Tevatron Graduation Day

Tevatron Impact Symposium

Keynote

Lisa Randall

Graduation

- **grad·u·a·tion**
- [graj-oo-ey-shuhn
- noun 1. an act of graduating; the state of being graduated.
- 2. the ceremony of conferring degrees or diplomas, as at a college or school.

- Today we celebrate the impact and legacy of the Tevatron
- Both in terms of science and in its influence on technology and creative scientific thinking

Legacy

- Momentous time in particle physics.
  - Transition.
  - Many eyes on LHC.
- But really what got a lot of us into particle physics was what was happening “next door.”
- Which is to say here in Batavia Illinois.
- Spectacular successes
  - Advances both in technology
  - And science
  - As successful as it could have been

- Tevatron (and engineers and scientists who created and ran it) graduate
  - summa cum laude

My First Fermilab Experience

- Predates Tevatron
- Summer student 1982
- Charm fixed target E516

  (thanks to David Bintinger and Mike Sokoloff, Drasko Jovanovic, Chris Quigg)
- Great opportunity to get acquainted with particle physics
- Could dive right into analysis
- Learn a number of things:

What I Learned

- People and buffalo can live in close promixity
- Feed corn never gets soft, no matter how long you cook it

  (dinner party from fellow student…)
- Chicago mayors buy the loyalty of the populace with some rather excellent free festivals:
  - Chicago Jazz Festival
    - Miles Davis AND Alberta Hunter (among others…)

And of course

- Standard Model and its implications
- Physics experiments absorbing
- Fitting it all together very satisfying
- And many excellent people involved

Other experiences

- Stayed on site with other visitors
- British experimenter returning from a drunken binge
- “CERN has to find the “bloody vector boson”
  - Made an impression.
- “All the discoveries being made in America and it was time for Europe.”
- Before the Tevatron.
  - Impressive feats of ingenuity.
  - Optimize existing facility

25 Major Years for Particle Physics

- A quarter century of Tevatron
  - Centerpiece from December 1985 until 2011
- A quarter century of running of LHC preparation
  - Essentially same time frame
- A quarter century of my physics career
  - And those of my cohorts

Achievements

- Explored physics up to 1.96 TeV
- Initial design luminosity $10^{30}\ cm^{-2}\ sec^{-1}$
  - Delivered over 400 times that to both D0 and CDF experiments

    A machine that ran BETTER than projected

- Many notable milestones
  - Even when setbacks came back on target or better

- Many critical technological advances

The Energy Saver/Doubler

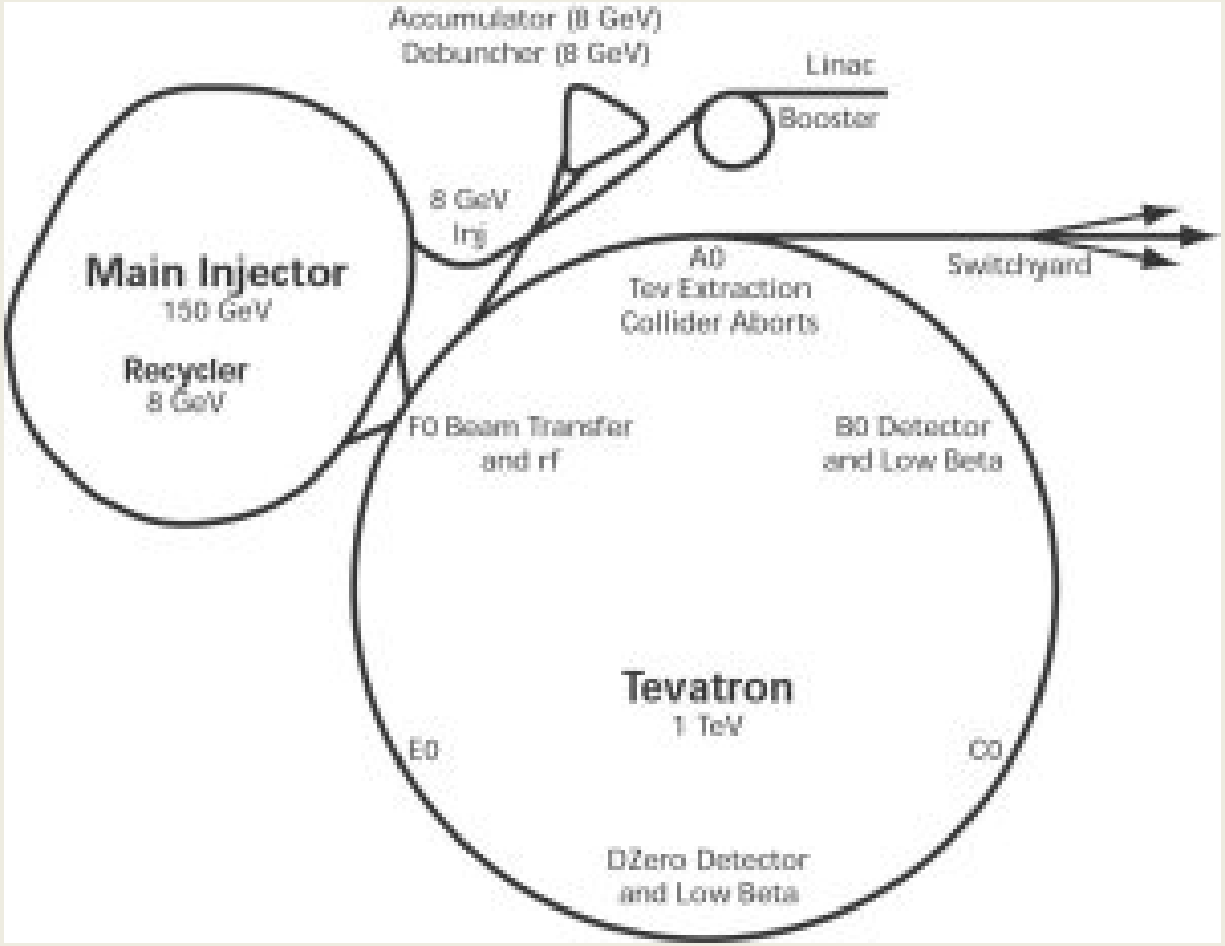
- Bob Wilson originally intended to double energy from 500 GeV to 1 TeV
- Key idea: reduce power consumption through superconducting magnets
- Major technology advance we take for granted today
  - Allowed Tevatron with original 6.3 km Main Ring
    - 1970s development
    - 1983 original commissioning
    - Fixed target accelerator that year

The Tevatron

- Antiproton Source 1985
- 1st collisions with proto-CDF
  - Real data starting in 1987
  - More 1988,1989
  - 5 pb^{-1} at 1800 GeV cm
  - Design luminosity exceeded!
- Run Ia, 1b (1993)
  - Impressive improvements
  - 1.6 10^{31} cm^{-2} sec^{-1}
  - 60% Improvement over Run I goal

Main Injector Synchrotron and Recycler Storage Ring

- March 2001 to Sept 2011
- Luminosity goal 8 10^{31} (x 2.5) cm^{-2} sec^{-1}
- Setbacks but ultimately 3.4 10^{32} cm^{-2} sec^{-1}
  - Again in excess of expectations
- Peak luminosity grew by over 50 during ten years
  - Series of improvements throughout operation


Accumulator (8 GeV)
Debuncher (8 GeV)
Linac
Booster
8 GeV
Inj
Main Injector
150 GeV
Recycler
8 GeV
A0
Tev Extraction
Collider Aborts
Switchyard
F0 Beam Transfer
and rf
B0 Detector
and Low Beta
Tevatron
1 TeV
E0
C0
D2ero Detector
and Low Beta

Technology Advances

- Superconducting magnets
  - Used in all major accelerators since
  - Design issues addressed: strands, geometry, support, cooling, protection
- Recycler permanent magnets
- Stochastic cooling of antiprotons
- Other improvements you will hear about later…

Experimental Advances

- Silicon Vertex Detectors
  - Introduced key possibilities for 3rd generation physics
  - Clever use of information that was being lost
- Calorimetry
- Triggering Techniques
- Analysis Techniques

Not my focus but…

- Impressive to watch development of machine
  - And experiments
- Maximize use of the existing facility until its ultimate expiration date
- Ingenuity, hard work, and diligence combined to get performance to where it was
- Resulting in beautiful physics results…

Physics of the Tevatron: The Unsung Hero

- Discovery
  - Top quark in particular
  - Could have been other stuff had it existed at those energies…
- AND precision measurements
  - At a hadron collider!
  - Precision measurements for electroweak physics, QCD, and flavor

Flagship achievement

- Discovery of top quark 1995
  - ONLY place it was made for 15 years
- After years of not finding it…
  - No reason to expect it to be so heavy
- Heavy enough had to look for decays into b and W
  - Which themselves decay
  - Many analysis teams had to work together to find evidence and establish its existence
- Since: mass measurement, cross section, interactions…

QCD

- Jet cross sections
- Gluon initiated jets
- Parton distributions
- Strong coupling measurement
- Agreement with SM constrains physics beyond SM

Precision Electroweak

- *W* mass measurement
- Top quark mass measurement
  - Recall top mass parameter present in addition to ew parameters themselves
  - Isolating top depce determines (Higgs and) new physics constraints
- Electroweak gauge boson production rates

Report Of The Electroweak Interactions Theoretical Issues Working Group.

Mitchell Golden (Fermilab), H. Baer, Vernon D. Barger, U. Baur, Ikaros I.Y. Bigi, E. Eichten, Tao Han, C.S. Kim, D. Morris, Lisa Randall *et al.* *Show all 14 authors*

Nov 1989
14 pp.

In *Breckenridge 1989, Proceedings, Physics at Fermilab in the 1990's* 112-125 and Fermilab Batavia - FERMILAB-Conf-90-043 (89,rec.Mar.90) 14 p

Presented at Conference: C89-08-15
FERMILAB-CONF-90-043-T,C89-08-15,FNAL-C-90-43-T

Keyword(s): INSPIRE: talk | anti-p p: interaction | interaction: anti-p p | W: hadroproduction | hadroproduction: W | Z0: hadroproduction | hadroproduction: Z0 | photon: associated production | associated production: photon | electroweak interaction: validity test | validity test: electroweak interaction | jet: associated production | associated production: jet | jet: multiple production | multiple production: jet | quantum chromodynamics: validity test | coupling: (3gauge boson) | (3gauge boson): coupling | intermediate boson: mass | mass: intermediate boson | Z0: decay | decay: Z0 | angular distribution: asymmetry | asymmetry: angular distribution | postulated particle: Z' | Z': hadroproduction | hadroproduction: Z' | mass: Z' | Z': mass | grand unified theory: E(6) | Higgs particle: hadroproduction | hadroproduction: Higgs particle | mass: top | top: mass | Weinberg angle | numerical calculations | proposed experiment | bibliography | 2000-3600 GeV-cms

Radiative Corrections To Electroweak Parameters In Technicolor Theories.

Mitchell Golden (Fermilab), Lisa Randall (LBL, Berkeley)

May 1990
25 pp.

Nucl.Phys. B361 (1991) 3-23

FERMILAB-PUB-90-083-T,LBL-29050,NSF-ITP-90-82

- Tevatron also played role in precision electroweak studies
- Not only in experiment but inspiring theory
- Better understanding W boson mass was critical to theoretical developments
- From ρ parameter and beyond

Other Heavy Flavor Physics

- *D* Mesons
- Mass, lifetime B_s
- *B* baryons
- Rare decays
- B_s mixing 2006
  - Phenomenal achievement

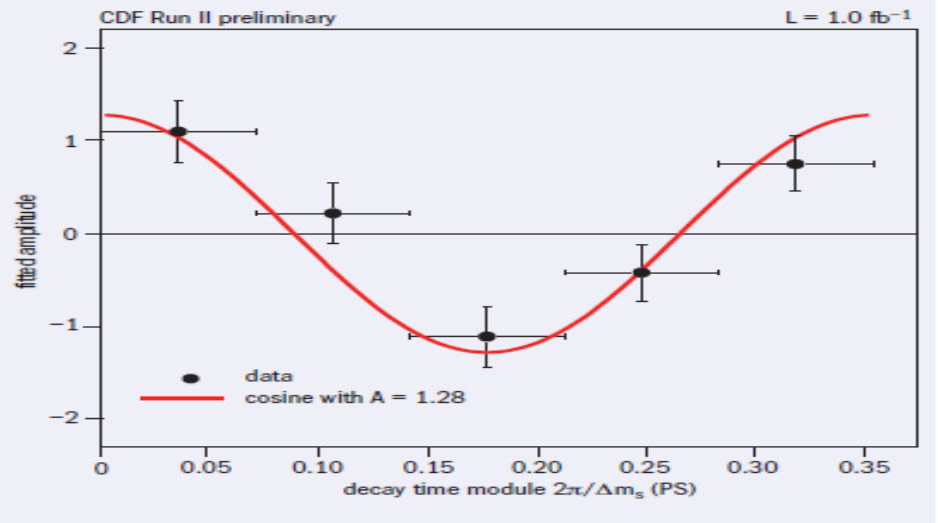


Fig. 4. CDF's $B_s - B_s$ oscillation signal measured in five bins of proper decay-time modulo the measured oscillation period.

Inspired to Study CP Violating Leptonic Decays

- **CP violating lepton asymmetries from *B* decays and their implication for supersymmetric flavor models.**
- Lisa Randall, Shu-fang Su (MIT, LNS).

  Jul 1998
  21 pp.

  Nucl.Phys. B540 (1999) 37-57
  Nucl. Phys. B540 (1999) 37-57
- hep-ph/9807377,MIT-CTP-2755,CERN-TH-98-159
  e-Print: **hep-ph/9807377 Abstract:** The lepton and dilepton charge asymmetries from *Bd* and *Bs* are predicted to be small in the standard model, whereas new physics could increase their values significantly. In this paper, we explore the use of the lepton asymmetries as a probe of the flavor structure of supersymmetric theories. In particular, we determine the sensitivity to parameters of various models. We find that in many interesting models which attempt to address the supersymmetric flavor problem, the mixing structure is such that it could be possible to detect new physics. The predictions are model dependent; with a measurement in both the *Bs* and *Bd* systems one can hope to constrain the flavor physics model, especially once squarks are detected and their masses measured. Thus, lepton charge asymmetries can be used as an alternative means of searching for new physics and distinguishing among potential solutions to the flavor problem. They are interesting precisely because they are small in the standard model and are therefore necessarily evidence of new physics.

Told not possible...

Evidence for an anomalous like-sign dimuon charge asymmetry

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on behalf of the DØ Collaboration
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The DØ Collaboration has recently measured the charge asymmetry of same-sign dimuon events in 6.1 fb^{-1} of data collected in $p\bar{p}$ collisions at the Fermilab Tevatron collider. This allows the extraction of the same-sign dimuon charge asymmetry in semileptonic b-hadron decays, which is predicted to be extremely small in the standard model. The result is found to differ by 3.2 standard deviations from the standard model value, providing the first evidence for anomalous CP-violation in the mixing of neutral B mesons. The analysis, and the method used to extract the result are described in detail.

And of course…Higgs Physics

- Constrain mass
  - Contributing to precision electroweak constraints
- Excluding large parameter region directly
- Even possibly seeing hint of decay into bottoms

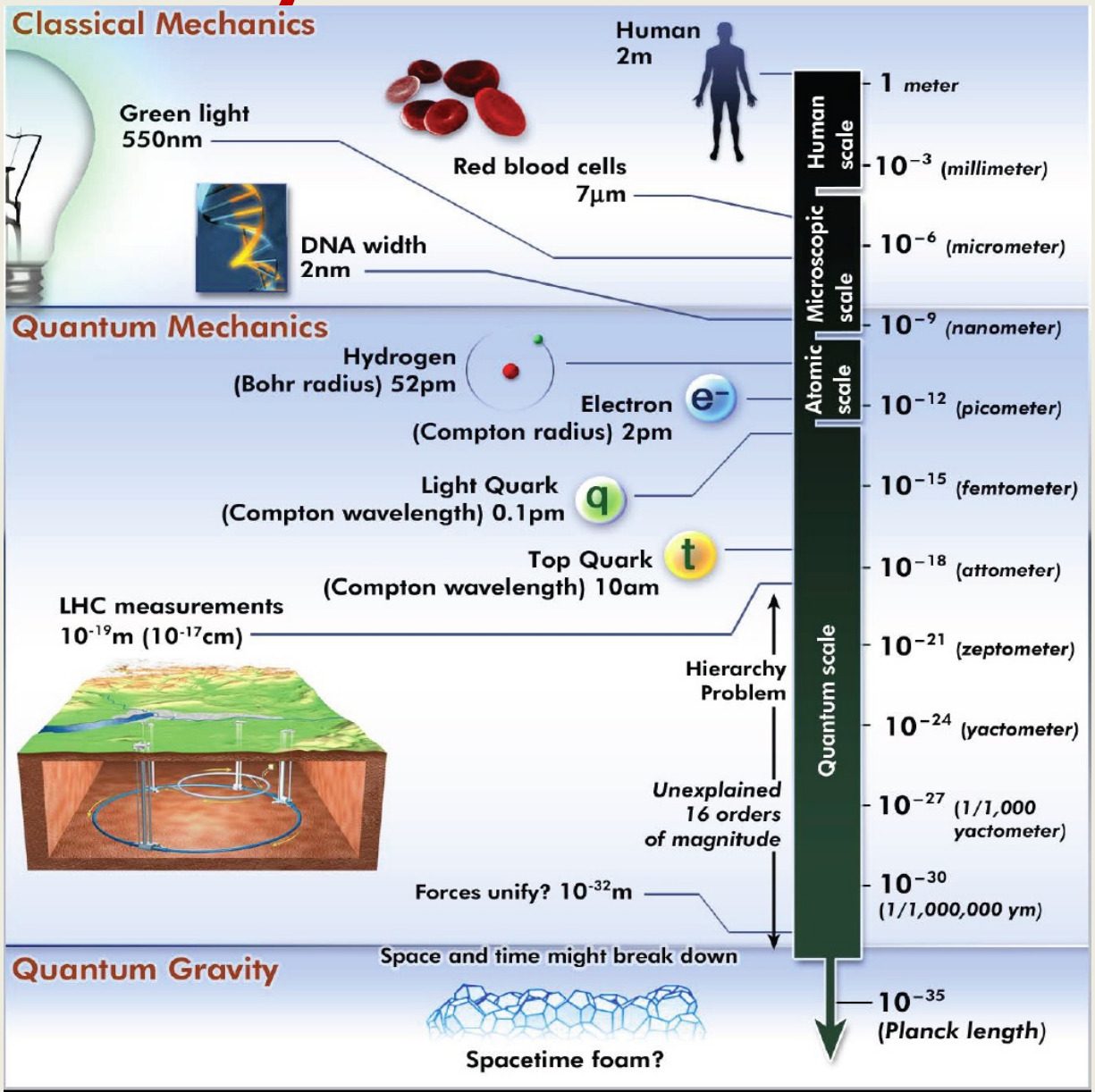
For me…

- Summer student experience
- Working on SM precision EW
- Working beyond SM
  - Seeing measurements we thought wouldn't be possible get realized
- Detailed understanding
- Truly inspirational

Role of Tevatron

- Explore frontiers—energy or intensity
- Inspire people with what is possible
- Technological achievements
  - Not just gadgets—true advances in techniques and knowledge
- Theoretical ideas
- Inspire big thoughts
- Key steppingstone on path to understand small scales

Study Small Scales



Reach for the Stars

- Small scales as inspirational
- And contain the real mysteries

Steve Jobs' Words

- Again, you can't connect the dots looking forward; you can only connect them looking backwards. So you have to trust that the dots will somehow connect in your future.

Honorary Degree

DIPLOMA

This certificate of graduation is presented to

The Tevatron

on

June 11

by

All Evolved Lifeforms

xx

Signature