Physics at the DØ Experiment

Past Results, Future Prospects, Present Status

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Outline

- What is a “DØ ”?
- The Standard Model
- The Tools: Tevatron
- The Tools: DØ Detector
- Previous Results (RunI)
- The Upgrade
- Future Results (RunII)
- Current Status

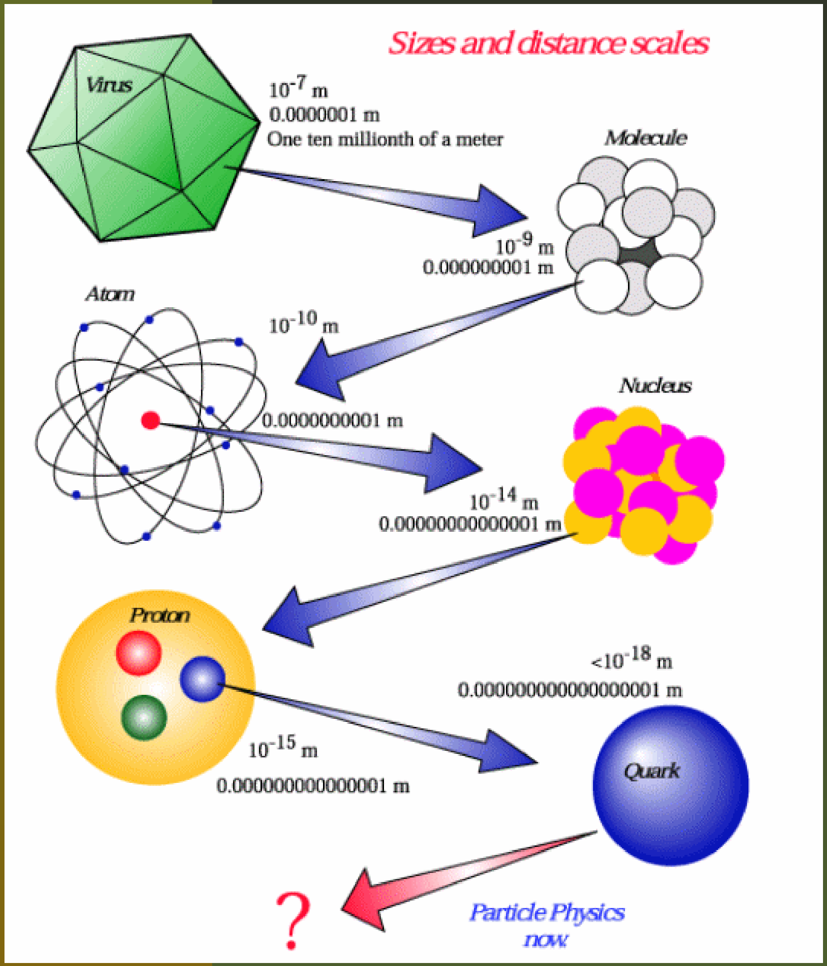
What is a DØ ?

- DØ is a group of people (not just Dugan Ø'Neil), a detector, and an experiment
- The DØ collaboration is a group of $\simeq$ 550 physicists from $>$75 institutions in 18 countries ($\simeq$50% US)

What is a DØ ?

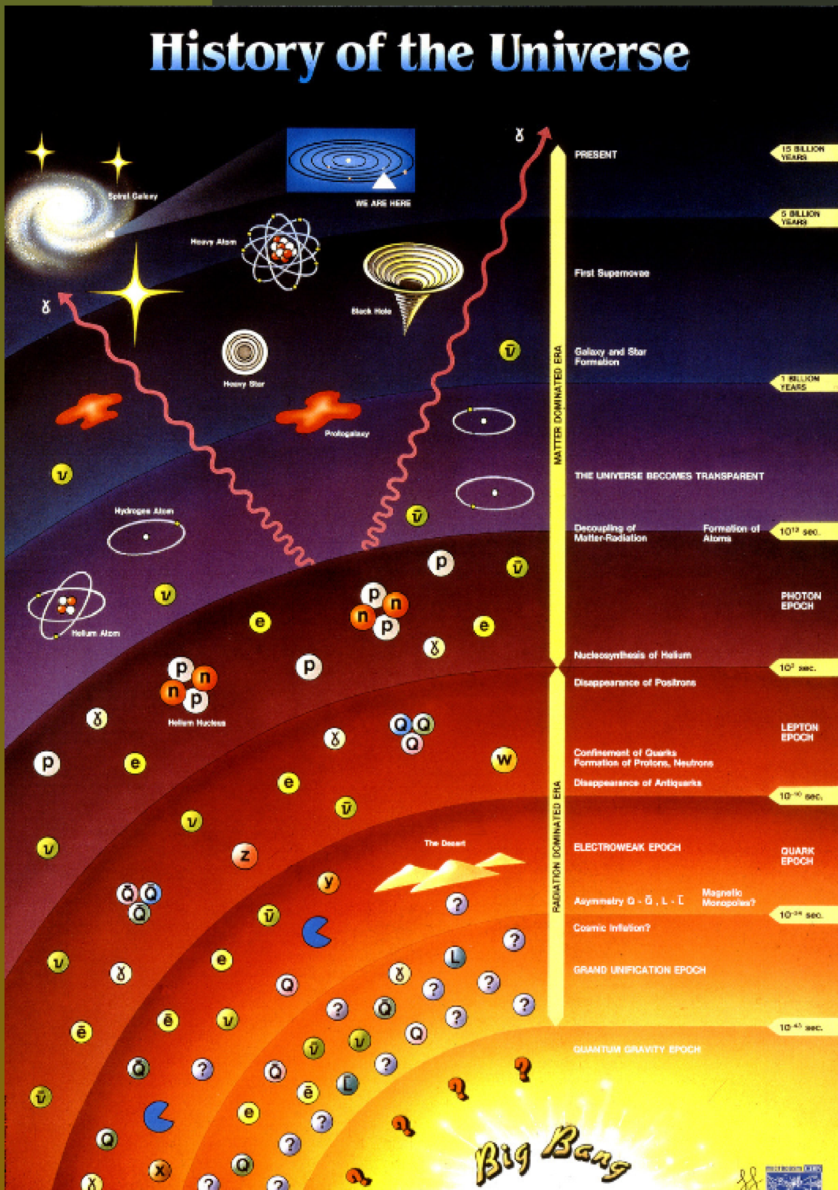
- DØ is a large (5000 ton) detector at the Tevatron $p\bar{p}$ collider in Batavia, Illinois, USA.
- Officially (http://www-d0.fnal.gov/):
  "...research is focused on precise studies of interactions of protons and antiprotons at the highest available energies. It involves an intense search for subatomic clues that reveal the character of the building blocks of the universe."
- Or: "We look for evidence of new physics through precision tests of the Standard Model and direct searches for new phenomenae".
- Or: "It is a particle physics experiment".

The Fundmental Building Blocks



- Force high-energy interactions between particles
- Probe smaller and smaller scales
- Requires larger and larger energies
- Colliders create temperatures not seen since the early universe

Recreate the Early Universe



Now (15 billion years)

Stars form (1 billion years)

Atoms form (300,000 years)

Nuclei form (180 seconds)

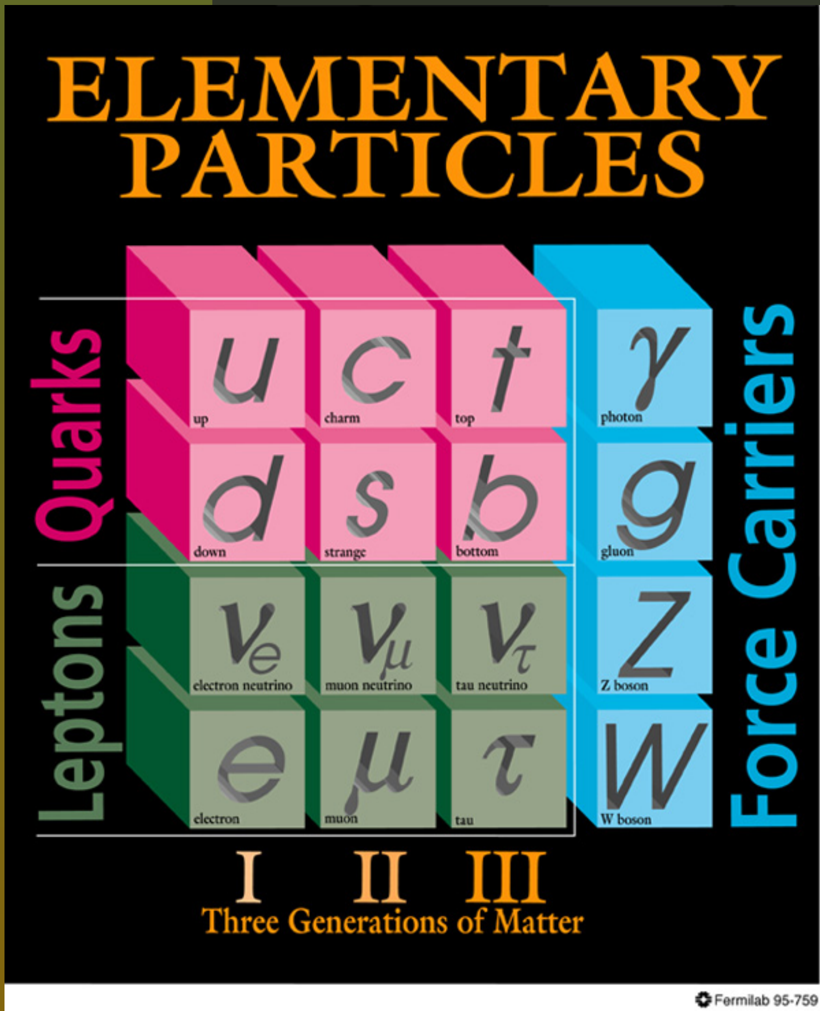
Protons and neutrons form (10^{-10} seconds)

Quarks differentiate (10^{-34} seconds?)

