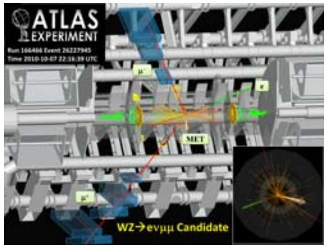
Diboson Physics at LHC

Haijun Yang

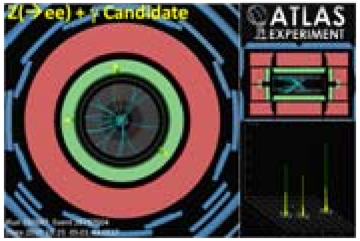
University of Michigan

UM HEP Seminar

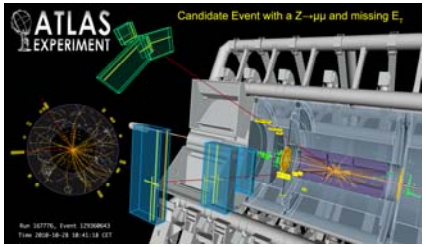
April 4, 2011



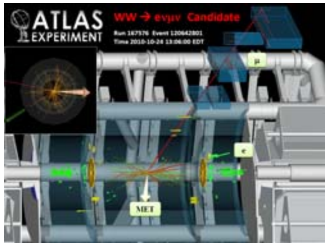
WW



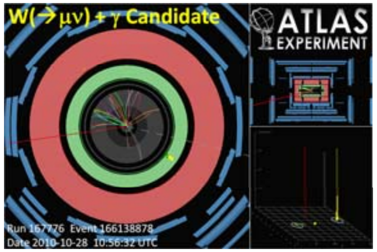
Zγ



ZZ



WZ

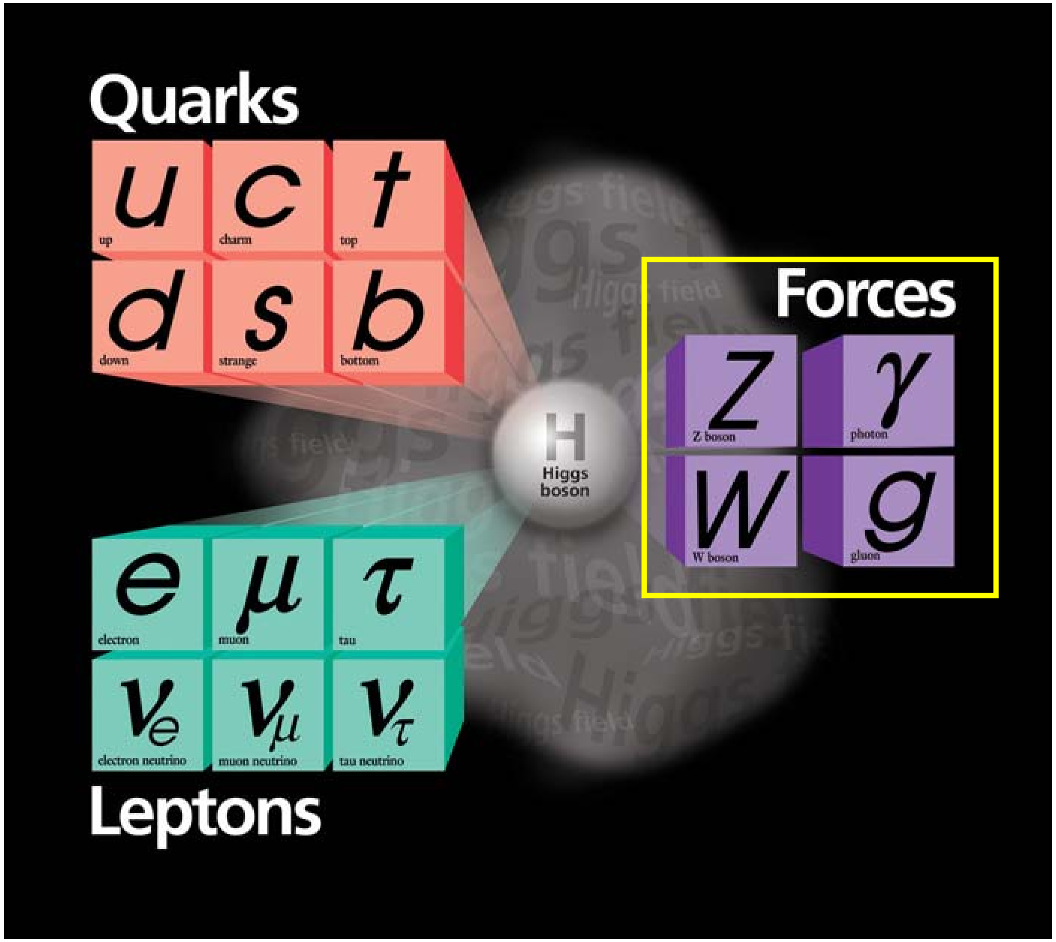


Wγ

Outline

- Motivations
- Previous Measurements from LEP and Tevatron
- Diboson Physics Programs at LHC
- Results with the First Year Data (2010)
- Prospect of Diboson Physics at LHC in 2011-2012

Standard Model



- ➔ **Based on SU(2)xU(1) symmetry; Gauge** sector and **matter** sector are very successfully tested !

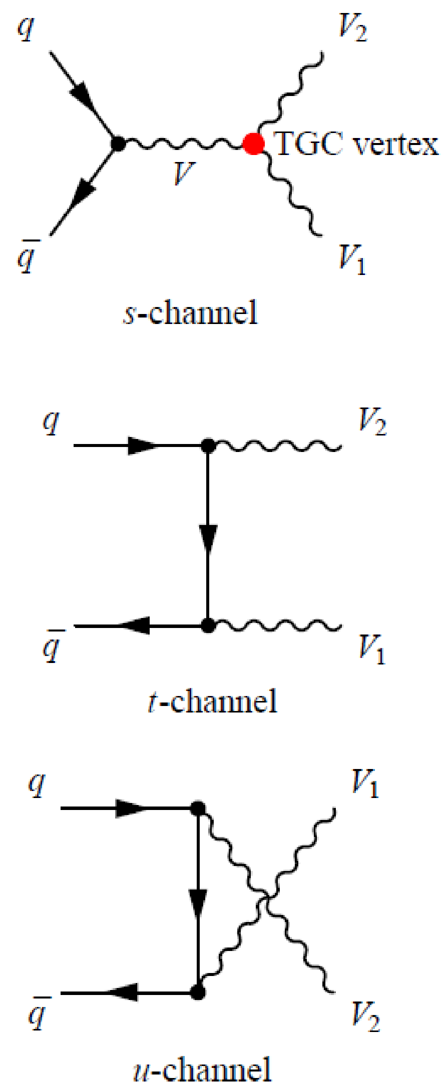
  But the **Higgs** sector which describes the electroweak symmetry breaking (EWSB) is totally dark.

- ➔To find the mystery of EWSB is one of the major motivations for experimental high energy physics.

- ➔ Focus on Di-boson productions (Wγ, Zγ, WW, WZ, ZZ) in this talk.

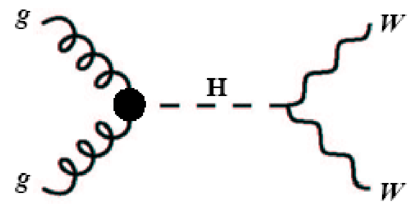
Introduction - Diboson Physics

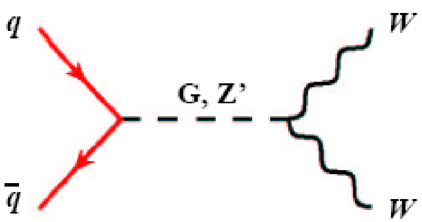
- ➔ Vector boson self-interactions are fundamental prediction of the Standard Model, resulting from the non-Abelian nature of the $SU_L(2) \times U(1)$ gauge theory.
- ➔ The measurement of vector boson pair production at LHC provides an important test of high energy behavior of electroweak interactions.
- ➔ Measurements of diboson production cross sections ($W\gamma$, $Z\gamma$, WW, WZ, ZZ) at LHC are important milestones for initial physics program.
- ➔ Diboson detection will be initially focused on W and Z leptonic decay modes.
- ➔ Search for new physics at LHC can be carried out through diboson final states as well as through probing of the anomalous triple gauge boson couplings (TGCs).



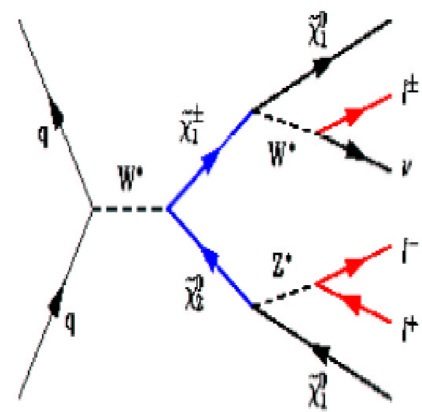
New Physics Signatures with Diboson Final States

- WW → $\ell\nu\ell\nu$ (signal: $\ell\ell$ + MET):
  - Higgs → WW (SM, MSSM)
  - Graviton G → WW (mSUGRA, ED)
  - Z' → WW



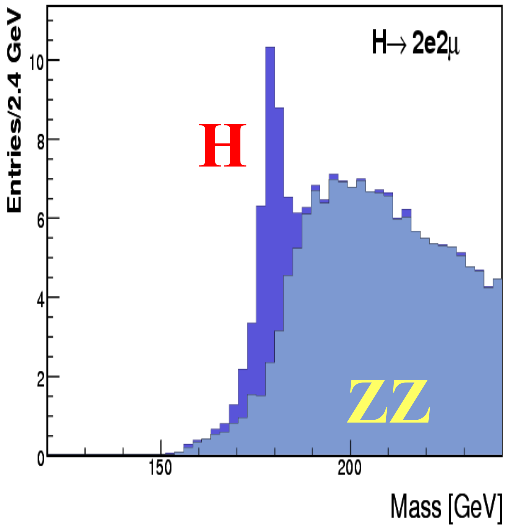


- WZ → $\ell\nu\ell\ell$ (signal: tri-lepton + MET):
  - pp → $W^* \to \tilde{x}_1^{\pm}\tilde{x}_2^0 \to (W^{\pm}x_1^0)(z^0\tilde{x}_1^0)$ (SUSY)
  - $\rho_T^{\pm}$ → $W^{\pm}$ Z (Technicolor)

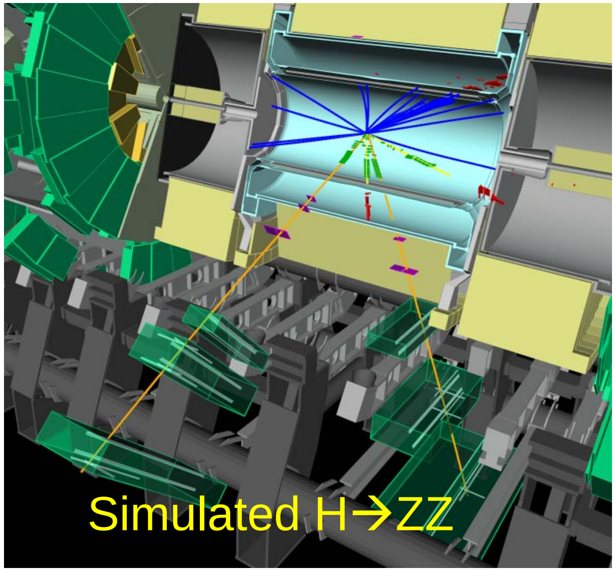


New Physics Signatures with Diboson Final States

- ZZ → $\ell\ell\ell\ell$, $\ell\ell\nu\nu$:
  - H → ZZ (SM, MSSM)
  - $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to Z(\ell^+\ell^-)Z(\ell^+\ell^-)\tilde{G}\tilde{G}$, (GMSB)



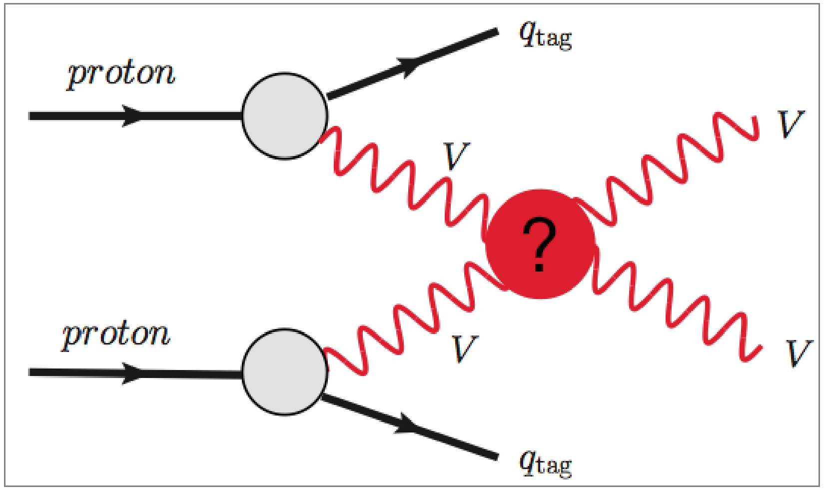
- Wγ → $\ell\nu\gamma$:
  - $\rho_T^{\pm}$, $a_T^{\pm}$ → $W^{\pm}\gamma$ (Technicolor)
  - General GMSB (Wino-like neutralino)

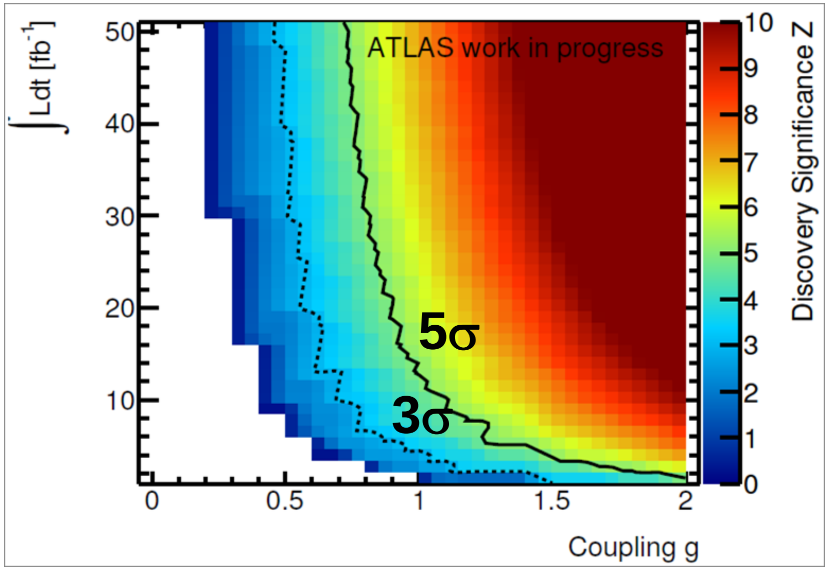


- Zγ → $\ell\ell\gamma$:
  - $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to Z(\ell^+\ell^-)\gamma\tilde{G}\tilde{G}$ (Zγ+MET)
  - ω_T → Zγ (Technicolor resonance)
  - General GMSB (Bino-like neutralino)

Generic Search for New Particles with Diboson through VBF Process

- Vector-Boson Fusion (VBF) Process: $qq \rightarrow q_{tag}\, q_{tag} V\, V$ ($V = W, Z$)
  - Two vector bosons with two tagged jets in F/B regions
  - Production rate ~ 2.5% of $qq \rightarrow WW$ (Tim Barklow, WHIZARD with PDF MRST2004)
- An example of ATLAS sensitivity to a 850 GeV spin-zero resonance produced in VBF process (at 14 TeV).





Search for new physics through Anomalous TGCs with Diboson Events

- Effective Lagrangian with charged/neutral triple-gauge-boson interactions

$$L/g_{WWV} = ig_1^V (W^*_{\mu\nu} W^\mu V^\nu - W_{\mu\nu} W^{*\mu} V^\nu) + i k^V W^*_\mu W_\nu V^{\mu\nu} + \frac{i\lambda^V}{M_W^2} W^*_{\rho\mu} W^\mu_\nu V^{\nu\rho}$$

$$L = -\frac{e}{M_Z^2}[f_4^V (\partial_\mu V^{\mu\beta}) Z_\alpha (\partial^\alpha Z_\beta) + f_5^V (\partial^\sigma V_{\sigma\mu}) \tilde{Z}^{\mu\beta} Z_\beta]$$

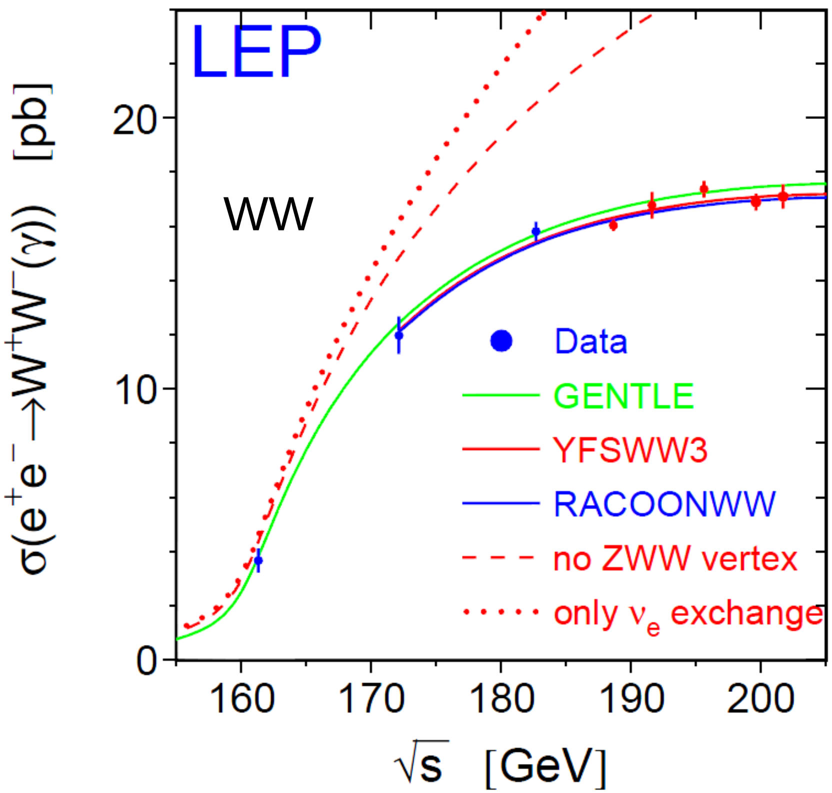
- The anomalous parameters: Δg_1^Z, $\Delta\kappa_Z$, λ_Z, $\Delta\kappa_\gamma$, λ_γ, f_4^Z, f_5^Z, f_4^γ, f_5^γ, h_3^Z, h_4^Z, h_3^γ, h_4^γ

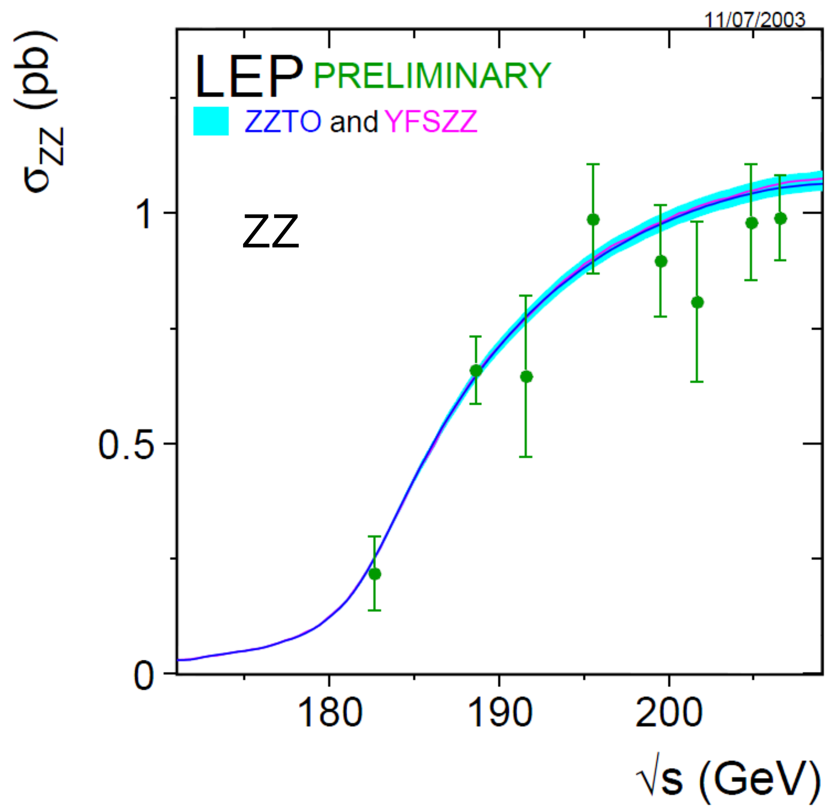
- Complementary studies through different Diboson channels ($\hat{s} = M^2_{VV}$)

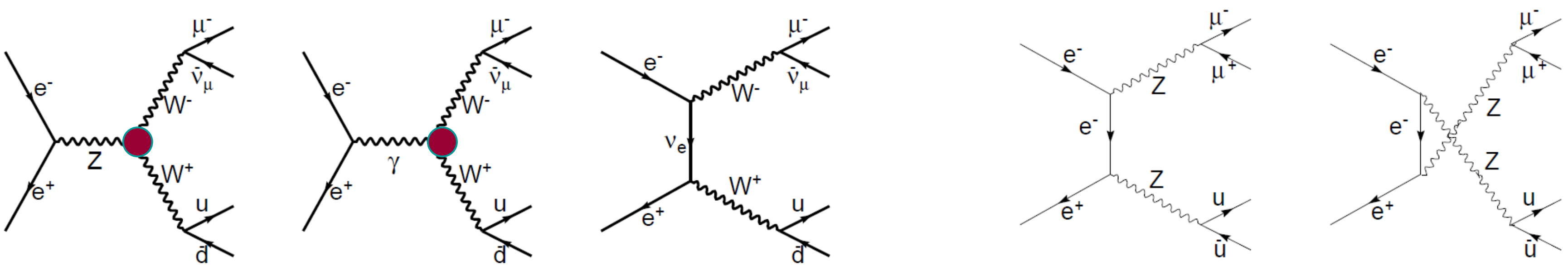
Production	$\Delta\kappa_Z$, $\Delta\kappa_\gamma$ term	Δg_1^Z term	λ_Z, λ_γ term
WW	**grow as $\hat{s}$**	**grow as $\hat{s}^{1/2}$**	**grow as $\hat{s}$**
WZ	grow as $\hat{s}^{1/2}$	grow as $\hat{s}$	grow as $\hat{s}$
Wγ	grow as $\hat{s}^{1/2}$	---	grow as $\hat{s}$

WW/ZZ Cross Sections from e^+e^- (LEP)

CERN-PH-EP/2006-042







Diboson Production at Tevatron

Process	Cross-section (pb)	Data (Experiment)
WW	12.1 $\pm$ 0.9 11.5 $\pm$ 2.2	3.6 fb^{-1} (CDF) 1.0 fb^{-1} (D0)
WZ	4.1 $\pm$ 0.7 3.9 + 1.1 (-0.9)	6.0 fb^{-1} (CDF) 4.1 fb^{-1} (D0)
ZZ	1.7 + 1.2 (– 0.7) 1.6 $\pm$ 0.65	6.0 fb^{-1} (CDF with $\ell\ell\ell\ell$) 2.7 fb^{-1} (D0 with $\ell\ell\ell\ell$ and $\ell\ell\nu\nu$)
Zγ	4.6 $\pm$ 0.5 4.96 $\pm$ 0.42	1.1 fb^{-1}(eeγ), 2.0 fb^{-1}($\mu\mu\gamma$) (CDF) 1.1 fb^{-1} (D0)
Wγ	18.0 $\pm$ 2.8 14.8 $\pm$ 2.1	1.1 fb^{-1} (CDF) 0.16 fb^{-1} (D0)

http://www-cdf.fnal.gov/physics/ewk
http://www-d0.fnal.gov/Run2Physics/WWW/results/ew.htm

WZ and Wγ can only be produced from hadron colliders

Limits on Anomalous Couplings

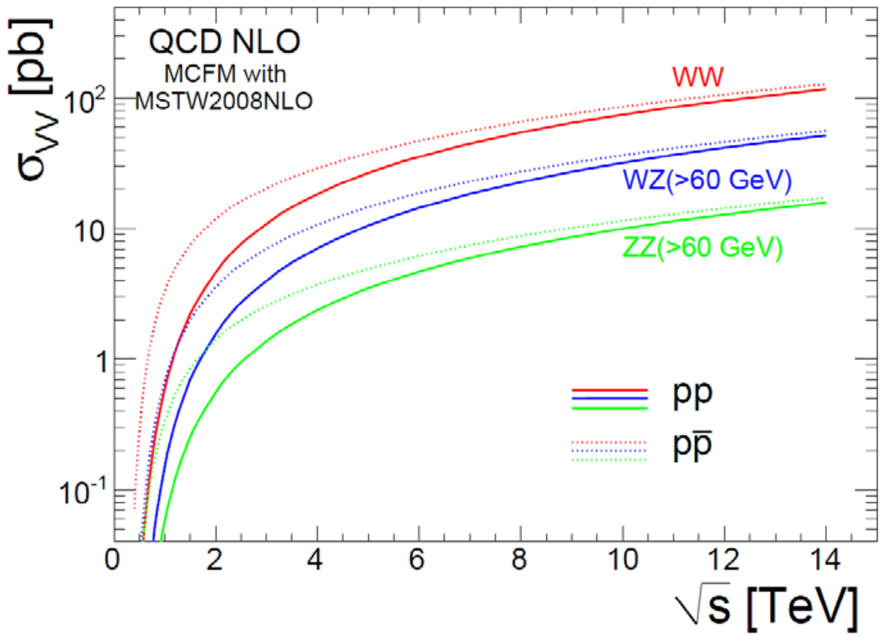
	λ_Z	$\Delta\kappa_Z$	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
WW (D0, 1.1fb^{-1})	$\lambda_Z = \lambda_\gamma$	$\Delta\kappa_z = \Delta\kappa_\gamma$	[-0.14, 0.30]	[-0.54, 0.83]	[-0.14, 0.18]
WW (LEP)	$\lambda_Z = \lambda_\gamma$	$\Delta\kappa_z = \Delta g_1^Z - \Delta\kappa_\gamma \tan^2\theta_w$	[-0.051,0.034]	[-0.105,0.069]	[-0.059,0.026]
WZ (D0, 4.1fb^{-1})	[-0.075,0.093]	[-0.376,0.686]	[-0.053,0.156]		
WZ (CDF, 1.9fb^{-1})	[-0.14,0.15]	[-0.81,1.29]	[-0.14,0.25]		
Wγ (D0, 0.7 fb^{-1})				[-0.51,0.51]	[-0.12,0.13]

Λ = 1.2 TeV	f_4^Z	f_5^Z	f_4^γ	f_5^γ
ZZ (CDF, 1.9fb^{-1})	[-0.12,0.12]	[-0.13,0.12]	[-0.10,0.10]	[-0.11,0.11]
ZZ (D0, 1.1fb^{-1})	[-0.28,0.28]	[-0.31,0.29]	[-0.26,0.26]	[-0.30,0.28]
ZZ (LEP combined)	[-0.30,0.30]	[-0.34,0.38]	[-0.17,0.19]	[-0.32,0.36]

Λ = 1.5 TeV	h_3^Z	h_4^Z	h_3^γ	h_4^γ
Zγ (CDF, 5.0fb^{-1})	[-0.017,0.0167]	[-0.0006,0.0005]	[-0.017,0.016]	[-0.0006,0.0006]
Zγ (D0, 3.6fb^{-1})	[-0.033,0.033]	[-0.0017,0.0017]	[-0.033,0.033]	[-0.0017,0.0017]
Zγ (LEP combined)	[-0.30,0.30]	[-0.34,0.38]	[-0.17,0.19]	[-0.32,0.36]

Diboson Production Cross Sections

SM cross section	Tevatron (ppbar,1.96 TeV, pb)	LHC (pp,7TeV, pb)	LHC (pp,14 TeV, pb)
WW	12.4	44.9	111.6
WZ	3.7	18.5	47.8
ZZ	1.4	6.0	14.8
Wγ	19.3*	69.0#	120.1#
Zγ	4.7*	13.8#	28.8#



(∗) $E_T^{\gamma} > 7$ GeV and $\Delta R(\ell,\gamma) > 0.7$, for W/Z e/μ decay channels only
(#) $E_T^{\gamma} > 10$ GeV and $\Delta R(\ell,\gamma) > 0.7$, for W/Z e/μ decay channels only

➔ Diboson production rates at LHC (7 TeV) are ~3-5 times of Tevatron

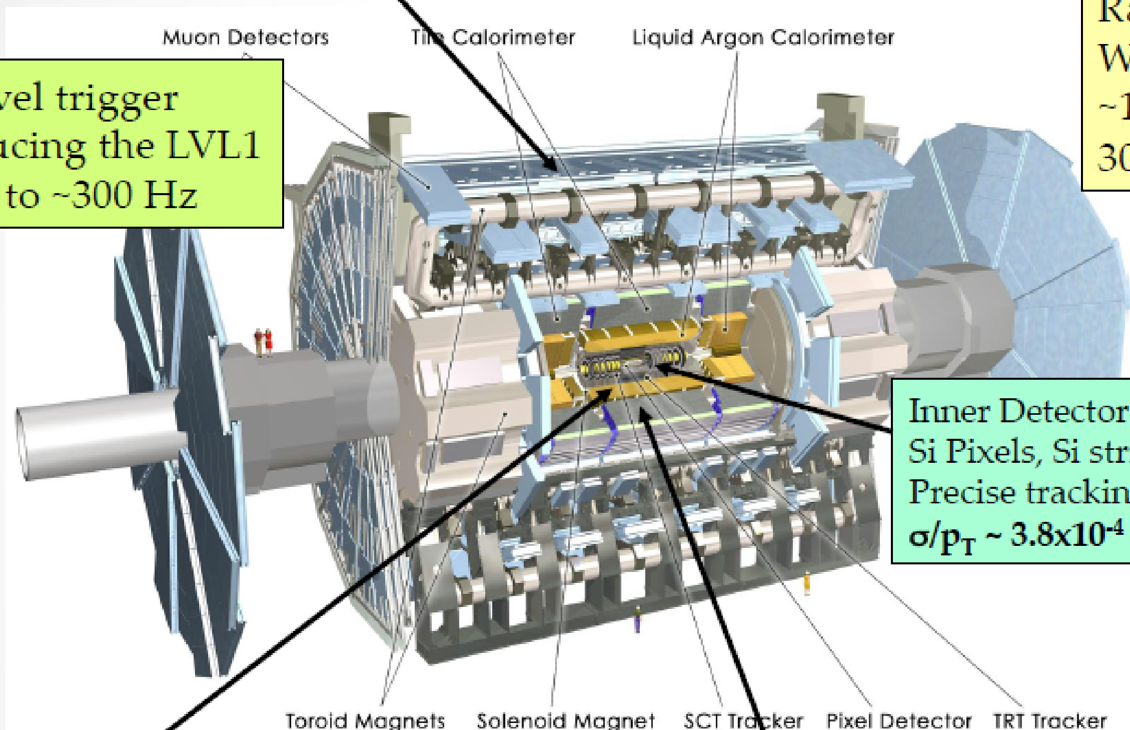
➔ √s at LHC is higher than Tevatron (3.5x-7x) which greatly enhances the detection sensitivity to anomalous triple-gauge-boson couplings

ATLAS Detector

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution **< 10% up to E_μ ~ 1 TeV**

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

3-level trigger reducing the LVL1 rate to ~300 Hz

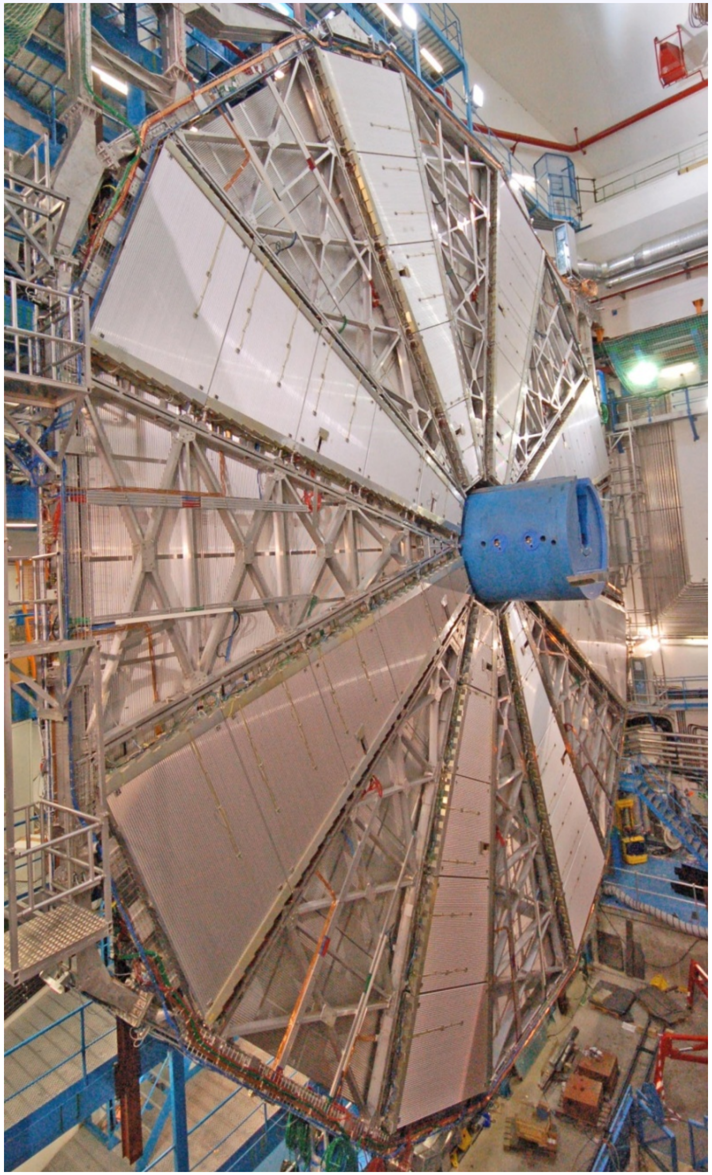


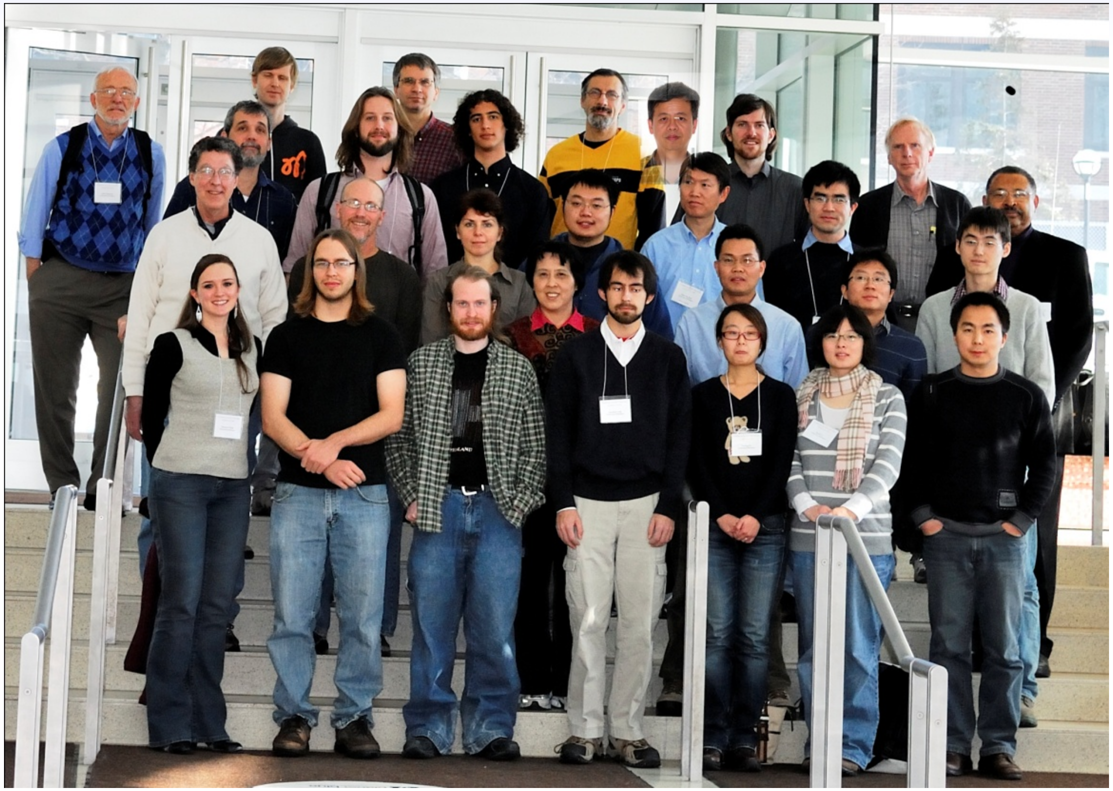
Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, TRT
Precise tracking and vertexing,
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T$ (GeV) $\oplus$ 0.015

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.007$
High granularity

Hadron calorimetry ($|\eta|<4.9$)
Fe/scintillator Tiles (central), Cu-LAr (endcap)
E-resolution: **$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$**
FWD calorimetry:Cu/W-LAr **$\sigma/E \sim 90\%/\sqrt{E} \oplus 0.07$**

ATLAS Muon Precision Chambers

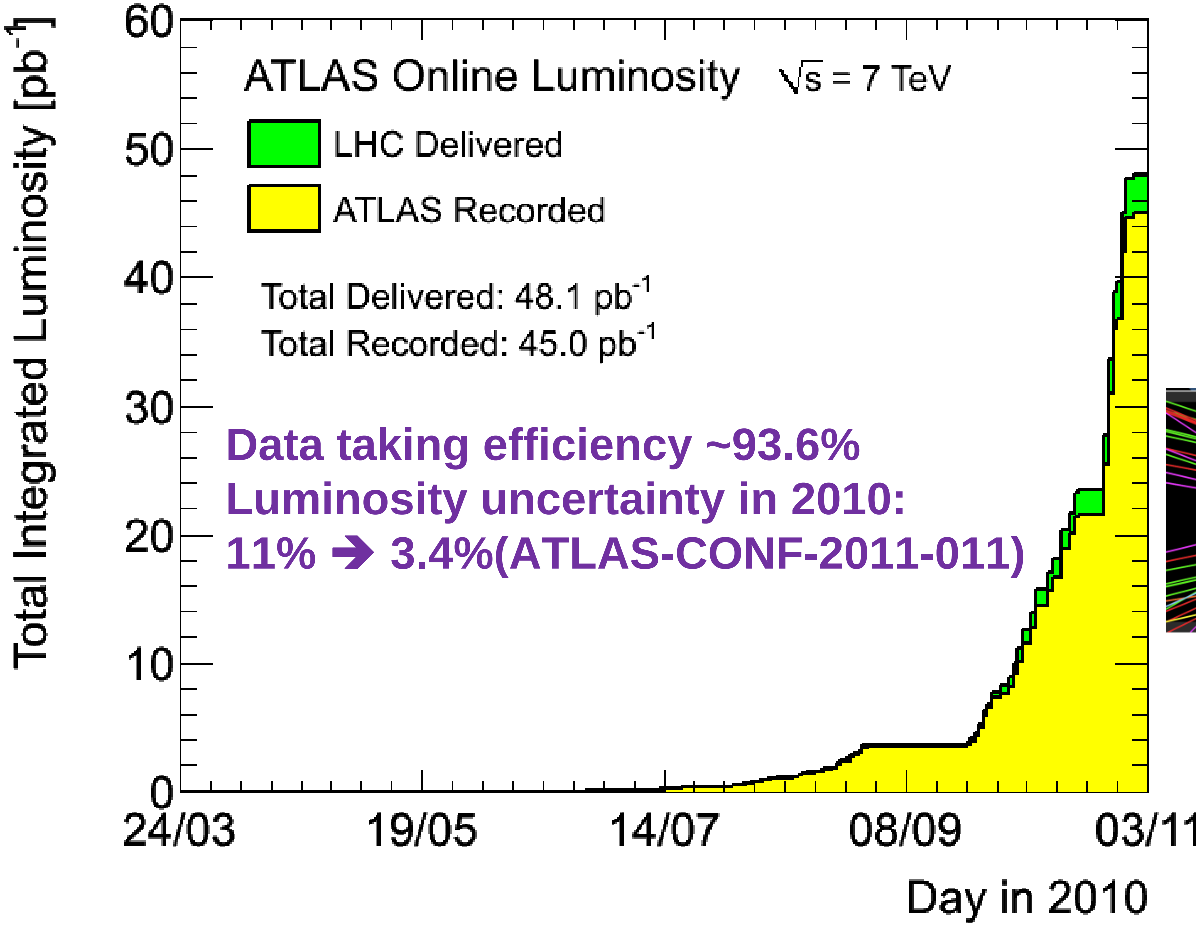




University of Michigan ATLAS group was heavily involved in construction and commissioning of Monitored Drift Tube (MDT) chambers

Integrated Luminosity (2010-present)

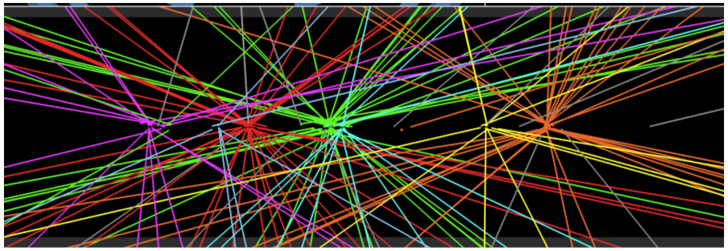
Peak luminosity is $2.52 \times 10^{32}\ cm^{-2}s^{-1}$



➔ LHC restarted 7 TeV stable beam Collision on 03/13/2011

➔ATLAS data-taking efficiency is 94.5%

➔$1.15*10^{11}$ protons/bunch, max 138 bunches, pileup: up to 10 / crossing



➔25.9 pb^{-1} data delivered in the first two weeks this year

➔ LHC is expected to deliver 1-3 fb^{-1} in 2011

ATLAS SM Physics Program in 2010

Soft QCD
- Particle Multiplicities
- Underlying Event
- Total pp Cross Section

QCD
- Inclusive Jets
- Inclusive γ
- Jet Shapes
- W/Z + Jets
- Top pair production

Electro-weak
- W/Z cross section
- $Z \rightarrow \tau\tau$
- W Asymmetry
- Diboson:
  $W\gamma$ / $Z\gamma$ / WW
- Single Top

Standard Model as Standard Candles:

Use the Signals we expect to see to ...

- Understand Detector

- Refine Analysis techniques

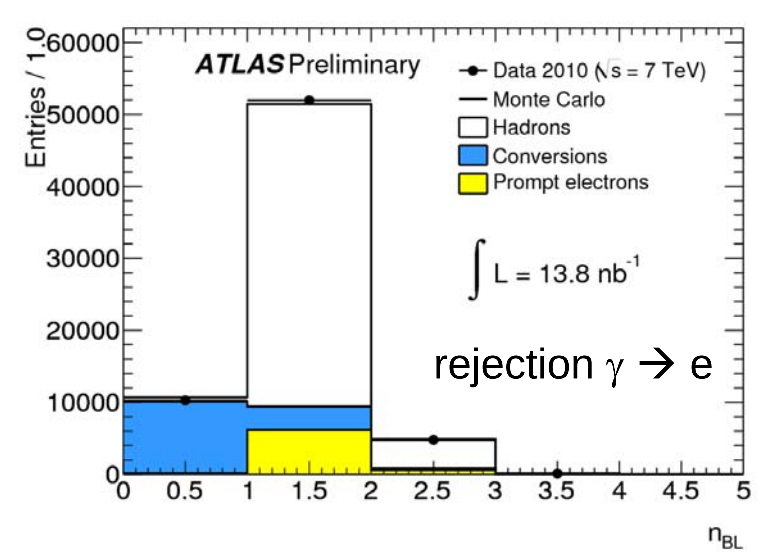
Important for physics objects used everywhere:

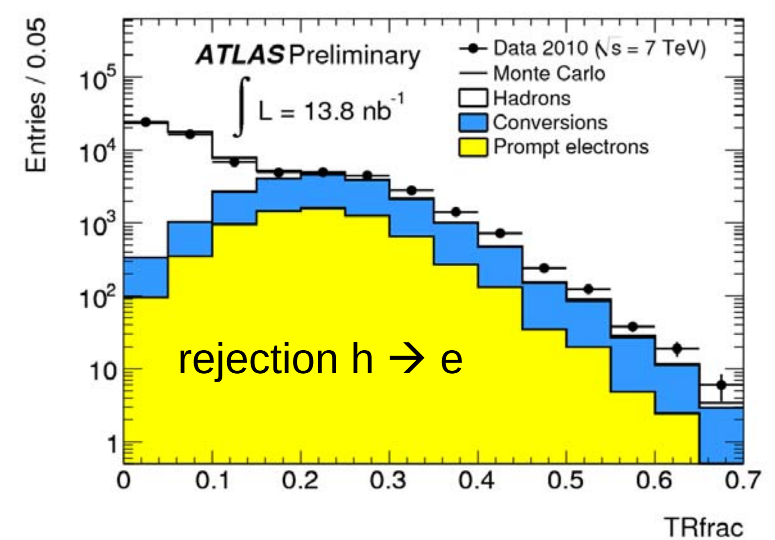
Charged Leptons / Missing E_T / Jets / Photons

Diboson Physics Studies at LHC

- LHC 7 TeV collision data collection started on Mar. 30, 2010 and finished on Nov. 2, 2010. LHC restarted 7 TeV collision on Mar. 13, 2011.
- Measurements of Diboson production cross sections and anomalous couplings for $W\gamma$, $Z\gamma$ and WW.
- The main objects of Diboson final states include electron, muon, photon, hadronic jet and missing transverse energy which are well studied using initial LHC data.
- Clear experimental signature of diboson events are observed and measured by both experiments.

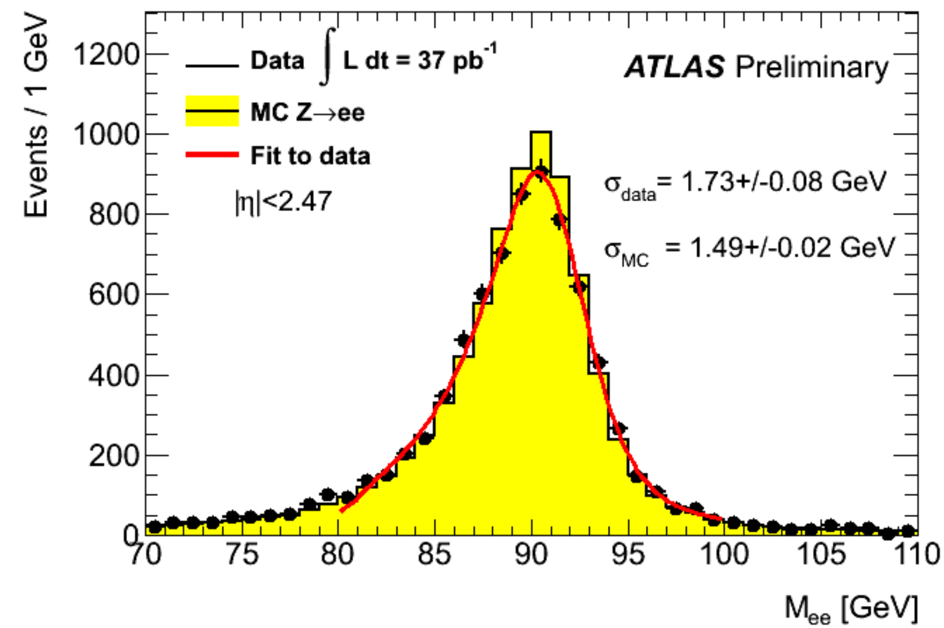
Electron Identification and Measurements





Different electron identification flavors:

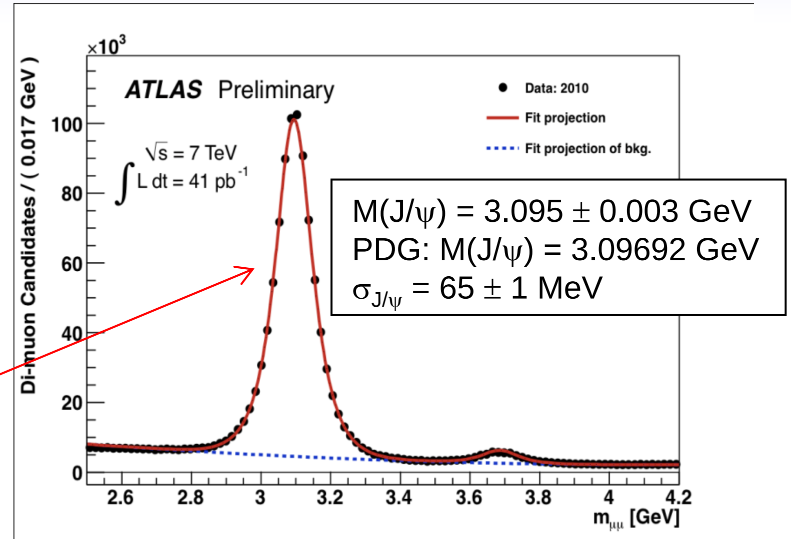
- **Loose**
  - acceptance, minimum track quality, EM shower width
- **Medium**
  - strip layer info, Efrac, lateral shower size
  - pixel+sct hits, d0, fiducial b-layer, cluster-track matching
- **Tight**
  - hadronic leakage, 3x7/7x7 cell energy ratio
  - E/p, inner pixel layer hits(nBL), TRT high threshold hits

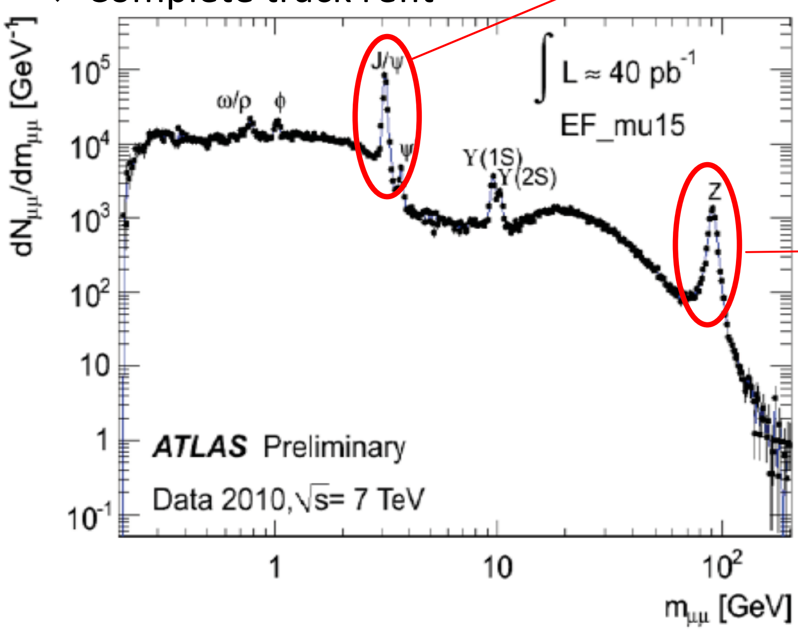


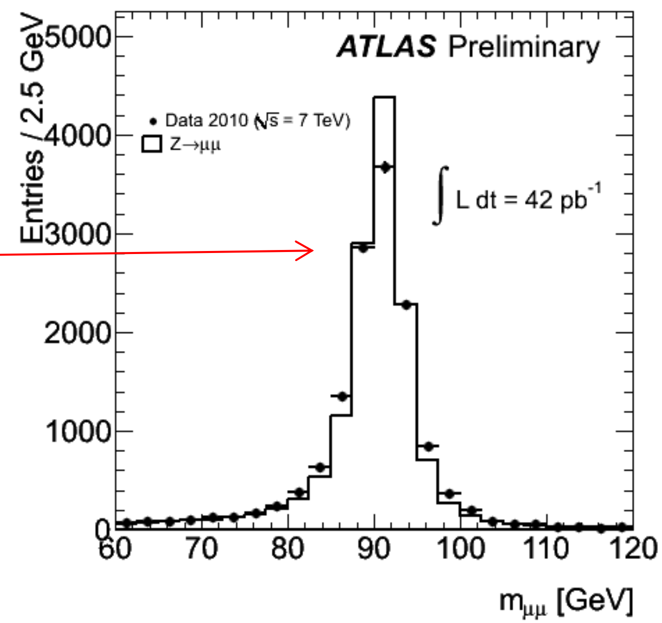
Muon Identification and Measurements

ATLAS muon reconstruction / Identification

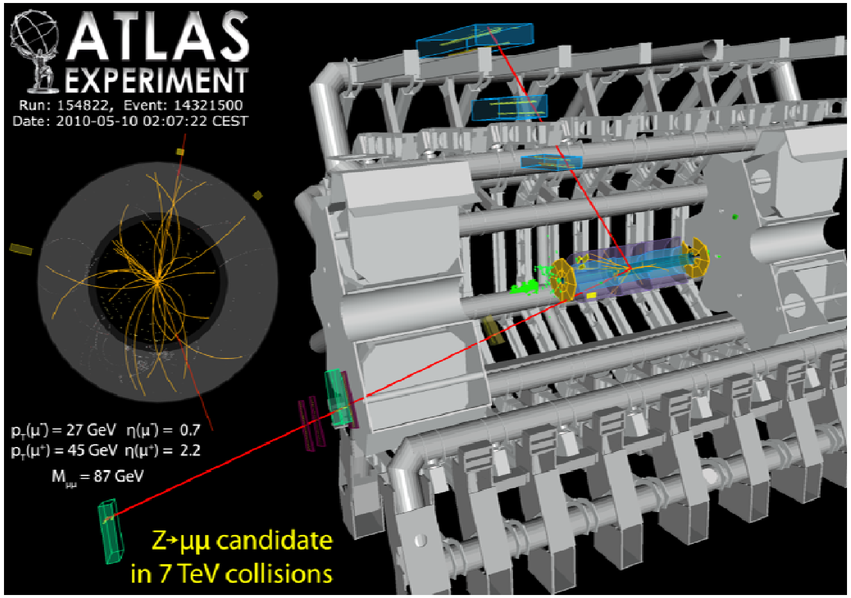
- ❖ **Inner Detector Tracker (ID)**
- ❖ **Muon Spectrometer (MS)**
  - ❖ MS standalone
  - ❖ ID + segment tagged
  - ❖ ID + calorimeter tagged
  - ❖ ID + MS combined
- ❖ **ID + MS Combined Muons**
  - ❖ Statistical combination of ID and MS tracks
  - ❖ Complete track refit





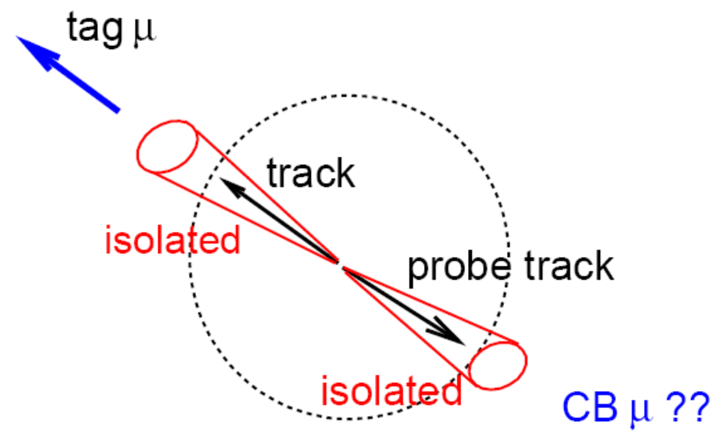


Determine Lepton, ID and Isolation Efficiencies

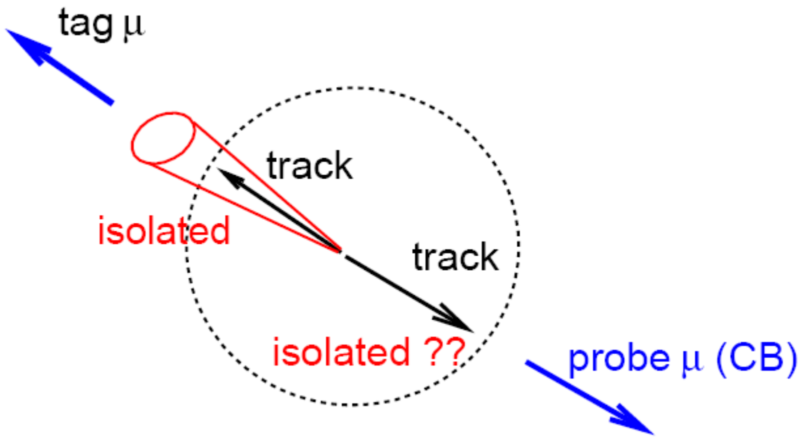


Z → ℓℓ Tag-Probe

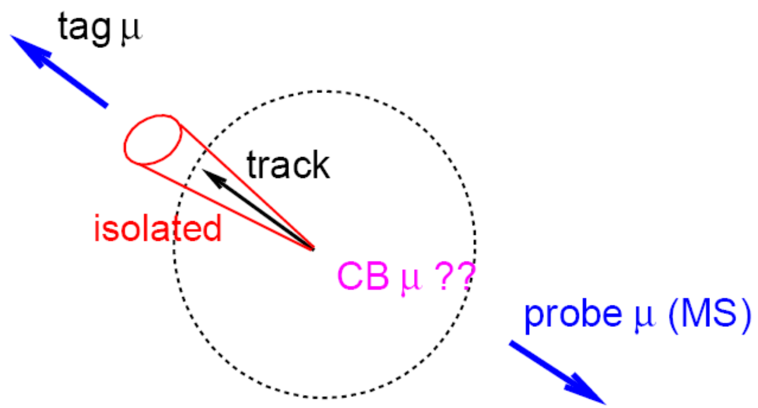
Efficiency Ratio (Data/MC) > 0.98



Muon Spectrometer Tracking Efficiency



Isolation Efficiency



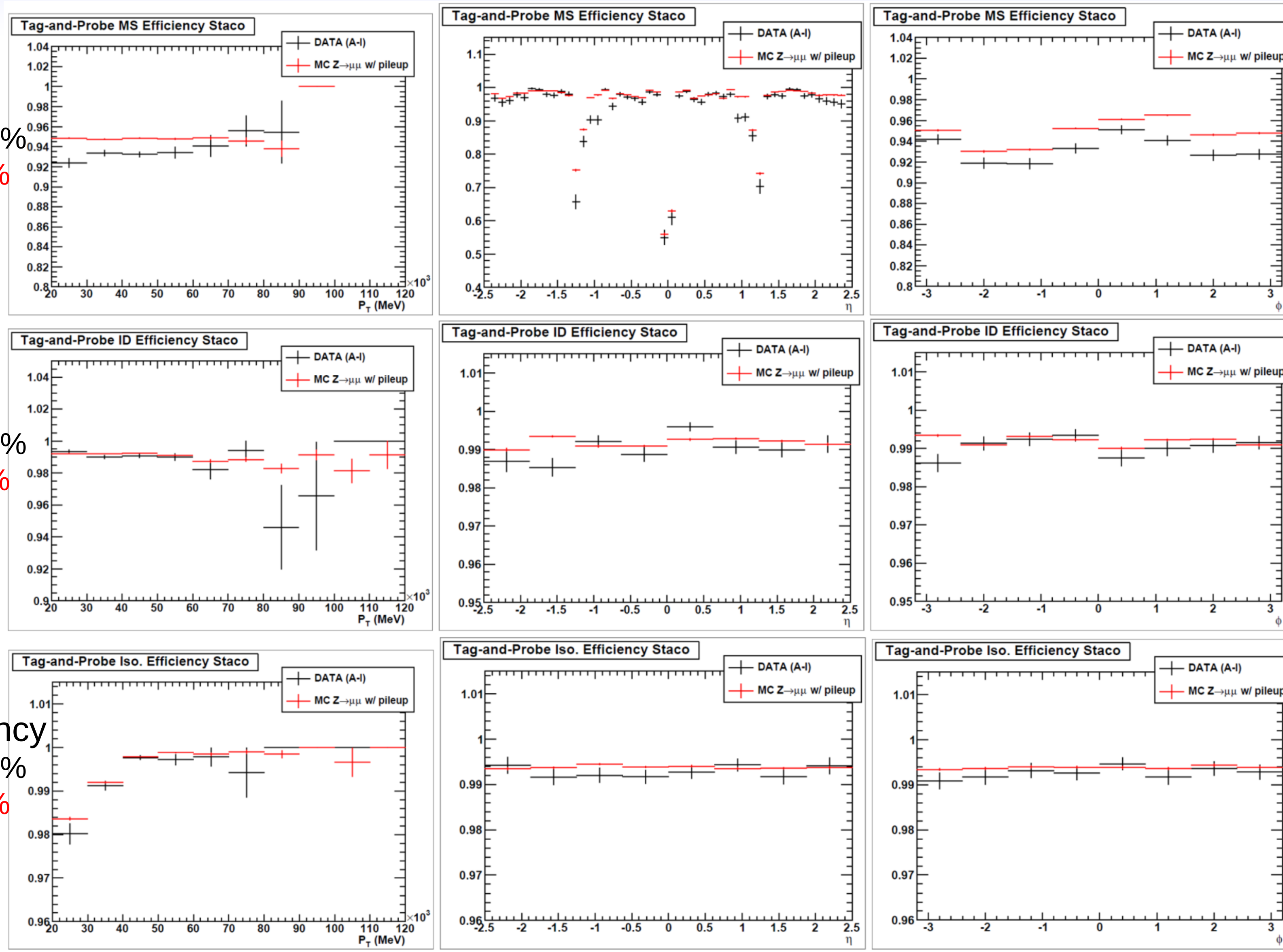
Inner Detector Tracking Efficiency

Z→$\mu^+\mu^-$ Tag-Probe Efficiency

MS Efficiency
Data (93.2±0.17)%
MC (94.8±0.03)%

ID Efficiency
Data (99.0±0.07)%
MC (99.2±0.01)%

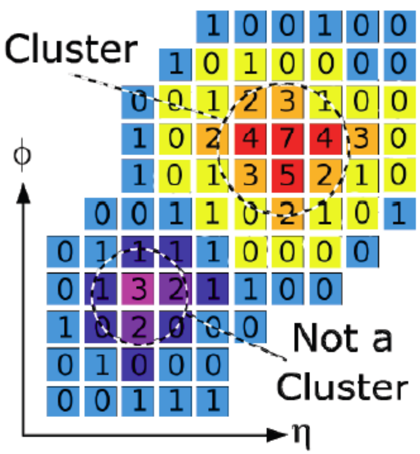
Isolation Efficiency
Data (99.3±0.06)%
MC (99.4±0.01)%

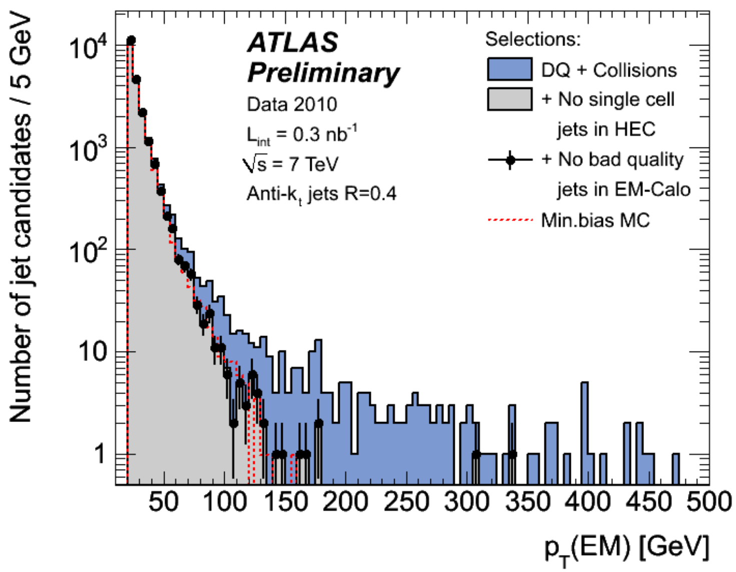


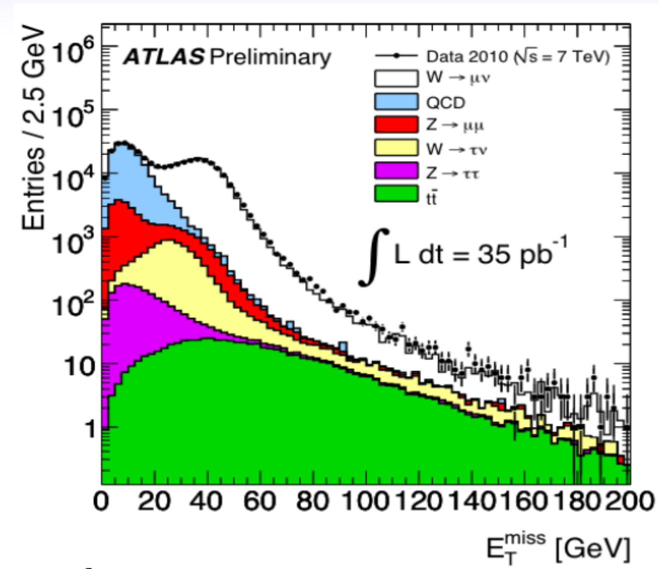
Missing E_T Construction and Measurement

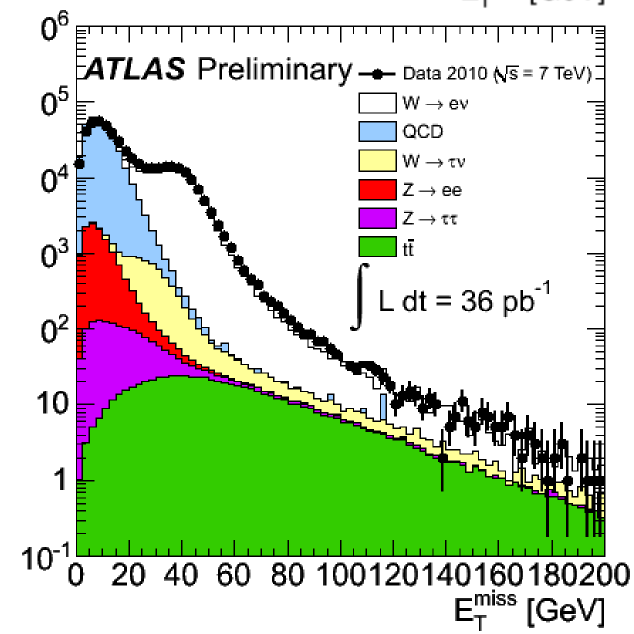
$$E_{x(y)}^{miss} = E_{x(y)}^{miss,calo} + E_{x(y)}^{miss,muon} + E_{x(y)}^{miss,cryo}$$

$$E_T^{miss} = \sqrt{(E_x^{miss})^2 + (E_y^{miss})^2}$$



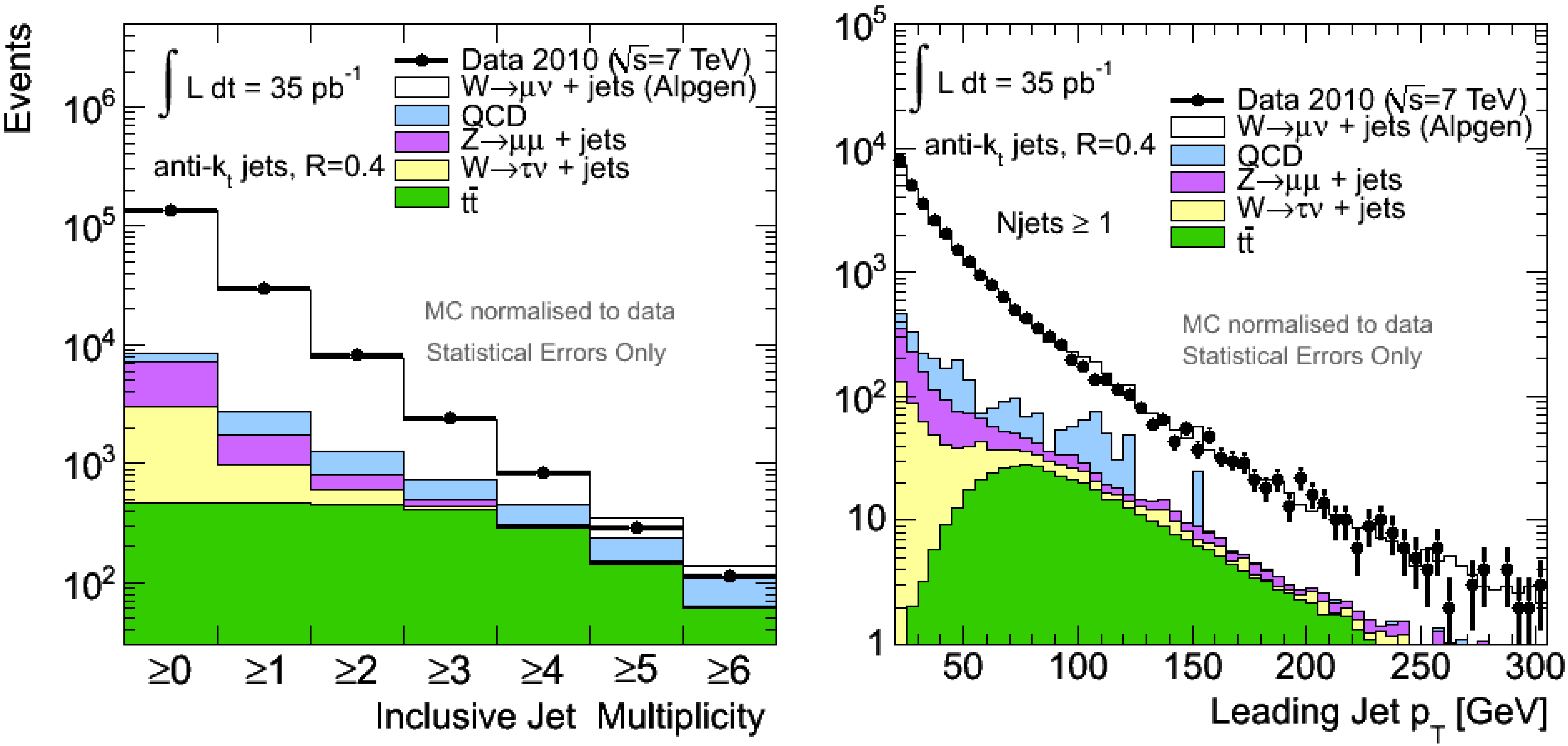






- Cells with $|E_{cell}| > 4\sigma_{noise}$ seed the cluster
- Neighboring cells with $|E_{cell}| > 2\sigma_{noise}$ added iteratively
- Single layer of neighboring cells added

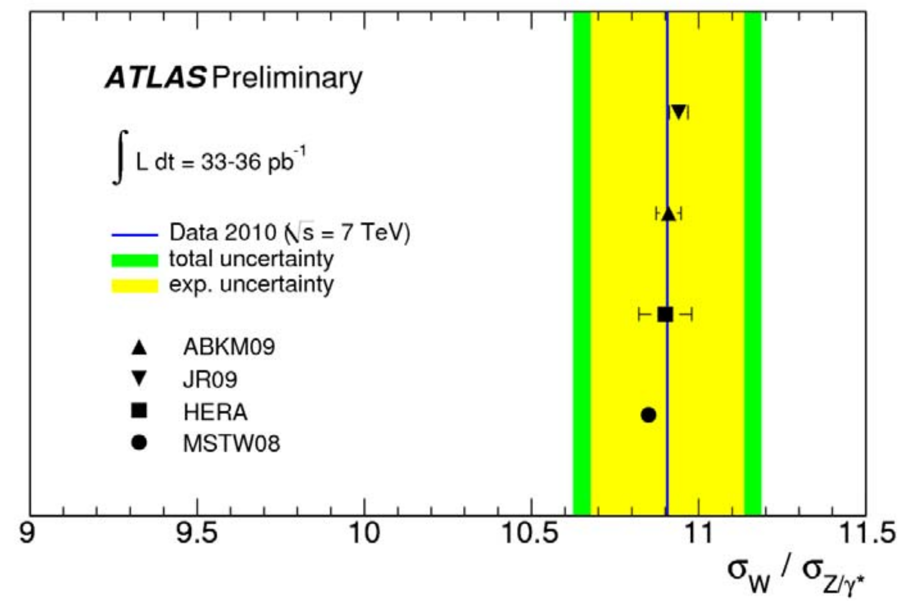
Jet Measurement



W/Z Cross Sections Measurement

Ref: ATLAS-CONF-2011-041

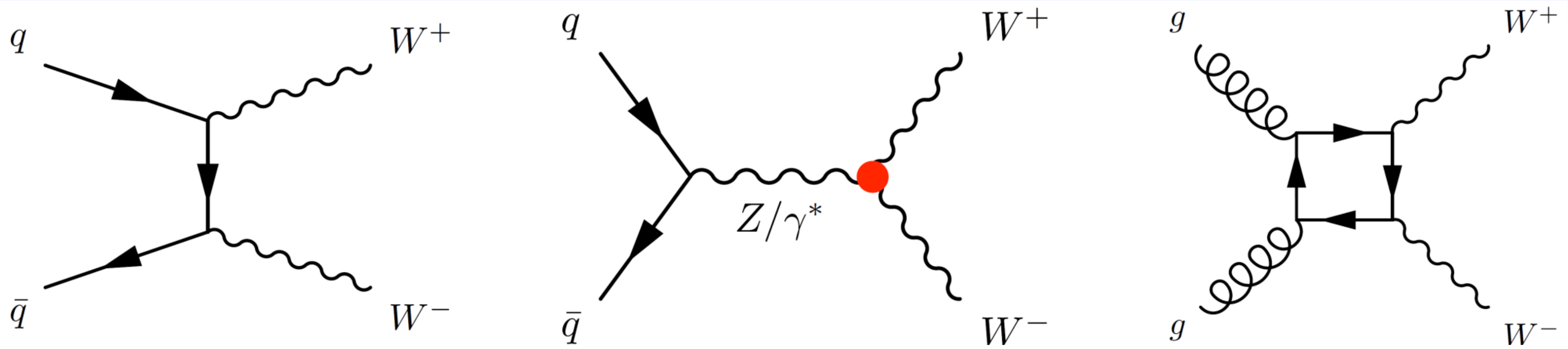
	N	B
W^+	84103	6214 ± 784
W^-	55163	5569 ± 812
$W^+ + W^-$	139266	11783 ± 1580
Z	11669	66 ± 21



	$\sigma^{tot}_{W(\pm)} \cdot \mathrm{BR}(W \to \ell\nu)$ [nb]
W^+	$6.257 \pm 0.017(\mathrm{sta}) \pm 0.152(\mathrm{sys}) \pm 0.213(\mathrm{lum}) \pm 0.188(\mathrm{acc})$
W^-	$4.149 \pm 0.014(\mathrm{sta}) \pm 0.102(\mathrm{sys}) \pm 0.141(\mathrm{lum}) \pm 0.124(\mathrm{acc})$
W	$10.391 \pm 0.022(\mathrm{sta}) \pm 0.238(\mathrm{sys}) \pm 0.353(\mathrm{lum}) \pm 0.312(\mathrm{acc})$

	$\sigma^{tot}_{Z/\gamma^*} \cdot \mathrm{BR}(Z/\gamma^* \to \ell\ell)$ [nb], $66 < m_{ee} < 116$ GeV
Z/γ^*	$0.945 \pm 0.006(\mathrm{sta}) \pm 0.011(\mathrm{sys}) \pm 0.032(\mathrm{lum}) \pm 0.038(\mathrm{acc})$

WW Production



MC@NLO /HERWIG/Jimmy

σ_{WW} = 43.15 ± 2.2 pb (using CTEQ6.6 PDF)

σ_{WW} = 44.76 ± 2.4 pb (using MSTW2008 PDF)

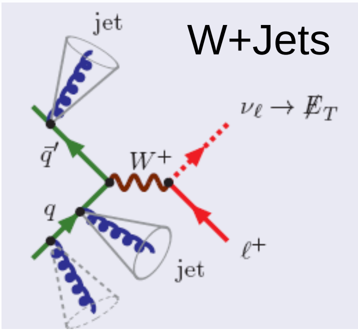
gg2ww/HERWIG/Jimmy

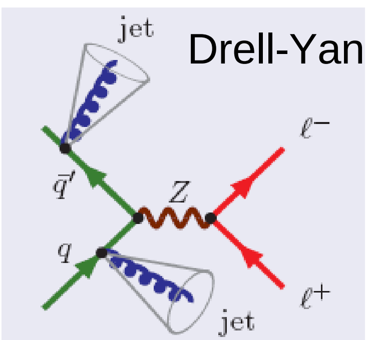
$\sigma_{gg2WW \to \ell\nu\ell\nu}$ = 1.3 pb

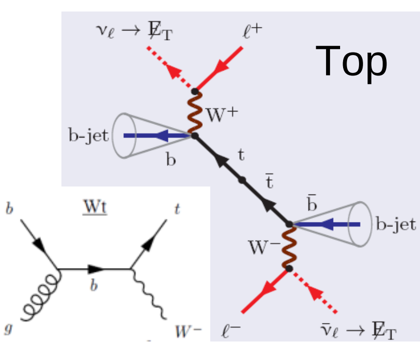
~3% of WW production

- Motivations:
  - Test electro-weak theory at the high energy frontier
  - Search for new physics with anomalous couplings
  - Dominant background to H→WW search
- Signature (leptonic decay channels, WW → $\ell^+\ell^-$ + E_T^{miss}):
  - Two opposite-sign charge leptons (e, μ)
  - Large Missing Transverse Energy (MET)

Major $\ell^+\ell^-$ $+E_T^{miss}$ Background



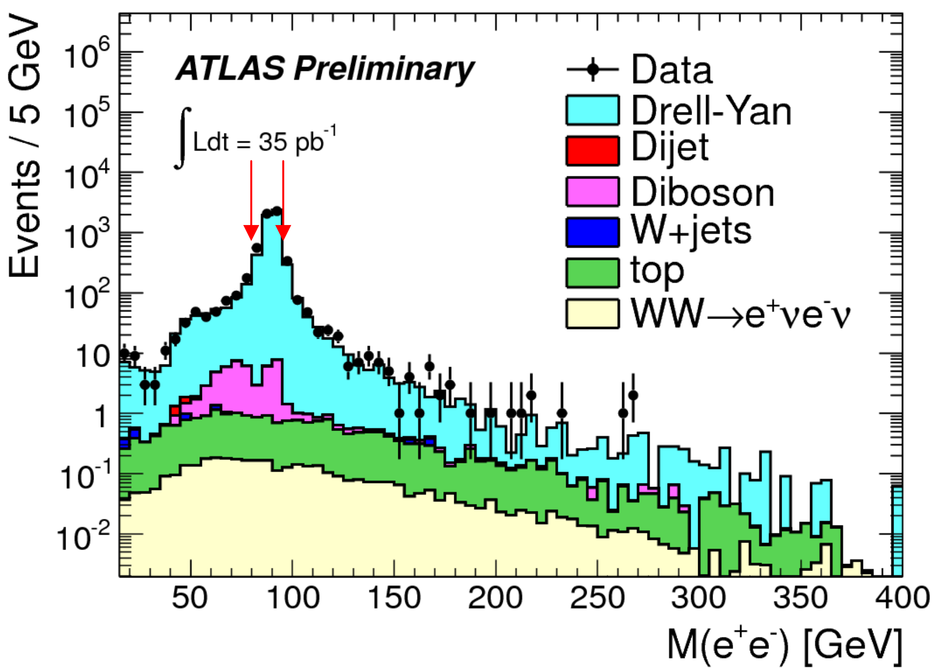


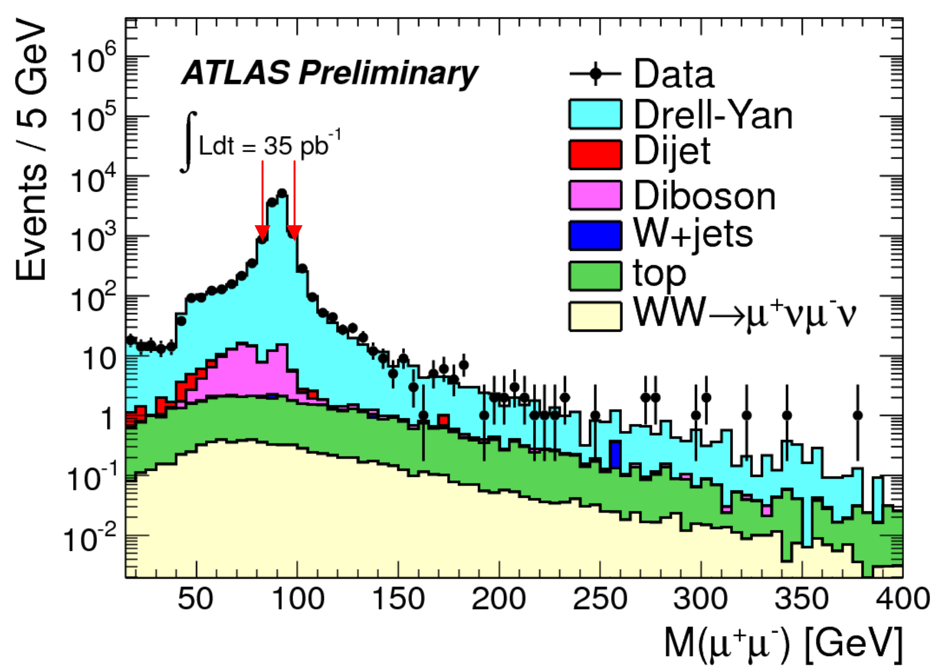


- **W+jets**
  - W leptonic decay produces a high P_T charged lepton and large missing E_T.
  - Associated jets can fake a second charged lepton.
  - **Suppressed by lepton identification.**
- **Drell-Yan**
  - high P_T charged lepton pairs produced from leptonic decays of Drell-Yan bosons.
  - Missing E_T either from mis-measurement of leptons or of associated jets, or from $Z \rightarrow \tau\tau$.
  - **Reduced by *Z* mass veto and missing E_T cut.**
- **Top**
  - *WW* pairs produced in *tt* or single top processes.
  - **Rejected by vetoing on high-P_T jets.**
- **Di-boson (*WZ,ZZ,W/Z+*γ)**
  - Leptons from boson decays or faked by photons.
  - Missing E_T from neutrino production or e/μ escape.
  - **Suppressed by the criteria mentioned above plus the requirement of exactly two high P_T charged leptons.**

WW Event Selections

Cuts	$e^+e^-+E_T^{miss}$	$\mu^+\mu^- +E_T^{miss}$	$e^\pm\mu^\mp +E_T^{miss}$
2 leptons (SS and OS)	6096	12802	134
2 leptons (OS)	6057	12798	126
$M_{\ell\ell} > 15$ GeV	6044	12724	-
Z veto ($\lvert M_{\ell\ell} - M_Z\rvert > 10$ GeV)	872	1935	-
$E_{T, Rel}^{miss}$ cut	12	14	39
Jet veto (No. of jet=0)	1	2	5

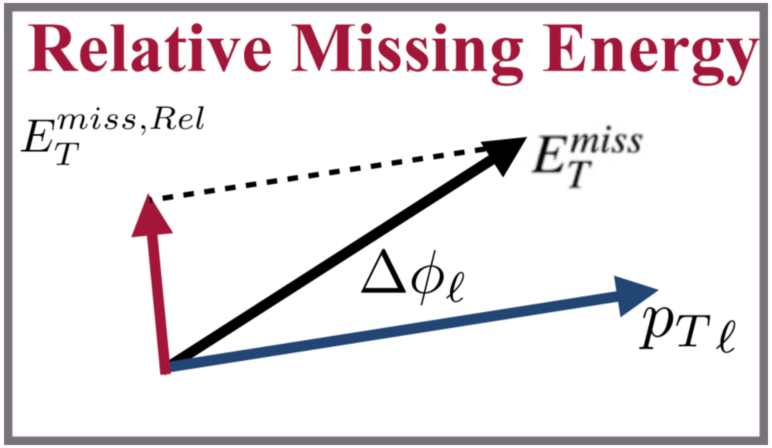


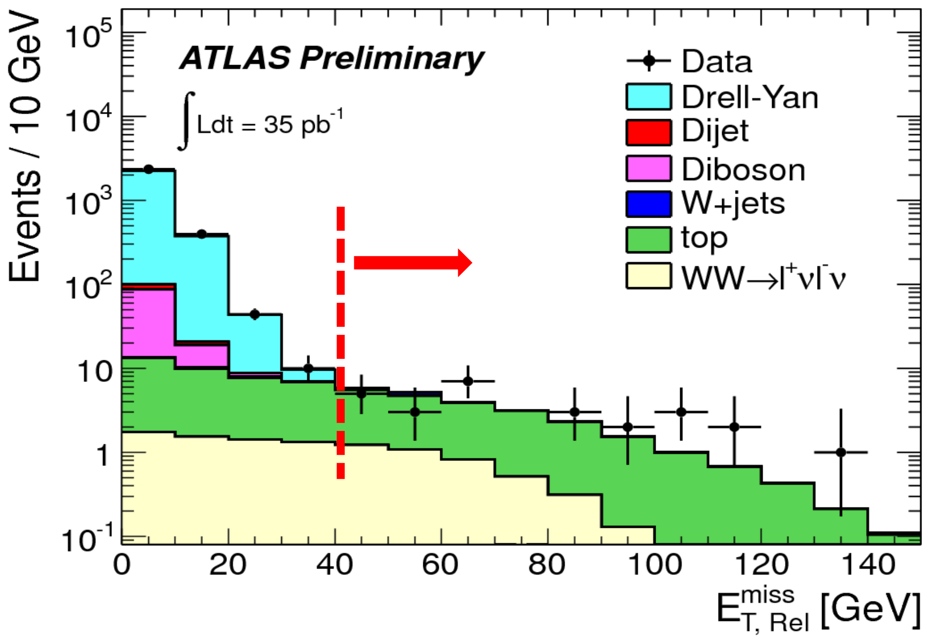


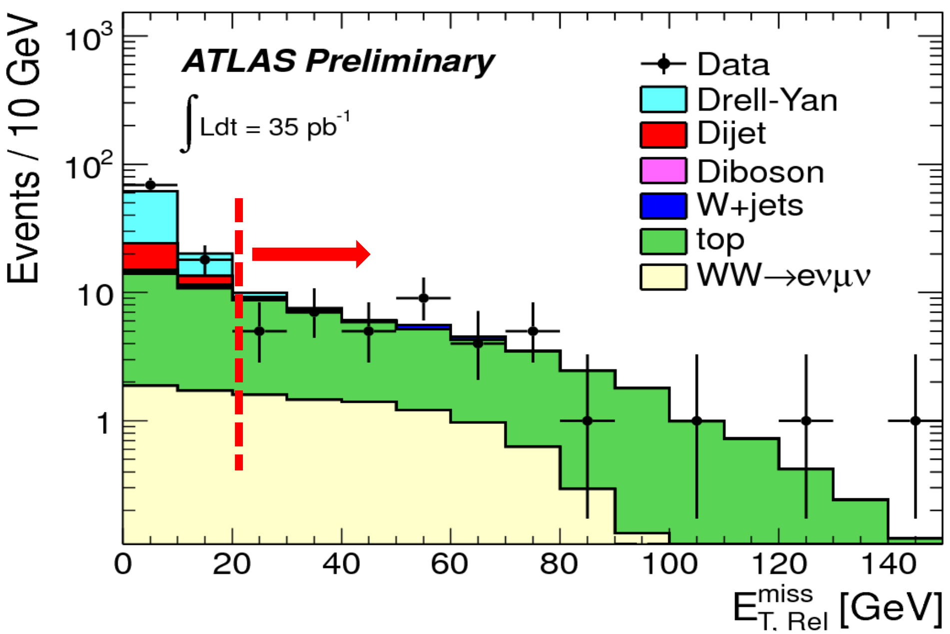
Relative Missing Energy (MET_Rel)

- The remaining Drell-Yan after the Z mass veto can be effectively removed by cutting on MET_Rel .

- less sensitive to mis-measured leptons or jets
- higher sensitivity to real E_t^{miss} from neutrinos.
- Better signal-background ratio

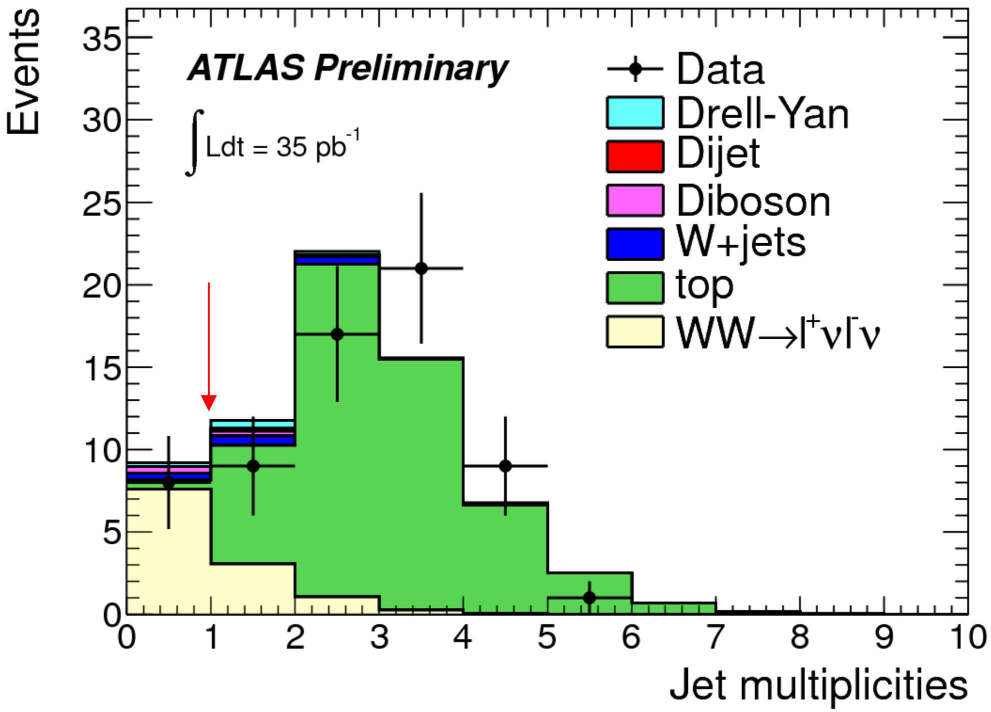






Jet veto and Efficiency Correction

Most of the top background can be removed by Jet veto (N_{jets}= 0)



→A data vs MC comparison from Z (high statistics, low background) is used to derive a correction of jet veto efficiency for WW.

$$\epsilon_{WW}^{data} = \epsilon_{Z}^{data} \frac{\epsilon_{WW}^{MC}}{\epsilon_{Z}^{MC}}$$

→Includes effects from ISR, underlying events and jet energy scale

→ Systematics are based on MC generator level study of Drell-Yan and WW production.

→Jet Veto correction is:

0.966 ± 0.06 (syst)

WW Signal Acceptance

Cuts	eeE_T^{miss} Channel		$\mu\mu E_T^{miss}$ Channel		$e\mu E_T^{miss}$ Channel	
	$e\nu e\nu$	$\tau\tau/e\tau\nu\nu$	$\mu\nu\mu\nu$	$\tau\tau/\mu\tau\nu\nu$	$e\nu\mu\nu$	$\tau\tau/\mu\tau/e\tau\nu\nu$
Total Events	18.99	7.27	18.99	7.27	37.98	14.55
2 leptons (opposite charge)	3.46	0.41	7.70	0.85	10.36	1.16
$M_{\ell\ell} > 15$ GeV & Z veto	2.93	0.34	6.43	0.69	10.36	1.16
$E_{T,\,Rel}^{miss}$ cut	1.21	0.11	2.76	0.21	7.17	0.74
Jet veto	0.78	0.07	1.63	0.12	4.38	0.43
Overall acceptance	4.1%	0.9%	8.6%	1.6%	11.5%	2.9%

- The numbers are normalized to the data integrated luminosity of 35 pb^{-1} using the SM W^+W^- cross-sections.
- All MC efficiency correction factors ($\varepsilon_{data}/\varepsilon_{MC}$) have been applied.
- Overall systematic acceptance uncertainty: 7.4%

Acceptance Uncertainty

Source	Mean	Uncertainty
ee trig. SF	100%	0.02%
$\mu\mu$ trig. SF	100%	0.04%
eμ trig. SF	100%	0.02%
μ eff. SF (Overall)	98.0%	1.0%
e eff. SF (Overall)	97.0%	3.3%
μ Pt Scale/Resolution ($\mu\mu$)	-	0.56%
μ Pt Scale/Resolution ($e\mu$)	-	0.22%
Vertex Reweighting	-	0.5%
E_T^e dependent eff. uncertainty (ee)	-	6.0%
E_T^e dependent eff. uncertainty ($e\mu$)	-	3.4%
ee SF (trigger and ID)	94.1%	7.6%
$\mu\mu$ SF (trigger and ID)	96.0%	1.5%
$e\mu$ SF (trigger and ID)	95.1%	4.9%
Jet Veto Eff. SF (W^+W^- signal)	96.6%	6.0%
ee SF (overall)	90.9%	9.7%
$\mu\mu$ SF (overall)	92.7%	6.2%
$e\mu$ SF (overall)	91.9%	7.7%
PDF Uncertainty on Acc.	-	1.2%

The overall systematic uncertainty on the combined (ee,μμ,eμ) W^+W^- selection acceptance is **7.4%**.

W+Jets Background Estimation

- Data driven method to estimate W + Jets
  - Define a fake factor f : the ratio of the number of jets satisfying the full lepton identification to those satisfying the jet-rich lepton selection

$$f_l \equiv \frac{N_{\text{lepton ID}}}{N_{\text{Jet-Rich ID}}}$$ → Determined using di-jet sample in data

  - The W+jet background to WW is calculated by scaling the number of events in the W+jet control sample ($N_{\text{lepton ID + Jet-Rich ID}}$) by the fake factor f

$$N_{W\text{+jet Bkg}} = f_l \times N_{\text{lepton ID + Jet-Rich ID}}$$

$$N^{e\mu\text{-ch}}_{W\text{+jet Bkg}} = f_e \times N_{\mu\text{ ID + Jet-Rich e}} + f_\mu \times N_{\text{elec. ID + Jet-Rich }\mu}$$

Channel	Estimated W+jets from Data
ee-channel	0.08±0.05(stat.)±0.03(syst.)
$\mu\mu$-channel	0±0.29(stat.)±0.10(syst.)
$e\mu$-channel	0.46±0.12(stat.)±0.17(syst.)
$ee + \mu\mu + e\mu$-channel	0.54±0.32(stat.)±0.21(syst.)

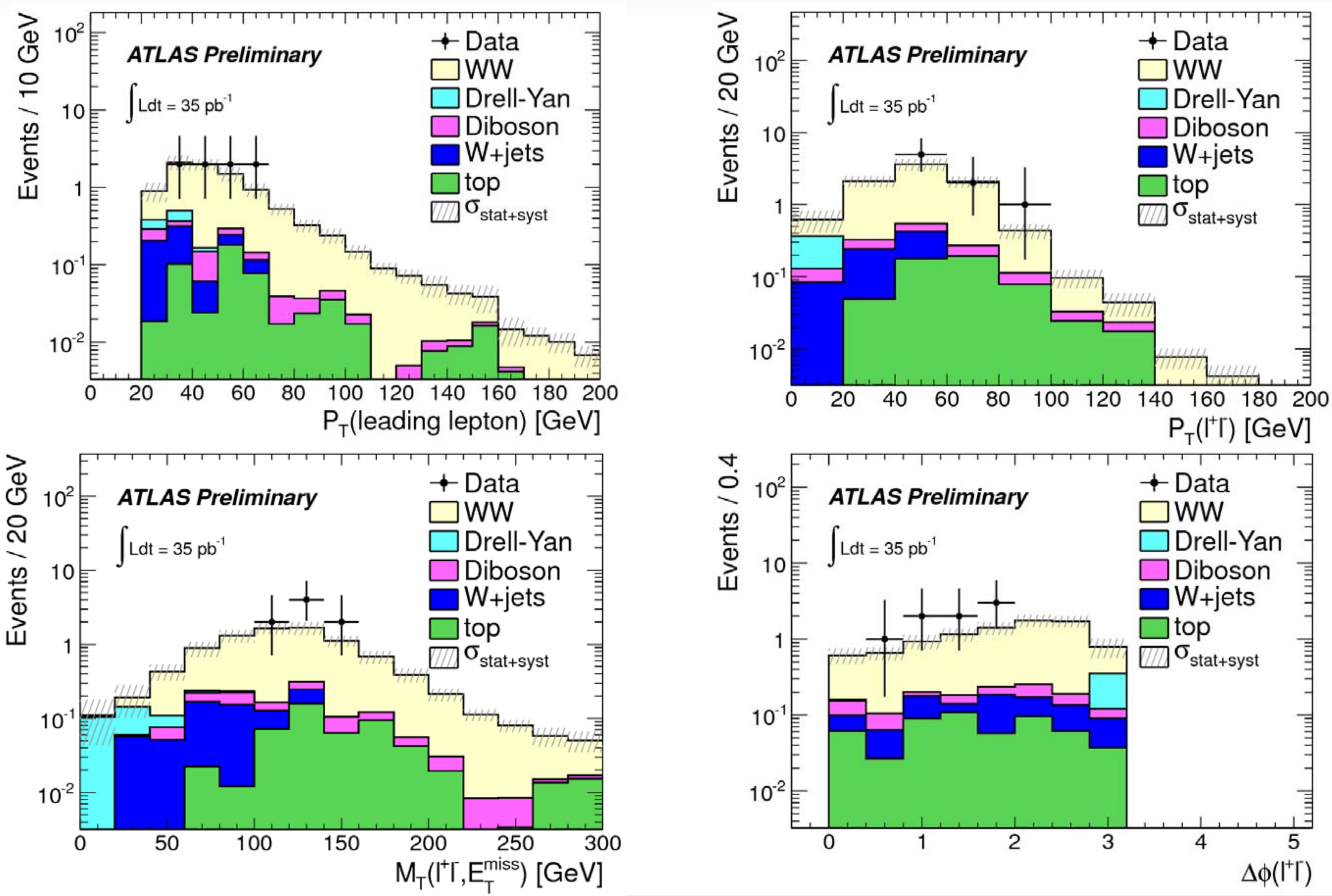
WW Observation and MC Expectation

Final State	$e^+e^-E_T^{miss}$	$\mu^+\mu^-E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	combined
Observed Events	1	2	5	8
MC WW Signal	0.85±0.02±0.13	1.74±0.04±0.24	4.81±0.06±0.68	7.40±0.07±1.05
Backgrounds				
Top (MC)	0.04±0.02±0.03	0.15±0.06±0.08	0.36±0.10±0.19	0.55±0.12±0.30
W+jets (data)	0.08±0.05±0.03	0.00±0.29±0.10	0.46±0.12±0.17	0.54±0.32±0.21
DY (MC/data)	0.00±0.10±0.07	0.01±0.10±0.07	0.23±0.06±0.15	0.24±0.15±0.17
Other dibosons (MC)	0.05±0.01±0.01	0.10±0.01±0.01	0.24±0.05±0.03	0.39±0.04±0.06
Total Background	0.17±0.11±0.09	0.26±0.31±0.15	1.29±0.17±0.32	1.72±0.37±0.45
Signal / Background	5.0	6.7	3.7	4.3

- $N_{observed}$ = 8, N_{signal} = 7.4 ± 1.1, $N_{background}$ = 1.7 ± 0.6
- Probability for the total background 1.7 ± 0.6 to fluctuate to 8 or more events is 1.4×10^{-3}

➔ Signal observation significance: 3σ

Kinematic Distributions of WW Candidates



WW Cross Section

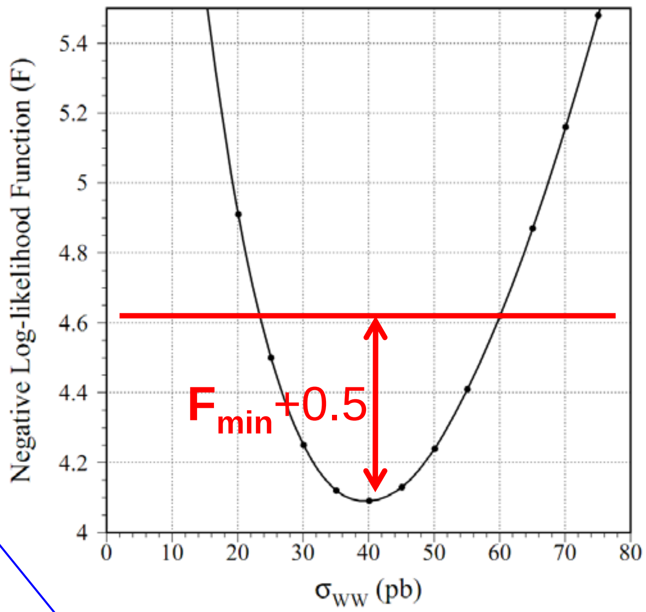
- The W^+W^- production cross-section is determined using the maximum log-likelihood method. The likelihood function based on Poission statistics is constructed as

$$F = \ln \prod_{i=1}^{3} \frac{e^{-(N_s^i+N_b^i)}(N_s^i+N_b^i)^{N_{obs}^i}}{N_{obs}^i!}$$

$$N_s^i = \sigma_{WW} \times Br^i \times \mathscr{L} \times A^i$$

$$\sigma_{syst}/\sigma_{WW} = \sqrt{(\Delta\mathscr{L}/\mathscr{L})^2 + (\Delta A/A)^2 + (\Delta N_b/(N_{obs}-N_b))^2}$$

$$\sigma_{WW} = 40^{+20}_{-16}(\text{stat}) \pm 7(\text{syst}) \text{ pb}$$



Source	Uncertainty
Luminosity	11%
Background	9.6%
Acceptance	7.4%
Systematic	**16.4%**
Statistical	**44%**

CMS Results: 13 data, 10.2 WW and 3.3 background
σ_{WW} = 41.1 ± 15.3(stat) ± 5.8(syst) ± 4.5(lumi) pb

Ref: ATLAS-CONF-2011-015
CMS-EWK-10-009 (arXiv:1102.5429)

Probing the Anomalous TGCs

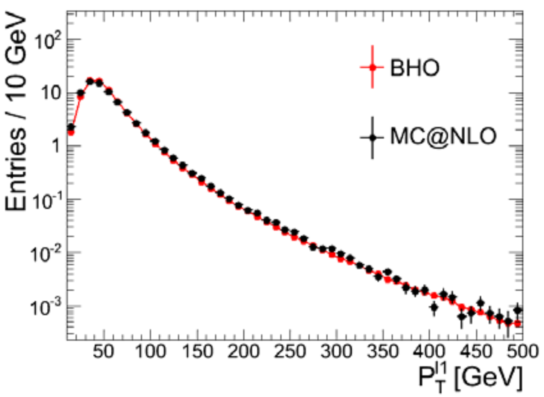
(Ref: Baur, Han, Ohnemus, Phys. Rev. D53, 1098, 1996)

To probe the anomalous couplings we need a model of the kinematic distributions for various couplings. We use

NLO generators:

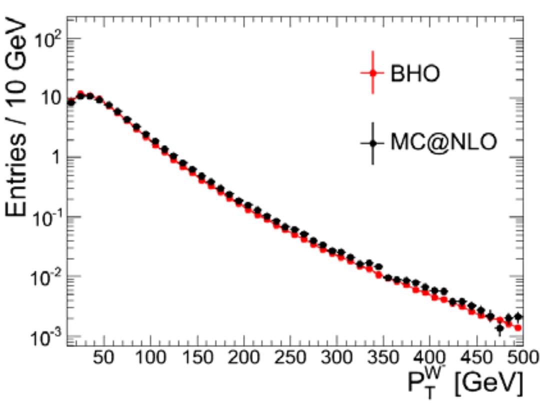
MC@NLO produces events that are fully simulated in ATLAS

BHO MC (CTEQ6M) is used to generate events with anomalous couplings. MC@NLO agrees with BHO.



Reweighting:

Using kinematic distributions from BHO, we reweight the fully simulated MC@NLO events to produce expected distributions for anomalous couplings.



Three different constraints:

→ LEP scenario (three free parameters)

$$\Delta\kappa_\gamma = (\cos^2\theta_W/\sin^2\theta_W)(\Delta g_1^Z - \Delta\kappa_Z), \quad \lambda_Z = \lambda_\gamma$$

→ HISZ scenario (two free parameters)

$$\Delta g_1^Z = \Delta\kappa_Z/(\cos^2\theta_W - \sin^2\theta_W), \quad \Delta\kappa_\gamma = 2\Delta\kappa_Z\cos^2\theta_W/(\cos^2\theta_W - \sin^2\theta_W),$$

→ Equal couplings (two parameters)

$$\Delta\kappa_Z = \Delta\kappa_\gamma, \quad \lambda_Z = \lambda_\gamma$$

Anomalous TGCs Reweighting Method

Ref: V.M. Abazov et al. (D0), Phys. Rev. D80, 053012 (2009)

- **Basic idea**: differential cross section has quadratic dependence on anomalous TGCs, *X* is a set of kinematic distributions:

$$d\sigma(non-SM) = const \times |M|^2_{SM} \frac{|M|^2}{|M|^2_{SM}} d\vec{X} = d\sigma(SM) \times R(\vec{X}; \Delta k_Z, \lambda_Z, \Delta g_1^Z, \Delta k_\gamma, \lambda_\gamma)$$

- **LEP parameterization (eg.)**:

$$R(\vec{X}; \Delta k, \lambda, \Delta g_1) = 1 + A(\vec{X})\Delta k + B(\vec{X})\Delta k^2 + C(\vec{X})\lambda + D(\vec{X})\lambda^2 + E(\vec{X})\Delta g_1 + F(\vec{X})\Delta g_1^2 + G(\vec{X})\Delta k\lambda + H(\vec{X})\Delta k\Delta g_1 + I(\vec{X})\lambda\Delta g_1$$

- **Method based on nine anomalous TGCs points:**

$$R1 = 1 + C|\lambda| + D|\lambda|^2$$
$$R2 = 1 - C|\lambda| + D|\lambda|^2$$
$$R3 = 1 + A|\Delta k| + B|\Delta k|^2$$
$$R4 = 1 - A|\Delta k| + B|\Delta k|^2$$
$$R5 = 1 + E|\Delta g_1| + F|\Delta g_1|^2$$
$$R6 = 1 - E|\Delta g_1| + F|\Delta g_1|^2$$
$$R7 = 1 + A|\Delta k| + B|\Delta k|^2 + C|\lambda| + D|\lambda|^2 + G|\Delta k\lambda|$$
$$R8 = 1 + A|\Delta k| + B|\Delta k|^2 + E|\Delta g_1| + F|\Delta g_1|^2 + H|\Delta k\Delta g_1|$$
$$R9 = 1 + C|\lambda| + D|\lambda|^2 + E|\Delta g_1| + F|\Delta g_1|^2 + I|\lambda\Delta g_1|$$

	R1	R2	R3	R4	R5	R6	R7	R8	R9
Δk	0	0	+0.4	-0.4	0	0	+0.4	+0.4	0
λ	+1.4	-1.4	0	0	0	0	+1.4	0	+1.4
Δg_1	0	0	0	0	+0.8	-0.8	0	+0.8	+0.8

Binned Likelihood Function

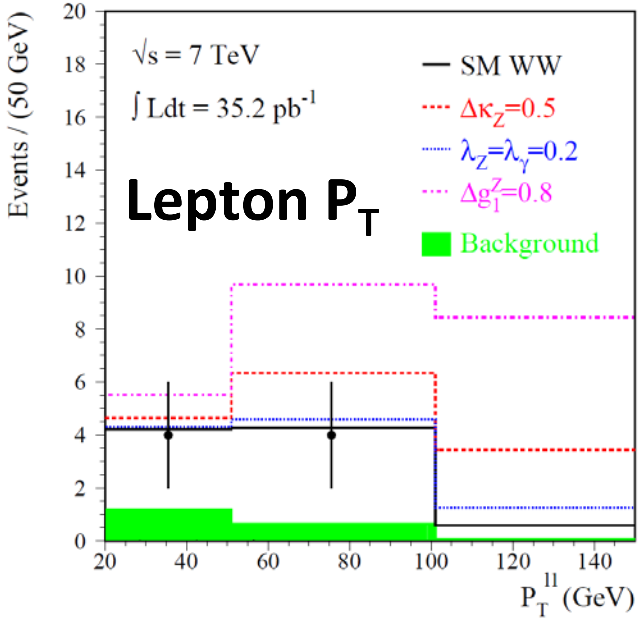
➔Assuming systematic uncertainties of luminosity (σ_c=11%), signal (σ_s=9%) and background (σ_b=32%) are Gaussian and uncorrelated, we convolve three Gaussian distributions with a Poisson distribution to form a binned likelihood function.

$$L = \int_{1-3\sigma_c}^{1+3\sigma_c} \int_{1-3\sigma_b}^{1+3\sigma_b} \int_{1-3\sigma_s}^{1+3\sigma_s} \frac{[f_c(f_s N_s + f_b N_b)]^{N_{obs}} \, e^{-f_c(f_s N_s + f_b N_b)}}{N_{obs}!} \, g_s \, g_b \, g_c \, d f_s \, d f_b \, d f_c$$

$$g_j = \frac{e^{-(1-f_j)^2/2\sigma_j^2}}{\sqrt{2\pi}\sigma_j} \quad j = s,b,c \; ; \qquad N_s = \mathscr{L}\varepsilon\sigma_{SM} R(\Delta k_Z, \lambda_Z, \Delta g_1^Z, \Delta k_\gamma, \lambda_\gamma)$$

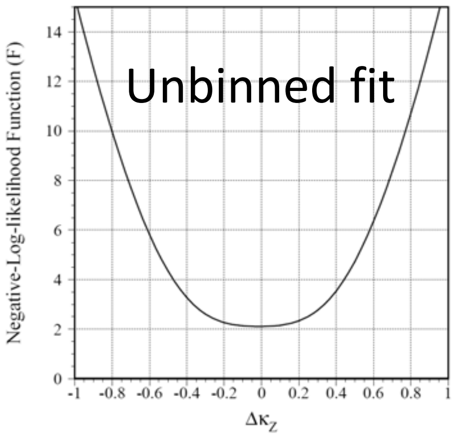
$$F = -\sum_{k=\text{channels}} \sum_{i=\text{bins}} \ln L_i^k$$

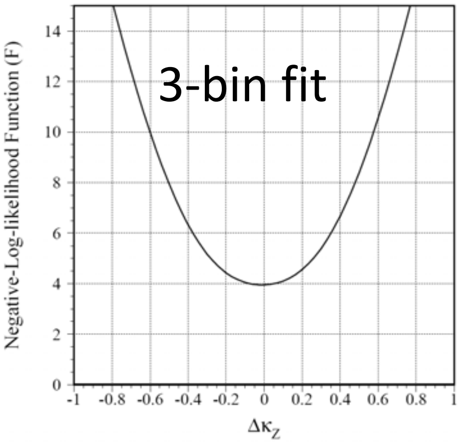
➔ N_s is expected signal events which depends on reweighting function R (as a function of the anomalous couplings).



95% C.L. Limits of Anomalous TGCs using $P_T^{\ell 1}$ for Reweighting and Fit

➔ Using three-bin fit of the $P_T^{\ell 1}$ distribution gives better sensitivities on the anomalous TGC parameter limits





Fit $P_T^{\ell 1}$	Δk_Z	$\lambda_Z = \lambda_\gamma$	Δg_1^Z	Δk_γ
Unbinned fit with systematic uncertainties included				
LEP (Log-Likelihood)	[-0.47,0.44]	[-0.42,0.42]	[-0.38,0.45]	-
LEP (Bayesian)	[-0.44,0.41]	[-0.40,0.39]	[-0.35,0.43]	-
HISZ (Log-Likelihood)	[-0.33,0.39]	[-0.42,0.42]	-	-
HISZ (Bayesian)	[-0.31,0.36]	[-0.40,0.39]	-	-
Equal (Log-Likelihood)	[-0.51,0.61]	[-0.45,0.44]	0	$\Delta k_Z = \Delta k_\gamma$
Equal (Bayesian)	[-0.47,0.57]	[-0.42,0.41]	0	$\Delta k_Z = \Delta k_\gamma$
Three-bin fit with systematic uncertainties included				
LEP (Log-Likelihood)	[-0.36,0.34]	[-0.31,0.31]	[-0.29,0.35]	-
LEP (Bayesian)	[-0.36,0.33]	[-0.30,0.30]	[-0.28,0.35]	-
HISZ (Log-Likelihood)	[-0.24,0.29]	[-0.31,0.31]	-	-
HISZ (Bayesian)	[-0.24,0.29]	[-0.30,0.30]	-	-
Equal (Log-Likelihood)	[-0.38,0.46]	[-0.32,0.32]	0	$\Delta k_Z = \Delta k_\gamma$
Equal (Bayesian)	[-0.37,0.45]	[-0.31,0.31]	0	$\Delta k_Z = \Delta k_\gamma$

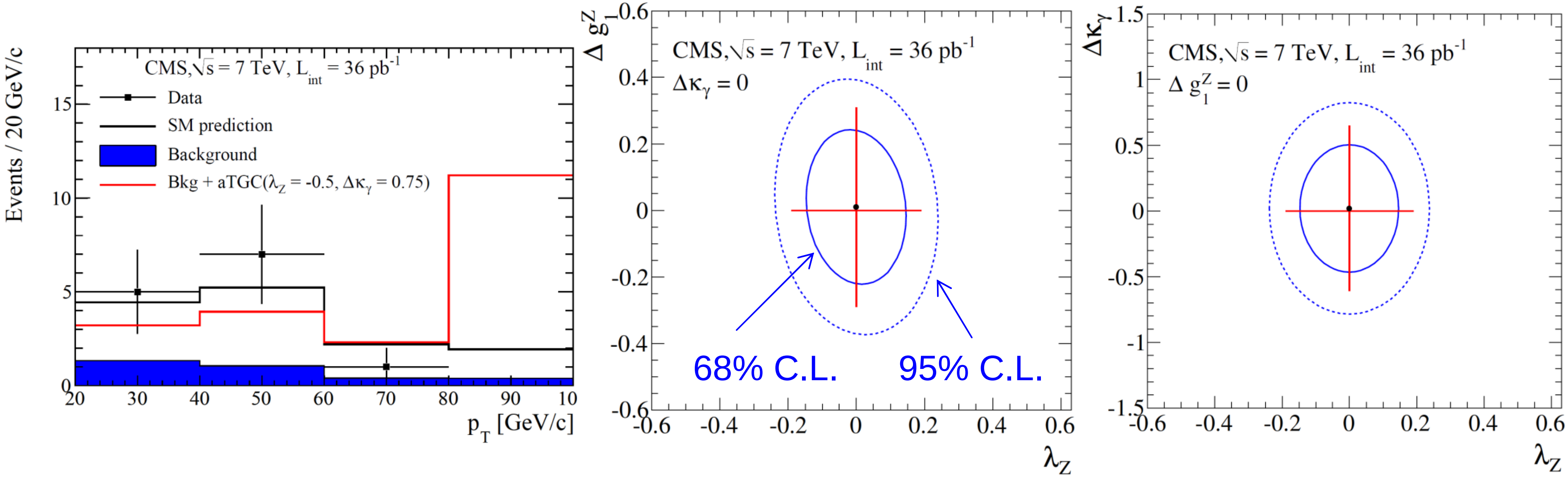
Limits on the Anomalous TGCs

- Using constraints of LEP scenario, the limits of the anomalous TGCs using leading lepton P_T for reweighting and log-likelihood function fit are:

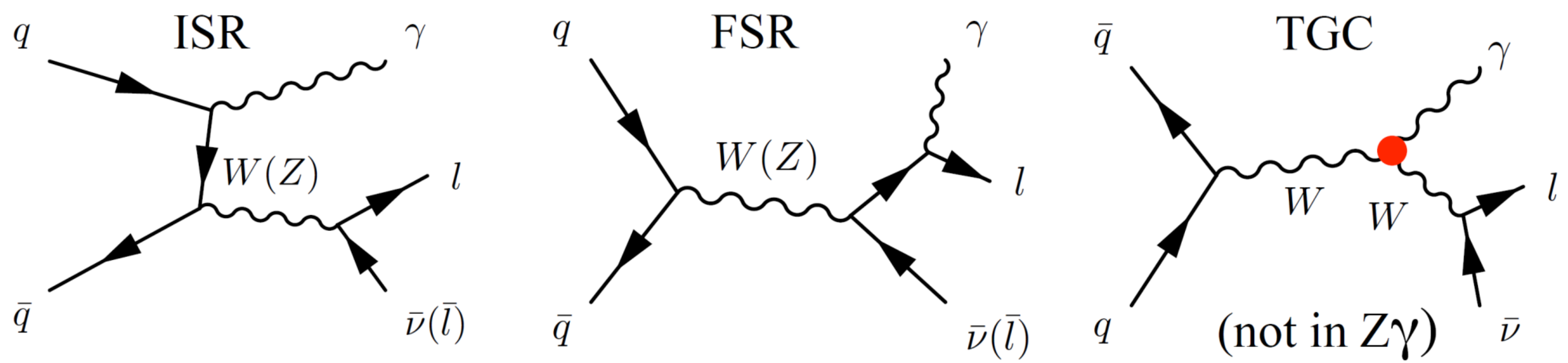
ATLAS: $-0.31 < \lambda_Z < 0.31$, $-0.29 < \Delta g_1^Z < 0.35$, $-0.36 < \Delta\kappa_Z < 0.34$

➔ CMS(HISZ): $-0.19 < \lambda_Z < 0.19$, $-0.29 < \Delta g_1^Z < 0.31$, $-0.61 < \Delta\kappa_\gamma < 0.65$

Ref: CMS-EWK-10-009 (arXiv:1102.5429)



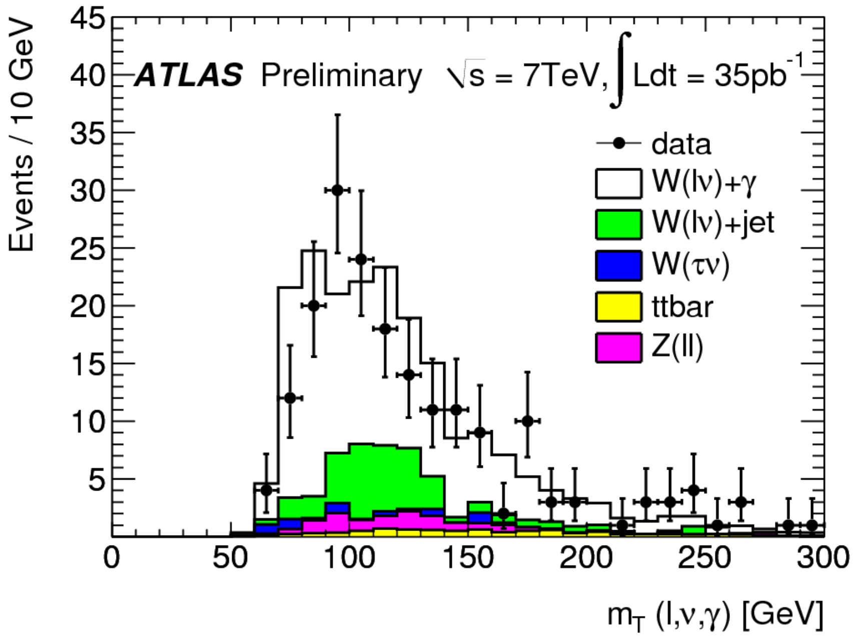
Wγ and Zγ Productions

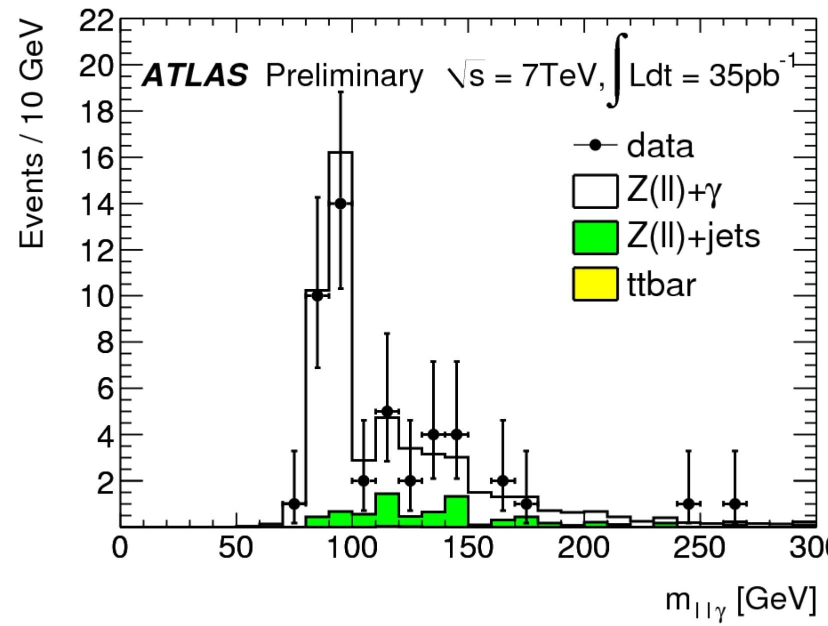


- Motivations:
  - First Wγ and Zγ cross section measurements at 7 TeV
  - Test Electroweak model, sensitive to anomalous TGCs
- Signatures (in leptonic decay channels):
  - W candidate: $E_T^{\ell} > 20$ GeV, MET > 25 GeV, $M_T^W > 40$ TeV
  - Z candidate: $E_T^{\ell} > 20$ GeV, $M_{\ell\ell} > 40$ GeV
  - Isolated γ: $E_T^{\gamma} > 15$ GeV, $E_T^{Iso} < 5$ GeV, $\Delta R(\ell,\gamma)>0.7$

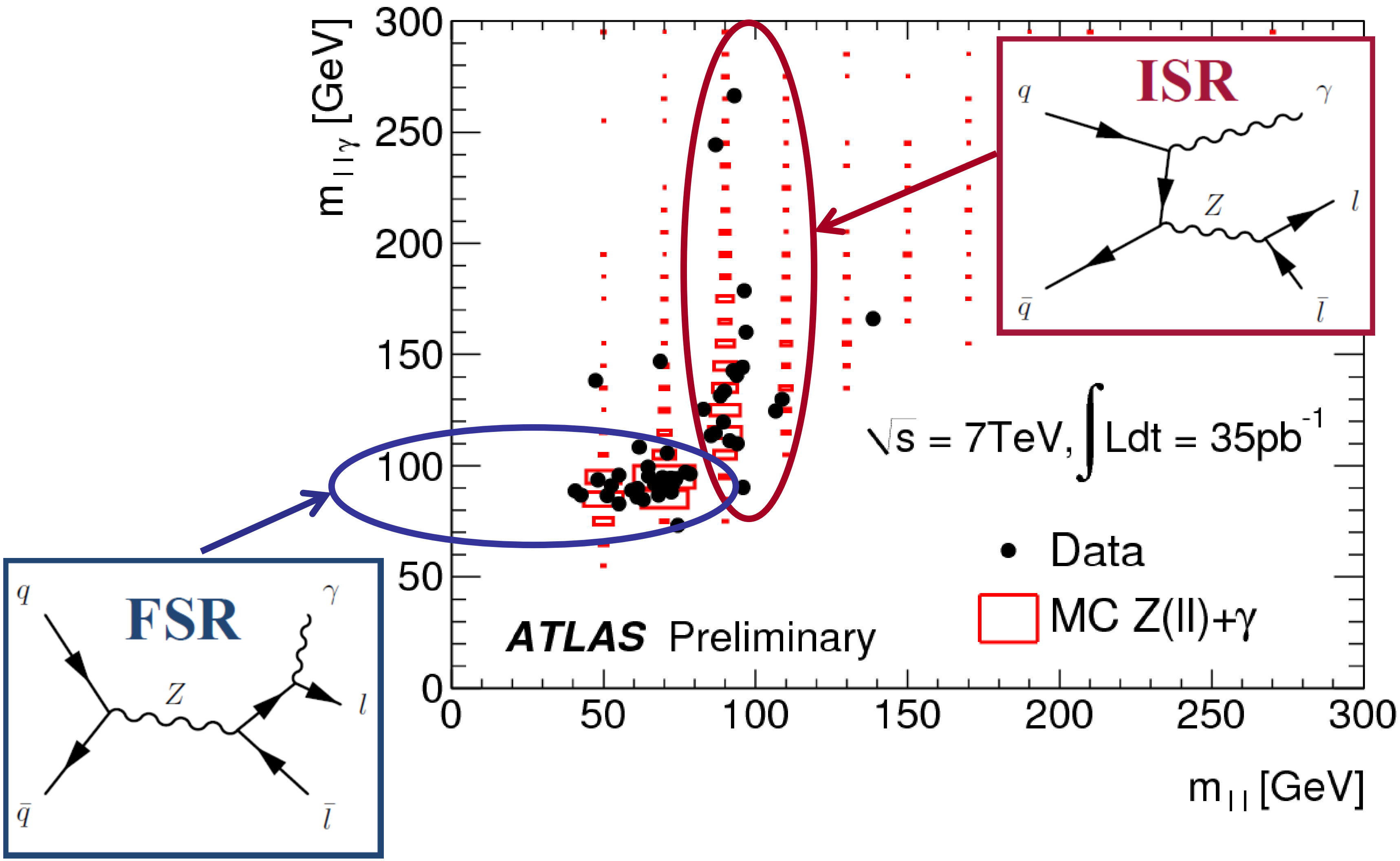
Wγ and Zγ Event Selections

	Process	Observed events	non W+jets background	W+jet background	Extracted Signal
Wγ	$pp \to e\nu\gamma$	95	$10.1 \pm 0.8 \pm 1.2$	$16.9 \pm 6.4 \pm 7.3$	$67.9 \pm 9.5 \pm 7.3$
	$pp \to \mu\nu\gamma$	97	$12.4 \pm 0.9 \pm 1.4$	$16.8 \pm 4.7 \pm 7.3$	$67.8 \pm 9.3 \pm 7.4$
	Process Process	Observed events	Total Background		Extracted Signal
Zγ	$pp \to e^+e^-\gamma$	25	3.8 ± 3.8		$21.2 \pm 5.8 \pm 3.8$
	$pp \to \mu^+\mu^-\gamma$	23	3.4 ± 3.4		$19.6 \pm 4.8 \pm 3.4$





Zγ (ISR vs FSR)



$m_{ll\gamma}$ [GeV]
300
250
200
150
100
50
0
0
50
100
150
200
250
300
m_{ll} [GeV]
$\sqrt{s}$ = 7TeV, $\int$Ldt = 35pb^{-1}
Data
MC Z(ll)+γ
ATLAS Preliminary
ISR
q
γ
Z
l
$\bar{q}$
$\bar{l}$
FSR
q
γ
Z
l
$\bar{q}$
$\bar{l}$

Wγ and Zγ Cross Sections

Ref: ATLAS-CONF-2011-013

$$\sigma^{fid}_{pp\to l\nu\gamma(l^+l^-\gamma)} = \frac{N^{sig}_{W\gamma(Z\gamma)}}{C_{W\gamma(Z\gamma)} \cdot L_{W\gamma(Z\gamma)}}$$

$$C_{W\gamma} = \varepsilon^{W\gamma}_{event} \cdot \varepsilon_{lep} \cdot \varepsilon^{W\gamma}_{trig} \cdot \varepsilon^{\mathrm{ID}}_{\gamma} \cdot \varepsilon^{\mathrm{iso}}_{\gamma} \cdot \alpha^{W\gamma}_{reco}$$

$$C_{Z\gamma} = \varepsilon^{Z\gamma}_{event} \cdot (\varepsilon_{lep})^2 \cdot \varepsilon^{Z\gamma}_{trig} \cdot \varepsilon^{\mathrm{ID}}_{\gamma} \cdot \varepsilon^{\mathrm{iso}}_{\gamma} \cdot \alpha^{Z\gamma}_{reco}$$

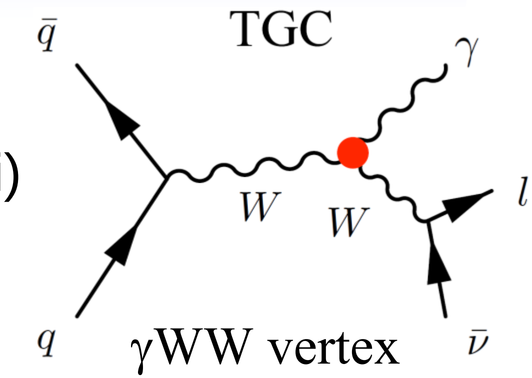
$$\sigma^{total}_{pp\to l\nu\gamma(pp\to l^+l^-\gamma)} = \frac{\sigma^{fid}_{pp\to l\nu\gamma(pp\to l^+l^-\gamma)}}{A_{W\gamma(Z\gamma)}}$$

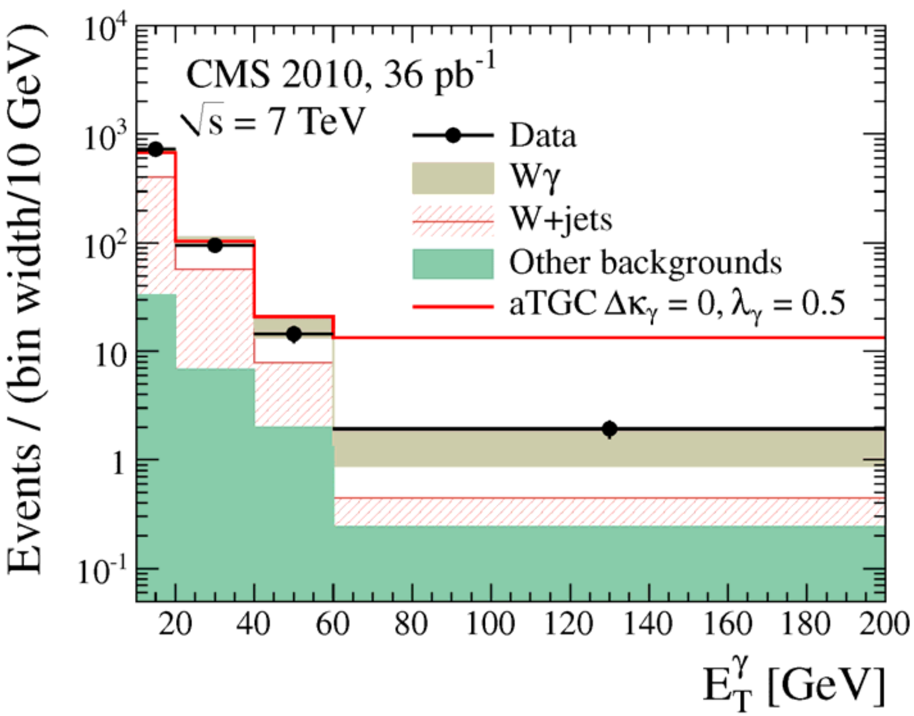
	$e\nu\gamma$	$\mu\nu\gamma$	$e^+e^-\gamma$	$\mu^+\mu^-\gamma$
Fiducial Cross Section				
Lepton $E_t(p_T)$ cut	$E_T^e > 20$ GeV $p_T^\nu > 25$ GeV	$p_T^\mu > 20$ GeV $p_T^\nu > 25$ GeV	$E_T^e > 20$ GeV	$p_T^\mu > 20$ GeV
Lepton η cut	$\lvert\eta_e\rvert < 2.47$ excluding $1.37 < \lvert\eta_e\rvert < 1.52$	$\lvert\eta_\mu\rvert < 2.4$	$\lvert\eta_e\rvert < 2.47$ excluding $1.37 < \lvert\eta_e\rvert < 1.52$	$\lvert\eta_\mu\rvert < 2.4$
Boson mass cut	$m_T > 40$ GeV	$m_T > 40$ GeV	$m_{ee} > 40$ GeV	$m_{\mu\mu} > 40$ GeV
Photon cut	$E_T^\gamma > 15$ GeV $\lvert\eta_\gamma\rvert < 2.47$ (excluding $1.37 < \lvert\eta_\gamma\rvert < 1.52$) $\Delta R(l,\gamma) > 0.7$ photon isolation fraction $\varepsilon_h^p < 0.5$			
Total Cross Section				
Photon cut	$E_T^\gamma > 10$ GeV $\Delta R(l,\gamma) > 0.5$ photon isolation fraction $\varepsilon_h^p < 0.5$			

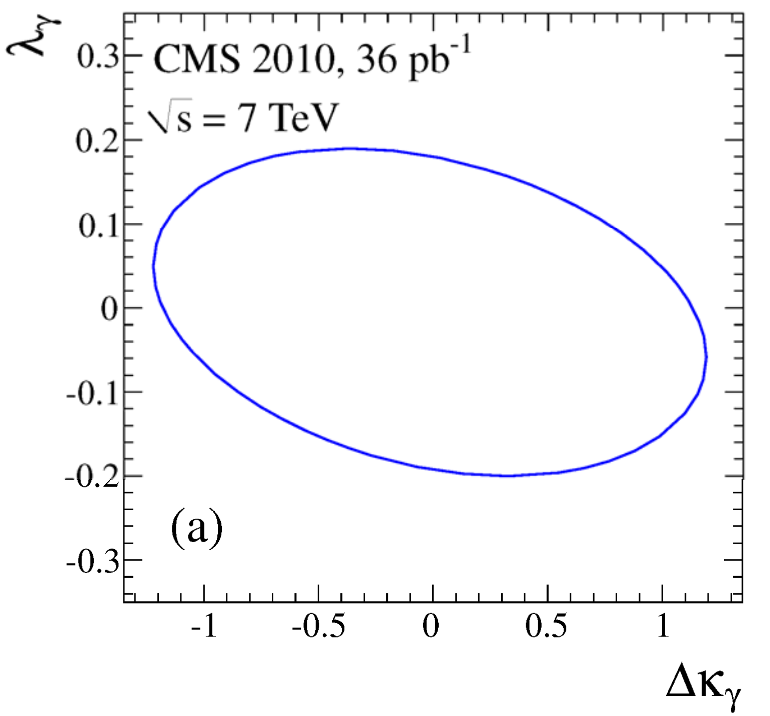
	experimental measurement	SM model prediction
	$\sigma^{fid}[pb]$(measured)	$\sigma^{fid}[pb]$(predicted)
$pp \to e\nu\gamma$	$5.1 \pm 0.7(stat) \pm 0.9(syst) \pm 0.6(lumi)$	4.6 ± 0.3(syst)
$pp \to \mu\nu\gamma$	$4.2 \pm 0.6(stat) \pm 0.7(syst) \pm 0.5(lumi)$	4.9 ± 0.3(syst)
$pp \to e^+e^-\gamma$	$2.0 \pm 0.6(stat) \pm 0.5(syst) \pm 0.2(lumi)$	1.7 ± 0.1(syst)
$pp \to \mu^+\mu^-\gamma$	$1.3 \pm 0.3(stat) \pm 0.3(syst) \pm 0.1(lumi)$	1.7 ± 0.1(syst)
	$\sigma^{total}[pb]$(measured)	$\sigma^{total}[pb]$(predicted)
$pp \to e\nu\gamma$	$73.9 \pm 10.5(stat) \pm 14.6(syst) \pm 8.1(lumi)$	69.0 ± 4.6(syst)
$pp \to \mu\nu\gamma$	$58.6 \pm 8.2(stat) \pm 11.3(syst) \pm 6.4(lumi)$	69.0 ± 4.6(syst)
$pp \to e^+e^-\gamma$	$16.4 \pm 4.5(stat) \pm 4.3(syst) \pm 1.8(lumi)$	13.8 ± 0.9(syst)
$pp \to \mu^+\mu^-\gamma$	$10.6 \pm 2.6(stat) \pm 2.5(syst) \pm 1.2(lumi)$	13.8 ± 0.9(syst)

Limits on Anomalous TGCs

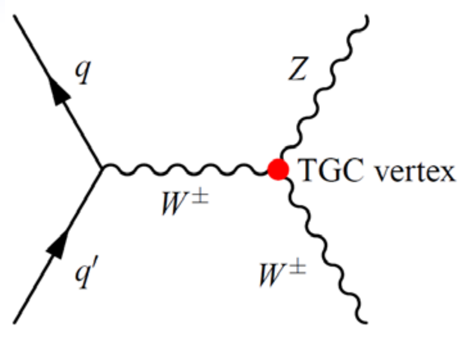
- CMS Results (CMS-EWK-10-008):
  - $\sigma(pp \rightarrow W\gamma) = 55.9 \pm 5.0(stat) \pm 5.0(stat) \pm 6.1(lumi)$
  - $\sigma(pp \rightarrow Z\gamma) = 9.3 \pm 1.0(stat) \pm 0.6(stat) \pm 1.0(lumi)$
  - For $E_T^\gamma > 10$ GeV, $\Delta R(\ell,\gamma) > 0.7$

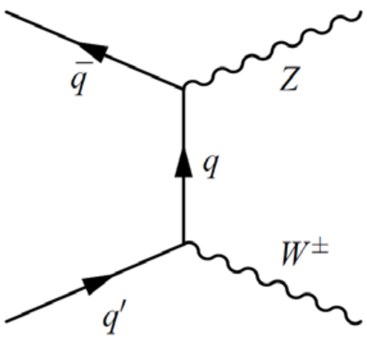






WZ → $\ell\nu\ \ell\ell$ Observation

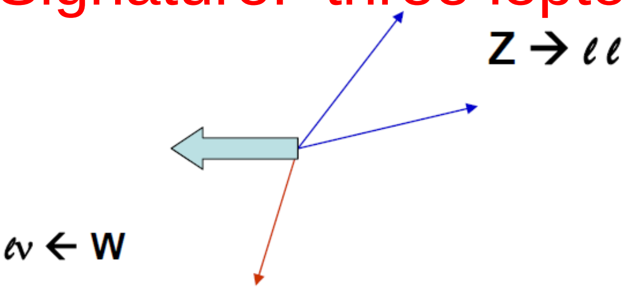




Motivation:

- Test Electroweak model
- WZ cross section measurement
- Sensitive to ZWW coupling

Signature: three leptons + MET



Major backgrounds:

ZZ → $\ell\ell\ell\ell$	one lepton escape the detection
tt → $\ell\ell$ + X	non-isolated lep. from b decay
Z+X → $\ell\ell$+X	jet / γ fake lepton

WZ Leptonic Channels	**Inclusive**	**μμμ**	**μμe**	**μee**	**eee**
Exact 3 leptons	8	4	2	0	2
$\lvert M_{\ell\ell} - M_Z \rvert$<20 GeV	4	2	1	0	1
Pt(3rd lep.)> 20 GeV	3	2	1	0	0
Mt(3rd lep., MET)>20 GeV	3	2	1	0	0
MET > 20 GeV	**3**	**2**	**1**	**0**	**0**

35 pb^{-1} int. lumi.

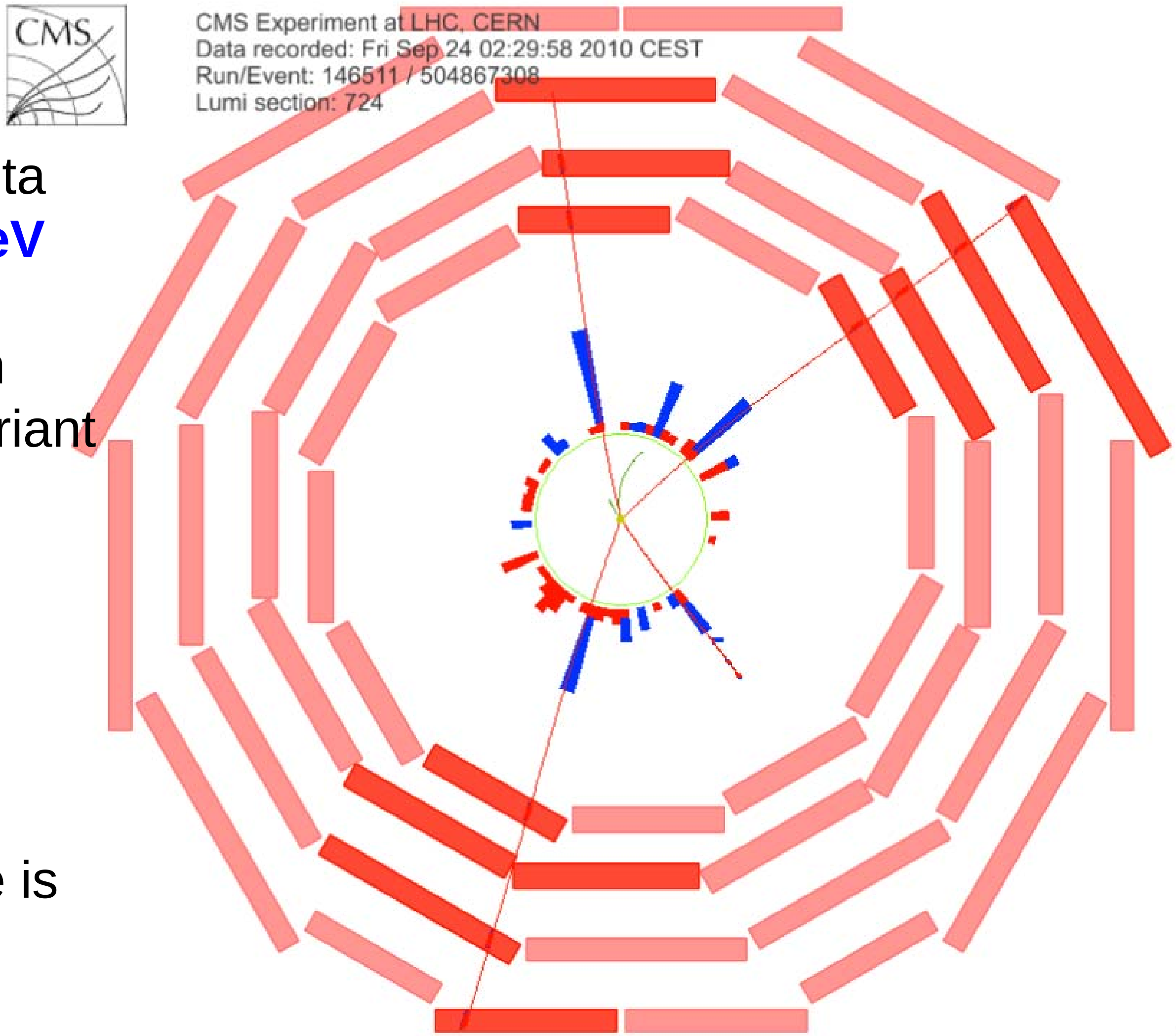
ATLAS Data:
3 candidates

MC Expectations:

WZ signal : 1.4

Bkgd: 0.14

The First Golden ZZ →$\mu^+\mu^-\mu^+\mu^-$ candidate in CMS



✓ Muons transverse momenta are **48.1, 43.4, 25.9, 19.6 GeV**

✓ Two pairs of opposite sign muons separately have invariant masses around Z mass: **92.1** and **92.2 GeV.**

✓ The invariant mass of the 4 muons is **201.7 GeV.**

✓ The expected ZZ→4ℓ rate is 0.19 for 35 pb^{-1}

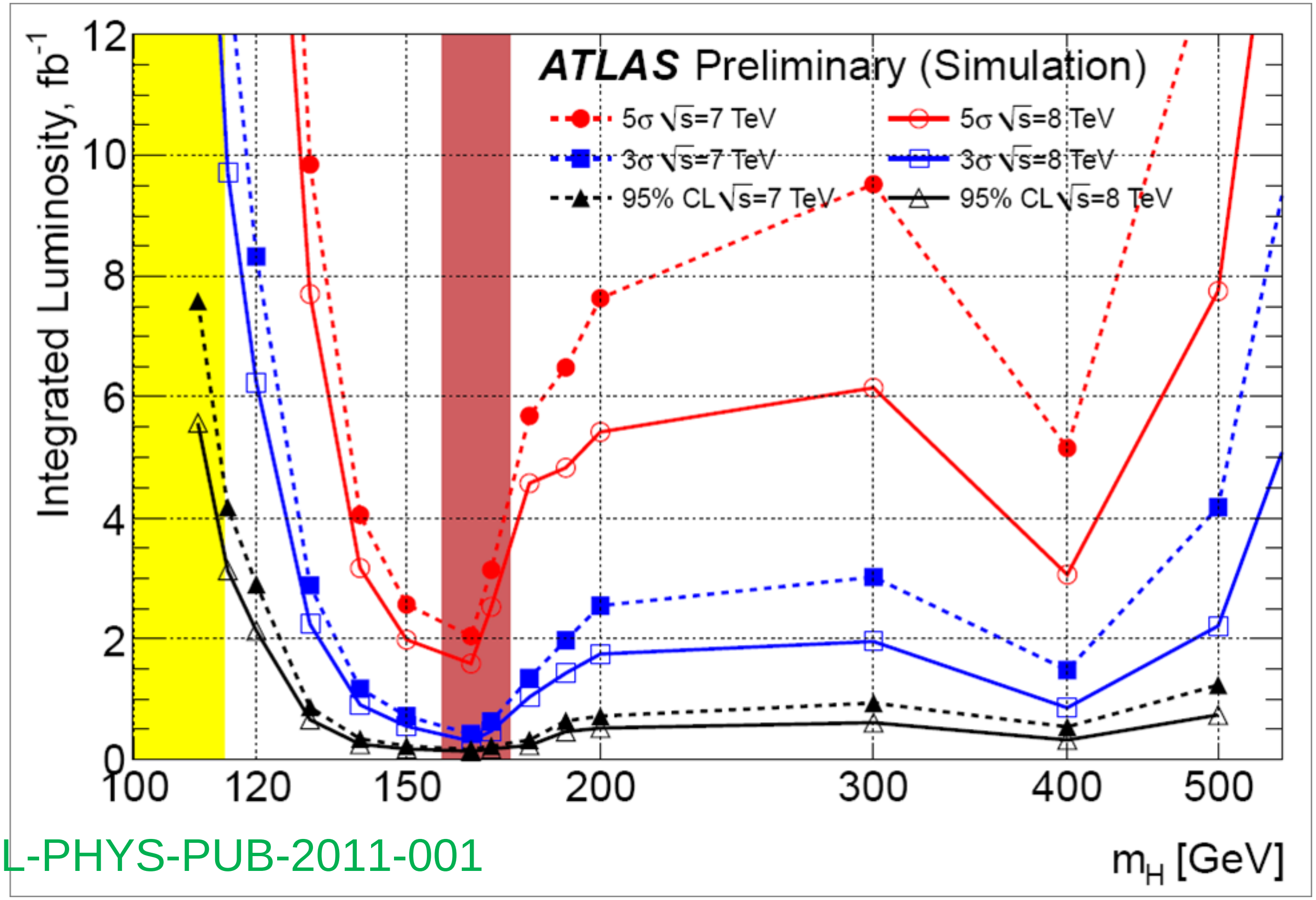
Prospect in 2011-2012

- LHC is expected to deliver ~ 5 fb^{-1} in 2011-2012
- The estimated Diboson events (leptonic channels) are:
  - ~19300 $W\gamma \rightarrow \ell\nu\gamma$ with ~ 7950 background events
  - ~ 5820 $Z\gamma \rightarrow \ell\ell\gamma$ with ~ 1020 background events
  - ~ 1050 $WW \rightarrow \ell\nu\ell\nu$ with ~ 240 background events
  - ~ 200 $WZ \rightarrow \ell\nu\ell\ell$ with ~ 20 background events
  - ~ 27 $ZZ \rightarrow \ell\ell\ell\ell$ with ~ 2 background events
- Multivariate analysis techniques (ANN, BDT etc.) will be applied to improve signal acceptance and to reduce background contamination.
- Precision measurements of all Diboson cross sections
- Sensitivity to the anomalous couplings at a level of $O(10^{-2})$.

- For vector-boson-fusion WW, we expect to observe about 26 $WW \rightarrow \ell\nu\ell\nu$ events associated with two tagged jets in the forward and backward regions.

Higgs Discovery Potential Through Diboson Final States ($\gamma\gamma$, WW, ZZ)

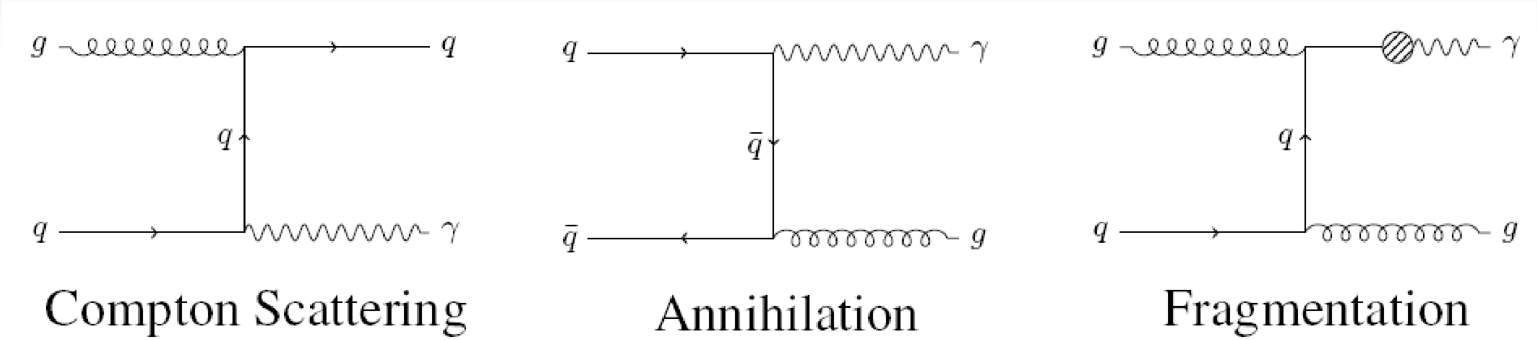
For about 3 fb^{-1} integrated luminosity, we can observe a 3σ evidence for Higgs mass greater than 130 GeV if the Higgs boson exists in this range.



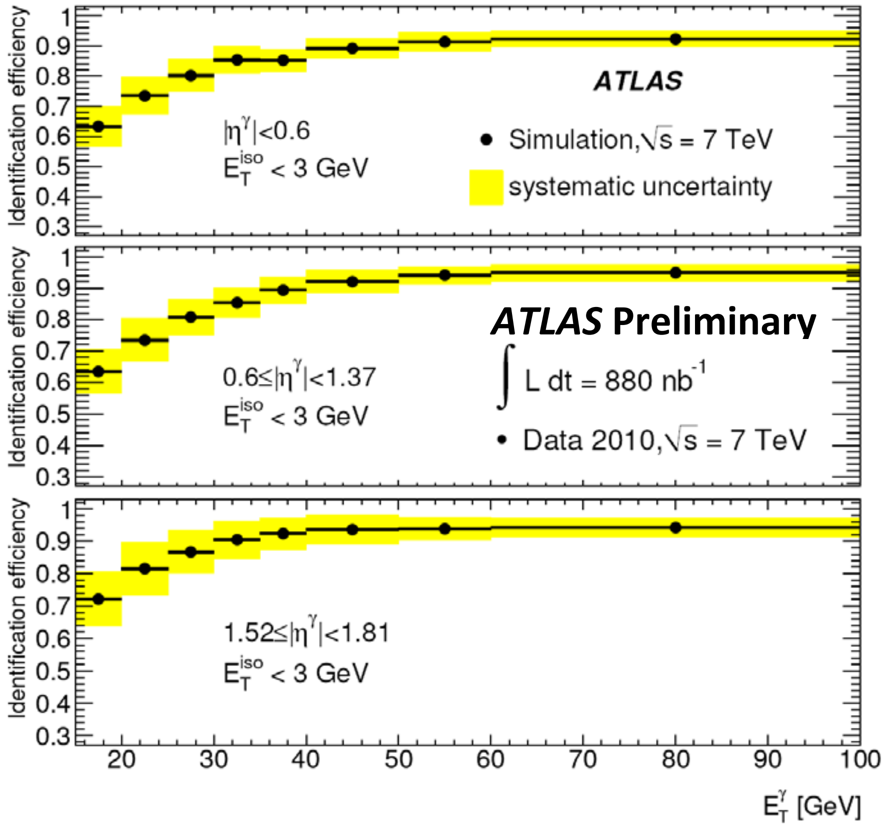
Ref: ATL-PHYS-PUB-2011-001

Backup Slides

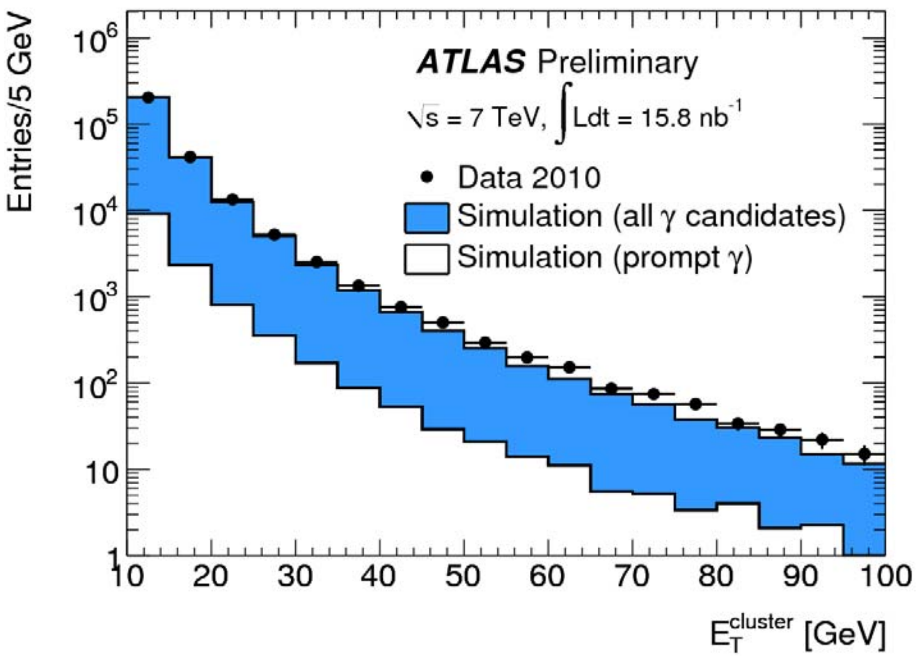
Photons



g
q
q
q
γ
Compton Scattering
q
γ
q̄
q̄
g
Annihilation
g
γ
q
q
g
Fragmentation

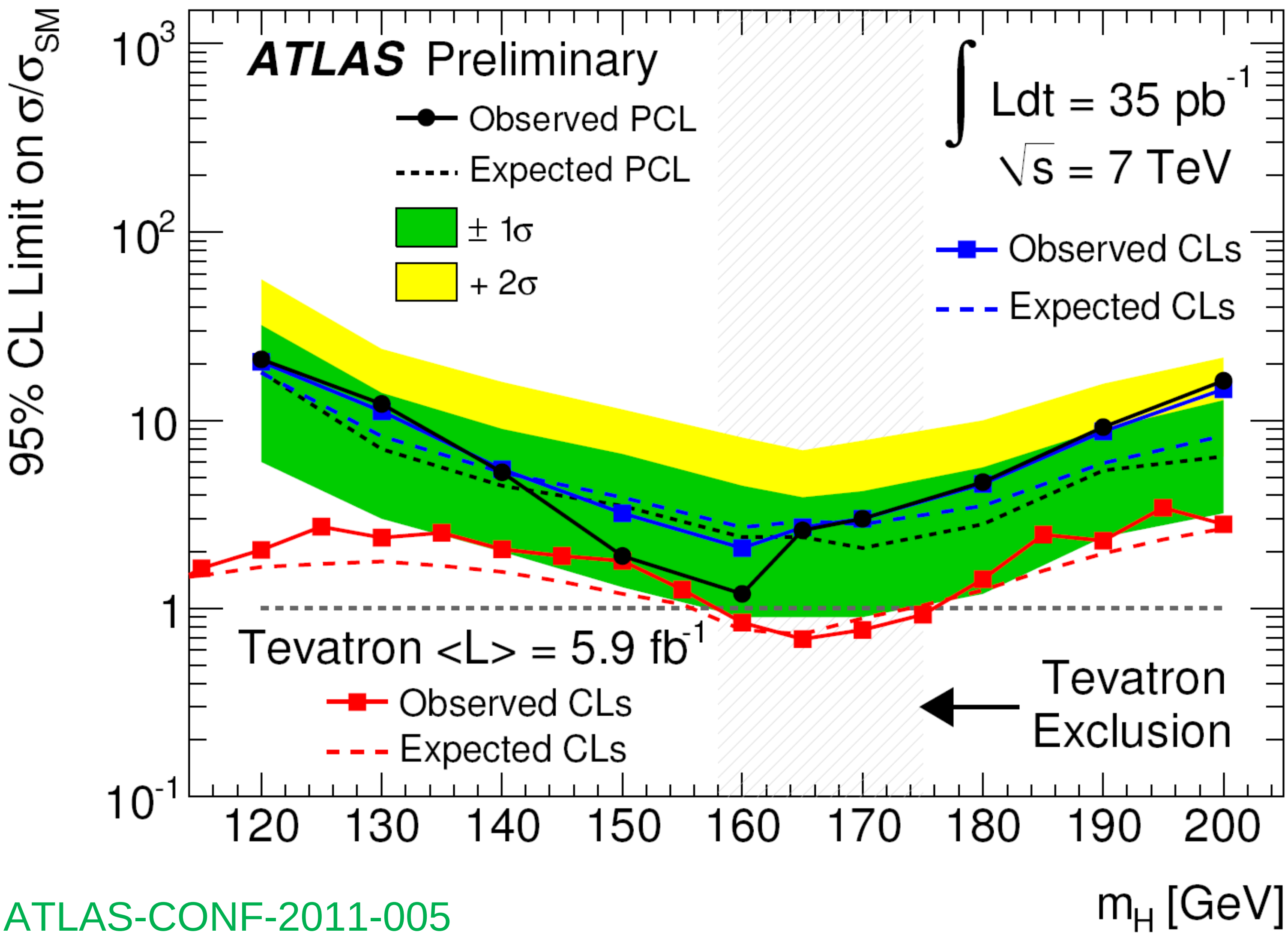


Identification efficiency
ATLAS
|η^γ|<0.6
E_T^iso < 3 GeV
Simulation,√s = 7 TeV
systematic uncertainty
ATLAS Preliminary
0.6≤|η^γ|<1.37
E_T^iso < 3 GeV
∫ L dt = 880 nb^-1
Data 2010,√s = 7 TeV
1.52≤|η^γ|<1.81
E_T^iso < 3 GeV
E_T^γ [GeV]



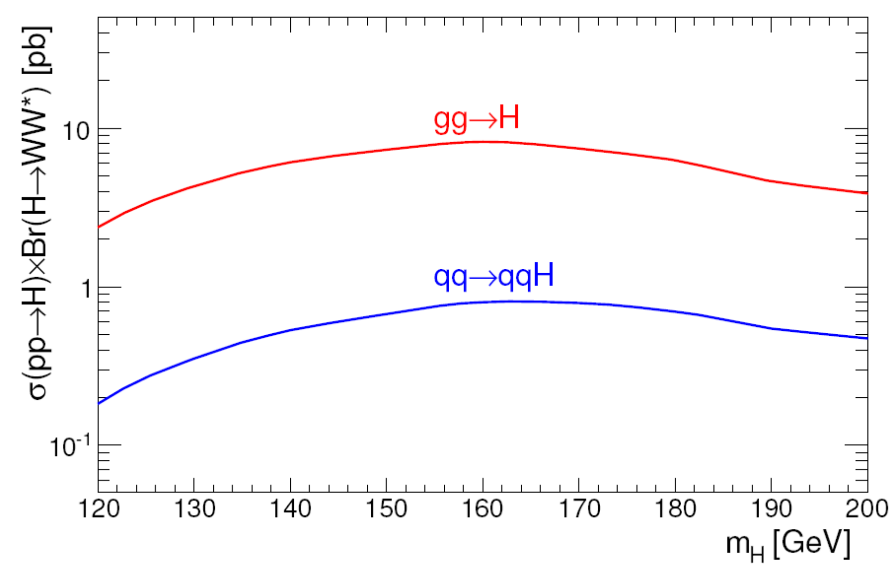
Entries/5 GeV
ATLAS Preliminary
√s = 7 TeV, ∫Ldt = 15.8 nb^-1
Data 2010
Simulation (all γ candidates)
Simulation (prompt γ)
E_T^cluster [GeV]

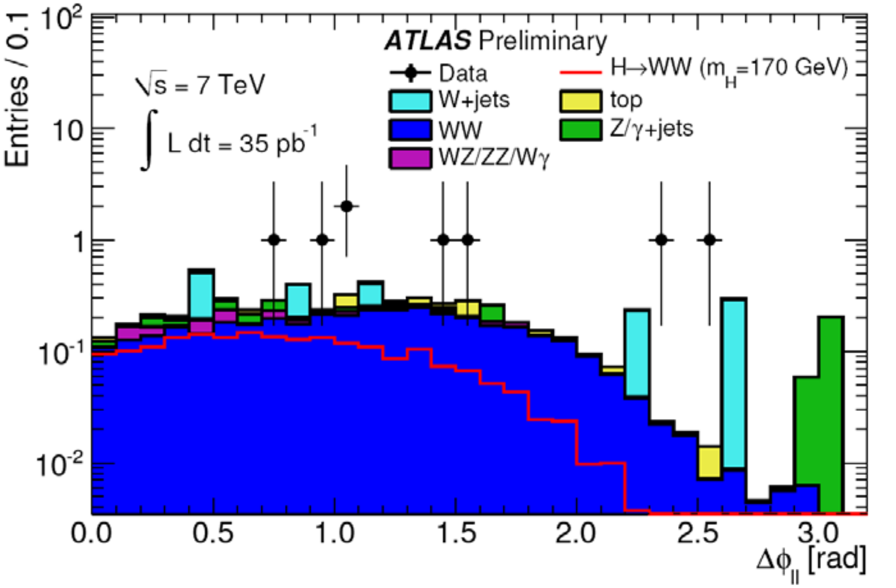
Higgs Discovery Potential



Ref: ATLAS-CONF-2011-005

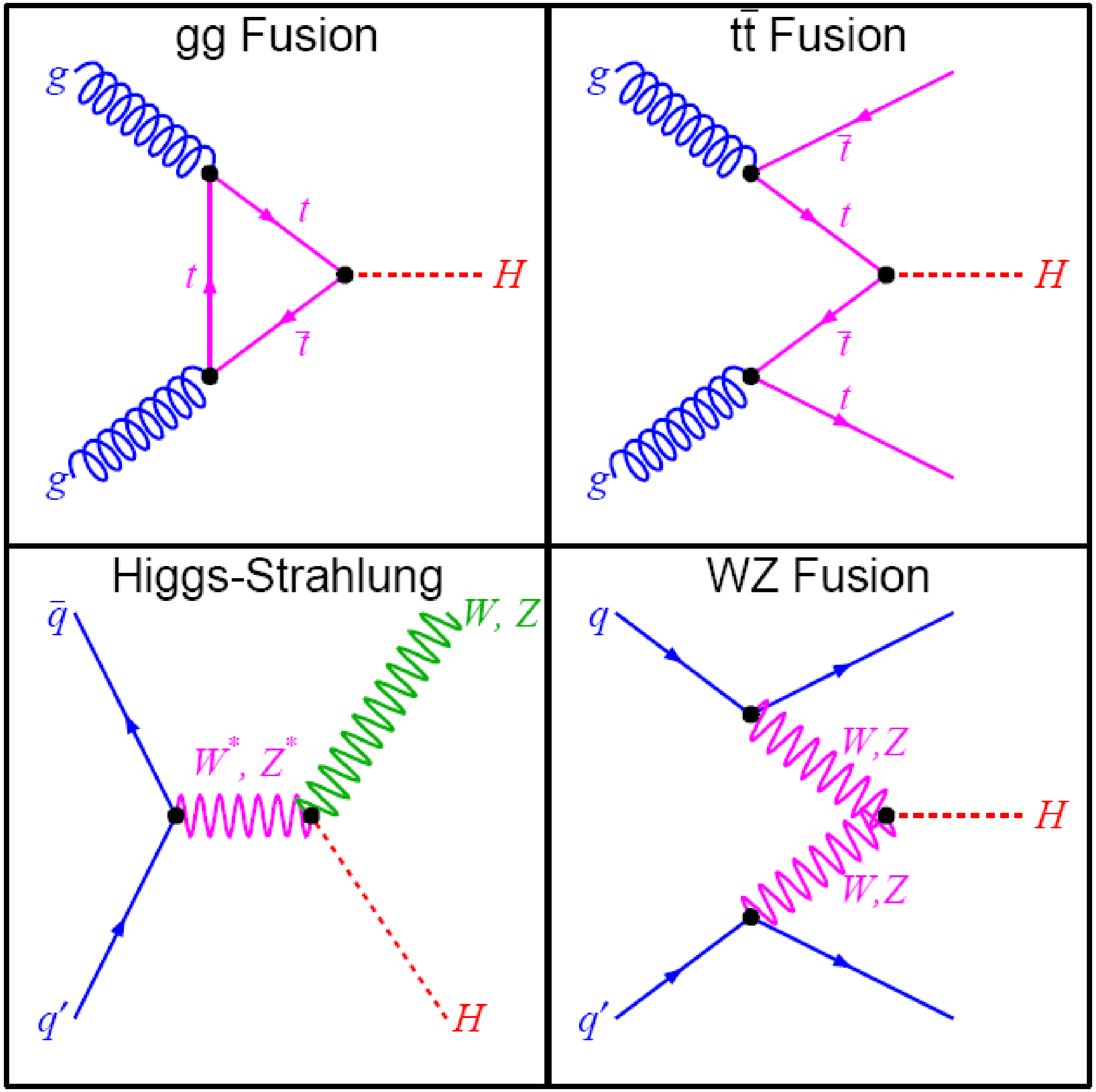
Higgs Discovery Potential



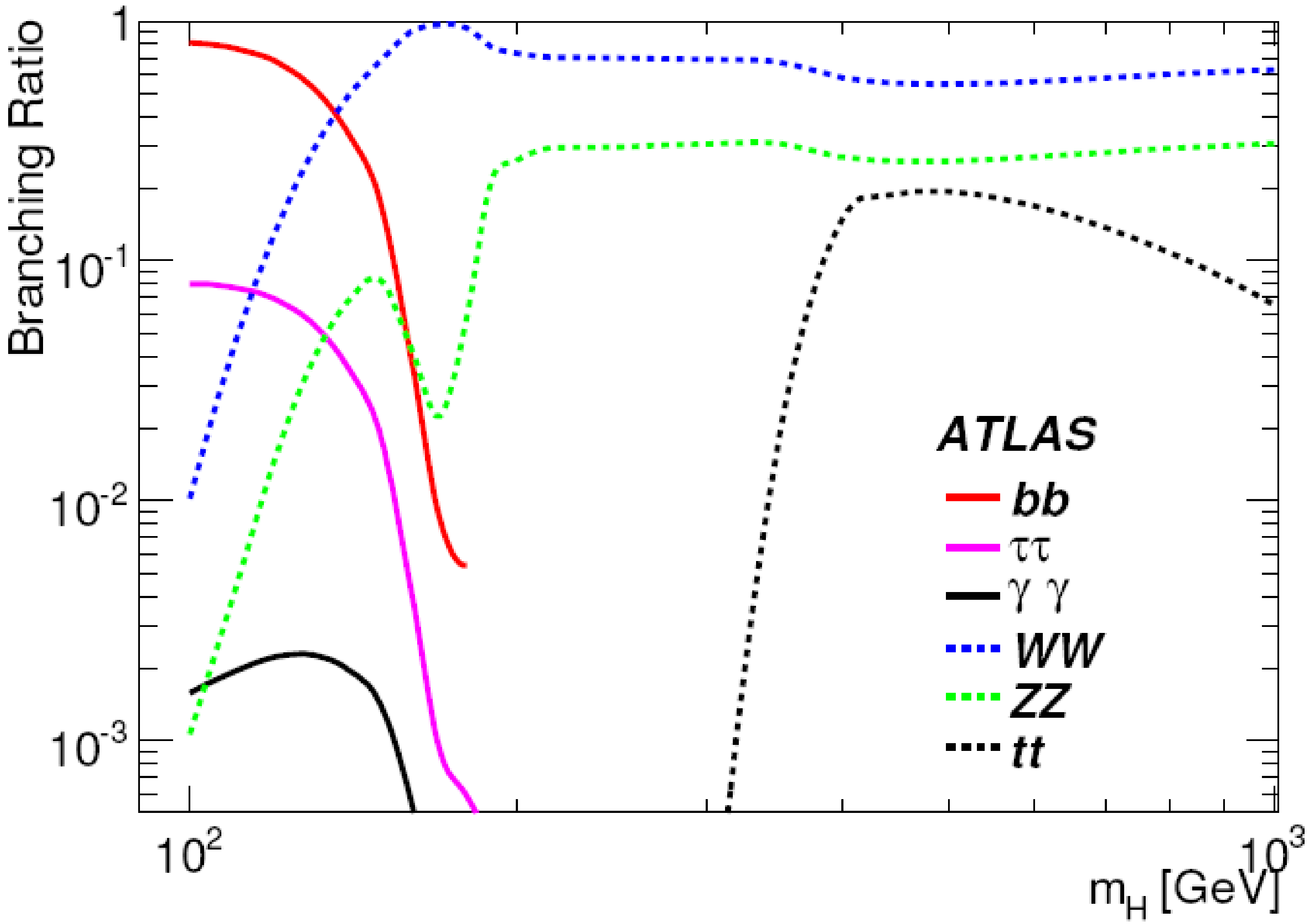


m_H [GeV]	Jet bin	Signal	Total Bkg.	Observed
	$H+0j$	0.15	0.87	1
120	$H+1j$	0.05	1.05	1
	$H+2j$	0.01	0.00	0
	$H+0j$	0.34	0.97	2
130	$H+1j$	0.13	1.07	1
	$H+2j$	0.03	0.01	0
	$H+0j$	0.56	1.07	2
140	$H+1j$	0.22	1.02	0
	$H+2j$	0.03	0.03	0
	$H+0j$	0.78	1.12	1
150	$H+1j$	0.32	1.03	0
	$H+2j$	0.04	0.03	0
	$H+0j$	1.11	1.09	1
160	$H+1j$	0.50	0.93	0
	$H+2j$	0.06	0.03	0
	$H+0j$	1.13	1.03	2
165	$H+1j$	0.50	0.93	0
	$H+2j$	0.06	0.02	0
	$H+0j$	1.26	1.70	3
170	$H+1j$	0.6	1.26	1
	$H+2j$	0.06	0.02	0
	$H+0j$	0.85	1.33	3
180	$H+1j$	0.42	1.25	1
	$H+2j$	0.05	0.01	0
	$H+0j$	0.45	0.97	3
190	$H+1j$	0.24	1.12	1
	$H+2j$	0.03	0.01	0
	$H+0j$	0.29	0.72	3
200	$H+1j$	0.15	0.85	1
	$H+2j$	0.02	0.01	0

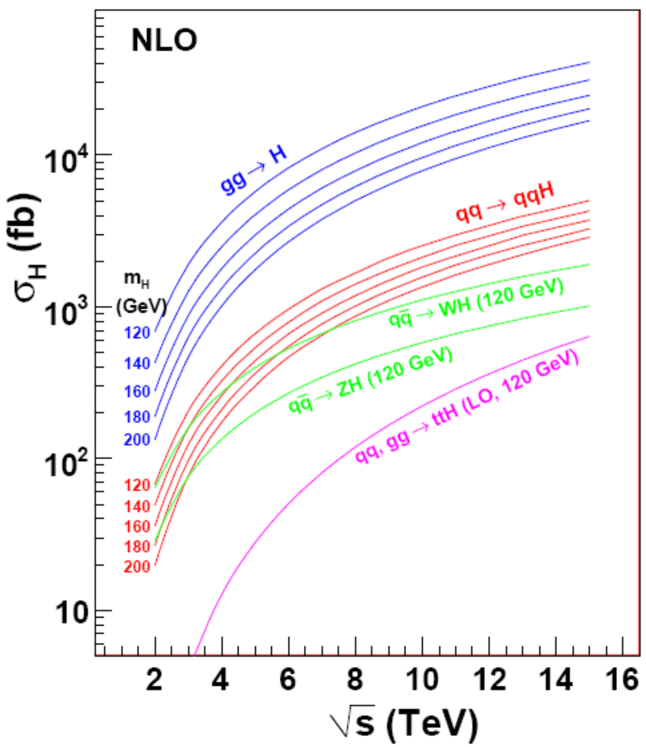
Higgs Discovery Potential

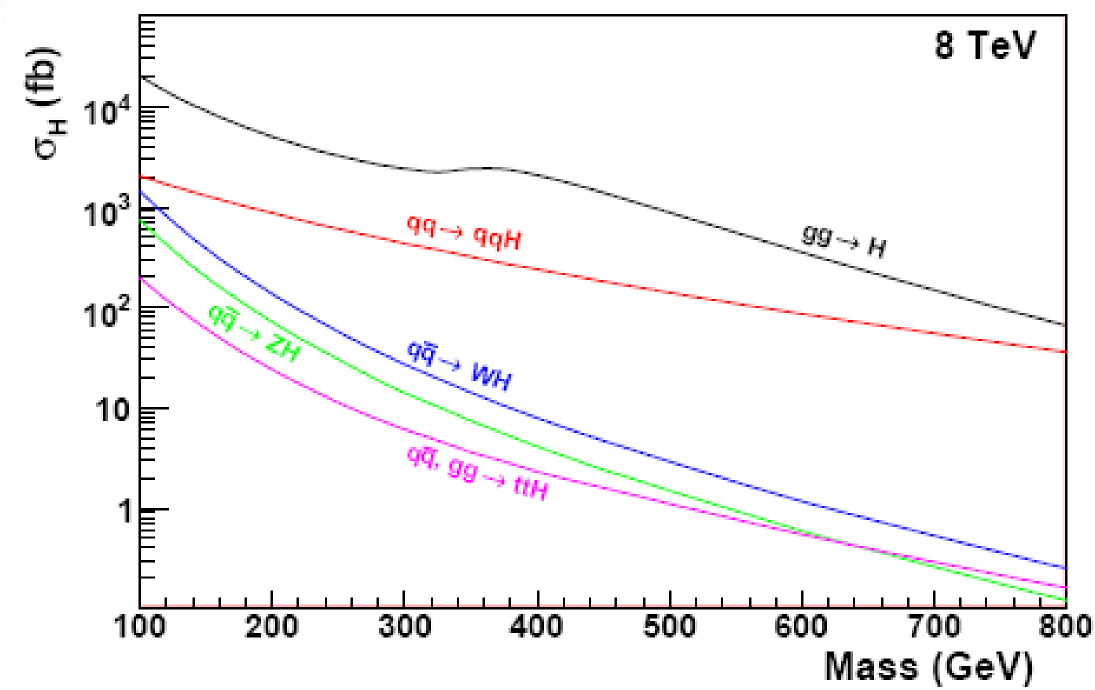


Higgs Discovery Potential



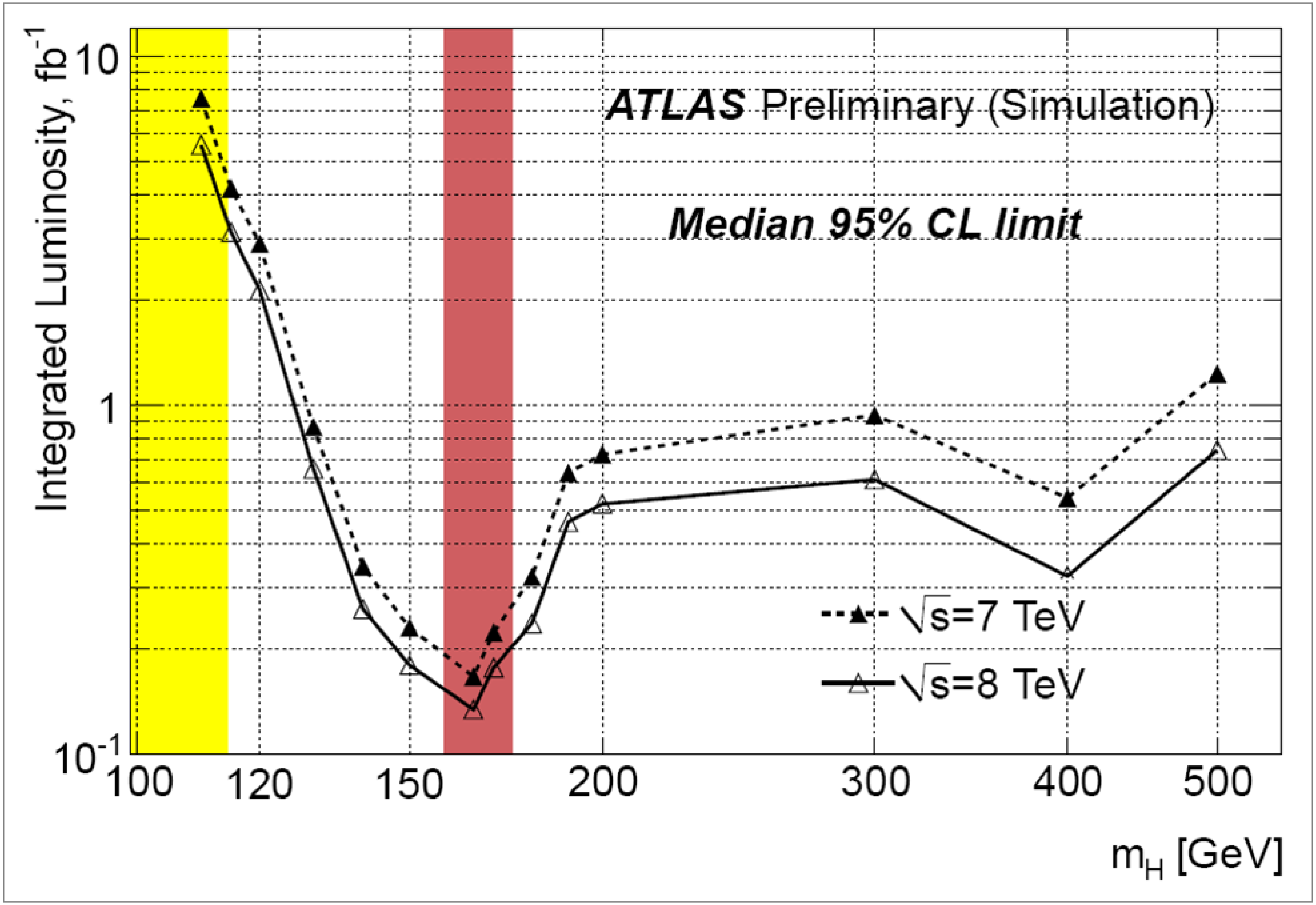
Higgs Discovery Potential



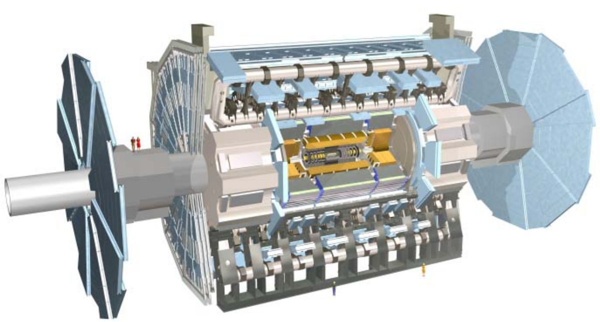


√s (TeV)	Tevatron	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Order
SM Higgs @ 120 GeV (PROC = 111, 211, 91/96, 101, 190)																
gg → H	669.3	705.4	1,940	3,687	5,858	8,385	11,217	14,315	17,645	21,183	24,907	28,799	32,845	37,032	41,348	NLO
qq → qqH	72.29	65.95	202.6	405.9	665.2	969.9	1,327	1,715	2,130	2,554	3,074	3,555	4,082	4,603	5,156	NLO
qq → W^+H	78.25	47.81	112.7	186.7	265.5	347.4	431.8	518.2	604.2	692.0	783.1	872.4	964.5	1,055	1,148	NLO
qq → W^-H	78.25	17.36	48.01	87.68	133.3	183.4	236.8	292.6	350.9	411.4	473.3	536.5	600.4	665.3	731.5	NLO
qq → ZH	95.41	30.24	79.13	139.0	205.8	277.0	351.3	428.9	507.8	589.8	674.5	752.3	844.0	932.6	1,021	NLO
qq/gg → ttH	6.294	0.538	4.345	13.62	29.20	51.55	81.10	118.18	162.5	214.4	274.8	341.9	418.6	501.8	594.2	LO
SM Higgs @ 160 GeV (PROC = 111, 211)																
gg → H	252.4	267.7	834.0	1,701	2,834	4,199	5,768	7,520	9,435	11,497	13,694	16,014	18,447	20,986	23,622	NLO
qq → qqH	38.51	34.43	119.9	256.1	437.9	658.4	918.0	1,202	1,517	1,830	2,204	2,572	3,000	3,397	3,845	NLO

Higgs Discovery Potential



Data, Trigger, Physics Objects



GRL (35.2 pb^{-1})

Trigger:

Single e with E_T > 15 GeV
Single m with p_T > 13 GeV
Efficiency plateau $E_T(p_T)$ > 20 GeV
Dilepton ε(data)/ε(MC) = 1.0 (σ_{syst} < 0.1%)

Primary vertex:

Vertex with max. sum track p_T^2
N_{track} > = 3 (with p_T > 150 MeV)
Two leptons from primary vertex
MC pile-up reweighted to reproduce data

'RobusterTight' electron

E_T > 20 GeV; $|\eta|$ < 2.5, (remove [1.37--1.52])
Isolation: Sum $E_T{}^i{}_{Cone=0.3}$ < 6 GeV
d0/σd0 < 10; |z0| < 10 mm
ε(data)/ε(MC) = 0.97 (with σ_{syst} ~ 5.3%)

'Combined' Muon:

p_T > 20 GeV; $|\eta|$ < 2.4
p_T^{MS} > 10 GeV; | (p_T^{MS} – p_T^{ID})/ p_T^{ID} | < 0.5
Isolation: (Sum $p_T{}^i{}_{Cone=0.2}$)/ p_T^{μ}< 0.1
d0/σd0 < 10; |z0| < 10 mm
ε(data)/ε(MC) = 0.98 (with σ_{syst} ~ 1.0%)

Jet:

Anti-Kt, R = 0.4; $|\eta|$ < 3.0; p_T > 20 GeV
Discarded if ΔR (jet, electron) < 0.2
Jet veto SF = 0.97 (with σ_{syst} ~ 6.0%)

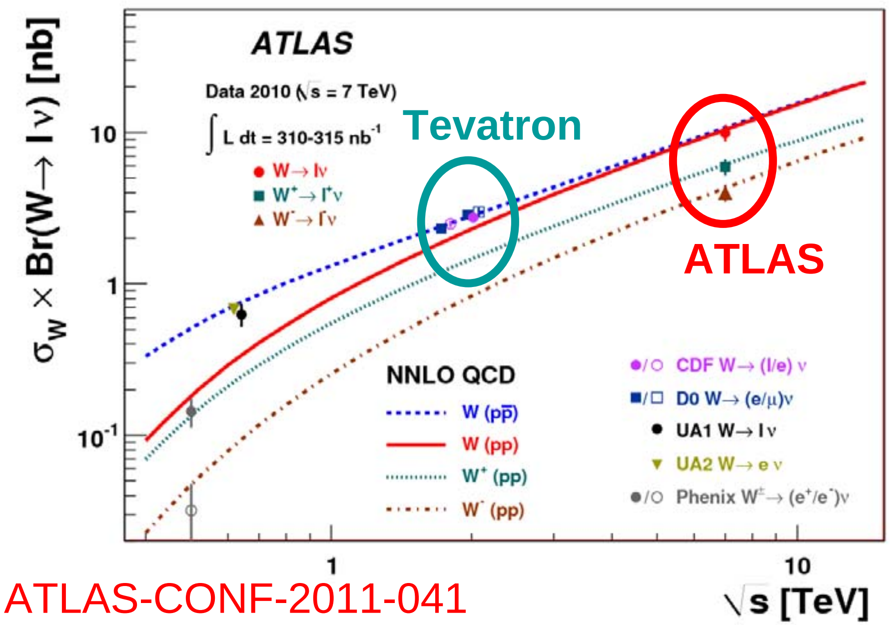
E_T^{miss}:

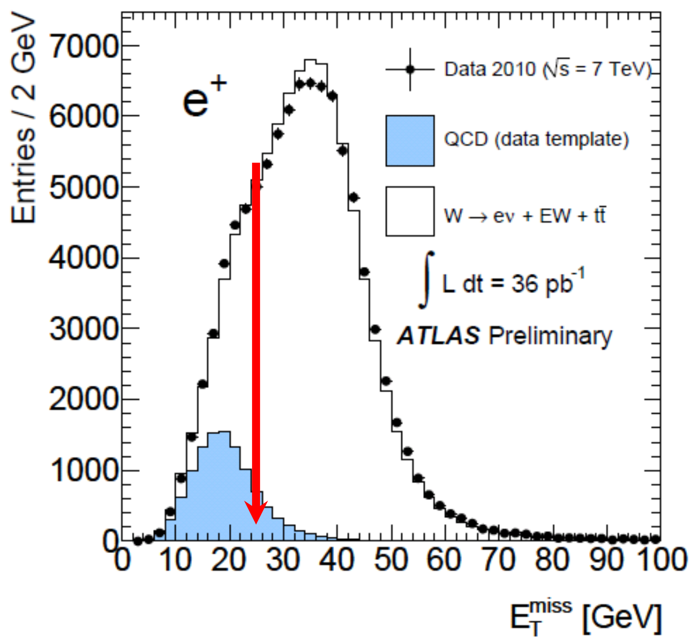
MET_LocHadTopo ($|\eta|$<4.5), account for μ's

$$E_{T,\,\mathrm{Rel}}^{miss} = \begin{cases} E_T^{miss} \times \sin\left(\Delta\phi_{\ell,j}\right) & \text{if } \Delta\phi < \pi/2 \\ E_T^{miss} & \text{if } \Delta\phi \geq \pi/2 \end{cases}$$

Inclusive W → ℓ ν cross section

JHEP 12 (2010) 060





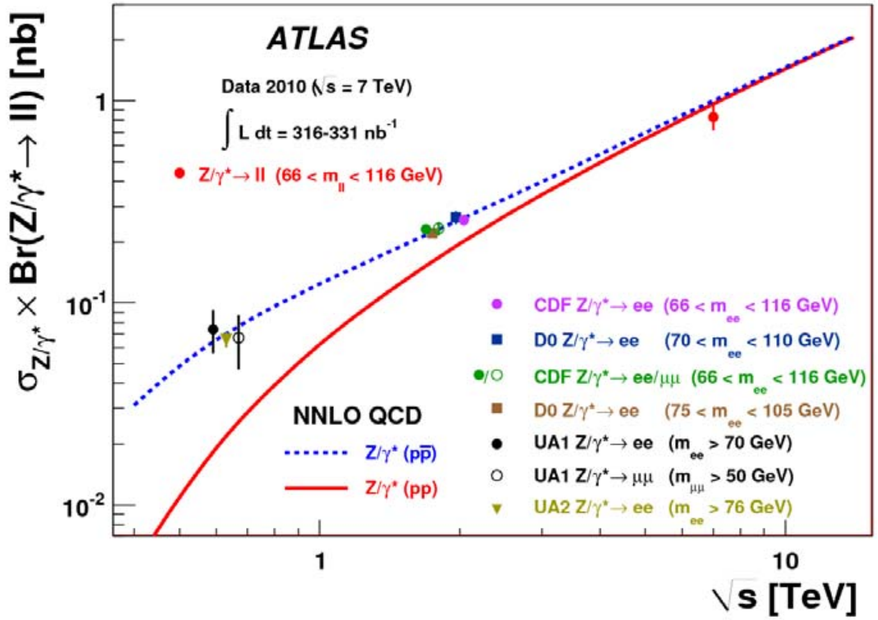
ATLAS-CONF-2011-041

	$\sigma_{tot} \times$ BR (W→lν) 35pb^{-1}
W → eν	10.551 ± 0.032 (stat) ± 0.300 (sys) ± 0.359 (lumi) ± 0.316 (acc) [nb]
W → μν	10.322 ± 0.030 (stat) ± 0.249 (sys) ± 0.377 (lumi) ± 0.310(acc) [nb]
W → lν	10.391 ± 0.022 (stat) ± 0.238 (sys) ± 0.353 (lumi) ± 0.312(acc) [nb]

Standard Model predictions including NNLO order QCD corrections $\sigma^{NNLO}_{tot} = 10.46 \pm 0.52$ [nb]

Inclusive Z/γ*→ll cross section

JHEP 12 (2010) 060



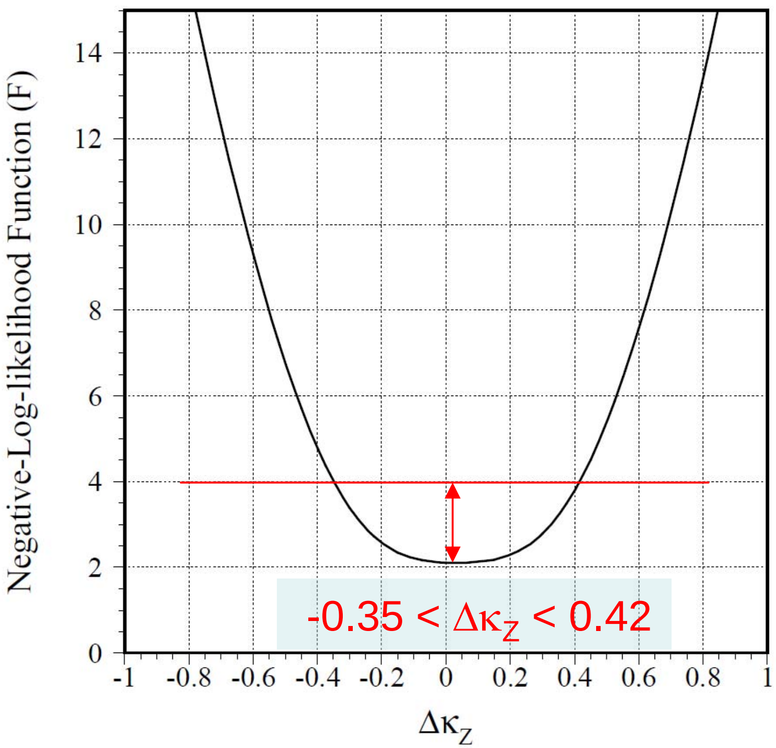
ATLAS-CONF-2011-041

	$\sigma_{tot} \times$ BR(Z→ll), 66 GeV< M(ll)< 116 GeV 35pb^{-1}
Z → ee	Central 0.972 ± 0.010 (stat) ± 0.034 (sys) ± 0.033 (lumi) ± 0.038 (acc) [nb] Forward 0.903 ± 0.022 (stat) ± 0.087 (sys) ± 0.033 (lumi) ± 0.035 (acc) [nb]
Z → μμ	0.941 ± 0.008 (stat) ± 0.011 (sys) ± 0.032 (lumi) ± 0.037 (acc)[nb]
Z → ll	0.945 ± 0.006 (stat) ± 0.011 (sys) ± 0.032 (lumi) ± 0.038 (acc)[nb]

Standard Model predictions including NNLO order QCD corrections σ^{NNLO}_{tot} = 0.96 ± 0.05 [nb]

Methods to Determine 95% C.L. Limits

- Log-likelihood Function (F_{min} + 1.92)

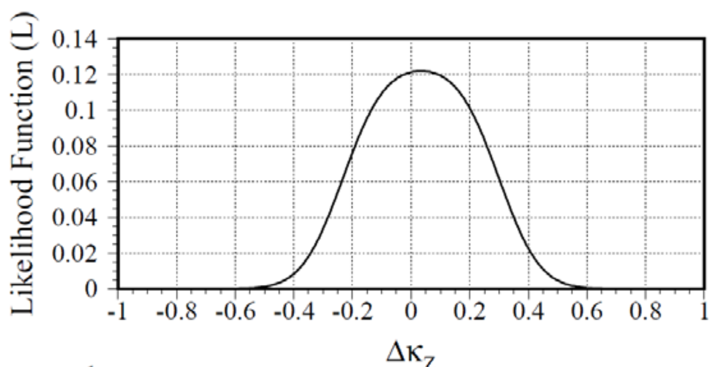


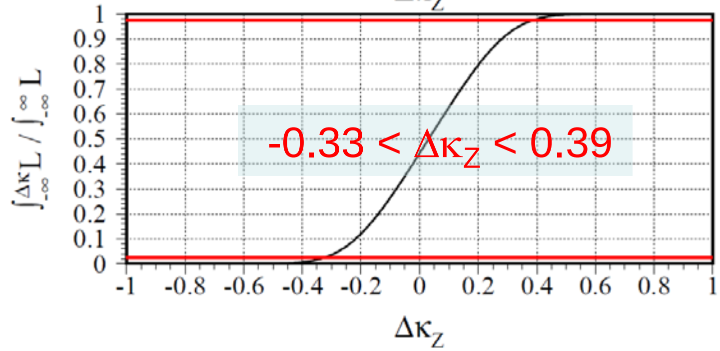
➔95% C.L. Limits determined from two methods are consistent.

- Bayesian Estimator

$$CL = \frac{\int_{\text{low limit}}^{\text{high limit}} L}{\int_{-\infty}^{+\infty} L} = 95\%$$

$$(1 - CL)/2 = \frac{\int_{-\infty}^{\text{low limit}} L}{\int_{-\infty}^{+\infty} L} = 2.5\%$$





Expected Diboson Detection Sensitivities at LHC

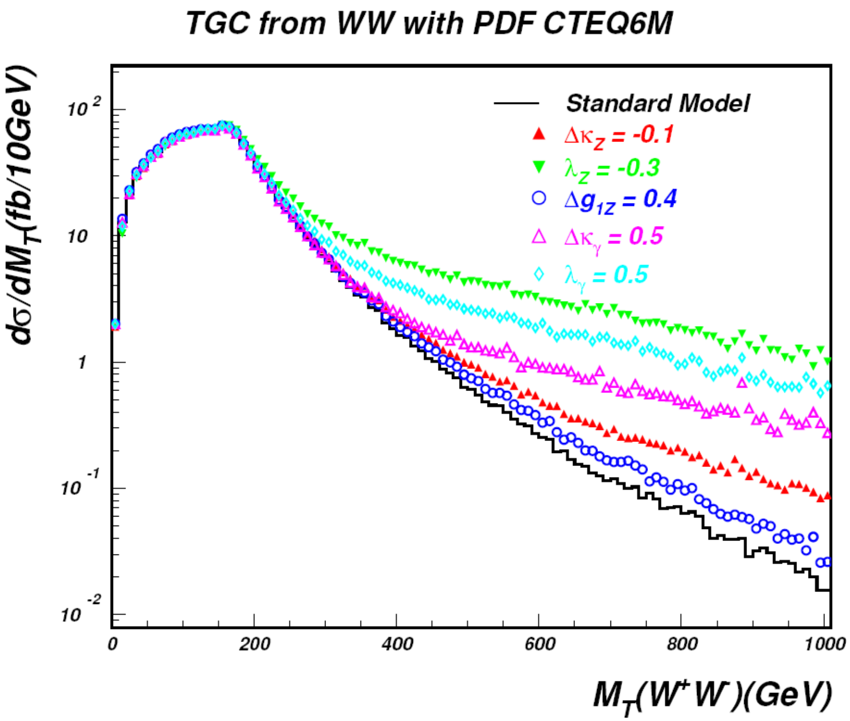
ATLAS Collab., arXiv:0901.0512v4, CERN-OPEN-2008-020 (2009)

➔ Summary of Diboson signal, backgrounds and sensitivities for 1 fb^{-1} at 14 TeV

Diboson mode	Signal	Background	Signal eff.	σ_{stat}^{signal}	p-value	Sig.
$W^+W^- \to e^\pm \nu \mu^\mp \nu$	347±3	64±5	12.6% (BDT)	5.4%	3.6×10^{-166}	27.4
$W^+W^- \to \mu^+ \nu \mu^- \nu$	70±1	17±2	5.2% (BDT)	12.0%	8.8×10^{-30}	11.3
$W^+W^- \to e^+ \nu e^- \nu$	52±1	11±2	4.9% (BDT)	13.9%	1.9×10^{-24}	10.1
$W^+W^- \to \ell^+ \nu \ell^- \nu$	103 ± 3	17±2	2.0% (cuts)	9.9%	1.4×10^{-54}	15.5
$W^\pm Z \to \ell^\pm \nu \ell^+ \ell^-$	128 ± 2	16 ± 3	15.2% (BDT)	8.8%	3.0×10^{-76}	18.4
	53 ± 2	8 ± 1	6.3% (cuts)	13.7%	3.1×10^{-30}	11.4
$ZZ \to 4\ell$	17 ± 0.5	2 ± 0.2	7.7% (cuts)	24.6%	6.0×10^{-12}	6.8
$ZZ \to \ell^+ \ell^- \nu \bar{\nu}$	10 ± 0.2	5 ± 2	2.6% (cuts)	31.3%	7.7×10^{-4}	3.2
$W\gamma \to e \nu \gamma$	1604 ± 65	1180 ± 120	5.7% (BDT)	2.5%	significance > 30	
$W\gamma \to \mu \nu \gamma$	2166 ± 88	1340 ± 130	7.6% (BDT)	2.1%	significance > 30	
$Z\gamma \to e^+ e^- \gamma$	367 ± 12	187 ± 19	5.4% (BDT)	5.2%	1.2×10^{-91}	20.3
$Z\gamma \to \mu^+ \mu^- \gamma$	751 ± 23	429 ± 43	11% (BDT)	3.6%	5.9×10^{-171}	27.8

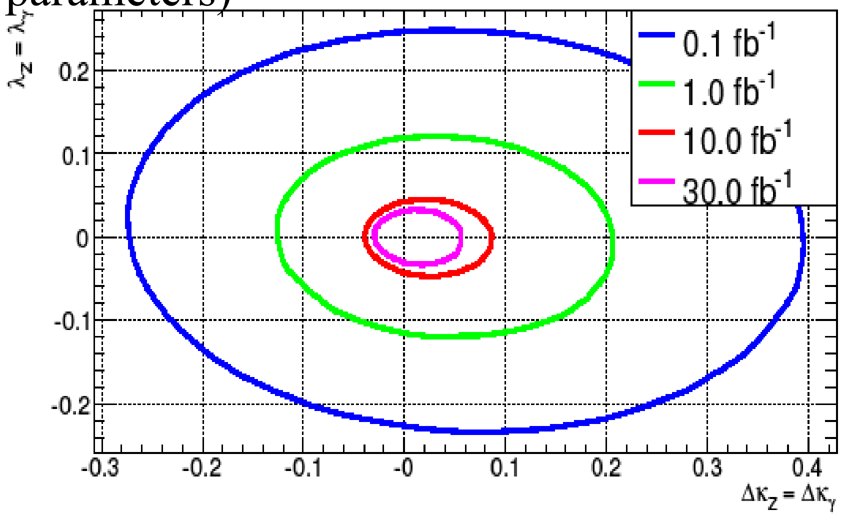
(Include 20% systematic error for significance estimation) ⇧

Anomalous TGCs in WW Analysis



"Standard" assumption:

$\lambda_Z = \lambda_\gamma$, $\Delta\kappa_Z = \Delta\kappa_\gamma$ (3 parameters)



Int. Lumi (fb^{-1})	$\Delta\kappa_Z$	λ_Z	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
0.1	[-0.242, 0.356]	[-0.206, 0.225]	[-0.741, 1.177]	[-0.476, 0.512]	[-0.564, 0.775]
1.0	[-0.117, 0.187]	[-0.108, 0.111]	[-0.355, 0.616]	[-0.240, 0.251]	[-0.259, 0.421]
10.0	[-0.035, 0.072]	[-0.040, 0.038]	[-0.149, 0.309]	[-0.088, 0.089]	[-0.074, 0.165]
30.0	[-0.026, 0.048]	[-0.028, 0.027]	[-0.149, 0.251]	[-0.056, 0.054]	[-0.052, 0.100]

ATLAS Collab., arXiv:0901.0512v4, CERN-OPEN-2008-020 (2009)

Anomalous TGCs in WZ Analysis

ATLAS Collab., arXiv:0901.0512v4, CERN-OPEN-2008-020 (2009)

Cutoff Λ = 2 TeV	$\Delta\kappa_Z$	λ_Z	Δg_1^Z
WZ (D0, 4.1fb^{-1})	[-0.376,0.686]	[-0.075,0.093]	[-0.053,0.156]
WZ (CDF, 1.9fb^{-1})	[-0.81,1.29]	[-0.14,0.15]	[-0.14,0.25]

Int. Lumi (fb^{-1})	Cutoff Λ (TeV)	$\Delta\kappa_Z$	λ_Z	Δg_1^Z
0.1	2.0	[-0.440, 0.609]	[-0.062, 0.056]	[-0.063, 0.119]
1.0	2.0	[-0.203, 0.339]	[-0.028, 0.024]	[-0.021, 0.054]
10.0	2.0	[-0.095, 0.222]	[-0.015, 0.013]	[-0.011, 0.034]
30.0	2.0	[-0.080, 0.169]	[-0.012, 0.008]	[-0.005, 0.023]
0.1	3.0	[-0.399, 0.547]	[-0.050, 0.046]	[-0.054, 0.094]
1.0	3.0	[-0.178, 0.281]	[-0.020, 0.018]	[-0.017, 0.038]
10.0	3.0	[-0.135, 0.201]	[-0.015, 0.013]	[-0.013, 0.018]
30.0	3.0	[-0.069, 0.131]	[-0.008, 0.005]	[-0.003, 0.016]

➔The sensitivity of anomalous TGCs from WZ production at LHC using 0.1 fb^{-1} integrated luminosity is comparable to that from Tevatron.

Anomalous TGCs in ZZ Analysis

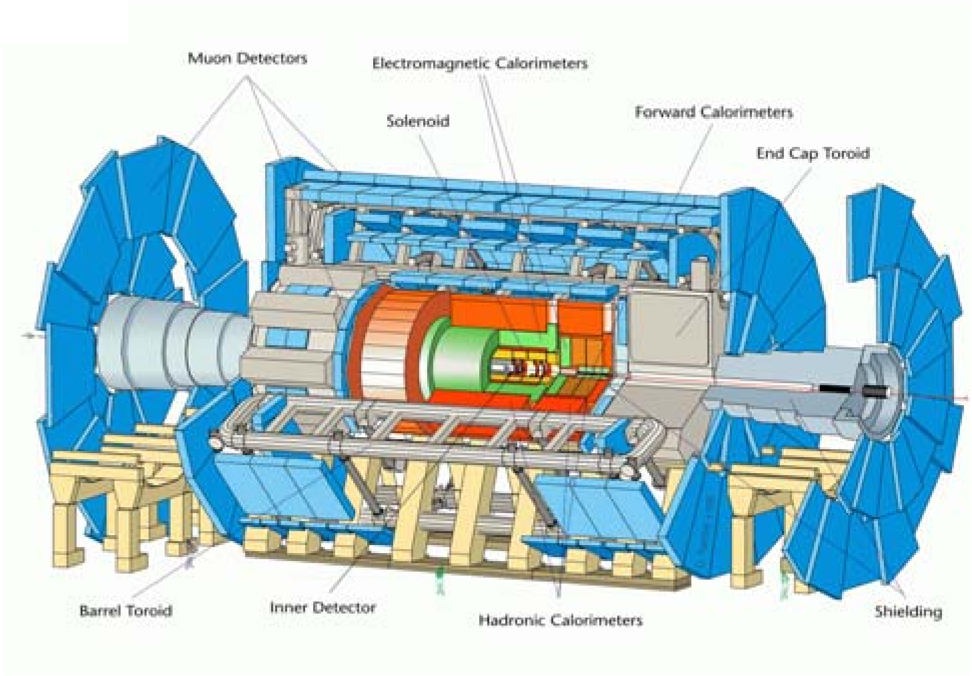
ATLAS Collab., arXiv:0901.0512v4, CERN-OPEN-2008-020 (2009)

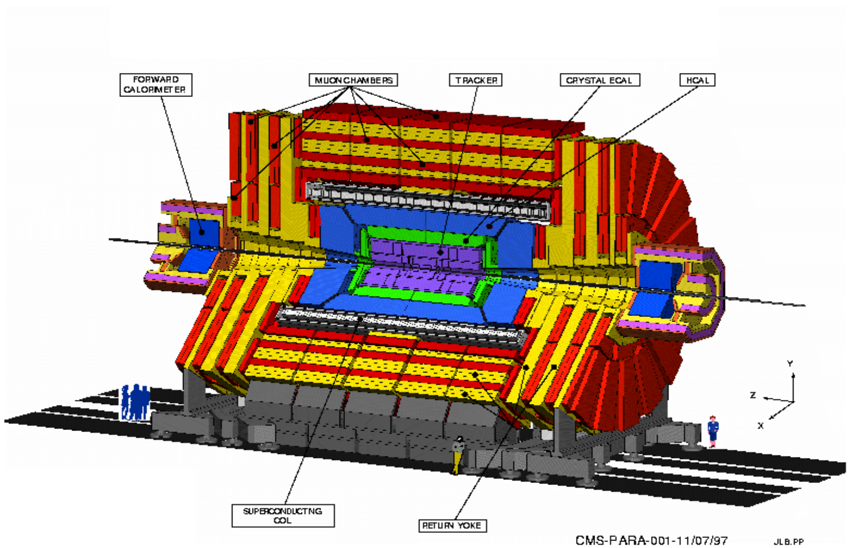
Λ = 1.2 TeV	f_4^Z	f_5^Z	f_4^γ	f_5^γ
ZZ (CDF, 1.9fb^{-1})	[-0.12,0.12]	[-0.13,0.12]	[-0.10,0.10]	[-0.11,0.11]
ZZ (D0, 1.1fb^{-1})	[-0.28,0.28]	[-0.31,0.29]	[-0.26,0.26]	[-0.30,0.28]
ZZ (LEP combined)	[-0.30,0.30]	[-0.34,0.38]	[-0.17,0.19]	[-0.32,0.36]

	Int. Lumi / fb^{-1}	f_4^Z	f_5^Z	f_4^γ	f_5^γ
$ZZ \to \ell\ell\ell\ell$	1	[−0.023, 0.023]	[−0.024, 0.024]	[−0.028, 0.028]	[−0.029, 0.028]
	10	[−0.010, 0.010]	[−0.010, 0.010]	[−0.012, 0.012]	[−0.013, 0.012]
	30	[−0.008, 0.008]	[−0.008, 0.008]	[−0.009, 0.009]	[−0.009, 0.009]
$ZZ \to \ell\ell\nu\nu$	1	[−0.024, 0.024]	[−0.024, 0.025]	[−0.029, 0.029]	[−0.030, 0.029]
	10	[−0.012, 0.012]	[−0.012, 0.012]	[−0.014, 0.014]	[−0.015, 0.014]
	30	[−0.009, 0.009]	[−0.009, 0.009]	[−0.011, 0.011]	[−0.011, 0.011]
Combined	1	[−0.018, 0.018]	[−0.018, 0.019]	[−0.022, 0.022]	[−0.022, 0.022]
	10	[−0.009, 0.009]	[−0.009, 0.009]	[−0.010, 0.010]	[−0.011, 0.010]
	30	[−0.006, 0.006]	[−0.006, 0.007]	[−0.008, 0.008]	[−0.008, 0.008]

➔About one order of magnitude improvement of sensitivity to anomalous TGCs at LHC using 1 fb^{-1} integrated luminosity compared with Tevatron and LEP.

Two General Purpose Experiments at LHC





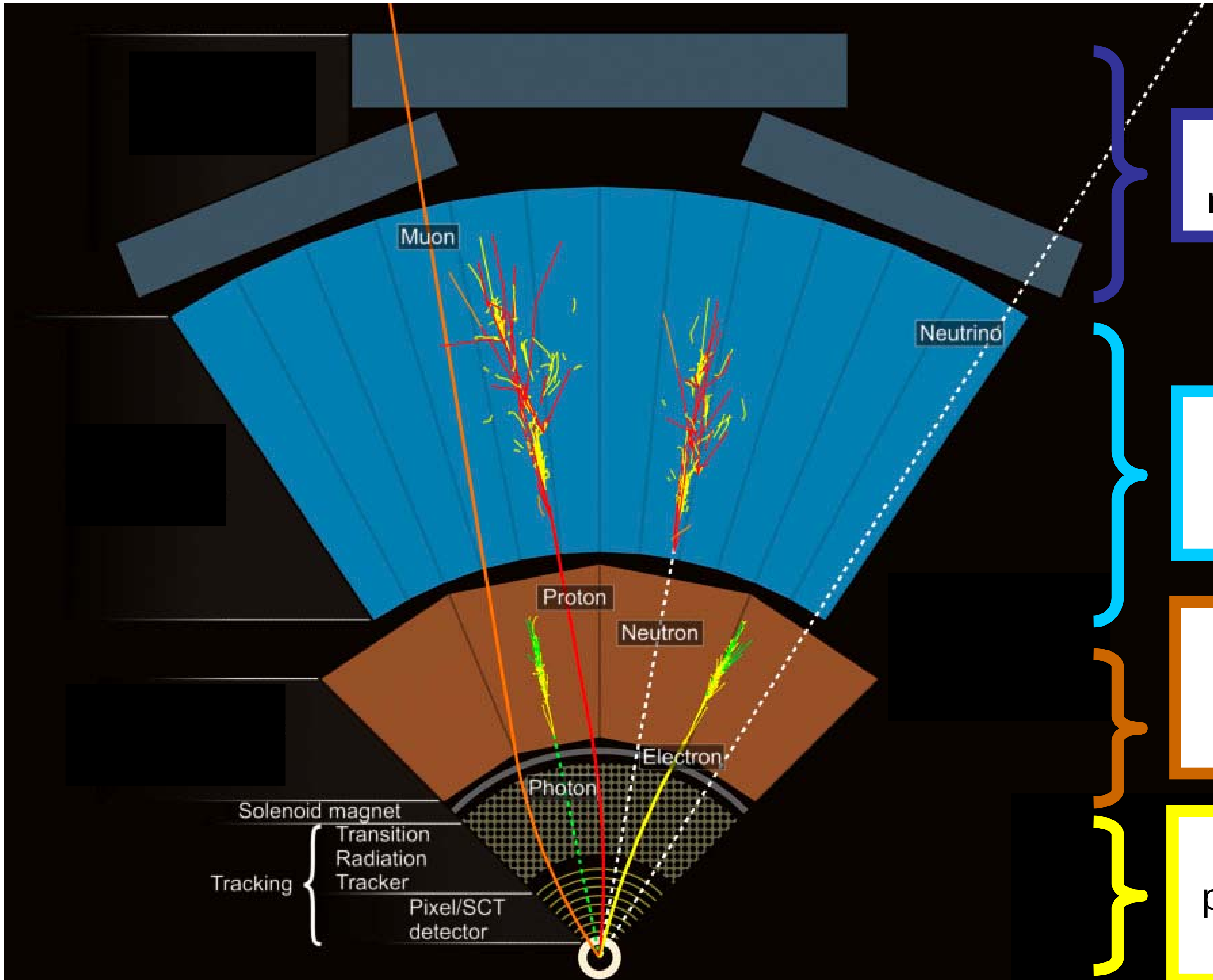
ATLAS

Length : ~45 m
Diameter : ~24 m
Weight : ~ 7,000 tons
Electronic channels : ~ 10^8
Solenoid : 2 T
Air-core toroids

CMS

Length : ~22 m
Diameter : ~14 m
Weight : ~ 12,500 tons
Solenoid : 4 T
Fe yoke
Compact and modular

Particle Detection in the ATLAS



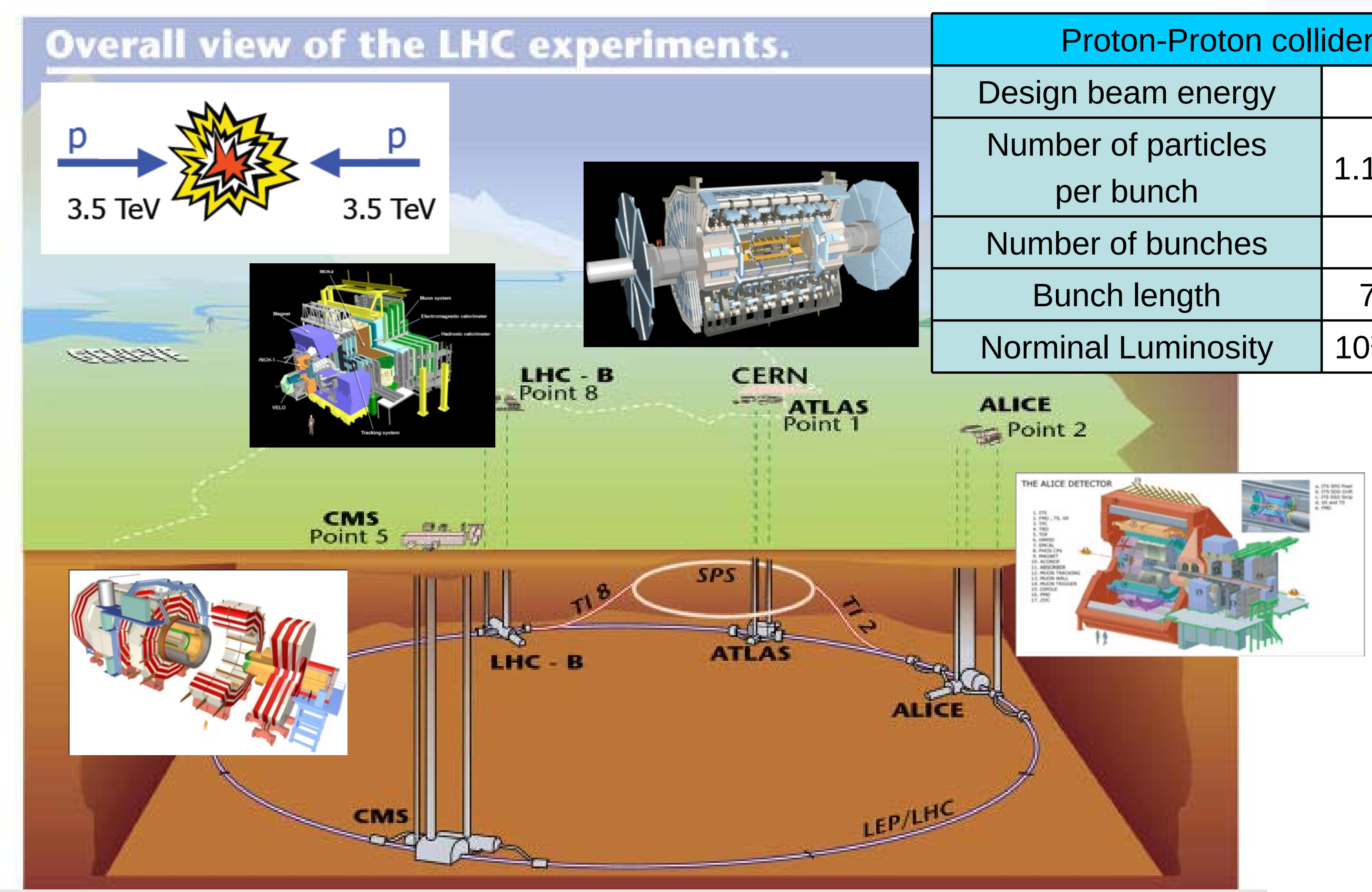
Muon Spectrometer:
muon trigger and tracking

Hadronic calorimeter:
trigger, measurement of jets and E_T^{miss}

Electromagnetic calo:
e/γ trigger, identification and measurement

Tracking system:
precise tracking, vertexing and e/π separation

Large Hadron Collider (LHC)



Proton-Proton collider	
Design beam energy	7TeV
Number of particles per bunch	1.15×10^{11}
Number of bunches	2808
Bunch length	7.55cm
Norminal Luminosity	$10^{34}cm^{-2}s^{-1}$

Main goals: Search for the Standard Model Higgs boson and search for New Physics (NP) beyond the Standard Model