Standard Model at LHC

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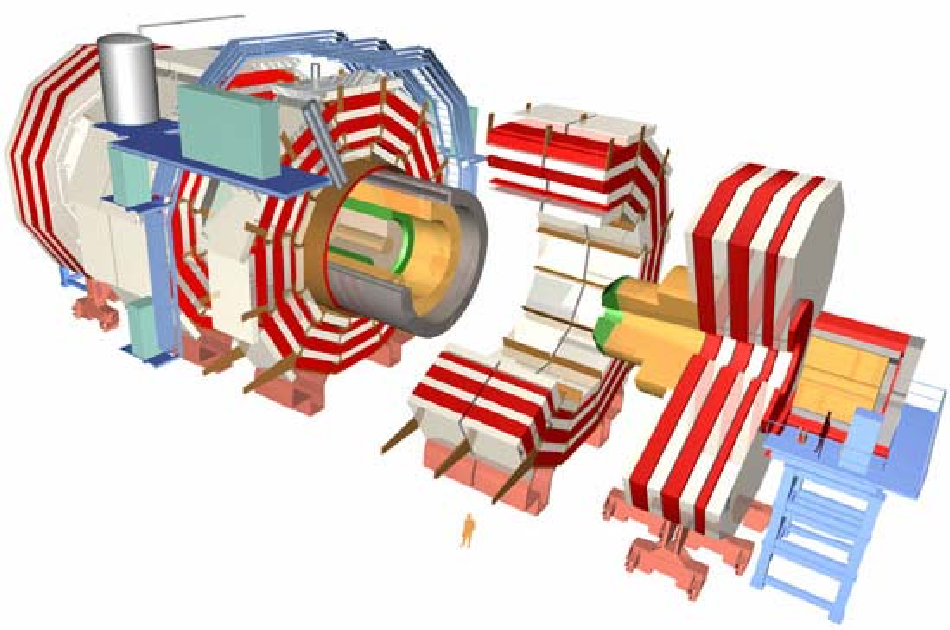
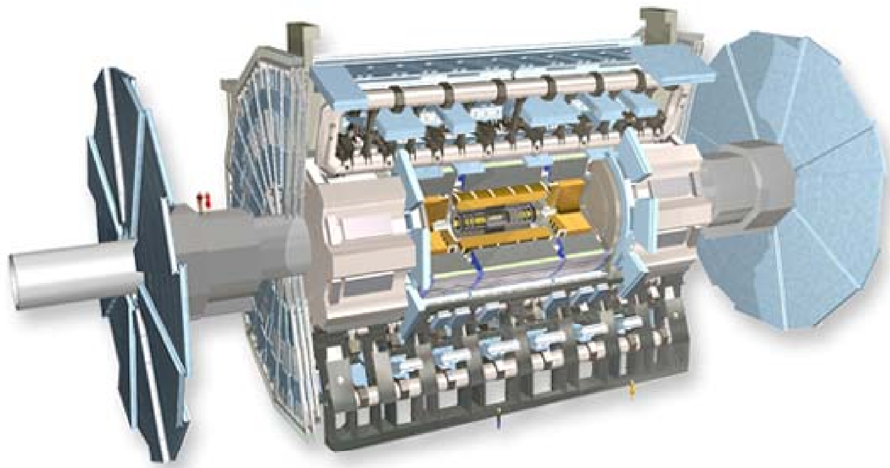
On behalf of the ATLAS and CMS collaborations

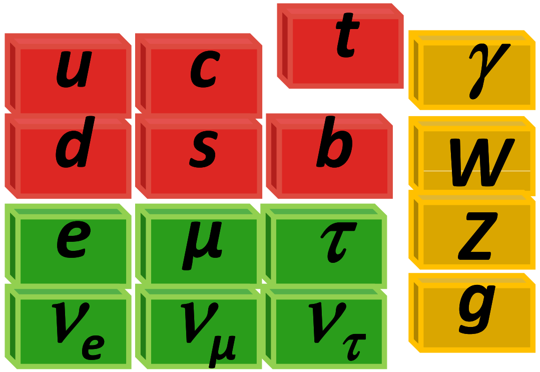




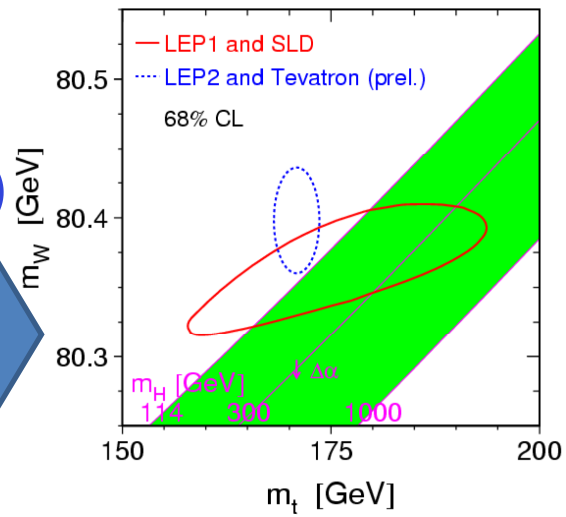
HEP-MAD 07, Antananarivo, Madagascar

2007, september 14

Motivation



- SM successfully tested at current energy
- LHC ⇒ prospect physics at higher energy :
  - Able to search directly beyond SM
  - But also precise measurements of SM parameters
- Goal for SM physics:
  - Deeper understand the SM with :
    - Precision EW measurements (M_W, $sin^2\theta_W$,…)
    - Top physics (mass,cross section,… measurement)
  - Indirect estimate the Higgs mass
    - Using M_W, m_{Top}, $sin^2\theta_W$ precise measurement
  - Search for deviation from SM

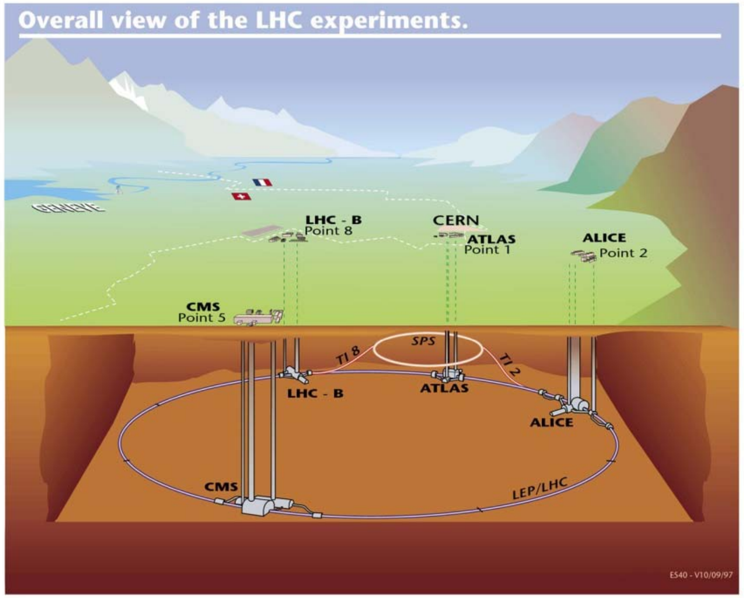


Experimental Framework

The LHC

- CERN (Geneva)
- pp collision @ √s = 14 TeV (10 × Tevatron)
- Luminosity :
  - Low luminosity phase L~10^{33} $cm^{-2}s^{-1}$ (2008-2009?) [10 fb^{-1}/year : 10× TV]
  - High luminosity phase L~10^{34} $cm^{-2}s^{-1}$ (2010?-X) [100 fb^{-1}/year : 100×TV]

