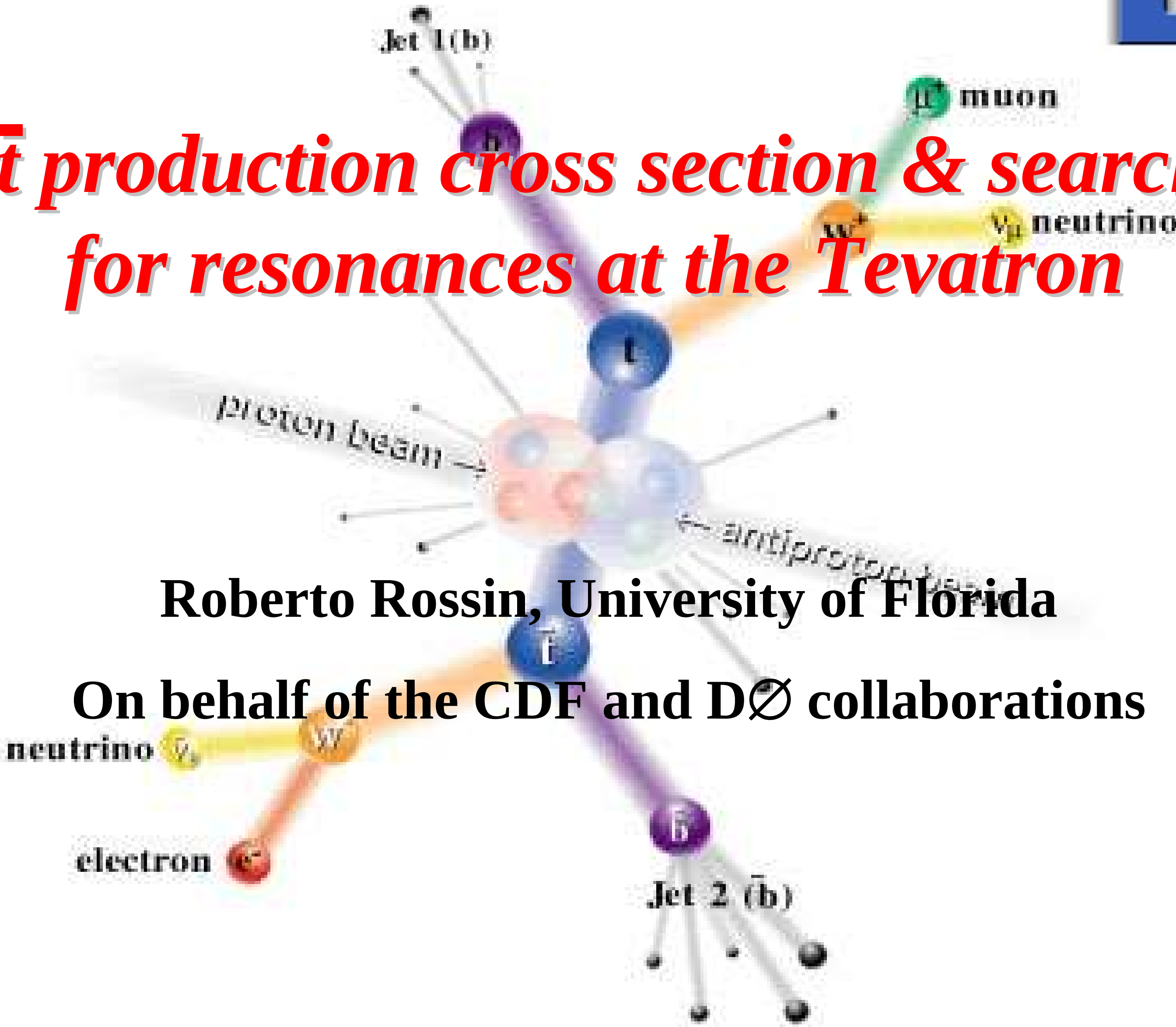
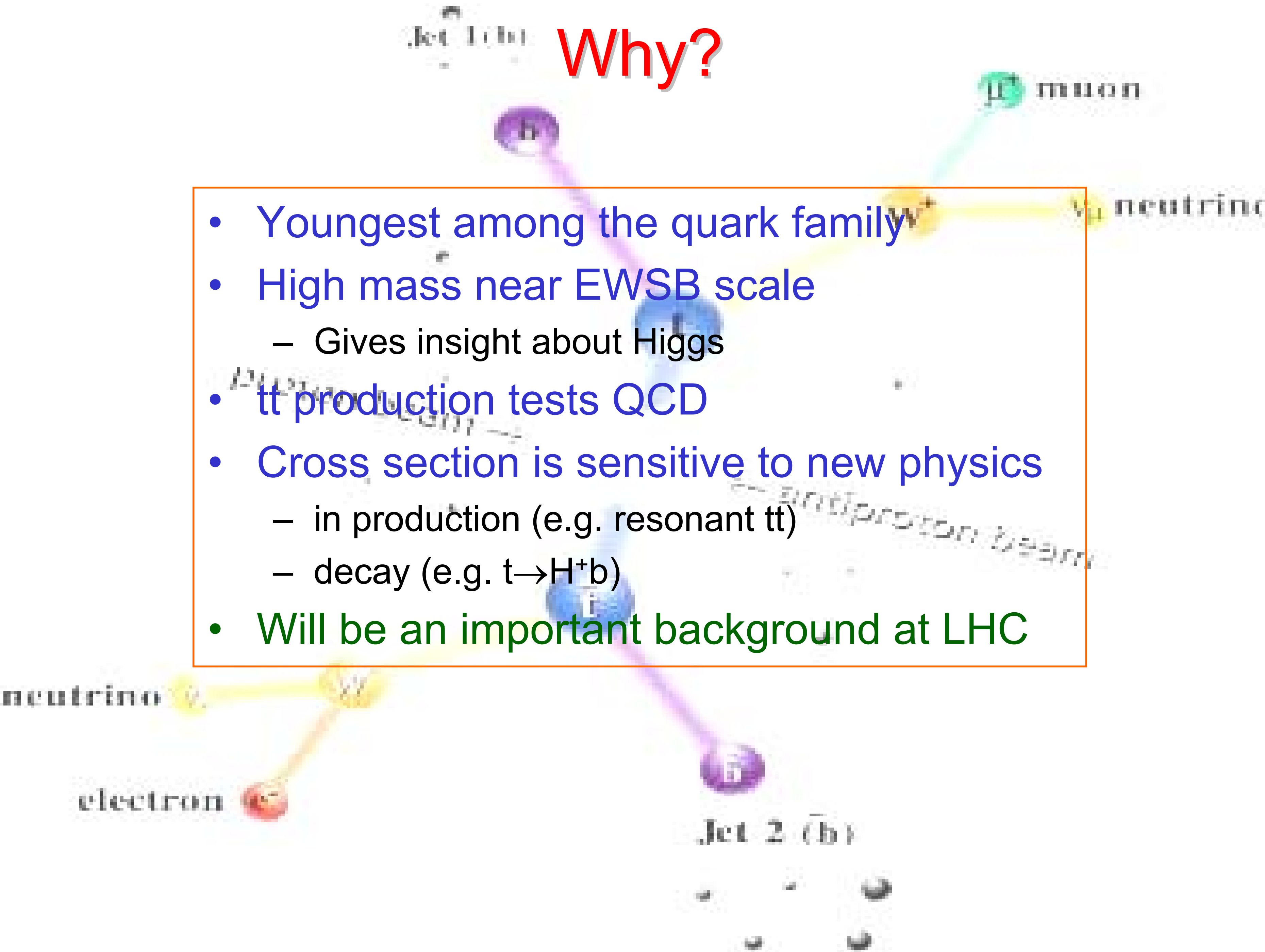
$t\bar{t}$ production cross section & search for resonances at the Tevatron



Roberto Rossin, University of Florida

On behalf of the CDF and D∅ collaborations

Why?

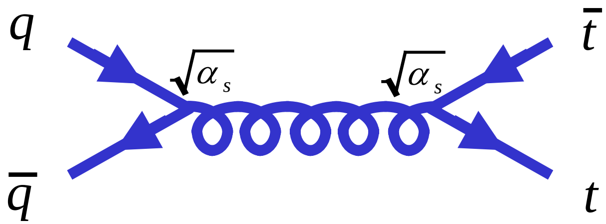


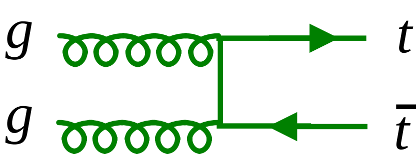
- Youngest among the quark family
- High mass near EWSB scale
  - Gives insight about Higgs
- tt production tests QCD
- Cross section is sensitive to new physics
  - in production (e.g. resonant tt)
  - decay (e.g. $t \to H^+ b$)
- Will be an important background at LHC

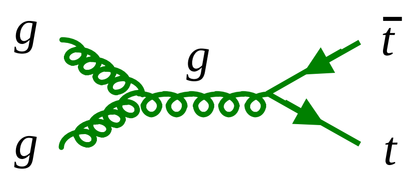
tt production

Production via strong interaction:

- qq annihilation
- gluon fusion





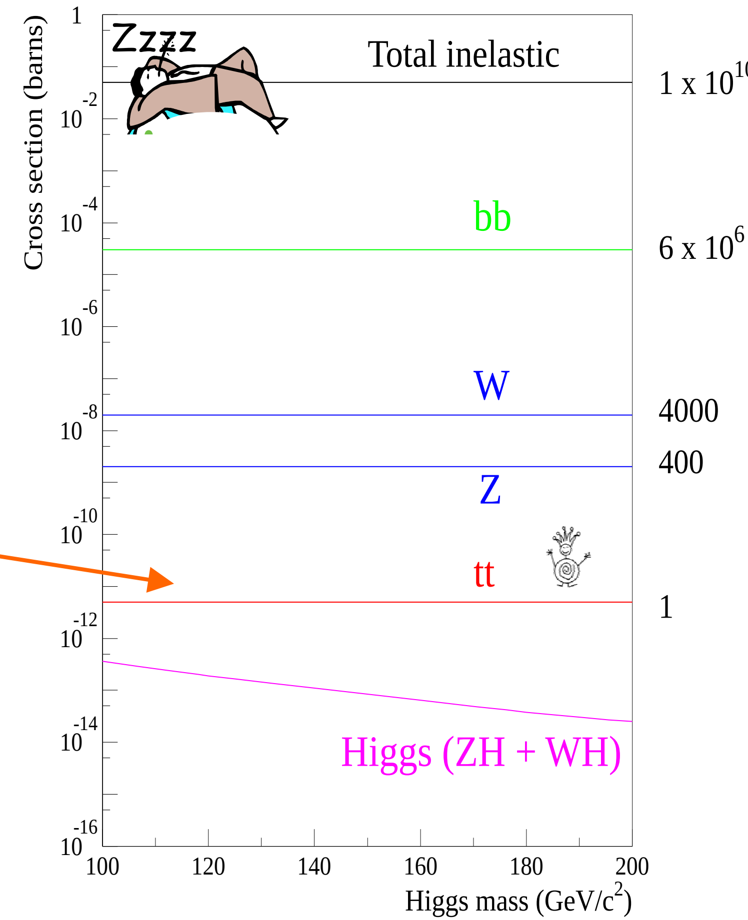


√s [TeV]	σ [pb]	qq %	gg %	Rate
1.96	$6.7^{+0.7}_{-0.9}$	85	15	~1/hr
14	800±100	10	90	~1/2 s

Theoretical predictions at NLL.

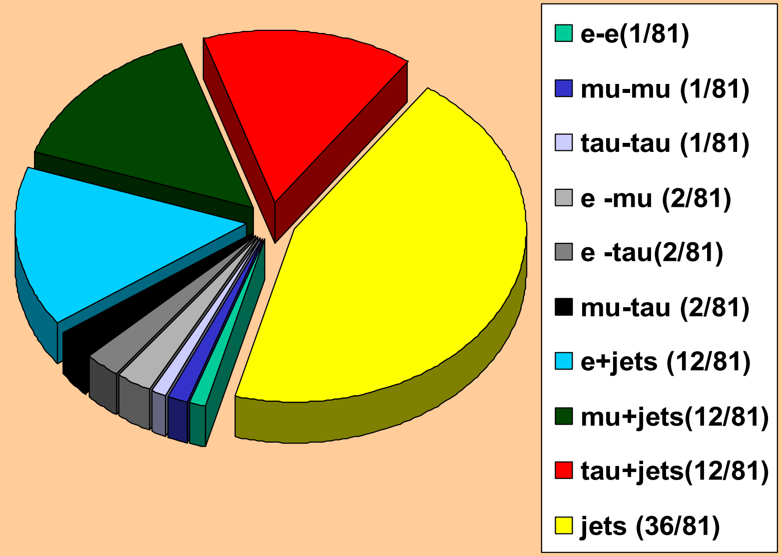
Uncertainties due to renormalization/factorization scale and PDFs

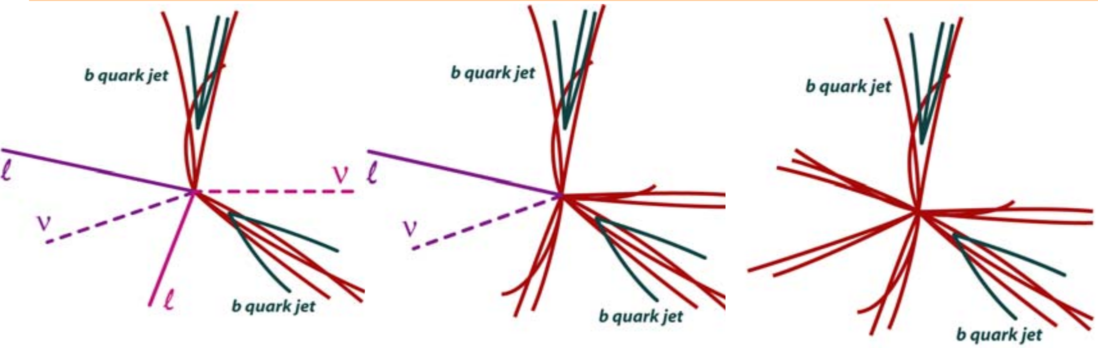
Central, spherical events, Large E_T



tt decays

Top decays via weak interaction: t→Wb
tt signatures depend on Ws decays
All include 2b jets





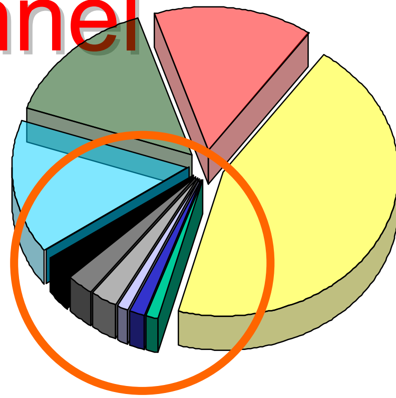
What do we know experimentally about cross section?

