Searches for New Massive Resonances Decaying to Leptons at CMS

16th Lomonosov Conference
Moscow

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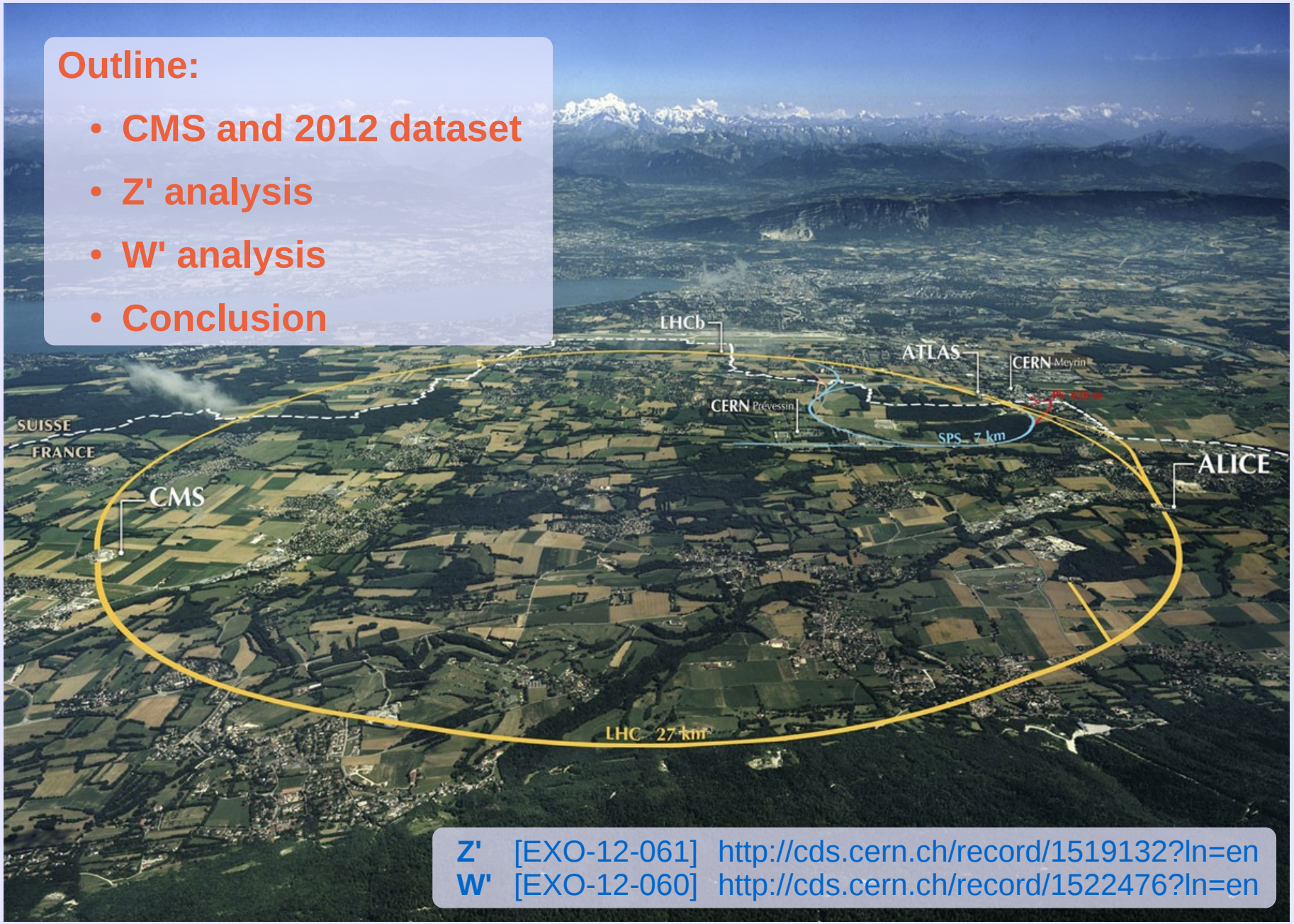
Overview

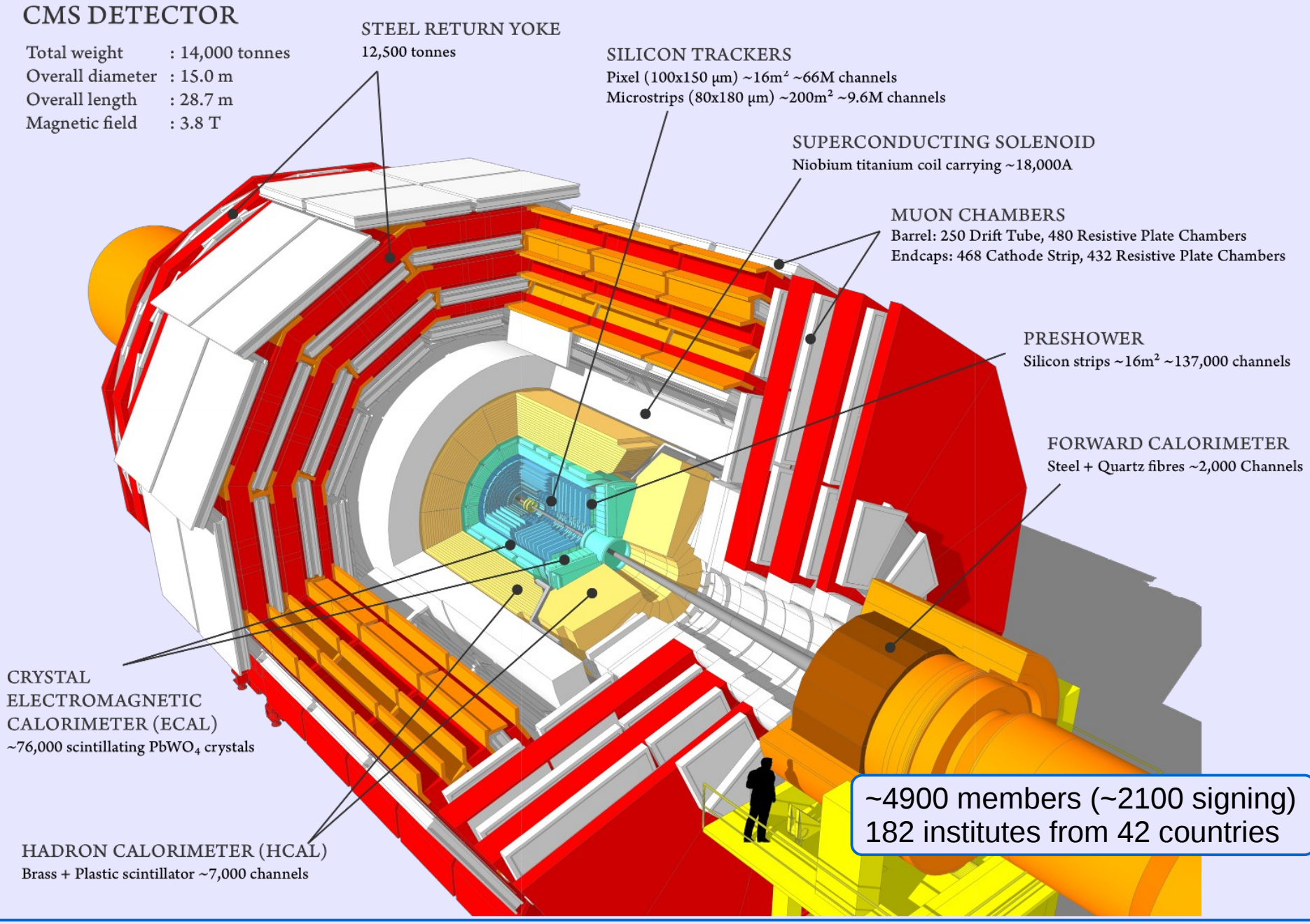
Outline:

- **CMS and 2012 dataset**
- **Z' analysis**
- **W' analysis**
- **Conclusion**



Z' [EXO-12-061] http://cds.cern.ch/record/1519132?ln=en
W' [EXO-12-060] http://cds.cern.ch/record/1522476?ln=en

CMS Experiment

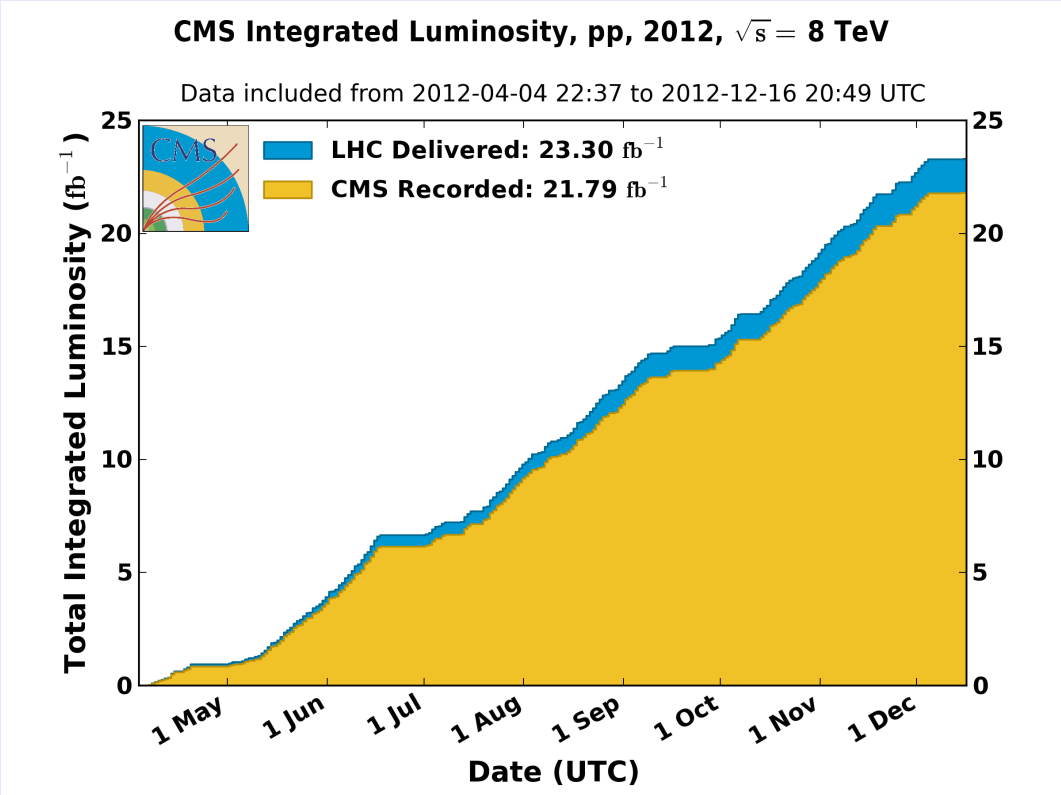


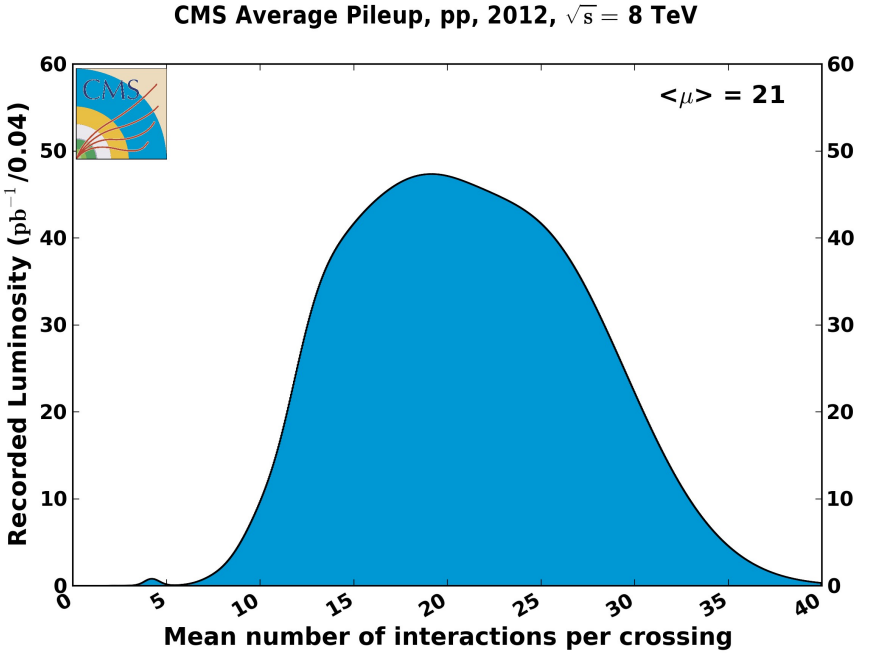
~4900 members (~2100 signing)
182 institutes from 42 countries

2012 Dataset

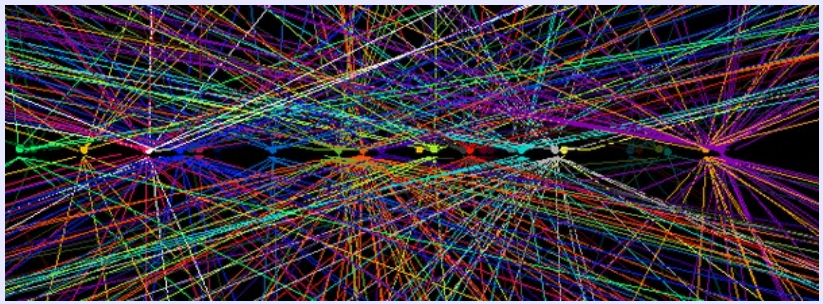
Excellent performance of accelerator and detector

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



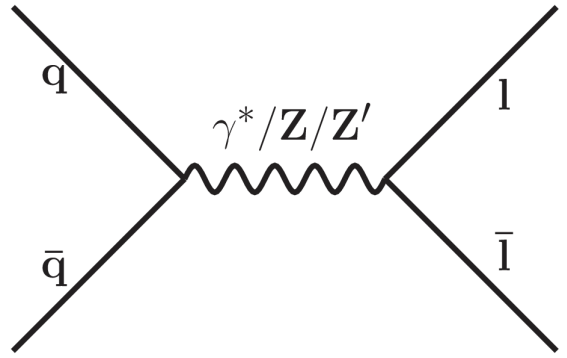
Event with 29 reconstructed vertices

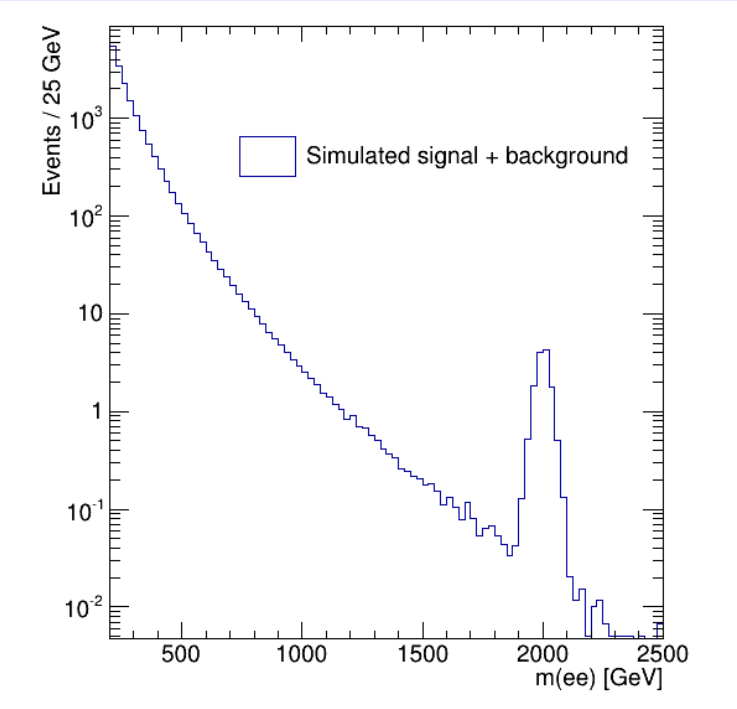
$Z' \rightarrow e^-e^+/\mu^-\mu^+$

[EXO-12-061]

Models

- Generic search for narrow peak in dilepton mass spectrum
- 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





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

Event Selection

Electron object selection

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

Electron event selection

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

→ Analysis split in 2 channels:

  - 2 barrel electrons
  - 1 barrel + 1 endcap electron

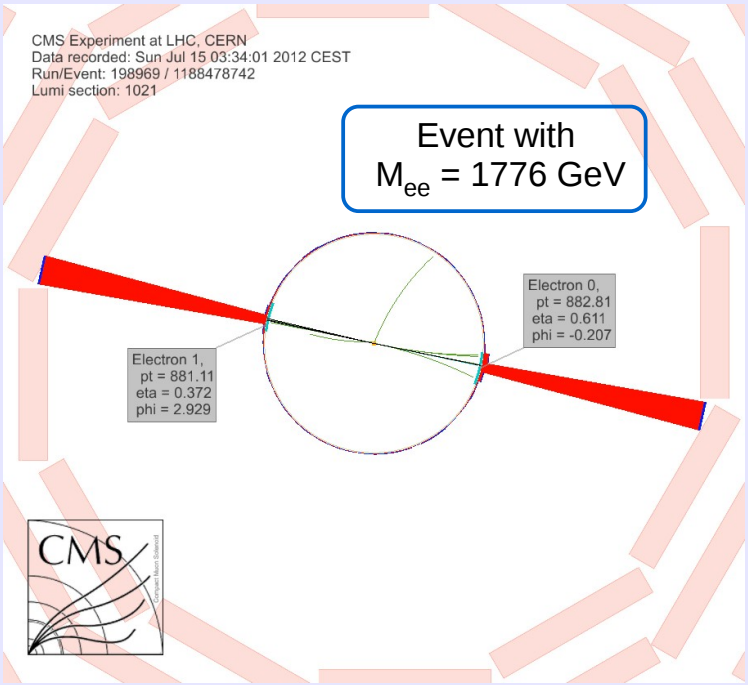
High p_T muon object selection

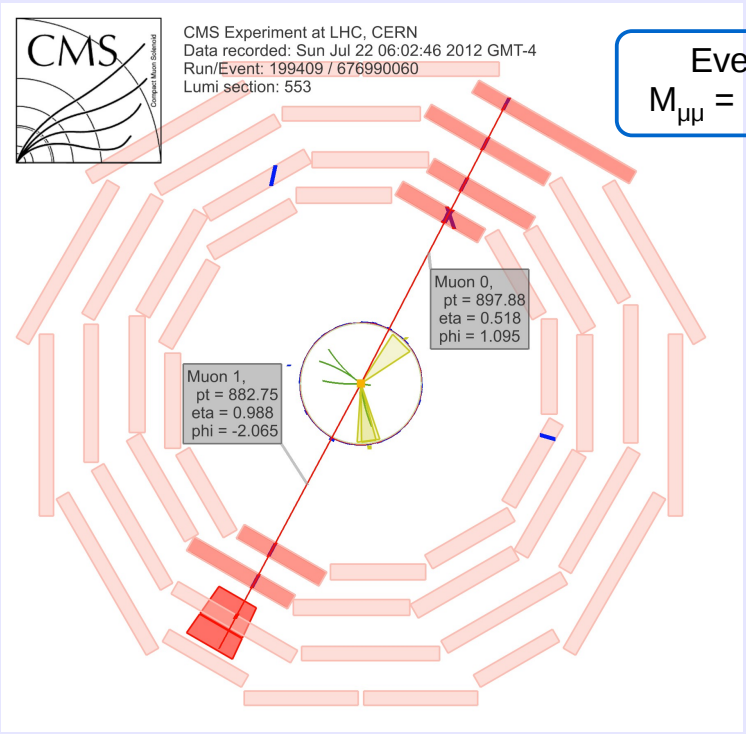
- Muon candidate reconstructed independently from tracker and from tracker+muon system
- Fitted track must include hits from pixel and strip detectors and from muon stations
- Small transverse distance to vertex
- Isolated track to reject jets
- Small relative p_T error

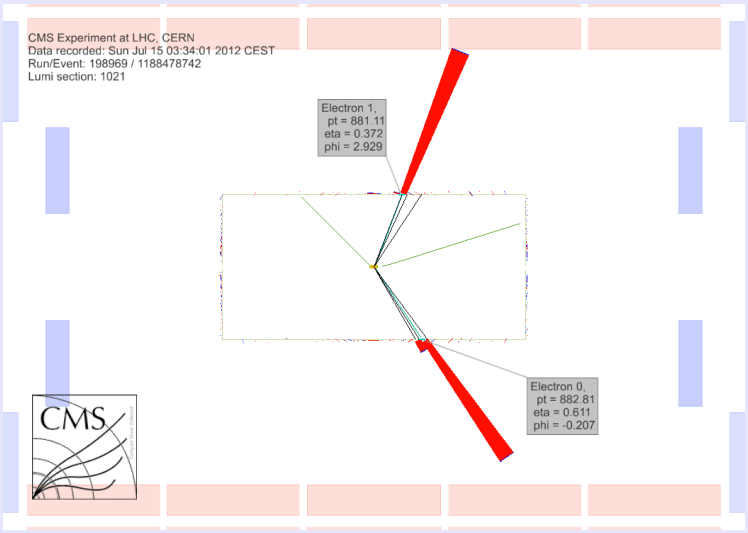
Muon event selection

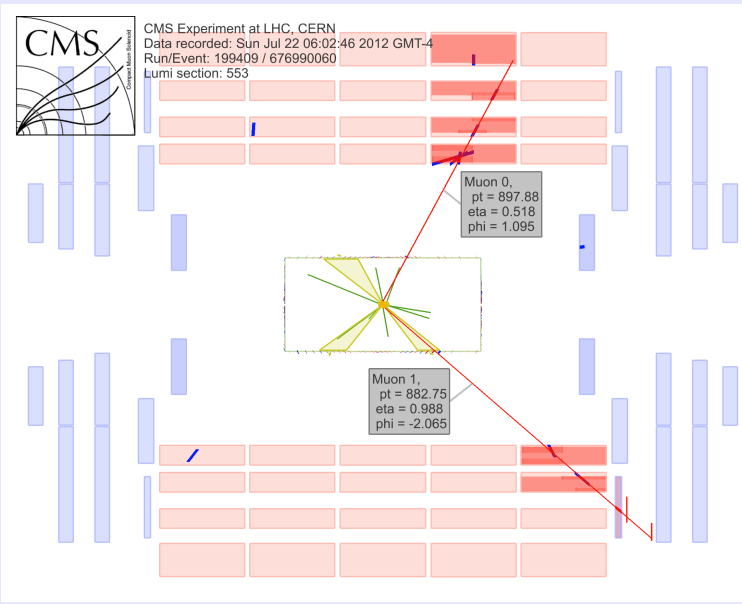
- Event triggered by a single muon trigger
- 2 muons with $p_T > 45$ GeV
  with one muon matched to trigger object
- Candidates have opposite charge and common vertex
- 3D angle between muons < π–0.02

Event Displays









Invariant Mass Spectrum

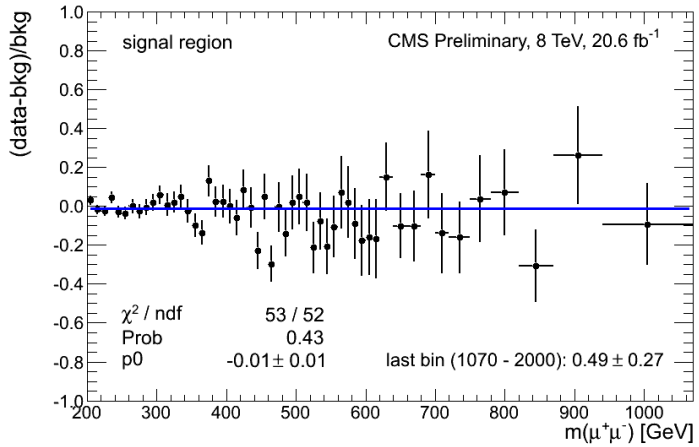
Z peak (60 Gev – 120 GeV)

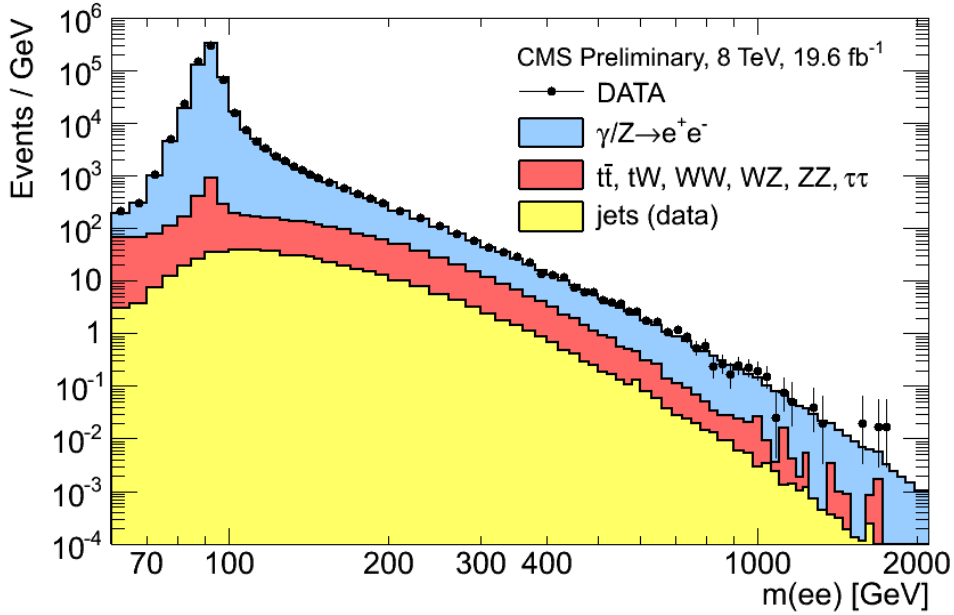
- Normalization of Monte Carlo
- Energy scale calibration
- Selection efficiency measurement and data / simulation scale factor determination with tag & probe method

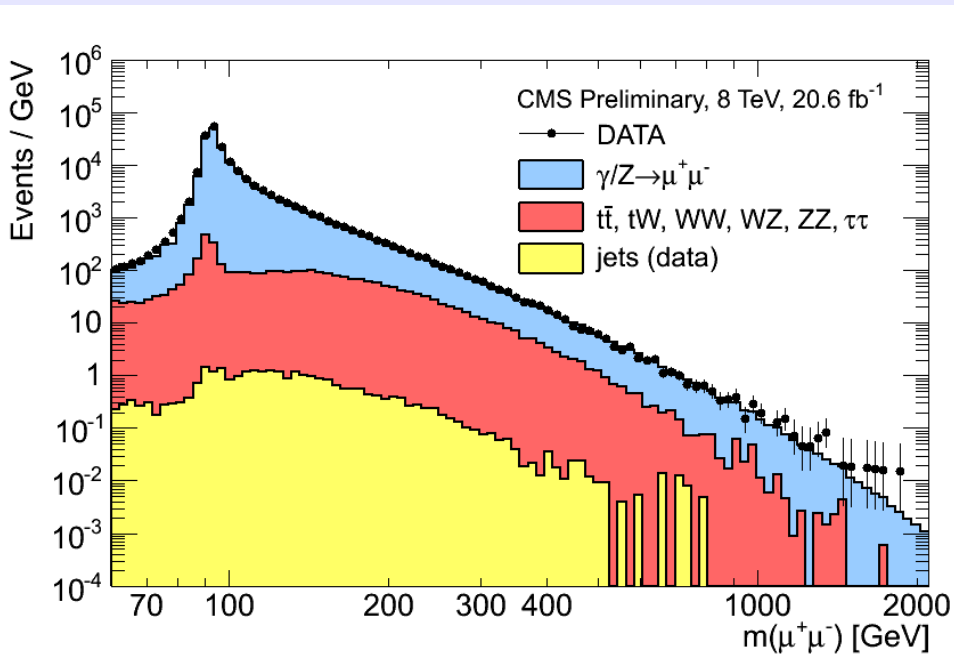
Control region (120 GeV – 200 GeV)

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

Search region (>200 GeV)

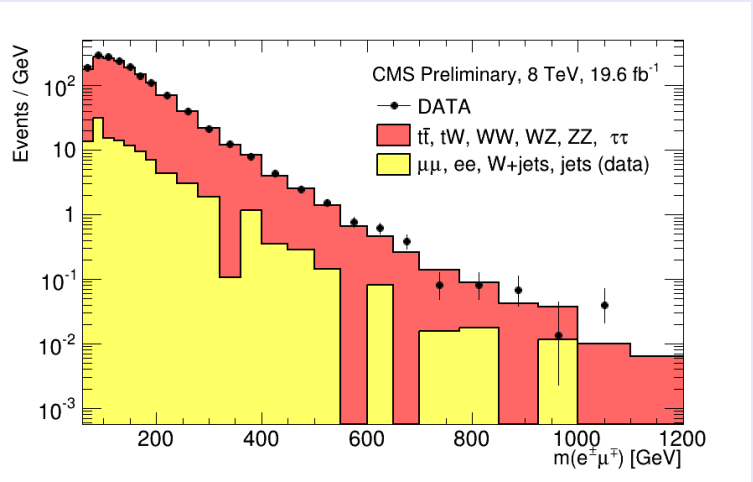






Backgrounds

- **Drell – Yan**
  - Irreducible background
  - Accounts for ~85% of the background events above the Z peak
  - Estimated from simulations and normalized 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
  - Data driven approach
- **Cosmic muons**
  - Suppressed by muon selection



Limits

Full shape based Bayesian limits

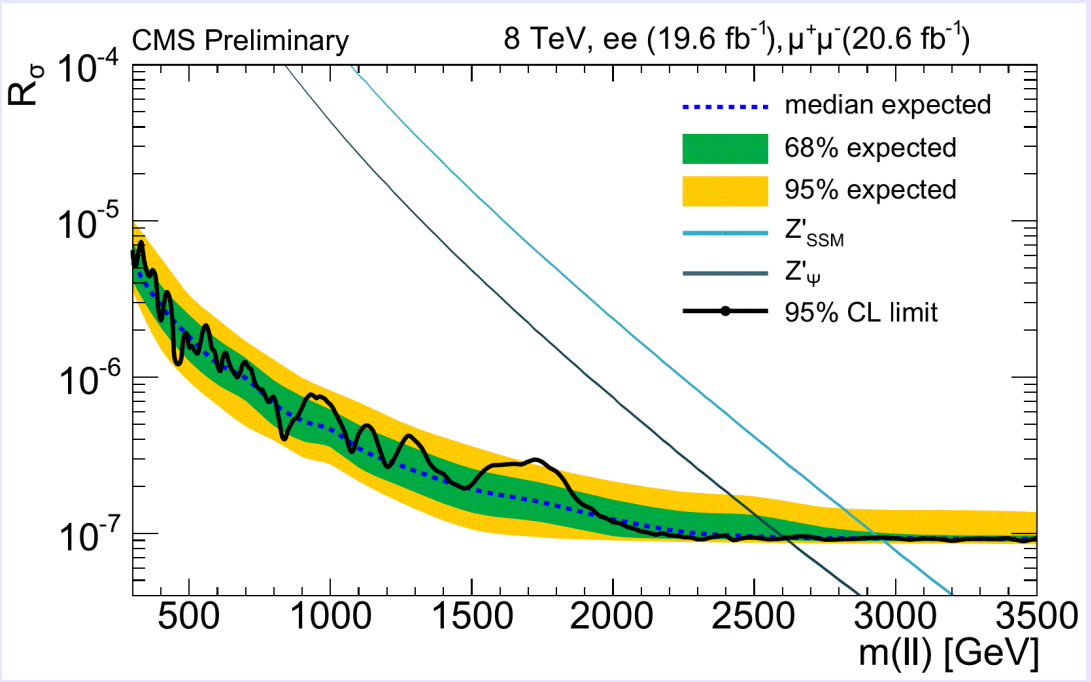
We use the ratio (R_σ) of cross section times branching ratio of a new Z' boson to the Z boson

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

Main systematics from
acceptance times efficiency (3-6%),
background fit (2-20%)

95% CL lower limits on resonance mass:

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



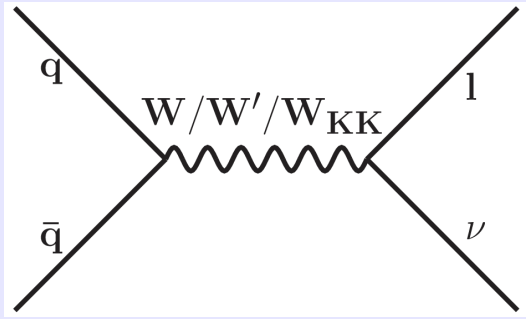
Observed and expected upper limit on R_σ plus predicted ratios for Z'_{SSM} and Z'_{ψ} from simulated events.

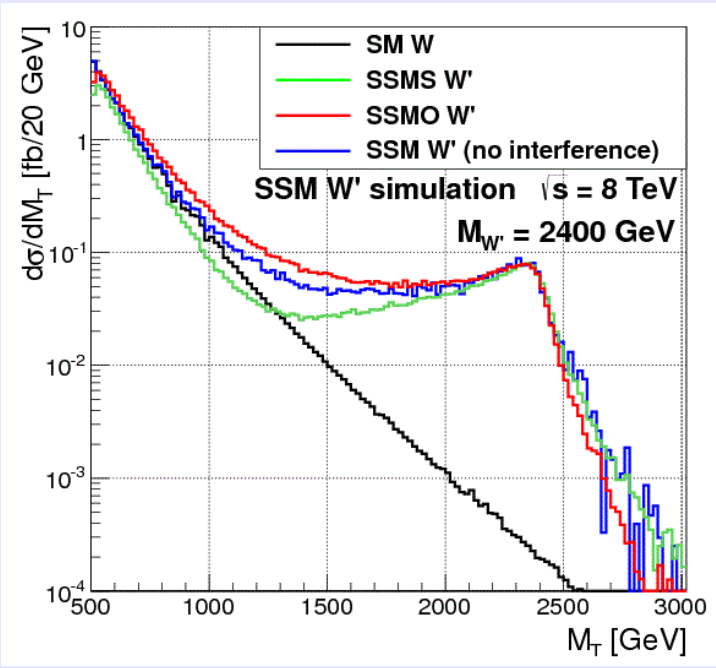
W' → eν/μν

[EXO-12-060]

Models

- W' from SSM:
  - W' is a heavy analogue of W with similar branching fractions
  - Constructive (opposite sign coupling) or destructive (same sign coupling) interference with W
- Right handed W' from left-right symmetric models
  - No interference with W
- Universal extra dimension models with bulk fermions (split-UED)
  - Extended space time with compact fifth dimension of radius R
  - Kaluza-Klein (KK) partners for all SM particles
  - Only even KK modes of W^n_{KK} couple to fermions
  - Only n=2 accessible by LHC
  - Decay kinematically identical with SSM like W'





Search for a **Jacobian peak** in the falling M_T distribution of the standard model

Event Selection

Lepton selection

- Same electron selection as for Z'
- Base muon selection same as for Z'
  - Tighter cut on distance of muon track to vertex

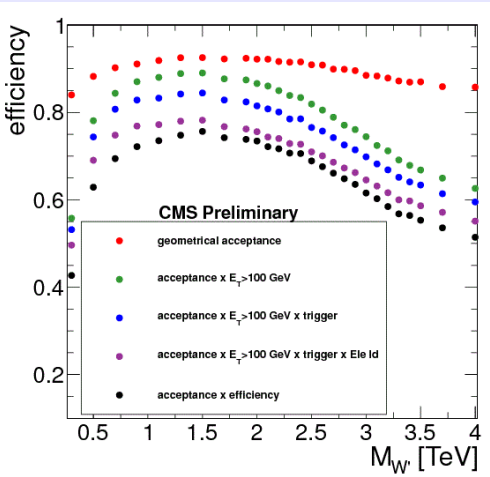
Missing transverse energy (E_T^{miss})

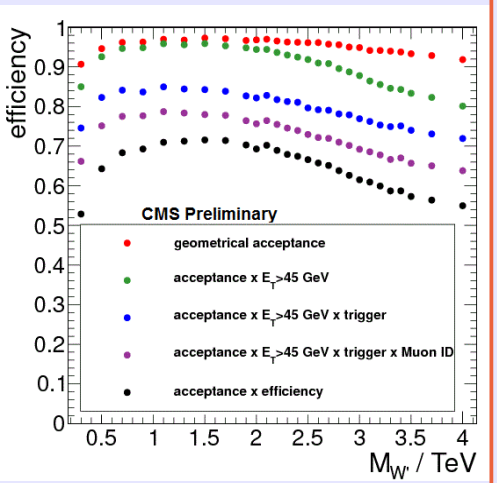
- Measured with particle flow algorithm
  - Complete list of particles reconstructed using all subdetectors
- Opposite of transverse momentum vectorial sum of all reconstructed particles defines missing transverse energy

$$M_{\mathrm{T}} = \sqrt{2 \cdot p_{\mathrm{T}}^{\ell} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

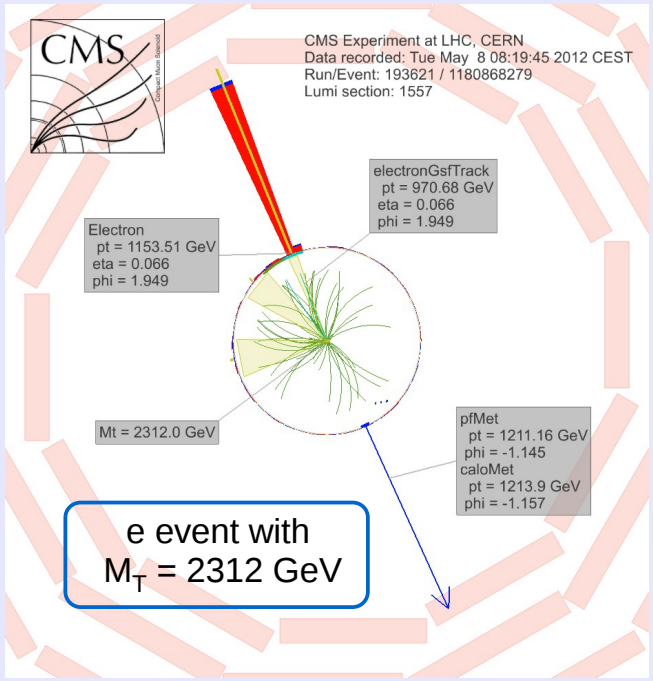
Event selection

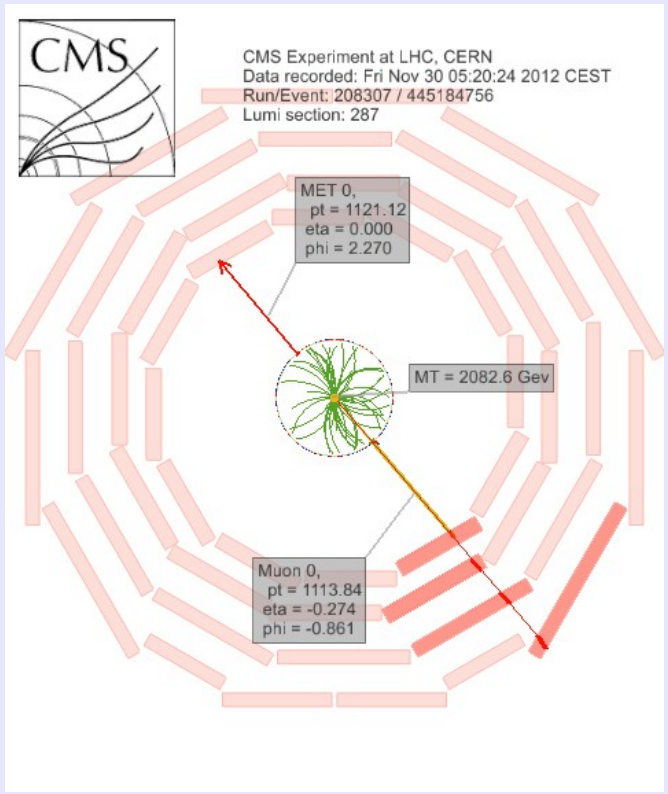
- Exactly 1 electron candidate with $E_T > 100$ GeV, selected by single electron trigger
- Or exactly 1 muon candidate with $p_T > 45$ GeV, selected by single muon trigger
  - No second muon above $p_T > 25$ GeV
- Additional kinematic cuts:
  - $0.4 < p_T / E_T^{miss} < 1.5$
  - angular difference between lepton and E_t^{miss} $\Delta\varphi_{l,\nu} > 0.8\pi$

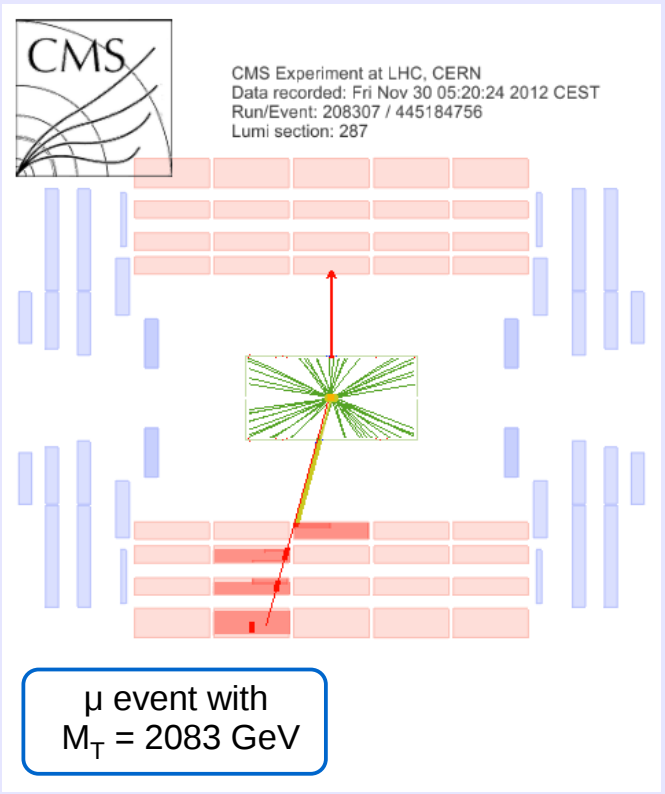


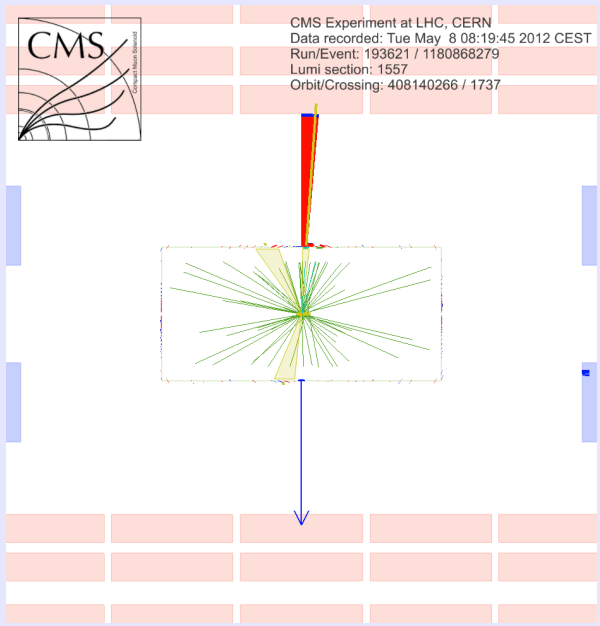


Event Displays

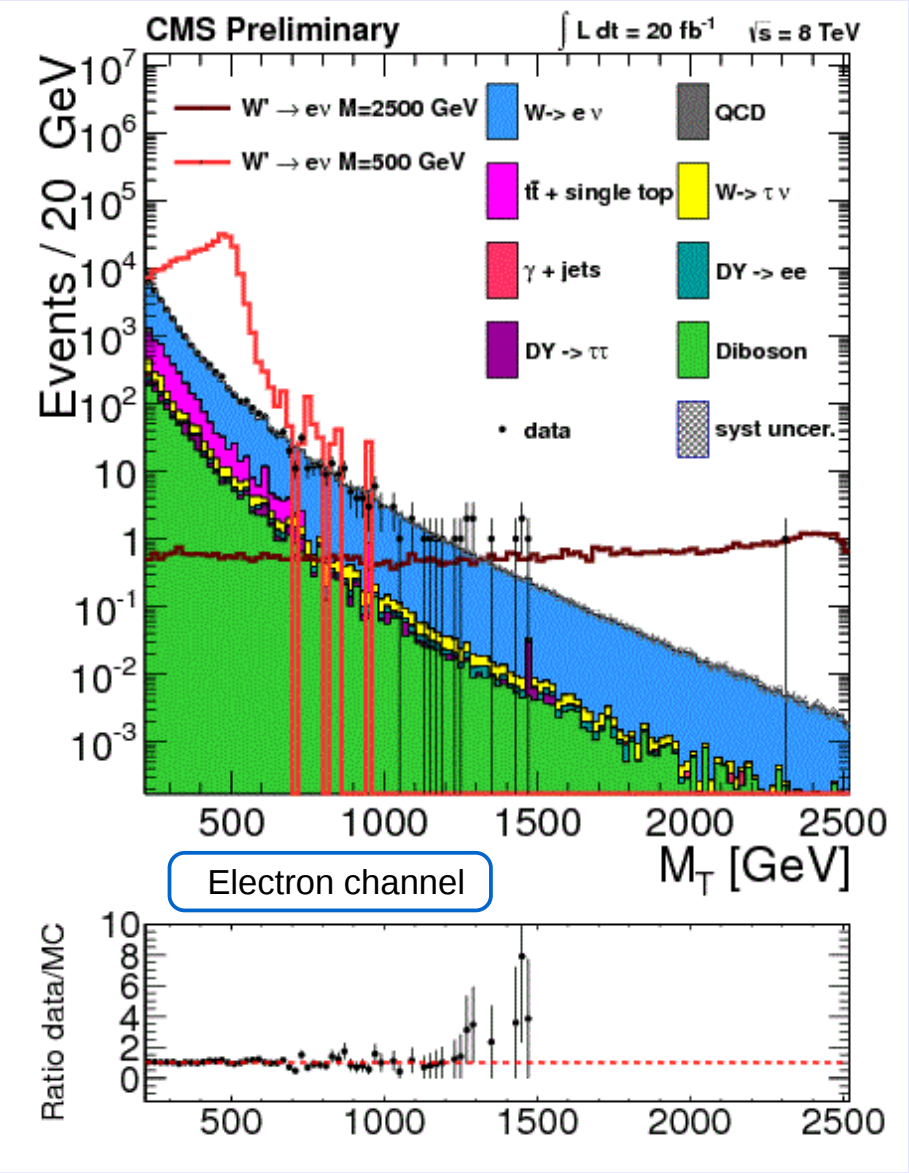


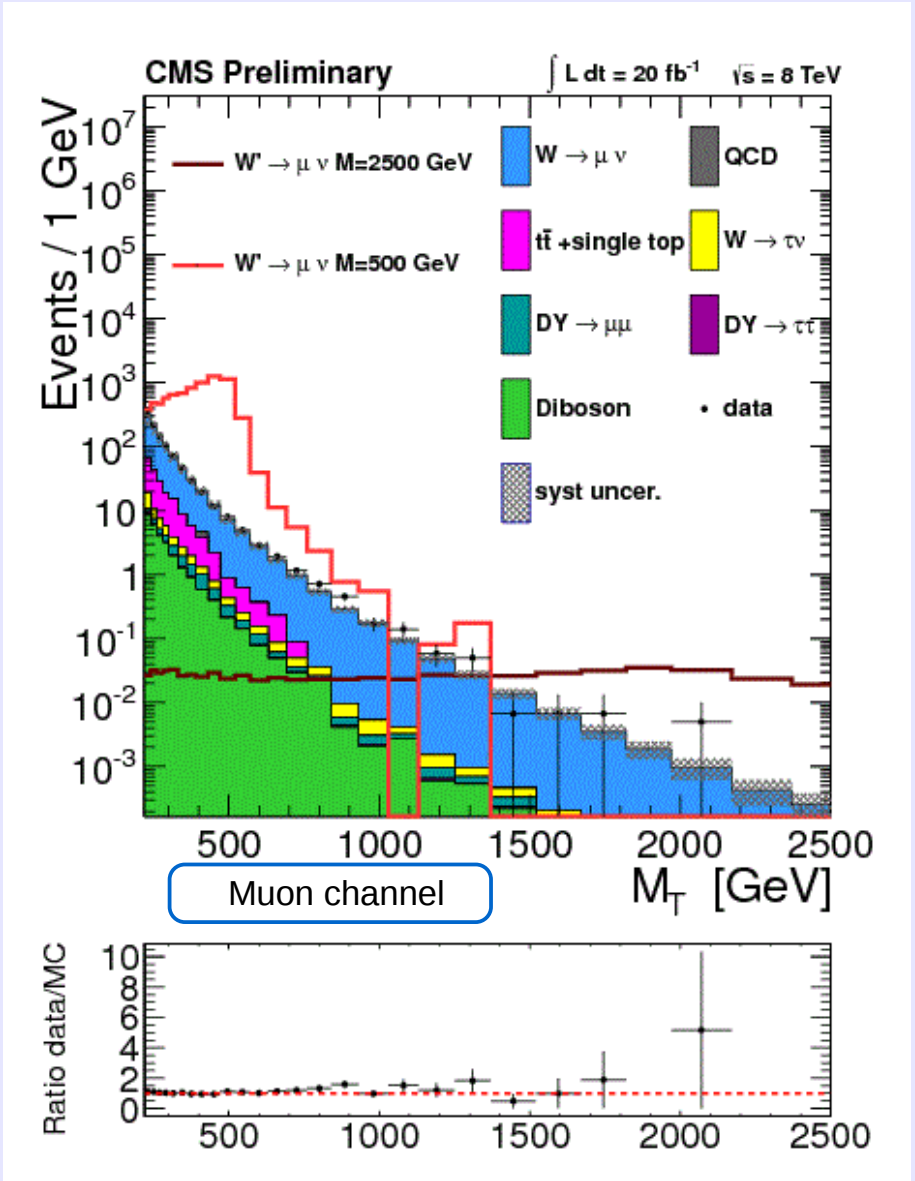






M_T Spectrum


CMS Preliminary
∫ L dt = 20 fb⁻¹ √s = 8 TeV
W' → eν M=2500 GeV
W' → eν M=500 GeV
W-> e ν
tt̄ + single top
γ + jets
DY -> ττ
data
QCD
W-> τ ν
DY -> ee
Diboson
syst uncer.
Events / 20 GeV
M_T [GeV]
Ratio data/MC
Electron channel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data
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W → τν
DY → ττ
Events / 1 GeV
M_T [GeV]
Ratio data/MC
Muon channel

Backgrounds

➔ All background estimated from simulation with data / simulation scale factors measured with tag & probe method

- **W → lν** is the irreducible background

  W → τν, where τ decays to e or μ suppressed by branching fraction

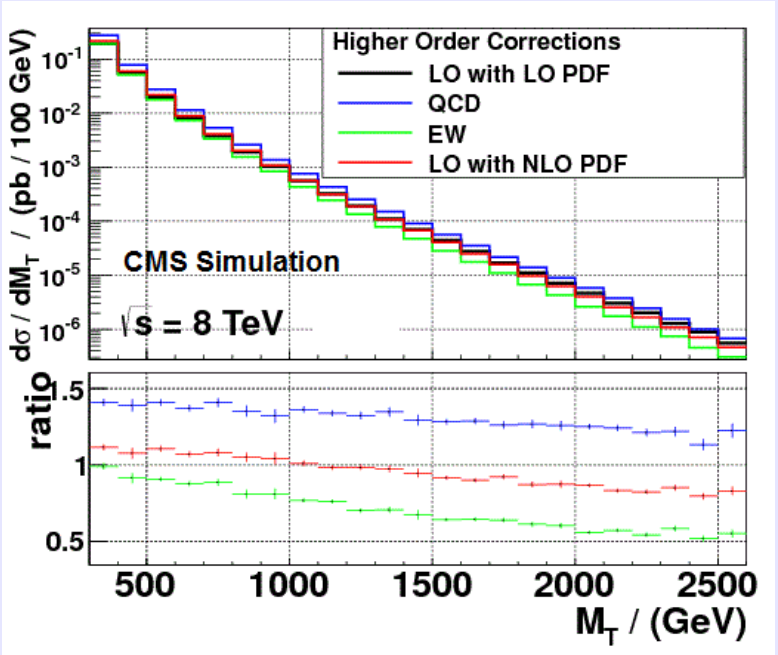
- $t\bar{t}$, single top, diboson, Drell-Yan and QCD multijet events largely rejected by selection

- Cosmic muons suppressed by muon selection

- Mass dependent K factors for W to account for NLO QCD and electroweak corrections

- Background is parametrised by an empirical function

$$f(M_{\mathrm{T}}) = \frac{a}{(M_{\mathrm{T}}^3 + bM_{\mathrm{T}} + c)^d}$$



Limits

Bayesian multiple bin counting method with uniform prior for signal

Systematic uncertainties included as nuisance parameters with log-normal prior

Upper limits on production cross section times branching fraction

95% CL lower limits on resonance mass:

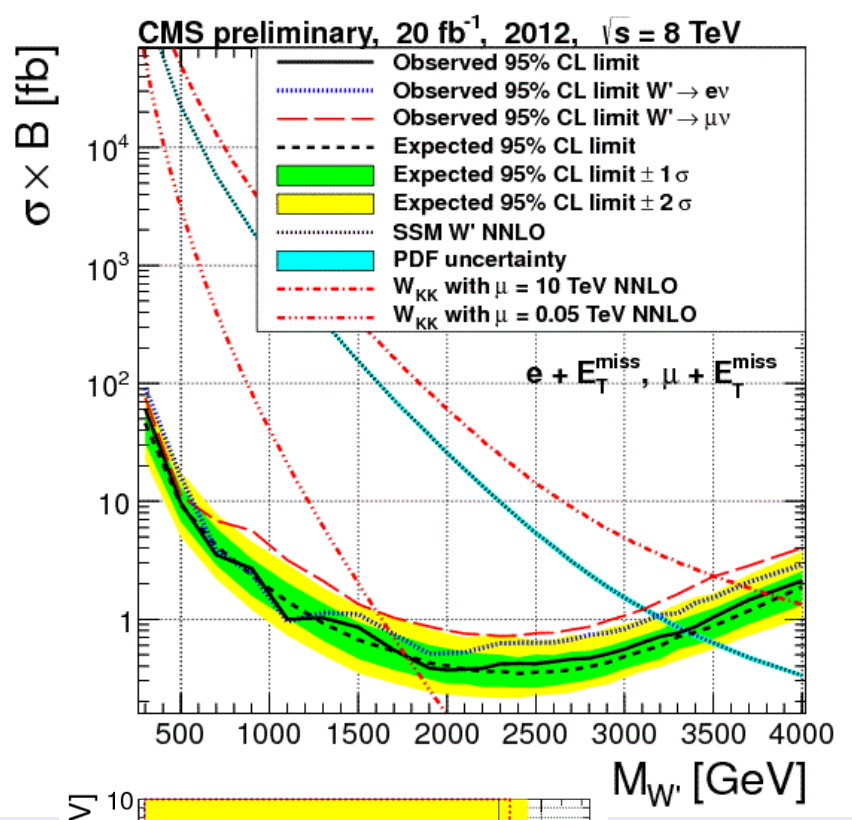
- Non interfering W'_{SSM}:

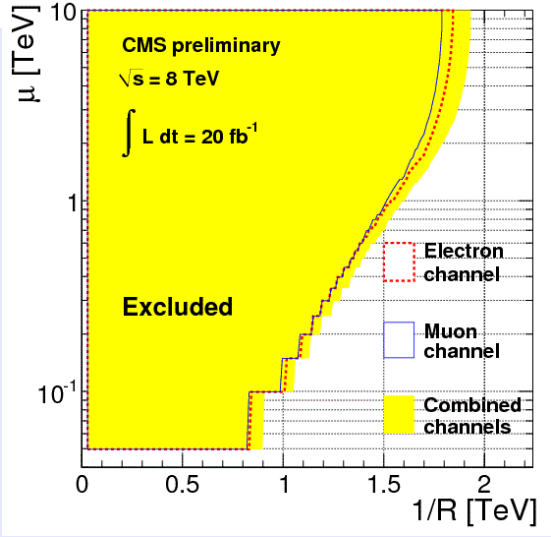
  observed(expected)

  electron: 3.20(3.25) TeV
  muon: 3.15(3.10) TeV
  combined: 3.35(3.40) TeV

- W_{KK} with different fermion bulk mass parameter μ:

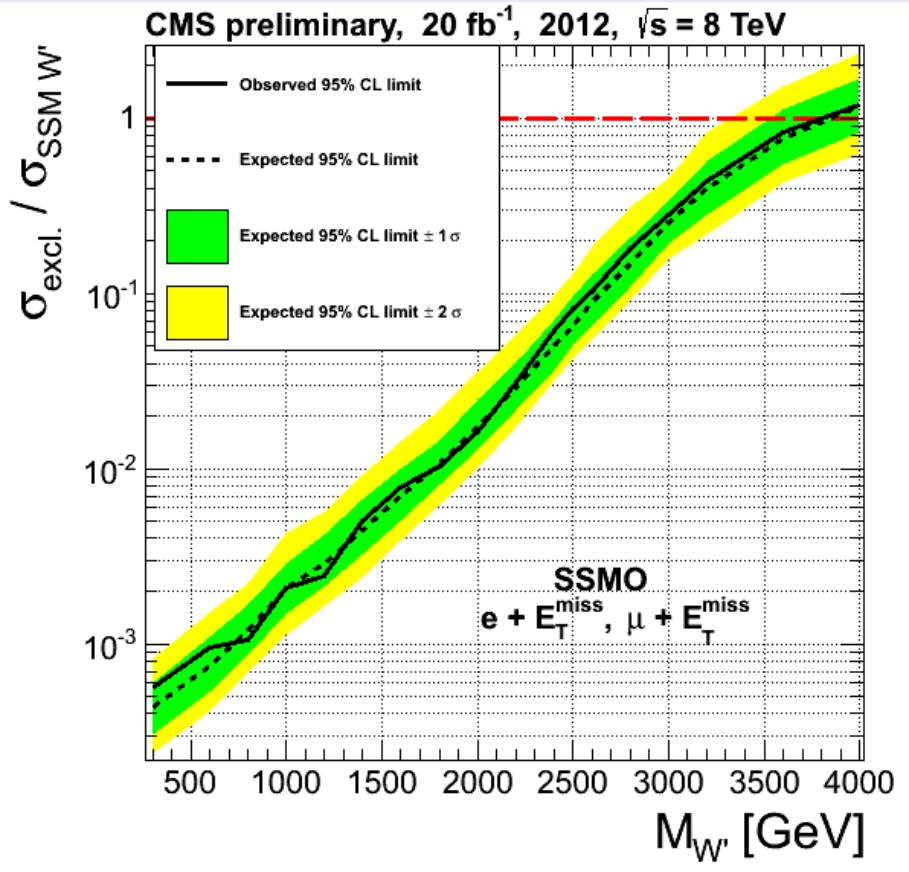
  μ=0.05TeV: 1.7(1.7) TeV
  μ=10.0TeV: 3.7(3.6) TeV

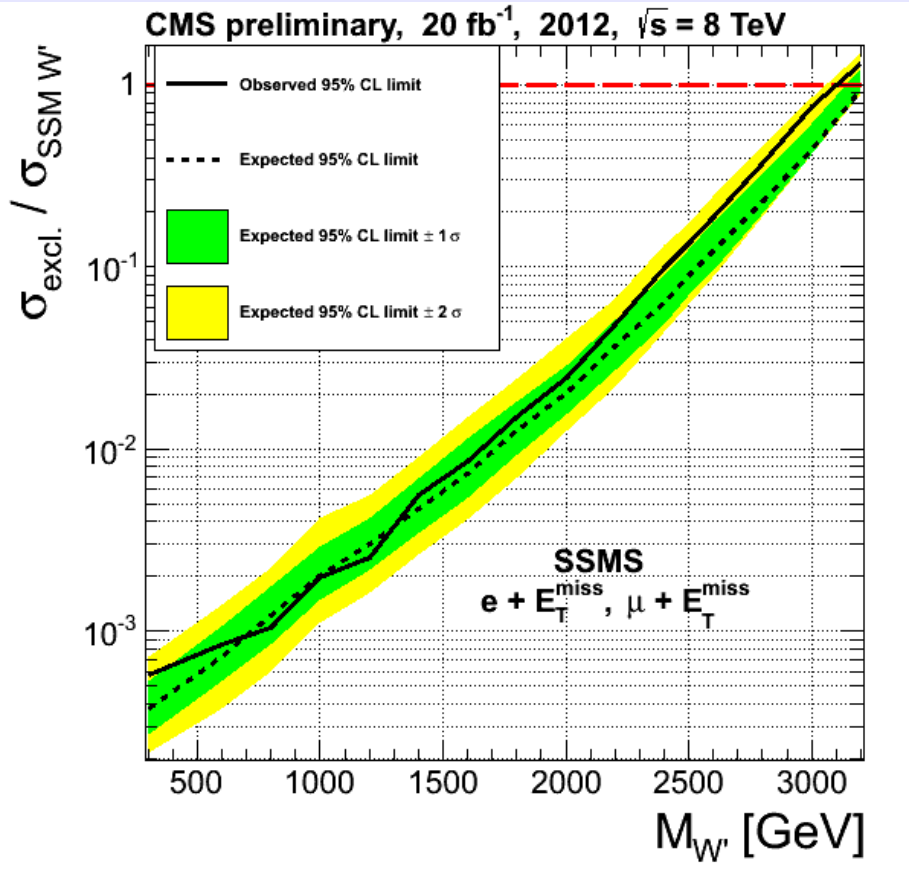




Limits with W-W' Interference

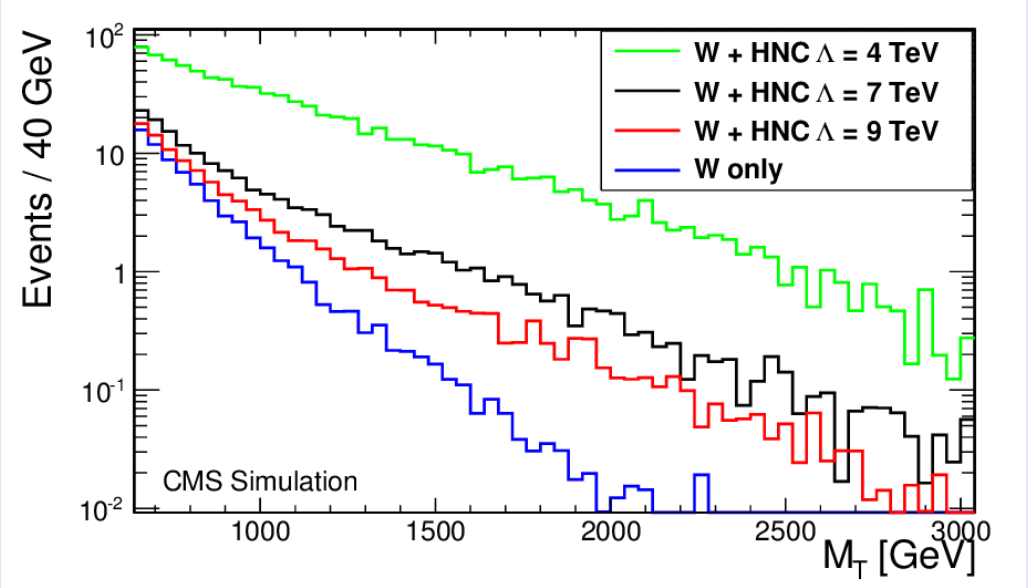
- Difference $\Delta\sigma$ in M_T spectrum between W-W' signal sample and W-only sample is considered
- Opposite sign couplings (SSMO) increase W' mass limit. $M_{W'} > 3.60(3.60)$ TeV
- Same sign couplings (SSMS) decrease W' mass limit. $M_{W'} > 3.10(3.20)$ TeV

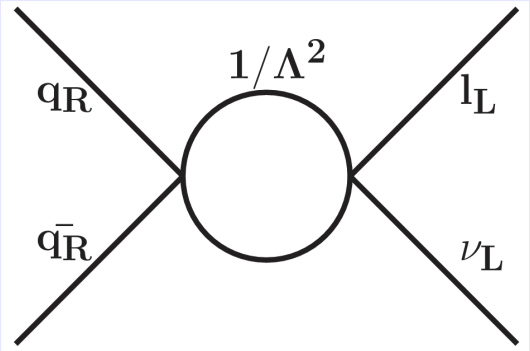




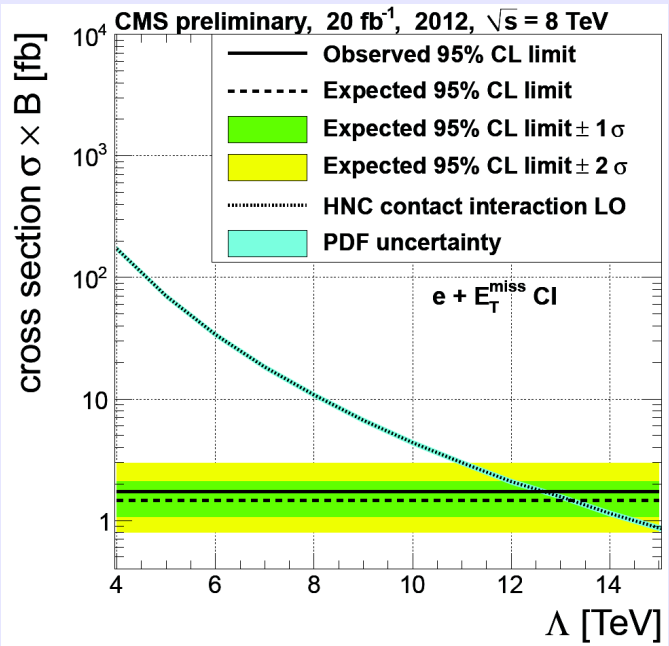
Contact Interaction Model

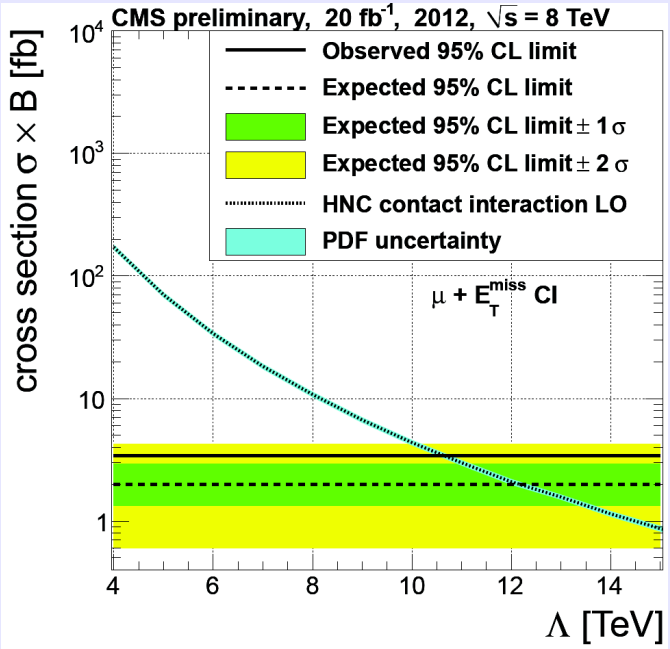
- Reinterpretation as 4-fermion contact interaction (CI) model
- Helicity non-conserving, non-resonant model
- Limit on binding energy scale Λ
- Bayesian limits with uniform prior





Observed(expected) limits
Electron channel:
Λ > 13.0(13.3) TeV
Muon channel:
Λ > 10.9(12.2) TeV





Summary

- Search for new massive resonances is theoretically well motivated
- 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 various models for Z' and W' bosons

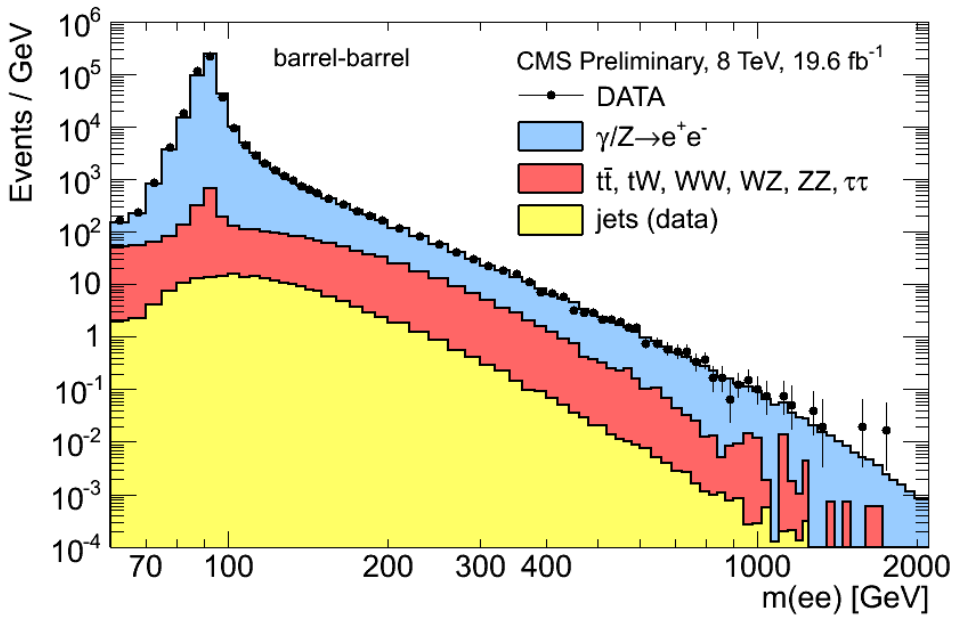
$M_{Z'SSM} > 2.96$ TeV $M_{W'SSM} > 3.35$ TeV

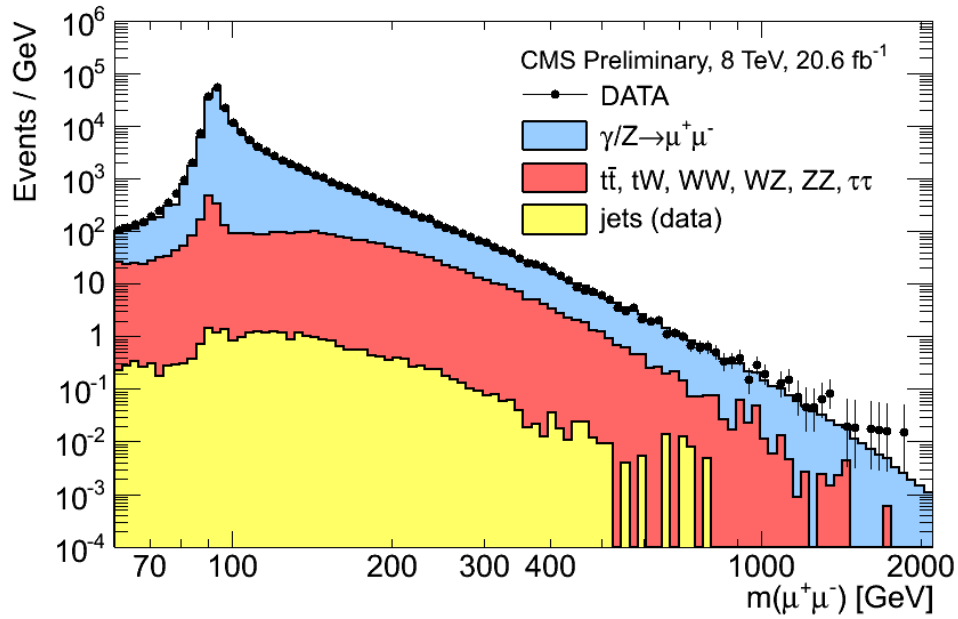
- Anticipating higher collision energy in 2015

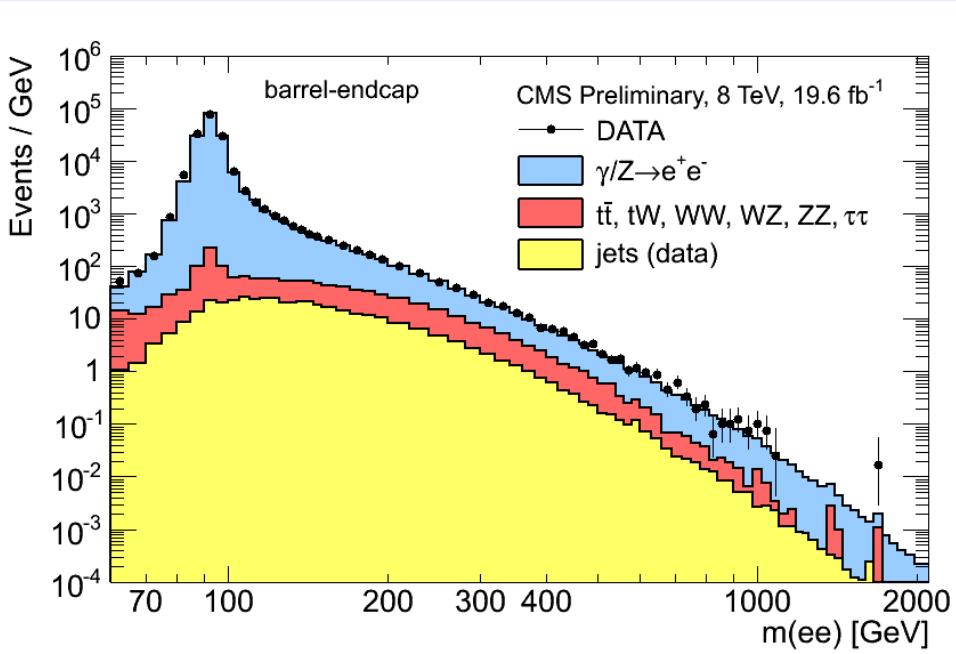
Thank you.

Additional Slides

Invariant Mass Spectra



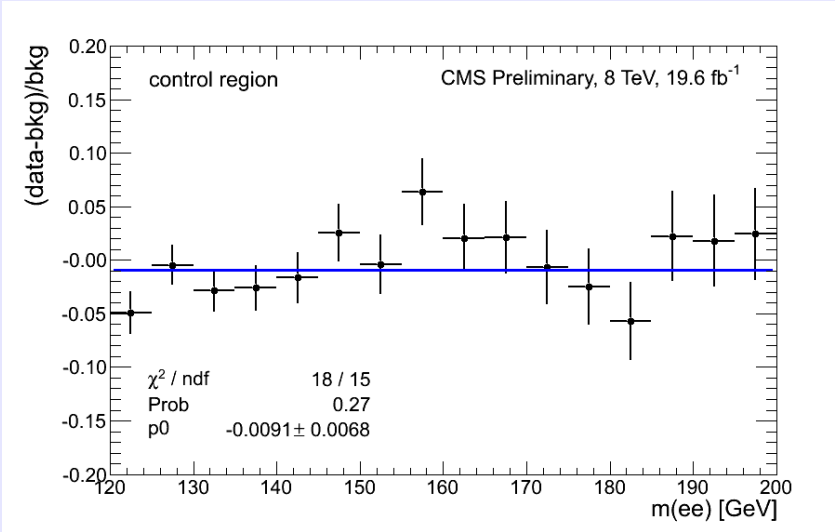


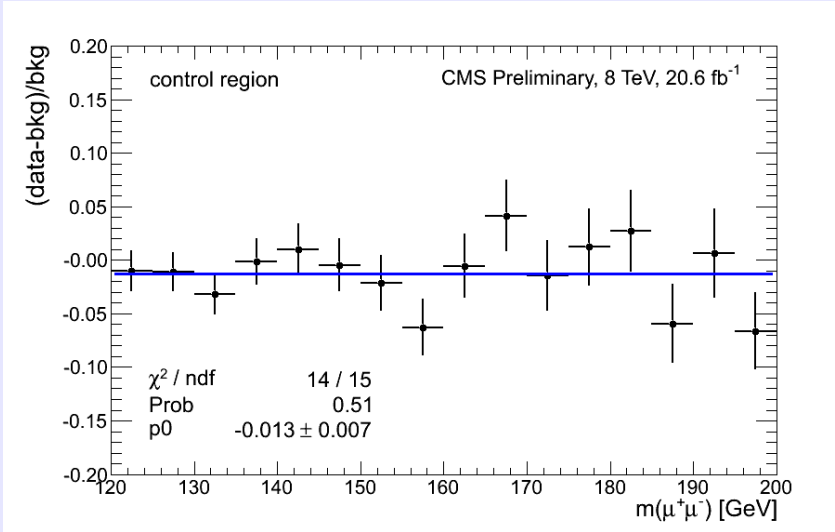


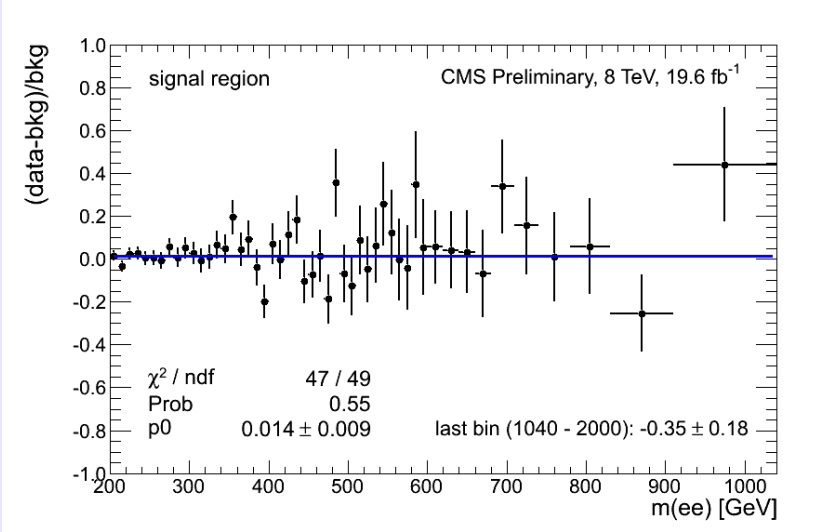
Cross section measurement in the range 60 – 120 GeV

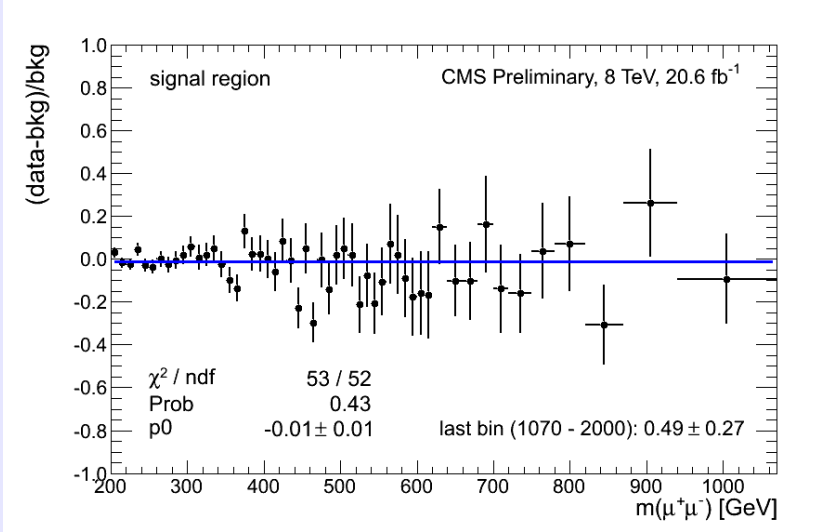
- Theory NNLO cross section: 1117 pb
- μμ: 1103±7(stat)±48(lumi) pb
- ee barrel-barrel: 1099±1(stat)±48(lumi) pb
- ee barrel-endcap: 1063±1(stat)±48(lumi) pb

Data / MC Ratio

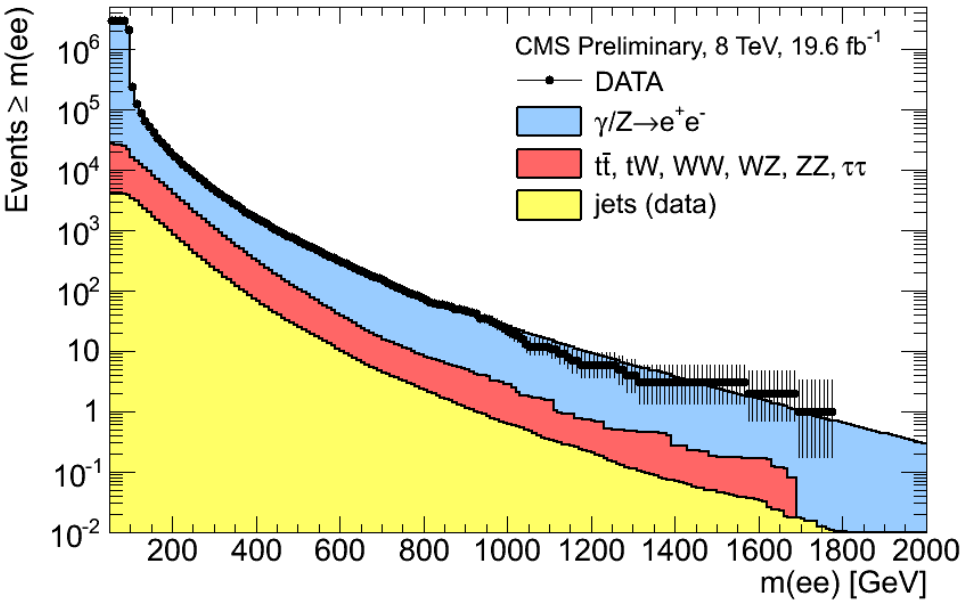


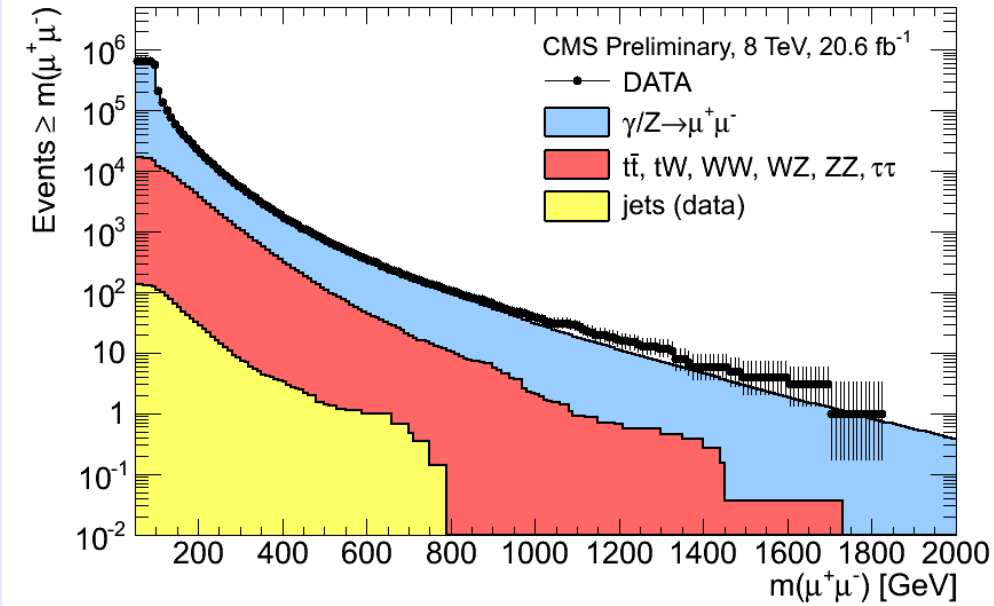




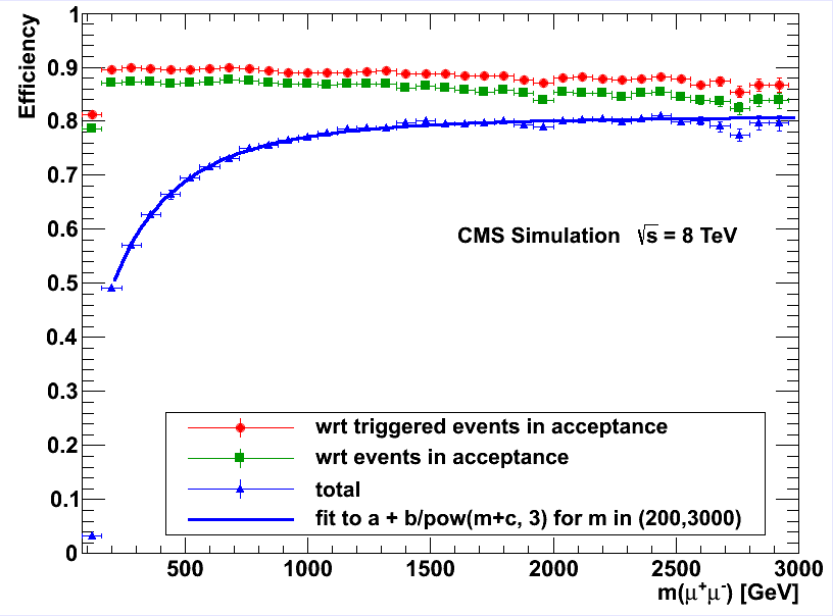


Cumulative Invariant Mass Spectra

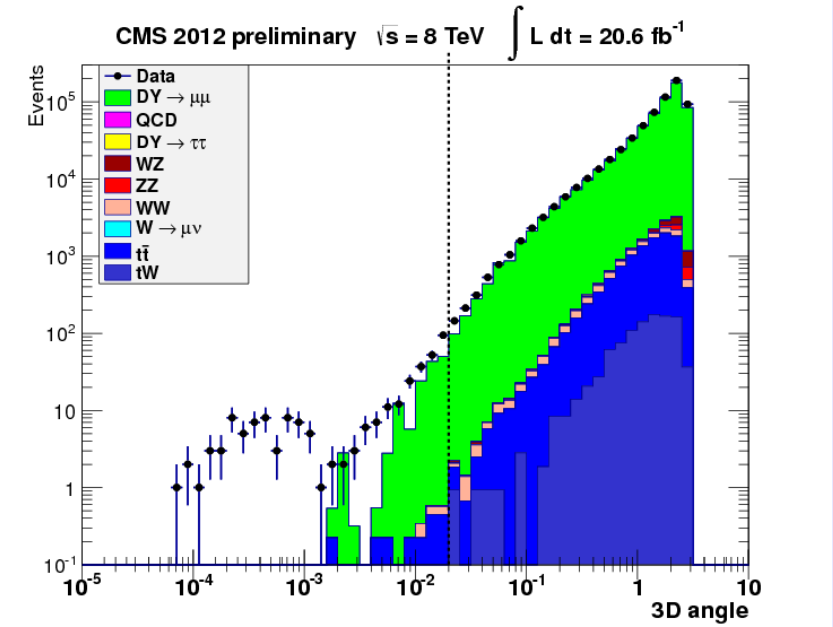




Additional Muon Plots



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

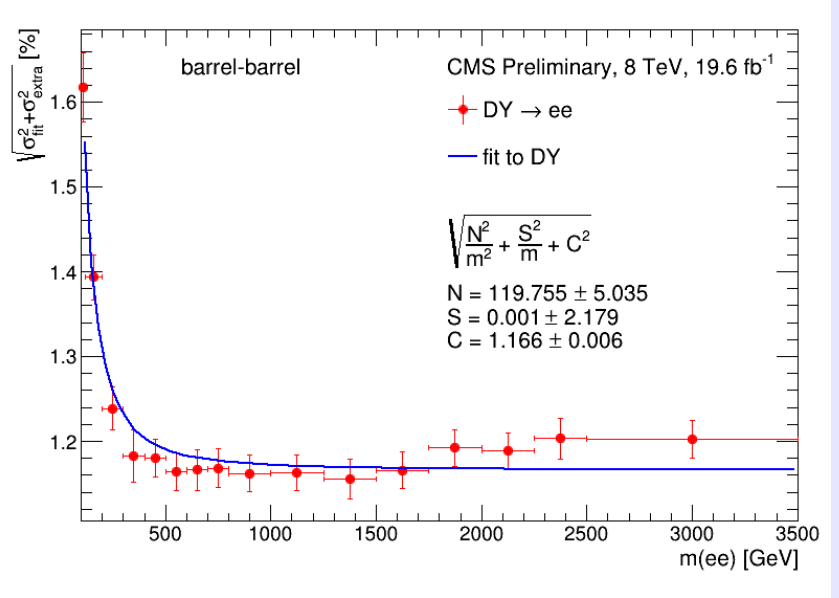


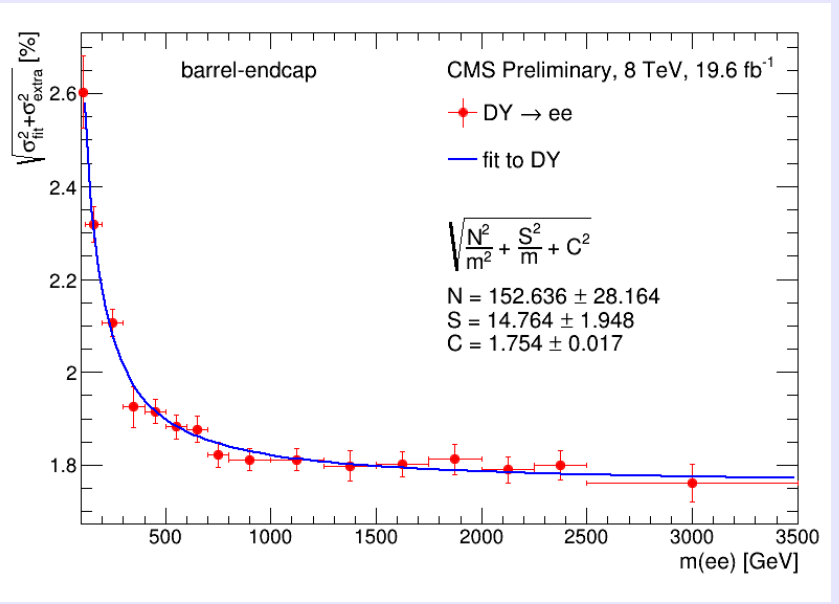
3D angle between the muons for muons passing all selection cuts except the 3D angle cut and the requirement of a primary vertex

Electron Mass Resolution

High mass resolution:

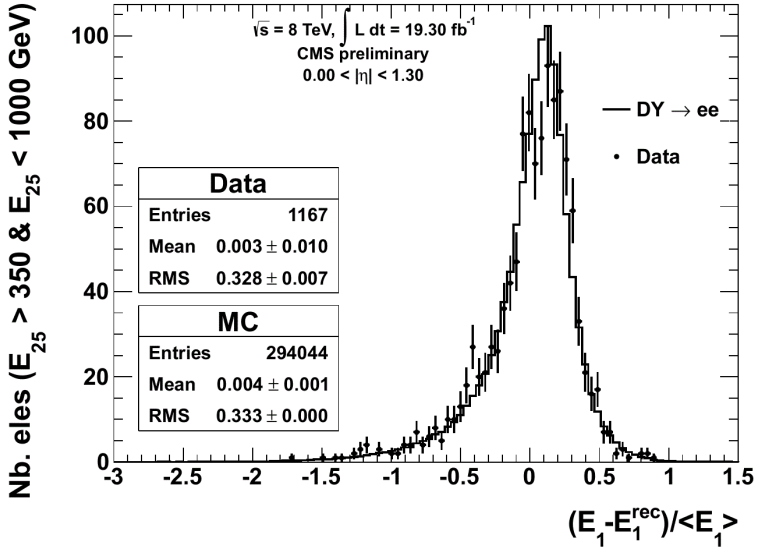
- Width of the fit of a double sided Crystal Ball function to $m_{RECO} - m_{true}$ from Drell-Yan samples
- Correction with extra smearing from width difference of data and MC at the Z peak
- Resolution reaches plateau of ~1.2% above 1TeV
- Cross check with Z' signal MC samples

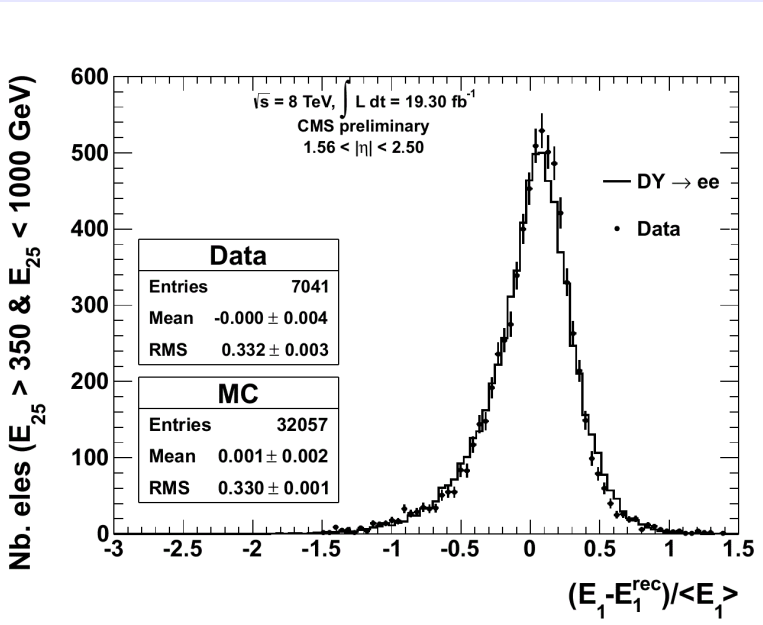




ECAL High Energy Response

- 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})

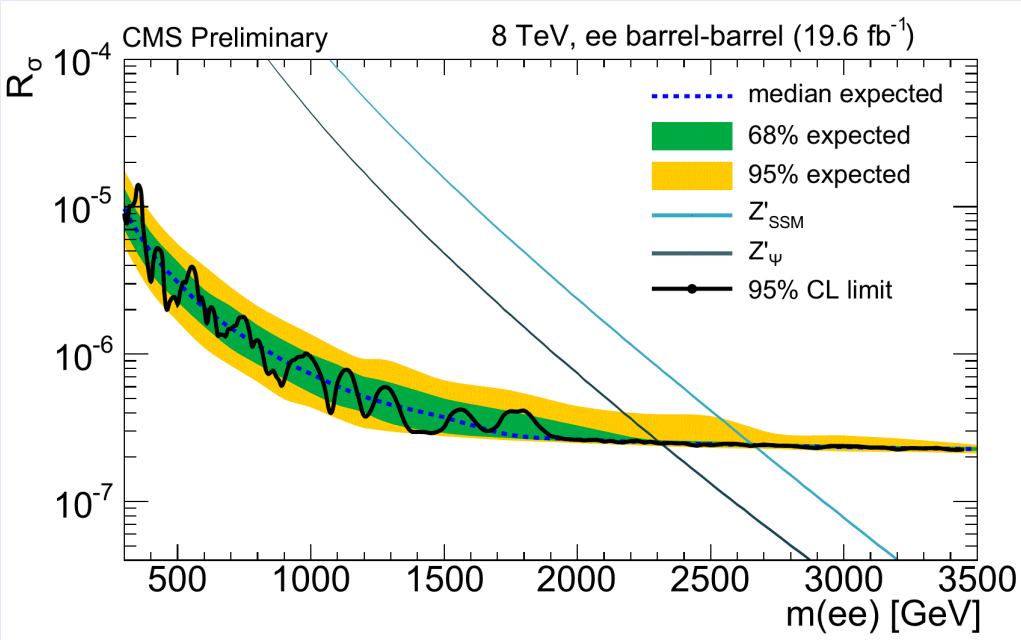


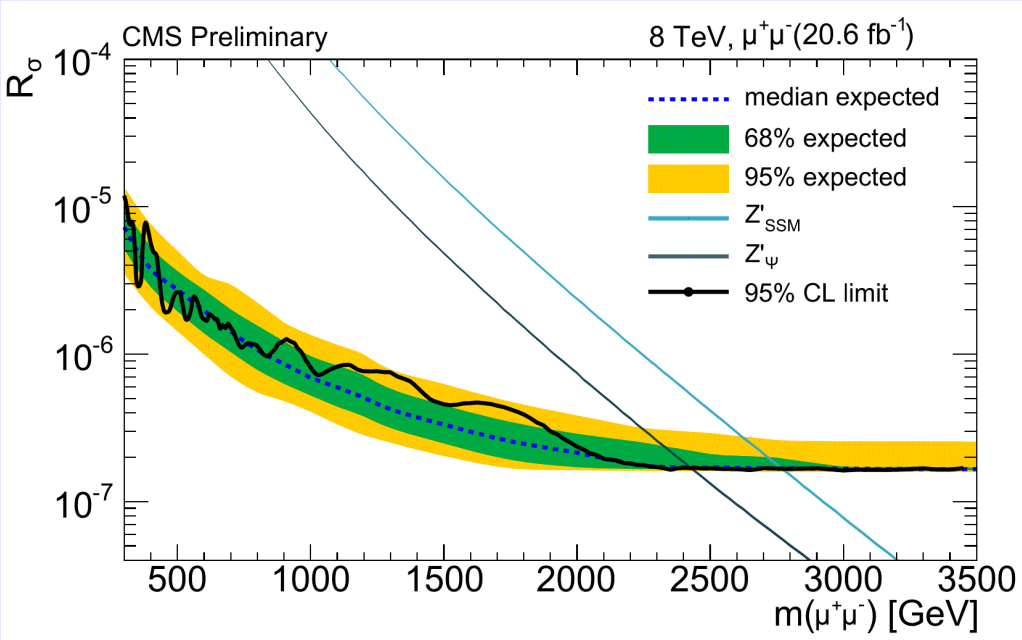


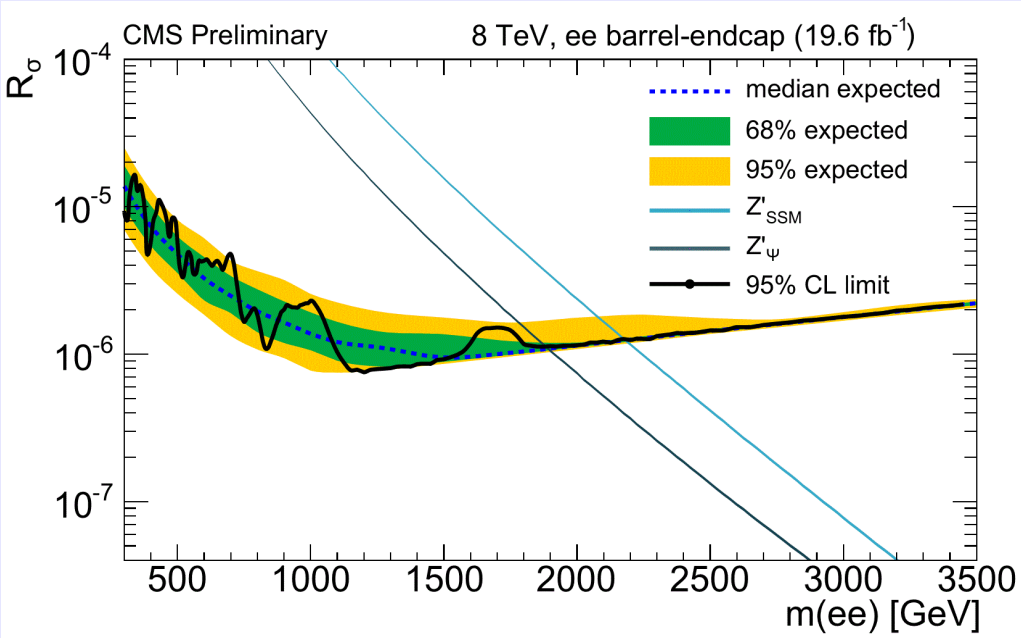
Z' Systematics

- 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 per Channel





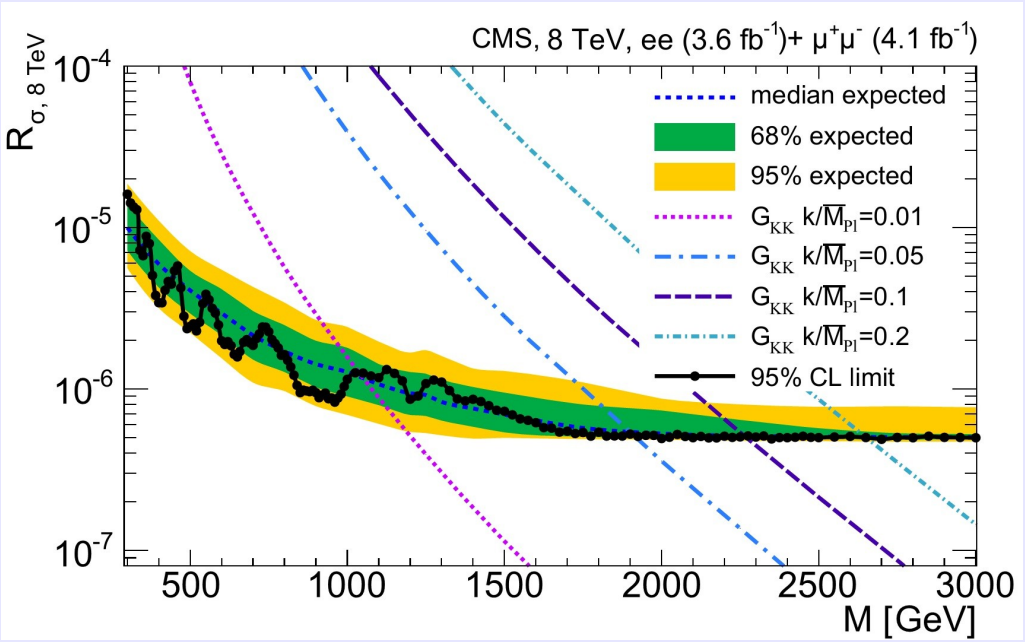


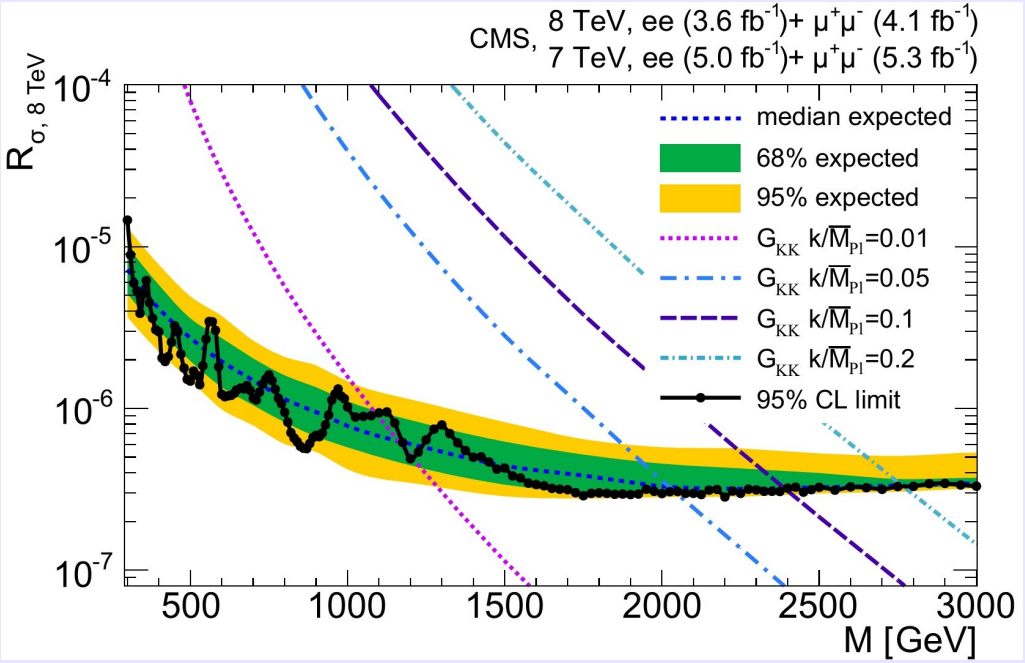
Electron channel barrel-barrel:
- Z'_{SSM}: 2.65 TeV
- Z'_{ψ}: 2.31 TeV

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

Limits with W-W' Interference

Observed(expected) limits

Electron channel:

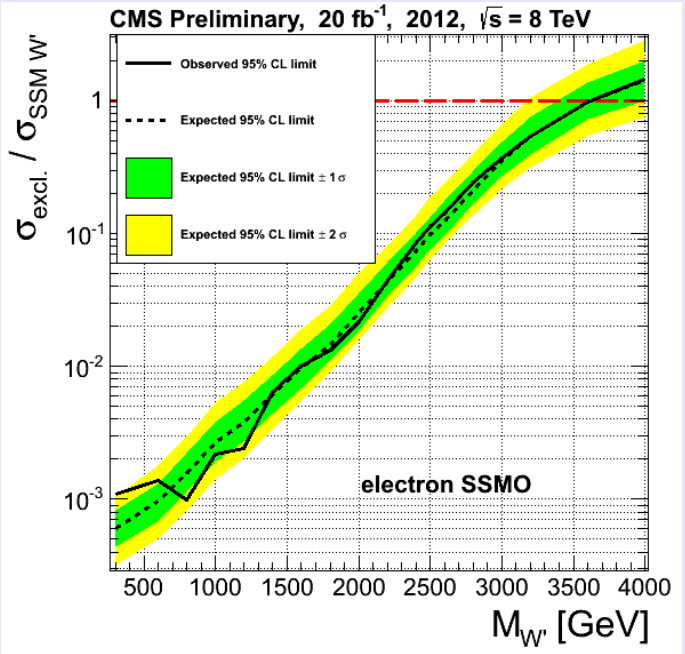
SSMO: 3.60(3.60) TeV

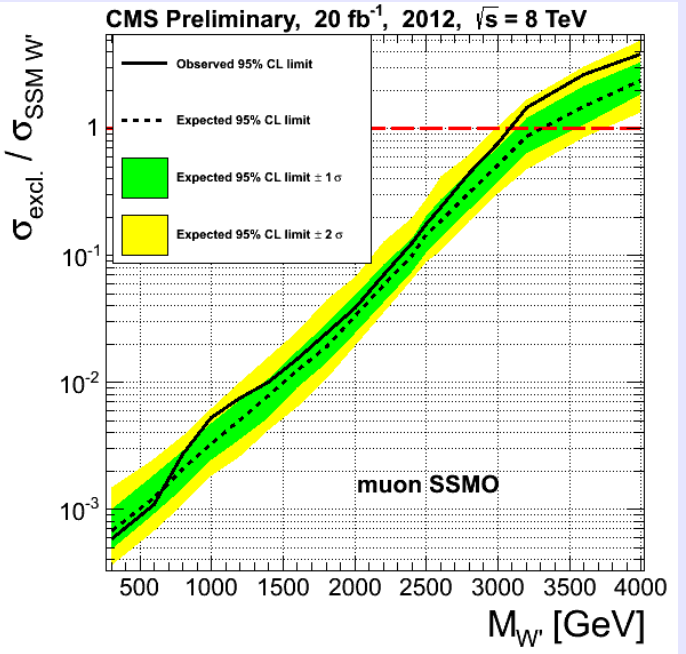
SSMS: 3.00(3.10) TeV

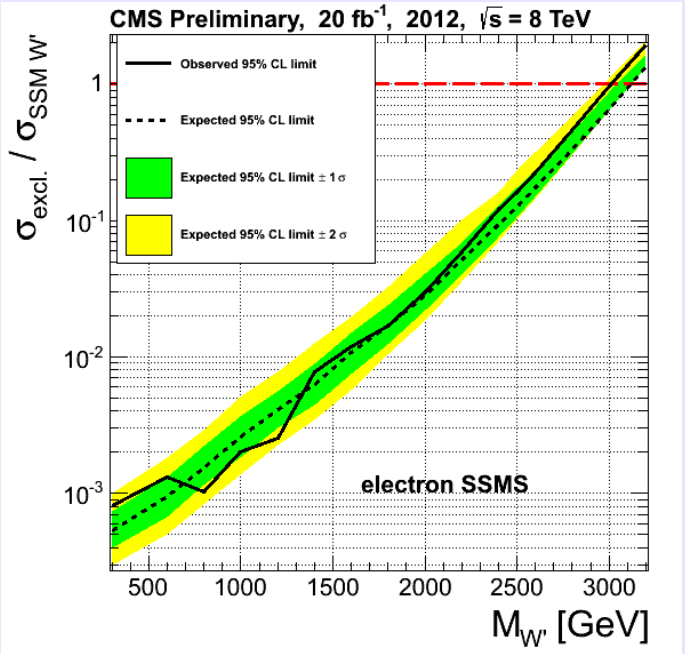
Muon channel:

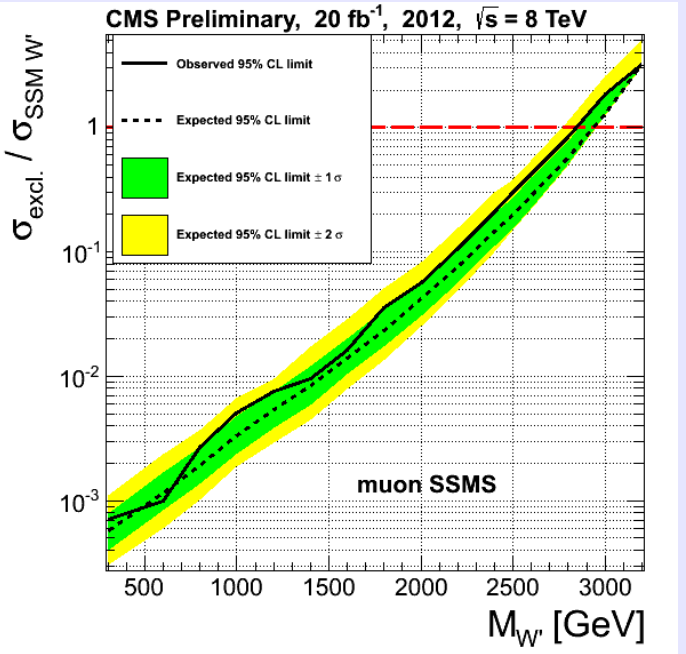
SSMO: 3.05(3.30) TeV

SSMS: 2.80(2.90) TeV





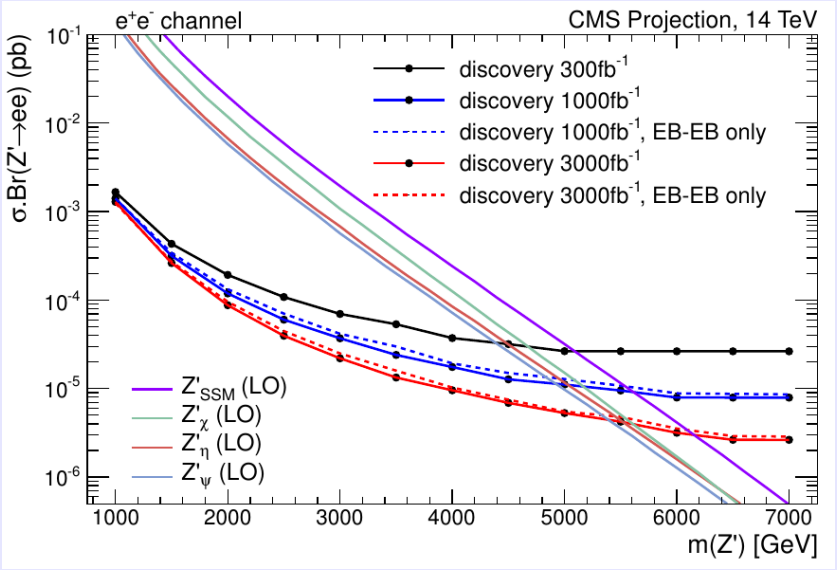


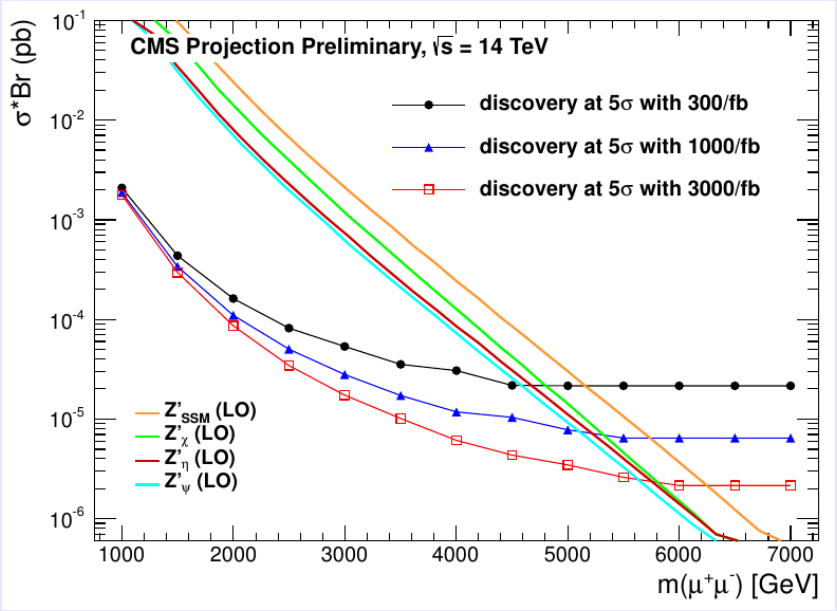


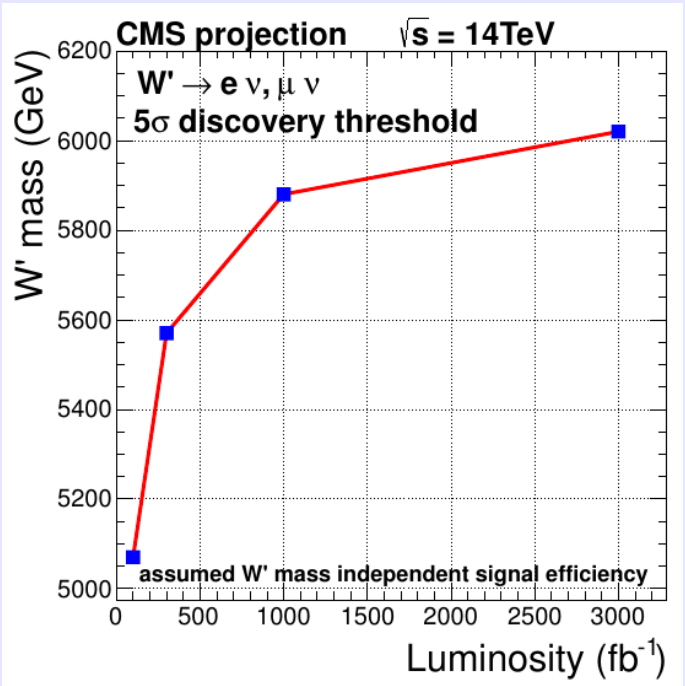
W' Systematics

- Dominant uncertainty electron channel: Electron energy scale
- Dominant uncertainty muon channel: Muon transverse momentum scale
- Uncertainties due to lepton energy or momentum resolution and scale: 1-10%
- Luminosity uncertainty: 4.4%

Projections for Higher Energies







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

Ref: arXiv:1307.7135