Top mass measurement at the Tevatron

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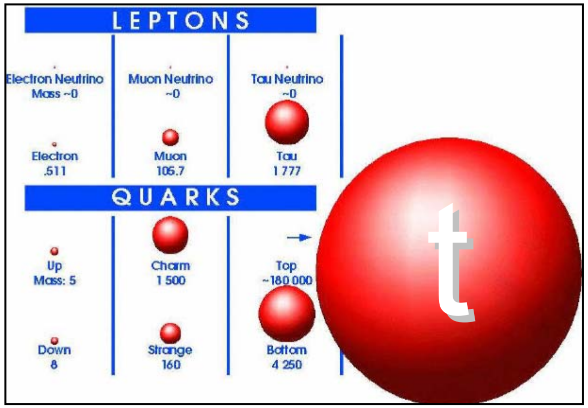
42nd Rencontres de Moriond, Electroweak Interactions and Unified Theories

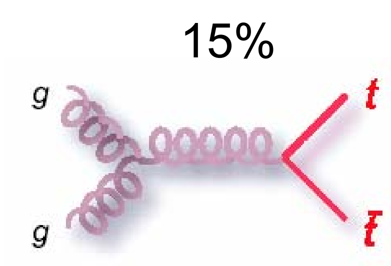


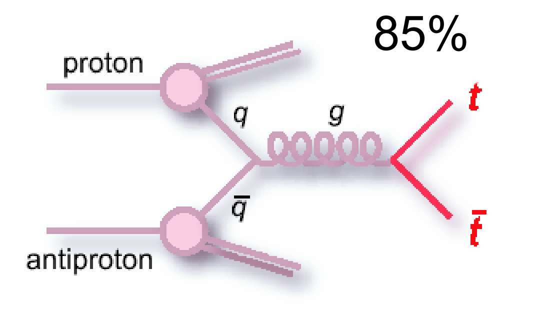
- Top quark physics and the Top quark mass.
- Mass measuring techniques.
- Most recent and/or most precise results in lepton+jets, dilepton and all hadronic final states.
- Conclusions and outlook.

Top Quark Production and Decay

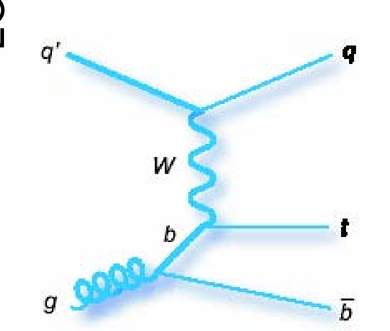
- In proton anti-proton collisions at Tevatron energies, top quarks are primarily produced in pairs via strong interactions: we measure the mass in this production mode.

LO diagrams

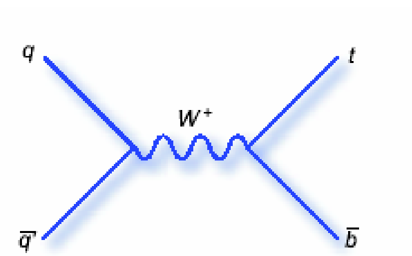




- EW single top production: evidence in 2006.

