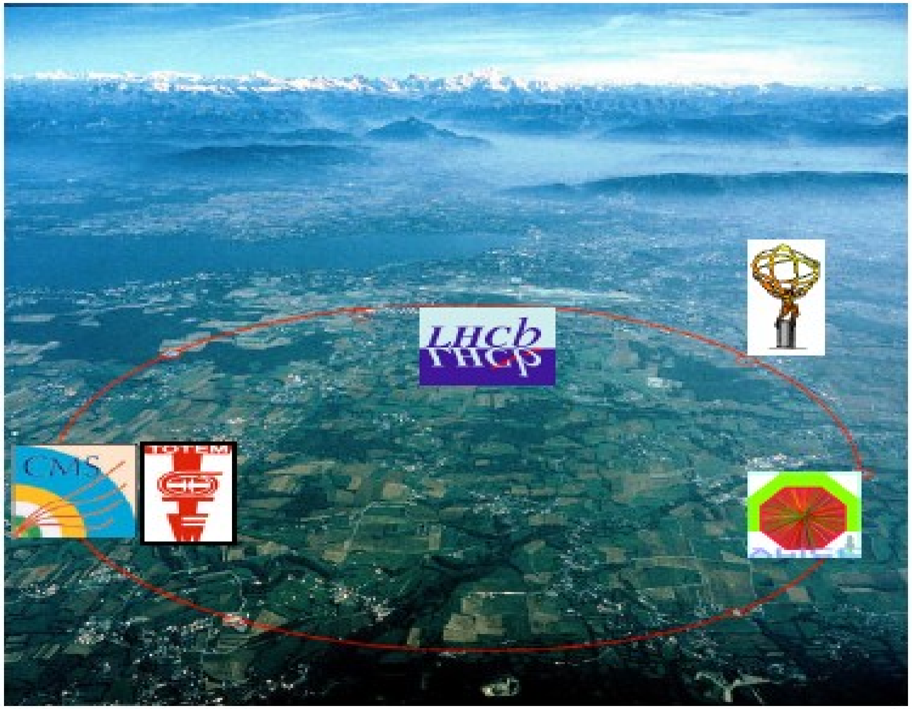
Physics with first fb^{-1}

at Large Hadron Collider

Today:

- **Precision measurements in Standard Model**
- **Physics with dibosons**

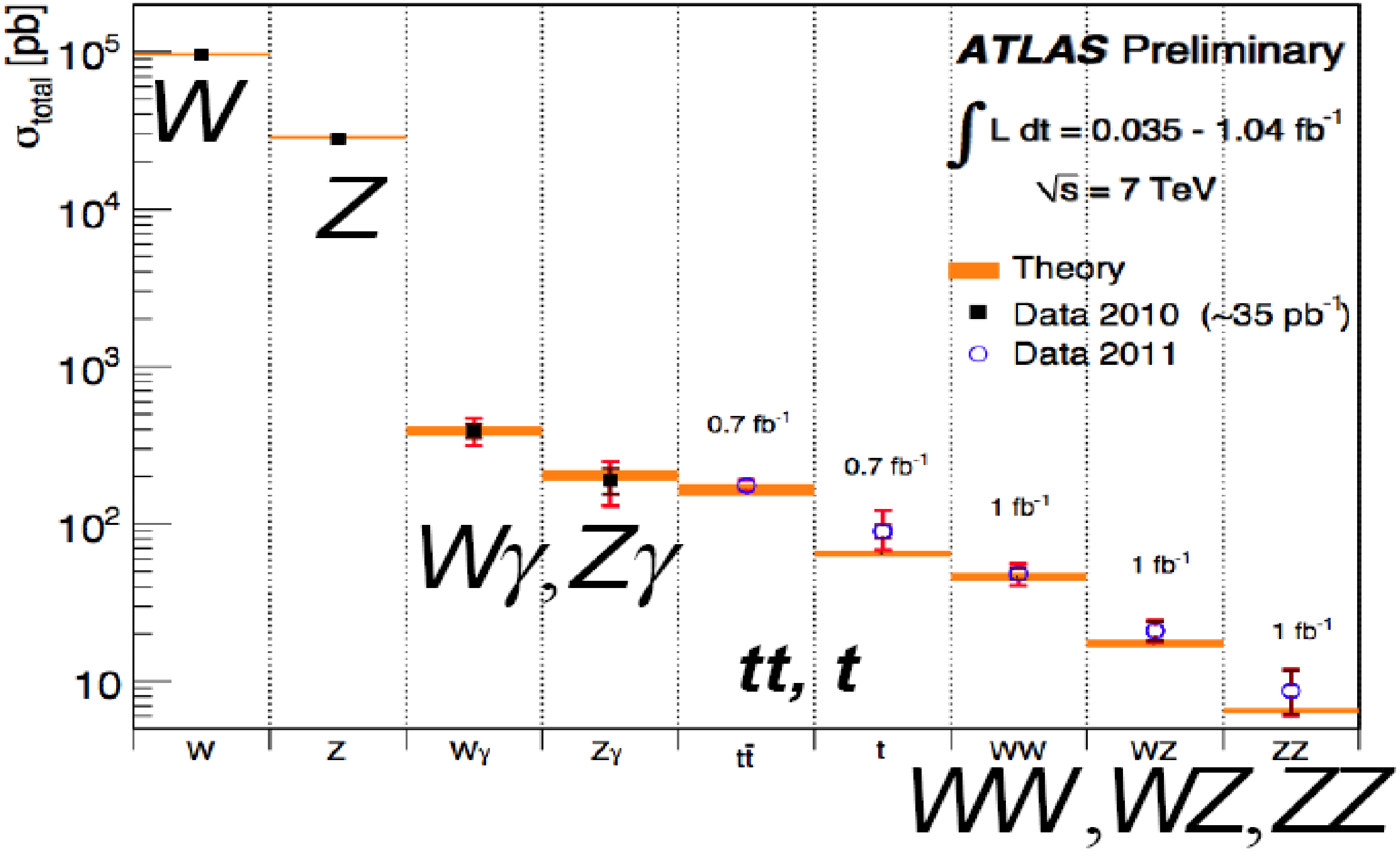


News from CERN

- Seminar on the Higgs searches from each experiment, given by spokespersons
  - **13.12.2011, at 14pm, video**
  - Analysis with up to 5.6fb^{-1}/experiment

The Standard Model

- SM measurements are the foundations of all searches (33 papers on measurements to date)



The Standard Model

The electroweak theory is tested to $O(10^{-4})$

Result of 30 years of experimental and theoretical progress

Demonstrate the need for 1 loop corrections to describe adequately the precision experimental results

Some tension in the overall fit, but so far no real discrepancy observed

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ_{had}^{0} [nb]	41.540 ± 0.037	41.479
R_l	20.767 ± 0.025	20.742
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21579
R_c	0.1721 ± 0.0030	0.1723
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.399 ± 0.023	80.379
Γ_W [GeV]	2.085 ± 0.042	2.092
m_t [GeV]	173.3 ± 1.1	173.4

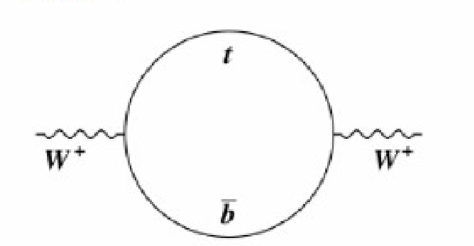
Discussed today

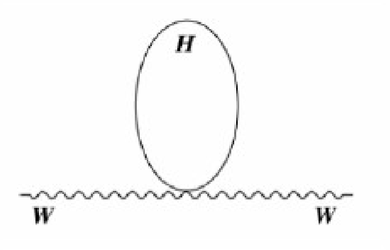
W boson mass

W mass is a key parameter in the Standard Model. This model does not predict the value of the W mass, but it predicts this relation between the W mass and other experimental observables:

$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}} \frac{1}{\sin\theta_W \sqrt{1-\Delta r}}$$

Radiative corrections (Δ r) depend on M_t as ~M_t^2 and on M_H as ~log M_H. They include diagrams like these:



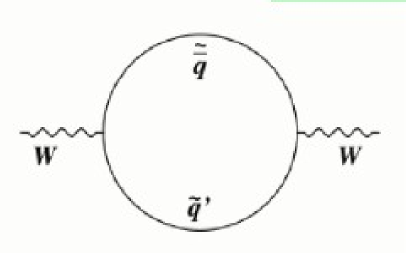


Precise measurements of M_W and M_t constrain SM Higgs mass.

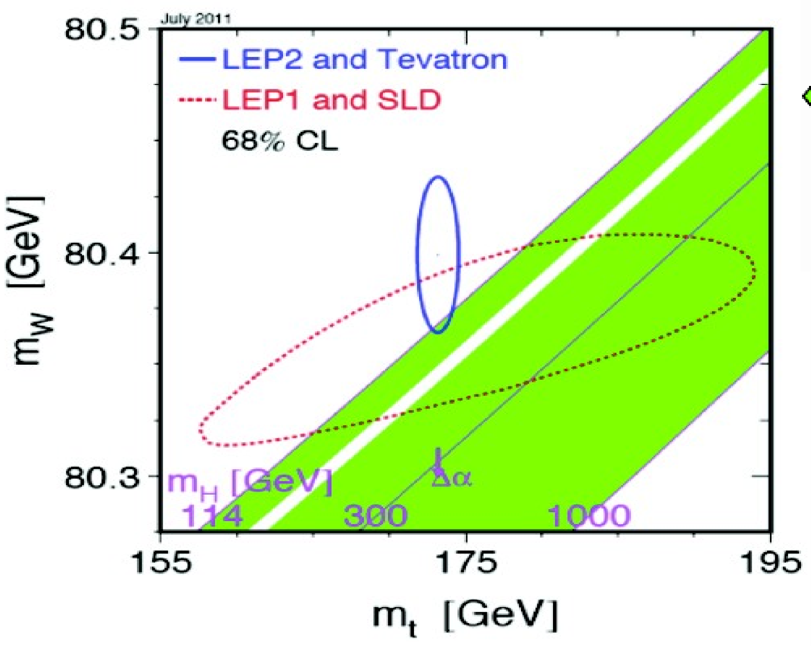
For equal contribution to the Higgs mass uncertainty need:
$\Delta M_W \approx 0.006 \, \Delta M_t$.

The limiting factor here will be ΔM_W, not ΔM_t !

Additional contributions to Δr arise in various extensions to the Standard Model, *e.g.* in SUSY:

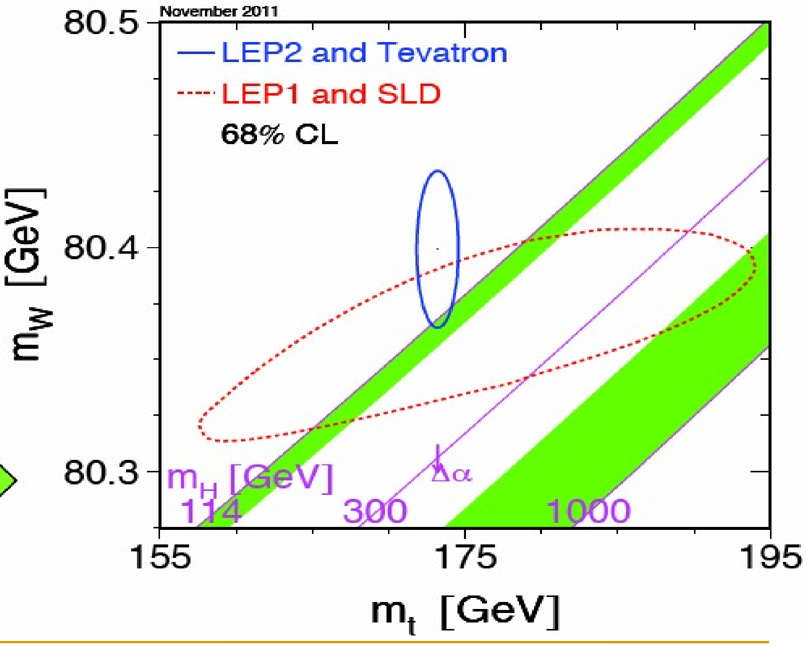


Impact of the new limits on the green band

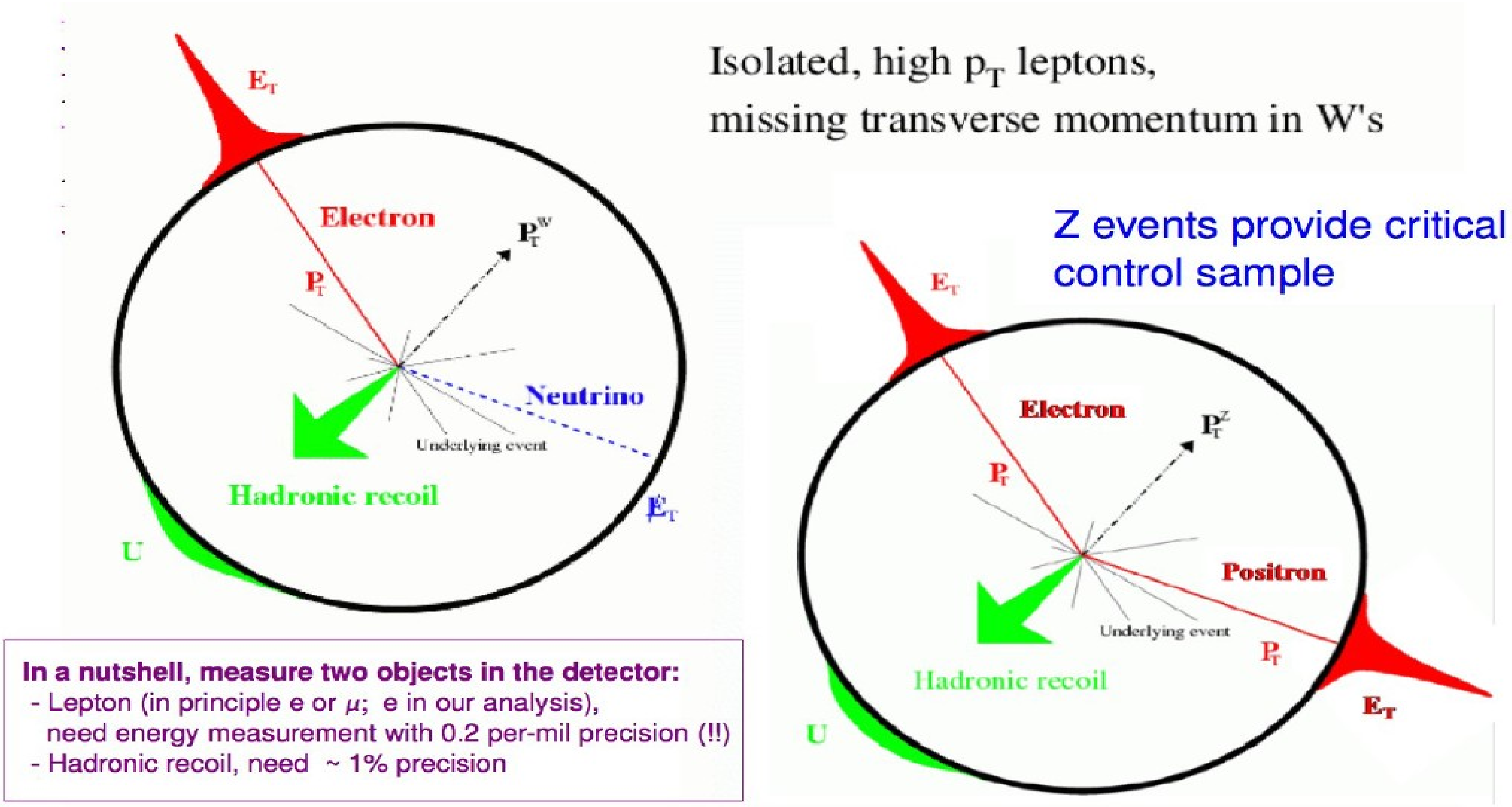


Before LHC 2011 Run

With < 2.3 fb^{-1} from LHC



W mass measurement

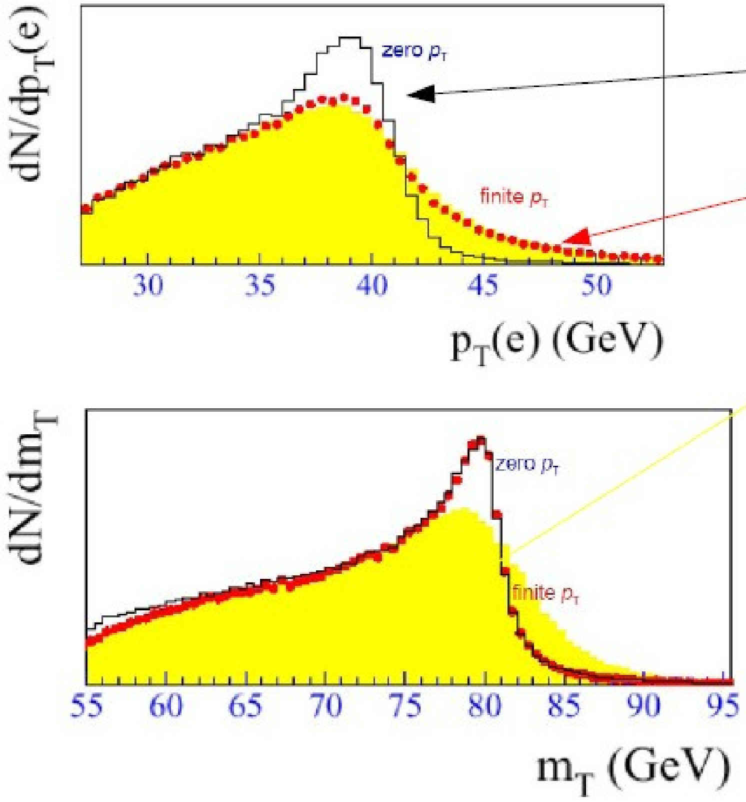


Isolated, high p_T leptons,
missing transverse momentum in W's

Z events provide critical control sample

In a nutshell, measure two objects in the detector:
- Lepton (in principle e or μ; e in our analysis), need energy measurement with 0.2 per-mil precision (!!)
- Hadronic recoil, need ~ 1% precision

W mass measurement



True distribution

Including p_T(W) effects

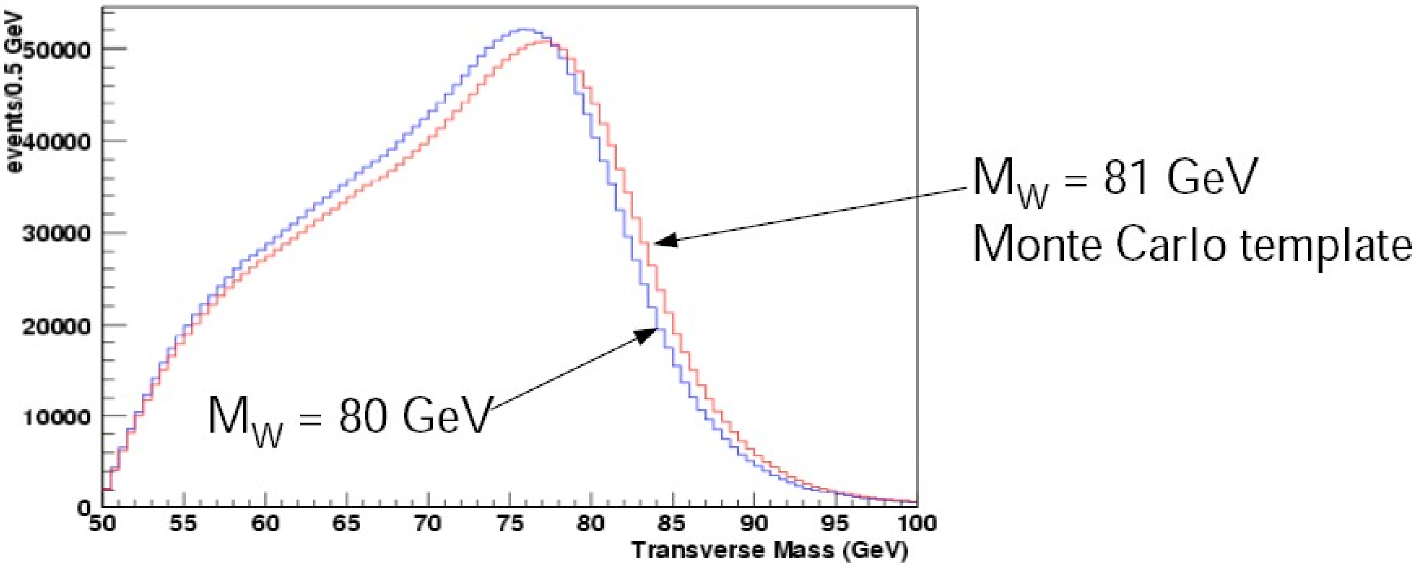
Including detector effects

p_T(e) not sensitive to detector effects, requires p_T(W) knowledge

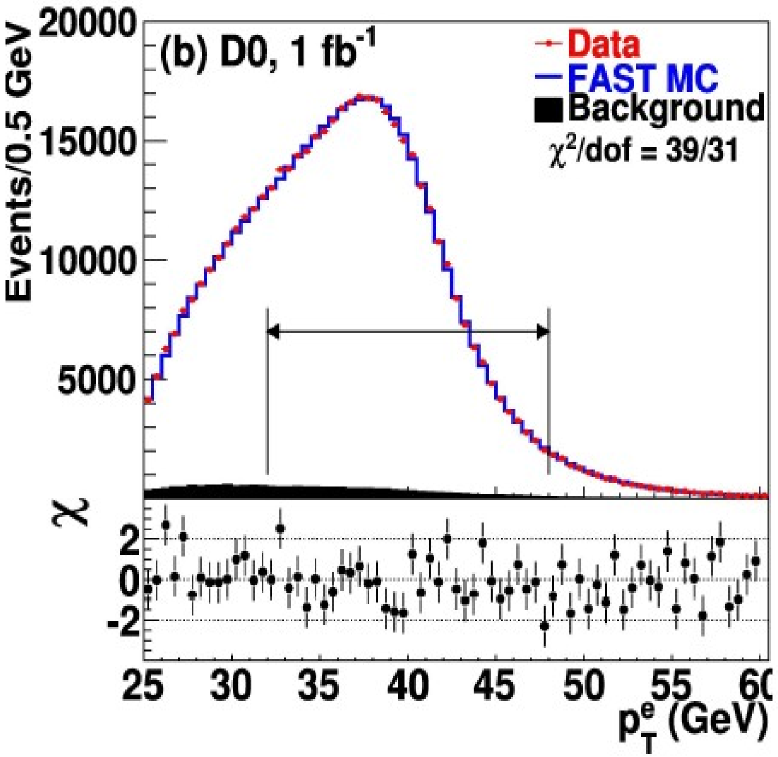
Transverse mass less sensitive to p_T(W), requires good modeling of missing E_T

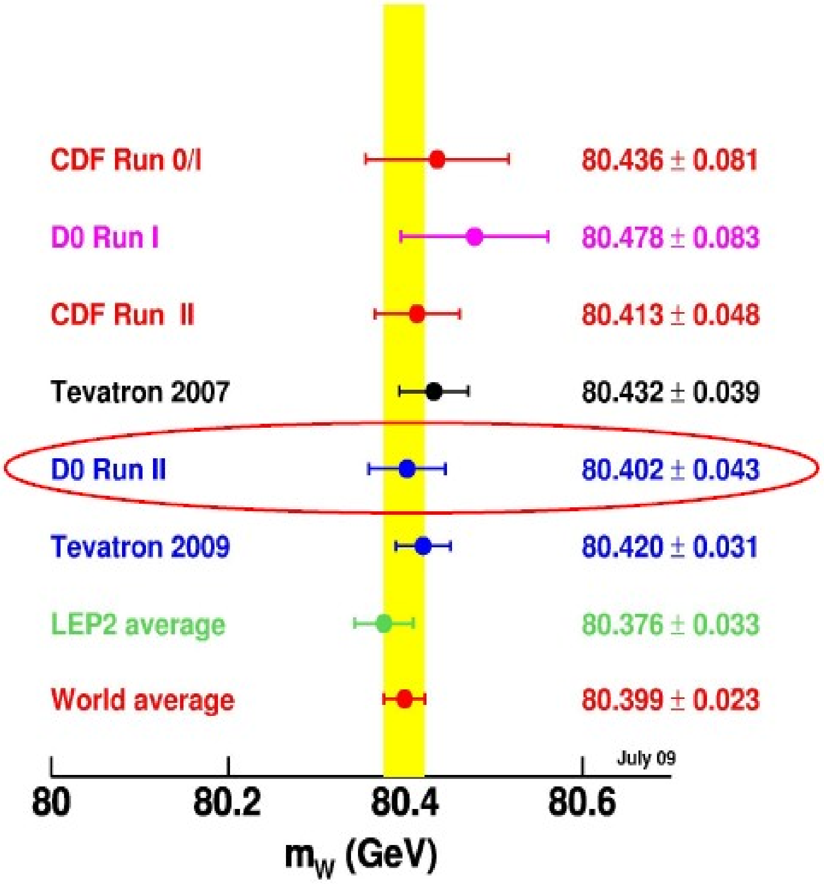
Template fitting

- Custom fast Monte Carlo makes smooth high-statistics templates. Perform binned maximum likelihood fits to the data
  - And provides analysis control over key ingredient of the simulation



W mass measurement

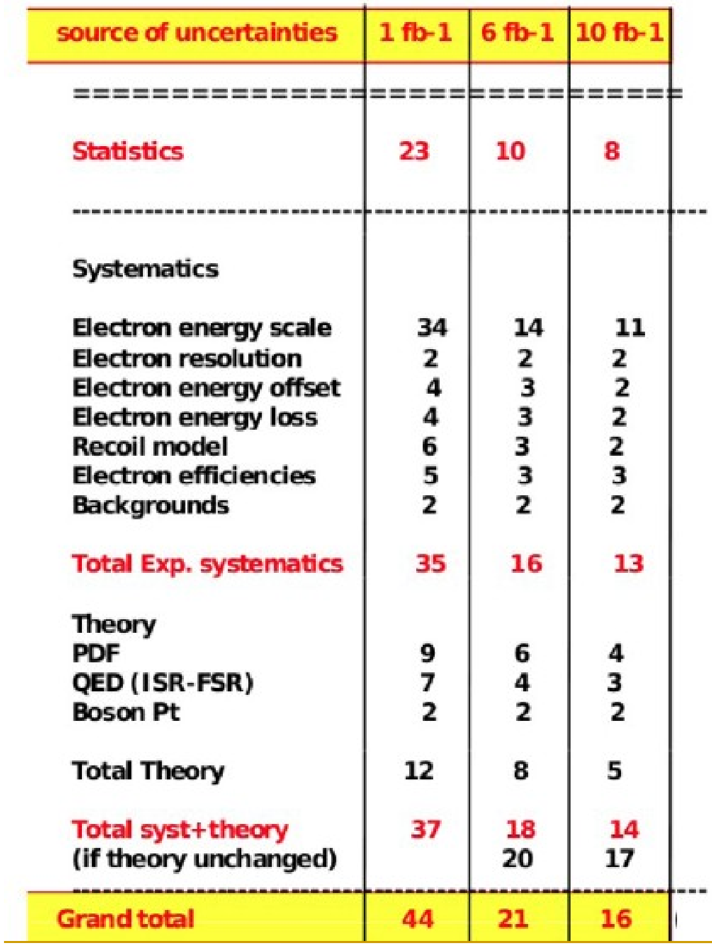




W mass measurement

With 1 fb^{-1} uncertainties are mainly statistical (including 'systematics' from limited data control samples). Let's extrapolate:

DØ projection



source of uncertainties	1 fb-1	6 fb-1	10 fb-1
Statistics	23	10	8
Systematics			
Electron energy scale	34	14	11
Electron resolution	2	2	2
Electron energy offset	4	3	2
Electron energy loss	4	3	2
Recoil model	6	3	2
Electron efficiencies	5	3	3
Backgrounds	2	2	2
Total Exp. systematics	35	16	13
Theory			
PDF	9	6	4
QED (ISR-FSR)	7	4	3
Boson Pt	2	2	2
Total Theory	12	8	5
Total syst+theory	37	18	14
(if theory unchanged)		20	17
Grand total	44	21	16

At end of Run II, expect total uncertainty on W mass of 16 MeV from DØ alone.

Expect similar performance from CDF, and combined error of 12 MeV.

This legacy measurement will be in the textbooks for decades to come.

Could be an important contribution to getting the standard model into trouble in the near future:

with $\delta m_W = 15$ MeV, $\delta m_t = 1$ GeV

and $m_W = 80.400$ GeV :

$$m_H = 71^{+24}_{-19}\ \text{GeV} \quad < 117\ \text{GeV} \ @\ 95\%\ \text{cl}$$

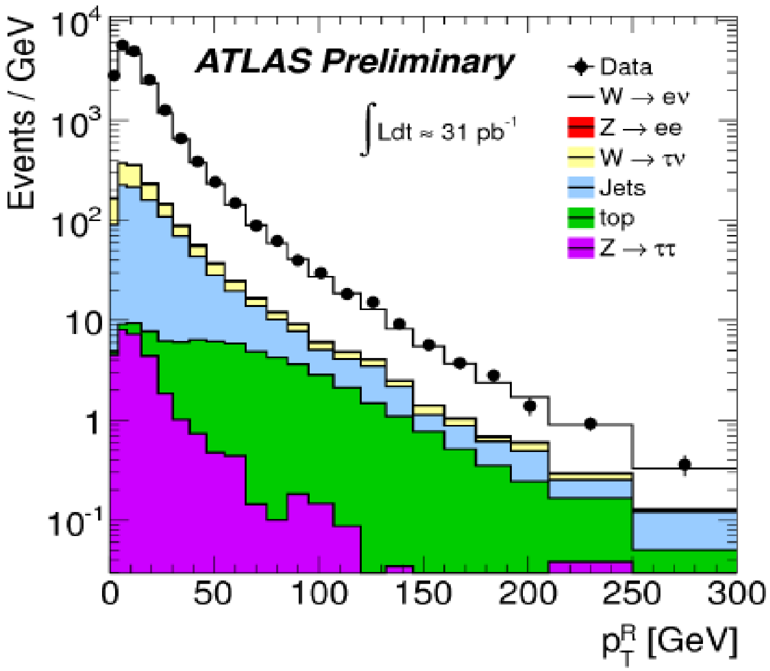
(P. Renton, ICHEP 2008)

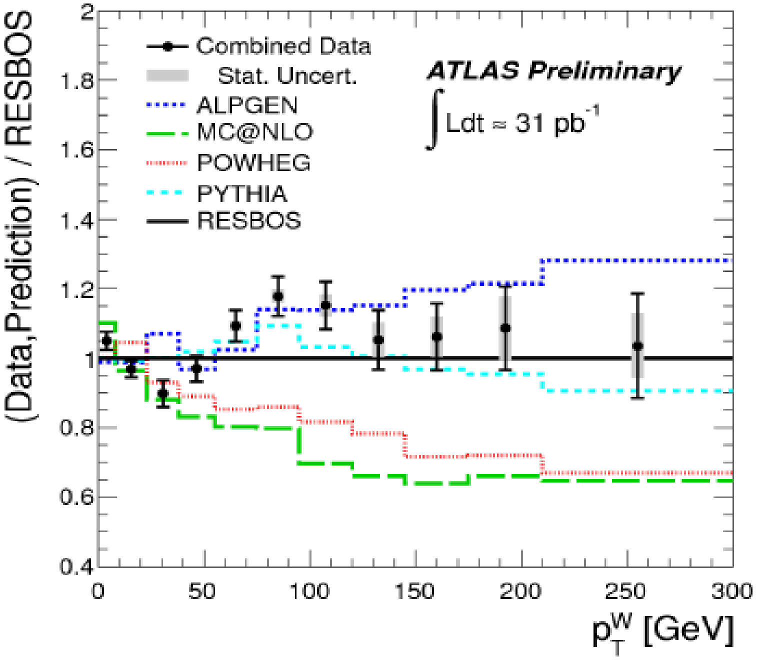
p_T^W distribution measurement

First direct measurement of the W boson transverse momentum spectrum by ATLAS.

W boson transverse momentum (p_T^W) is inferred from the energy deposition in the calorimeter from the recoil to the W.

Detector and FSR effects removed by “unfolding”
(invert a response matrix that parameterises the probabilistic mapping from recoil p_T^R to W boson p_T^W).





Z/γ^* forward-backward asymmetry

- **In the process:** $q\bar{q} \to Z/\gamma^* \to e^+e^-$
- **fermion-γ^* coupling contains only vector component**
- **fermion-Z coupling contains both vector and axial-vector components**

Vector coupling: $g_v^f = I_3^f - 2Q_f \boxed{\sin^2\theta_W}$

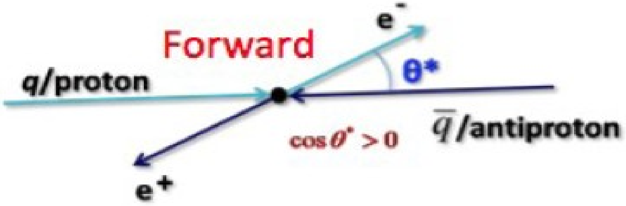
Axial-vector coupling: $g_a^f = I_3^f$

effective weak mixing angle

- **Give rise to non-zero Forward-Backward Asymmetry (A_{FB}) in the final states**

$$\frac{d\sigma(q\bar{q} \to e^+e^-)}{d\cos\theta^*} = A(1-\cos^2\theta^*) + B\cos\theta^*$$

functions of vector and axial-vector couplings.



A_{FB} is related to :

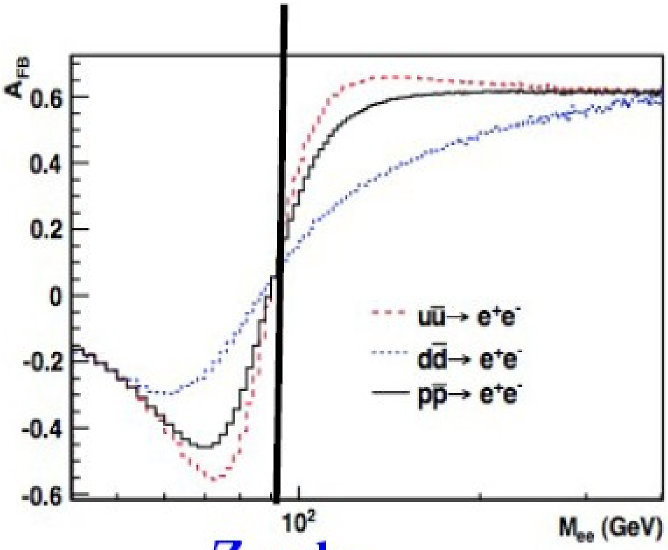
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{8} \cdot \frac{B}{A} = f(\boxed{g_v^f, g_a^f, sin^2\theta_w}, \ldots)$$

Forward: $\cos\theta^* > 0$ **Backward:** $\cos\theta^* < 0$

Z/γ^* forward-backward asymmetry

- At Tevatron, Z/γ^* is mostly produced by light valence quark pair, u-ubar or d-dbar
- From the observable A_{FB}, we can:
- Precisely measure $\sin^2\theta_W$ based on Z to light quark couplings
- Directly probe the coupling of Z/γ^* to light quarks

- Investigate possible new phenomena, e.g. new neutral gauge boson Z'
- Around Z-pole, A_{FB} is dominated by interference of vector and axial-vector couplings of Z to quarks
- Far away above Z-pole, A_{FB} is dominated by Z/γ^* interference, which is sensitive to new physics.

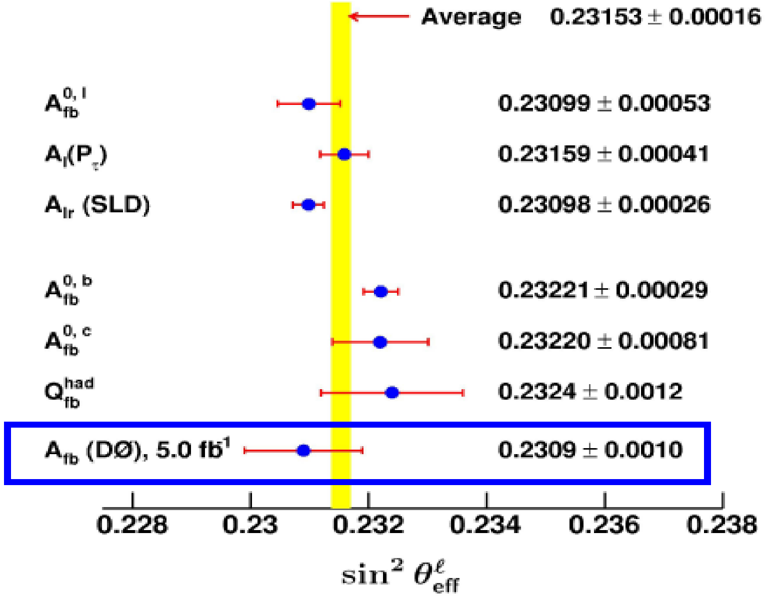


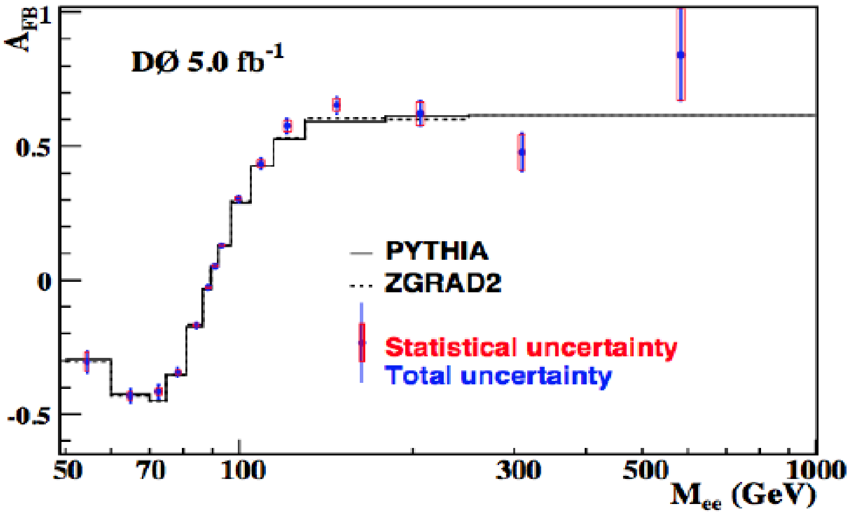
Z-pole

Z/γ^* forward-backward asymmetry

- Unfolded AFB agrees well with theoretical prediction
- No evidence for new physics at high mass
- Extracted $\sin^2\theta^l_{eff}$

$= 0.2309 \pm 0.0008$ (stat.) ± 0.0006 (syst.)

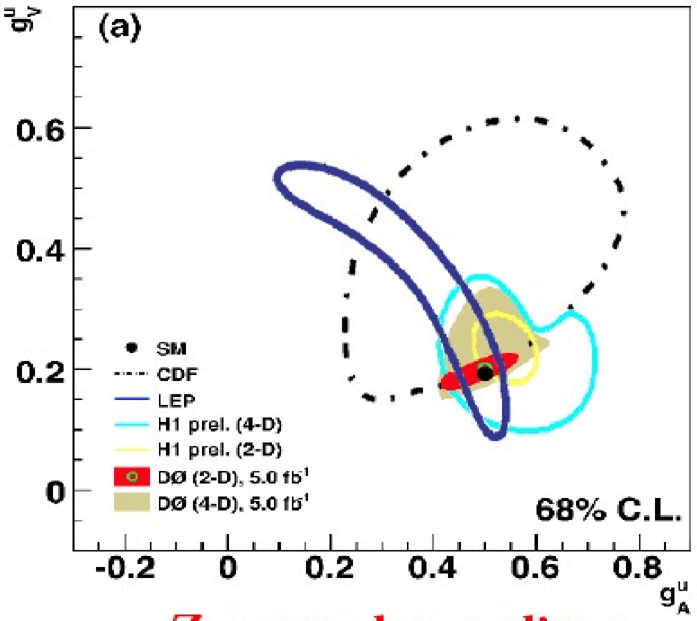




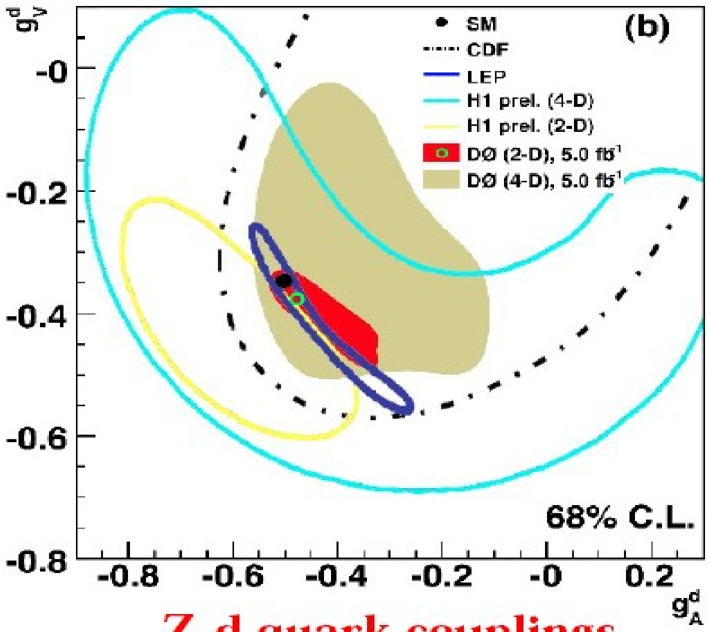
- Statistical uncertainty is still dominant
- PDF uncertainty (0.00048) is dominant in systematic uncertainty
- Most precise measurement based on Z to light quark couplings

Published: Phys. Rev. D 84, 012007 (2011)

Z/γ^* forward-backward asymmetry



Z-u quark couplings



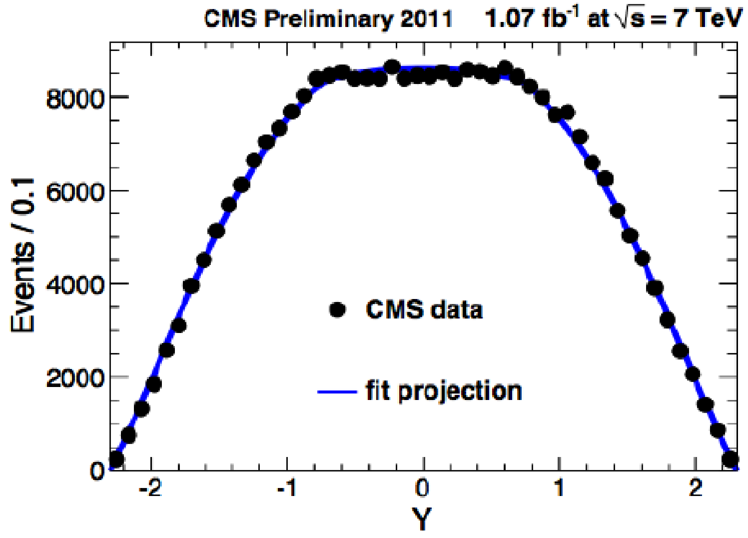
Z-d quark couplings

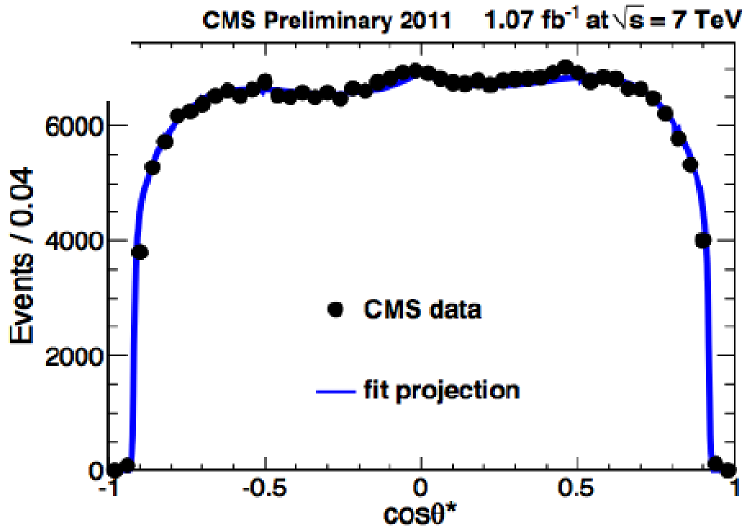
Most precise direct measurement of couplings of Z to light quarks u and d.

Published: Phys. Rev. D 84, 012007 (2011)

Z/γ^* forward-backward asymmetry

A first measurement of the effective weak mixing angle at the LHC is available from CMS.





The effective weak mixing angle is extracted from the di-muon data using an unbinned extended maximum-likelihood fit.

In this fit, each event is characterised by three observables: di-lepton rapidity, di-lepton invariant mass squared, cos θ^*_{CS}

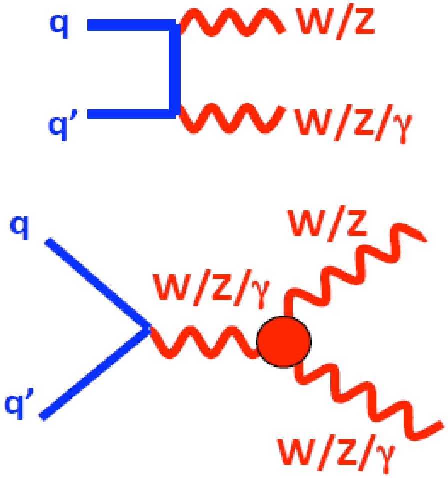
Result: $\sin^2\theta_{\rm eff} = 0.2287 \pm 0.0020(\rm stat.) \pm 0.0025(\rm syst.)$

source	correction	uncertainty
PDF	–	±0.0013
FSR	–	±0.0011
LO model (EWK)	–	±0.0002
LO model (QCD)	+0.0012	±0.0012
resolution and alignment	+0.0007	±0.0013
efficiency and acceptance	–	±0.0003
background	–	±0.0001
total	+0.0019	±0.0025

Gauge couplings

- In Standard Model (SM) non-abelian nature of $SU(2)_L$ x $U(1)_Y$ allow gauge bosons to interact with one another
  - Coupling between 3 gauge bosons=> triple Gauge-Boson Coupling (TGC)
- SM only allows charged coupling (WWZ, WWγ), does not allow pure neutral coupling (ZZZ,ZZγ,Zγγ,γγγ) since Z/γ has no charge nor weak isospin.
- Physics beyond SM can introduce anomalous TGCs which may allow neutral couplings or increase the charged TGCs couplings strenght.

Dibosons



$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = i\left[g_1^V\left(W^\dagger_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{\dagger\mu}V^\nu\right) + \kappa^V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2} W^\dagger_{\rho\mu} W^\mu_\nu V^{\nu\rho}\right]$$

$$\mathcal{L} = -\frac{e}{M_Z^2}\left[f_4^V(\delta_\mu V^{\mu\beta})Z_\alpha(\delta^\alpha Z_\beta) + f_5^V(\delta^\sigma V_{\sigma\mu})Z^{\mu\beta}Z_\beta\right]$$

EM gauge invariance and C and P conservation
→ 5 independent TGCs for WW $\{g_1^Z, \kappa_Z, \kappa_\gamma, \lambda_Z, \lambda_\gamma\}$

Wγ sensitive to κ_γ, λ_γ
WZ sensitive to g_1^Z, κ_Z, λ_Z

Standard Model: $g_1^Z = \kappa_Z = \kappa_\gamma = 1$ so consider Δg_1^Z, $\Delta\kappa_Z$
$\lambda_Z = \lambda_\gamma = 0$

$$\Delta a(\hat{s}) = \frac{\Delta a_0}{(1 + \hat{s}/\Lambda^2_{NP})^n}$$

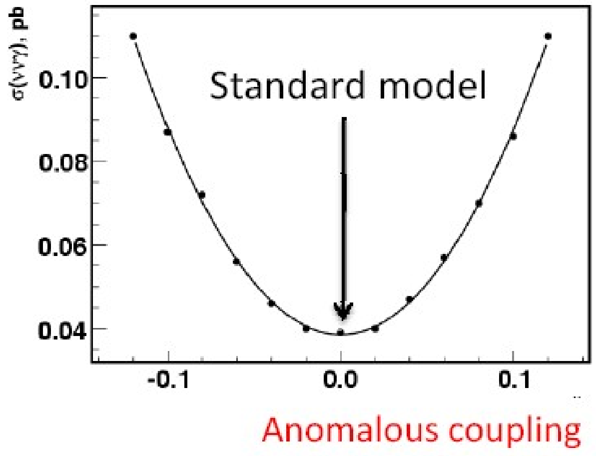
ZγZ vertex: Zγ sensitive to $h_3^Z, h_3^\gamma, h_4^Z, h_4^\gamma$
ZZγ vertex: ZZ sensitive to $f_4^Z, f_4^\gamma, f_5^Z, f_5^\gamma$ all zero in SM

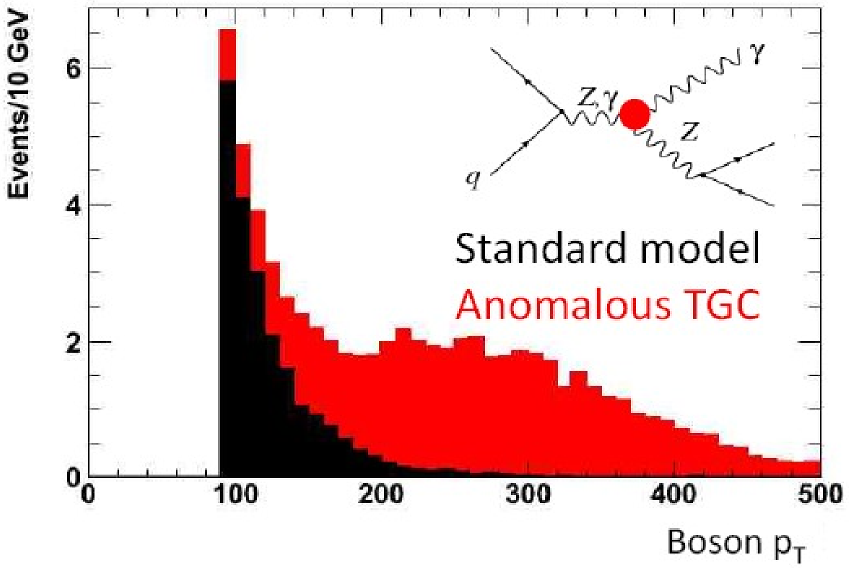
Characteristic of the triple gauge-boson couplings

- Sensitivity to TGCs comes from four different types of information
  - Cross section: parabolic increase of cross-section with TGC due to the linear Lagrangian: $\sigma \sim (\mathrm{TGC})^2$
  - Energy behaviour: TGC lead to a broad increase in the differential cross-section at large invariant mass $M_{WV,ZV}$ ($V=Z,\gamma$) and transverse momentum $P_T(V)$ ($V=W,Z,\gamma$)
  - Production angle: angular information of the bosons
  - Polarisation: different TGCs contribute to different boson helicity states. Decay angular information enhance sensitivity to individual TGCs.

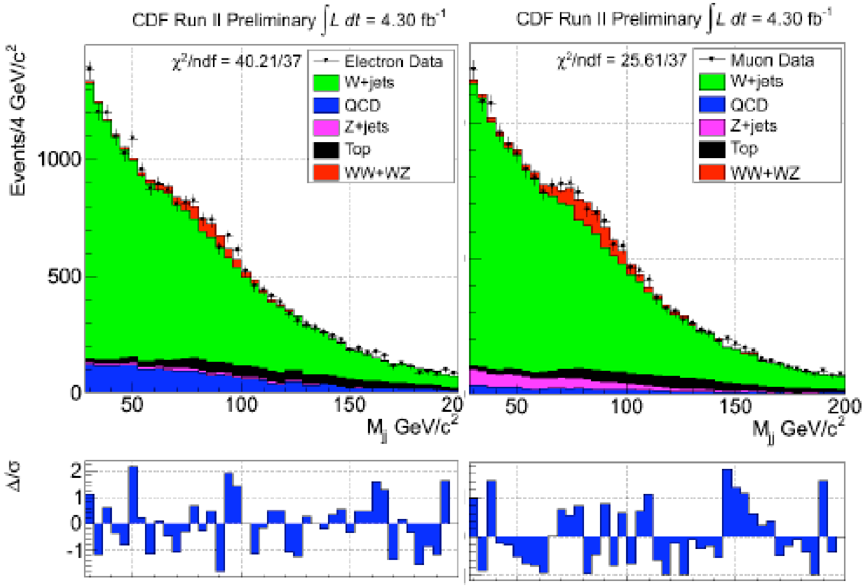
Effect of anomalous coupling

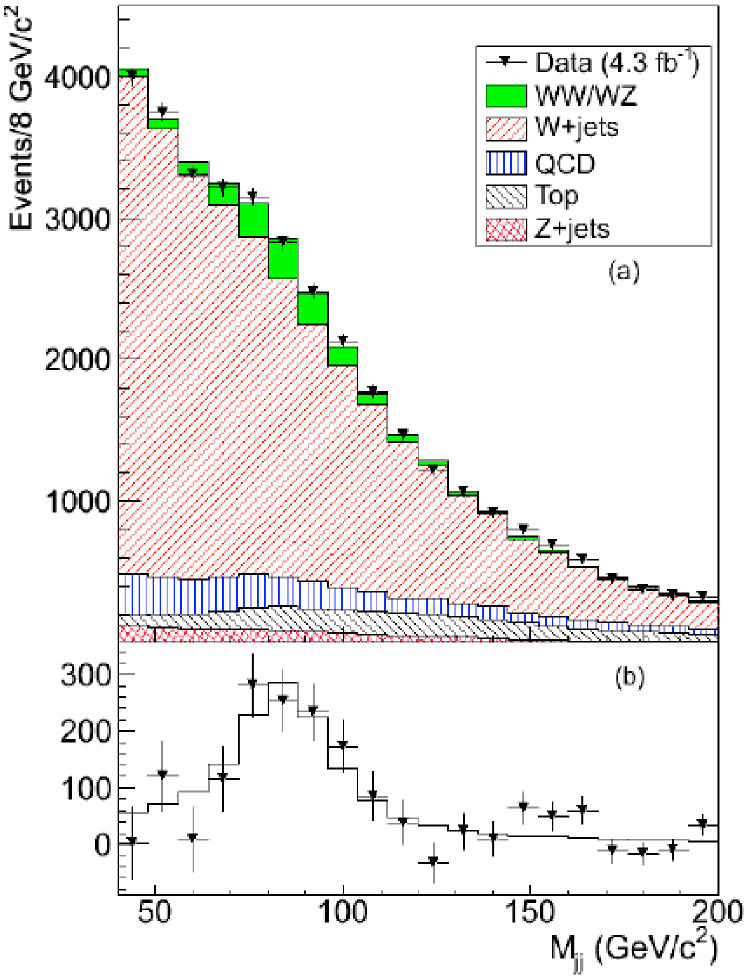
- Any non-zero coupling result in crease of the cross-section and harder p_T spectrum of the outgoing boson.
  - Can be simulated by a number of generators, such as Sherpa, MCFM, Baur, etc.





$WW/WZ \to \ell\nu jj$

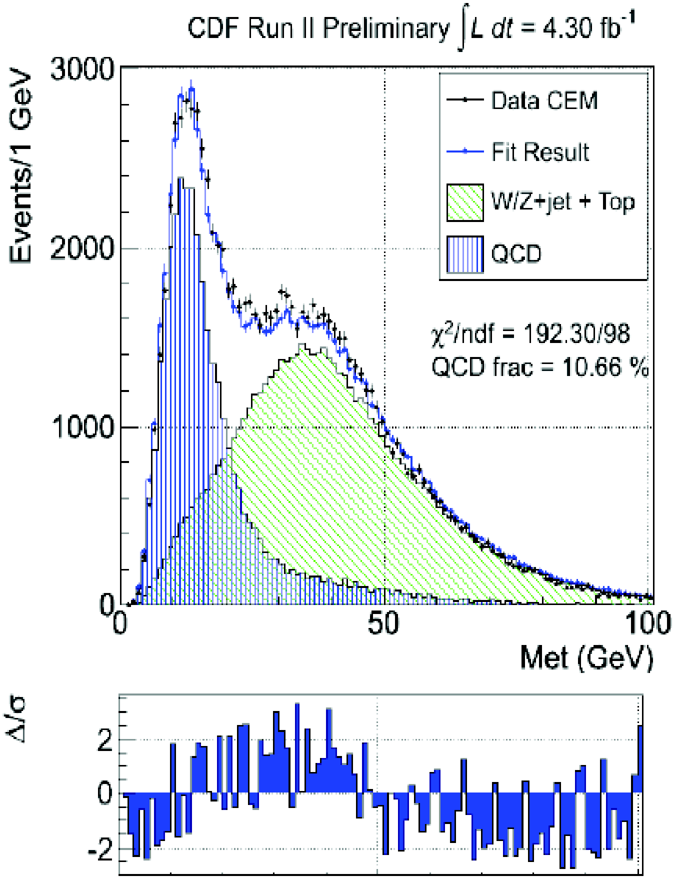


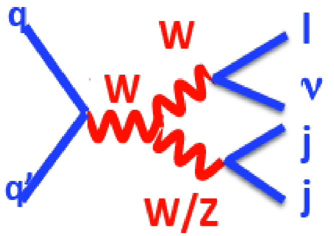


$\sigma(WW+WZ)$
$= 18.1 \pm 3.3(\text{stat}) \pm 2.5(\text{sys})$ pb

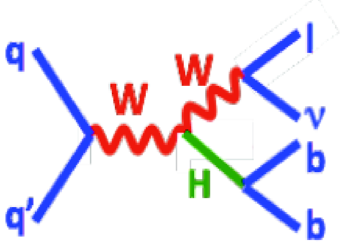
5.2σ significance

WW/WZ → $\ell\nu jj$





Similar final state to low-mass Higgs:

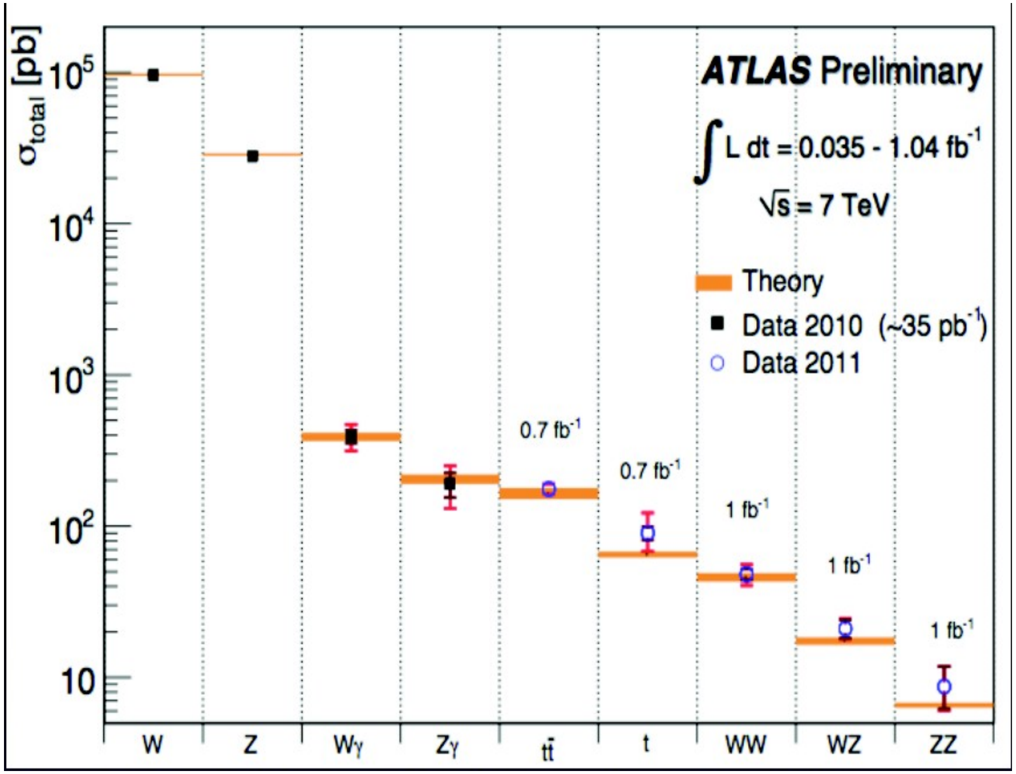


Sample	Electrons	Muons
MC W +jets	18010 ± 531	16673 ± 482
MC Z+jets	353 ± 42	966 ± 115
diboson	750 ± 68	651 ± 59
top	1324 ± 134	1149± 115
QCD (from data)	2314 ± 462	639 ± 159
Total MC + QCD	22751	20078
data	22204 ± 149	19738 ± 141

Cross-sections

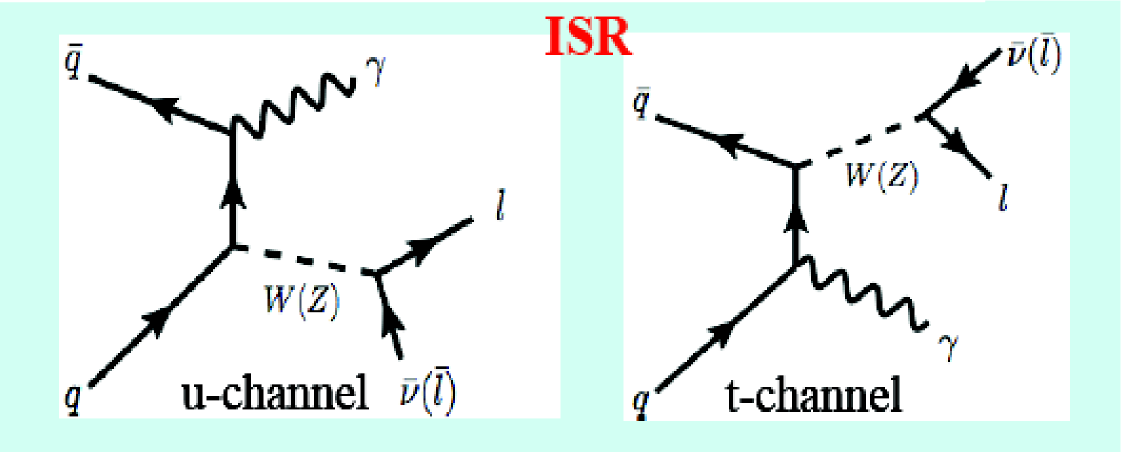
- $\sigma(W)BR(W \to e\nu) \sim 10$nb
- $\sigma(WW)BR(W \to e\nu)^2 \sim 100$fb

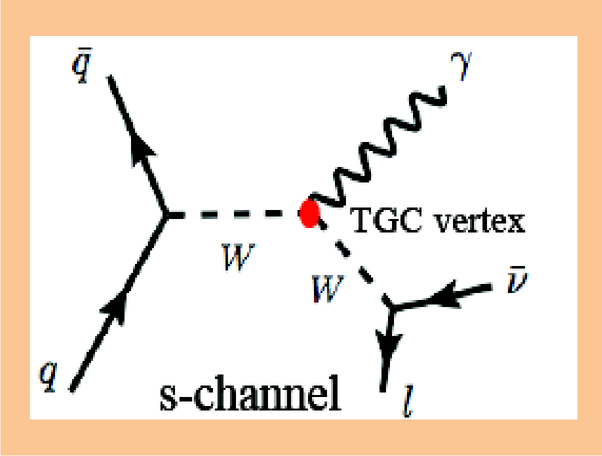
- $\sigma(Z)\ BR(Z \to ee) \sim 1$ nb
- $\sigma(ZZ)\ BR(Z \to ll)^2 \sim 10$ fb



- Eg with fb^{-1}
- ~ 10^6 W and ~10^5 Z events per experiment and lepton channel
- ~ 100 WW and ~10 ZZ per experiment including all lepton channels

Wγ and Zγ production





- Measurement of Wγ and Zγ production provides a direct test of the Triple Gauge Boson Coupling (TGC) of the Electroweak theory
  - Measure the WWγ vertex in the s-channel
  - Probing the existence of the ZZγ and Zγγ TGC (forbidden in SM at the tree level)

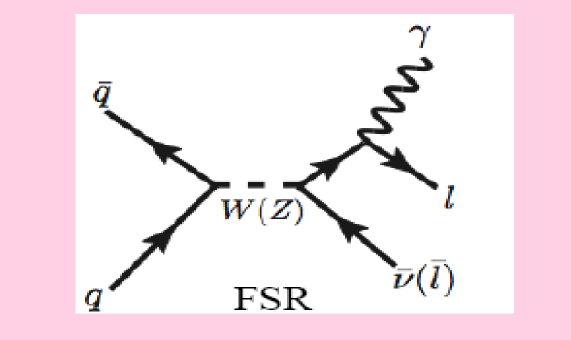
Definition of the signal

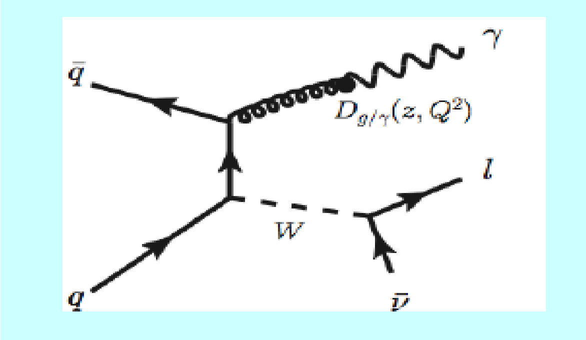
- Measurement of Wγ, Zγ in the final state :
  - Wγ : $l\,\nu\,\gamma + X$
  - Zγ : $l^+ l^- \gamma + X$

l : e , μ

γ : is isolated

- Final state can include contributions from :
  - Final State Radiation (FSR) γ from inclusive W(Z) production
  - Photon from fragmentation of jets produced in association with W or Z boson



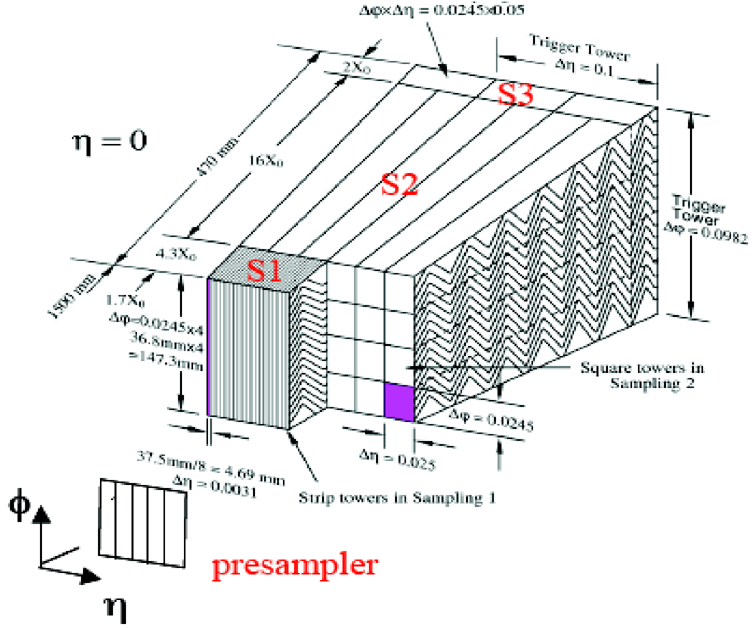


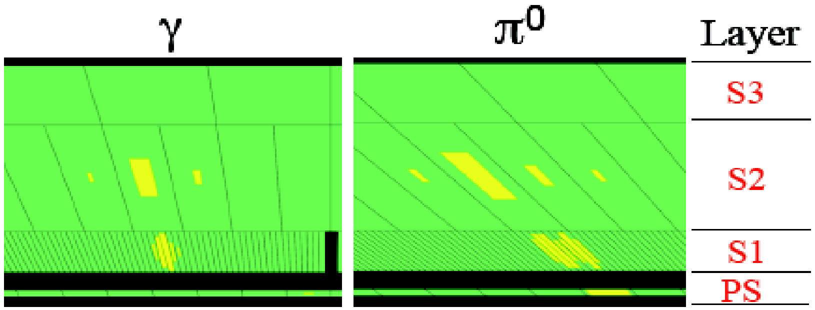
γ from fragmentation

- Phase space of production measurement :
  - $E_T^{\gamma} > 15$ GeV
  - $M(l^+l^-) > 40$ GeV (for Zγ)
  - $dR(l, \gamma) > 0.7$ (to reduce FSR contribution)
  - particle level isolation : $\sum_{\Delta R<0.4} E_T^{had} < 0.5 \times E_T^{\gamma}$

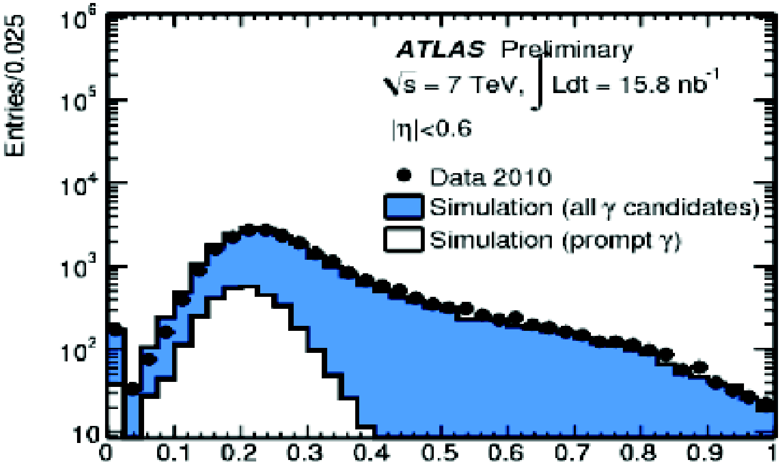
Photon identification

- γ identified in ATLAS LAr calorimeter





Fine granularity in S1 for γ/π^0 separation



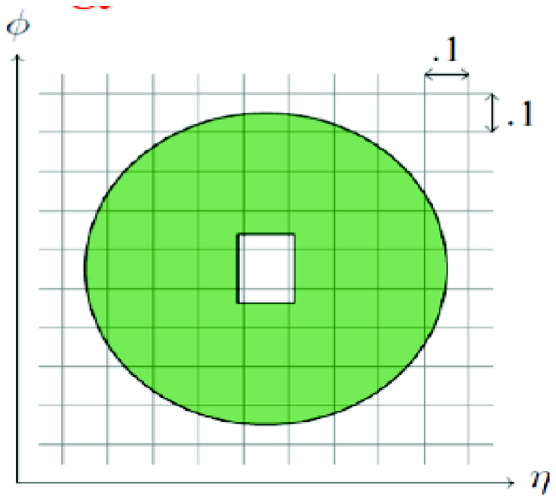
Fraction of energy outside shower core in layer S1

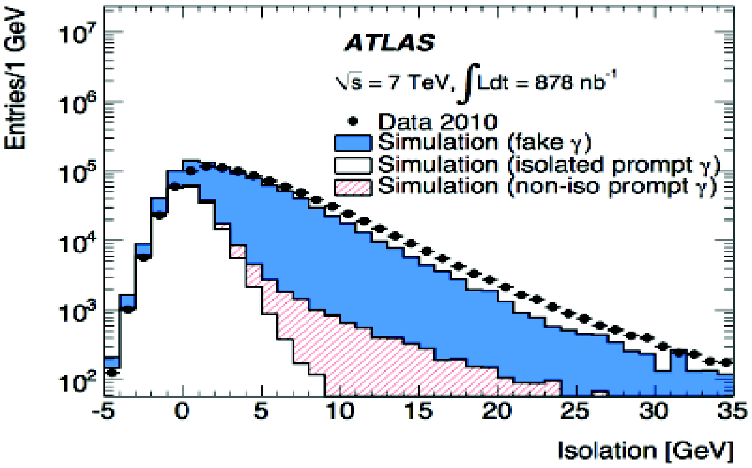
γ Reconstruction :

- Narrow energy cluster, require no/small energy leakage into hadronic calorimeter
- Cut on shower shape variables to discriminate γ from jets and π^0, η

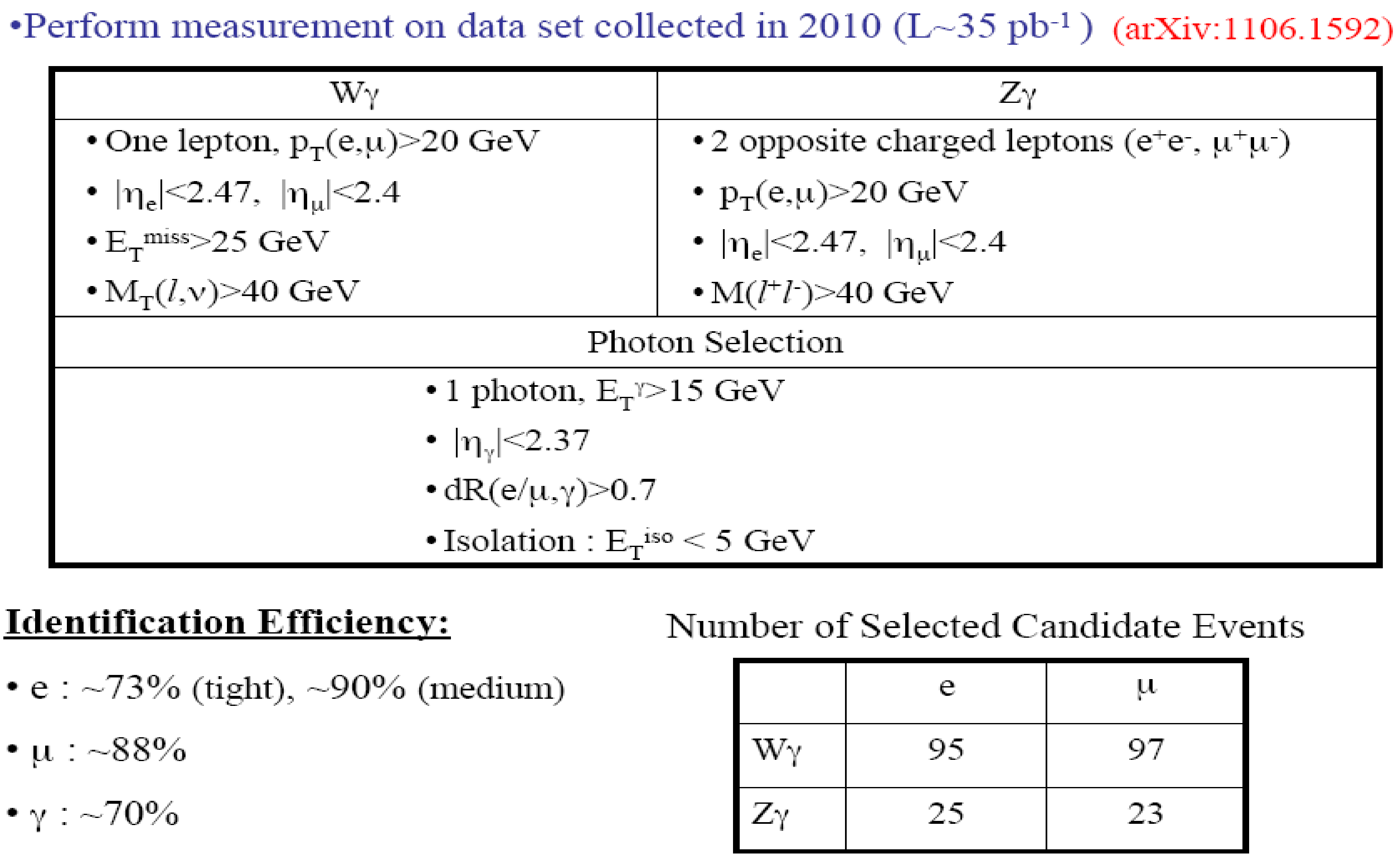
Photon isolation efficiency

- Isolation energy is another important quantity to discriminate γ from jet
- Isolation : sum of transverse energy in ΔR=0.4 cone around γ
- Exclude energy from central core
- Correction :
  - Remove energy leakage from photon energy into isolation cone
  - Remove energy deposition from pile-up and underlying event by using "jet area/median" method (Cacciari, Salam and Sapeta, JHEP 04 (2010) 065) to measure the ambient energy density
- Photon isolation energy different between direct photon and photon from fragmentation
- Isolation not well modeled by simulation





Event selection



- Perform measurement on data set collected in 2010 ($L \sim 35\ pb^{-1}$) (arXiv:1106.1592)

Wγ	Zγ
• One lepton, $p_T(e,\mu) > 20$ GeV • $\lvert\eta_e\rvert < 2.47$, $\lvert\eta_\mu\rvert < 2.4$ • $E_T^{miss} > 25$ GeV • $M_T(l,\nu) > 40$ GeV	• 2 opposite charged leptons (e^+e^-, $\mu^+\mu^-$) • $p_T(e,\mu) > 20$ GeV • $\lvert\eta_e\rvert < 2.47$, $\lvert\eta_\mu\rvert < 2.4$ • $M(l^+l^-) > 40$ GeV
Photon Selection	
• 1 photon, $E_T^\gamma > 15$ GeV • $\lvert\eta_\gamma\rvert < 2.37$ • $dR(e/\mu,\gamma) > 0.7$ • Isolation : $E_T^{iso} < 5$ GeV	

Identification Efficiency:

- e : ~73% (tight), ~90% (medium)
- μ : ~88%
- γ : ~70%

Number of Selected Candidate Events

	e	μ
Wγ	95	97
Zγ	25	23

Background estimation

- Main sources of background:

Wγ :
- W+jets *
- W→τν
- Z→*ll*
- ttbar
- negligible contribution from QCD multi-jet, WW, single-top

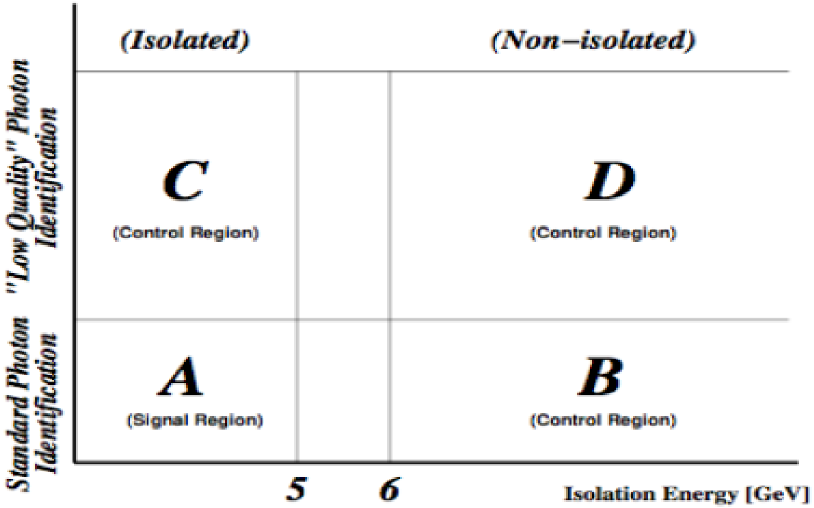
Zγ :
- Z+jets *
- Z→ττ
- ttbar

*: most dominating source, jet fakes as photon.

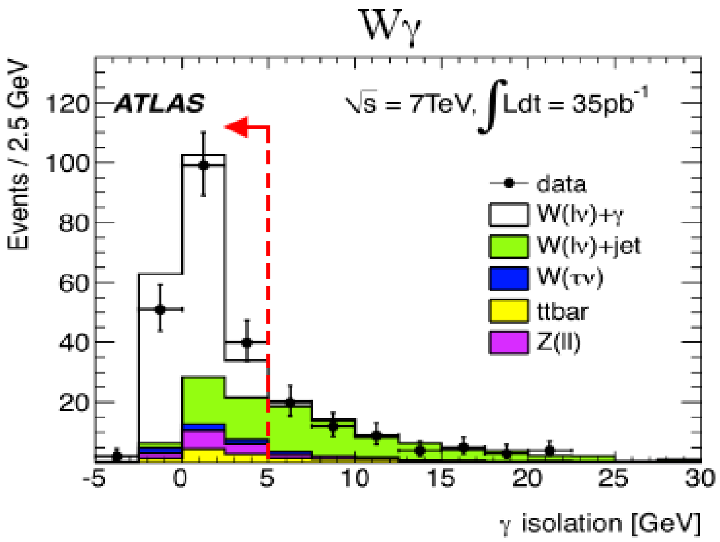
- For Wγ, estimate W+jets background from data control regions
- Assume photon identification (ID) cuts not strongly correlated to photon isolation for W+jets

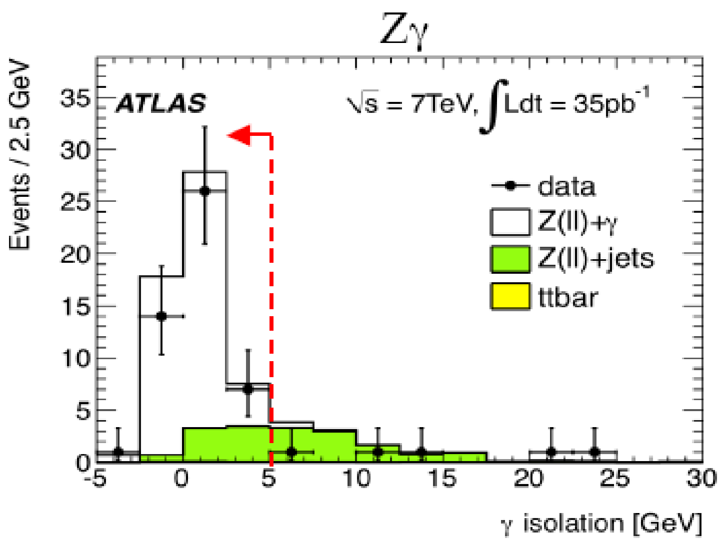
$$N_A^{W+jets} = N_B \cdot \frac{N_C}{N_D}$$

(Contributions from non-W+jets backgrounds and signal leakage in control regions B,C and D are removed)



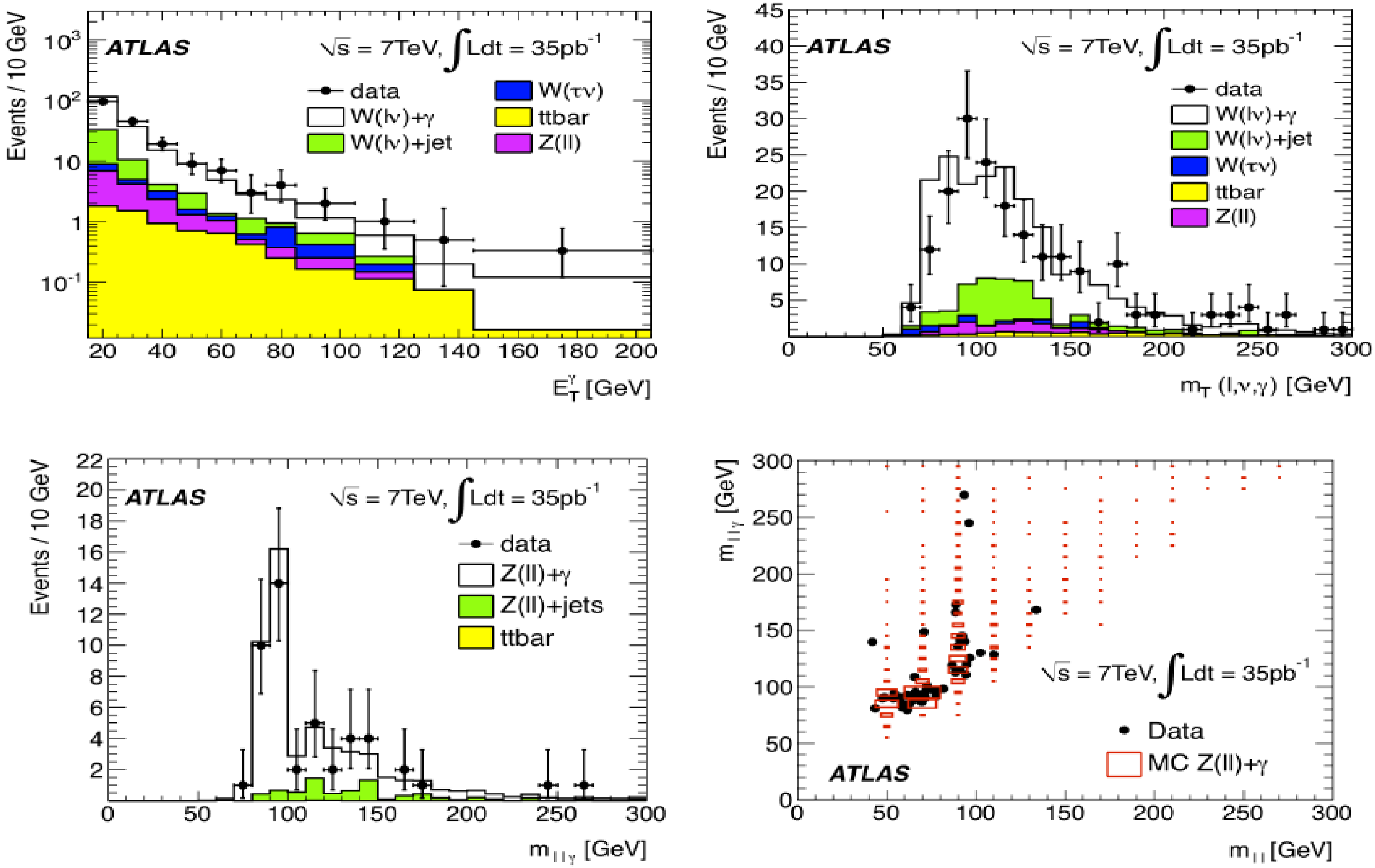
Background estimation



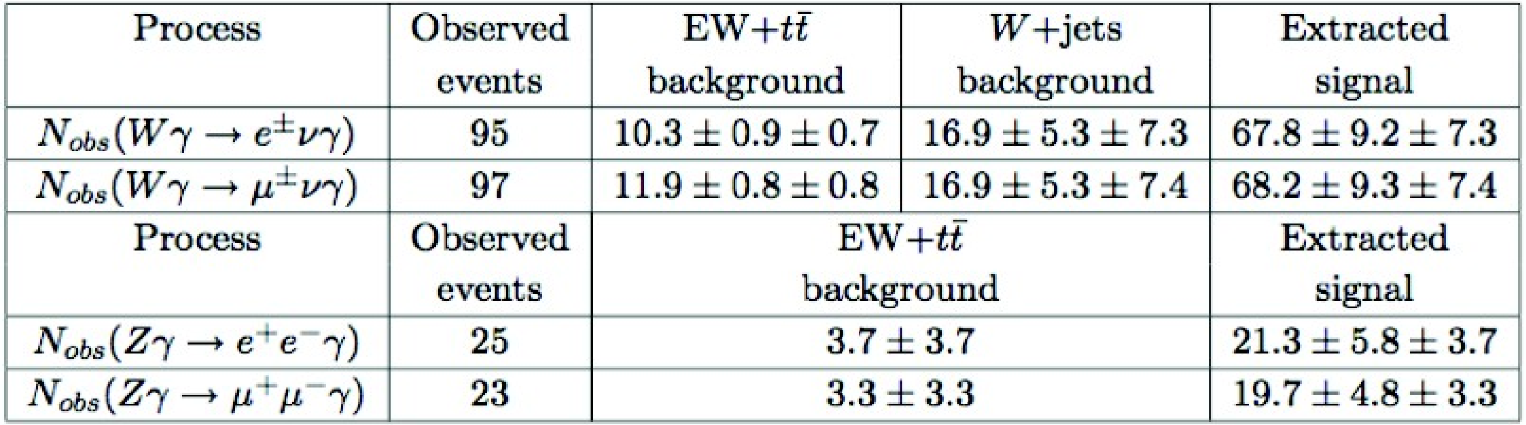


- W+jets background (green) isolation shape is taken from data's "low-quality" ID control region
- Since low statistics in Zγ events, estimate Z+jets background based on simulation (assign large systematic uncertainty)

Kinematic distributions



Signal yield



Process	Observed events	EW+$t\bar{t}$ background	W+jets background	Extracted signal
$N_{obs}(W\gamma \rightarrow e^{\pm}\nu\gamma)$	95	$10.3 \pm 0.9 \pm 0.7$	$16.9 \pm 5.3 \pm 7.3$	$67.8 \pm 9.2 \pm 7.3$
$N_{obs}(W\gamma \rightarrow \mu^{\pm}\nu\gamma)$	97	$11.9 \pm 0.8 \pm 0.8$	$16.9 \pm 5.3 \pm 7.4$	$68.2 \pm 9.3 \pm 7.4$
Process	Observed events	EW+$t\bar{t}$ background		Extracted signal
$N_{obs}(Z\gamma \rightarrow e^{+}e^{-}\gamma)$	25	3.7 ± 3.7		$21.3 \pm 5.8 \pm 3.7$
$N_{obs}(Z\gamma \rightarrow \mu^{+}\mu^{-}\gamma)$	23	3.3 ± 3.3		$19.7 \pm 4.8 \pm 3.3$

Systematic Uncertainties on Extracted Signal:

- Stability of control regions using shower shape : ~9%
- Stability of control regions using isolation : ~4%
- Modeling of signal leakage : ~3%
- Background correlation in control regions : ~3%

Uncertainties

Electron Channel

Parameter	$\frac{\delta C_{W\gamma}}{C_{W\gamma}}$	$\frac{\delta C_{Z\gamma}}{C_{Z\gamma}}$
Channel	$e^{\pm}\nu\gamma$	$e^{+}e^{-}\gamma$
Trigger efficiency	1%	0.02%
Electron efficiency	4.5%	4.5%
Photon efficiency	10.1%	10.1%
EM scale and resolution	3%	4.5%
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale and resolution	2%	-
Inoperative readout modeling	1.4%	2.1%
Photon simulation modeling	0.3%	0.3%
Photon isolation efficiency	3.3%	3.3%
Total uncertainty	12.1%	12.5%

Muon Channel

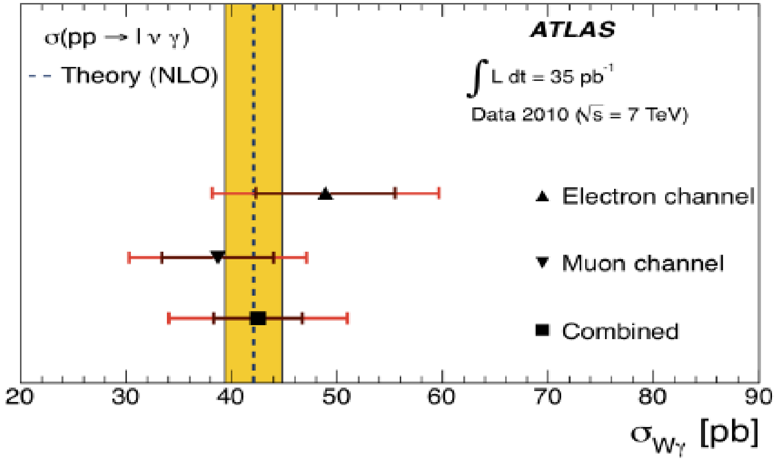
Parameter	$\frac{\delta C_{W\gamma}}{C_{W\gamma}}$	$\frac{\delta C_{Z\gamma}}{C_{Z\gamma}}$
Channel	$\mu^{\pm}\nu\gamma$	$\mu^{+}\mu^{-}\gamma$
Trigger efficiency	0.6%	0.2%
Muon efficiency	0.5%	1%
Muon isolation efficiency	1%	2%
Momentum scale and resolution	0.3%	0.5%
Photon efficiency	10.1%	10.1%
EM scale and resolution	4%	3%
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale and resolution	2%	-
Inoperative readout modeling	0.7%	0.7%
Photon simulation modeling	0.3%	0.3%
Photon isolation efficiency	3.3%	3.3%
Total uncertainty	11.6%	11.2%

Dominant Uncertainties :

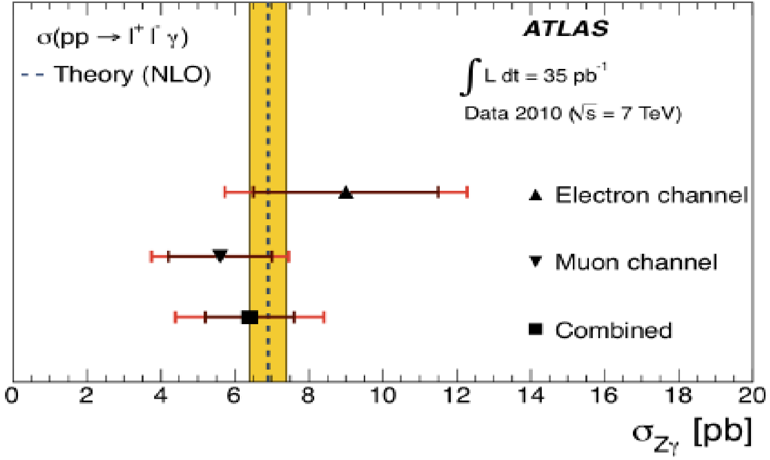
- Photon reconstruction/ID efficiency : ~10% (uncertainty in upstream material and contribution from fragmentation photon)
- Electron reconstruction/ID : ~4.5%
- Electromagnetic energy scale and resolution : ~3 - 4.5%

Cross-section

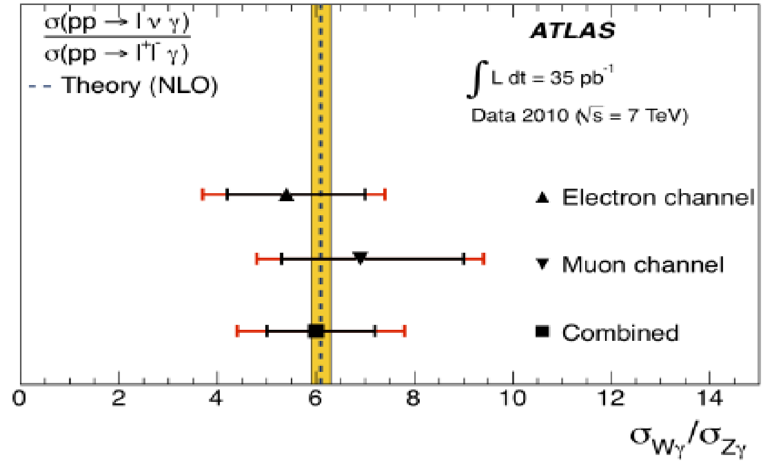
σ(Wγ)



σ(Zγ)



σ(Wγ)/σ(Zγ)



- All measurements are consistent within their uncertainties with the SM expectation

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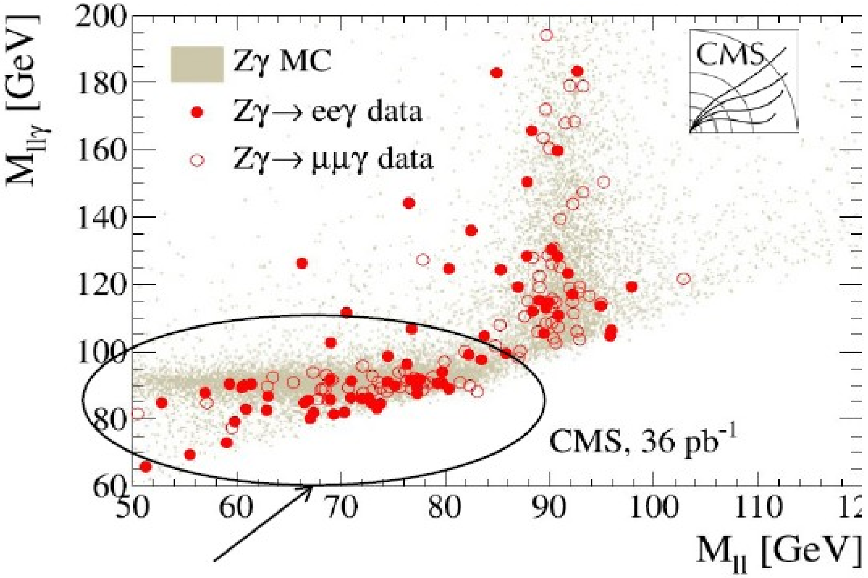
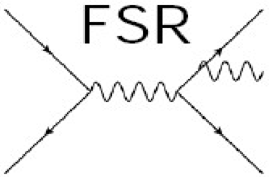
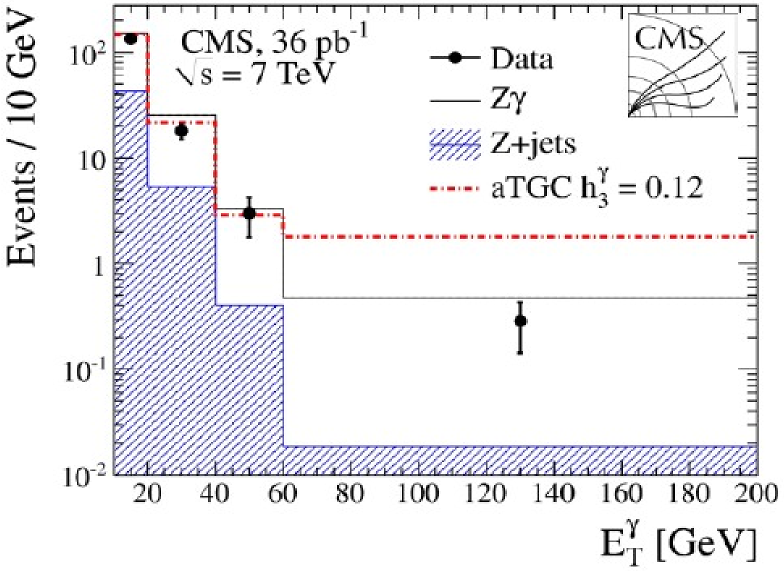
Zγ

- Look for non-CP violating couplings h_3, h_4
- NP enhances high pt photons, high $M_{ll\gamma}$ $E_{t\gamma}$







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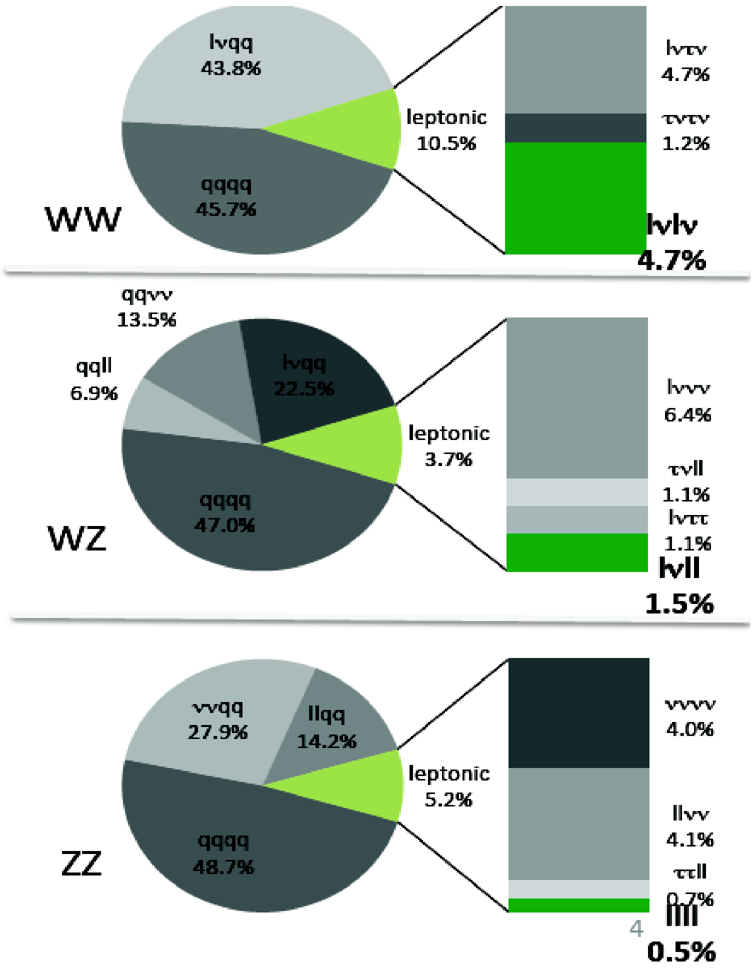
Heavy boson production

- Use leptonic decays:
  - Small Branching Ratios
  - Low background
- Tau decays contribute to e/μ channels
  - Accounted for in cross section extraction.
- Clean but small signal.



Backgrounds

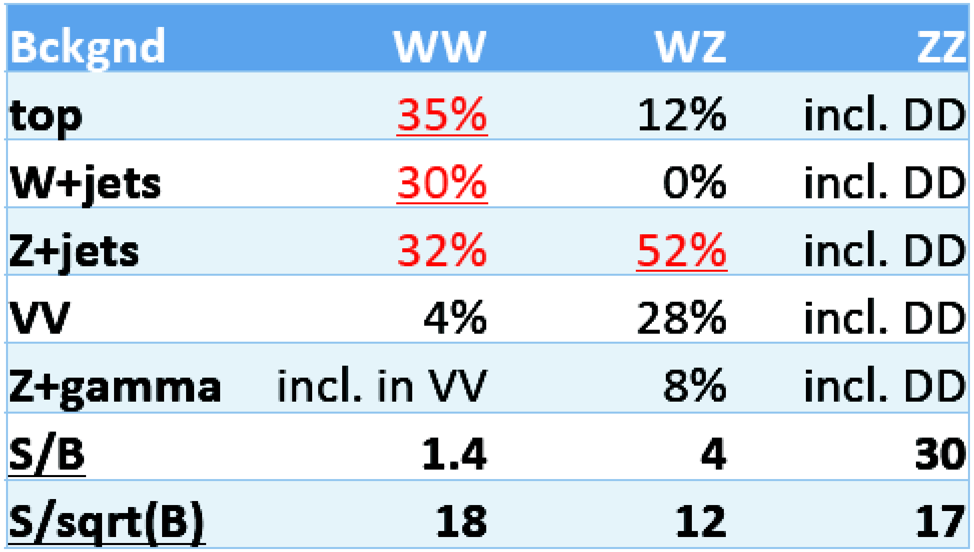
Multi-lepton finals states from top-quark decays.

Use data driven techniques.

Fake leptons from jets associated with Z/W. Use data driven techniques.

Di-Boson is signal and background for other VV channels.

2l+MET | 3l+M_Z+MET | 2M_Z



Bckgnd	WW	WZ	ZZ
top	35%	12%	incl. DD
W+jets	30%	0%	incl. DD
Z+jets	32%	52%	incl. DD
VV	4%	28%	incl. DD
Z+gamma	incl. in VV	8%	incl. DD
S/B	1.4	4	30
S/sqrt(B)	18	12	17

WW-> lνlν

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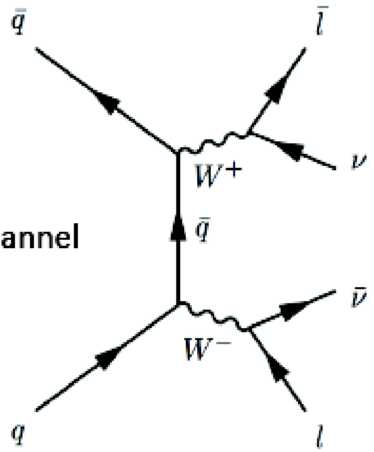
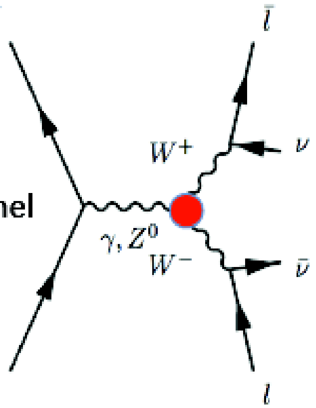
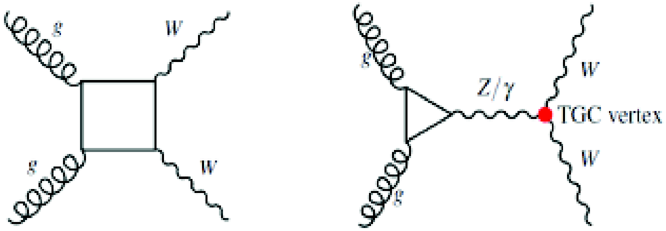
t-channel



s-channel

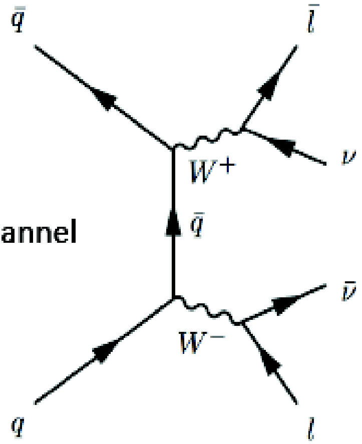


- Signature two leptons and MET.
- Small contribution (3%) from gg:

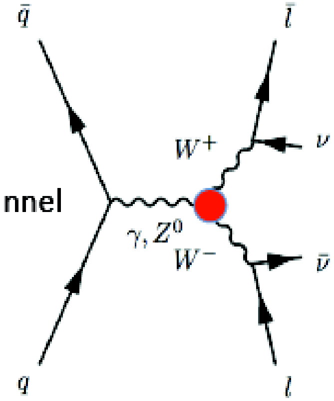


- Important background to H->WW studies!

WW-> $l\nu l\nu$



t-channel



s-channel

<u>Selection</u>

- Exactly 2 leptons opposite signs, $p_T > 20$GeV
- Leading electron $p_T > 25$ GeV
- $m_{ll} > 15$GeV, $m_{e\mu} > 10$GeV
- Z veto ($|m_{ll}-m_Z| < 15$GeV
- MET (rel) > (45,40,25) GeV, ($\mu\mu$,ee,eμ)
- Jet veto (pT>30GeV, |eta|<4.5,anti-kt,DR=0.4)

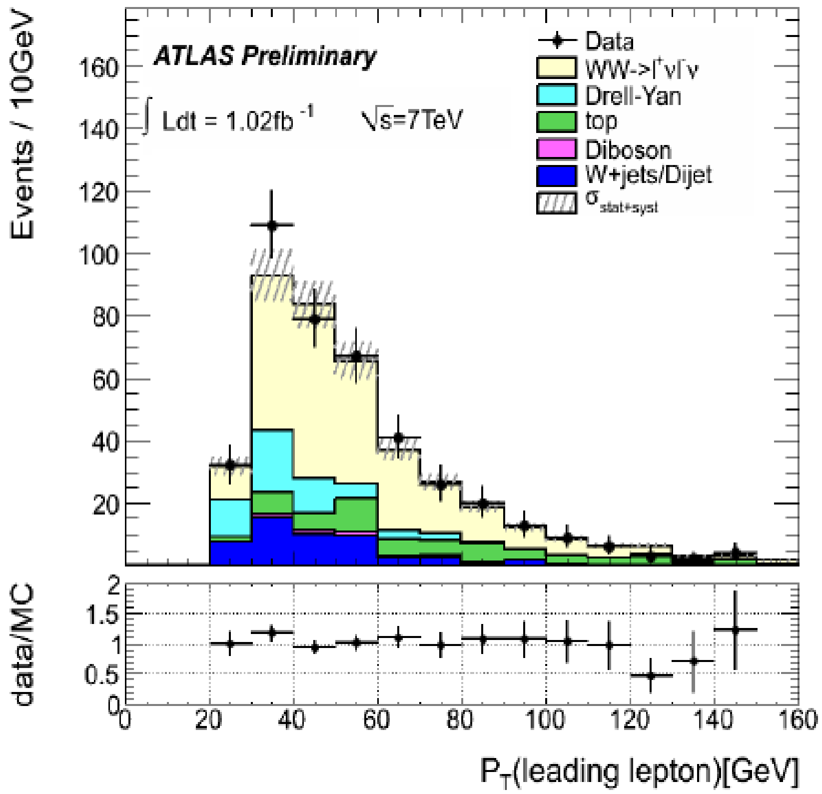
- MET:
  - Use MET relative to nearest lepton: $MET_{rel}=\sin(\Delta\phi)*MET$ for $\phi < 90°$
  - Reduces DY contribution for miss-measured jets/leptons and Z->$\tau\tau$.
- Backgrounds:
  - Use DD backgrounds for W+jets and ttbar.
  - Use MC for DY and Di-Boson.

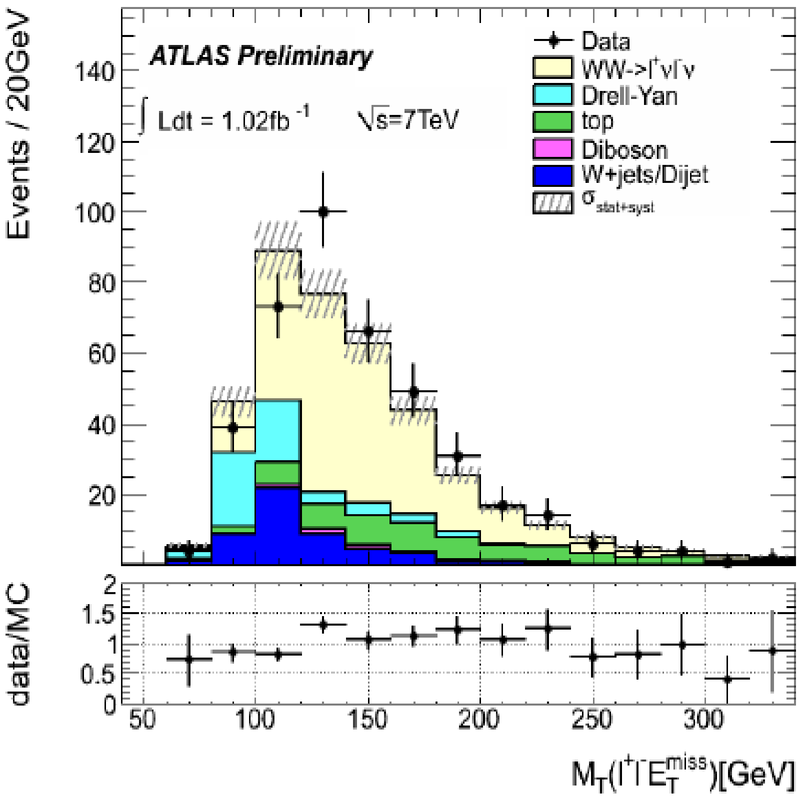
WW-> lνlν

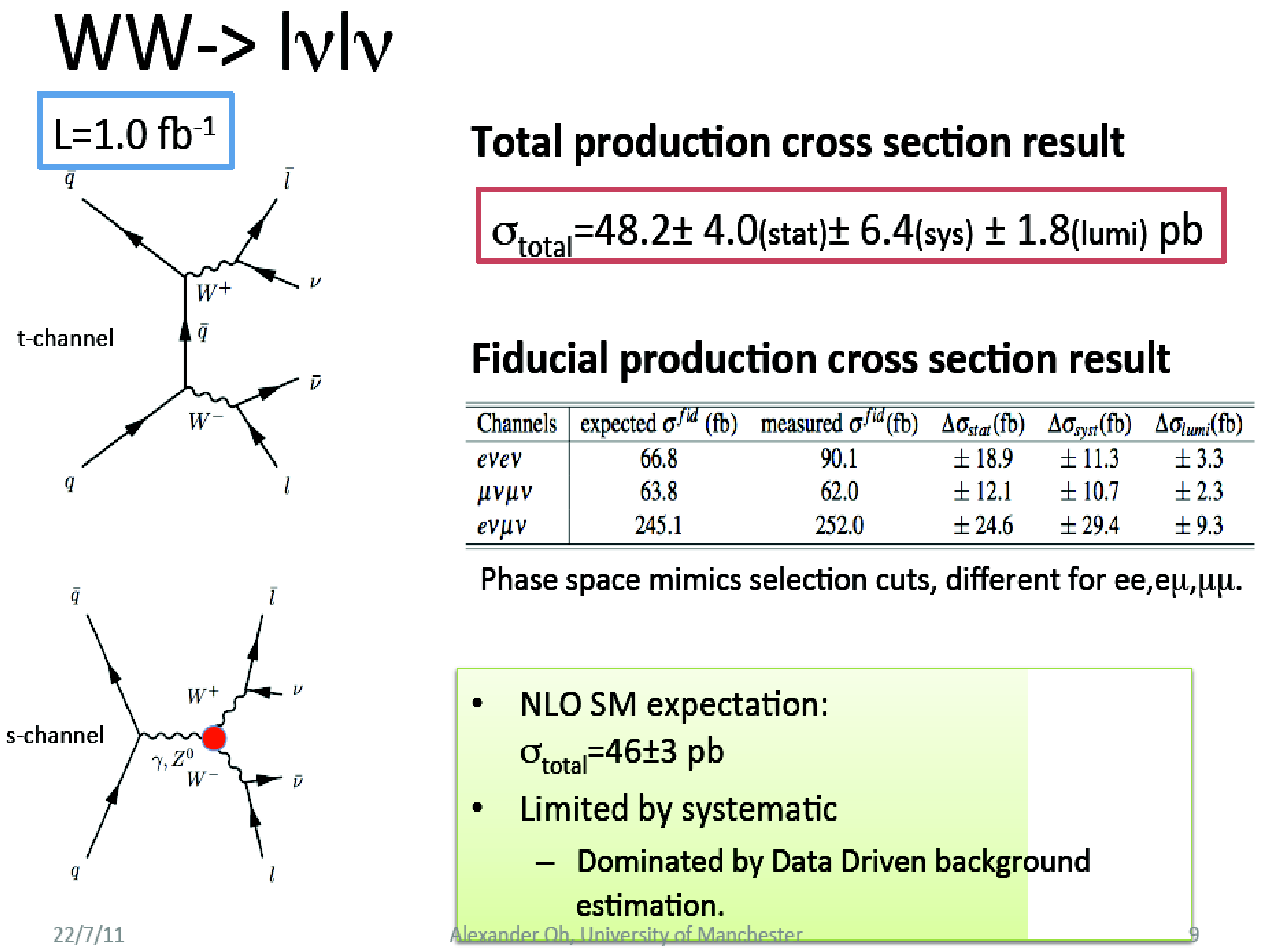
L=1.0 fb^{-1}

Kinematic Distribution after all selection cuts

N(cand) = 414 , N(bckgnd) = 170±28







WW-> lνlν

L=1.0 fb^{-1}

Total production cross section result

σ_{total}=48.2± 4.0(stat)± 6.4(sys) ± 1.8(lumi) pb

Fiducial production cross section result

Channels	expected σ^{fid} (fb)	measured σ^{fid}(fb)	$\Delta\sigma_{stat}$(fb)	$\Delta\sigma_{syst}$(fb)	$\Delta\sigma_{lumi}$(fb)
$e\nu e\nu$	66.8	90.1	± 18.9	± 11.3	± 3.3
$\mu\nu\mu\nu$	63.8	62.0	± 12.1	± 10.7	± 2.3
$e\nu\mu\nu$	245.1	252.0	± 24.6	± 29.4	± 9.3

Phase space mimics selection cuts, different for ee,eμ,μμ.

- NLO SM expectation:
  σ_{total}=46±3 pb
- Limited by systematic
  - Dominated by Data Driven background estimation.

WZ-> lllν

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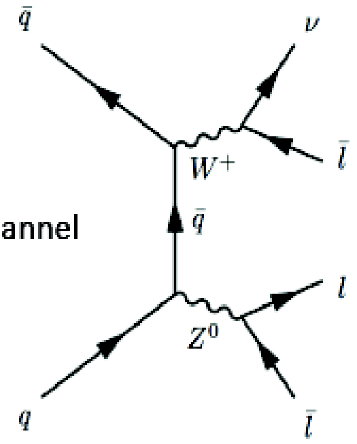
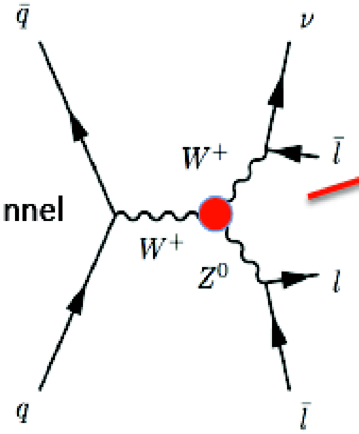


t-channel

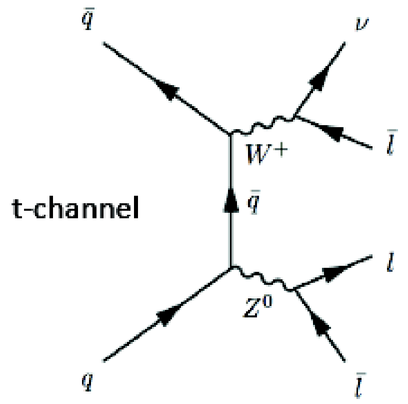


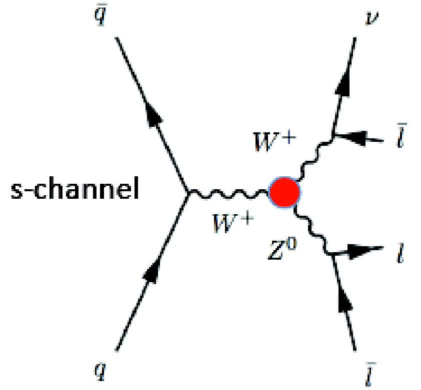
s-channel

- Signature:
  Three leptons and MET.
- Presence of Z allows effective suppression of ttbar backgrounds.
  - Dominant background source Z +jets.
- Cross section and anomalous **<u>triple gauge couplings</u>** determined.

WZ-> lllν

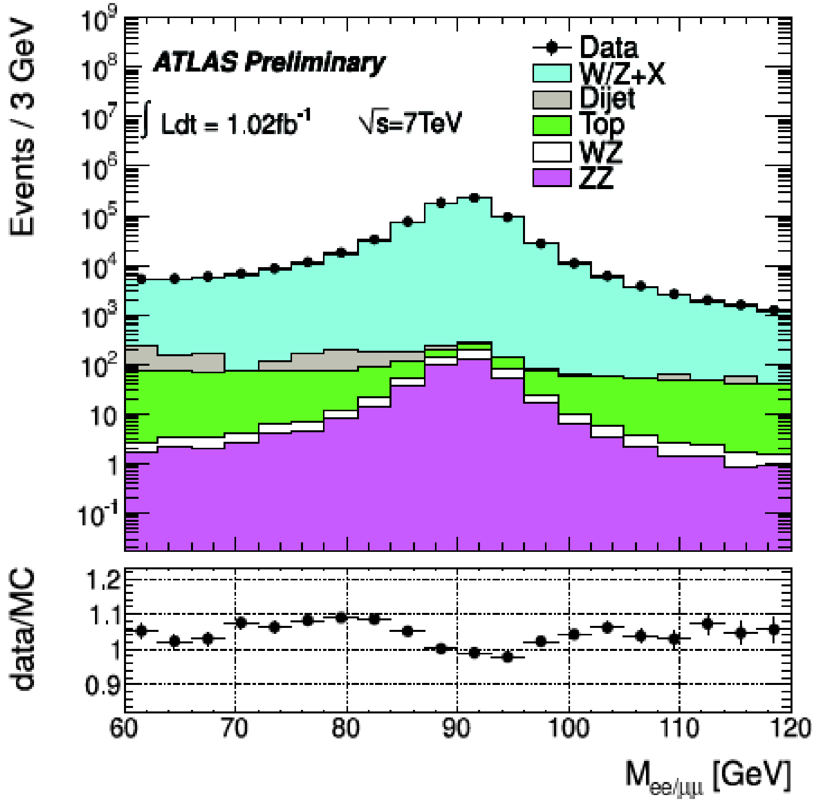
L=1.0 fb^{-1}





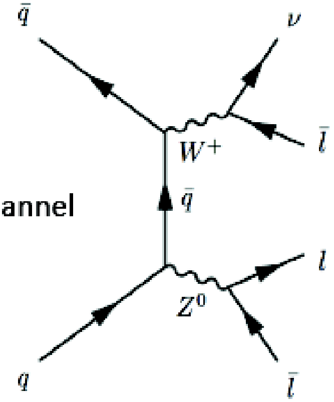
Selection

- Z $|m_{ll}-m_Z| < 10$ GeV
- 3 leptons, $p_T > 15$ GeV
- MET > 25GeV
- W MT > 20 GeV
- Trigger Match with $p_T(e,\mu) > (25,20)$ GeV



WZ-> lllν

L=1.0 fb^{-1}



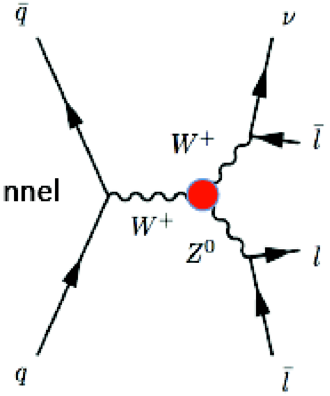
t-channel

Total cross section:

$$\sigma^{tot}_{WZ} = 21.1^{+3.1}_{-2.8}(\text{stat})\ ^{+1.2}_{-1.2}(\text{syst})\ ^{+0.9}_{-0.8}(\text{lumi})\ \text{pb.}$$

SM NLO expectation 17.2±1pb

Good agreement with the Standard Model.



s-channel

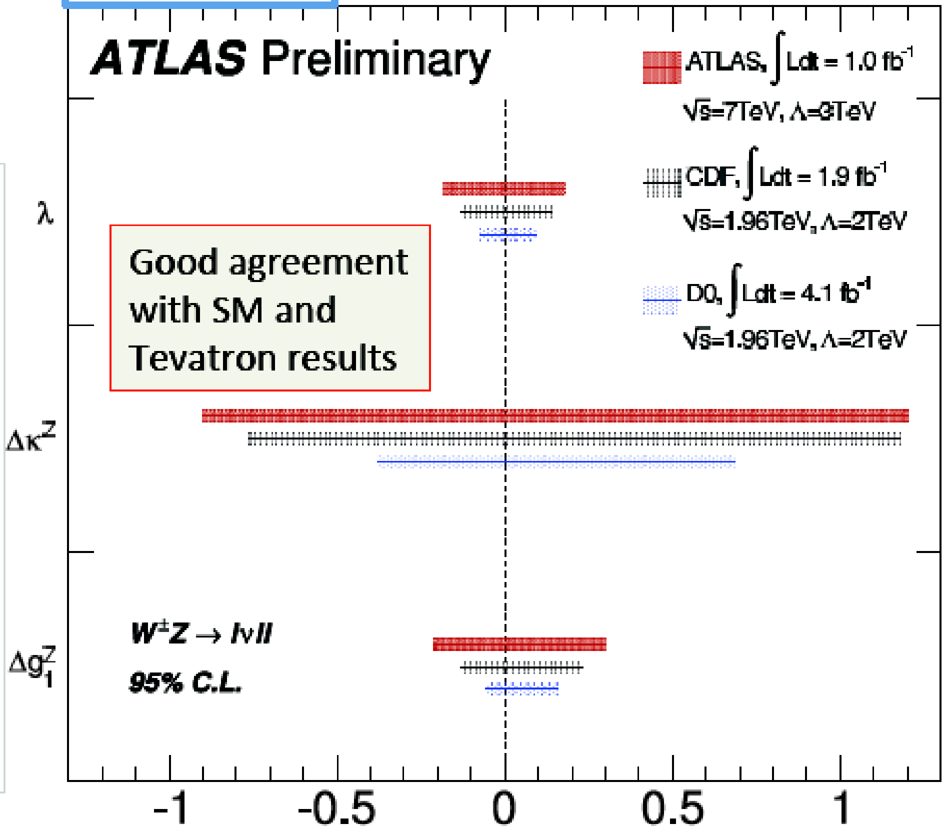
Fiducial Cross section:

- $p_T(l) > 15$ GeV, $|\eta| < 2.5$, $pT(\nu) > 25$ GeV
- $M(ll) - M_Z < 10$ GeV
- $M_T(W) > 20$ GeV

$$\sigma^{fid}_{WZ\to\ell\nu\ell\ell} = 118^{+18}_{-16}(\text{stat})\ ^{+6}_{-6}(\text{syst})\ ^{+5}_{-5}(\text{lumi})\ \text{fb}$$

WZ-> lllν

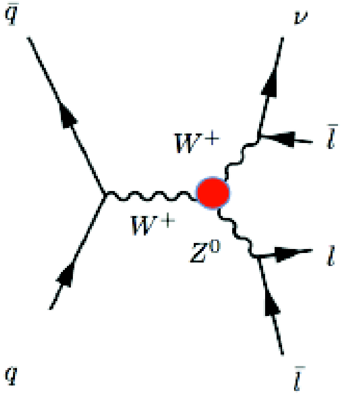
L=1.0 fb^{-1}



Good agreement with SM and Tevatron results

<u>Extraction of anomalous triple gauge boson couplings</u>

- Use total cross section to fit TGC.
- NLO MC with reweighting technique.
- Use cut-off of Λ=3TeV
- Profile likelihood ratio, including systematics as nuisance parameters.
- Confidence Intervals obtained by Neyman construction based on cross section.



Anomalous Coupling	Limits of the 68% C.I.	Limits of the 95% C.I.
Δg_1^Z	$[-0.17, -0.05], [0.13, 0.26]$	$[-0.21, 0.30]$
$\Delta\kappa^Z$	$[-0.8, -0.2], [0.5, 1.0]$	$[-0.9, 1.2]$
λ	$[-0.15, -0.06], [0.06, 0.15]$	$[-0.18, 0.18]$

ZZ-> llll

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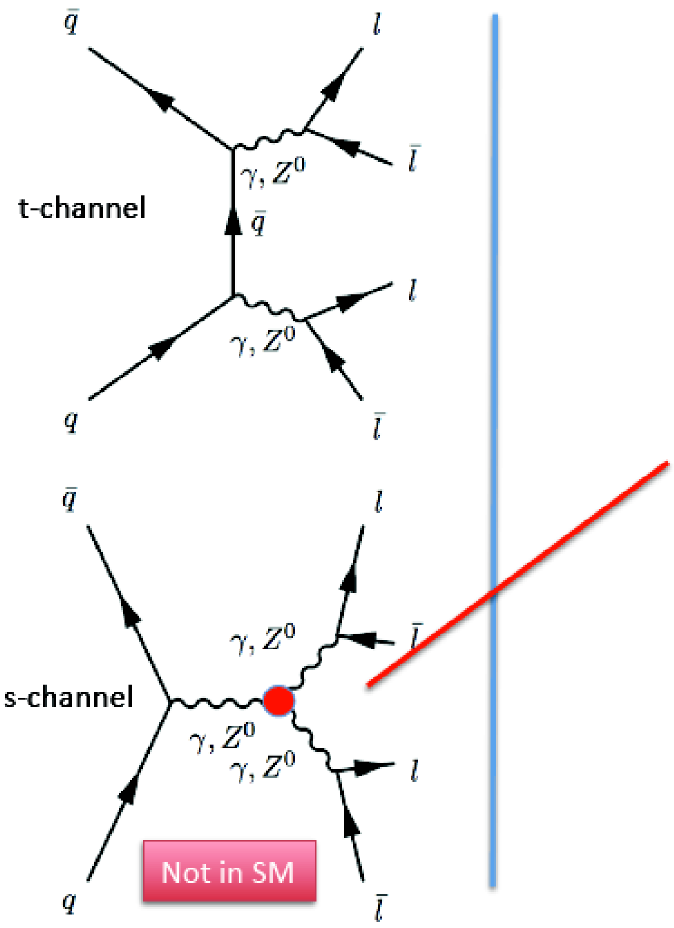


Not in SM

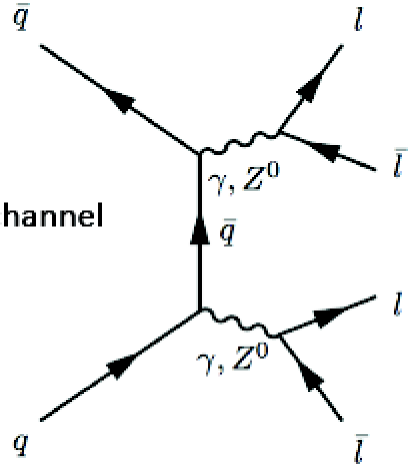
- Signature:
  Four leptons.
- Presence of two Z make this channel effectively background free.
  - Enhanced acceptance by loosened object definitions.
- Cross section and **anomalous triple gauge couplings** determined.

ZZ-> llll

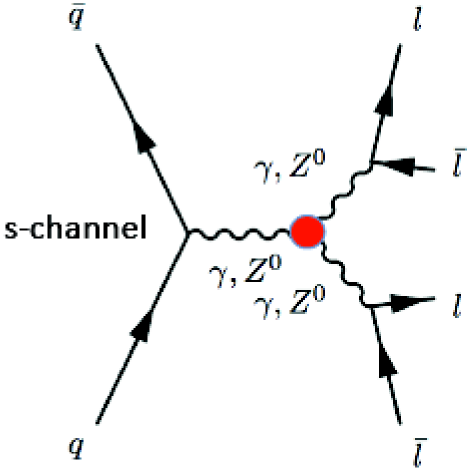
L=1.0 fb^{-1}

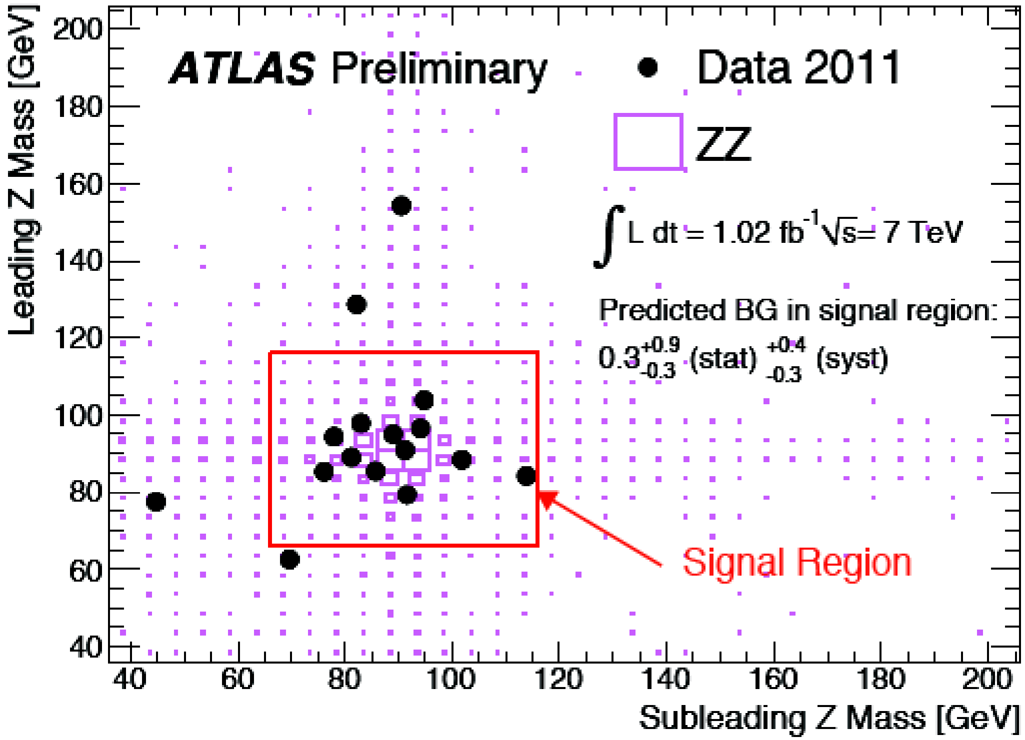
- Anomalous coupling vertex in s-channel (forbidden in SM).
- Selection:
  - 4 leptons, pT>15GeV, |η|<2.5, leading μ(e) pT>20 (25) GeV
  - 2 Z candidates with $|M_{ll}-M_z| < 25$GeV.
- Background estimate from Data driven methods.

t-channel



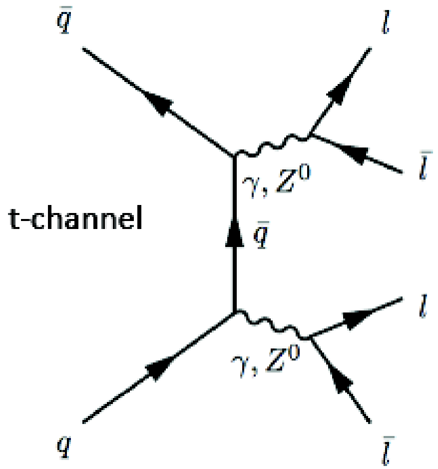
s-channel

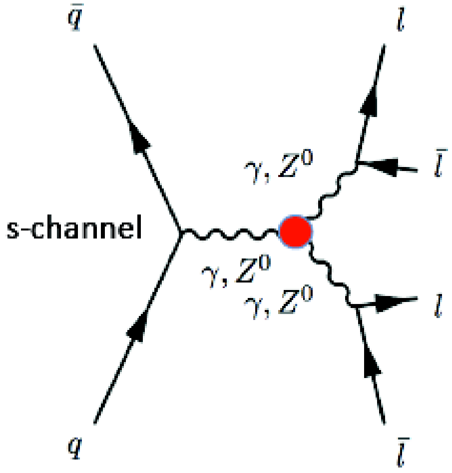




ZZ-> llll

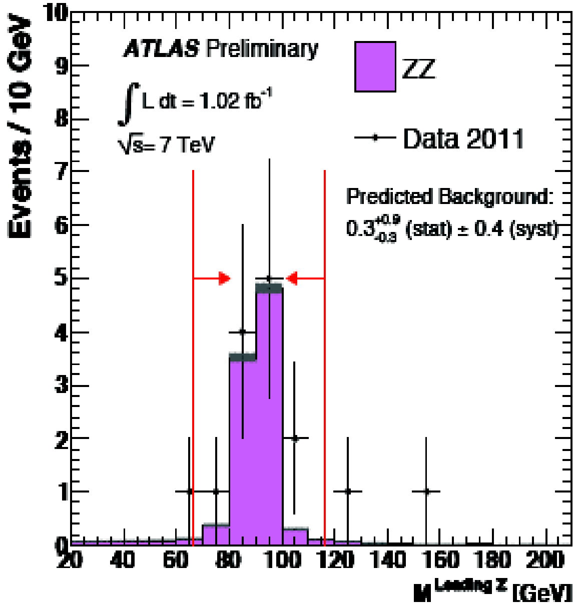
L=1.0 fb^{-1}

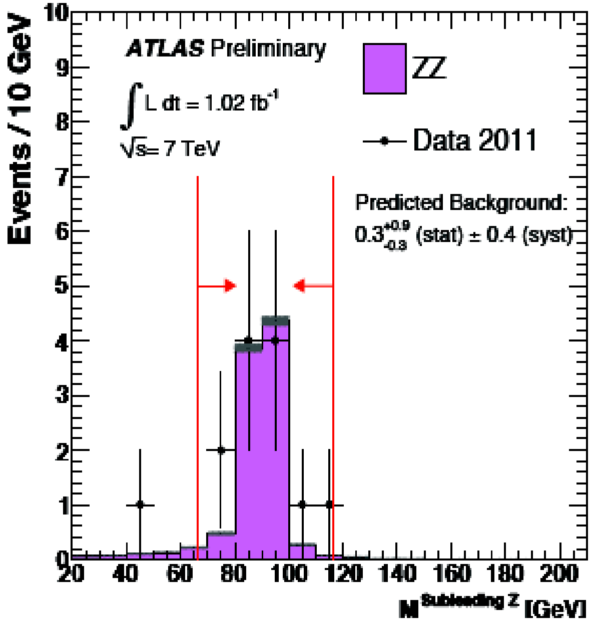




- Found 10 candidate events.

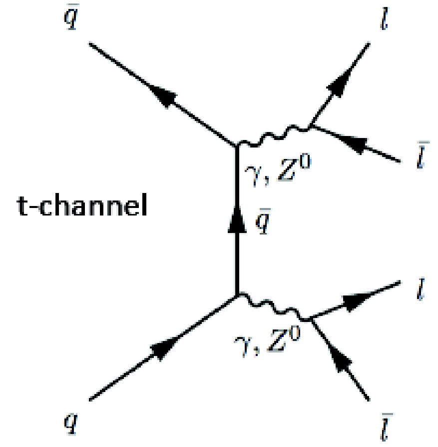
Final State	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell^+\ell^-$
Observed	1	7	2	10
Signal	1.3±0.04±0.1	2.5±0.1±0.2	3.6±0.1±0.2	7.4±0.1±0.3
Bkg(data-driven)	$0.01^{+0.03+0.05}_{-0.01-0.01}$	$0.3^{+0.9}_{-0.3}\pm0.3$	<0.02±0.03	$0.3^{+0.9+0.4}_{-0.3-0.3}$

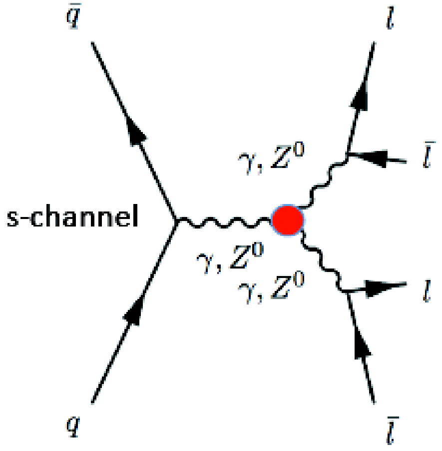




ZZ-> llll

L=1.0 fb^{-1}





Total cross section:

$$\sigma_{ZZ}^{\text{tot}} = 8.7^{+3.1}_{-2.5}\ (\text{stat})\ ^{+0.5}_{-0.9}\ (\text{syst})\ \pm 0.4\ (\text{lumi})\ \text{pb}$$

SM NLO expectation 6.5±0.3pb

Good agreement with the Standard Model.

Fiducial Cross section:

- $p_T(l) > 15$ GeV, $|\eta| < 2.5$
- $|M(ll)-M_Z| < 25$ GeV

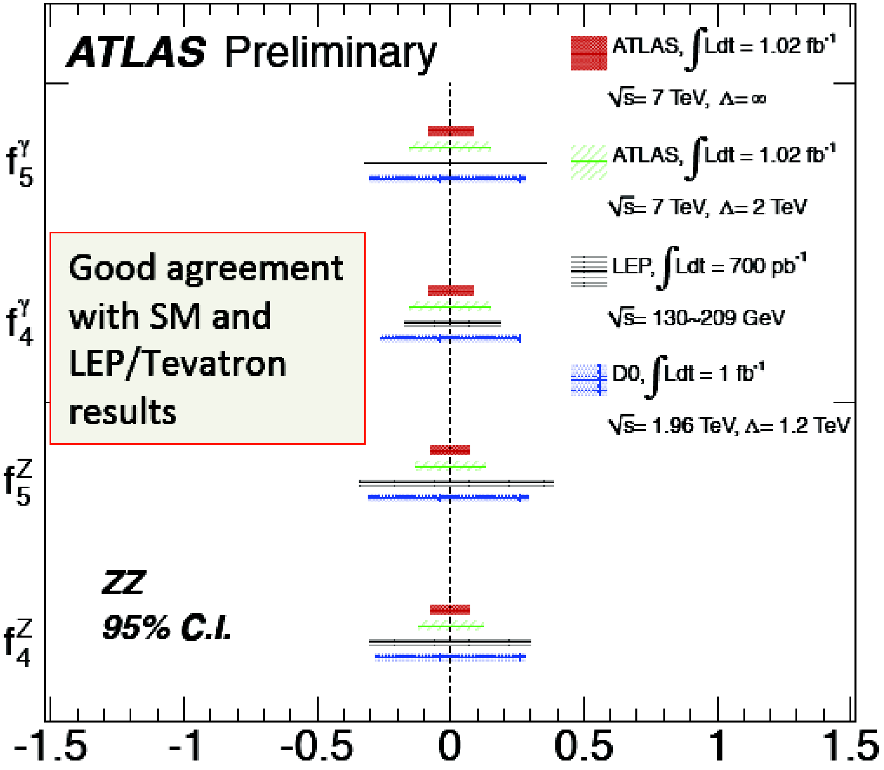
$$\sigma^{\text{fid}}_{ZZ\to\ell^+\ell^-\ell^+\ell^-} = 5.0^{+1.8}_{-1.5}\ (\text{stat})\ ^{+0.3}_{-0.5}\ (\text{syst})\ \pm 0.2\ (\text{lumi})\ \text{fb}$$

ZZ-> llll

L=1.0 fb^{-1}

Extraction of anomalous triple gauge boson couplings

- Use total cross section to fit TGC.
- LO reweighting technique with NLO correction (Baur-Rainwater + Sherpa)
- Use cut-off of Λ=2TeV, ∞
- Profile likelihood ratio, including systematics as nuisance parameters.
- 95% Confidence Intervals obtained by ΔL=1.92



Good agreement with SM and LEP/Tevatron results

Coupling 95% CI	f_4^γ	f_4^Z	f_5^γ	f_5^Z
$\Lambda = 2$ TeV	$[-0.15, 0.15]$	$[-0.12, 0.12]$	$[-0.15, 0.15]$	$[-0.13, 0.13]$
$\Lambda = \infty$	$[-0.08, 0.08]$	$[-0.07, 0.07]$	$[-0.08, 0.08]$	$[-0.07, 0.07]$

Maximum deviation from SM allowed by LEP bounds:

$$\Delta g^Z = -0.027, \qquad \Delta\lambda^Z = \Delta\lambda^\gamma = -0.044, \qquad \Delta\kappa^\gamma = -0.112$$

TGCs

All 95% CL

D0 Wγ 4.2/fb

$-0.4 < \Delta\kappa_\gamma < 0.4$

$-0.08 < \lambda_\gamma < 0.07$

D0 WZ 4.1/fb (Λ=2TeV)

$-0.400 < \Delta\kappa_Z < 0.675$

$-0.077 < \lambda_Z < 0.093$

$-0.056 < \Delta g_1^Z < 0.154$

D0 1/fb Combination

$-0.29 < \Delta\kappa_\gamma < 0.38$

$-0.08 < \lambda_Z < 0.08$

$-0.07 < \Delta g_1^Z < 0.16$

D0 WW 1/fb (Λ=2TeV)

$-0.54 < \Delta\kappa_\gamma < 0.83$

$-0.14 < \lambda_\gamma = \lambda_Z < 0.18$

$-0.14 < \Delta g_1^Z < 0.30$

D0 WW/WZ $\rightarrow \ell\nu jj$ 1/fb (Λ=2TeV)

$-0.44 < \Delta\kappa_\gamma < 0.555$

$-0.10 < \lambda_Z = \lambda_\gamma < 0.11$

$-0.12 < \Delta g_1^Z < 0.20$

CDF Zγ 5.1/fb (Λ=1.5TeV)

$-0.020 < h_3^Z < 0.021$

$-0.0009 < h_4^Z < 0.0009$

$-0.022 < h_3^\gamma < 0.020$

$-0.0008 < h_4^\gamma < 0.0008$

D0 ZZ->4L 1/fb (Λ=1.2TeV)

$-0.28 < f_4^Z < 0.28$

$-0.26 < f_4^\gamma < 0.26$

$-0.31 < f_5^Z < 0.29$

$-0.30 < f_5^\gamma < 0.28$

Future trends

At Tevatron: W mass analyses, constraints on PDFs from W charge asymmetry, $\sin^2\theta_W$ determination, final constraints on TGCs, WZ with $Z \to b\bar{b}$

At LHC: observe all diboson final states, improve constraints on TGCs, detailed studies of differential cross sections,W mass analyses, constraints on PDFs from W charge asymmetry, $\sin^2\theta_W$ determination

New and unique at LHC: vector boson fusion, quartic gauge couplings

Progress in many of these areas requires continued effort from theoretical community in improving the calculations and the tools used in the analyses

Final goal: check consistency of electroweak fits after observation of Higgs boson or observation of physics beyond the SM (GFitter)

Plan

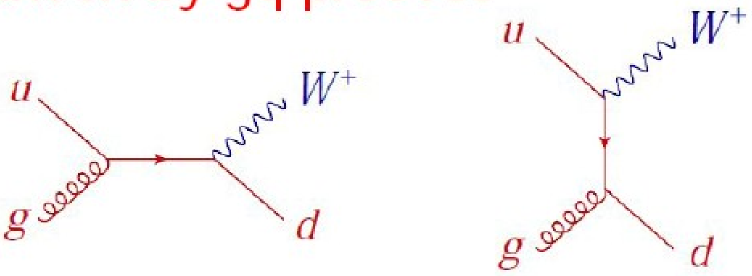
- Amazing how much could have been done with only 36pb^{-1} data accumulated in 2010: numbers of results are still in the pile-line but already theory is being tested quantitatively.... and is holding its own (unfortunately)

  4.01 Higgs boson... where we stand?

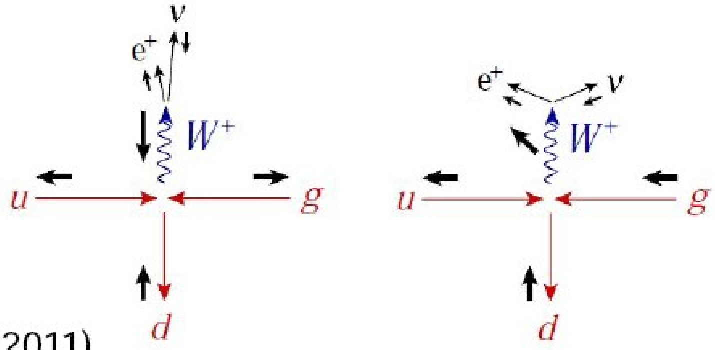
  18.01 What's new from New Physics searches?

W polarisation

- pp: initial state not C invariant
- Polarization driven by gq process



- Polarization sensitive to gluon spin



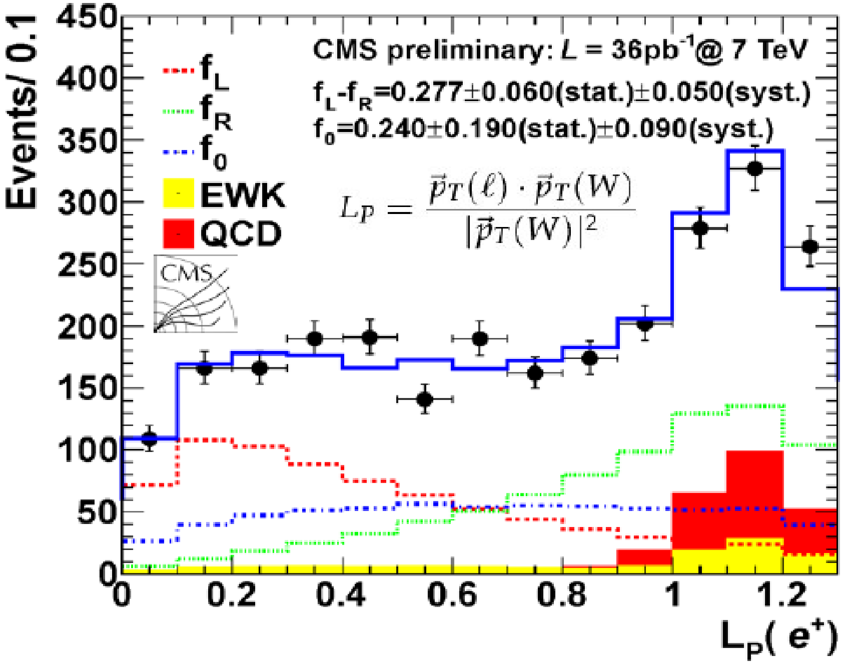
Left handed gluon
=> left handed W

Right handed gluon
=> No polarization
Right handed at
High pt

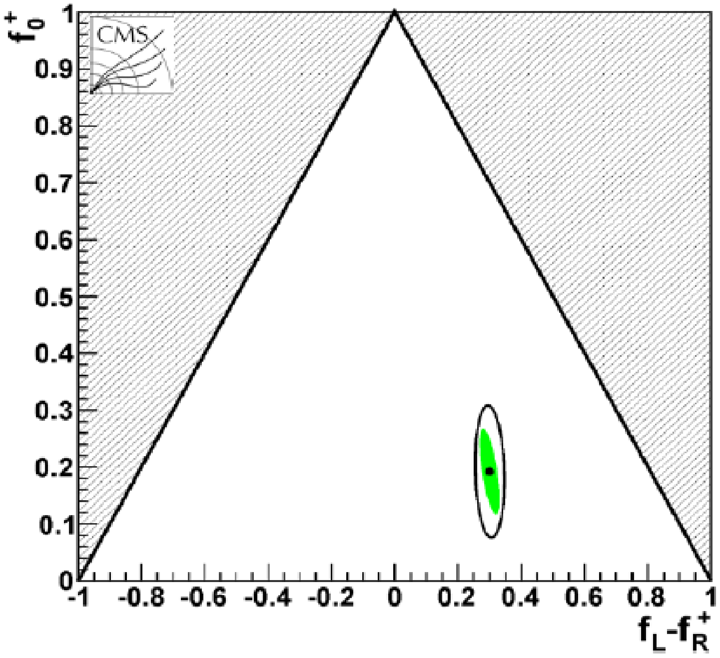
Phys. Rev. D84, 034008 (2011)

W polarisation

- W decay self analyzing via decay asymmetry
- Look at cosϑ^* distribution

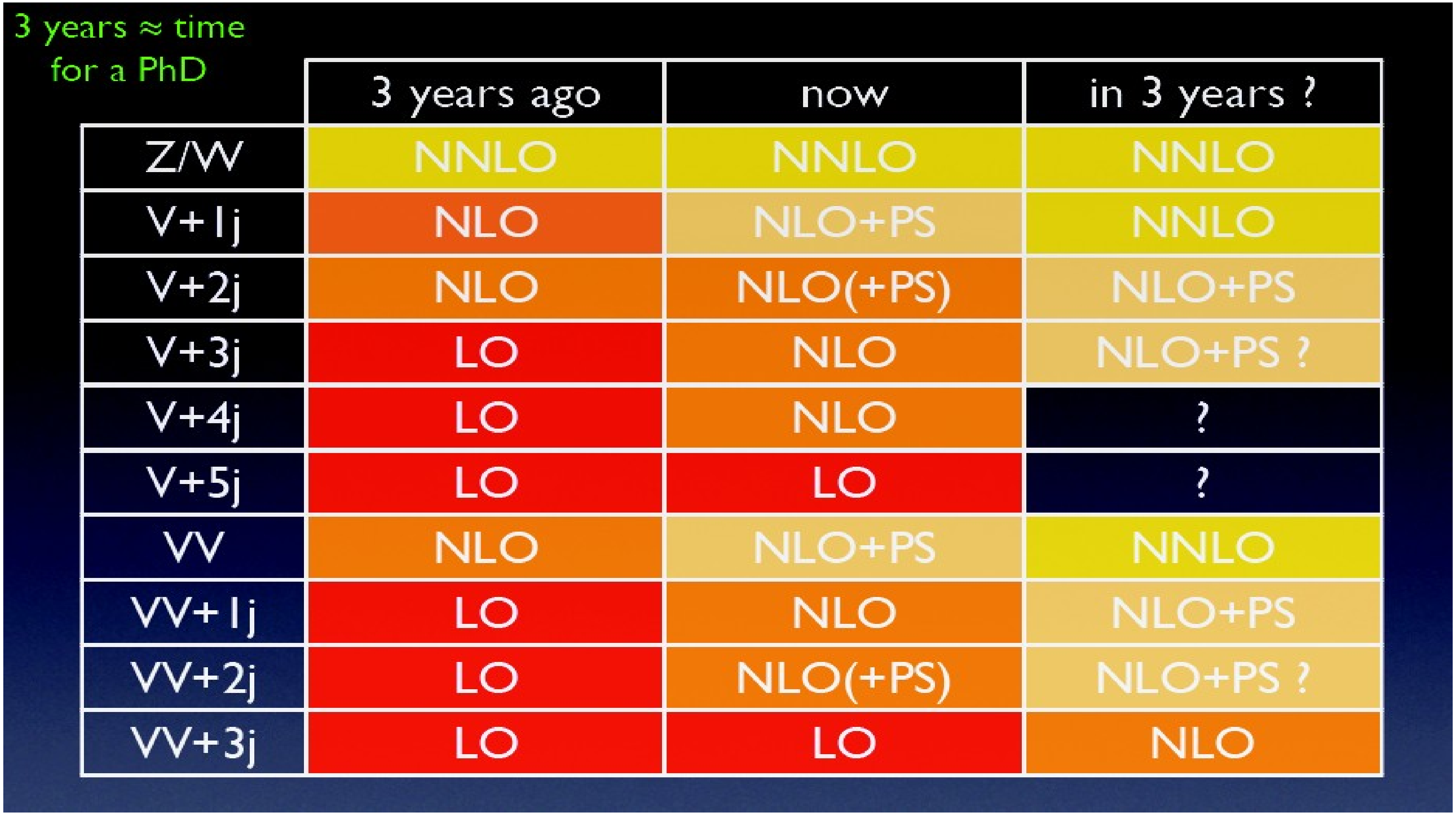


PRL 107, 021802 (2011)



- cosϑ^* not measurable: use L_p(~ 0.5cosϑ^* +0.5)
- Template fit to extract polarization

V+jets: past, present and future

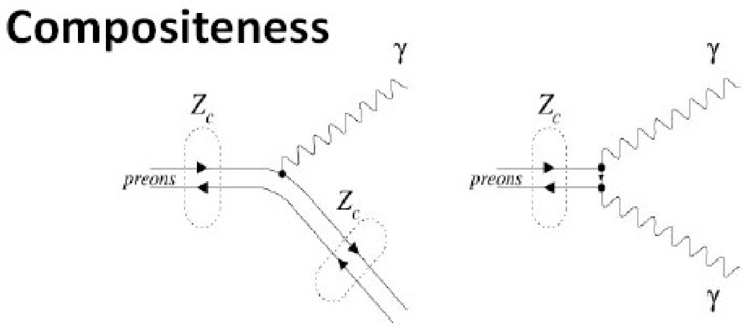


3 years ≈ time for a PhD

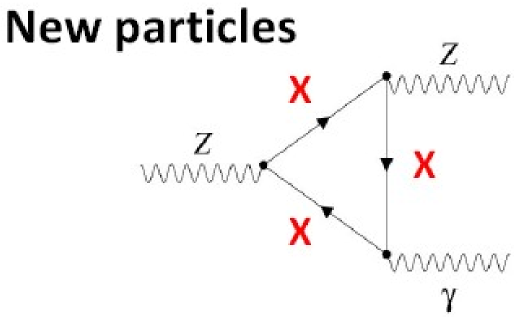
	3 years ago	now	in 3 years ?
Z/W	NNLO	NNLO	NNLO
V+1j	NLO	NLO+PS	NNLO
V+2j	NLO	NLO(+PS)	NLO+PS
V+3j	LO	NLO	NLO+PS ?
V+4j	LO	NLO	?
V+5j	LO	LO	?
VV	NLO	NLO+PS	NNLO
VV+1j	LO	NLO	NLO+PS
VV+2j	LO	NLO(+PS)	NLO+PS ?
VV+3j	LO	LO	NLO

TGCs and new physics

- Numerous possible extensions of the Standard Model result in anomalous couplings
  - Example: neutral TGCs: ZZγ and Zγγ

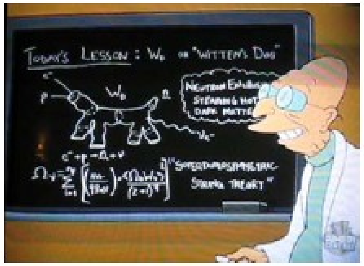


Compositeness



New particles

Something else?

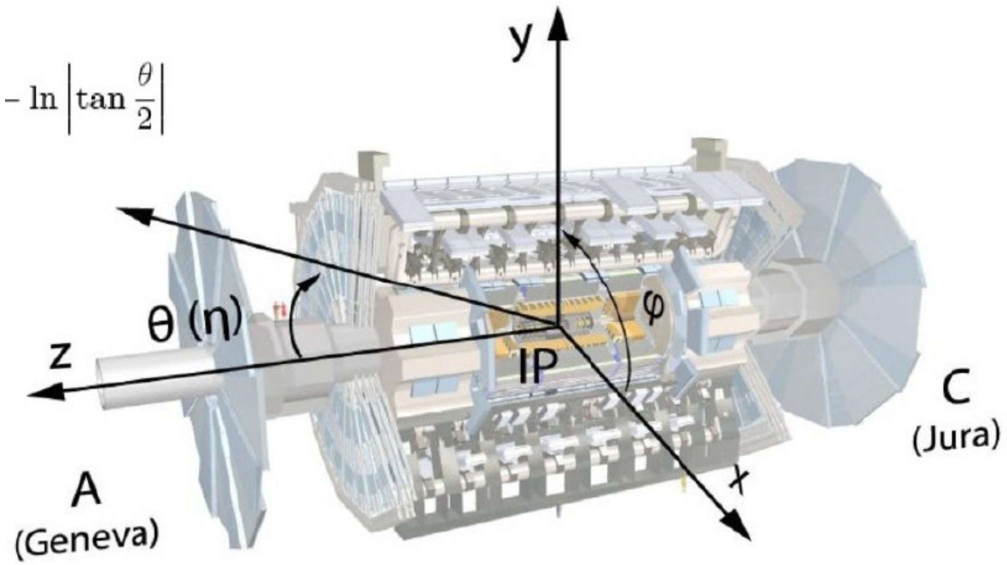


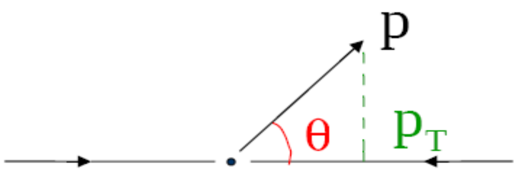
- Follow effective Lagrangian approach
  - Parametrize the ZZγ/Zγγ vertex in the most general way
  - One coupling is usually described in terms of many parameters

ATLAS Detector

THE ATLAS DETECTOR IS REALLY BIG!

- Length : $\sim$ 46 m
- Radius : $\sim$ 12 m
- Weight : $\sim$ 7000 tons
- $\sim 10^8$ electronic channels
- 3000 km of cables





Transverse momentum

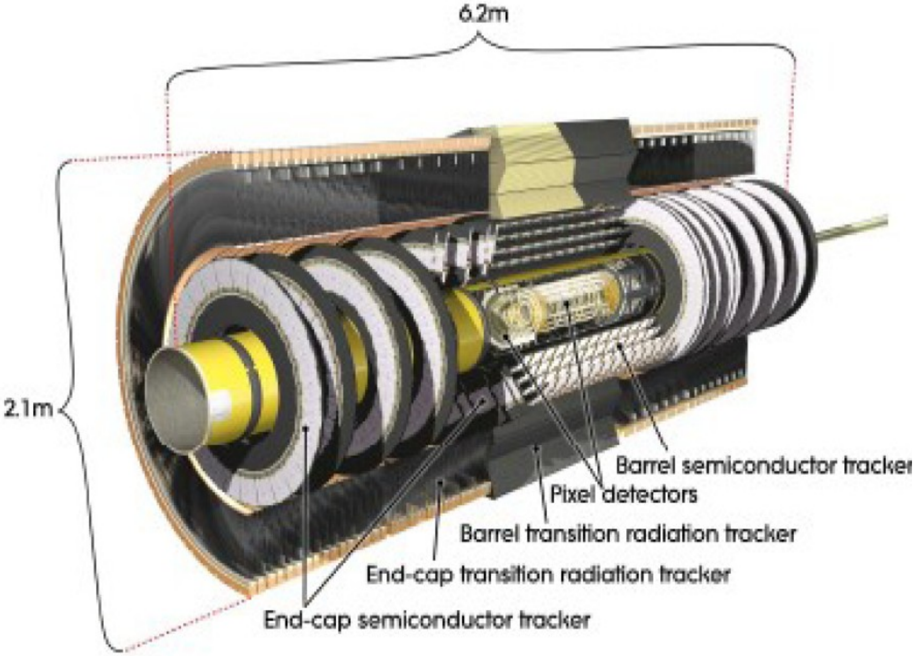
(in the plane perpendicular to the beam)

$$p_T = p \sin\theta$$

Rapidity: $\eta = -\log\left(\mathrm{tg}\,\frac{\theta}{2}\right)$

$\theta = 90^\circ \rightarrow \eta = 0$
$\theta = 10^\circ \rightarrow \eta \cong 2.4$
$\theta = 170^\circ \rightarrow \eta \cong -2.4$

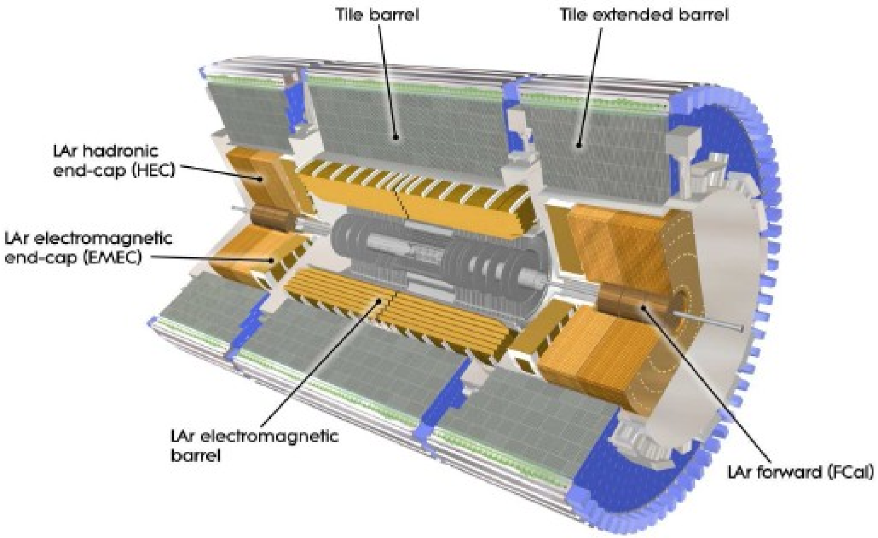
ATLAS Inner Detector



The inner detector $|\eta| < 2.5$ consists of

- Pixel detectors, semi-conductor tracker (SCT), transition radiation tracker
    - $\approx$ 87 million readout channels
    - Immersed in 2T solenoidal magnetic field
- Resolution of $\sigma/p_T = 5 \times 10^{-4} \oplus 0.015$

ATLAS Calorimeters



Electromagnetic and hadronic calorimeters

- Subsystem technology and granularity ↔ shower characteristics
- Transverse and longitudinal sampling ≈ 200000 readout cells up to $|\eta| < 4.9$

Electromagnetic Calorimeters:

- Fine granularity $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ in central region
- Energy resolution $10\%/\sqrt{E}$

Hadronic Calorimeters:

- Granularity $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ in central region, less segmented in forward region
- Energy resolution $50\%/\sqrt{E} \oplus 0.03$