Top Mass Measurement at CDF

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Outline

- Motivation for measuring top mass
- Run I Measurements
- Event Topology
- Lepton + jet channel

    Template method

    Jet Energy Scale dependent template method (World's best result!)

    Dynamical Likelihood Method

- Dilepton channel

    Neutrino Weighing Algorithm

    p_z of $t\bar{t}$ system

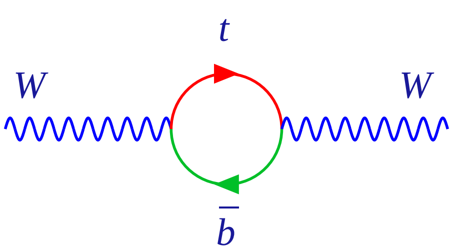
    ϕ of ν

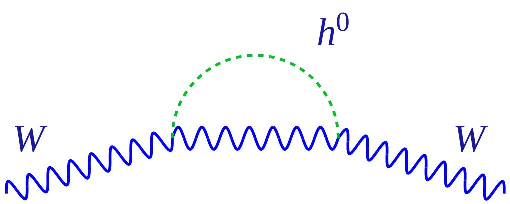
- Latest results

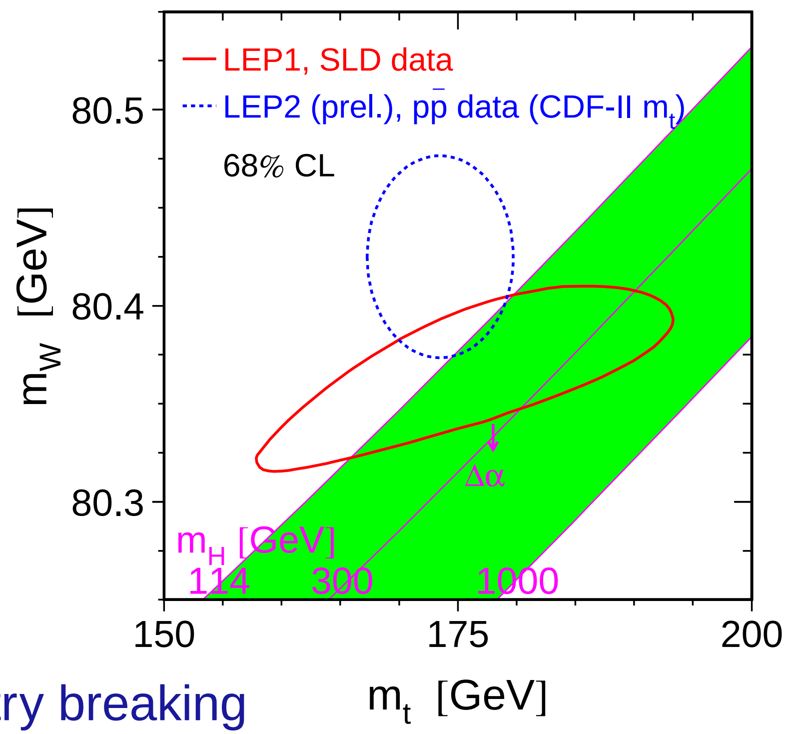
Motivation for measuring top mass

New Higgs mass prediction!

- Measuring M_{top} and M_W constrains the Higgs mass
- Consistency check for the Standard Model







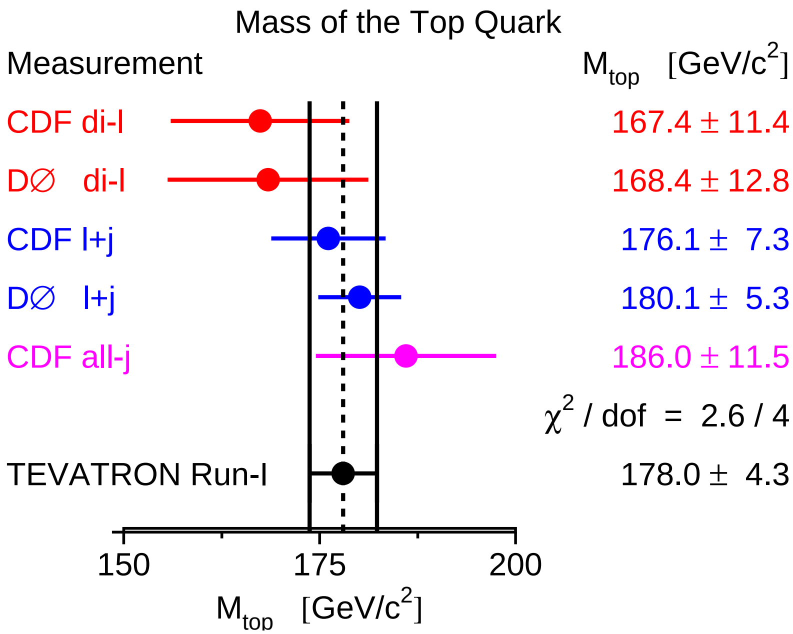
- Mass close to the scale of electroweak symmetry breaking

  Yukawa coupling: $Y_t \equiv \frac{\sqrt{2}M_{top}}{v} = 1$ within 3%

  $\Rightarrow$ Does the top quark play a role in ESB?

Previous measurements of the Top Quark Mass

- CDF and D0 run I combined uncertainty: $4.3\,\mathrm{GeV}/c^2$
- With more statistics and better detector acceptance, we can improve the result



$t\bar{t}$ events at the Tevatron

- Standard Model predicts $q\bar{q}$ annihilation is dominant production process
- SM predicts branching fraction of $t \to Wb$ close to 100%
- W can decay as $q\bar{q}$ or $l\nu$

$\Rightarrow$ Dilepton + ≥ 2 j + $\not{E}_T$: $\simeq 5\%$

no b tag: 8 kinematic solutions

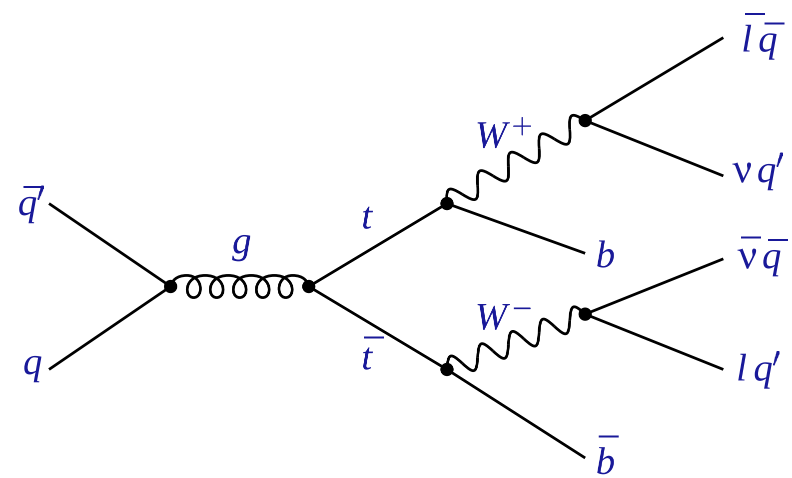
$\Rightarrow$ Lepton + ≥ 4j + $\not{E}_T$: $\simeq 30\%$

