Measurement of Top Quark Mass in Dilepton Channel at CDF and D0

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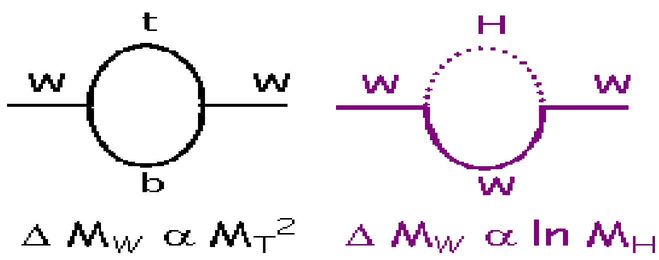
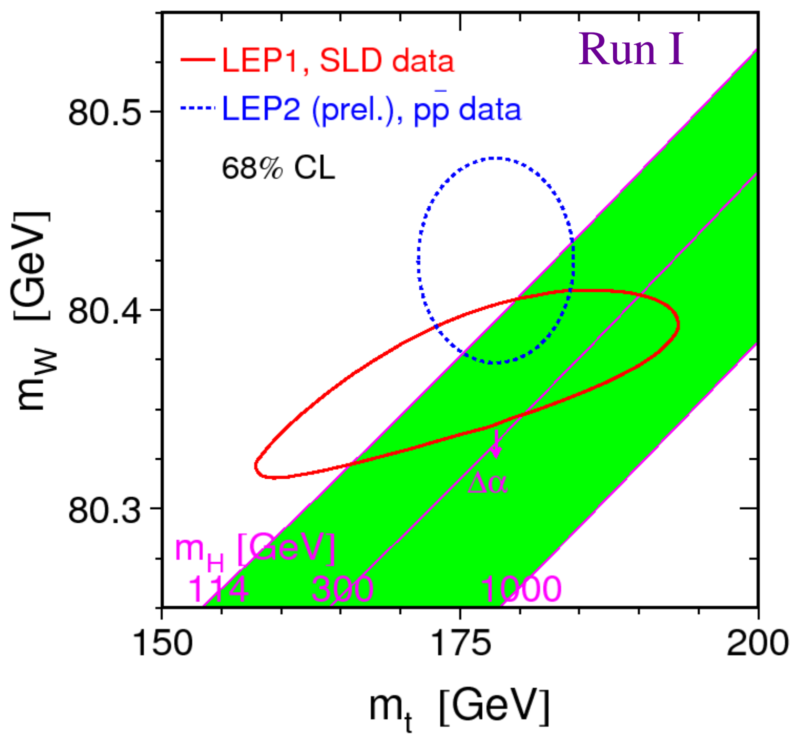
for CDF and D0 collaborations

Introduction

Direct measurements of m_t:

- tests SM predictions
- constrains SM Higgs mass
- key to EWSB





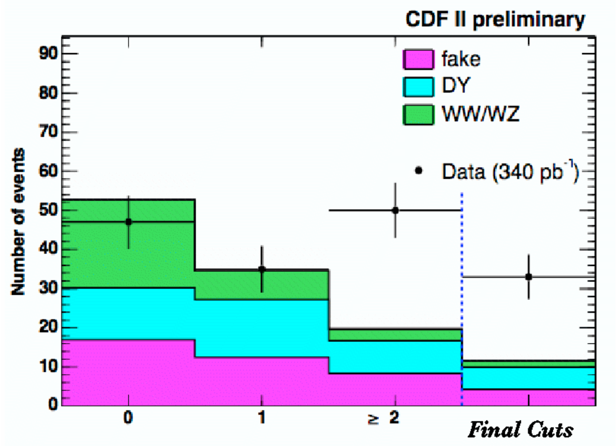
Higgs mass tied to m_t and m_W

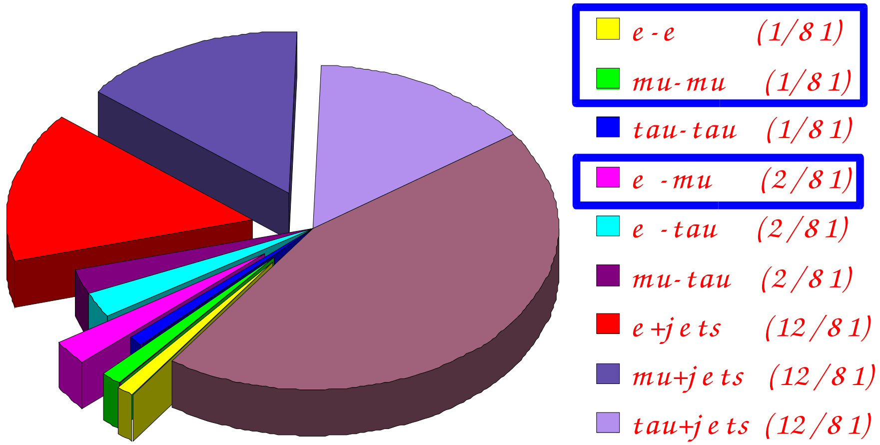
Measurement of m_t in dileptonic channel important consistency check