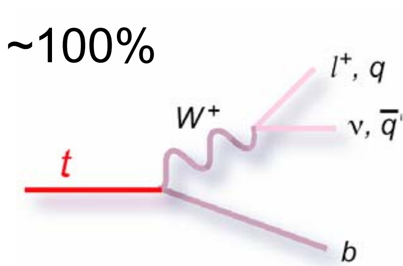


t-channel

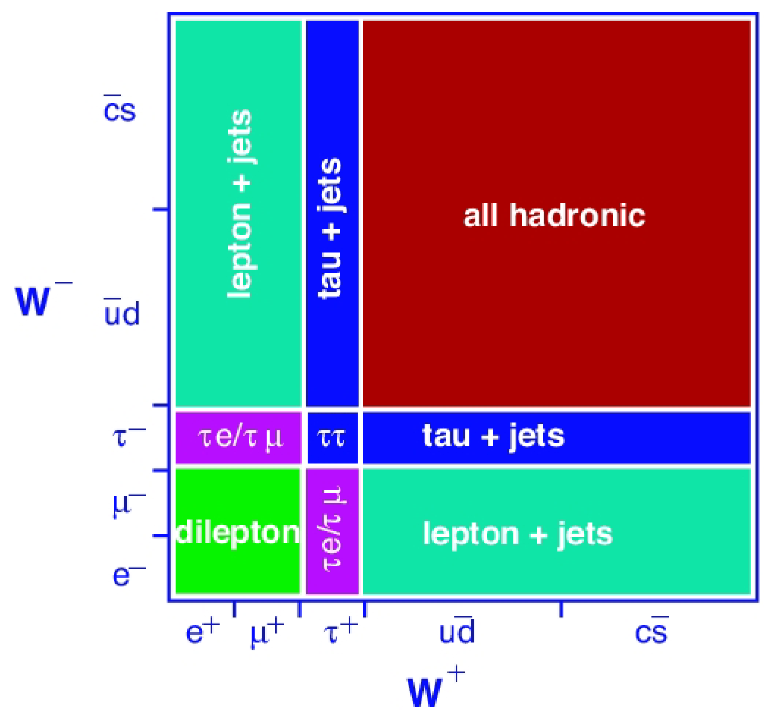


s-channel

- Br($t \to Wb$) ~100%



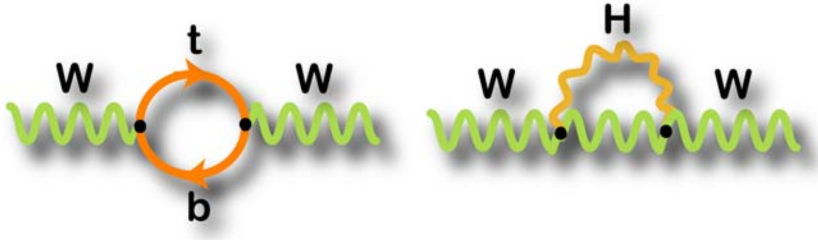
$t\bar{t}$ decay modes



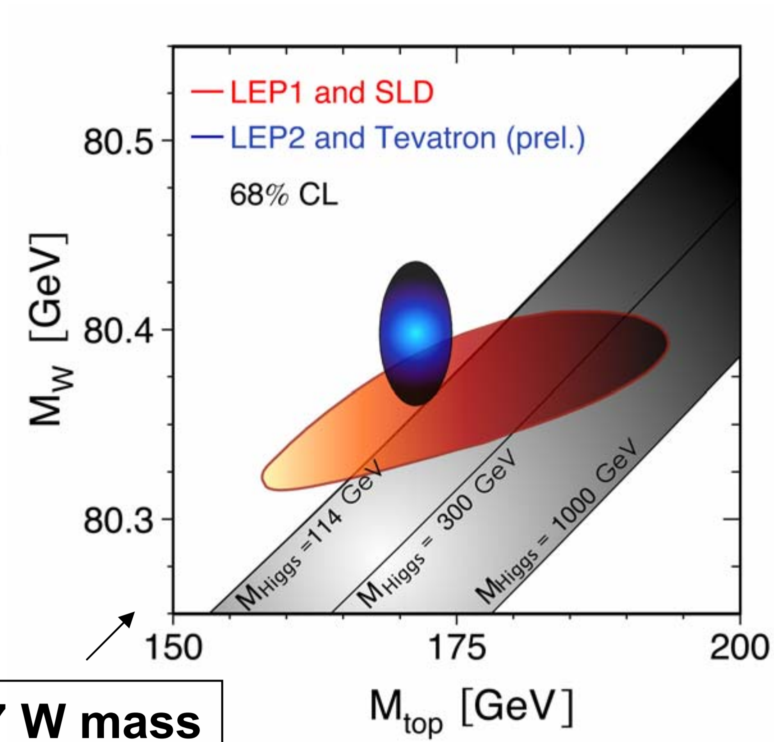
The Top Quark mass

Fundamental parameter of the Standard Model

- Affects predictions of SM via radiative corrections
  $\Rightarrow m_t$ can be related, with m_W, to the Higgs mass $\delta m_W \propto m_t^2, ln(m_H)$



- m_t is roughly ½ the vacuum expectation value of the Higgs field
  $\Rightarrow$ probing the EWSB mechanism (new physics?)



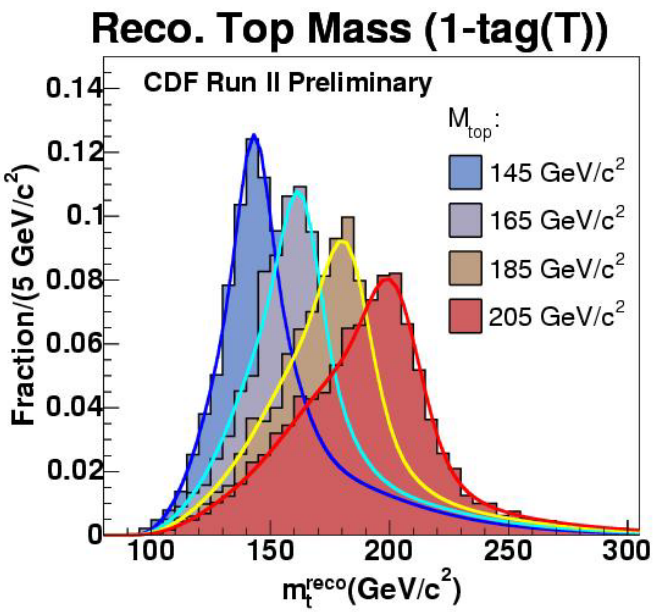
Summer '06 + Jan'07 W mass

Precision measurement $\Rightarrow$ 2(8) fb^{-1} projection: $\delta m_t \sim 1.5(1)$ GeV.

Measurement techniques

Main mass extraction techniques:

- Template methods: typically, one mass per event from kinematic fit, compare data to MC templates.



- Dynamical methods: event by event weights according to quality of agreement with Standard Model top and background differential cross-sections.

$$P(x;m_{top}) = \frac{1}{\sigma}\int d^n\sigma(y;m_{top})\,dq_1 dq_2\, f(q_1) f(q_2)\, W(x\,|\,y)$$

differential cross-section (LO matrix element)

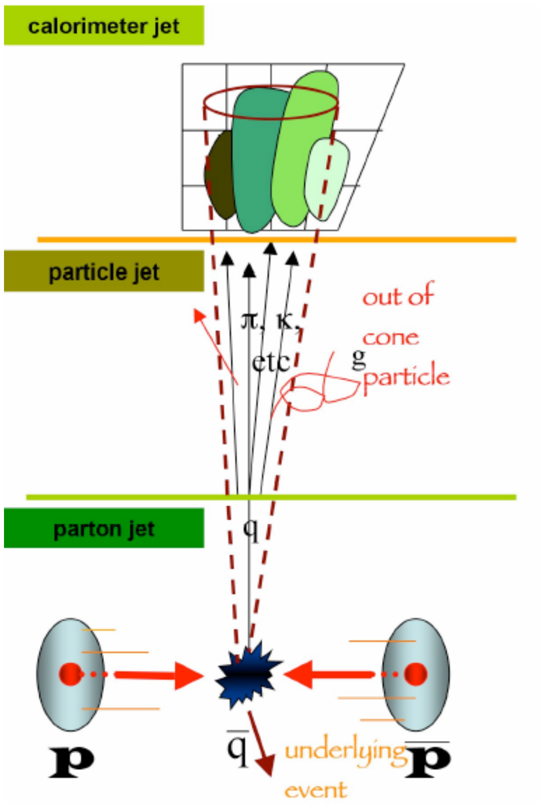
PDF's

Transfer function: mapping from parton level variables (y) to reconstructed level variables (x)

- Highest precision measurements from dynamical methods, and ℓ+jets final states (although other final states and methods can be competitive). All of the results presented here use dynamical methods, at least in part.

Challenges of Top quark measurements

- Top quark physics exercises the understanding of all detector components.
- It is a rare process with significant backgrounds.
- We measure jets, not quarks.
- We detect $\not{E}_T$, not neutrinos.



With increased statistics: focus is now on systematics

Handles on systematic uncertainties:

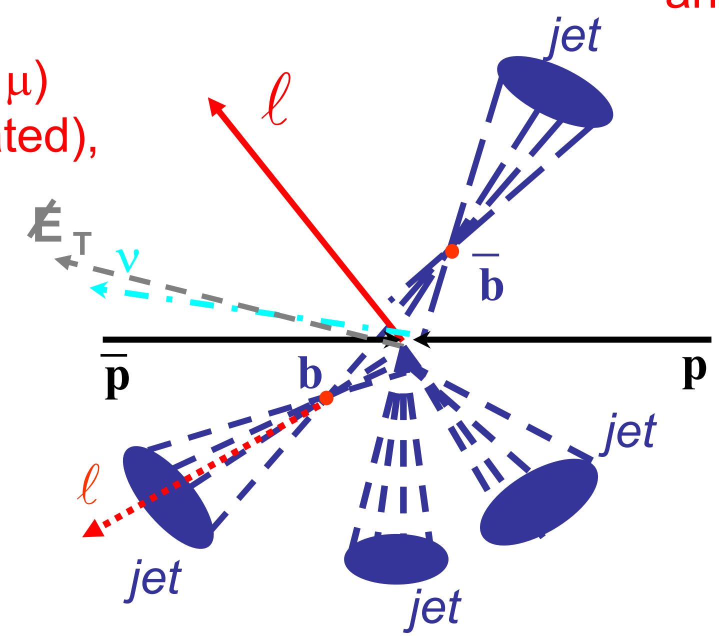
- Jet energy scale systematic can be reduced with in situ calibration of the hadronic W mass in top decays.
- b-jets identification (b-tagging) can be used to reduce physics backgrounds as well combinatorial.
- Many systematical uncertainties expected to decrease with larger data samples.