1 b-tag: 12 kinematic solutions

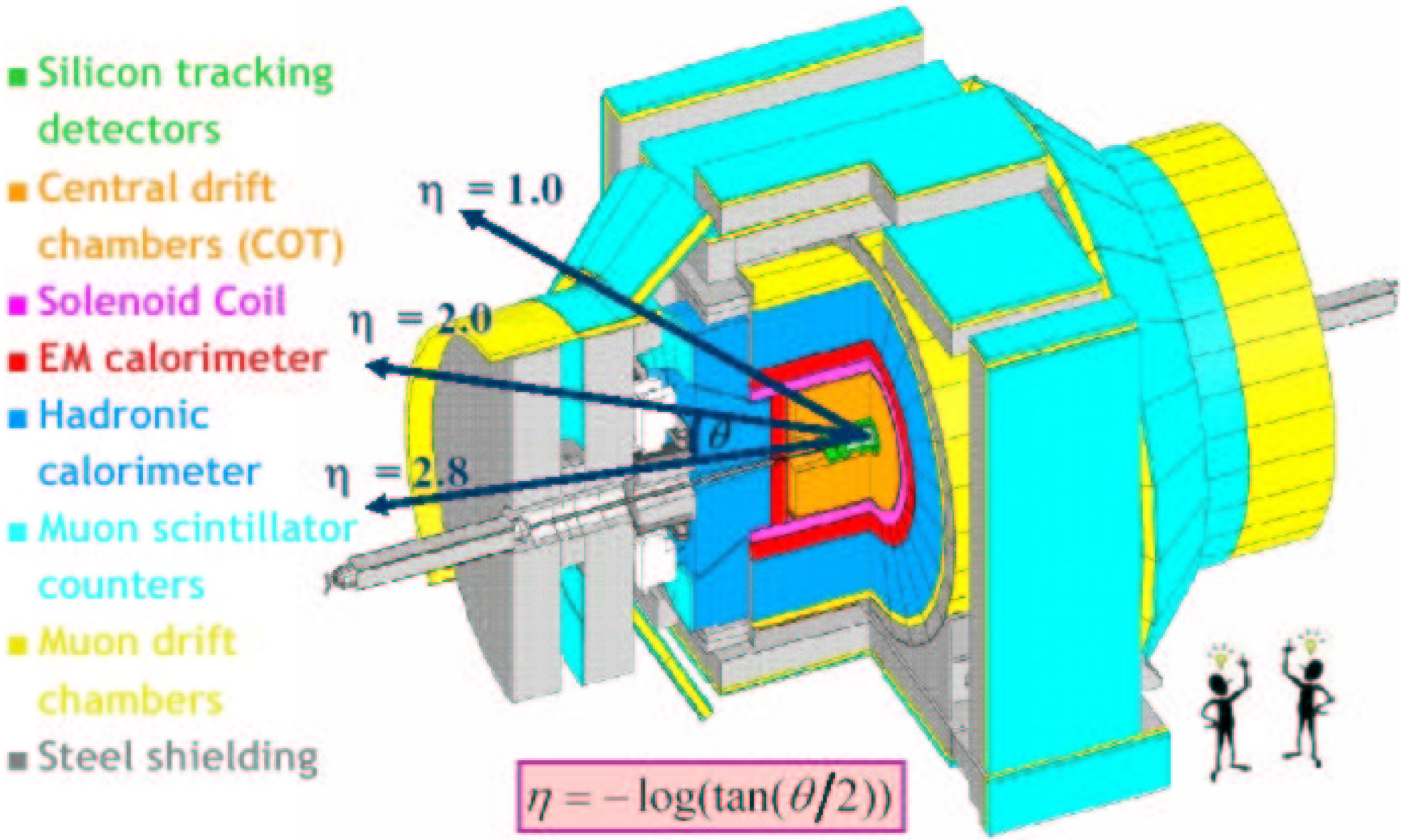
2 b-tag: 4 kinematic solutions

$\Rightarrow$ ≥ 6 j: $\simeq 44\%$

- Possible contribution from hard ISR or FSR



The CDF Detector



The Lepton + jets channel

- Selections:

  Select 4 jets ($E_t > 15GeV$) or 3.5 jets (4th jet $E_t > 8GeV$)

  0, 1 or 2 b jets identified through secondary vertex measurement

  $\not{E}_T$ and identified charged lepton

- Expected n_{events} (for b-tag≥ 1): n_{sig} = 79.5 and n_{back} = 18.5

- Template method: kinematic fit of the top mass

- Improvement to the template method:

  Use additional information for b identification

  Jet energy scale dependent template method

- Dynamical Likelihood Method

Lepton + jets: Template Method

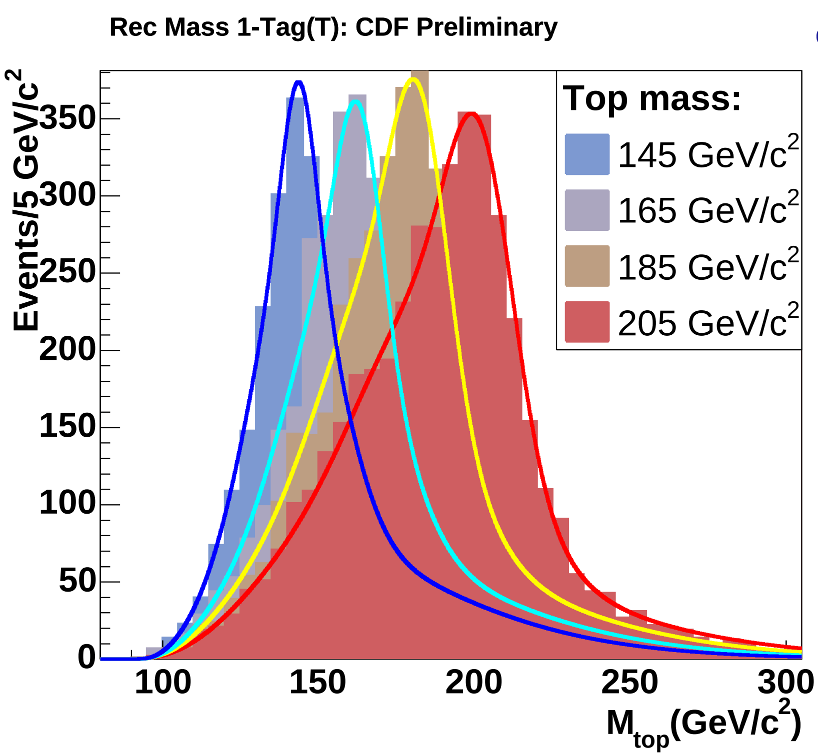
- Select 1 lepton + 4 jets + $\not{E}_T$
- Select b-tag jet using secondary vertex
- Assume four highest E_T jets associated with 4 quarks
- ν reconstructed with $\not{E}_T$ and by constraining $M_{l\nu} = M_W$
- χ^2 function is minimized for each of the 24 solutions (0 b-tag) 12 solutions (1 b-tag) or 4 solutions (2 b-tag):

$$\chi^2 = \sum_{l,jets} \frac{(\hat{P}_T - P_T)^2}{\sigma^2_{P_T}} + \sum_{i=x,y} \frac{(\hat{U}_i' - U_i')^2}{\sigma^2_{U_i'}} + \frac{(M_{l\nu} - M_W)^2}{\sigma^2_{M_W}} + \frac{(M_{jj} - M_W)^2}{\sigma^2_{M_W}} + \frac{(M_{l\nu j} - M_t)^2}{\sigma^2_{M_t}} + \frac{(M_{jjj} - M_t)^2}{\sigma^2_{M_t}}$$

- For each event, obtain top mass from solution with lowest χ^2

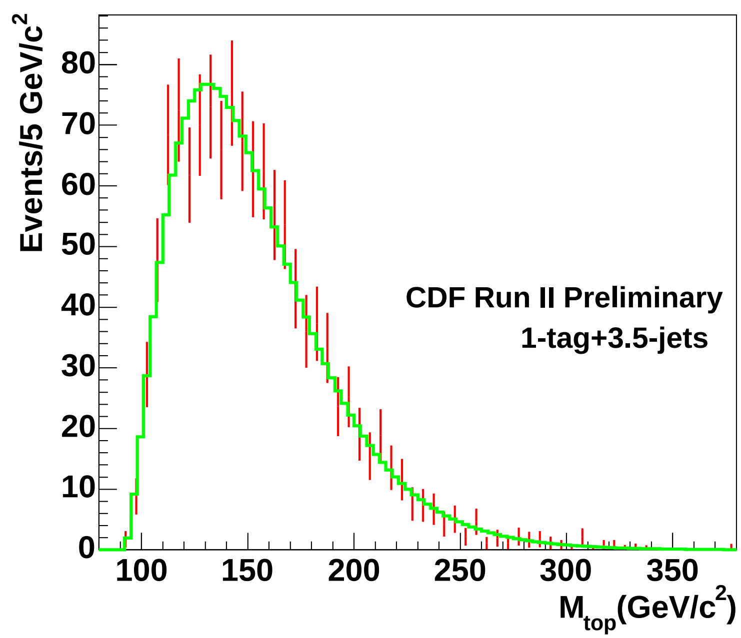
Lepton + jets Template Method: signal and background

- Fit top mass dependent signal template



- Background dominated by W + high E_t jets

- Fit background template

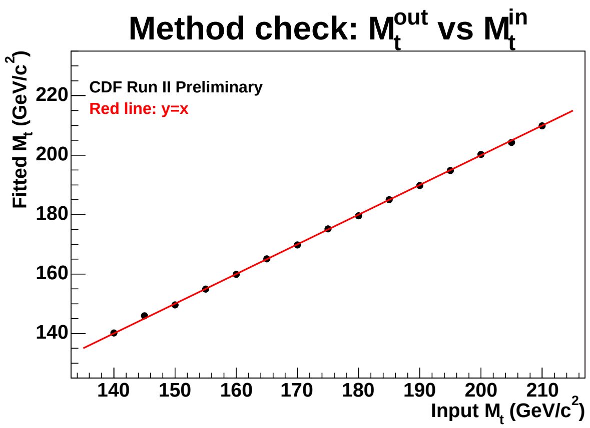


- Likelihood function: perform shape analysis to extract best top mass

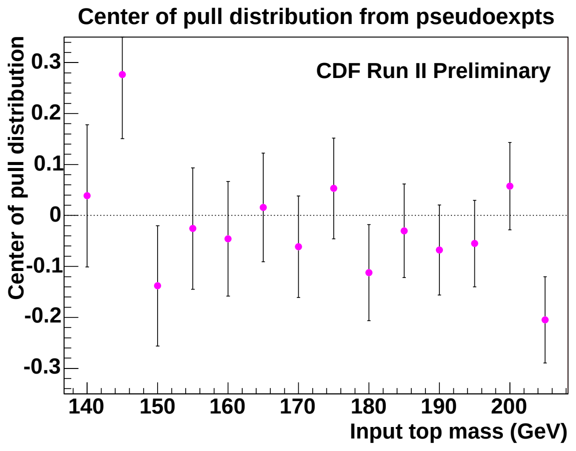
Lepton + jets Template Method: method check

