Tevatron results on *Electroweak, Top and Higgs*

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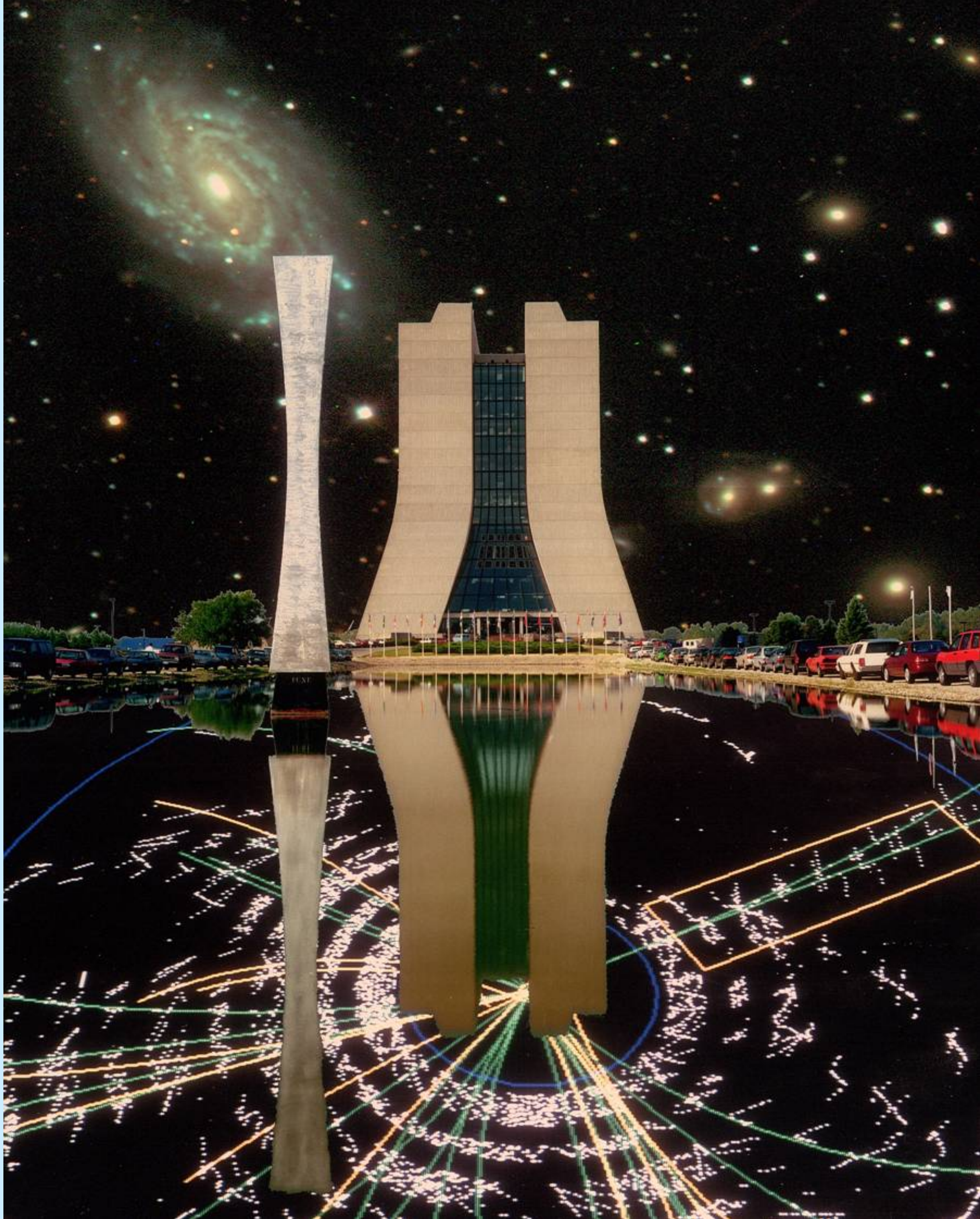
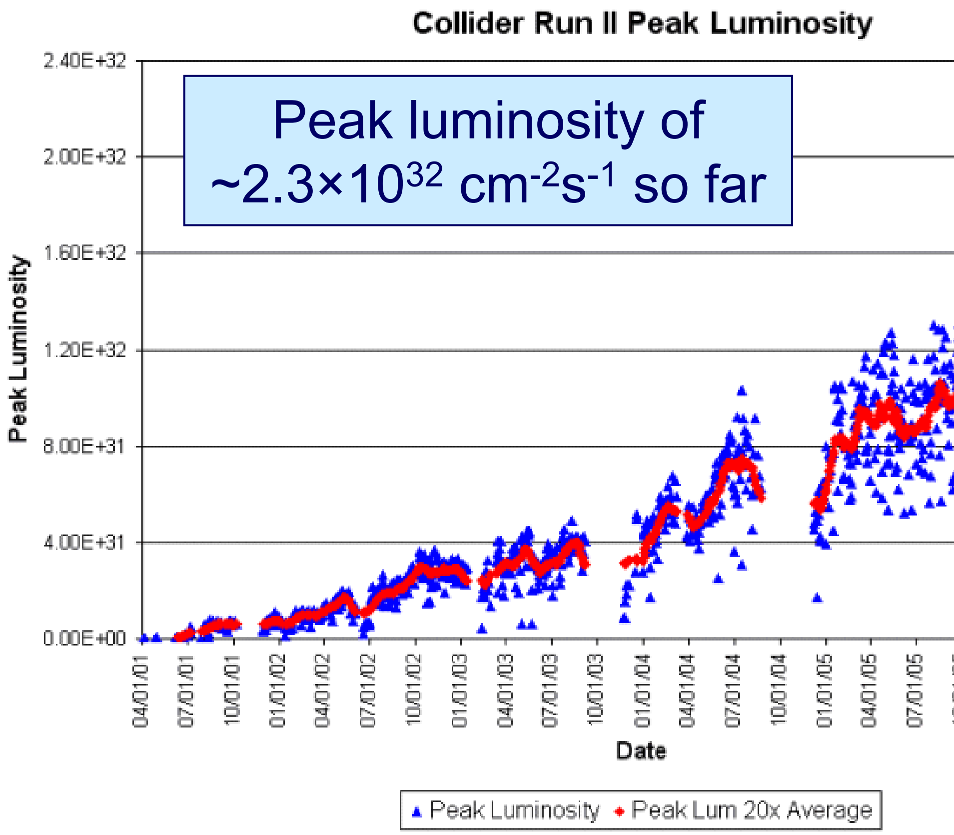
for the CDF and DØ Collaborations

Outline

- **Introduction**
  - Tevatron, CDF and DØ
- **Electroweak measurements**
  - W and Z properties
  - Di-boson production
- **Top physics**
  - Cross section, mass, charge
  - Single top
- **Higgs searches**
  - The SM
    - ZH → $\nu\nu bb$
    - WH → $e\nu bb$
    - WH → WWW* → $\ell^{\pm}\ell^{\pm}X$
    - H → WW* → $\ell^{+}\ell^{-}\nu\nu$
    - ttH → W(→$\ell\nu$)W(→jj)bbbb
  - SUSY
    - bh/bbh(→bb)
    - h → $\tau\tau$
- **Summary**

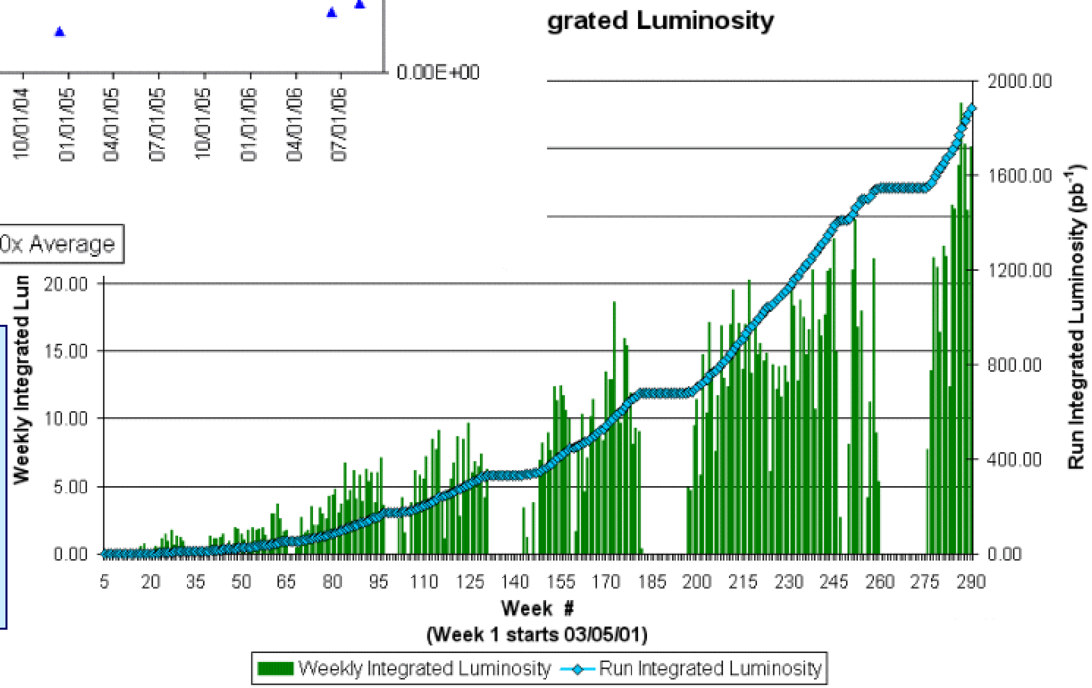


Tevatron peak and integrated luminosities, Sep ‘06



Peak luminosity of ~2.3×10^{32} $cm^{-2}s^{-1}$ so far

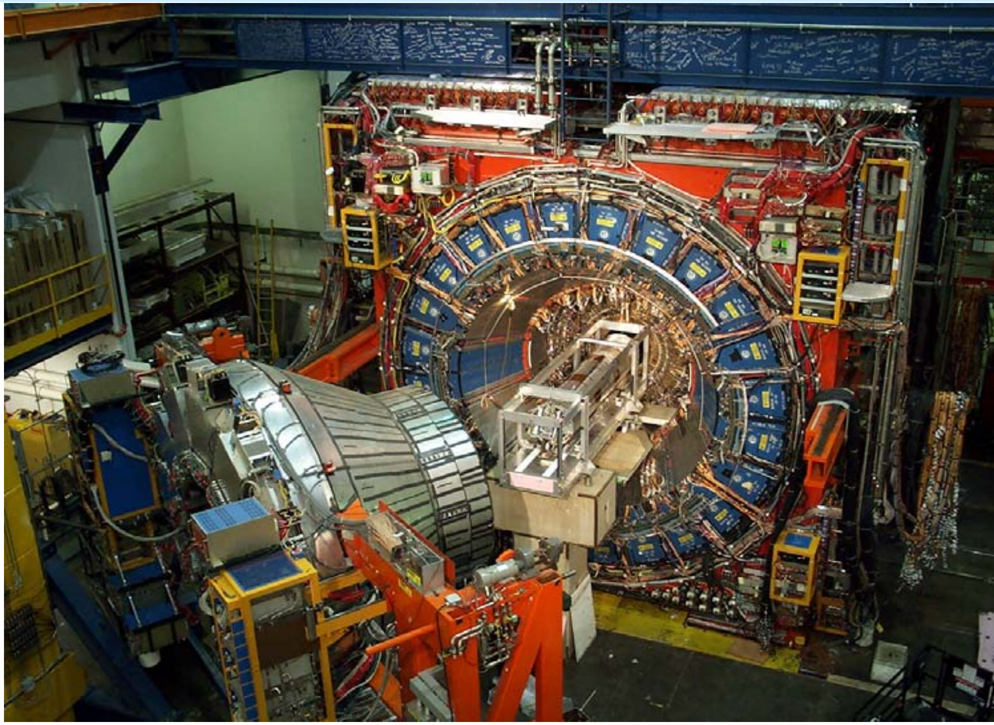
- Delivered integrated luminosity ~2 fb^{-1}
- Data set has doubled every year
- Expect 4 – 8 fb^{-1} by the end of 2009

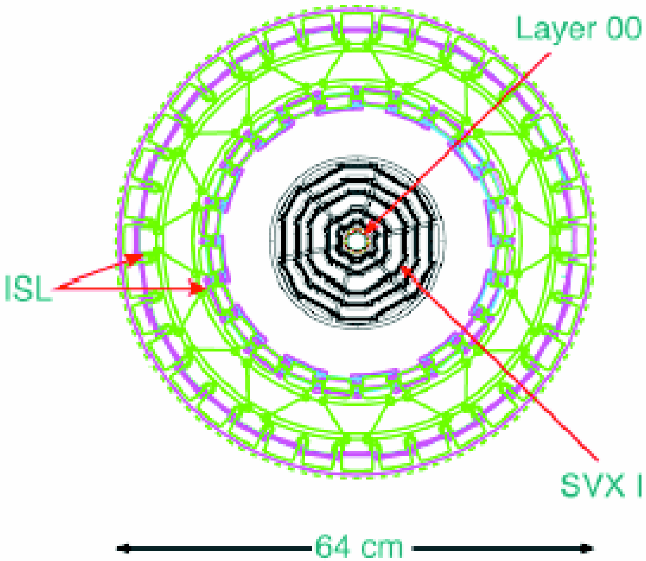


- CDF/DØ operate at ~85% efficiency
- Results in the following are based on 0.3 – 1 fb^{-1} of data

The upgraded CDF II

- Major upgrades for Run II:
  - Drift chamber: COT
  - Silicon: SVX, ISL, L00 at r ~ 1.5 cm
    - 8 layers
    - 700 k readout channels
    - 6 m^2
    - material:15% X_0
  - Forward calorimeters
  - Forward muon system
    - Improved central muon system
  - Time-of-flight
  - Preshower detector
  - Timing in EM calorimeter
  - Trigger and DAQ



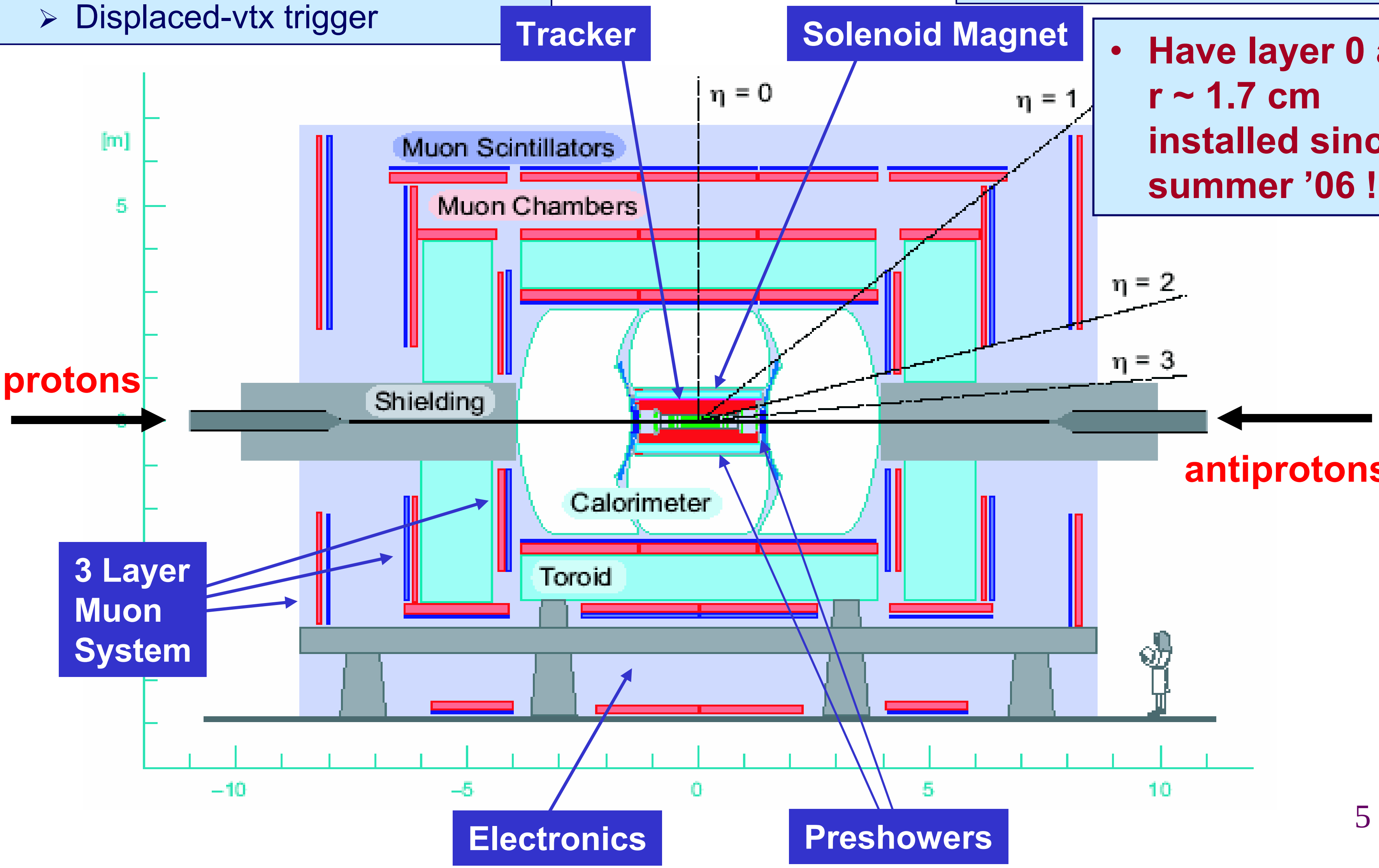


The upgraded DØ detector in Run II

- Upgraded
  - Muon system, cal. electronics
  - DAQ, (track) trigger system
  - Displaced-vtx trigger

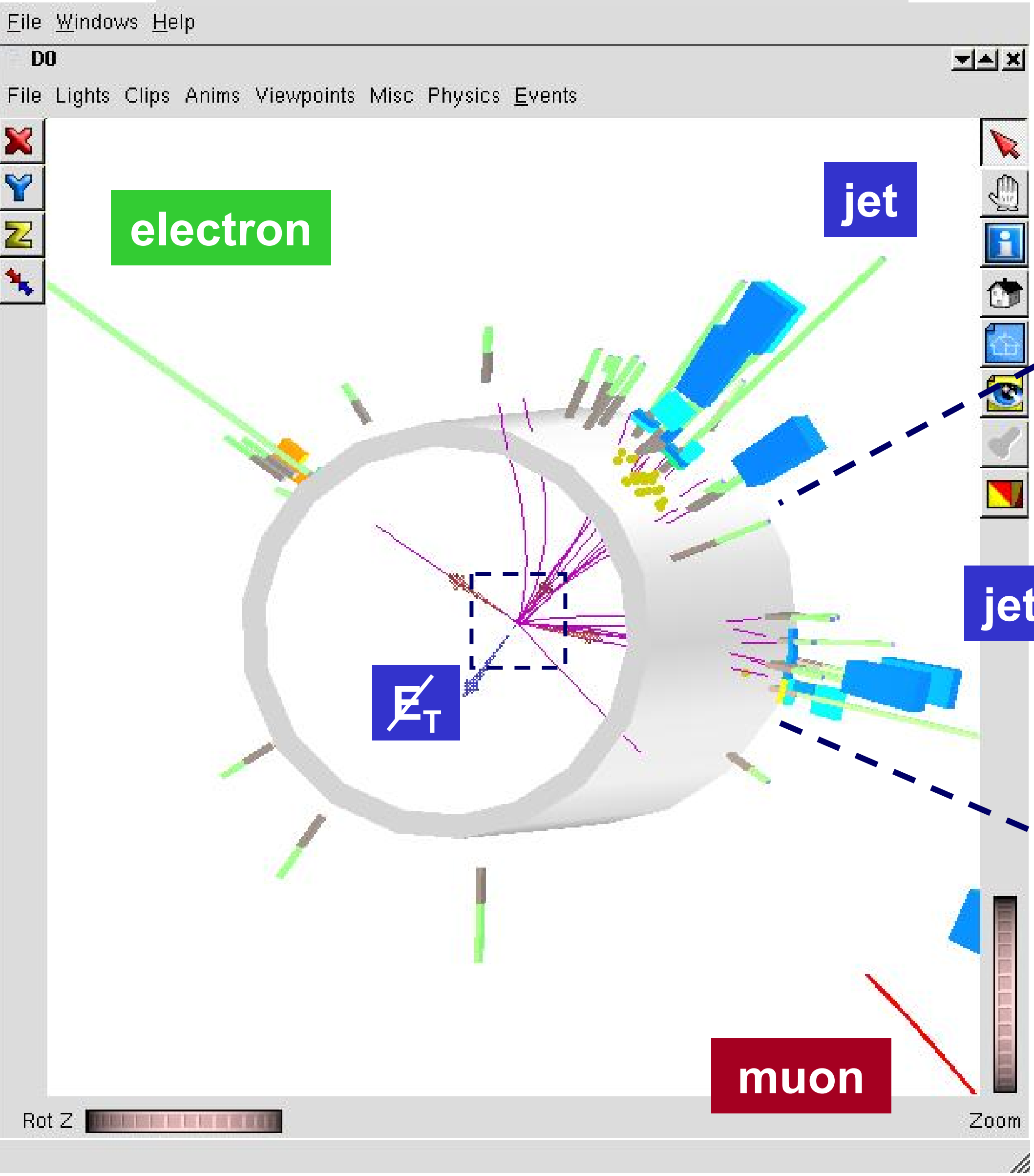
- New (tracking in B-field)
  - Silicon detector
  - Fiber tracker

- **Have layer 0 at r ~ 1.7 cm installed since summer ’06 !**

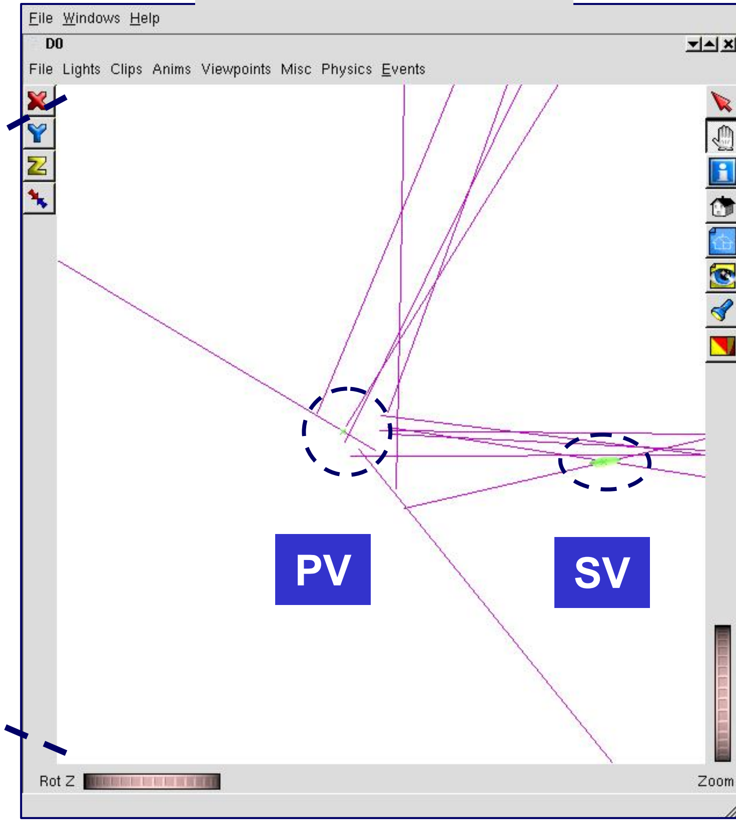


… and how it works

Run / event: 169261 / 6854840



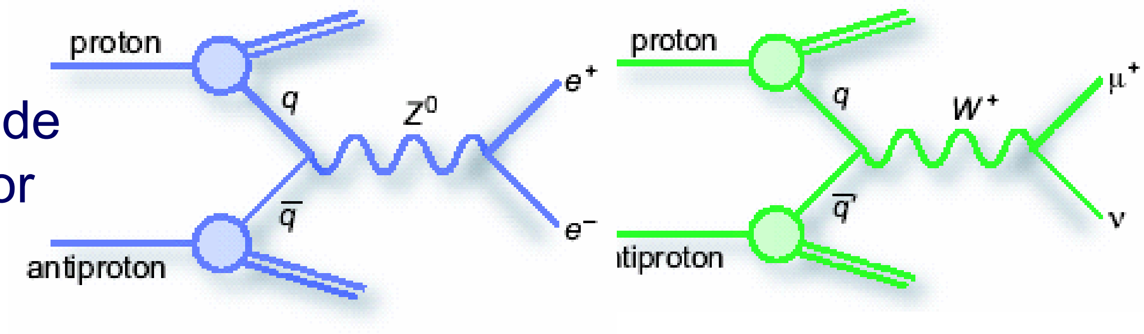
Two b-tagged jets



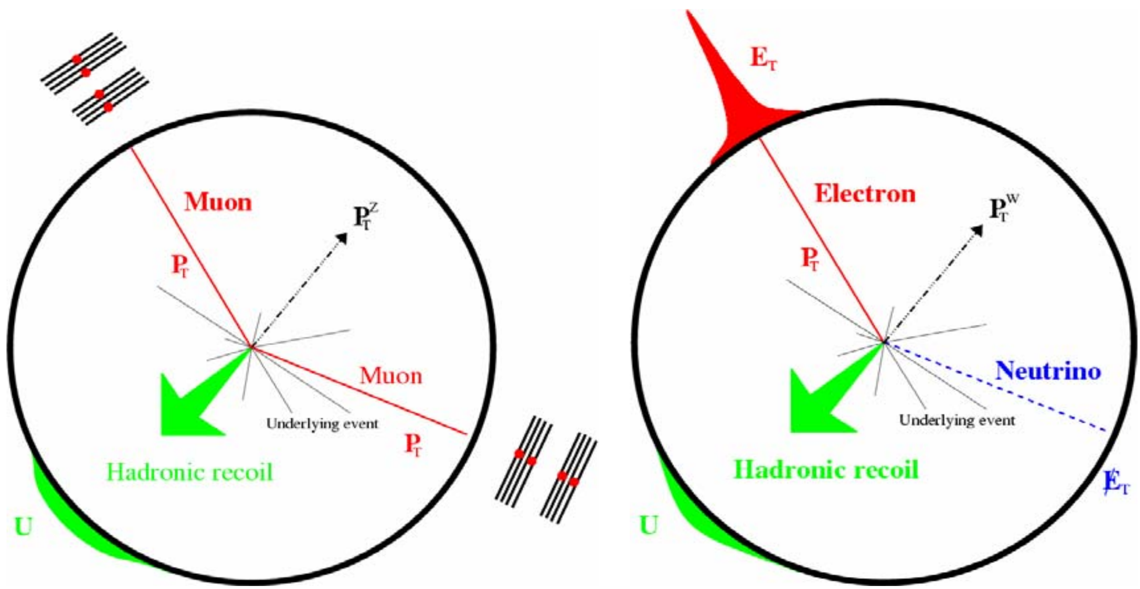
Electroweak measurements

W and Z bosons

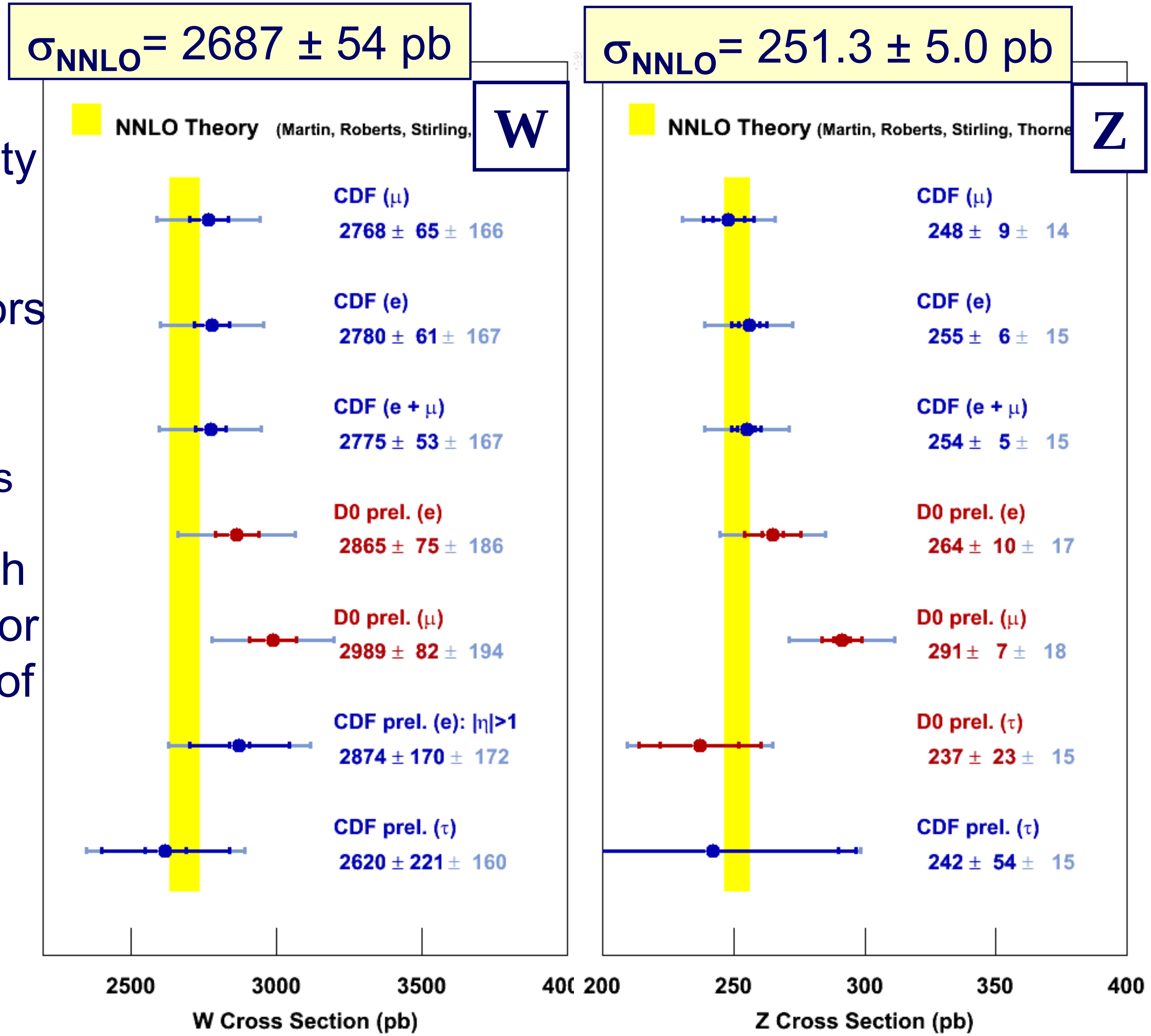
- Along with many interesting physics topics, W and Z provide excellent calibration signals for
  - Electron energy scale
  - Track momentum scale
  - Lepton ID & trigger efficiencies
  - Missing E_T resolution
  - Luminosity



- Z selection
  - Two isolated leptons with $E_T > 20$ GeV
  - Electron, muon, tau
- W selection
  - One isolated lepton with $E_T > 20$ GeV
  - Large missing E_T>20 GeV due to escaping neutrinos



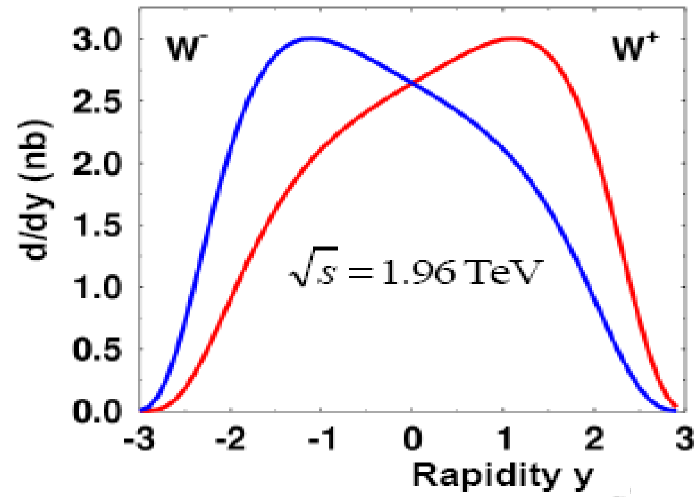
W and Z production cross section



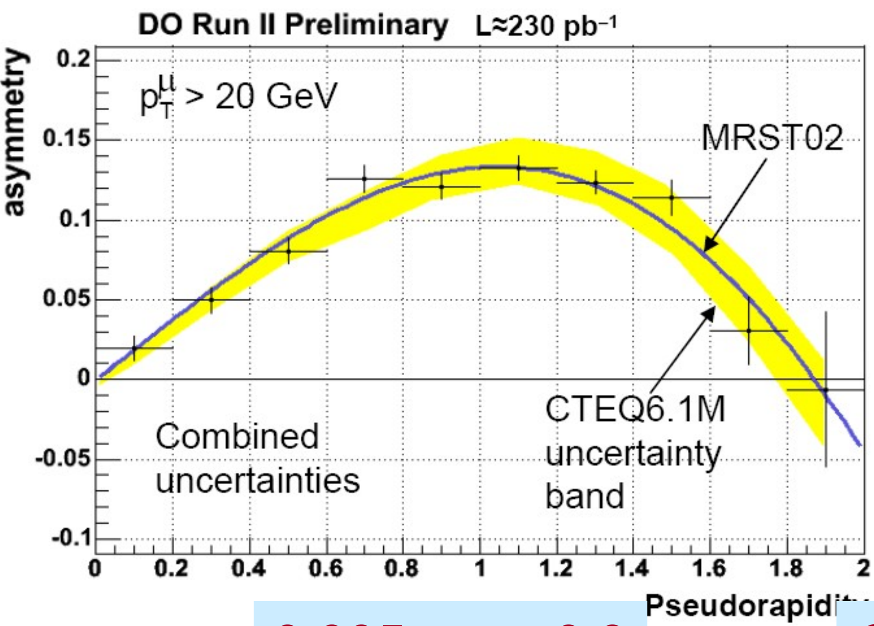
- Uncertainty on luminosity ~ 6% is dominant
- Other experimental errors ~ 2%
  - Comparable in size to theoretical calculations
- Is theory reliable enough to use W/Z production for absolute normalization of luminosity ?

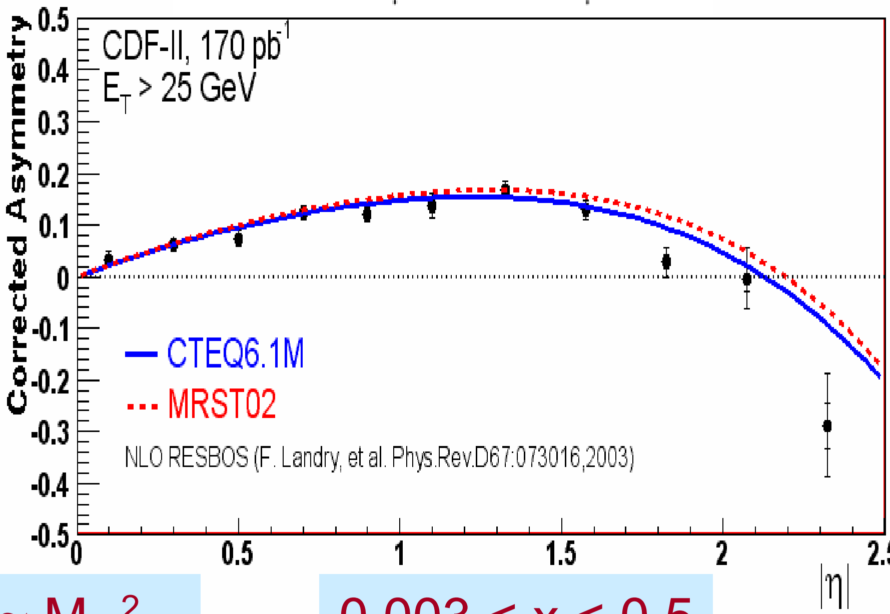
W charge asymmetry

- Typically the u quark carries more of the proton momentum → W^+ is boosted in the direction of the proton
- **DØ:** Isolated μ, $p_T > 20$ GeV in $|\eta| < 2$, $E_T^{miss} > 20$ GeV, $M_T > 40$ GeV
- **CDF:** Isolated e, $p_T > 25$ GeV in $|\eta| < 2.5$, $E_T^{miss} > 25$ GeV, $50 < M_T < 100$ GeV
- Charge mis-id ~ 0.01% (μ) and ~ 1% (e)



$$A(y_\mu) = \frac{N_{\mu^+}(y_\mu) - N_{\mu^-}(y_\mu)}{N_{\mu^+}(y_\mu) + N_{\mu^-}(y_\mu)}$$





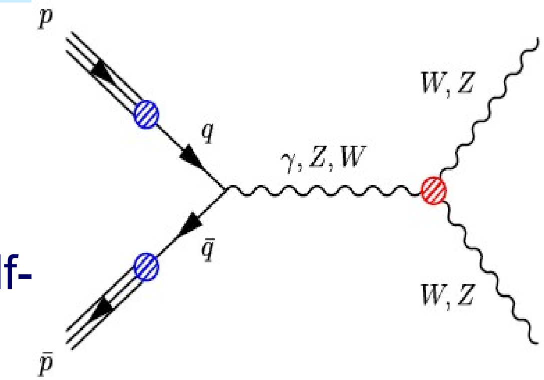
0.005 < x < 0.3

$Q^2 \sim M_W^2$

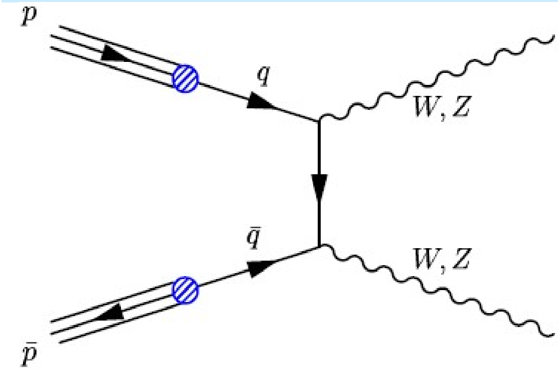
0.003 < x < 0.5

Di-boson production

- Measure cross sections and anomalous couplings
  - Probe non-Abelian nature of $SU(2)_L \otimes U(1)_Y$ gauge boson self-interactions
  - Rate inconsistent with the SM expectation would indicate new physics



s-channel



t-channel

$$q\bar{q}' \to W^{(*)} \to W\gamma : WW\gamma \text{ only}$$
$$q\bar{q}' \to W^{(*)} \to WZ : WWZ \text{ only}$$
$$q\bar{q} \to Z/\gamma^{(*)} \to WW : WW\gamma, WWZ$$
$$q\bar{q} \to Z/\gamma^{(*)} \to Z\gamma : ZZ\gamma, Z\gamma\gamma$$
$$q\bar{q} \to Z/\gamma^{(*)} \to ZZ : ZZ\gamma, ZZZ$$

Absent in SM

- Excursions from the SM can be described via effective Lagrangian:

$$L_{WWV}/g_{WWV} = g_V^1 (W_{\mu\nu}^+ W^\mu V^\nu - W_\mu^+ V_\nu W^{\mu\nu}) + \kappa_V W_\mu^+ W_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2} W_{\lambda\mu}^+ W_\nu^\mu V^{\nu\lambda}$$

where $V = Z, \gamma$

- In SM:

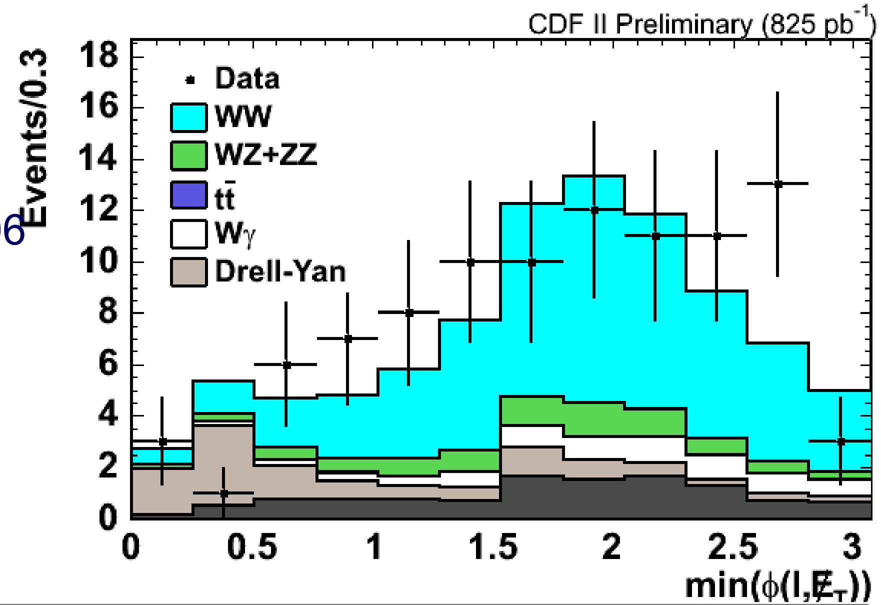
$$g_V^1 = \kappa_V = 1, \quad \lambda_V = 0$$

- Determine deviation from SM values:

$$\Delta g_V^1 = g_V^1 - 1, \quad \lambda_V, \quad \Delta\kappa_V = \kappa_V - 1$$

CDF: WW → ℓℓ + E_T^{miss} cross cection

- Event selection
  - 2 opposite-sign leptons, e/μ, $p_T > 20$ GeV
  - Missing transverse energy, MET > 25 GeV
  - If both leptons are same flavor and $76 < M_{\ell\ell} < 106$ GeV → require MET/√(ΣE_T) > 3.0
  - Δφ (MET, nearest ℓ) > 0.3 if MET < 50 GeV
  - No jets with E_T> 15 GeV in |η| < 2.5
- Observe 95 events; expect 52.4 ± 4.3 WW and 37.8 ± 4.8 bkgd. events

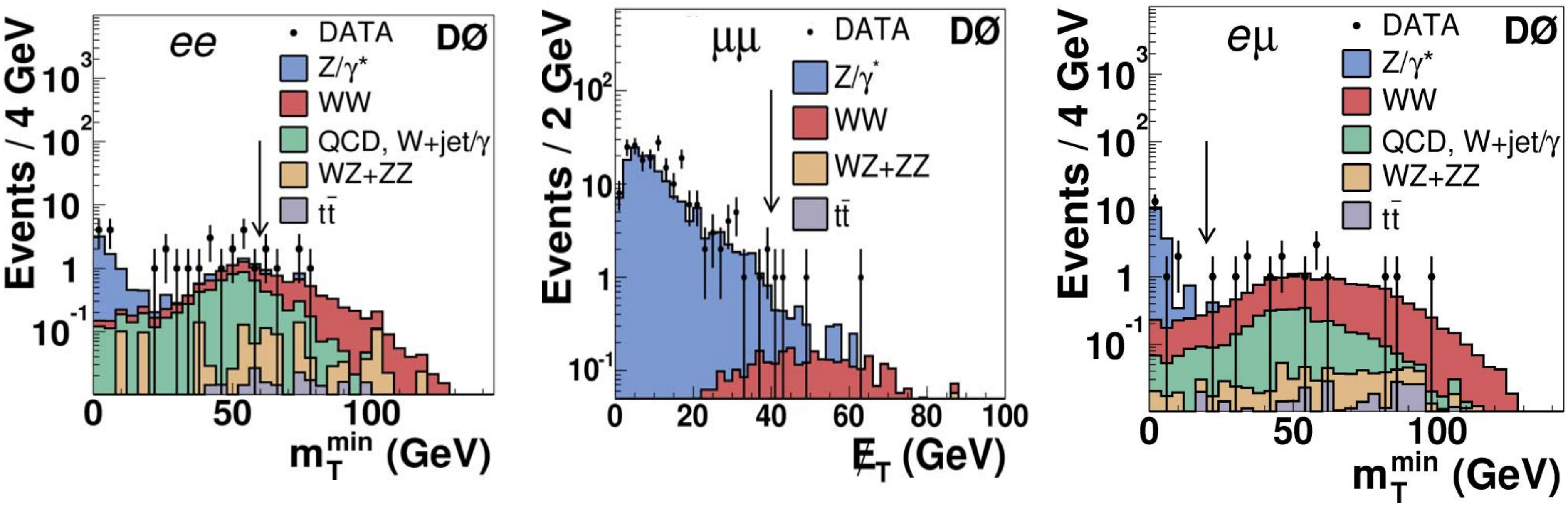


Mode	ee	$e\mu$	$\mu\mu$	ll
WW	12.8 ± 0.1 ± 1.1	28.8 ± 0.1 ± 2.4	10.7 ± 0.1 ± 0.9	52.4 ± 0.1 ± 4.3
Drell-Yan	5.0 ± 0.5 ± 1.3	3.8 ± 0.4 ± 1.0	3.0 ± 0.4 ± 0.8	11.8 ± 0.8 ± 3.1
$t\bar{t}$	0.1 ± 0.0 ± 0.0	0.1 ± 0.0 ± 0.0	0.0 ± 0.0 ± 0.0	0.2 ± 0.0 ± 0.0
$WZ+ZZ$	3.6 ± 0.0 ± 0.4	0.9 ± 0.0 ± 0.1	3.4 ± 0.0 ± 0.3	7.9 ± 0.0 ± 0.8
$W\gamma$	3.6 ± 0.1 ± 0.7	3.2 ± 0.1 ± 0.7	0.0 ± 0.0 ± 0.0	6.8 ± 0.2 ± 1.4
W+jets	3.0 ± 0.2 ± 0.7	6.7 ± 0.4 ± 2.0	1.3 ± 0.2 ± 0.5	11.0 ± 0.5 ± 3.2
Sum Bkg	15.2 ± 0.6 ± 1.7	14.8 ± 0.6 ± 2.3	7.8 ± 0.4 ± 1.0	37.8 ± 0.9 ± 4.7
Expected	28.0± 0.6 ± 2.0	43.7± 0.6 ± 3.3	18.5± 0.4 ± 1.3	90.2± 0.9 ± 6.4
Data	29	47	19	95

σ = 13.6 ± 2.3 (stat) ± 1.6 (sys) ± 1.2 (lumi) pb

DØ: WW → ℓℓ + E_T^{miss} cross section

- Look for two oppositely charged leptons, e/μ plus missing E_T
- DØ and CDF selection for WW signal are similar
- Found 25 (6 ee, 4 μμ, 15 eμ) candidates in ~ 240 pb^{-1}
- Expected bkgd 8.1 ± 0.6 (stat) ± 0.6 (sys) ± 0.5 (lumi)
- First 5.2σ observation of WW production at the Tevatron



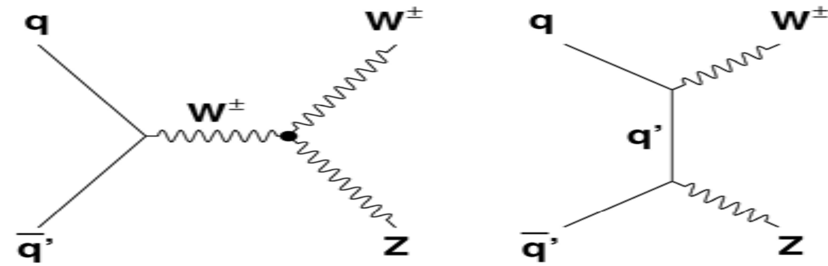
$\sigma(WW) = 13.8\ ^{+4.3}_{-3.8}(\text{stat})\ ^{+1.2}_{-0.9}\ (\text{sys}) \pm 0.9\ (\text{lumi})$ pb

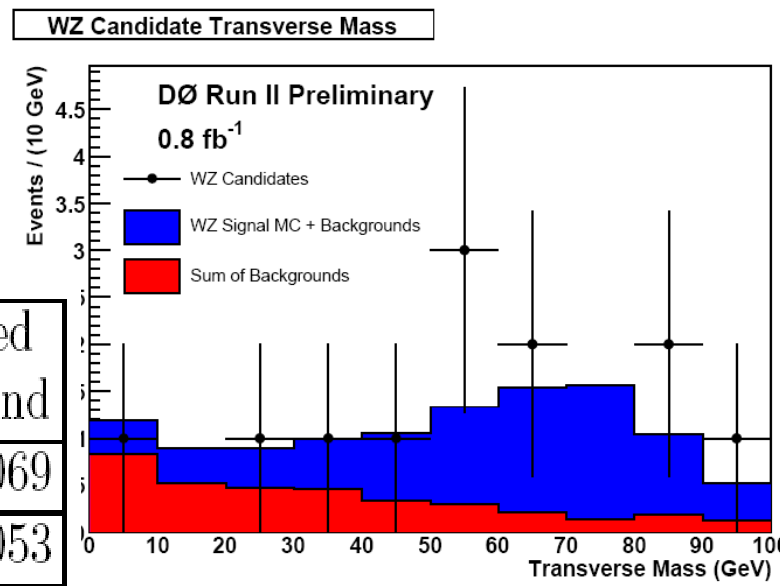
$-0.32 < \Delta\kappa < 0.45$
$-0.29 < \lambda < 0.30$

- Both CDF/DØ measurements consistent with the SM

DØ: WZ → 3ℓ (ℓ=e,μ) production

- Direct probe of the WWZ trilinear coupling
- Select 2 leptons ee/μμ, $p_T > 15$ GeV
- $E_T^{miss} > 20$ GeV
- Additional high p_T lepton
- Reject top events by $E_T^{HAD} < 50$ GeV
- Instrumental bkgd: Z+j from data
- Physics bkgd: ZZ, top, W+DY





Decay Channel	Number of Candidates	Overall Efficiency	Expected Signal	Estimated Background
eee	2	0.158±0.012	1.81±0.18	0.960±0.069
$ee\mu$	1	0.167±0.029	1.88±0.52	0.485±0.053
$\mu\mu e$	7	0.175±0.043	1.77±0.66	0.963±0.080
$\mu\mu\mu$	2	0.205±0.033	2.04±0.54	1.203±0.143
Total	12	-	7.5±1.36	3.61±0.20

- **First evidence at 3.3σ level for WZ production**

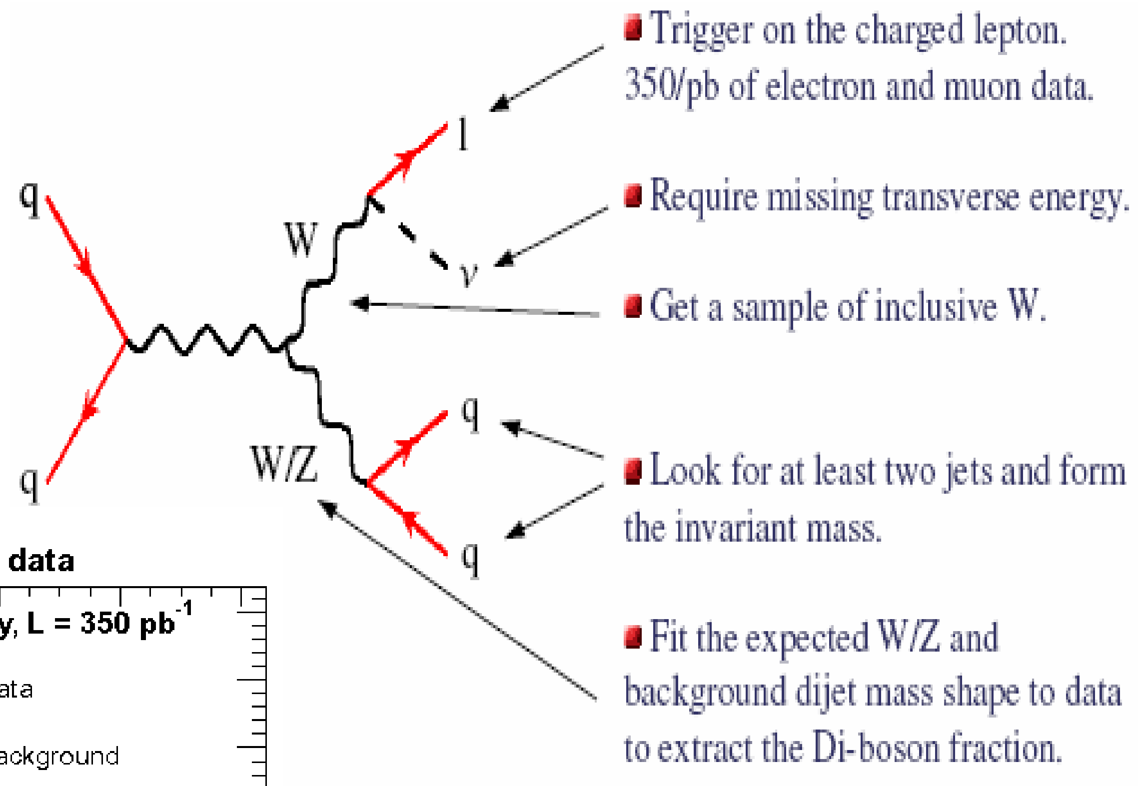
$\sigma = 3.9^{+1.9}_{-1.5}$ pb

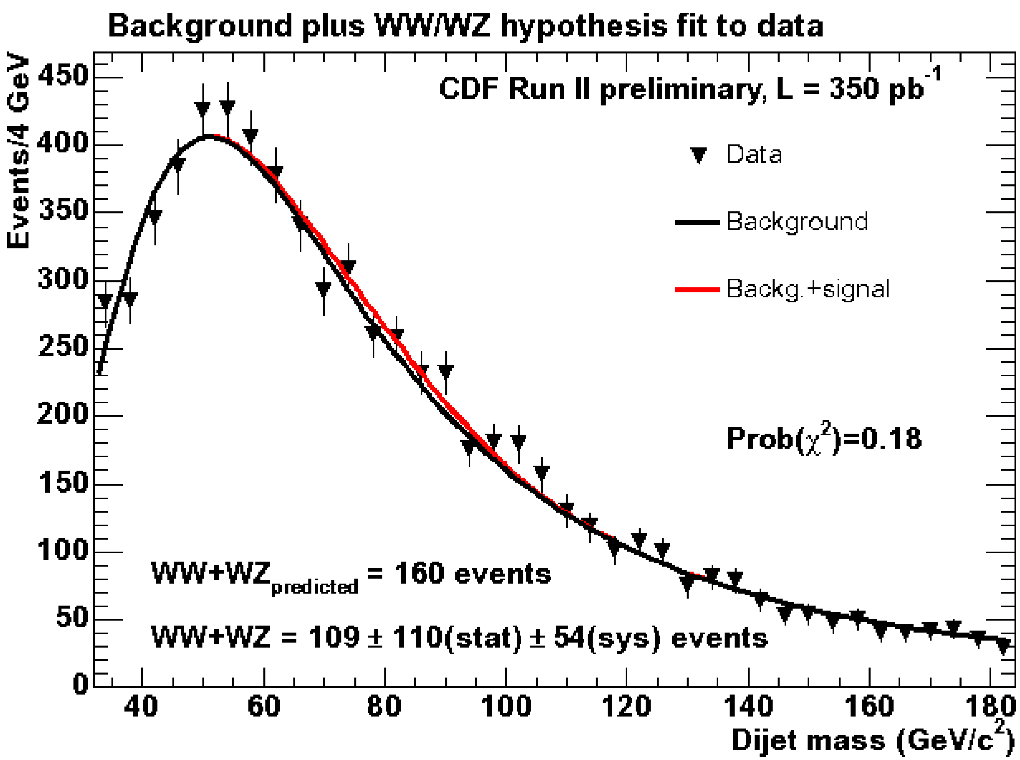
$\sigma_{SM} = 3.7 \pm 0.3$ pb

CDF preliminary with 825 pb^{-1} of data:
$\sigma < 6.35$ pb at 95% CL

CDF: WW/WZ → ℓνjj cross section

- Higher branching fraction, but large W+jets background
- Event Selection
  - Isolated Lepton p_T>25 GeV
  - $\geq$ 2 jets w/ E_T>15 GeV
  - MET > 25 GeV
  - Dijet mass 32 - 184 GeV





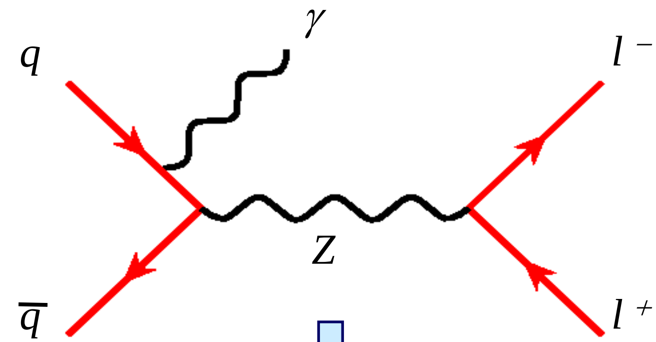
σ(WW+WZ) < 36 pb at 95% C.L.

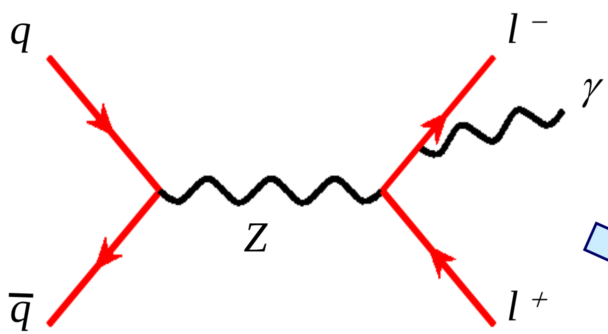
$-0.51 < \Delta\kappa < 0.44$

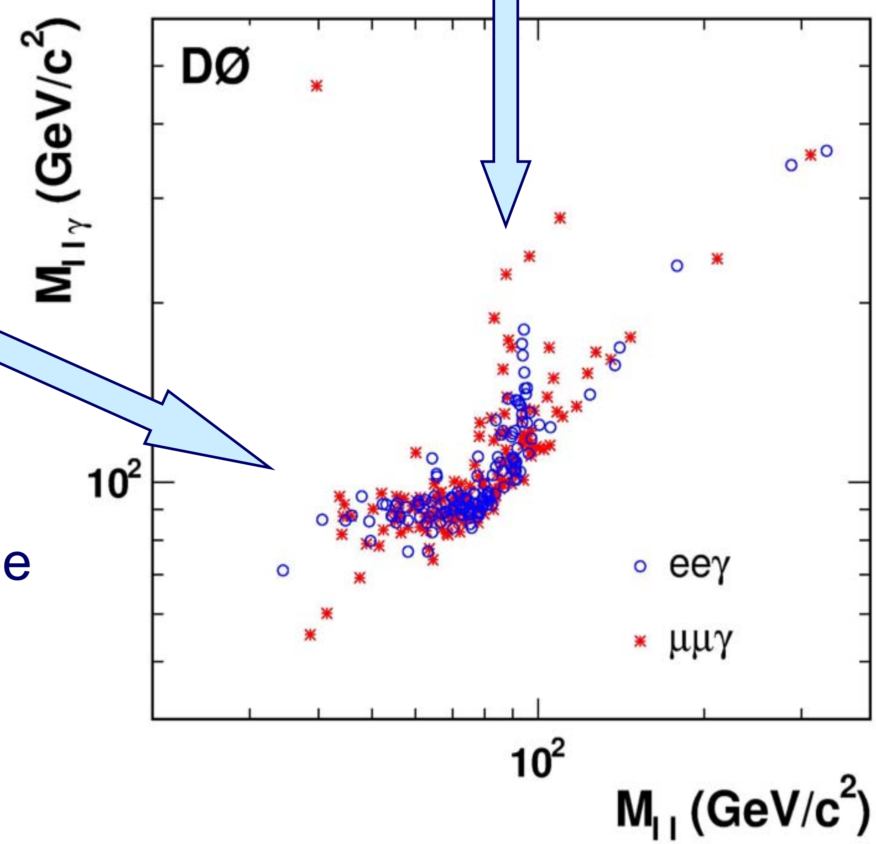
$-0.28 < \lambda < 0.28$

Zγ production

- ISR and FSR contribution at tree level, but no ZZγ or Zγγ vertices in SM







- Study final states with Z decaying to ee or μμ events containing ee/μμ + γ
- Main background from Z+jet(s) where jet mis-identified as γ
- Theoretical cross section: ~ 4 - 5 pb

Zγ production

	DØ		CDF	
Channel	eeγ	μμγ	eeγ	μμγ
$\int$ L dt, pb^{-1}	324	286	202	192
SM Zγ	109 ± 7	128 ± 8	31.3 ± 1.6	33.6 ± 1.5
Total bkgd	23.6 ± 2.3	22.4 ± 3.0	2.8 ± 0.9	2.1 ± 0.7
Observed	138	152	36	35
A×ε	11.3%	11.7%	3.4%	3.7%
σ×BR, pb	-	-	4.8±0.8±0.3	4.4±0.8±0.2

- Cross section from combined electron and muon channels

DØ:

$$\sigma((Z\to\ell\ell)\gamma,\ E_T^{\gamma}>8GeV,\ \Delta R(\ell,\gamma)>0.7)=4.2\pm0.4(stat+sys)+0.3(lumi)\ \ pb$$

SM expectation : 3.9 ± 0.2 pb

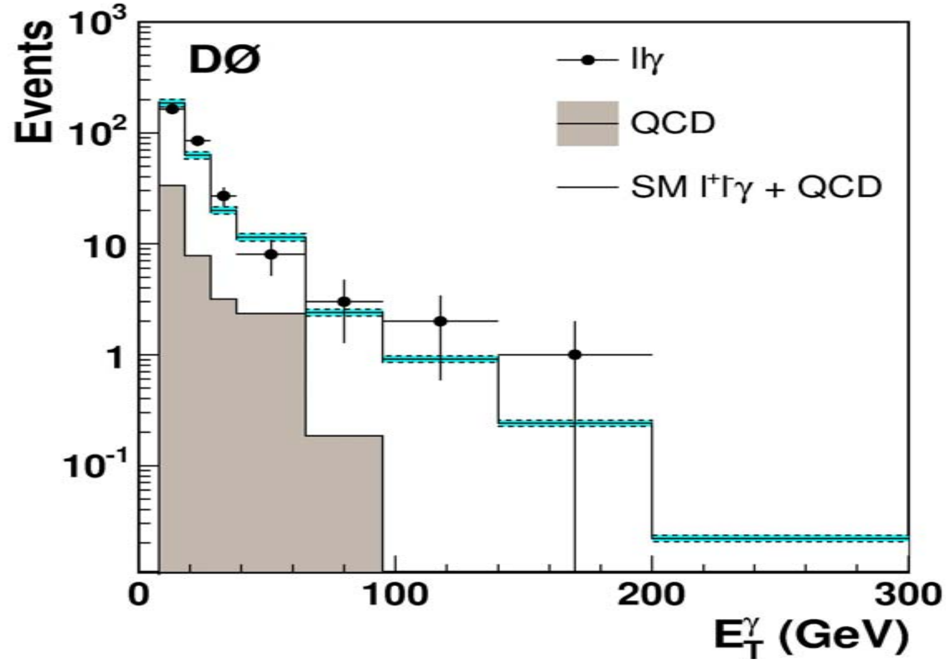
CDF:

$$\sigma((Z\to\ell\ell)\gamma,\ E_T^{\gamma}>7GeV,\ \Delta R(\ell,\gamma)>0.7)=4.6\pm0.6\,pb$$

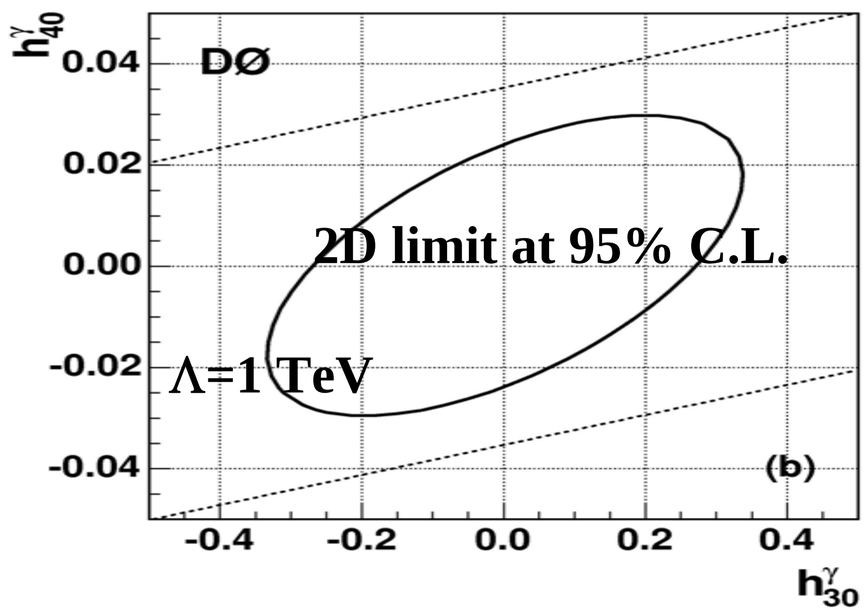
SM expectation : 4.5 ± 0.3 pb

Zγ: AC limits from DØ

- Effective Lagrangian has 8 coupling parameters:
  - h^V_{10}, h^V_{20}, h^V_{30}, h^V_{40} (V=Z,γ)
  - All of these = 0 in SM
- Photon E_T sensitive to presence of anomalous coupling



1D limits at 95% C.L. for Λ=1 TeV
$|h^{\gamma}_{10,30}| < 0.23$, $|h^{\gamma}_{20,40}| < 0.019$
$|h^{Z}_{10,30}| < 0.23$, $|h^{Z}_{20,40}| < 0.020$



- Some are most stringent limits to date

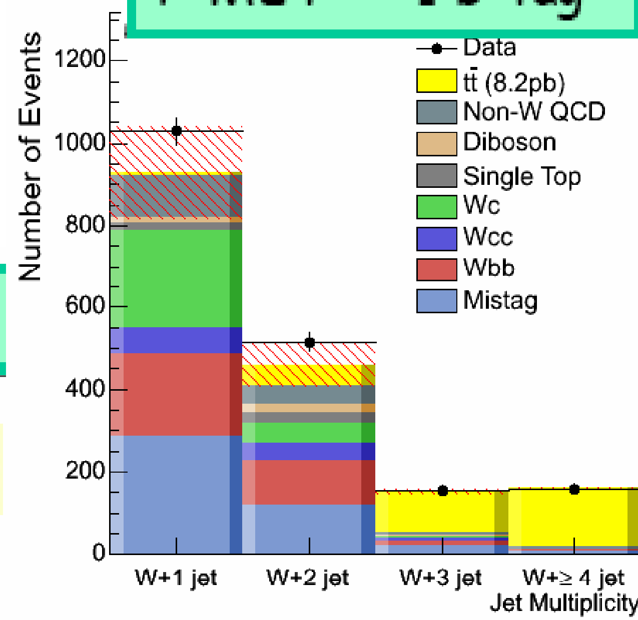
Top physics

Lepton+jets cross section

- Golden channel due to high yield and relative purity (after b-tag)
- Are used in top property measurements, single top and Higgs searches

CDF has single best results in 750 pb^{-1}

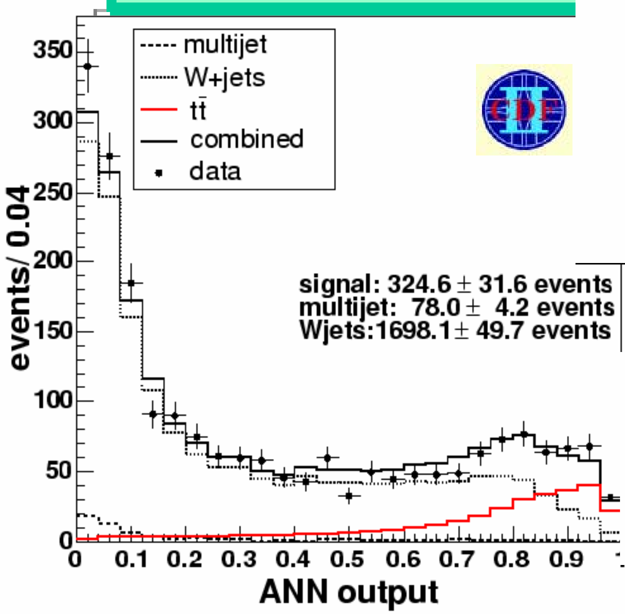
l +MET+ >=1 b-tag



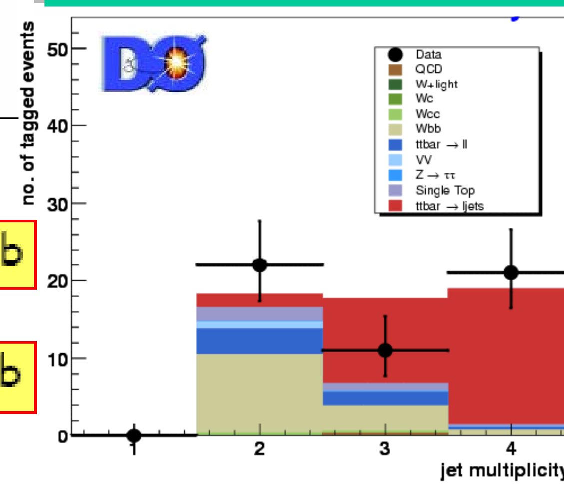
DØ has results for 370 pb^{-1} with 1 and 2 b-tags

$\sigma_{t\bar{t}}(\text{btag}) = 8.1 \pm 1.2_{stat+syst} \pm 0.5_{lumi}$ pb

l +MET+ >=3jets



l +MET+ 2 b-tag

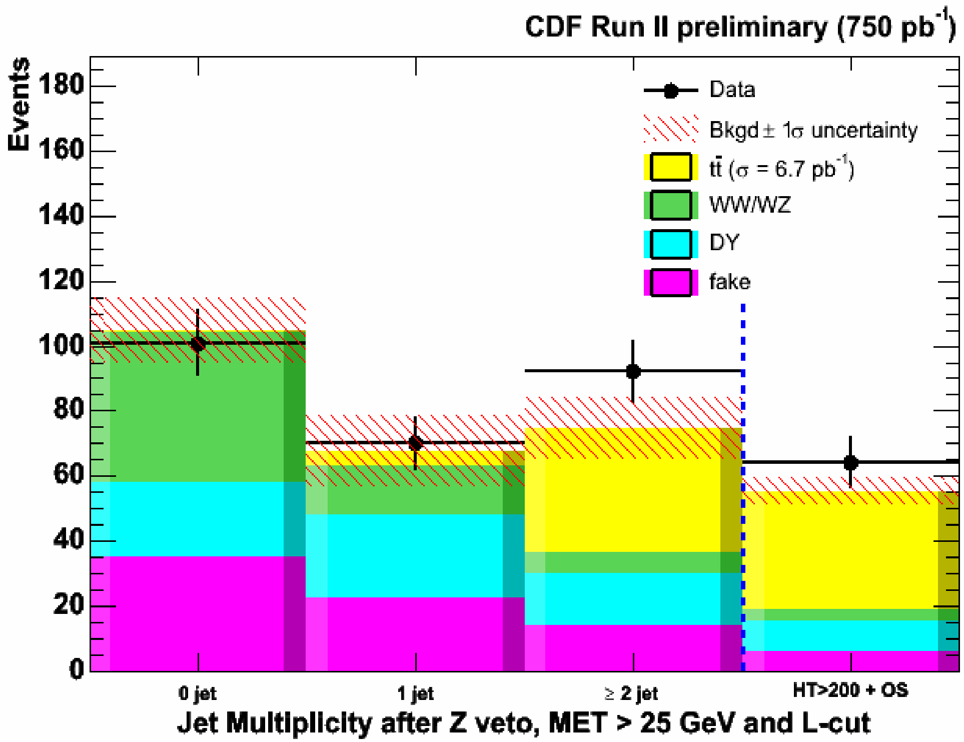


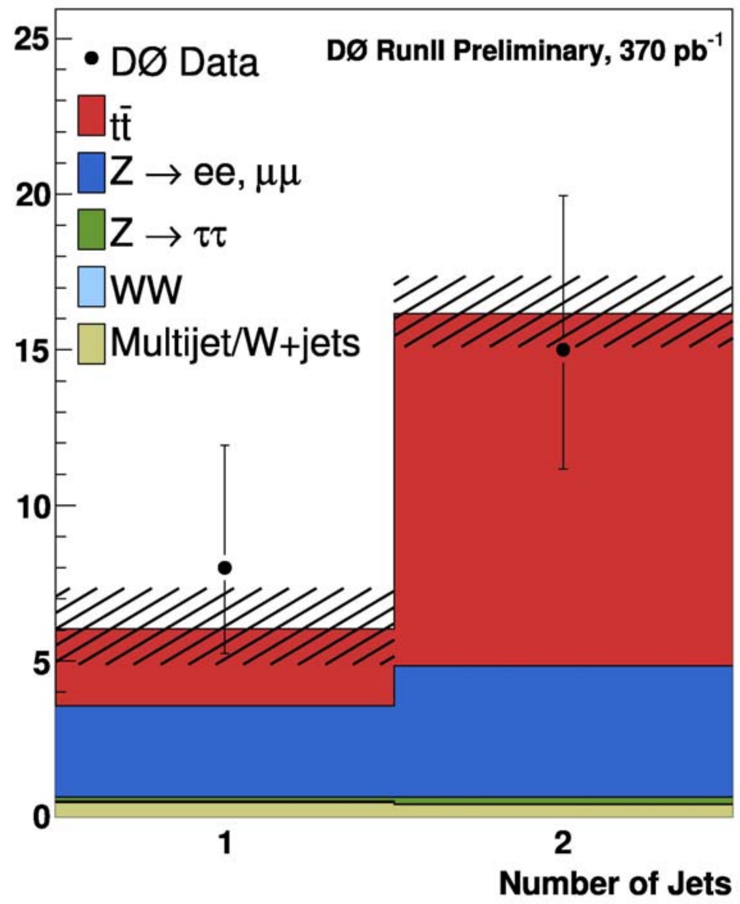
$\sigma_{t\bar{t}}(\text{btag}) = 8.2 \pm 0.6_{stat} \pm 1.0_{syst}$ pb

$\sigma_{t\bar{t}}(\text{notag}) = 6.0 \pm 0.6_{stat} \pm 1.1_{syst}$ pb

Di-lepton final states

- Signal to background ratio already good enough with ℓ + MET + ≥2 jets
- Even more pure sample with b-tagging





$\sigma_{t\bar{t}}(\text{notag}) = 8.3 \pm 1.5_{stat} \pm 1.0_{syst} \pm 0.5_{lumi}$ pb

$\sigma(t\bar{t}) = 8.6^{+1.9}_{-1.7}(\text{stat}) \pm 1.3(\text{syst})\text{pb}$

Cross section in all hadronic final states

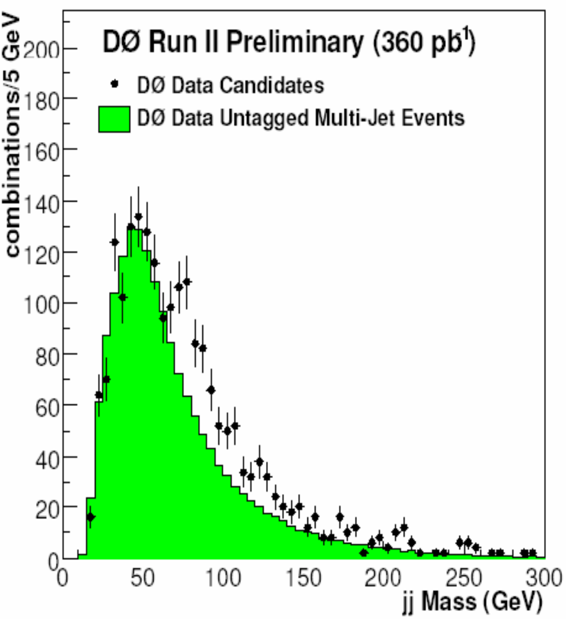
- Start from a sample ≥ 6 jets → QCD multi-jet bkgd is huge
- Combine topological selection and b-tagging
- Evaluate the background (shape) from data

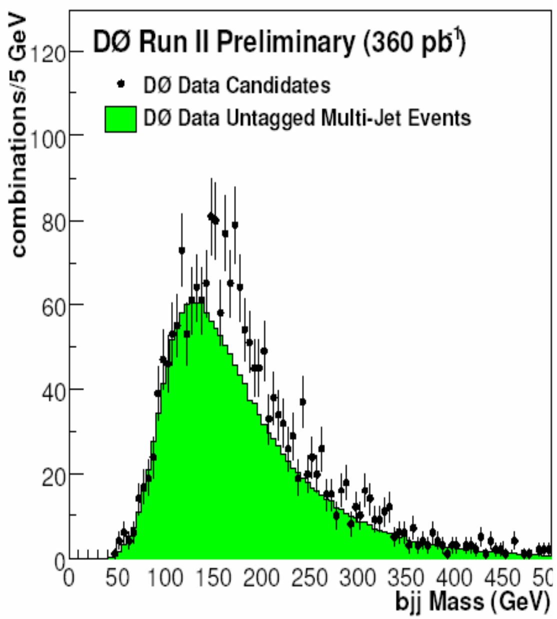
- Require 2 b-tags
- Fit the (un-tagged) di-jet and one b-tagged 3-jet distributions

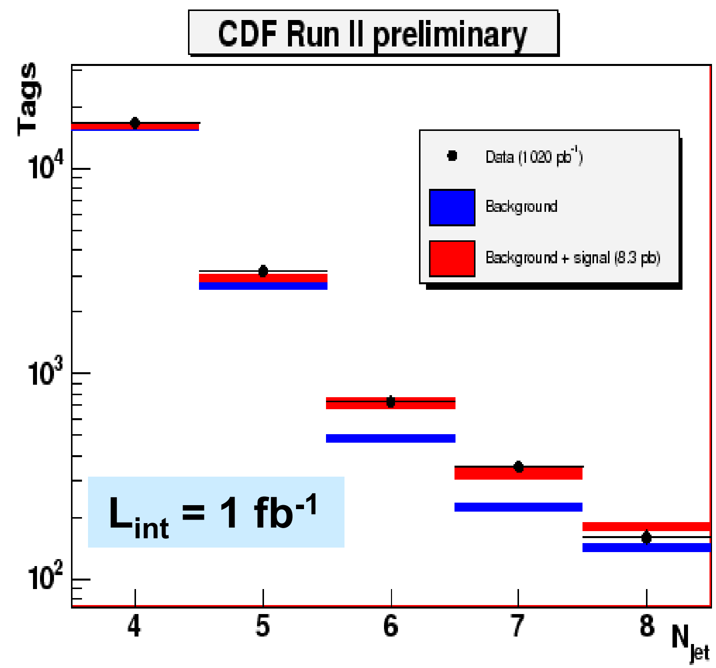
- NN discriminates between top and multi-jet bkgd
- Control in pre-tag sample and 4- and 5-jet bins

$\sigma = 12.1 \pm 4.9\ (stat) \pm 4.6\ (sys)$ pb

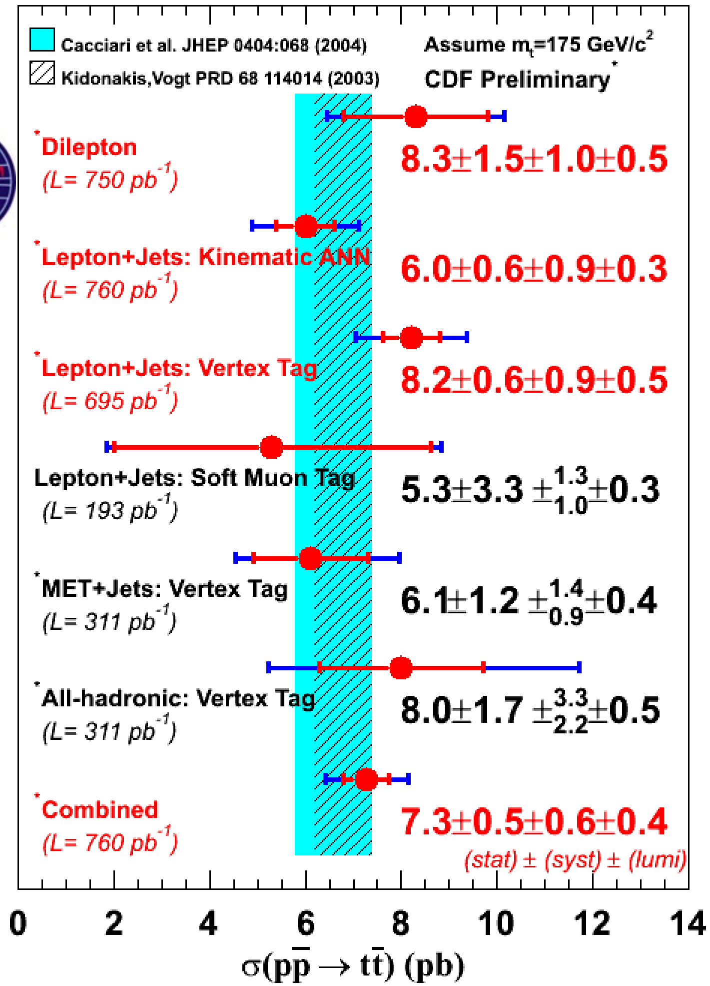
$\sigma = 8.3 \pm 1\ (stat)^{+2}_{-1.5}(sys) \pm 0.5\ (lumi)$ pb

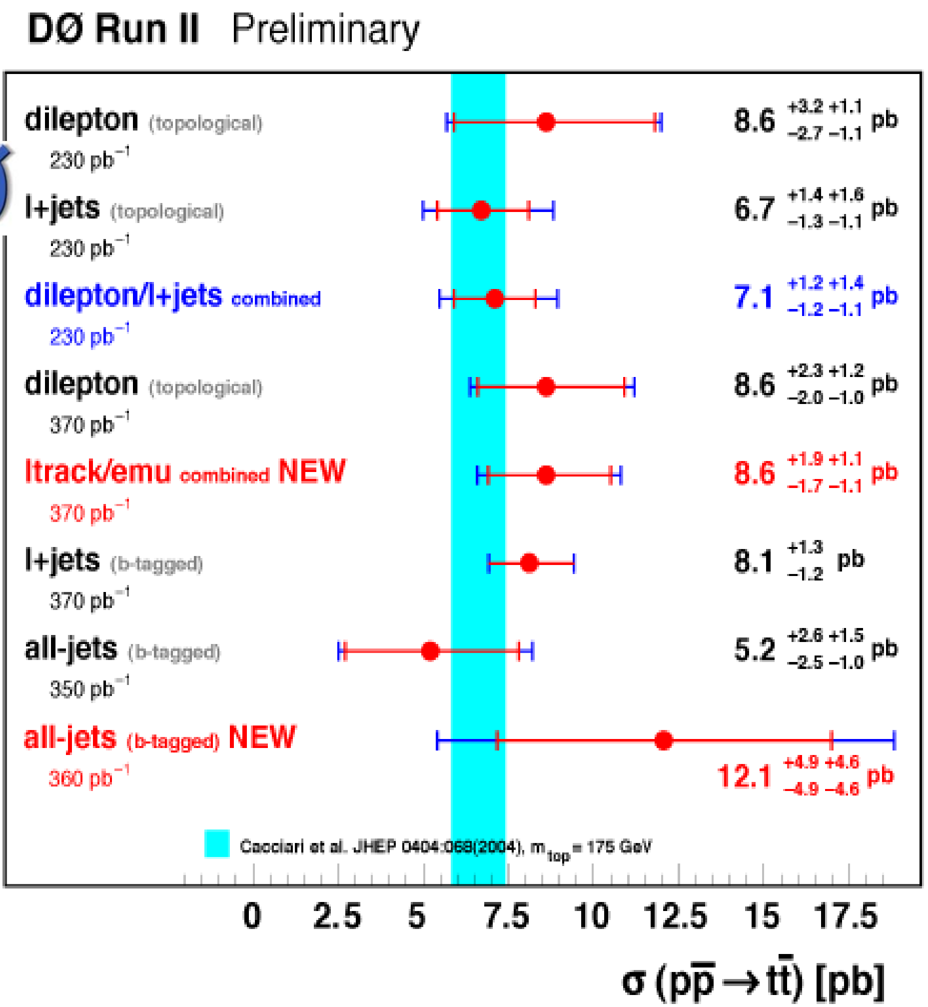






tt cross section summary





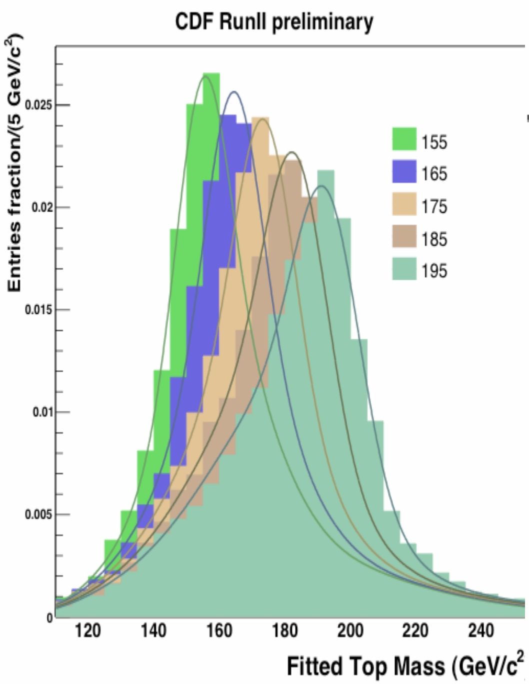
- Different channels and techniques all in agreement
- Precision at 14%. No combined result as of yet

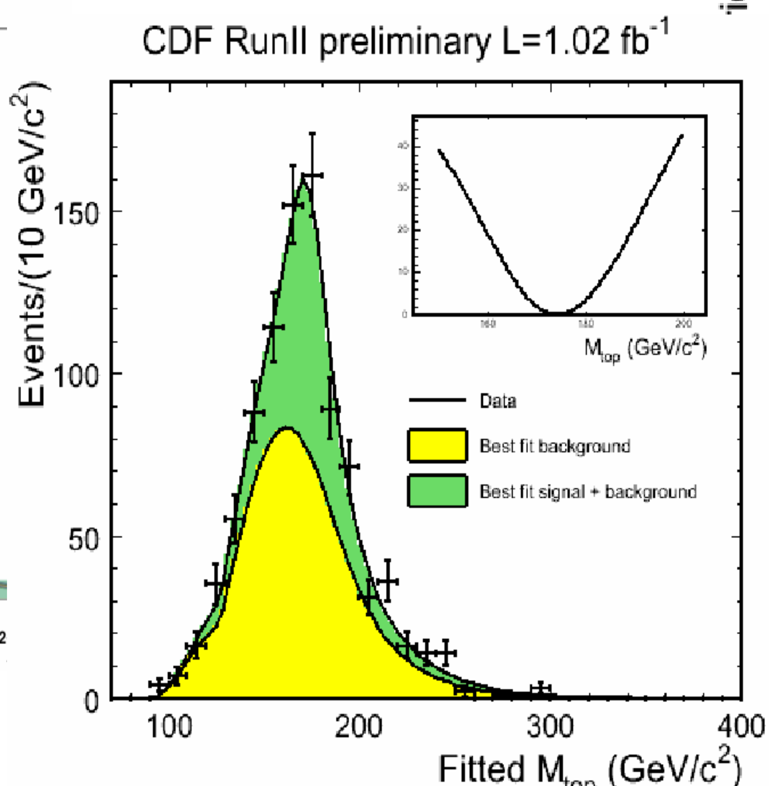
Tevatron goal: 10% uncertainty/experiment with 2 fb^{-1}

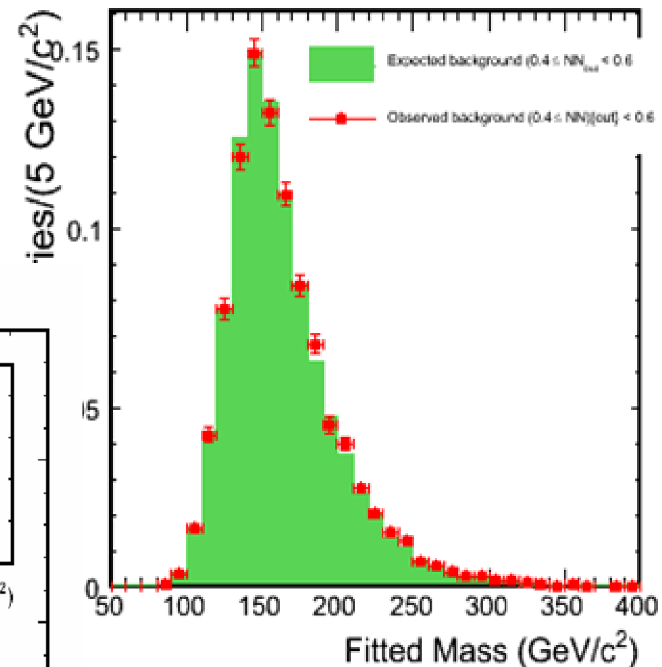
CDF: top mass in all-jets final state

- Critical to keep background under control
  - S/B ≈ 1/2
  - Check it in bkgd enriched regions
- Use templates for the signal and bkgd shapes

Background control
0.4 < NN < 0.6





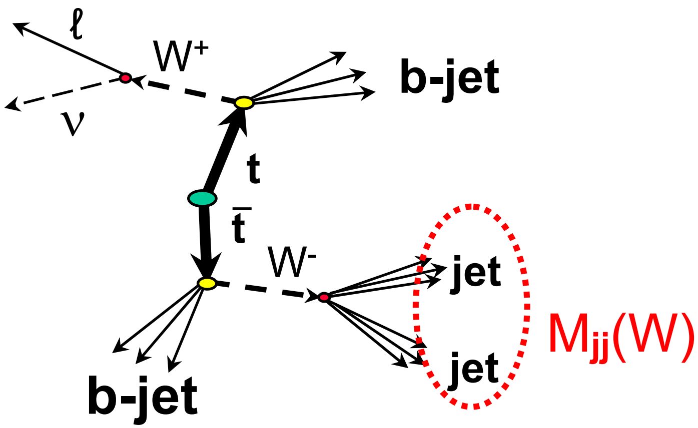


L_{int} = 1.02 fb^{-1}
772 events

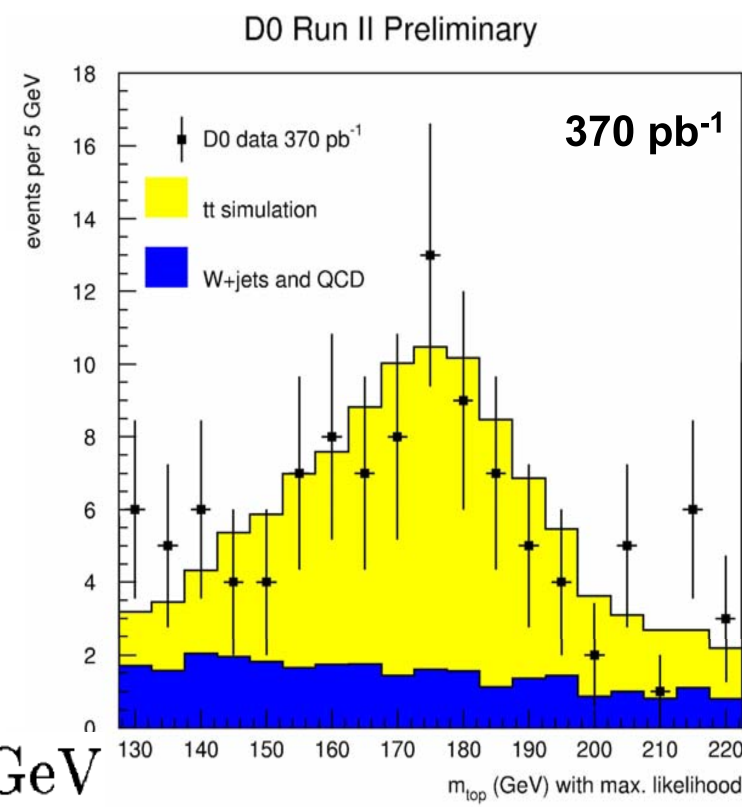
m_{top} = 174.0 ± 2.2 (stat) ± 4.8 (sys) GeV/c^2

DØ: top mass in ℓ+jets channel using ideogram method

- Method
  - Calculate a likelihood for each event based on kinematic fit that includes all possible jet assignments and probability that an event is signal or background
- Use b-tag information when available
- In situ calibration of JES using jets from W
- Selections
  - Lepton p_T > 20 GeV, MET > 20 GeV, ≥4jets with p_T > 20 GeV and $|\eta|$ < 2.5



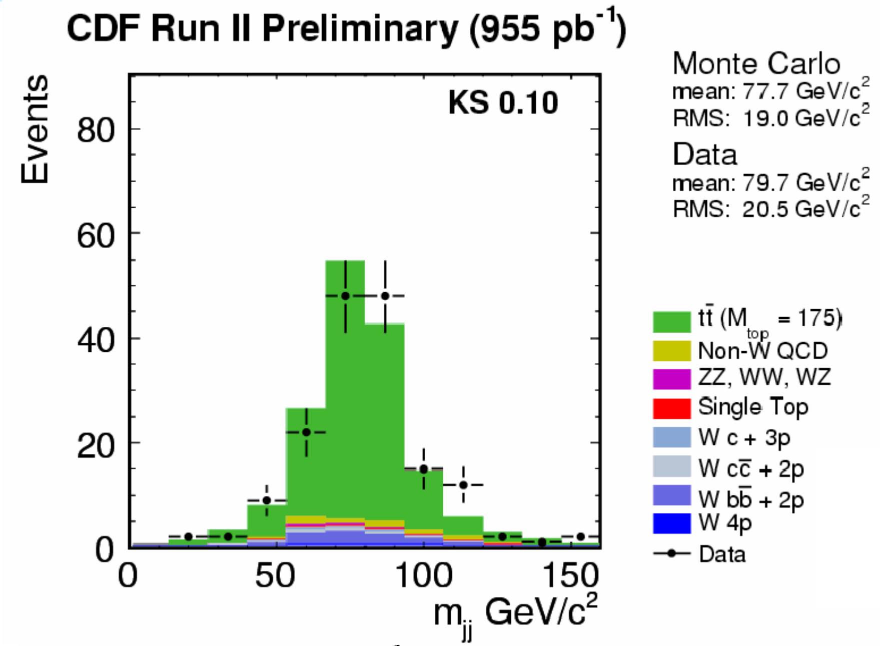
	electron+jets	muon+jets
no. of events observed in data	116	114
estimated sample composition:		
$t\bar{t}$	61.5 ± 8	45.6 ± 8
W+jets	35.6 ± 5	63.0 ± 8
QCD	18.9 ± 3	5.4 ± 1

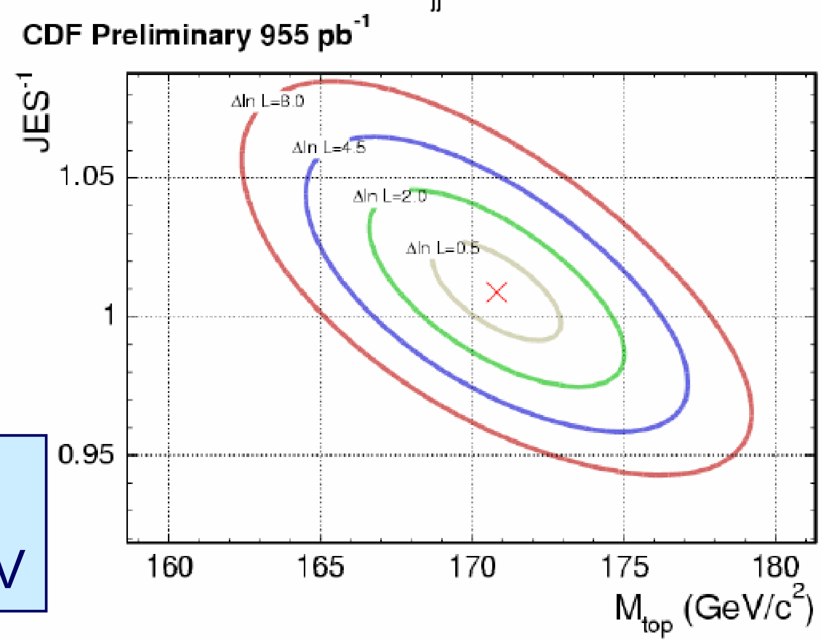


$$m_t = 173.7 \pm 4.4\ (\text{stat} + \text{JES})^{+2.1}_{-2.0}\ (\text{syst})\ \text{GeV}$$

CDF: top mass in ℓ+jets channel using ME method

- Matrix Element method
  - Calculate likelihood for each event using LO ME for tt and W+jets diff. cross section and parameterized parton showering
- Select events with ≥1 b-tag
  - Signal/Background = 4/1
- One unknown, three constraints
  - Overconstrained
- Add jet energy scale as the 2nd unknown and fit for it
  - Obtain ΔJES = 0.99 ± 0.02
  - Consistent with a priori knowledge
  - Uncertainty only 2% !





Single most precise measurement:

m_{top} = 170.9 ± 2.2 (stat+JES) ± 1.4 (sys) GeV

Top mass in di-lepton final states

- Underconstrained system
  - 2 neutrinos, 18 kinematic quantities
  - 14 measured + 3 constraints

Both experiments use (among others)

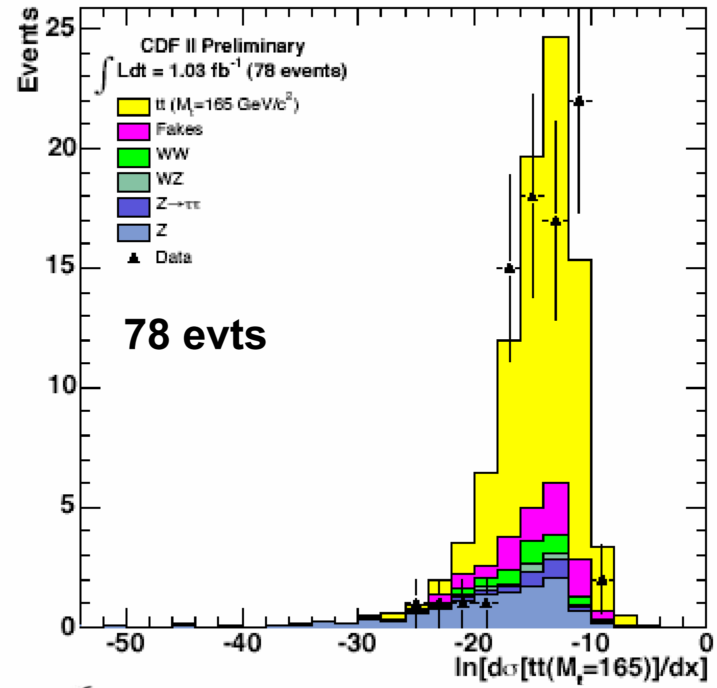
- ME technique
  - Calculate event-by-event signal probability curve (rather than single m_{rec}) using decay matrix element and transfer functions
- Neutrino weighting technique
  - Start by ignoring observed missing E_T, assume top mass and η for each ν and extract ν 4-momenta. Weight each solution

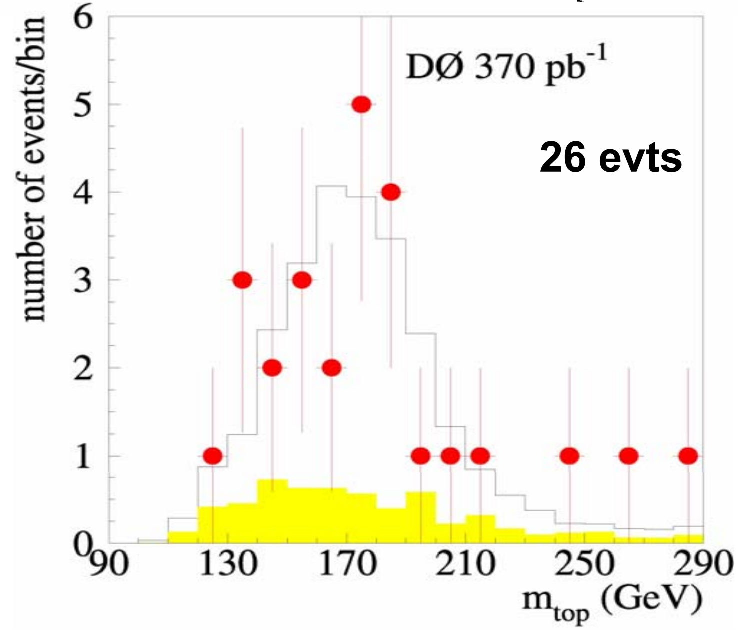
CDF's best result with ee, eμ and $\mu\mu$:

m_{top}=164.5±3.9 (stat) ±3.9 (sys) GeV

DØ's resent with ee, eμ, $\mu\mu$ and ℓ+track:

m_{top}= 178.1±6.7 (stat) ±4.8 (sys) GeV





Top mass summary (July 2006)

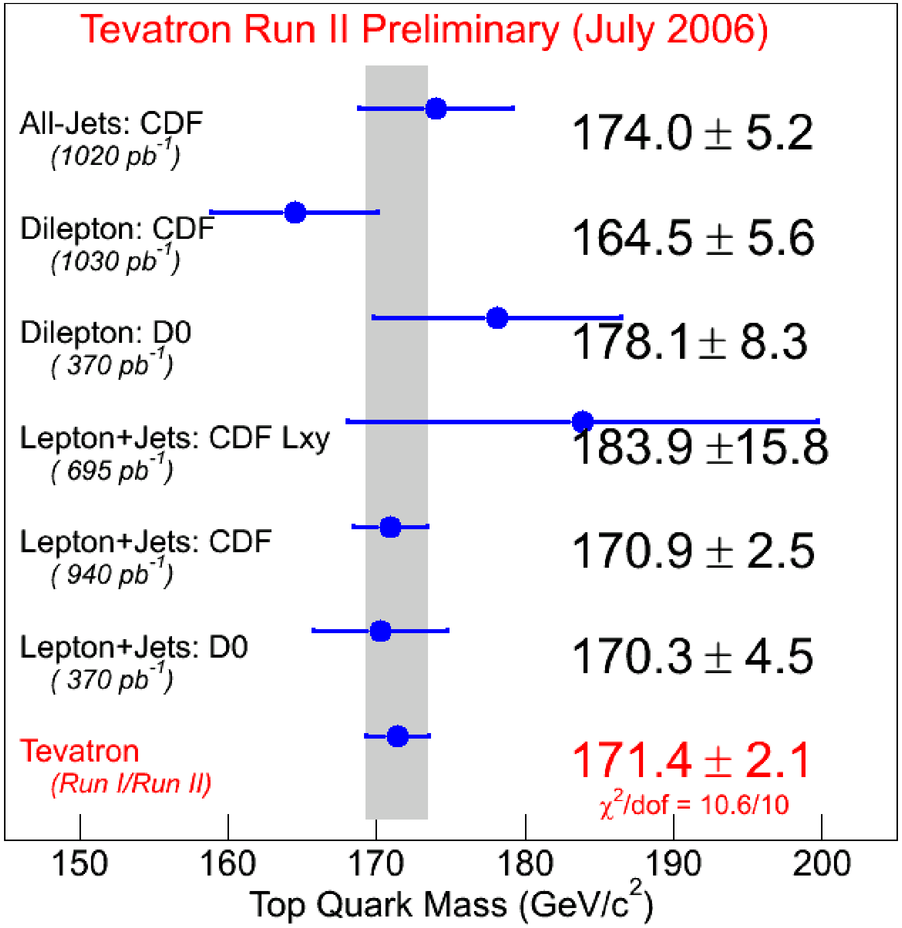
- Excellent results in each channel
- Combine CDF + D0, Run I + Run II
- Account for all correlations
- m_{top} = 171.4 + 2.1 GeV
- Uncertainty:

  δm_{top}(stat) = $\pm$1.2 GeV

  δm_{top}(JES) = $\pm$1.4 GeV

  δm_{top}(syst) = $\pm$1.0 GeV

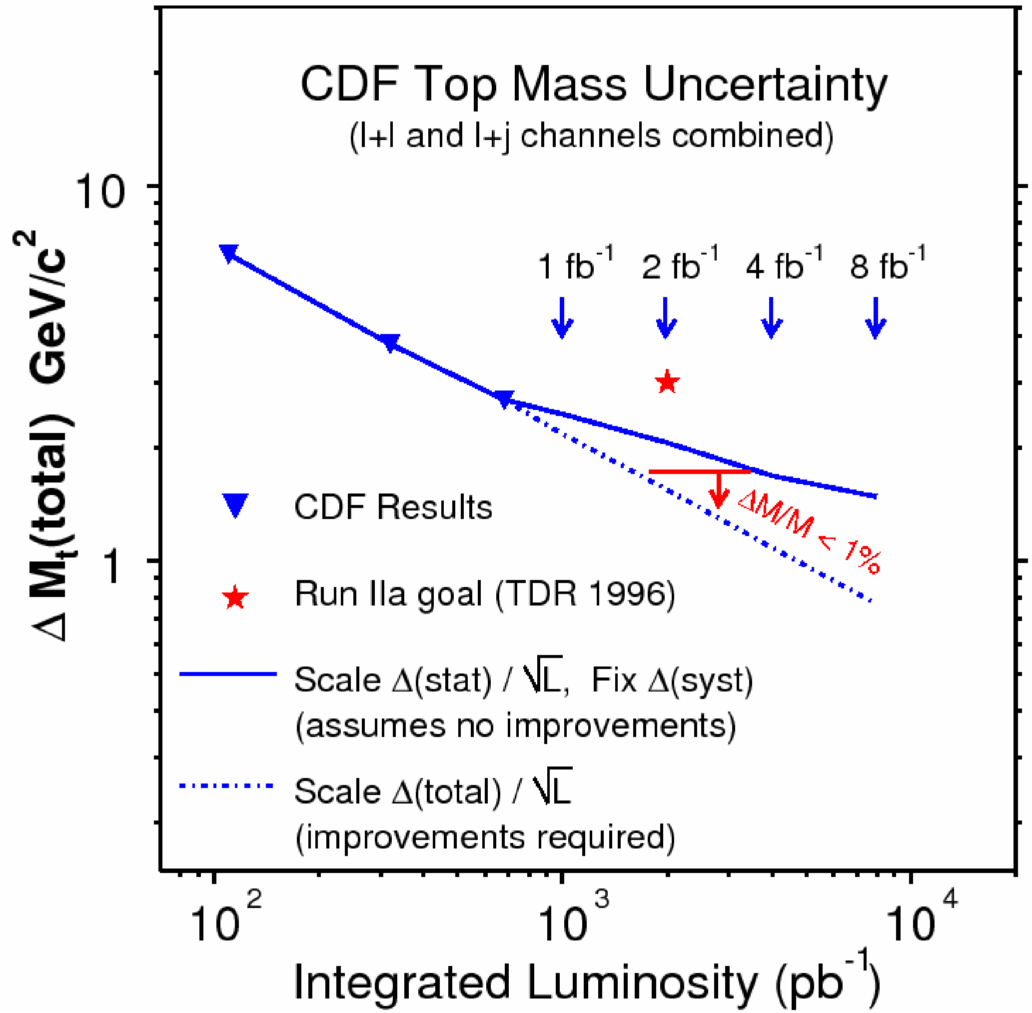
- Contributing factors
  - ISR, FSR, bkgd evaluation, PDF, NLO effects, b-tagging
- Jet Energy Scale is the leading systematic in all channels



m_{top} determined to 1.2% !

Top mass: prospects

- Extrapolations based on present methods
  - Solid: pessimistic
  - Dash: optimistic
  - Reality: in between
- Have surpassed Run II goal
- The top mass at the Tevatron will be measured with < 1% precision



DØ: top quark charge

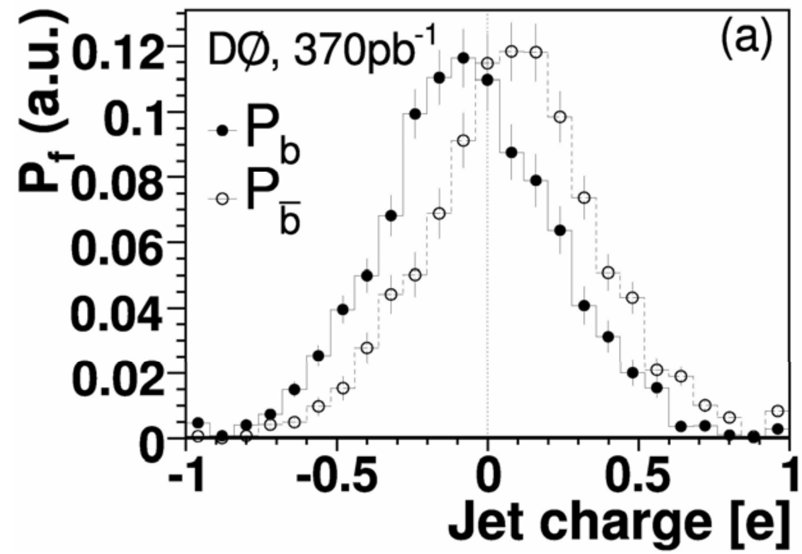
- t → Wb could mean top has charge – 4/3
- Jet charge estimator

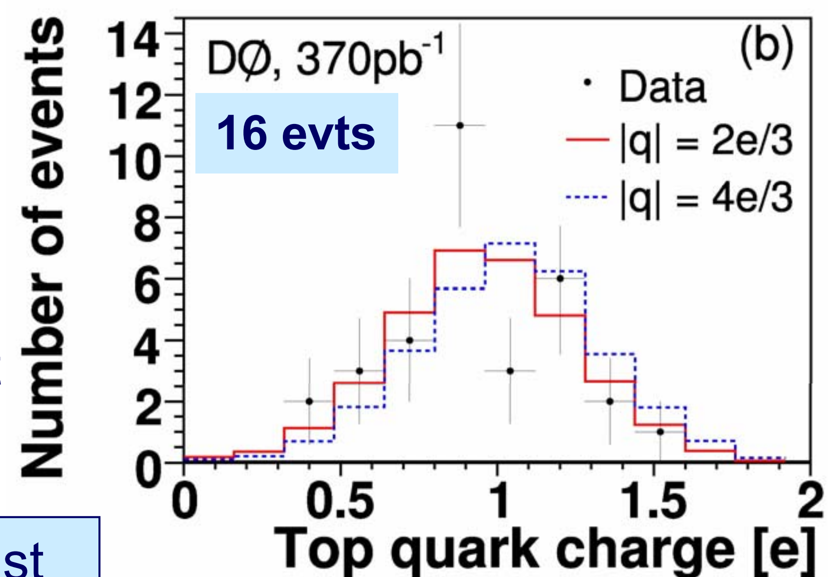
$$q_{\text{jet}} = \frac{\sum q_{\text{track}} * p_T^{0.6}}{\sum p_T^{0.6}}$$

- b/c jet charge distributions derived from data → use them in simulations
- ℓ+jet sample of double b-tag tt candidates
  - Use kinematic/mass constraint fit to pair lepton with the correct b jet
- Have two entries per event:

$Q_1 = |q_\ell + q_{b\ell}|$ ← leptonic side of the evt

$Q_2 = |-q_\ell + q_{bh}|$ ← hadronic side of the evt

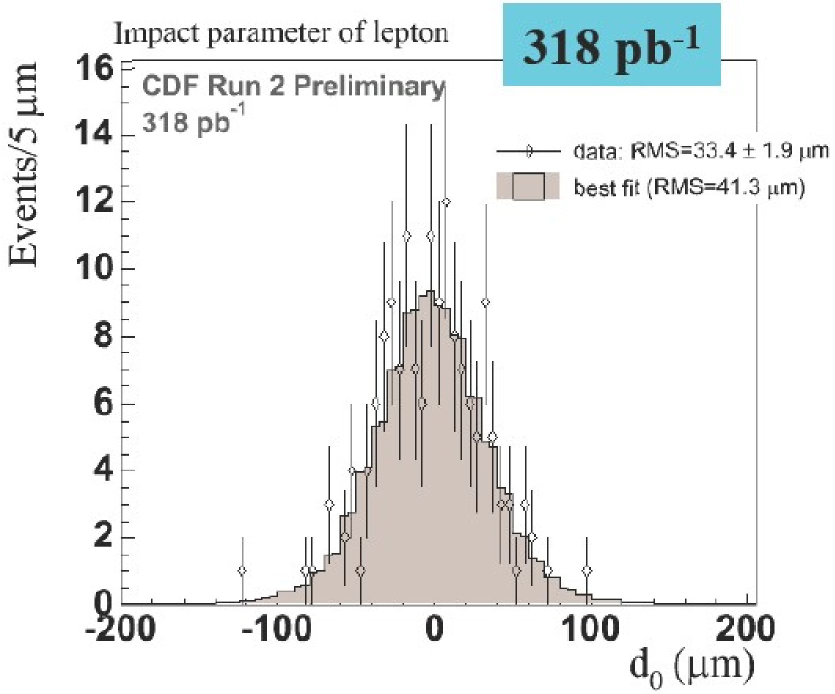




Exclude at 92% CL that the sample consist of only QQ pairs with charge |q| = 4e/3

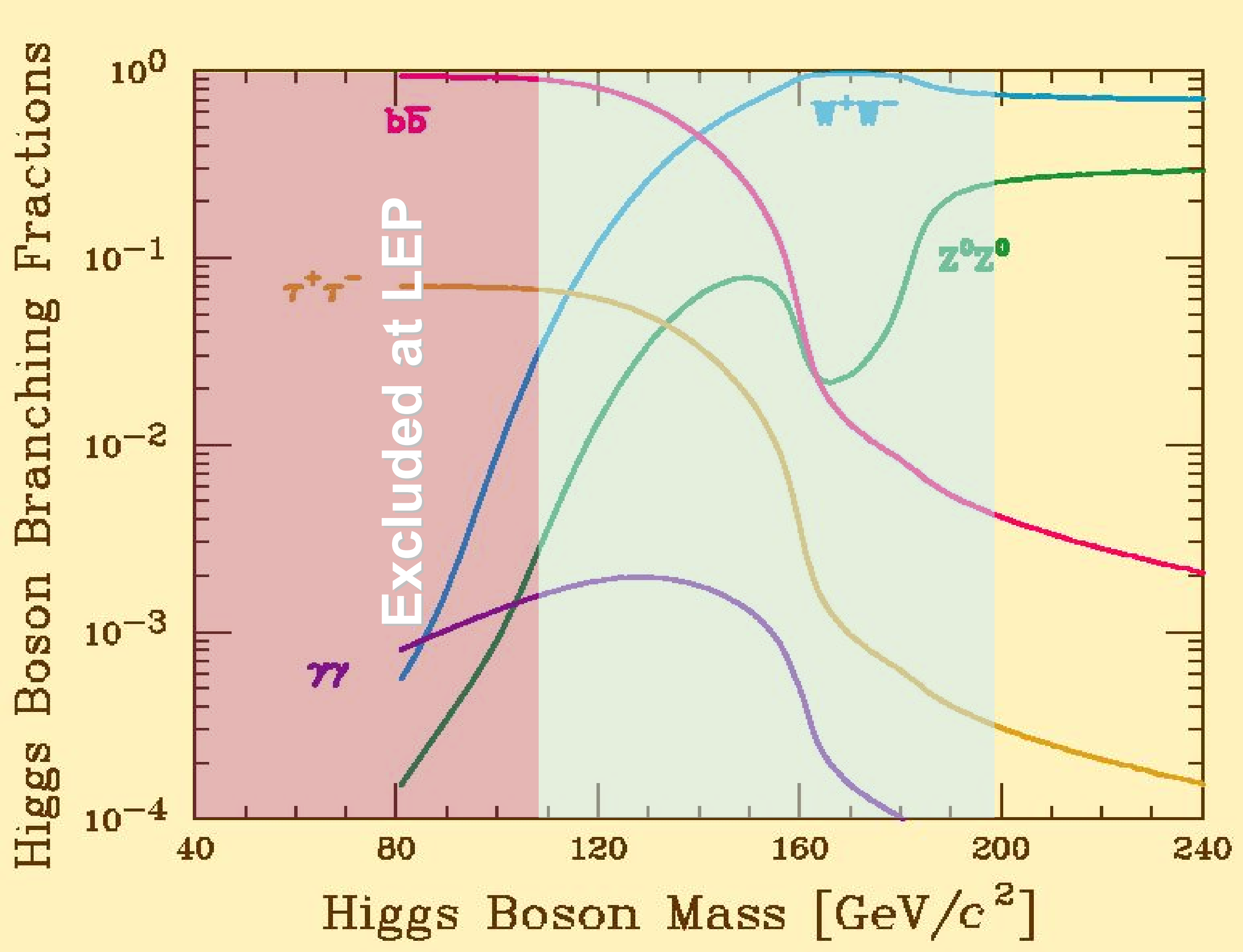
Other active top topics (not discussed here)

- Single top production
  - Current limits approach the SM expectations: $\sigma(t) < 2.9$ pb, $\sigma(s) < 3.2$ pb
  - The next step would be the observation, cross section measurement → V_{tb}
- W helicity in top decays
  - SM: longitudinal fraction $f_0 \sim 0.7$, right-handed fraction $f_+ \sim 10^{-4}$
  - Several methods: lepton p_T, M_{lb}^2, $\cos\theta^*$
  - $f_0 = 0.606 \pm 0.12(stat) \pm 0.06(sys)$ assuming $f_+ = 0$; $f_+ < 0.09$ at 95% CL
- BR($t \rightarrow Wb$) / BR($W \rightarrow Wq$)
  - $1.03^{+0.19}_{-0.17}$
- Top quark lifetime
  - $c\tau < 52.5\ \mu m$ ($\sim 1.8 \times 10^{-13}$ s) at 95% CL
- Search for tt resonances
  - m(X) > 725 GeV at 95% CL
- 4th generator t' quark
  - m(t') > 258 GeV at 95% CL
- Search for W' → tb decays
  - $m(W'_L/W'_R) > 610/630$ GeV at 95% CL



Higgs searches

The SM Higgs boson decays

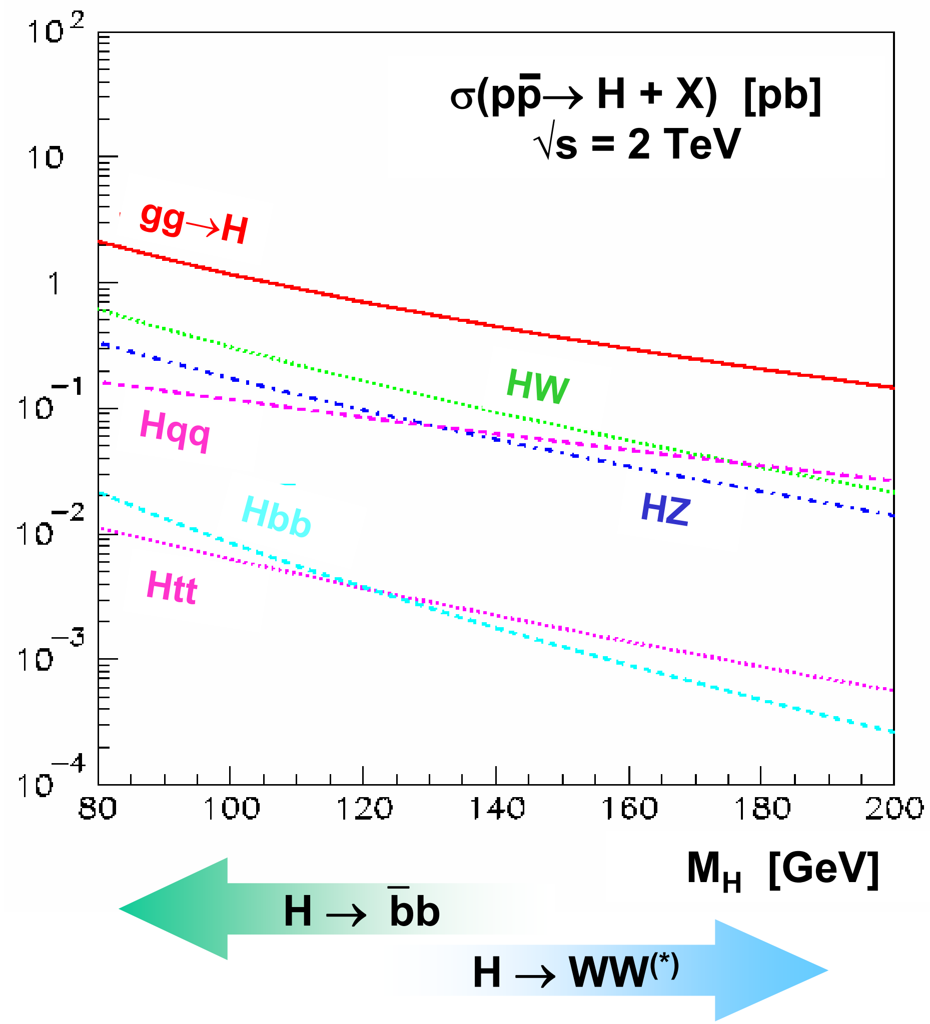


Tevatron can explore bb and WW decay modes

Higgs search strategies: low mass region

M_H < 135 GeV: H → bb

- Higgs produced in gluon fusion has too large QCD/bb background
- Search for (W/Z)H production where W/Z decay leptonically
    - **qq' → W* → WH → ℓνbb**
        - **Bkgd: Wbb, WZ, tt, single top**
    - **qq → Z* → ZH → $\ell^+\ell^-$bb**
        - **Bkgd: Zbb, ZZ, tt**
    - **qq → Z* → ZH → ννbb**
        - **Bkgd: QCD, Zbb, ZZ, tt**
- Search for **ttH** associated production
    - **Final states with ℓ+ ≥5 jets**
- Identify leptons (e/μ) and missing transverse energy from neutrinos
- Tag b-jets
- Disentangle H → bb peak in di-b-jet mass spectrum



Dominant decay modes

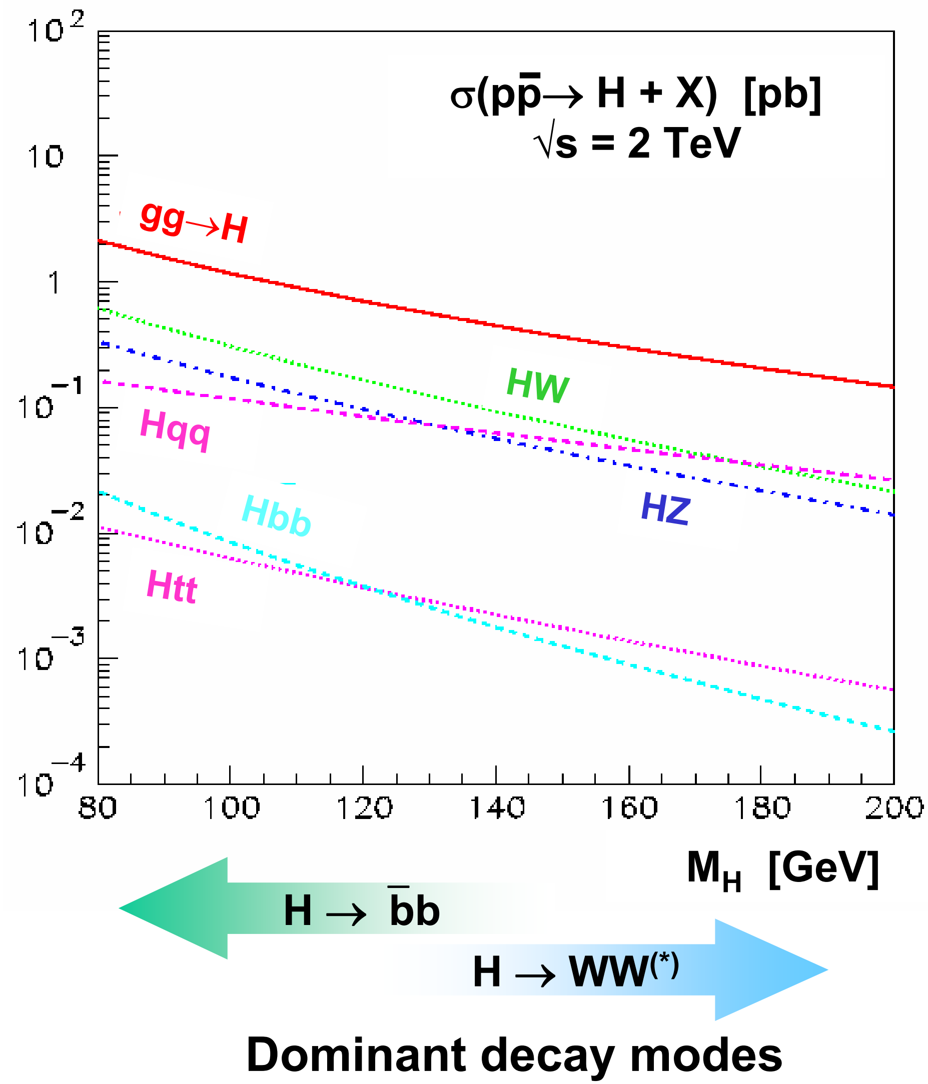
Higgs search strategies: high mass region

M_H > 135 GeV: H → W^+W^-

- Higgs production in gluon fusion and leptonic decays of W's
  - **gg → H → WW* → $\ell^+\nu\ell^-\nu$**
  - Bkgd: Drell-Yan, WW, WZ, ZZ, tt, tW, $\tau\tau$
- Identify leptons (electrons/muons) and missing transverse energy from neutrinos
  - Explore angular correlations to separate signal from background

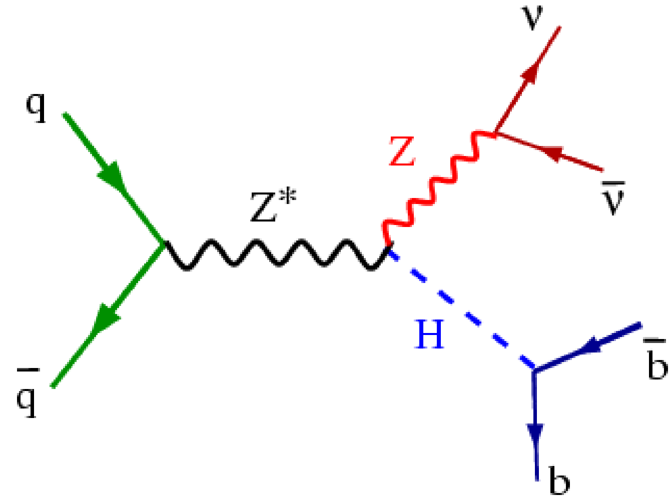
M_H < 200 GeV

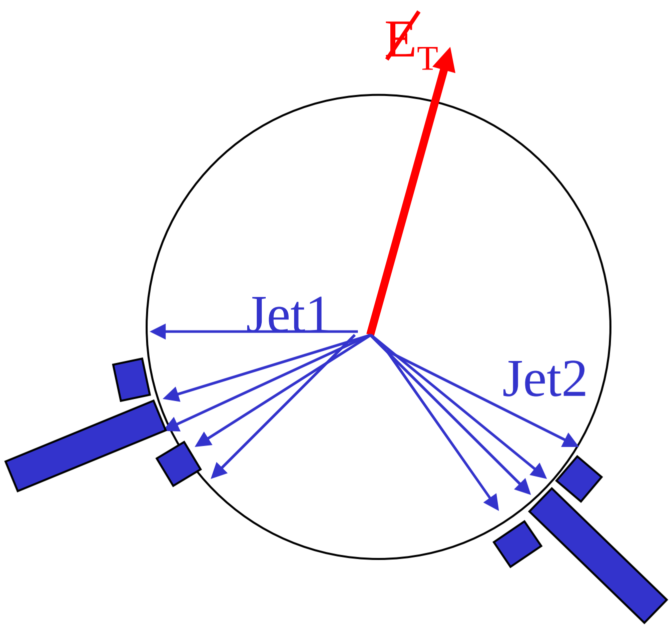
- WH associated production
  - **WH → WWW* → $\ell^\pm\nu\ell'^\pm\nu'$ + X**
  - Bkgd: Charge flips, QCD, WZ, ZZ



ZH→ννbb searches

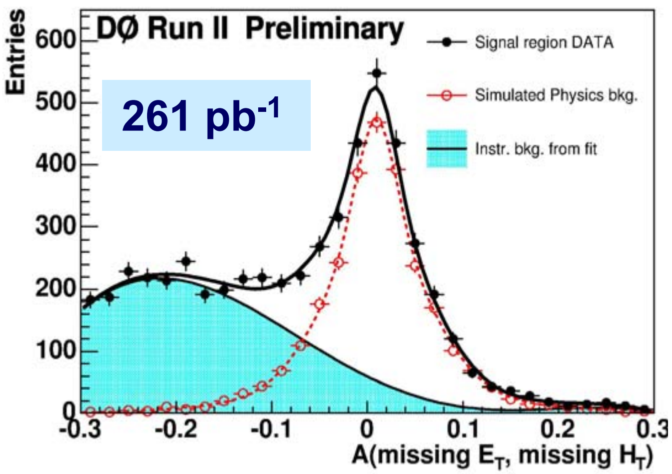
- Missing E_T from Z→νν and 2 b jets from H→bb
  - Large missing E_T > 25 GeV
  - 2 acoplanar b-tagged jets, $E_T > 20$ GeV, $|\eta| < 2.5$
- Backgrounds
  - "physics"
    - W+jets, Z+jets, top, ZZ and WZ
  - "instrumental"
    - QCD multijet events with mismeasured jets
      - Huge cross section & small acceptance
- Strategy
  - **DØ:** trigger on events with large missing H_T
    - H_T defined as a vector sum of jets' E_T
  - **CDF:** trigger on di-jet events with large E_T
  - **DØ:** estimate "instrumental" background from data; **CDF:** evaluate it with MC → control in data
  - Search for an event excess in di-b-jet mass distribution

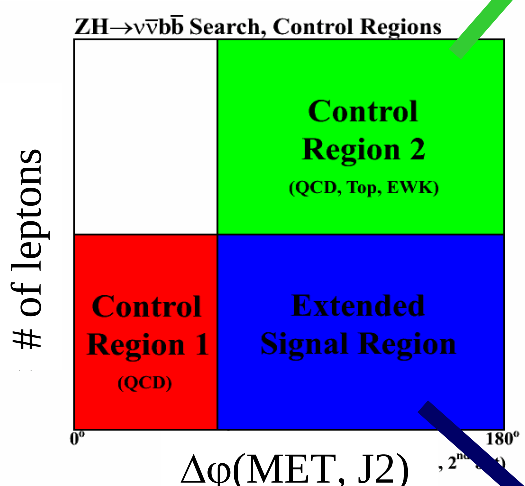


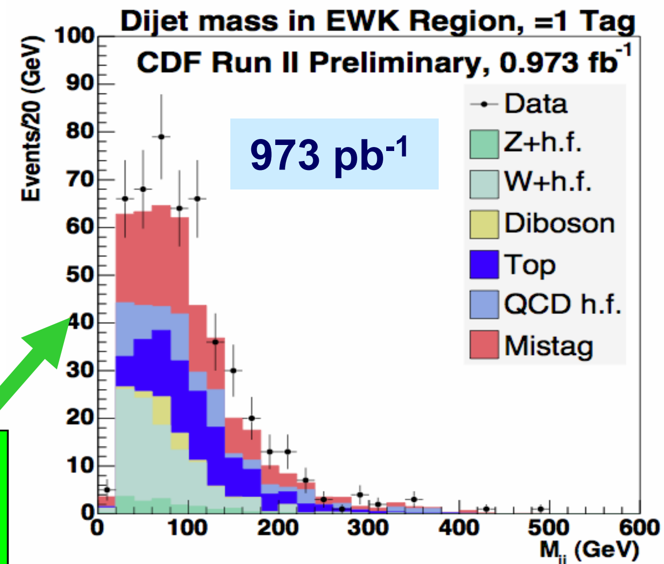


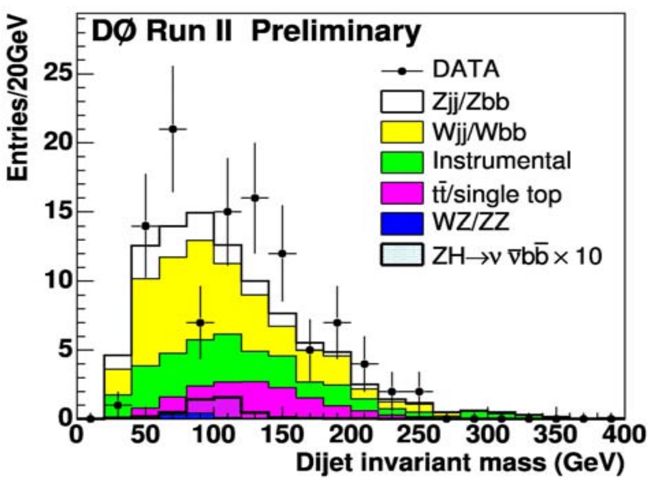
ZH → ννbb searches

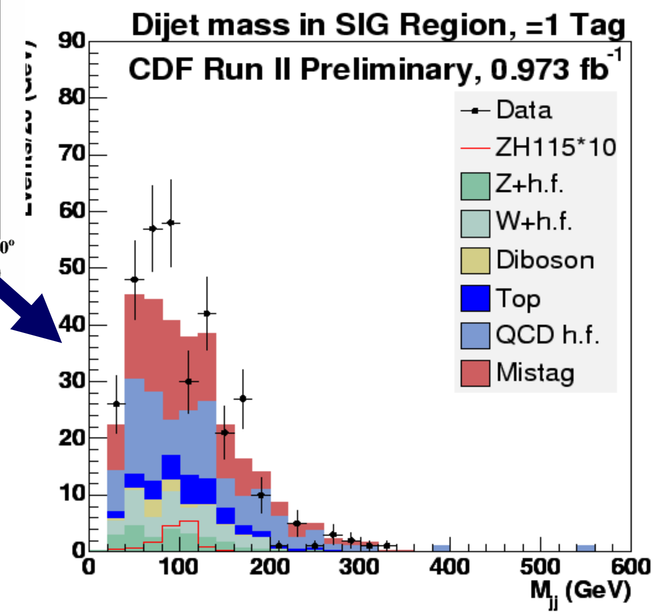
Asymmetry, $(E_T^{miss} - H_T^{miss})/(E_T^{miss}+H_T^{miss})$, distribution discriminates S/B and used to estimate instrumental bkgd in signal region











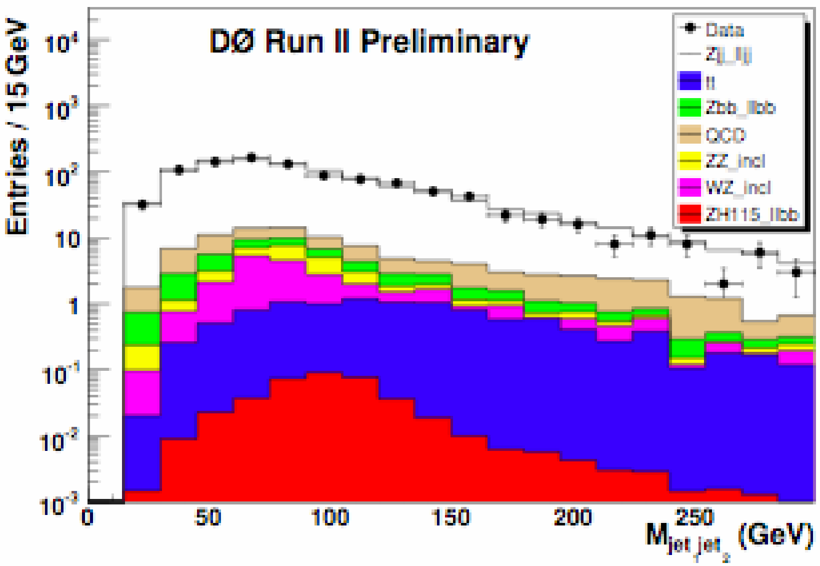
σ_{ZH} < 3.4 pb for m_H= 115 GeV

σ_{ZH} /SM = 14 for m_H= 115 GeV

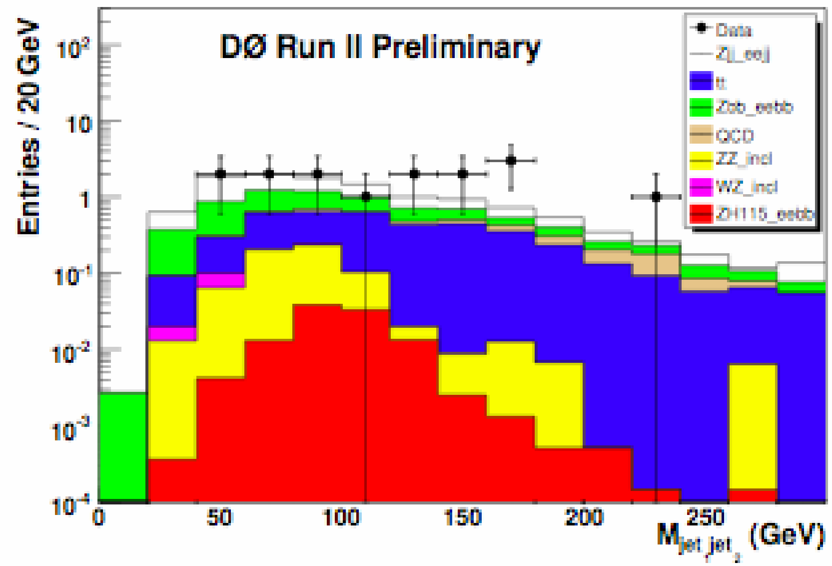
DØ: ZH → ℓℓbb searches

Analysis with 389 pb^{-1} (Z → ee), 320 pb^{-1} (Z → $\mu^+\mu^-$)

Dijet mass before b-tagging



Dijet mass after 2 b-tags



Process	before b-tag	after 2 tags
Z+bb	17	3
Z+jj	937	5
ttbar	11	4
ZZ+ZW	26	0.6
QCD	44	0.6

$ZH_{M=115}$ = 0.1 evts

Total bkgd 13 evts

Result: di-jet mass fit

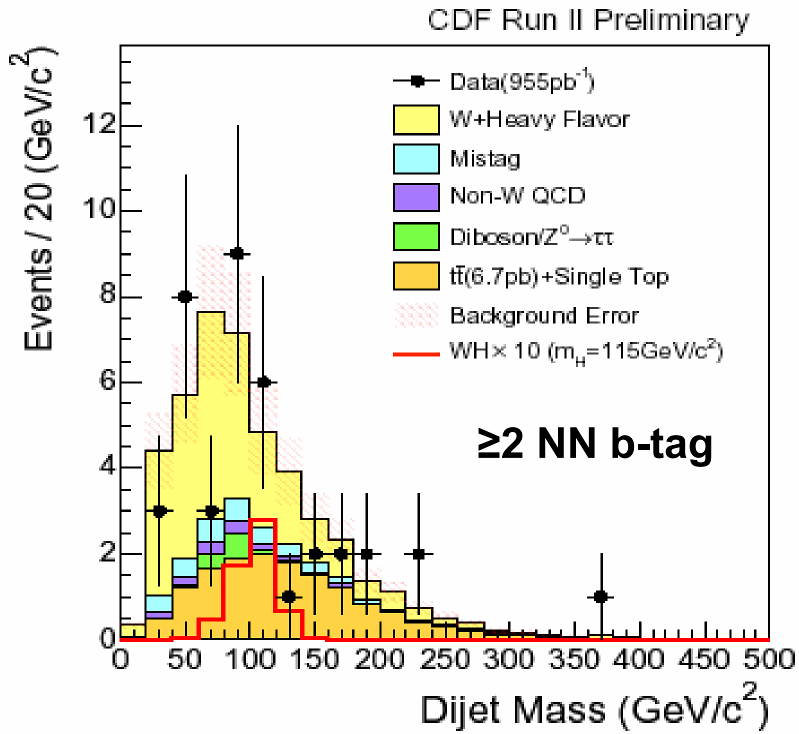
σ_{ZH} < 7.9 pb (Z->ee)

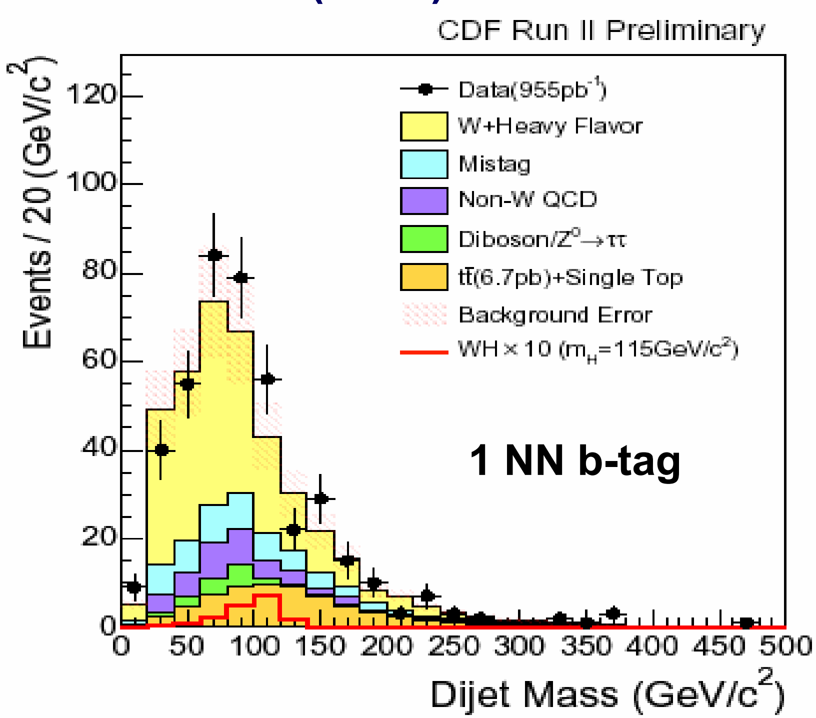
σ_{ZH} < 11 pb (Z->$\mu\mu$)

for m_H = 115 GeV

CDF: WH → ℓνbb channel

- Lepton, missing E_T and 2 jets
  - One or two b-tags
- New since last year
  - NN b-tagger
  - Include double-tag
  - Include full 1 fb^{-1} dataset
  - Luminosity equivalent gain
    - **$(S/\sqrt{B})^2=1.25^2=1.6$**





σ_{WH} < 3.9 - 1.3 pb for m_H= 110 - 150 GeV
Measured limit/SM rate = 23 (m_H=115 GeV)

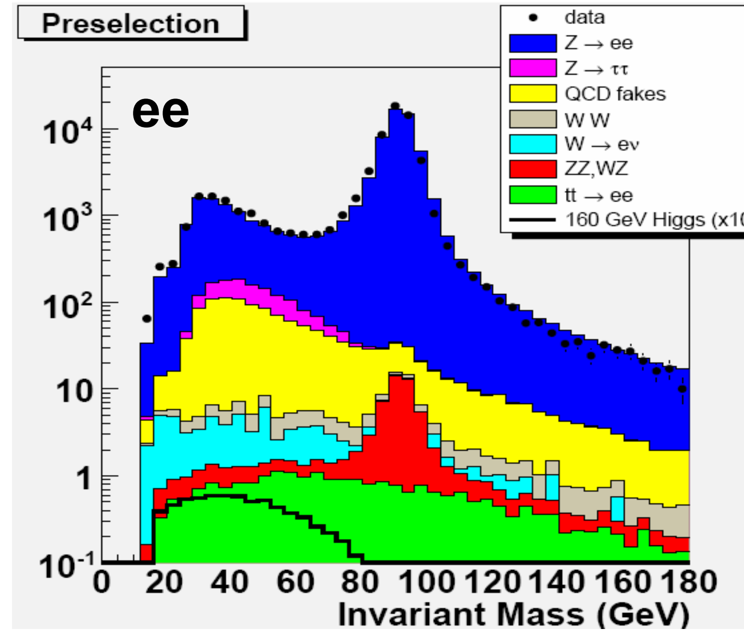
DØ: H → WW* → $\ell^+\ell^-\nu\nu$ decays; ℓ = e, μ (1)

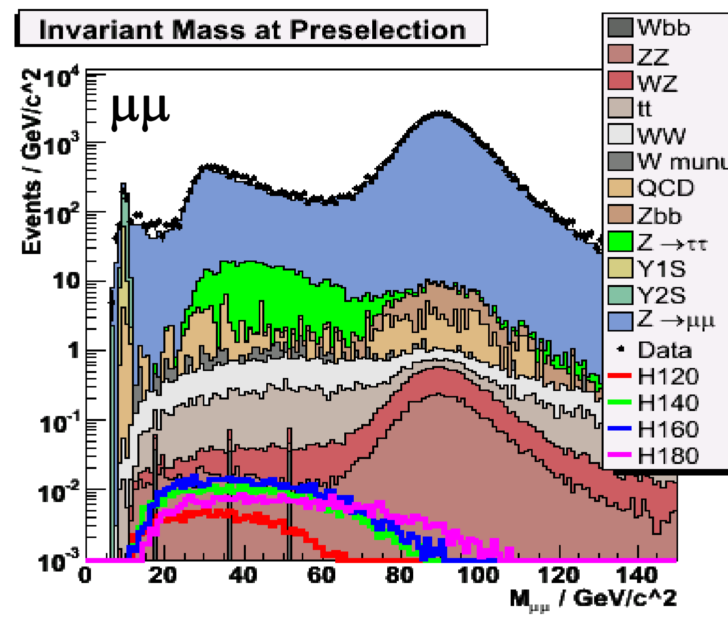
- Event selection include
  - Isolated lepton
    - $p_T(\ell_1) > 15$ GeV, $p_T(\ell_2) > 10$ GeV
  - Missing $E_T > 20$ GeV
  - Scaled missing $E_T > 15$ (suppress evts. with mismeasured jet energy)

$$\not{E}_T^{\mathrm{Sc}} = \frac{\not{E}_T}{\sqrt{\sum_{\mathrm{jets}}\left(\Delta E^{\mathrm{jet}}\cdot\sin\theta^{\mathrm{jet}}\cdot\cos\Delta\phi\left(\mathrm{jet},\not{E}_T\right)\right)^2}}$$

  - Veto on
    - Z resonance
    - Energetic jets

Data vs MC after evt. preselection



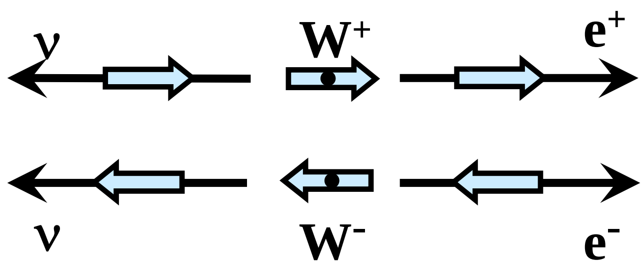


- Data correspond to integrated lumi. of 950-930 pb^{-1} depending on the final states

DØ: H → WW* → ℓ⁺ℓ⁻νν decays (2)

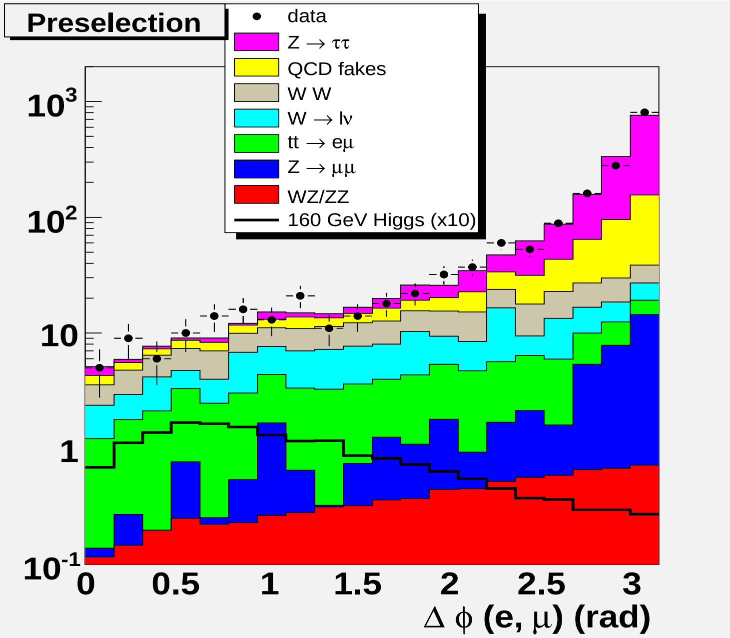
- Higgs mass reconstruction not possible due to two neutrinos

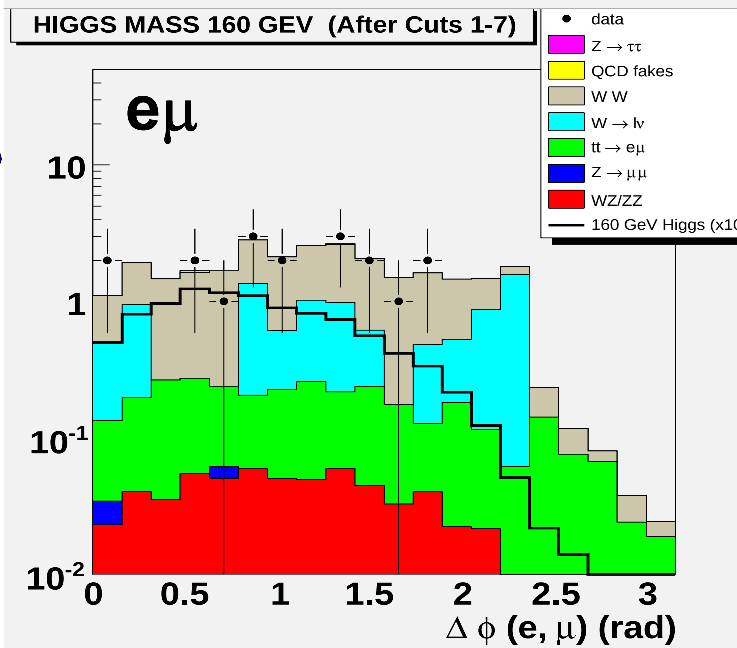
- Employ spin correlations to suppress the bkgd.
  - Δφ(ℓℓ) variable is particularly useful



- Leptons from Higgs tend to be collinear

Good agreement between data and MC after all selections and in all final states

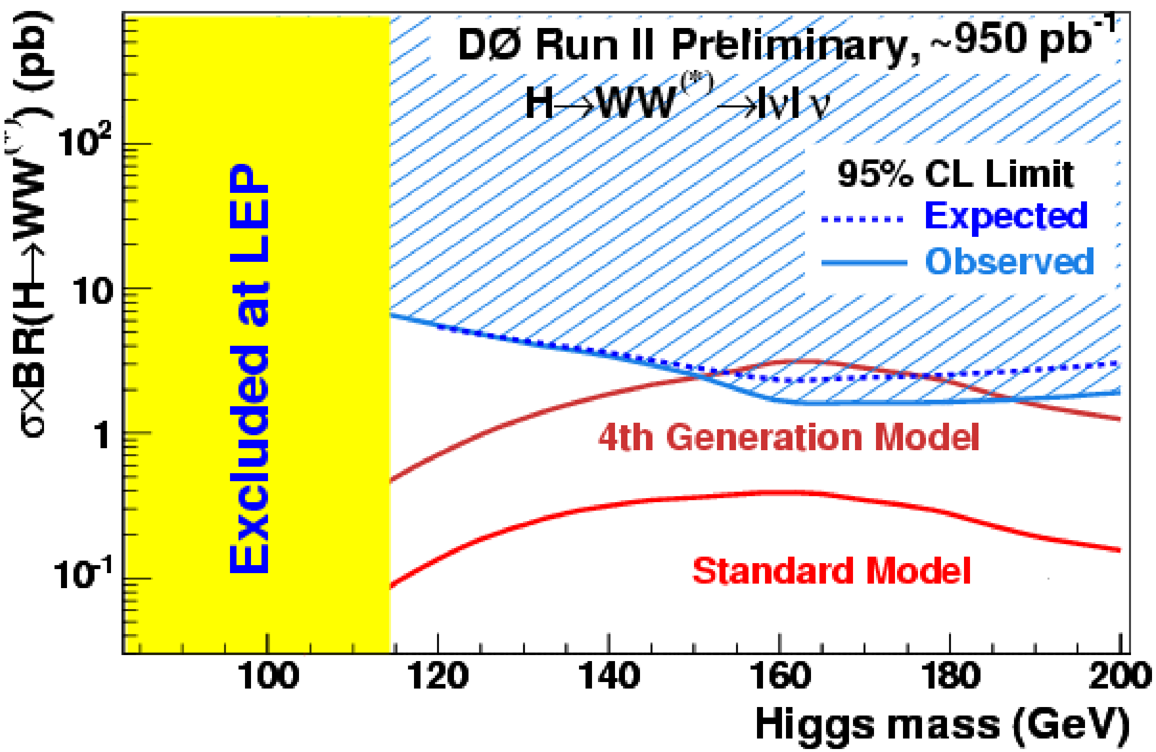




DØ: results on H → WW*

Expected/Observed # of events for m_H = 160 GeV (L ~ 950 pb^{-1})

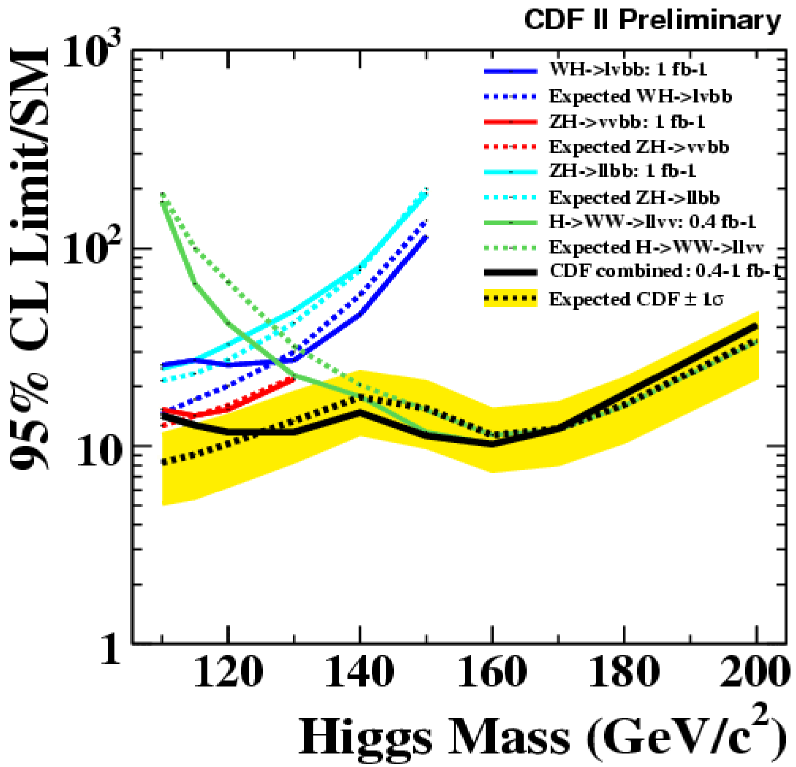
	Data	Sum BGND	WW	W+jet/γ	Z/γ *	tt(bar)	WZ / ZZ	QCD	H--> WW*
e e	10	10.3 ± 0.6	7.0 ± 0.2	1.4 ± 0.6	0.0 ± 0.0	1.1 ± 0.1	0.8 ± 0.1	0.06 ± 0.02	0.415
e μ	18	24.4 ± 1.5	16.4 ± 0.1	5.3 ± 1.5	0.02 ± 0.01	2.1 ± 0.1	0.6 ± 0.1	0.1 ± 0.05	0.97
μμ	9	9.8±0.8	6.6±0.1	1.0±0.4	0.6±0.4	0.5±0.1	0.5±0.1	0.6±0.6	0.35

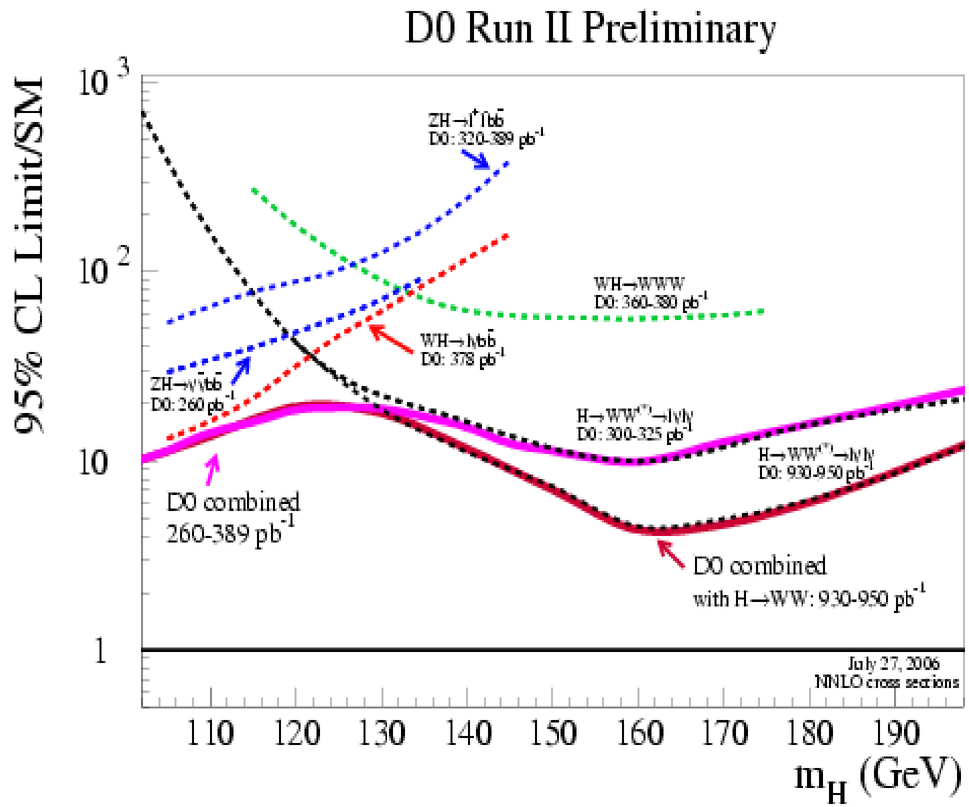


- If m_H= 160 GeV then might have a couple of Higgses in our sample already !

- SM only a factor 4 away
- 4^{th} generation models with m_H=150-185 GeV excluded

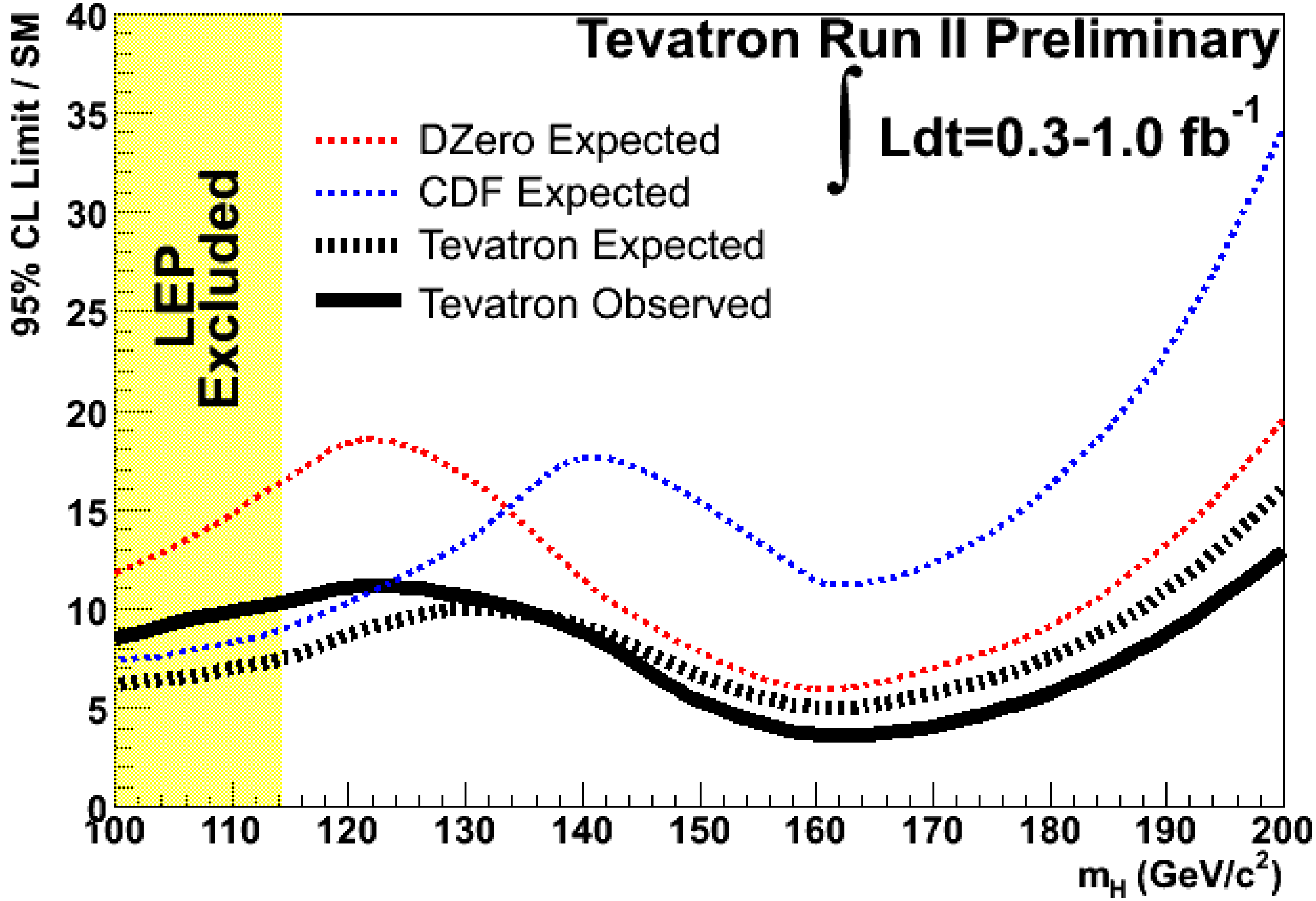
Limits from CDF and DØ





Analysis	**CDF**, M_H = 115 GeV (factor above SM)	**DØ**, M_H = 115 GeV (factor above SM)
ZH → ννbb	Includes WH w/ miss ℓ (14)	3.4 pb (41)
WH → ℓνbb	3.4 pb (23)	2.4 pb (16)
ZH → ℓℓbb	2.2 pb (27)	6.1 pb (75)

Limits from CDF and DØ combined



Can we close the gap ?

- CDF's view (most of these are valid for DØ too)
  - Assume current analyses as starting point
  - Scale current systematic uncertainties by $1/\sqrt{L}$
  - Reevaluated all improvements using latest knowledge

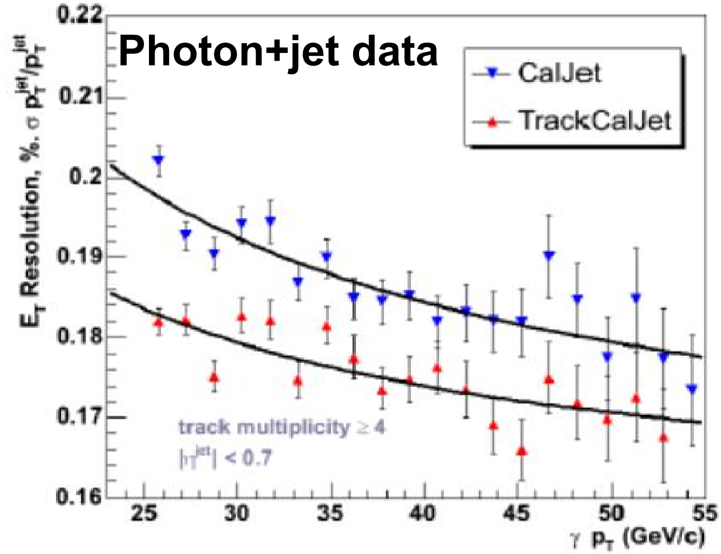
Luminosity equivalent $(s/\sqrt{b})^2$

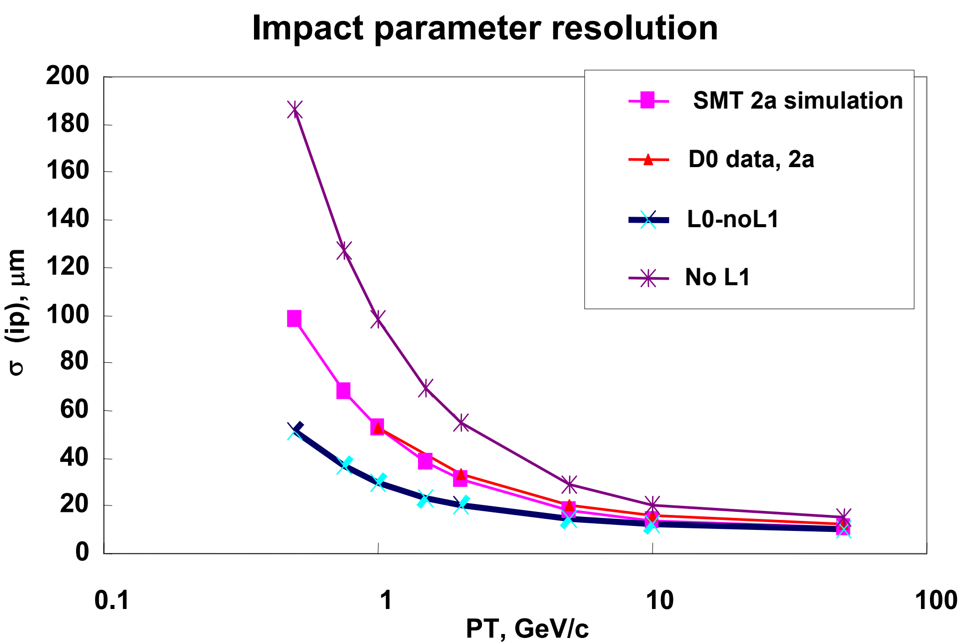
Improvement	WH→lνbb	ZH→ννbb	ZH→ℓℓbb
Mass resolution	1.7	1.7	1.7
Continuous b-tag (NN)	1.5	1.5	1.5
Forward b-tag	1.1	1.1	1.1
Forward leptons	1.3	–	1.6
Track-only leptons	1.4	–	1.6
NN Selection	1.75	1.75	1.0
WH signal in ZH	–	2.7	–
Product of above	8.9	13.3	7.2
CDF+DØ combination	2.0	2.0	2.0
All combined	17.8	26.6	14.4

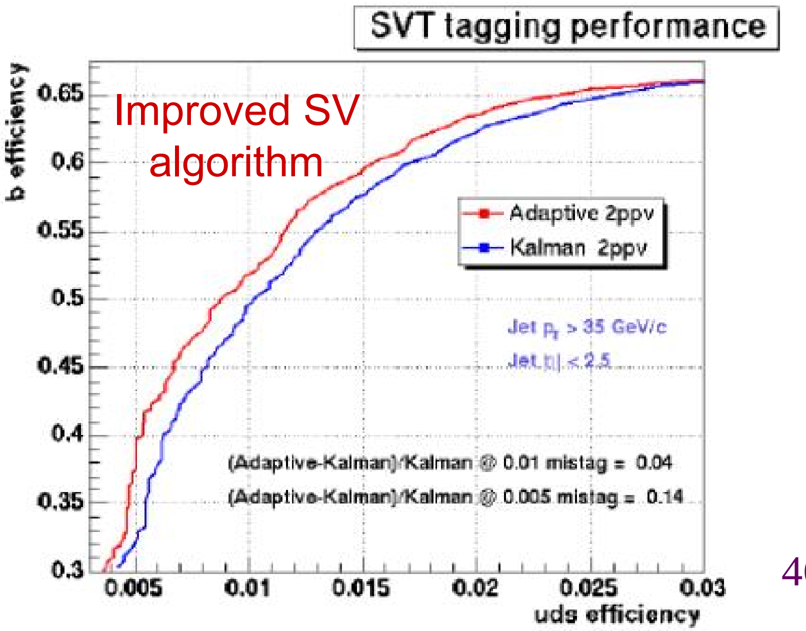
Expect ~10 times more luminosity per channel

DØ: improvements in the object ID

- Jet energy resolution (using track-jet algorithm)
  - Subtract expected energy deposition in calo.
  - Add the track momentum
  - Add the energy of out-of-cone tracks
- Improve the jet energy resolution by ~10% ➔
- b-tagging capability
  - Improvements would come from L0 of the Silicon Tracker (DØ) and the use of more sophisticated algorithms







Searches for SUSY Higgs bosons

- In MSSM have two Higgs doublet fields
  - H_u (H_d) couple to up- (down-) type fermions
  - The ratio of their VEV's
    $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$
  - 5 Higgs particles after EWSB
    h, H, A, H^+, H^-
  - h is 'guaranteed' to be light
    m_h <~ 130-140 GeV

- At large tanβ, coupling to down-type quarks, i.e. b's, is enhanced wrt SM
  - At tree level ~ tanβ → production cross section rise as $\tan\beta^2$

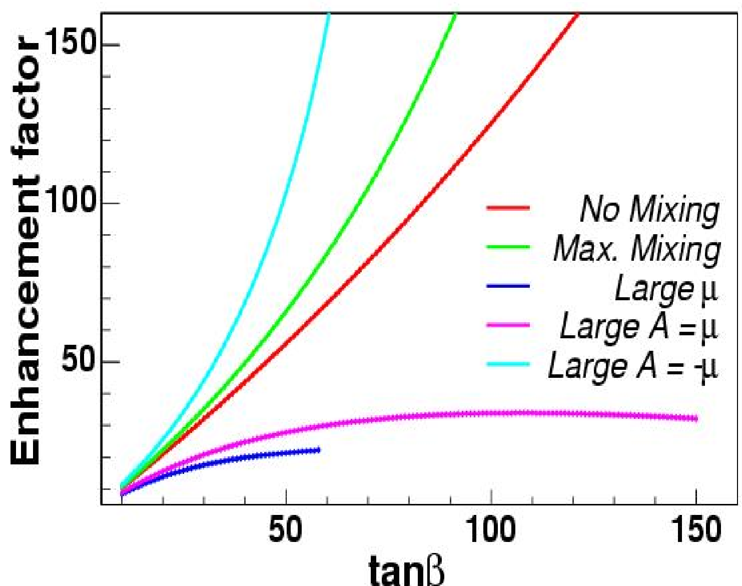
- CP conservation is assumed in the following analyses

Loop level corrections to x-section and BR

$$\sigma \times BR_{SUSY} = 2 \times \sigma_{SM} \times \frac{\tan\beta^2}{(1+\Delta_b)^2} \times \frac{9}{[9+(1+\Delta_b)^2]}$$

$$\text{with} \quad \Delta_b = \frac{\Delta h_b}{h_b} \times \tan\beta$$

Function of various SM/SUSY parameters: $X_t = A_t - \mu\cot\beta$, μ, M_g, M_q, etc.



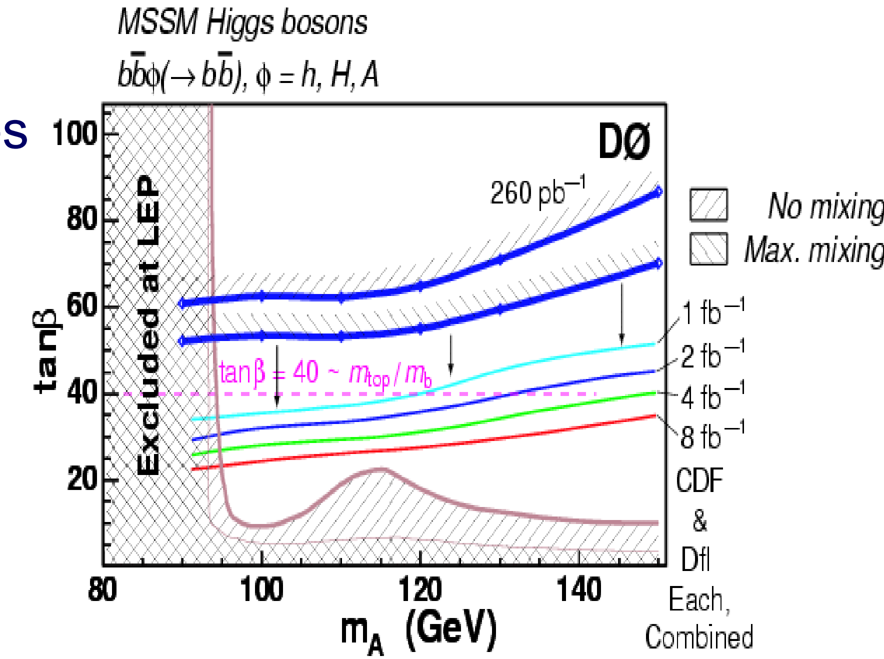
MSSM higgs searches

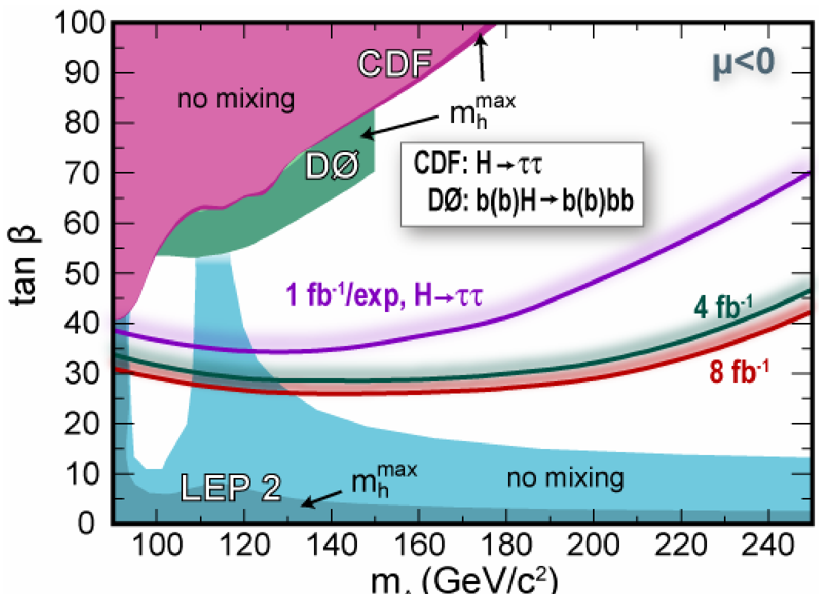
Associated production with b quarks

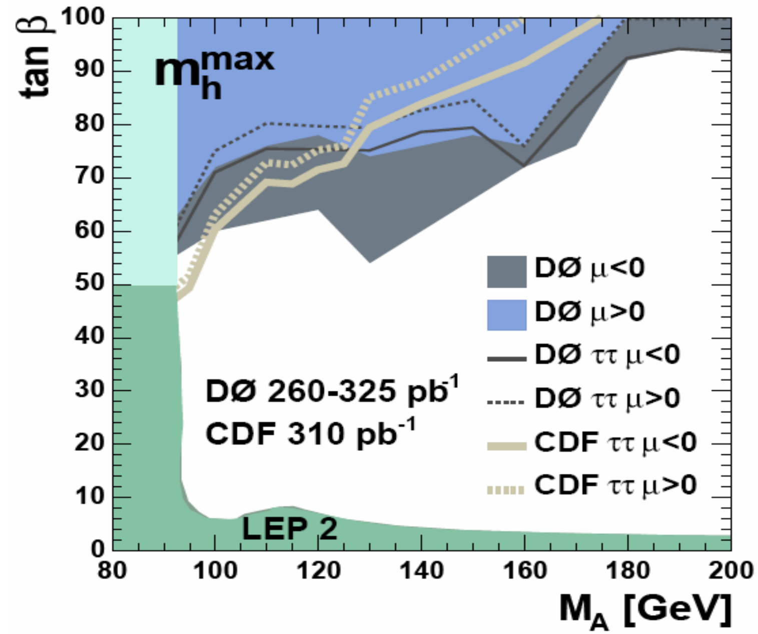
- DØ: bh/bbh(→bb) → 3/4 b's in final states
  - Require ≥ 3 b-tagged jets
  - Background evaluated from data
  - Look for excess in di-jet mass window

Inclusive production

- CDF and DØ: h → ττ → eτ_h, μτ_h, or eμ
  - Look for excess in M_{vis} (= mass of visible τ decay products and missing E_T) spectrum







Summary

- Upgraded for Run II Tevatron, CDF and DØ are performing well and contribute to world class physics results
- Most of Run I Electroweak measurements are improved and new processes are established, such as di-boson production
  - Good agreement with the SM so far
- Both experiments are in the era of precision top quark measurements
  - Many results are now systematics limited that will improve with more data
- In coming years, the CDF and DØ concerted efforts will offer a real opportunity to find the SM, or non-SM, Higgs boson or exclude a very interesting low-mass region
- Tevatron will bring more order to many scenarios before the LHC start up !


Alternative scenarios

Backups

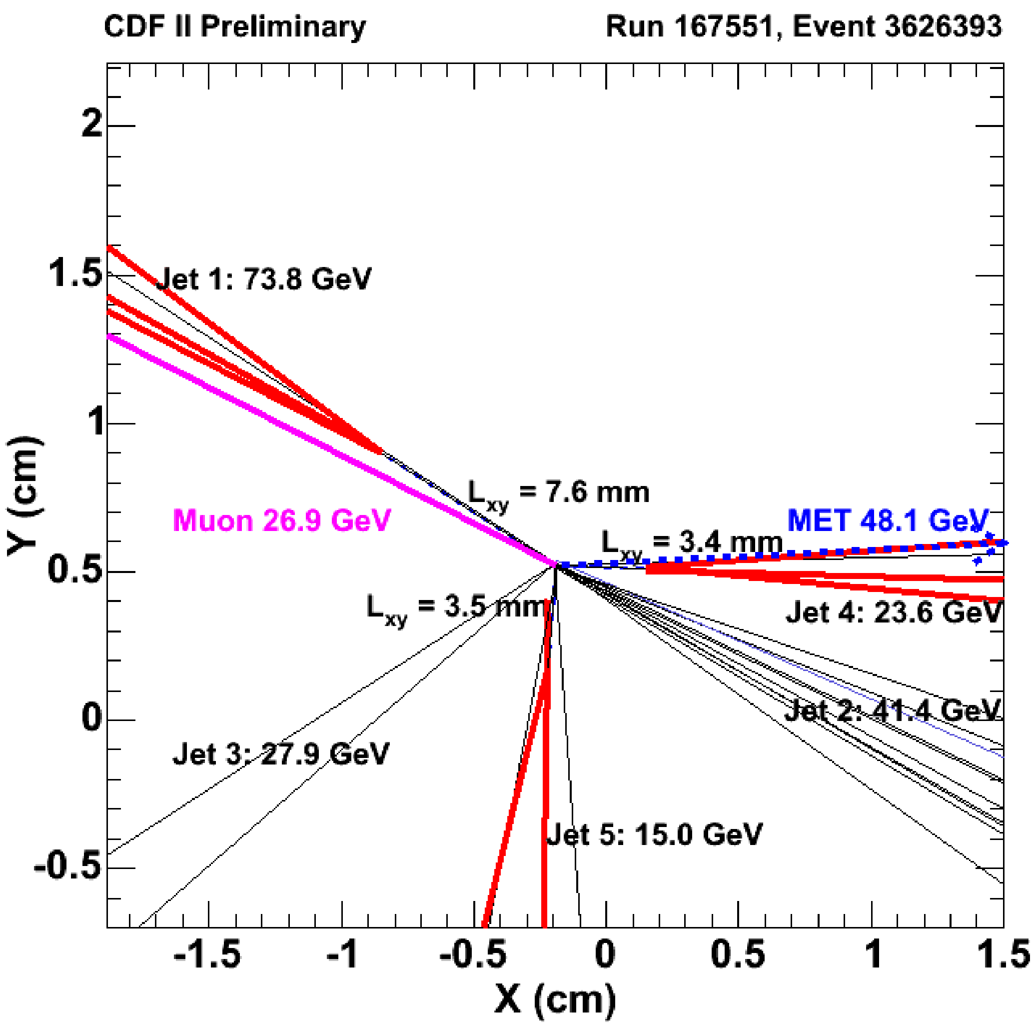
Top mass: individual channels

	ℓ+jets	All-jets	Di-lepton
m_{top}	170.9	174.0	164.5
δ(JES)	1.6	4.5	3.5
δ(signal)	1.1	0.7	0.7
δ(bkgd)	0.2	0.9	0.9
δ(other)	0.5	1.0	1.3
δ(syst)	1.9	4.7	3.9
δ(stat)	1.6	2.2	3.9
δ(total)	2.5	5.2	5.5

Higgs searches in ttH associated production

Final states with W(→ℓν)W(→jj)bbbb

- Event selection
  - Exactly one electron or muon with p_T > 20 GeV
  - ≥ 5 jets with E_T > 15 GeV, $|\eta|$ < 2
  - E_T^{miss} > 10 GeV
  - Veto events consistent with Z production
  - ≥ 3 b-tagged jets
- Data sample of 320 pb^{-1}
- Signal region "blinded" while evaluating bkgd composition



Higgs searches in ttH associated production

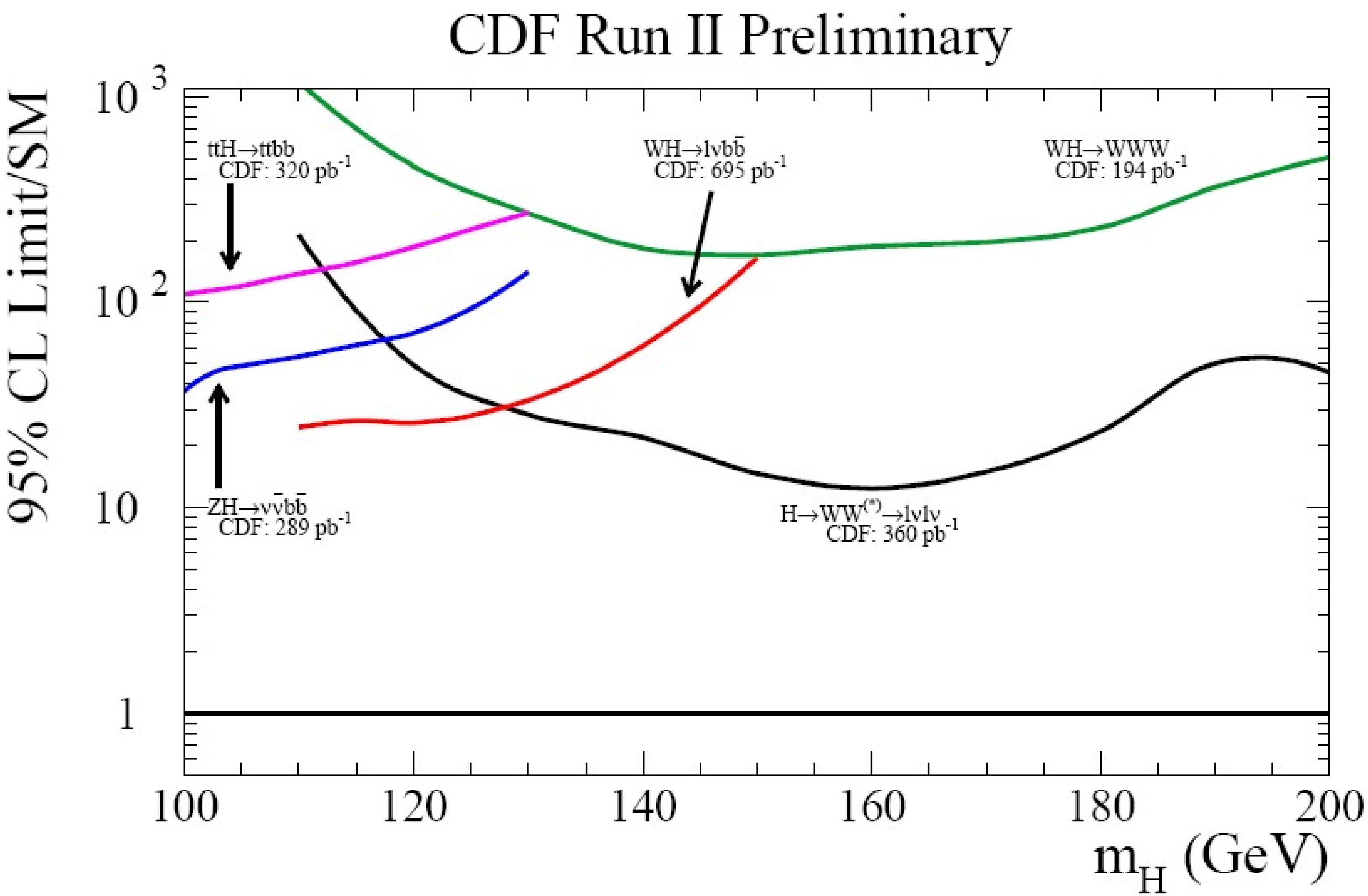
Exepected signal and bkgd evts

Source	Event Yield
Mistag	0.49 ± 0.10
Irreducible	0.36 ± 0.07
QCD	0.04 ± 0.04
Total Background	0.89 ± 0.12
Signal (m_H=115 GeV)	0.024 ± 0.005
Observed	1

Systematic uncertainties

Source	Uncertainty (%)
Jet Energy Scale	4.2
PDF	1.0
ISR/FSR	1.6
MC Modelling	0.5
Lepton ID Efficiency	5.1
BTag Efficiency	18
MC Stats	1
Total	19

ttH in CDF


CDF Run II Preliminary
95% CL Limit/SM
10^3
10^2
10
1
100
120
140
160
180
200
m_H (GeV)
ttH→ttbb
CDF: 320 pb-1
WH→lνbb̄
CDF: 695 pb-1
WH→WWW
CDF: 194 pb-1
ZH→νν̄bb̄
CDF: 289 pb-1
H→WW(*)→lνlν
CDF: 360 pb-1