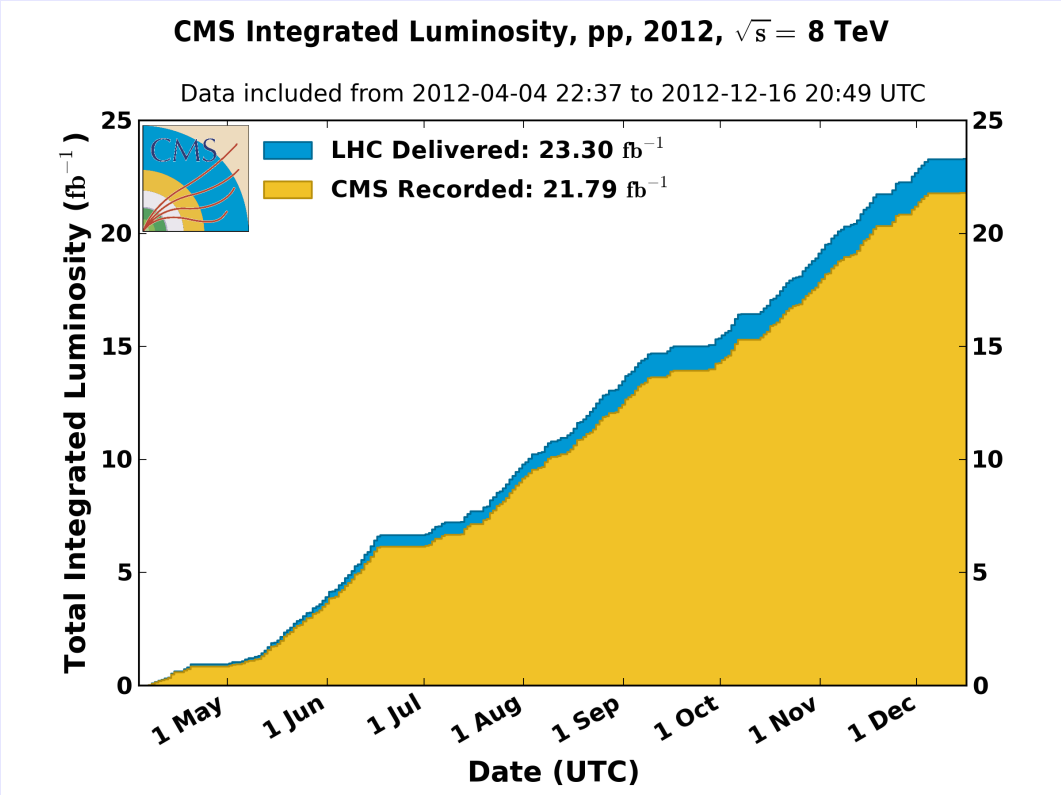


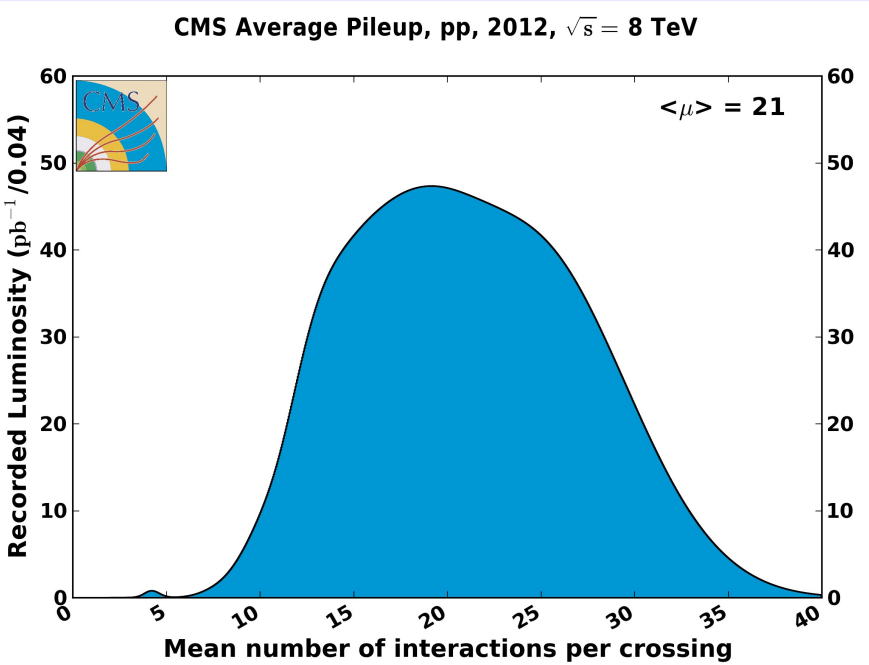
~4300 members (~2100 signing)
182 institutes from 42 countries

2012 Dataset

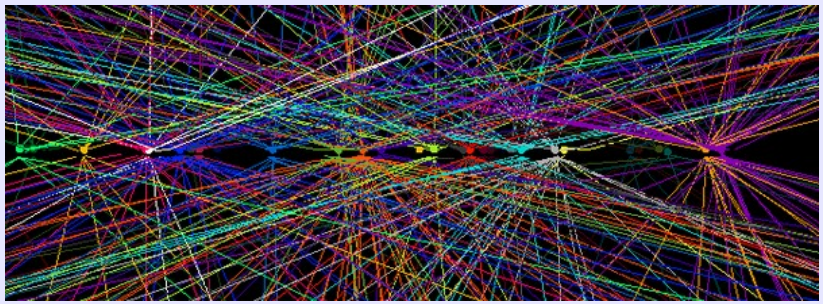
Excellent performance of LHC and detector

8 TeV center-of-mass energy with high instantaneous luminosity and 50 ns bunch spacing





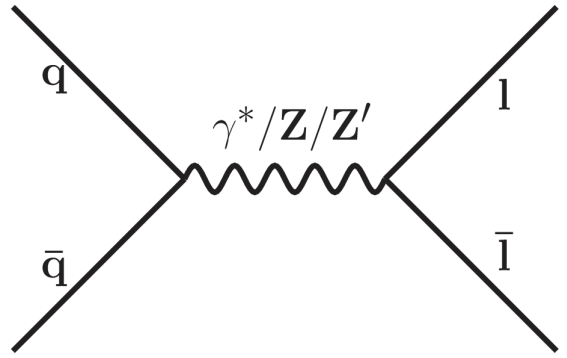
19.6 fb^{-1} good for all physics analysis
20.6 fb^{-1} good for muon analysis

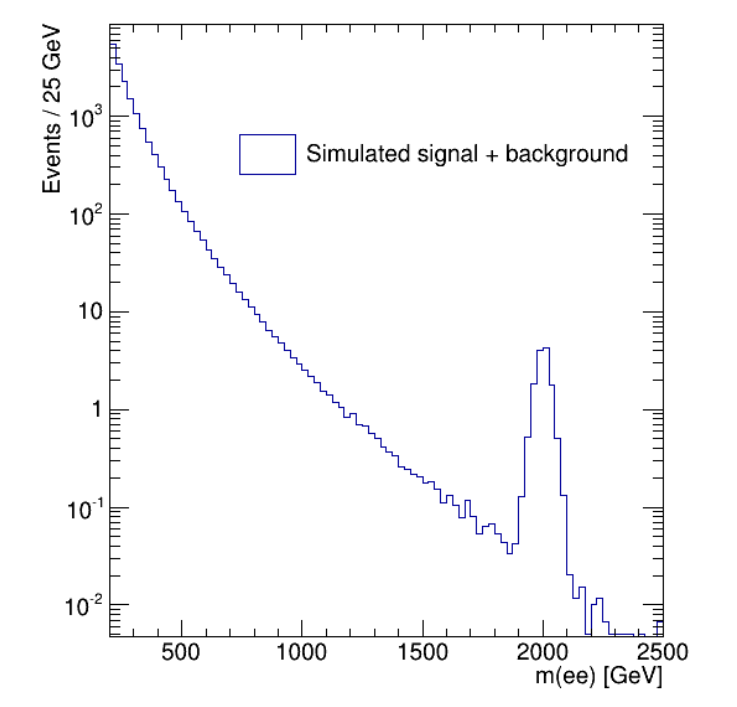


Event with 29 reconstructed vertices

Models

- Generic search for narrow peak in dielectron and dimuon mass spectrum
- Interpretation of results with two specific models
  - Z'_{SSM} from sequential standard model (SSM) with the same couplings as the Z
  - Z'_{ψ} from superstring inspired theories, arising in E6 or SO(10) GUT group





Toy simulation of a Z'_{ψ} with zero-width approximation, background fit and resolution from parametrisation, normalised for 8 TeV, 19.6 fb^{-1}

Event Selection - Electrons

High E_T electron object selection

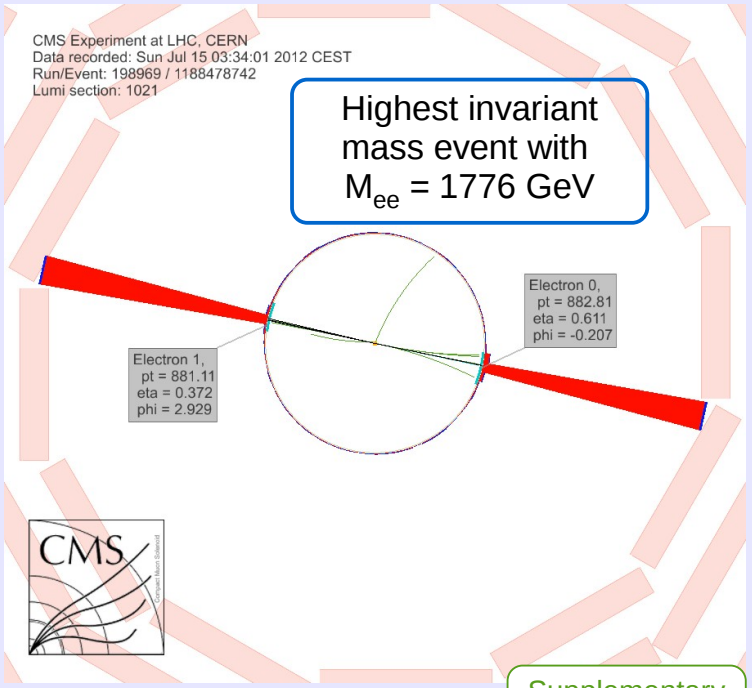
- Reconstructed electron candidate from ECAL energy deposit
- Good ECAL shower shape
- Small relative energy deposit in HCAL behind ECAL deposit
- Isolation in ECAL and HCAL
- ECAL energy deposit matched to isolated track
- Not more than one missing inner tracker hit

