Top Mass Measurements at CDF

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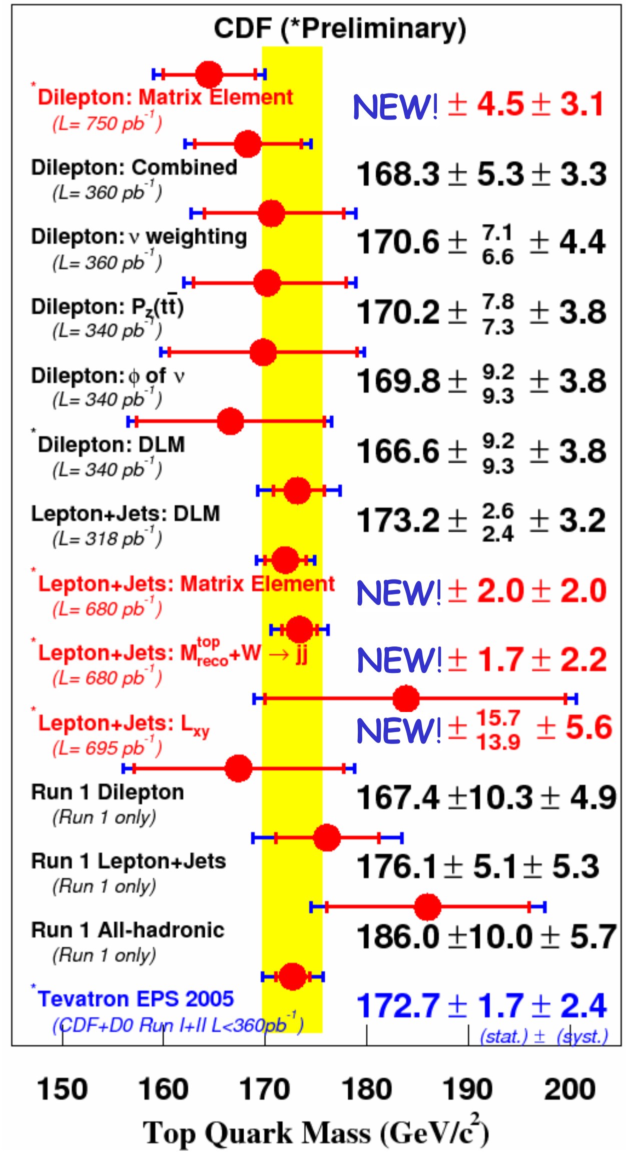
History and Status

- Long history—first M_{top} measurement published in 1995.
- Improved M_{top} sensitivity important motivation for run II upgrades.

Current status

	Run I	≤ 360 pb^{-1}	≤ 750 pb^{-1}
Dilepton	✓	5	1
Lepton + Jets	✓	3	3
All-Hadronic	✓	0	Soon…



How to Weigh Truth

TEMPLATES

1. Pick a test statistic (e.g. reconstructed mass).
2. Create "templates" using events simulated with different M_{top} values (+ background).
3. Perform maximum likelihood fit to extract measured mass.

MATRIX ELEMENT

1. Build likelihood directly from PDFs, matrix element(s), and transfer functions that connect quarks and jets.
2. Integrate over unmeasured quantities (e.g. quark energies).
3. Calibrate measured mass and error using simulation.

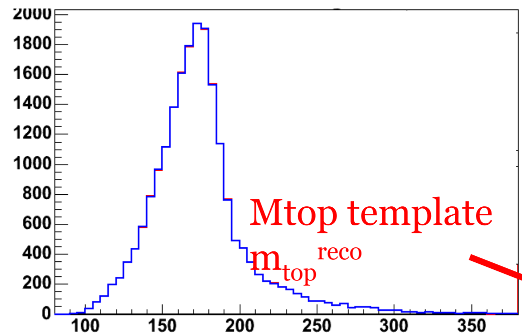
Template Method Overview

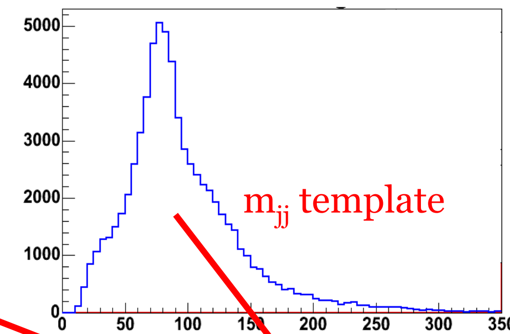
Datasets
- Data
- Background MC
- ttbar MC

Mass fitter

W->jj dijet mass distribution is a resonance
- Resonance peaks stands out at 80.4 GeV/c^2
- Sensitive to shifts in jet energy scale (JES)

Separate into 4 samples by b tags, jet E_T





Parameterize

Mass Fitter
- Finds best top mass and jet-parton assignment
- One # per event based on overconstrained system
- Additional selection cut on resulting χ^2

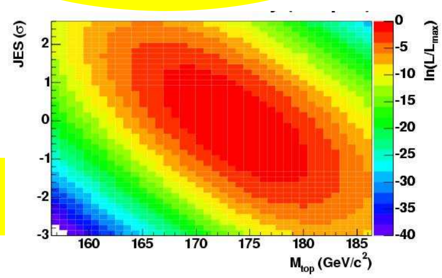
Likelihood Fit
- Fit m_{top}^{reco} and w_{jj} distributions in data to sum of signal and background parameterizations
- Constrain background and JES with prior knowledge

gives JES, top mass!

