QCD & Electroweak Results from the Tevatron

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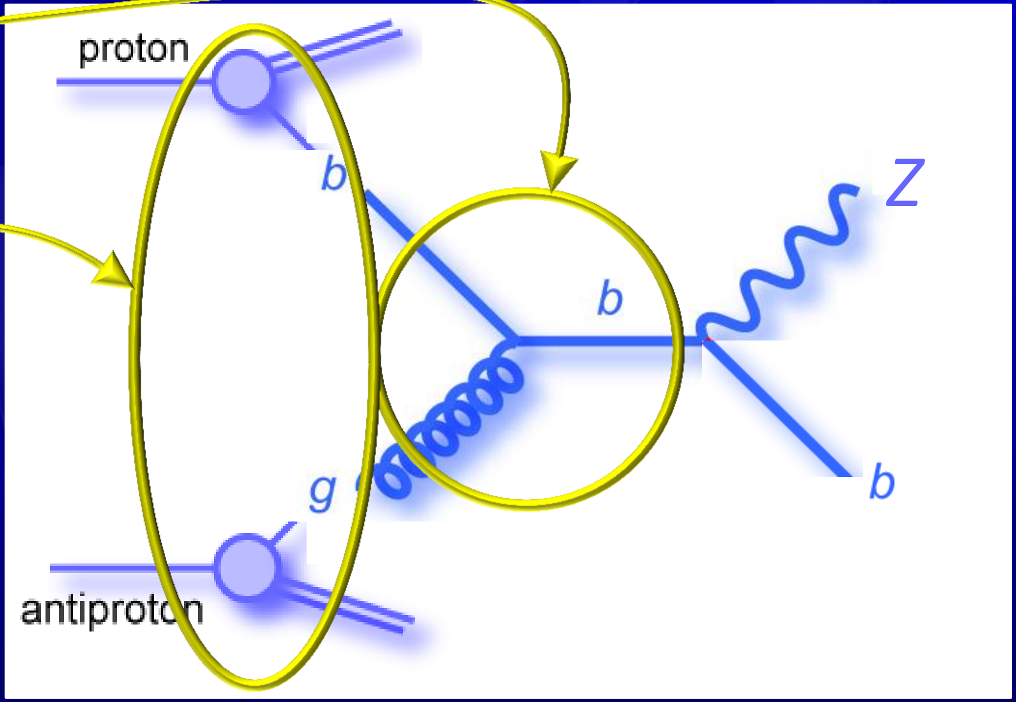
On behalf of the CDF and DØ Collaborations

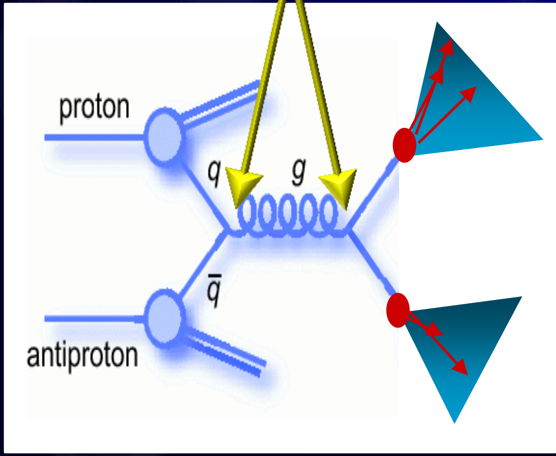
45th Annual Fermilab Users' Meeting
June 12, 2012

QCD Physics

- **Vector Bosons + Jets, Diphotons**
  - Stringent tests of pQCD
  - Sensitive to quark, gluon content of proton – constrain PDFs
  - Irreducible backgrounds to many searches



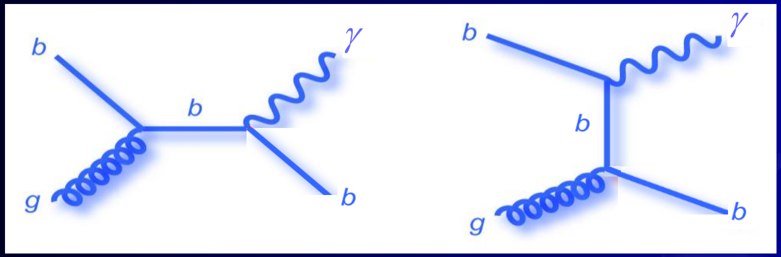
- **Inclusive jet production**
  - Extract α_S

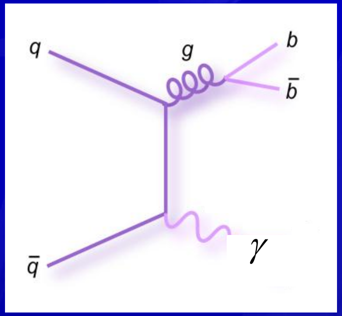


- **Elastic $p\bar{p} \rightarrow p\bar{p}$ scattering**
  - Proton structure

$\gamma + b/c + X$: CDF

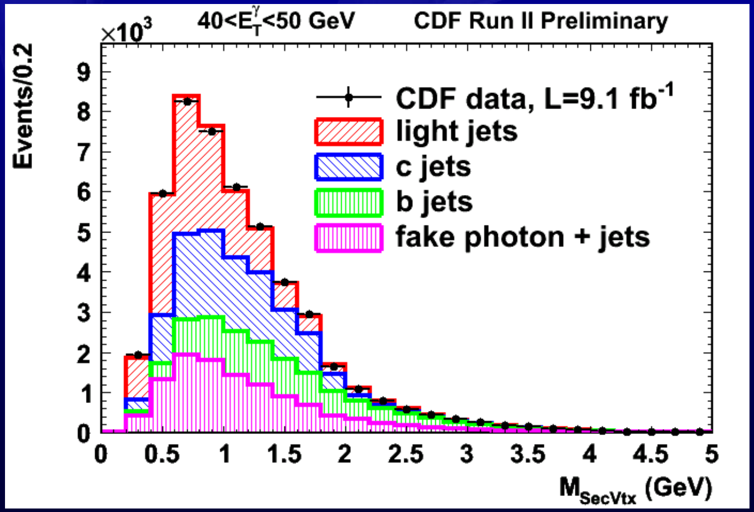
- Compton scatt. ($E_T^\gamma \leq 70$ GeV) $q\bar{q}$ annih. ($E_T^\gamma \geq 70$ GeV)





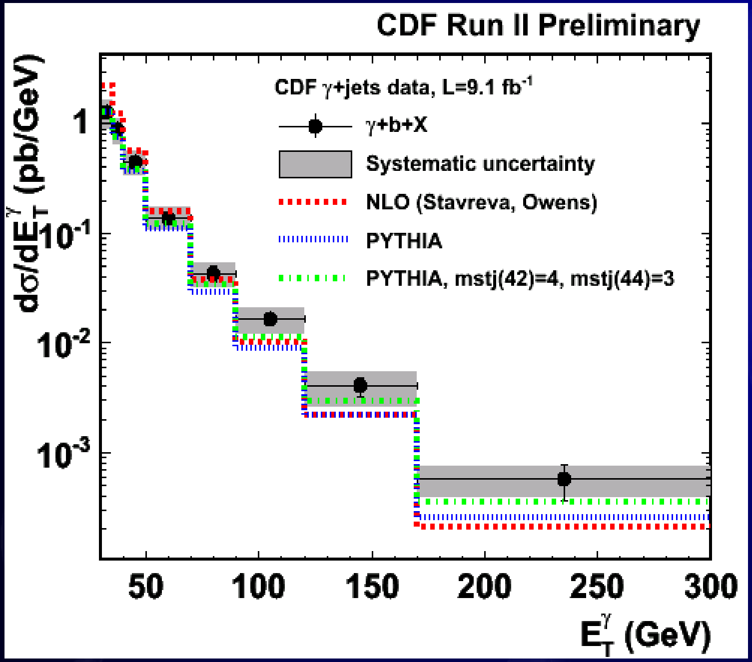
- Sensitive to b, c, g content for PDFs

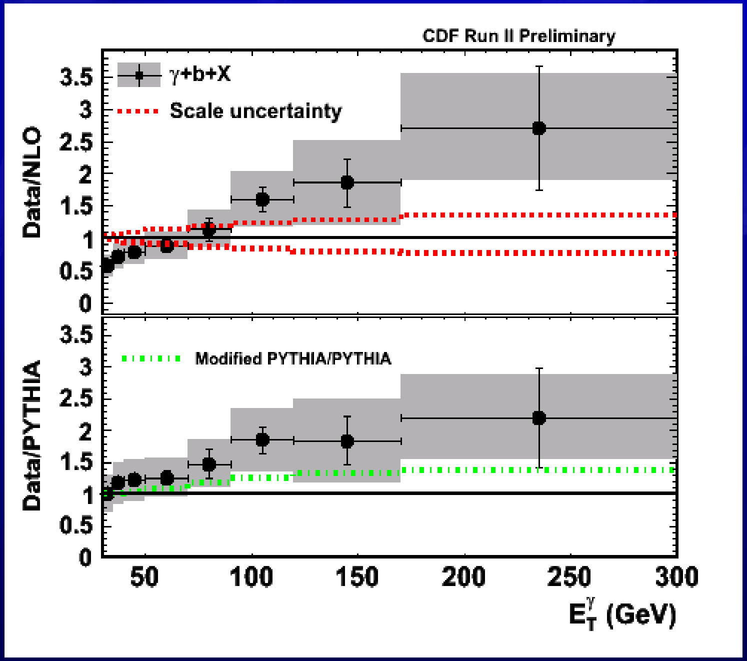
- Measure jet fractions via template method in 8 bins of E_T^γ
- Calculate cross sections covering $30 < E_T^\gamma < 300$ GeV , $|y^\gamma| < 1.0$ $E_T^{jet} > 20$ GeV , $|y^{jet}| < 1.5$



$\gamma + b/c + X$: CDF

	Measured	NLO	PYTHIA
$\sigma(p\bar{p} \to \gamma + b + X)$	$19.7 \pm 0.7^{stat} \pm 5.0^{syst}$	$27.3^{+2.3}_{-1.5}$	17.0
$\sigma(p\bar{p} \to \gamma + c + X)$	$132.2 \pm 4.6^{stat} \pm 19.2^{syst}$	$152.6^{+12.2}_{-9.6}$	101.3





- **Modeling deficiencies at high E_T^{γ}** — CDF Note 10818
  - Higher order corrections; mis-modeled gluon splitting (e.g. improved with increased g splitting to HF q in PYTHIA)

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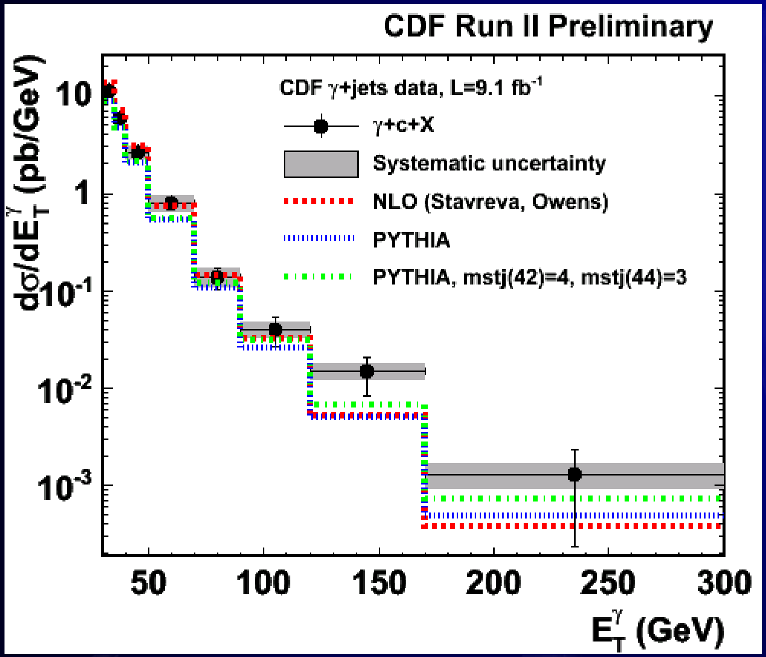
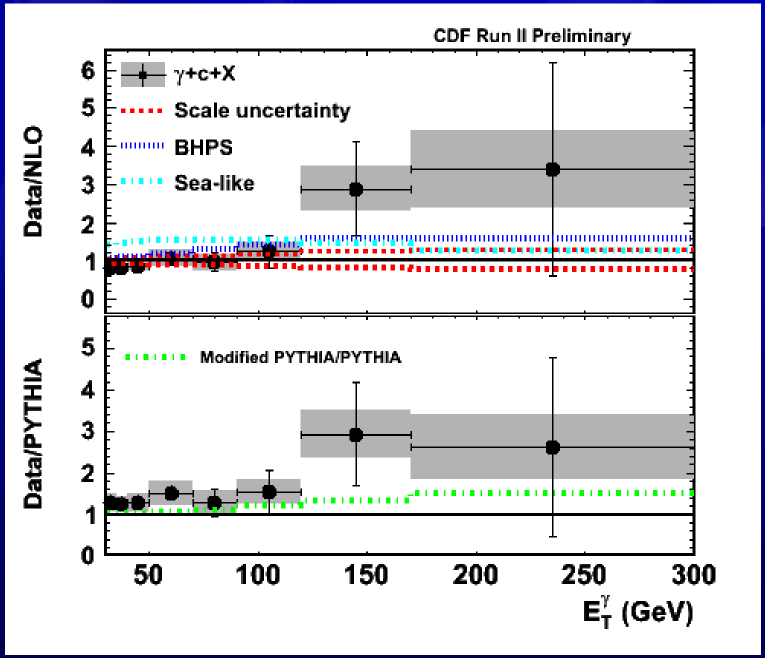




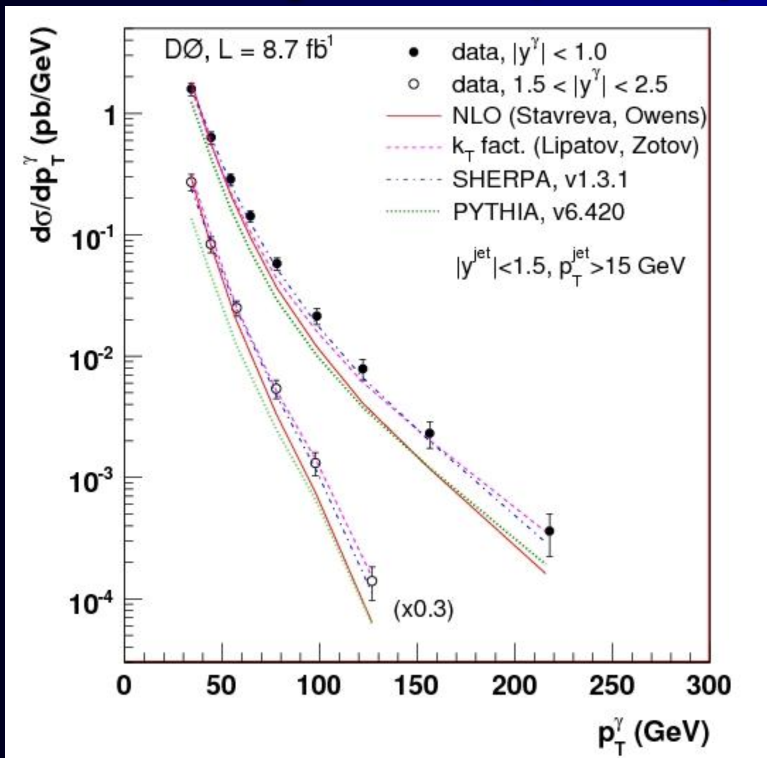
- **Modeling deficiencies at high E_T^γ**

