Top-Quark Mass Measurement in Dilepton Channel

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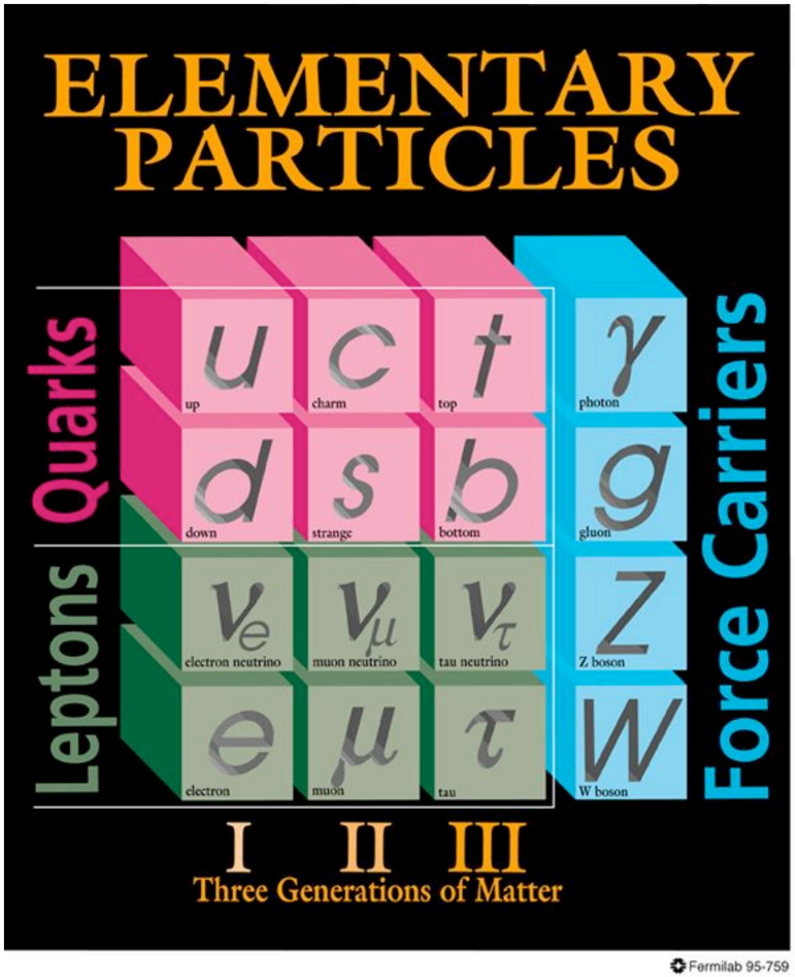
The 20th Nordic Particle Physics Meeting
Spåtind, Norway, 3 - 7 January 2008

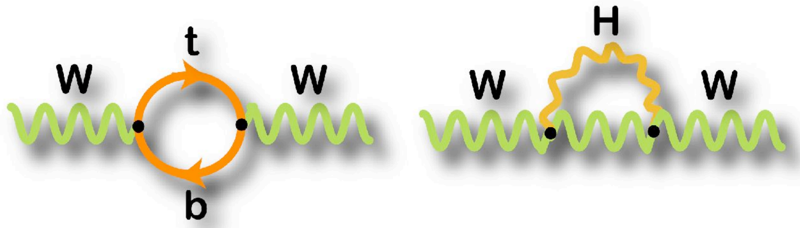
Introduction to top quark

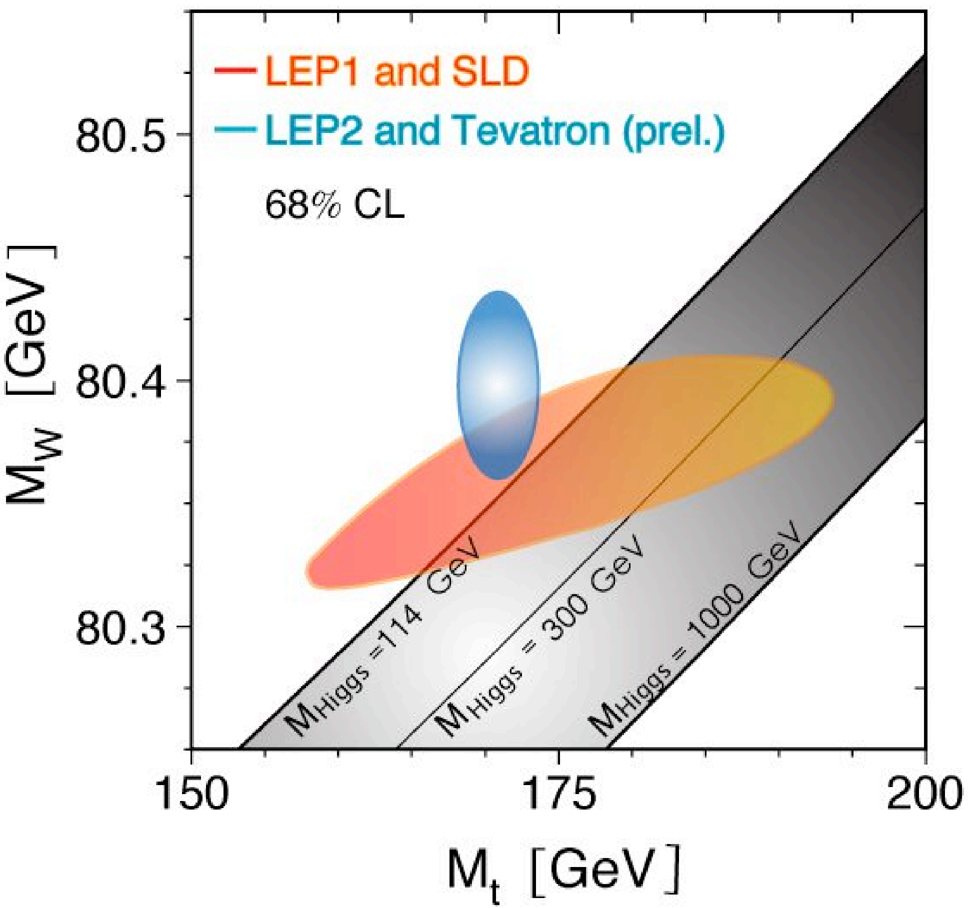


- Top quark discovered in 1995 at Fermilab
- Top-quark mass suprisingly large
  - *~35x heavier than bottom quark*
  - *5 orders of magnitude between top- and up-quark masses*
- As top quark is so heavy, it decays before hadronization
  - *only quark which decays before hadronization*

