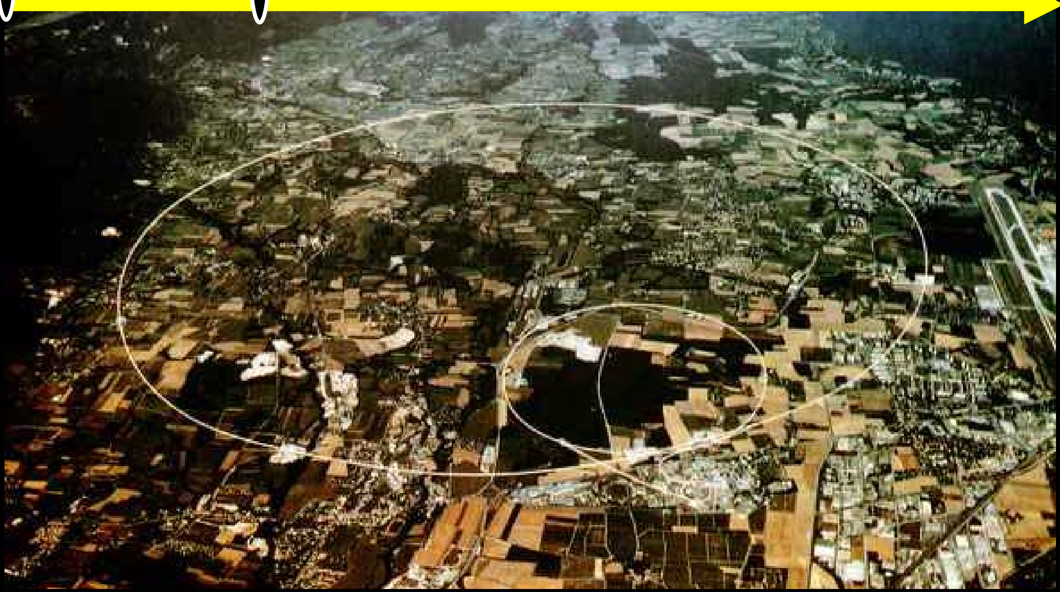
Passing the Baton: Tevatron-LHC Team

Young-Kee Kim
The University of Chicago and Fermilab

Colloquium
Fermilab, August 9, 2006

Tevatron: 2 TeV proton-antiproton

Now Nov ‘07 Sept ‘09

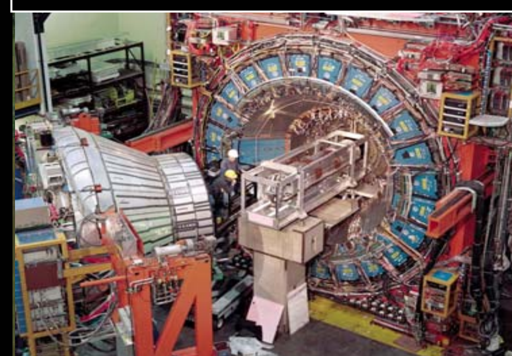


LHC: 14 TeV proton-proton


Don’t tell me you discovered Higgs!!

Many generations of Accelerators created.
Discovered many surprises.

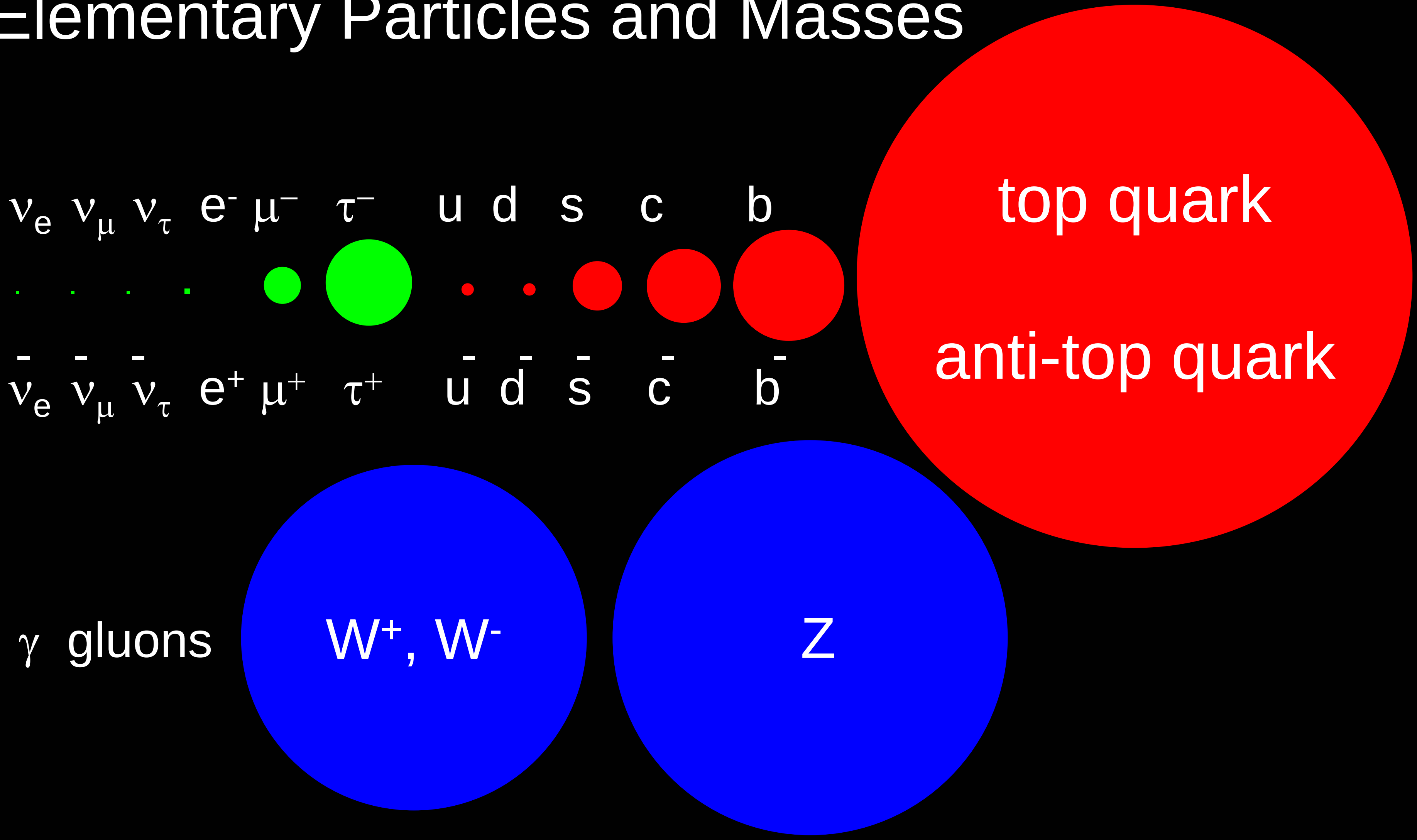
CDF ~1500 Scientists DØ



Particle physics field has been tremendously successful in creating and establishing "Standard Model of Particle Physics" answering "what the universe is made of" and "how it works".

Answers themselves led to even more questions!

Elementary Particles and Masses



(Mass proportional to area shown: proton mass = ●)

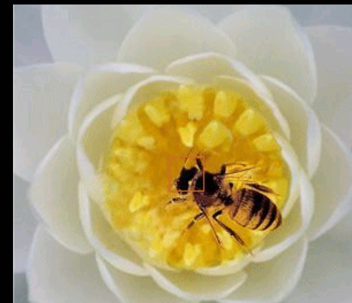
Are they the smallest things?

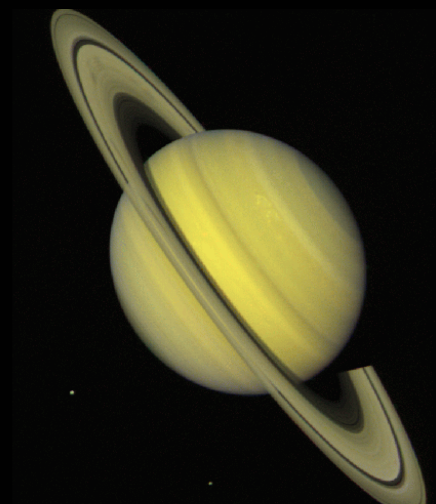
Why are there so many?

Where does mass come from?

Everything is made of electrons, up quarks and down quarks.





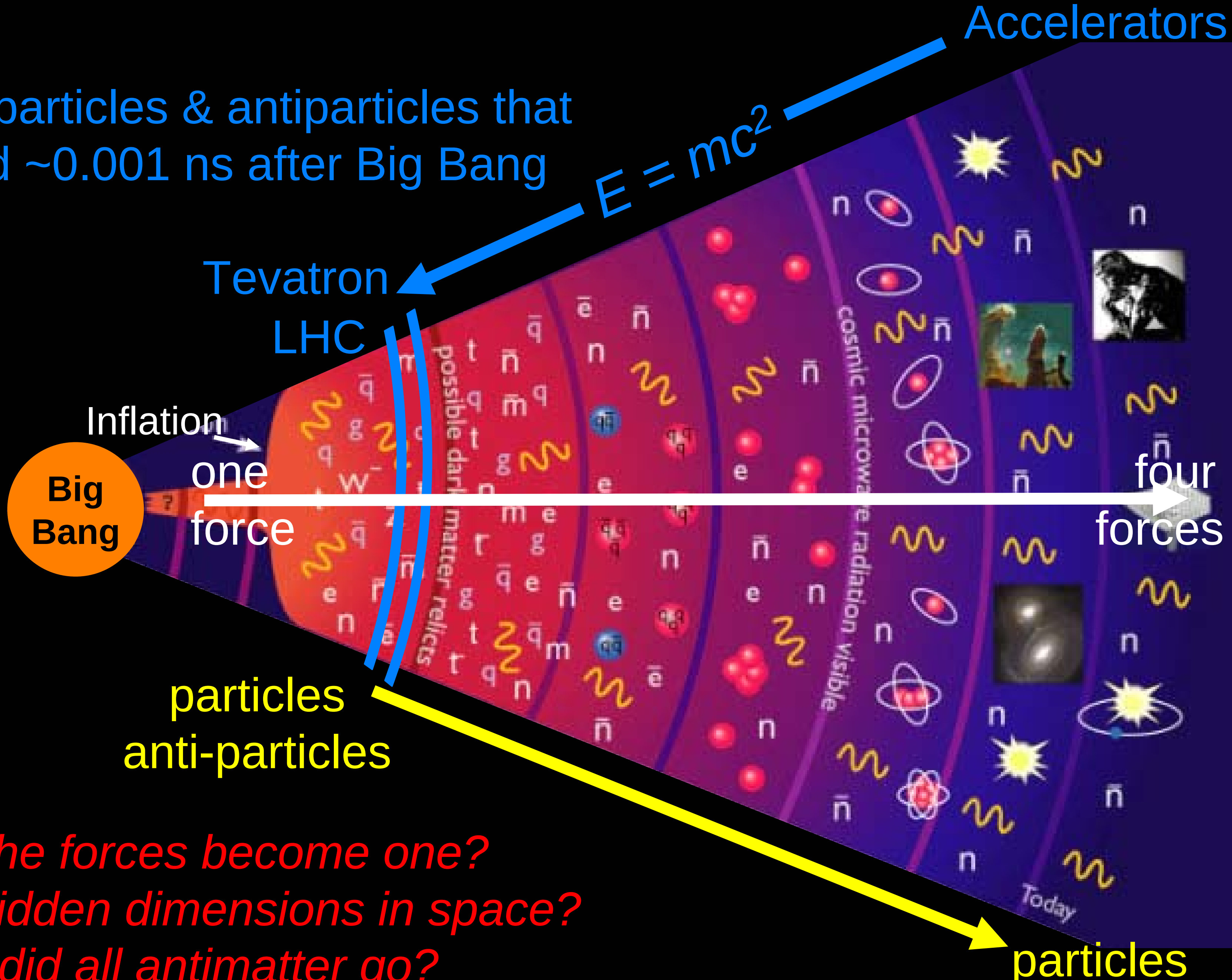




Galaxies are held together by mass far bigger (x5) than all stars combined.

Dark Matter - What is it?

Can we make it in the laboratory?

Create particles & antiparticles that existed ~0.001 ns after Big Bang



Do all the forces become one?

Extra hidden dimensions in space?

Where did all antimatter go?

Universe; not only expanding, but accelerating! Dark Energy


What is the world made of?
What holds the world together?
Where did we come from?

1. Are there undiscovered principles of nature: New symmetries, new physical laws?
2. How can we solve the mystery of dark energy?
3. Are there extra dimensions of space?
4. Do all the forces become one?
5. Why are there so many kinds of particles?
6. What is dark matter? How can we make it in the laboratory?
7. What are neutrinos telling us?
8. How did the universe come to be?
9. What happened to the antimatter?

“Quantum Universe”
and
“Discovering the Quantum Universe”

Evolved Thinker

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Origin of Mass

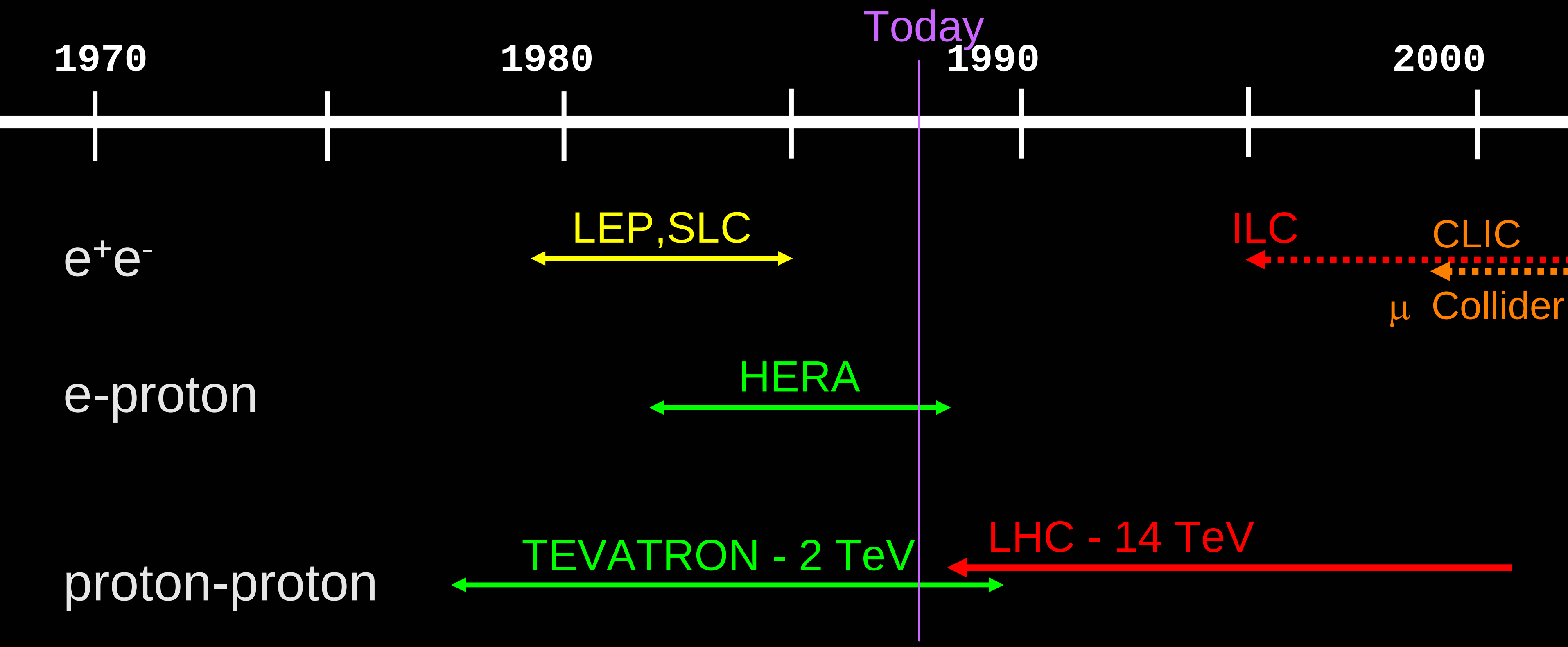
Unification

Energy Frontier Colliders

"Quantum Universe"
and
"Discovering the Quantum Universe"

