Top Quark Measurements at the Fermilab Tevatron

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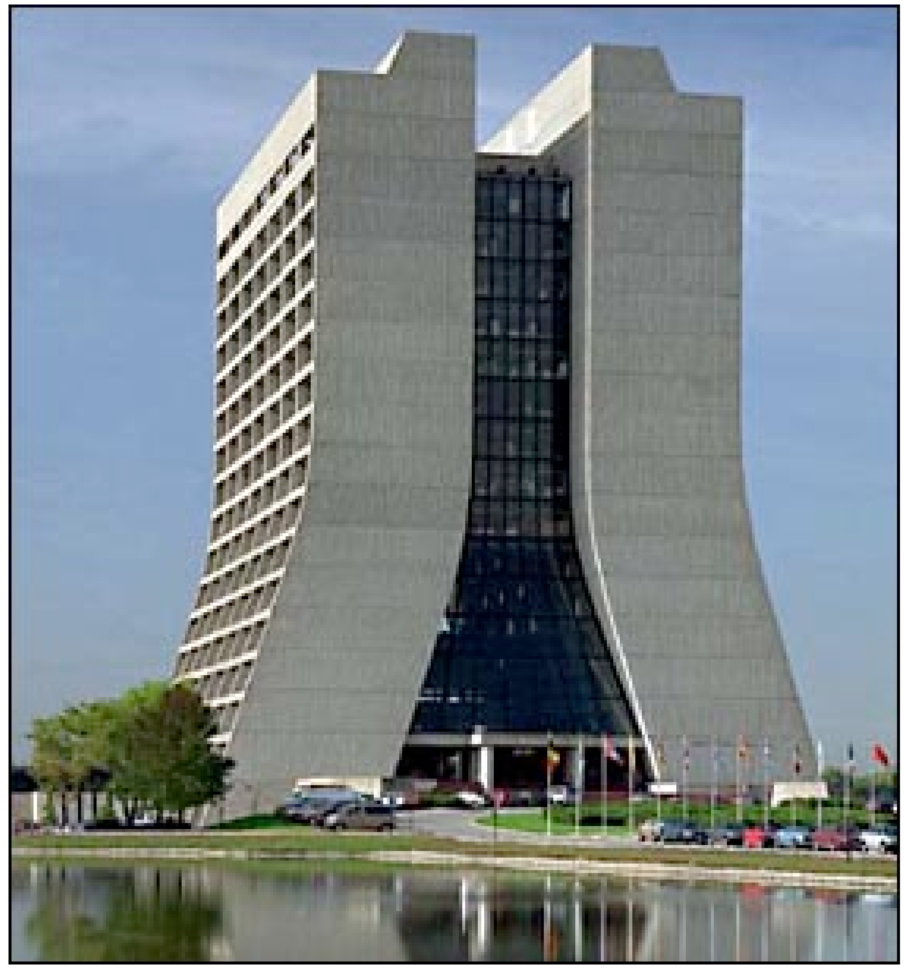
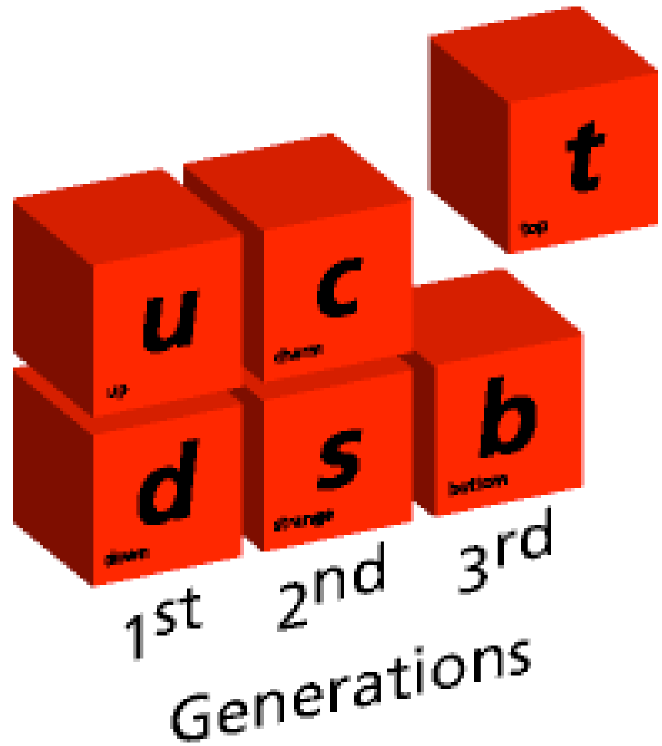


Introduction

- Top quark was expected in the Standard Model (SM) of electroweak interactions as a partner of b-quark in SU(2) doublet of weak isospin for the third family of quarks
  - Evidence for top in 1994 (CDF)
  - Observation in 1995 (CDF&D0)



- In Run I statistical uncertainties dominated:
  - Overall consistency with the SM picture
  - but…still a few loose ends
- In anticipation of much increased statistics in Run II:
  - Rich physics menu
  - Increased luminosity → increased precision
  - Surprises?
    - Preliminary results on: cross section, mass, W helicity and single top

Tevatron has exclusivity on top physics for the next several years!

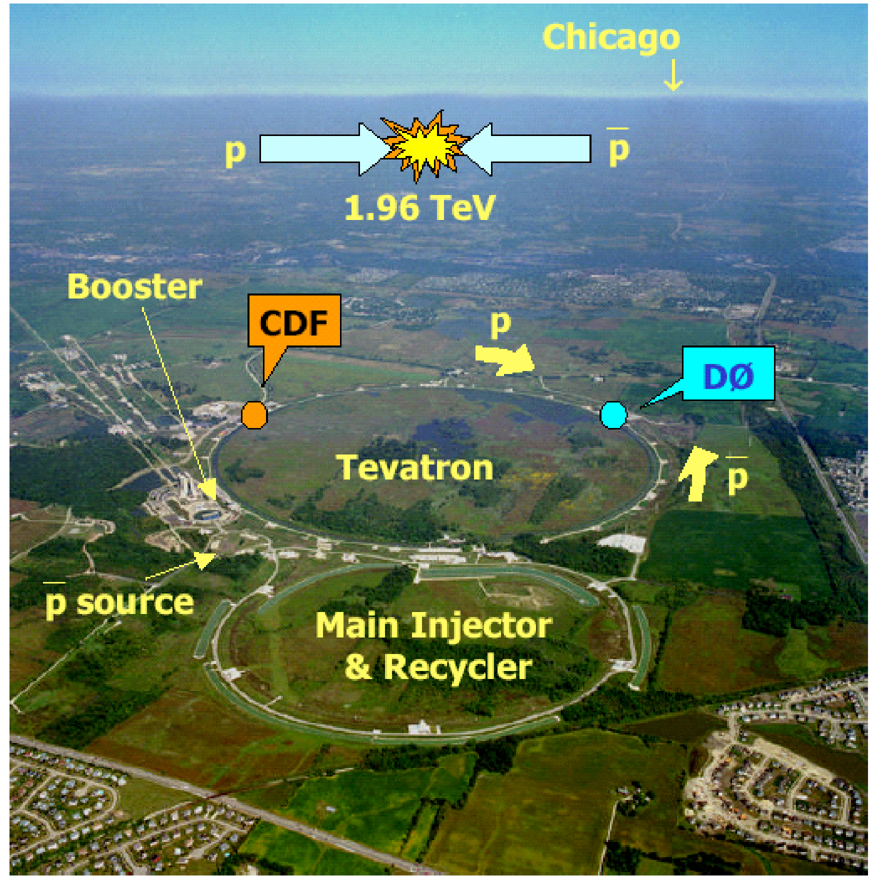
Tevatron collider in Run II

- The Tevatron is a proton-antiproton collider with 980 GeV/beam

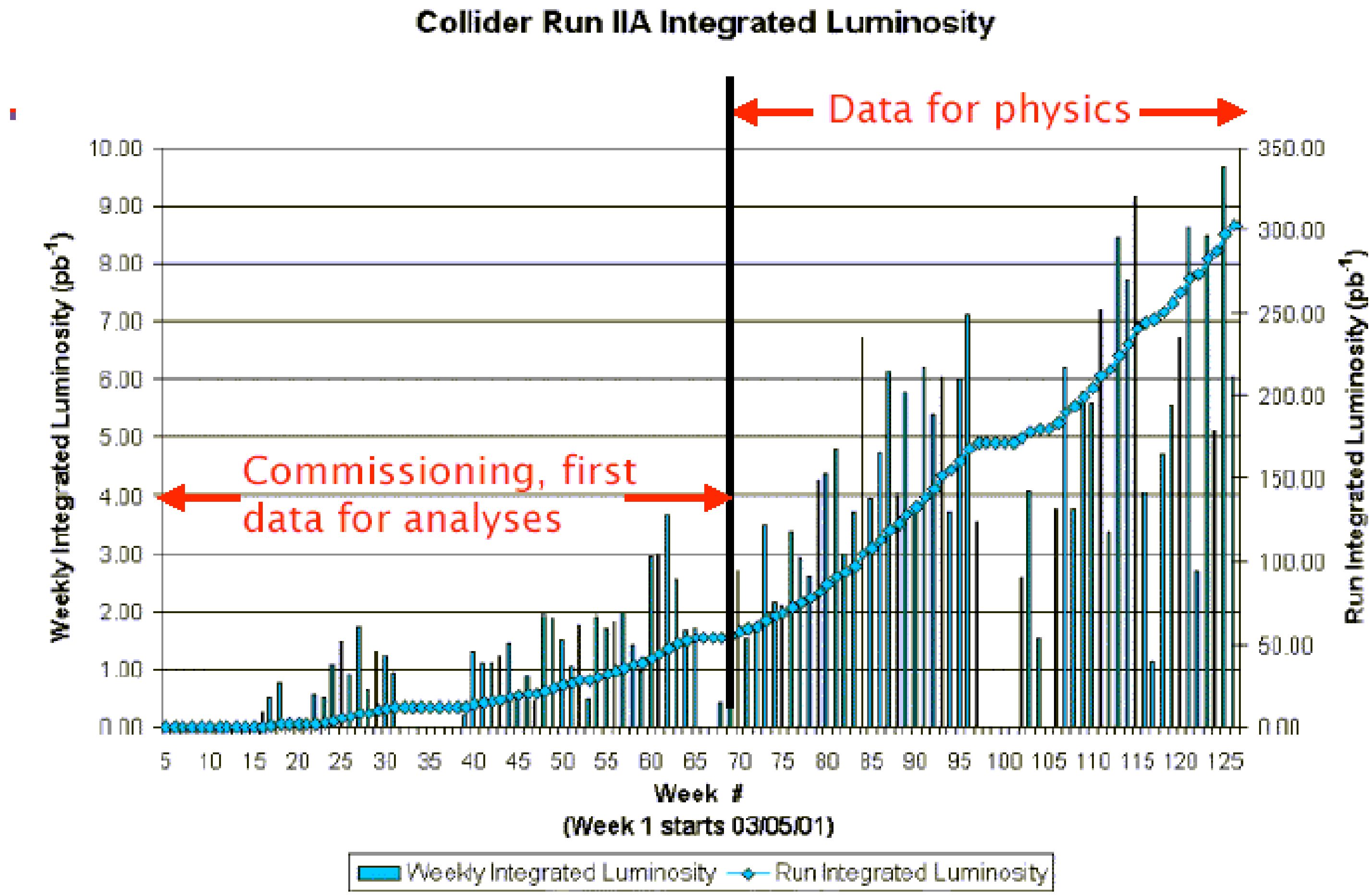
$\sqrt{s}$ = 1.96TeV in RunII (1.8TeV RunI)

- 36 p and $\bar{p}$ bunches →396 ns between bunch crossing
  - Increased from 6x6 bunches with 3.5□s in Run I

- Increased instantaneous luminosity:
  - Run II goal 30 x 10^{31} cm^{-2} s^{-1}
  - Current: 3÷4.5 x 10^{31} cm^{-2} s^{-1}



Run II Data Taking Status



- L_{int}~300 pb^{-1} delivered by the Tevatron
- Good quality data since Spring 2002
- Data collection efficiency 85÷90%

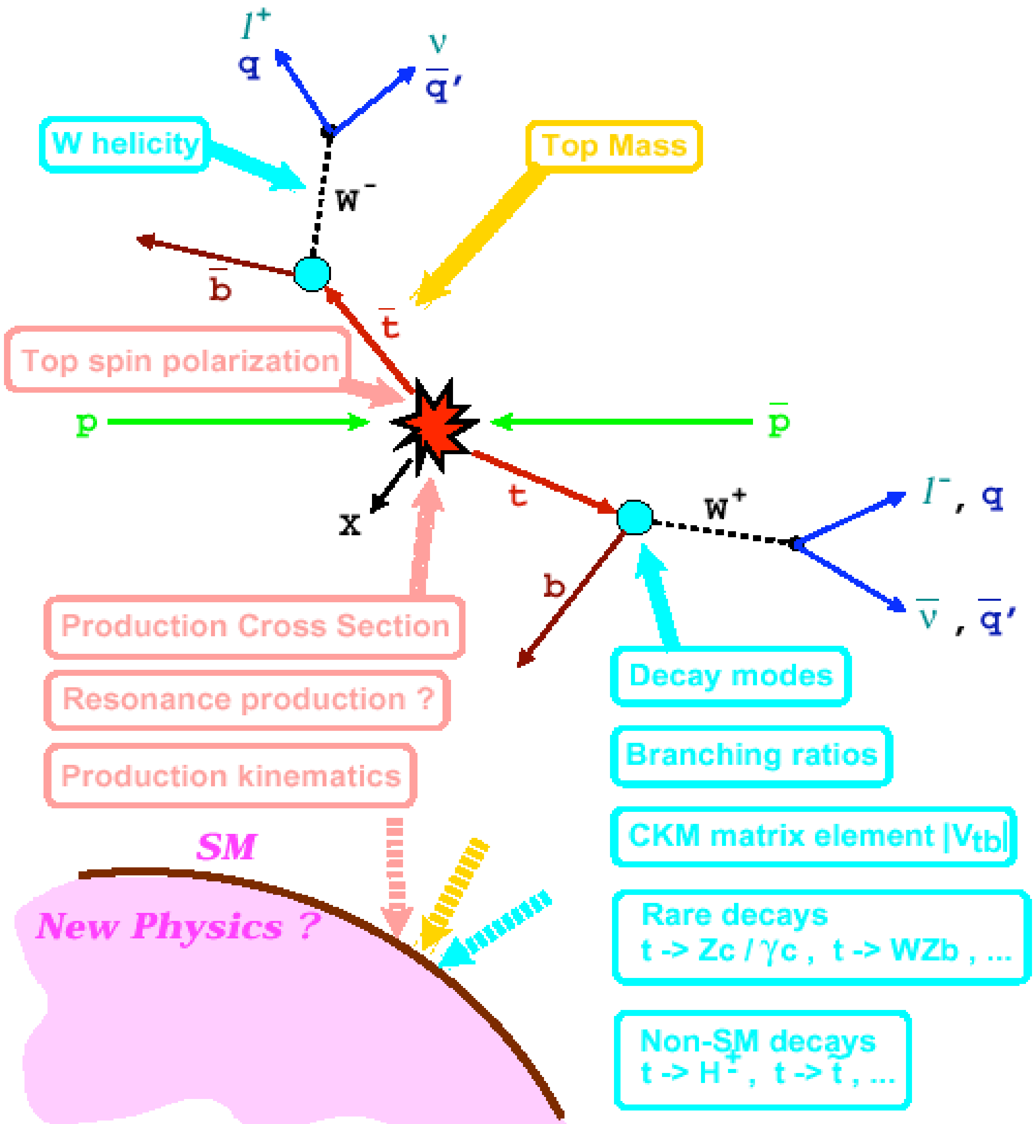
Next Year projection:
additional 310÷380pb^{-1} delivered

Tevatron Collaborations

12 countries, 62 institutions
767 physicist

19 countries
83 institutions, 664 physicists

Top physics understanding

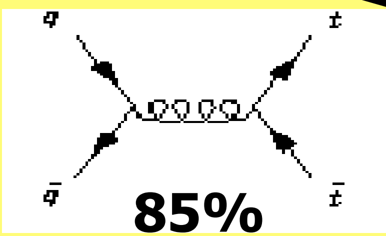


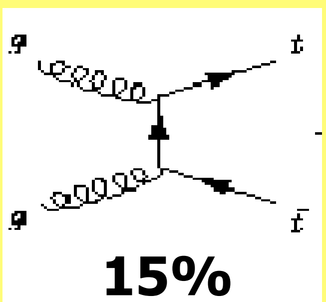
Program

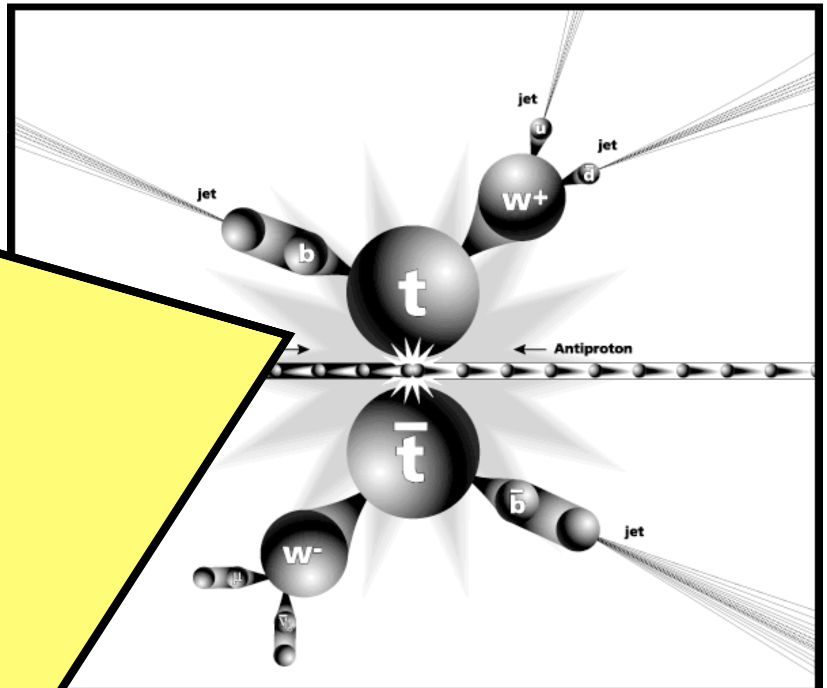
- Top production & decay
- Tools
- Cross section
- Single top
- W helicity
- Mass

Top Quarks at the Tevatron

Pair production







B(t_Wb) = 100%

W's decay modes used to classify the final states

•Dilepton (e,μ)	BR=5%
•Lepton (e,μ) +jets	BR=30%
•All jets	BR=44%
• τ_{had}+X	BR=21%

Methodology & tools

Full characterization of the chosen final state signature in terms of SM background processes (control region)

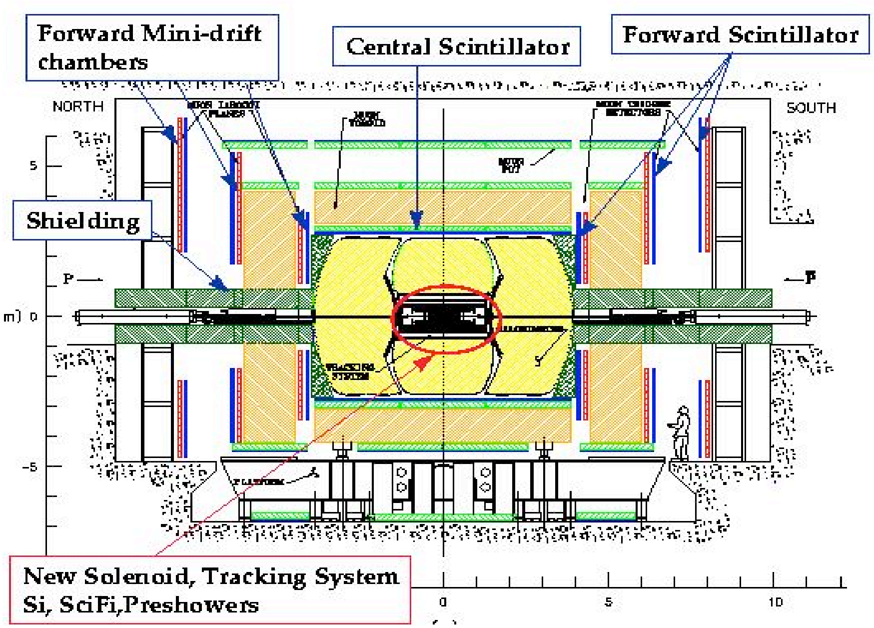
- Optimize signal region for best measurement precision

- How to separate signal from background:
  - Top events have very distinctive signatures
    - o Decay products (leptons, neutrinos, jets) have large p_T's
    - o Event topology: central and spherical
    - o Heavy flavor content: always 2 b jets in the final state!

- Tools (need multipurpose detectors!):
  - Lepton ID: detector coverage and robust tracking
  - Calorimetry: hermetic and well calibrated
  - B identification: algorithms pure and efficient
  - Simulation: essential to reach precision goals

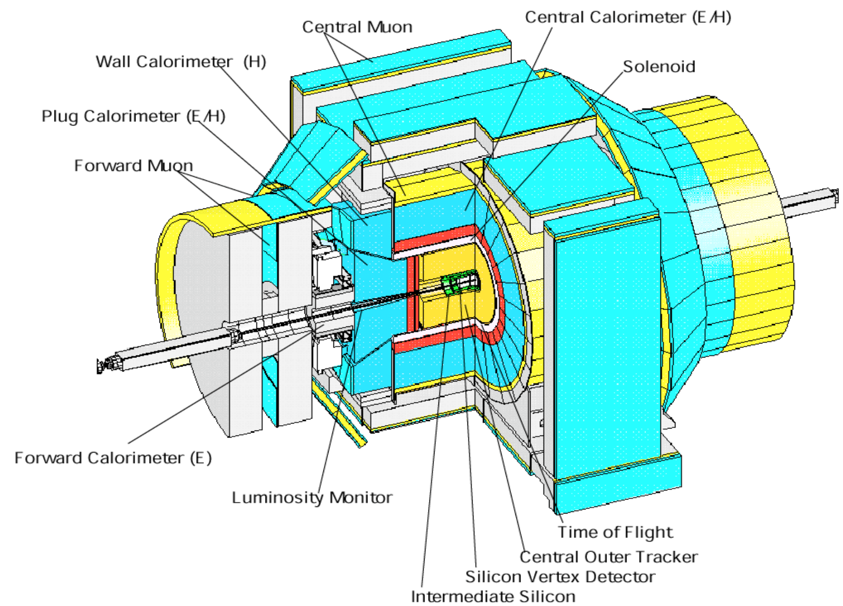
The upgraded detectors

D0



- New tracking: silicon and fibers in magnetic field
- Upgraded muon system
- Upgraded DAQ/trigger (displaced track soon)

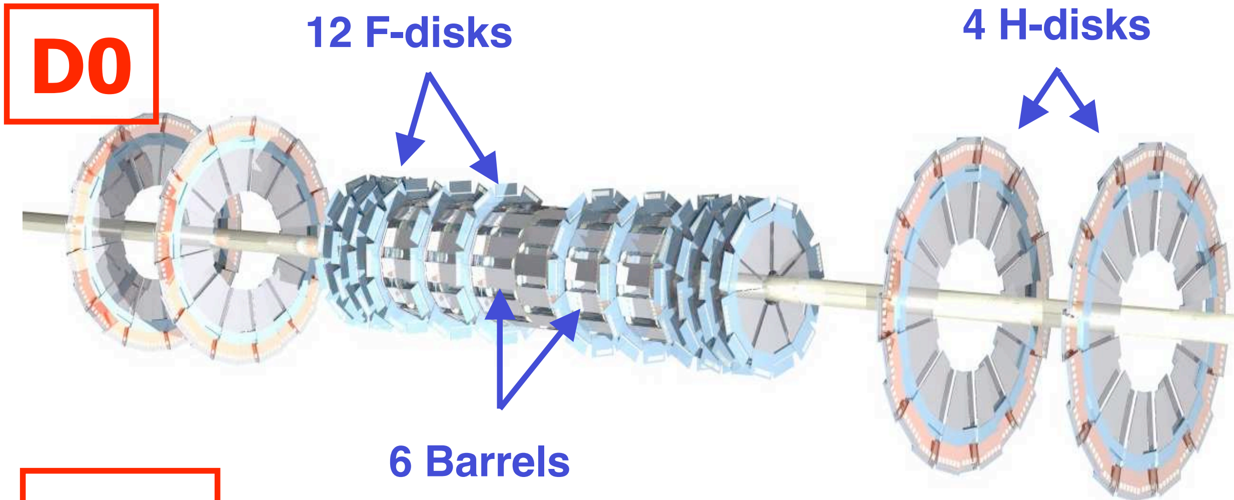
CDF



- New bigger silicon, new drift chamber
- Upgraded calorimeter,
- Upgraded DAQ/trigger, esp. displaced-track trigger

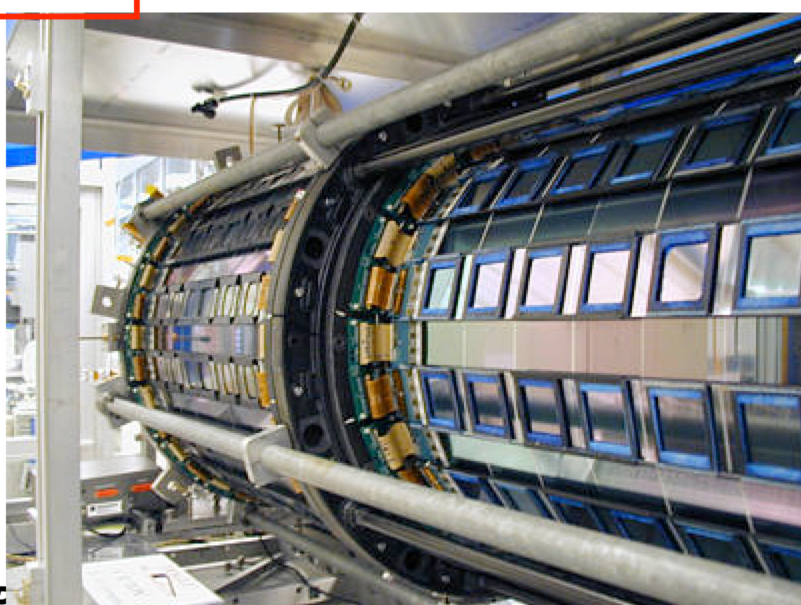
The new Silicon detectors

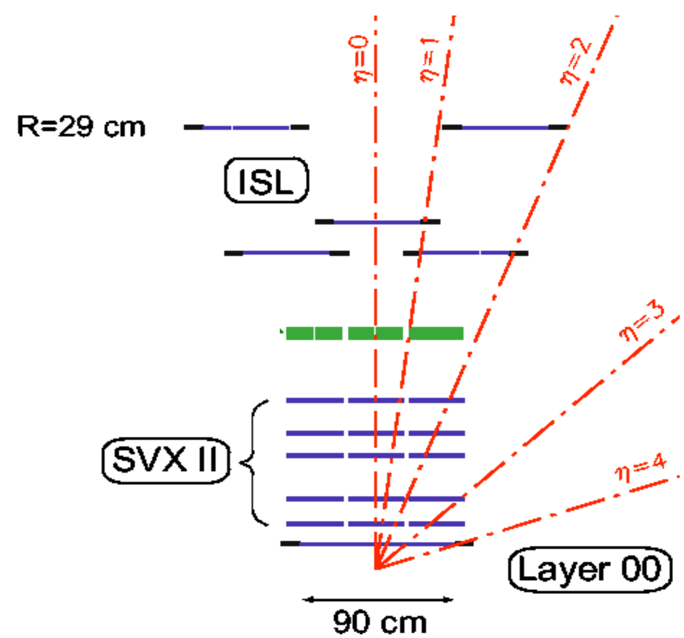
D0



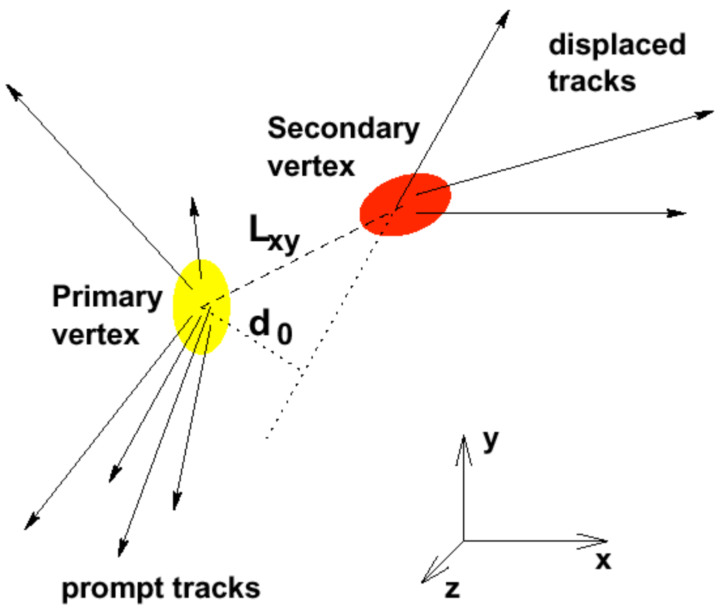
Common features:
- Coverage of the luminous regions
- Extended acceptance at large pseudo-rapidity
- 3D Tracking capability
- Excellent I.P. resolution

CDF





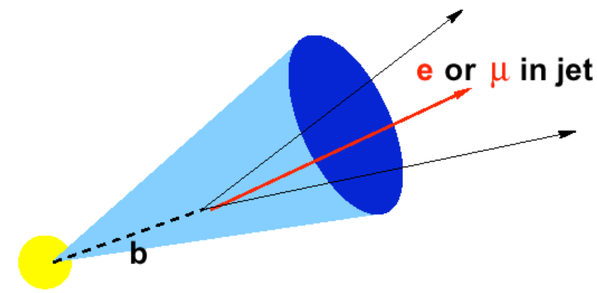
How to tag a high p_T B-jet



Silicon Vertex Tag

Signature of a b decay is a displaced vertex:

- Long lifetime of b hadrons ($c\tau \sim 450\ \mu m$)+ boost
- B hadrons travel L_{xy}~3mm before decay with large charged track multiplicity



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

Soft Lepton Tag

- Exploits the b quarks semi-leptonic decays
  - These leptons have a softer p_T spectrum than W/Z leptons
  - They are less isolated

B-tagging at hadron machines established:
- •crucial for top discovery in RunI
- •essential for RunII physics program

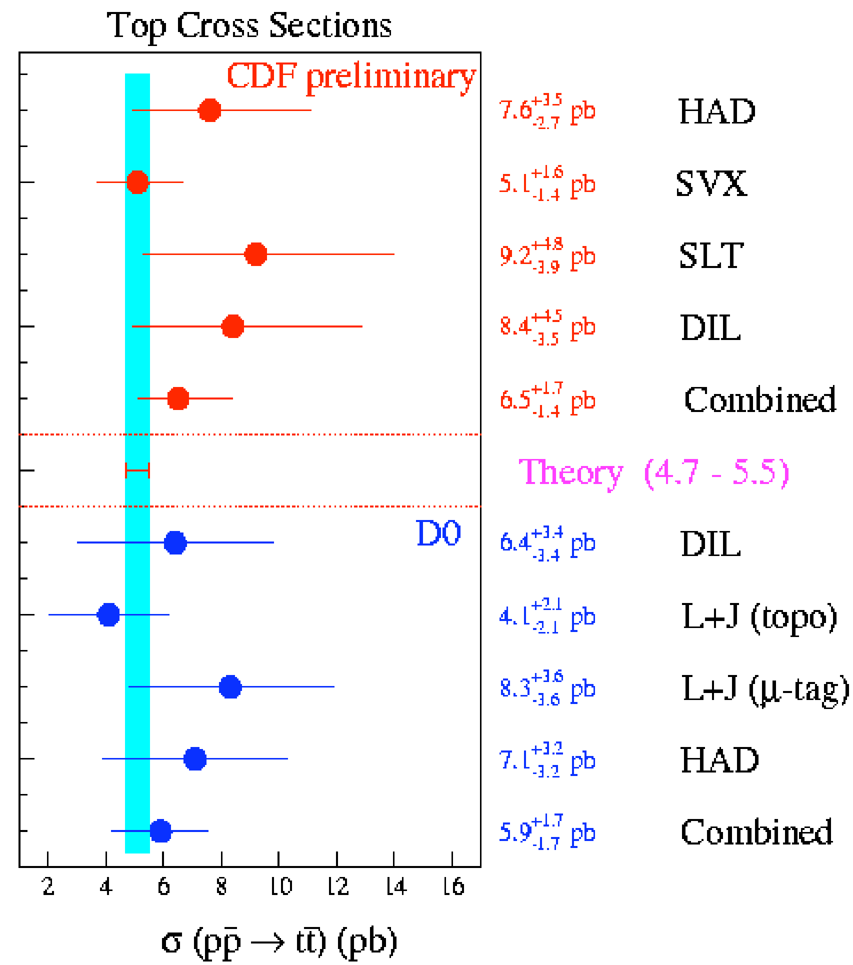
Production cross section

- Test of QCD
  - discrepancies from QCD might imply non SM physics
    - o SUSY processes
    - o Top-color objects
  - Current uncertainty is statistics dominated

- Experimental handles for RunII:
  - Larger overall efficiency (lepton ID, trigger, btagging) w/ better background rejection
  - Main data driven systematics (jet energy scale, ISR, ϵ_{btag}) scale with $1/\sqrt{N}$

RunII($2fb^{-1}$) $\delta\sigma_{tt}/\sigma_{tt} \lesssim 10\%$

Run I Summary



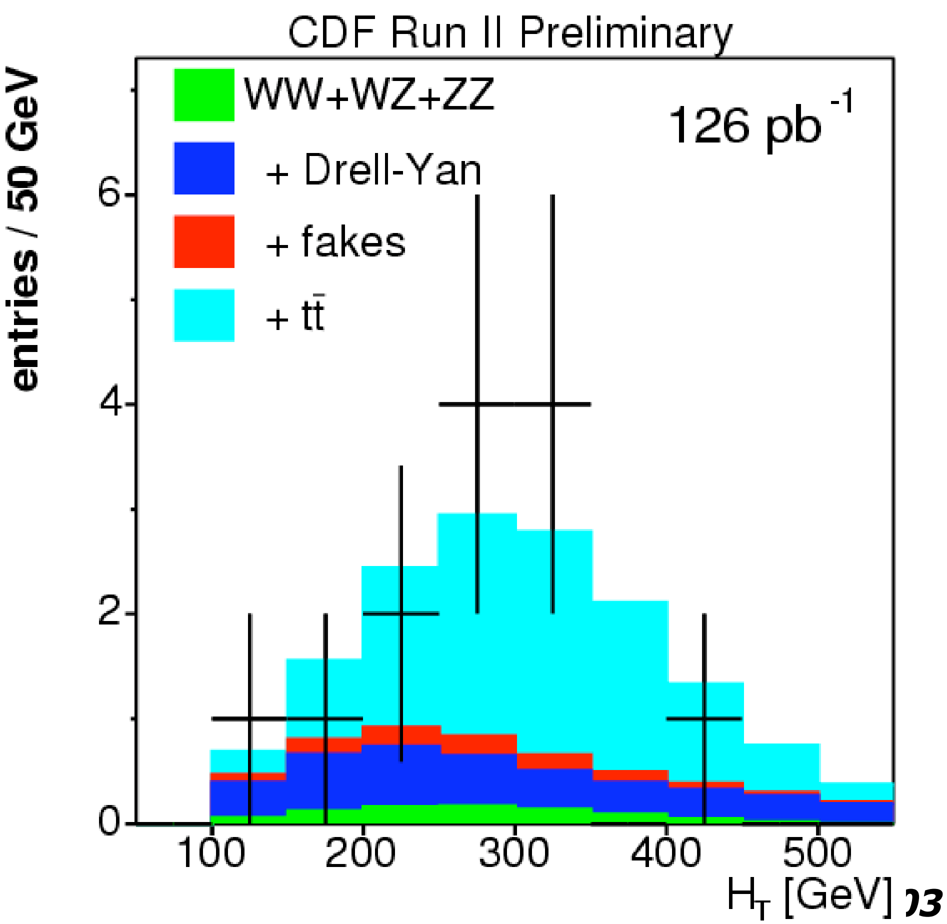
Run II cross section – Dilepton channel

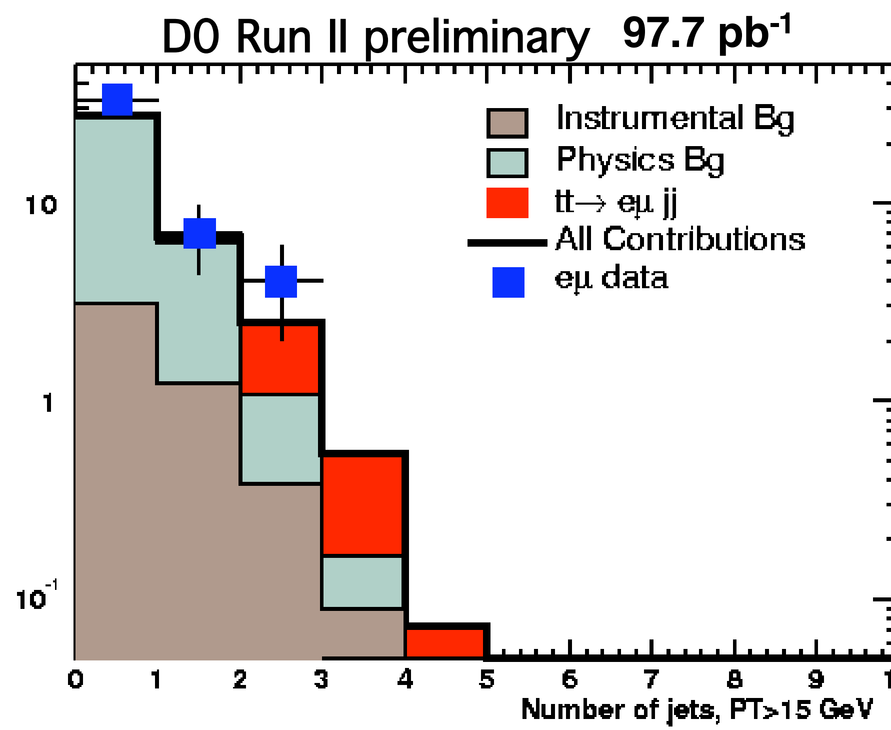
2 high p_T leptons (e,μ,τ,iso track)

Large Missing E_T

2 central jets

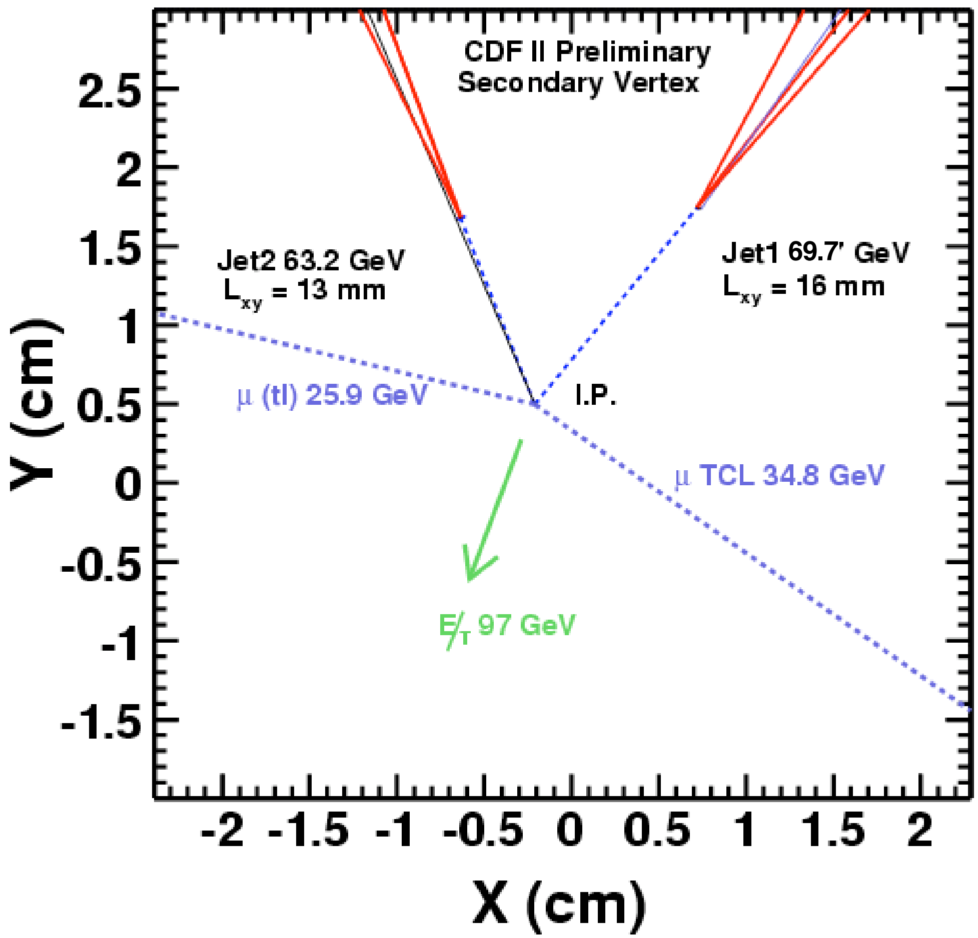
H_T: scalar sum of all the measured "objects" E_T's (leptons,jets)

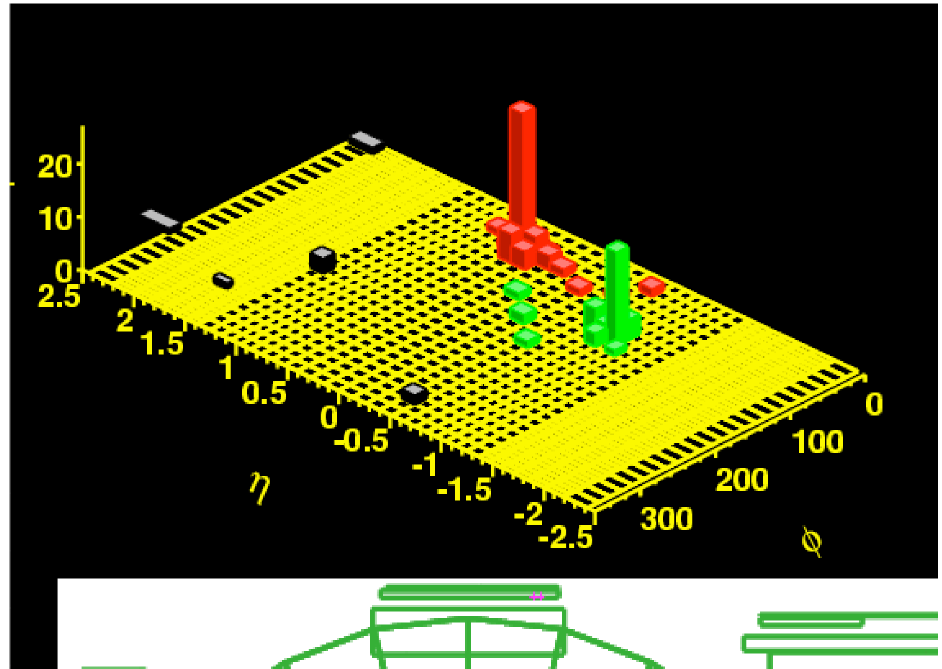


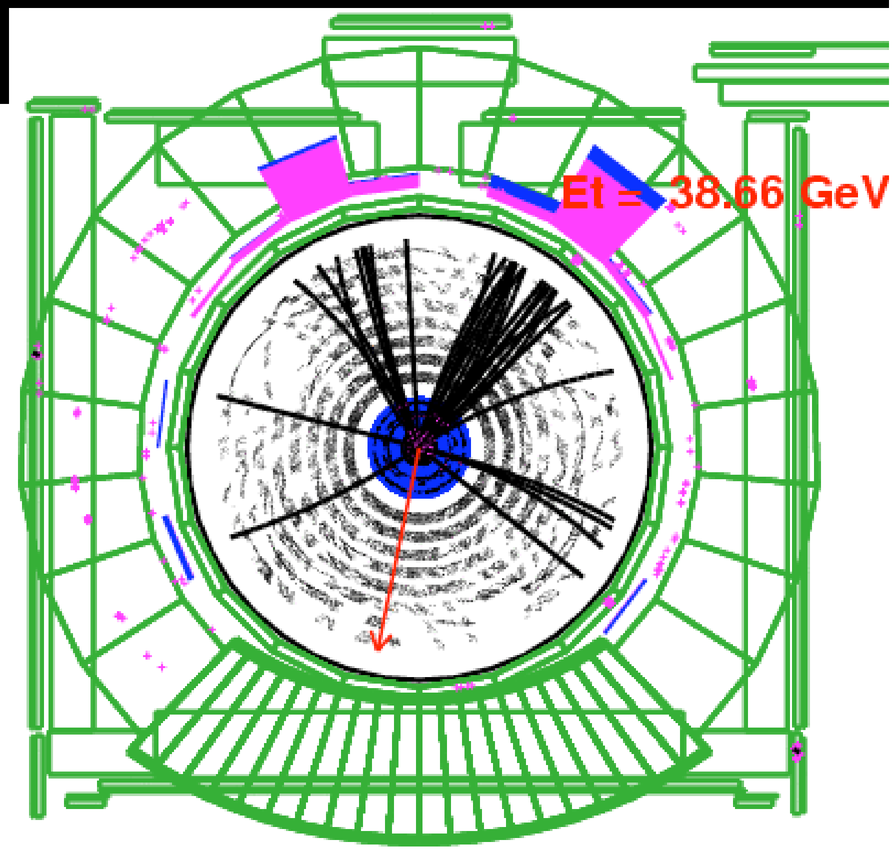


Double b-tagged dilepton event @ CDF

Run 162820 Event 7050764 Sun May 11 16:53:57 2003







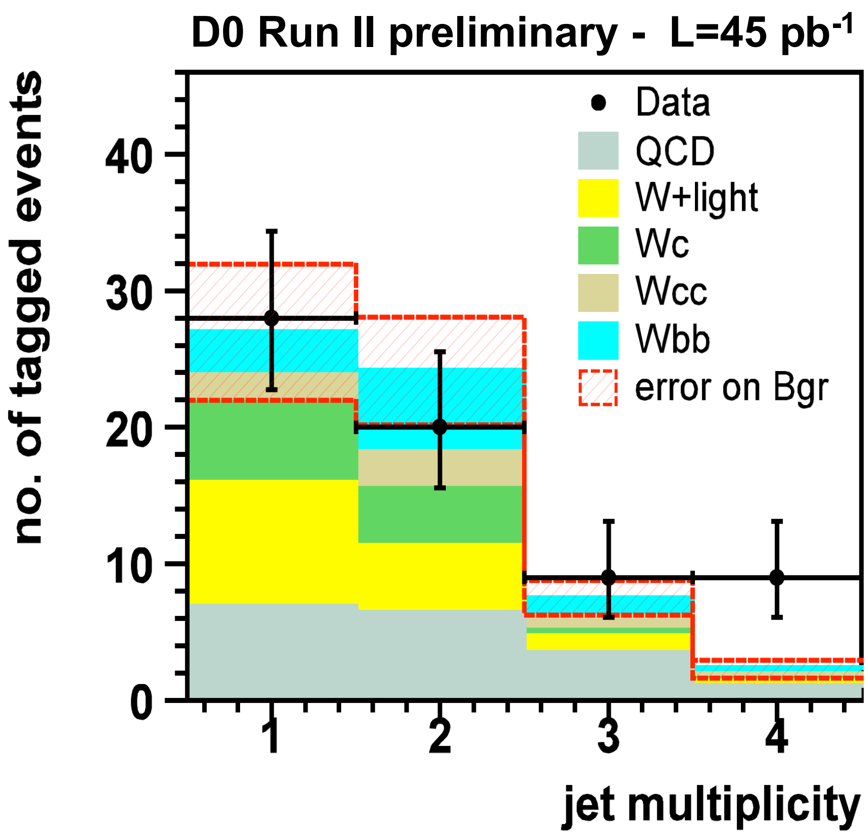
Run II cross section – lepton+jets

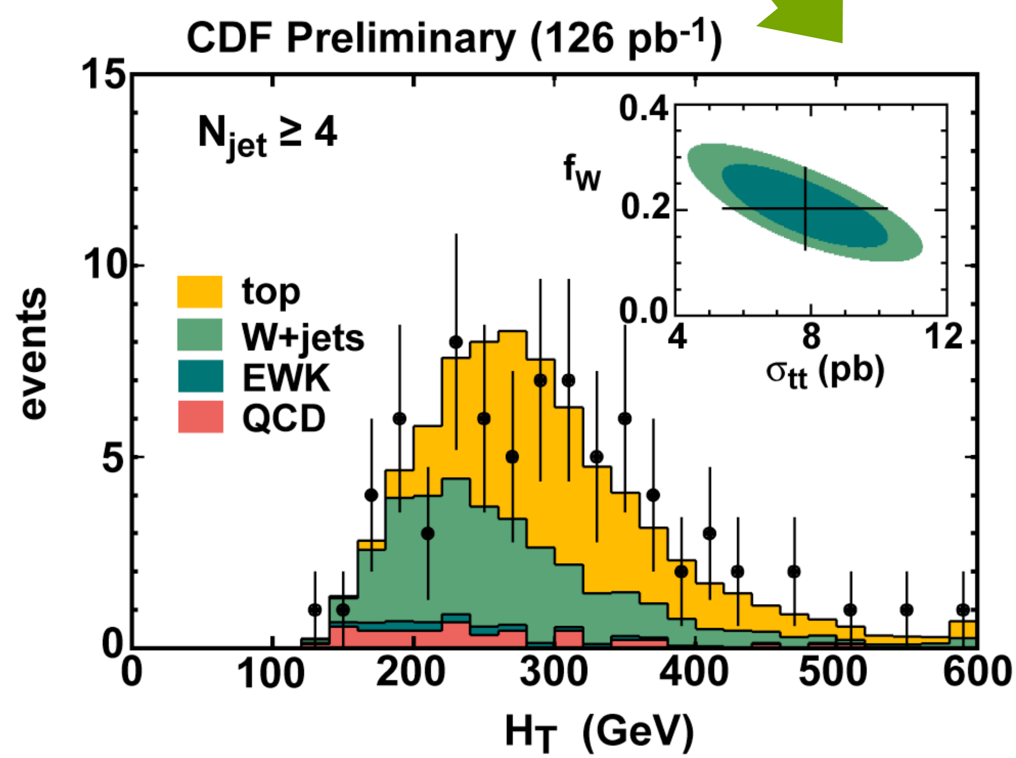
1 high p_T lepton(e,□)

Large Missing E_T

≥3 central jets

This signature suffers from large W+jets background. Isolate signal using: **SVX B-tag** and/or **kinematics**





μ+jets double tagged event @D0

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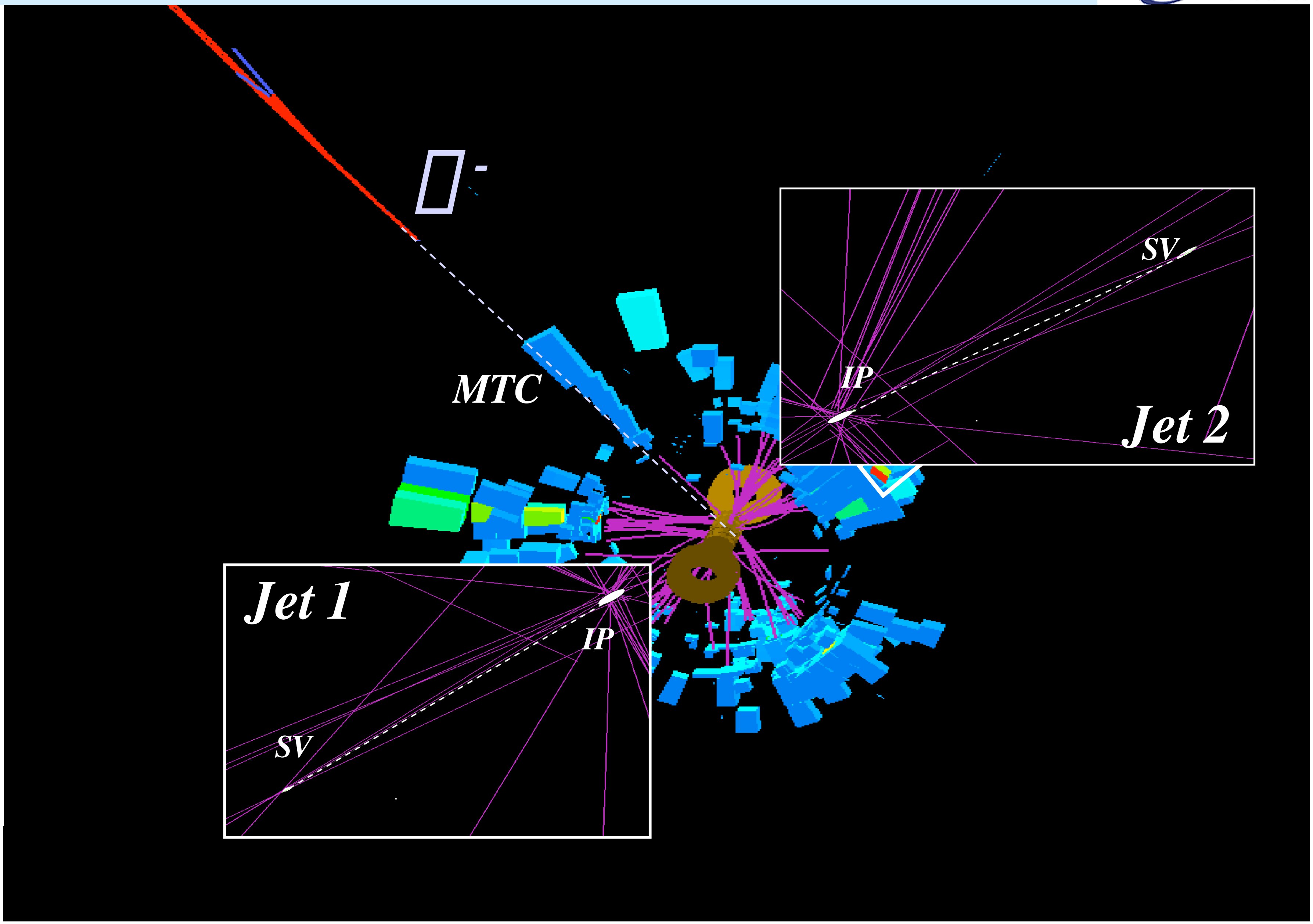
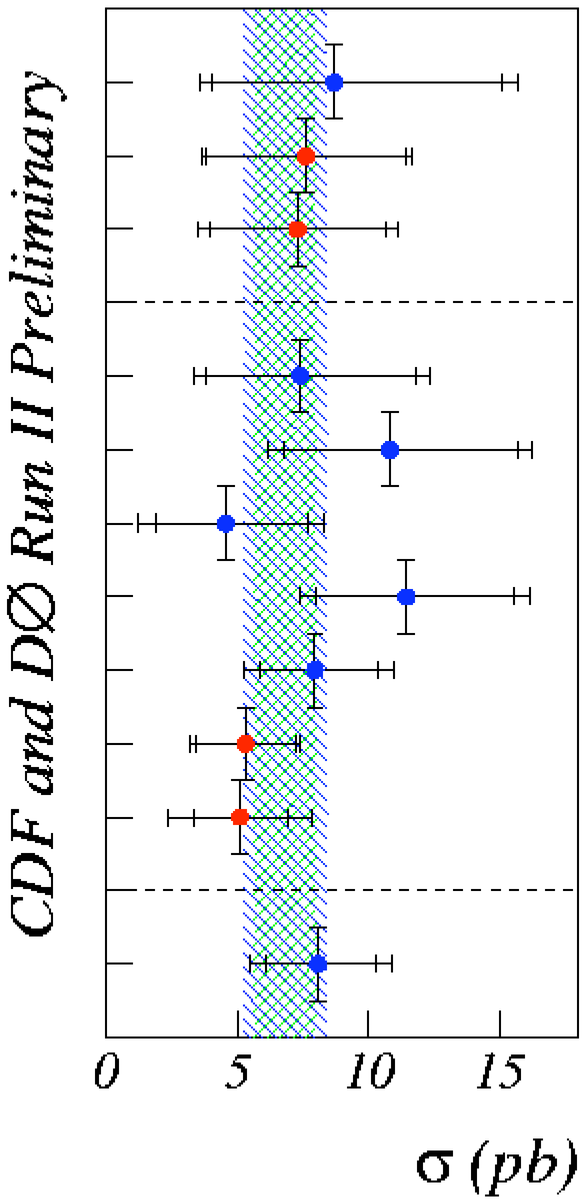
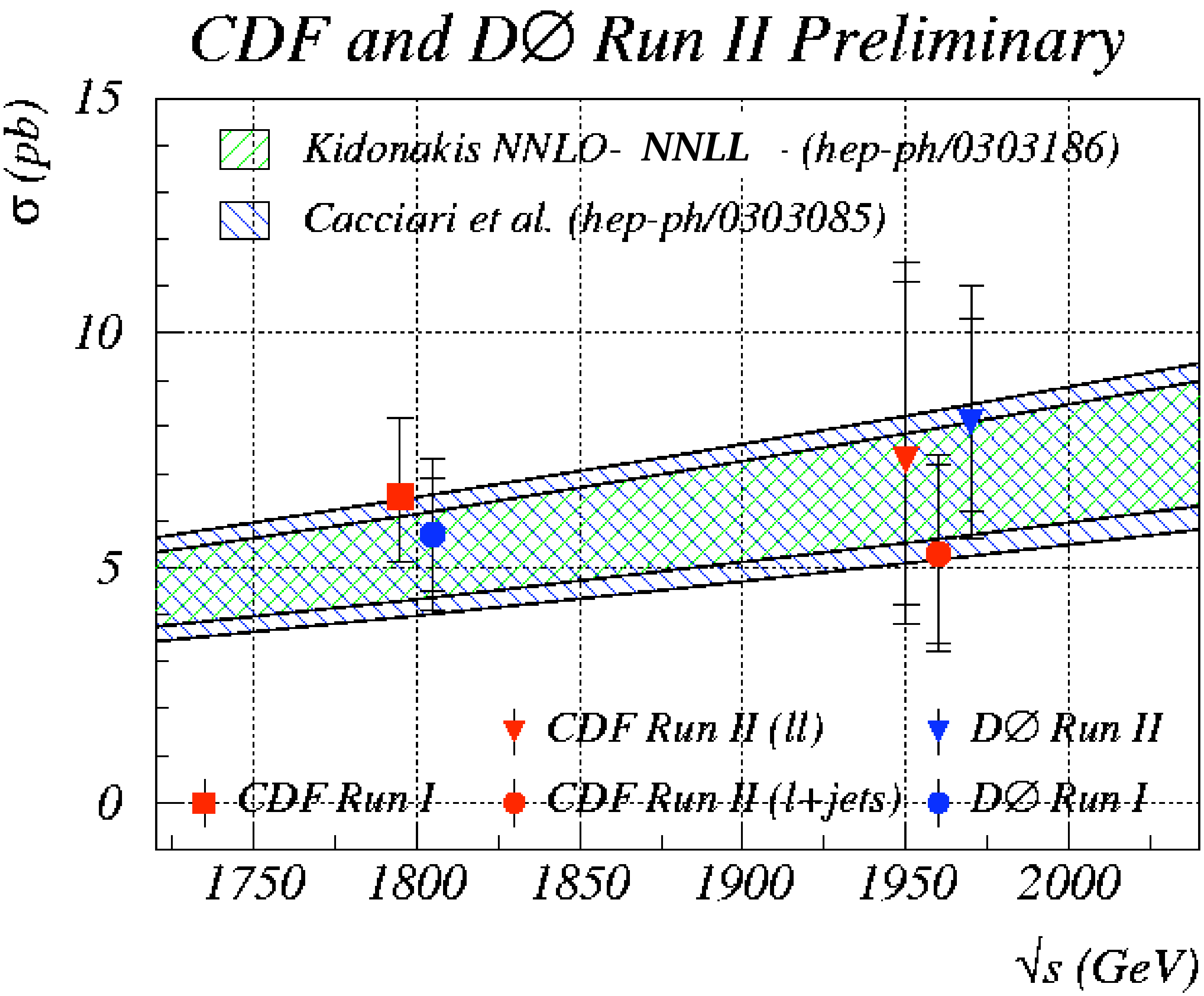


Run II cross section summary



DØ Dileptons 90-107 pb^{-1}	$8.7^{+6.4}_{-4.7}(stat)^{+2.7}_{-2.0}(syst) \pm 0.9(lum)$
CDF Dileptons 126 pb^{-1}	$7.6^{+3.8}_{-3.1}(stat)^{+1.5}_{-1.9}(syst)$
CDF L+Track 126 pb^{-1}	$7.3 \pm 3.4(stat) \pm 1.7(syst)$
DØ L+jets/CSIP 45 pb^{-1}	$7.4^{+4.4}_{-3.6}(stat)^{+2.1}_{-1.8}(syst) \pm 0.7(lum)$
DØ L+jets/SVT 45 pb^{-1}	$10.8^{+4.9}_{-4.0}(stat)^{+2.1}_{-2.0}(syst) \pm 1.1(lum)$
DØ L+jets/topo 92 pb^{-1}	$4.6^{+3.1}_{-2.7}(stat)^{+2.1}_{-2.0}(syst) \pm 0.5(lum)$
DØ L+jets/soft muon 92 pb^{-1}	$11.4^{+4.1}_{-3.5}(stat)^{+2.0}_{-1.8}(syst) \pm 1.1(lum)$
DØ L+jets combined 92 pb^{-1}	$8.0^{+2.4}_{-2.1}(stat)^{+1.7}_{-1.5}(syst) \pm 0.8(lum)$
CDF L+jets/SVX 57 pb^{-1}	$5.3 \pm 1.9(stat) \pm 0.9(syst)$
CDF L+jets/HT 126 pb^{-1}	$5.1 \pm 1.8(stat) \pm 2.1(syst)$
DØ Combined 90-107 pb^{-1}	$8.1^{+2.2}_{-2.0}(stat)^{+1.6}_{-1.4}(syst) \pm 0.8(lum)$

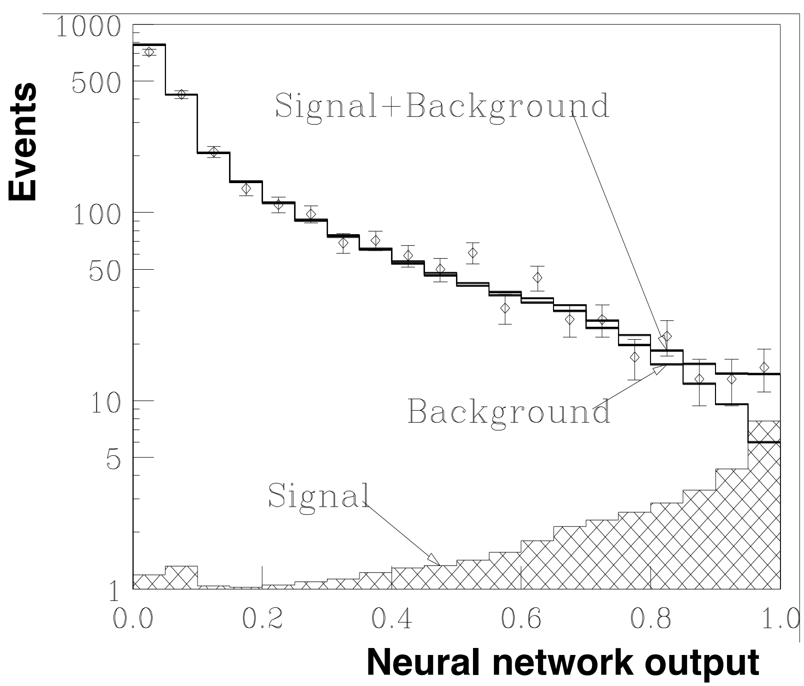
Cross section s dependence



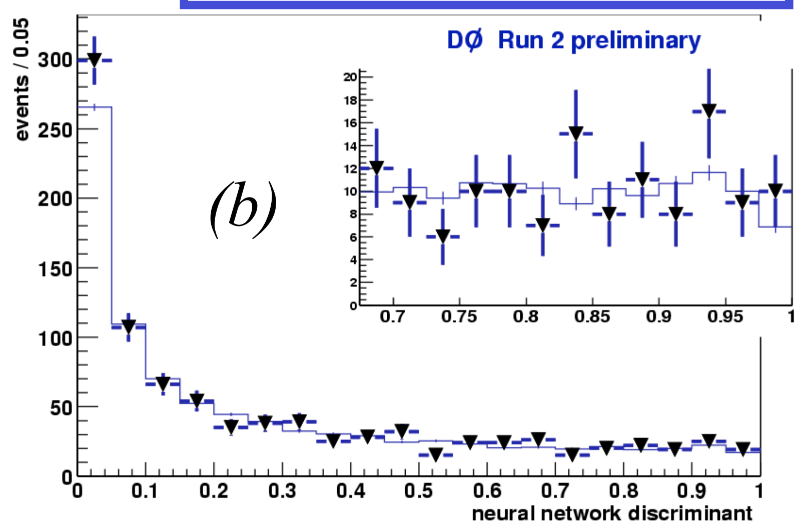
First Run II look at the all jets channel

- Challenging signature: very low S/B!
  → cross section & mass measured in RunI (CDF,D0)
- Best tools needed:
  kinematical quantities, neural networks, b-tagging algorithms
  •Currently considered very difficult/impossible at LHC…

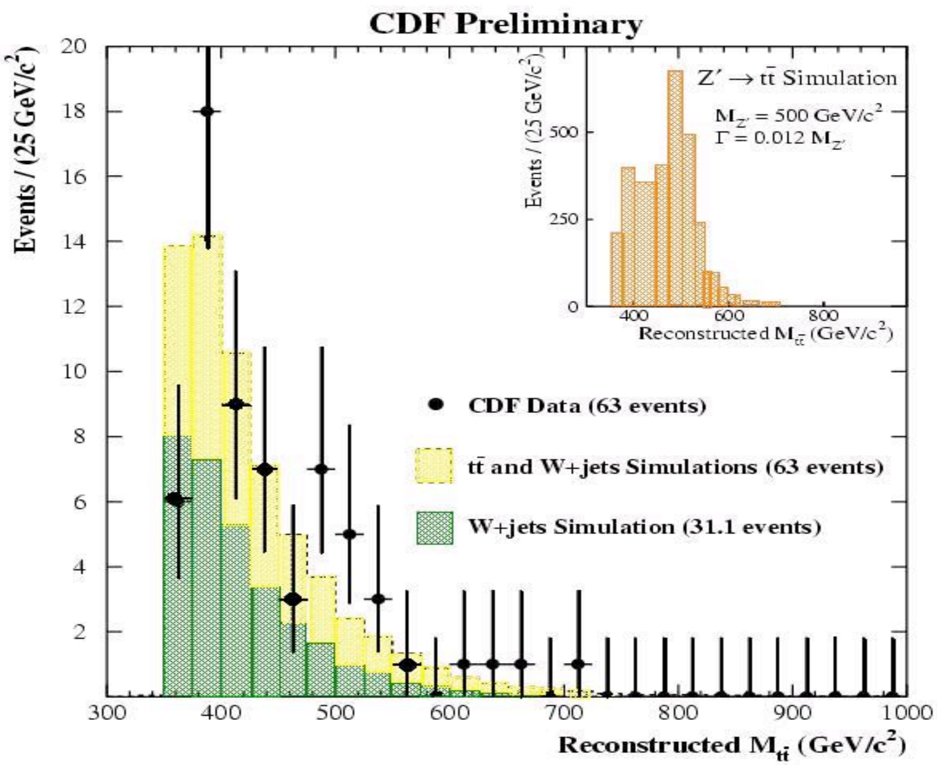
D0 Run I all hadronic channel

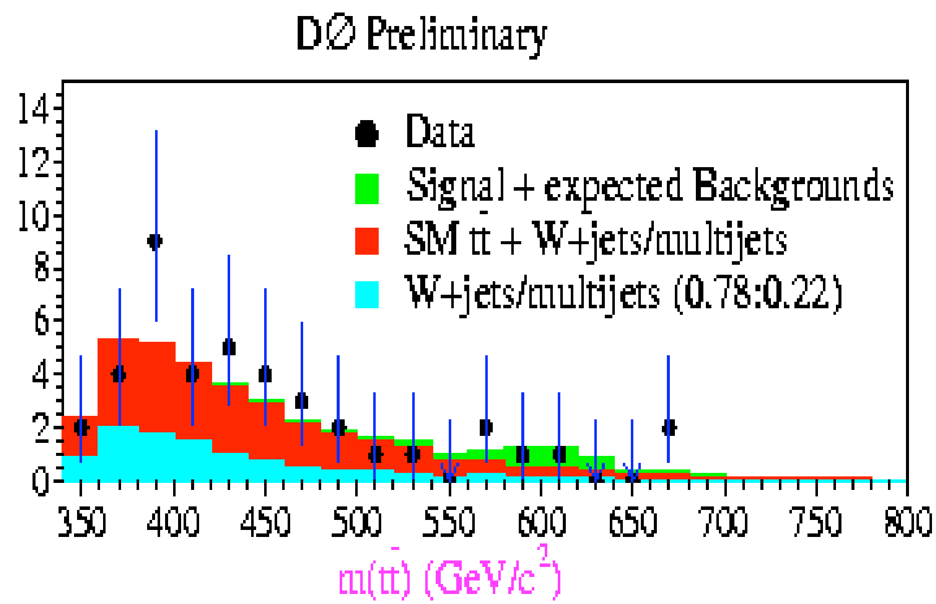


Luminosity 80.7 pb^{-1}
 # Selected events : 78
Expected Bkg. : 68.0±1.6



Test for new physics in $t\bar{t}$ production

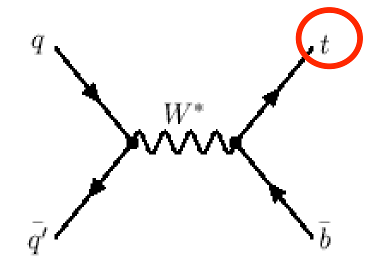




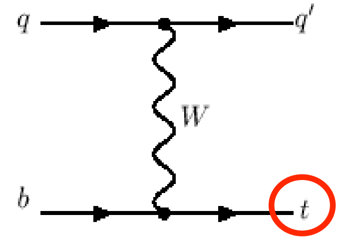
Model independent search for a narrow resonance X→tt exclude a narrow, leptophobic X boson with m_X < 560 GeV/c^2 (CDF) and m_X < 585 GeV/c^2 (D0)

Single Top Physics

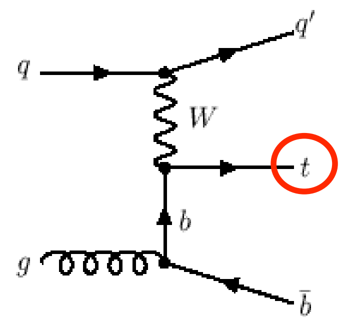
- Production cross section about _ of tt
  - Same signature as SM Higgs associated production:
    - o W+2 jets bin!
  - Single top samples have less objects in the final state:
    - o larger background



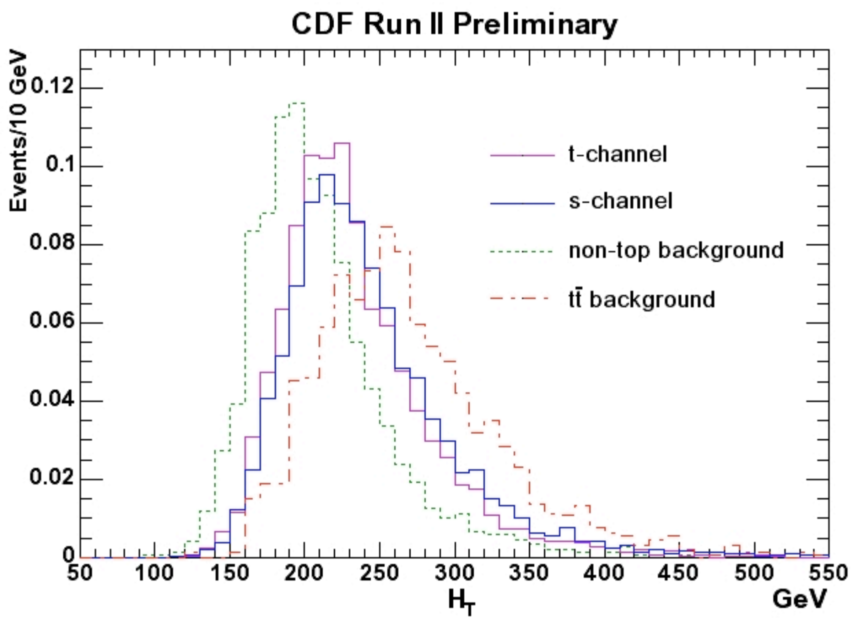
(a)



(b)



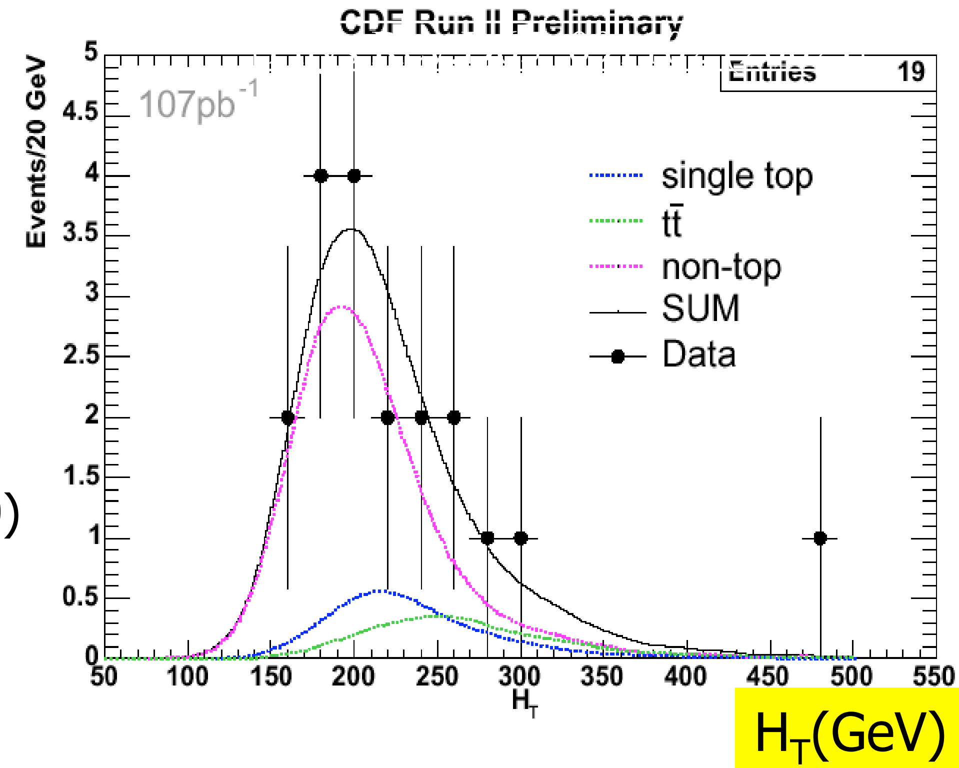
(c)



Uncertainty	$2fb^{-1}$
□□ (tbX)	26%
□□ (t□ Wb)	28%
□|V_{tb}|	14%

Search for Single top in Run II

- Main measurements: production cross section(s)→ V_{tb}, mass:
  - Two production modes, different sensitivities to new physics:
    - t-channel:anomalous couplings, FCNC
    - s-channel: new charged gauge bosons
- In Run I a separate search (CDF,D0) and combined (CDF) have been performed
  - Same method is applied in RunII for these preliminary results:



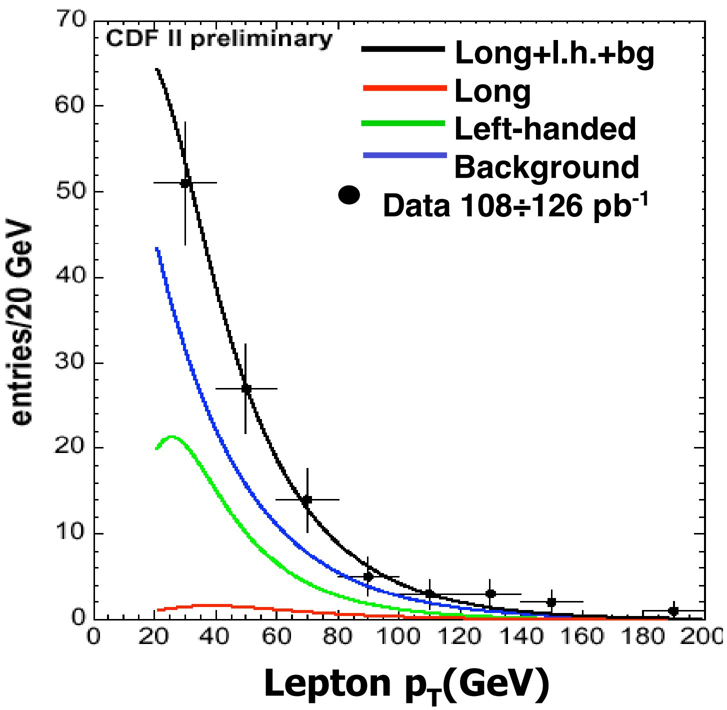
σ_t(t-channel)<15.4pb @95% C.L.

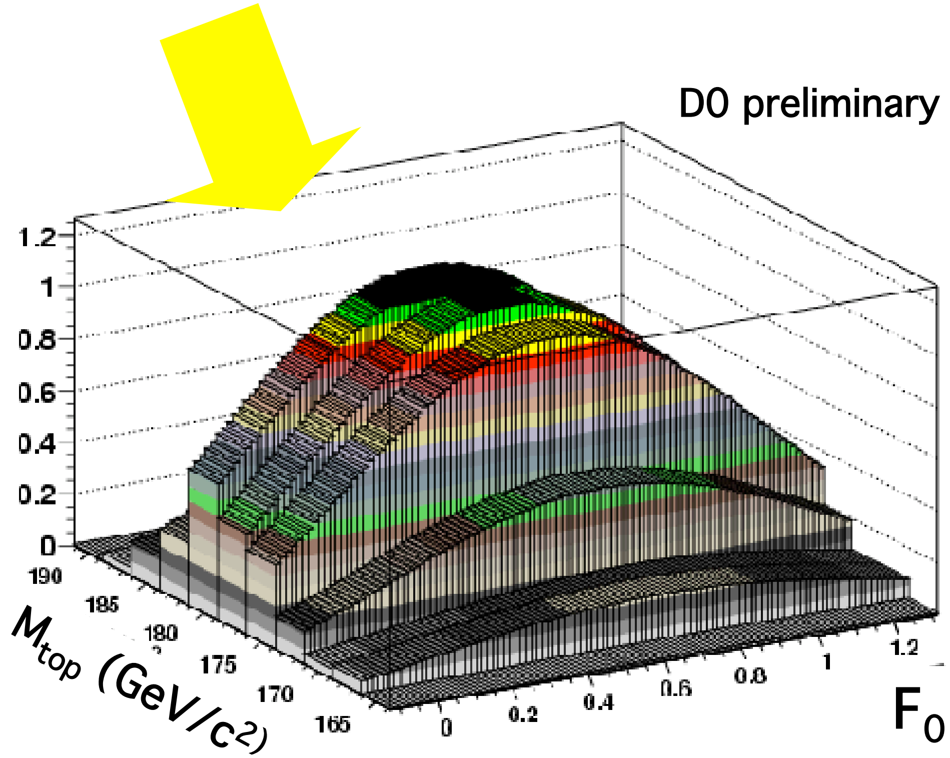
σ_t(combined)<17.5pb @95% C.L.

W helicity in top decays

- Top Mass is LARGE: top is produced and decays free:
  - The helicity information is preserved and reflected in several kinematical quantities (W lepton p_T or M(lb))
  - F_0 is naturally included in the ME calculation (SM prediction: F_0=0.70):
    - New Run I measurement from D0 with better statistical power:

F_0= 0.56 ± 0.31(stat)±0.04(syst)



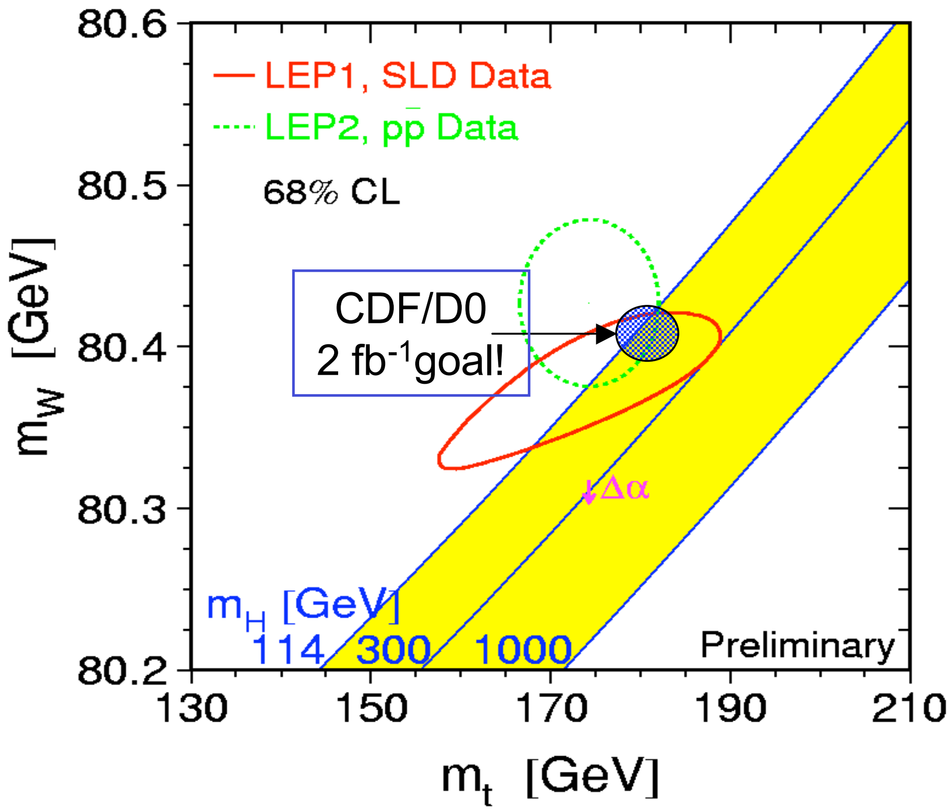


Top Mass

- **Top Mass:** Fundamental SM parameter
  - needed to determine ttH coupling
  - important in radiative corrections:

  constrain M_h/M_h to 35% in RunII

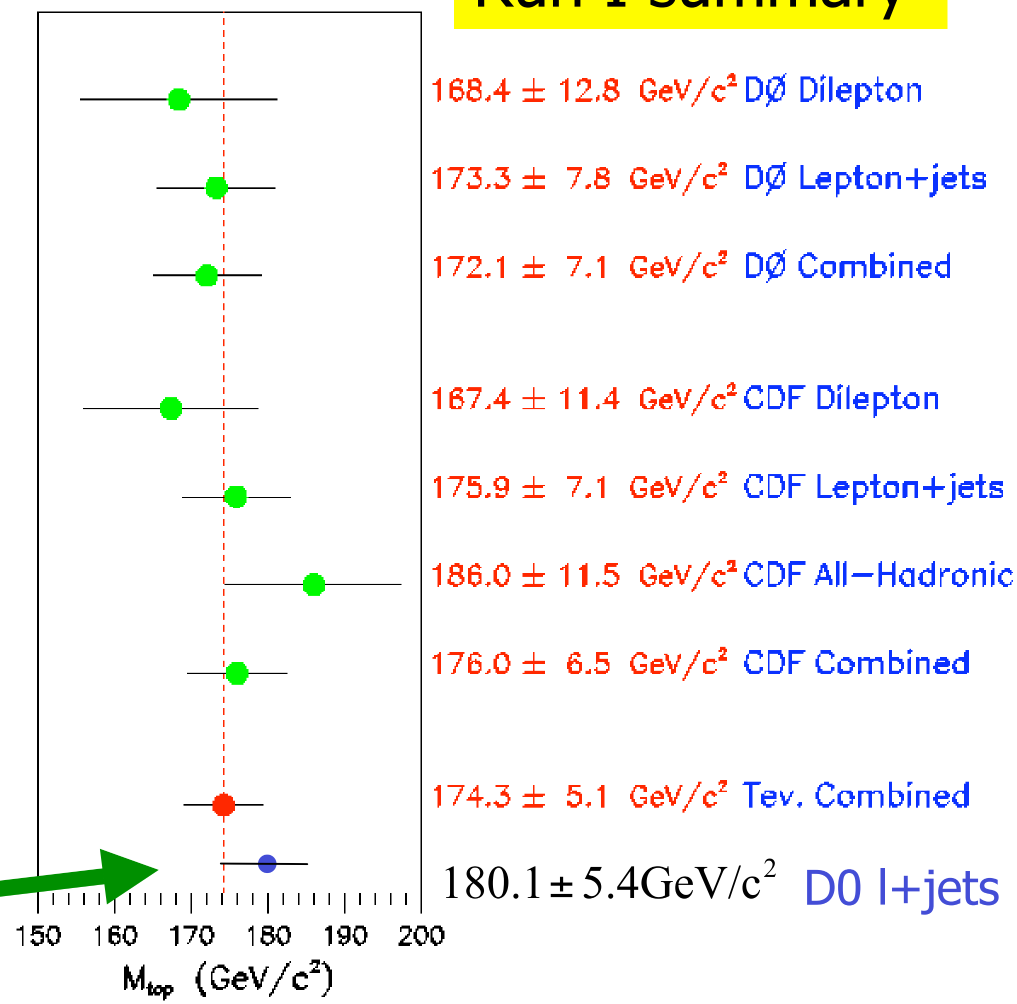
- Experimental handles:
  - B tagging: reduce background & combinatorial
  - Data driven systematics scale with 1/ N (energy scale, gluon radiation)