??? (Before that)

Fermilab
4×10^{-12} seconds
LHC
10^{-13} Seconds

The Standard Model



- fundamental particles/interactions
- 3(2) forces:
  - Strong
  - Weak
  - EM
- Something's missing (H)

The Standard Model

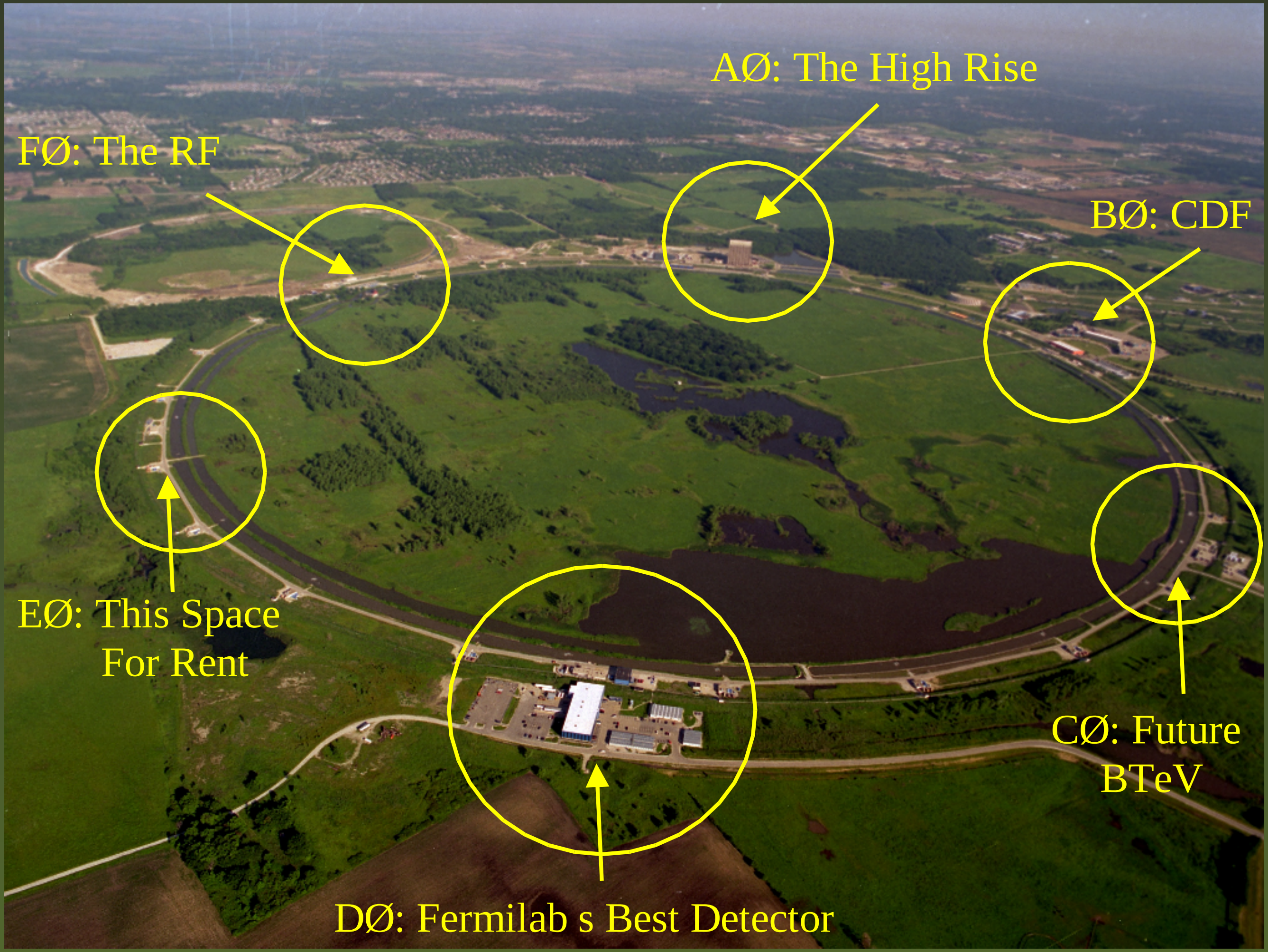
- Unified Electromagnetic and Weak forces. Numerous predictions including existence and mass of W, Z bosons have proved correct.
- An annoyingly successful model. Has been tested extensively for >20 years...it is always right
- This model is looking a little smug
- However, it has weaknesses:
  - many (19) free parameters
  - no unification of forces
  - what about gravity?
  - dark matter?
  - no Higgs (yet)

The Standard Model

- Low-energy effective theory
- We test the SM by measuring with great precision the predictions of the model
- We simultaneously look for new particles, interactions which are not predicted by the model at all.
- Many theories (including SM) expect new physics between EW scale and TeV scales (100-1000 GeV). We are probing some of this energy range this now (and will push farther soon).

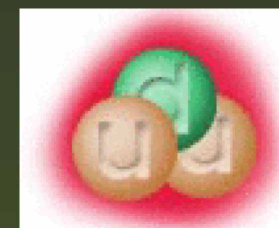
The Tools: Tevatron

- These energies cannot be acheived in your basement



The Tools: Tevatron

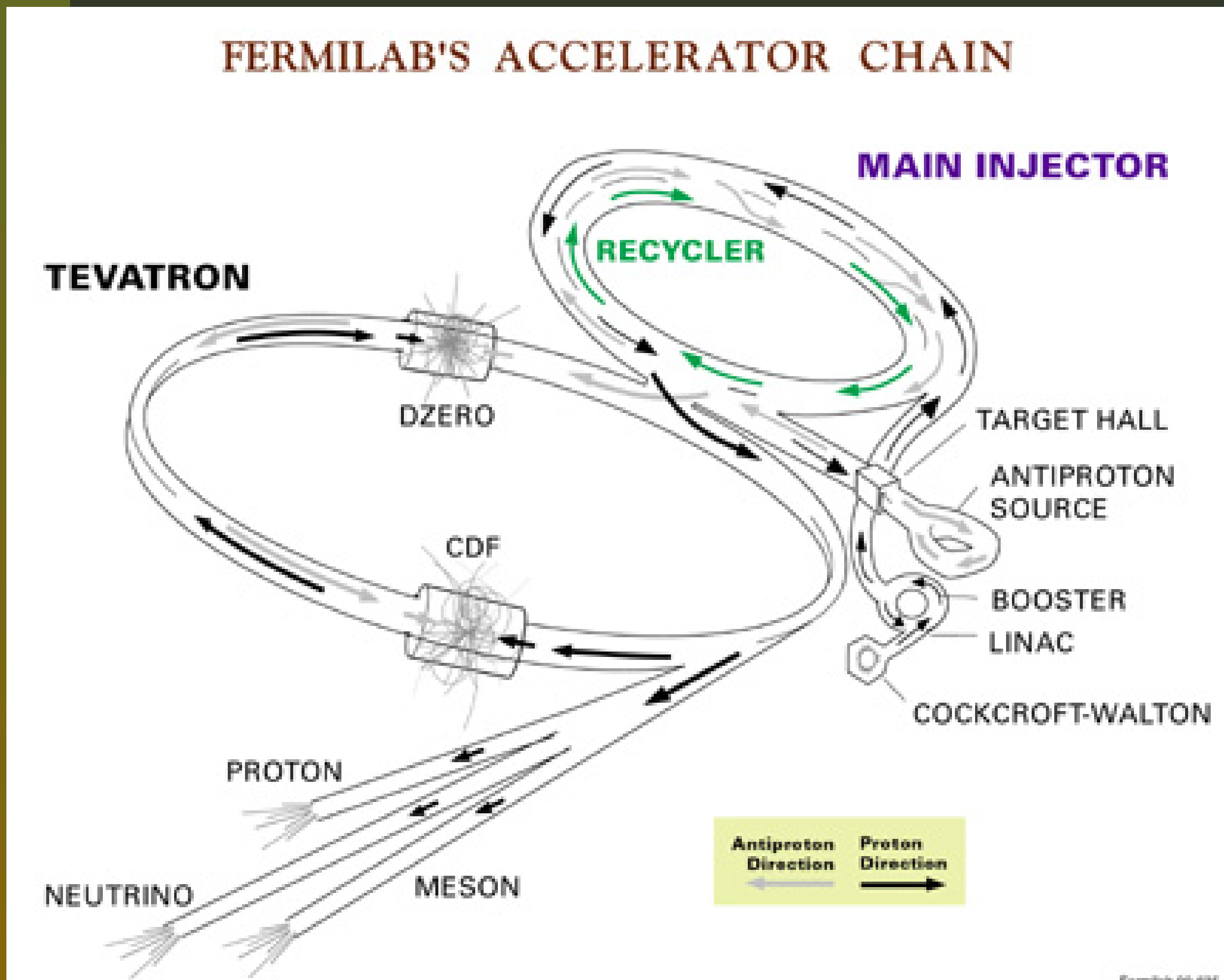
- World's highest energy collider
- Collides bunches of protons with bunches of anti-protons at two interaction points (BØ and DØ)
- Boring Tevatron statistics:



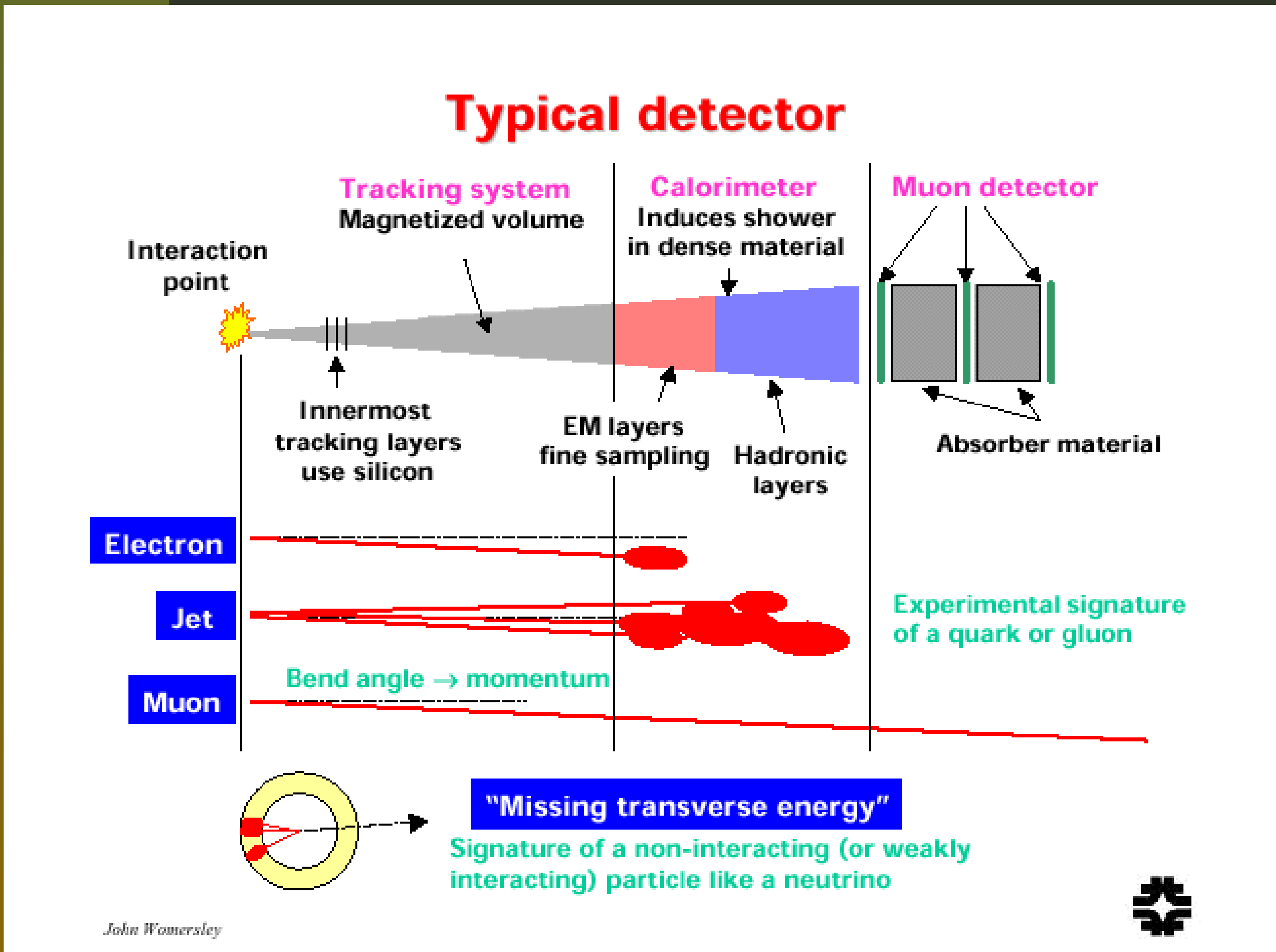
  - 6.2 km circumference
  - center of mass energy is 1.96 TeV
  - design luminosity is $5x10^{32}$ $cm^{-2}s^{-1}$
- A broadband quark and gluon collider (1 GeV - 1 TeV)