Evolved Thinker

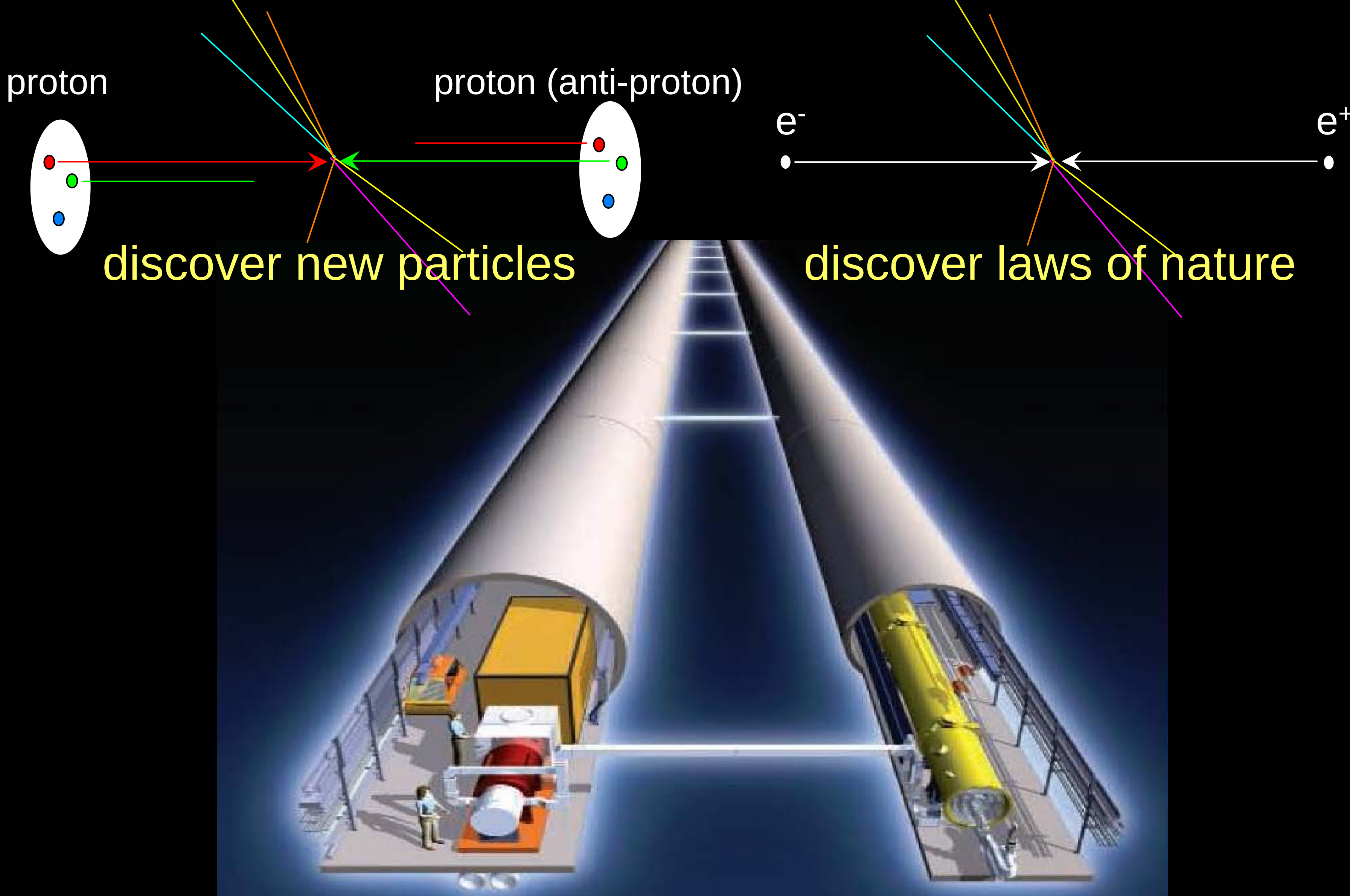
Energy Frontier Colliders



The world HEP community endorsed the ILC as the next accelerator to extend the discovery reach of LHC.

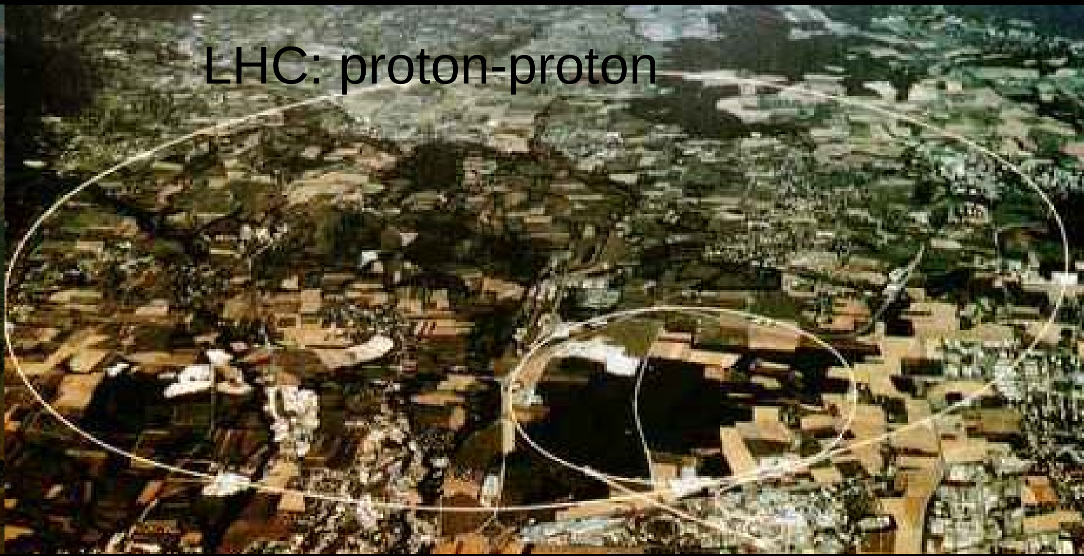
International Linear Collider (ILC)

0.5 TeV → ~1 TeV e^+e^- collider



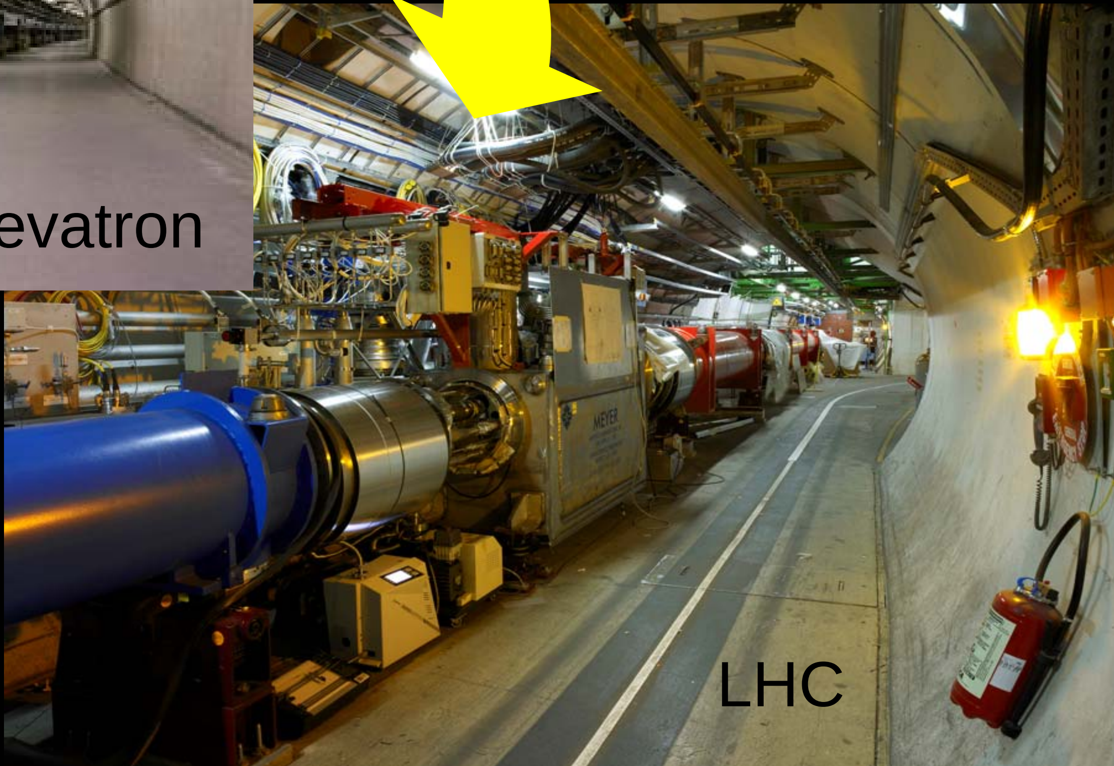
LHC Challenges:

Energy: 14 TeV =	7 x Tevatron
Length: 27 km =	4 x Tevatron
Magnetic Field: 8.3 T =	2 x Tevatron
Beam Energy: 350 MJ =	250 x Tevatron
Bunch Collisions: 40 MHz =	20 x Tevatron
Instantaneous Luminosity =	60 x Tevatron
# of Collisions in an event =	10 x Tevatron
Data Rate: 1 Terabyte / sec =	50 x Tevatron
# of Detector Channels: 100 M =	100 x Tevatron
# of Scientists (~2500/expt) =	3 x Tevatron



Accelerator Challenges

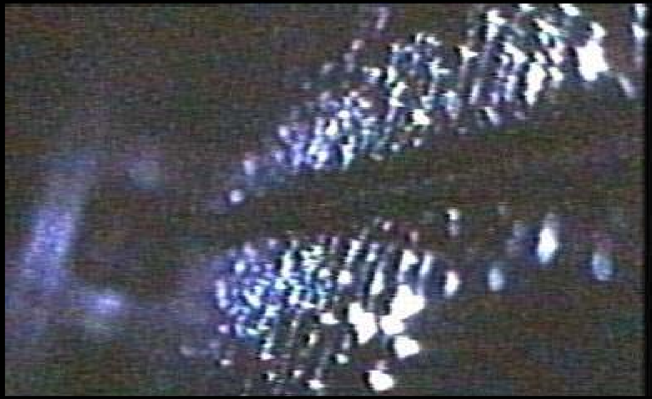
Tevatron team in
LHC commissioning



Unanticipated Beam Incidents

Each proton bunch is like a bullet!

Tevatron Beam Incident

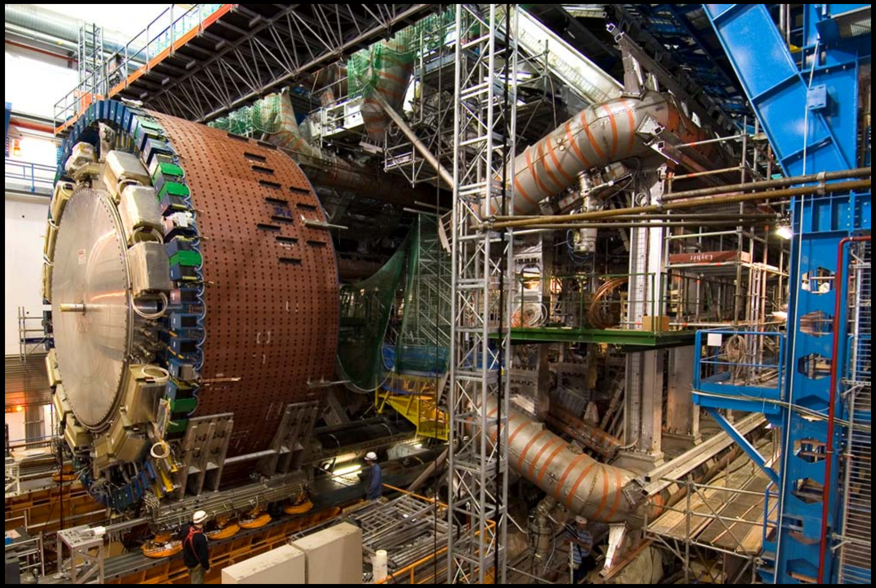


LHC beam power = 250 x Tevatron!

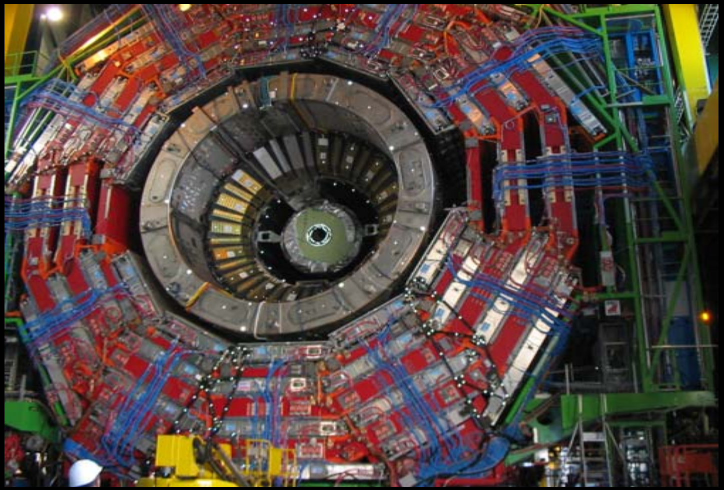
Tevatron: Single Event Failure in Collision Hall Electronics

LHC, ATLAS, CMS failure modes will not be the same.
Importance: monitoring, diagnostic tools, collimater system, shielding, communication between machine and experiment teams

Experimental Challenges



ATLAS: 24 m x 45 m, 7k tons, 10^8 channels



CMS: 14 m x 22 m, 12.5k tons
10^8 channels

Collecting data at energy frontier is non-trivial:

- Detector's radiation safety issues
- Small bunch spacing and large # of interactions per crossing
  → event synchronization, complex event topology
- Unexpected problems!

Commissioning CDF and DØ Detectors

	Tevatron	LHC
Cosmic Ray Run Engineering Run with Partial Detectors	2000 Oct. 2000	2006
Detector Completion	Jan. 2001	Spring 2007
Commissioning Run	Mar. 2001 - Feb. 2002	Nov 2007 (1 TeV) Spring 2008 (14 TeV)
Beginning of Physics Run	Feb. 2002	2008?

- Timing-in Electronics:
    - Across all detector subsystems, and across trigger subsystems
- Commissioning beam loss monitors
- Calibration and alignment of each system
- Establish “stable” detector configuration and “stable” trigger table

Unanticipated Problems

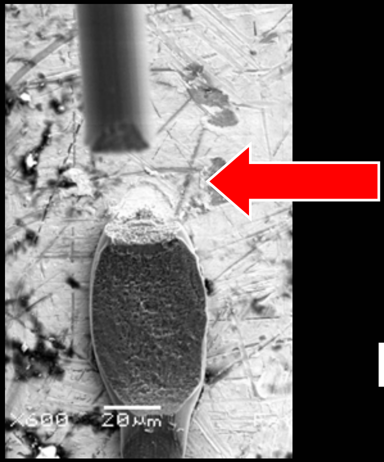
Apply 100 mA current at ~20kHz

A small but steadily growing number of CDF silicon detector modules were dying. Breakage of a wirebond carrying power.

