

# $t\bar{t}$ cross section at the Tevatron

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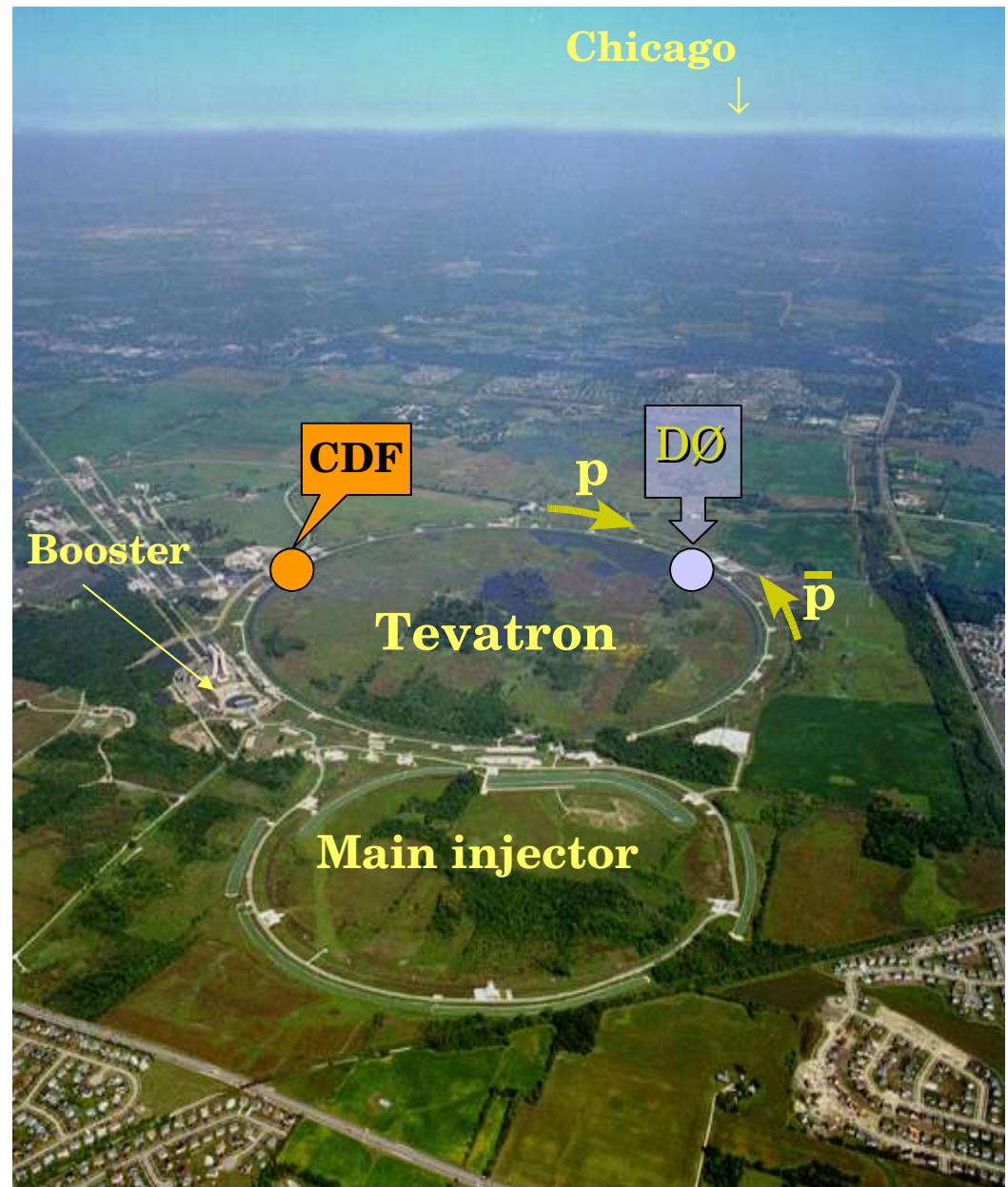
On behalf of the CDF and DØ collaborations

# Outline

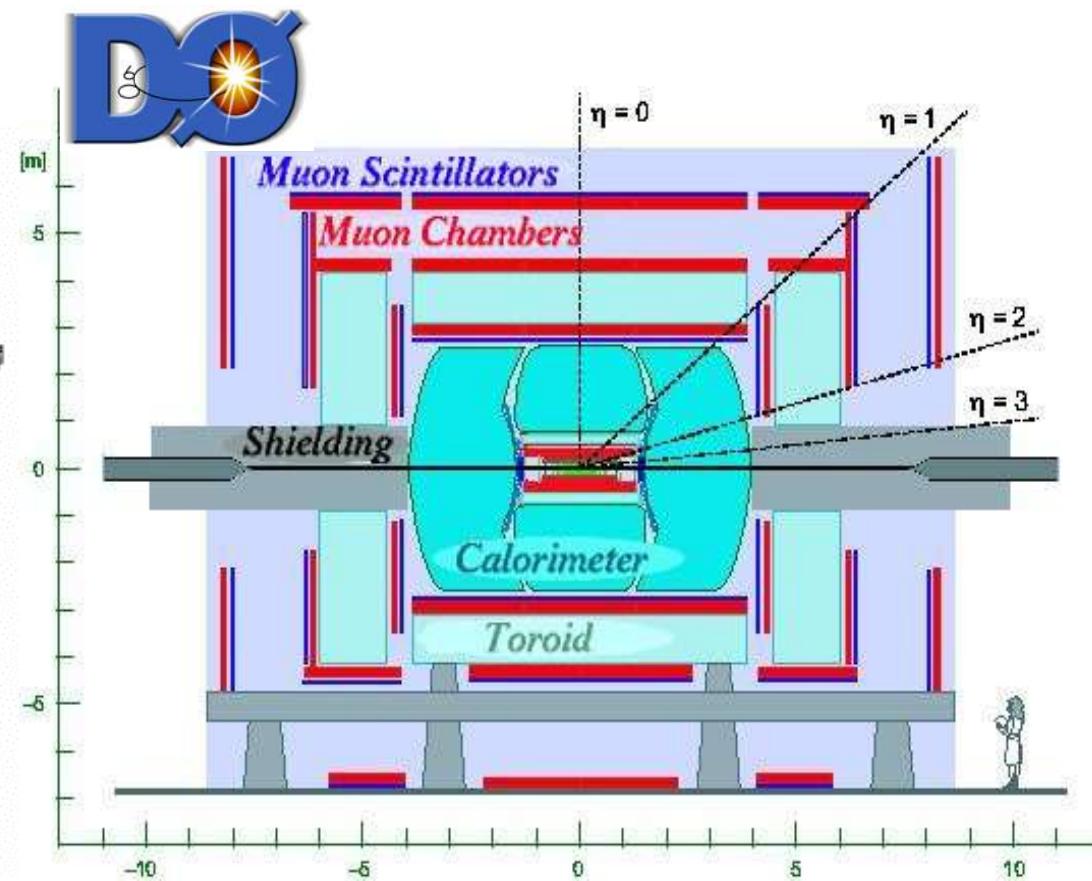
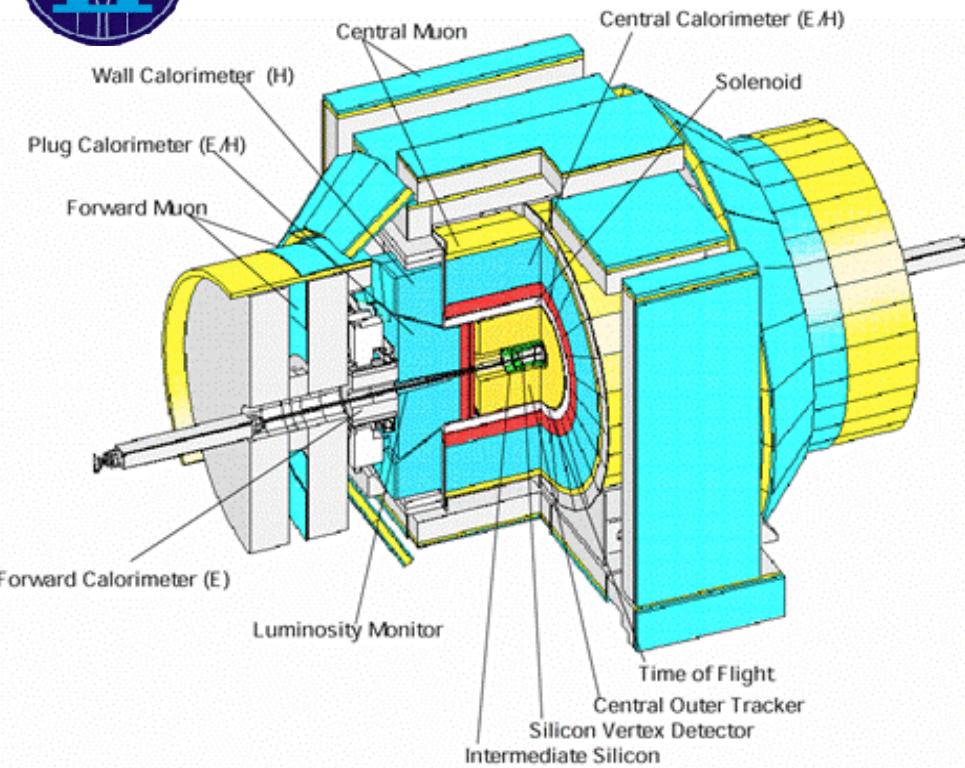
- ✗ Introduction
- ✗  $t\bar{t}$  production cross section in
  - Di-lepton channel
  - Lepton+jets channel
  - All-jets channel
- ✗ Summary