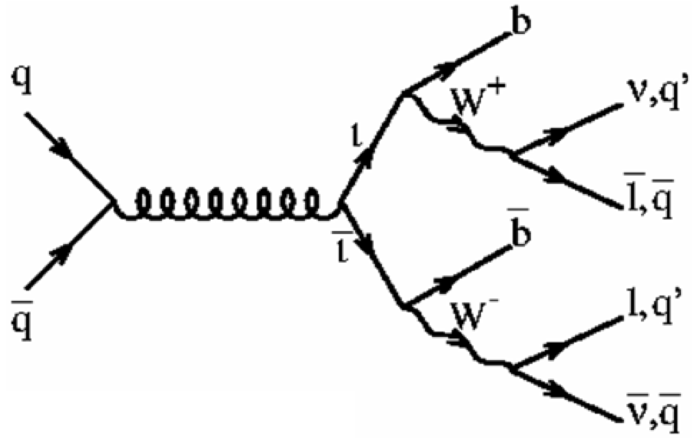
- any discrepancy between top mass measurements in different channels could indicate new physics

Top quark production and decay

- Top mass measurements use pair produced top quarks
- Dileptonic events: 5% BR in total
  - + clean signature
  - + only two possible parton-jet assignments
  - – lowest statistics
  - – two neutrinos in final state ⇒ under-constraint system for fitting of top mass







Techniques

Template methods

- Scan kinematic variables to compensate under-constraint system
- Reconstruct event-by-event m_{reco}
- Create templates using events simulated with different m_t values
- Perform likelihood fit to extract measured m_t

Matrix element method

- Build likelihood from matrix element, PDFs and transfer functions
- Integrate over unmeasured quantities
- Calibrate measured m_{reco} and uncertainty using simulation
- Determination of m_t by joint likelihood maximum

Dileptonic template methods

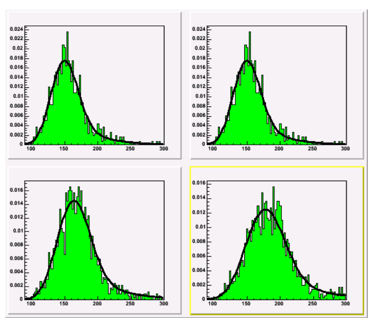
selected events

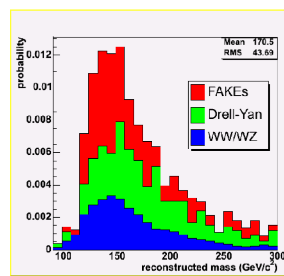
Mass calculation

Mass calculation:

Because of the two neutrinos, dileptonic ttbar decay is underconstraint $\Rightarrow$ make an assumption, and scan over the assumed variable. Calculate the most probable m_{reco} for each event

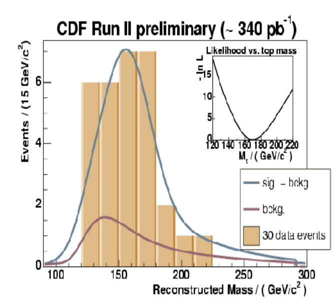
templates





Likelihood fit

result



Likelihood fit:

Fits the data m_{reco} distribution to MC templates $\Rightarrow$ m_t result

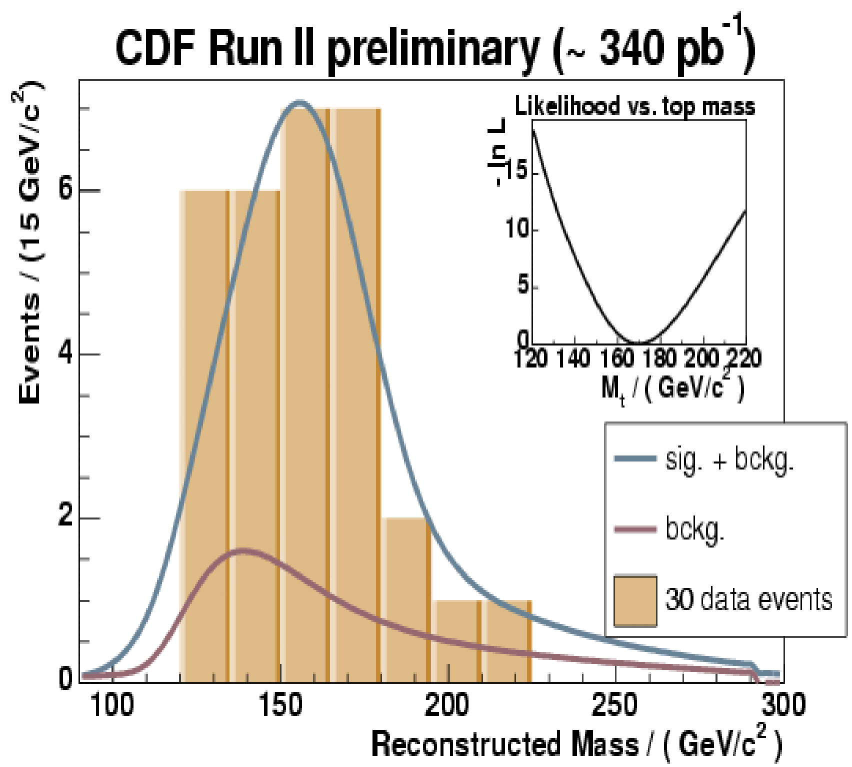
Dileptonic template methods at CDF

Method	Scanning variable	Distribution of variable
Kinematic	P_z of $t\bar{t}$ system	Gaussian distribution with $\sigma = 180$ GeV/c^2
NWA-η	η_1 and η_2 of the two neutrinos	Gaussian distribution with $\sigma = 0.998$
NWA-ϕ	ϕ_1 and ϕ_2 of the two neutrinos	Flat