Dielectron event selection

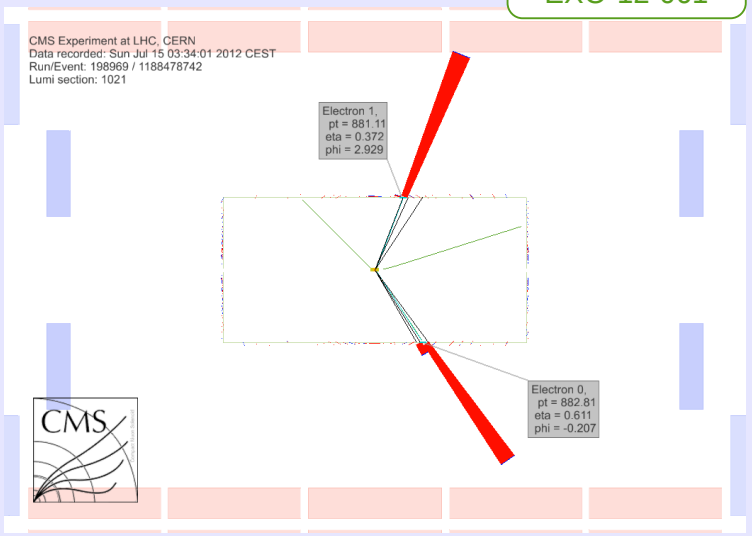
- Event triggered by a double electron trigger
- 2 selected electrons with $E_T > 35$ GeV
- At least one electron in the barrel of the detector

→ Analysis split in 2 channels:

  - 2 barrel electrons ($|\eta| < 1.442$)
  - 1 barrel + 1 endcap ($1.56 < |\eta| < 2.5$) electron



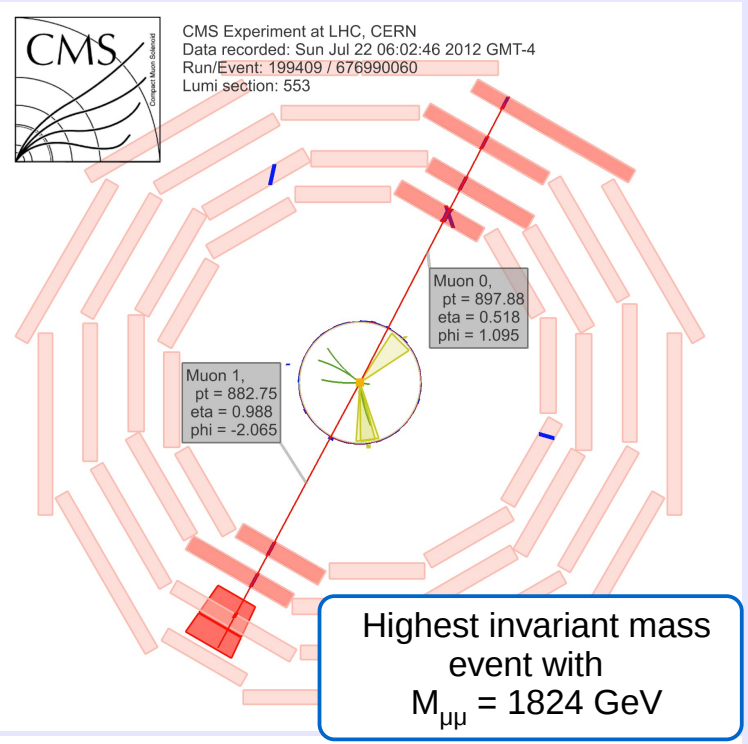
Supplementary EXO-12-061



Event Selection - Muons

High p_T muon object selection

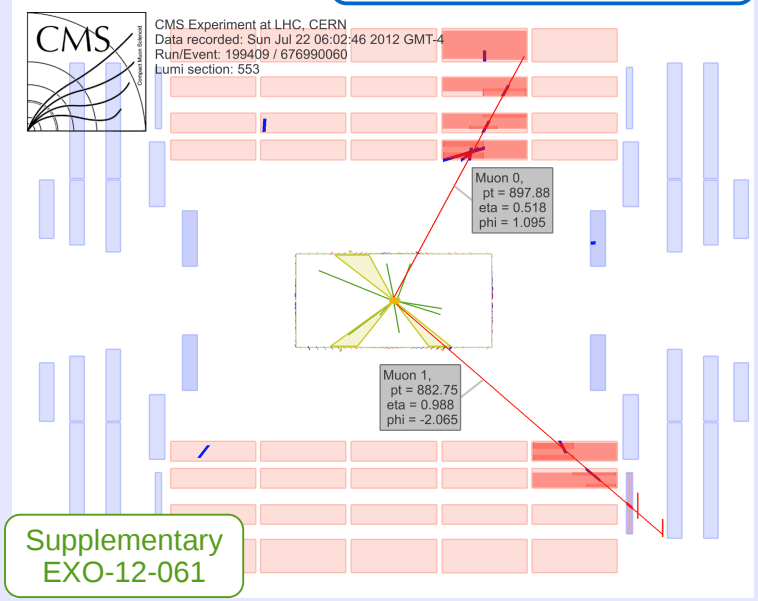
- Muon tracks are reconstructed independently from inner tracker and from muon system and then matched to form a global muon candidate
- Fitted track must include hits from pixel and strip detectors and from muon stations
- Small transverse distance to vertex
- Isolated track to reject jets
- Small relative p_T error



Highest invariant mass event with $M_{\mu\mu}$ = 1824 GeV

Dimuon event selection

- Event triggered by a single muon trigger
- 2 muons with $p_T > 45$ GeV
  with one muon matched to trigger object ($|\eta| < 2.1$)
  $|\eta| < 2.4$ for the other muon
- Candidates have opposite charge and common vertex
- 3D angle between muons < π–0.02



Supplementary EXO-12-061

Invariant Mass Spectra

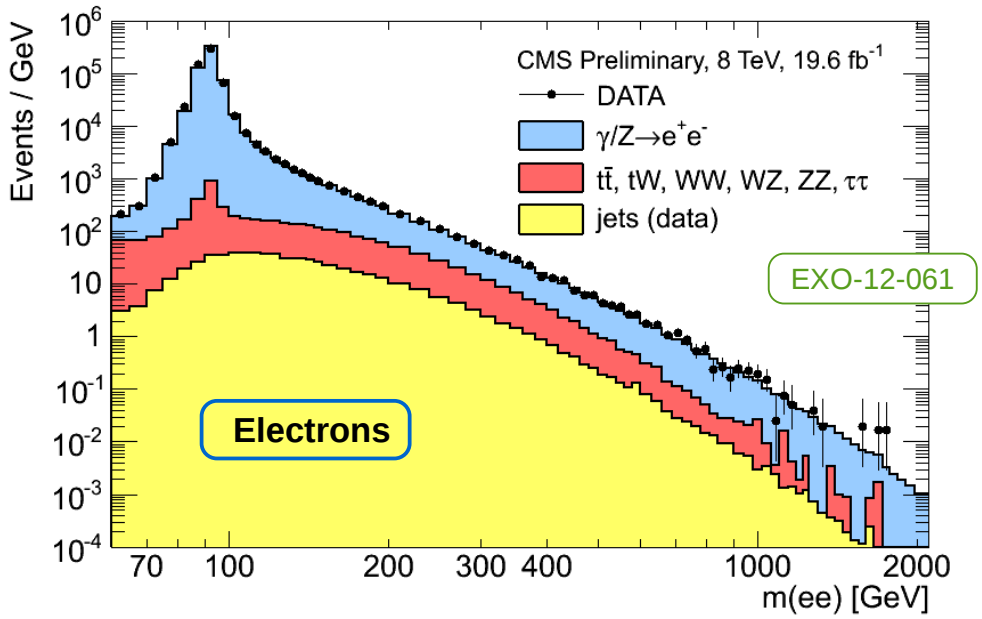
Z peak (60 Gev – 120 GeV)

