Top Quark Mass Measurement in dilepton channel at CDF

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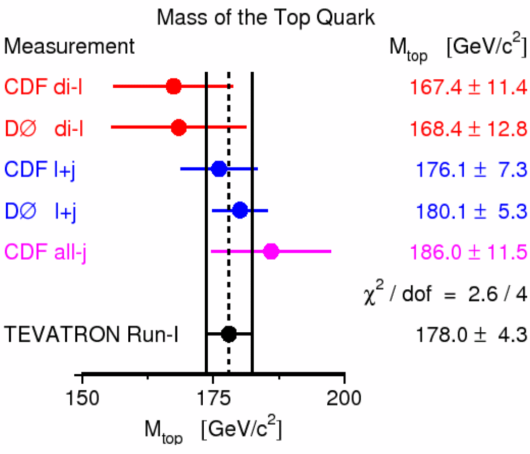
Outline

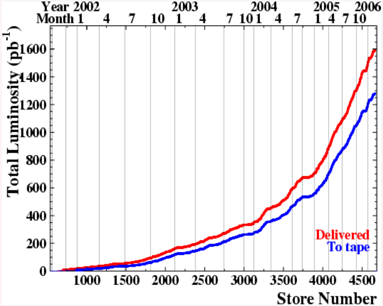
Top Quark History

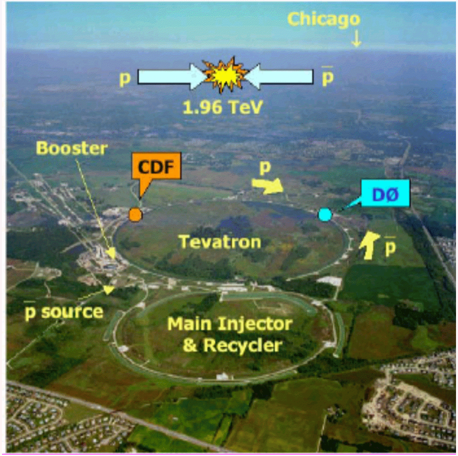
- discovered by CDF and D0 in 1995 in Run 1 ($\mathcal{L} \sim 100\, pb^{-1}$)
- also mass measured in Run 1 (1992-1996): $M_{top} = 178.0 \pm 4.3\, GeV$
- aim for Run 2 (2001 - 2009): $\delta M_{top} = 1.5\, GeV$ ($\mathcal{L} = 4.4 - 8.5\, fb^{-1}$)



Tevatron

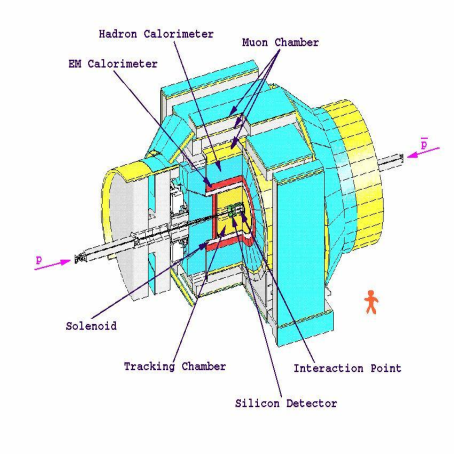
- Run 2: $p - \bar{p}$ @ $\sqrt{s} = 1.96$ TeV
- integrated luminosity ~ 1.3 fb^{-1} (300 – 750 pb^{-1}analyzed)





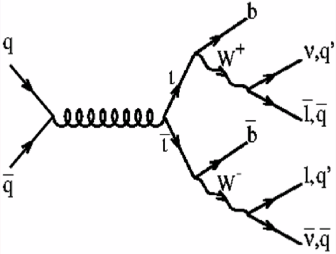
CDF experiment

- CDF collaboration: ~800 members
- CDF detector is symmetric, classical “onion” structure:
  - tracking in magnetic field, $|\eta| < 2.0$
  - calorimeters (el.mag. and hadron), $|\eta| < 3.6$
  - muon detectors



