Top Quark Production and Asymmetry at Tevatron

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On behalf of the CDF/D0 collaborations

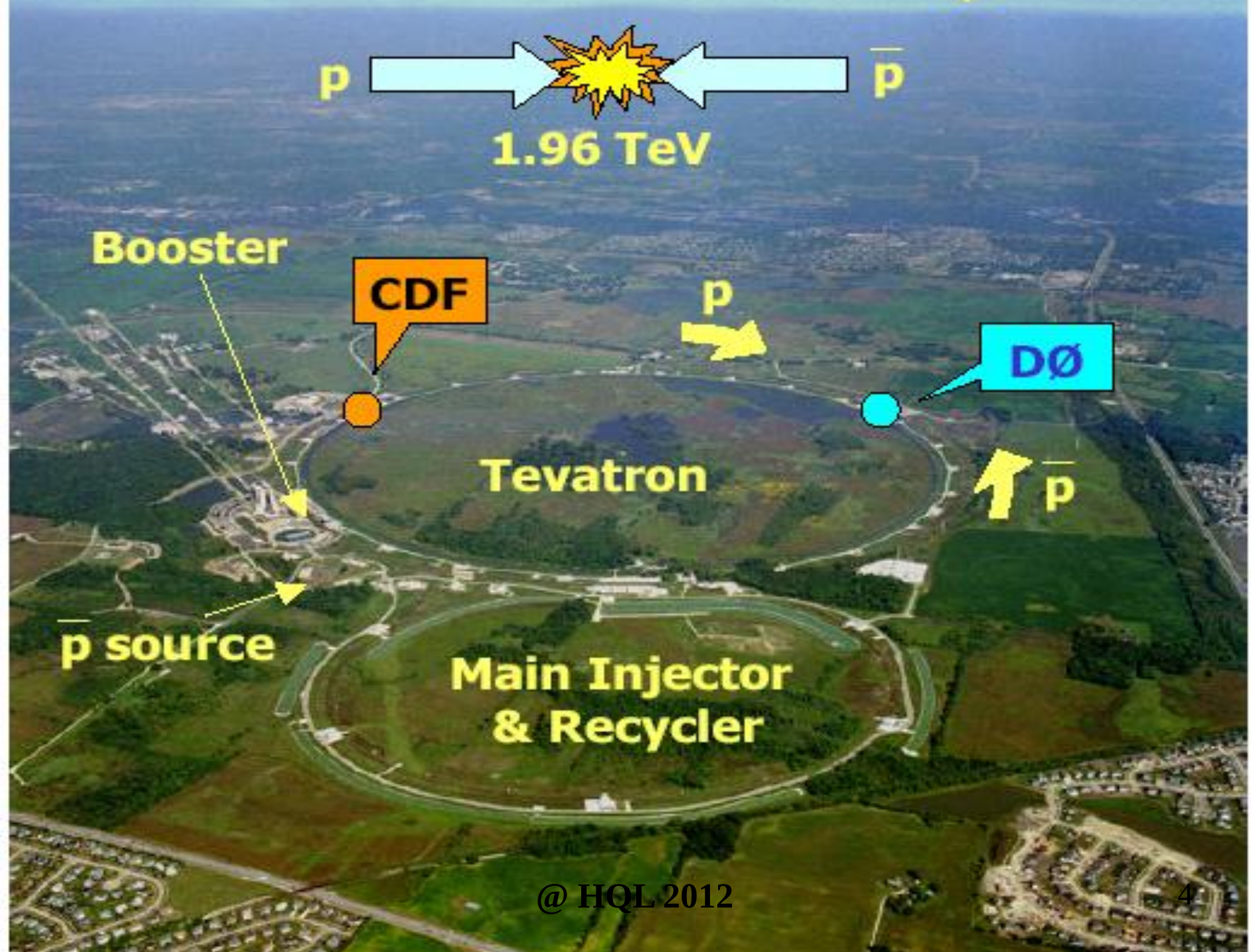
June 11-21, 2012 @HQL2012

Outline

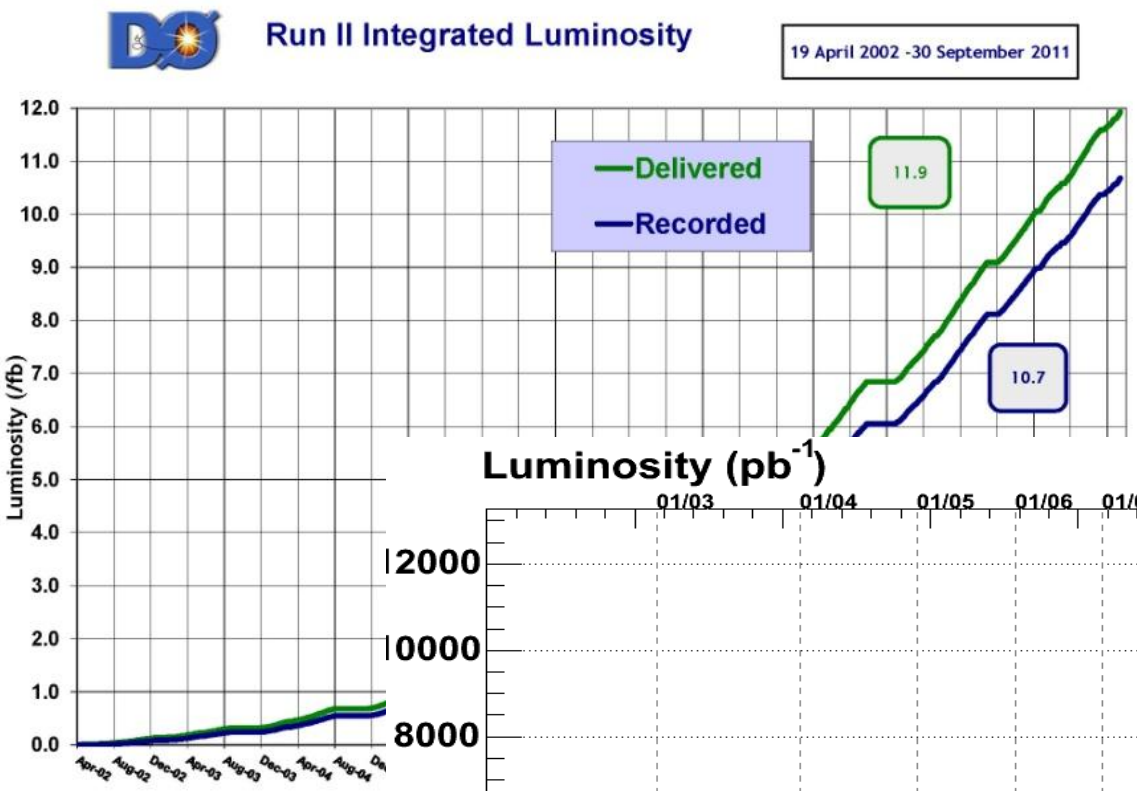
- **The Top quark**
- **Tevatron summary**
- **The CDF/D0 experiments**
- **Top quark production**
- **Production asymmetry**
- **Conclusion**

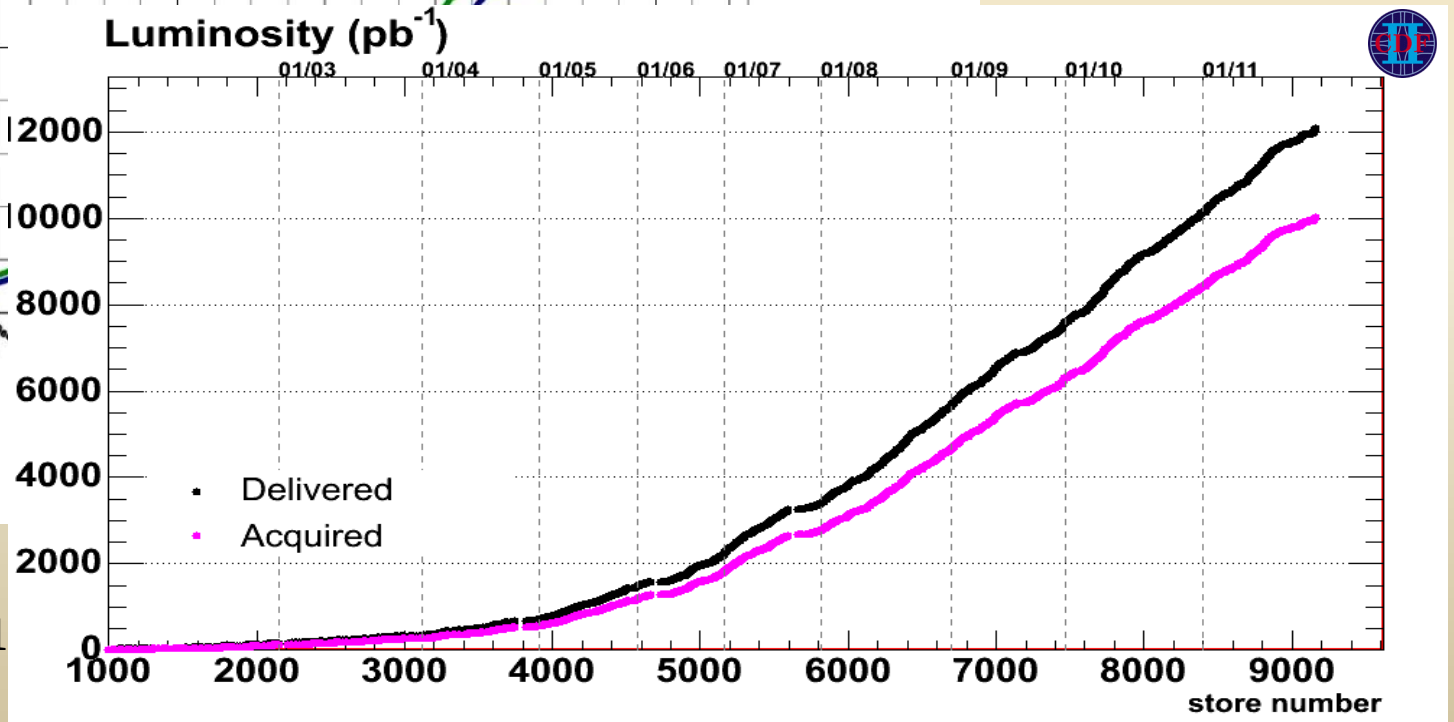
The Top quark

- Properties
  - ➢ Standard Model
    - Charge : + 2/3
    - Spin : 1/2
    - Mass : A free parameter
    - Life time: $\sim 10^{-25}$ s
- Top quark pairs are produced via proton antiproton collisions at Tevatron.