Results shown here: ≤1 fb^{-1}. Current data on tape: ~2.1 fb^{-1}

Mass in the ℓ+jets channel

Backgrounds:
Medium, mostly W+jets, and QCD multijet.

Event signature:
One high p_T lepton (e or μ) four jets (b-tag incorporated), large $\not{E}_T$.



Added bonus:
in-situ calibration of light quark jets using the hadronically decaying W mass.

$t(\rightarrow W^{\pm}b)\ t(\rightarrow W^{\pm}b)$
$\quad\hookrightarrow e^{\pm},\mu^{\pm} \quad \hookrightarrow qq$

Matrix Element Method

Dynamical method pioneered by DØ with re-analysis of Run I data.
Currently yielding the most precise results for both experiments.

Makes maximal use of information in each event by calculating event-by-event probability to be signal or background, based on the respective matrix elements:

$$P_{evt}(x; m_{top}, JES) = f_{top} P_{sig}(x; m_{top}, JES) + (1 - f_{top}) P_{bkg}(x; JES)$$

- x: reconstructed lepton and jets kinematics
- JES from M_W constraint.
- Signal and background probabilities: from differential cross-sections

$$P(x; m_{top}) = \frac{1}{\sigma} \int d^n\sigma(y; m_{top})\, dq_1\, dq_2\, f(q_1)\, f(q_2)\, W(x, y)$$

- All events are combined in a likelihood

$$-\ln L(x_1, \ldots, x_n; m_{top}, JES) = -\sum_{i=1}^{n} \ln P_{evt}(x_i; m_{top}, JES)$$

- Likelihood is maximized as a function of m_{top} and JES.

ℓ+jets Matrix Element Method

Combined Likelihood JES (or 1/JES) vs M_{top}

Simultaneous fit of m_{top}, JES, and f_{top}:

CDF :M_{top}=170.9±2.2(stat.+JES)±1.4(syst.)GeV/c^2

NEW

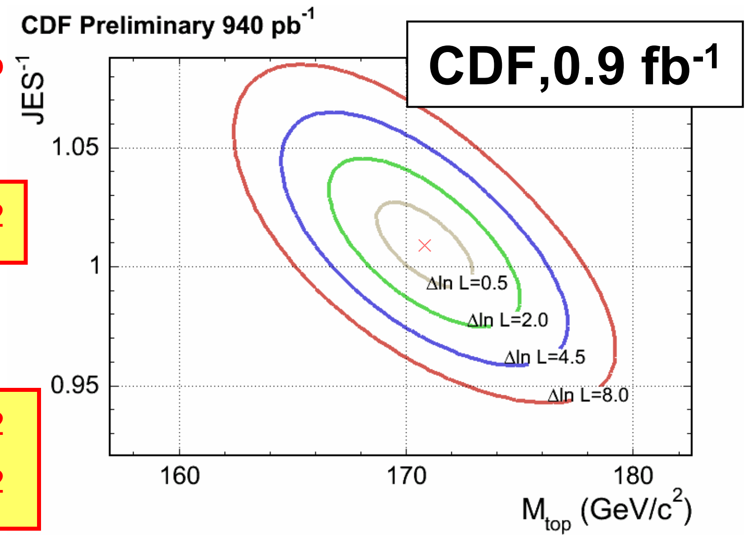
untagged ⇓

DØ :M_{top}=170.5±2.5 (stat.+JES)±1.4 (syst.)GeV/c^2

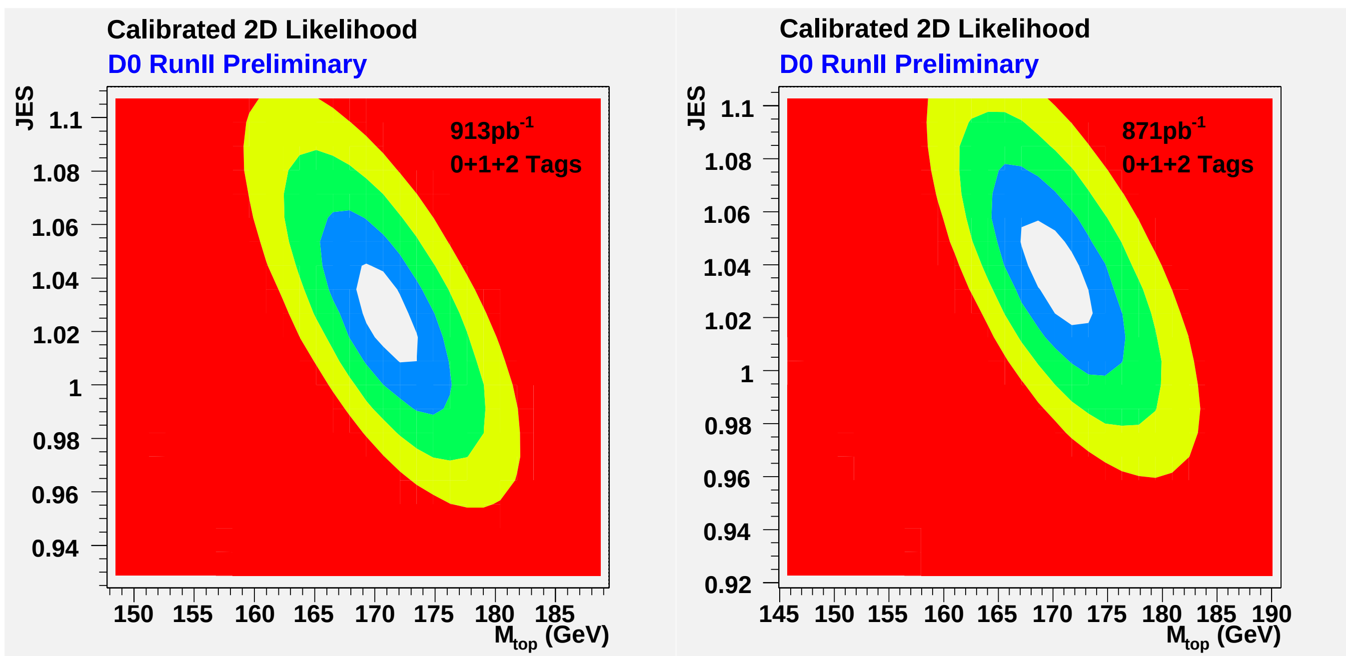
DØ :M_{top}=170.5±2.4 (stat.+JES)±1.2 (syst.)GeV/c^2

with b-tagging ⇑

CDF,0.9 fb^{-1}



DØ, 0.9 fb^{-1}



ℓ+jets Ideogram Method

Same kinematic fitting and discriminant as the Template analysis.
Event-by-event likelihood, each event gives a distribution of masses.