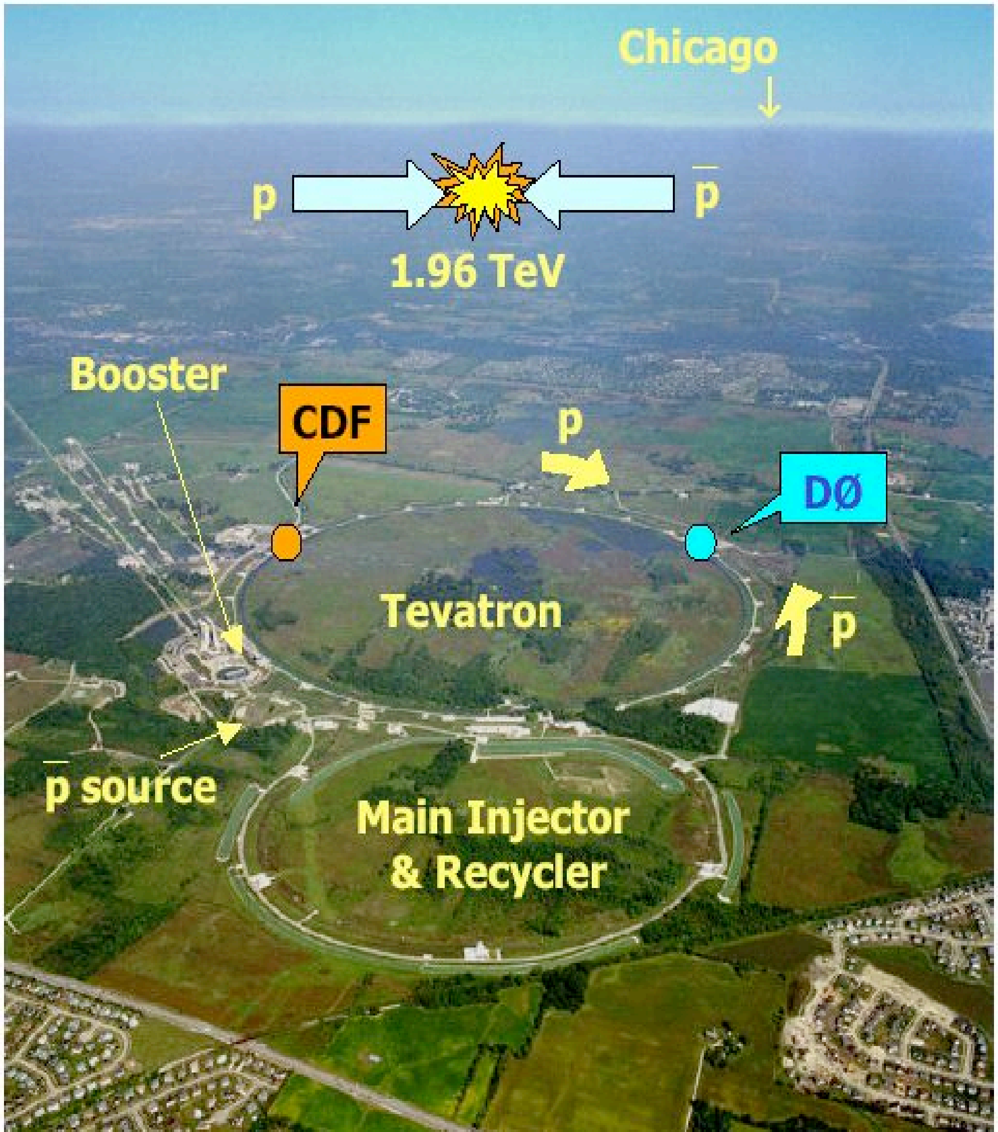
Motivation for top mass

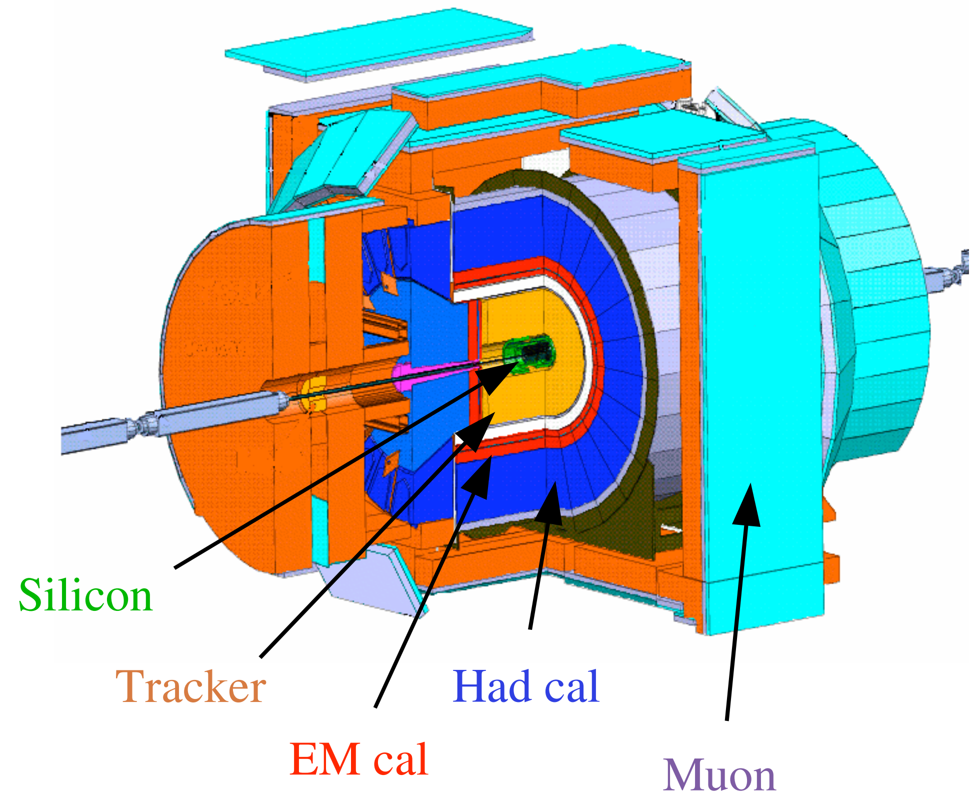
- Top mass fundamental SM parameter:
  - *tests SM predictions*
  - *important in radiative corrections*
  - *constrains SM Higgs mass*
- Top mass close to scale of electroweak symmetry breaking
- Constraints on models beyond SM