The Tools: Tevatron

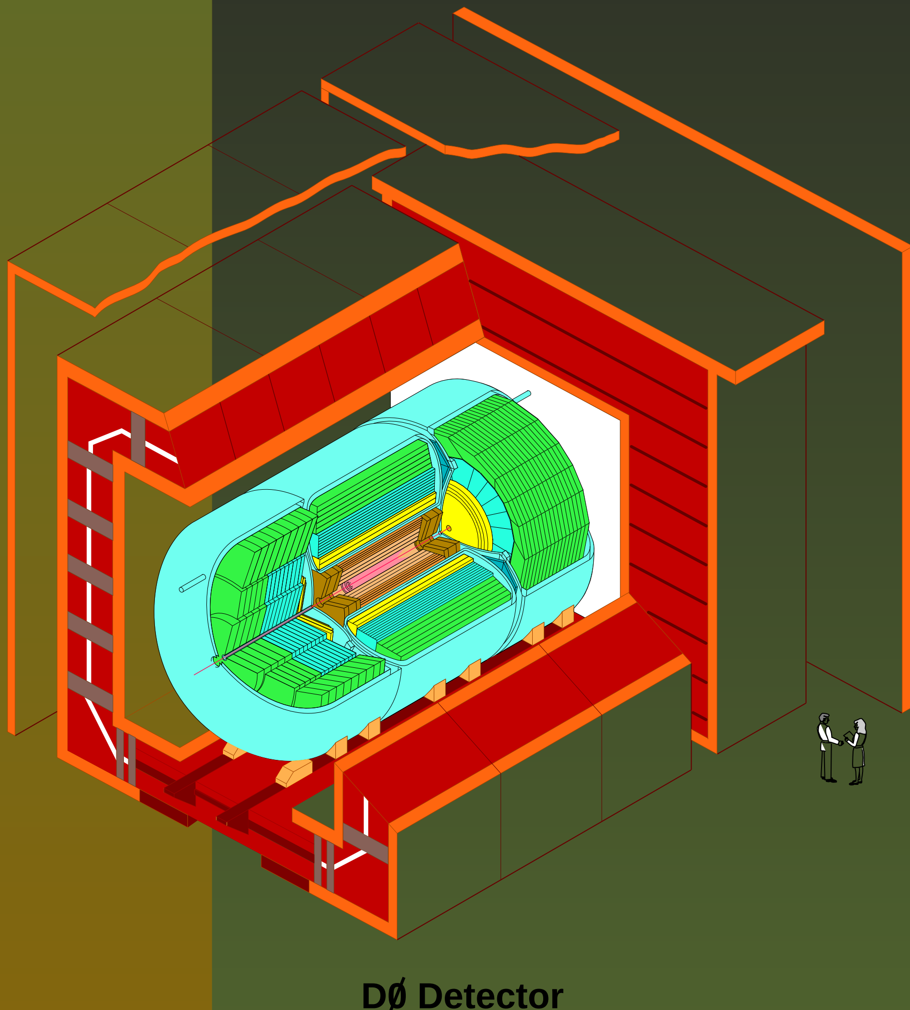
- Multi-stage process to reach these energies



The Tools: DØ Detector

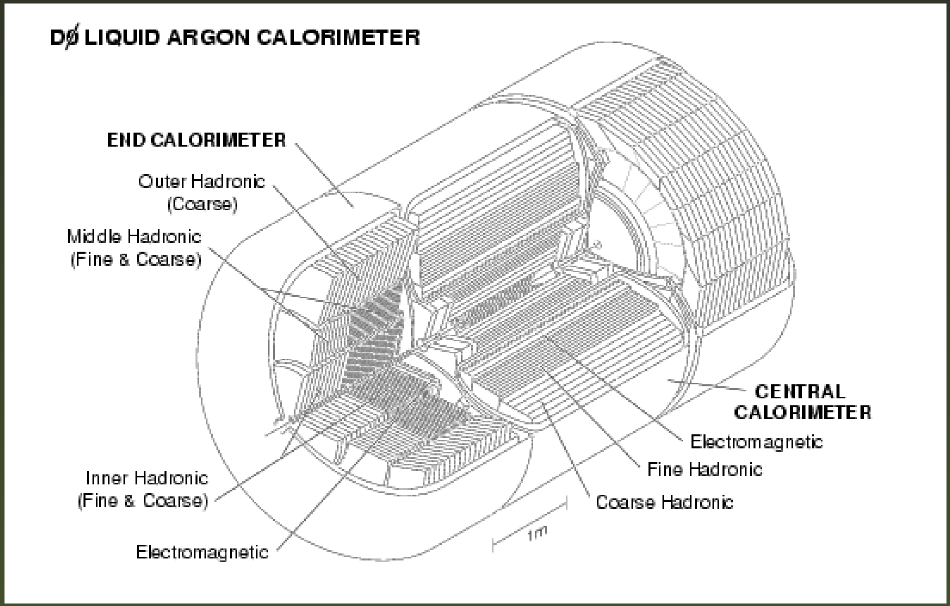


The Tools: DØ Detector



- DØ as it was for RunI
- Calorimeter: LAr/Uranium
- Muon: 1.9T field
- Tracking: tracker (drift chambers), no mag field, no silicon

The Tools: DØ Detector - Cal



- Measure energies of particles
- DØ is noted for quality calorimetry. First use of LAr-Uranium calorimeter.

The Tools: DØ Detector - Cal

- Boring Statistics
  - 3 detector types in depth: EM, FH, CH
  - nearly compensating e/h=1.04-1.11
  - granularity 0.05x0.05 - 0.1x0.1
  - energy resolution:

$$\text{electrons}: \frac{\sigma}{E} = \frac{16\%}{\sqrt{E}} \oplus \frac{0.14}{E} \oplus 0.003$$

$$\text{pions}: \frac{\sigma}{E} = \frac{41\%}{\sqrt{E}} \oplus \frac{1.28}{E} \oplus 0.03$$

$$\text{jets}: \frac{\sigma}{E} \approx \frac{80\%}{\sqrt{E}}$$

DØ Timeline

1983	first meeting at StonyBrook
1984	Approval from DOE
1985-1987	Detector R&D
1988-1991	Construction
1992-1996	Data-Taking - RunI
1993	First Paper Published
1995	Discovery of Top Quark
1996-2000	Upgrade for RunII
2000	100th Paper Published
2001	January Roll-in for RunII

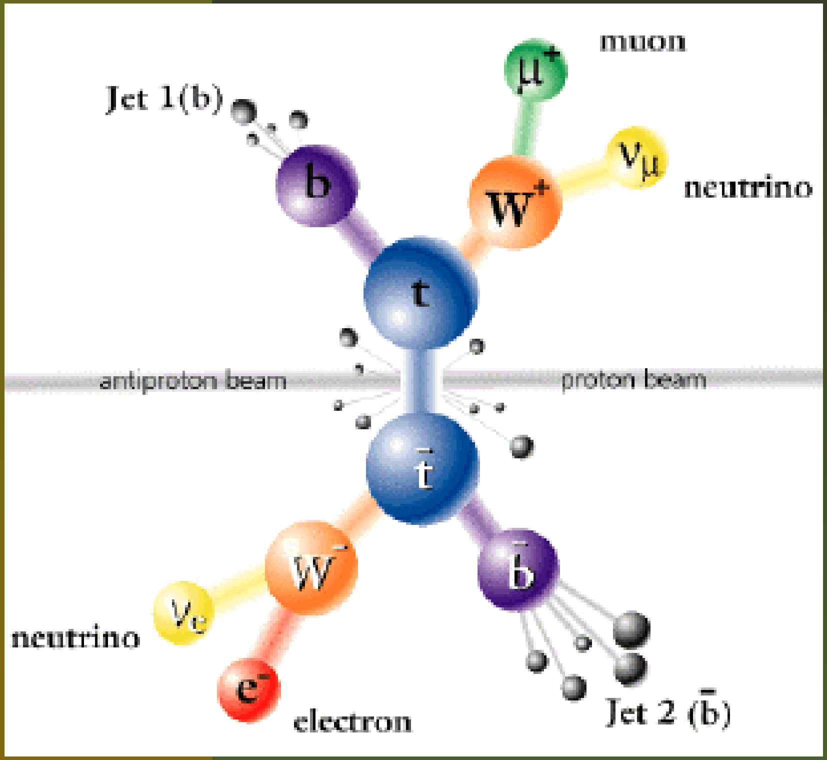
Previous Results: RunI

- RunI Info:
  - 1992-1996
  - Tevatron energy 1.8 TeV
  - main ring through DØ
  - luminosity $\simeq 10^{31} cm^{-2} s^{-1}$
  - integrated luminosity $120 pb^{-1}$
  - collisions every 3.5μs
  - DØ read out 120000 channels

RunI

- Main areas of study:
  - the top quark
  - electroweak (W/Z) studies
  - QCD
  - the bottom quark
  - searches for new phenomenae