p
p̄
1.96 TeV
Booster
CDF
p
DØ
Tevatron
p̄
p̄ source
Main Injector
& Recycler

Tevatron Integrated luminosity

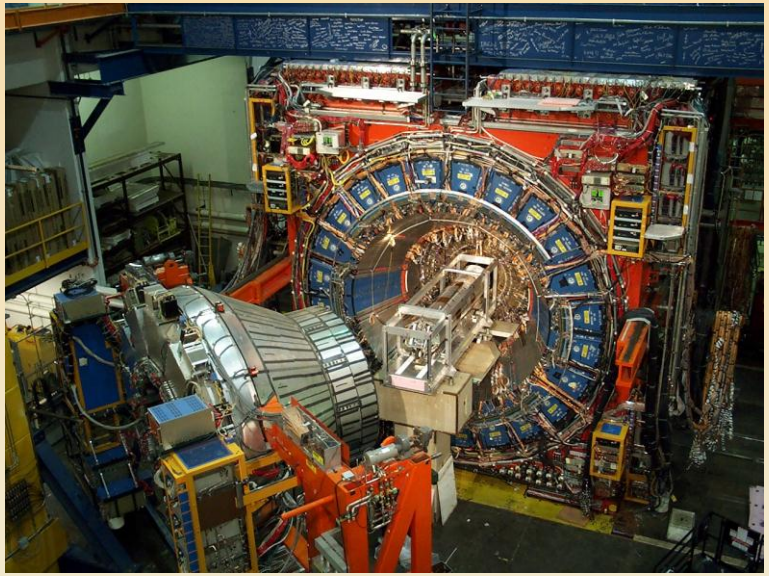


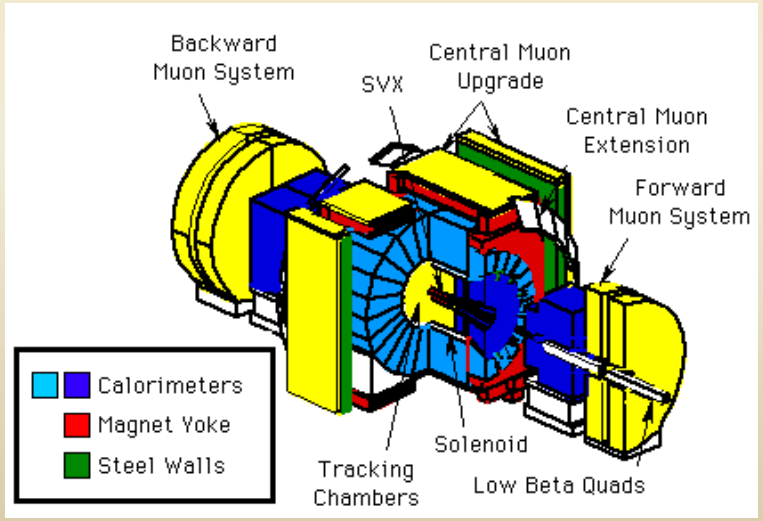


June, 11-21, 201

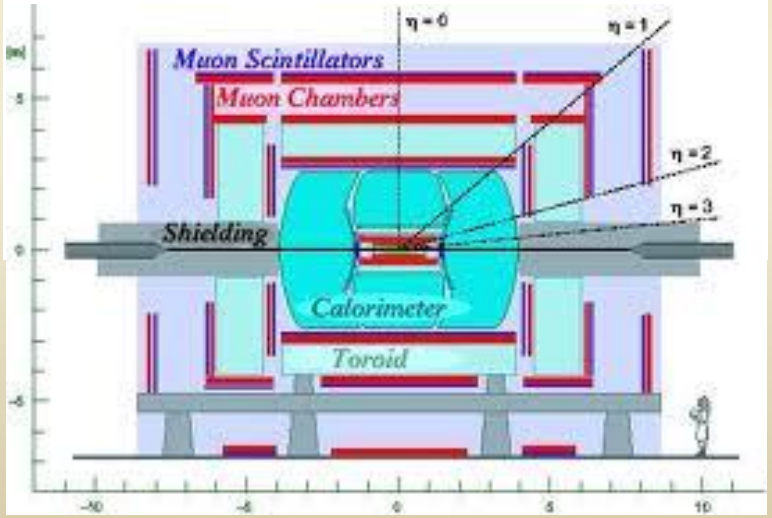
The detectors

CDF

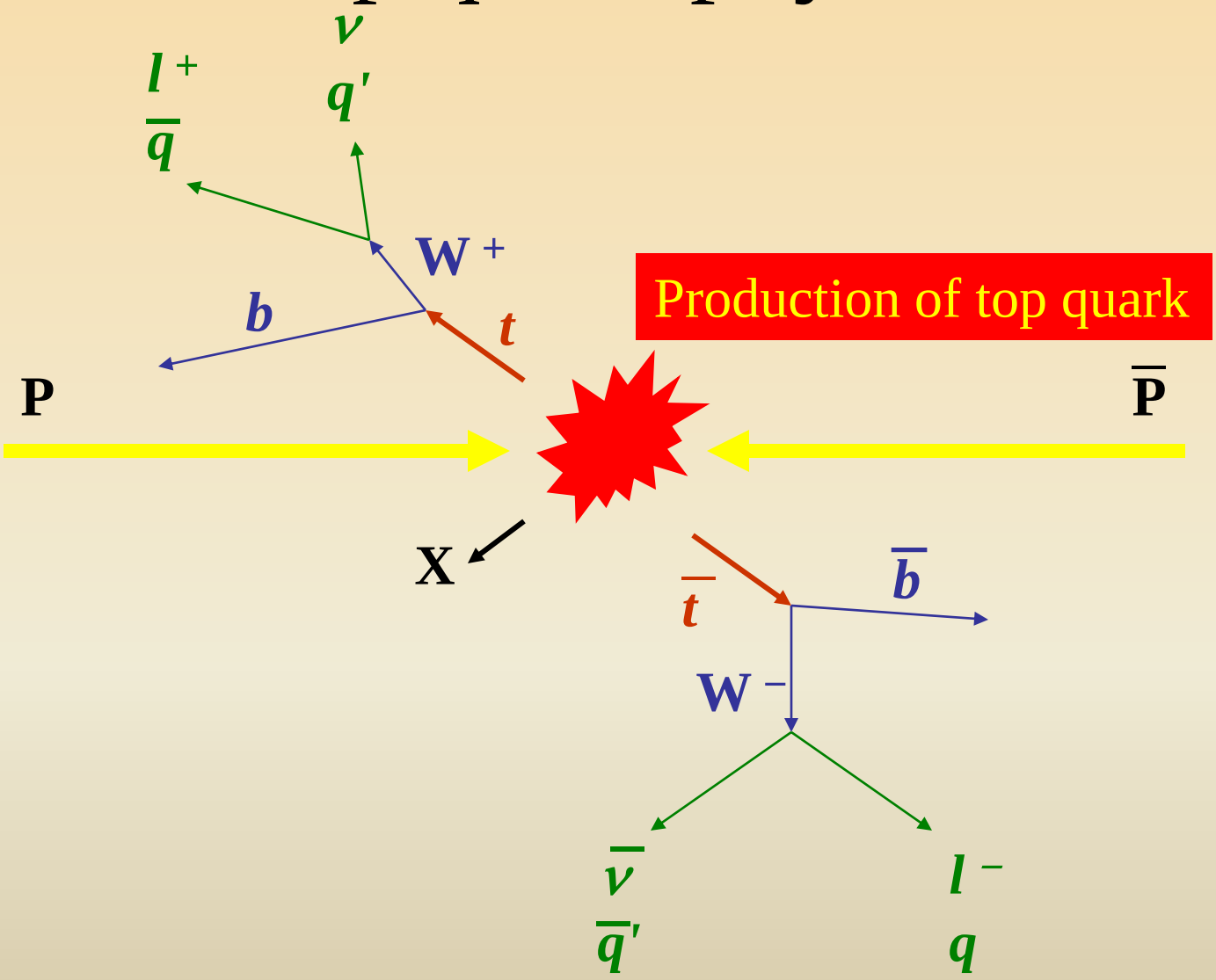




D0

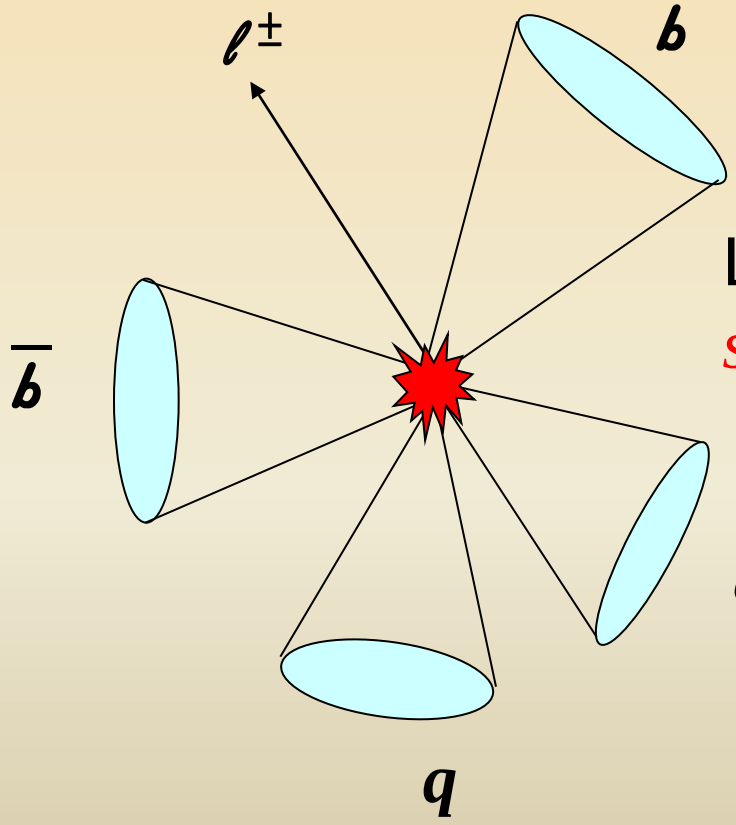


Top quark physics



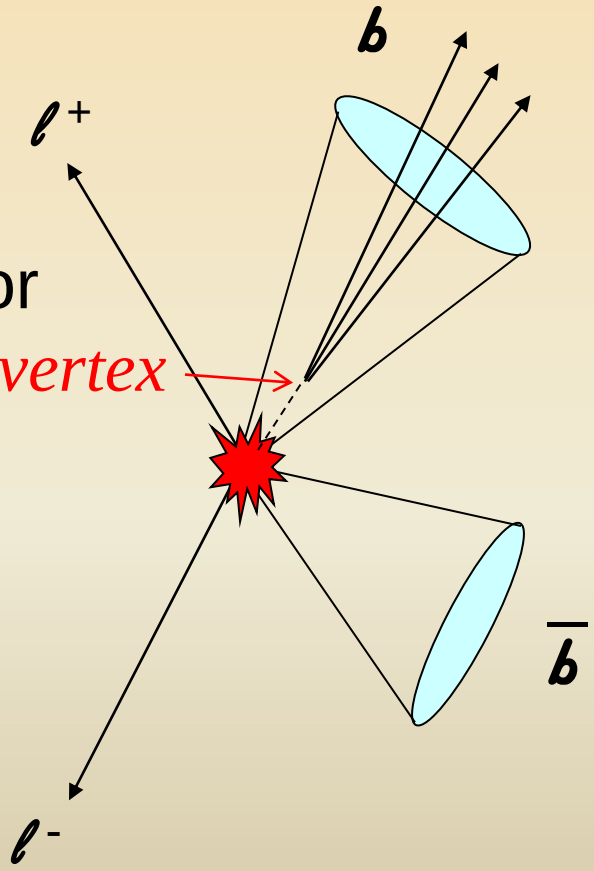
$t\bar{t}$ decay channels used

Lepton + Jets, **LJ**



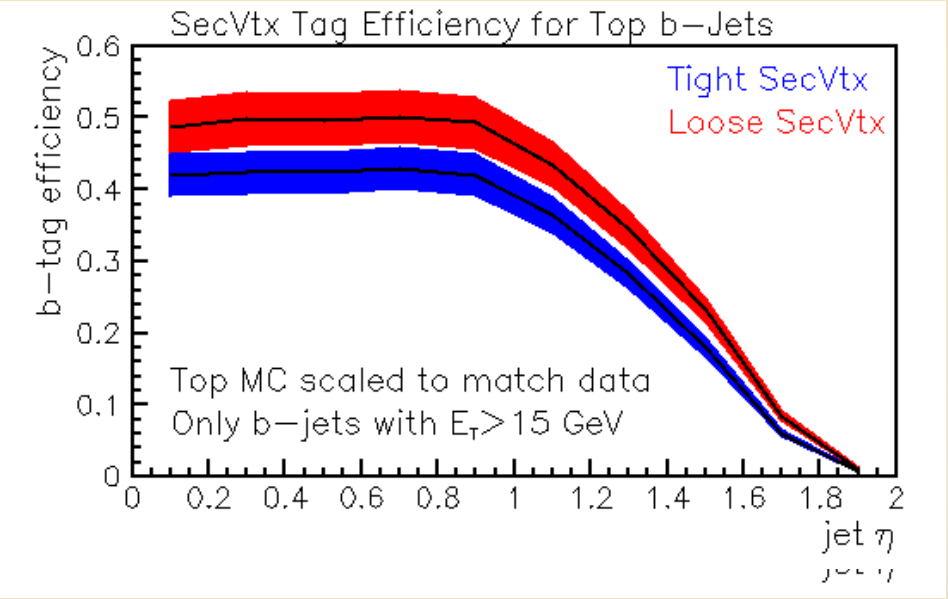
Looking for
secondary vertex

Di-lepton, **DIL**

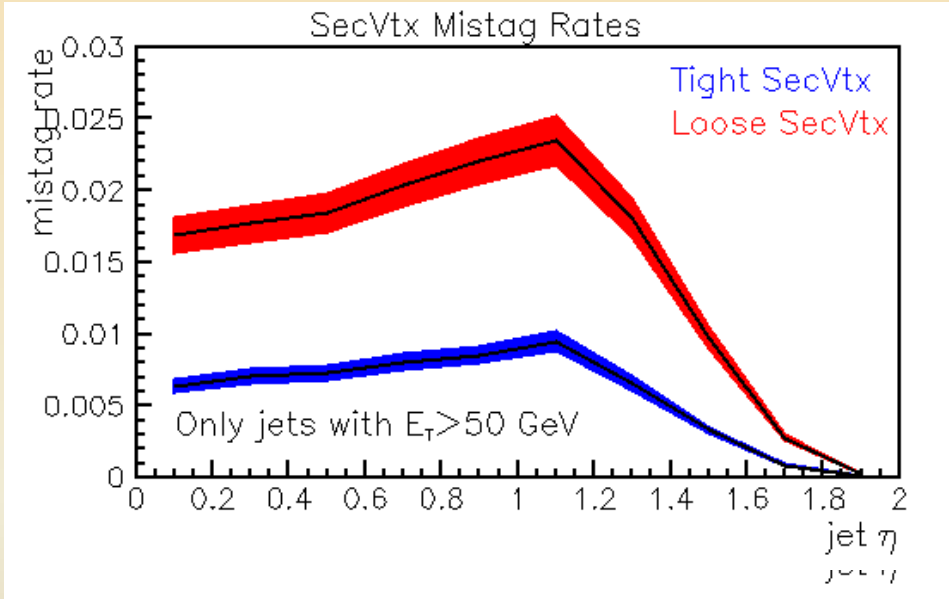


B tagging via Secondary vertex (SVX)