Tevatron





- I will show results using 1.2 fb^{-1} of data
- Tevatron will run until end of 2009, maybe longer
- Expected delivered luminosity 6-7 fb^{-1} by end of 2009

Production of top quarks

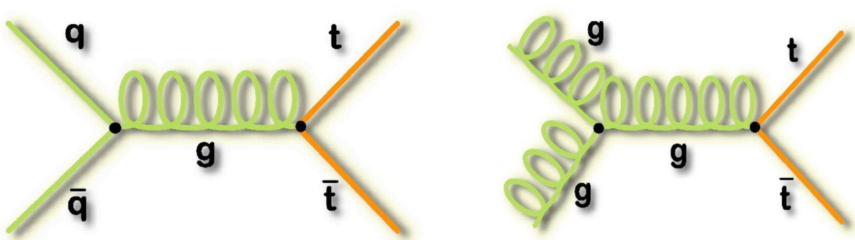
At Tevatron, **top quarks are predominantly pair produced via strong interaction**

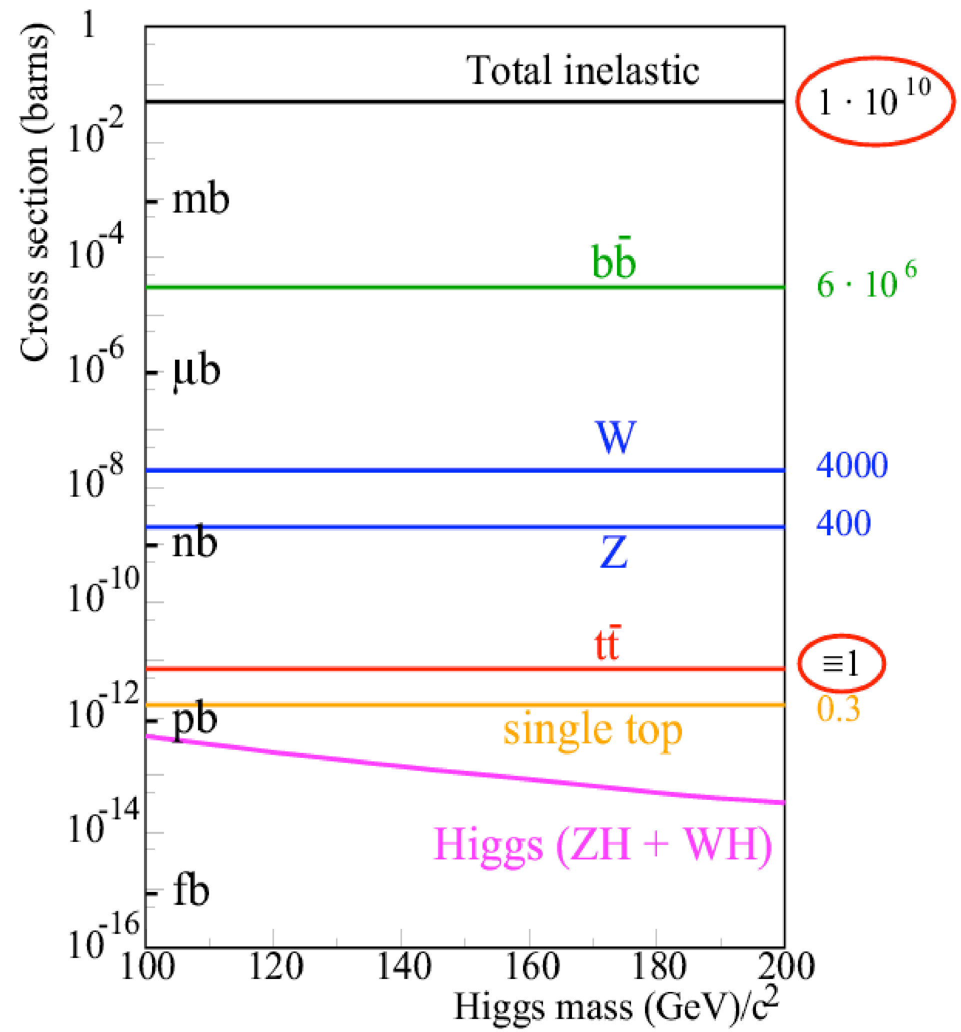
σ_{tt} = 6.7 pb for m_{top}=175 GeV/c²

(JHEP 0404:068 (2004))