CDF Note 10818

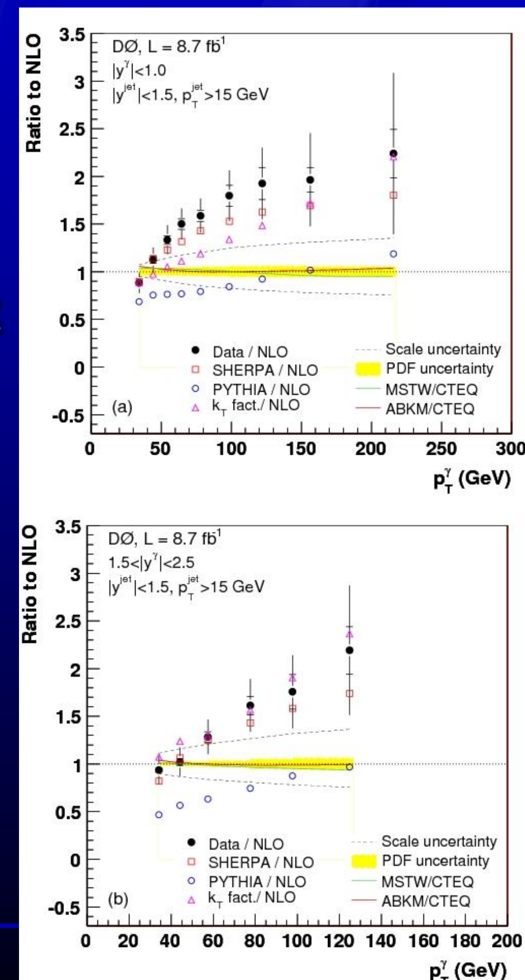
  - Higher order corrections; mis-modeled gluon splitting (e.g. improved with increased g splitting to HF q in PYTHIA)

$\gamma + b + X : D\emptyset$

- Diff. cross sections as a function of p_T^γ measured for central photons ($30 < p_T^\gamma < 300$ GeV, $|y^\gamma| < 1.0$) & forward photons ($30 < p_T^\gamma < 200$ GeV, $1.5 < |y^\gamma| < 2.5$)



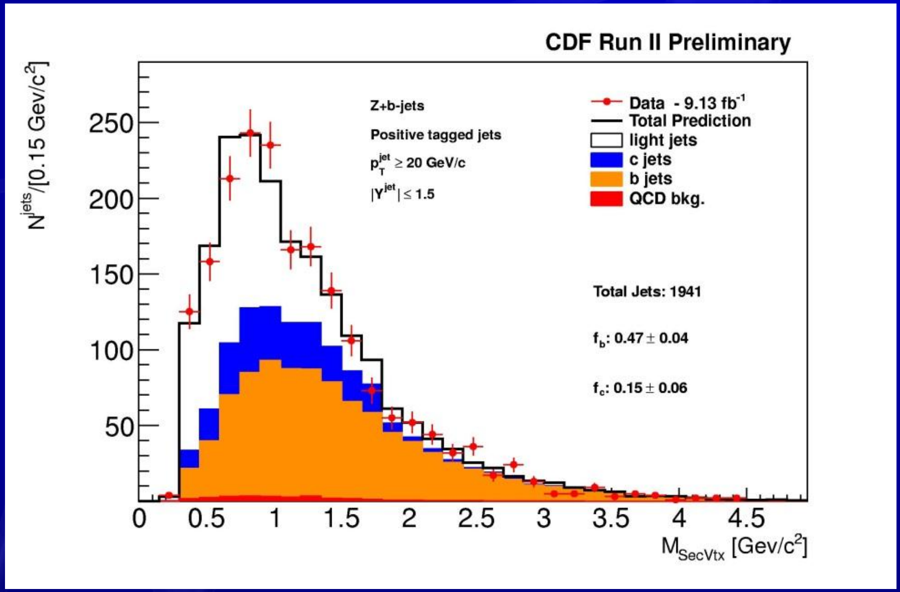
PLB, submitted 3/28/12
arXiv:1203.5865

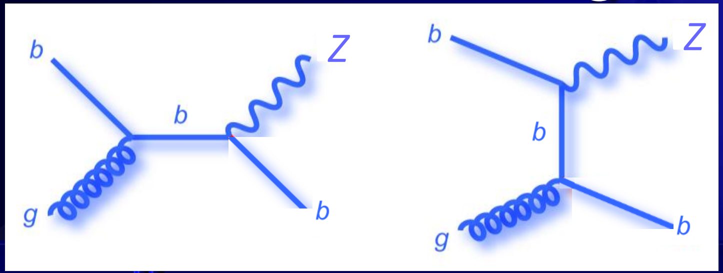


- High p_T^γ deficiencies for NLO & PYTHIA, but k_T factorization and SHERPA perform much better

$Z + b$: CDF

- Fundamental background to $ZH \to Zb\bar{b}$, SUSY b partners
- Sensitive to b quark PDF (important for EW single t prod)
- ANN key improvement over 2 fb^{-1} result (acceptance improves 40%)
- Uncertainties reduced using ratios



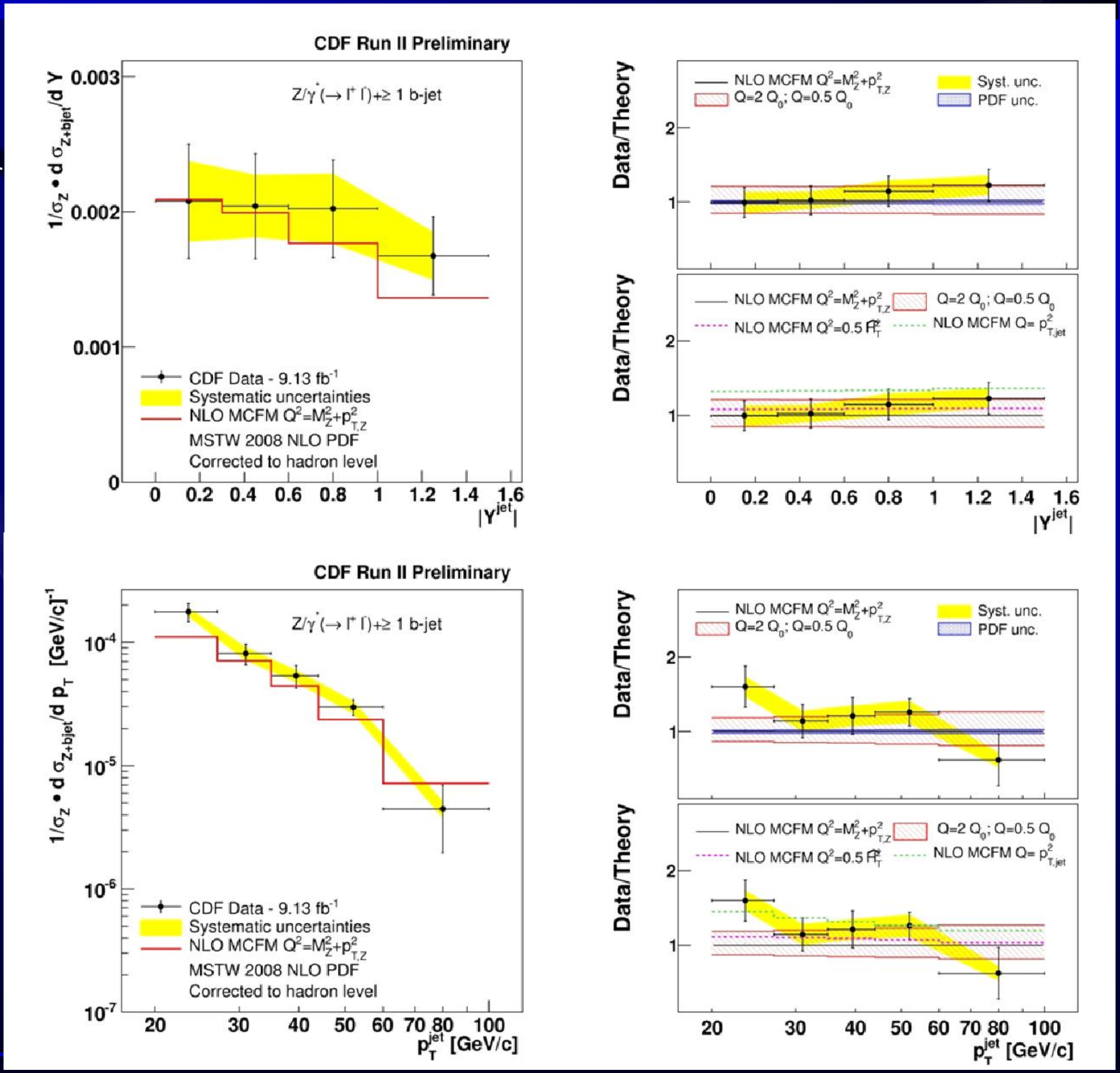


	Measured	NLO with MCFM	
		$Q^2 = m_Z^2 + p_{T,Z}^2$	$Q^2 = \langle p_{T,jet}^2 \rangle$
$\frac{\sigma_{Z\_bjet}}{\sigma_Z}$	$0.261 \pm 0.023^{stat} \pm 0.023^{syst}\%$	0.23%	0.29%
$\frac{\sigma_{Z\_bjet}}{\sigma_{Zjet}}$	$2.08 \pm 0.18^{stat} \pm 0.27^{syst}\%$	1.8%	2.2%

$Z + b$: CDF

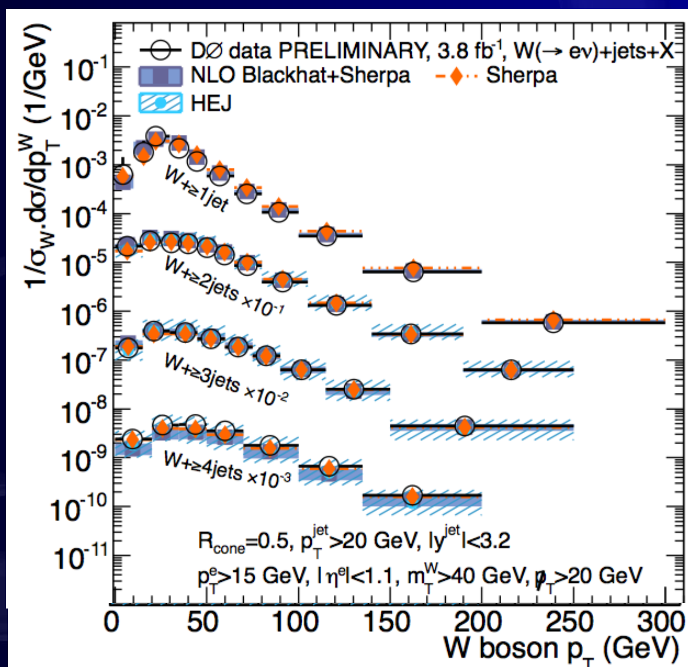
- **Differential cross section as function of jet p_T and $|y|$**
- **Normalized to inclusive Z cross section**
- **25% scale uncert. for NLO MCFM**

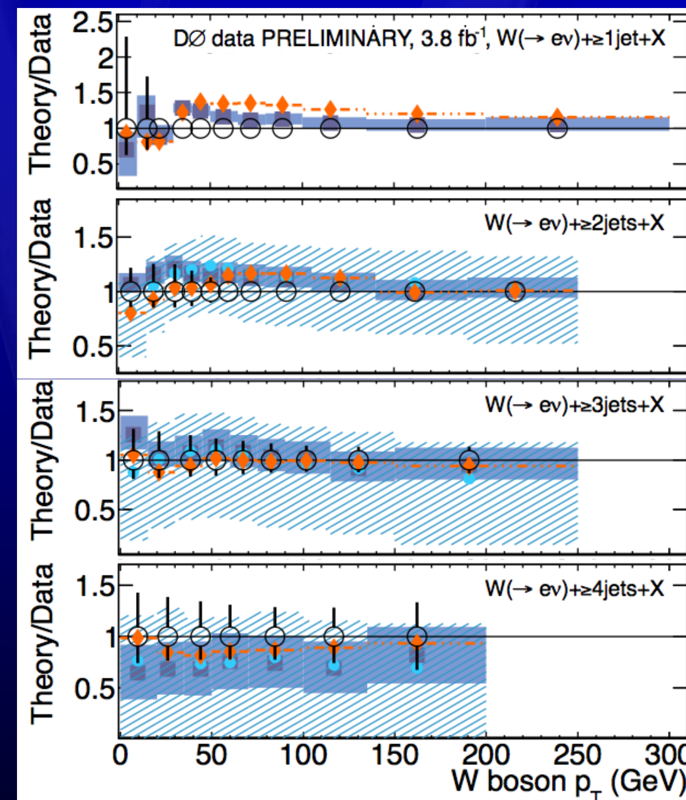
CDF Note 10594



Inclusive W + jets : DØ

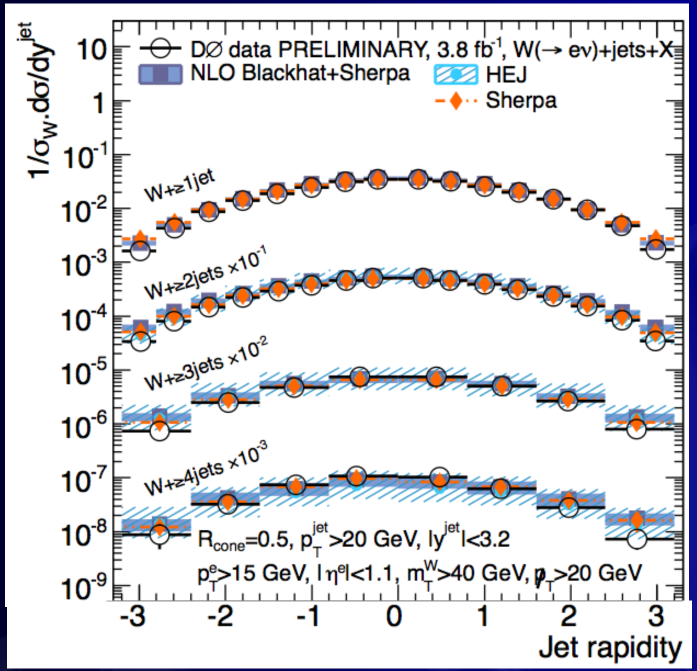
- Dominant background to t and $t\bar{t}$ production, SM Higgs, etc.
- Precision measurements critical for enhancing ability to identify new physics
- New measurements of differential cross sections as functions of jet rapidity, dijet invariant mass, and W transverse momentum
  - Follows up previous results on total cross section and differential with respect to p_T^{jet}

