Electroweak Physics: then, now and in the future

DØ Collaboration Meeting
10th June 2014

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University of Manchester.

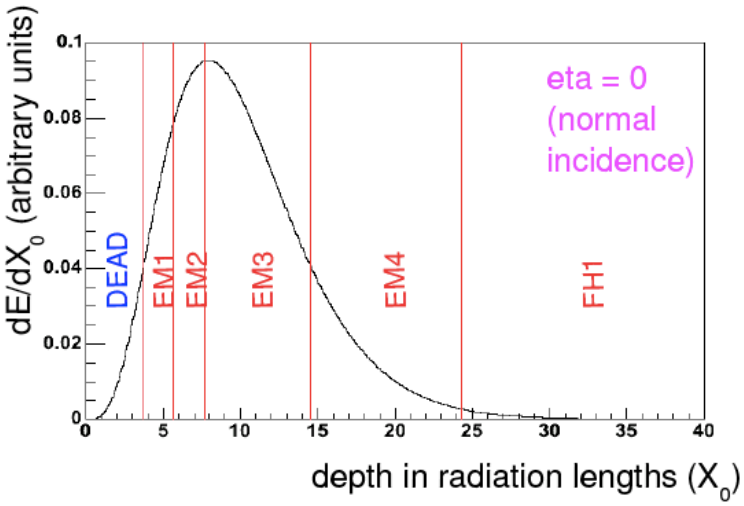
Joined DØ in $\tau_{D\emptyset}/2$

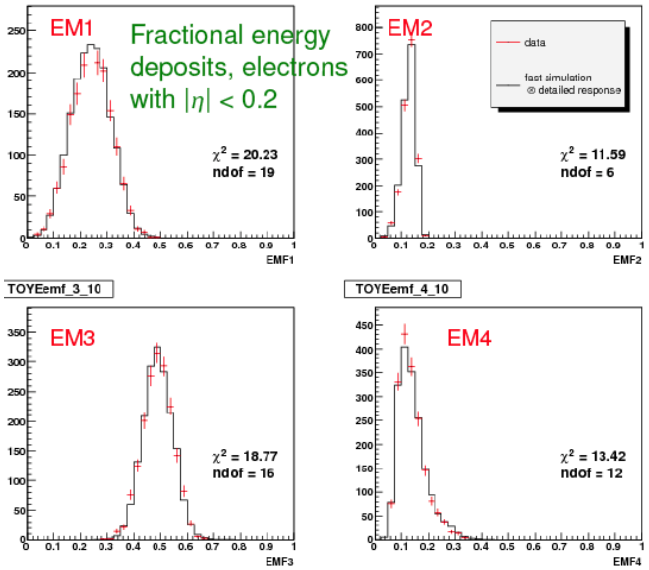
Introduction/Overview

- Events containing W & Z bosons tell us about:
  - EW physics (of course!)
  - phenomenology of high energy (anti)proton-proton collisions
  - the DØ detector
- Topics
  - Single W/Z boson "EW"
    - W boson mass
    - Z boson forward-backward asymmetry ➔ $\sin^2\theta_W^{eff}$
  - Single W/Z boson "QCD"
    - Z boson transverse momentum and ϕ^*_η
    - Boson rapidity
  - Di-bosons
  - Longer term future of EW physics
  - A few personal reflections
- In this talk I shall cover measurements using exclusively the leptonic decay products of W and Z bosons
  - Bob's QCD talk (jets produced in association with leptonically decaying W & Z)

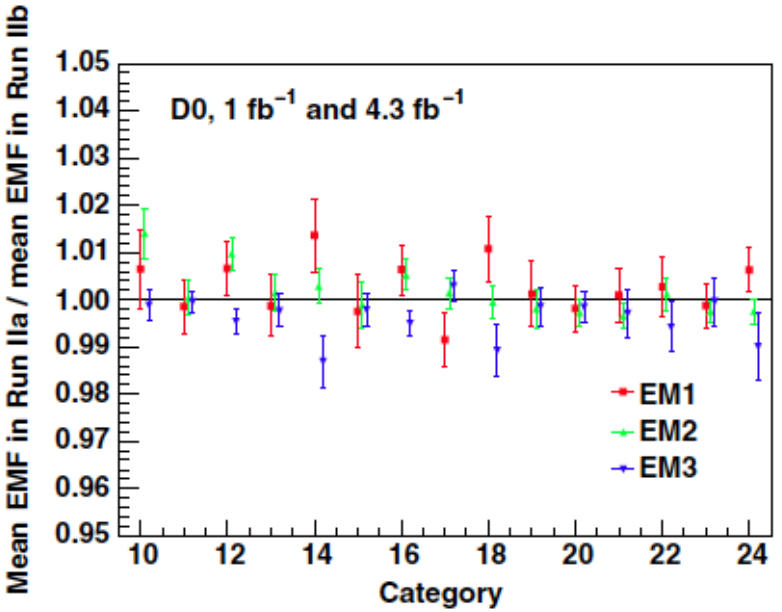
W boson mass (W→eυ)

- 5.3 fb^{-1}: ~2.2M W→eυ events, ~75k $Z \to e^+e^-$ events
- The main challenge:
  - Measure electron energy response at better than per mille level
    - Including dependence on energy, |η|, etc.
    - Including effect of ~4 X_0 dead material in front of calorimeter
  - Calibrate using $Z \to e^+e^-$ events making use of information from:
    - four samplings in depth in EM calorimeter, |η| dependence



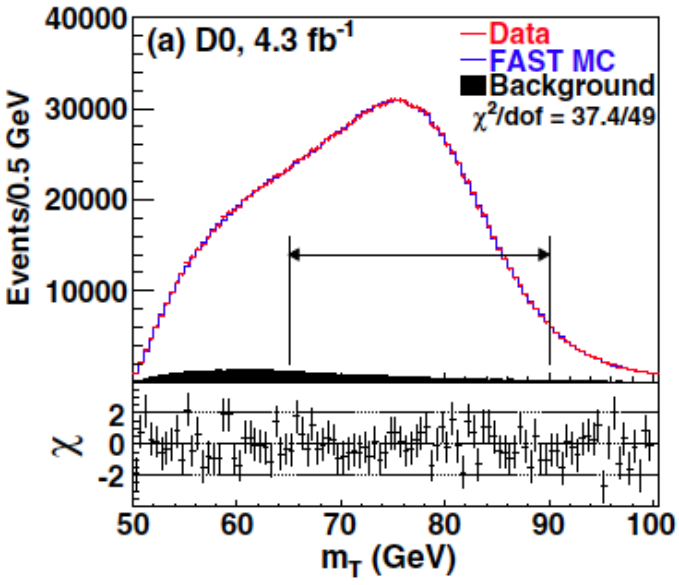


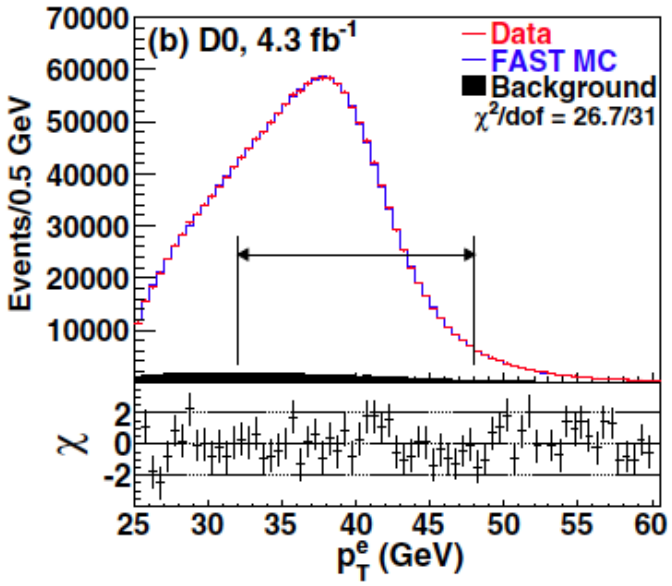
Dead material known to ±0.01X_0!