Top Quark Production at Tevatron

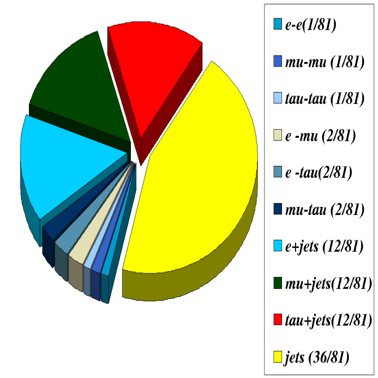
- **dominant production in pairs through strong interaction:** $\sigma(p\bar{p} \rightarrow t\bar{t} \,@\, M_{top} = 175GeV) \approx 6.7pb$
- single top production not observed yet (expect 3σ evidence with 1.5 pb^{-1})
- Decay: $BR(t \rightarrow Wb) \approx 100\%$



$q\bar{q} \rightarrow t\bar{t} \sim 85\%$
$gg \rightarrow t\bar{t} \sim 15\%$
$\Rightarrow$opposite to LHC

$t\bar{t}$ decay modes

- $t\bar{t}$ events classified according W decays (leptonic or hadronic):
  - dilepton channel (5 %) (2 charged leptons, $2\nu \Rightarrow$ large missing E_T, 2 jets)
  - lepton+jet channel (30 %)
  - all-hadronic channel (44 %)
  - $\tau + X$ (21 %), ID of τ is problematic



Event Selection

- 2 identified leptons (e/μ) with $E_T > 20\ GeV$ ($\geq$ 1isolated)
- $\geq$ 2jets (jet cone $R \equiv \sqrt{\Delta\phi^2 + \Delta\eta^2} \leq 0.4$) with $E_T > 15\ GeV, |\eta| < 2.5$
- missing transverse energy $\not{E}_T > 25\ GeV$ ($\Delta\phi(\not{E}_T, \ell\ or\ jet) > 20^\circ$ if $\not{E}_T < 50$)
- if $76\ GeV < M_{\ell^- \ell^+} < 106\ GeV \Longrightarrow$ jet signific. > $8\sqrt{GeV}$ ($JetSig \equiv \frac{\not{E}_T}{\sqrt{\sum_{\cos\Delta\phi(\not{E}_T, \vec{E}_{T_j})>0} \vec{E}_{T_j} \cdot \left(\frac{\vec{\not{E}}_T}{\not{E}_T}\right)}}$)
- $H_T > 200\ GeV$ (scalar transverse energy sum of leptons, jets and $\not{E}_T$)

Principles of Top Mass Reconstruction in Dilepton Channel

- 2 neutrinos in final state $\Longrightarrow$ system is under-constrained (not enough measured quantities)!
- introducing variable $P_{t\bar{t}_z} = 0, \sigma(P_{t\bar{t}_z}) = 180\,GeV$
- solve kinematic equations

$$
\begin{aligned}
P_{W^+} &= P_{l^+} + P_{\nu} \\
P_{W^-} &= P_{l^-} + P_{\bar{\nu}} \\
P_{t} &= P_{b} + P_{W^+} \\
P_{\bar{t}} &= P_{\bar{b}} + P_{W^-} \\
P_{\nu_{1x}} + P_{\nu_{2x}} &= \not{E}_{T\,x} \\
P_{\nu_{1y}} + P_{\nu_{2y}} &= \not{E}_{T\,y} \\
P_{t\,z} + P_{\bar{t}\,z} &= P_{t\bar{t}_z}
\end{aligned}
$$

moreover we suppose:
$m_{\nu,\bar{\nu}} = 0, M_t = M_{\bar{t}}, M_{W^{\pm}} = 80.4\,GeV$