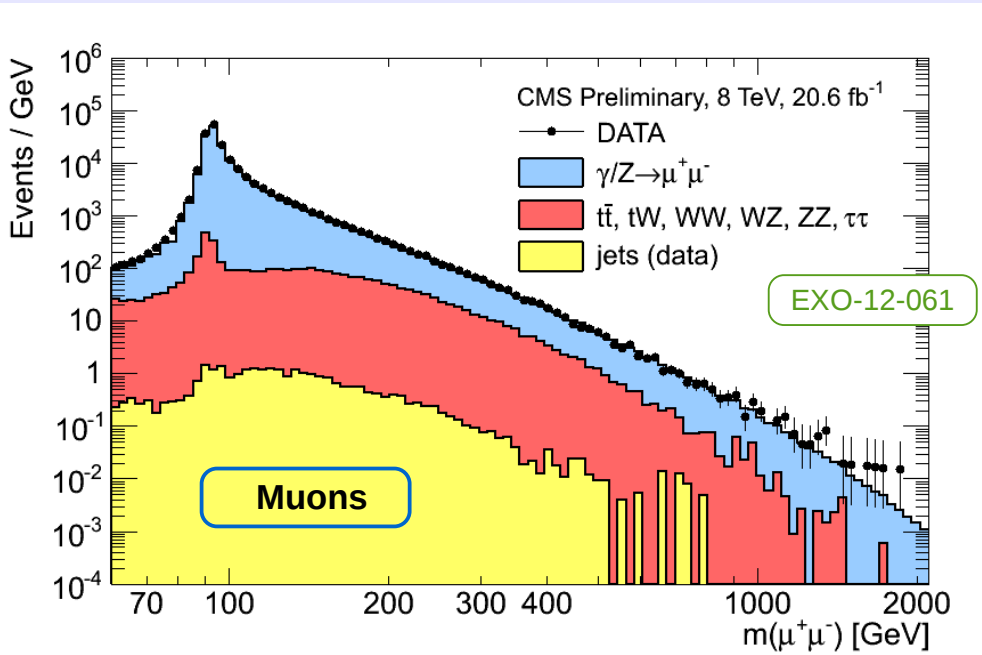
- Normalisation of simulations
- Energy scale calibration
- Selection efficiency measurement with Tag & Probe method

Control region (120 GeV – 200 GeV)

- No new physics expected
- Check high mass behaviour of analysis

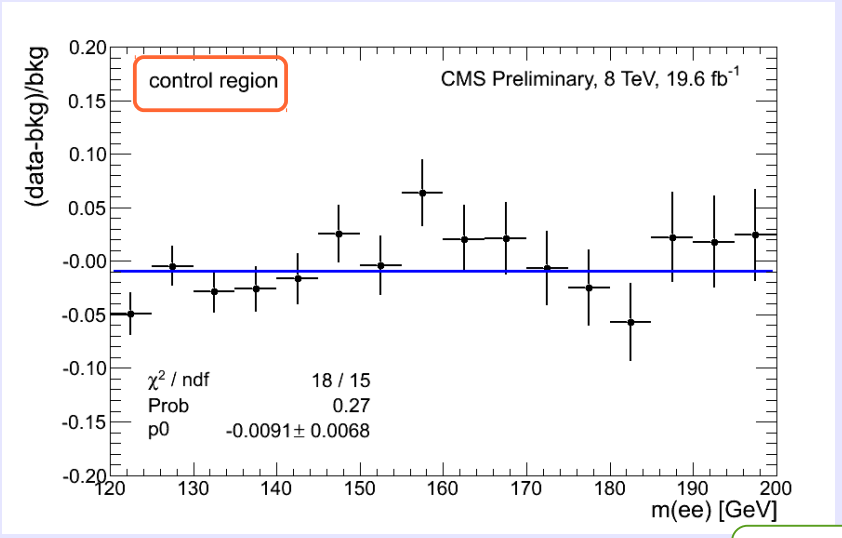
Search region (>200 GeV)



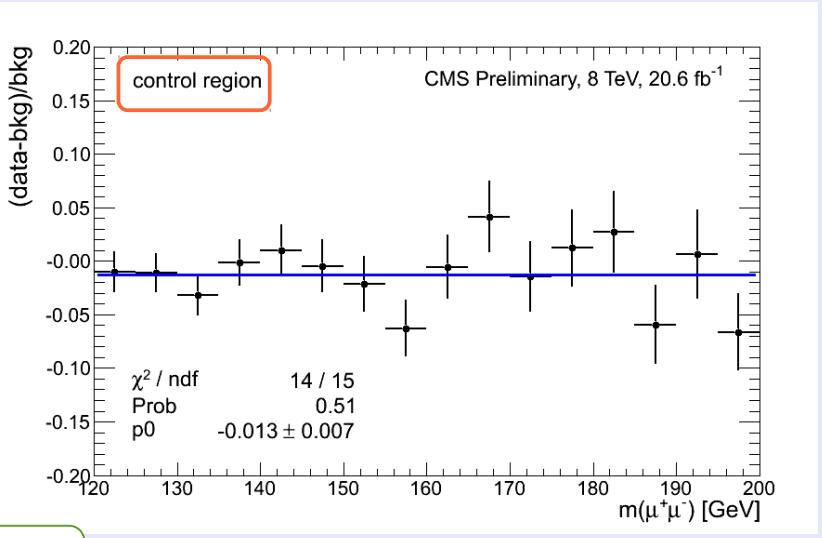


Data / Background Ratio

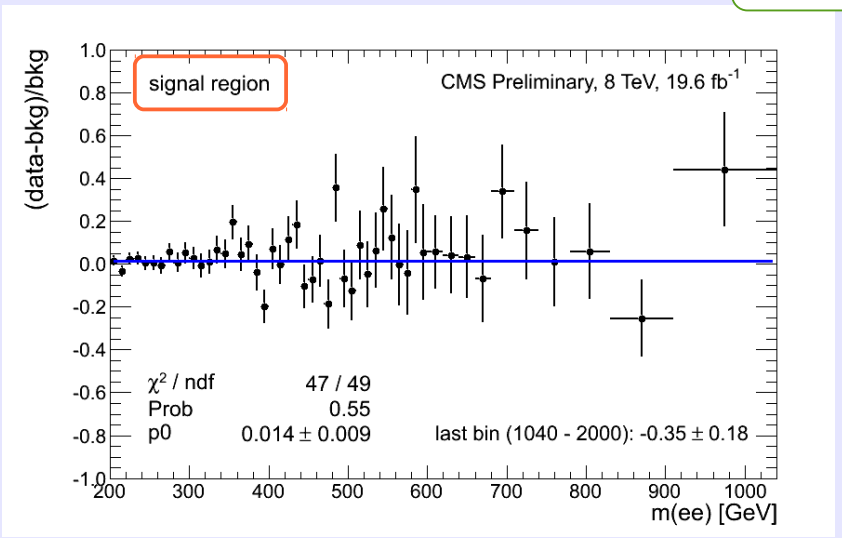
Electrons

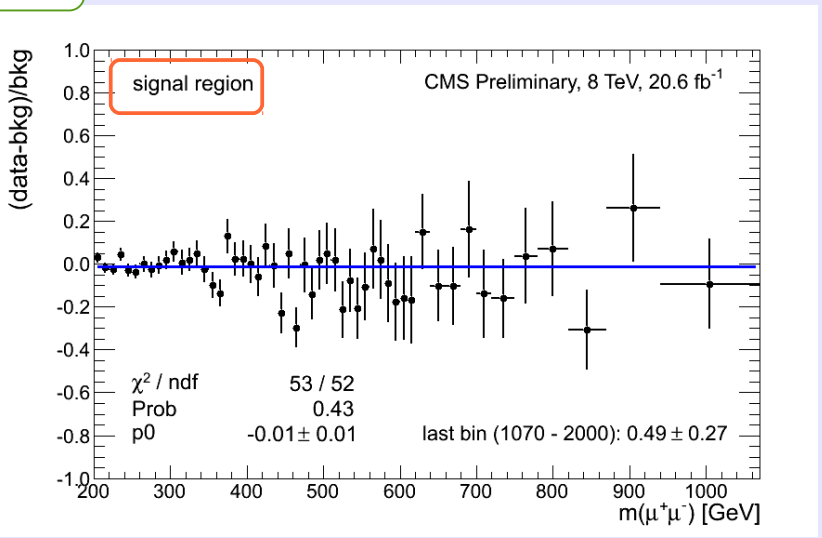


Muons



Supplementary EXO-12-061

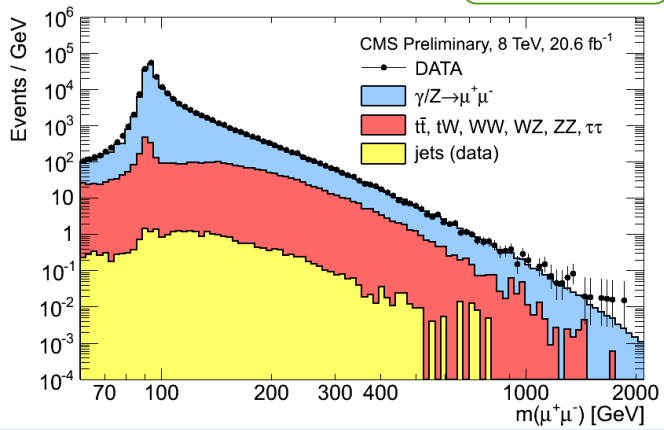




Backgrounds

- **Drell – Yan**
  - Irreducible background
  - Accounts for ~85% of the background events above the Z peak
  - Estimated from simulations and normalised to the data at the Z peak
- Processes giving **two real electrons/muons** in the final state
  - Dominated by $t\bar{t}$, with contributions from dibosons and tW
  - Spectrum taken from simulations
  - Cross check with data driven method with electrons and muons in the final state
- **Jet background** with one or multiple jets misidentified as leptons
  - More important for electron channel
  - Data driven approach
- **Cosmic muons**
  - Suppressed by muon selection