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.

- Some broke
  during a trigger test at ~20 kHz
- Oriented orthogonal to 1.4 T B field
- Fundamental frequency
  for 2 mm Al bond ~20 kHz

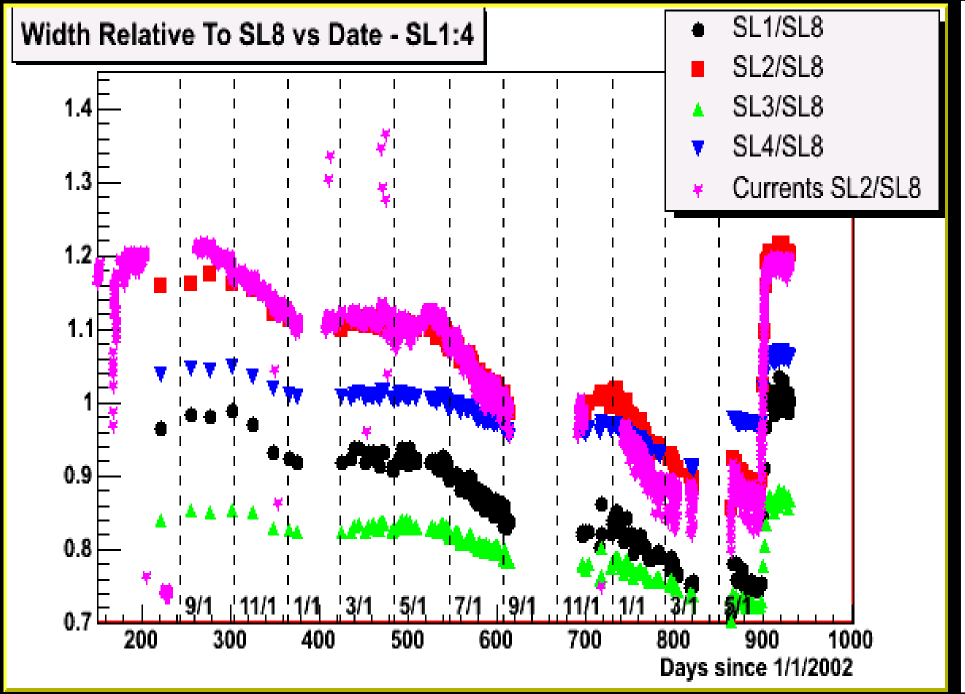
Lorentz force was the reason!!



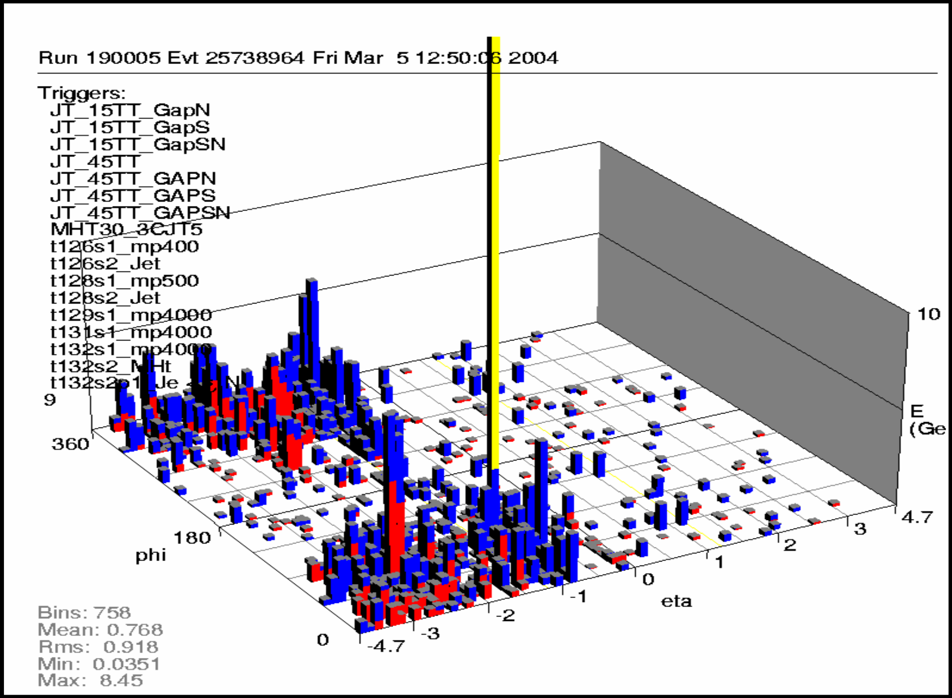
Resolved!

Unanticipated Problems

CDF central tracking chamber:
Aging → resolved



DØ LAr calorimeter:
Welding induced noise → resolved



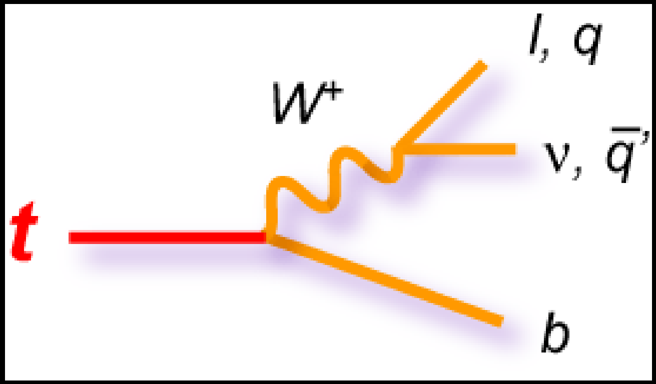
Large missing energy
Not new physics!

“Trigger” Commissioning and Operations

Tevatron: 2 million bunch collisions → 100 events (per second)
LHC: 40 million bunch collisions → 200 events (per second)
Making decisions extremely fast! → use limited information

At hadron colliders, triggers determine Physics capability.

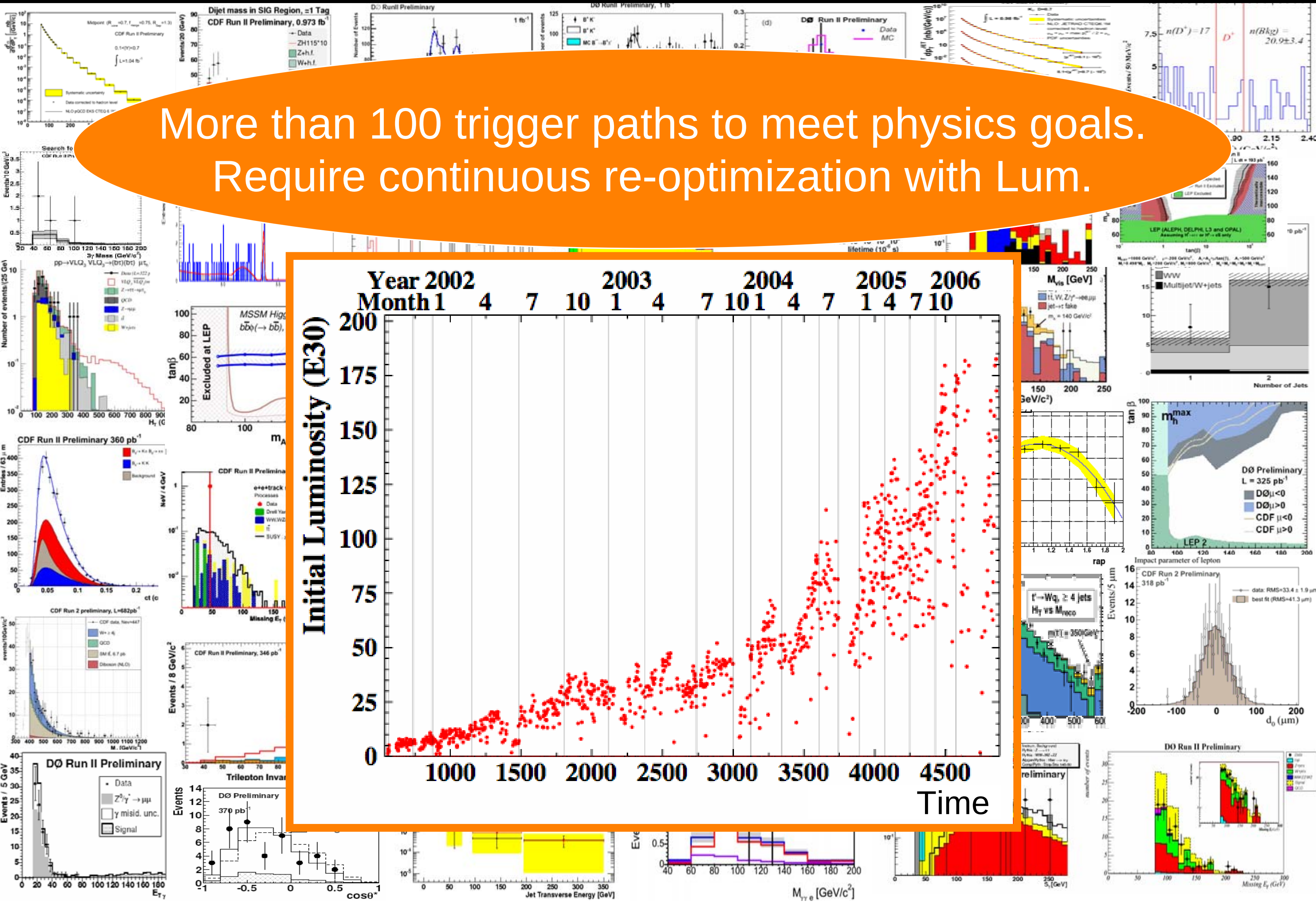
e.g. Top Quark Events



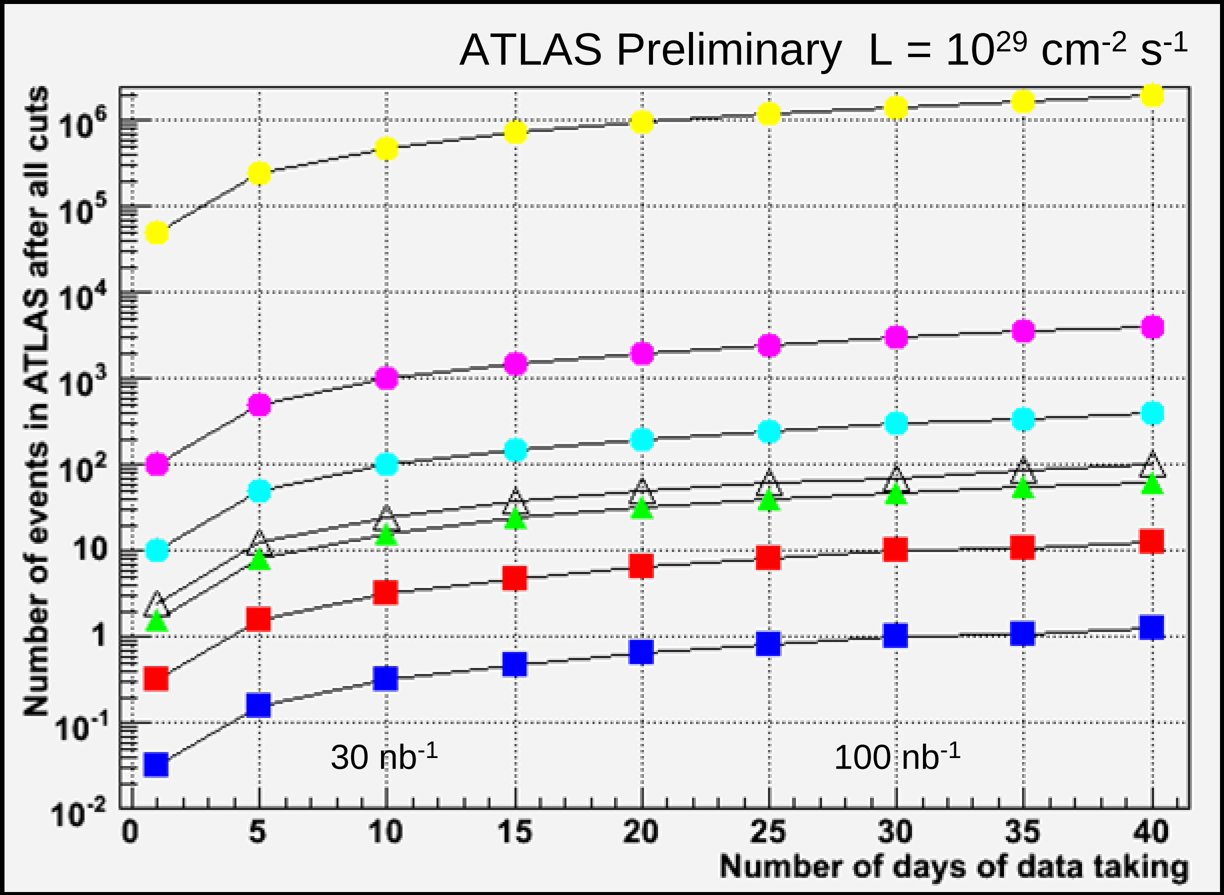
- Trigger Paths
  - High p_T electron (track + calorimeter)
  - High p_T muon (track + calorimeter + muon)
  - High p_T tau lepton (track + calorimeter)
  - Multi jets (track + silicon + calorimeter)
- Other Paths for trigger validation
- Trigger Paths for calibration (jet E, etc.)

Many many searches and measurements at Tevatron

More than 100 trigger paths to meet physics goals.
Require continuous re-optimization with Lum.



2007 (Nov-Dec) LHC Data Samples at $\sqrt{s}$ = 0.9 TeV



Jets with p_T > 15 GeV

Jets with p_T > 50 GeV

Jets with p_T > 70 GeV

$\Upsilon \to \mu\mu$, $J/\psi \to \mu\mu$

$W \to e\nu, \mu\nu$

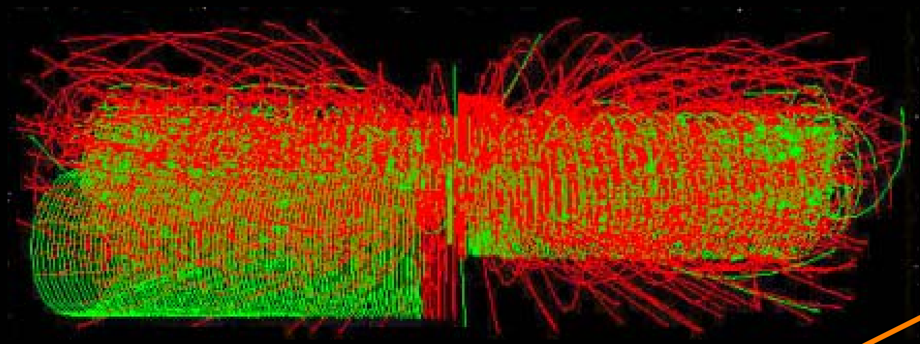
$Z \to ee, \mu\mu$

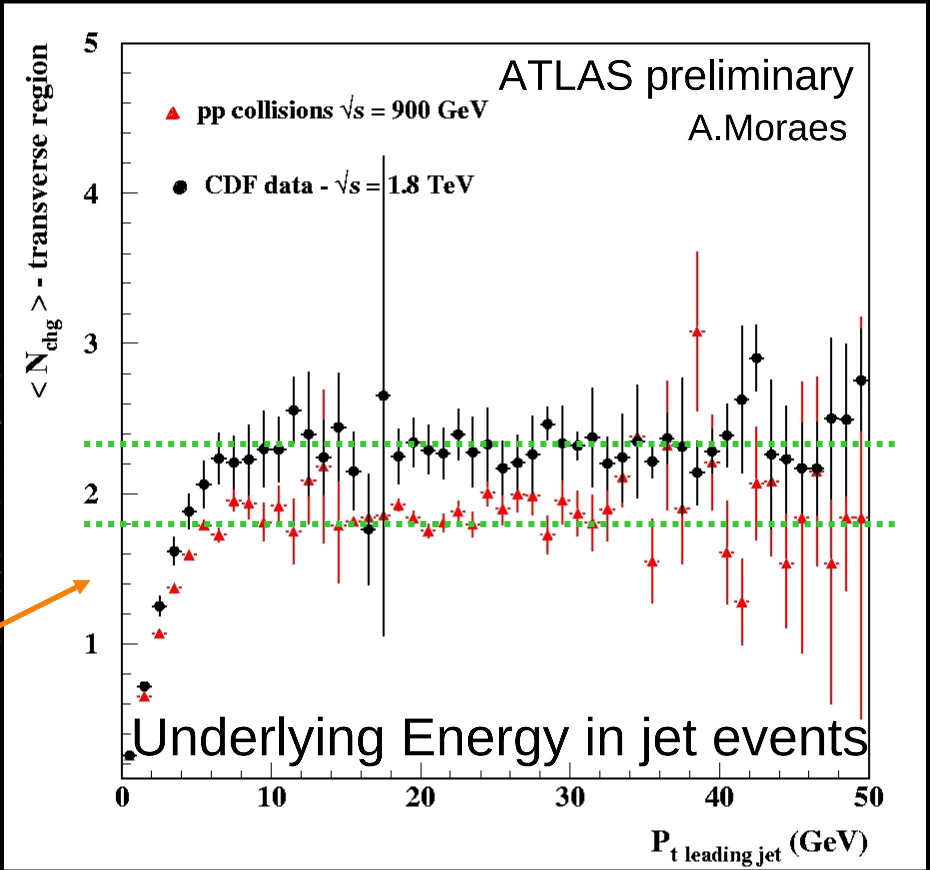
+ 1 million minimum-bias/day

Start to commission triggers, detectors in real LHC environment.
Observe a few $W \to l\nu$, $\Upsilon \to \mu\mu$, $J/\psi \to \mu\mu$?