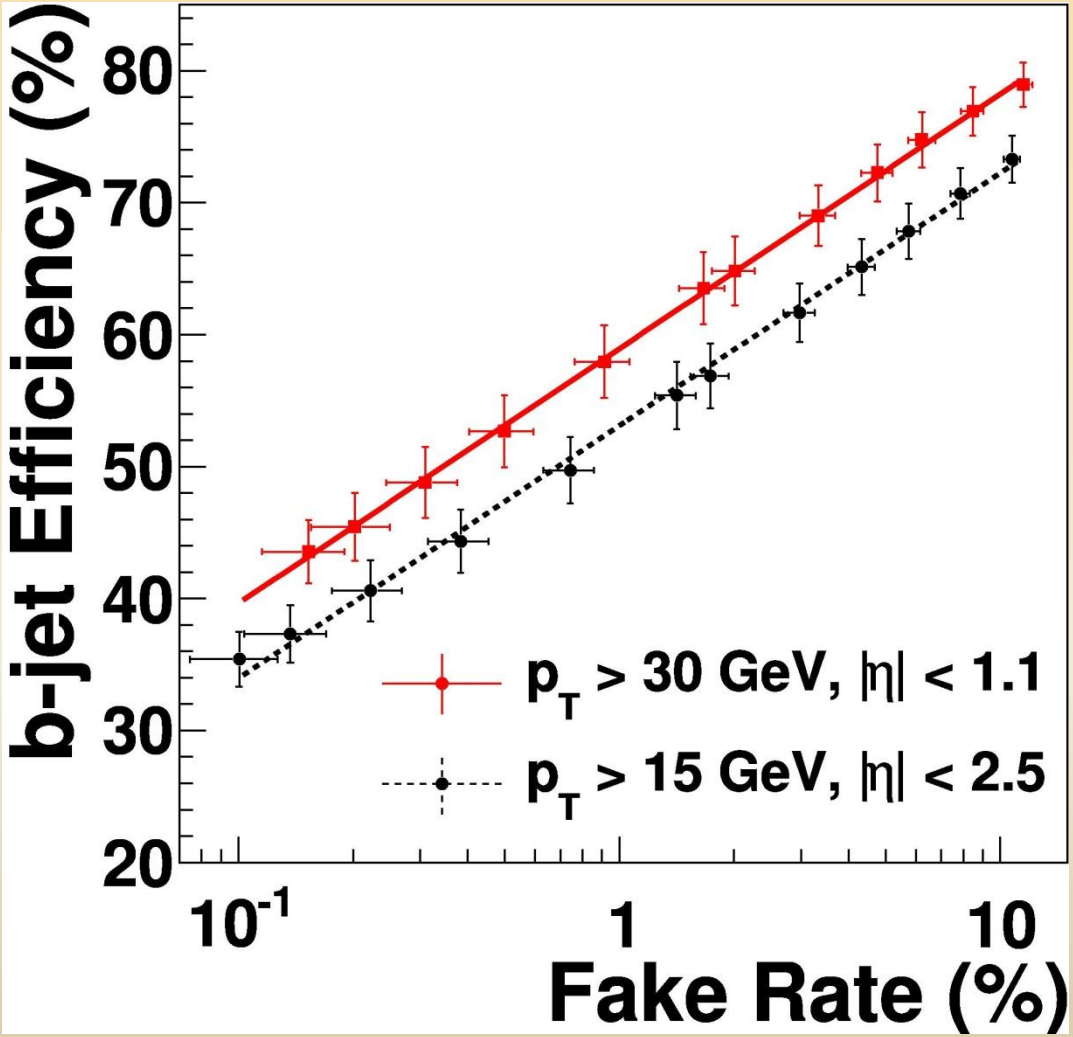
Efficiency



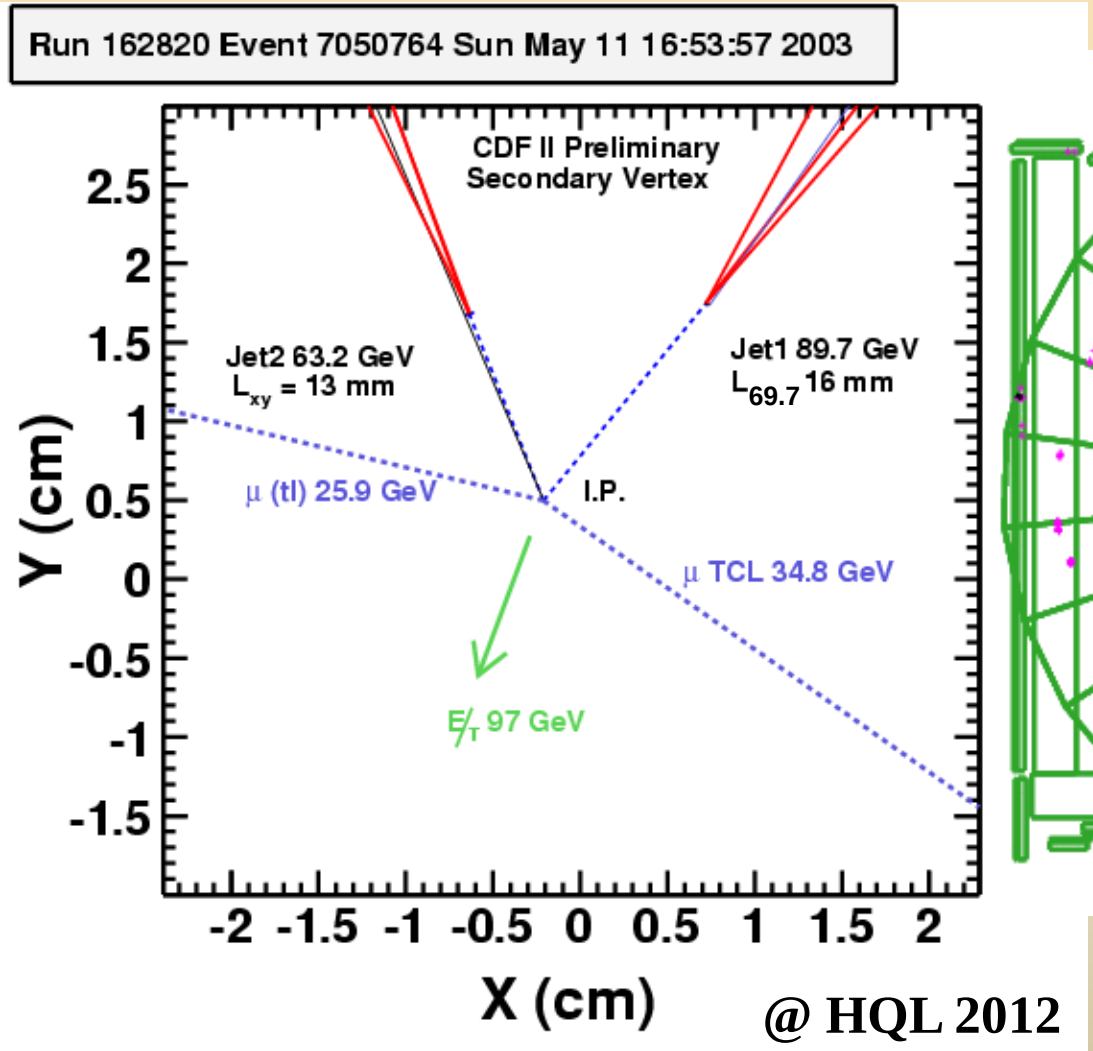
Mistagging

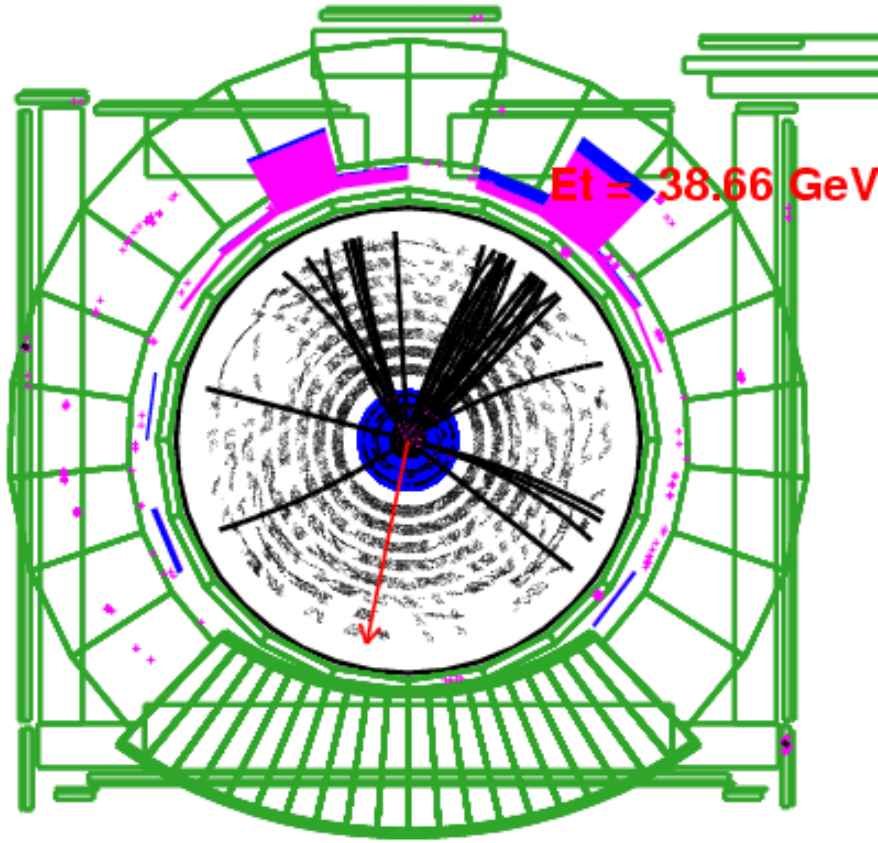


B tagging at D0



Top di-lepton event candidate





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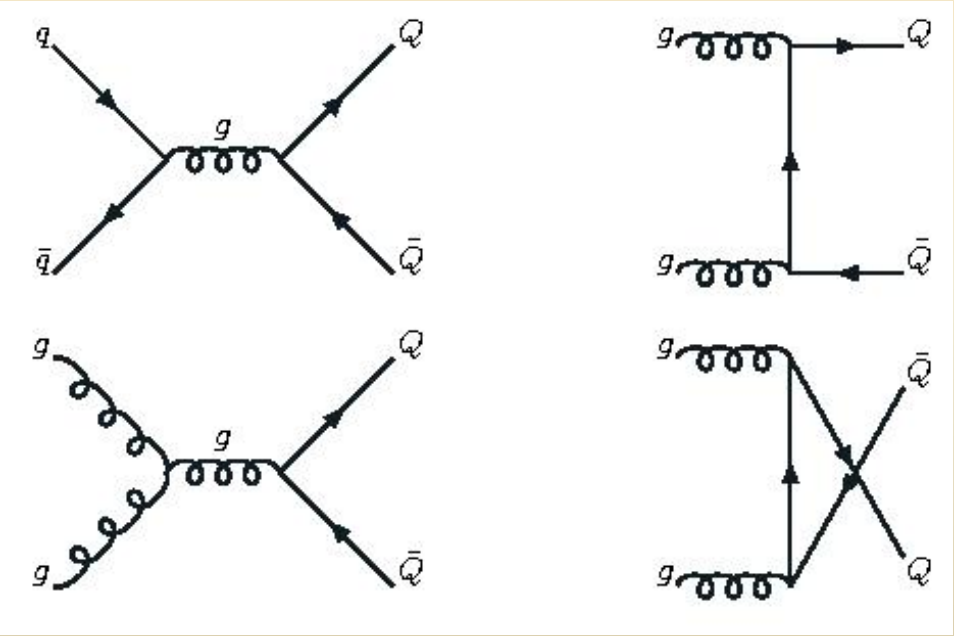
Top quark production

- $p\bar{p} \rightarrow t\bar{t}$
  - $\sigma \sim 7.22$ pb at $\sqrt{S} = 1.96$ TeV:

    (NNLL, C. Schwinn, arXiv:1205.0988)
  - 90% $q\bar{q} \rightarrow t\bar{t}$; 10% $gg \rightarrow t\bar{t}$

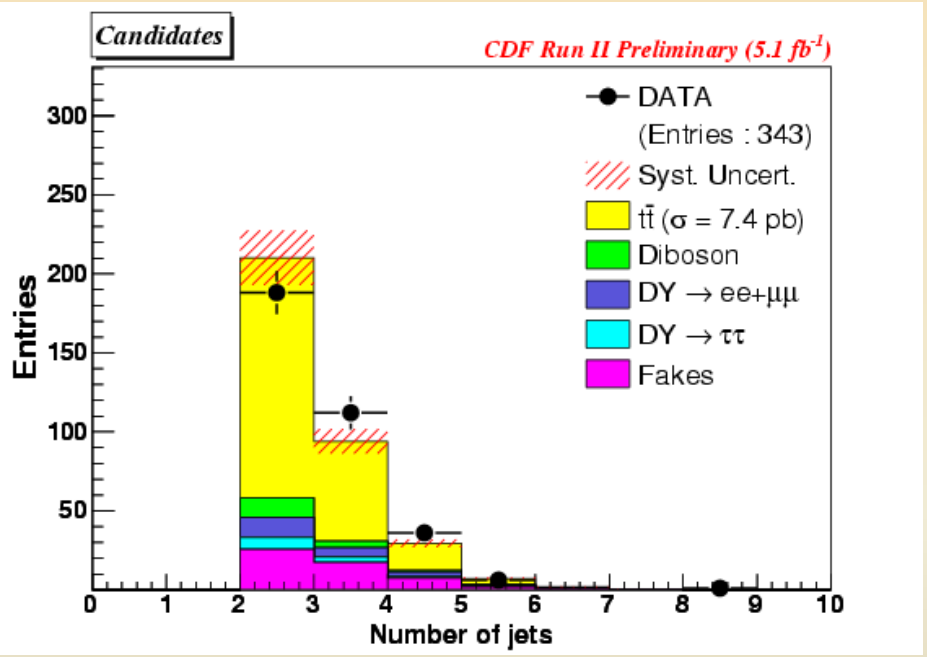


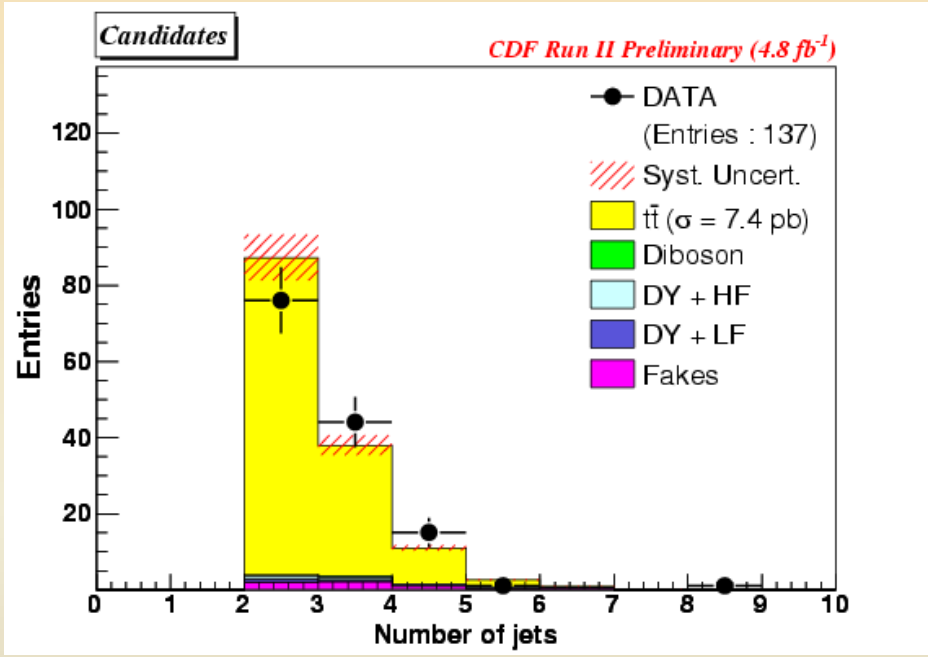
+ …

DIL event selection

- Two high p_T leptons
  - > 20 GeV (CDF), > 15 GeV(D0)
  - $|\eta| < 2$
- High missing E_T due to the two neutrinos being missing in detection
- Suppressing of Z boson events
- High total transverse energy
- Two or more jets

Cross section
using dilepton events, 5.1 fb^{-1}
$M_{top} = 172.5\ GeV/c^2$

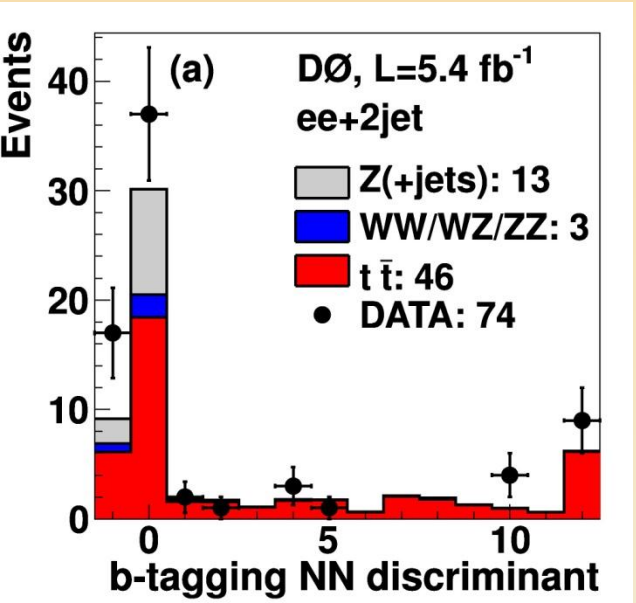


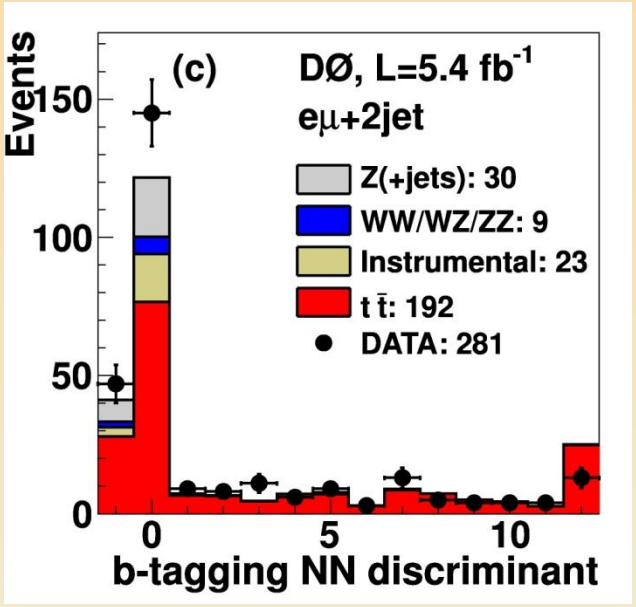


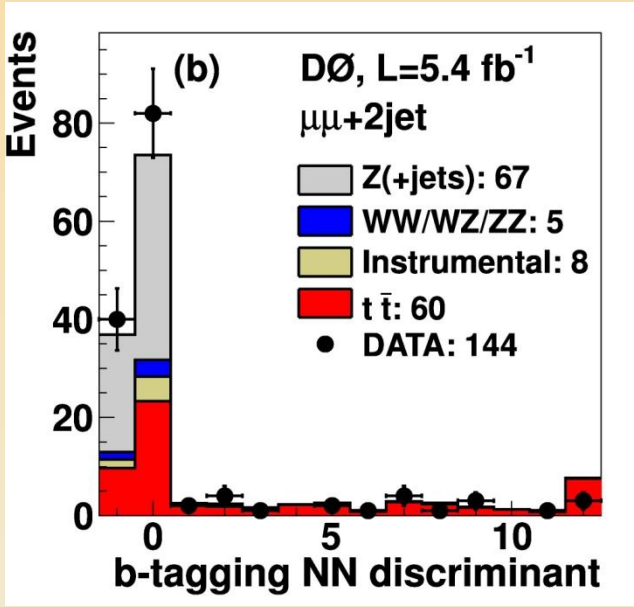
$\sigma_{pretag} = 7.40 \pm 0.58_{stat} \pm 0.63_{syst} \pm 0.45_{lumi}$ pb

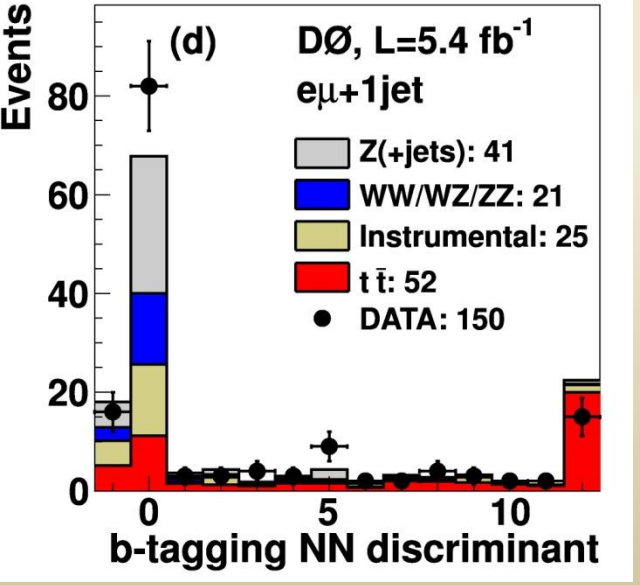
$\sigma_{btag} = 7.25 \pm 0.66_{stat} \pm 0.47_{syst} \pm 0.44_{lumi}$ pb

Production cross section







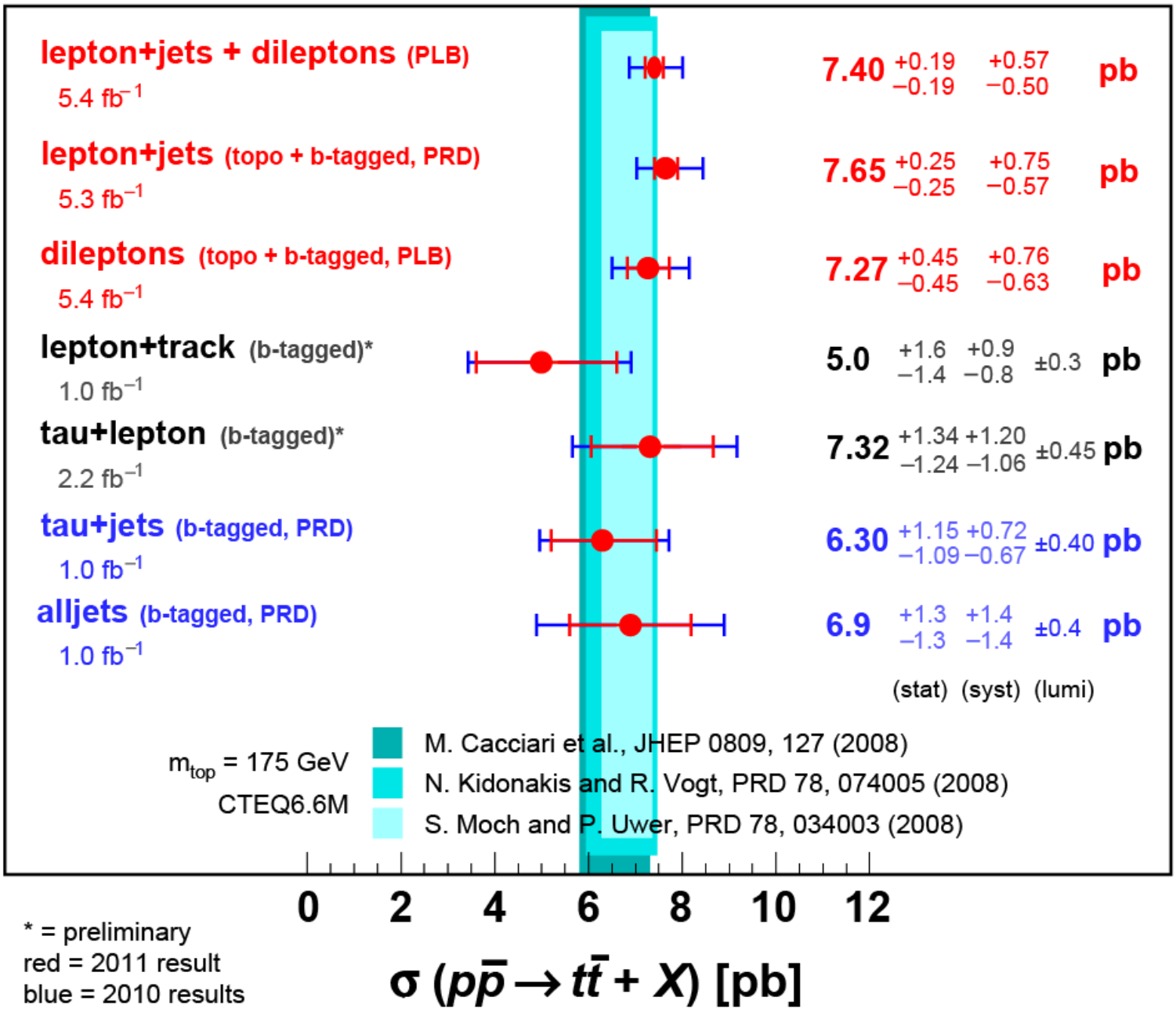


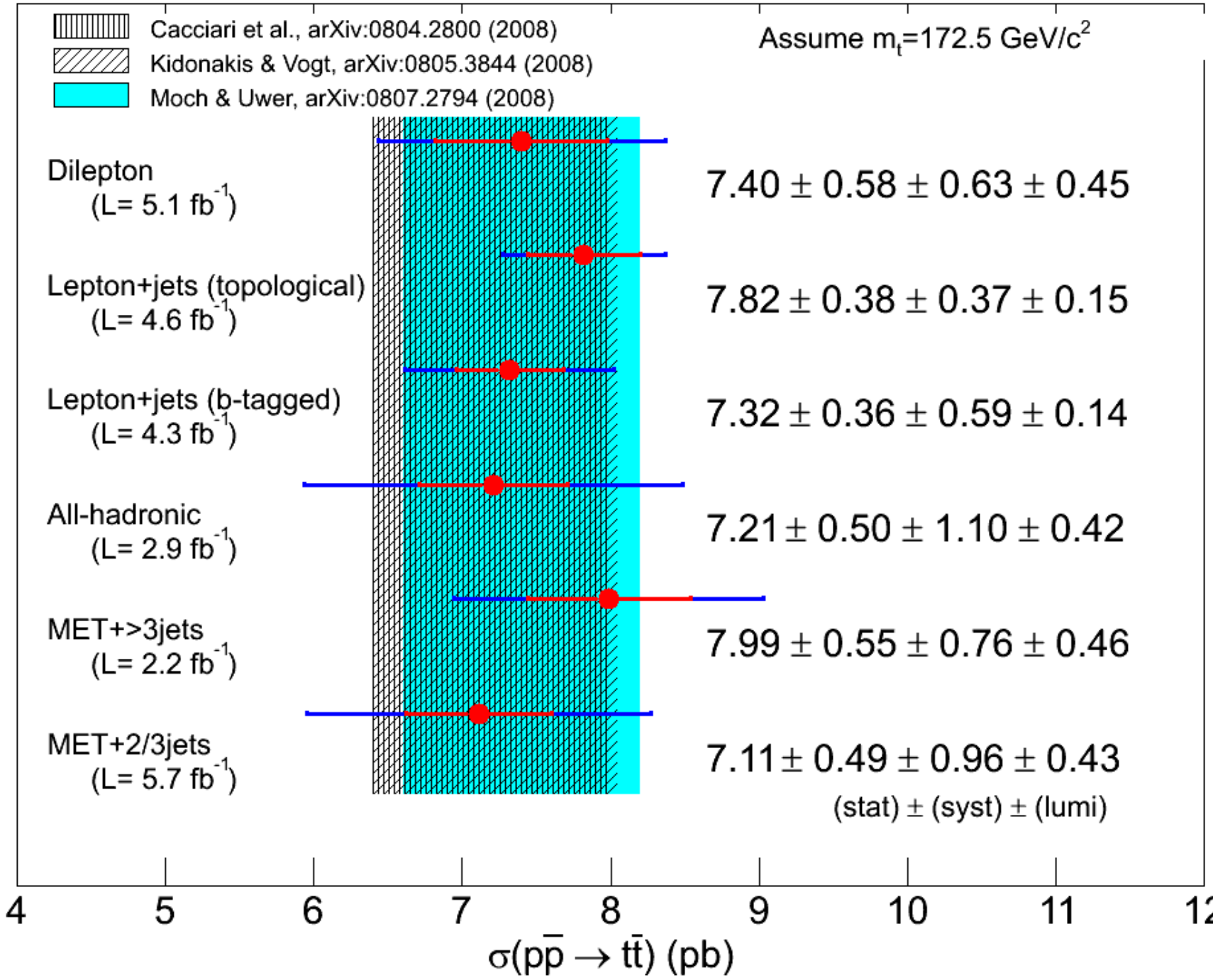
DIL alone: (m_{top}=172.5 GeV)

σ = 7.36 +0.90 -0.79 (stat + syst +lumi) pb

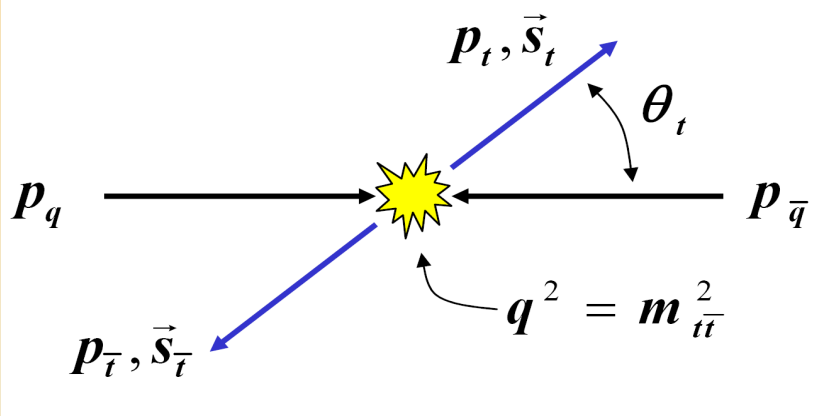
Combined with LJ:

$\sigma = 7.56\ ^{+0.63}_{-0.56}$ (stat+syst + lumi) pb


DØ Run II
July 2011
lepton+jets + dileptons (PLB)
5.4 fb−1
7.40 +0.19 −0.19 +0.57 −0.50 pb
lepton+jets (topo + b-tagged, PRD)
5.3 fb−1
7.65 +0.25 −0.25 +0.75 −0.57 pb
dileptons (topo + b-tagged, PLB)
5.4 fb−1
7.27 +0.45 −0.45 +0.76 −0.63 pb
lepton+track (b-tagged)*
1.0 fb−1
5.0 +1.6 −1.4 +0.9 −0.8 ±0.3 pb
tau+lepton (b-tagged)*
2.2 fb−1
7.32 +1.34 −1.24 +1.20 −1.06 ±0.45 pb
tau+jets (b-tagged, PRD)
1.0 fb−1
6.30 +1.15 −1.09 +0.72 −0.67 ±0.40 pb
alljets (b-tagged, PRD)
1.0 fb−1
6.9 +1.3 −1.3 +1.4 −1.4 ±0.4 pb
(stat) (syst) (lumi)
mtop = 175 GeV
CTEQ6.6M
M. Cacciari et al., JHEP 0809, 127 (2008)
N. Kidonakis and R. Vogt, PRD 78, 074005 (2008)
S. Moch and P. Uwer, PRD 78, 034003 (2008)
0 2 4 6 8 10 12
* = preliminary
red = 2011 result
blue = 2010 results
σ (pp̄ → tt̄ + X) [pb]


Cacciari et al., arXiv:0804.2800 (2008)
Kidonakis & Vogt, arXiv:0805.3844 (2008)
Moch & Uwer, arXiv:0807.2794 (2008)
Assume m_t=172.5 GeV/c^2
Dilepton
(L= 5.1 fb^{-1})
7.40 ± 0.58 ± 0.63 ± 0.45
Lepton+jets (topological)
(L= 4.6 fb^{-1})
7.82 ± 0.38 ± 0.37 ± 0.15
Lepton+jets (b-tagged)
(L= 4.3 fb^{-1})
7.32 ± 0.36 ± 0.59 ± 0.14
All-hadronic
(L= 2.9 fb^{-1})
7.21 ± 0.50 ± 1.10 ± 0.42
MET+>3jets
(L= 2.2 fb^{-1})
7.99 ± 0.55 ± 0.76 ± 0.46
MET+2/3jets
(L= 5.7 fb^{-1})
7.11 ± 0.49 ± 0.96 ± 0.43
(stat) ± (syst) ± (lumi)
4
5
6
7
8
9
10
11
12
$\sigma(p\bar{p} \rightarrow t\bar{t})$ (pb)

Top production asymmetry



- Differential cross section

$$\frac{d\sigma}{d\cos\theta} \propto \frac{\alpha_s^2}{q^2}\left[1+\cos^2\theta^* + (1-\beta^2)\sin^2\theta^* + \frac{q^2}{q^2-M^2}\cos\theta^*\right]$$

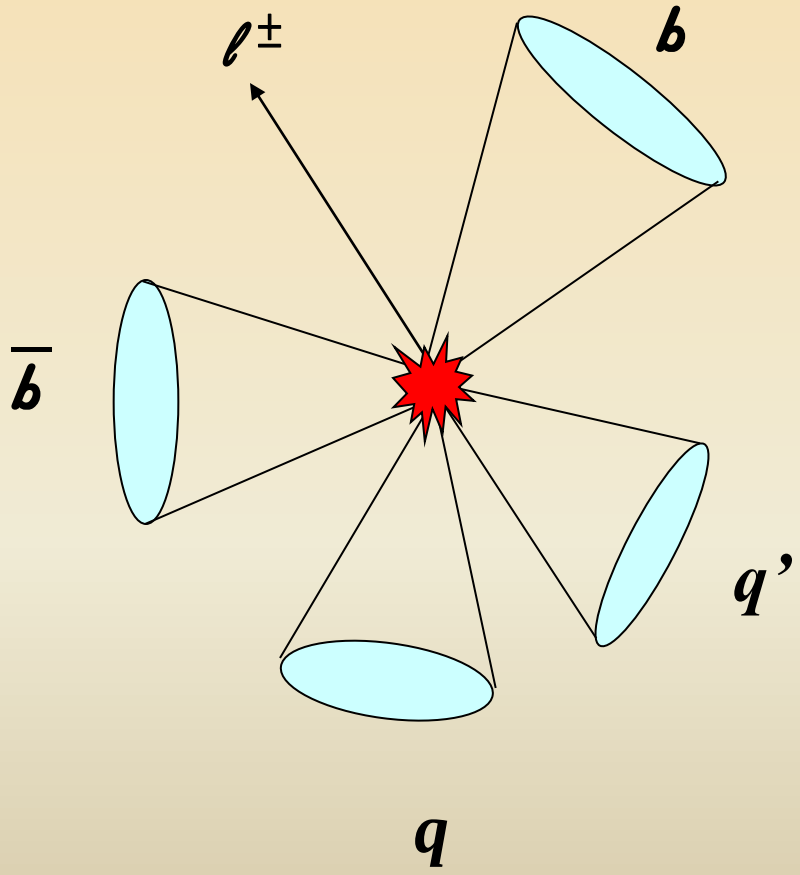
- Dependent on q^2 and $\theta^* \rightarrow M_{t\bar{t}}$ and Δy
- There is asymmetry with respect to beamline

Theoretical interest

- Exotic gluons
  - massive chiral color
  - RS gluon
  - color sextets, anti-triplets
- Intermediate Vector B´
  - Z´, W´,…
- …

- Model building must contend with
  - total σ in good agreement with SM
  - $d\sigma/dM_{tt}$ in good agreement with SM

Using the lepton + jets events

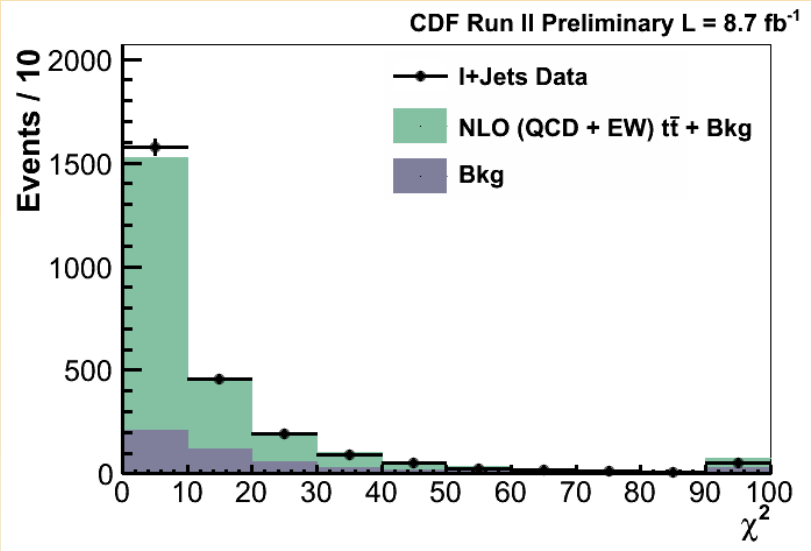


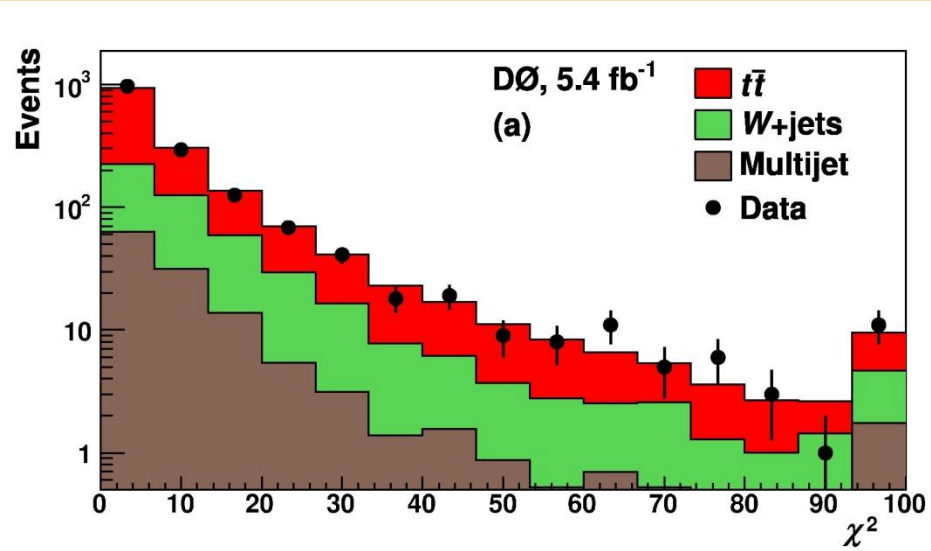
CDF, full RUN II data,
with good silicon, 8.7 fb^{-1}

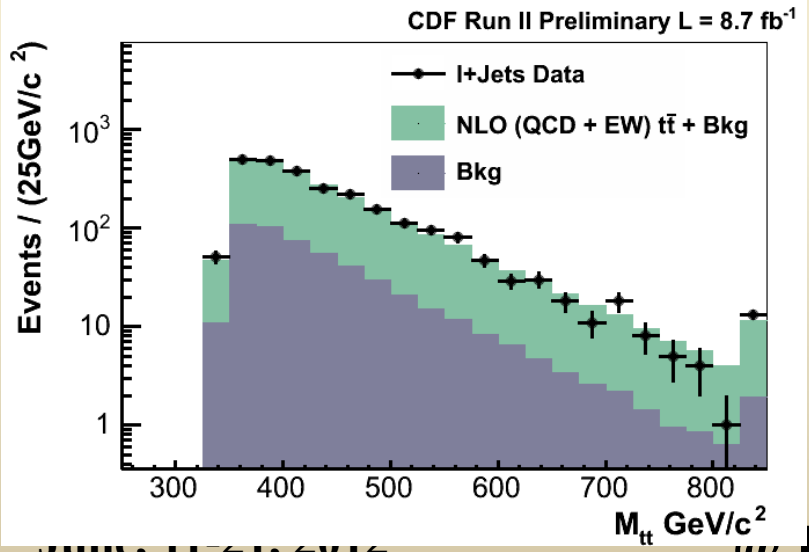
- high p_T lepton (e/μ)
  - $E_t/p_t > 20$ GeV (/c)
  - $|\eta| < 1.0$
- missing E_T
- Four or more jets
  - $|\eta| < 2.0$
- at least one b-tagged jet
  - $|\eta| < 1.0$

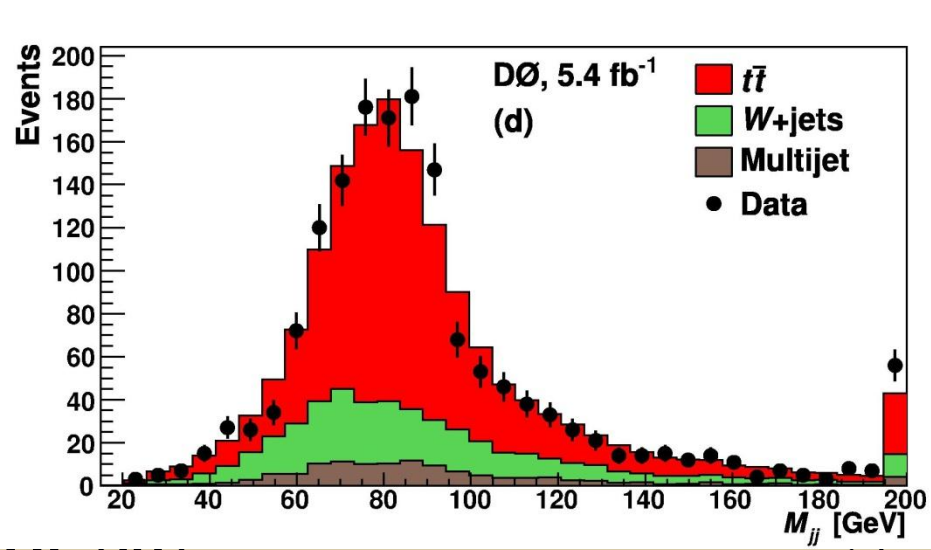
- 2498 events
- 505±123 non-tt background
  - mostly W+jets

Top reconstruction









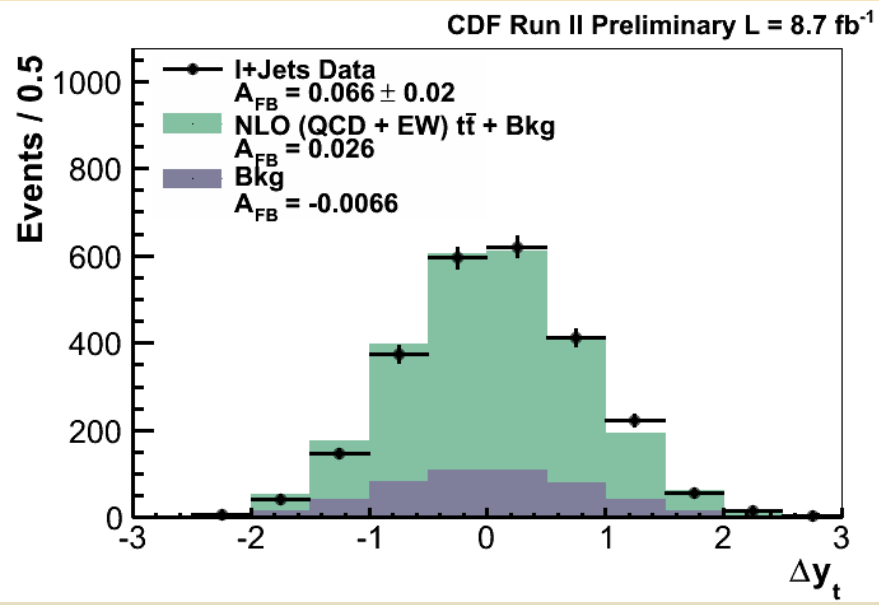
Asymmetry in the $t\bar{t}$ rest frame

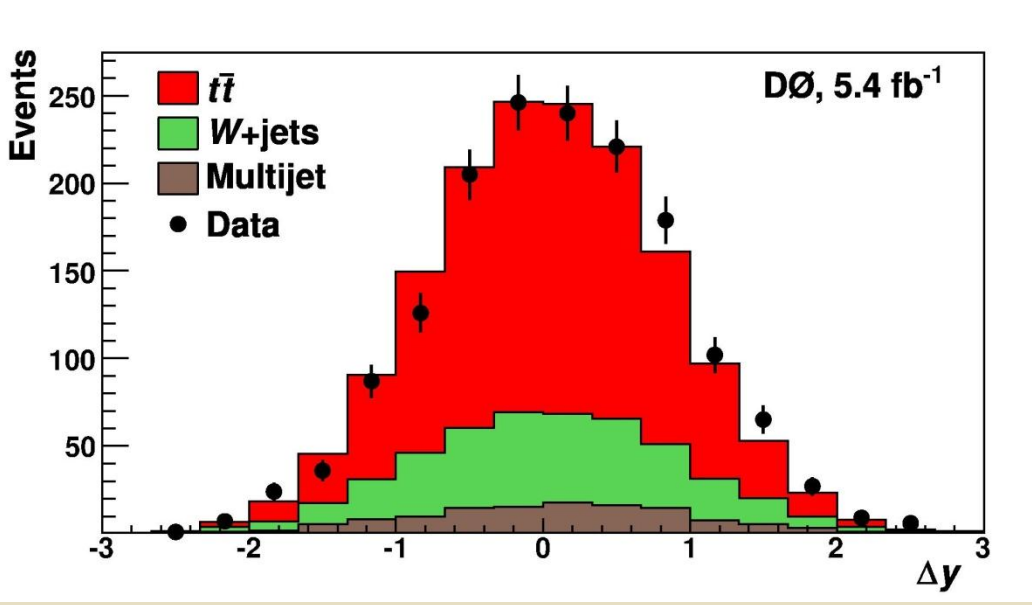
$$\Delta y_{t\bar{t}}$$

$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

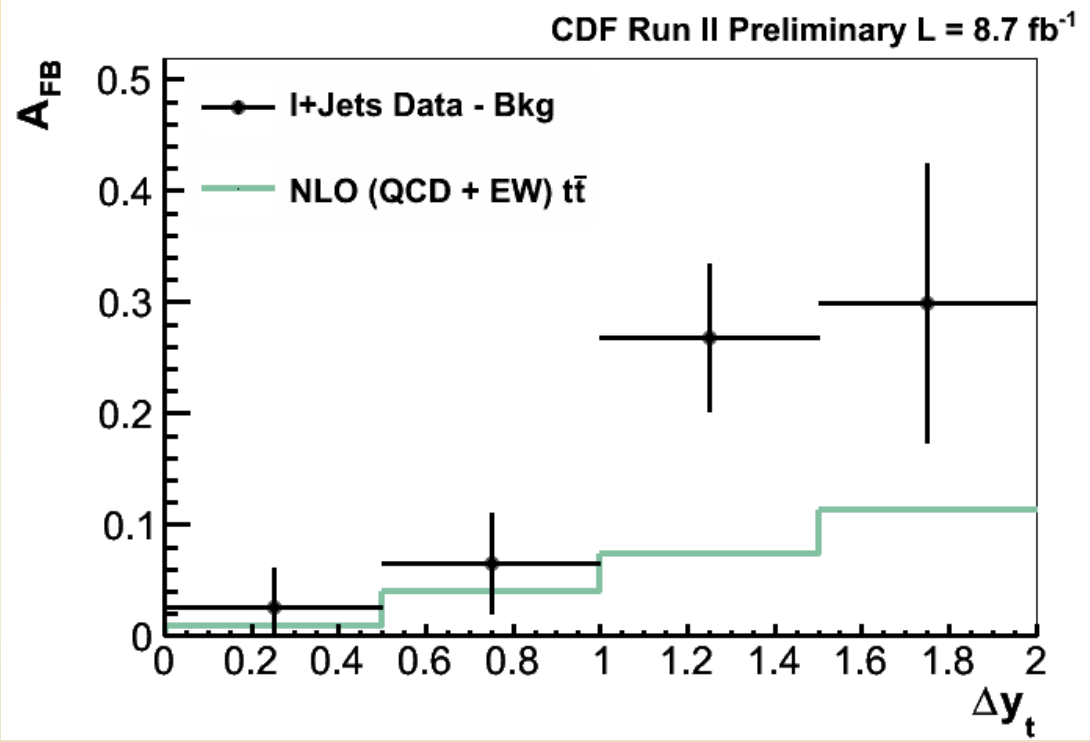
$$= \frac{N(y_t^{t\bar{t}} > 0) - N(y_t^{t\bar{t}} < 0)}{N(y_t^{t\bar{t}} > 0) + N(y_t^{t\bar{t}} < 0)}$$