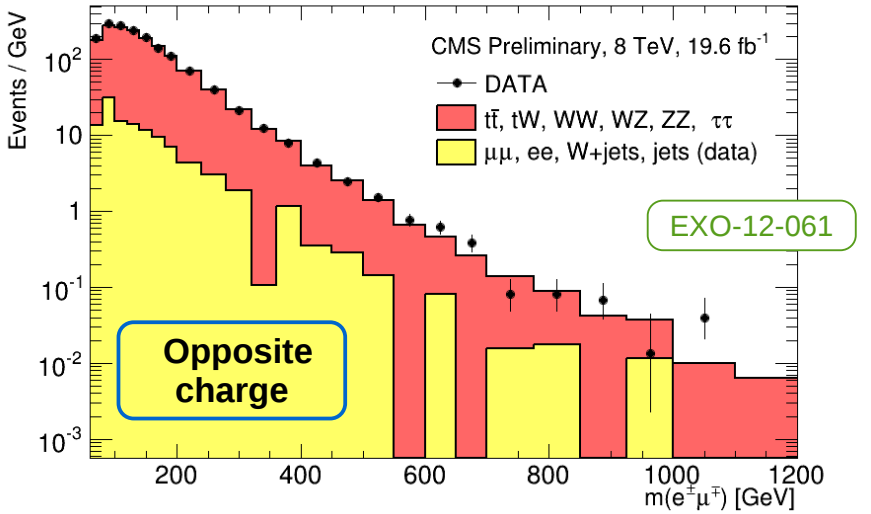
EXO-12-061

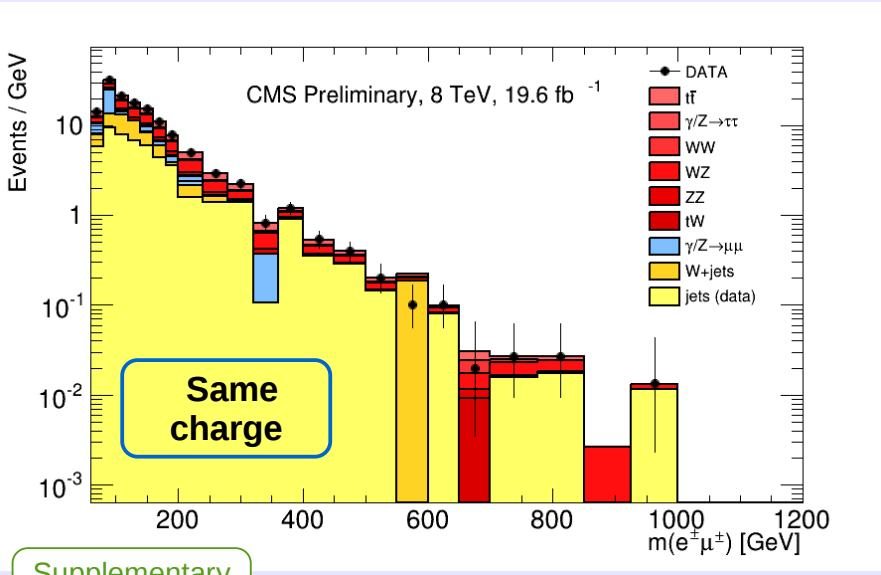


eμ Spectrum

Cross check for the spectrum from two real electrons/muons in the final state

- Without acceptance times efficiency differences the eμ spectrum should yield twice as many events as the ee and μμ spectrum respectively
- Multijet contribution estimated from the same charge spectrum
- Good agreement between data and simulation for opposite charge spectrum



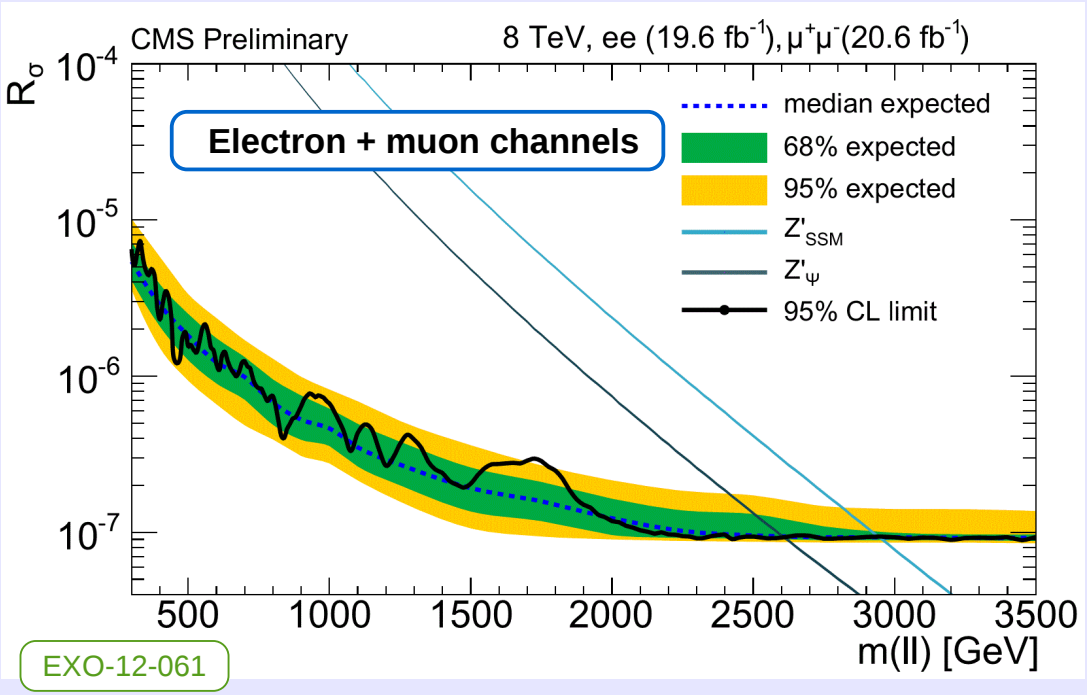


Supplementary EXO-12-061

Systematics

- Dominant uncertainty: Ratio of acceptance times efficiency for Z' to Z is 3% for muon, 4% for barrel-barrel and 6% for barrel-endcap electron events
- Uncertainty for background fit function from PDF and higher order corrections ranges from 2% (200 GeV) to 20% (3000 GeV)
- Absolute PDF uncertainty not important since we normalise to the Z peak
- Background uncertainties from jet background and $t\bar{t}$ are small compared to other uncertainties

Limits



Observed and expected upper limit on R_σ plus predicted ratios for Z'_{SSM} and Z'_ψ from simulated events.

Full shape based Bayesian limits

We use the ratio (R_σ) of cross section times branching ratio of a new Z' boson (on-shell mass ± 40%) to the Z boson (on-shell mass ± 30 GeV)

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to ll + X)}{\sigma(pp \to Z + X \to ll + X)}$$

- Cancels uncertainty on luminosity
- Reduces dependence on efficiencies and acceptance

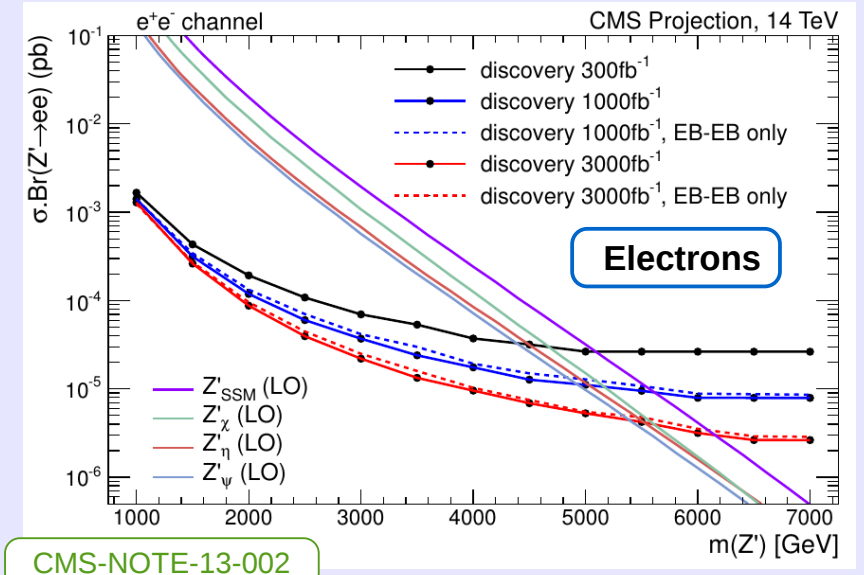
95% CL lower limits on resonance mass:

- Z'_{SSM}: $M_{Z'} > 2.96$ TeV
- Z'_ψ: $M_{Z'} > 2.60$ TeV

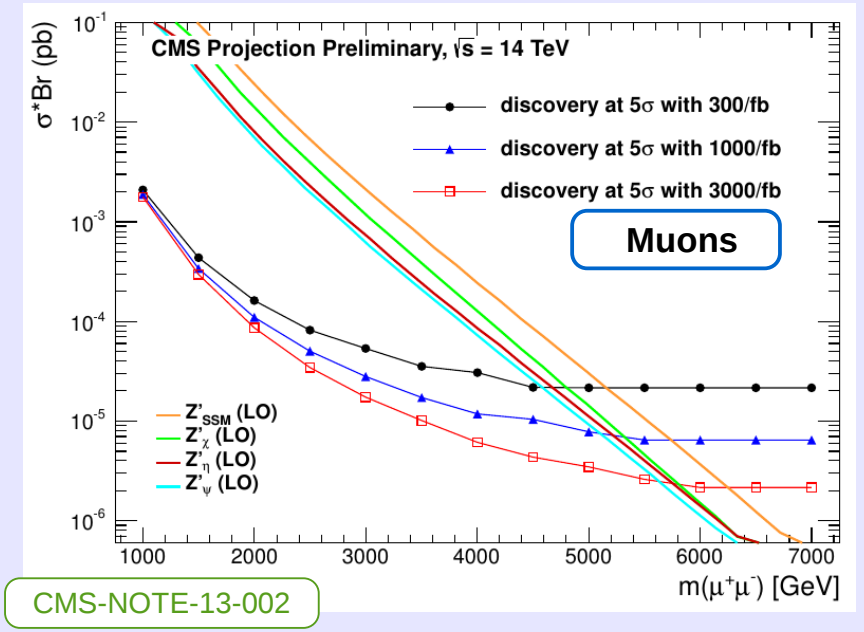
Projections for Future Runs

Discovery projections for 14 TeV center-of-mass energy for Z' searches

- Generator level simulations
- Acceptance, Efficiencies and resolutions taken from 8 TeV data
- Saturation of single ECAL crystal readout electronics (above ~1.7 TeV for barrel, ~3.0 TeV for endcap) included
- No jet background included
- Reduced acceptance scenario because of ECAL degradation in the endcaps -> Barrel only electrons