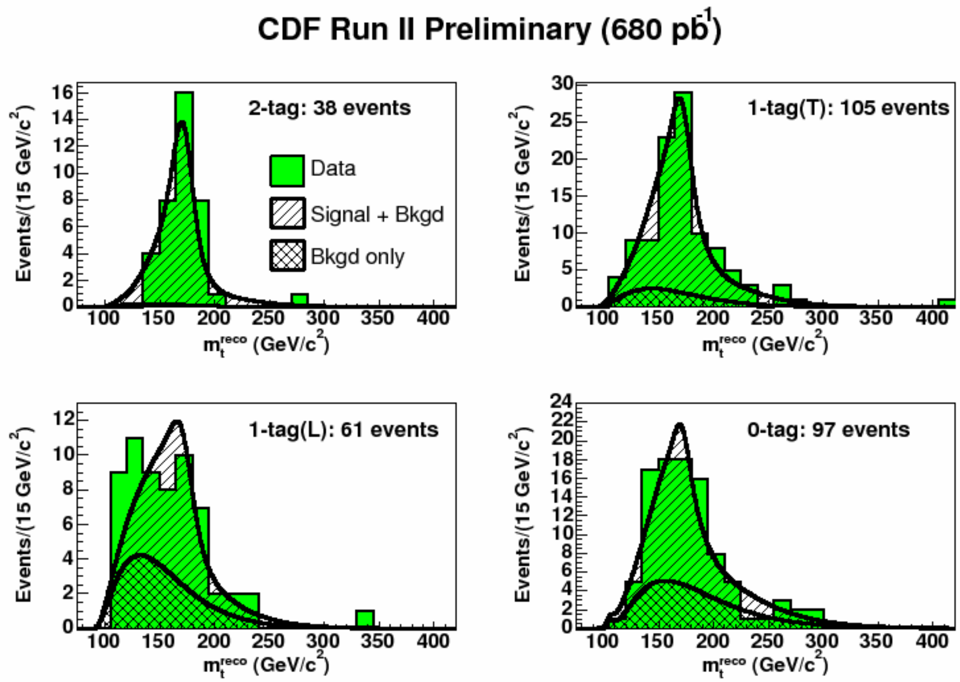
Likelihood Fit

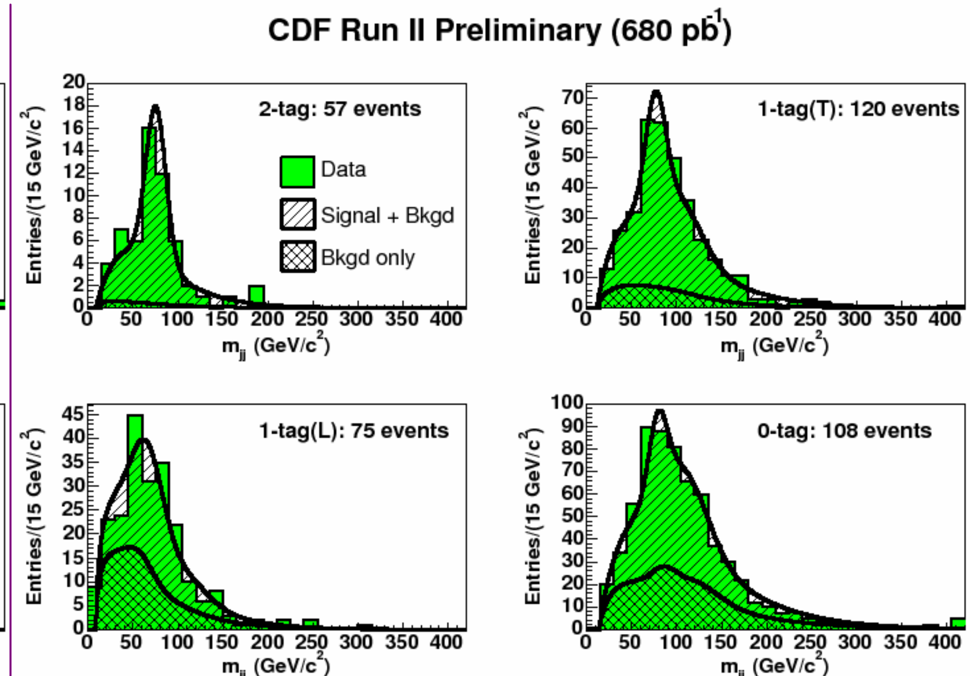
Parameterizations
- For both templates, as a function of top mass and JES

For both signal and background



Template Results—680 pb^{-1}





m_t^{reco} templates w/ fit overlaid | m_{jj} templates w/ fit overlaid

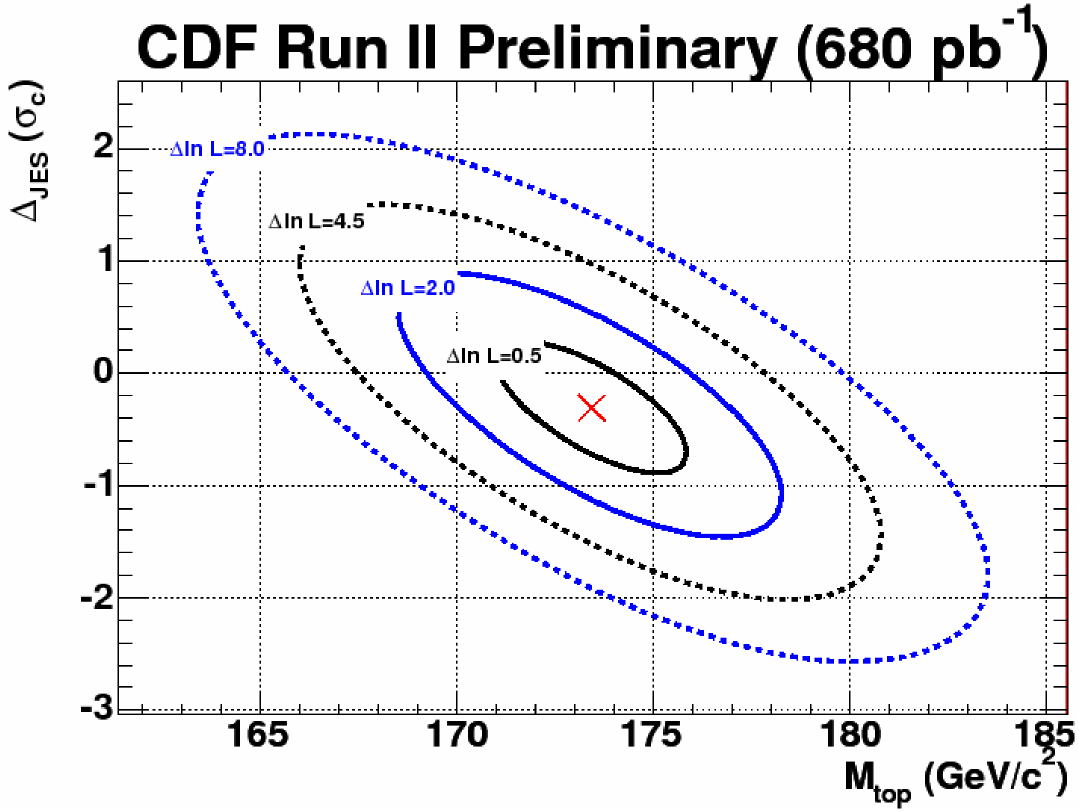
$$M_{top} = 173.4 \pm 2.5\ (\text{stat.} + \Delta_{JES})\ \text{GeV}/c^2$$

Δ_{JES} = -0.3 ± 0.6 (stat. + M_{top}) σ_c → Miscalibration in units of σ_c, external calib.

318 pb^{-1}: M_{top} = 173.5 $^{+3.9}_{-3.8}$ (stat. + Δ_{JES}) GeV/c^2

Template Results—680 pb^{-1}

Likelihood contours in M_{top}-Δ_{JES} plane



Systematic	ΔM_{top} (GeV/c^2)
Residual JES	0.7
B-jet energy scale	0.6
Bkgd JES	0.4
Bkgd Shape	0.5
ISR	0.5
FSR	0.2
Generators	0.3
PDFs	0.3
MC stats	0.3
B-tagging	0.1
TOTAL	**1.3**

$$M_{top}(\text{Templ}) = 173.4 \pm 2.5\,(\text{stat}) \pm 1.3\,(\text{syst})\ \text{GeV}/c^2$$

Matrix Element Overview

Likelihood simultaneously determines M_{top}, Jet Energy Scale, and signal fraction

