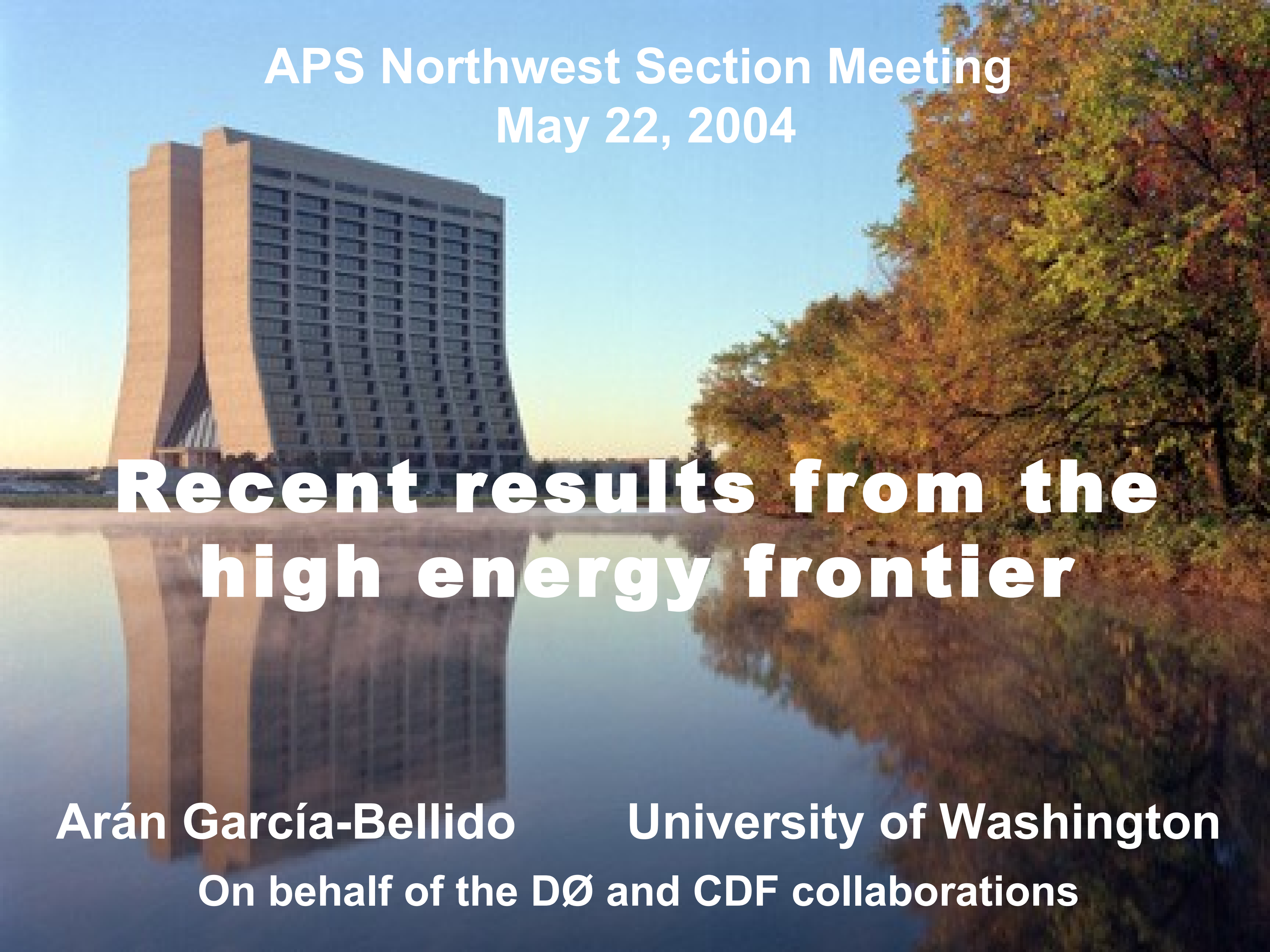


APS Northwest Section Meeting
May 22, 2004

Recent results from the high energy frontier

Arán García-Bellido University of Washington

On behalf of the DØ and CDF collaborations

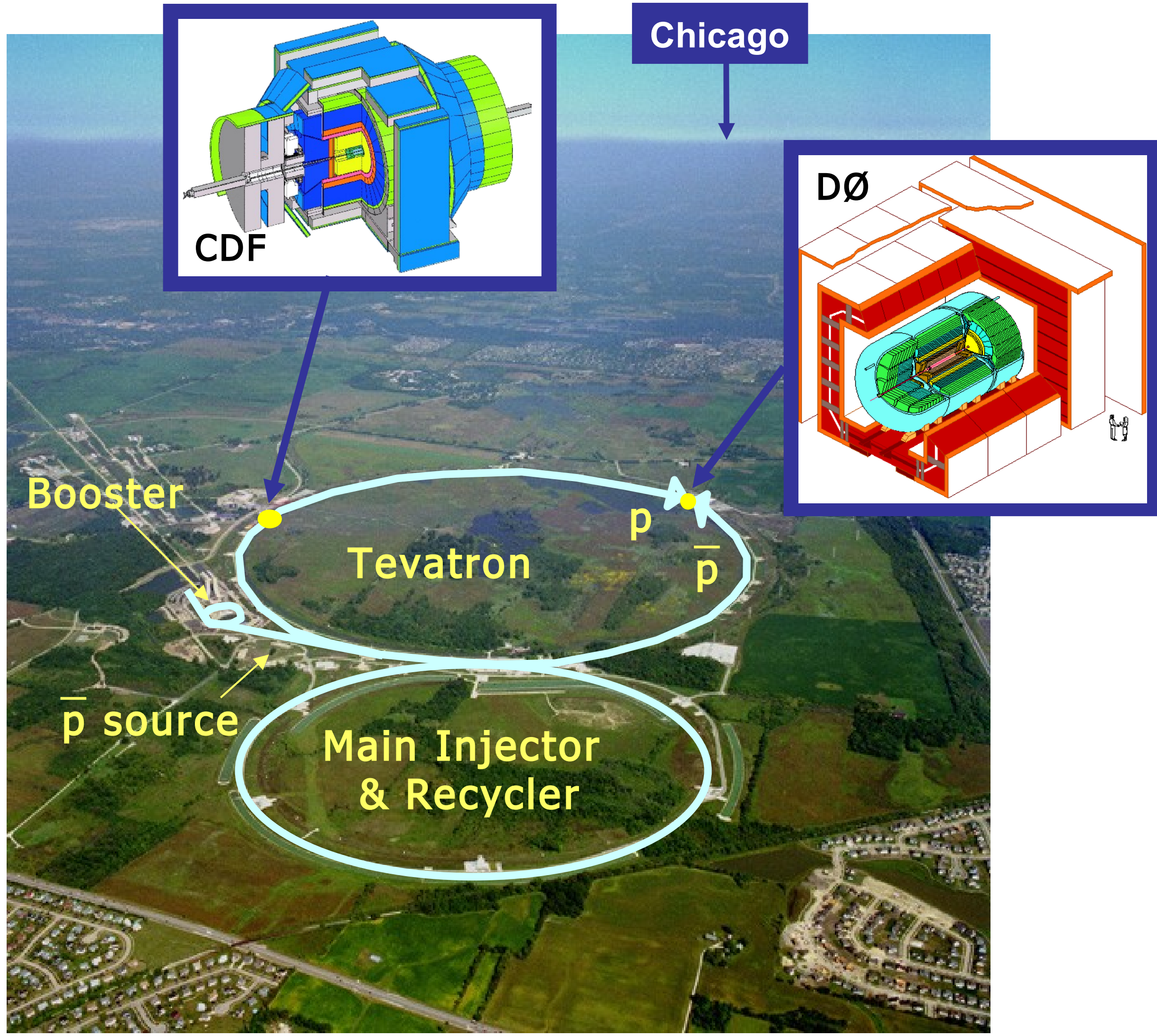
The Fermilab Tevatron

Run I 1992-95

- Top quark discovered!

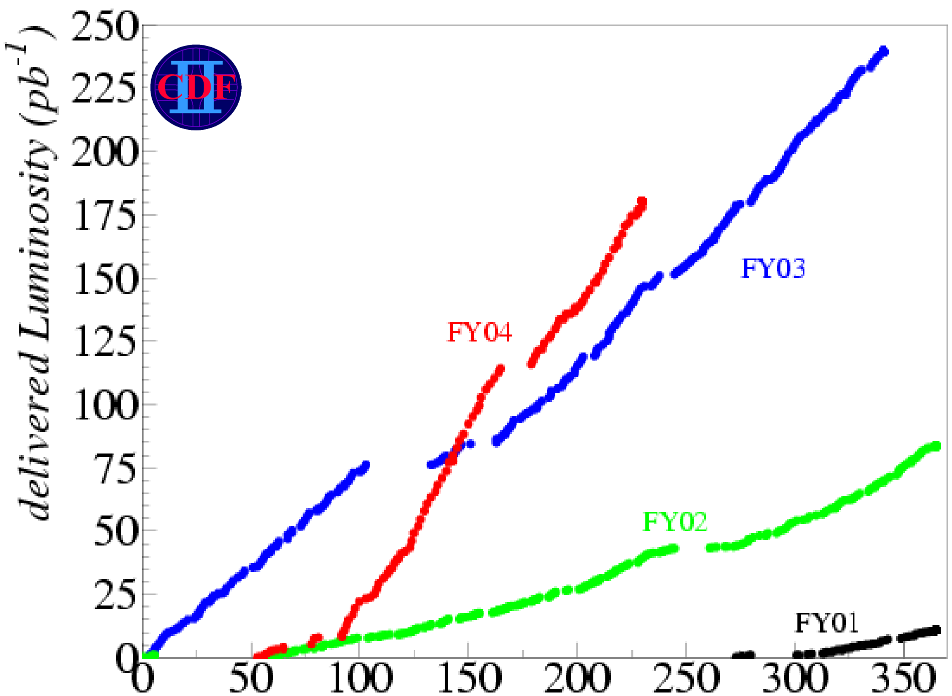
Run II 2001-2009

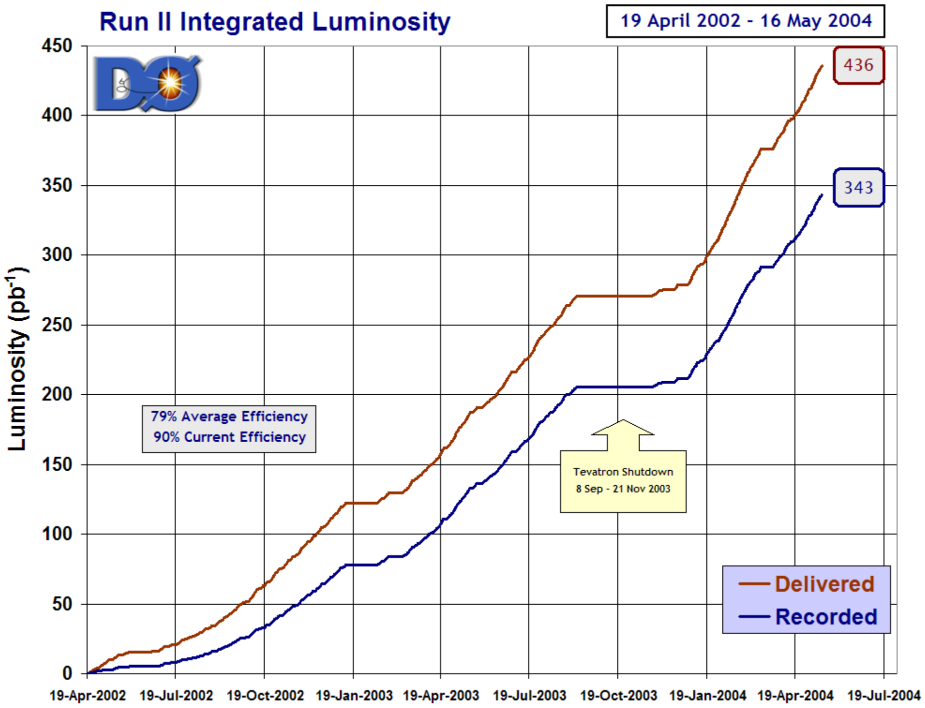
- $\sqrt{s} = 1.96$ TeV
- $\Delta t = 396$ ns
- 36x36 bunches
- Peak Lum 7×10^{31} $cm^{-2}s^{-1}$
- Delivered ~450 pb^{-1}
- (> x2 previously collected)



Unprecedented window into the nature of matter…

Current performance



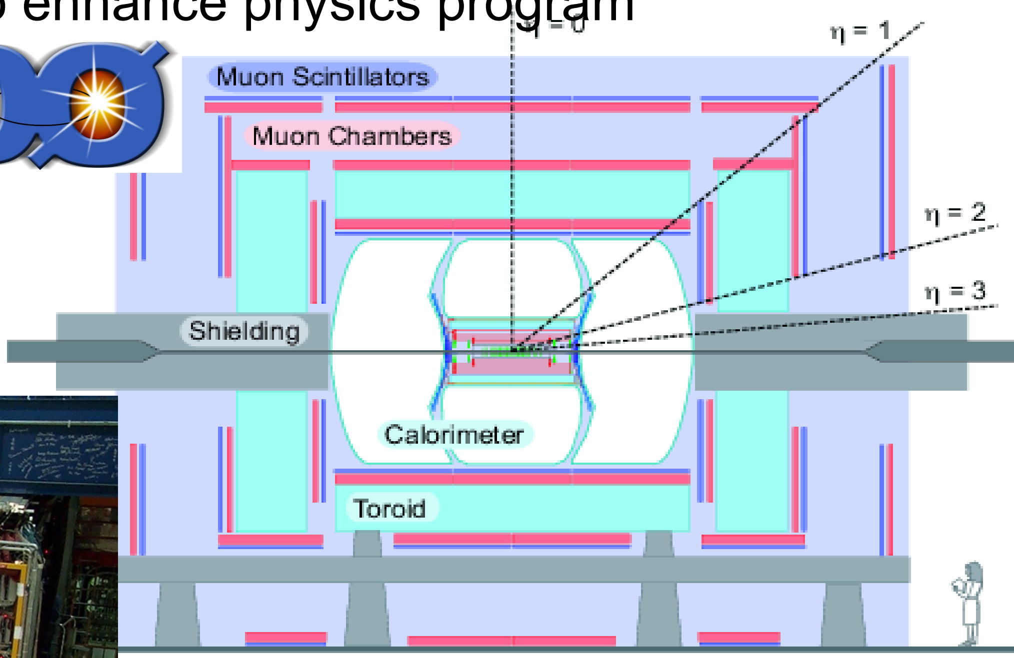


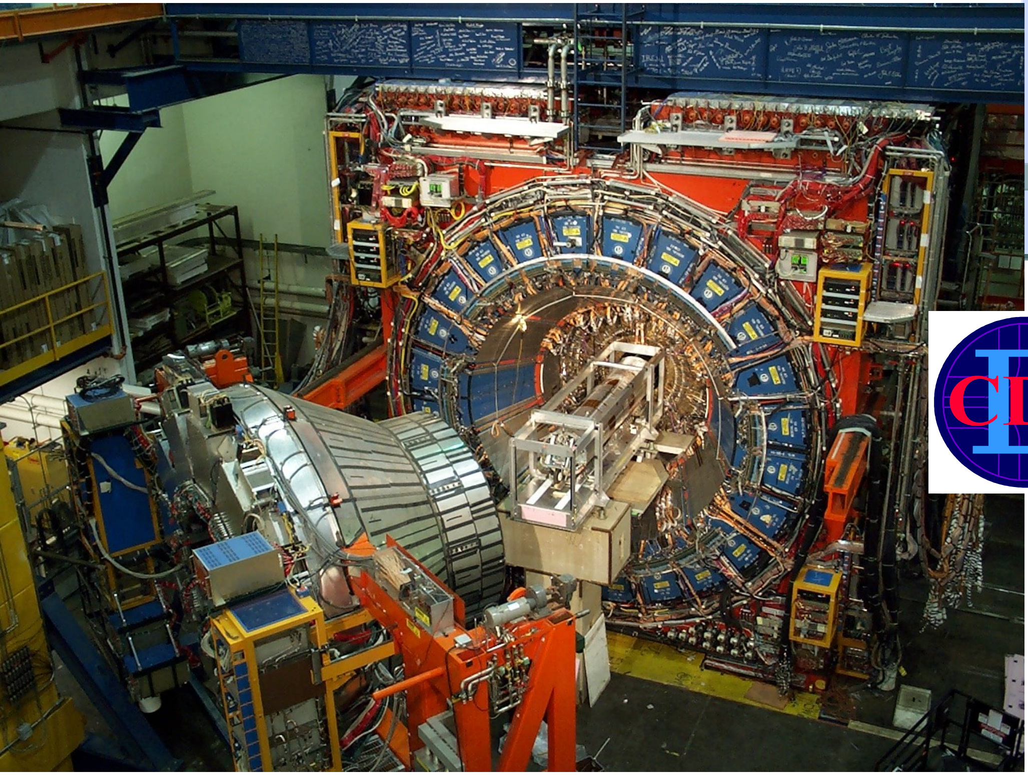
- Continuous improvements
- Excellent running in 2004, beyond expectations
- Around 12 pb^{-1} per week, stores last an average of 20 hours
- More than 300 pb^{-1} on tape per experiment
- Data taking efficiency is usually 85-90%
- Analyses shown here with 100-250 pb^{-1}

CDF and DØ RunII detectors

Upgraded detectors to enhance physics program

- Si + Fiber tracker + Preshowers
- 2T solenoid
- ULAr calo up to |η|=4.2 new electronics
- Muon system up to |η|=2 & shielding
- DAQ & Trigger





- Large Si + Time of flight detectors
- “Plug” calo up to |η|=3.6
- Forward detectors
- Muon system up to |η|=1.5 (gaps filled)
- DAQ & Trigger

Exploring the TeV frontier

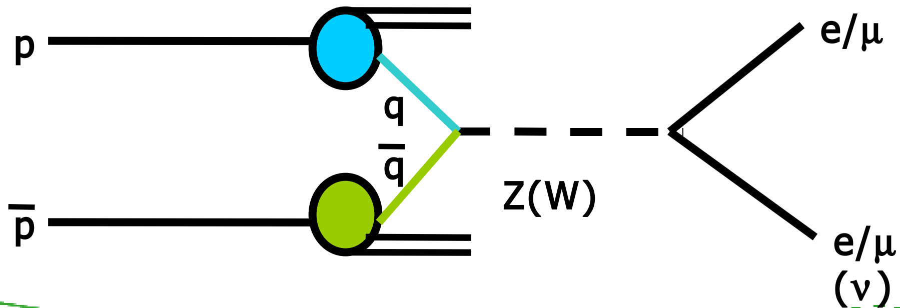
- LEP legacy: the Standard Model at VERY HIGH precision
- SK, SNO: Neutrinos have mass
- Belle & BaBar exploring the origins of anti-matter asymmetry
- Expanding Universe: dark matter & dark energy

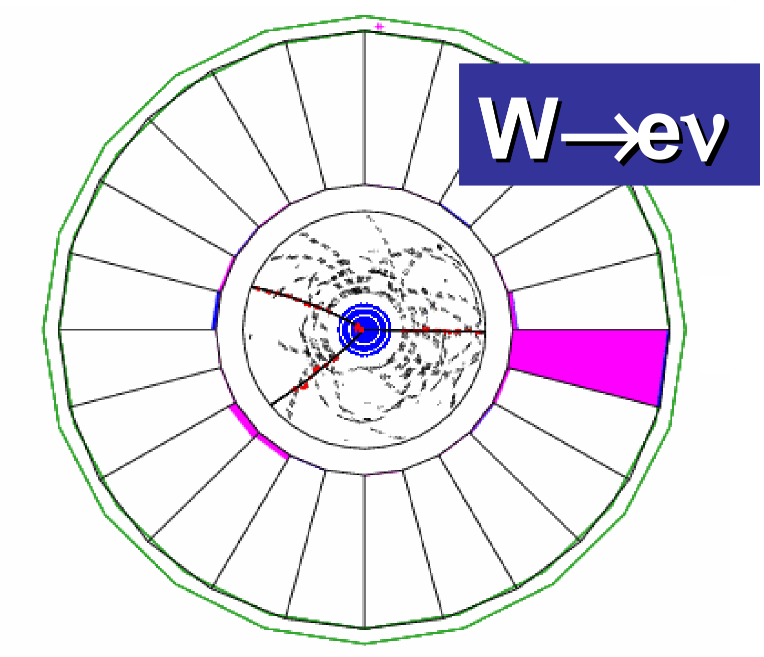
Fermilab Tevatron Run II physics program:

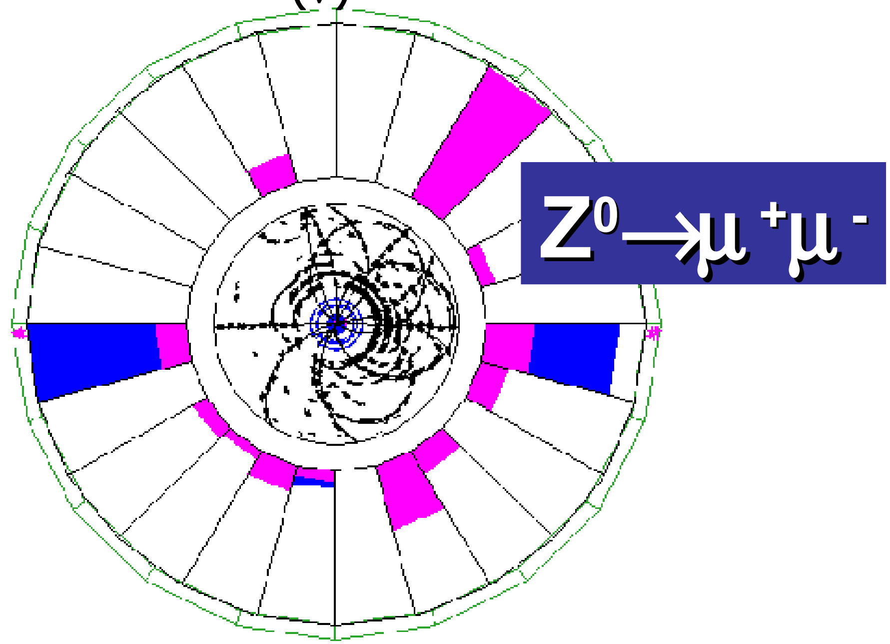
- Continue and improve precision EW measurements
- Jet physics and QCD studies
- B-physics: lifetimes, branching ratios, mixing
- Study in detail the top-quark
- Investigate EW symmetry breaking: Higgs hunt
- Expect the unexpected: supersymmetry, extra dimensions, …

Electroweak measurements

- With 2 fb^{-1}: millions of $W\rightarrow\ell\nu$ events and 100k $Z\rightarrow\ell\,\ell$ events:
  W/Z cross sections, mass, width, asymmetries, TGC's, ℓ universality,…
- Benchmark studies to understand the detectors
- Important backgrounds to top and Higgs physics



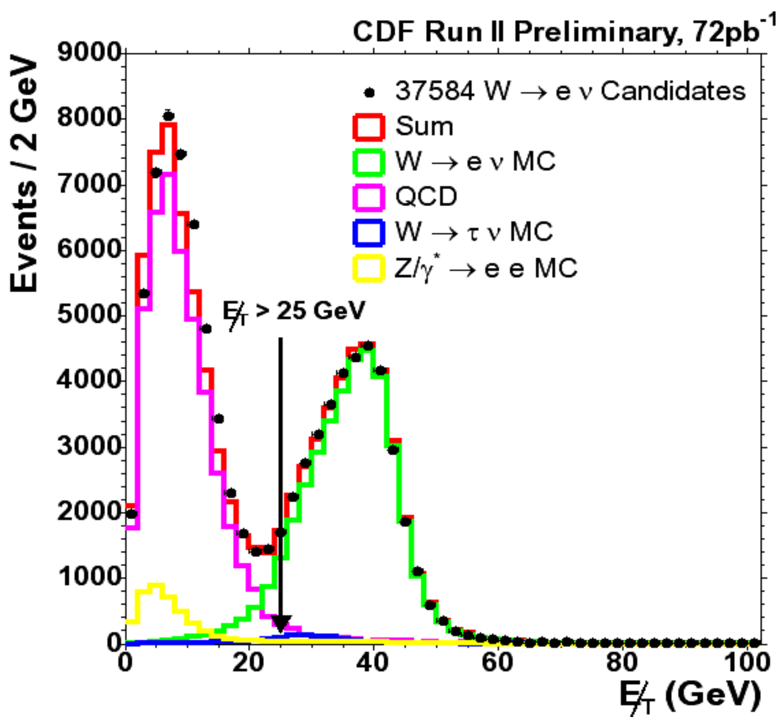


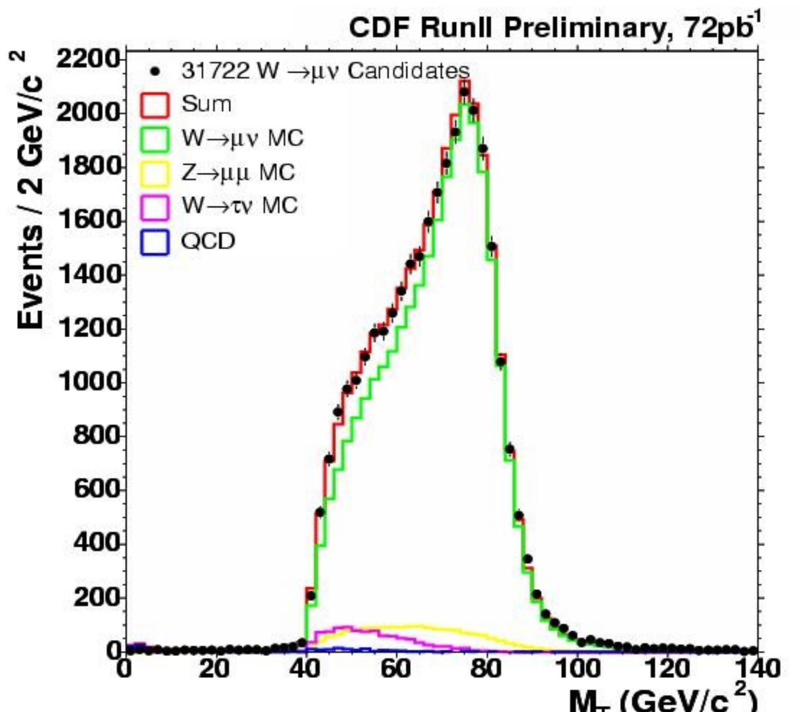


Inclusive W cross section

$$\sigma \cdot \mathrm{BR} = \frac{N_{obs} - N_{bkg}}{A\varepsilon \int L dt}$$

Candidate events		Estimated Bkg	Acceptance·Efficiency
$W \to \mu\nu$	31,722	(10.6 ± 0.4)%	(14.39 ± 0.32)%
$W \to e\nu$	37,574	(4.4 ± 0.8)%	(17.94 ± 0.35)%



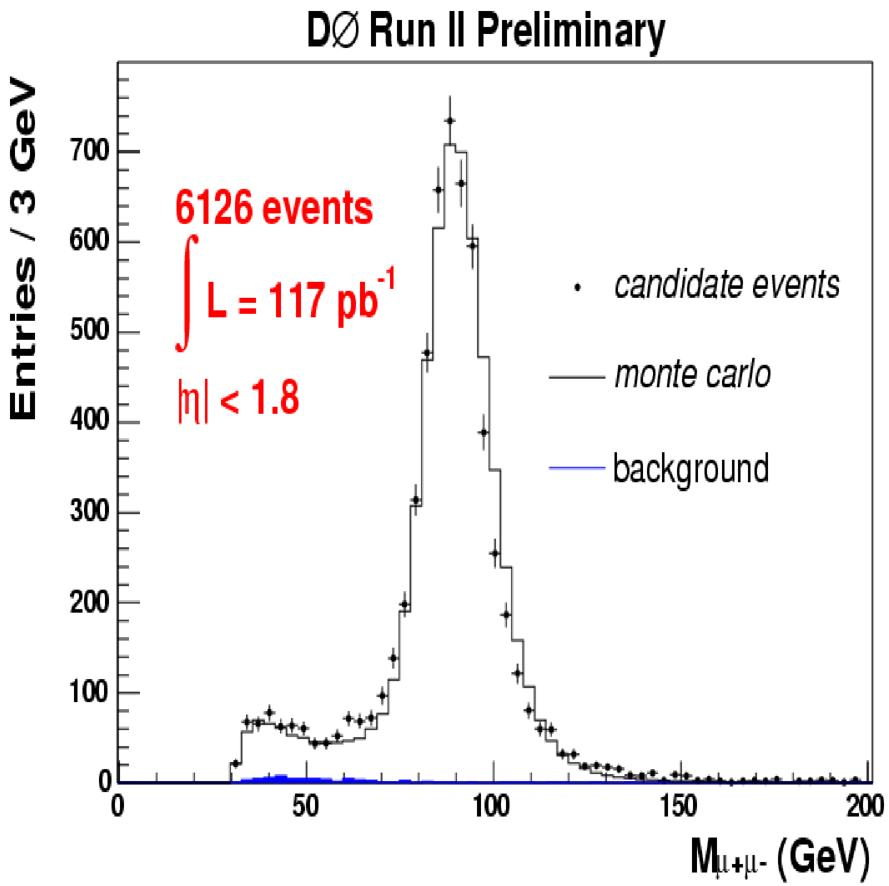


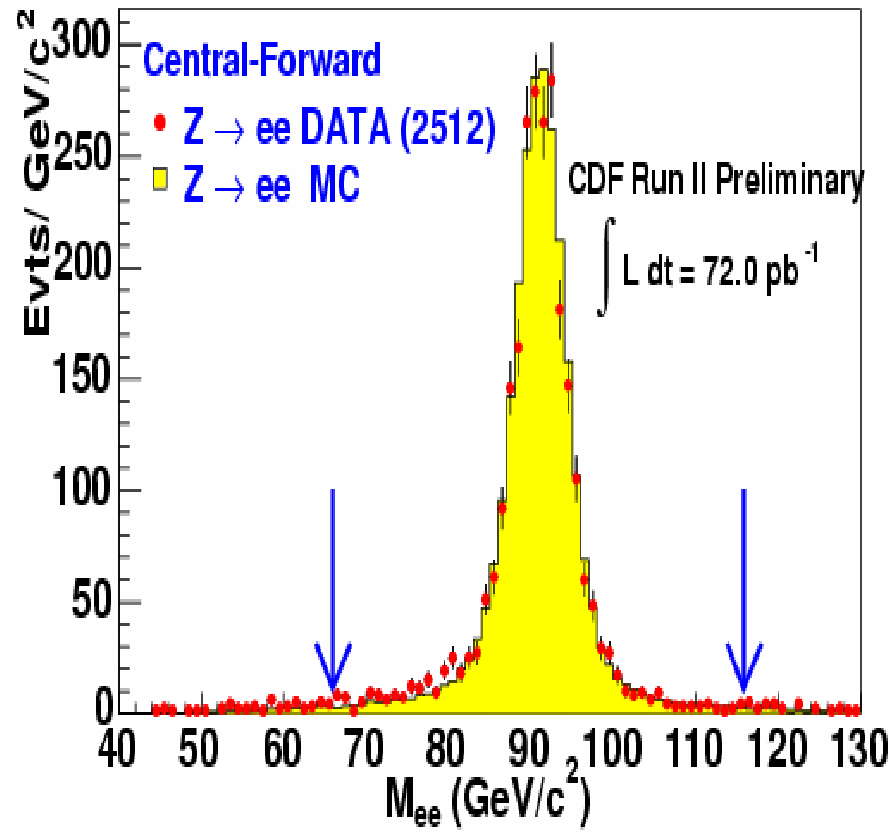
$$M_T = \sqrt{E_T(\ell)\cdot E_T(\nu) - p_x(\ell)\cdot p_x(\nu) - p_y(\ell)\cdot p_y(\nu)}$$

$$\sigma \cdot \mathrm{BR}(p\bar{p} \to W \to \mu\nu) = 2772 \pm 16(stat)^{+64}_{-60}(syst) \pm 166(lum)\,\mathrm{pb}$$

$$\sigma \cdot \mathrm{BR}(p\bar{p} \to W \to e\nu) = 2782 \pm 14(stat)^{+61}_{-56}(syst) \pm 167(lum)\,\mathrm{pb}$$

Inclusive Z cross section

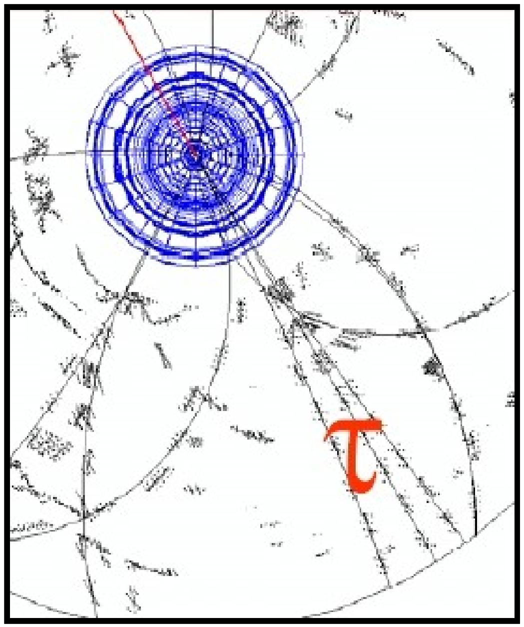


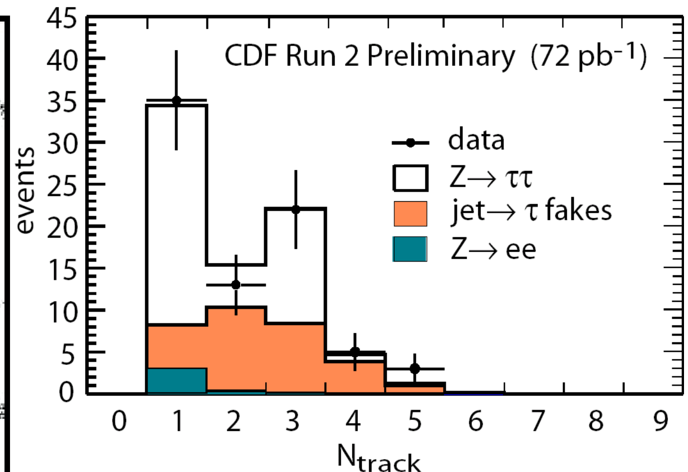


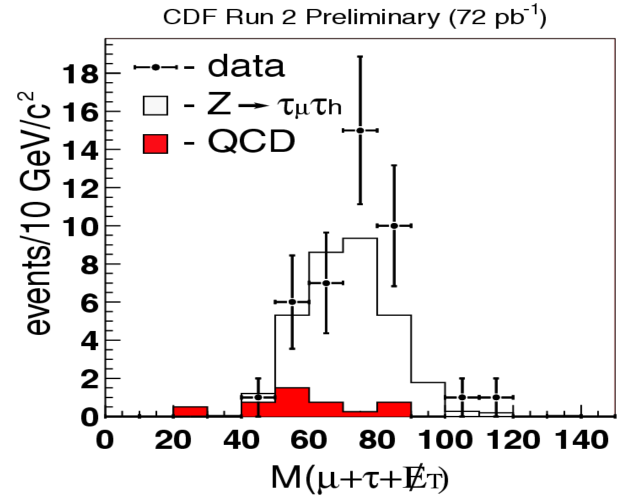
$$\sigma \cdot \mathrm{BR}(Z \to \mu\mu) = 261.8 \pm 5.0(stat) \pm 8.9(syst) \pm 26.2(lum)\,\mathrm{pb}$$

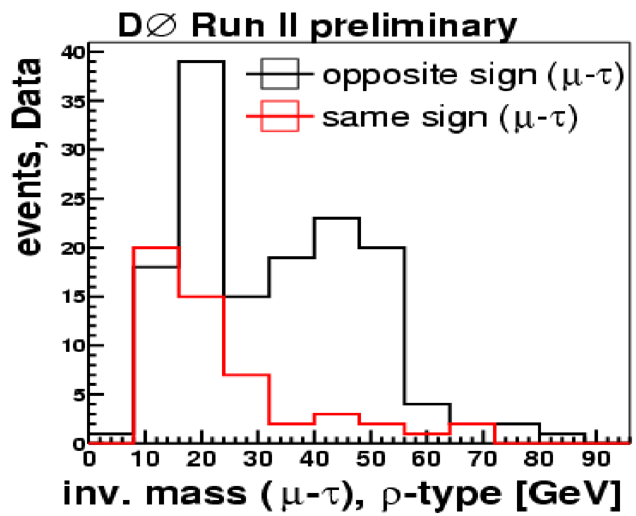
$$\sigma \cdot \mathrm{BR}(Z \to ee) = 255.2 \pm 3.9(stat) \pm 5.5(syst) \pm 15.3(lum)\,\mathrm{pb}$$

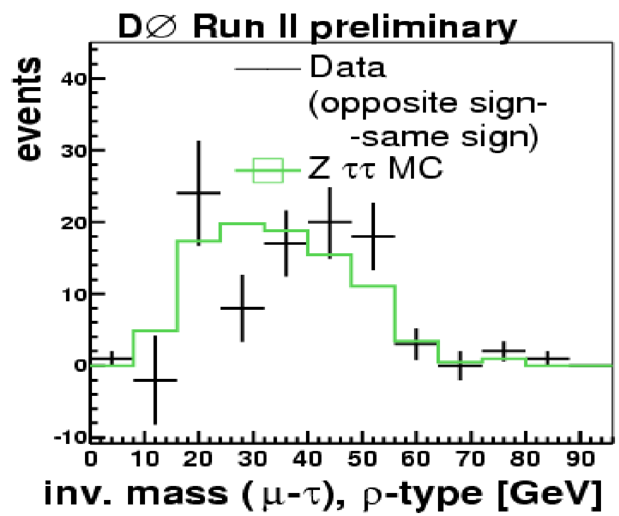
First hadron collider result on
Z→τ τ





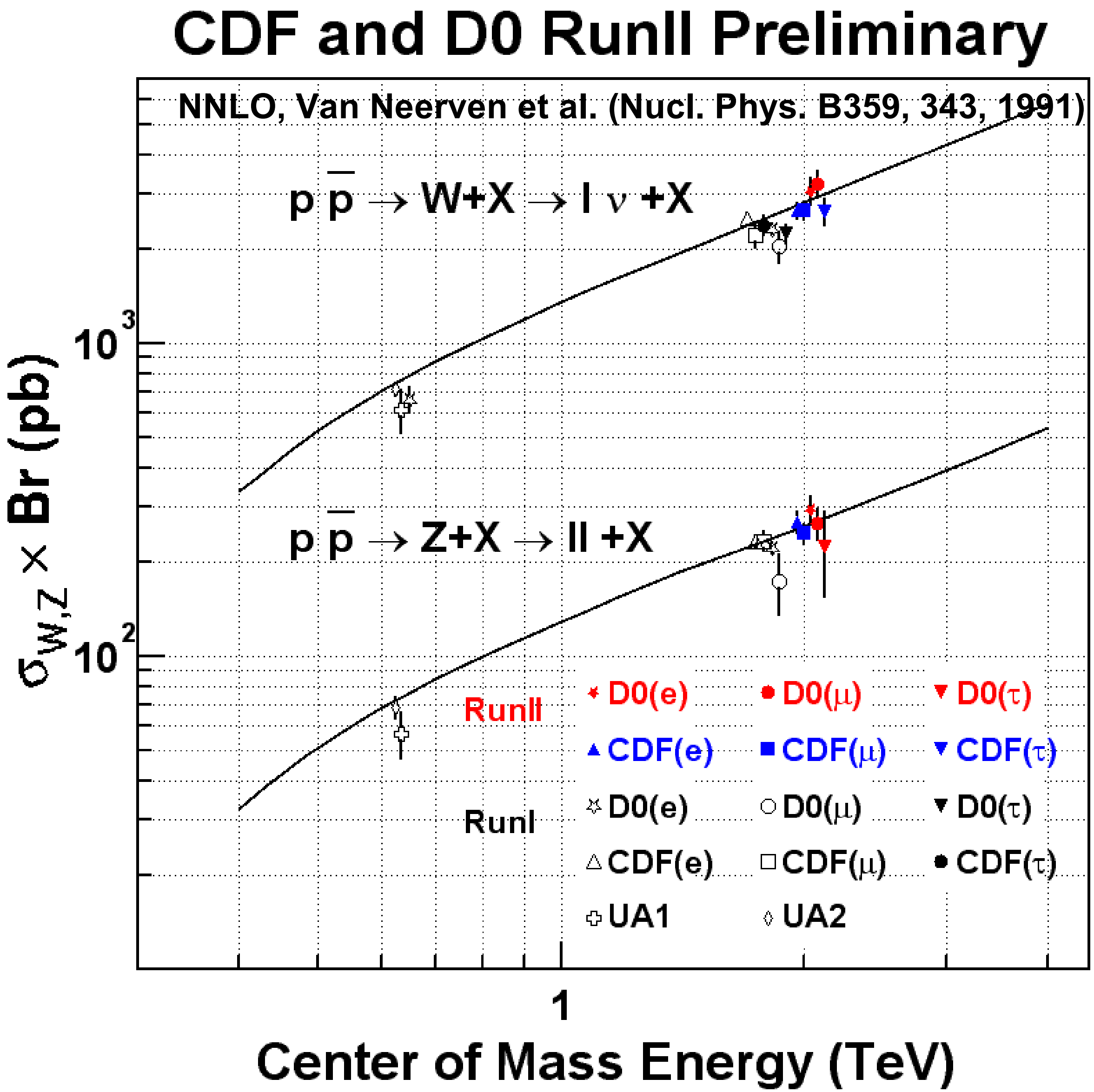






$$\sigma \cdot \mathrm{BR}(Z \to \tau\,\tau) = 222.1 \pm 32.8(stat) \pm 56.8(syst) \pm 22.2(lum)\,\mathrm{pb}$$

W/Z σ compared to theory



Results compatible with SM

Many other results:

- Diboson (WW, WZ, Wγ, Z γ) σ
  No deviations (…yet!)
- W+jets, Z+jets, Wb, Zb
- σ(Z+b)/σ(Z+jets)
  sensitive to b PDF
- Γ(W) improves world average
- Forward-backward asymmetry
- W mass is a more complicated beast

Tevatron EW Working Group:
http://tevewwg.fnal.gov

QCD and Jet physics

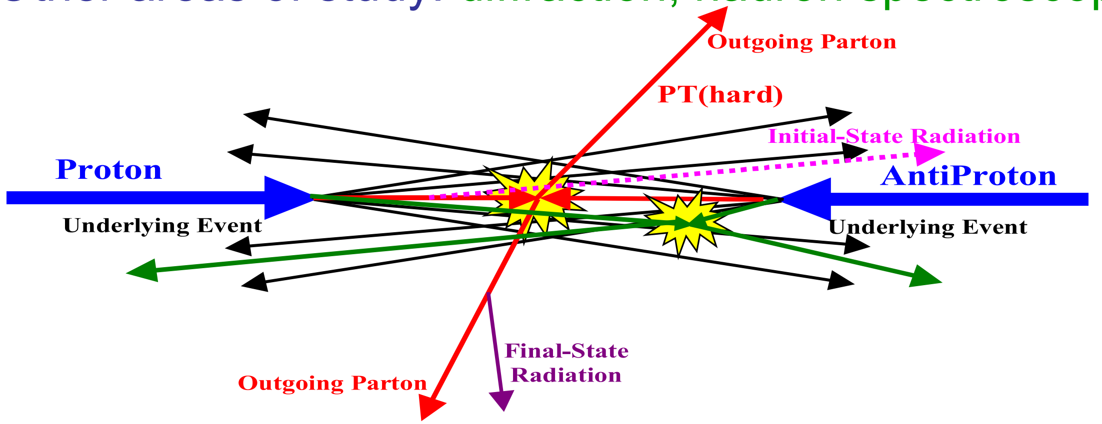
- The Tevatron is the highest energy jet-factory: everything is QCD related
- Highest Q^2 probed ~10^{-17}cm → precise test of perturbative QCD at NLO:

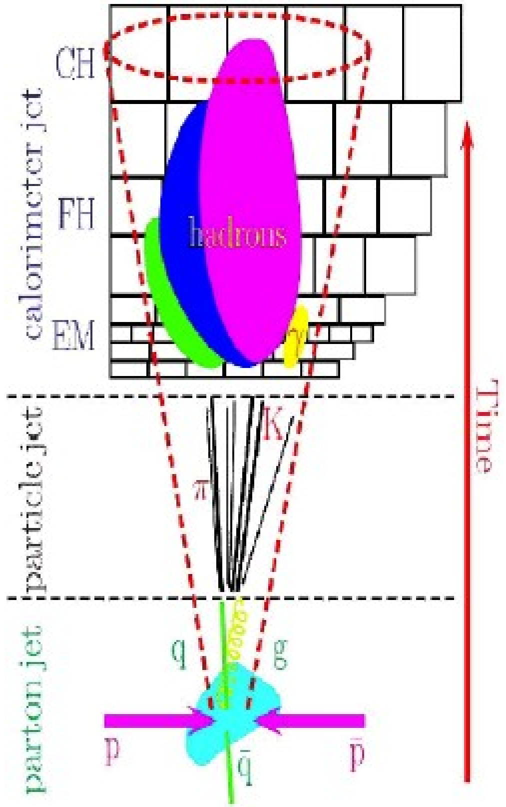
  jet and dijet cross sections, PDFs at high x, W/Z+jets, diphotons,

  jet evolution, heavy flavor quark production, azimuthal decorrelation,...
- Look for deviations and new physics

  quark compositeness, α_s ,…
- Study of phenomenology on non-perturbative regime:

  underlying event modeling
- Other areas of study: diffraction, hadron spectroscopy,…



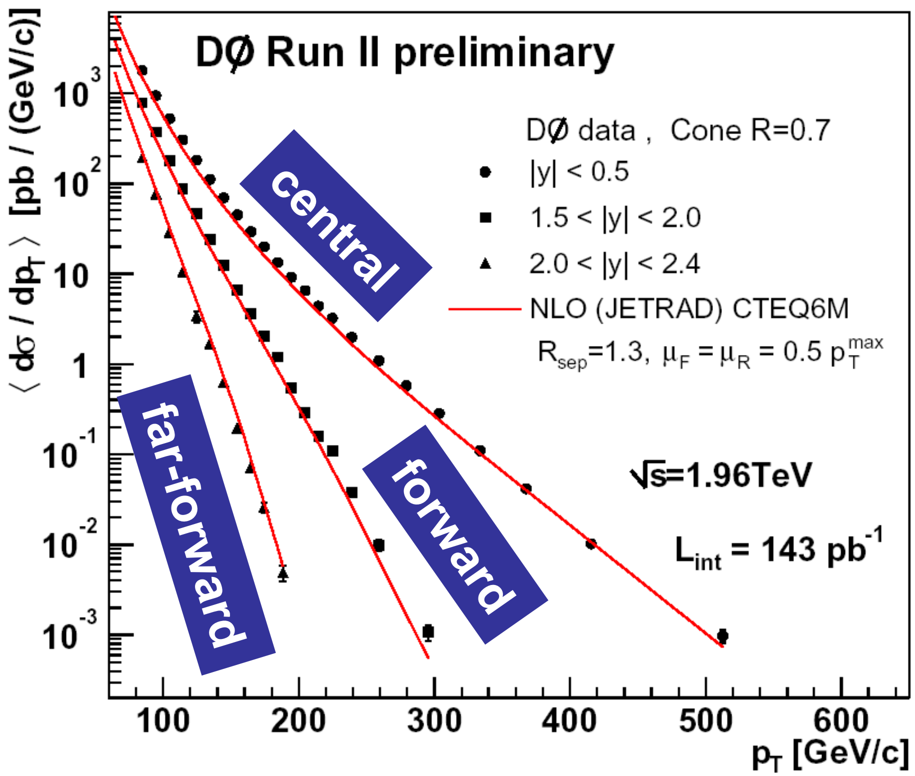


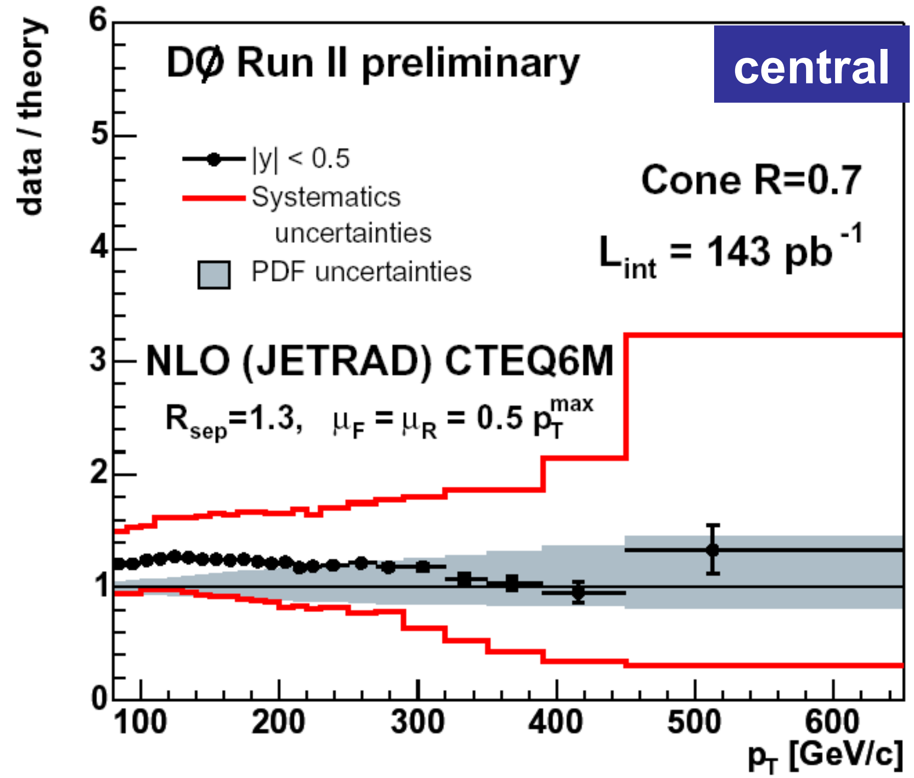
Inclusive jet cross section

Run I left an excess at high E_T now attributed to high x contribution in the gluon PDF

Central region is most sensitive to new physics and PDFs

Forward regions are less sensitive to new physics but still sensitive to PDFs

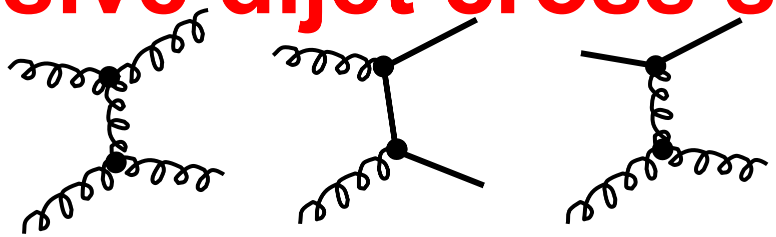


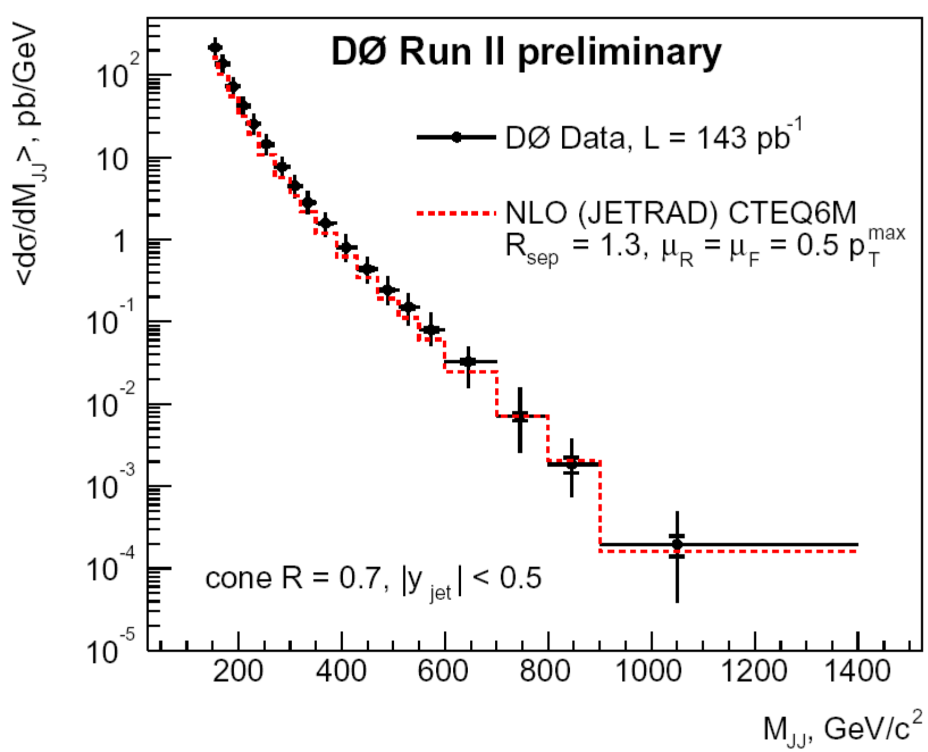


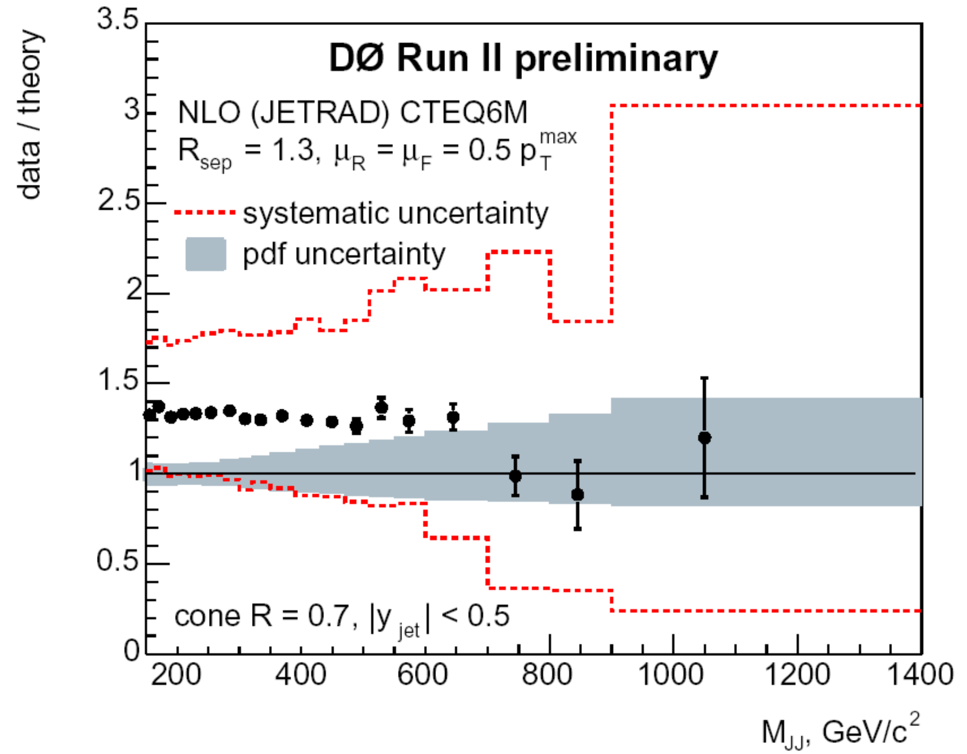
Data and theory agree within errors for all rapidity-regions

Experimental uncertainties dominated by Jet Energy Scale (JES)

Inclusive dijet cross section





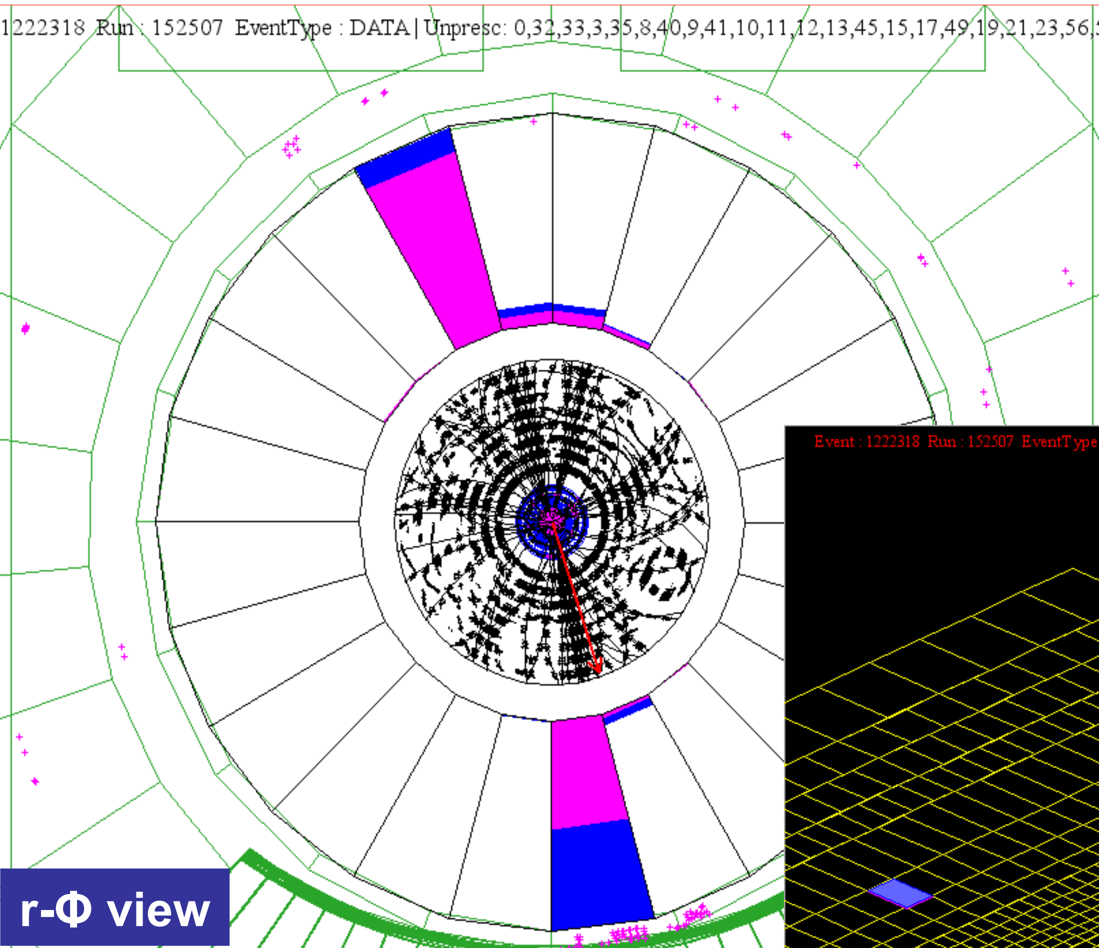


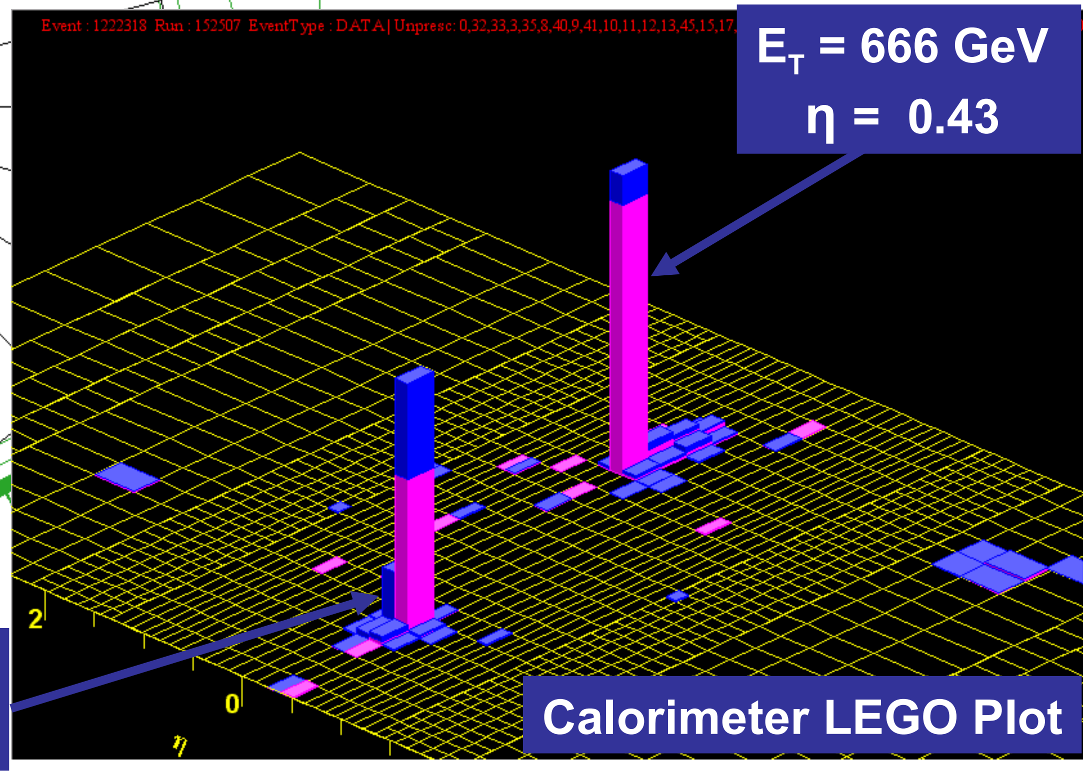
Data is well described by NLO MC throughout the whole kinematic region

Now working on improving the Jet Energy Scale uncertainty

Highest mass dijet event

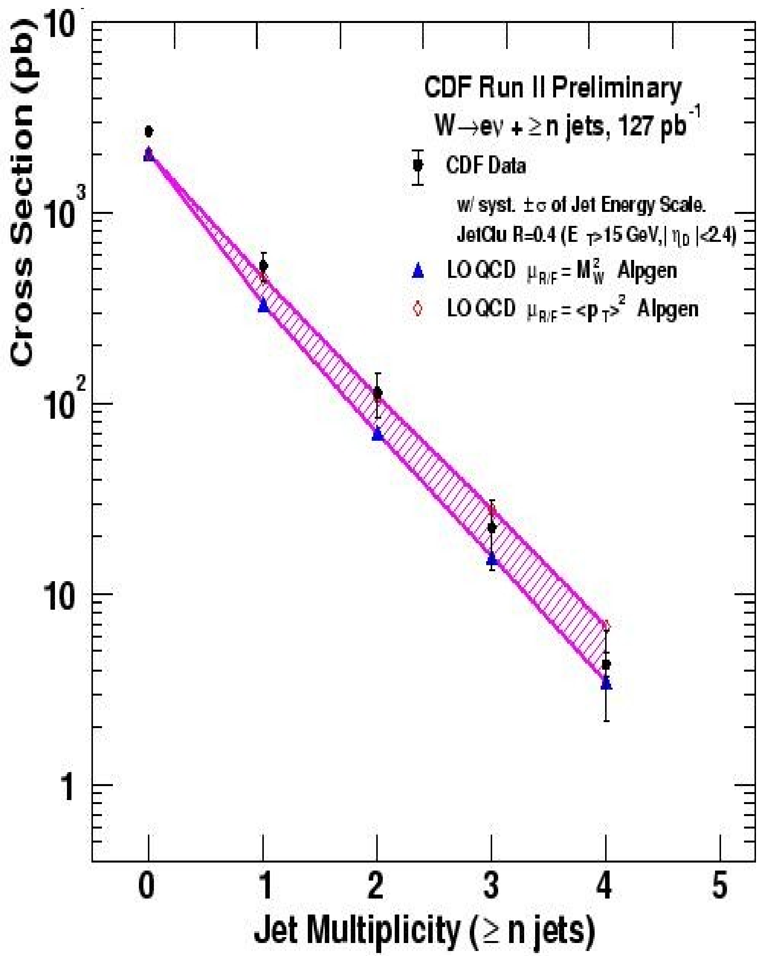
Recorded by CDF:
Mass = 1364 GeV/c^2

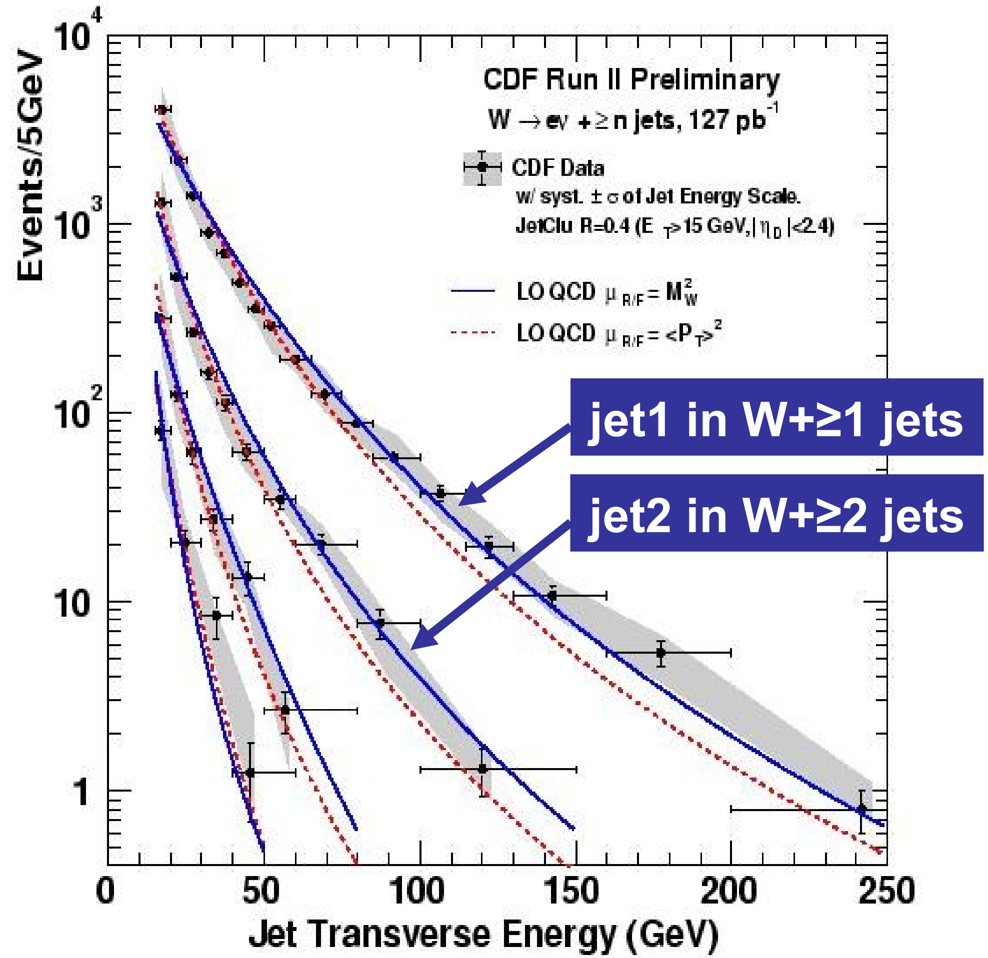




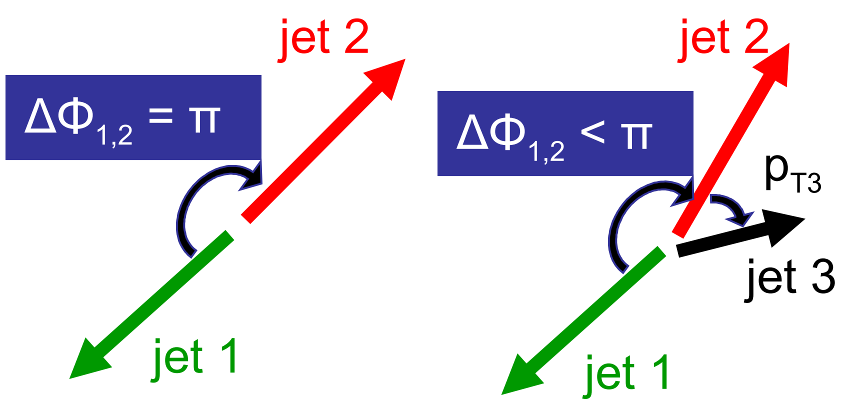
W→eν +jets differential cross section

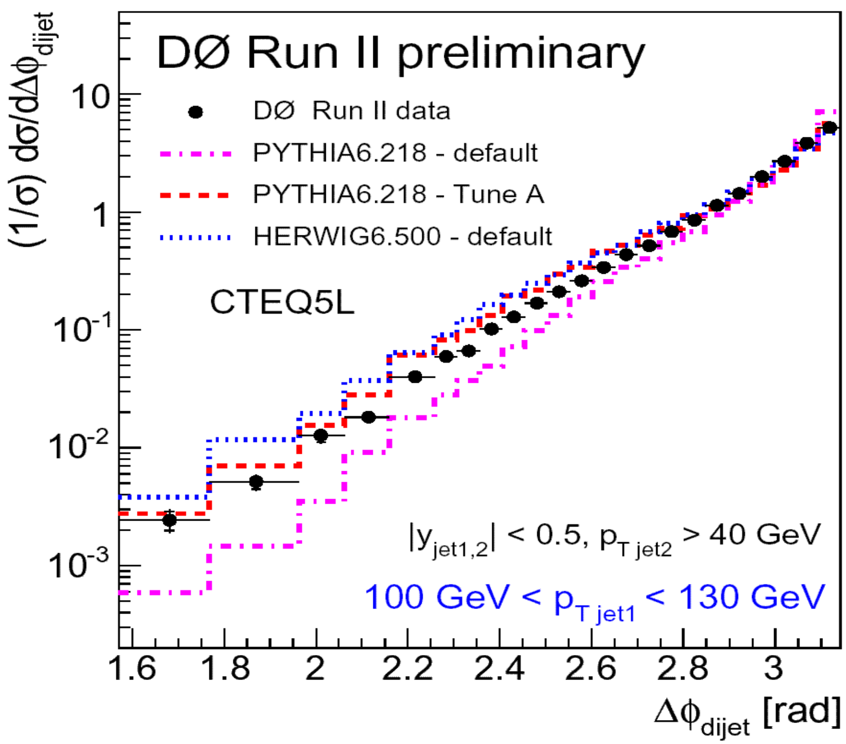
- Test of QCD predictions at high Q^2
- Fundamental channel for top/Higgs
- Signature: high-pt isolated e + MET + jets (ET>15)
- Backgrounds: fakes in all jet bins, top in 4th bin





Jet studies: azimuthal decorrelation





- DØ has measured $\Delta\Phi_{dijet}$ in two jet events
- At higher orders of α_s^2 additional jets induce azimuthal decorrelation:

$\Delta\Phi_{dijet}<\pi$ indicates additional hard radiation

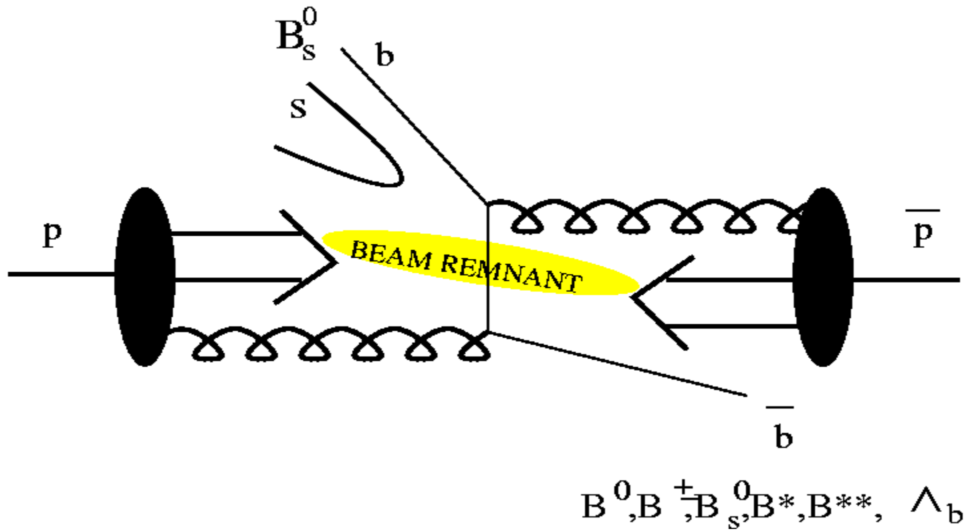
$$\lim_{p_{T3}\to 0} \Delta\phi_{dijet} = \pi$$

- $\Delta\Phi_{dijet}$ is sensitive to jet formation without having to measure the third jet directly
- Meas. $d\sigma/d\Delta\Phi_{dijet}$ incompatible with LO MC
- NLO pQCD agrees well in all kinem. regions
- "Tuned" (for underlying event) Pythia gives best agreement

B-physics

The study of B-hadrons is challenging at a hadron collider:

The bb production cross section is huge ~100μb and all B species are produced…

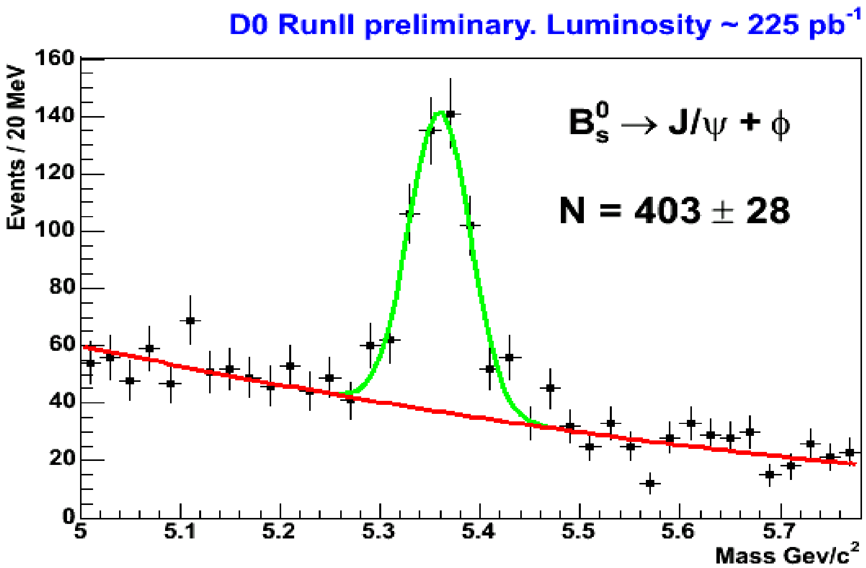


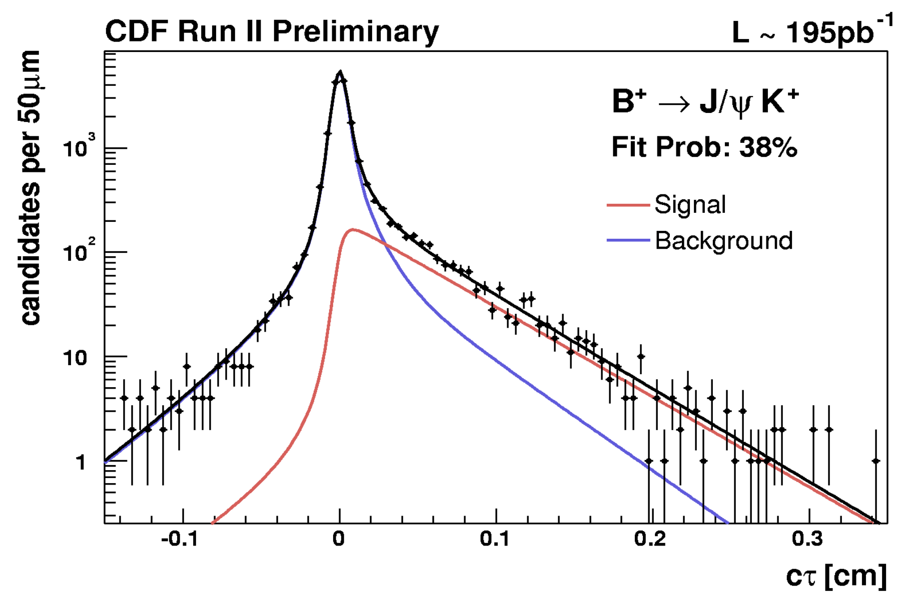
B_s and Λ_b not accessible at b-factories

… But huge inelastic cross section: S/B ~ 10^{-3} → Need specialized triggers:

- ►Single lepton triggers
- ►Dilepton triggers such as $J/\psi \to \mu^+ \mu^-$
- ►L2 trigger on displaced tracks using SVX allows CDF to trigger purely hadronic B decays such as $B_0 \to \pi^+\pi^-$, $B_s \to D_s^-\pi^+$ ...

B-lifetimes



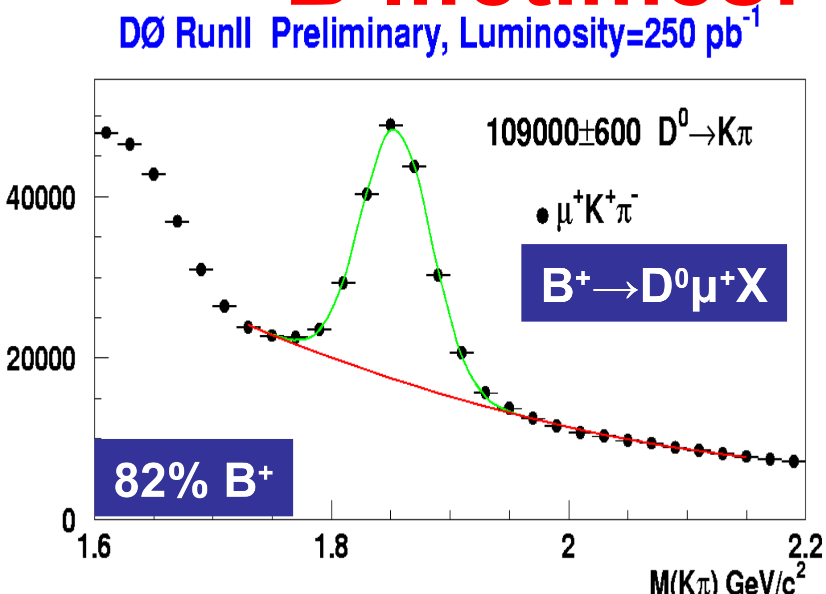


DØ has collected the world's largest sample of exclusive $B_s \rightarrow J/\psi \Phi(\rightarrow K^+K^-)$

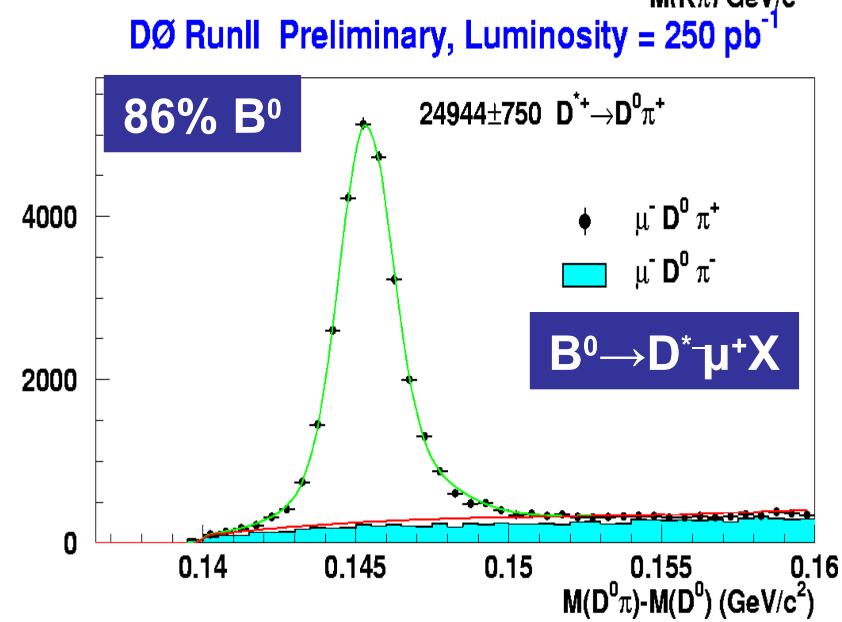
CDF is competitive in all B lifetimes thanks to excellent momentum and vertex resolution

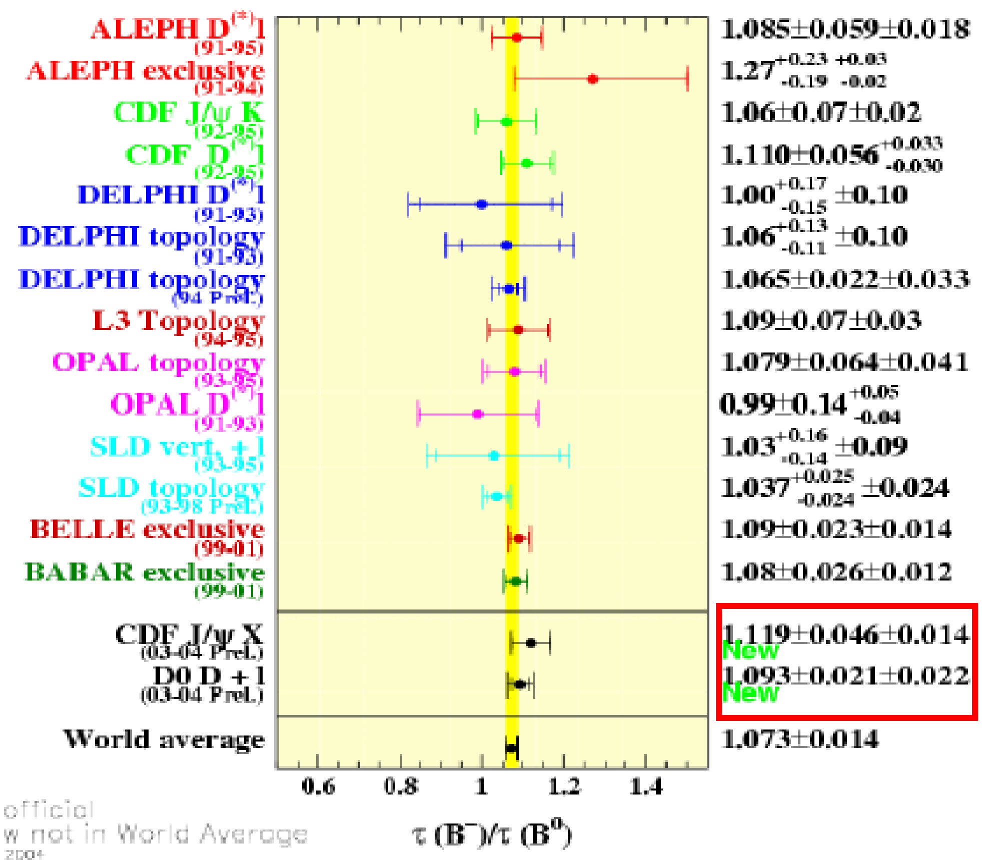
B-hadron	CDF measurement (ps)	PDG value (ps)	cτ (μm)
B^+	1.66 ± 0.04 ± 0.02	1.674 ± 0.018	502
B^0	1.49 ± 0.05 ± 0.03	1.542 ± 0.016	462
B_s	1.33 ± 0.14 ± 0.02	1.461 ± 0.057	438
Λ_b	1.25 ± 0.26 ± 0.10	1.229 ± 0.080	368

B lifetimes: τ (B⁺)/τ (B⁰) ratio

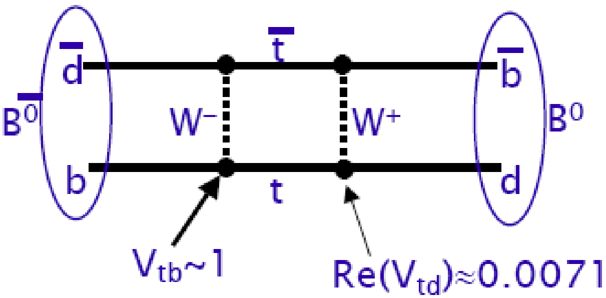


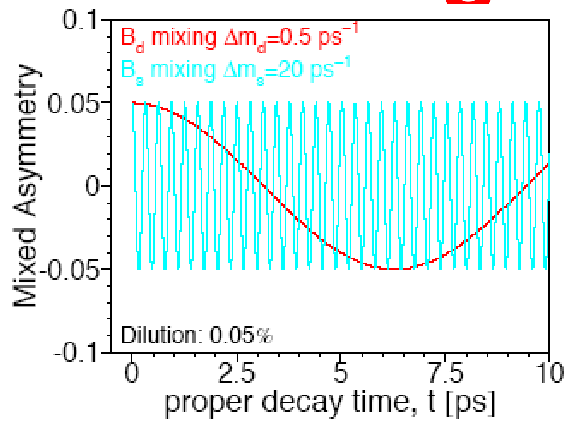
Novel technique to measure $\tau(B^+)/\tau(B^0)$:
Measure directly the ratio $r=N(D^*\mu)/N(D^0\mu)$ at different decay distances

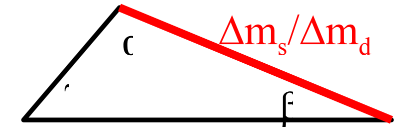


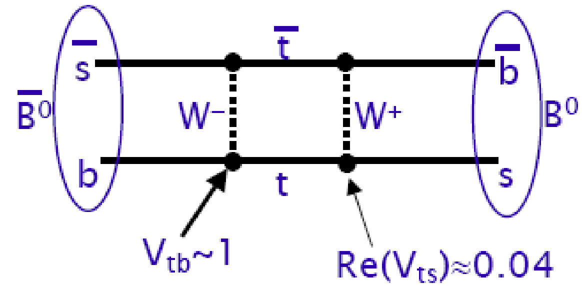


B mixing









B_d fully mixes in about 4.1 lifetimes

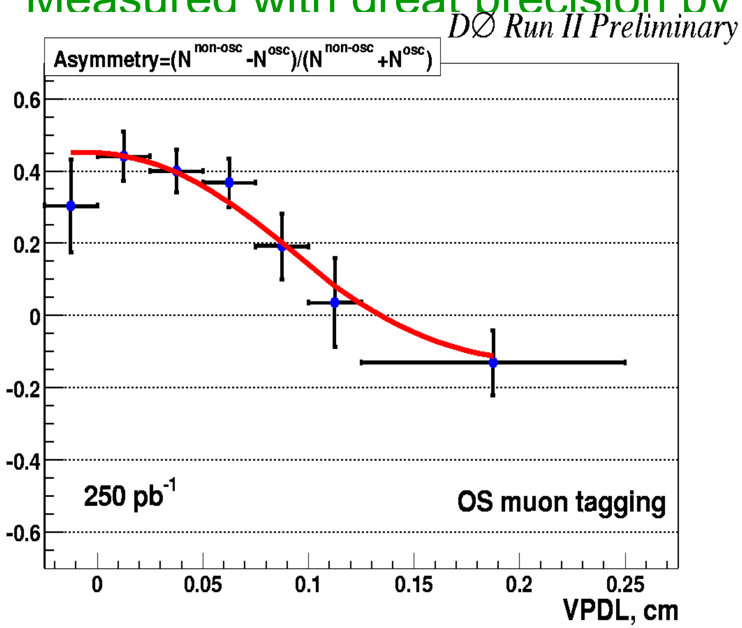
Δm_d = 0.502± 0.006 ps^{-1} (world comb.)

Measured with great precision by Belle & BaBar

B_s fully mixes in <0.15 lifetimes!!

Δm_s > 14.4 ps^{-1} 95%CL (world comb.)

Only reachable at hadron colliders



DØ uses its large sample of semileptonic B_d decays to measure the oscillation frequency:

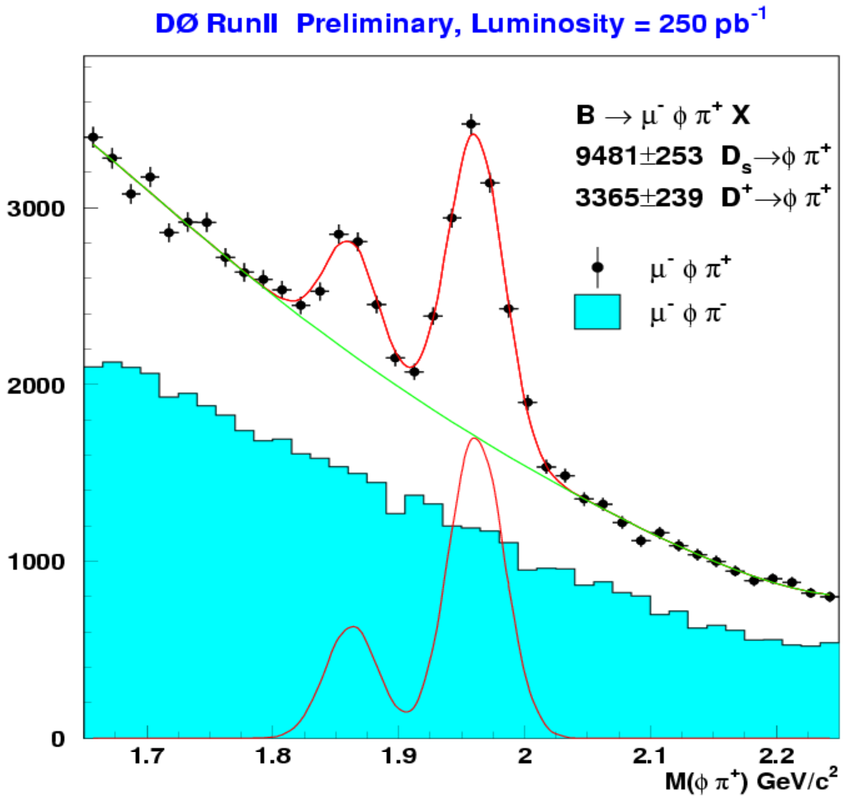
$$\Delta m_d = 0.506 \pm 0.055(stat) \pm 0.049(syst)\, ps^{-1}$$

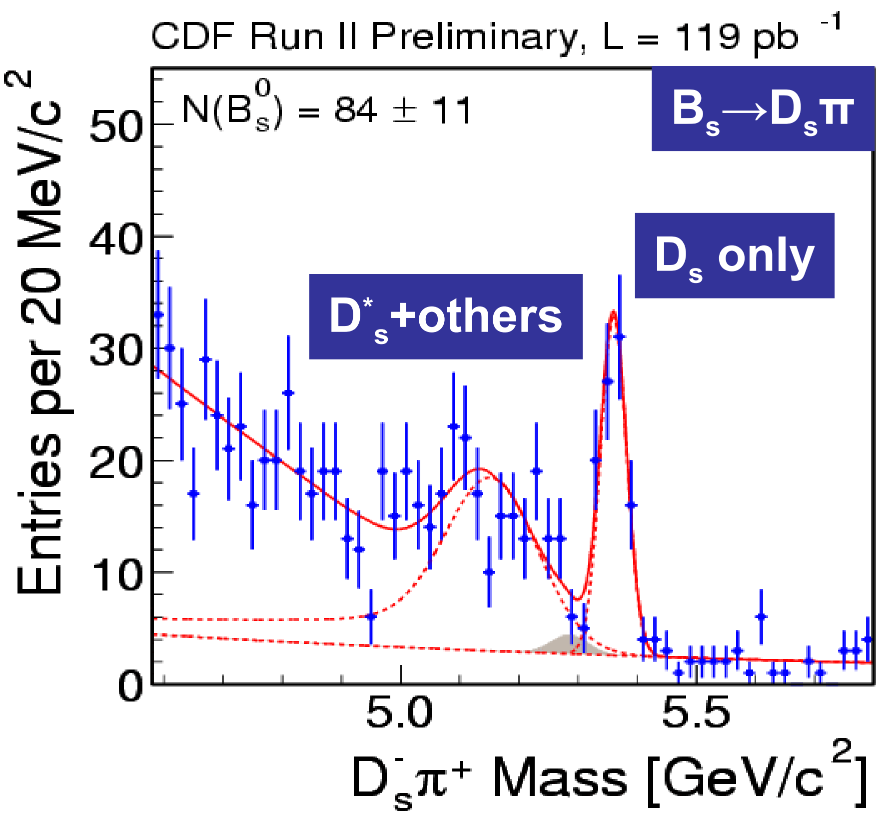
Use opposite side muon to tag initial state:

- ►Same lepton charge for oscillated mesons
- ►Opposite lepton charge for non-oscillated mesons

Towards B_s mixing

Excellent B_d yield, ideal control sample for B_s mixing studies



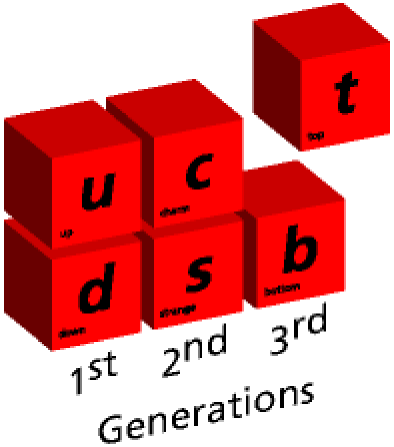


Semileptonic decays:

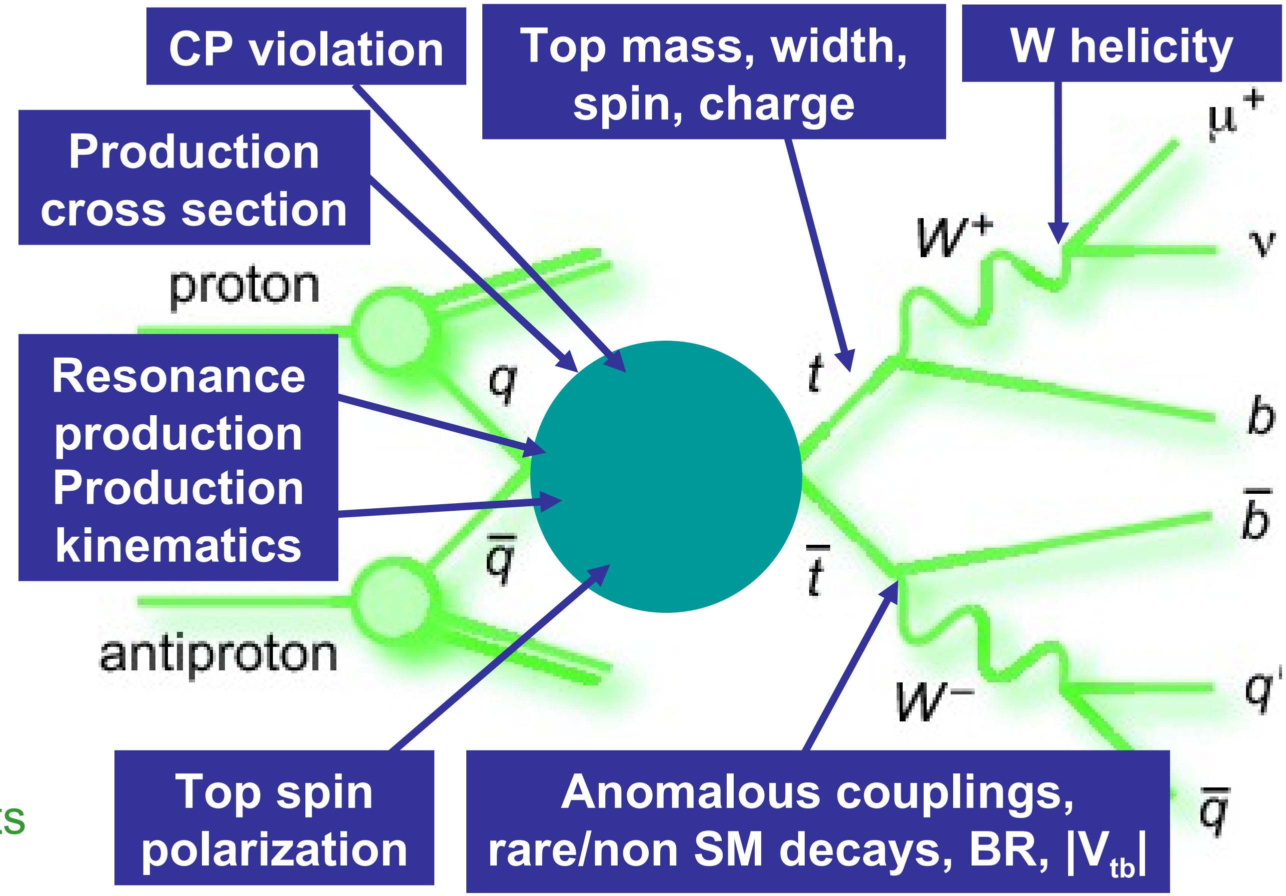
- ►Very good statistics but poorer time resolution
- ►If $\Delta m_s \cong$ 15 ps^{-1} expect a 1-2 σ measurement with 500 pb^{-1}

Fully reconstructed hadronic decays:

- ►Poorer statistics, excellent time resol.
- ►Need a few fb^{-1} of data to reach $\Delta m_s \cong$ 15 ps^{-1}



Top quark physics in Run II



The Tevatron is the world's only source of top quarks!

Top quark has a special place in the SM: $M_t \sim v/\sqrt{2}$

Run I:
Identified ~100 top events

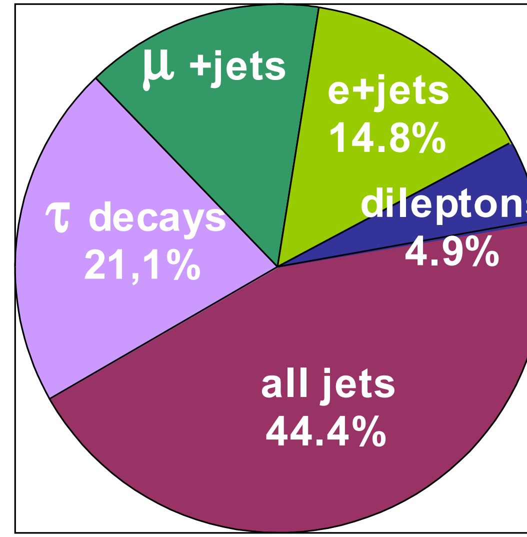
Run II:
with high precision we hope to answer questions such as:

- ► Why is top so heavy?
- ► Is it or the third generation special?
- ► Is top involved in EWSB?
- ► Is it connected to new physics?

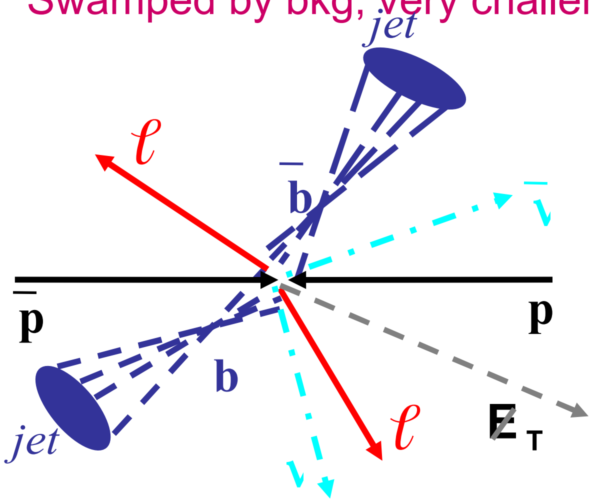
Talk by Thomas Gadfort on searches for electroweak production of top at DØ

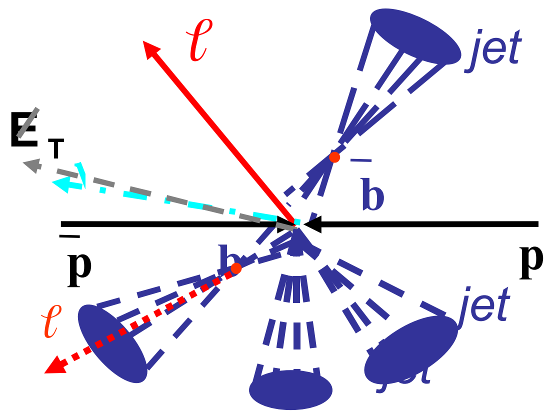
Top decay modes

In the SM: BR($t \to Wb$)~100%, classify topologies according to W decays from ttbar:



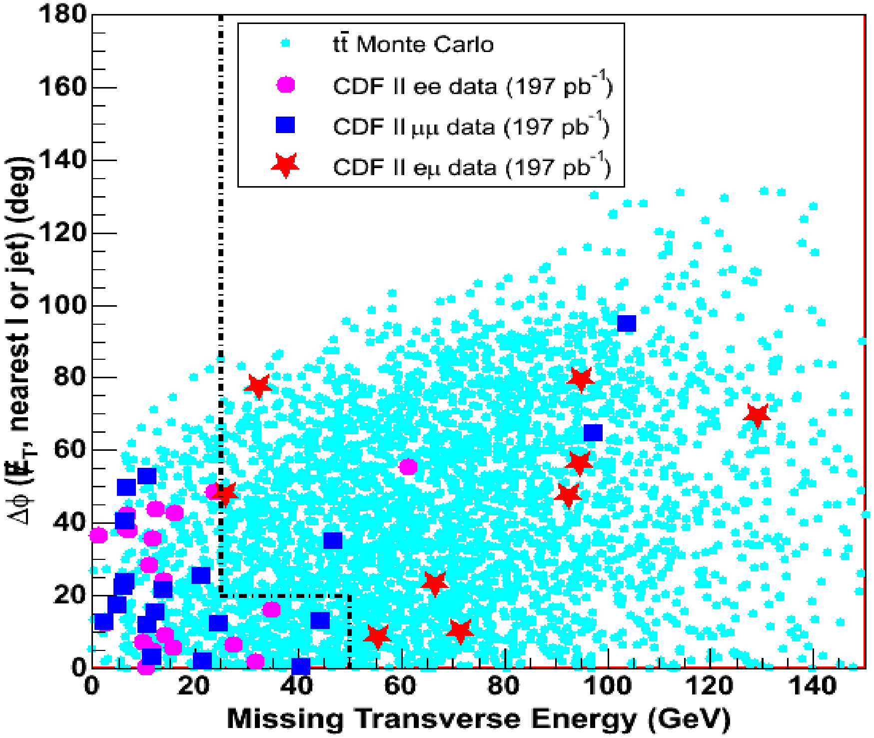
- **dilepton:** 2 high p_T leptons, 2 *b*-jets, large E_T^{mis}
  - Small BR, but cleaner signal and small systematics. No *b*-tagging
  - Physics bkgs: WW/WZ, DY
  - Instrumental: fake leptons in W+jets and QCD and fake E_T^{miss}
- **lepton+jets:** 1 high p_T lepton, 4 jets (2 *b*'s), large E_t^{mis}
  - Larger yield, larger bkg $\Rightarrow$ Use event topology, *b*-tagging (and SLT)
  - Backgrounds: W+jets and fake leptons in QCD
- **all jets:** 6 jets (2 *b*'s)
  - Swamped by bkg, very challenging, but impossible at LHC! Use NN

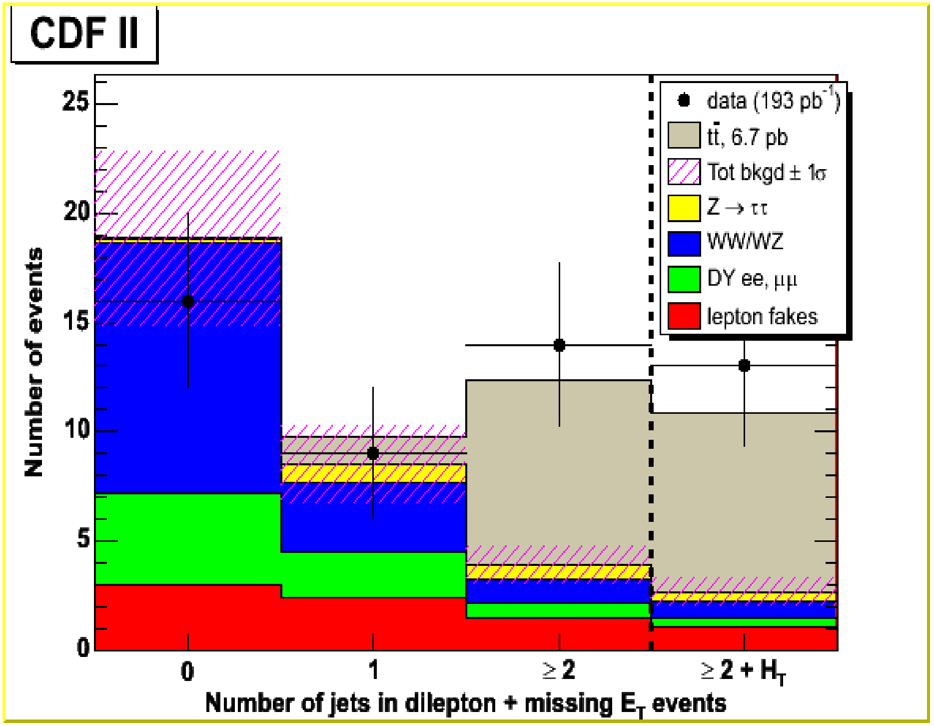




Top dilepton cross section

hep-ex/0404036 $\sigma(t\bar{t}) = 7.0^{+2.4}_{-2.1}(stat)^{+1.6}_{-1.1}(syst) \pm 0.4(lum)\ \mathrm{pb}$



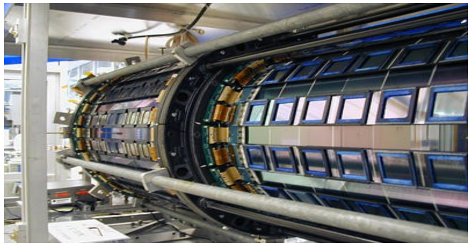


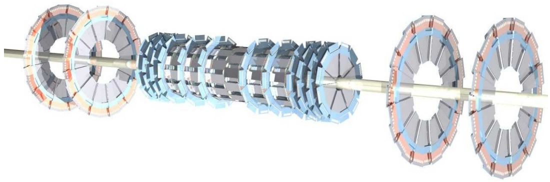
Flavor distribution is consistent with expectation (there was an excess of eμ in CDF I)

Error is statistics dominated

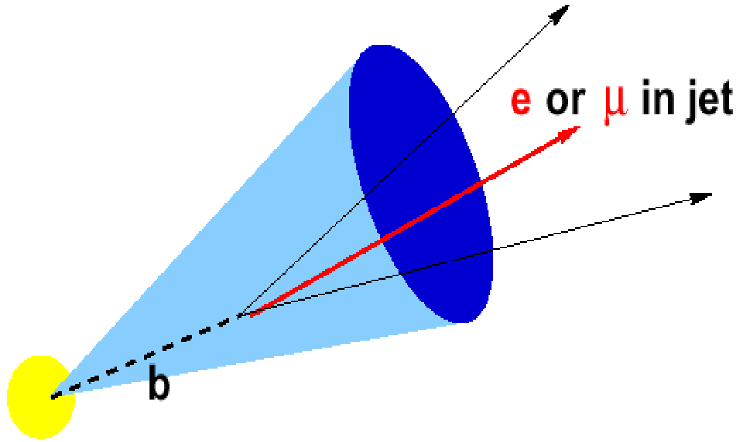
Both experiments clearly re-establish top signal!

Tagging b-jets



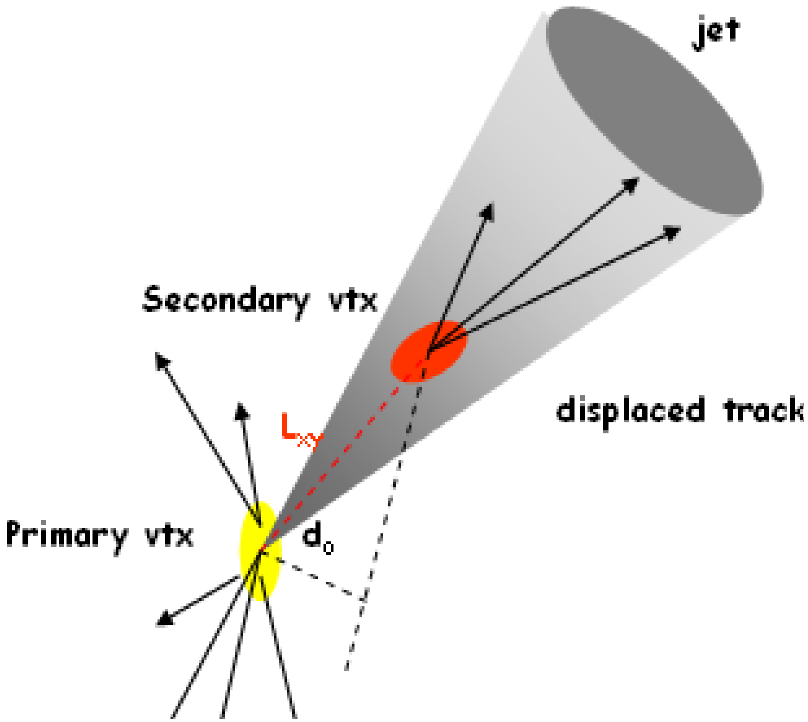


B-mesons can decay semileptonically
►Identify low-p_T muon from decay



- $b \to \ell \nu c$ (BR ~ 20%)
- $b \to c \to \ell \nu s$ (BR ~ 20%)

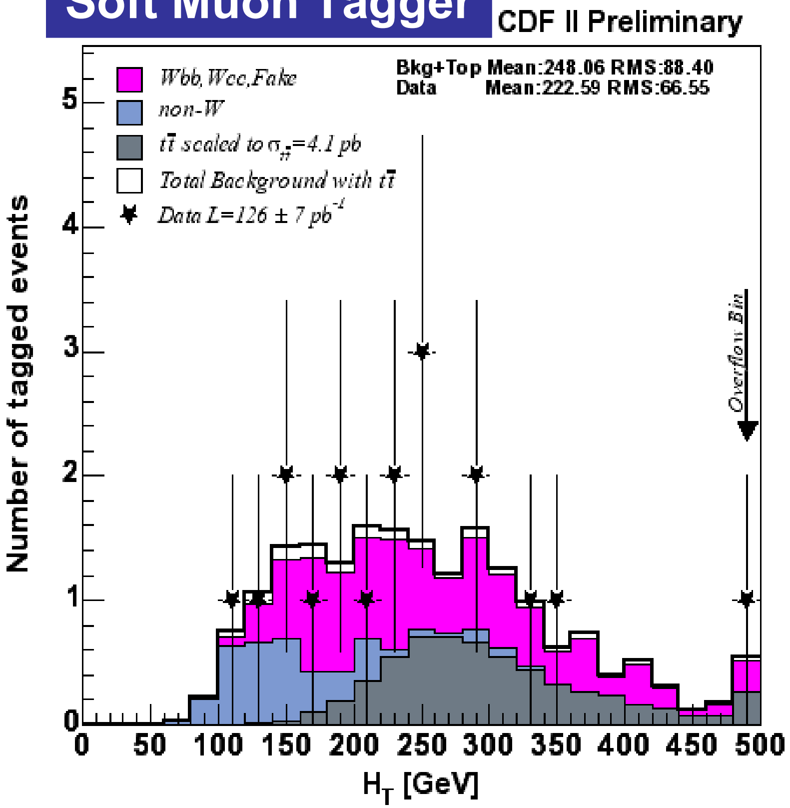
B-mesons are long-lived and massive
►Identify vertex of displaced tracks



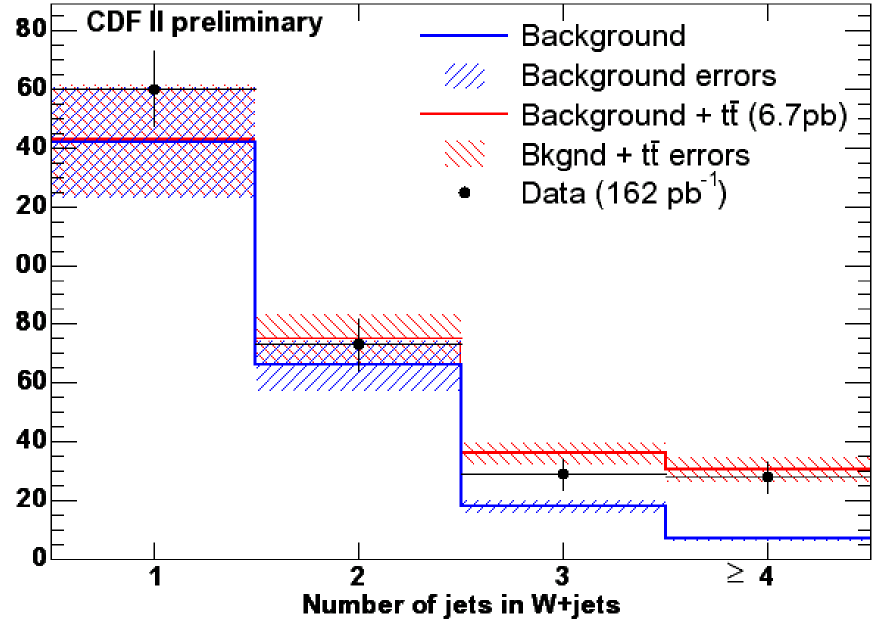
Both experiments can tag b-jets with up to 55% efficiency for 0.5% fake rate tag (SVX)

Tagged Top ℓ+jets cross section

Soft Muon Tagger



Secondary Vertex Tagger

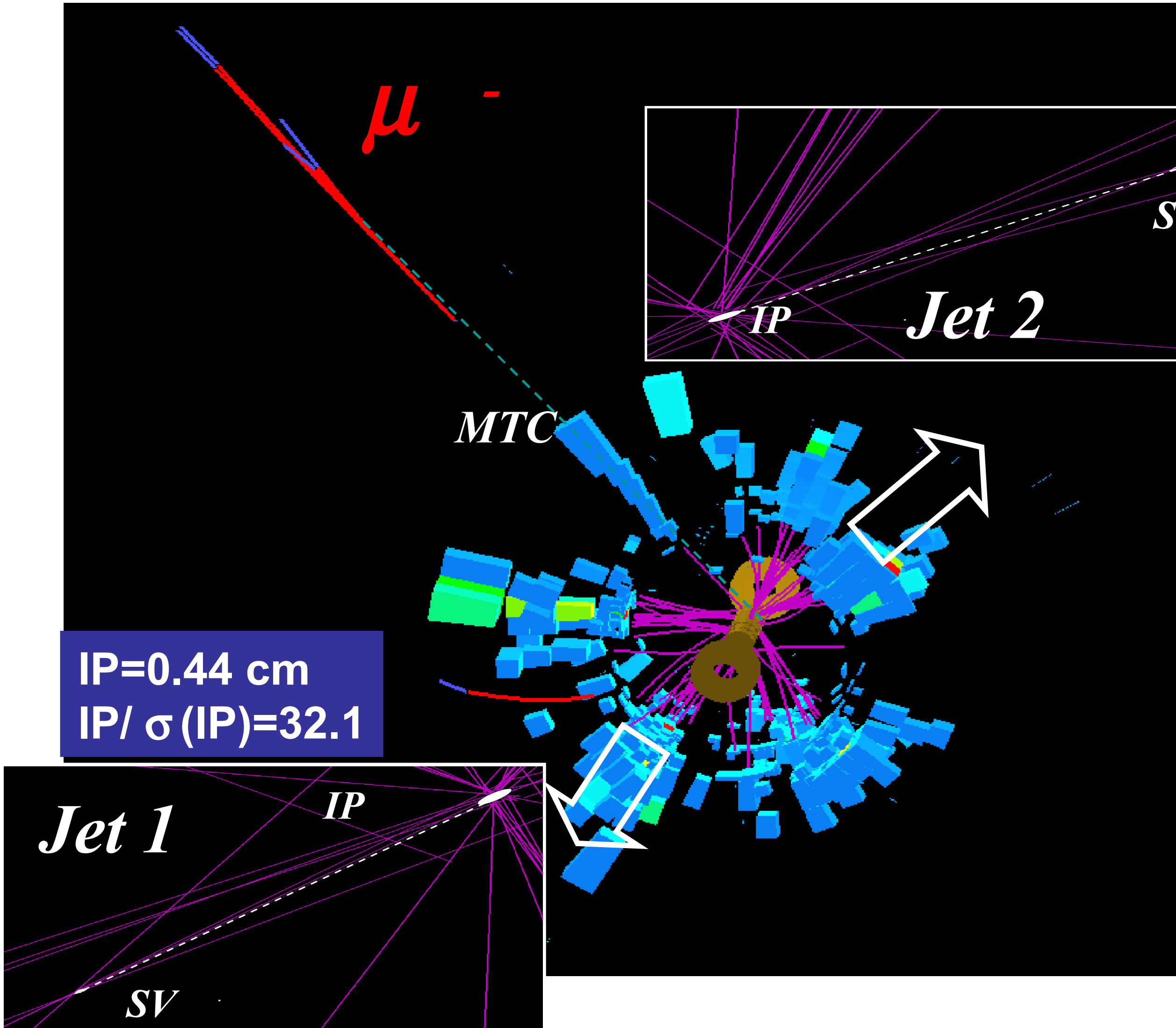


$$\sigma(t\bar{t}) = 5.6^{+1.2}_{-1.0}(stat)^{+1.0}_{-0.7}(syst)\ \text{pb}$$

Use MC for diboson and W+heavy flavor estimates

Use data for non-W QCD and fake tags

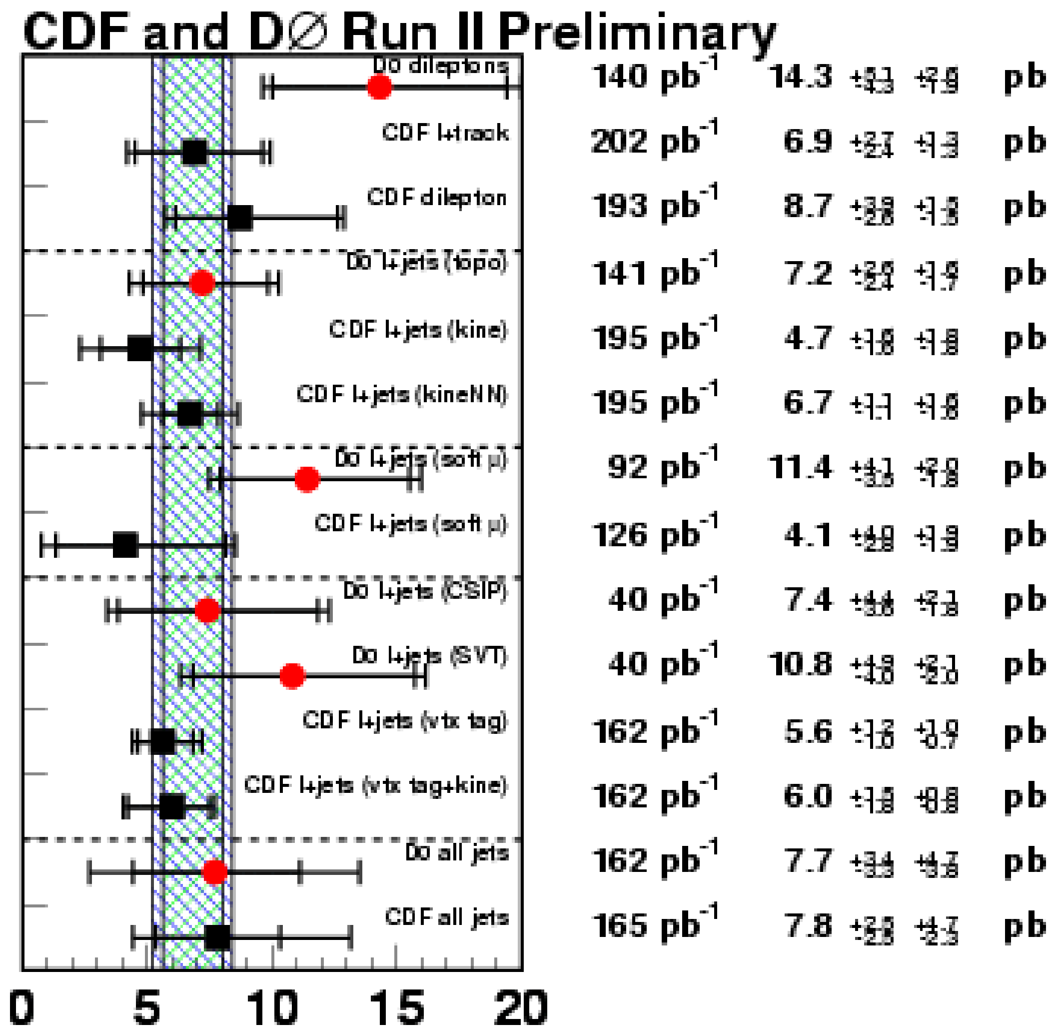
Doubly tagged μ+jets event



IP=0.53 cm
IP/ σ (IP)=14.9

$p_T(\mu)$ = 47.9 GeV
$\not{E}_T$= 55.1 GeV
6 jets
H_T = 482 GeV
A = 0.16

Top cross section measurements



σ (pb)

Kidonakis (hep-ph/303186)
Cacciari et al. (hep-ph/0303085)

Top quark mass status

- ►All methods rely on templates for different top mass hypothesis
- ►Build templates which predict the distribution of an observable that depends on m_t
- ►This "mass estimator" can be:
  - ►Single number like reconstructed top mass from kinematic fit
  - ►Continuous curve: matrix element method using individual event probabilities

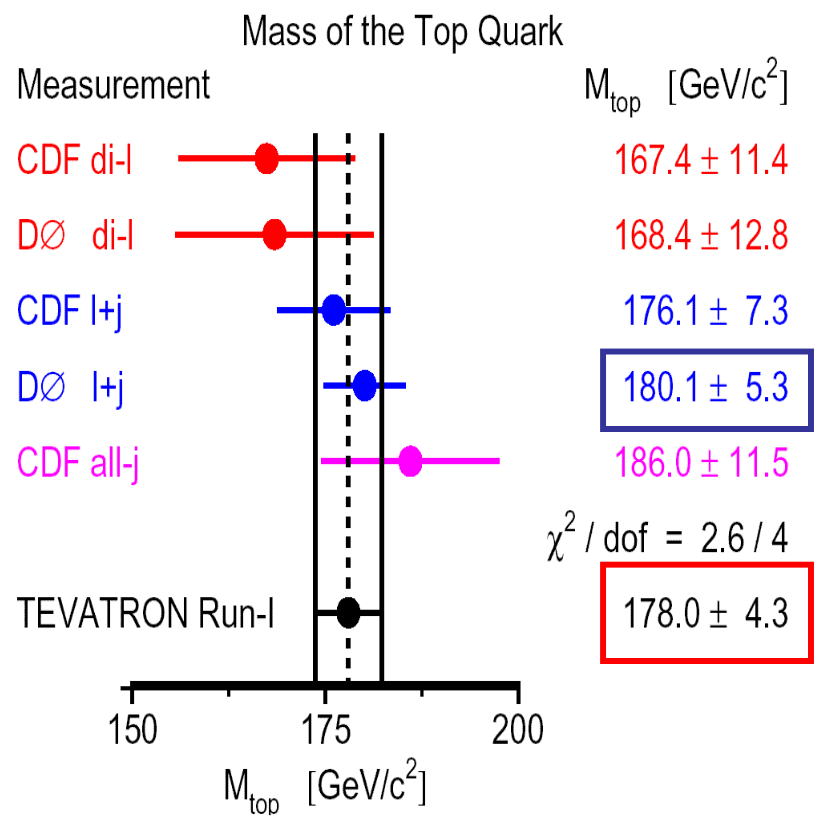
DØ Run I ℓ+jets top mass with reduced statistical uncertainty from multidimensional probabilistic estimator has been included on a new Run I Tevatron combination (hep-ex/0404010):

Old Run I TeV m_t = 174.3±3.2±4.0 GeV/c^2

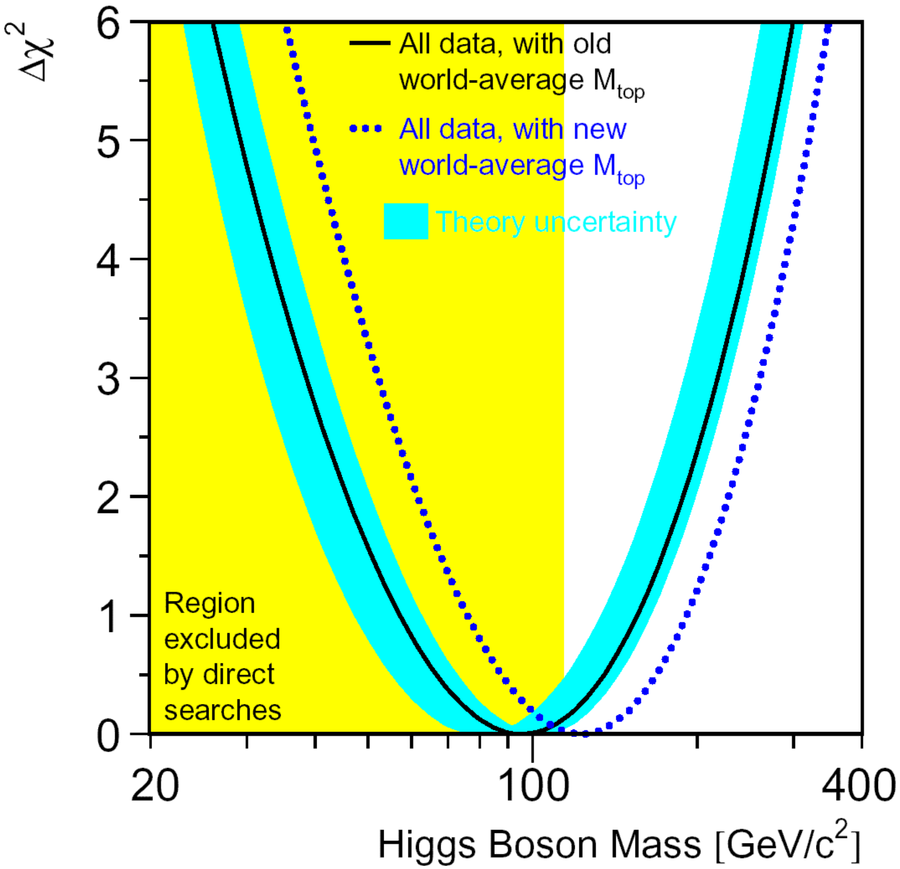
New Run I TeV m_t = 178.0±2.7±3.3 GeV/c^2

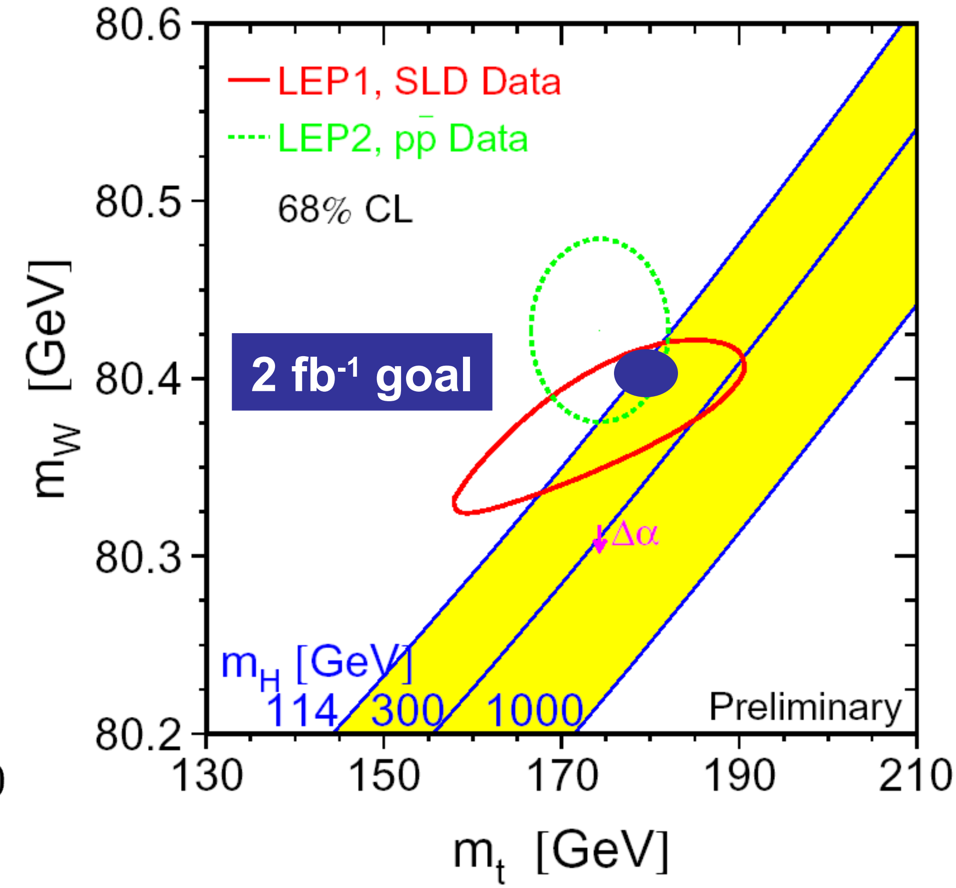
First competitive RunII top mass result from CDF ℓ+jets (L=162pb^{-1}) using prob. estimator:

$$m_t = 177.8^{+4.5}_{-5.0}(stat) \pm 6.2(syst) GeV/c^2$$



Electroweak fits



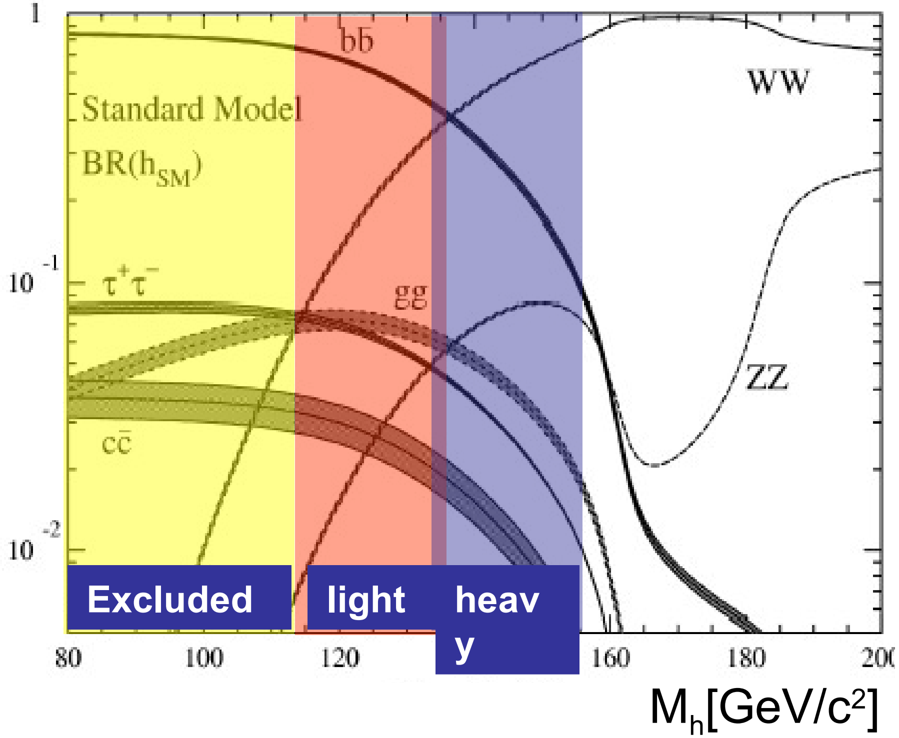


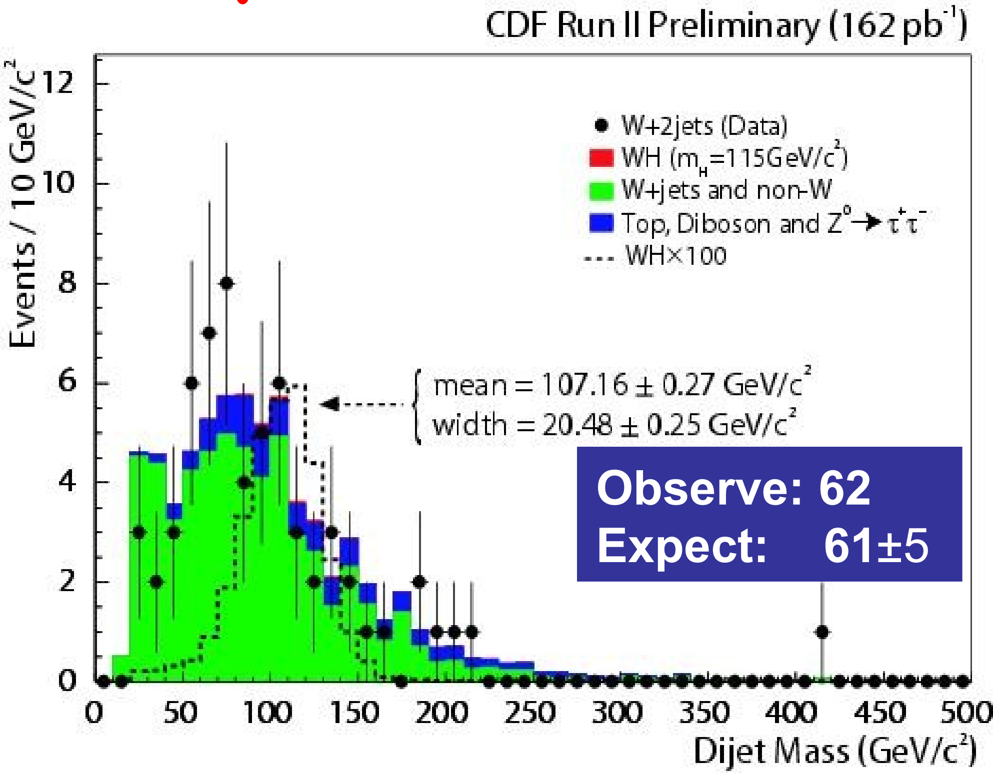
New most likely value: $m_H = 117^{+67}_{-45}$ GeV or $m_H < 251$ GeV (95% C.L.)

Excluded with direct searches at LEP2: $m_H > 114.4$ GeV (95% C.L.)

Tevatron goal with 2 fb^{-1} measure m_t to ±3 GeV and m_W to ±15 MeV

Light Higgs: W(→eν/μν)H(→bb)





Simulations performed with Alpgen + Herwig and detailed detector response

Main backgrounds:

Mistags, Wbb, Wcc, QCD, tt, single top

CDF Run II limit: $\sigma(WH \to \ell\nu bb) < 5$ pb
Exceeds CDF's Run I limit: $\sigma < 14$ pb

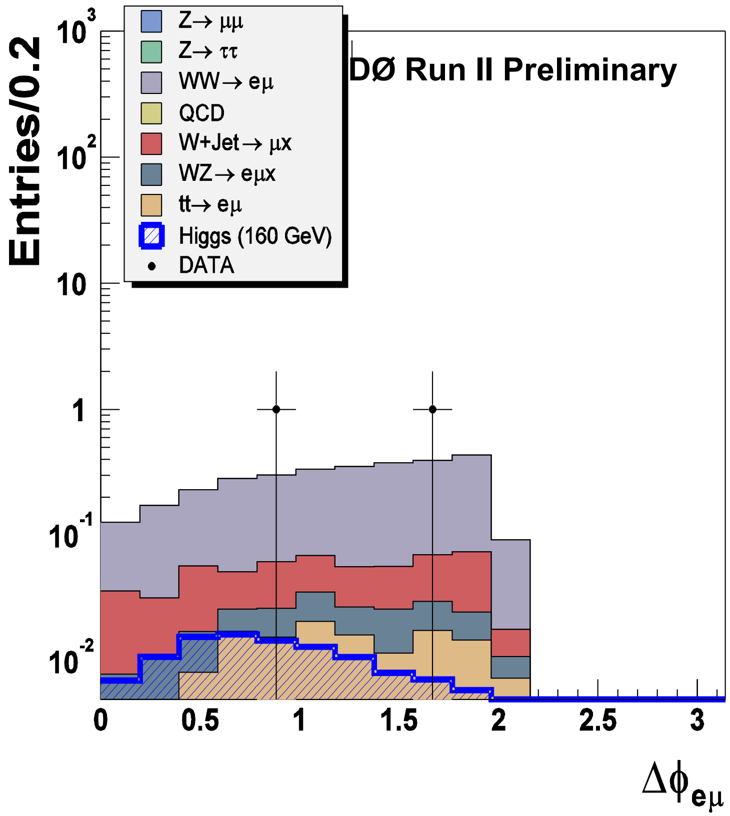
Heavy Higgs: $H \to WW^{(*)} \to \ell^+ \ell^- \nu \nu$

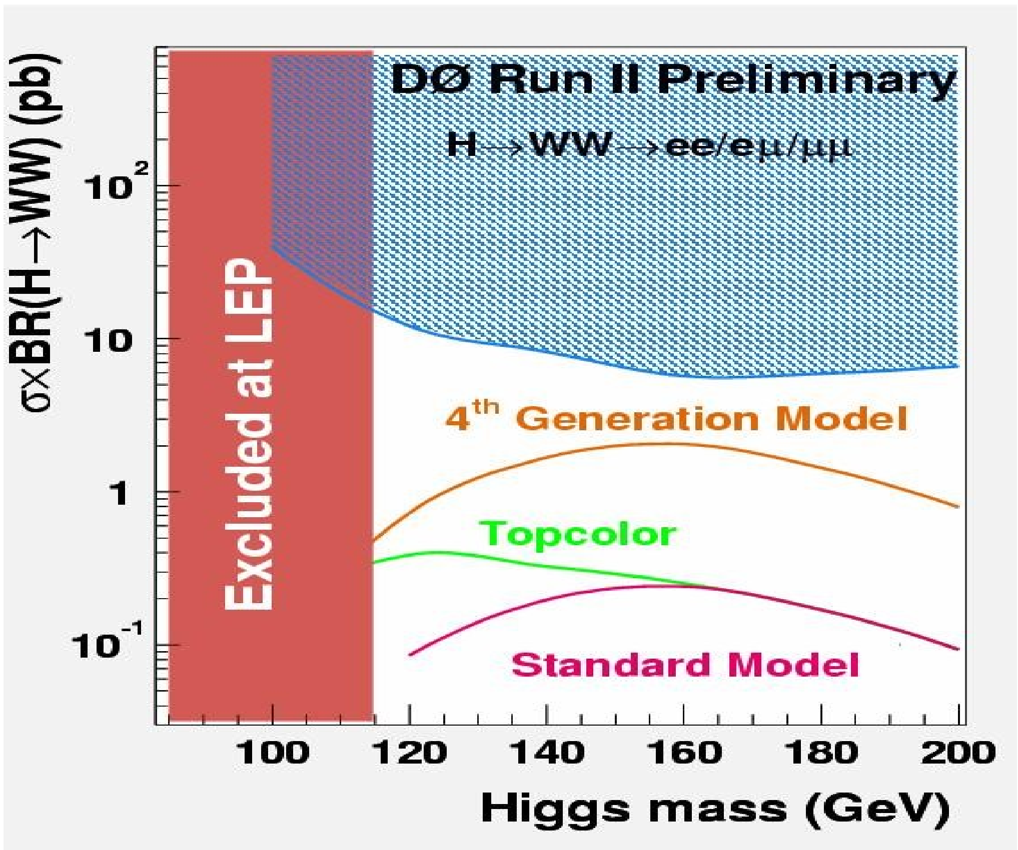
	ee	eμ	μμ
Observed	2	2	5
Expected	2.7±0.4	3.1±0.3	5.3±0.6

Cannot reconstruct H mass

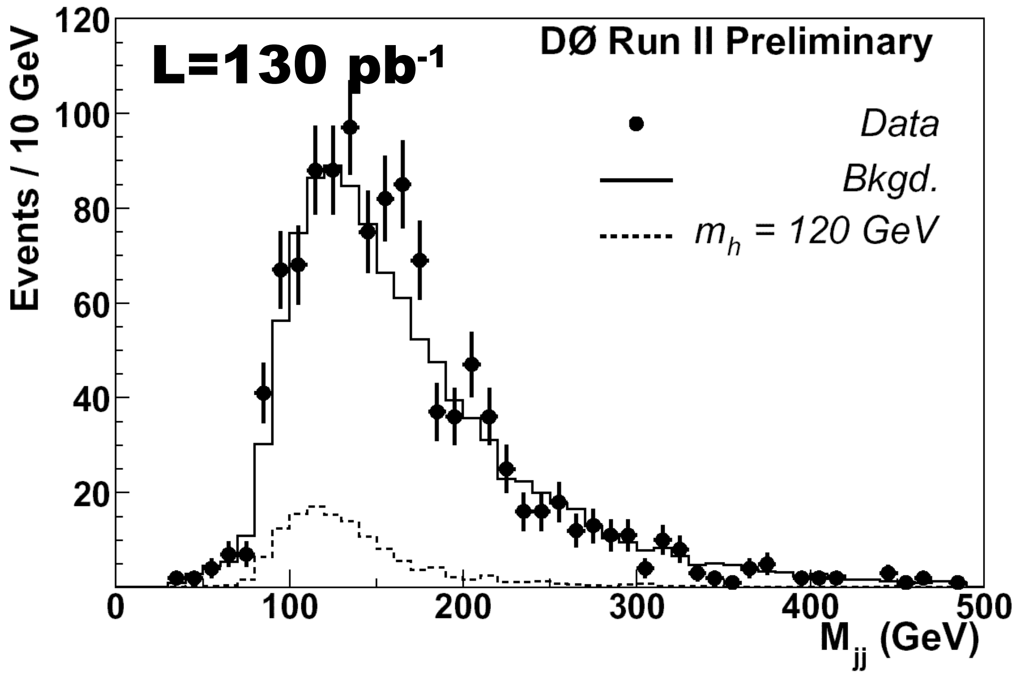
Use spin correlations to suppress bkg

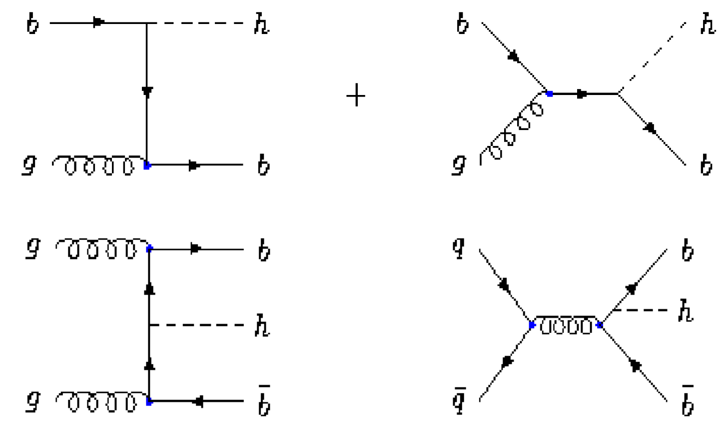
Good agreement in all final states

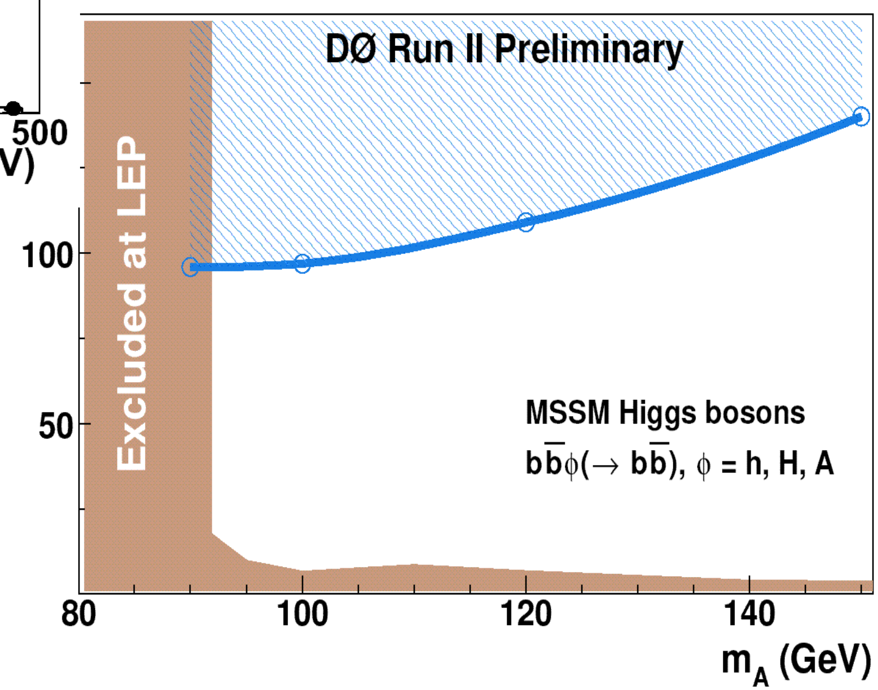




Light SUSY Higgs at high tanβ







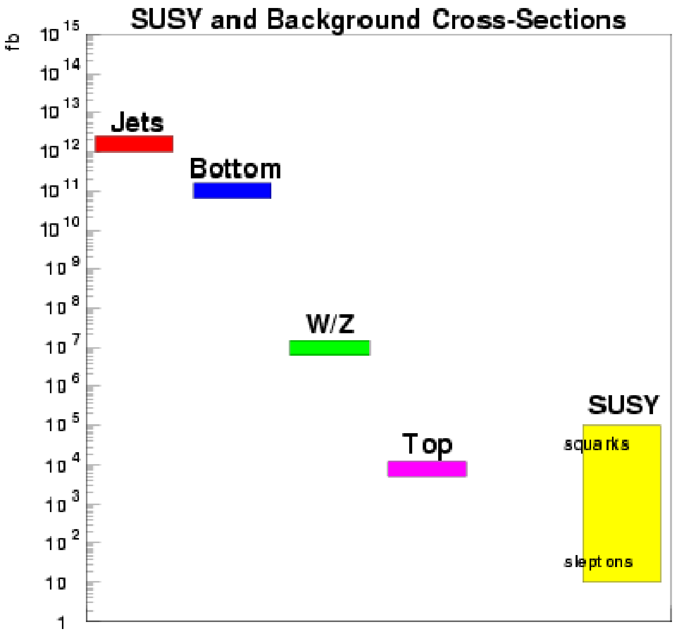
Require 3 b-tags

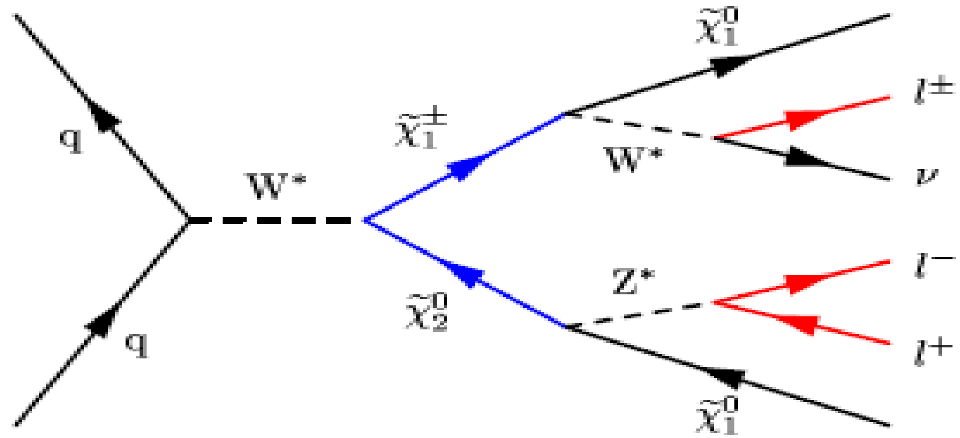
Look for mass resonance in M_{jj}

Backround shape determined from data

Will reach tanβ~40 at m_A=100 with 1.6 fb^{-1}

mSUGRA searches: trileptons

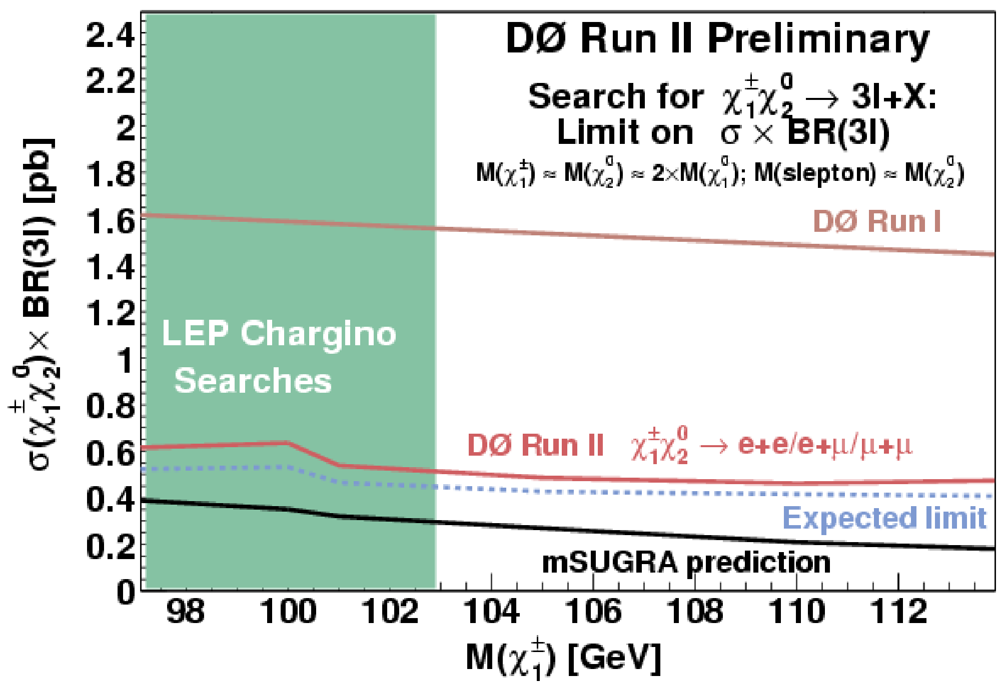




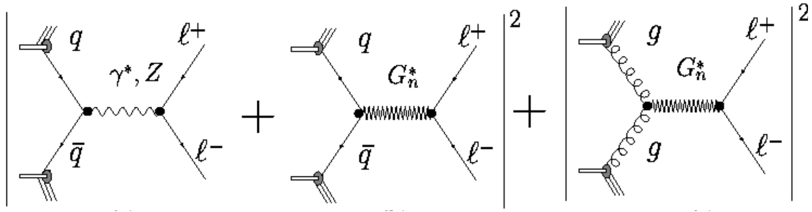
Clean signature, but low σ

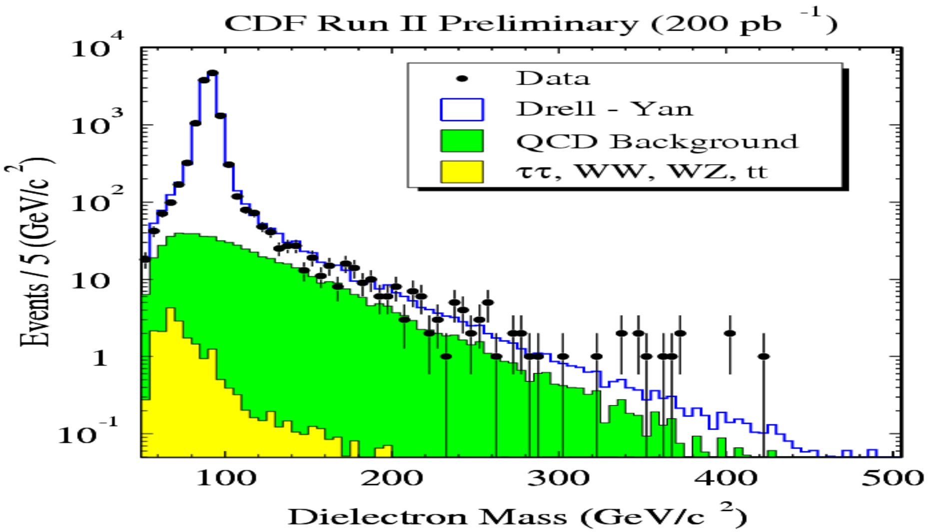
Low SM bkg

L=158pb^{-1}	ee	eμ	μμ
Observed	1	1	1
Expected	0.27	2.9	0.23

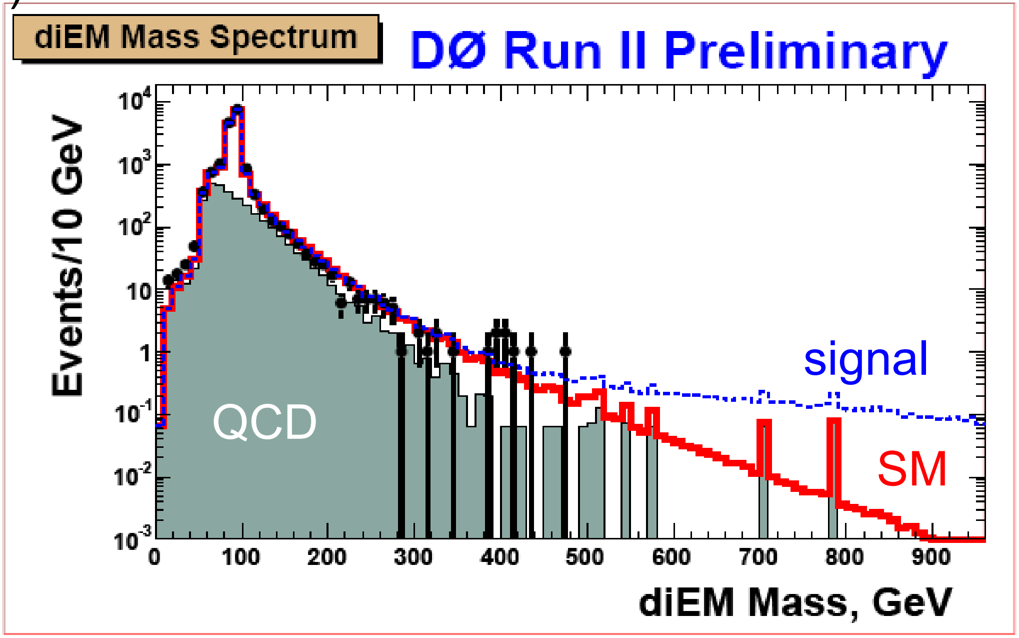


Large extra dimensions





Signature: dileptons or diphotons
(also for Z', SUSY RPV, techincolor…)
No deviations are observed



CDF Run II $M_S > 1.11$ **TeV**

DØ Run II $M_S > 1.36$ **TeV**

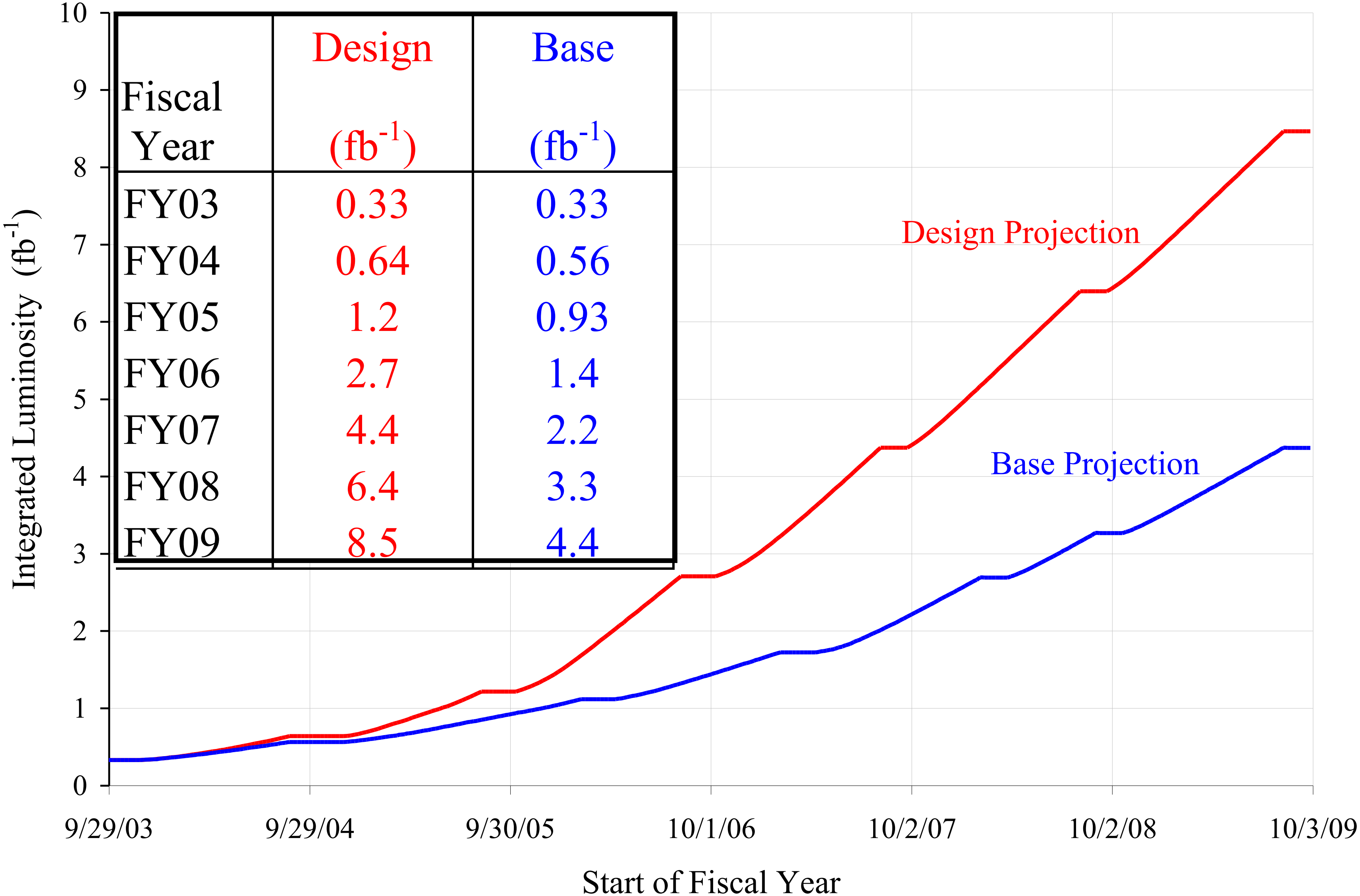
(M_S is (3+n)-dimensional Plank scale)

Conclusions

- The Tevatron Run II is progressing well
- CDF and DØ are collecting data efficiently: more than twice in Run I
- Providing the physics results they were designed for
- First published papers with Run II data and many more on the pipeline

- Electroweak measurements provide ideal scenario to test the SM and are fundamental to understand the detectors
- Increased $\sqrt{s}$ at Run II allows testing of higher Q^2
- Extensive top-quark studies
- Understanding of backgrounds for Higgs searches is improving, new better limits
- Searches limits have now surpassed Run I sensitivity

Run II luminosity prospects



Fiscal Year	Design (fb^{-1})	Base (fb^{-1})
FY03	0.33	0.33
FY04	0.64	0.56
FY05	1.2	0.93
FY06	2.7	1.4
FY07	4.4	2.2
FY08	6.4	3.3
FY09	8.5	4.4

Back up: Initial B-flavor tagging