CMS-NOTE-13-002



CMS-NOTE-13-002

Ref: arXiv:1307.7135

Summary

- Leptons in final state provide clean experimental access but high energy objects require care in event selection
- No excess over the standard model background found so far
- Set limits on two models for Z' bosons

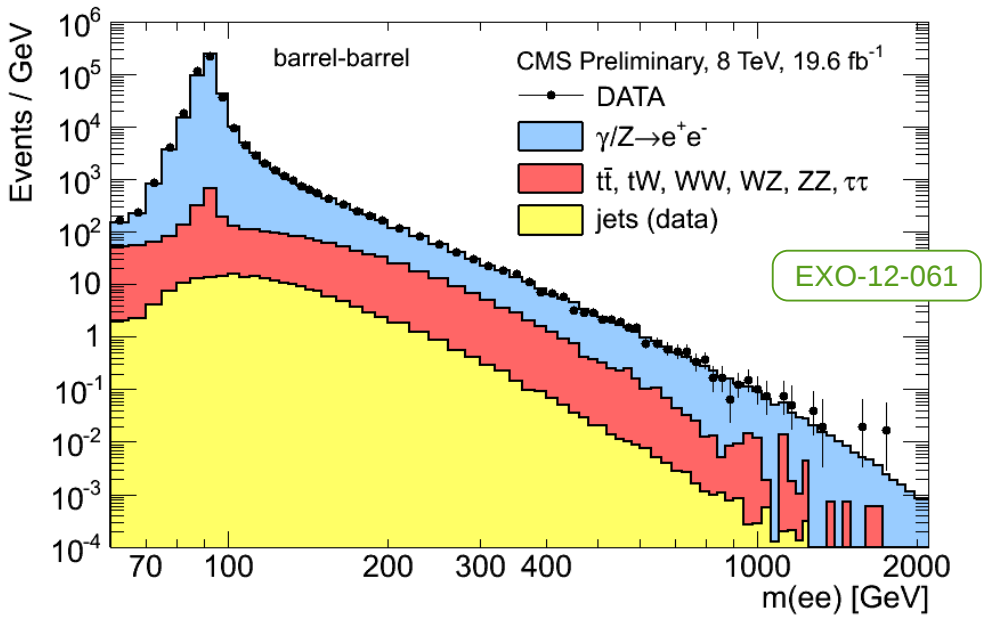
$M_{Z'SSM} > 2.96$ TeV $M_{Z'\psi} > 2.60$ TeV

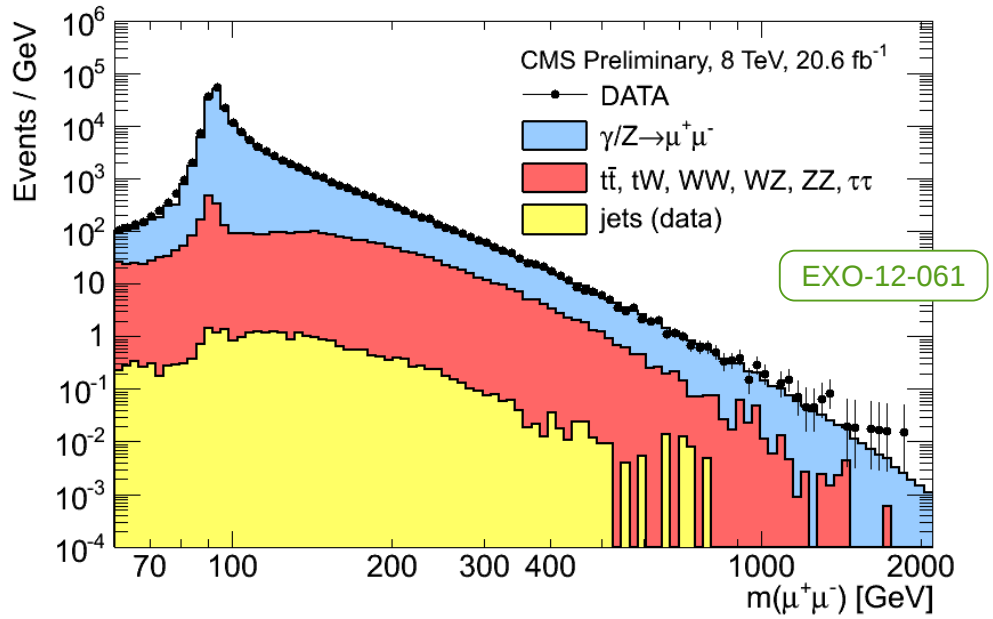
- Anticipating higher collision energy in 2015
  - Projections show discovery potential up to $M_{Z'}$ ~5 TeV for 300 /fb at 14 TeV center-of-mass energy

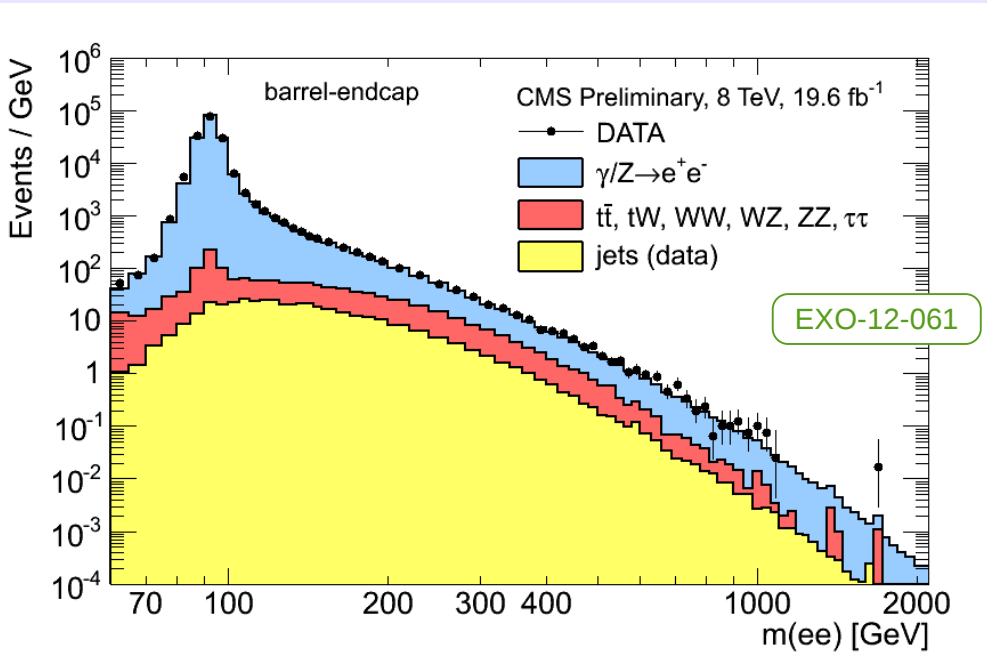
Thank you.

Additional Slides

Invariant Mass Spectra



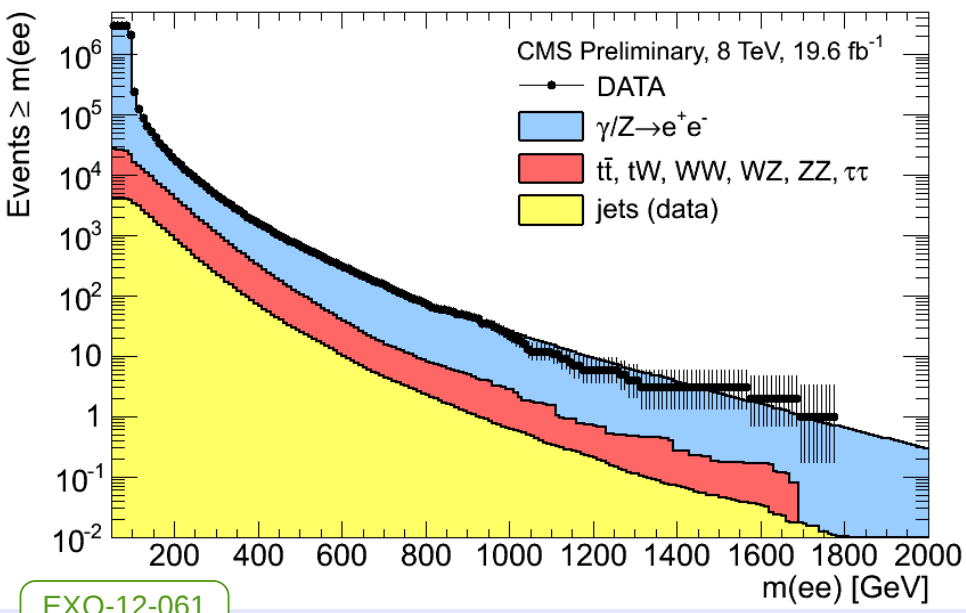




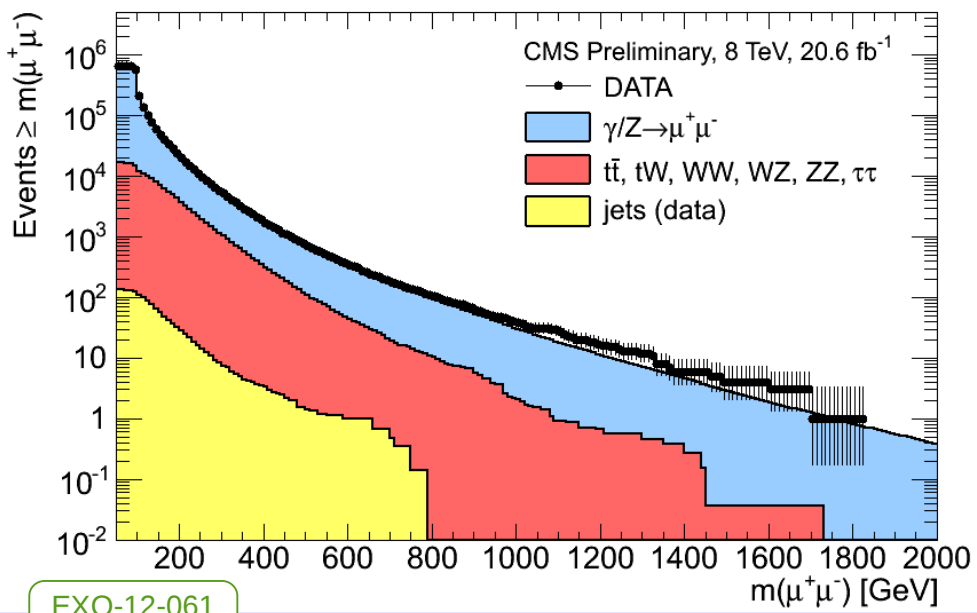
Cross section measurement in the range 60 – 120 GeV

