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

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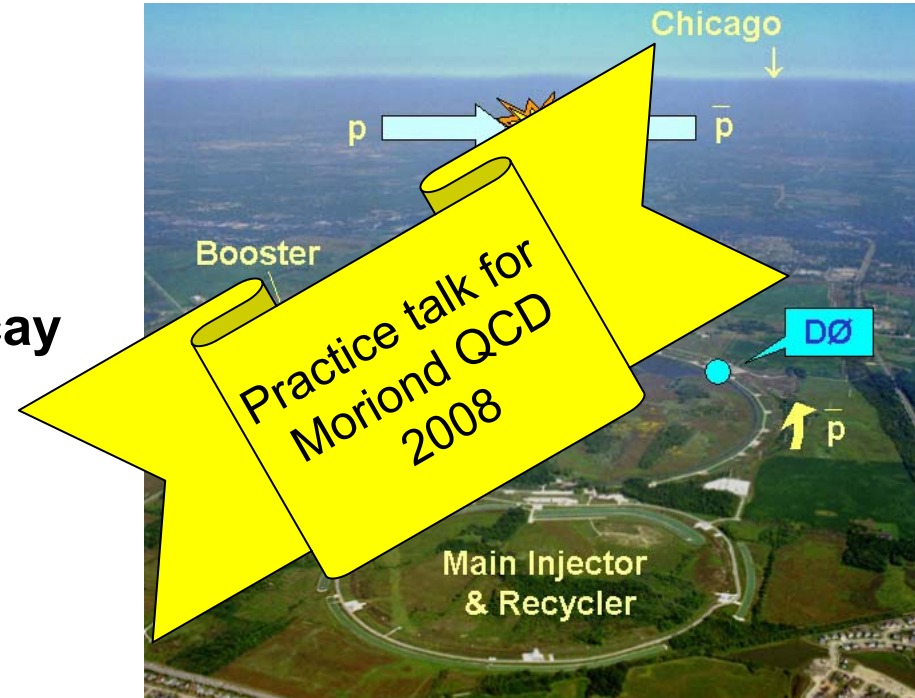
On behalf of CDF and D0 collaborations

Please send comments/suggestion to: cortiana@fnal.gov

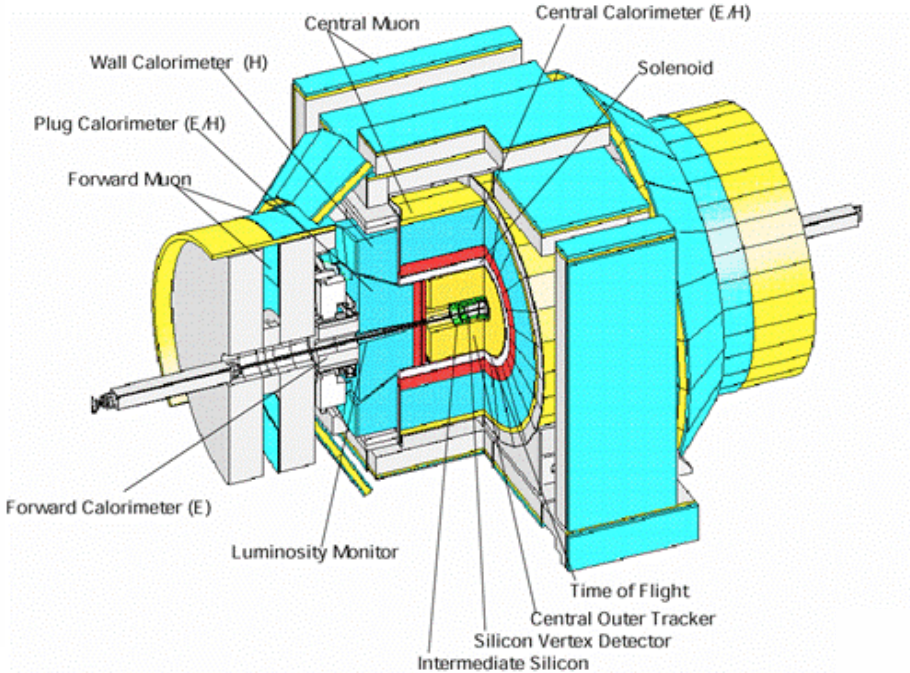
Outline:

- **CDF/D0 and Tevatron overview**
- **Top quark pair production and decay**
- **Cross section measurements and related properties**
- **Conclusions**

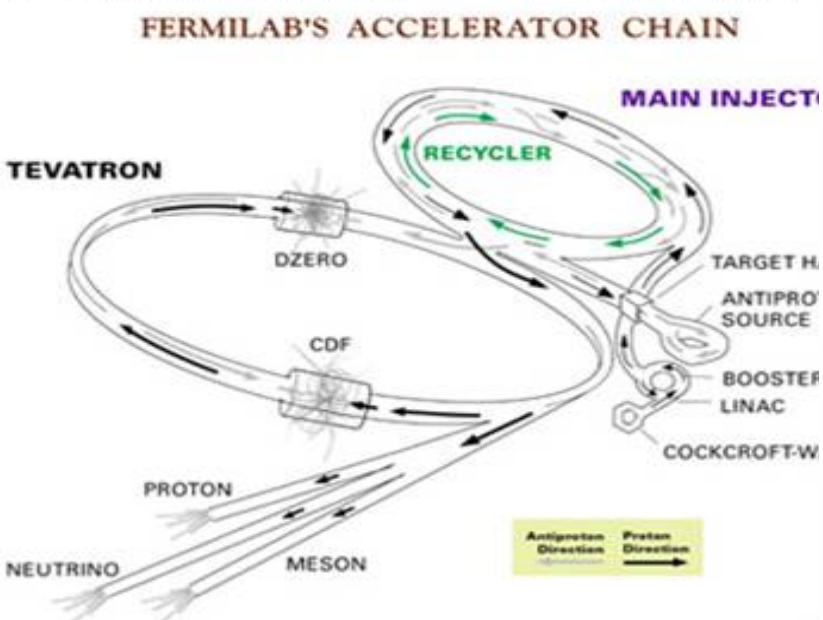


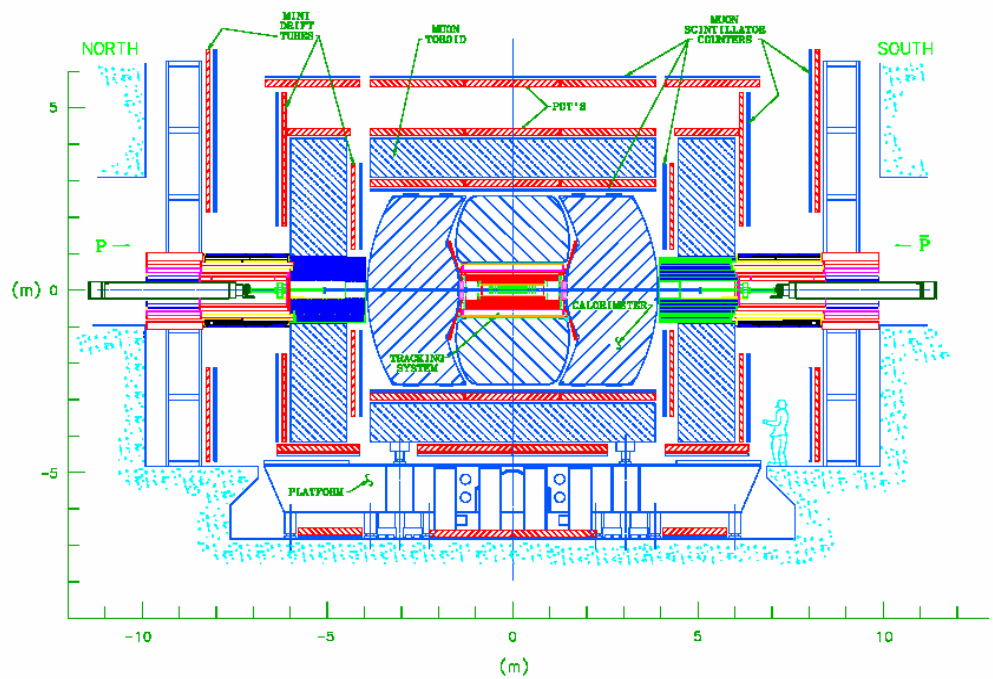
Practice talk for Moriond QCD 2008

CDF/D0 and Tevatron overview

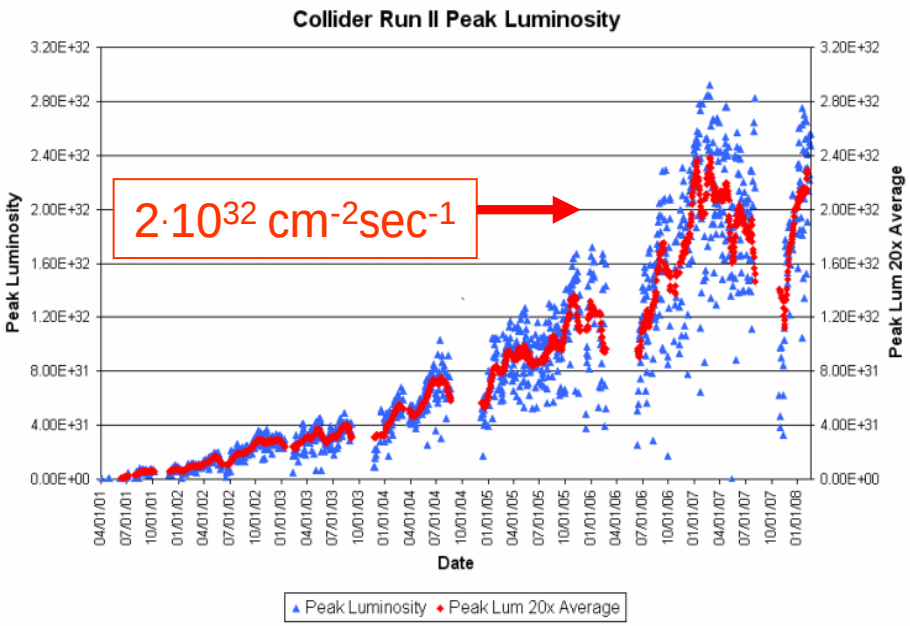


CDF and D0 are multi purpose detectors built to study ppbar interactions @ √s=1.96 TeV.
The tracking system is composed by multi wire drift (or scintillating fiber) tracking chambers surrounding silicon vertex detectors, crucial to detect secondary vertices from heavy flavor decays.
Energy measurements are provided by electromagnetic and hadronic calorimeters.
Finally muon chambers cover the outer detector region.





CDF/D0 and Tevatron overview



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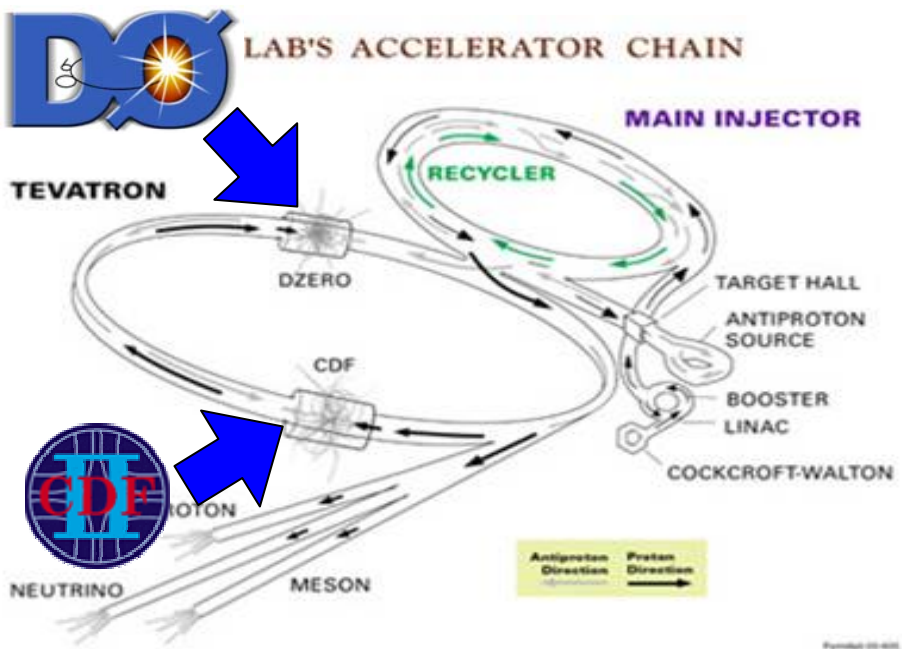
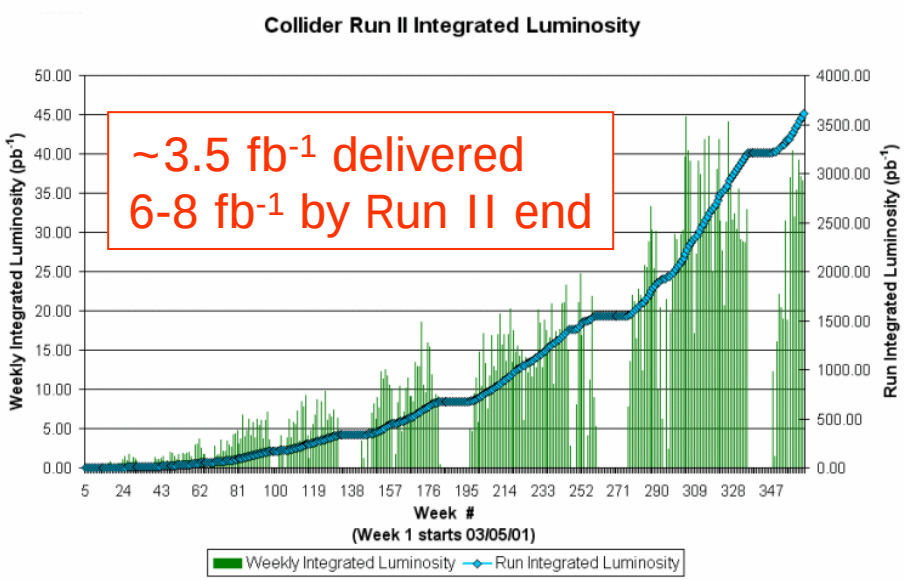
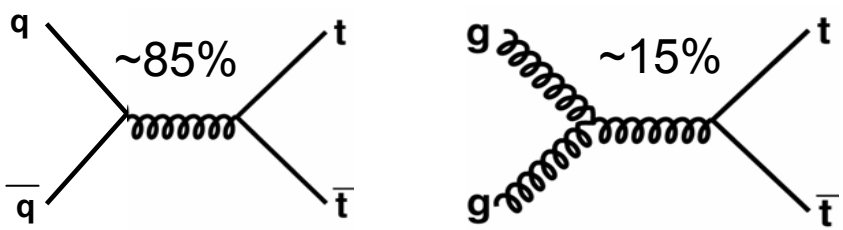