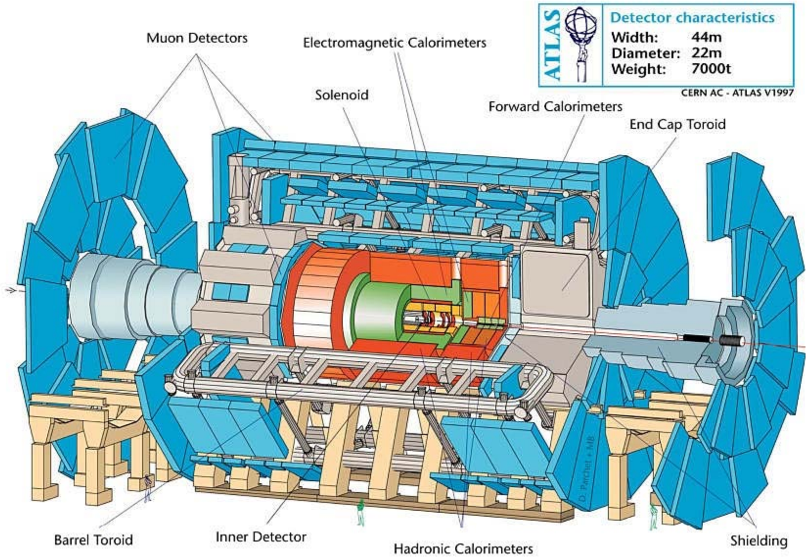
EW precision measurement

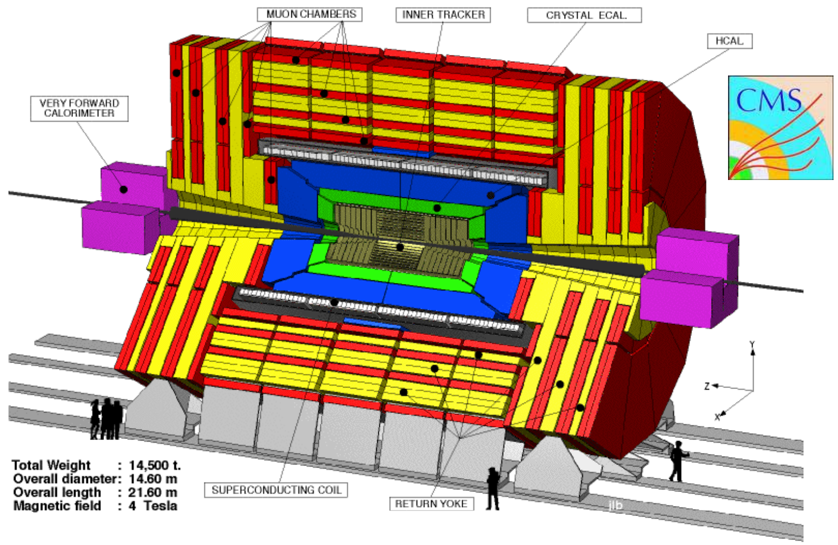


Experiments

ATLAS and CMS ⇒ general purpose physics
LHCb ⇒ b physics
ALICE ⇒ heavy ion physics

Experimental Framework

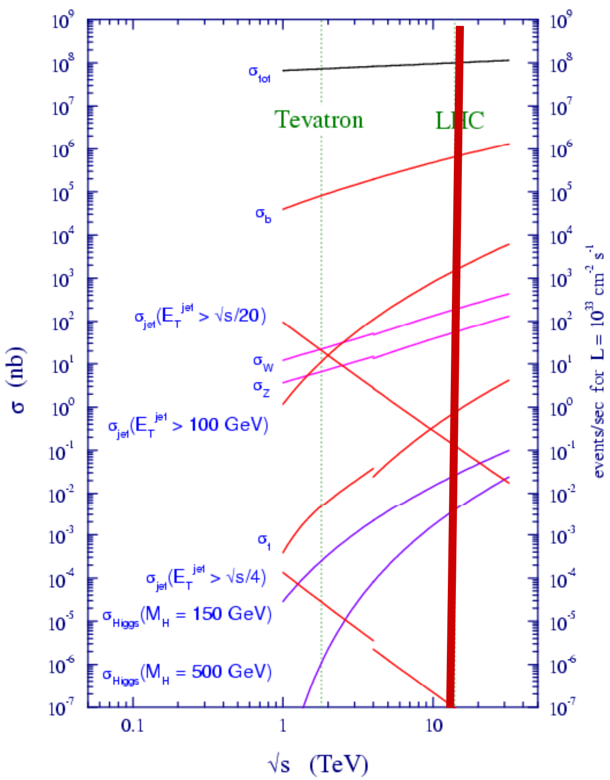




- **Tracking (|η|<2.5, B=2T) :**
  - Si pixels and strips
  - Transition Radiation Detector (e/π separation)
- **Calorimetry (|η|<5) :**
  - EM : Pb/LAr with Accordeon shape
  - HAD : Fe/scintillator (central), Cu-W/Lar (forward)
- **MuonSpectrometer (|η|<2.7) :**
  - air-core toroids with muon chambers

- **Tracking (|η|<2.5, B=4T) :**
  - Si pixel and strips
- **Calorimetry (|η|<5) :**
  - EM : $PbWO_4$ crystals
  - HAD : brass/scintillator (central,end-cap), Fe/Quartz (forward)
- **MuonSpectrometer (|η|<2.5) :**
  - return yoke of solenoid instrumented with muon chambers

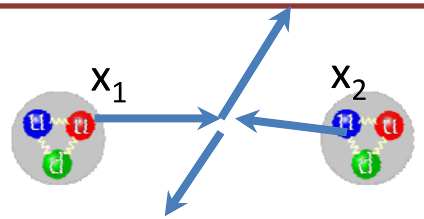
p-p collisions



Cross section and Event rate

Process	σ (nb)	Evt/y (Low L:10 fb^{-1})
Minimum Bias	10^8	~ 10^{15}
Inclusive jets (p_T>200 GeV)	100	~ 10^9
$W \rightarrow l\nu$ (l=e,μ)	30	~ 10^8
$Z \rightarrow e^+e^-$	1.5	~ 10^7
$t\bar{t}$	0.83	~ 10^6
$b\bar{b}$	5.10^5	~ 10^{12}

1 or 2 orders of magnitude larger than Tevatron



Hadron collider problem :
PDF to be better known

LHC is a W, Z, top factory :

- small statistical errors in precision measurements
- large samples for studies of systematic effects (calibration and syst. controls)

SM physics @ LHC

- W/ Z physics (precision EW measurement)
  - Parameters related to indirect M_H measurement :
    - W mass and width
    - $\sin^2\Theta_W$
  - Constraints on the PDF
    - W/Z inclusive cross section as well as W/Z+jets
    - W rapidity
  - Measurement of gauge boson pair production
    - Triple Gauge Boson Coupling
- Top physics
  - Parameters related to indirect M_H measurement :
    - Top mass/cross section
  - Deeper understanding of Top quark :
    - Top spin correlation, probe of the Wtb vertex, single Top cross section, Top charge
- QCD (→ see Albert talk on tuesday)
- Higgs boson direct search
- B physics
- …

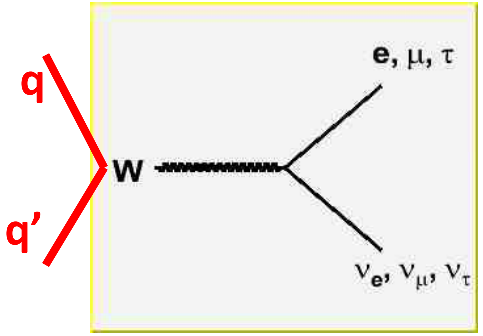
SM physics at LHC covers a large number of topics ⇒ just focus on few items in this talk

Precision EW Measurement

M_W measurement

- LHC expects :

$\delta M_W < 15$ MeV



- W channel : same as the Tevatron

  $\Rightarrow$ using $W \rightarrow l\nu$ decay

But LHC statistics is higher (60M recons. $W \rightarrow l\nu$ @ low Lumi [10× TV])

Event selection:

- 1 isolated lepton (e,μ) $p_T > 25$ GeV in $|\eta| < 2.4$
- missing $E_T > 25$ GeV
- No jet with $p_T > 30$ GeV
- Recoil $|u| < 20$ GeV

- Several methods available:

✓ $R = M^T_W / M^T_Z$ spectrum $\Rightarrow$ Small syst, sample /10

✓ p_T^l spectrum $\Rightarrow$ pile-up , theo. know. of P^T_W

✓ $M^T_W \Rightarrow$ high stat, pile-up

Precision EW Measurement

M_W measurement

✓ Use Transverse mass to cope with unmeasured p_L^ν

$$M_W^T = \sqrt{2 p_T^l p_T^\nu (1 - \cos\Delta\phi^{l,\nu})},\ l = e, \mu$$

✓ p_T^ν from p_T^l & recoil

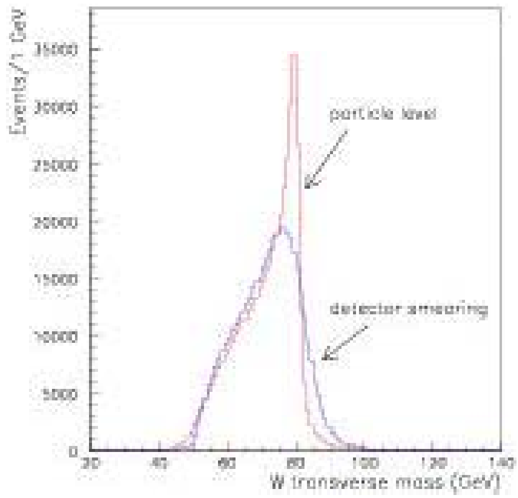
✓ Use the knowledge on the Z boson to constrain the W mass

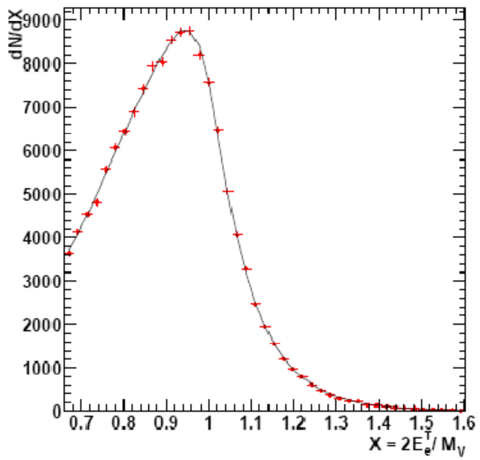
$$P_T^{l,Z} = \frac{M_Z}{M_W} P_T^{l,W}$$

