Top Quark Mass Measurement with In Situ Jet Energy Scale Calibration at CDF-II

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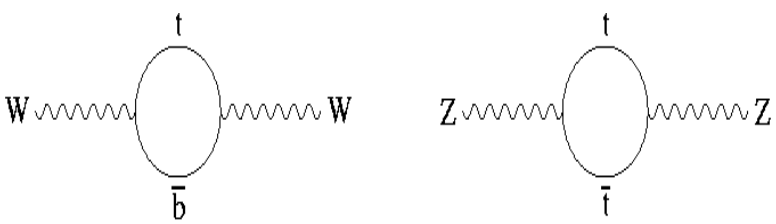
Fermilab Users' Meeting
June 1st, 2006

Outline

- Motivation
- Challenges for measuring M_{top} in Run II
- Description of the method
- Impact of the result

Motivation for Measuring M_{top}

- Loop involving top quarks: dominant corrections to predictions of many SM observables

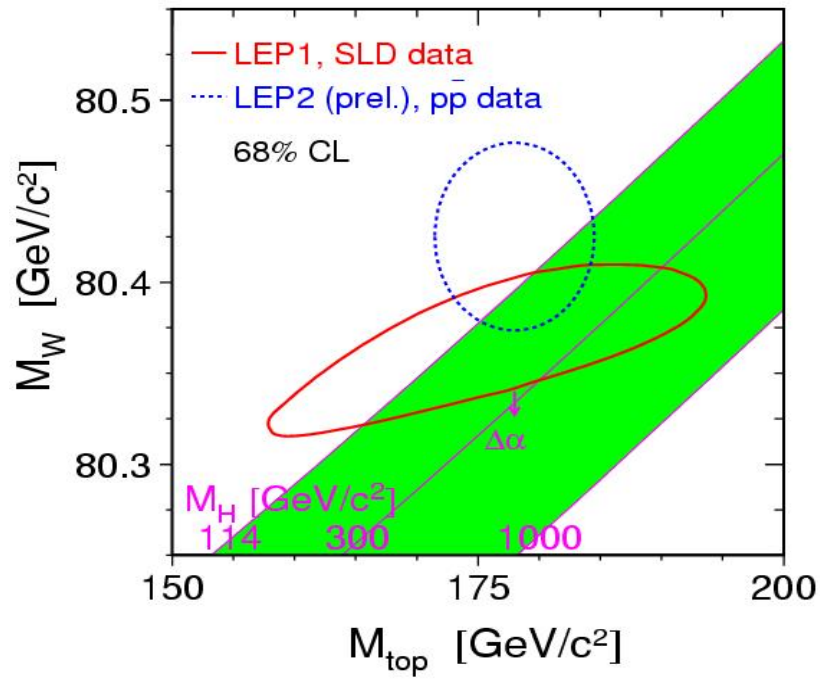


- Correction factor from top loops:

$$\Delta\rho = \frac{G_F N_c M_t^2}{8\sqrt{2}\pi^2}$$

- Using Run I world average:

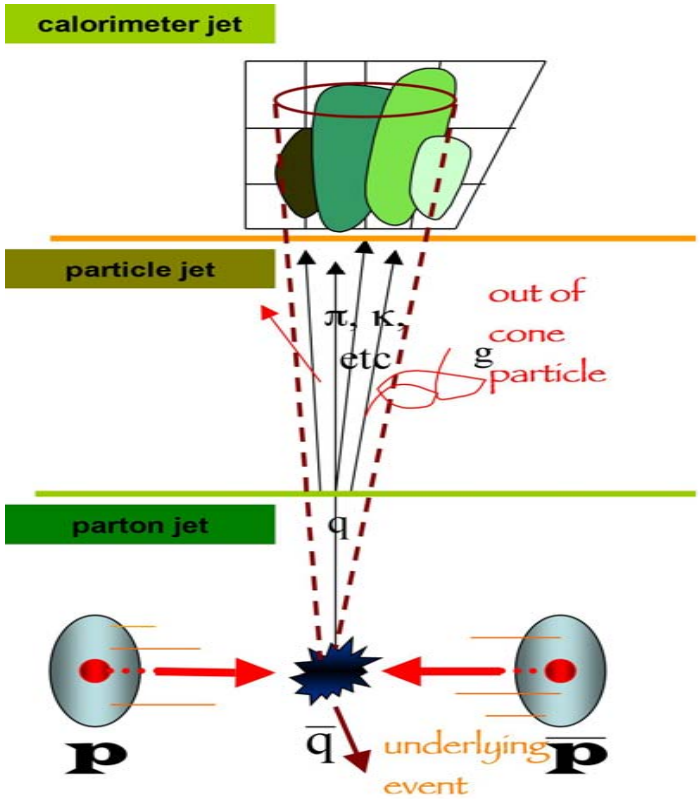
$$M_{top} = 178.0 \pm 4.3 GeV/c^2$$



Challenges for Measuring M_{top} at CDF-II

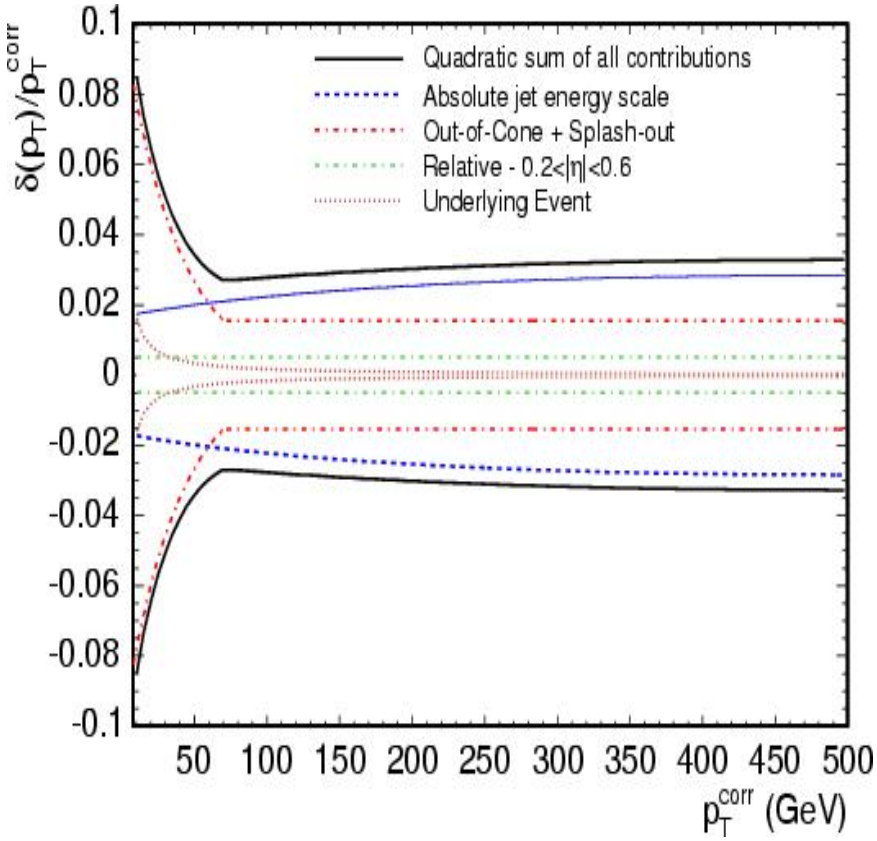
- World average uncertainty of 4.3 GeV/c^2 (~100pb^{-1}) has two major contributors:
  - Statistics: 2.7 GeV/c^2
  - Jet energy scale (JES): 2.6 GeV/c^2
- Run II: collect 4-8 fb^{-1}
  - Thus stat. uncertainty will become small
- → Particular attention should be brought to JES uncertainty in Run II

- JES uncertainty due to complexity of jet fragmentation and detection:



Jet Energy Scale at CDF-II

- Jet energy scale studied in various types of events (dijet, gamma+jets, etc)
- Jet energy response in MC calibrated to be compatible with data
- Uncertainty on calibration is $\pm 1\sigma_c$
- This uncertainty is applied to M_{top} measur. yield ~3 GeV/c^2



Novel approach in thesis: further reduce JES uncert. using W→jj decays

Selecting top-antitop Events

- Selecting events in the lepton+jets channel:

$$t\bar{t} \rightarrow l\nu q\bar{q}'b\bar{b}$$

- Event selections:
  - High-p_T e or μ
  - Large missing E_T
  - ≥4 large E_T jets

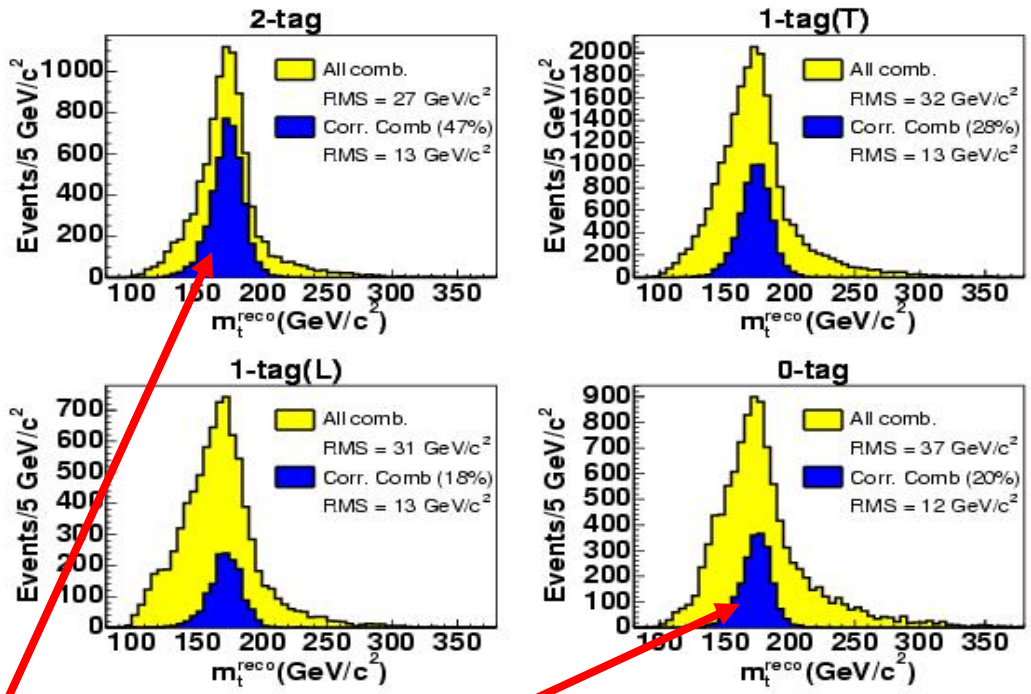
- Background: W+jets, QCD multijets, etc.
- Separation in four subsamples

Four events category:

Category	2-tag	1-tag(T)	1-tag(L)	0-tag
j1-j3 j4	E_T>15 E_T>8	E_T>15 E_T>15	E_T>15 15>E_T>8	E_T>21 E_T>21
S:B	10.6:1	3.7:1	1.1:1	0.9:1