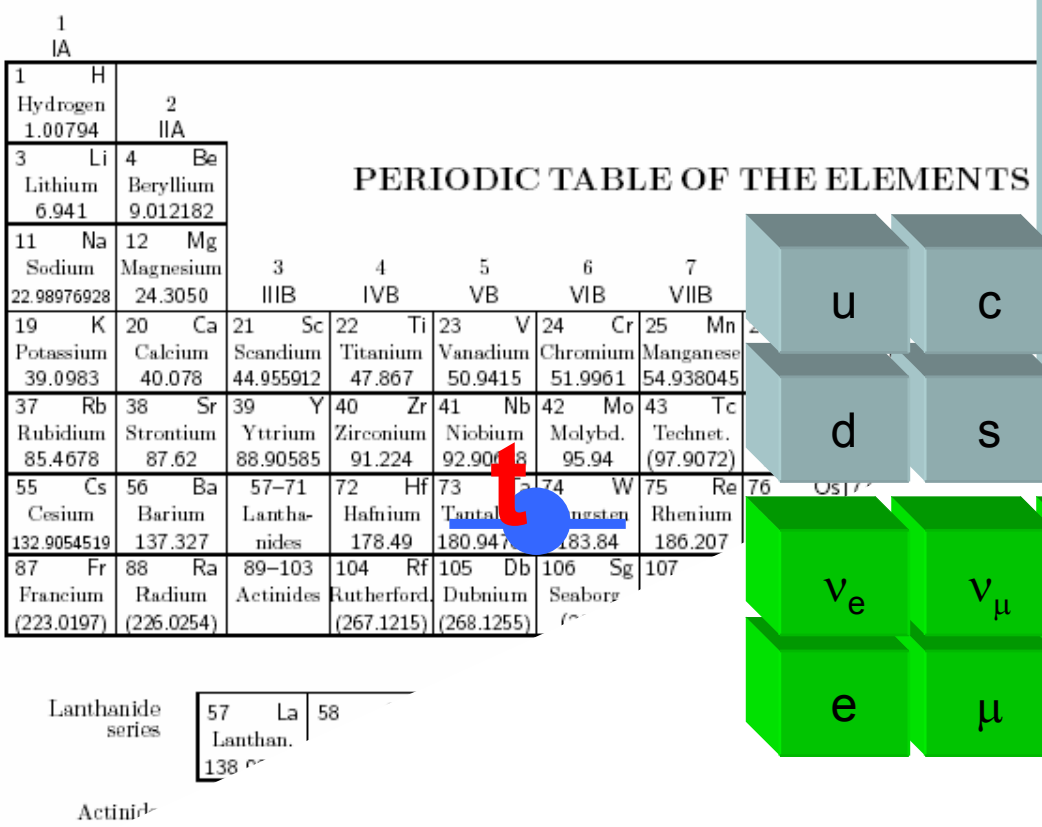


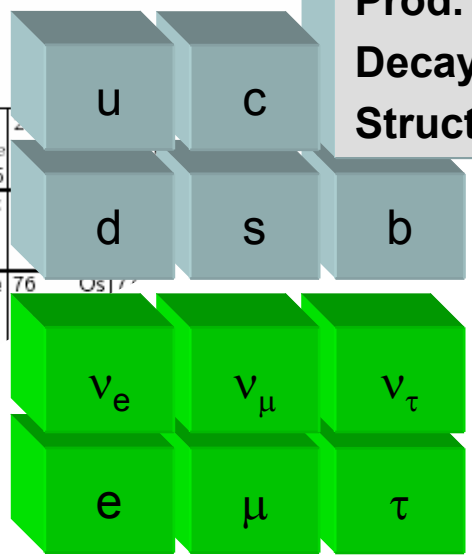
The top quark:



@ 1.96 TeV

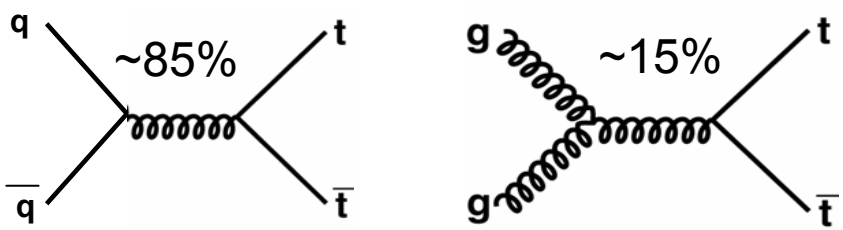
1st quark	3rd generation
Symbol	t
Mass	170.9 ± 1.8 GeV/c²
	183.56 u
Charge	+2/3 e
Prod. Energy	p-pbar @ 1.96 TeV
Prod. Mecc.	gg (~15%), qq (~85%)
Decay	~100% Wb
Structure	Elementary



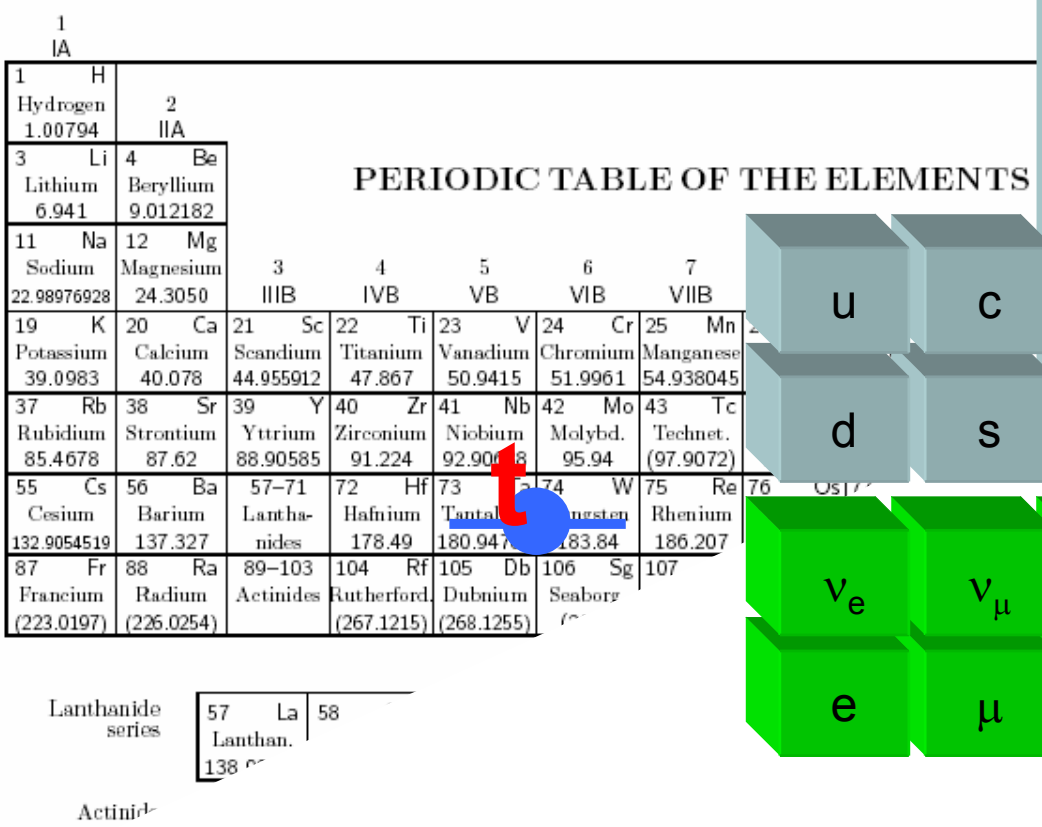


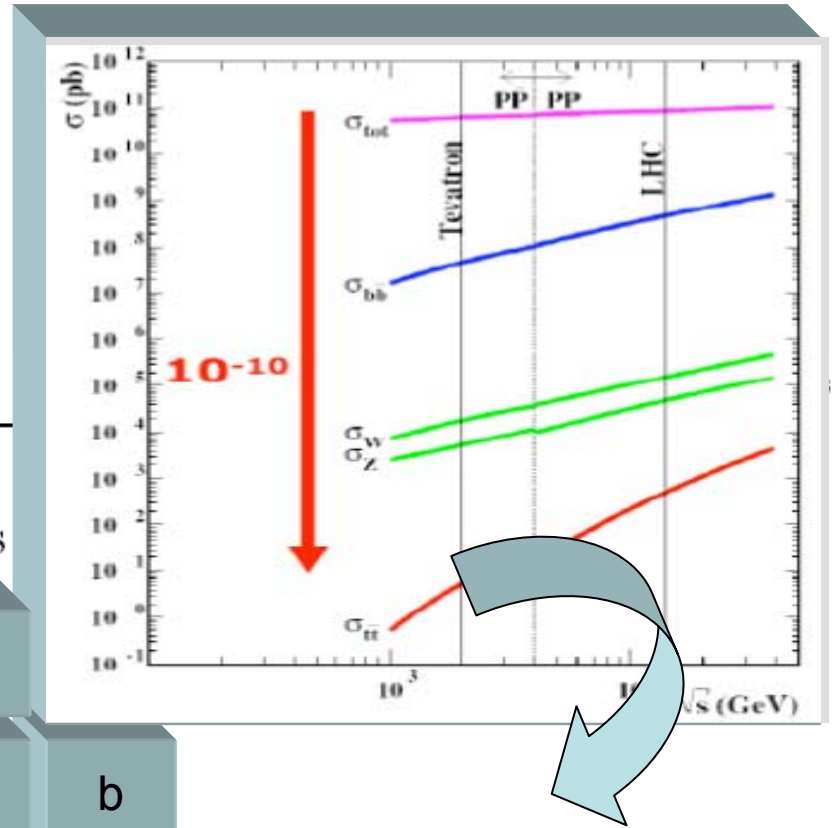
1 u ≈ 1.660538782(83) × 10^{-27} kg ≈ 931.494028(23) MeV/c^2

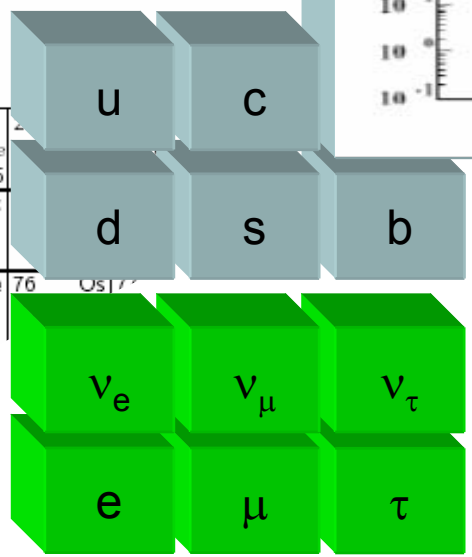
The top quark:



@ 1.96 TeV







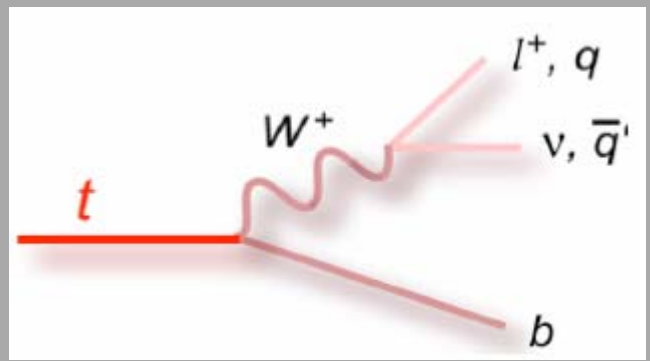
$\sigma_{tt}(175.0\ \mathrm{GeV}/c^2) = 6.7\ ^{+0.7}_{-0.9}$ pb

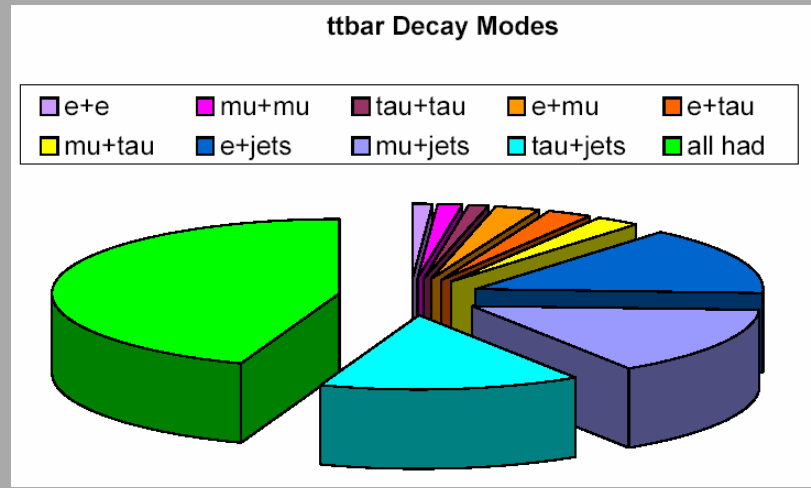
$m_t = 175\ \mathrm{GeV}/c^2$
assumed in this talk

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

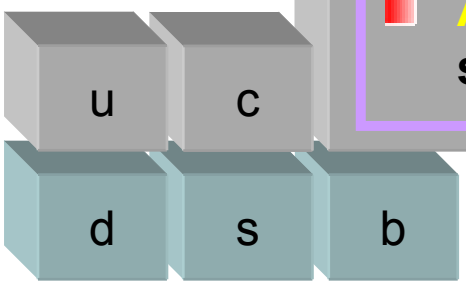
The top quark decays:

BR(t→Wb)~100%



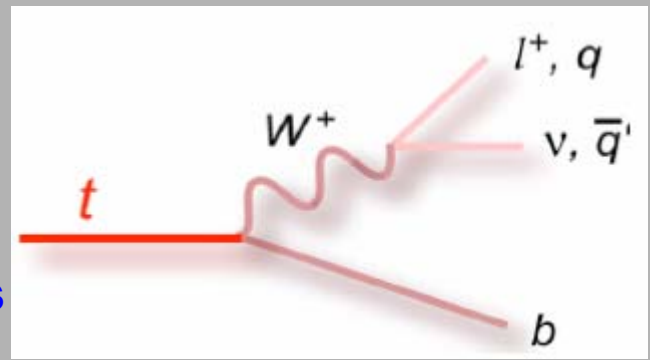


- **Dilepton: BR = 11% (ee/eμ/μμ only = 5%) cleanest sample, lowest statistics**
- **Lepton+jets: BR = 44% (e/μ + jets = 29%) golden channel w/ high statistics and reasonable S/B**
- **All-Hadronic: BR = 44% most challenging channel w/ high statistics but large backgrounds**



The top quark pair cross section measurements

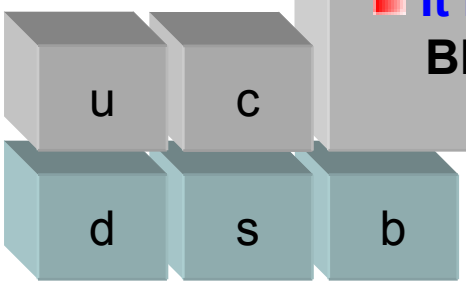
$$\sigma(p\bar{p} \rightarrow t\bar{t}) = \frac{N_{obs} - N_{bkg}}{A_{tot} \int L dt}$$



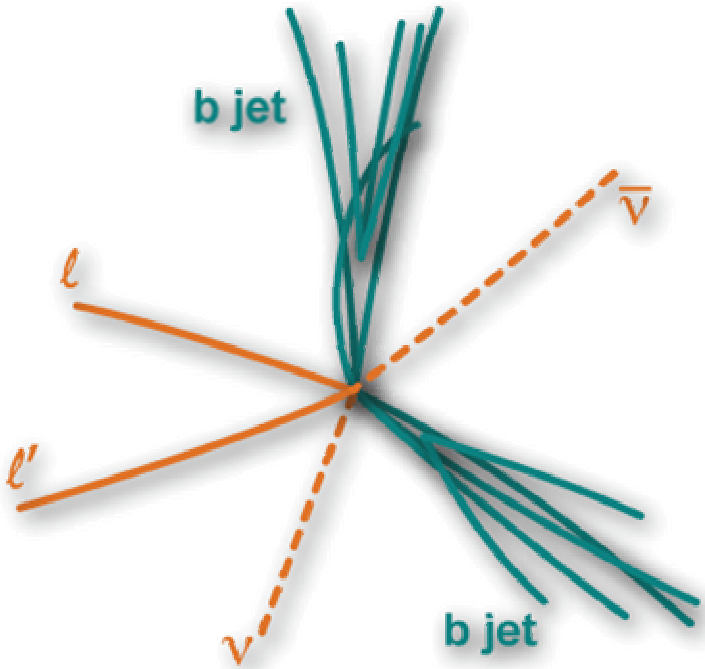
- **Important test of QCD calculations**
  Probe towards new production processes (like resonant prod, Z'/G)

- **It is measured in different decay channels**
  Exotic top decays (i.e. $t \rightarrow H^+b$) 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($t \rightarrow Wb$)~100% assumption.**



Dilepton - channel



Basic Signature:

- 2 high-P_T leptons (or lepton+track)
- Missing E_T
- 2 high-E_T jets (can be required to be b-jets)

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

Main Physics Backgrounds (from MC)

- Z/γ+jets
- WW/ZW/ZZ +jets

Instrumental backgrounds (from data)

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

Dilepton

Combination of dilepton and lepton+track

Dilepton:

- **2 e/μ p_T>15GeV/c** |η|<1.1/(2.0)
- 1 or 2 jets E_T>20 GeV
- Missing E_T
- + selections on sphericity, Z fit, H_T
- 4 independent channels, ee, μμ, e/μ + 1/2jets

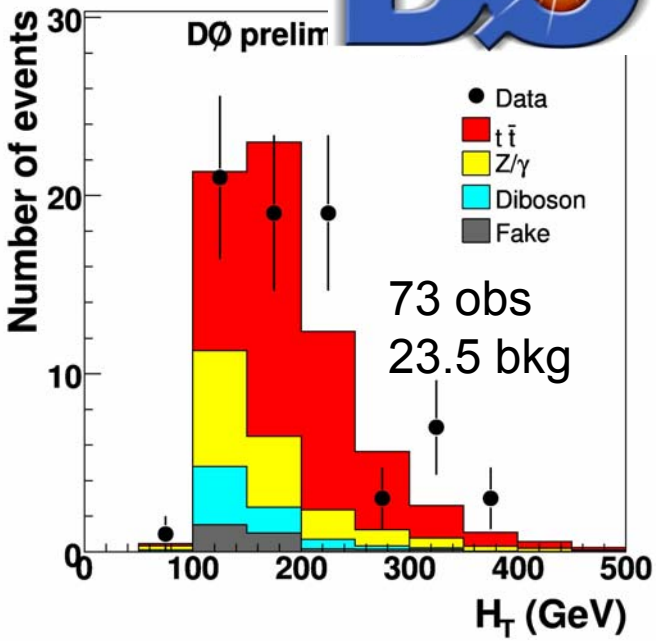
Lepton+track:

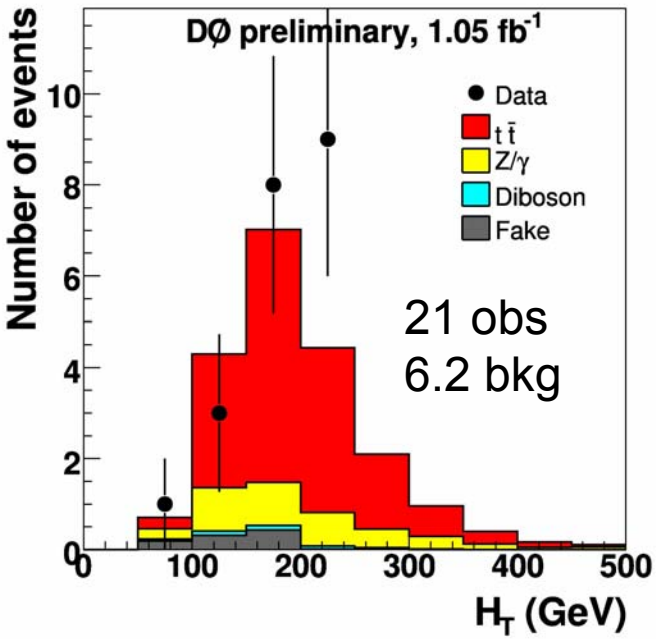
- **1 e/μ p_T>15GeV/c** |η|<1.1/2.0
- **isolated track p_T > 15 GeV/c**
- Missing E_T > 20 (35) GeV
- jets E_T>20 GeV (40 for the leading jet)
- **1 b-tag** (D0NN cut at 0.65)
- 4 independent channels, e/μ + 1/2jets combined

Dilepton and lepton+track combined: $\Delta\sigma/\sigma$~19%

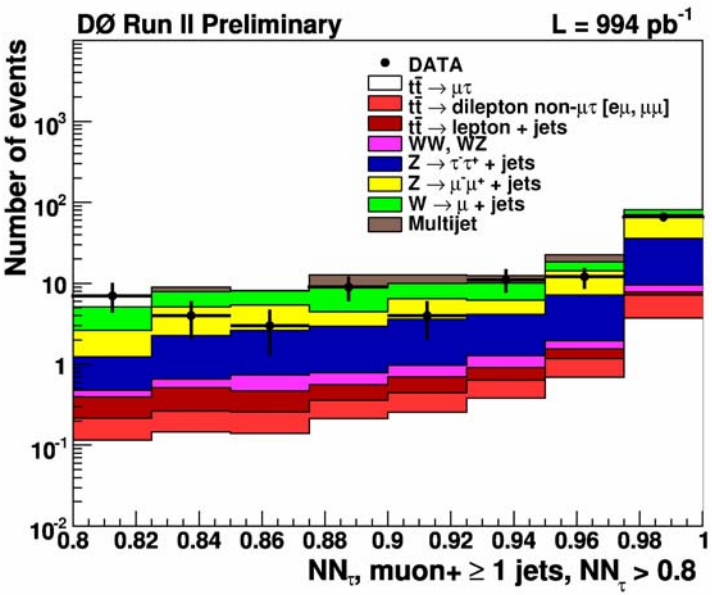
σ = 6.2 ± 0.9(stat) ± 0.7(syst) ± 0.5(lumi) pb

Main syst: lepton-id, JES, BGK/MC normaliz. b-tag

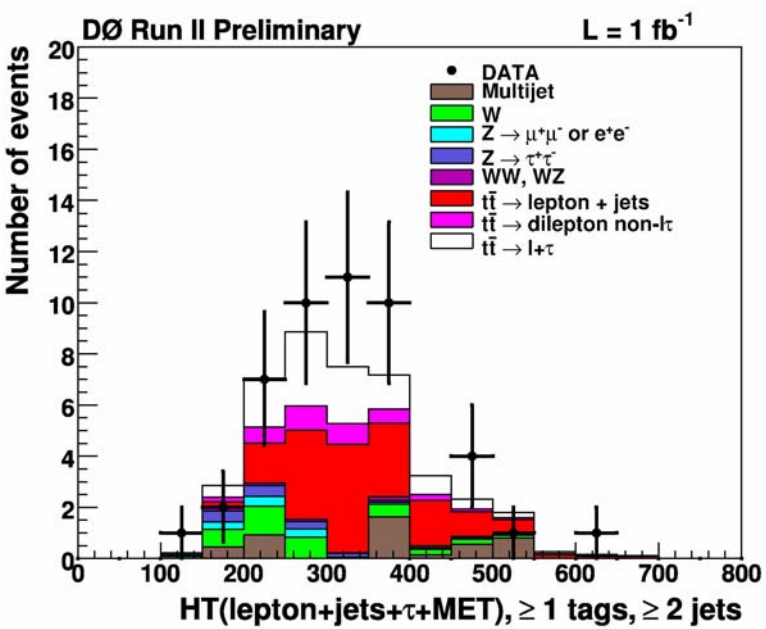




Dilepton e/μ+τ+btag



- **e/μ p_T>20GeV/c** (15) |η|<1.1/(2.0)
- Standard di-lep or same type veto
- Missing E_T >15 GeV
- **NN_τ** (+ NN antielectrons)
  (Ntrk, cluster size, isolation, track-calo correlation)
- jets E_T>20 GeV (30 for the leading jet)
- **≥ 1 b-tag**



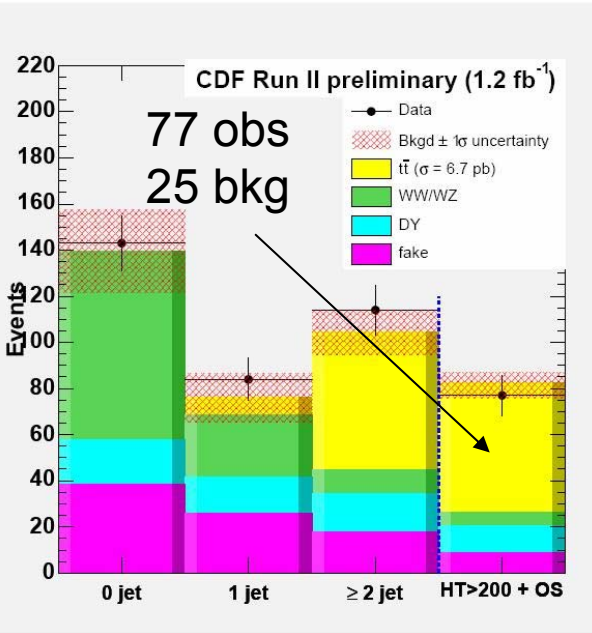
eτ + μτ combined: **(extra acceptance from l+jets)**

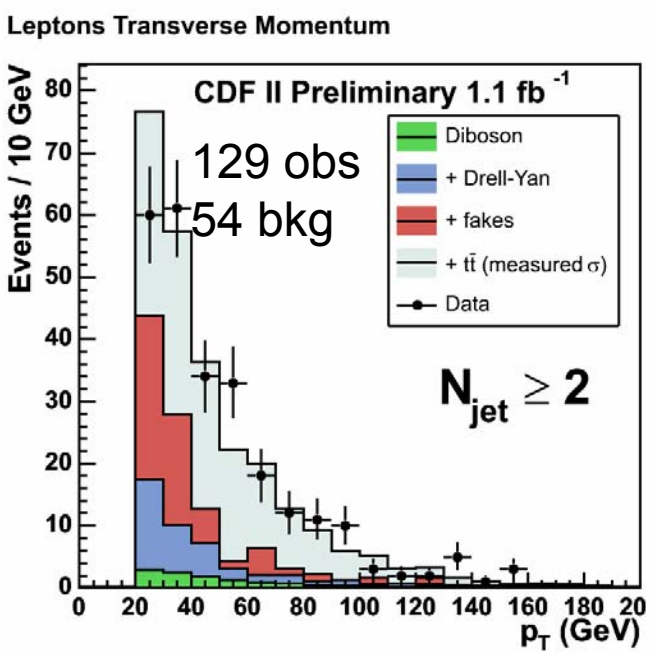
$\sigma = 8.3\ ^{+2.0}_{-1.8}(\text{stat})\ ^{+1.4}_{-1.2}(\text{syst}) \pm 0.5(\text{lumi})$ pb

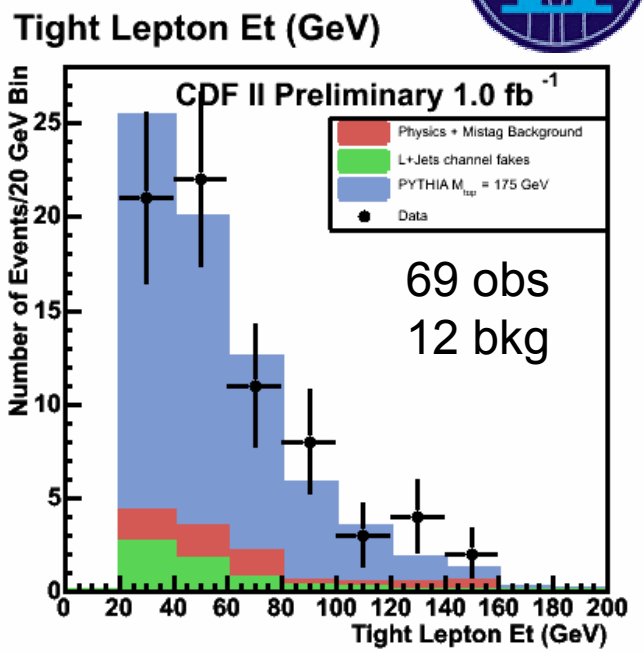
σ*BR(tt→l+τ+2ν+2b) =
0.19±0.08(stat) ± 0.07(syst) pb
(extra acceptance from l+jets, dil are treated as bkg!)

Main syst: lepton-id, JES, BGK/MC normaliz. b-tag

Dilepton







Dilepton:
σ = 6.2 ± 1.0(stat) ± 0.7(sys) ± 0.4(lumi) pb.

$\Delta\sigma/\sigma \sim 20\%$

Lepton+track
σ = 8.3 ± 1.3(stat) ± 0.7(sys) ± 0.5(lumi) pb.

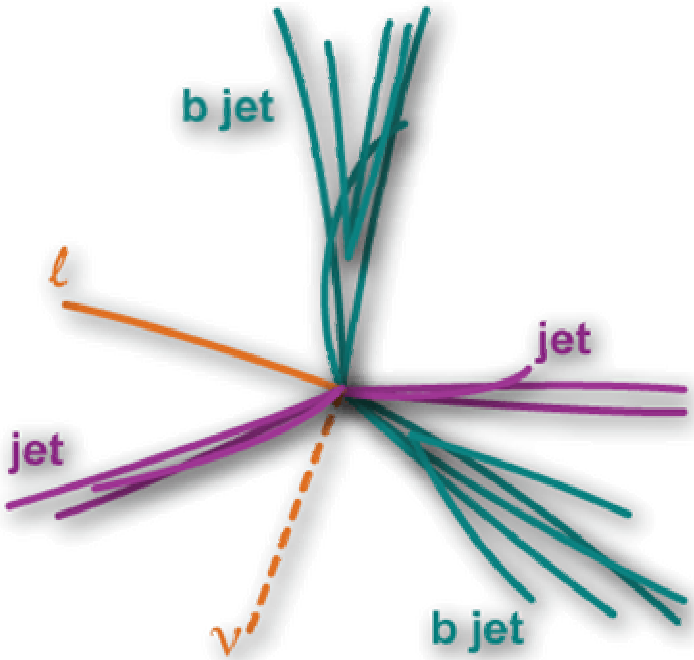
$\Delta\sigma/\sigma \sim 18\%$

Possible new CDF dil+btag here

Lepton+Track + btag
σ = 10.1 ± 1.8(stat) ± 1.1(sys) ± 0.6(lumi) pb.

Lepton+jets decays

widely used for top quark properties determination



Basic Signature:

- **1 high-P_T lepton**
- **Missing E_T**
- **≥3 high-E_T jets (2 can be required to be b-jets)**

Analyses: Lepton+jets + kinematics w/ and w/o b-tag

Main Physics Backgrounds (estimated from data and MC):

- **W+jets**
- **$Z \rightarrow \tau\tau$**
- **Single top**

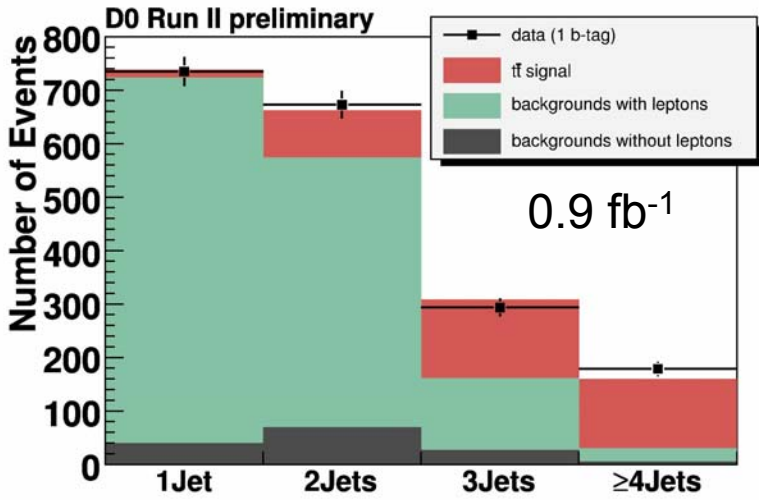
Instrumental backgrounds (estimated from data)

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

Lepton+jets

Basic events selection:

- 1 e/μ p_T>20GeV/c $|\eta|$<1.1(2.0)
- ≥3 jets E_T>20 GeV (40 GeV for leading)
- Missing E_T > 20 GeV (25 GeV for μ+jets)



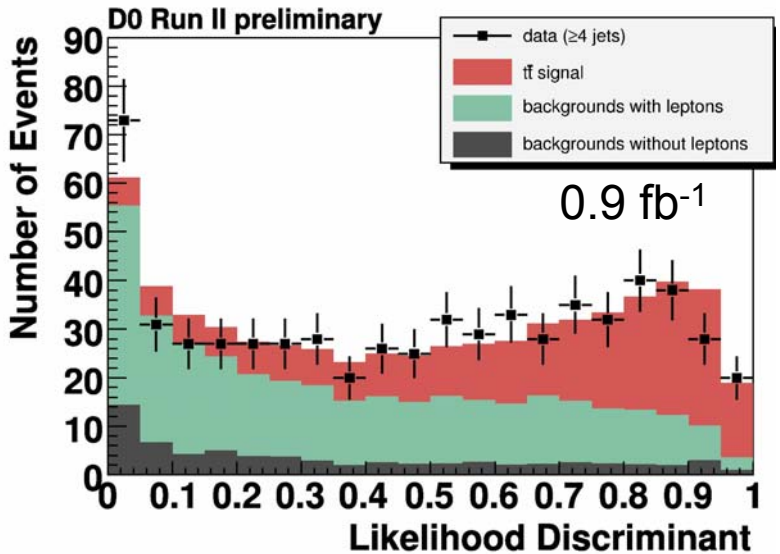
Complementary measurement using:

- **NN-b-tag:** 8 channels (e/μ, 3/≥4 jets, 1/≥2 tags)

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

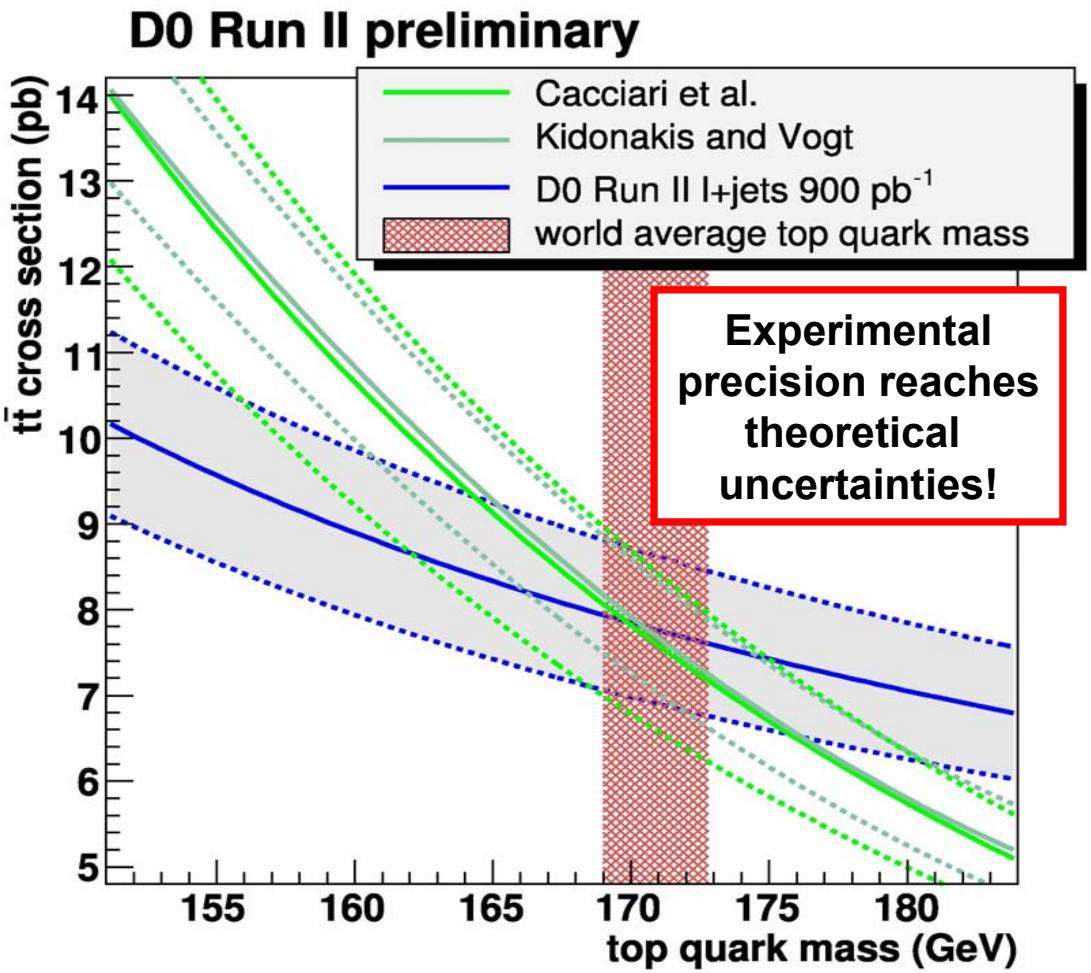
- **topological discriminant**: (e/μ, 3/≥4 jets)

