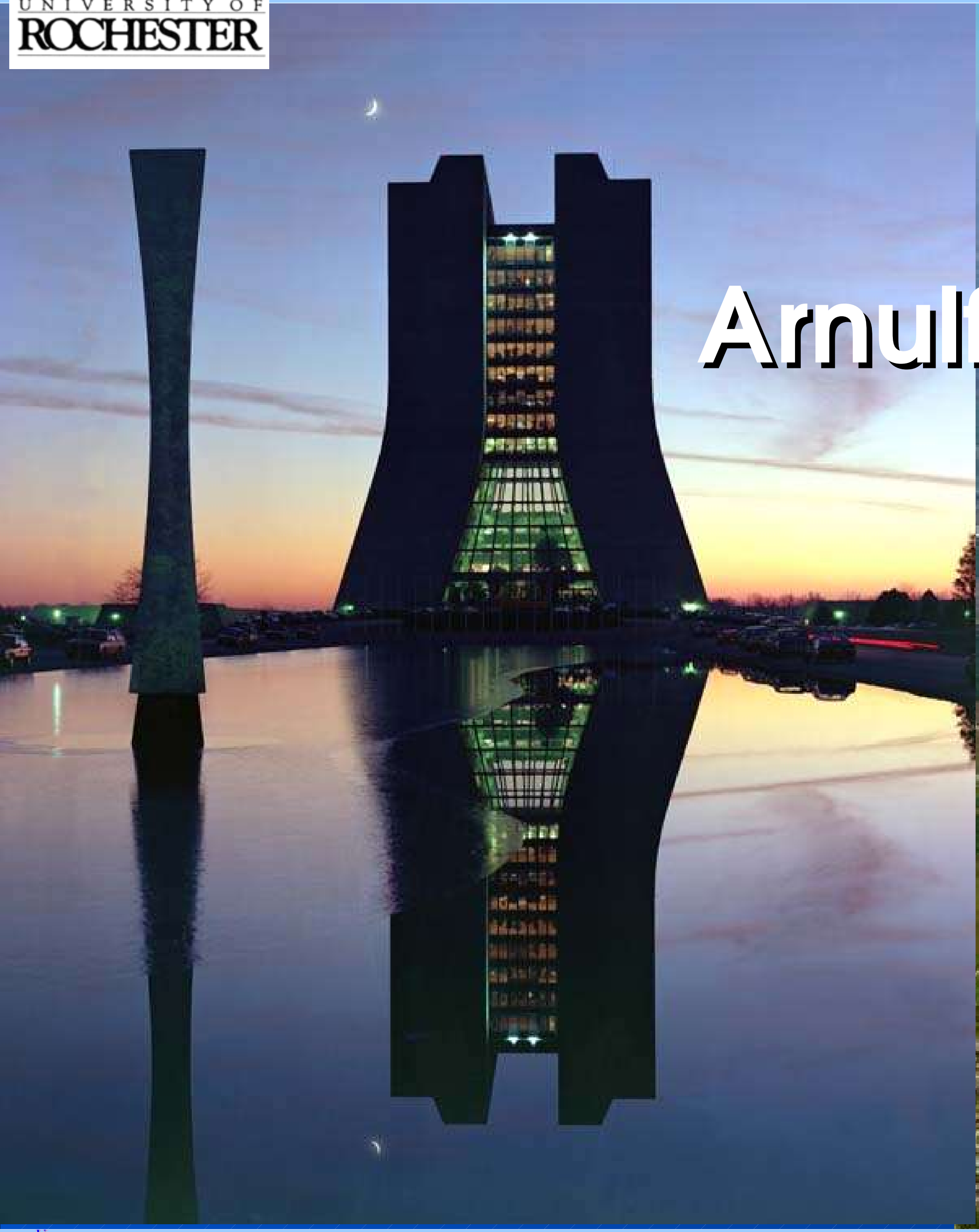
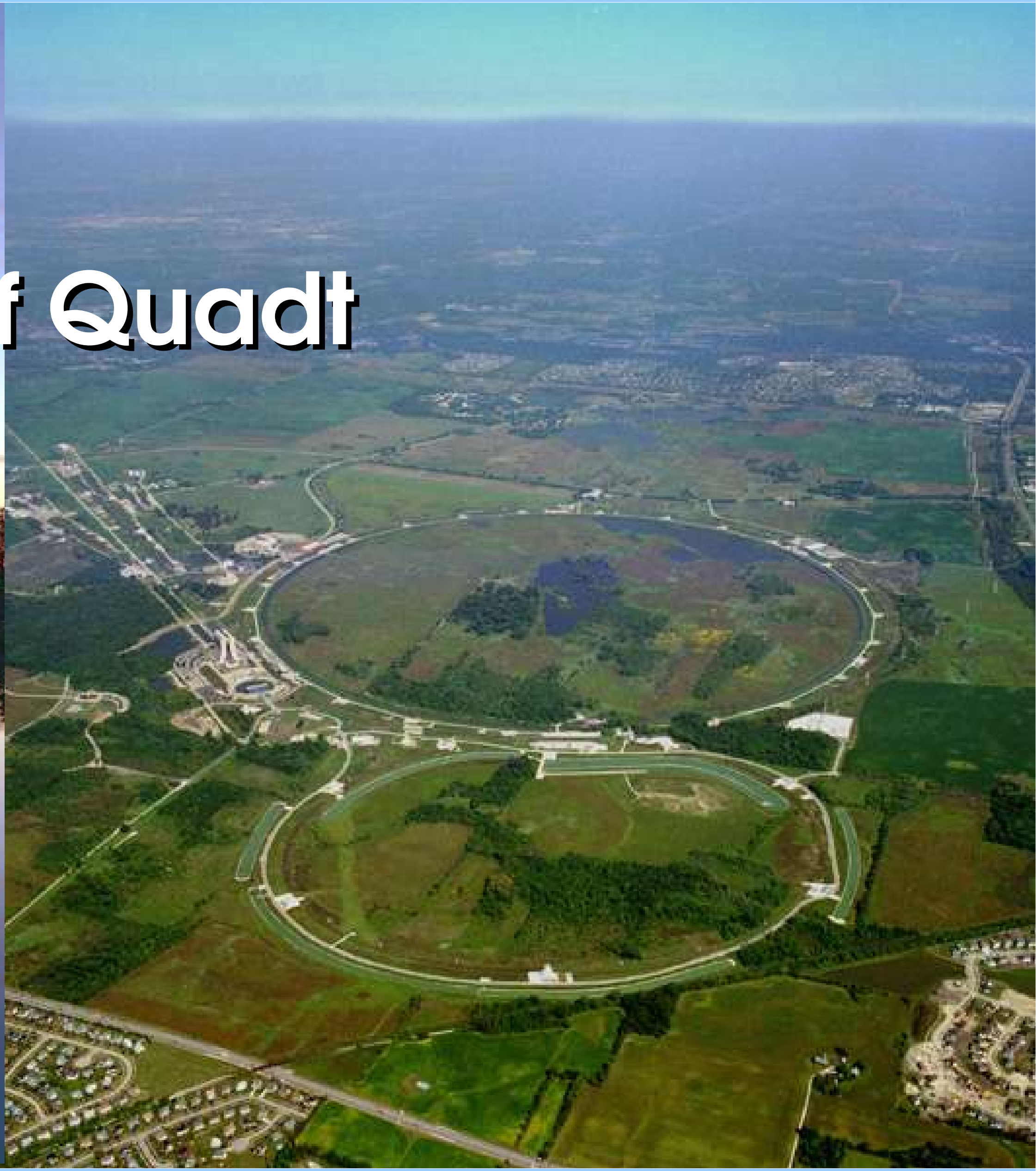
Recent Results from the Tevatron

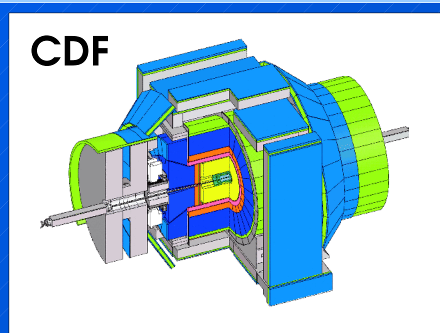
Arnulf Quadt

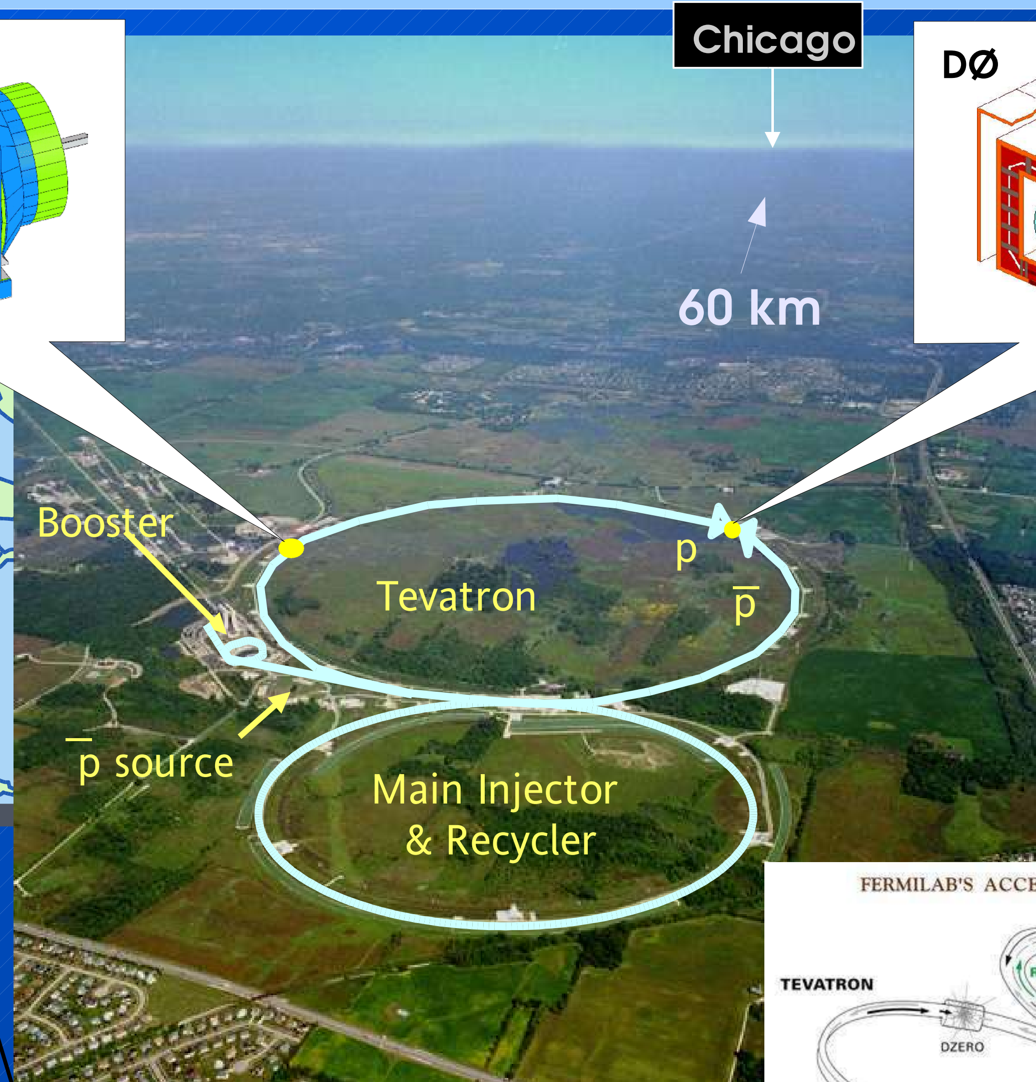
Outline

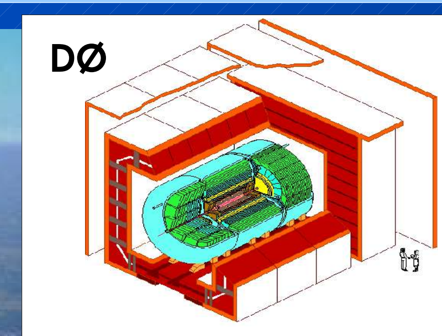
- QCD Studies
- Electroweak Measurements
- Top Physics
- Higgs Searches
- New Phenomena Searches
- B-Physics

... here only a selection is presented ...

The TEVATRON at Fermilab (1)







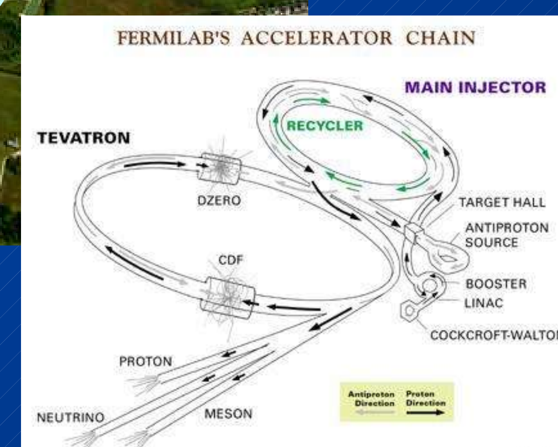
$\sqrt{s}$ =1.96 TeV

Δt = 396 ns

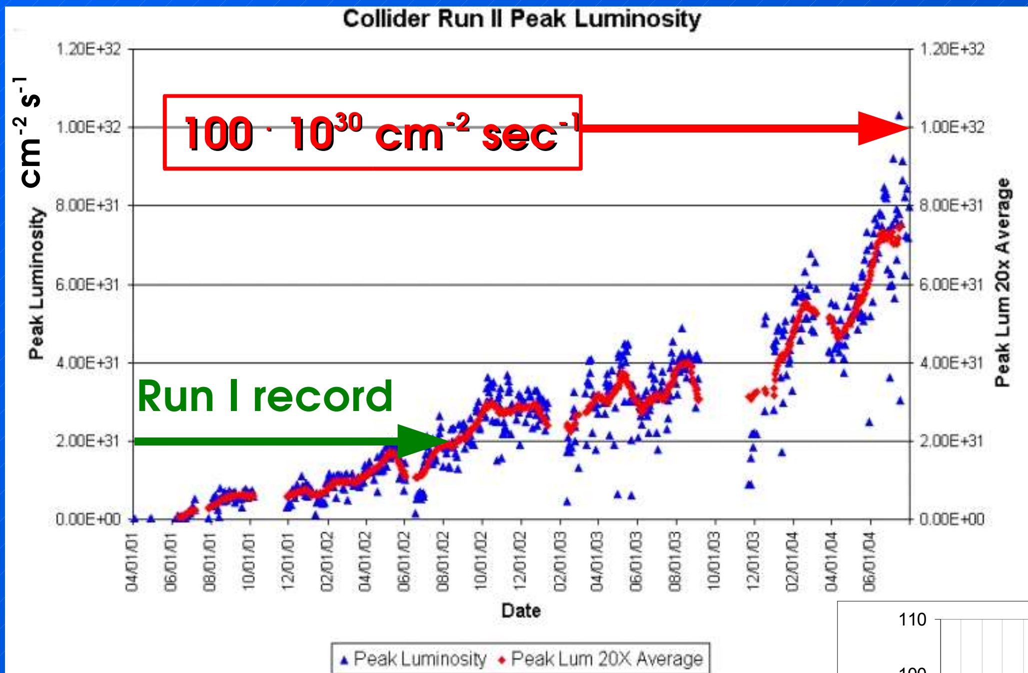
Run I 1987 (92)-95 L_{int} ~ 125 pb^{-1}

Run II 2001-09(?)

> 40-times larger dataset at increased energy

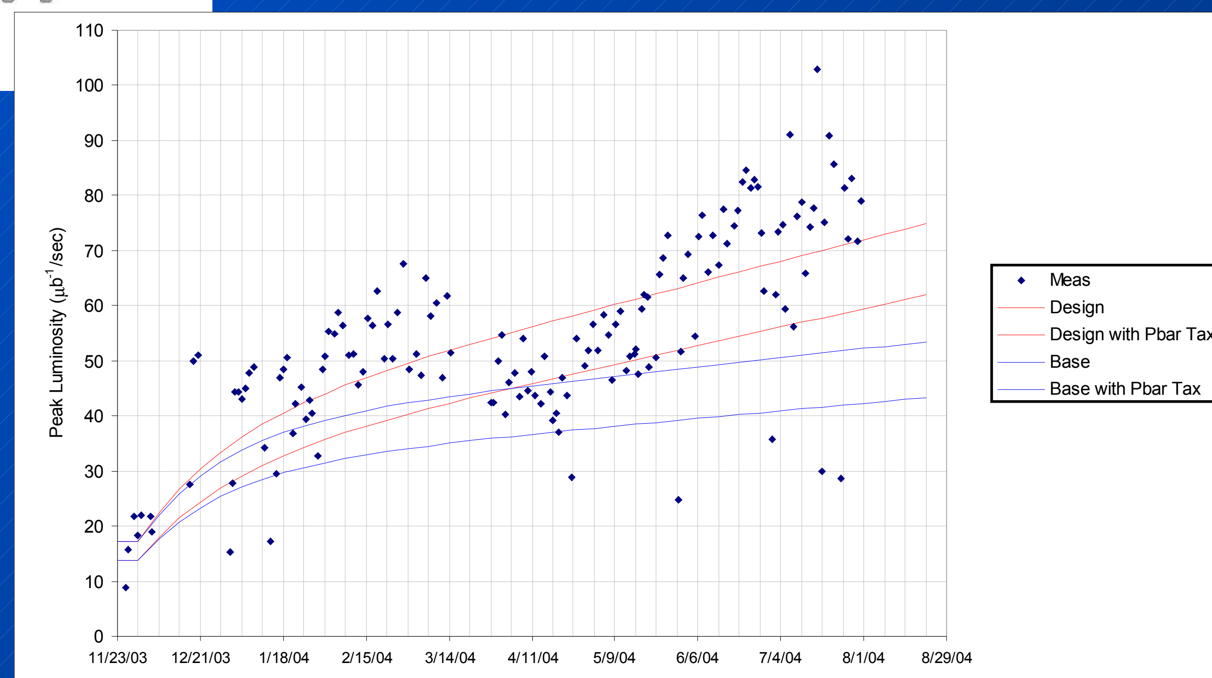


The TEVATRON Performance (1)

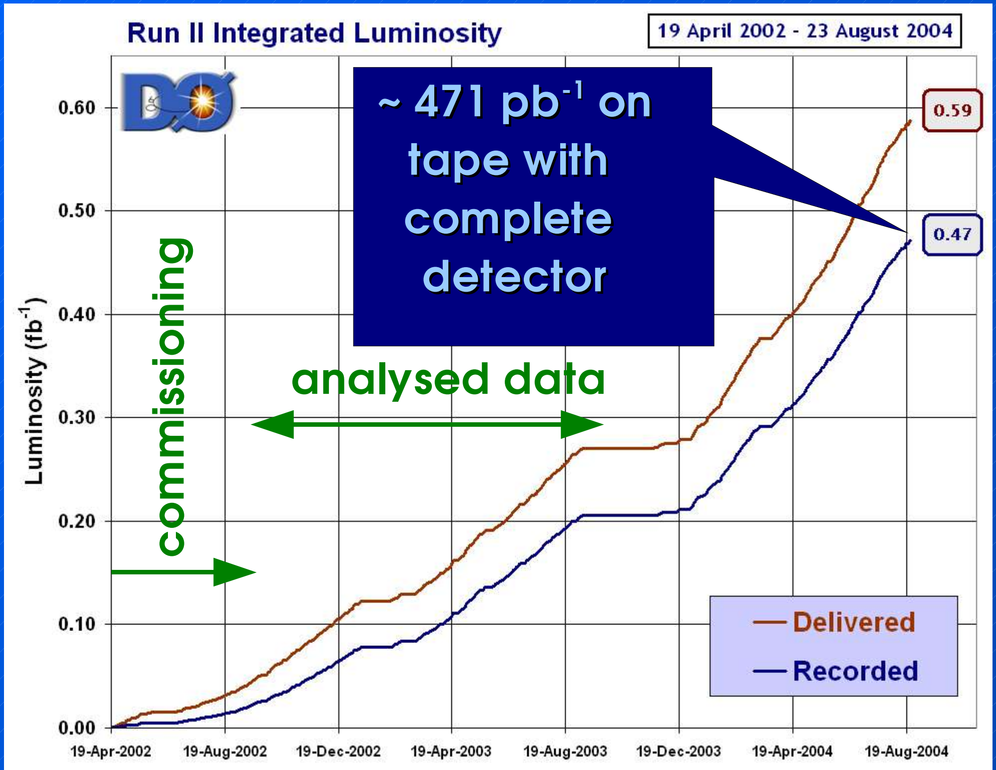


Peak luminosity:

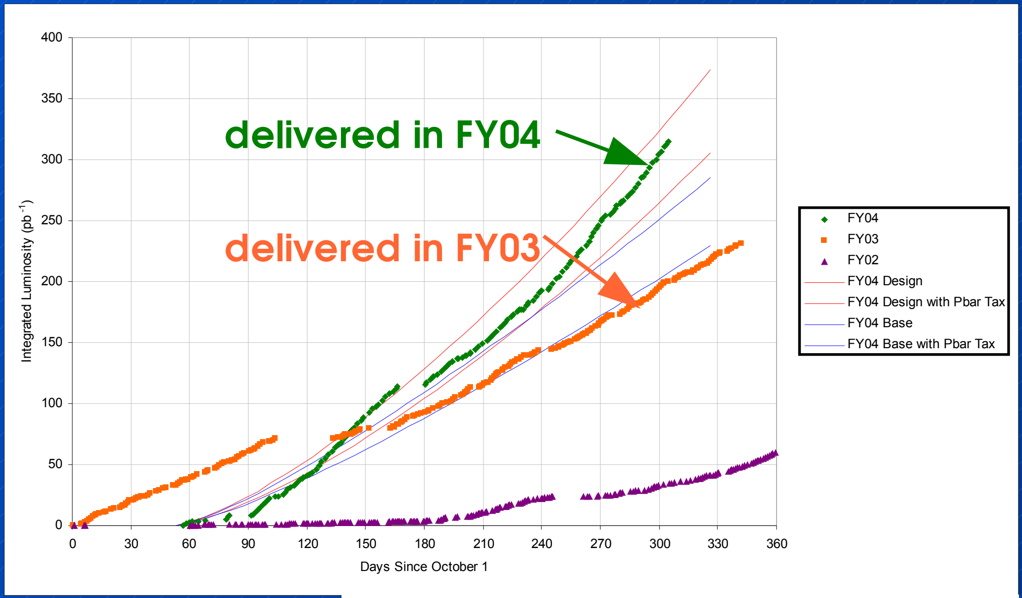
- $1 \cdot 10^{12}\ \bar{P}$, twice the SPPS number !
- in spring 2002 passed Run I record
- in 2004 often above optimistic design scenario

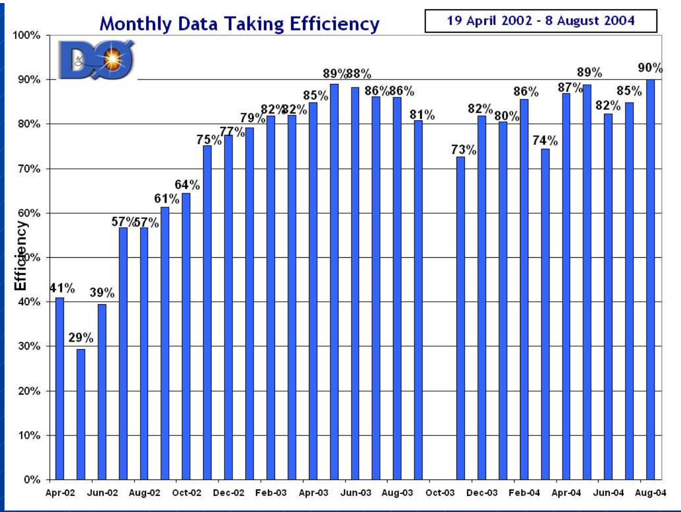


The TEVATRON Performance (2)



- TEVATRON at upper limit of optimistic scenario





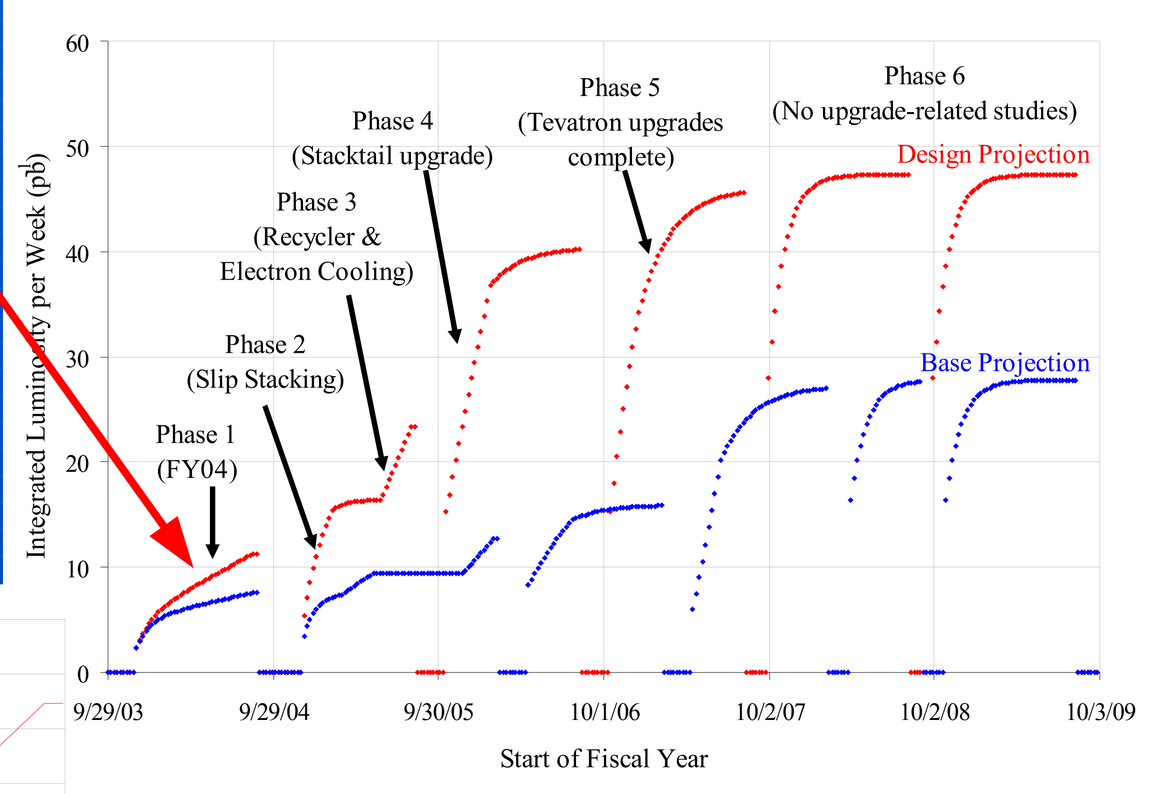
- CDF and DØ ~500 pb^{-1} recorded each
- typical data taking efficiency ~90%
- commissioning is over

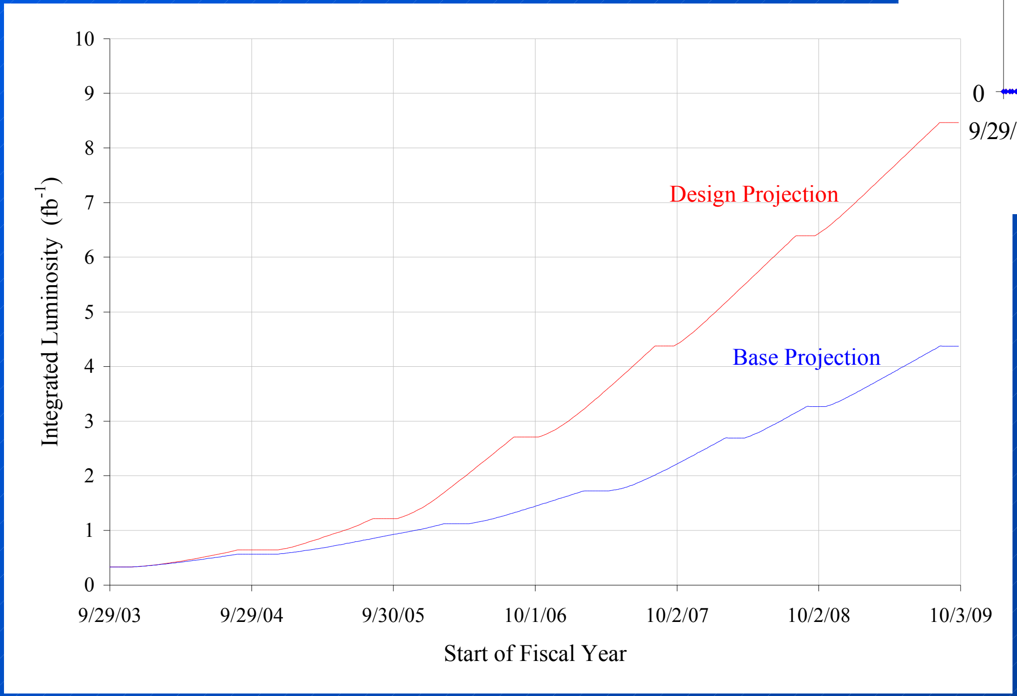
The TEVATRON until 2009

luminosity projection (fb^{-1})

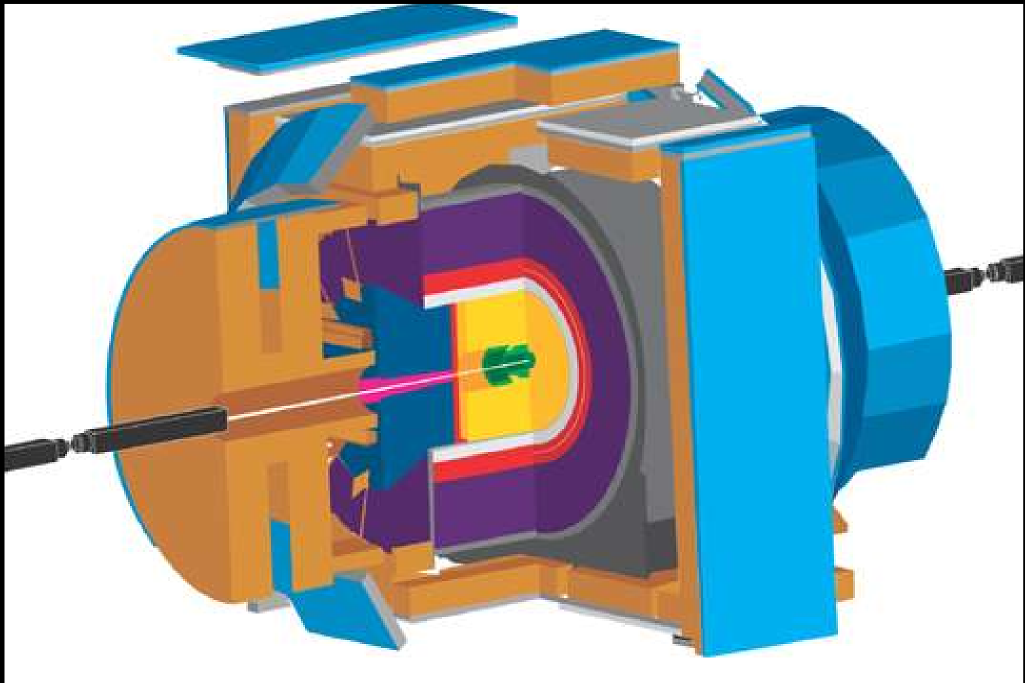
year	baseline	design
2003	0.28	0.3
2004	0.59	0.68
2005	0.98	1.36
2006	1.48	2.24
2007	2.11	3.78
2008	3.25	6.15
2009	4.41	8.57

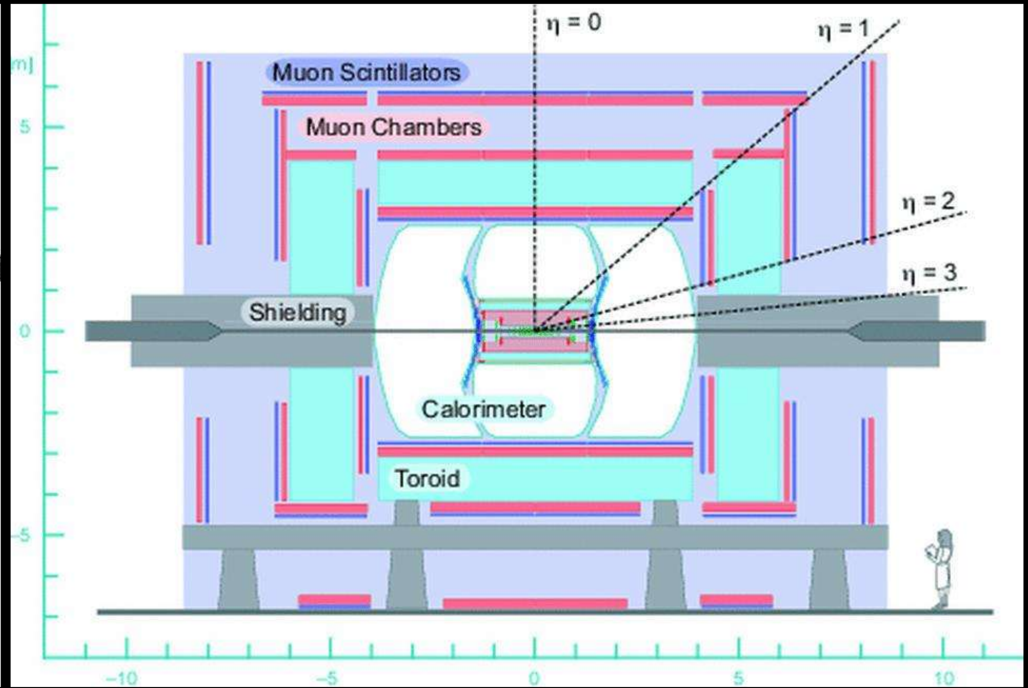
we are here





The CDF and DØ Experiment

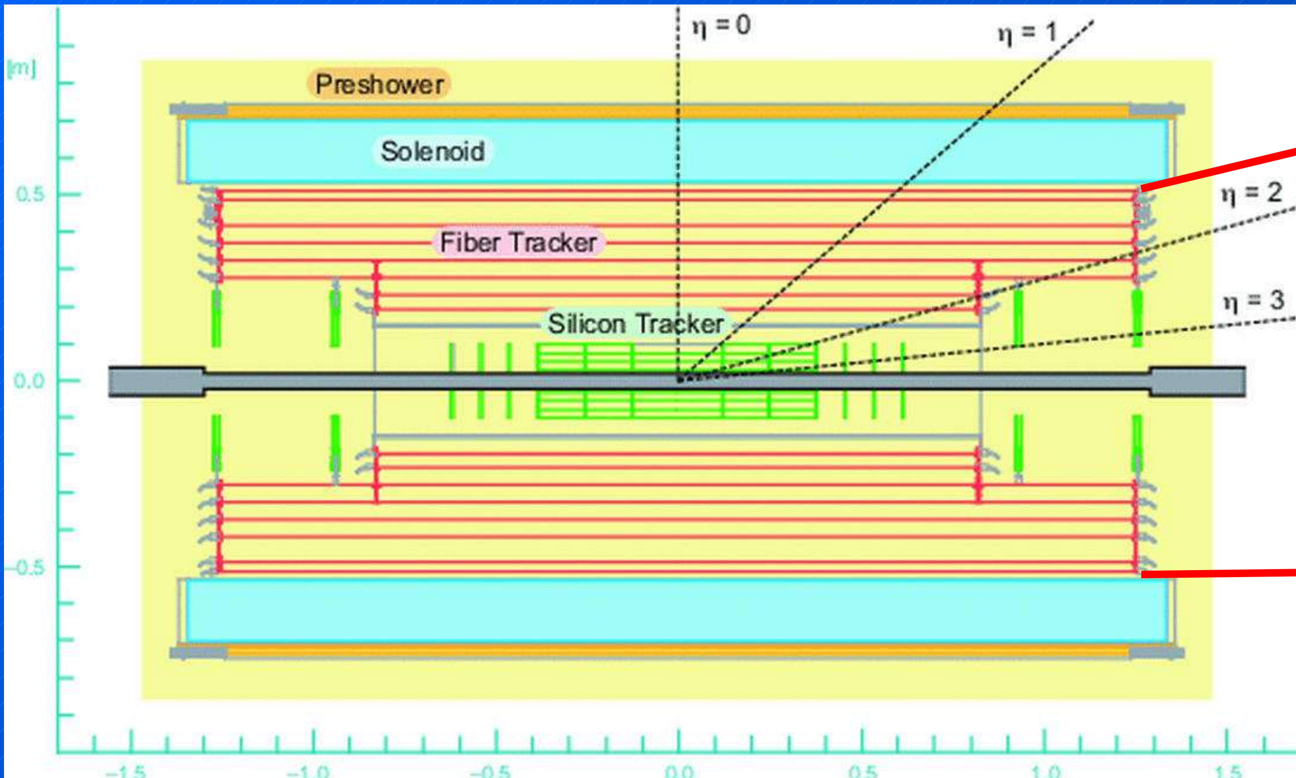


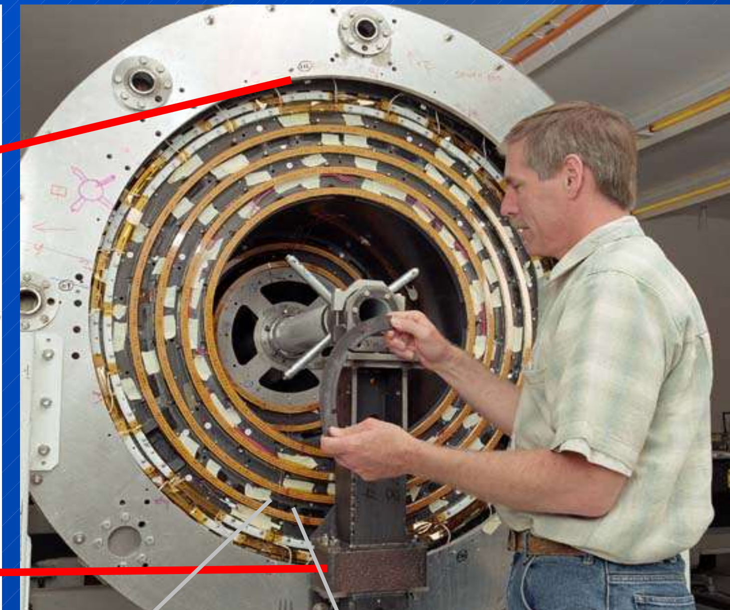


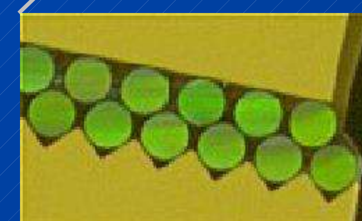
- new bigger silicon, new drift chamber, TOF
- Upgraded calorimeter and muon system
- Upgraded DAQ/trigger
- Displaced track trigger
- ~750 physicists

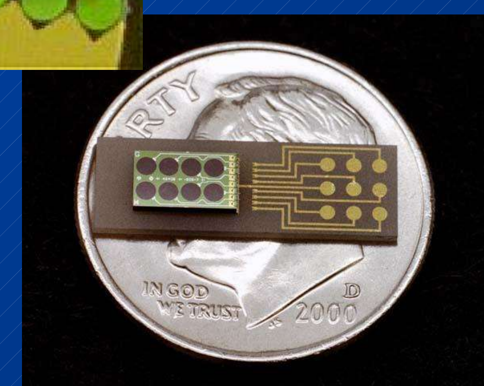
- new silicon and fibre tracker
- new ~2 T solenoid
- upgraded muon system
- upgraded (track) trigger/DAQ
- 19 countries, 83 institutes, 664 physicists

The DØ Fiber Tracker



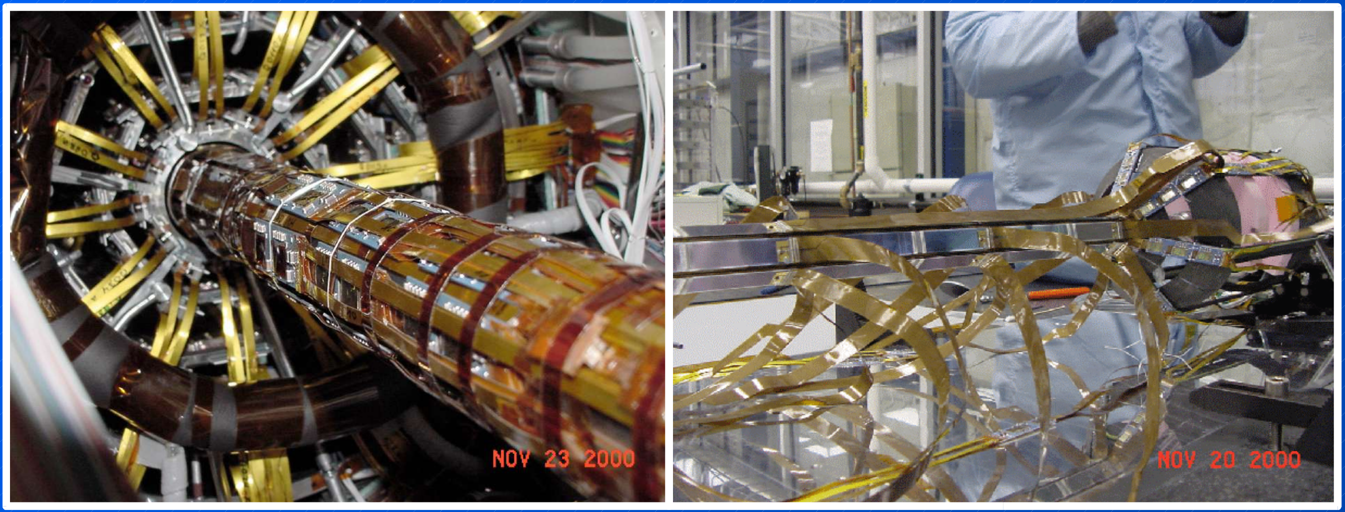


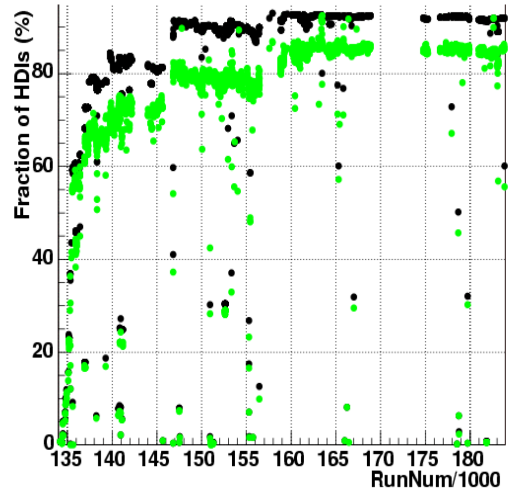




- Central Fiber Tracker:
  - 77k fibers in eight barrels, 800 μm diameter fibers
  - 3° stereo layers in each barrel
  - VLPC readout, ~7 photo-electrons/track at $\eta = 0$

Upgrade more ... L00

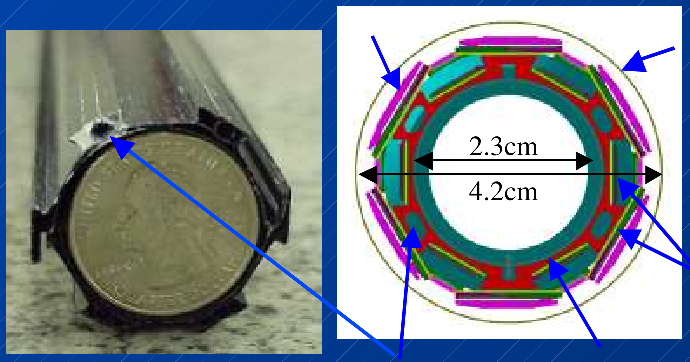




Precision position measurement before scattering

single-sided layer mounted on beam pipe

- 24 μm pitch; every other strip read out
- 0.6 % X_0 (no cooling) –
  1.0% X_0 (cooling, 15% of phi)
- actively cooled
- electronics at either end, large radii
- rad hard silicon; capable of 500V bias
  (will outlast SVXII inner layer)



QCD Studies

QCD Overview

- Rapidity Gaps/Diffractive/Elastic Physics
- PDF' sdouble parton interactions, W charge asymmetry
- non-perturbative QCD: jet shapes, W/Z boson p_T spectra
- perturbative QCD, particle cross section, W/Z bosons, prompt photons, jets, top, b/c quarks
- Perturbative QCD with W/Z bosons
- Perturbative QCD with jets: α_s, jet topologies
- ...

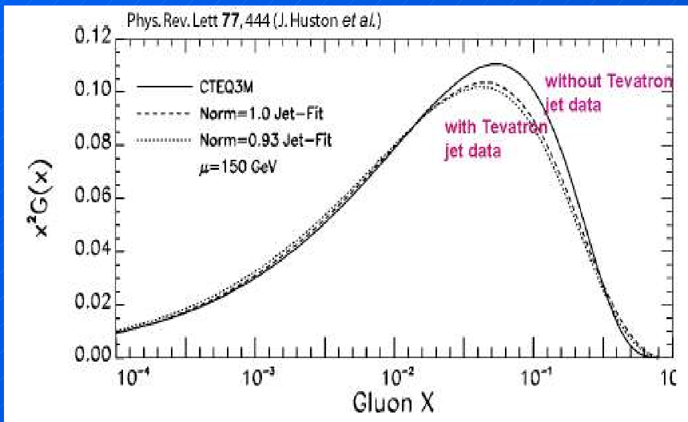
- Inclusive jet cross section
- Dijet mass spectra
- uncorrected dijet $\Delta\varphi$
- jet multiplicities in W+jet events

... here only a small selection ...

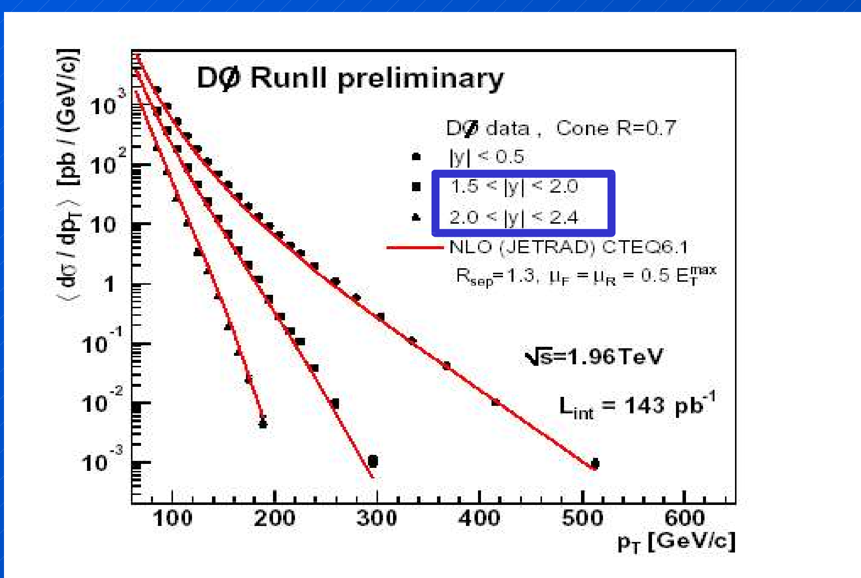
Inclusive Jet Cross Section (1)

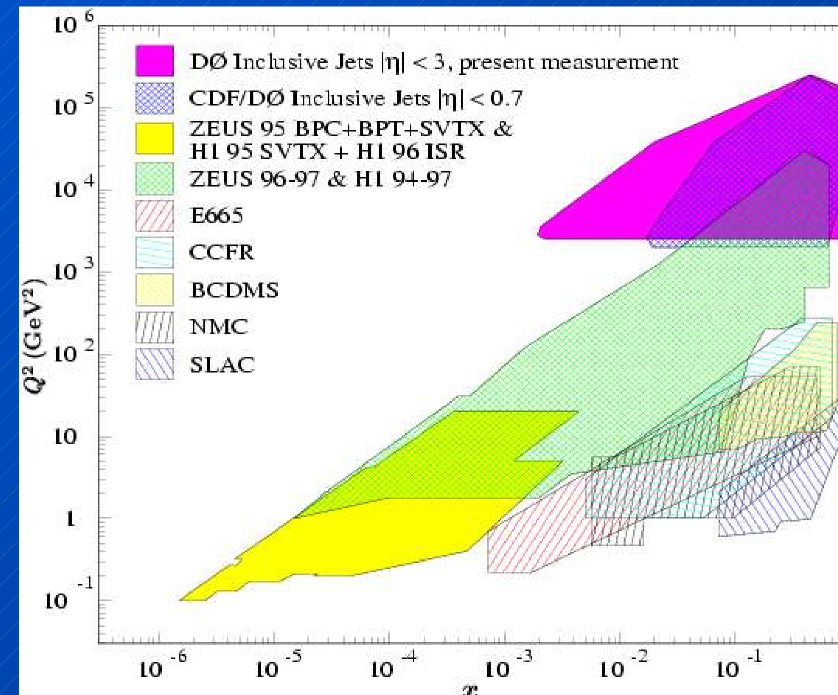
High E_T jets probe large x PDF's, especially gluon

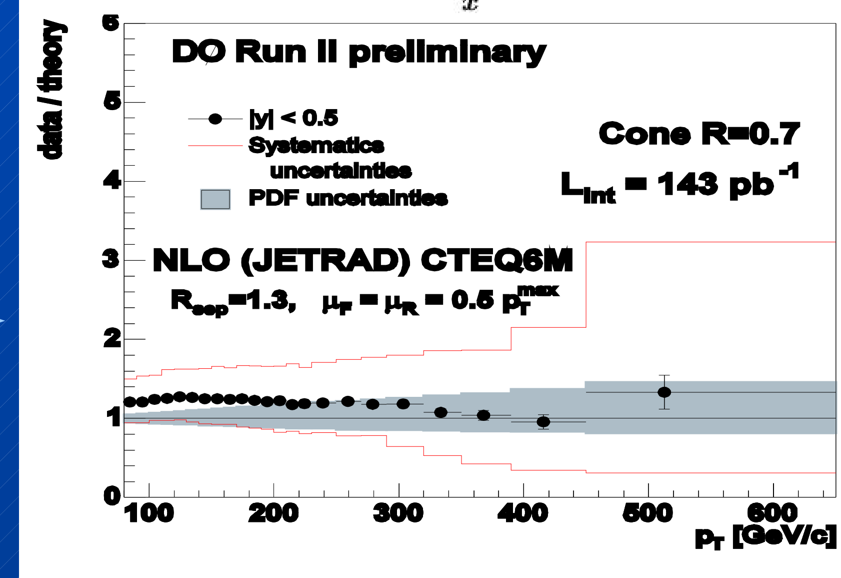
PDF: Run II has extended reach in jet E_T



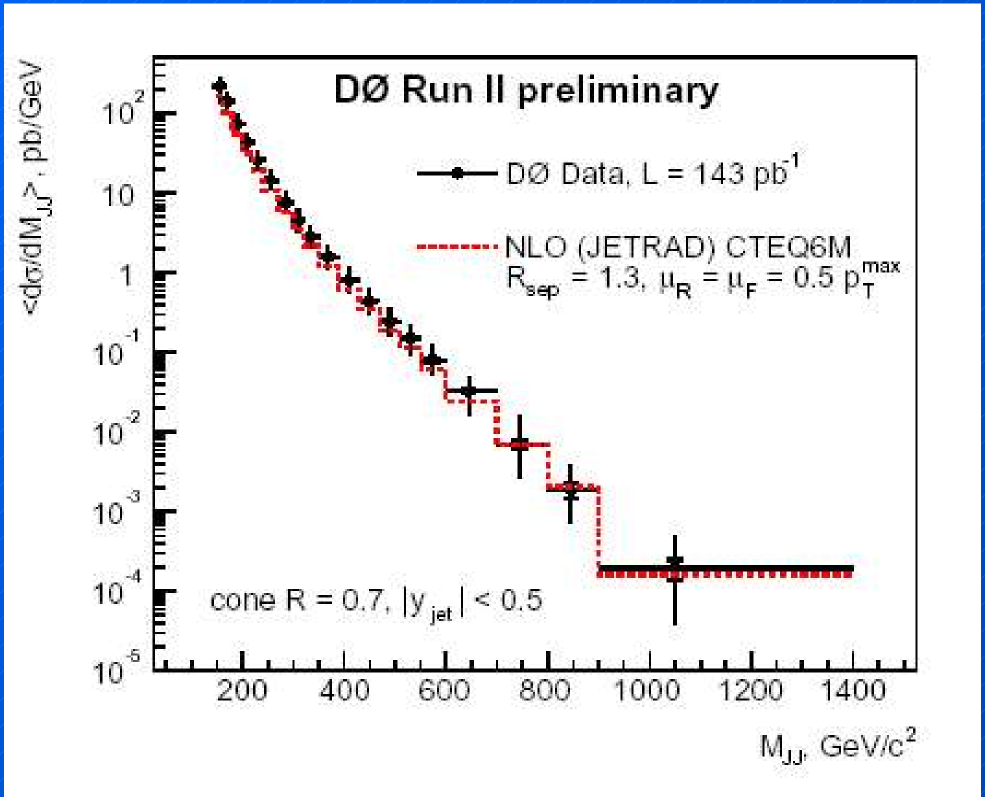
important info is in the cross section versus rapidity

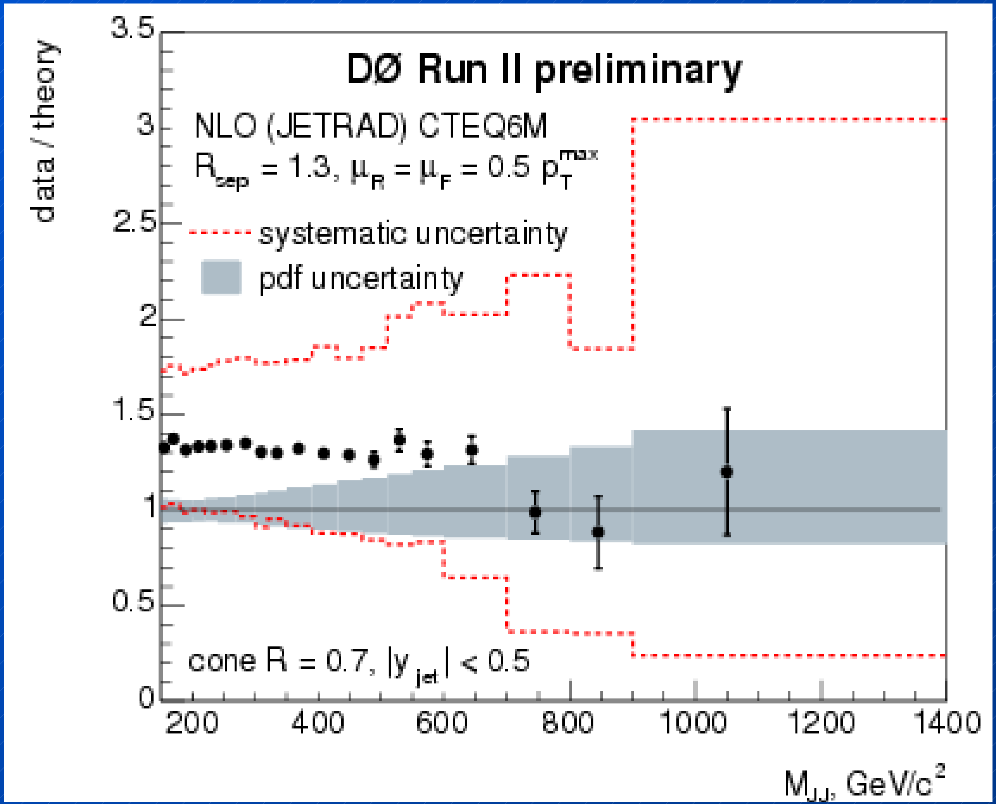






Dijet Cross Section



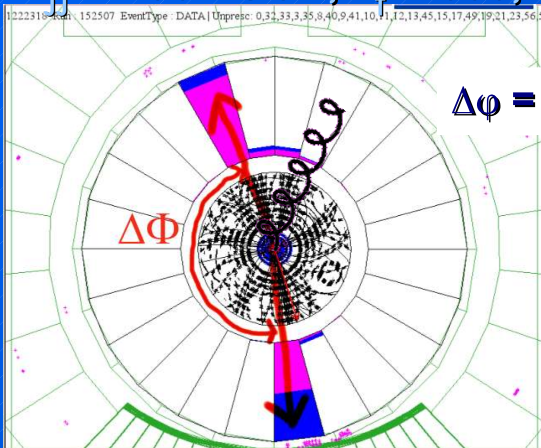


- Central region $|y_{jet}| < 0.5$, data sample ~ 143 pb^{-1}
- Run II midpoint algorithm
- sensitive to hadronically decaying resonances
- Good agreement between data and theory (NLO)
- Large uncertainties due to jet energy scale

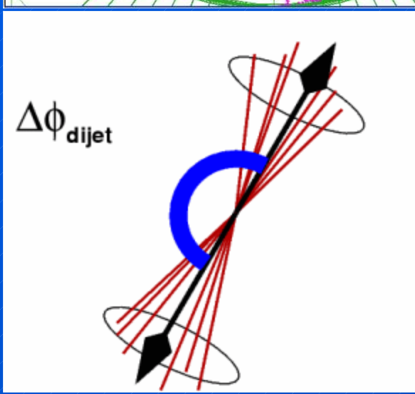
ΔΦ Decorrelation

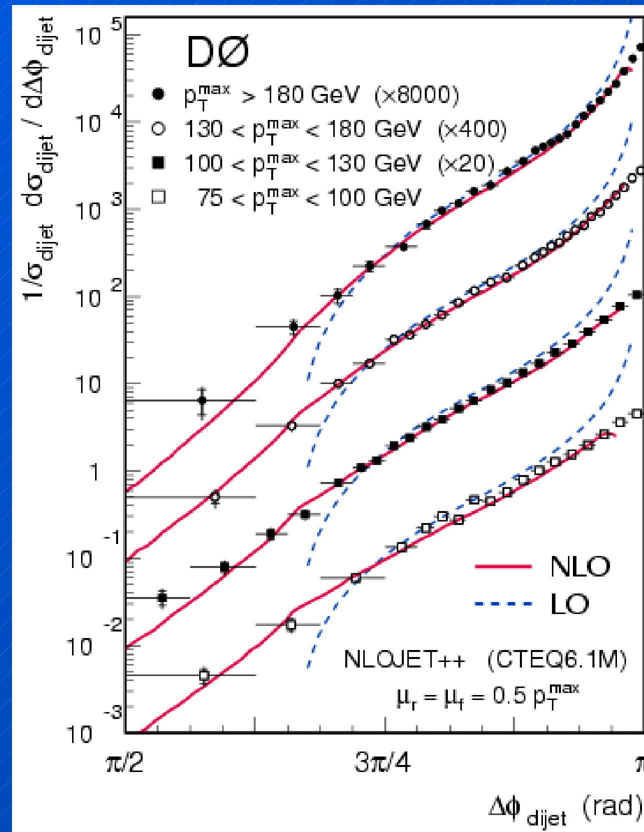
high mass event:

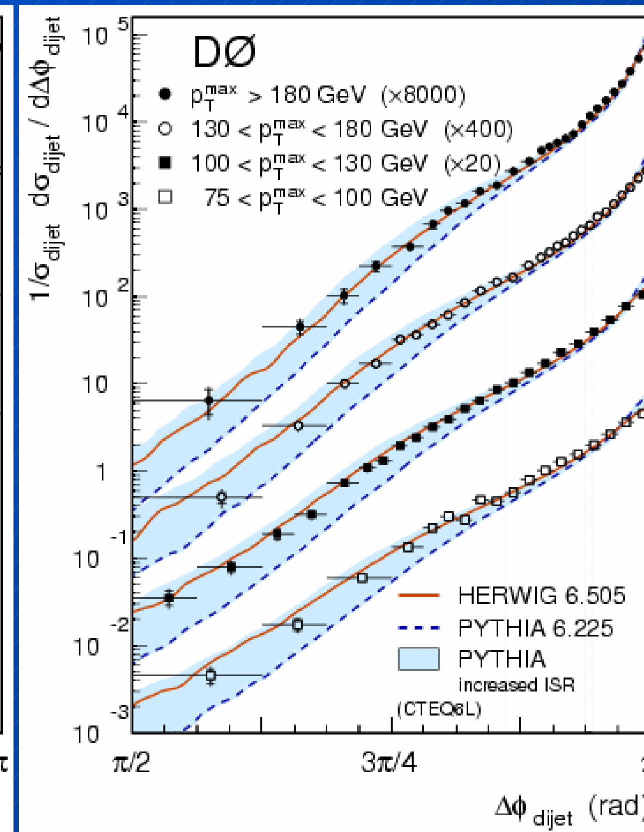
M_{jj} = 1364 GeV, E_T = 633, 666 GeV



Δφ = 180° at LO





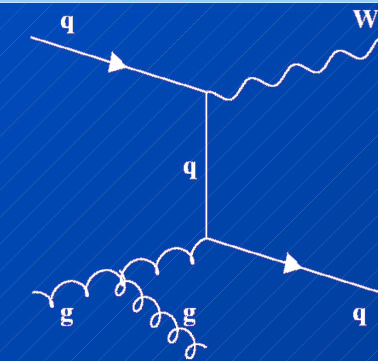


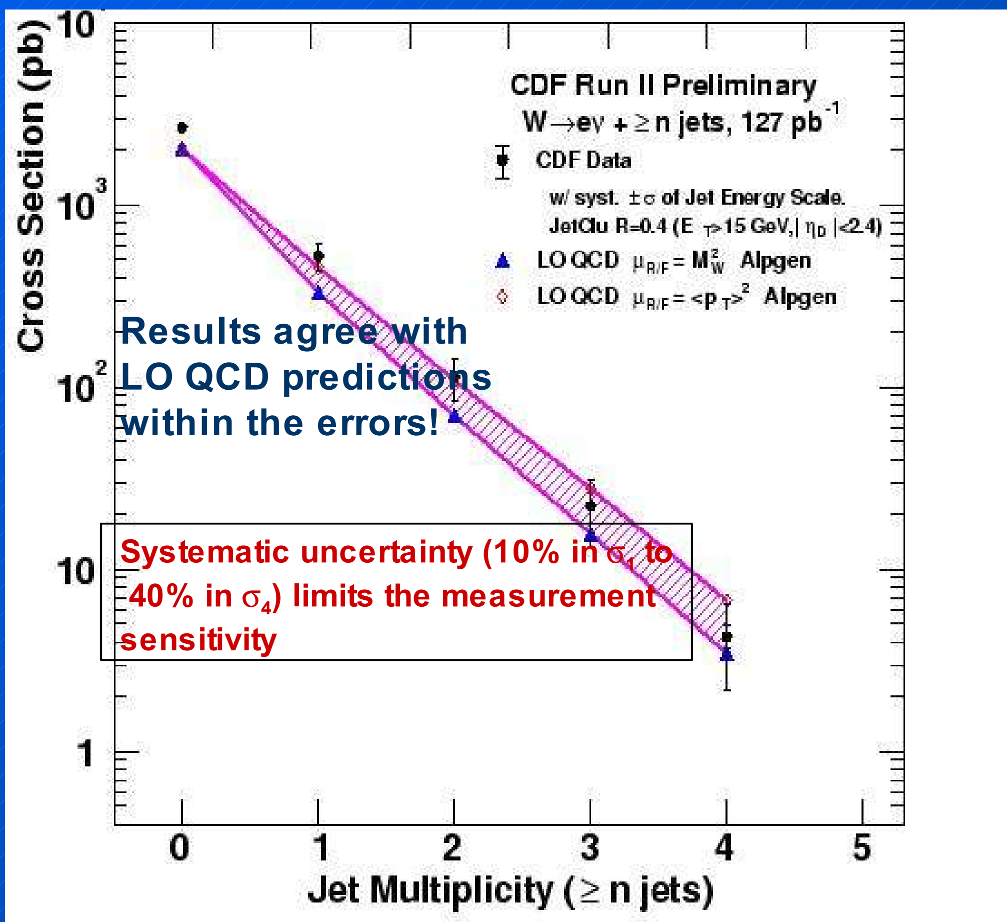
- test of multi-parton radiation
- pQCD & phenomenology
- sensitive to radiation/jets without measuring them ...
- 150 pb^{-1}

- observe increased decorrelation towards smaller p_T
- NLO pQCD describes data except for large Δφ (pQCD not predictive)

W+Jet Events

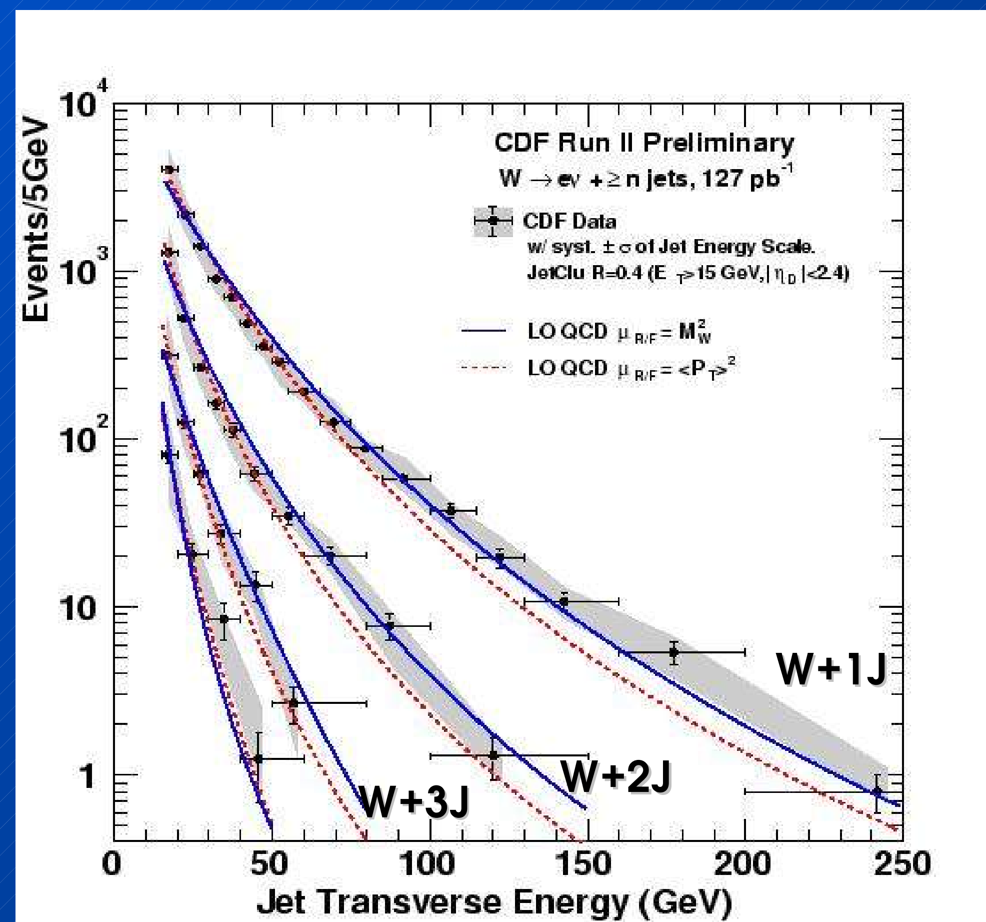
- Crucial to be able to calculate/understand this process for top & Higgs physics
- ALPGEN LO matrix element interfaced to HERWIG for parton shower
- not more than one parton associated with a reconstructed jet





Results agree with LO QCD predictions within the errors!

Systematic uncertainty (10% in σ_1 to 40% in σ_4) limits the measurement sensitivity



Electroweak Physics

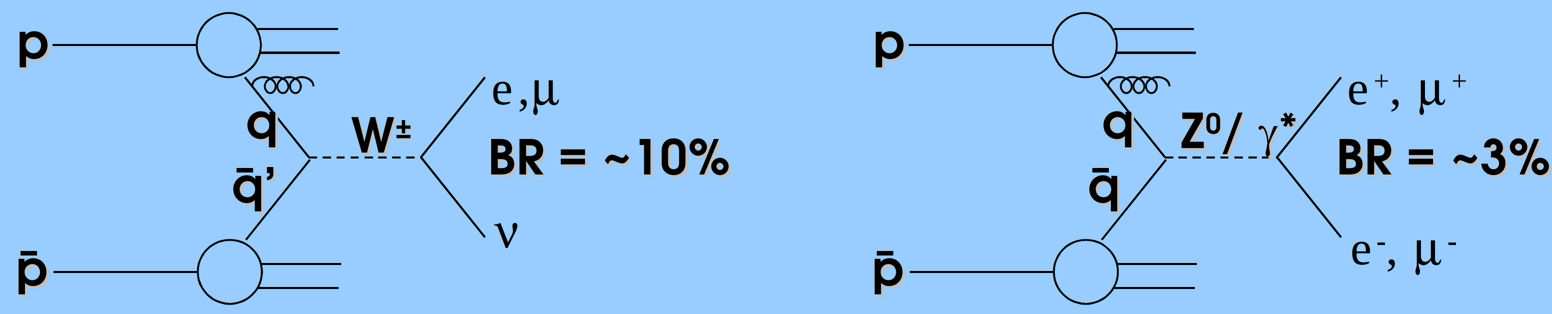
Electroweak Overview

- W/Z Production at the Tevatron
  - inclusive W/Z production cross section
- Z Production Characteristics
  - Drell-Yan, Asymmetry, ...

... here only a small selection ...

- W Production Characteristics
  - M_W, charge asymmetry, ...
- Associated Production of Vector Bosons
  - WW, WZ, Wγ, Zγ, ...

W and Z Production

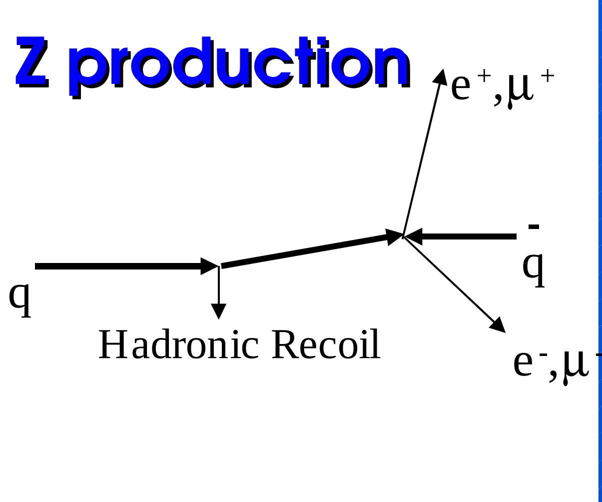


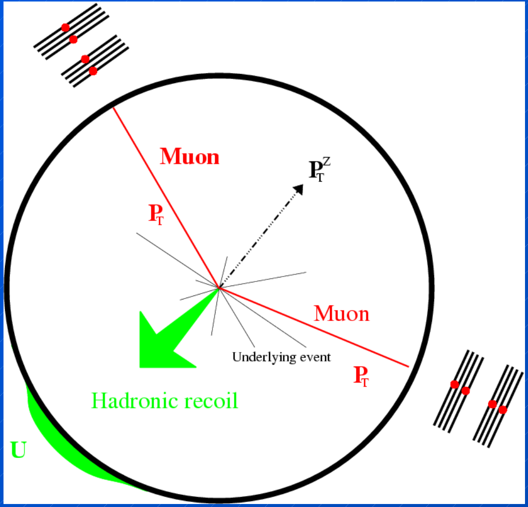
well understood event signatures

- leptonic decay modes avoid high jets background
- increase understanding of detector by studying W/Z production
- cross section relatively well known and high

σ_W *Br(W → ln) ~ 2.7 nb $\sigma_{Z/\gamma}$ * Br(Z/γ → ll) ~ 0.25 nb

Z Production

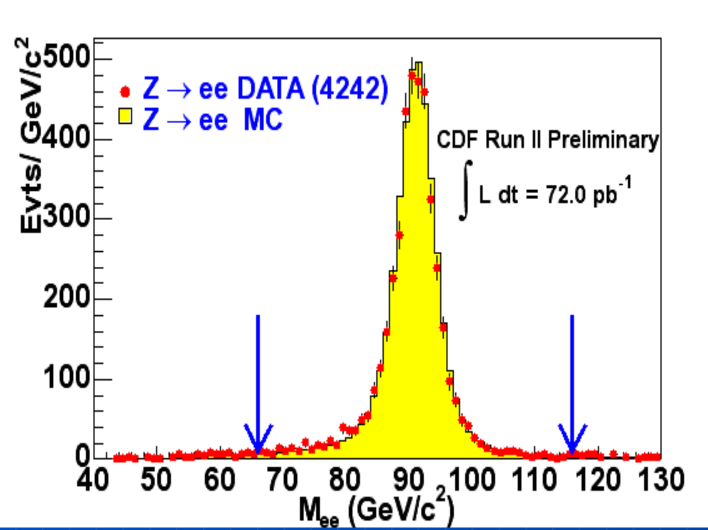




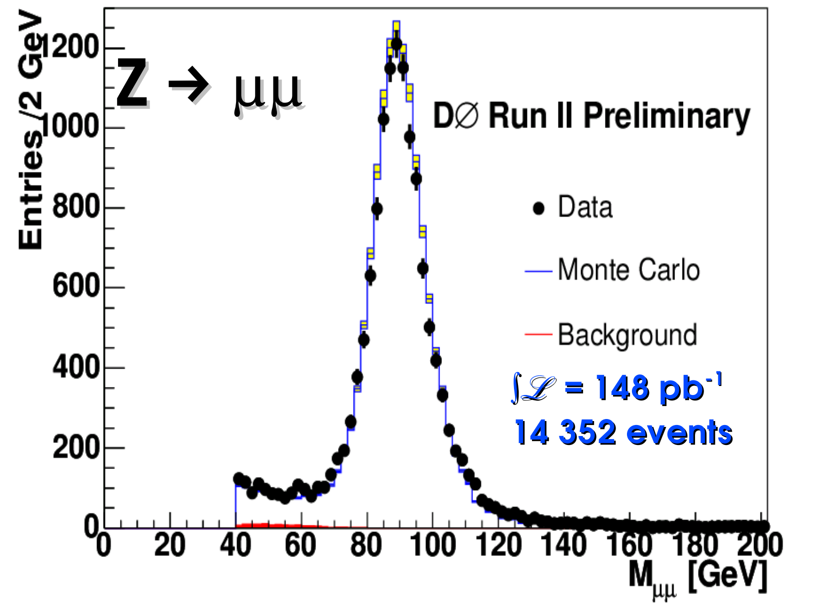
$$M_{l^+l^-} = \sqrt{(p_{l^+} + p_{l^-})^2} = \sqrt{2(E_{l^+}E_{l^-} - \vec{p}_{l^+}\vec{p}_{l^-})}$$

M_Z = 91.1876 ± 0.0021 (LEP/PDG)

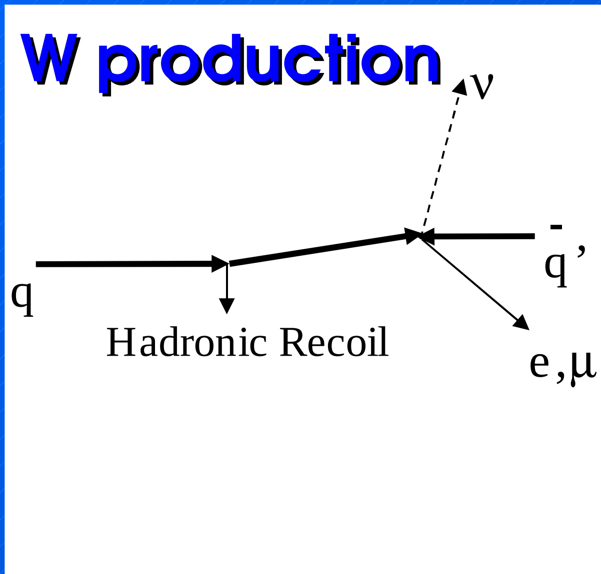
- select 2 opposite charged high-p_T leptons
- backgrounds: Z → ττ and qq/bb production for ee/μμ
- systematics: lepton-ID, PDF, acceptance, background
- correct from Z*/γ* to Z using MC

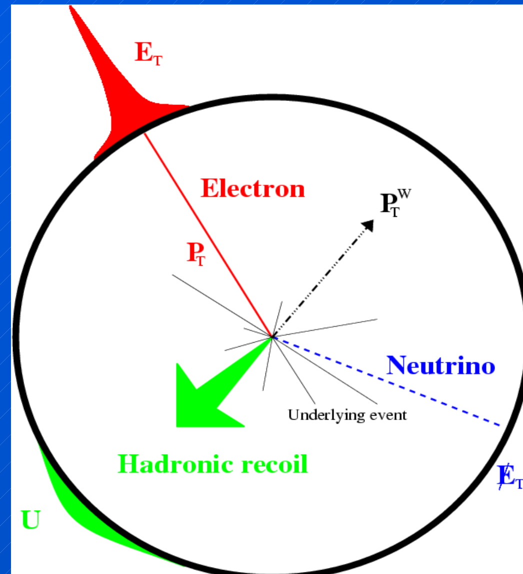


eff*acc ~ 16 – 29% !!!



W Production





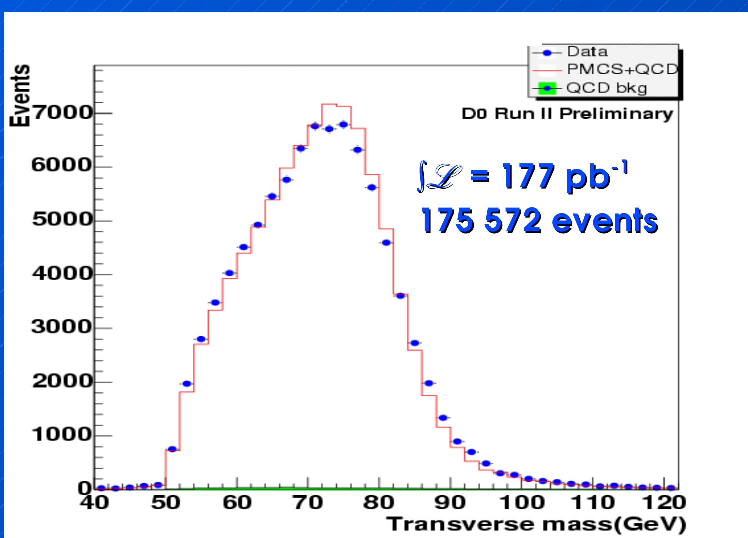
$M_{l\nu} = ?$ cannot measure p_z of ν

$$M_T = \sqrt{2(E_T^l E_T^{miss}(1-\cos\Delta\phi^{l,miss}))}$$

M_W = 80.425 ± 0.038 (LEP/TeV/PDG)

- select 1 high-p_T charged lepton and large missing E_T

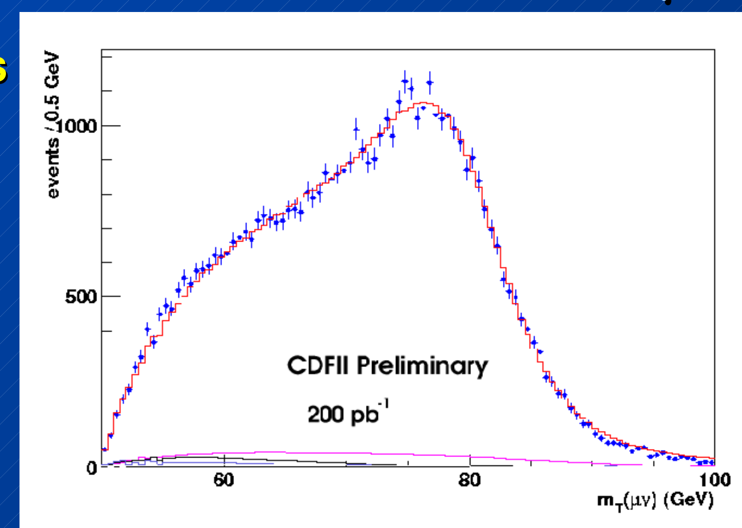
W → eν



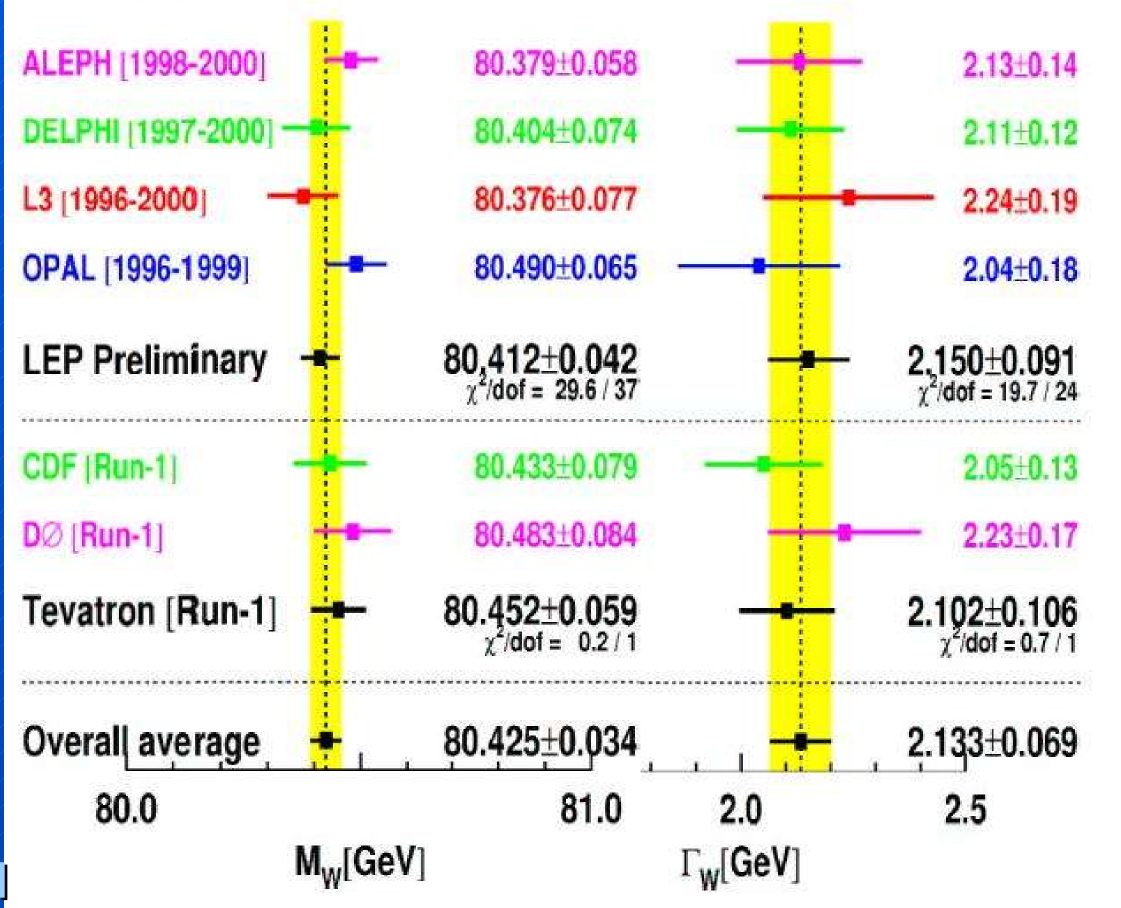
... can use this analysis as luminosity measurement; goal $\Delta\sigma$ = ±1% ...

... with 2 fb^{-1} expect: δm_W 40 MeV

W → μν



W Mass



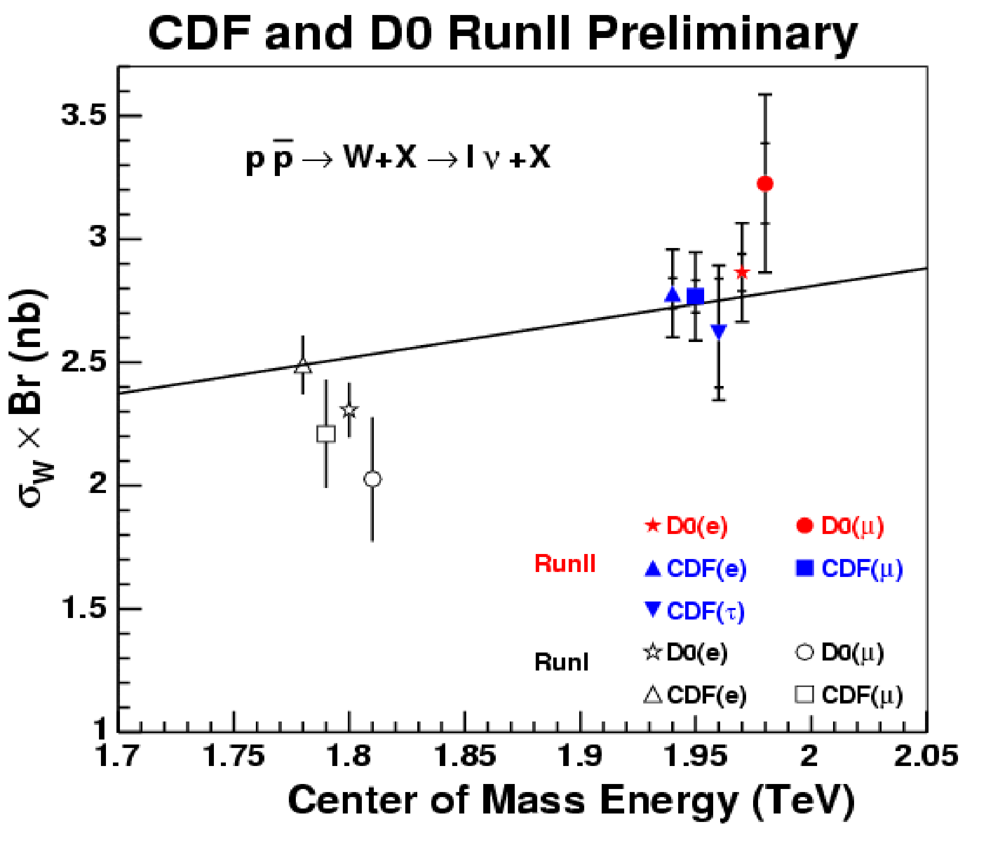
Tevatron W mass and width

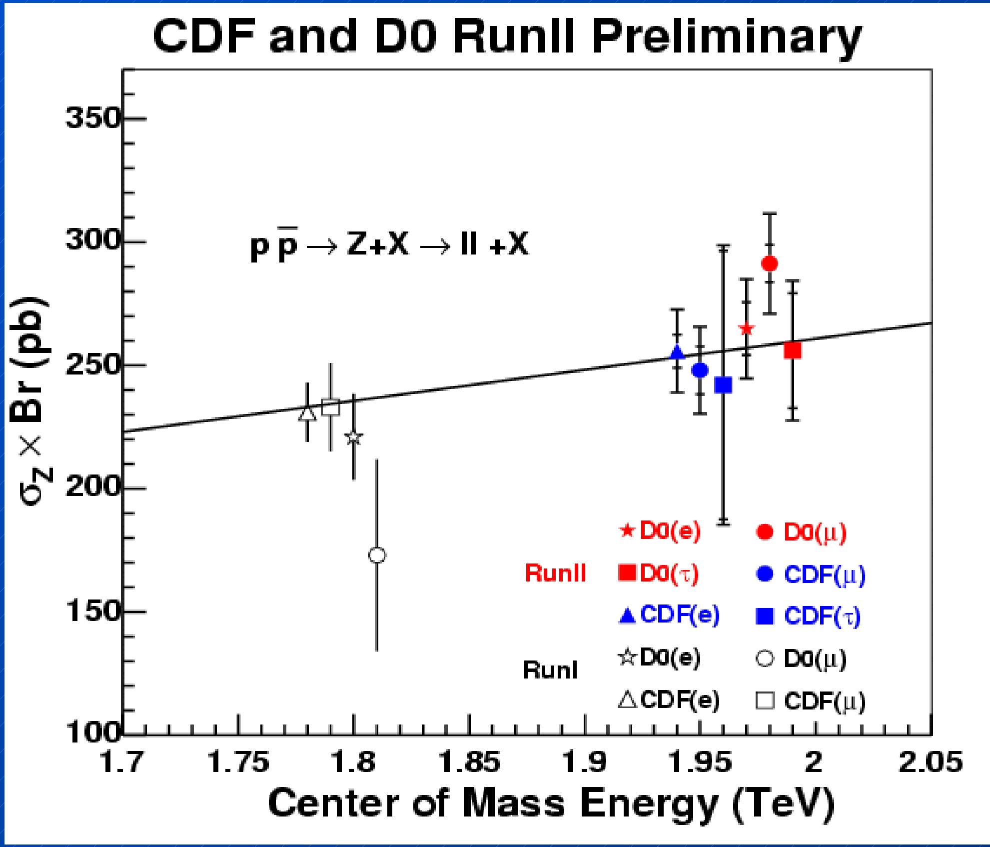
- from fits to M_T spectrum
  expect Δm_W = 40 MeV
  per experiment, 25 MeV combined

LEP-2 W mass and width

- from reconstructing W' s
  ee → WW → qqqq or qqlv
  difference between two final states: Δm_W = 22 +- 43 MeV

Summary of W/Z Cross Section





here CDF and DØ use different normalization
common normalization agreed recently for Run-II
... combination of results easier ...

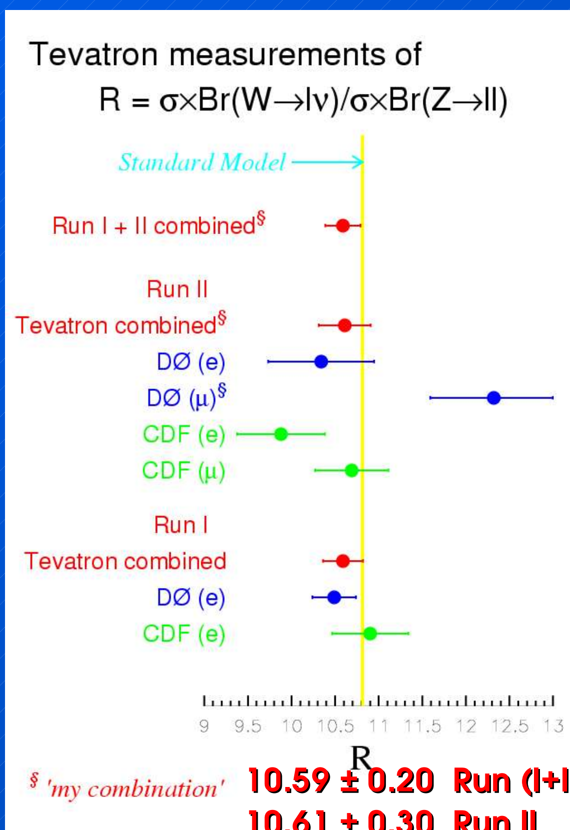
Indirect Measurement of Γ_W

measurement :

$$R = \frac{\sigma_W \cdot Br(W \to l\,\nu)}{\sigma_Z \cdot Br(Z \to l^+ l^-)}$$

- luminosity error cancels
- other systematics partially cancel:
  - PDFs
  - experi.: high pT, isolated leptons

summer'03

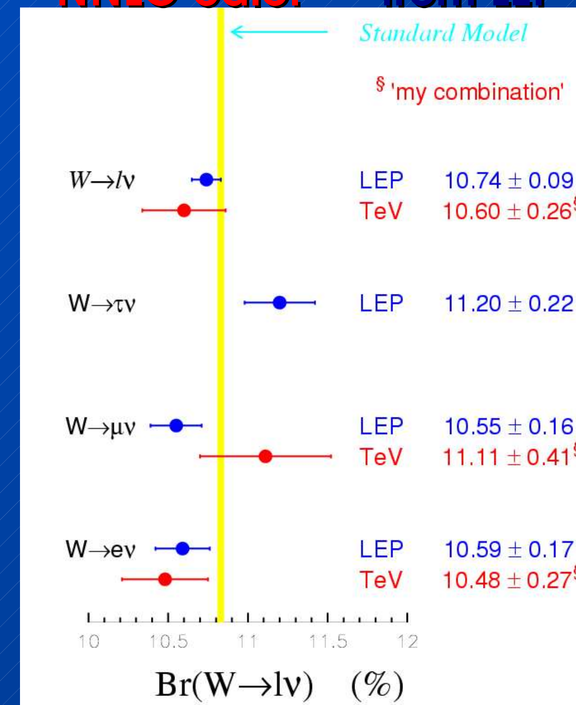


interpretation :

$$R = \frac{\sigma_W}{\sigma_Z} \cdot \frac{Br(W \to l\,\nu)}{Br(Z \to l^+ l^-)}$$

measurement (→ $Br(W \to l\nu)$)

NNLO calc. (→ σ_W/σ_Z) from LEP (→ $Br(Z \to l^+l^-)$)



$$Br(W \to l\nu) = \Gamma(W \to l\nu)\,/\,\Gamma_W$$

Tevatron combined : $\Gamma(W \to l\nu) = 2.135 \pm 0.053$ GeV

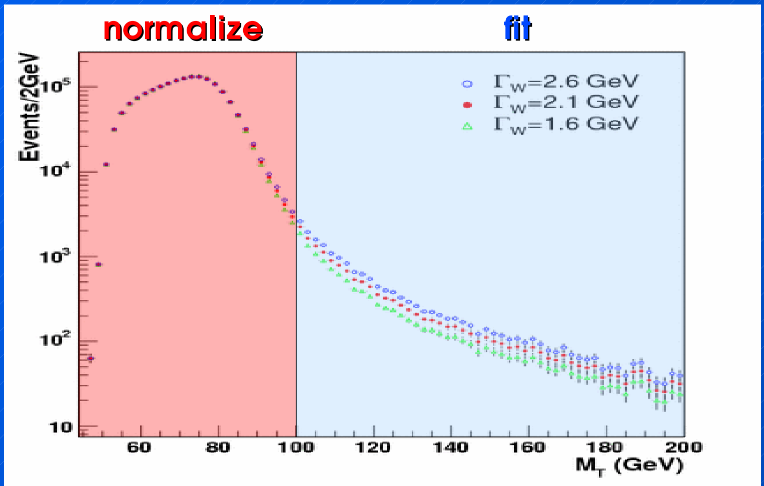
LEP & Tevatron direct: $\Gamma(W \to l\nu) = 2.139 \pm 0.069$ GeV

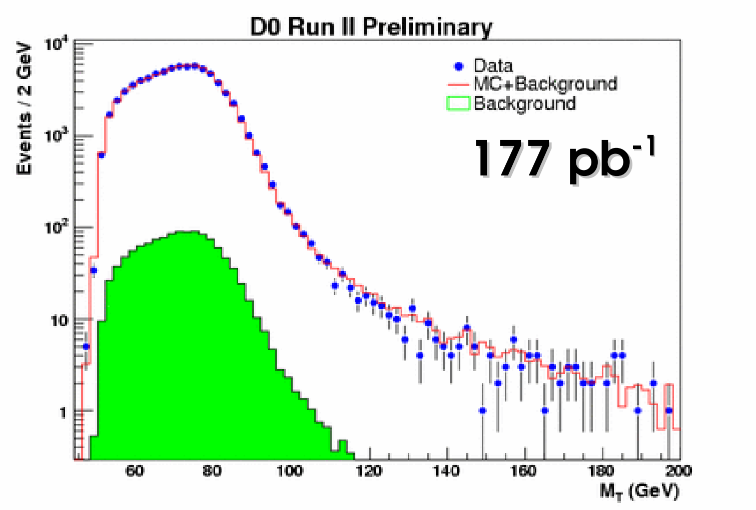
direct measurement of Γ_W from lineshape of M_T distribution

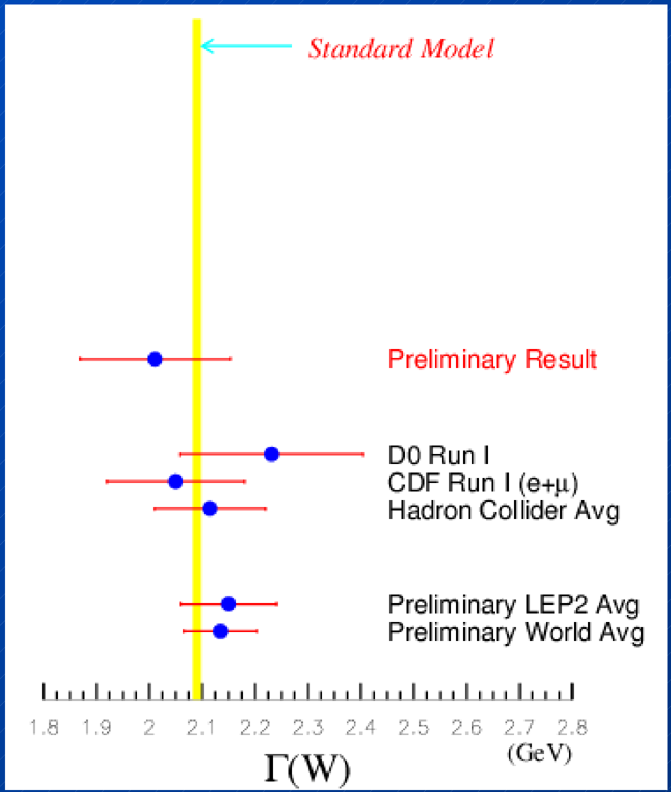
... consistency test of direct and indirect Γ_W ...

W-Boson Width (Direct)

- Γ_W precisely predicted in SM (masses and couplings)
- normalize m_T templates to 72285 W → eν candidates (50 < M_T < 100 GeV)
- fit predicted shape to 625 candidates in tail region (100 < M_T < 200 GeV)





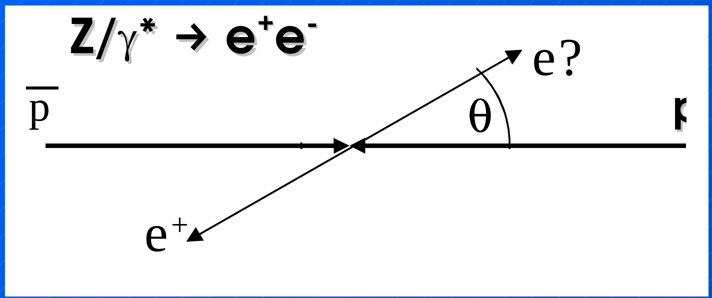


result: Γ_W = 2.011 ± 0.093 (stat) ± 0.107 (syst) GeV

consistent with SM and indirect measurement

syst. error dominated by EM & HAD resolution and underlying event

Forward-Backward Asymm. in Z Production



coupling ~ $(g_V + g_A\gamma^5)$

$g_V = I_3 - 2Q_f \sin^2\theta_W$

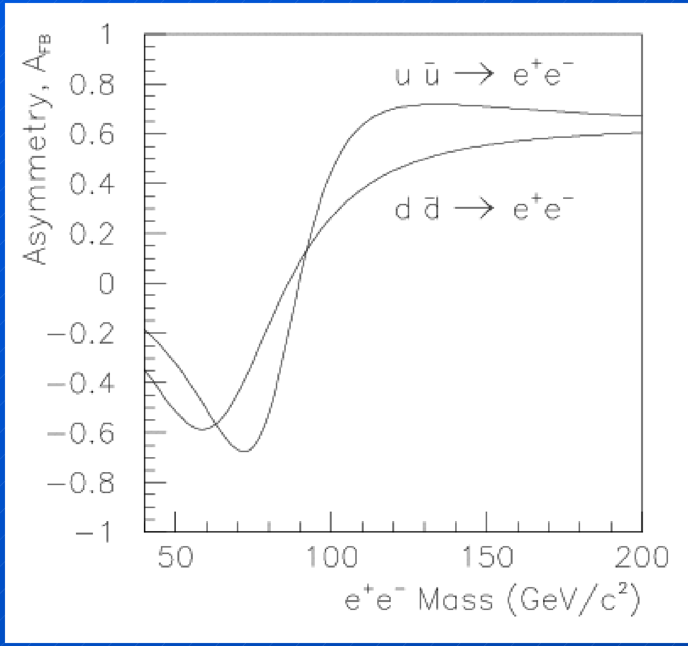
$g_A = I_3$

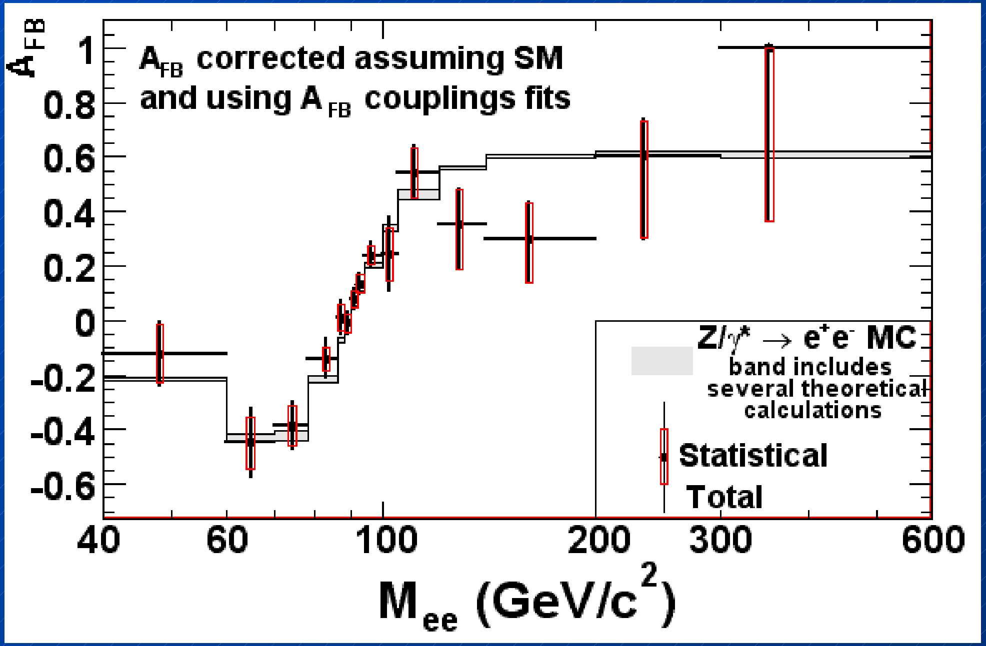
$$\frac{1}{\sigma}\frac{d\sigma(s)}{d\cos\theta^*} = \frac{3}{8}(1+\cos^2\theta^*) + A_{FB}(s)\cos\theta^*$$

$$\Rightarrow \quad A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

- at Tevatron can measure at Z pole, and above and below
- directly probes V-A, extract $\sin^2\theta_W$ and u/d couplings to Z

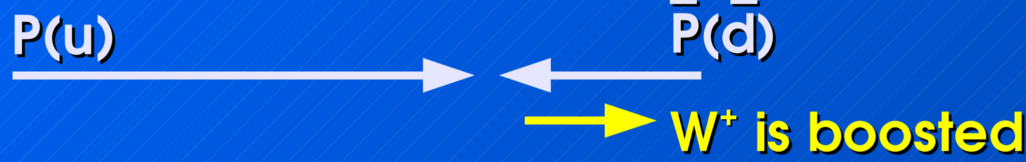
$\sin^2\theta_W = 0.2238 \pm 0.0046(\text{stat.}) \pm 0.0020(\text{syst.})$





W Charge Asymmetry (1)

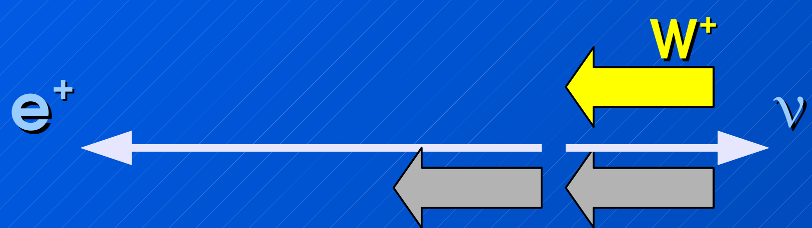
W production is asymmetric



u-quark in proton carries more momentum then d-quark (dbar-quark in antiproton)

- ⇨ more W^+ in direction of P
- ⇨ more W^- in direction of Pbar

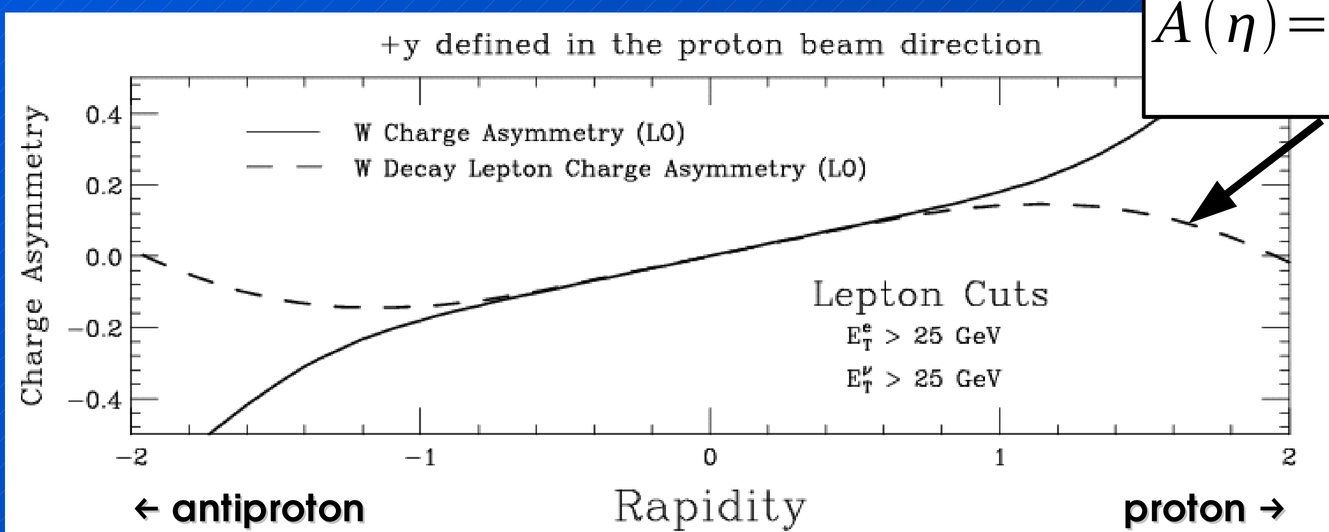
V-A decay: opposite asymmetry



W almost fully polarized
lepton decay angular distribution
$\propto (1 - \cos\theta^*)^2$

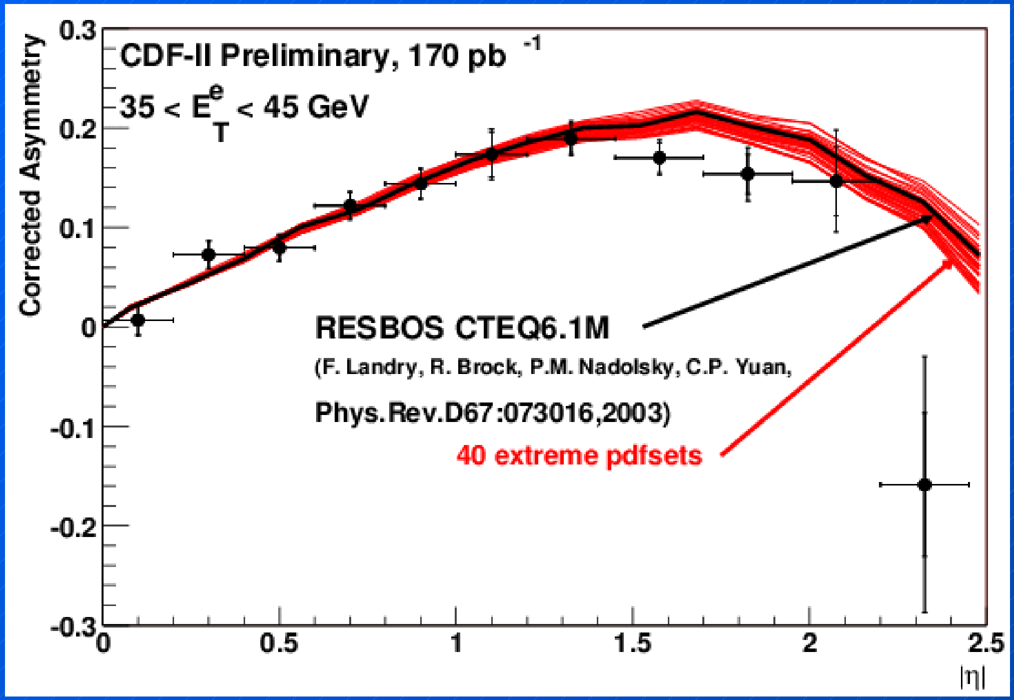
- ⇨ more e^+ in direction of Pbar
- ⇨ more e^- in direction of P

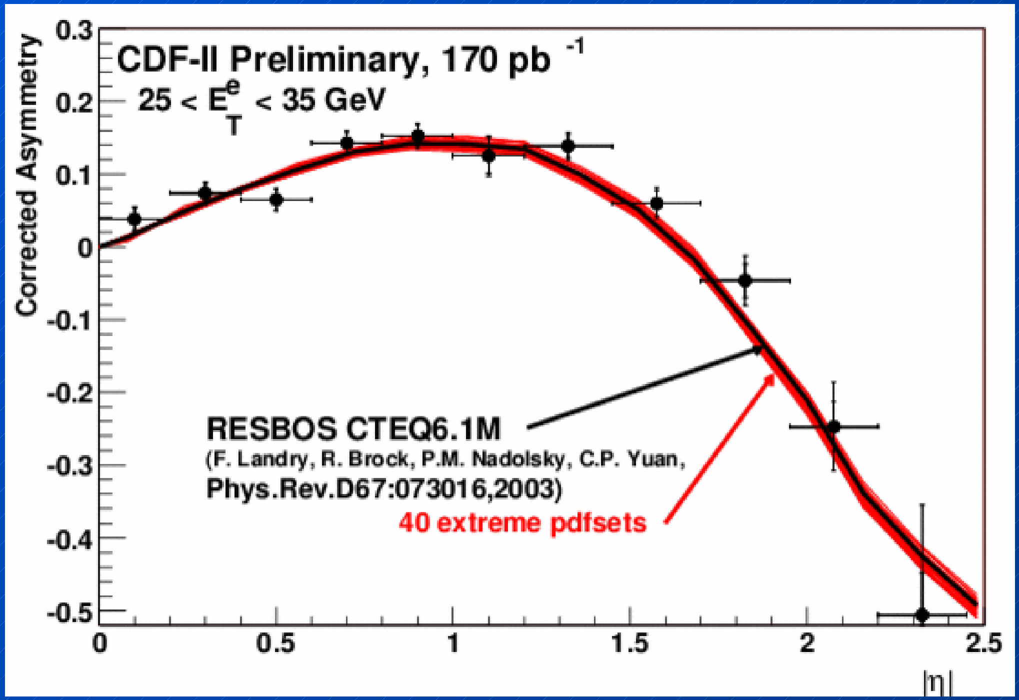
$$A(\eta) = \frac{d\sigma/d\eta(e^+) - d\sigma/d\eta(e^-)}{d\sigma/d\eta(e^+) + d\sigma/d\eta(e^-)}$$



... probes u(x)/d(x) ratio ...

W Charge Asymmetry (2)

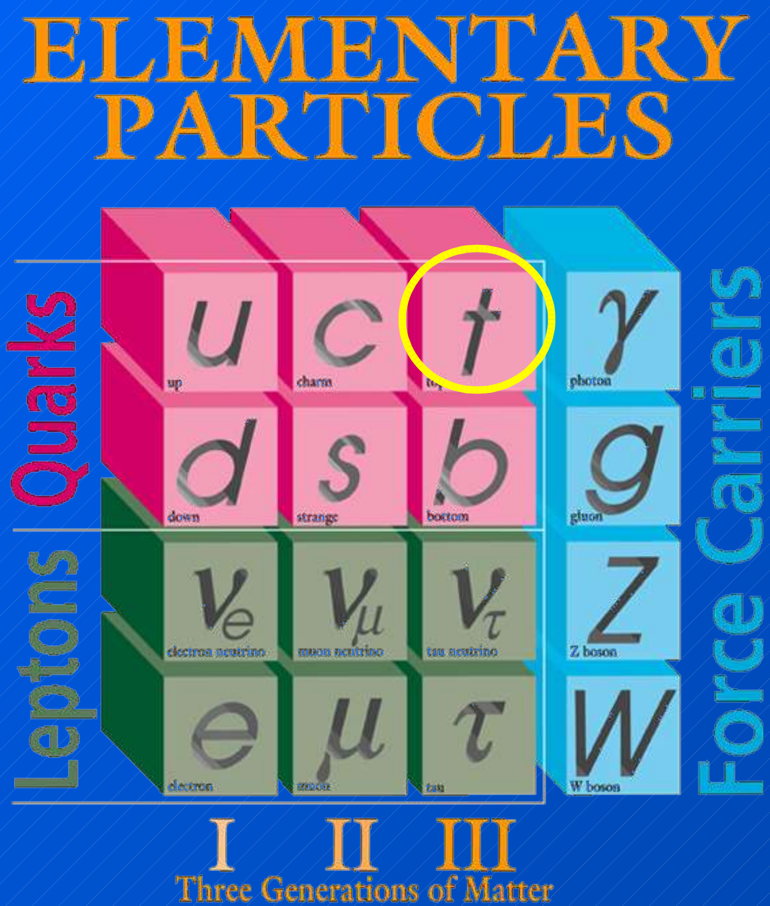




... Tevatron measurement provides
main constraint of high-x PDF' s at large scales ...

Top Quark Physics

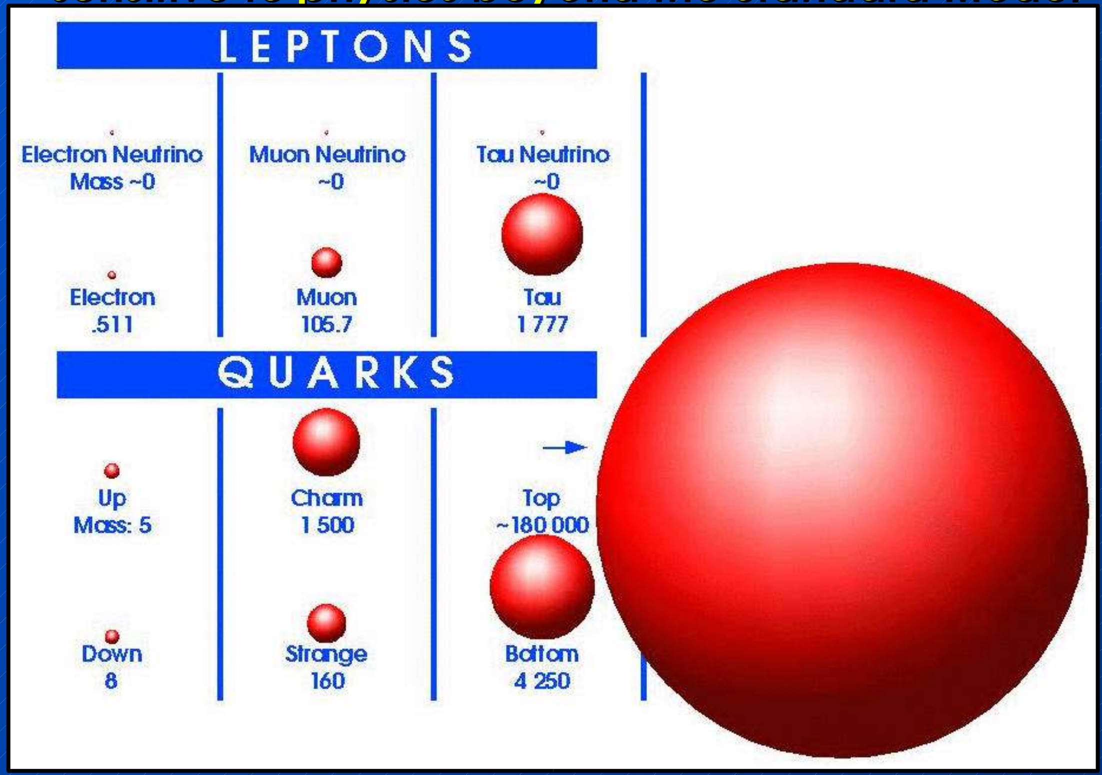
Top Quark in the Standardmodel



Discovery of the Top Quark in 1995 by the CDF and DØ Collaborations.

Why is the Top Quark so interesting ?

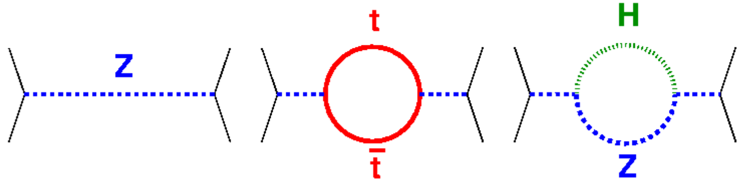
- ✗ completes the quark sector
- ✗ large mass $m_{top} \sim 180\ GeV / c^2$
- ✗ short lifetime $\tau \sim 5 \cdot 10^{-25} s \ll \Lambda^{-1}_{QCD}$
- ✗ sensitive to physics beyond the Standard Model



Higgs-Boson coupling to fermions : $g \sim m_f$

$m_t \sim v/\sqrt{2}$, Yukawa coupling $\lambda_t \sim 1$

Top Quark in the Standardmodel

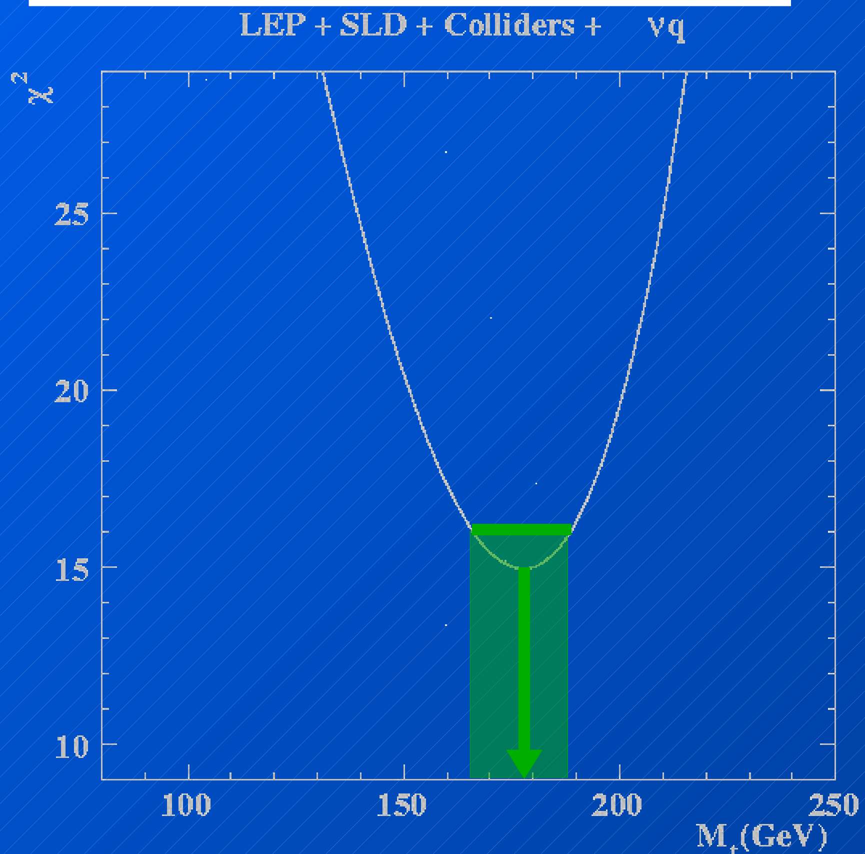


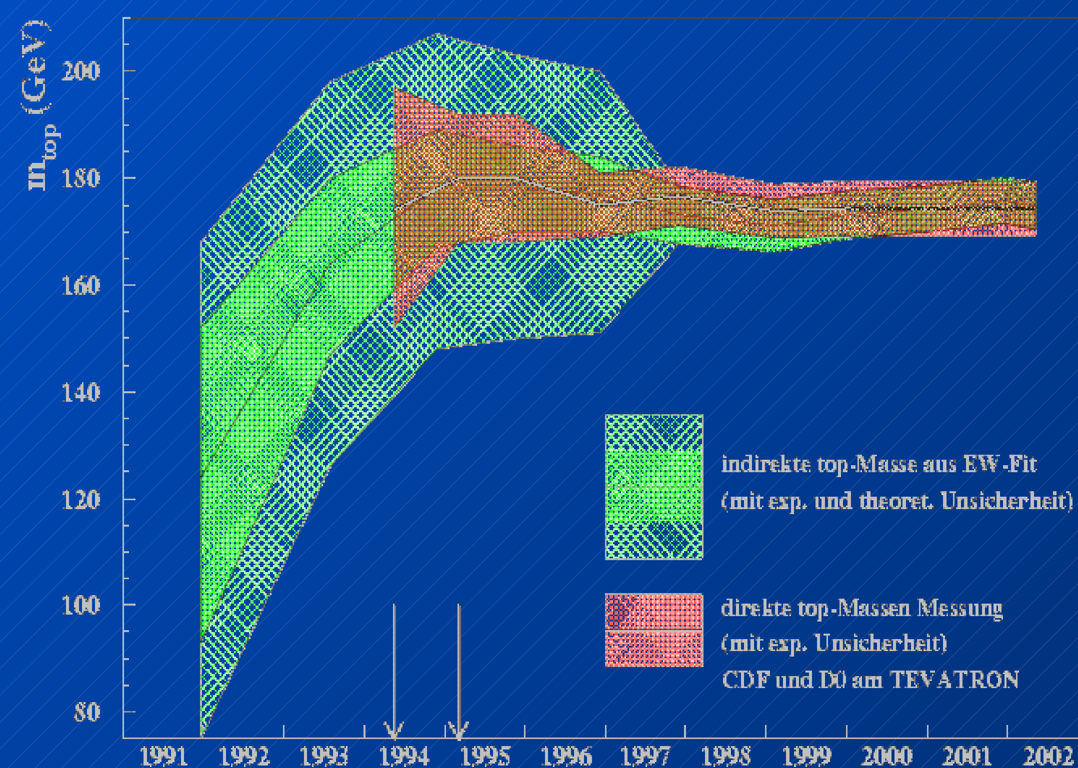
$$M_Z^2 = M_Z^{2\ 0.Ordnung} \cdot (1 + \Delta)$$

$$\Delta^{-1} = \ldots M_t^2 \ldots + \ldots \ln M_H \ldots$$

corrections to W and Z boson mass from top quark and Higgs boson loops allow prediction of the top quark and the Higgs boson mass

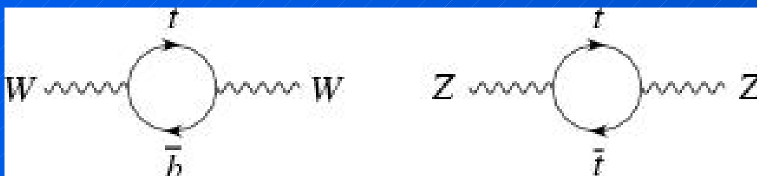
comparison of precision EW measurement ↔ corrections
⇒ prediction of top quark mass



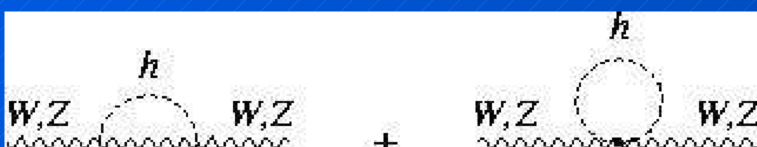


Top Quark in the Standardmodel

corrections to W and Z boson mass from top quark and Higgs boson loops allow prediction of the top quark and the Higgs boson mass



corrections: ~ m_{top}^2

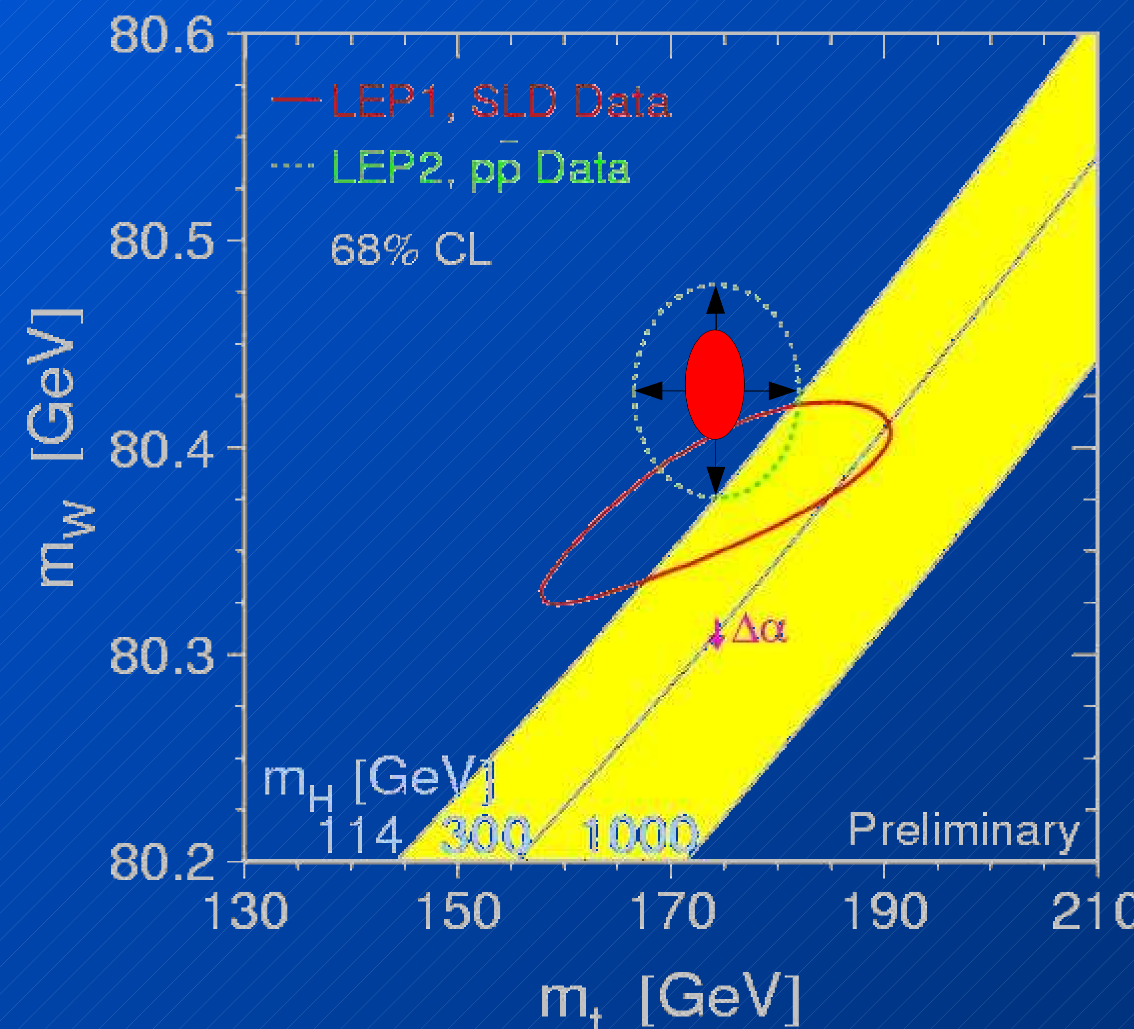


corrections: ~ ln (m_{higgs})

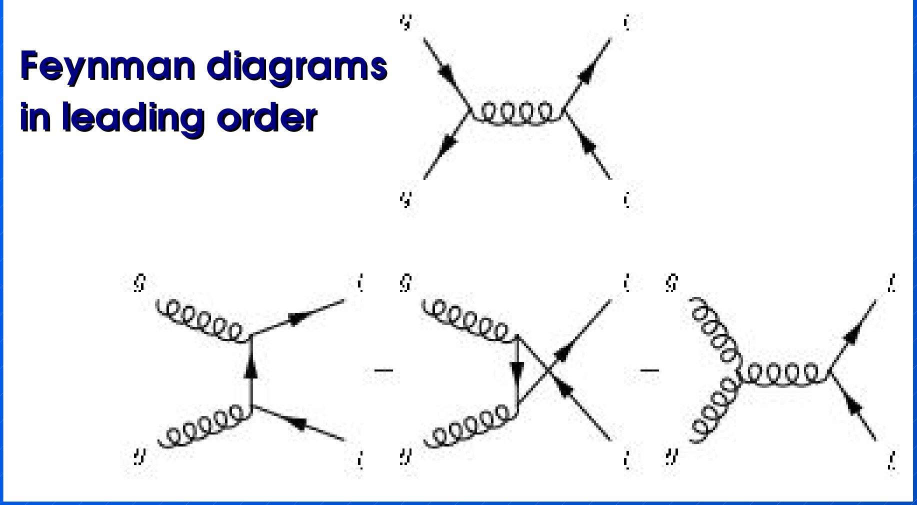
goal for Tevatron in Run II:

Δm_{top} = 2-3 GeV

Δm_W = 20 MeV

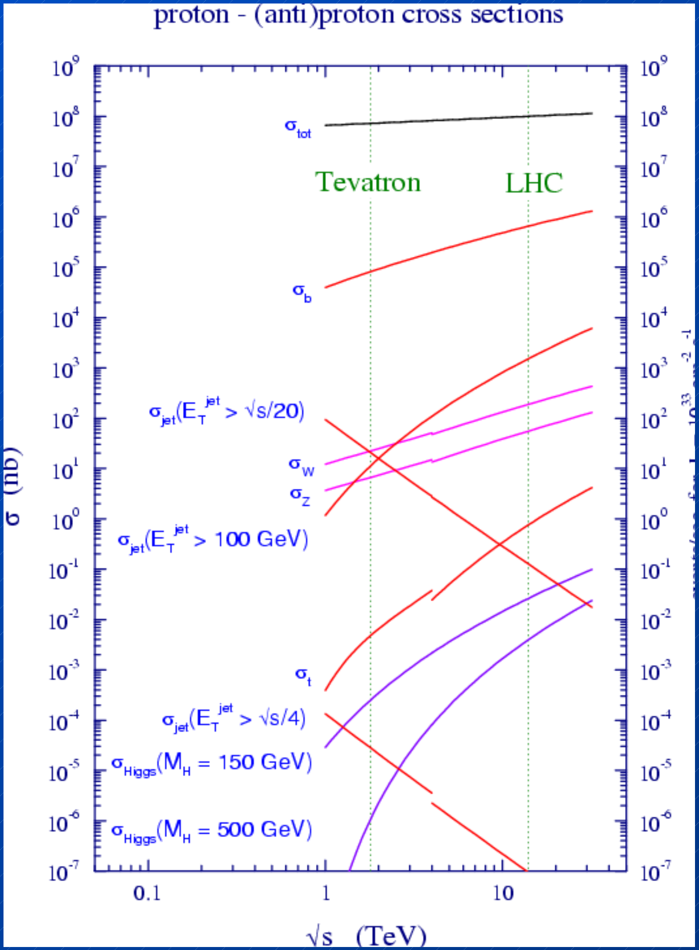


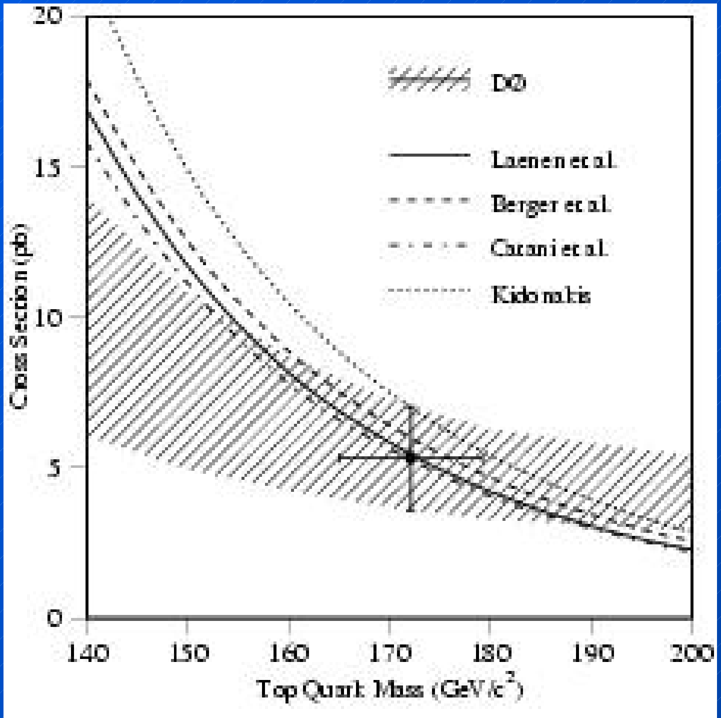
Top Quark in the Standardmodel



qq ~ 85 %

gg ~ 15 %

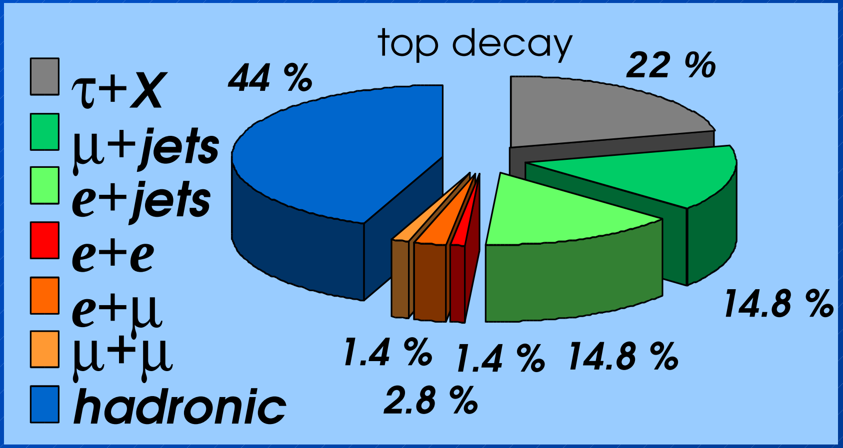




	Run I	Run II (2 fb^{-1})	LHC (10 fb^{-1})
ttbar (m_t sample 1 b-tag)	20	800	$8 * 10^6$
single top	4	100	...

- establish top signal
- measure cross section as QCD test
- cross section and topology close to Higgs physics

W-Decay Determines Topology



Top quarks decay predominantly (~100%) to a W-Boson and a b-quark

Top-Antitop Signatures:

`dilepton channel'

5% : 2 jets, 2 charged leptons, 2 ν

' lepton+jets channel'

30%: 4 jets, 1 charged lepton, 1 ν

signal signature

' dl-jets channel'

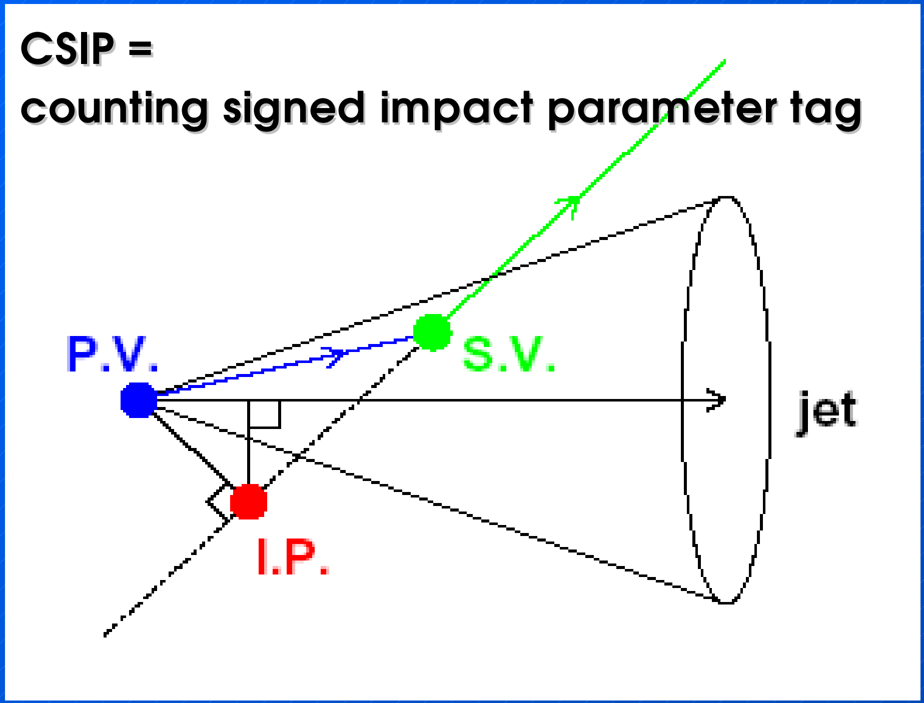
40%: 6 jets

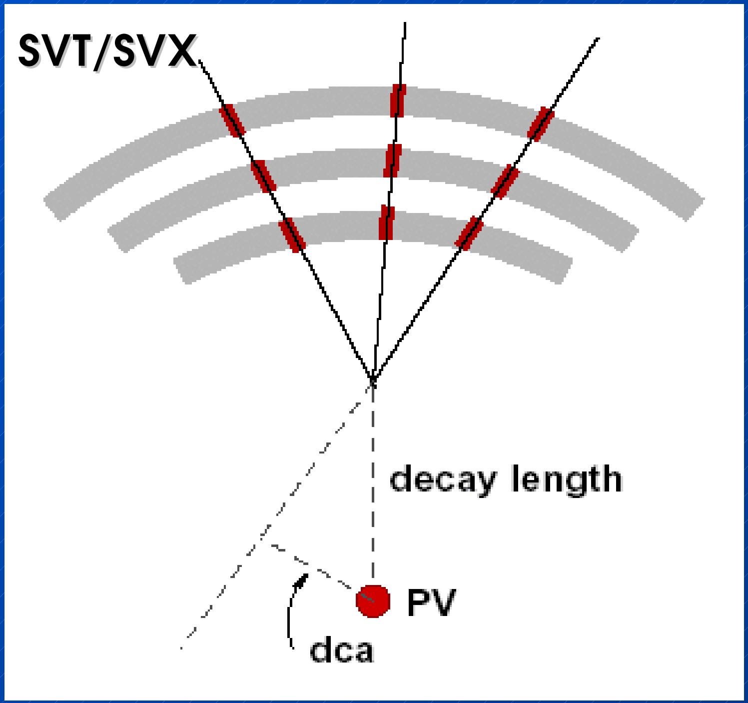
always 2 jets are b-jets

also look for lifetime- or μ-tag

... measure top production cross section (strong and weak) and properties ...

b-tagging in CDF and DØ



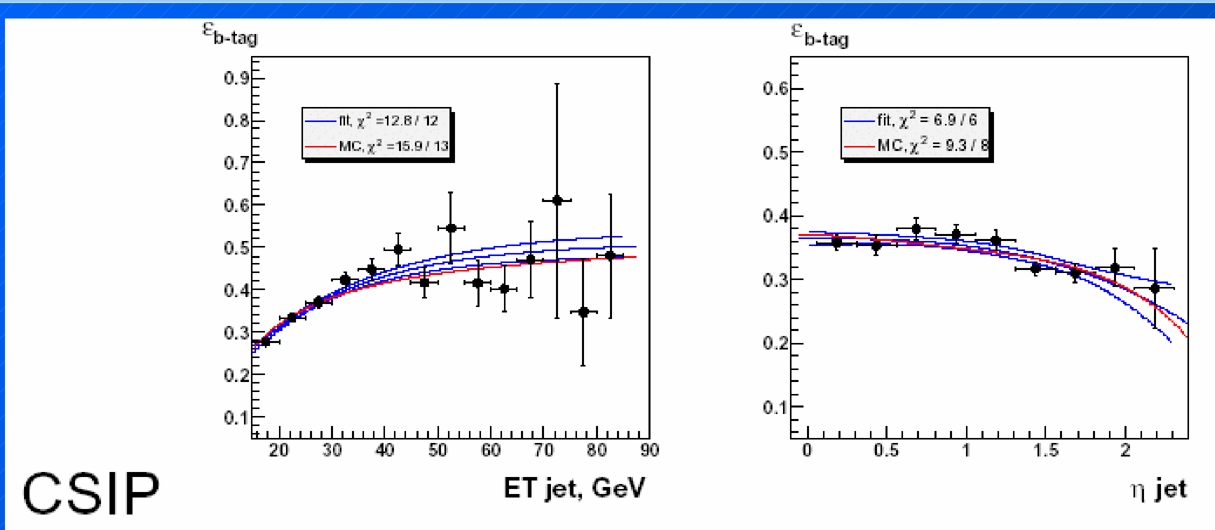


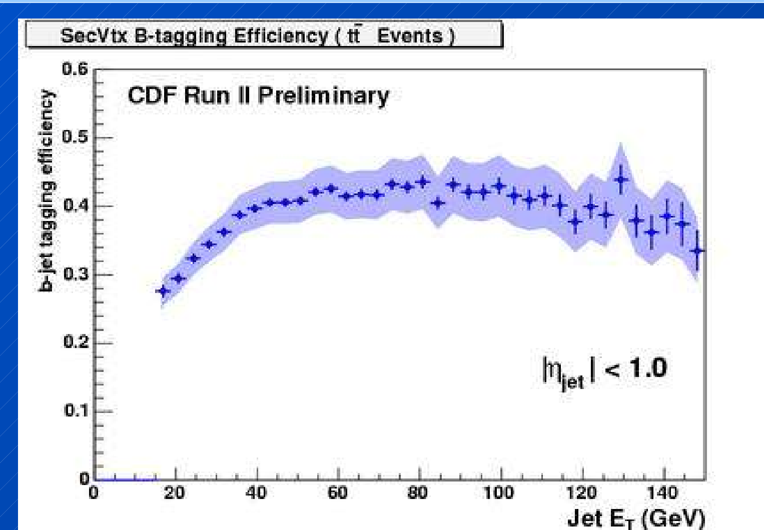
- count the number of track with large positive DCA significance σ
- jet is tagged if
  $N_{tr}(\sigma>2)>3$ or
  $N_{tr}(\sigma>3)>2$

- explicitely reconstruct 3d vertices out of track jets
- cut on decay length significance

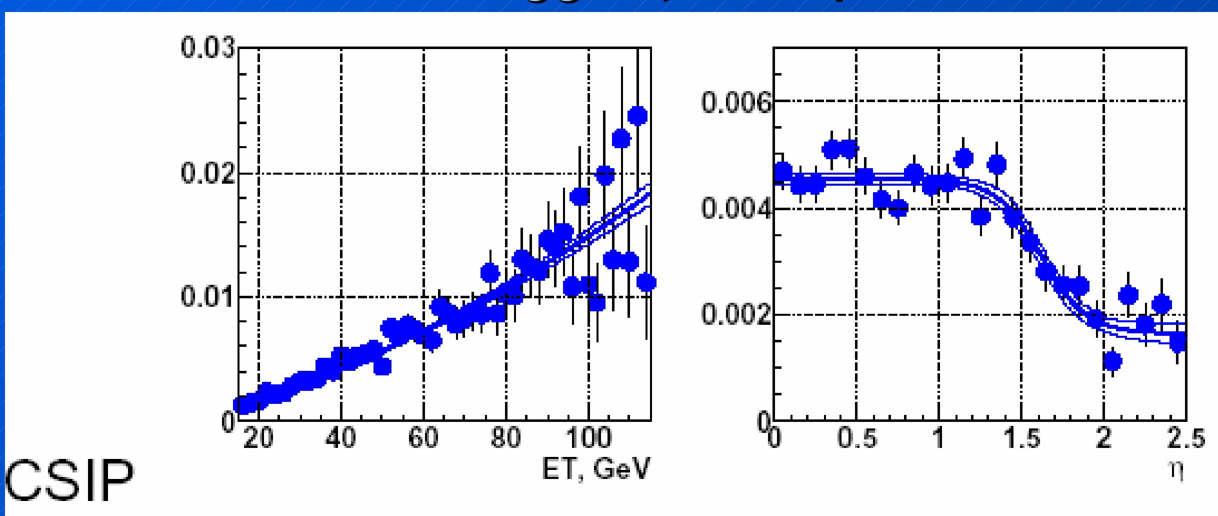
⇨ can also tag muon in jet from soft-lepton decay

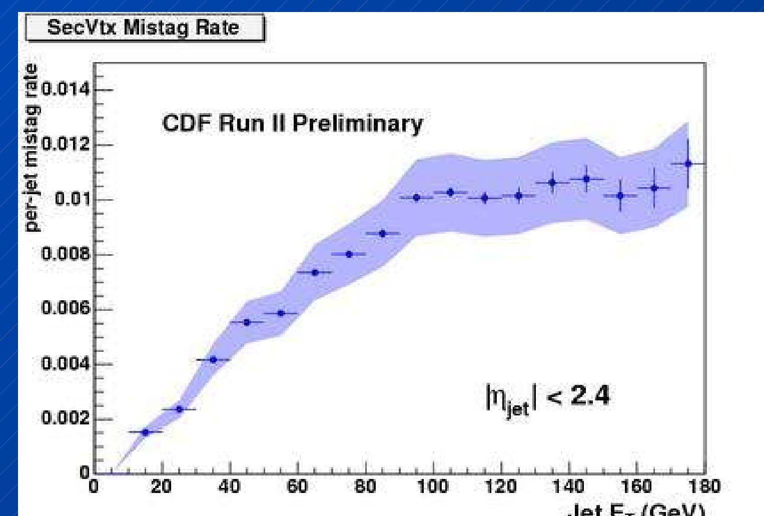
b-tagging Efficiency and Fake Rate





measured in muon-tagged jet sample

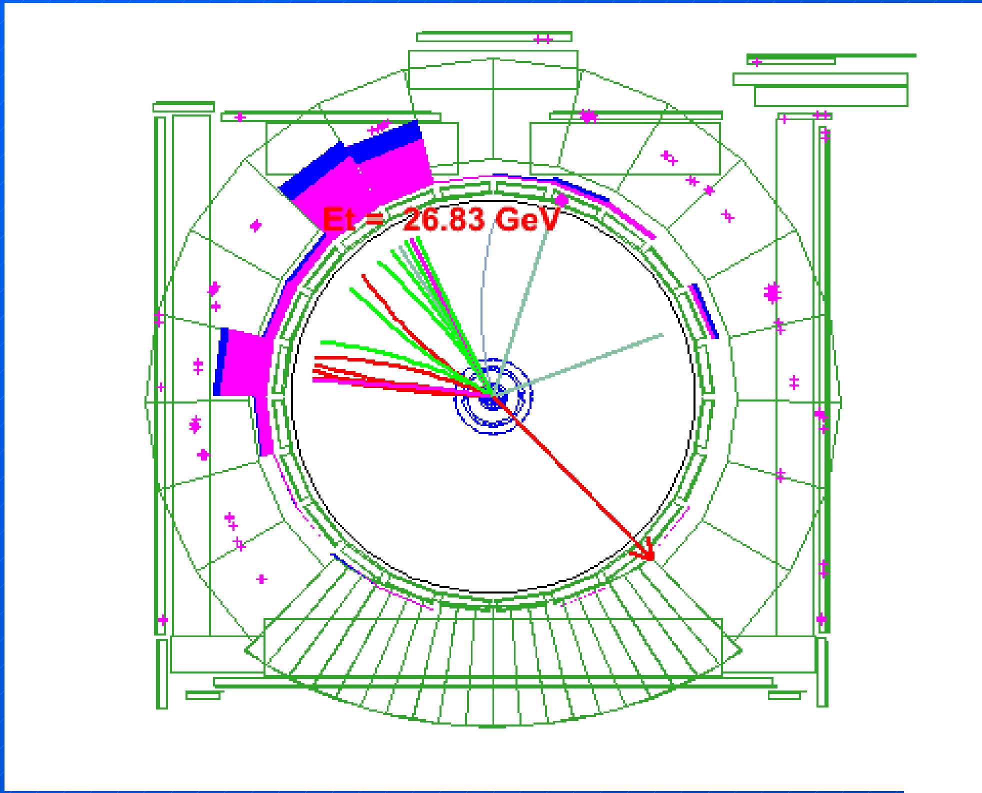


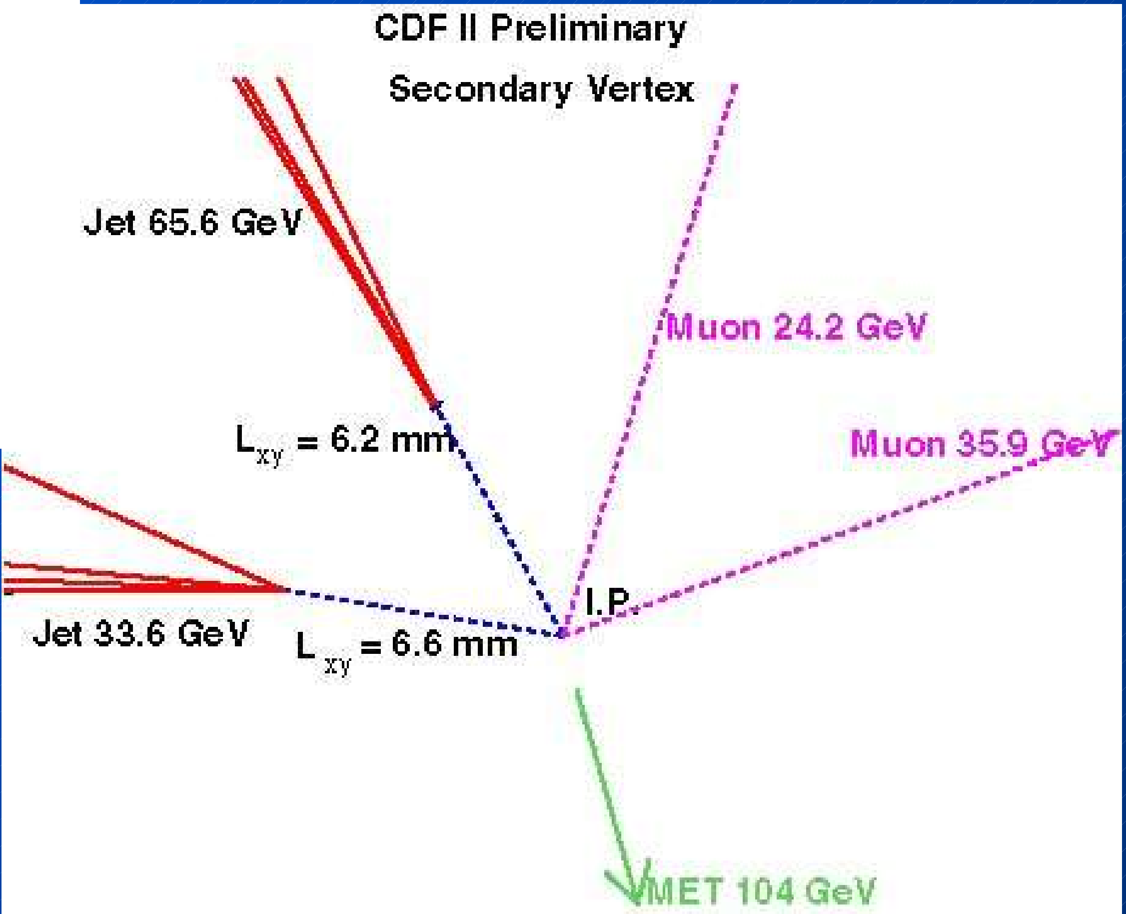


measured in inclusive sample, converted to light-tag rate using MC

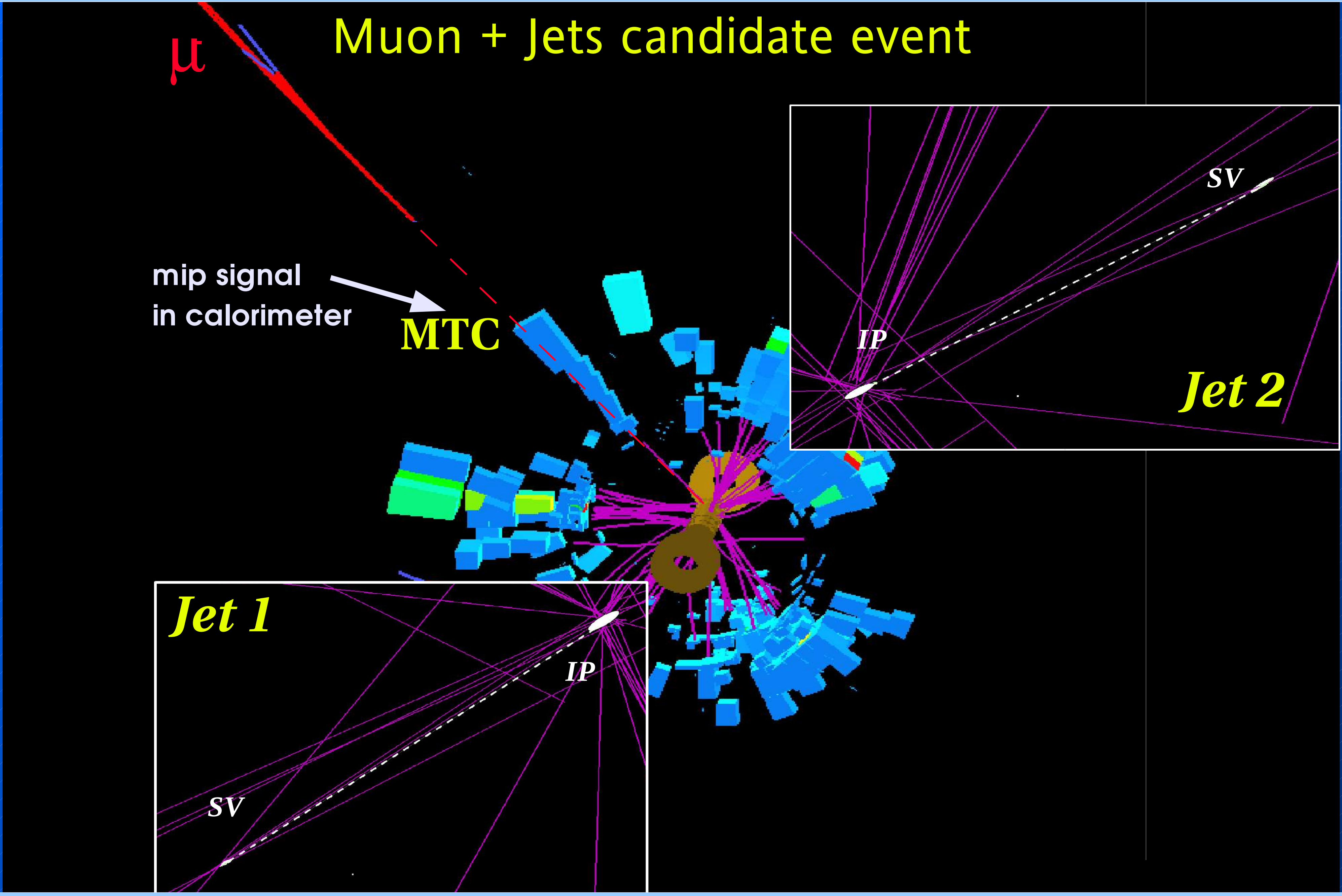
DØ CSIP/SVT slightly higher/lower fake rate ⇒ CDF/DØ similar performance

An Example μμ-Event



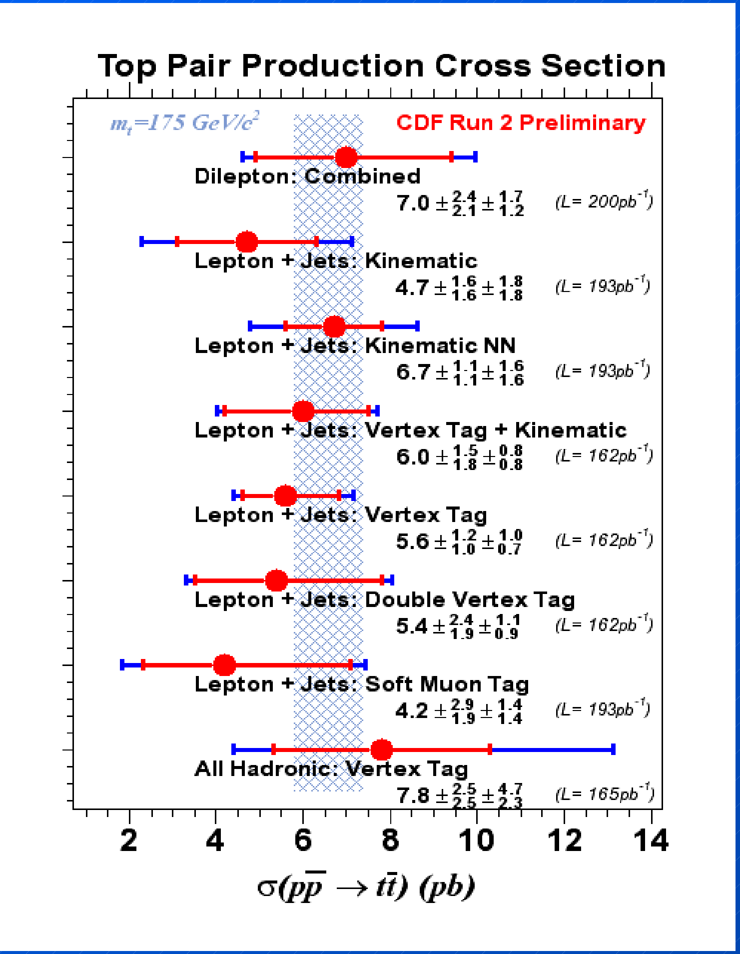


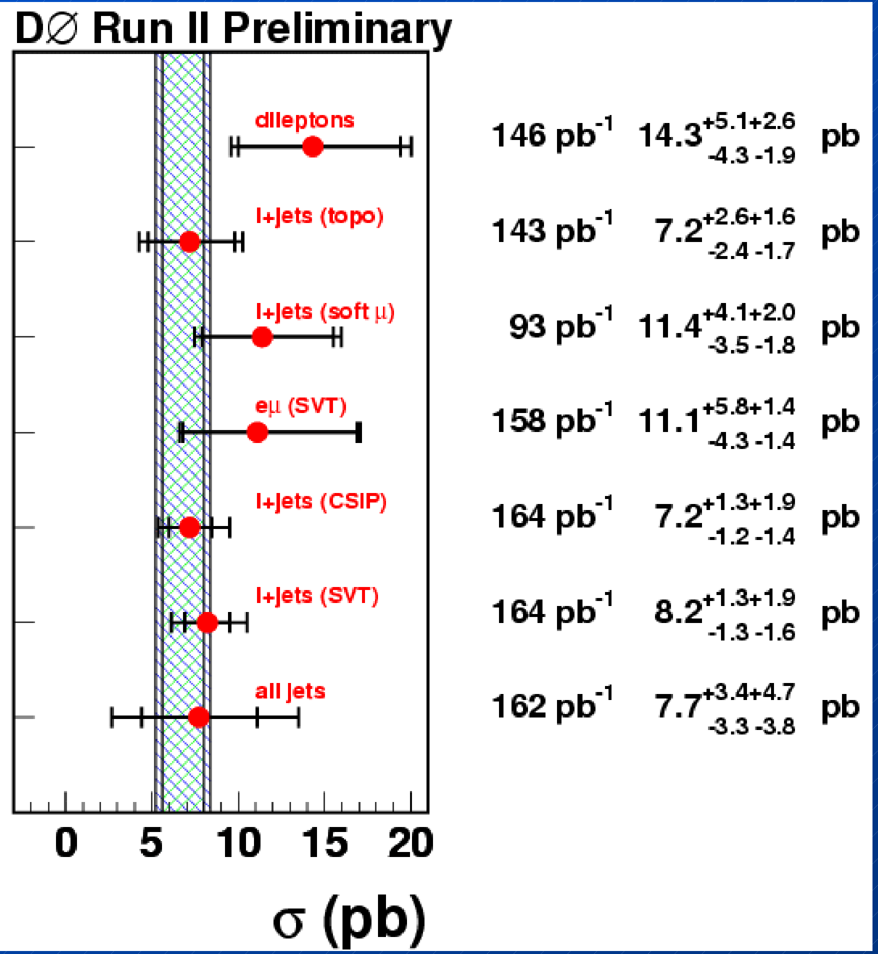
A Typical μ+Jets Candidate Event



Run II Top Cross Section - Summary

errors between different channels are correlated



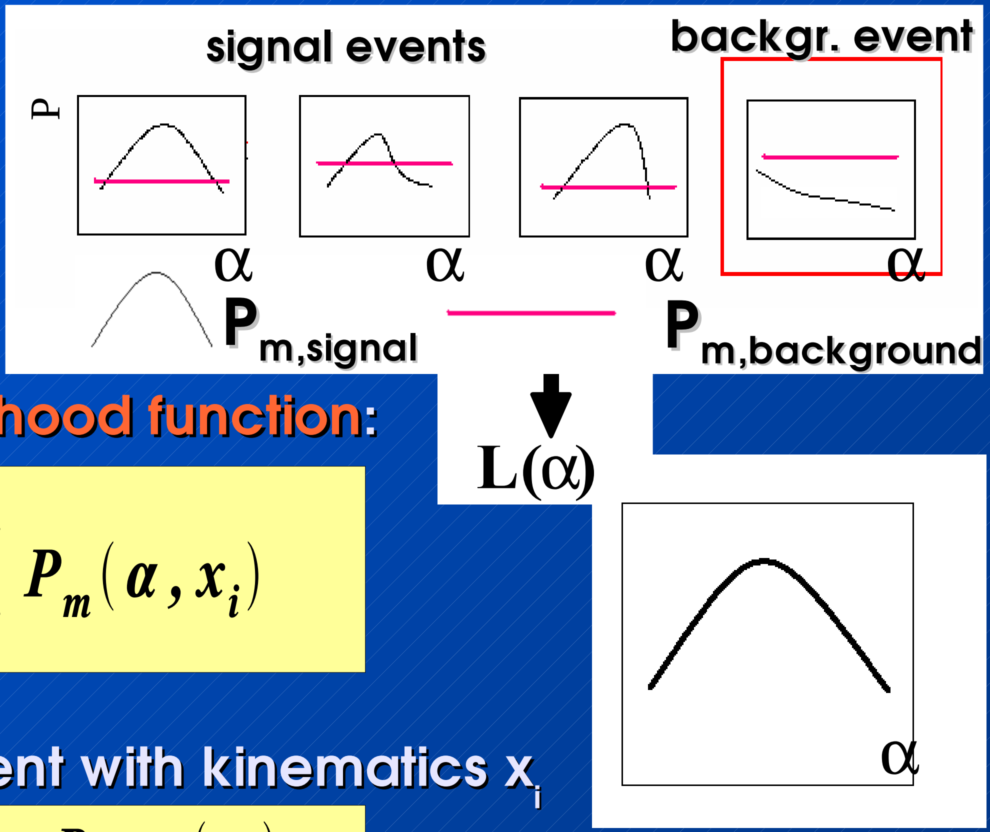


- Measurements demonstrate success of various top detection techniques
- Results within errors consistent with NNLO SM prediction for 1.96 TeV of ~7 pb^{-1}

Measurement of the Top Mass in L+jets

- quantity α

- N events with reconstructed objects (leptons, jets, ...) and kinematics x_i



- best estimate by maximizing the **Likelihood function**:

$$L(\alpha;x_1\ldots x_N)=e^{-N\int P_m(\alpha,x)dx}\prod_{i=1}^{N}P_m(\alpha,x_i)$$

- $P_m(\alpha,x_i)$: probability to measure an event with kinematics x_i

$$P_m(\alpha;x_i)=c_1 P_{m,t\bar{t}}(\alpha,x_i)+c_2 P_{m,bkg}(x_i)$$

- include **background**:

- minimize -log-Likelihood to measured a and fix the signal/bkg.-fractions !

- the challenge: **obtain the P(α,x)** !

Measurement of the Top Mass in L+jets

- Obtain probabilities by folding differential X-section with object resolutions:

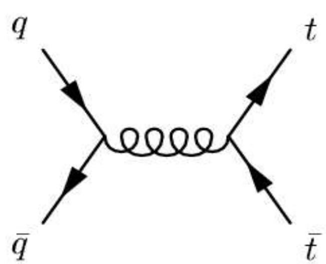
$$P_m(\alpha, x) = Acc(x) \times \frac{1}{\sigma} \int d^n\sigma(y;\alpha)\, dq_1\, dq_2\, f(q_1)\, f(q_2)\, W(x,y)$$

Acceptance (selection, trigger,...)

LO-Matrix element x phase space

PDF's

Transfer Functions (Probability to measure x when y was produced)



Signal (No ISR or FSR)

Background (VECBOS-ME)
W+ 4 Jets
(also found adequate for QCD bkg.)

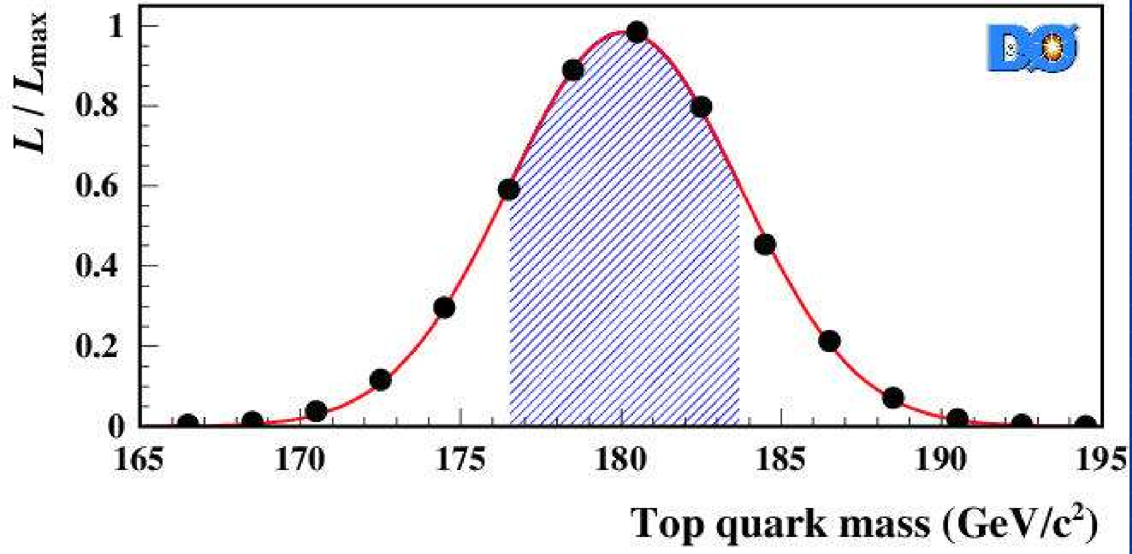
→ need to constrain to exactly 4 Jets

- take permutations (jet-parton-assignment) and reconstruction ambiguities into account by summing over different possibilities
- Transfer functions are set to δ-functions for well-measured quantities (jet-angles, electron momentum)
- for jet-energies: $W_{jets}(E_{part}, E_{jet})$ relating parton- and jet-energies, obtained as parametrization for b- and non-b-Jets from MC

Application to Run-I Data

$M_t = 180.1 \pm 3.6_{stat} \pm 4.0_{sys}$ GeV

Nature 429, 638-642 (10 June 2004)



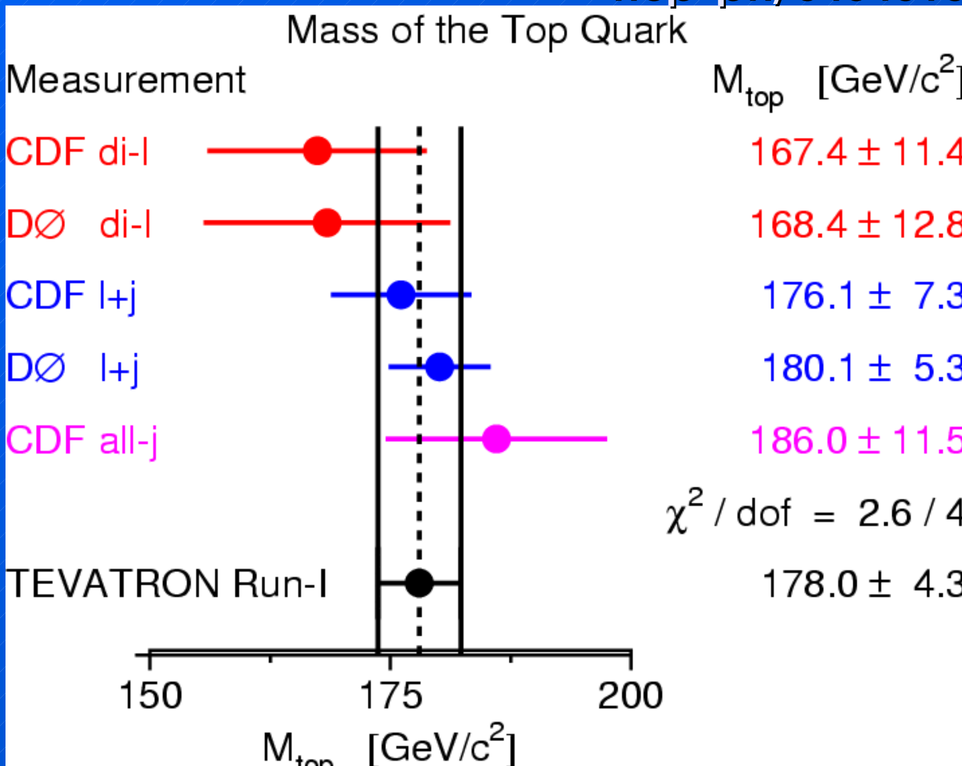
- improvement corresponds to 2.4-times statistics !
- result compatible with previous measurement in the lepton+jets channel at about the 1.7 sigma level !

ttbar model	1.5 GeV
W+jets model	1.0 GeV
Noise and multiple i.a.	1.3 GeV
Jet energy scale (JES)	3.3 GeV
PDF's	0.2 GeV
Acceptance correction	0.5 GeV

Error estimated by rescaling jet energies by the JES uncertainty and taking the maximum difference.

World Average m_{top} and Higgs Mass

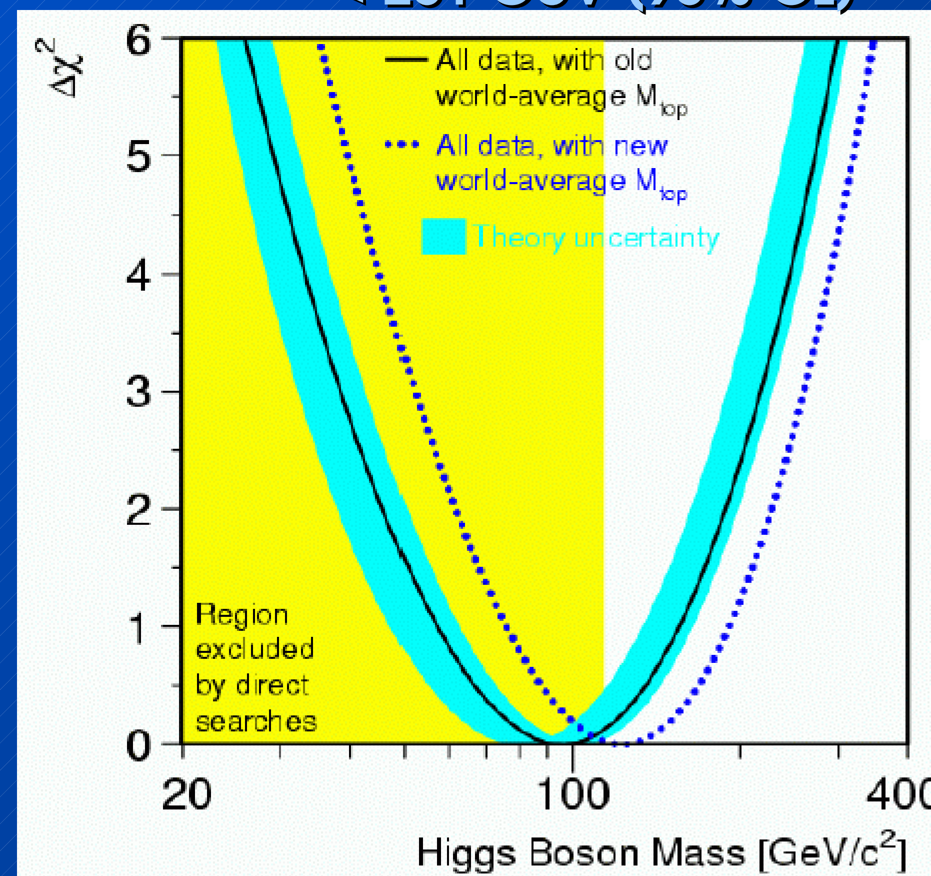
hep-ph/0404010



$\log M_H = 2.07^{+0.20}_{-0.21}$

$M_H = 117^{+67}_{-45}$ GeV

< 251 GeV (95% CL)



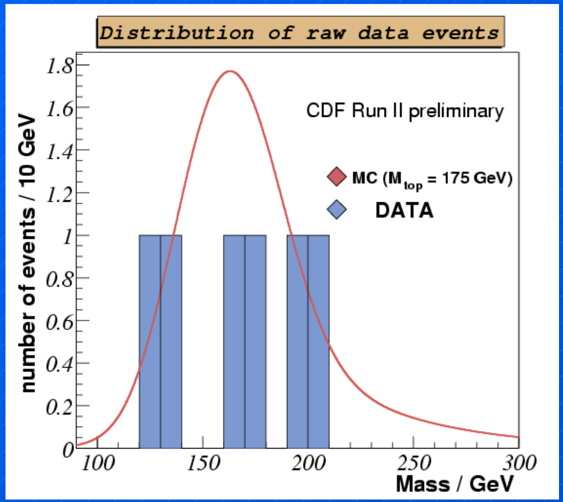
new world average

(TeV EW/TOP working group, 1.April'04):

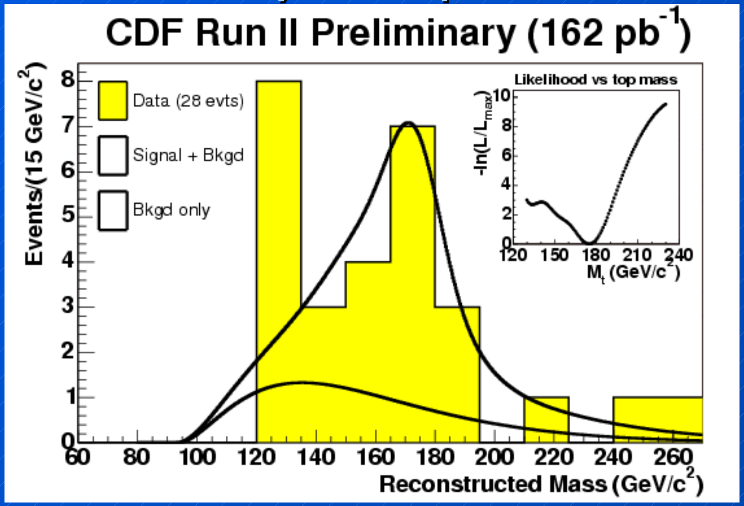
178.0 ± 4.3 GeV/c^2

Run II Top Mass Measurement in CDF

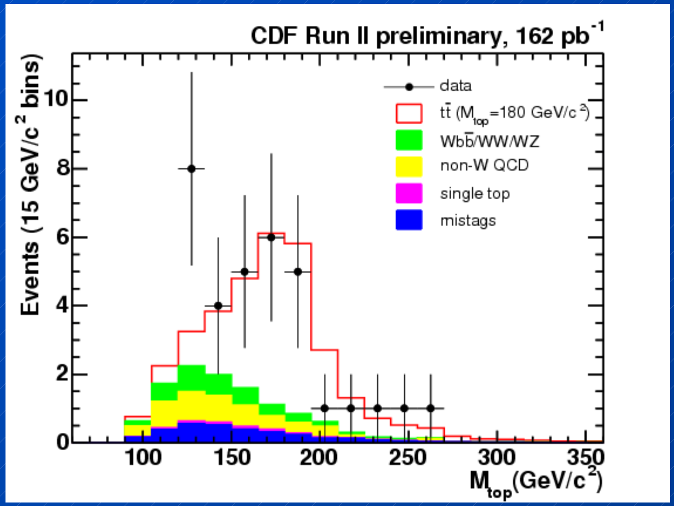
Run I style `template' method



Di-leptons

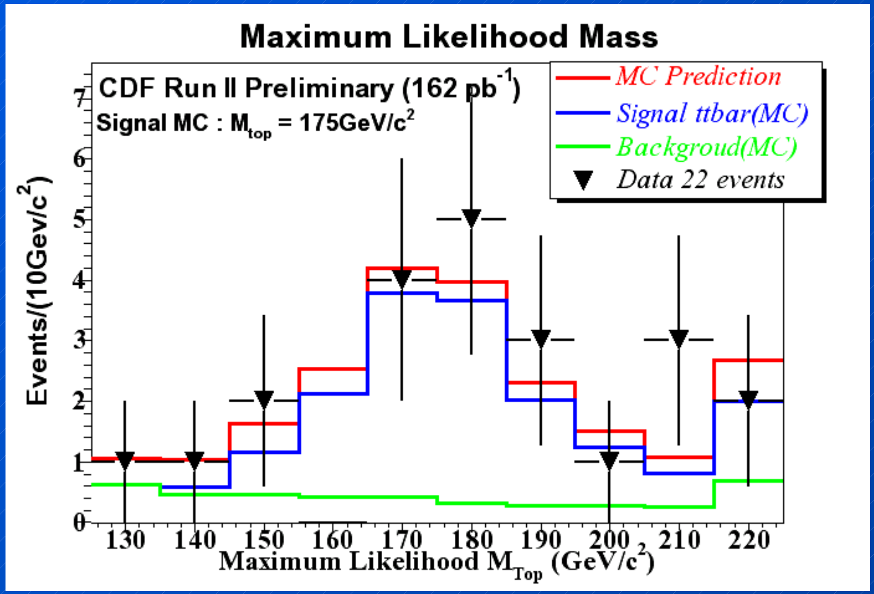


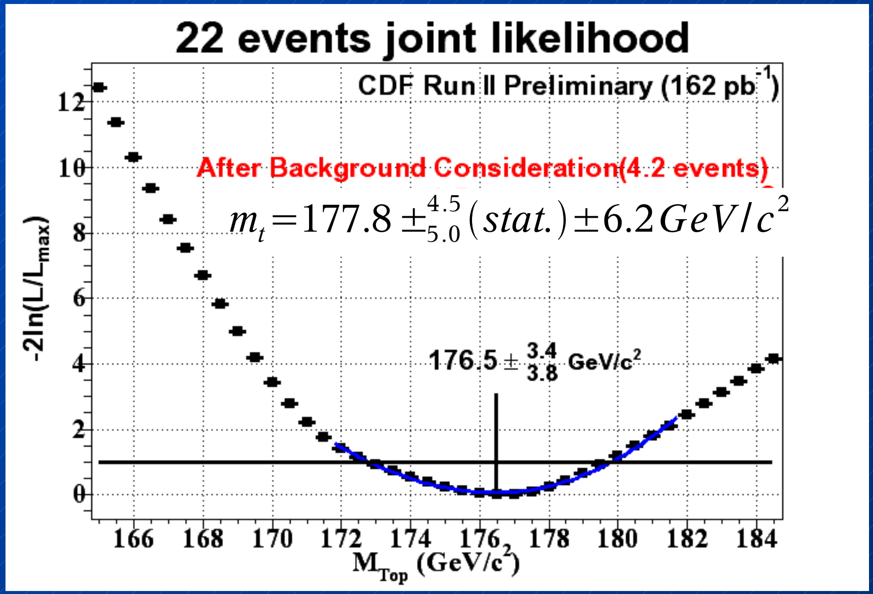
l+jets, b-tagged



l+jets, b-tag+jet E_T

Dynamical Likelihood Method is similar to DØ `matrix element method'

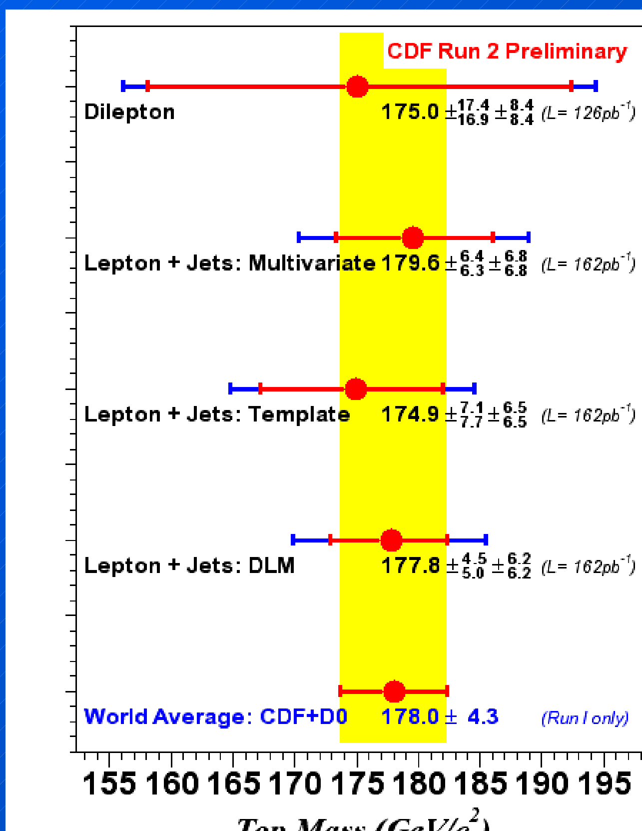


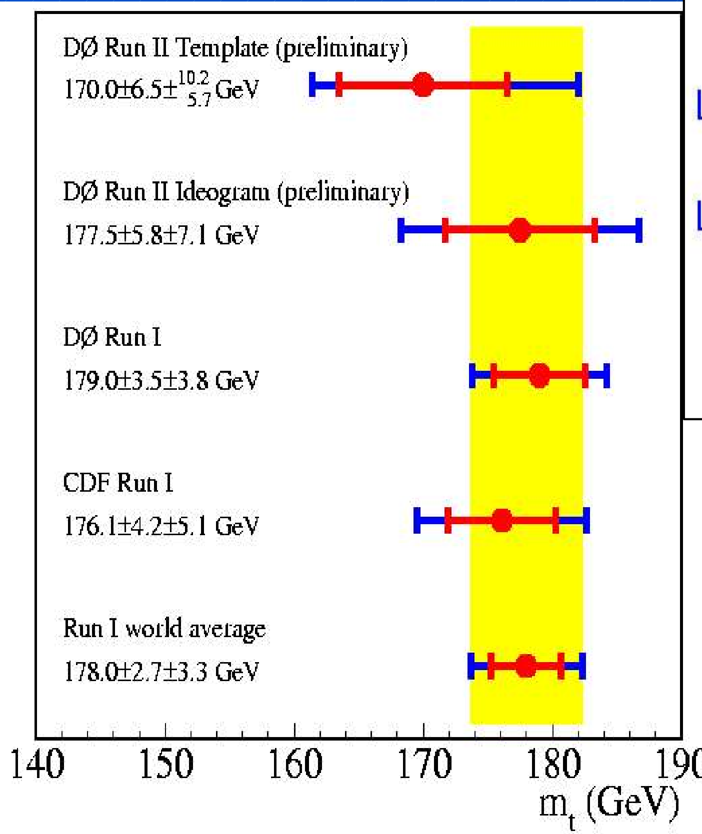


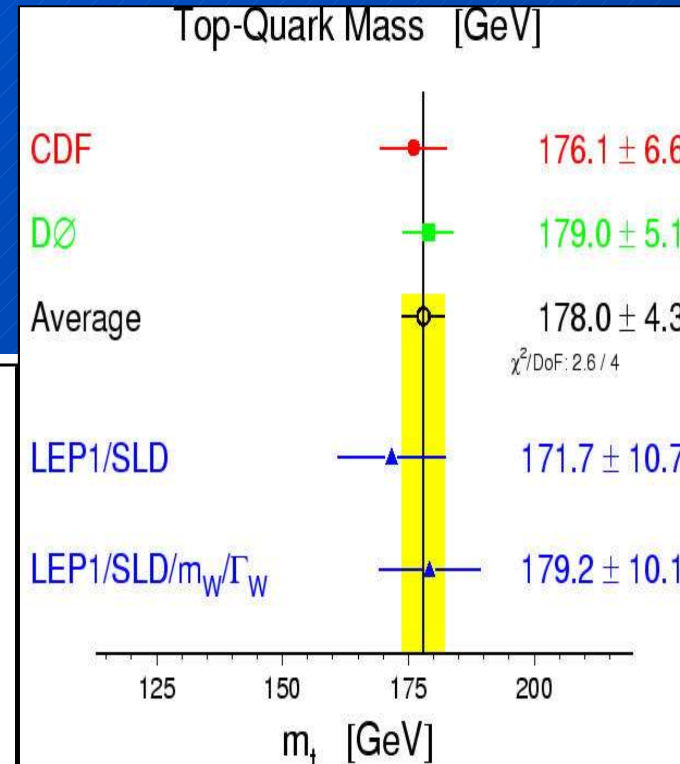
Top Mass Summary

new combined Run I result → $m_t = 178.0 \pm 4.3$ GeV

(was $m_t = 174.3 \pm 5.1$ GeV)





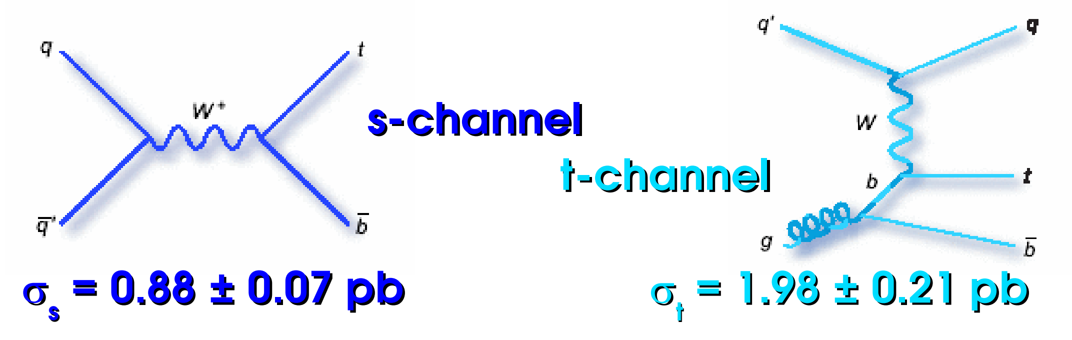


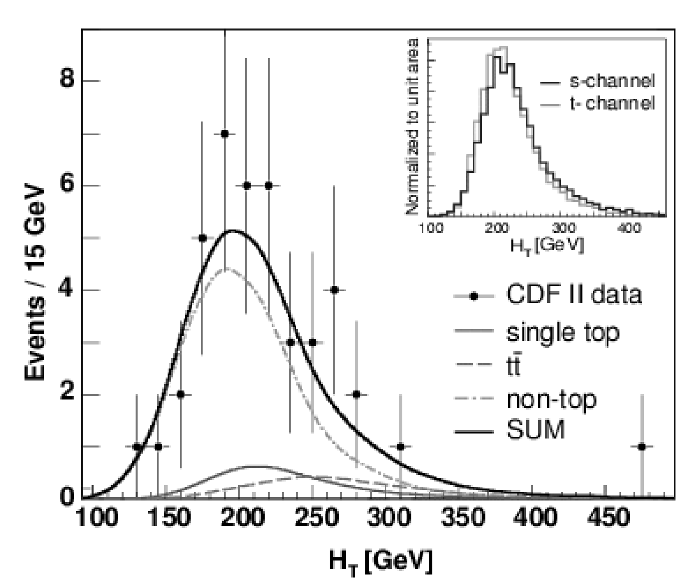
systematics limited:
- jet energy scale
- ttbar modeling
- W+jets modeling
- ...

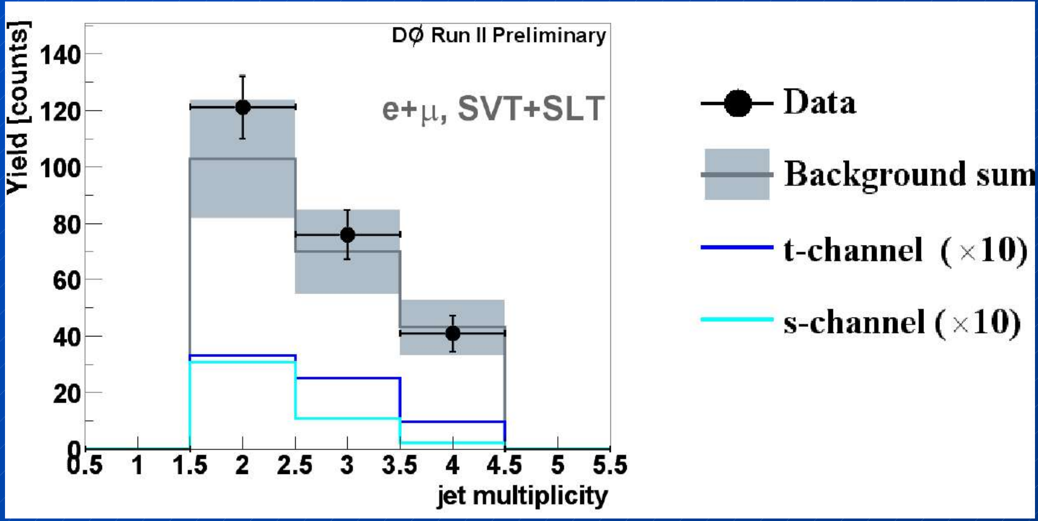
TeV EWWG is working on combination of Run II m_t measurement from CDF and DØ

Search for Single Top Production

EW production of top quark
similar strength as strong production !!!
- direct probe of $|V_{tb}|$
- search for new physics
- topology similar to ttbar in l+jets,
  but lower jet multiplicity and more forward more background (W+jets, tt, dibosons, ...)







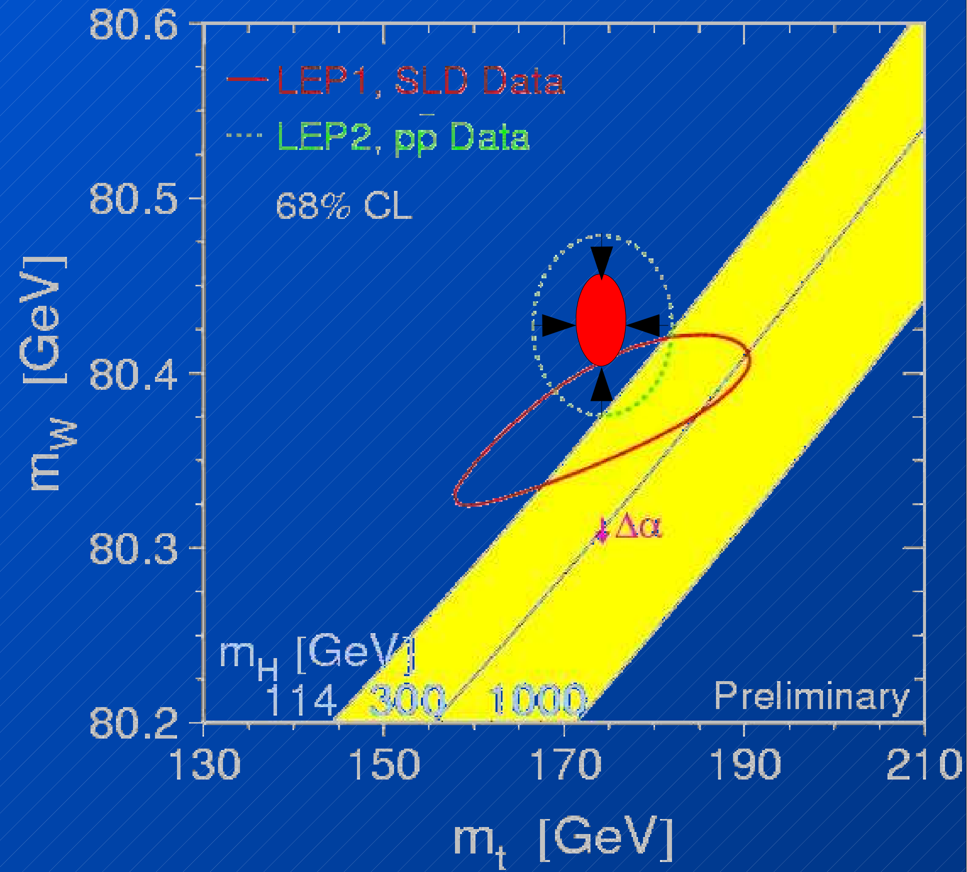
need ~ 1 fb^{-1} for observation

95% CL limits	CDF	DØ
σ(s-channel)	< 13.6 pb	< 19 pb
σ(t-channel)	< 10.1 pb	< 25 pb
σ(s+t channels)	< 17.8 pb	< 23 pb

Top Quark Outlook

further top properties measurements in preparation:

- W-helicity in top decays
- top coupling
- anomalous kinematics
- rate of top decays to $\tau\nu b$ (charged Higgs)
- branching ratios
- top charge
- ...



CDF + DØ combined expected precision with 2 fb^{-1}

ATLAS/CMS separate with 10-30 fb^{-1}

(mass precision from total lumi)

	CDF+DØ	ATLAS/CMS		CDF+DØ	ATLAS/CMS
W helicity F_0, F_+	0.09, 0.03	...	single top	20.00%	0.71%
$R_{2b/1b}$	4.50%	~0.2%	Γ_t from single top	25.00%	...
$\lvert V_{tb} \rvert$	from R	...	$\lvert V_{tb} \rvert$ from single top	12.00%	0.36%
$B(t \to \gamma q)$	$2 * 10^{-3}$	$1.0*10^{-4}$	$B(t \to Zq)$	0.02	$1.1*10^{-4}$
Δm_{top}	2 GeV	1-2 GeV	Higgs	discovery ?	discovery !
Δm_W	20 MeV	20 MeV	Yukawa Coupl. y_t	---	12-16%

Summary and Conclusion

- **Tevatron has a very rich physics program**
  today highlights from
  - QCD
  - Electroweak Physics
  - Top Quark Physics

- **CDF and DØ doing pretty well**
  Large number of competitive results already now

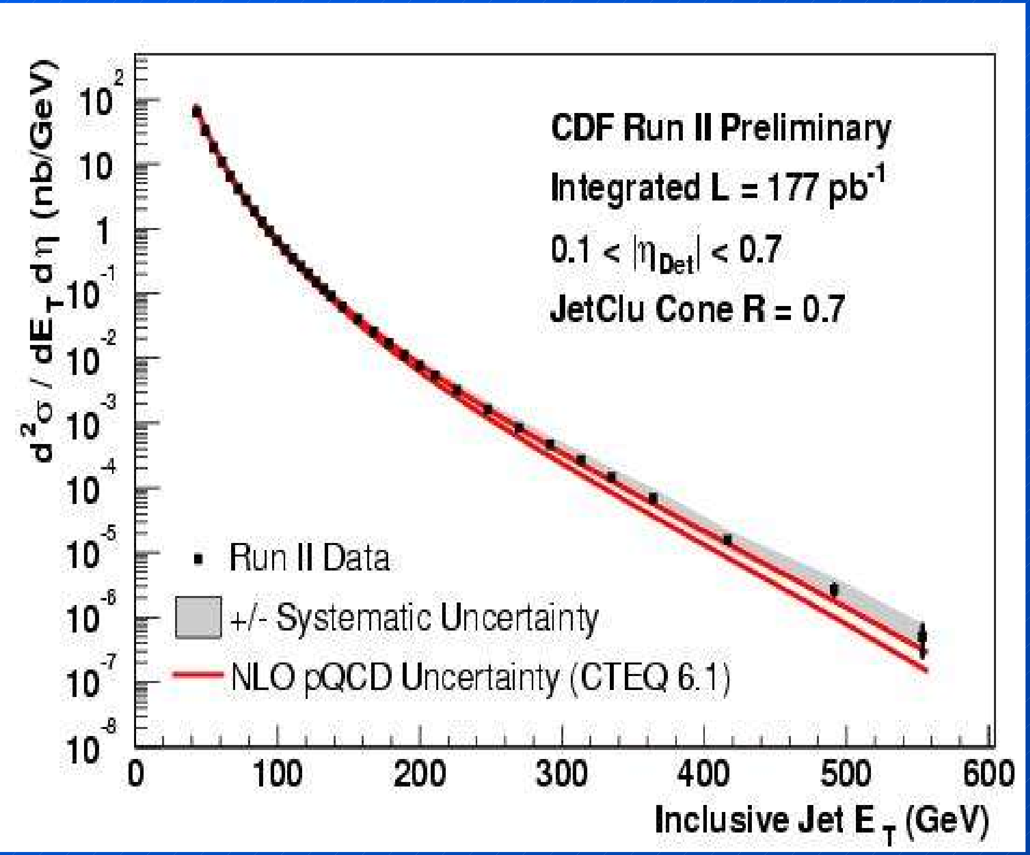
- **More luminosity and Run-IIb upgrade coming soon**

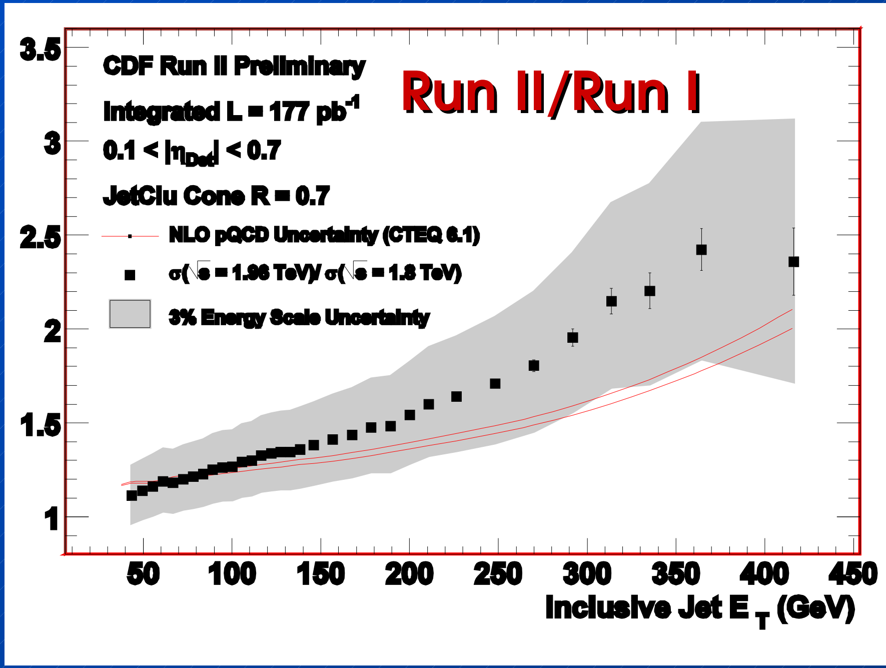
It's fun to be there ...

Backup Slides

Inclusive Jet Cross Section (2)

- Run I reach extended by 150 GeV
- Data agree with NLO prediction within errors (Run I JETCLU used)
  - Need to be corrected for hadronization/underlying event
  - Watch the high p_T-tail...

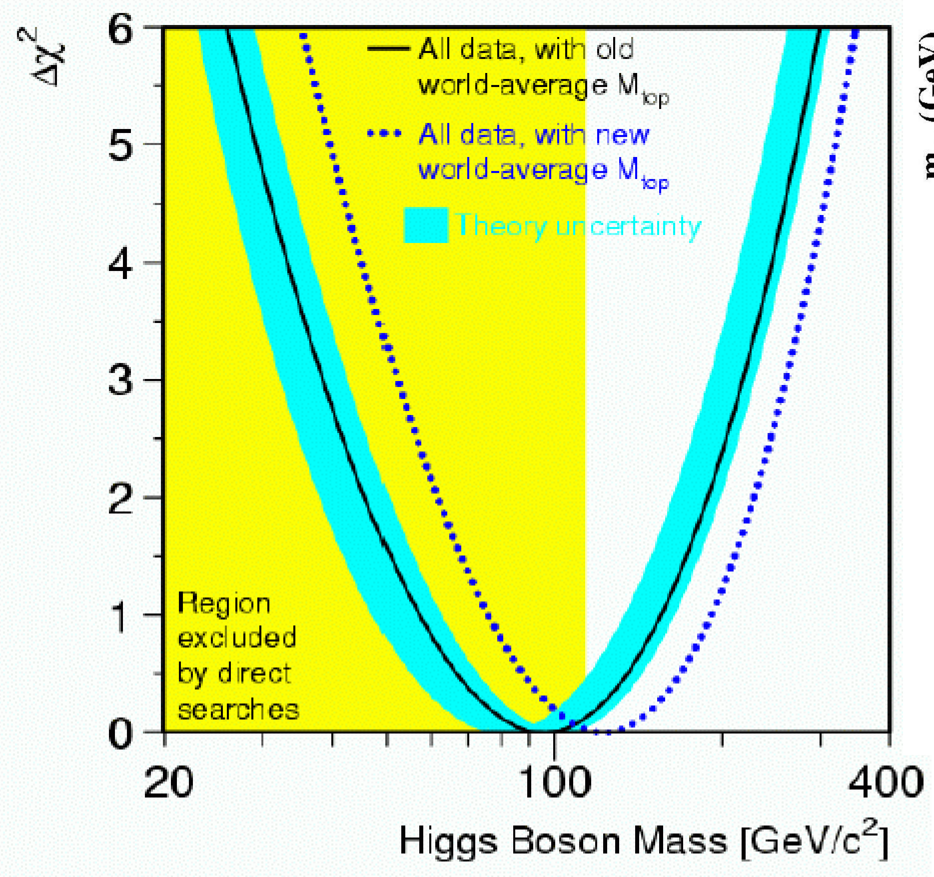


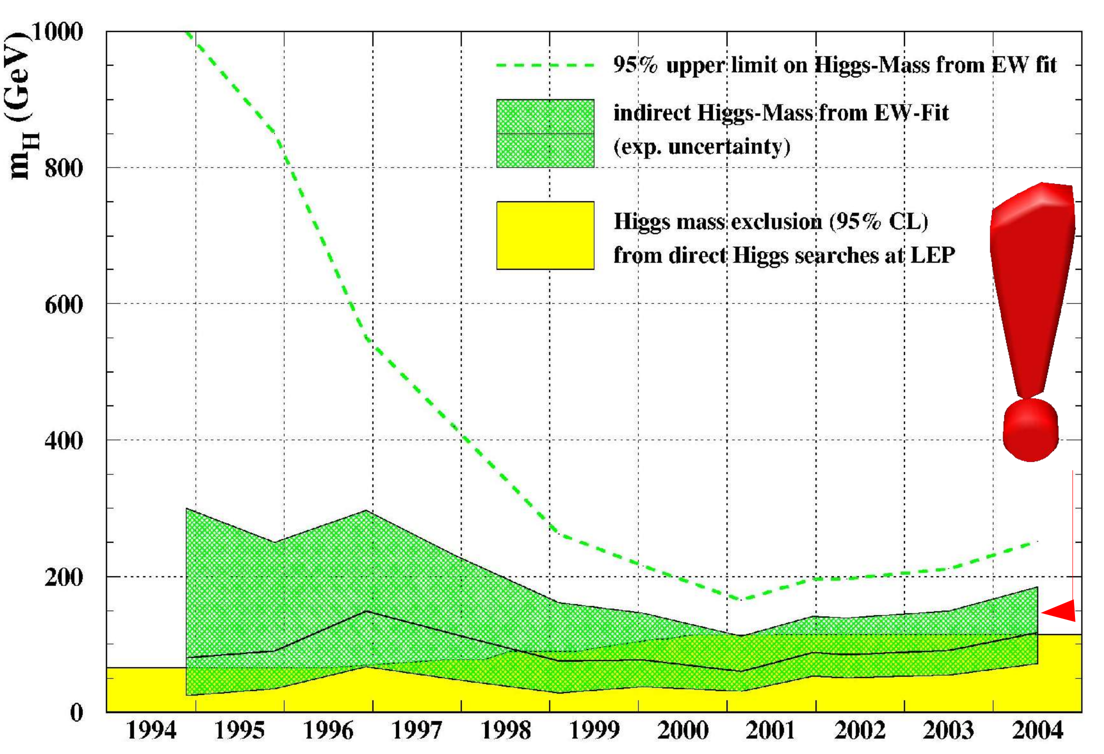


- Rapidity-dependent measurement in the works

Higgs Searches

Search for the Standard Model Higgs Boson





- Last missing particle in SM (EW symmetry breaking – mass)
- Light SM Higgs preferred
- Key to understand beyond-SM-physics (in MSSM m_H < 135 GeV)
- Search strategy a function of production and decay channel ...
- b-tagging a crucial tool

The final word from LEP:

- mass limits:

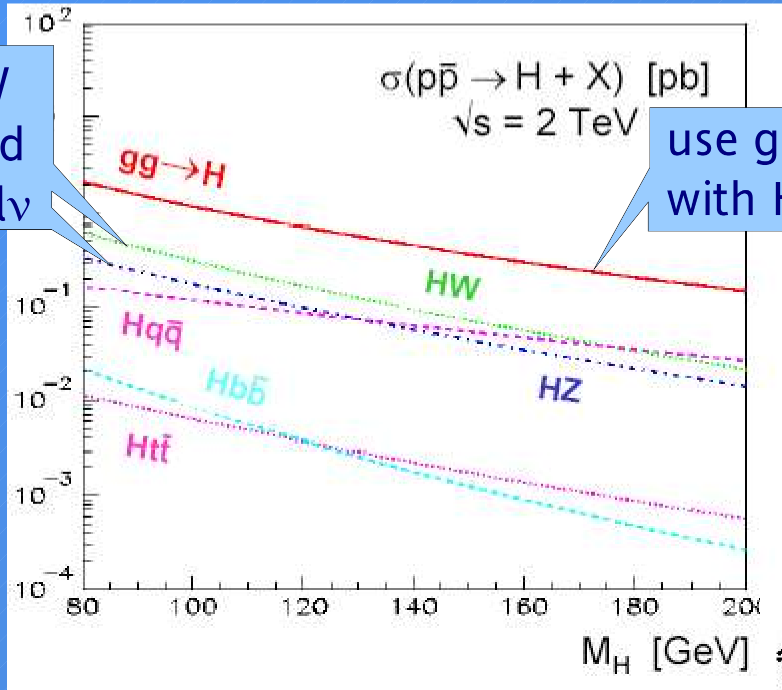
  obs. m_h > 114.4 GeV

  exp. m_h > 115.3 GeV

Search for the Standard Model Higgs Boson

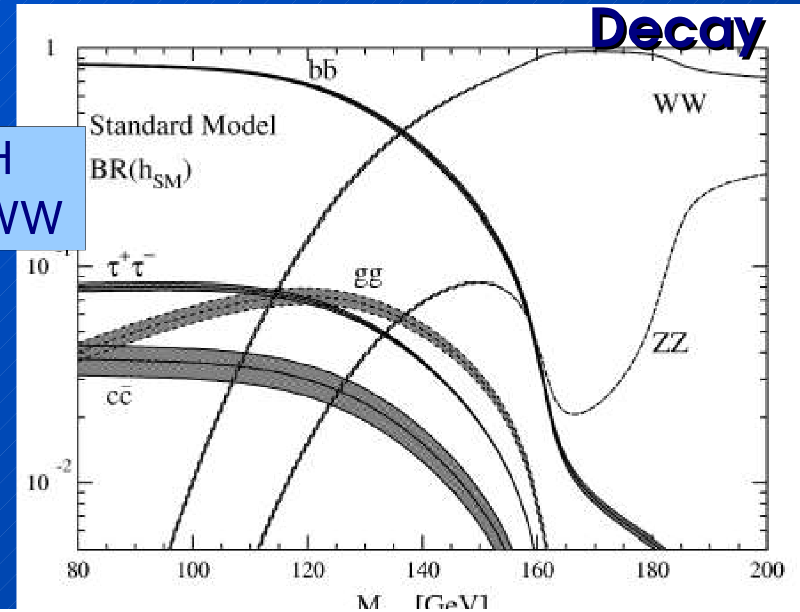
Production

use HZ and HW
with H→ bb and
Z→ ll/νν, W→ lν



use gg → H
with H → WW

Decay

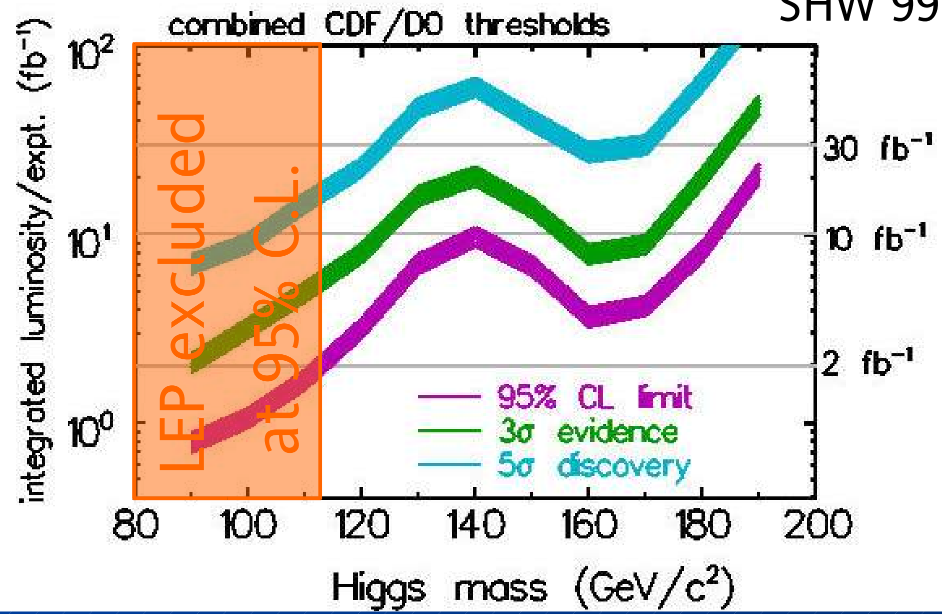


H → bb̄

H → WW(*)

Dominant decay modes

SHW'99

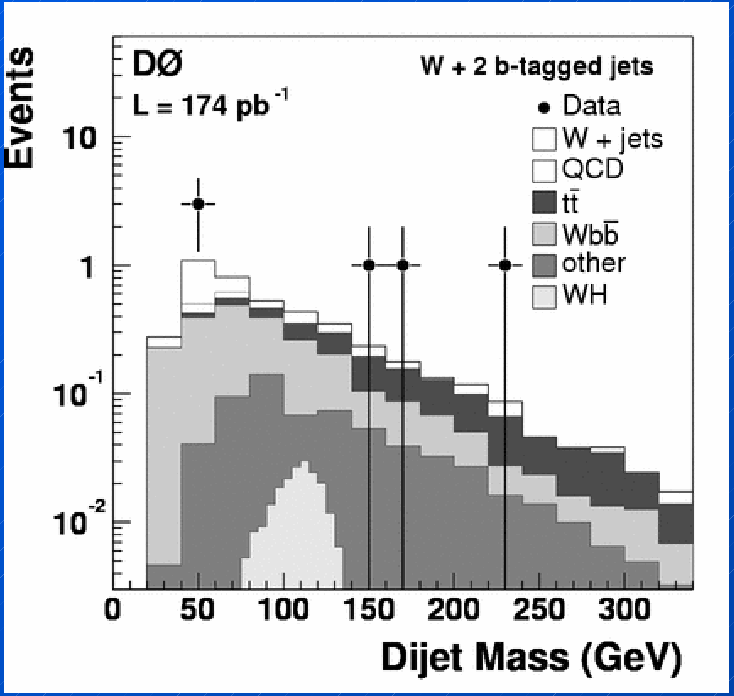


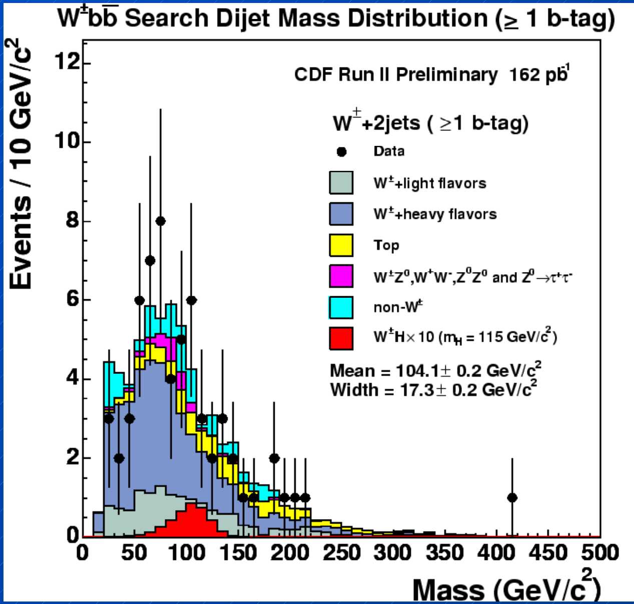
SM Higgs Search: WH → lνbb (M_h < 140 GeV)

DØ uses sample of W(eν)+2b tagged jets
⇒ require exactly 2 jets to suppress top background
6 events expected and 4.4 ± 1.2 events observed

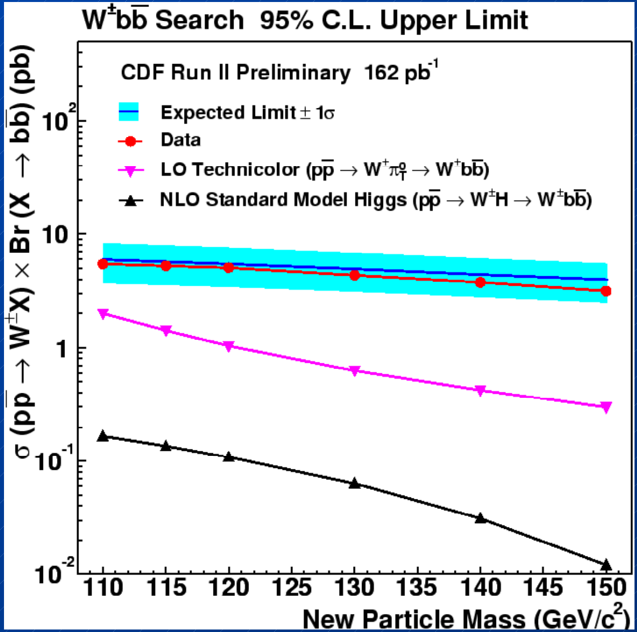
CDF uses e & μ channels
⇒ require at least 1 jet
to be b-tagged

for m_h = 115 GeV:
$\sigma(WH) * BR(H \to bb) < 9\ pb^{-1}$ at 95% CL

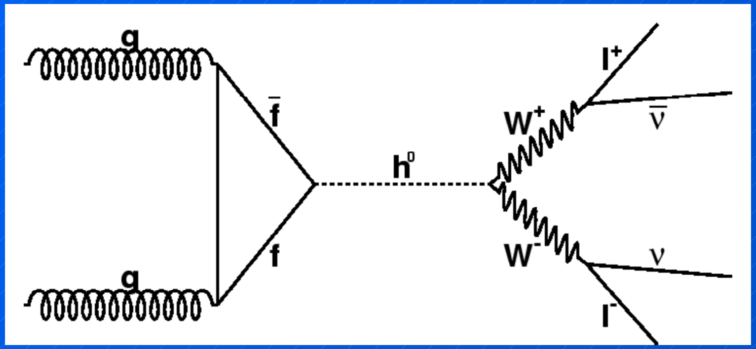


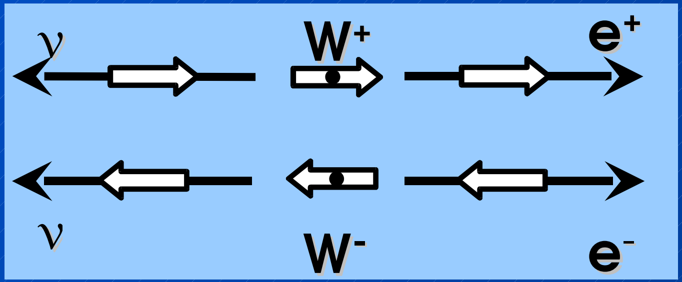


future improvements:
- extended b-tagging acceptance, efficiency
- additional kinematic variables
- better m_{bb} resolution
- add ννbb channel



SM Higgs Search: H → WW → llν (M_h > 140 GeV)

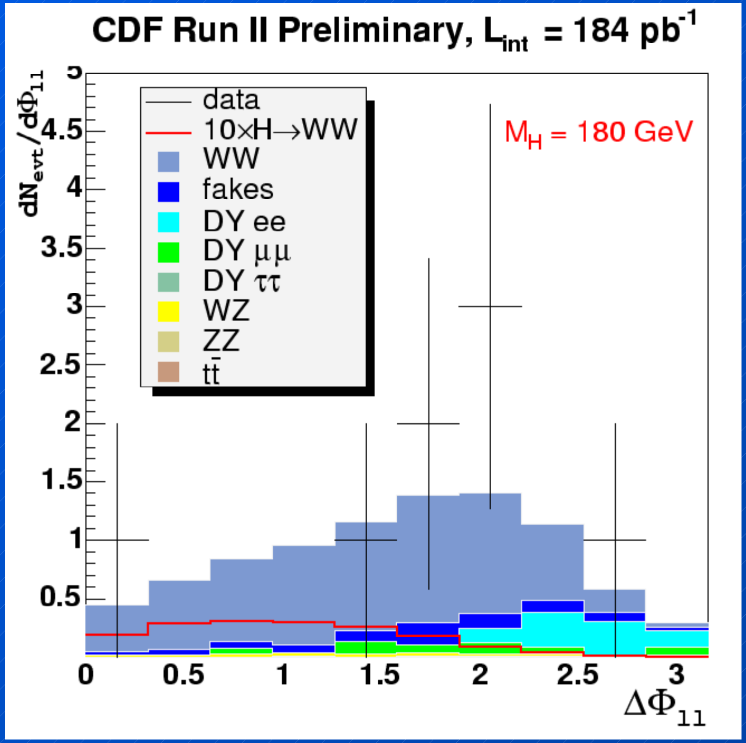


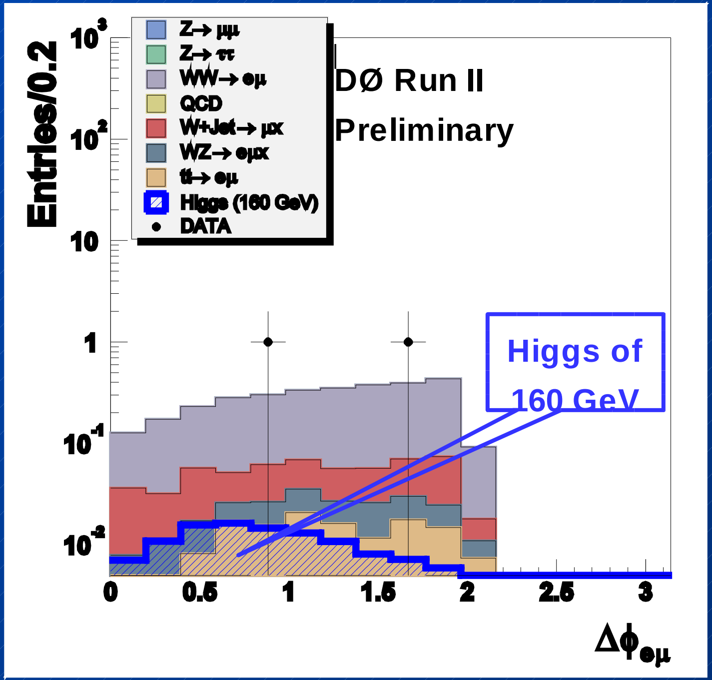


search strategy:

→ 2 high p_T leptons + missing E_T

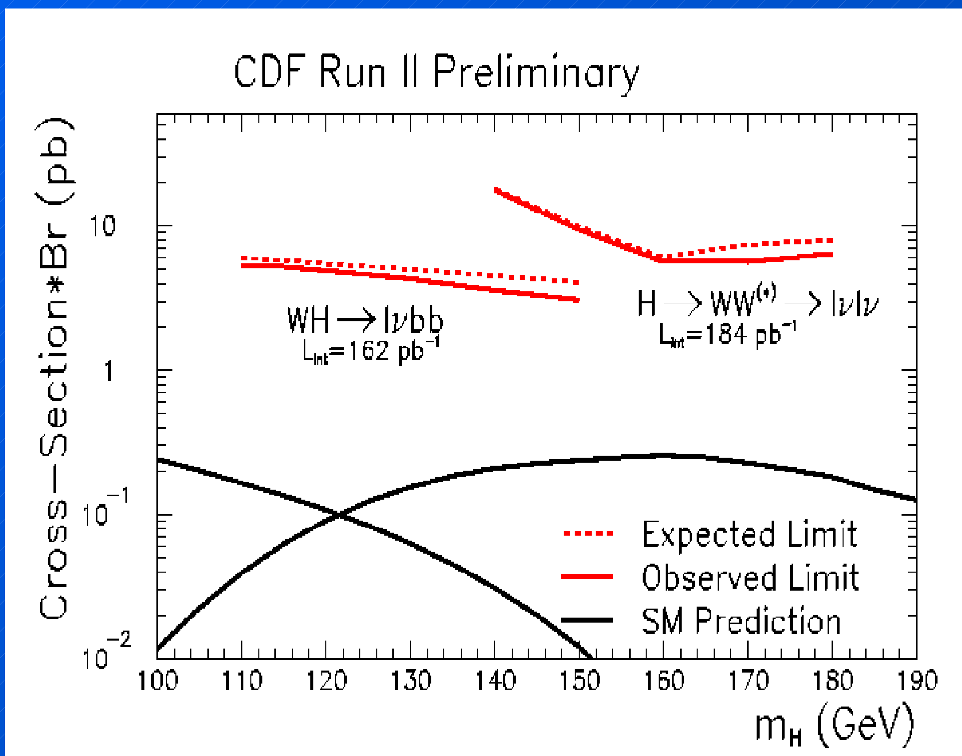
→ WW comes from spin 0 Higgs: charged leptons prefer to point in the same direction



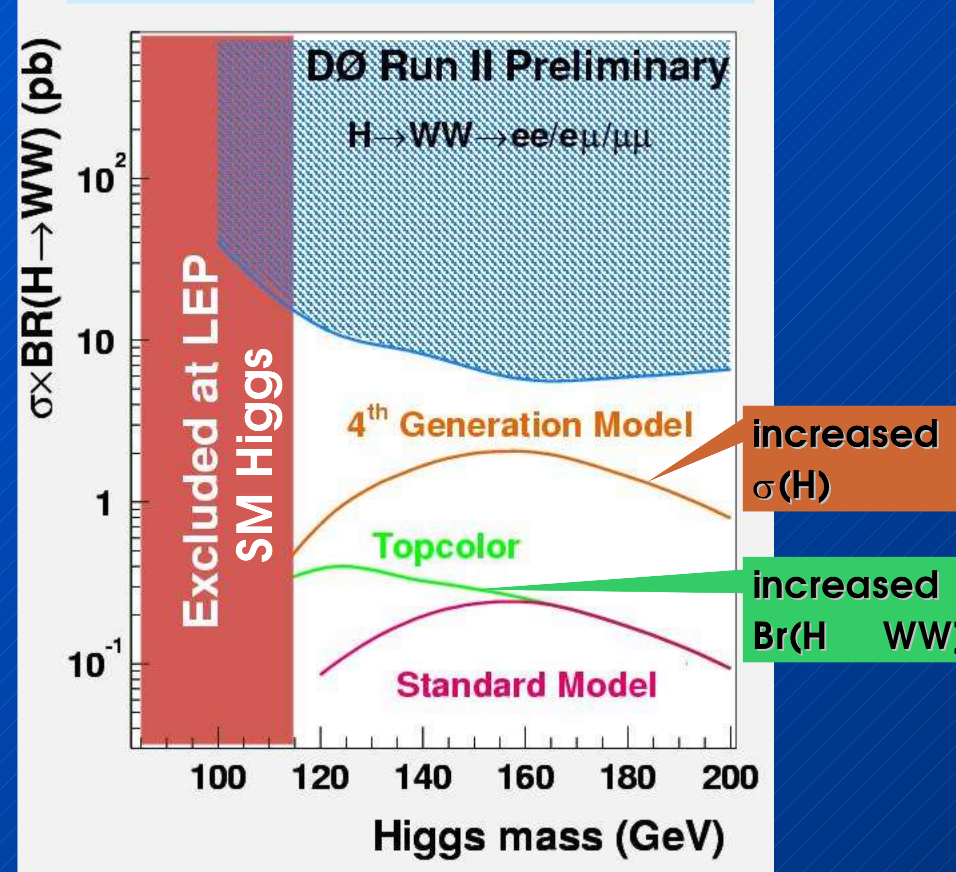


Current Limits on SM Higgs Search

both CDF and DØ set 95% CL limits on SM Higgs production



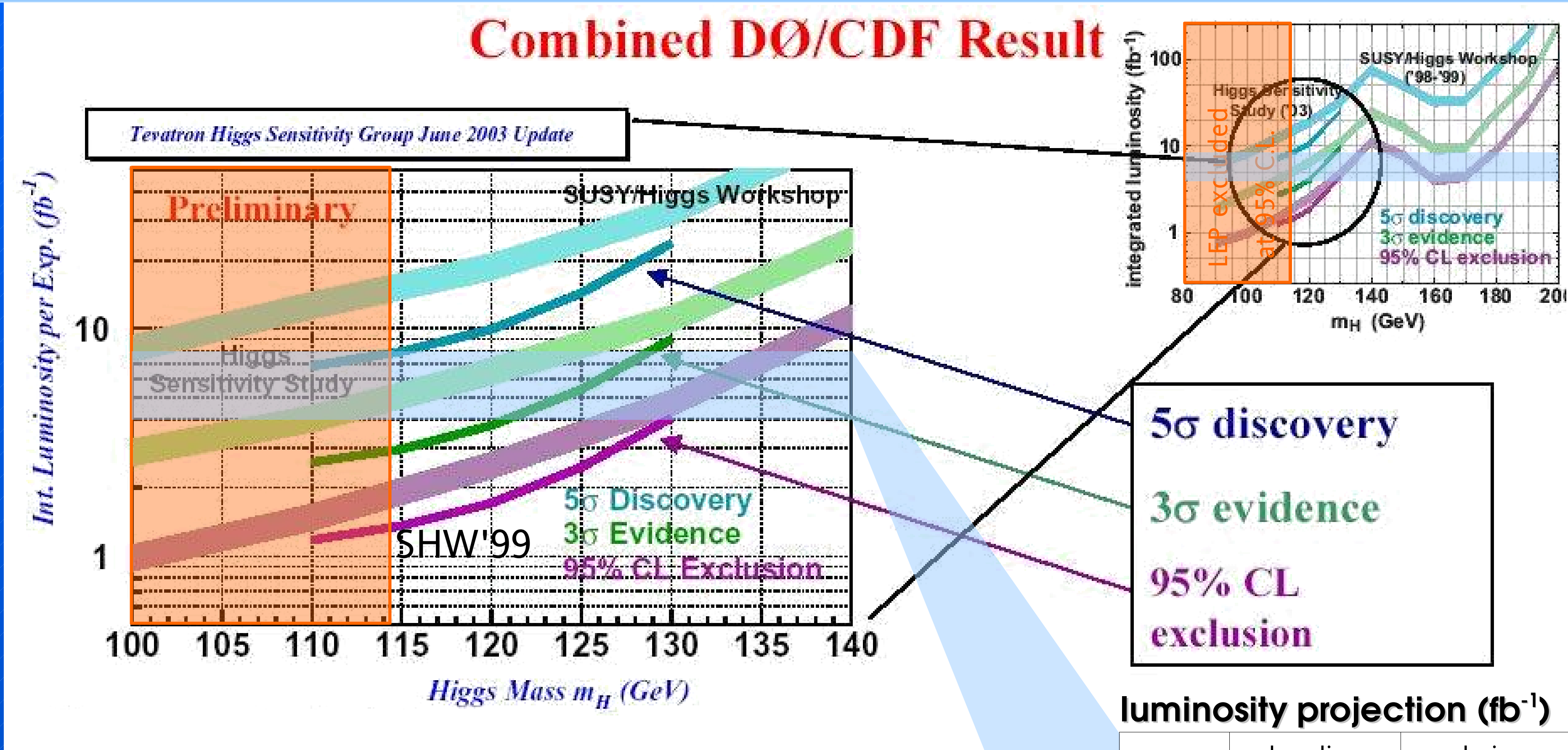
Excluded cross section times Branching Ratio at 95% C.L.



... limits already exceeding Run I results ...

DØ light (115 GeV) Higgs search limit
σ(WH) * BR(H → bb) < 12.4 pb-1 at 95% CL

Tevatron SM Higgs Hunting Outlook



luminosity projection (fb^{-1})

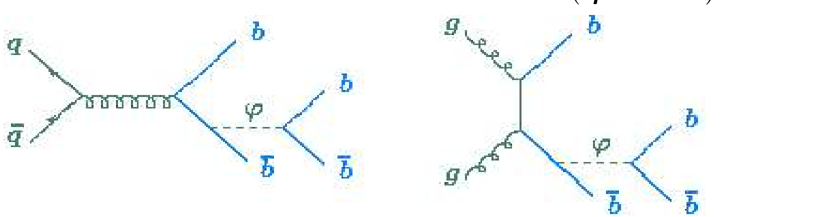
year	baseline	design
2003	0.28	0.3
2004	0.59	0.68
2005	0.98	1.36
2006	1.48	2.24
2007	2.11	3.78
2008	3.25	6.15
2009	4.41	8.57

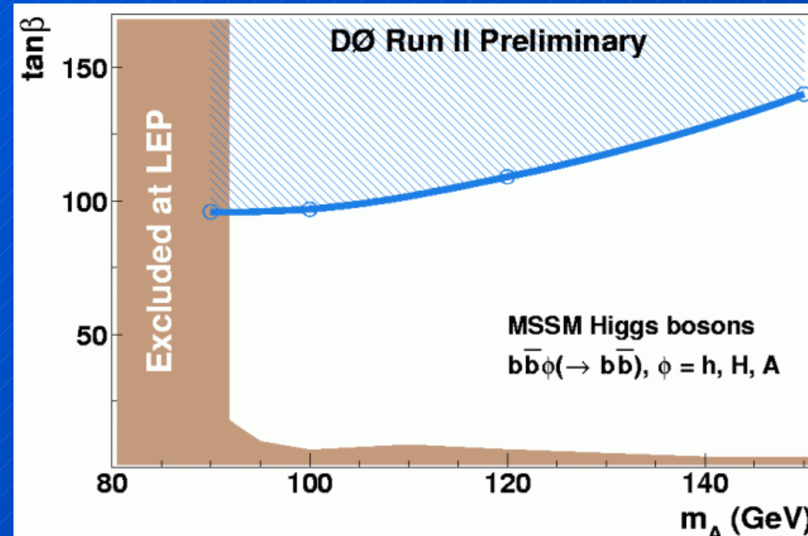
- combined ll, $\nu\nu$, lν channels
- no systematics included yet
- no H WW* channel; impacts m_H > 125 GeV
- assumes upgraded detector
- reaching interesting sensitivity with 2 fb^{-1}

Search for MSSM Higgs at the Tevatron

Two Higgs Doublets $\mathcal{H}_1, \mathcal{H}_2$ and 5 physical states

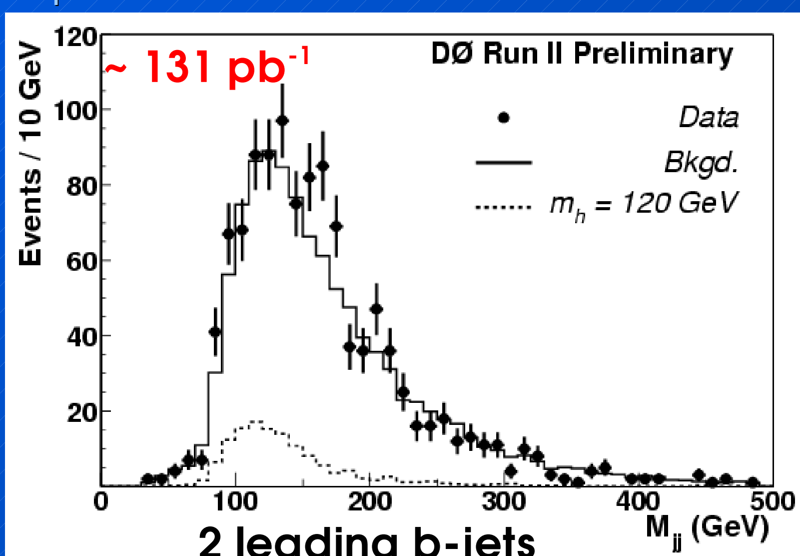
2 CP-even neutral Higgses	h^0, H^0	$m_h < m_H$
1 CP-odd neutral Higgs	A^0	
2 charged Higgses	$H^\pm$	
Free parameters:	$\tan\beta = v_2/v_1$	(VEV ratio)
	α	(mixing angle of h, H)
	μ	Higgs mass parameter
	A_0	common trilinear Higgs-sfermion coupling
tree level:	$m_h < m_Z < m_H$	
rad.corrected:	$m_h < 130$ GeV	$Br(\phi \to b\bar{b}) \sim 90\,\%$

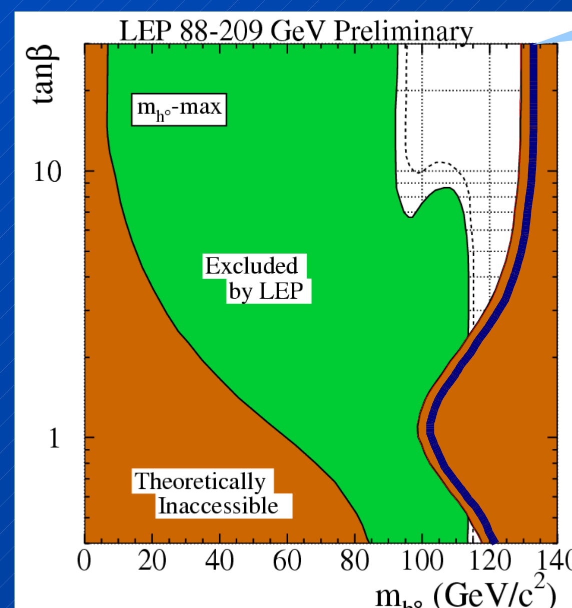




- significant improvements expected from reprocessing
- ... bbττ coming next year ...

- multi-jet sample (≥3 b-tagged jets)
- E_T cuts on jets optimized for Higgs masses





$$\Delta m_h^2 \sim \frac{m_t^4}{m_W^2} \times \left(\log \frac{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}{m_t^4} + \ldots \right)$$

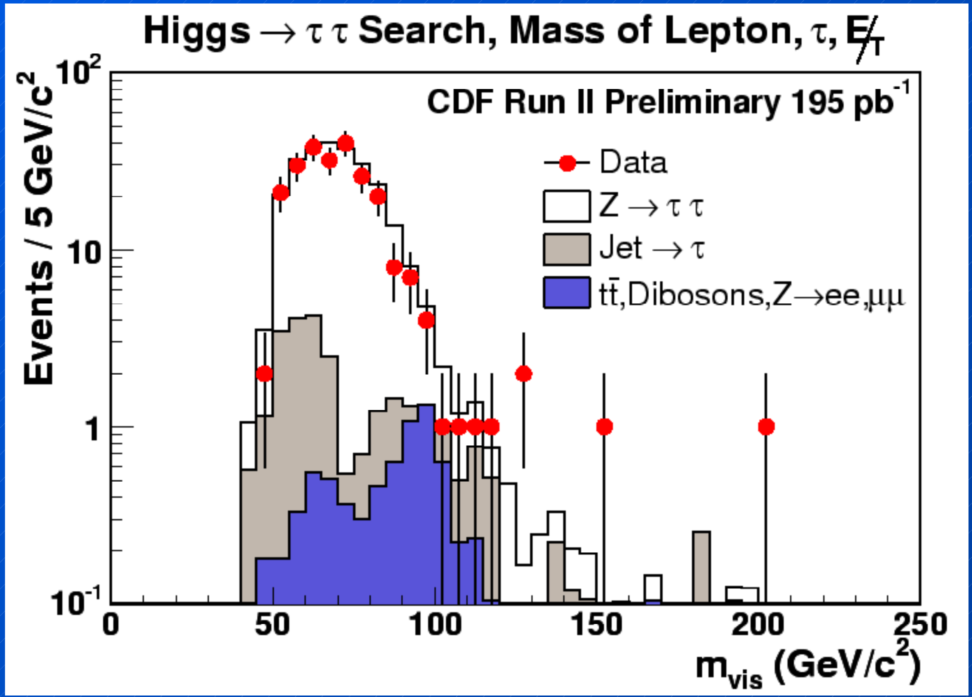
re-interpretation of LEP data due to new m_{top}

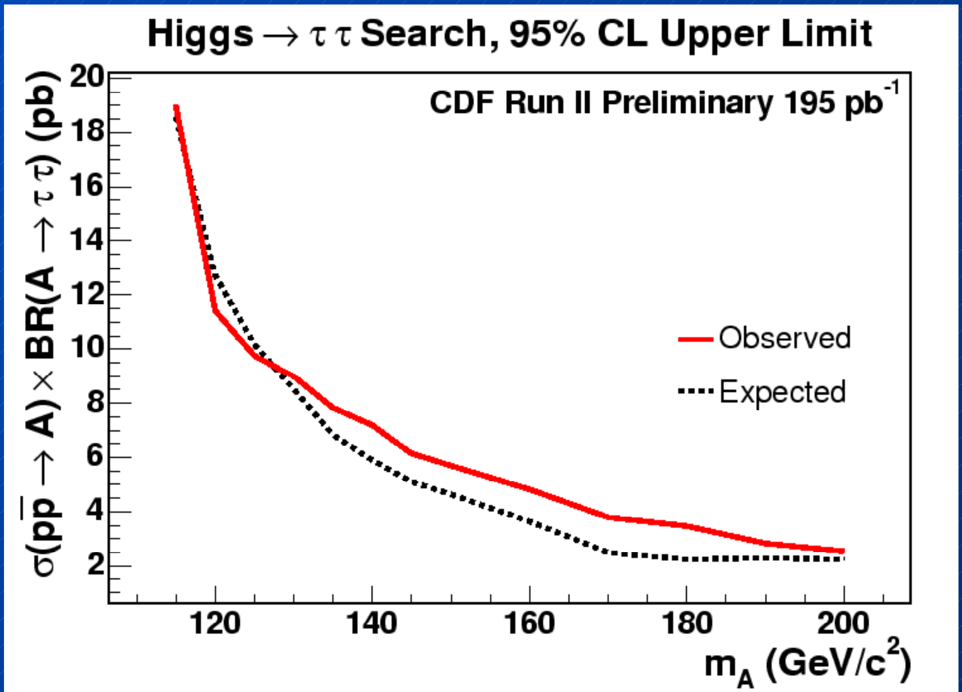
Search for MSSM Higgs at the Tevatron

CDF searches for $p\bar{p} \rightarrow h/A + X$

- with A decaying into ττ pair
- ~8% branching ratio at high tanβ
- lower backgrounds then $b\bar{b}$ pairs
- no access seen over backgrounds

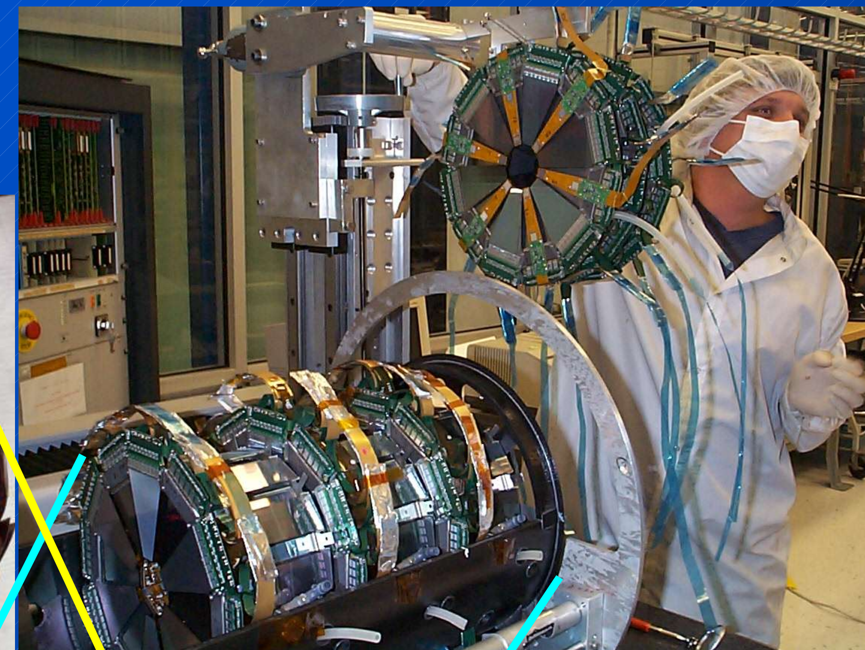
	$\tau_h\tau_e$	$\tau_h\tau_\mu$	Combined
$Z \rightarrow \tau\tau$	132.3 ± 17.1	104.1 ± 13.3	236.4 ± 29.5
$Z \rightarrow ll$	1.8 ± 0.2	4.9 ± 0.4	6.7 ± 0.6
$t\bar{t}, VV$	0.7 ± 0.1	0.8 ± 0.1	1.5 ± 0.1
$jet \rightarrow \tau$	12.0 ± 3.6	7.0 ± 2.1	19.0 ± 5.7
Total predicted	146.8 ± 17.5	116.8 ± 13.5	263.6 ± 30.1
Data	133	103	236

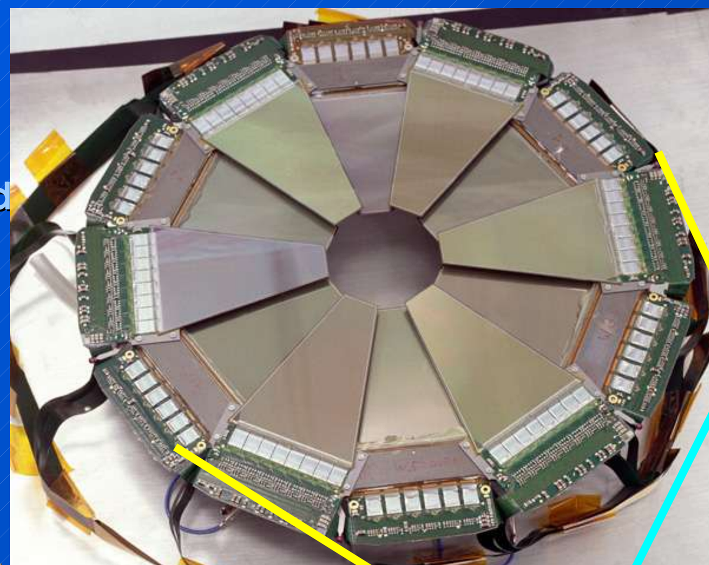




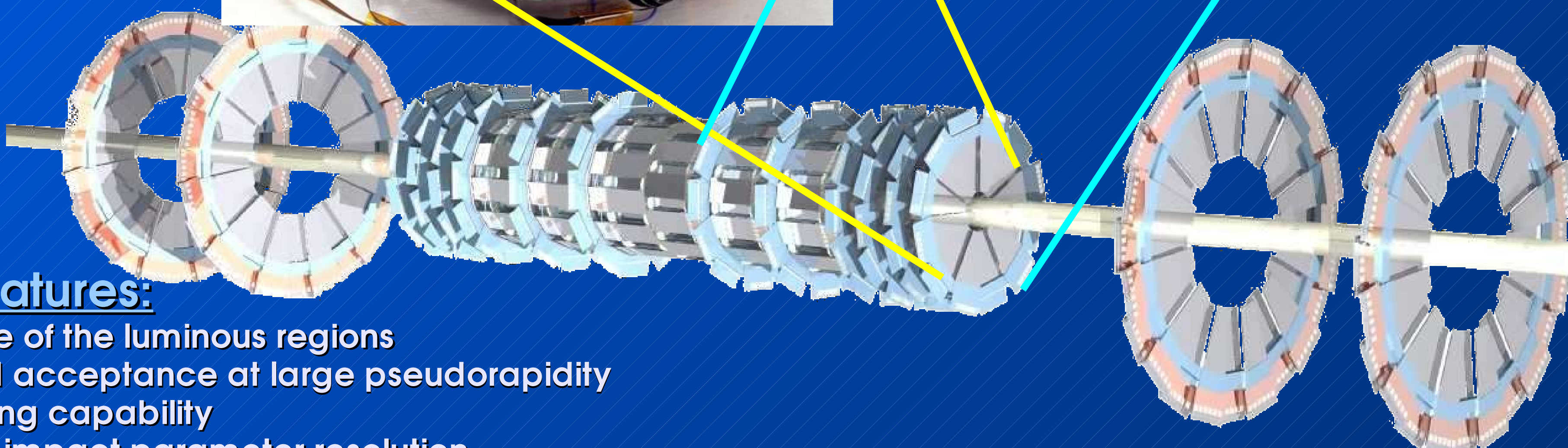
The DØ Silicon Tracker

- **Silicon Microstrip Tracker (SMT):**
  - 6 barrels, 14 disks
  - Tracking out to ~ $\eta = 3$





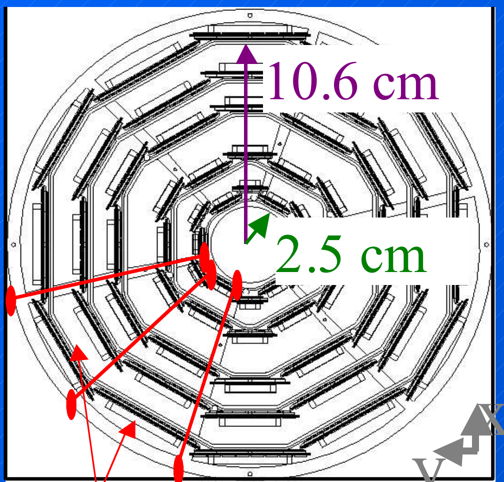
- axial, double-sided small-angle stereo and double-sided 90° detectors
- 800k channels, SVX2 readout



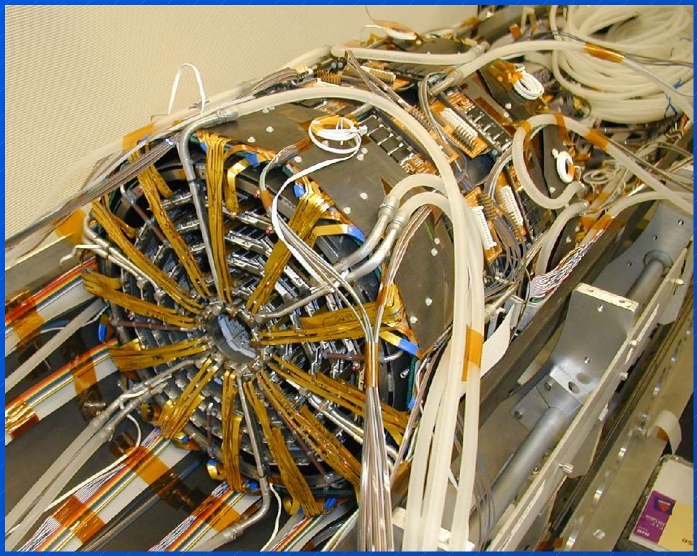
Main features:

- Coverage of the luminous regions
- Extended acceptance at large pseudorapidity
- 3D Tracking capability
- Excellent impact parameter resolution

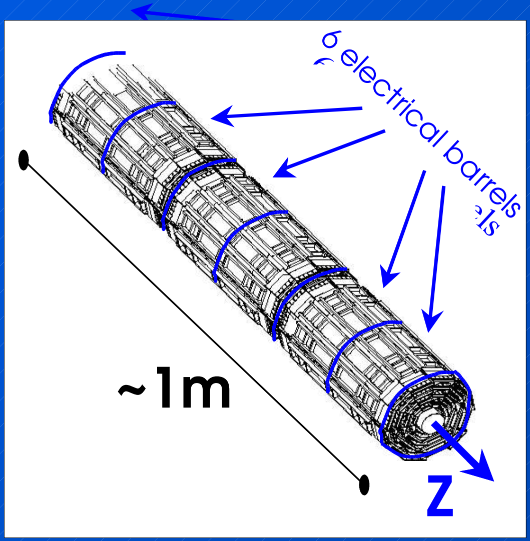
Baseline Upgrade: SVX II



Note wedge symmetry



- 7-8 silicon layers
- 722, 432 channels
- $r\varphi$, rz views
- z^{max} = 45 cm, η^{max} =3
- 1.3 < r < 30 cm



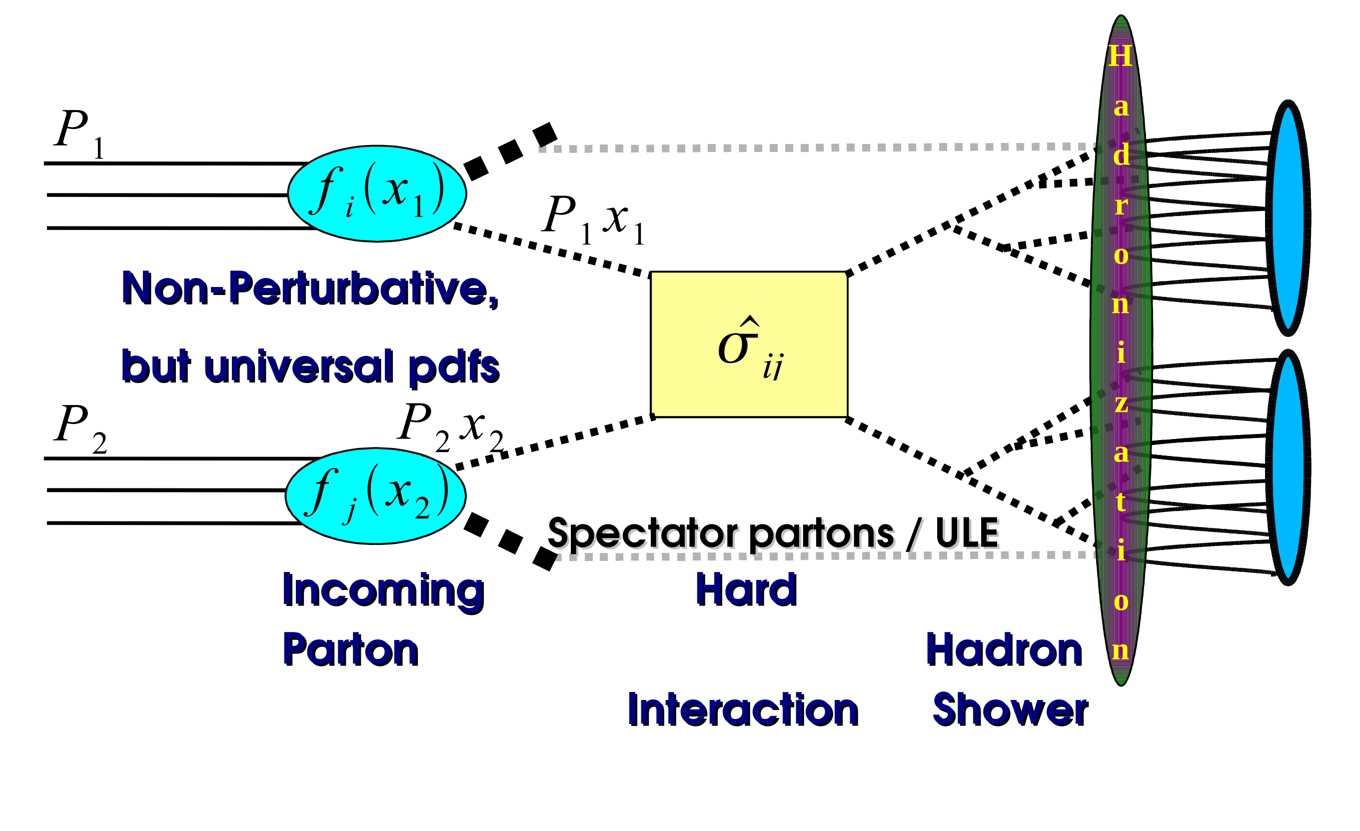
- 5 double-sided layers
  - 5 axial, 3 x 90°, 2 x 1.2°
- Tight alignment tolerances
  - for displaced track trigger
- Highly symmetric
  - 12-fold in φ
  - 6-fold in z

Run II physics goals
properties of top quark
precision Electroweak
CKM, B_s mixing
search for new phenomena
tests of QCD

heavy flavour tagging
B reconstruction efficiency
increased forward acceptance
improved σ_{d0} (~20 μm)

Soft Underlying Event

The **"underlying event"** consists of hard initial & final-state radiation plus the "beam-beam remnants" and possible multiple parton interactions.

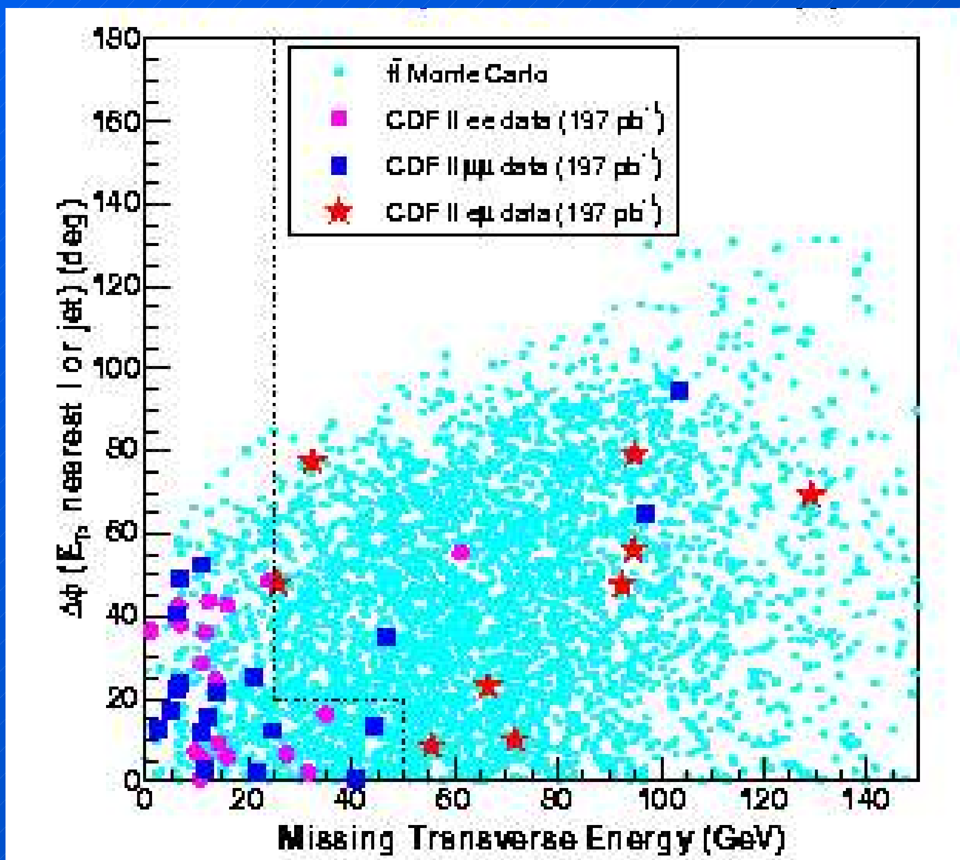


Learn through studies of min bias events, Jet events. Look at distributions/correlations of charged particles with $\eta<1$, $p_T>500$ MeV

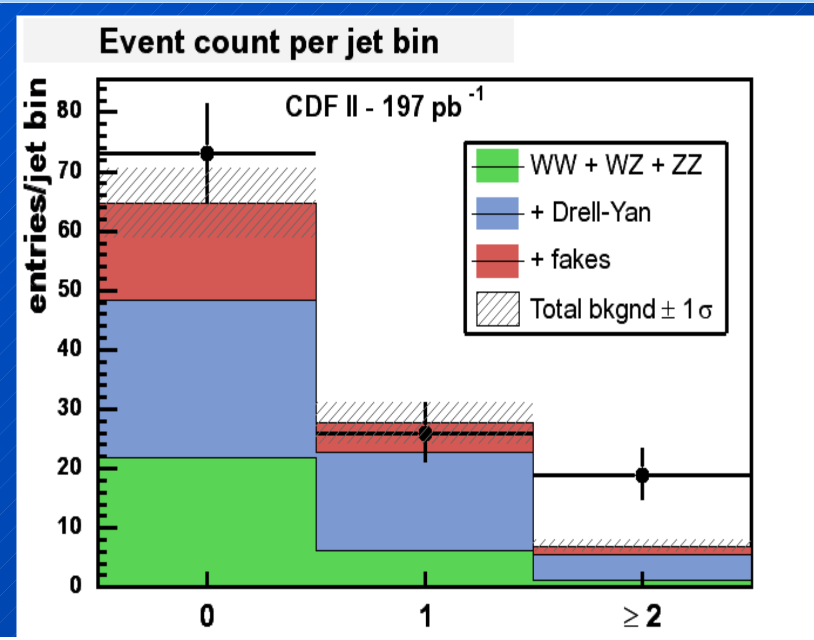
Also, studies of mini-jets in min bias events

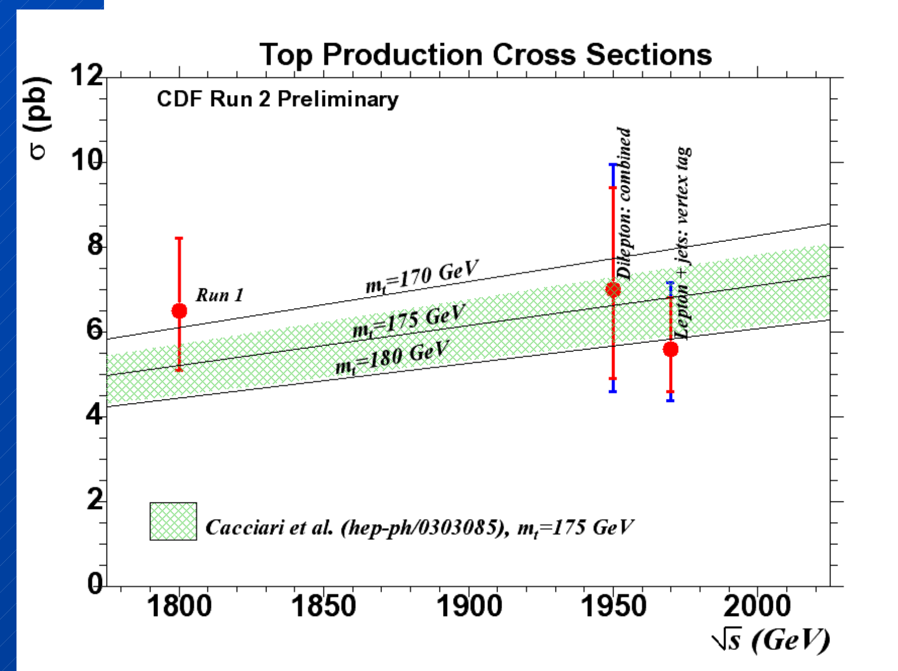
CDF Top Cross Sections in Di-Leptons

- 197 pb^{-1} data sample for all channels
- combine ee, $\mu\mu$ and eμ channels for best precision



$$\sigma_{t\bar{t}} = 7.0^{+2.4}_{-2.1}(\mathrm{stat.})^{+1.6}_{-1.1}(\mathrm{syst.}) \pm 0.4(\mathrm{lum.})$$

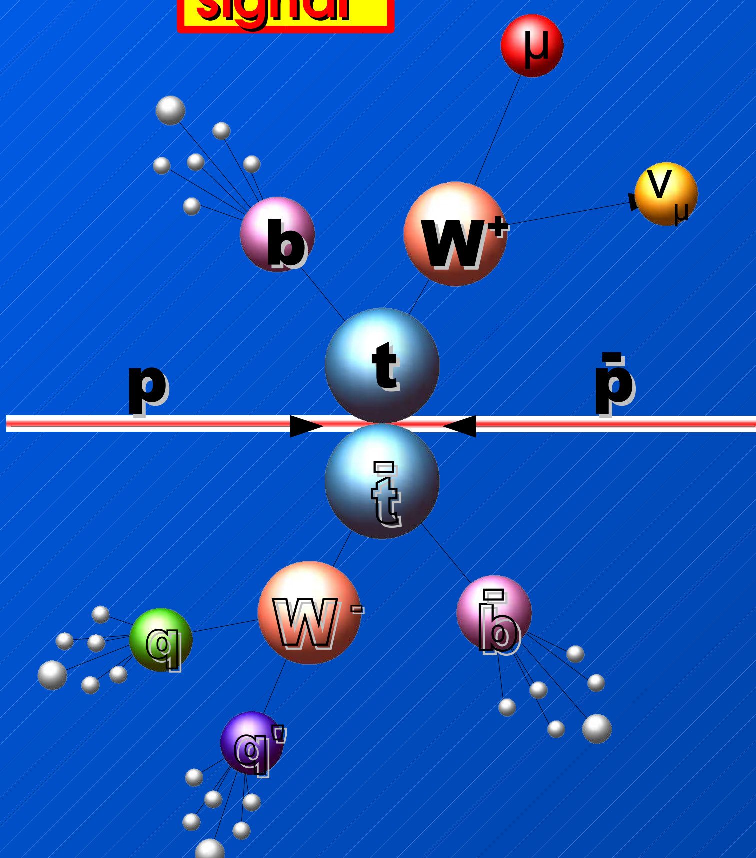




Event Topology in Lepton+Jets

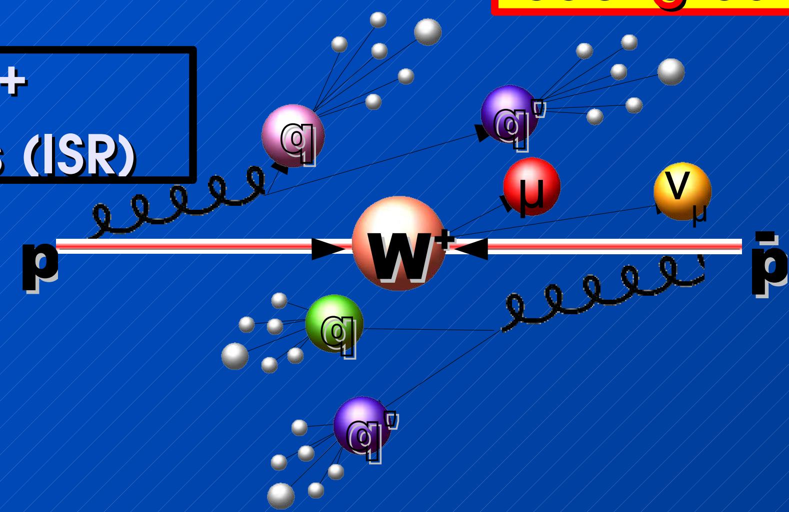
- 1 lepton with high p_T
- 1 ν (reconstructed as transverse energy (met))
- ≥ 4 jets

signal

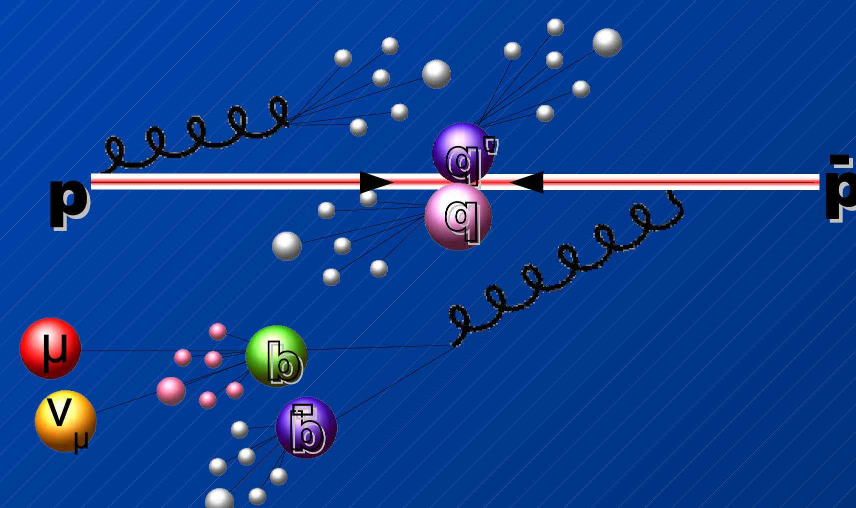


background

W → l +
≥ 4 jets (ISR)

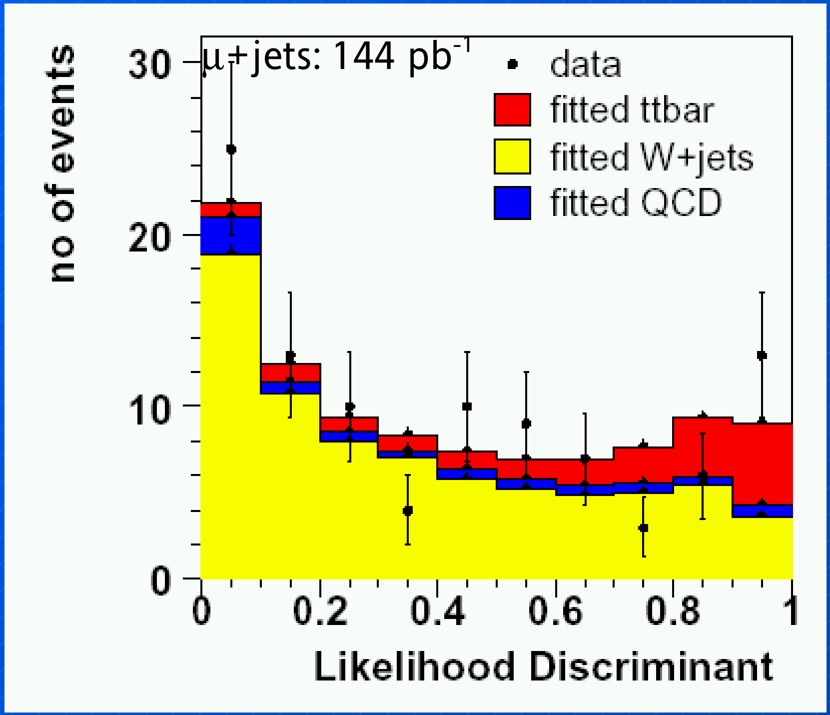


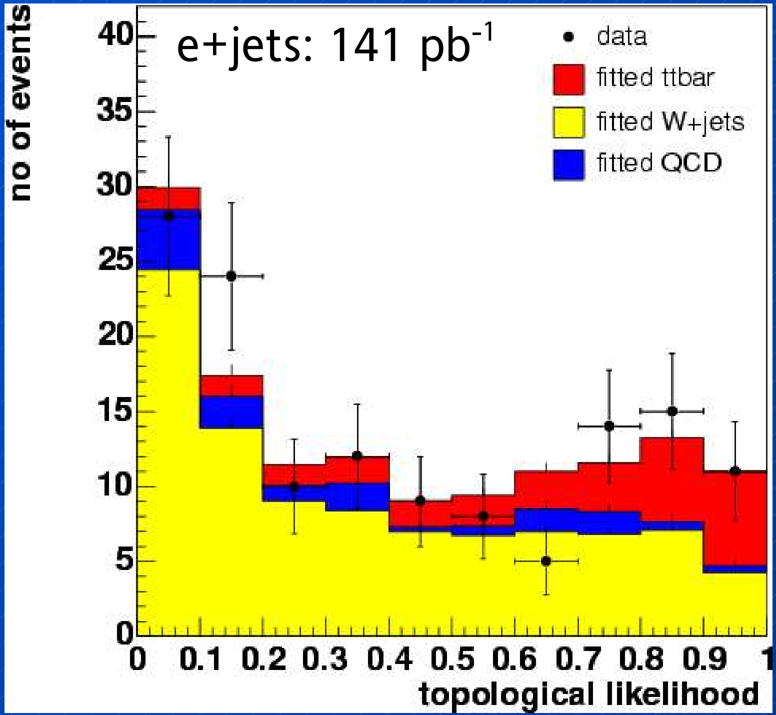
multijet background (QCD)
+ misreconstructed met
+ fake isolated μ or e



Likelihood Fits in l+jets Channel

fit linear combination of QCD (inverted tight selection in data), W+4jet and ttbar to data





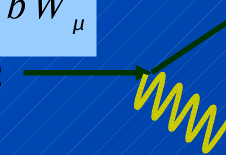
	muons	electrons
Nev	100	136
fitted N^W	74.7 + 12.7 – 12.0	94.6 + 15.8 - 15.0
fitted N^{QCD}	7.1 + 0.9 – 0.9	14.1 + 1.2 - 1.2
fitted N^{tt}	17.8 + 9.9 – 8.7	27.5 + 12.7 - 11.7

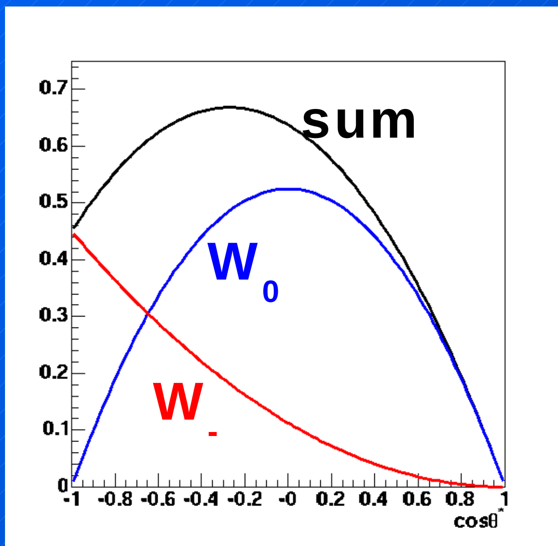
Helicity of the W in ttbar Events

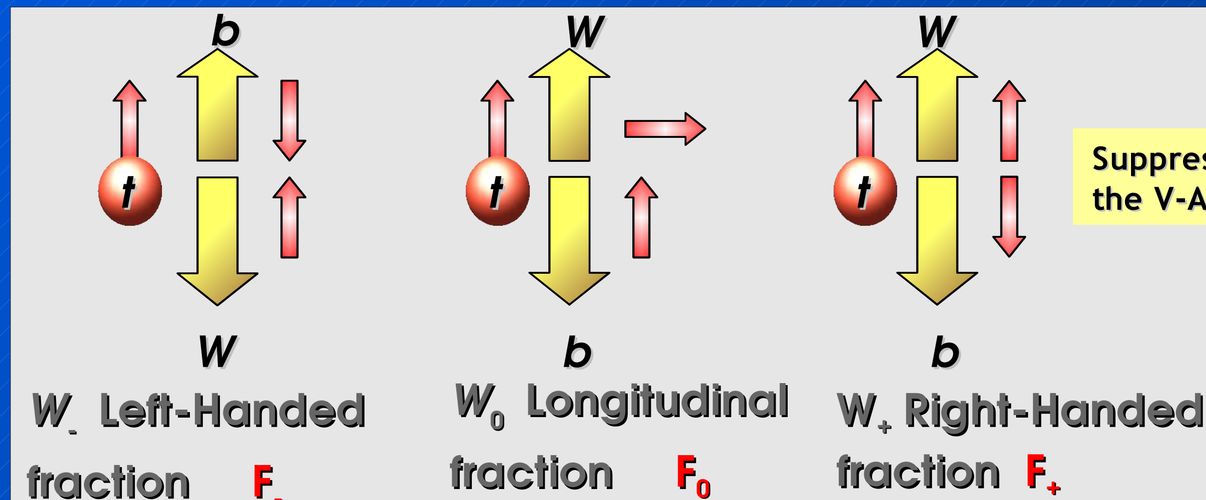
Top Standard Model weak decay →
V-A coupling as it is for all the other fermions

$$\frac{-i\,g}{2\sqrt{2}}\,\bar{t}\,\gamma^{\mu}\left(1-\gamma^{5}\right)V_{tb}\,b\,W_{\mu}$$

V-A







Suppressed by the V-A coupling

$$w(\cos\phi_{l\bar{b}}) = F_{-}\cdot\frac{3}{8}(1-\cos\phi_{l\bar{b}})^{2} + F_{0}\cdot\frac{3}{8}(1-\cos^{2}\phi_{l\bar{b}}) + F_{+}\cdot\frac{3}{8}(1+\cos\phi_{l\bar{b}})^{2}$$

In SM (with m_b=0, M_{top} = 175 GeV and m_W = 80.4 GeV),

$$F_{-} = \frac{2\frac{m_W^2}{M_{top}^2}}{1+2\frac{m_W^2}{M_{top}^2}} \approx 0.30$$

$$F_{0} = \frac{1}{1+2\frac{m_W^2}{M_{top}^2}} \approx 0.70$$

$$F_{+} = 0$$

Helicity of W manifests itself in decay product kinematics

Helicity of the W in ttbar Events (Run I)

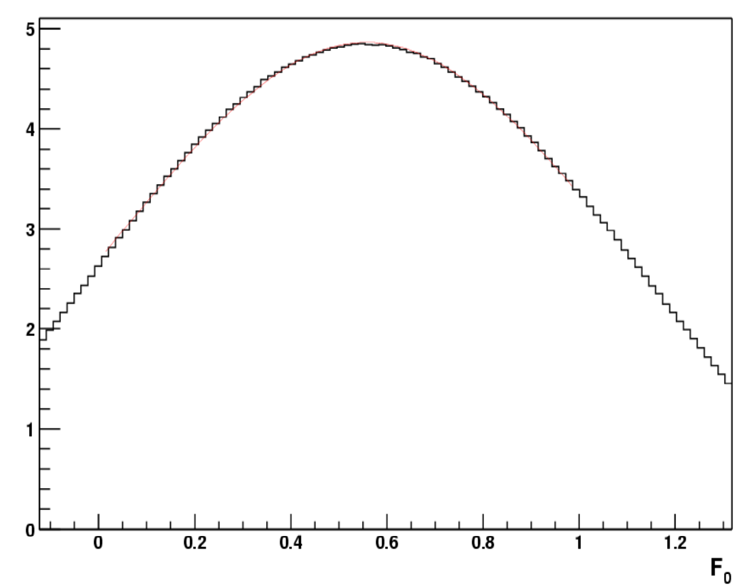
- Uncertainty on the top mass translates into a systematic error on the measurement of F_0

$$L(F_0) = \int L(M_{top}, F_0)\, dM_t$$

DØ Run I analysis using `Matrix Element' technique

- Integrate over M_{top} from 165 to 190 GeV
- Most probable value and 68.27% interval using M_{top}=175 GeV

- 22 events pass our cuts => from fit, 12 signal + 10 background events

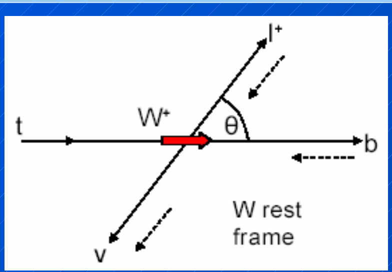


$F_0 \pm \delta F_0$(Stat+ M_{top}) = 0.558 ± 0.306

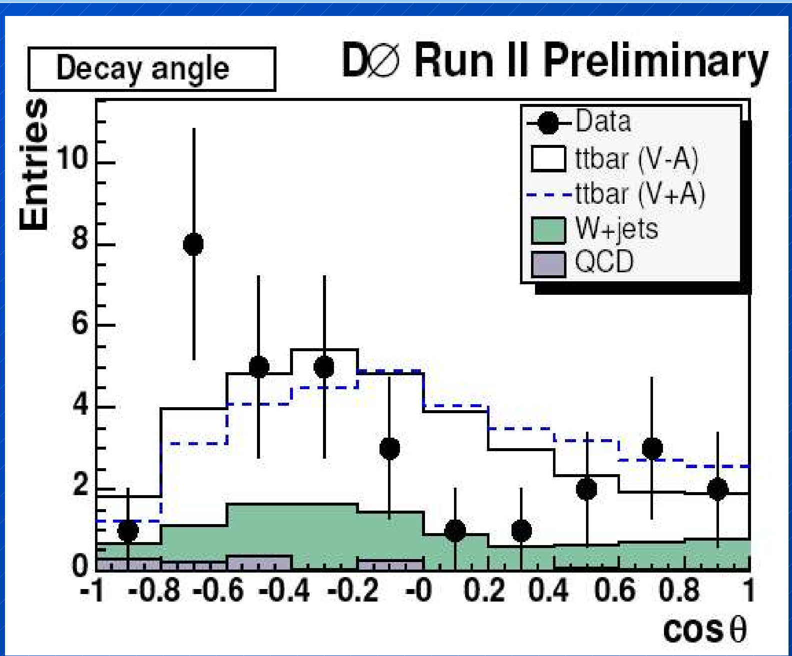
	Statistics + M_{top} uncertainty	0.306
From data	Jet Energy Scale	0.014
From data	Parton Distribution Function	0.007
From data	Acceptance-Linearity Corr.	0.021
From Monte Carlo	Background	0.010
From Monte Carlo	Signal Model	0.020
From Monte Carlo	Multiple Interactions	0.009
From Monte Carlo	ttbar Spin Correlations	0.008

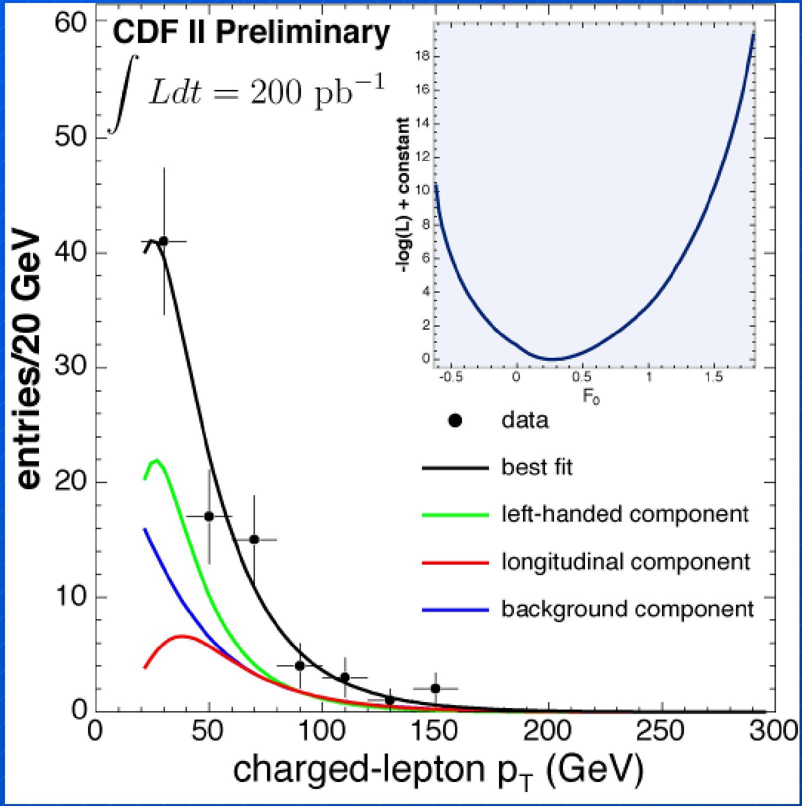
Helicity of the W in ttbar Events (Run II)

- DØ (l+jets, 160 pb^{-1})
- b-tag or topol. selection
- kinematic ttbar fit → boost into W rest frame
- decay angle distribution



$F_+ < 0.24$ @ 90% CL





- CDF (l+jets and dilepton, 200 pb^{-1})
- charged lepton p_T in lab. frame

$F_0 = 0.27^{+0.35}_{-0.24}$

... no deviations from SM predictions
eventually simultaneous fit for F_0 and F_+ ...

Unexpected Top Decay Modes ?

Assuming three generation CKM unitarity, $|V_{tb}|=0.999$ $\Rightarrow$ R = BR(t → Wb) / BR(t → Wq) > 0.998

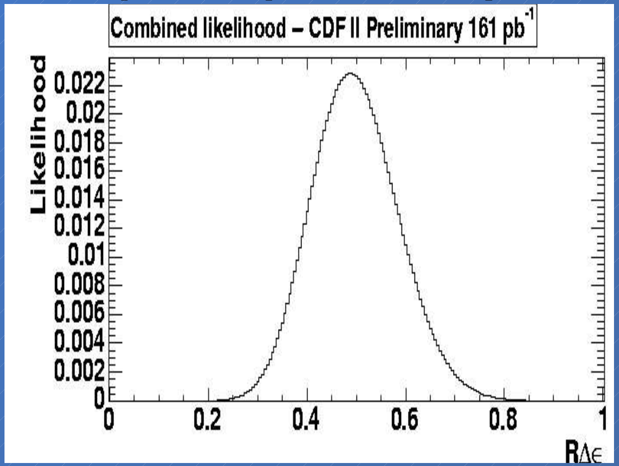
b=BR(t → Wb)

Can measure ratio by checking the b-quark content of the top sample decay if efficiency to tag a b-quark is ε_b (~0.45 at CDF), then

$\varepsilon_2=(b\,\varepsilon_b)^2$ "double tagged"

$\varepsilon_1=2b\,\varepsilon_b(1-b\,\varepsilon_b)$ "single tagged"

$\varepsilon_0=(1-b\,\varepsilon_b)^2$ "un-tagged"



BR(t → Wb) / BR(t → Wq) > 0.62 @ 95% CL

Does top decay into something else than Wb ?
like Xb, where X → qq (100%) or Yb, where Y → lν (100%) ?
estimate using ratio of top cross section $\sigma_{ll} / \sigma_{ljets}$

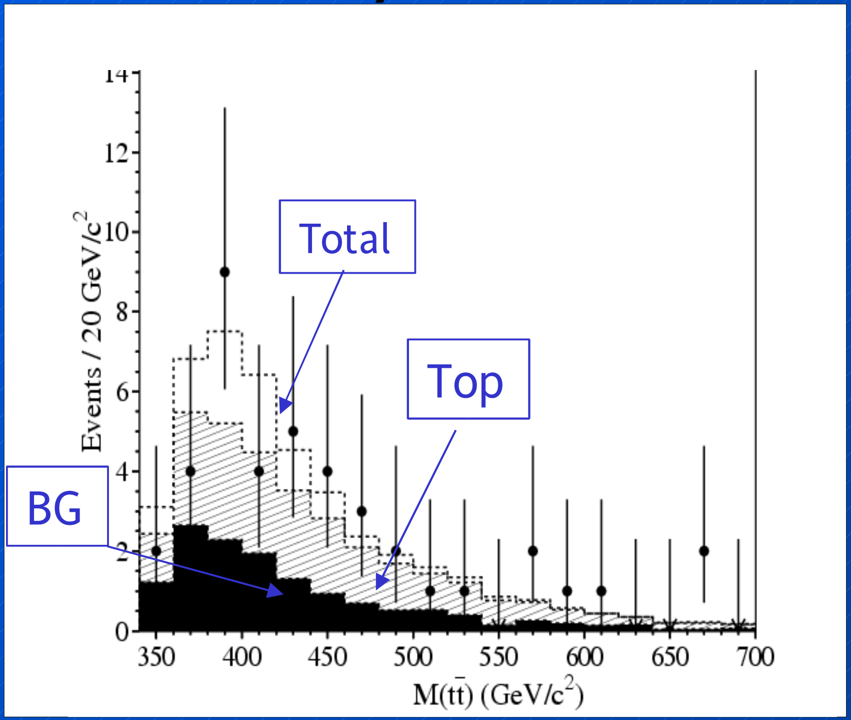
BR(t Xb) < 0.46 @ 95% CL
BR(t Yq) < 0.47 @ 95% CL

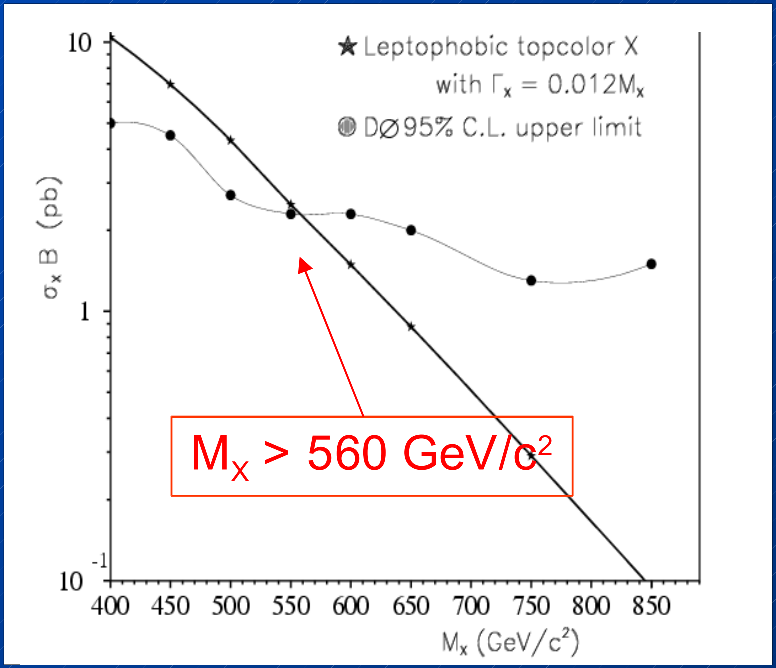
Resonances in tt System ?

No resonance production in tt system is expected in SM (cc, bb, ...)
some models predict particles which decay into ttbar
example: topcolour-assisted technicolour
⇒ predicts leptophobic Z' with strong 3rd-generation coupling

experiment: search for bumps/peaks in ttbar effective mass spectrum

DØ Run I analysis





New Phenomena Searches

Preliminary:

- Search for LED in the Dimuon Channel
- Search for LEP in the Dielectron and Diphoton Channels
- Search for LED in Jets+MET Topology
- Search for Randall-Sundrum Gravitons in the Dielectron and Diphoton Final States
- Search for Large and TeV-1 ED in the Dielectron Channel
- ➔ Search for Chargino/Neutralino in the eel Final State
- ➔ Search for Chargino/Neutralino in the $\mu\mu$l Final State
- ➔ Search for Chargino/Neutralino in the eμl Final State
- ➔ Search for Chargino/Neutralino in the Like-sign Muon Channel
- ➔ Search for Chargino/Neutralino in the Trilepton (combined) Final State
- Search for R-parity Violating Resonant Slepton Production
- Search for Supersymmetry with R-parity Violation in the eel Final State
- Search for Supersymmetry with R-parity Violation in the $\mu\mu$l Final State
- Search for Quark-electron Compositeness in ee Production
- Search for Technicolor Particles in the Dielectron Channel
- Search for Heavy Z' Bosons in the Dimuon Channel
- Search for Heavy Z' Bosons in the Dielectron Channel
- Search for Scalar Leptoquarks in the Acoplanar Jet Topology
- Search for First Generation Leptoquarks
- Search for Technirho Production in the Mode $\pi_T \rightarrow W\rho_T$
- ➔ Search for Anomalous Heavy-Flavor Production in Association with W Bosons
- Search for Squarks and Luinos in the Jets+MET Topology

Submitted:

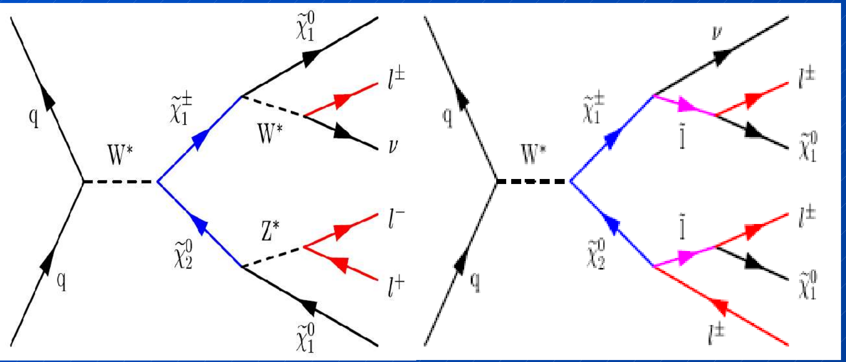
- ➔ Search for Supersymmetry with Gauge-Mediated Breaking in Diphoton Events at DØ
  FERMILAB-PUB-04/198-E, hep-ex/0408146, submitted to PRL

SUSY - Trilepton Final States

Associate production of Chargino and Neutralino

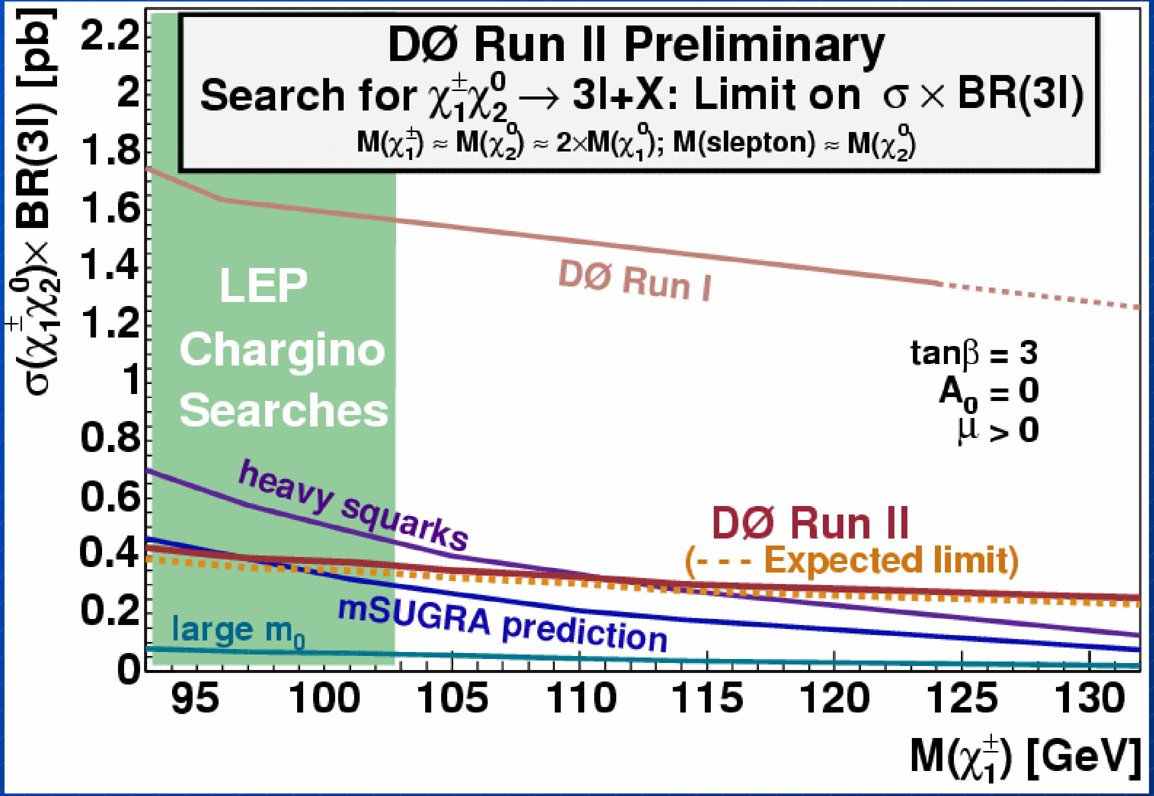
$p\bar{p} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow 3\ell\nu\tilde{\chi}_1^0\tilde{\chi}_1^0$

Signature $= 3\ell + \not{E}_T$



Searches in leptonic channels with

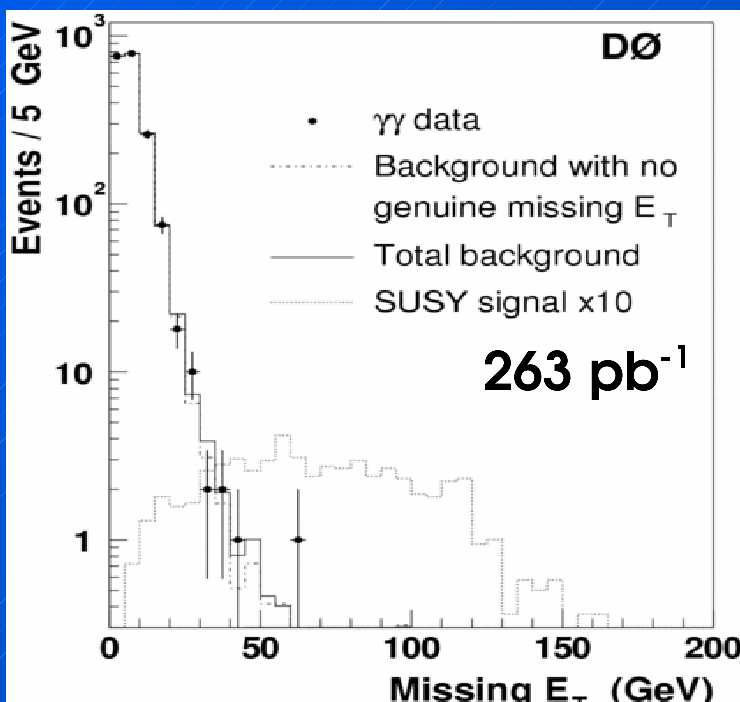
- e + e + l (track)
- e + μ + l (track)
- μ + μ + l (track)
- like sign μ + μ
- 147 – 249 pb^{-1}

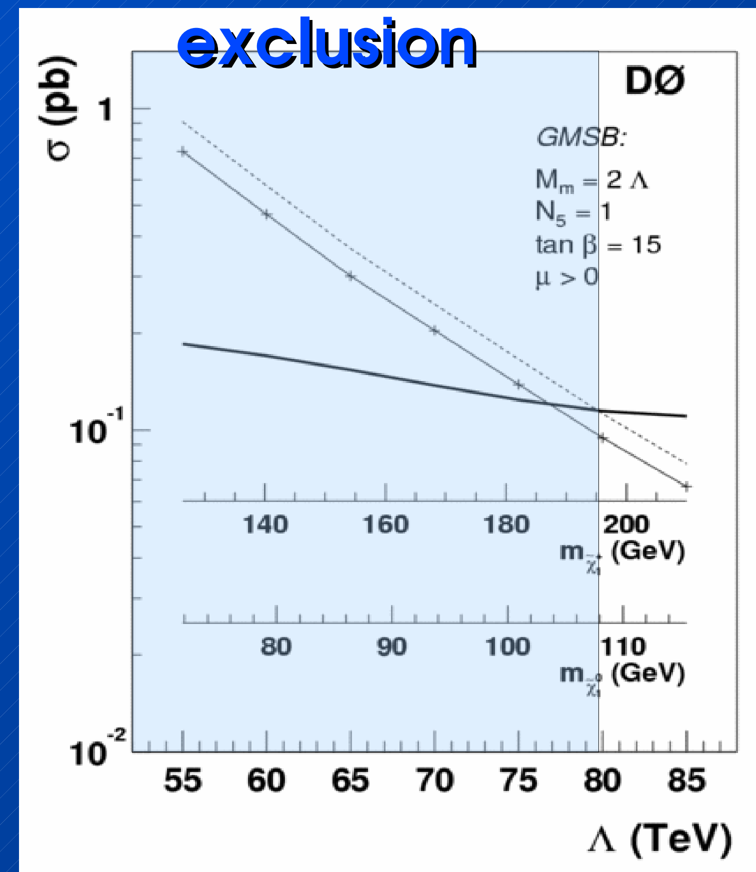


- vast improvement over Run-I limits
- in mSUGRA exclude $m(\chi_1^{\pm}) < 97$ GeV
- with 25% more data expect to reach LEP exclusion
- in models without sfermion mass universality: $m(\chi_1^{\pm}) > 111$ GeV

Diphotons Events in GMSB

- Gauge-mediated SUSY – SUSY breaking at scale Λ, mediated by messengers
- Gravitino is LSP, NLSP is a neutralino or a slepton
- Assume here NLSP is neutralino:
  Search for two photons with large missing E_T





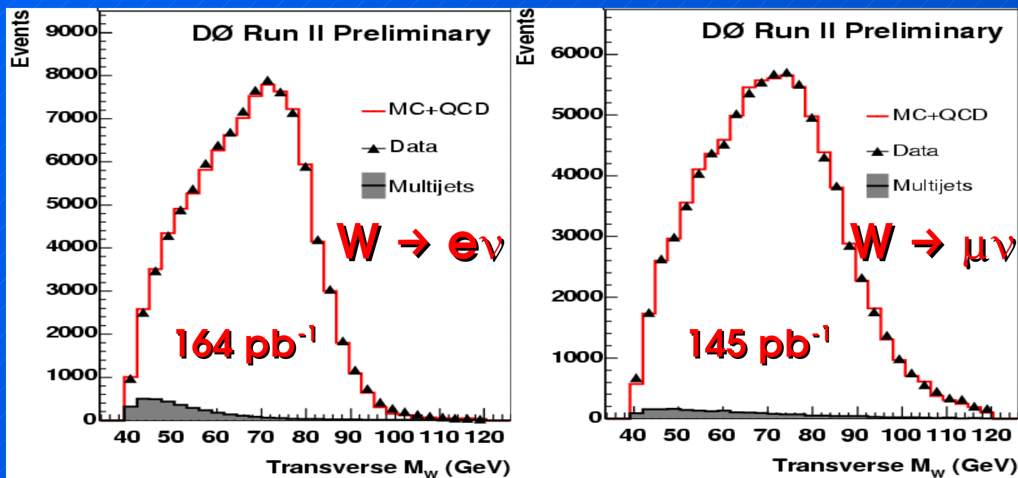
... most stringent limits for models where neutralino is NLSP ...

$m(\chi_1^0) > 108$ GeV @ 95% CL

$m(\chi_1^+) > 195$ GeV @ 95% CL

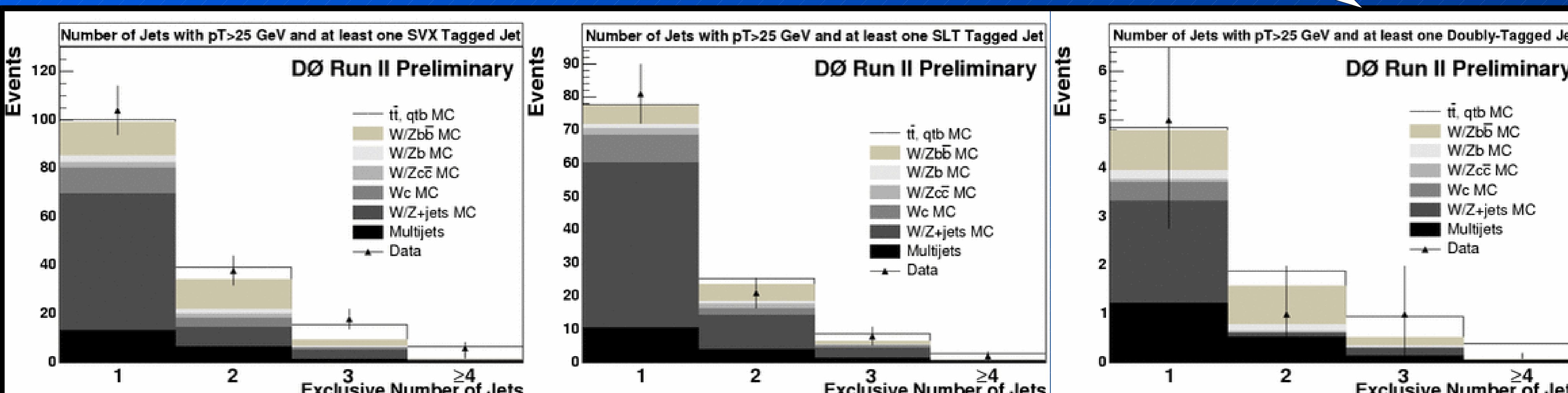
Anomalous Wbb Production

Heavy flavor content of W+jets events sensitive test of Standmodel



no significant departure from predicted rate

source	W+1jets	W+2jets	W+3jets	W+≥4jets
Data obs.	5	1	1	0
SM predict.	4.8±1.1	1.9±0.4	0.9±0.2	0.3±0.05
95% CL limit (evts)	6.78	3.88	4.17	3



≥1 SVT b-tagged jet | ≥1 SLT-tagged jet | ≥1 SVT & SLT b-tagged jet ... highest purity ...

b-Quark Physics

Preliminary:

- Reconstruction of Λ_b in Semi-Leptonic Decays
- Reconstruction of $B_s \to \mu D_s X$ Decays
- Reconstruction of B-Hadron Signals at DØ
- ➔ Observation of B_c Mesons and a Study of its Properties
- Observation of Semileptonic B decays to Narrow D** Mesons
- ➔ Study of excited B-mesons (B**)
- Flavor Oscillations in B_d Mesons with 3-combined Taggers
- Flavor Oscillations in B_d Mesons with SS Tagging
- Flavor Oscillations in B_d Mesons with OS Muon Tagging
- Measurement of Upsilon (1S) Production Cross Section

Submitted:

- Measurement of the Λ_b lifetime in the decay $\Lambda_b \to J/\psi\Lambda^0$
  FERMILAB-PUB-04/286-E, hep-ex/0410054, submitted to PRL
- ➔ Measurement of the ratio of B^+ and B^0 meson lifetimes
  FERMILAB-PUB-04/284-E, hep-ex/0410052, submitted to PRL
- ➔ A Search for the flavor-changing neutral current decay $B_s \to \mu\mu$
  FERMILAB-PUB-04/215-E, hep-ex/0410039, submitted to PRL
- Measurement of the B_s lifetime in the exclusive decay channel $B_s \to J/\psi\phi$
  FERMILAB-PUB-04/225-E, hep-ex/0409043, submitted to PRL

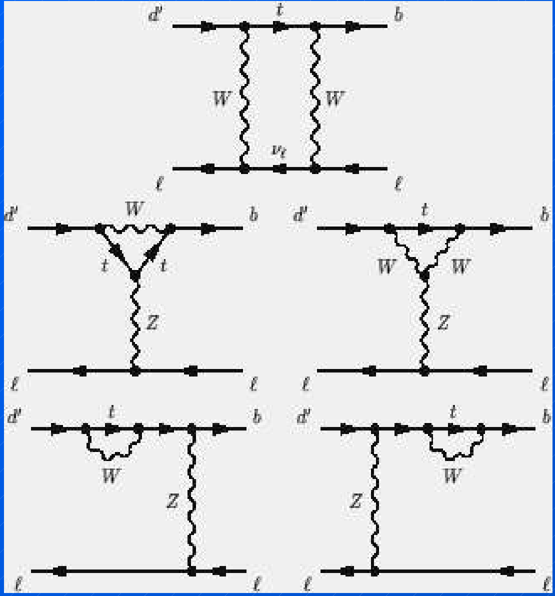
first submitted/published Λ_b exclusive lifetime

most precise submitted/published single measurement of the B_s lifetime

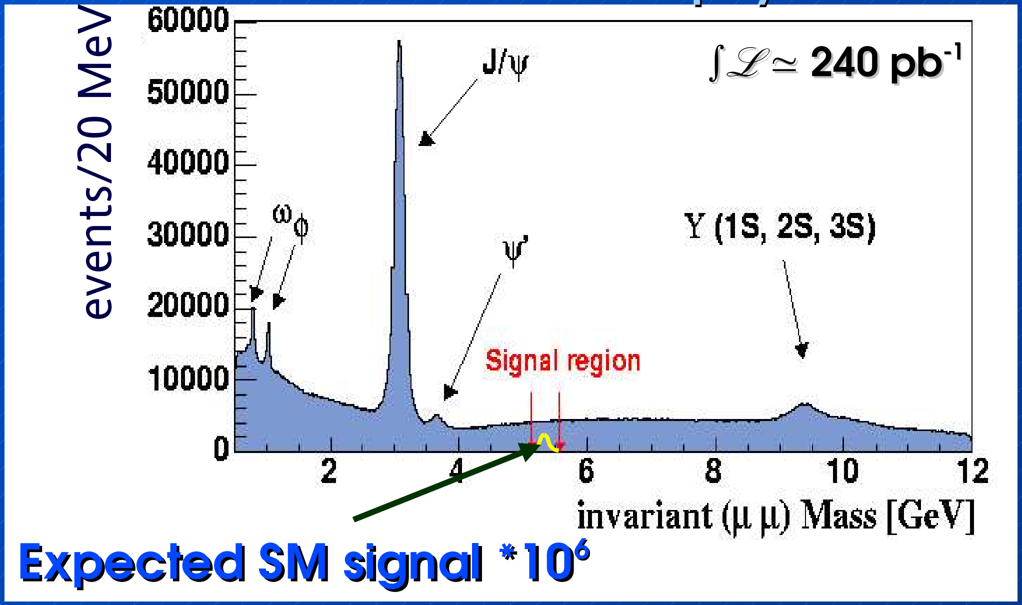
Published:

- Observation and Properties of the X(3872) Decaying to $J/\psi\pi^+\pi^-$
  FERMILAB-PUB-04/061-E, hep-ex/045004, Phys.Rev.Letters 93, 162002 (2004)

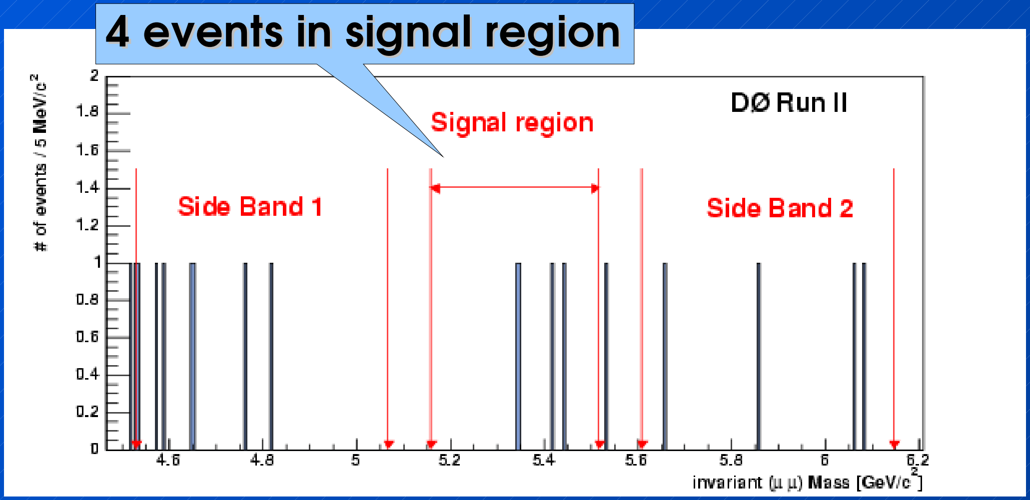
$B_s \rightarrow \mu^+\mu^-$



- Standard Model prediction: $BR(B_s \rightarrow \mu^+\mu^-) = (3.4 \pm 0.5) * 10^{-9}$
- Excellent place to look for SUSY and other new physics



- Background prediction (from sidebands) = 3.7 ± 1.1 events



$BR(B_s \rightarrow \mu^+\mu^-) < 5.0 * 10^{-7}$ @ 95% CL

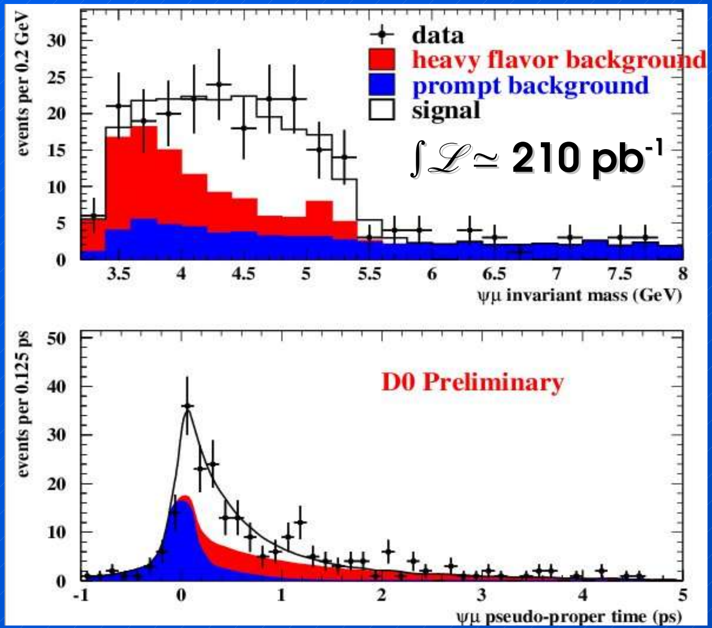
... new best limit ...

... will keep improving with time ...

B_c Observation & B** Studies

B_c last ground state to be clearly observed

Here: $B_c \rightarrow (J/\psi \rightarrow \mu\mu)\ \mu + X$



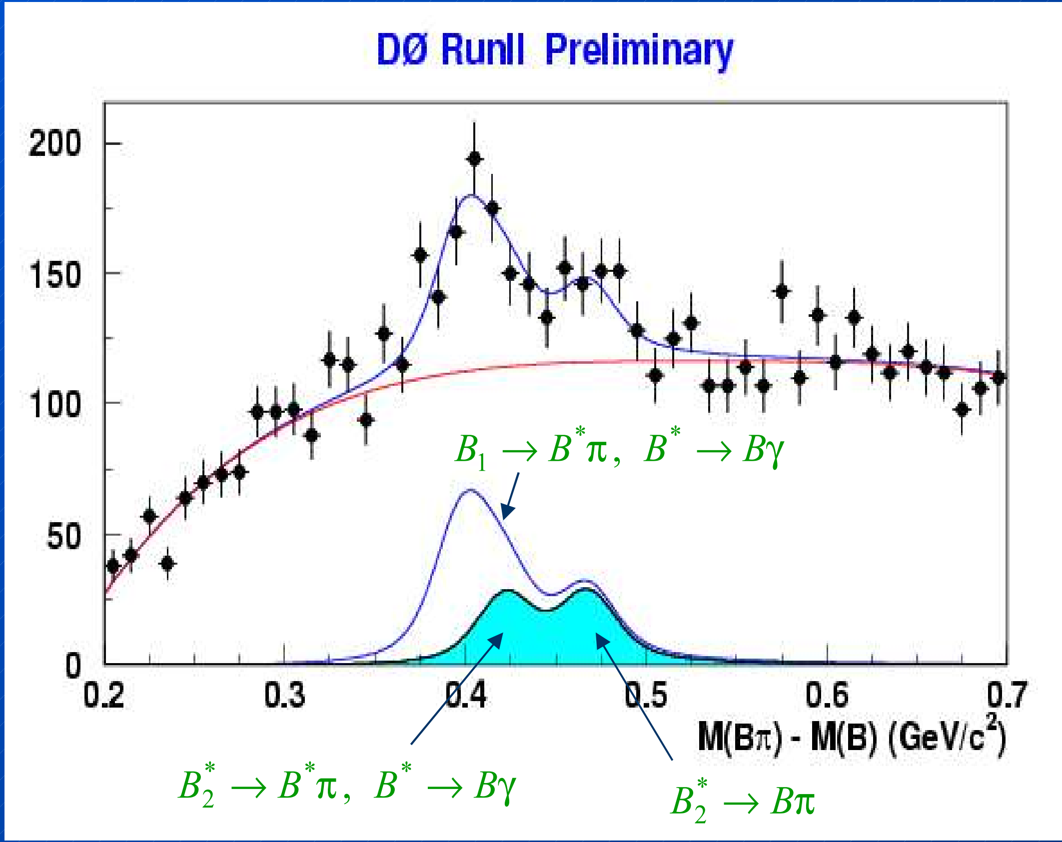
combined lifetime and mass fit:

- $N(B_C) = 95 \pm 12 \pm 11$
- $m(B_C) = 5.95 \pm 0.14 \pm 0.34\ GeV/c^2$
- $\tau(B_C) = 0.45 \pm 0.12 \pm 0.12$ ps

models expect: $m(B_C) \sim 6.5\ GeV/c^2$,

$\tau(B_C) \sim 0.3\text{-}0.5$ ps

So far only B^+, B_d^0, B_s^0 ($J^P=0^-$) and B^* ($J^P=1^-$) established separately



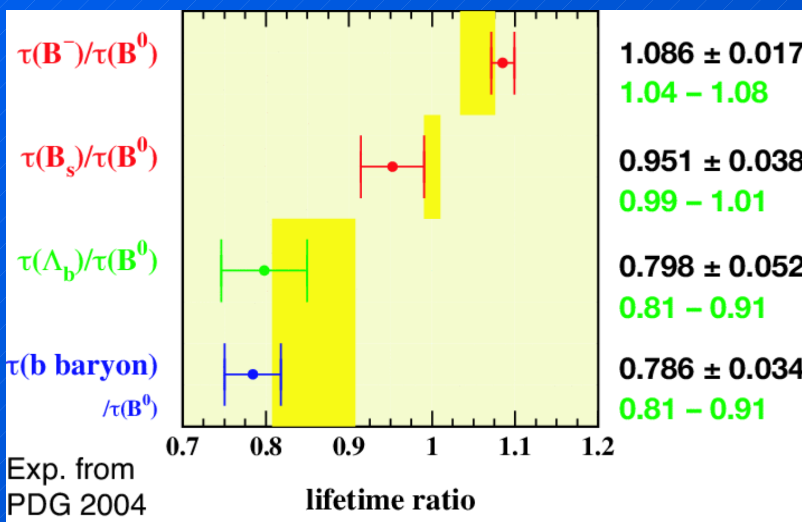
First observation of separated narrow states !

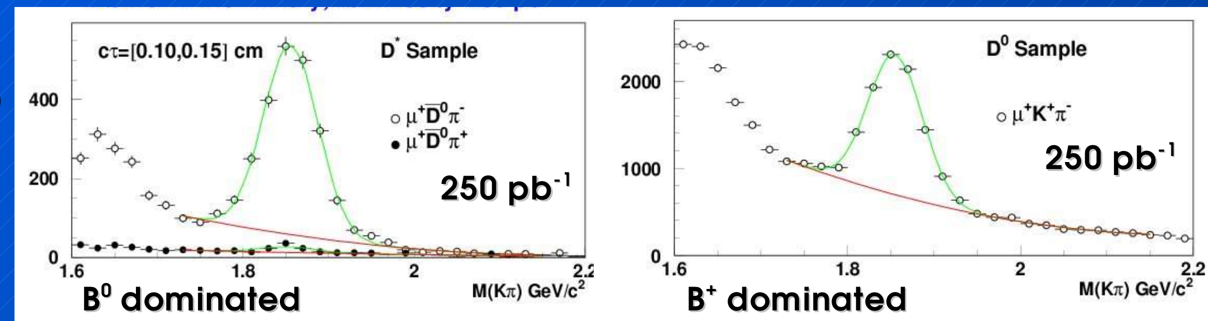
$m(B_1) = 5724 \pm 4(stat) \pm 7(syst)\ MeV/c^2$

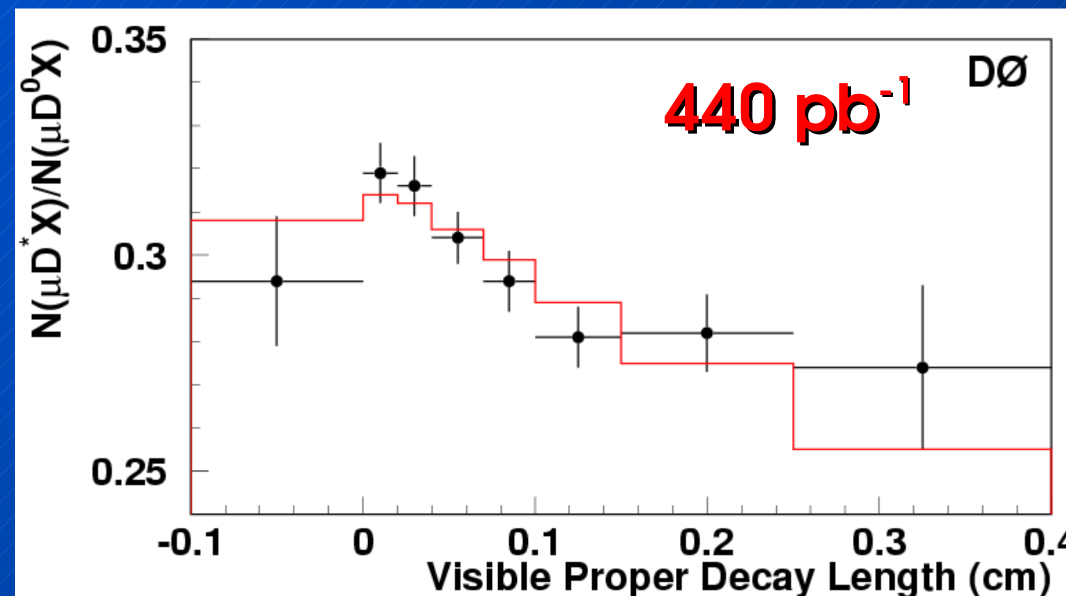
$m(B_2^*) - m(B_1) = 23.6 \pm 7.7(stat) \pm 3.9(syst)\ MeV/c^2$

$\tau(B^+)$ / $\tau(B^0)$

Good test of theory:
- Operator production expansion (OPE)
- Heavy quark effective theory (HQET)
- lattice gauge predictions







$\tau(B^+)$ / $\tau(B^0)$ = 1.080 ± 0.016(stat) ± 0.014(syst)

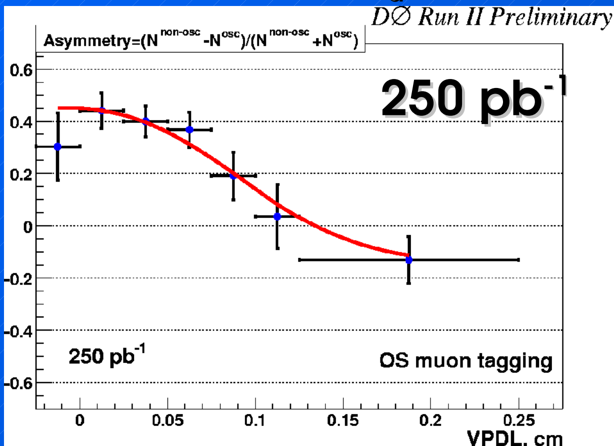
1.086 ± 0.017 world average

- Novel technique using large semileptonic B samples
- taking ratio of D mass peaks in 8 pseudo time bins
- many systematic errors cancel

... worlds most precise submitted/published measurements ...

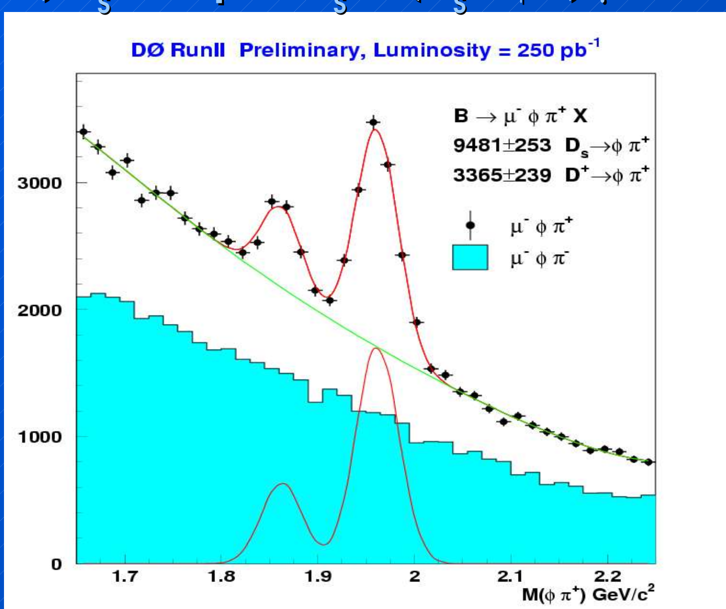
B_s Status and Plans

1.) Demonstrate B_d mixing



$\Delta m_d = 0.506 \pm 0.055 \pm 0.049\ ps^{-1}$

2.) B_s sample: $B_s \to (D_s \to \phi\pi)\ \mu\nu$



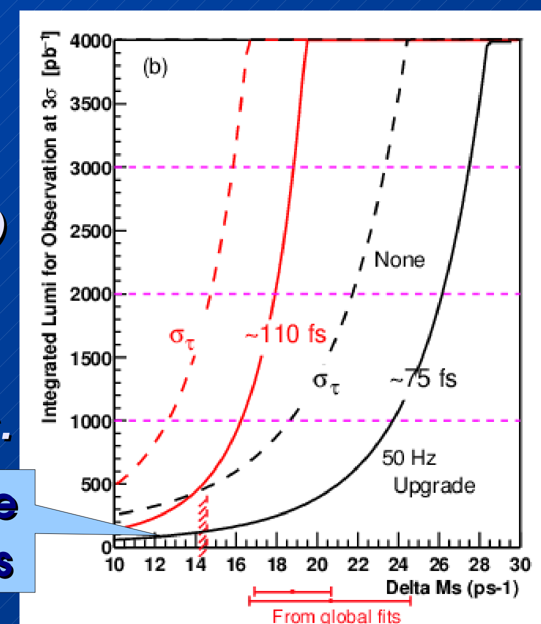
3.) upgrade L3 trigger bandwidth and Si layer 0

- *following the PACs earlier encouragement, DØ has been actively investigating offsite facilities for primary reconstruction that would permit us to significantly increase the number of b-physics trigger that we record (and greatly enhance our B_s mixing reach)*

- *two DØ universities (Indiana and Oklahoma) have now pledged very significant funds on a one-to-one matching basis*

- *we are working an a specific proposal to DOE (perhaps NSF) for the support of such a facility at the universities*
  ⇨ *Collaboration review in Dec.*

MC studies: DØ proper lifetime resolution with layer 0: 63-87 fs

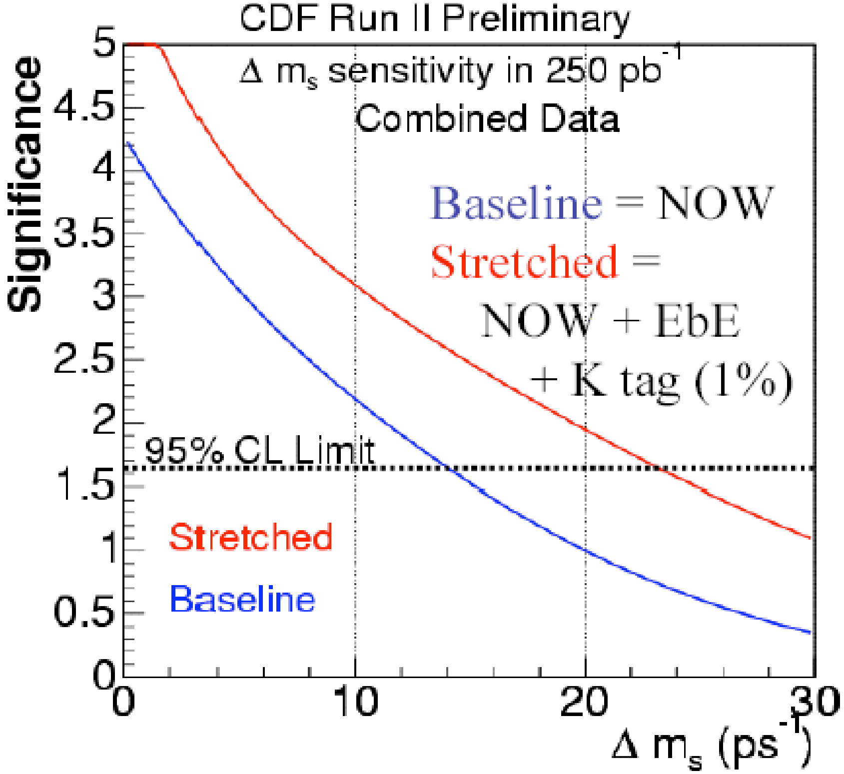


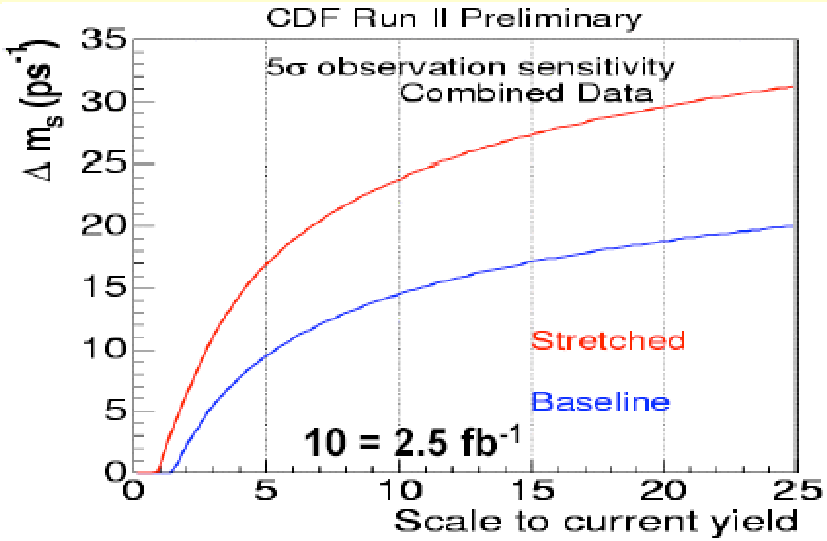
B_s Status and Plans

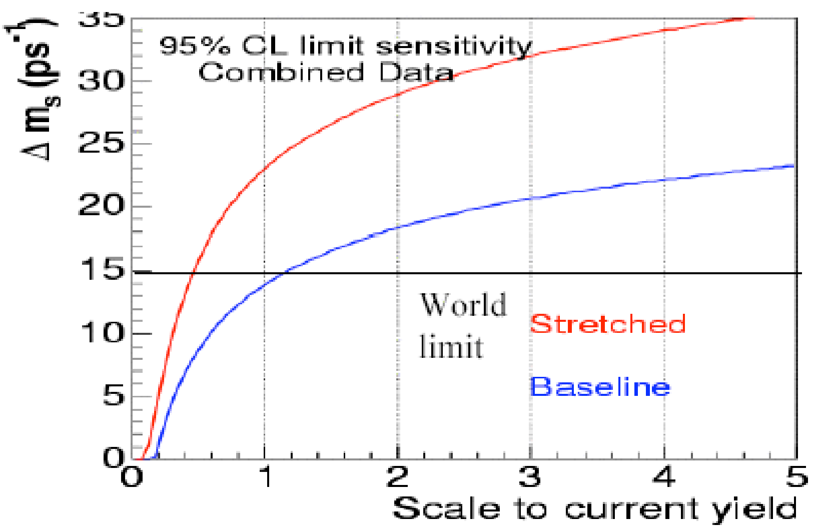
Limit / Measurement of B_s Oscillation

World limit: $\Delta m_s > 14.4\ ps^{-1}$

SM pred.: $15 < \Delta m_s < 27\ ps^{-1}$ (99% prob.)







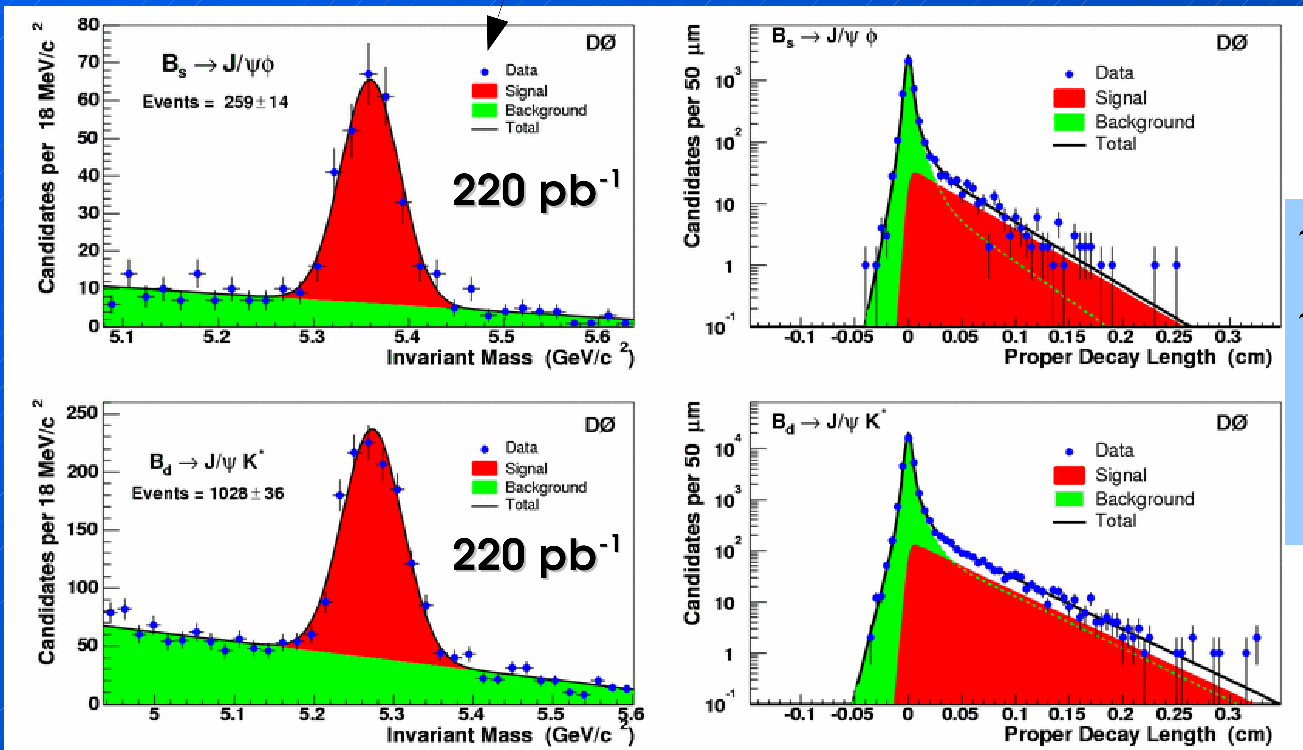
$1 = 250\ pb^{-1}$

B_s lifetime

In b-sector lifetime differences (B_d, B_s, ...) expected to be small

Lifetime difference of B_s and $\bar{B}_s$ postulated

B_s semileptonic and $B_s \to J/\psi\phi$ have different composition of B_s and $\bar{B}_s$



from simultaneous fit to mass and proper decay lengths:

$\tau(B_s^0) = 1.444\,^{+0.098}_{-0.090}(\text{stat}) \pm 0.020(\text{syst})$ ps

$\tau(B^0) = 1.473\,^{+0.052}_{-0.050}(\text{stat}) \pm 0.023(\text{syst})$ ps

$\tau(B_s^0) / \tau(B^0) =$

$0.980\,^{+0.075}_{-0.070}(\text{stat}) \pm 0.003(\text{syst})$ ps

... most precise submitted/published single measurement of the B_s^0 lifetime ...