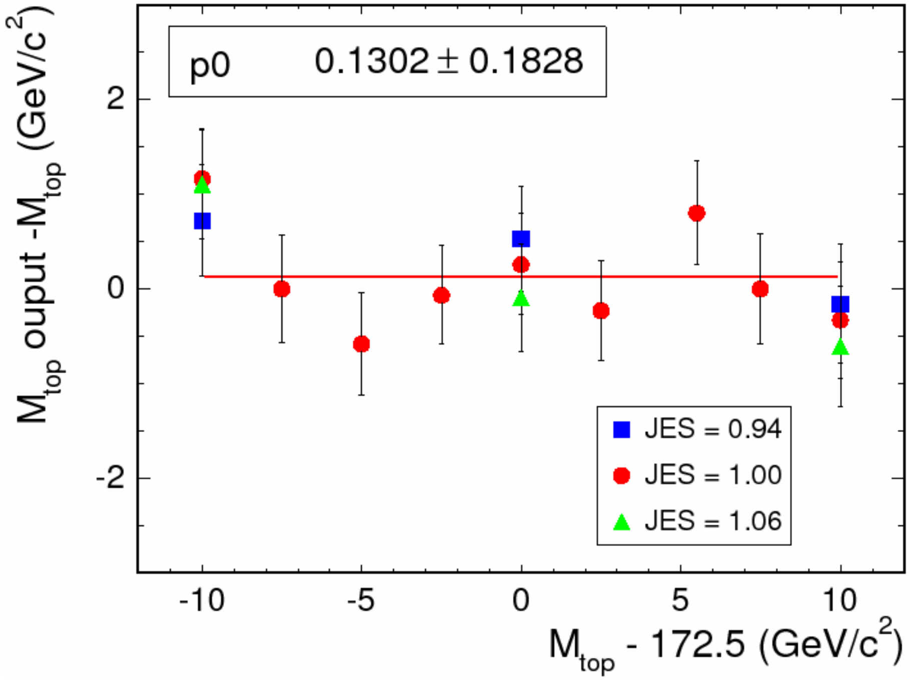
$$P_o(\vec{x}; m_t, JES, c_s) \equiv c_s P_{t\bar{t}}(\vec{x}; m_t, JES) + (1-c_s) P_{W+jet}(\vec{x}; JES)$$

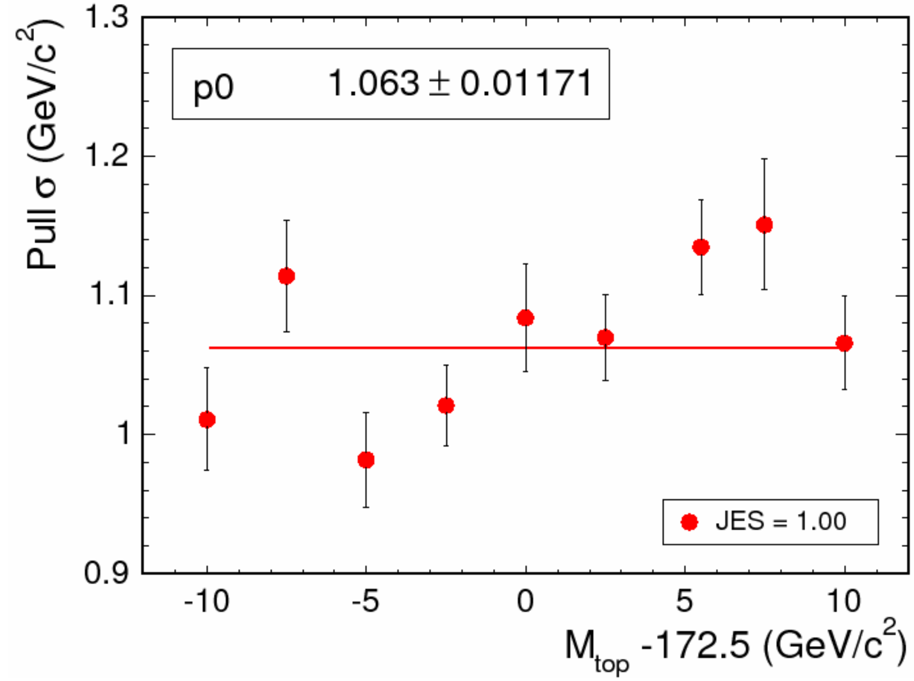
Probabilities built from matrix element, transfer functions, and parton distribution functions

$$P_{t\bar{t}}(\vec{x}; m_t, JES) = \frac{1}{\sigma} \int d\sigma_{t\bar{t}}(\vec{y}; m_t) dq_1 dq_2 f(q_1) f(q_2) W(\vec{x}, \vec{y}, JES)$$

- JES sensitivity comes from W resonance.
- Uses kinematic & dynamical features of each event.
- All jet-parton assignments are considered, weighted.
- Select events with exactly 4 jets, well described by LO ME.

Matrix Element Technique (L+jets)

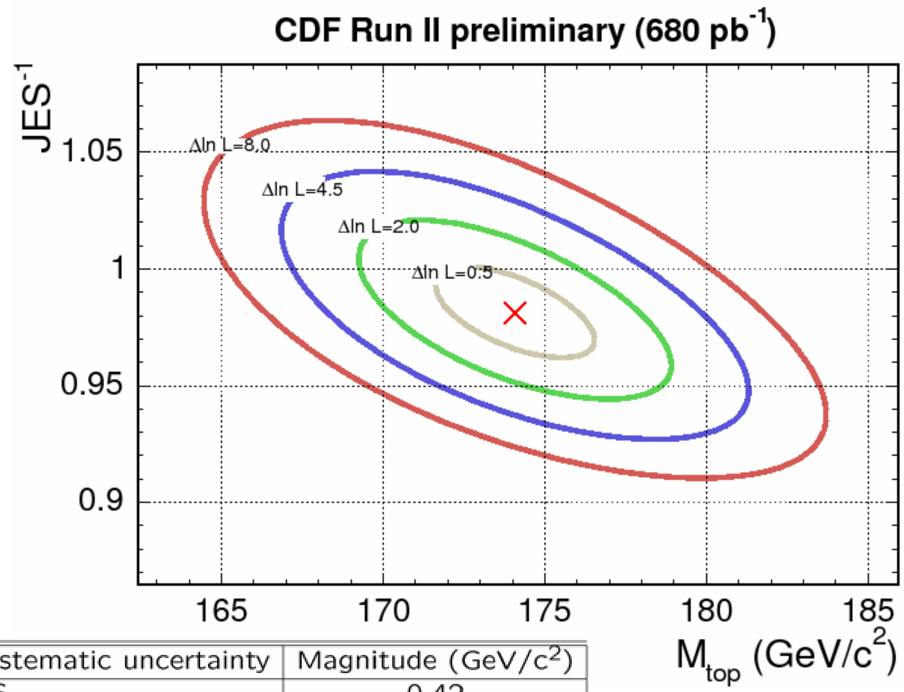




- Calibrate method against MC samples.
  - Shows unbiased measurement.
  - Error are rescaled to account for observed pull width—due to approximations in integration.

Matrix Element (LJ) Results—680 pb^{-1}

- JES here is constant multiplicative factor.
  - $E^{data} = E^{MC}/JES$
- JES = 1.02 ± 0.02.
  - Consistent with template method
- Virtually identical sensitivity with fewer events!