We measure it in all channels:

- combine
  - smaller uncertainty
- consistency across channels
  - test for possible New Physics contamination (e.g. $t \to H^+ b$)
- consistency with measured mass
  - tests for possible New Physics production mechanisms (e.g. via Z')

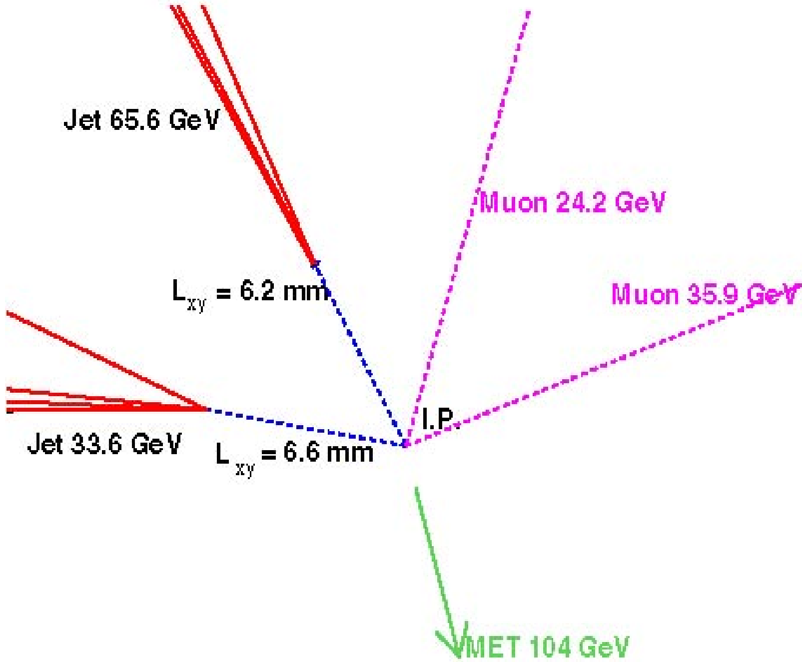
Measure in different ways

Cross section in dilepton channel



- Signature
  - 2 high P_T leptons (ee, μμ, eμ)
    - Ev sel: 2 tracks matching objects in calorimeter or μ chambers
  - Large missing ET
    - E_T^{miss}>25÷40GeV (*)
  - 2 b-jets
    - ≥2 jets with E_T>20GeV
    - no b-tagging (*)
- Backgrounds
  - Physics: Z →ττ →ll' and WW, WZ production (ee, μμ, eμ)
  - "Fake" leptons from W→lν
  - Drell-Yan

Counting experiments



✓ **Cleanest channel. S/B~1.5÷3 :1**

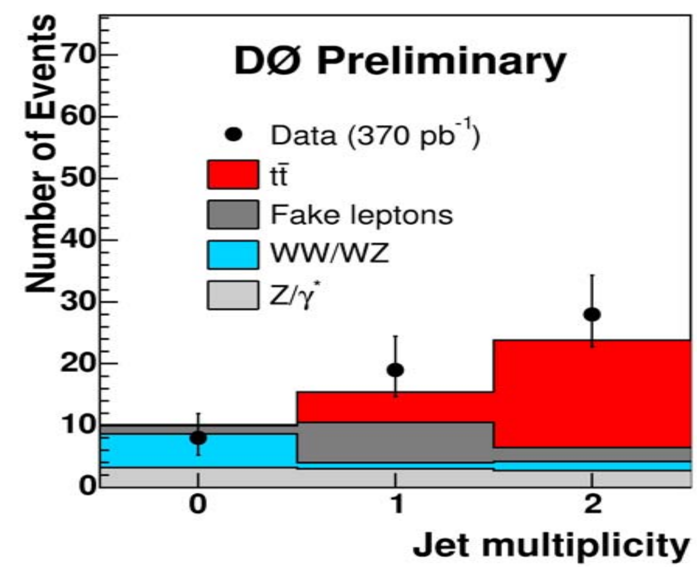
- Small branching ratio ~5%
- Total acceptance wrt tt ≤1%

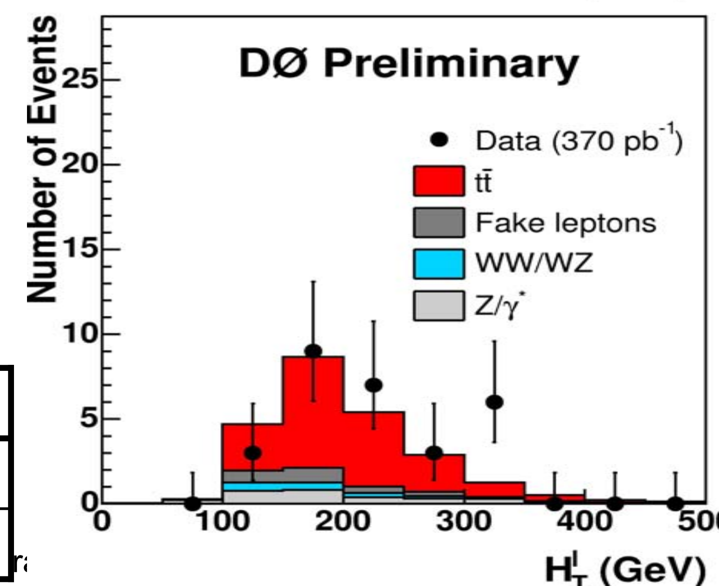
Dilepton channel

Ev sel: 2 well identified leptons

- ll:
  - $E_T^{miss} > 35 \div 40$
    - remove $Z/\gamma^* \to ll$
- ee:
  - Z veto [80-100GeV]
  - Sphericity>0.15
    - reject gluon radiation (planar)
- $\mu\mu$:
  - χ^2 cut in $Z \to \mu\mu$ hypothesis
  - $\Delta\phi(E_T^{miss}, \mu_1) < 175°$
    - remove nonreconstructed jet
- $e\mu$:
  - $H_T^{\ell} = p_T^{\ell} + \Sigma(p_T^{j}) > 122$GeV
    - remove $Z \to \tau^+\tau^-$ and dibosons
  - NO E_T^{miss} cut

$$\sigma(t\bar{t}) = 8.6 \pm^{2.3}_{2.0} (\text{stat}) \pm^{1.2}_{1.0} (\text{syst})\text{pb}$$





Events	ee	$\mu\mu$	$e\mu$	Total
Bkg	1.0±0.3	1.3±0.4	4.5±2.2	6.8±2.2
Data	5	2	21	28

Dilepton channel: eμ with b-tagging

Increase purity further

Ev sel:

- e&μ: isolated track with P_T>15GeV
- Jets : E_T>15GeV
- Missing E_T>25GeV
- b-tagging

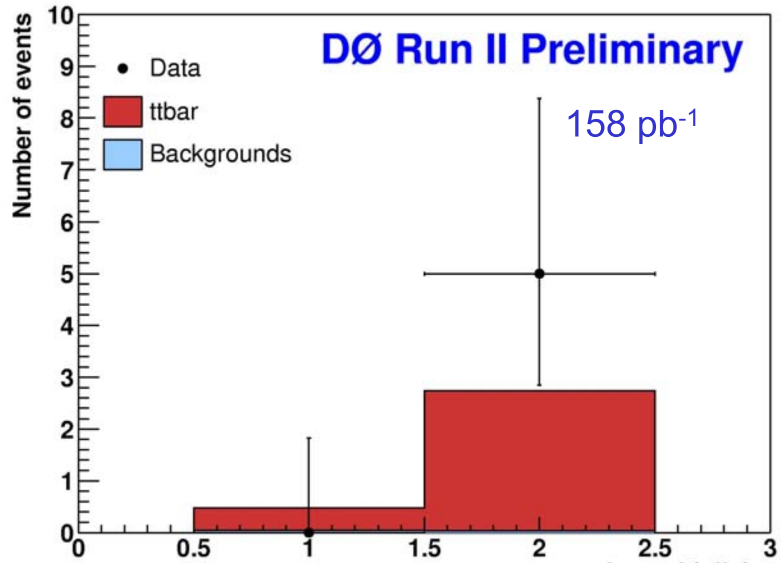
<u>Ultra-pure signal sample</u>

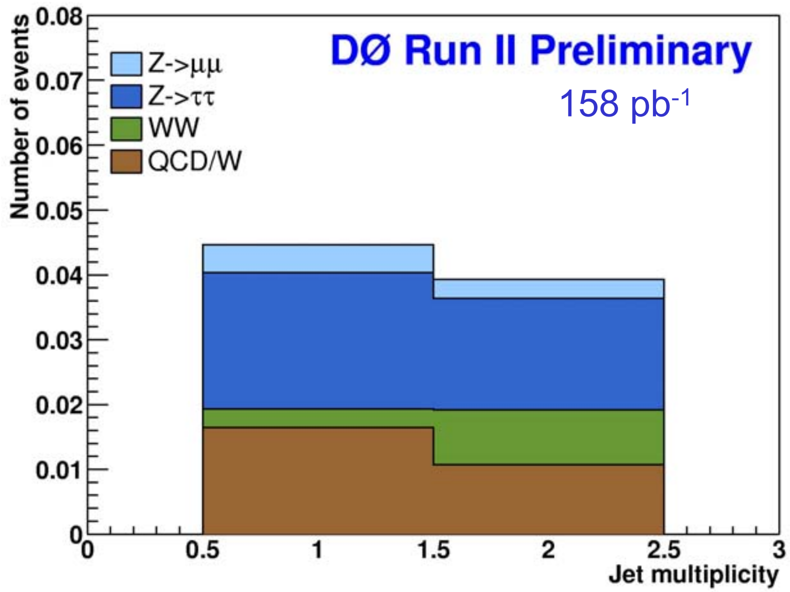
Expected signal: >3 events

Expected backgrounds: < 0.1 events

Useful for study of top properties

$$\sigma(t\bar{t}) = 11.1 \pm^{5.8}_{4.3} (\text{stat}) \pm 1.4 (\text{syst}) \text{pb}$$





Dilepton channel: lepton+track

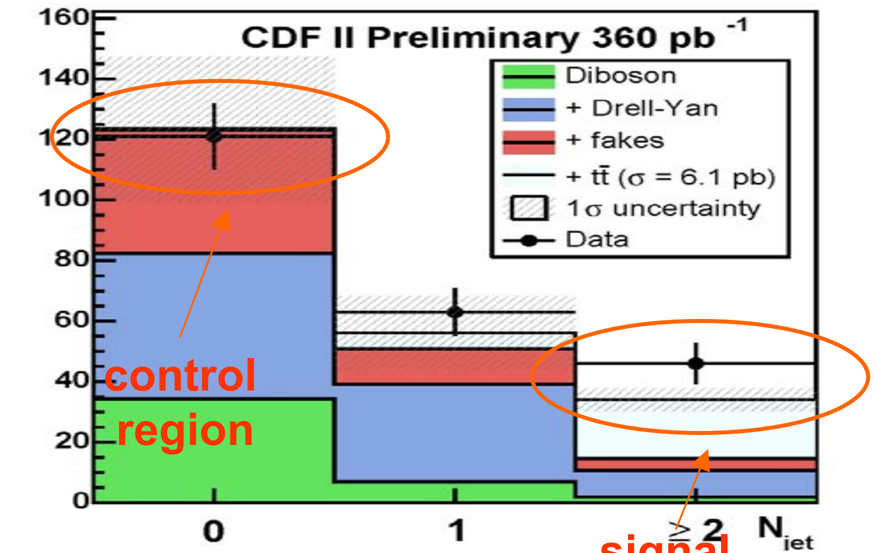
Increase acceptance by loosing cuts

- 1 lepton with strict ID requirements:
  - well reconstructed track
  - isolated signature on calorimeter
    - e: shower profile
    - μ: MIP
- 2nd lepton:
  - well reconstructed and isolated track
  - NO calorimeter requirements
- Recover acceptance from uninstrumented regions
- Accept single prong τ had decay

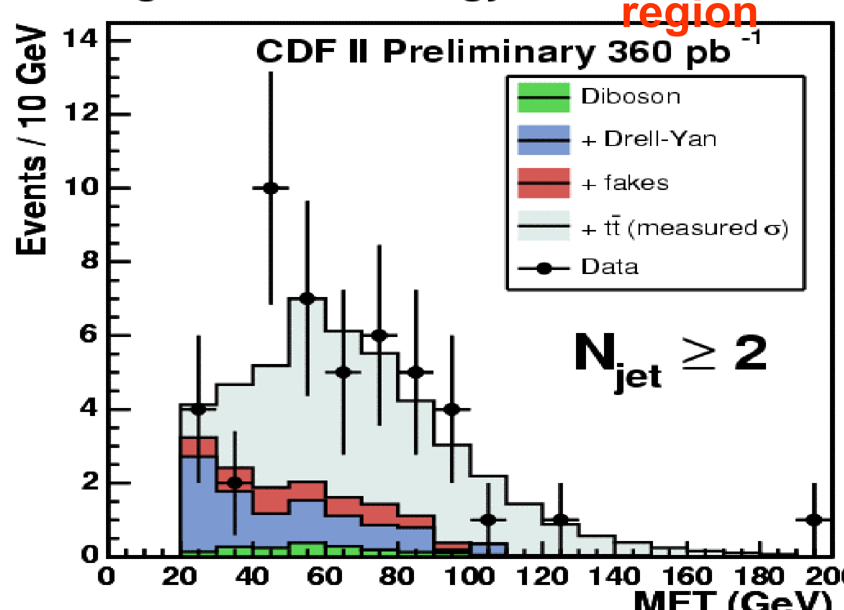
Dominant background: DY $Z/\gamma^* \rightarrow \ell\ell$, evaluated from data and MC adds major contribution to systematics (~10%)

$$\sigma(t\bar{t}) = 9.9 \pm 2.1(\text{stat}) \pm 1.3(\text{syst})\text{pb}$$

Event count per jet bin



Missing Transverse Energy



Dilepton channel: global fit

Increase acceptance by loosing cuts

- ➢Look into the most "natural" distribution: N_{jets} VS E_T^{miss}.
- ➢Fit for different contributions to the sample: e.g, in eμ sample fit with ttbar, WW, $Z\rightarrow\tau\tau$ and extract their cross sections.
- ➢Same technique applied to ee and $\mu\mu$ sample

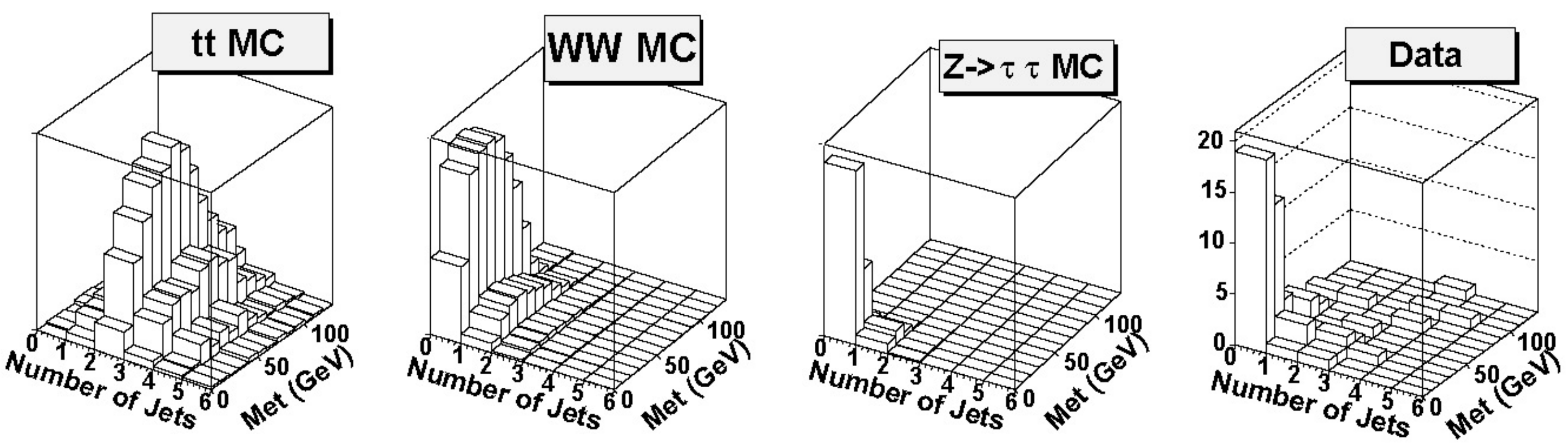
Major systematics due to Jet Energy Scale (JES) & missing E_T modeling and jet multiplicity (ISR/FSR)

$$\sigma(t\bar{t}) = 8.6 \pm^{2.5}_{2.4} \text{(stat)} \pm 1.1 \text{(syst)pb}$$

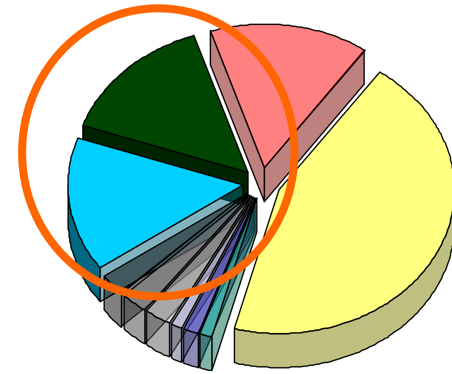
$$\sigma(WW) = 12.6 \pm^{3.2}_{3.0} \text{(stat)} \pm 1.3 \text{(syst)pb} \leftrightarrow \text{Th}: 12.5$$

$$\sigma(Z \rightarrow \tau\tau) = 233 \pm^{45}_{42} \text{(stat)} \pm 17 \text{(syst)pb} \leftrightarrow \text{Th}: 250.5$$

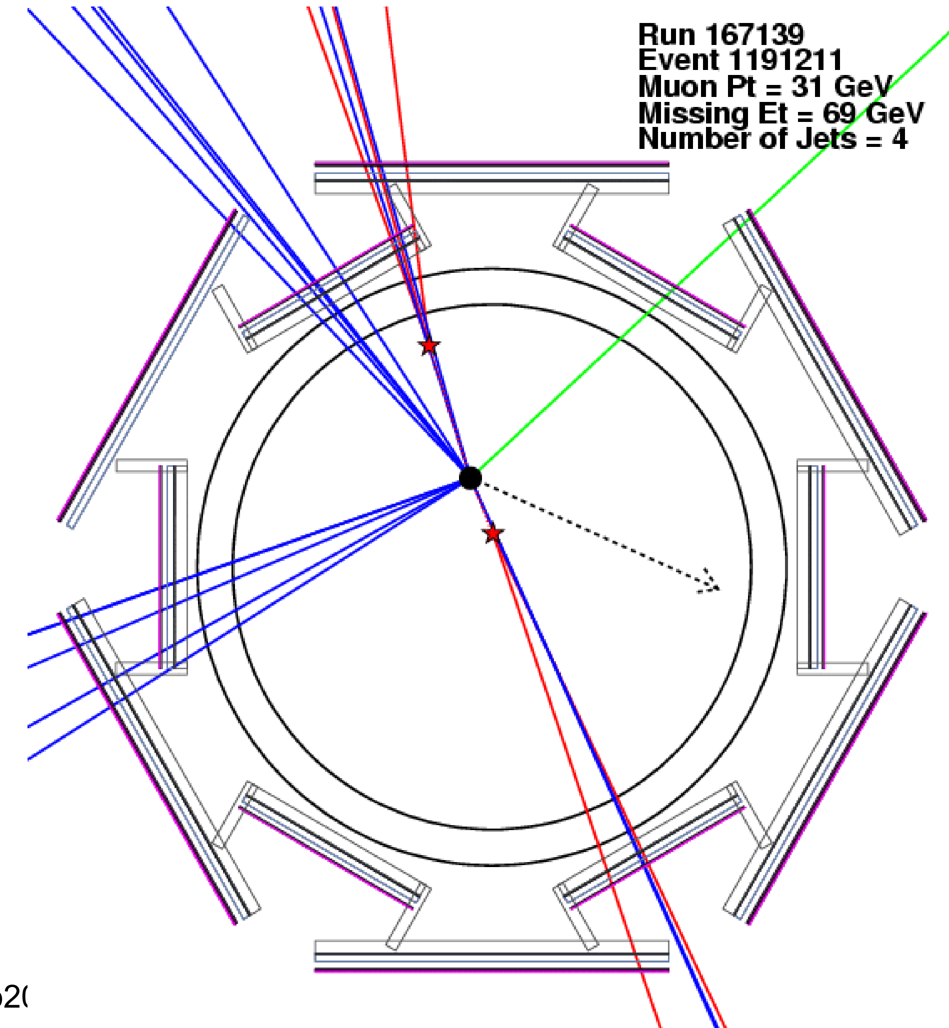
CDF Preliminary (200 pb^{-1})



Lepton+jets



- Signature:
  - 1 high PT lepton
    - P_T>20 GeV
  - 4 jets
    - ≥3 jets with E_T>15GeV
  - Large missing ET
    - E_T^{miss}>20GeV
- Backgrounds:
  - W+jets mainly
    - also QCD (=fake lepton), diboson, single Top



✓ Higher yield & background wrt dilepton

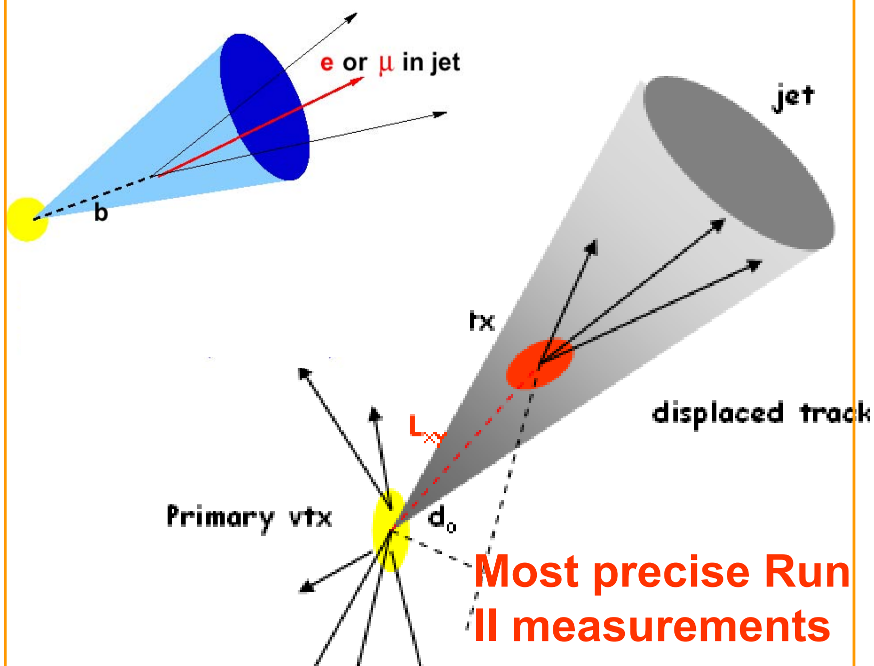
✓ Sample used for other measurements: t mass, W helicity..

- Branching Ratio ~22%
- Total acceptance wrt tt ~5%

Lepton+jets: Approaches

Counting experiments

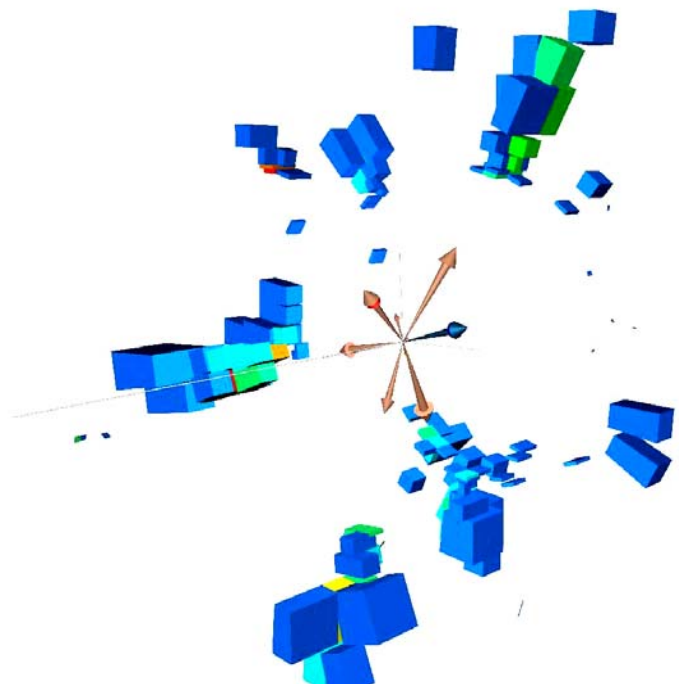
- b-tagging: secondary vertex, displaced tracks, leptonic decays of B-hadrons
  - S/B=2÷4
  - double-tagging !
    - S/B>10



Most precise Run II measurements

Fit to event kinematics

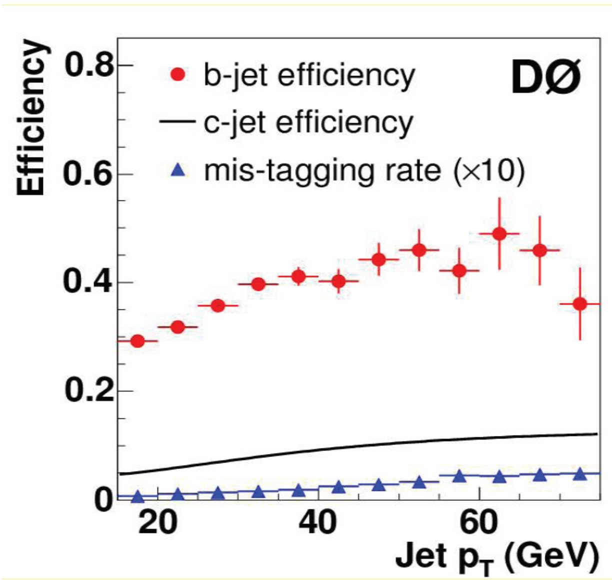
- b-tagging
  - fit the E_T^{j1}
- NO b-tagging
  - i.e. likelihood fit to Ht, A, C..
  - i.e NN Ht



Lepton+jets: b-tagging

Secondary vertex tagger.

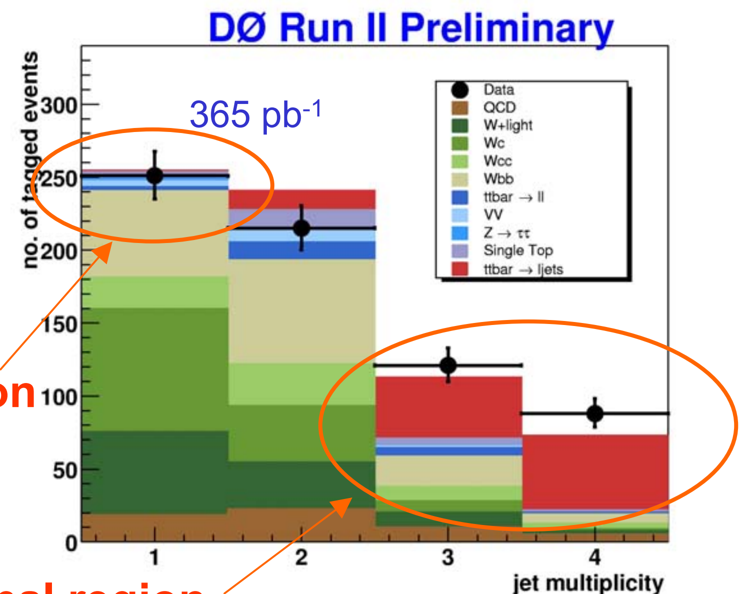
Good rejection of c and light jets background



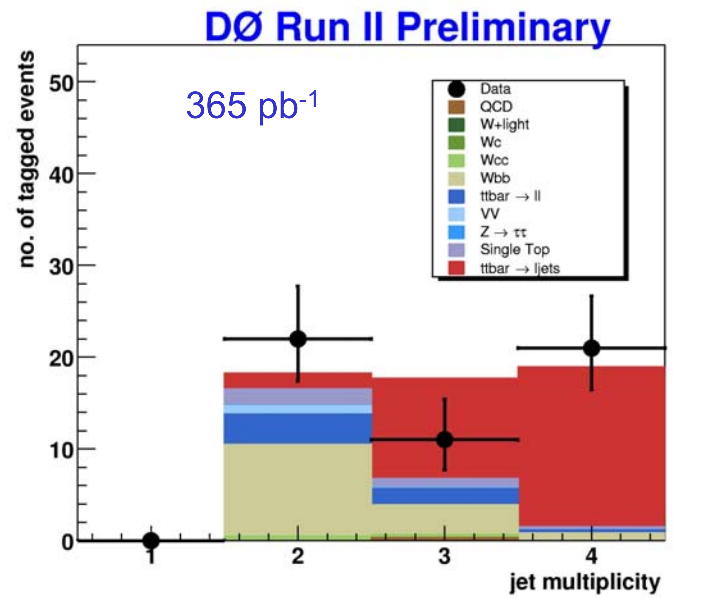
1 tag

control region

signal region



≥2 tags



Major systematics sources:

- W fractions
- b-tagging efficiency
- trigger efficiency.

$$\sigma(t\bar{t}) = 8.1 \pm^{1.3}_{1.2} \text{ pb}$$

16% uncertainty!!

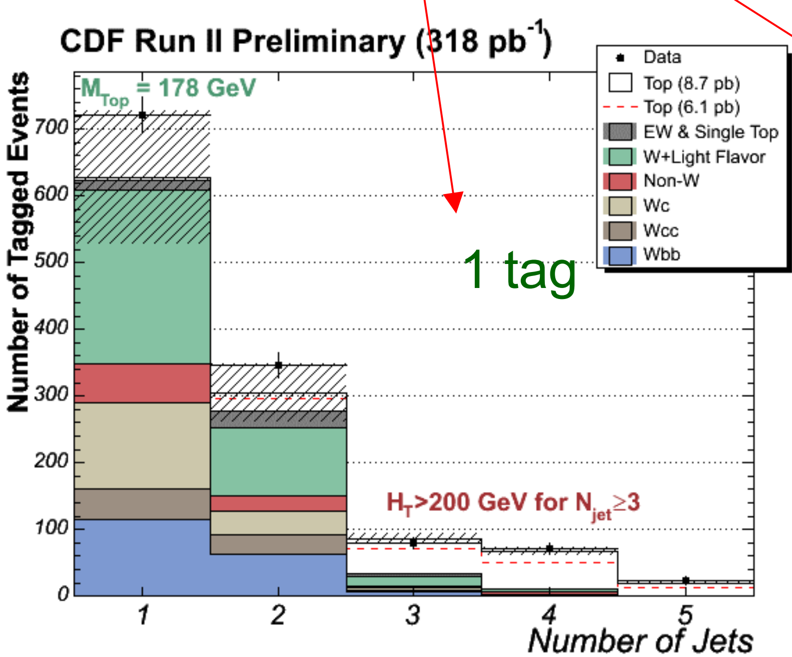
Lepton+jets: b-tagging

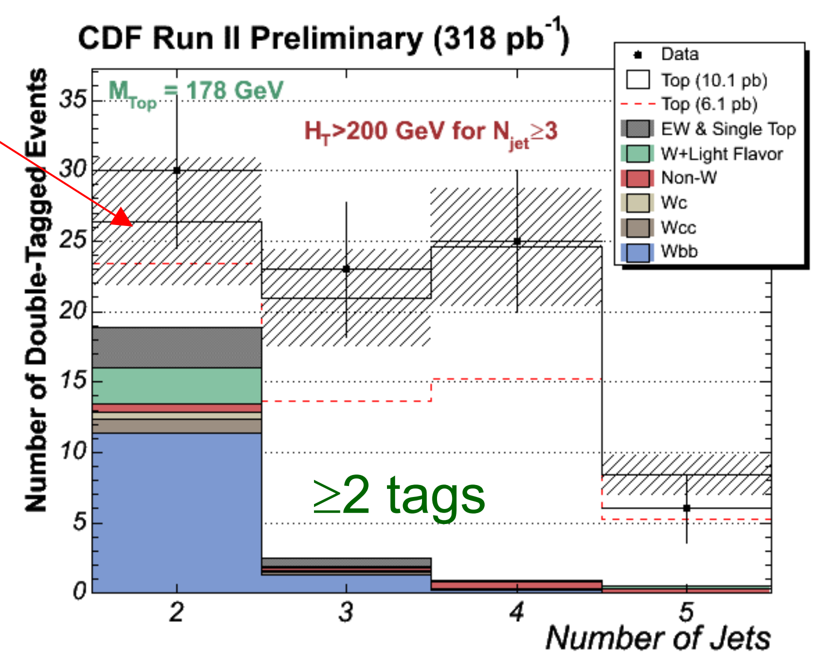
Different algorithms:

- Jet probability tagger $\sigma(t\bar{t}) = 8.9 \pm 1.0 \pm 1.1 \text{pb}$
- SecVtx tagger $\sigma(t\bar{t}) = 8.9 \pm 0.9 \pm^{1.2}_{0.9} \text{pb}$
  - tight or loose (ε_{ev}=48%)
- Soft muon tagger (200pb^{-1}) $\sigma(t\bar{t}) = 5.3 \pm 3.3 \pm^{1.3}_{1.0} \text{pb}$

Background estimation from data as much as possible.

Major systematics from:
- lepton ID
- b-tag efficiency,
- sample composition uncertainty





Lepton+jets: kinematic analyses

Use event shape to discriminate tt from W+jets and multijet.

ANN with 6 variables:

•best S to B separation

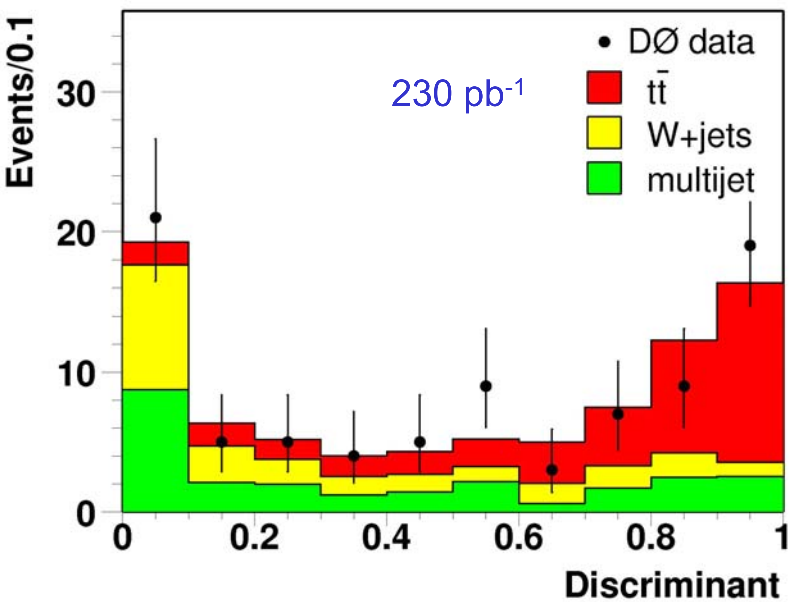
– H_T (4 leading jets)

– Centrality

•least syst dependence

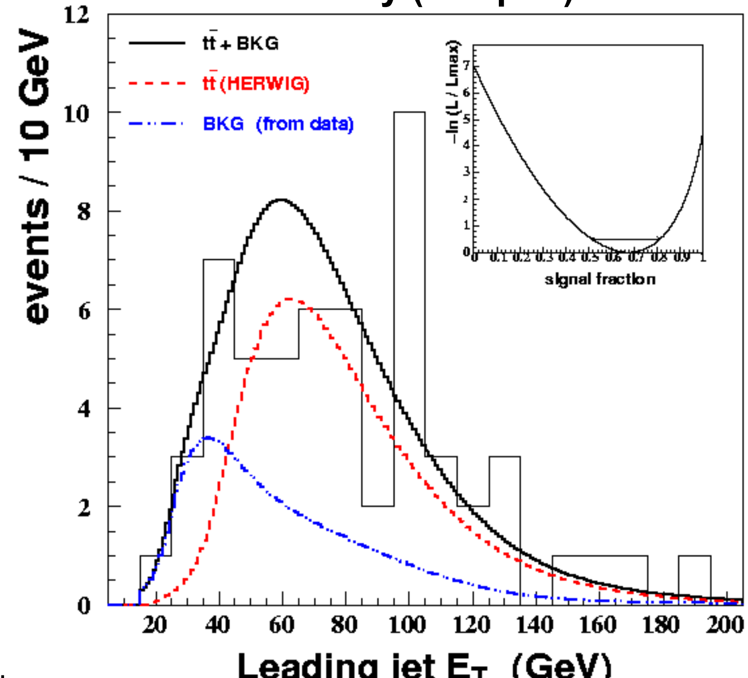
– angular variables

$$\sigma(t\bar{t}) = 6.7 \pm^{1.4}_{1.3} \pm^{1.6}_{1.1} \text{ pb}$$

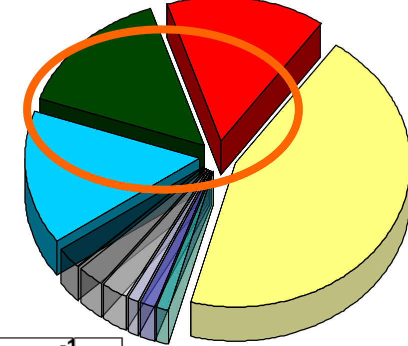


- Fit to the leading jet E_T spectrum
  - b-tagging

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



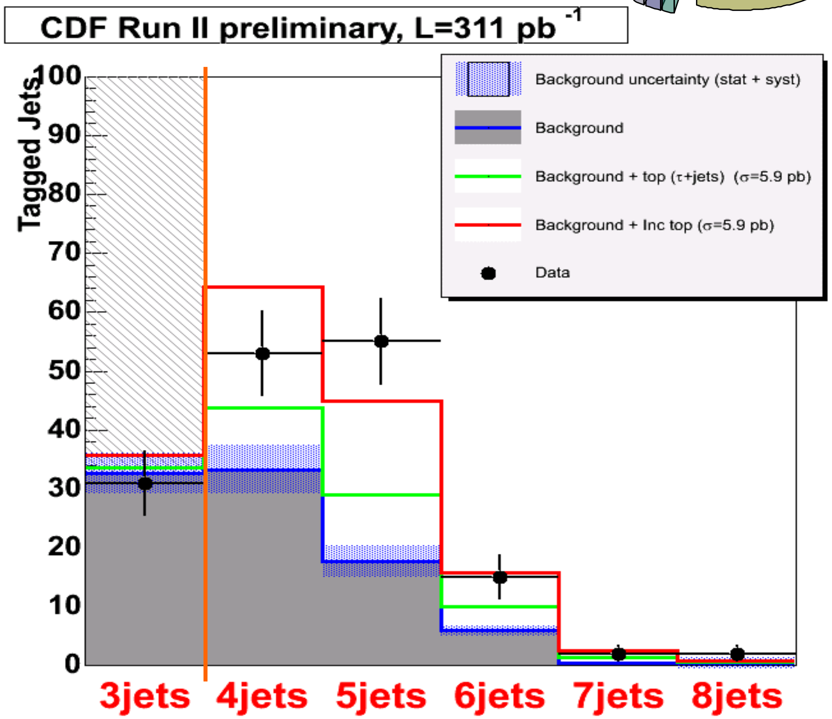
Lepton+jets: MET+jets+b-tags



Selection. 1 b-tag:

- Veto on lepton (looking into the dumpster!!)
  - to include also τ decays
  - to recover part of e, μ
- $\Sigma E_T^{jets} > 125$GeV
- ≥ 4 jets with $E_T > 15$GeV
- Large missing E_T
- $\Delta\Phi(E_T^{miss}, \text{Jet}) \geq 0.4$rad
  - to suppress QCD

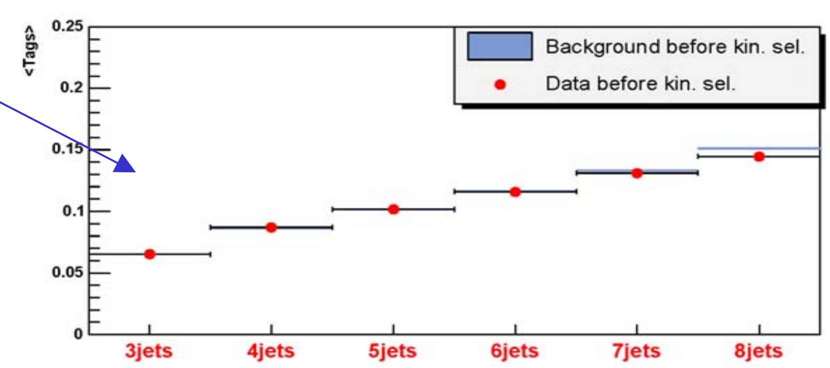
Counting experiment
Count b-tags



Background from data

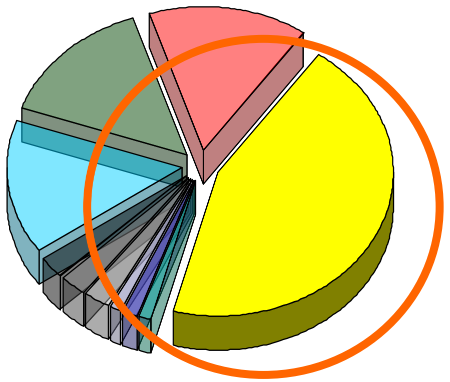
Major systematics:

- trigger efficiency
- tagging efficiency



$$\sigma(t\bar{t}) = \frac{N_{obs}^{tag} - N_{exp}^{tag}}{\varepsilon_{kin} \times \varepsilon_{tag} \times L} = 5.9 \pm 1.1 \pm_{1.1}^{1.6} \text{ pb}$$

all-hadronic channel



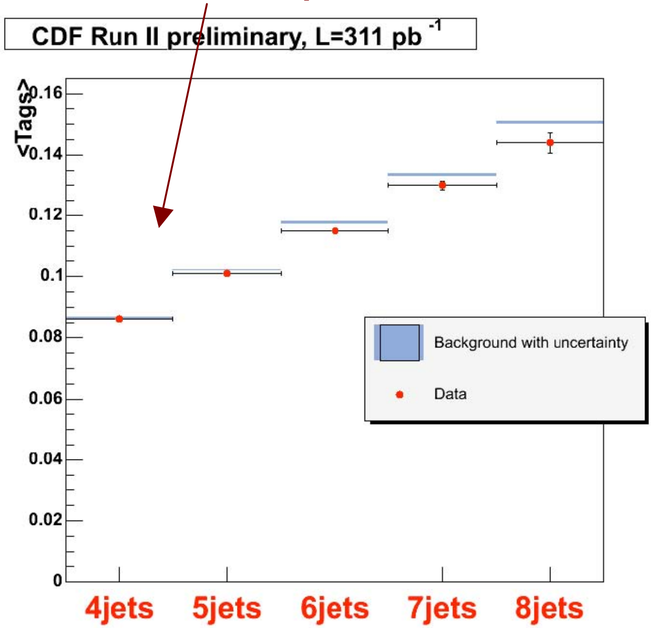
- ✓Largest BR (~45%)
- ✓Fully reconstructed events
- Signature:
  - – Large total E_T
    - $\Sigma E_T^{jets} > 125$GeV
  - – High jet multiplicity
    - ≥ 6 jets with $E_T > 15$GeV
  - – Low missing E_T
  - – No isolated leptons

- ✓Background:
  - – Overwelming QCD background. S/B~1/3500 (after specifically designed trigger)
- ➢To remove it:
  - – Kinematic selection
  - – b-tagging

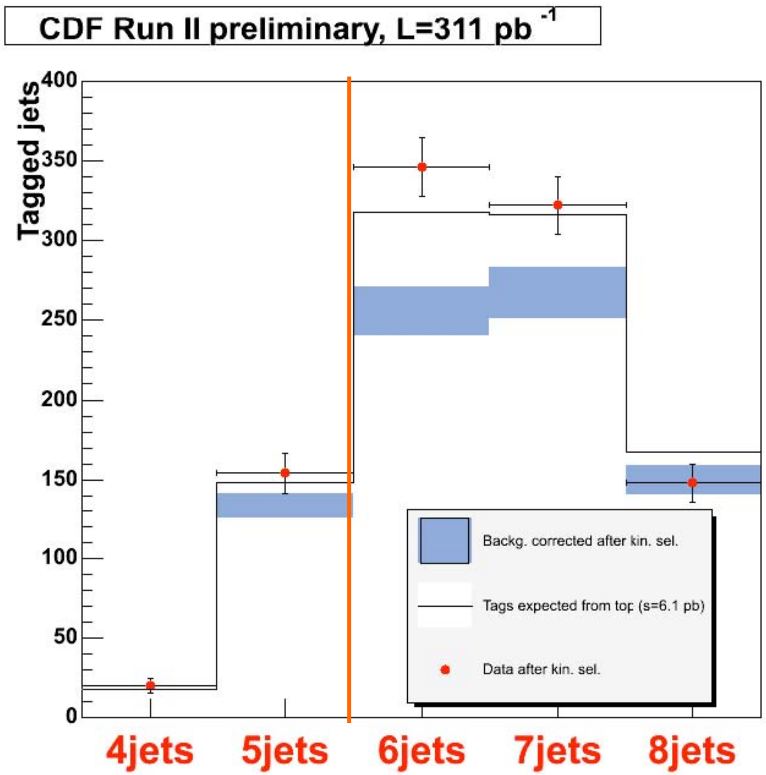
all-hadronic channel

- kinematic selection to optimize $S/\sqrt{(S+B)}$:
  - $\Sigma E_T \geq 280GeV$
  - Centrality≥0.78
  - Aplanarity+0.005·$\Sigma_3 E_T \geq 0.96$
- require >1b-tag
  - S/B~1:5

Estimate background tags from data with no top contribution



Counting tags, likelihood calculation



$$\sigma(t\bar{t}) = 7.5 \pm 1.7 \pm^{3.3}_{2.2} \text{ pb}$$

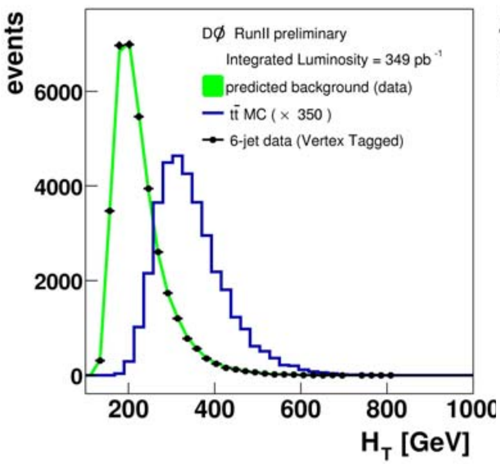
Major systematics from JES uncertainty

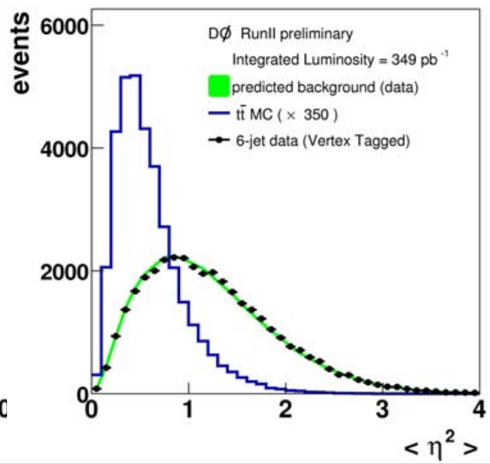
all-hadronic channel

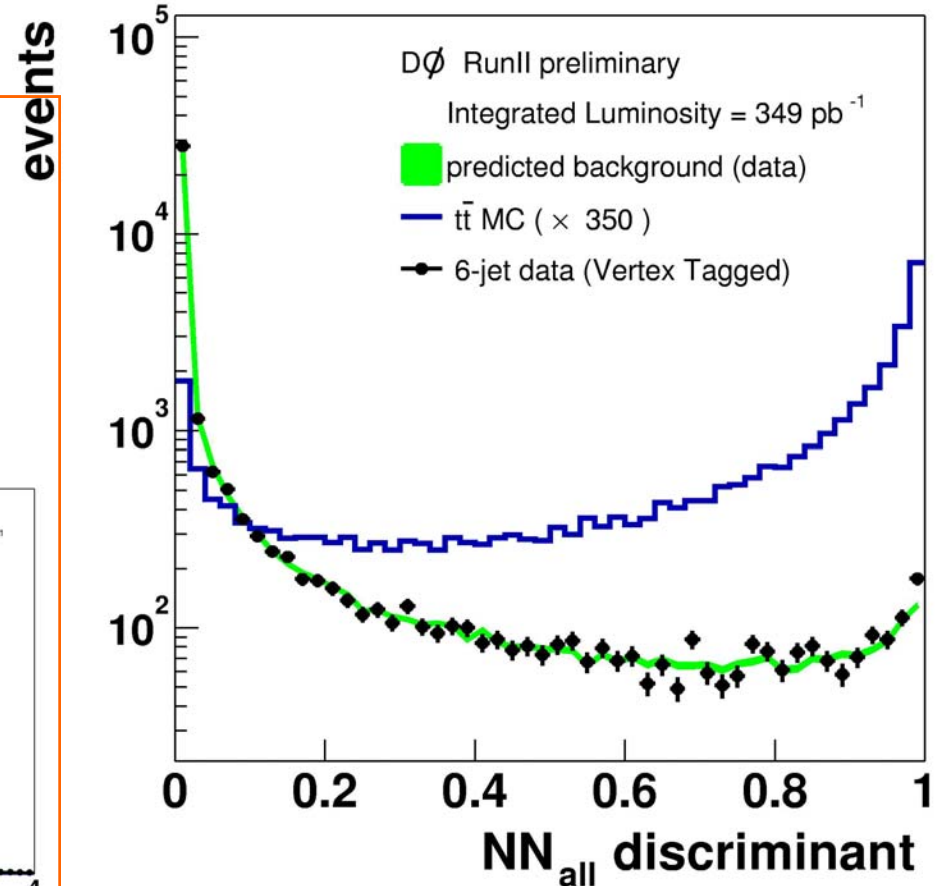
ANN. Require b-tagging.

6 variables related to:

- Event energy
- Event shape
- Rapidity distributions







After applying NN_{all}>0.9

Nobs=541   Nexp=494

$$\sigma(t\bar{t}) = 5.2 \pm^{2.6}_{2.5} \pm^{1.5}_{1.0} \text{ pb}$$

Background from data

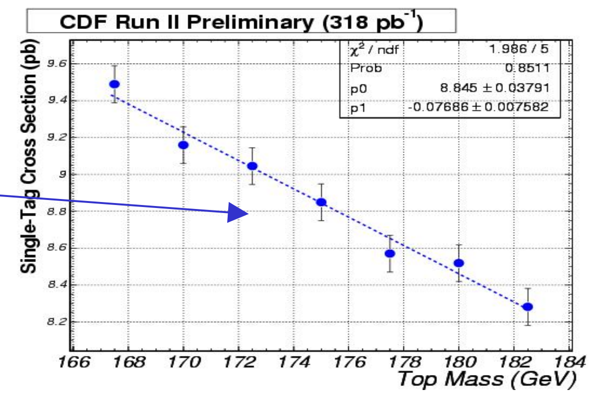
Major systematics from Jet Energy Scale uncertainty ~20%

Global tt xsec results. Top mass

Top mass affects:

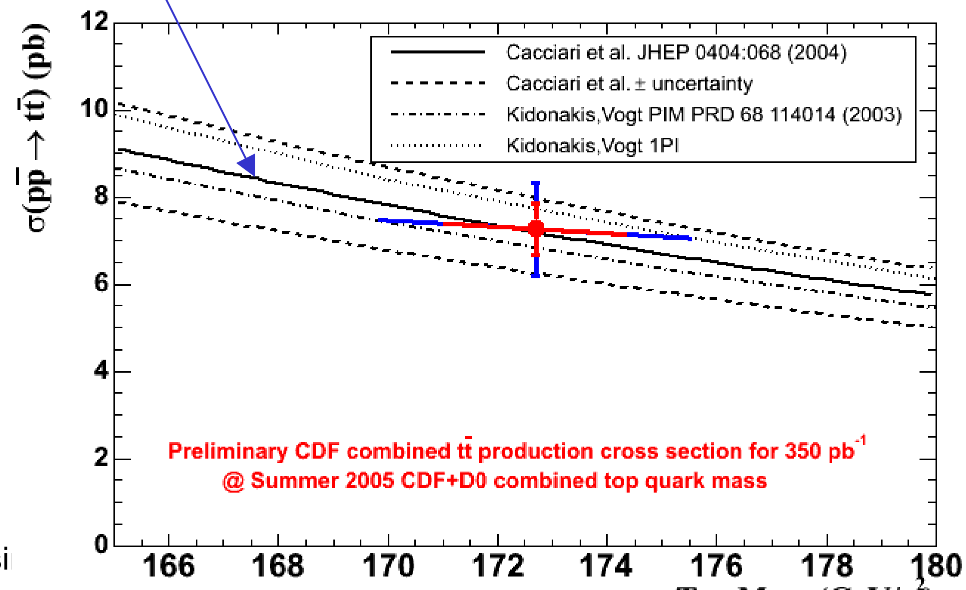
- Theoretical prediction
- Experimental measurement:
  - e.g.: acceptances

When making a measurement you assume a specific mass. Changing the mass will change the central values as well as the errors.

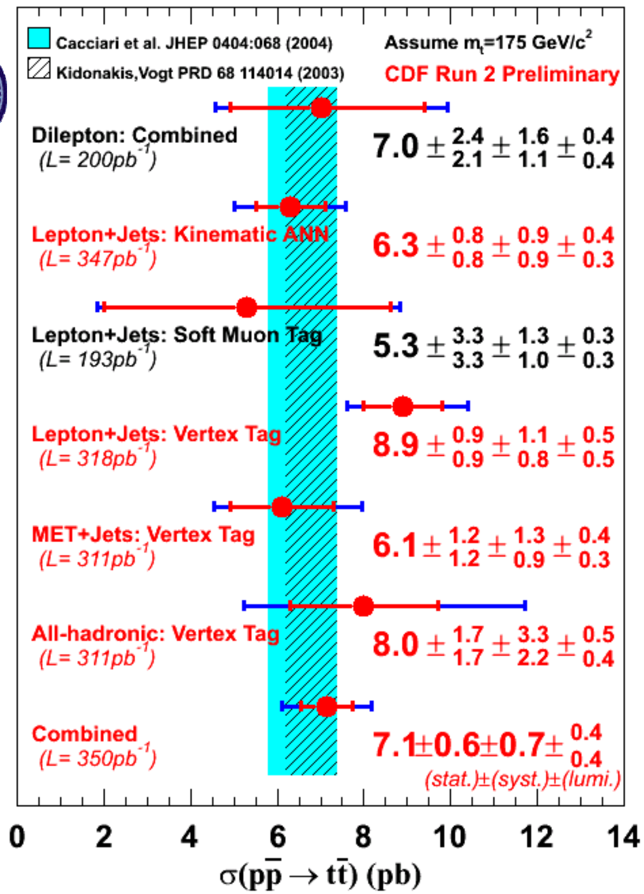


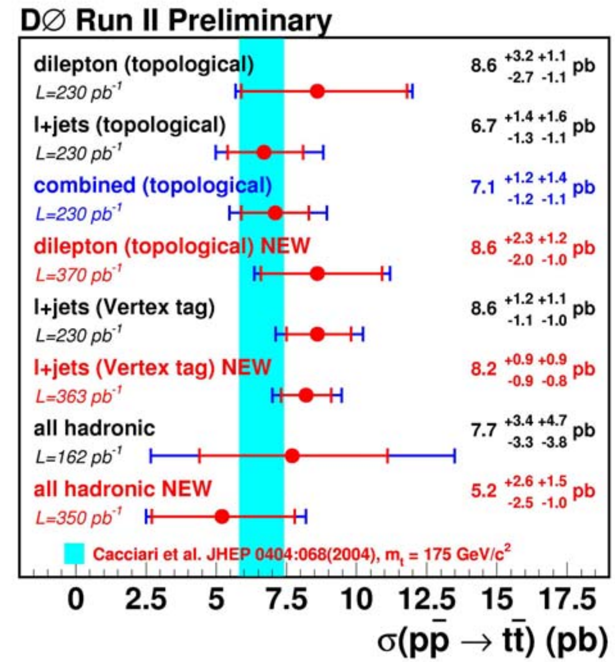
CDF assumed m_t=178GeV for all the analysis presented. D∅ assumed m_t=175GeV.

CDF results have been recalculated at m_t=175GeV for the following comparison.



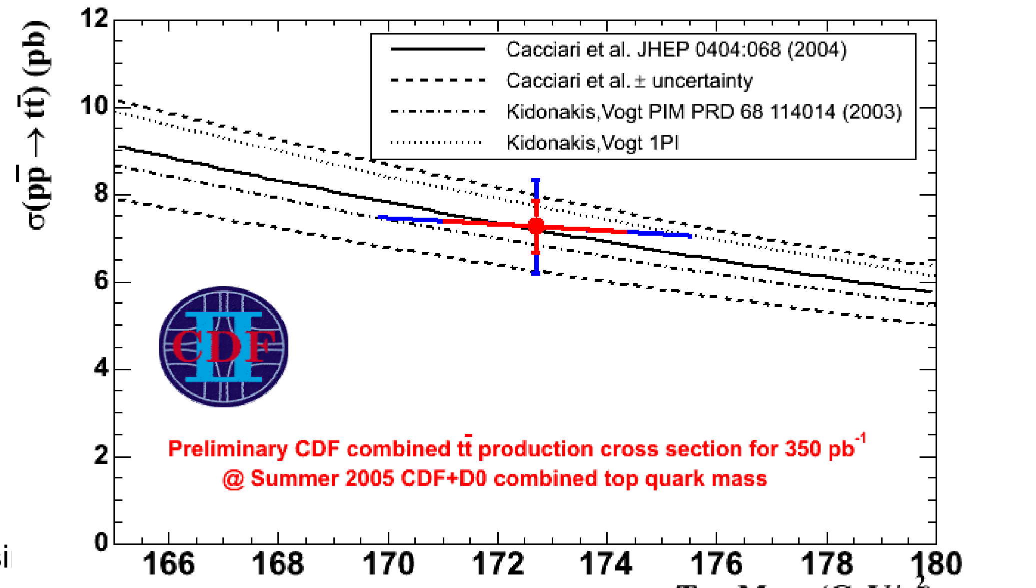
Global tt xsec results





Good agreement with SM prediction.

With new data will be able to reach 10% uncertainty



tt resonance production searches

tt resonance production searches

- No resonance production is expected in **SM**
- Why is Top so heavy ?
  - Indication of coupling to New Physics ?
  - Third generation 'special' ?
- Theoretical models predict it
  - Leptophobic topcolor assisted technicolor
    - Couples predominantly to third generation quarks

    Harris, Hill, Parke hep-ph/9911288

  - And many others…
- Top production is relatively unknown experimentally, needs investigation

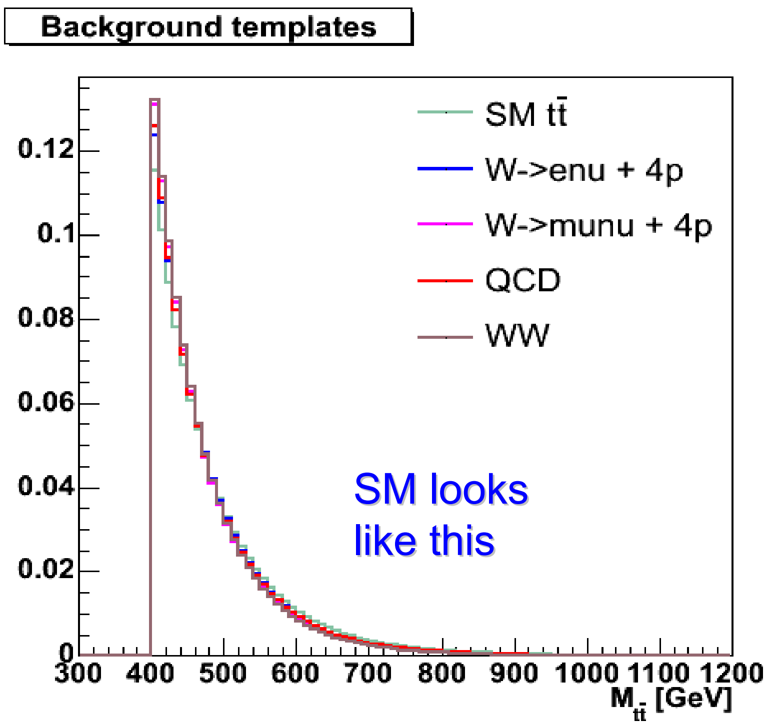
Where to look?

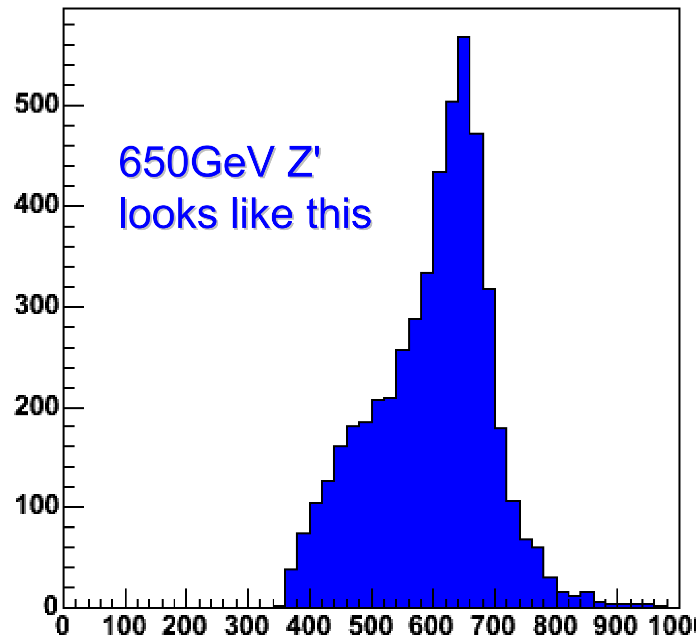
Data sample:

Lepton + Jets overall best choice for M_{tt} reconstruction

Where, in l+jets:

Since we are looking for resonant tt production, the natural choice is to look into the tt invariant mass spectrum.





M_{tt} reconstruction

Issues with a direct inv mass reconstruction :

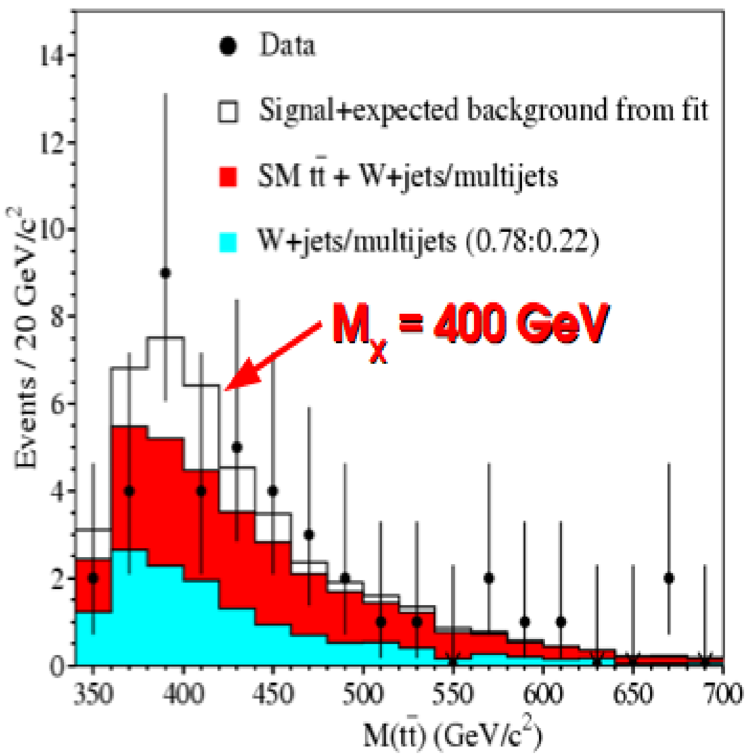
- Neutrino is elusive
  - Longitudinal momentum not known
  - Transversal momentum indirectly reconstructed (E_T^{miss}),not very precise
- Jet energy is loosely correlated with the parton energy
  - Limited intrinsic detector resolution
  - Extra jets (ISR/FSR) $\Rightarrow$ difficult tt jets identification

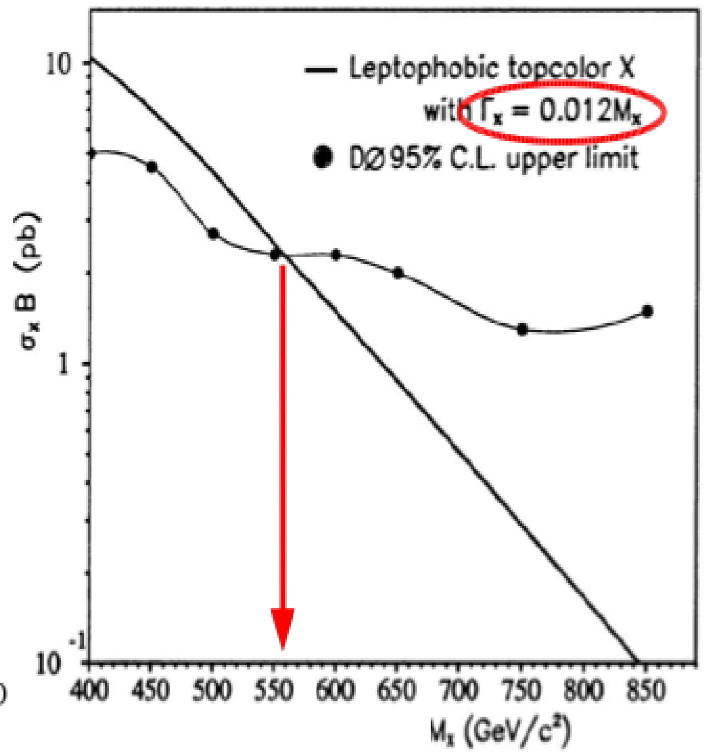
SUMMARY:

4 (parton energies) + 3 (ν momenta) = 7 unknowns

History: Run I Results

Phys. Rev. Lett. 92, 221804 (2004)





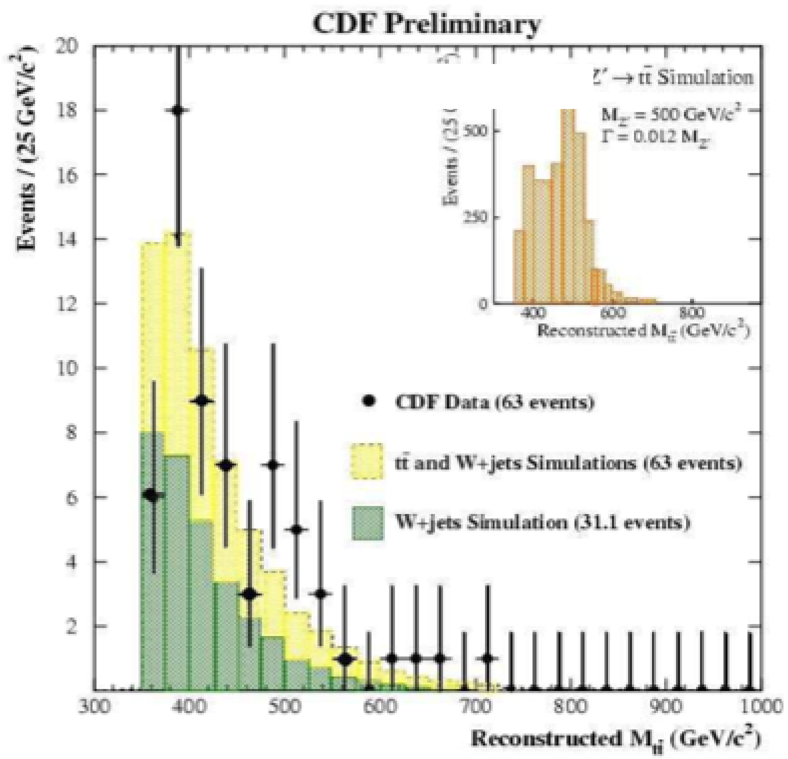
L = 130 pb^{-1}

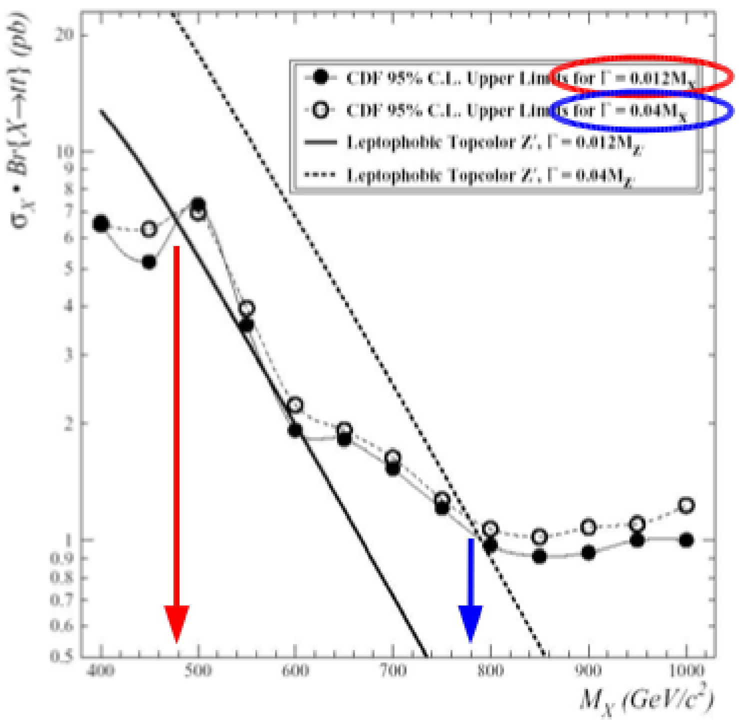
N = 41 events

M_x > 540 GeV , $\Gamma_x = 0.012 M_x$

History: Run I Results

Phys. Rev. Lett. 85, 2062 (2000)





$M_x > 480$ GeV

$\Gamma_x = 0.012M_x$

$M_x > 780$ GeV

$\Gamma x = 0.04Mx$

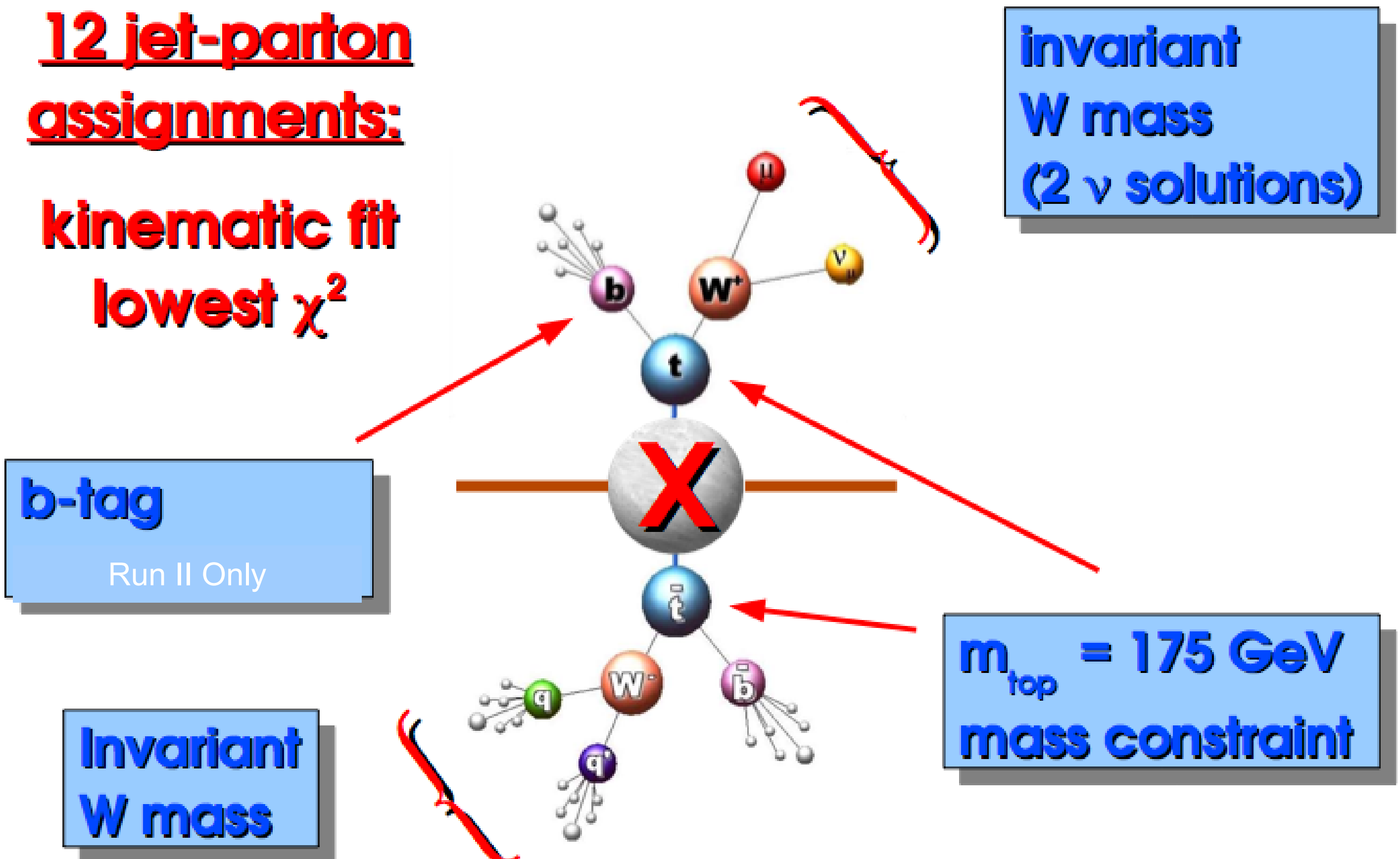
$L = 109\ pb^{-1}$

N = 63 events

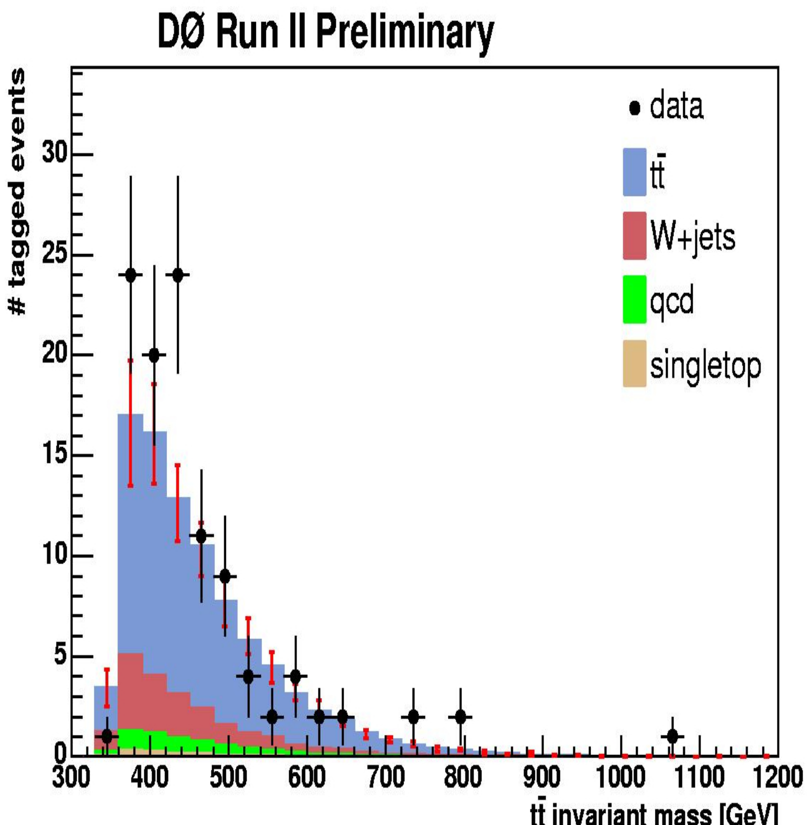
$t\bar{t}$ invariant mass reconstruction

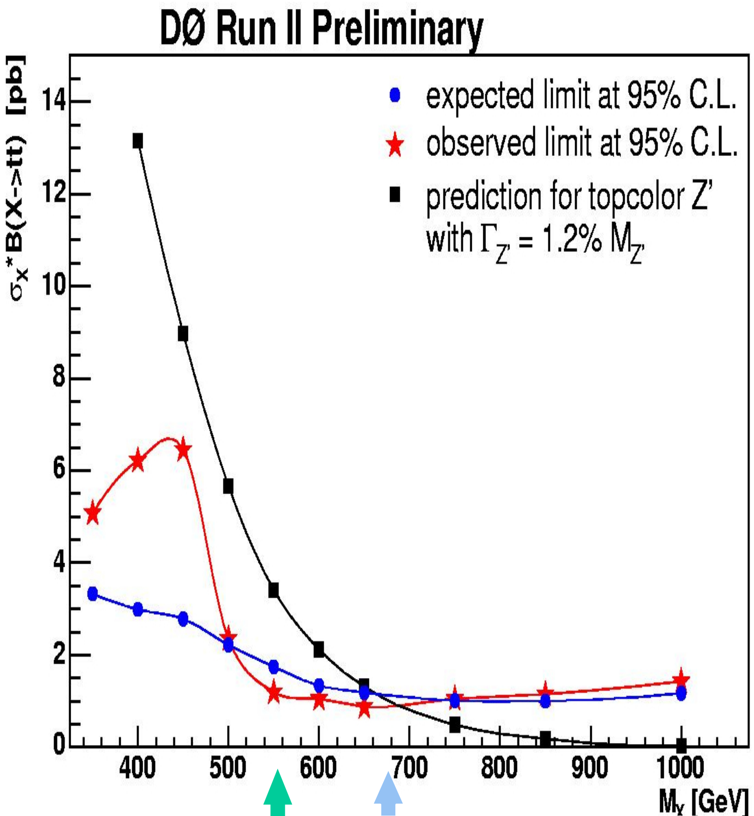
Unknown quantities : 4 quark momenta and neutrino 3-momentum

Solution : find most likely values based on jet energy resolutions
And kinematical constraints like W, Top masses using a kinematic fit



Run II Results





D0 Run I
M_X > 560GeV

D0 Run II
M_X > 680GeV

L = 370 pb^{-1}

N = 108 events

Requires 1 or more b-tagged jets

tt invariant mass reconstruction

Assume the top mass to be known , Mtop = 175 GeV

For each event, for each combination, build the posterior probability density:

$$\pi^{post}(p_b, p_{\bar{b}}, p_q, p_{\bar{q}}, \vec{p_\nu} | \vec{j_1}, \vec{j_2}, \vec{j_3}, \vec{j_4}, \vec{p_l})$$

$$\pi^{post}(\{p\}|\{j\}) \propto \pi^{prior}(\{p\}) \cdot T(\{j\}|\{p\})$$

Parton-to-jet transfer functions

Probability of measuring jet energy j knowing parton energy p

The *prior* is the ttbar differential cross-section

$$d\sigma(\vec{p}_i|p_k, p_l) = \frac{|\mathcal{M}|^2}{4E_k E_l |v_k - v_l|} \cdot (2\pi)^4 \delta^4(p_k + p_l - \sum_{i=1}^{6} p_i) \cdot \prod_{i=1}^{6} \frac{d^3\vec{p}_i}{(2\pi)^3 \cdot 2E_i}$$

The posterior allows the derivation of the **event** Mtt probability density:

$$\rho^{post}(x|\{j\}) = \int \{dp\} \pi^{post}(\{p\}|\{j\}) \cdot \delta(x - M_{t\bar{t}}(\{p\}))$$

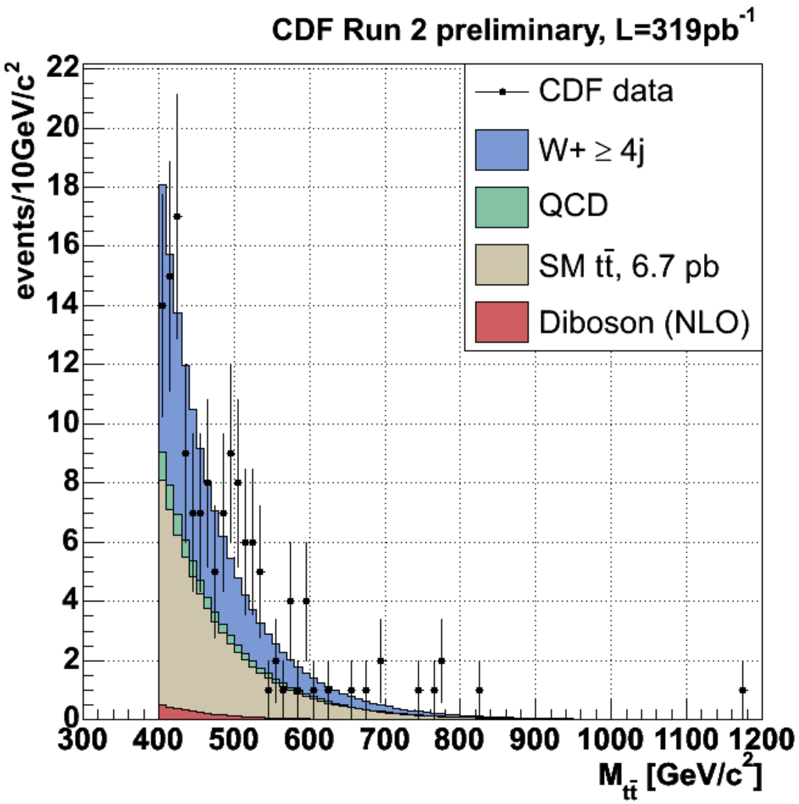
We 'project' the multidimensional posterior on one 'dimension' of our choice, Mtt in this case

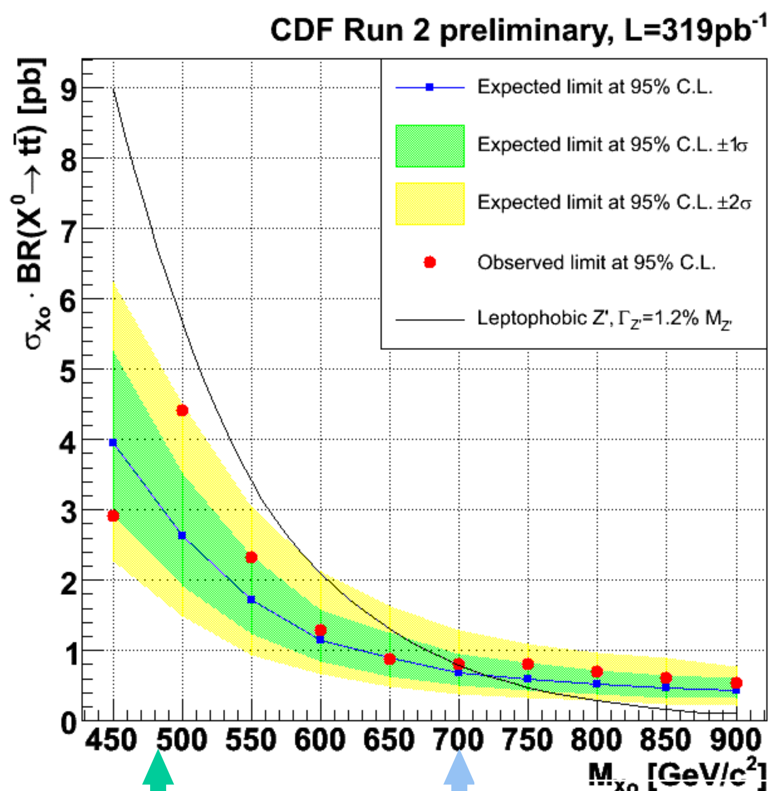
We average over all jet-parton assignments allowed by b-tagging information

The mean Mtt value defines the 'reconstructed' event Mtt.

$$\mathcal{M}_{t\bar{t}} = < \rho^{post}(x|\{j\}) >$$

Run II Results





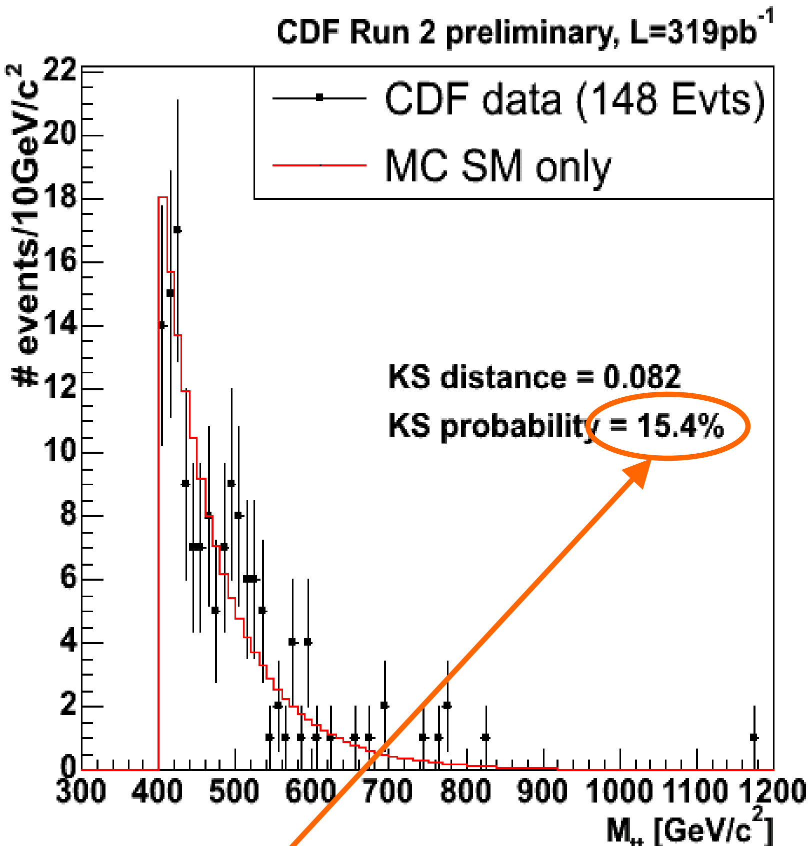
CDF Run I
$M_X > 480$GeV

CDF Run II
$M_X > 700$GeV

L = 319 pb^{-1}
N = 148 events

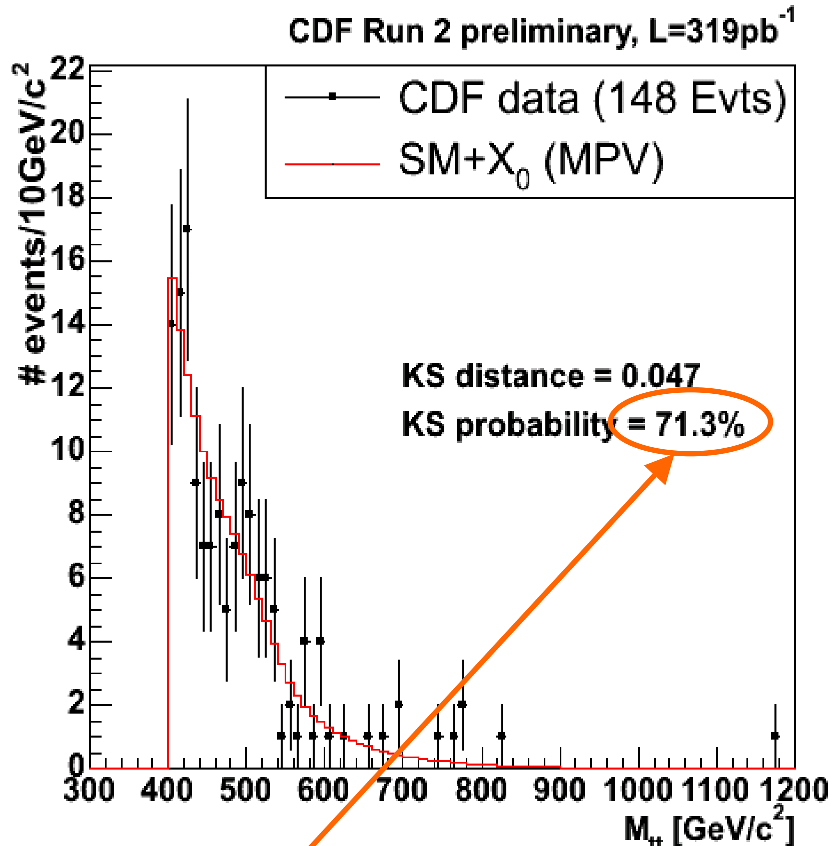
Run II Results

KS test, SM only



Still compatible with SM

KS test, SM + X(500GeV) at most probable x-sec 2pb



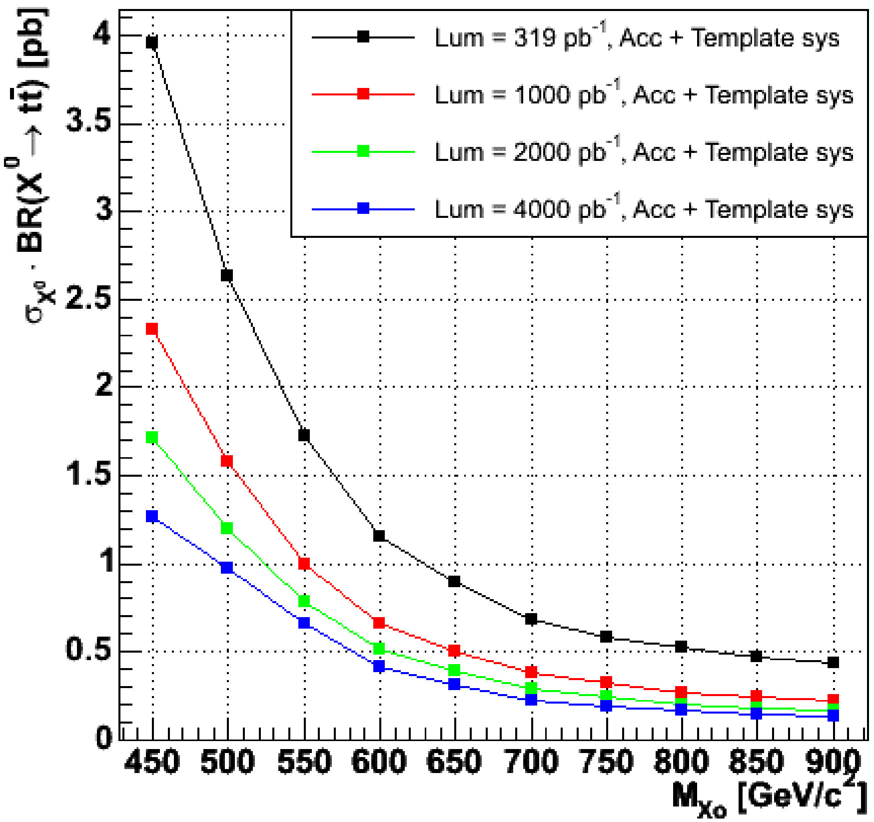
Data fit better with resonant component

Summary Resonance

	Run I	Run II
D0	Method : Kinematical fit B-tags : any Limit : 560 GeV	Method : Kinematical fit B-tags : 1 or more Limit : 680 GeV
CDF	Method : Kinematical fit B-tags : any Limit : 480 GeV	Method : Matrix Element B-tags : any Limit : 700 GeV

- No evidence for a new resonance found, but....
- Cross section limits were improved compared to Run I
- Leptophobic Z′ model :
  - New limit $M_{Z'} > 700$ GeV for $\Gamma_{Z'} = 0.012 M_{Z'}$

Expected sensitivity for the future



We are going to add data in few... days! Stay tuned

Conclusions

We are testing SM production more and more stringently:

- Measuring cross section absolute value at ~15%
  - measuring branching ratios
- Testing for specific non-SM production mechanisms such as resonances at the <10% level of contamination.
- Uncertainties are going to be reduced to the level of the theoretical uncertainty
  - Systematics need to be improved, usually more data helps here too!!

Tevatron is running well , more data are coming...

Conclusions

We are testing SM production more and more stringently:

- Measuring cross section absolute value
  - measuring branching ratios
- Testing for specific non-SM production mechanisms such as resonances at the <10% level of contamination.
- Uncertainties are going to be reduced to the level of the theoretical uncertainty
  - Systematics need to be improved, usually more data helps here too!!

Tevatron is running well , more data are coming...

- ...not time to go to LHC. (yet)