LHC "Soft Collision" Meas. at $\sqrt{s}$ = 0.9 TeV

At LHC design luminosity
"each interesting physics event"
contains 25 "soft" collisions.





Single collision: Comparison of plateau's between LHC and Tevatron will tell if detector performance, reconstruction tools and physics (simulation) are under control.

2008 LHC Data Samples at 14 TeV (0.1 - 1 fb^{-1})

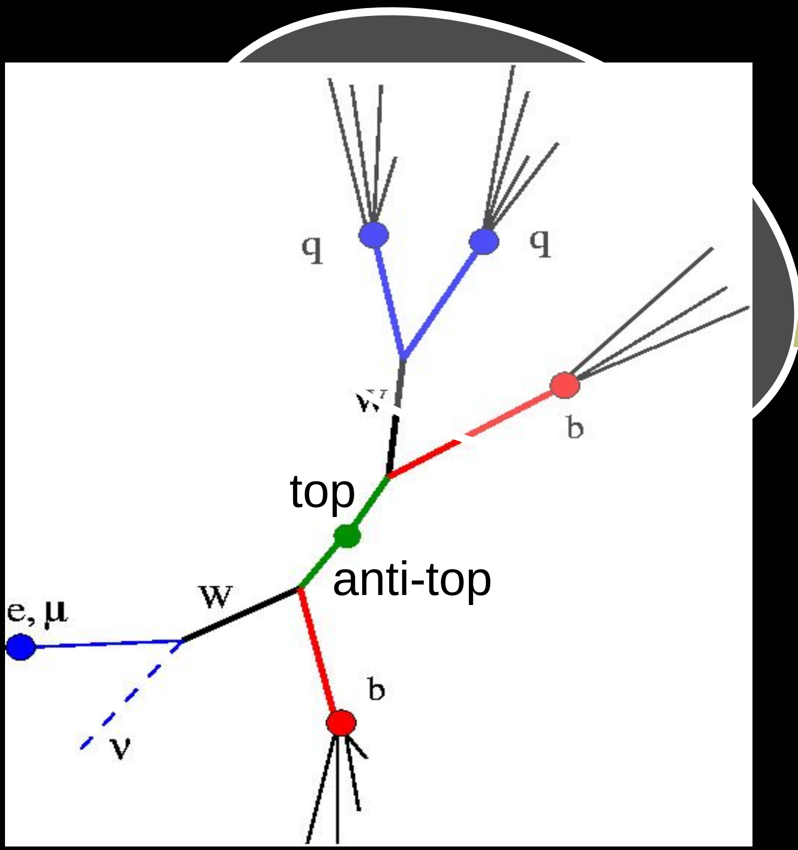
Sample	LHC events	Tevatron events
$W \rightarrow \mu\, \nu$	10^6 - 10^7	10^6
$Z \rightarrow \mu\, \mu$	10^5 - 10^6	10^5
$tt \rightarrow Wb\ Wb \rightarrow \mu\, \nu + X$	10^4 - 10^5	10^4
QCD jets with $p_T > 1$ TeV	10^3 - 10^4	-

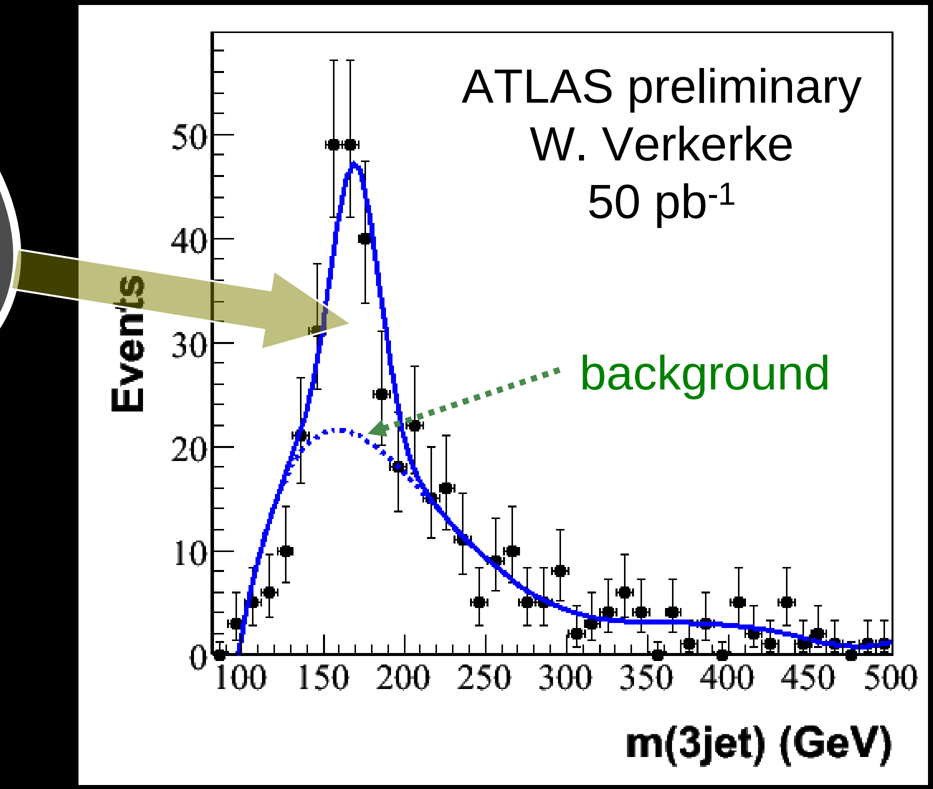
- Understand and calibrate detectors
  in situ using well-known physics samples

- Measure Standard Model physics
  - W, Z, tt, QCD jets …
  - omnipresent backgrounds to New Physics

2008 LHC Data Samples at 14 TeV

Understanding detector and physics with top quark events.





Compare this peak to
Tevatron top mass measurement.

Tevatron - LHC Physics Connection

Origin of Mass

Unification

New Forces

New Fermions

……

The Unknowns

There might be something (new particle?!) in the universe that gives mass to particles