~85% from qq→tt

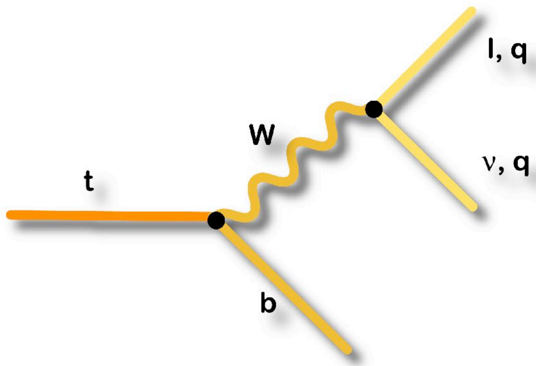
~15% from gg→tt





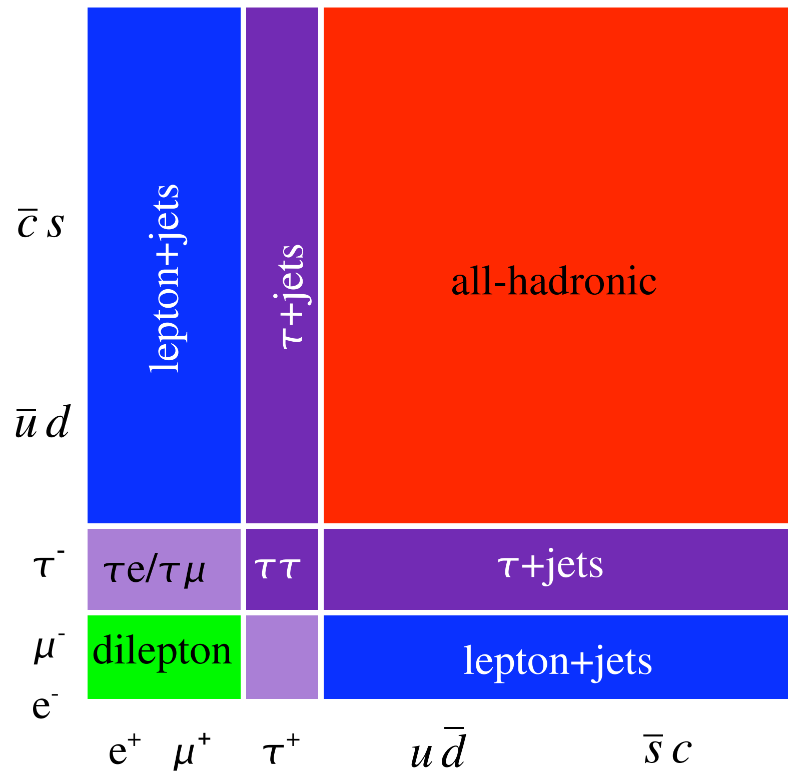
Rare at Tevatron: One top pair per 10 billion inelastic collisions

Classification of $t\bar{t}$ events



$BR(t \to Wb) \sim 100\%$

- *ttbar events can be classified according to W decays*



All-hadronic channel
- *6 quarks*
- *high background*

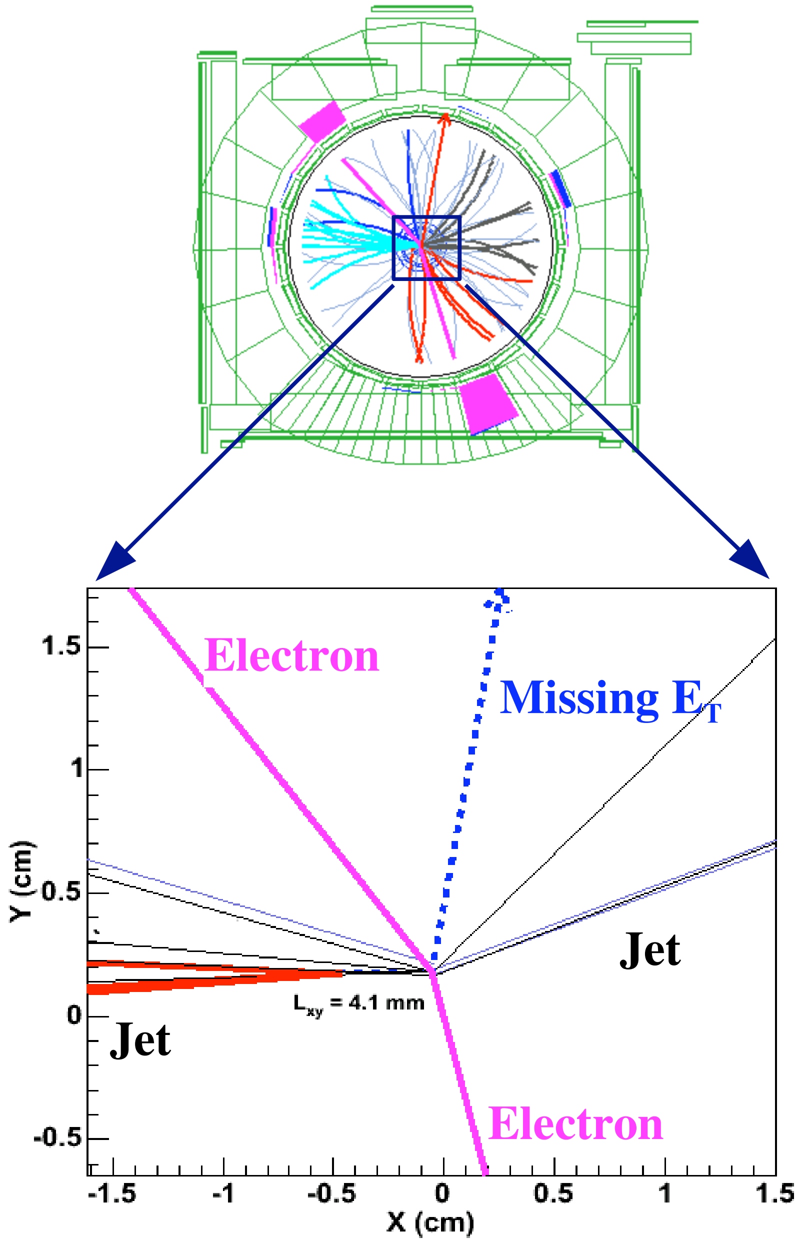
Dilepton channel
- *2 leptons (e,μ), 2 neutrinos, 2 quarks*
- *low background*

τ-leptons difficult to identify
- *partially included in other categories*

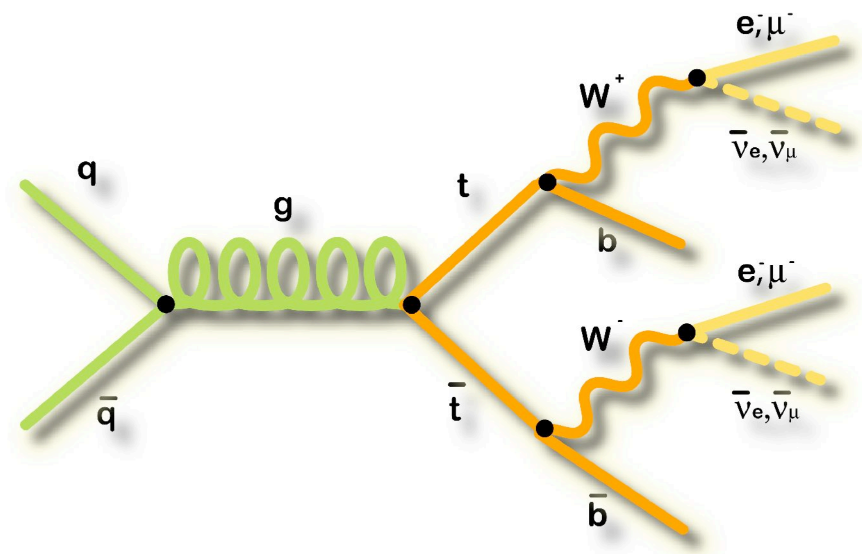
Lepton+jets channel
- *1 lepton (e,μ), 1 neutrino, 4 quarks*
- *managable background*

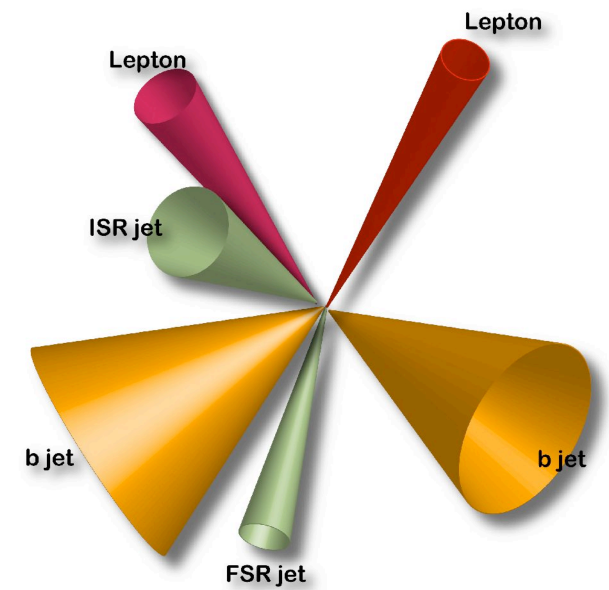
Challenges of measuring top mass

- Neutrinos escape detector
  - *partial information can be measured as missing E_T*
- Quarks hadronize and form jets
  - *measured energy of jets has to be corrected back to parton level*
  - *many ways to assign a jet to a parton*
- Background processes mimic top events



Dilepton channel





- Event signature:
  - *two high p_T leptons (e or μ)*
  - *at least two jets*
  - *large missing E_T*
- Backgrounds:
  - *Drell-Yan*
  - *W+jets where a jet fakes lepton*
  - *diboson*
- Advantage for top mass:
  - *low background*
  - *only two possible jet-parton assignments*
- Challenge for top mass:
  - *under-constrained for top mass fitting*
  - *low statistics*

Expected number of events

	1.2 fb^{-1}
Diboson	5.8±0.9
$Z/\gamma \rightarrow ll$, $l=e,\mu,\tau$	10.9±2.3
Misidentified leptons	8.8±3.9
Total	25.6±5.5
ttbar (M_t=170 GeV/c^2)	62.1±4.3
Total expected	87.7±8.9
Data	77

Divide sample into two subsamples:

- **b-tagged**
  - *at least one of the jets b-tagged*
  - *expected S/B~11:1*
  - *32 data events*
- **non-tagged**
  - *none of the jets b-tagged*
  - *expected S/B~1:1*
  - *45 data events*

Mass reconstruction method

- Write kinematic equations for dilepton events
  - *conservation of energy and momentum*
  - *missing transverse energy equals transverse energy of neutrinos*
  - *known masses of final state particles*
  - *known W-boson mass*
  - *mass of the top and antitop quark equal*

- 23 equations for 24 unknown variables

$$\vec{p}_b + \vec{p}_{W^+} = \vec{p}_t$$

$$\vec{p}_{\bar{b}} + \vec{p}_{W^-} = \vec{p}_{\bar{t}}$$

$$\vec{p}_{l^+} + \vec{p}_{\nu} = \vec{p}_{W^+}$$

$$\vec{p}_{l^-} + \vec{p}_{\bar{\nu}} = \vec{p}_{W^-}$$

$$p_{\nu}^{x} + p_{\bar{\nu}}^{x} = E_{miss}^{x}$$

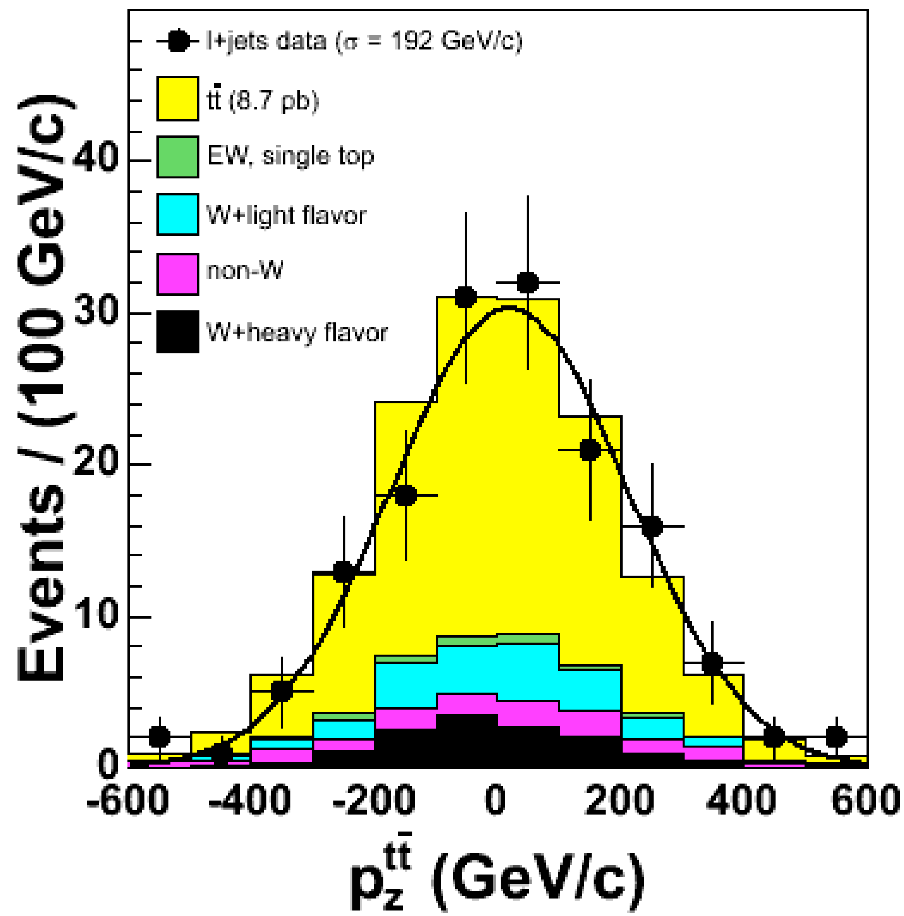
$$p_{\nu}^{y} + p_{\bar{\nu}}^{y} = E_{miss}^{y}$$

$$M_{W^\pm} = 80.4\,GeV$$

$$M_t = M_{\bar{t}}$$

Mass reconstruction method continued

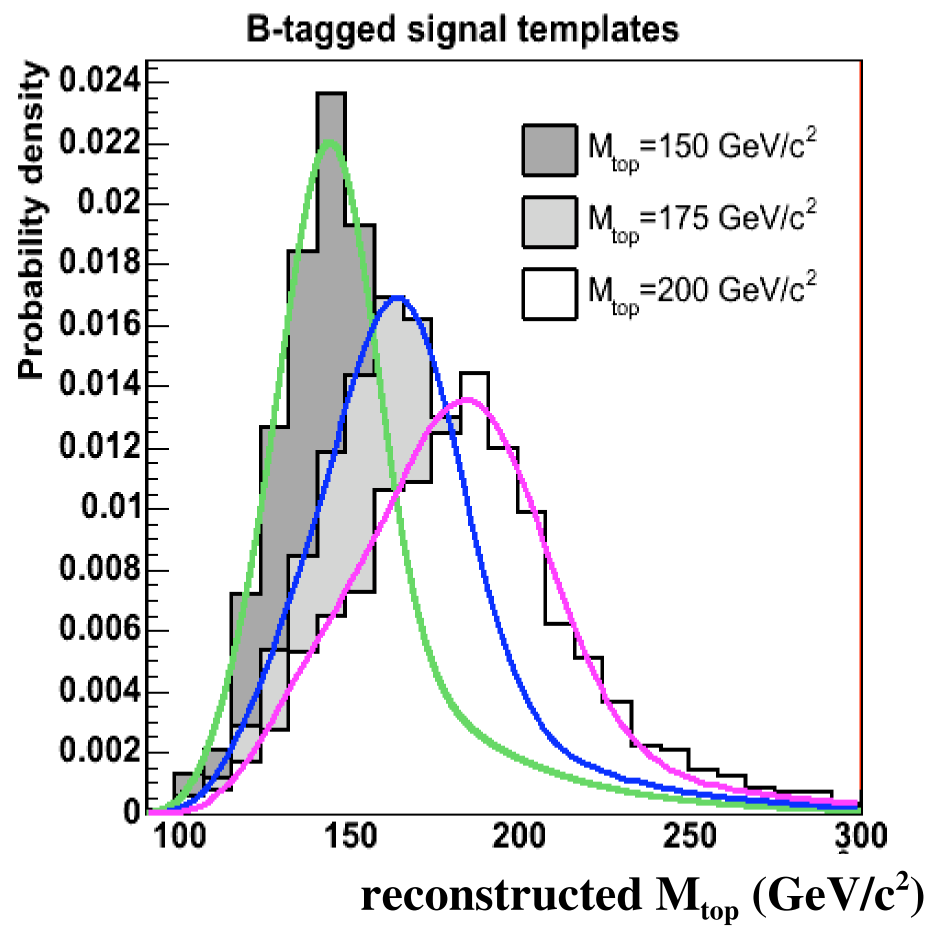
- Additional constraint from top mass independent distribution
  - *we take* $p_z^{t\bar{t}}$
- Simulated $p_z^{t\bar{t}}$ prediction validated in lepton+jets channel
  - *good agreement between data and simulation*
  - *can trust simulation*
- Randomly draw values from $p_z^{t\bar{t}}$ distribution 10000 times
- Select the most probable solution as per-event reconstructed top mass



Templates

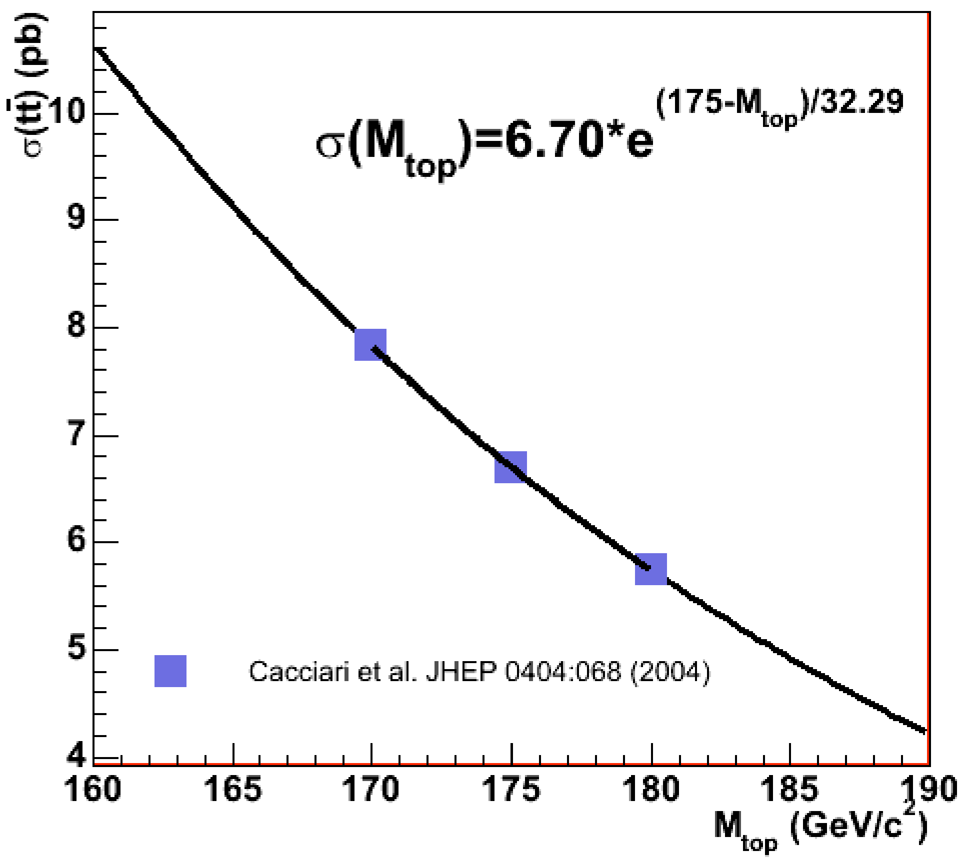
- Generate **signal templates** from Monte Carlo samples with different generated top masses

- Generate **background templates** for each background source. Combine according to expected yield



Theoretical cross-section

- Expected number of top events depends on top mass
  - ***top mass information can be extracted from observed number of events***
- Main dependence comes from theoretical $\sigma_{t\bar{t}}$



Expected number of signal events

Expected number of signal events:

$$n_s(M_t) = \sigma_{t\bar{t}}(M_t) * a(M_t) * L * p_{mass}^{rec}$$

$\sigma_{t\bar{t}}(M_t) =$ theoretical cross section

$a(M_t) =$ acceptance

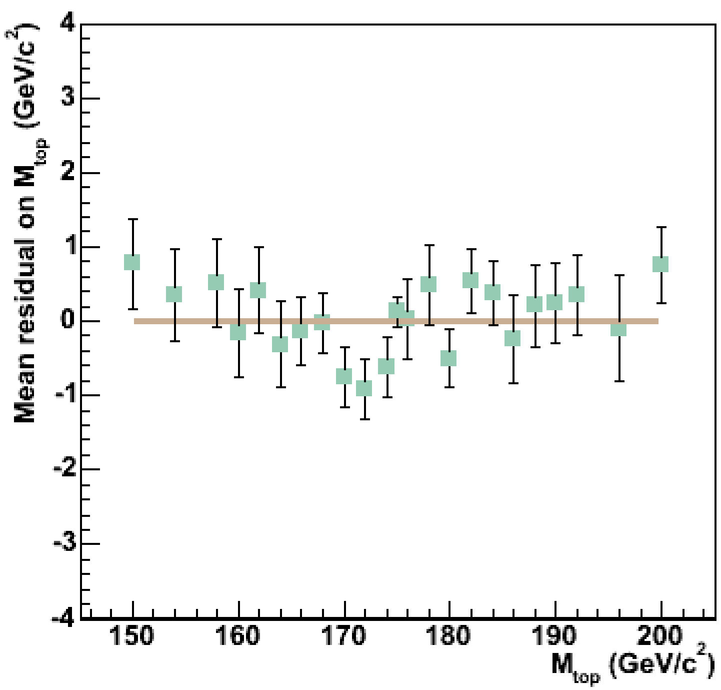
$L =$ integrated luminosity

$p_{mass}^{rec} =$ mass reconstruction probability

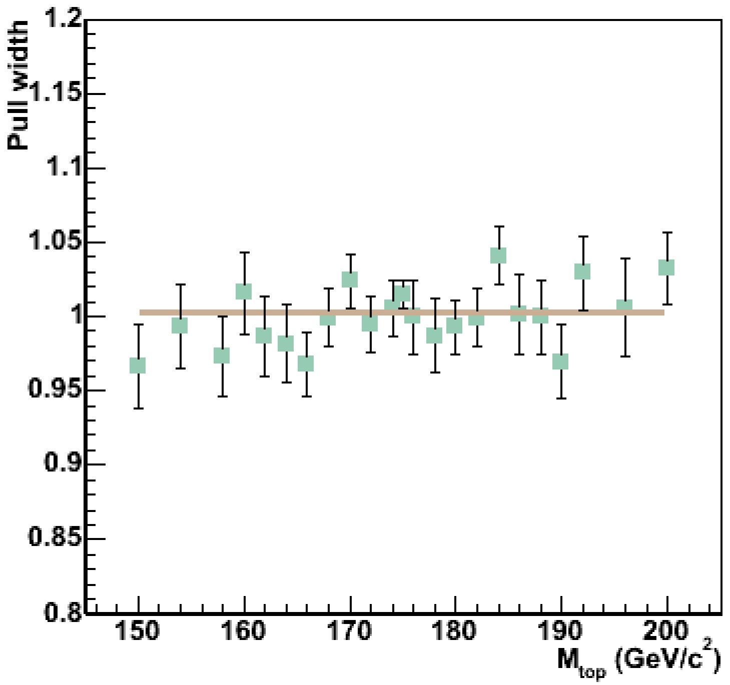
- Final top mass estimate from likelihood fit
  - *compare reconstructed top mass distribution to templates*
  - *compare observed number of events to expectation*

Pseudo-experiments

- Purpose of pseudo-experiments is to test how method works
  - *Randomly select expected number of signal and background events from Monte Carlo samples*
  - *Perform mass reconstruction and likelihood fit for these events*
  - *Repeat 10000 times*



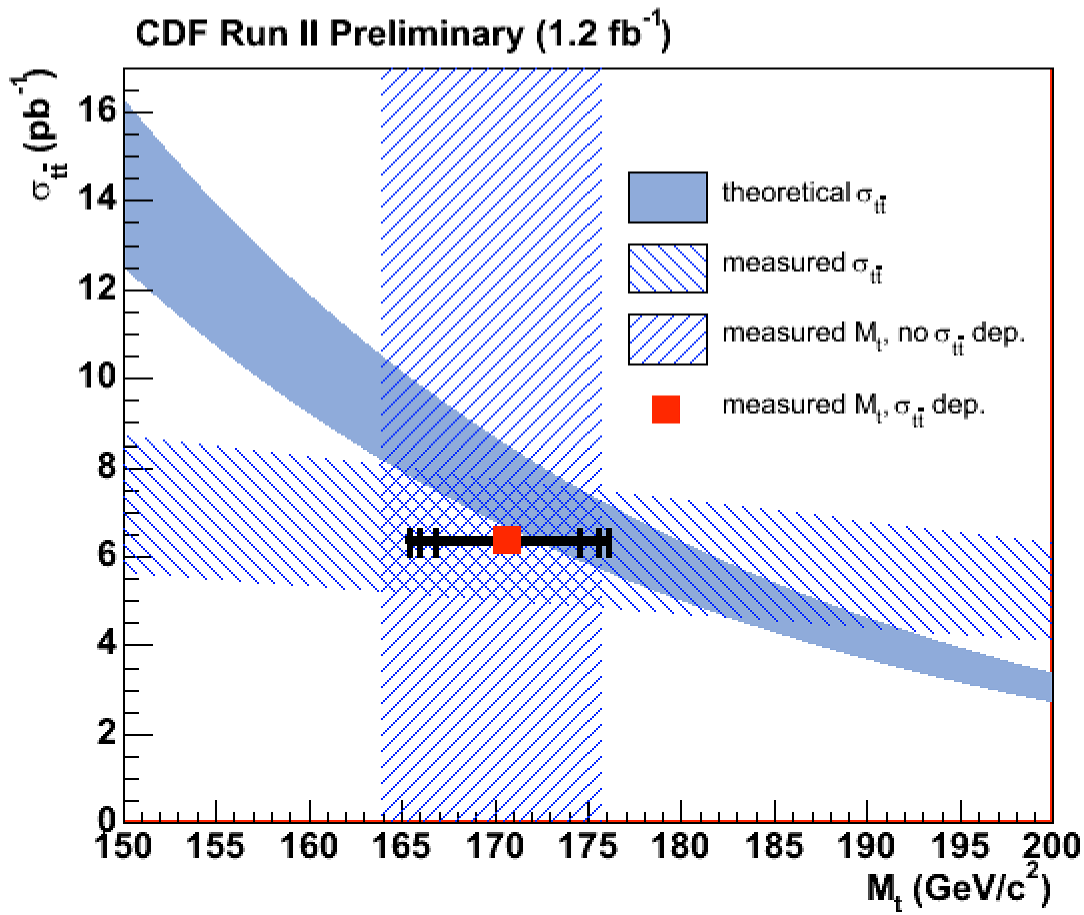
$$residual = M_t^{measured} - M_t^{generated}$$