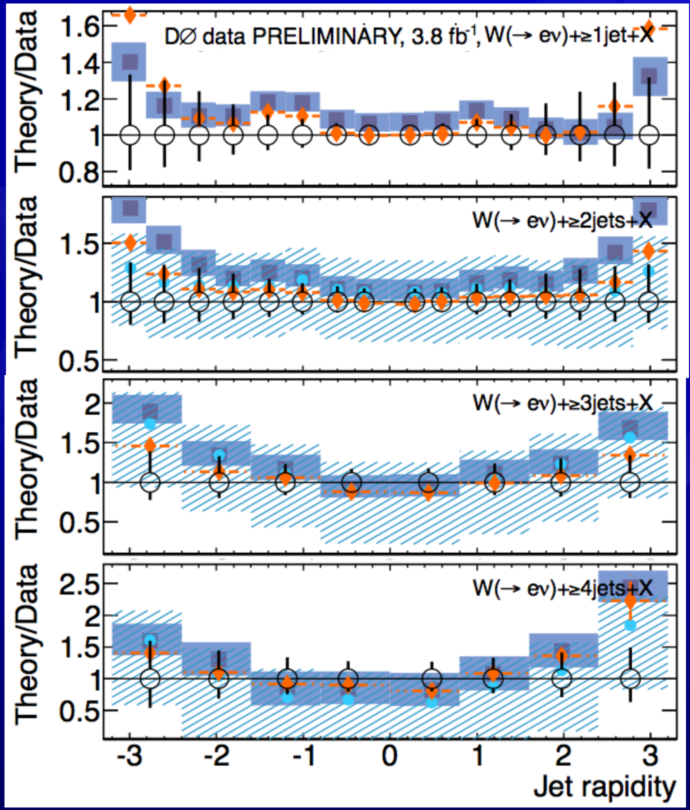




- Good agreement with each theory approach

Inclusive W + jets : DØ





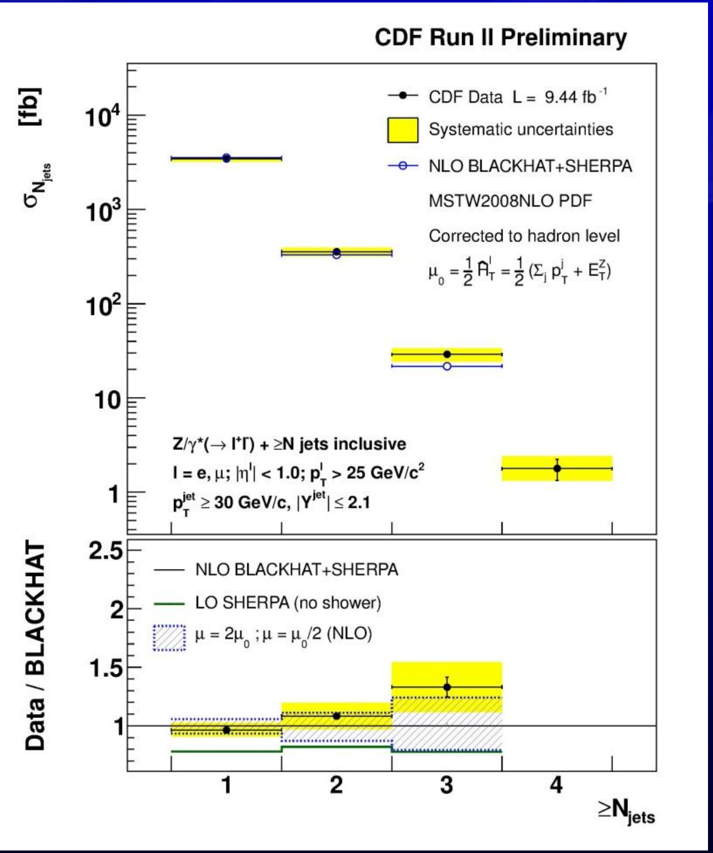
PLHC2012 Talk

- **Central region described well by theory, with low uncertainty**
- **In forward regions where low p_T jets dominate, theory overestimates cross section**
- **Many analyses quite sensitive to jet rapidity modeling**

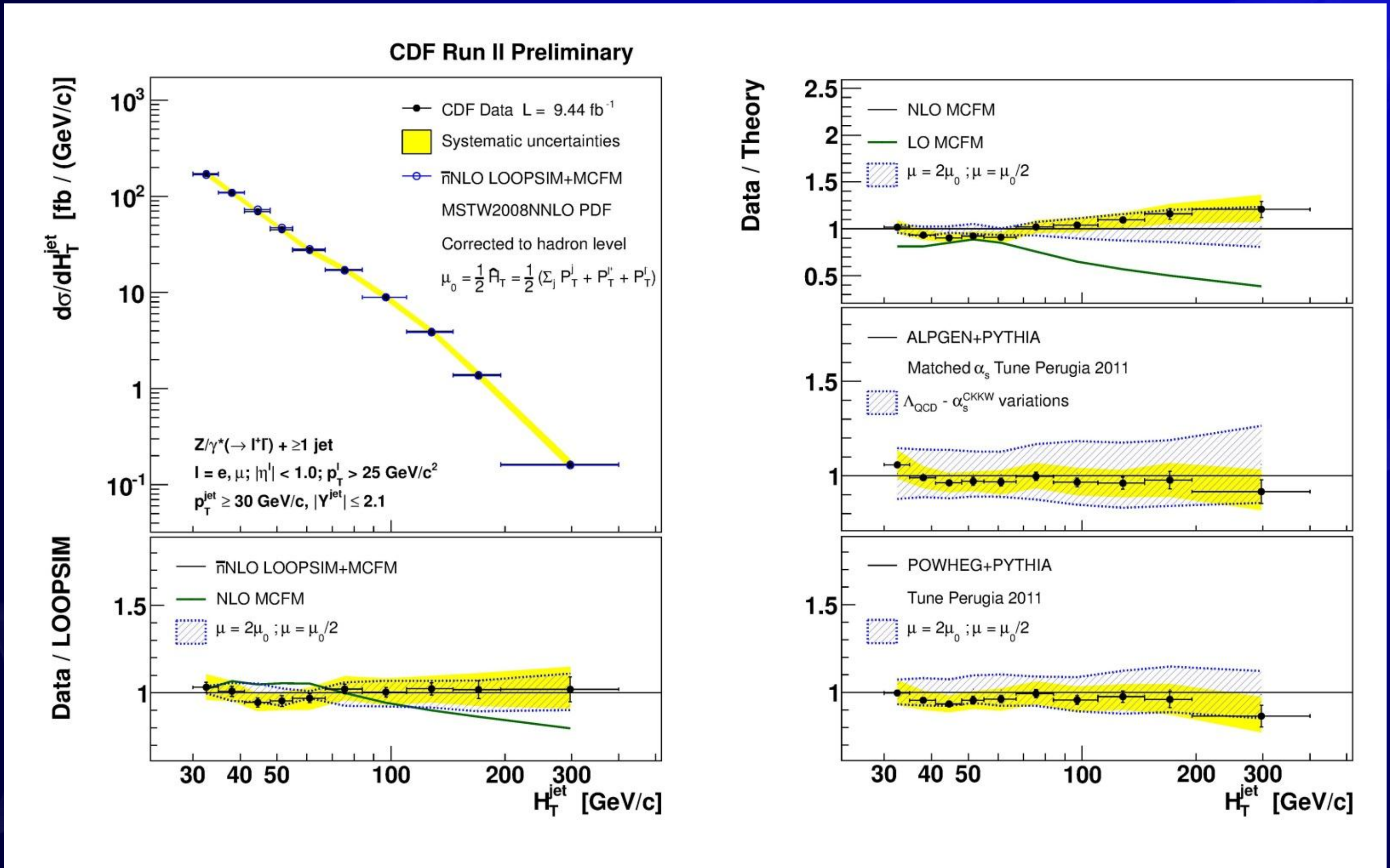
Inclusive Z + jets : CDF

- Main background for *ZH*, SUSY in MET+jets, etc.
- Includes $Z \rightarrow e^+e^-$ and $Z \rightarrow \mu^+\mu^-$ events
- Extensive analysis of differential cross sections as functions of several variables, over different jet multiplicities, with comparisons to many theoretical frameworks

- Cross section as a function of jet multiplicity
  - Shows improved performance of NLO BLACKHAT+SHERPA calculation over LO only



Inclusive Z + jets : CDF

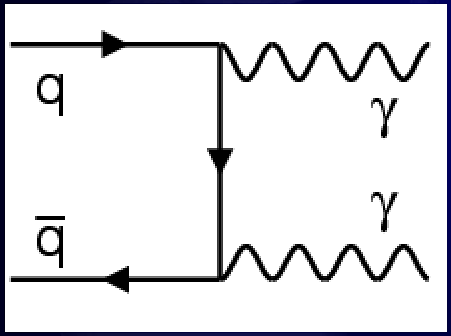


- **NNLO contributions expected to be greater for some distributions such as H_T**
  - LOOPSIM "nNLO" addition clearly describes data better at high H_T
- **Dozens more distributions on public webpage**

Diphotons

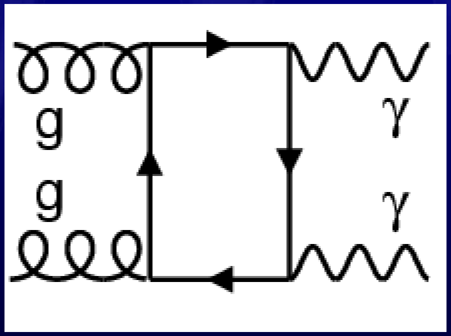
- **Prompt photon pairs represent large irreducible background to low mass $H \rightarrow \gamma\gamma$, searches for heavy resonances, extra spatial dimensions, etc.**
- **Tool to check pQCD soft gluon resummation techniques**
  - Particularly effective because prompt photons do not interact with other FS particles, and are well-measured by EM calorimeters
- **Can come from**

annihilation



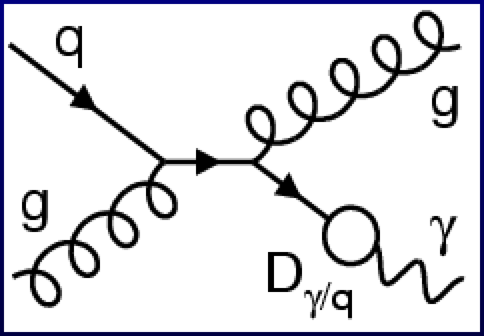
leading order, dominant at high mass

gluon fusion



important at low mass

fragmentation



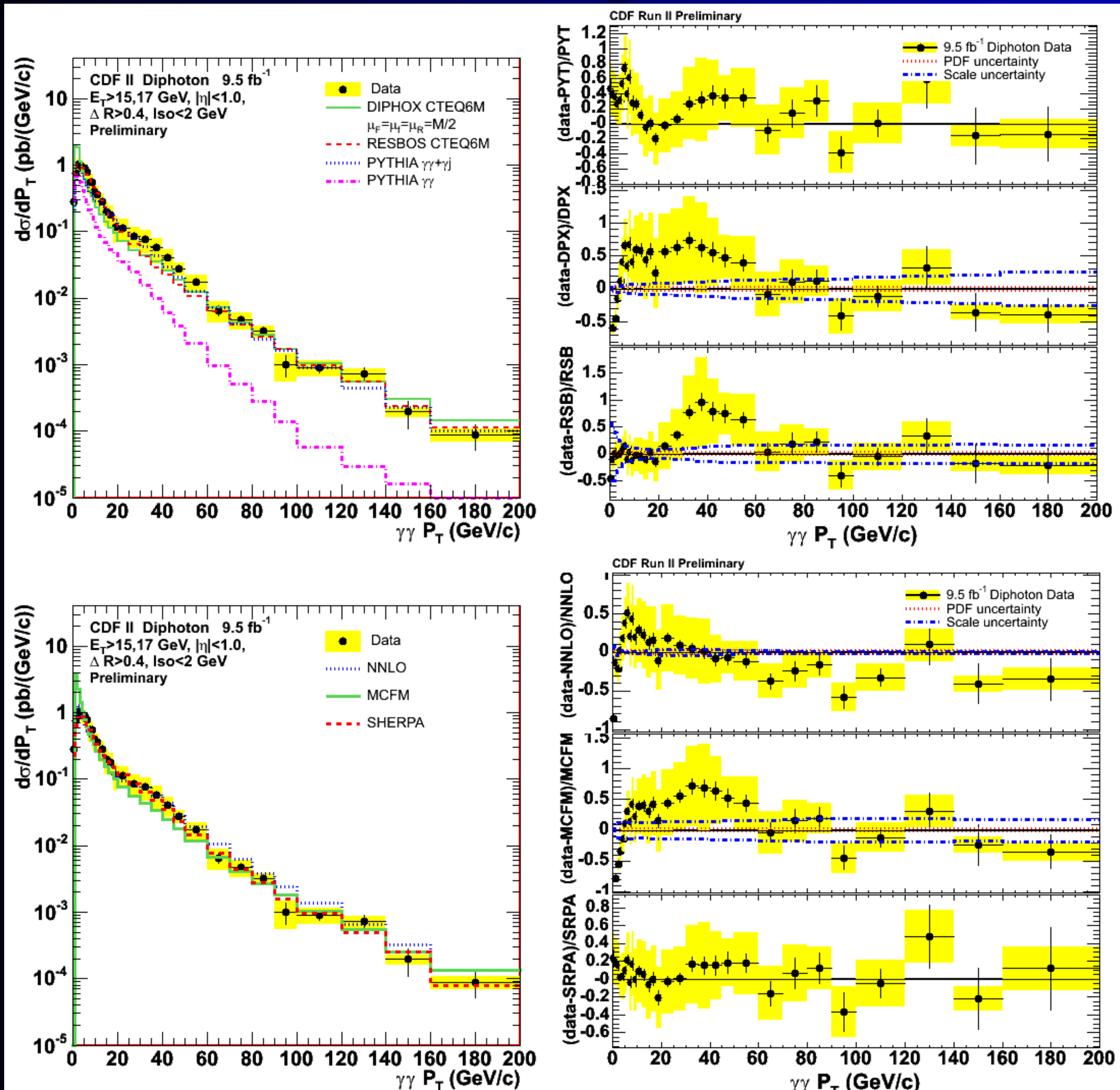
suppressed by photon isolation

Diphotons : CDF

- **Prompt photon pairs represent large irreducible background to low mass $H \rightarrow \gamma\gamma$, searches for heavy resonances, extra spatial dimensions, etc.**
- **Tool to check pQCD soft gluon resummation techniques**
  - Particularly effective because prompt photons do not interact with other FS particles, and are well-measured by EM calorimeters

Total Cross Section (pb)	
Data	$12.28 \pm 0.15^{stat} \pm 3.52^{syst}$
Diphox: NLO prompt, NLO frag	10.6 ± 0.5
MCFM: NLO prompt, LO frag	11.6 ± 0.3
ResBos: anal. resummed low pt to NLO high pt	11.3 ± 2.5
Sherpa: LO shower, improved hard-soft match	10.9
Pythia: LO shower	9.19
NNLO	$11.8 + 1.7 - 1.6$

Diphotons : CDF

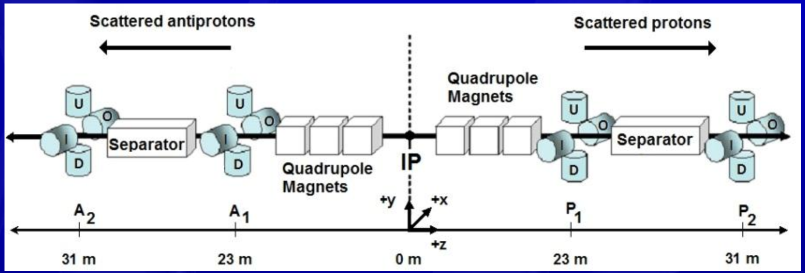


- RESBOS – good at low p_T where resummation important, poor in regions of strong fragmentation (low mass, low $\Delta\phi$)
- NNLO – best overall agreement with data including 20-50 GeV fragmentation "shoulder

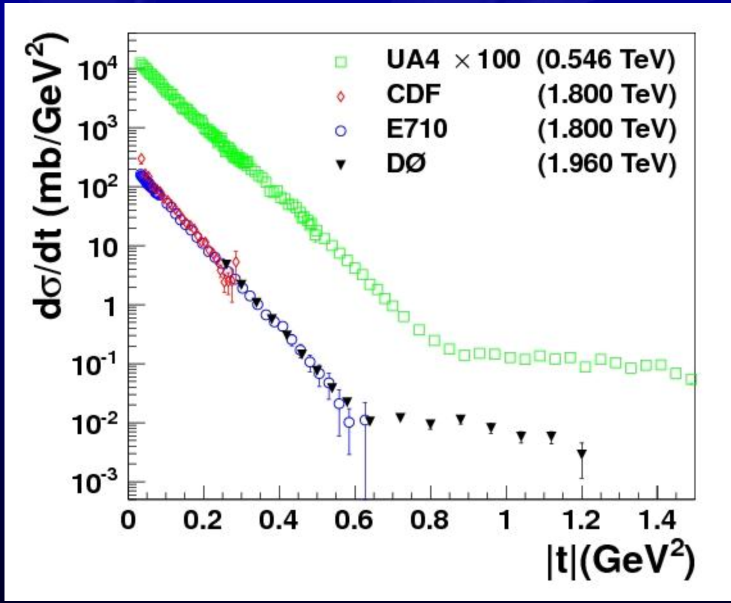
CDF Note 10160

Elastic Scattering : DØ

- Measure $\frac{d\sigma}{dt}(p\bar{p} \rightarrow p\bar{p})$, t = 4-mom^2
- Investigate proton structure, constrain soft diffractive models
- Performed in a dedicated run using forward proton detectors