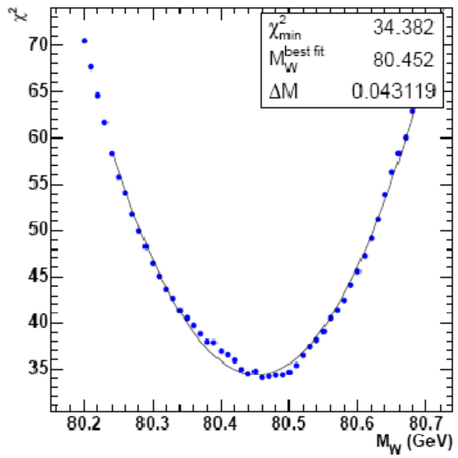
✓ p_T^l spectrum shape is sensitive to M_W

✓ p_T^ν not necessary

W mass : fit exp. shape to MC sample with different Values of M_W







M_W measurement : systematics

- LHC goals : $W \to l\nu$: one lepton species, low $\mathcal{L}$, per experiment, after 1 year

source	CDF RunII, combined channel	LHC
	200 pb^{-1}	*60Mevts, 10fb^{-1}*
Statistics	0 MeV	<2 MeV
Lepton scale	17 MeV	15 MeV
Energy resolution	3 MeV	5 MeV
Recoil model	12 MeV	5 MeV
Lepton id.	---------	5 MeV
P^T_W	3 MeV	5 MeV
PDF	11 MeV	10 MeV
W width	---------	7 MeV
Radiative decays	11 MeV	<10 MEV
Background	0 MeV	5 MeV
TOTAL	26 MeV	<25 MeV

stat. error : negligible

syst. error :
- MC modelling of phys.
- detector responses

physics

P^T_W spectrum	$Z \to ll$
PDF	LHC data
W width	$Z \to ll$,R,Tevatron
W rad. decays	Theo. calculation
Background	MC

detector

lepton E&p scale	$Z \to ll$, E/p for $e^{\pm}$
Lepton resolution	$Z \to ll$, E/p for $e^{\pm}$
Recoil	$Z \to ll$

- Combining channels and ATLAS/CMS exp., should reach $\Delta M_W \approx 15$ MeV

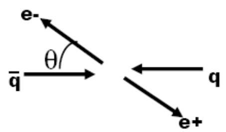
Precision EW Measurement

Determination of $\sin^2\Theta_W$

Use A_{FB} in p-p→Z/γ*→l^+l^-

- Parity violation in neutral current ⇒ Asymmetry in the angular distribution of leptons from Z decay (θ-dependence of cross-section)

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta} = \frac{3}{8}N_c[1 + \frac{4}{3}A_{FB}\cos\theta + \cos^2\theta]$$



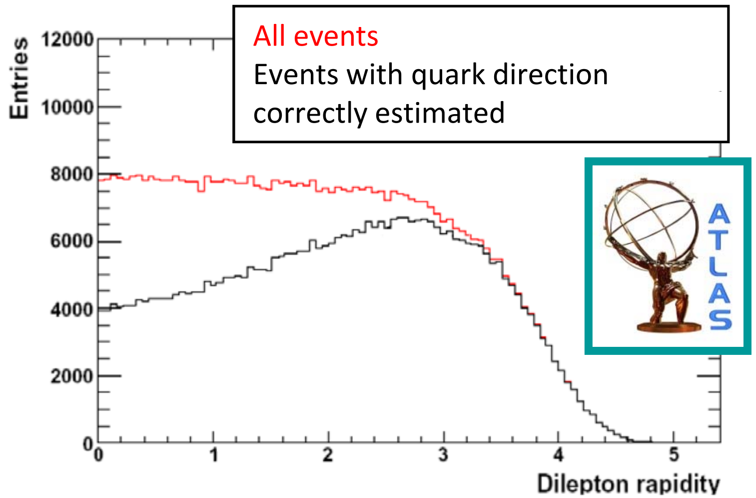
Test of the Standard Model (universality)

- At the Z pole, A_{FB} comes from the interference of vector and axial component of the coupling

$$A_{FB} = b(a - \sin^2\theta_W)$$

Where a, b calculated to NLO QED and QCD

- Assumption for p-p colliders : the quark direction is the same as the boost of the Z
  - Correct for large di-lepton rapidities
  - Only EM calorimeters provide the required large η-coverage (Z→e^+e^-)



Determination of $\sin^2\Theta_W$

Event selection:

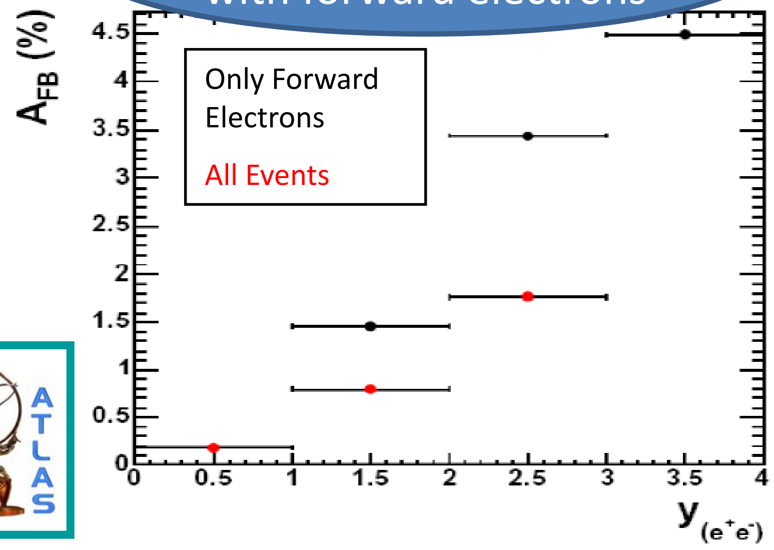
- $p_T^e > 20$ GeV
- $85.2 < M_{ee} < 97.2$ GeV

- Results

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

y cuts – e^+e^- (|y(Z)| > 1)	ΔA_{FB} (Stat)	$\Delta\sin^2\theta_W$ (Stat)
$\lvert y(l_{1,2})\rvert < 2.5$	3.0×10^{-4}	4.0×10^{-4}
$\lvert y(l_1)\rvert < 2.5$ + $\lvert y(l_2)\rvert < 4.9$	2.3×10^{-4}	1.4×10^{-4}

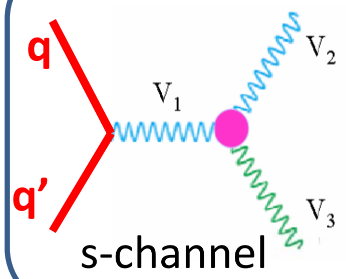
Sensitivity increases with forward electrons



- Current error on world average 1.6×10^{-4}
- need small systematic error :
  - PDF uncertainty,
  - precise knowledge of lepton acceptance and efficiency
  - effects of higher order QCD

Triple gauge boson coupling

➢ Probe the non abelian structure of SM



- LO Feynman diagram :

V1, V2, V3 = Z, W, $\gamma \rightarrow$ WW, ZW, Wγ

- Diboson final states have predictable $\sigma_{production}$ and **manifest the gauge boson coupling**
- In SM, only charged coupling WW γ and WWZ are allowed

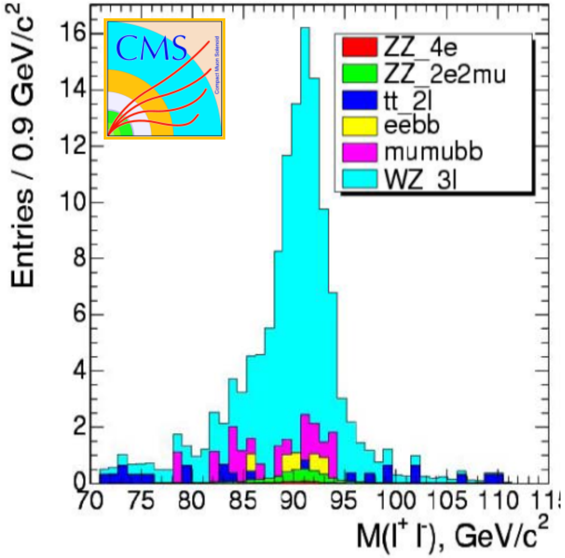
- 14 possible WWγ and WWZ coupling
- Use 5 independent, CP conserving, EM gauge invariance preserving couplings : g_1^Z, κ_γ, κ_Z, λ_γ, λ_Z
  - At SM tree level, $g_1^Z=\kappa_\gamma=\kappa_Z=1$ and $\lambda_\gamma=\lambda_Z=0$
  - λ_γ and λ_Z grow with s $\Rightarrow$ big advantage for LHC
  - $\Delta\kappa_\gamma = \kappa_\gamma$-1, $\Delta g_1^Z = g_1^Z$-1, $\Delta\kappa_Z = \kappa_Z$-1 grow with $\sqrt{s}$

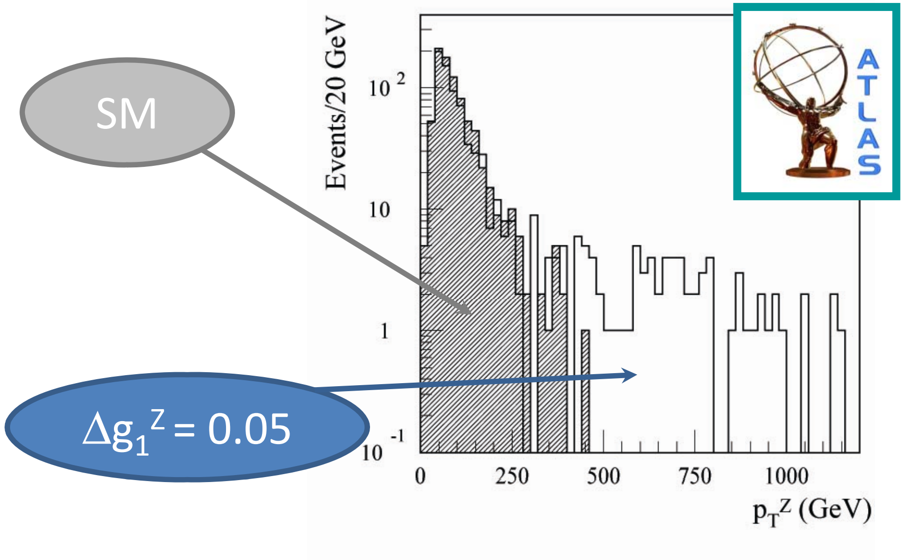
TGC manifest in :
- Cross section enhancement
- High pT(V=W, Z, γ)
- Production angle

Triple gauge boson coupling

Exemple of WZ production

- **Use only leptonic final state**
- Event selection:
  - Exactly 3 leptons with pT>25 GeV
  - At least one pair of leptons with same flavour and opposite charge and |mll-MZ|<10 GeV
  - …





Coupling	Present Value	LHC Sensitivity (95% CL, 30 fb-1, 1 exp)
Δg_1^Z	$-0.016^{+0.022}_{-0.019}$	0.005-0.011
$\Delta\kappa_\gamma$	$-0.027^{+0.044}_{-0.045}$	0.03-0.076
$\Delta\kappa_Z$	$-0.076^{+0.061}_{-0.064}$	0.06-0.12
λ_γ	$-0.028^{+0.020}_{-0.021}$	0.0023-0.0035
λ_Z	$-0.088^{+0.063}_{-0.061}$	0.0055-0.0073

Measurement of W/Z cross sections

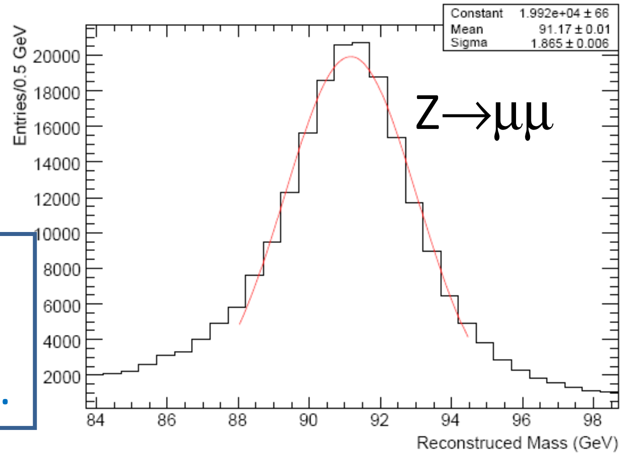
Estimation of the cross section

$$\sigma(pp \to Z/W + X \to \mu\mu) = \frac{N_{Candidates}(1 - f_{Background})}{\varepsilon_{total}\int Ldt}$$

Event selection:

Z : 2 isolated μ, $p_T^{\mu} > 20$ GeV, $|\eta|<2$, $84<M_{\mu\mu}<99$ GeV,...

W : 1 isolated μ, $p_T^{\mu} > 25$ GeV, $|\eta|<2$, $40<M_T(\mu,E_T^{Miss})<200$GeV,...

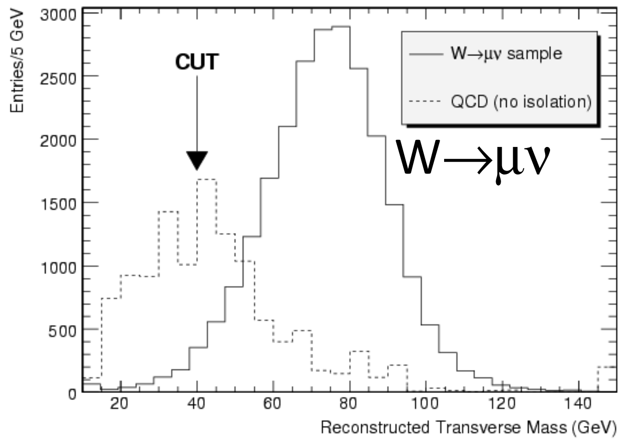


CERN/LHCC 2006-021
CMS TDR 8.2

- **Results** ($\mathcal{L}$=1 fb-1 [~600k Z→μμ, ~6M W→μν])

σ(Z→μμ + X) = 1160 ± 1.5 (stat) ± 27 (syst) ± 116 (lumi) pb

σ(W→μν + X) = 14700 ± 6 (stat) ± 485 (syst) ± 1470 (lumi) pb



Already dominated by systematics

Systematics come mainly from theory
(acceptance+PDF uncertainty).

At a later stage these processes can be used as luminosity monitor (Error on luminosity: ~5%)

Constraints on PDF using W rapidity distributions

- At LHC, experimental uncertainty is dominated by systematics (large event production)
- The theoritical uncertainties are dominated by PDFs

➢ Exp. uncertainty sufficiently small to distinguish between different PDF sets

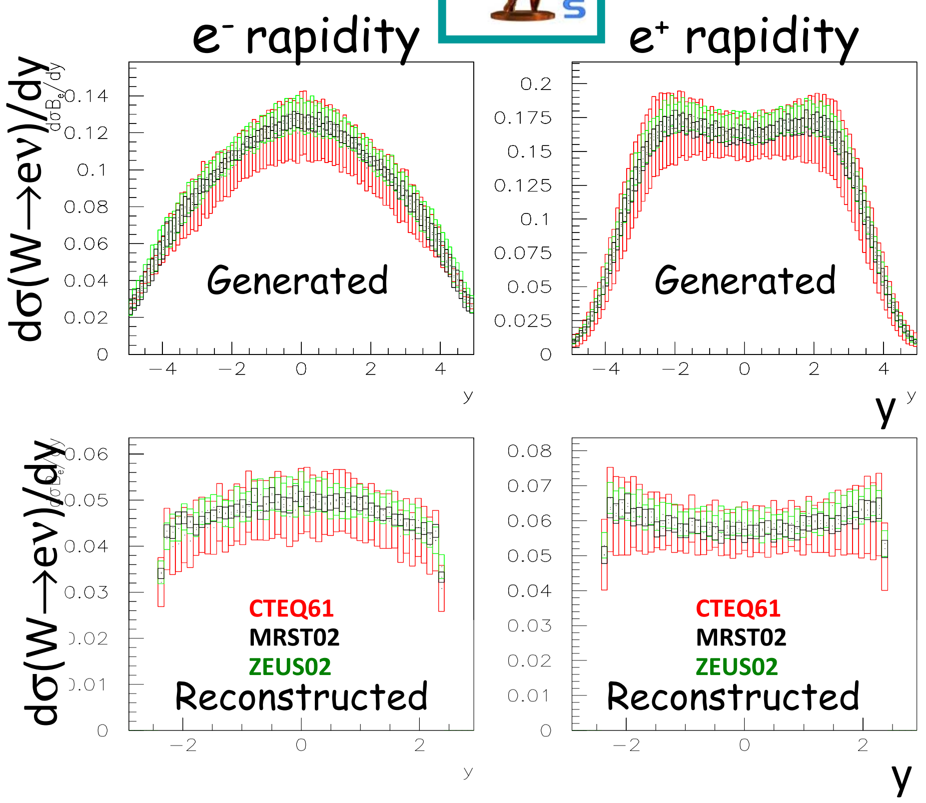
☑ PDF error sensitive to W→eν rapidity distribution

- ➢ e$^{\pm}$ rapidity spectrum shape sensitive to gluon shape parameter (valence quark density)