Testing the procedure with pseudoexperiments

- Fitted mass linear

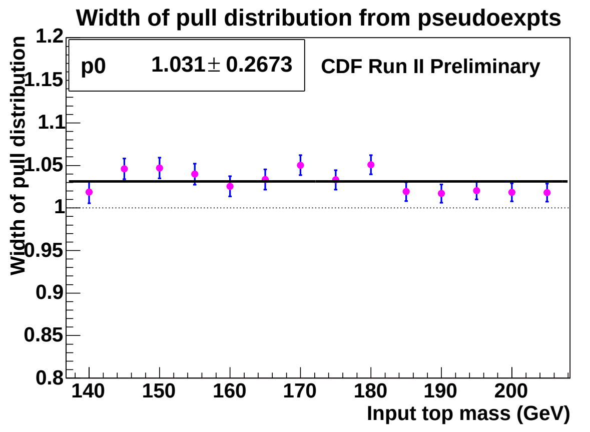


- Pull=$(m_{output} - m_{input})/\sigma$
- Pull center consistent with 0



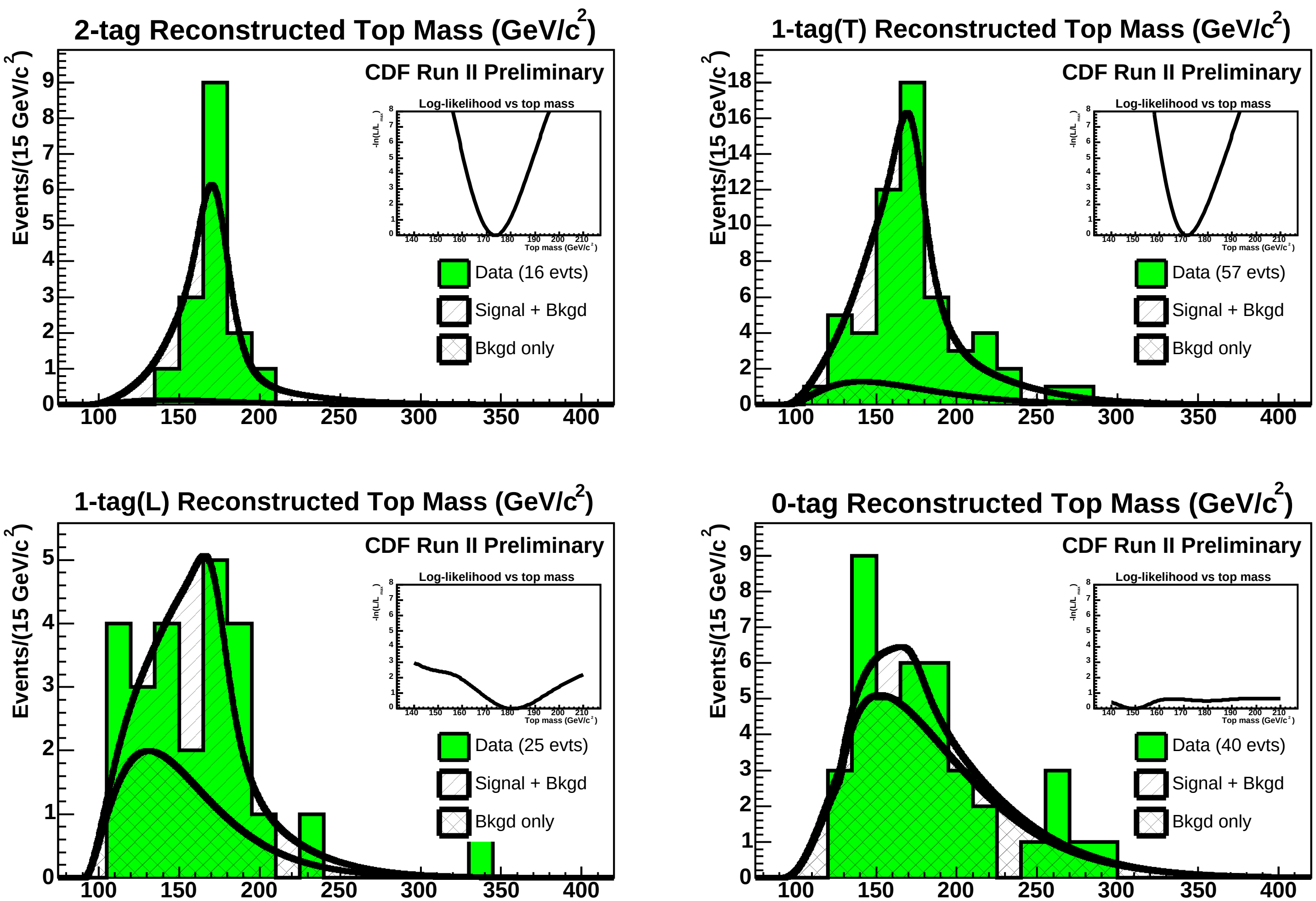
- Pull width $\simeq 1.03$

$\Rightarrow$ Scale statistical error



Lepton + jets Template Method: data results

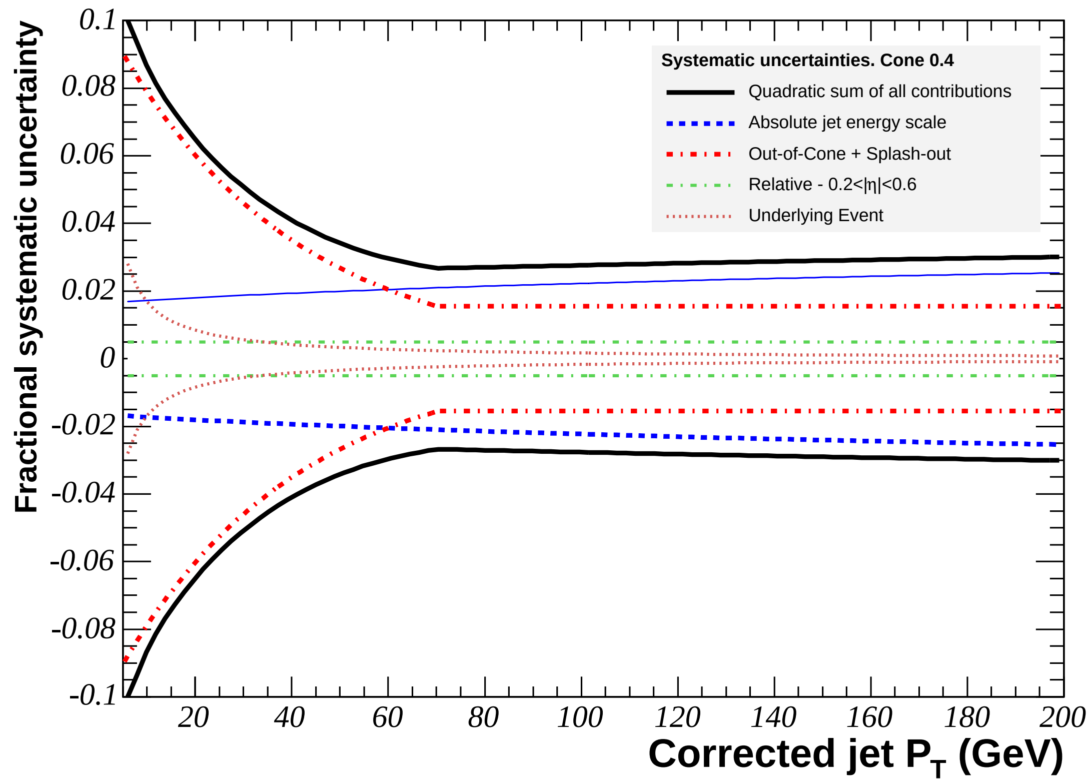
Data results by subsample:



Combined result for template method: $173.2^{+2.9}_{-2.8}(stat\ only)\,GeV/c^2$

Lepton + jets Template: Jet Energy Scale systematic uncertainty

- Calorimeter energy response
- Energy falls outside the jet re-construction cone
- Non-uniformity of the calorime-ter
- Energy from underlying event



Jet Energy Scale systematic uncertainty on top mass: $3.1\,GeV/c^2$

Lepton + jets Template: systematic uncertainties

Source of Systematics	ΔM_{top} (GeV/c^2)
Jet Energy	3.1
ISR	0.4
FSR	0.4
PDFs	0.4
Generators	0.3
Background Shape	1.0
b-jet Energy	0.6
b tagging	0.2
MC statistics	0.4
Total	3.4

Final result for template method (with $318 pb^{-1}$): $173.2^{+2.9}_{-2.8}(stat) \pm 3.4(syst) GeV/c^2$

Lepton + jets Template Method with improved b identification

- Default b jet identification performed by reconstructing secondary vertex
- Use additional information:

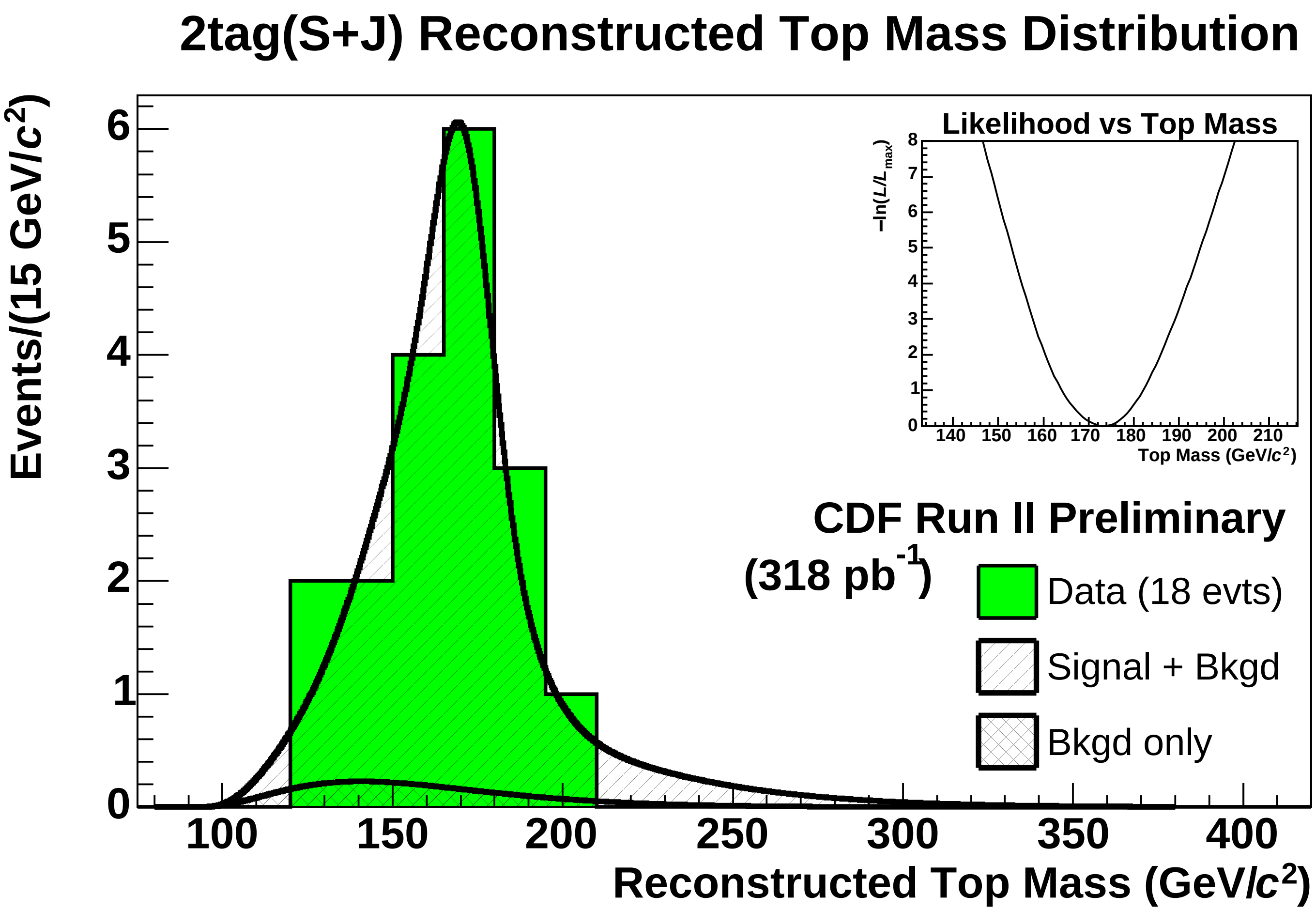
  Transverse displacement of track with respect to primary vertex

  Calculate probability that track is not from primary vertex

  Combine information from both b-tagging methods

Lepton + jets with improved b identification: data results

Data results by subsample:

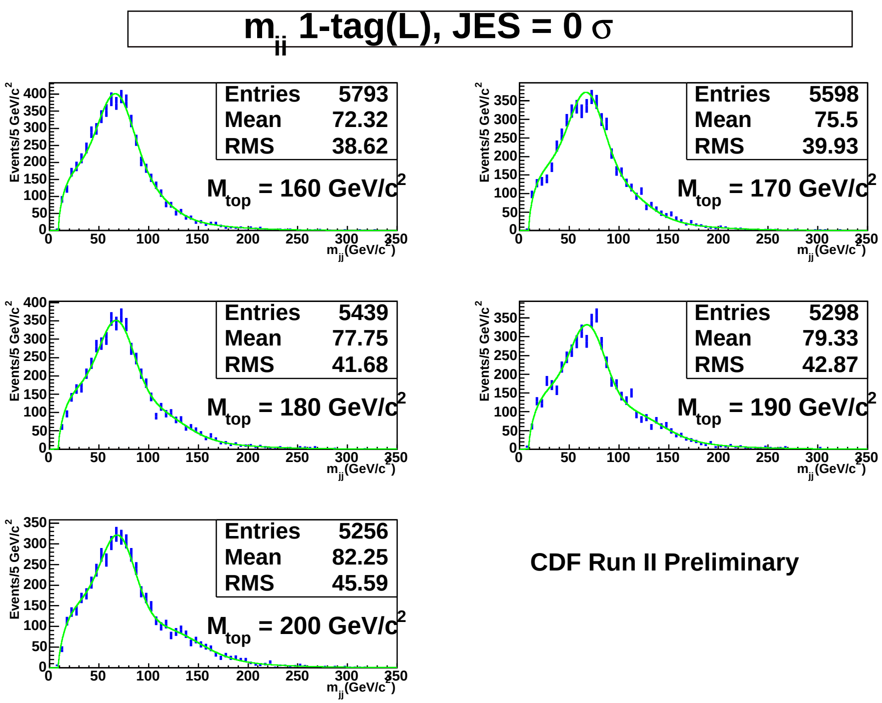


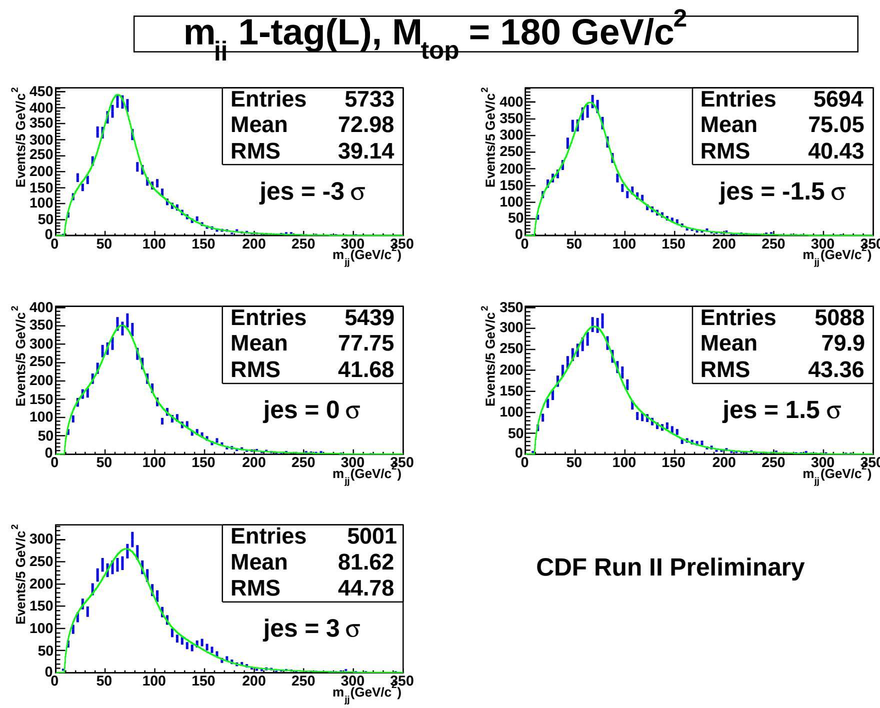
Final result with improved b identification: $173.0^{+2.9}_{-2.8}(stat) \pm 3.3(syst) GeV/c^2$

Lepton + jets Template Method fitting Jet Energy Scale

- W invariant mass dependent of JES, but not on top mass
- Use W mass to estimate JES

