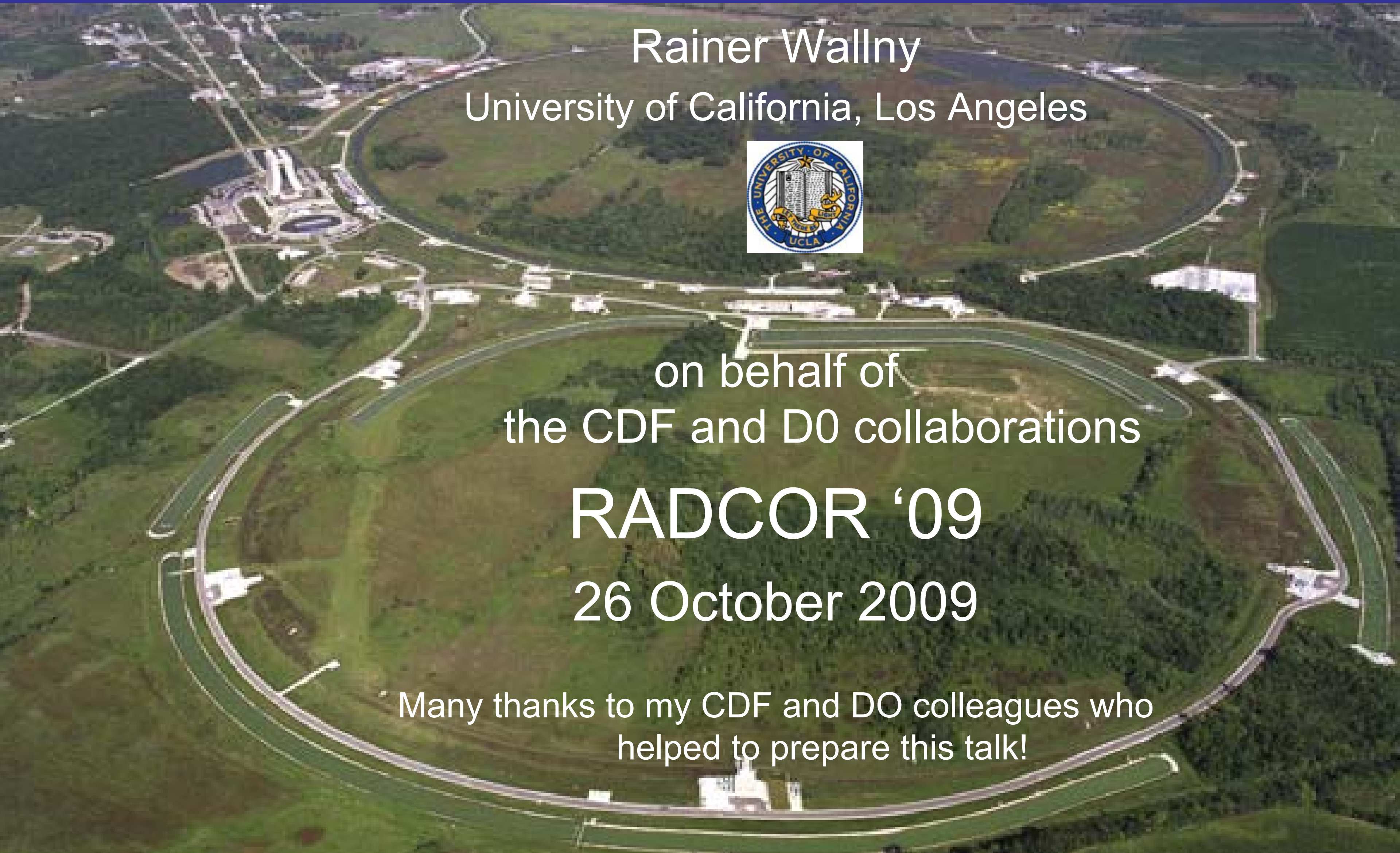
Recent Results from the Tevatron Experiments



Rainer Wallny
University of California, Los Angeles

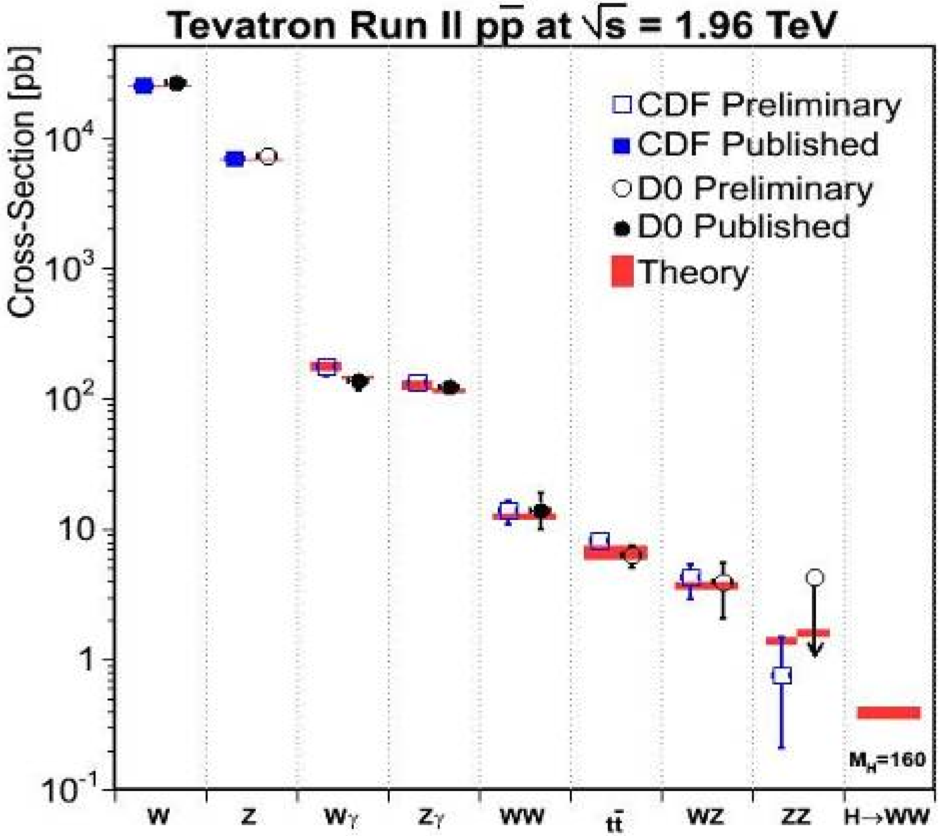
on behalf of
the CDF and D0 collaborations

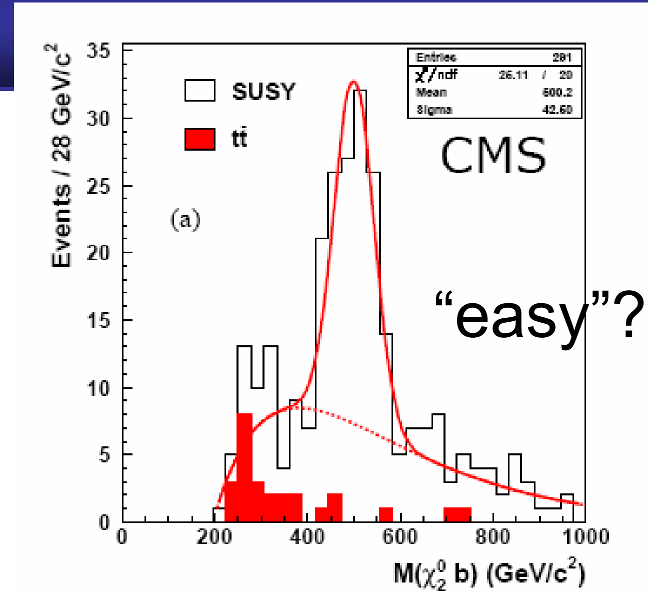
RADCOR ‘09

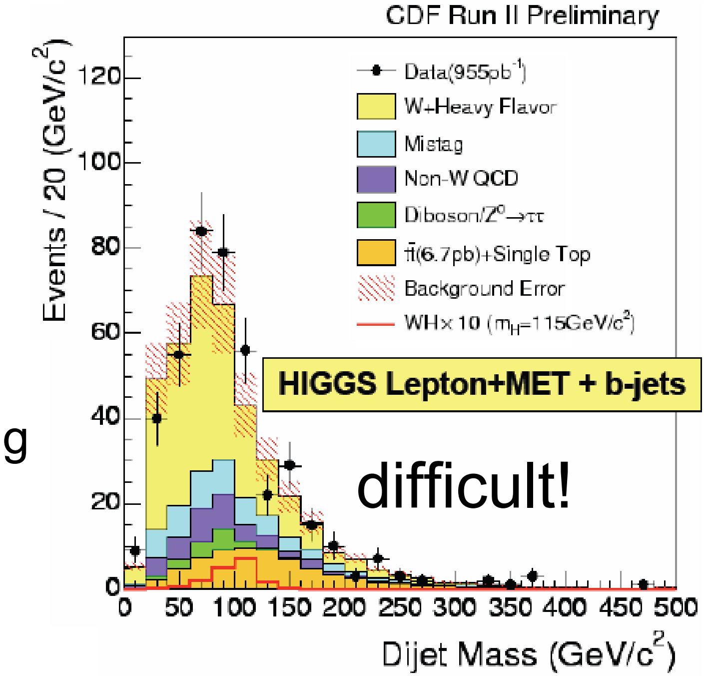
26 October 2009

Many thanks to my CDF and DO colleagues who helped to prepare this talk!

The Challenge







- So far new physics has proven to be elusive
  - probing smaller and smaller cross sections + taking advantage of high luminosity hadron colliders
- Theory understanding vital to fight the signal/back-ground challenge
- **(Some) discovery may be easy at LHC – maybe**.

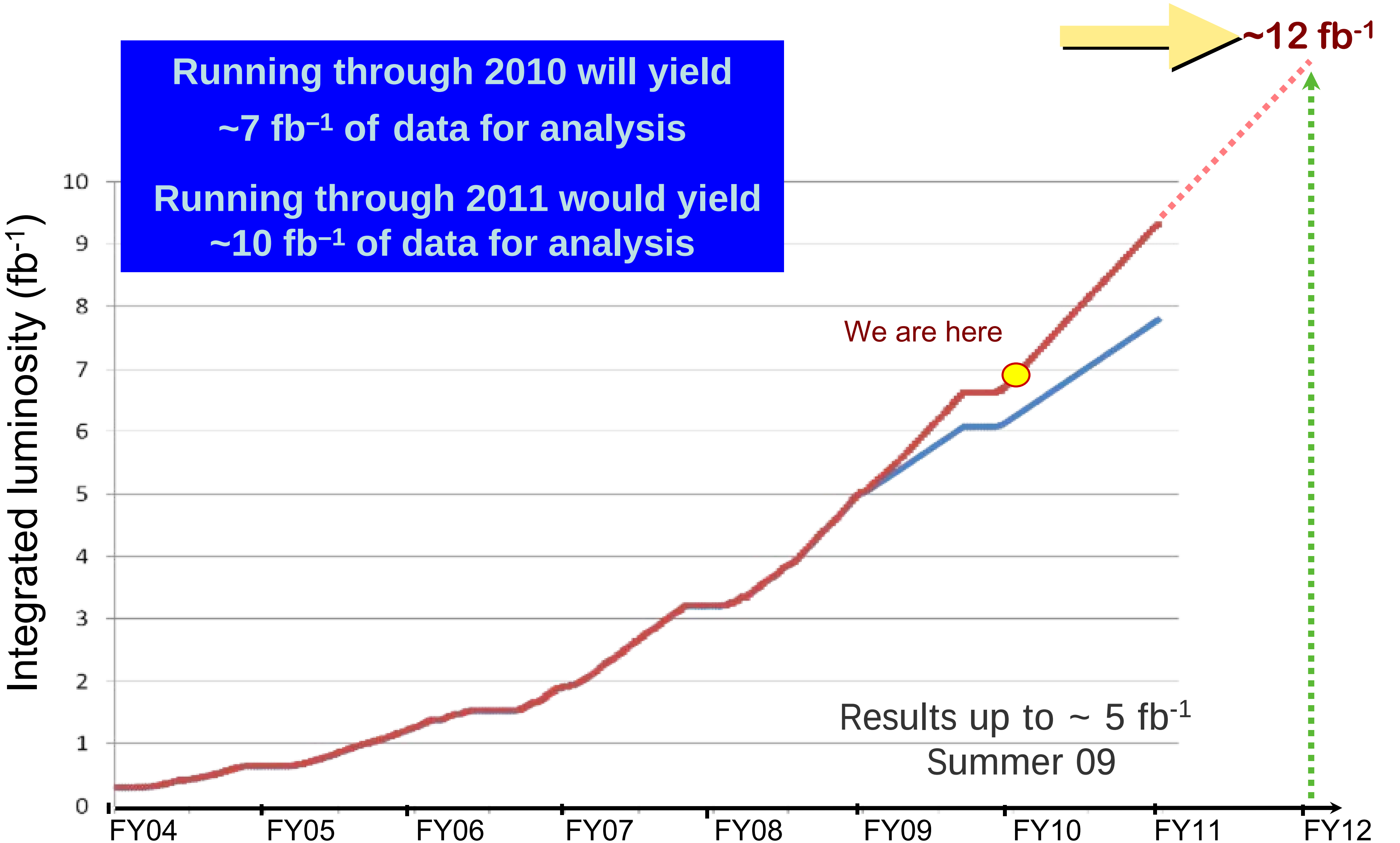
The Tevatron Accelerator Complex

- Still world's highest energy collider
- Proton-antiproton Synchrotron
  - Experiments CDF and DØ
- Run I (1992-1996)
  - $\sqrt{s}$ = 1.8 TeV
  - 100 pb^{-1} int. luminosity
- Major upgrade to accelerator complex and detectors
  - Main Injector (x5)
  - Pbar Recycler (x2)
- Run II (2001-2010 (2011 being discussed))
  - $\sqrt{s}$ = 1.96 TeV
  - Delivered luminosity so far: 7 fb^{-1} - on tape:~6 fb^{-1}
    - Record per week 73 pb^{-1}
    - > 2 fb^{-1} in 2008

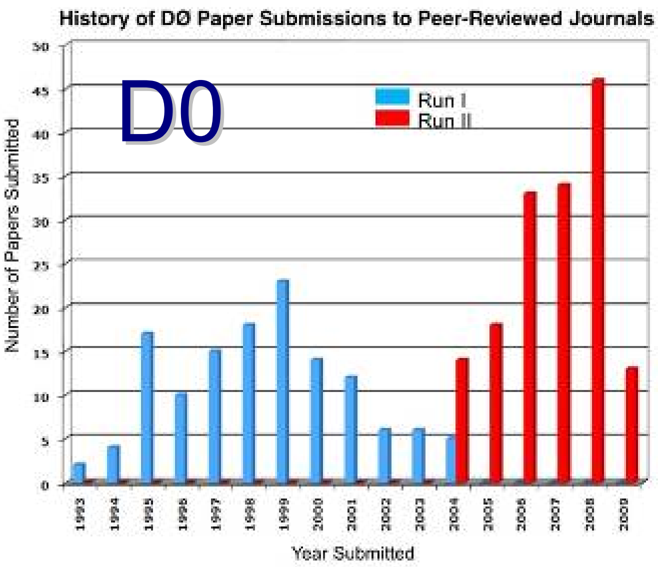
Luminosity Projections [delivered]

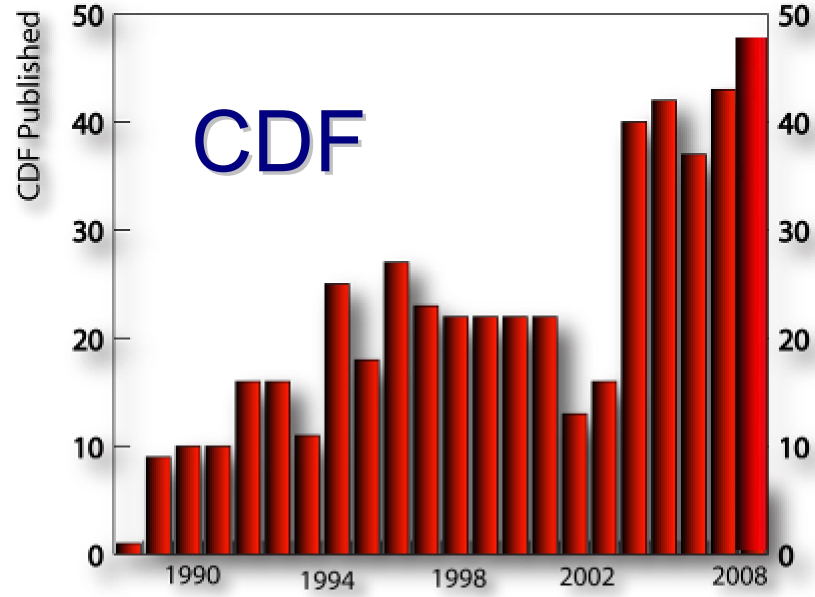
Running through 2010 will yield ~7 fb^{-1} of data for analysis

Running through 2011 would yield ~10 fb^{-1} of data for analysis



Tevatron Physics Publications





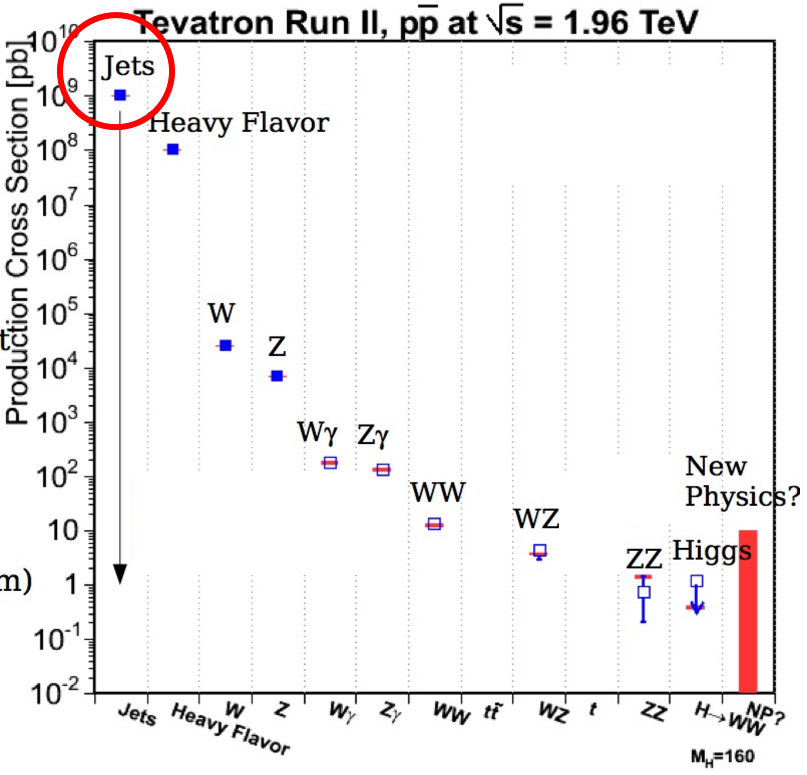
- Nearly 100 journal publications last year alone
- About 60 Ph.D.'s / year over the last few years

I selected a few most recent results (hopefully) relevant to this audience:

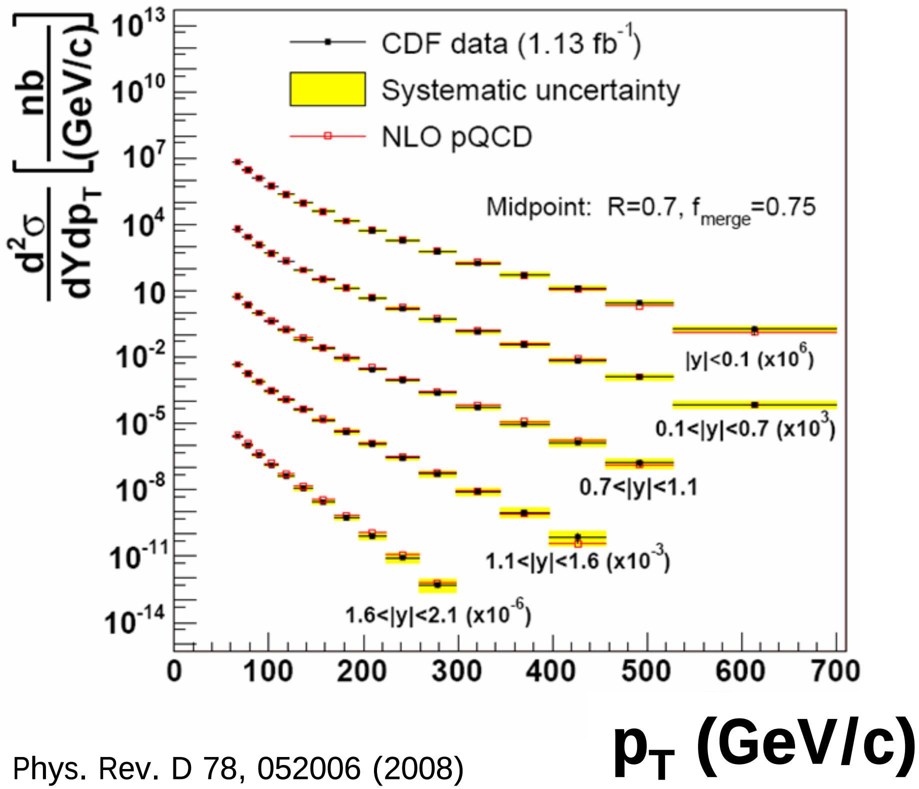
- QCD + PDF
- Vectorboson + jets
- Flavor Physics
- EWK
- top
- Higgs

Not comprehensive - apologies for omissions etc.

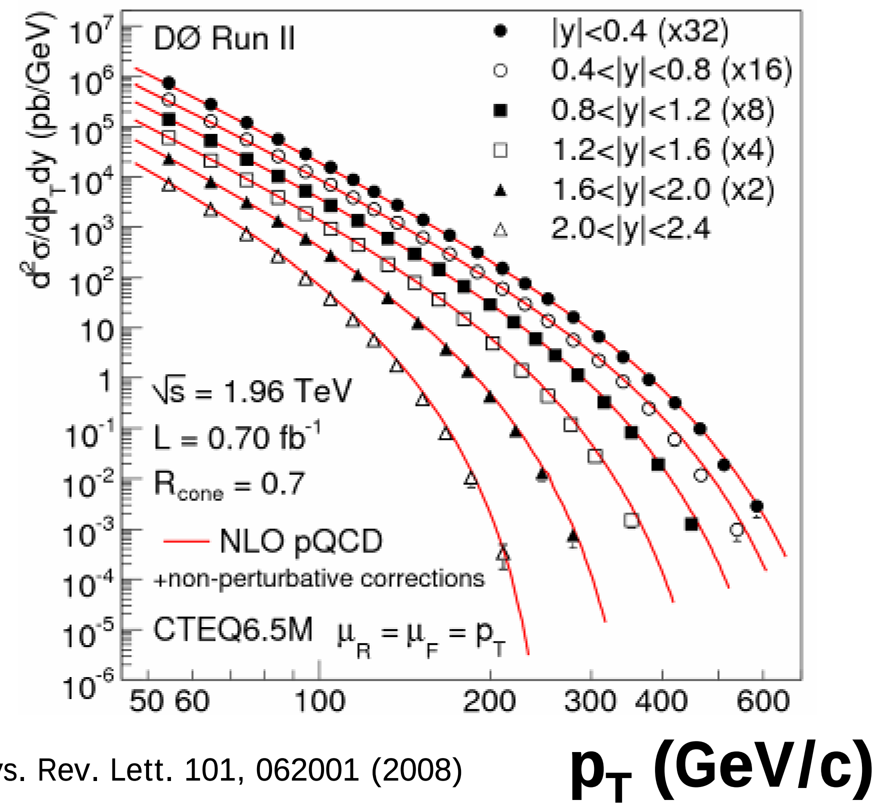
QCD and PDFs



- Inclusive and di-jet Production
  - High-x gluon parton distribution
- α_s
- W asymmetry
- Z $d\sigma/dy$



Phys. Rev. D 78, 052006 (2008)

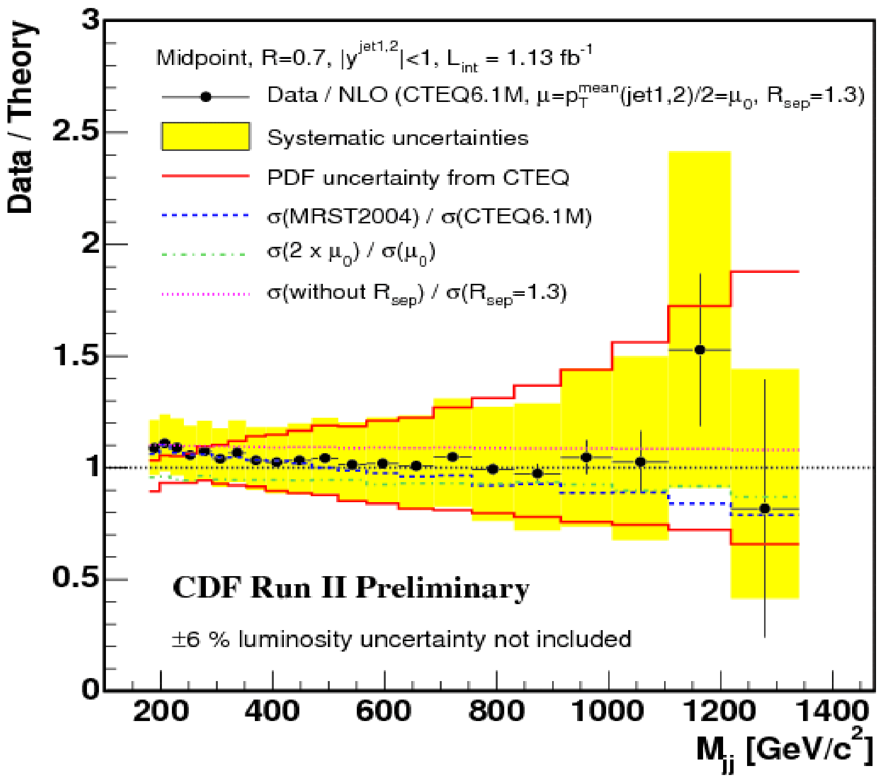


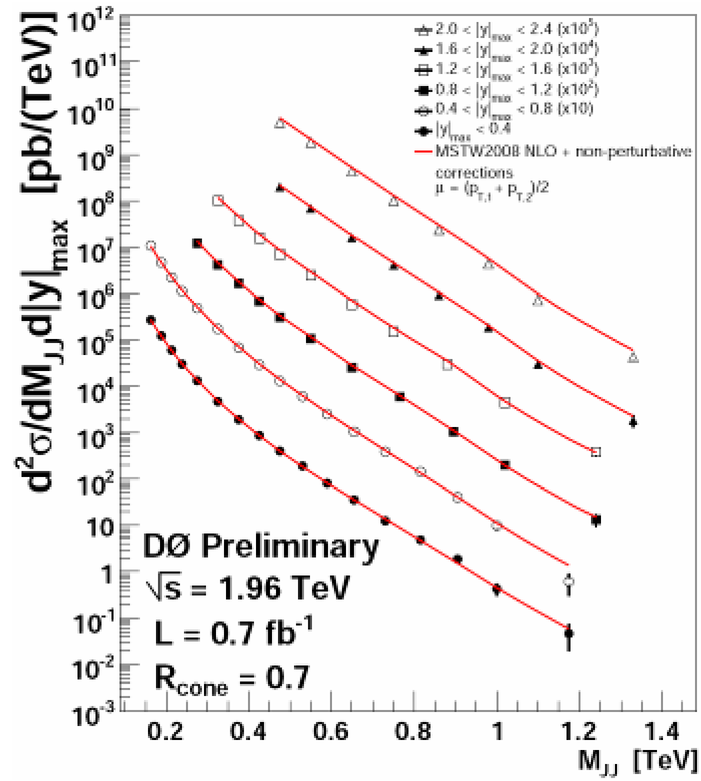
Phys. Rev. Lett. 101, 062001 (2008)

- Test pQCD over 9 order of magnitude in $d\sigma^2/dp_T dy$
- Steeply falling spectrum:1% error in jet energy calibration → 5-10% uncertainty central, 10-25% forward cross sections
- Highest p_T^{jet} > 600 GeV/c
- Sensitive to high –x pdf (gluon distribution)

Dijet Production

- Dijet production at Tevatron tests pQCD prediction over large rapidity range
- sensitive to new particles decaying into dijets: excited quarks, Z', W', Randall-Sundrum gravitons, …





→ data with Mjj > 1.2 TeV!

→ all described by NLO pQCD

no indications for resonances

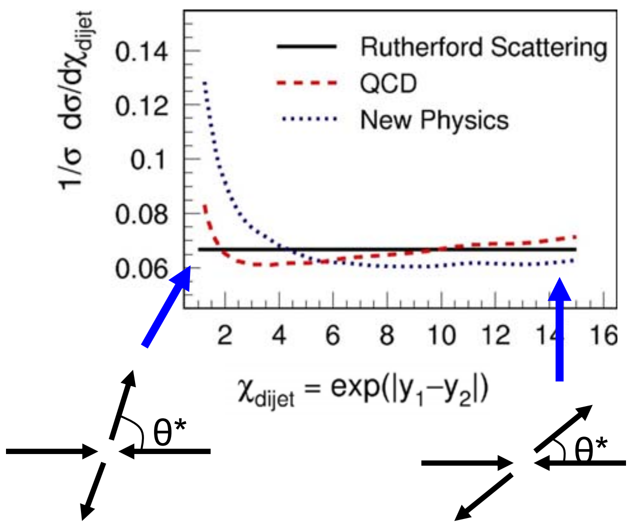
Dijet Angular Distribution

- Normalized angular distribution:

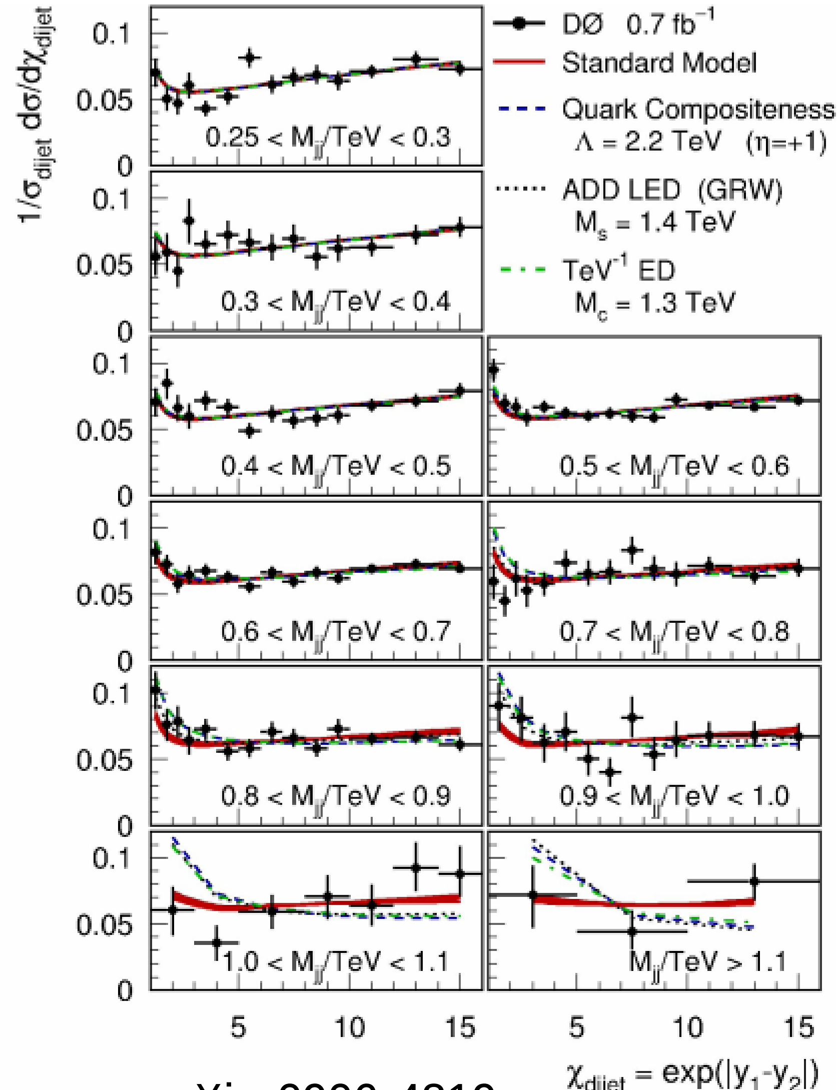
$$\chi_{dijet} = \exp(|y_1 - y_2|)$$

- at LO, related to CM scattering angle

$$\chi_{dijet} = \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

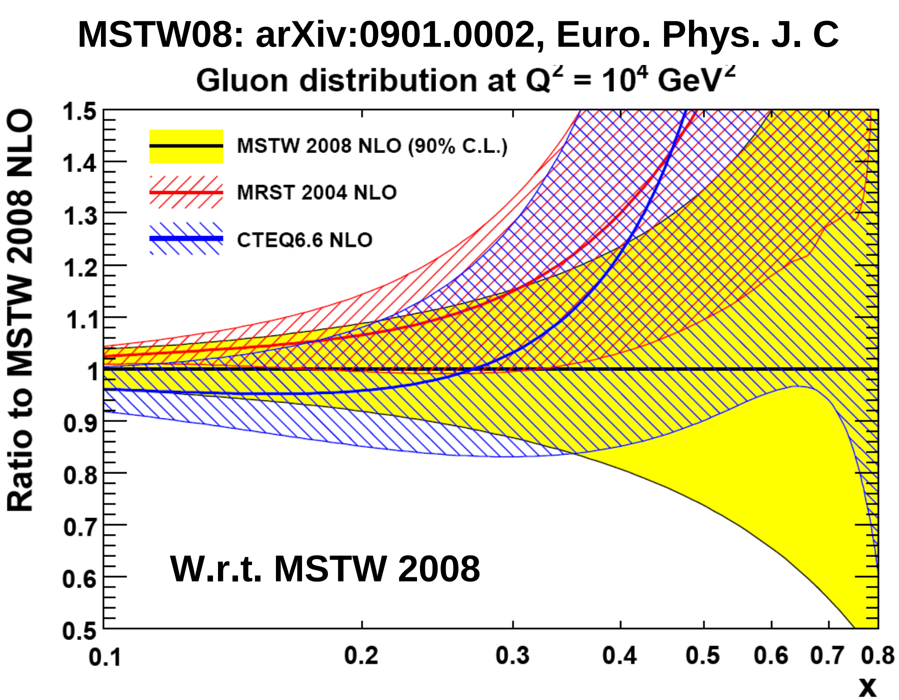


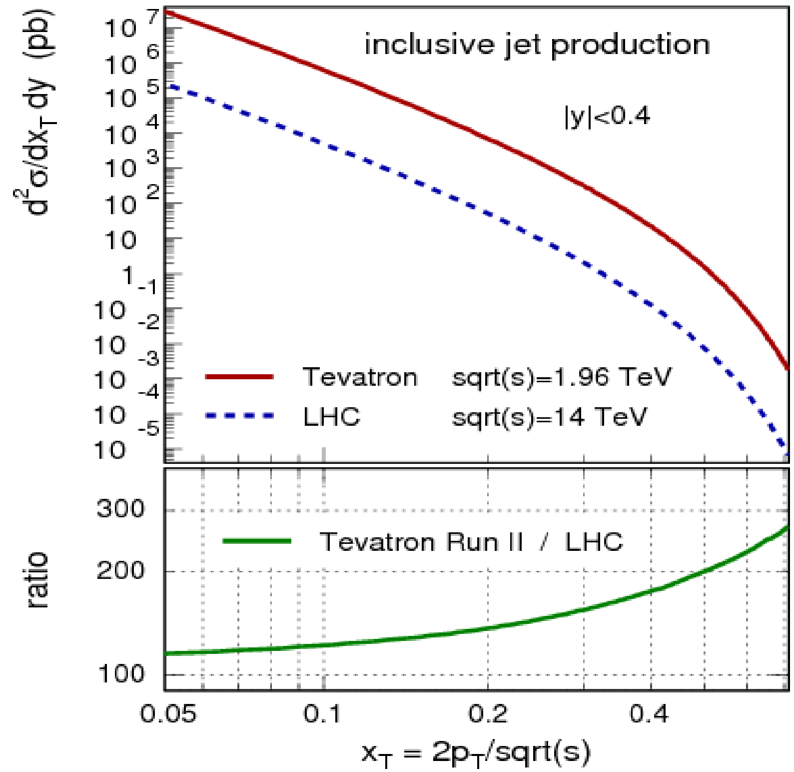
- Consistent with NLO pQCD
- Limits on Compositeness & LED



arXiv:0906.4819

Gluon PDF with Recent Tevatron Jet Data



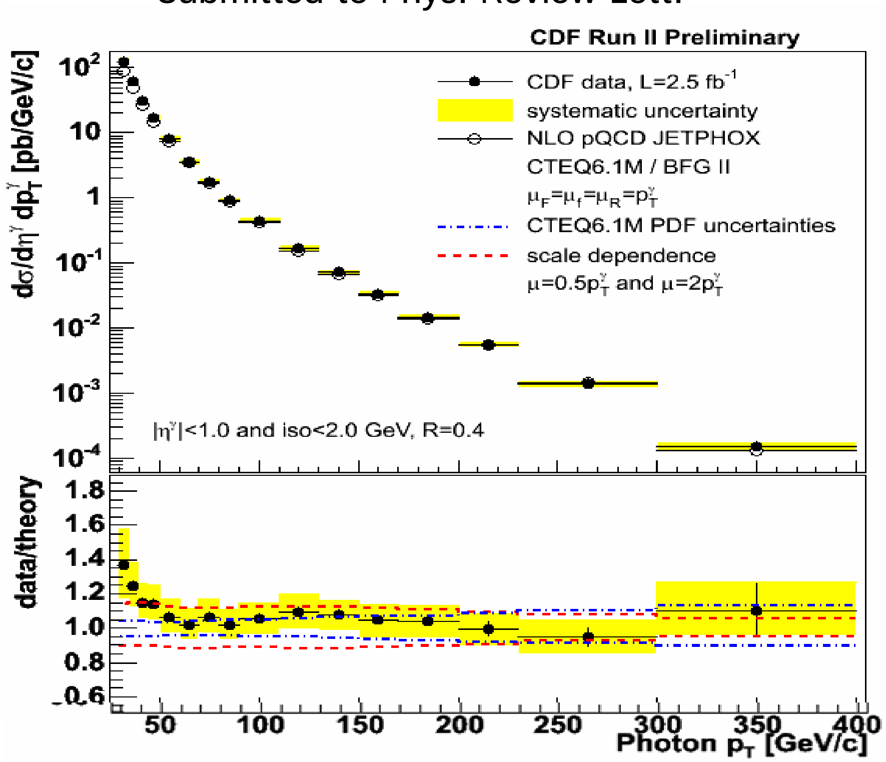


- Tevatron Run II data lead to softer high-x gluons (more consistent with DIS data) and help reducing uncertainties
- Tevatron (ppbar) cross section >100x higher than LHC (pp) for all x_T & jet energy scale understanding

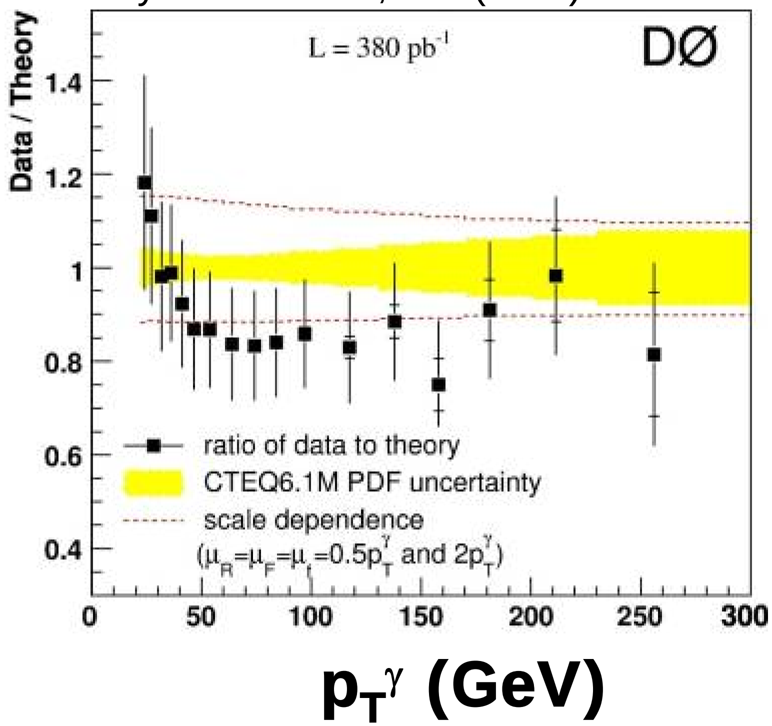
=> Tevatron results will dominate high-x gluon for some years

Inclusive Isolated Photons

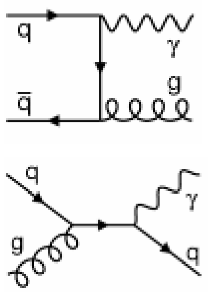
Submitted to Phys. Review Lett.



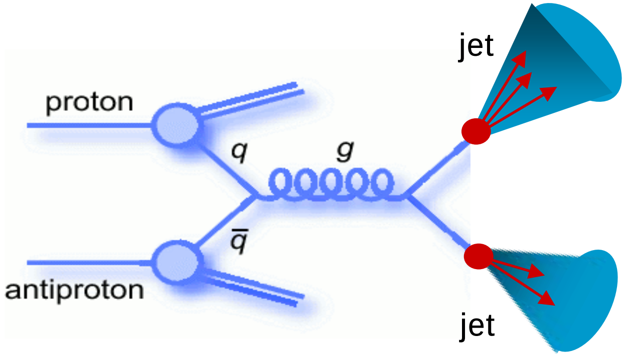
Phys. Lett. B 639, 151 (2006)



- Direct photon production probes hard scattering process directly
  => access to high-x pdf (gluon)
- CDF and D0 measurements: 20< p_T <400GeV → agreement
- data/theory: difference in low p_T shape – resummation ?
- experimental and theory uncertainties > PDF uncertainty
  → no PDF sensitivity yet



Strong Coupling Constant

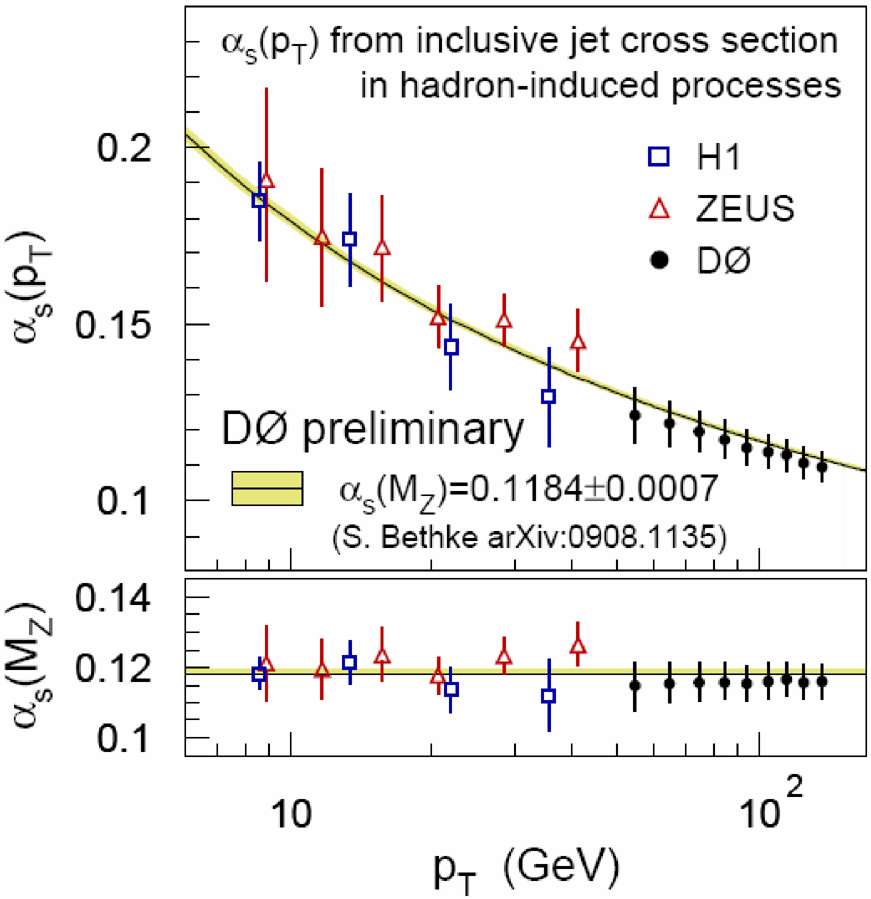


$$\sigma_{\text{pert}}(\alpha_s) = \left(\sum_n \alpha_s^n c_n\right) \otimes f_1(\alpha_s) \otimes f_2(\alpha_s)$$

- NLO + 2-loop threshold corrections
- MSTW2008NNLO PDFs

$$\alpha_s(M_Z) = 0.1173^{+0.0041}_{-0.0049}$$

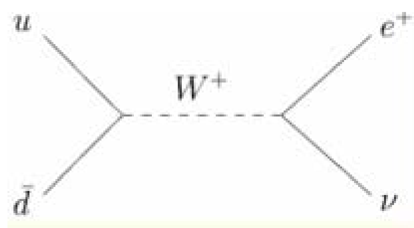
- Extend results from HERA to high p_T

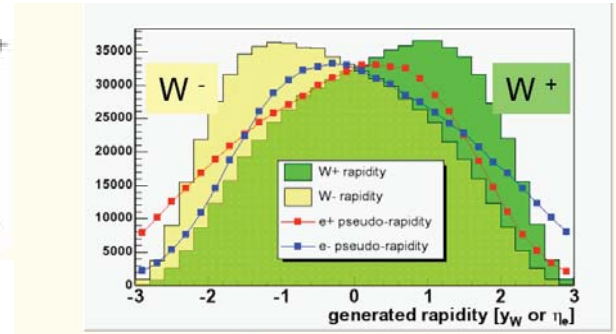


result	uncertainty contributions				
$\alpha_s(M_Z)$	exp. uncorrel.	exp. syst.	non-pert.	PDF	scale $\mu_{r,f}$
0.1173	$^{+0.0001}_{-0.0001}$	$^{+0.0034}_{-0.0029}$	$^{+0.0010}_{-0.0010}$	$^{+0.0012}_{-0.0011}$	$^{+0.0021}_{-0.0029}$

W Lepton/Charge Asymmetry

- u quark carries higher x
  - W+ boosted in proton direction, W- in anti-proton direction

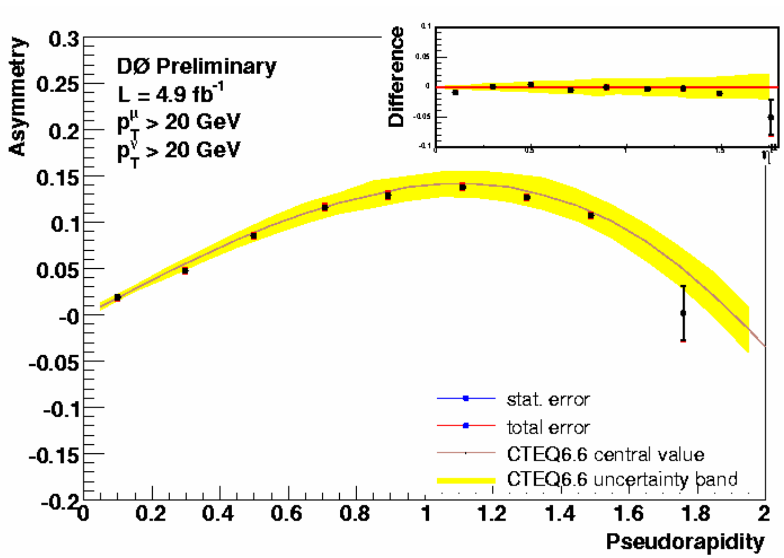


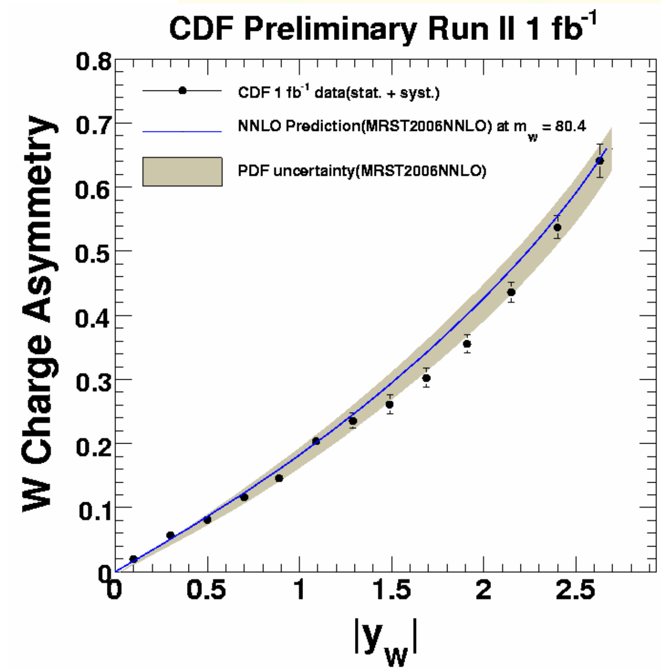


$$A(\eta_l) = \frac{d\sigma_+/d\eta_l - d\sigma_-/d\eta_l}{d\sigma_+/d\eta_l + d\sigma_-/d\eta_l} \sim \frac{d(x)}{u(x)}$$

$= A(y_W) \otimes (V\text{-}A)$

=> access to d/u





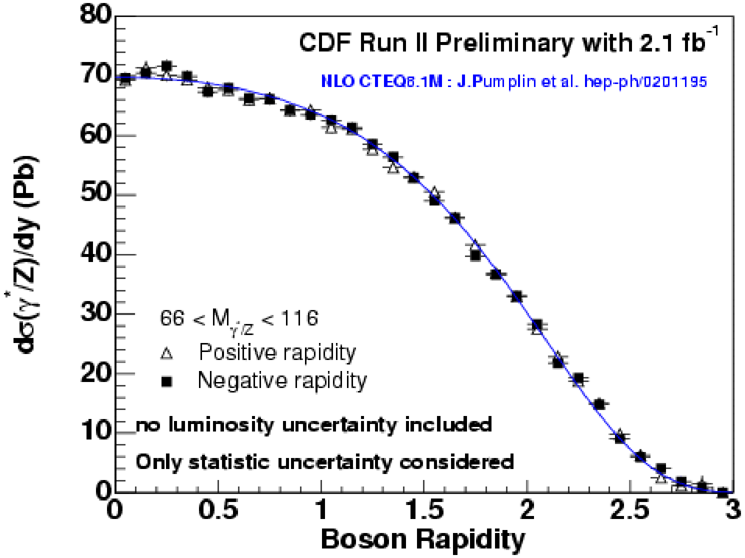
Uncertainties smaller than PDF one
Compare NLO and NNLO

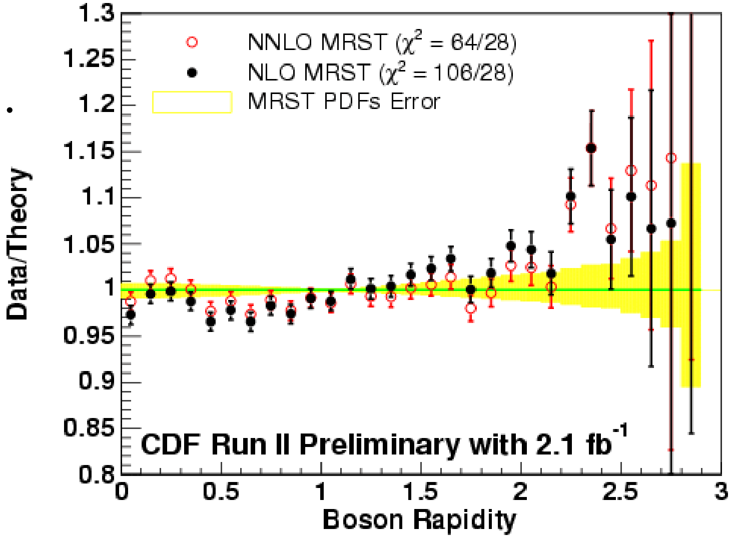
CDF weighting method to access Y_W directly

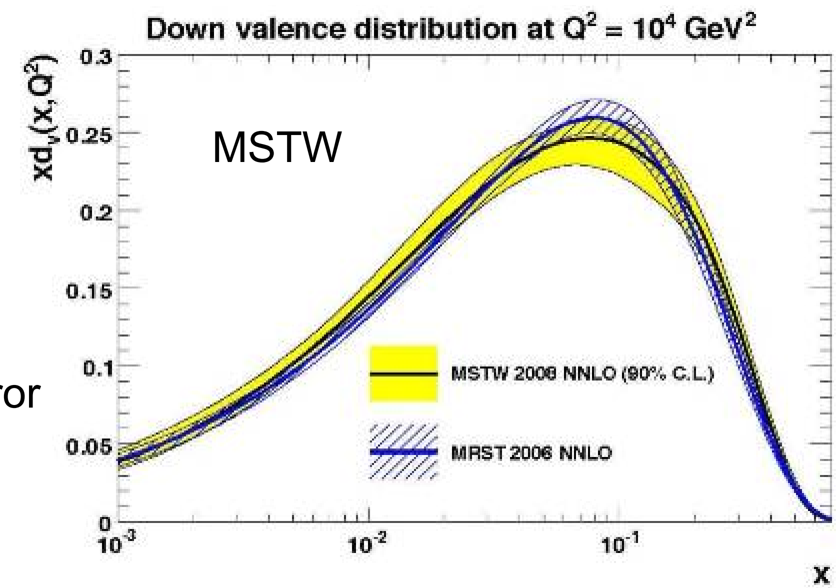
A. Bodek at al. Phys.Rev D 79 031101 (2009)

Z-Rapidity

- Z-Boson rapidity reconstructed from leptonic decays
- High rapidity (y) probes
  high-x parton region (mainly d_v) $x_1, x_2 = (M/\sqrt{s})e^{\pm y}$.







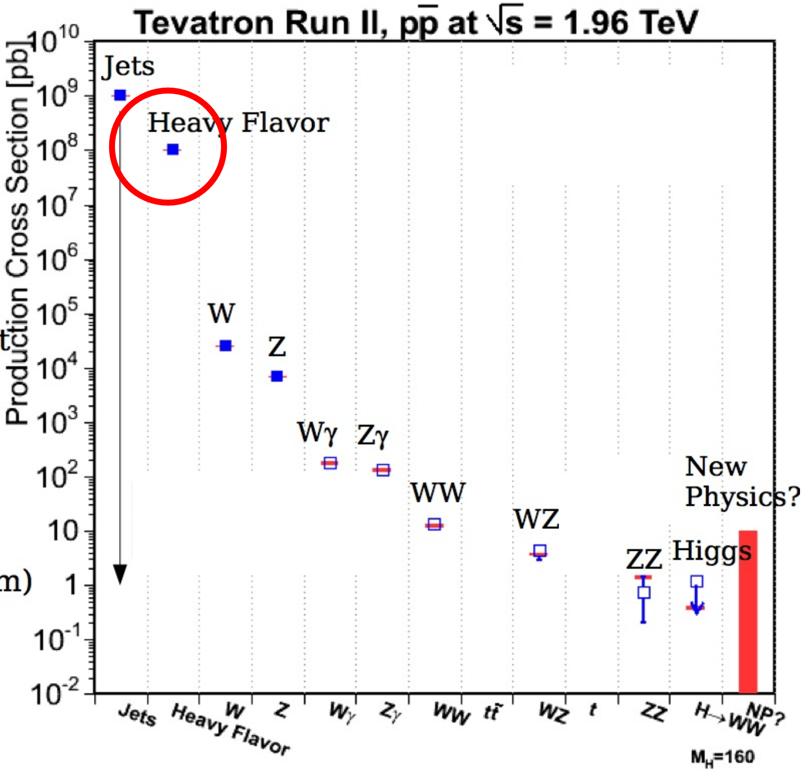
- Shape described well by NLO QCD
- Total cross section |y| <2.9:

σ=256.0±0.7(stat)±2.0(syst) pb + 6% luminosity error

236.1±1.93 pb NLO CTEQ6M
252.6 ±3.1 pb NNLO MRST 2006

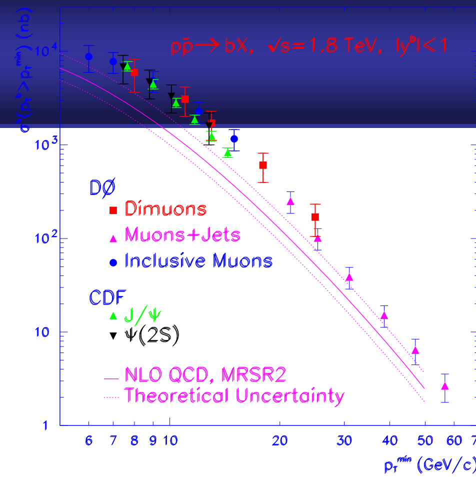
=> impact d_v in global fits

B-Production



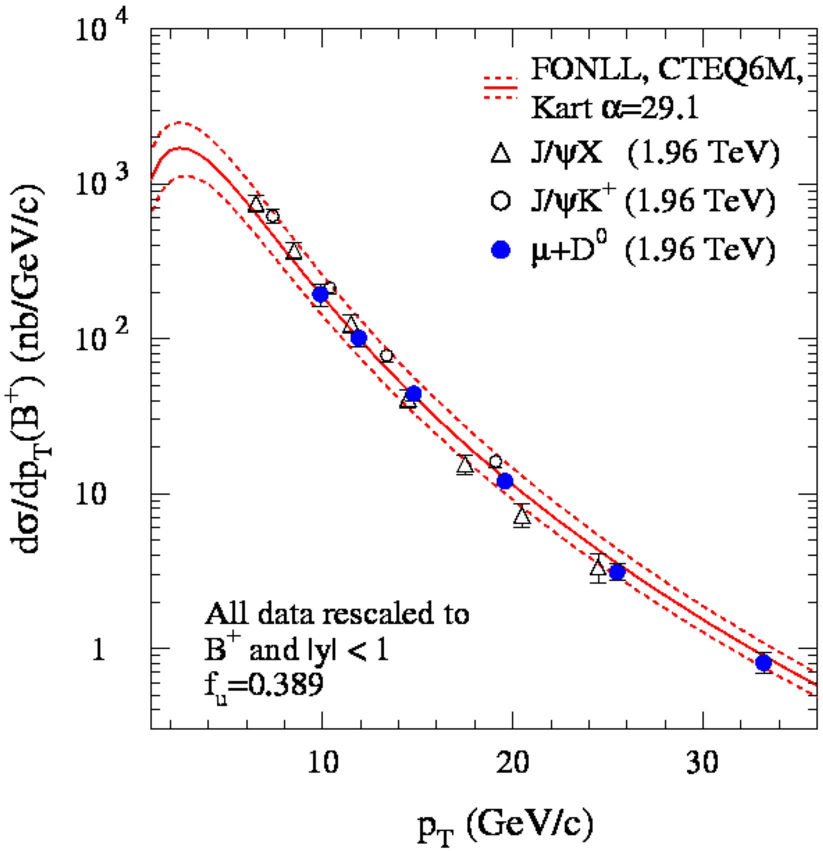
- CP violation sin $2\beta_s$
- Ω_b
- Y polarization

Inclusive σ_b



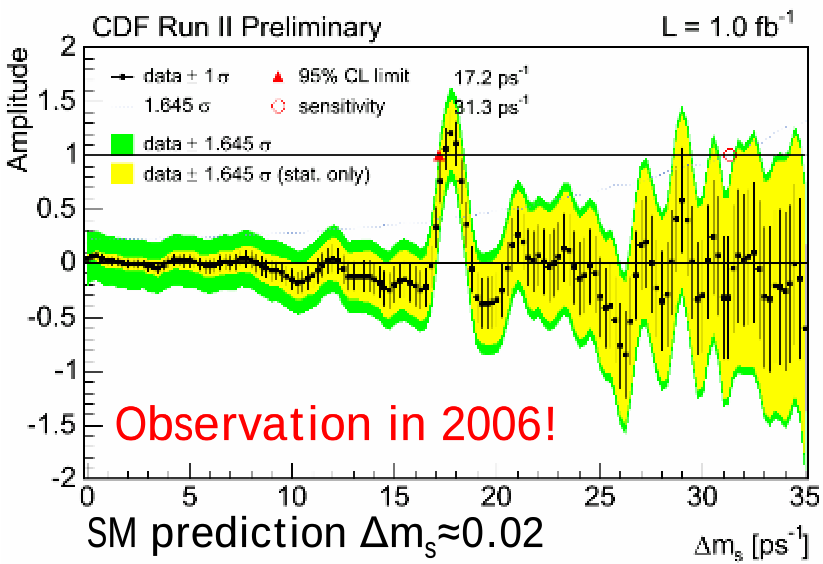
- Tevatron Run I (1992-1996): Inclusive cross sections systematically higher than NLO theory

- Tevatron Run II: Remeasure inclusive cross sections
  - Better acceptance
  - Higher statistics
  - Smaller uncertainties



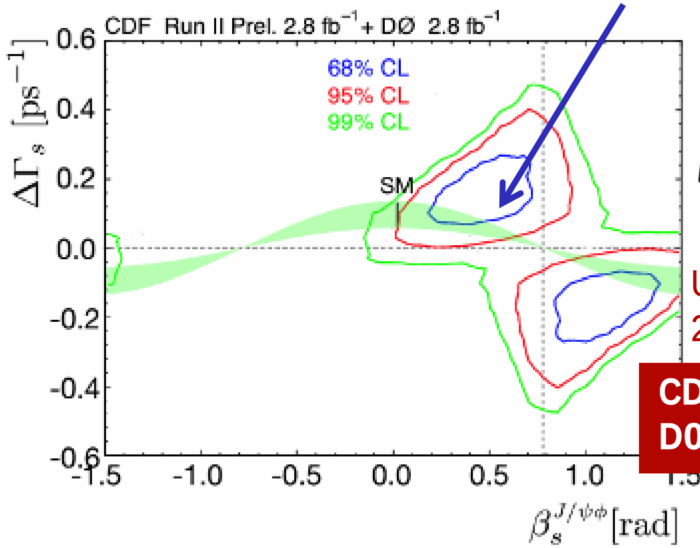
- See better agreement with theory now
  (FONLL M. Cacciari, S. Frixione, P.Nason)

CP-Violation in $B_s \rightarrow \Psi\Phi$



SM prediction $\Delta m_s \approx 0.02$

Current Tevatron MPV $\Delta m_s = 0.2$

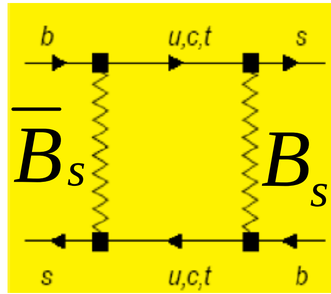


Update 2.8 fb^{-1}

CDF: 1.8 σ
D0: 1.7 σ

B_s system unique to the Tevatron

- Mixing frequency ~Δm_s of mass eigenstates

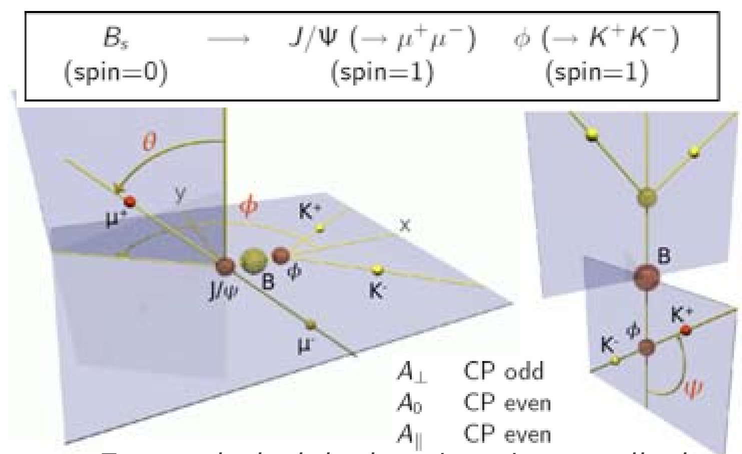


$$\Delta m_s = 17.77 \pm 0.10 \pm 0.07\, ps^{-1}$$

Now, use $B_s \rightarrow J/\Psi\phi$ decay as a CP violation probe:

Analyze time evolution of $B_s \rightarrow J/\Psi\varphi$

Perform un-binned maximum likelihood fit to:
Lifetime, Mass (input) and decay amplitudes (angular distr.)
→Extract $\Delta\Gamma_s$ and β_s

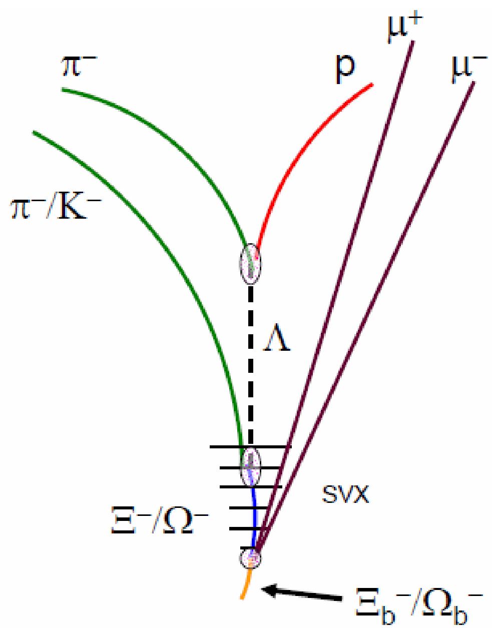


Transversity basis leads to three decay amplitudes
L = 0, 2 → CP even (short lived or light B_s)
L = 1 → CP odd (long lived or heavy B_s)

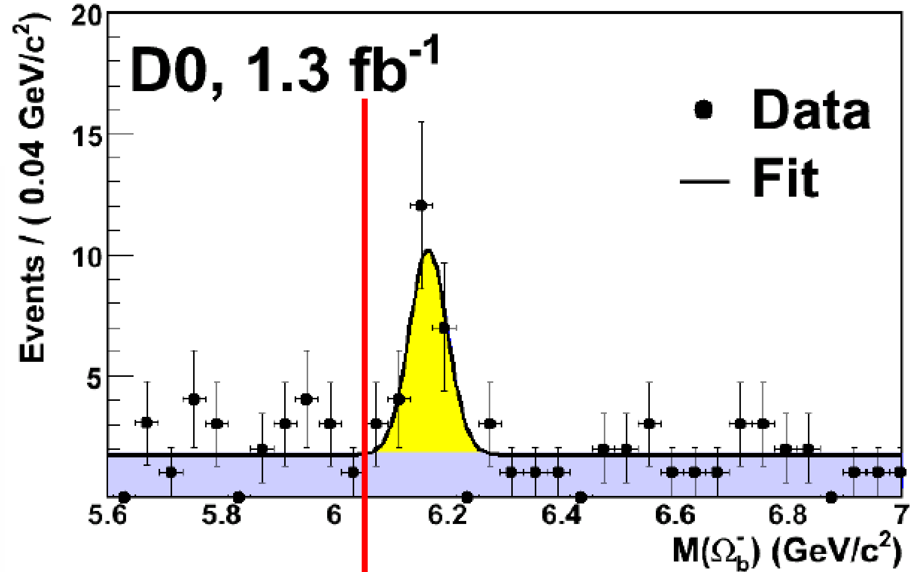
Observation of Ω_b

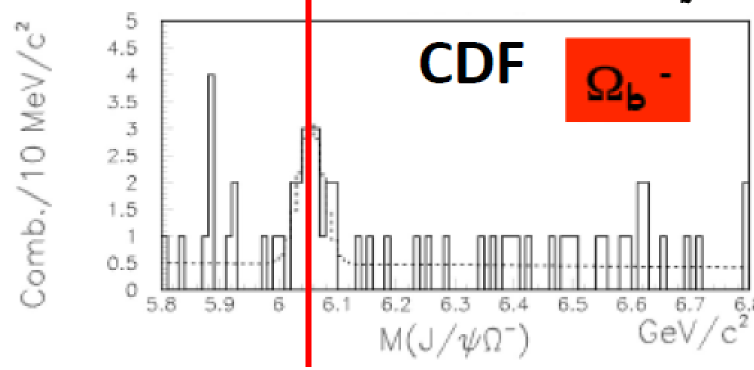
Observation of Ω_b (= |bss>) baryon in $\Omega_b \rightarrow J/\Psi\Omega$

- Precise mass measurement
- First fully reconstructed lifetime measurement



Mass: 6.165 ± 0.010(stat) ± 0.013(syst) GeV





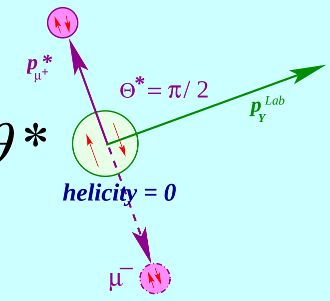
$m(\Omega_b^-)$: 6054.4 ± 6.8(stat.) ± 0.9(syst.) MeV/c^2

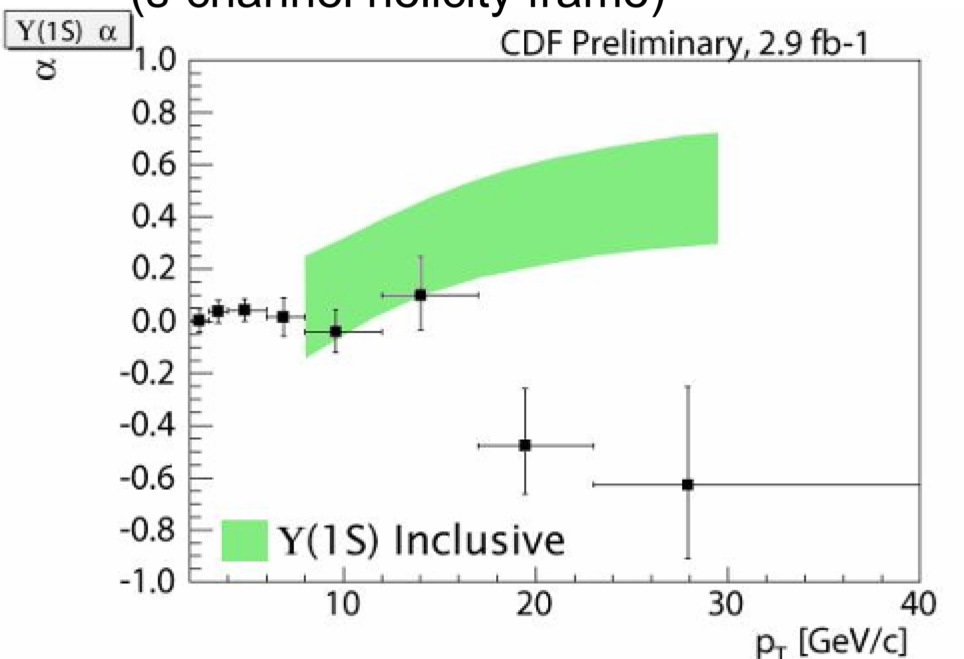
- CDF and D0 mass results differ ~ 6σ
  - D0 1.5-2σ > theory
- theory uncertainties 50 -100 MeV
  - (HQET, Feynman-Hellmann NRQCD)

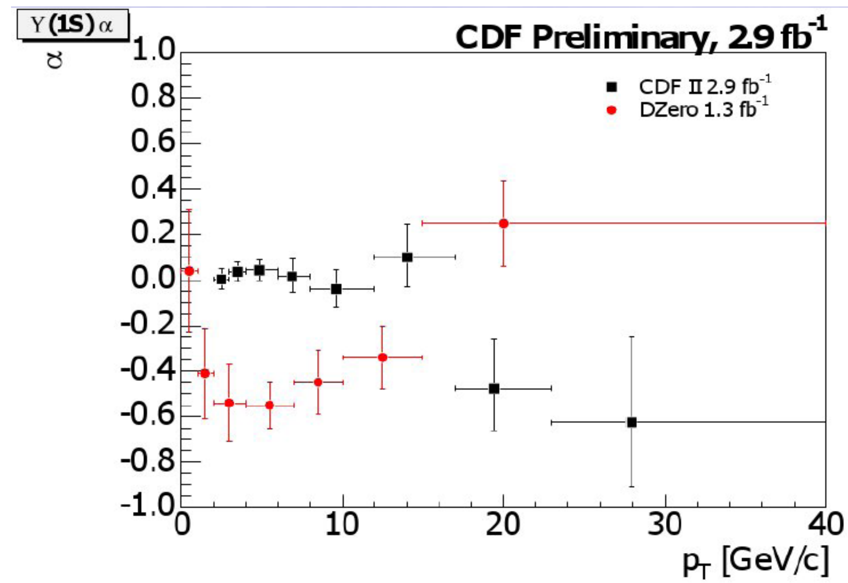
Measurement of Y(1S) Polarization

NRQCD predicts transverse polarization of Y:
=> Measure angle θ* between μ^+ in Y rest frame and Y direction in lab frame (s-channel helicity frame)

$$\frac{d\Gamma}{d\cos\theta^*} \propto 1 + \alpha\cos^2\theta^*$$



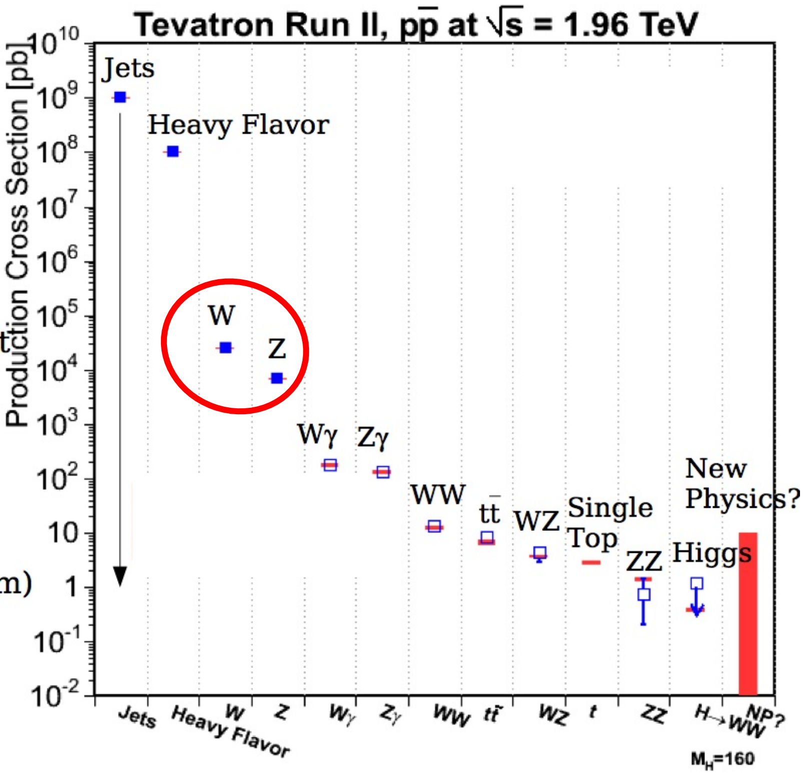




Find longitudinal polarization at high-p_T
=> disagreement with NRQCD (including feed down of Y(nS)
(Braaten and Lee, PRD 63, 071501 (2001))

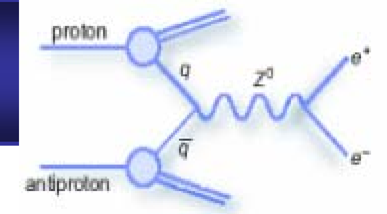
CDF and D0 results show opposite trends

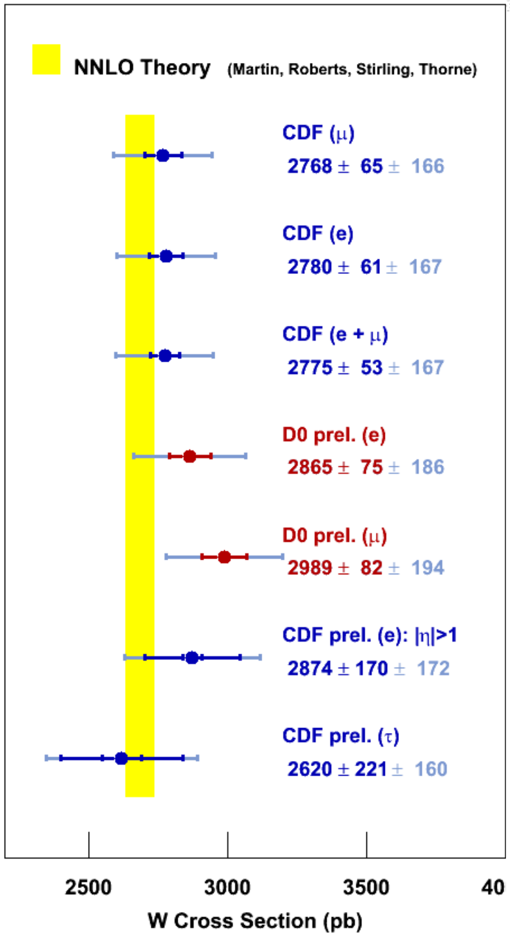
W and Z Production

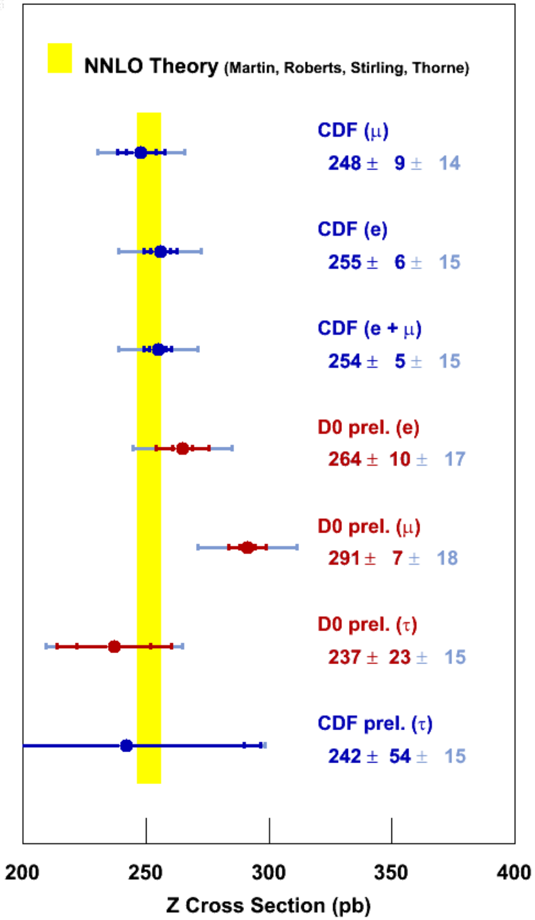


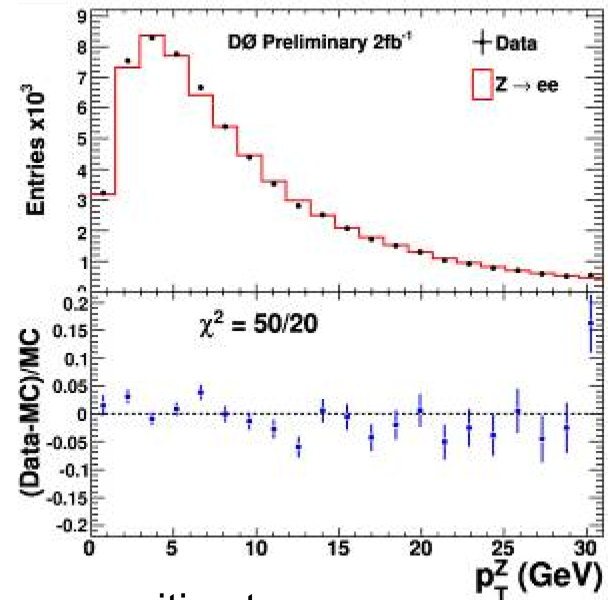
- W mass and width
- A_{fb} (Z)
- Z dy
- W asymmetry

W and Z production

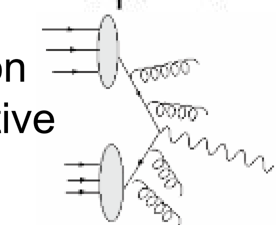








- Low Z p_T sensitive to multiple soft gluon emission → absorb in non-perturbative form factor g_2



J. Collins, D. Soper, G. Sterman, Nucl. Phys. B250 (1985) 199.
G.A. Ladinsky, C.P. Yuan, Phys. Rev. 50 4239 (1994)
C. Balazs, C.P. Yaun, Phys. Rev. A56 5558 (1997)

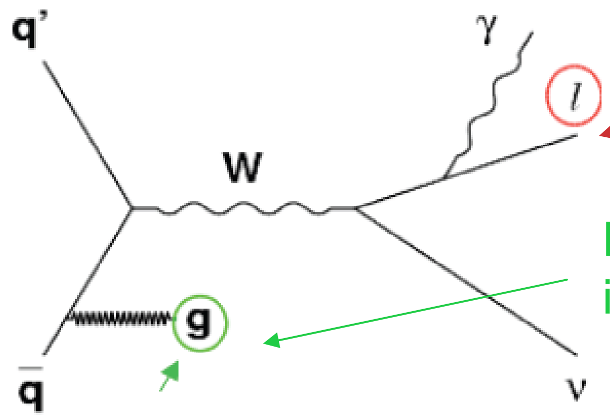
- High precision measurements
  - Agree with NNLO QCD predictions

DØ ($2fb^{-1}$)

g_2 =0.63 ± 0.02 (exp.) ± 0.04 (PDF)

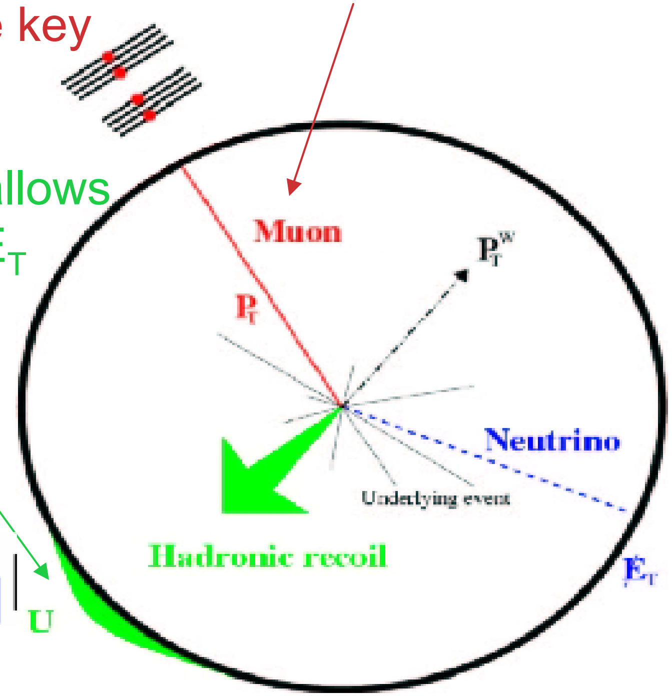
W-Mass at the Tevatron

- LEP legacy: M_W=80.367±0.033 GeV (0.04%)
- At Tevatron: mainly qq' annihilation



precise charged lepton measurement is the key

Recoil measurement allows inference of neutrino E_T



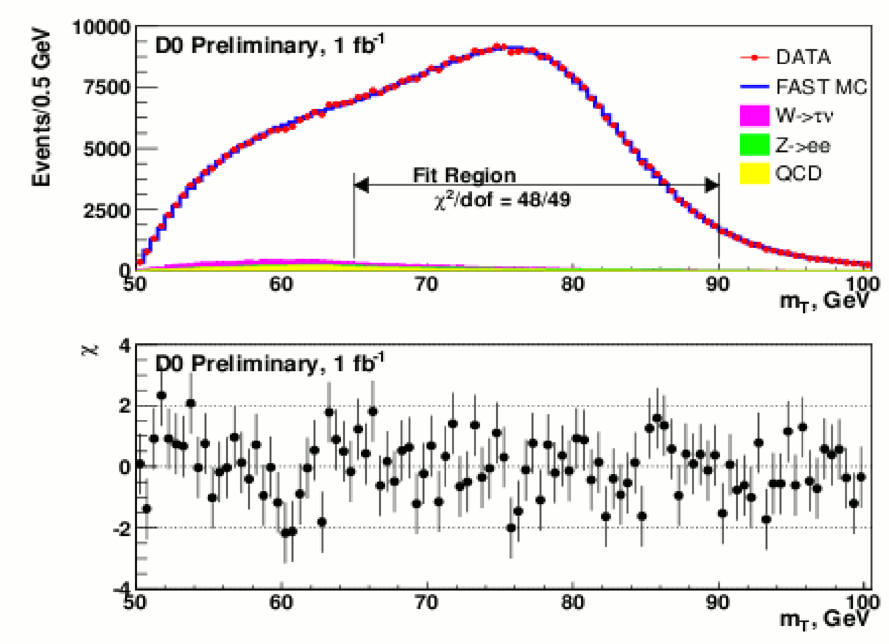
- Main ingredients lepton p_T and hadronic recoil parallel to lepton $u_{||}$

$$m_T = \sqrt{2 p_T^l p_T^\nu (1 - \cos\Delta\phi)}; \quad p_T^\nu \approx |p_T^l + u_{||}|$$

U

- Z→ ll superb calibration sample
- NLO Signal MC: RESBOS (C. Balazs, C-P Yuan Phys. Rev. D56, 5558 (1997))
  QED radiation: D0 PHOTOS (multi-γ E.Bariero, Z. Was Comp Phys Com 79 291 (1994))
  CDF WGRAD (full O(α) EW corrections U. Baur et al. Phys. Rev. D56 013002 (1998))

Tevatron W-Mass



D0 (1 fb^{-1}):

m_W=80401±21(stat)±38(syst) MeV

→Single most precise result

Measure ratio W/Z mass to reduce effects of higher order corrections

CDF (200 pb^{-1})

m_W=80413±34(stat)±34(syst)MeV

→ update w/ 2 fb^{-1}

D0 m_W systematic uncertainties (1 fb^{-1})

SystematicSource	δm_W(MeV)
Electron energy scale	34
Electron energy resolution model	2
Electron energy nonlinearity	4
W and Z electron energy loss differences	4
Recoil model	6
Electron efficiencies	5
Backgrounds	2
PDF	9
QED	7
Bosonp_T	2
Total	**37**

Improve w/ statistics

Ultimately limit precision

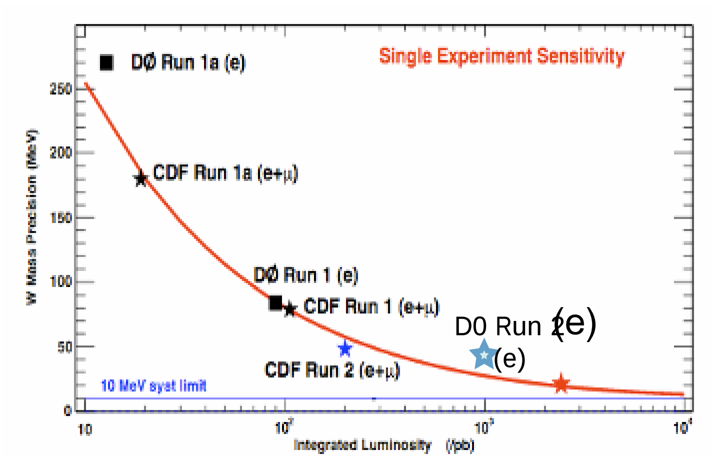
Tevatron Run II precision goal:

Δm_W < 25 MeV/experiment

CDF: use HORACE for QED corrections

(C.M. Carloni Calam et al., JHEP 0710:109 (2007))

Tevatron W Mass Combination

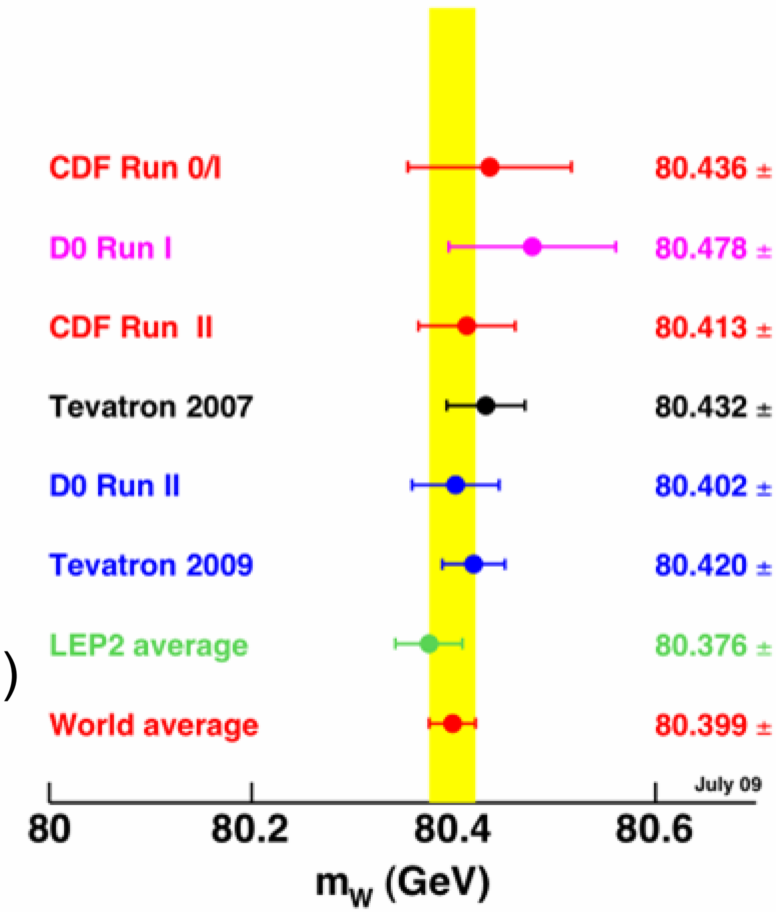


- New Tevatron combination:

  m_W=80420±31MeV (0.038%)

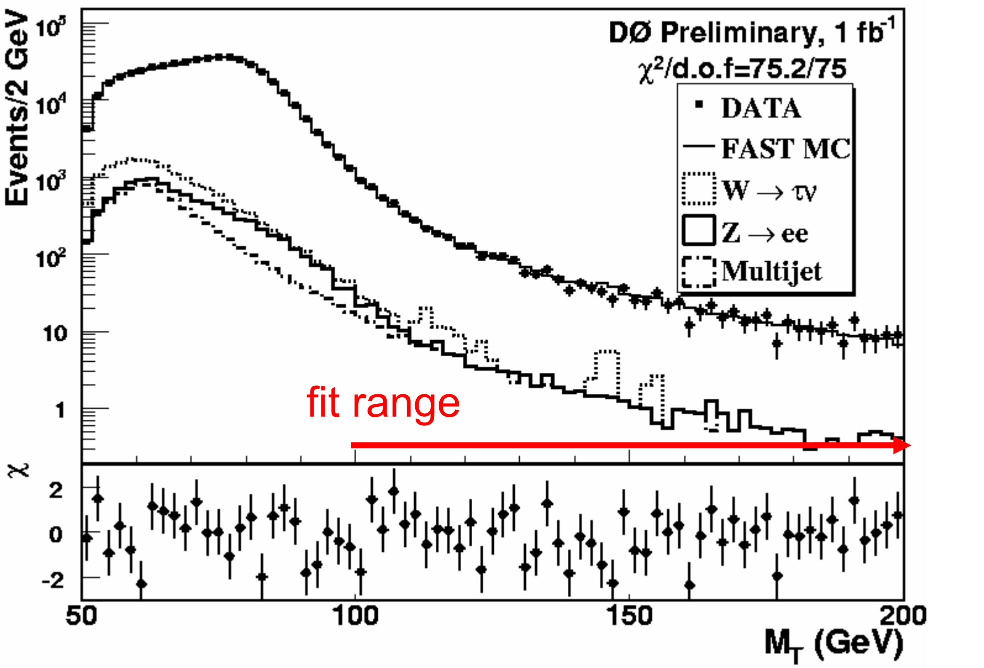
  => more precise than LEP-II combination
- New World Average (Summer 2009)

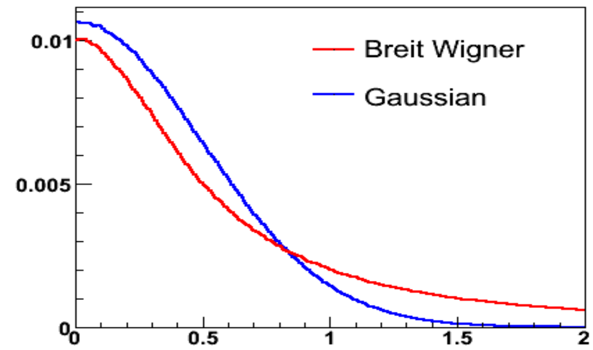
  m_W=80399±23MeV



The high m_T tail contains information on the W boson width:

- Exploit slower falloff of Breit-Wigner compared to Gaussian resolution





Source	$\Delta\Gamma_W$ (MeV)
Electron energy scale	33
Electron resolution model	10
Recoil model	41
Electron efficiencies	19
Backgrounds	6
PDF	20
Electroweak radiative corrections	7
Boson p_T	1
M_W	5
Total Systematic	61

D0 (1 fb^{-1}): Γ_W = 2028 ± 72(stat+syst) MeV

arXiv: hep-ex 0909.4814 submitted to PRL

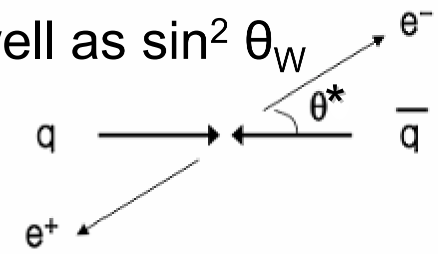
CDF (350pb^{-1}): Γ_W = 2032 ± 73(stat+syst) MeV

PRL 100 071801 (2008)

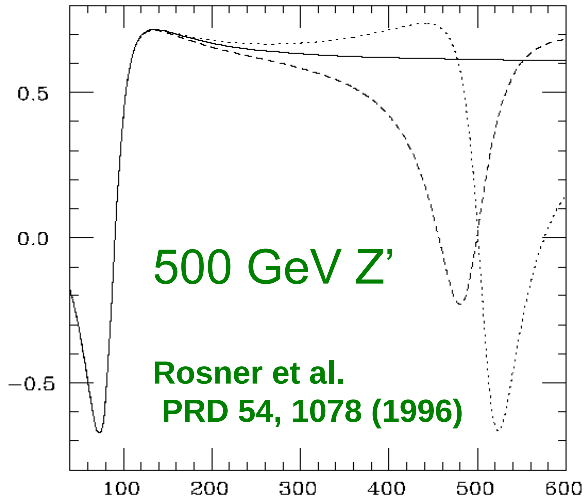
SM Γ_W = 2093 ± 20 MeV

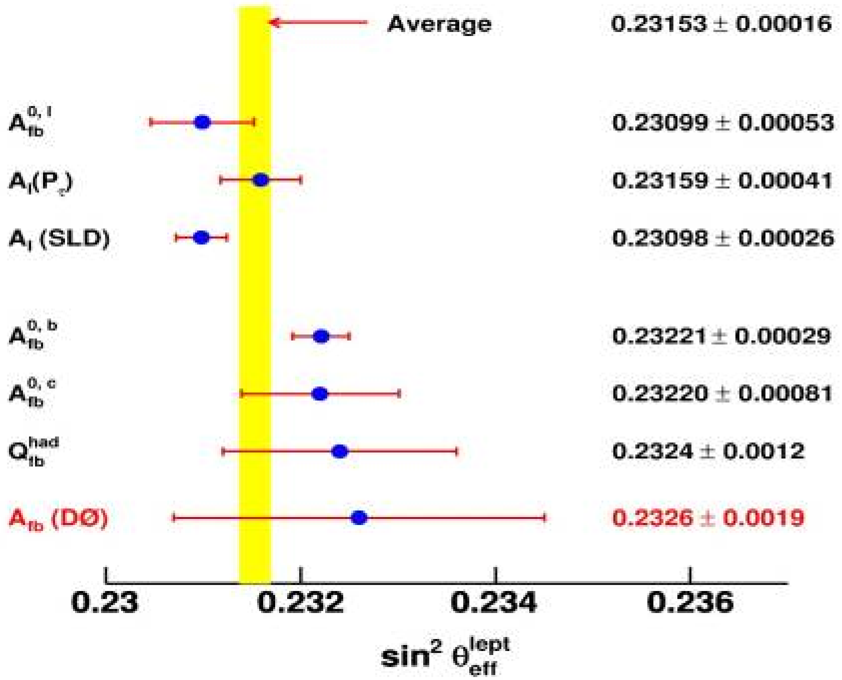
Z Forward Backward Asymmetry A_{fb}

- A_{FB} determines the relative strengths of V-A boson-fermion couplings as well as $\sin^2\theta_W$



- A_{FB} sensitive to new resonance (f.g Z') via interference with $Z/\gamma*$

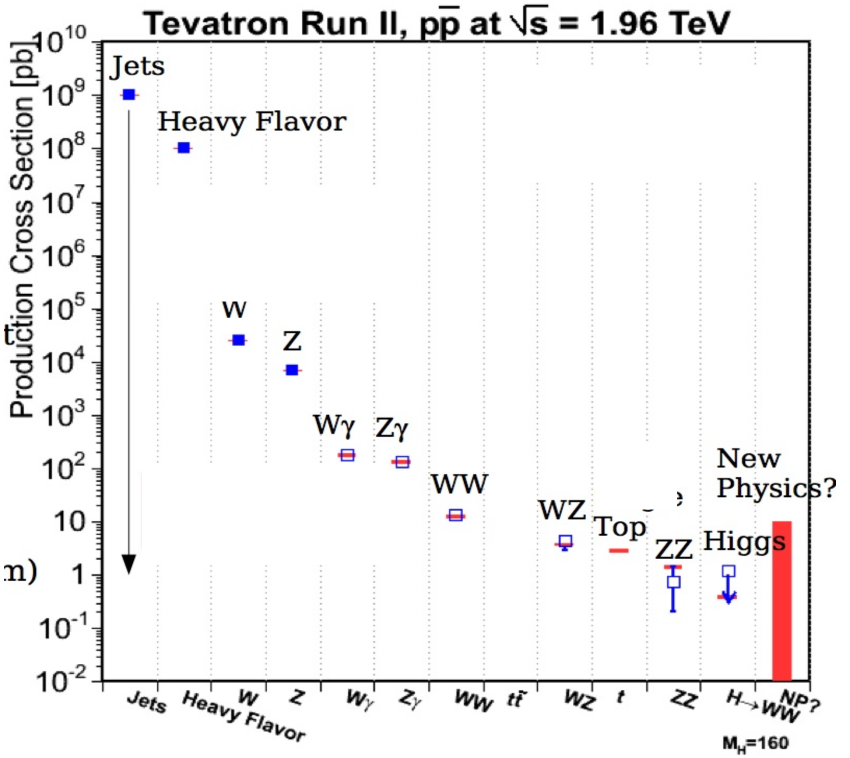




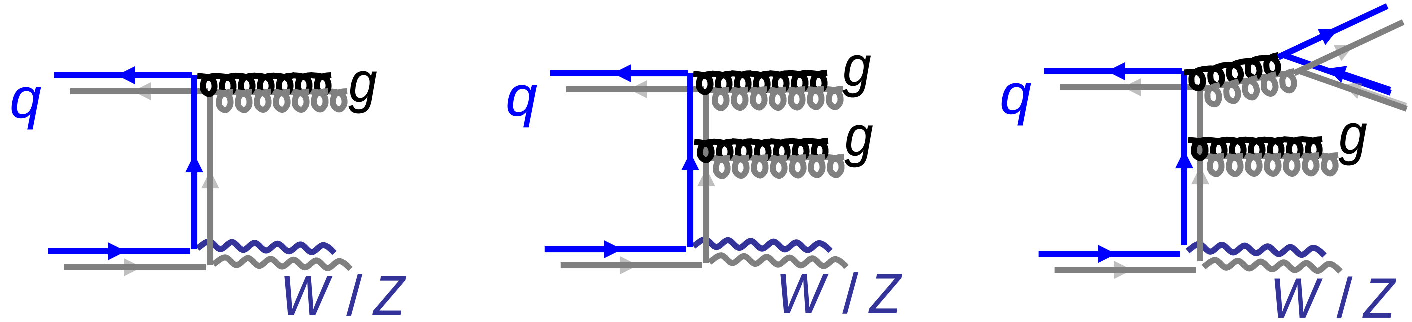
D0: $\sin^2\theta_W = 0.2326 \pm 0.0018(\text{stat.}) \pm 0.0006(\text{syst.})$
World $= 0.23153 \pm 0.00016$
Future Tevatron precision ~ 0.0005

- QED radiative corrections: Pythia (multi-photon LO) /ZGRAD (1-photon NLO)

Vector Bosons + Jets



W/Z+Jets Production



- Critical for physics at the Tevatron and LHC: top, Higgs, SUSY, and other BSM
- Tests pQCD calculations
- NLO pQCD calculations are available up to >=2(3) jets

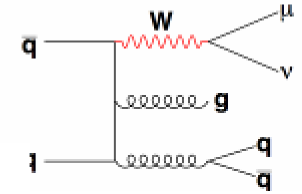
  New NLO W+3 jets prediction:

  BlackHat: Berger et al , hep-ph 0803.4180, 0808.0941

  Rocket: Giele, Zanderighi, hep-ph 0805.2152

  Ellis, Melnikov, Zanderighi, hep-ph 0901.4101, hep-ph 0906.1445
- Many Monte Carlo tools are available
  - LO + Parton shower Monte Carlo (Pythia, Herwig,)
  - Matched tree level matrix element + parton shower Monte Carlo (ALPGEN, Sherpa,)
- These calculations and tools need “validation” by experimental measurements

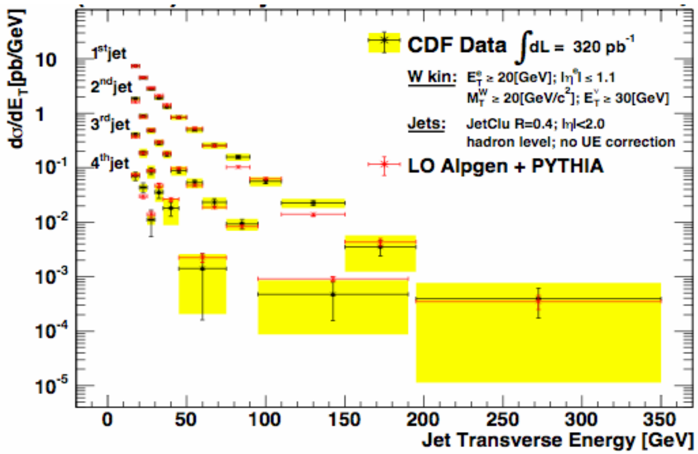
W + jets Production

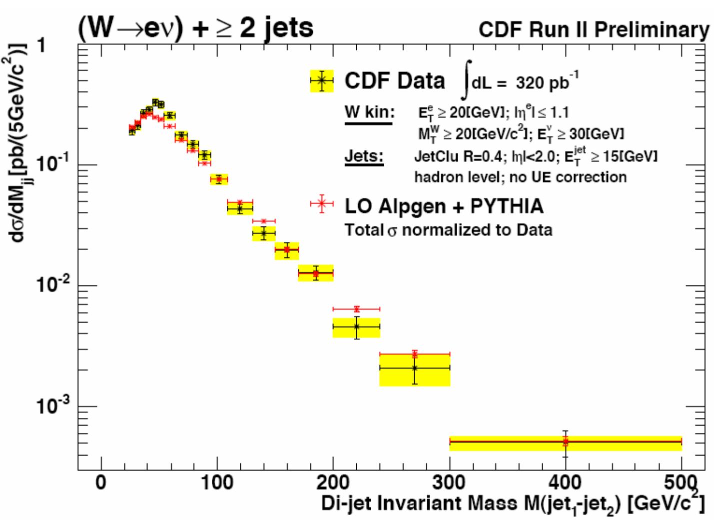


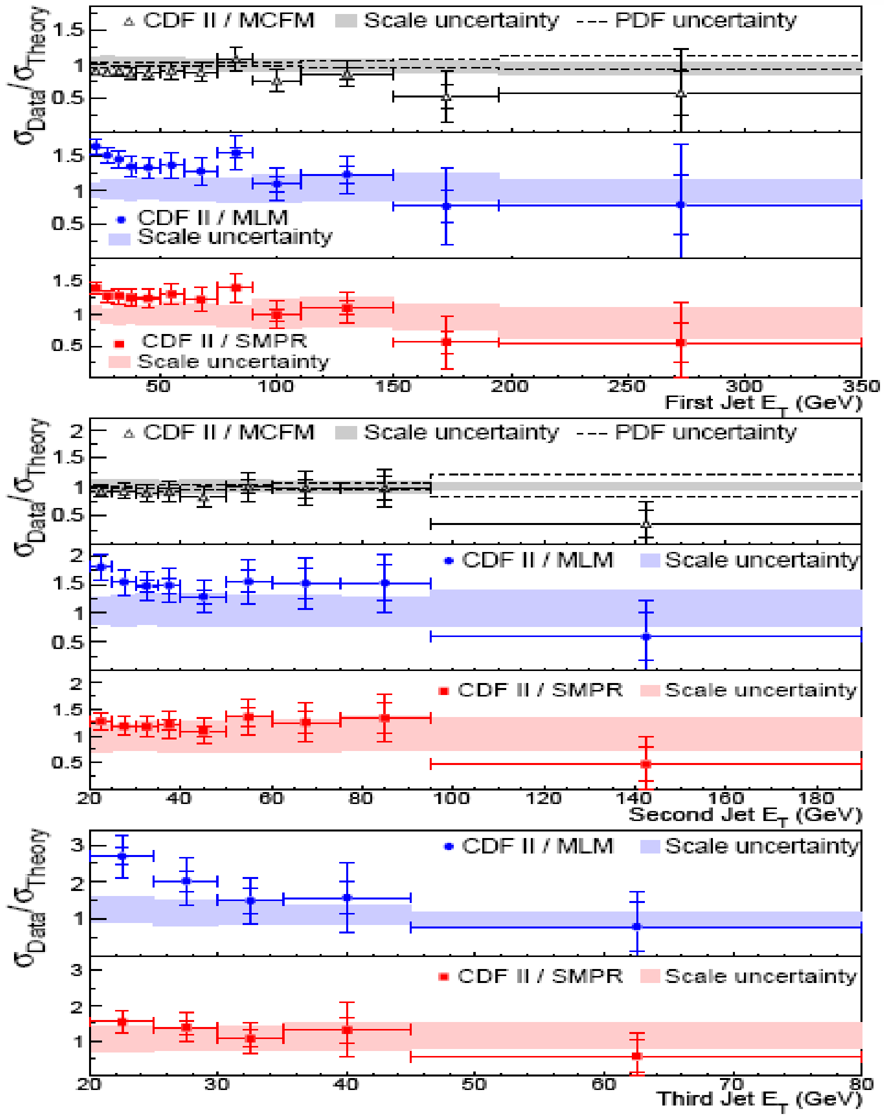
MCFM

LO+MLM
J. Alwall et al

LO+CKKW
S. Mrenna et al.



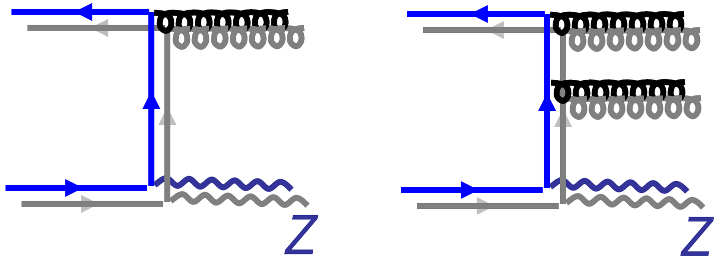




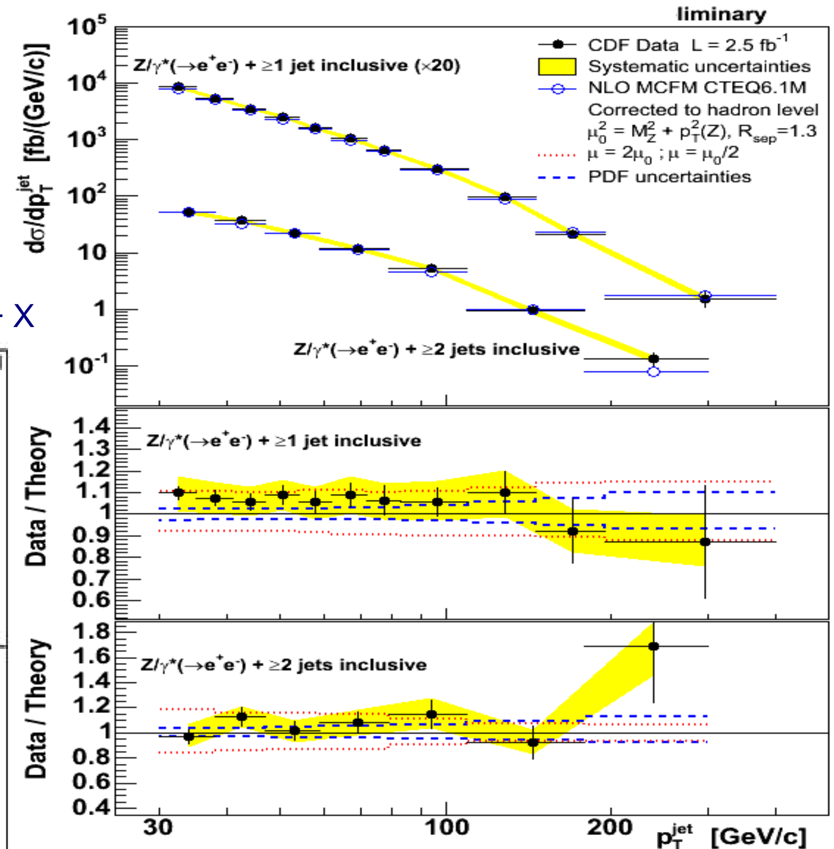
Good description of shapes by ME+PS (ALPGEN)

ME+PS normalization to data ~ 1.5

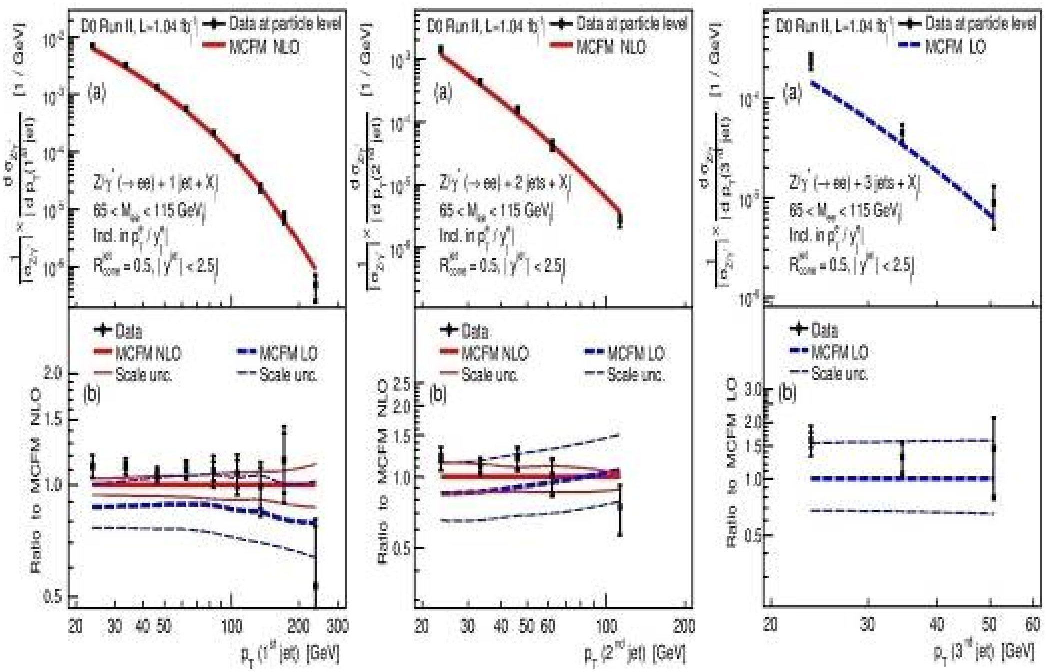
Z+Jets Production



Phys. Rev. Lett 100, 102001 & update



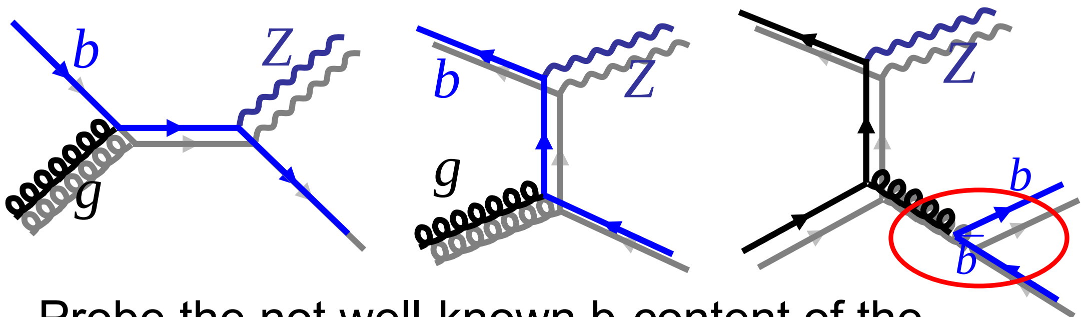
Leading jet in Z + jet + X   Second jet in Z + 2jet + X   Third jet in Z +3jet+ X

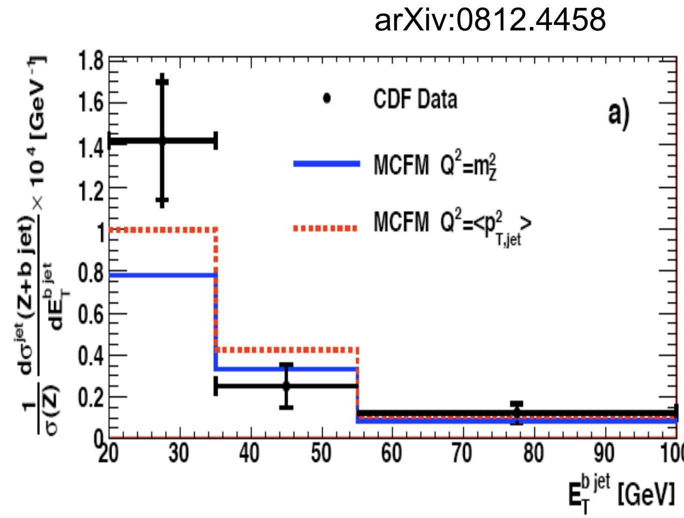


Phys. Lett. B 669, 278 (2008)

Data and NLO pQCD in good agreement

Z+*b*-jets Production

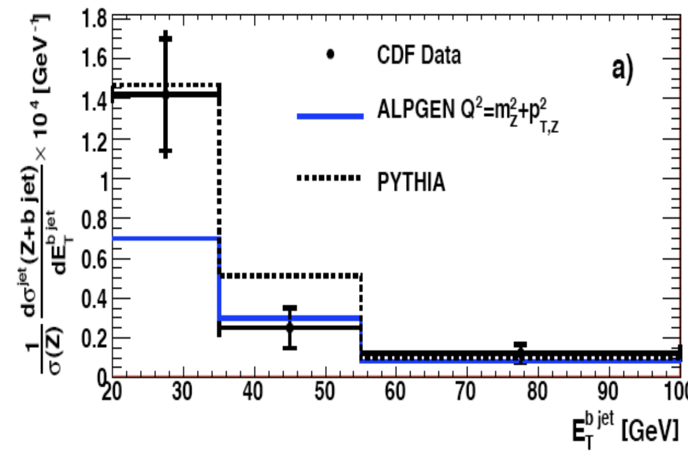




- Probe the not well-known b-content of the proton
- Backgrounds for SM Higgs Search ($ZH \rightarrow \nu\nu bb$) and SUSY

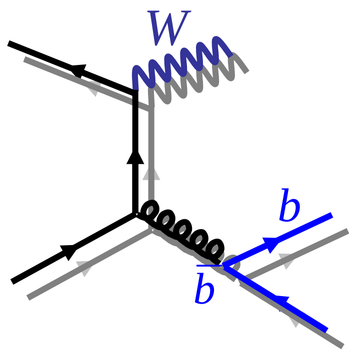
$$\frac{\sigma(Z+b)}{\sigma(Z+jets)} = 2.08 \pm 0.33 \pm 0.34 (\%)$$

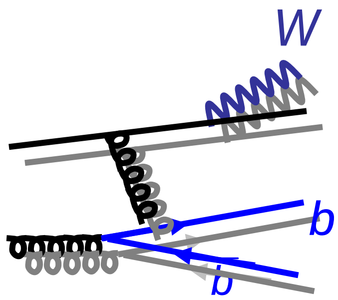
$$pQCD(MCFM): 1.8\% \, (Q^2 = M_Z^2 + P_{T,Z}^2) \, ; 2.2\% (Q^2 = <P_{T,Jet}^2>)$$

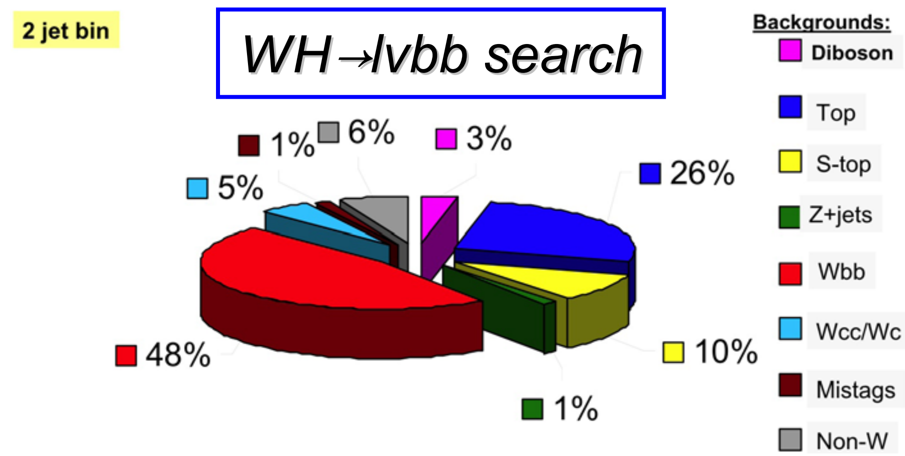


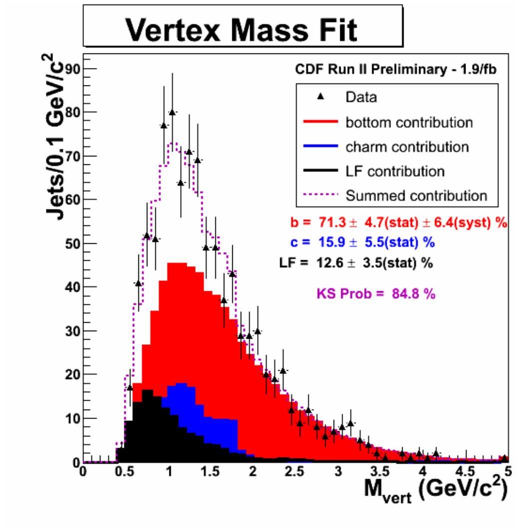
- Data and MC compatible within error but large theory uncertainties (Z+bb not complete in NLO)

Large variations between MC models (important inputs for tuning)









Important background for:

- SM Higgs (WH) production
- Single top quark production production

$\sigma \cdot B = 2.74 \pm 0.27(\text{stat}) \pm 0.42(\text{syst})\,\text{pb}$

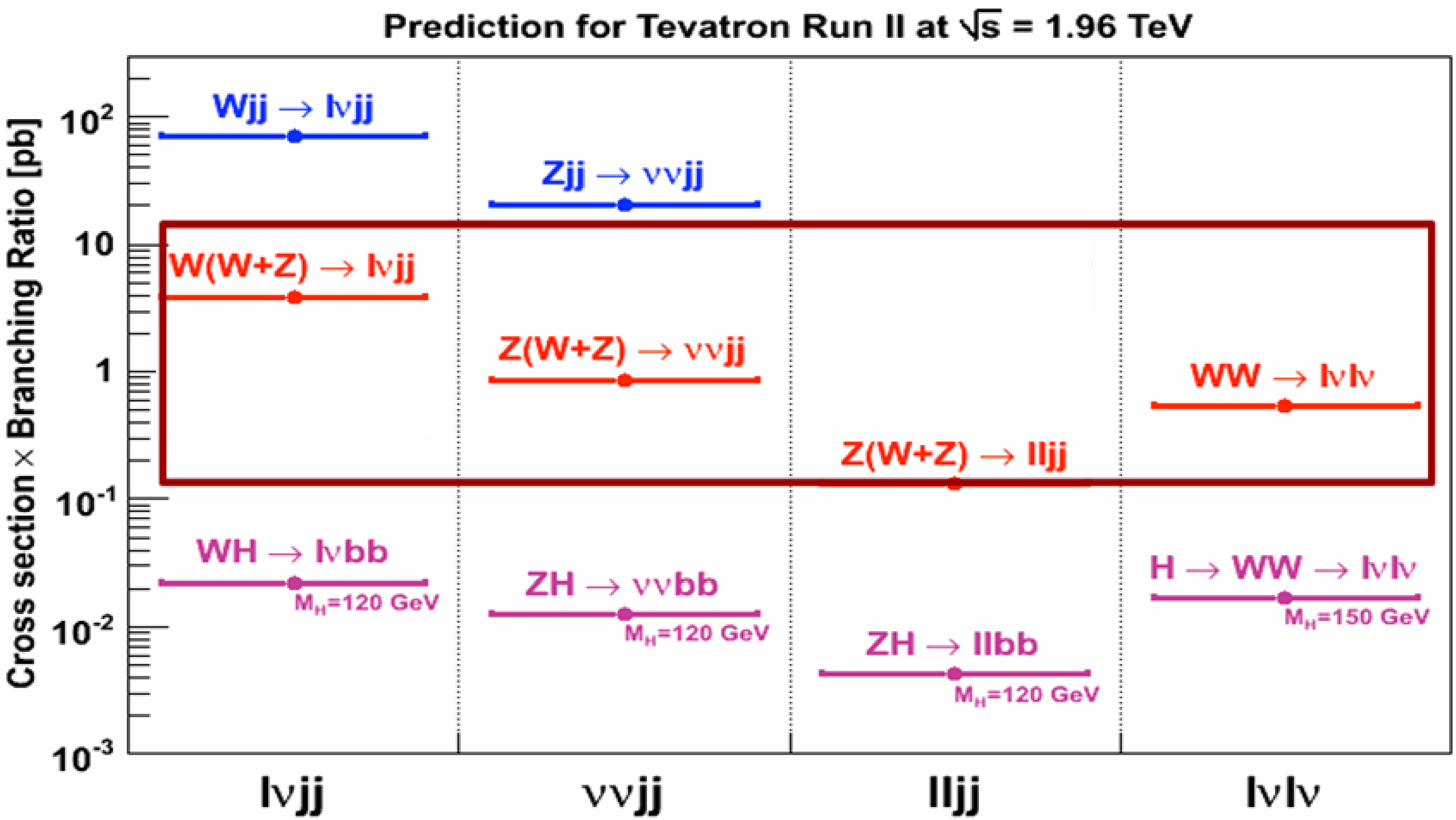
NLO: $2.28 \pm 0.22\,\text{pb}$

Alpgen: $0.78\,\text{pb}$

arXiv:0909.1505

Agreement with NLO QCD.

Diboson Production

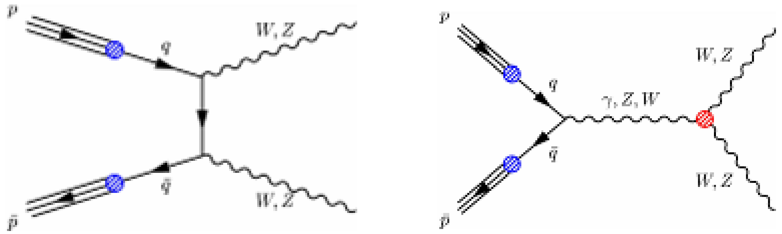


Tevatron opening up the more difficult channels

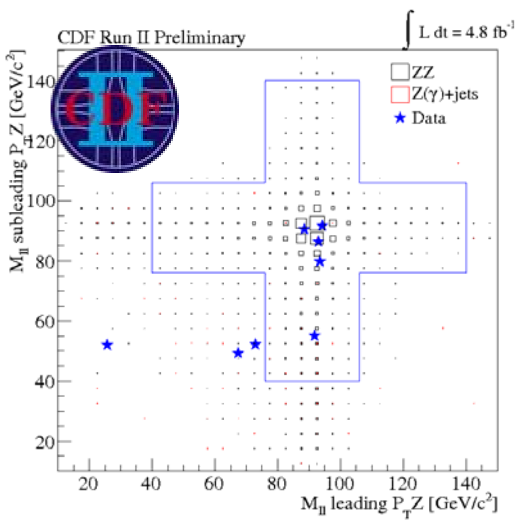
ZZ Production

Two channels:

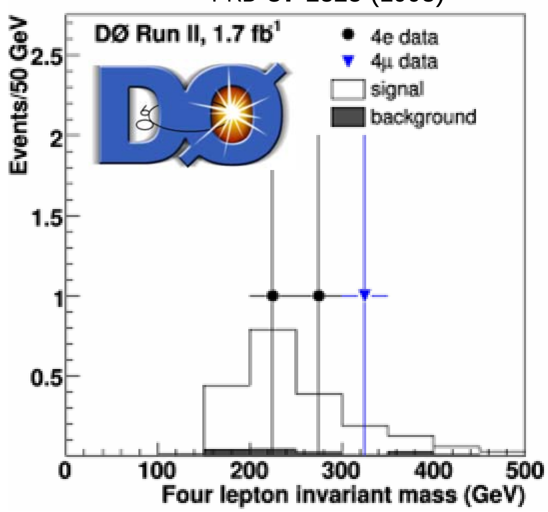
- Select 4-lepton candidate events (4e, 4μ)
  → Extremely pure sample
- Select dilepton + $\not{E}_T$ events (2e2ν, 2μ2ν)



σ_{ZZ}=1.3 pb ± 0.2 pb (NLO)



PRD **57** 2823 (1998)

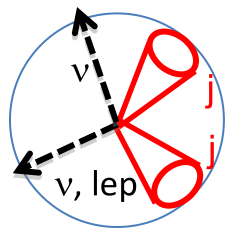


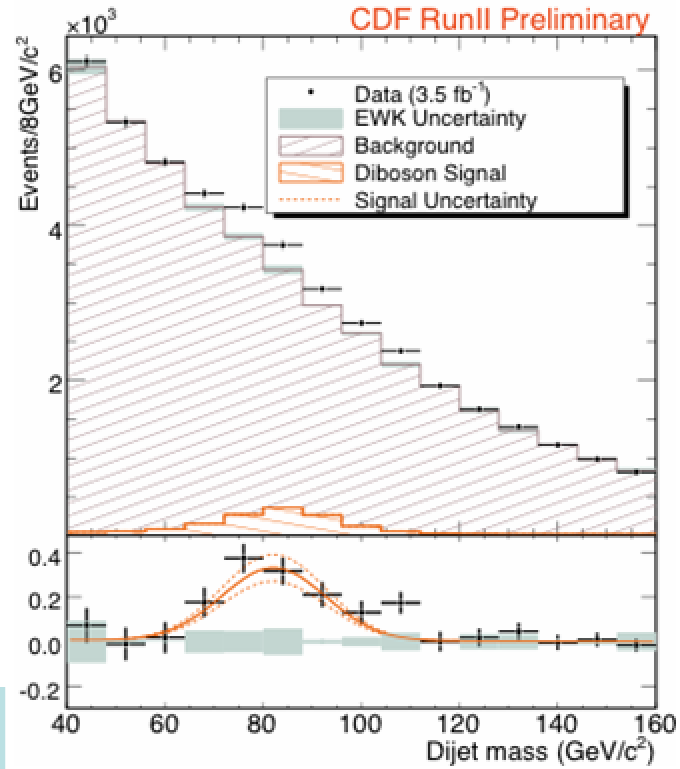
$\sigma_{ZZ} = 1.56^{+0.80}_{-0.63}$ (stat.) ± 0.25 (syst)
Significance 5.4σ

$\sigma_{ZZ} = 1.75^{+1.27}_{-0.86}$ (stat.) ± 0.13 (syst.)
Significance 5.4σ

Diboson Production in $\not{E}_T$+jj

- Search for $\nu\nu$jj and lνjj final states
- Sensitive to WW, WZ and ZZ
- Signal Significance 5.3σ
- Technical benchmark for ZH → $\nu\nu$ bbar and WH →lν bbar
- Challenging due to large W/Z+jets and huge QCD background

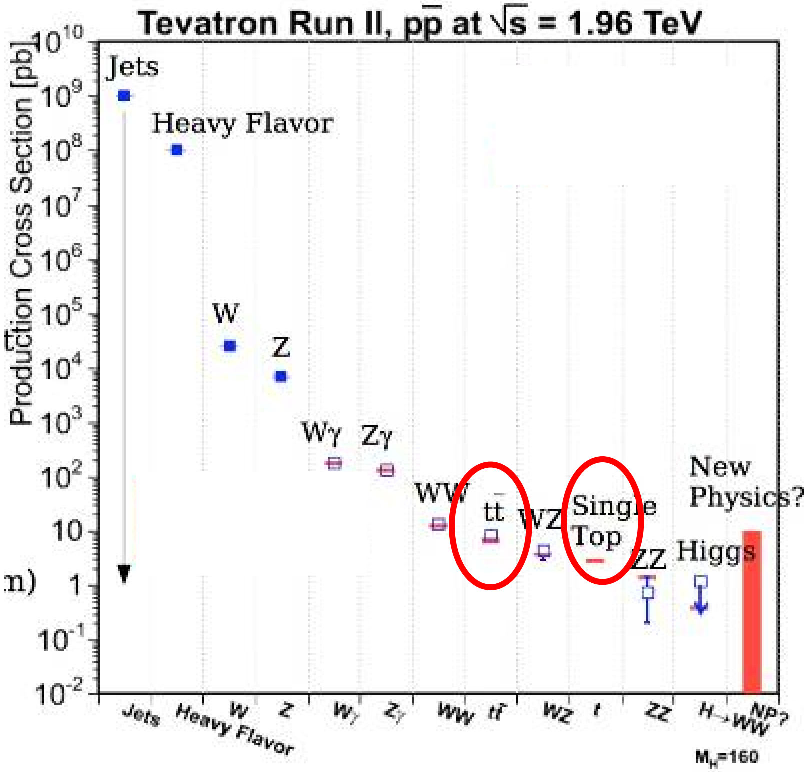




σ(pp→VV) , V=W,Z , with one V→jj [pb]	
Data	*18.0 ± 2.8 (stat.) ± 2.4 (syst.) ± 1.1 (lumi.)*
NLO prediction	*16.8 ± 0.5*

CDF 3.5 fb^{-1}

Top Production



- Top Pair Production Cross section
- Top Mass
- Electroweak Single Top Production

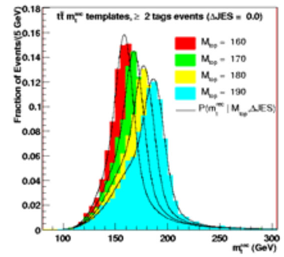
Analysis Strategies

background model validation

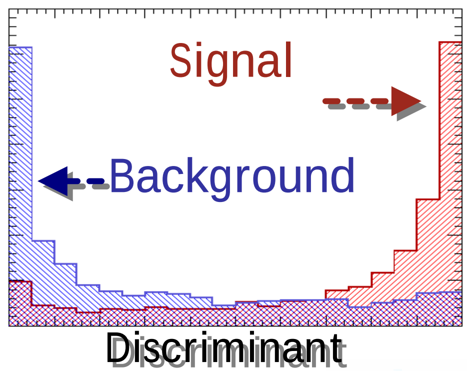
- Counting Experiment
  - Establish event selection and estimate background

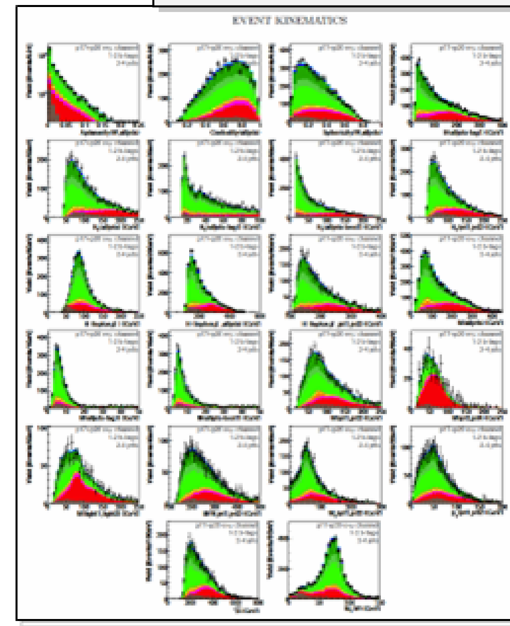
$$\sigma = \frac{N_{observed} - N_{background}}{\int \text{Luminosity}\, dt \cdot \varepsilon}$$

- Template Analysis
  - Fit 1D signal + background distribution to data



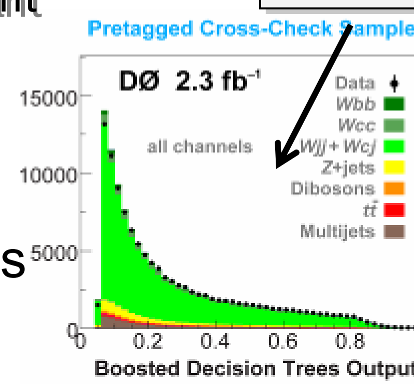
- Matrix Element
  - Use tree level matrix elements to classify signal and background like events

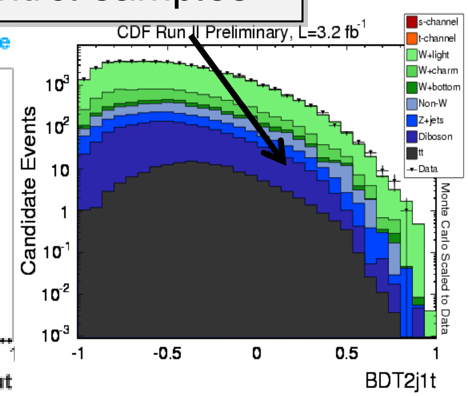




Evaluate discriminants in control samples

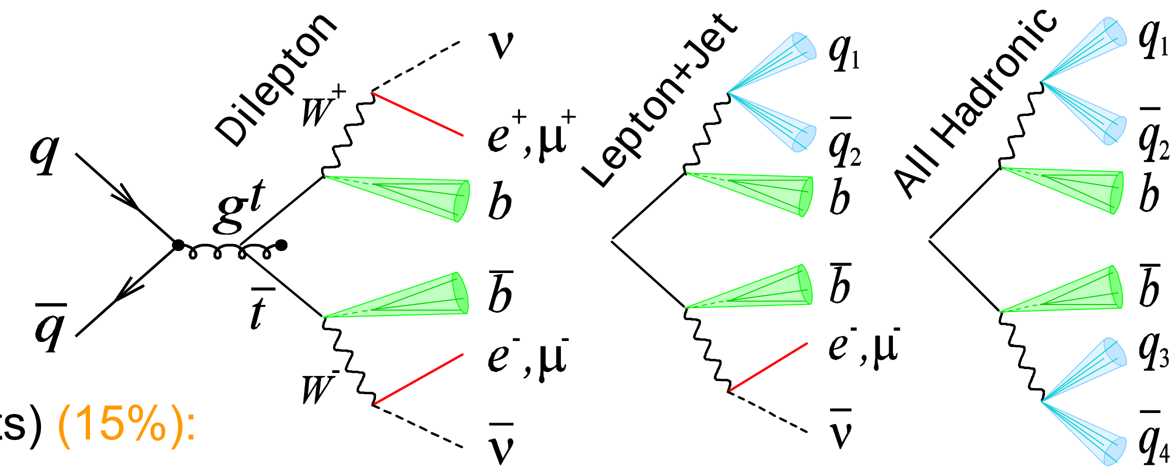
- Neural Networks, Decision Trees
  - Machine learning algorithm to classify signal and background events based on many input features





Top Quark Pair Production

$Br(t \rightarrow W^+ b) \sim 100\%$



Dilepton(lepton = e or μ) (7%):

Small rate, small backgrounds

Main background: Drell-Yan

Taus(hadronic decay +lepton/jets) (15%):

Small rate, large backgrounds

Main backgrounds: multijet and W+jets

Lepton+Jets(lepton = e or μ) (34%):

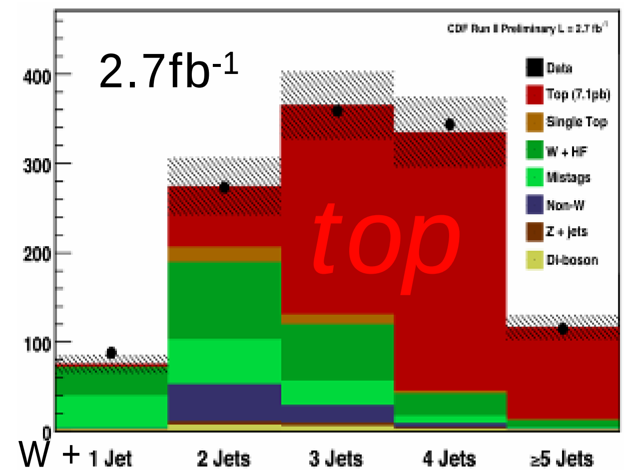
Good rate and manageable backgrounds

Main background: W+jets

All-hadronic (44%):

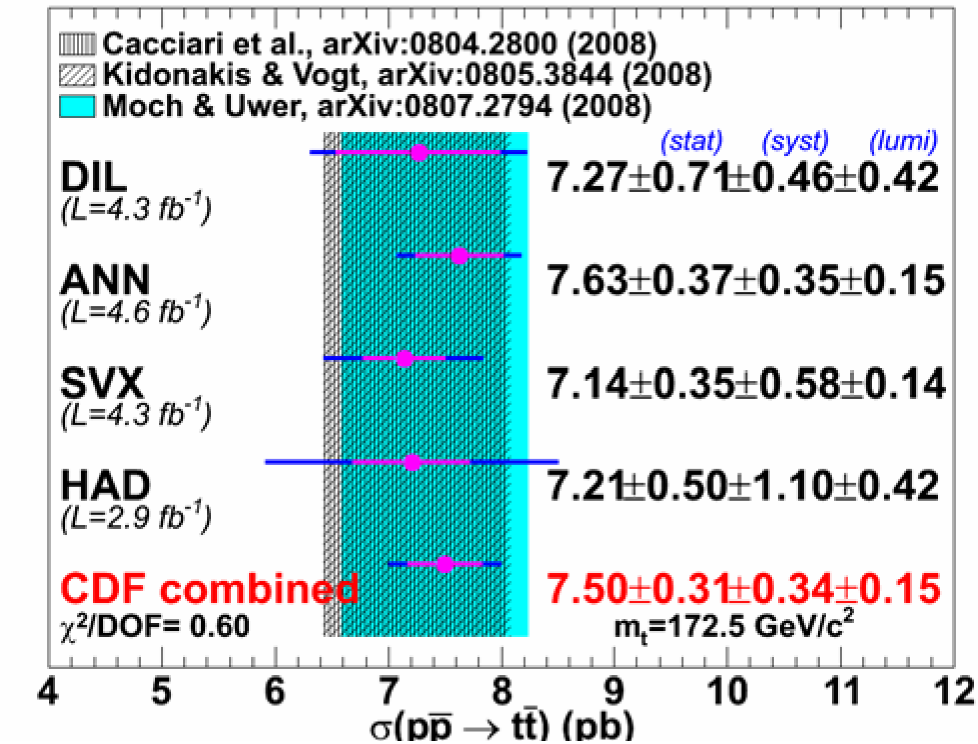
Large rate, large background

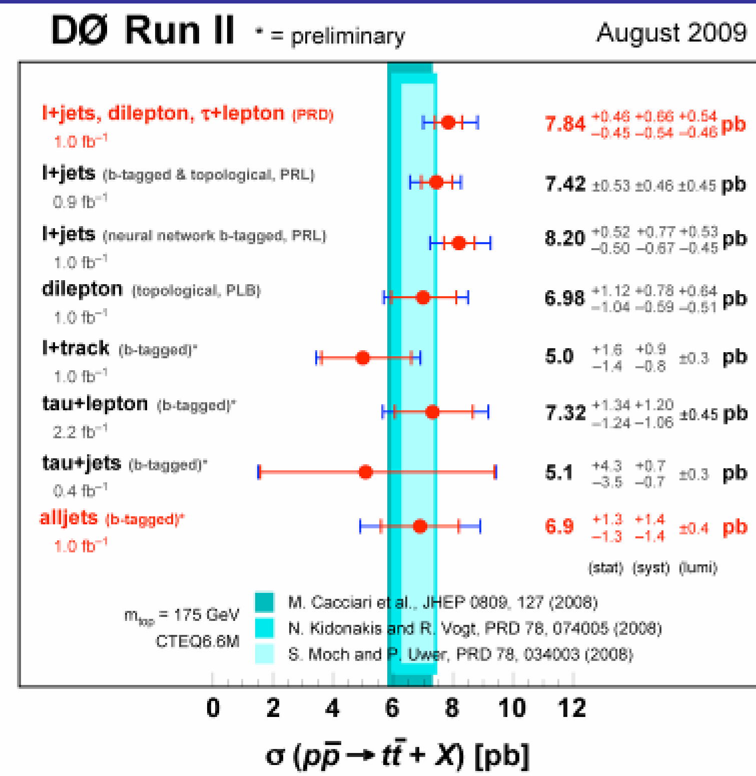
Main background: multijet



Lepton+Jets+2 b-tags

Top pair production cross section

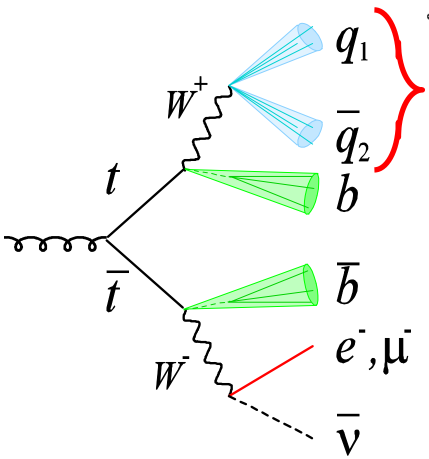


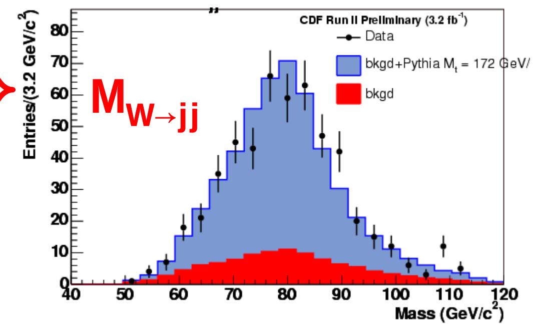


- Precision ~ 6.5% →approaches theory level
  - reduce luminosity uncertainty by normalizing to Z-cross section
- Lepton+ jets + all hadronic limited by systematic uncertainties
- Consistency across channels and different methods and with theory
- Tevatron combination underway

Top Quark Mass

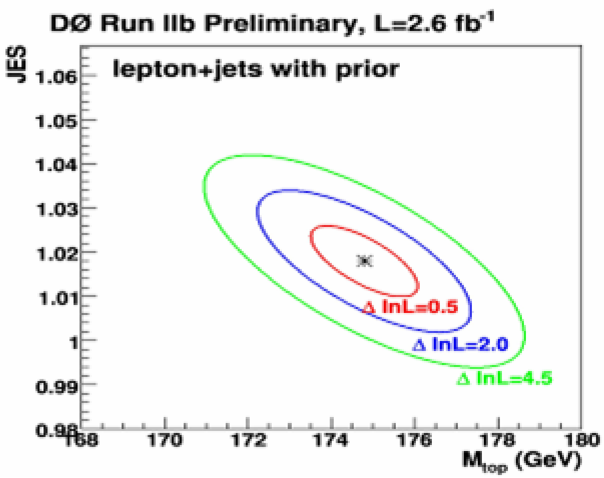
- Extraction techniques: Template and Matrix element method
- In-situ JES calibration (*W* constraint)
- Main uncertainties:
  - -Jet energy scales and resolution
  - - MC modeling, ISR+FSR, …

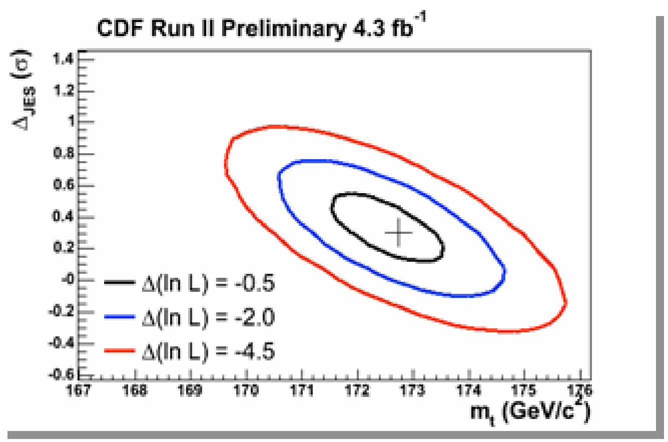




CDF l+j 4.3 fb^{-1}

SystematicSource	m_{top}(GeV)
Calibration	0.1
MC generator	0.5
Radiation	0.4
Residual jet energy scale	0.5
b-jet energy scale	0.4
Lepton p_T	0.2
Multiple hadron interactions	0.1
PDFs	0.2
Background	0.5
Color reconnection	0.3
Total	**1.1**





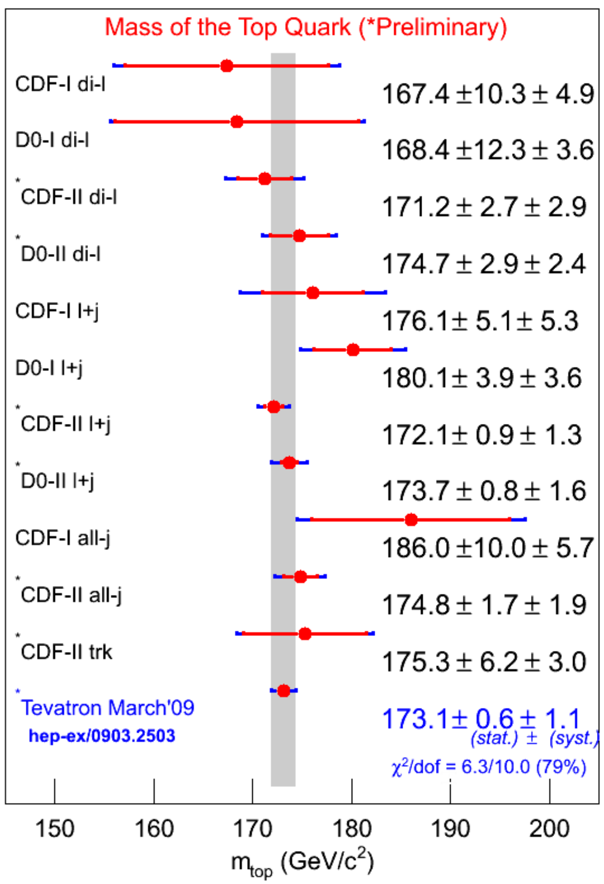
D0 (3.6 fb^{-1}):

m_t(l+j)=173.7±0.8(stat) ±0.8(JES) ±1.4(syst)GeV

CDF (4.3 fb^{-1}):

m_t(l+j)=172.6±0.9(stat) ±0.7(JES) ±1.1(syst)GeV

Top Quark Mass: Tevatron Combination

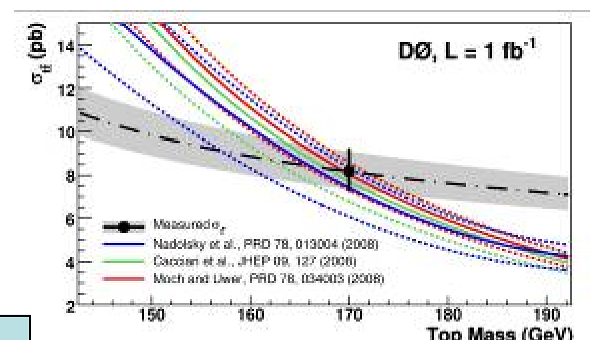


- Best single measurement precision approaches ~ 1 GeV
- Consistency across channels and methods
- Working on improving systematic uncertainties
- Are all phenomenological uncertainties
- accounted for ? => Working with theory community

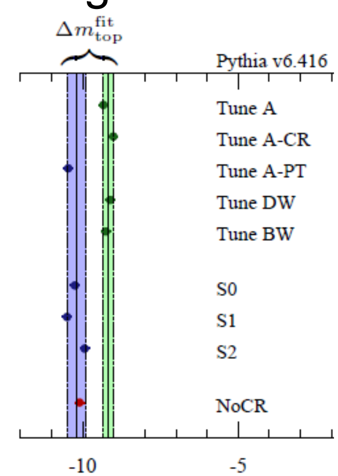
Tevatron (Winter 09): hep-ex 0903.2503

m_t=173.1 ± 0.6 (stat) ± 1.1 (syst) GeV

m_t=173.1 ± 1.3 (stat+syst) GeV ~0.8%

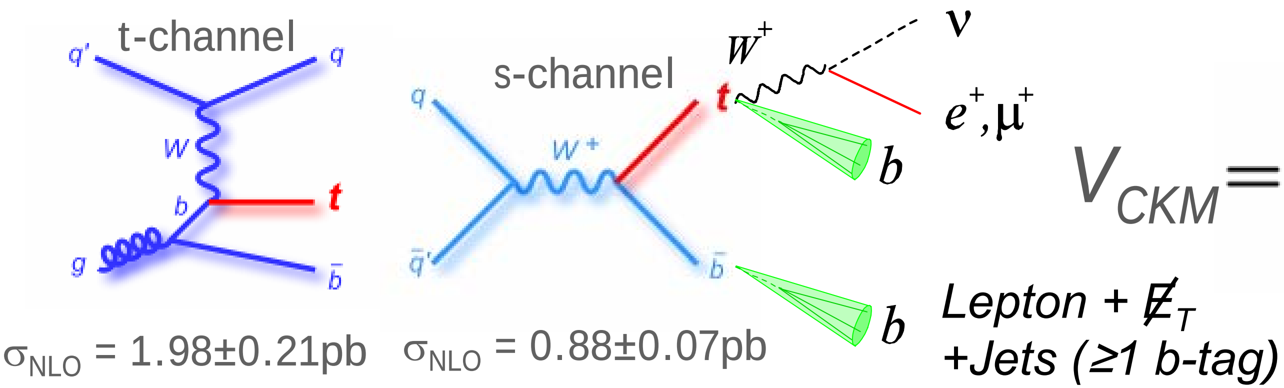


Top (pole) mass from cross section



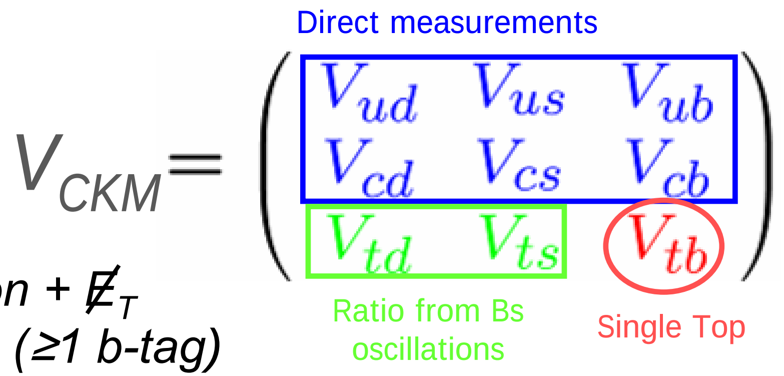
Color reconnection study
P.Skands, D. Wicke
Eur.Phys.J.C52:133-140,2007
+ update hep-ph. 0807.3248

Electroweak Single Top Production

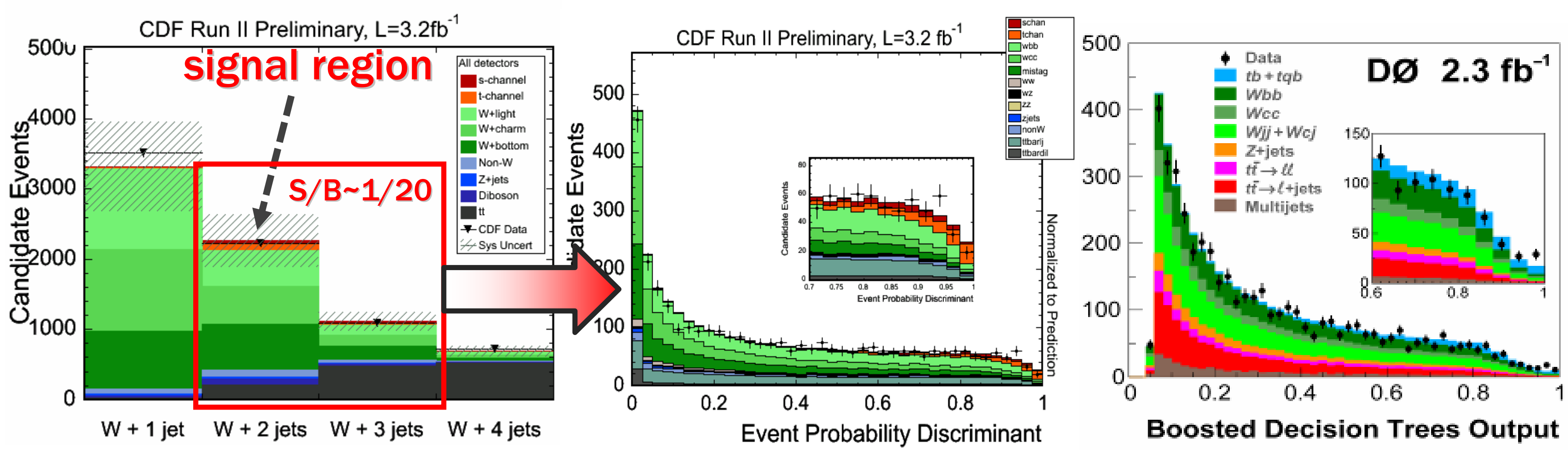


σ_{NLO} = 1.98±0.21pb σ_{NLO} = 0.88±0.07pb

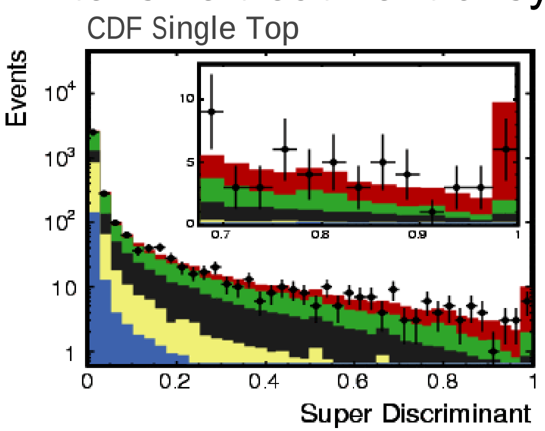
B.W. Harris et al., Phys. Rev. D66, 054024 Z. Sullivan, Phys. Rev. D70, 114012.

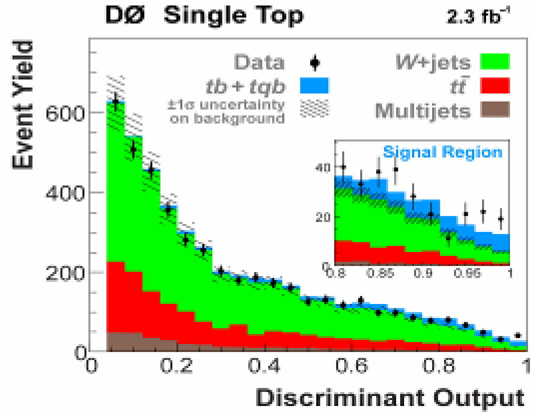


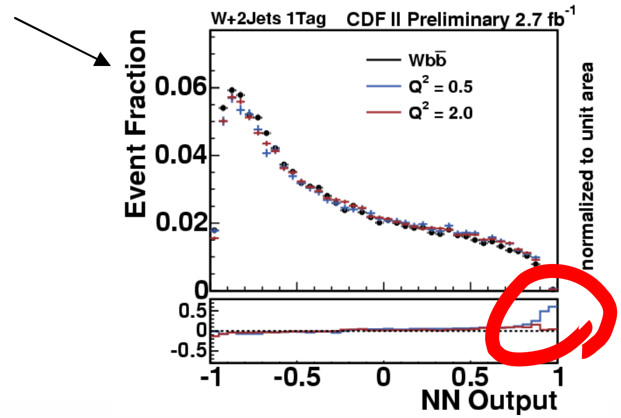
- Single top signature less distinct than top pairs
- Large backgrounds from W + jets (heavy flavor)
- Multivariate analyses essential to establish small signal



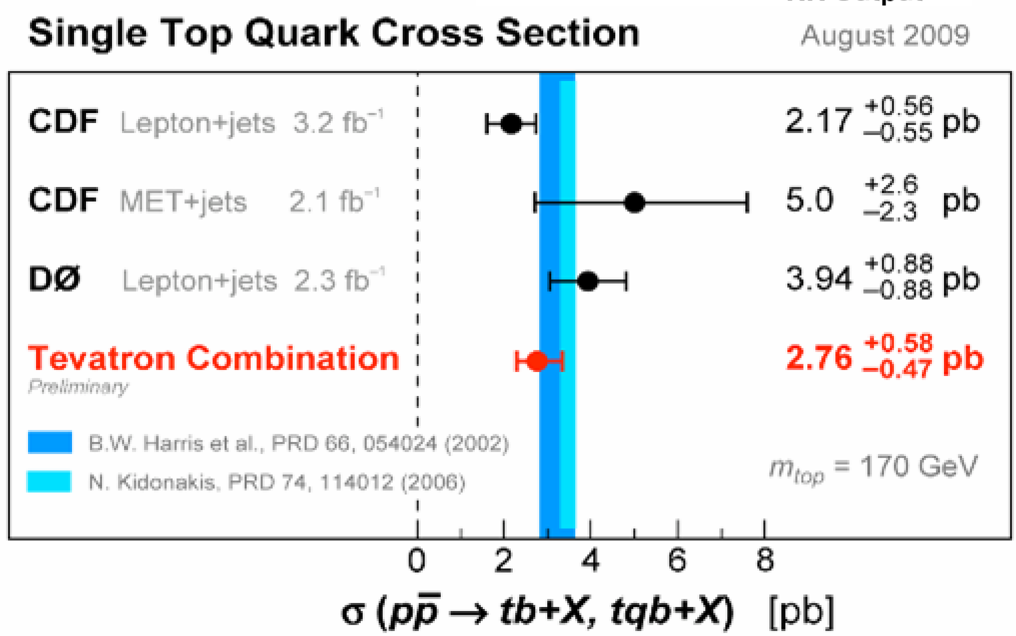
- "Blind analysis": extensive cross checks in data control regions to test MC modeling
- Extensive treatment of systematic uncertainties (normalization + shape)







	Data	Sensitivity	Observed
CDF	$3.2 fb^{-1}$	>5.9σ	5.0σ
D0	$2.3 fb^{-1}$	4.5σ	5.0σ



Tevatron combination:

$|V_{tb}|=0.91 \pm 0.08$ (stat+syst)

Top Quark Properties

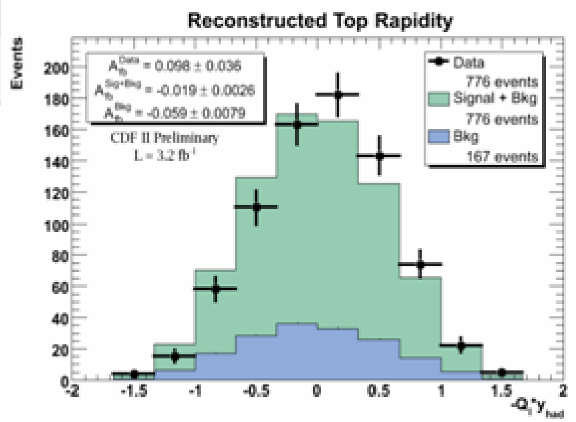
Property	Run II Measurement	SM prediction	Luminosity (fb^{-1})
m_t	CDF: 172.6 ± 0.9(stat) ± 1.2(syst) GeV D0: 174.2 ± 0.9(stat) ± 1.5(syst) GeV		4.3 3.6
σ_{ttbar}(@m_t=172.5GeV) σ_{ttbar}(@m_t=170GeV)	CDF: 7.50 ± 0.31 (stat) ± 0.34 (syst) ± 0.15 (lumi) pb D0: 7.84 $^{+0.46}_{-0.45}$ (stat) $^{+0.66}_{-0.54}$ (syst) $^{+0.54}_{-0.46}$ (lumi) pb	7.4 ± 0.6 pb 8.06 +0.6 pb	4.5 1
$\sigma_{singletop}$(@m_t=170GeV)	Tevatron: 2.76 $^{+0.58}_{-0.47}$ (stat+syst)	2.86±0.8 pb	3.2-2.3
$\lvert V_{tb} \rvert$	Tevatron: 0.91 ± 0.08 (stat+syst)	1	3.2-2.3
σ(gg->ttbar)/σ(qq->ttbar)	D0: 0.07+0.15-0.07(stat+sys)	0.18	1
$m_t - m_{tbar}$	D0: 3.8 ± 3.7 GeV	0	1
σ(tt→ll)/σ(tt→l+jets)	D0: 0.86 $^{+0.19}_{-0.17}$ (stat+syst)	1	1
σ(tt→τl)/σ(tt→ll + l+jets)	D0: 0.97 $^{+0.32}_{-0.29}$ (stat+syst)	1	1
$\sigma_{ttbar+jets}$(@m_t=172.5GeV)	CDF: 1.6 ± 0.2 (stat) ± 0.5 (syst)	1.79+0.16-0.31pb	4.1
cτtop	CDF: 52.5μm @ 95%C.L.	10^{-10} μm	0.3
Γtop	CDF: <13.1 GeV @ 95%C.L.	1.5 GeV	1
BR(t->Wb)/BR(t->Wq)	CDF: >0.61 @ 95% C.L. D0: 0.97 $^{+0.09}_{-0.08}$ (stat+syst)	1	0.2 0.9
F_0	CDF: 0.62 ± 0.11 D0: 0.490 ±0.106 (stat) ±0.085 (syst)	0.7	2 2.7
F_+	CDF: -0.04 ± 0.05 D0: 0.110 ±0.059 (stat) ±0.052 (syst)	0.0	2 2.7
Charge	CDF: -4/3 excluded with 87% C.L. D0: 4e/3 excluded at 92% C.L.	2/3	1.5 0.37
Spin correlations	CDF: κ = 0.32 + 0.55 - 0.78, -0.46 < K < 0.87 @ 68%C.L. D0: κ = −0.17 $^{+0.65}_{-0.53}$ (stat + syst)	$0.78^{+0.027}_{-0.022}$	2.8 4.2
Charge asymmetry	C D		

CDF (3.2 fb^{-1}) A_{fb} =0.193 ± 0.07 (stat) ± 0.02 (syst)%

D0 (1.0 fb^{-1}) A_{fb} = 0.12 ± 0.08 (stat) ± 0.01 (syst) %

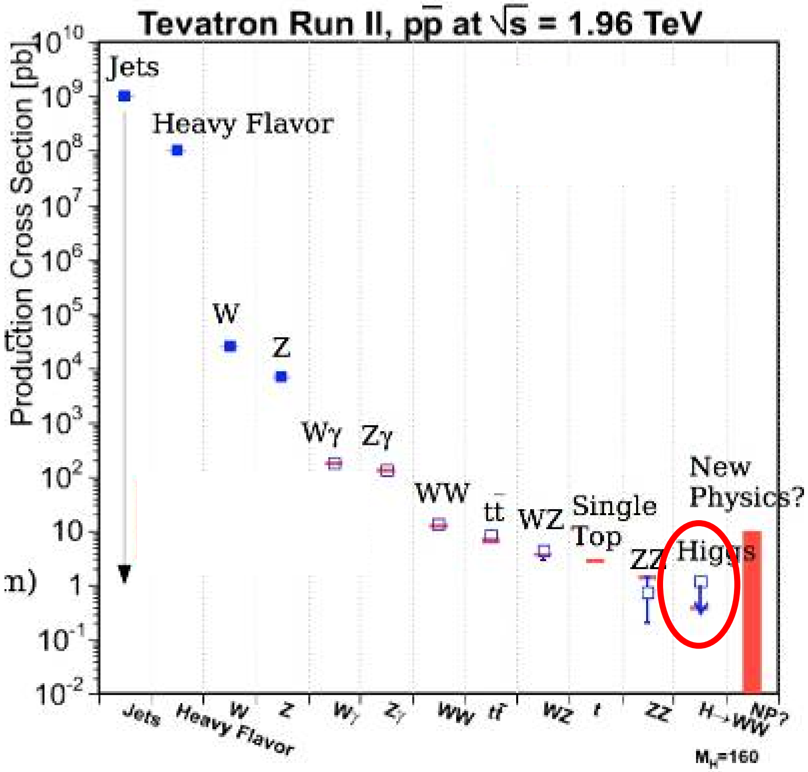
SM NLO A_{fb} =0.05 ± 0.015 %

~2σ



Beginning precision measurement of top quark properties

Higgs Boson Search

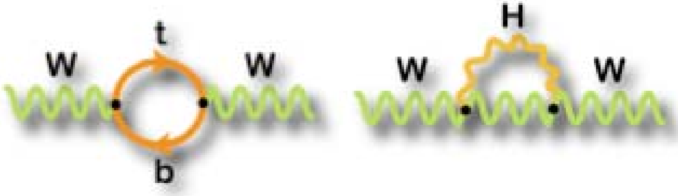


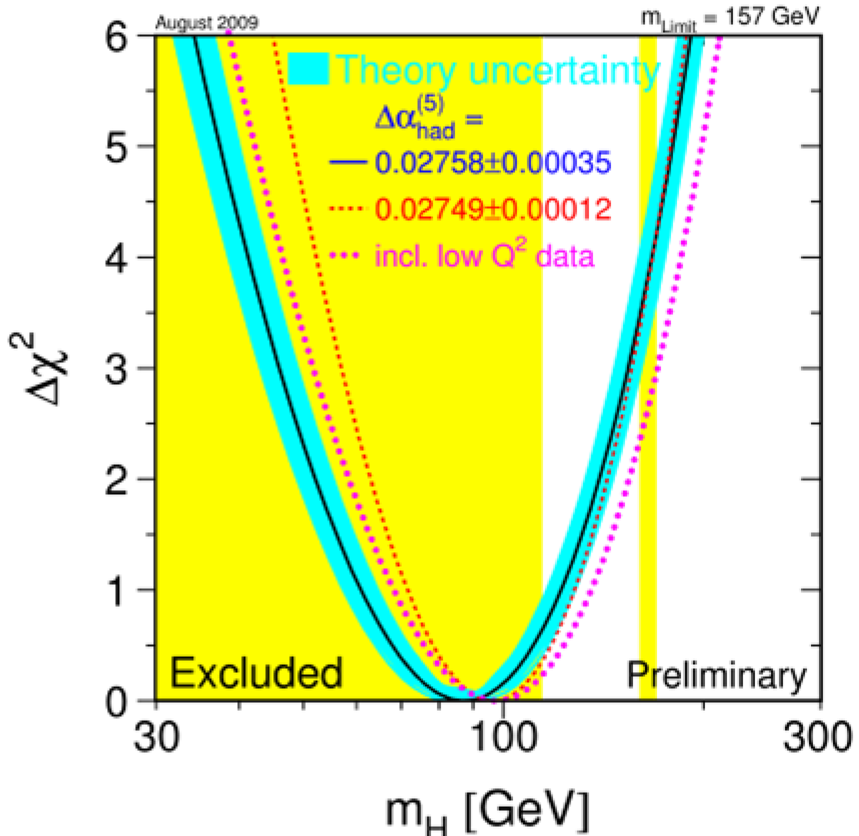
- low Mass < 140 GeV
- high Mass > 140 GeV
- Tevatron Combination
- Tevatron Prospects

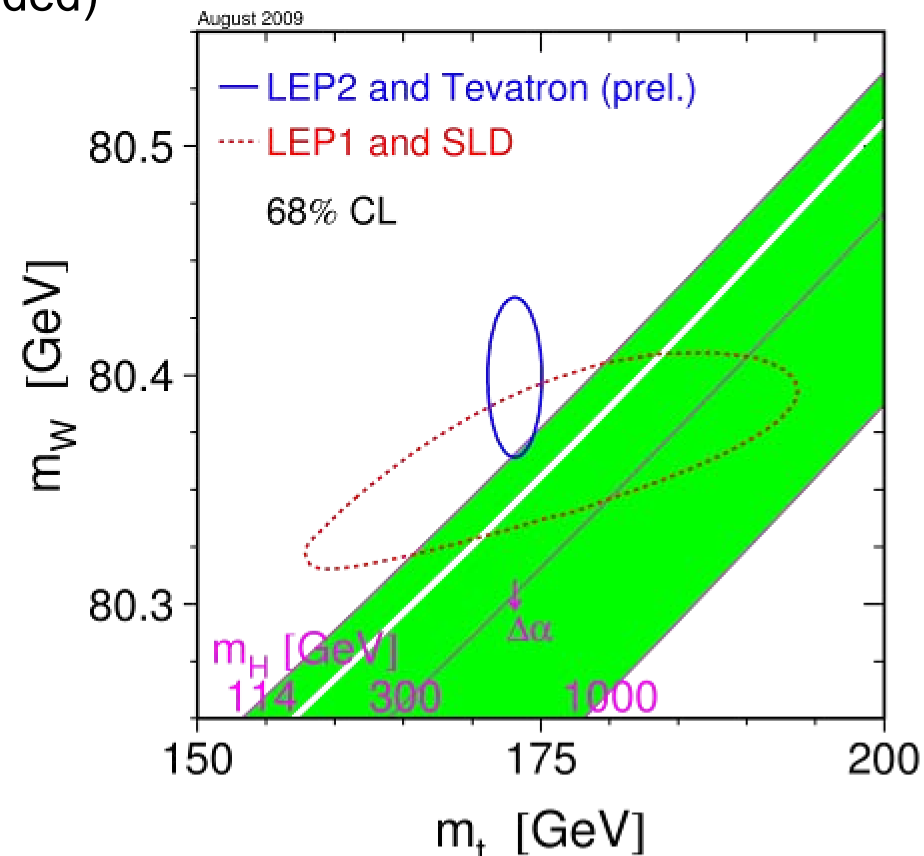
SM Higgs Mass Constraints

– World top quark mass and W boson mass included (LEP/TEVEWK working group August 2009) :

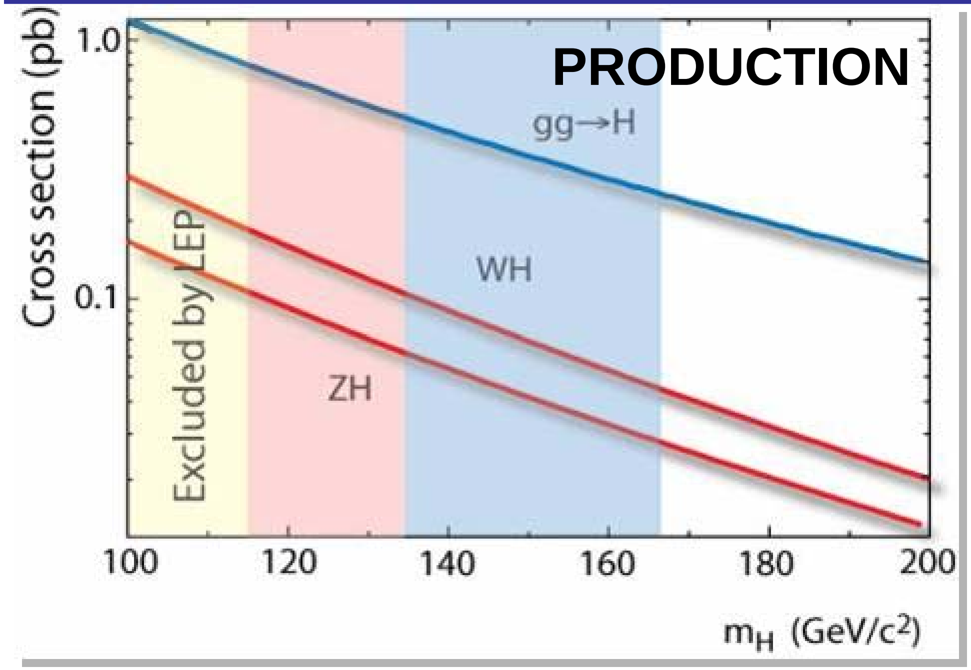
- $m_H = 87^{+35}_{-26}$ GeV
- $m_H < 157$ GeV (95% CL)
- $m_H < 186$ GeV (when LEP limit included)



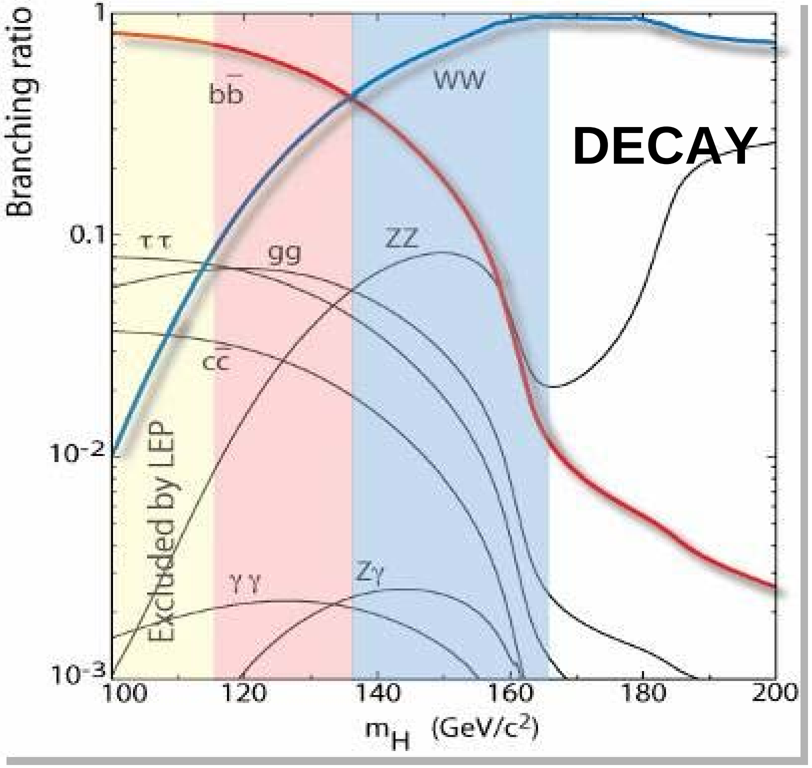




Higgs boson at the Tevatron



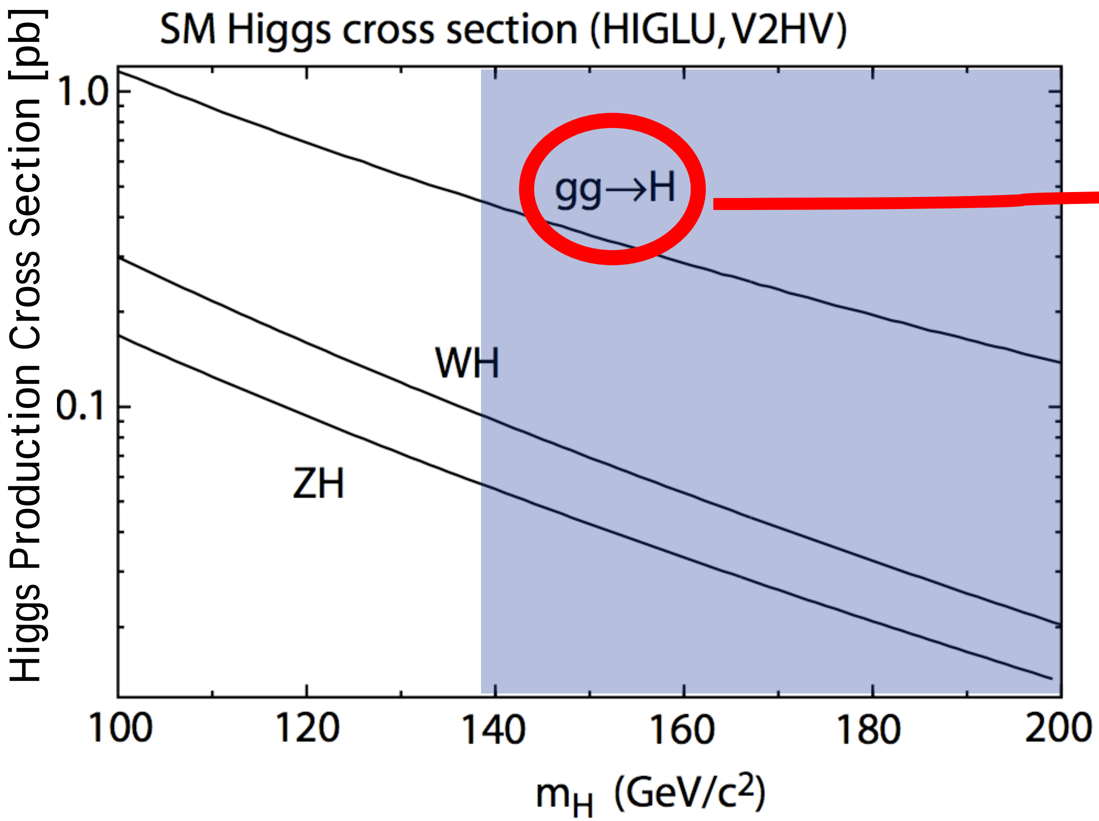
- Gluon fusion is the dominant production mode: σ ~1.1-0.1 pb
- W/Z associated production next most frequent mode: σ ~0.2-0.01 pb

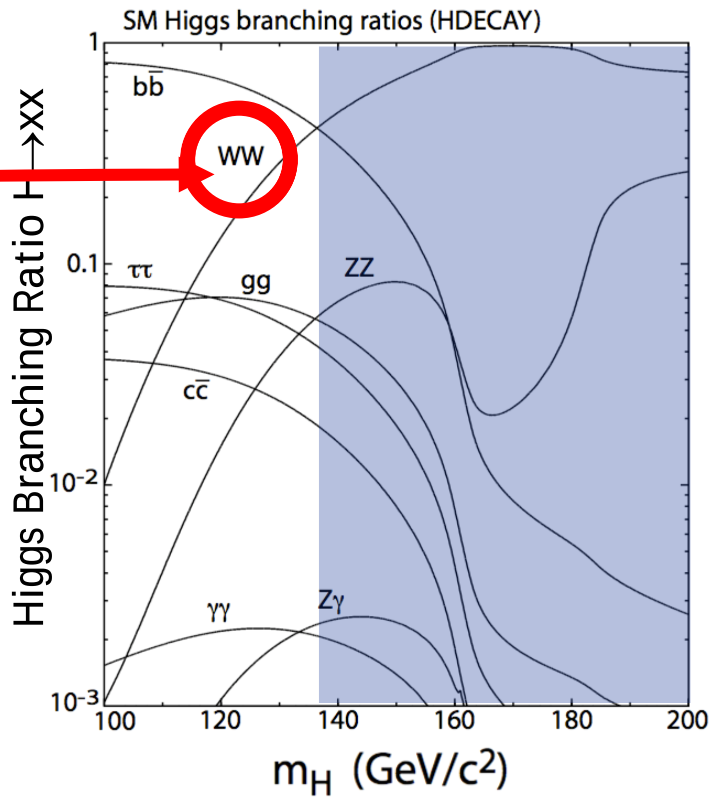


Low mass

High mass

Higgs Production and Decay



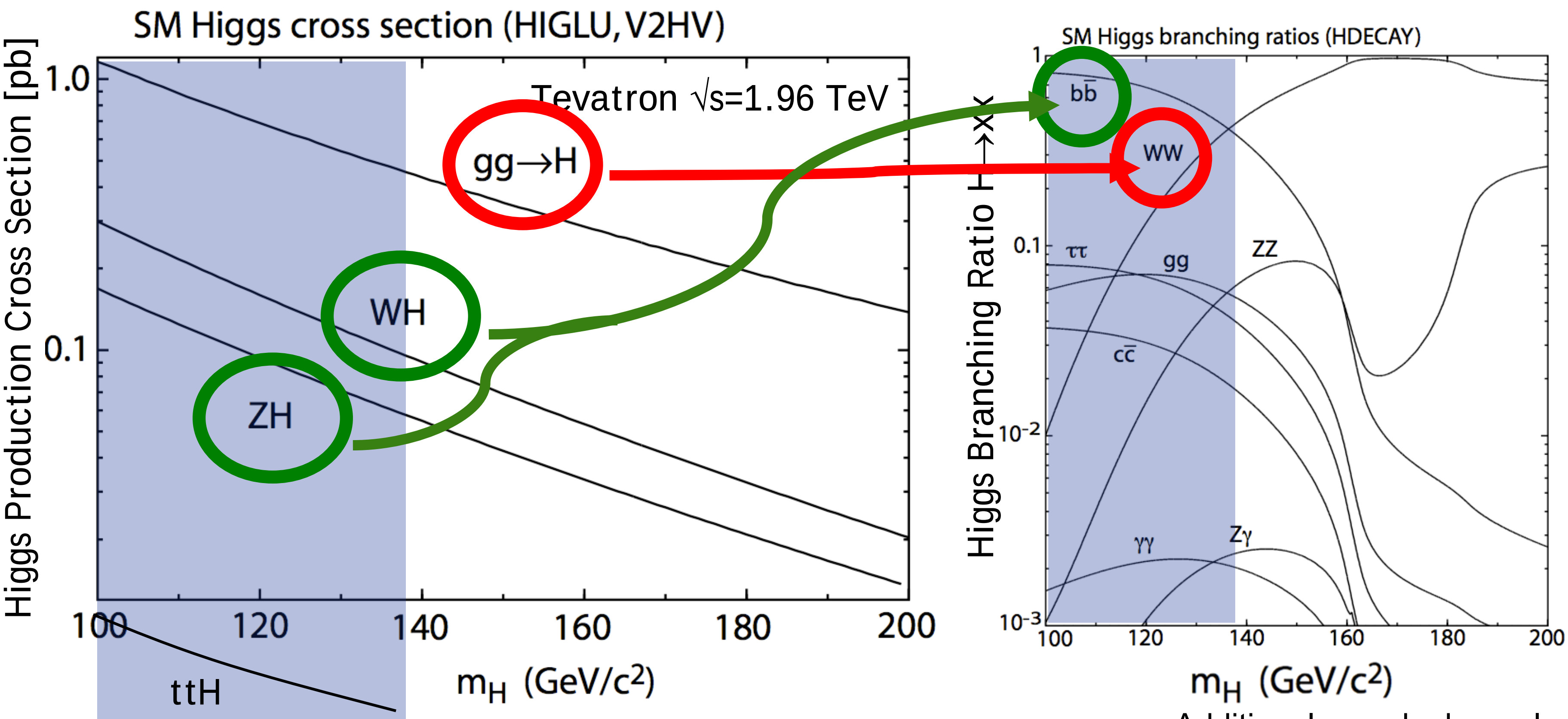


High mass Higgs, m_H > 140 GeV/c^2

gg → H → WW dominates

WH/ZH → WWW/ZWW contributes

Higgs Production and Decay



Additional search channels

- $WH \rightarrow \tau\nu bb$
- $VH \rightarrow qqbb$
- $H \rightarrow \tau\tau$ (with jets)
- $H \rightarrow \gamma\gamma$
- $ttH \rightarrow l\nu bbbbqq$

Low mass, $m_H < 140$ GeV/c^2

gg→ H→ bb dominates

Direct production swamped by huge QCD background - close to impossible

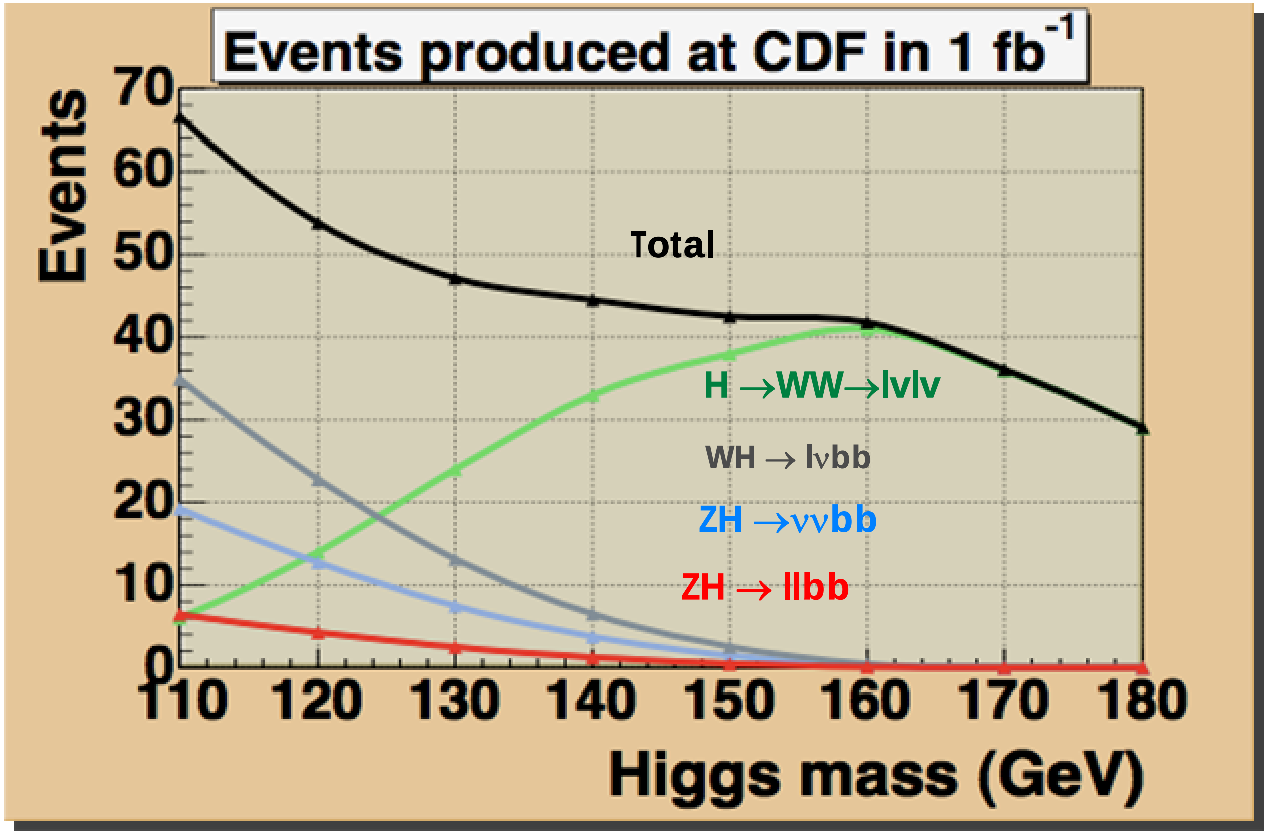
$WH \rightarrow l\nu bb$

$ZH \rightarrow llbb$

$VH \rightarrow \nu\nu bb, \nu(l)bb$

VH={WH,ZH}

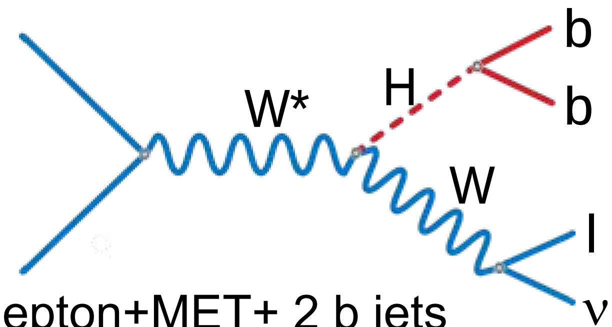
The Higgs Boson is being produced !



In theory …

Higgs boson traveling back in time to prevent its production ? New York Times, October 12th, 2009

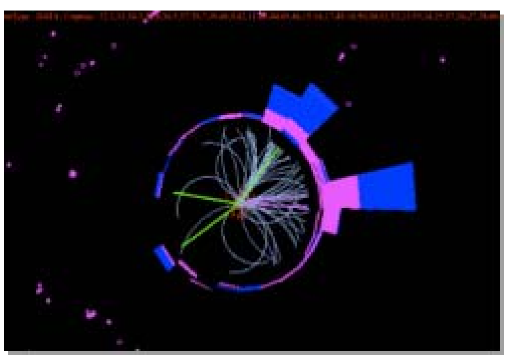
Low Mass Higgs

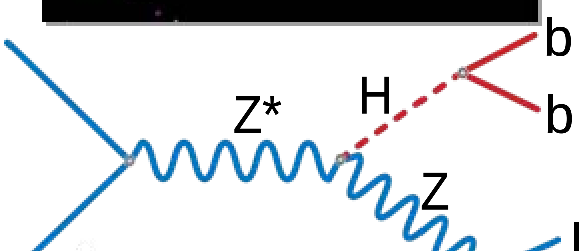


1 lepton+MET+ 2 b jets

About 3-4 events / 1 fb^{-1}

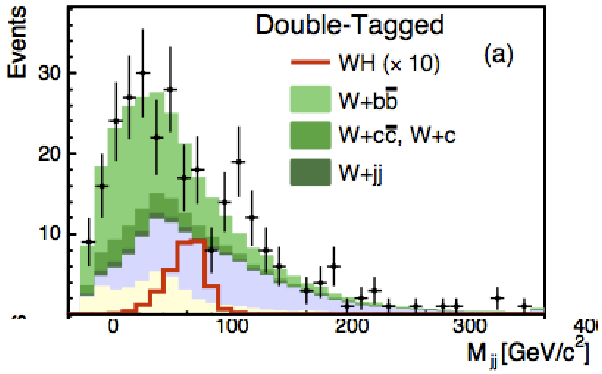
→*Most sensitive channel*





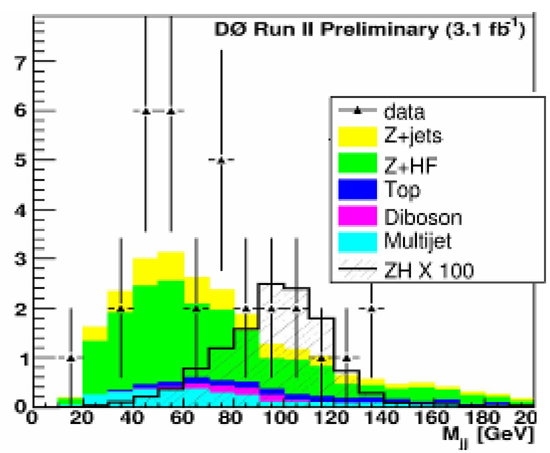
- 2 leptons + 2 b jets
- About 1 event / 1fb^{-1}

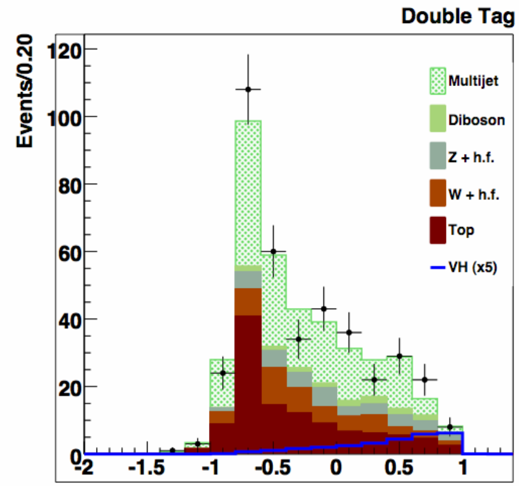
→ *Cleanest signature*

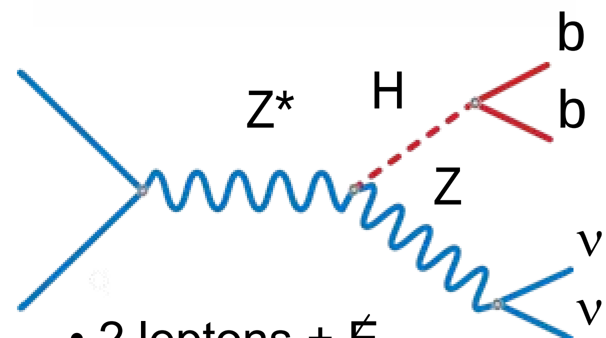


Latest improvements:

- Loose double tagging
- Extend/looser lepton ID
- Improved jet resolution
- New trigger paths
- ME+BDT/NN discriminators







- 2 leptons + $\not{E}_T$
- About 3 event / 1 fb^{-1}

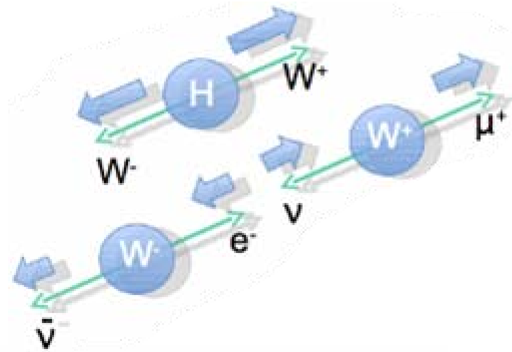
→ *highest Z branching fraction*

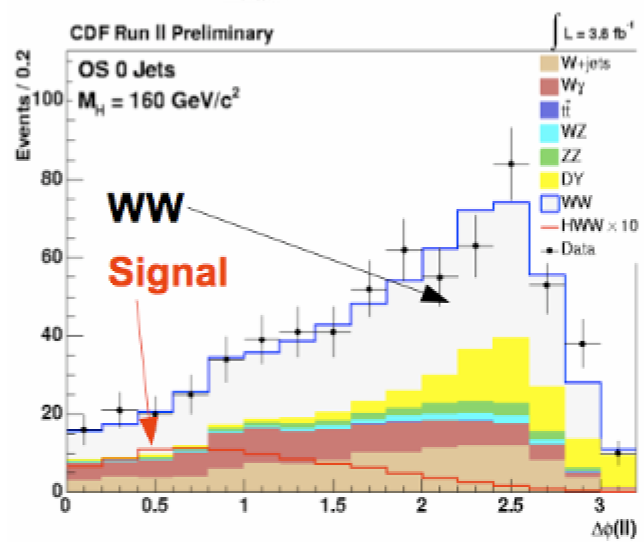
→ *recovers WH with missing lepton*

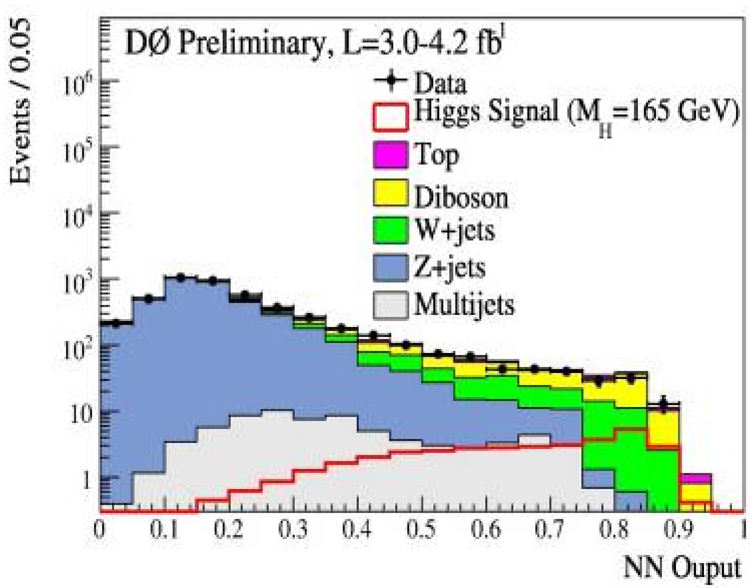
High Mass Higgs

- Golden channel at high mass

  gg → H →WW* → lν l'ν' (l, l'=e,μ)
- Add WW + N jets to include VBF and VH acceptance
- dilepton opening angle Δφ discriminates against WW background (spin 0 Higgs)
- Improving lepton acceptance is key
- High discriminant region S:B ~ 1 !







D0: 23 Higgs events over ~5000 background events

Recent H→WW Theory Development

- ICHEP'08 reported Tevatron combination reported exclusion m_H = 170 GeV:
  - NNLL cross section: S. Catani, D. de Florian, M. Grazzini, and P. Nason, JHEP 07, 028 (2003), hep-ph/0306211 CTEQ5L
  - include two loop EW diagrams: U. Aglietta, B. Bonciani, G. Degrassi, and A. Vivini (2006), hep-ph/0610033.

  ~ +7% @m_H = 165 GeV

- Theoretical progress:
  - mixed QCD-EWK corrections + better treatment of running b-mass

    D. de Florian, M. Grazzini, hep-ph/0901.2427
    C Anastasiou, R Boughezal, F Petriello, hep-ph/0811.3458

    ~ +7% @m_H = 165 GeV

    cf. also C. Anastasiou et al. hep-ph/0905.3529

- 2009 MSTW PDFs: Martin Sterling Thorne Watt hep-ph/0901.0002

  ~ -15% @m_H = 165 GeV

- Moriond '09 already included state of the art
  - -uncertainties both rate and shape

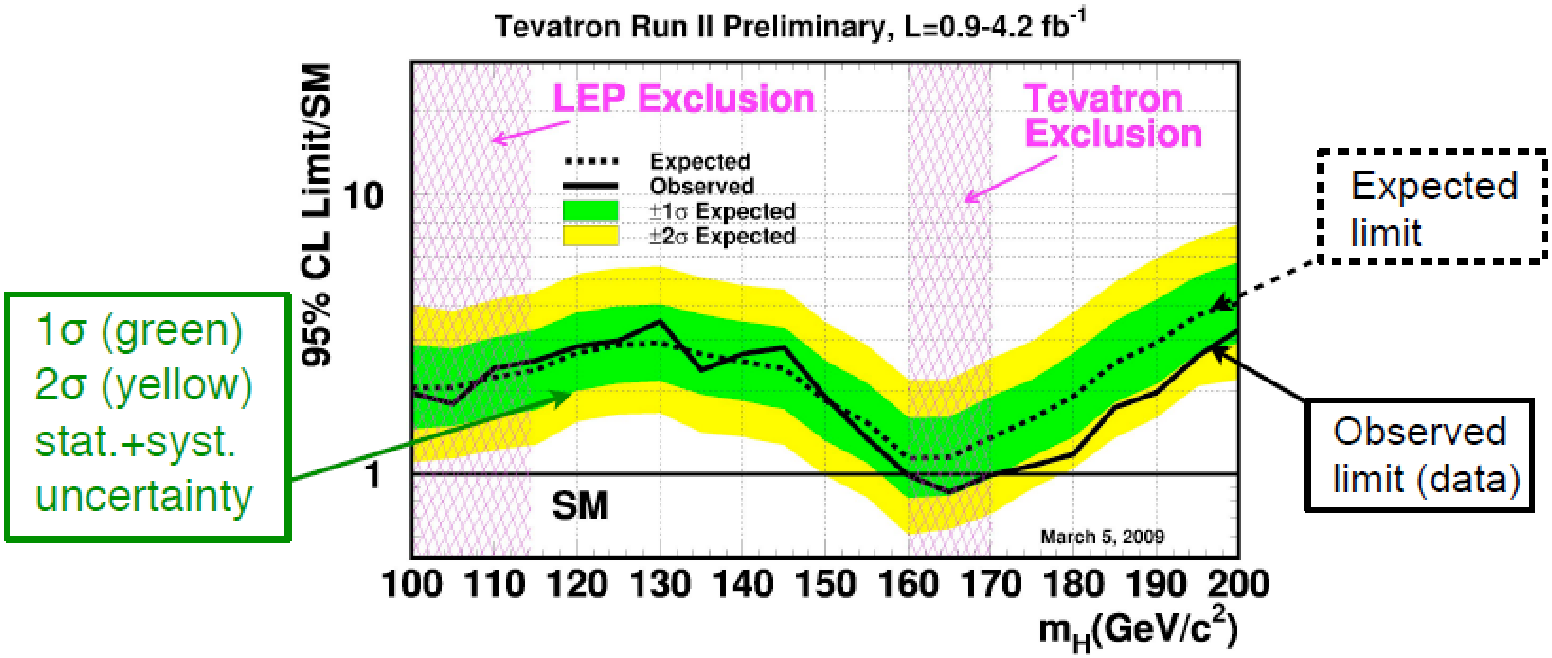
    Shape: Scale variations (in jet bins), ISR, gluon pdf, Pythia vs. NNLO kinematics, DY pt distribution, jet energy scale, lepton fake rate

CDF: $H \to WW \to \ell^{\pm}\ell^{\mp}$ + 0 Jets Analysis

Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet	$gg \to H$	WH	ZH	VBF
Cross Section											
Scale								10.9%			
PDF Model								5.1%			
Total	*10.0%*	*10.0%*	*10.0%*	15.0%	5.0%	10.0%		12.0%			
Acceptance											
Scale (leptons)								2.5%			
Scale (jets)								4.6%			
PDF Model (leptons)	1.9%	2.7%	2.7%	2.1%	4.1%	2.2%		1.5%			
PDF Model (jets)								0.9%			
Higher-order Diagrams	5.5%	10.0%	10.0%	10.0%	5.0%	10.0%					
Missing Et Modeling	1.0%	1.0%	1.0%	1.0%	20.0%	1.0%		1.0%			
Conversion Modeling						20.0%					
Jet Fake Rates											
(Low S/B)							21.5%				
(High S/B)							27.7%				
MC Run Dependence	3.9%			4.5%		4.5%		3.7%			
Lepton ID Efficiencies	2.0%	1.7%	2.0%	2.0%	1.9%	1.4%		1.9%			
Trigger Efficiencies	2.1%	2.1%	2.1%	2.0%	3.4%	7.0%		3.3%			
Luminosity	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%		5.9%			

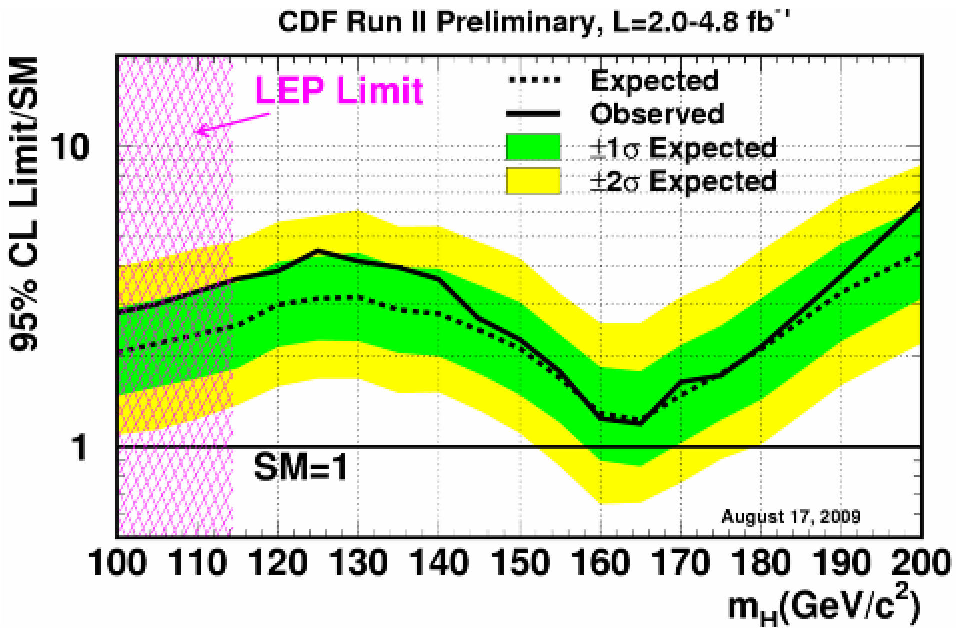
Tevatron Combination (Moriond 09)

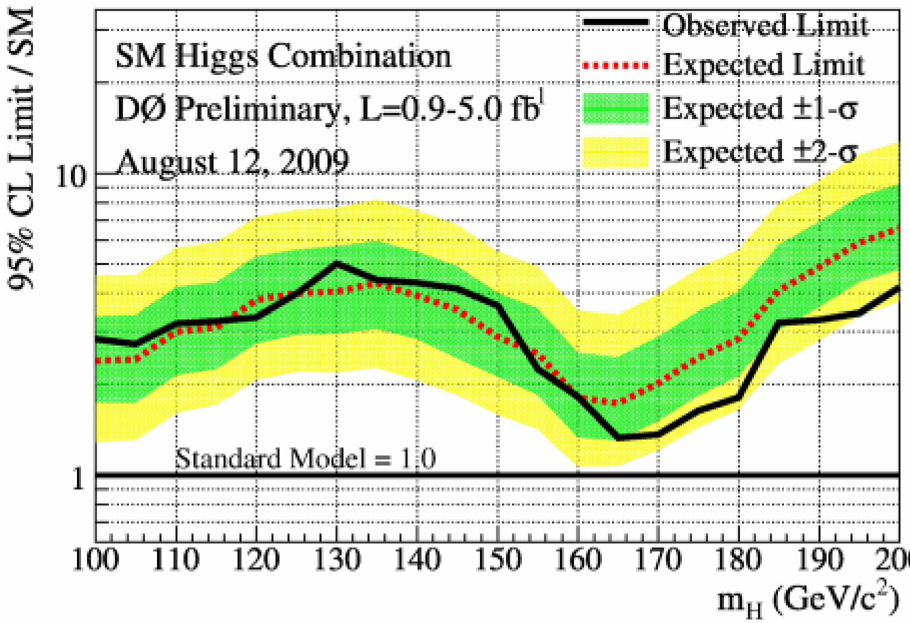
- Tevatron combination is a big task!
  - 14 analyses, 75 channels
  - 106 independent systematic errors!
- Set a (95% C.L.) limit on the "multiplier" $\sigma^{exp}/\sigma^{theory}$



First 95% C.L. exclusion at m_H =160-170 GeV

Summer conference update





CDF combination from Winter 2009 →Summer 2009

M_H=115 GeV

Expected limit 3.2 σ_{SM} → 2.5σ_{SM}

Observed limit 3.8 σ_{SM} → 3.6σ_{SM}

M_H=165 GeV

Expected limit 1.7 σ_{SM} →1.2 σ_{SM}

Observed limit 1.6 σ_{SM} →1.2 σ_{SM}

DØ combination from Winter 2009 →Summer 2009

M_H=115 GeV

Expected limit 3.6 σ_{SM} → 3.1 σ_{SM}

Observed limit 3.7 σ_{SM} → 3.2 σ_{SM}

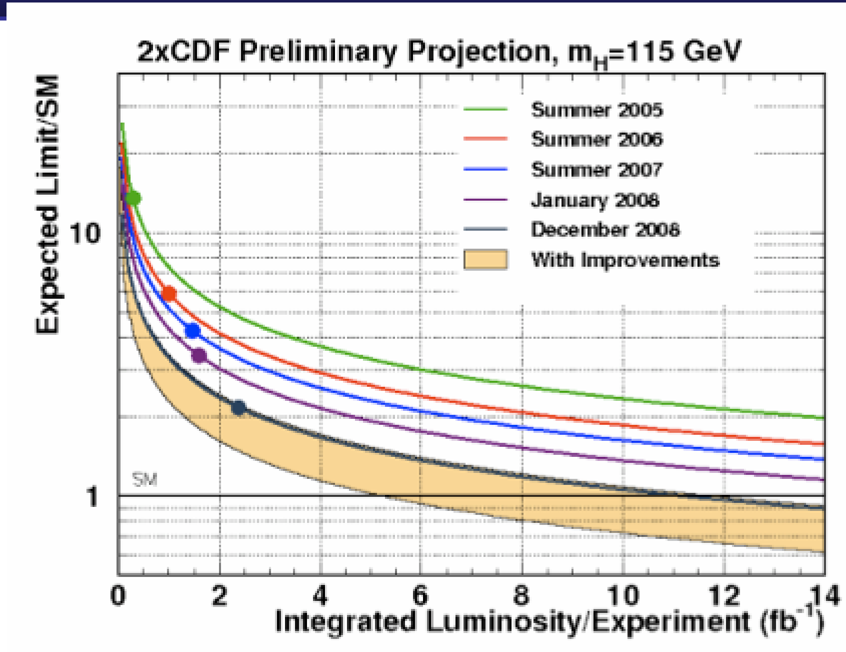
M_H=165 GeV

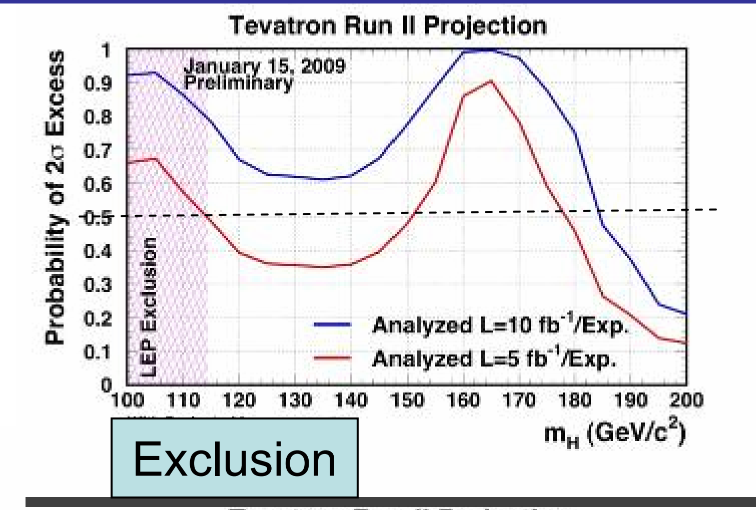
Expected limit 1.7 σ_{SM}

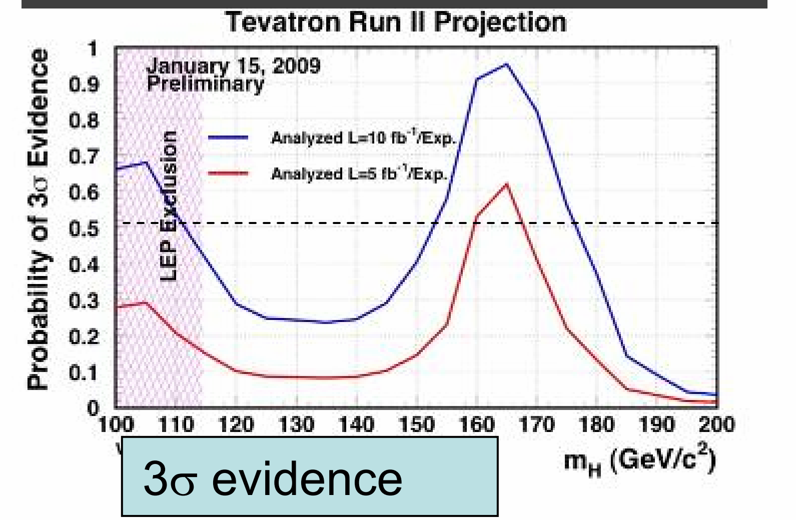
Observed limit 1.3 σ_{SM}

New Tevatron combination being prepared (→HCP)

Tevatron Prospects for Higgs







Improvements in the pipeline: (CDF)

- Better flavor tagging
- Complementary triggers
- Tau identification
- Better jet, E_T resolution

Run II Reach:

- exclude all masses
- 3-sigma sensitivity m_H=150-170 GeV

Tevatron Prospects for Higgs

versus

stolen from Sergo Jindariani, Fermilab Wine and Cheese Seminar

Conclusions

- Precision Era at the Tevatron: (7 fb^{-1} delivered)
  - < 1% top quark mass
  - <0.4% W mass – better than LEP
  - 6.5% top production cross section
  - Inclusive jet production constrains high-x gluon
  - ….
- Many of these legacy measurements for years to come.

- Precision requires theory – experiment interplay
  - Recent examples: top mass definition, color reconnection, gg → H→WW …

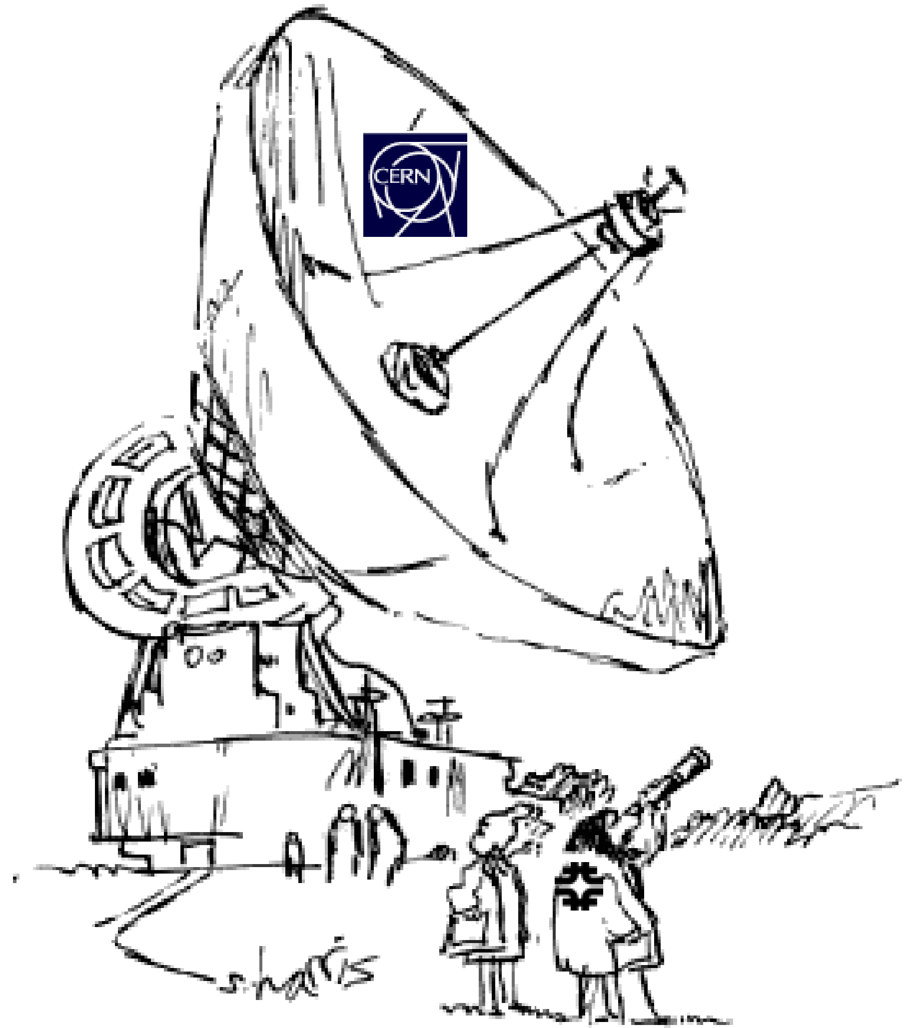
- Tevatron has started to exclude Higgs boson mass range m_H = 160-170 GeV
  - Sensitivity continues to fall faster than luminosity scaling
  - Run II (12 fb^{-1} delivered if 2011 running) provides 95% C.L. eclusion in full accessible mass range and 3σ evidence 150-170 GeV

- New Tevatron Higgs combination imminent – stay tuned!

The Tevatron

The LHC

The Tevatron



Stolen from Mario Martinez-Perez

BACKUP