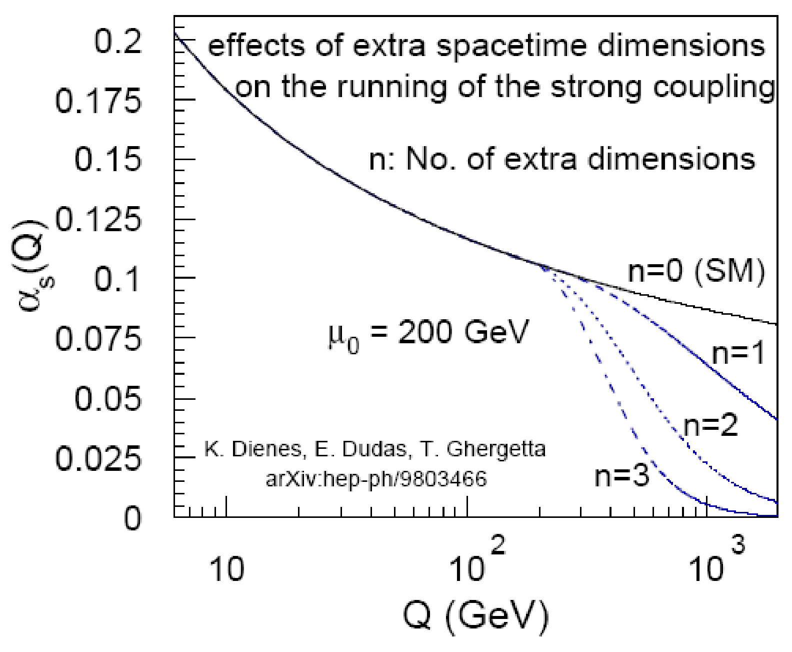
- Two expected features observed
  - |t| position of the local minimum where the logarithmic slope changes is reduced at higher center of mass energy (compare to UA4)
  - Local minimum is less pronounced for $p\bar{p}$ than for pp (e.g. TOTEM result)



PRD, submitted 6/5//12
arXiv:1206.0687

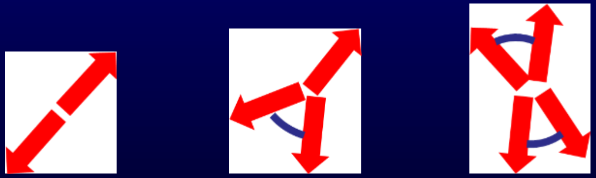
α_S Extraction : DØ

- Running of α_S has only been tested up to momentum transfer scale $Q = 208\ GeV$. At higher scales, modified by ESD



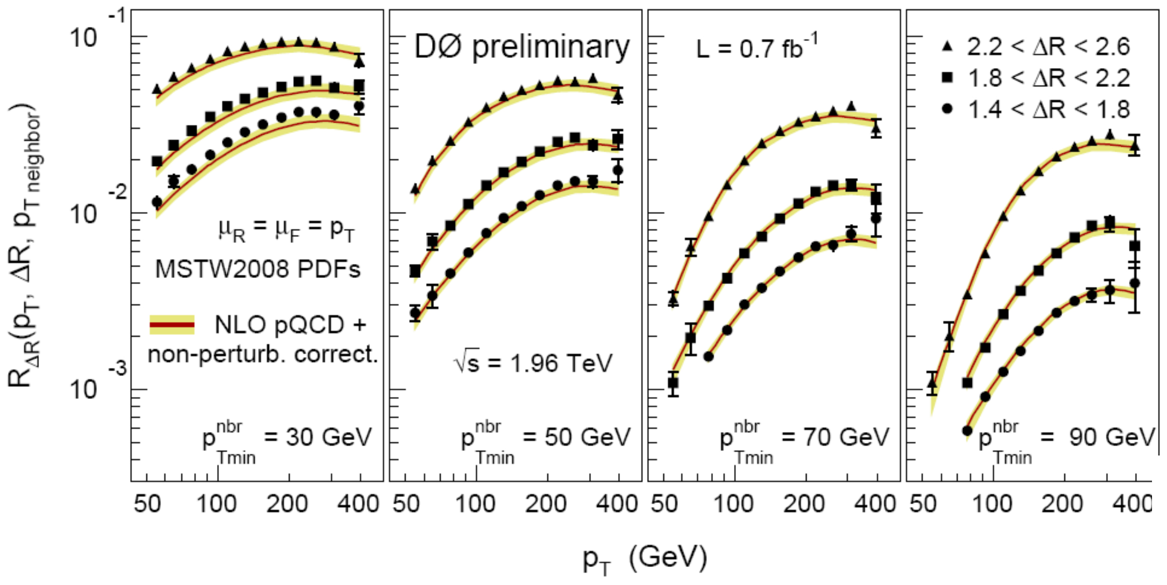
- α_S depends on renormalization scale – renormalization group equation relates $\alpha_S(Q_0)$ at one scale to $\alpha_S(Q)$ at another , but does not give value of α_S
- Previous α_S extractions at high Q, used inclusive jet cross sections. PDFs involved use RGE to run α_S to high scales – not an independent test!
    - Cross section ratios reduce, but do not eliminate PDF dependence
- New "angular correlation of jets" variable

$$R_{\Delta R} = \frac{\#\ neighboring\ jets}{\#\ inclusive\ jets}$$



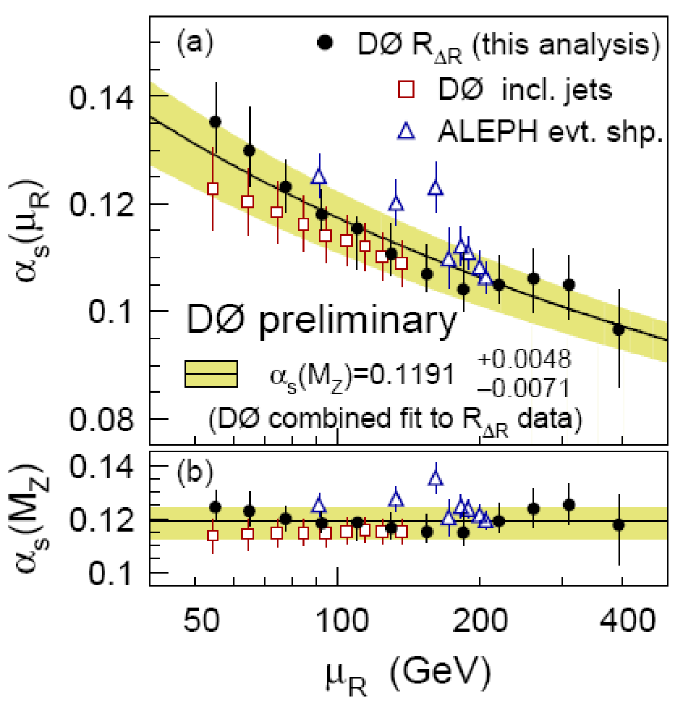
$R_{\Delta R} =$ 0 | 2/3 | 1

α_S Extraction : DØ



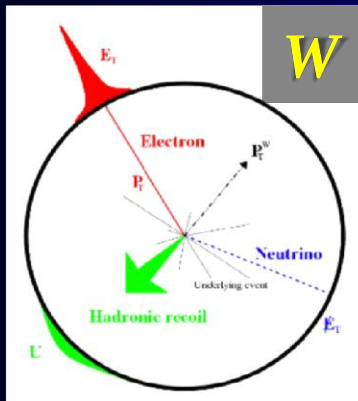
D0 Analysis	$\alpha_S(M_Z)$
$R_{\Delta R}$	$0.1191^{+0.0048}_{-0.0071}$
Inclusive jets	$0.1161^{+0.0041}_{-0.0048}$

- **Results agree with previous ALEPH, D0**
- **First independent test of RGE and α_S running up to 400 GeV**
- **Confirm RGE prediction that α_S continues to decrease as p_T increases above 208 GeV**

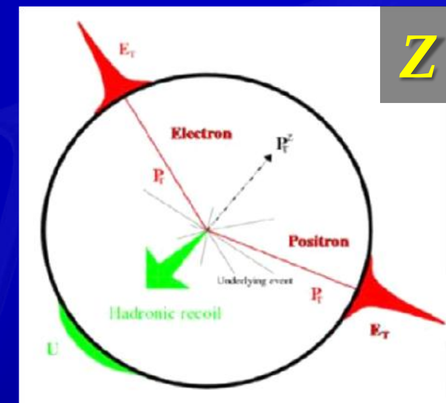


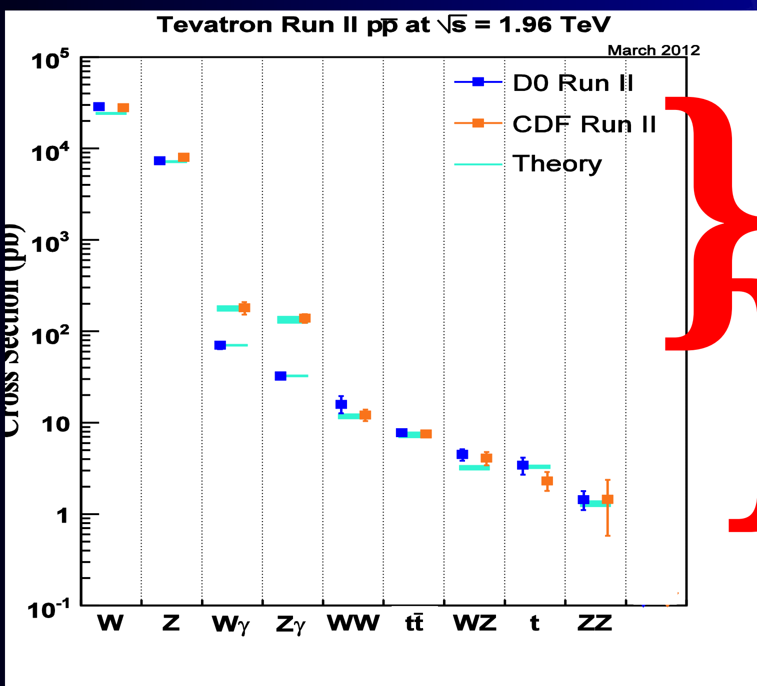
Wine & Cheese 5/18/12

Electroweak Physics



- **Clean signatures**
  - Isolated lepton(s) {$W(Z)$}
  - Missing E_T {W}
  - Little recoil/underlying evt
- **Well-understood physics**



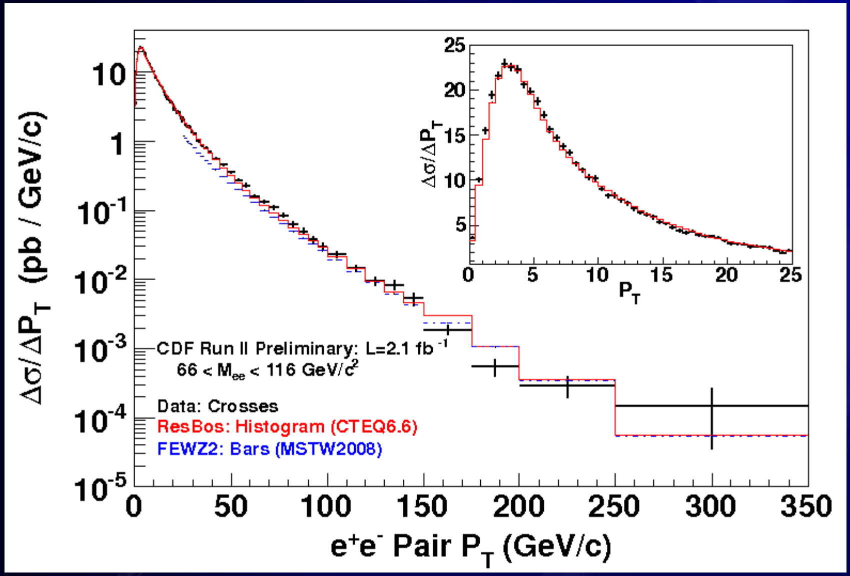


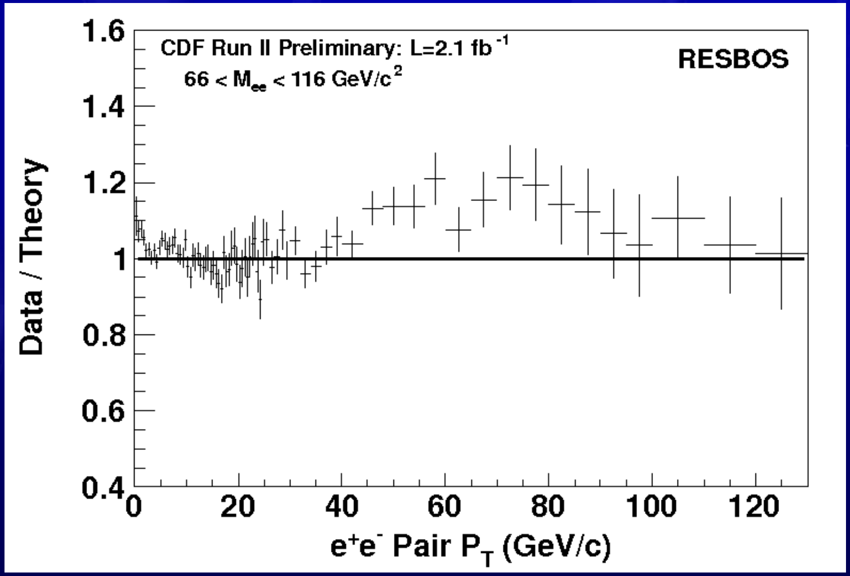
- **Calibrating detectors**
- **Precision SM measurements**
- **Deviations from SM**
- **Backgrounds to and "proof-of-principle" for Higgs searches**

$Z/\gamma^* P_T$ Distribution : CDF

- **Measurement of $d\sigma/dP_T$ in $p\bar{p} \rightarrow Z/\gamma^* + X \rightarrow e^+e^- + X$**
  - 66 GeV < M_{ee} < 116 Gev
  - All boson rapidity and decay electron phase space

Total σ integrated over all bins (pb)
$257.1 \pm 0.7^{stat} \pm 2.6^{syst} \pm 2.6^{lumi}$





- **Test of higher order QCD corrections – lowest order predicts no P_T in Z/γ^* production**

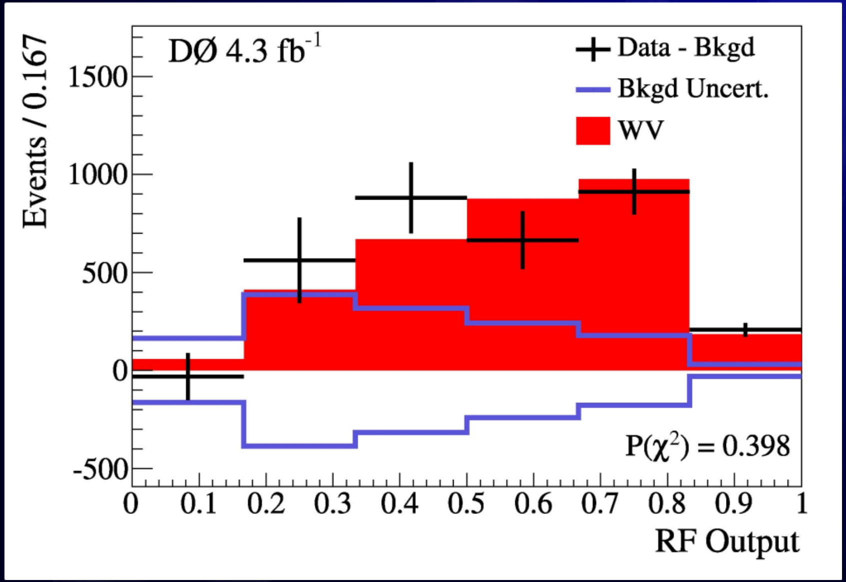
CDF Note 10699

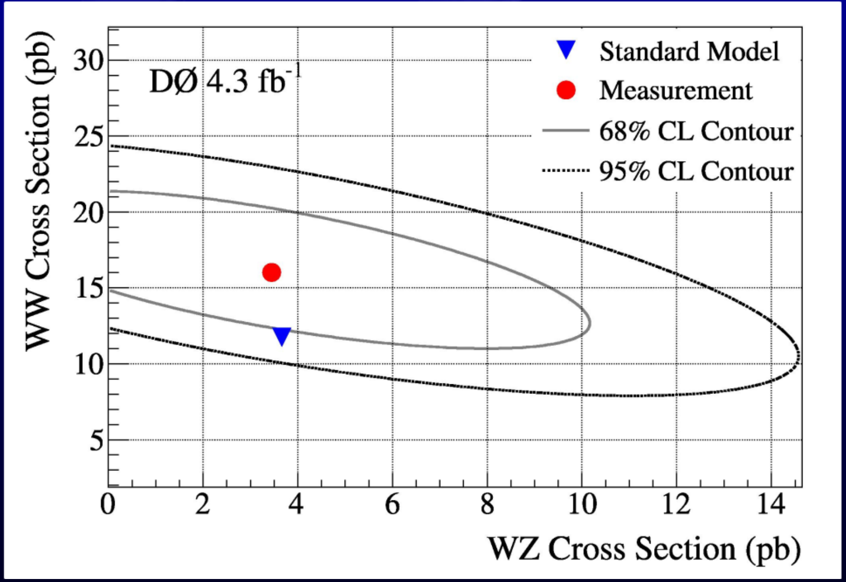
WW/WZ : DØ

- DØ produced a $\sigma(WW+WZ)$ measurement using *Wjj* final state events
- Uses a Random Forest MVA to extract the signal
- Assume SM $\sigma(WW)/\sigma(WZ)$ when fitting RF output for $\sigma(WV)$
- Then fit $\sigma(WW)$ and $\sigma(WZ)$ simultaneously, allowing both to float
- Cross check with fit to M_{jj}

σ (pb)	Observed	SM
WV	$19.6^{+3.2}_{-3.0}$	
WW	$15.9^{+3.7}_{-3.2}$	11.7 ± 0.8
WZ	$3.3^{+4.1}_{-3.3}$	3.5 ± 0.3

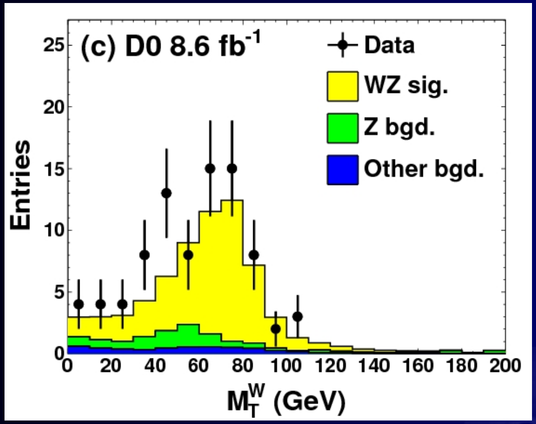
PRL 108, 181803 (2012)

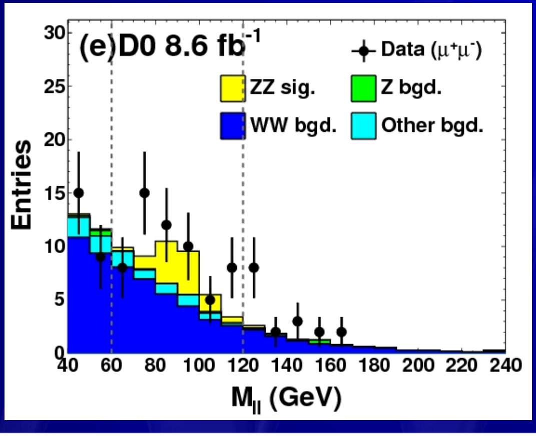




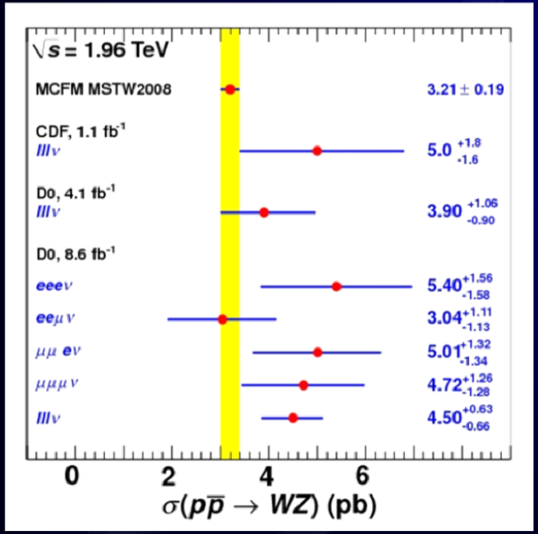
WZ/ZZ : DØ

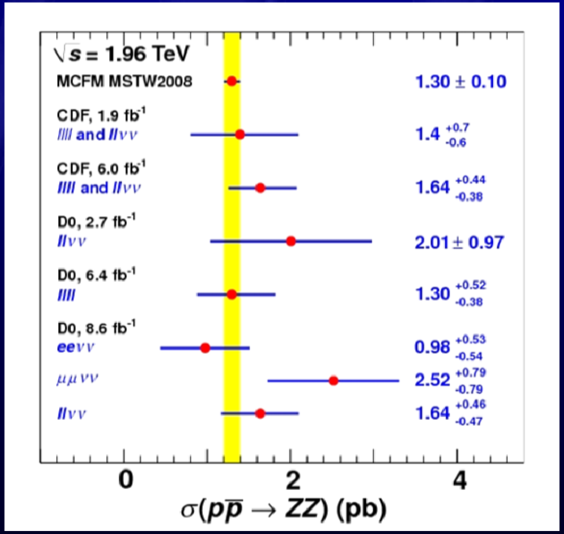
- Look at leptonic final states: $WZ \rightarrow l\upsilon ll$, $ZZ \rightarrow ll\upsilon\upsilon$
- Looser requirements than previous analyses to maximize yields





σ (pb)	Observed
$WZ_{l\upsilon ll}$	$4.50^{+0.63}_{-0.66}$ SM: 3.21 ± 0.19
$ZZ_{ll\upsilon\upsilon}$	1.64 ± 0.46 SM: 1.3 ± 0.1
ZZ_{comb}	$1.44^{+0.35}_{-0.34}$





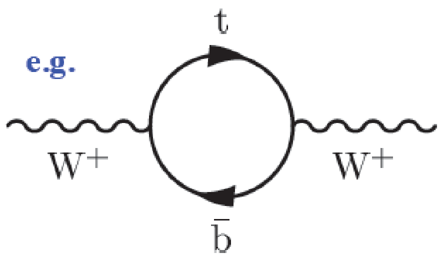
- PRD, accepted 4/8/12
arXiv:1201.5652

- **SM prediction of the W mass**

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

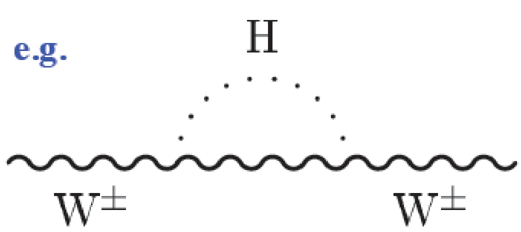
$$\Delta r \propto M_t^2$$

e.g.

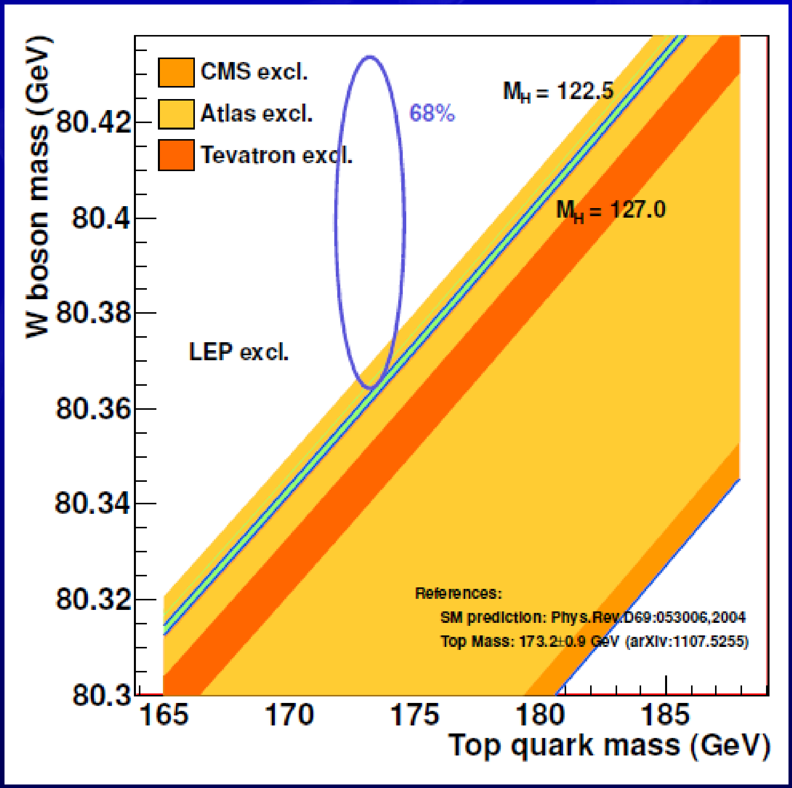


$$\Delta r \propto \ln M_H$$

e.g.



- **Prior to February 2012…**

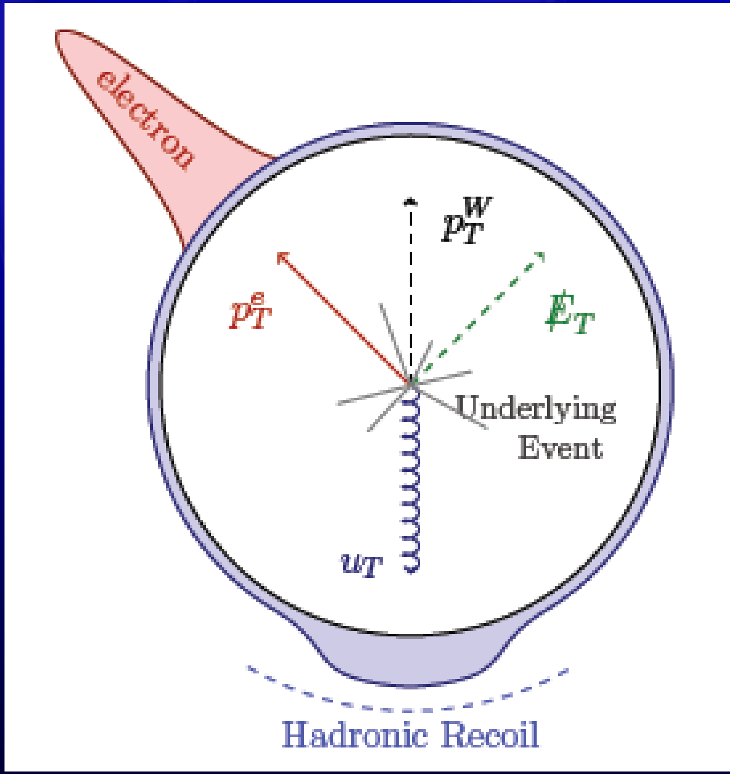


Higgs most sensitive to W mass for equal Higgs mass constraint

$$\Delta m_W \sim 0.006 \Delta m_t$$

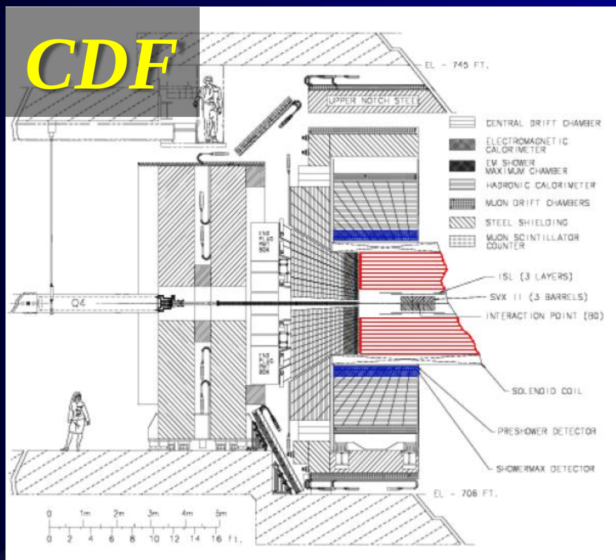
W Mass: Same Strategy

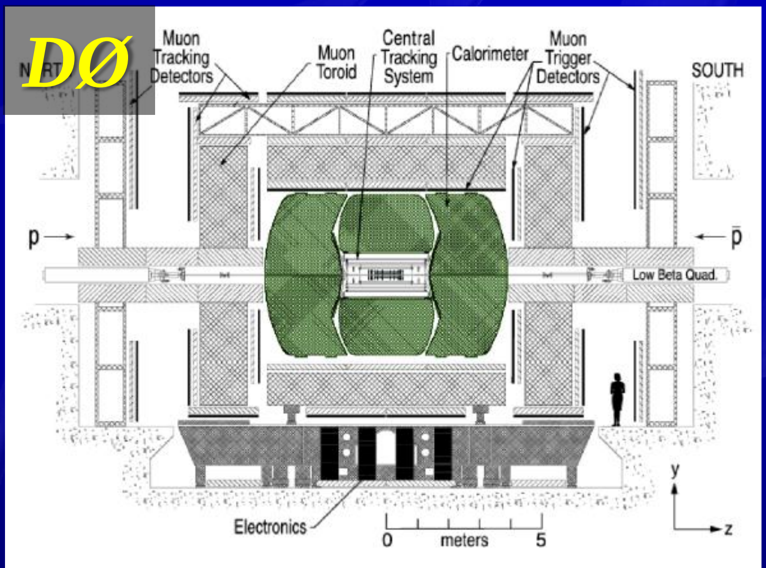
- **Transverse momentum carries mass information in $W \to l\upsilon$ events. Examine three kinematic distributions**
  - Transverse mass: $m_T = \sqrt{p_T^l \not{E}_T (1 - \cos \Delta\emptyset)}$
  - Lepton transverse momentum: p_T^l
  - Missing transverse energy: $\not{E}_T$
- **Use a parameterized fast MC detector simulation to generate templates to compare with data**
- **Calibrate fast MC with data**
  - Verify with the Z mass peak
- **Binned likelihood fit of data to templates to extract W mass**
- **Combine result from the different distributions since they are not completely correlated**



W Mass: Different Tactics

- **CDF and D0 employ very different methods, in order to capitalize on strength of their unique detectors**



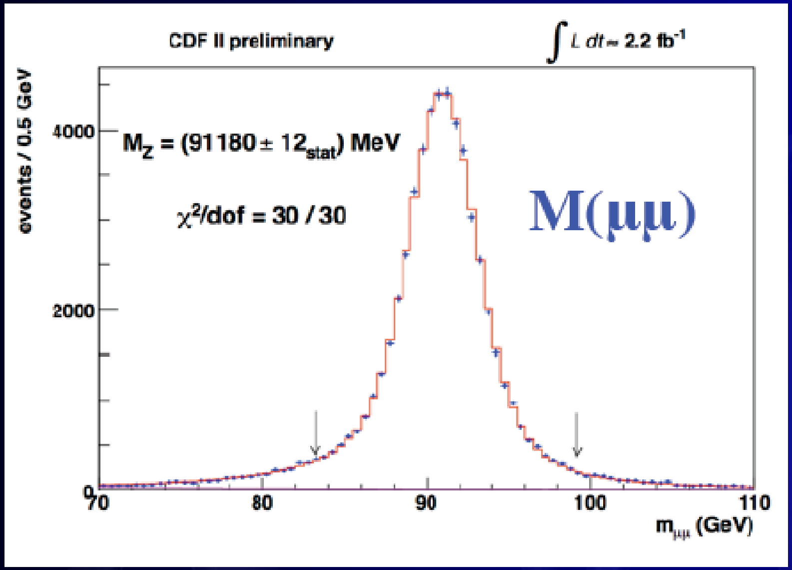


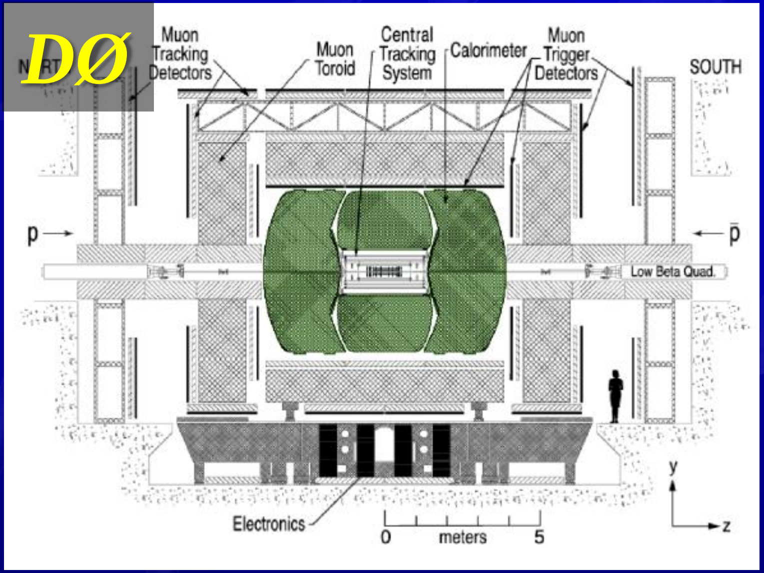
- **Central tracking provides very good lepton momentum measurement**
  - Muon resolution = 3.2% (at p_T = *45 GeV)*
- **Use $W\rightarrow e\upsilon$ and $W\rightarrow \mu\upsilon$ events**
- **Detailed tracker model**
- **Momentum scale calibration focus**
  - Using $J/\psi \rightarrow \mu\mu$, $\Upsilon \rightarrow \mu\mu$, $Z \rightarrow \mu\mu$

- **EM calorimeter provides very good electron energy measurement**
  - Energy resolution = 3.3% (at E = *45 GeV)*
- **Use $W\rightarrow e\upsilon$ events**
- **Detailed calorimeter model**
- **Energy scale calibration focus**
  - Using $Z \rightarrow ee$

W Mass: Different Tactics

- CDF and DØ employ very different methods, in order to capitalize on strength of their unique detectors





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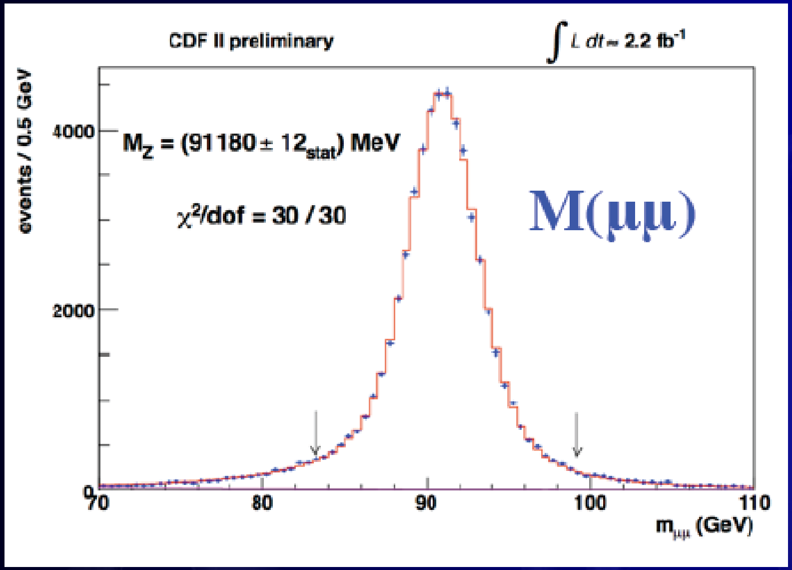

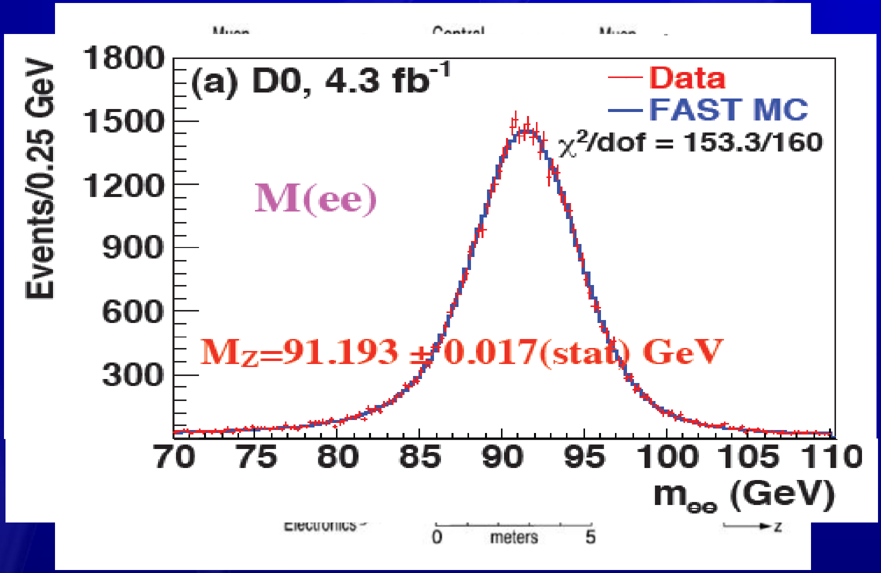

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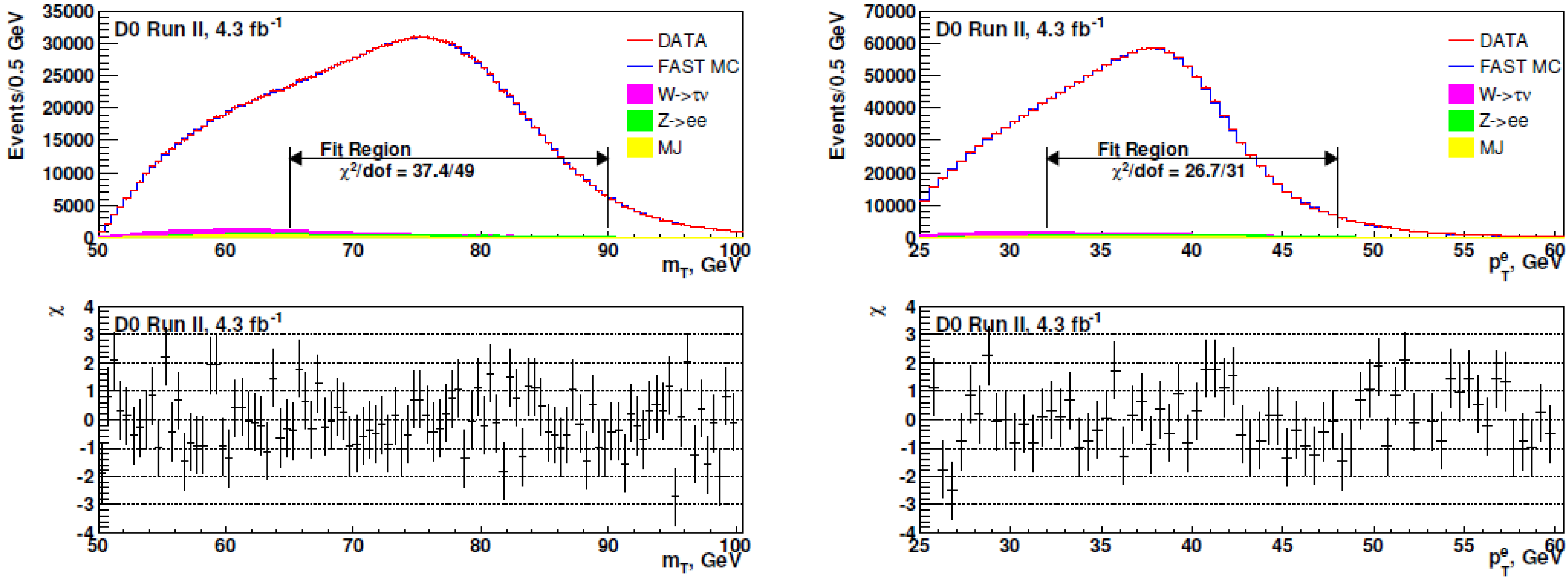
- Energy scale calibration focus
  - Using $Z \rightarrow ee$

W Mass: Systematic Uncertainty

- Systematic uncertainty breakdown in m_T measurement

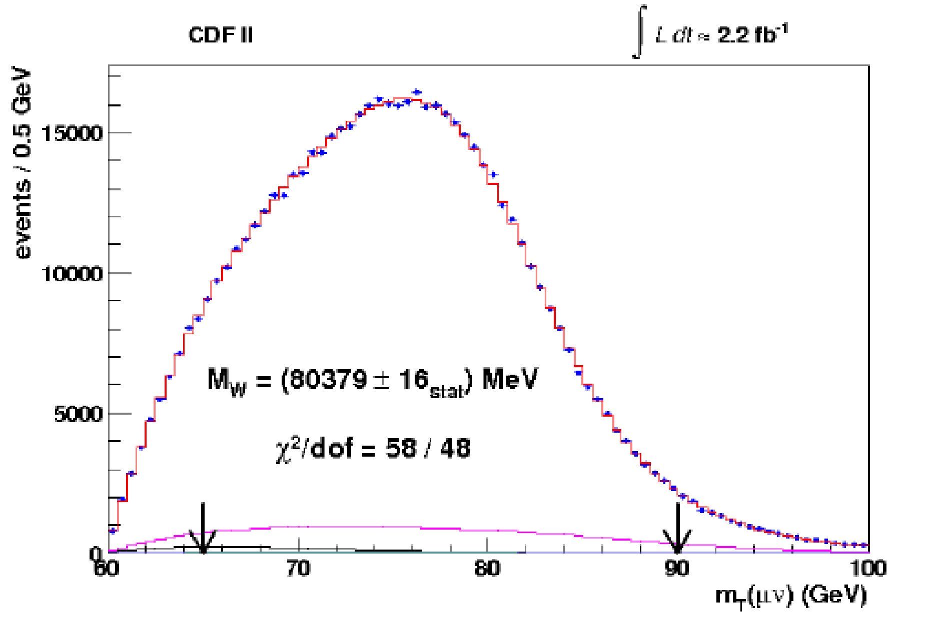
Source	CDF $m_T(\mu,\nu)$	CDF $m_T(e,\nu)$	DØ $m_T(e,\nu)$
Experimental – Statistical power of the calibration sample.			
Lepton Energy Scale	7	10	16
Lepton Energy Resolution	1	4	2
Lepton Energy Non-Linearity			4
Lepton Energy Loss			4
Recoil Energy Scale	5	5	
Recoil Energy Resolution	7	7	
Lepton Removal	2	3	
Recoil Model			5
Efficiency Model			1
Background	3	4	2
W production and decay model – Not statistically driven.			
PDF	10	10	11
QED	4	4	7
Boson p_T	3	3	2

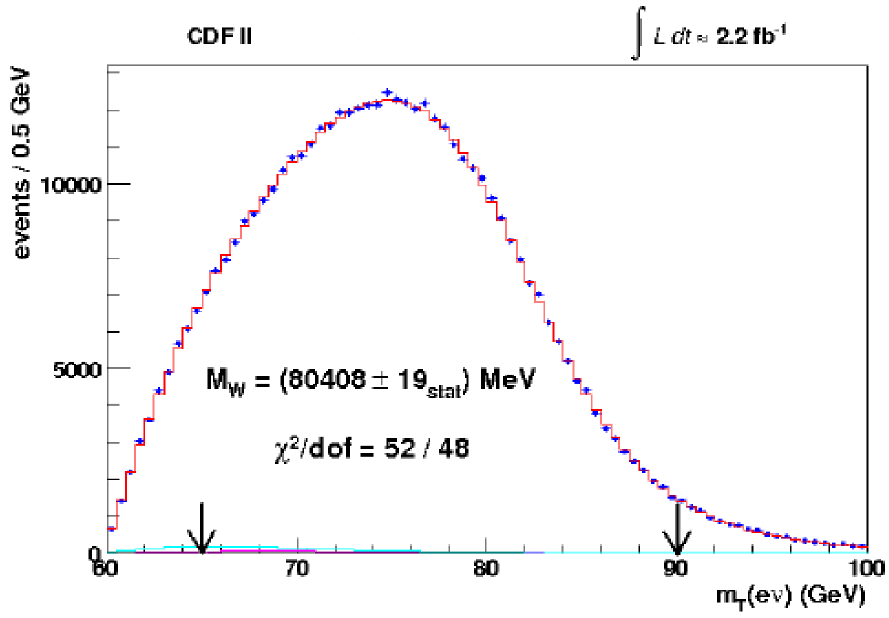
W Mass: D0 Result



Method $(4.3\ fb^{-1})$	M_W (MeV)
$m_T(e,\nu)$	80371 ± 13(stat)
$p_T(e)$	80343 ± 14(stat)
$\not{E}_T(e,\nu)$	80355 ± 15(stat)
Combination $m_T \oplus p_T$ $(4.3\ fb^{-1})$	80367 ± 26(syst + stat)
Combination $(5.3\ fb^{-1})$	**80375 ± 23**(syst + stat)

