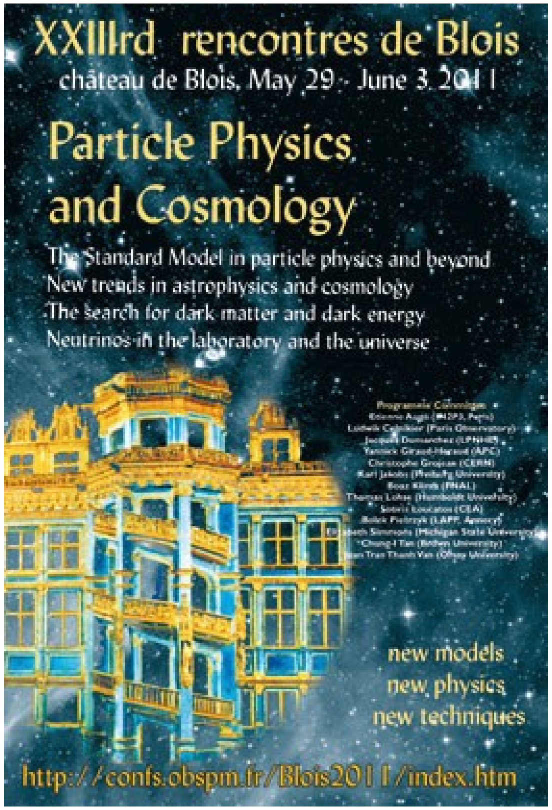
Marco Verzocchi
Fermilab

Status of Electroweak Physics



Outline

Status of the SM and the electroweak fits
- **Areas for improvements**

Observation and measurements with weak bosons at 2 and 7 TeV
- **New cross section results from the LHC**

Differential cross sections and polarization studies
- **A_{fb} and $\sin^2\theta_W$**
- **W charge asymmetry and constraints on PDFs**

W mass measurements
- **... or the fight against multiple interactions per bunch crossing**

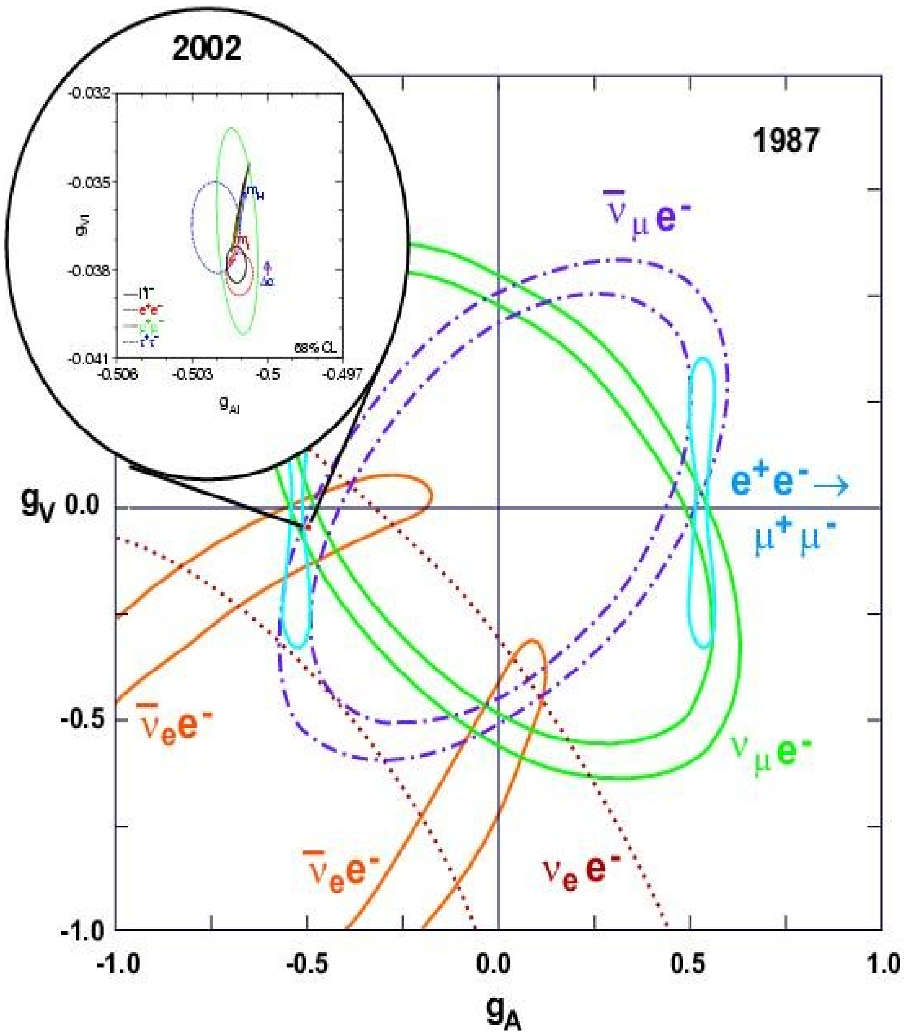
Future trends

The Standard Model (I)

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

Result of 30 years of experimental and theoretical progress

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



The Standard Model (II)

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

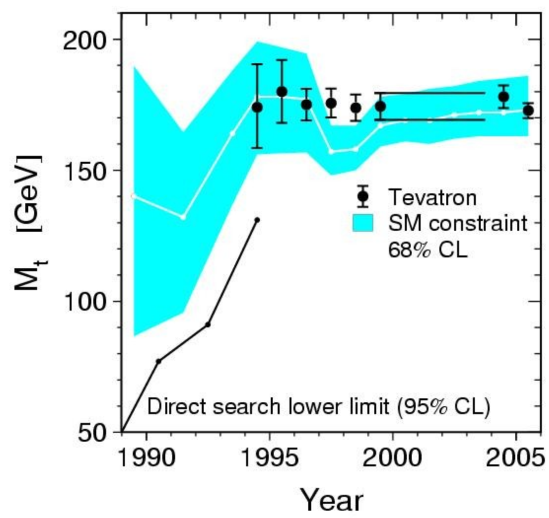
Result of 30 years of experimental and theoretical progress

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

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

The Standard Model (III)

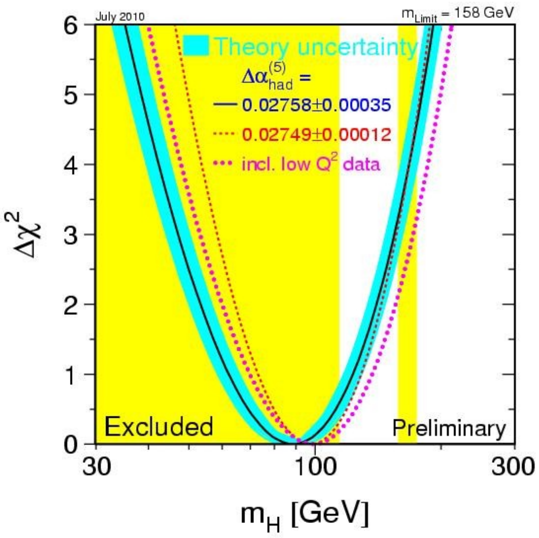
Can describe all measurements with a limited set of parameters

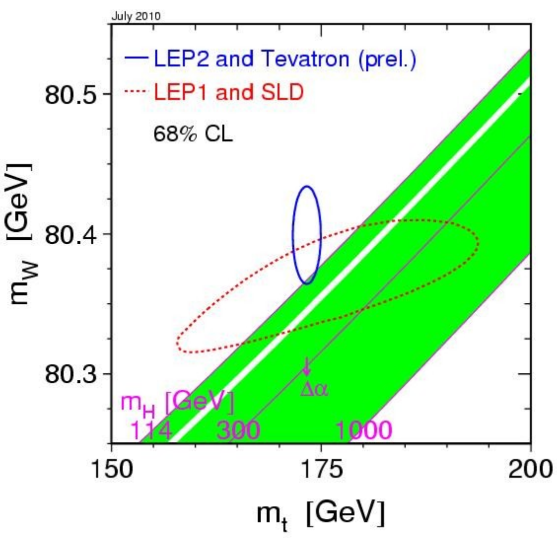


Use radiative corrections to constrain yet unobserved particles

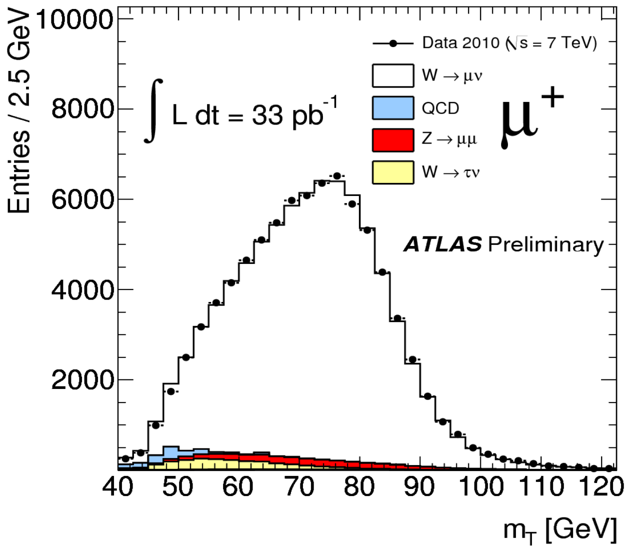
Sensitivity to m_H only through log terms

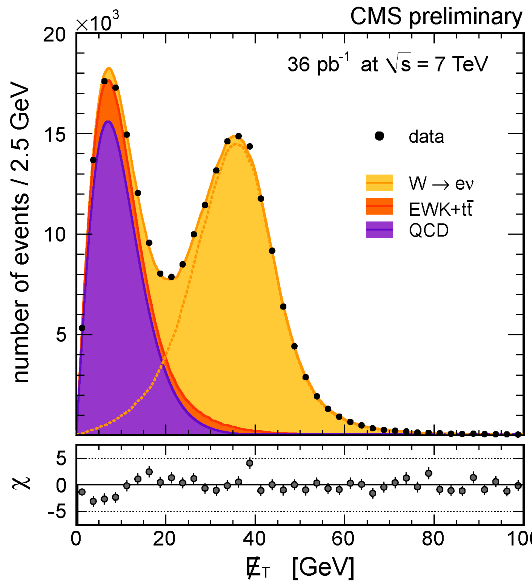
Reason for continued precision improvements in m_t, m_W and $\alpha_{em}(M_z)$ measurements



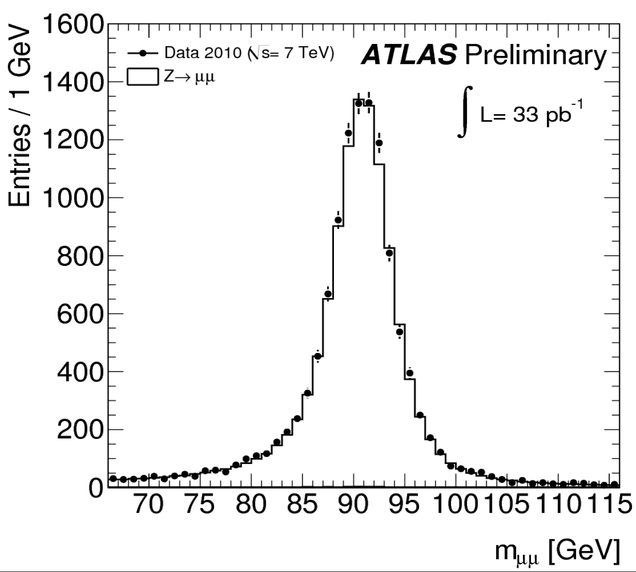


From 2 to 7 TeV: W and Z

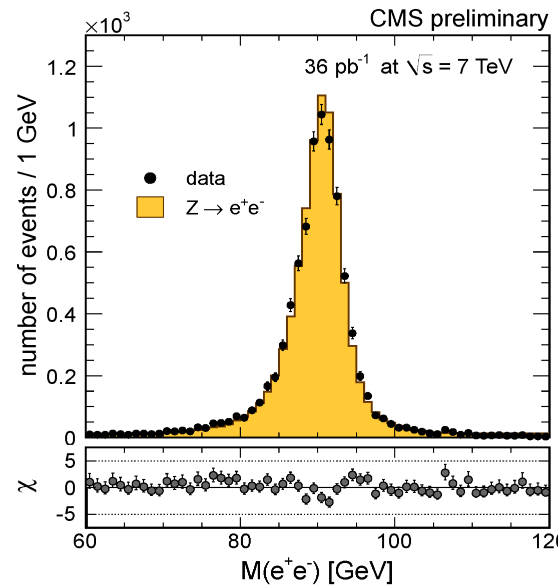




W and Z production measured at Atlas and CMS in both e and μ channels .....

