Particle Physics with the DØ Detector at the Fermilab Tevatron Collider

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Outline of Talk

- What Do We Study?
- The "Standard Model "
- The Fermilab Tevatron Collider
- The DØ Detector
- Physics Topics

Particle (High Energy) Physics

$\Rightarrow$ **Study of fundamental particles in universe and the forces and interactions between them**

molecules $\rightarrow$ atoms $\rightarrow p, n, e^- \rightarrow$ quarks, leptons $\rightarrow$?

Fundamental Particles

leptons	quarks
e	u
ν_e	d
μ	c
ν_μ	s
τ	t
ν_τ	b

Interactions

Force	Mediator Particles
weak	$W^\pm, Z$
electromagnetic	γ
strong	g
gravity	(graviton?)

$\star$ **Also have Higgs particle which gives mass to the fundamental particles**

Interactions between Fundamental Particles

Particle Physics

Currently have "Standard Model" (SM) of fundamental particles and forces describing ElectroWeak and Strong forces

$\longrightarrow$ **Electroweak:**

$\longrightarrow$ **Strong:**

The Standard Model...

Parameters needed in mathematical formulas describing SM:

- **masses of particles**
- **strength of forces**

Experiments in High Energy Physics

$\longrightarrow$ **Aim for higher energy interactions**
$+$ **better precision measurements**

$\star$ **test Standard Model predictions**
$\star$ **Search for results not predicted by Standard Model $\longrightarrow$ Is the SM the final answer?**

DØ experiment designed in mid-1980's

⇒ **ElectroWeak theory recently verified by discovery and measurement of $W^{\pm}, Z^{\circ}$ particles**

⇒ **QCD theory recently verified**
  - describes quarks, gluons and their interactions via strong force

⇒ **still searching for *top* quark and *Higgs* boson**

⇒ **want to study properties of $W^{\pm}, Z^{\circ}$**

⇒ **want to study properties of Strong and Electroweak interactions**

⇒ **Need to produce these particles and interactions so we can measure them!**

Use the Fermilab “Tevatron” collider

$\star$ **particle accelerator located in Batavia, Illinois**

Need high energies to study high-mass particles

$\star$ **remember!** $E = mc^2$

$\Rightarrow$ **use** $p + \bar{p}$ **collisions**

900 GeV protons **900 GeV anti-protons**

- **protons and antiprotons accelerated up to energy** ≈ 1 **TeV** $(= 10^{12}$ **eV)**
  where 1 eV $= 1.6 \times 10^{-19}$ **joules**

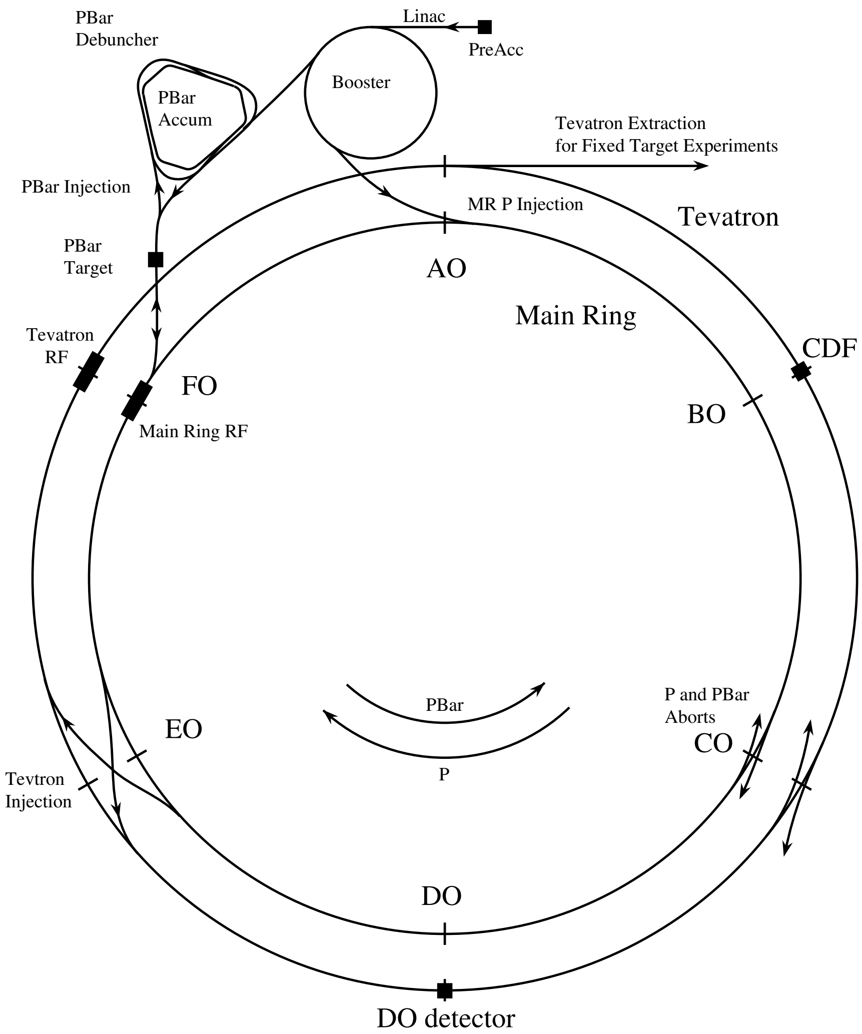
relativistic particles: $E^2 = m^2c^4 + p^2c^2$

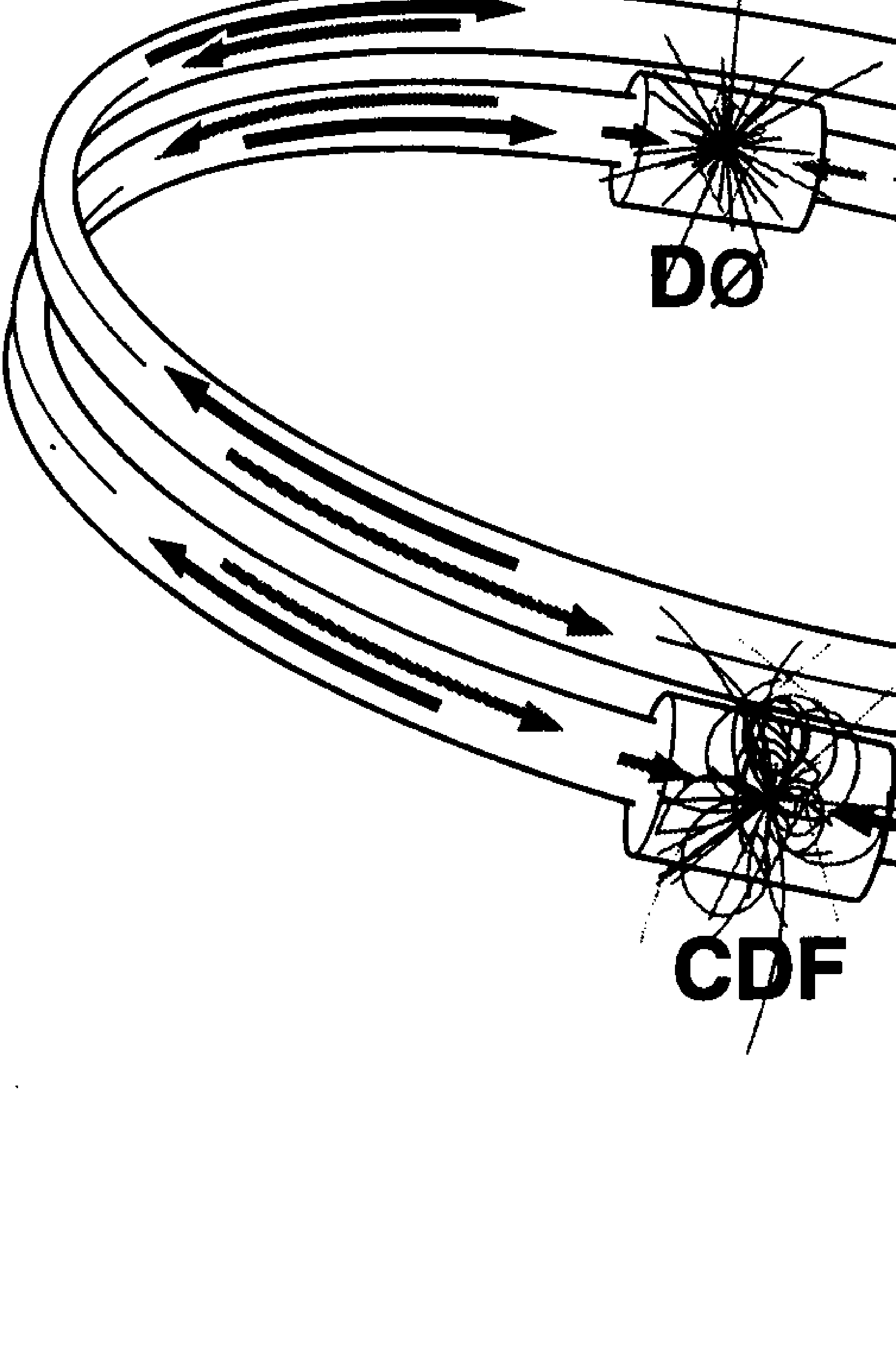
set speed of light $c \equiv 1$

therefore E, m, p **expressed in GeV** $(= 10^9$ **eV)**

$\star$ **We measure properties of final-state particles from the** $p + \bar{p}$ **collisions**

Fermilab Collider




DØ
CDF

The Fermilab $p\bar{p}$ Tevatron Collider...

$\star$ $\approx 10^{12}$ protons and $\approx 3 \times 10^{11}$ antiprotons are
accelerated to energy of 900 GeV

$\star$ the p and $\bar{p}$ collide at two places in ring
$\longrightarrow$ at the DØ and CDF experimental areas

$\Rightarrow$ **Oct. 1985 - test run**

$\Rightarrow$ **1987 - first operating run (CDF only)**

$\Rightarrow$ **1992-1993: Run 1A**

$\Rightarrow$ **1994-1995: Run 1B**

$\Rightarrow$ **1999? start Run 2**

Experiments at the Tevatron

- **CDF and DØ detectors built to study final states of $p + \bar{p}$ collisions**

DØ Experiment at Fermilab

$\longrightarrow$ large multi-purpose detector
$\rightarrow$ can detect final-states from ElectroWeak or Strong interactions

$\star$ **mid 1984, experiment approved by laboratory**

$\star$ **Feb 1992, detector built and rolled into beamline**

$\star$ **May 1992, first collisions measured in detector**

$\star$ **Aug 1992, start taking data (run 1)**

$\star$ **Jan 1996, end of Run 1**

Proton-antiproton Collisions

- Each quark carries only fraction of p or $\bar{p}$ momentum

- different processes can take place
  - depends on momentum and types of partons (quarks,gluons) that interact

DØ Physics Menu

- **final states we look for $\Rightarrow$**

  - **discovery of *top* quark and measure properties $\rightarrow$**

  - **measure properties of $W^{\pm}, Z^{\circ}$ bosons $\rightarrow$**

  - **study strong interactions (QCD) $\rightarrow$**

  - **plus many other measurements of properties!!!**

The DØ Detector

Consists of 3 Main Parts:

- **Tracking System**
- **Calorimeters**
- **Muon System**

Tracking System - Drift Chambers

Construction:

- parallel anode wires strung throughout chamber:
  anode wires at + voltage
- cathode plane at − voltage
- electric potential created

Operation:

- chamber filled with gas
- charged particles pass through and ionize electrons in the gas
- the electrons drift towards the anode
- near the anode, they have enough energy to ionize many more electrons forming an "avalanche"
- charge collected on anode → get a signal on this wire
- therefore, find "track" from a charged particle

Calorimeters

⇒ **measures energy of charged or neutral particle**
- **incident particle interacts in dense material and deposits all its energy**

- **consists of alternating layers of sampling and absorber material**
- **absorber material: Uranium**
  - **dense material where particle loses energy**
- **sampling material: Liquid Argon**
  - **collects signal proportional to incident energy**

⋆ **incident hadrons lose energy due to inelastic nuclear collisions**

⋆ **incident electrons and photons lose energy due to ionization**

⇒ **therefore size of “shower” in calorimeter due to hadrons different than due to electrons, photons**

Muon System

⇒ **muons pass through calorimeter and only deposit fraction of their energy**

- use magnetic spectrometer to identify and measure momentum of muons:

- **find signals in tracking chambers which are outside of calorimeter**
- **angle of bend of trajectory gives measurement of momentum**

Particle Detection

Use detector to measure final products of collision

- **then can reconstruct event using conservation of momentum**

$\Rightarrow$ calorimeter - energy measurement
$\Rightarrow$ muon system - momentum measurement of muons
$\Rightarrow$ tracking system (drift chambers)
- charged particle tracking

electrons

photons

muons

quarks,gluons $\longrightarrow$ "jets" of hadrons

neutrinos

Data Collection

$p + \bar{p}$ **interaction rate** $\approx 10^5$ Hz

have $\approx 100,000$ **signals from electronics**
to read from detector

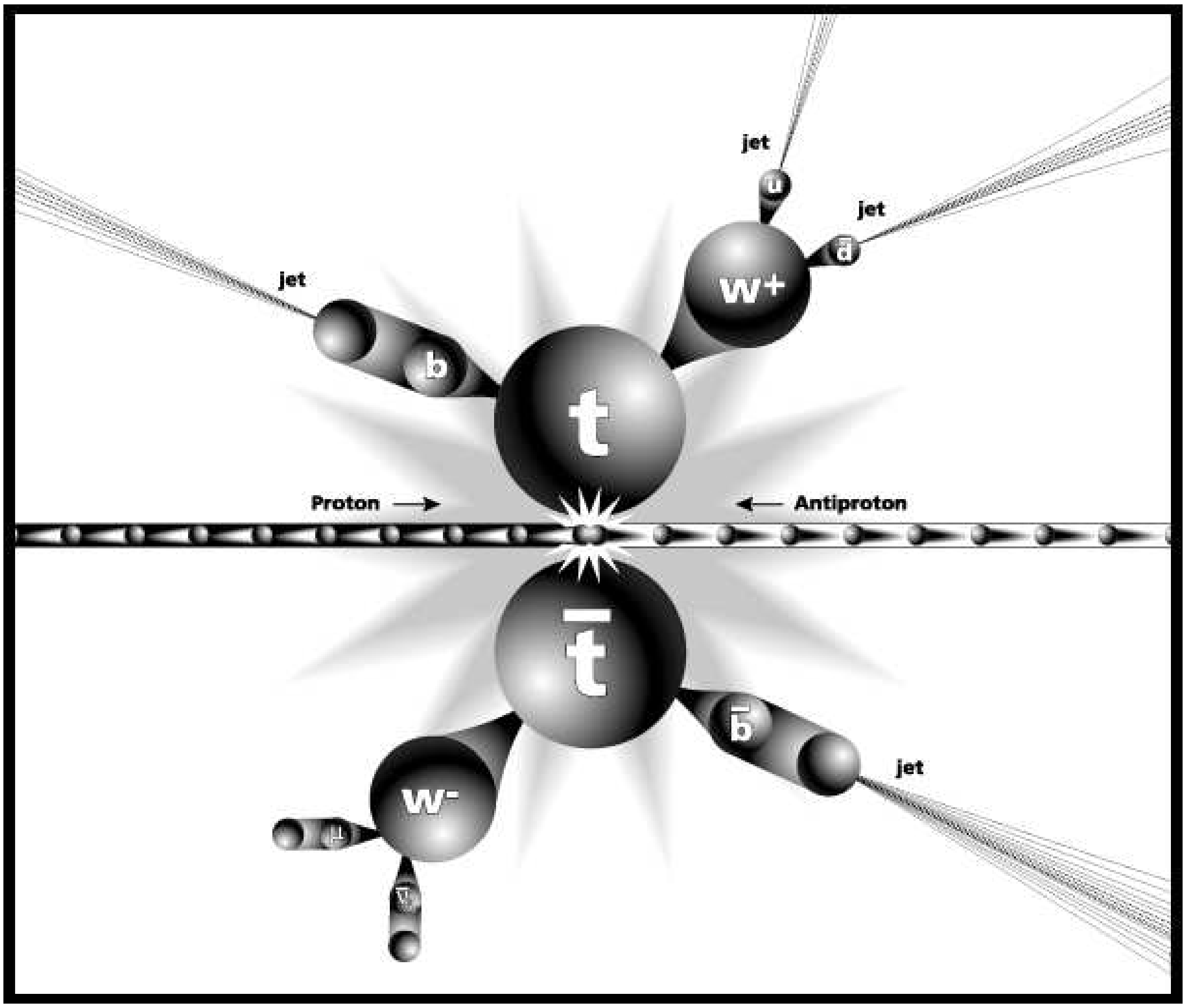
- most interactions not interesting (soft collisions)

- "trigger" to select and keep only interesting events

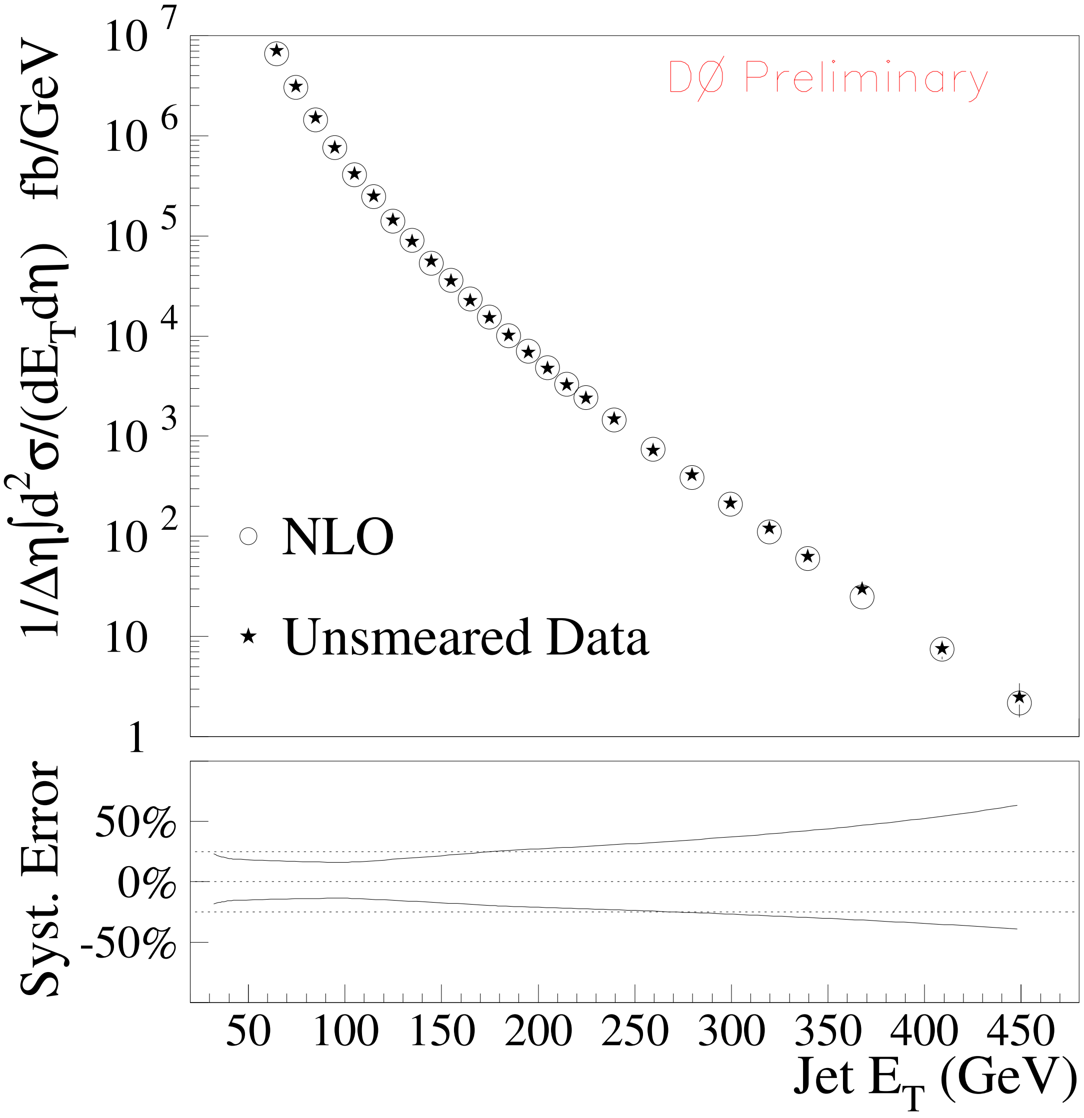
- use fast measurement of energy in calorimeter to make decision if we want to keep event

- **if event passes trigger, write data from all detectors to magentic tape**
- **analyse data on computer to reconstruct events and make measurements**

TOP quark production and decay



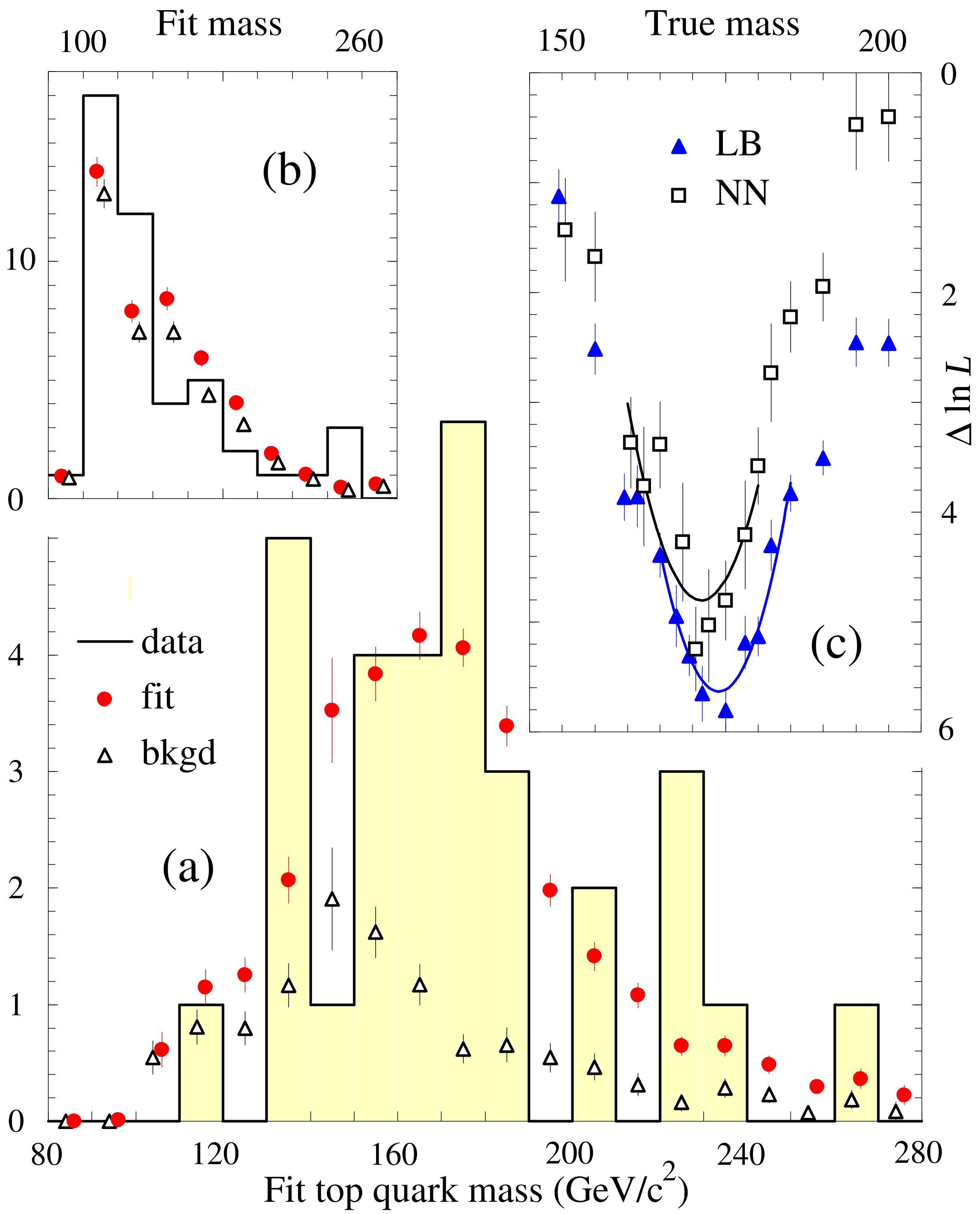
Jet production



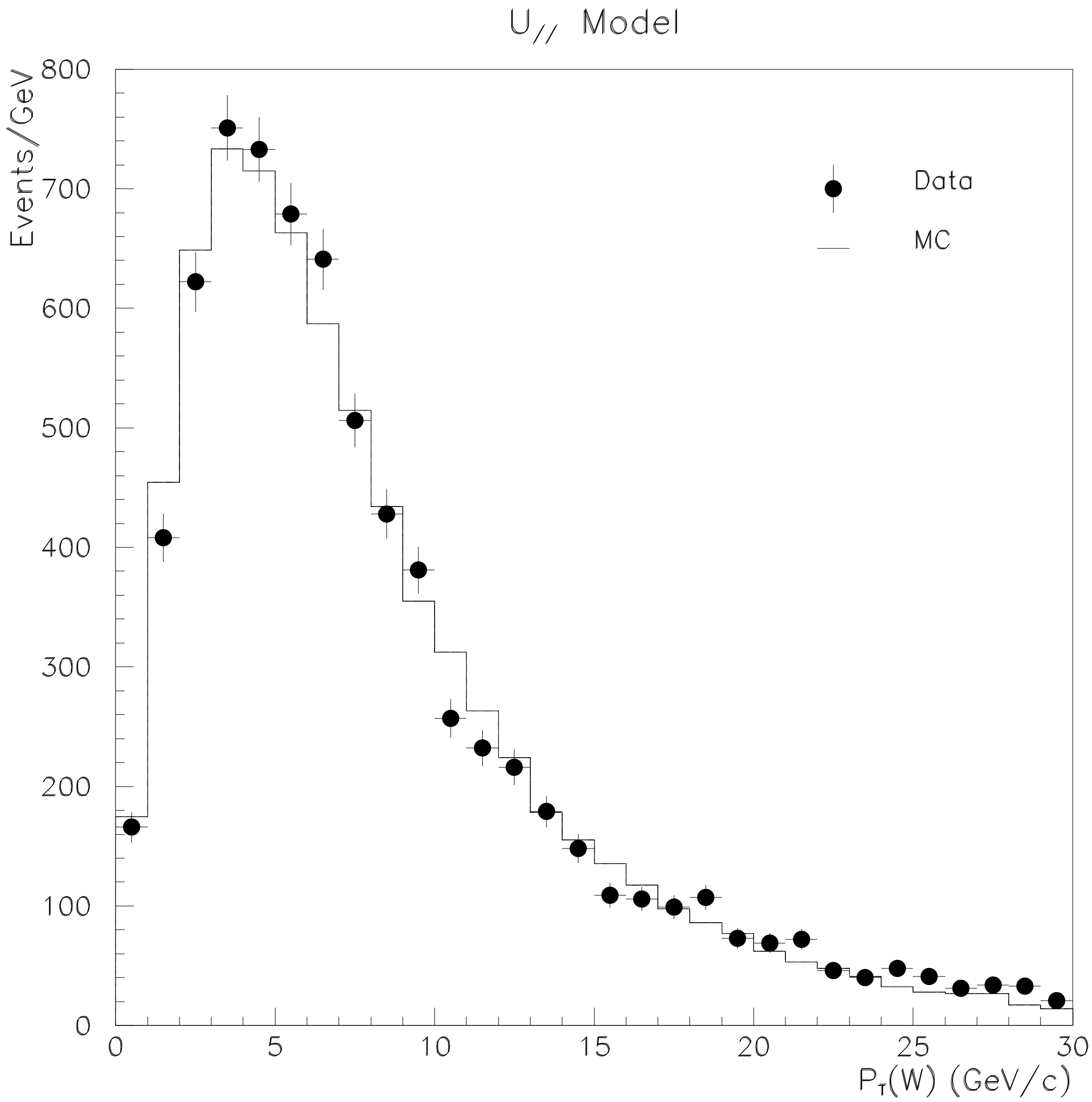
Measurement of M_W

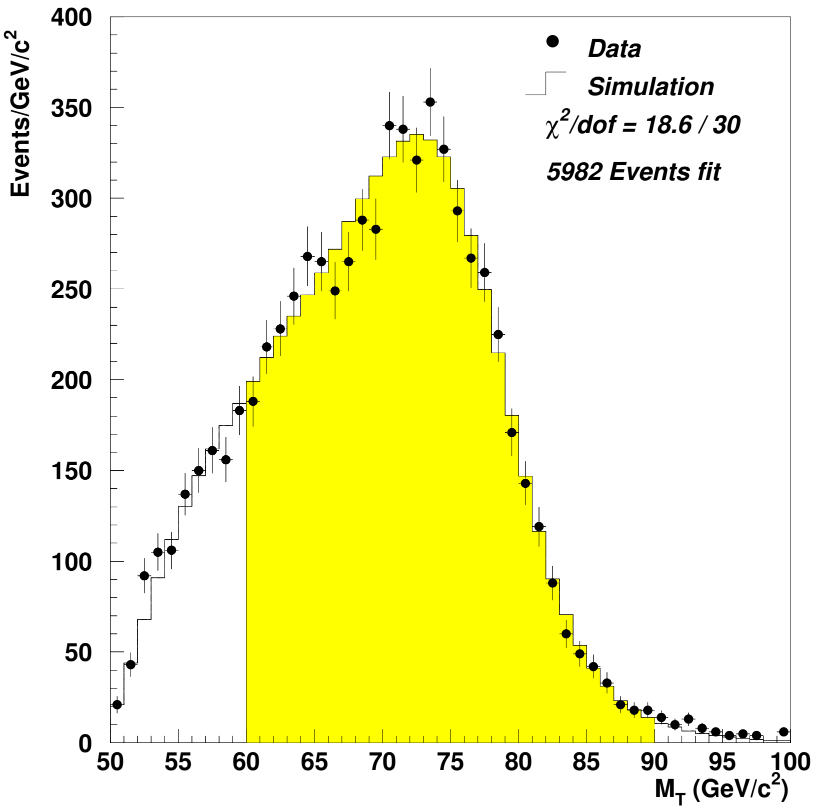
$$M_W(\mathrm{Run1A}) = 80.350 \pm 0.270\ \mathrm{GeV/c^2}$$

$$M_W(\mathrm{Run1B}) = 80.358 \pm 0.170\ \mathrm{GeV/c^2}$$



Fit mass
100
260
(b)
10
0
True mass
150
200
LB
NN
0
2
4
6
$\Delta \ln L$
(c)
data
fit
bkgd
(a)
4
3
2
1
0
80
120
160
200
240
280
Fit top quark mass (GeV/c^2)


U// Model
Events/GeV
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
$P_T(W)$ (GeV/c)
Data
MC



Data
Simulation
$\chi^2/dof = 18.6 / 30$
5982 Events fit
Events/GeV/c^2
M_T (GeV/c^2)
0
50
100
150
200
250
300
350
400
50
55
60
65
70
75
80
85
90
95
100