$$\mathcal{L}_{evt}(m_{top}, P_{sample}) = P_{evt} \int \sum e^{-\frac{1}{2}\chi_i^2} G(m_i, m', \sigma_i) BW(m', m_{top}) dm' + (1 - P_{evt}) \sum e^{-\frac{1}{2}\chi_i^2} BG(m_i)$$

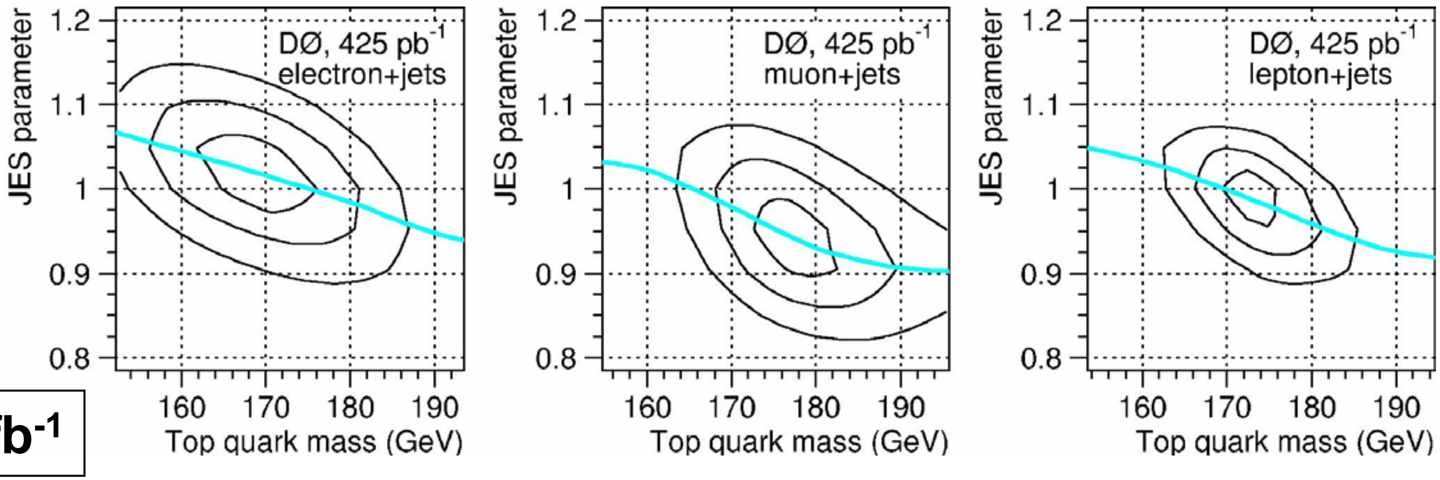
discriminant

combinatorics weight

Gaussian resolutions

Signal Breit-Wigner's

Background shape



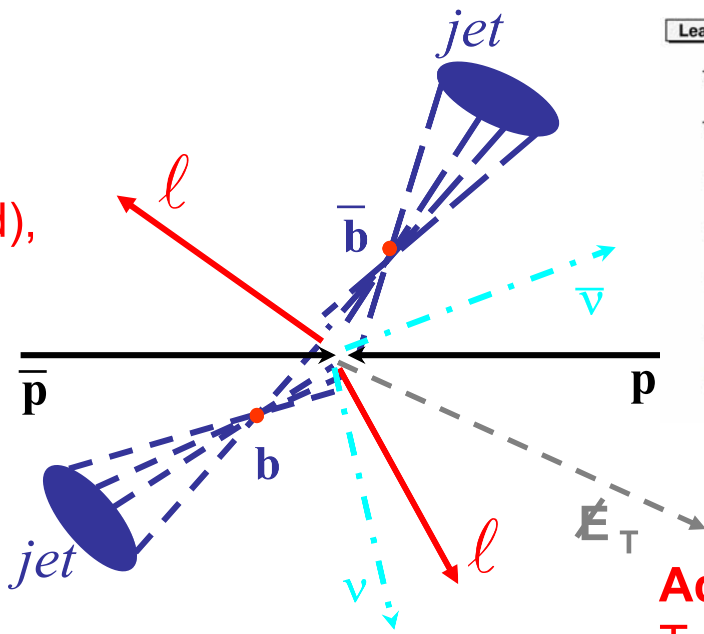
DØ, 0.4 fb^{-1}

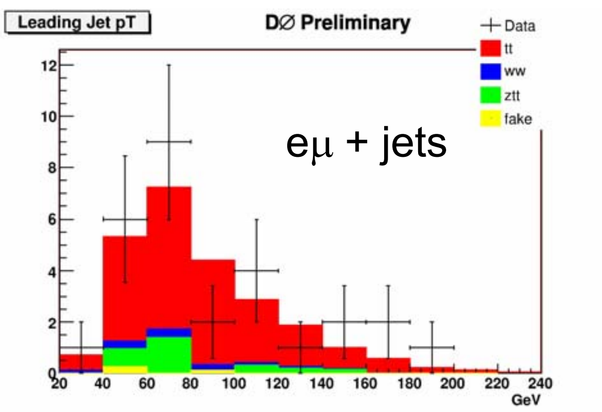
M_{top}=173.7 ± 4.4(stat.+JES)+2.1 -2.0(syst.)GeV/c^2

Mass in the $\ell\ell$+jets channel

Backgrounds: low.
Diboson, W/Z+jets.

Event signature:
Two high p_T lepton (e or μ)
two jets (b-tag incorporated),
large $\not{E}_T$.





Added challenge:
Two neutrinos.

$t(\rightarrow W^+b)\ t(\rightarrow W^-b)$

$\quad \rightarrow e^+, \mu^+ \qquad \rightarrow e^-, \mu^-$

Template Methods with Weighting

General: the dilepton channel is underconstrained. Template methods assume values for certain variables in order to extract a solution, and assign weights to the different solutions.