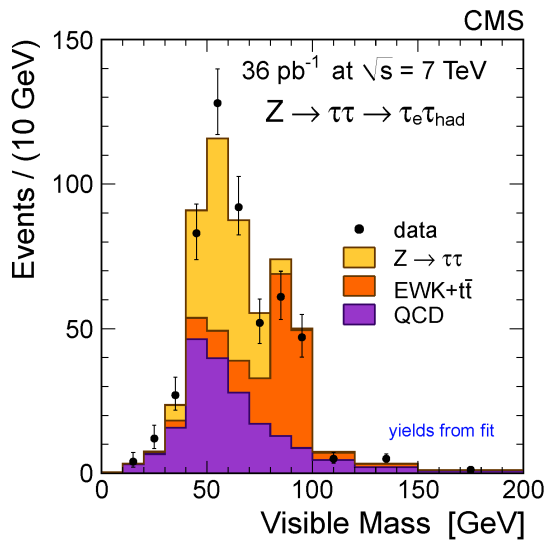


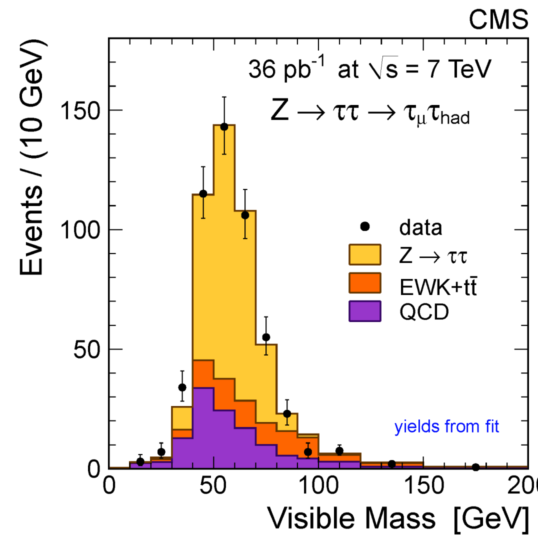
Measurements already systematics limited (luminosity)



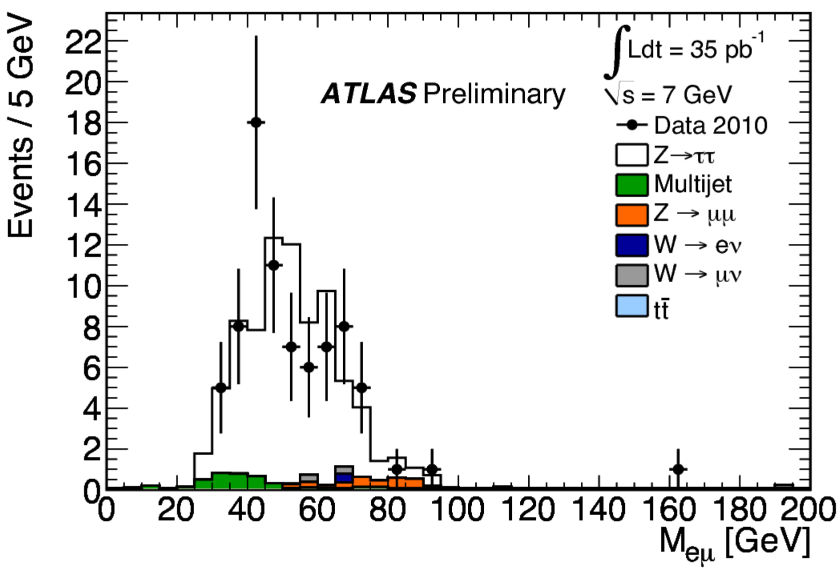
From 2 to 7 TeV: τ decays (I)

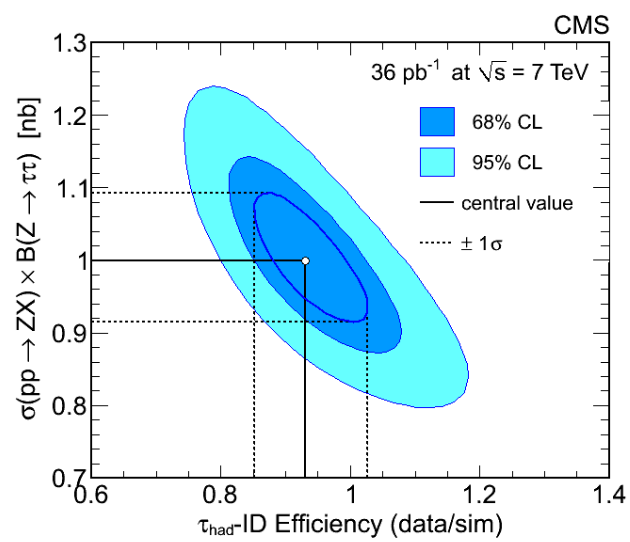
.... and also in τ decays



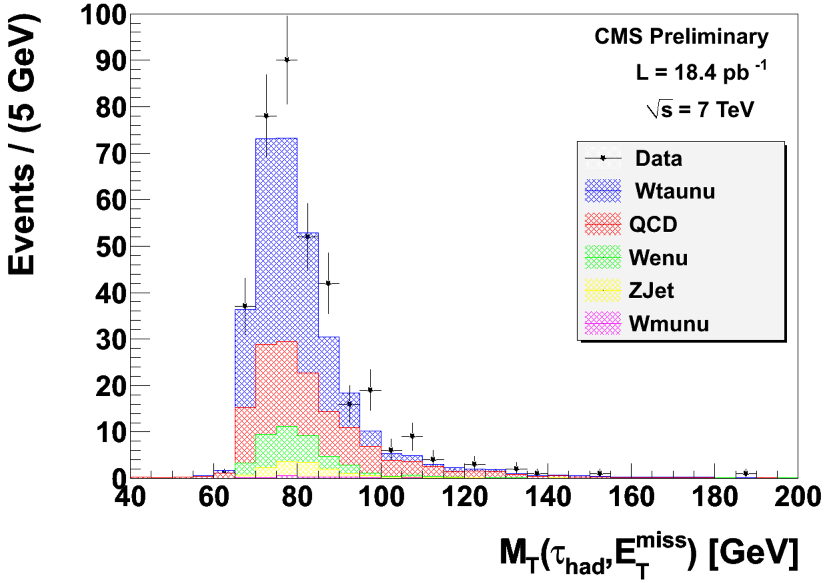


Paves the road for
H→ττ studies

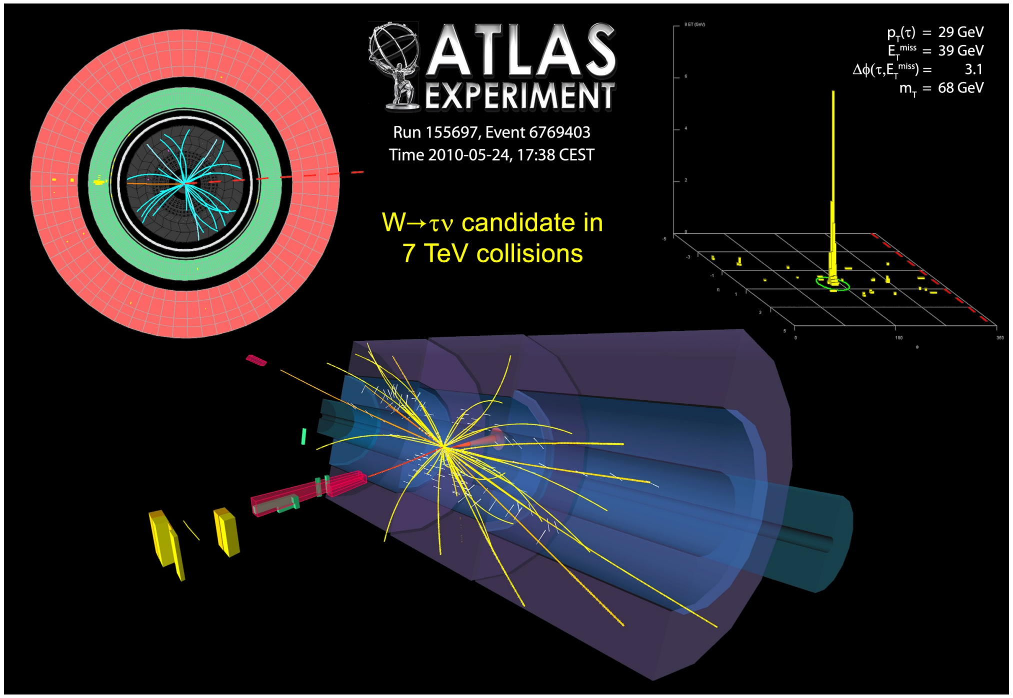




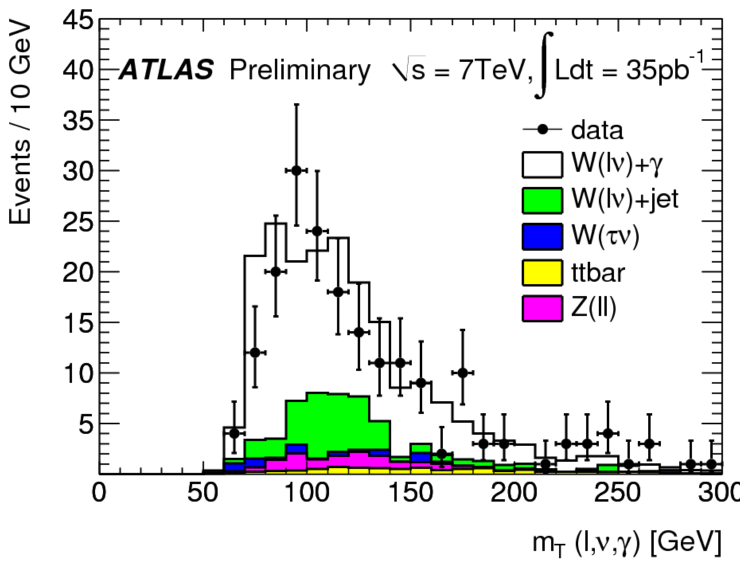
From 2 to 7 TeV: τ decays (II)