Top Quark Mass Reconstruction

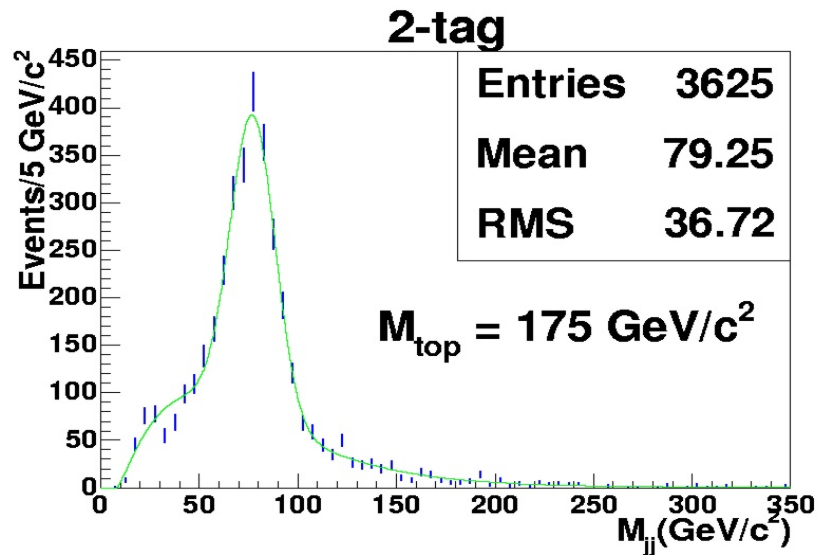
- Event-by-event mass m_t^{reco} from kinematic fit
- Try all jet-parton assignments: use mass yielding best chi-square
- Assign b-tag jets to b-quarks

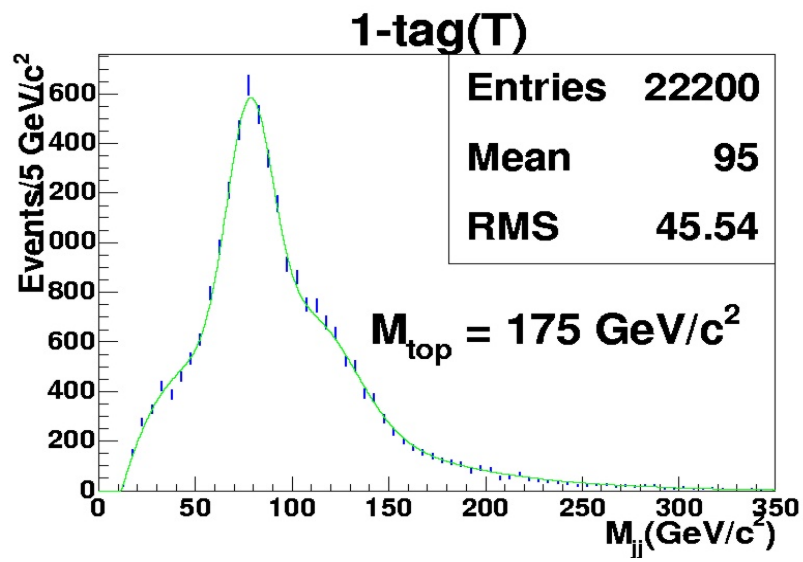


More correct combinations with b-tags!

Hadronic W Boson Mass

- Novelty: monitor simultaneously W →jj invariant mass to reduce JES uncert.
- Principle:
  - Reconstruct m_{jj} using all jet-parton assignments
  - m_{jj} sensitive to JES but mostly independent on M_{top}





Application of $W \rightarrow jj$ to M_{top} Measurement?

1) Can we use $W \rightarrow jj$ to calibrate b-jets?

B-Jet Systematic Source	Uncertainty (GeV/c^2)
HQ Fragmentation (Peterson ε_b=25-60x10^{-4})	0.4
Semileptonic decay	0.4
B-jets color flow	0.3
Total	**0.6**

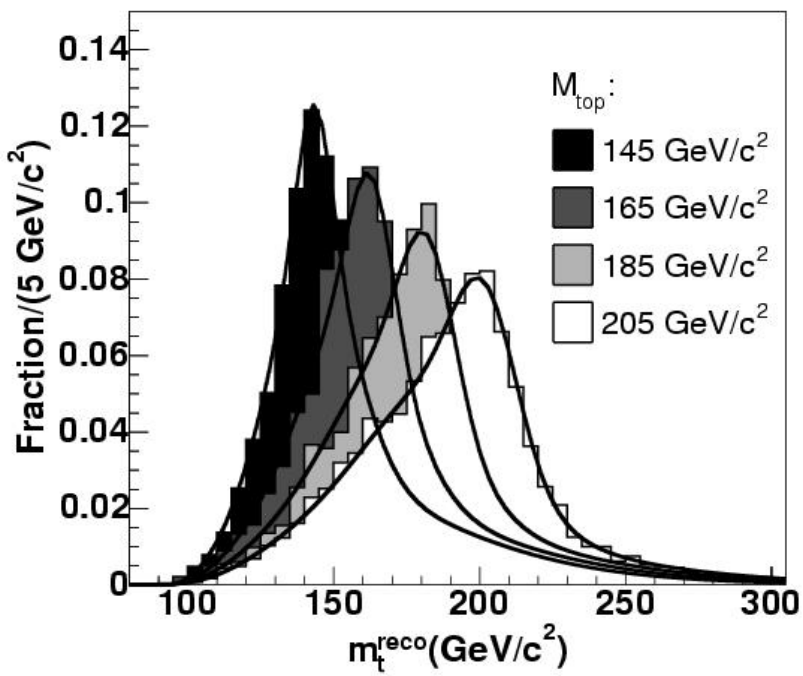
→ b-jets energy scale can be mostly set using $W \rightarrow jj$

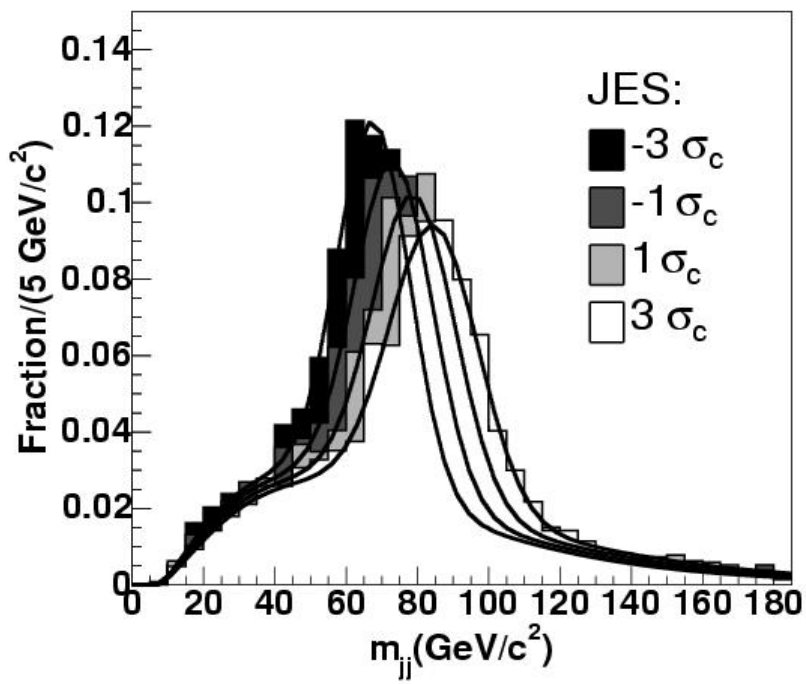
2) How to take into account correlations M_{top}-JES?

- m_{jj} displays some dependence on M_{top}
- Therefore, fitted JES is correlated to true top mass
- **Solution: simultaneous fit of M_{top} and JES**

Mass Templates

- Templates of m_t^{reco} and m_{jj} created as a function of M_{top} and JES:



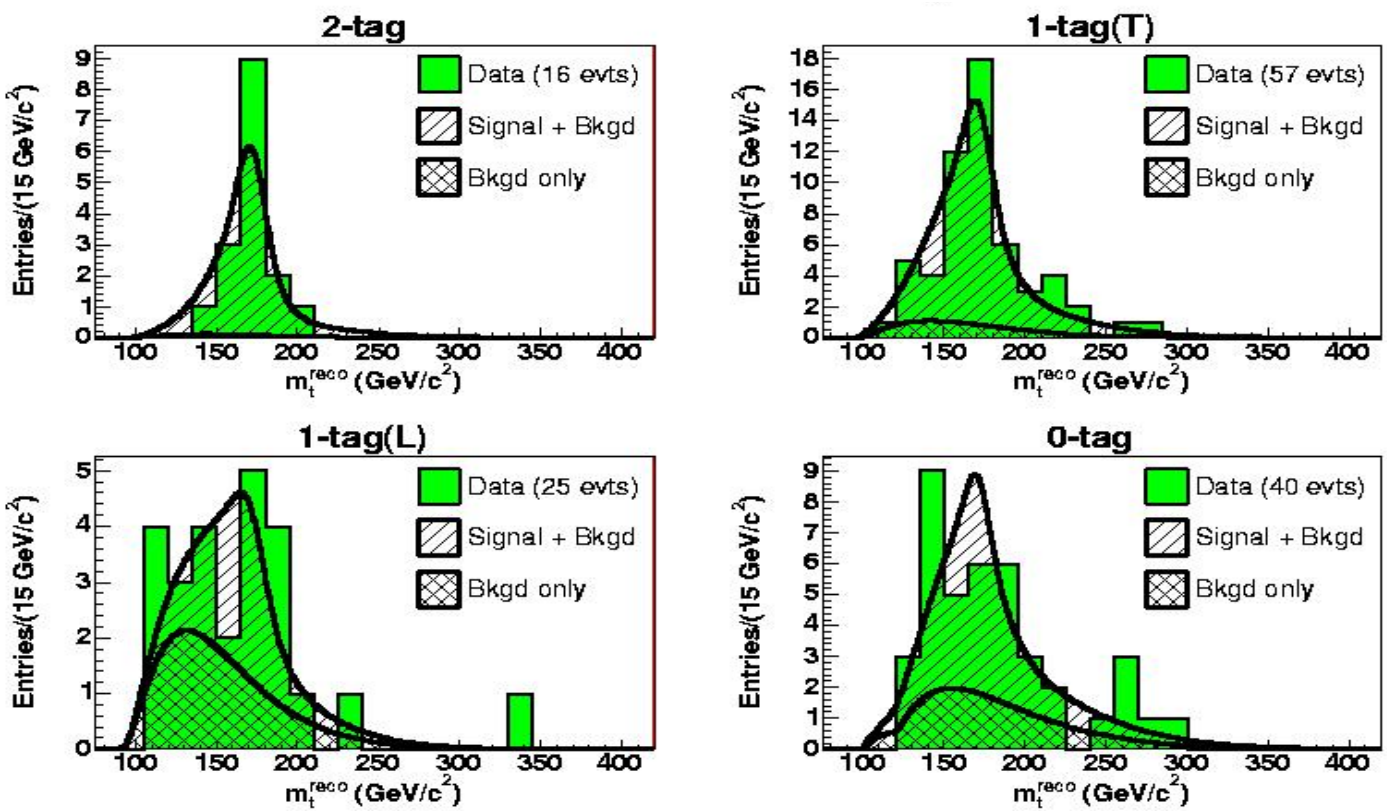


- Likelihood fit employed to extract M_{top} and JES
- Additional constraint on JES: use information from traditional CDF calibration

Results on Data I

$$M_{top} = 173.5^{+3.7}_{-3.6}(stat. + JES)GeV/c^2$$

Reconstructed top quark mass (318pb^{-1}):

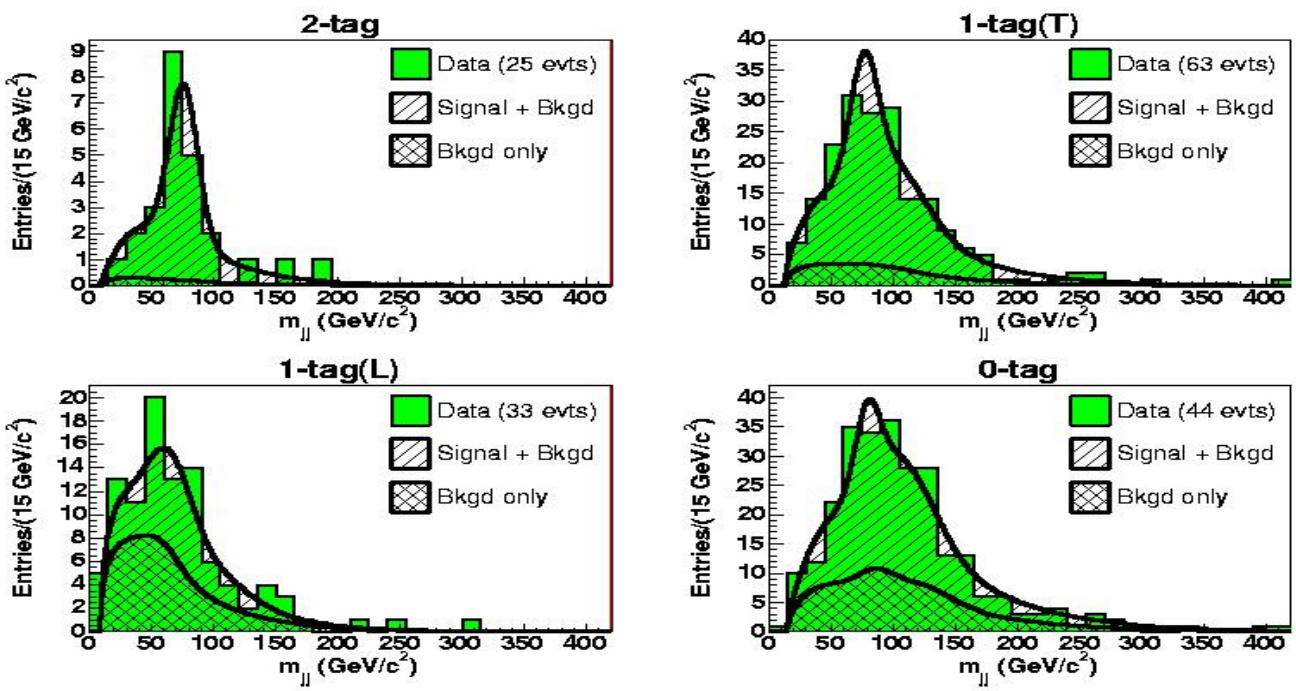


Results on Data II

$$JES = -0.10^{+0.78}_{-0.80}\,\sigma_c$$

- Very good agreement data-MC JES
- Combined W→jj and traditional calibration yield **20% better JES uncert.**

Reconstructed W boson mass:



Systematic Uncertainties

- Systematic uncertainties apart from JES (included in the fit) are small
- Novelty: introduce b-jets modeling uncertainty
- Total: 1.3 GeV/c^2

Source	ΔM_{top}(GeV/c^2)
b-jets modeling	0.6
Method	0.5
ISR	0.4
FSR	0.6
Background shape	0.5
PDF	0.3
Other MC modeling	0.4
Total	1.3

Impact of Measurement

- Most precise single measurements to date:

$$M_{top} = 173.5^{+3.9}_{-3.8} GeV/c^2$$ Thesis (318 pb^{-1})

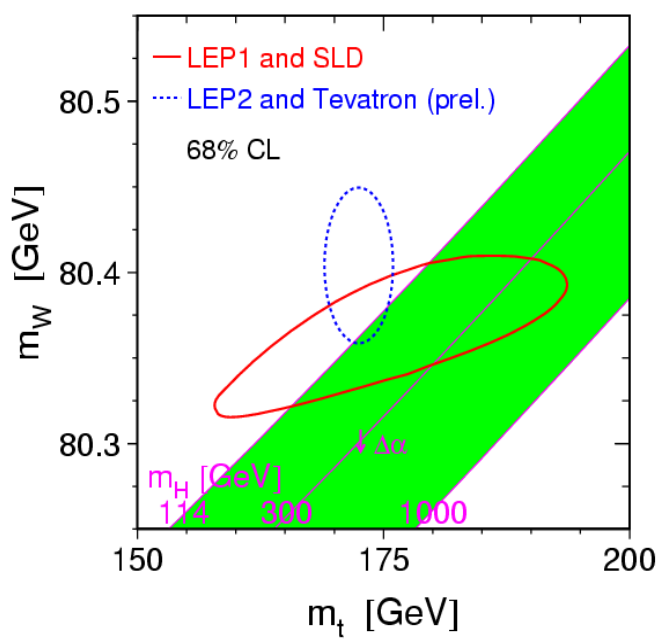
$$M_{top} = 173.4 \pm 2.8 GeV/c^2$$ Update (680 pb^{-1})

- Highest weight in the world average:

$$M_{top} = 172.5 \pm 2.3 GeV/c^2$$

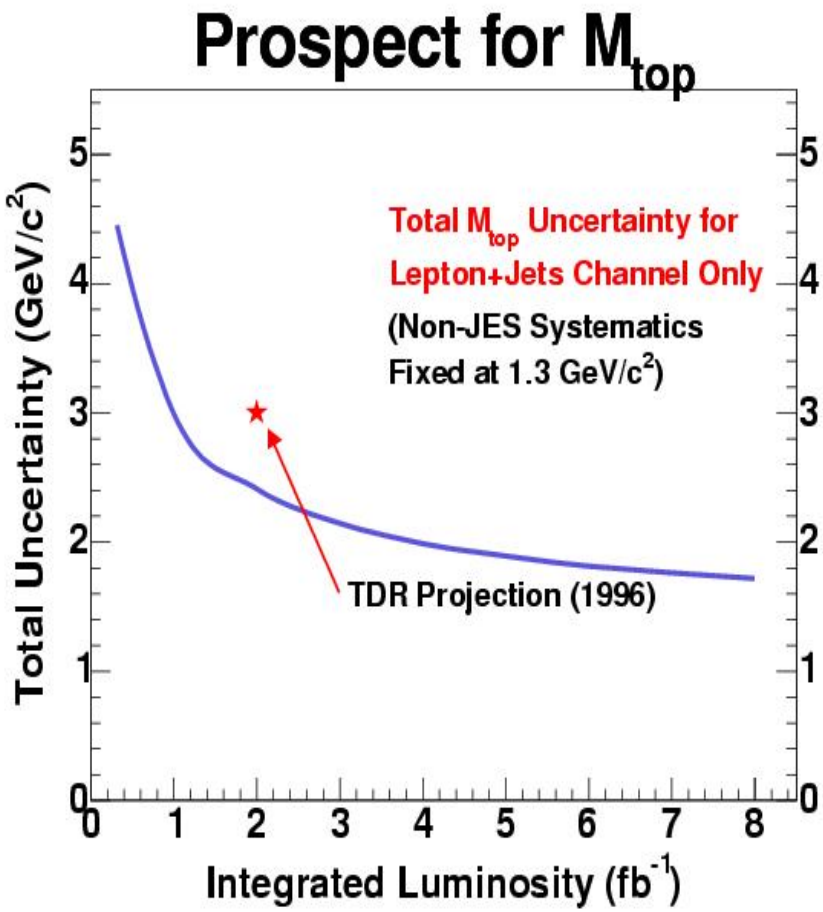
- New Higgs mass fit:

$$M_{Higgs} = 89^{+42}_{-30} GeV/c^2$$



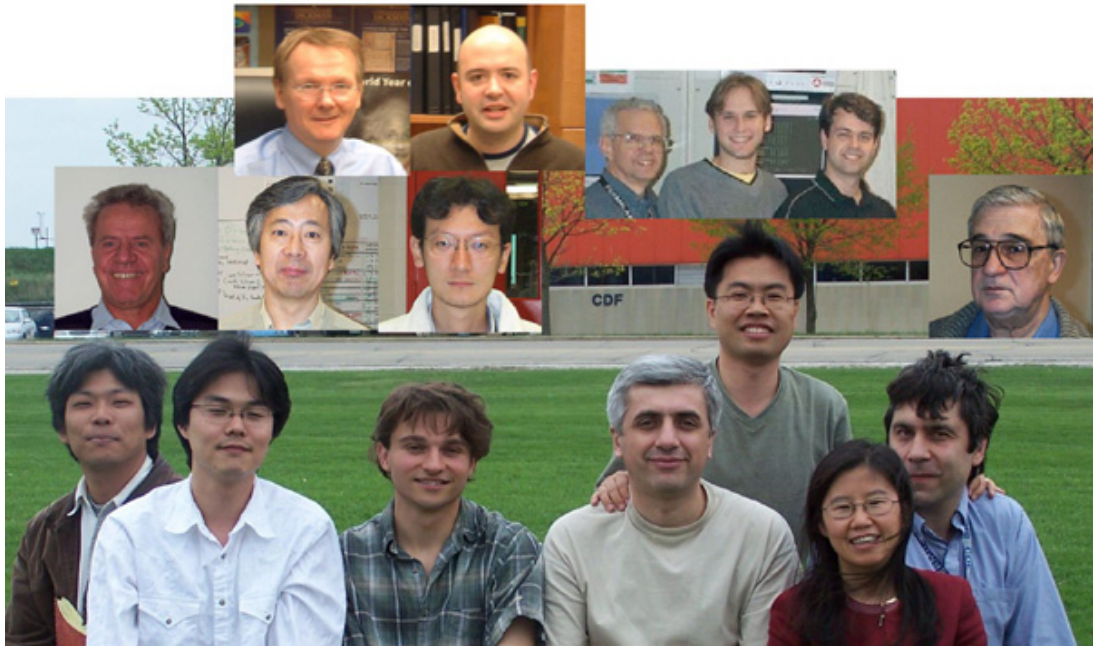
Future of Analysis with W→jj

- Using W→jj: JES uncertainty becomes essentially statistical
- Can reach JES uncert. below 1 GeV/c^2 in Run II
- Total M_{top} uncertainty: can reach 2 GeV/c^2 without improvement on systematics



I am grateful to…

- My **super**visor: Pekka
- Template top mass group (Erik, Un-Ki, Young-Kee, Mel, George, Jahred, Guram, Koji, Tomo, and more …)
- All CDF people that helped me!



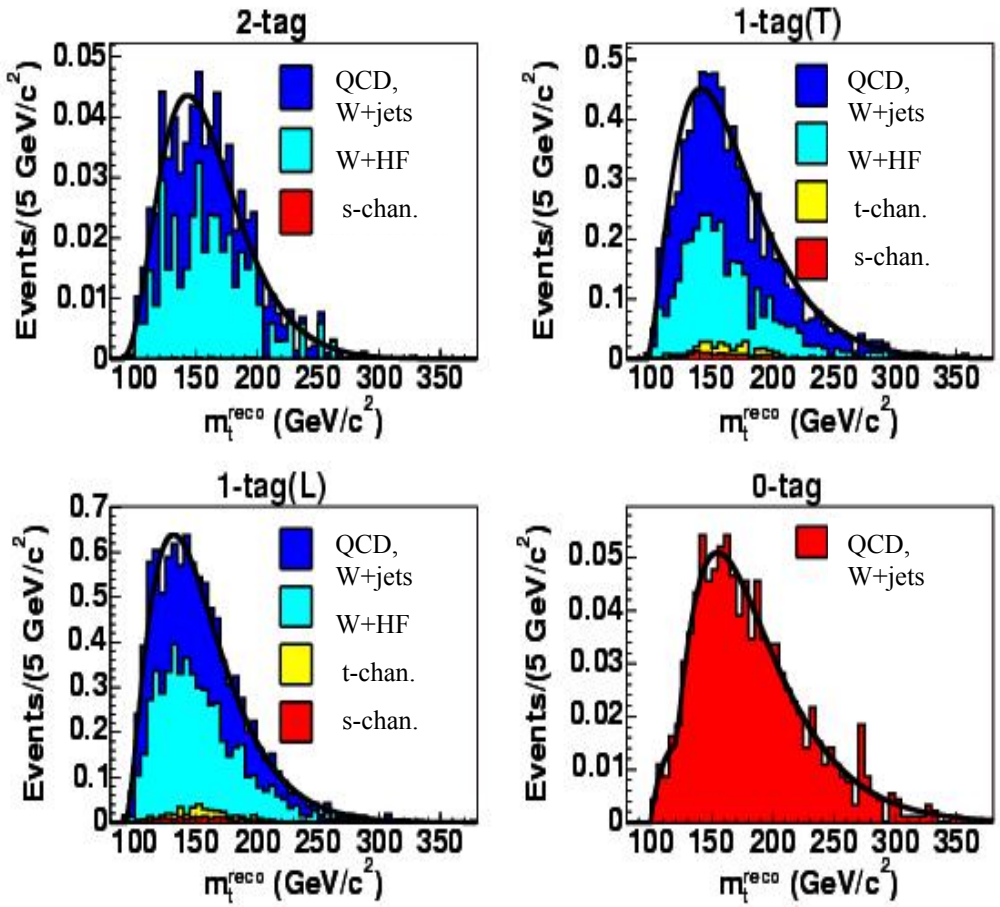
Back-up slides

Background contamination

Background sources:

- >=1-tag events:
  - W+jets mistag
  - QCD multijets
  - W+heavy flavor
  - Others (WW/WZ, single top)
- 0-tag events:
  - W+jets
  - QCD multijets

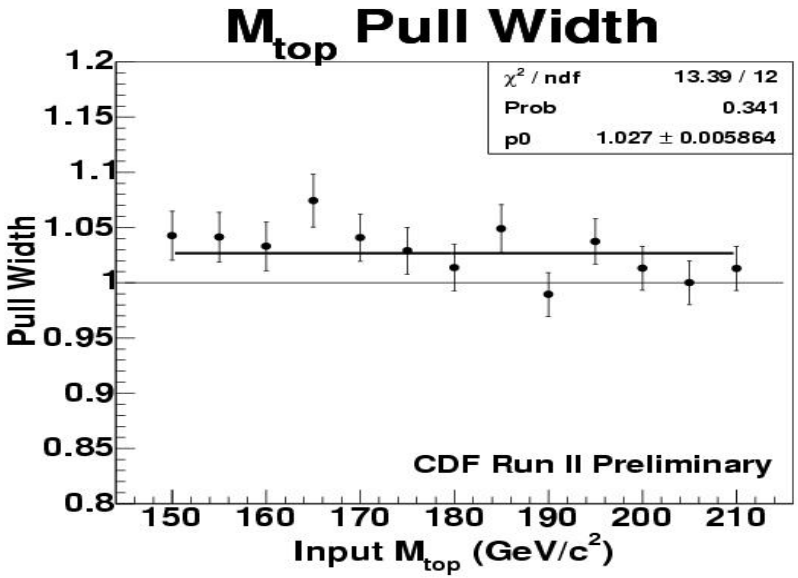
Use MC events to get background expected distributions:

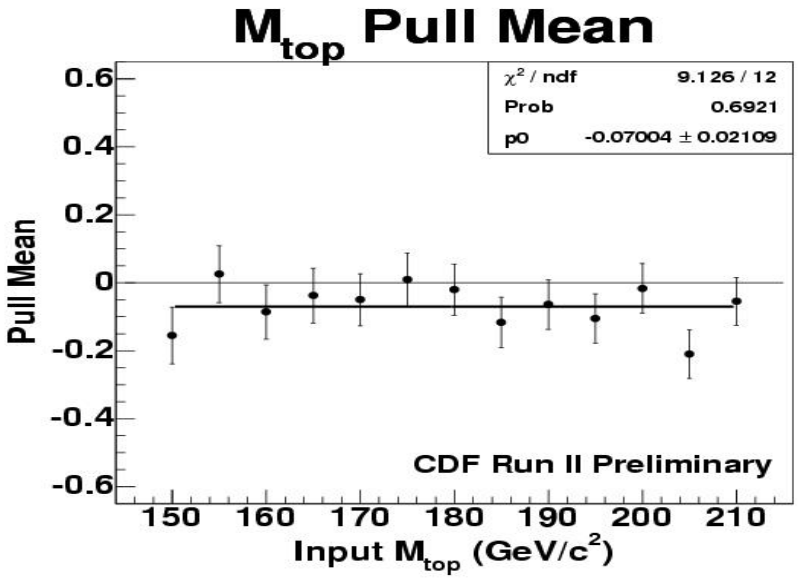
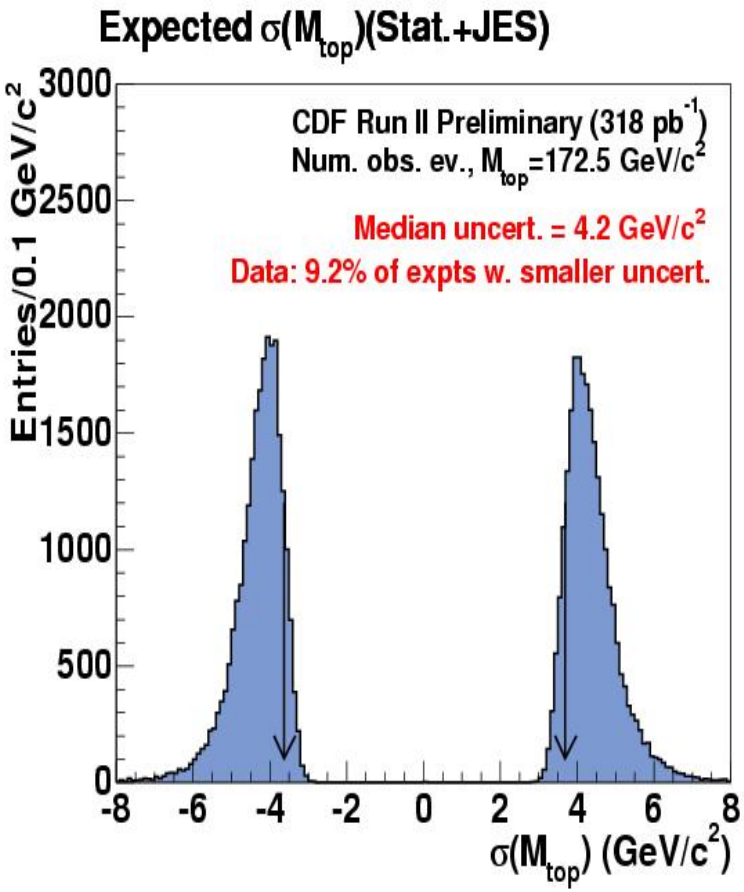
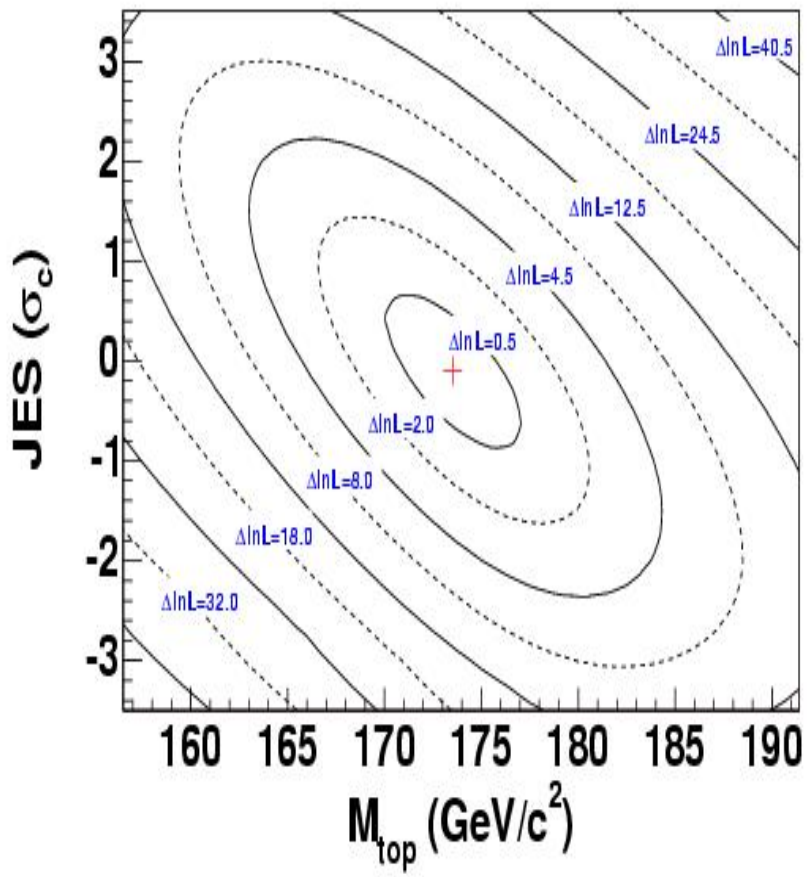


Extracting M_{top}

Unbinned likelihood fit:

- Compare data reconstructed mass distributions with templates extracted from Monte Carlo
- Background constrained to expectations
- Combined fit: multiply subsamples likelihood





Results on Data III