# Tevatron at Fermilab

- Proton antiproton collider  
 $\sqrt{s} = 1.96 \text{ TeV}$  (Run I :  $1.8 \text{ TeV}$ )
- $36 \times 36$  bunches (Run I :  $6 \times 6$ )
- Collision period : 396 ns
- 2 interactions/crossing @  $1.10^{32} \text{ cm}^{-2} \text{ s}^{-1}$



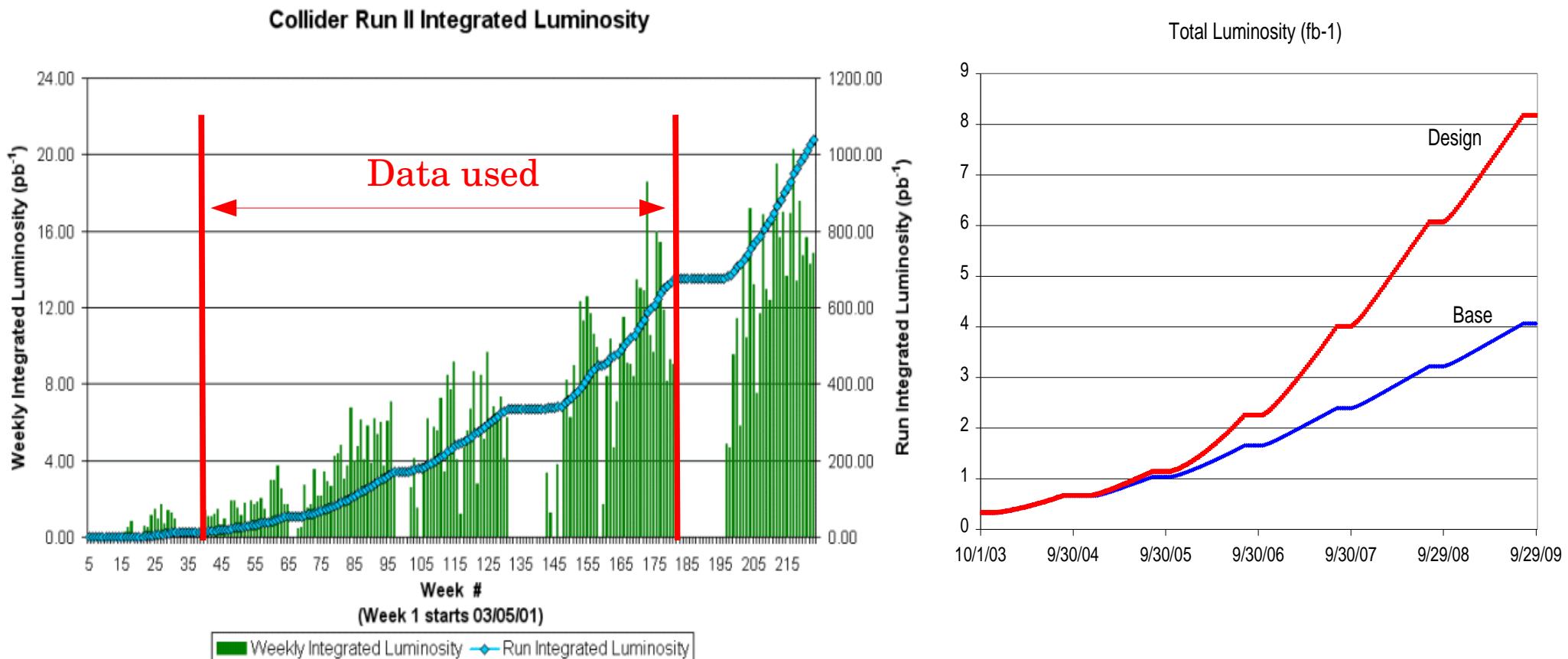
# CDF and DØ in Run II



- New Silicon Detector
- New Central Drift Chamber
- New End Plug Calorimeter
- Extended muon coverage
- New trigger and electronics

- New tracking system (silicon detector and central fiber tracker in a 2T solenoid)
- Upgraded muon system
- New trigger and electronics

# Run II performances and data sample

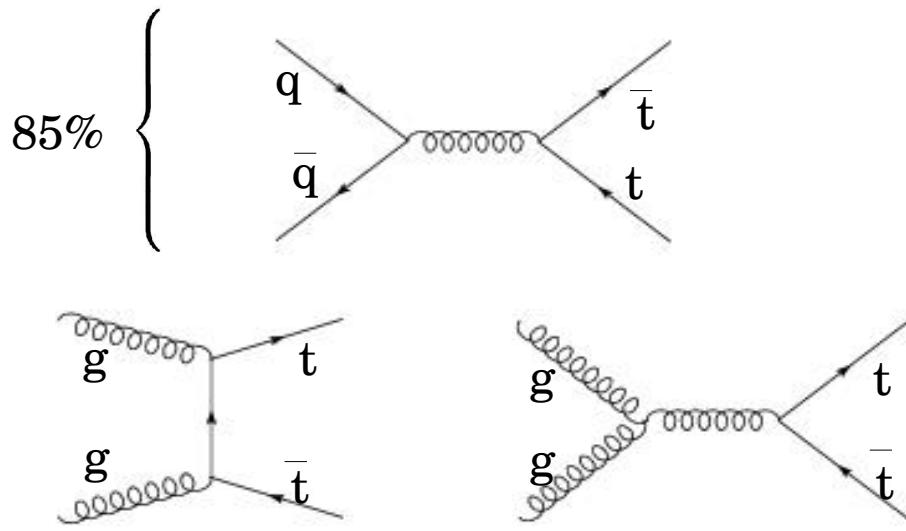


- Run II physics data taking started in July 2002
- Data taking efficiency is now of ~85 %
- Results are based on data taken until summer 2004
- Analysis shown based on 160 – 350 pb<sup>-1</sup>

- Long term luminosity goals (end of year 2009) :  
Base line : 4 fb<sup>-1</sup>  
Design : 8fb<sup>-1</sup>

# $t\bar{t}$ production at the Tevatron

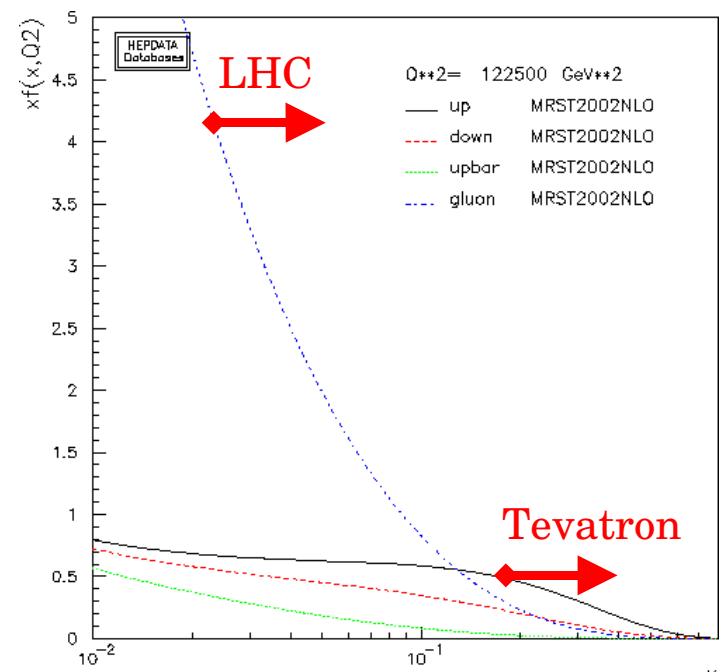
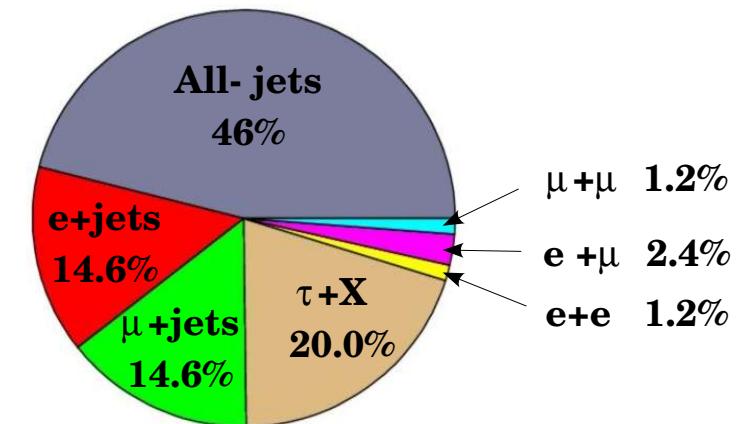
- At Tevatron, top quarks are primarily produced in pairs
- $t \rightarrow Wb$  in  $\sim 100\%$  of cases  
 $\Rightarrow$  final state determined by  $W$  decay
- Three main signatures considered :
  - Di-lepton : 2 high  $p_T$  leptons, 2 b-jets, large  $E_T^{\text{miss}}$
  - Lepton+jets : 1 high  $p_T$  lepton, large  $E_T^{\text{miss}}$ , 4 jets (2 b's)
  - All-jets : 6 jets (2 b's)