NWA = Neutrino Weighting Algorithm

Kinematic: $P_z(t\bar{t})$

- Assume Gaussian distribution of $P_z(t\bar{t})$ with sigma value of 180 GeV/c
- Scan over $P_z(t\bar{t})$, parton energies and missing E_T
- Perform kinematic reconstruction of m_t at each point
- Pick the most probable value of m_t as m_{reco}



m_{top} = 170.2+7.8/-7.2(stat)±3.8 (syst) GeV/c^2

$\int \mathcal{L} = 340\ pb^{-1}$

Measured masses

Method	Data sample	Measured top mass
Kinematic	340 pb^{-1}	170.2+7.8/-7.2(stat)$\pm$3.8 (syst) GeV/c^2
NWA-η	359 pb^{-1}	170.6+7.1/-6.6(stat)$\pm$4.4 (syst) GeV/c^2
NWA-ϕ	340 pb^{-1}	169.8+9.2/-9.3(stat)$\pm$3.8 (syst)GeV/c^2

Matrix element method at CDF

- Use LO **Matrix Element** for $t\bar{t}$ production and decay to build differential cross-section

$$P(\mathbf{x}|M_t) = \frac{1}{\sigma(M_t)} \frac{d\sigma(M_t)}{d\mathbf{x}}$$

- Parametrize detector response to jets by constructing **Transfer Functions** which map parton energies to observed jet energies

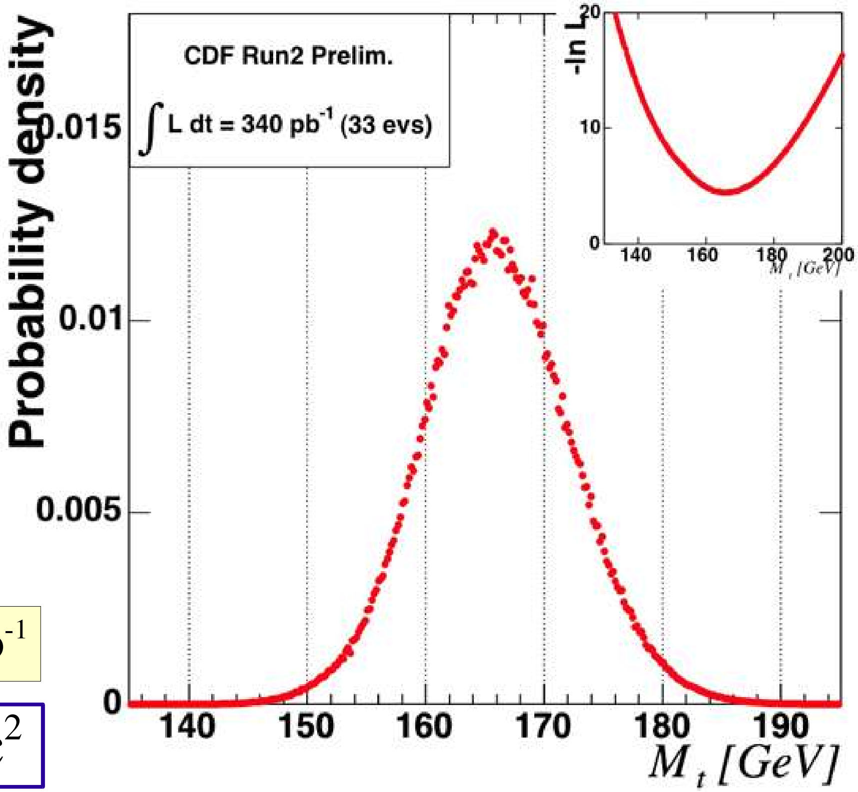
$$P(\mathbf{x}|M_t) = \frac{1}{N} \int d\Phi_6 |\mathcal{M}_{t\bar{t}}(p; M_t)|^2 \prod_{jets} f(p_i, j_i) f_{PDF}(q_1) f_{PDF}(q_2)$$

- Evaluate differential cross-sections **for backgrounds**
- Weld together the above pieces to get expression for m_t posterior distribution (given data)

$$P(\mathbf{x}|M_t) = P_s(\mathbf{x}|M_t) P_s + P_{bg1}(\mathbf{x}) P_{bg1} + P_{bg2}(\mathbf{x}) P_{bg2} \ldots$$

Matrix element

- Integrate over 6 unmeasured parton quantities: 2x3 (neutrino momentum) + 2x1 (quark energy) – 2 (p_T conservation)
- Calibrate the result



