Top Mass and Decay Properties

DIS 2007

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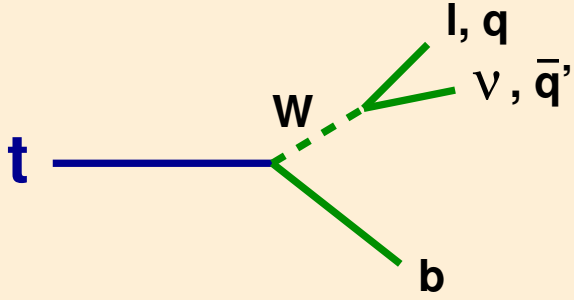
for the DØ and CDF Collaborations

Top mass:

- Most precise results of DØ and CDF for each decay channel

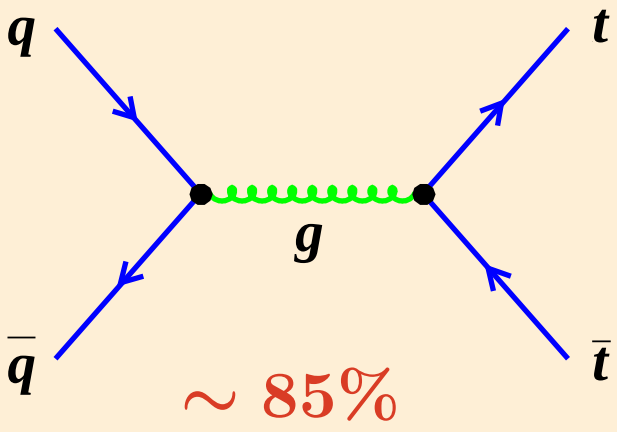
Decay properties:

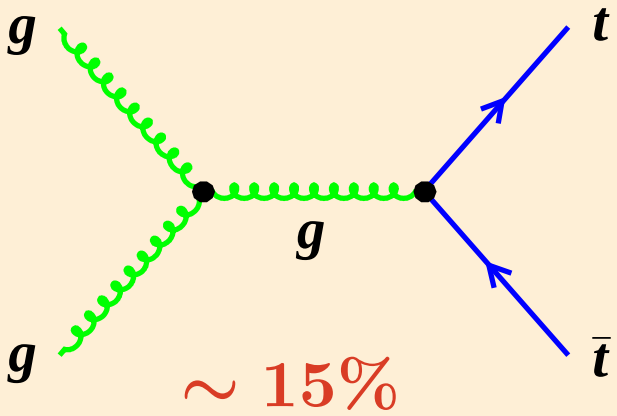
- W-helicity in top decays
- Br$(t \to bW)$/Br$(t \to qW)$, lifetime



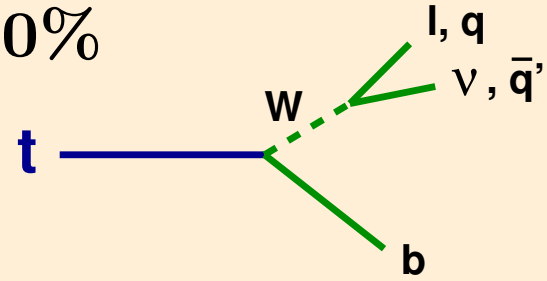
Top Quark Production and Decay

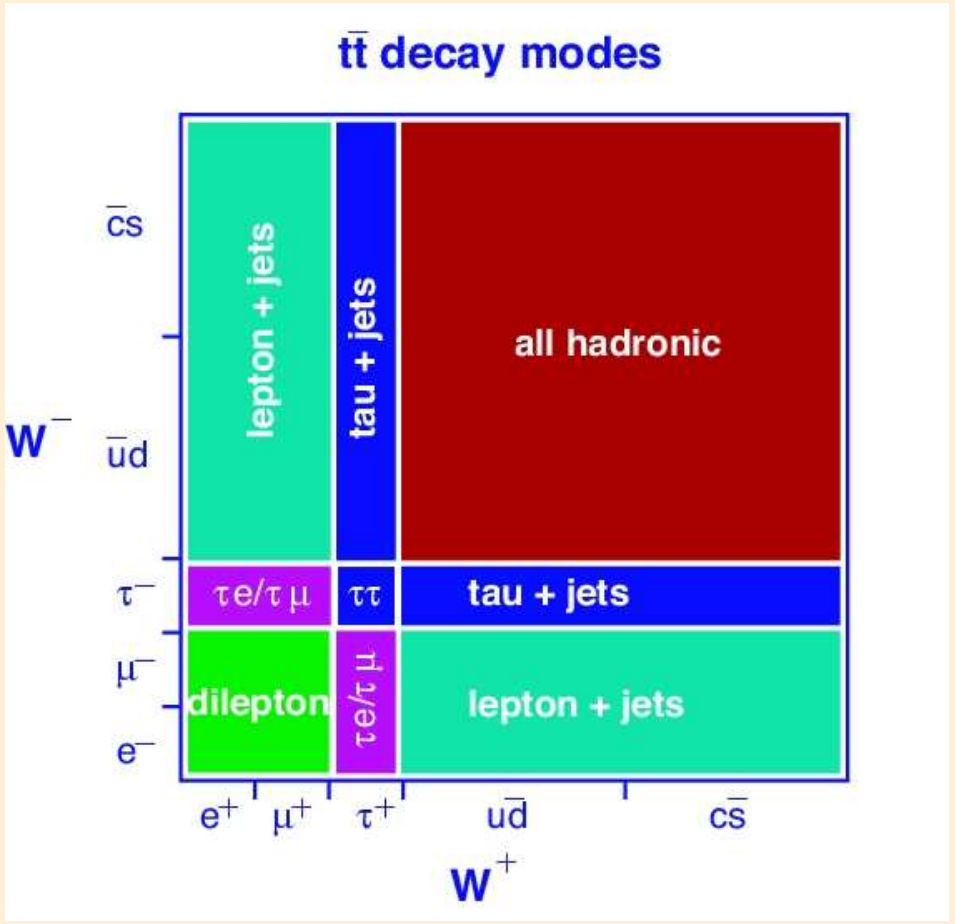
Dominant process:
Top pair production





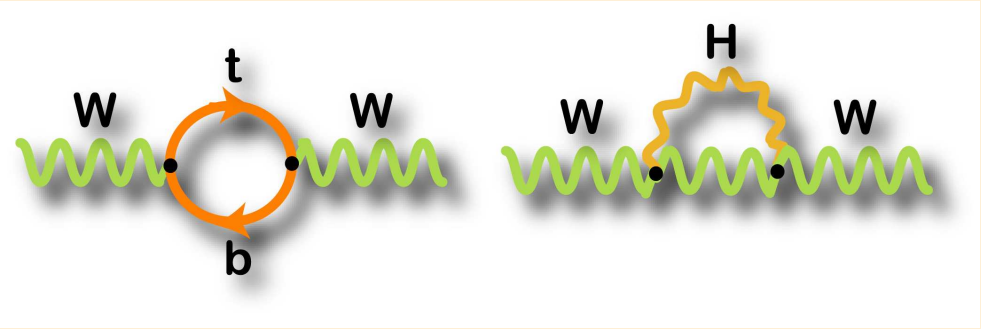
$\mathrm{Br}(t \to Wb) \sim 100\%$





Precision Top Quark Mass Measurements

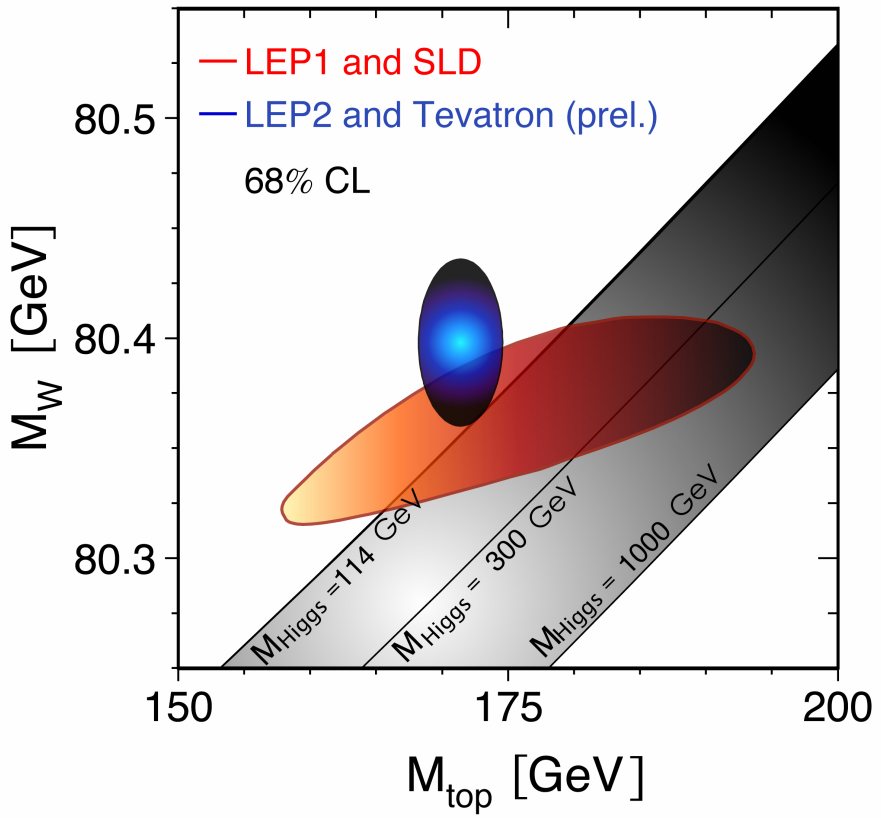
- Allows together with the W mass for predictions on Higgs mass