☑ Probe low-x gluon PDF at $Q^2=M_W^2$

☑ PDF uncertainties only slightly degraded after detector simulation and selection cuts

$$u\bar{d} \to W^+ \to e^+\nu$$
$$d\bar{u} \to W^- \to e^-\bar{\nu}$$

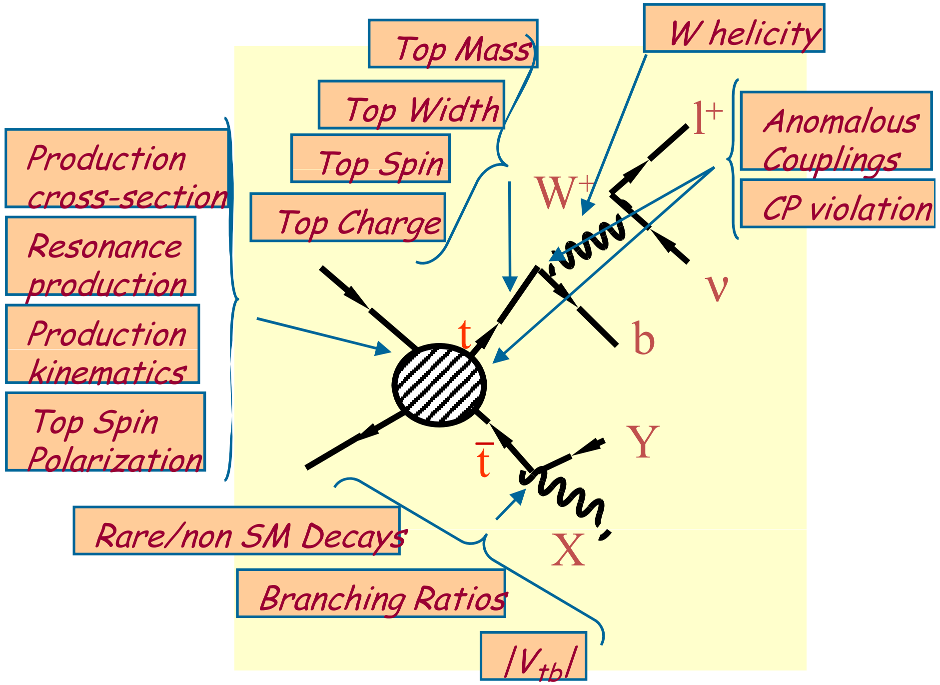


Top Quark Physics

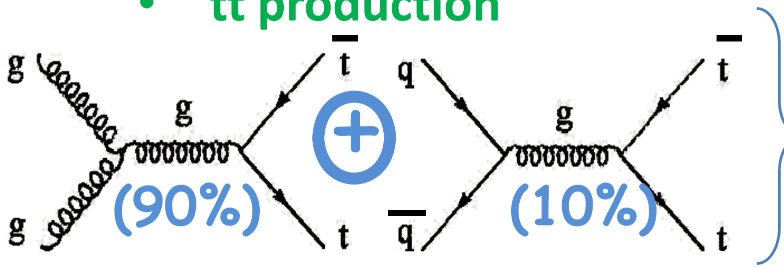
- Direct discovery in 1995 (Fermilab)
- Completes the 3 family structure of the SM
- Very high mass ~ 175 GeV

$\tau_{had} = \Lambda_{QCD}^{-1} >> \tau_{decay}$

$\Rightarrow$ No Top Hadron : Opportunity to measure parameters of a free quark

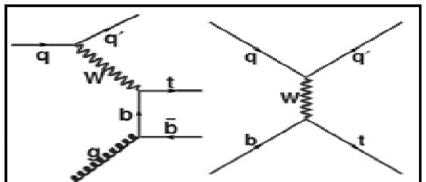


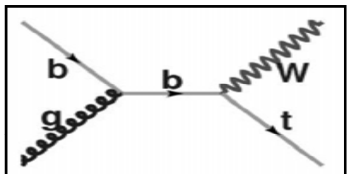
- Production at LHC:
  - tt production

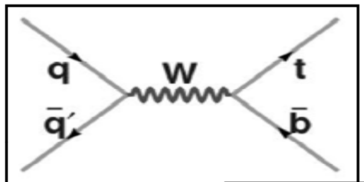


σ ~ 833±100pb @ 14TeV (NLO)
8M evts/y @ Low Lum

  - single top production



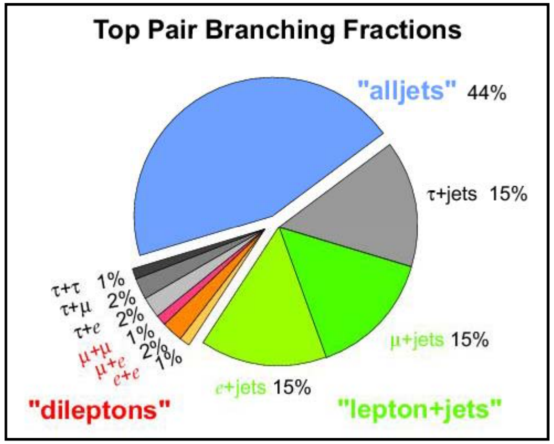


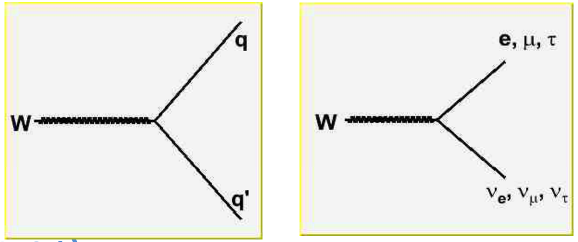


t-channel	σ ~ 250 pb	Wt-channel	σ ~70pb	W* (s-channel)	σ ~ 10 pb

$t\bar{t}$ Physics

- **Decay** : Determined by decay of Ws

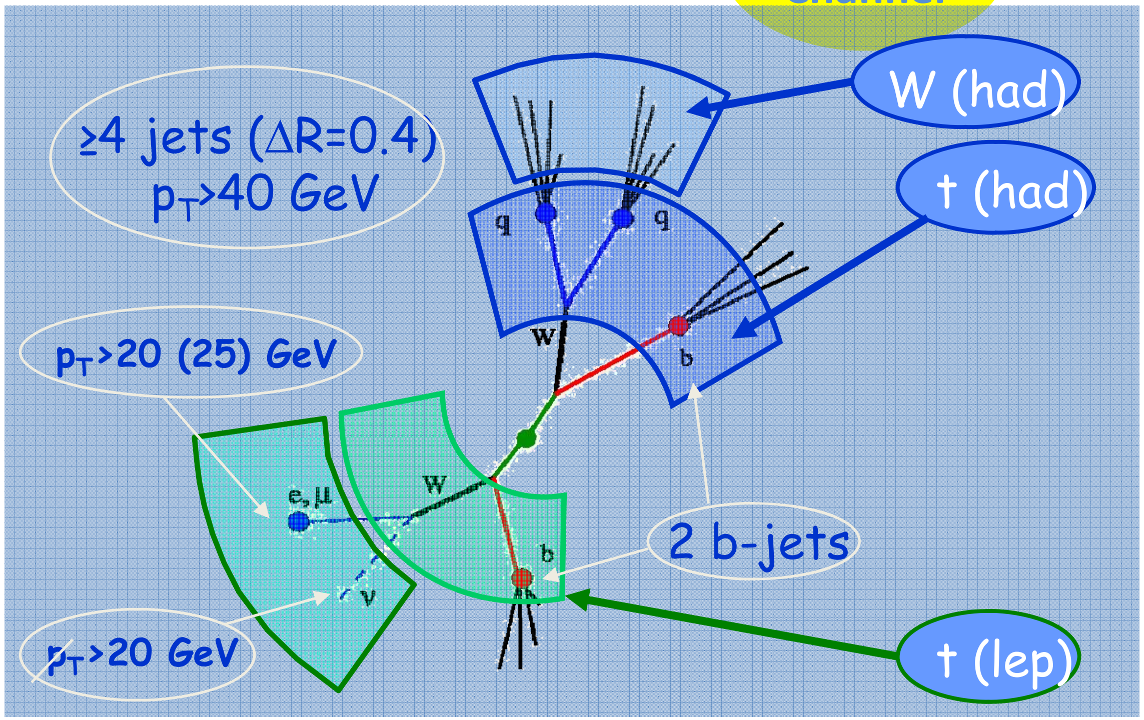




- Fully hadronic channel (44 %)
- Di-leptonic channel (5 %)
- Semi-leptonic channel (30 % no τ)

Golden Channel

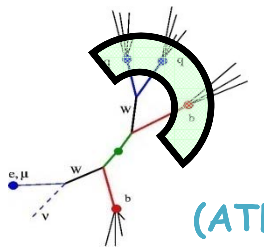
- **Selection** :
  - Only e/μ events
  - ⇒ Trigger
  - large event yield
  - small backbround



Top quark mass measurement (Invariant mass spectrum of reconstructed Had. Top : most straightforward technique)

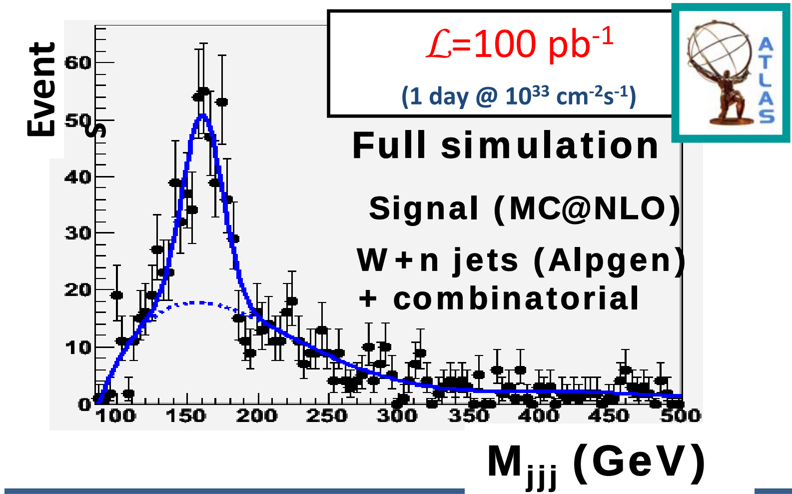
Without b-tagging (early data)

Event topology: 3 jets with highest $\sum p_T$

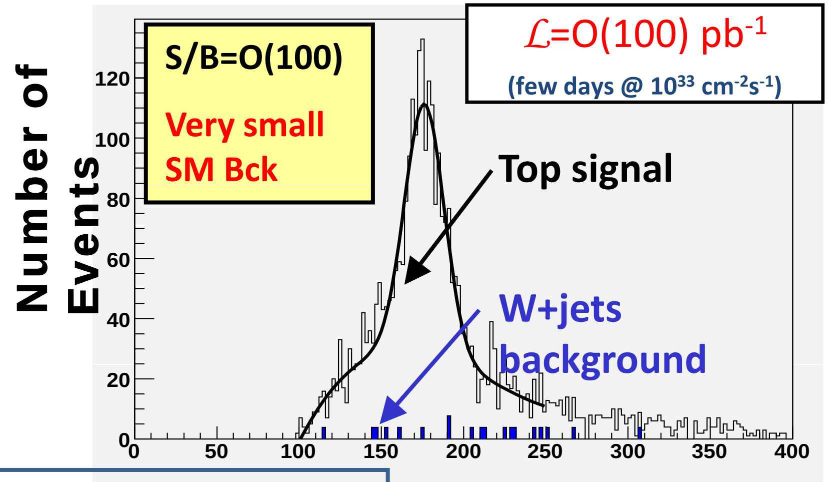


Selection efficiency :
ε=5.3 %

(ATL-PHYS-PUB-2005-024)



With b-tagging



Top mass (GeV)

Selection efficiency :
ε=1-2%

In this way, **Δm(top) ~1.3 GeV**
When Kinematical Fit (using the leptonic side) is used, **Δm(top) ~1 GeV**

$t\bar{t}$ Physics

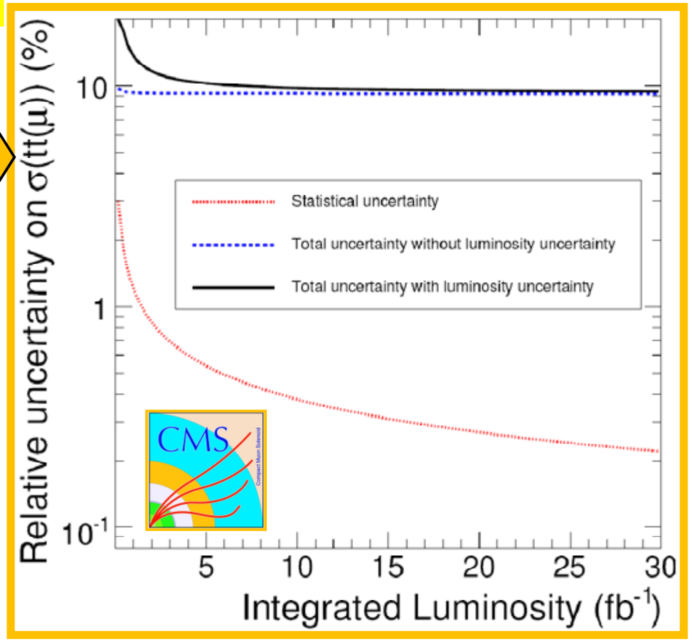
tt cross section

CERN/LHCC 2006-021
CMS TDR 8.2

- Semi-leptonic channel ($tt \to bbqq\,\mu\nu_l$): **L=10fb^{-1}**

$\Delta\sigma_{tt}/\sigma_{tt}$= 9.7%(syst)±0.4%(stat)±3%(lum)

ε_{reco} = 6.3%



- Di-leptonic channel ($tt \to bb\ l\nu_l\, l\nu_l$): **L=10fb^{-1}**

$\Delta\sigma_{tt}/\sigma_{tt}$= 11%(syst)±0.9%(stat)±3%(lum)

ε_{reco} = 5% (S/B=5.5)

With Tau leptons ($tt \to bb\ \tau\nu_\tau\, l\nu_l$, $\tau \to$hadrons):

$\Delta\sigma_{tt}/\sigma_{tt}$= 16%(syst)±1.3%(stat)±3%(lum)

[ε_{reco}=2%, S/B~1, $\varepsilon_{\tau\text{-tag}}$=30%]

- Fully Hadronic channel: **L=1fb^{-1}**

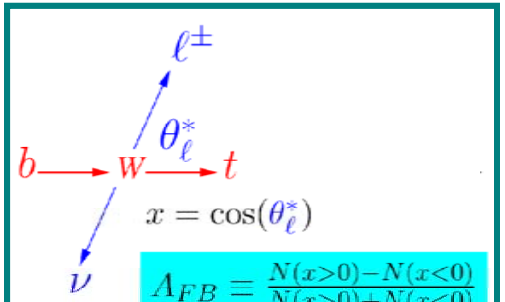
$\Delta\sigma_{tt}/\sigma_{tt}$= 20%(syst)±3%(stat)±5%(lum)

ε_{reco}=2%, S/B<1/9 (QCD)

Top polarization

Test the $t \to bW$ decay vertex

Measure W polarization (F_0, F_L, F_R) through lepton angular distribution in W cm system:

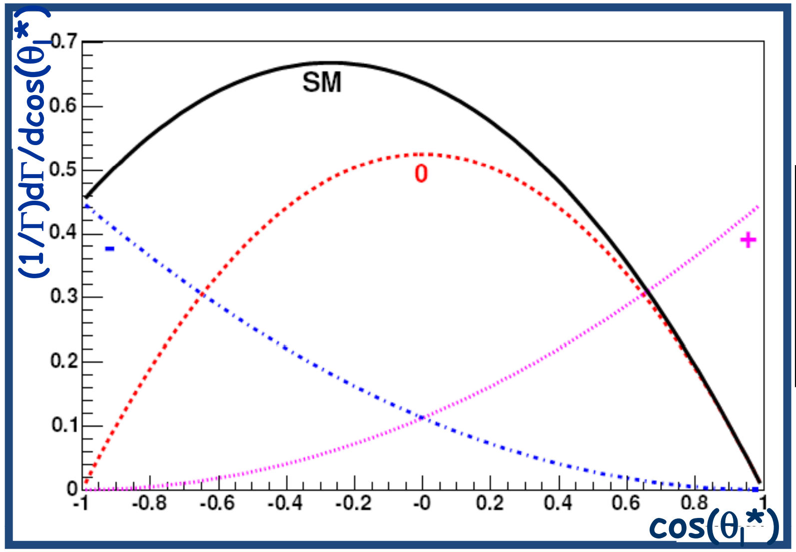


$x = \cos(\theta_\ell^*)$

$A_{FB} \equiv \frac{N(x>0)-N(x<0)}{N(x>0)+N(x<0)}$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell^*} = \frac{3}{8}(1+\cos\theta_\ell^*)^2\, F_R + \frac{3}{8}(1-\cos\theta_\ell^*)^2\, F_L + \frac{3}{4}\sin^2\theta_\ell^*\, F_0$$

(Eur.Phys.J.C44S2 2005 13-33)



Semilep. + Dileptonic

L=10fb^{-1}

	SM (M_t=175 GeV)	Error (±stat ±syst)
F_0	0.703	± 0.004 ± 0.015
F_L	0.297	± 0.003 ± 0.024
F_R	0.000 (m_b=0)	± 0.003 ± 0.012

- Syst ($E_{b\text{-jet}}$, m_{top}, FSR)
- $\delta F_0 / F_0 \sim 2\%$; $\delta F_R \sim 0.01$

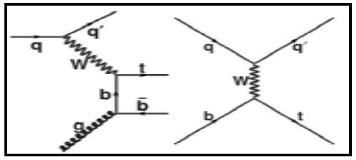
single Top Physics

Production cross section

Common feature: (ATL-PHYS-PUB-2007-005)

1 lepton, pT>25GeV/c
High Missing E_T
≥2 jets (at least 1 b-jet)

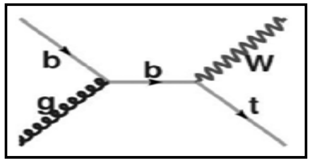
$L=30fb^{-1}$ Separate Channels by (N_j,N_b) in final state:



t-channel: $(N_j=2,N_b=1)$

Stat: 7000 events (S/B=3)

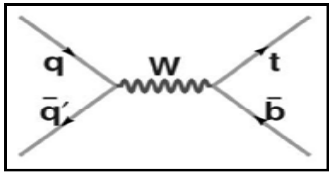
$\Delta\sigma/\sigma$= 12%(syst)±1%(stat)±5%(lum)



Wt-channel: $(N_j=3,N_b=1)$

Stat: ε~1% (S/B=15%)

$\Delta\sigma/\sigma$= 14%(syst)±1.5%(stat)±5%(lum)



s-channel: $(N_j=2,N_b=2)$

Stat: 1200 events for tb (S/B=10%)

$\Delta\sigma/\sigma$= 16%(syst)±12%(stat)±5%(lum)

$L=10fb^{-1}$ (CERN/LHCC 2006-021, CMS TDR 8.2)

t-channel: $\Delta\sigma/\sigma$= 8%(syst)±2.7%(stat)±5%(lum)
Wt-channel: $\Delta\sigma/\sigma$= 23.9%(syst)±8.8%(stat)±9.9%(MC)
s-channel: $\Delta\sigma/\sigma$= 31%(syst)±18%(stat)±5%(lum)

Conclusion

- Precision measurements are possible with hadron collider, as demonstrated by the Tevatron
- LHC will prospect higher energy physics
  - ☒ Detector to be understood with early data
  - ☑ Higher luminosity
  - ☑ Better S/B ratio
- LHC goals are ambitious
  - $\delta M_W < 15$ MeV
  - $\delta m_{top} < 1$ GeV
  - $\delta \sin^2\theta_W \sim 10^{-4}$

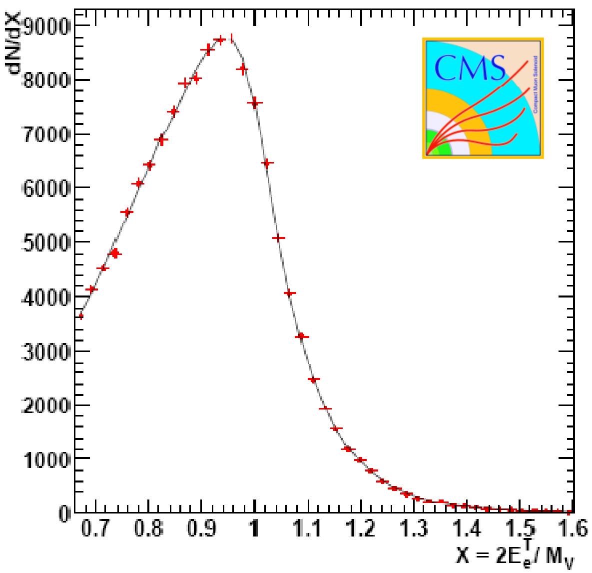
But reachable …

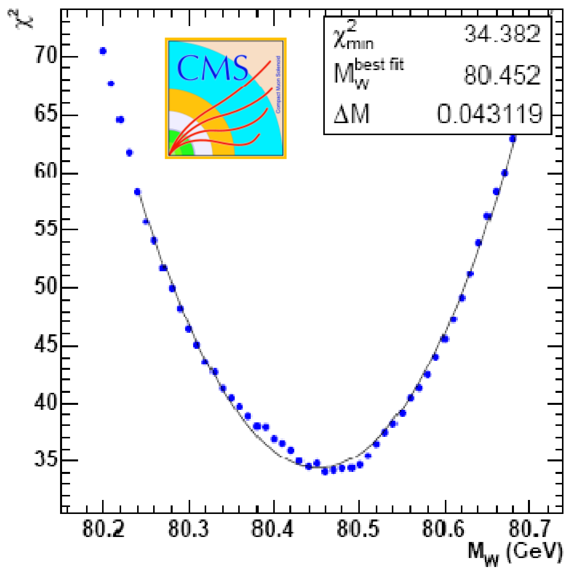
as soon as the detectors performances and the systematics will be understood

Back-up Slides

M_W measurement

✓ Simple and powerful in principle : consider p_T^l spectrum correlation between Z and W decay





CMS NOTE 2006/061

✓stat. error negligible (~2 MeV)

✓ BUT need to predict the spectrum precisely !

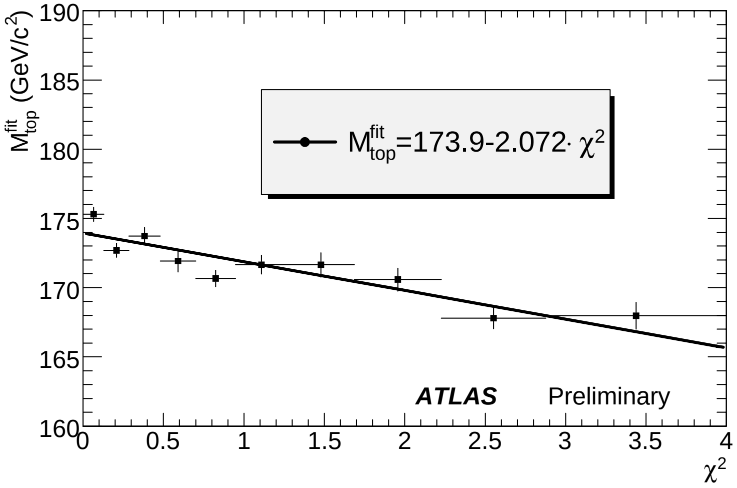
Kinematical Fit (use leptonic side)

– Minimization of a χ^2 function with constraints on W and Top masses

$$\chi^2 = \sum_{i=jets}\left(\left(\frac{\eta_i^{meas}-\eta_i^{fit}}{\sigma_\eta^i}\right)^2+\left(\frac{\varphi_i^{meas}-\varphi_i^{fit}}{\sigma_\varphi^i}\right)^2\right)+\sum_{i=jets,lepton}\left(\frac{E_i^{meas}-E_i^{fit}}{\sigma_E^i}\right)^2+\sum_{i=x,y,z}\left(\frac{P_{i\,\nu}^{meas}-P_{i\,\nu}^{fit}}{\sigma_{i\,\nu}}\right)^2$$

$$+\left(\frac{M_{jj}-M_W^{PDG}}{\sigma_W}\right)^2+\left(\frac{M_{l\nu}-M_W^{PDG}}{\sigma_W}\right)^2+\left(\frac{M_{jjb_h}-M_{Top}^{fit}}{\sigma_t}\right)^2+\left(\frac{M_{jjb_l}-M_{Top}^{fit}}{\sigma_t}\right)^2$$

- ☑ Reduces FSR systematics
- ☑ Cleaner event sample (using a cut on χ^2)
- ☑ measure m_{top} as a function of χ^2

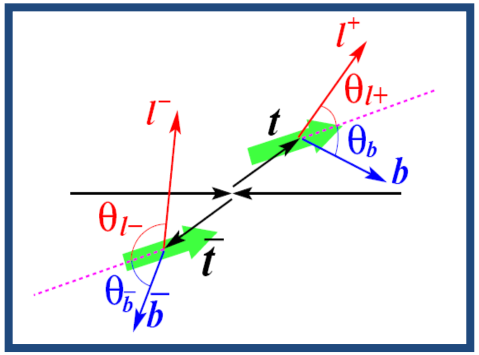


uncertainty	Δm(top) [GeV] Hadronic Top	Δm(top) [GeV] Kinematical Fit
light-jet nergy scale (1%)	0.2	0.2
b-jet nergy scale (1%)	0.7	0.7
FSR	1	0.5
TOTAL	1.3	0.9

Top spin correlation

Testing the $t\bar{t}$ Production cross-section

Although t and $\bar{t}$ are produced unpolarized their spins are correlated

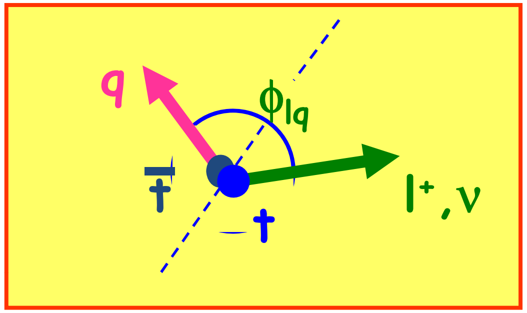


$$A = \frac{\sigma(t_L\bar{t}_L) + \sigma(t_R\bar{t}_R) - \sigma(t_L\bar{t}_R) - \sigma(t_R\bar{t}_L)}{\sigma(t_L\bar{t}_L) + \sigma(t_R\bar{t}_R) + \sigma(t_L\bar{t}_R) + \sigma(t_R\bar{t}_L)}$$

SM:

A(LO)	0.319
A(NLO)	0.326

Other angular distributions:



$$\frac{1}{N}\frac{dN}{d\cos\phi} = \frac{1}{2}\left(1 - A_D \alpha_X \alpha_{X'} \cos\phi\right)$$

SM:

A_D(LO)	-0.217
A_D(NLO)	-0.237

α_X=spin analysing power of X

Top spin correlation

A) Spin correlations and angular distributions: L=10fb^{-1}

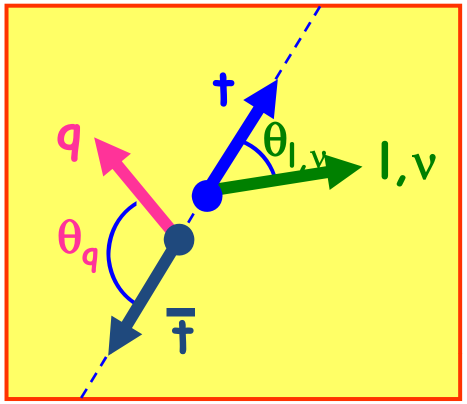
	SM M_{tt}<550 GeV	Error (±stat ±syst)
A	0.42	±0.014 ±0.023
A_D	-0.29	±0.008 ±0.010

(Eur.Phys.J.C44S2 2005 13-33)

- Semileptonic + Dileptonic
- Syst ($E_{b\text{-}jet}$, m_{top}, FSR)
- ~4% precision

(CERN/LHCC 2006-021, CMS TDR 8.2)

B) Spin Asymmetries can also be used (X-check)



$$A_{X\bar{X}'} \equiv \frac{N(\cos\theta_X \cos\theta_{\bar{X}'} > 0) - N(\cos\theta_X \cos\theta_{\bar{X}'} < 0)}{N(\cos\theta_X \cos\theta_{\bar{X}'} > 0) + N(\cos\theta_X \cos\theta_{\bar{X}'} < 0)} = \frac{1}{4} A \alpha_X \alpha_{\bar{X}'}$$

$$\tilde{A}_{xx'} \equiv \frac{N(\cos\phi > 0) - N(\cos\phi < 0)}{N(\cos\phi > 0) + N(\cos\phi < 0)} = -\frac{1}{2} A_D \alpha_X \alpha_{X'}$$

(for L=10fb^{-1} precision A, A_D below 10%)

(hep-ex/0605190, subm. to Eur.Phys.J.C)

$t\bar{t}$ Physics

Probe the Wtb vertex

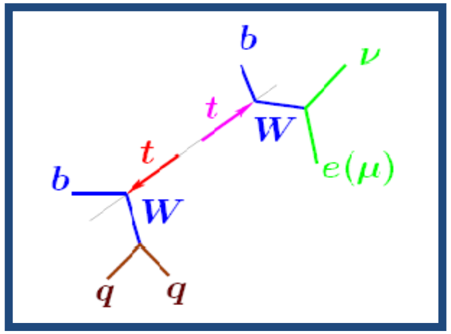
B) Anomalous Couplings in the $t\rightarrow bW$ decay

PRD45 (1992) 124:

$$f_1^R \equiv V_R$$
$$f_2^L \equiv -g_L$$
$$f_2^R \equiv -g_R$$

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^\mu\,(V_L P_L + V_R P_R)\,t\,W_\mu^- - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_\nu}{M_W}\,(g_L P_L + g_R P_R)\,t\,W_\mu^- + \mathrm{h.c.}$$

(PRD67 (2003) 014009, $m_b \neq 0$)



Angular

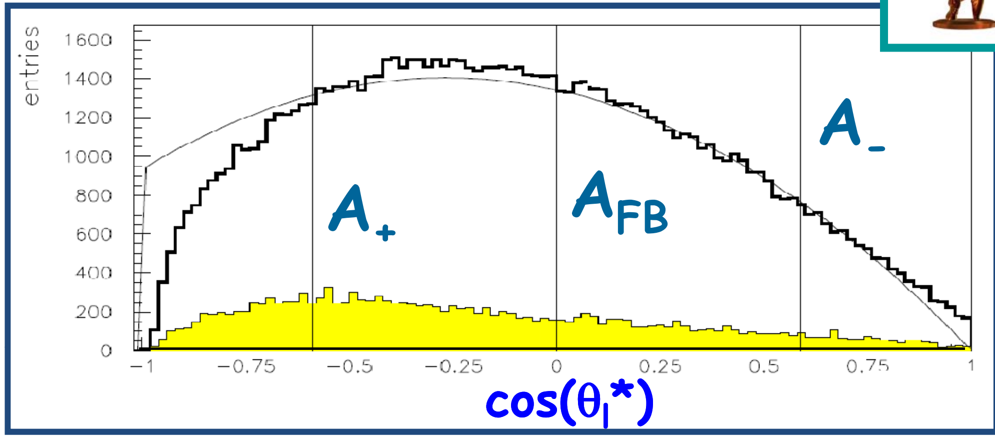
$$A_t = \frac{N(x>t) - N(x<t)}{N(x>t) + N(x<t)}$$

$$A_{FB} = \frac{3}{4}\,[F_R - F_L],$$
$$A_+ = 3\beta\,[F_0 + (1+\beta)F_R],$$
$$A_- = -3\beta\,[F_0 + (1+\beta)F_L],$$

SM(LO):

$$A_{FB} = -0.2225,\ A_+ = 0.5482,\ A_- = -0.8397$$

A_{FB} [t=0] $A_\pm$ [$t = \mp(2^{2/3}-1)$]



Probe the Wtb vertex

B) Anomalous Couplings in the $t \rightarrow bW$ decay

$A_{FB} = -0.2237 \pm 0.0035$ (stat) ± 0.0144 (sys)

$A_{+} = 0.5472 \pm 0.0032$ (stat) ± 0.0099 (sys)

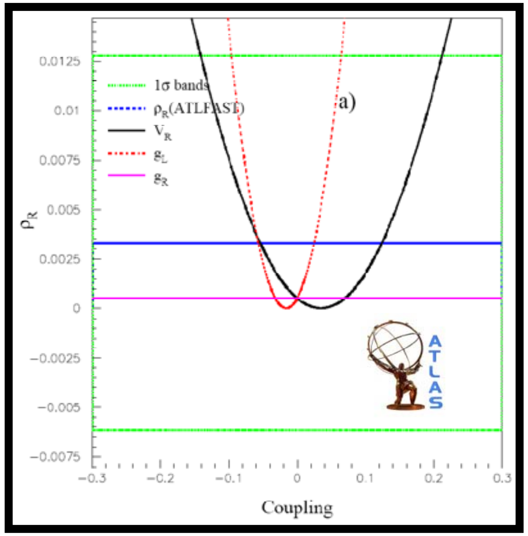
$A_{-} = -0.8387 \pm 0.0018$ (stat) ± 0.0028 (sys)

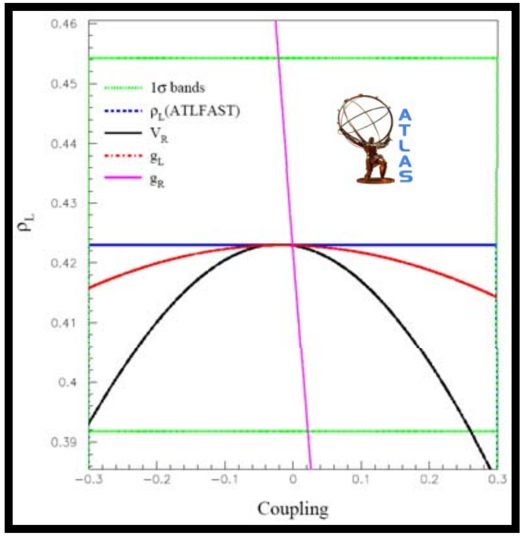
$$\rho_L = \frac{F_L}{F_0}$$
$$\rho_R = \frac{F_R}{F_0}$$

SM(LO)

$\rho_L = 0.423$

$\rho_R = 0.0005$ ($m_b \neq 0$)





1σ Results:

Observable	V_R	g_L	g_R
A_{FB}	$[-0.16, 0.19]$	$[-0.120, 0.085]$	$[-0.030, 0.025]$
$A_{\pm}$	$[-0.10, 0.15]$	$[-0.08, 0.05]$	$[-0.021, 0.017]$
F_0, F_L, F_R	$[-0.12, 0.19]$	$[-0.085, 0.053]$	$[-0.030, 0.024]$
$\rho_{R(L)}$	$[-0.14, 0.21]$	$[-0.10, 0.06]$	$[-0.021, 0.022]$
$\rho^{fit}_{R(L)}$	$[-0.05, 0.12]$	$[-0.05, 0.02]$	$[-0.028, 0.022]$