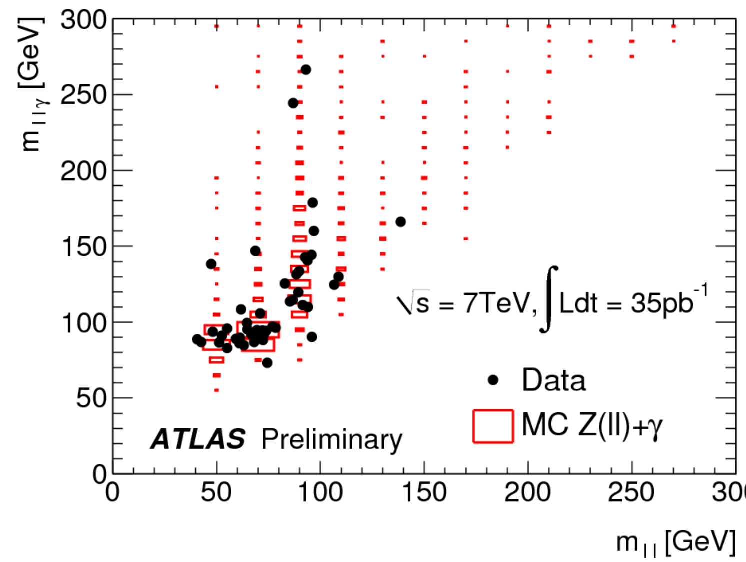


... and also $W \to \tau\nu_\tau$



Diboson Production at LHC (I)

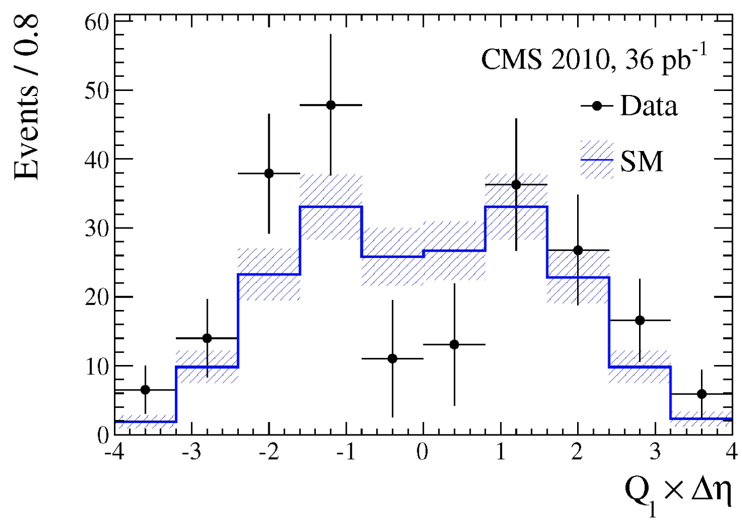


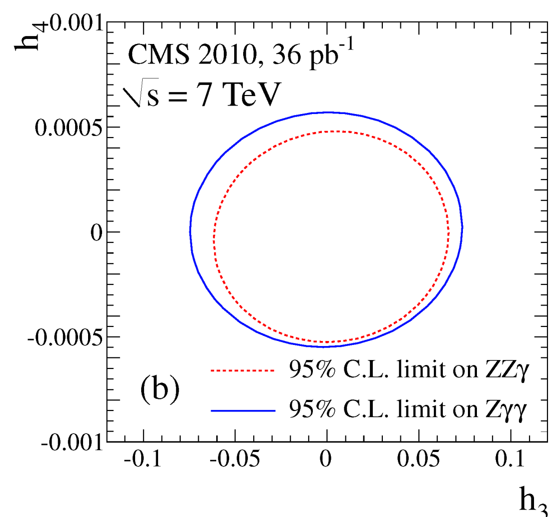


Wγ and Zγ

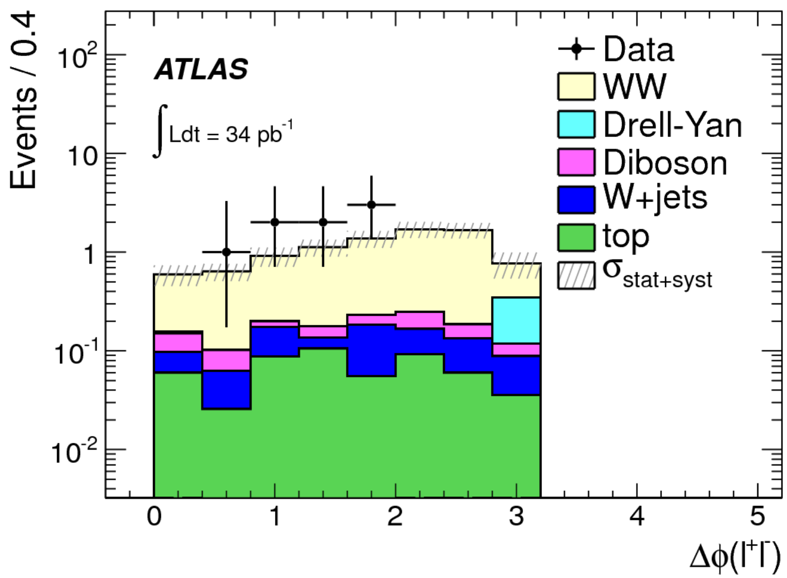
Total and differential cross sections, limits on TGC

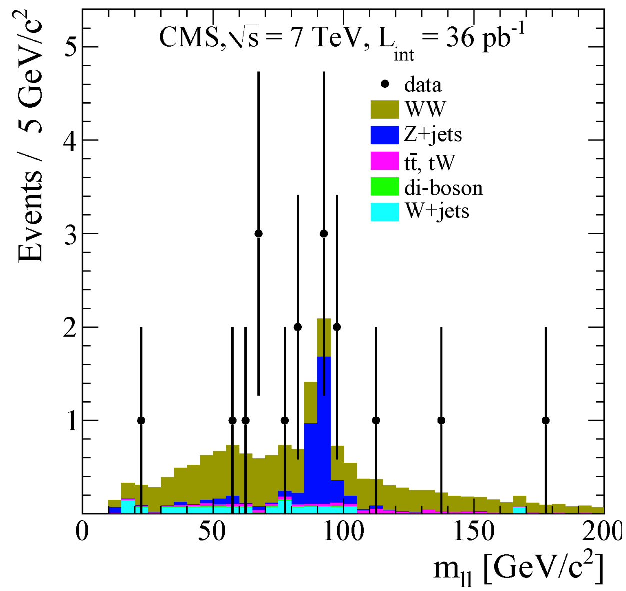
Both Atlas and CMS





Diboson Production at LHC (II)



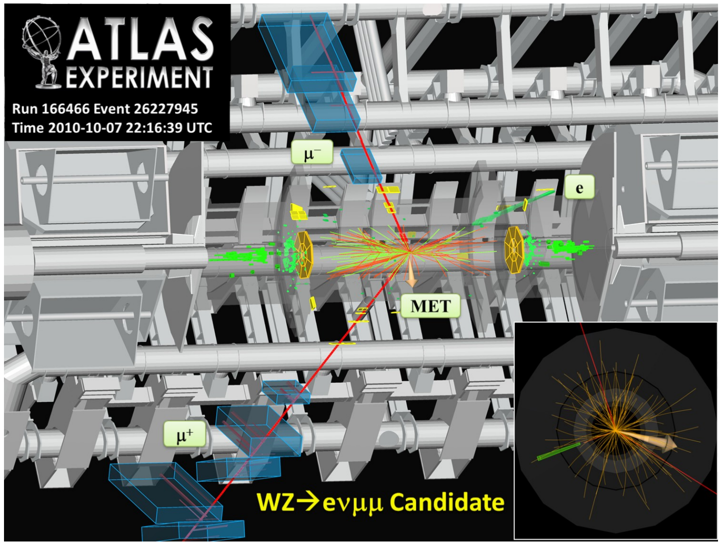


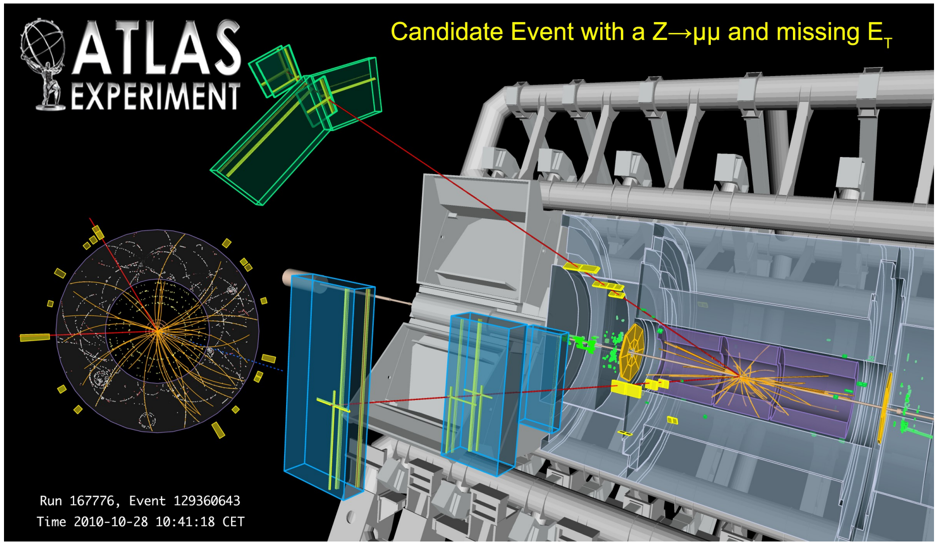
WW production measured in both experiments – O(10) events

Basis for H$\rightarrow$WW search

Start investigating kinematic distributions, jets multiplicities

Diboson Production at LHC (III)

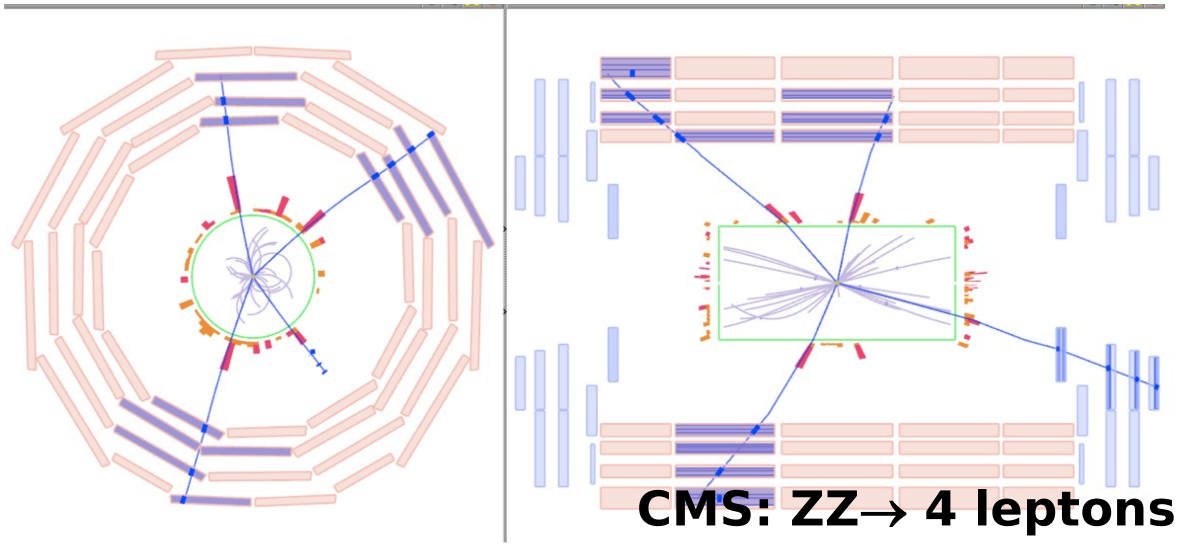




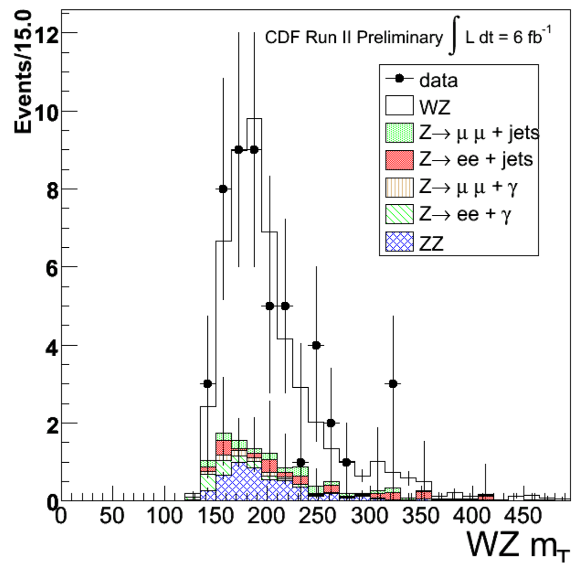
2010 luminosity insufficient for WZ/ZZ observation