$\Rightarrow$ Sensitive to JES but insensitive to M_{top}



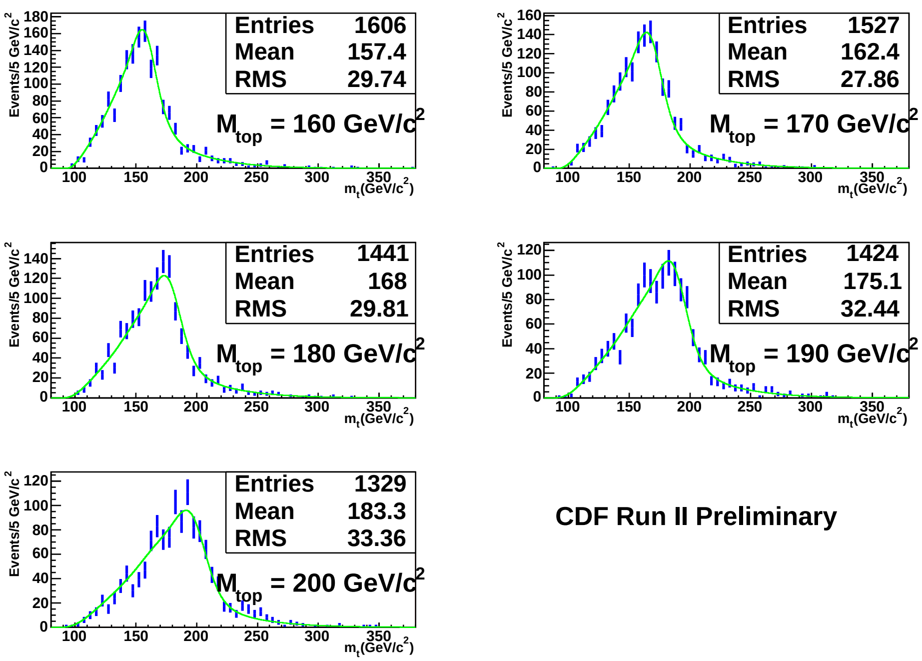


- We obtain: JES = $(-0.76 \pm 1.30)\sigma$

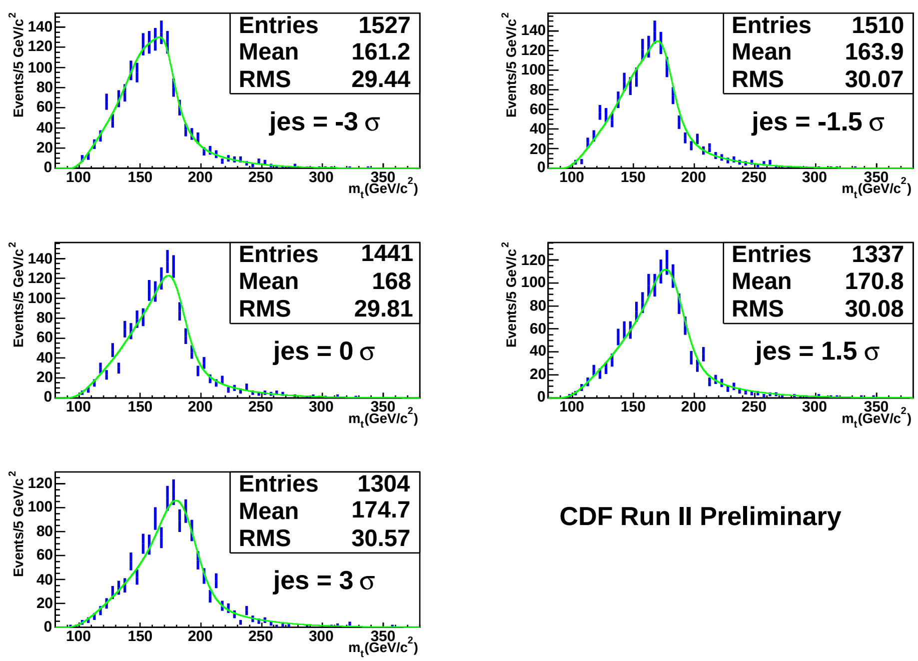
Lepton + jets Template Method fitting Jet Energy Scale

- Jet energy scale dominant systematic uncertainty
- Along with top mass, fit Jet Energy Scale
- 2D templates dependent on both top mass and Jet Energy scale

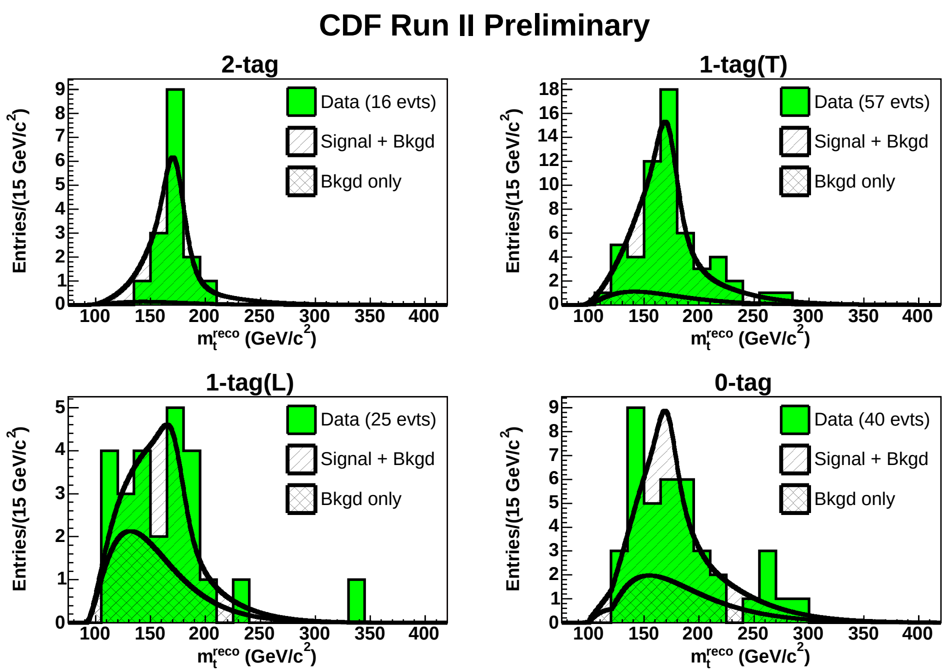
m_t 1-tag(L), JES = 0 σ

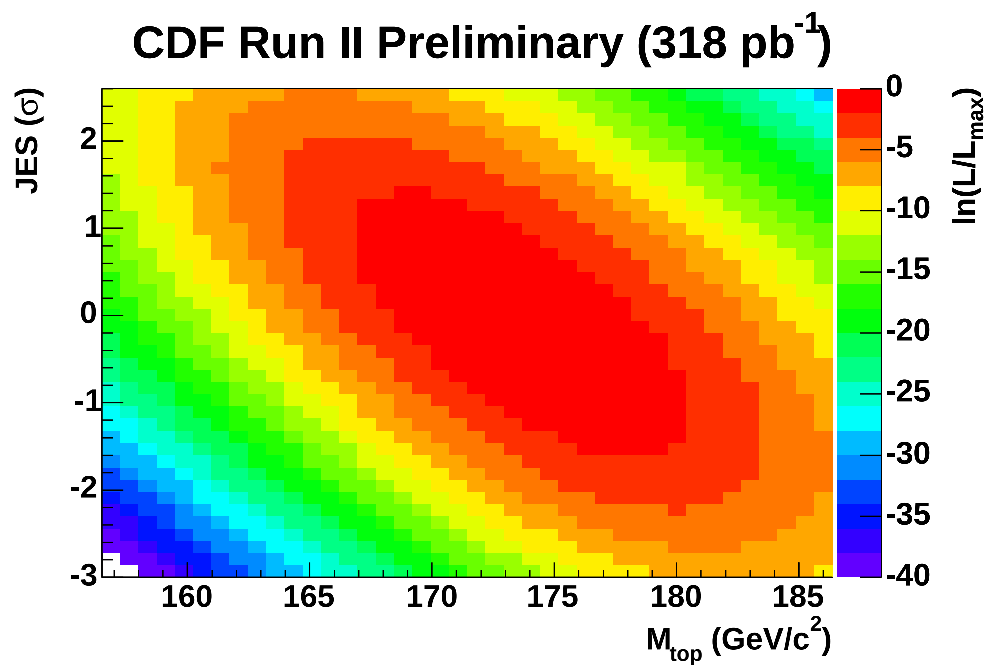


m_t 1-tag(L), M_{top} = 180 GeV/c^2



Lepton + jets Template Method fitting Jet Energy Scale result





- Obtain JES = $(-0.10 \pm 0.90)\sigma$

$\Rightarrow$ Consistent with W invariant mass JES estimate

Result (with 318 pb^{-1}) $173.5^{+2.7}_{-2.6}(stat) \pm 2.5(JES) \pm 1.7(syst) GeV/c^2$

Best Top Mass measurement in the World!

Lepton + jets Dynamical Likelihood Method

- Integrate differential cross section
- Obtain likelihood of obtaining final state as a function of M_{top} for each event:

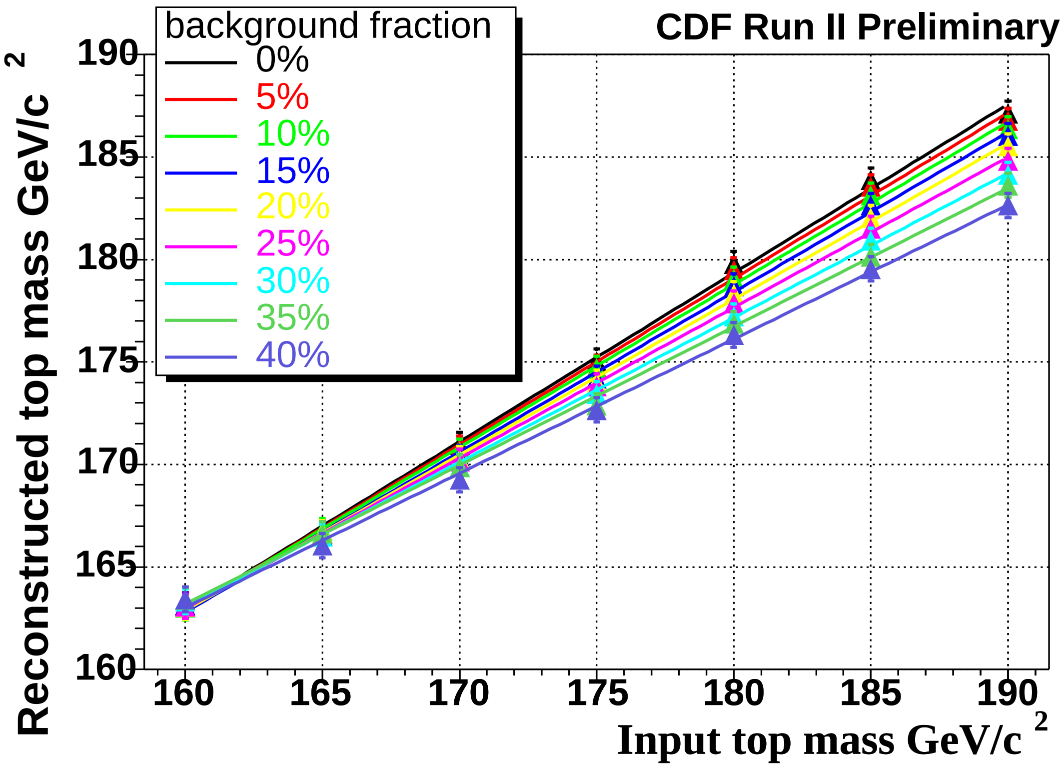
$$L^i(M_{top}) = \int \sum_{jet\,comb} \sum_{sol} \frac{2\pi^4}{Flux} |M|^2 F(z1,z2) f(p_t) w(x,y_t;\alpha) dx$$

- M: Matrix element of $t\bar{t}$ process
- $F(z1,z2)$: parton distribution function
- $f(p_t)$: $t\bar{t}$ system transverse distribution function
- $w(x,y_t;\alpha)$: transfer function x (truth) $\rightarrow$ y (observation)

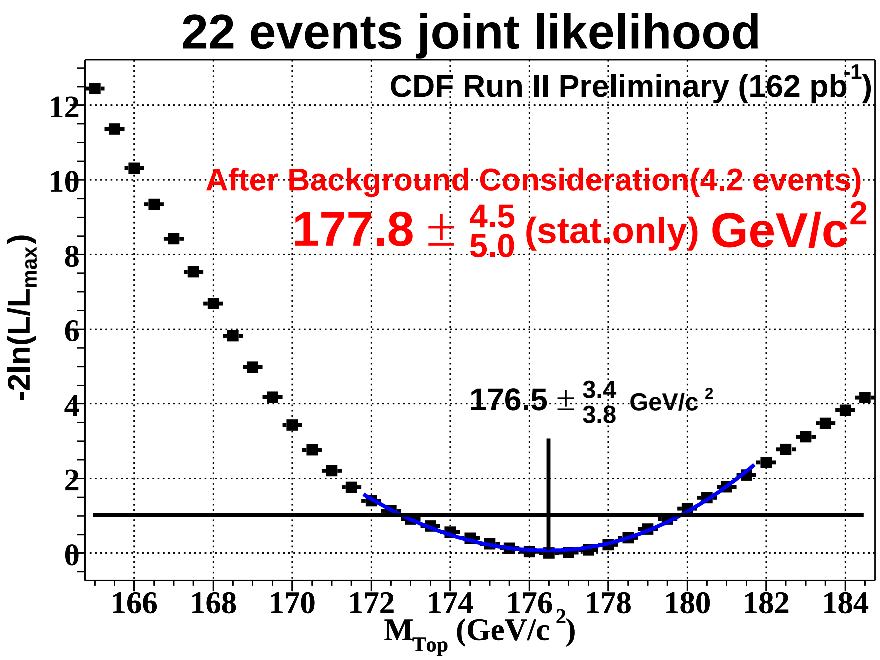
- Combine likelihood for all events: $\prod_{events} L^i(M_{top})$

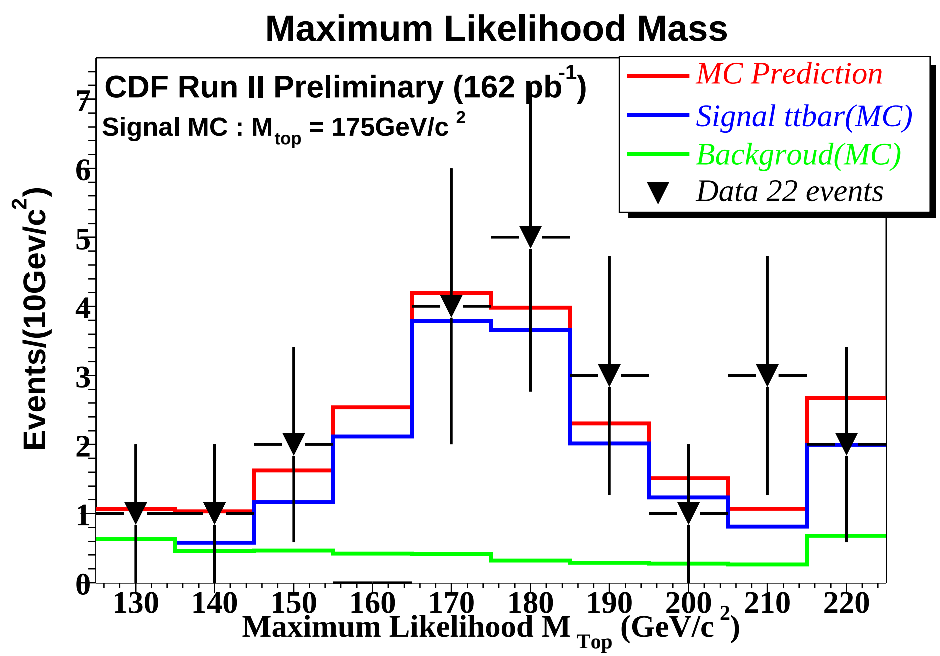
Lepton + jets Dynamical Likelihood Method background

- First, consider all events $t\bar{t}$ signal
- Use pseudoexperiments to simulate background effect
- Mapping function:



Lepton + jets Dynamical Likelihood Method result





- With only 168 pb^{-1} M_{top} = $177.8^{+4.5}_{-5.0}(stat) \pm 6.2(syst) GeV/c^2$
- New result with $\sim 318 pb^{-1}$ soon!

The Dilepton channel

- Advantages:

  Less combinatorics

- Disadvantages:

  Smaller branching fraction ($\simeq 5\%$)

  Two neutrinos

- Select events with 2 jets + $\not\!\!E_T$ + 1 lepton + 1 track (or 2 leptons)

  Expected n_{events}: n_{sig} = 11.5 and n_{back} = 6.6

- Underconstrained problem. 3 approaches:

  Neutrino Weighing Algorithm

  p_z of $t\bar{t}$ system

  ϕ of ν

The Neutrino Weighing Algorithm

- Keep $\not{E}_T$ measurement aside
- Try all possible $\eta(\nu)$ and $\eta(\bar{\nu})$ possible pair
    - η step = 0.1
- Solve E-P conservation: get 0 or 2 solution for each ν
- Assign weight to solution from consistency with measured $\not{E}_T$

$$w_i(m_{top},\eta(\nu),\eta(\bar{\nu})) = e^{\left(-\frac{(\not{E}_{T\,x}-P_x(\nu)-P_x(\bar{\nu}))^2}{2\sigma^2_{\not{E}_T}}\right)} e^{\left(-\frac{(\not{E}_{T\,y}-P_y(\nu)-P_y(\bar{\nu}))^2}{2\sigma^2_{\not{E}_T}}\right)}$$