Principles of Mass Reconstruction(2)

previous system of equations can be rewritten:

$$
\begin{aligned}
f_1(P_{\nu_{1x}}, P_{\nu_{1y}}, P_{\nu_{1z}}) &\equiv (E_{l_1} + E_{\nu_1})^2 - (\vec{P}_{l_1} + \vec{P}_{\nu_1})^2 - M_W^2 &= 0 \\
f_2(P_{\nu_{1x}}, P_{\nu_{1y}}, P_{\nu_{1z}}) &\equiv (E_{l_2} + E_{\nu_2})^2 - (\vec{P}_{l_2} + \vec{P}_{\nu_2})^2 - M_W^2 &= 0 \\
f_3(P_{\nu_{1x}}, P_{\nu_{1y}}, P_{\nu_{1z}}) &\equiv (E_{l_1} + E_{\nu_1} + E_{b_1})^2 - (\vec{P}_{\nu_1} + \vec{P}_{l_1} + \vec{P}_{b_1})^2 & \\
&- (E_{l_2} + E_{\nu_2} + E_{b_2})^2 + (\vec{P}_{\nu_2} + \vec{P}_{l_2} + \vec{P}_{b_2})^2 &= 0
\end{aligned}
$$

- solve it with Newton numerical method
- complications: existence of more solutions, possibility of more than 2 jets in final state, more possible combinations of lepton and jet, quantities are measured with some precision

Reconstruction Method in Practical Use

- for each event the kinematic quantities are smeared around measured values and according the errors $\rightarrow$ each event is reconstructed many times (10000) using smeared quantities
- we get “raw top mass” distribution for given event and MPV is top mass estimate for given event
- reconstructing top mass for all events in given MC sample we get PDF $\equiv$TEMPLATE
- final top mass estimate: comparing “raw mass distribution” from data to MC templates using likelihood fit:

$$\mathcal{L} \equiv \mathcal{L}_{shape} \times \mathcal{L}_{bg}$$

$$\mathcal{L}_{shape} \equiv \frac{e^{-(n_s+n_b)}(n_s+n_b)^N}{N!} \prod_{i=1}^{n} \frac{n_s \times f_s({m_{t_i}}^{rec}, m_t^{orig}) + n_b \times f_b({m_{t_i}}^{rec})}{n_s+n_b}$$

$$-\ln \mathcal{L}_{bg} \equiv \frac{(n_b - n_b^{exp})^2}{2\sigma_{n_b}^2}$$

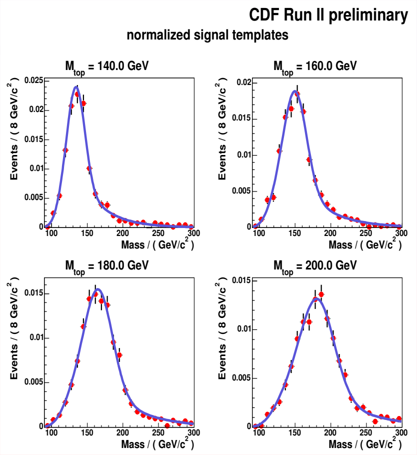
MC signal templates

- create MC $t\bar{t}$ templates for $M_{top} = 140 - 220\,GeV$
- global fit of all templates at once using "Landau"+ Gauss distribution:

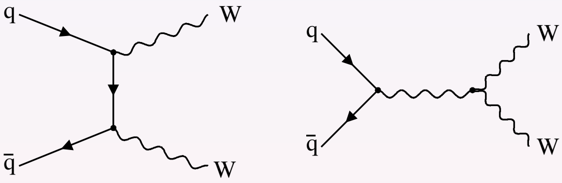
$$\lambda = \frac{m_t^{rec} - p_1(m_t^{orig})}{p_2(m_t^{orig})}$$

$$f(m_t^{rec}, m_t^{orig}) = \frac{p_3(m_t^{orig})}{I_1} e^{(-0.5(\lambda + e^{-\lambda}))} + \frac{(1. - p_3(m_t^{orig}))}{I_2} e^{(-0.5\lambda^2)}$$

