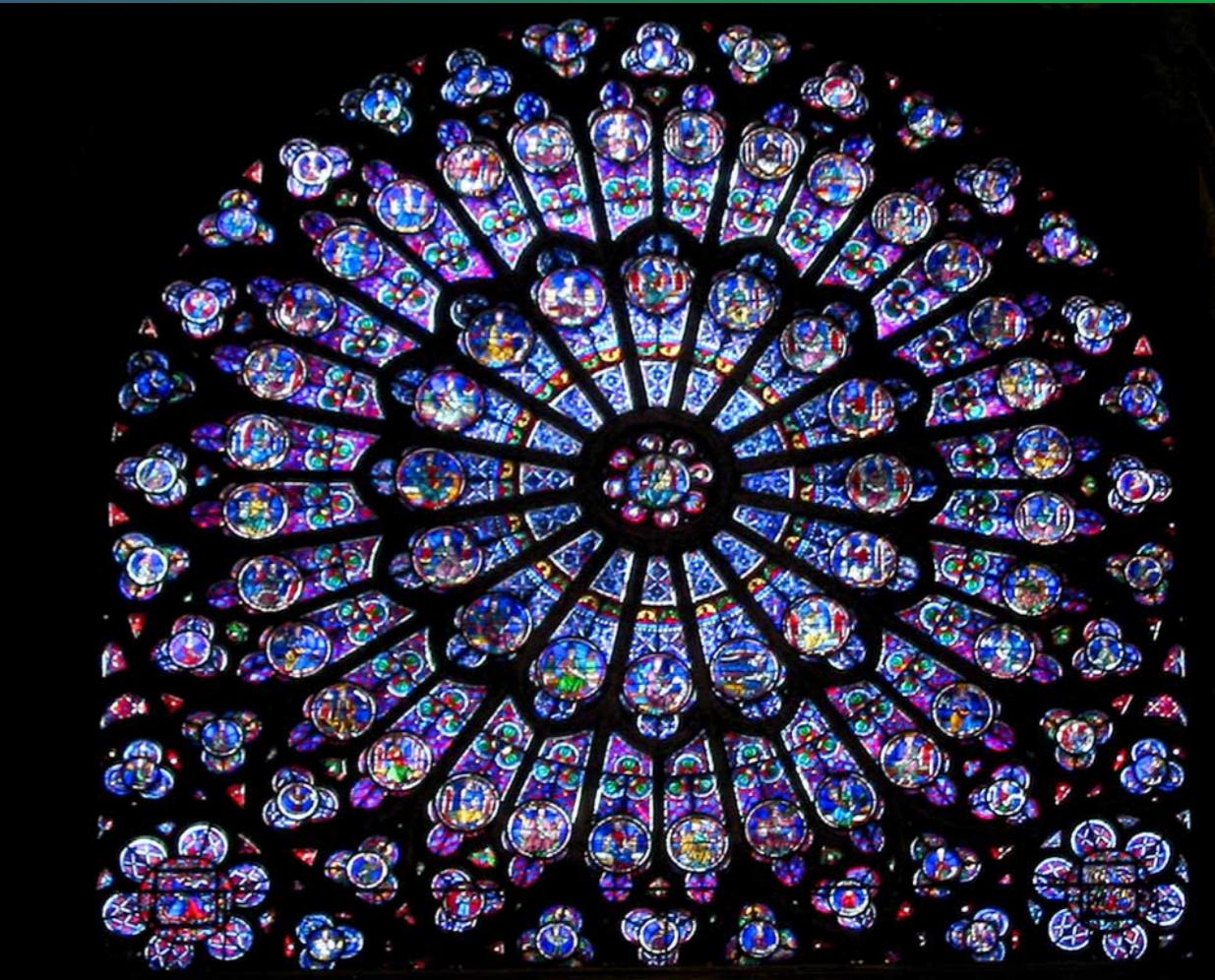
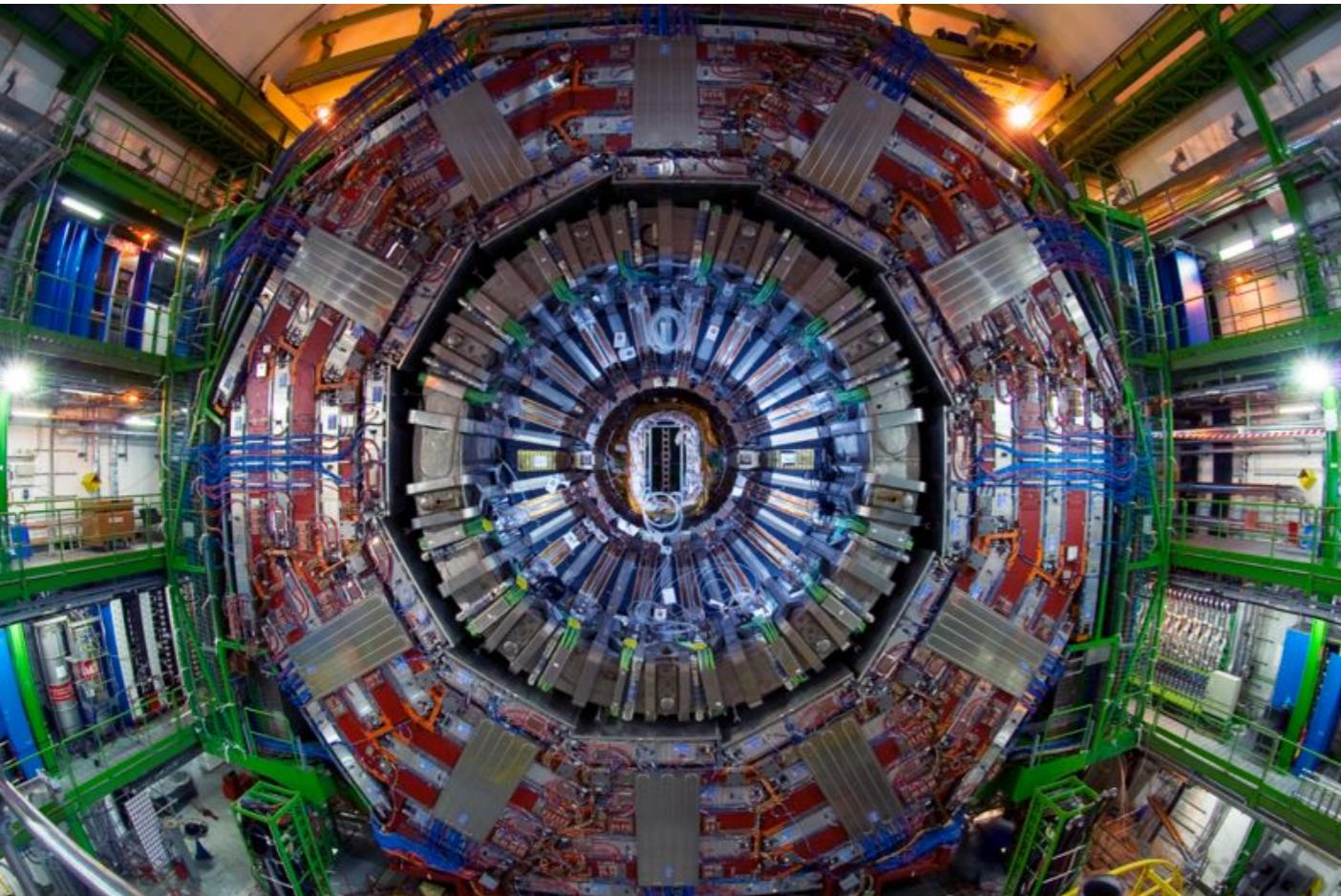




Dibosons @ CMS

Tulika Bose, Arabella Martelli

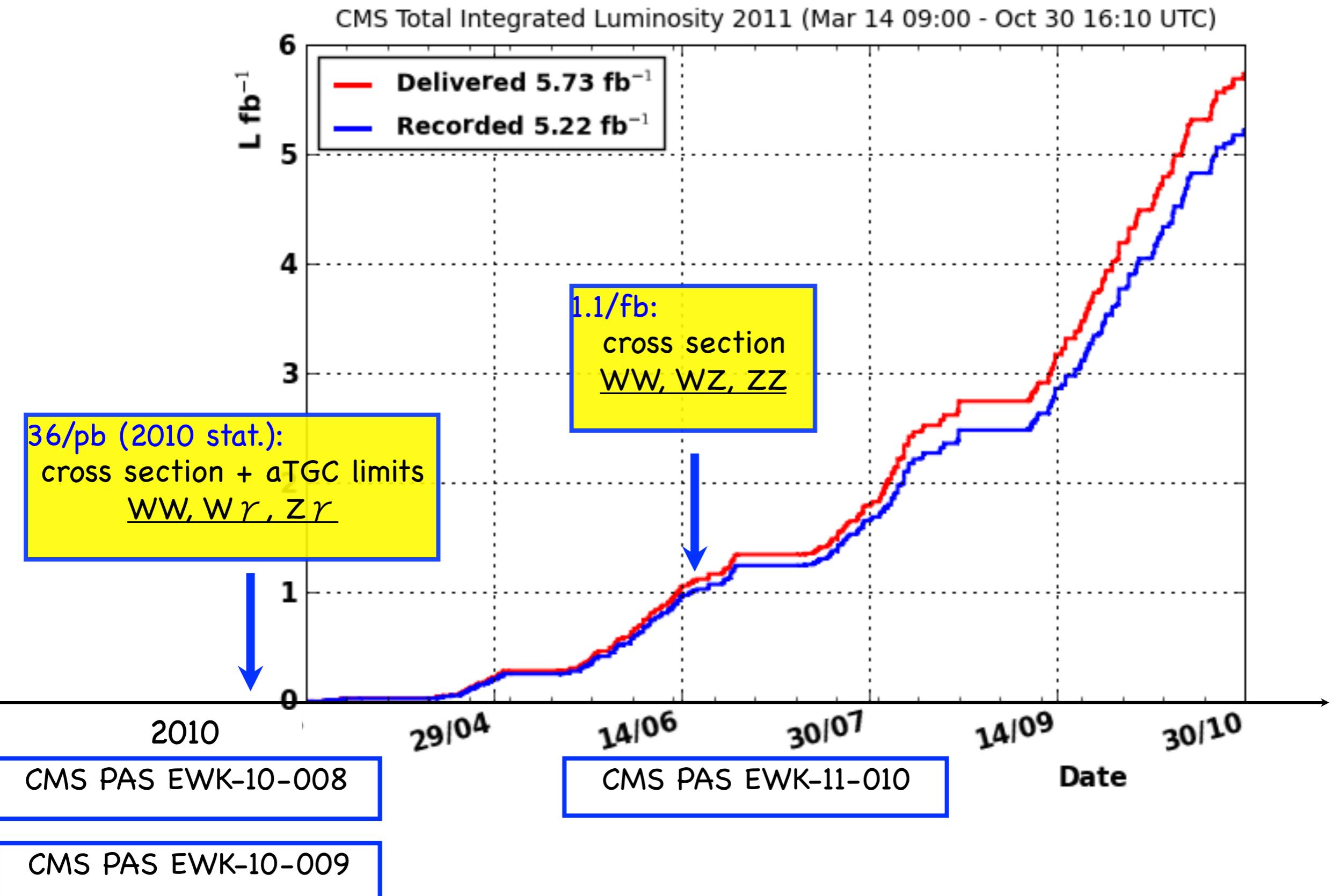
On behalf of the CMS Collaboration



HCP 2011, Paris
15th November, 2011

Dibosons @ CMS

- Leptonic decay channels only



Physics Motivation

- Important test of the Standard Model, sensitivity to self-interactions between bosons

- Diboson production as indirect probe of New Physics

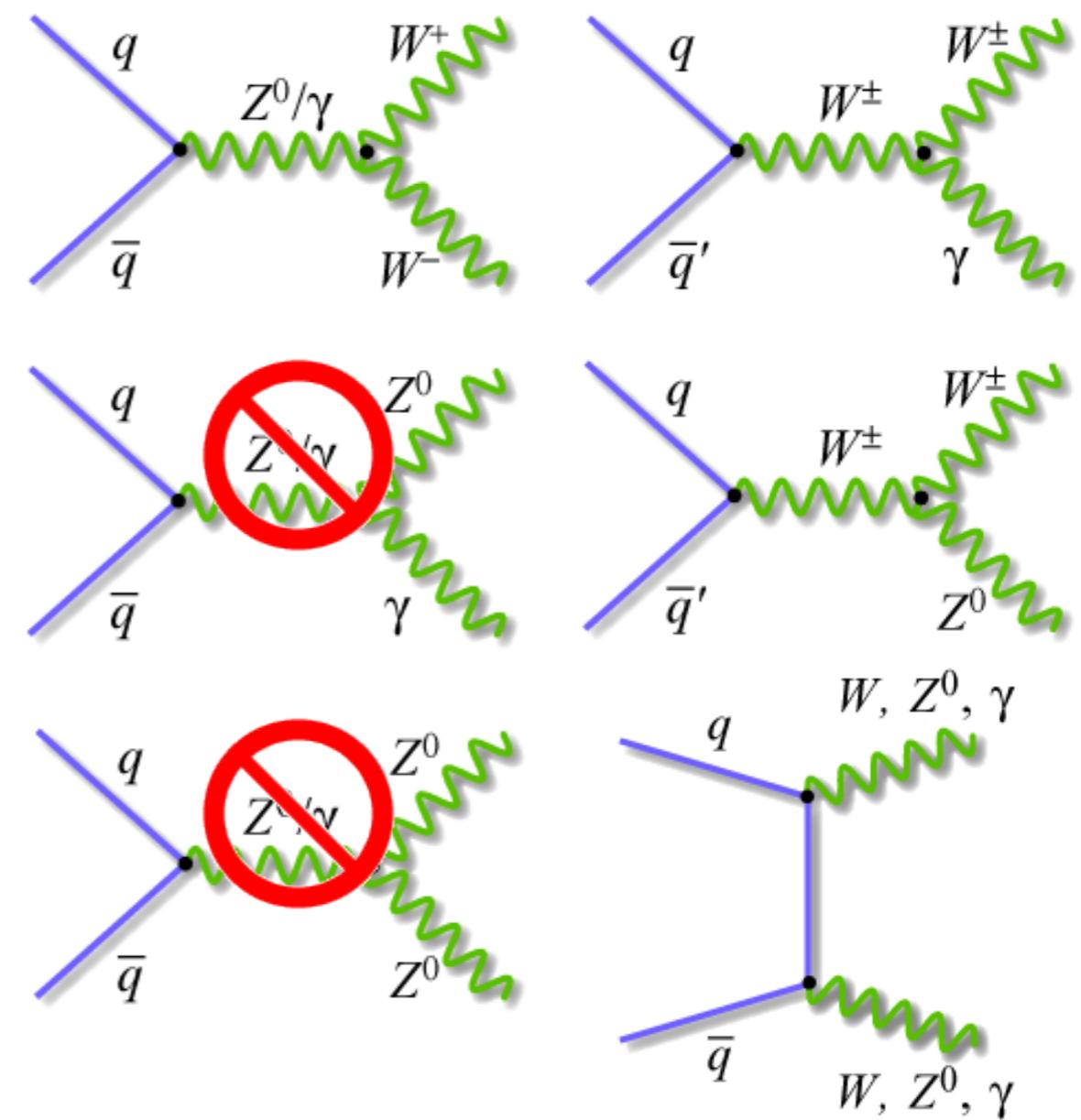
- enhancement of production cross section
 - anomalous TGC
 - hint of new physics, if not high enough energy for direct production

- Improve background modeling for

- Exotic channels (WZ , ZZ)
 - Higgs searches (WW , ZZ)

- Interest here in measuring:

- production cross section, TGCs
 - leptonic mode:
clean signature, low QCD background
(reduced BR)



TGC measurements

- Considering CP conserving effective Lagrangian + SU(2)xU(1) gauge invariance

- WWZ/WW γ

o $L_{eff}^{WWV} = -i g_{WWV} \left[g_1^V (W_{\mu\nu}^\dagger W^{\mu\nu} - W_\mu^\dagger V^\nu W^{\mu\nu}) + k_V W_\mu^\dagger W_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W_{\rho\nu}^\dagger W_\nu^\mu V^{\rho\nu} \right]$
where $V = \gamma, Z$ $g_{WW\gamma} = e$, $g_{WWZ} = e \cot\theta_W$

- ZZ γ

o $\Gamma_{ZZ\gamma}^{\alpha\beta\mu} = \frac{P^2 - q_1^2}{m_Z^2} (h_1^Z (q_2^\mu g^{\alpha\beta} - q_2^\alpha g^{\mu\beta}) + \frac{h_2^Z}{m_Z^2} P^\alpha [(P \cdot q_2) g^{\mu\beta} - q_2^\mu P^\beta] + h_3^Z \epsilon^{\mu\alpha\beta\rho} q_{2\rho} + \frac{h_4^Z}{m_Z^2} P^\alpha \epsilon^{\mu\beta\rho\sigma} P_\rho q_{2\sigma})$

- Z $\gamma\gamma$

- o by replacing

$$\frac{P^2 - q_1^2}{m_Z^2} \rightarrow \frac{P^2}{m_Z^2} \text{ and } h_i^Z \rightarrow h_i^\gamma, i = 1, \dots, 4$$

- SM expectation: $g^V_1 = 1, k^V_1 = 1, \lambda_V = 0 \quad h^V_3, h^V_4 = 0$ (tree level SM)

- Measure here, deviation from SM expectation: $\Delta g_1, \Delta k_\gamma, \Delta k_Z, \lambda_\gamma, \lambda_Z$

$$\Delta g_1^Z \equiv g_1^Z - 1, \Delta k_Z \equiv k_Z - 1, \lambda_Z$$

Objects used (CMS)

- Profit from precise measurements
 - high eff. reco & ID on a wide range

- Photons:

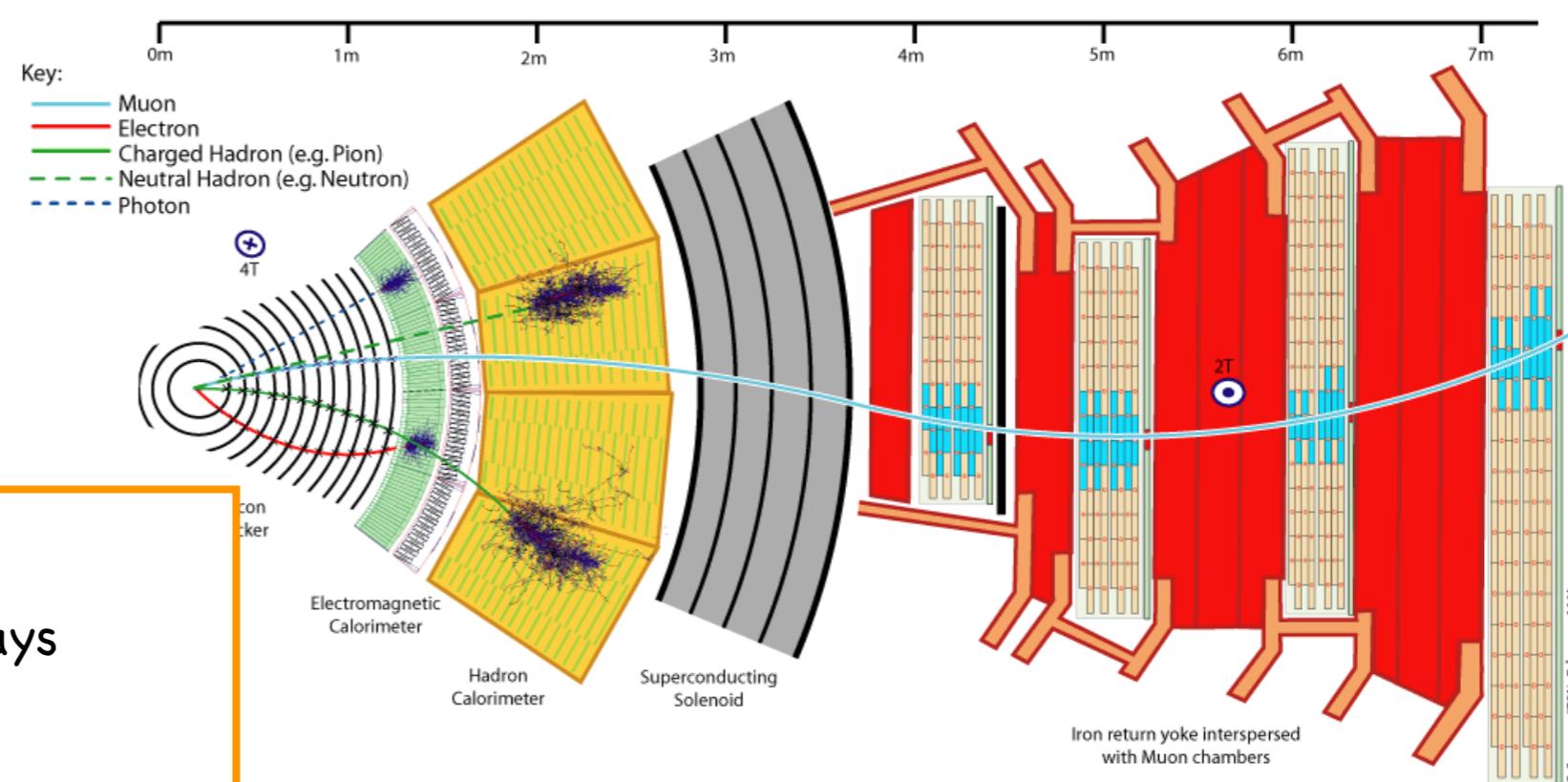
- $|\eta| < 1.44 \parallel 1.57 < |\eta| < 2.5$
- $E_T > 10\text{GeV}$
- energy scale within 2%
(FSR $Z \rightarrow \mu\mu\gamma$ to cross check)

- Electrons:

- $|\eta| < 2.5$
- $p_T > 10\text{GeV}/c$
- (down to $7\text{GeV}/c$ for ZZ)

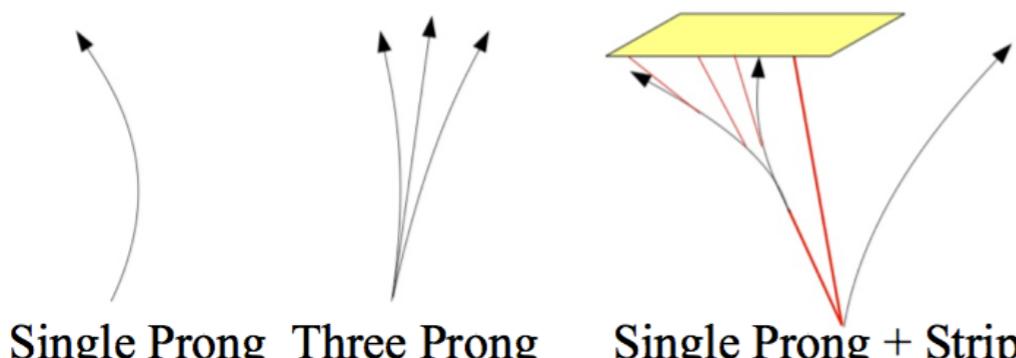
- Muons:

- $|\eta| < 2.4$
- $p_T > 10\text{GeV}/c$
- (down to $5\text{GeV}/c$ for ZZ)



- Taus:

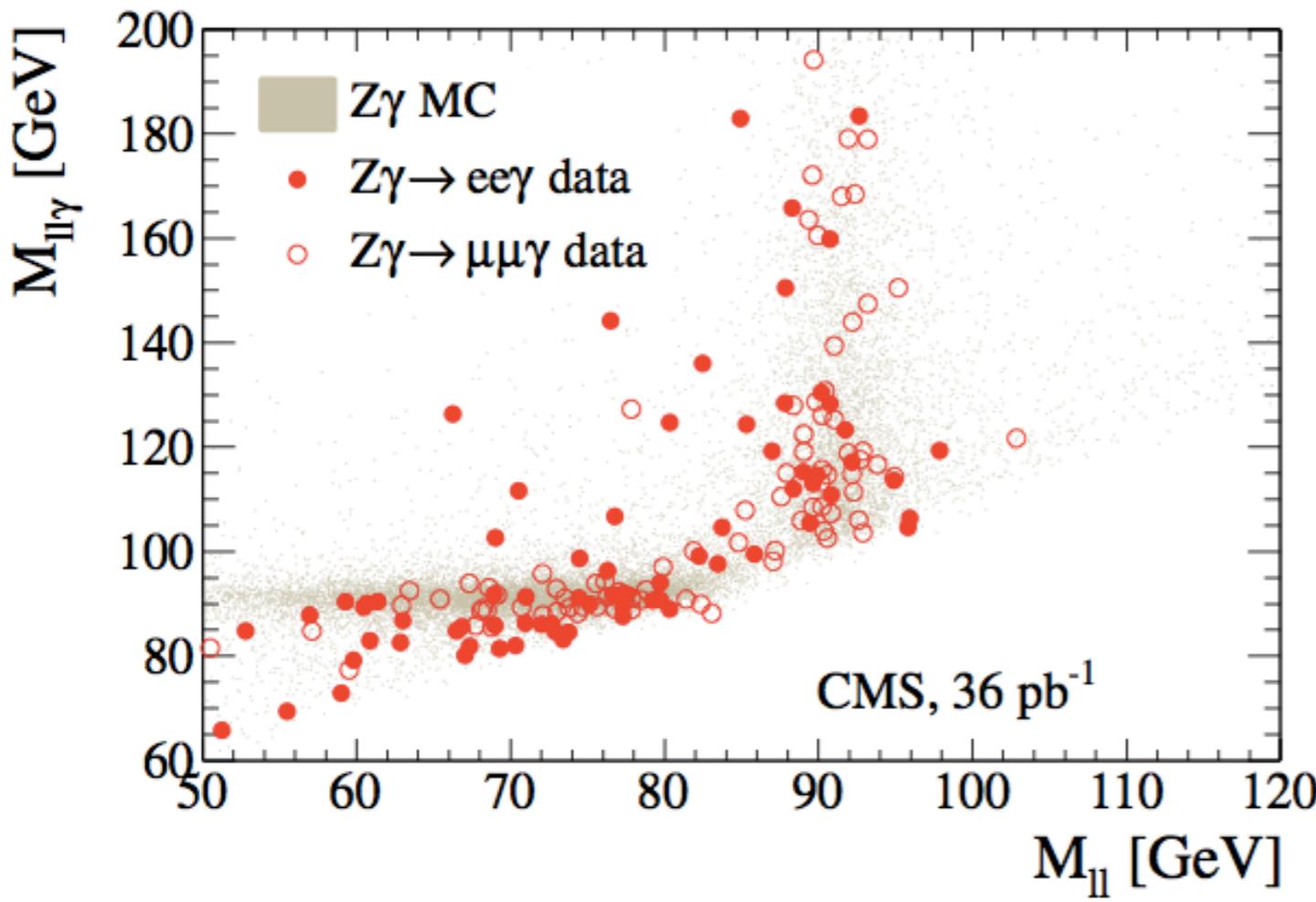
- reconstructed in e, μ hadron decays
- $\tau_{\text{had}}: |\eta| < 2.3$
- $\tau_{\text{had}}: p_T > 20\text{GeV}/c$



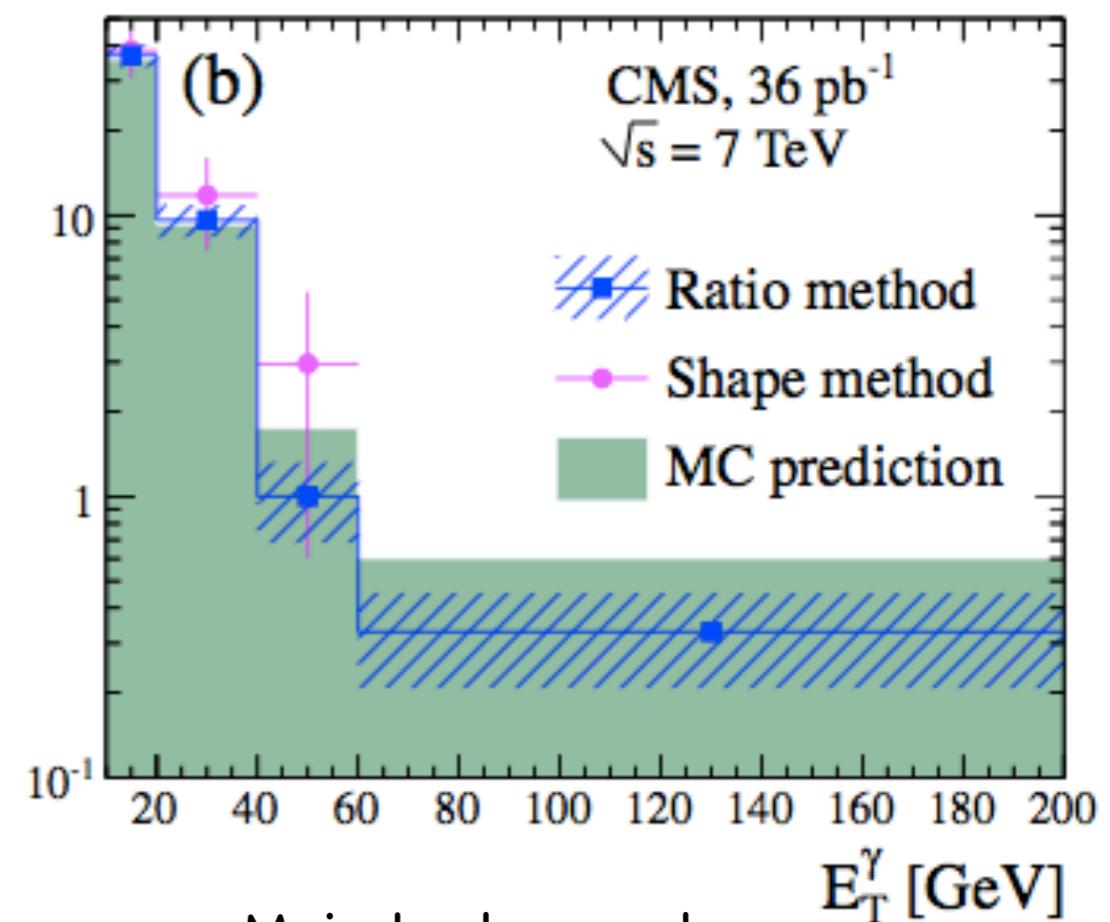
Algorithms safe-against pileup
(2011 analysis)

- Signature:

- 2 Iso-Id lepton + Iso-Id γ
 - $pT(l) > 20\text{GeV}/c$
 - $M(ll) > 50\text{GeV}/c^2$
 - $ET(\gamma) > 10\text{ GeV}$
 - $\Delta R(l, \gamma) > 0.7$
- against soft γ divergence*

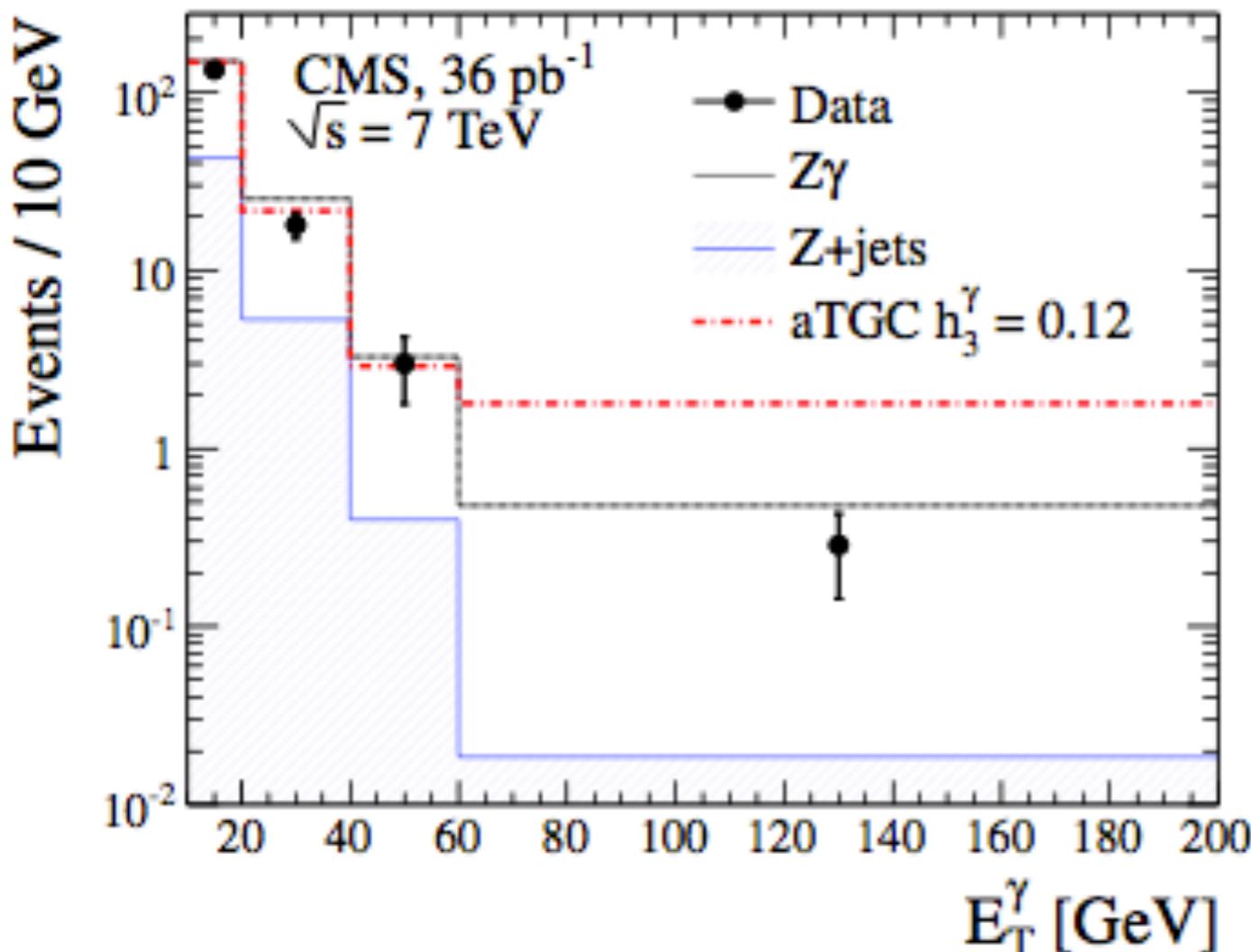


Events



- Main backgrounds
 - QCD / $t\bar{t}$ / Diboson
 - ZJets
- Background estimate:
 - Jets faking photons: Z+Jets
 - fake rate (ratio method)
 - cross checked with template method (cluster shape)

- Main uncertainties



	uncertainty	main sources
$A\epsilon$	4.3 – 5.8%	PDFs / energy scales
ρ	1.5%	γ / lepton ID-Isolation
backgrounds	9.3 – 11.4%	Z + jet

Event summary

process	N_{bkg}^{ee}	$N_{bkg}^{\mu\mu}$
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

- CMS 36/pb:

$$\sigma(pp \rightarrow Z\gamma + X) \times B(Z \rightarrow ll) = 9.4 \pm 1.0(stat.) \pm 0.6(syst.) \pm 0.4(lumi)pb$$

$$\sigma(pp \rightarrow Z\gamma + X) \times B(Z \rightarrow \mu\mu) = 9.2 \pm 1.4(stat.) \pm 0.6(syst.) \pm 0.4(lumi)pb$$

$$\sigma(pp \rightarrow Z\gamma + X) \times B(Z \rightarrow ee) = 9.5 \pm 1.4(stat.) \pm 0.7(syst.) \pm 0.4(lumi)pb$$

- NLO prediction (Bauer):

$9.6 \pm 0.4 pb$

- Signal selection:

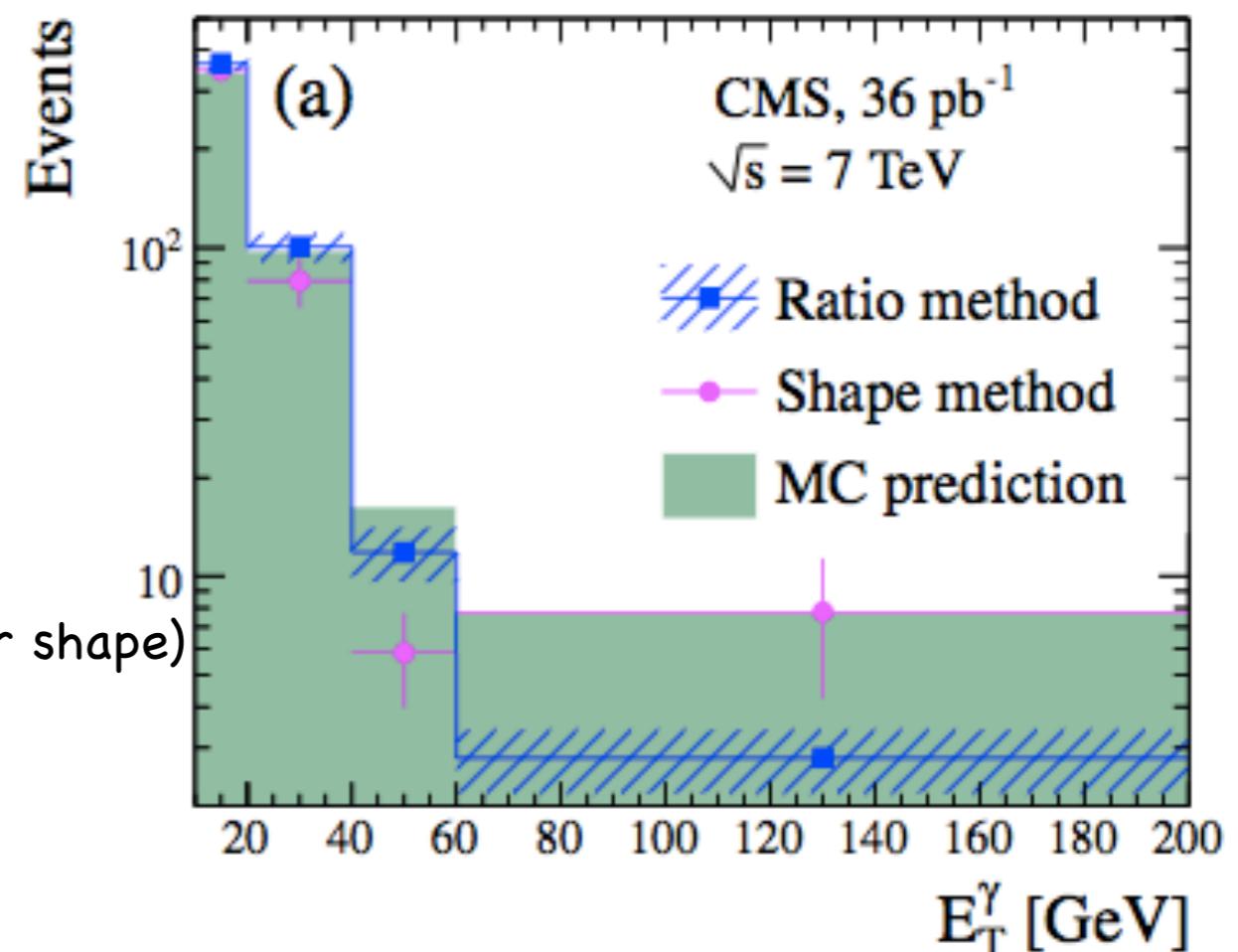
- Iso-Id lepton + Iso-Id γ + MET > 25GeV
 - $pT(l) > 20\text{GeV}/c$ $|\eta(\mu)| < 2.1$
 - 2nd lepton veto
 - $ET(\gamma) > 10\text{ GeV}$
 - $\Delta R(l, \gamma) > 0.7$
- against soft γ
divergence

- Background estimate:

- Jets faking photons: W+Jets
 - fake rate (ratio method)
 - cross checked with template method (cluster shape)
- $W\gamma \rightarrow \tau$ as background ($f_\tau \sim 0(3\%)$ from MC)

- Main Backgrounds:

- WJets/ttJets/ZJets
- QCD/PhotonJet
- ZZ/WW/WZ
- $Z\gamma$

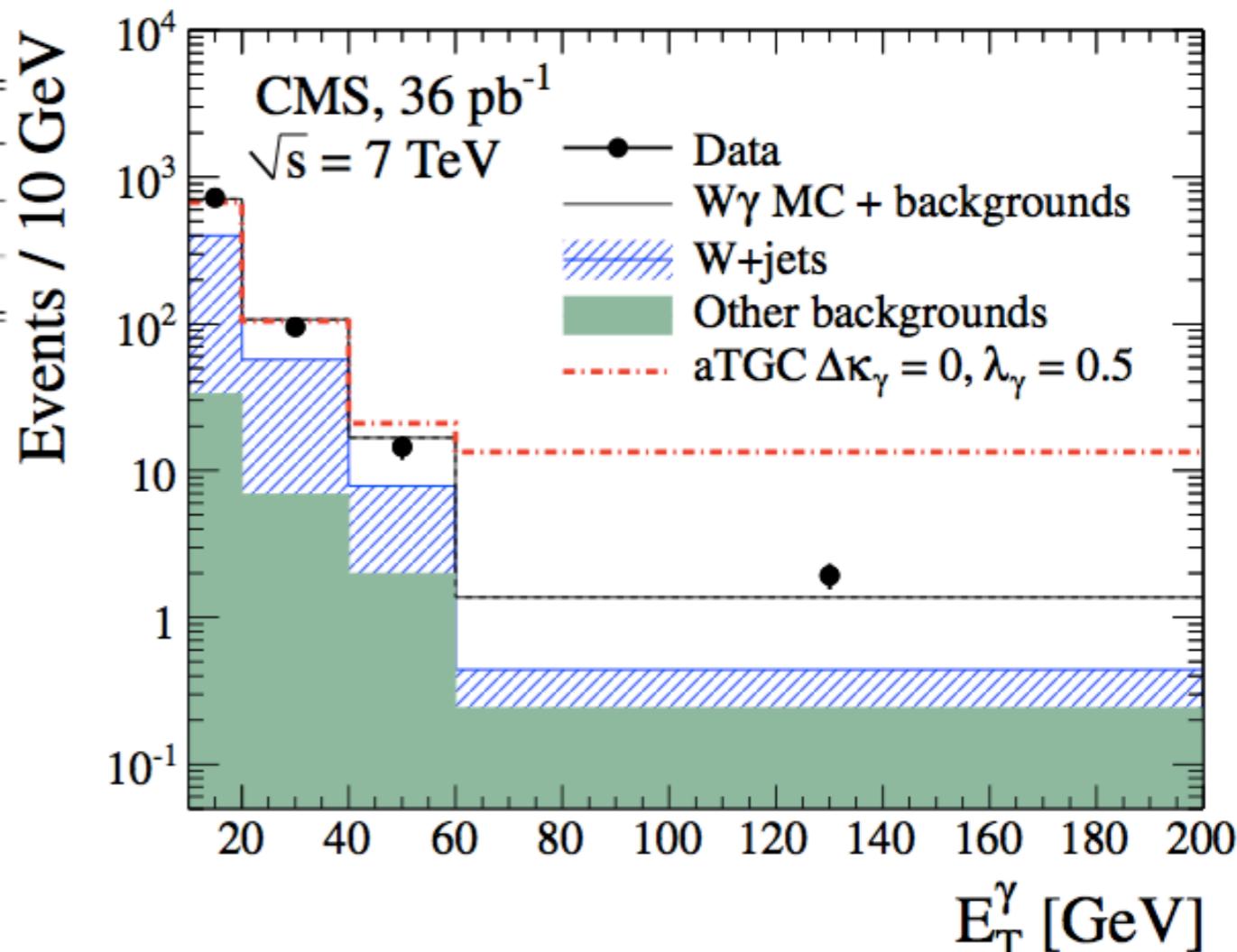


- Main uncertainties

	uncertainty	main sources
A_e	5.2 – 6.1%	PDFs / energy scales
ρ	1.6 – 1.9%	γ ID-Isolation / E_T^{miss} selection
backgrounds	6.3%	$W + \text{jet}$

Event summary

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



- CMS 1.1/fb:

$$\sigma(pp \rightarrow W\gamma + X) \times B(W \rightarrow l\nu) = 56.3 \pm 5.0(\text{stat.}) \pm 5.0(\text{syst.}) \pm 2.3(\text{lumi})$$

$$\sigma(pp \rightarrow W\gamma + X) \times B(W \rightarrow e\nu) = 57.1 \pm 6.9(\text{stat.}) \pm 5.1(\text{syst.}) \pm 2.3(\text{lumi})$$

$$\sigma(pp \rightarrow W\gamma + X) \times B(W \rightarrow \mu\nu) = 55.4 \pm 7.2(\text{stat.}) \pm 5.0(\text{syst.}) \pm 2.2(\text{lumi})$$

- NLO prediction (Bauer):

$$49.4 \pm 3.8 \text{ pb}$$

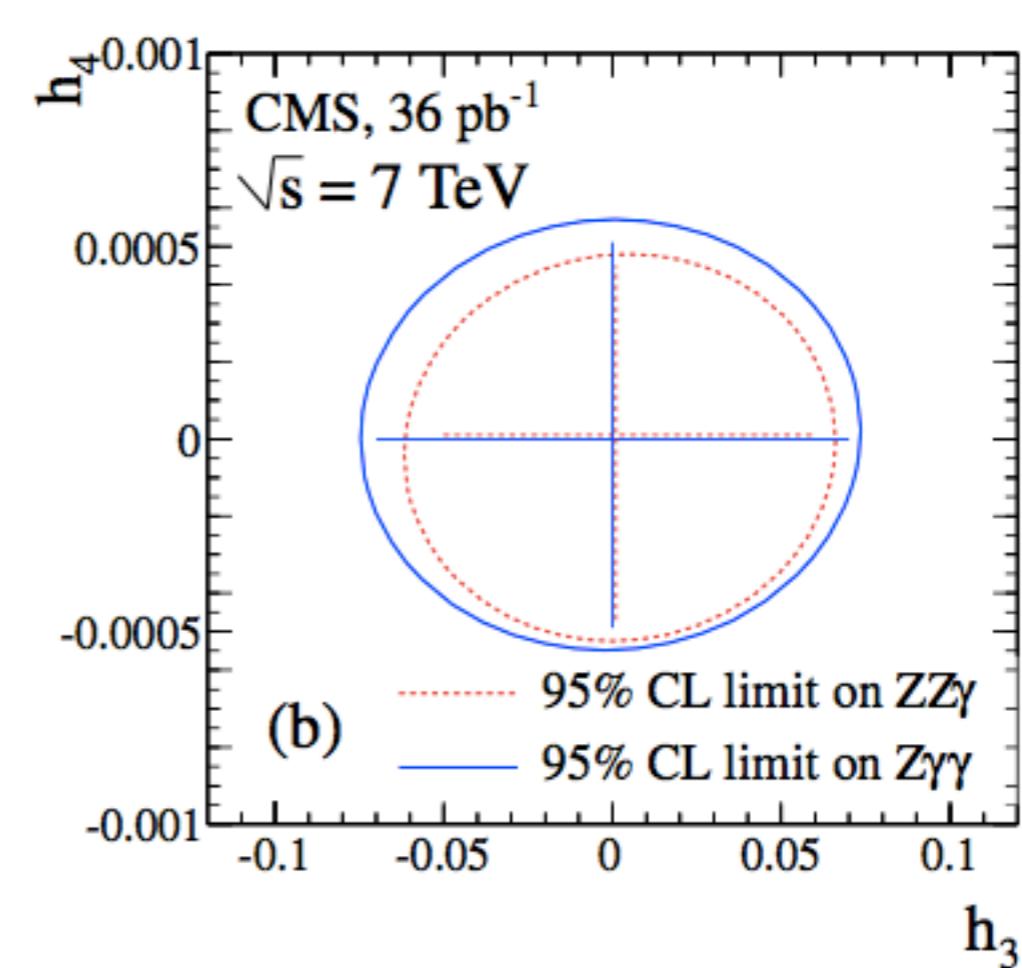
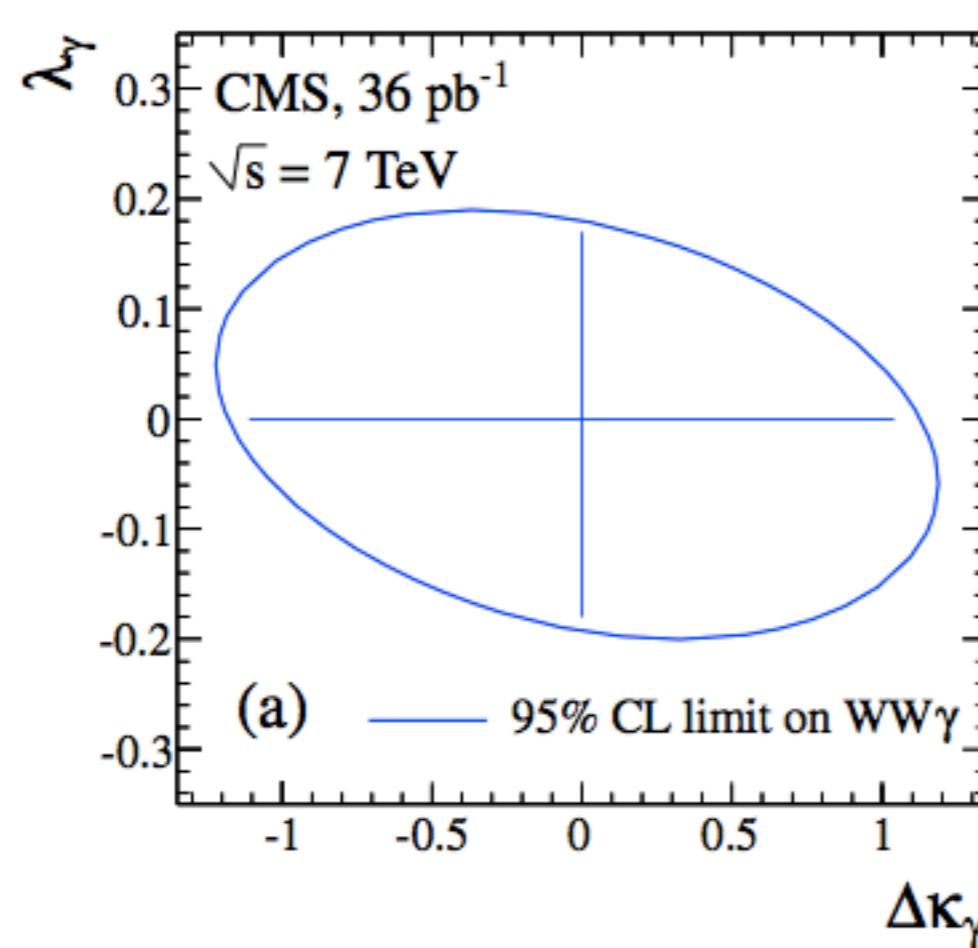
- 36/pb (2010 data)

limits at $\sqrt{s} = 7 \text{ TeV}$

- E_T photon spectrum as reference
- profile likelihood fit
- Sherpa + Bauer

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WW γ	ZZ γ	Z $\gamma\gamma$
$-1.11 < \Delta\kappa_\gamma < 1.04$	$-0.05 < h_3 < 0.06$	$-0.07 < h_3 < 0.07$
$-0.18 < \lambda_\gamma < 0.17$	$-0.0005 < h_4 < 0.0005$	$-0.0005 < h_4 < 0.0006$



- Signature:

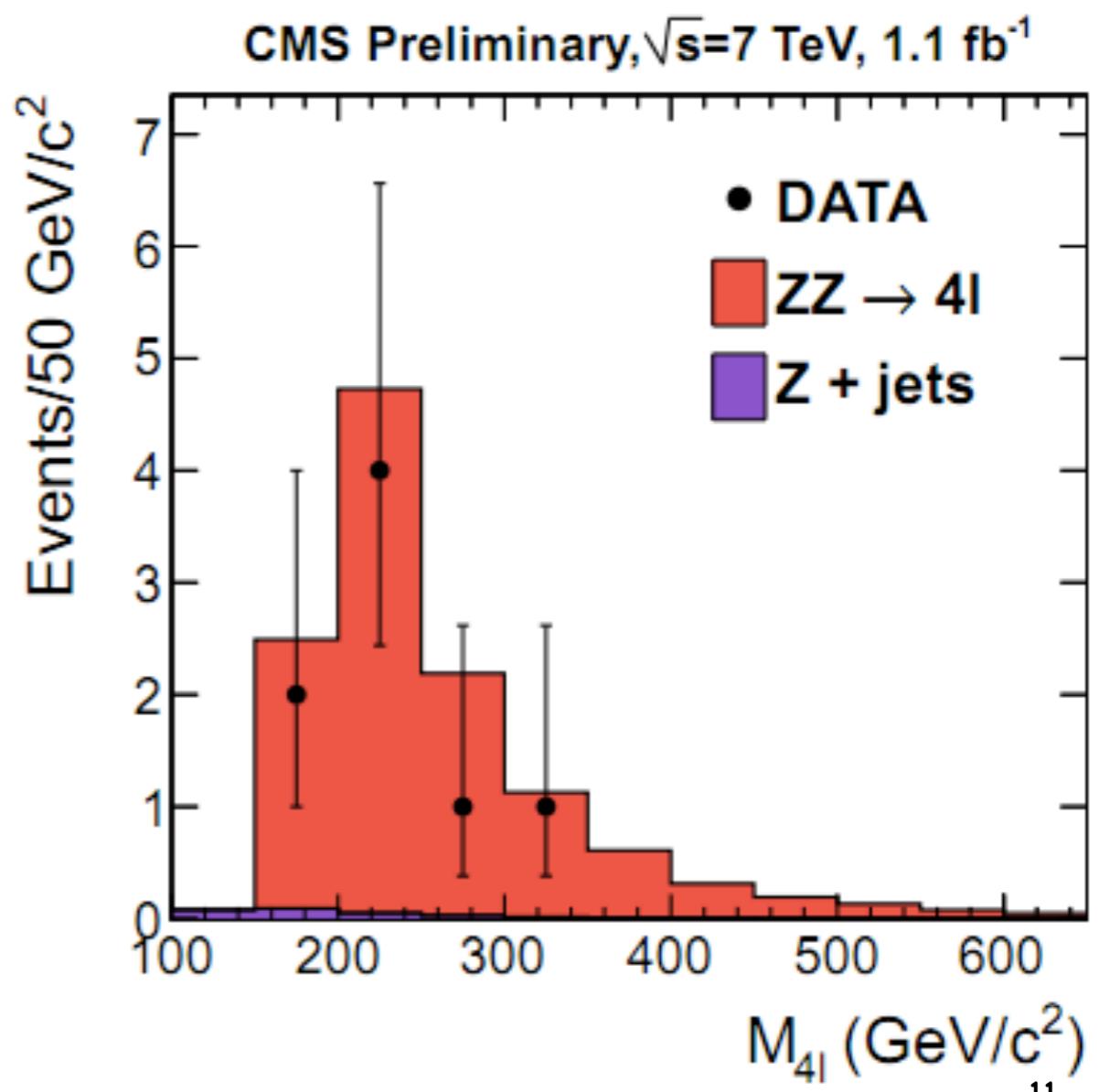
- 4 Iso-Id leptons ($l^+_a l^-_a, l^+_b l^-_b$)
- Z1: ee, μμ
 - $pT(l) > 20, 10 \text{ GeV}/c$
 - $60 < M < 120 \text{ GeV}/c^2$
- Z2: ee, μμ
 - $pT(e, \mu) > 7, 5 \text{ GeV}/c$,
 - $60 < M < 120 \text{ GeV}/c^2$
- $\tau \tau$ (->e, μ, hadronic)
 - $pT(\tau \rightarrow e, \mu) > 10 \text{ GeV}/c$, $pT(\tau \rightarrow \text{had}) > 20 \text{ GeV}/c$
 - $30 < M(\tau \tau^{\text{visible}}) < 80 \text{ GeV}/c^2$

+

- SIP_{3D} cut

- Main Backgrounds:

- heavy flavor jets: tt/Zbb
 - control region on SIP_{3D} reverted
- Jets faking leptons: Z+Jets
 - fake rate
- Jets faking τ : Z+Jets/WZ
 - fake rate



- Acceptance:

- order 60% for $4e$, 4μ , $2e2\mu$
- order 20% for $2l2\tau$

Event summary		B data-driven	S
Final state	N_{obs}	$N_{\text{estimated}}^{\text{backg.}}$	$N_{\text{expected}}^{\text{ZZ}}$
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

- Main uncertainties

source	uncertainty
trigger	1.5%
lepton identification	3%
lepton isolation	2%
lepton energy scale	1%
τ reconstruction	6%
τ energy scale	3%

- Simultaneous constrained fit on all channels,

- CMS 1.1/fb: $\sigma(pp \rightarrow ZZ + X) = 3.8^{+1.5}_{-1.2}(\text{stat.}) \pm 0.2(\text{sys.}) \pm 0.2(\text{lumi.}) \text{ pb}$
- NLO prediction (MCFMv6): $6.4 \pm 0.6 \text{ pb}$

- Signature:

- 3 Iso-Id leptons + MET ($l^+_a l^-_a l_b$)
- Z candidate:
 - $pT(e) > 20, 10 \text{ GeV}/c$ $pT(\mu) > 15, 15 \text{ GeV}/c$
 - $60 < M < 120 \text{ GeV}/c^2$
- W candidate:
 - $pT(l) > 20 \text{ GeV}/c$
 - MET > 30GeV

+

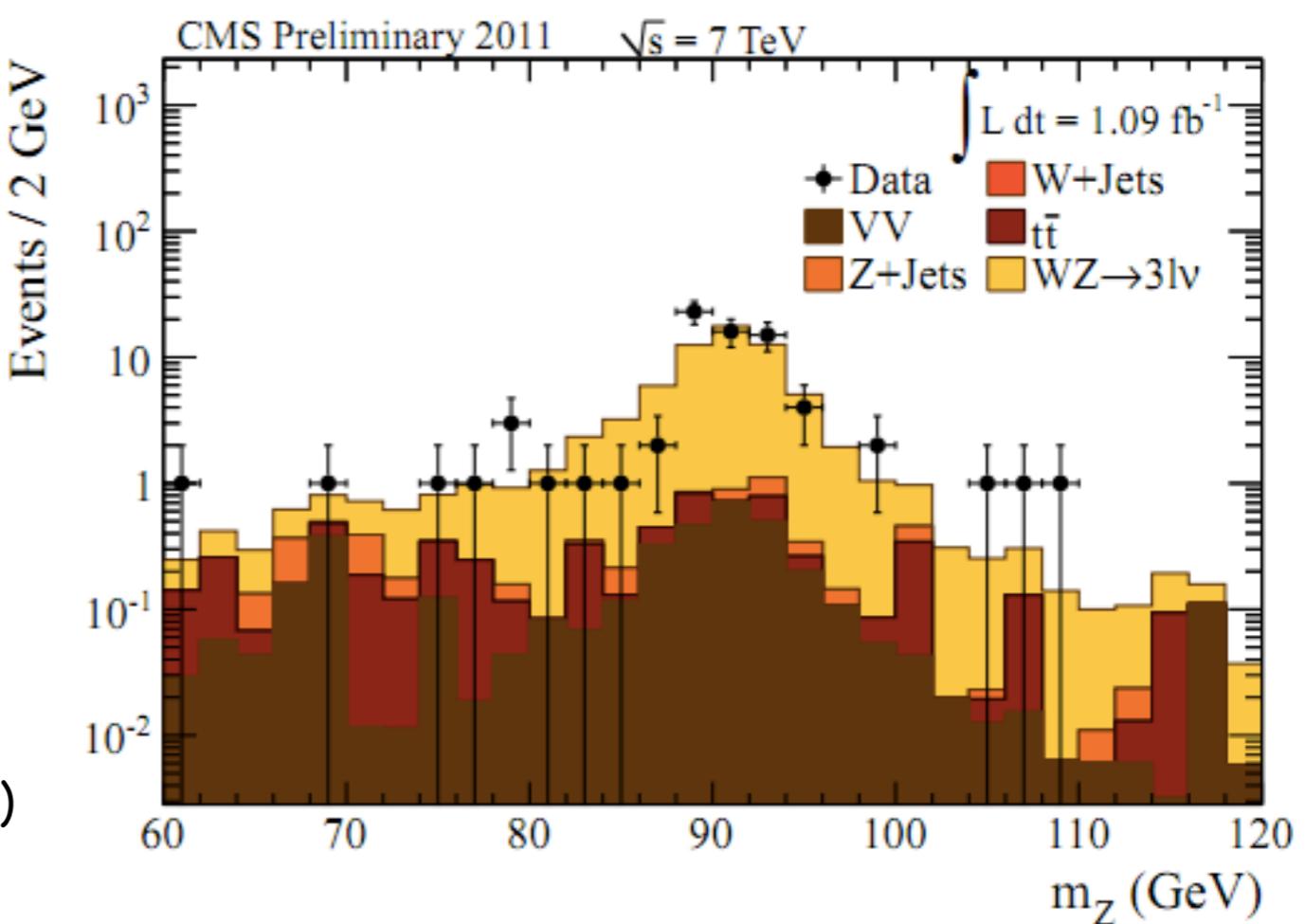
- second Z veto

- Main Backgrounds:

- jets faking leptons: Z+Jets/tt
 - Matrix Method

$$N_{obs.} = \epsilon N_{signal} + p_{fake} N_{bkg}$$

- mis-reconstructed objects: ZZ/Zγ
- WZ→τ as background ($f_\tau \text{ O}(6\%)$ from MC)
 - $(1-f_\tau)$ subtracted



- Acceptance

- kinematic A order 50%

- Main uncertainties

	uncertainty	main sources
$\mathcal{F} = A \cdot \epsilon$	2.8 – 3.2%	NLO Effects / PDFs / Lepton energy scale
ρ	3.6 – 6.7%	reconstruction/ ID /isolation
background	1.5 – 2.8%/3.5 – 5.5%	top / Z+jet

Event summary

Sample	3e0 μ	2e1 μ	1e2 μ	0e3 μ
ZJets + $t\bar{t}$	1.76 ± 0.67	2.54 ± 0.86	1.60 ± 0.58	2.18 ± 0.76
$ZZ \rightarrow 4l$	0.40 ± 0.02	0.95 ± 0.03	0.40 ± 0.02	0.97 ± 0.03
$V\gamma$	0.8 ± 0.4	0.1 ± 0.1	0.03 ± 0.03	0.00
$WW \rightarrow l\nu l\nu$	0.02 ± 0.02	0.04 ± 0.03	0.00	0.00
Background	2.98 ± 0.78	3.63 ± 0.87	2.03 ± 0.58	3.15 ± 0.76
$WZ \rightarrow l\nu ll$	14.47 ± 0.28	17.4 ± 0.31	13.95 ± 0.28	18.56 ± 0.32
AllMC	17.45 ± 0.83	21.03 ± 0.92	15.98 ± 0.64	21.71 ± 0.83
Data	22	20	13	20

B data-driven

S

- Cross section * BR for each channel

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

- 2011 1.1/fb CMS:

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

- NLO prediction (MCFMv6): $18.75^{+1.05}_{-0.80}$ pb

2011 1/fb

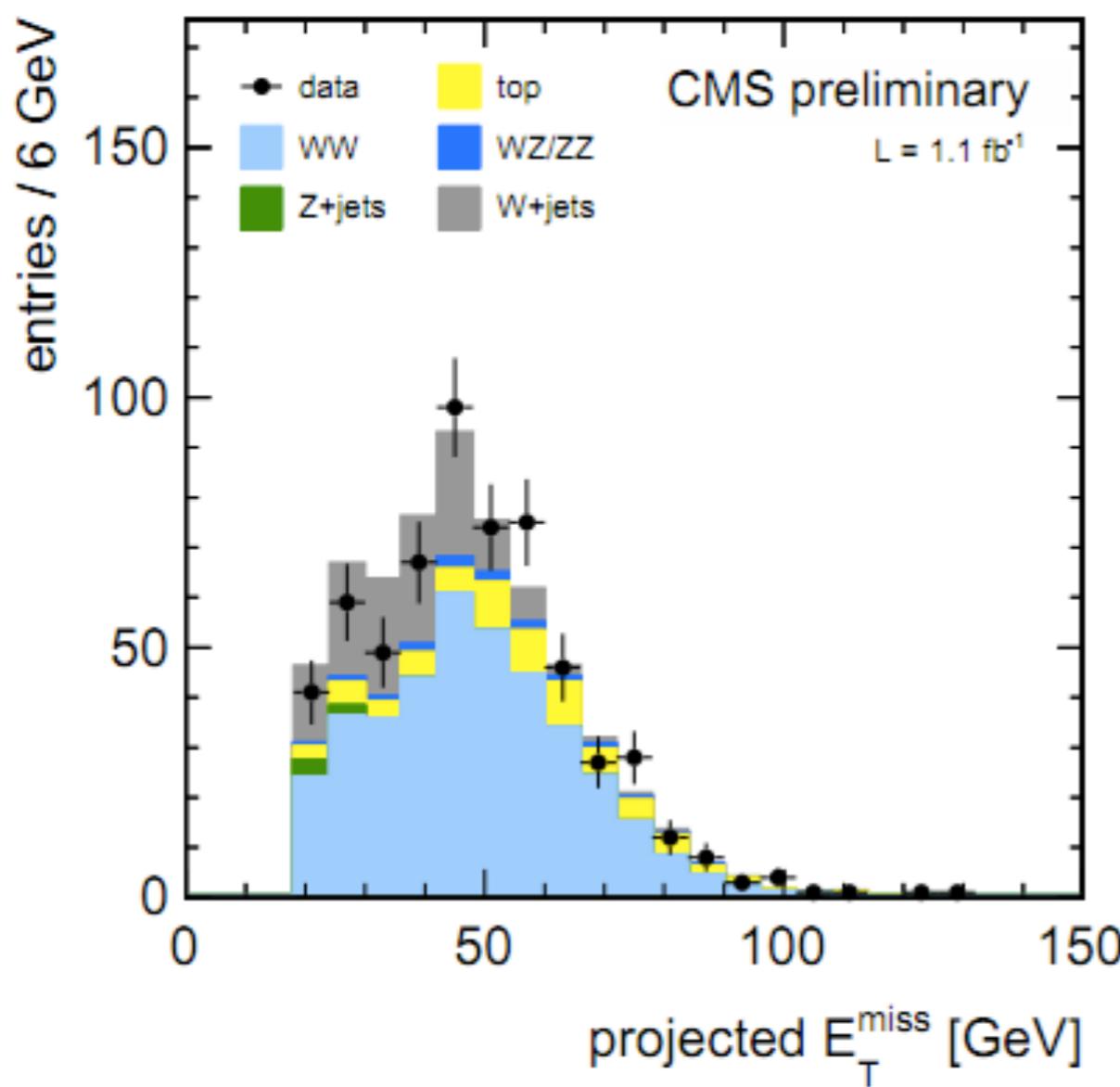
WW $\rightarrow l\nu, l\nu$ ($l = e, \mu$)

- Signature:

- 2 Iso-Id leptons ($l^+_a l^-_b$) + MET
- $p_T(l) > 20, 10$ GeV/c (leading, trailing)

+

- jet veto ($p_T > 30$ GeV)
- b-tagging veto
- Zmass veto (within ± 15 GeV)
- $\Delta\phi(l\bar{l}, \text{jet}) < 165^\circ$ ($p_T(\text{jet}) > 15$ GeV)
- 3rd lepton veto
- proj. MET > 40 GeV ($ee, \mu\mu$) MET > 20 GeV ($e\mu$)
 - transverse component to closest lepton if $\Delta\phi(\text{MET}, l) < \pi/2$



- Main Backgrounds:

- Jets faking leptons: QCD/W+Jets
 - fake rate
- hard-flavor jets: tt/tW
 - b-tagging mis-tag rate
- mis-reconstructed lepton: DY
 - control region in Zmass window

- Acceptance:

- kinematic A order 70%

Event summary

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

S

B data-driven

- Main 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%

- CMS 1.1/fb:

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

- CMS 36/pb:

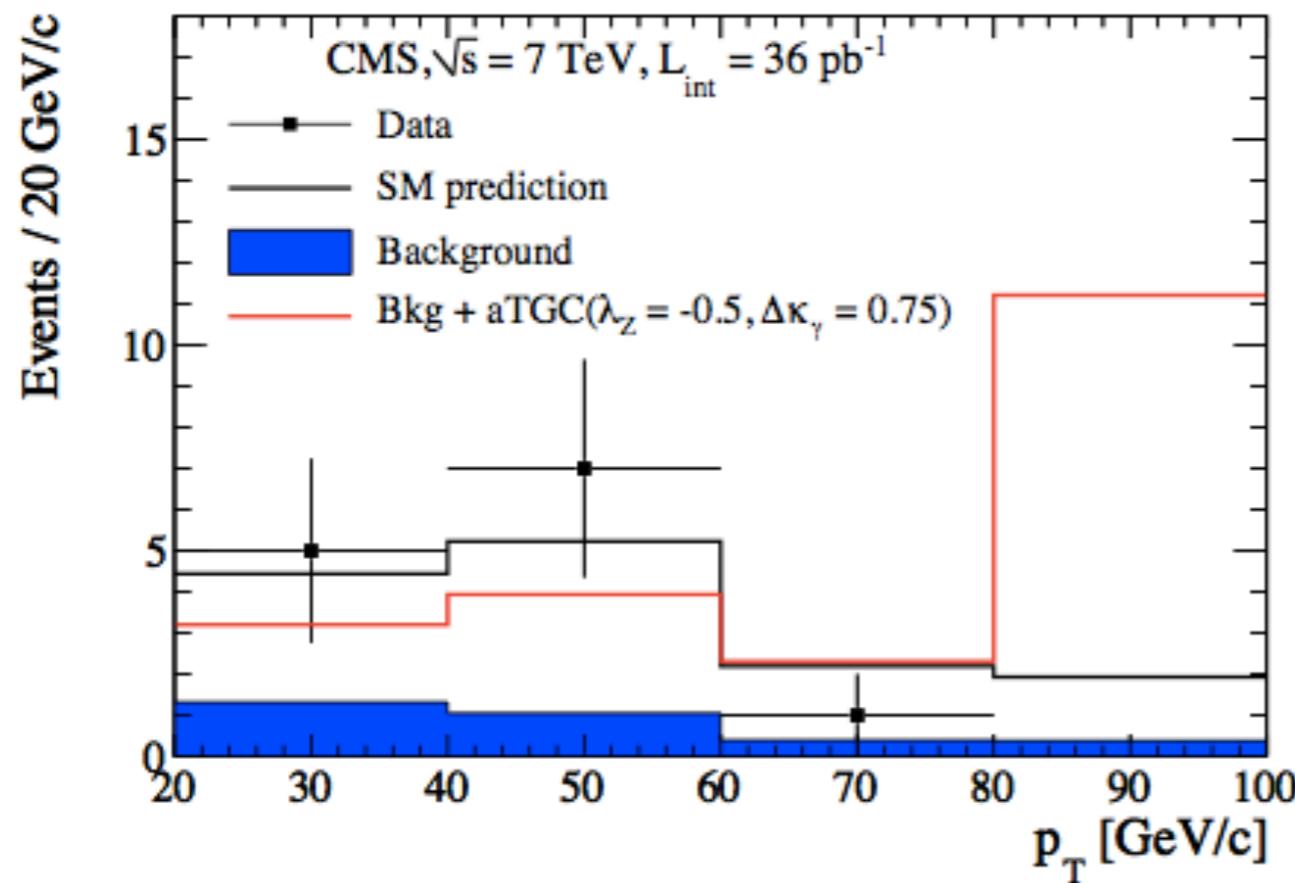
$$41.1 \pm 15.3 \text{ (stat.)} \pm 5.8 \text{ (syst.)} \pm 4.5 \text{ (lumi.)} \text{ pb}$$

- NLO prediction (MCFM v5.8):

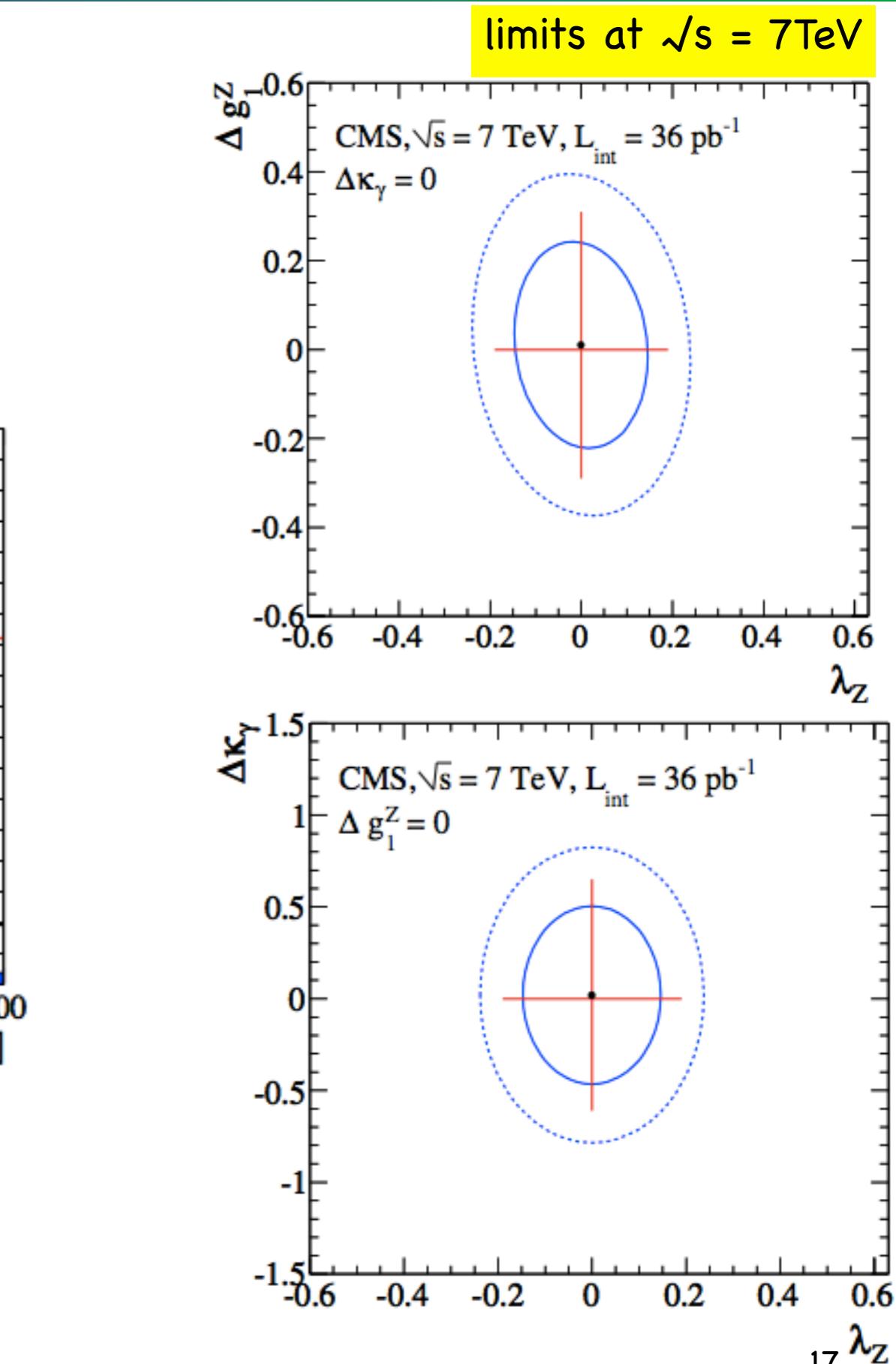
$$44.5 \text{ pb} = [43.0 \pm 2.0 (\text{qq-} \rightarrow \text{WW}) + 1.5 (\text{gg-} \rightarrow \text{WW})] \text{ pb}$$

- 36/pb (2010 data)
 - leading lepton p_T spectrum as reference
 - Sherpa + MCFM

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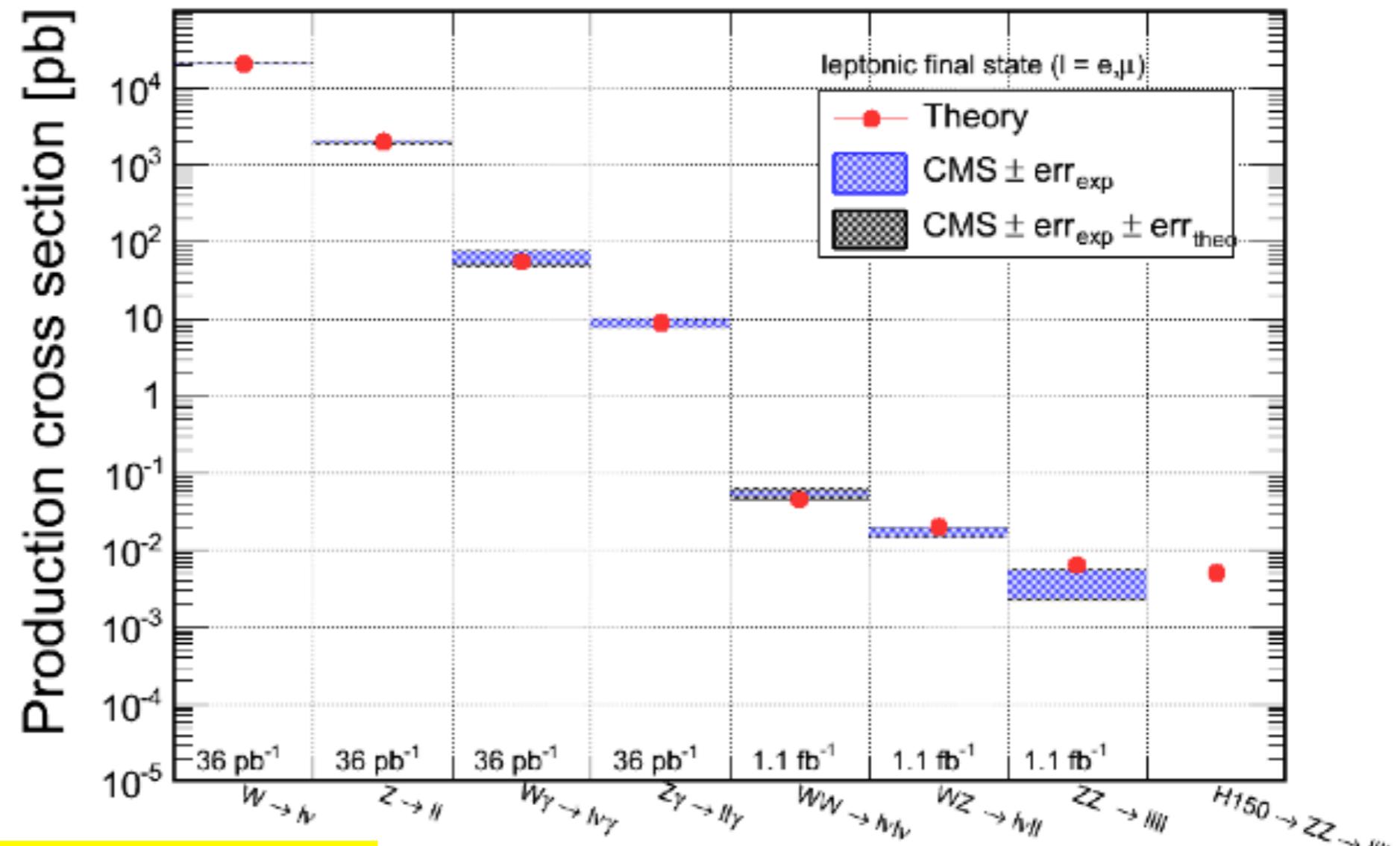


	λ_Z	Δg_1^Z	$\Delta\kappa_\gamma$
Unbinned fit	$[-0.19, 0.19]$	$[-0.29, 0.31]$	$[-0.61, 0.65]$



Summary

- Diboson cross section measured
 - WW,WZ,ZZ 1/fb data (2011)
 - W γ ,Z γ 36/pb data (2010)
- TGC measured for
 - WW, W γ ,Z γ 36/pb data (2010)



All results in agreement with SM expectation...

...crucial results to come (> 5/fb available now + combination from all channels)