Top Mass Measurement

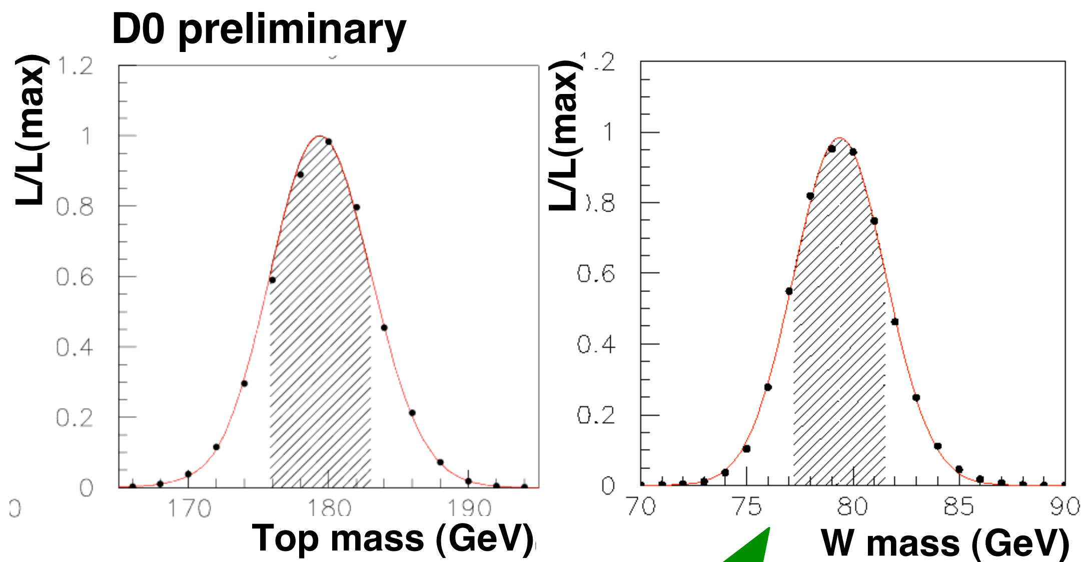
- Template method:
  - Kinematic fit under the tt hypotesis
  - Combinatorial issues
  - best χ^2 combination chosen
  - Likelihood fit
- Dynamical method:
  - Event probability of being signal or background as a function of m(t)
  - Better use of event information → increase statistical power
  - Well measured events contribute more
    - New D0 Run I result: factor 2.5 improvement on the statistical uncertainty!

Run I summary



Handles for a precision measurement

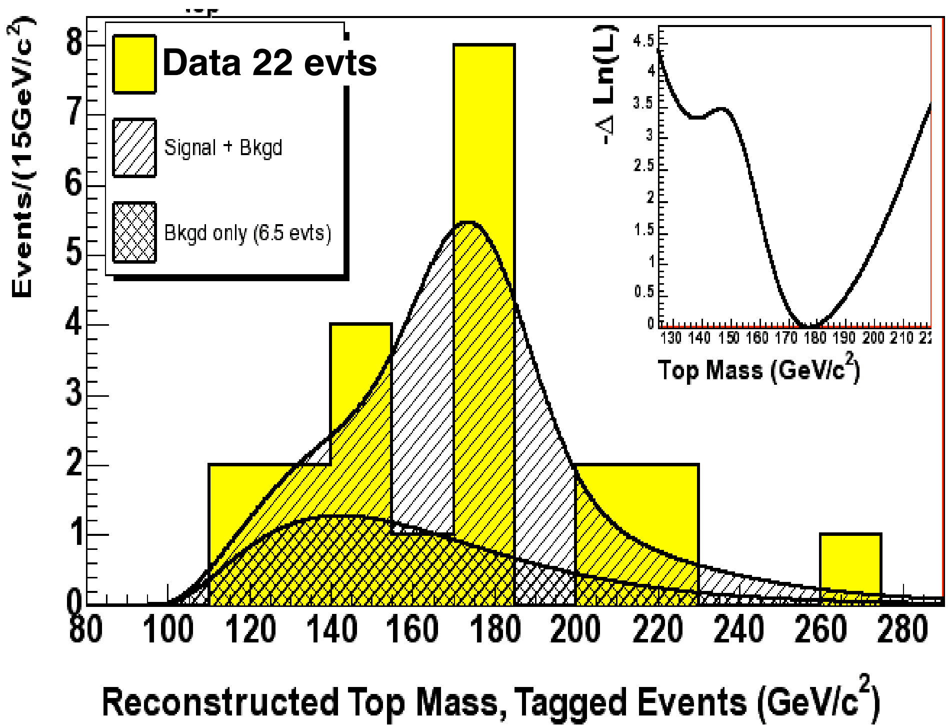
A precise measurement of the top mass combines cutting edge theoretical knowledge with state of the art detector calibration



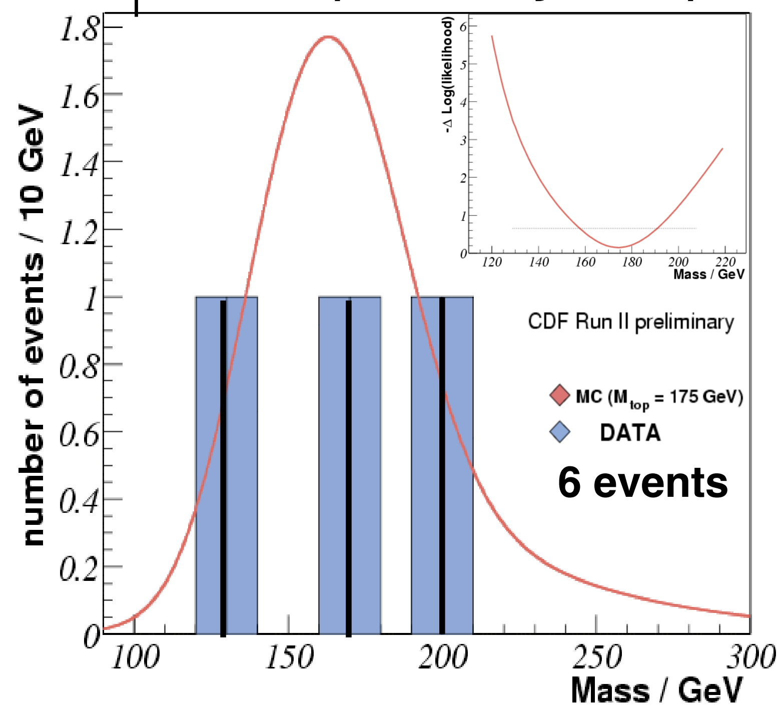
- Jet energy scale
  - gamma-jet balancing: basic in situ calibration tool
  - Z+jet balancing: interesting with large statistics
  - Hadronic W mass: calibration tool in tt double tagged events
  - Z→bb mass: calibration line for b-jets, dedicated trigger
- Theory/MC Generators: understand ISR/FSR, PDF's
- Simulation: accurate detector modeling
- Fit methodology: how to optimally use event information
- Event selection: large statistic will allow to pick best measured events

First look at top mass in Run II

CDF RunII preliminary, 108 pb^{-1}



CDF RunII preliminary, 126 pb^{-1}



Mass in lepton+jets channel with a b-tagged jet

$$177.5^{+12.7}_{-9.4}\,(\mathrm{stat}) \pm 7.1\,(\mathrm{syst})\quad \mathrm{GeV/c^2}$$

Mass in dilepton channel

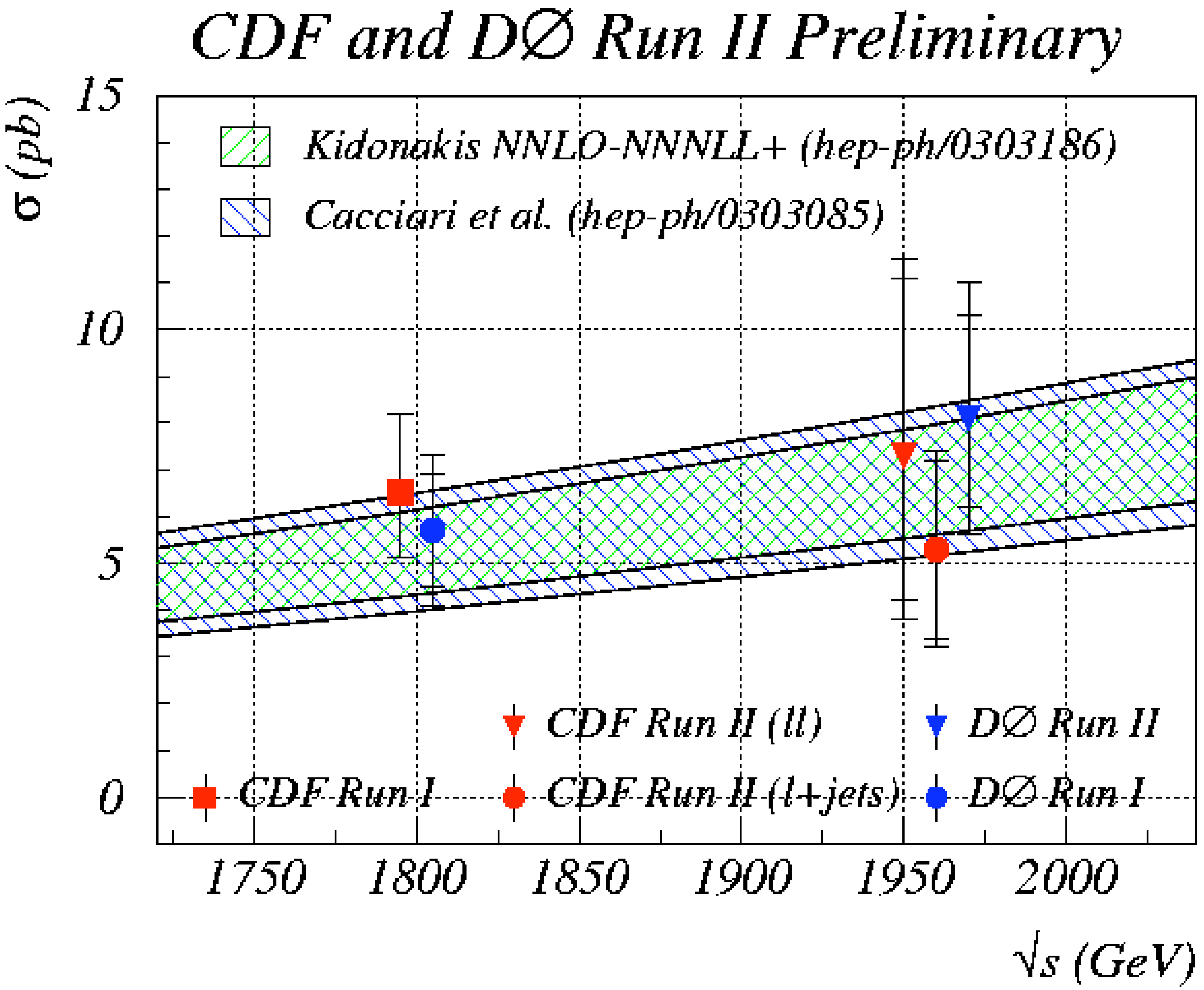
$$175.0^{+17.4}_{-16.9}\,(\mathrm{stat}) \pm 7.9\,(\mathrm{syst})\ \mathrm{GeV/c^2}$$

Conclusions

- Top quark existence established at the Tevatron in 1995
- Several top properties studied using Run I data
  - limited statistic
- The Tevatron is the top quark factory until LHC:
  - Run II ~50 times Run I statistics → precision measurements
  - Constraints on the SM Higgs boson mass and SM consistency
  - …or surprises?
  - First Run II results cover a variety of channels and topics
  - CDF and D0 are exploiting their upgraded detector features

A very rich top physics program is underway:

let's see what the top quark can do for us!



to be continued…