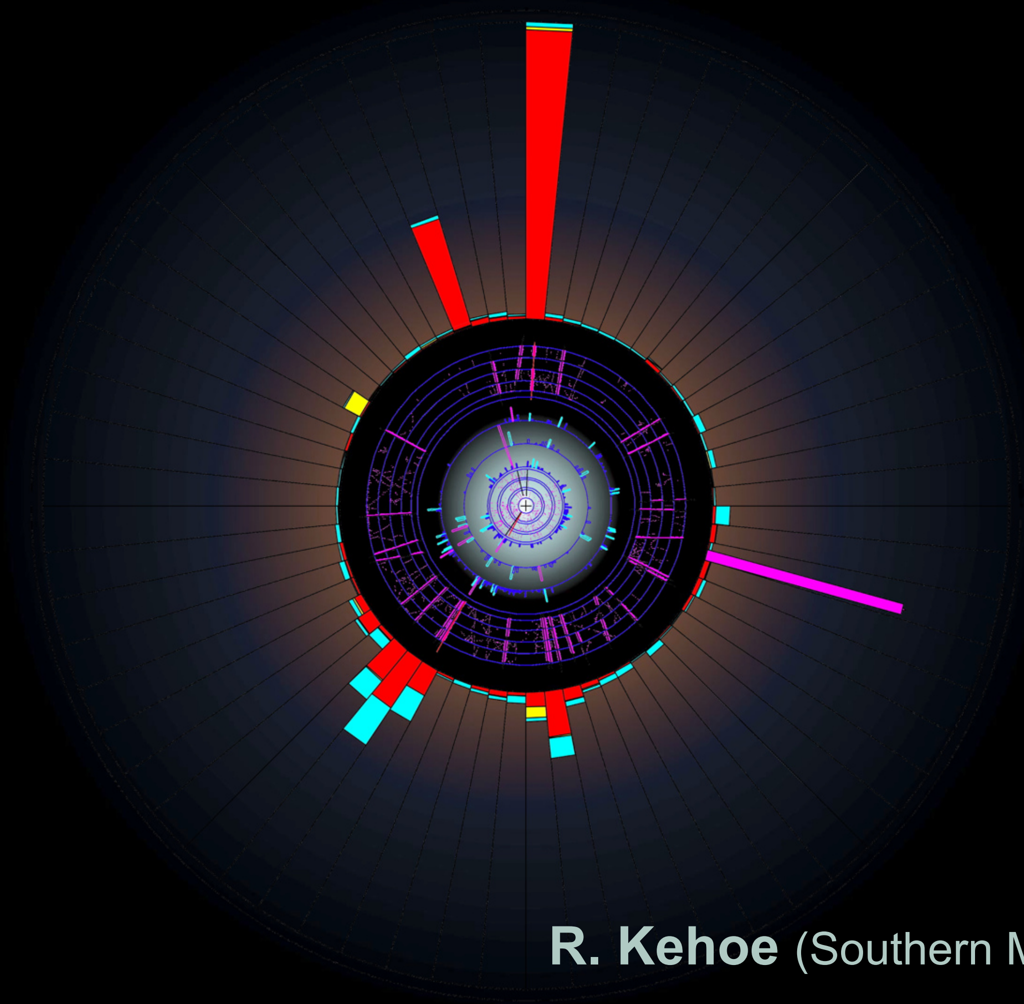
Top Quark Physics at the Tevatron



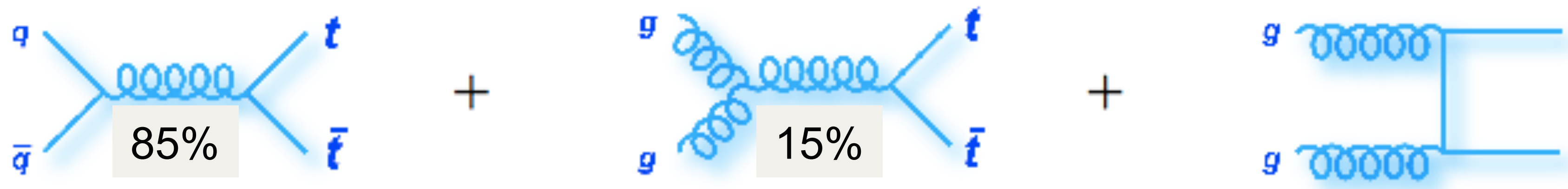
R. Kehoe (Southern Methodist University)