$\int \mathcal{L} = 340\ pb^{-1}$

$m_{top} = 165.2 \pm 6.1(stat) \pm 3.4\ (syst)\ GeV/c^2$

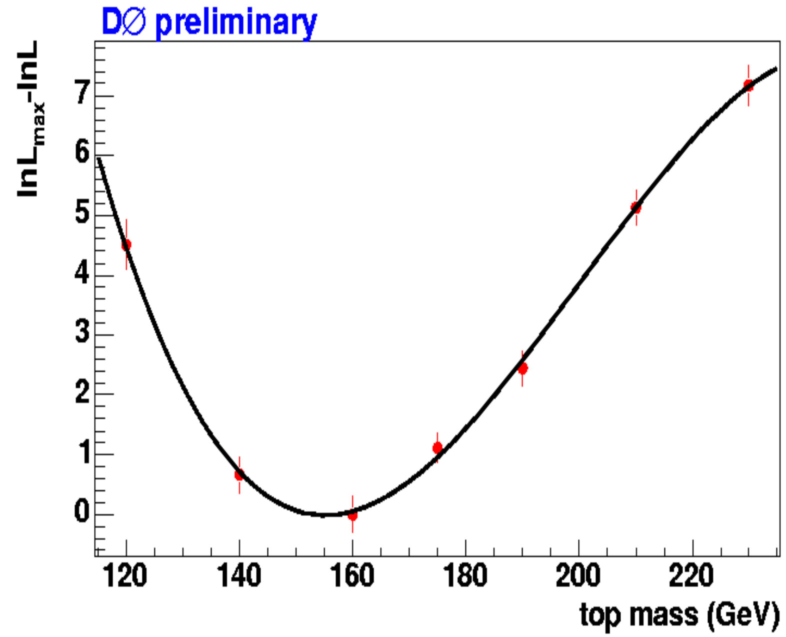
D0 template

$$W(M_{top}) = \sum_{solution} PDF_{a/p}(x_1) \cdot PDF_{b/\bar{p}}(x_2) \times p(E_l^* \mid M_{top}) \cdot p(E_{\bar{l}}^* \mid M_{top})$$

- Assume x_1,x_2, scan over the values
- Calculate weight
- Weight comes from Matrix Element
- Pick m_t with largest weight as m_{reco}

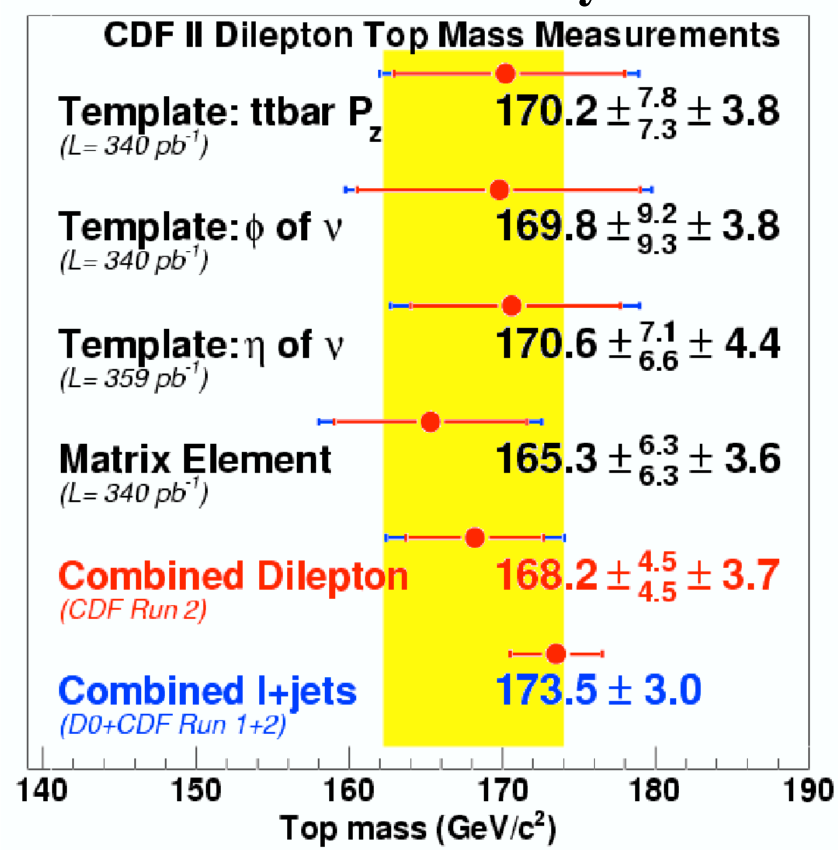
$\int \mathcal{L} = 230\ pb^{-1}$

m_{top} = 155+14/-13(stat)±7 (syst) GeV/c^2



Combination of CDF results

Preliminary



Weight achieved via studies of correlation in pseudo-experiments which model data

	ME	NWA	KIN	PHI
Weight	42%	31%	16%	12%

Combined dilepton top mass from CDF

$$m_{top} = 168.2 \pm 4.5(\text{stat}) \pm 3.7\ (\text{syst})\ \text{GeV}/c^2$$

In the current top mass world average, dileptonic measurements have 11% weight

Systematics

	Matrix Element	Template (KIN)	Template
JES	2.6	3.2	5.6
b-jet modeling	0.5	0.6	N/A
ISR	0.5	0.6	N/A
FSR	0.5	0.3	N/A
PDFs	1.1	0.5	0.9
Generators	1.0	0.6	3.0
Bckg shape	0.8	1.5	1.0
MC statistics	1.3	0.8	1.1
...	...	...	...
Total	3.6	3.8	6.7