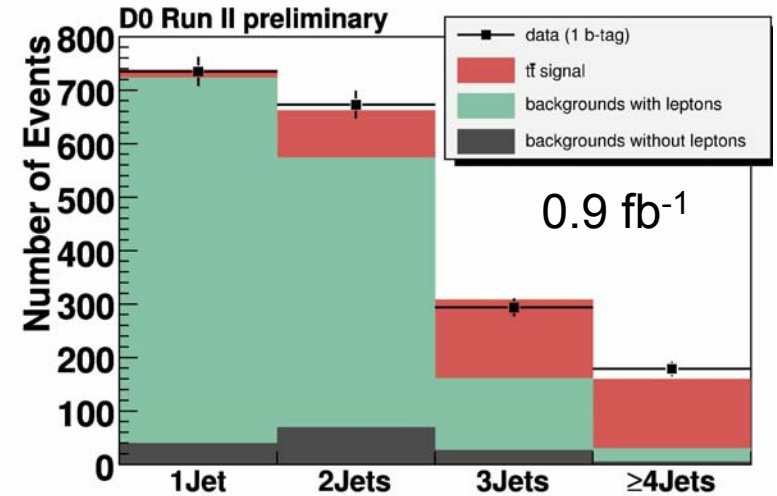
  σ_{tt}= 6.62 ± 0.78(stat) ± 0.36 (syst) ± 0.4 (lum) pb

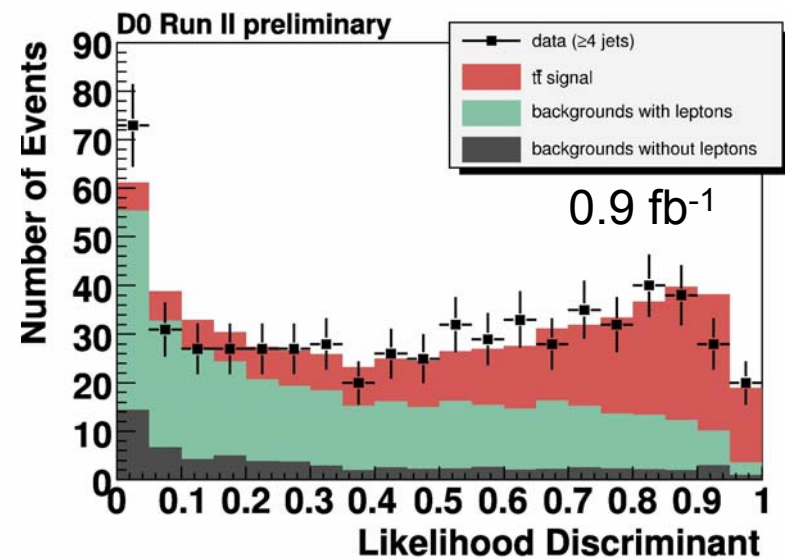


Combined: σ_{tt}**= 7.42 ±0.53(stat) ± 0.46(syst) ± 0.45(lumi) pb**

Lepton+jets







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

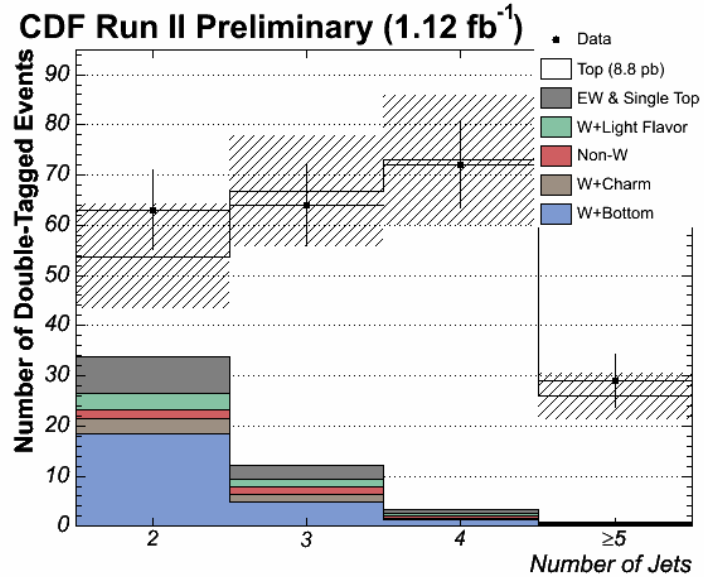
In the same dataset, simultaneous

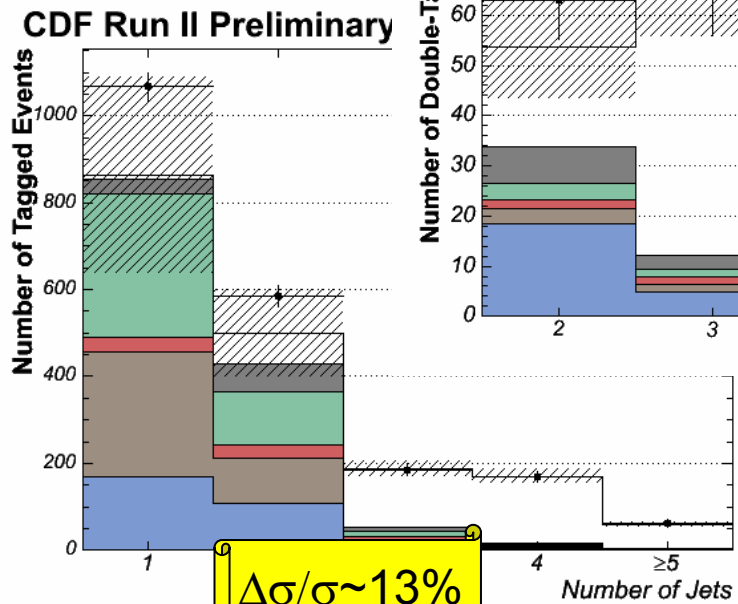
$$R = \frac{B(t \to Wb)}{B(t \to Wq)} = 0.97^{+0.09}_{-0.08}(stat + syst)$$

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

$\Delta\sigma/\sigma \sim 10\%$

Lepton+jets





Core event selection:

- 1 e/μ p_T>20GeV/c $|\eta|$<1.1(2.0)
- ≥3 jets E_T>20 (15)GeV
- Missing E_T > 30 GeV
- H_T > 250 GeV (200 for 2 btags)

- **b-tag: ≥1/≥2 b-tags**

$\Delta\sigma/\sigma \sim 13\%$

$\sigma_{\geq 1tag}$ = 8.2 ± 0.5 (stat) ± 0.8 (syst) ± 0.5 (lum) pb

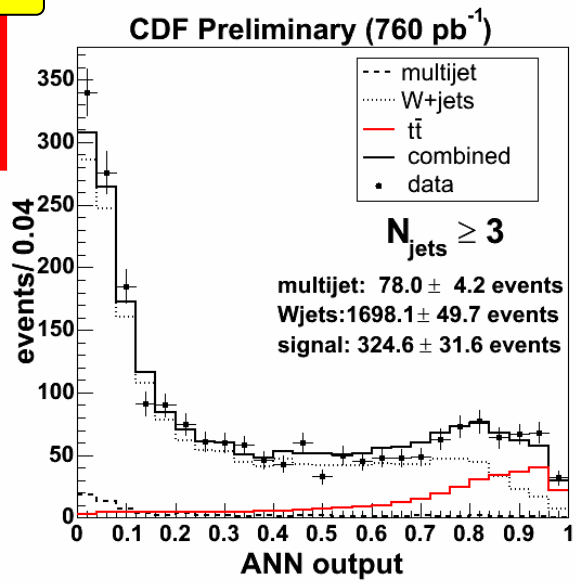
$\sigma_{\geq 2tag}$ = $8.8^{+0.8}_{-0.7}$ (stat) ± 1.2 (syst) ± 0.5 (lum) pb

- **topological discriminant:**

  σ_{tt} = 6.0 ± 0.6 (stat) ± 0.9 (syst) pb (700 pb^{-1})

- **Secondary vertex and NN btag :**

  σ_{tt} = 8.5 ± 0.6 (stat) ± 1.0 (syst) pb (700 pb^{-1})



Main syst: lepton-id, JES, BGK/MC normaliz. b-tag

All-hadronic:

Basic Signature:

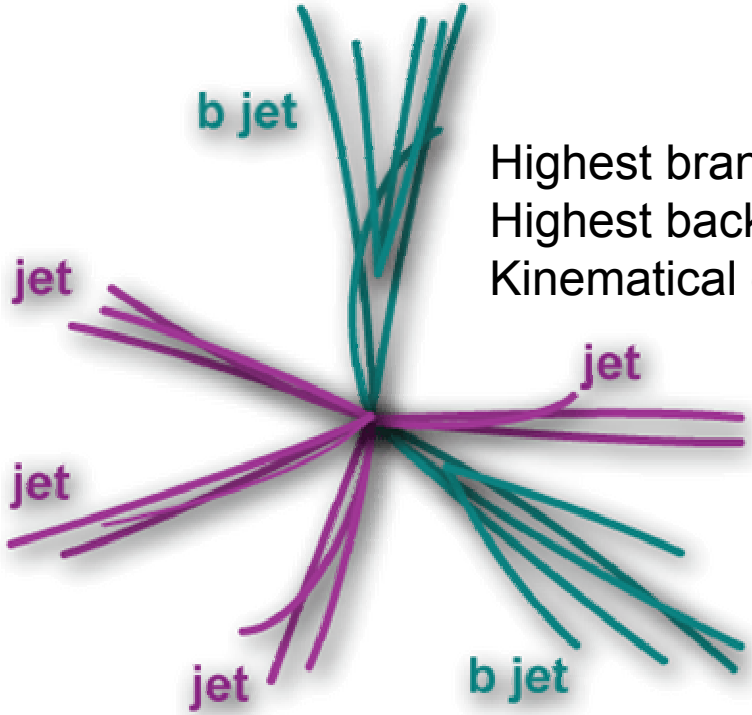
- **6 or more high-E_T jets**
- **2 of which from b-quarks**

Main Physics Backgrounds:

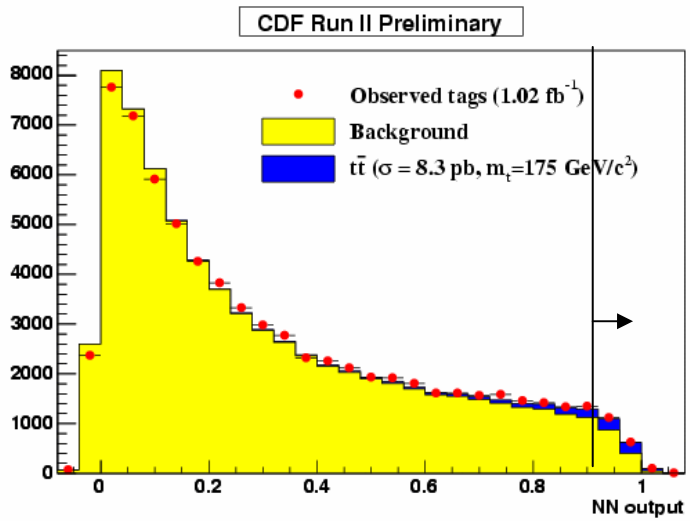
- **QCD multijet production**

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

Decays top as expected?