- Theory NNLO cross section: 1117 pb
- μμ: 1103±7(stat)±48(lumi) pb
- ee barrel-barrel: 1099±1(stat)±48(lumi) pb
- ee barrel-endcap: 1063±1(stat)±48(lumi) pb

Cumulative Invariant Mass Spectra



EXO-12-061

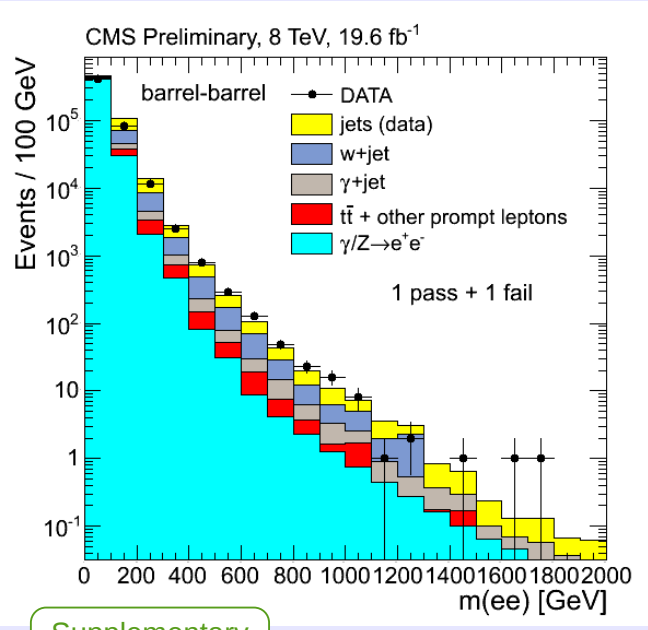


EXO-12-061

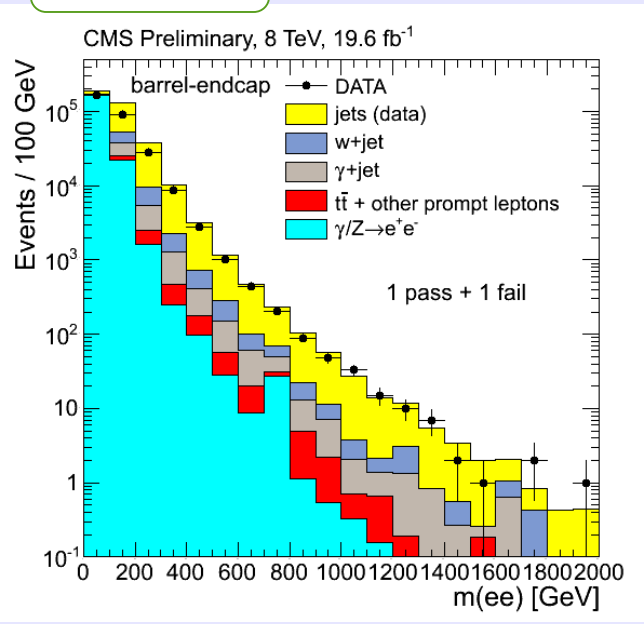
Multijet Background - Electrons

Background from one or more jets misidentified as electrons

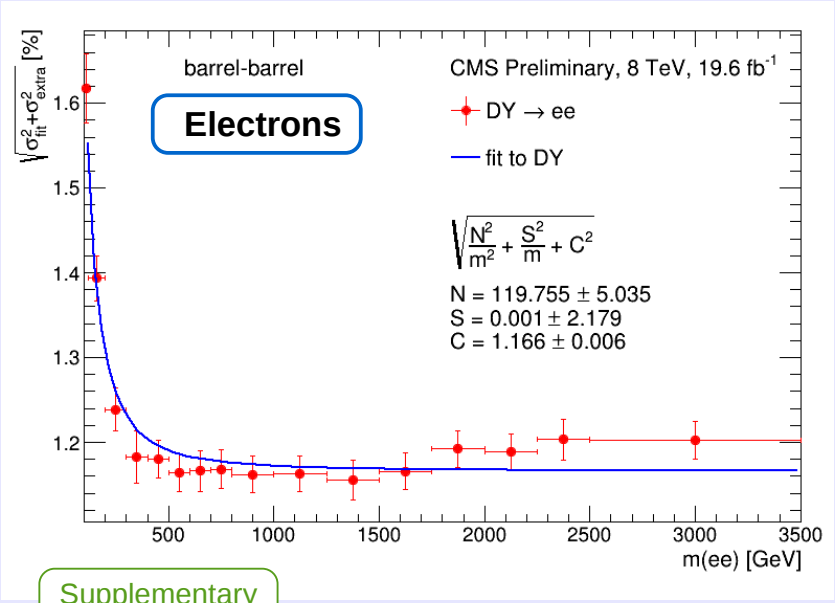
- Data driven estimation of contribution to invariant mass spectrum
- Measurement of *fake rate* (FR) of jets from jet enriched sample that pass the electron selection
- Estimation of jet background by applying the fake rate to both electrons candidates that fail the selection of a two electron candidate sample
- Sample weighted by FR / (1-FR) for each electron candidate
- Cross check with sample with one passing electron candidate and one failing
- 40% systematic uncertainty applied



Supplementary EXO-12-061



Mass Resolution



Supplementary EXO-12-061

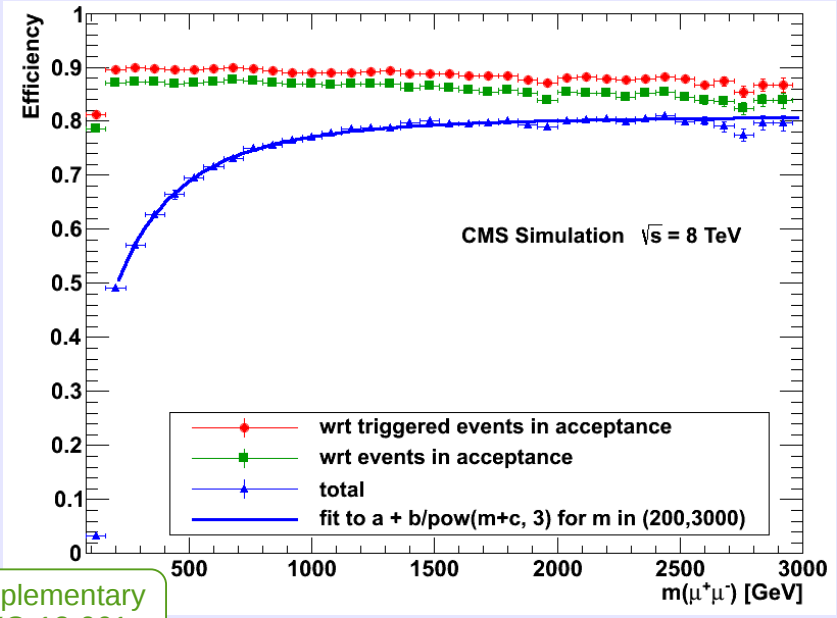
Electron Channel:

- Width of the fit of a double sided Crystal Ball function to $m_{RECO} - m_{true}$ from simulated Drell-Yan samples
- Correction with extra smearing from width difference of data and MC at the Z peak
- Resolution reaches plateau of ~1.2% above 1 TeV

Muon Channel:

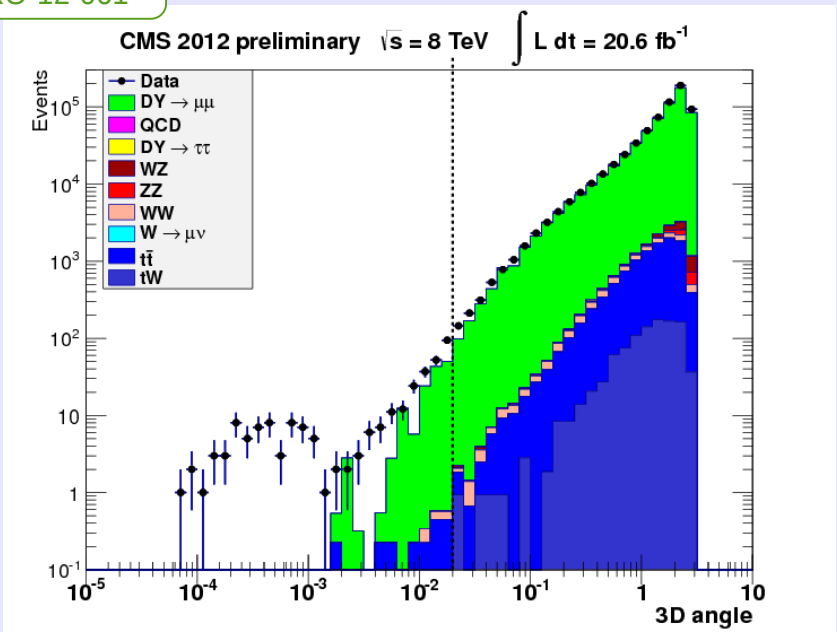
- Width of a Gaussian fit to $(m_{RECO} - m_{true}) / m_{true}$ from signal samples
- Parametrisation with second-order polynomial
- ~6.7% at 2 TeV