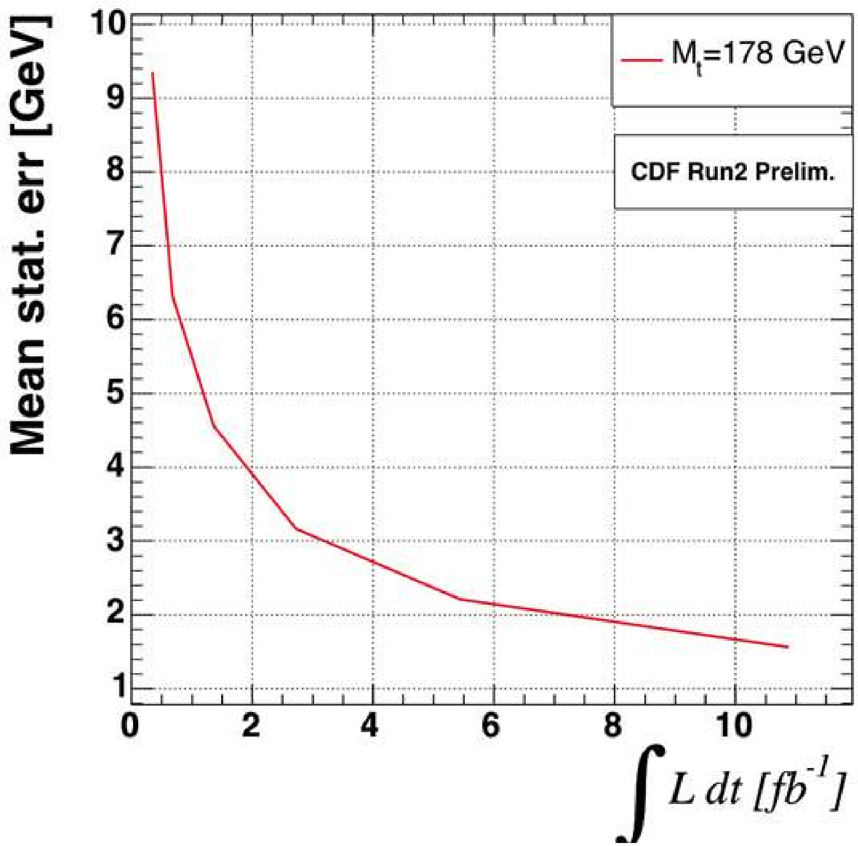
Improves with more CPU power

Improves with more data and smarter algorithm

Not much

b-jet energy scale can be checked with $Z \rightarrow b\bar{b}$

Projected statistical uncertainty



- Projection is only for CDF matrix element method
- With 2.5 fb^{-1} of data, the projected statistical error is of the same order than the current systematic error from the method
- Dilepton top mass becomes precision measurement

Summary

- Comparison of top mass in l+jets and dilepton channels has sensitivity to new physics
- Top mass measurement in dileptonic channel has potentially smaller systematics than in other top decay channels.
- The combined CDF top mass measurement in dileptonic channel

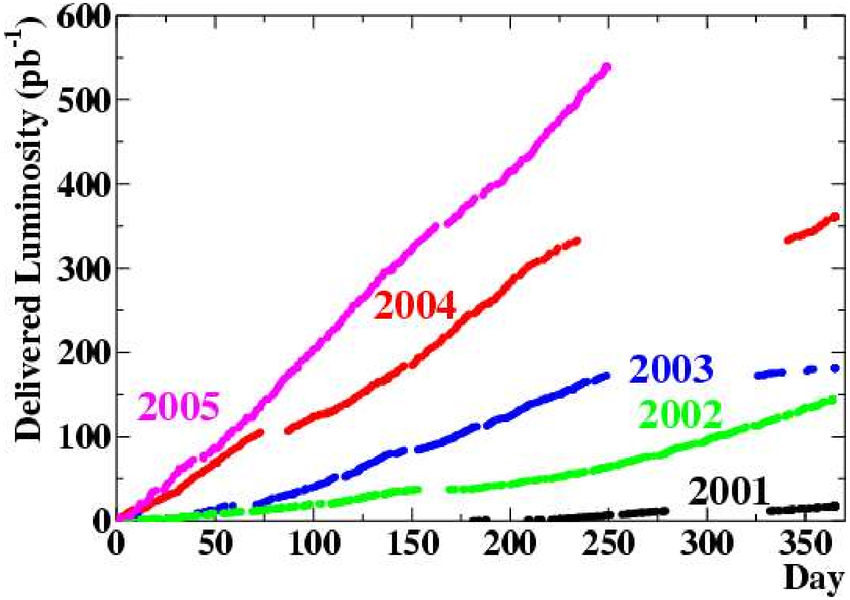
  m_{top} = 168.2±4.5(stat)±3.7 (syst) GeV/c^2 $\int \mathcal{L} = 340 – 359\ pb^{-1}$
- D0 top mass measurement in dileptonic channel

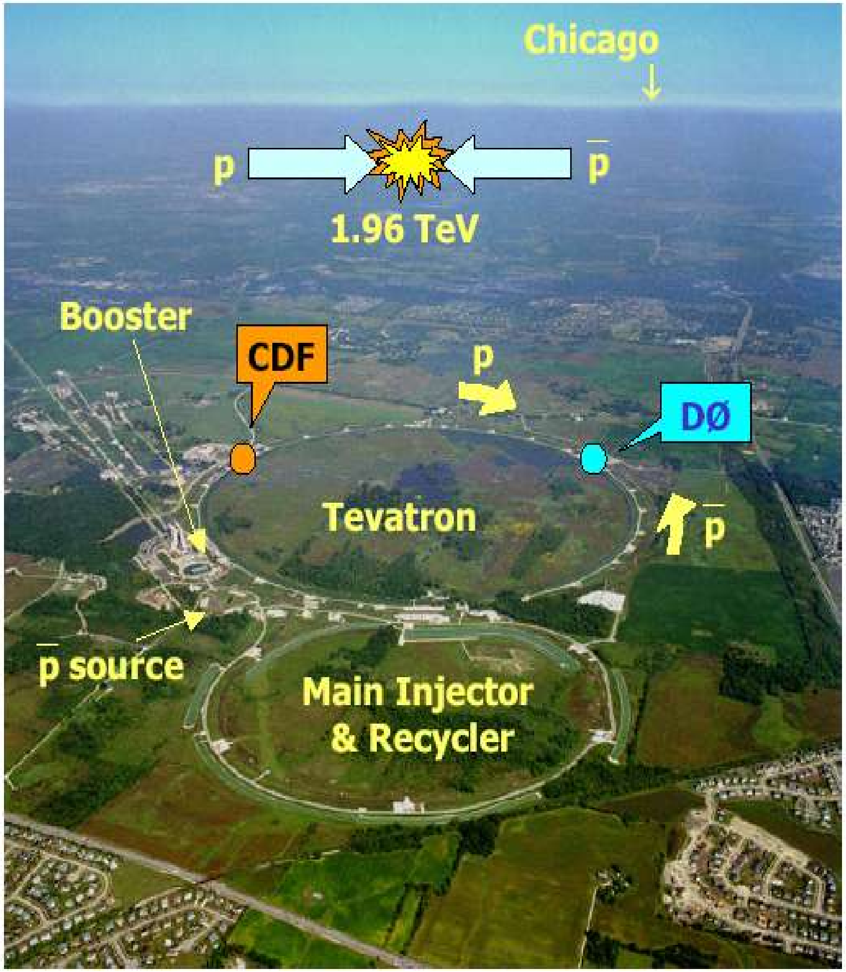
  m_{top} = 155+14/-13(stat)±7 (syst) GeV/c^2 $\int \mathcal{L} = 230\ pb^{-1}$
- With 2.5 fb^{-1} of data, the statistical error is expected to be of the same order than the current systematic error (matrix element method)

Backup

Tevatron Run II

- 1 fb^{-1} of data per experiment on tape
- Peak luminosity 1.5 x $10^{32}cm^{-2}s^{-1}$
- Presented analysis use 200-350 pb^{-1}



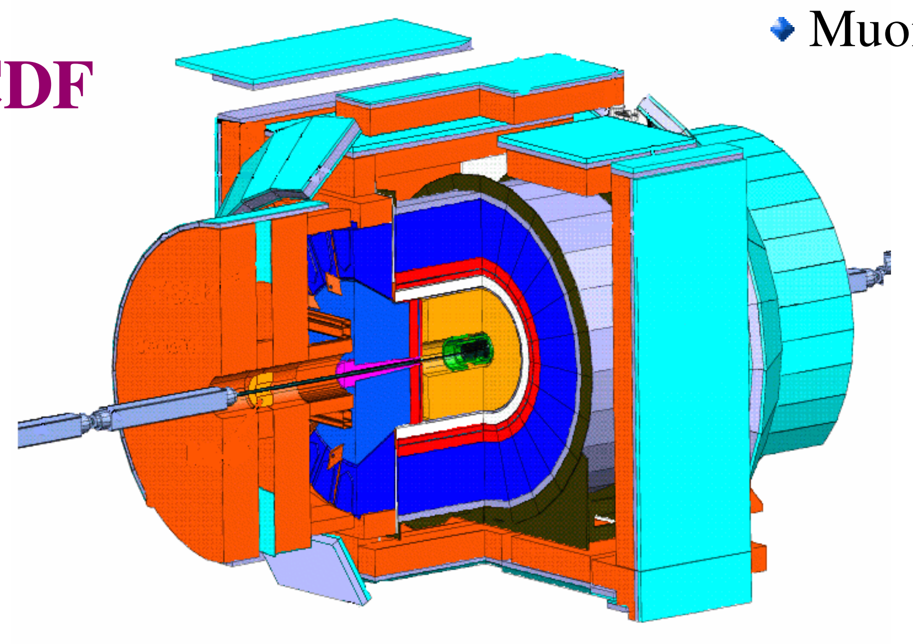


CDF and D0 detectors

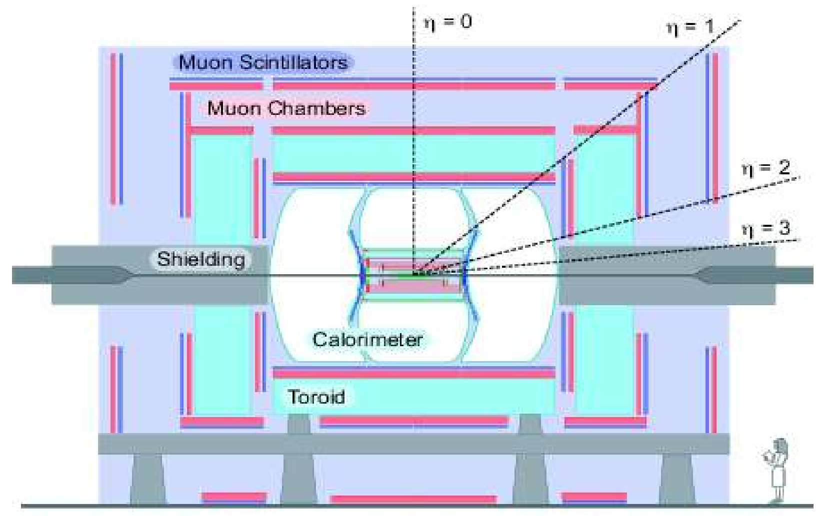
Both are multi-purpose detectors, designed for precision measurement and search for new physics

- Tracking in magnetic field
- Precision tracking with silicon
- Calorimeters
- Muon chambers

CDF

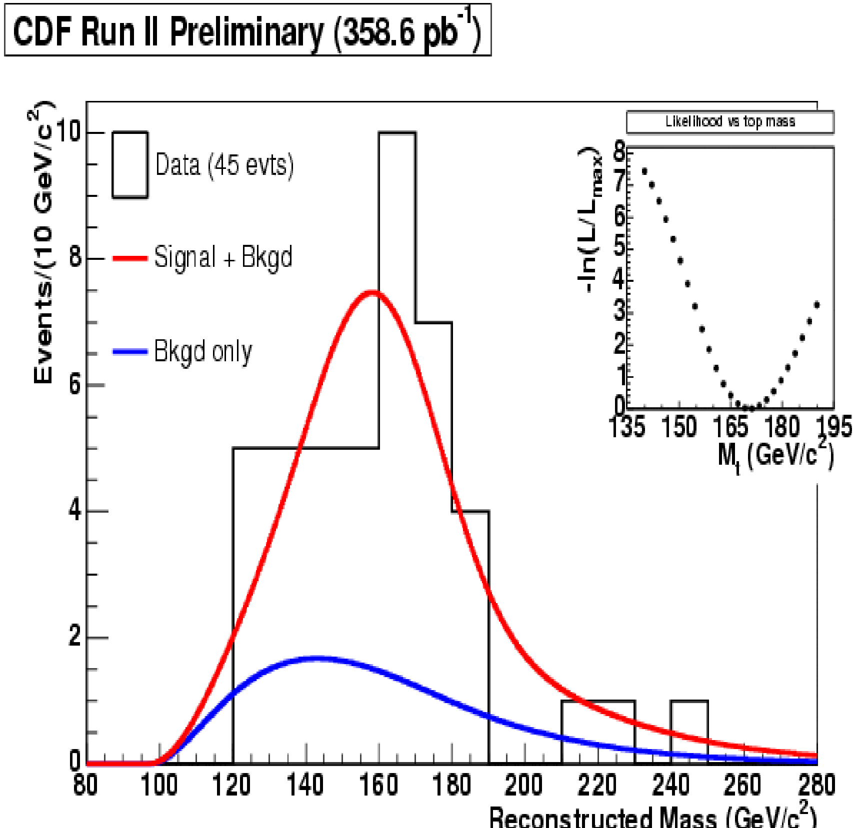


D0



NWA-η

- Assume η_1, η_2 of the two neutrinos and m_t
- Integrate over unknowns
    - Lepton-jet pairing
    - Neutrino η
    - Missing energy
- Calculate the probability of measuring the observed missing E_T
- m_{reco} is the m_t with largest probability



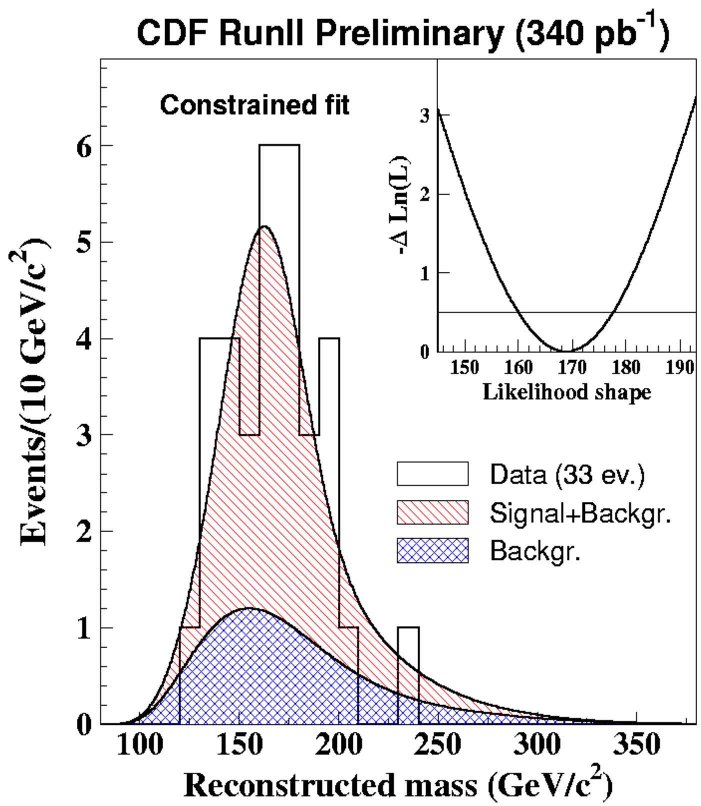
m_{top} = 170.6+7.1/-6.6(stat)±4.4 (syst) GeV/c^2

$\int \mathcal{L}$ = 359 pb^{-1}

NWA-ϕ

$$\chi^2 = \sum_{i=l,jets} \frac{(P_T^{i,fit} - P_T^{i,meas.})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(UE_j^{j,fit} - UE_j^{j,meas.})^2}{\sigma_j^2}$$
$$+ \frac{(M_{l_1\nu_1} - M_W)^2}{\Gamma_W} + \frac{(M_{l_2\nu_2} - M_W)^2}{\Gamma_W} + \frac{(M_{l_1\nu_1 b_1} - M_{top})^2}{\Gamma_{top}} + \frac{(M_{l_2\nu_2 b_2} - M_{top})^2}{\Gamma_{top}}$$

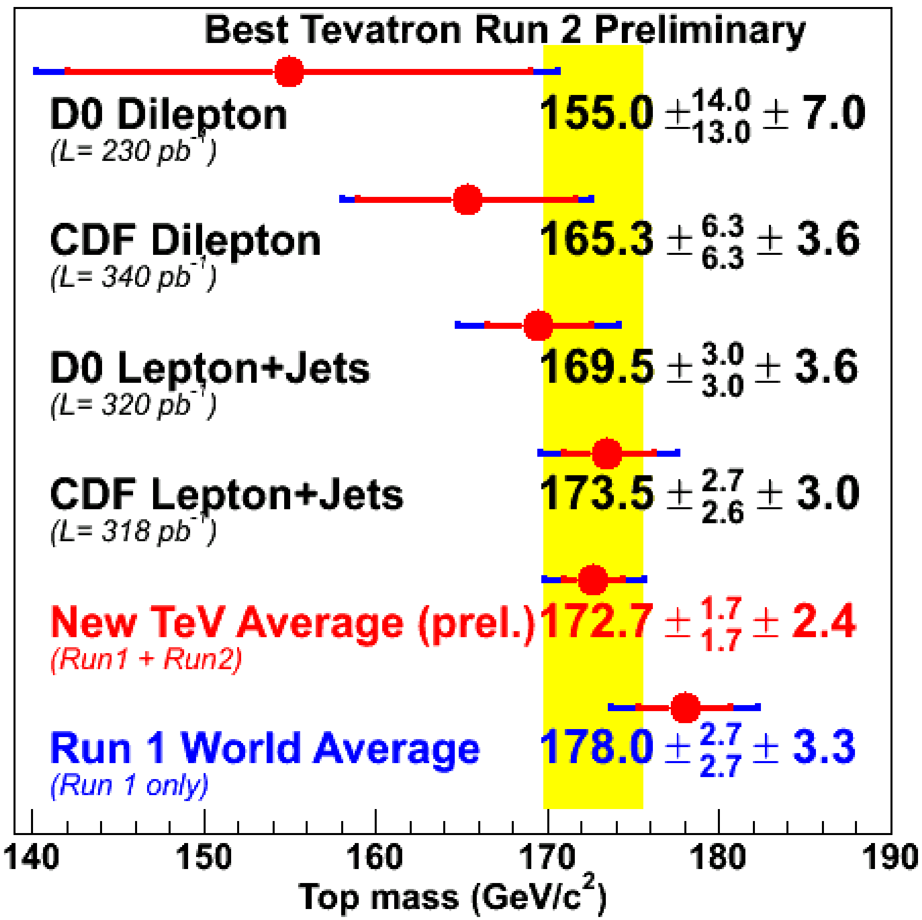
- Assume ϕ_1, ϕ_2 of the two neutrinos, scan over plane
- Calculate χ^2
- Weight each point in ϕ_1- ϕ_2 space by $e^{-\chi^2/2}$
- Select mean of reconstructed m_t distribution as m_{reco}



m_{top} = 169.8+9.2/-9.3(stat)±3.8 (syst)GeV/c^2

$\int \mathcal{L}$ = 340 pb^{-1}

Top mass world average



- The mass of top quark is known with accuracy of 1.7%
- In the current top mass world average (only the best measurement from each channel/experiment used), dileptonic measurements have 11% weight