Example 1: the matrix Weighting method (**MWT**) scans over top masses and assigns a weight to the solution, based on the Matrix Element predictions for the lepton p_T's:

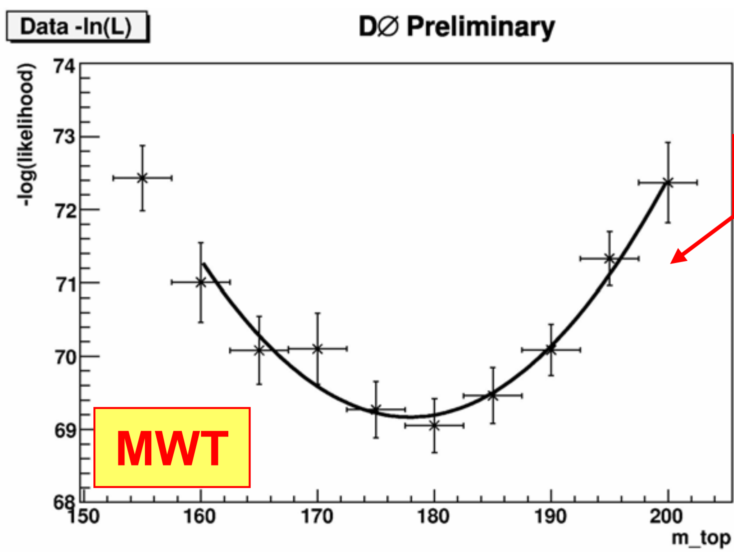
$$W_o(m_{top}) = \sum_{solutions} \sum_{jets} f_{PDF}(x) f_{PDF}(\overline{x}) p(E_l^* \mid m_{top}) p(E_{\bar{l}}^* \mid m_{top})$$

Example 2: the Neutrino Weighting method (ν**MT**) scans over top masses and the η's of the two neutrinos and assigns a weight (as a function of m_{top}) to the solution, based on the agreement of the calculated neutrino p_T's and the observed $\not{E}_T$

$$w = \frac{1}{N_{iter}} \sum_{i=1}^{N_{iter}} exp\left(\frac{-(\not{E}_{x,i}^{calc} - \not{E}_x^{obs})^2}{2\sigma_{E_x}^2}\right) exp\left(\frac{-(\not{E}_{y,i}^{calc} - \not{E}_y^{obs})^2}{2\sigma_{E_y}^2}\right)$$

- maximum likelihood fit to signal and background templates

$\ell\ell$+jets Template Methods with weighting



DØ, 0.8 fb^{-1}

eμ channel only

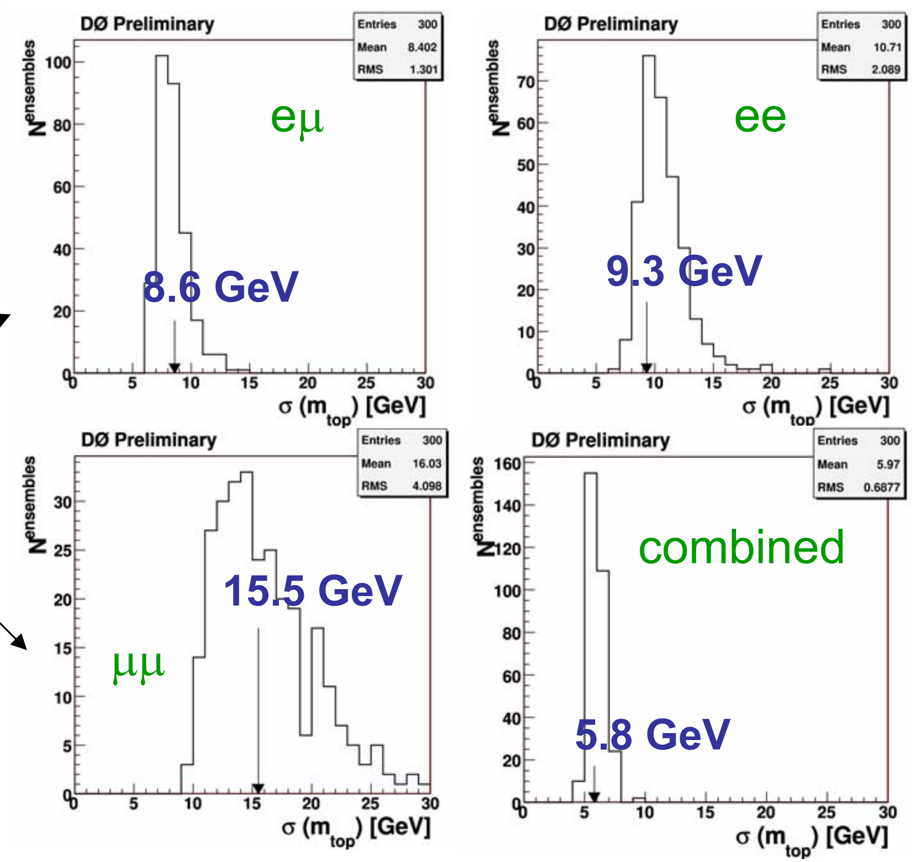
M_{top}=177.7±8.8(stat.)+3.7 -4.5 (syst.) GeV/c^2

eμ, $\mu\mu$, ee channel combined,
new DØ ν**WT** measurement

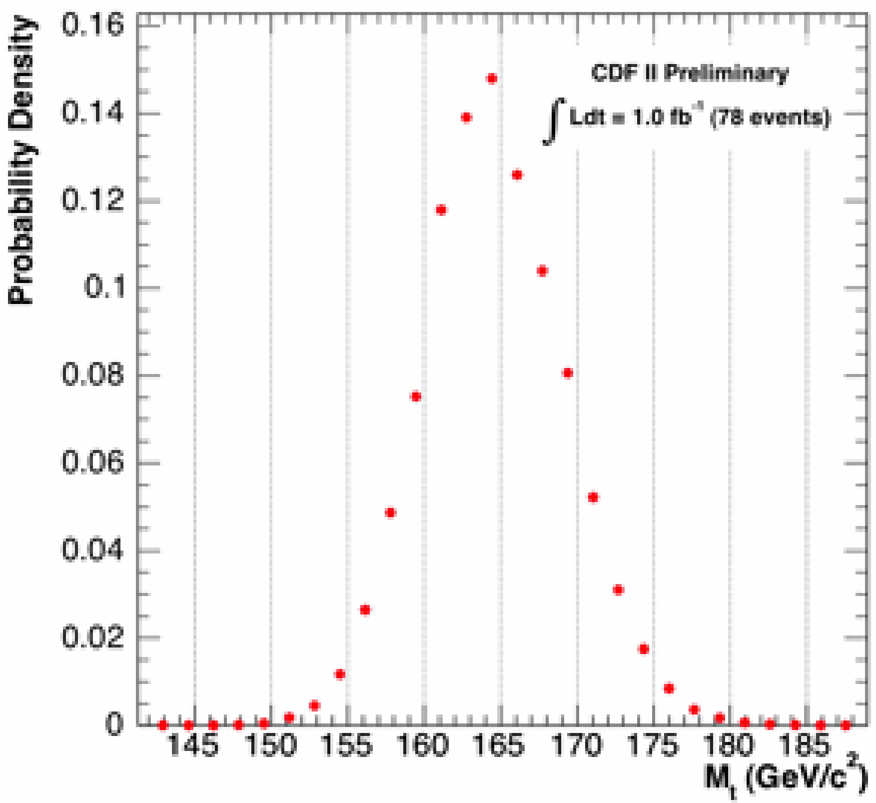
M_{top} = 172.5 ± 5.8 (stat.) ± 5.5 (syst.) GeV/c^2

NEW

DØ, 1 fb^{-1}



ℓℓ+jets Matrix Element Method



⇐ Joint probability density:

Best dilepton measurement

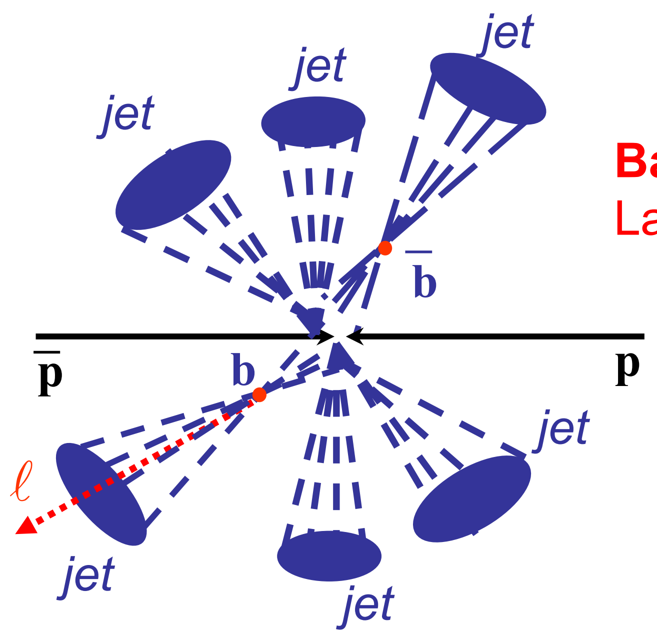
CDF, 1 fb^{-1}

M_{top} = 164.5 ± 3.9 (stat.) ± 3.9 (syst.) GeV/c^2

with b-tagging: M_{top} = 167.3 ± 4.6 (stat.) ± 3.8 (syst.) GeV/c^2

Mass in the all-hadronic channel

Event signature:
six jets (≥ 1 b-tagged),
additional selection
on event topology.



Backgrounds:
Large, from QCD multijet.

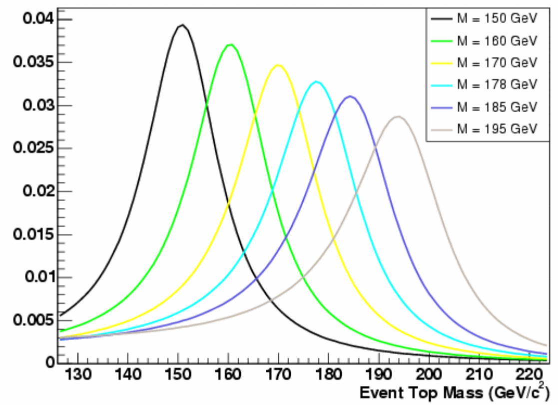
Added bonus:
in-situ calibration of
light quark jets using
the hadronically
decaying W mass.

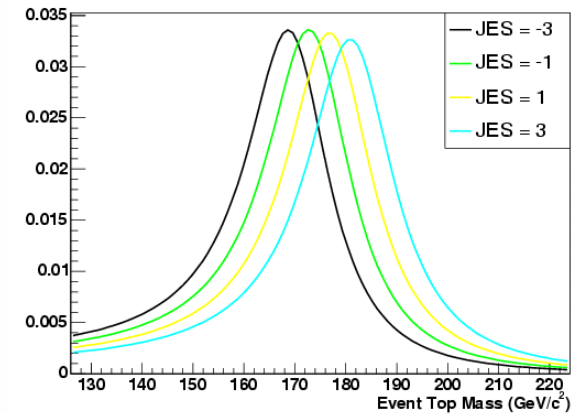
$t(\rightarrow W^{\pm}b)\ t(\rightarrow W^{\pm}b)$
$\quad \llcorner\!\rightarrow qq \qquad \llcorner\!\rightarrow qq$

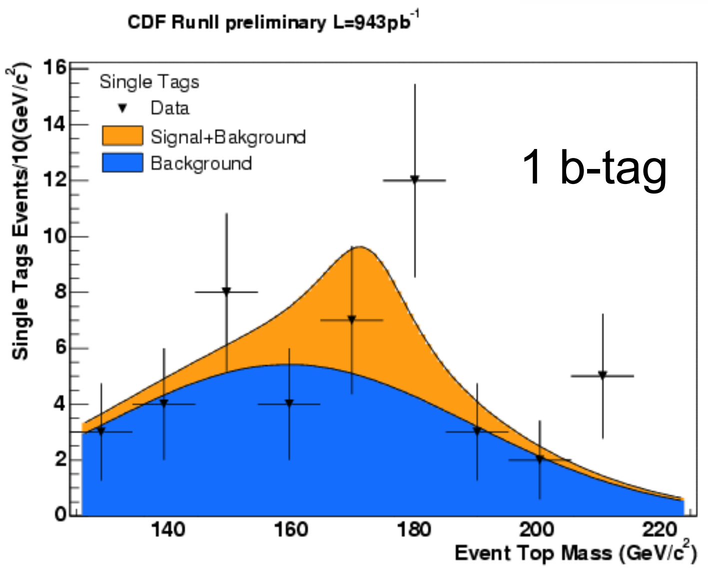
All-hadronic Matrix Element assisted Template Method

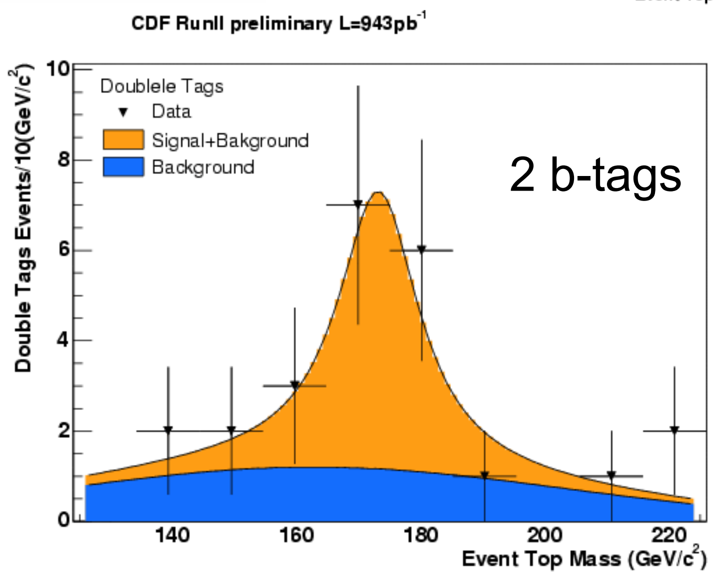
New 2D (M_{top},JES) template Analysis:

signal Templates from Matrix Element calculation, background templates from data-driven model.