RunI: The Top Quark



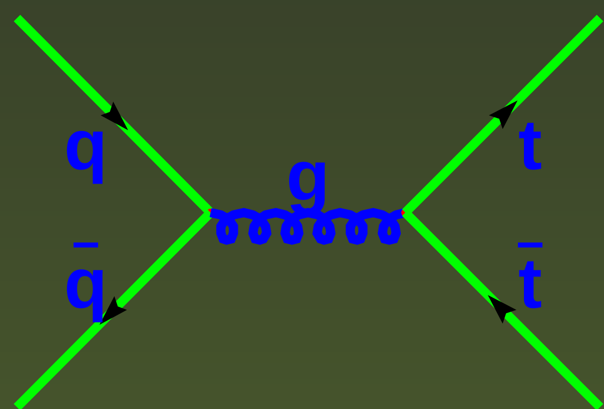
- Bottom quark discovered - 1977. Requires a partner.
- Hunt for that partner quark (top) lasted nearly 20 years
- Lower limit on mass was 90 GeV
- Top quark search high priority from the start
- Discovery of top: highlight of RunI

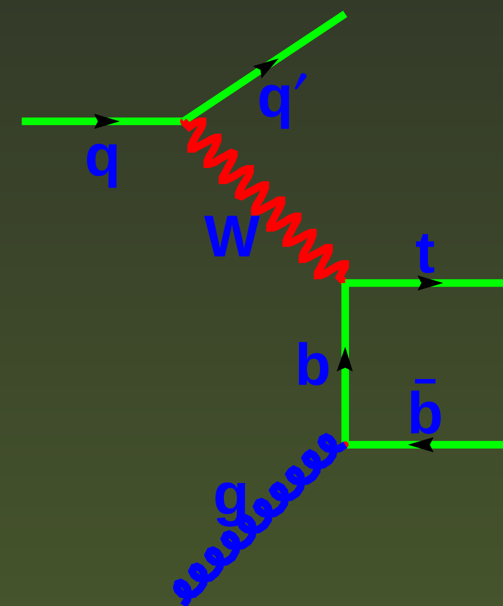
RunI: The Top Quark

- Why look for the top? Because it should be there!
- So, why study the top quark?
  - Top is VERY heavy - 35 times b mass, heavy as an atom of gold!
  - Mass is close to EW scale, is top involved in breaking EW symmetry?
  - Measuring top and W mass constrains Higgs boson mass
  - Decay of top is very fast (10^{-24}s). Faster than hadronization (10^{-23}s). Study bare quark!
  - General tests that properties match SM predictions

RunI: The Top Quark

- A few different ways to make a top at the Tevatron





- First is known as $t\bar{t}$ or top-pair production. Observed.
- Electroweak (single) top production
- Top decays to Wb

RunI: Top Quark Results

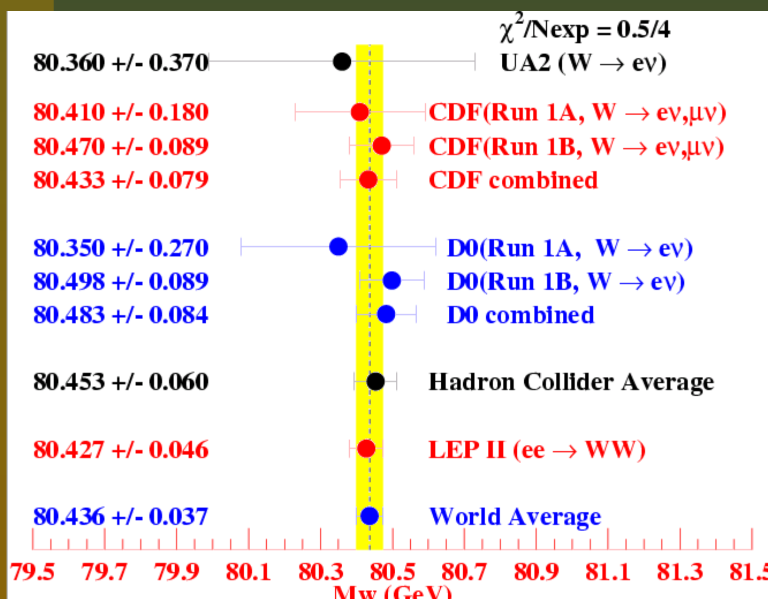
- Number of events:

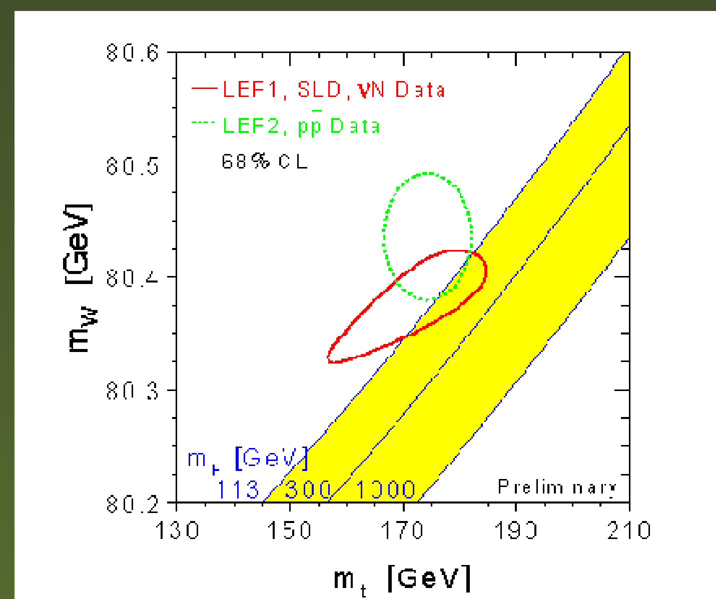
dilepton (ee,eμ,$\mu\mu$)	5
l + jets (lepton b-tag)	11
l + jets (topological)	19
all jets	41
eν	4

  You could get to know each event personally
- Top cross-section: 5.9 ± 1.7 pb - agrees with theory. Maybe this really is t$\bar{\text{t}}$ ...
- Top mass: $172.1 \pm 5.2 \pm 4.9$ GeV - best measured mass of all quarks!

RunI: Electroweak Results

- The discovery of W and Z bosons was announced in 1983. Total of 14 events.
- In RunI DØ accumulated over 100000 Ws and 10000 Zs
- DØ used the Zs to calibrate the detector and made many important improvements in W measurements





RunI: Quaero

- Would you like to analyze some RunI data?
- DØ analysis of RunI data is more-or-less complete
- A number of RunI datasets have been made publicly available through quaero: see quaero.fnal.gov
- Announced in Nature in November 2001. Also see hep-ex/0106039.
- Are you feeling lucky....

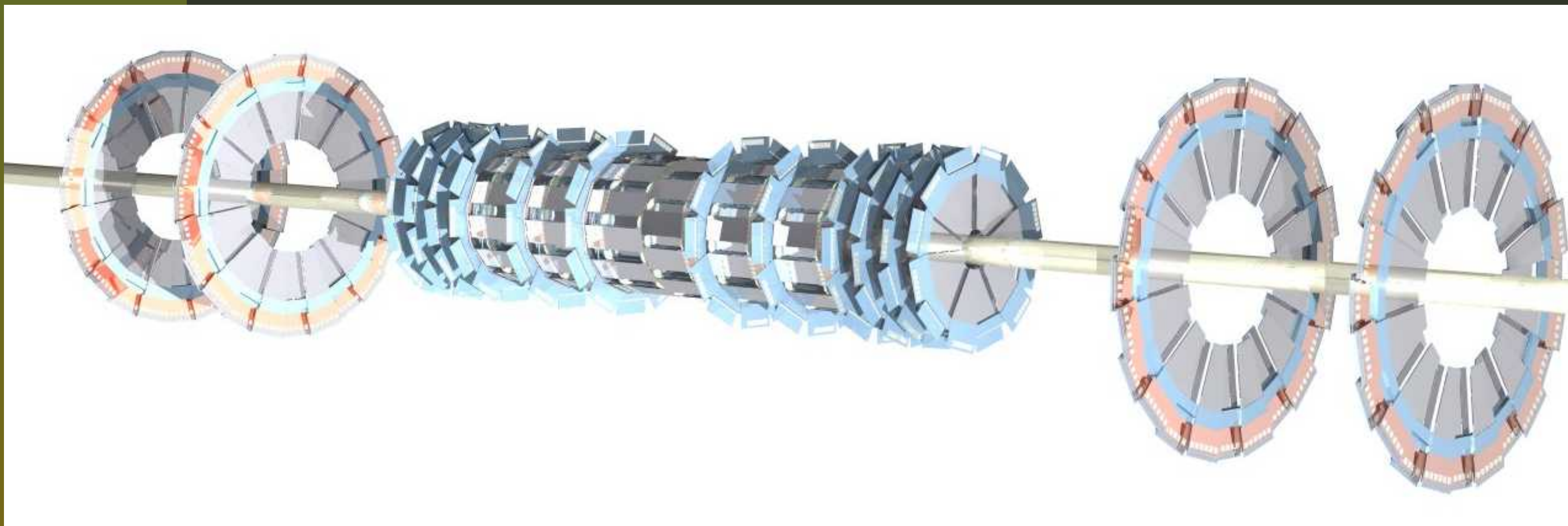
RunI: SLEUTH

- Attempt a model-independent search for new physics. Design a generic bump-finder!
- Not as sensitive to a given effect as a dedicated study, however, you don't have to only see what you are looking for.
- RunI data has been fed to the algorithm and has not found anything significant we missed.
- During RunII we will be SLEUTHing!

The Upgrade

- RunI ended in 1996. What has happened since?
- Tevatron has been overhauled. Main Ring replaced with Main Injector.
  - Energy 1.8 TeV $\rightarrow$ 1.96 TeV (almost 40% increase in top)
  - Luminosity $10^{31} \rightarrow 5 \times 10^{32} cm^{-2} s^{-1}$
  - Bunch spacing $3.5 \mu s \rightarrow 396 ns \rightarrow 132 ns$
- RunIIa = 2fb^{-1}, RunII = 15fb^{-1}. 20-150 times more data
- Both CDF and DØ have been radically changed. Tracking and trigger upgrades extensive!
- DØ is really a NEW detector

The Upgrade: D0



- No magnetic field in RunI
- No silicon detector in RunI
- Buy a 2 T magnet, build a silicon detector, build a new Central Fibre Tracker!

The Upgrade: D0

- New tracking system enhances identification of electrons and muons, improves calorimeter energy calibration and allows us to study/tag b-quarks!
- 800000 channels of silicon (RunI had 120k channels total!), coverage to $|\eta| = 2.5$.
- Central Fibre Tracker uses 77000 fibres in 8 layers (stereo + axial) read out with solid state visible light photon counters (VLPCs).
- RunI calorimeter stays. However, completely replace all readout electronics.
- Central muon system stays, but rebuild forward system and separate precision readout and trigger functionality.

The Upgrade: DØ Trigger

- We cannot possibly record, reconstruct and analyze every event that occurs in our detector (2 TB/s!!!)
- Need massive data reduction before writing to tape. Only write “interesting” events (5-10 MB/s).
- Trigger system is responsible for making online decisions for which data will be kept and which will be thrown away.
- Triggering in a hadron collider environment is never easy:
  - Lots of data!!
  - Varied physics programme. Each physics group (eg. top, higgs, SUSY) has as many people as a “big” experiment $\simeq$ 100 people

The Upgrade: DØ Trigger

- RunII accelerator upgrade makes it more challenging still
  - Luminosity increases by factor of more than 10
  - Time between crossings $3.5\mu s \rightarrow 132ns$
- rates:

Level	Input Rate	
1	8 MHz	Hardware + Firmware
2	10 kHz	Hardware + Software
3	1 kHz	PCs + Software
to tape	20-50 Hz	Large Tape Robot

Prospects for RunII

- New detector, upgraded accelerator. Lots more physics to explore in RunII!
  - Precision measurements + SM favour a light Higgs. In reach?
  - Several theories beyond SM (eg. SUSY) are potentially accessible
  - Studies of top quark properties in RunI were severely limited by small number of events.
  - Increased sample of W/Z lead to increased precision
  - Study the b-quark at DØ for the first time
  - QCD studies with high energy jets, etc.
  - Model-independent searches (SLEUTH)

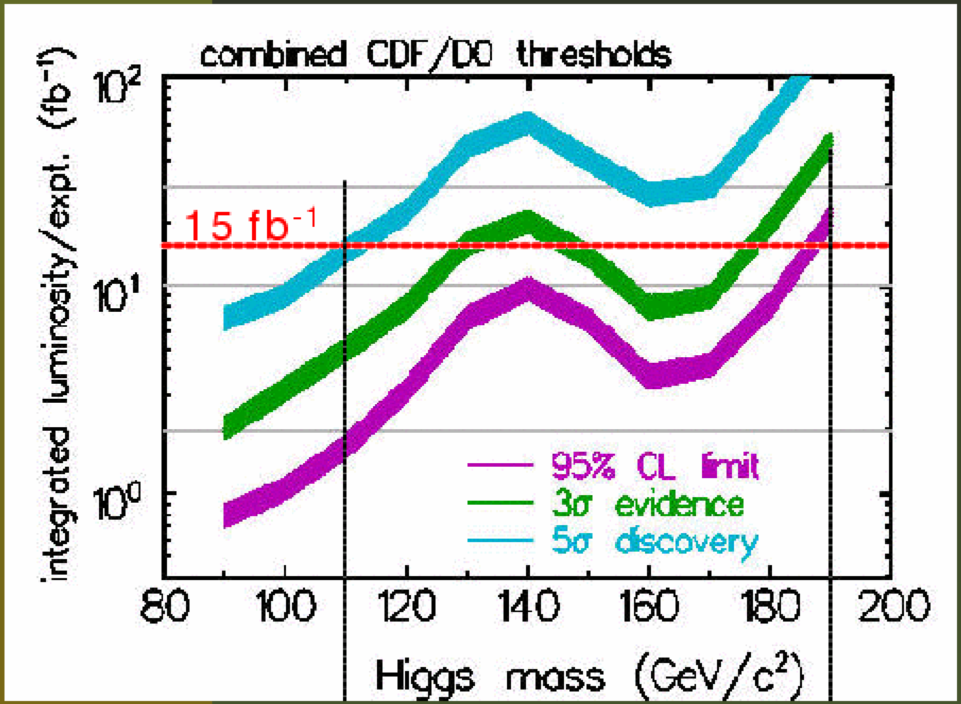
RunII: Higgs

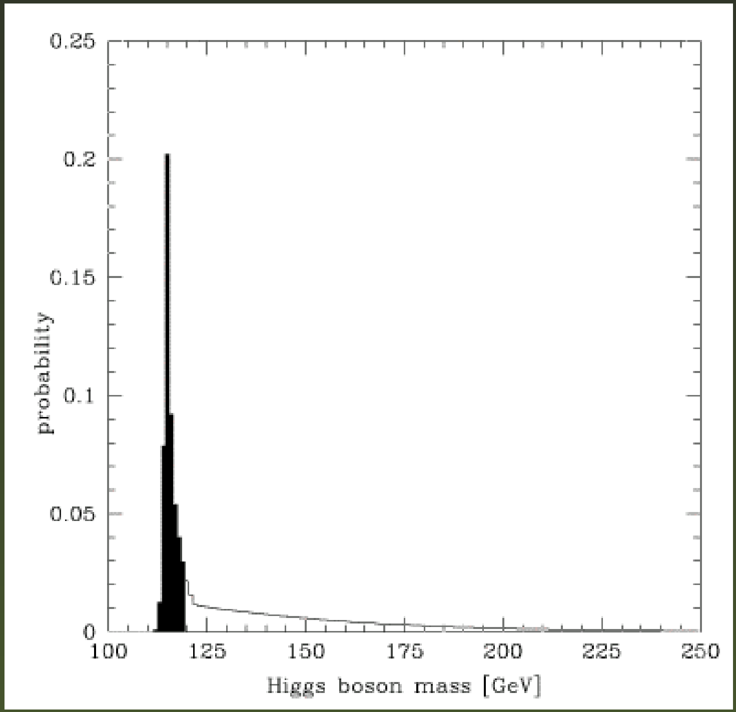
- Where does mass come from? How can we get it in the SM?
- EW symmetry breaking occurs through introduction of a scalar field.
- Consequence of the symmetry-breaking mechanism...existence of a Higgs particle.
- This is the highest priority search in particle physics!
- Fermilab is the only place to look for Higgs before 2007.
- Can we find it?

RunII: Higgs

- Direct searches at LEP have excluded Higgs below 113 GeV.
- Precision measurments of W/Z bosons and Top indicate that Higgs is less than 200 GeV.
- Example: m_H=115 GeV
  - 2 fb^{-1} (2003) - exclude at 95% confidence
  - 5 fb^{-1} (2004-5) - evidence at 3σ
  - 15 fb^{-1} (2007) - evidence at 5σ

RunII: Higgs



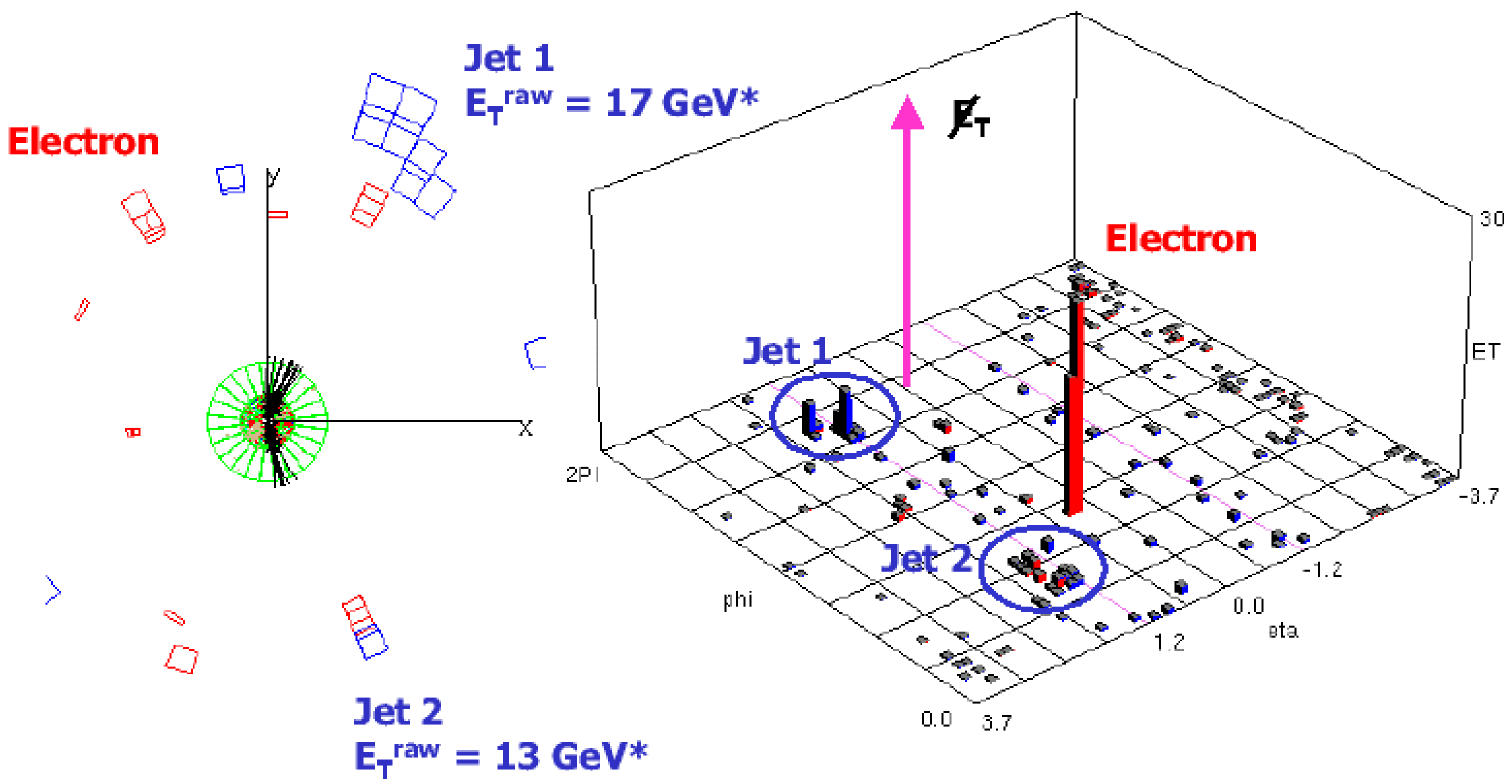


- If mass is low we have a shot. Will take a lot of data.

RunII: Higgs

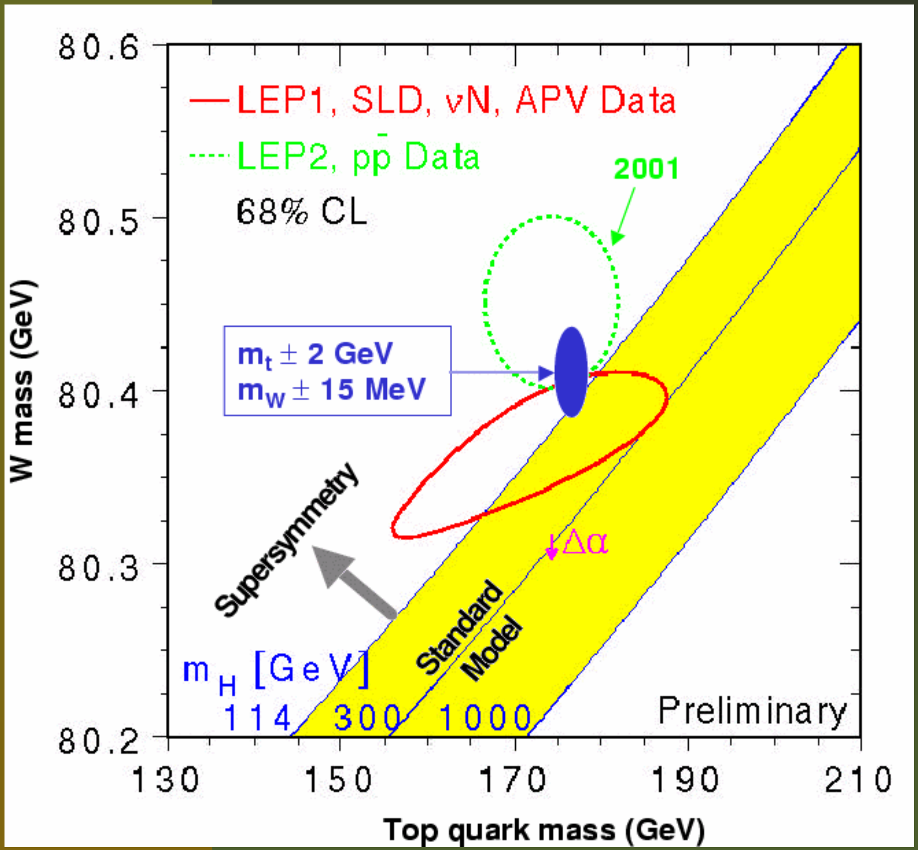
Higgs Candidate (just kidding…)

DØ W + 2 jet candidate



*** Jet E_T corrections will be relatively large**

RunII: Top

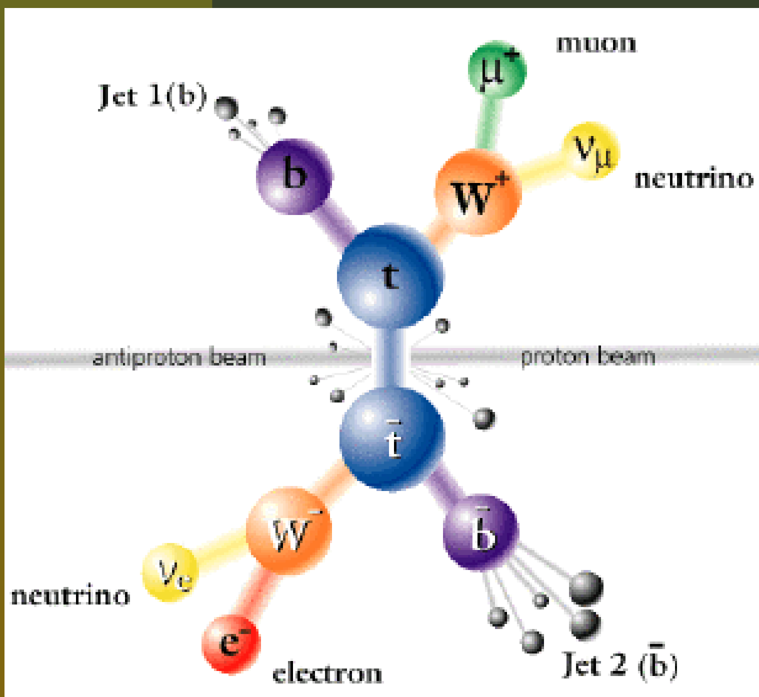


- RunI total number of events for DØ <100.
- RunII: write a few thousand top events to tape.
- b-tagging with efficiency greater than 50%.
- Expected ($2fb^{-1}$)

  mass 2-3 GeV

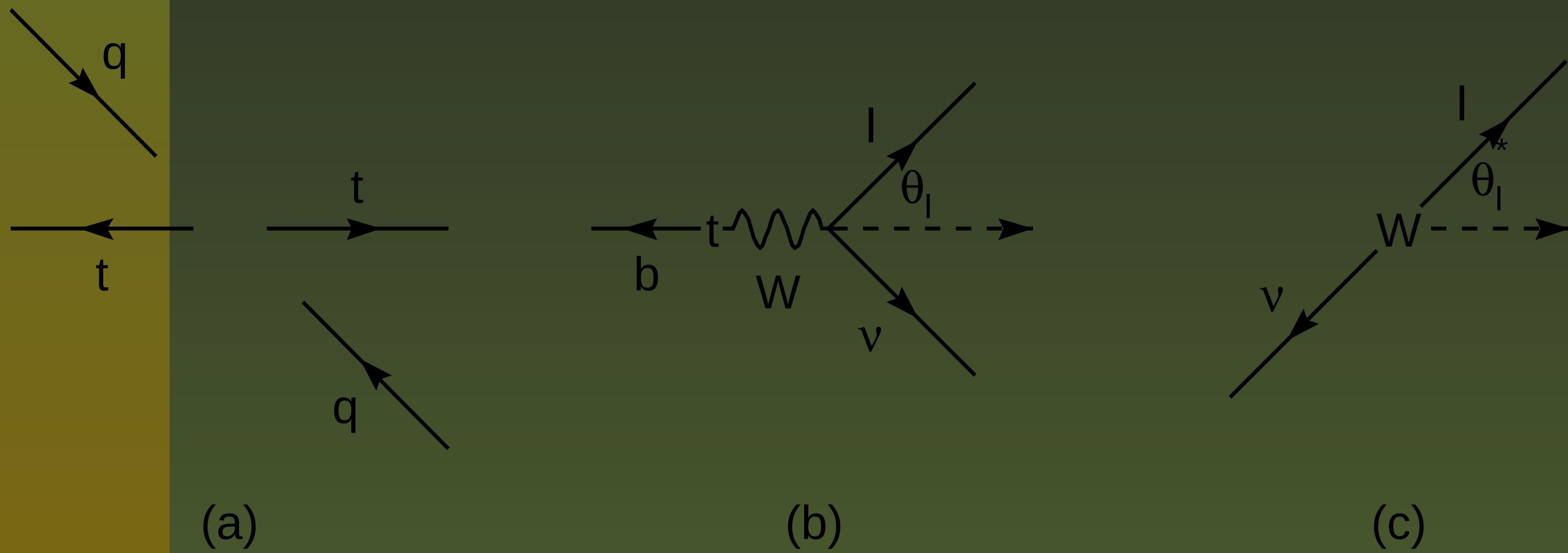
  σ 8%

RunII: Top - W helicity



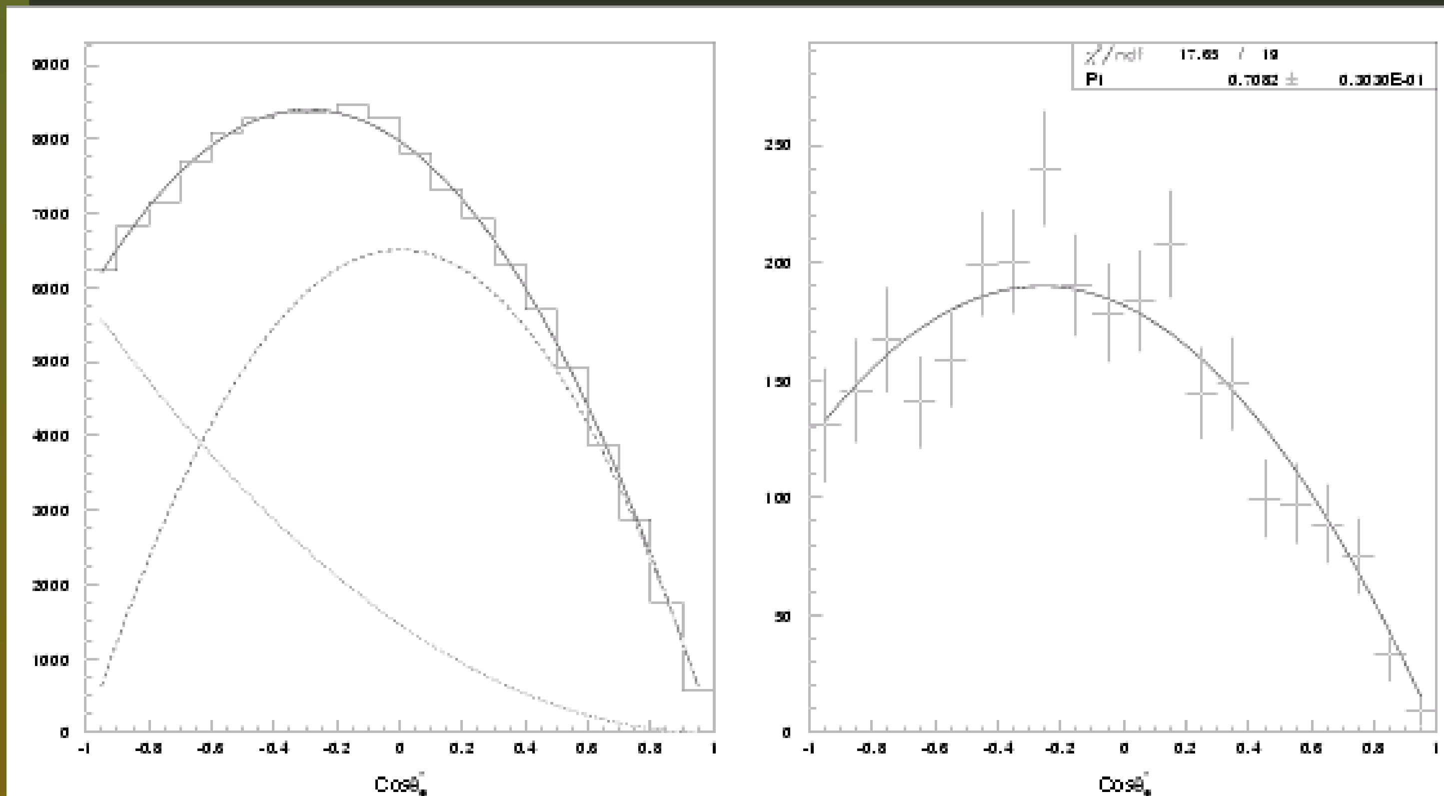
- Top quarks decay to Wb nearly 100% of the time
- Produced Ws are never right-handed. 70% long., 30% left.
- Angular distribution of lepton sensitive to helicity of W.
- Only previous measurement from CDF has very large errors
- Should measure to 5% in RunII

RunII: Top - W helicity



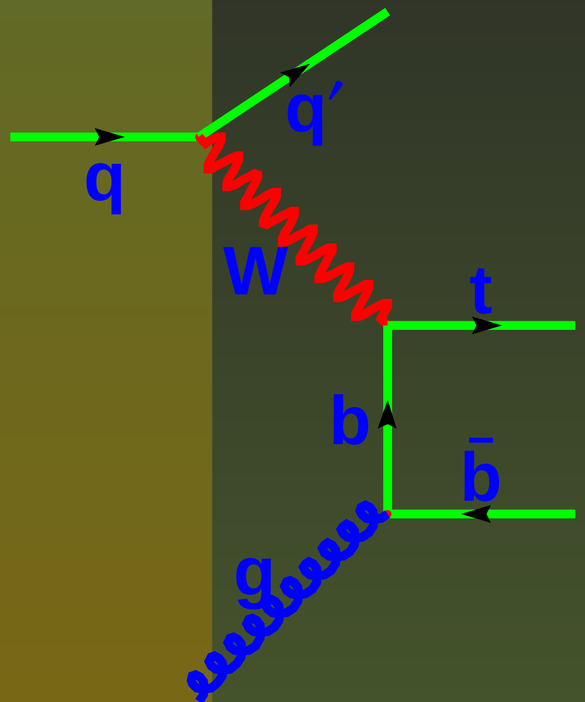
$$\cos\theta_l^* \approx \frac{2m_{lb}^2}{m_{lb\nu}^2 - m_W^2} - 1$$

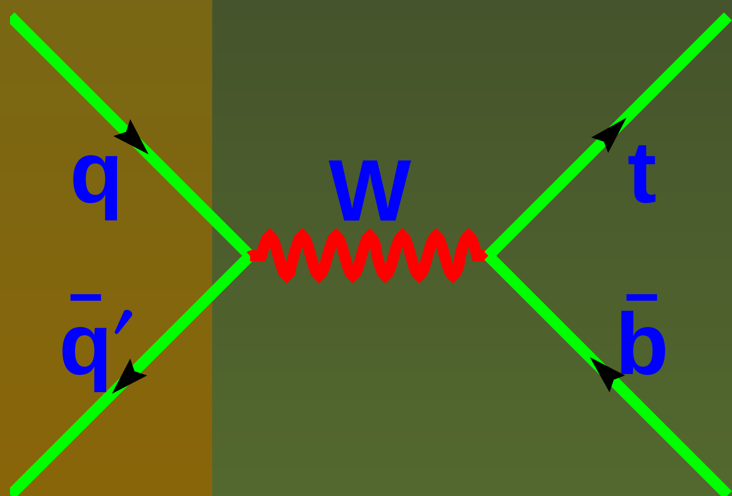
RunII: Top - W helicity



- Want to measure Br(W_{long}) to 5%

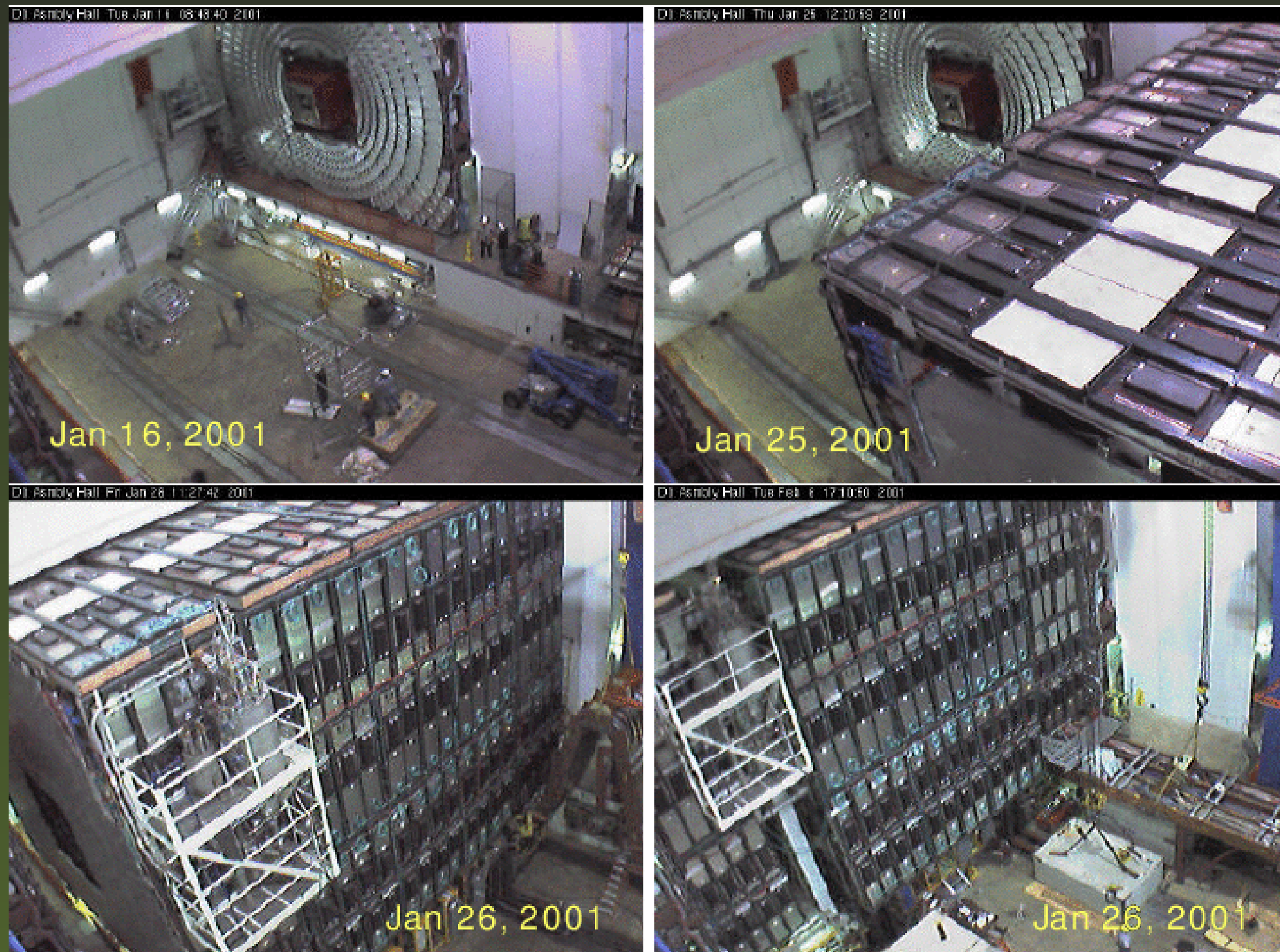
RunII: Single Top





- Needs to be discovered!
- Cross-section proportional to V_{tb}
- Source of polarized top quarks
- First chance to study polarization of a "bare" quark!
- Estimate discovery (or close) in RunIIa

Current Status



- Mechanically complete detector rolled-in to collision hall in Jan. 2001

Current Status

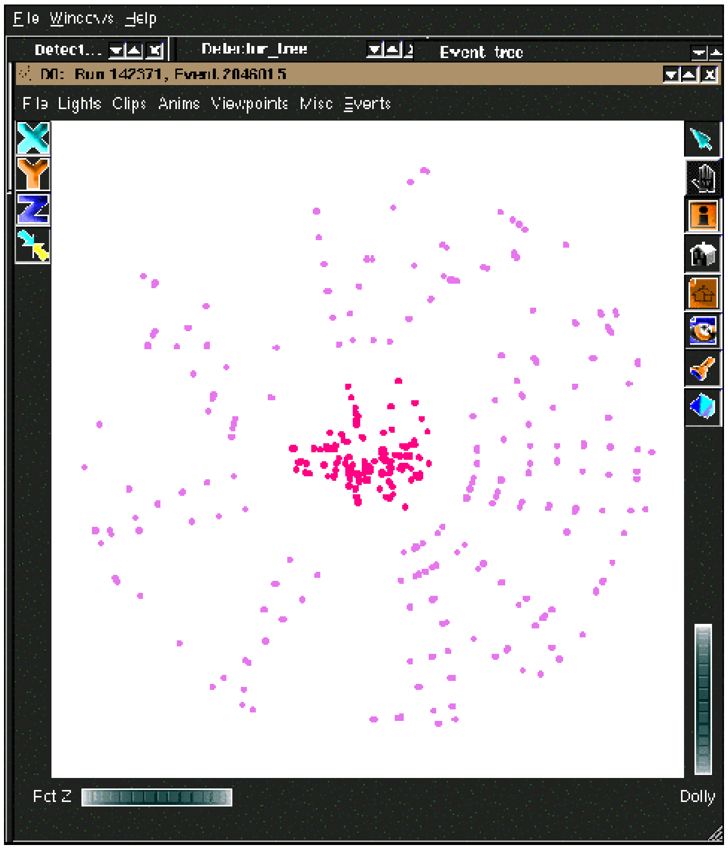
- RunII officially began March 1, 2001 (by decree).
- RunII really began in April 2001. First collisions April 3.
- The accelerator and detectors have been slowly ramping-up ever since.
- Accelerator: Still below RunI luminosities, major upgrade this summer (recycler). New schedule:
  - 200 pb^{-1} by end 2001
  - 2001-2004: RunIIa, 2 fb^{-1}
  - Short shutdown for detector upgrades
  - 2004-2007: RunIIb, 15 fb^{-1}
  - 2007-?: depends on LHC

Current Status

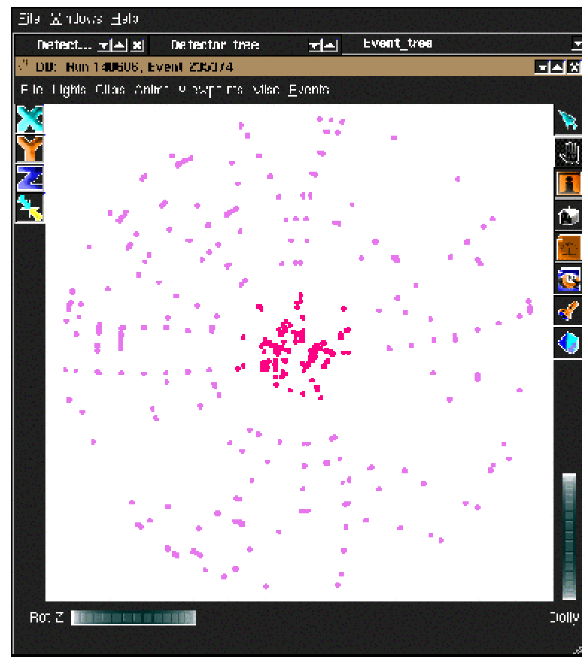
- Detector was mechanically complete on roll-in in January 2001. However, not electronically complete.
- Full fibre tracker readout only installed during October 2001 shutdown.
- Pieces of trigger electronics were also missing. Have slowly been added since the beginning of the run.
- We have not made any startling physics discoveries yet, but....
- We have been making tremendous progress in understanding the detector! Remember, it is like a whole new experiment!

Current Status

Hits in SMT and CFT



Avto Kharchilava, Notre Dame

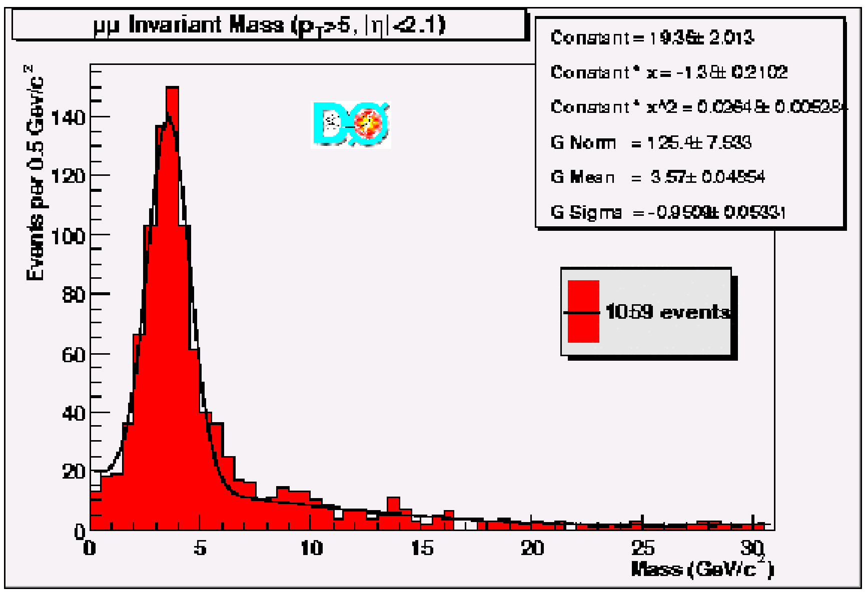


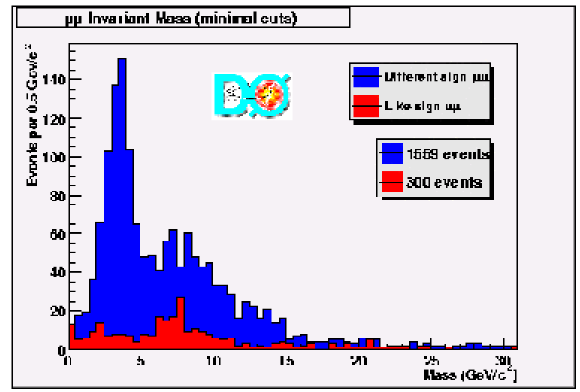
Boaz Klima - Latest results from Run 2 at DØ

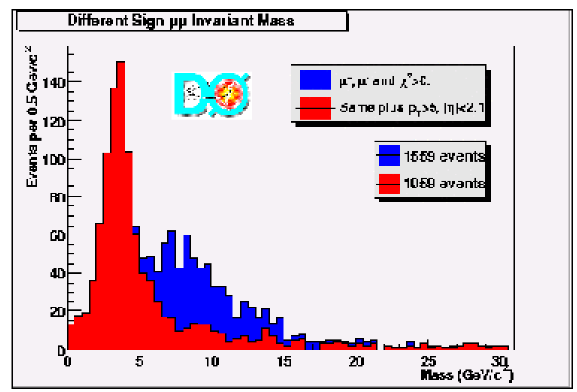
Current Status

$J/\psi \rightarrow \mu^+\mu^-$

Di- muons reconstructed in the forward region

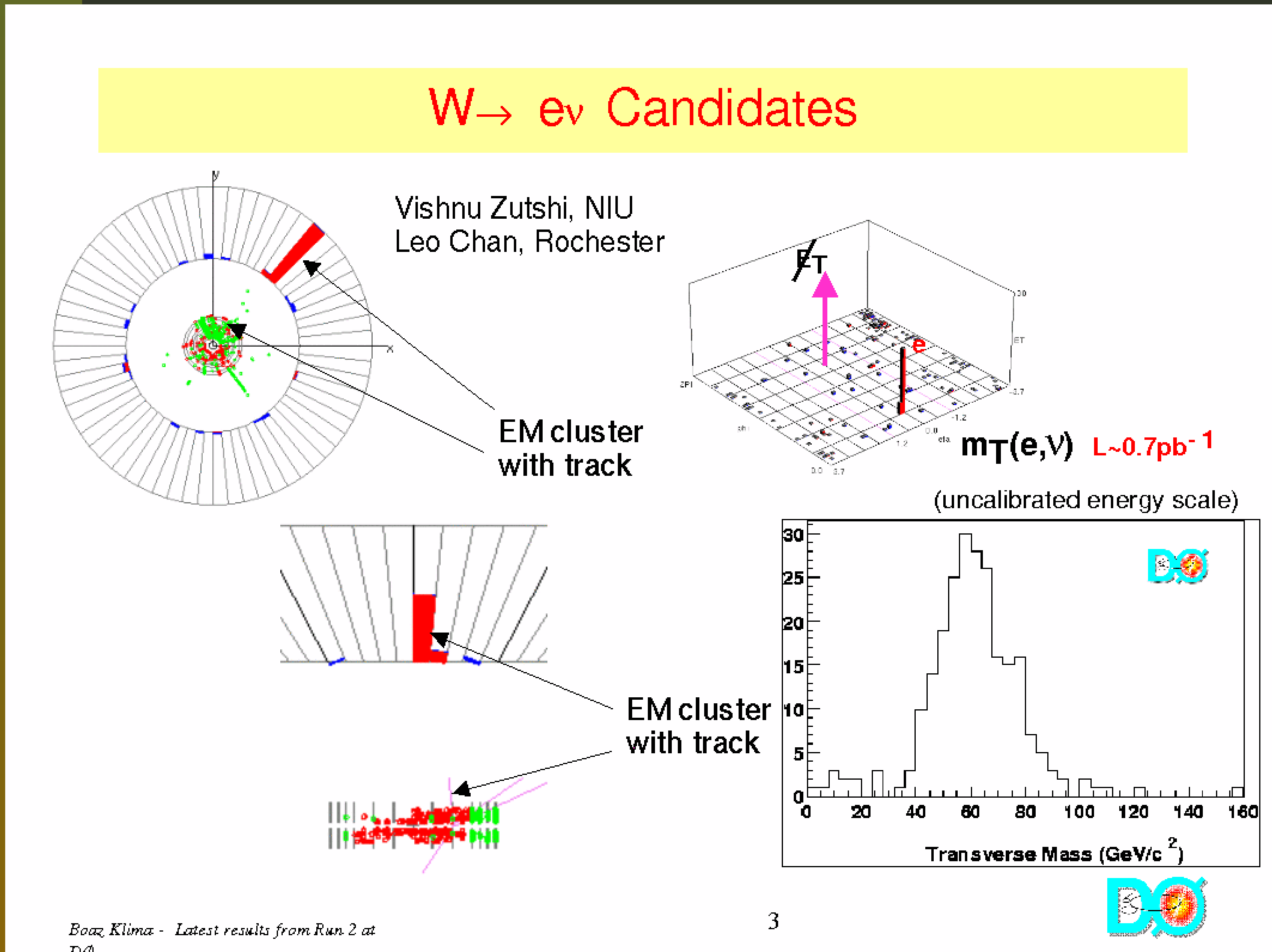






Roger Moore and
Adam Yurkewicz, MSU

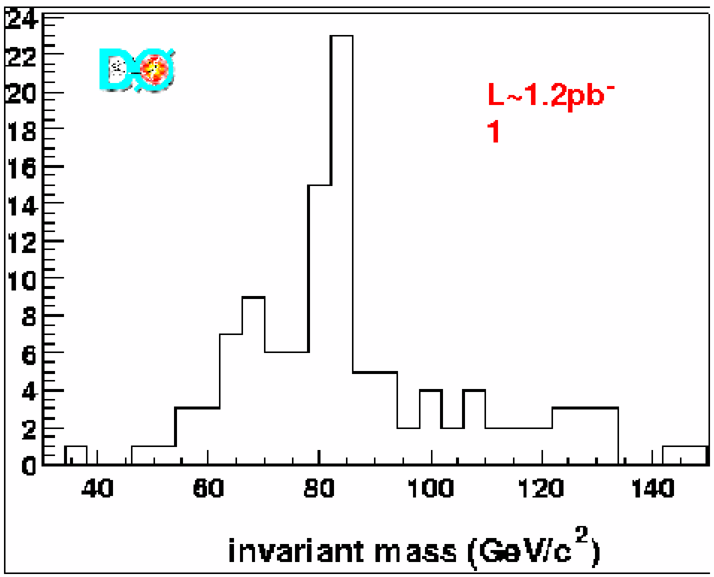
Current Status



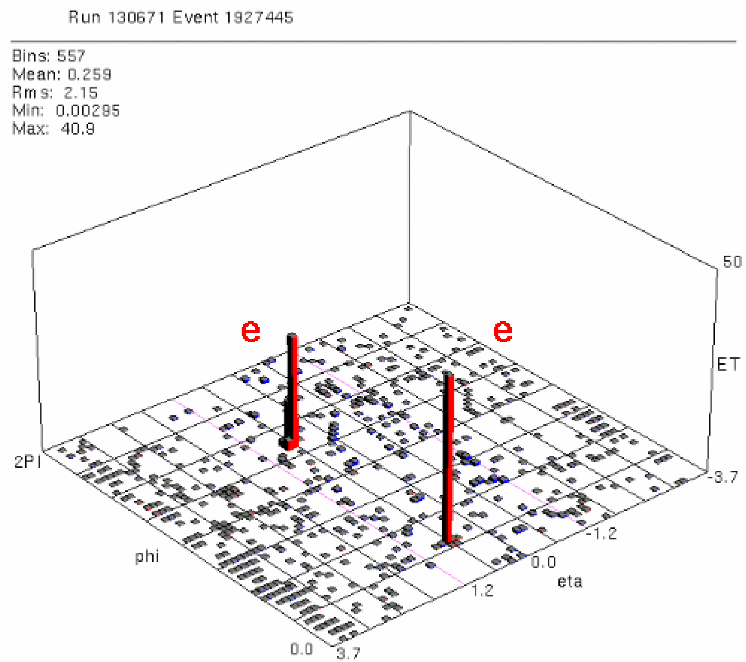
Current Status

$Z \rightarrow e^+e^-$ Candidates

2 EM objects, $E_T > 20$ GeV,
isolation and shower shape cuts



(uncalibrated energy scale)



Leo Chan, Rochester

Summary

- RunI was a great success at DØ (discovery of top, etc.)
- This is a very exciting (and busy) time to be at DØ !!!!!
- DØ is a new detector in RunII
- Upgraded accelerator and detector gives great new physics reach!
- We have started taking data (April 2001). We are understanding our data and our detector.
- Expect something to be shown at summer conferences (70 pb^{-1})
- Double RunI dataset by end of this year.

Acknowledgements

- Thanks to the entire DØ collaboration for providing something to talk about.
- Special thanks to those DØ members from whom I directly stole slides: Don Lincoln and John Womersley.