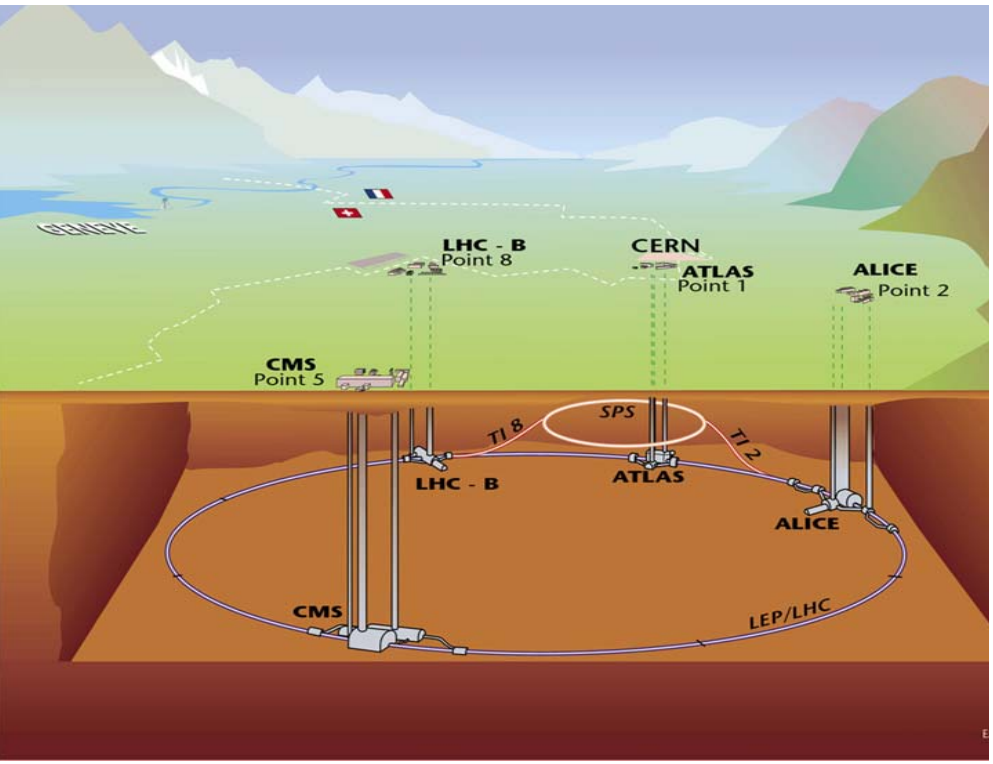
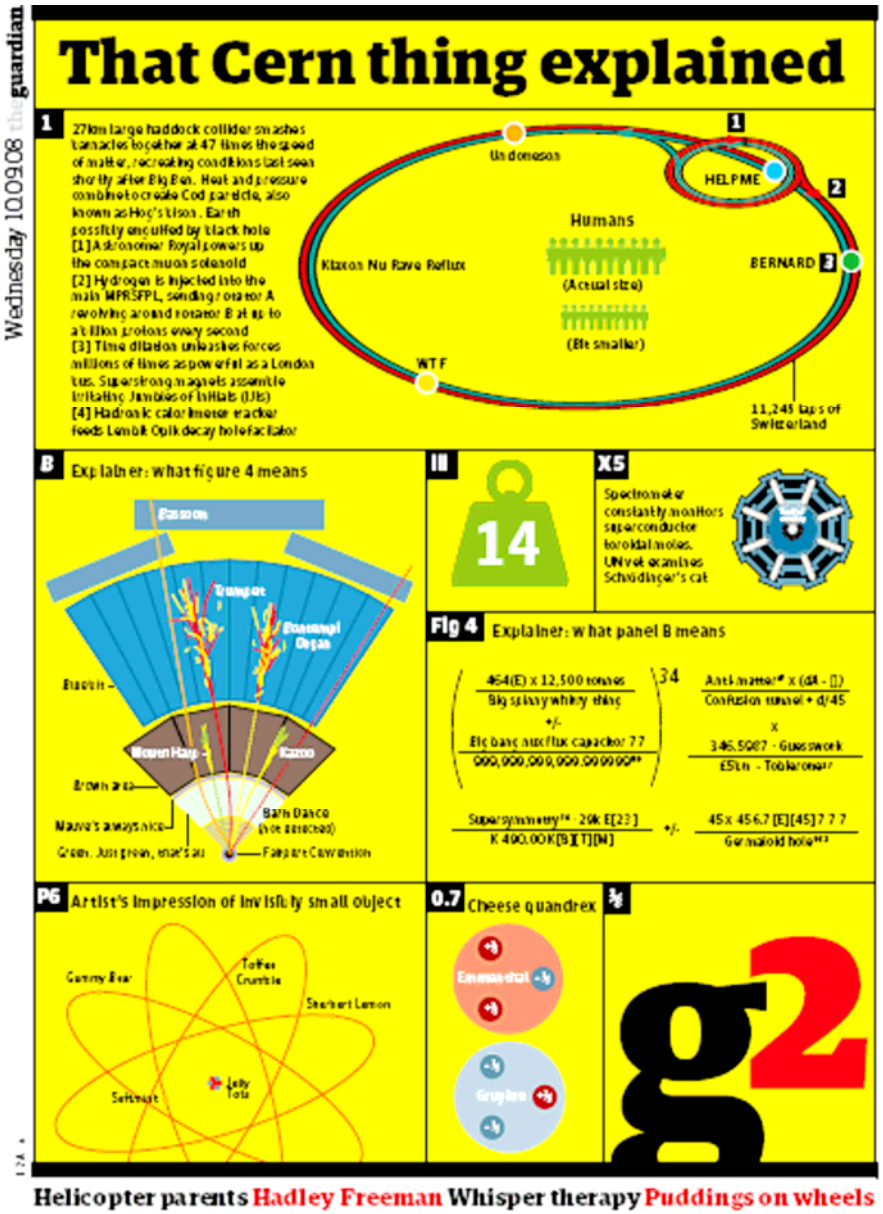
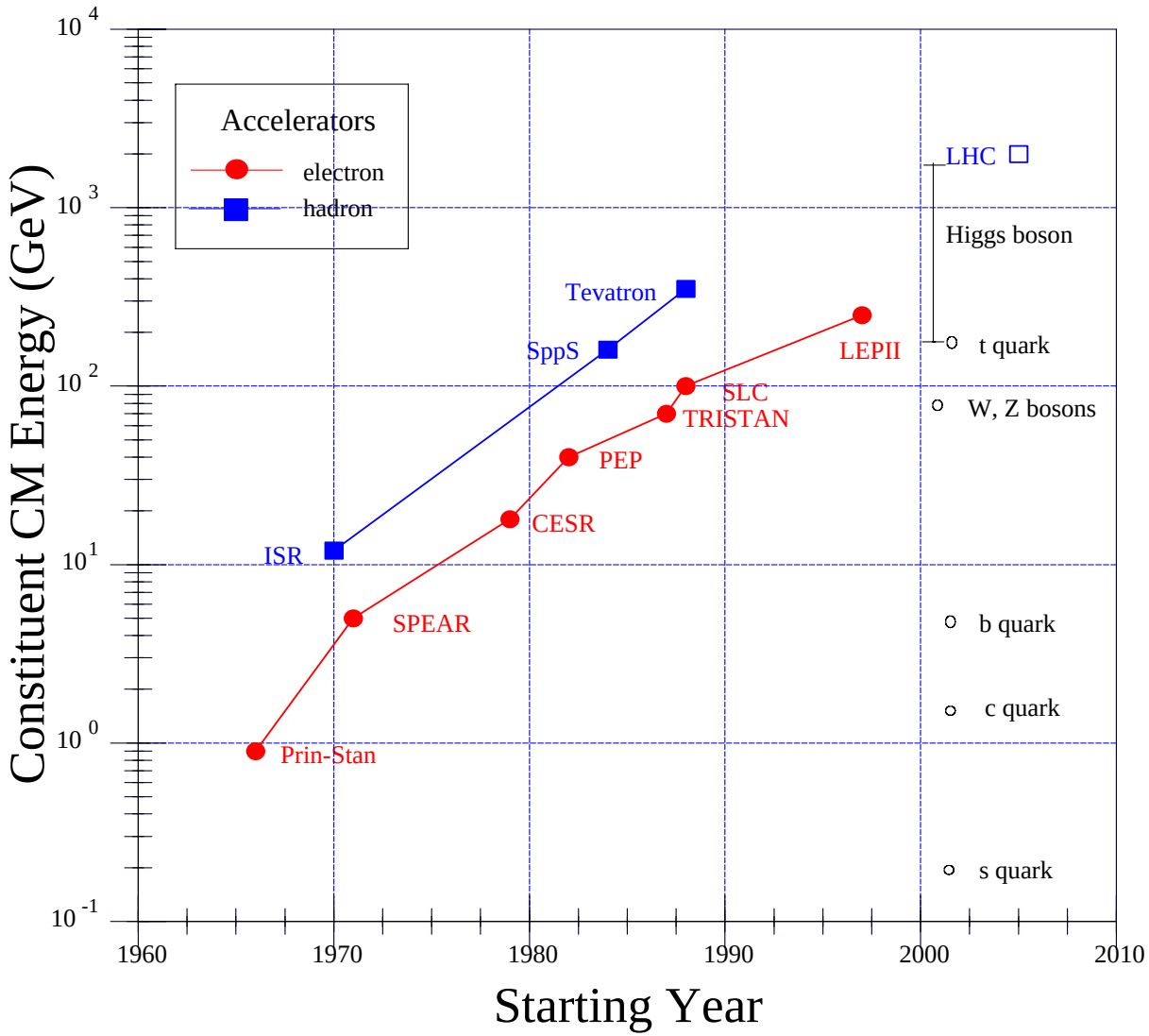
Last Lecture: e p Facilities, HERA and DIS





Today's Lecture: pp and ppbar Physics: TeVatron and the LHC

Reminder: Livingstone Plot



Particle physics energies and timescales….

Recent History of pp Machines

- 1971 – CERN `Intersecting Storage Rings' >= 31GeV x 31GeV

- Mid 1970s – CERN SPS and Fermilab `Main Ring`
  200-400 GeV fixed target.
  Circular machine used to accelerate only, fast losses!
  Fermilab discovered b quark (1977)

1981 – CERN SPS converted to ppbar collider, 270 x 270GeV
UA1 (UA2) at CERN discover W, Z, win nobel prize
– Fermilab upgraded in energy first, then built a collider

1985- Fermilab TeVaton collider, now at 1TeV x 1TeV

2008- CERN LHC 7TeV x 7TeV

An interesting question …

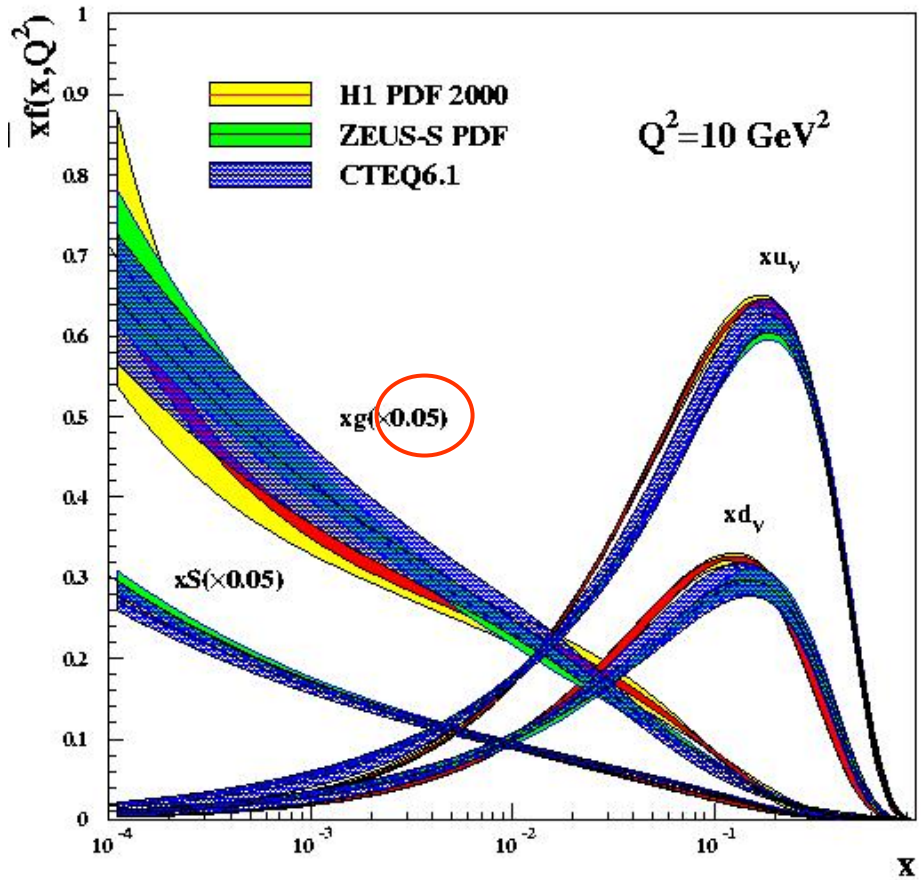
- Top quark mass is ~ 175 GeV
- SppS Centre of mass energy was 540 GeV

… why didn't the SPS discover the top quark?

… the answer lies in the parton densities of the proton

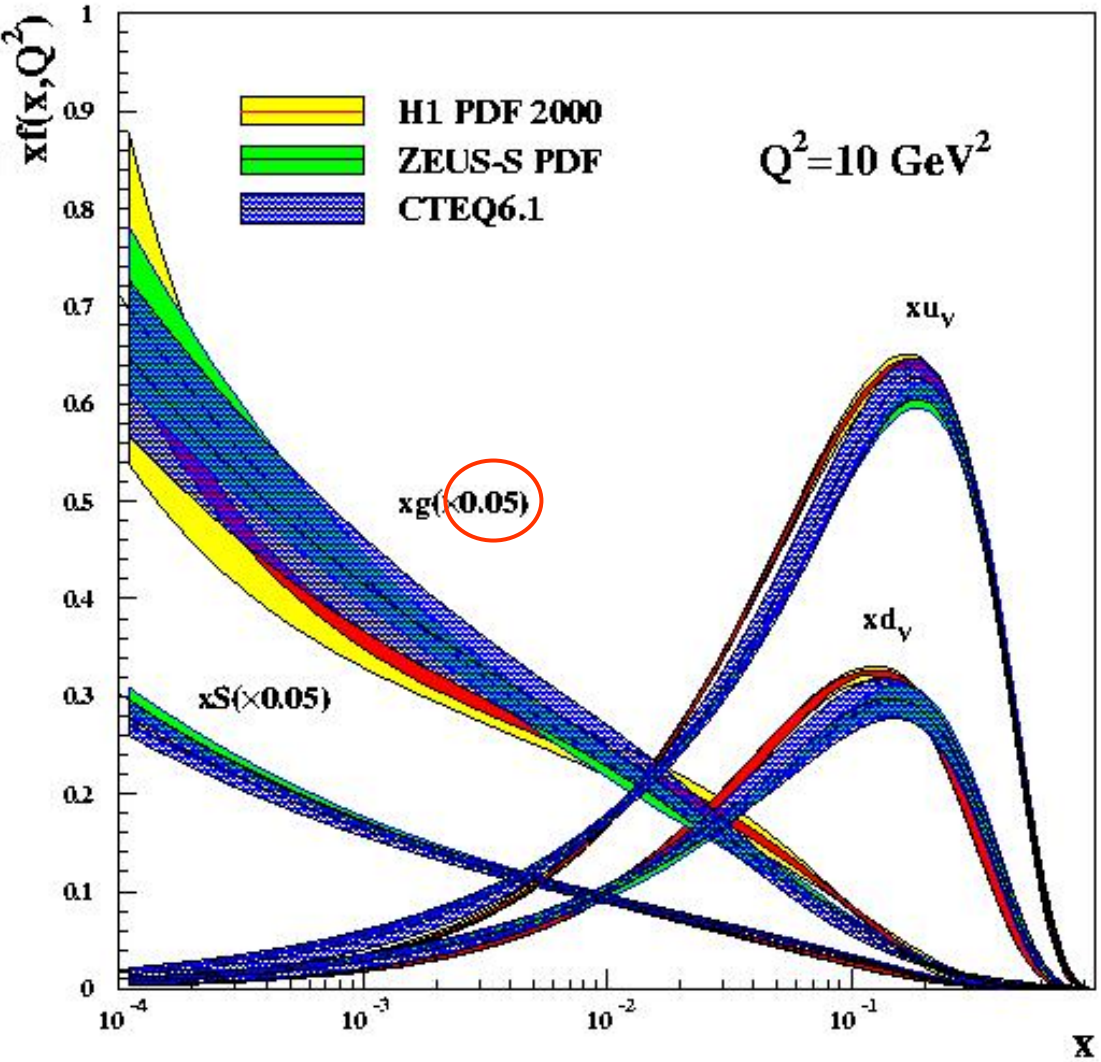
… and the relatively low Luminosity of the SppS

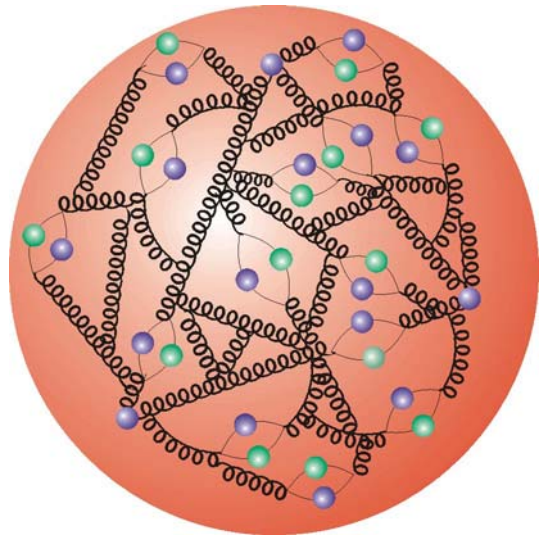
… and the difficult backgrounds



The Quark and Gluon Content of the Proton

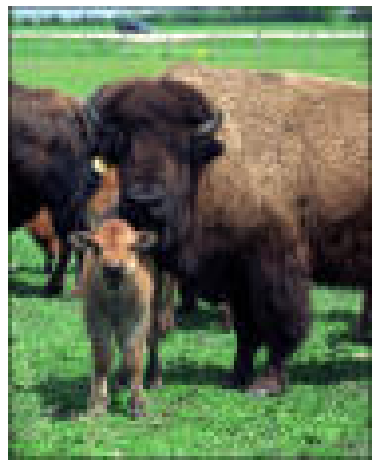
u_v and d_v are valence quarks
S is sea, g is gluon





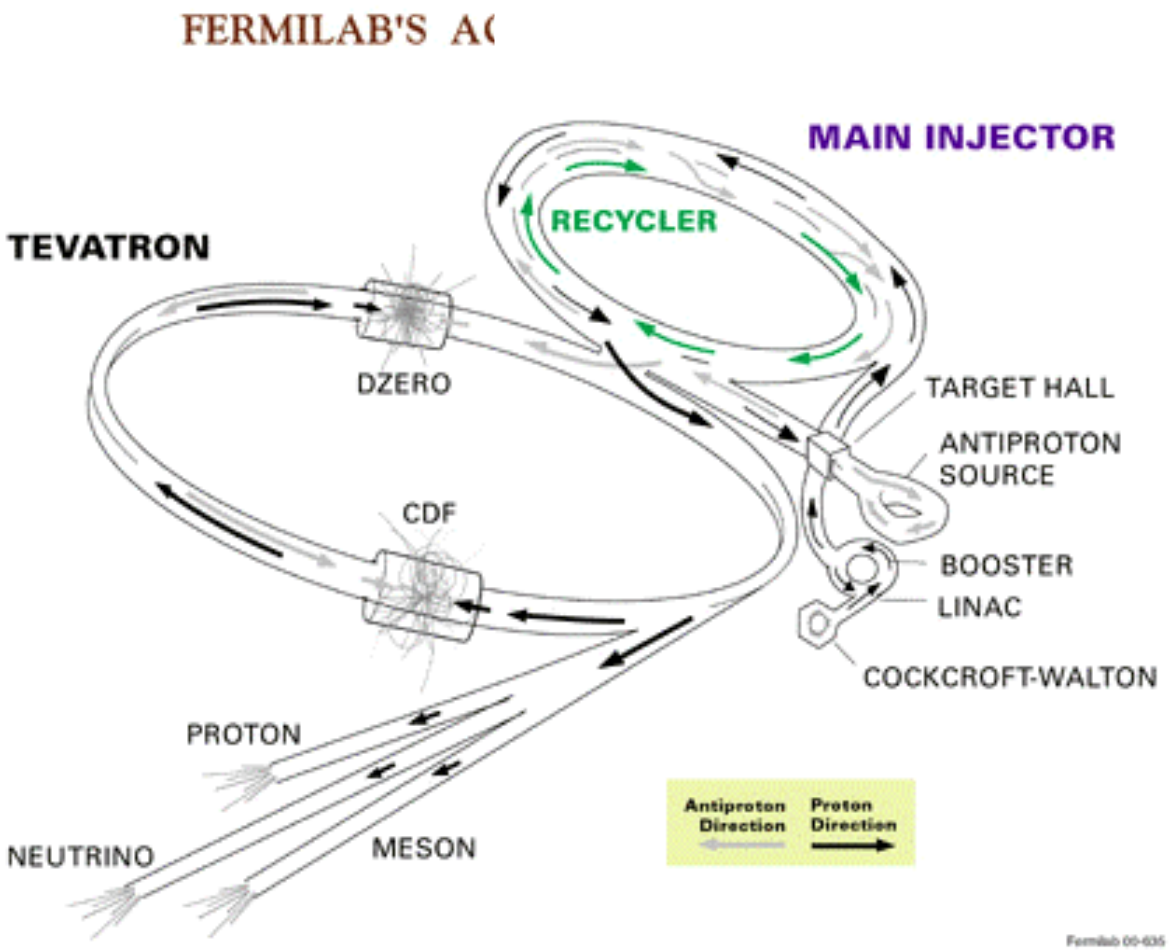
Detailed and precise HERA charged and neutral current data lead to new understanding of the proton and QCD, especially at low x … just How big can the gluon density become?!?

Tevatron (Fermilab, Chicago)



Proton-Antiproton collisions at
1TeV x 1TeV in nature reserve!

Fermilab's Accelerator Chain



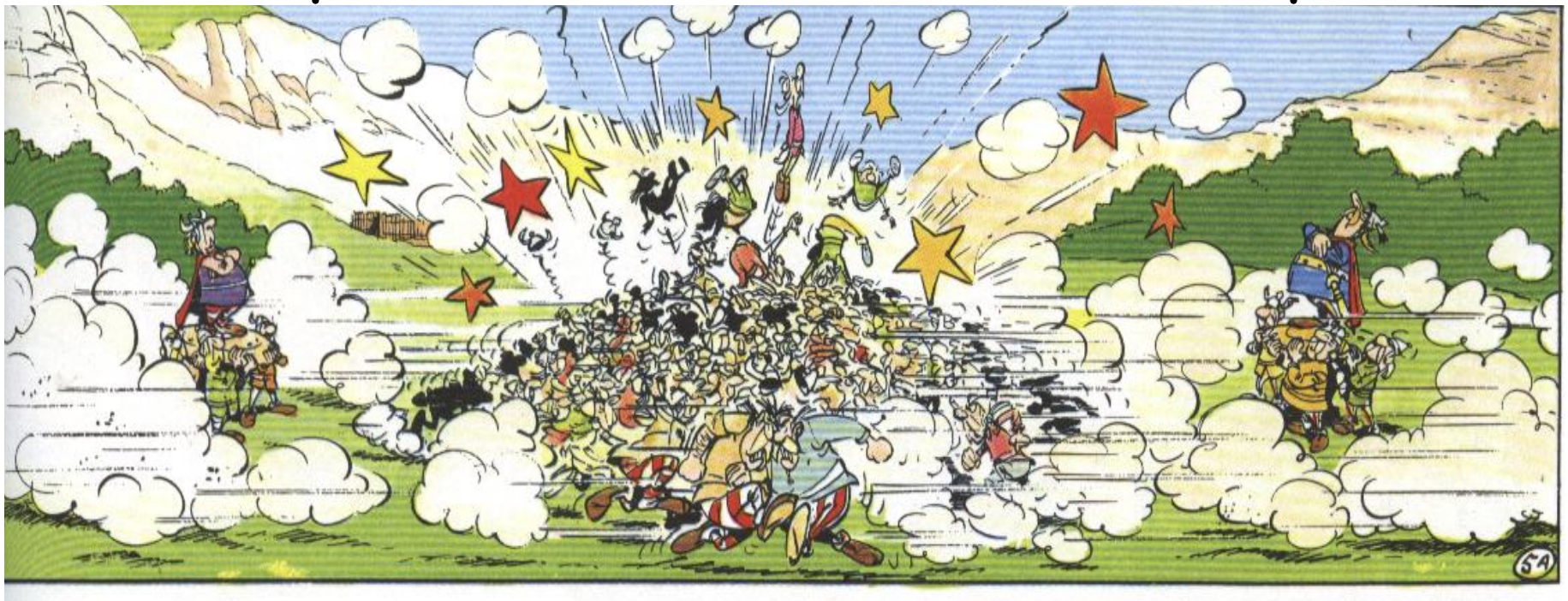
Run I (1992-6)
Lumi = 125 pb^{-1}

Run I (2001-6)
Lumi = 1.2 fb^{-1}

Run I (2006-9)
Lumi = 5-8 fb^{-1}

- Colliding beam experiments CDF and D0
- Multi-purpose facility, also providing proton, pion and neutrino beams to fixed target facilities (e.g. Minos)

Proton proton collision are, err, complex



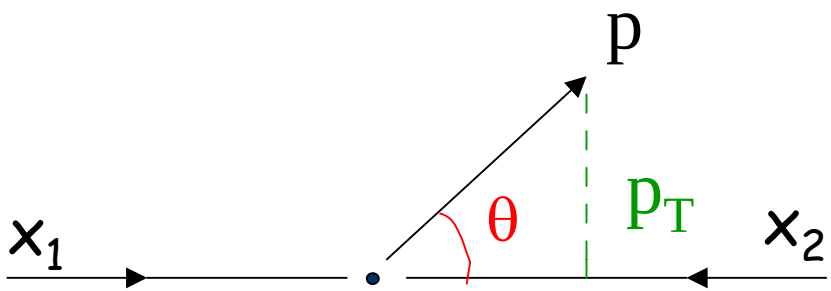
… but at any given time, they provide the highest available energies, so usually the best sensitivity to new physics.

c.f. synchrotron radiation power ~ $1/m^4$ … electron beam energies are limited!

… but pp detector requirements are tough to meet, especially at the LHC, where several events per bunch crossing!

Variables to describe Hadron Collider physics

… need to find Lorentz invariants, which are (ideally) also invariant under boosts in z direction (don't always know x_1, x_2)



As well as azimuthal angle, use transverse momenta:

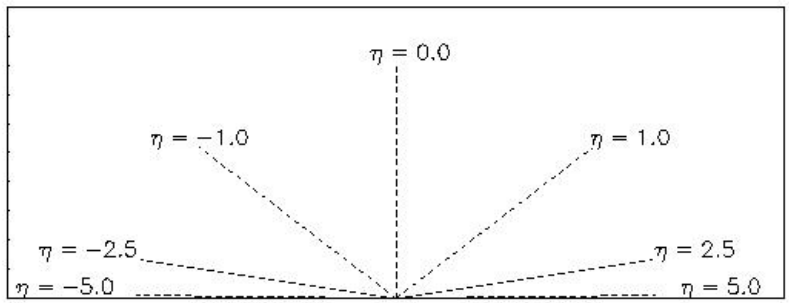
$p_T = p \sin\theta$

Polar angles are often given in terms of the pseudorapidity

$\eta = -\ln \tan \theta/2,$

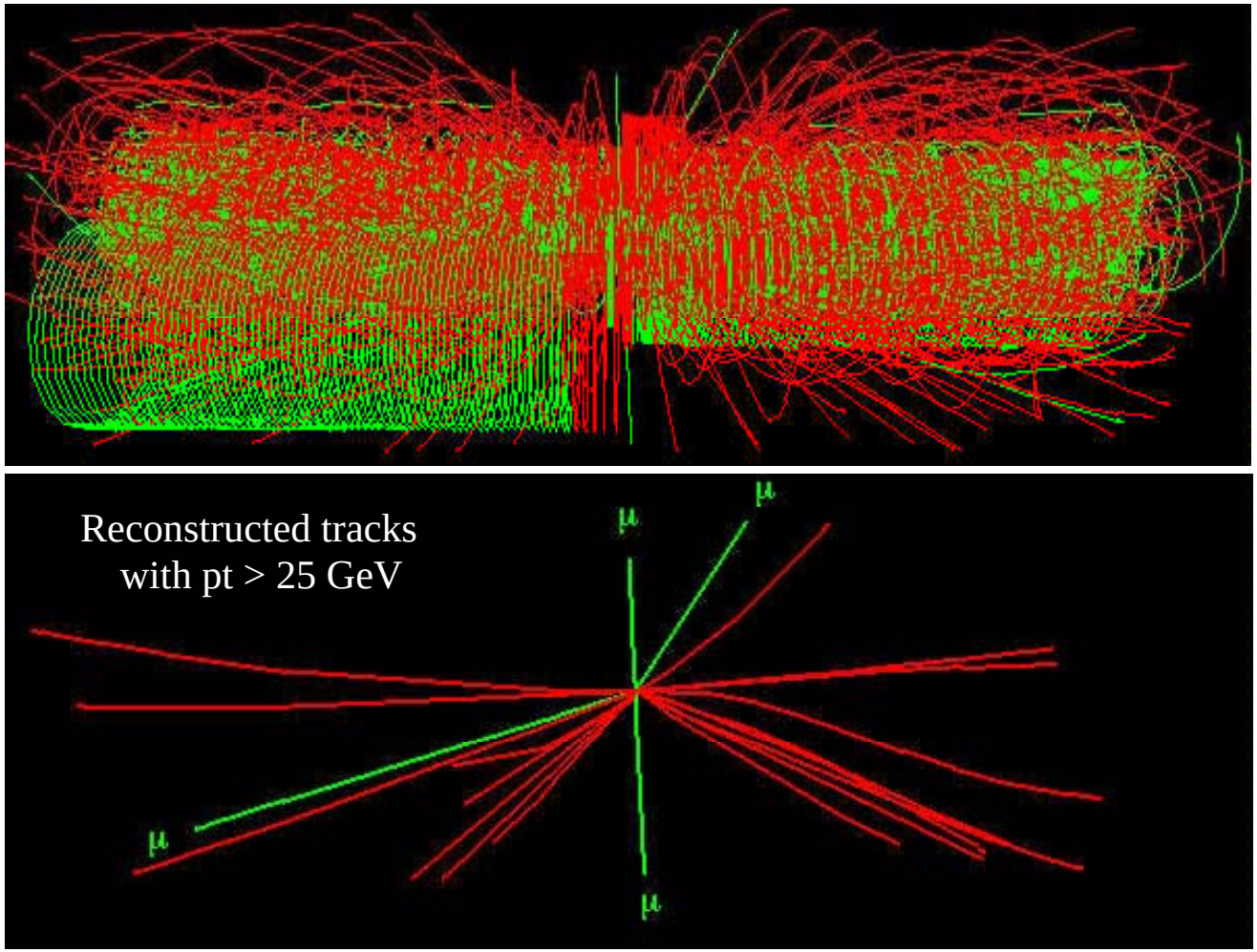
derived from rapidity …

$$y = \frac{1}{2} \ln \frac{E + p_z}{E - p_z}$$



e.g. particle producion roughly constant as a function of y … and Δy is Lorentz invariant

The joys of large transverse momentum (or how to see the wood for the trees)

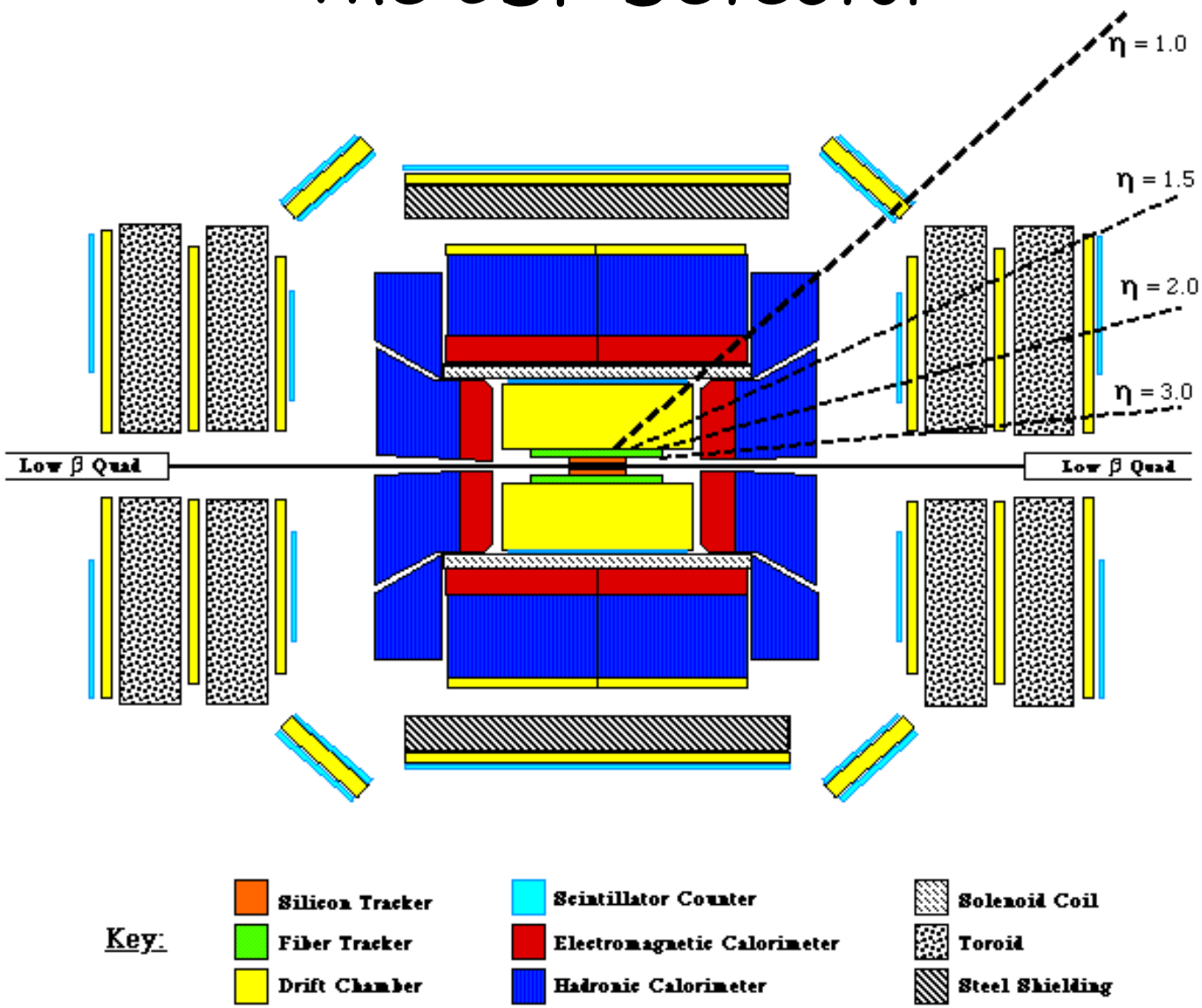


The CDF Detector

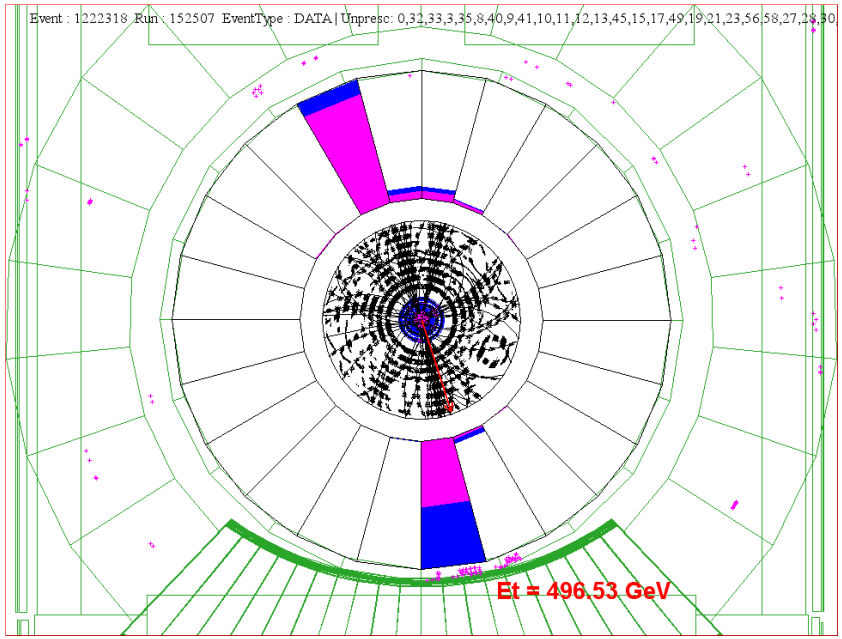
$\theta = 90^o \rightarrow \eta = 0$

$\theta = 10^o \rightarrow \eta \cong 2.4$
$\theta = 170^o \rightarrow \eta \cong -2.4$

$\theta = 1^o \rightarrow \eta \cong 5.0$

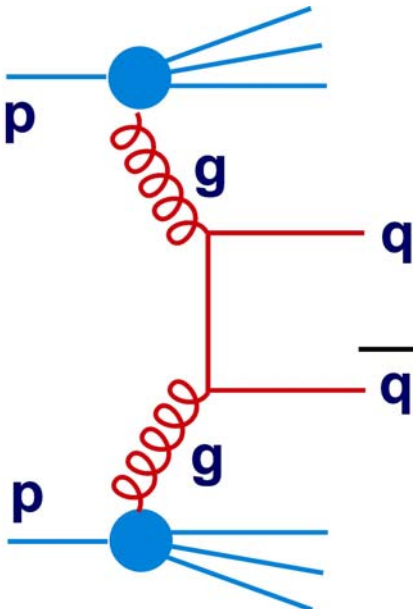


A two jet event at the Tevatron (CDF)

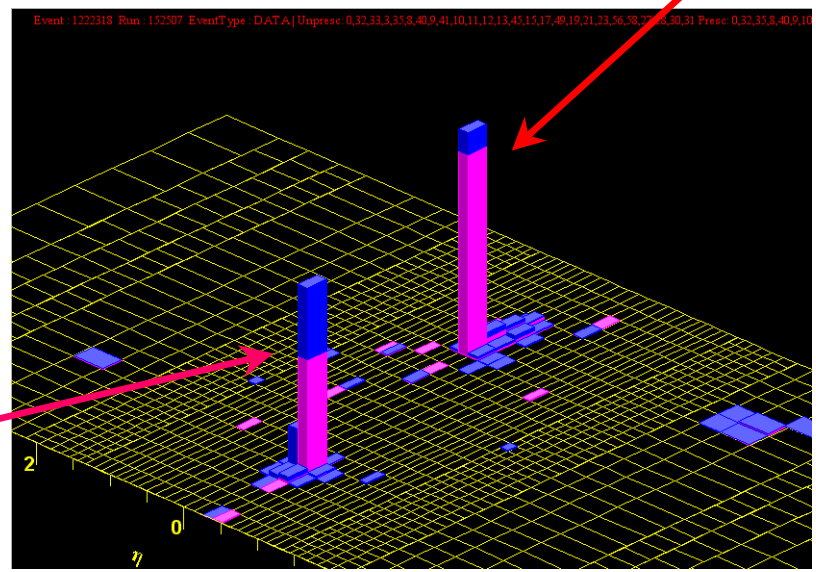


Dijet Mass = 1364 GeV/c^2

E_T = 666 GeV
η = 0.43



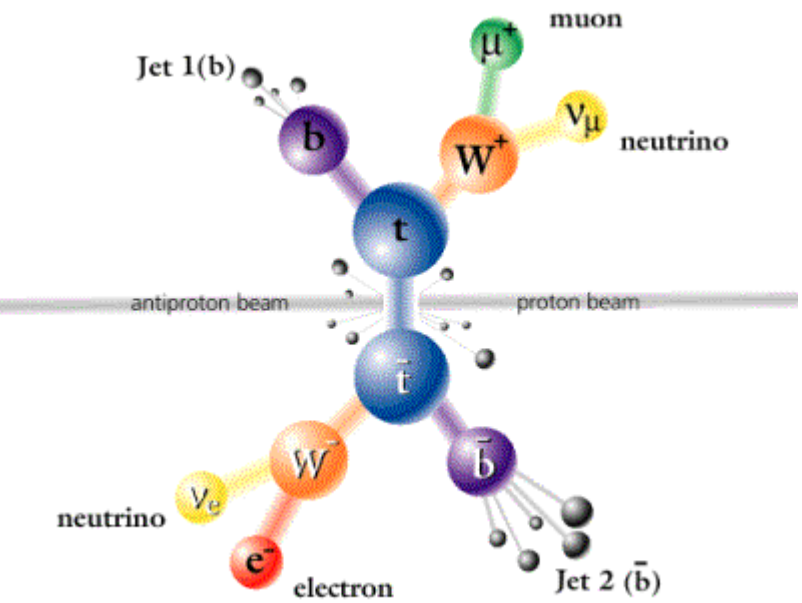
E_T = 633 GeV
η = -0.19



Energy deposits on an η–ϕ `lego' plot

Top Discovery at the Tevatron (1995)

Observed ttbar where t→bW (~100% branching ratio)



e + 4 jet event

40758_44414

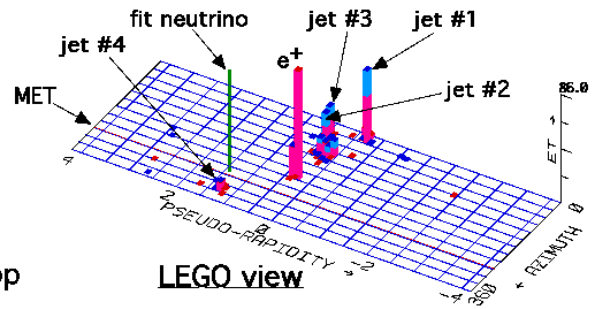
24-September, 1992

TWO jets tagged by SVX

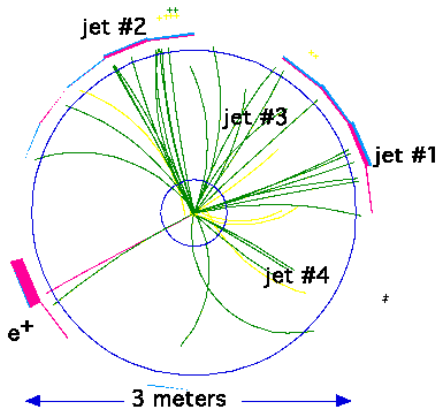
fit top mass is 170 +- 10 GeV

e^+, Missing E_t, jet #4 from top

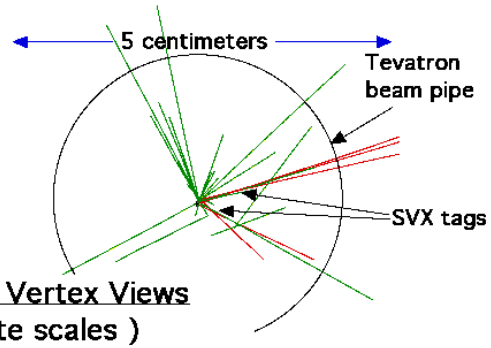
jets 1,2,3 from top (2&3 from W)



LEGO view

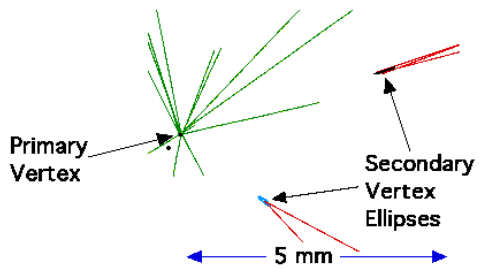


Tracking View



Two Vertex Views

(note scales)



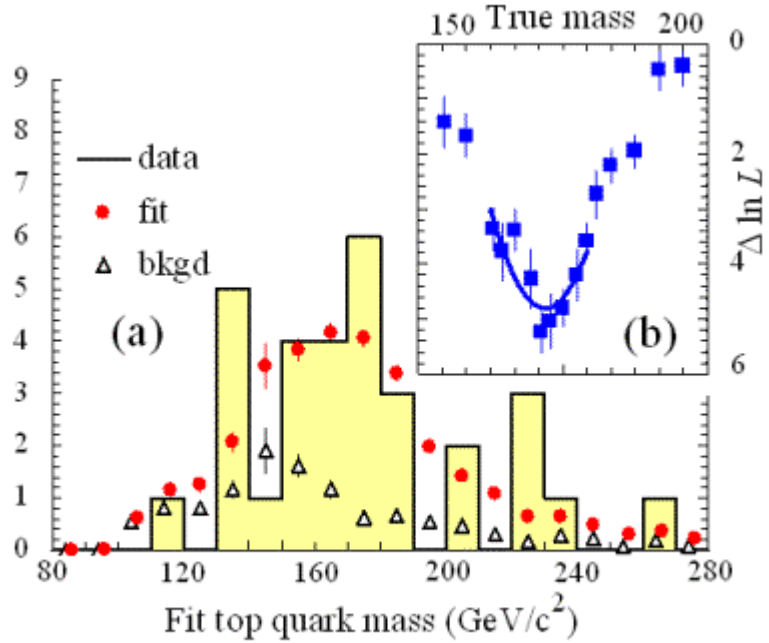
Search for .....

4 jets + lepton + ptmiss

(1ν, so can reconstruct mass)

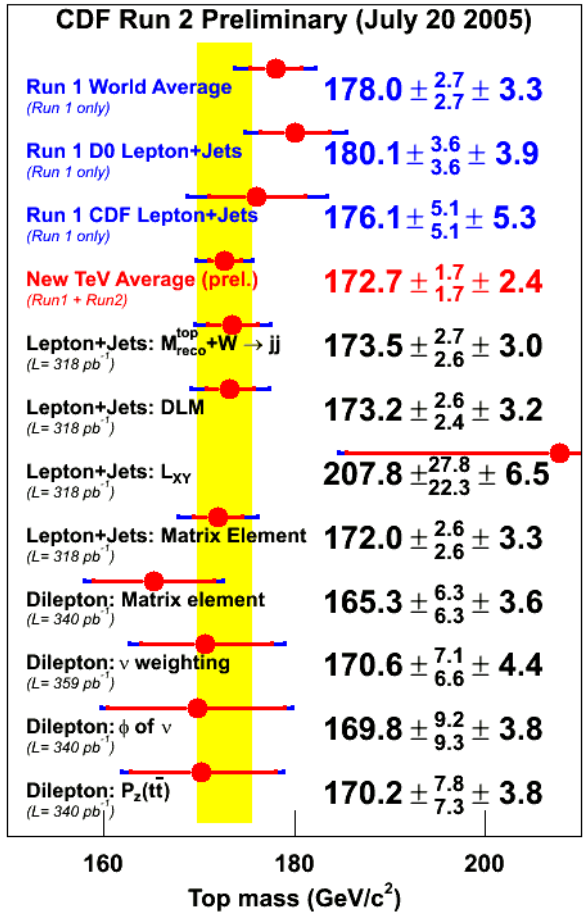
... or 2 jets, 2 leptons, ptmiss (2ν, so can't reconstruct mass)

Top Signal then, now and future …



Mass distribution 1995,
1 lepton, 4 jets, missing p_T

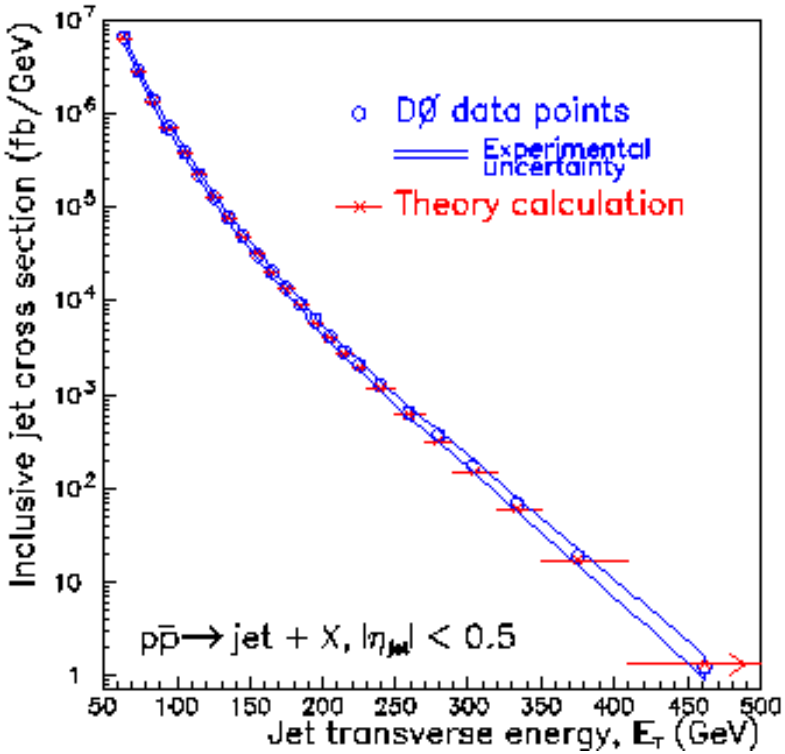
… "mass about 170 GeV"

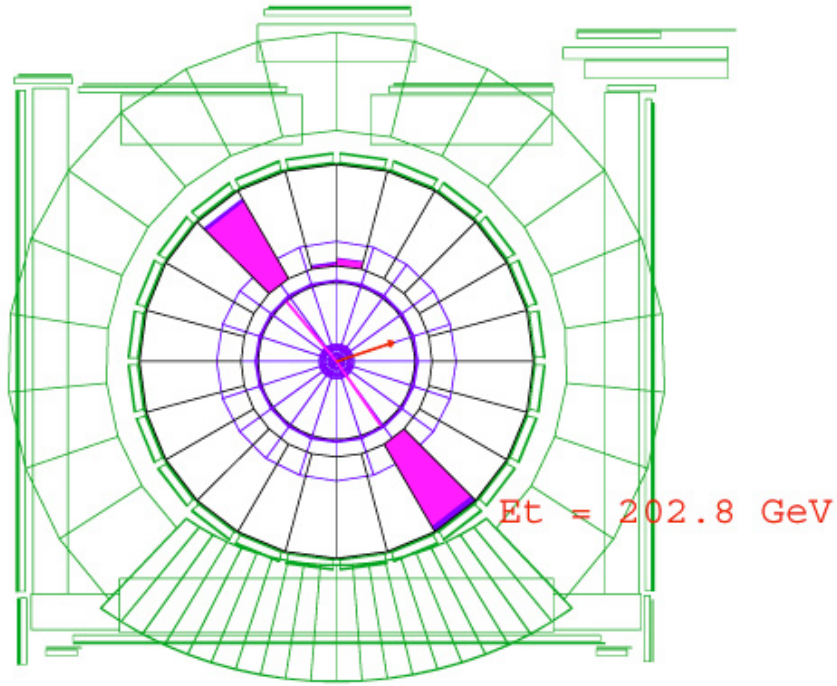


Many contributing channels
178 +/-3 (stat) +/-3 (sys) GeV

LHC will get top mass to <1 GeV

More (very selected) Tevatron Physics





Dielectron mass 375

Jet cross sections varying over 7 orders of magnitude and reaching ~500 GeV beautifully described by QCD

High sensitivity to new physics …. this one (and ~all others) described by standard model …. As a $\gamma\gamma$ interaction