Additional Muon Plots



Supplementary EXO-12-061

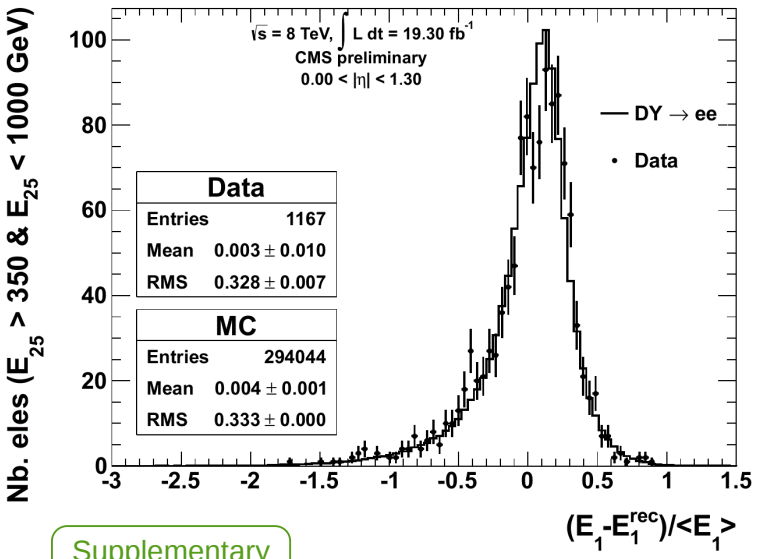
Acceptance times efficiency for muon selection from simulated Drell-Yan events



3D angle between the muons for muons passing all selection cuts except the 3D angle cut and the requirement of a primary vertex

ECAL High Energy Response

- Relation between central crystal and surrounding ones from 5 x 5 matrix determined from Monte Carlo simulations
- Plot relative difference of highest energy crystal E_1 with the estimation of E_1 by the surrounding 24 crystals (E_1^{rec})



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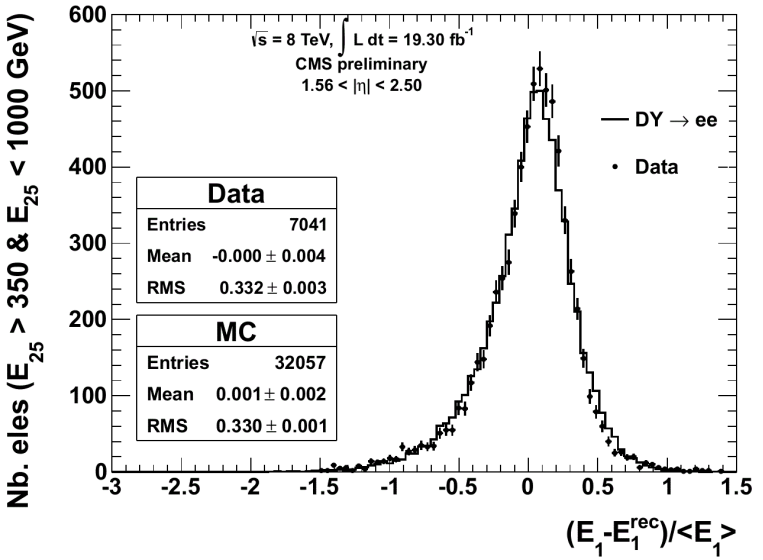
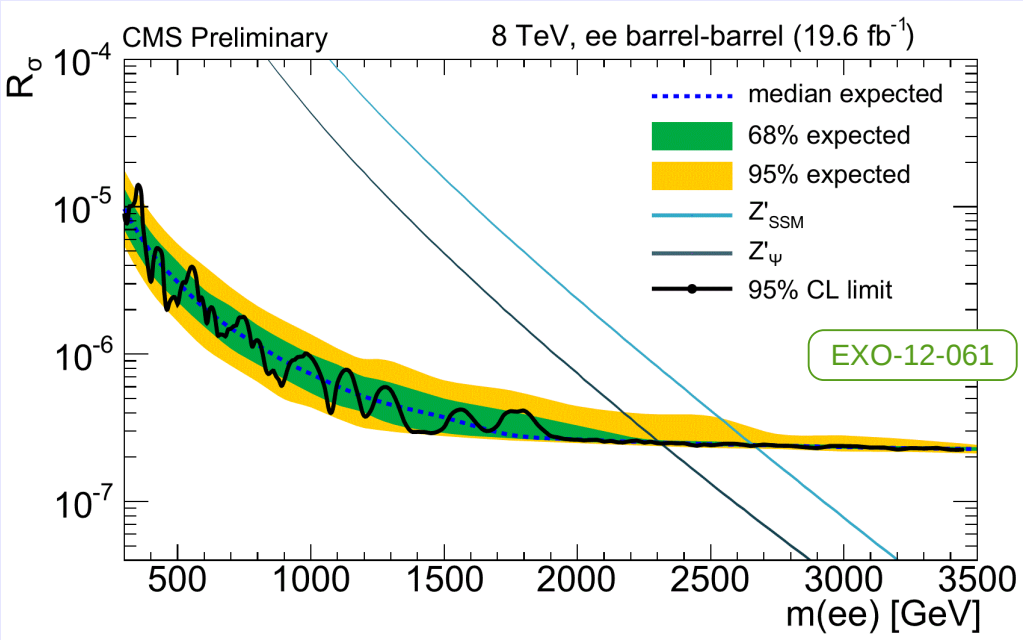
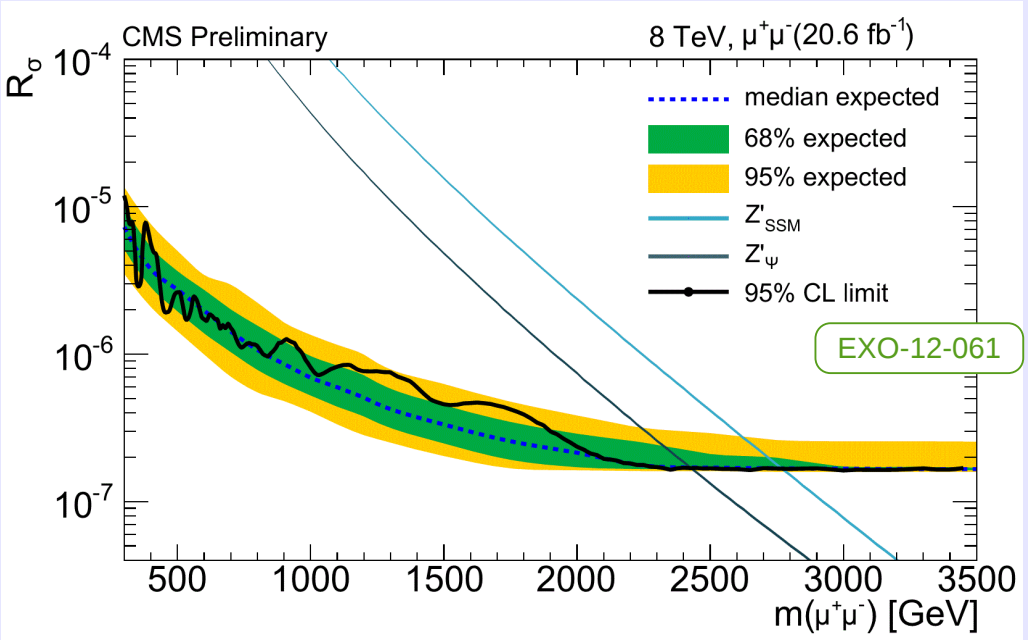
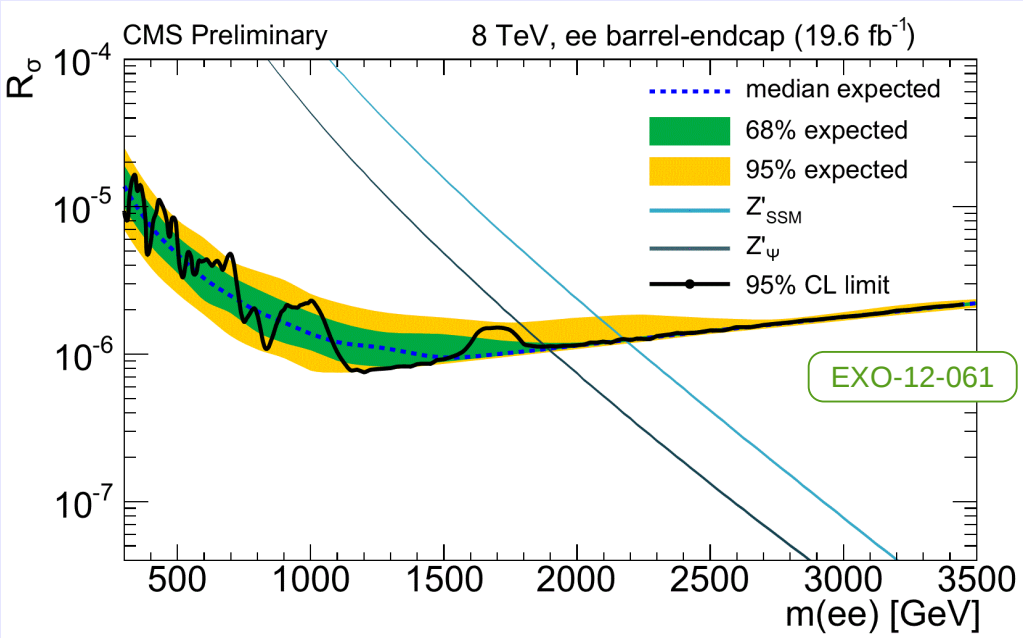