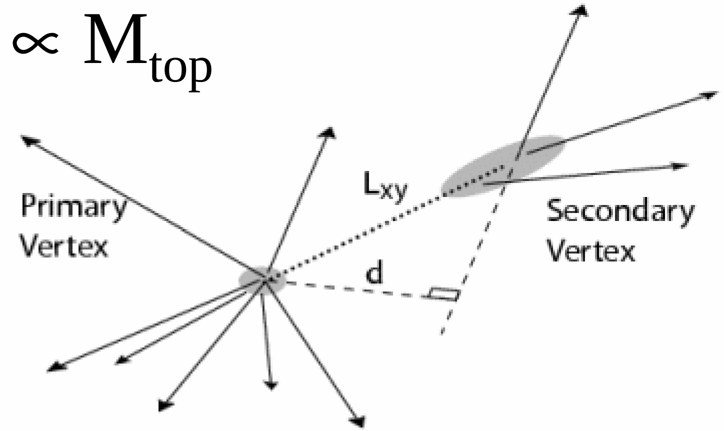


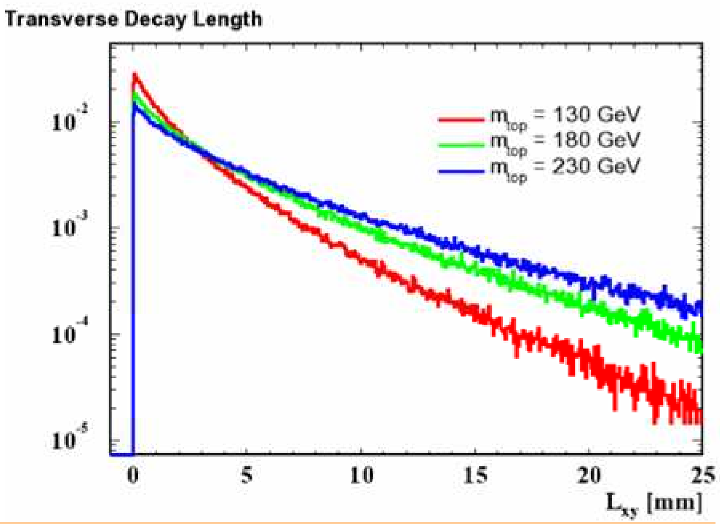
Source of systematic uncertainty	Magnitude (GeV/c^2)
Residual JES	0.42
b-JES	0.60
Generator	0.19
ISR	0.72
FSR	0.76
b-tag E_T dependence	0.31
Background composition	0.21
PDF	0.12
Monte Carlo statistics	0.04
Total	1.35

$$M_{top}\,(\mathrm{ME/LJ}) = 174.1 \pm 2.5\,(\mathrm{stat}) \pm 1.4\,(\mathrm{syst})\ \mathrm{GeV}/c^2$$

Decay Length Technique

- B hadron decay length ∝ b-jet boost ∝ M_{top}
- Difficult—measure slope of exponential.
- But systematics dominated by tracking effects
  → small correlation with traditional measurements!
- Statistics limited now
  - Can make significant contribution at LHC

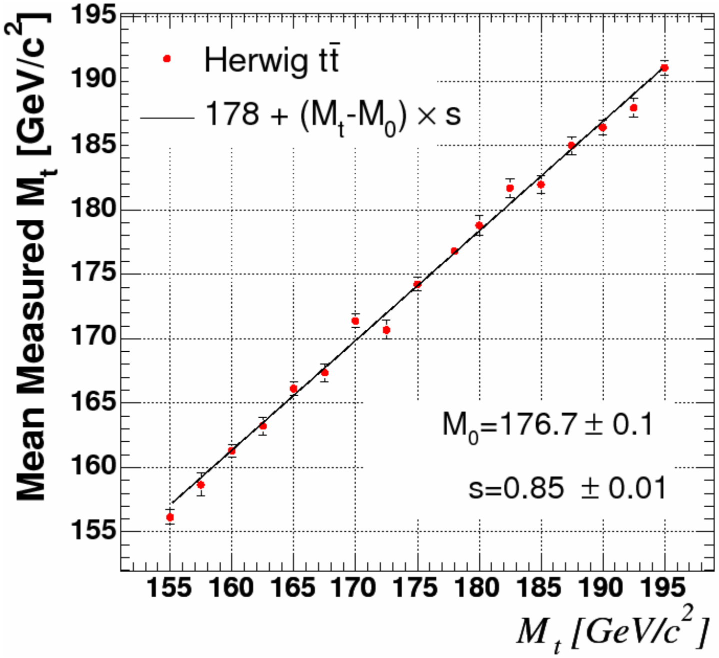




$$M_{\text{top}}(L_{xy}) = 183.9^{+15.7}_{-13.9}\,(\text{stat}) \pm 5.6\,(\text{syst})\ \text{GeV}/c^2$$

Matrix Element technique (Dilepton)

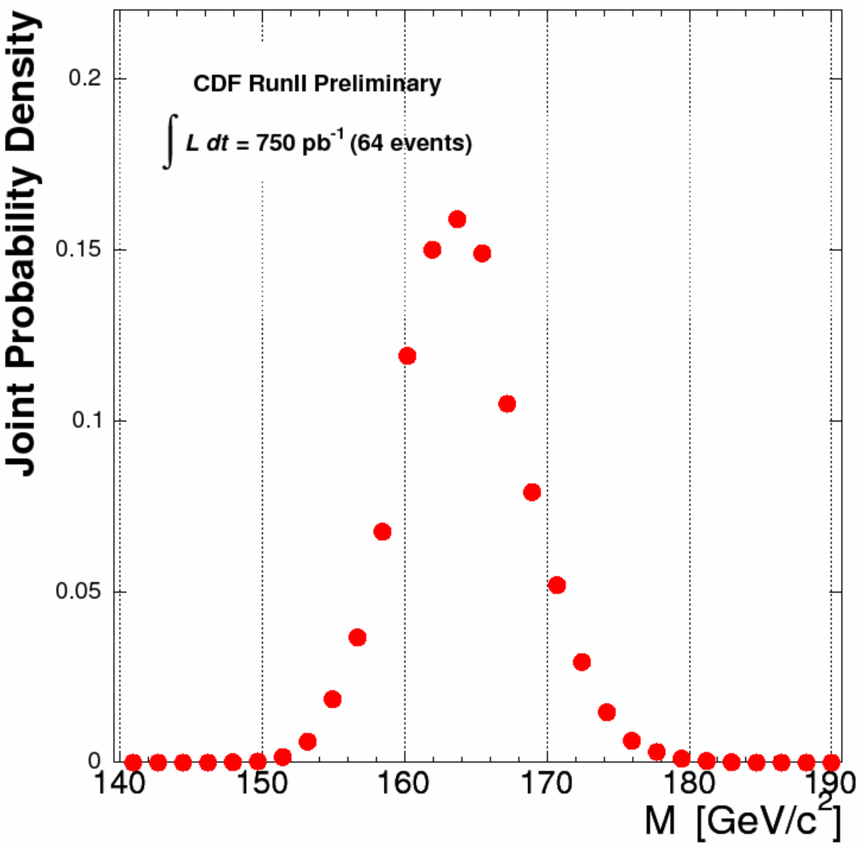
- Harder to reconstruct M_{top} in dilepton events: two neutrinos make system underconstrained.
  - More amenable to ME approach?
- Determination of probability is similar to L+jets.
  - No W resonance → no fit for JES
- Approximations have significant effect
  - MC calibration essential
  - Correct fitted mass for slope 0.85
  - Correct for pull width of 1.49



Matrix Element (Dil) results—750 pb^{-1}

- Best measurement in challenging dilepton channel.
- Could reach 2 GeV (stat) sensitivity by end of run II.