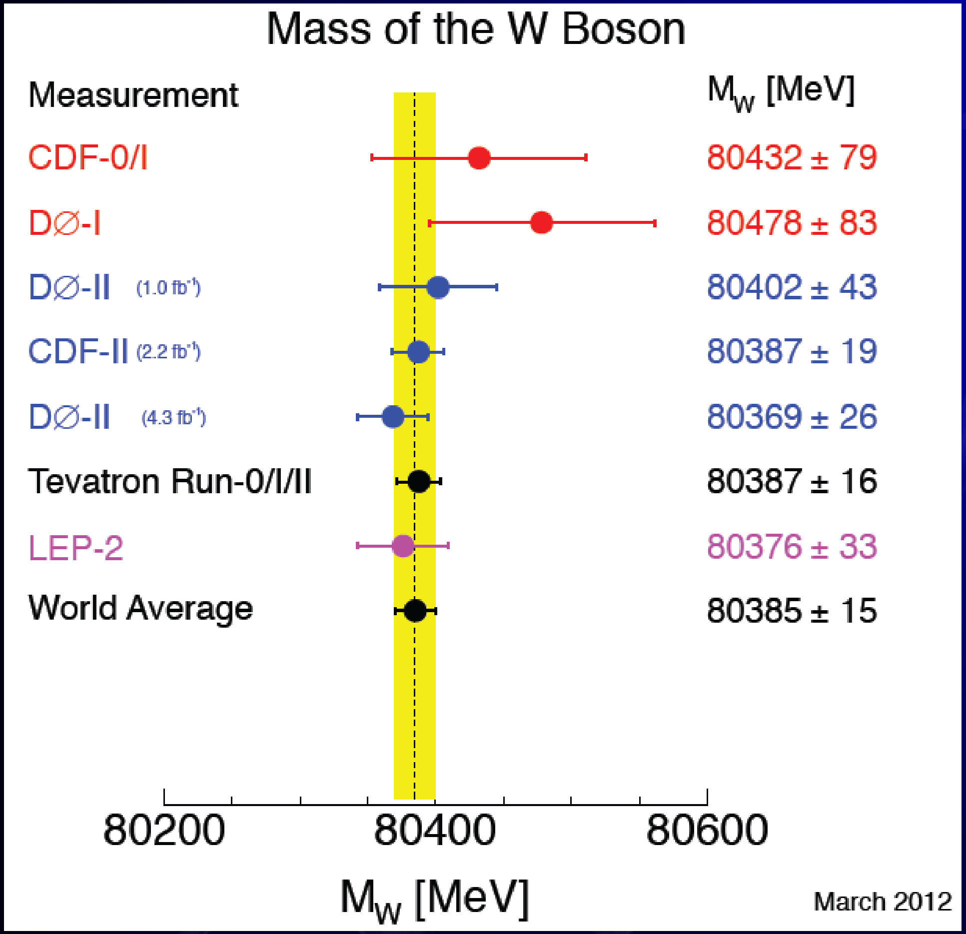
W Mass: CDF Result





Method $(2.2\ fb^{-1})$	M_W (MeV)	Method $(2.2\ fb^{-1})$	M_W (MeV)
$m_T(\mu,\nu)$	80379 ± 16(stat)	$m_T(e,\nu)$	80408 ± 19(stat)
$p_T(\mu)$	80348 ± 18(stat)	$p_T(e)$	80393 ± 21(stat)
$\not{E}_T(\mu,\nu)$	80406 ± 22(stat)	$\not{E}_T(e,\nu)$	80431 ± 25(stat)
Combination $(2.2\ fb^{-1})$	**$80387 \pm 19\ MeV$ (syst + stat)**		

W Mass: New World Average



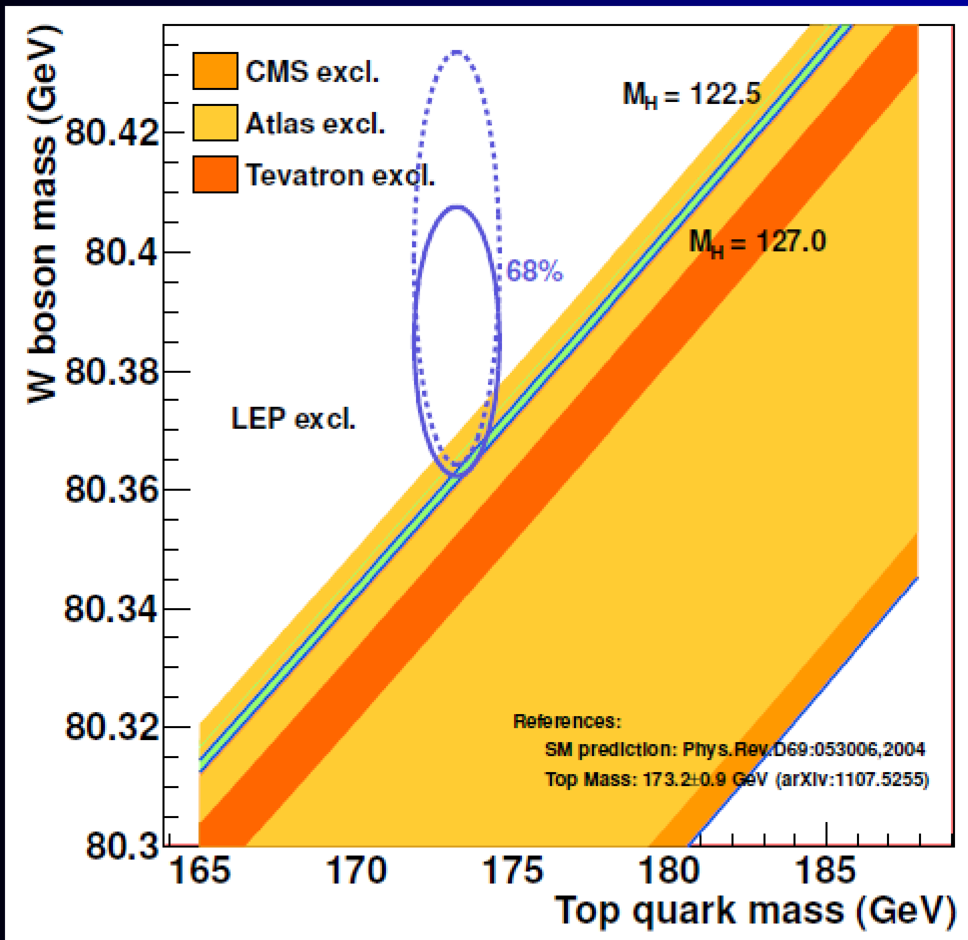
- **Both CDF and D0 results reach precision of previous world average**
- **CDF result is most precise W mass measurement**
- **Theory uncertainties now become limitation**
  - Reduce PDF uncertainty – include forward electrons, use W charge asymmetry
- **Full Tevatron data set can bring down uncertainty to 10 MeV!**

CDF: PRL **108**, 151803 (2012)

DØ: PRL **108**, 151804 (2012)

Tevatron Combination Note

W Mass: New Higgs Constraint



- **Both CDF and D0 results reach precision of previous world average**
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- **Full Tevatron data set can bring down uncertainty to 10 MeV!**
- **New indirect Higgs measurement still consistent with SM Higgs region allowed by direct searches**

Other Results from Past Year

- **CDF QCD: http://www-cdf.fnal.gov/physics/new/qcd/QCD.html**
  - W+c: CDF Note 10089
- **DØ QCD: http://www-d0.fnal.gov/Run2Physics/qcd/**
  - Inclusive jets: PRD **85**, 052006 (2012)
  - Inclusive W+jet (p_T^{jet}): PLB **705**, 200 (2011)
- **CDF EW: http://www-cdf.fnal.gov/physics/ewk/**
  - ZZ resonance: PRD **85**, 012008 (2012)
  - WZ: arXiv:1202.6629
- **DØ EW: http://www-d0.fnal.gov/Run2Physics/wz/**
  - WW/WZ: PRL **108**, 181803 (2012)
  - Zγ: PRD **85**, 052001 (2012)
  - Wγ: PRL **107**, 241803 (2011)

Summary

- **Full impact of QCD and Electroweak measurements using the full Tevatron data set are starting to be seen**
  - Extraction of fundamental parameters, e.g. α_S
  - Evaluating the best theoretical calculation models and improving PDFs
  - Providing well-measured backgrounds crucial for new physics searches
- **Many more full data set measurements still to come**
- **Precision QCD and Electroweak results will be a very big part of the Tevatron legacy!**

Backup Slides

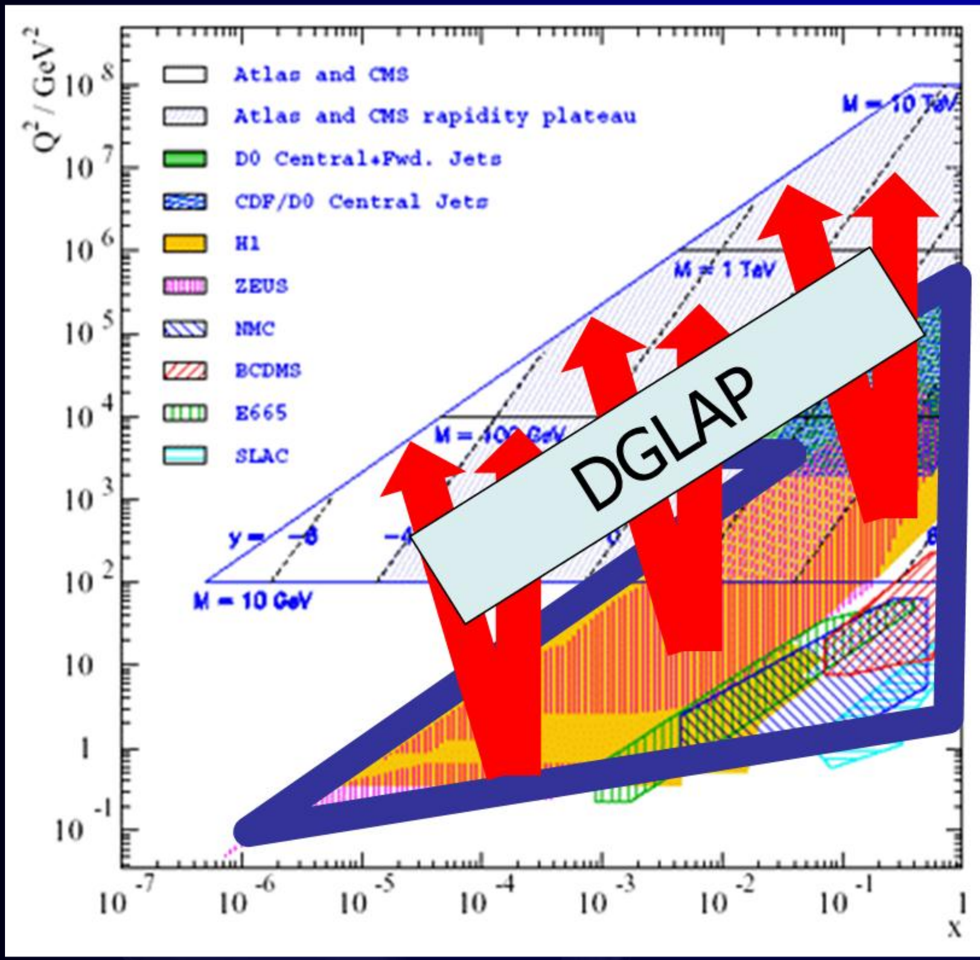
α_S Extraction : DØ

- **Renormalization Group Equation**

$$Q^2 \frac{\partial \alpha_s(Q^2)}{\partial Q^2} = \beta\left(\alpha_s(Q^2)\right)$$

$$\beta(\alpha_s(Q^2)) = -\beta_0 \alpha_s^2(Q^2) - \beta_1 \alpha_s^3(Q^2) - \beta_2 \alpha_s^4(Q^2) - \beta_3 \alpha_s^5(Q^2) + \mathcal{O}(\alpha_s^6)$$

α_S Extraction : DØ



PDFs are determined in global analyses:
CTEQ, MSTW, NNPDF

Most experimental constraints on PDFs are from data at **lower scales**

PDF knowledge at high scales from "DGLAP" evolution
→ **uses RGE for α_s(Q)**

$$\frac{\partial g(x,Q^2)}{\partial \ln Q^2} = \frac{\alpha_s(Q^2)}{2\pi}\left[\int_x^1 \left(P_{gq}(\frac{x}{x_1})q_s(x_1,Q^2) + P_{gg}(\frac{x}{x_1})g(x,Q^2)\right)\right].$$

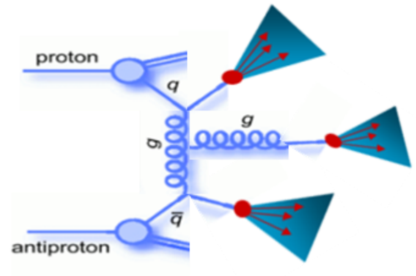
DGLAP: Dokshitzer–Gribov–Lipatov–Altarelli–Parisi

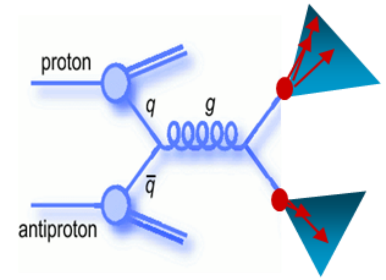
α_S Extraction : DØ

Goal: test pQCD (and α_s) **independent** of PDFs

→ Ratios of cross sections for 3-jet and 2-jet observables

R =





- Sensitive to α_s (3-jets: α_s^3 / 2-jets: α_s^2)
- Significantly reduced PDF sensitivity

α_S Extraction : DØ

1. Start with central inclusive jet sample ($|y|<1$)

2. Loop over all inclusive jets
   For each inclusive jet: count No. of neighboring jets
   - in distance ΔR in $(\Delta\phi,\Delta y)$
   - with $p_{Tnbr} > p_T{}^{min}{}_{nbr}$

3. Ratio: sum of all neighboring jets / total number of inclusive jets
   → average number of neighboring jets $R_{\Delta R}(p_T, \Delta R, p_T{}^{min}{}_{nbr})$

Note: for $\Delta R < \pi$ → only contributions from (at least) 3-jet events

→ $R_{\Delta R}$ looks at any jet and any neighboring jet
… more inclusive than $R_{3/2}$ (require to tag three leading jets)
… more inclusive than $R_{\Delta\phi}$ (require to tag two leading jets)

W Mass

CDF analysis

- Analyzed $2.2\, fb^{-1}$.
- Uses $W \to e\nu$ and $W \to \mu\nu$ decay channels.
- Central leptons $|\eta| < 1$ with $30 < p_T < 55\, GeV$
- Missing transverse energy $30 < \not{E}_T < 55\, GeV$
- Transverse mass $60 < m_T < 100\, GeV$
- Hadronic recoil momentum $u_T < 15\, GeV$

DØ analysis

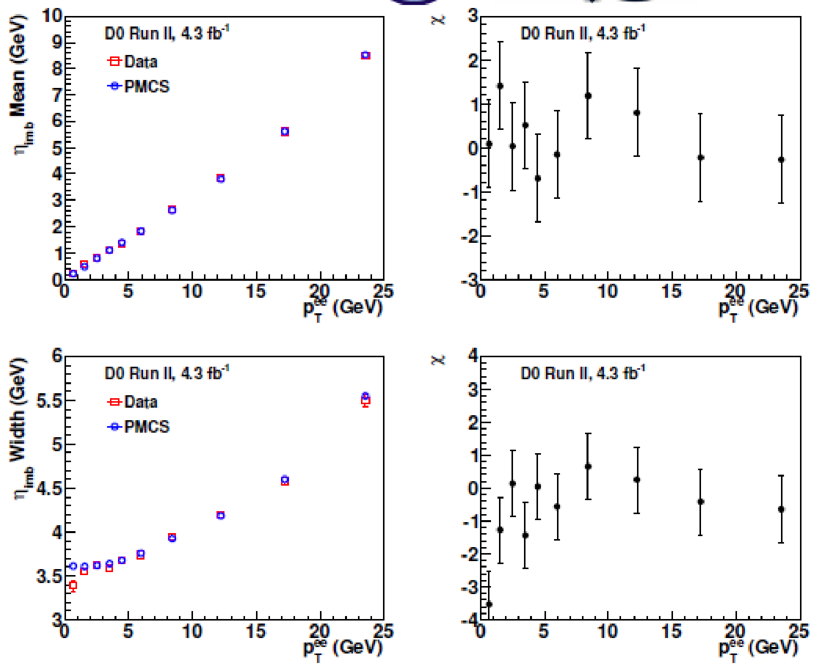
- Analyzed $4.3\, fb^{-1}$ ($1\, fb^{-1}$ analyzed before)
- Uses $W \to e\nu$ decay channel.
- Central electrons $|\eta| < 1.05$ with $p_T > 25\, GeV$
- Missing transverse energy $\not{E}_T > 25\, GeV$
- Transverse mass $50 < m_T < 200\, GeV$
- Hadronic recoil momentum $u_T < 15\, GeV$