Asymmetry
for reconstructed $t\bar{t}$

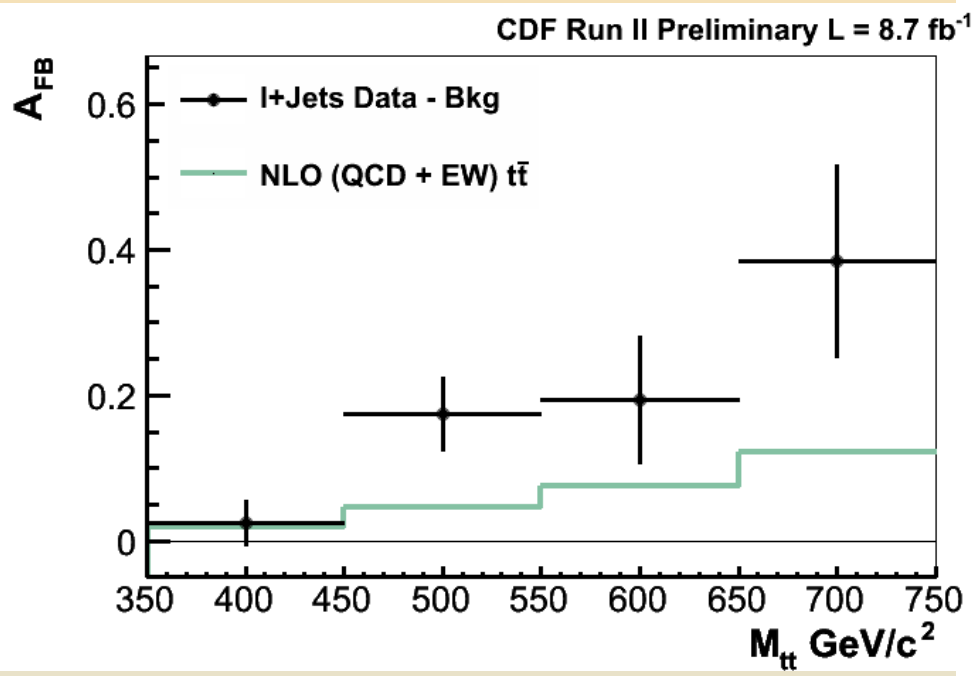


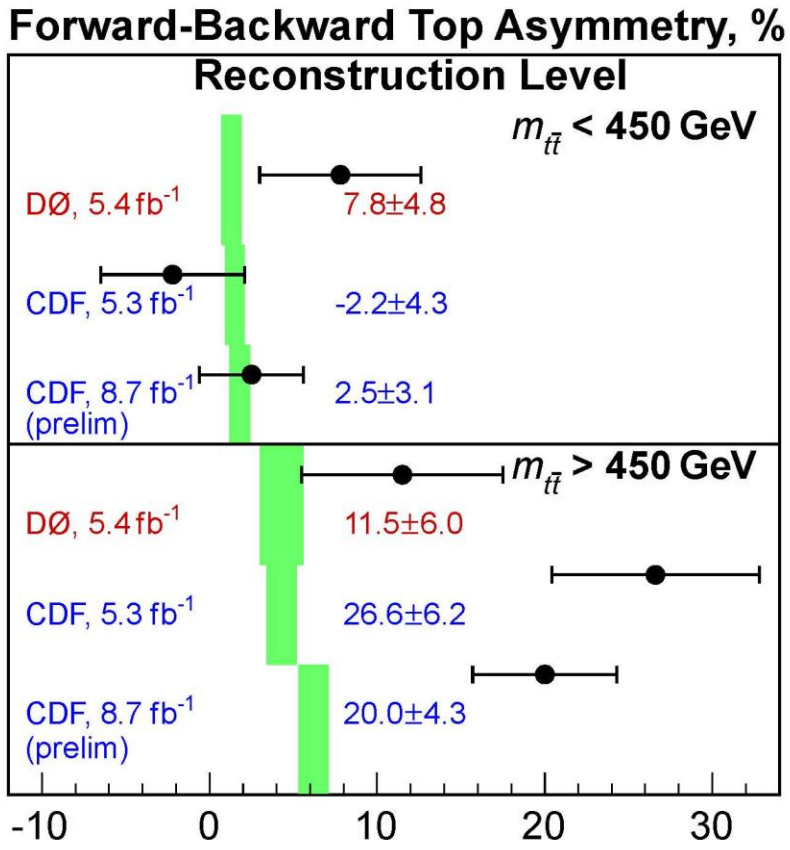


Dependence on $\Delta y_{t\bar{t}}$ background subtracted



Dependence on $M_{t\bar{t}}$





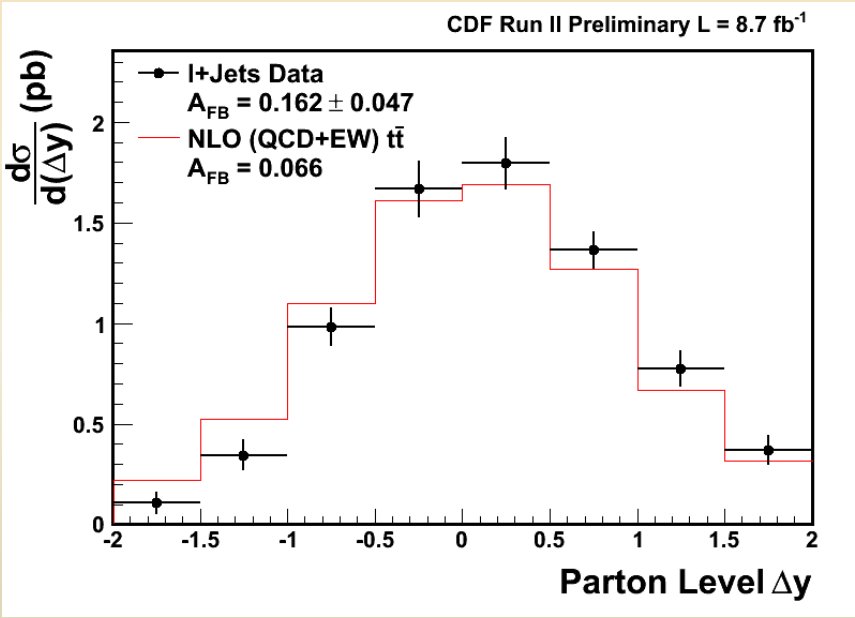
A_{fb} in parton level

- Using *Unfolding Matrix* to correct for the bias caused by acceptance of the detector/trigger and the reconstruction.
- CDF, 8.7 fb^{-1}

  $A_{fb} = 0.162 \pm 0.047$

- D0, 5.4 fb^{-1}

  $A_{fb} = 0.196 \pm 0.065$

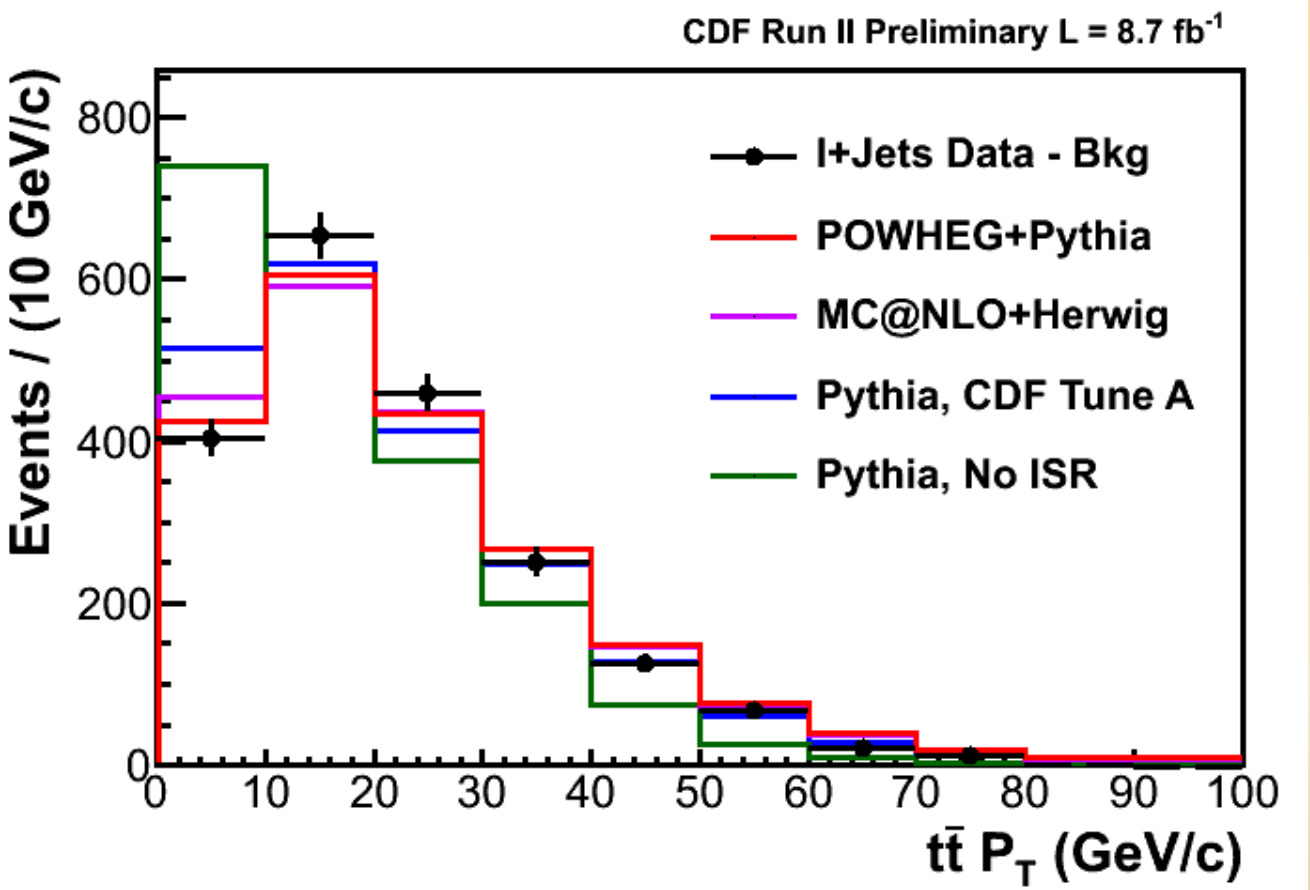


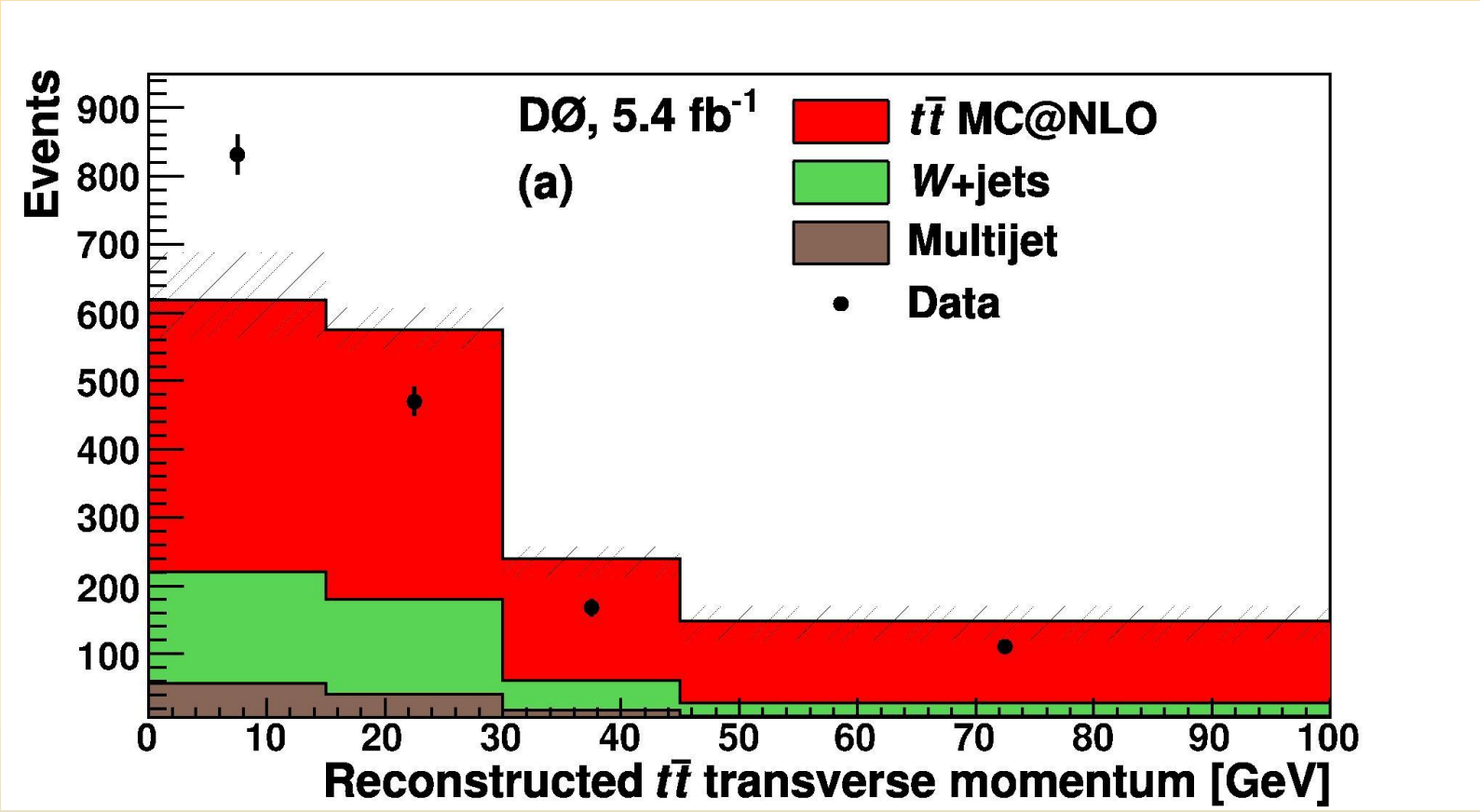
PRD **84**, 112005

Conclusion

- Both CDF and D0 have measured the total tt production cross section. The results are consistent between the two experiments and with the Standard Model.
- Both CDF and D0 observe a large production asymmetry.
- CDF observe dependence on the $\Delta y_{t\bar{t}}$ and $M_{t\bar{t}}$. But the dependence on $M_{t\bar{t}}$ is not very strong at D0.
- More studies from both CDF and D0 will come in the near future.
  - Differential cross section in terms of $cos\theta$, etc.
  - Result from DIL channel

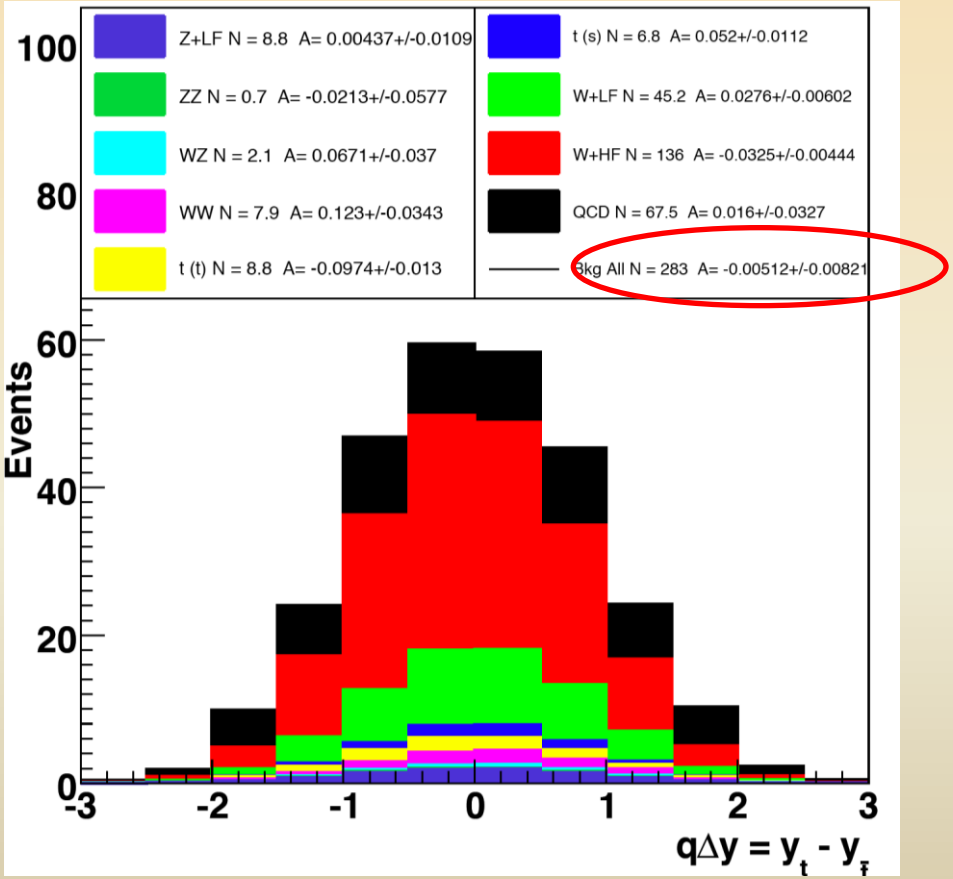
Thank you!!!


CDF Run II Preliminary L = 8.7 fb-1
Events / (10 GeV/c)
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
tt̄ PT (GeV/c)
l+Jets Data - Bkg
POWHEG+Pythia
MC@NLO+Herwig
Pythia, CDF Tune A
Pythia, No ISR

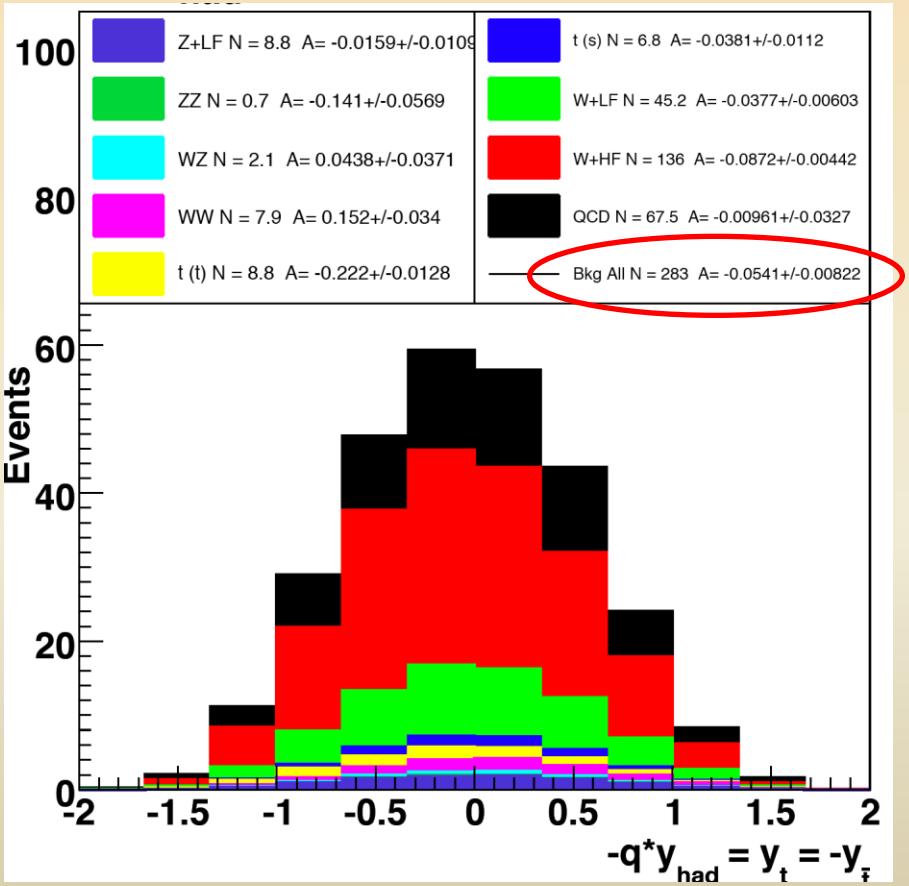

DØ, 5.4 fb-1
(a)
tt̄ MC@NLO
W+jets
Multijet
Data
Events
900
800
700
600
500
400
300
200
100
0
10
20
30
40
50
60
70
80
90
100
Reconstructed tt̄ transverse momentum [GeV]

Asymmetry from background is small but not zero!

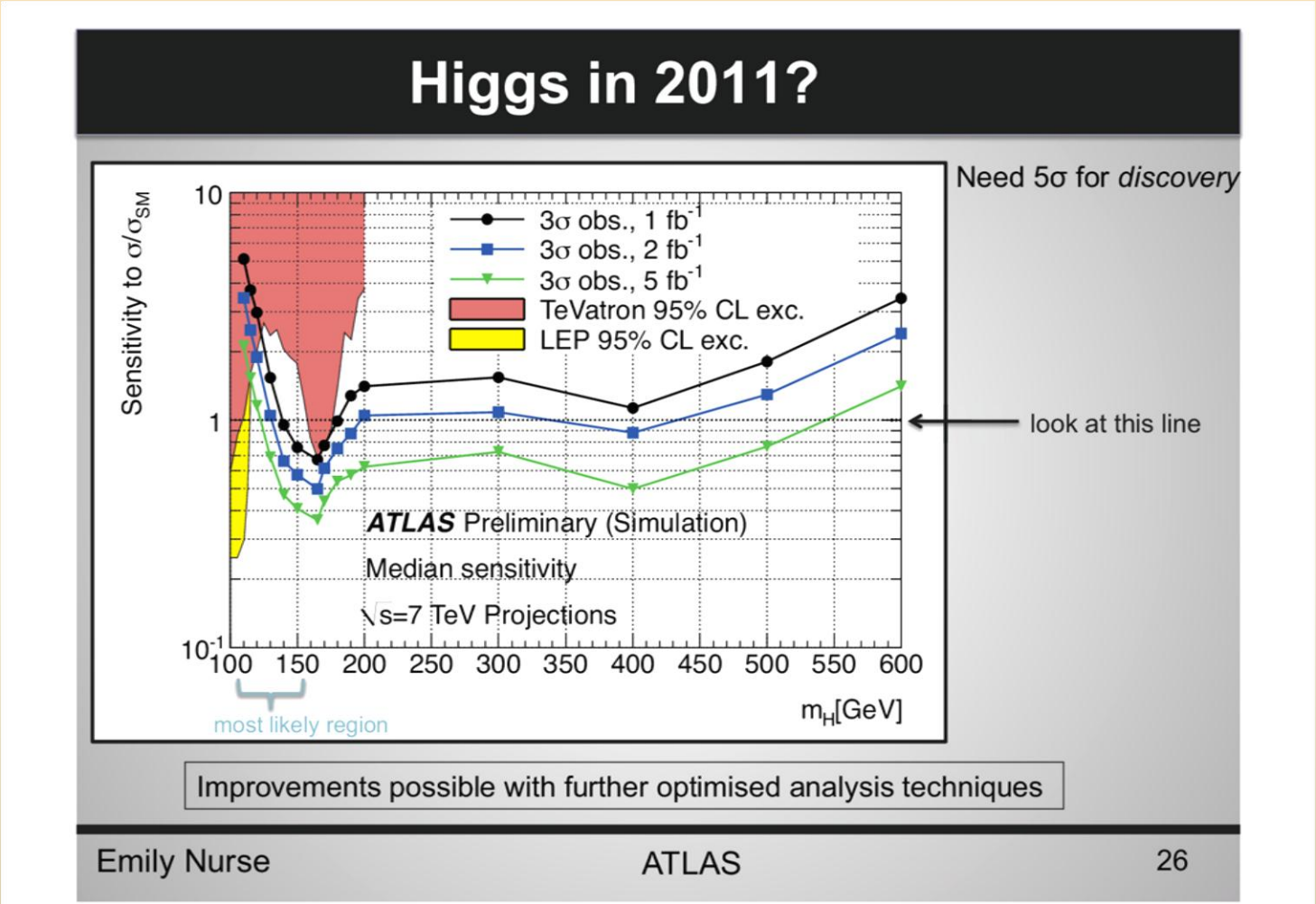
tt rest frame

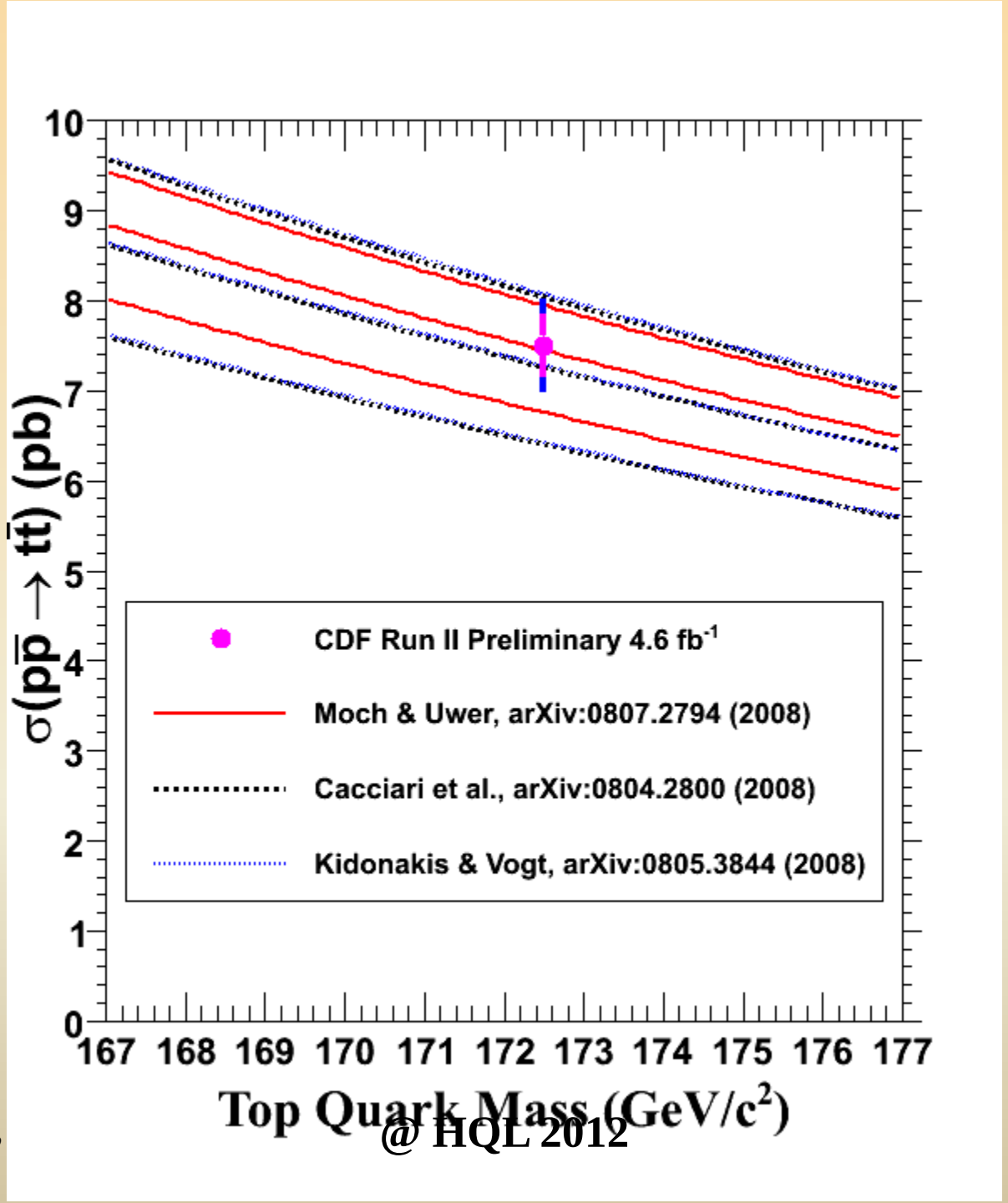


lab frame



Expecting Higgs at LHC/ATLAS




10
9
8
7
6
5
4
3
2
1
0
167 168 169 170 171 172 173 174 175 176 177
$\sigma(p\bar{p} \rightarrow t\bar{t})$ (pb)
Top Quark Mass (GeV/c^2)
CDF Run II Preliminary 4.6 fb^{-1}
Moch & Uwer, arXiv:0807.2794 (2008)
Cacciari et al., arXiv:0804.2800 (2008)
Kidonakis & Vogt, arXiv:0805.3844 (2008)

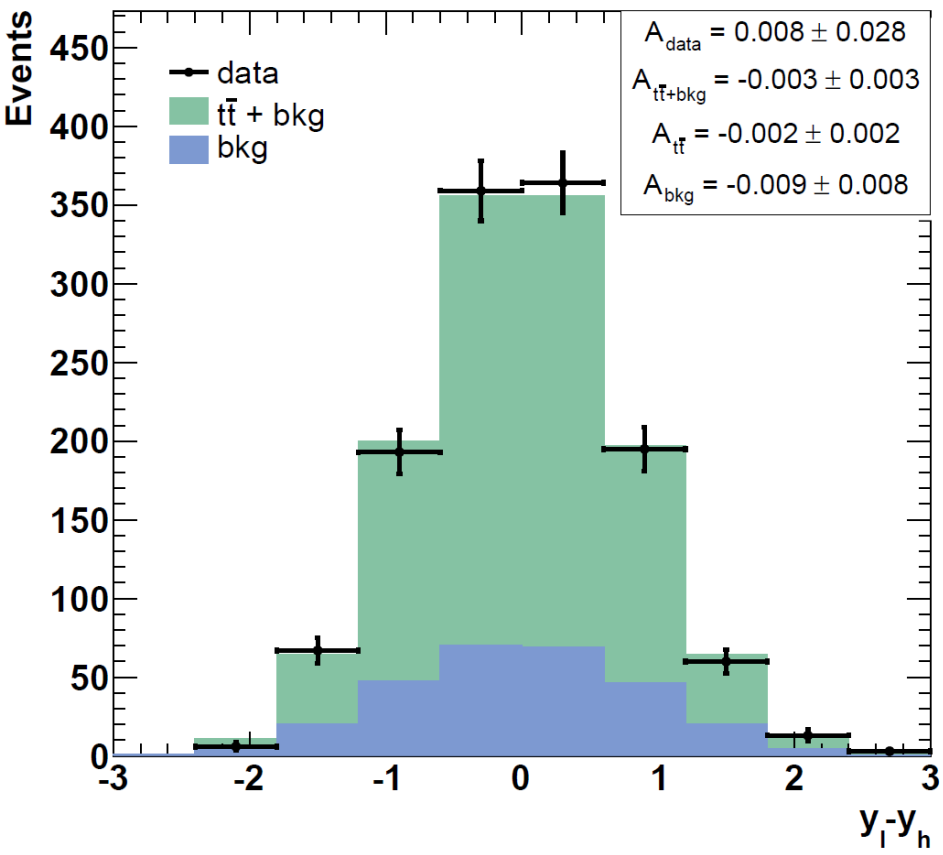
Top reconstruction

$$\chi^2 = \sum_{lep,\,jets} \frac{\left(p_t^{i,\,meas} - p_t^{i,\,fit}\right)^2}{\sigma_i^2} + \sum_{j=x,\,y} \frac{\left(p_j^{UE,\,meas} - p_j^{UE,\,fit}\right)^2}{\sigma_j^2} +$$