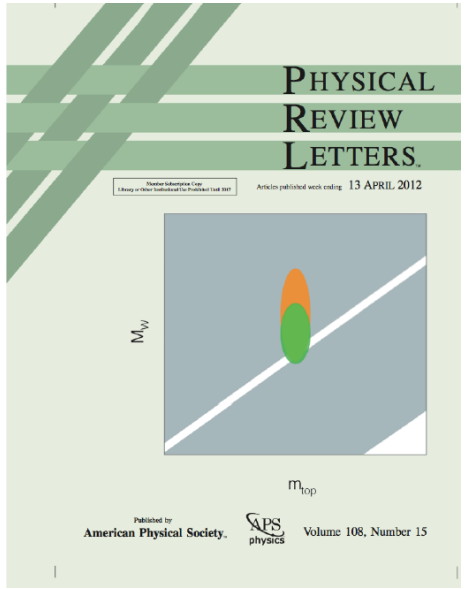


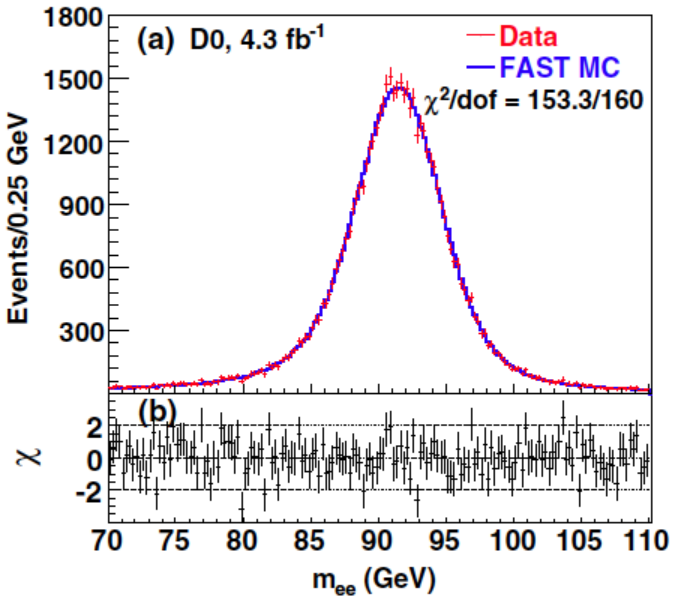
cross check of run IIa and IIb

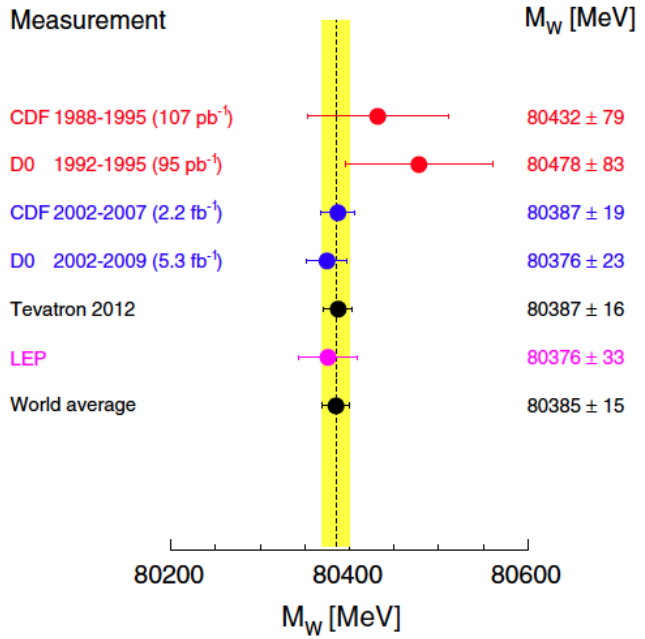
W boson mass (W→eυ)











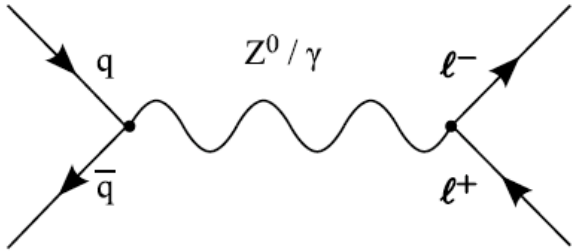
W boson mass (W→eυ)

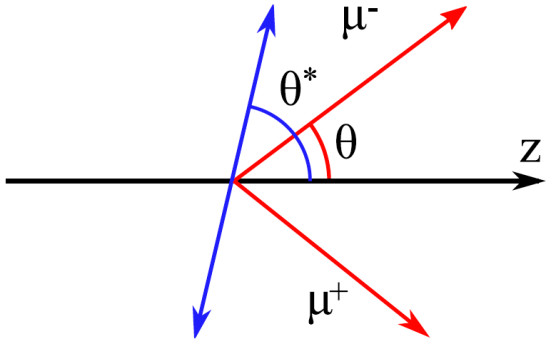
Source	Public. 2009 ($1.0\ fb^{-1}$)	Public. 2012 ($4.3\ fb^{-1}$)	Proj. $10\ fb^{-1}$	Proj. $10\ fb^{-1}$ improv.	Proj. $10\ fb^{-1}$ improv. + EC
Statistical	23	13	9	9	8
Experimental syst.					
Electron energy scale	34	16	11	11	10
Electron energy resolution	2	2	2	2	2
EM shower model	4	4	4	2	2
Electron energy loss	4	4	4	2	2
Hadronic recoil	6	5	3	3	2
Electron ID efficiency	5	1	1	1	1
Backgrounds	2	2	2	2	2
Subtotal experimental syst.	35	18	13	12	11
***W* production and decay model**					
PDF	9	11	11	11	5
QED	7	7	7	3	3
boson p_T	2	2	2	2	2
Subtotal *W* model	12	13	13	12	6
Total systematic uncert.	37	22	19	17	13
Total	**44**	**26**	**21**	**19**	**15**

combination: 23

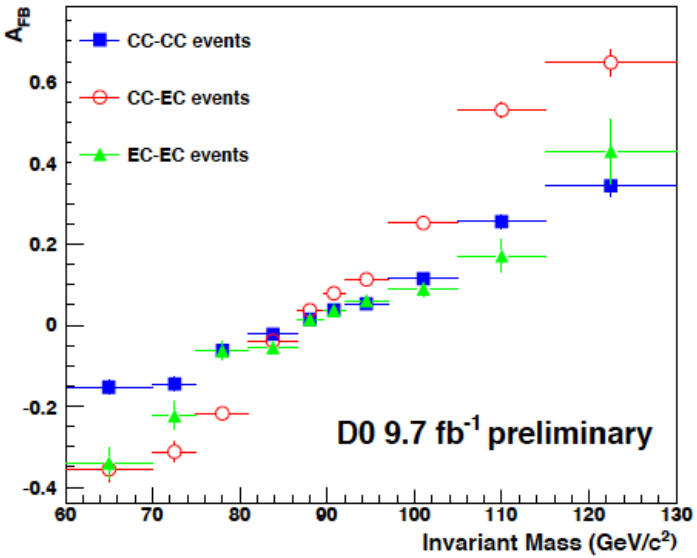
- An opportunity/need for new people to get involved in EC analysis!
- DØ's most important legacy from Run II?

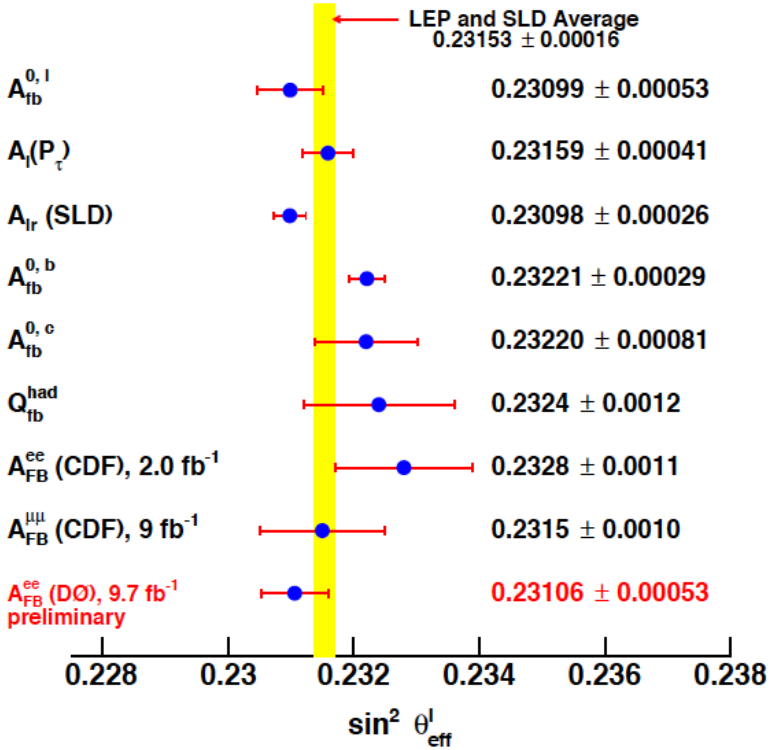
Z boson forward-backward asymmetry





- Sensitive to couplings of u and d quarks
- 560k Z→ee events
- $\sin^2\theta_W^{lept,eff} \approx 0.23106 \pm 0.00043\ (stat.) \pm 0.00012\ (syst.) \pm 0.00029\ (PDF)$