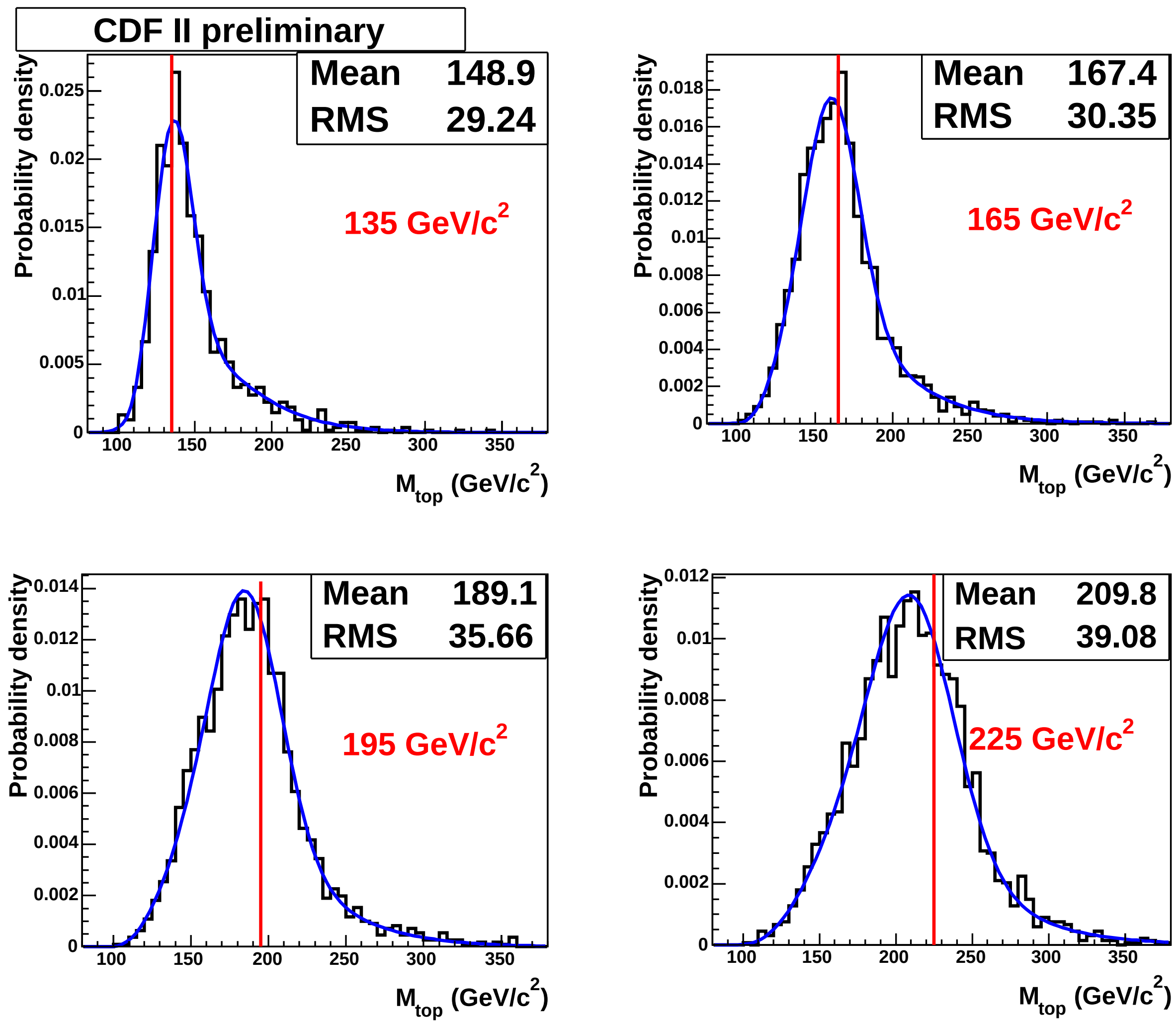
- For given mass, add weights:

$$W(m_{top}) = \sum_{jetcomb}\sum_{\eta(\nu)\eta(\bar{\nu})} P(\eta(\nu),\eta(\bar{\nu}))\sum_i^4 w_i(m_{top},\eta(\nu),\eta(\bar{\nu}))$$

- We keep most probable mass for each event

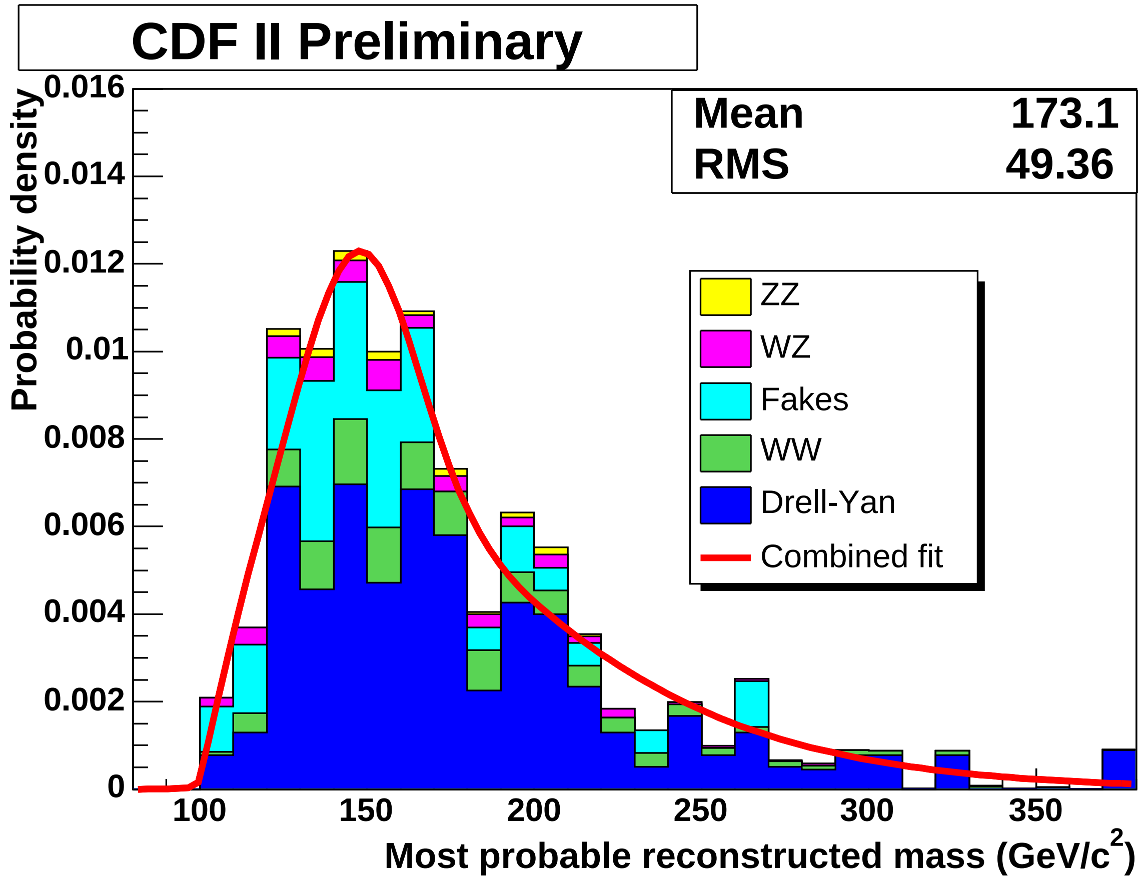
Dilepton signal templates

- Build signal templates with generated mass from $135 GeV/c^2$ to $225 GeV/c^2$
- Parametrize with top mass dependent function