$$\sigma^{\text{theo}}(t\bar{t}) = 6.77 \pm 0.42 \text{ pb}$$

R. Bonciani *et al.*, Nucl. Phys. B529, 424 (1998) ; N. Kidonakis and R. Vogt, Phys. Rev. D68, 114014 (2003) ; M. Cacciari *et al.*, JHEP, 404, 68 (2004)

Final state in  $t\bar{t}$  events



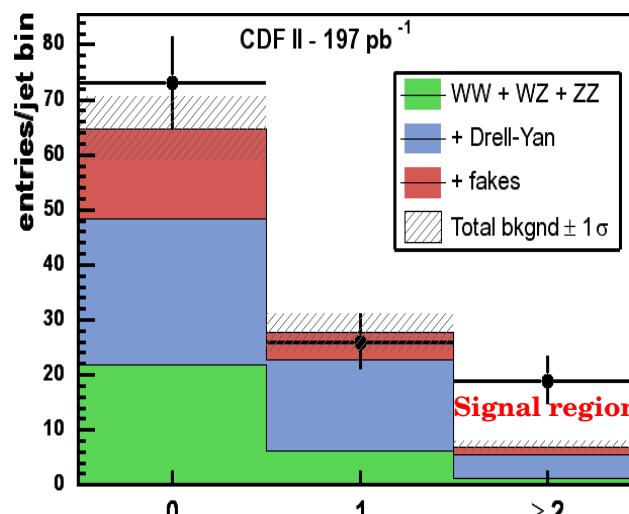
# Di-lepton (I)

PRL 93, 142001

Small branching ratio, relatively few SM backgrounds :  
 Di-boson, Drell-Yan and multijet QCD (fake  $E_T^{\text{miss}}$ )

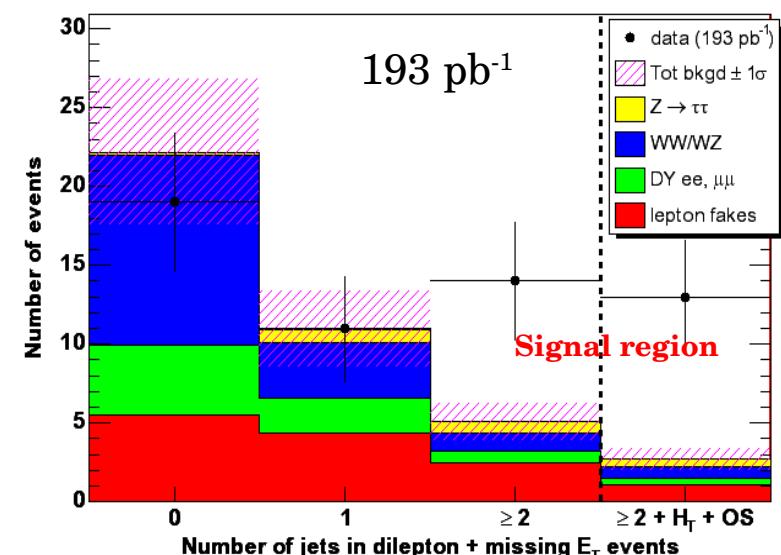
## Lepton + Isolated track

- 1 electron (muon) with  $p_T > 20 \text{ GeV}$  and  $|\eta| < 2 (1)$
- + 1 isolated track with  $p_T > 20 \text{ GeV}$  and  $|\eta| < 1$
- $E_T^{\text{miss}} > 25 \text{ GeV}$
- $\geq 2$  jets ( $p_T > 20 \text{ GeV}$ ,  $|\eta| < 2$ )



2 well identified leptons  
 $ee, e\mu, \mu\mu$

- $p_T(\text{leptons}) > 20 \text{ GeV}$
- Require two jets
- Total transverse energy  $> 200 \text{ GeV}$

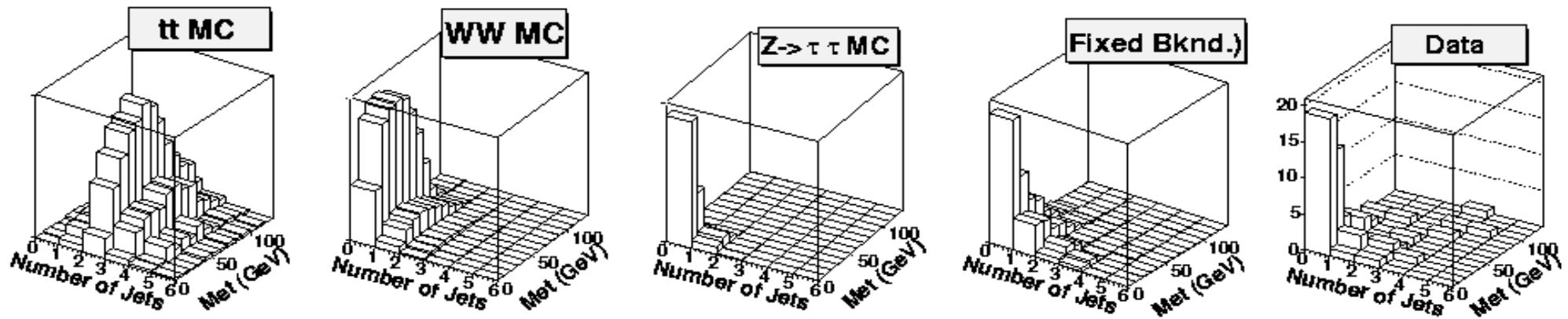


Combination of the two analysis

$$\sigma(t\bar{t}) = 7.0^{+2.4}_{-2.1} (\text{stat})^{+1.7}_{-1.2} (\text{syst}) \text{ pb}$$

## Di-lepton (II)

- Measure cross section in di-lepton inclusive channel (no other cuts than two lepton requirement)
- Alternative approach to counting experiment
- In case of same flavour :  $Z \rightarrow ee, \mu\mu$  dominates  
⇒ Require significant  $E_T^{\text{miss}}$



Fit data for  $t\bar{t}$ , WW,  $Z \rightarrow \tau\tau$  contributions in two dimensional space ( $E_T^{\text{miss}}$ ,  $N_{\text{jets}}$ )

	$e\mu$ only	$ee + \mu\mu + e\mu$	Theory
$\sigma(t\bar{t})$ (pb)	$8.6^{+3.4}_{-3.2} \pm 0.9$	$8.6^{+2.5}_{-2.4} \pm 1.1$	$6.7 \pm 0.3$
$\sigma(WW)$ (pb)	$11.5^{+3.6}_{-3.6} \pm 0.6$	$12.6^{+3.2}_{-3.0} \pm 1.2$	$12.5 \pm 0.8$
$\sigma(Z \rightarrow \tau\tau)$ (pb)	$233^{+45}_{-42} \pm 17$	–	$253.1 \pm 0.5$

# Di-lepton

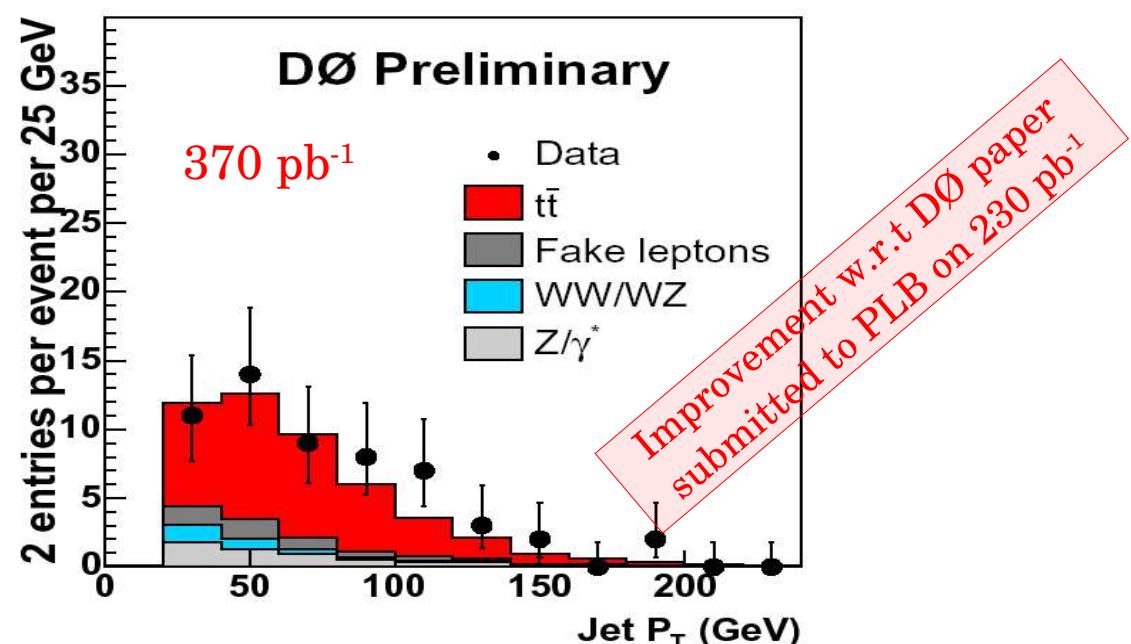
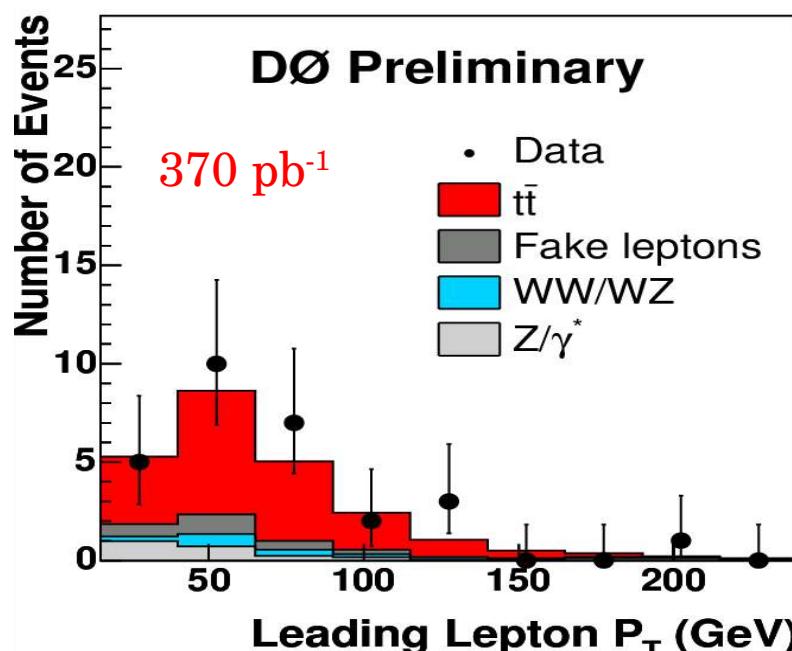
2 well identified leptons, opposite charge

( $p_T > 15 \text{ GeV}$ ;  $|\eta| < 1.1$  or  $1.5 < |\eta| < 2.5$  for electrons;  $|\eta| < 2$  for muons)

Large  $E_T^{\text{miss}}$  ( $> 25 \text{ GeV}$ )

## cut based analysis

- three independent analysis : ee, e $\mu$ ,  $\mu\mu$
- cross section extracted from  $\geq 2$  jets events



$$\sigma(t\bar{t}) = 8.6^{+2.2}_{-2.0}(\text{stat})^{+1.2}_{-1.0}(\text{syst}) \pm 0.6 \text{ (lumi)} \text{ pb}$$

# Lepton + Jets - Topological

Large branching ratio, SM backgrounds :  
 $W+jets$  and multijet QCD (fake  $E_T^{\text{miss}}$ )

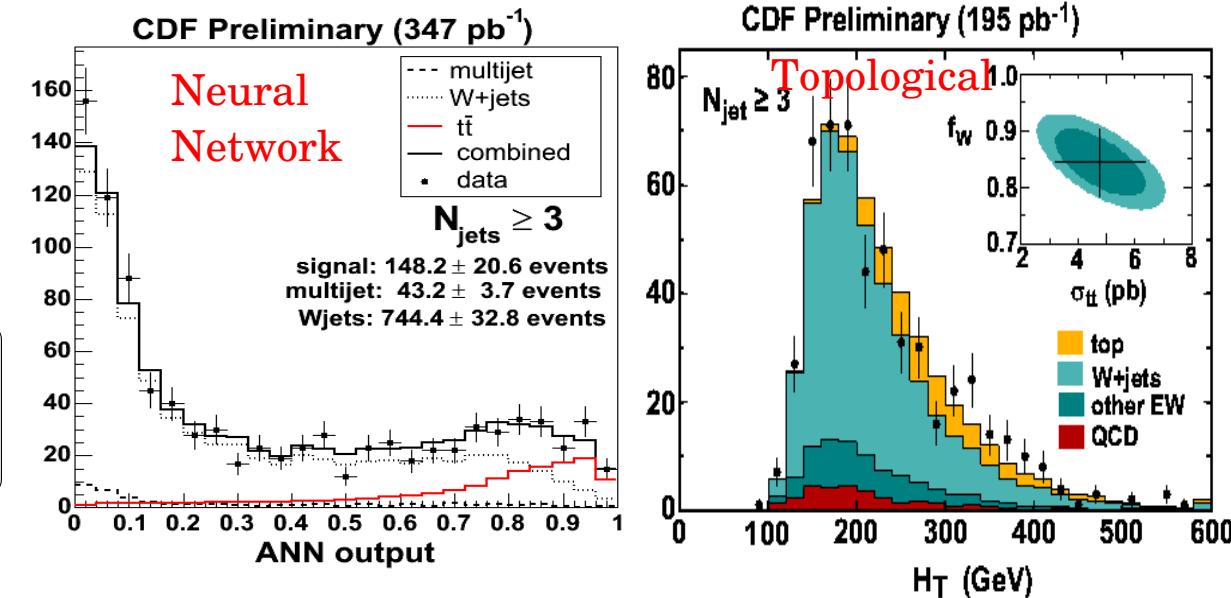
- Preselection
  - One charged high  $p_T$  lepton
  - $\geq 3$  high  $p_T$  jets
  - Large  $E_T^{\text{miss}}$

- Fit  $t\bar{t}$  and  $W+jets$  contributions to  $H_T$  distribution/NN output

- Choice of variables for NN :
  - Maximal significance
  - Minimal JES dependence

- $W+jets$  actually includes :
  - $W+3p$ ,  $Wbb+1p$ ,  $Z \rightarrow ll$ ,
  - $W \rightarrow \tau\nu + 2p$ ,  $WW+1p$ ,
  - $WZ$ , single top

- Multijet background is fixed in the fit



$$\sigma(t\bar{t}) = 6.0 \pm 0.8 \text{ (stat)} \pm 1.0 \text{ (syst)} \text{ pb}$$

Neural Network

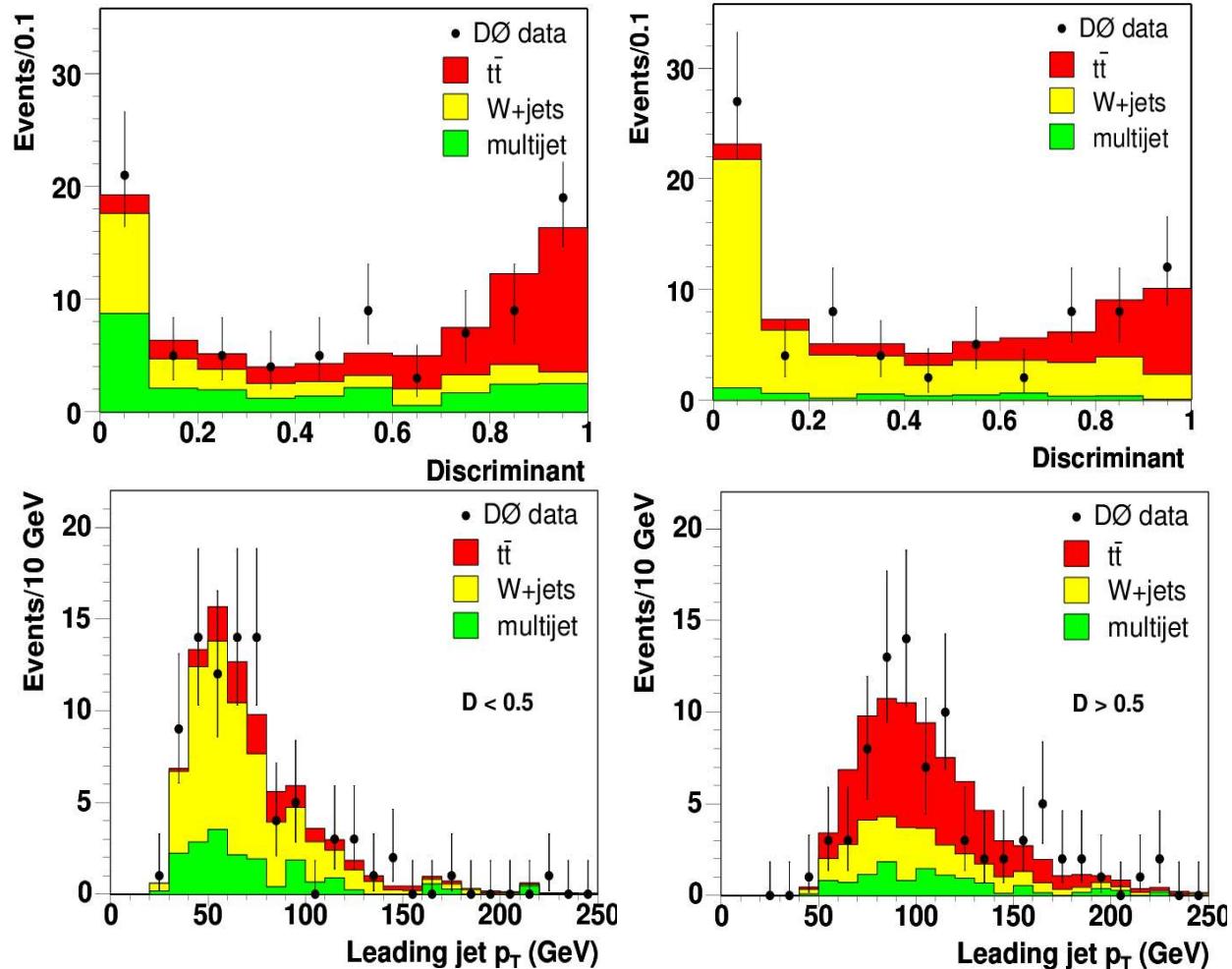
Topological →

$$\sigma(t\bar{t}) = 4.7 \pm 1.6 \text{ (stat)} \pm 1.8 \text{ (syst)} \text{ pb}$$

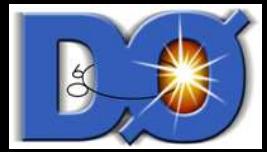
230 pb<sup>-1</sup>

- Preselection
  - One charged high p<sub>T</sub> lepton
  - ≥4 high p<sub>T</sub> jets
  - Large E<sub>T</sub><sup>miss</sup>

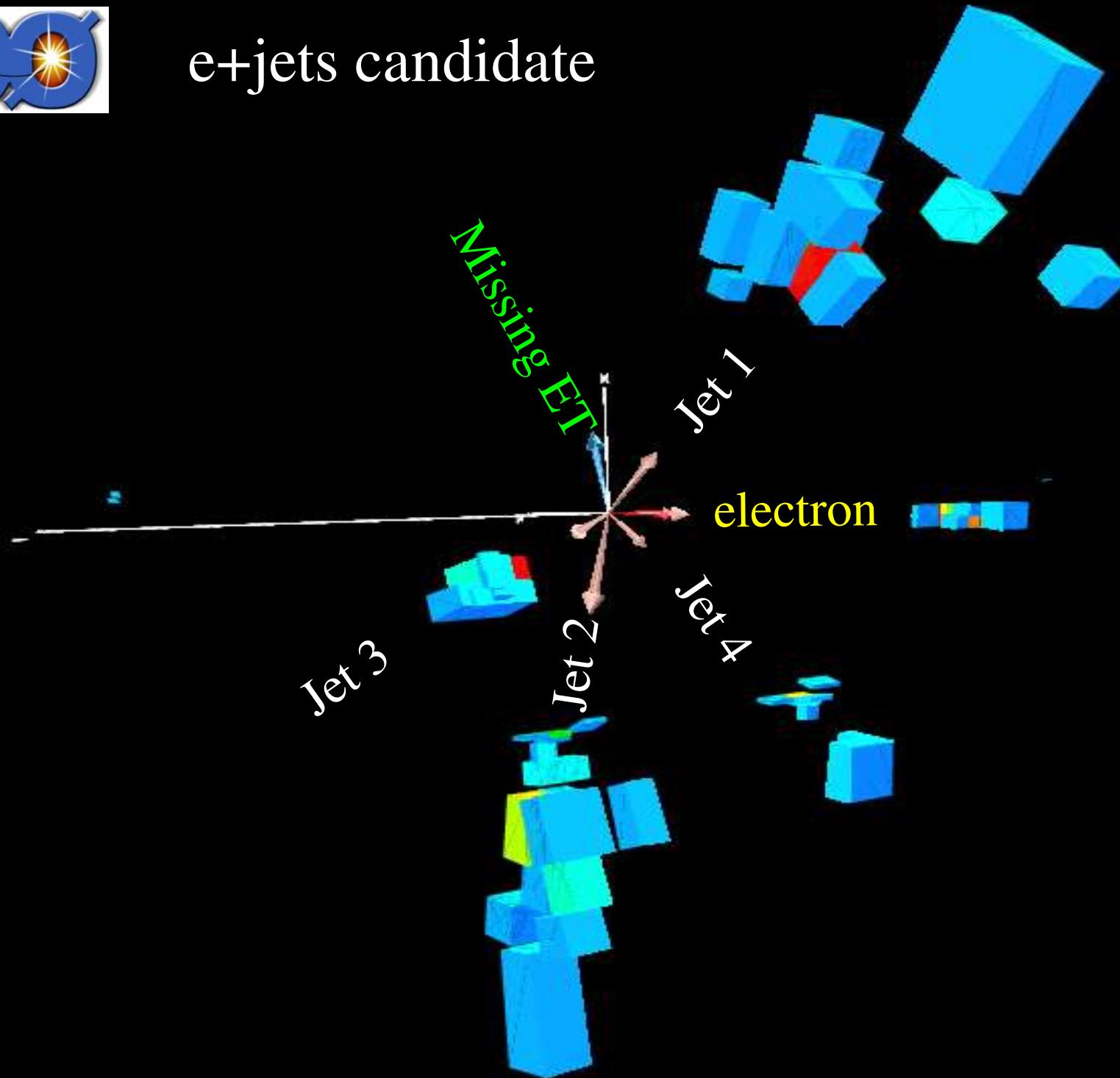
- Combine topological variables in likelihood discriminant
- Choice of variables :
  - Maximal significance
  - Minimal JES dependence
- Number of  $t\bar{t}$  events extracted from the fit



$$\sigma(t\bar{t}) = 6.7^{+1.4}_{-1.3}(\text{stat})^{+1.6}_{-1.1}(\text{syst}) \pm 0.4 \text{ (lumi)} \text{ pb}$$

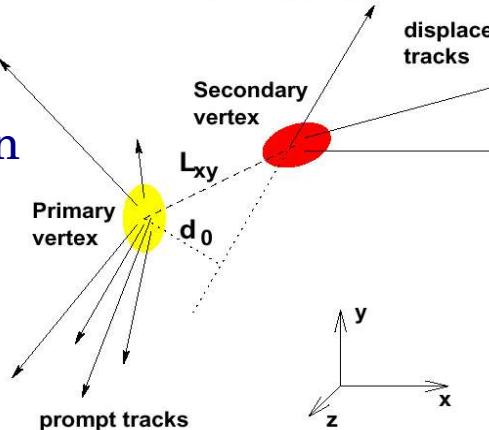


# e+jets candidate

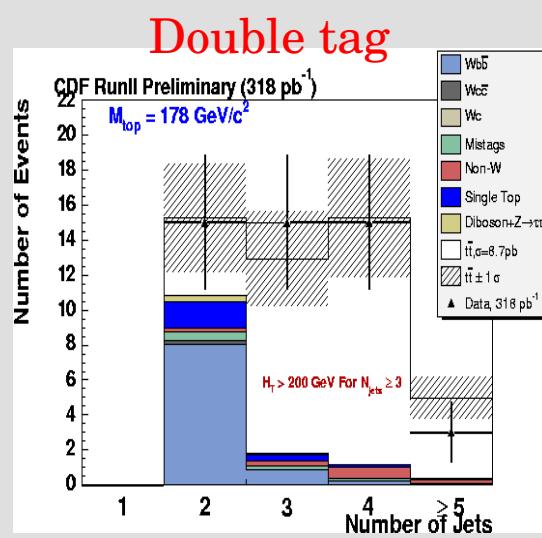
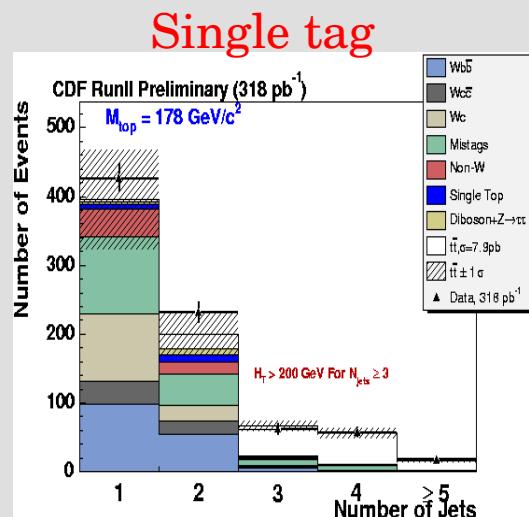


# Lepton + Jets with btagging

- Preselection
  - One charged high  $p_T$  lepton
  - $\geq 3$  high  $p_T$  jets
  - Large  $E_T^{\text{miss}}$



$\geq 1$  tag,  $\geq 2$  tags counting experiment

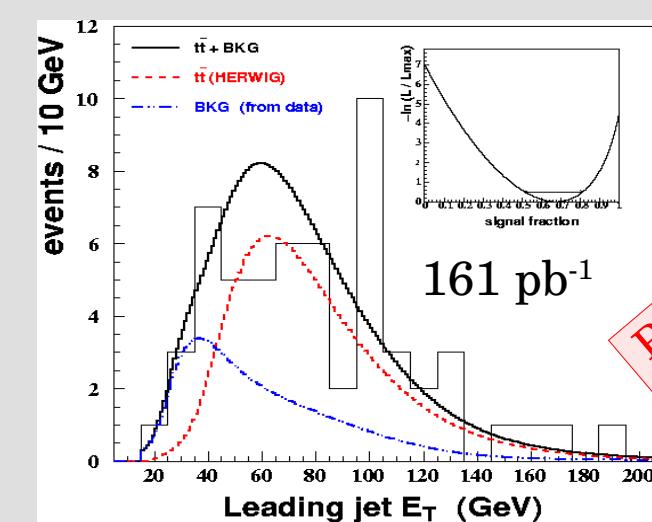


$\geq 1$  tag :  $\sigma(\bar{t}t) = 7.9 \pm 0.9 \text{ (stat)} \pm 0.9 \text{ (syst)} \text{ pb}$

$\geq 2$  tag :  $\sigma(\bar{t}t) = 8.7 \pm 1.7 \text{ (stat)} \pm 1.5 \text{ (syst)} \text{ pb}$

- B hadrons have long life time  
 $\rightarrow$  travel  $\sim 3 \text{ mm}$  before decay
- ⇒ Identify heavy quark jets by reconstructing secondary vertices

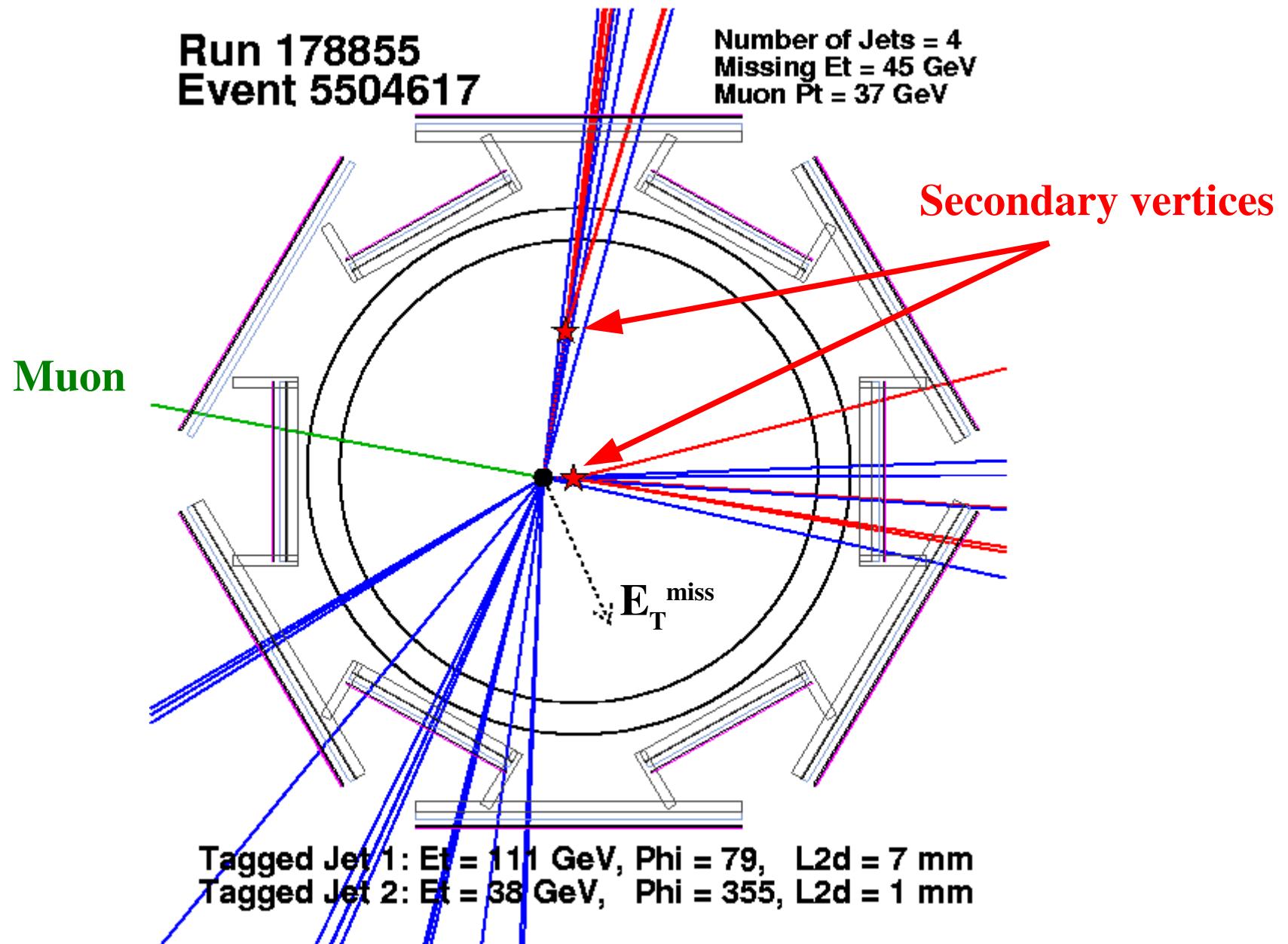
$\geq 1$  tag and fit to leading jet  $p_T$  distribution



$\sigma(\bar{t}t) = 6.0 \pm 1.6 \text{ (stat)} \pm 1.2 \text{ (syst)} \text{ pb}$

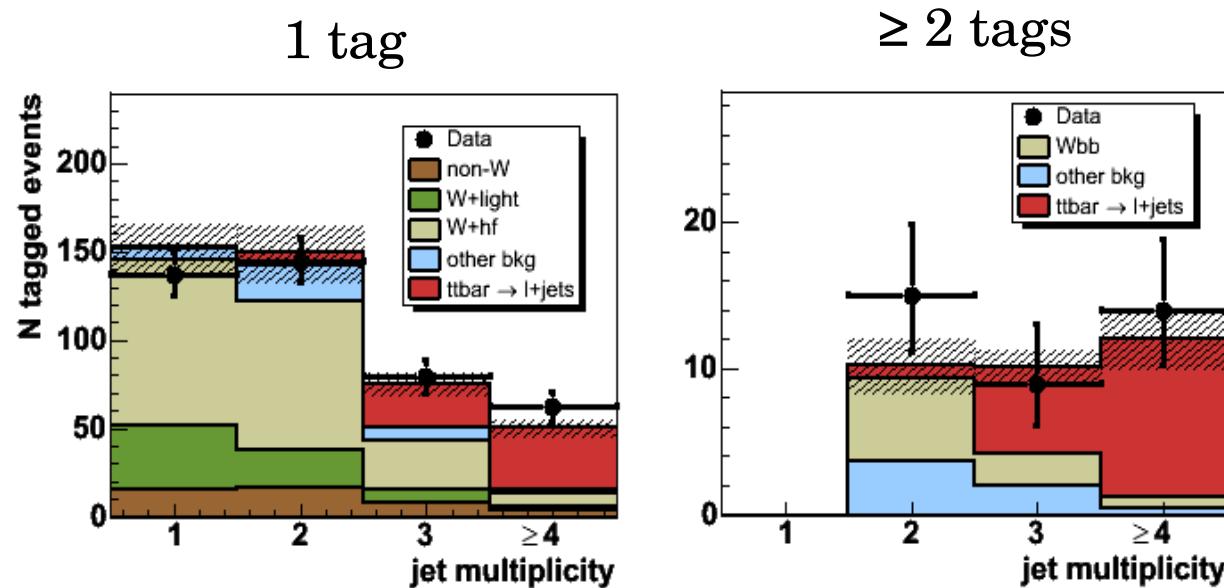
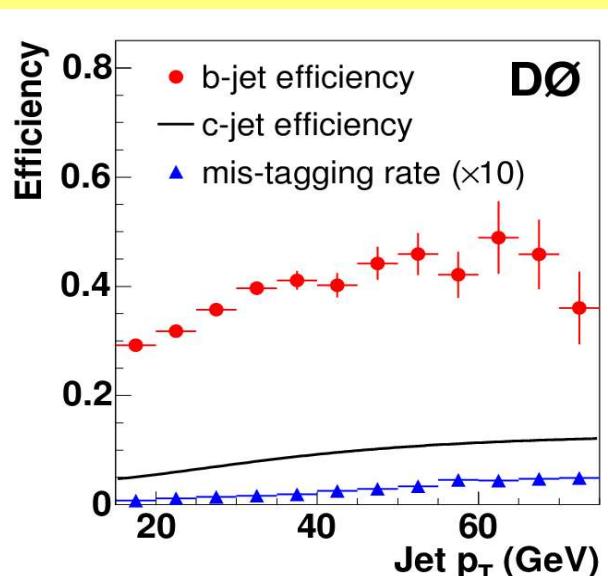
PRD 71, 072005

## Muon+jets candidate



Submitted to PLB

- Secondary vertex tagging  
 $\Rightarrow$  very good rejection of c and light jets background



230 pb<sup>-1</sup>

- Eight independent analysis channels considered :  
 e,  $\mu$ , 3 jets,  $\geq 4$  jets,  
 1 tagged jet,  $\geq 2$  tagged jets.

$$\sigma(t\bar{t}) = 8.6^{+1.6}_{-1.5} (\text{stat + syst}) \pm 0.6 \text{ (lumi)} \text{ pb}$$

# All-Jets

Very large branching ratio, overwhelmed by multijet background

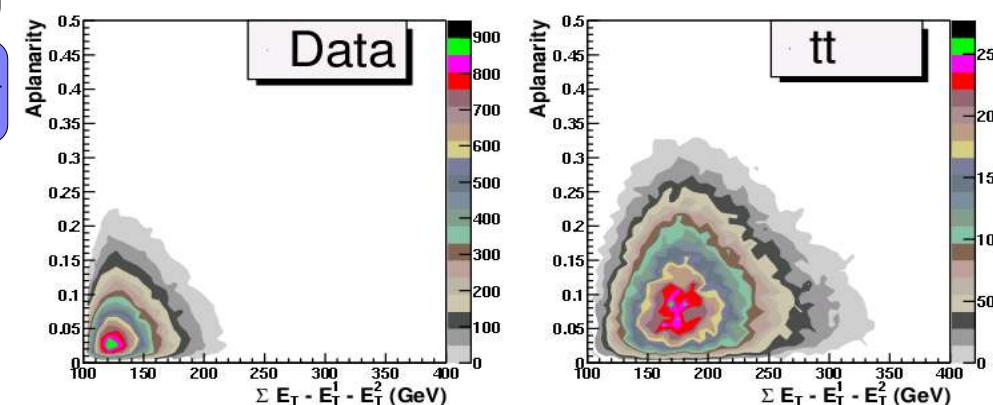
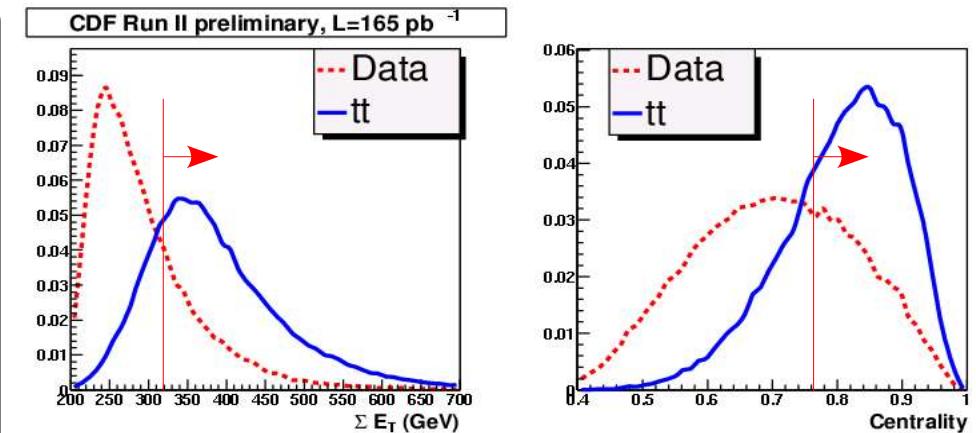
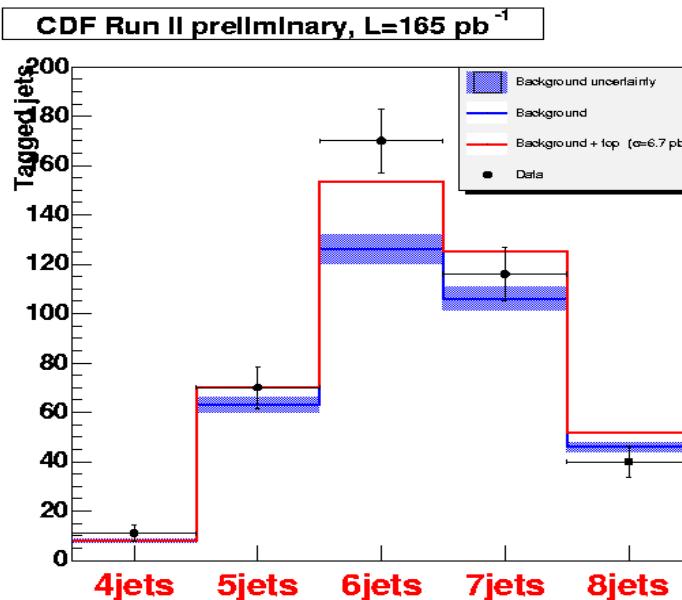
- Event selection :

- Strong kinematical selection  
→ criteria on aplanarity, centrality,  $H_T$
- $6 \leq N_{\text{jets}} \leq 8$  ( $p_T > 20 \text{ GeV}$ ,  $|\eta| < 2.0$ )

- Need b-tagging to extract the signal :

→ require  $\geq 1$  *b*-tagged jet

- Multijet background estimated with data only

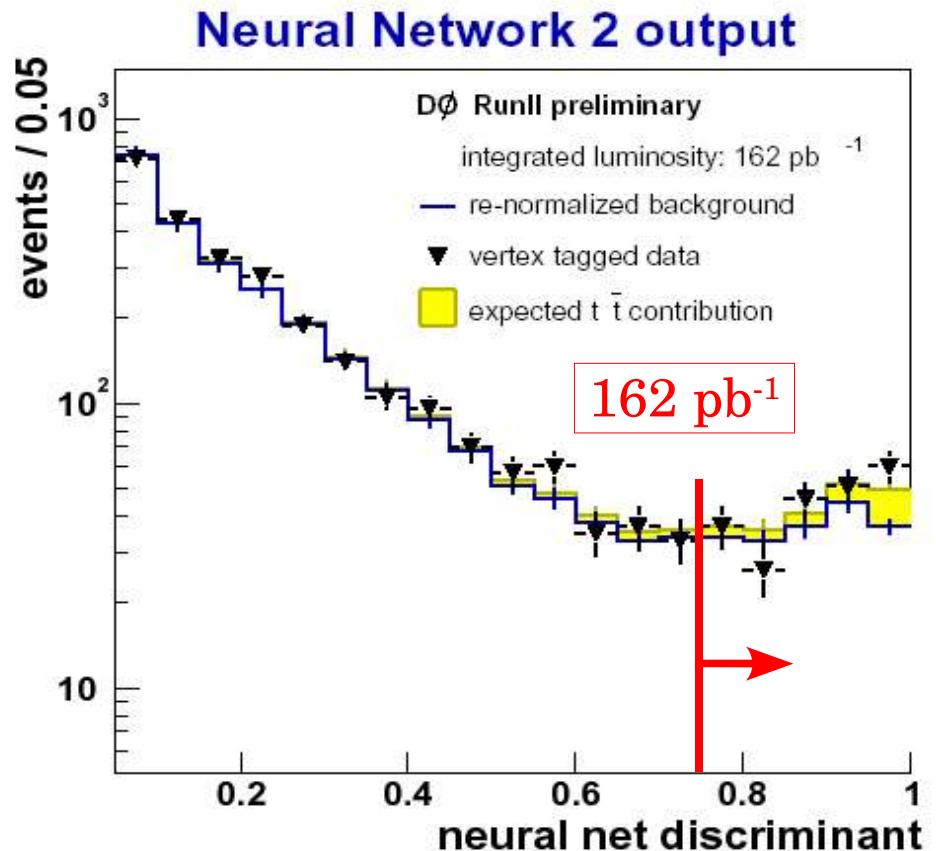
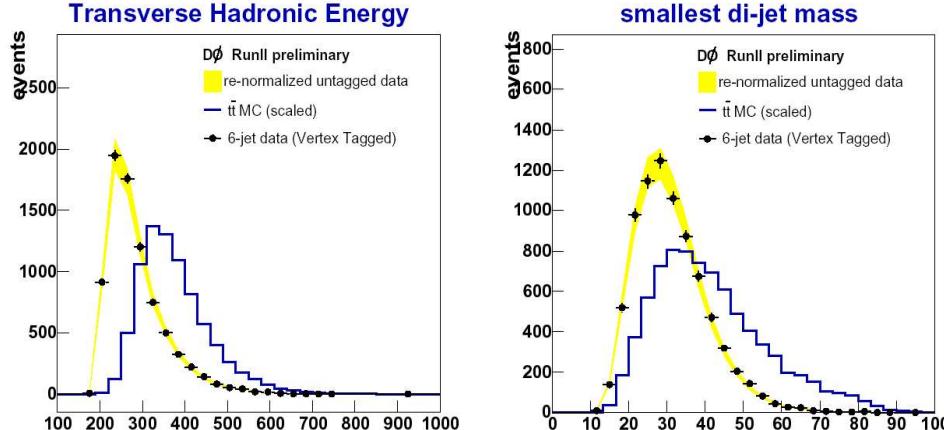


$$\sigma(t\bar{t}) = 7.8 \pm 2.5 \text{ (stat)} {}^{+4.7}_{-2.3} \text{ (syst)} \text{ pb}$$



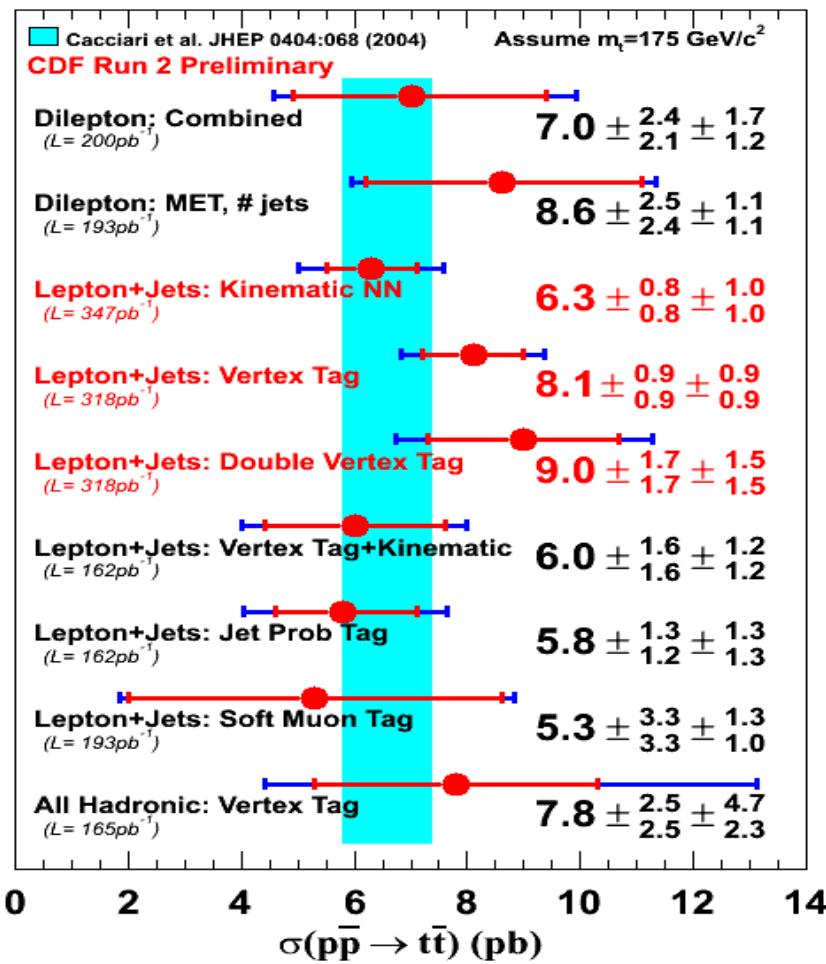
# All Jets

- Require  $\geq 6$  jets :
    - $p_T > 15 \text{ GeV}$ ,  $|\eta| < 2.5$
  - Require  $\geq 1$  tagged jet
  - Chain of three neural networks to separate signal from background
- Choice of variables :
- Event energy
  - Event Shape
  - Rapidity distributions
  - Top properties

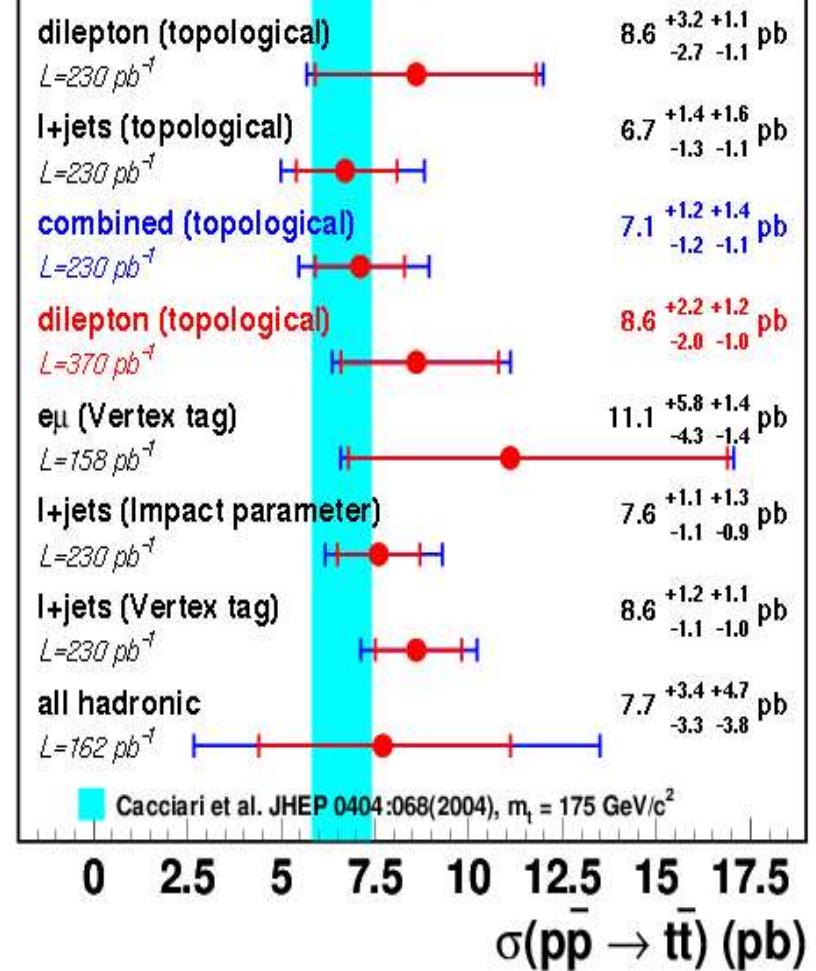


$$\sigma(t\bar{t}) = 7.7^{+3.4}_{-3.3}(\text{stat})^{+4.7}_{-3.8}(\text{syst}) \pm 0.5 \text{ (lumi)} \text{ pb}$$

# Summary (I)



## DØ Run II Preliminary



All measurements are in good agreement with the standard model prediction

# Summary (II)

- Top pair production cross section has been measured by CDF and DØ collaborations in di-lepton, lepton+jets and all-jets final states.
  - all measurements in good agreement with standard model prediction
- We are at the level where systematic errors  $\sim$  statistical errors
  - next generation of measurements will be limited by systematics