$\Delta M_W \propto M_t^2 \quad \Delta M_W \propto \ln M_H$

- Consistency check of the standard model
- Constraint on Higgs can point to physics beyond the standard model

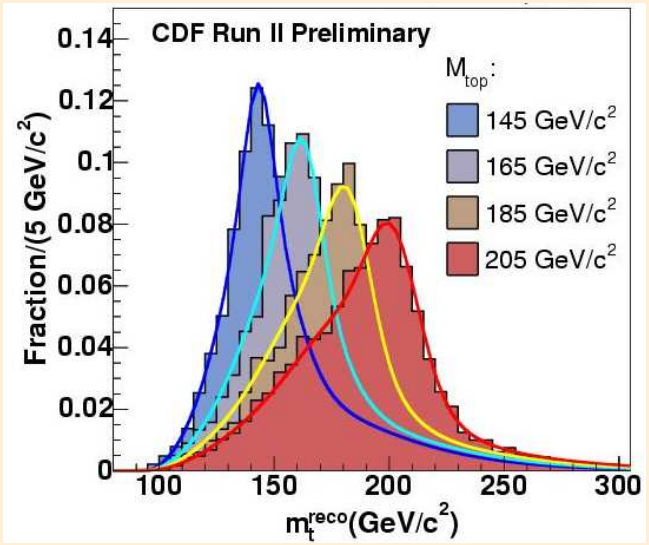
Summer'06 top mass + Jan'07 W mass



Top Mass Measurements Techniques

Template methods:

- Calculate a per-event observable strongly correlated with M_t
- Extract M_t by comparing simulated distributions (sig+bg) with varying M_t with data



Matrix Element (ME) analyses:

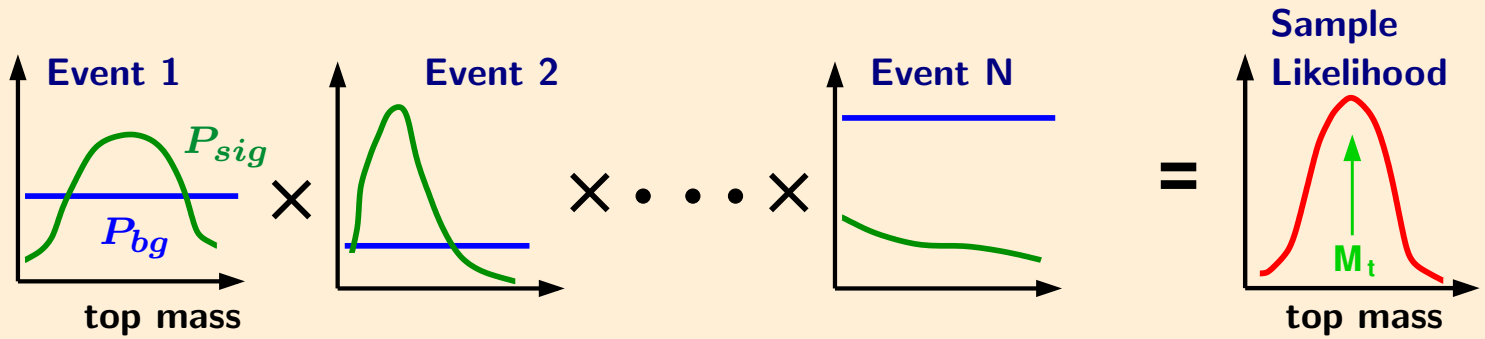
- Calculate a per event probability density for sig+bg as function of M_t:

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

LO diff. cross section — PDF's — Tranfer function: parton (y) $\longrightarrow$ rec. object (x)

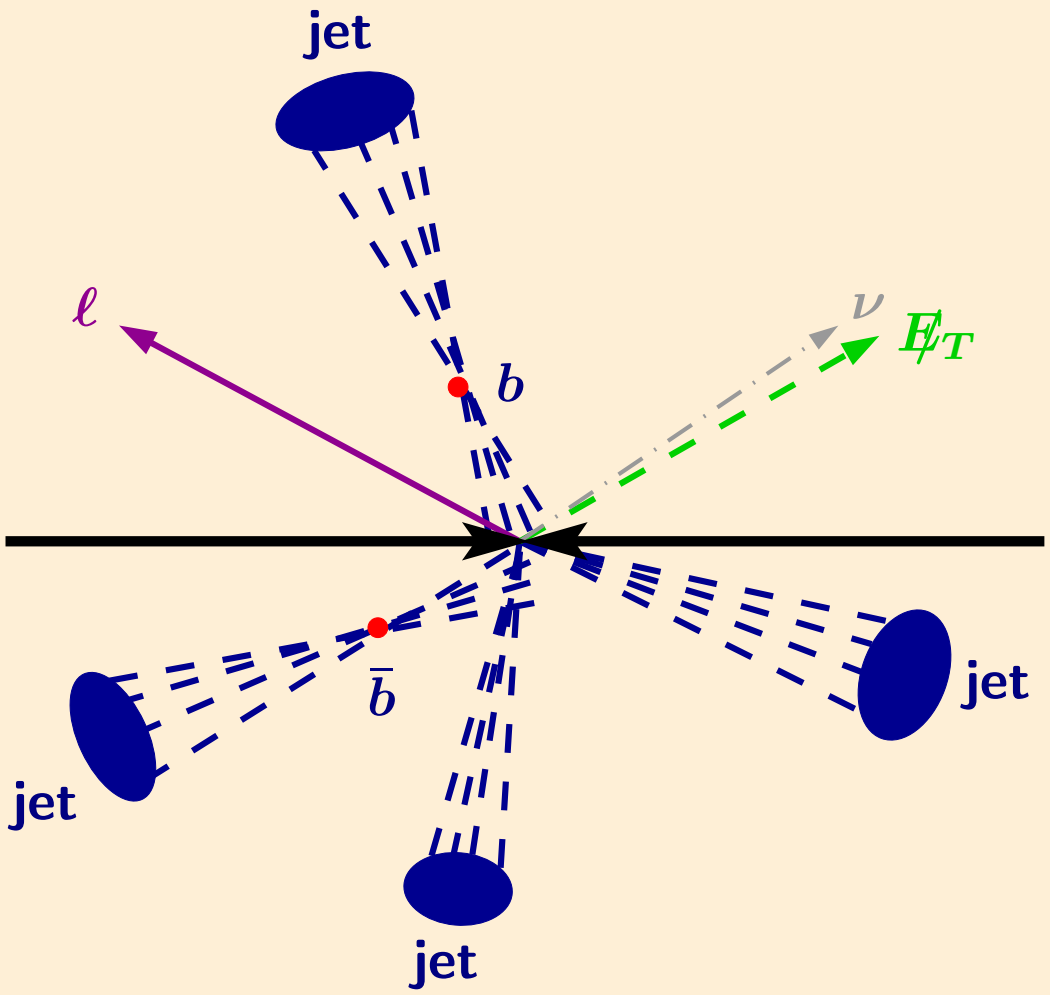
$$P_{evt} = f_{top} \cdot P_{sig} + (1 - f_{top}) \cdot P_{bg}$$

- Obtain most likely M_t by multiplying event likelihoods



Mass in the ℓ + Jets Channel

$$t \longrightarrow W^+ b \;,\quad \bar{t} \longrightarrow W^- \bar{b} \quad (+\text{cc.})$$
$$\hookrightarrow \ell^+ \nu \qquad\qquad \hookrightarrow q\bar{q}'$$



Event signature:

- 1 high p_T lepton (e or μ)
- Large missing transverse energy $\not\!\!E_T$
- 4 jets (≥ 1 b-jet)

Backgrounds:

- Medium amount
- Mostly W +jets, and QCD multijets

Bonus:

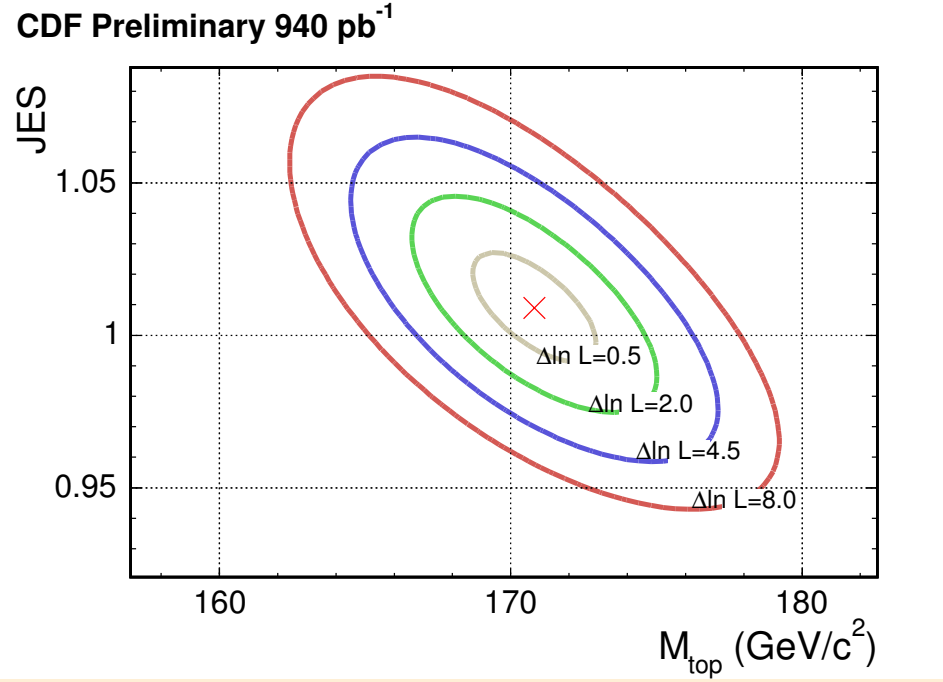
- In-situ calibration of light quark jets using $M_{W \to q\bar{q}'}$
- Crucial for current level of top mass precision