Nothing in the universe | Something in the universe

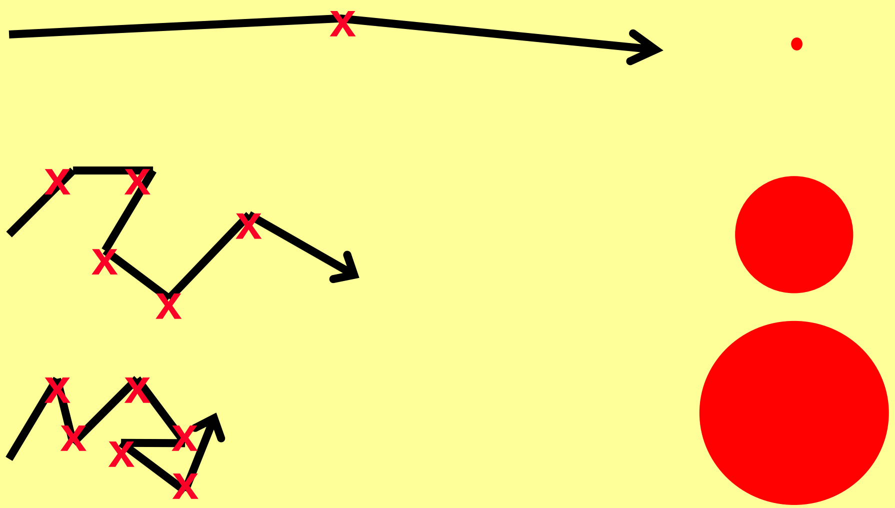
Higgs Particles

mass

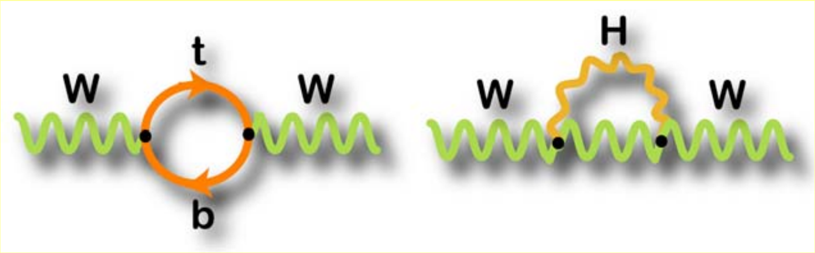
Electron →

Z,W Boson →

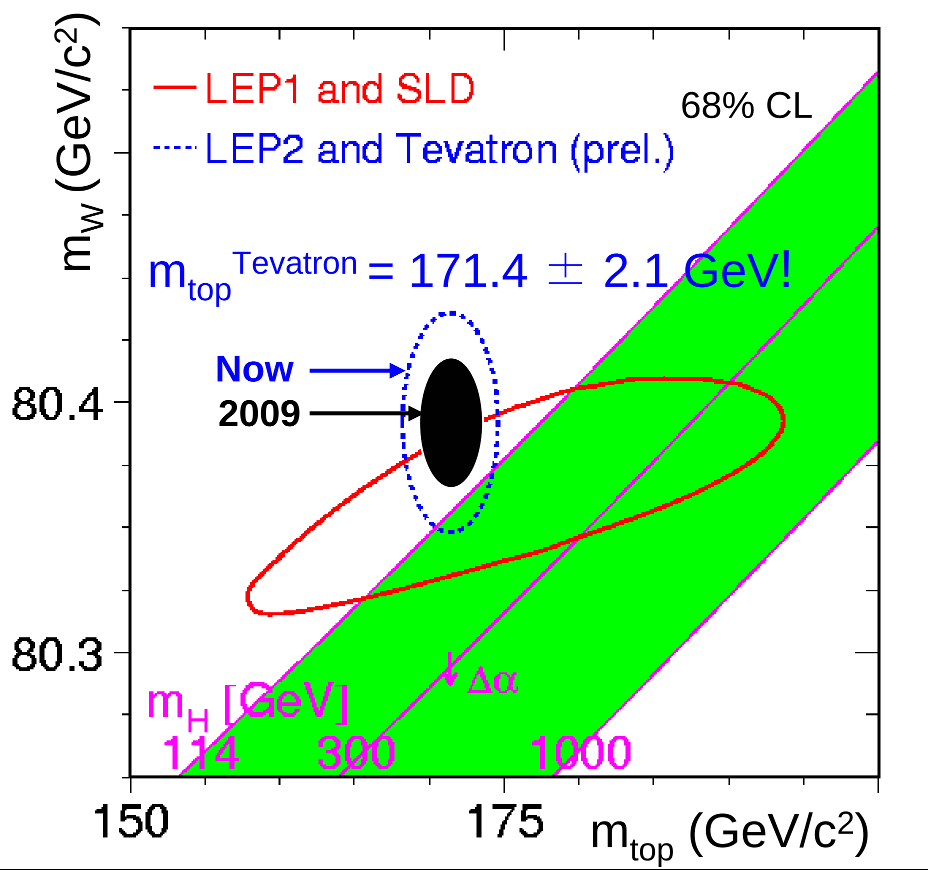
Top Quark →

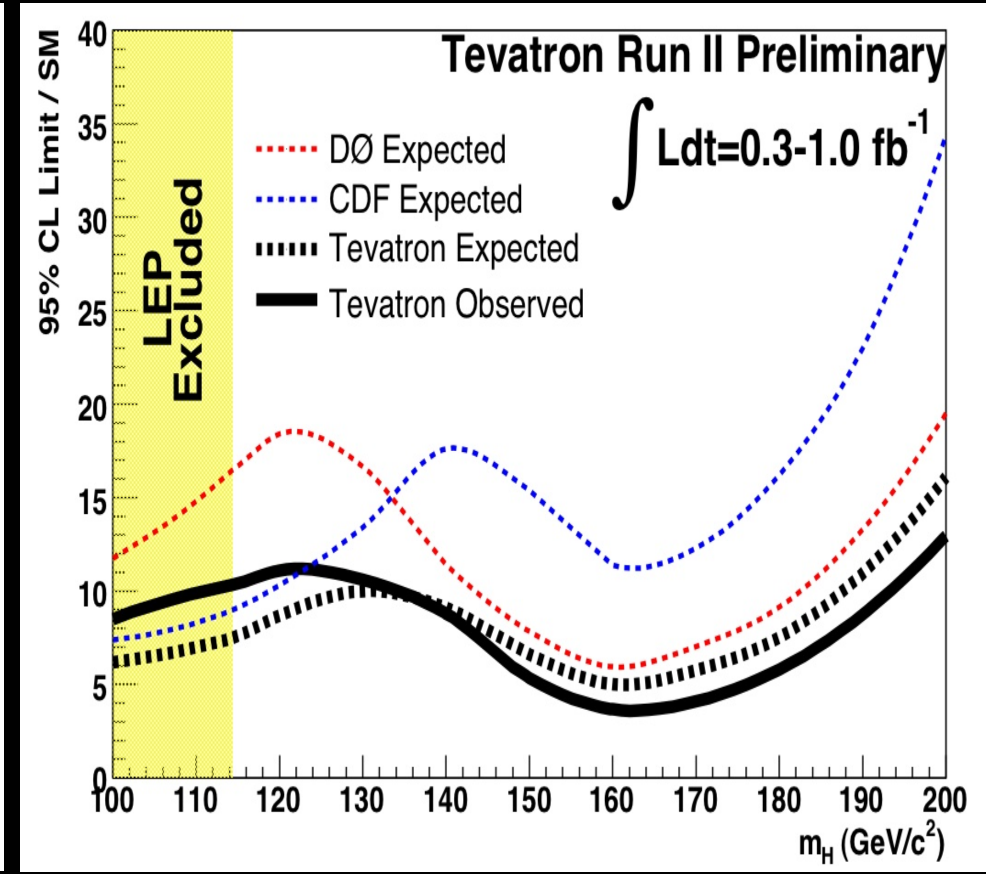


M ∞ coupling strength to Higgs



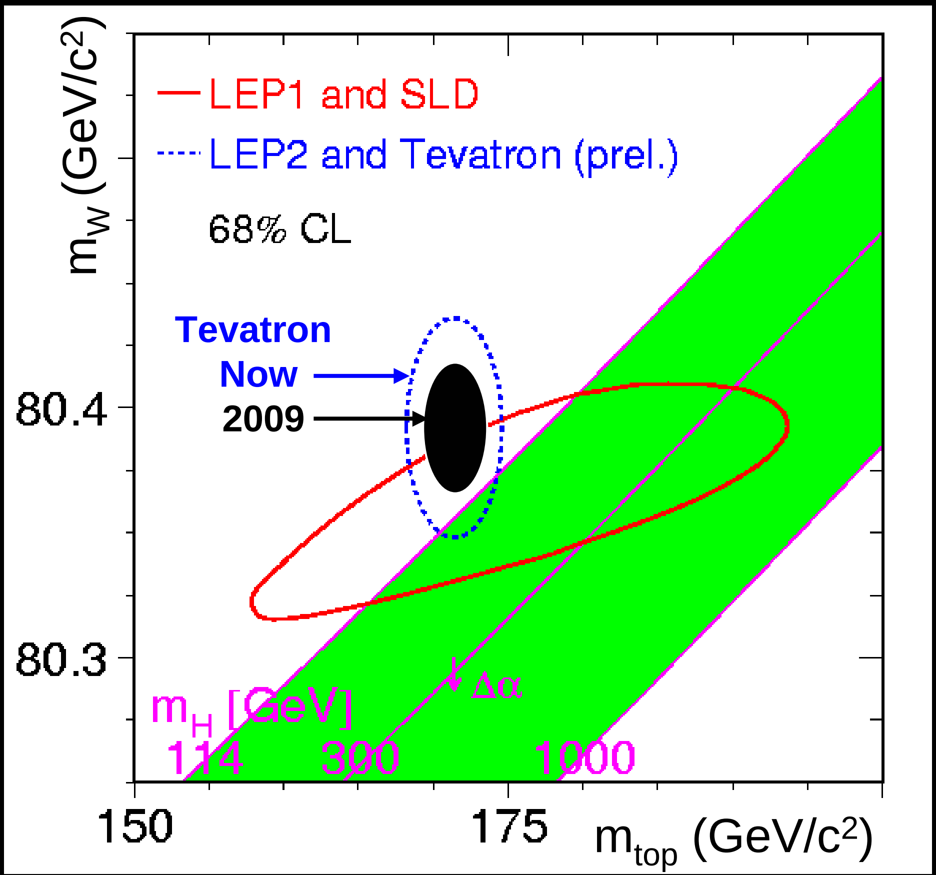
Tevatron: Improve Higgs Mass Pred. via Quantum Corrections
Searches for Higgs with mass < 200 GeV/c^2

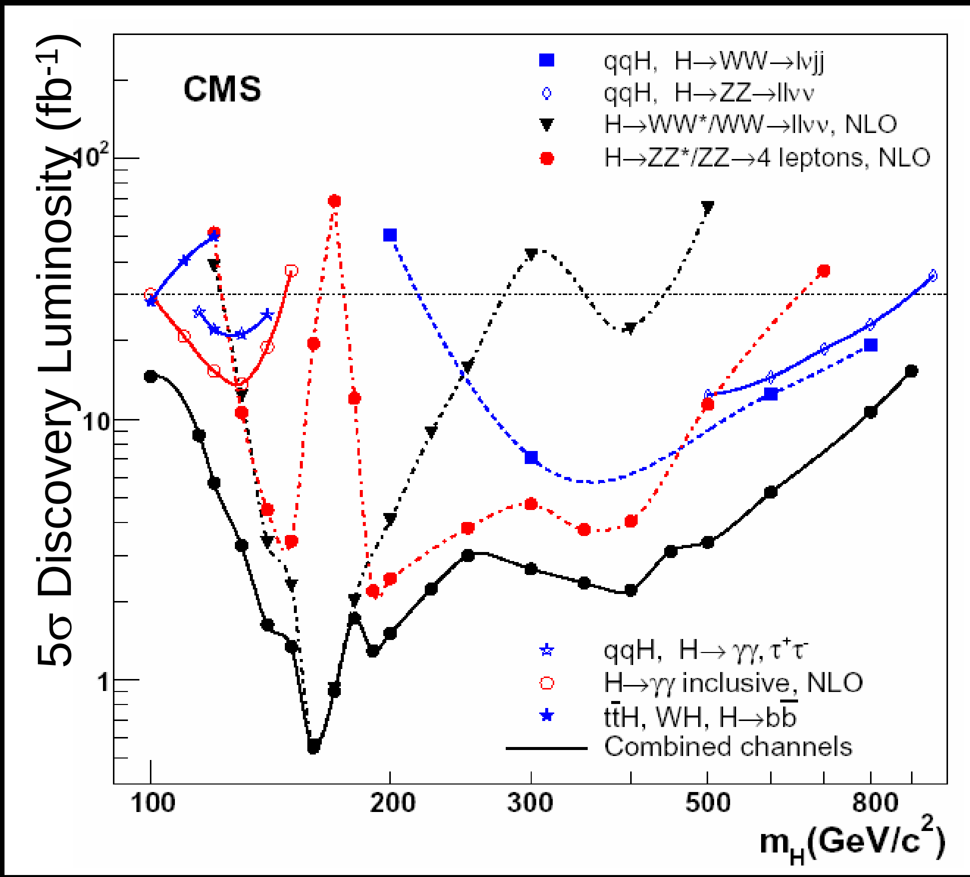




Current precision measurements indicate Higgs is light (<166 GeV), where Tevatron sensitivity is best!

Tevatron: Improve Higgs Mass Pred. via Quantum Corrections
Searches for Higgs with mass < 200 GeV/c^2
LHC: Designed to discover Higgs with M_{higgs} = 100 ~ 800 GeV



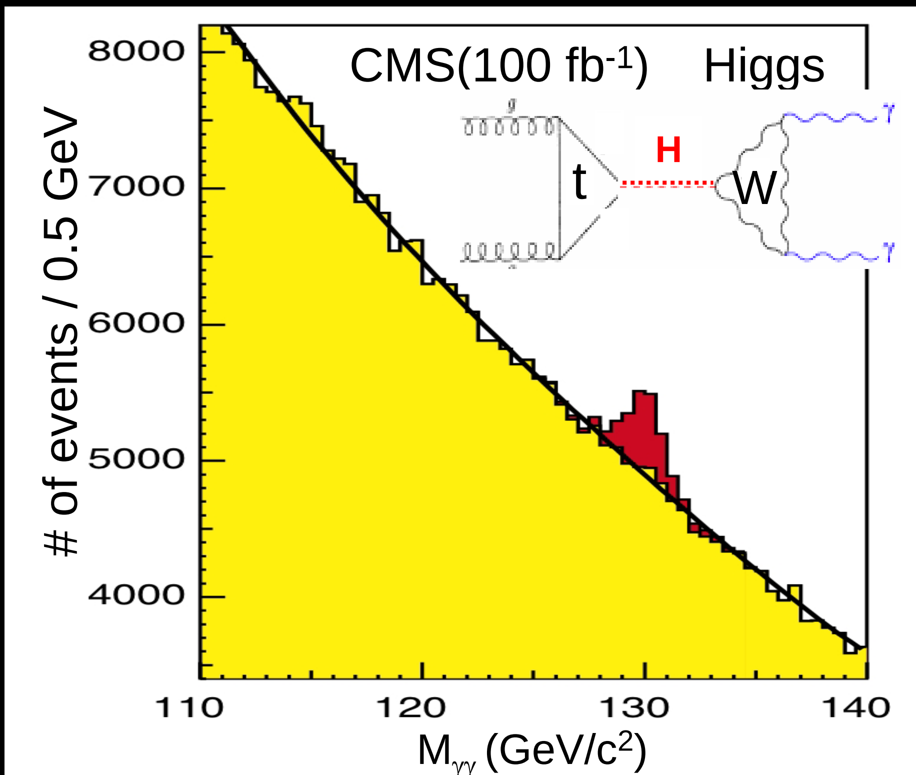


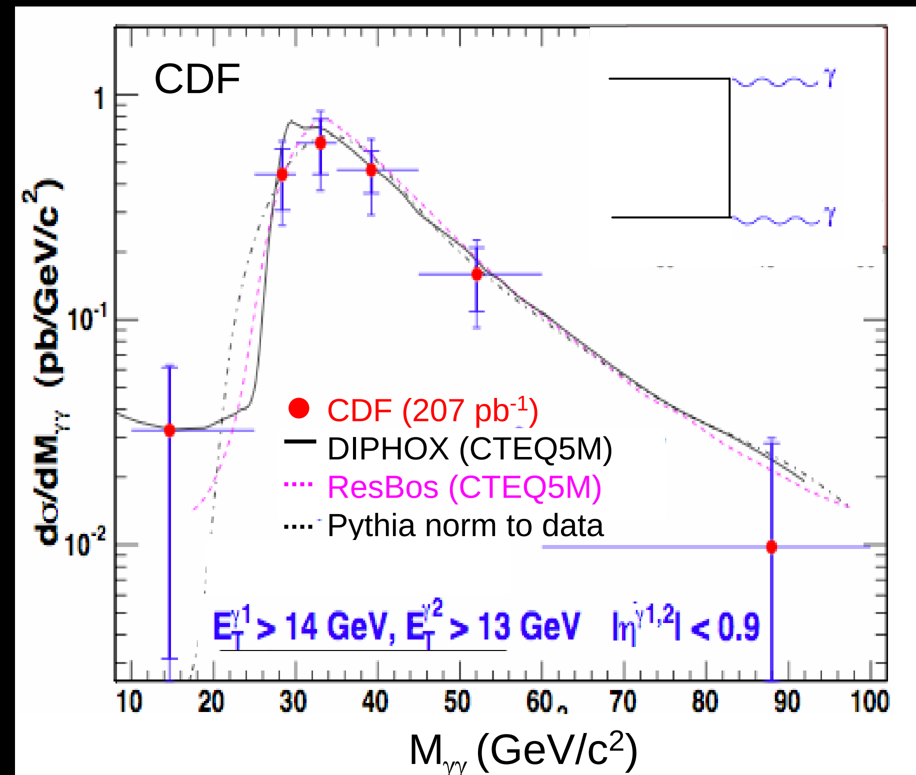
Current precision measurements indicate Higgs is light (<166 GeV), where Tevatron sensitivity is best!

Will the Tevatron's prediction agree with what LHC sees?

Validating Monte Carlo Generators with Tevatron

very important for LHC to reach the discovery quickly.





What LHC needs:

- Good γ energy resolution: narrow peak
- Good γ identification: γ - π^0 separation
- Accurate estimation of $\gamma\gamma$ background (dominant):
  - New improved calculation of pp, $p\bar{p} \rightarrow \gamma\gamma$
  - Validation with Tevatron data

Supersymmetric Extensions of SM (SUSY)

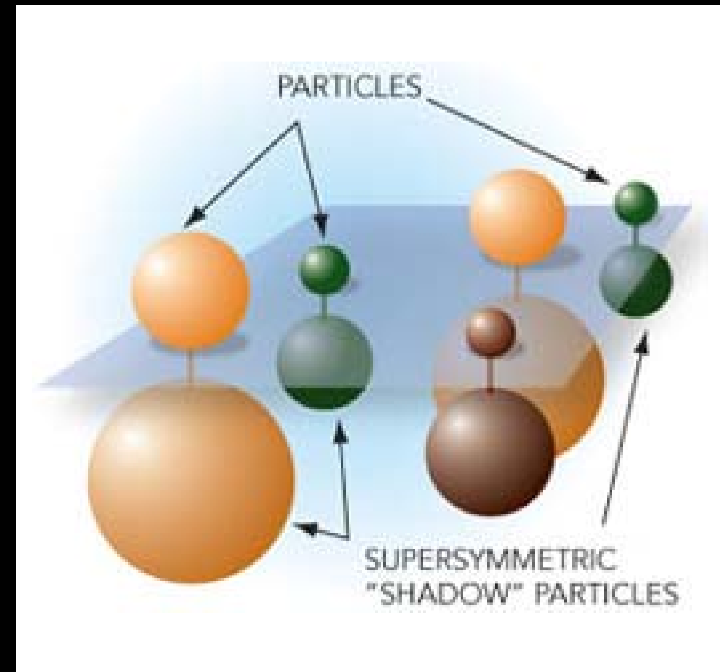
Symmetry between
fermions (matter) and bosons (forces)
“Undiscovered new symmetry”

e → e^+, e^-

superparticle → e, $\tilde{e}$

spin 1/2 spin 0

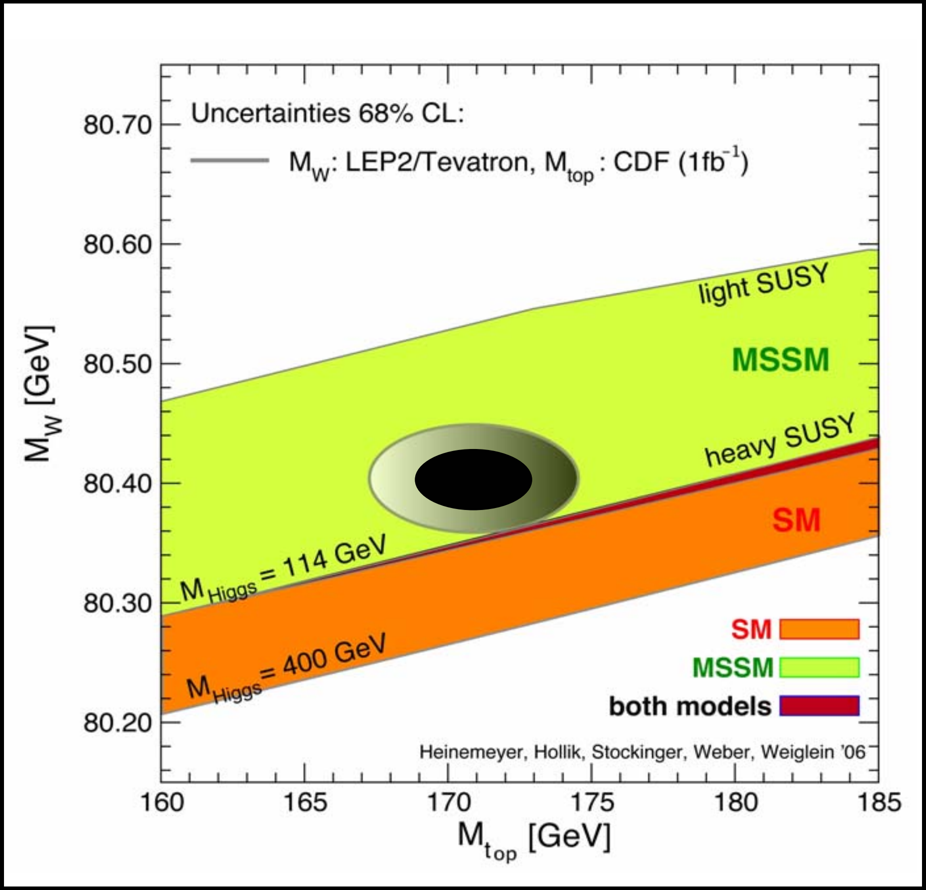
$M_e \neq M_{\tilde{e}}$

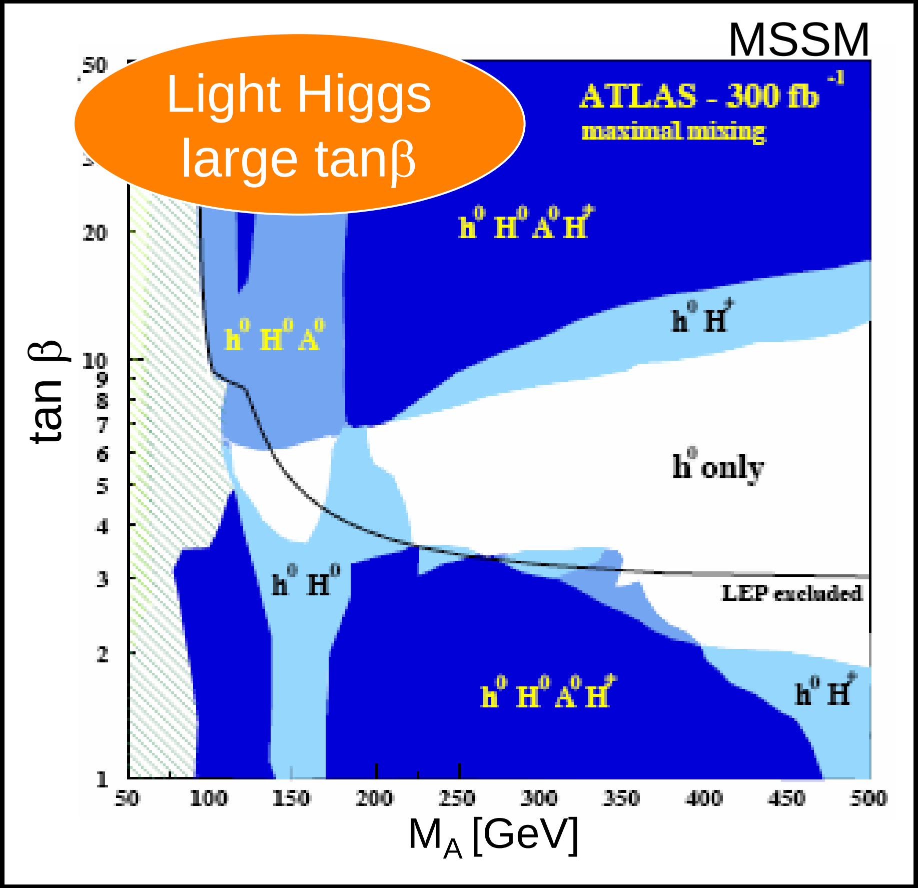


SUSY solves Standard Model problems:
Higgs mass calculation
Unification
SUSY provides a candidate particle for Dark Matter.

Laws of Nature will be much more elegant at high energy.

Higgs in SUSY Models





Higher precision M_W and M_{top} measurements enable to distinguish between SM, Light vs. Heavy SUSY

LHC - the best place to discover Higgs!
Tevatron can reach light Higgs at large tanβ
(favored by precision measurements)

The Higgs is Different!

All the matter particles are spin-1/2 fermions.
All the force carriers are spin-1 bosons.

Higgs particles are spin-0 bosons.
The Higgs is neither matter nor force;
The Higgs is just different.

This would be the first fundamental scalar ever discovered.

If we discover a “Higgs-like” particle, is it alone responsible for giving mass to W, Z, fermions?

The Higgs field is thought to fill the entire universe.
Could give some handle of dark energy(scalar field)?

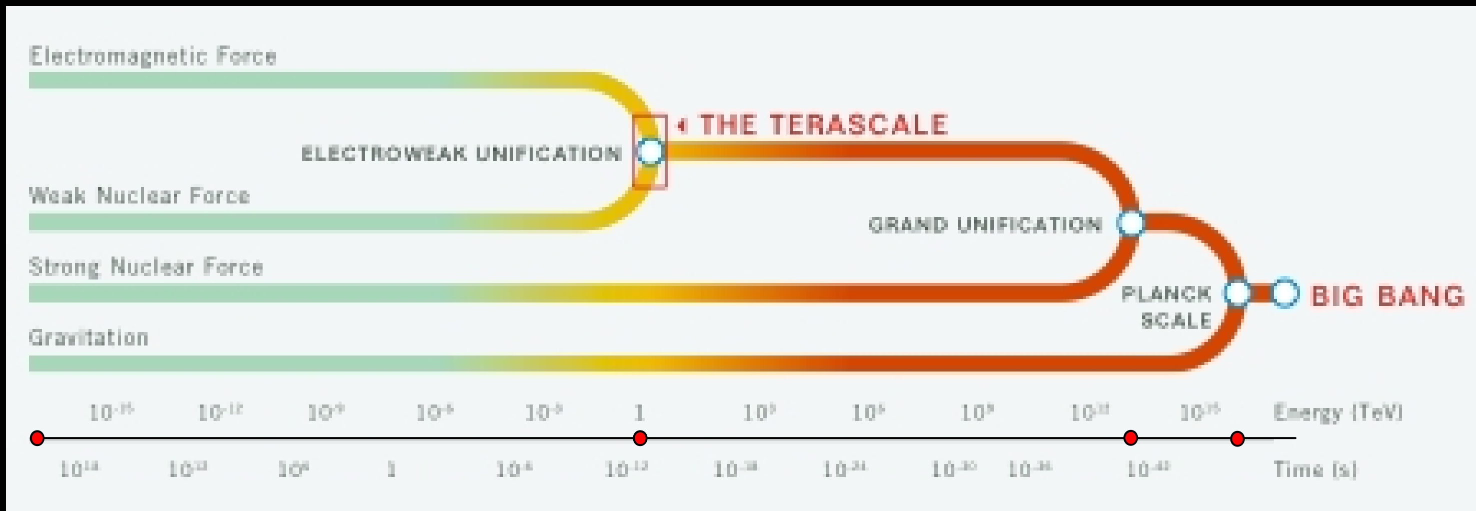
The Higgs is a very powerful probe of new physics.

Experimenters must precisely measure
the properties of the Higgs particle
without invoking theoretical assumptions.

Hadron collider(s) will discover the Higgs.

ILC will use the Higgs
as a window viewing the unknown.

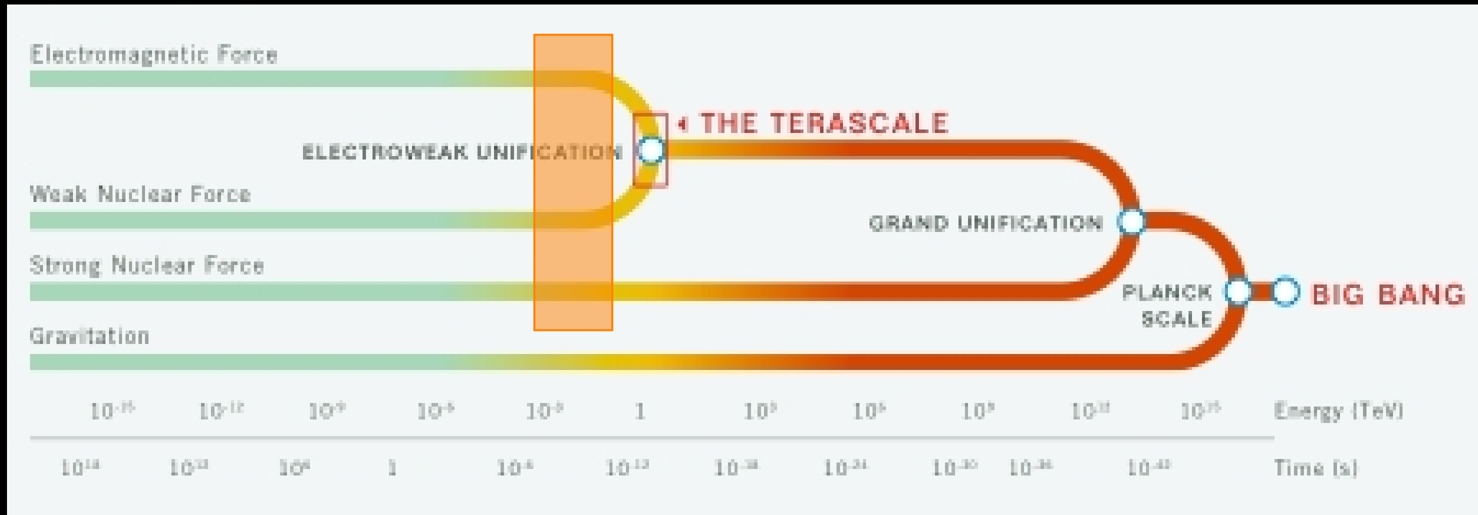
Unification



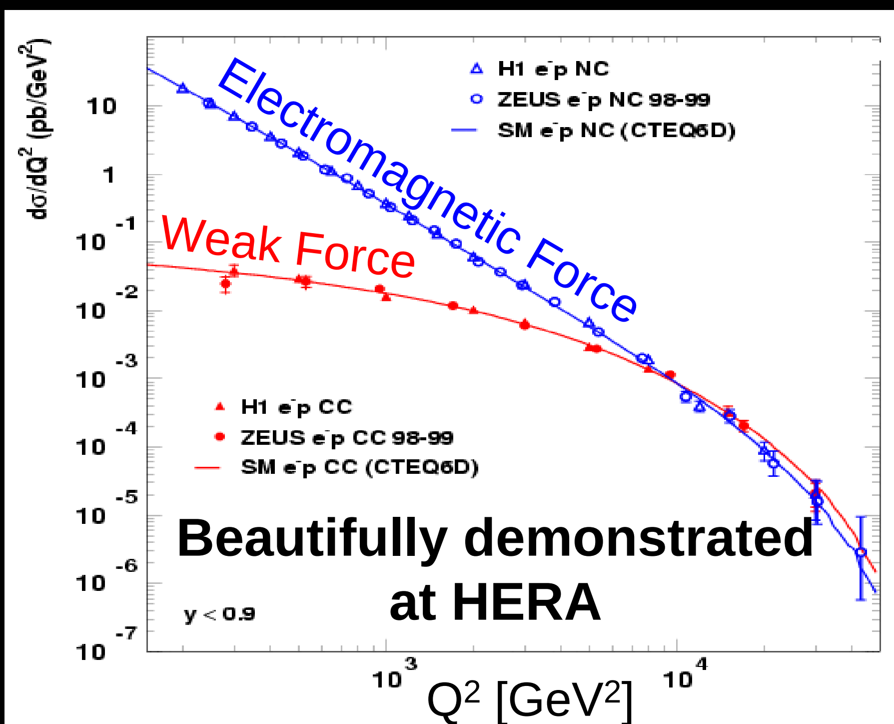
2.3×10^{-13} GeV	1TeV = 10^{3}GeV	10^{16}GeV	10^{19}GeV	Energy
(2.7K)	(10^{16}K)	(10^{29} K)	(10^{32}K)	Temp
12×10^{9} y	10^{-11} s	10^{-38} s	10^{-41} s	Time

We want to believe
that there was just one force after the Big Bang.

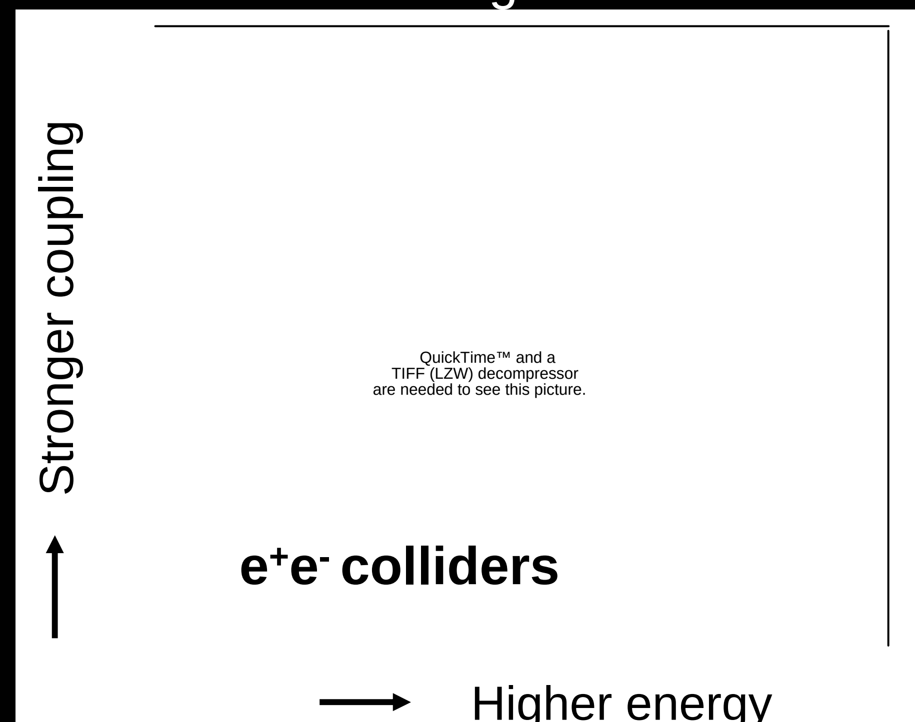
As the universe cooled down,
the single force split into the four that we know today.

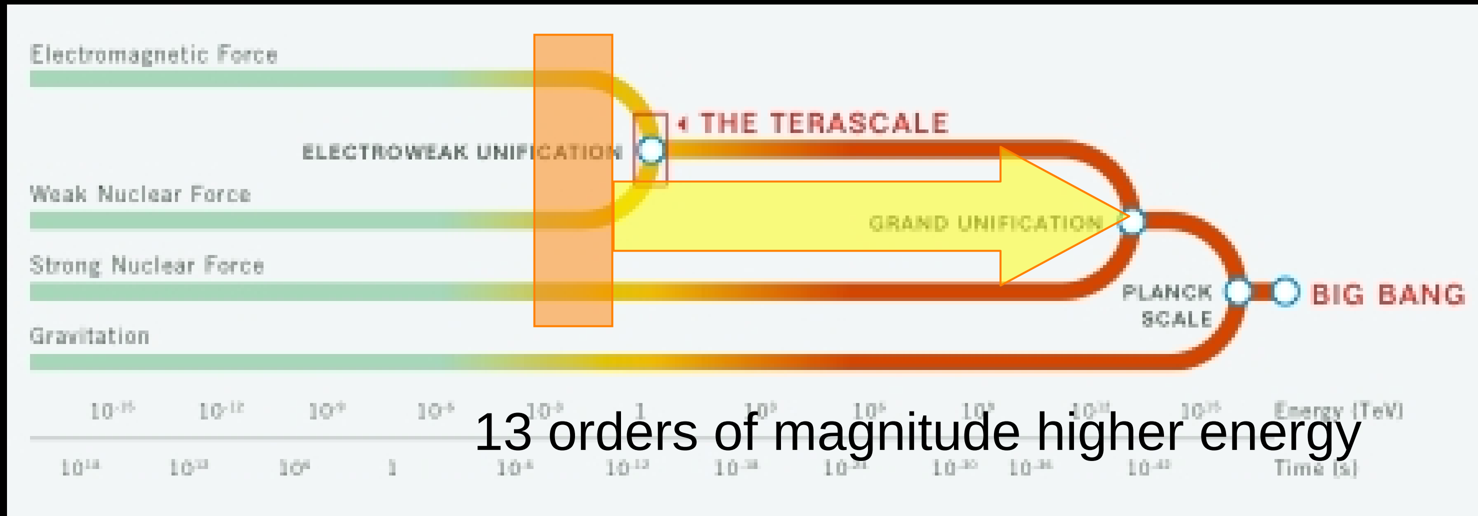


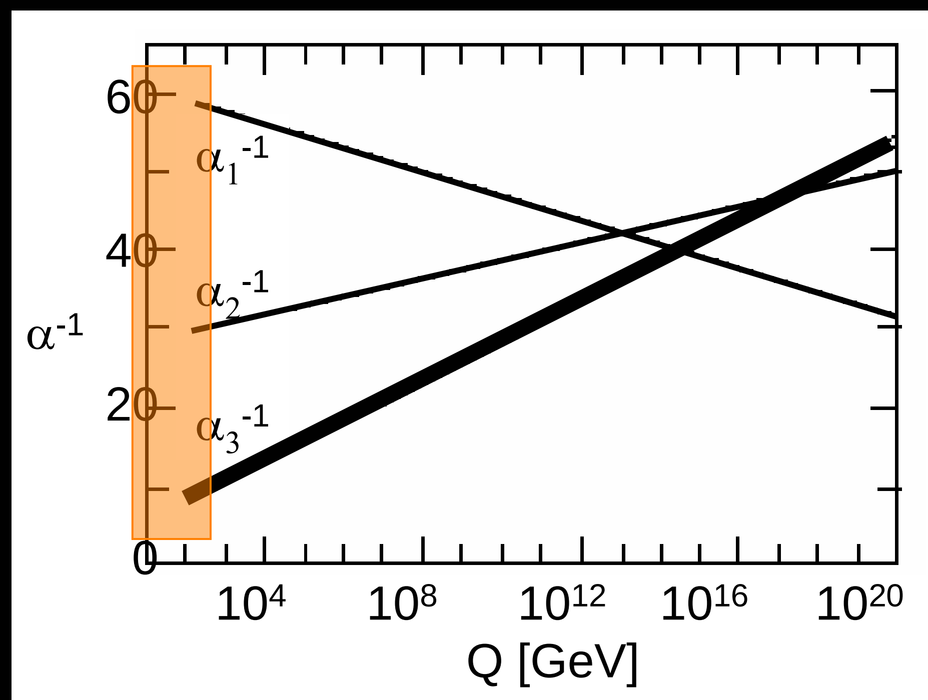
Unification of EM and Weak Forces



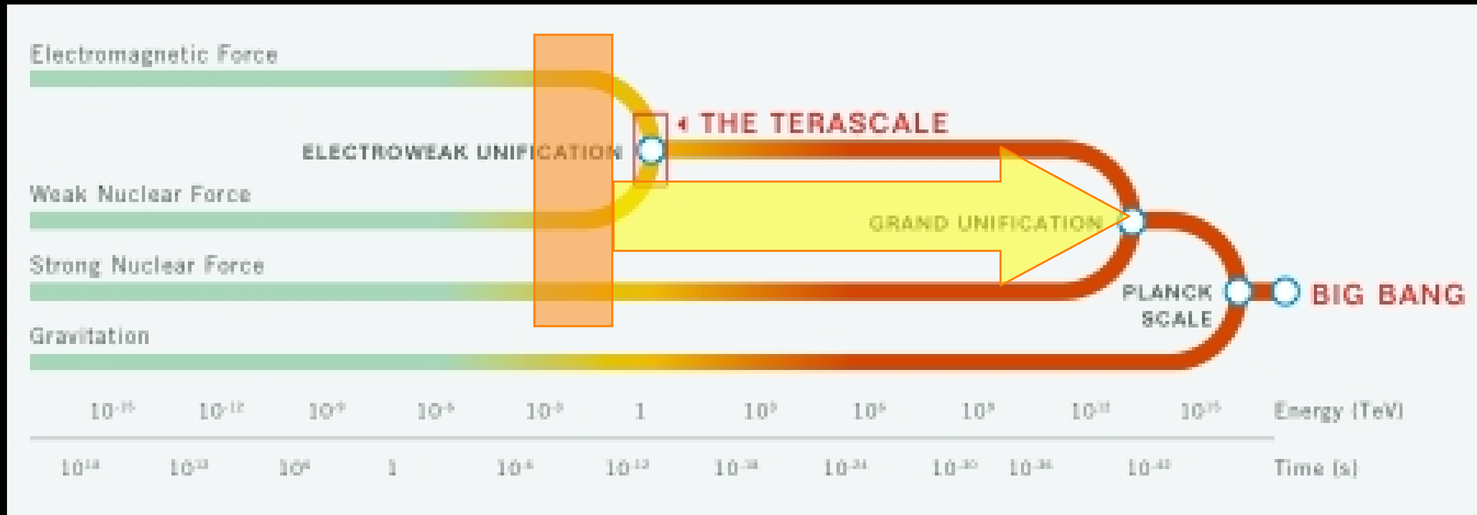
Strong Force

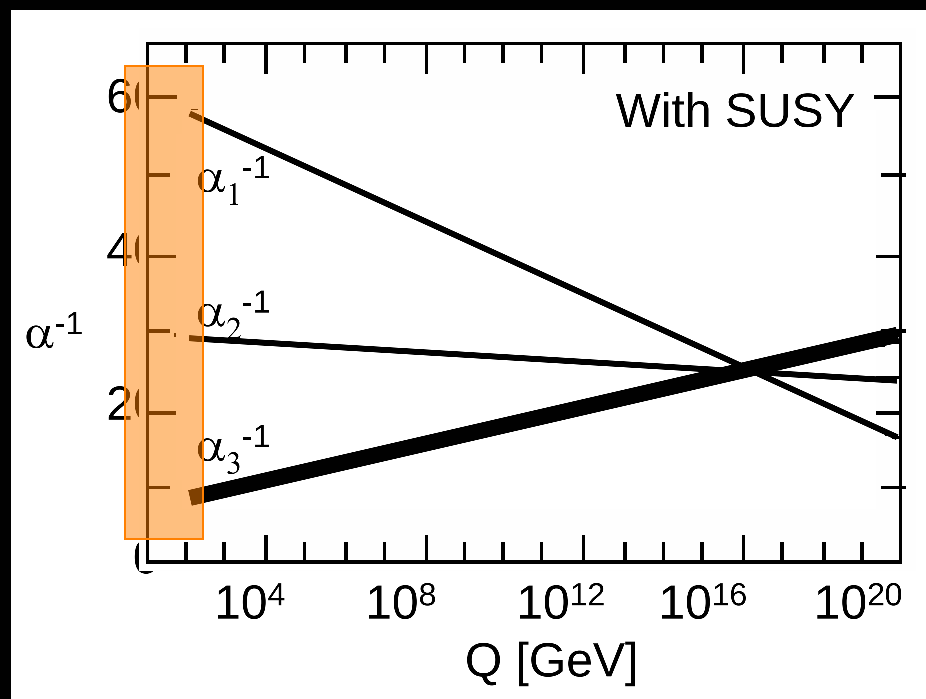




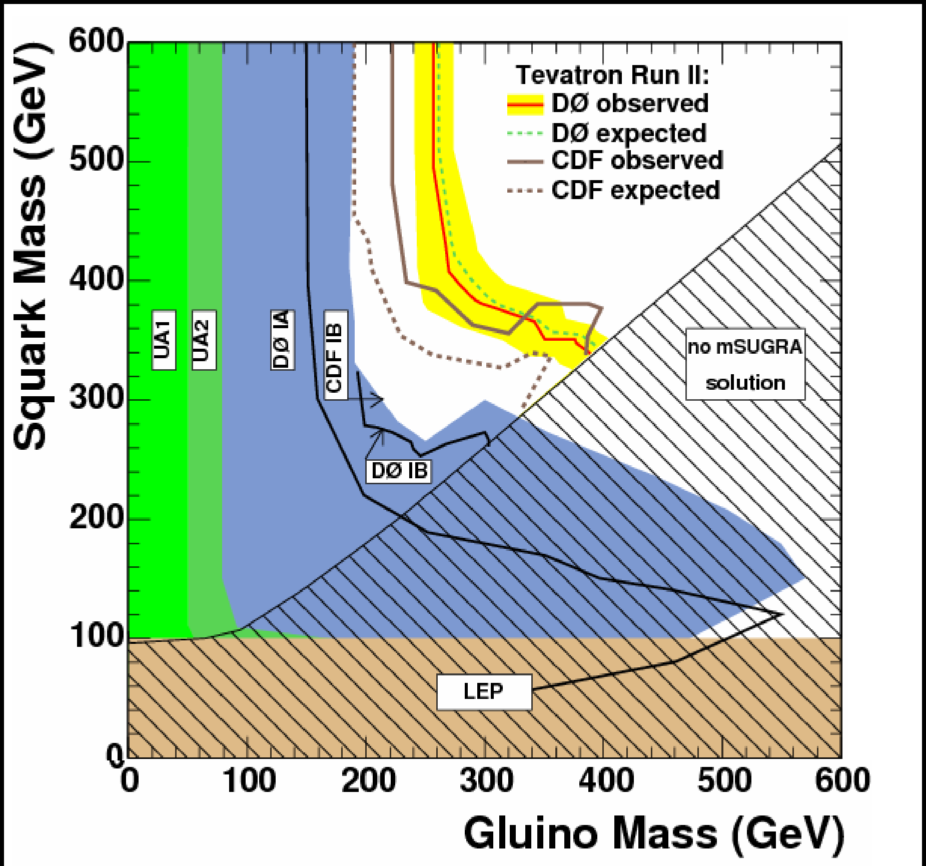


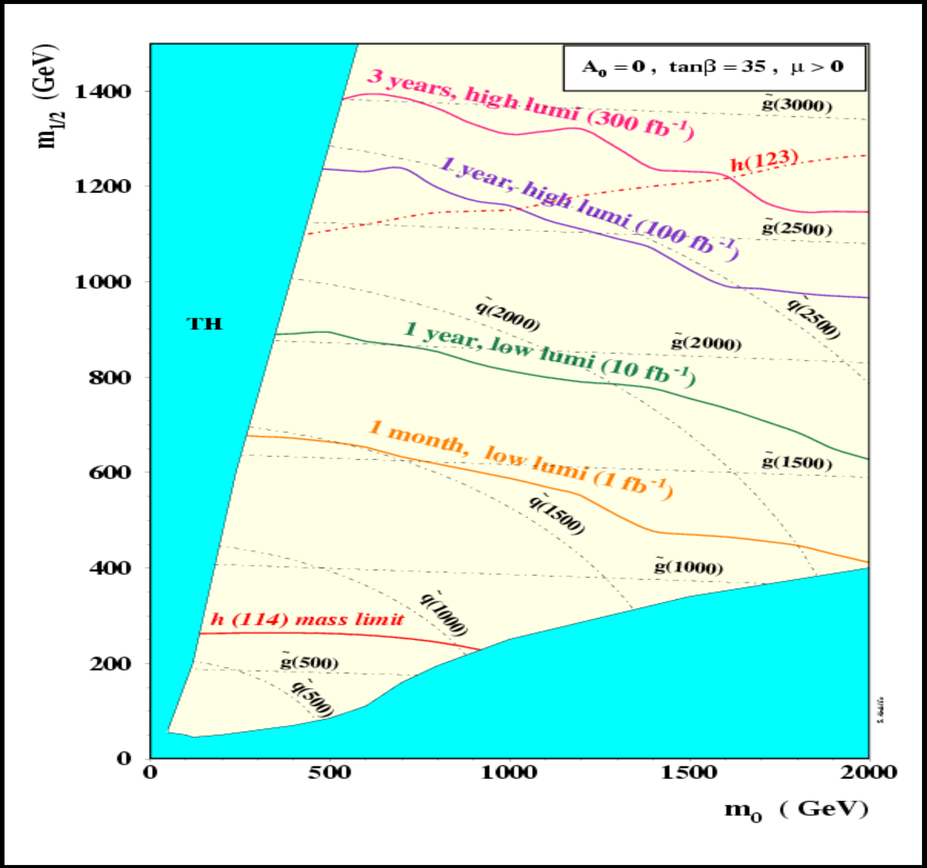
The standard model fails to unify the strong and electroweak forces.


Electromagnetic Force
ELECTROWEAK UNIFICATION
THE TERASCALE
Weak Nuclear Force
GRAND UNIFICATION
Strong Nuclear Force
PLANCK SCALE
BIG BANG
Gravitation
Energy (TeV)
Time (s)


With SUSY
α_1^{-1}
α_2^{-1}
α_3^{-1}
α^{-1}
10^4 10^8 10^{12} 10^{16} 10^{20}
Q [GeV]

Supersymmetric Extension of SM

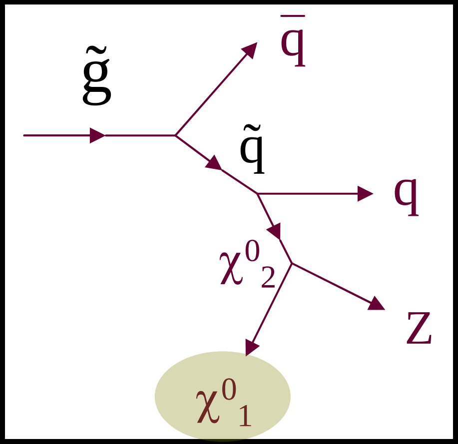


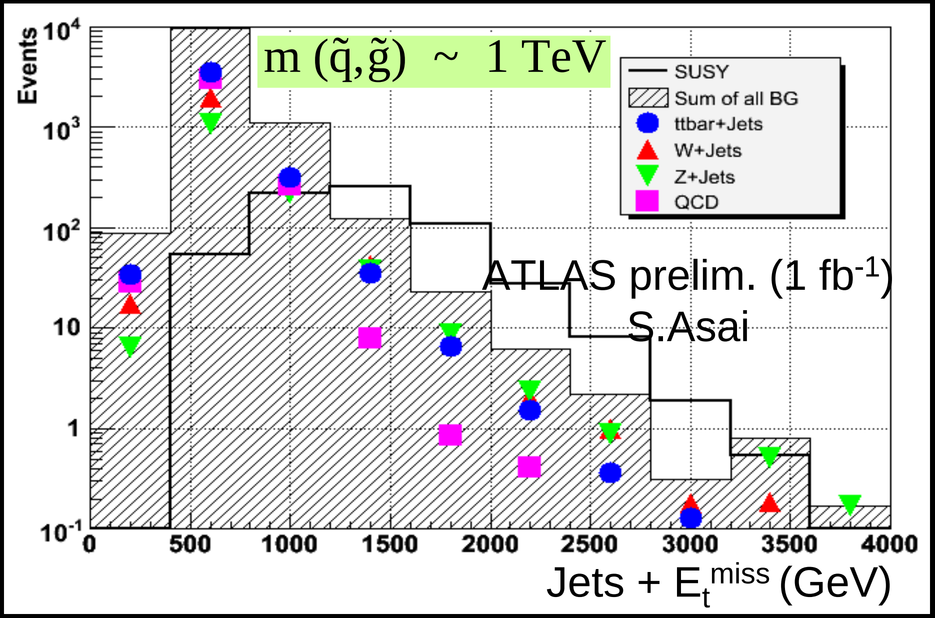


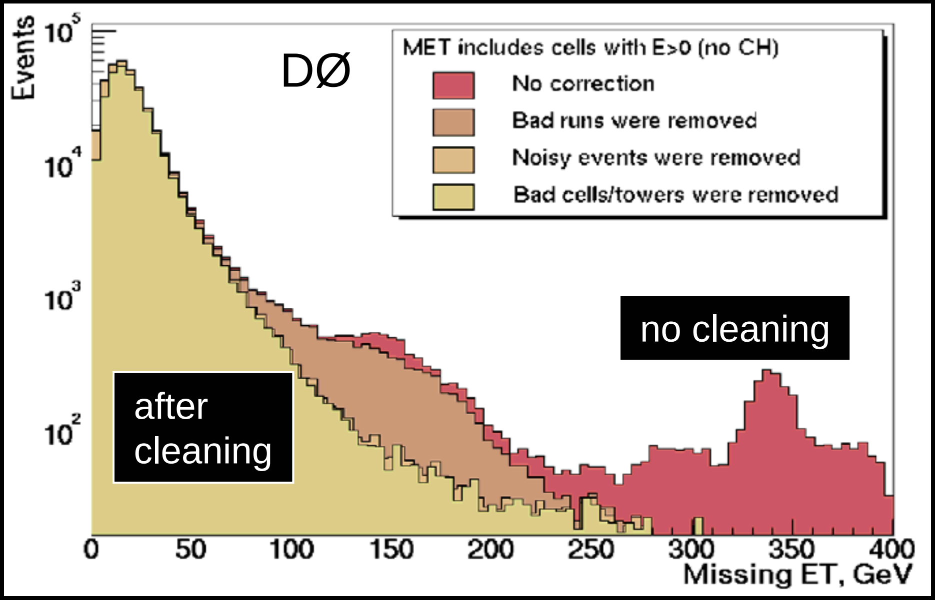
LHC is a fantastic place to discover SUSY partners!
But Tevatron can reach some if they are light.

Understanding Missing Energy

e.g. SUSY at Tev scale







E_T^{miss} spectrum contaminated by cosmics, beam-halo, machine/detector problems, etc.

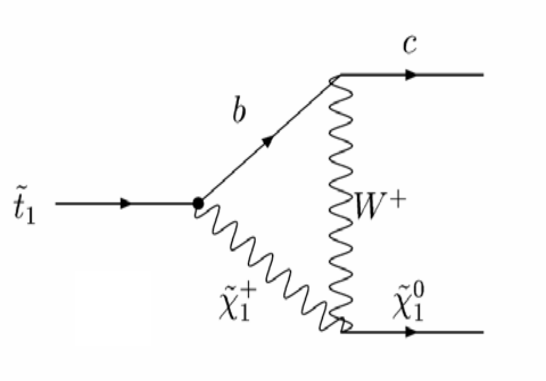
Supersymmetric Extension of SM

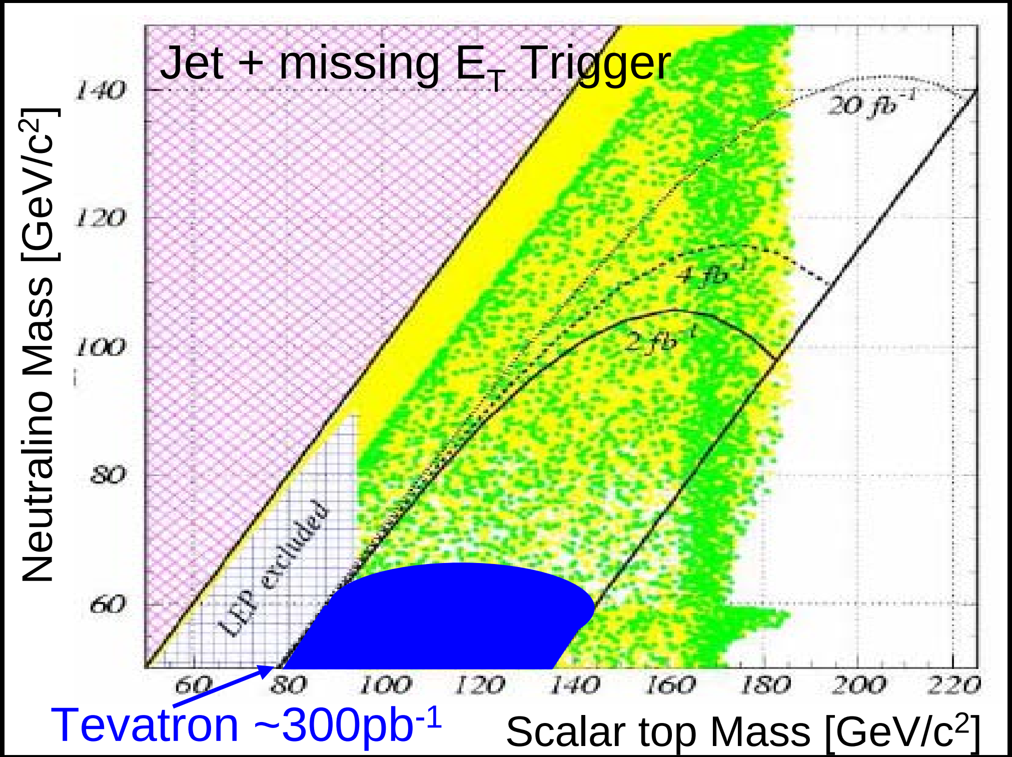
Why might Tevatron do physics that could be challenging at LHC?

- Backgrounds: lower, different
- Triggering might be hard

Super partner of top quark (stop)

- Might be light - favored by some scenarios (hep-ph/0403224)
- This could be challenging at both Tevatron and LHC
- Backgrounds and triggering

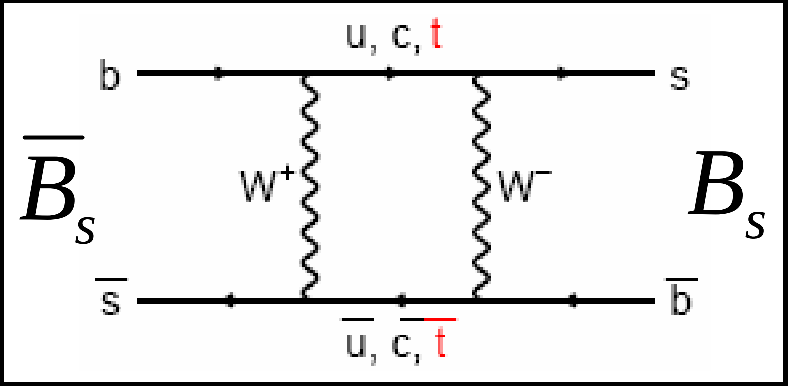




Ruling Out New Physics Models

Many SUSY models affect significantly the rate that B_s particles

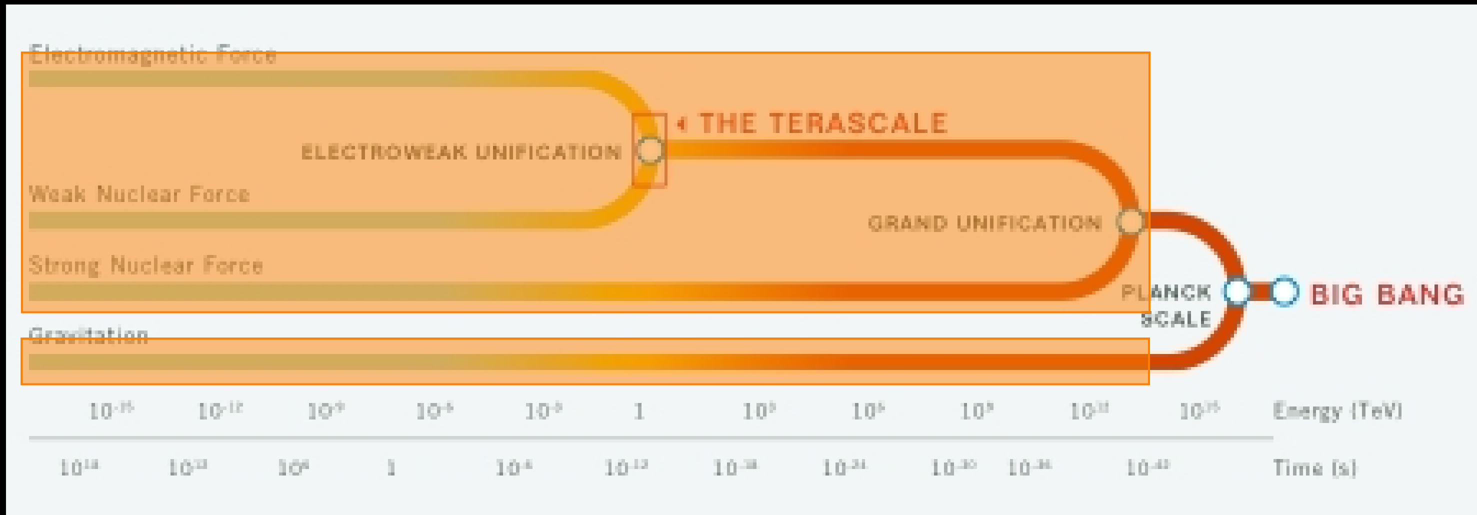
- change into their anti-particles: Δm_s
- decay: $Br(B_s \rightarrow \mu\mu)$



DØ: Δm_s = 17 - 21 ps^{-1} at 90%CL (hep-ex/0603029) PRL
CDF: $\Delta m_s = 17.31\ ^{+0.33}_{-0.18} \pm 0.07\ ps^{-1}$ (hep-ex/0606027) PRL
(agreeing well with SM)

$Br(B_s \rightarrow \mu\mu) < 1.0 \times 10^{-7}$ (CDF,1 fb^{-1}), 3.7×10^{-7} (DØ, 300 pb^{-1})

Already puts stringent limits on SUSY models.
There is little room left for generic supersymmetry models that produce large new flavor-changing effects.



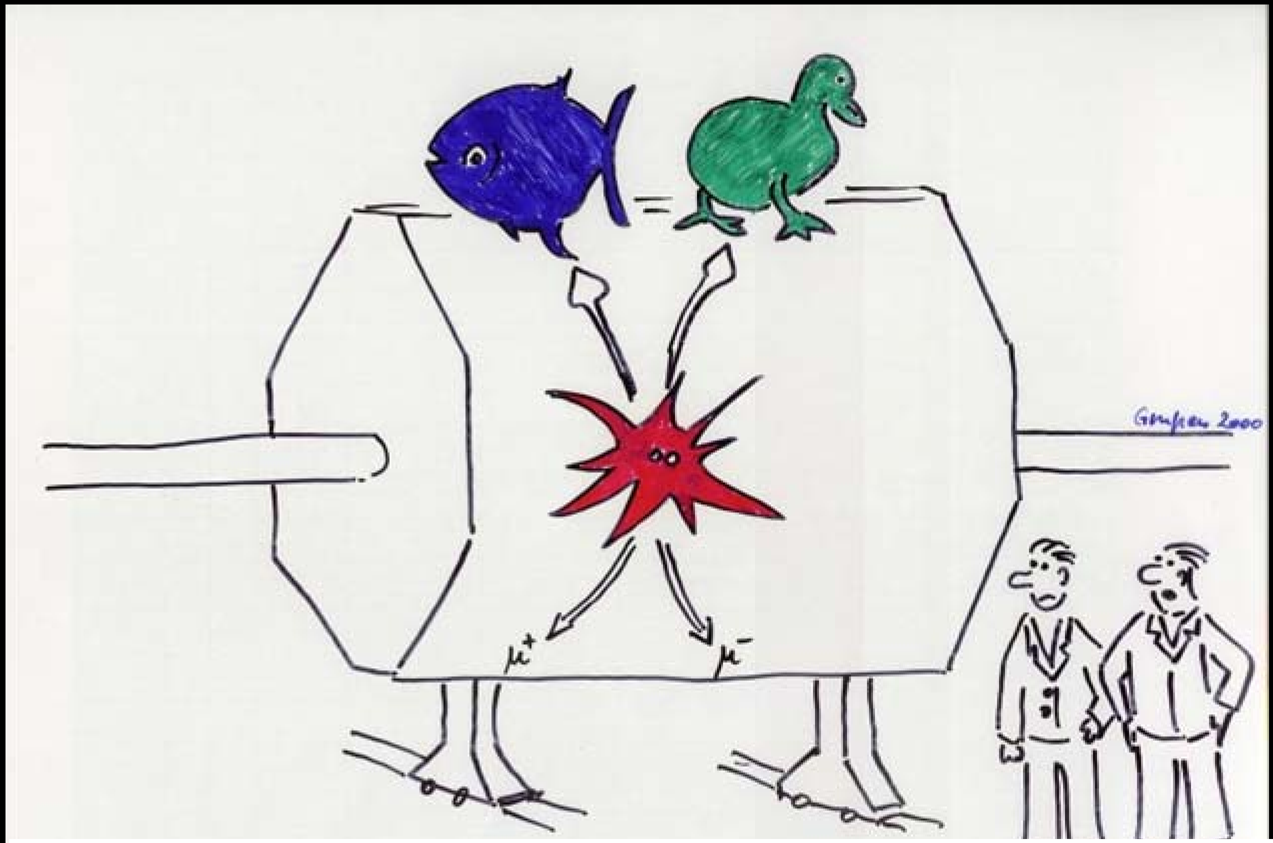
Unifying gravity to the other 3 is accomplished by String theory.

String theory predicts extra hidden dimensions in space beyond the three we sense daily.

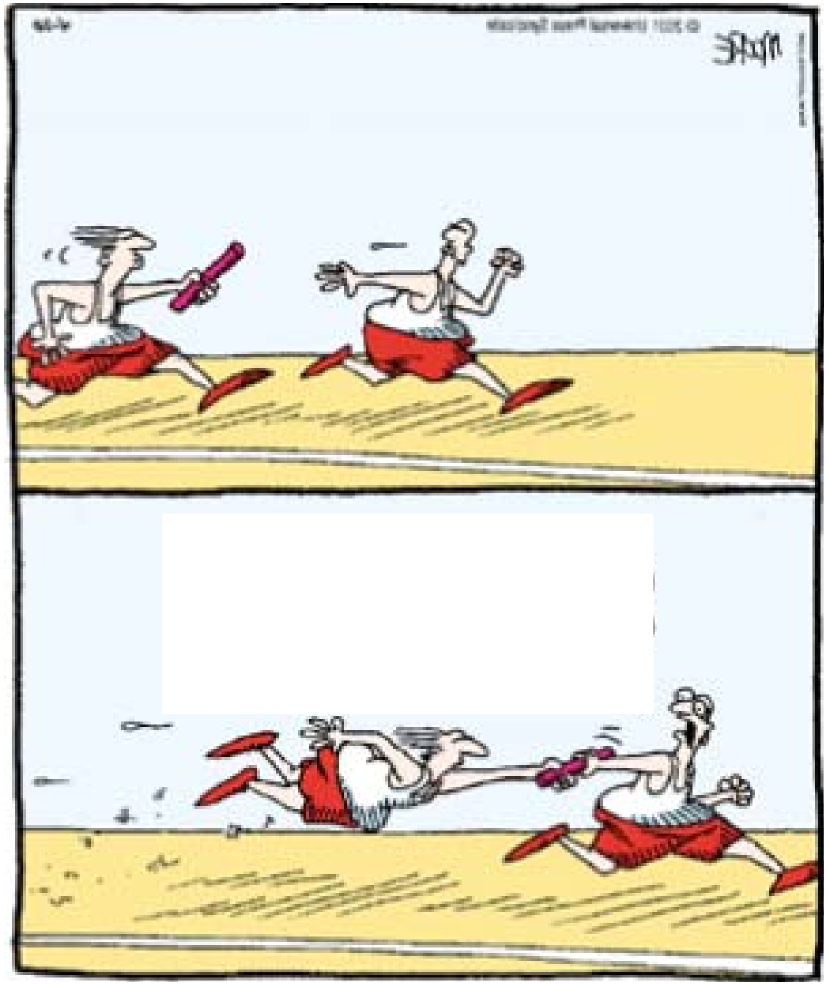
Can we observe or feel them? too small?
Other models predict large extra dimensions:
large enough to observe up to multi TeV scale.

Tevatron up to ~2 TeV - LHC up to ~10 TeV

The Unknowns!!



“Oink? This is not what



LHC Physics Center