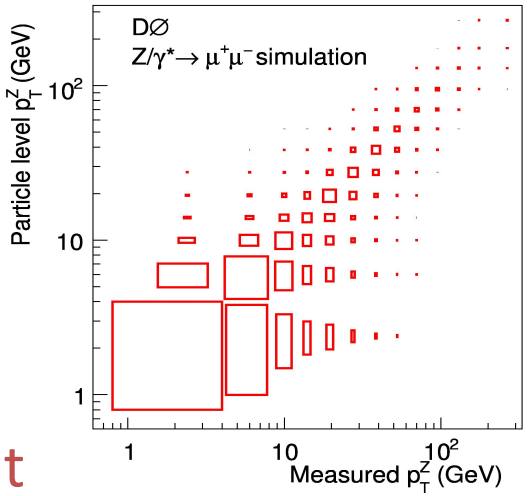




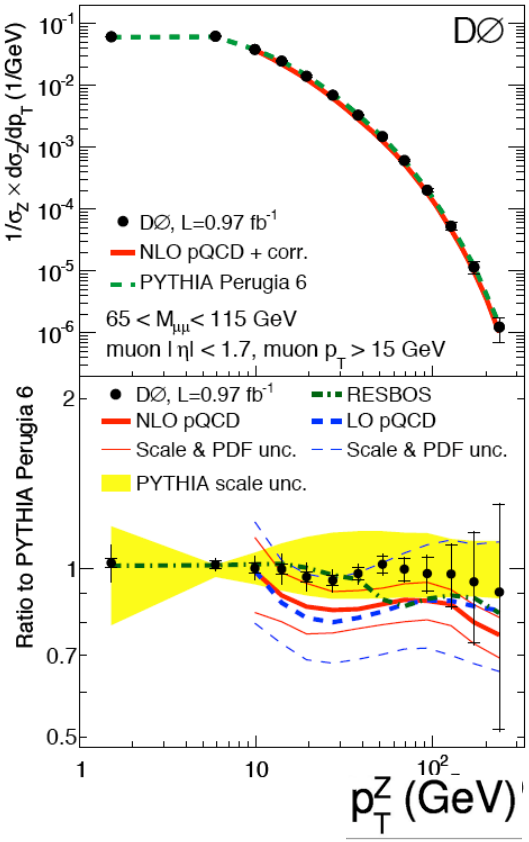
DØ e^+e^- competitive with, e.g., LEP-combined A_{FB}^{lept}
…. but not (yet) included in standard EW fits

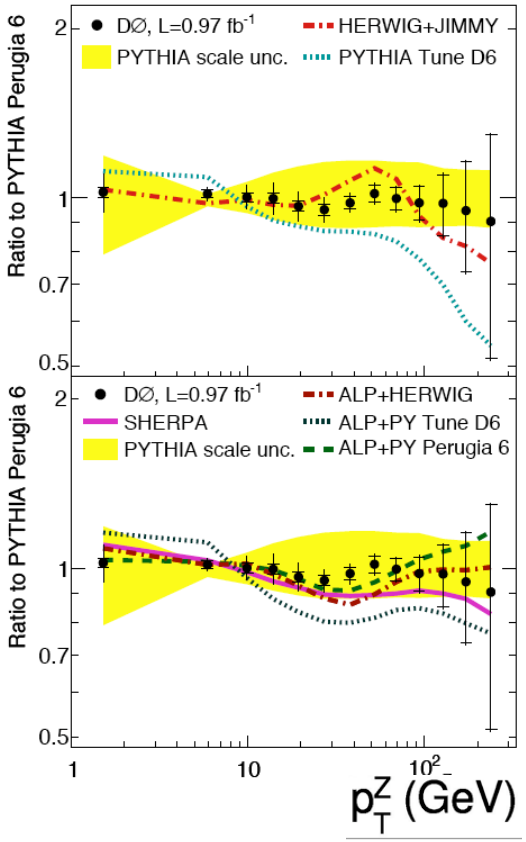
Z boson transverse momentum

- $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$, 1 fb^{-1}
- Unfold p_T^Z resolution
- For $p_T^Z < 30$ GeV
  - $\sigma_{syst} \sim 5\%$
  - cf. $\sigma_{stat} \sim 1\%$
  - dominated by p_T^μ resolution systematics
  - and restricts choice of bin widths

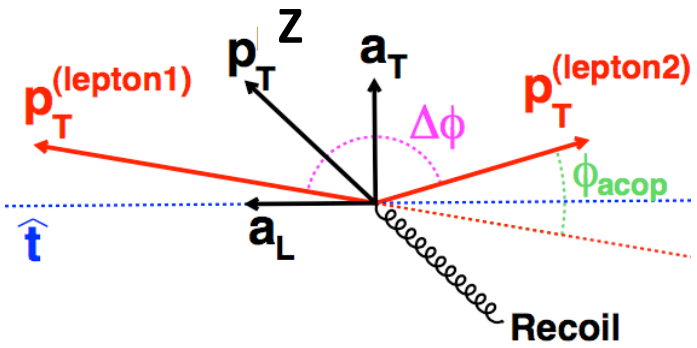


Data-MC agreement





Study of Z boson transverse momentum using ϕ^*_η



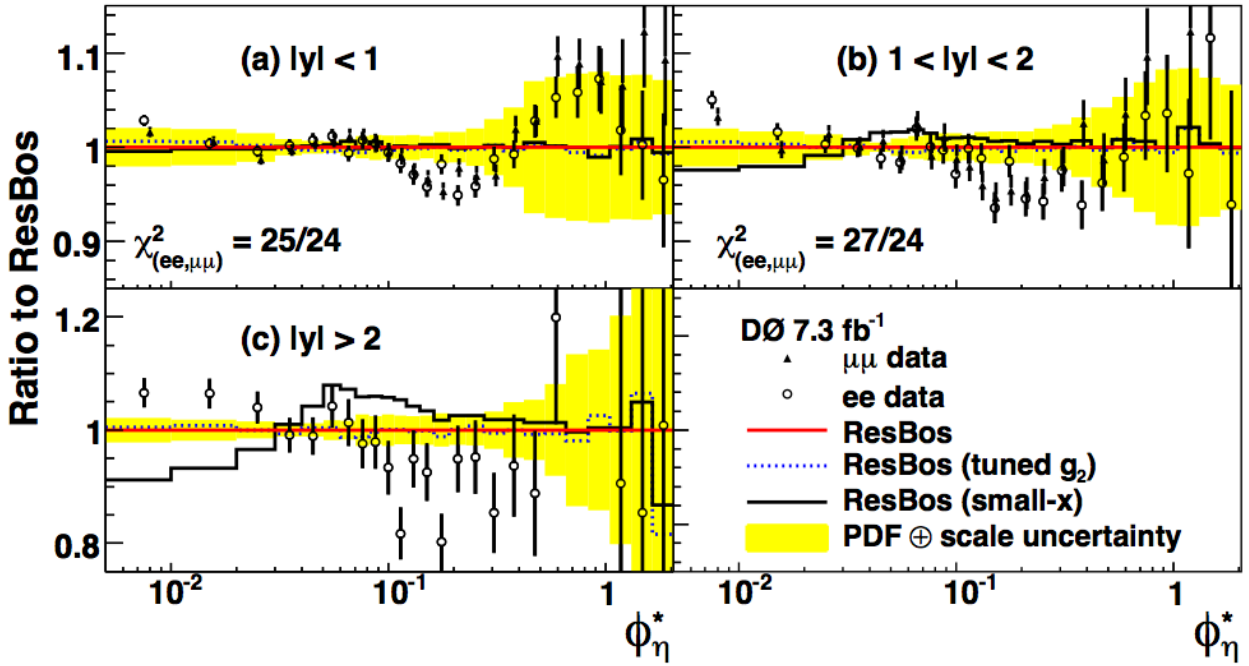
$$\phi^*_\eta = \tan\left(\frac{\phi_{\rm acop}}{2}\right)\sin(\theta^*_\eta)$$

$$\cos(\theta^*_\eta) = \tanh\left(\frac{\eta^- - \eta^+}{2}\right)$$

Measured using only the directions of the leptons and thus very well measured

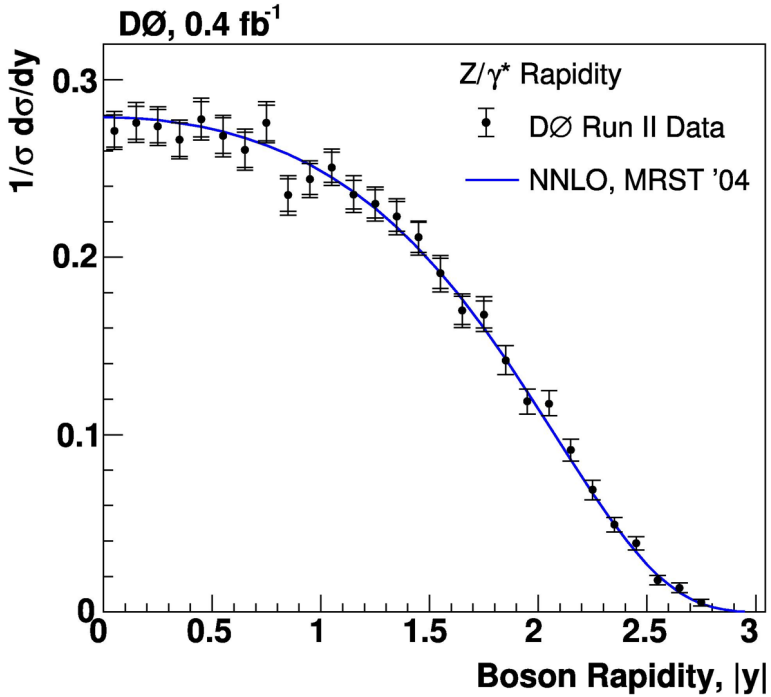
About 1 M Z→ee+ Z→μμ events

- At low ϕ^*_η : narrow bins, σ_{stat} ~ 5 per mille and σ_{syst} ~ 1 per mille



Z boson rapidity

- Z boson rapidity distribution is sensitive to PDFs



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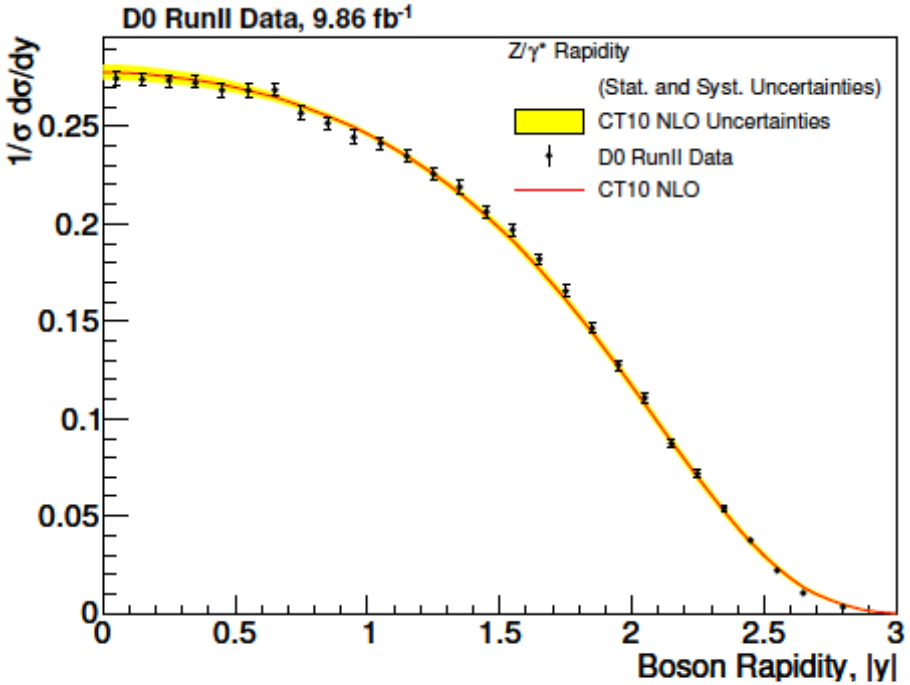
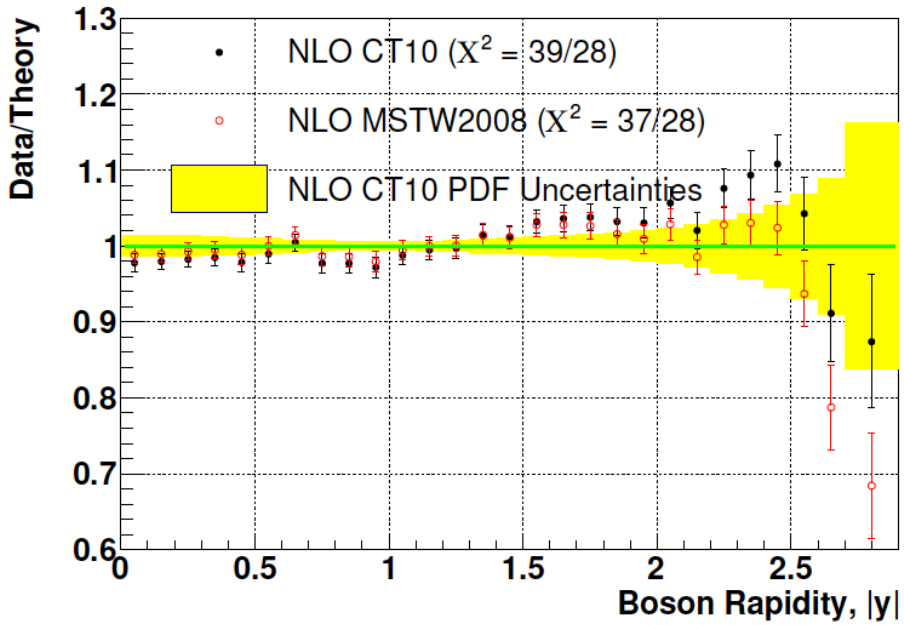
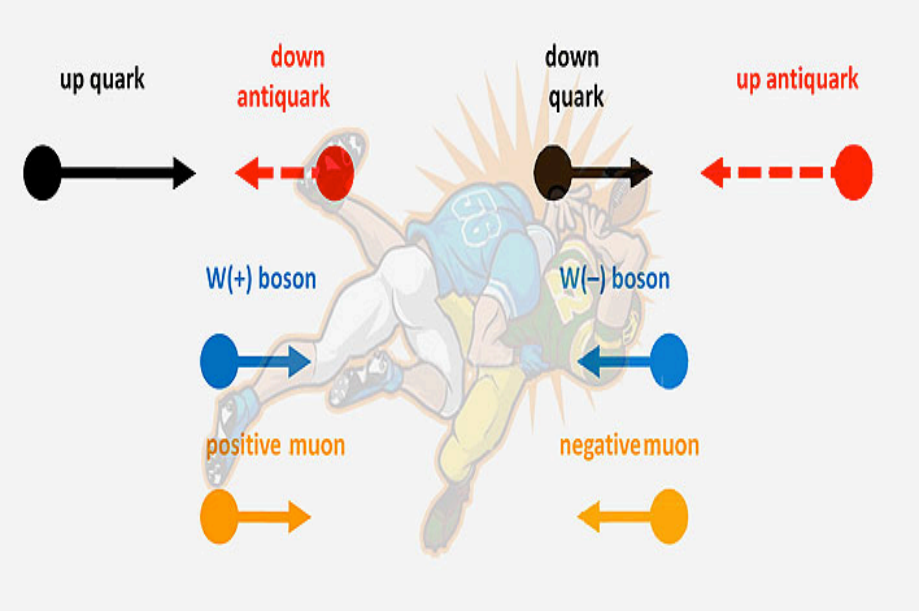


(a) CT10 NLO

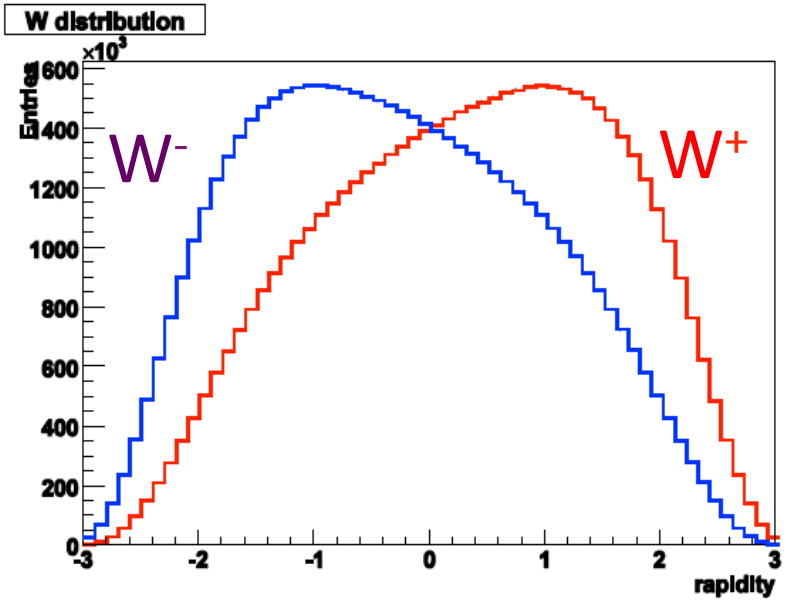


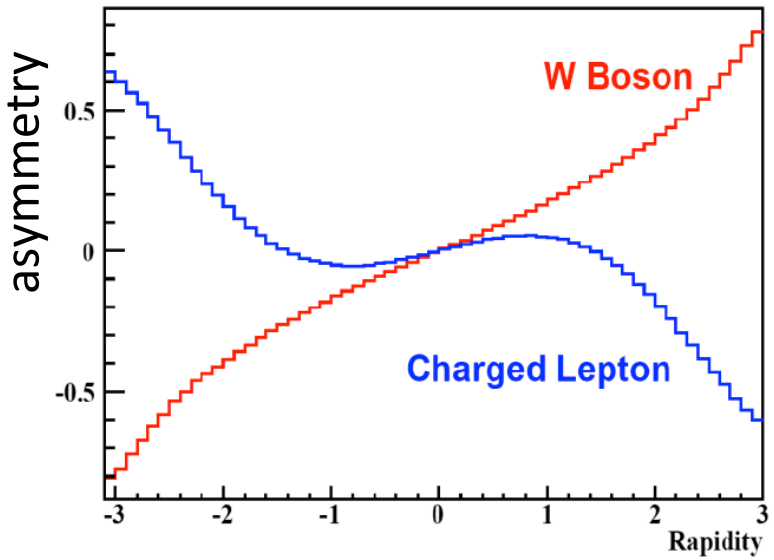
Pengfei Ding PhD thesis (November 2013) paper in preparation

W boson asymmetry and PDFs



- u quark PDF is harder than d quark PDF
- W^+ (W^-) tends to be boosted along proton (antiproton) direction
- asymmetry = $(N^+-N^-)/(N^++N^-)$
- We actually observe the charged lepton
  - Left-handed couplings in W production and decay partially washes out asymmetry





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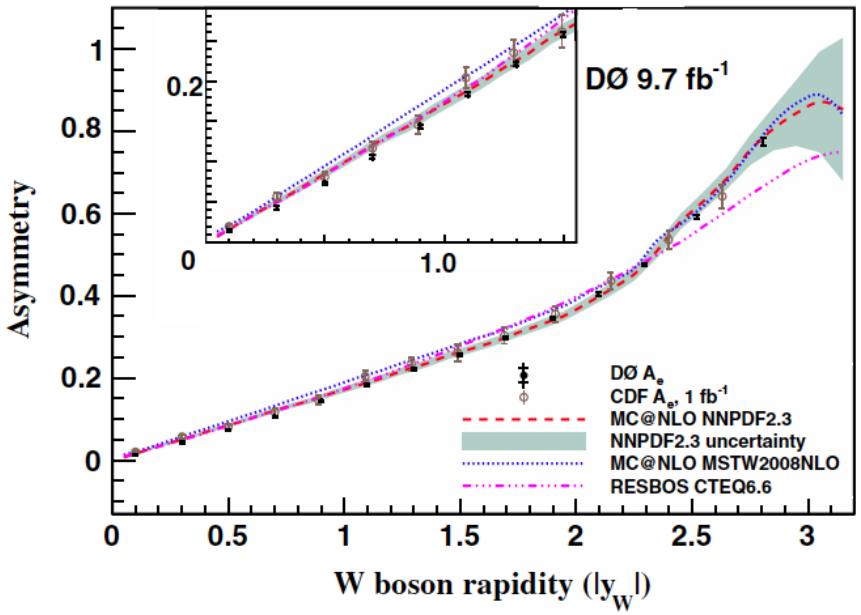
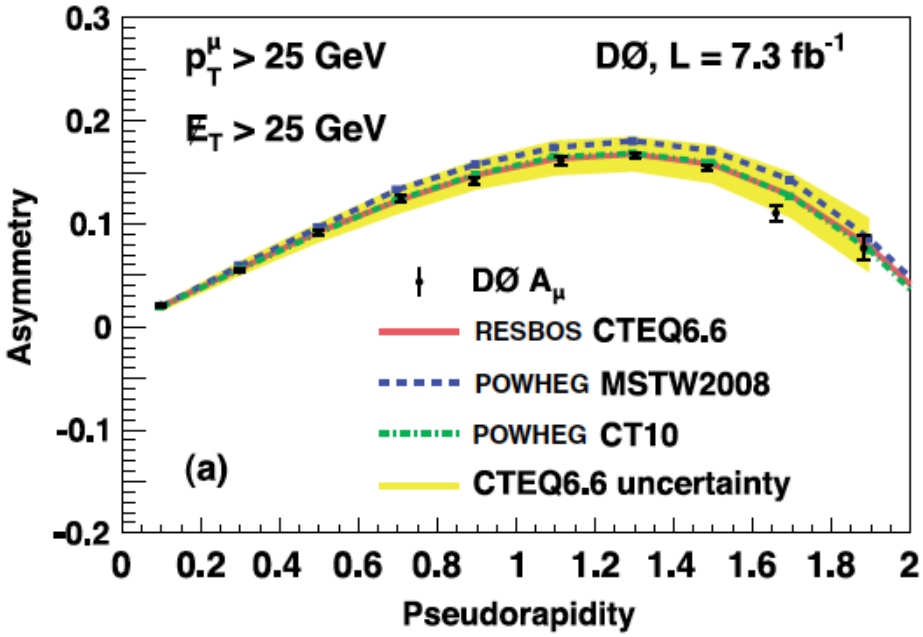
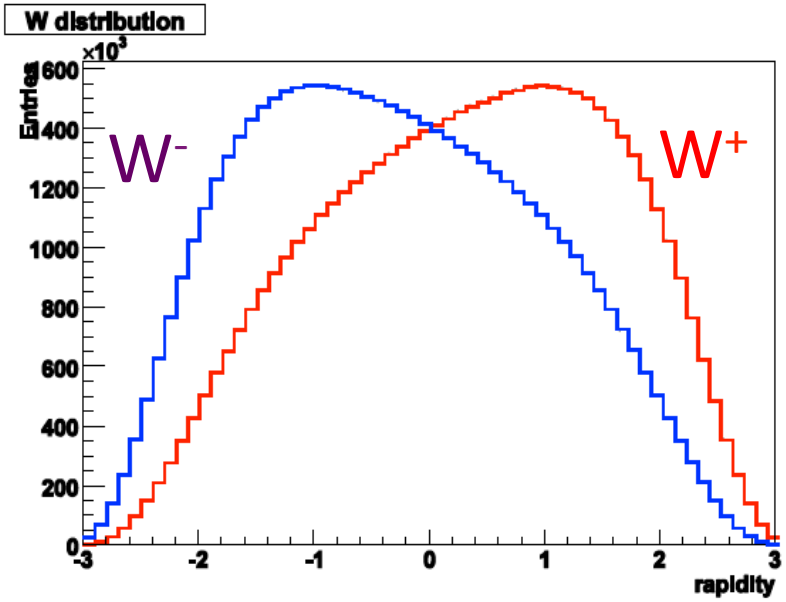
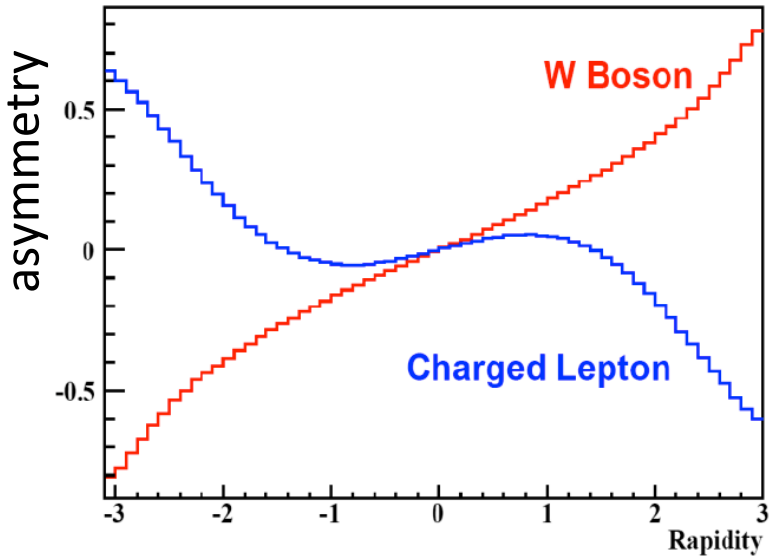


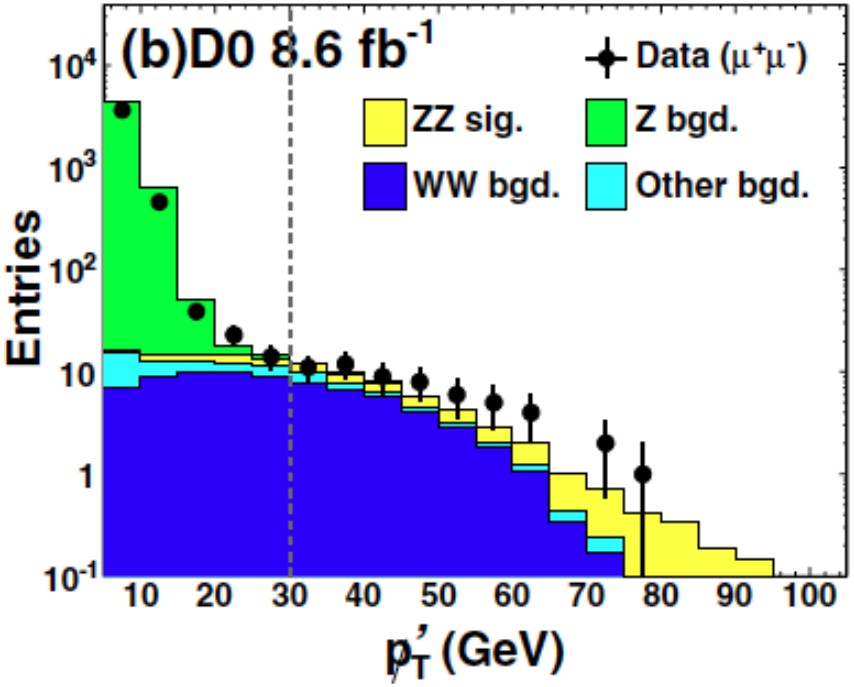




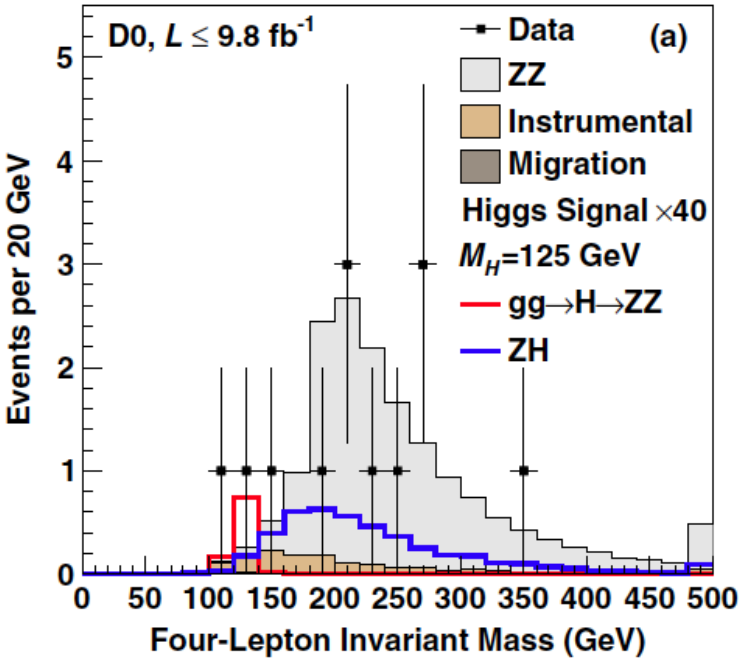


Di-bosons: ZZ production

$ZZ \rightarrow ll\upsilon\upsilon$



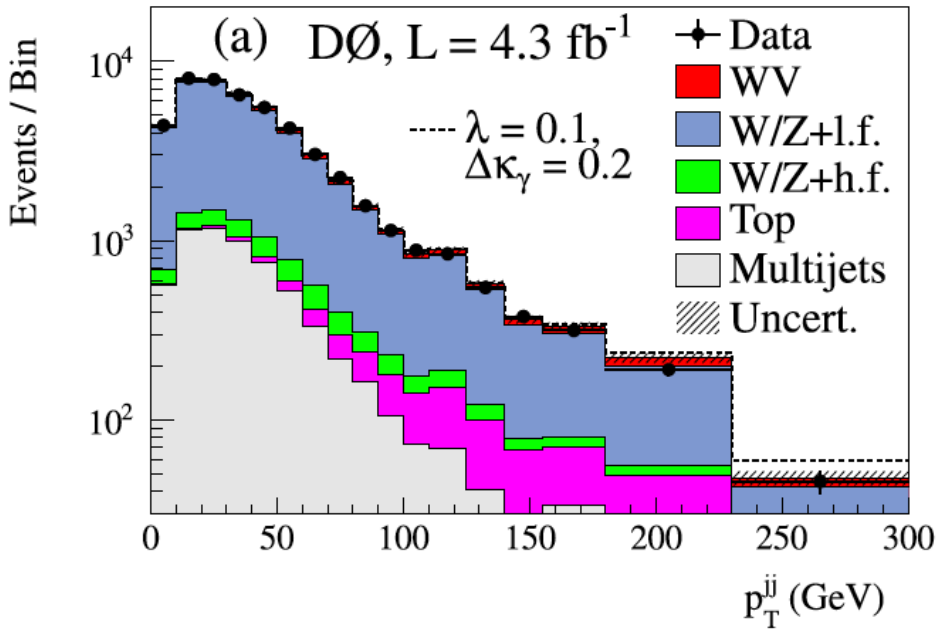
$ZZ \rightarrow llll$

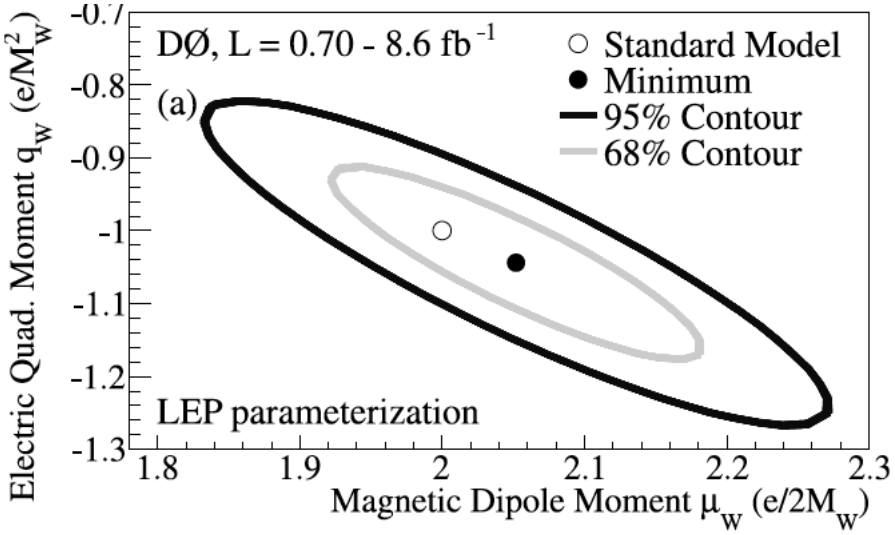


ZZ cross section measurement of $1.32^{+0.29}_{-0.25}(\text{stat}) \pm 0.12(\text{syst}) \pm 0.04(\text{lumi})$ pb.
consistent with the standard model expectation of 1.43 ± 0.10 pb

Di-bosons: WZ production

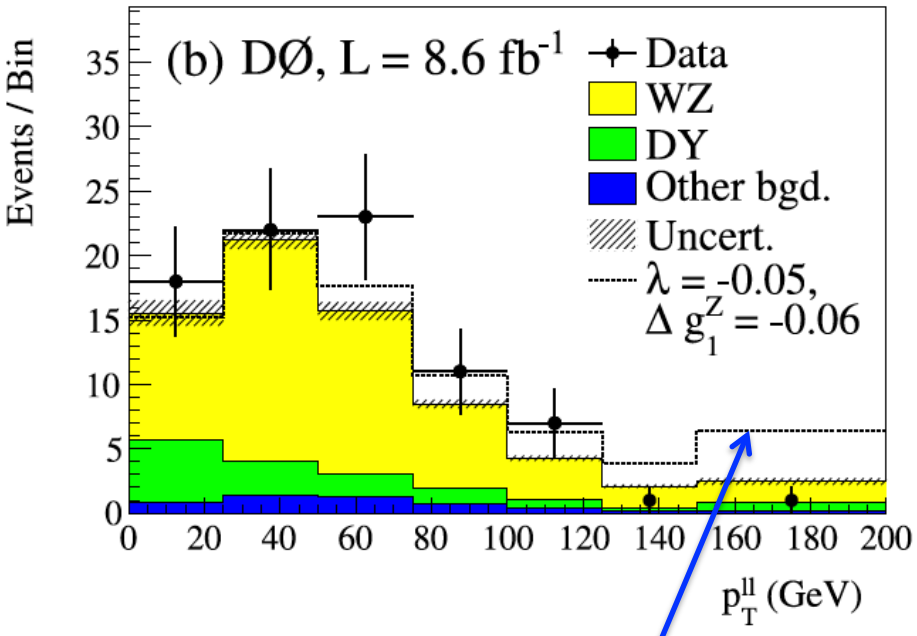
WW + WZ →lυqq





$WW + WZ \to \ell\nu jj$, $WZ \to \ell\nu\ell\ell$, $W\gamma \to \ell\nu\gamma$, and $WW \to \ell\nu\ell\nu$

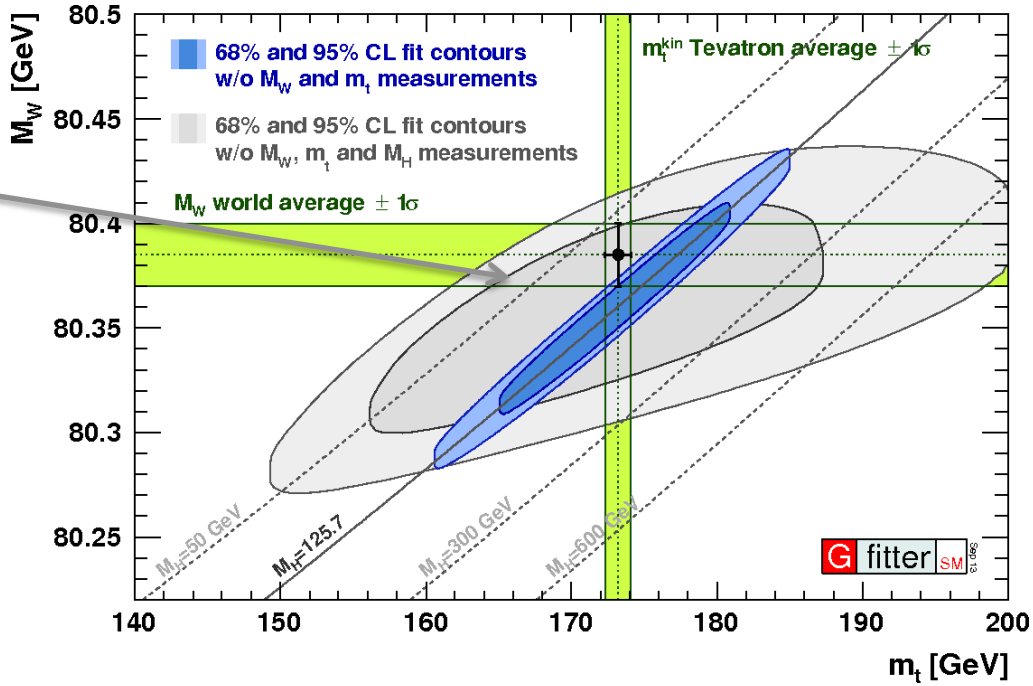
WZ →lυll



- Sensitive to anomalous vector boson couplings
- LHC will dominate here
  - higher di-boson mass
  - higher L

Precise EW measurements in the future

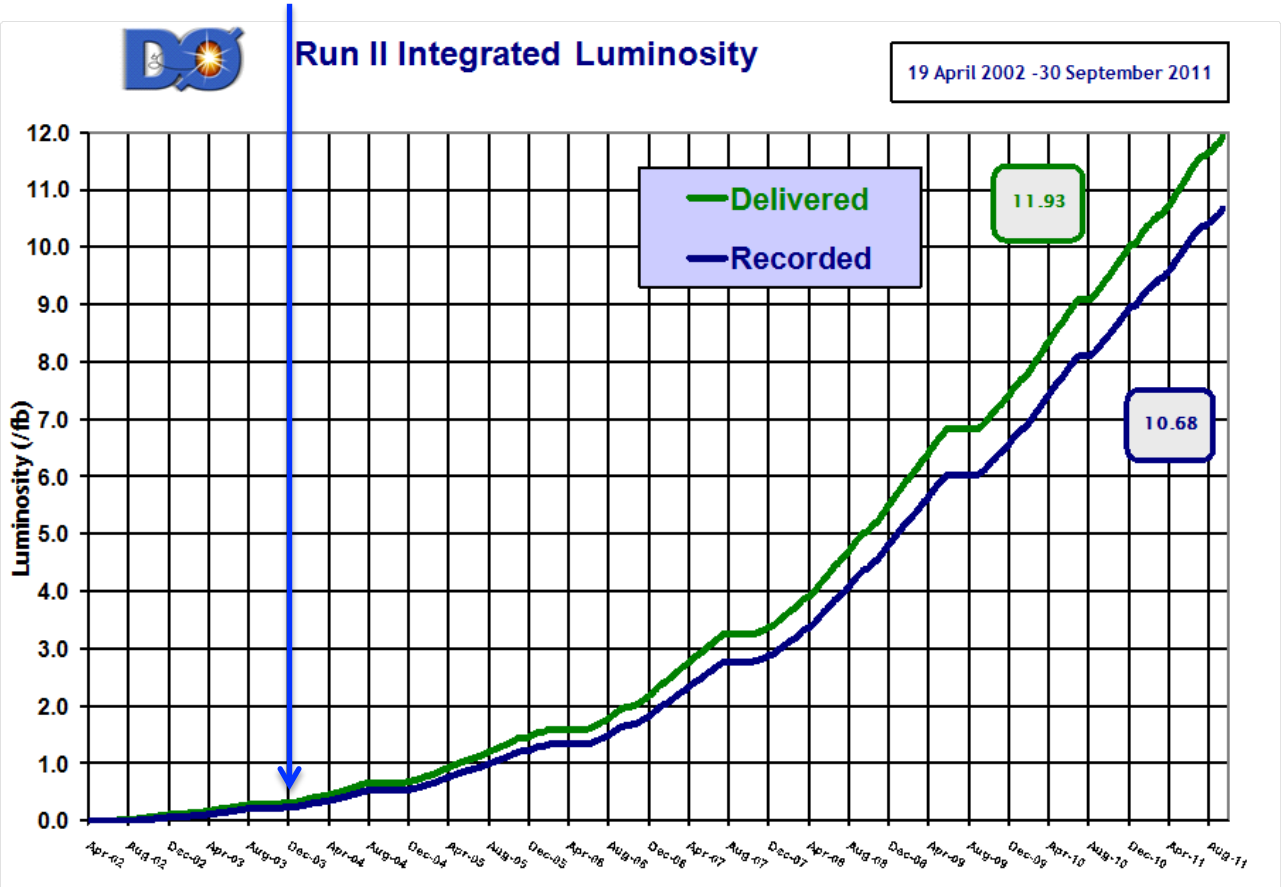
- $\sin^2\theta_W^{eff}$ starts to look like the poor relation in this plot!
  - Significant theoretical progress would be required in the interpretation of more precise experimental measurements in this area!



- W mass, $\sin^2\theta_W$, etc.
  - Measurements possible at LHC
    - Competitive with the LEP/Tevatron precision
      - but unlikely to make huge gains relative to LEP/Tevatron
- New e^+e^- machines running at $\sqrt{s} = m_Z$, $\sqrt{s} = 2m_W$, $\sqrt{s} = m_Z+m_H$ and $\sqrt{s} = 2m_{top}$
  - could give order of magnitude or more improvements
    - e.g., $\sin^2\theta_W$ from polarization and forward-backward asymmetries
    - e.g., $\Delta m_W \sim 0.5 – 1.0$ MeV, $\Delta m_{top} \sim 100$ MeV, $\Delta m_H \sim 50$ MeV?

There were some disasters along the way

- Magnet misalignments
- Lack of beam orbit measurements
- Lack of simulations
- L ≈ 0.1 fb^{-1}/year in the first two years

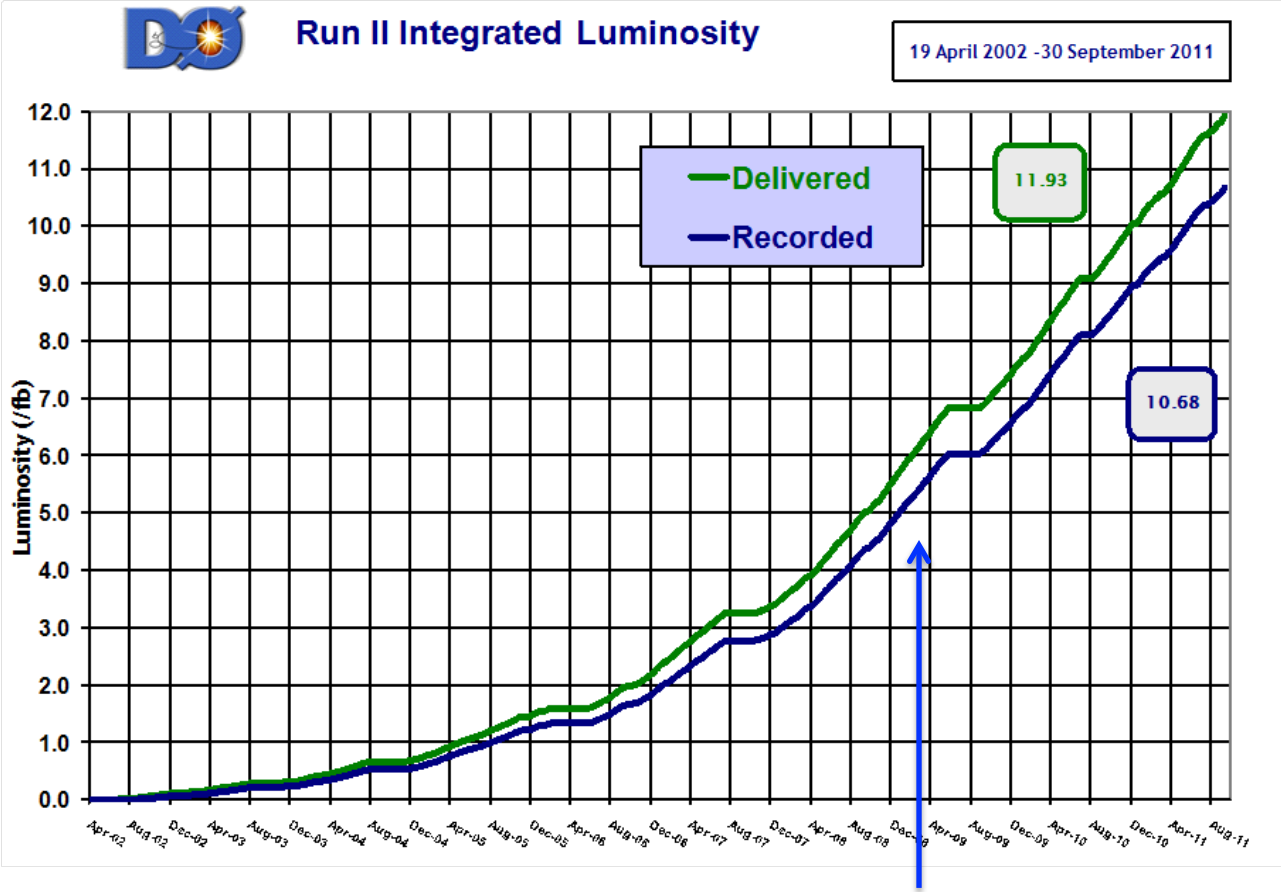


Luckily, total disaster was avoided ……

- "There are many challenges facing you in the coming months and years but the systematic approach to solving problems that has been characteristic of the past year will serve the Laboratory well. …… We are particularly pleased with the palpable change in the Accelerator Division under the leadership of Roger Dixon and Dave McGinnis".
  - March 12th 2004: Don Hartill – chair, board of overseers

……. but there were casualties

- Abandonment of plan to move to 108x108 bunches
- Cancellation of the Run 2b silicon tracker replacements

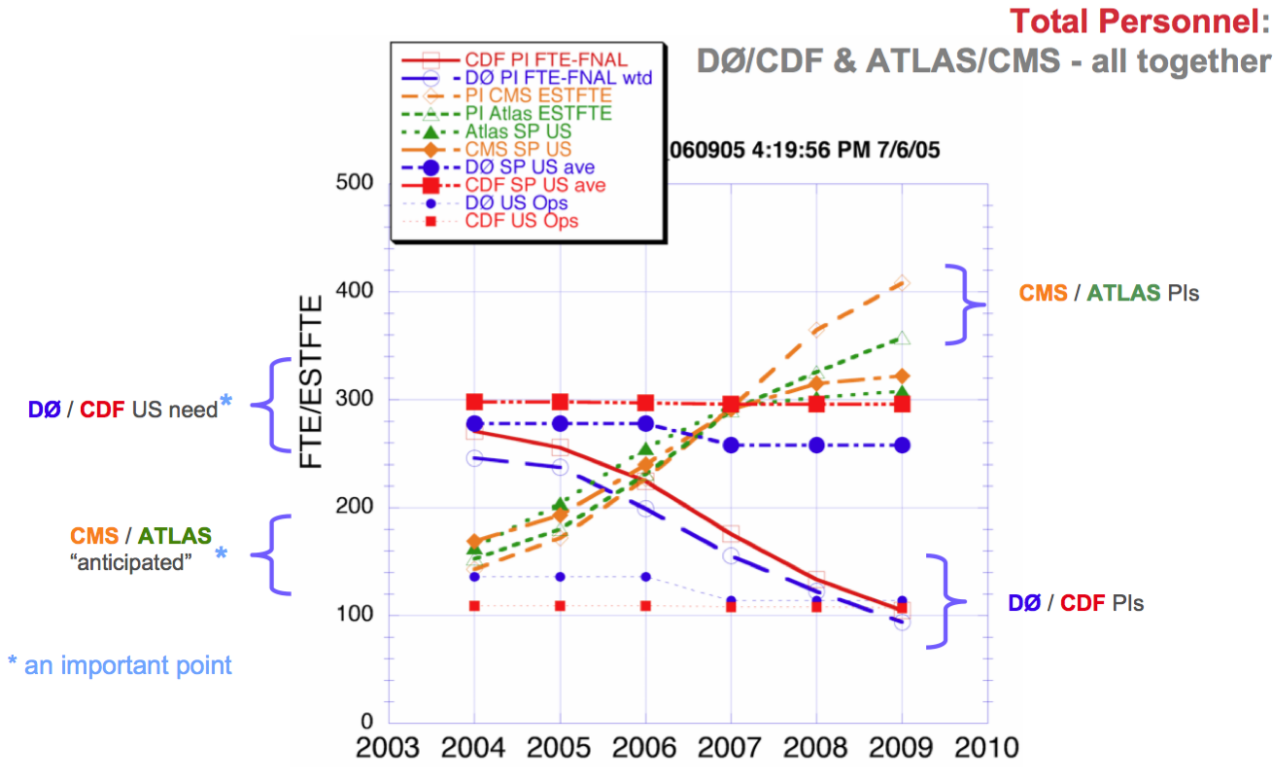


- ~ Constant luminosity/year over last 4-5 years of programme
- In spite of this we did manage to avoid the “spiral of death”

Some disasters never happened …

(although we got very worked up about them at the time ;-)

e.g., HEPAP manpower projections 2005



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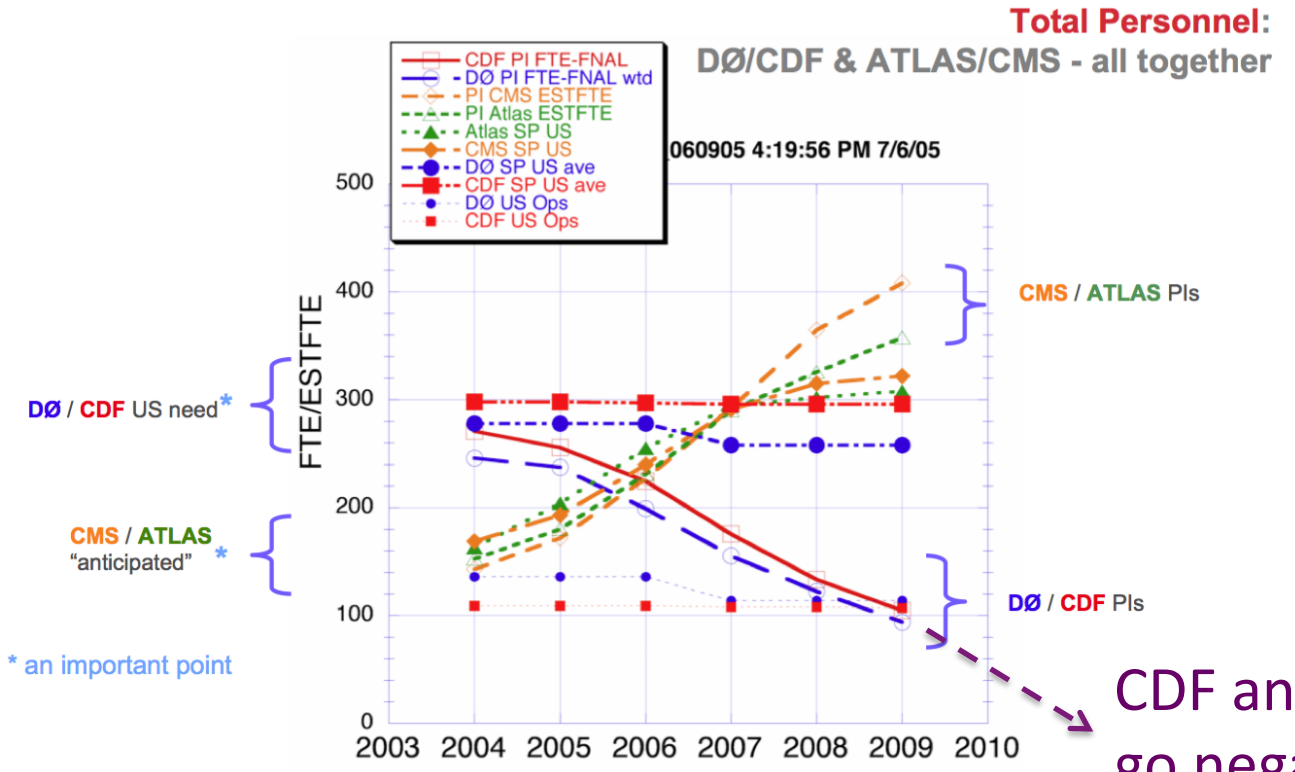

CDF and DØ manpower go negative in 2011