On behalf of the D0 and CDF Collaborations

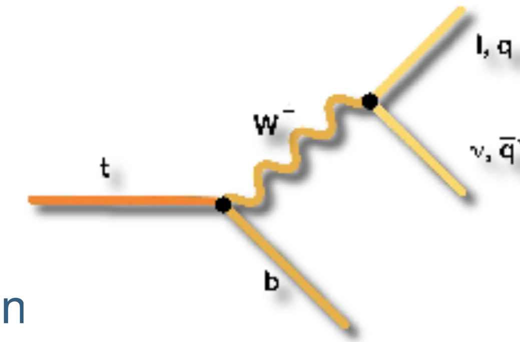
Rencontres du Blois, 2014

Top Quark Menu

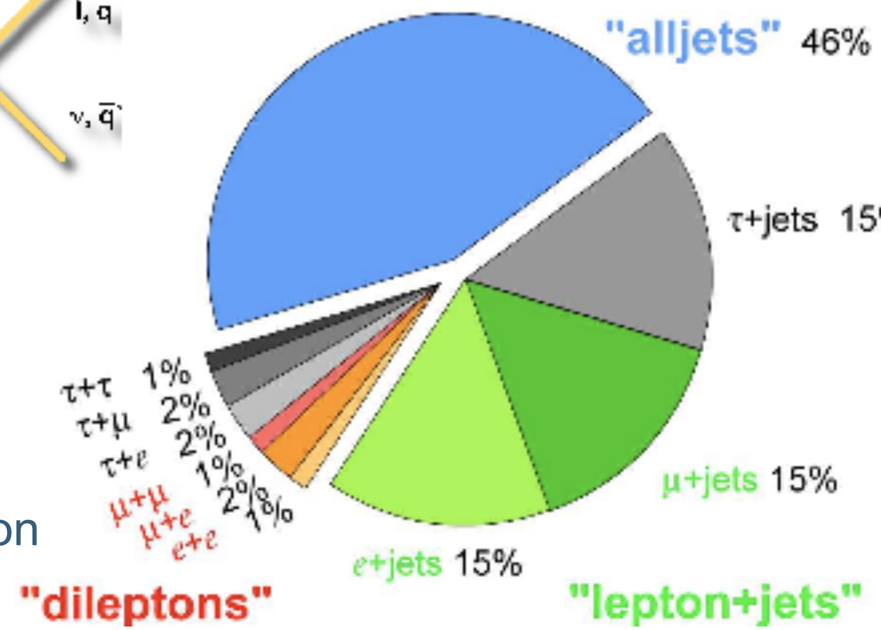
- Production



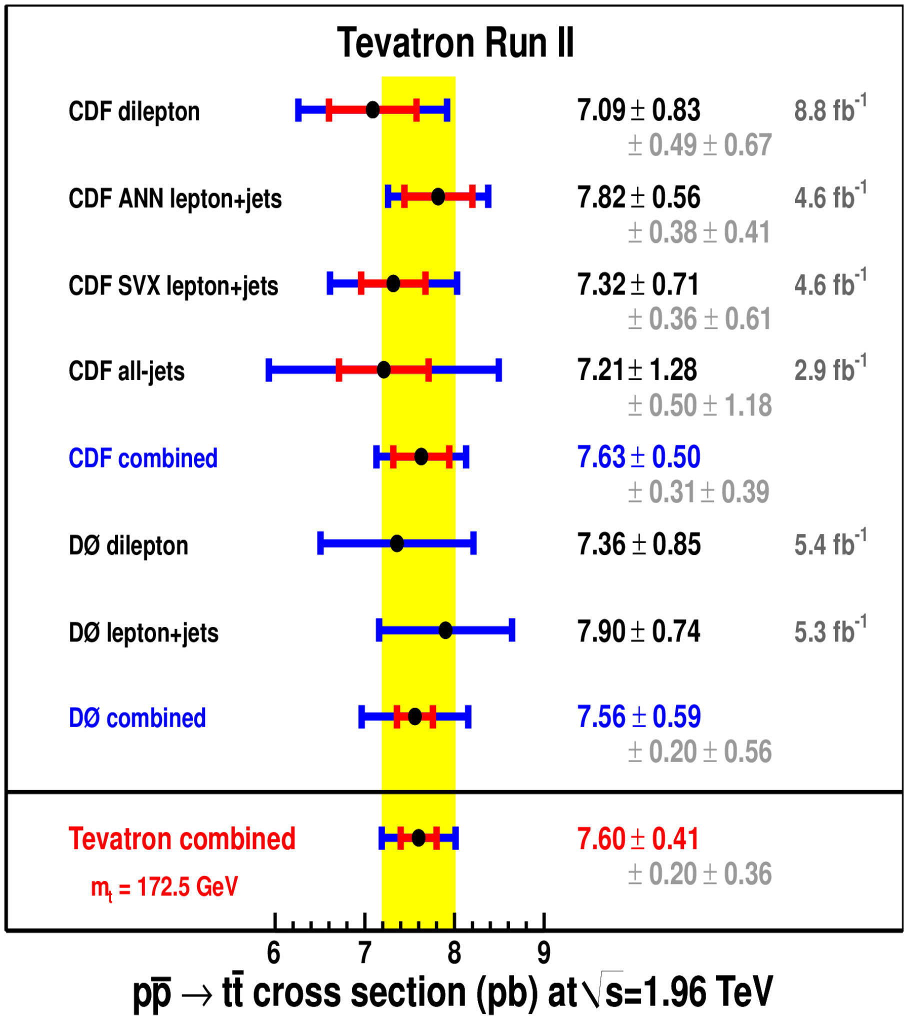
  - Inclusive and differential cross sections
- Properties



  - Top quark width
  - Branching fraction
  - Charge asymmetry
- Mass
  - Precision measurement
  - First Tevatron/LHC world combination



Inclusive $t\bar{t}$ Cross Section



$$\sigma_{t\bar{t}} = 7.35^{+0.11}_{-0.21}(\text{scales})^{+0.17}_{-0.12}(\text{PDF})\ \text{pb}$$

NNLO+NNLL; PRL 110:252004 (2013)

- 4 (2) CDF (D0) measurements
  - 60/40 weight
  - Combined w/BLUE method
- Dominant systematic
  - Signal modeling

$$\sigma_{t\bar{t}} = 7.60 \pm 0.20(\text{stat}) \pm 0.36(\text{syst})\ \text{pb}$$

$$(\text{D0} + \text{CDF})$$ **5.4% precision**

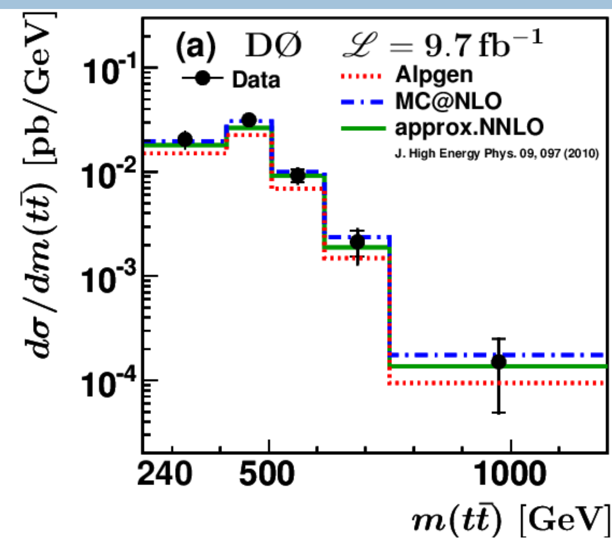
PRD 89:072001 (2014)

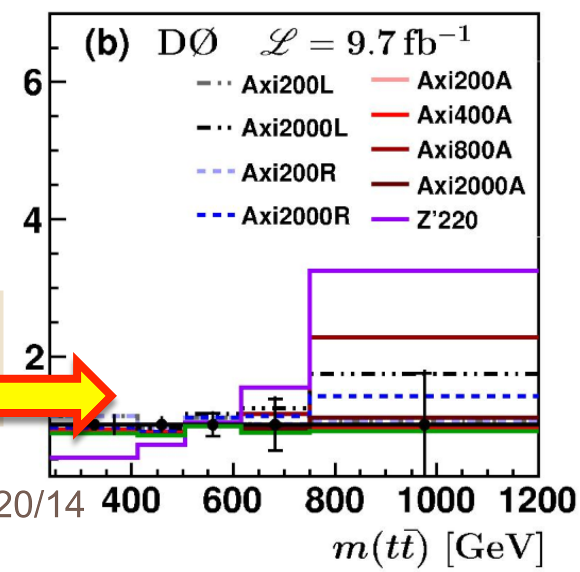
Differential $t\bar{t}$ Cross Sections

- QCD test
  - Better modeling in new physics search
- Tests axigluon models

- Lepton+jets events
  - Single b-tag
  - χ^2 minimization for kinematic reconstruction
  - Extract parton-level quantities
    - M_{tt}, $p^T{}_t$, y_t
  - Good counterpoint asymmetry analyses
  - Signal modeling dominant systematic

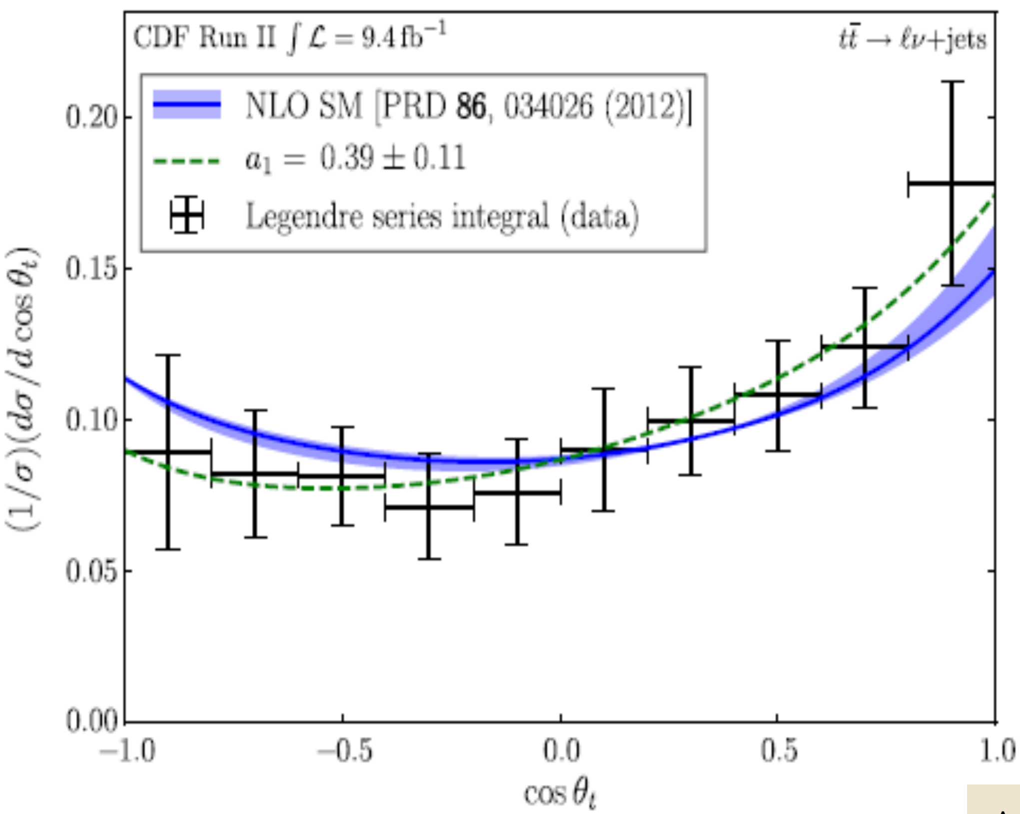
arXiv:1401.5785, subm. to PRD





Ratio to data

Differential Angular Cross Section



PRL 111 182002 (2013)

- Lepton+jets 9.4 fb^{-1}
  - extract angular information
    - Legendre polynomials

$$\frac{d\sigma}{d(\cos\theta_\ell)} = \sum_{\ell=0}^{\infty} a_\ell P_\ell(\cos\theta_\ell),$$

    - Discriminates SM and BSMs
- 1st moment
  - a_l(data): 0.40±0.12
  - a_l(SM): $0.15^{+0.07}_{-0.03}$

Δ~2σ

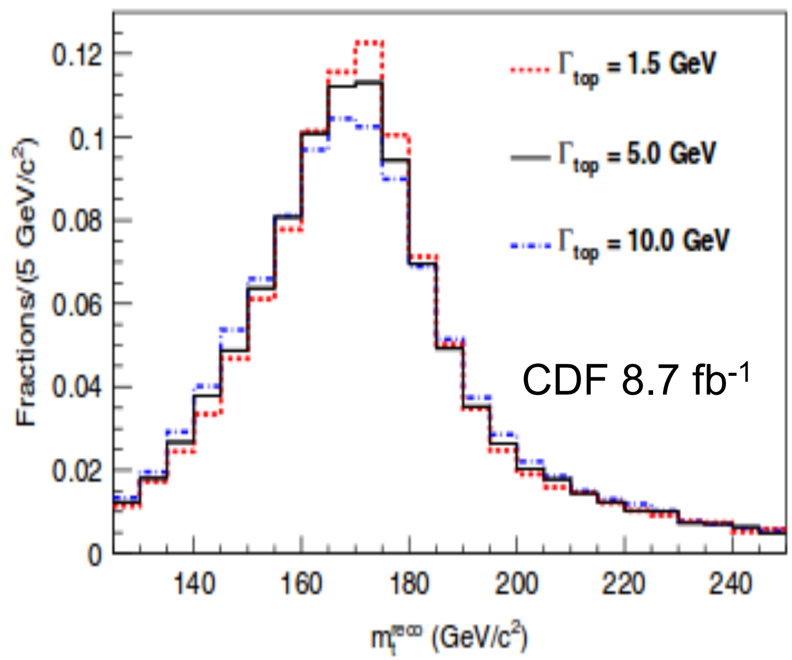
Width of the Top Quark

- Expected largest of known fermions
  - Possible extra contributions
    - Charged Higgs, SUSY partners, etc
- D0 indirect measure
  - lepton+jets, 5.4 fb^{-1}
  - t-channel → partial top width
    - Use BR(t→Wb) for total width

$$\Gamma_t = 2.00^{+0.47}_{-0.43}\ \text{GeV}$$

PRD 85, 091104 (2012)

- CDF direct measure
  - Template approach
    - Extract Γ_t from reconstructed m_t



$$\Gamma_t = 2.21^{+1.84}_{-1.11}\ \text{GeV}$$

PRD 111, 202001 (2013)