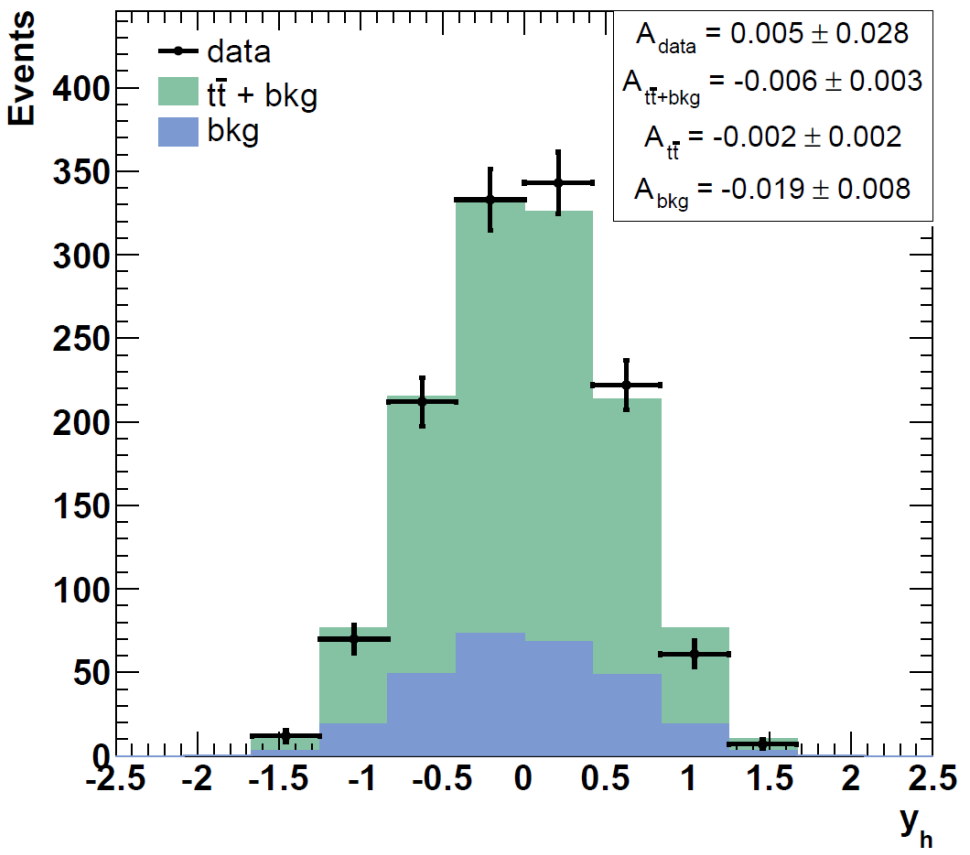
$$\frac{\left(M_{jj} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(M_{l\nu} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(M_{bjj} - M_{top}\right)^2}{\Gamma_t^2} + \frac{\left(M_{blv} - M_{top}\right)^2}{\Gamma_t^2}$$

Inclusive asymmetry

Δy

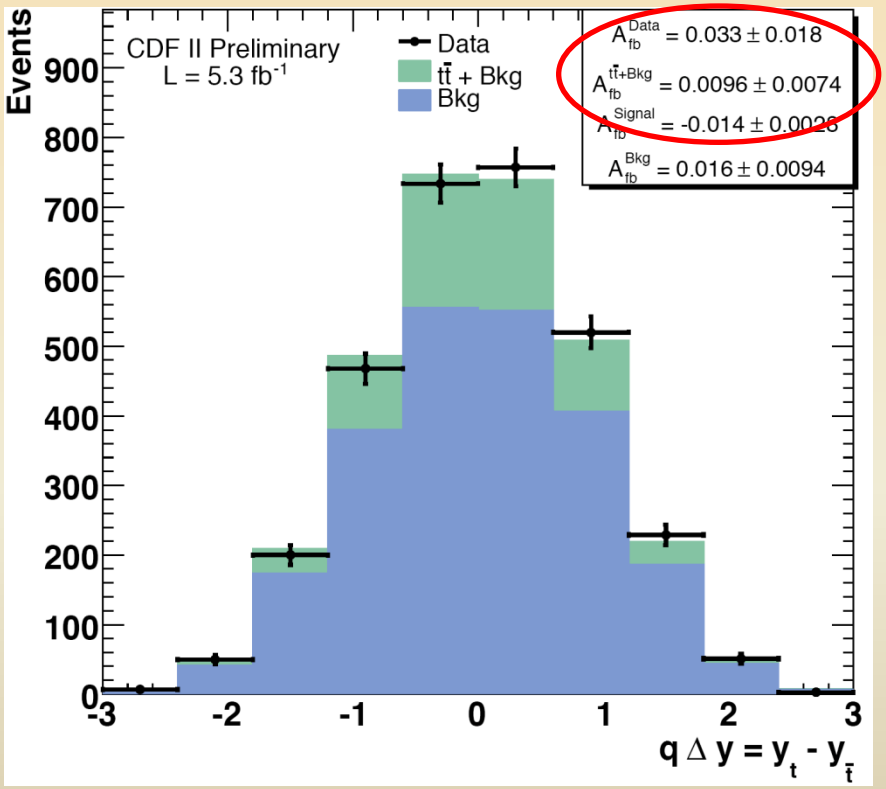


y_h

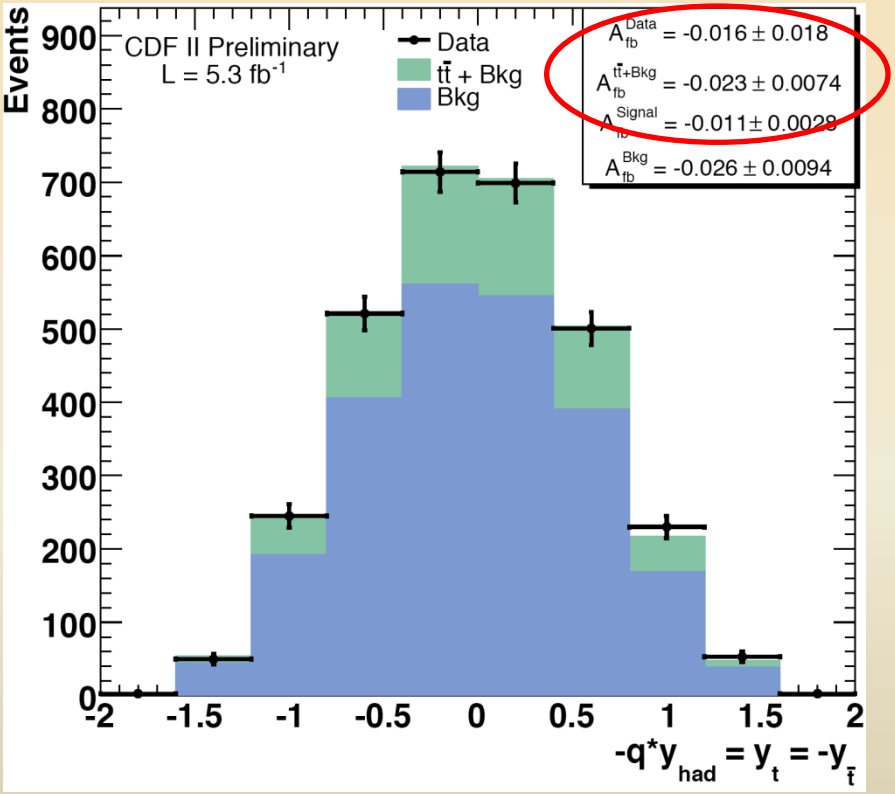


Apply to not b tagged sample
S:B = 0.3

tt frame



lab frame



A_{fb} from di-lepton channel

- In progress of blessing
- Shows also strong asymmetry
- Combining with the result from the lepton + jets channel and using full dataset we could reach 5 sigma, if this asymmetry is true.
- Also some puzzles similar to lepton + jets result!
  - Such as smaller asymmetry in the not b tagged sample
  - Is this just statistical or is it telling us something that we are not aware of?

Asymmetry categorized

selection	N events	all M	$M < 450$ GeV/c^2	$M \geq 450$ GeV/c^2
standard	1260	0.057±0.028	-0.016±0.034	0.212±0.049
electrons	735	0.026±0.037	-0.020±0.045	0.120±0.063
muons	525	0.105±0.043	-0.012±0.054	0.348±0.080
data $\chi^2 < 3.0$	338	0.030±0.054	-0.033 ± 0.065	0.180 ± 0.099
data no-b-fit	1260	0.062±0.028	0.006 ± 0.034	0.190 ± 0.050
data single b-tag	979	0.058±0.031	-0.015±0.038	0.224±0.056
data double b-tag	281	0.053±0.059	-0.023±0.076	0.178±0.095
data anti-tag	3019	0.033±0.018	0.029±0.021	0.044±0.035
pred anti-tag	-	0.010±0.007	0.013±0.008	0.001±0.014
pre-tag	4279	0.040±0.015	0.017±0.018	0.100±0.029
pre-tag no-b-fit	4279	0.042±0.015	0.023±0.018	0.092±0.029

Separated by number of jets

- data: the high mass asymmetry is significantly reduced for 5 jet events

selection	N events	all M	$M < 450$ GeV/c^2	$M \geq 450$ GeV/c^2
data 4-jet	939	0.065±0.033	-0.023±0.039	0.26±0.057
data 5-jet	321	0.034±0.056	0.0049±0.07	0.086±0.093

- the NLO QCD asymmetry has a strong N_{jet} dependence

selection	all M	$M < 450$ GeV/c^2	$M \geq 450$ GeV/c^2
inclusive	0.024 ± 0.004	0.015 ± 0.005	0.043 ± 0.007
4-jet	0.048 ± 0.005	0.033 ± 0.006	0.078 ± 0.009
5-jet	-0.035 ± 0.007	-0.032 ± 0.009	-0.040 ± 0.012

In the lab frame

- Cross check using $-qy_h = y_t^{p\bar{p}}$

selection	all M	$M < 450$ GeV/c^2	$M \geq 450$ GeV/c^2
data reco	0.073±0.028	0.059±0.034	0.103±0.049
MC@NLO	0.017±0.004	-0.008±0.005	0.022±0.007
A_h^+	-0.076±0.039	-0.085±0.047	-0.053±0.072
A_h^-	0.070±0.040	0.028±0.050	0.148±0.066
single b-tags	0.095±0.032	0.079±0.034	0.130±0.057
double b-tags	-0.004±0.060	-0.023±0.076	0.028±0.097

?

Production asymmetry

- "Evidence for a Mass Dependent Forward-Backward Asymmetry in Top Quark Pair Production",
  - "Wine & Cheese" at Fermilab, Jan. 7, 2011.
- Paper submitted to PRD.
- D0 also see similar effect.

prior measurements

- CDF, 1.9 fb^{-1} , inclusive, corrected to "parton-level"
  - tt rest frame $A^{t\bar{t}} = 0.24 \pm 0.14$
  - NLO QCD $A^{t\bar{t}} = 0.06 \pm 0.01$

PRL 101, 202001 (2008)

  - lab (pp) frame $A^{p\bar{p}} = 0.17 \pm 0.08$
  - NLO QCD $A^{p\bar{p}} = 0.04 \pm 0.01$

prior measurements

- D0, inclusive, background subtracted "data-level"
  - tt rest frame $A^{t\bar{t}} = 0.12 \pm 0.08$ 0.9 fb^{-1}

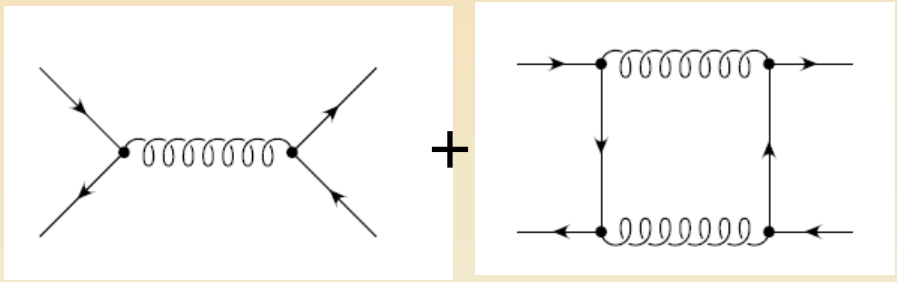
    PRL 100, 142002 (2008)

$A^{t\bar{t}} = 0.08 \pm 0.04$ 4.3 fb^{-1}

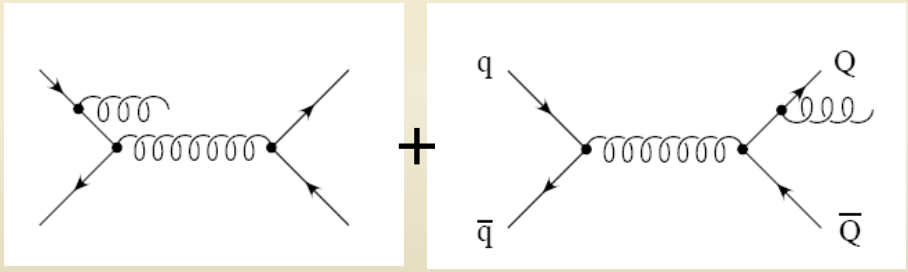
ICHEP 2010

Top charge asymmetry in QCD

- Halzen, Hoyer, Kim; Brown, Sadhev, Mikaelian; Kuhn, Rodrigo; Ellis, Dawson, Nason; Almeida, Sterman, Vogelsang; Bowen, Ellis, Rainwater

$t\bar{t}$ 

C = - 1 C = +1

$t\bar{t}j$ 

C = + 1 C = -1

In t t rest frame:

A_{FB} ~ +10-12 % NLO

A_{FB} ~ -7 % NLO

A_{FB} ~ 6 ± 1 % NLO

Asymmetry in $t\bar{t}$ and $p\bar{p}$ frame

- The asymmetry in the lab. Frame is reduced by the uncontrolled boost along the beamline:

$$A_{FB}^{t\bar{t}} \approx 1.5 \times A_{FB}^{p\bar{p}}$$

MC NLO study

- MCFM NLO calculation at "parton level"
- MC@NLO + CDFSIM

model	level	$A^{p\bar{p}}$	$A^{t\bar{t}}$
MCFM	parton	0.038 ± 0.006	0.058 ± 0.009
MC@NLO	parton	0.032 ± 0.005	0.052 ± 0.008
MC@NLO	$t\bar{t}$	0.018 ± 0.005	0.024 ± 0.005
MC@NLO	$t\bar{t}$+bkg	0.001 ± 0.003	0.017 ± 0.004

truth

sim + reco

sim + reco +bkg

- Pythia remains good approximation of SM

Correction to parton level

- Bin by bin in the histogram
  - P_j : parton level distribution
  - A_j: acceptance of the analysis
  - S_{ij}: smearing of the reconstruction
  - T_i: top signal

$$T_i = S_{ij} \times A_j \times P_j$$

  - B_i: background
  - D_i: data distribution

$$P_j = A_j^{-1} \times S_{ij}^{-1} \times (D_i - B_i)$$

Asymmetry is a function of Δy_{tt} and M_{tt}