Source	ΔM_t (GeV/c^2)
Jet Energy Scale	2.6
Generator	0.5
Response uncertainty	0.3
Sample composition uncertainty	0.7
Background statistics	0.8
Background modeling	0.8
ISR modeling	0.5
FSR modeling	0.5
PDFs	0.6
Total	3.1



$$M_{top}(\mathrm{ME/Dil}) = 164.5 \pm 4.5\,(\mathrm{stat}) \pm 3.1\,(\mathrm{syst})\ \mathrm{GeV}/c^2$$

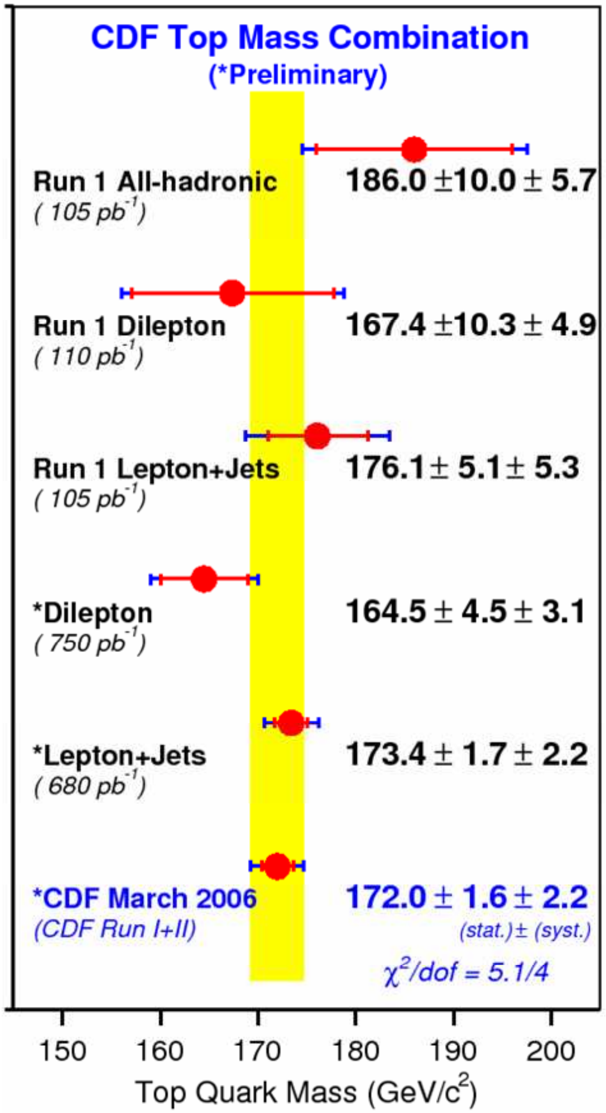
Other CDF top mass results

- Three **template-style** analyses in dilepton channel using 340-360 pb^{-1}.
  - Combined result: 170.1 ± 6.0 (stat) ± 4.1 (syst) GeV/c^2.
  - Includes stat. correlations.
- Dynamical Likelihood Method (**ME**) using 320-340 pb^{-1}.
  - Lepton + jets: 173.2 +2.6/-2.4 (stat) ± 3.2 (syst) GeV/c^2.
  - Dilepton: 166.6 +7.3/-6.7 (stat) ± 3.2 (syst) GeV/c^2.
- All consistent with more recent measurements reported here.

Combination of CDF results

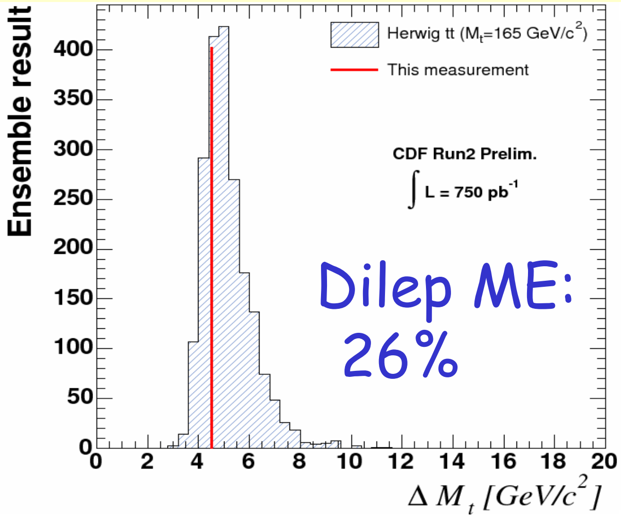
- Use BLUE (Best Linear Unbiased Estimator) technique.
  - *NIM* ***A270*** *110,* ***A500*** *391*.
- Accounts for correlations in systematics.
- Stat correlations in progress.
  - So far only combine measurements on independent datasets.

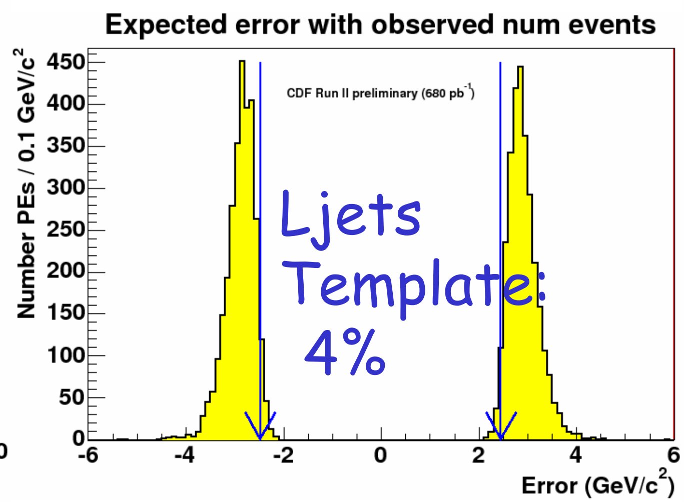
$$M_{top}(\mathrm{CDF}) = 172.0 \pm 1.6\,(\mathrm{stat}) \pm 2.2\,(\mathrm{syst})$$
$$= 172.0 \pm 2.7\ \mathrm{GeV}/c^2$$
$$\chi^2 = 5.1/4\,(28\%)$$

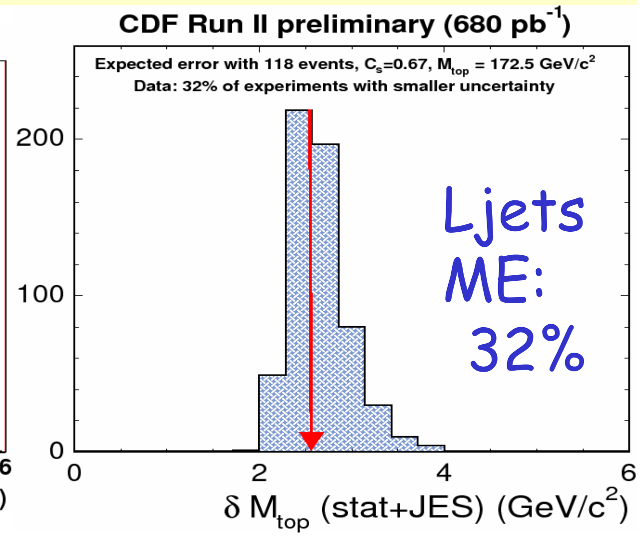


Updated CDF+D0 combined result coming…

Keep an eye on…

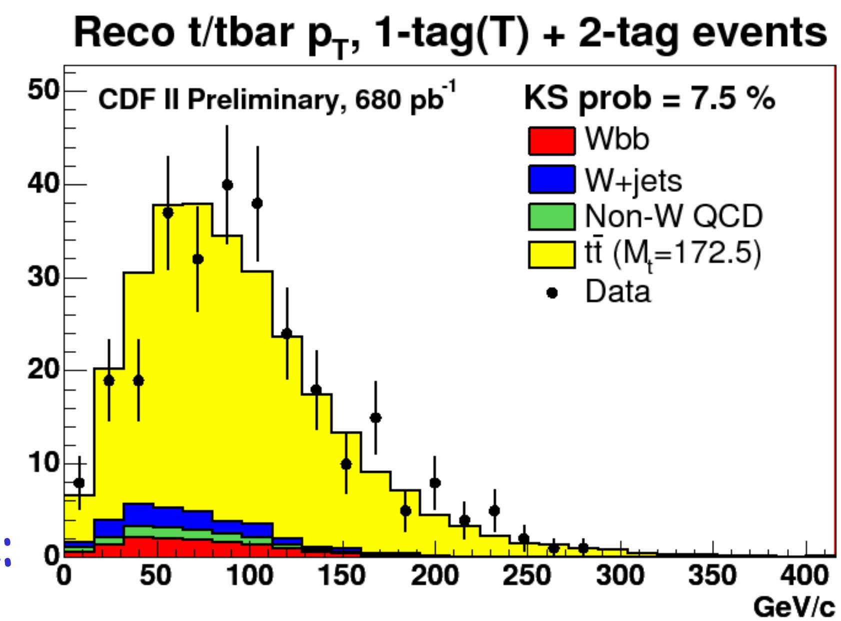






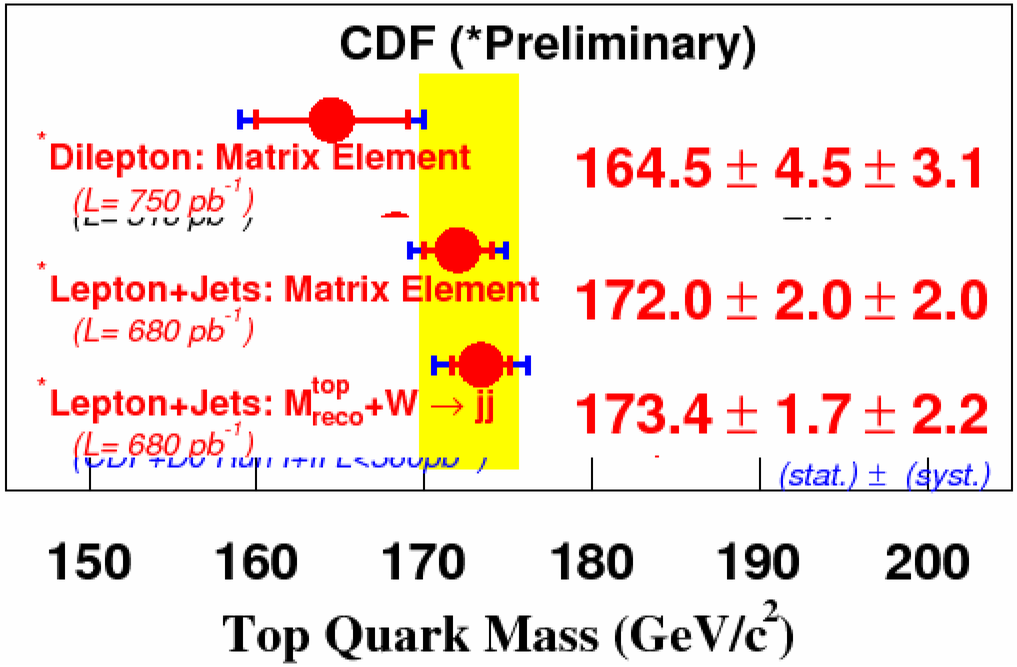
- Since first run I analysis, CDF measurements have tended to be "lucky".
- Related to kinematic differences w/r/t model?

e.g. L+jets top p_T:



Keep the other eye on…

- Discrepancy btw L+jets, Dilepton channel measurements…?
- Is it statistical?
  - ME(dil) vs Templ(L+jets): χ^2 **= 2.9/1, p=0.09**. (Accounts for correlated systematics)
- Is there a missing systematic?
- Is our assumption of SM ttbar incorrect??

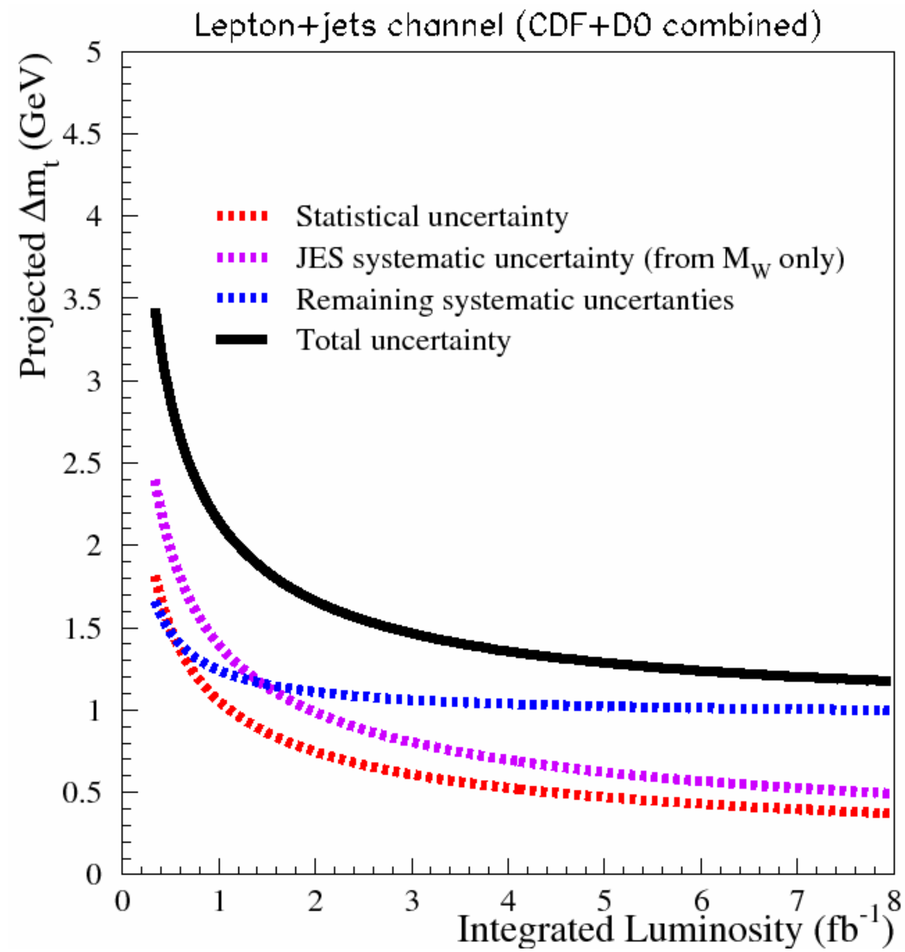


Stay tuned…

Conclusions

$$M_{\text{top}}(\text{CDF}) = 172.0 \pm 2.7\ \text{GeV}/c^2$$

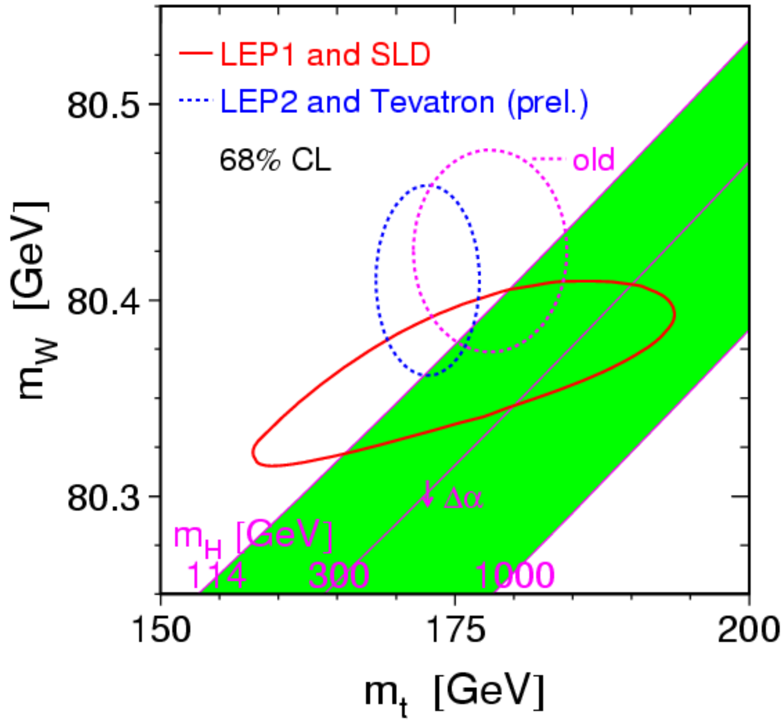
- CDF surpassed run II goal of 3 GeV/c^2 precision on M_{top}.
  - Goal assumed 2 fb^{-1}!
- With *in situ* JES calibration, dominant "systematic" now scales as 1/sqrt(N).
- Expect 2 GeV/c^2 precision by LHC turn-on.
  - Or better as we concentrate on reducing remaining systematics



Backup/potential slides

Why Measure Top Quark Mass?

- Fundamental parameter of SM.
  - Unexpectedly large: m_b x 35
- Related through radiative corrections to other EW observables.
  - Important for precision tests of SM.
  - With m_W, constrains m_H.
- SM Yukawa coupling ~ 1 → Special role in EWSB??

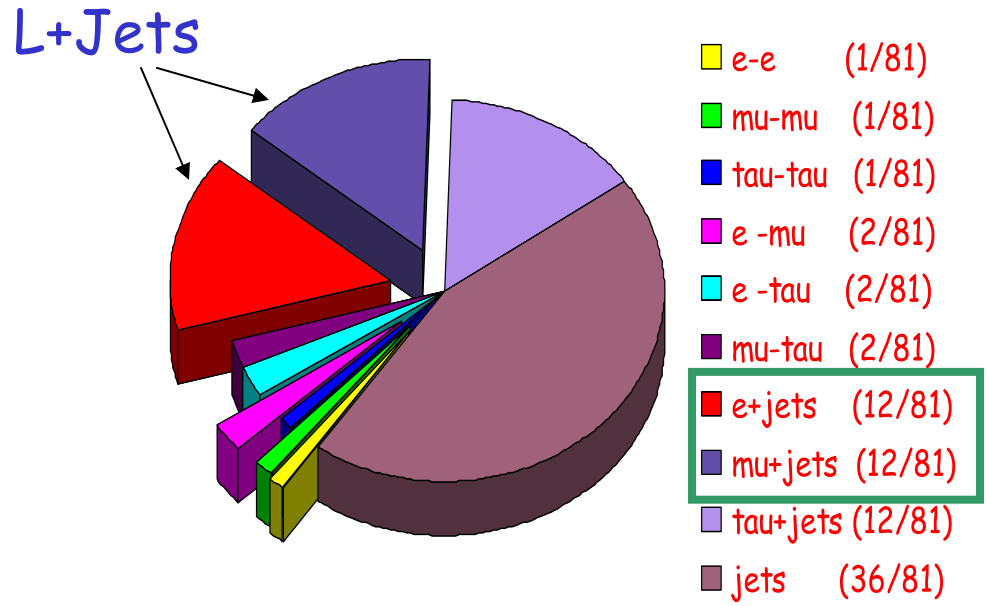


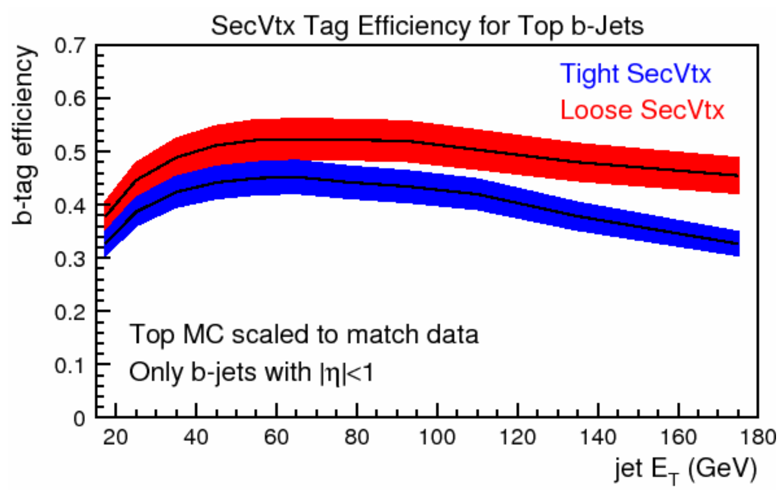
$$M_t = \frac{1}{\sqrt{2}} \lambda_t v$$

$$\Rightarrow \lambda_t = \frac{M_t}{173.9\,\mathrm{GeV}/c^2}$$

Top phenomenology

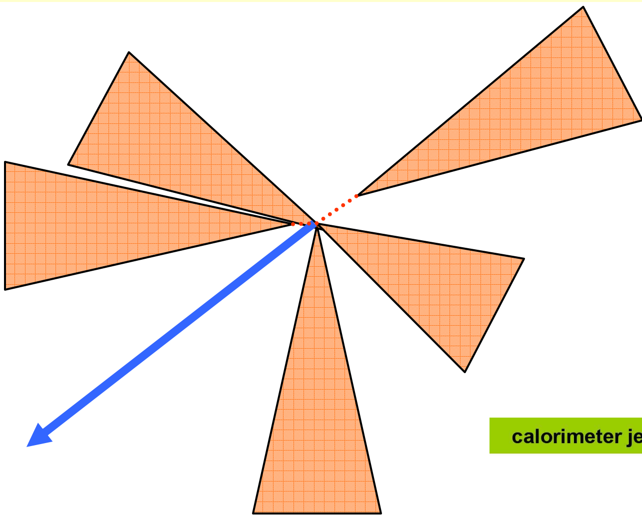
- Mass analyses use t-tbar pair events.
  - σ = 6.7 (5.7) pb @ M_t = 175 (180) GeV/c^2.
  - ~85% quark annihilation, ~15% gluon fusion.
- Top always decays to W boson and b quark.
  - Events classified by decay of W to leptons or quarks
    - Dilepton: 2*e|μ, MET, 2 jt
    - L+jets: e|μ,MET,4 jt
    - All-hadronic: 6 jt
  - B tagging (SecVtx, JPB) improves S/B ratio



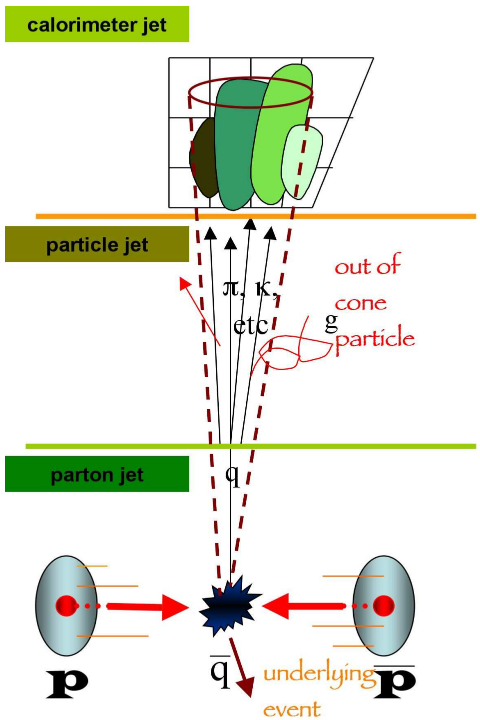


Difficult Measurement

- Complicated events
  - Only ~50% of evts have leading 4 jets from tt decay.
  - 12 ways to interpret 4 jets ↔ 4 partons.



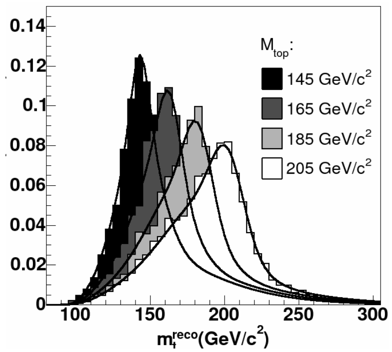
- Jet energy resolution and scale systematics
  - Resolution $84\%/\sqrt{E_T} \rightarrow$ statistical uncertainty.
  - Systematic 3% → systematic uncertainty.
- Background contamination
  - Well understood S:B of 1:1–10:1.
  - Must be treated properly to avoid bias.



Analysis Overview

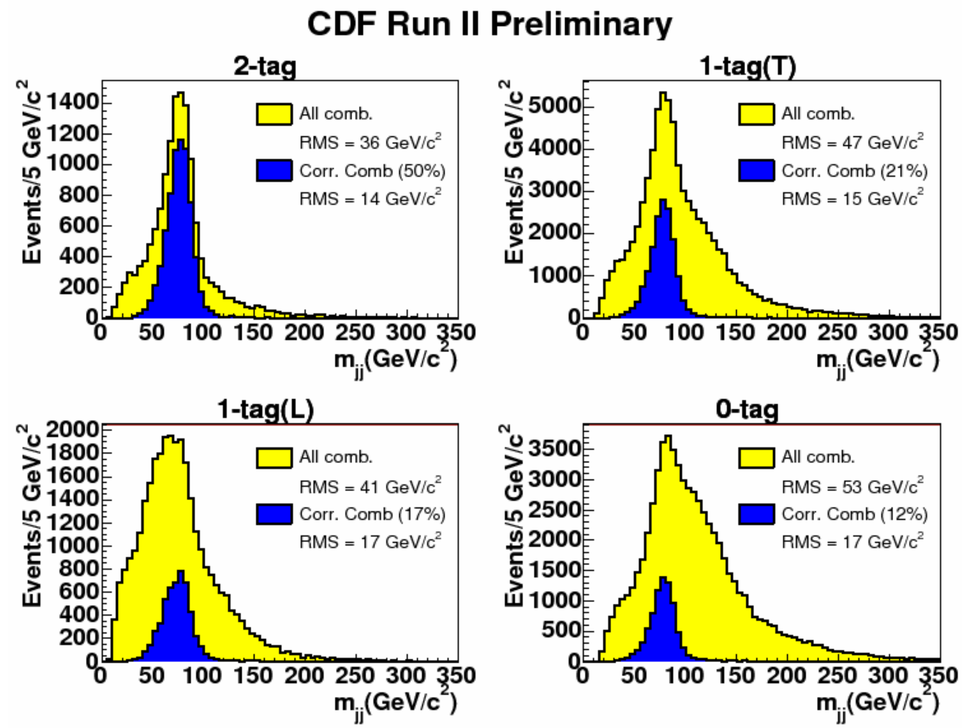
Observables m_t^{reco}

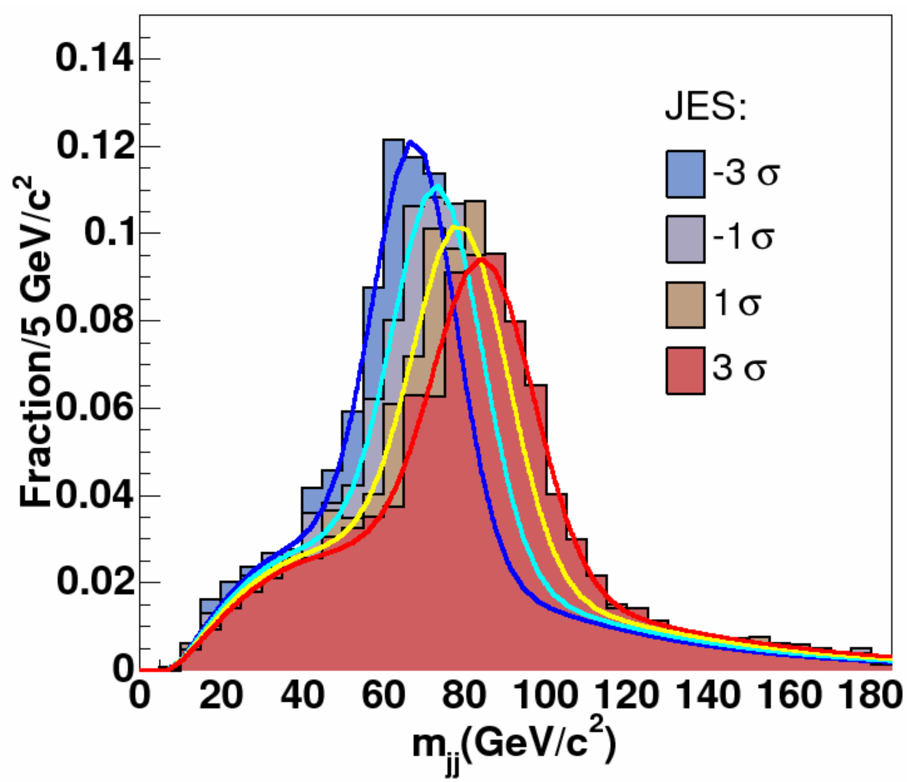
Parameters M_{top}



Measure JES using dijet mass

- Build templates using invariant mass m_{jj} of all non-tagged jet pairs.





- Rather than assuming JES and measuring M_W...
- Assume M_W and measure JES
- Parameterize $P(m_{jj};JES)$ same as $P(m_t^{reco};M_{top})$

Systematics: ISR/FSR/NLO

- Method in hand to use Drell-Yan events to understand and constrain extra jets from ISR.
  - Constraint scales with luminosity.
  - Easily extendible to FSR.
- MC@NLO sample shows no add'l NLO uncertainty is needed.