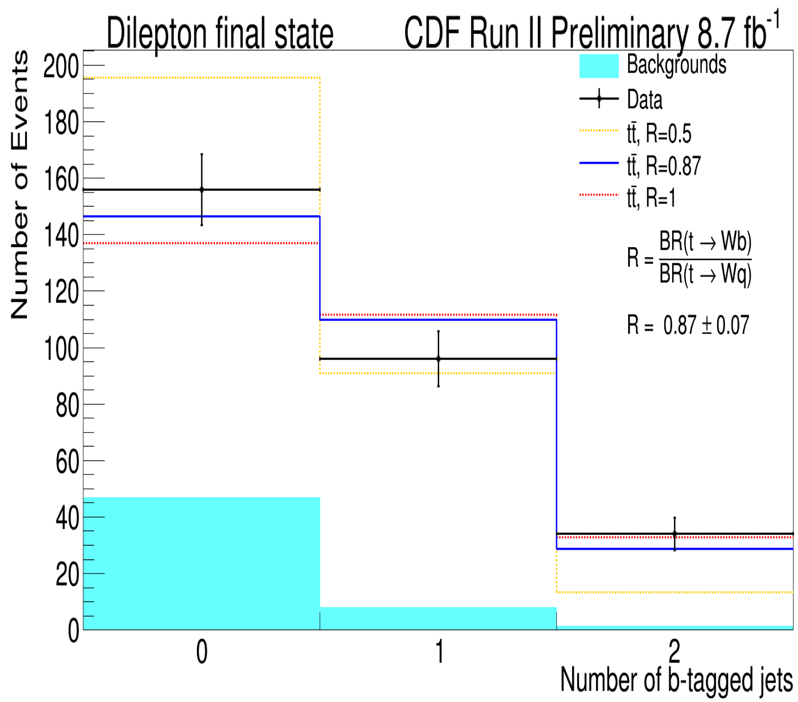
Branching Fractions

- Consider rate of t→b

$$R = \frac{\mathscr{B}(t \to Wb)}{\mathscr{B}(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

  - V_{tb} determination
  - If not ~1
    - possible 4th gen

- dilepton events
  - 8.7 fb^{-1}
  - Analysis in bins
    - Lepton flavor
    - # b-tags
  - Likelihood w/R floating



R = 0.87 ± 0.07 (stat+syst)

$|V_{tb}|$ = 0.93 ± 0.04 (stat+syst)

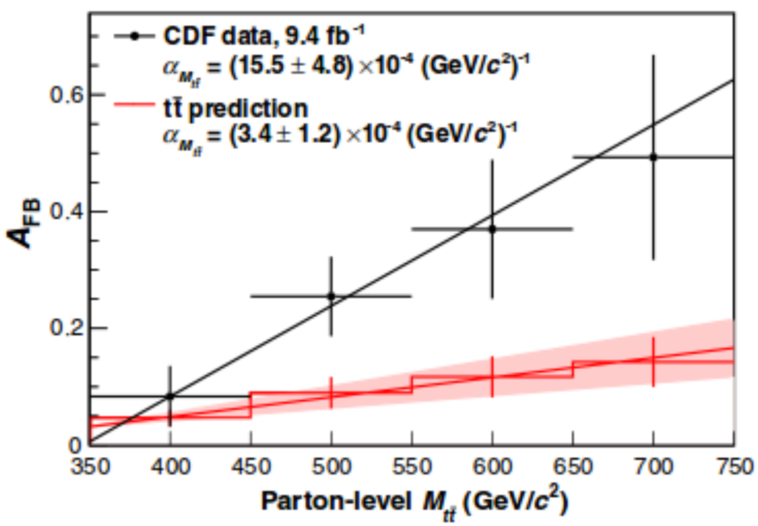
CDF note 11048

$t\bar{t}$ Forward-Backward Asymmetry

- CDF Results

$$A_{FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

  - Where $\Delta y = y_t - y_{tbar}$

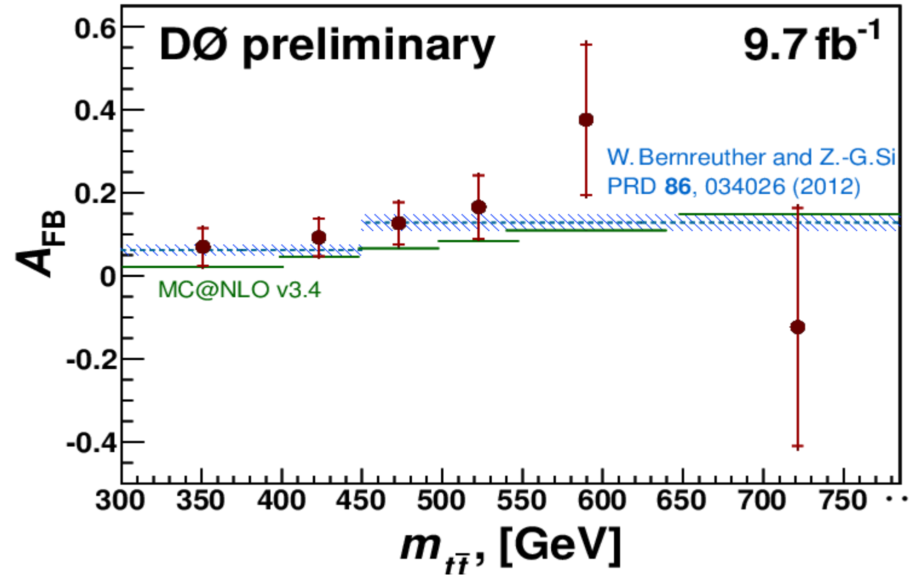


$$A_{fb} = 0.164 \pm 0.039(\text{stat}) \pm 0.026(\text{syst})$$

PRD 87, 092002 (2013)

  - Slopes differ from SM
    - **2.4σ** vs. m_{tt}

- D0 Results



$$A_{fb} = 0.106 \pm 0.027(\text{stat}) \pm 0.013(\text{syst})$$

arXiv:1405.0421, subm. To PRD

In agreement w/CDF and w/SM

- Lepton asymmetry analyses
  - Several from D0 and CDF

Top Quark Mass

Implications

- only quark mass measurable directly
  - Hadronization takes too long
- Key SM free parameter
  - Predicts Higgs boson mass
  - Or checks EWK consistency
- Top Yukawa coupling
  - Seems to be ~1
  - Something special going on here?
- Analysis yields excellent absolute calibration for jets
  - Via W→jj in lepton+jets events

Strategies

- Matrix element (ME)
  - Use kinematics and correlations
  - Calculate probability of event vs. m_t
  - Eg. D0 dilepton ME (5.4 fb^{-1})

$$m_t = 174.0 \pm 1.8(\text{stat}) \pm 2.4(\text{syst})\ \text{GeV}$$

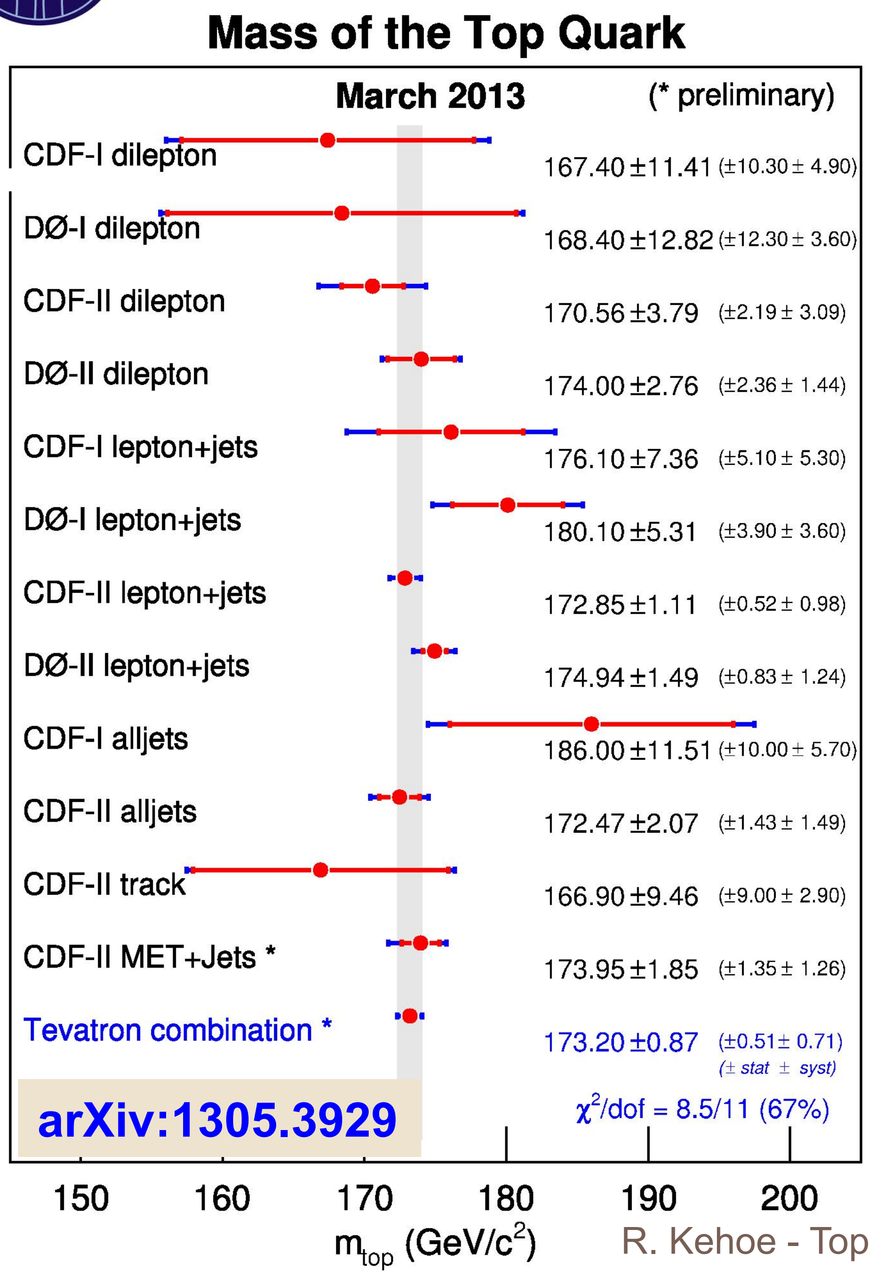
- Template approach
  - Use event kinematics
  - Construct f.o.m correlated w/m_t
  - Fit to models of varying m_t
  - Eg. D0 dilepton neutrino weighting (NW) (5.4 fb^{-1})

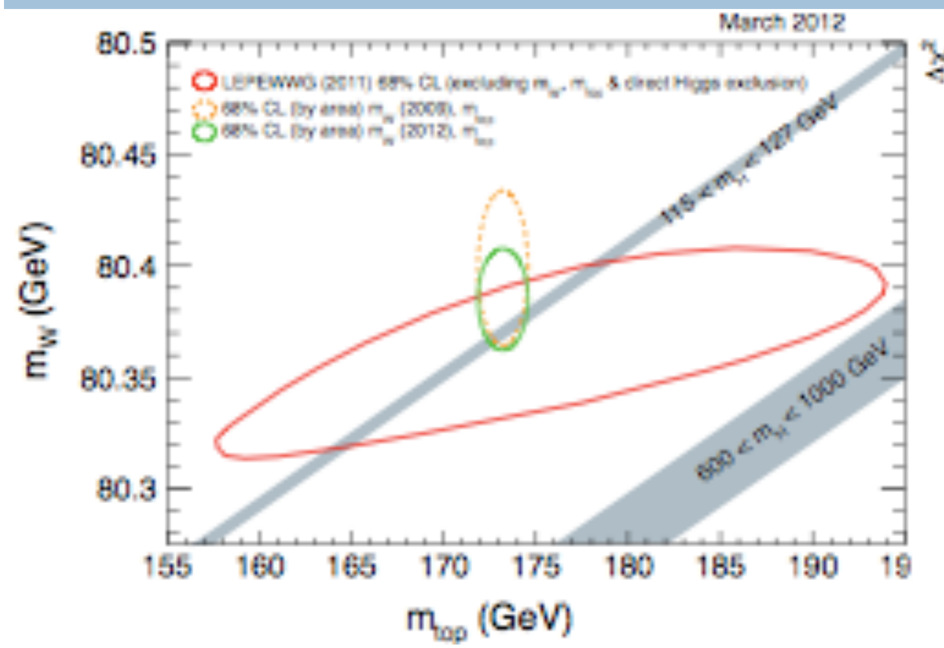
$$m_t = 174.0 \pm 2.4(\text{stat}) \pm 1.4(\text{syst})\ \text{GeV}$$

Dominant JES uncertainty reduced by 2.5x

1.6% measurement possible by carry over of l+jets calibration: **1st time used outside parent sample**

Tevatron Combination





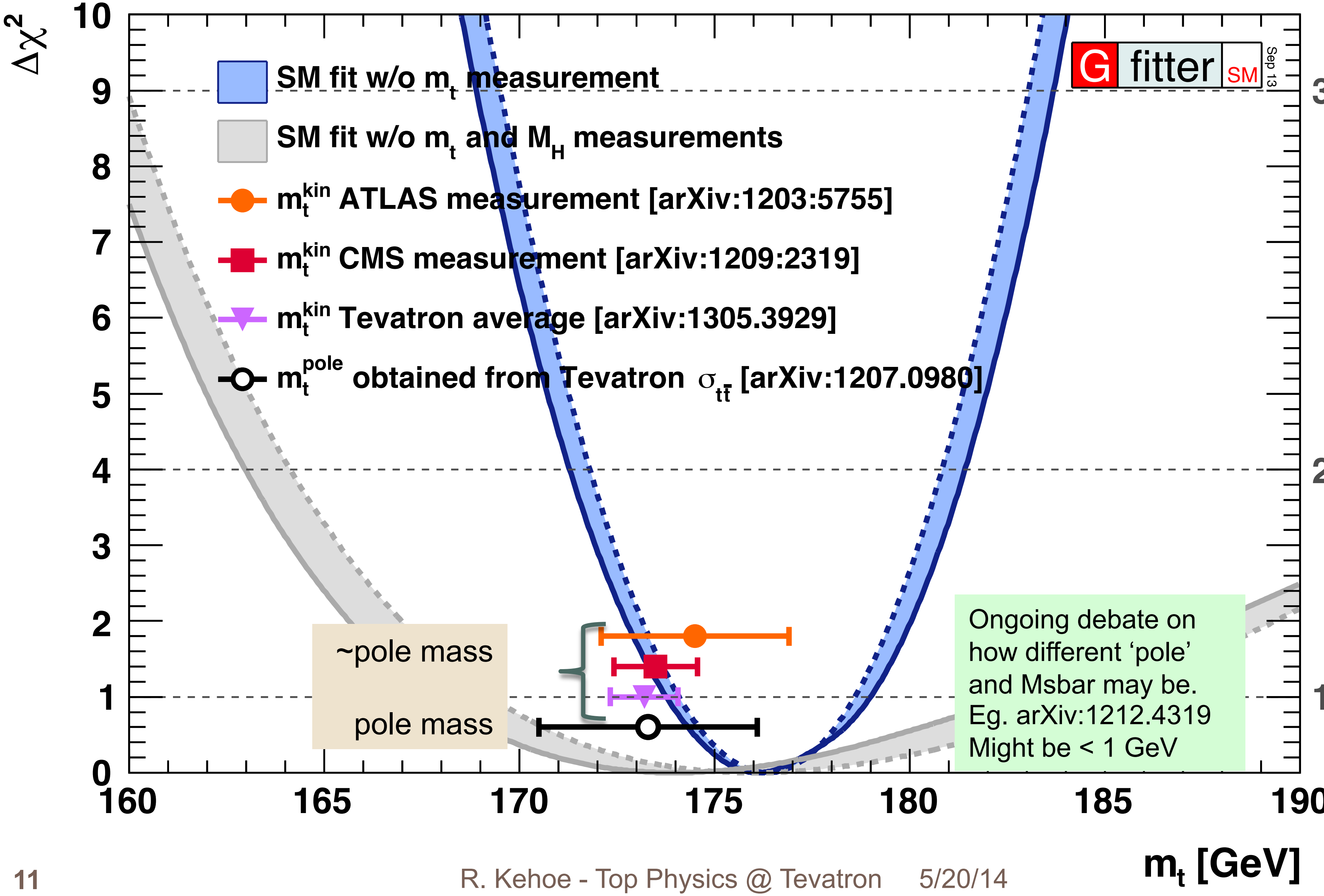
m_t = 173.20 ± 0.51 (stat) ± 0.71 (syst) GeV

= 173.20 ± 0.87 GeV

Δm/m = 0.50%

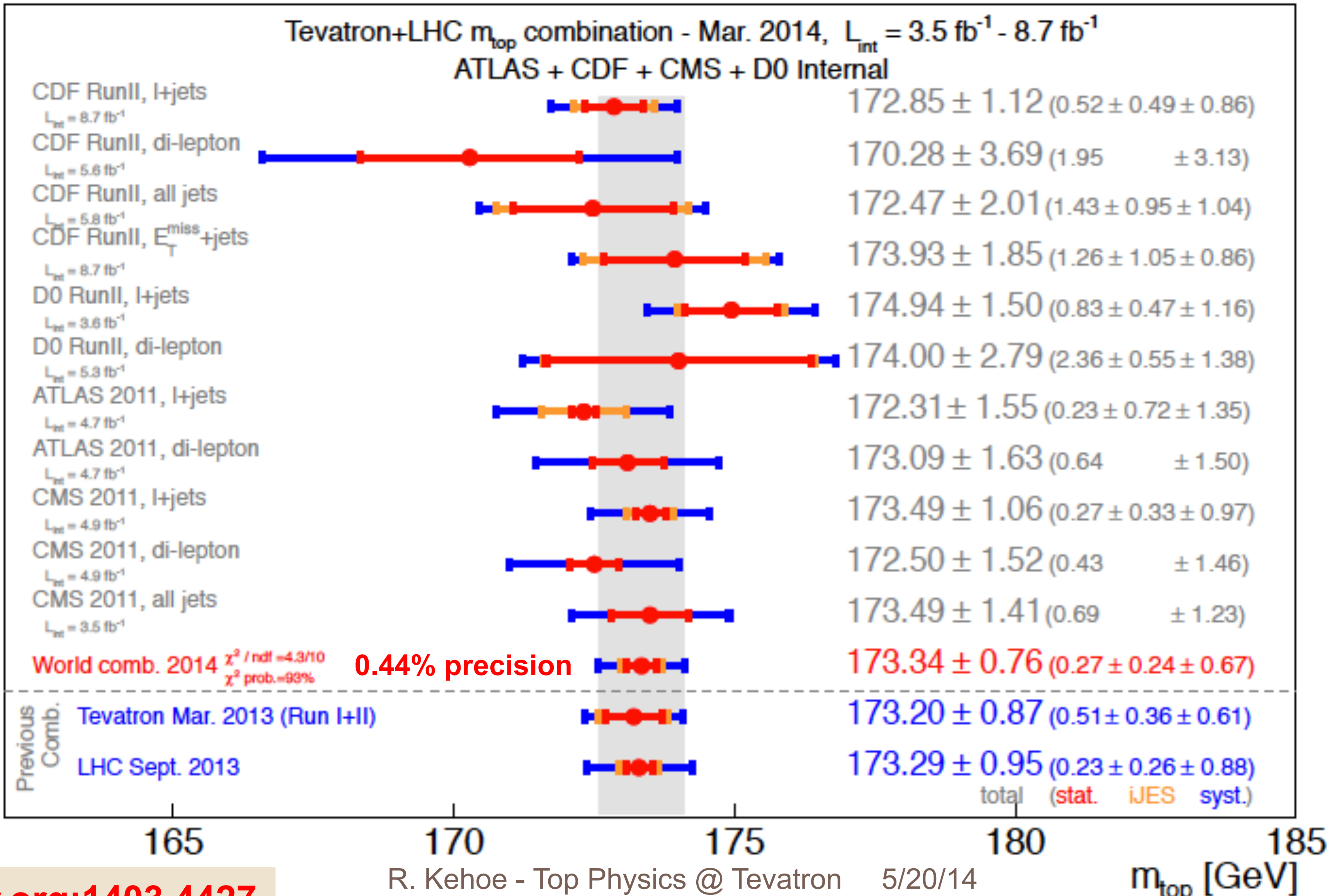
Limited by systematics:

- **signal modeling**
- **jet energy calibration**



$\Delta\chi^2$
SM fit w/o m_t measurement
SM fit w/o m_t and M_H measurements
m_t^{kin} ATLAS measurement [arXiv:1203:5755]
m_t^{kin} CMS measurement [arXiv:1209:2319]
m_t^{kin} Tevatron average [arXiv:1305.3929]
m_t^{pole} obtained from Tevatron $\sigma_{t\bar{t}}$ [arXiv:1207.0980]
G fitter SM
Sep 13
3σ
2σ
1σ
~pole mass
pole mass
Ongoing debate on
how different 'pole'
and Msbar may be.
Eg. arXiv:1212.4319
Might be < 1 GeV
m_t [GeV]

First Tevatron/LHC Combination



arXiv.org:1403.4427

New Dilepton Mass

- Template (NW) method
  - Hybrid variable added

$$M_L^{eff} = w * M_L^{reco} + (1-w) * M_L^{alt}$$

Reconstructed top quark mass

Alternate mass insensitive to JES

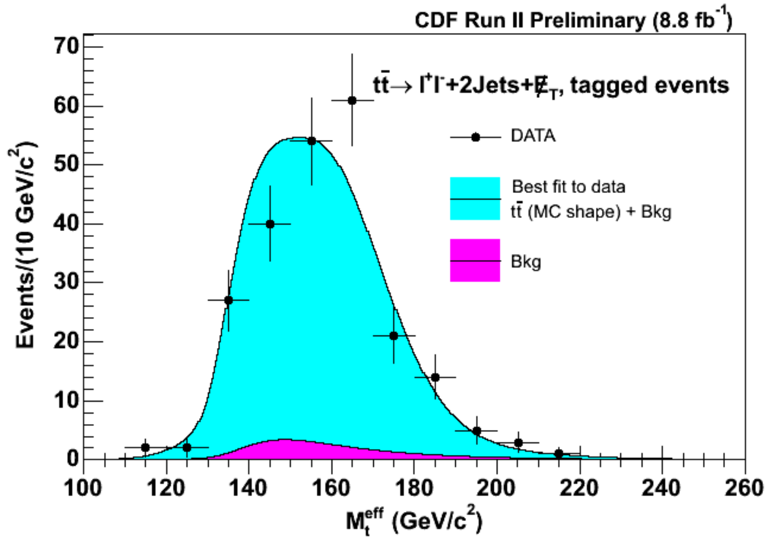
  - Reduced stat+JES by 12%
- Further optimized
  - Consider b-tagged, and untagged channels

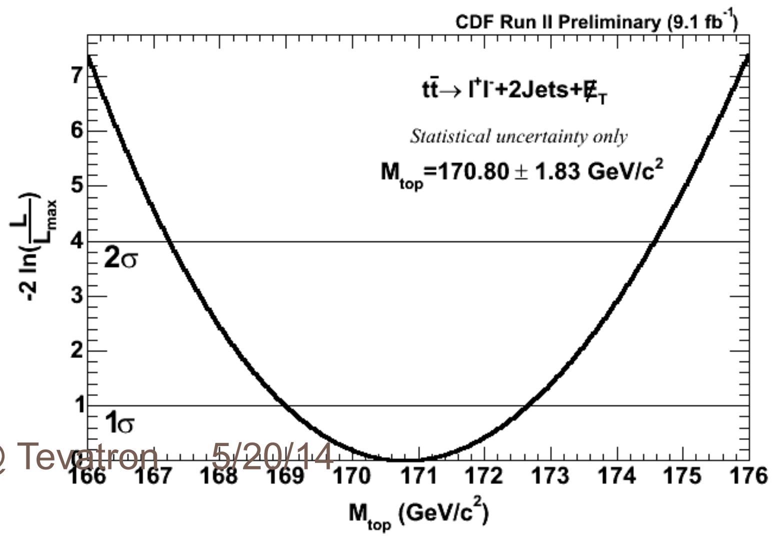
$$m_t = 170.80 \pm 1.83(\text{stat}) \pm 2.69(\text{syst})\ \text{GeV}$$

1.9% precision

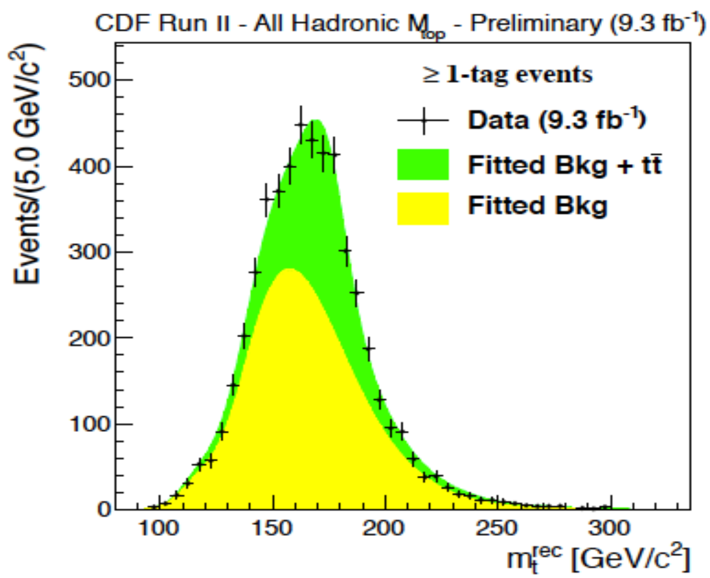
CDF note 11072

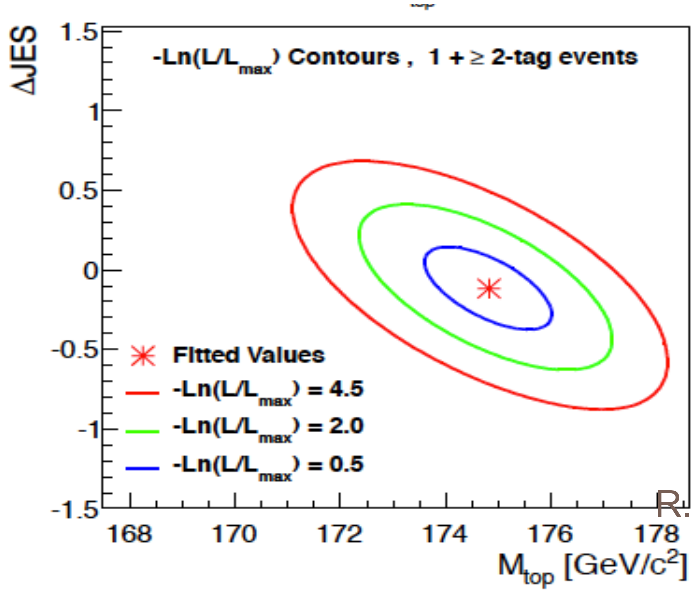
- Primary systematic uncertainty
  - JES: 2.4 GeV