Limits per Channel





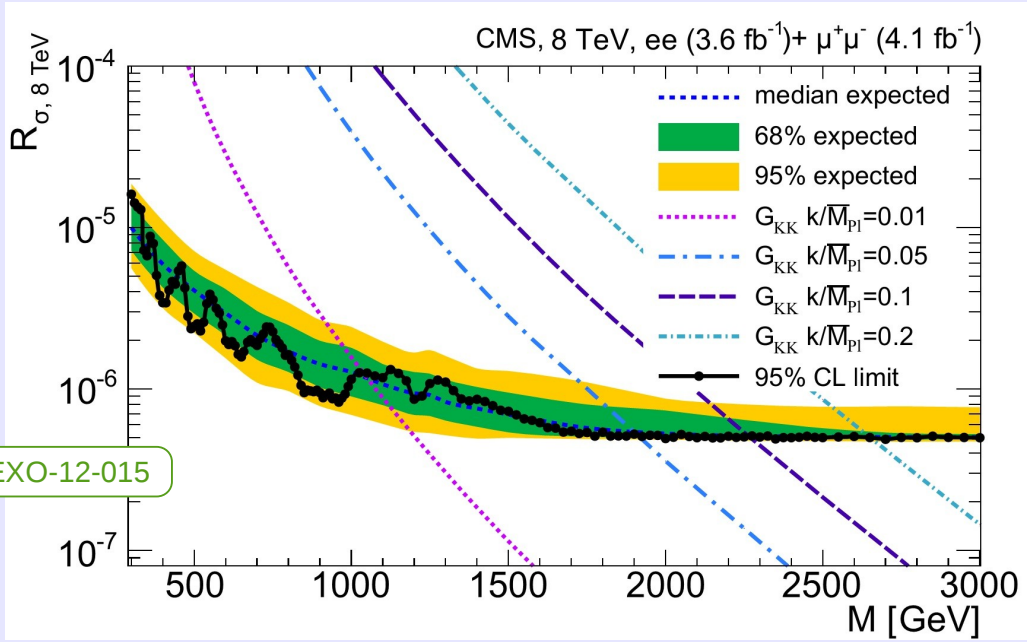


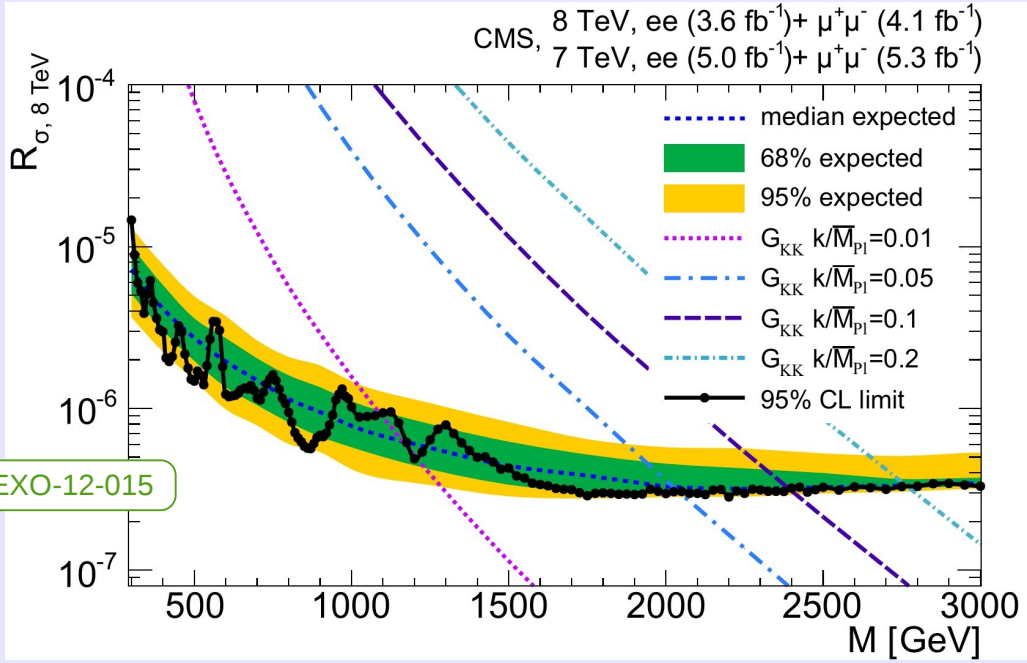
Electron channel barrel-barrel:
- Z'_{SSM}: 2.65 TeV
- Z'_{ψ}: 2.31 TeV

Electron channel barrel-endcap:
- Z'_{SSM}: 2.18 TeV
- Z'_{ψ}: 1.90 TeV

Muon channel:
- Z'_{SSM}: 2.77 TeV
- Z'_{ψ}: 2.43 TeV

Limits on Spin 2 Resonance





Combination of 2011 (7 TeV) and 2012 (8 TeV) dataset

Combination only valid for same fraction of $q\bar{q}$ to gg coupling than RS graviton

Limits (8 TeV only):

G_{KK} ($k/\overline{M}_{Pl}$=0.1): 2.26 TeV

G_{KK} ($k/\overline{M}_{Pl}$=0.05): 1.90 TeV

Limits (7 TeV + 8 TeV):

G_{KK} ($k/\overline{M}_{Pl}$=0.1): 2.39 TeV

G_{KK} ($k/\overline{M}_{Pl}$=0.05): 2.03 TeV

Ref: Phys. Lett. B 720 (2013) 63
DOI:10.1016/j.physletb.2013.02.003

Projections for Future Runs

Discovery projections for 14 TeV center-of-mass energy for Z' searches

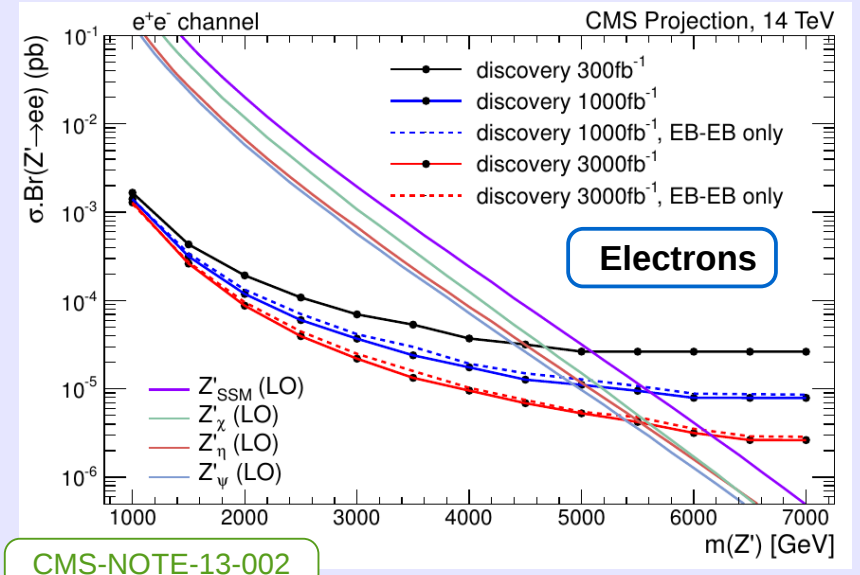
- Generator level simulations
- Efficiencies and resolutions measured from 8 TeV data
- Acceptance as for the 8 TeV search
- Reduced acceptance scenario because of ECAL degradation in the endcaps -> Barrel only electrons
- Saturation of single ECAL crystal (above ~1.7 TeV for barrel, ~3.0 TeV for endcap) included

→ Drell-Yan events give largest contribution to the background

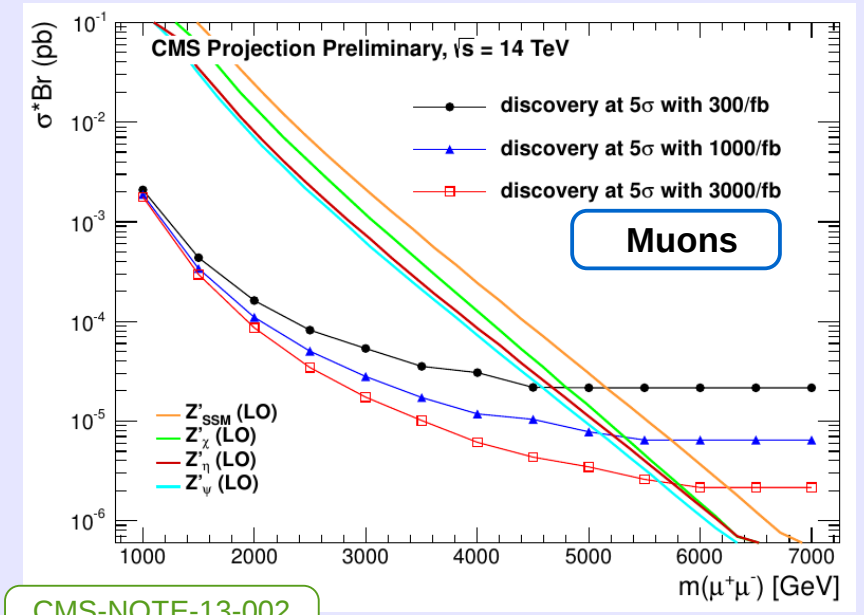
→ $t\bar{t}$ background self-vetos above ~1 TeV due to failed isolation criteria for the leptons because of close b-jet

→ WW dominant non-DY background above ~1 TeV

→ No jet background included



CMS-NOTE-13-002



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Ref: arXiv:1307.7135