Top quark pair production cross section at E_{cm}=1.96 TeV

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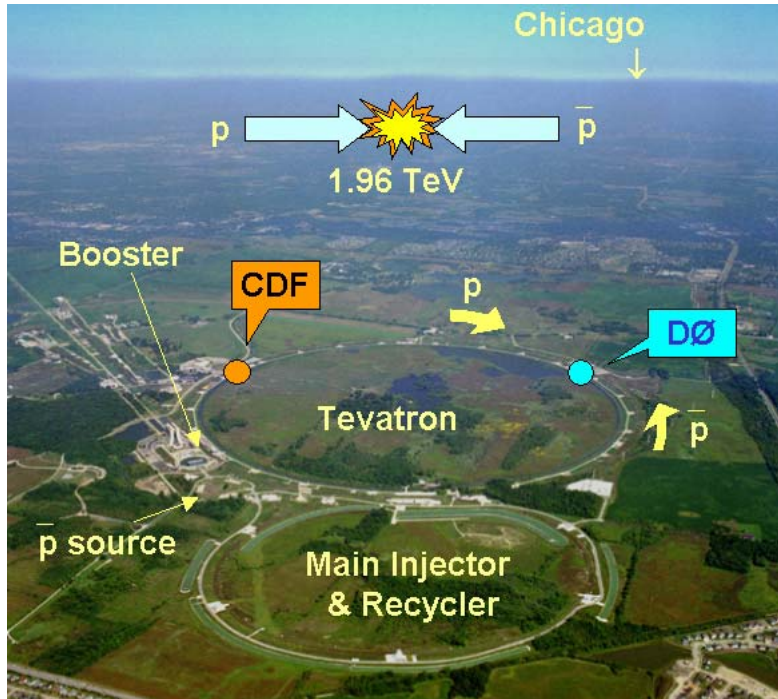
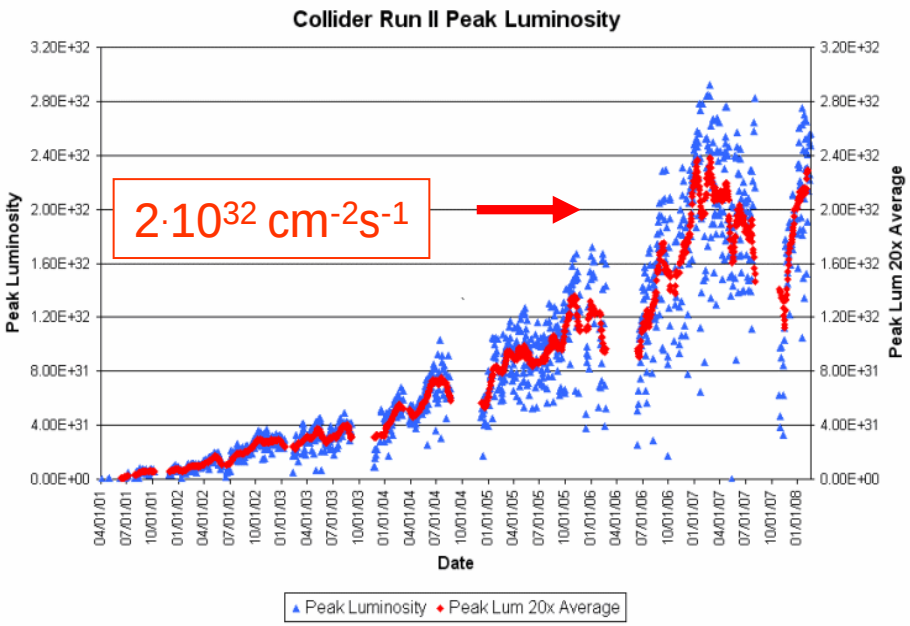
On behalf of CDF and D0 collaborations

Outline:

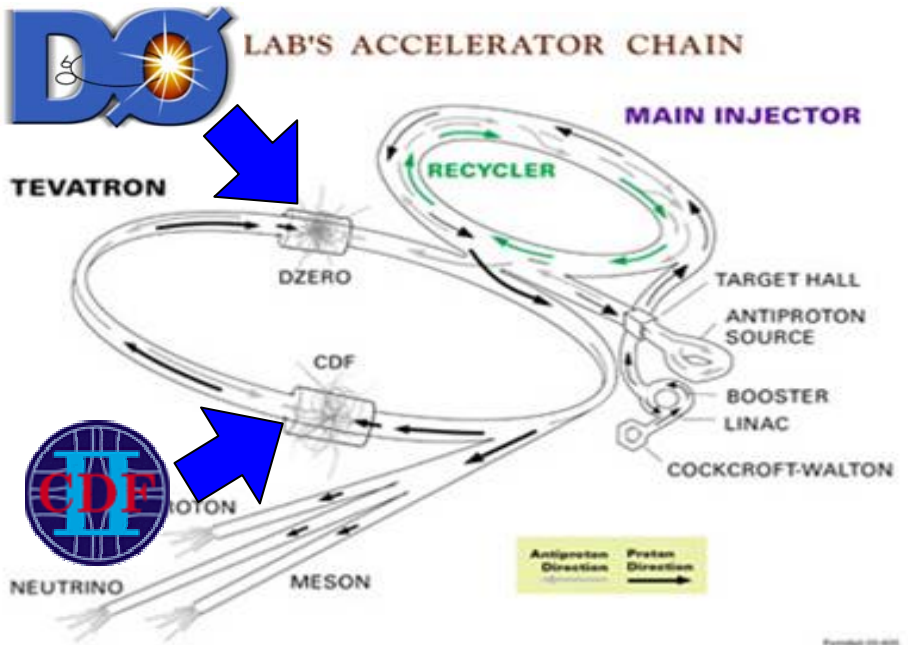
- Tevatron complex overview
- Top quark pair production and decays
- Cross section measurements and some related properties
- Conclusions

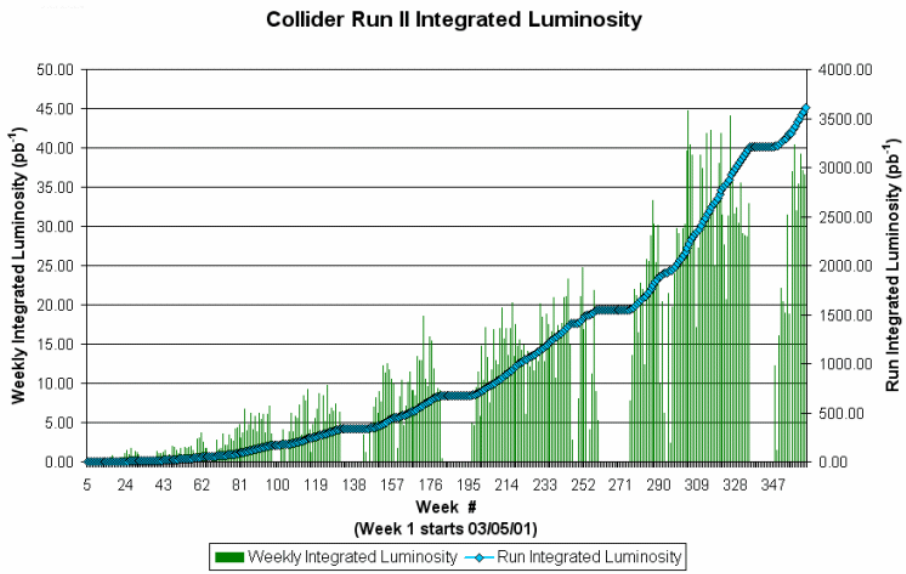


CDF/D0 and Tevatron overview

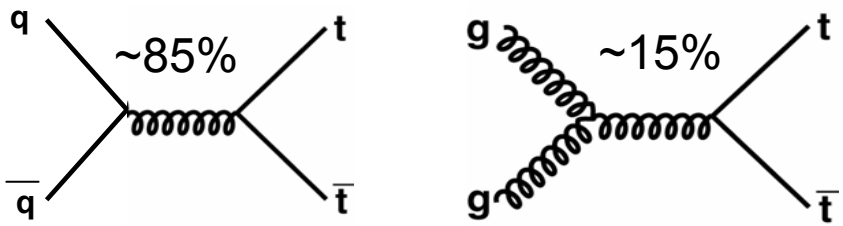


- CDF and D0 are a multi purpose detectors
- **Tevatron: ppbar interactions @ √s=1.96 TeV.**
- Accelerator performances are steadly increasing since 2001.
- Record Luminosity: 292x10^{30}cm^{-2}s^{-1}
- **3.5 fb^{-1}delivered so far**
  6-8 fb^{-1} expected for the Run II end.





The top quark:



@ 1.96 TeV

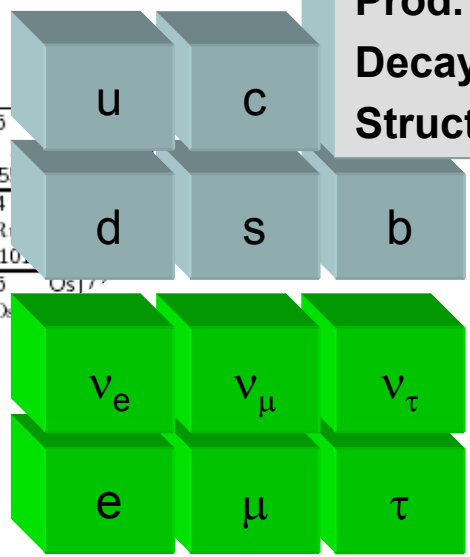
1st quark	3rd generation
Symbol	t
Mass	172.6 ± 1.4 GeV/c²
	185.3 u
Charge	+2/3 e
Prod. Energy	p-pbar @ 1.96 TeV
Prod. Mecc.	gg (~15%), qq (~85%)
Decay	~100% Wb
Structure	Elementary

PERIODIC TABLE OF THE ELEMENTS

1 IA																	2 IIA
1 H Hydrogen 1.00794																	2 He Helium 4.002602
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB		8	9	10	11 IB	12 IIB	13 Al Aluminum 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26										
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybd. 95.9	43 Tc Technet. (97.9072)	44										
55 Cs Cesium 132.9054519	56 Ba Barium 137.327	57–71 Lantha-nides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74	75 Re	76										
87 Fr Francium (223.0197)	88 Ra Radium (226.0254)	89–103 Actinides	104 Rf Rutherford. (267.1215)	105 Db Dubnium (268.1255)	106 Sg Seaborg	107											

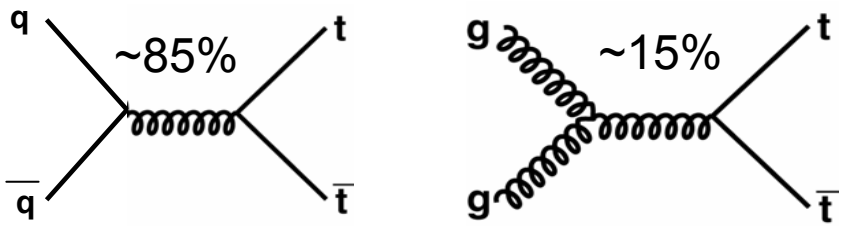
Lanthanide series: 57 La Lanthan. 138 | 58