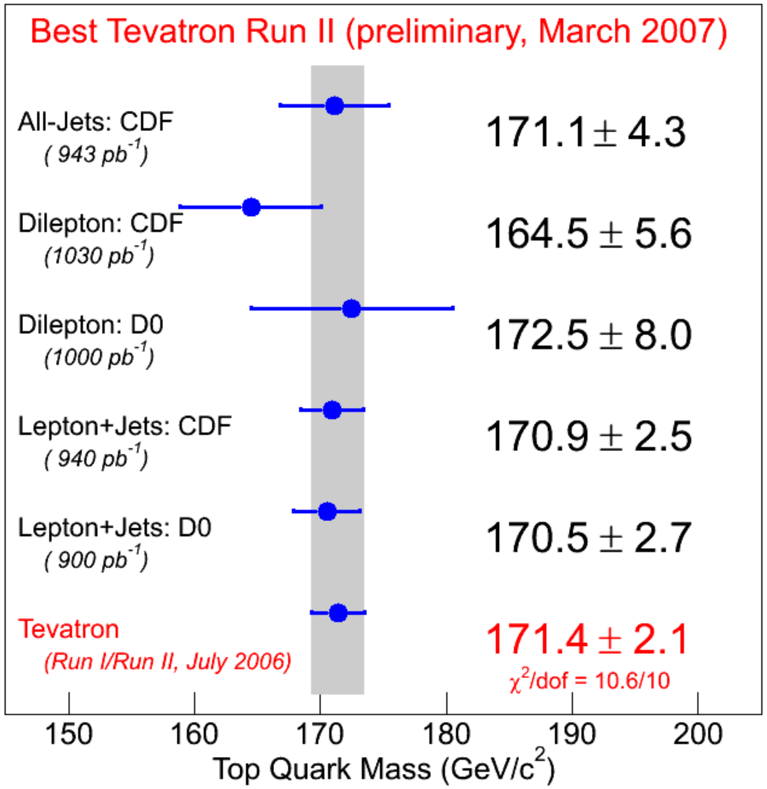


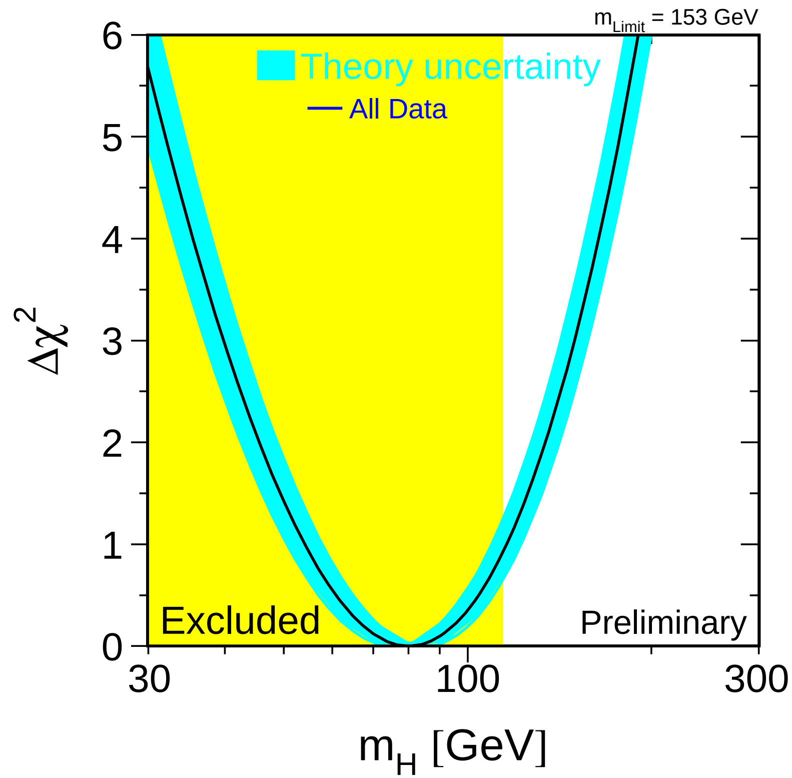
CDF, 0.9 fb^{-1}

M_{top} = 171.1 ± 3.7 (stat.+JES) ± 2.1 (syst.) GeV/c^2

Top quark mass: Summary

Top world average still from Summer '06.





Summer'06 + Jan'07 W mass

M_{top}=171.4 ± 1.2(stat.) ± 1.4(JES) ± 1.0(syst.)GeV/c²

1.2% relative uncertainty

Conclusions and outlook

- Results on the measurement of the Top quark mass presented for datasets up to 1 fb^{-1}.
- All ~1fb^{-1} measurements are converging, analysis of the >2 fb^{-1} dataset started.
- Measurements now extend to final states once considered “challenging”, i.e. the all-hadronic channel, with results competitive in precision with other channels.
- Current relative uncertainty on the Top quark mass: 1.2%.
- Aiming at ~1 GeV uncertainty (<1%) at 8 fb^{-1}.
- The excellent performance of the Tevatron and the CDF and DØ experiments are the key to precision measurements in top physics.

Back-up slides

CDF: ℓℓ+jets Matrix Element Method 1030 pb^{-1}

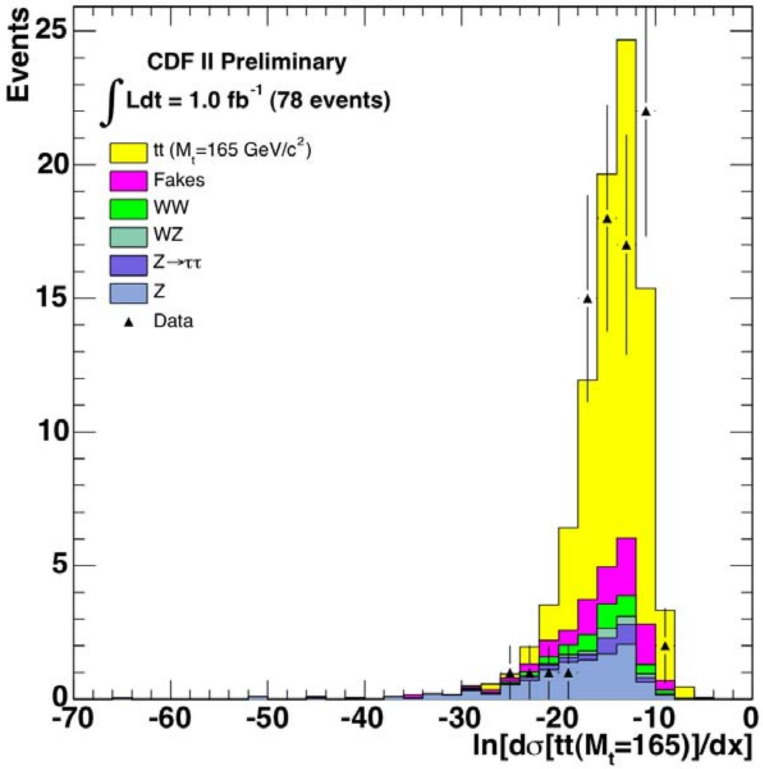
Uses a per-event probability for the mass as a weighted sum of the differential cross-section for LO top quark pair production and of the differential cross section for background processes:

signal/backg fractions

$$P(\boldsymbol{x}\,|\,M_t) = P_s(\boldsymbol{x}\,|\,M_t)\,p_s + P_{bg1}(\boldsymbol{x})\,p_{bg1} + P_{bg2}(\boldsymbol{x})\,p_{bg2} + \ldots$$

