Study of Diboson Production at CMS

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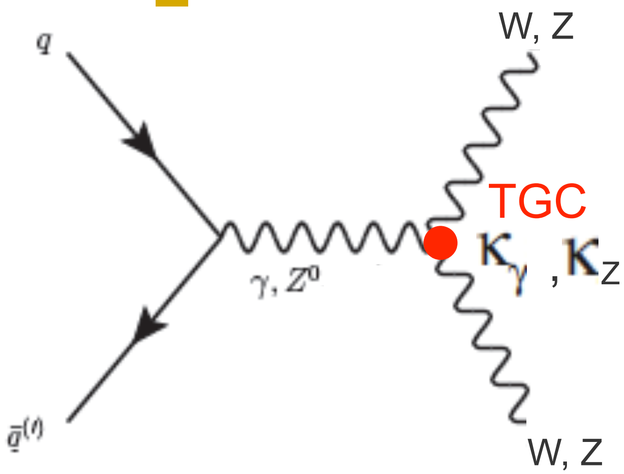
Fermilab

CMS Collaboration

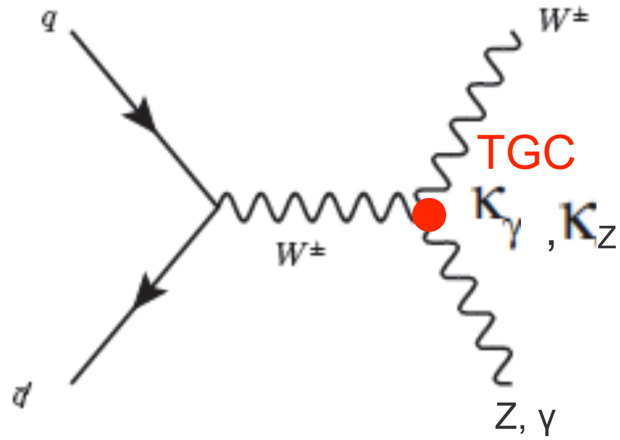
- Mechanism to produce diboson events at LHC
- Measurement of cross sections for WW, WZ, ZZ, Wγ, and Zγ
- Limits on anomalous triple gauge couplings

DPF 2011 at Brown University, August 12, 2011

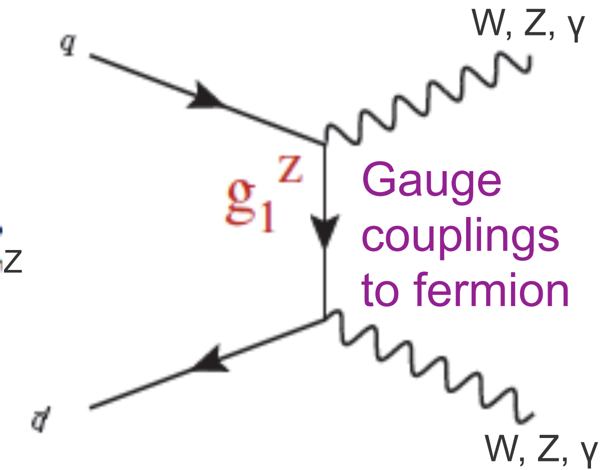
Diboson production at LHC at Leading Order in α_S



s-channel production of WW, ZZ



s-channel WZ, Wγ production



t-channel production of WW, Wγ, Zγ, WZ, ZZ

Some quick Observations

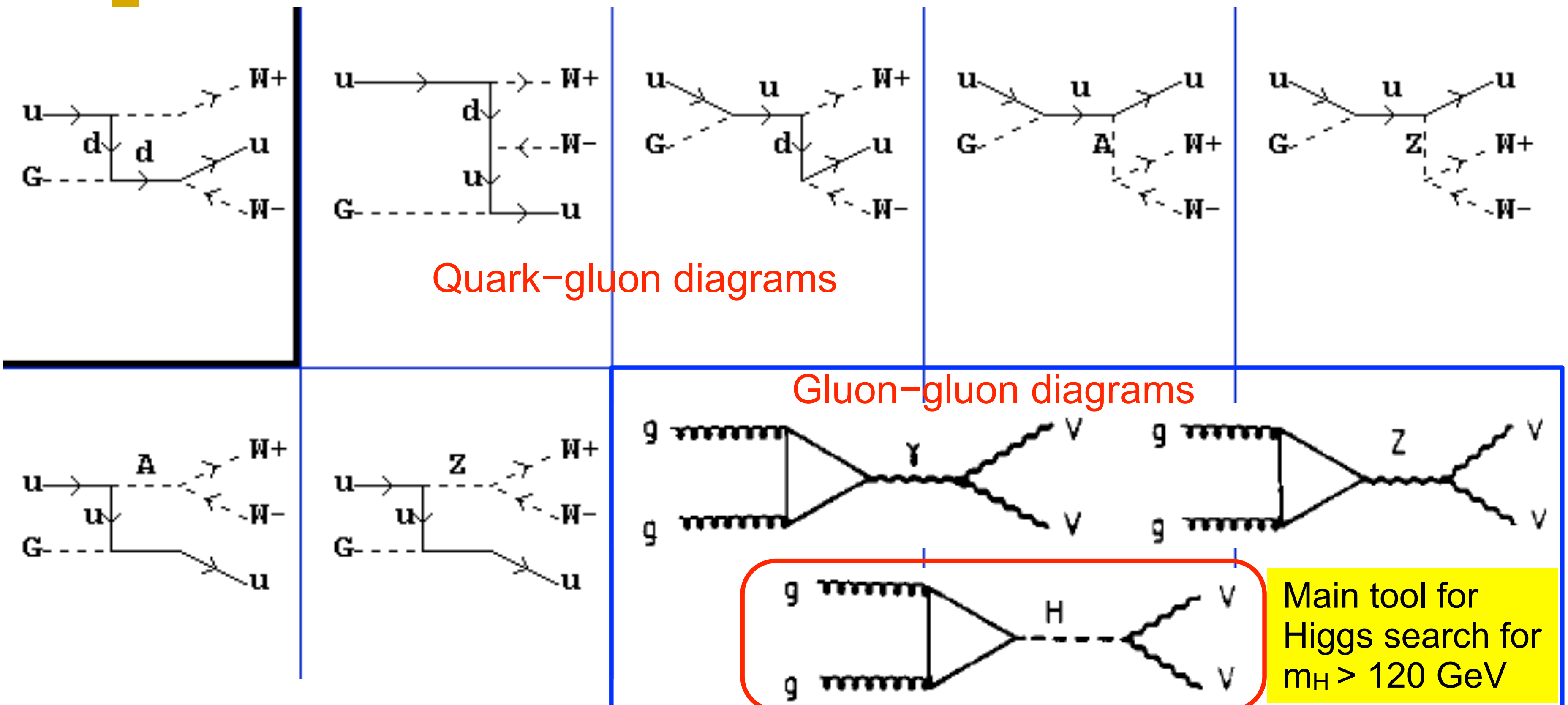
✦In SM, the s- and t-channel WW diagrams are divergent but when combined these divergencies cancel out miraculously.

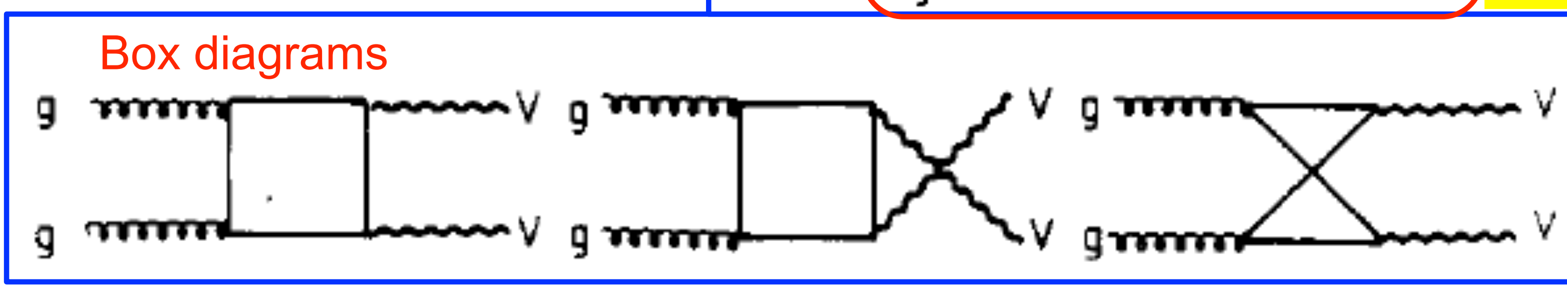
✦Because of qq initial state the production rate at LHC only ~3x Tevatron.

✦Allow test of the triple-gauge coupling (TGC) of the SM. Deviation from SM values can give clues about EWK symmetry breaking mechanism.

It gets even more interesting at NLO →

Diboson production mechanism at NLO

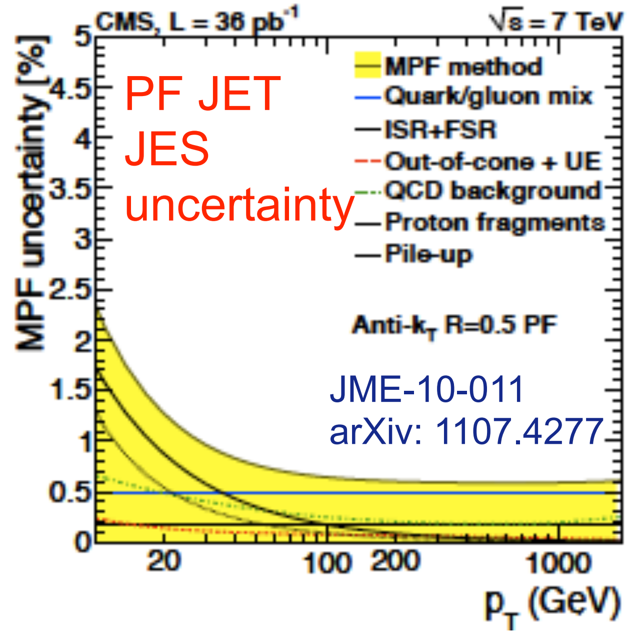




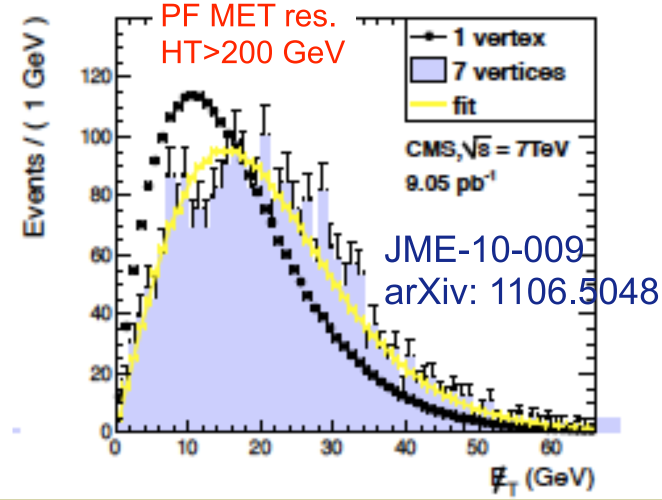
Plus more diagrams from NLO in α_{EWK}

Building blocks for diboson analysis: jet & $\not{E}_T$

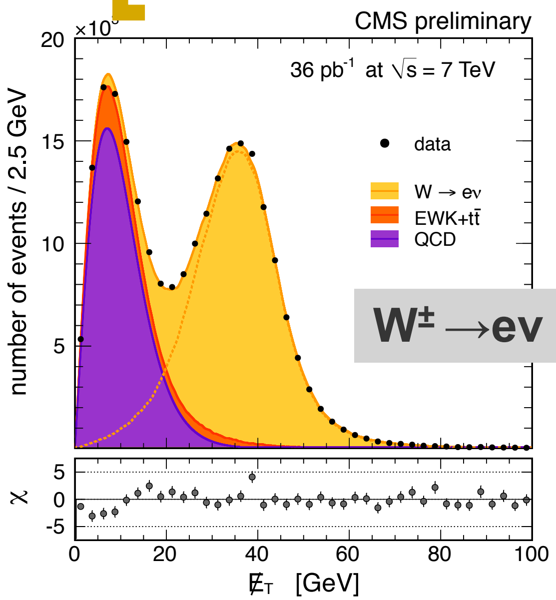
✦Jet and Missing ET reconstruction uses **Particle Flow** (PF) technique:
- -All tracks/energy deposits sorted into charged/neutral hadron, electron, photon, or muon candidates
- -Resulting set of corrected particles input to jet clustering, MET determination, H_T, M_T, etc.
- -Significant improvement over traditional "CaloJets" for ~low-medium p_T jets with tracker coverage

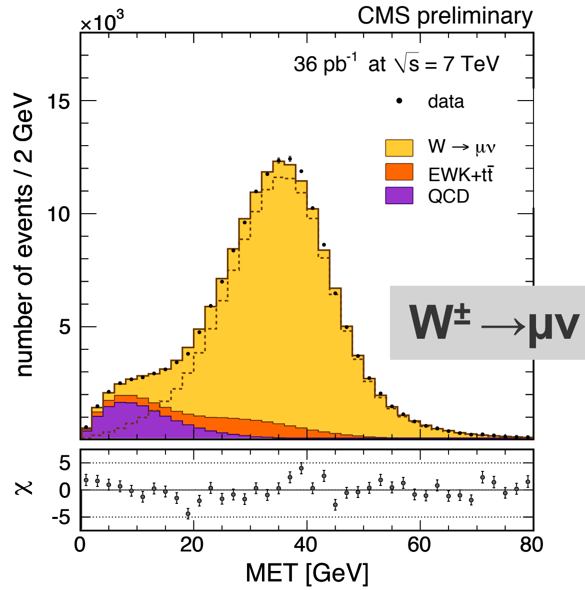


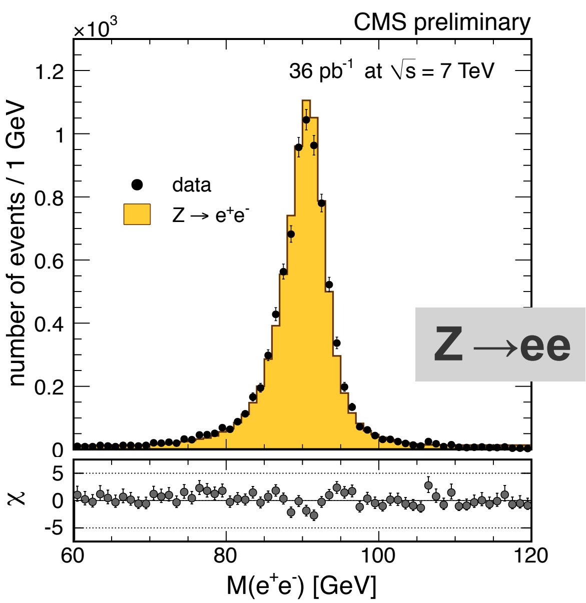
✦**Anti-kT clustering with R=0.5**
- -Jet Energy Scale known to 1−3%
- -MET resolution in dijet events ~10 GeV

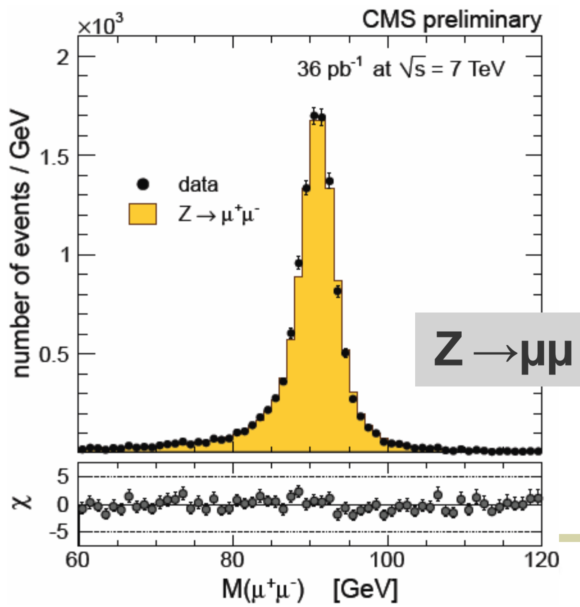


Leptons & MET: W and Z reconstruction









arXiv:1107.4789, CMS-EWK-10-005
JHEP Vol. 2011, Number 1, 1-40

- ✦Fully reco'ble, high purity
- ✦MET well understood
- ✦Lepton energy scale and resolution well measured
- ✦Tiny experimental errors
  - -luminosity, theory dominate uncertainty

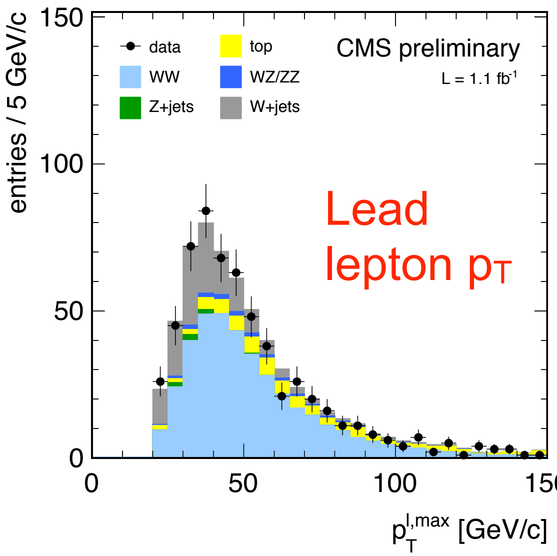
280000 W's in 36 pb^{-1}

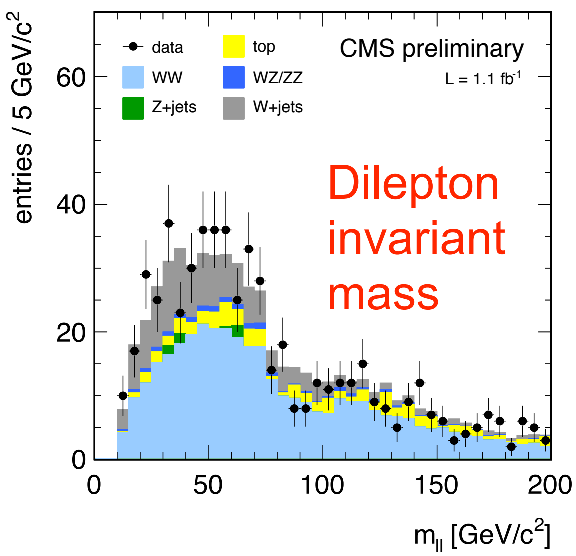
cross section x BR = 10.31 ± 0.02 (stat) ± 0.09 (syst) ± 0.10 (th.) ± 0.41 (lumi) nb

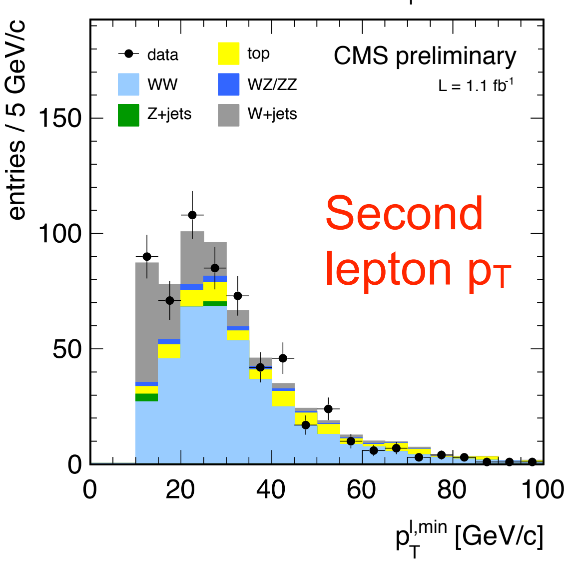
20000 Z's in 36 pb^{-1}

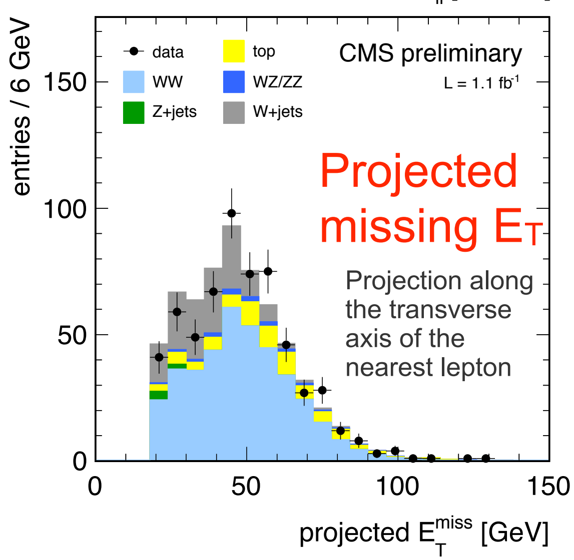
cross section x BR = 0.975 ± 0.007 (stat) ± 0.007 (syst) ± 0.018 (th.) ± 0.039 (lumi) nb

WW→2l2ν analysis









http://cdsweb.cern.ch/record/1370067?ln=en

arXiv:1102.5429, CMS-PAS-EWK-11-010
Phys. Lett. B 699: 25-47 (2011)

- ✦Signal: 2 iso leptons+ MET
- ✦Reduction of major bkgs:
  - –W+jets, ttbar: central jet veto (above 30 GeV), b-veto
  - –DY reduced by MET requirement, and
    - $m_{ll} > 12$ GeV, and veto $76 < m_{ll} < 106$ GeV
    - $\Delta\phi$(dilepton, jet) <165°
  - –WZ/ZZ: veto 3rd lepton
  - –Z→ττ: projected MET
- ✦Use <u>counting</u> method to estimate #signal
- ✦Efficiency: *Tag&Probe*

WW→2l2ν cross section measurement (1.1 fb^{-1})

Number of events

Sample	Yield
$qq \to W^+W^-$	349.7 ± 30.3
$gg \to W^+W^-$	17.2 ± 1.6
W + jets	106.9 ± 38.9
$t\bar{t} + tW$	63.8 ± 15.9
$Z/\gamma^* \to \ell\ell + WZ + ZZ$	12.2 ± 5.3
$Z/\gamma^* \to \tau\tau$	1.6 ± 0.4
WZ/ZZ not in $Z/\gamma^* \to \ell\ell$	8.5 ± 0.9
$W + \gamma$	8.7 ± 1.7
signal + background	568.6 ± 52.2
Data	626

Main systematic uncertainties

source	uncertainty
background estimation	$\sim 20\%$
W + jet	36%
top	25%
signal efficiency	$\sim 8\%$
lepton efficiencies	1.5 – 2.5%
E_T^{miss} resolution	2.0%
jet counting	5.5%

Background components:

- Major Backgrounds
  - QCD / W+jet
  - Top
  - Z/WZ/ZZ

  Data Driven
- Smaller backgrounds
  - Wγ
  - *Z→ττ*
  - non resonant WZ/ZZ

  MC Simulation

Efficiencies

- Tag & Probe for lepton efficiencies
- Jet veto: simulation + correction with a Z+jet control sample
- Selection Missing ET

Total Efficiency(ε) = 6.7 ± 0.5 %

Acceptance = 72.5 ± 0.4 %

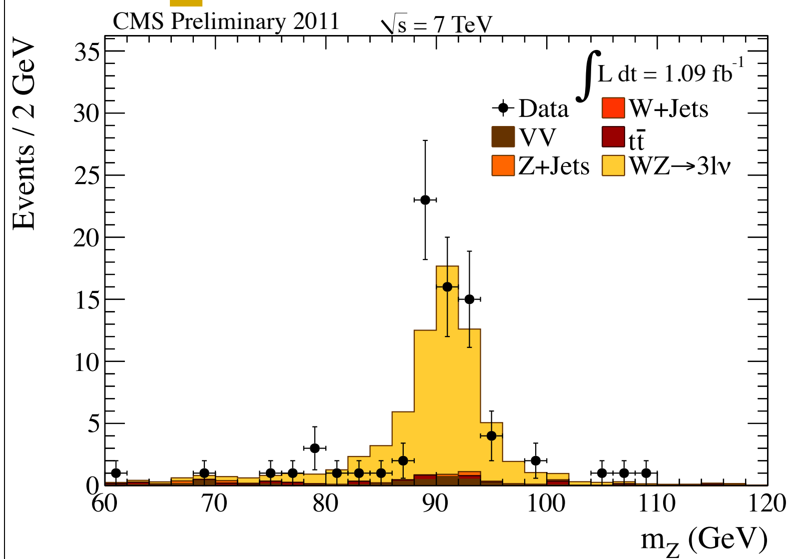
Cross section

$$\sigma \cdot Br = \frac{N_{candidates} - N_{background}}{Acceptance \cdot Efficiency \cdot L}$$

$$\sigma_{W^+W^-} = 55.3 \pm 3.3\,(stat) \pm 6.9\,(syst) \pm 3.3\,(lumi)$$

NLO: 43.0 ± 2.1 ($qq \to W^+W^-$) + 1.46 pb ($gg \to WW$)

WZ→3lν cross section measurement (1.1 fb^{-1})



http://cdsweb.cern.ch/record/1370067?ln=en
CMS-PAS-EWK-11-010

✦Two isolated leptons with p_T 20/10 GeV for electrons or p_T > 15 GeV for muons.
✦3rd isolated lepton p_T > 20 GeV, MET>30 GeV
✦60 < m_{ll} < 120 GeV. Ambiguities resolved by taking the Z candidate closest to M_Z. Veto 2nd Z.

Tiny background. Estimate TTbar and Z +jets from data using matrix method. Take Zγ and ZZ from MC.

Channel	A_{kin}	$A \cdot \epsilon$
eee	0.482 ± 0.003	$0.193 \pm 0.003(stat)$
$ee\mu$	0.488 ± 0.003	$0.234 \pm 0.003(stat)$
$\mu\mu e$	0.432 ± 0.003	$0.190 \pm 0.003(stat)$
$\mu\mu\mu$	0.454 ± 0.003	$0.249 \pm 0.003(stat)$

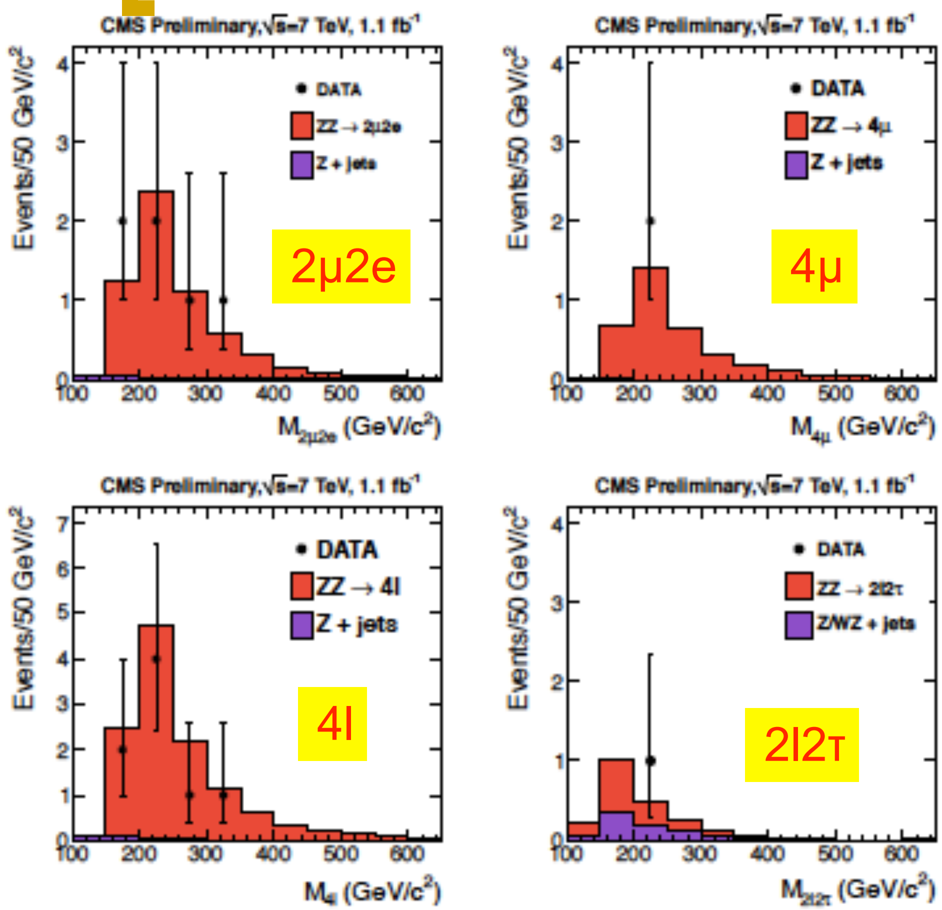
channel	$N_{observed}$	cross section (pb) x BR
$\sigma_{WZ \to eee\nu}$	22	$0.086 \pm 0.022(stat) \pm 0.007(syst) \pm 0.005(lumi)$
$\sigma_{WZ \to ee\mu\nu}$	20	$0.060 \pm 0.017(stat) \pm 0.005(syst) \pm 0.004(lumi)$
$\sigma_{WZ \to \mu\mu e\nu}$	13	$0.053 \pm 0.018(stat) \pm 0.004(syst) \pm 0.003(lumi)$
$\sigma_{WZ \to \mu\mu\mu\nu}$	20	$0.060 \pm 0.016(stat) \pm 0.004(syst) \pm 0.004(lumi)$

Main systematics: bkg estimation, efficiency, acceptance/theory.

$$\sigma(pp \to WZ + X) = 17.0 \pm 2.4\ (\text{stat.}) \pm 1.1\ (\text{syst.}) \pm 1.0\ (\text{lumi.})\ \text{pb}.$$

NLO prediction = 19.8 ± 0.1 pb

$ZZ \rightarrow 4l$ cross section measurement ($1.1\ fb^{-1}$)



http://cdsweb.cern.ch/record/1370067?ln=en

CMS-PAS-EWK-11-010

✦First Z: Two isolated leptons of same flavor with p_T 20/10 GeV, opposite sign, $60 < m_{ll} < 120$ GeV.

✦Second Z:

-for $ZZ \rightarrow 4e, 4\mu, 2e2\mu$ final states: same as first Z except p_T>7 (5) GeV for e(μ) for both leptons.

-for $ZZ \rightarrow 2l2\tau$ (l=e, μ) final state:

•Tau (p_T>15 GeV) → lepton (p_T>10 GeV) / hadron (p_T>20 GeV)

•30 < visible $m_{\tau\tau}$ < 80 GeV

Final state	N_{obs}	$N^{backg.}_{estimated}$	$N^{ZZ}_{expected}$
4μ	2	0.004 ± 0.004	3.7 ± 0.4
$4e$	0	0.14 ± 0.06	2.5 ± 0.2
$2e2\mu$	6	0.15 ± 0.06	6.3 ± 0.6
$2l2\tau$	1	0.8 ± 0.1	1.4 ± 0.1

Acceptance:

0.56–0.59 for the 4μ, $4e$ and $2e2\mu$

0.18–0.21 for the $2l2\tau$

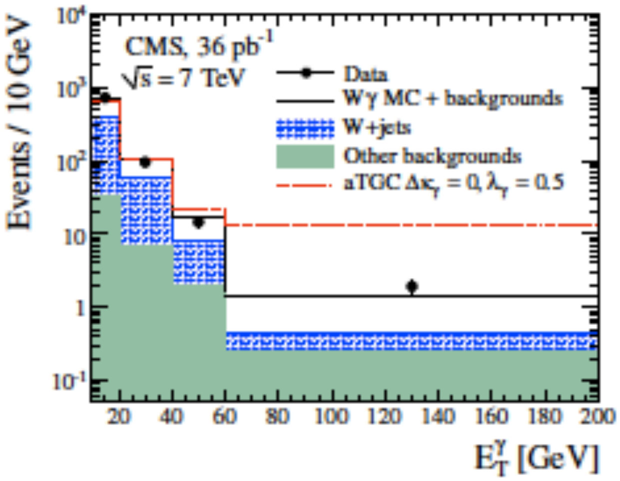
Efficiency: Similar to previous slide

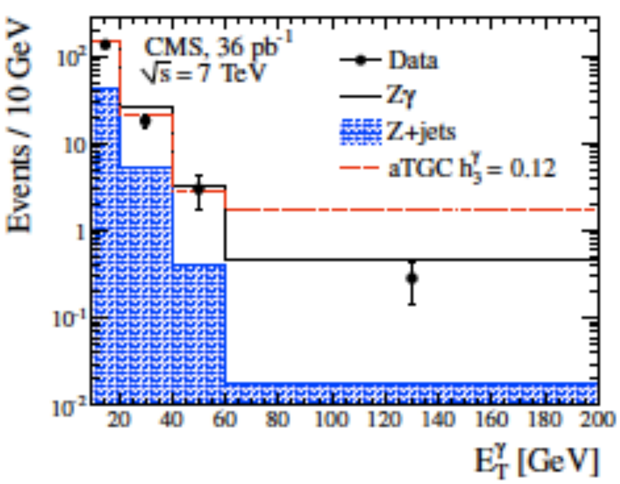
$$\sigma(pp \rightarrow ZZ + X) = 3.8^{+1.5}_{-1.2}(\text{stat.}) \pm 0.2(\text{sys.}) \pm 0.2(\text{lumi.})\ \text{pb}$$

NLO prediction = 6.4 ± 0.6 pb

W(→lν)γ and Z(→ll)γ cross section (36 pb^{-1})

arXiv:1105.2758, CMS-EWK-10-008
Phys. Lett. B 701, 535 (2011)





- W: isolated lepton p_T>20 GeV, MET>25 GeV
- Z: two isolated leptons p_T>20 GeV, m_{ll}>50 GeV
- γ: E_T>20 GeV, ΔR(l,γ) > 0.7, No additional lepton

Main background from W/Z+jets. Fit shower shape distribution in data to estimate. All other bkg from MC.

Wγ

process	$N_{bkg}^{e\nu}$	$N_{bkg}^{\mu\nu}$
W+jet	$220 \pm 16 \pm 14$	$261 \pm 19 \pm 16$
other backgrounds	7.7 ± 0.5	16.4 ± 1.0
all data	452	520

Zγ

process		
Z+jet	$20.5 \pm 1.7 \pm 1.9$	$27.3 \pm 2.2 \pm 2.3$
other backgrounds	neglected	
all data	81	90

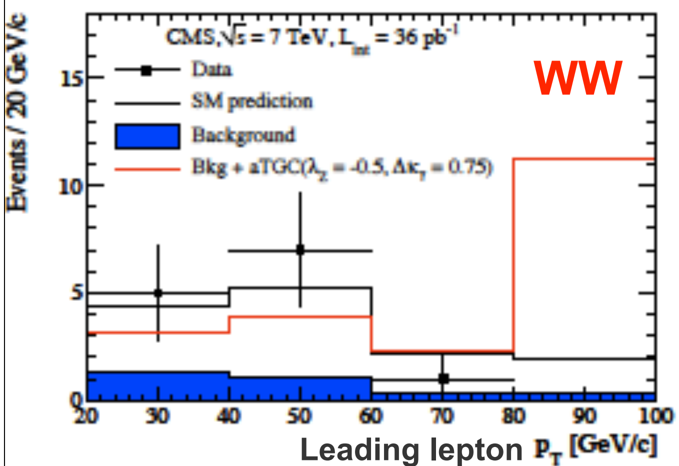
σ(pp→Wγ→eνγ) = 56.7 ± 6.9 (stat.) ± 5.1 (syst.) ± 6.2 (lumi.) pb
σ(pp→Wγ→μνγ) = 55.0 ± 7.2 (stat.) ± 5.0 (syst.) ± 6.1 (lumi.) pb
σ(pp→Wγ→lνγ) = 55.9 ± 5.0 (stat.) ± 5.0 (syst.) ± 6.1 (lumi.) pb
σ(pp→Wγ→lνγ) = 49.4 ± 3.0 pb (NLO)

σ(pp→Zγ→eeγ) = 9.4 ± 1.4 (stat.) ± 0.7 (syst.) ± 1.0 (lumi.) pb
σ(pp→Zγ→μμγ) = 9.2 ± 1.4 (stat.) ± 0.6 (syst.) ± 1.0 (lumi.) pb
σ(pp→Zγ→llγ) = 9.3 ± 1.0 (stat.) ± 0.6 (syst.) ± 1.0 (lumi.) pb
σ(pp→Zγ→llγ) = 9.6 ± 0.4 pb (NLO)

systematics dominated by background uncertainty

Limits on anomalous TGC from 36 pb^{-1} data

Limit set using p_T of the γ or leading lepton (MCFM/Sherpa/ Bour for aTGC)

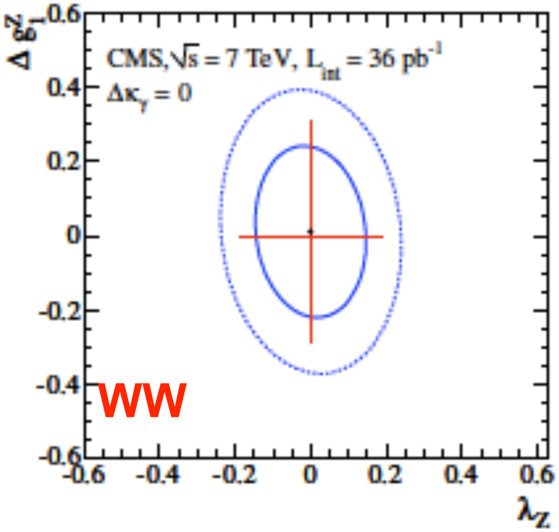


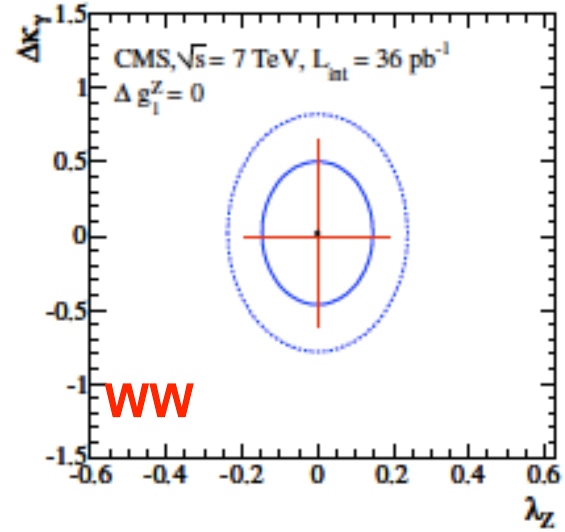
λ_Z	Δg_1^Z	$\Delta\kappa_\gamma$
$[-0.19, 0.19]$	$[-0.29, 0.31]$	$[-0.61, 0.65]$

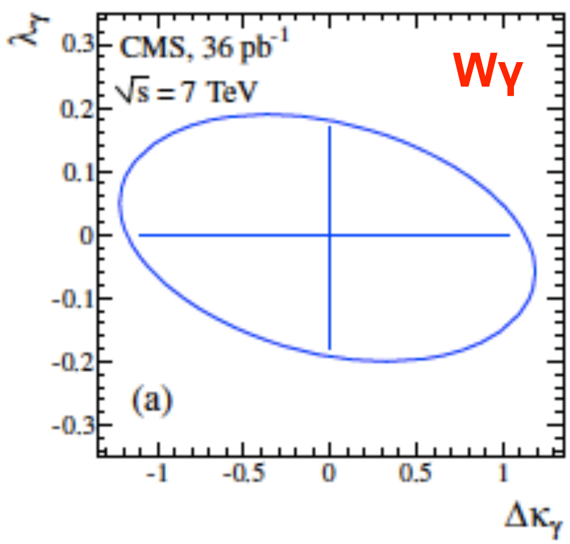
$WW\gamma$	$ZZ\gamma$
$-1.11 < \Delta\kappa_\gamma < 1.04$	$-0.05 < h_3 < 0.06$
$-0.18 < \lambda_\gamma < 0.17$	$-0.0005 < h_4 < 0.0005$

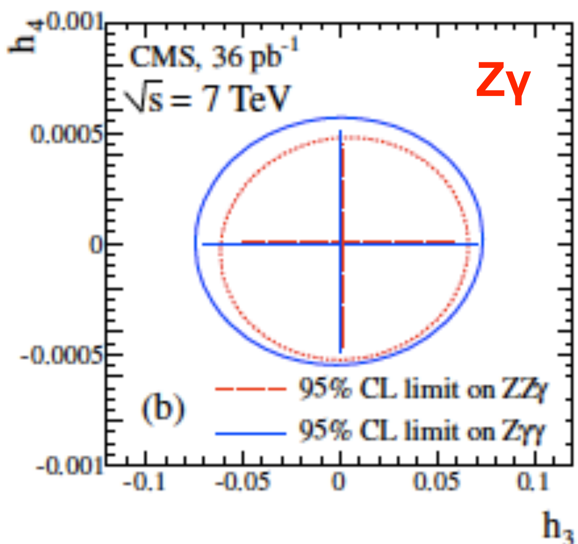
Similar sensitivity to Tevatron results presented in :

- Phys. Rev. Lett. 104 (2010) 201801
- Phys. Rev. Lett. 103 (2009) 191801





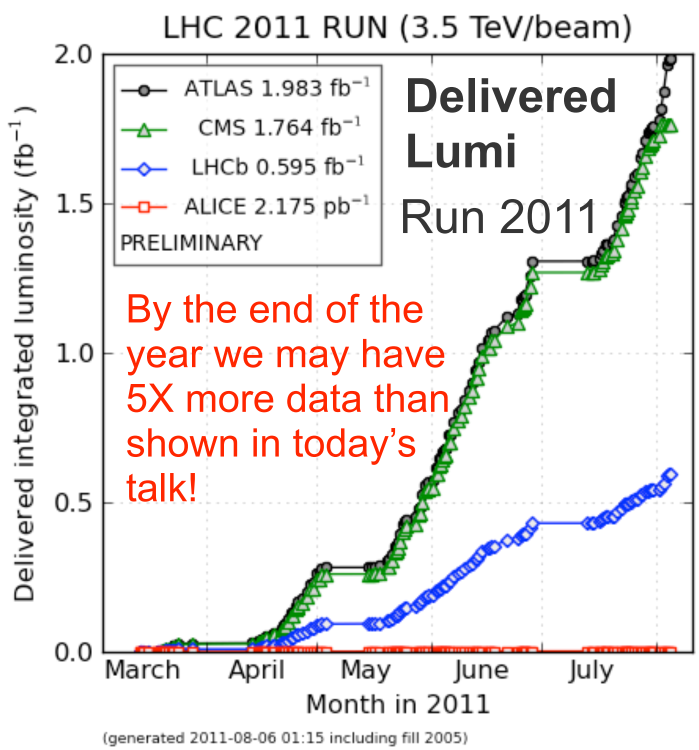




Outlook for 2011 data collection and beyond

Outlook is bright

Target:
To get 5–10 fb^{-1} at $\sqrt{s}$ = 7 TeV by year end. Aim for 5E33 instantaneous lumi.



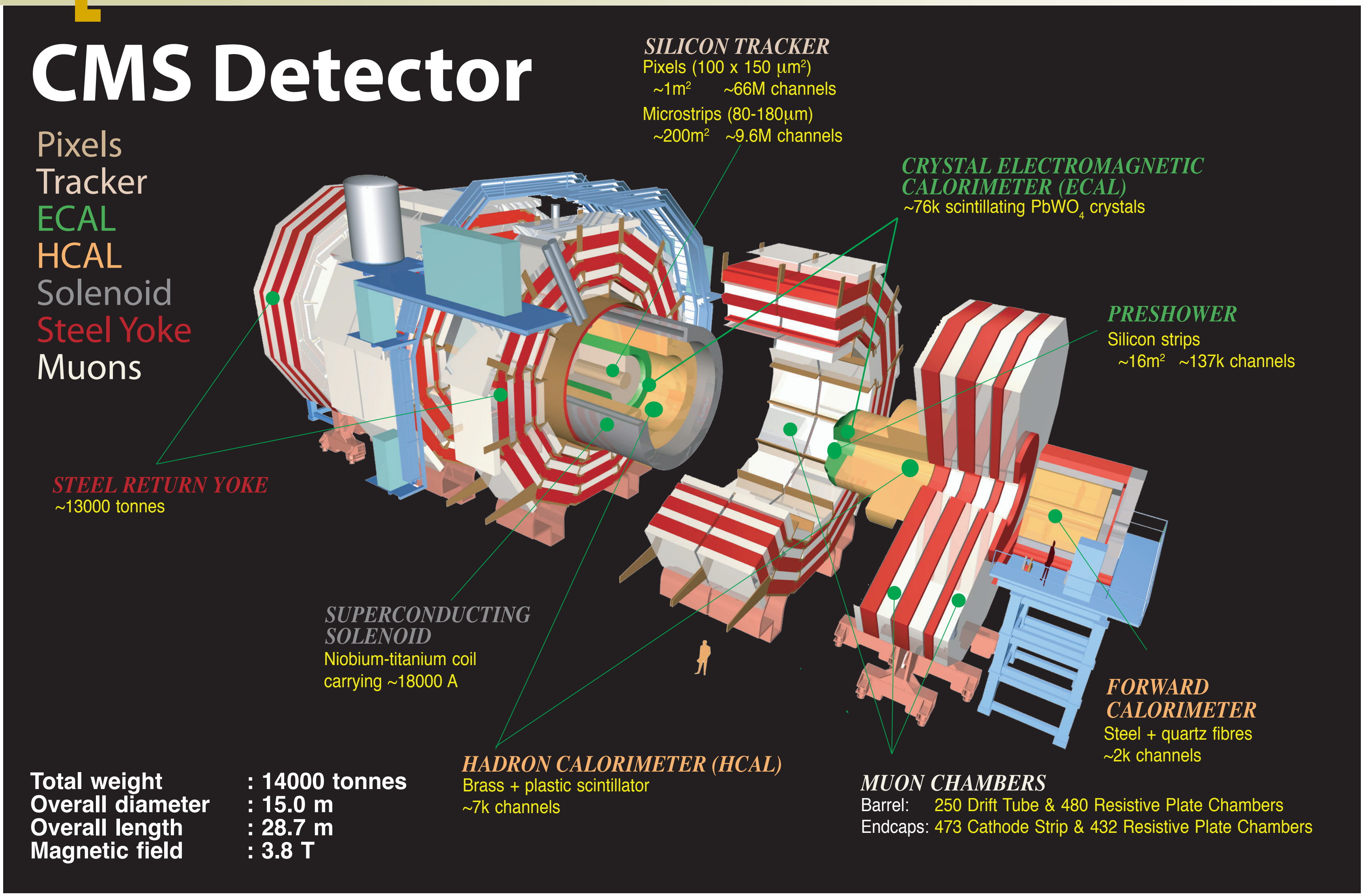
- Breaking news: LHC sets new world record luminosity: **2.09** $nb^{-1}s^{-1}$ (i.e., 2E33)
  - setting new world record ~every day
- On April 22nd LHC set a new world record for beam intensity at a hadron collider when it collided beams with a luminosity of 467 $\mu b^{-1}s^{-1}$
  - this exceeded the previous world record of 420 $\mu b^{-1}s^{-1}$ by the Tevatron
- Moving to continuous physics running
  - short technical stop in December, then physics run until end of 2012
  - already delivered **~2 fb^{-1}** per expt

Summary

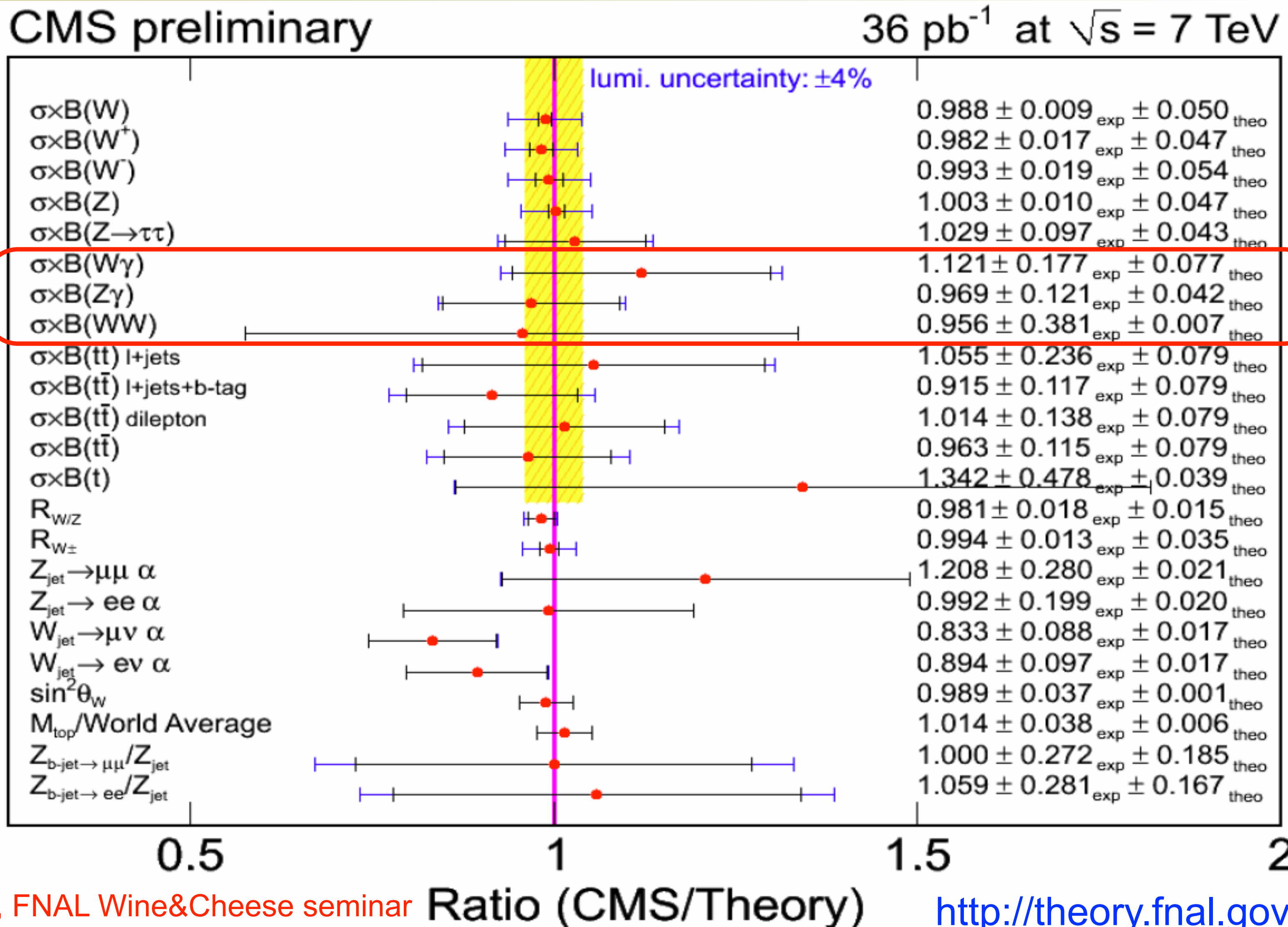
- ☑ Diboson processes WW, WZ, ZZ, Wγ, and Zγ measured in CMS
- ☑ All results show good agreement withthe SM predictions and with most of the state of the art MC predictions
- ☑ CMS measurements of anomalous triple gauge boson couplings competitive to Tevatron and LEP
- ☑ More golden opportunities and new exciting results with increasing integrated luminosity

BACKUP SLIDES

Understanding CMS detector



Measurement of well-known SM processes



J. Berryhill, FNAL Wine&Cheese seminar
March 25, 2011

http://theory.fnal.gov/jetp/