Most Precise ℓ + Jets Results

Use of in-situ technique $\longrightarrow$ strong reduction of the dominant syst. uncertainty of top mass measurements, the uncertainty on jet energy scale

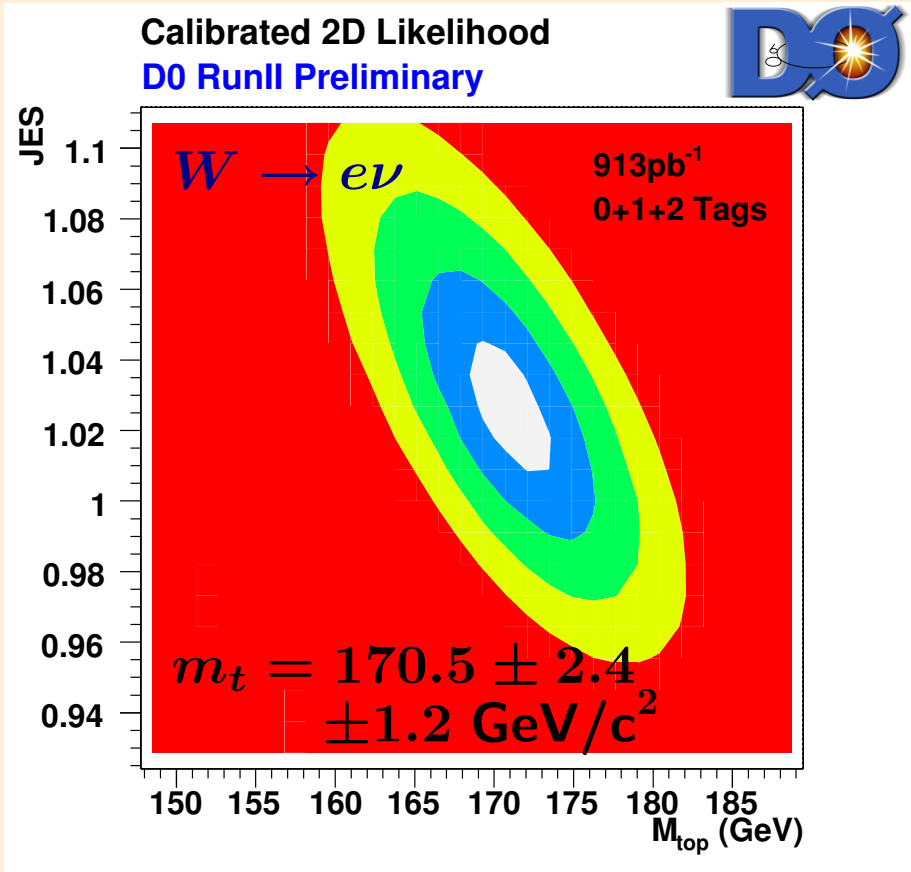
JES: Parameter used to adjust for a possible overall miscalibration of the jet energy scale (jet $\longrightarrow$ parton)

Matrix element method



$$m_t = 170.9 \pm 2.2 \pm 1.4 \text{ GeV/c}^2$$

Matrix element method



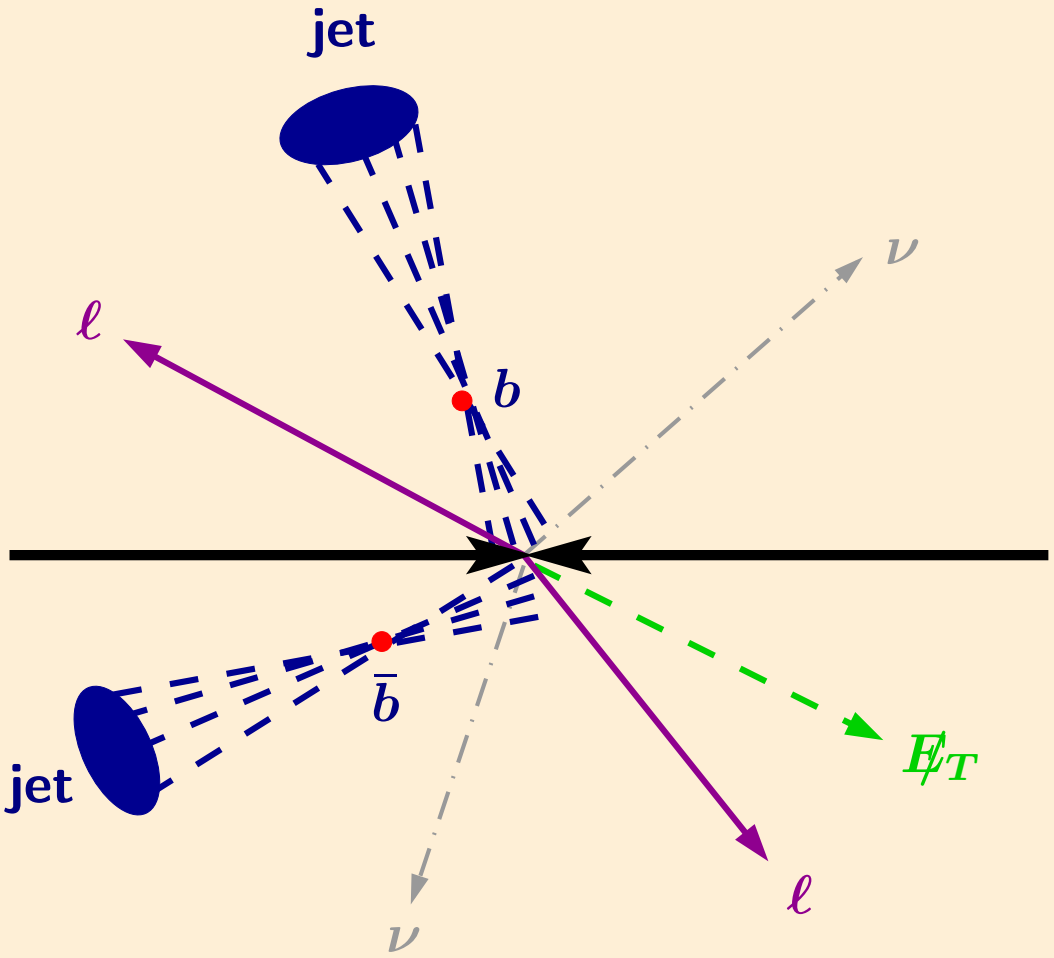
Example of Systematic Uncertainties

Source	ΔM_t [GeV/c^2]
JES residual	0.42
Initial state radiation	0.72
Final state radiation	0.76
Generator	0.19
BG composition and modeling	0.21
Parton distribution functions	0.12
b-JES	0.60
b-tagging	0.31
Monte Carlo statistics	0.04
Lepton p_t	0.22
Multiple interactions	0.05
Total	**1.36**

ℓ + jets measurement

Mass in the Dilepton Channel

$$t \longrightarrow W^+ b \;,\quad \bar{t} \longrightarrow W^- \bar{b}$$
$$\hookrightarrow \ell^+ \nu \qquad\qquad \hookrightarrow \ell^- \bar{\nu}$$



Event signature:

- 2 high p_T leptons (e or μ)
- Large missing transverse energy $\not\!\!E_T$
- 2 jets

Backgrounds:

- Low amount
- Diboson and W/Z + jets events

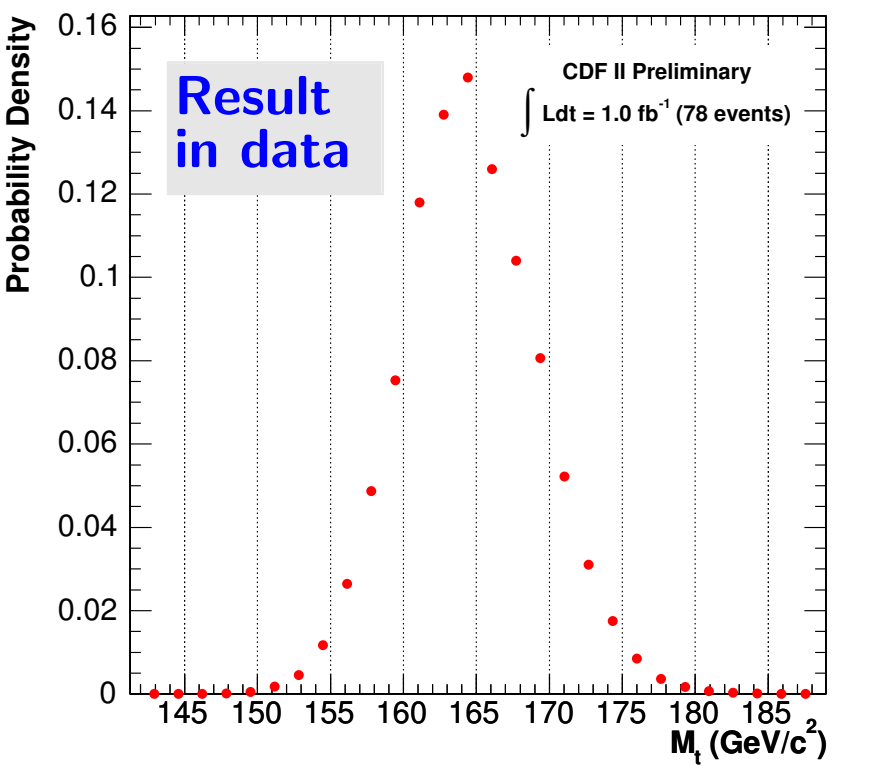
Challenge:

- Two neutrinos $\longrightarrow$ dilepton channel is underconstrained

Most Precise Dilepton Results

Matrix element method

Event probabilities are integrated over neutrino energies

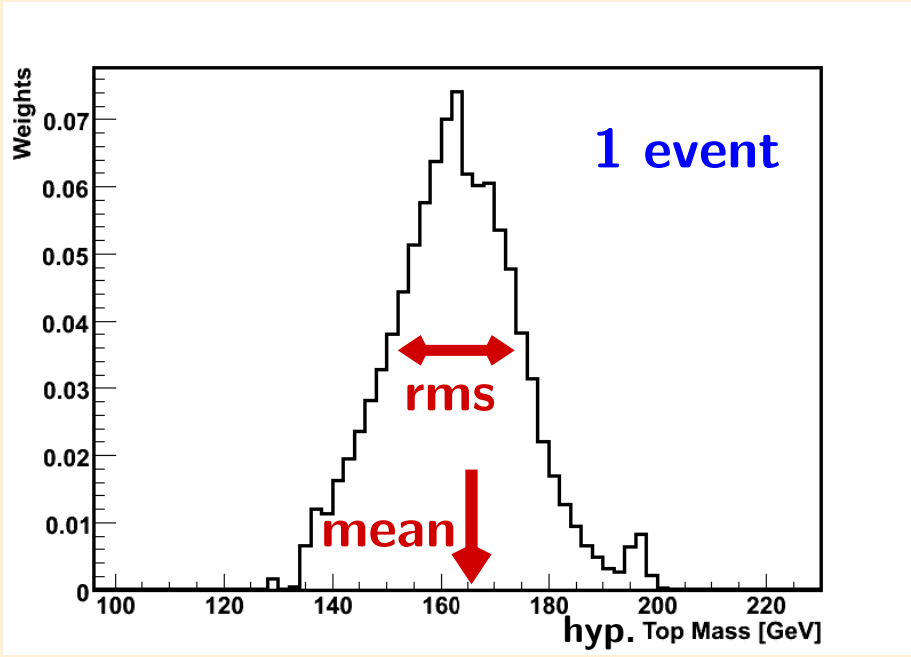


$m_t = 164.5 \pm 3.9 \pm 3.9$ GeV/c^2

Template method

Ignore $\not\!\!E_T$, assume m_t and η for each ν

Assign a weight to each $(m_t, \eta_{\nu_1}, \eta_{\nu_2})$ hypothesis based on agreement of calc. and obs. $\not\!\!E_T$

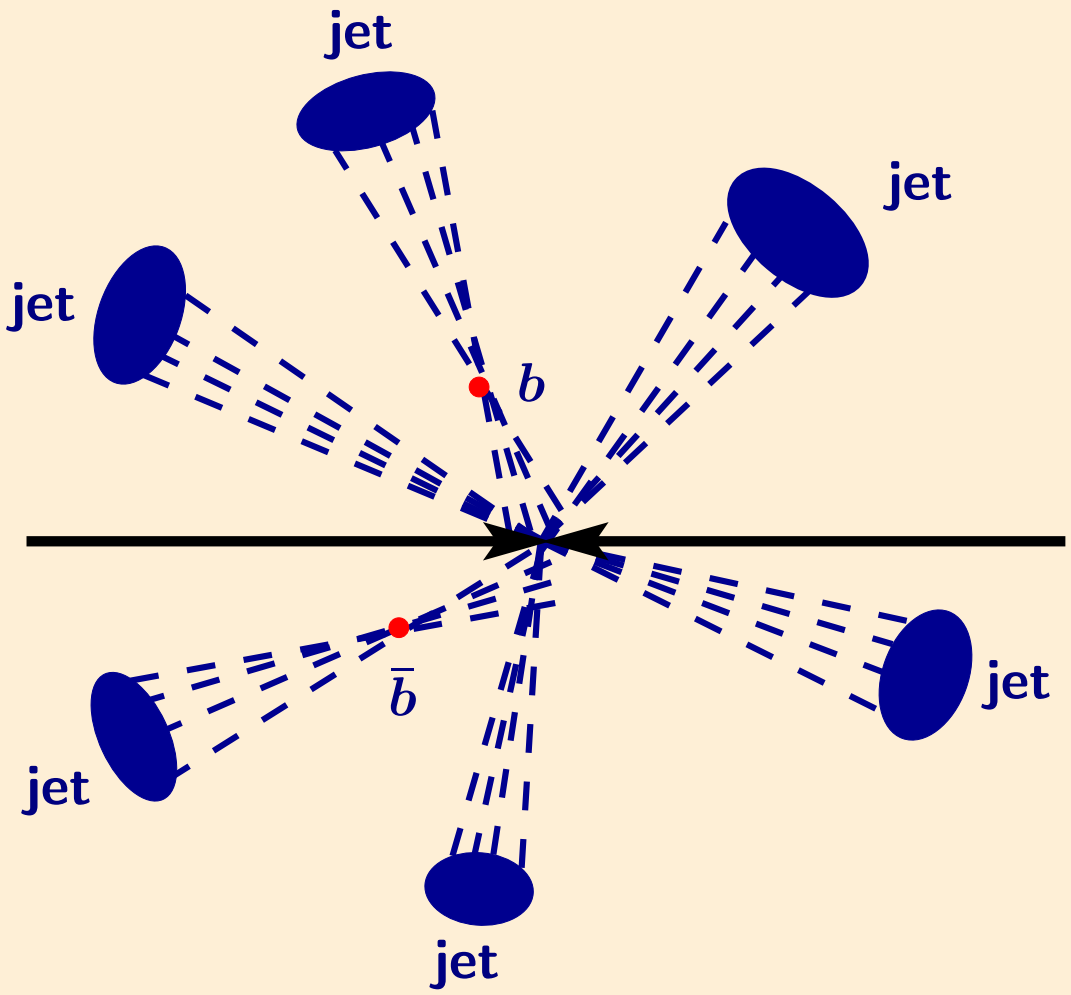


$m_t = 172.5 \pm 5.8 \pm 5.5$ GeV/c^2

($\int L\,dt = 1.0\,\text{fb}^{-1}$)

Mass in the All Hadronic Channel

$$t \longrightarrow W^+ b \;,\quad \bar{t} \longrightarrow W^- \bar{b} \quad (+\text{cc.})$$
$$\hookrightarrow q_1 \bar{q_1}' \qquad\qquad \hookrightarrow q_2 \bar{q_2}'$$



Event signature:

- Exactly 6 jets (≥ 1 b-tagged)
- Additional selection on event topology

Backgrounds:

- Large amount
- QCD multijets

Challenge:

- Reduction of background (e.g. ANN)

Bonus:

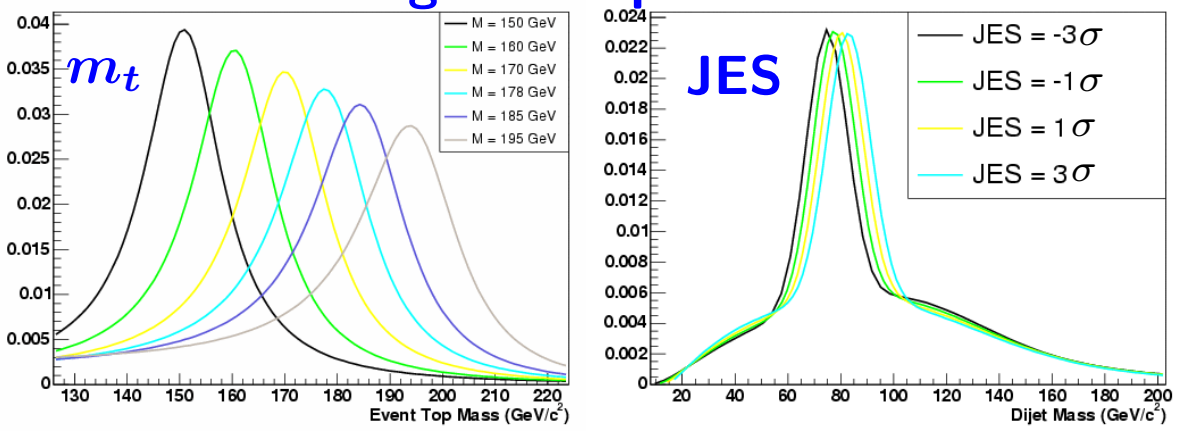
- In-situ calibration of light quark jets using $M_{W \to q\bar{q}'}$

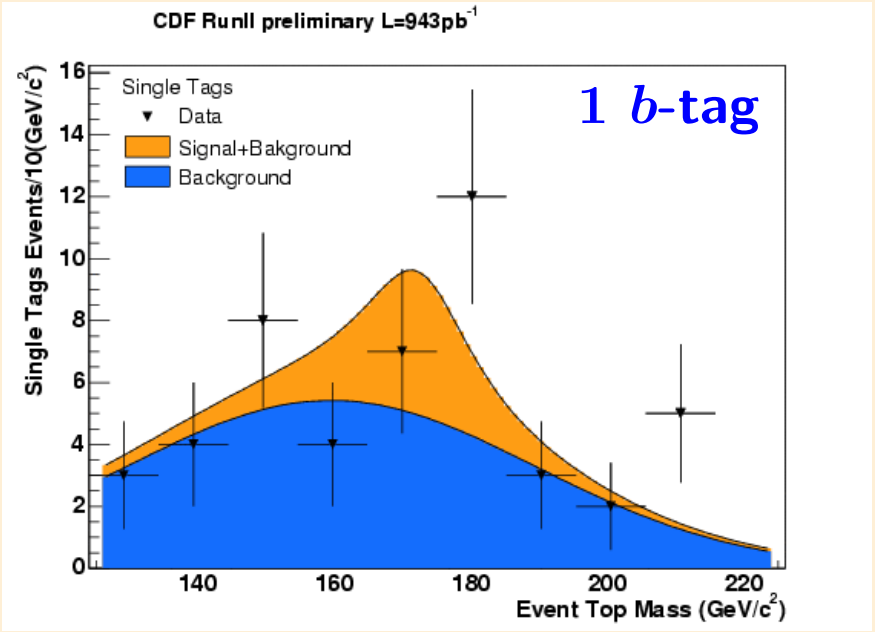
Most Precise All Hadronic Result

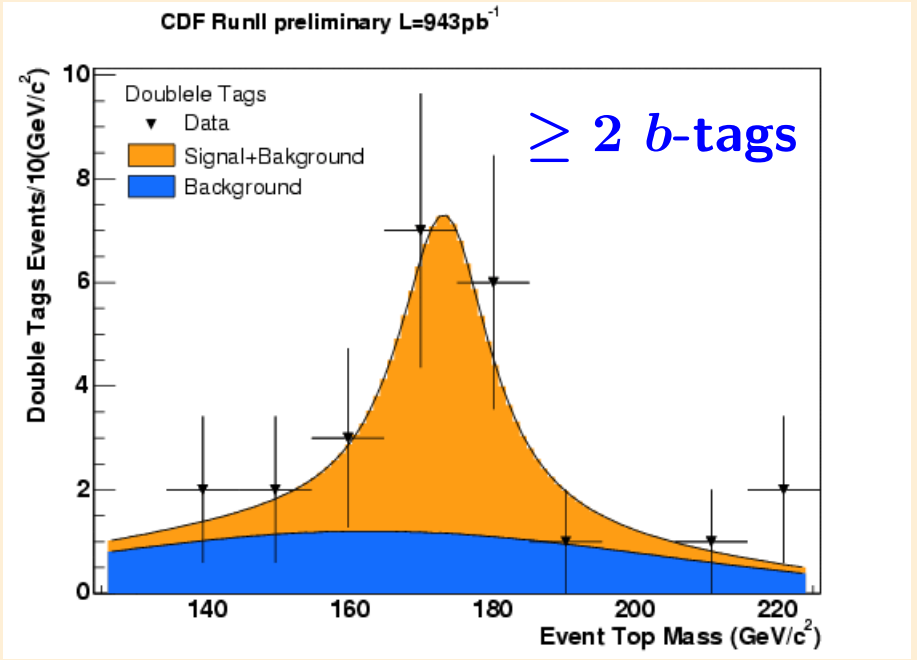
2D (m_t,JES) template analysis:

Signal templates from ME calculation, background templates from data-driven model

Signal templates



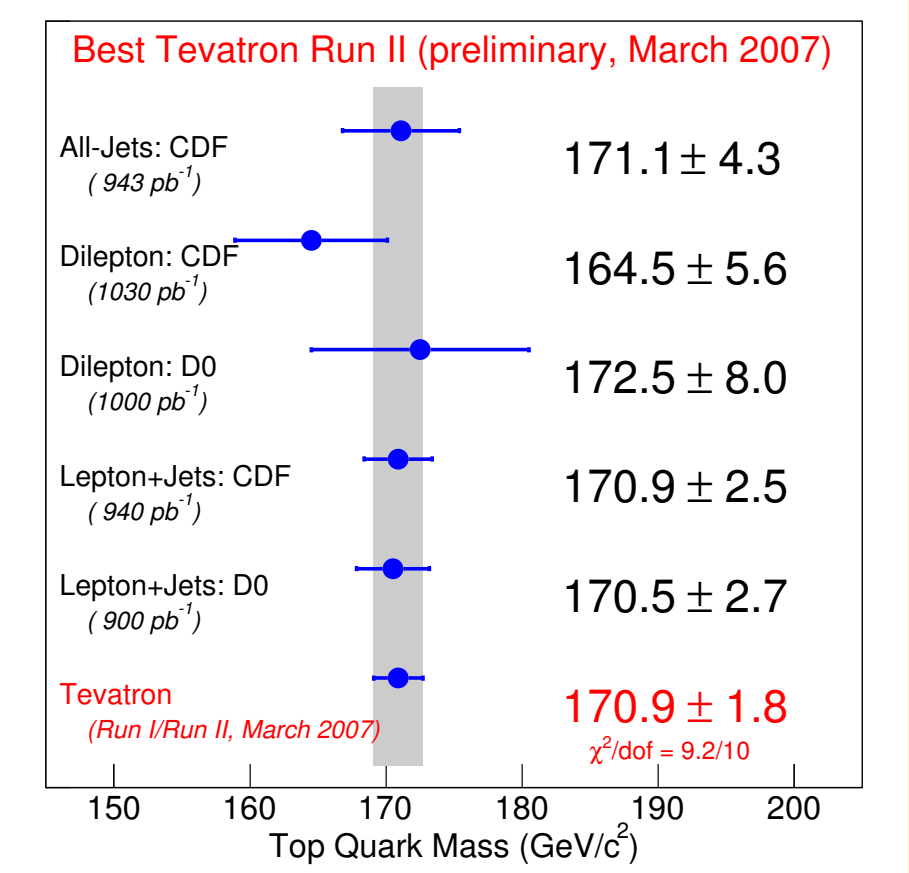


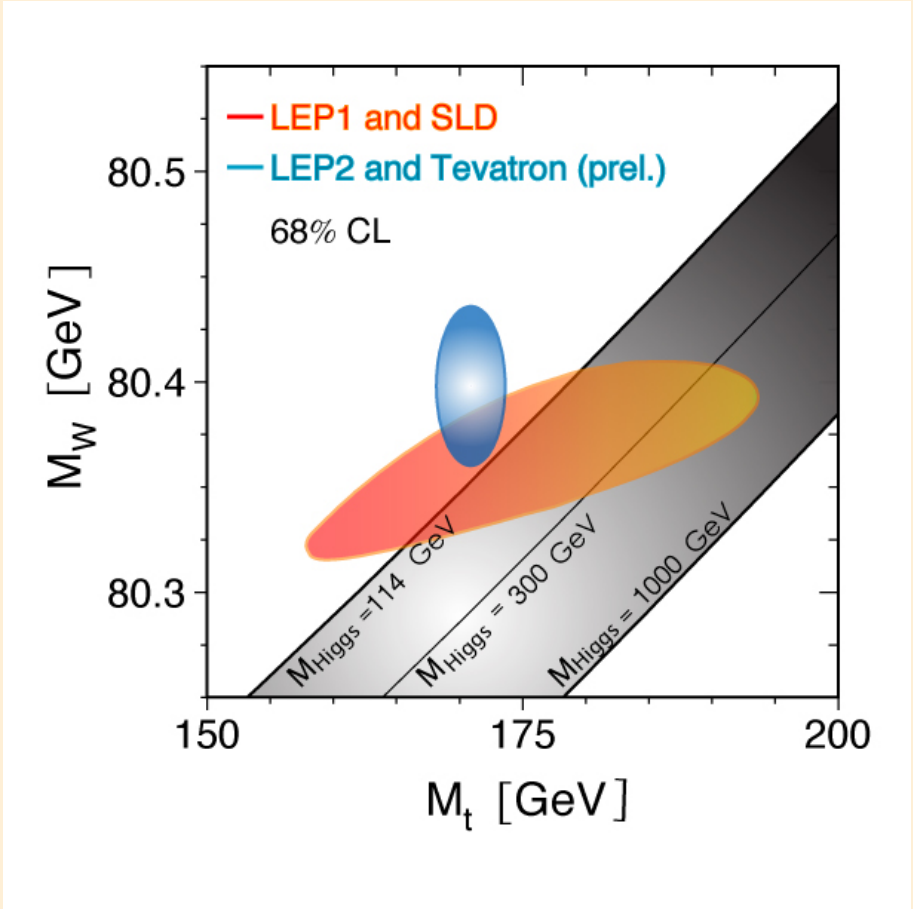


Result: $m_t = 171.1 \pm 3.7 \pm 2.1$ GeV/c^2

Top Mass Combination

Status of winter'07

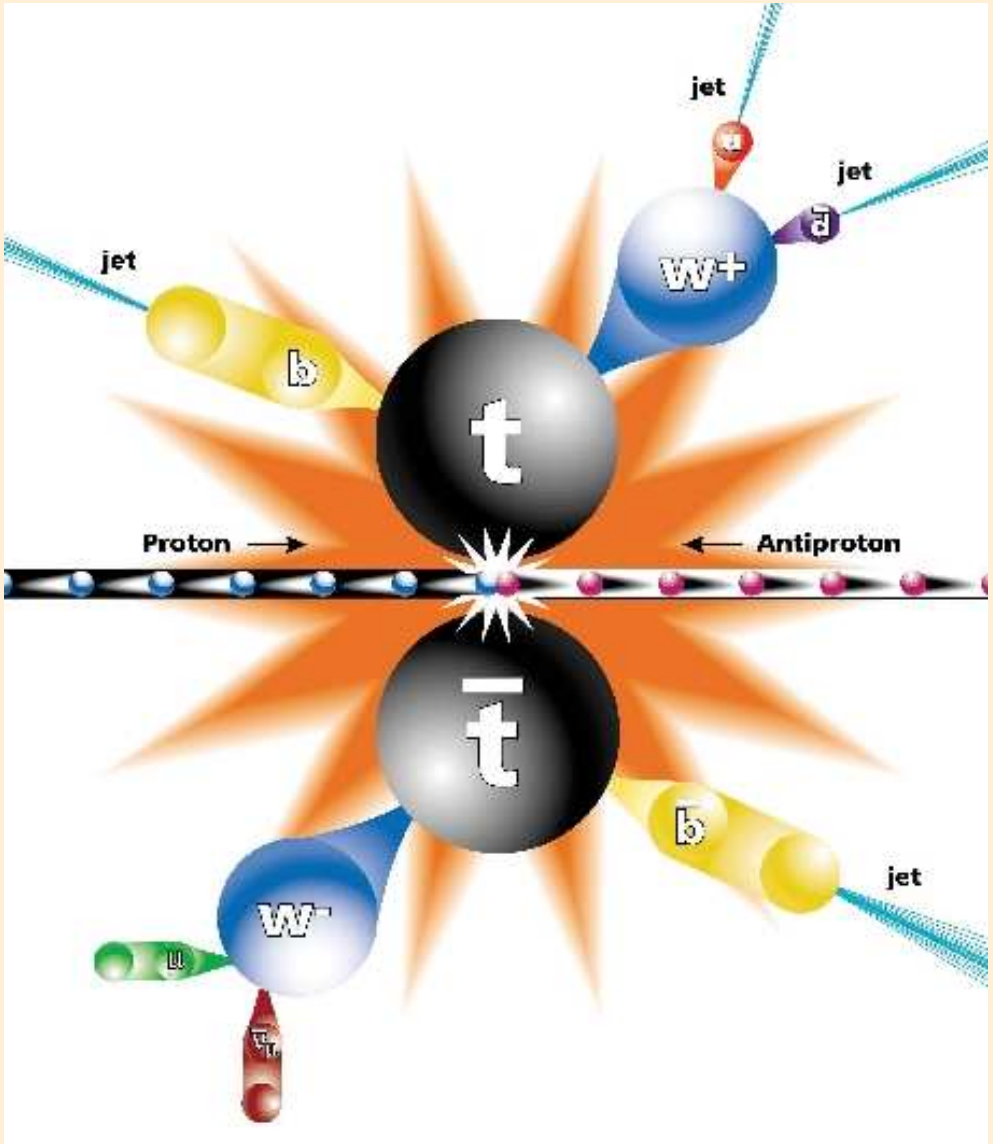




Relative uncertainty of $\sim 1\%$ achieved

Data prefer a low Higgs mass

Top Decay Properties



Is the Top really the Standard Model Top?

◇ **Production properties:**

production rate, production mechanism, charge, spin

Previous talk by Cecilia Gerber

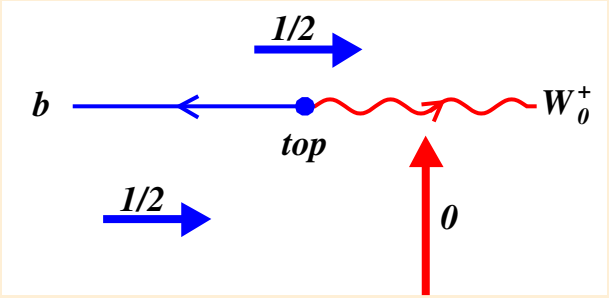
◇ **Decay properties:**

branching ratios, lifetime, couplings, W helicity

this talk

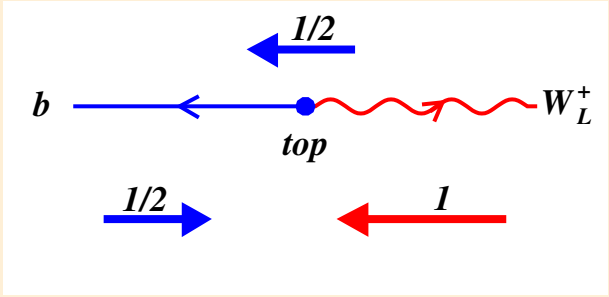
W Helicity in Top Decays

Longitudinal:



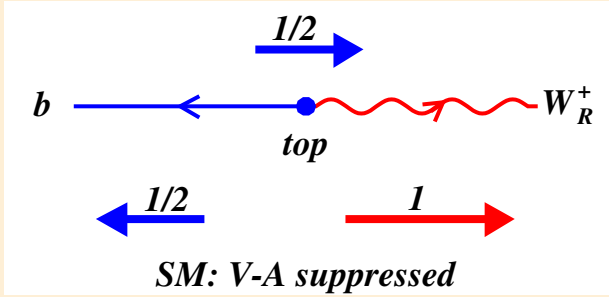
SM: $F_0 = 0.7$

Left-handed:



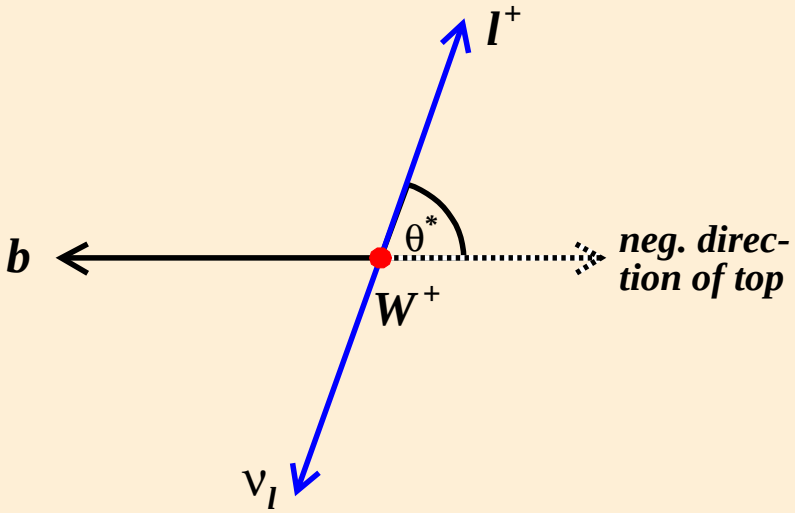
SM: $F_- = 0.3$

Right-handed:



SM: $F_+ = 0.0$

Use reconstructed $\cos\theta^*$ as observable

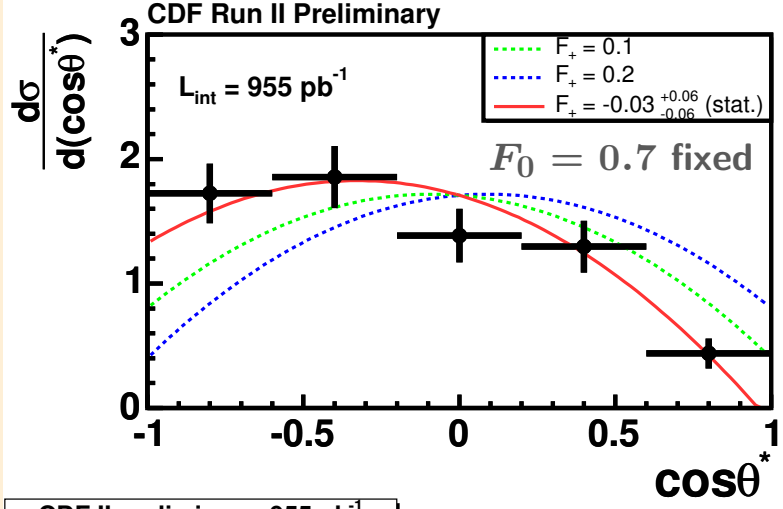


Deviations from SM values would indicate new physics:

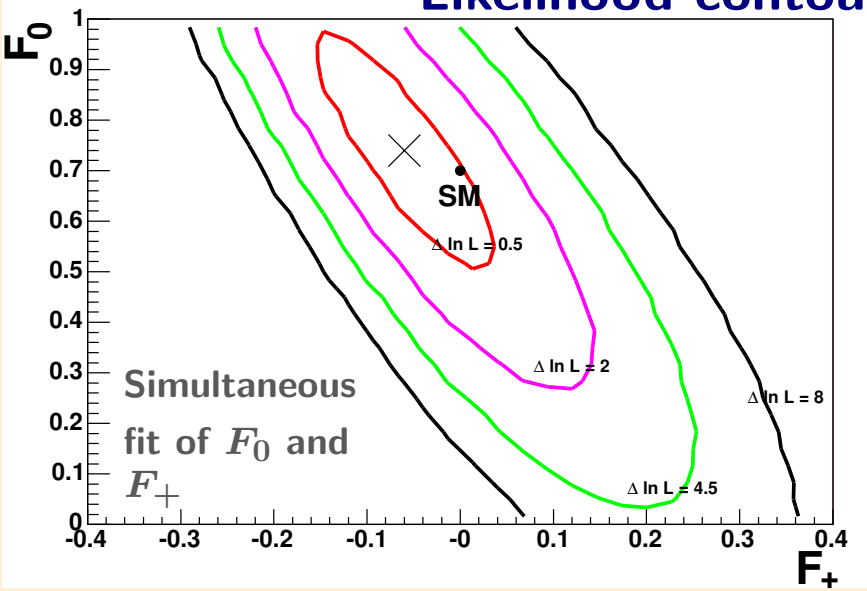
- Search for a possible $V + A$ coupling in weak top decays:
  $\Rightarrow$ **Altered F_+ value**
- Search for an indication of non-SM EW sym. breaking:
  $\Rightarrow$ **Altered F_0 value**

W Helicity: Results

Unfolded diff. cross section



Likelihood contours



ℓ+Jets, $\cos\theta^*$, 955 pb^{-1}

$F_+ = -0.03 \pm 0.07$

$F_0 = 0.59^{+0.14}_{-0.13}$

One parameter fixed

$F_+ = -0.06 \pm 0.10$

$F_0 = 0.74 \pm 0.26$

Simultaneous fit

ℓ+Jets & Dilepton, M^2_{lb}, 750 pb^{-1}

$F_+ = -0.02 \pm 0.08$ (F_0 fixed)

(Phys. Rev. Lett. 98, 072001 (2007))

ℓ+Jets & Dilepton, $\cos\theta^*$, 370 pb^{-1}

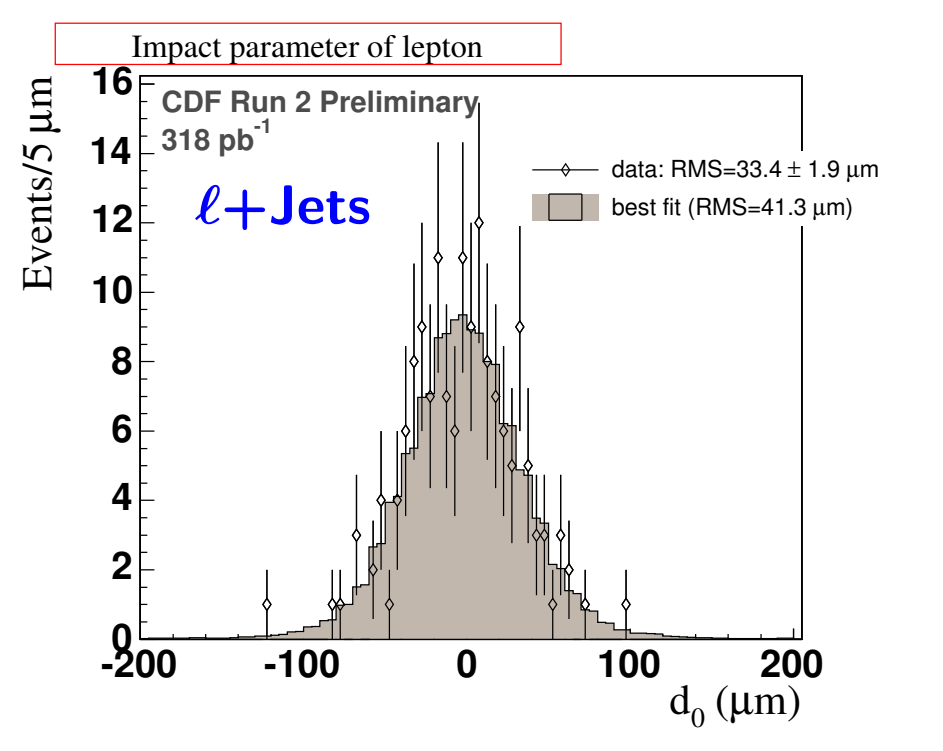
$F_+ = 0.06 \pm 0.10$ (F_0 fixed)

(Phys. Rev. D RC 75, 031102(R), (2007))

All DØ and CDF measurements are consistent with the SM

Lifetime and Branching Fraction

Impact parameter d_0 of ℓ correlated with τ_{top}



$c\tau_{top} < 52.5\,\mu\text{m}$ @ 95% C.L.

Top branching fraction:
R=Br$(t \to bW)$/Br$(t \to qW)$

ℓ+Jets & Dilepton, $162\,\text{pb}^{-1}$

$R = 1.12^{+0.27}_{-0.23}$

$R > 0.61$ @ 95% C.L.

(Phys. Rev. Lett. 95, 102002, (2005))

ℓ+Jets, $230\,\text{pb}^{-1}$

$R = 1.03^{+0.19}_{-0.17}$

$R > 0.61$ @ 95% C.L.

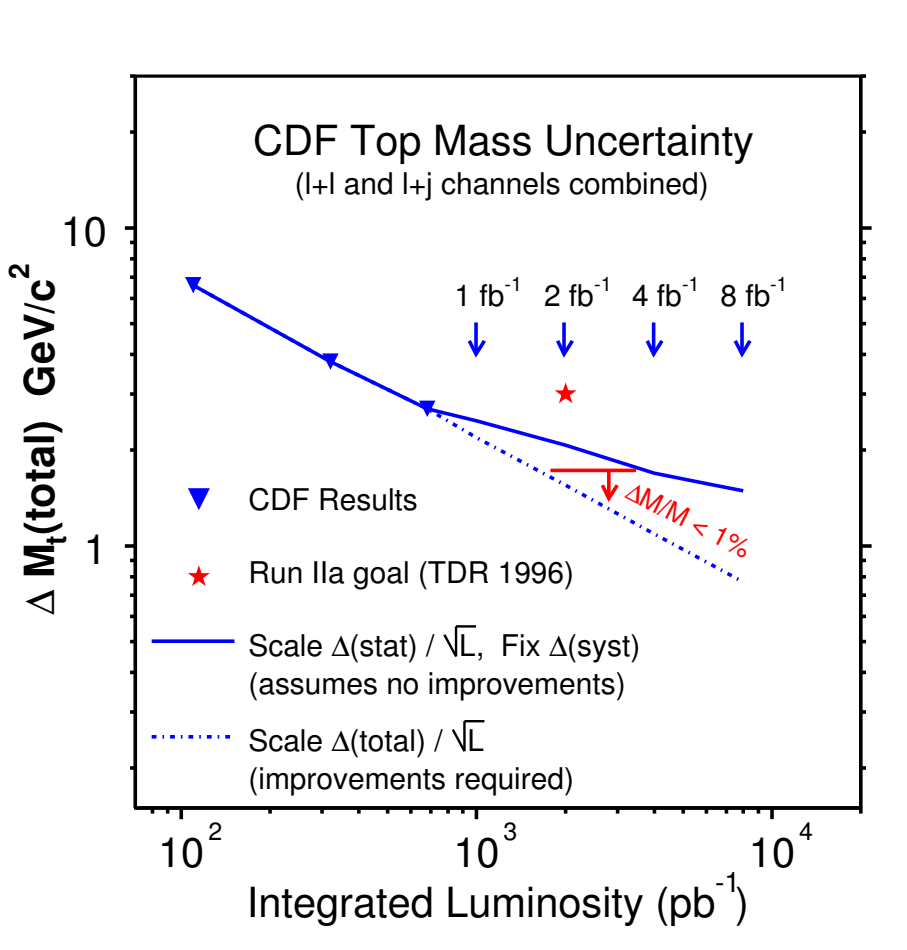
(Phys. Lett.B 639, 616-622, (2006))

Results consistent with SM

Summary

Top mass:

- Measurements are systematically limited
- $m_t = 170.9 \pm 1.8$ GeV/c^2 (Tevatron combination)
- Relative uncertainty $\sim 1\%$
- Hope to reach $\Delta m_t \sim 1$ GeV/c^2



Top decay properties:

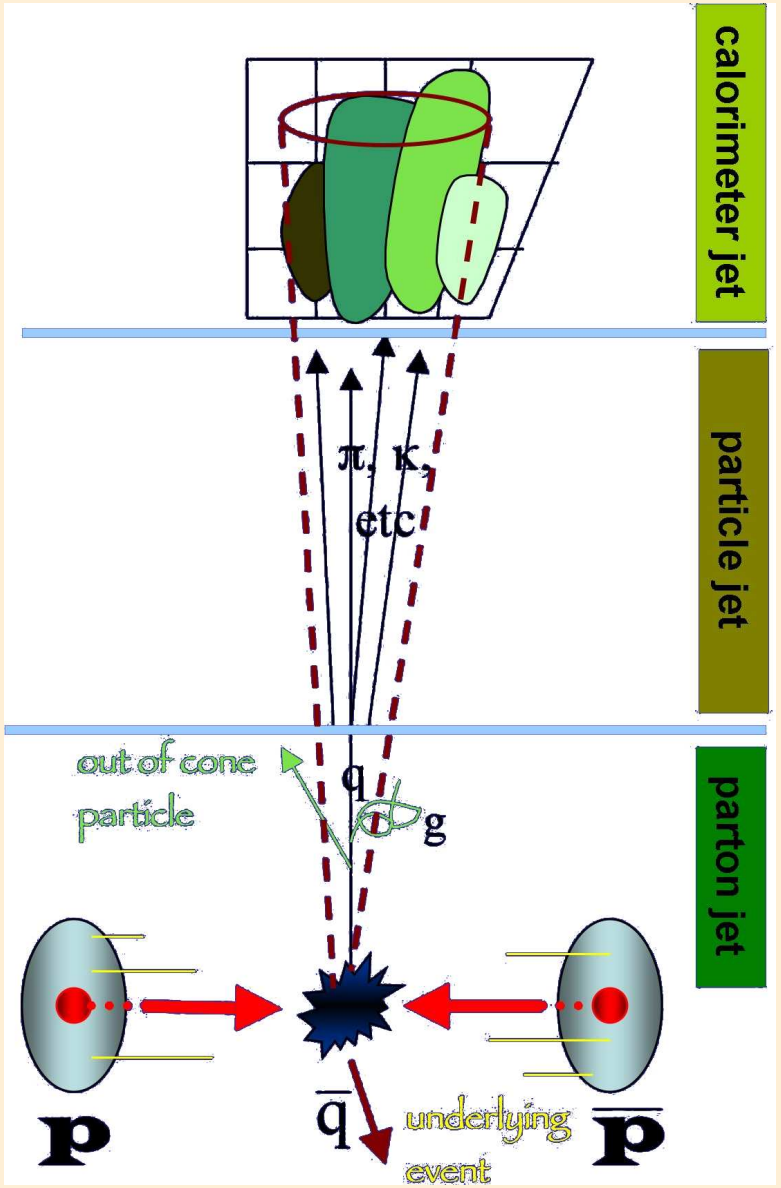
- Measurements are still statistically limited
- All decay properties are consistent with the Standard Model prediction

Backup Slides

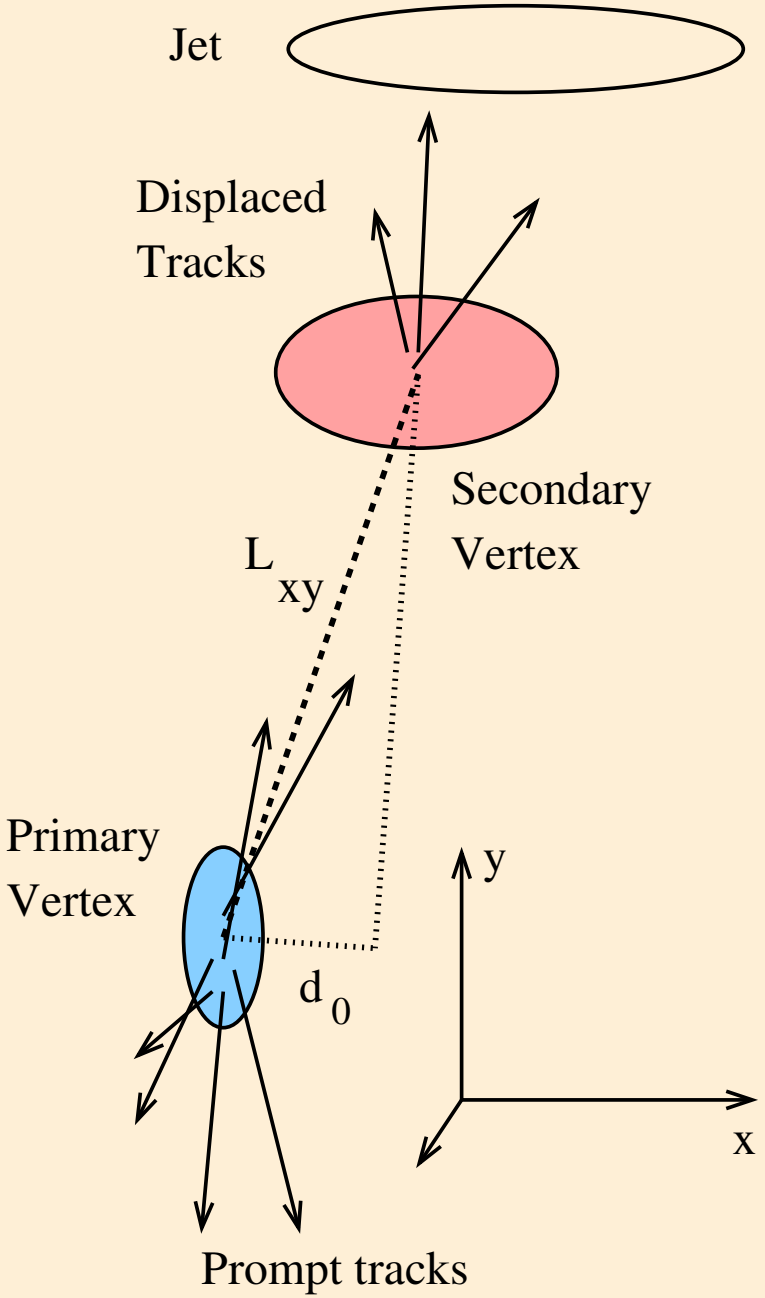
Challenges of Top Quark Physics

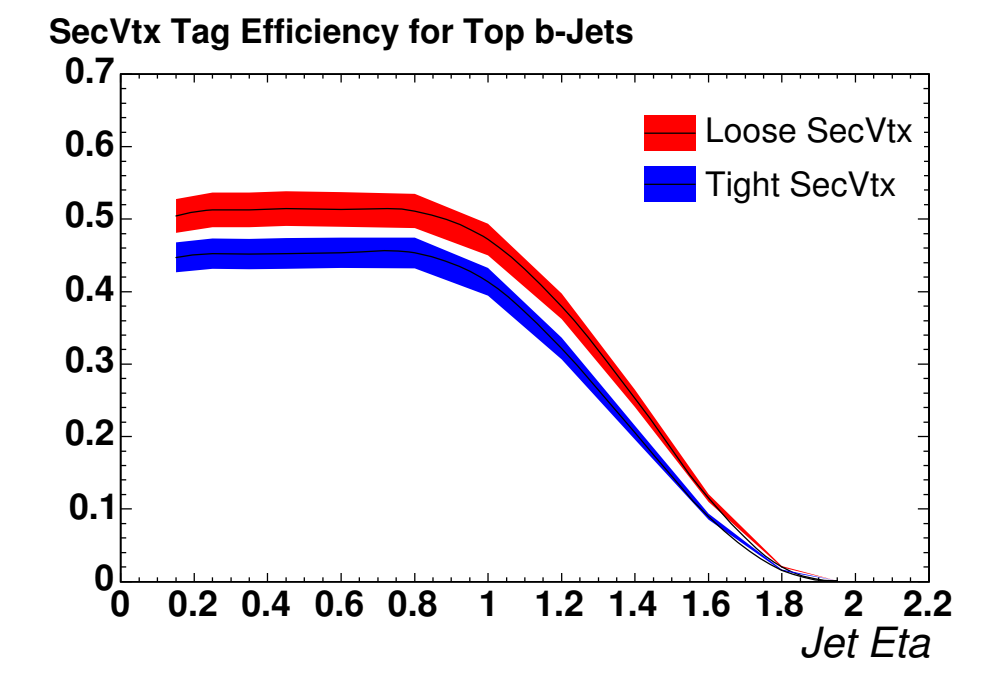
- Top quark physics requires the understanding of all detector components
- It is a rare process with significant backgrounds
- We measure jets, not quarks: Correct jet energies (JES) for detector effects, hadronization, mult. interactions

  JES known to $\sim 3\% \rightarrow$ dominant syst. uncertainty
- b-tagging can be used to reduce backgrounds and jet/quark combinatorics



B-Tagging at CDF





Loose: $L_{xy}/\sigma_{L_{xy}} > 6$, **Tight:** $L_{xy}/\sigma_{L_{xy}} > 7.5$

Tight: $\epsilon \approx 45\%$ **(b)**
$\epsilon \approx 0.7\%$ **(light)**
$\epsilon \approx 9\%$ **(c)**

d_0 **resolution for central tracks:** $\approx 50\,\mu m$

Including L00: $o(5)\,\mu m$ **improvement**