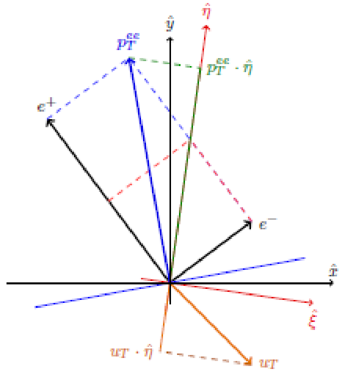
	$W \to e\nu$ candidates	$W \to \mu\nu$ candidates	Total
CDF $2.2\, fb^{-1}$	$470,126$	$624,708$	$1,094,834$
DØ $4.3\, fb^{-1}$ ($+1\, fb^{-1}$)	$1,677,394$	–	$1,677,394$ $2,177,224$

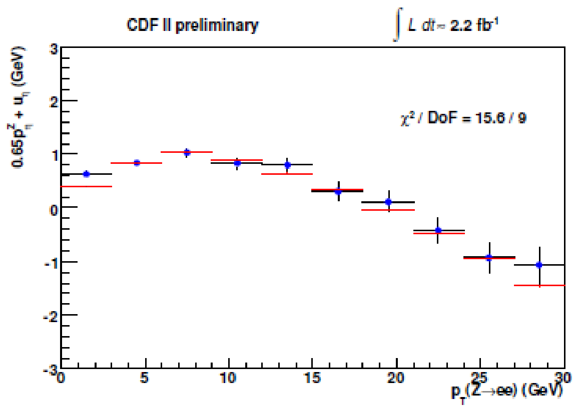
W Mass

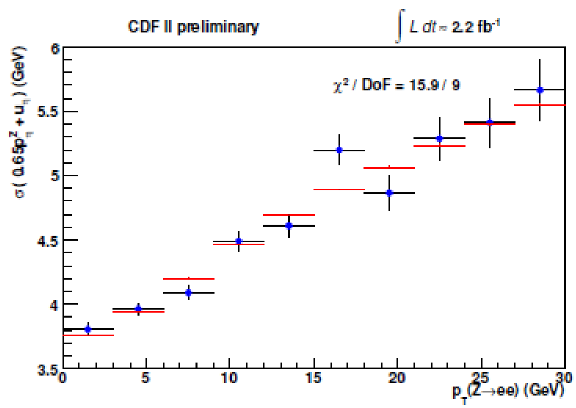
- **Hard recoil**: Parametrized from $Z \to \ell\ell$ events.
- **Soft recoil**: Data min-bias (CDF) or min-bias + zero-bias (DØ) events.
- **Lepton removal**: Hadronic energy reconstructed as lepton.
- **Out-of-cone FSR**: Photons reconstructed as recoil.

CDF and DØ: Final tune with $Z \to \ell\ell$ momentum imbalance.









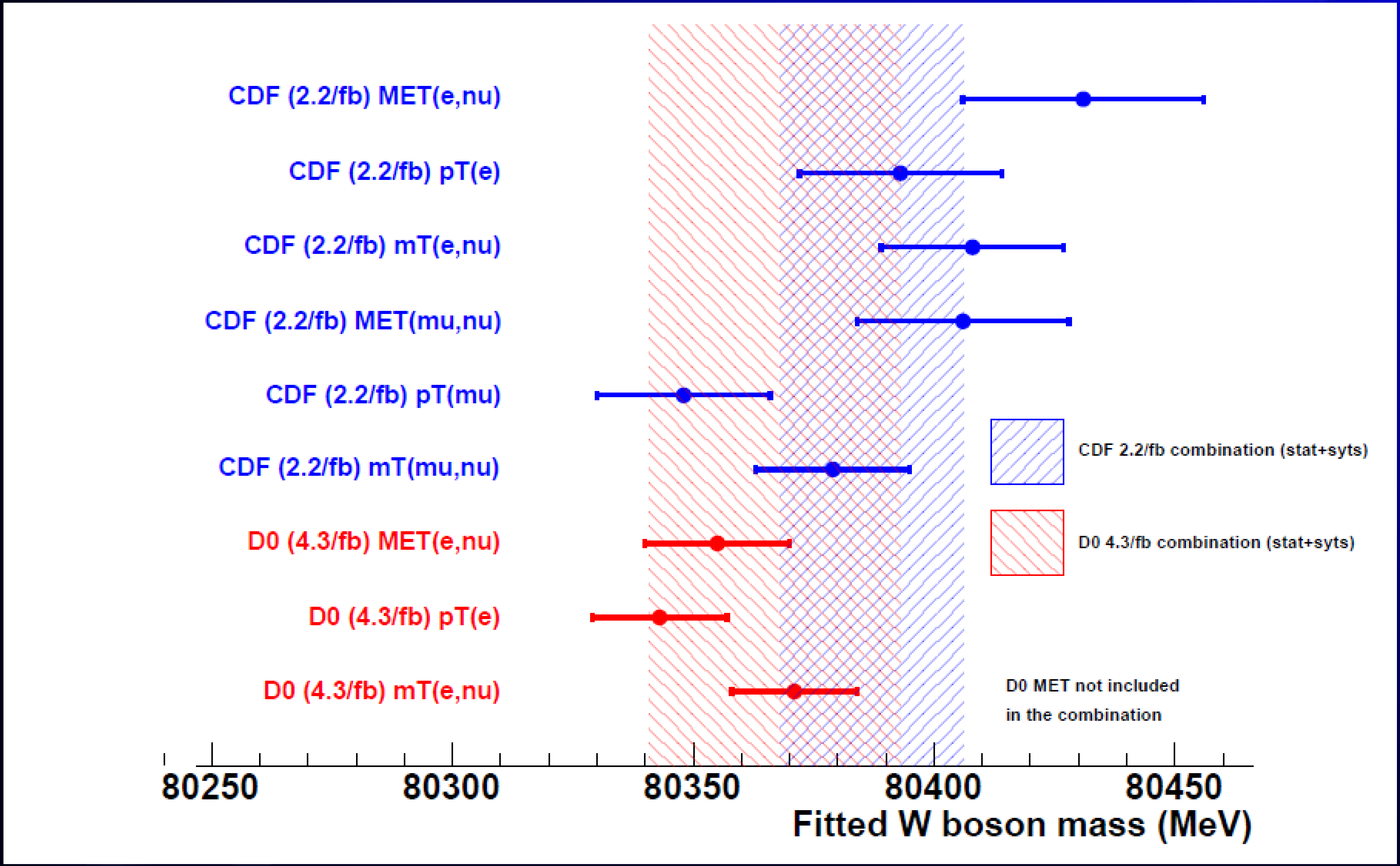
W Mass: CDF

Source	Uncertainty (MeV)
Experimental – Statistical power of the calibration sample.	
Lepton Energy Scale	7
Lepton Energy Resolution	2
Recoil Energy Scale	4
Recoil Energy Resolution	4
Lepton Removal	2
Background	3
Experimental Total	10
W production and decay model – Not statistically driven.	
PDF	10
QED	4
Boson p_T	5
W model Total	12
Total Systematic Uncertainty	15
W Statistics	12
Total Uncertainty	19

W Mass: DØ

Source	m_T MeV	p_T^e MeV	$\not{E}_T$ MeV
Experimental – Z statistics driven!			
Electron Energy Scale	16	17	16
Electron Energy Resolution	2	2	3
Electron Energy Nonlinearity	4	6	7
W and Z Electron energy loss differences	4	4	4
Recoil Model	5	6	14
Electron Efficiencies	1	3	5
Backgrounds	2	2	2
Experimental Total	18	20	24
W production and decay model – Not dependent on Z statistics!			
PDF	11	11	14
QED	7	7	9
Boson p_T	2	5	2
W model Total	13	14	17
Total Systematic Uncertainty	22	24	29
W Statistics	13	14	15
Total Uncertainty	26	28	33

W Mass

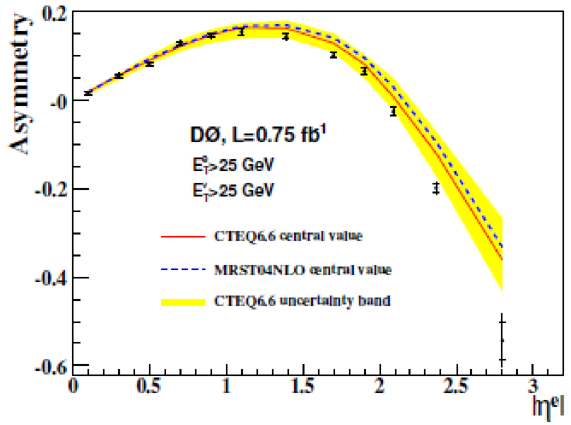


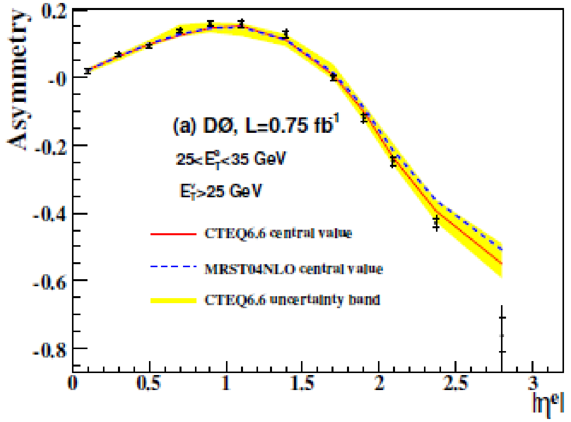
CDF (2.2/fb) MET(e,nu)
CDF (2.2/fb) pT(e)
CDF (2.2/fb) mT(e,nu)
CDF (2.2/fb) MET(mu,nu)
CDF (2.2/fb) pT(mu)
CDF (2.2/fb) mT(mu,nu)
D0 (4.3/fb) MET(e,nu)
D0 (4.3/fb) pT(e)
D0 (4.3/fb) mT(e,nu)
CDF 2.2/fb combination (stat+syts)
D0 4.3/fb combination (stat+syts)
D0 MET not included
in the combination
80250
80300
80350
80400
80450
Fitted W boson mass (MeV)

W Mass

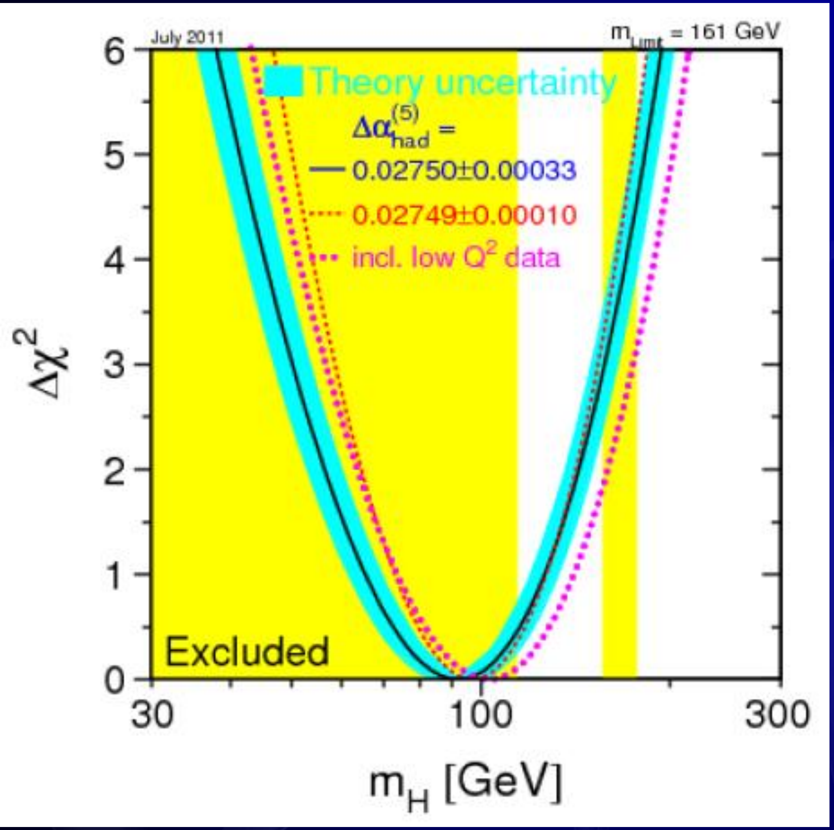
Ideas and developments to improve the model and theoretical uncertainties in the W mass measurement

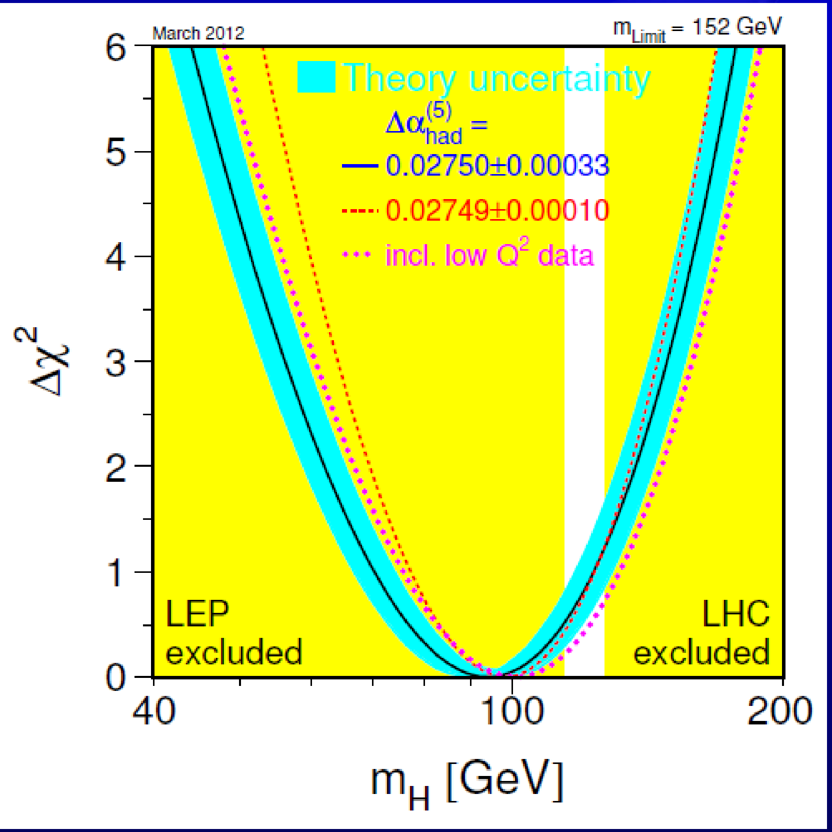
- Use a wider lepton η–acceptance to be less sensitive to PDF uncertainties. It has been done before at the Tevatron (DØ RunI). Phys.Rev.D**62**:092006,2000
- Use Tevatron W lepton charge asymmetry to constrain the u/d PDF instead of low energy experiments. Available: CT10W PDF set. Phys.Rev.D**82**:074024,2010
- Explore lepton longitudinal momentum to extract the W mass. Concrete example: JHEP **1108**:023,2011
- Study QED uncertianties in the measurement using NLO QCD $\oplus$ EW generators. Two recent implementations in the POWHEG framework. arXiv:1202.0465, arXiv:1201.4804





W Mass





Indirect measurement from precision EW data (Tevatron, LEP, SLD)

$$m_H = 92^{+0.34}_{-0.26}\ GeV$$

$$m_H = 94^{+29}_{-24}\ GeV$$

$$m_H < 152\ GeV (95\%\ CL)$$