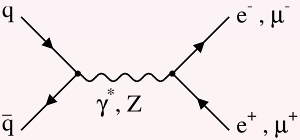
- parameters $p_i, i = 1, ..3$ are linearly dependent on m_{top}



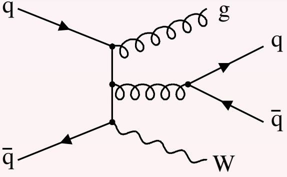
Background



diboson WW/WZ



Drell-Yan,

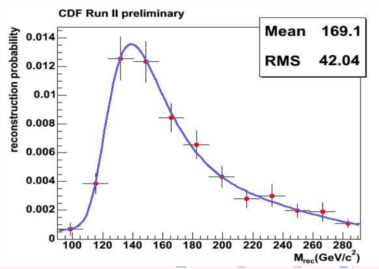


FAKES(W+3jets)

Background(2)

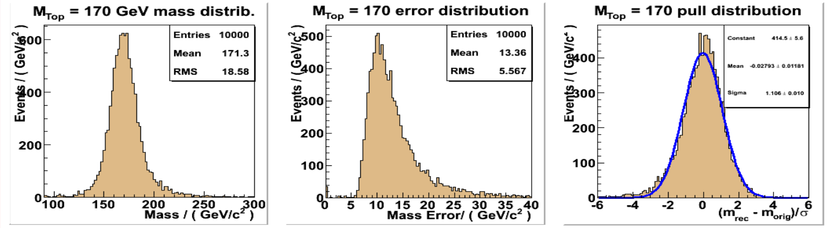
background	expect. num. ev. in 340 pb^{-1}	recons. probab.
WW/*WZ*	1.6 ± 0.3	0.65
Drell-Yan(e, μ, τ)	5.5 ± 1.2	0.62
FAKES	3.5 ± 1.4	0.60
total	10.5 ± 1.9	0.62

- backgrounds are weighted according expected number of events and also according probability of reconstruction



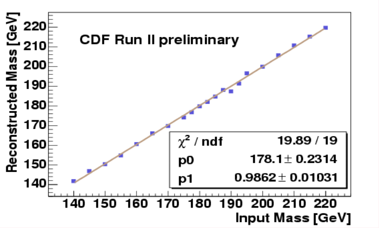
Testing the method - Pseudo-experiments (PE)

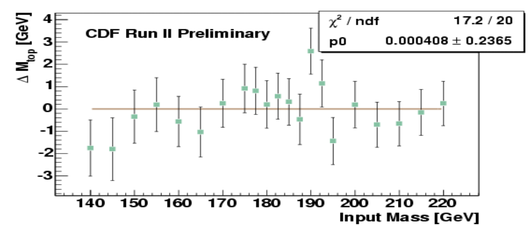
- PE - one possibility of testing the method
- testing on MC with known m_{top} (also “blind test” on unknown m_{top} MC performed)
- randomly choose “N” events from MC sample and reconstruct the mass for given set of events as it would be the data,perform it many times (10000)
- example ($m_{top} = 170\ GeV$):

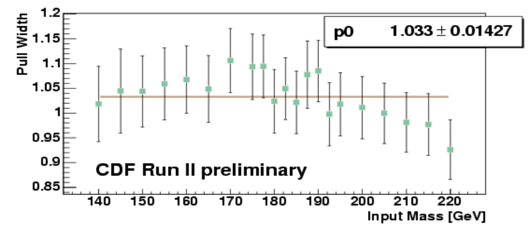


Pseudo-experiments (2)

- check recon. m_{top}: $\Delta M_{top} = m_{orig} - m_{rec}$
- check recon. $\sigma_{m_{top}}$: $\sigma_{pull} \equiv 1$