Actinide

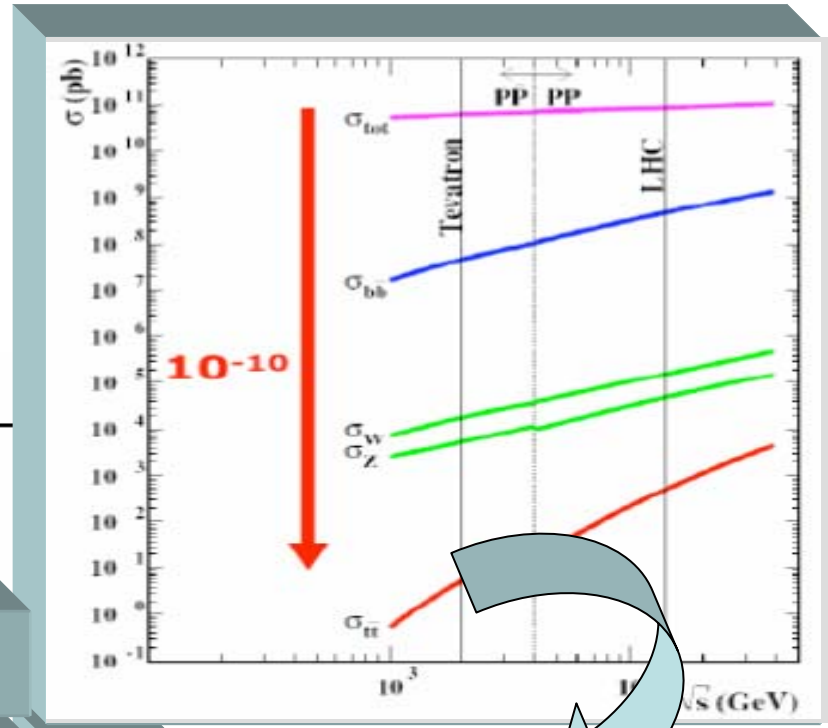


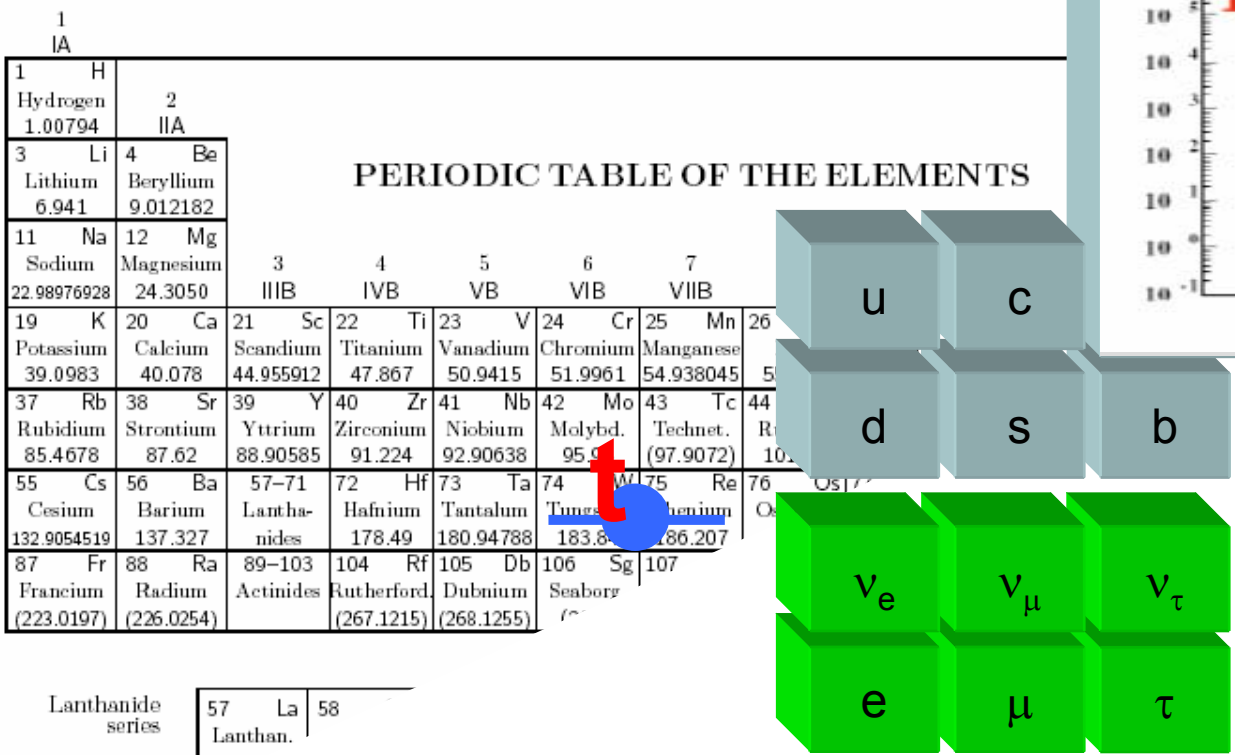
1 u ≈ 1.660538782(83) × 10^{-27} kg ≈ 931.494028(23) MeV/c²

The top quark:



@ 1.96 TeV





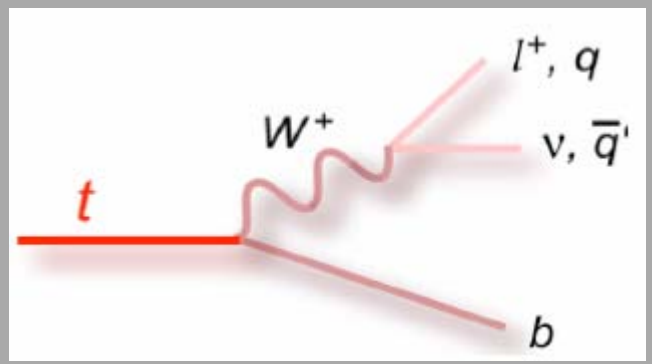
$\sigma_{tt}(175.0\ \text{GeV}/c^2) = 6.7\ ^{+0.7}_{-0.9}\ \text{pb}$

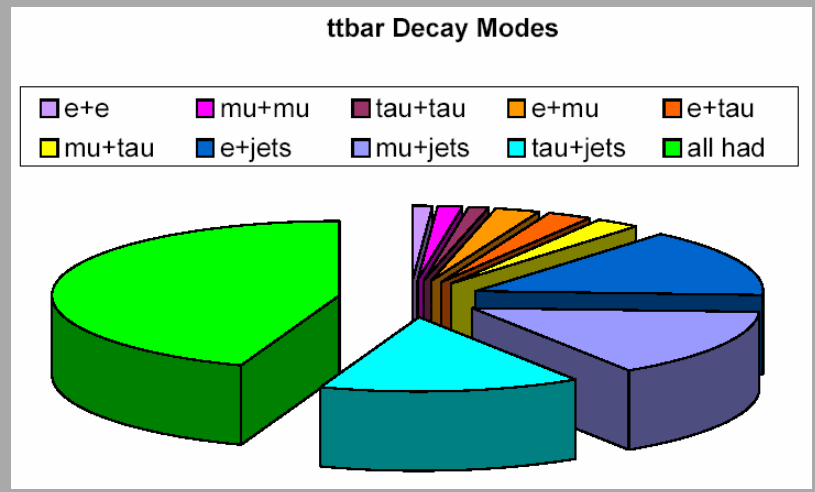
$m_t = 175\ \text{GeV}/c^2$
assumed in this talk

1 u ≈ 1.660538782(83) × 10^{-27} kg ≈ 931.494028(23) MeV/c^2

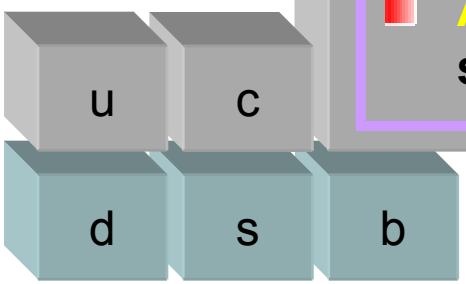
The top quark pair signatures:

BR(t→Wb)~100%



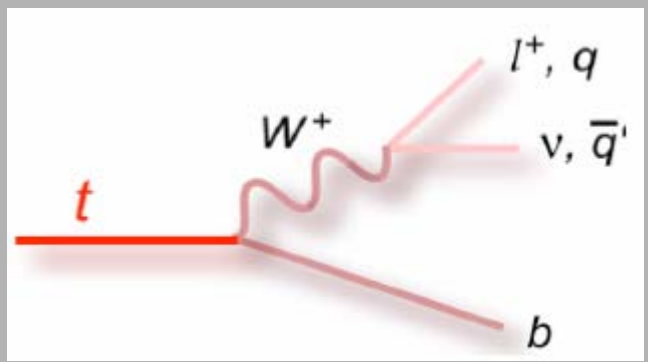


- **Dilepton:** **BR = 11% (ee/eμ/μμ only = 5%) clean sample, lowest statistics**
- **Lepton+jets: BR = 44% (e/μ + jets = 29%) golden channel w/ high statistics and good S/B**
- **All-Hadronic: BR = 44% most challenging channel w/ high statistics but large backgrounds**



The top quark pair cross section measurements

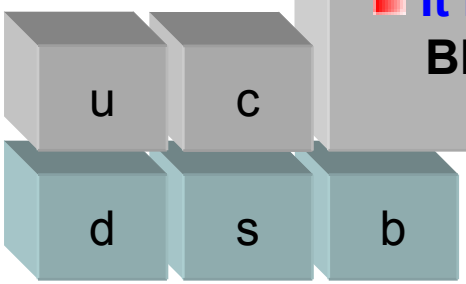
$$\sigma(p\bar{p} \to t\bar{t}) = \frac{N_{obs} - N_{bkg}}{A_{tot} \int Ldt}$$



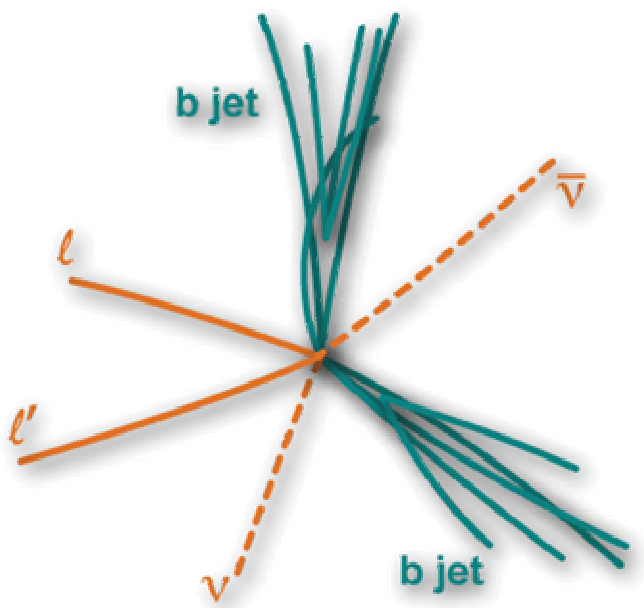
- **Important test of QCD calculations**
  Probe towards new production processes (like resonant prod, Z'/G)

- **It is measured in different decay channels**
  Exotic top decays (i.e. $t \to H^+b$) could modify contribution for different modes
  L+jets/Dilepton x-sec ratio is sensitive to non-W top decays.

- **It is measured using different methods**, to check BR(t→Wb)~100% assumption.



Dilepton channel



Basic Signature:

- 2 high-P_T leptons e/μ (or lepton+track) p_T>15 GeV/c
- Missing E_T > 20÷ 30 GeV pointing away from other objects
- 2 high-E_T jets (can be required to be b-jets) E_T> 15 ÷ 20 GeV

Main Physics Backgrounds (from MC)

- Z/γ+jets
- WW/ZW/ZZ +jets

Analyses: dilepton, lepton+isolated track both w/ and w/o b-tag

Instrumental backgrounds (from data)

- mis-identified isolated leptons (from bad reconstructed jets)
- missing E_T from detector resolution or jet energy mis-measurements.
- (mis-identified b-jets)

Main systematics: lepton-id, JES, BGK/MC normalization and b-tag

Dilepton

combination of dilepton and lepton+track

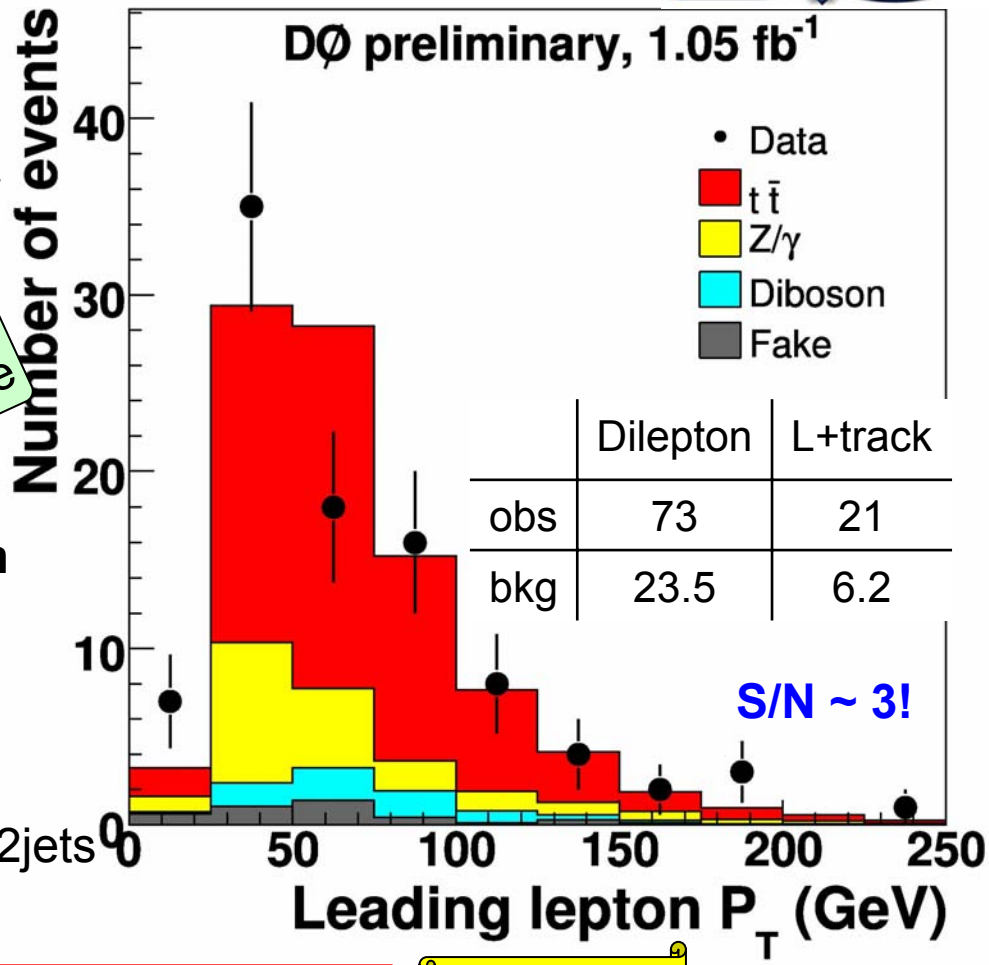
Two well reconstructed leptons:

- + selections on sphericity, Z fit, H_T
- 4 independent channels:
  ee, μμ, e/μ + 1/2jets

+ 30% acceptance

Lepton+isolated tracks:

- **Relax 2nd lepton identification to a isolated track**
  - increase acceptance also for τ decays
- **1 b-tag** (D0NN cut at 0.65)
- 4 independent channels, e/μ+1/2jets



	Dilepton	L+track
obs	73	21
bkg	23.5	6.2

S/N ~ 3!

combined: σ = 6.2 ± 0.9(stat) ± 0.7(syst) ± 0.5(lumi) pb

Δσ/σ~19%

Δσ/σ~20%

CDF dilepton (1.2 fb^{-1})
σ = 6.2±1.0±0.7±0.4 pb

Δσ/σ~18%

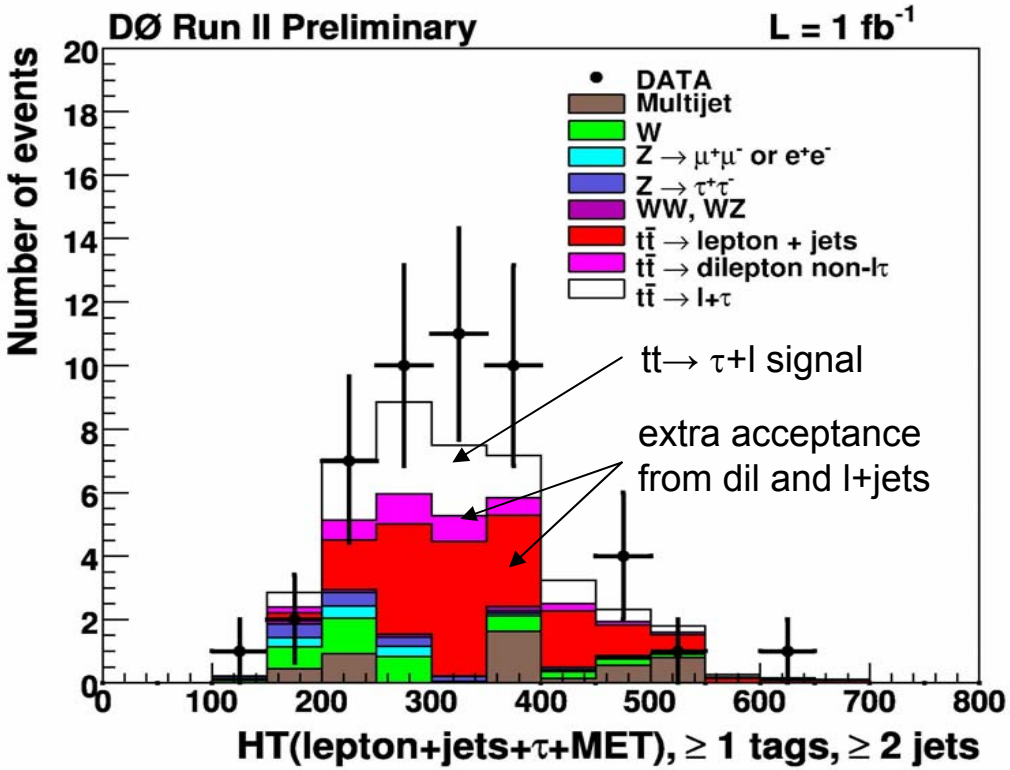
CDF L+track (1.1 fb^{-1}):
σ = 8.3 ±1.3±0.7±0.5 pb

Δσ/σ~22%

CDF L+Track + btag (1/fb)
σ = 10.1±1.8±1.1± 0.6 pb.

Dilepton e/μ + τ

Important to look for effects beyond the SM (t→H⁺b→τνb)



- only 1 well identified **e or μ**
- 1 τ candidate from **NN$_\tau$ output:** (N_{trk}, cluster size, isolation, track-calorimeter correlation)
- **≥ 1 b-tag**

Cross section measured in eτ + μτ combined:
(extra acceptance from l+jets and dil)

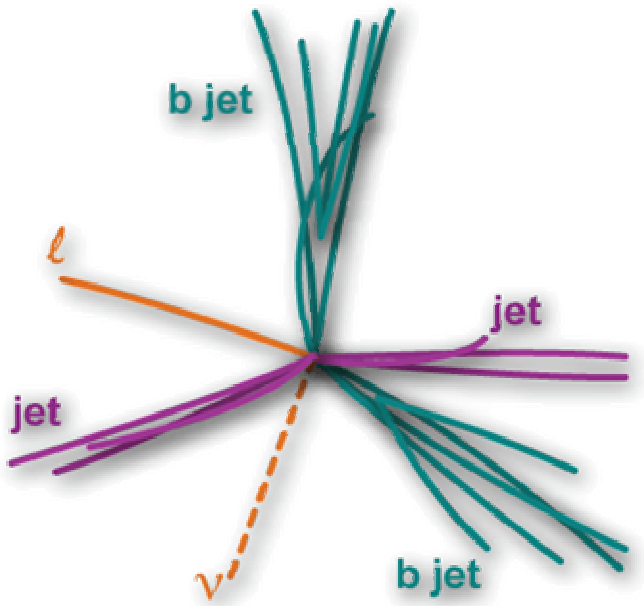
$$\sigma = 8.3\ ^{+2.0}_{-1.8}\ ^{+1.4}_{-1.2} \pm 0.5\ \text{pb}$$

	Measured (pb)	SM expect (pb)
σ*BR(tt→e+τ+2ν+2b)	$0.19^{+0.12}_{-0.10}$(stat) ± 0.07(syst)	0.13
σ*BR(tt→μ+τ+2ν+2b)	$0.18^{+0.13}_{-0.11}$(stat) ± 0.09(syst)	0.12

(extra acceptance from tt in l+jets and dilepton are treated as bkg!)

Lepton+jets channel

widely used for top quark properties determination



Basic Signature:

- **1 high-P_T lepton (P_T> 20 GeV/c)**
- **Missing E_T > 20÷30 GeV**
- **≥3 high-E_T jets (2 can be required to be b-jets) (E_T> 15÷20 GeV)**

Analyses: **w/ and w/o b-tag**

Physics Backgrounds (estimated from data and MC):

- **W+jets**
- **Z→ττ, Single top, diboson**

Instrumental backgrounds (estimated from data)

- **Mis-identified isolated lepton (from bad reconstructed jets)**
- **Missing E_T from detector resolution or jet energy mis-measurements.**
- **Mis-identified b-jets.**

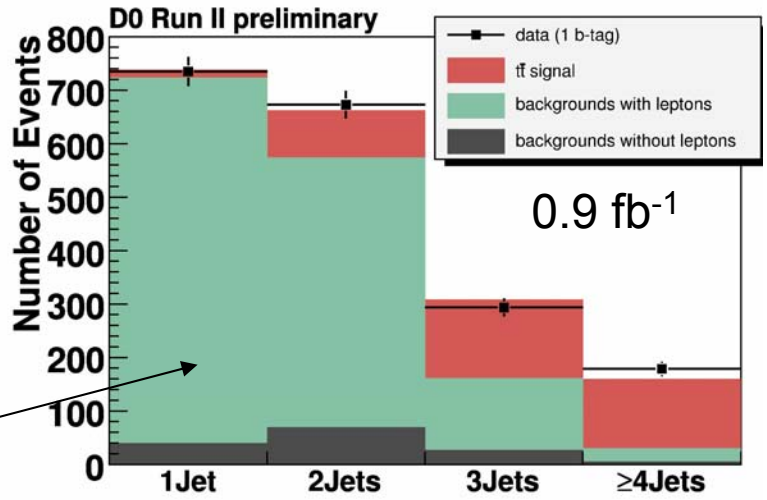
Main systematics: lepton-id, JES, BGK/MC normalization and b-tag

Lepton+jets

Combination of complementary measurement:

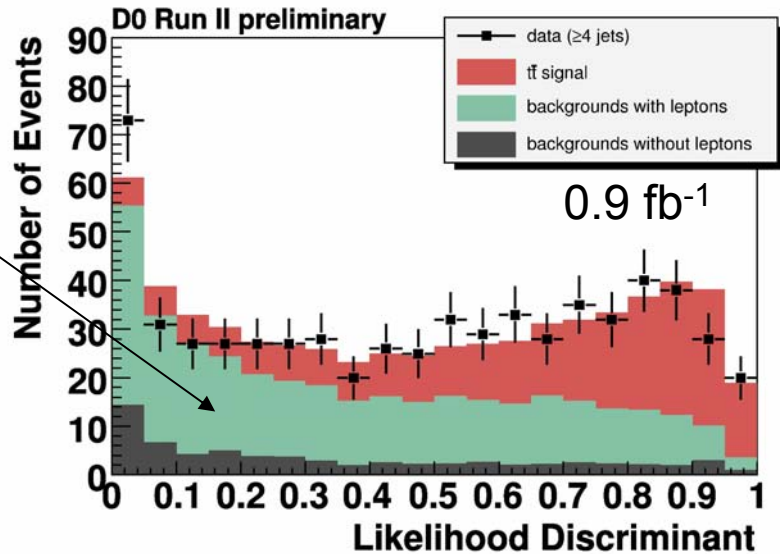
- **NN-b-tag:** 8 channels (e/μ, 3/≥4 jets, 1/≥2 tags)
  - 1 jet bin used for bkg cross check

σ_{tt}= 8.05 ± 0.54(stat) ±0.70 (syst) ± 0.49 (lum) pb



- **topological discriminant**: (e/μ, 3/≥4 jets)
  combining geometry- and energy-related vars
  ($\Delta R_{jj/jl}$, $\Delta\phi_{l/j,met}$, H_T, aplanarity and sphericity)
  - Independent from b-tagging, and BR(t→Wb) assumption

σ_{tt}= 6.62 ± 0.78(stat) ± 0.36 (syst) ± 0.4 (lum) pb



Combined: σ_{tt}= 7.42 ±0.53(stat) ± 0.46(syst) ± 0.45(lumi) pb

In the same dataset, simultaneous

$$R = \frac{B(t \to Wb)}{B(t \to Wq)} = 0.97^{+0.09}_{-0.08}(stat + syst)$$

$$\sigma_{tt} = 8.18^{+0.90}_{-0.84}(stat + syst) \pm 0.5(lumi)\, pb$$

$\Delta\sigma/\sigma$~10%

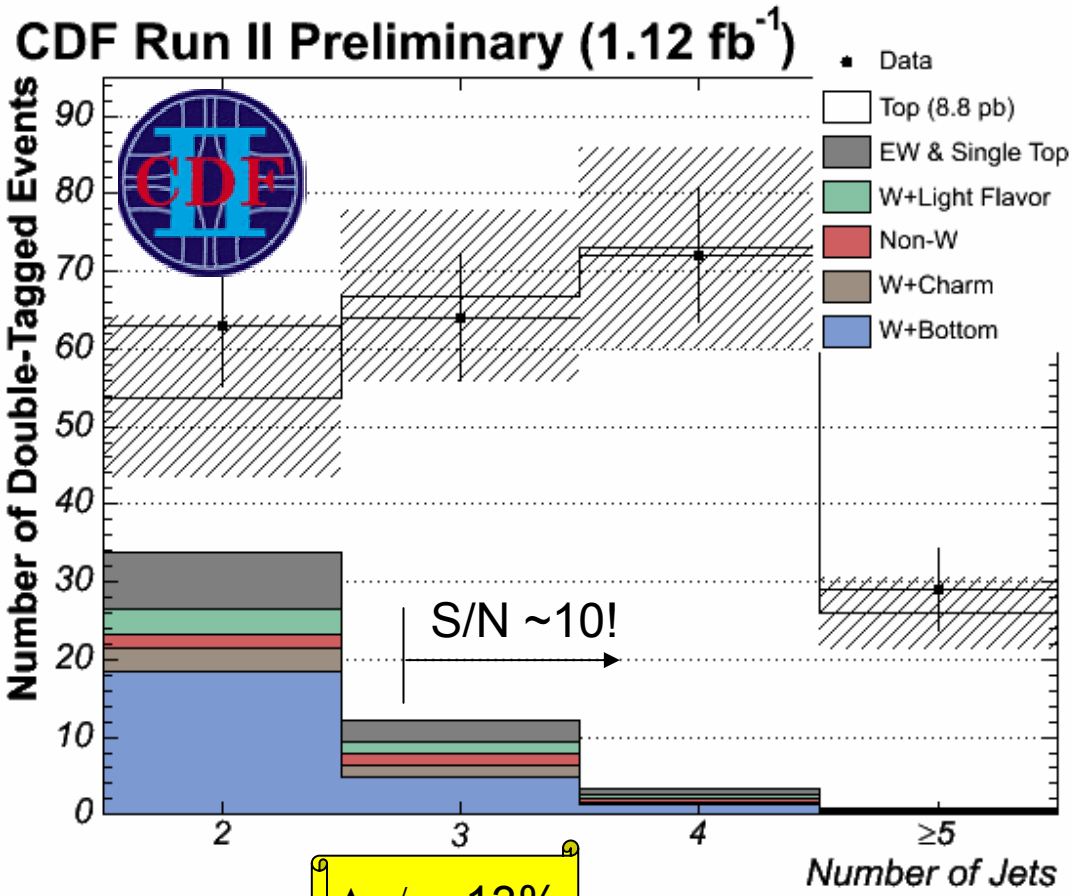
Lepton+jets

Core L+J event selection:

- + H_T > 250 GeV (200 for 2 btags)

- **b-tag: ≥1/**≥2 b-tags (tight + loose) as cross check.

For double tagged events, S/N ratio better than in standard dilepton analyses!



$\sigma_{\geq 1tag}$ = 8.2 ± 0.5 (stat) ± 0.8 (syst) ± 0.5 (lum) pb — Δσ/σ~13%

$\sigma_{\geq 2tag}$ = 8.8 $^{+0.8}_{-0.7}$ (stat) ± 1.2 (syst) ± 0.5 (lum) pb — Δσ/σ~17%

Other measurements from CDF

- **topological discriminant:**
  σ_{tt} = 6.0 ± 0.6 (stat) ± 0.9 (syst) pb (760 pb^{-1})

- **Secondary vertex and NN btag :**
  σ_{tt} = 8.5 ± 0.6 (stat) ± 1.0 (syst) pb (700 pb^{-1})

All-hadronic:

Basic Signature:

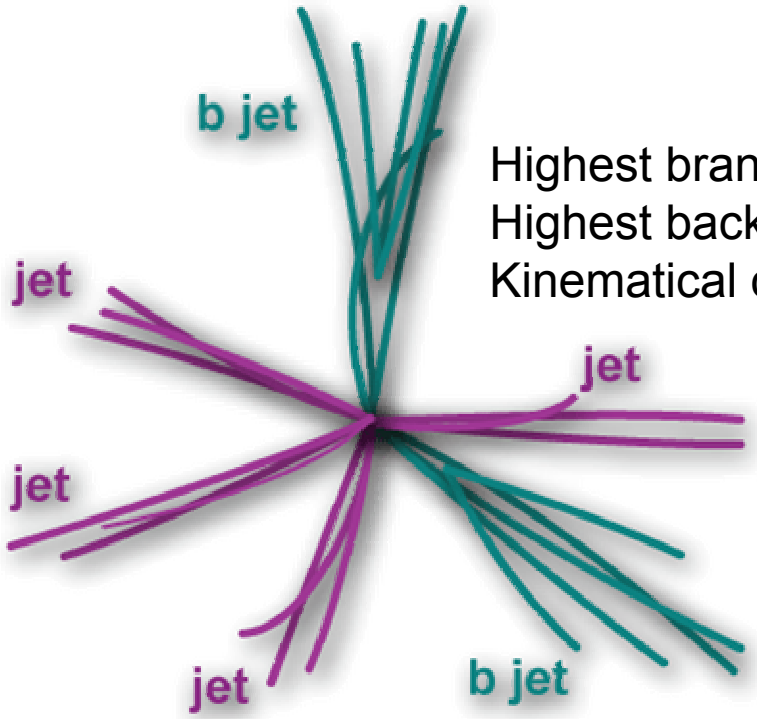
- **6 or more high-E_T jets**
- **2 of which from b-quarks**

Main Physics Backgrounds:

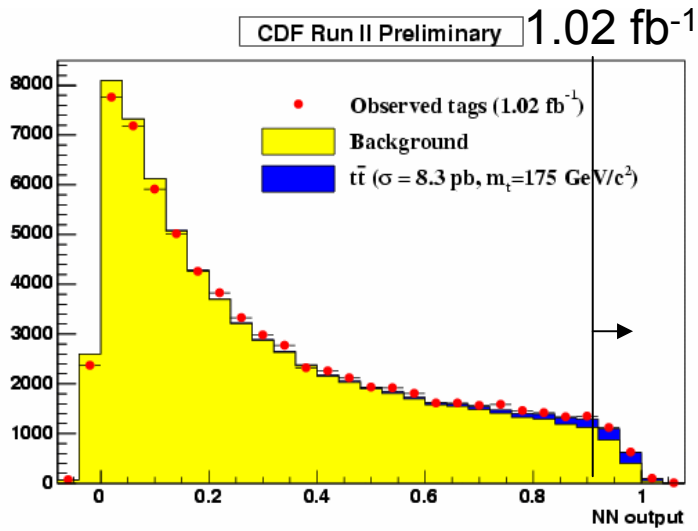
- **QCD multijet production**

Instrumental backgrounds

- **mis-identified b-jets.**



Highest branching fraction
Highest background
Kinematical overconstrained



NN with 11 kin vars: $\varepsilon_{NN>0.94}$ = 4.8%; S/B~1/16
With at least 1 btag S/N = 1/2.2
Main systematics jet energy scale ~16%.

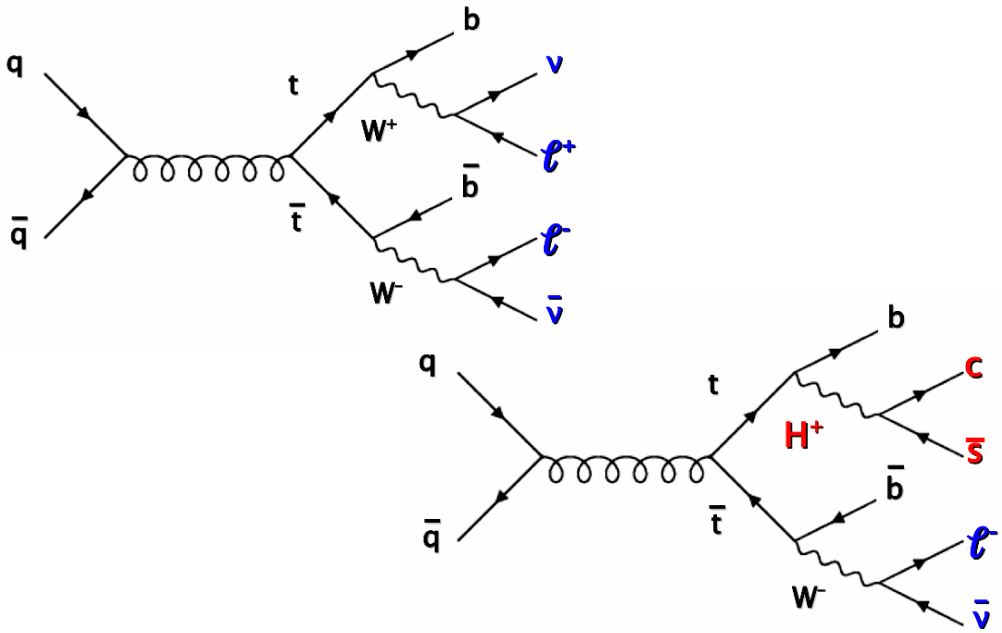
σ_{tt}= **8.3 ± 1.0 (stat) $^{+2.0}_{-1.5}$ (syst) ± 0.5 (lum) pb**

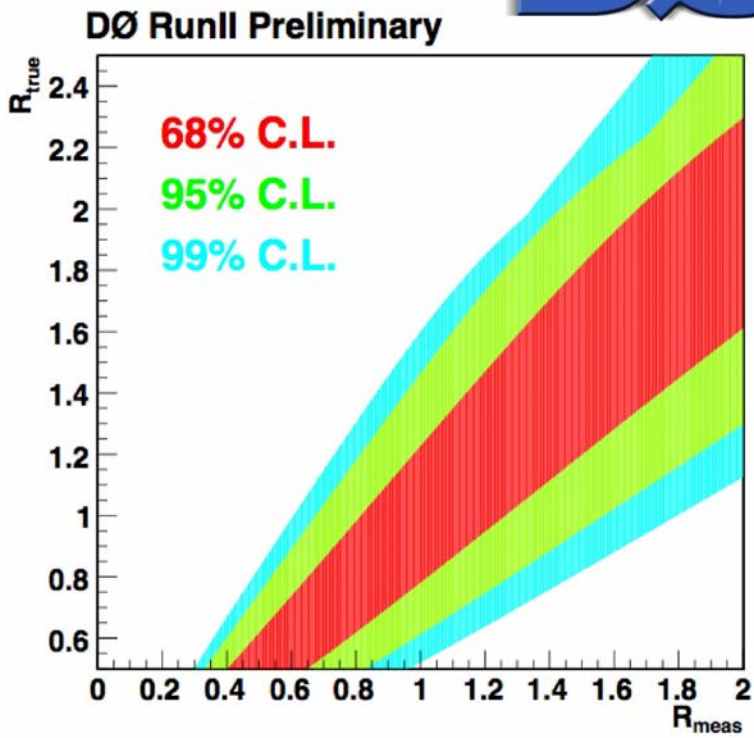
$\Delta\sigma/\sigma$~25%

D0: $\sigma_{tt} = 4.5\ ^{+2.0}_{-1.9}$ (stat) $^{+1.4}_{-1.1}$ (syst) ± 0.3 (lumi) pb (410 pb^{-1})

Decays top as expected?

Cross section ratio (l+jets/dil):
Sensitivity to W boson disappearance due to B(t→Xb)>0.





top quark pair decays involving charged Higgs could enhance the observed l+jets cross section while lowering the dilepton one

$$R_\sigma = \frac{\sigma(p\bar{p} \to t\bar{t})_{l+jets}}{\sigma(p\bar{p} \to t\bar{t})_{ll}} = 1.21^{+0.27}_{-0.26}(tot)$$

for $t \to H^+b \to csb$, and $m_{H^+} \sim 80$ GeV/c^2:

$B(t \to H^+b) < 0.35$ @ 95% C.L.

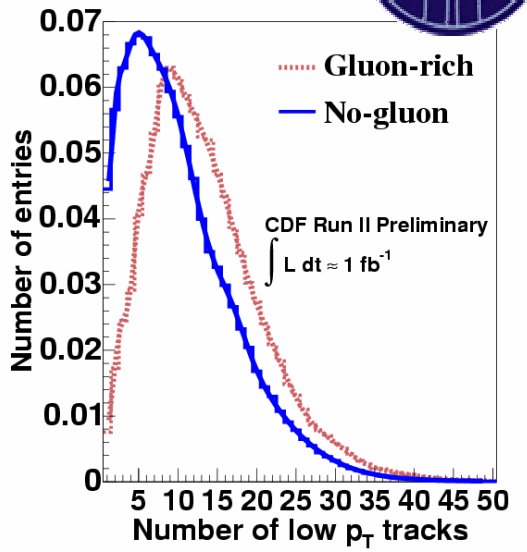
Is top produced as expected?

Measurement of relative fraction of gg fusion processes:

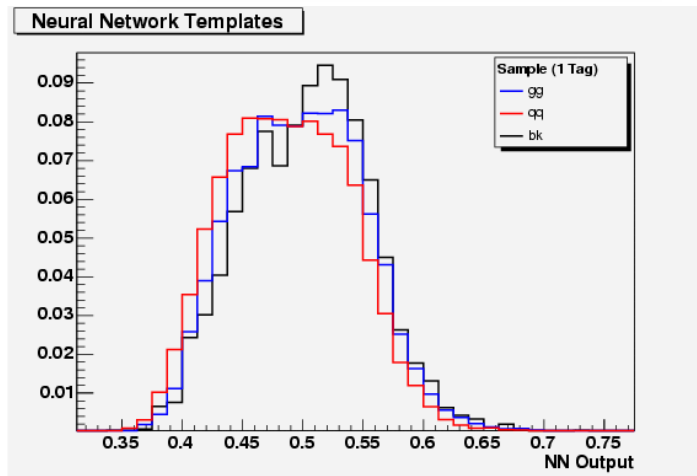
$$F_{GG} = \frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})}$$

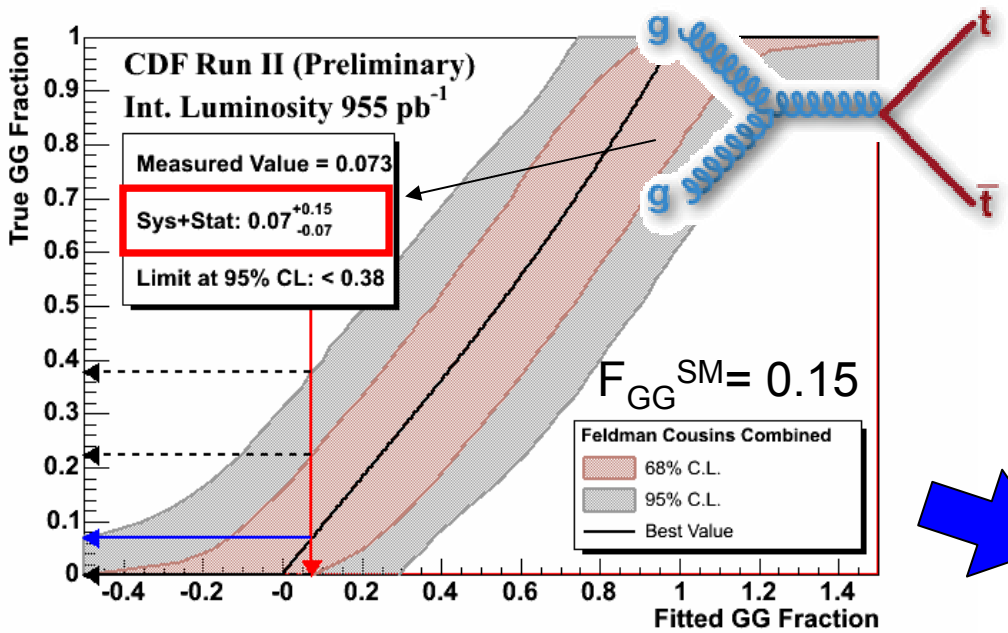
Combination of two methods:

- Low p_T tracks
  (gluons radiates more than quarks)



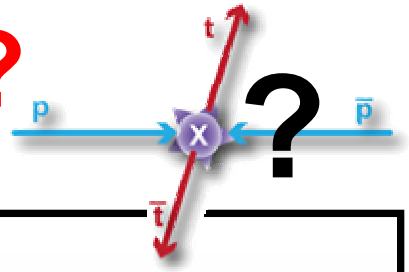
- Kinematical vars from gg and qq in NN training
  (gg produce unlike spin and forward top pairs)





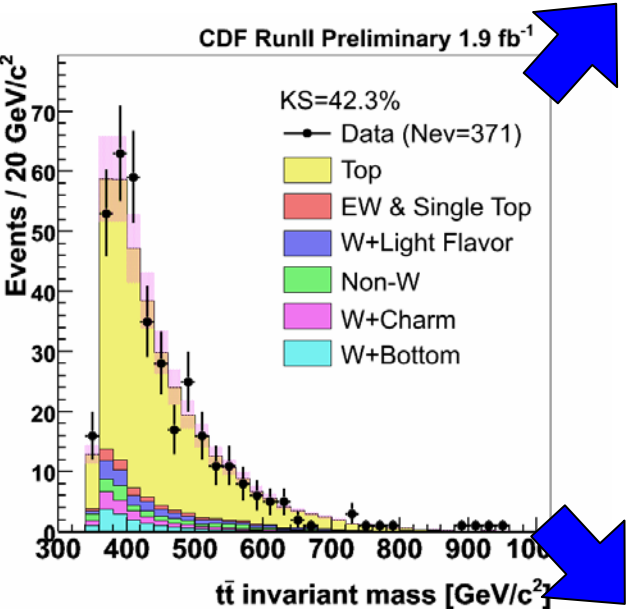
$F_{GG} = 0.07^{+0.15}_{-0.07}$ (stat+syst)
$F_{GG} < 0.38$ @ 95% C.L.

Is top produced as expected?



Searches for new physics in the tt invariant mass spectra:

In the ttbar invariant mass in the L+jets channel New Physics can yield shape distortion or bumps



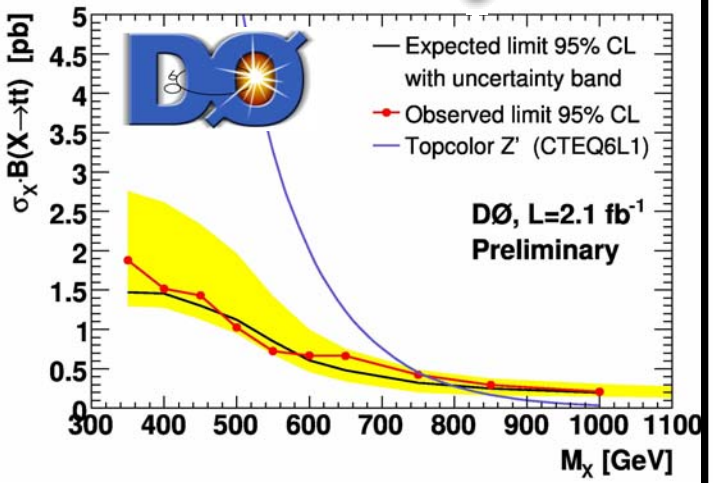
dσ/dM$_{tt}$ measurement

SM consistent!
p-value of 0.45

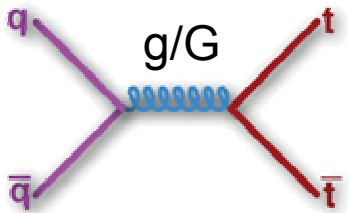
Z' searches:

M$_{Z'}$ > 760 GeV/c^2(D0)

M$_{Z'}$ > 720 GeV/c^2(CDF)
(0.95 fb^{-1})

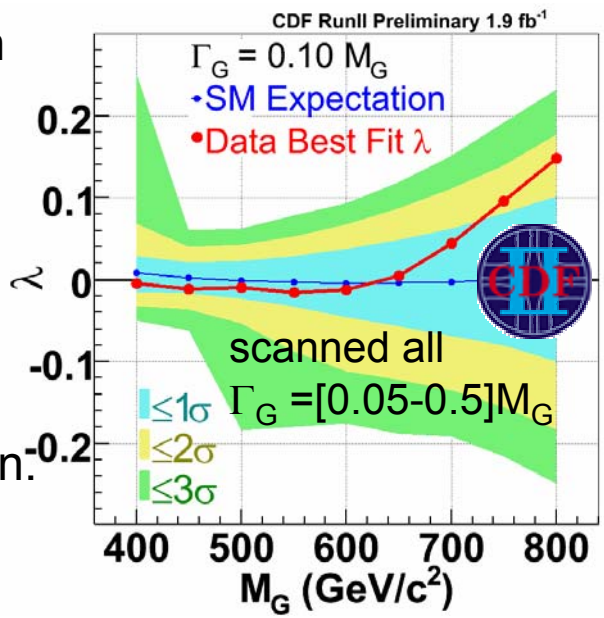


Searches for massive gluon decaying to t-tbar.

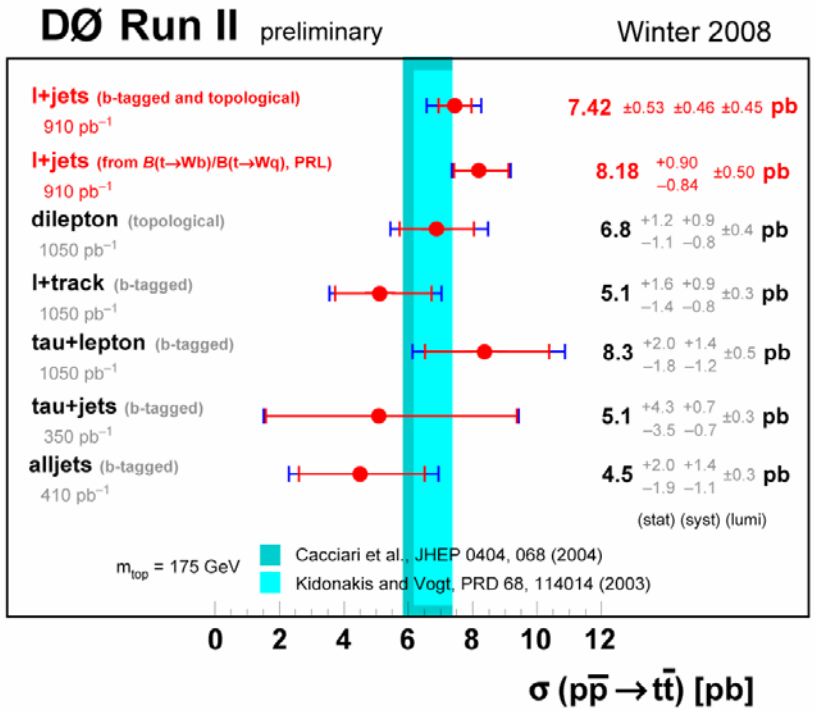


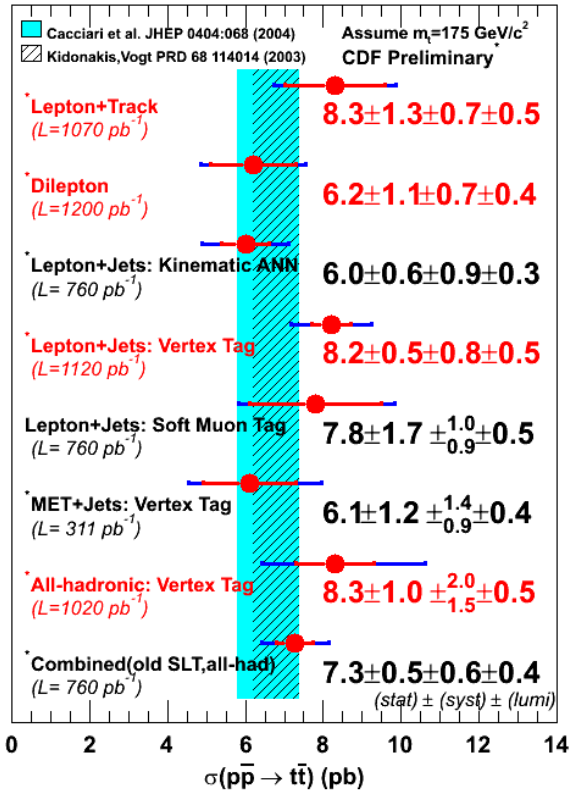
?

15% gg production assumed.
Use DLM for Mtt reconstruction.
Fitted coupling strength 1.7σ consistent w/ SM expectation.



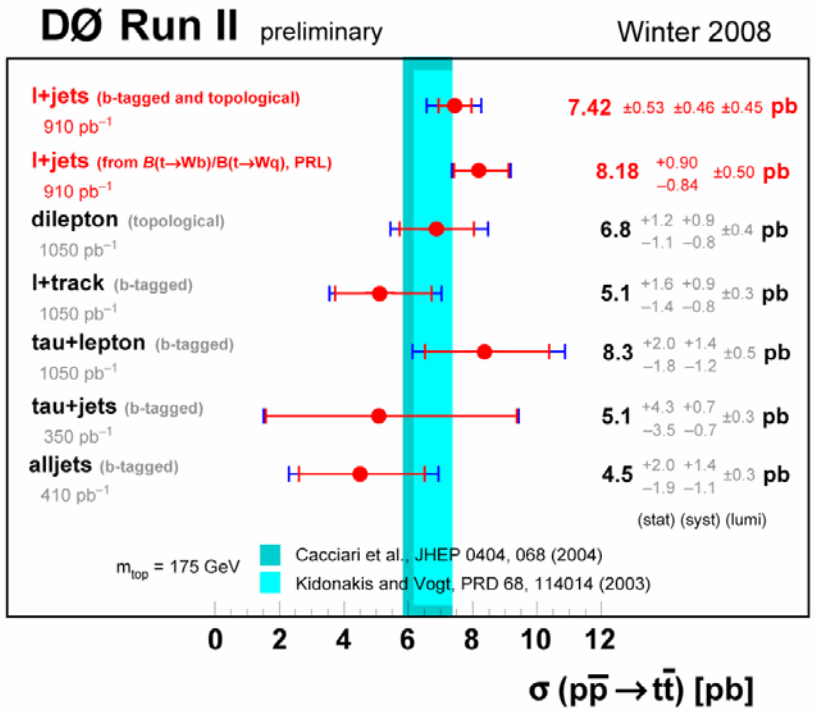
Conclusions

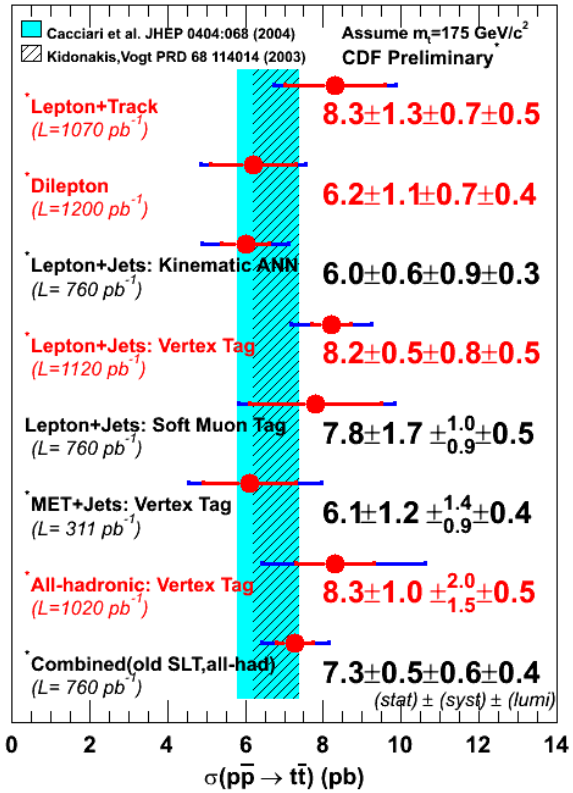




- Cross section measured in many different channel, to test SM prediction and search for new physics signals
- Investigated possible new production mechanisms (Z'/G).
- Good consistency w/ SM is found in all measurement for x-sec, experimental and theoretical uncertainty are at the same level
- More statistics is already available, expecting lots of updates and new measurements for the Summer.

Conclusions



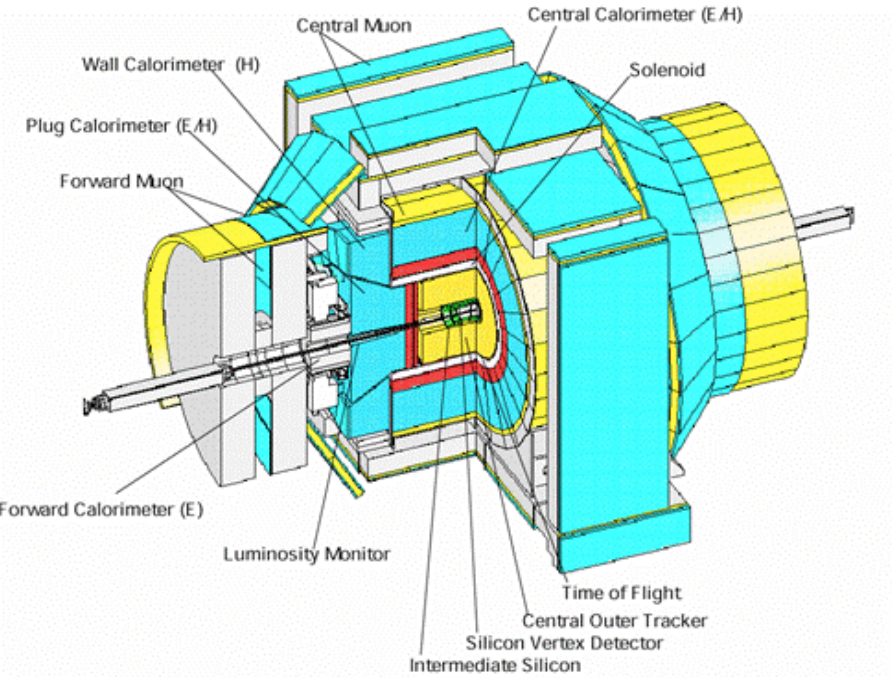


Not covered in this talk:

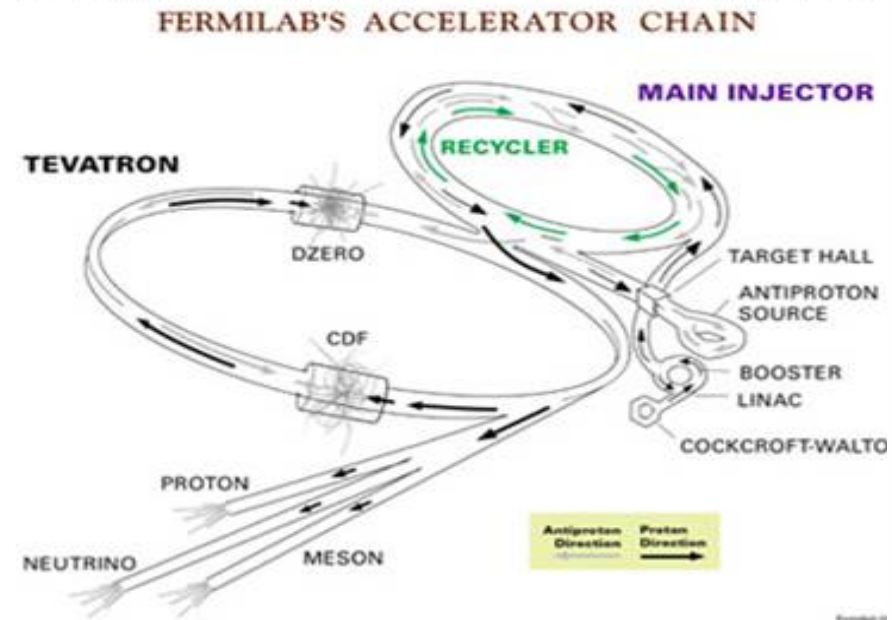
- **Top quark mass** see Ulrich Heintz'talks
- **Top mass from measured cross section** see Solene Chevalier-Thery's talk
- **Top quark properties** see Riccardo Eusebi's talk
- **Single top production** see Supriya Jain's talk

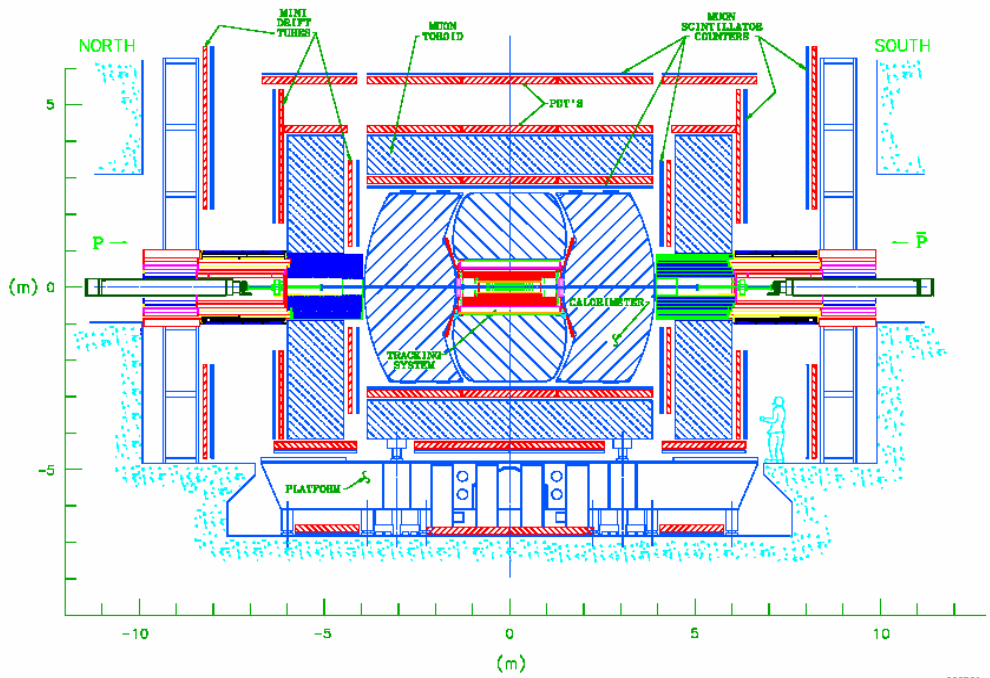
- backup -

CDF/D0 and Tevatron overview

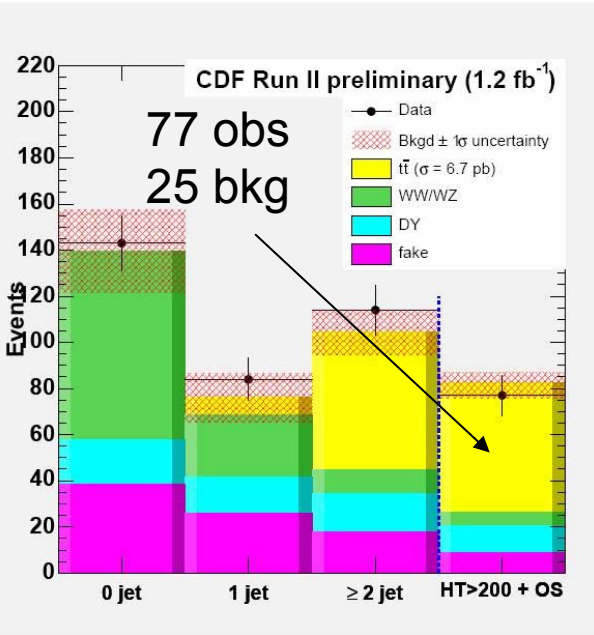


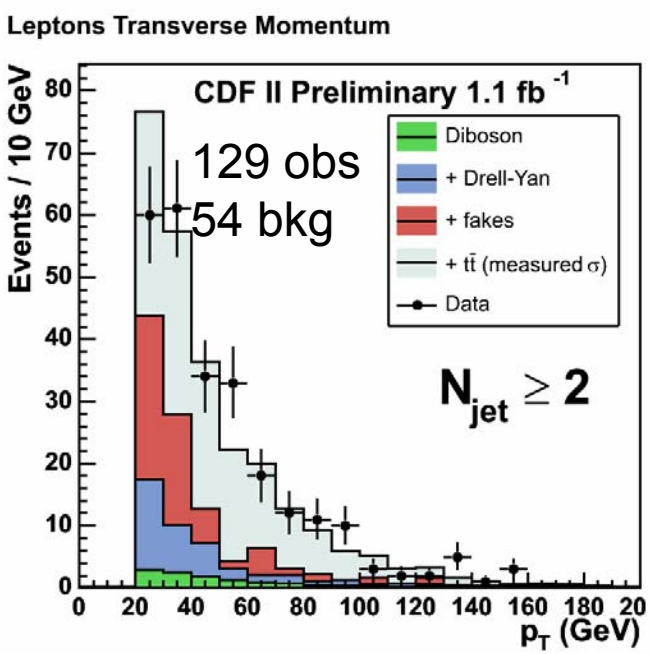
- **CDF and D0 are a multi purpose detectors**
- **The tracking systems**
  - ❑ multi wire drift/scintillating fiber tracking
  - ❑ silicon vertex detectors
- **Calorimeter systems:**
  - ❑ **Electromagnetic section**
  - ❑ **Hadronic section**
- **Muon chambers cover the outer regions.**

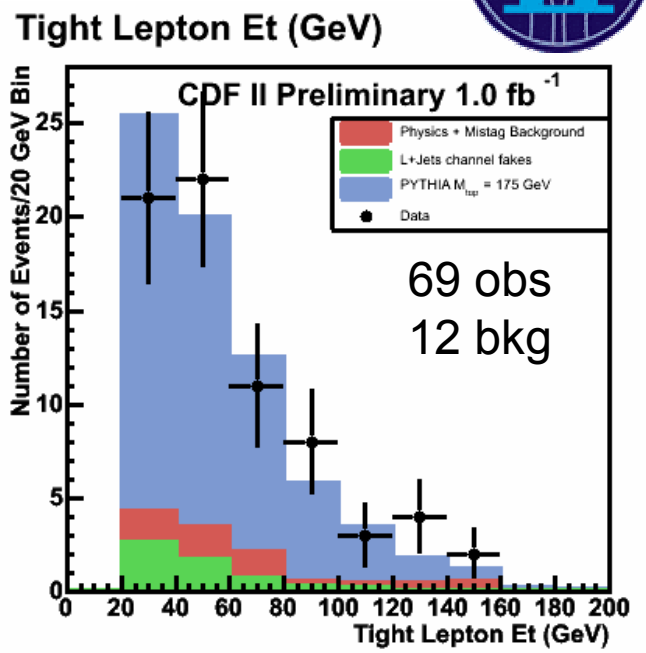




Other Dilepton x-sec:







Dilepton (1.2 fb^{-1}):
σ = 6.2 ± 1.0(stat) ± 0.7(sys) ± 0.4(lumi) pb.

Δσ/σ~20%

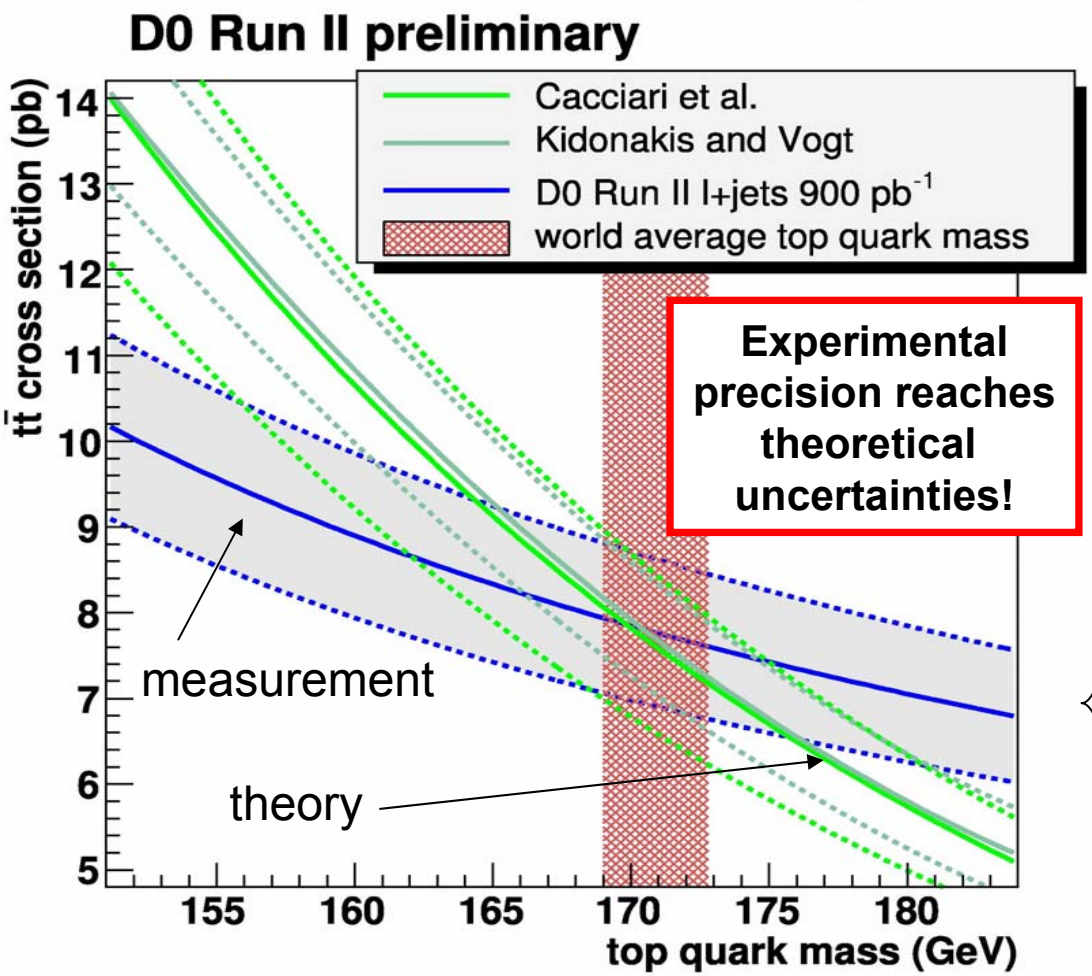
Lepton+track (1.1 fb^{-1})
σ = 8.3 ± 1.3(stat) ± 0.7(sys) ± 0.5(lumi) pb.

Δσ/σ~18%

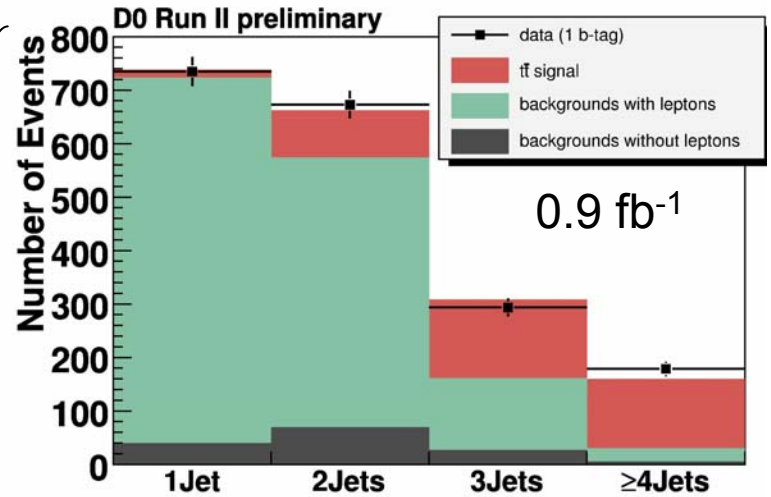
Lepton+Track + btag (1.0 fb^{-1})
σ = 10.1 ± 1.8(stat) ± 1.1(sys) ± 0.6(lumi) pb.

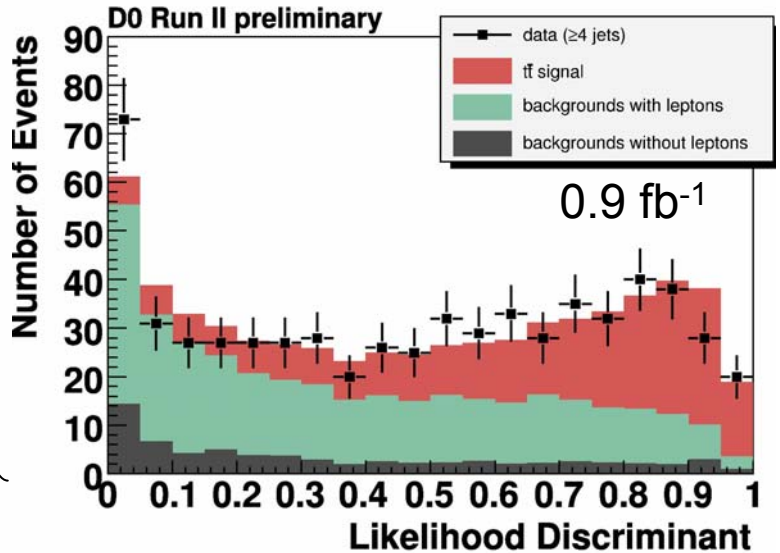
Δσ/σ~22%

Lepton+jets



Experimental precision reaches theoretical uncertainties!





Combined: σ_{tt} **= 7.42 ±0.53(stat) ± 0.46(syst) ± 0.45(lumi) pb**

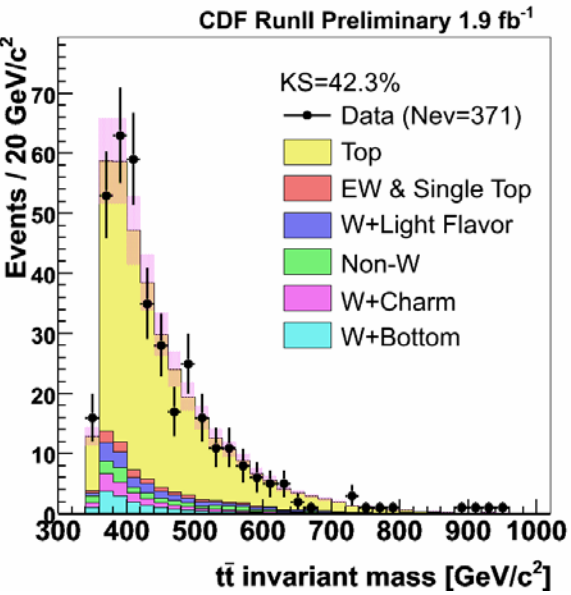
In the same dataset, simultaneous

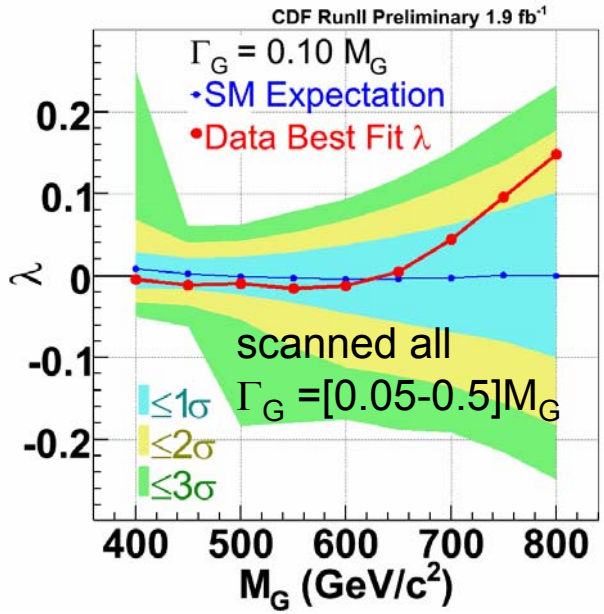
$$R = \frac{B(t \to Wb)}{B(t \to Wq)} = 0.97^{+0.09}_{-0.08}(stat + syst)$$

$$\sigma_{tt} = 8.18^{+0.90}_{-0.84}(stat + syst) \pm 0.5(lumi)\, pb$$

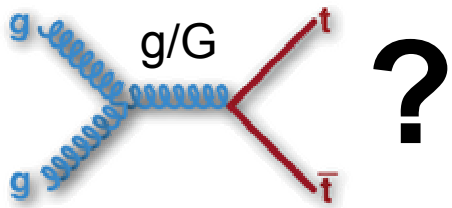
$\Delta\sigma/\sigma$~10%

Is top produced as expected?

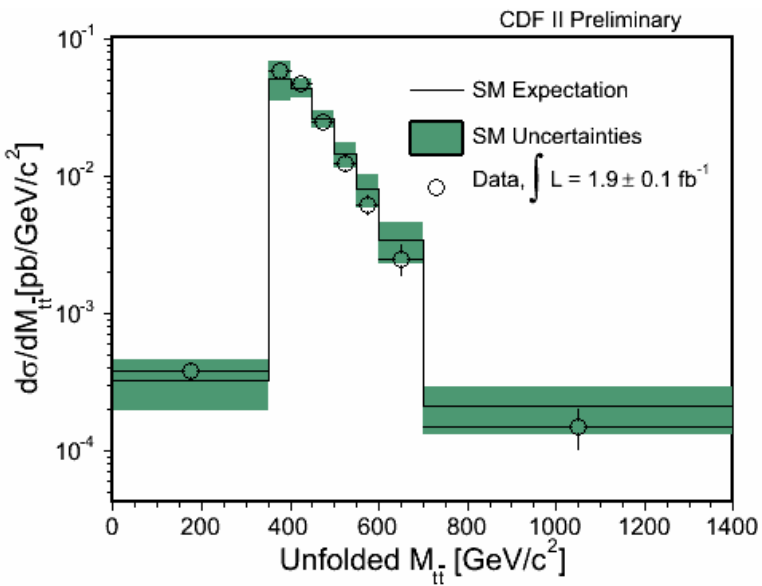


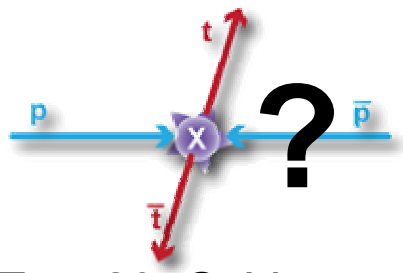


Searches for massive gluon decaying to t-tbar.



15% gg production assumed.
Use DLM for Mtt reconstruction.
Fitted coupling strength 1.7σ consistent w/ SM expectation.





$d\sigma/dM_{tt}$ measurement
e/μ pT>20GeV/c
≥ 4 jets ET>20 GeV, Missing E_T > 20 GeV
≥1 b-tag
Correct M_{tt} for distortions from detector effects
(SVD method)

Consistency w/ SM checked using Anderson-Darling statistics, with p-value of 0.45.

Dilepton Sample composition

- **Data Components for dilepton and lepton+track:**
  - tt
  - WW,WZ,ZZ,Z/$\gamma \rightarrow \tau\tau$
  - Wγ

  } Production cross section relatively well known, several correction, lepton-id + Njet SF.

  - Z/$\gamma \rightarrow$ ee/$\mu\mu$

  } Z boson data w/ MET – DY ratio Z sideband/Z peak

  - W+jets + fake lepton

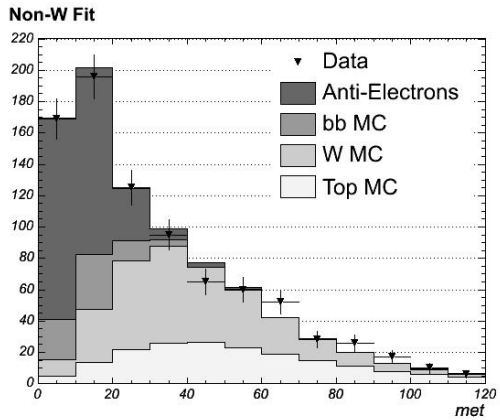
  } Lepton fake rate application from generic jet data or γ+jets

  or ele-likelihood fits and matrix method

- B-tagged background:
  - Physics and mistag background
  - Fake lepton background
    - W+jets
    - tt$\rightarrow$lepton+jets

  } positive mistag matrices for generic jets and tt

Lepton+Jets Sample composition



- **Sample-composition is estimated:**
  - Based on the pretag data
  - Predicts sample composition in the tagged sample by using ε^{tag}_{ave}
- **Components in pretag data:**
  - tt
  - WW,WZ,ZZ,Z/$\gamma \rightarrow \tau\tau$
  - single top
  - non-W (instrumental)
  - W+jets (W+HF, W+LF)

Production cross section relatively well known

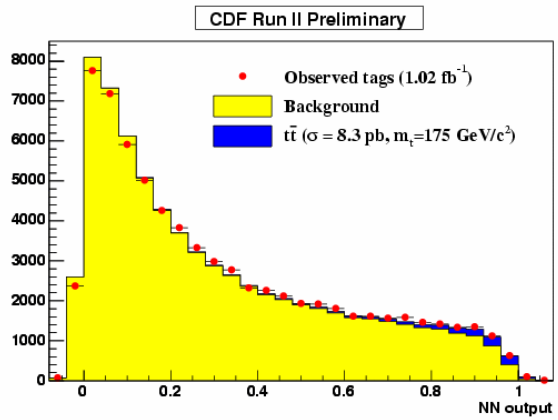
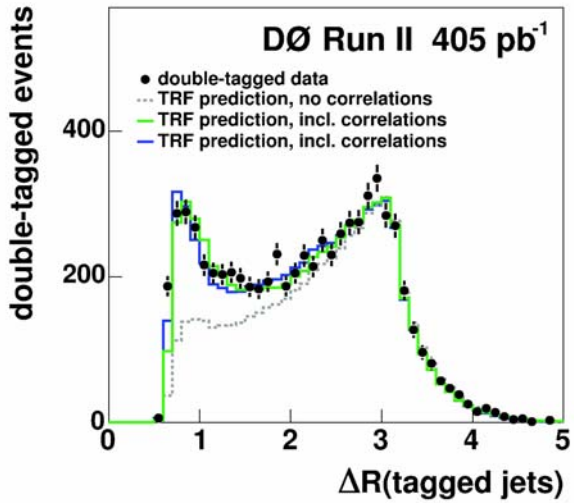
Handle on these processes: MET or matrix method

Theoretical cross section with large corrections

All-hadronic Sample composition

- Background comes from QCD production of HF and mistags

- Completely data driven estimate
  - per jet tag probability, parameterized using jet and global quantities
  - ≥1 tag inclusive prediction



  - Or per–event predictions, correcting for 2tags correlations as a function of $\Delta R(jj)$.