$$pull = \frac{M_t^{measured} - M_t^{generated}}{\sigma}$$

Cross-section-constrained result

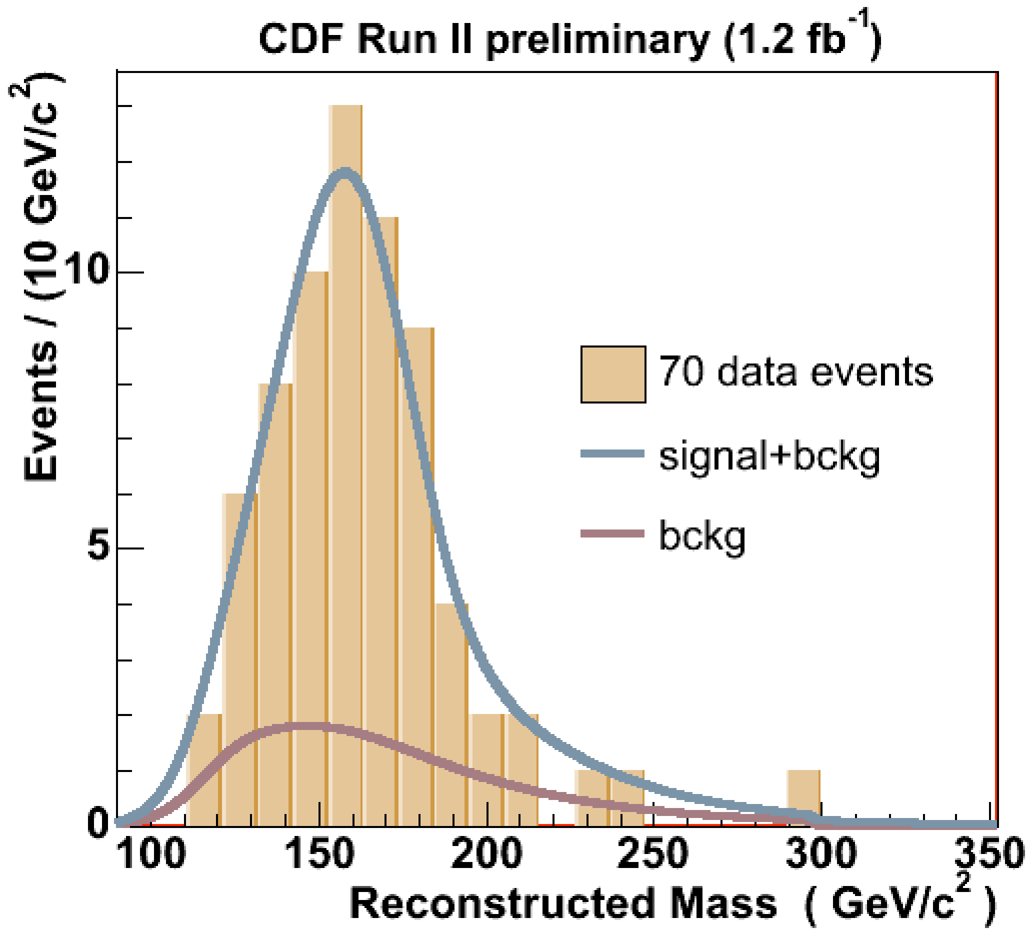
- In data sample corresponding to 1.2 fb^{-1}, **70 data events pass mass reconstruction criteria**
  - *31 b-tagged*
  - *39 non-tagged*



$$M_t = 170.7^{+4.2}_{-3.9}(stat.) \pm 2.6(syst.) \pm 2.4(theory)\, GeV/c^2$$

Template result

Measurement without cross-section-constraint



$$M_t = 169.7^{+5.2}_{-4.9}(stat.) \pm 3.1(syst.)\, GeV/c^2$$

Systematic uncertainties

Source	Magnitude	(GeV/c^2)
	T	C
Jet energy scale	2.9	1.8
Signal modeling	0.8	0.9
Background modeling	0.3	0.3
Template statistics	0.5	0.4
Lepton p_T	0.2	0.2
Expected number of events	n.a.	1.6
Total	3.1	2.6
Theory uncertainty	n.a.	2.4

- Cross-section-constrained (C) measurement less sensitive to jet energy scale
- Cross-section-constrained has additional uncertainties
  - *expected number of events: integrated luminosity, acceptance, mass reconstruction probability, and expected number of background events*
  - *theory uncertainty*

Summary

- Top-quark mass is an important parameter in Standard Model
  - *places constraints on SM Higgs, tunes beyond SM theories*
- Important to measure top mass in all decay channels
- Top-quark mass measurement from dilepton channel
  - *first measurement with cross-section constraint*

$$M_t = 170.7^{+4.2}_{-3.9}(stat.) \pm 2.6(syst.) \pm 2.4(theory)\,GeV/c^2$$

- World average of top mass measurements

$$M_t = 170.9 \pm 1.1(stat.) \pm 1.5(syst.)\,GeV/c^2$$

Backup

Top mass from cross section

- For cross check, we measure top mass from cross section only

$$M_t = 178.3^{+10.1}_{-8.0}(\exp)^{+4.0}_{-6.0}(theory)\, GeV/c^2$$