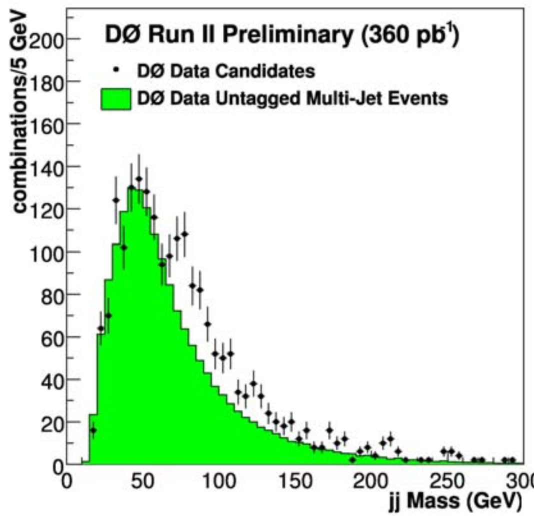
$$P_s(\boldsymbol{x}\,|\,M_t) = \frac{1}{\sigma(M_t)}\frac{d\sigma(M_t)}{d\boldsymbol{x}}$$

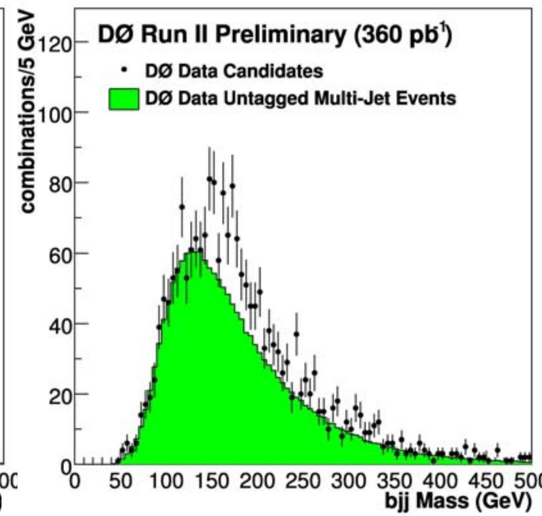
- Posterior probability density: product of a flat prior and the joint likelihood, (mean,σ) ⇒ (M_{top}, ΔM_{top}).



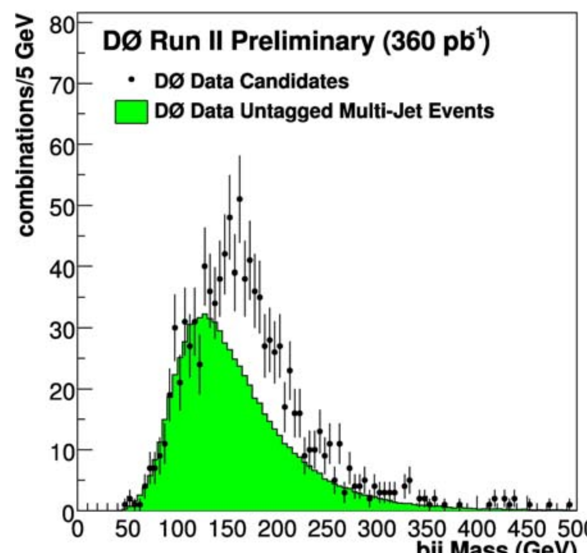
The all-hadronic channel signal

DØ W and Top quark
mass from di-jet
and tri-jet spectra ⇒

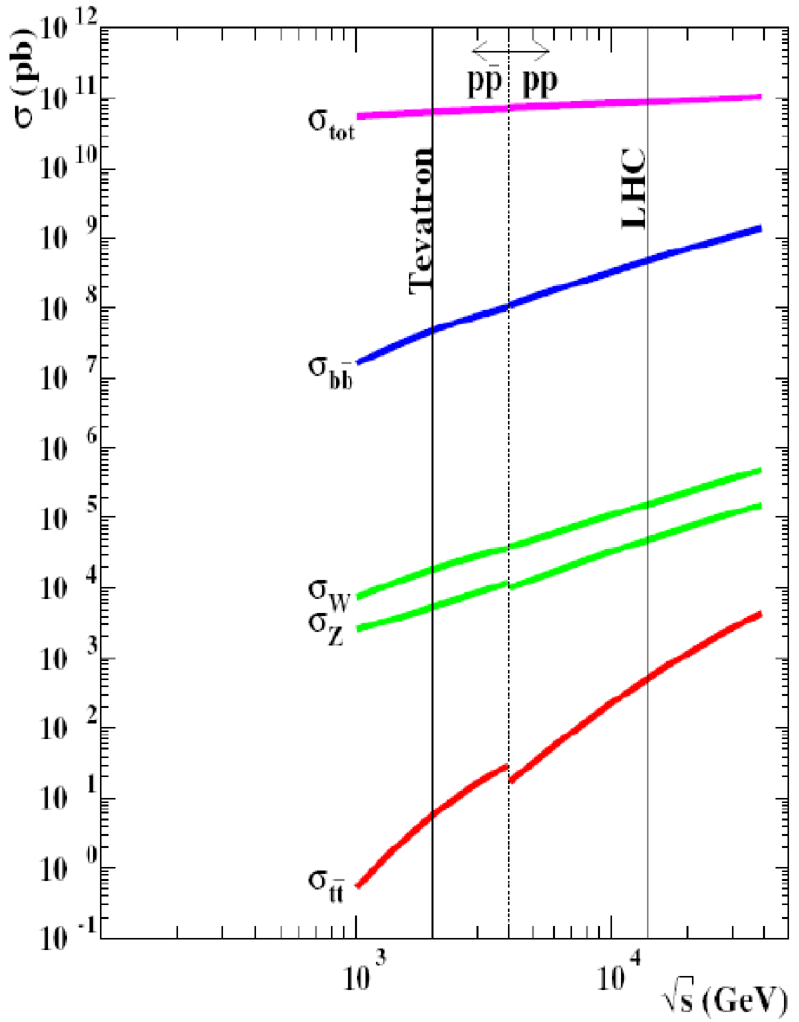




Tri-jet spectrum
with additional
topological constraints ⇒



Cross-sections: Tevatron, LHC



Top Mass Uncertainty Projections