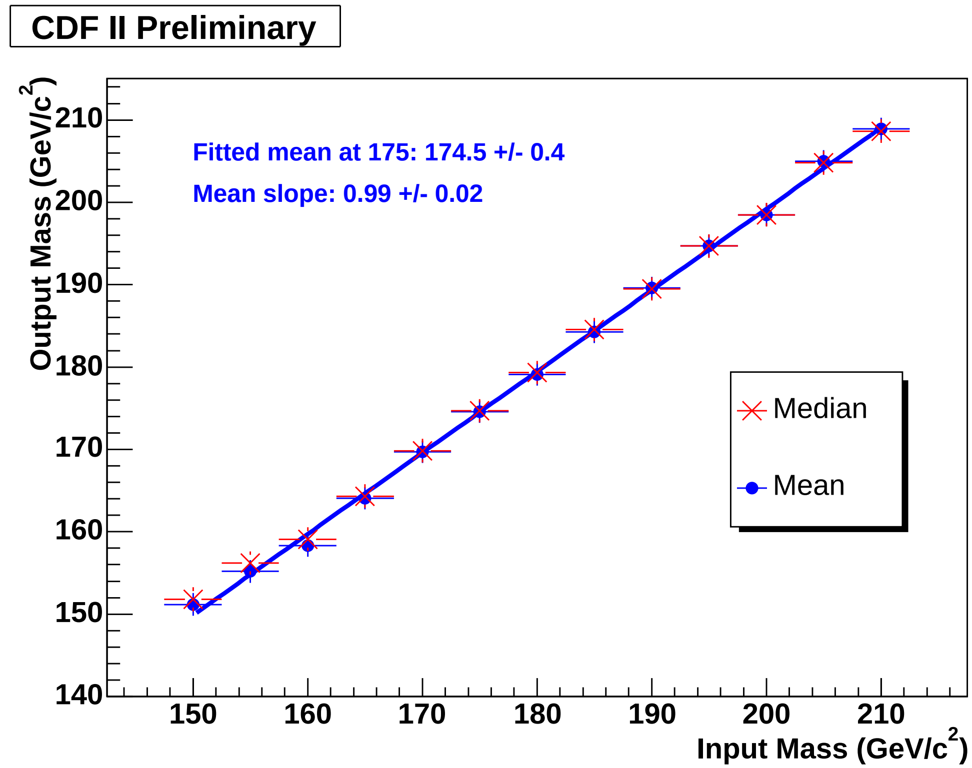
Dilepton background template

- Combine all background templates
- Parametrize

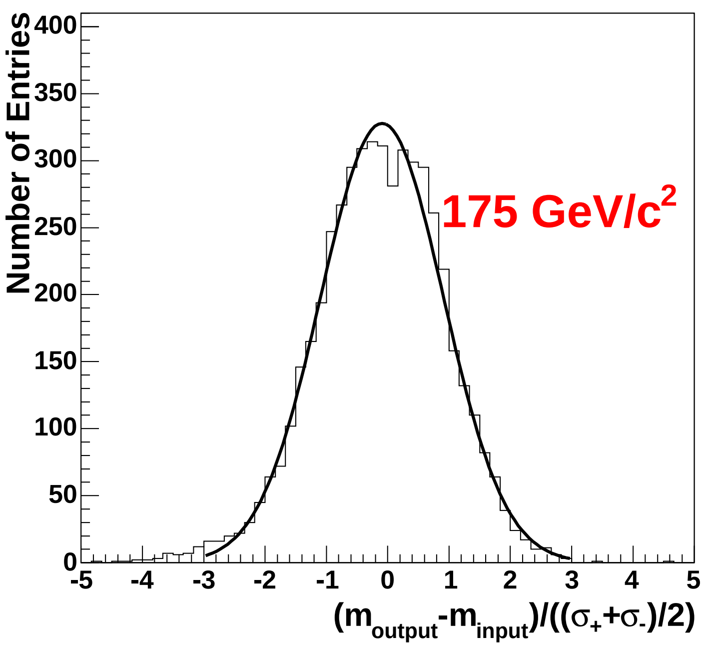


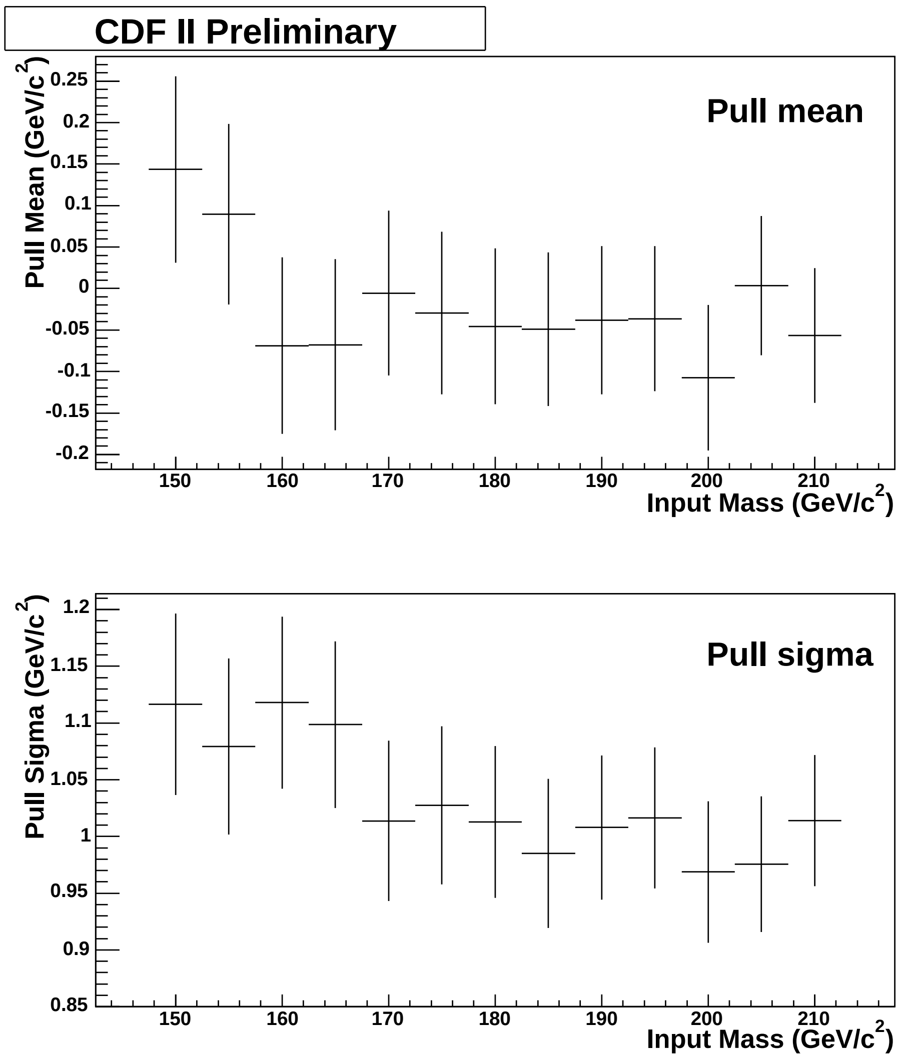
Testing the procedure with pseudo-experiments: linearity check

- Draw 5000 pseudo-experiments
- Keep mass that minimizes likelihood function
- Fitted mass linear



Testing the procedure with pseudo-experiments: pull distributions





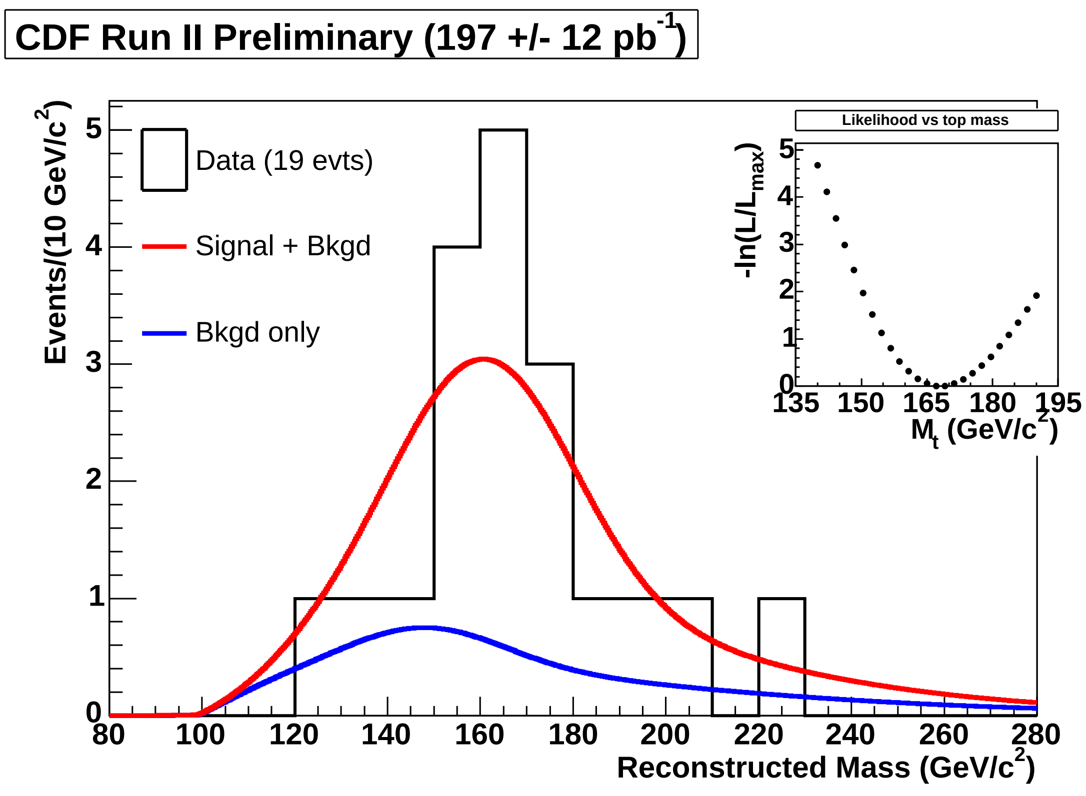
- Pull mean consistent with 0
- Pull sigma consistent with 1

Dilepton data results (NWA)

Integrated luminosity: $197 \pm 12 pb^{-1}$

$\Rightarrow$ 19 data events

- $M_{top} = 168.1^{+11.0}_{-9.8}(stat) \pm 8.6(syst)\mathrm{GeV/c^2}$
- New result with $\sim 360 pb^{-1}$ soon!



Dilepton p_z of $t\bar{t}$ system

- Introduce extra variable: p_z of $t\bar{t}$ system = 0 with σ = 180 GeV/c
- Smear measured quantities 10 000 times according to uncertainty

  Jet energies

  Lepton momentum

  $\not{E}_T$

- Take solution that has highest probability (most entries in histogram bin)

Dilepton ϕ of ν

- Try all possible $\phi(\nu)$ and $\phi(\bar{\nu})$ possible pair
  - 12×12 points
- With +1 constrain, we can use χ^2 fitter (similar to l+jet template method)

$$\chi^2 = \sum_{l,jets} \frac{(\hat{P}_T - P_T)^2}{\sigma^2_{P_T}} + \sum_{i=x,y} \frac{(\hat{U}'_i - U'_i)^2}{\sigma^2_{U'_i}} + \frac{(M_{l1\nu1} - M_W)^2}{\sigma^2_{M_W}} + \frac{(M_{l2\nu2} - M_W)^2}{\sigma^2_{M_W}} + \frac{(M_{l1\nu1j1} - M_t)^2}{\sigma^2_{M_t}} + \frac{(M_{l2\nu2j2} - M_t)^2}{\sigma^2_{M_t}}$$

- 8 solutions per point: take one with lowest χ^2
- Weigh M^{top}_{ij} (for minimal χ^2_{ij} solution) with:
  $exp(-\chi^2_{ij}/2)/\sum_i \sum_j exp(-\chi^2_{ij}/2)$

Summary

New CDF top mass better than world average!!!

$$M_{top} = 173.5^{+4.1}_{-4.0} GeV/c^2$$

Most probable Higgs mass value from EW fit precision estimates:

$$M_{Higgs} = 94^{+54}_{-35} GeV/c^2$$

Prospects for JES fit: