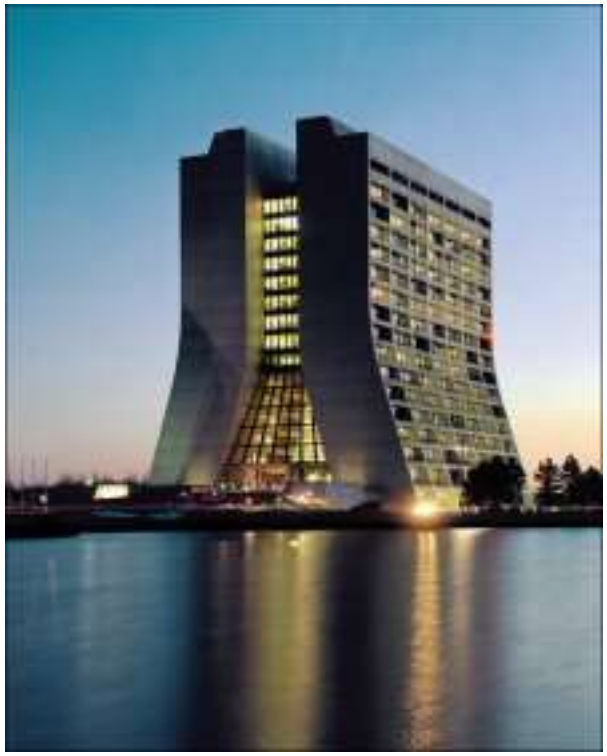
Measurement of the Top Quark Mass at DØ Using Dilepton Events

APS April meeting, Dallas 2006

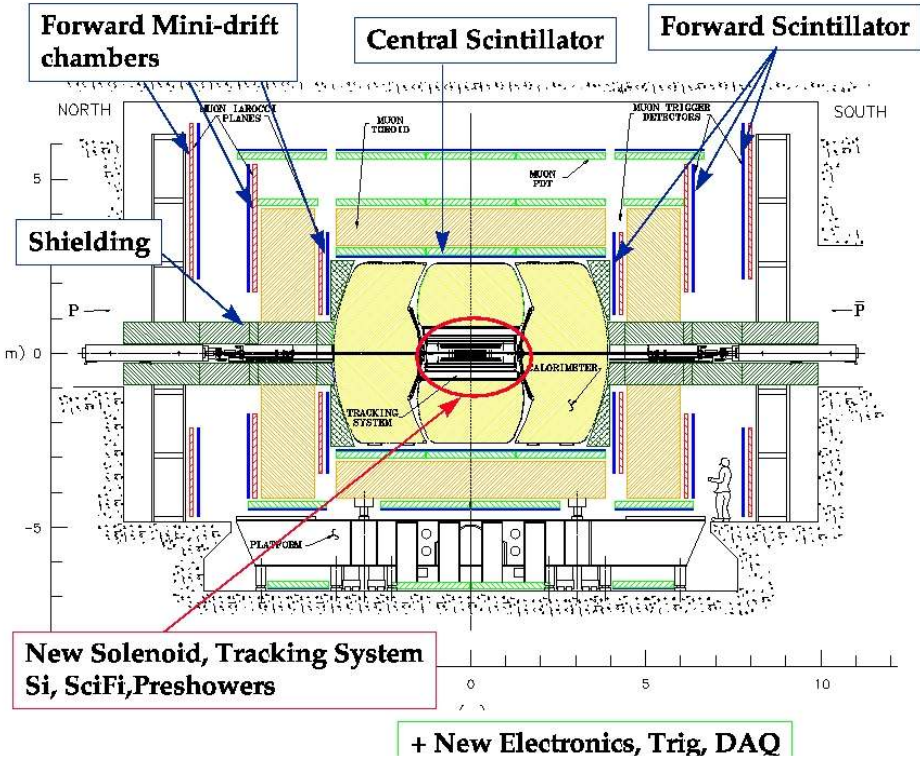


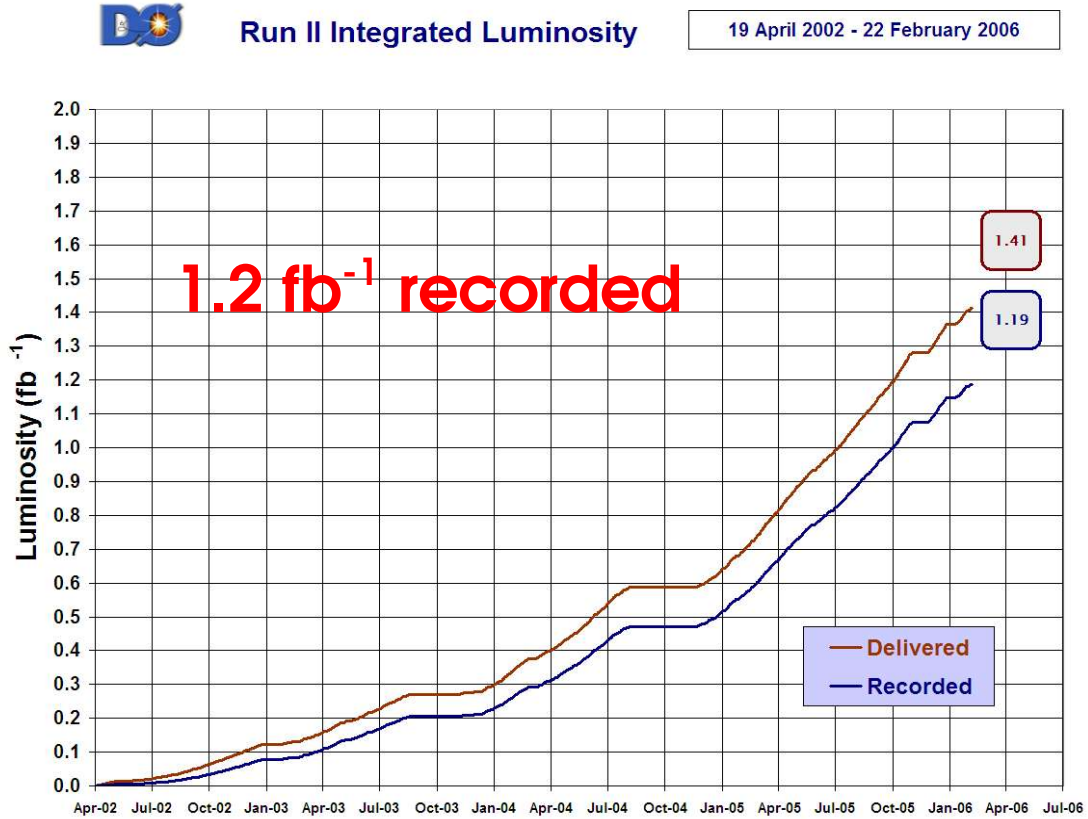
- DØ experiment at Tevatron
- Top quark properties
- Neutrino Weighting Method
- Matrix Weighting Method
- Selection
- Systematics and Results
- Summary

Jörg Meyer

on behalf of the DØ Collaboration

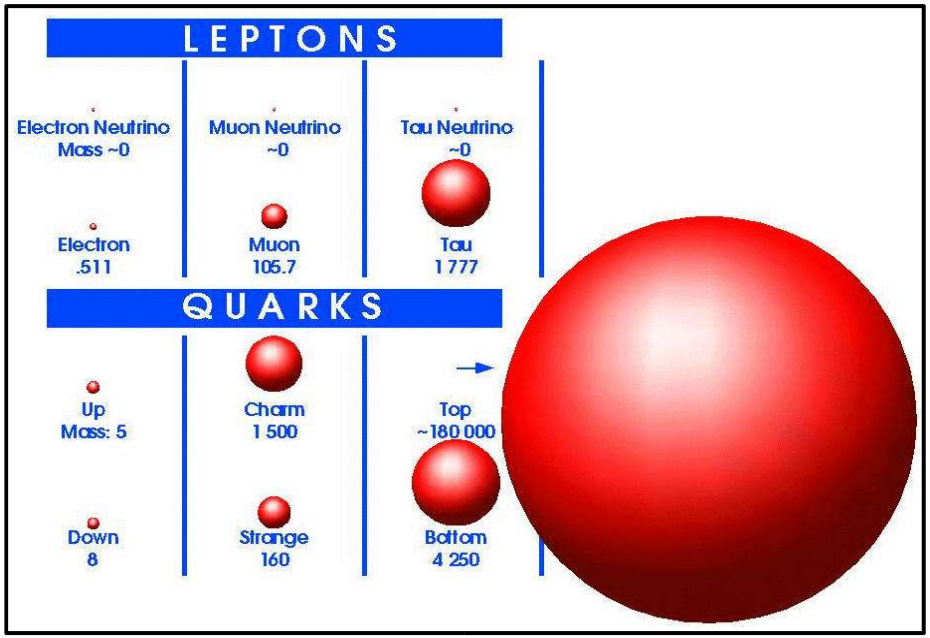
DØ – Detector and Data Taking





- 2 Tesla superconducting solenoid
- inner tracker: Silicon Microstrip Detector, Central Fiber Tracker
- Preshower Detectors, liquid argon calorimeter
- extended muon system, improved shielding
- faster electronics, new triggers and new DAQ

Top Quark in the Standard Model



- discovered in 1995 at Fermilab
- completes the quark sector
- large mass: 172.5 ± 2.3 GeV/c^2
- short life time:

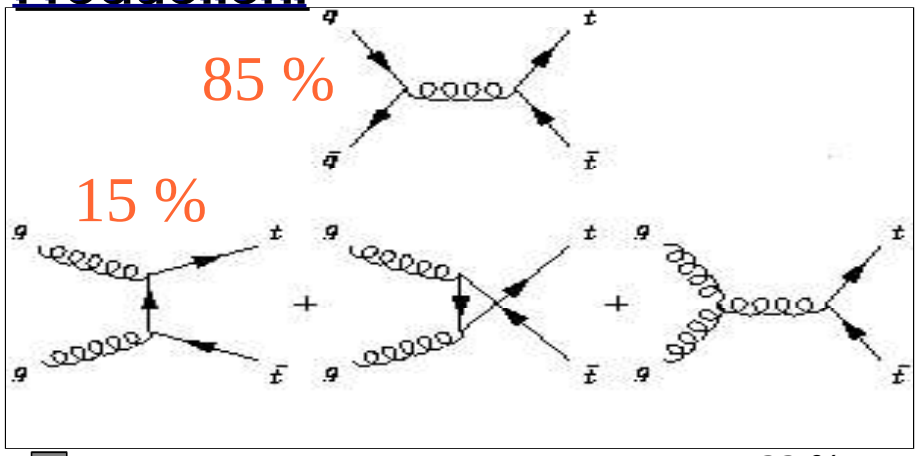
  $\sim 5 \cdot 10^{-25}$s $\ll \Lambda^{-1}_{QCD}$

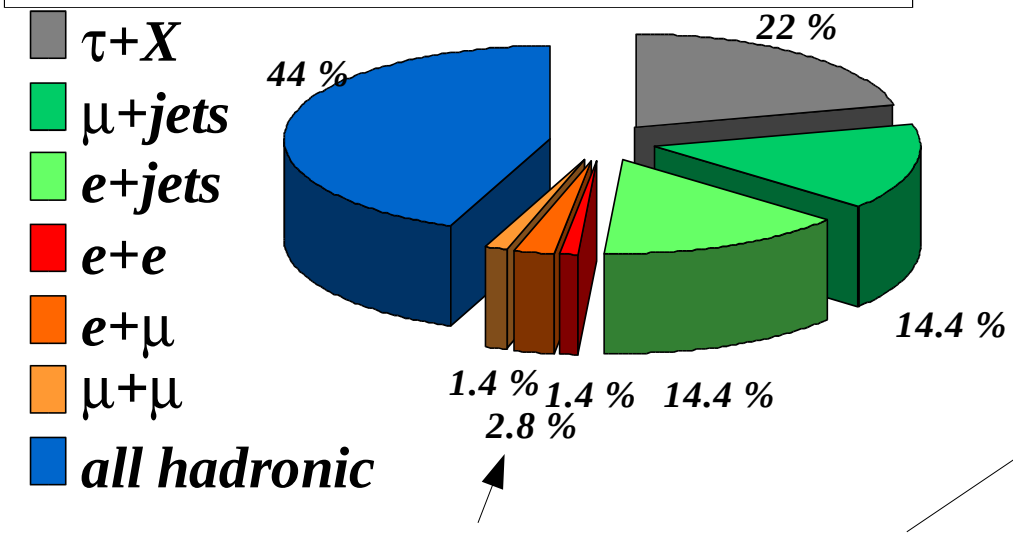
- W-boson and top quark mass constrain higgs mass in the Standard Model -> consistency check
- sensitive to new physics
- aim for Tevatron in Run II:

Δm_{top} = about 2 GeV per experiment

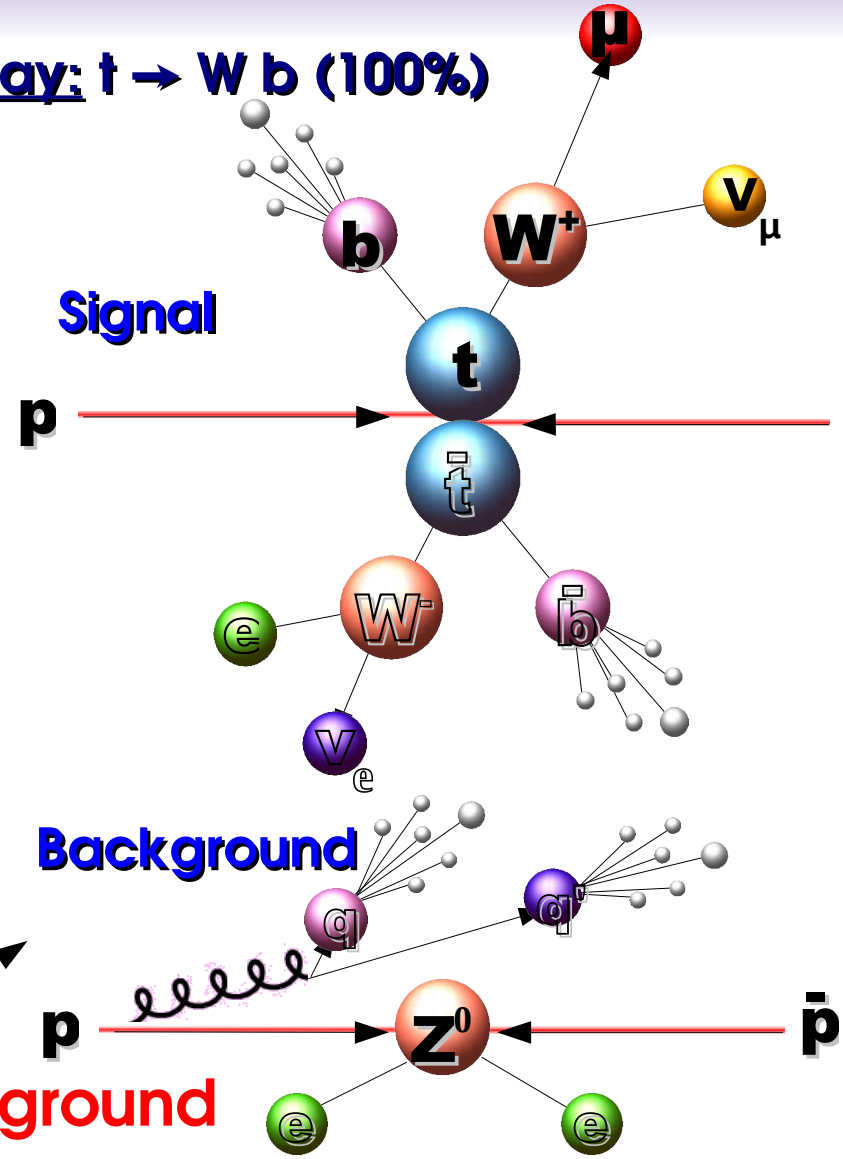
Top Quark Production and Decay

Production:



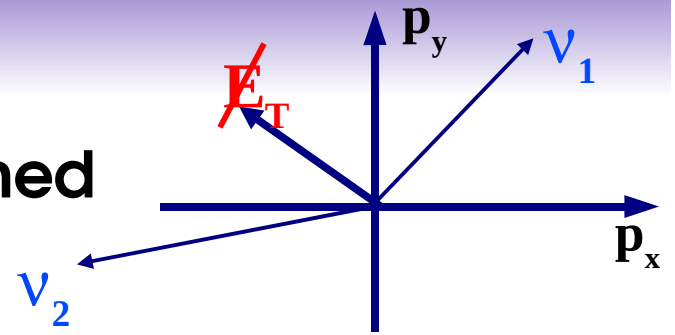


Decay: t → W b (100%)

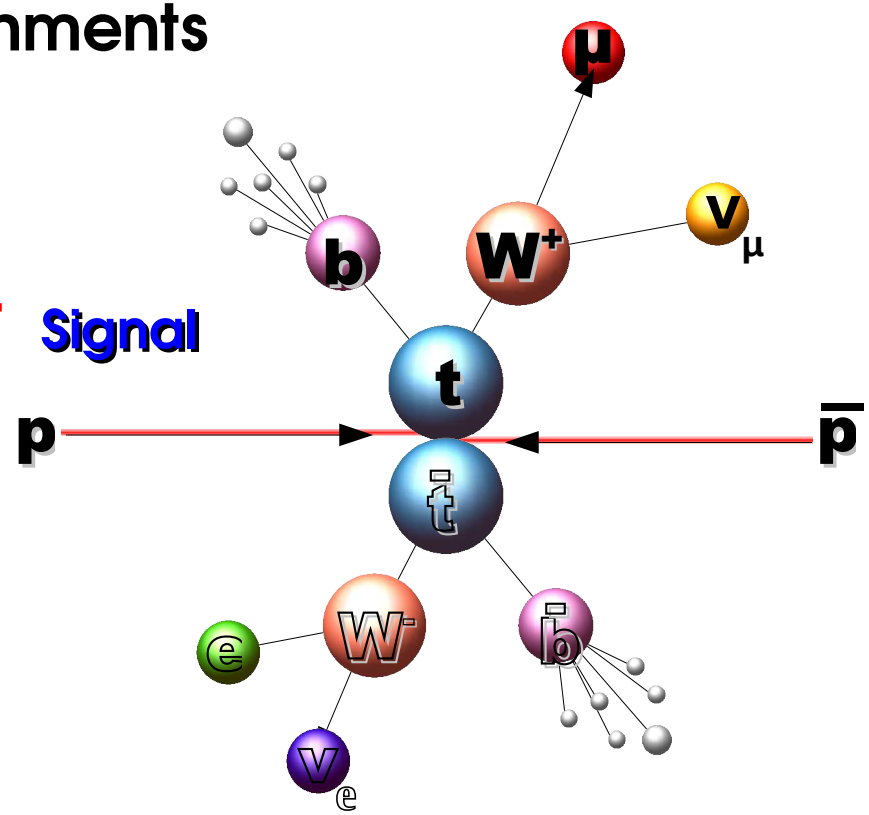


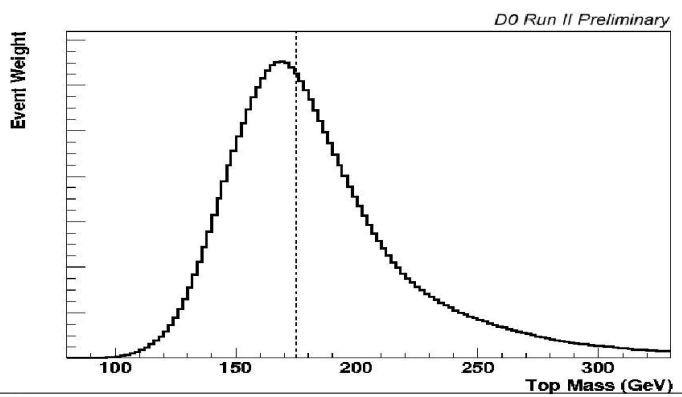
5% dilepton channel, small background

Dilepton Event Kinematics



- 2 neutrinos: kinematics is underconstrained by one degree of freedom
- several solutions, lepton-jet assignments
- use weighting algorithms
- -> different methods
  - Neutrino Weighting Method νWT
  - Matrix Weighting Method *M*WT



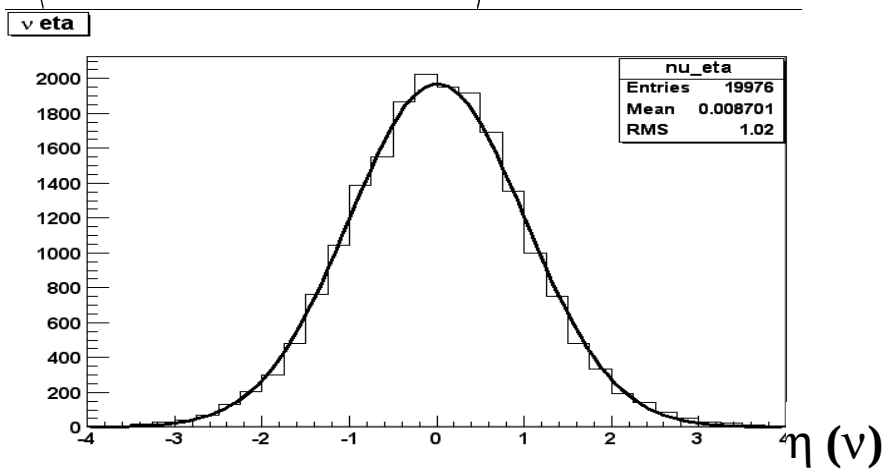


Neutrino Weighting Algorithm νWT

- assume: $m_t, \eta^{\nu}, \eta^{\bar{\nu}}$
- calculate $p_x^{\nu}, p_y^{\nu}, p_x^{\bar{\nu}}, p_y^{\bar{\nu}}$ using assumptions and kinematic constraints, but <u>not</u> $metx, mety$
- give each hypothesis a weight by comparing with measured missing transverse energy $metx, mety$:

$$w^{\nu}(m_t) = \exp\left(\frac{-\left(metx - p_x^{\nu} - p_x^{\bar{\nu}}\right)^2}{2\sigma^2}\right)\exp\left(\frac{-\left(mety - p_y^{\nu} - p_y^{\bar{\nu}}\right)^2}{2\sigma^2}\right)$$

- sum over all assumed $\eta^{\nu}, \eta^{\bar{\nu}}$, all kinematic solutions (2 for each neutrino) and both possibilities to assign the jets to the leptons



Matrix Weighting Algorithm *MWT*

- assume: m_t
- calculate $p_x^{\nu}, p_y^{\nu}, p_x^{\bar{\nu}}, p_y^{\bar{\nu}}$ using assumptions and kinematic constraints and $metx, mety$
- calculate probability density function for a given m_t as a function of the lepton energy E in the top quark rest frame:

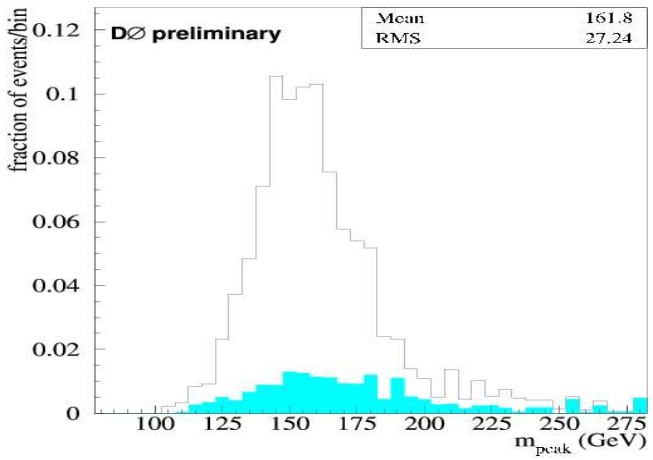
$$p(E|m_t) = 4\, m_t E \frac{m_t^2 - m_b^2 - 2\, m_t E}{(m_t^2 - m_b^2)^2 + m_W^2 (m_t^2 + m_b^2) - 2\, m_W^4}$$

- sum over all solutions and jet-lepton combinations

Weight Distributions vs. Top Quark Mass

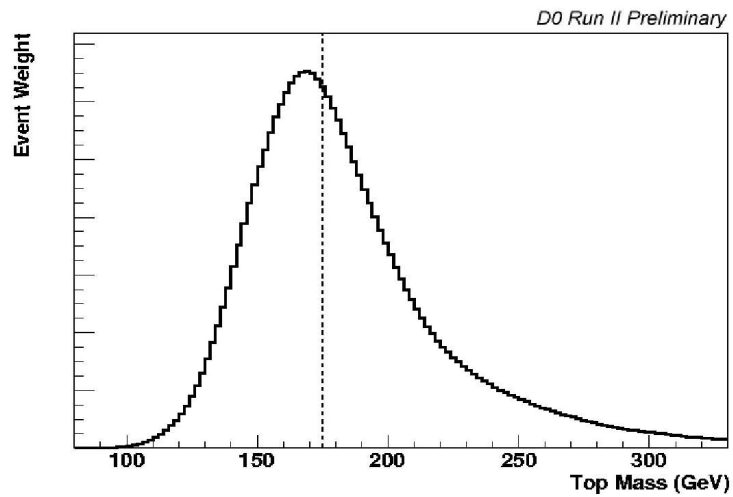
Matrix Weighting Method

MC with m_{top}=155 GeV



Neutrino Weighting Method

MC with m_{top}=175 GeV



- weight distributions peak at most probable top mass
- use weight distributions to construct a likelihood:

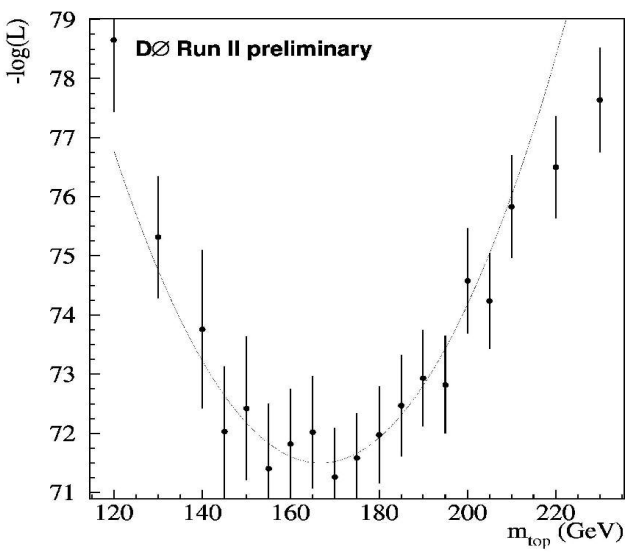
$$L(m_{top}) = L_{shape}(m_{top}) \times L_{n_b} \times L_{n_s+n_b}$$

Combined Maximum Likelihood Fits

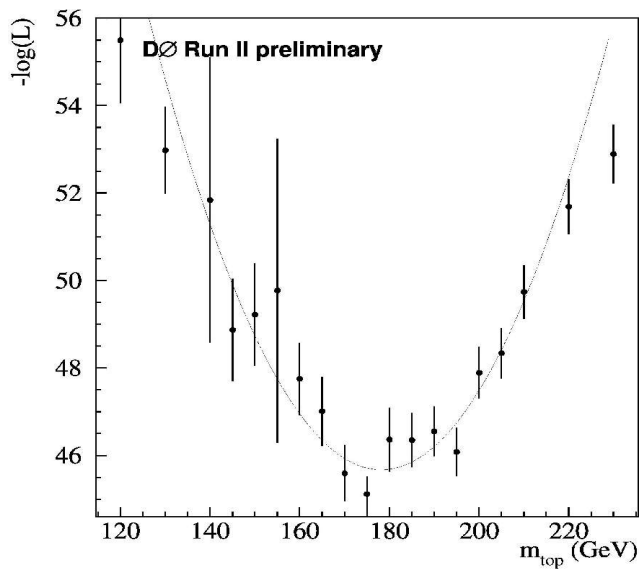
370pb^{-1}, 21events (ee+eμ+μμ)

source	$t\bar{t}$	WW,WZ	Z	fake ℓ	background	total	observed
Ref. [4]	17.4 ± 1.5	1.5 ± 0.5	3.0 ± 0.6	$2.4^{+2.5}_{-1.7}$	$6.9^{+2.6}_{-1.9}$	$24.2^{+3.0}_{-2.4}$	28
untagged	15.7 ± 1.3	1.3 ± 0.4	2.5 ± 0.5	0.31 ± 0.15	4.2 ± 0.7	19.9 ± 1.5	21
b-tagged	10.0 ± 0.8	0.04 ± 0.02	0.09 ± 0.02	0.08 ± 0.11	0.21 ± 0.12	10.2 ± 0.9	14

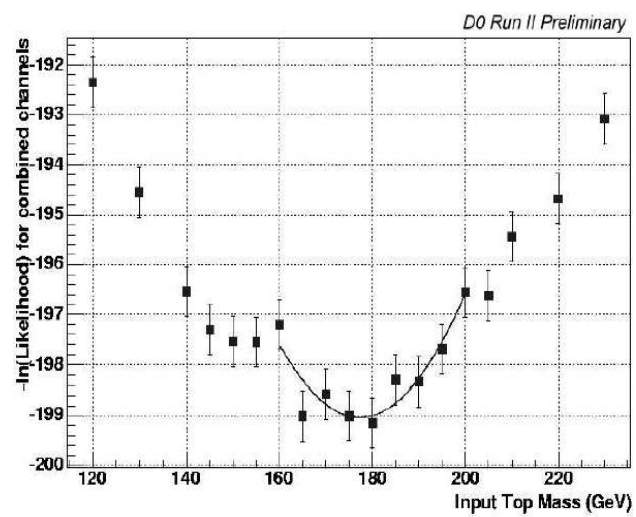
μWT



μWT b-tagged



νWT



Systematic Uncertainties and Results

	MWT	MWT b-tag	nuWT
Mass	165.0	176.6	175.6
Stat. Err.	13.5	11.2	10.6
-JES	3.5	3.5	5.3
-PDF	0.9	0.9	0.7
-gluon rad	0.8	0.8	2.0
-background	0.7	0.2	1.3
-calibration	0.6	0.6	-
-MC stat.	0.3	0.3	0.9
-jet resolution	-	-	0.5
-muon res.	-	-	0.4
-Syst. Err	3.8	3.8	6.0
TOTAL	14.0	11.8	12.2

MWT: Top Mass: 176.6 ± 11.2 GeV (stat.) ± 3.8 GeV (syst.)

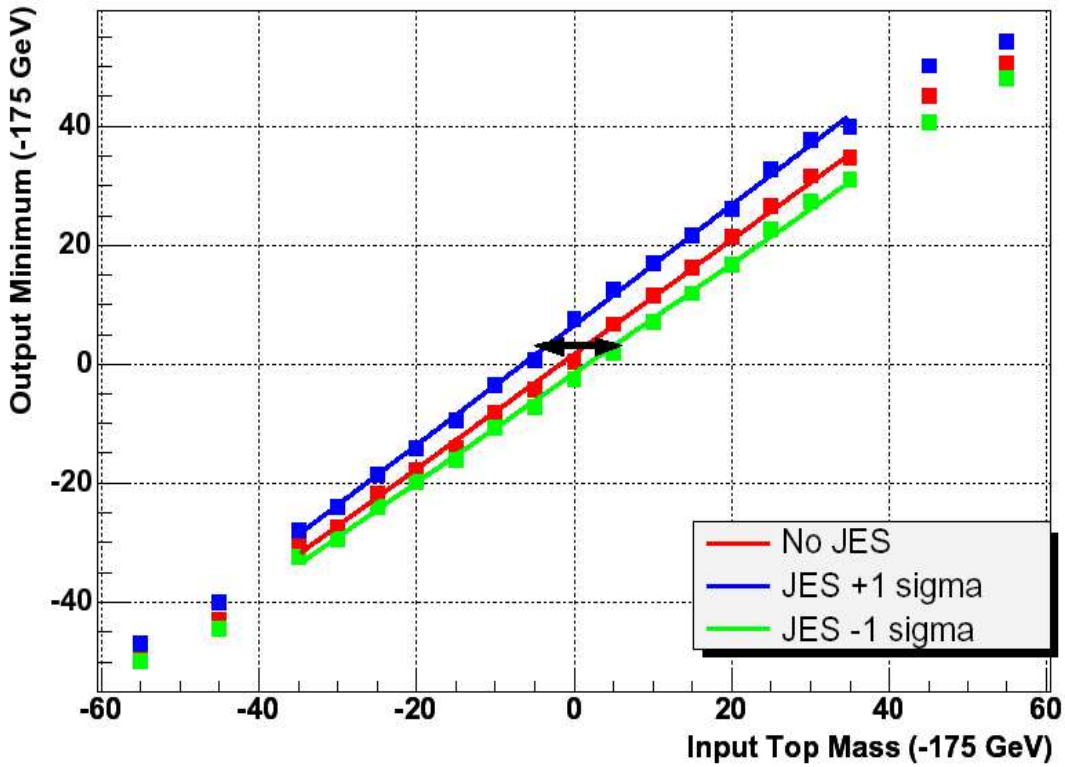
νWT: Top Mass: 175.6 ± 10.6 GeV (stat.) ± 6.0 GeV (syst.)

Jet Energy Scale (JES)

Monte Carlo ensemble tests: measure top mass for different input top masses

Vary jet energy scale by ± 1 sigma

νWT



1000 ensembles with 21 events

Δm_{top} = 5.3 GeV

Summary

- dilepton final state is kinematically underconstrained
- showed two methods to extract top mass
- two DØ preliminary results with 370 pb^{-1}:

MWT: Top Mass: 176.6 ± 11.2 GeV (stat.) ± 3.8 GeV (syst.)

νWT: Top Mass: 175.6 ± 10.6 GeV (stat.) ± 6.0 GeV (syst.)

- results are 60% correlated
- combination under way
- DØ has recorded more than 1 fb^{-1} of data
- importance of dilepton channel will increase with higher statistics soon!

Backup Slides

Kinematic Constraints

$$M_{W^+}^2=(E^\nu+E^{l^+})^2-(p_x^\nu+p_x^{l^+})^2-(p_y^\nu+p_y^{l^+})^2-(p_z^\nu+p_z^{l^+})^2=(80.4\,GeV/c^2)^2$$

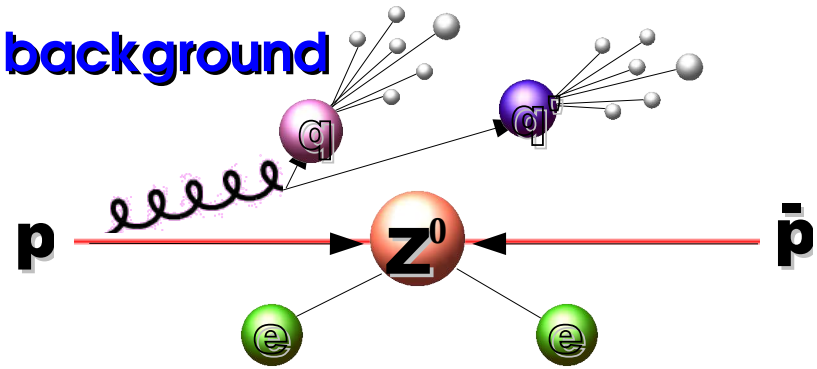
$$M_{W^-}^2=(E^{\bar\nu}+E^{l^-})^2-(p_x^{\bar\nu}+p_x^{l^-})^2-(p_y^{\bar\nu}+p_y^{l^-})^2-(p_z^{\bar\nu}+p_z^{l^-})^2=(80.4\,GeV/c^2)^2$$

$$M_t^2=(E^\nu+E^{l^+}+E^b)^2-(p_x^\nu+p_x^{l^+}+p_x^b)^2-(p_y^\nu+p_y^{l^+}+p_y^b)^2-(p_z^\nu+p_z^{l^+}+p_z^b)^2$$
$$=M_{\bar t}^2=(E^{\bar\nu}+E^{l^-}+E^{\bar b})^2-(p_x^{\bar\nu}+p_x^{l^-}+p_x^{\bar b})^2-(p_y^{\bar\nu}+p_y^{l^-}+p_y^{\bar b})^2-(p_z^{\bar\nu}+p_z^{l^-}+p_z^{\bar b})^2$$

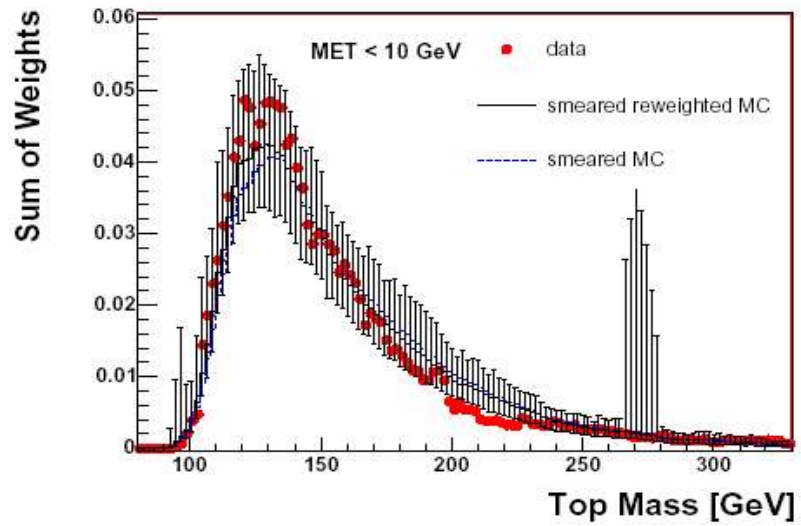
$$p_x^t=p_x^{\bar t}\quad p_y^t=p_y^{\bar t}$$

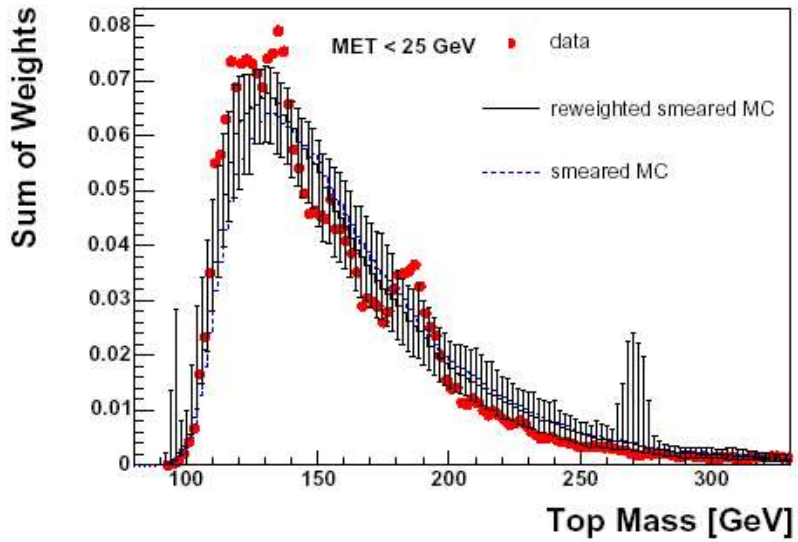
Background Modeling

- Study background modeling by data/MC comparison
- Select Z->ee+2 jets events



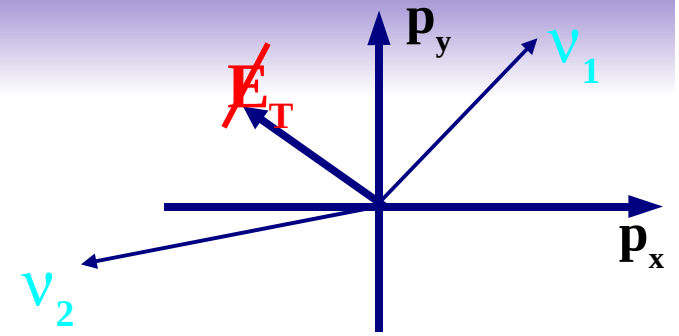
- weight distribution vs. top mass hypotheses for data and MC
- 2 MET ranges

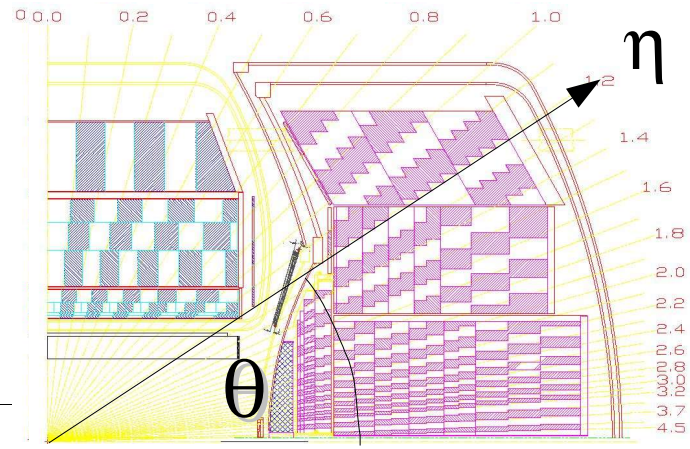


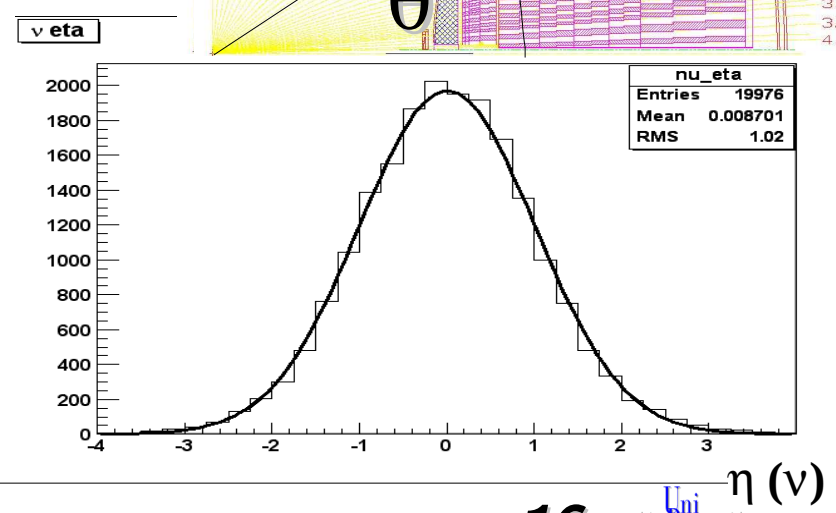


Dilepton Event Kinematics

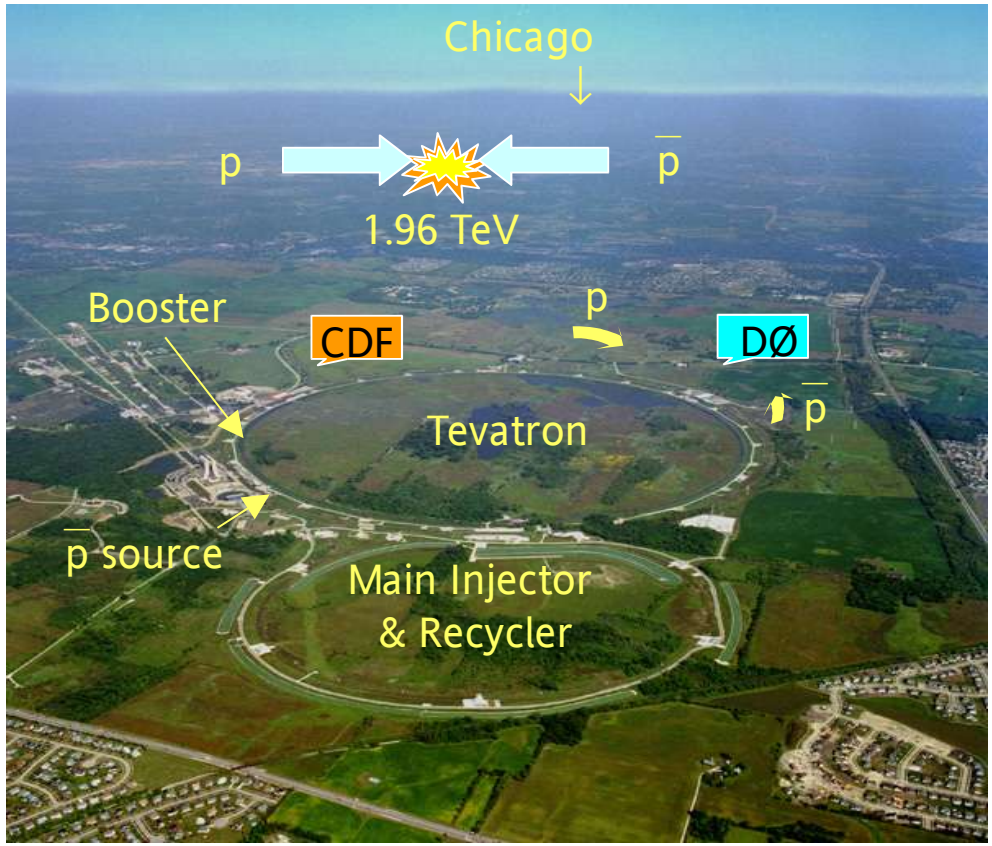
- $t\bar{t} \rightarrow W^+W^-bb \rightarrow l^+\nu\, b\, l^-\nu\, b$
- 6 particles in final state, masses known
  -> 18 degrees of freedom
- Energys/momenta of b-jets/charged leptons measured -> 6 degrees of freedom left
- 3 constraints:
  $mass(l^+,\nu) = mass(l^-,\nu) = m_W$
  $m_t = m_{\bar{t}} = mass(l,\nu,b)$
  -> 3 degrees of freedom left
- METx, METy: 2 further degrees of freedom
- -> 1 degree of freedom left:
  event kinematics underconstrained !
- Assumptions necessary to determine Top Mass -> different methods







Tevatron at FERMILAB



Run I (1992-1996):

- $\sqrt{s}$ = 1.8 TeV
- ~125 pb^{-1} / experiment

Run II (2001-2009)

- $\sqrt{s}$ = 1.96 TeV

~1 fb^{-1} / experiment

- 4-9 fb^{-1} til 2009

Selection

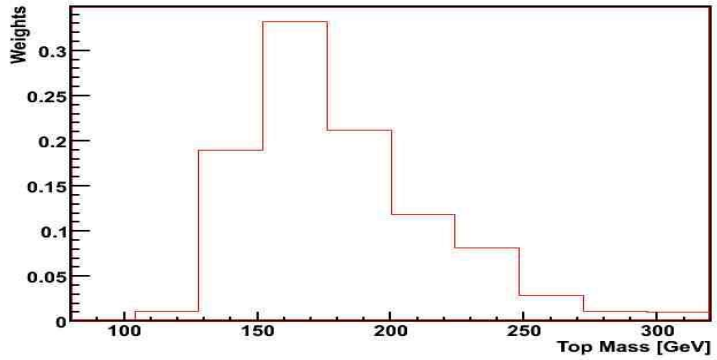
- 2 leptons (ee/eμ/μμ): p_T > 15 GeV
- 2 jets: E_T > 20 GeV
- high missing transverse energy (MET)
- cut on mass(ee) / fit at mass(μμ)
- cut on sphericity (ee-Kanal), Ht (eμ-Kanal)
- *MWT* uses b-tagging

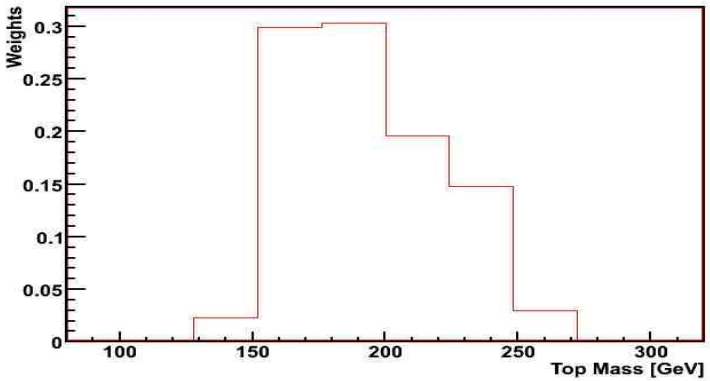
21 selected events, 370 pb^{-1}

source	$t\bar{t}$	WW,WZ	Z	fake ℓ	background	total	observed
untagged	15.7 ± 1.3	1.3 ± 0.4	2.5 ± 0.5	0.31 ± 0.15	4.2 ± 0.7	19.9 ± 1.5	21
b-tagged	10.0 ± 0.8	0.04 ± 0.02	0.09 ± 0.02	0.08 ± 0.11	0.21 ± 0.12	10.2 ± 0.9	14

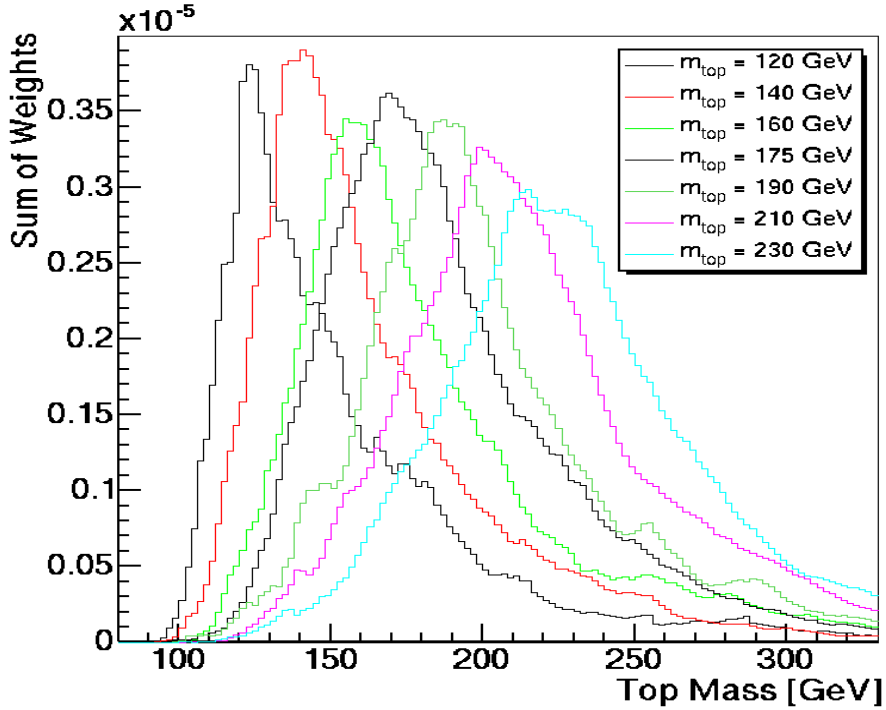
Weight Distributions vs. Top-Quark-Masse

weight distribution for single event for MC with m_{top}=175 GeV





Sum of weight distributions of all MC Events for different m_{top}



-> construct probability density functions from shape of weight distributions