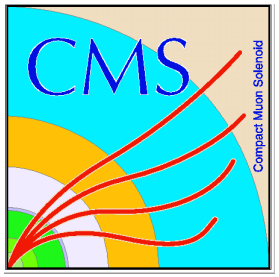



# Search for massive resonances in the dilepton mass spectrum in CMS

Philippe Miné,
LLR, Polytechnique

# Summary

Introduction : theory motivations, LHC status
CMS apparatus performances
Dielectron event selection
backgrounds
mass spectrum
beyond Standard Model signal
discovery or exclusion
Dimuon
Diphoton
W' in electron neutrino
Conclusions

# Theory motivations

High mass dilepton neutral resonances predicted by:

New gauge bosons, spin1: superstring, GUT, little Higgs, etc
- SSM
- $Z_\psi$, $Z_\eta$, $Z_\chi$ in $E_6$ and SO(10)
- $Z_{LRM}$, $Z_{ALRM}$ in left-right models
- $Z_{B-L}$, 2 parameters *M* and *c*

Kaluza-Klein massive graviton, spin 2: Randall-Sundrum
2 parameters *M* and *c*
decays also into $\gamma\gamma$ or ZZ

Tevatron limits: = 963 GeV for SSM, =848 for RS for $c = 0.1$

# LHC status

LHC commissioning December 2009
Expected running in 2010 3 months 2 x 3.5 TeV,
5 months 2 x 5 TeV

Peak luminosity $10^{32}$ $cm^{-2}$ $s^{-1}$

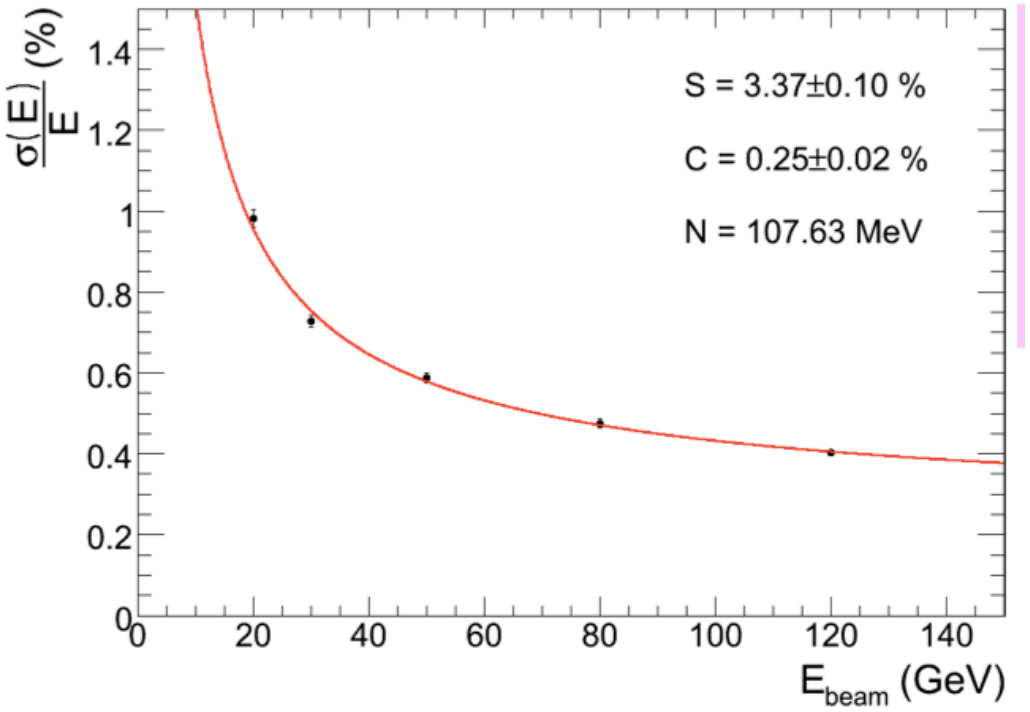
Integrated luminosity > 100 $pb^{-1}$ seams reasonable in one year

All simulations being recalculated for 10 TeV and 100 $pb^{-1}$

This presentation: dielectron at 10 TeV and 100 $pb^{-1}$
diphoton …
dimuon at 14 TeV
W' … in electron and neutrino BR ≈ 10 %
Altarelli et al. Z. Phys. C45 (1989) 109

# CMS apparatus performances

The detection of high energetic electrons relies on the 85848 lead tungstate crystals of the electromagnetic calorimeter

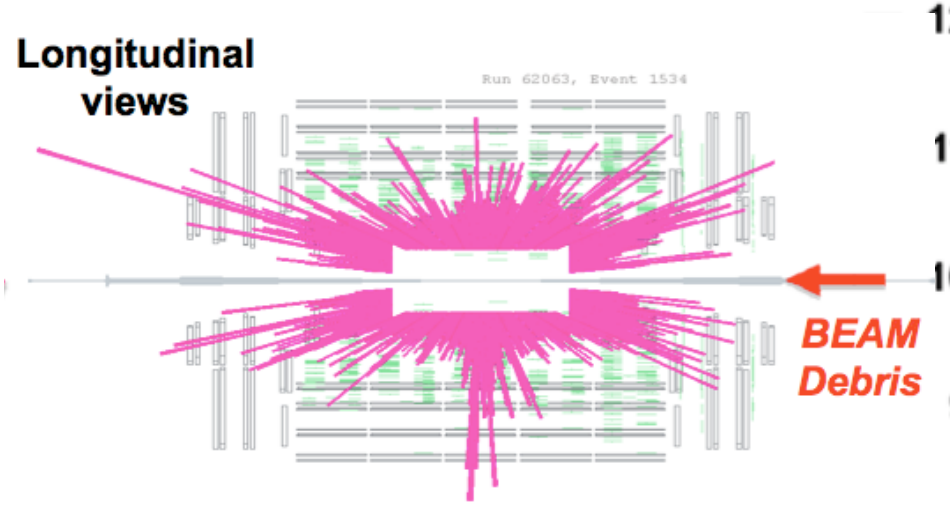


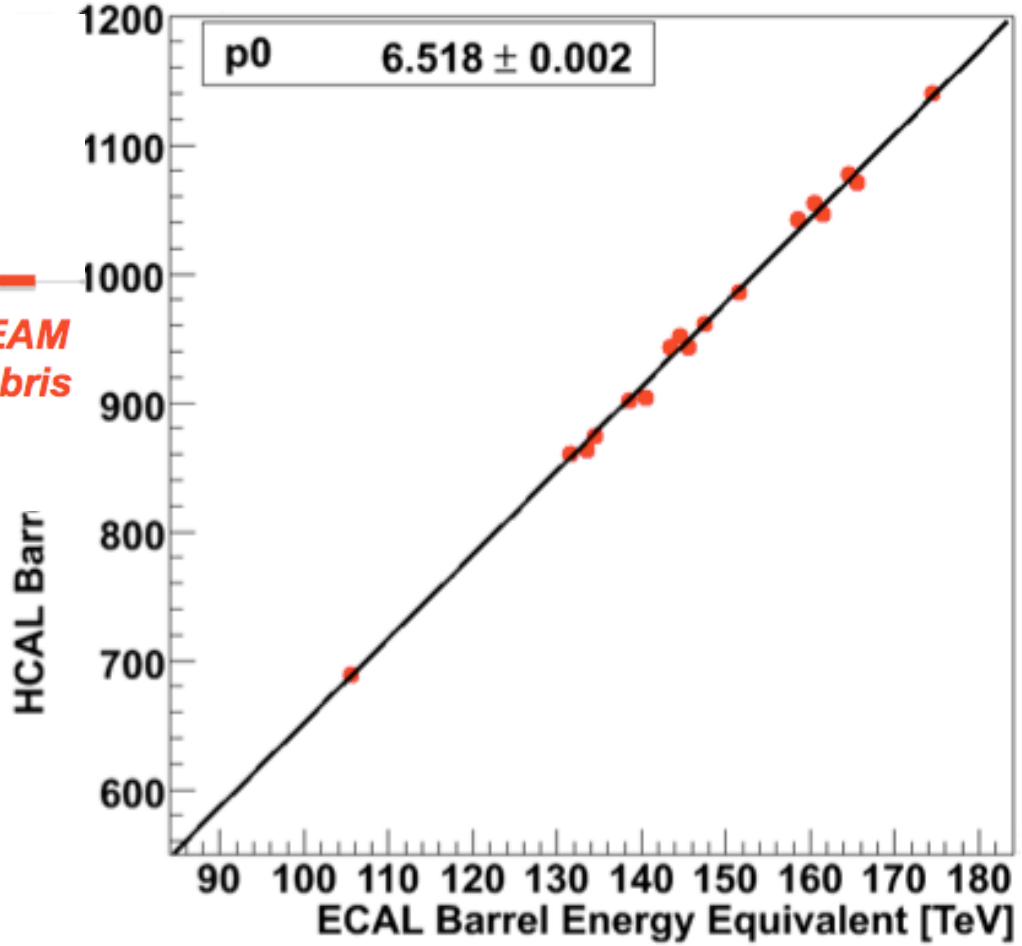

In test beam (20 – 230 GeV)
0.5 % ultimate resolution for unconverted photons
Noise 40 MeV (barrel)
Saturation of 1.7 TeV barrel, 3 TeV endcap; recovered by surrounding crystals

Charge and position measured by Si tracker and pixel
3.8 T solenoid magnet

Preshower in the endcaps

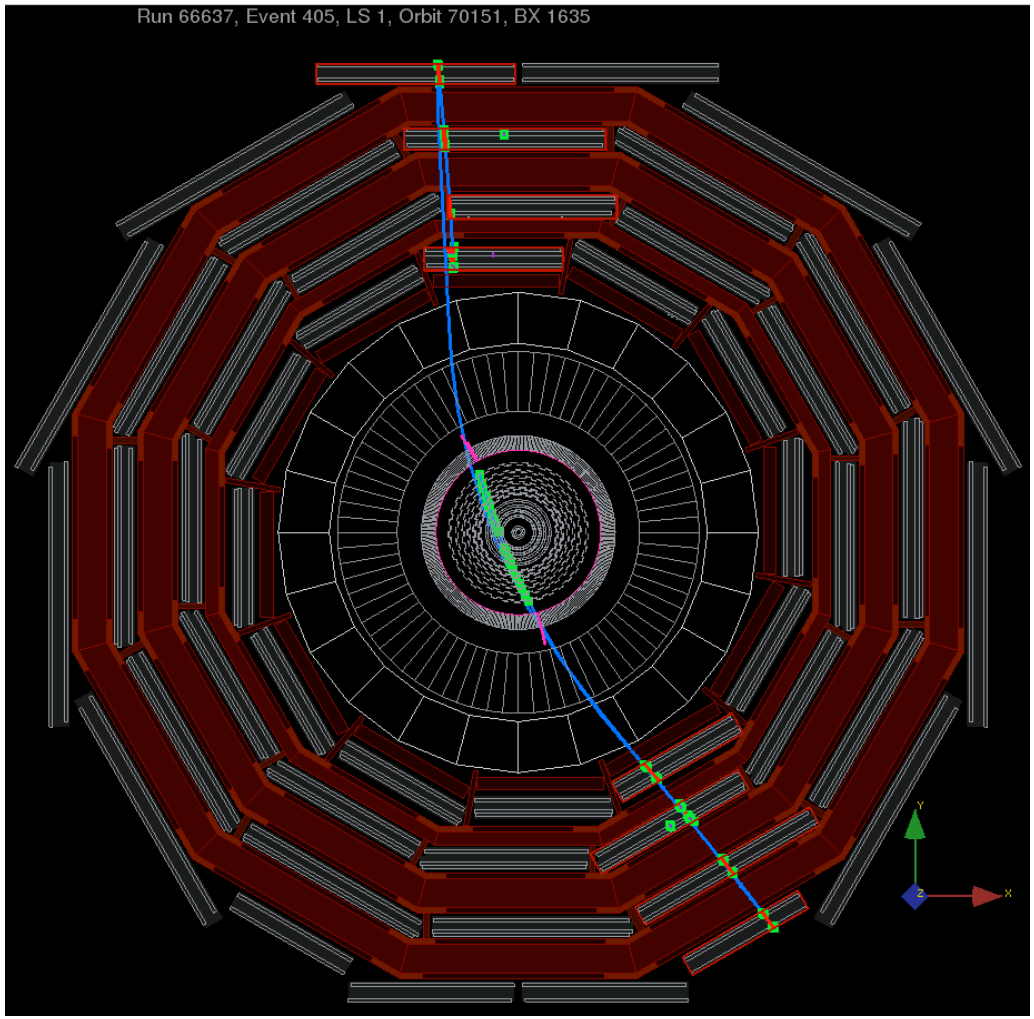
# CMS apparatus performances




10 September 2008:
beam splash events
2 x$10^9$ 450 GeV protons
onto collimators

# CMS apparatus performances



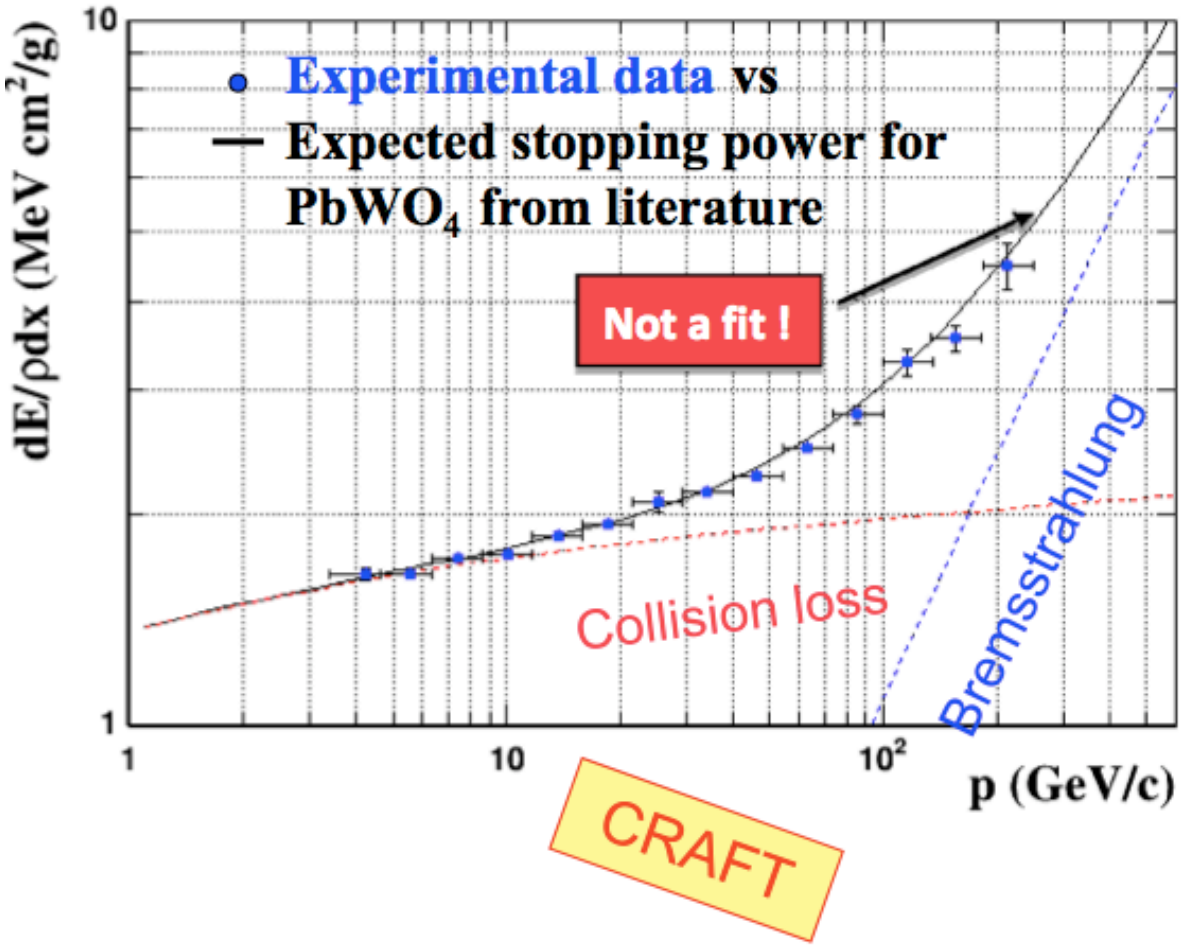

CMS apparatus is complete, with all subdetectors working, magnet 3.8 T

running on cosmics more than 300 millions events in 2009

- ECAL in magenta, HCAL in blue, tracker and muon hits in green

# CMS apparatus performances

Energy matching of ECAL versus Tracker for cosmic muons



# Dielectron : event selection

Dedicated triggers for HEEP (high energetic electrons pairs)

• Relaxed single electron

$E_t > 18$ GeV , matching in Tracker, isolation in ECAL, HCAL, Tracker

Z peak is visible

• High $E_t$

$E_t > 80$ GeV , no Tracker matching, loose isolation

Robust against alignment and calibration

• Very high $E_t$

$E_t > 200$ GeV

Very high efficiency for high mass

Global efficiency including reconstruction, identification and isolation

for $150 \text{ GeV} < E_t < 700 \text{ GeV}$

$89.4 \pm 0.1$ % for barrel  $88.1 \pm 0.1$ % for endcap

# Dielectron : event selection

| Process | Drell-Yan | | | | SSM Z′ |
|---|---|---|---|---|---|
| mass ($\mathrm{GeV}/c^2$) | $> 40$ | $> 120$ | $> 200$ | $> 500$ | 1000 |
| global acceptance, reconstruction and selection efficiency | 0.27 | 0.40 | 0.49 | 0.61 | 0.67 |
| final number of selected events | 33,700 | 487 | 76 | 3.4 | 15.7 |

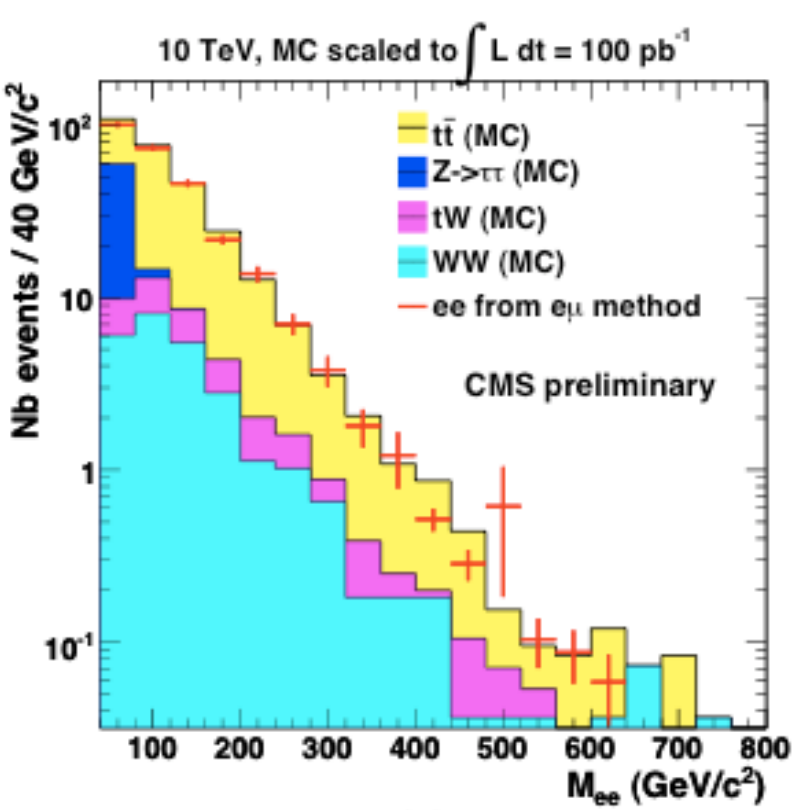
For 2 selected electrons (LO calculated cross sections)

Data driven methods “tag and probe” for efficiency and background evaluation

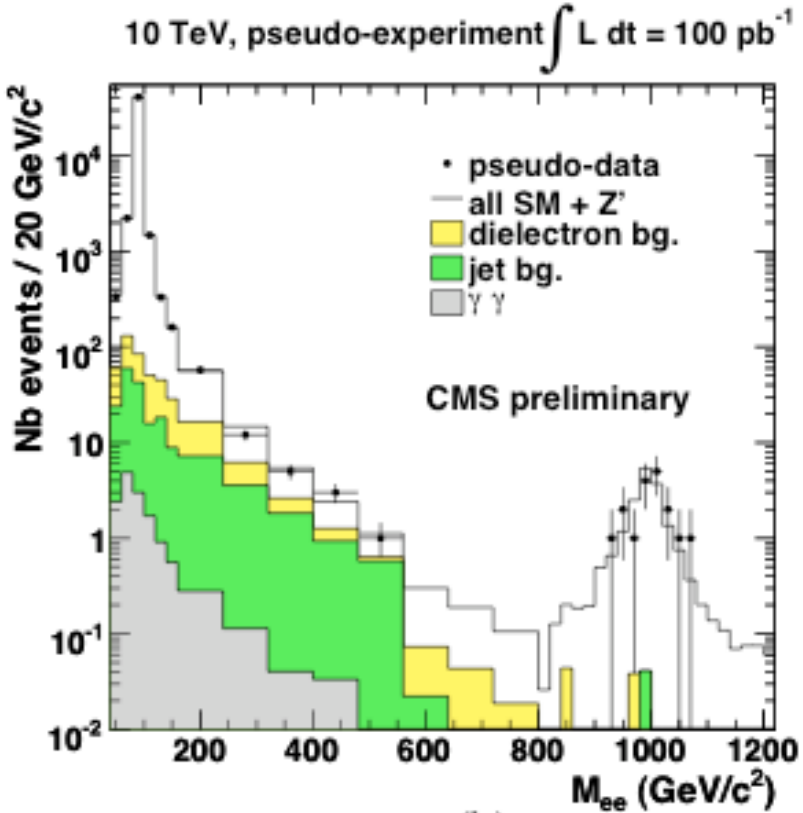
| | Barrel | | Endcap | |
|---|---|---|---|---|
| | $Z \to ee$ | jet bg. | $Z \to ee$ | jet bg. |
| efficiencies | $93.9 \pm 0.1\%$ | – | $94.3 \pm 0.2\%$ | – |
| rejection power | – | $99.8 \pm 0.1\%$ | – | $98.4 \pm 0.4\%$ |

and at high mass by selected DY events

# Dielectron: backgrounds




(a)



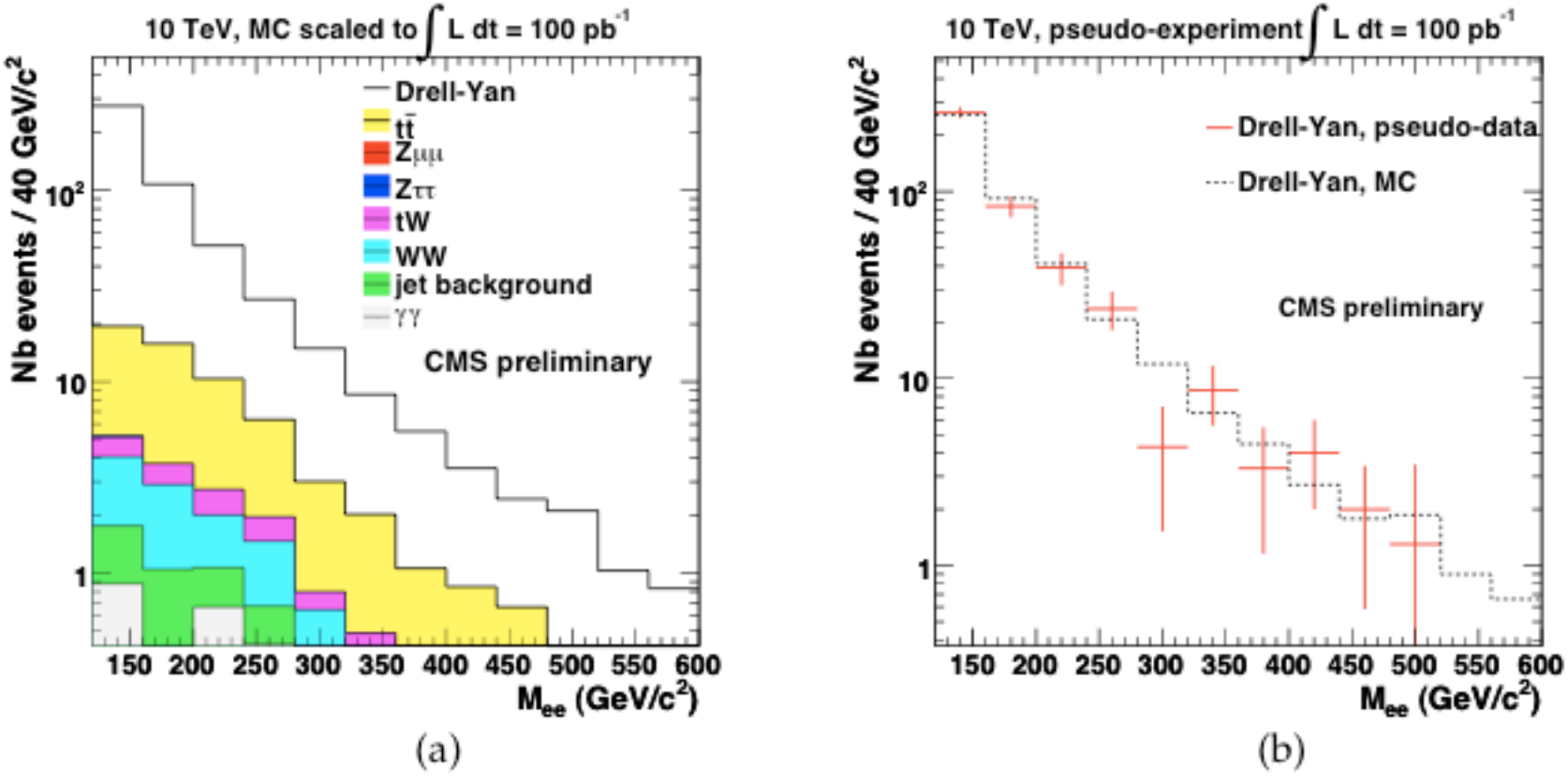

(b)

main background is tt,
also measured by b tagging

normalisation by Z peak

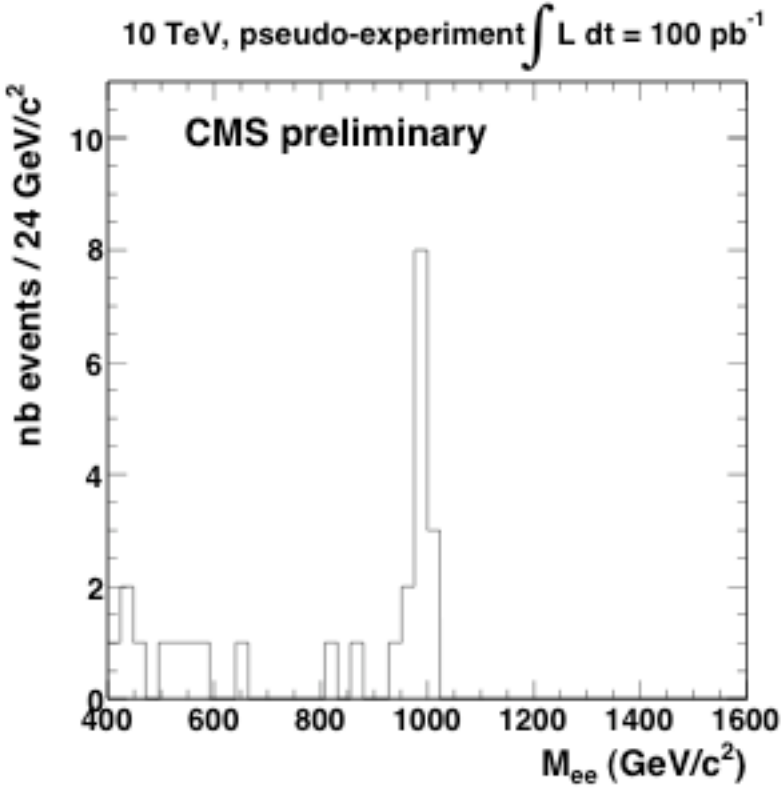
CMS EXO-09-006

# Dielectron: mass spectrum



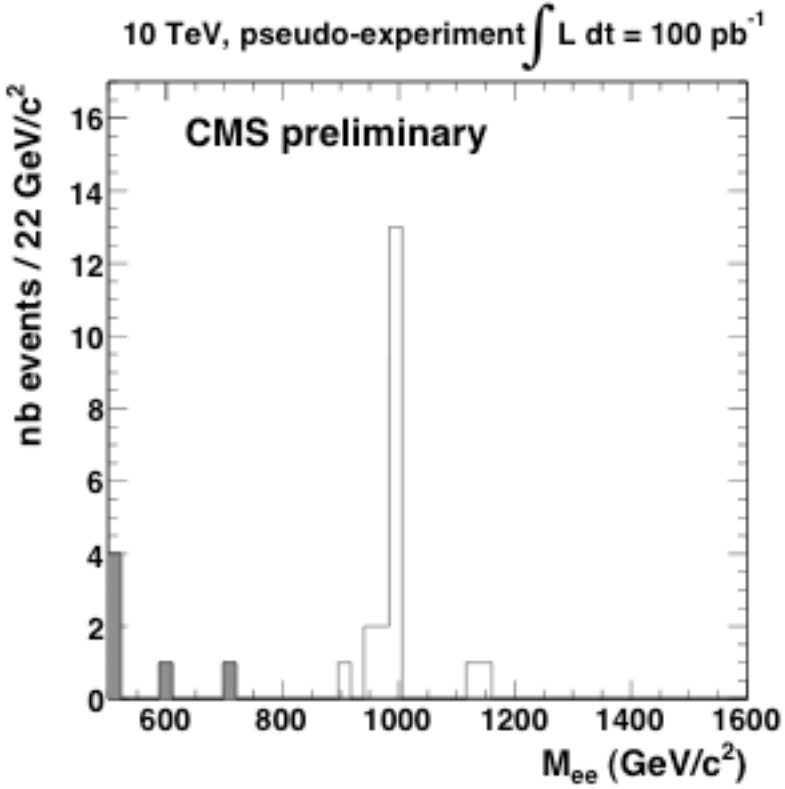

Drell-Yan is irreducible background, measured by Tevatron < 1 TeV
accurate measurement and calculation (LO, $K$=1.35 ) validates the procedure

# Dielectron: BSM signal




(a)

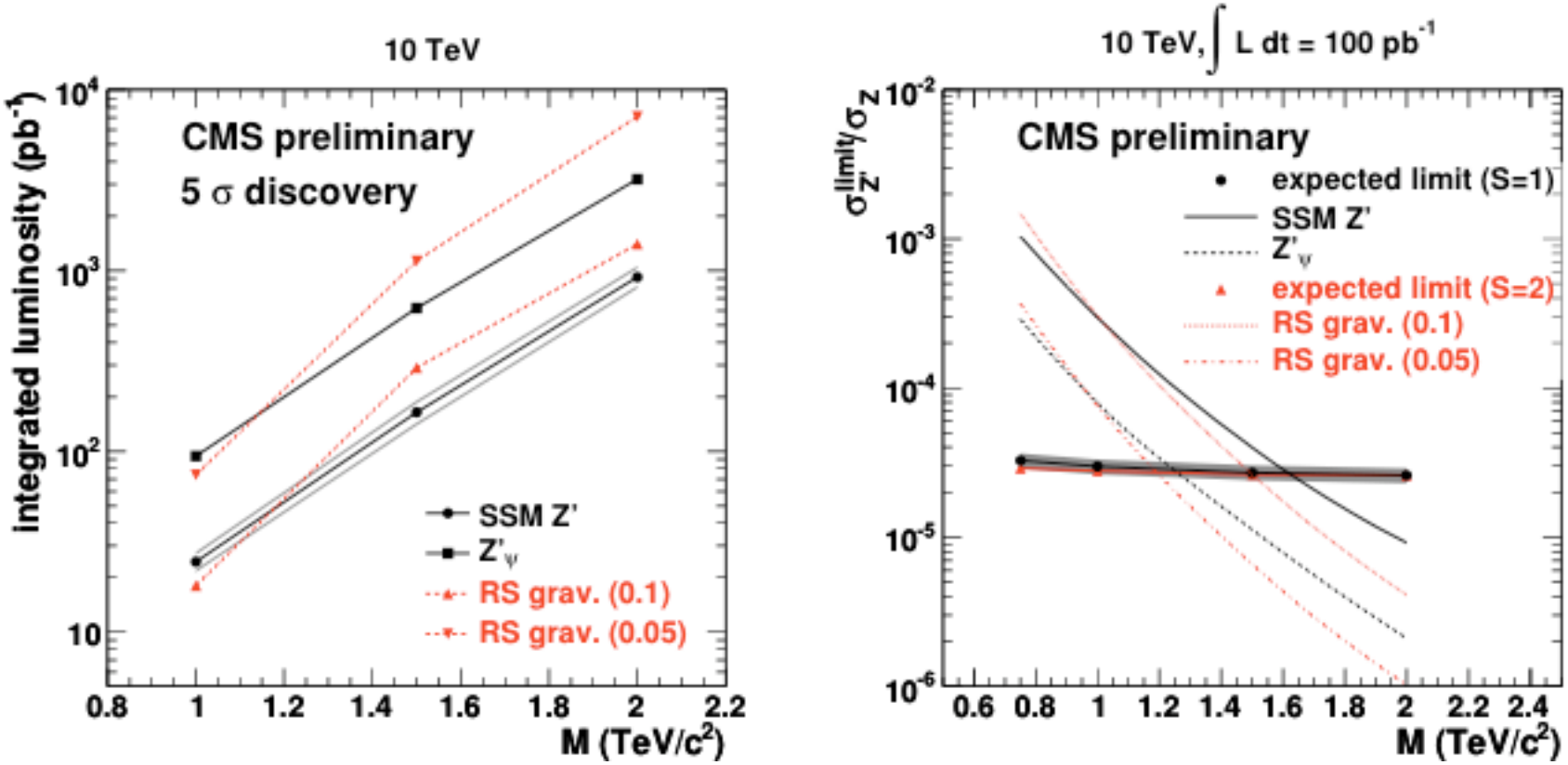
SSM Z', 1 TeV, 30 GeV width
Drell-Yan interference




(b)

RS 1 TeV, $c$ = 0.1, width 14 GeV
Drell-Yan (shaded)

# Dielectron: discovery or exclusion

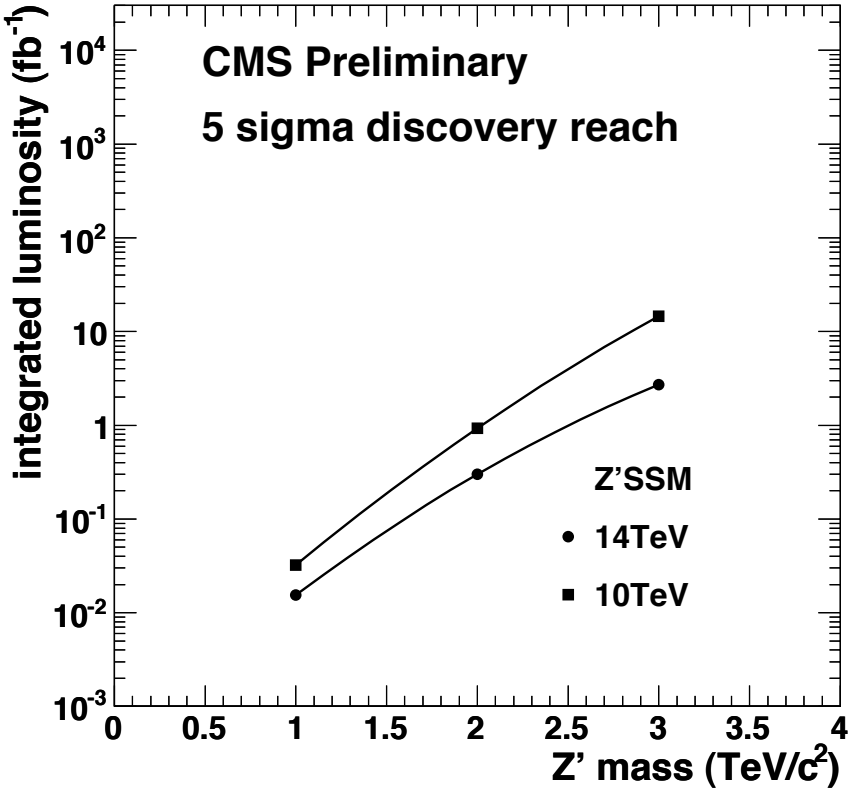


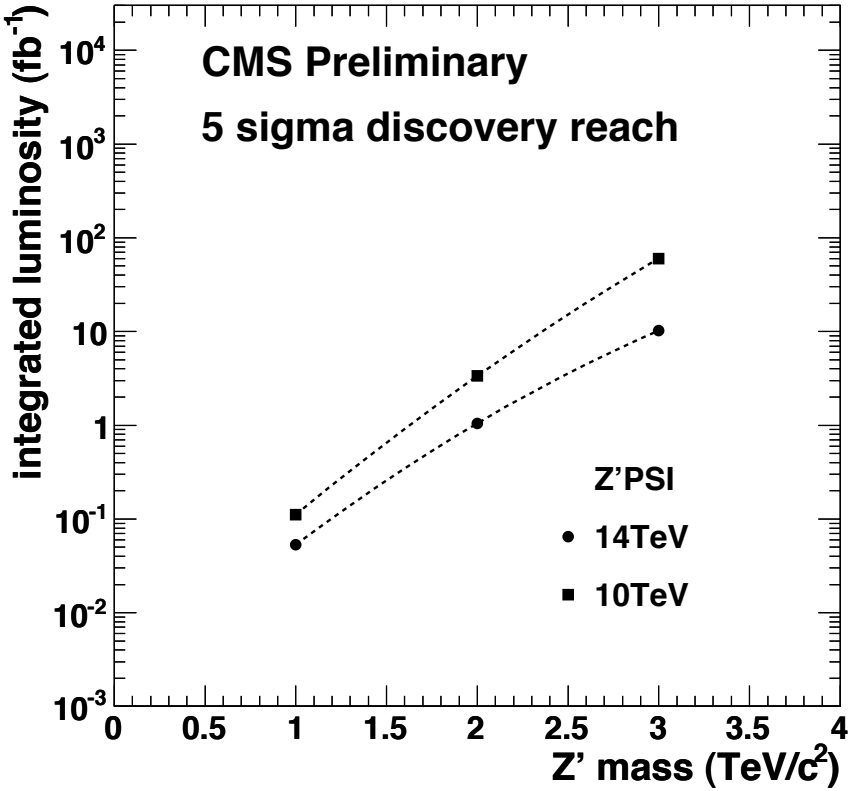

Cousins et al. CMS NOTE 2005-002, Bartsch et al. CMS NOTE 2005-004

Three lines, gray band: systematic uncertainties

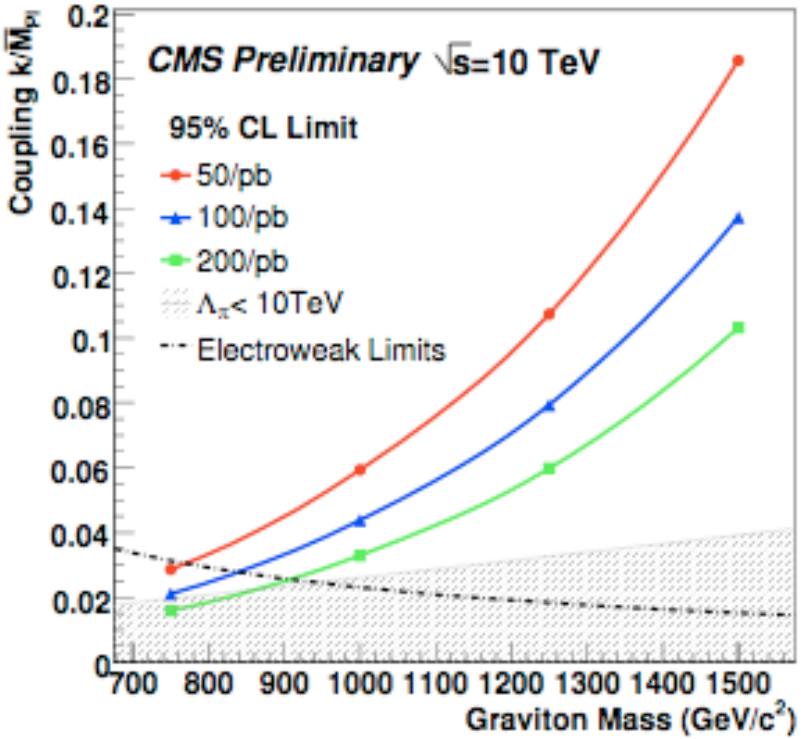
# Dielectron: discovery or exclusion

**CMS AN 2009/019**



# Diphoton: Randall-Sundrum limit




CMS EXO-09-009

Figure 3: Limit on RS parameters $(M_1, \tilde{k})$, extrapolated from the results of the large ED diphoton search for 100/pb. The area to the left of the curves is excluded. The gray shaded region shows the area excluded for $\Lambda_\pi < 10\,\mathrm{TeV}/c^2$. The area below the dash-dotted line is excluded by precision electroweak data [11].

# Dimuon: Z' and backgrounds (14 TeV)

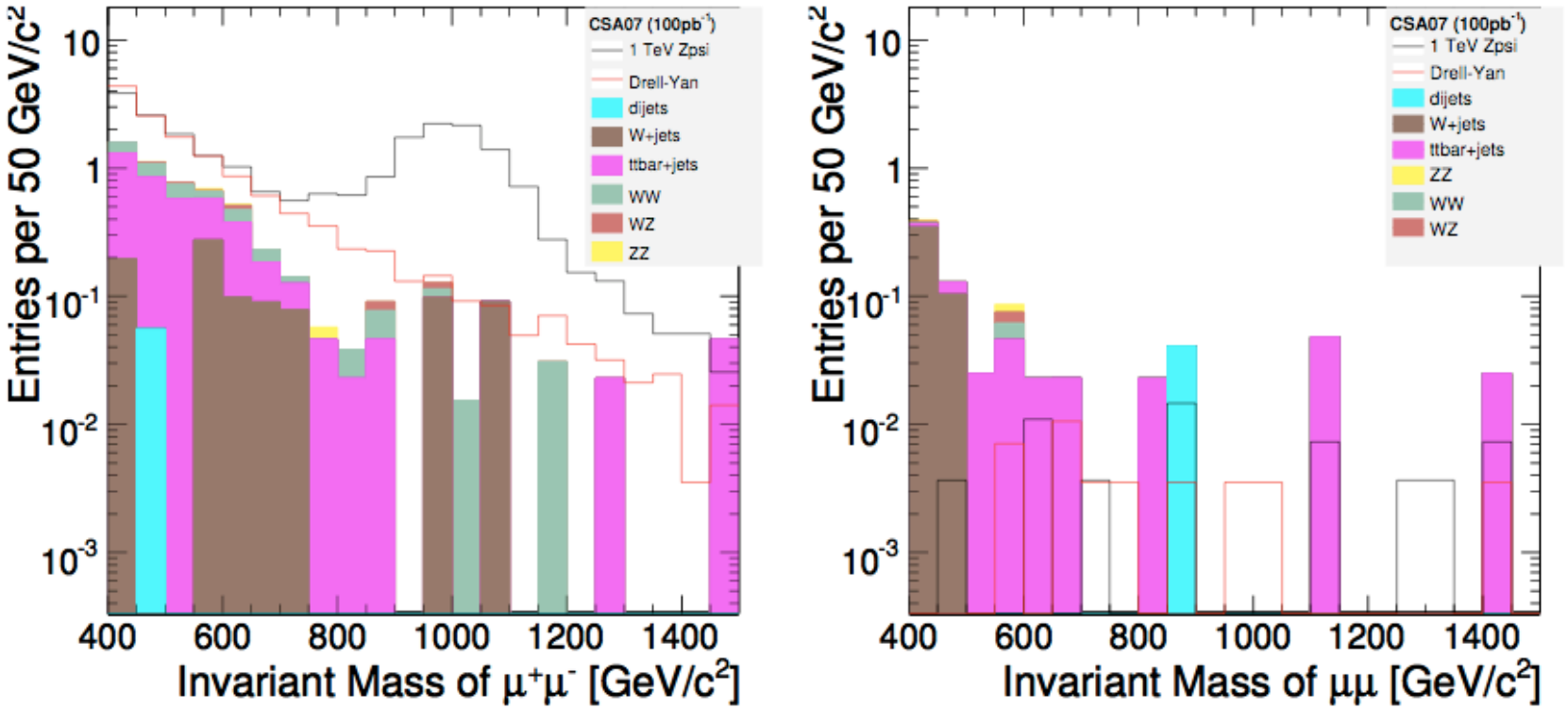


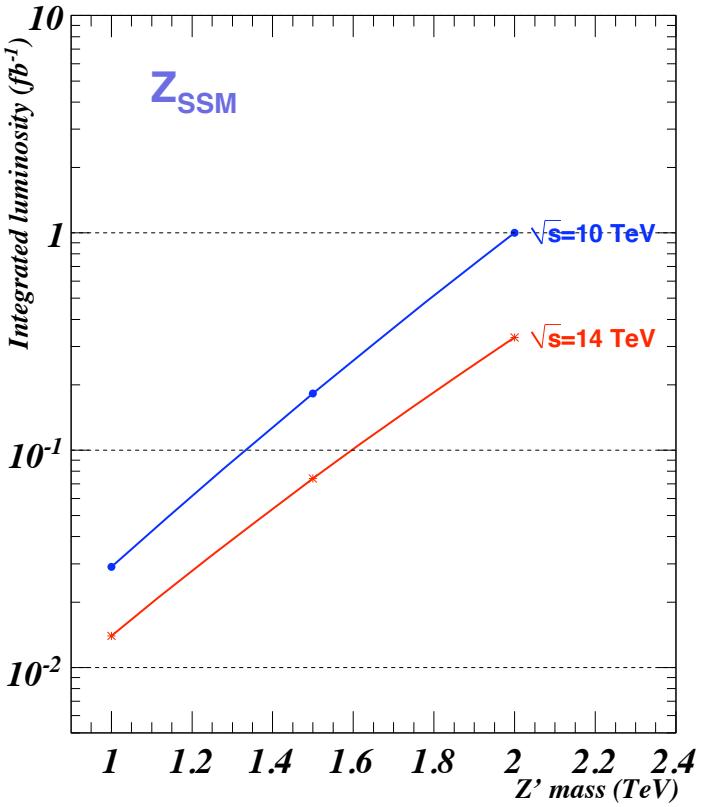

Figure 4: Invariant-mass distributions for opposite-sign (left) and same-sign (right) dimuons from 1 TeV/$c^2$ $Z_\psi$ and different background sources expected for $\int \mathcal{L}dt = 100$ pb$^{-1}$ after applying all event-selection criteria. The spectrum is shown in the mass range $400 < M_{\mu\mu} < 1500$ GeV/$c^2$. All histograms except for Drell-Yan and $Z_\psi$ are stacked.

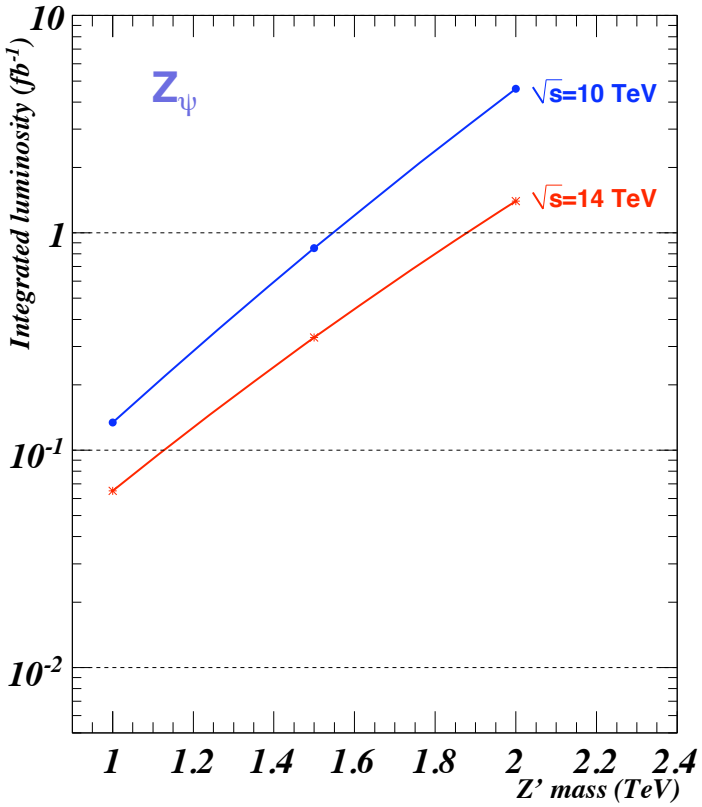
CMS SBM-07-002

# Dimuon: Z' and backgrounds (14 TeV)

Rescale 14 TeV curves by corresponding cross section ratios for Signal and Drell-Yan bkg → 10 TeV curves

**CMS AN 2009/017**

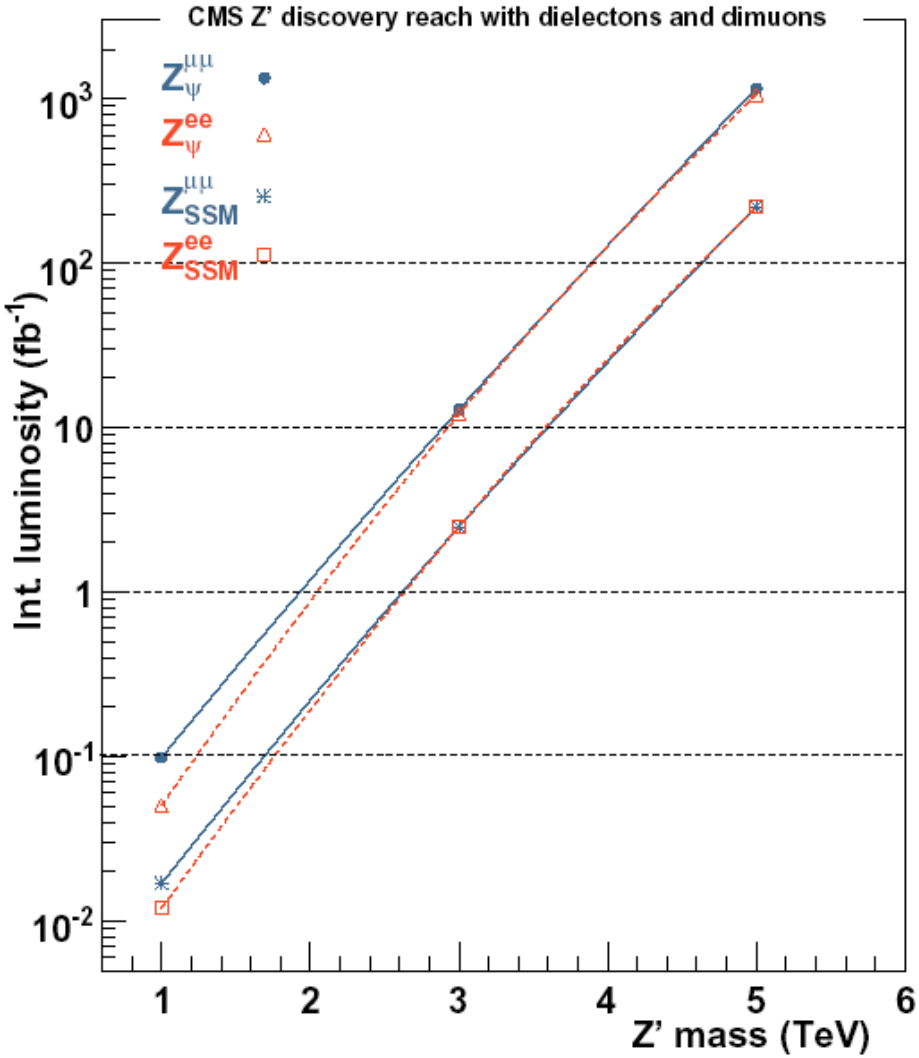


# Dimuon: Z' and backgrounds (14 TeV)

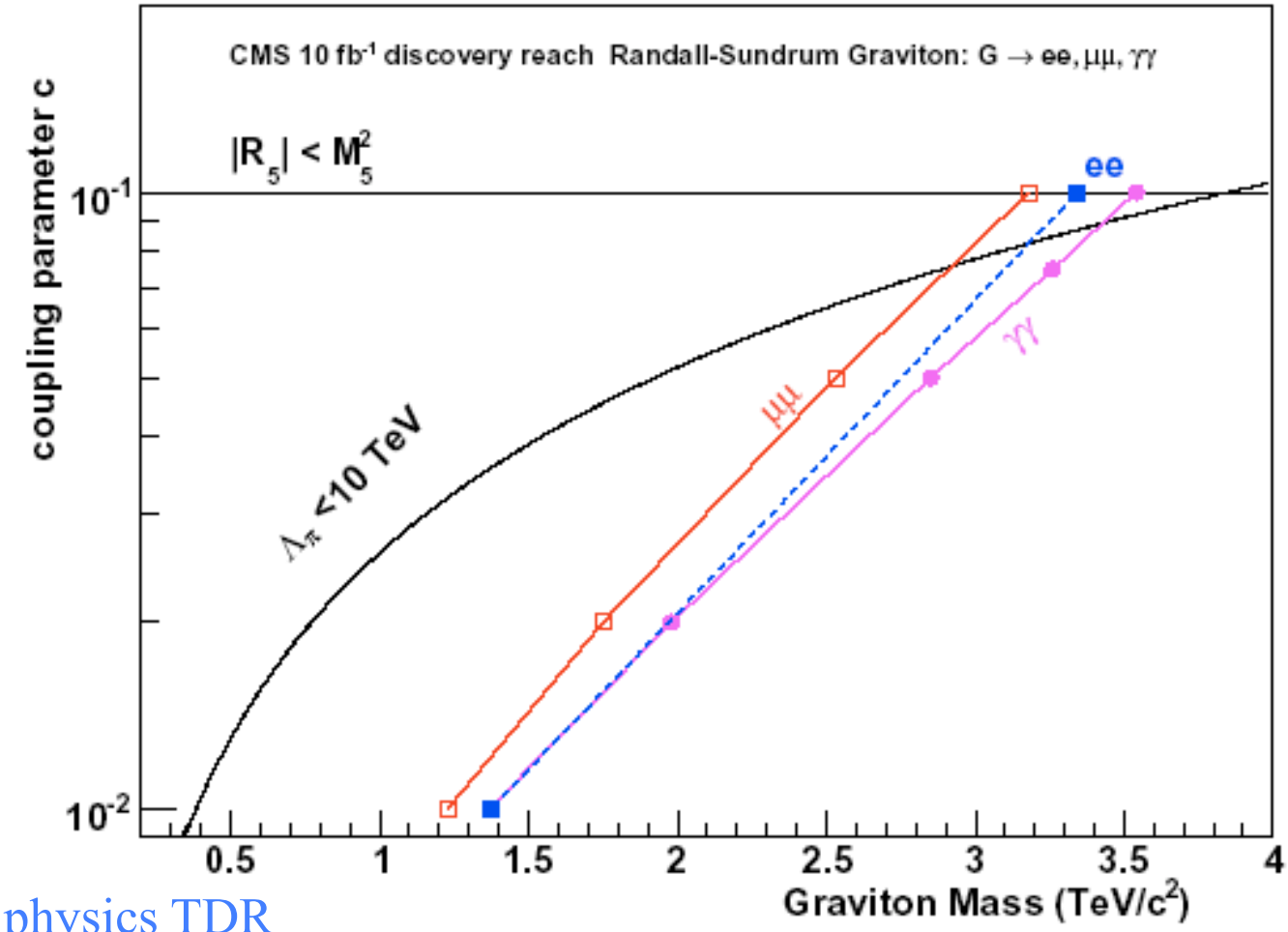
Z' comparison
dielectron
and dimuon
at 14 TeV

CMS physics TDR



# Dimuon: Z' and backgrounds (14 TeV)

14 TeV

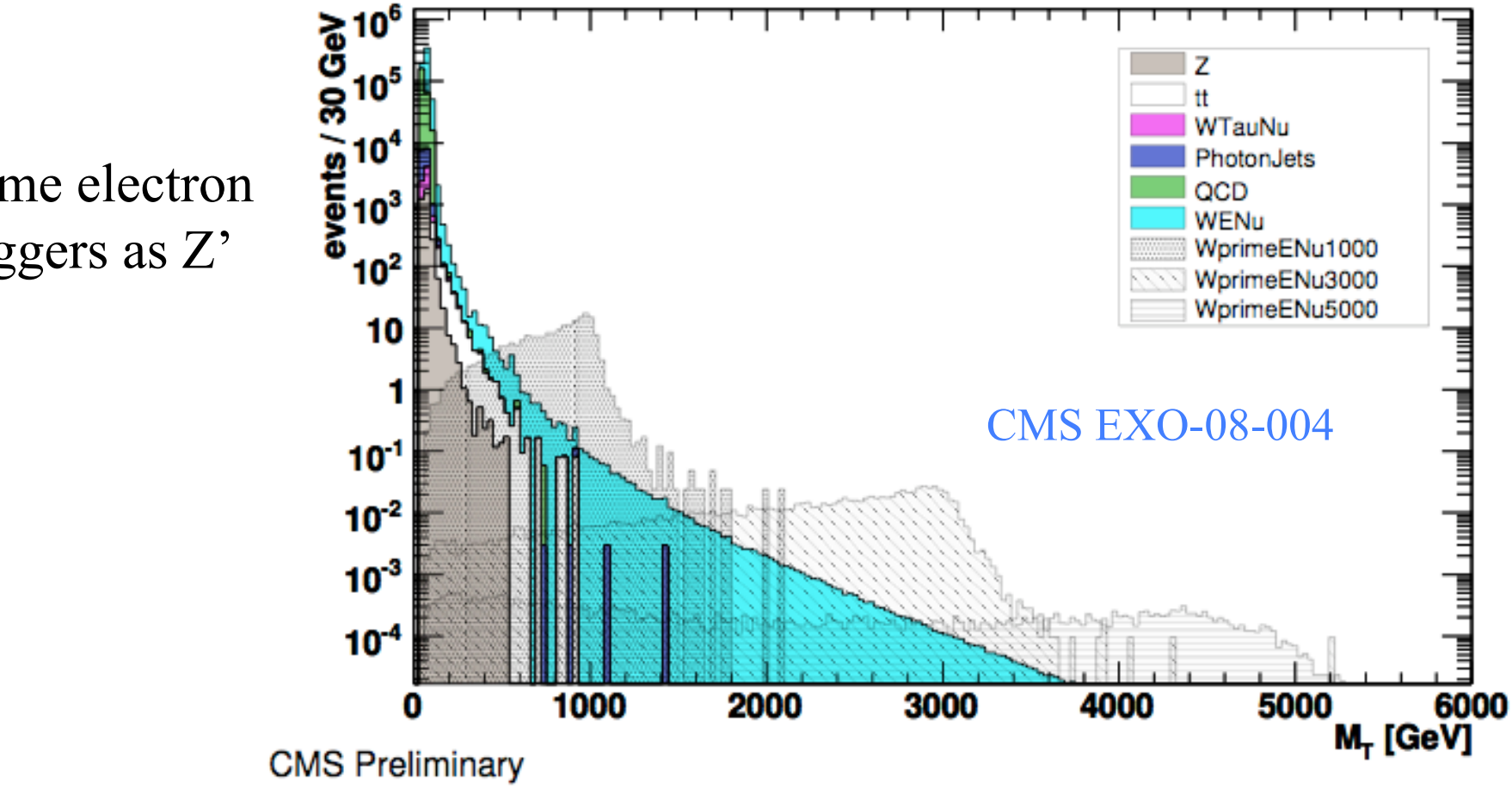



CMS physics TDR

# W': electron and missing $E_t$ (14 TeV)

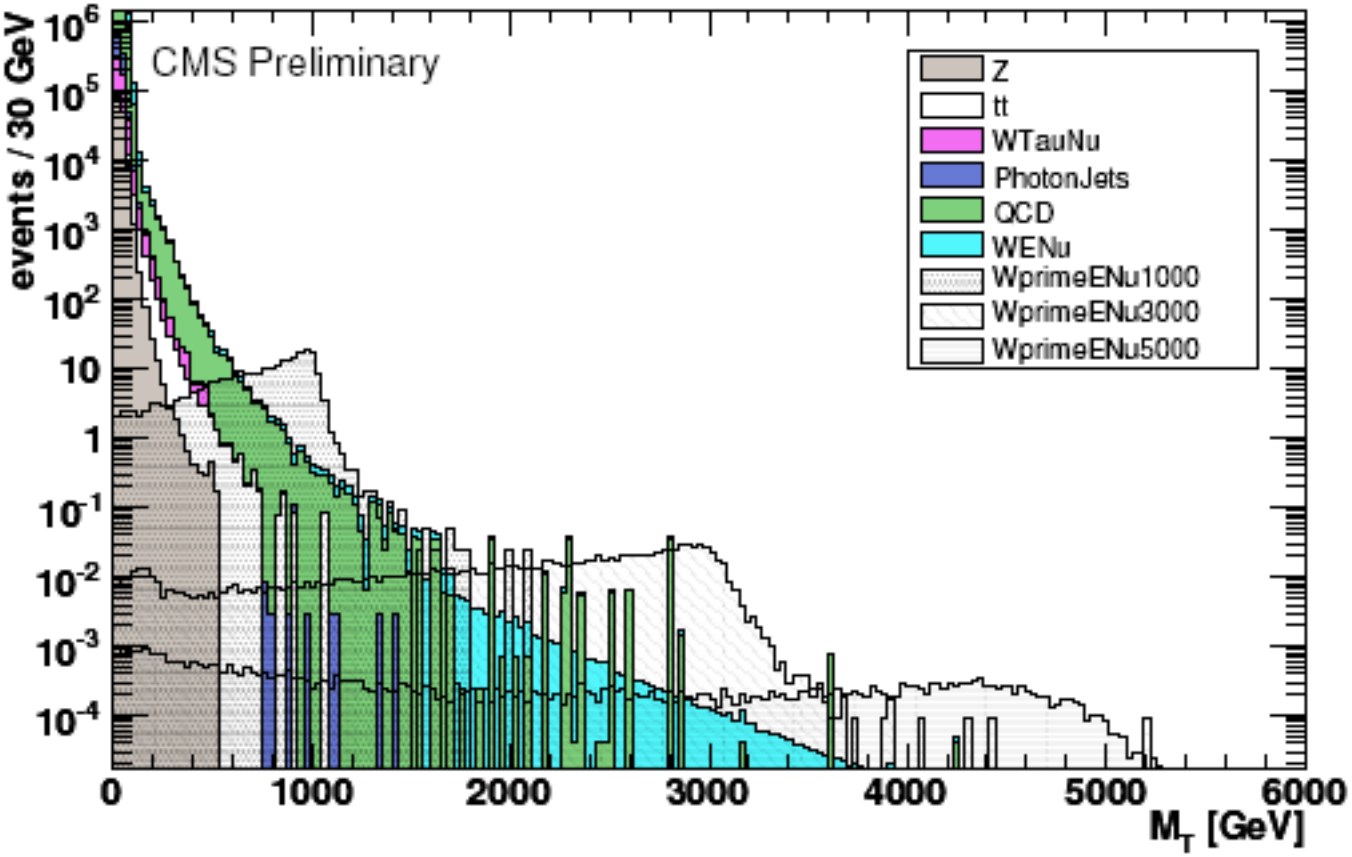
W' → e ν (1, 3, 5 TeV) transverse mass after selection

Same electron triggers as Z'



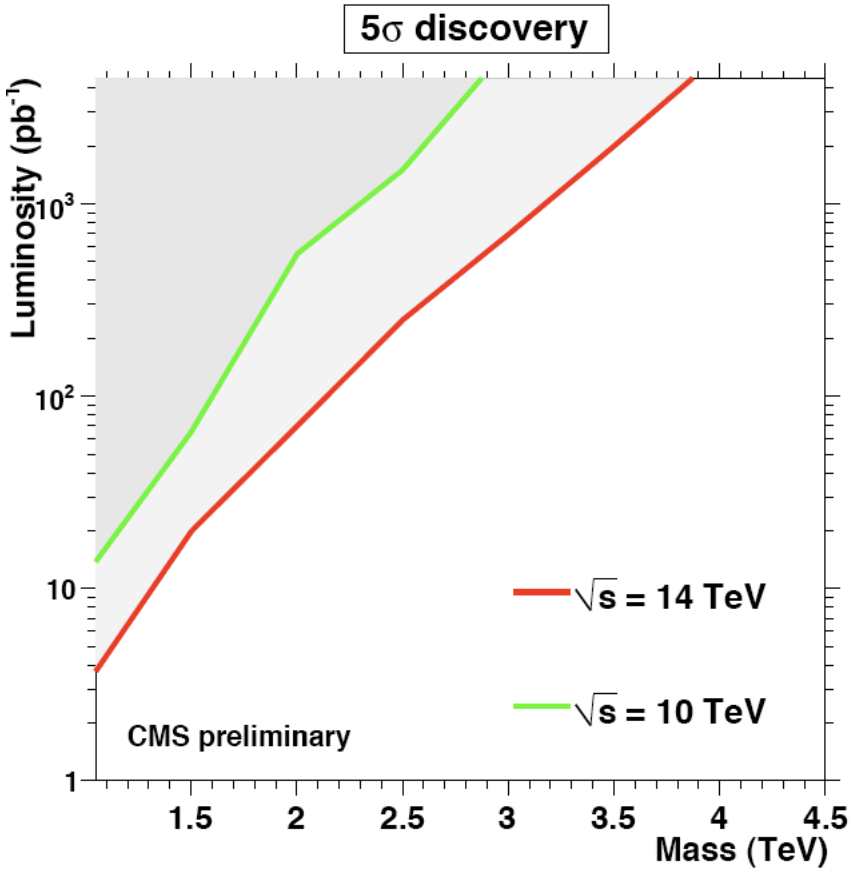
# W': electron and missing $E_t$ (14 TeV)

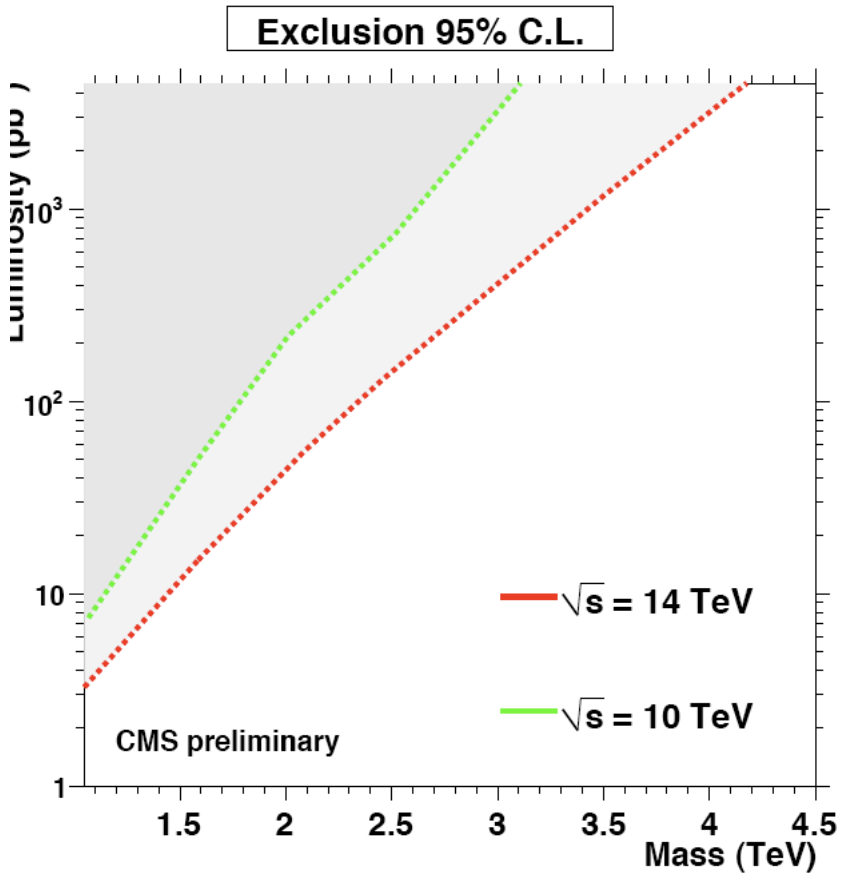
W' → e ν transverse mass before selection (trigger, energy ratio, angle, one electron, …) at 14 TeV



# W': electron and missing $E_t$ (14 TeV)

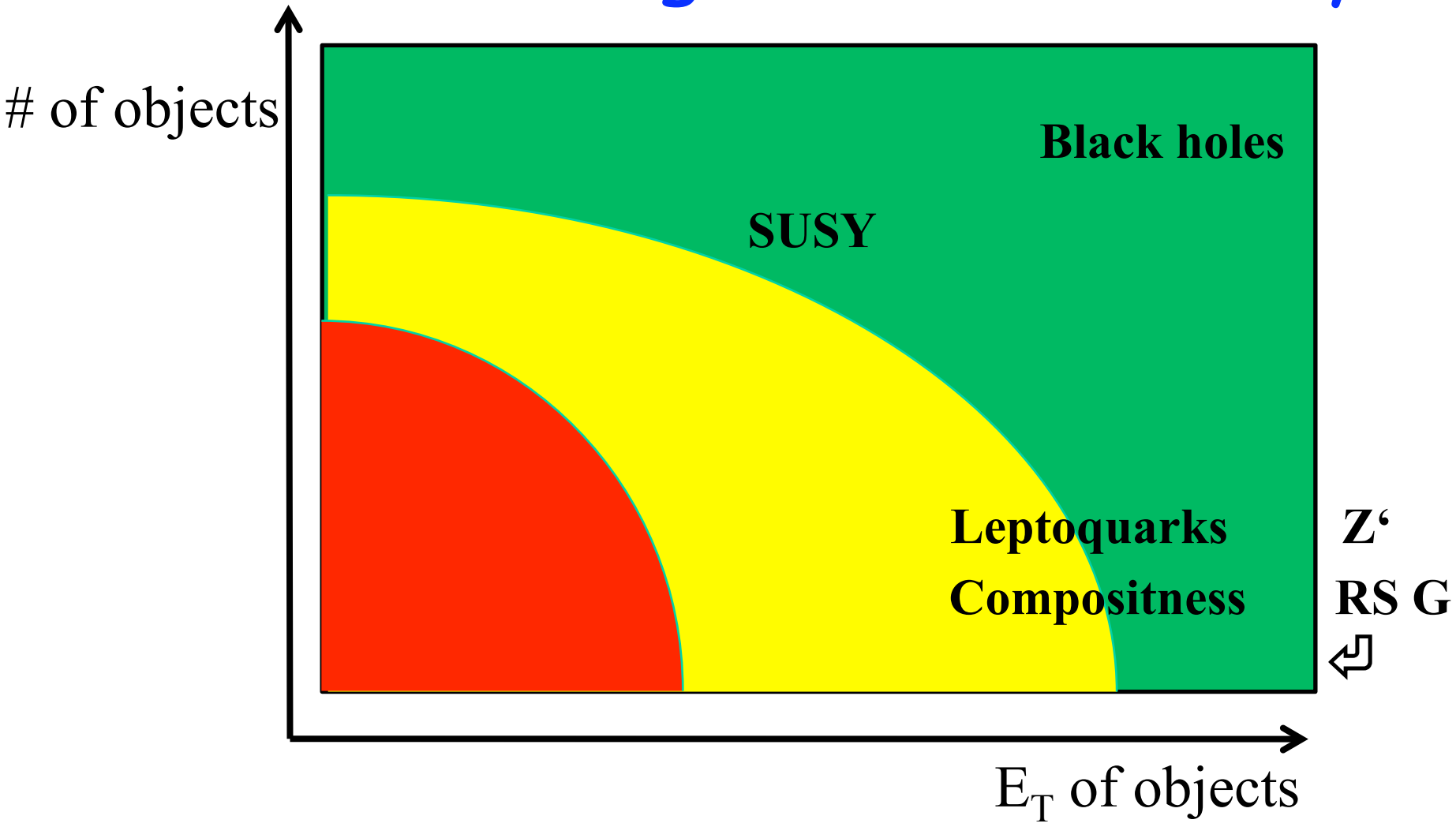
**CMS AN 2009/008**



From yesterday Rainer Stamen's talk

# Rastafari Diagram of difficulty



# Conclusions

For 100 $pb^{-1}$
measurement of DY cross section and data driven techniques
( 6% statistics, 7% systematics ) give

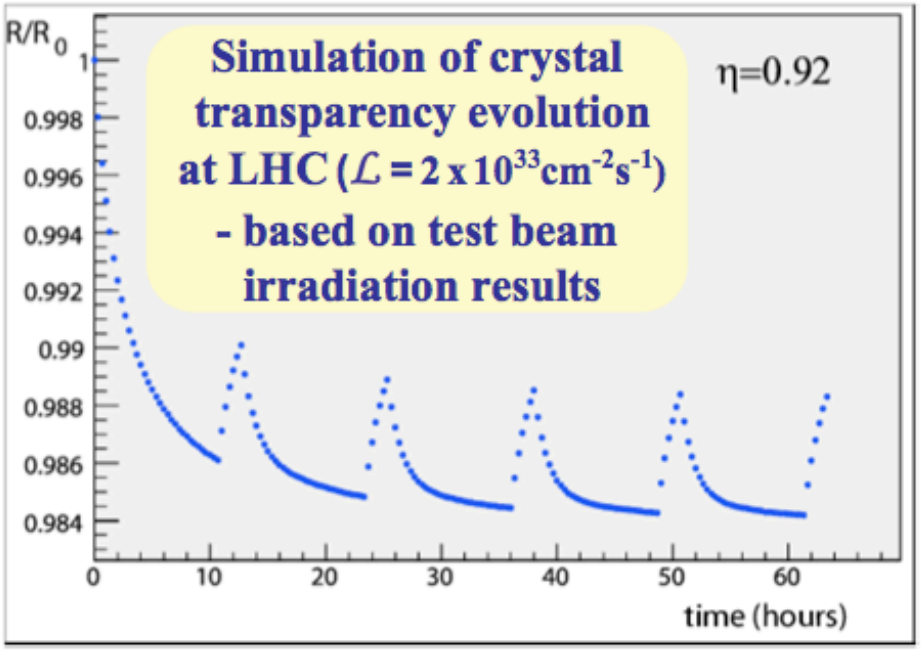
| | |
|---|---|
| 10 TeV discovery limit of Z' dielectron | 1.37 TeV/$c^2$ SSM, 1.02 $Z_\psi$ |
| | 1.31 RS ($c$ = 0.1), 1.06 ($c$ = 0.05) |
| exclusion limits (resp) | 1.59, 1.26 |
| | 1.49, 1.21 |
| exclusion limit of RS diphoton | 1.35 ($c$ = 0.1) |

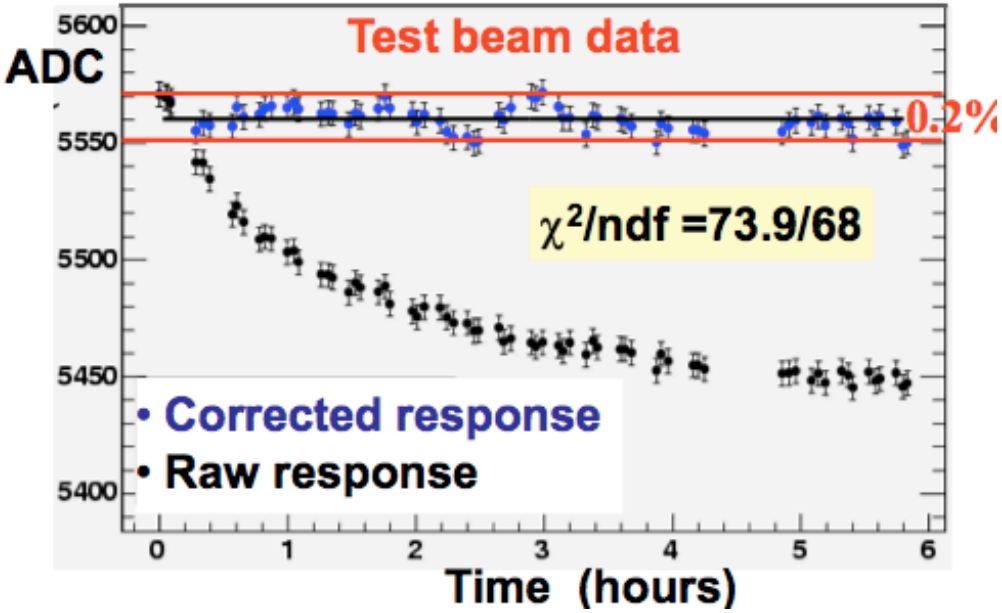
CMS is ready, expectations are competitive with Tevatron

# BACKUP

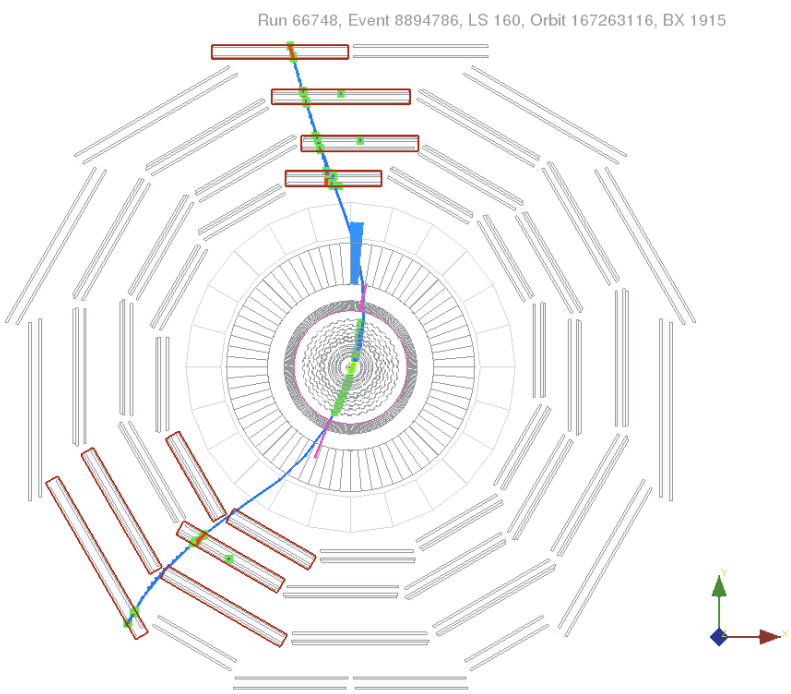
At high luminosity, radiation damages and recovery are monitored and corrected

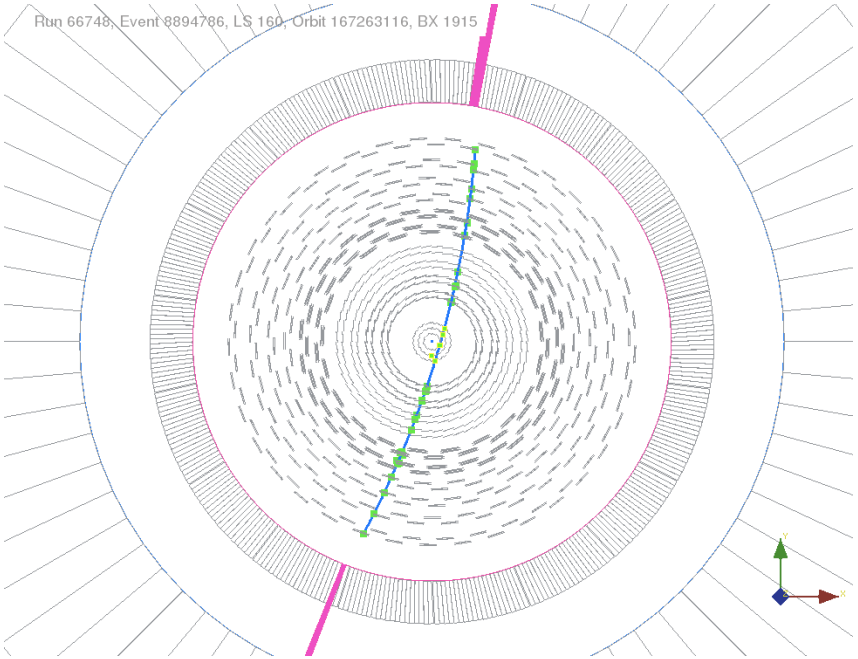
Laser pulses are injected during LHC “orbit gaps”



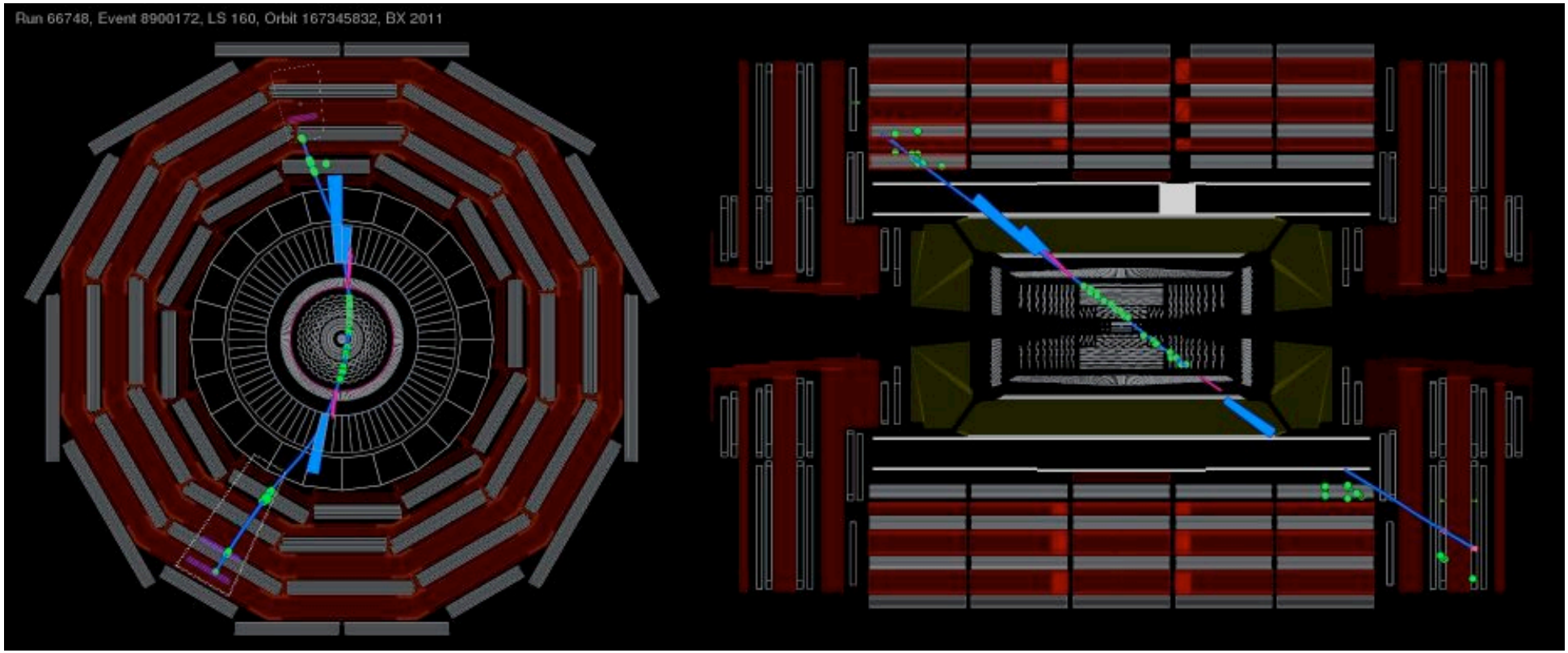
# Traversing Pixel Detector



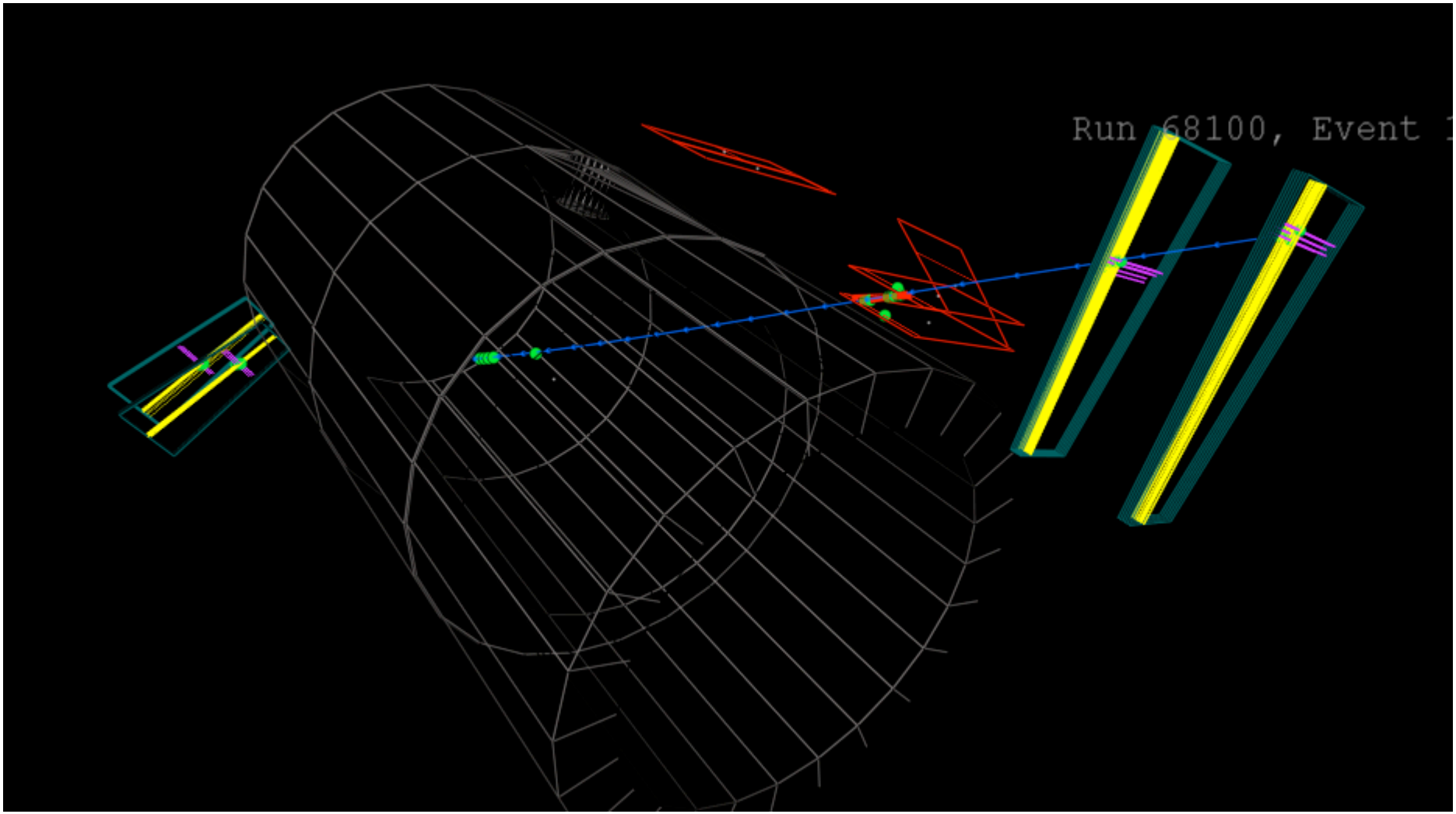




- ECAL in magenta, HCAL in blue, tracker and muon hits in green

# Endcap and Barrel Muon Detectors




- ECAL in magenta, HCAL in blue, tracker and muon hits in green




- RPC chambers in red, CSC strips in yellow, CSC wires in magenta
- Tracker and muon hits in green

| Mass ($GeV/c^2$) | $\Gamma$ ($GeV/c^2$) | $\sigma$ (pb) | mass window ($GeV/c^2$) | $N_{sig}$ | $N_{DY}$ |
|---|---|---|---|---|---|
| SSM $Z'$ | | | | | |
| 1000 | 30 | 0.319 | 950-1050 | 16.91 | 0.114 |
| 1500 | 45 | 0.0448 | 1425-1575 | 2.32 | 0.017 |
| 2000 | 80 | 0.0107 | 1900-2100 | 0.56 | 0.004 |
| $Z_\psi$ | | | | | |
| 1000 | 6 | 0.085 | 970-1020 | 4.33 | 0.060 |
| 1500 | 9 | 0.0126 | 1460-1520 | 0.64 | 0.007 |
| 2000 | 11 | 0.0024 | 1940-2020 | 0.13 | 0.001 |
| RS graviton ($c = 0.1$) | | | | | |
| 1000 | 14 | 0.351 | 950-1025 | 20.75 | 0.091 |
| 1500 | 21 | 0.0303 | 1450-1550 | 1.74 | 0.011 |
| 2000 | 28 | 0.0048 | 1925-2050 | 0.28 | 0.002 |
| RS graviton ($c = 0.05$) | | | | | |
| 1000 | 3.5 | 0.088 | 980-1010 | 4.87 | 0.036 |
| 1500 | 5.3 | 0.0076 | 1460-1520 | 0.45 | 0.007 |
| 2000 | 7 | 0.0012 | 1950-2020 | 0.07 | 0.001 |

Table 6: Mass, width and cross section for SSM $Z'$ and $E_6$ $Z_\psi$ [2] boson production and for RS graviton production with coupling $c = 0.1$ and $c = 0.05$, for a centre of mass energy of 10 TeV; in the quoted mass window, expected number of events for resonance production and for the Drell-Yan process, for an integrated luminosity of 100 $pb^{-1}$.

# 14 TeV limit on Z' in e+ e-

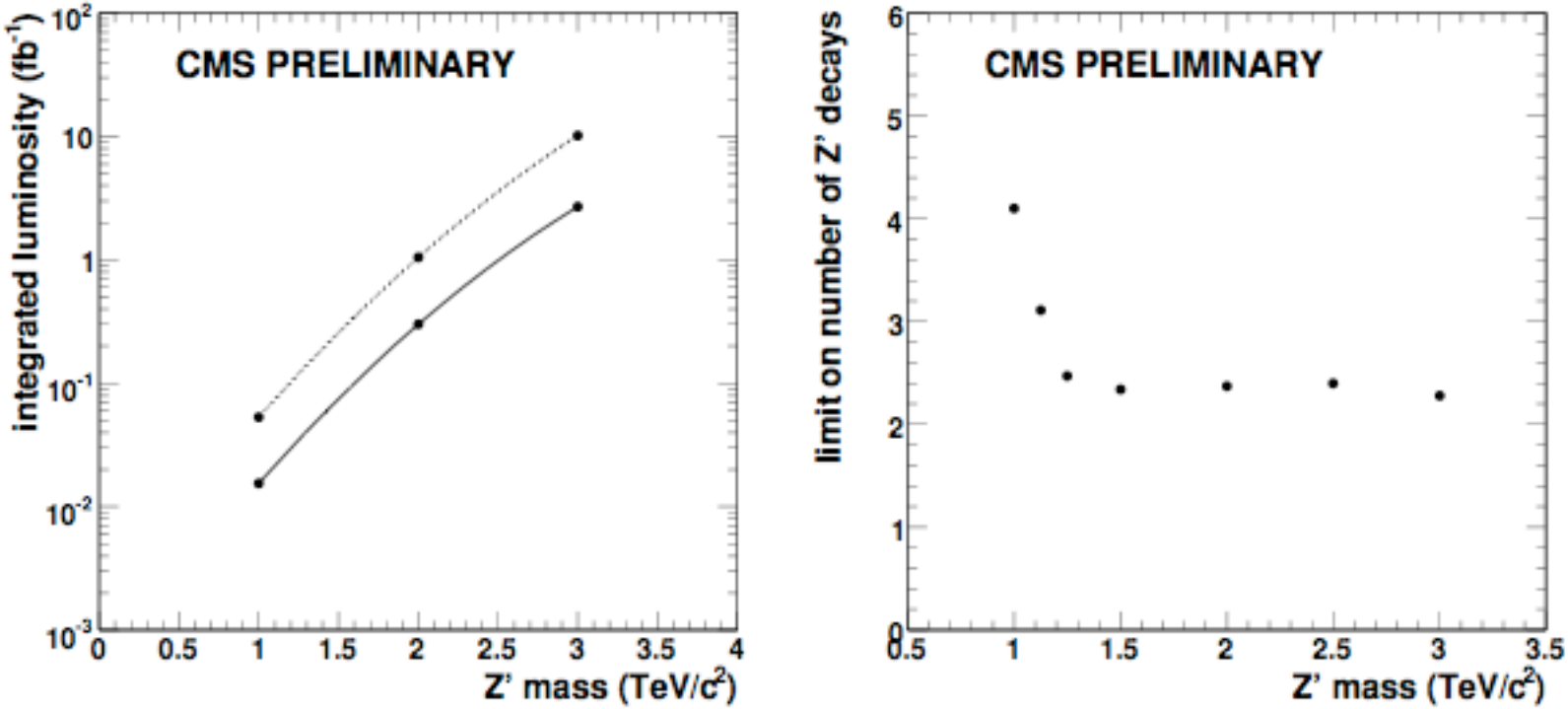
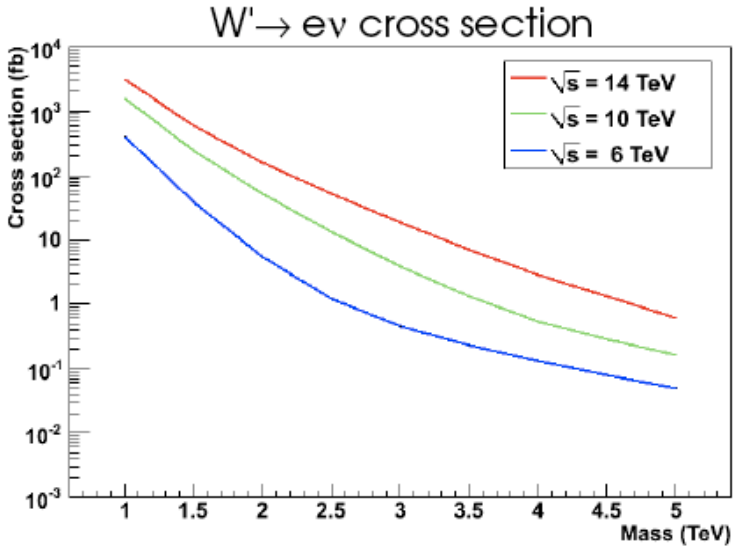
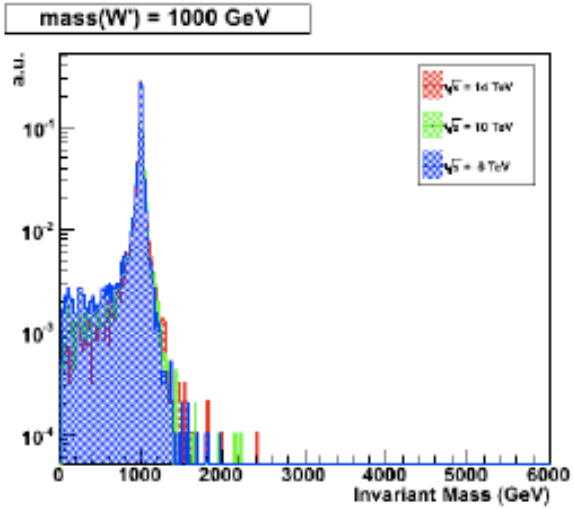


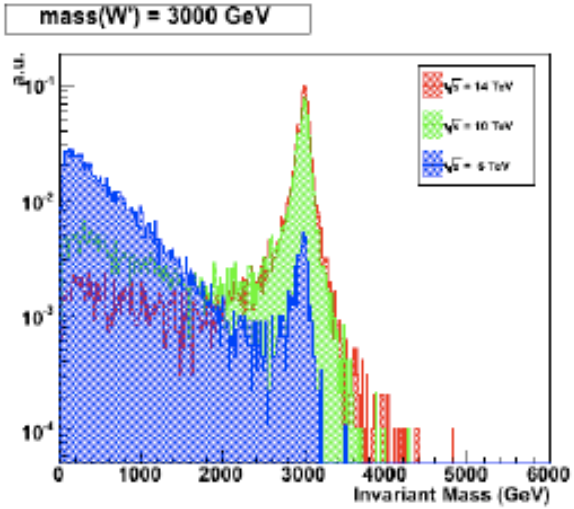

Figure 7: (a) Integrated luminosity needed to reach $5\sigma$ significance as a function of the mass, for a $\psi Z'$ (higher points) and a SSM $Z'$ resonance (lower points); (b) expected 95% CL limits on number of events as a function of the resonance mass.

CMS EXO-08-001

# e-nu




| Process | X-sec. @ 14 TeV | X-sec @ 10 TeV | X-sec @ 6 TeV |
|---|---|---|---|
| W→eν (M>200GeV) | 6.8 nb | 4.35 nb (0.640) | 2 nb (0.294) |
| DY ee | 1.79 nb | 1.23 nb (0.687) | 0.67 nb (0.374) |
| Ttbar | 480 pb | 241 pb (0.502) | 58 pb (0.121) |
| QCD | 54.7 mb | 51.5 mb (0.941) | 47.2 mb (0.863) |