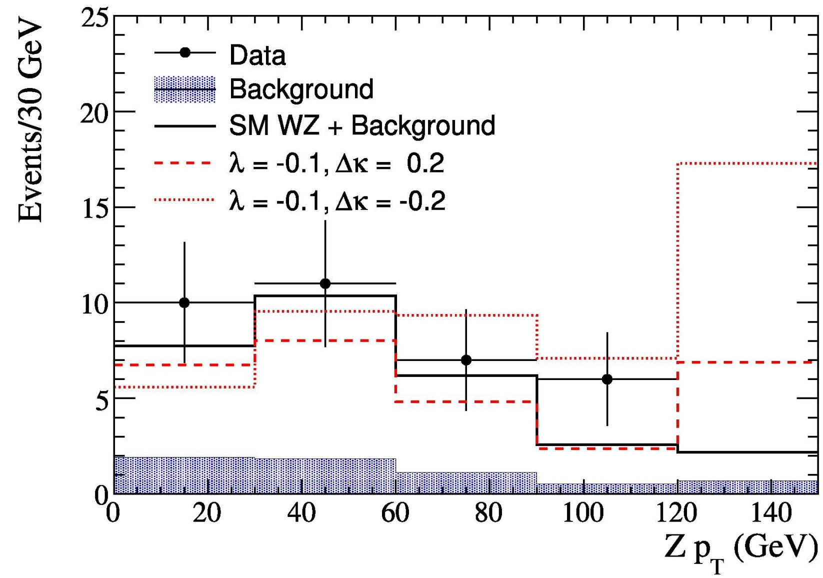
Few candidates

Already 10*times the data in 2011



Diboson Production at Tevatron (I)

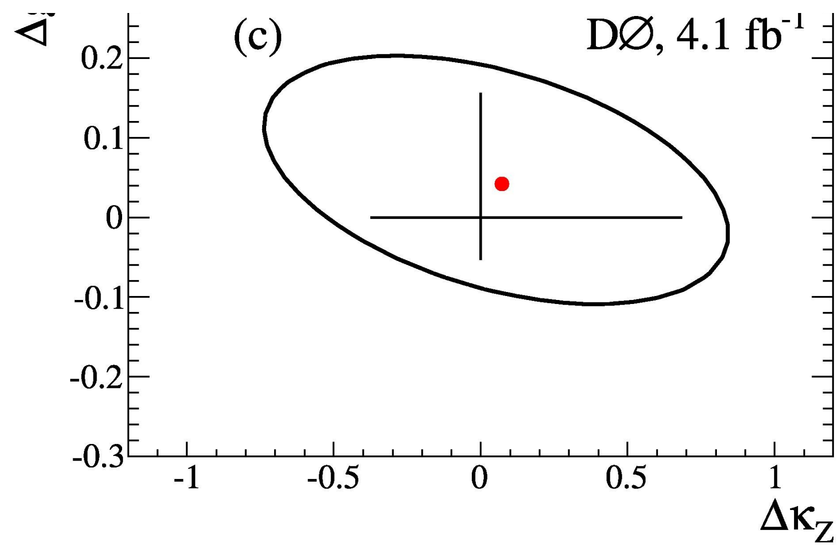




Tevatron WZ production:

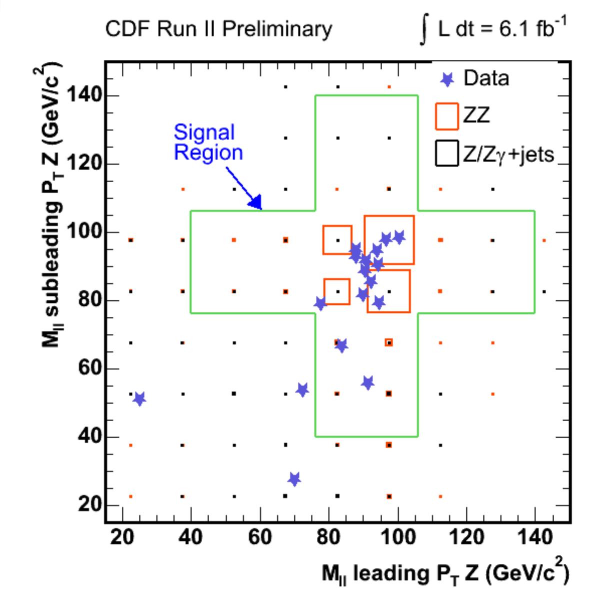
- σ= (3.7±0.8) pb (CDF)
- σ= (3.9±1.0) pb (DØ)

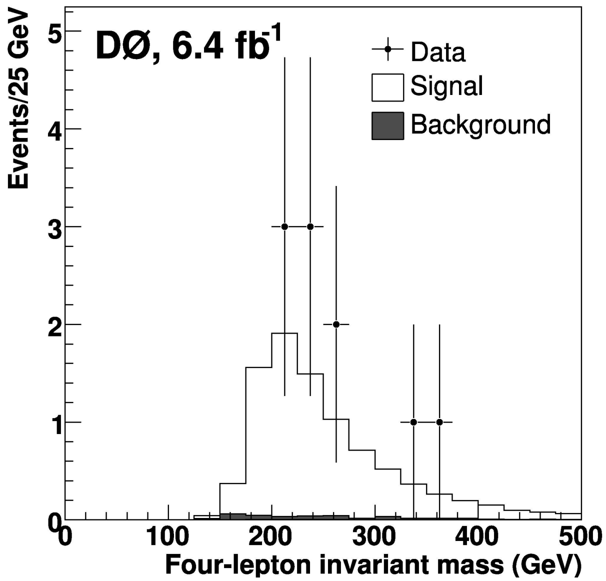
[QCD prediction (3.25 ±0.20) pb]



Best limits on couplings at WWZ vertices

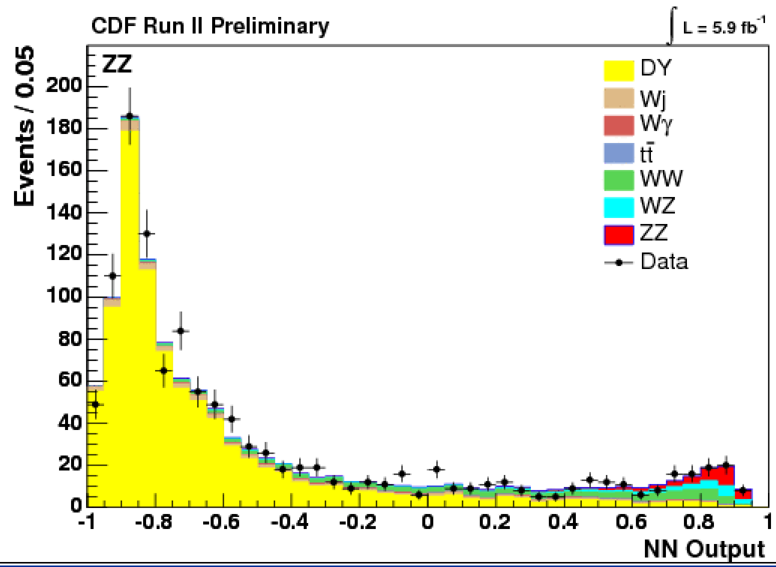
Diboson Production at Tevatron (II)





ZZ production observed at Tevatron

- **4 charged leptons final state**
- **2 leptons + 2 neutrinos (background from WW)**

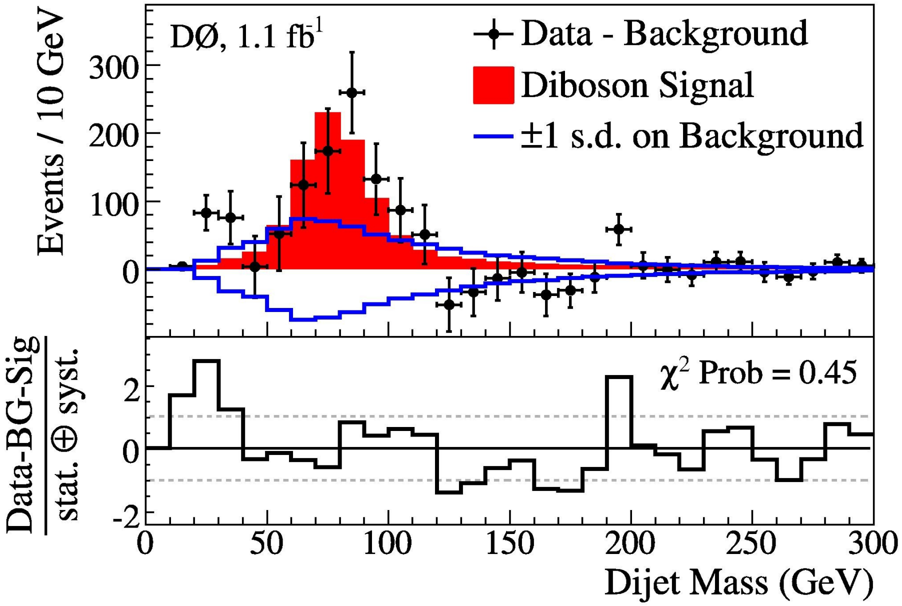


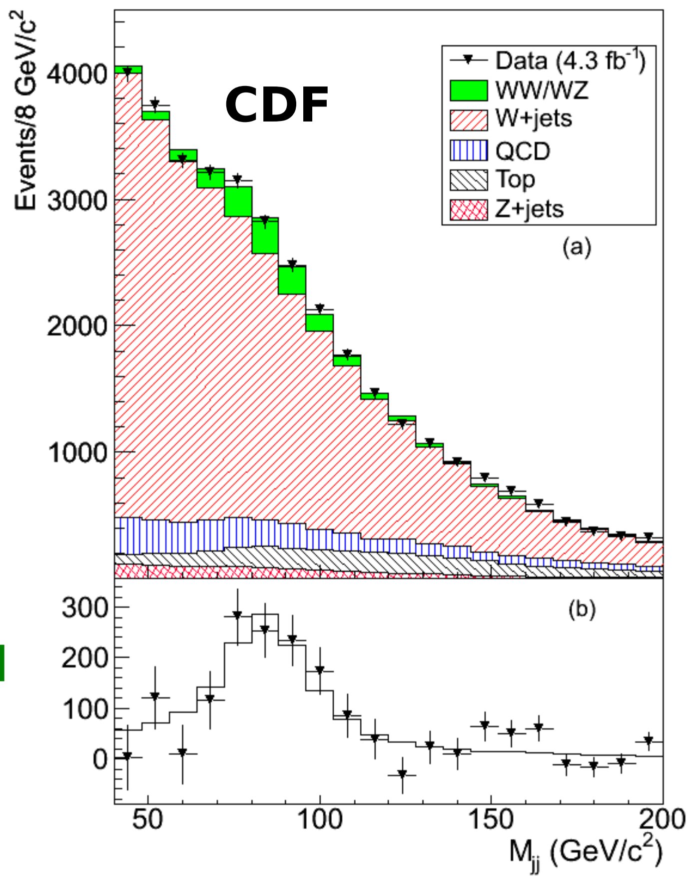
Cross section measurements:

σ= (1.45±0.55) pb (CDF)
σ= (1.40±0.45) pb (DØ)

[QCD prediction (1.4±0.1) pb]

Diboson Production at Tevatron (III)





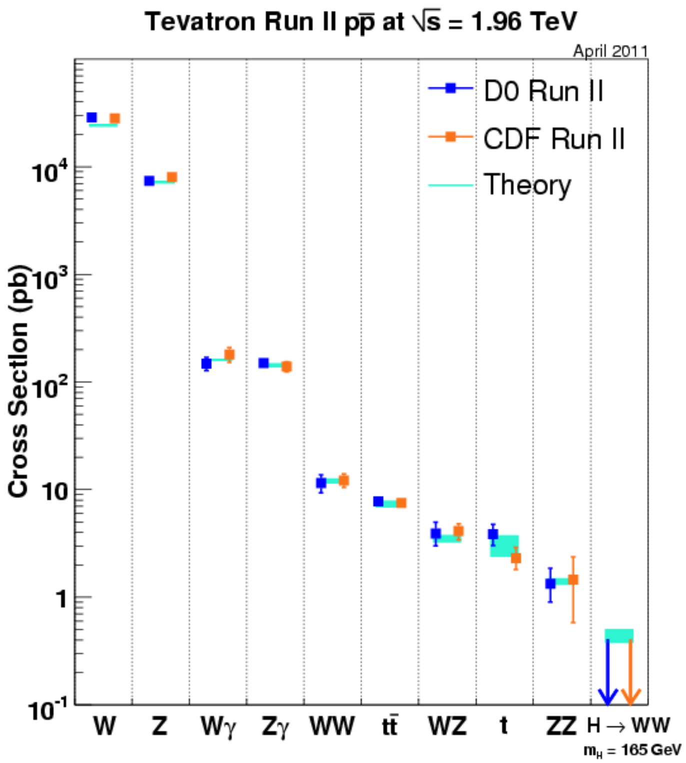
At Tevatron WW/WZ production also observed in final state with 1 leptonic and 1 hadronic weak boson decay

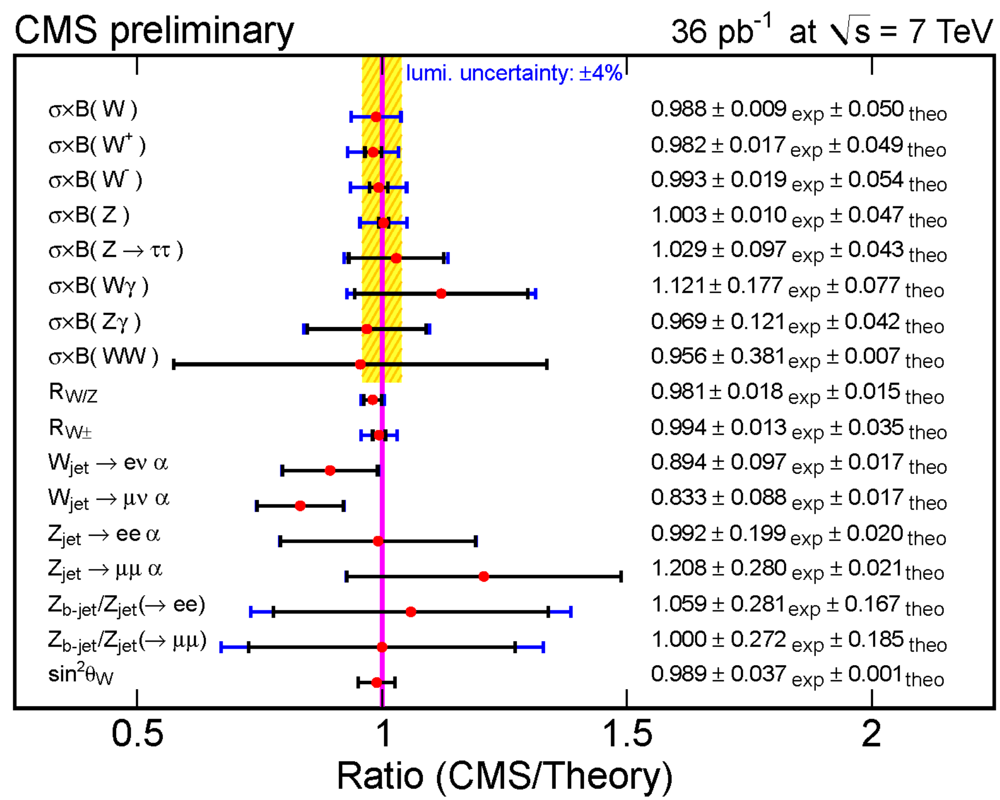
Test of techniques used in Higgs boson searches in WH/ZH channels

Next: WZ with $Z \to b\bar{b}$

Giovanni will discuss the bump ....

Cross Sections Summaries



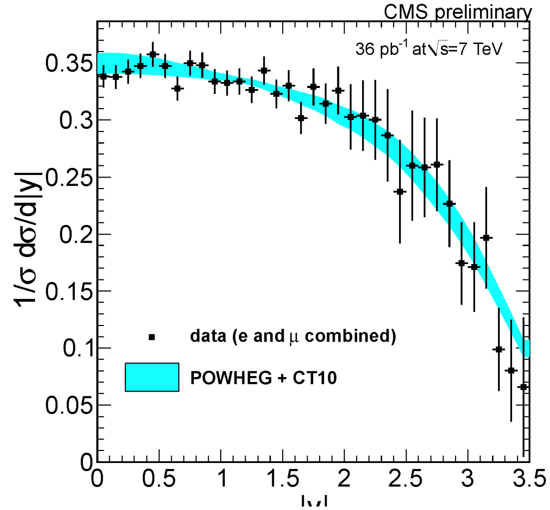


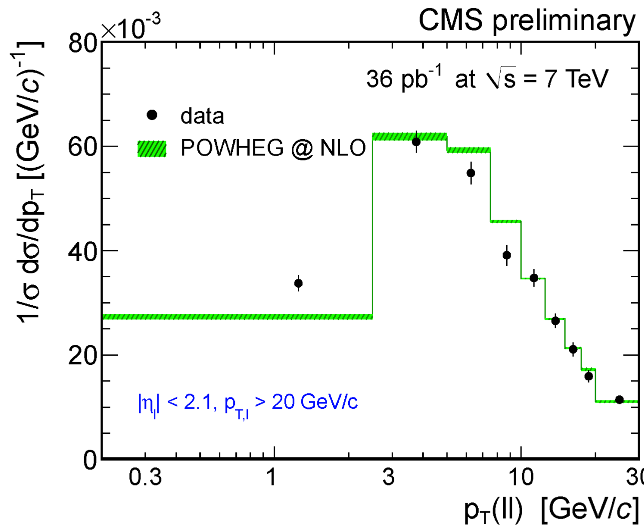
Impressive progress of LHC experiments in measurement of weak bosons production cross sections

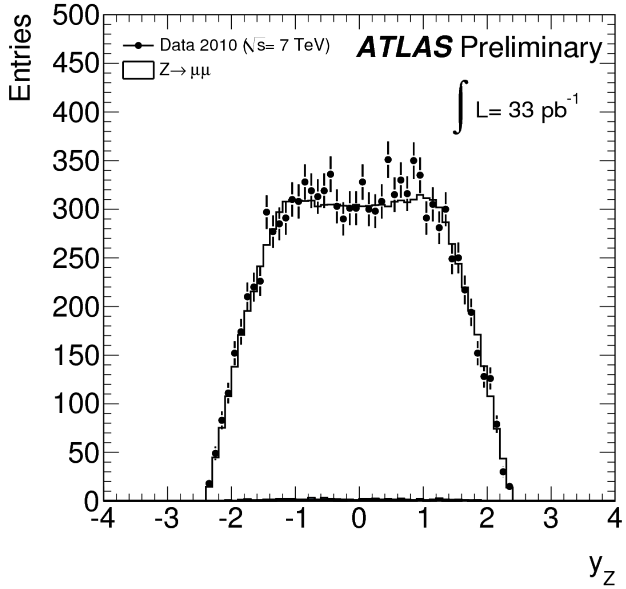
At Tevatron: measured cross sections O(1 fb)

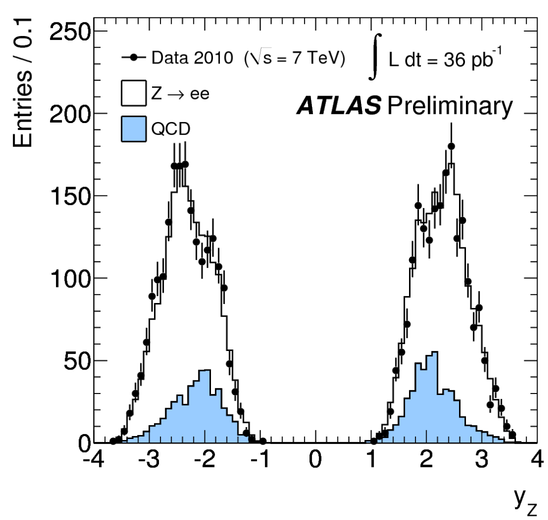
Differential Cross Sections (LHC)

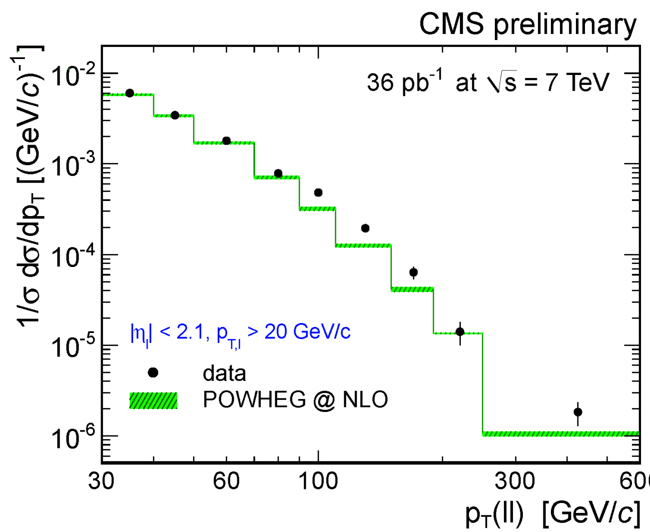
Start to investigate details of production and tuning of event generators: $d\sigma/dp_T$ and $d\sigma/dy$ for Z bosons









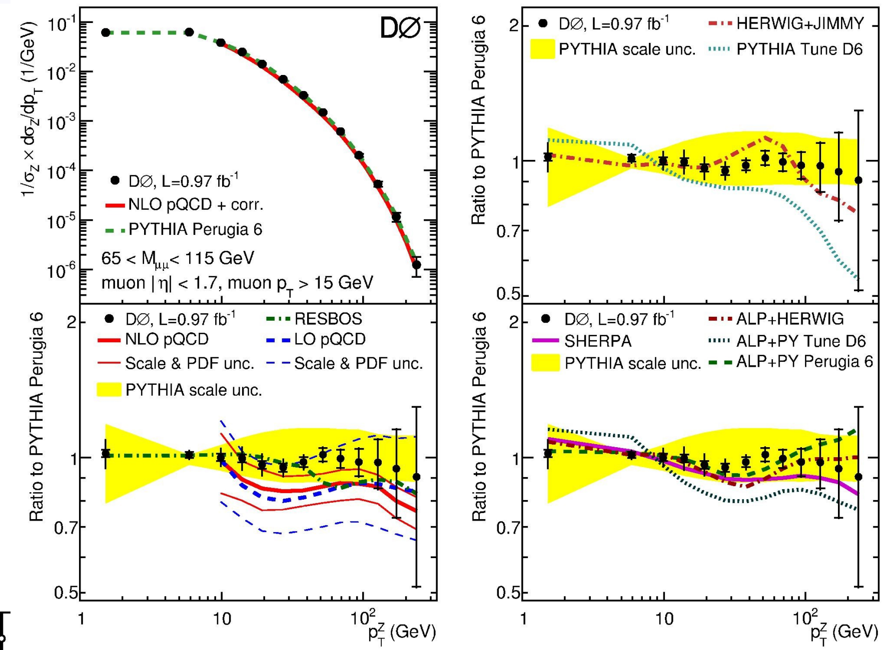


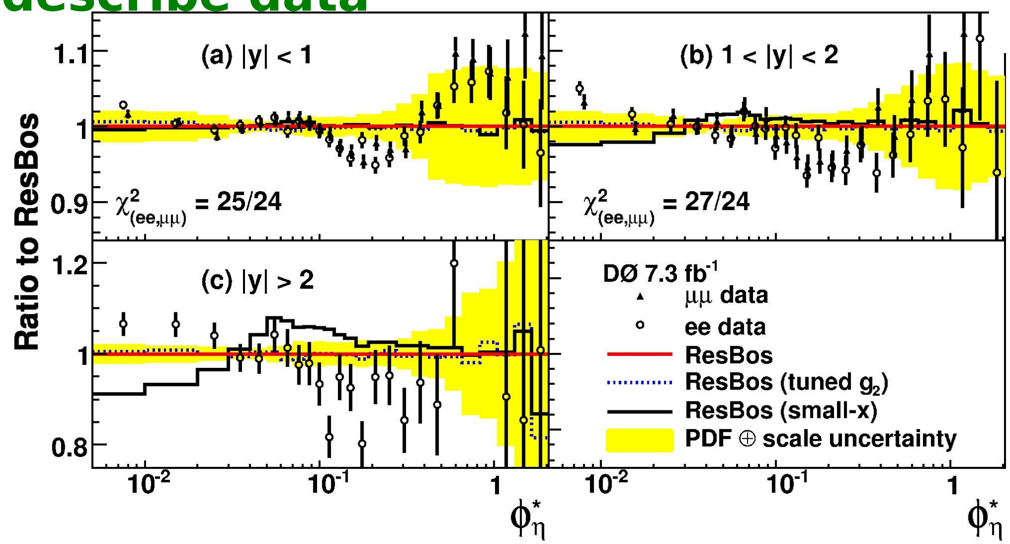
Differential Cross Sections (Tevatron)

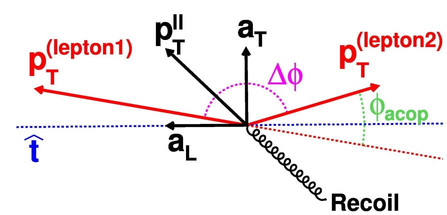
At large $p_T(Z)$ NLO calculations give adequate description of data

At low $p_T(Z)$ detector effects can be dominant, use different variables with minimal sensitivity to detector effects (DØ)

Resummed calculations fail to describe data







W polarization @ CMS

At LHC, W polarized if produced in association with jets:

- $u+g \rightarrow W^+ + q\text{-jet}$
- $d+g \rightarrow W^- + q\text{-jet}$

Select high p_T W to enhance qg vs $q\bar{q}$,$\bar{q}g$ contributions to cross section

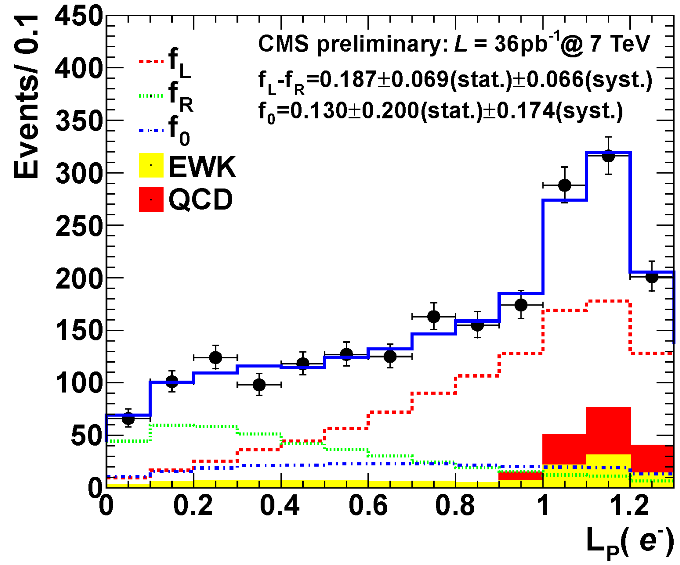
Standard method to analyze polarization: fit different components to angular distribution of lepton in W rest frame

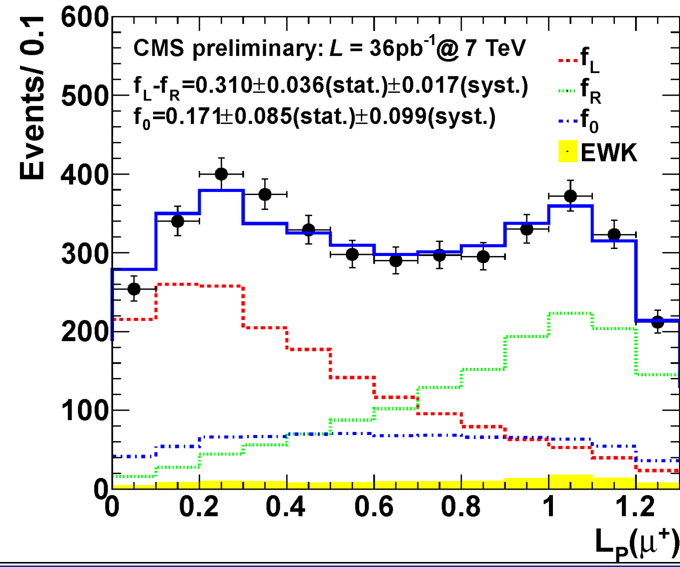
$$\frac{dN}{d\Omega} \propto (1+\cos^2\theta^*) + \tfrac{1}{2}A_0(1-3\cos^2\theta^*) + A_1\sin 2\theta^*\cos\phi^* + \tfrac{1}{2}A_2\sin^2\theta^*\cos 2\phi^* + A_3\sin\theta^*\cos\phi^* + A_4\cos\theta^*,$$

Instead measure variable built of $p_T(l)$ and $p_T(W)$:

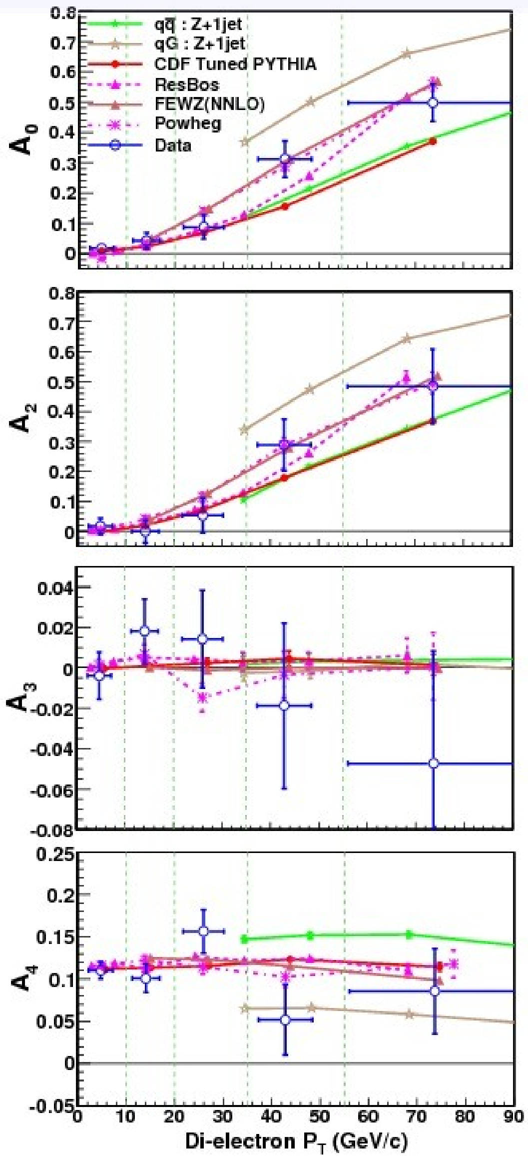
$$L_P = \frac{\vec{p}_T(\ell)\cdot\vec{p}_T(W)}{|\vec{p}_T(W)|^2}.$$

High p_T W produced predominantly in left handed polarization state





Z polarization @ CDF

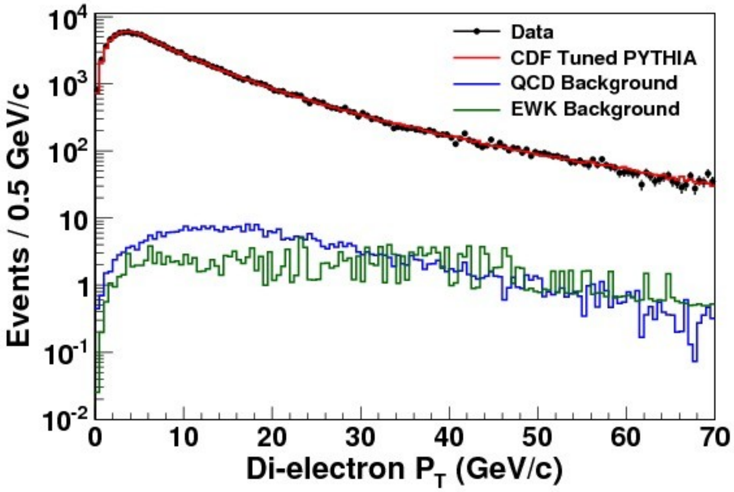


Measure angular distributions of Z decay products as a function of pT

Decompose angular distrubution according to terms with different sensitivities to $q\bar{q}$ and qg production mechanism

Angular distribution use also for determination of $\sin^2\theta_W$

$\sin^2\theta_W = (0.2329 \pm 0.0008(\text{meas.}) \pm 0.0009(\text{QCD}))$

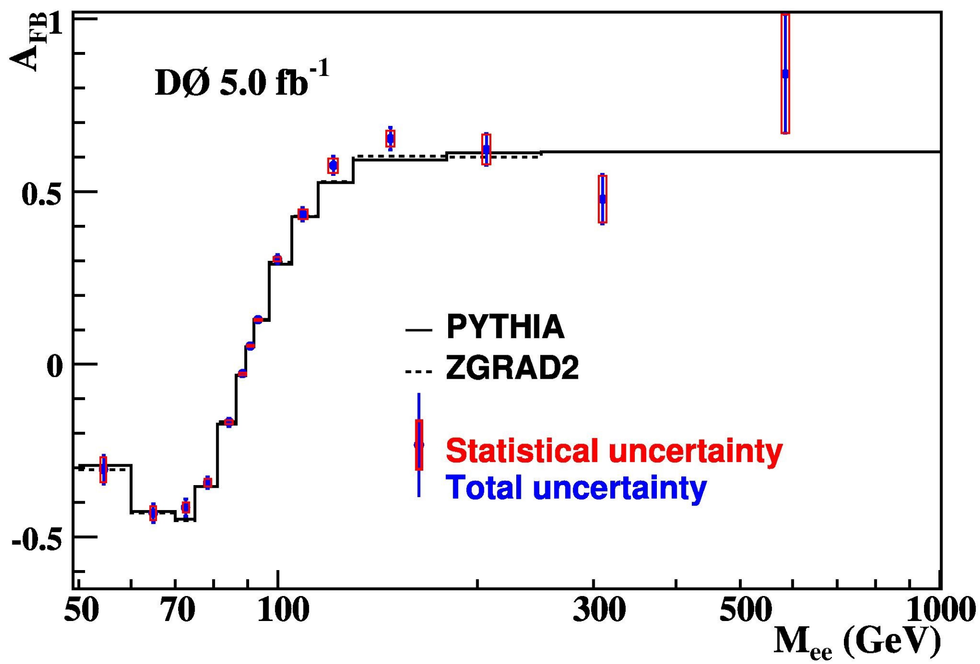


$\sin^2\vartheta_W$ at DØ (I)

Measure $u\bar{u}, d\bar{d} \to Z \to ee$, T reversal of reaction studied at LEP

Study forward-backward asymmetry vs $\sqrt{s}$

Sensitivity to Weinberg angle near Z pole



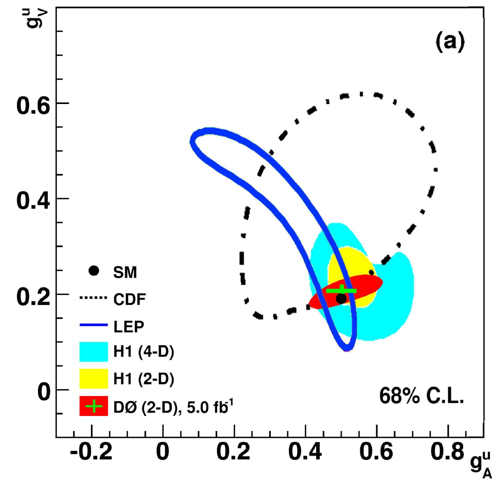
LHC experiments also considering this: first results from CMS

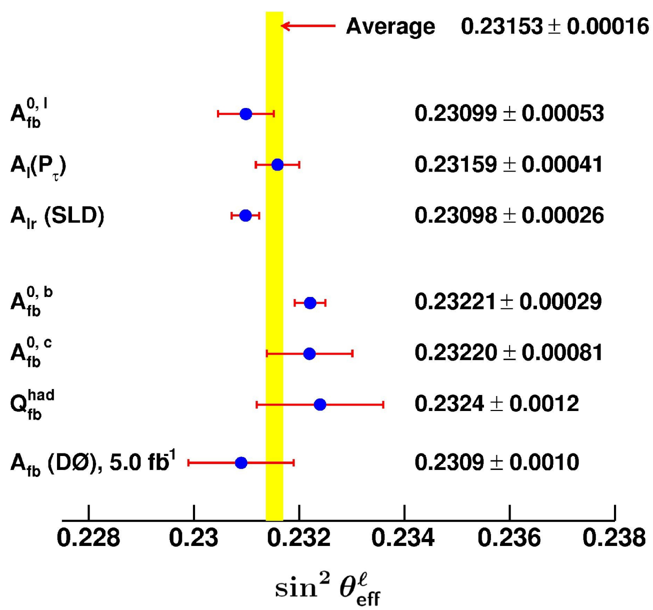
$\sin^2\vartheta_W$ at DØ (II)

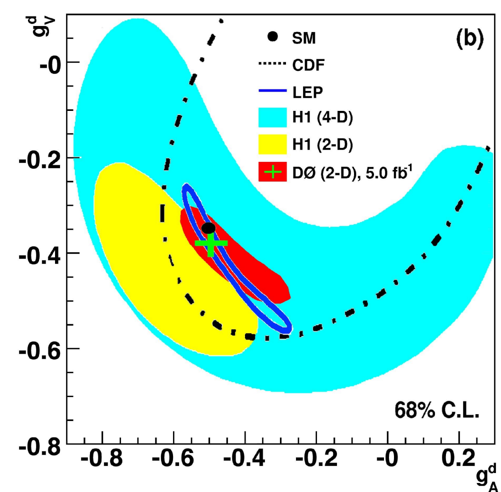
Most precise determination of light quark couplings of the Z boson

Surpassed LEP precision for $\sin^2\theta_W$ determination from inclusive jets

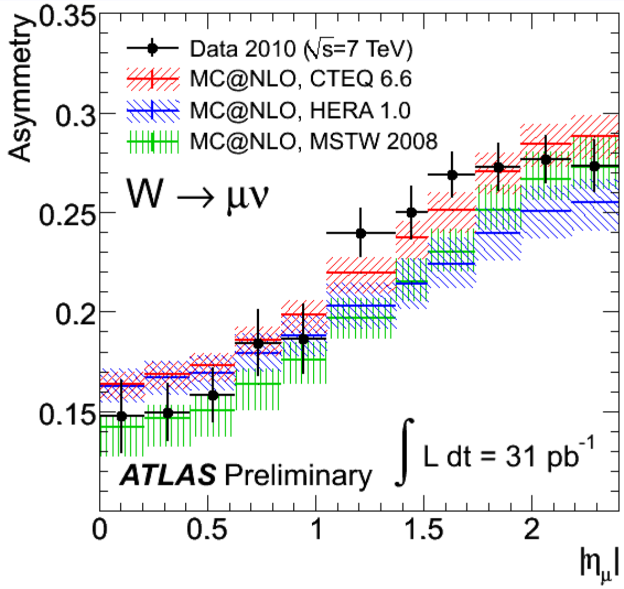
Contribute to resolve discrepancies with full dataset

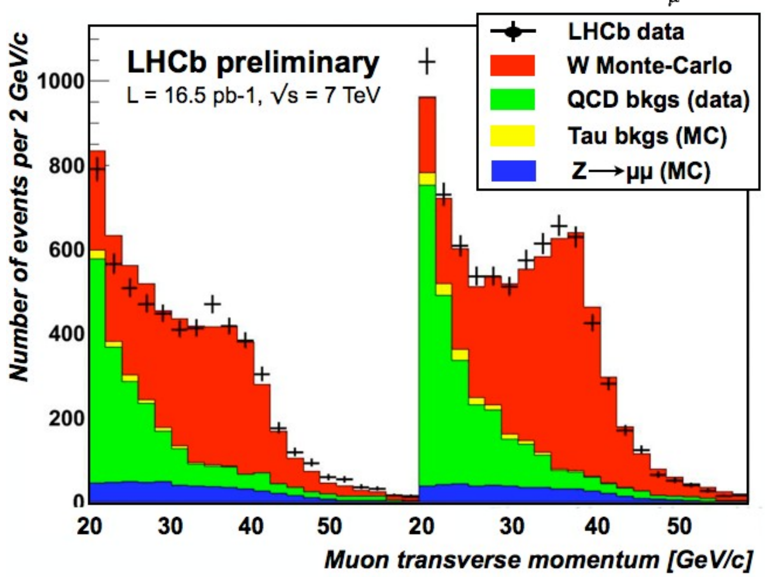


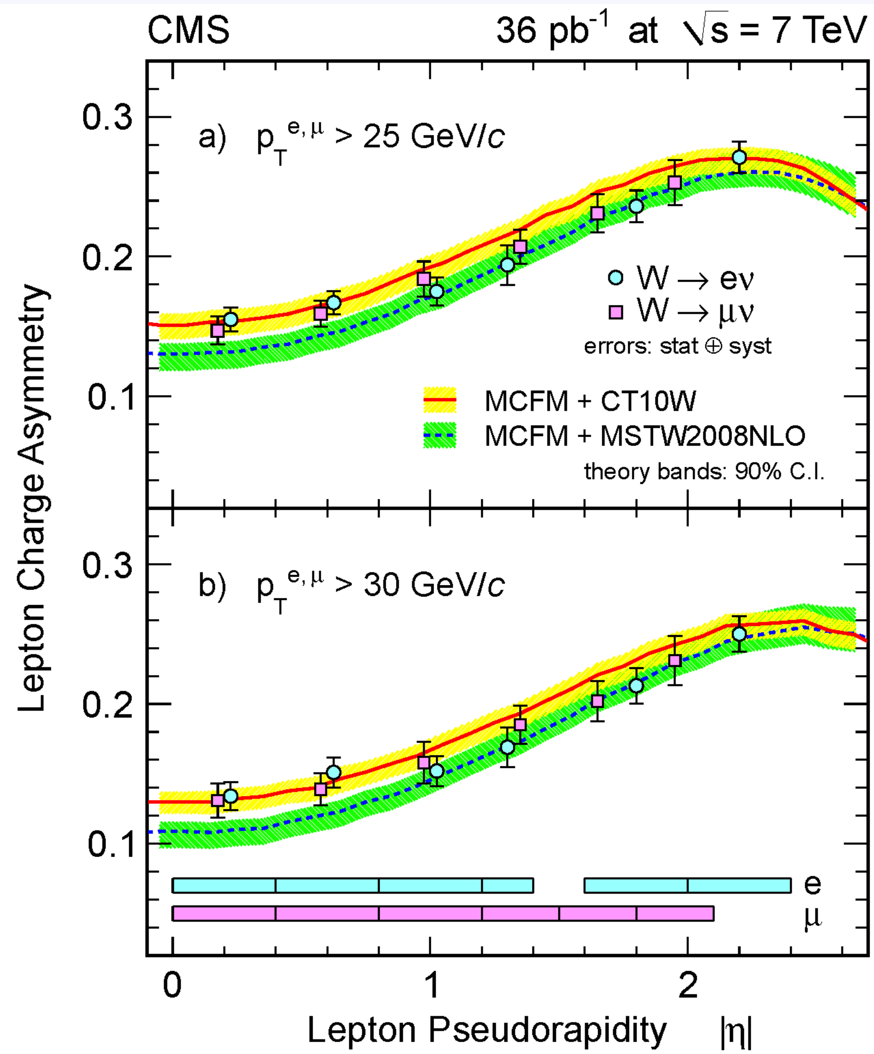




W Charge Asymmetry at LHC (I)





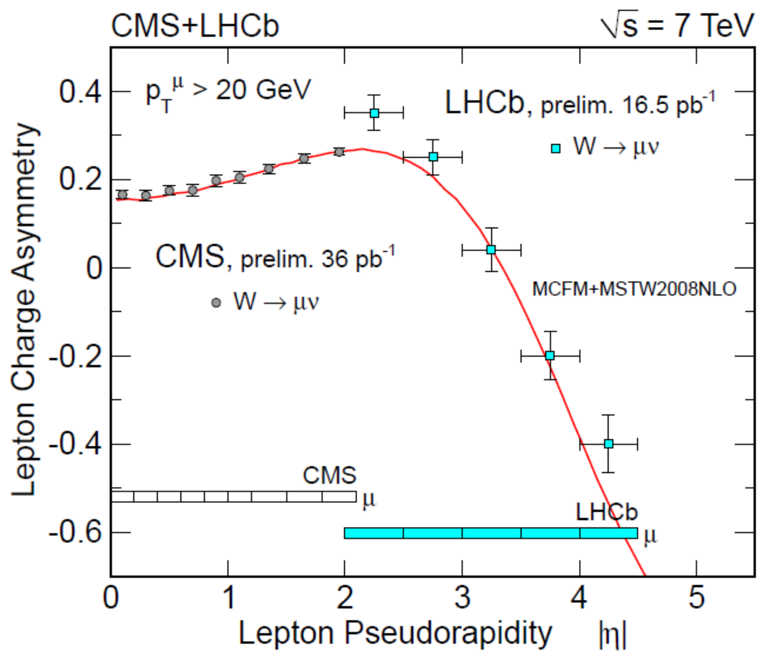


W Charge Asymmetry at LHC (II)

Forward-backward asymmetry for Z and W charge asymmetry are two areas with large interest at LHC

First combination of results from different experiments

LHCb complementary coverage relative to Atlas/CMS: will definitely contribute in this area



Actively pursued also at Tevatron, both CDF and D0 committed to continue these measurements with full dataset

Crucial for reducing uncertainty on u/d ratio, improve W mass determination

W Mass Measurement (I)

Question from the organizer: "When are you guys going to come out with the new W mass measurement ?"
Answer from the experiment: "We are trying very hard to get the result for the Summer...."

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12 months later

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(to our excuse, we learned not to specify the year.....)

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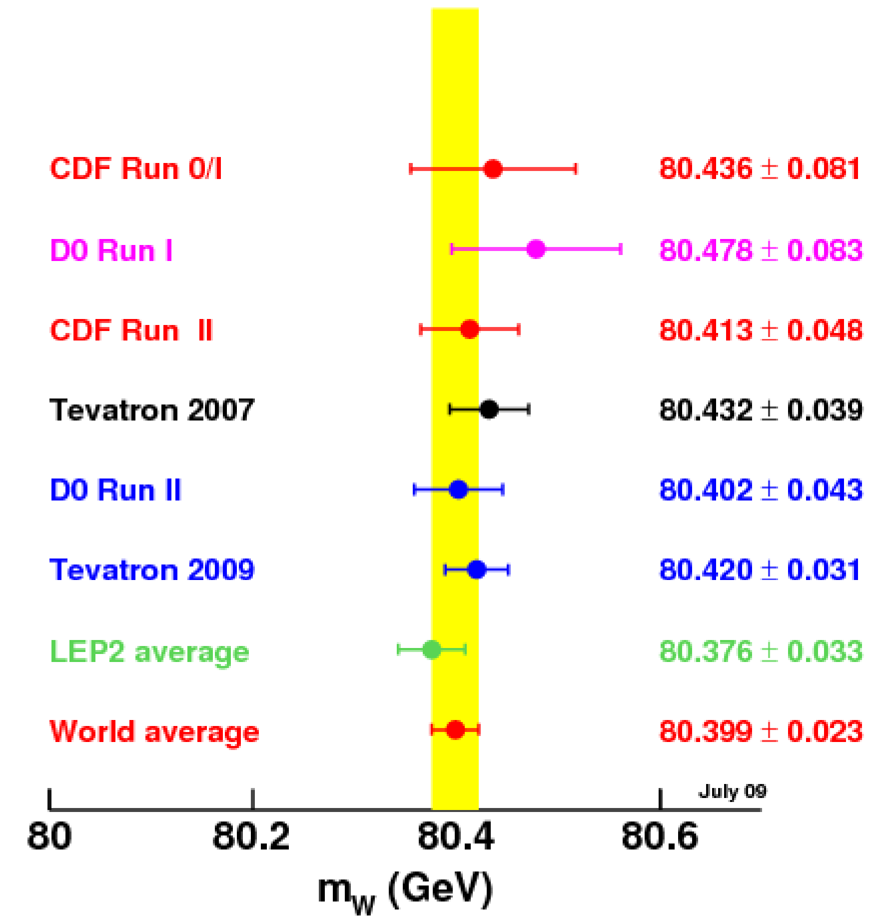
(to our excuse, we learned not to specify the year.....)

Need Δm_W<10 MeV to match contribution to uncertainties from m_t determination

Need also improvements on determination of $\alpha_{em}(M_z)$

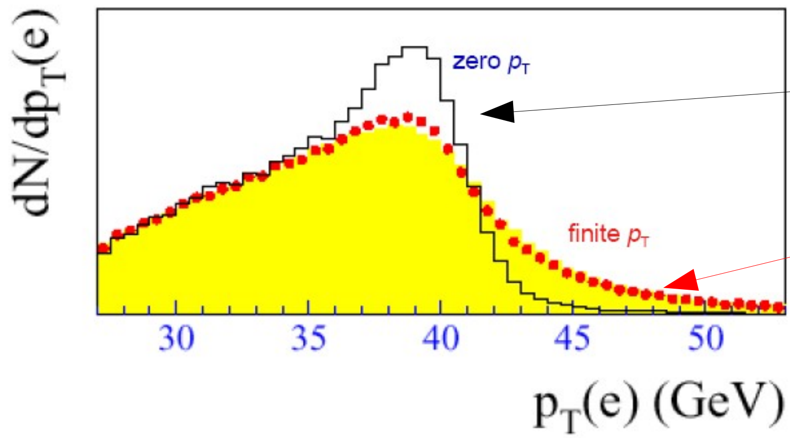
W Mass Measurement (II)



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

DØ: reach uncertainty of 16 MeV with full dataset

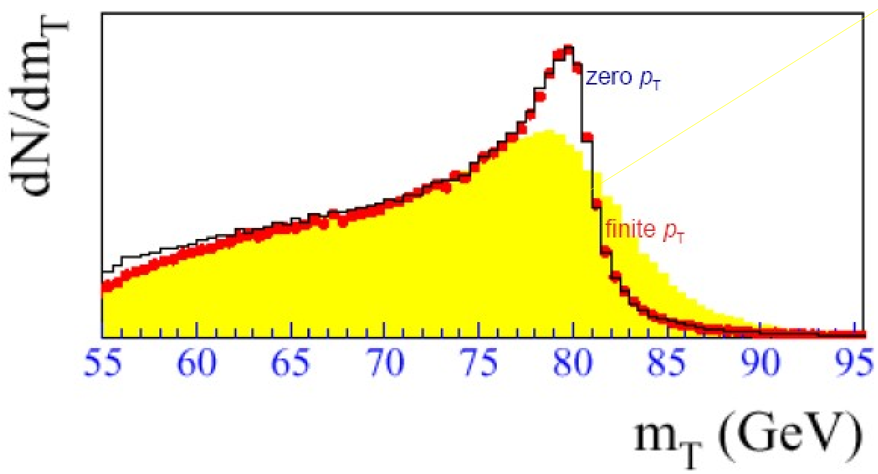
W Mass Measurement (III)



True distribution

Including p_T(W) effects

Including detector effects



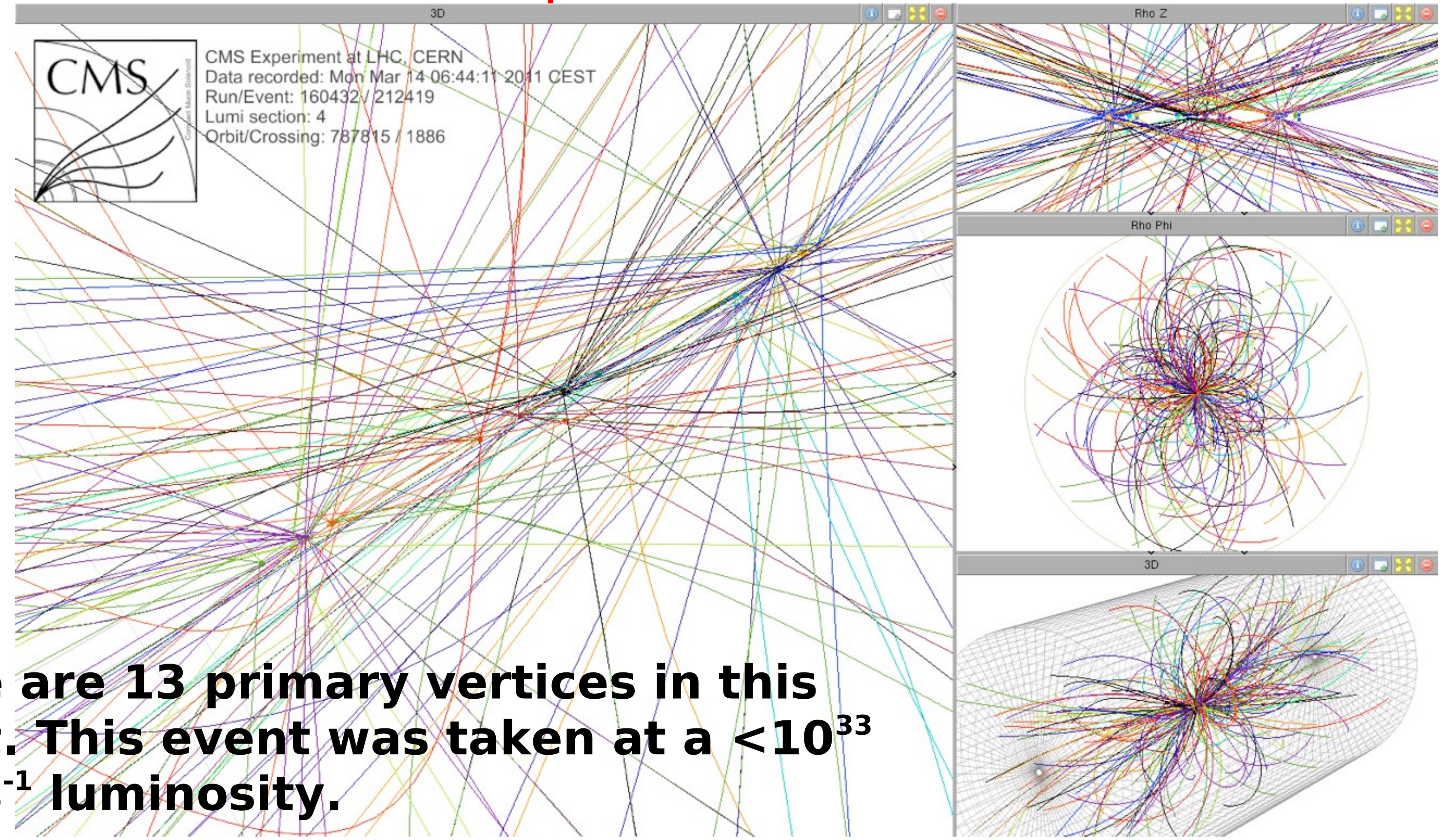
p_T(e) not sensitive to detector effects, requires p_T(W) knowledge

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

W Mass Measurement (IV)

Both Tevatron and LHC experiments taking data with large number of collisions per bunch crossing

Need detailed understanding of contributions from multiple interactions to missing E_T



There are 13 primary vertices in this event. This event was taken at a $<10^{33}$ cm^{-2} s^{-1} luminosity.

Future trends

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

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

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

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

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