New All-jets Mass





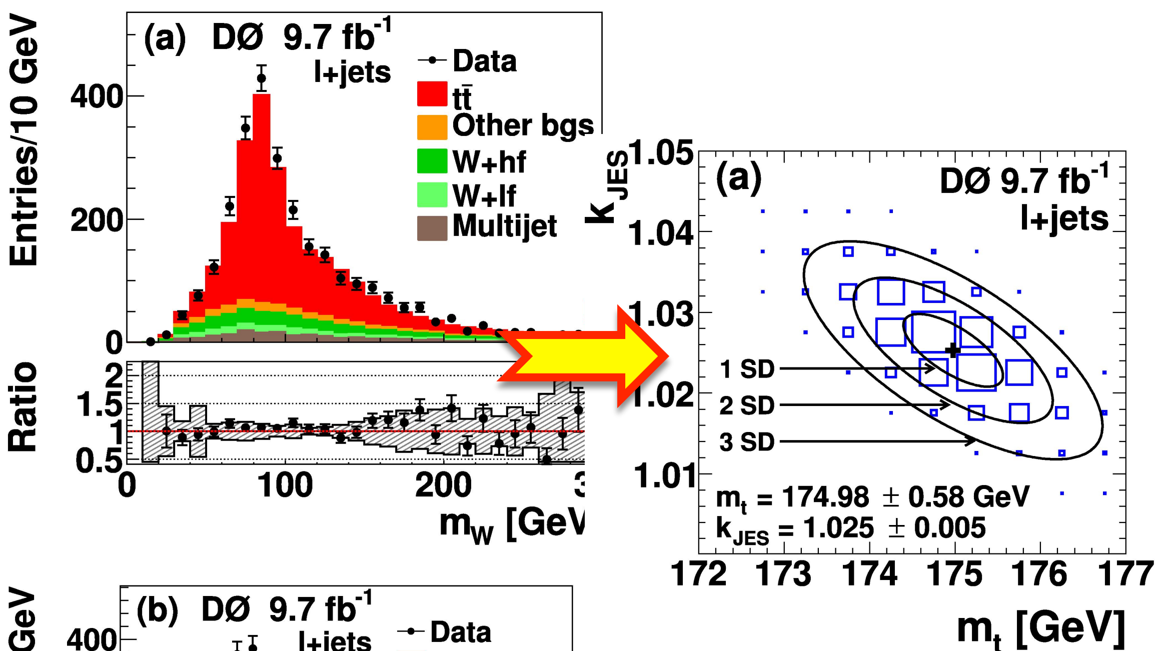
- event selection
  - 9.3 fb^{-1}
  - NN w/13 inputs
  - 1 and 2 b-tag subsamples
- Template approach
  - Kinematic reconstruction
    - Minimize χ^2 using 2 and 3 jet masses
- Jet calibration
  - extracted from the fit

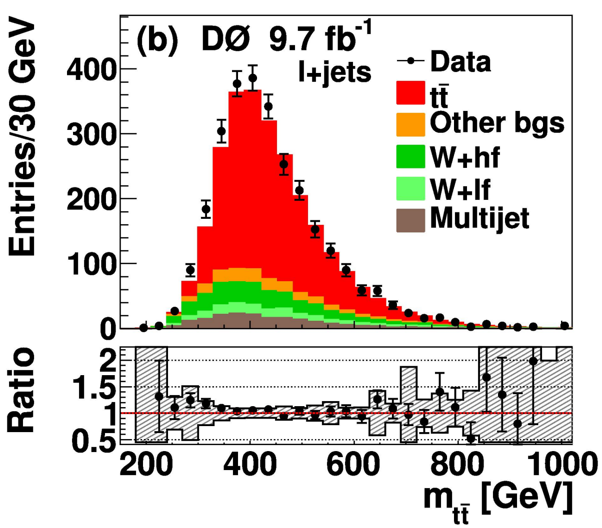
$$m_t = 175.1 \pm 1.2(\text{stat}) \pm 1.6(\text{syst})\ \text{GeV}$$

2.0% precision CDF-11084

- Leading systematic uncertainty
  - Trigger simulation

New lepton+jets Mass





- Full 9.7 fb^{-1}
- Matrix-element analysis
  - Single b-tag requirement
- Jet calibration
  - Extract from dijet mass
    - Omit tagged jets
- Major (2x) improvements:
  - Jet energy scale
  - Modeling systematics

$$m_t = 174.98 \pm 0.58(\text{stat}+\text{JES}) \pm 0.49(\text{syst})\ \text{GeV}$$
$$= 174.98 \pm 0.76\ \text{GeV}$$

0.44% precision!!

arXiv.org:1405.1756

World's most precise single measurement!

Modeling Uncertainties

- Major improvements to their determination

Source of uncertainty	Effect on m_t (GeV)
Signal and background modeling:	
Higher order corrections	$+0.15$ LO vs. NLO comparison
Initial/final state radiation	± 0.09
Hadronization and UE	$+0.26$
Color reconnection	$+0.10$

  - ISR/FSR: improve by Drell-Yan study and Pt(ttbar) reweighting
  - Hadronization: remove double counting JES effects
  - Color reconnection: new Perugia tune
    - Parametrize color string survival by overall rapidity range

Conclusions

Summary

- Production
  - Consistent w/SM
- Properties
  - Width ~ **2 GeV**
  - Branching ratio to Wb 90±4%
  - Charge asymmetry
    - CDF higher than SM
    - D0 consistent w/SM & CDF
- Mass
  - Tevatron precision = 0.5%
    - World combination to **0.44%**
    - Indirectly,
      $Y_t = \sqrt{2}\, m_t / v = 0.9965 \pm 0.0044$
  - 3 new results

Outlook

- D0 in progress
  - Dilepton, all-jets mass
  - Spin correlation, inclusive cross section
- Plans
  - Update final Tevatron combinations
  - Incorporate results to
    - world combinations
    - SM constraints
- Mass measurements pushing against theory challenges
  - QCD (and EWK) effects