Systematic Errors

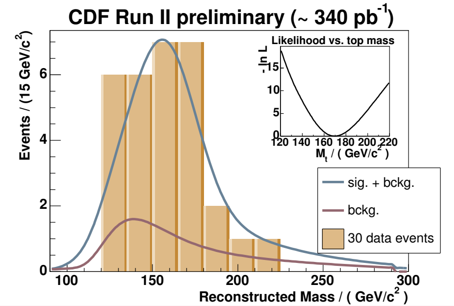
- with more data, systematic errors will start to dominate
- the biggest uncertainty from JES (transition from detector level to parton level)

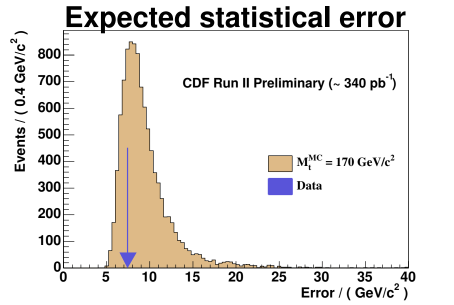
CDF Run II preliminary

system. type	ΔM_{top} (GeV/c^2)
Jet Energy Scale	3.2
B-Jet energy scale	0.6
MC Generators	0.6
ISR	0.6
FSR	0.3
PDFs	0.5
Background shape	1.6
Signal statistics	0.4
Background statistics	1.2
Total	4.0

Data

33 $t\bar{t}$ candidates in data in 340 pb^{-1}(30 get reconstructed):





$$M_{top} = 169.5^{+7.7}_{-7.2}(\text{stat.}) \pm 4.0(\text{syst.})\ \text{GeV}/c^2$$

Other m_{top} measurements in dilepton channel at CDF

- template methods:
  - NWA - assumption about $\eta_{\nu_1}, \eta_{\nu_2}$
  - PHI method - assumption about $\phi_{\nu_1}, \phi_{\nu_2}$
  - more solutions$\rightarrow$ minimalization of "χ^2"
  - all the rest is similar to our method (comparing MC templates with data)

a few weeks old result ($750\ pb^{-1}$):$164.5 \pm 4.5(stat.) \pm 3.1(syst.)$

- Matrix-Element method:
  - don't do simplifications about kinematic variables
  - calculate $P(\vec{x}_{meas.}|M_{top})$ using LO $\sigma_{q\bar{q}\rightarrow t\bar{t}}$ with ME
- combined result in dilepton channel (RunI+RunII):
  $M_{top\ dil} = 167.9 \pm 5.2(stat.) \pm 3.7(syst.)$

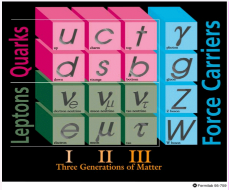
Conclusion

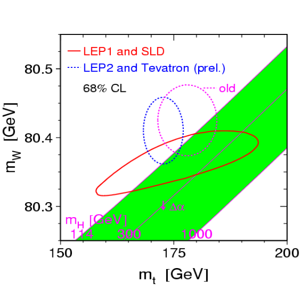
- our method established within CDF
- measured top quark mass with 340 pb^{-1} : $M_{top} = 170.2^{+7.8}_{-7.3}(\mathrm{stat.}) \pm 3.8(\mathrm{syst.})\ \mathrm{GeV}/c^2$ (results already sent for publication a few weeks ago)
- at the end of Run II : combined $\delta m_{top} \leq 1.5\ GeV$
- should be straightforward to use it at LHC!

Backup

Why is top quark interesting?

- fundamental particle of Standard Model(SM)
- by far the heaviest of all particles
  →possible hint to physics beyond SM
- only one to decay before hadronization
- m_{top} a m_W constrain Higgs boson mass





Summary of CDF top mass results

- best result:
  template method+JES calibration
  using $W \to jj$
- projection for Run 2: