Electroweak Physics at the LHC with ATLAS

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Outline

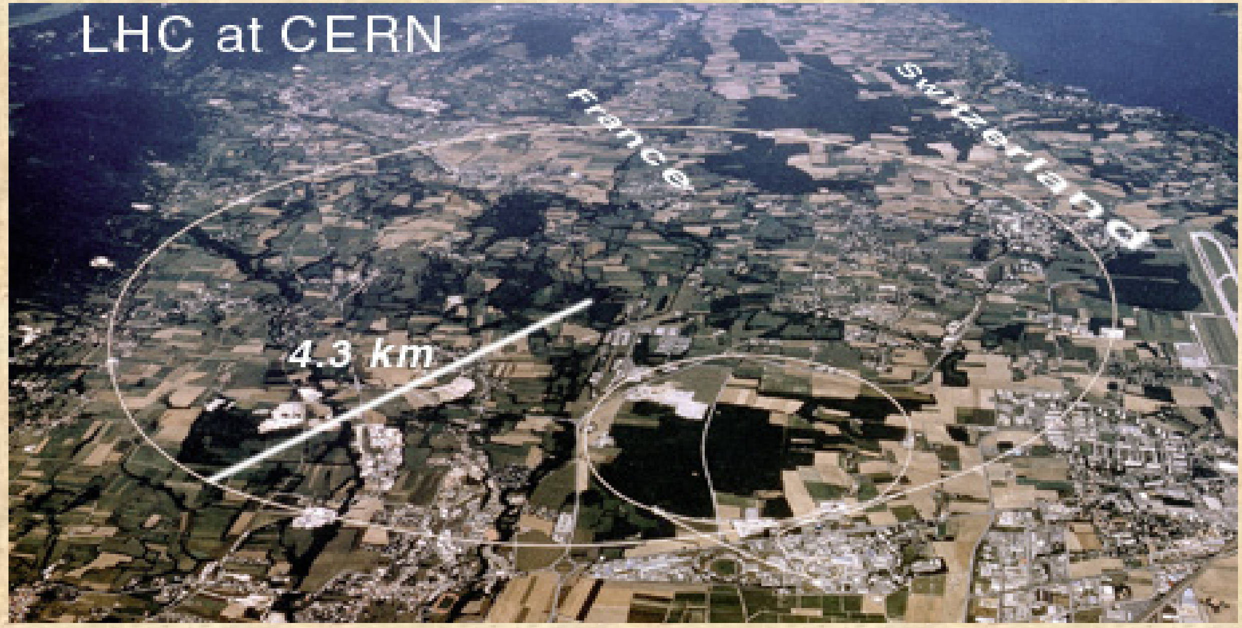
- LHC and ATLAS.
- **W mass** measurement
- Improvements in the mass of the top quark (**m_t**) measurements.
- A_{FB} asymmetry in dilepton production: **$\sin^2\theta_{eff}^{lept}(M_Z^2)$**.
- EW single top quark production: direct measurement of **V_{tb}**.
- Triple gauge boson couplings (TGC).
- Conclusion.

LHC (Large Hadron Collider):

- p-p collisions at $\sqrt{s}$ = 14 TeV
- bunch crossing every 25 ns

➢ low-luminosity: **L ≈ 2 x 10^{33}cm^{-2}s^{-1}**
($\mathcal{L}$ ≈ 20 fb^{-1}/year)

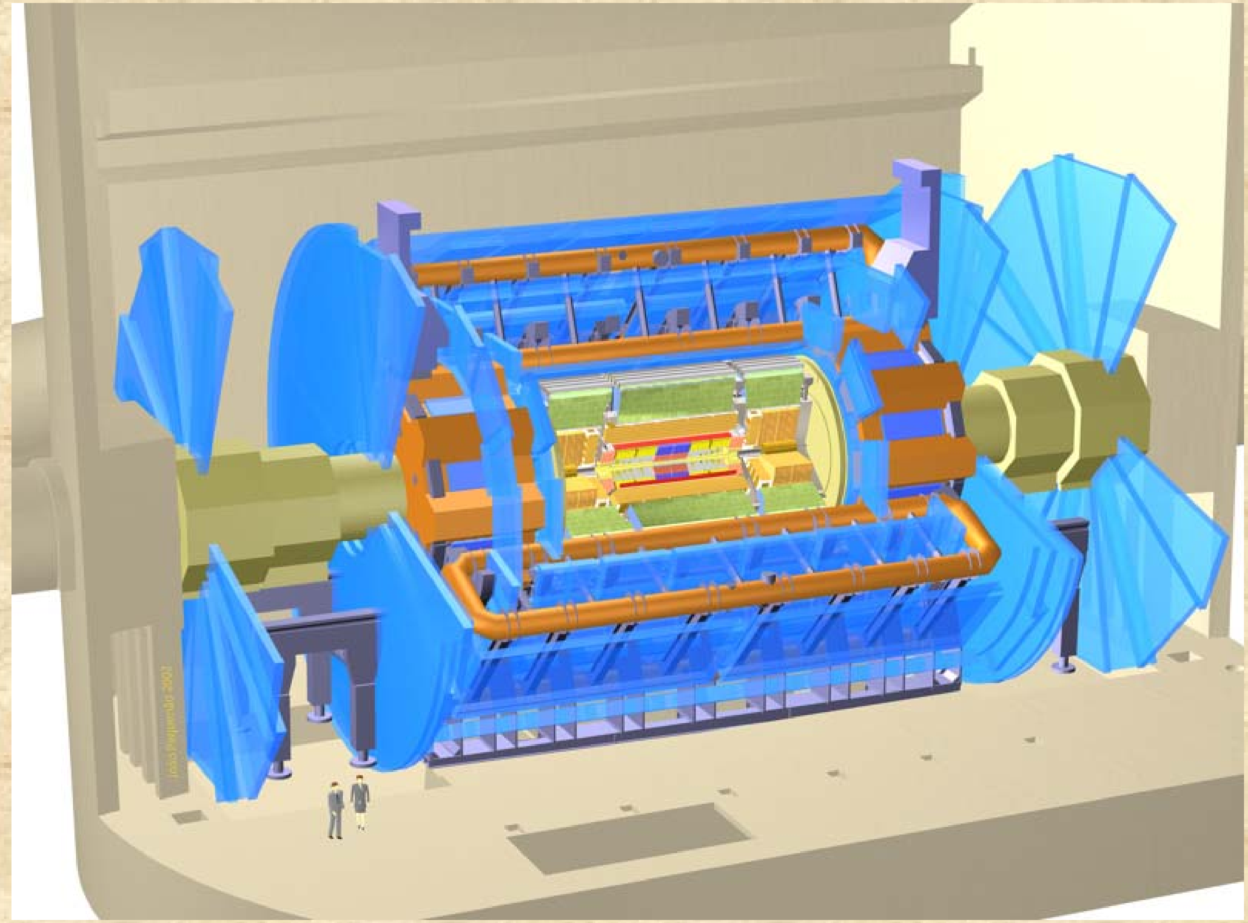
➢ high-luminosity: **L ≈ 10^{34}cm^{-2}s^{-1}**
($\mathcal{L}$ ≈ 100 fb^{-1}/year)



Process	**σ (nb)**	**Events/year ($\mathcal{L}$ = 20 fb^{-1})**
$W \rightarrow e\nu$	30	~ 10^8
$Z \rightarrow e^+ e^-$	3.0	~ 10^7
$t\bar{t}$	1.6	~ 10^7
Inclusive jets **p_T > 200 GeV**	200	~ 10^9

- Large statistics → **small statistical error!**
- Huge discovery potential for new physics: Higgs and Supersymmetry.

The Atlas Detector



Lepton energy scale: precision of 0.02% ($Z \rightarrow ll$)

Jet energy scale: precision of 1% ($W \rightarrow jj$; $Z(ll)$ + jets)

Absolute luminosity: precision ≤ 5% (machine, optical theorem, rate of known processes)

Inner Detector: $|\eta| < 2.5$
Silicon pixels and strips
Transition radiation tracker

EM Calorimeter: $|\eta| < 3.2$
Sampling Pb/LAr

$$\frac{\sigma}{E} = \frac{10\ \%}{\sqrt{E\ (GeV\ )}}$$

Hadronic Calorimeters: $|\eta| < 4.9$
Barrel: $|\eta| < 1.7$
Fe/Scintillating tiles/WLS fibres

$$\frac{\sigma}{E} = \frac{50\%}{\sqrt{E\,(GeV\,)}} \oplus 0.03$$

Endcaps: $|\eta| < 4.9$
Cu & W / LAr

Muon Spectrometer: $|\eta| < 3.7$
Drift tubes & Cathode strip
Tubes, resistive plate chambers

$$\frac{\sigma}{p_T} \cong 2 - 3\ \%$$

Magnet: 2T Solenoid

W mass measurement

- W mass is a fundamental parameter of the SM (α_{QED}, G_F, $\sin\theta_W$)

M_W = 80.425 ± 0.038 GeV (PDG)

- M_W= 80.3827-0.0579 ln(M_H/100)-0.008 ln²(M_H/100)+0.543[(m_t/175)²-1]+ f($\Delta\alpha$,α_s)

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

- Precise measurements will constrain the mass of the SM Higgs or the h boson of the MSSM;
- At the time of the LHC start-up the W mass will be known with a precision of about **30 MeV** (LEP + Tevatron)
- Equal weights in a Higgs mass χ^2 test:

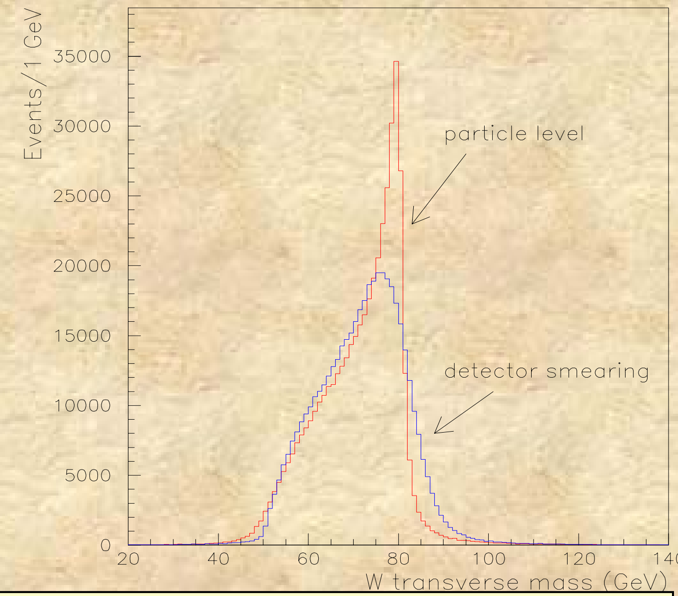
$$\Delta M_W \approx 0.7\times10^{-2}\,\Delta m_t$$

At the LHC **Δm_t~ 2 GeV**

M_W should be known with a precision of about **15 MeV** (combining e/μ and CMS data).

(achievable during the low-luminosity phase of LHC)

- **constrains M_H to ~25% .**



➢ **Detector resolution + pile-up** will smear significantly the transverse mass distribution.

Measurement of the W mass performed in the leptonic channels using the transverse mass:

$$M_T^W = \sqrt{2p_T^l p_T^\nu(1-\cos\Delta\phi)}$$

W mass measurement (new results)

Sources of uncertainty:

- **Statistical uncertainty**: **< 1.8 MeV** for $\mathcal{L} \approx 20\ fb^{-1}$

$$pp \to W + X$$
$$W \to l \nu_l$$

σ = 30 nb (l=e,μ)

6×10^8 events after cuts for each lepton species ($\mathcal{L} \approx 20\ fb^{-1}$)

- **Systematic errors**

a) physics: W p_t spectrum, structure functions, W width, radiative decays and background.

- p.d.f.'s & radiative corrections: improve theoretical calculations!

b) detector performance: lepton scale, energy/ momentum resolution, lepton identification and response to recoil.

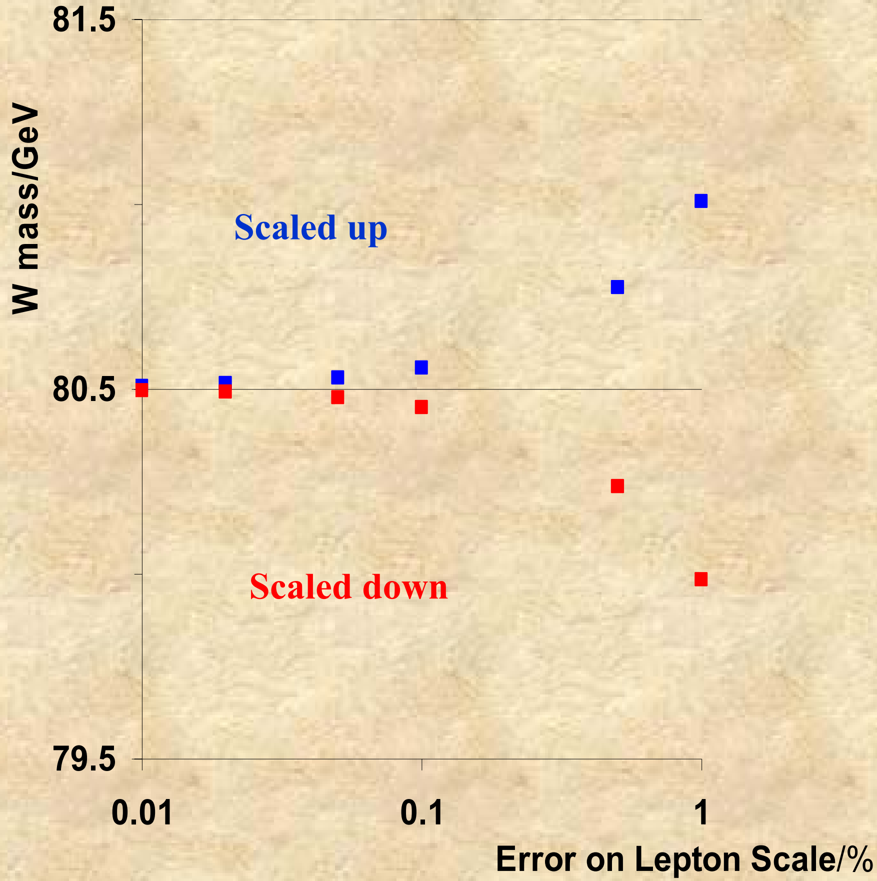
- Lepton energy and momentum scale:
~0.1% at Tevatron
~0.02% at ATLAS - tuned to: $Z \to l^+ l^-$

Expected values with Atlas, one channel, 20 fb^{-1}

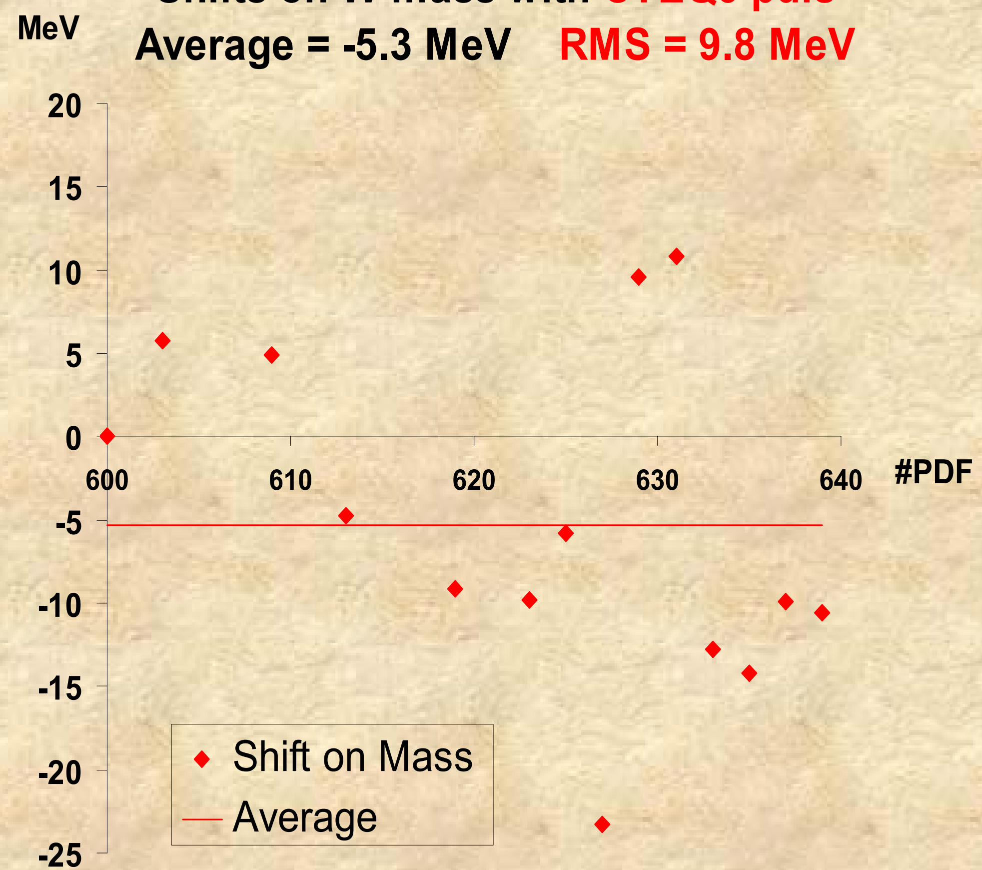
Source	ΔM_W /MeV
Statistics	~ 1.8
E-p scale	~ 11
Energy resolution	~ 5
Recoil model	~ 5
Lepton identification	~ 5
p^T_W	~ 5
PDFs	~ 10
W width	~ 7
Radiative decays	~ 10
Background	~ 5
Total	**~ 22 MeV**

New results on W mass measurement systematics uncertainties

W reconstructed mass versus error on Lepton Energy Scale
Shift on W mass = 550 MeV / 1%



Shifts on W mass with CTEQ6 pdfs
Average = -5.3 MeV RMS = 9.8 MeV



Determination of $\sin^2\theta_{eff}^{lept}(M_Z^2)$

- $\sin^2\theta_{eff}^{lept}$ a **fundamental parameter of the SM!**
- $\sin^2\theta_{eff}^{lept} = 0.231510+0.000523 \ln(M_H/100)-0.00278[(m_t/175)^2-1]+ g(\Delta\alpha,\alpha_s)$
- precise determination will **constrain the Higgs mass** and check **consistency of the SM**.
- $\sin^2\theta_{eff}^{lept}$ will be determined at the LHC by measuring **A_{FB} in dilepton production** near the **Z** pole.

➢ A_{FB} in $p\text{-}p \to Z,\gamma^* \to l^+ l^-$

$$A_{FB} = b \{ a - \sin^2\theta_{eff}^{lept}(M_Z^2) \}$$

a and **b** calculated to **NLO** in QED and QCD.

$\sigma (Z \to l^+l^-) \sim 1.5$ nb (for either e or μ)

$\sin^2\theta_{eff}^{lept}(M_Z^2) = 0.23126 \pm 1.7 \times 10^{-4}$ (global fit PDG)

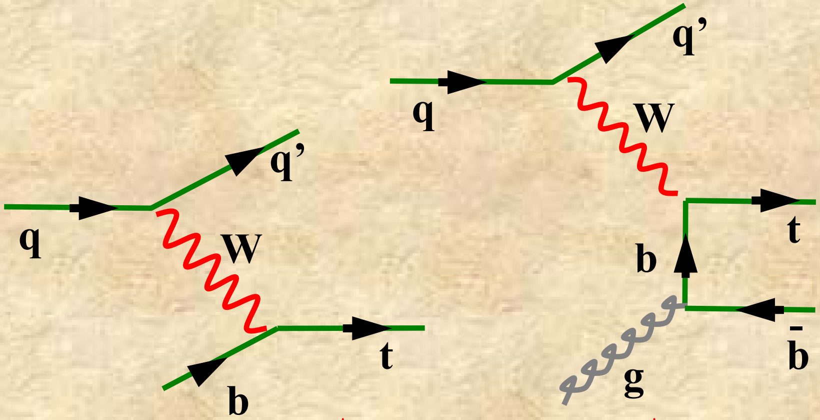
y cuts – e^+e^- ($\vert y(Z) \vert > 1$)	ΔA_{FB} (statistical)	$\Delta\sin^2\theta_{eff}^{lept}$ (statistical)
$\vert y(l_{1,2}) \vert < 2.5$	3.03×10^{-4}	4.0×10^{-4}
$\vert y(l_1) \vert < 2.5$; $\vert y(l_2) \vert < 4.9$	2.29×10^{-4}	1.41×10^{-4}

$\mathcal{L} = 100$ fb^{-1}

- Main systematic effect: **uncertainty on the p.d.f.'s**, lepton acceptance (~0.1%), radiative correction calculations.

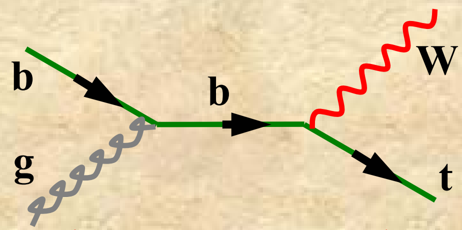
Can be further improved: **combine channels/experiments.**

EW single top quark production (not yet observed!)



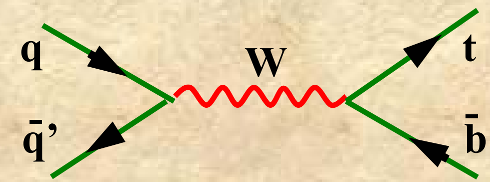
W-gluon fusion

σ_{Wg}~ 250 pb



Wt process

σ_{Wt}~ 60 pb



W* process

σ_{W^*}~ 10 pb

(lower theoretical uncertainties!)

for each process: $\sigma \propto |V_{tb}|^2$

- Probe the **t-W-b vertex**
- **Directly measurement** (only) of the CKM matrix element V_{tb} at ATLAS (assumes **CKM unitarity**)
- **New physics**: heavy vector boson W'
- Source of **high polarized tops!**
- Background: **$t\bar{t}$, $Wb\bar{b}$, Wjj**

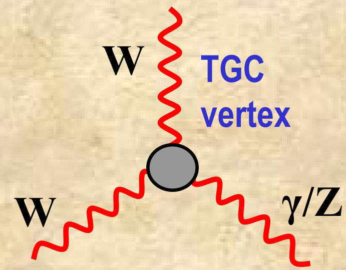
Process	S/B	S/√B	$\Delta V_{tb}/V_{tb}$ – statistical	$\Delta V_{tb}/V_{tb}$ – theory
W-gluon	4.9	239	0.51%	7.5%
Wt	0.24	25	2.2%	9.5%
*W**	0.55	22	2.8%	3.8%

$\mathcal{L}$ = 30 fb^{-1}

Systematic errors: b-jet tagging, luminosity ($\Delta\mathcal{L}$ ~ 5 – 10%), **theoretical (dominate V_{tb} measurements!).**

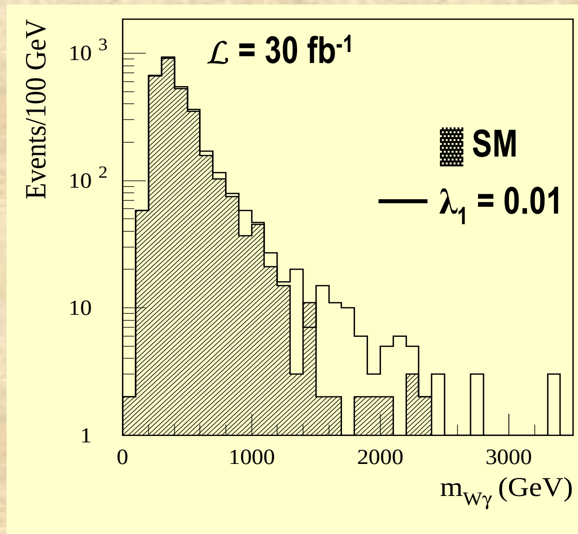
Triple gauge boson couplings

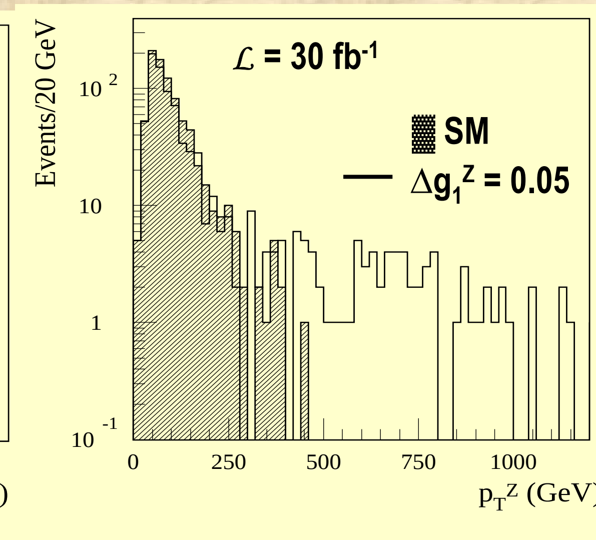
- TGC of the type **WWγ** or **WWZ** provides a direct test of the non-Abelian structure of the SM (EW symmetry breaking).



- It may also indicate hints of **new physics**: new processes are expected to give anomalous contributions to the TGC.

- New physics could show up as deviations of these parameters from their SM values.





- This sector of the SM is often described by 5 parameters: g_1^Z, κ_γ, κ_Z, λ_γ and λ_{γ}, (SM values are equal to g_1^Z = κ_γ = κ_Z = 1 and λ_γ = λ_{γ}, = 0, at the tree level).

Gauge, C and P invariance

- Anomalous contribution to TGC is **enhanced at high $\sqrt{s}$** (increase of production cross-section).

Triple gauge boson couplings

- Variables:

  Wγ: (p^T_γ) and ($p^T_\gamma \times p^T_{lW}$)

  WZ: (p^T_Z) and ($p^T_Z \times p^T_{lw}$)

- SM: vanishing helicity at low $|\eta|$
  Non-standard TGC: partially eliminates `zero radiation'

Systematic uncertainties:

- At the LHC, sensitivity to TGC is a combination of the very high energy and high luminosity.
- Uncertainties arising from low p_T background will be quite small: anomalous TGC signature will be found at high p_T.
- Theoretical uncertainties: p.d.f.'s & higher order corrections

Parameters	Statistical (at 95% C.L.)	Systematic (at 95% C.L.)
Δg_1^Z	- 0.0064 + 0.010	±0.0058
$\Delta\kappa_Z$	- 0.10 + 0.12	±0.024
λ_Z	- 0.0065 + 0.0066	- 0.0032 + 0.0031
$\Delta\kappa_\gamma$	- 0.073 + 0.076	- 0.015 + 0.0076
λ_γ	±0.0033	±0.0012

$\mathcal{L}$ = 30 fb^{-1}

Using max-Likelihood fit to (p^T_Z) and ($p^T_Z \times p^T_{lw}$)

Conclusions:

- LHC will allow precision measurements: unexplored kinematic regions, high-statistics (W, Z, b, t factory);
- ATLAS: valuable precision measurements of SM parameters;
- W mass can be measured with a precision of 15 MeV (combinig e/μ and ATLAS + CMS);
- Top mass: ~ 2 GeV (combined with Δm_W~15 MeV, constrains M_H to ~ 25%);
- $\sin^2\theta_{eff}^{lept}(M_Z^2)$ can be determined with statistical precision of 1.4×10^{-4} (competitive to lepton collider measurements!)
- EW single top production: direct measurement of V_{tb}; measurement of top polarization (Wg with statistical precision of ~ 1.6%);
- Sensitivity to anomalous TGC's: indicative of new physics!