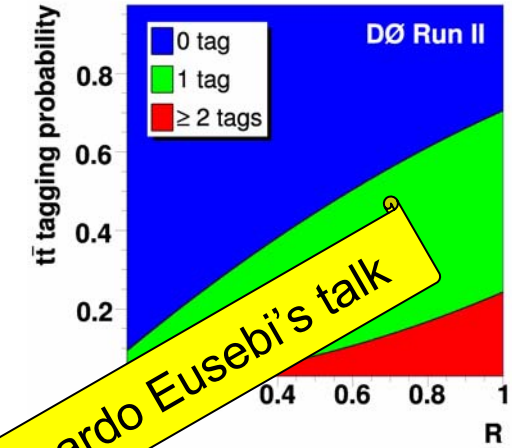
Simultaneous measurement of R and σ_{tt} (l+jets):

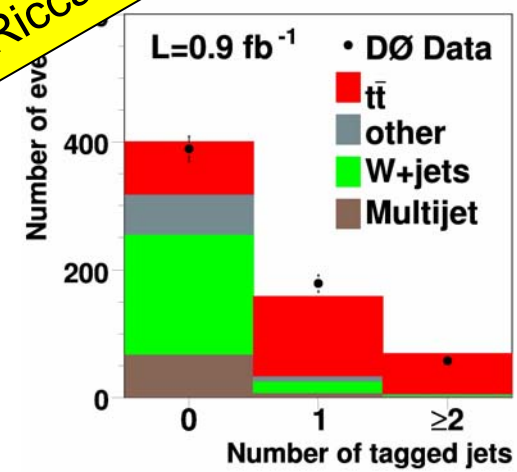
- Use NNb-tag + kinematics (for 0-tag)
- Exploit correlation for ε_b and R. **(reduce b-tag syst for σ)**
  - Fit data for R and σ_{tt} simultaneously:

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

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

see also Riccardo Eusebi's talk





Decays top as expected?

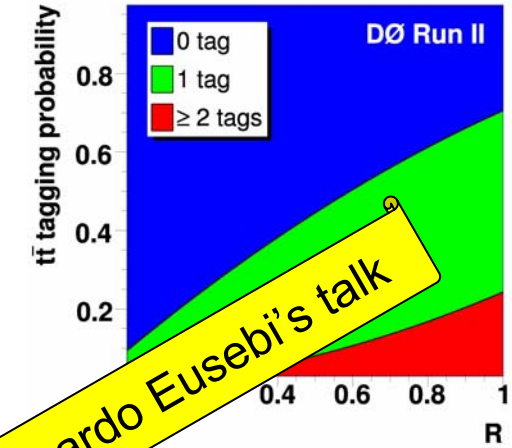
Simultaneous measurement of R and σ_{tt} (l+jets):

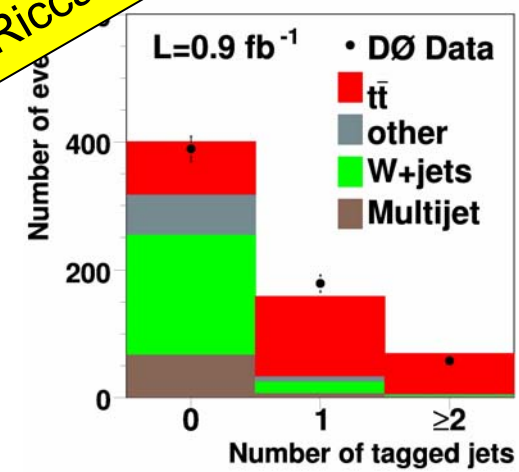
- Use NNb-tag + kinematics (for 0-tag)
- Exploit correlation for ε_b and R. **(reduce b-tag syst for σ)**
  - Fit data for R and σ_{tt} simultaneously:

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

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

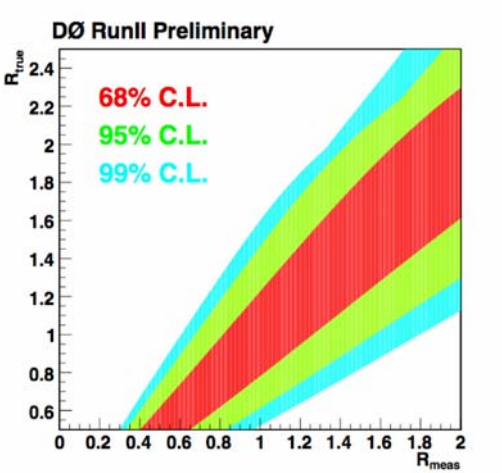
see also Riccardo Eusebi's talk





Cross section ratio (l+jets/dil):

Sensitivity to W boson disappearance due to B(t→Xb)>0.



+ ?

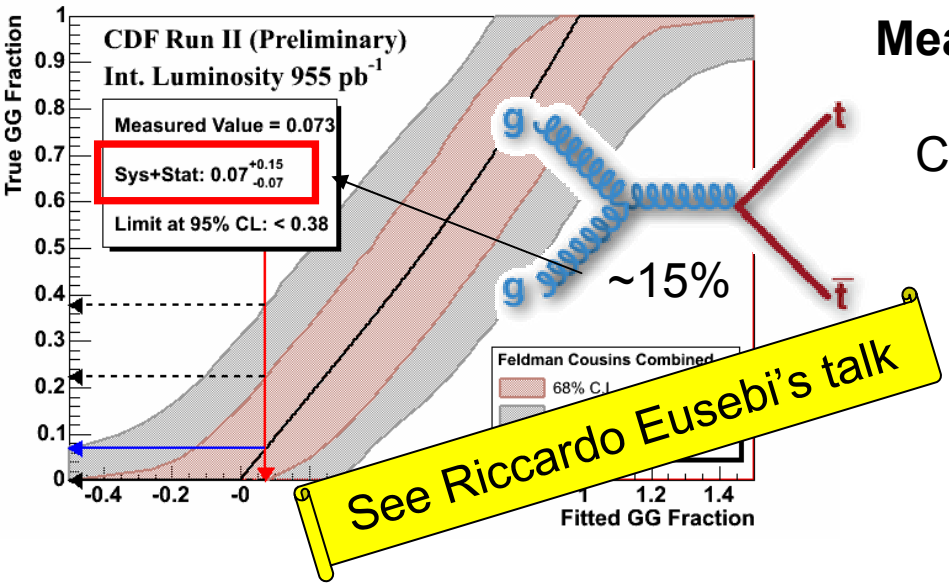
$$R_\sigma = \frac{\sigma(p\bar{p} \to t\bar{t})_{l+jets}}{\sigma(p\bar{p} \to t\bar{t})_{ll}} = 1.21^{+0.27}_{-0.26}(tot)$$

For example for $t \to H^+b \to c\bar{s}b$, and m_{H+}~80 GeV/c²:

B(t→ H⁺b) < 0.35 @ 95% C.L.

(expected <0.25 @95% C.L.)

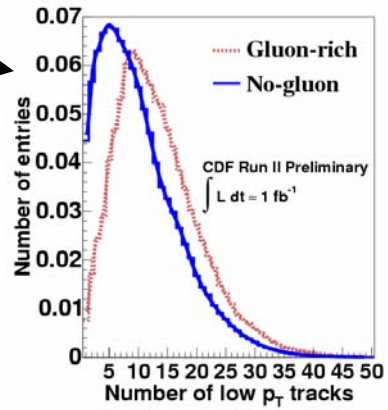
Is top produced as expected?



Measurement of relative fraction of gg fusion

Combination of two methods:

- Low p_T tracks
- Kinematical vars from gg and qq in NN training.



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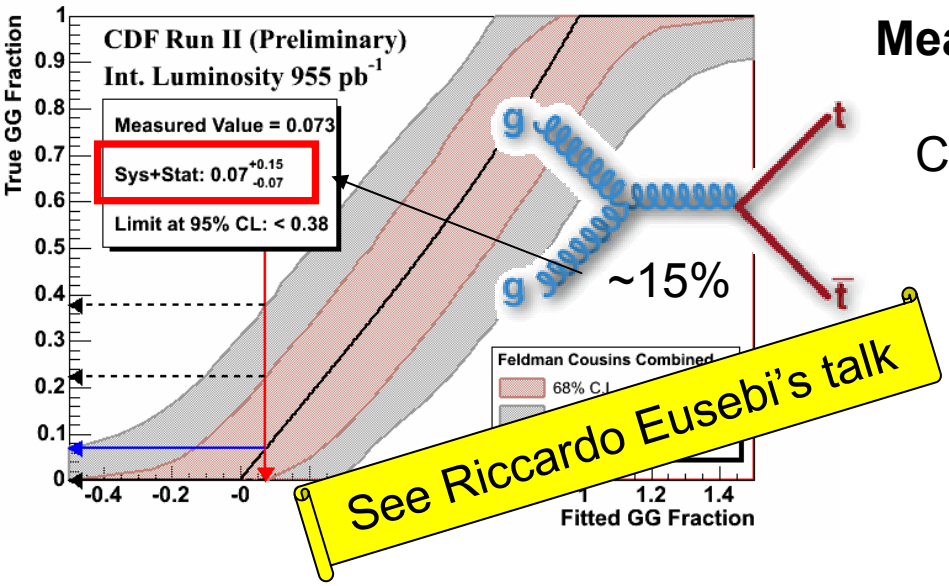

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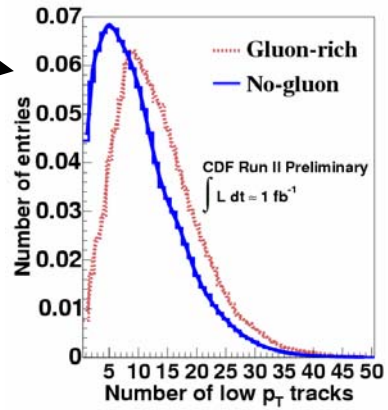
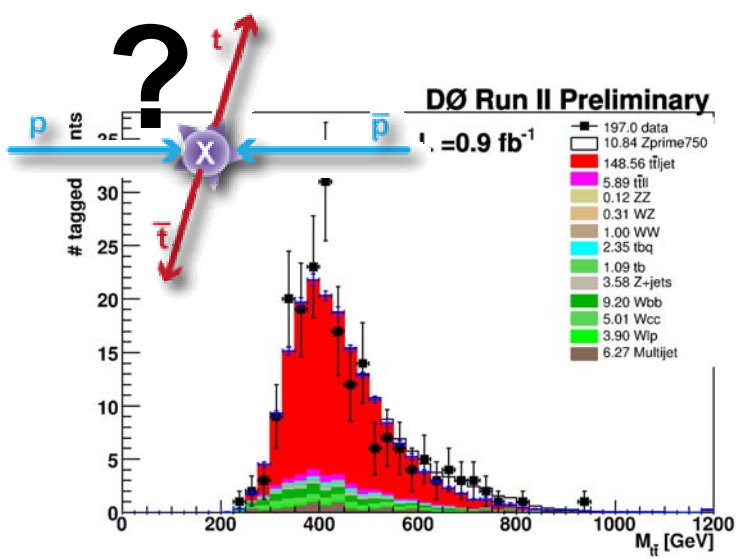
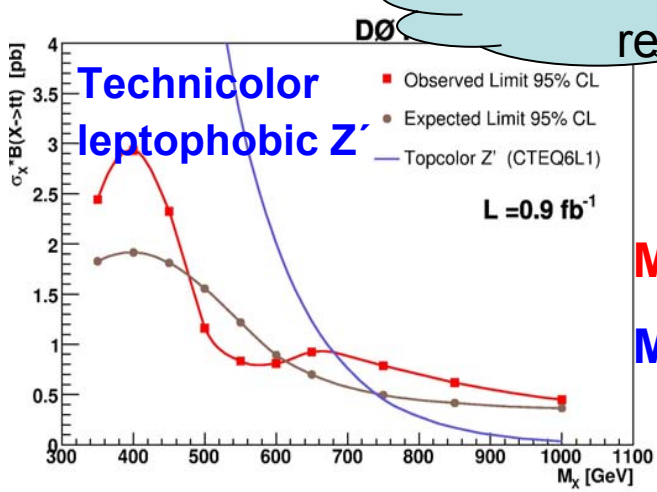


Searches for resonances in the tt invariant mass spectra:



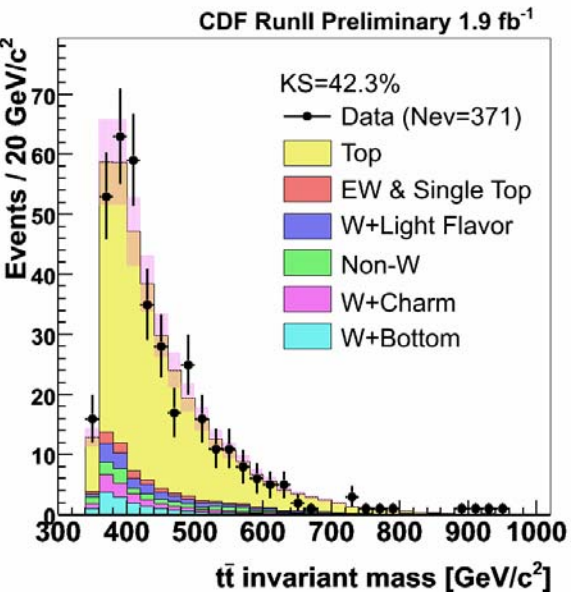


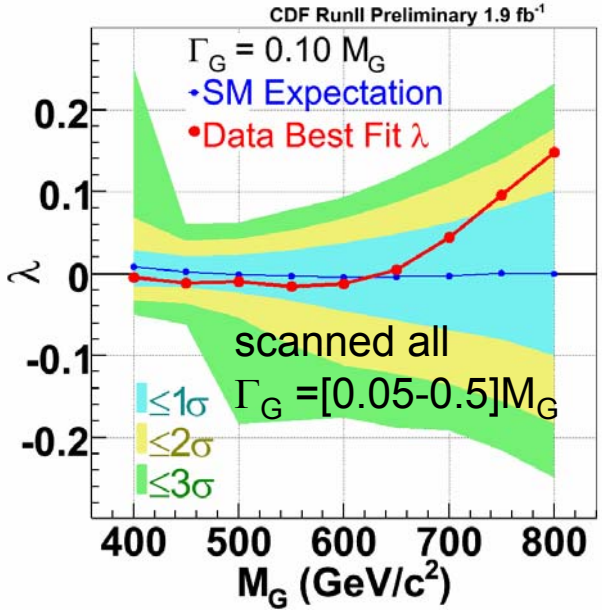
Possible new D0 result here

$M_{Z'}$ > 680 GeV/c^2(D0)

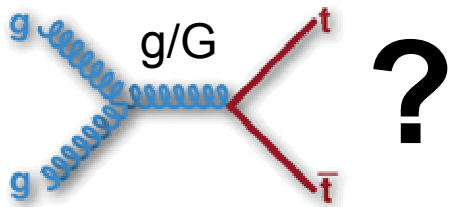
$M_{Z'}$ > 720 GeV/c^2(CDF)

Is top produced as expected?



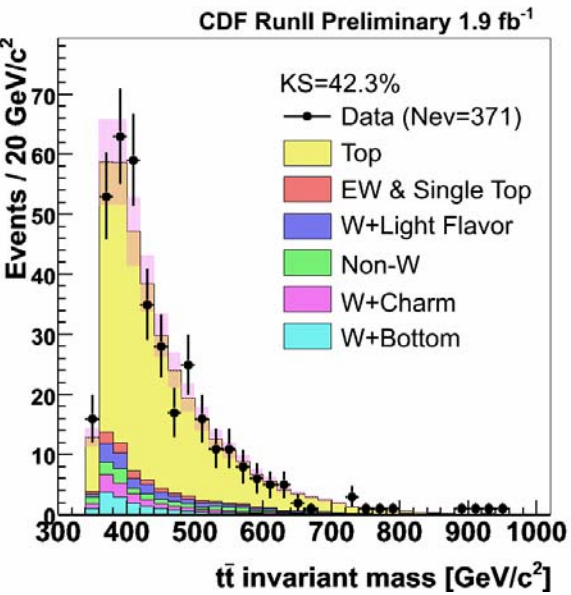


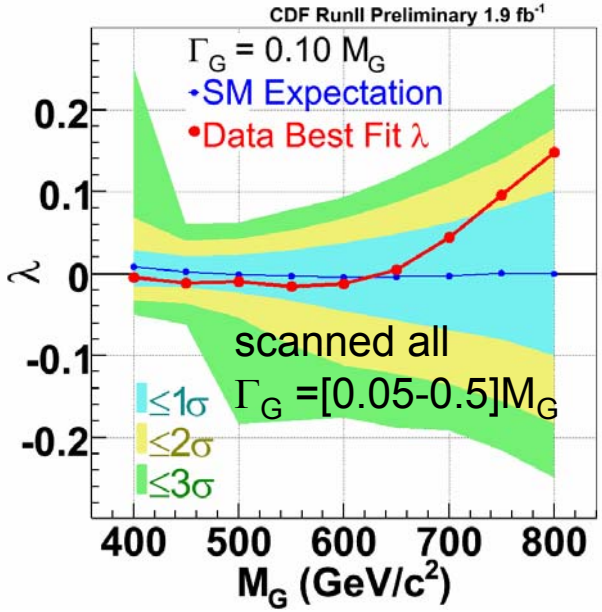
Searches for massive gluon decaying to t-tbar.



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

Is top produced as expected?





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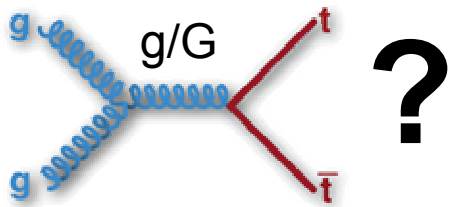

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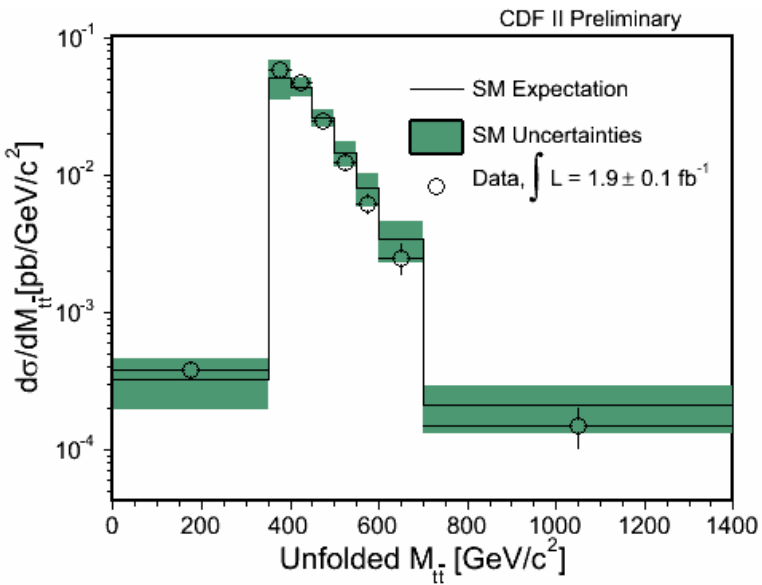
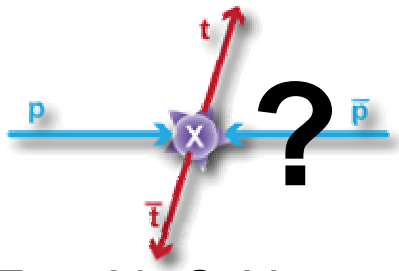




$d\sigma/dM_{tt}$ measurement

e/μ pT>20GeV/c

≥ 4 jets ET>20 GeV, Missing E_T > 20 GeV

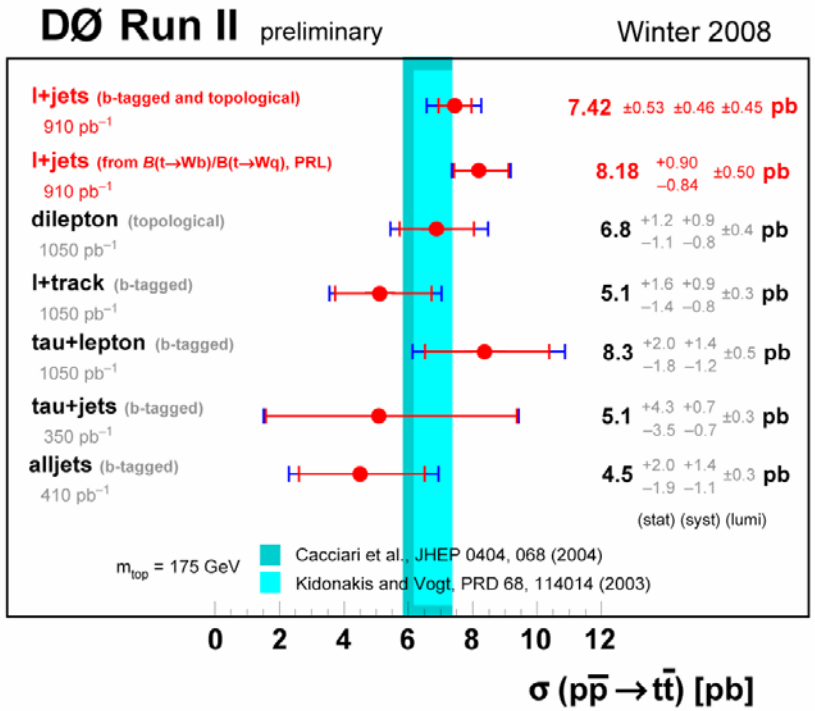
≥1 b-tag

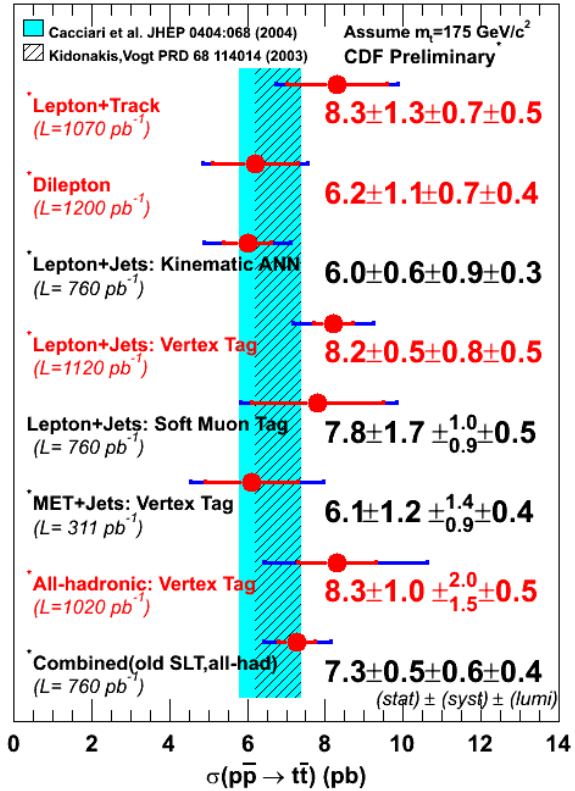
Correct M_{tt} for distortions from detector effects

(SVD method)

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

Conclusions



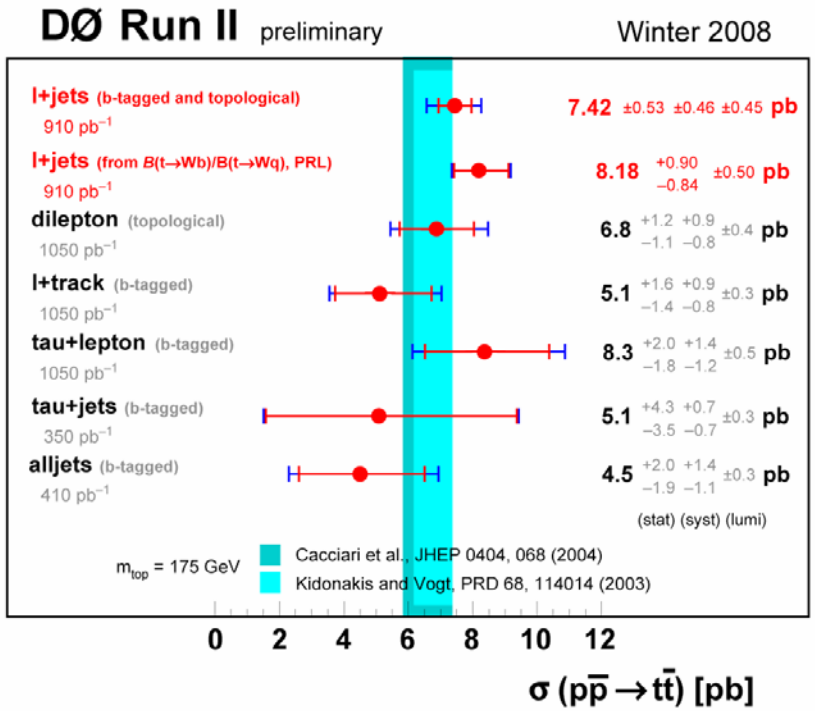


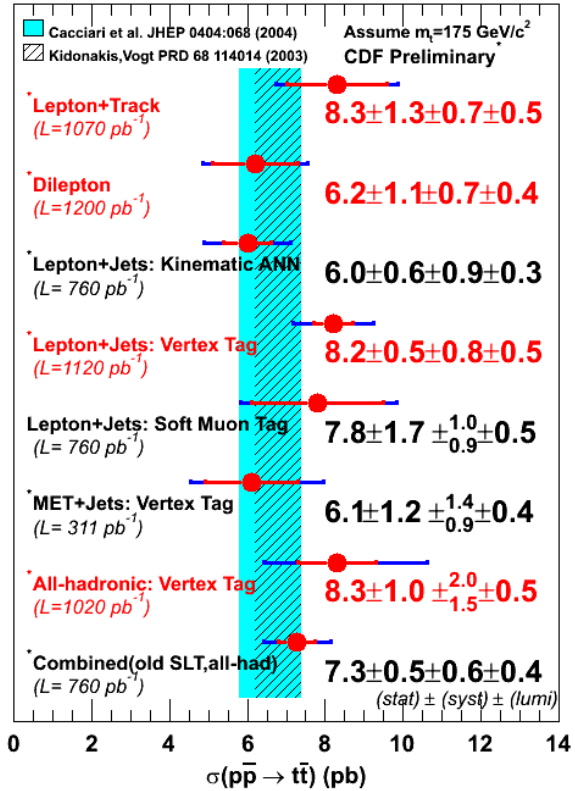
- **Cross section measurements are in good agreement w/ SM**
  experimental and theoretical uncertainty are at the same level

- **Production mechanism and top quark decays are consistent w/ SM expectation**

- **More statistics is already available, expecting lots of updates and new measurements for the Summer.**

Conclusions



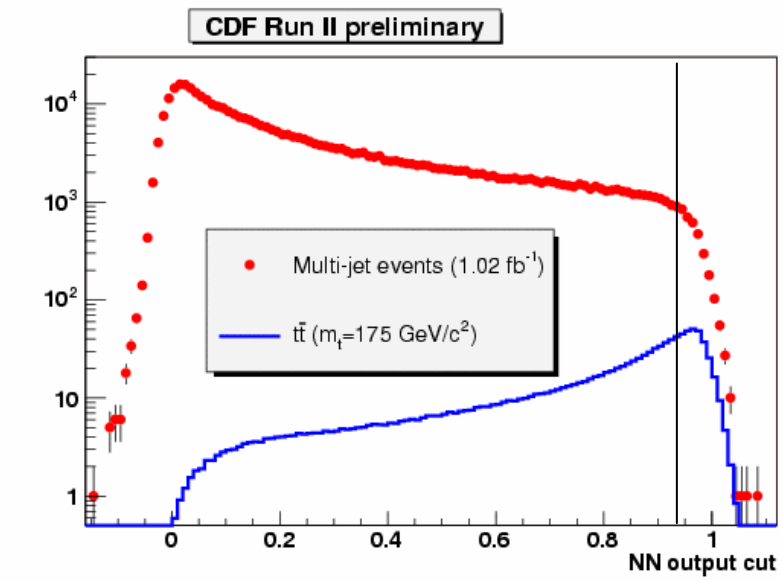


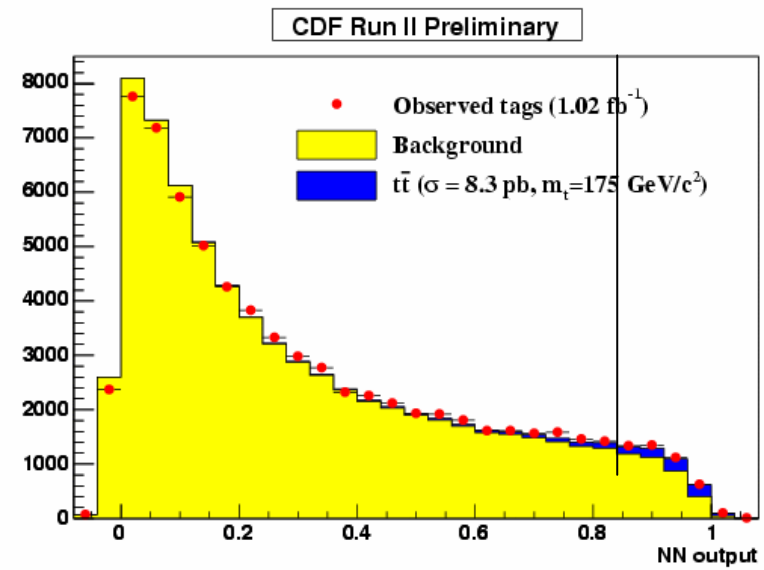
Not covered in this talk:

- **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 -

All-hadronic:





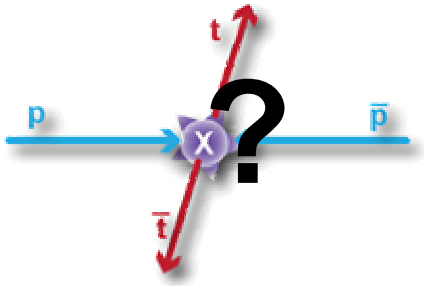
NN with 11 kinematical variable: $\varepsilon_{NN>0.94}$ = 4.8%; S/B~1/16
With at least 1 btag S/N = 1/2.2
Main systematics jet energy scale ~16%.

σ = 8.3 ± 1.0 (stat) + 2.0 - 1.5 (syst) ± 0.5 (lum) pb

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

4.5 +2.0 –1.9 (stat) +1.4 –1.1 (syst) ± 0.3 (lumi) pb (410 pb^{-1})

Is top produced as expected?



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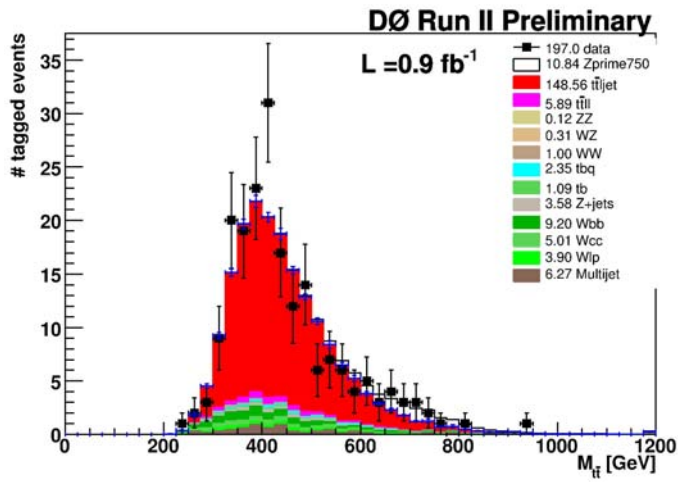
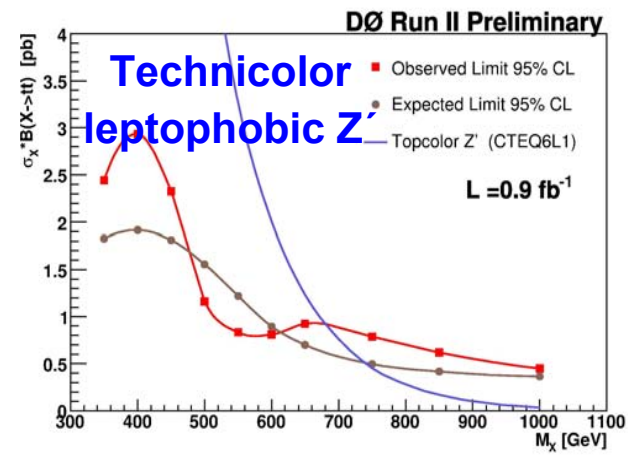
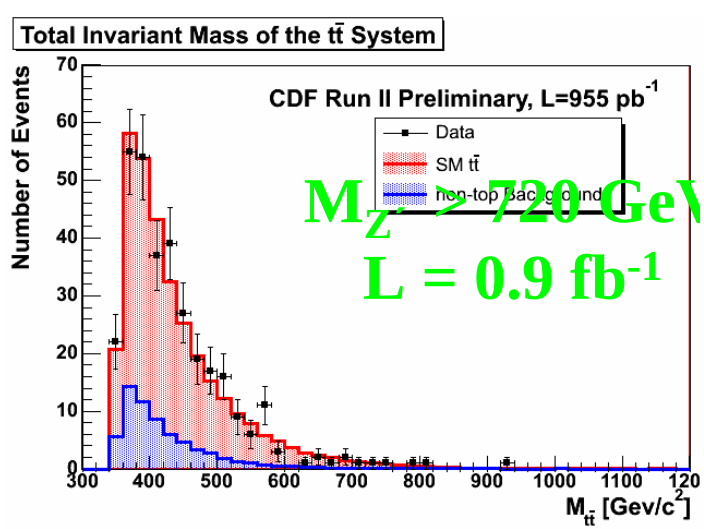




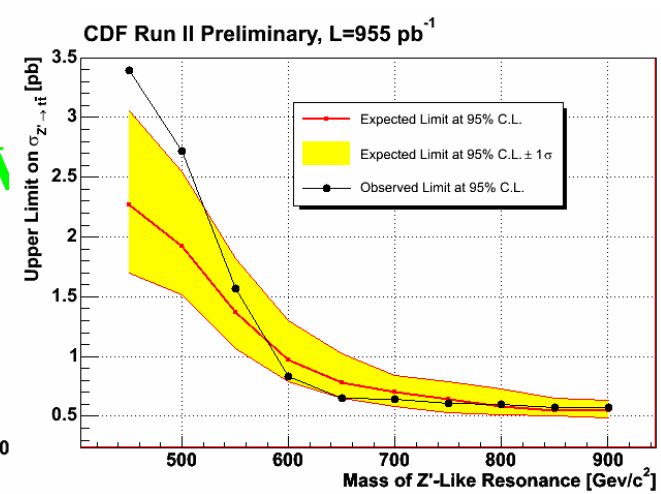
Exp.$M_{Z'}$ > 740 GeV

Obs. $M_{Z'}$ > 680 GeV

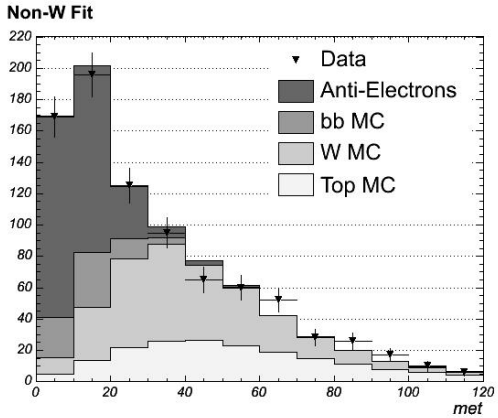


$M_{Z'}$ > 720 GeV

L = 0.9 fb^{-1}



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

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

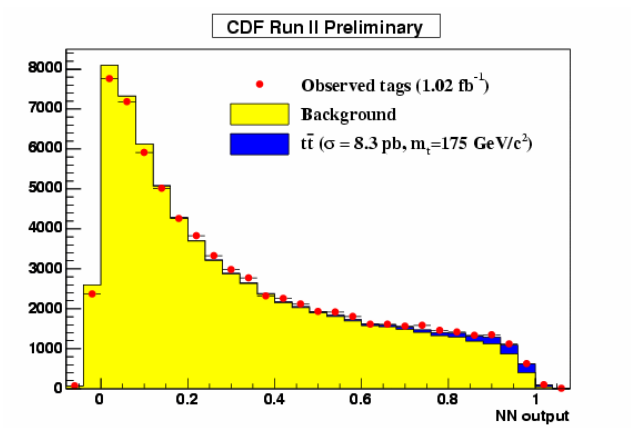
- B-tagged background:
  - Physics and mistag background
  - Fake lepton background
    - W+jets
    - tt$\rightarrow$lepton+jets

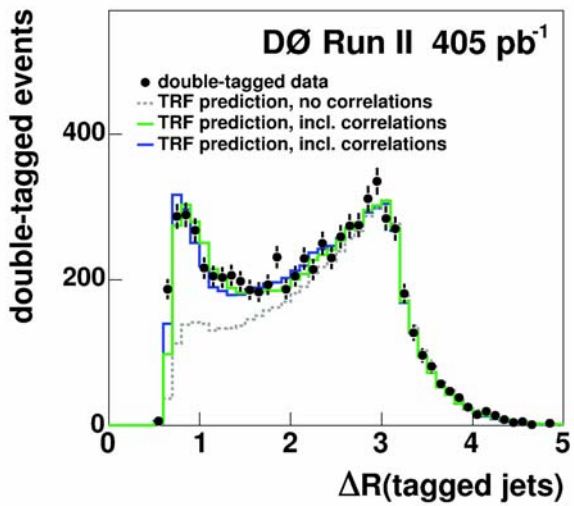
  positive mistag matrices for generic jets and tt

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 ΔR(jj).