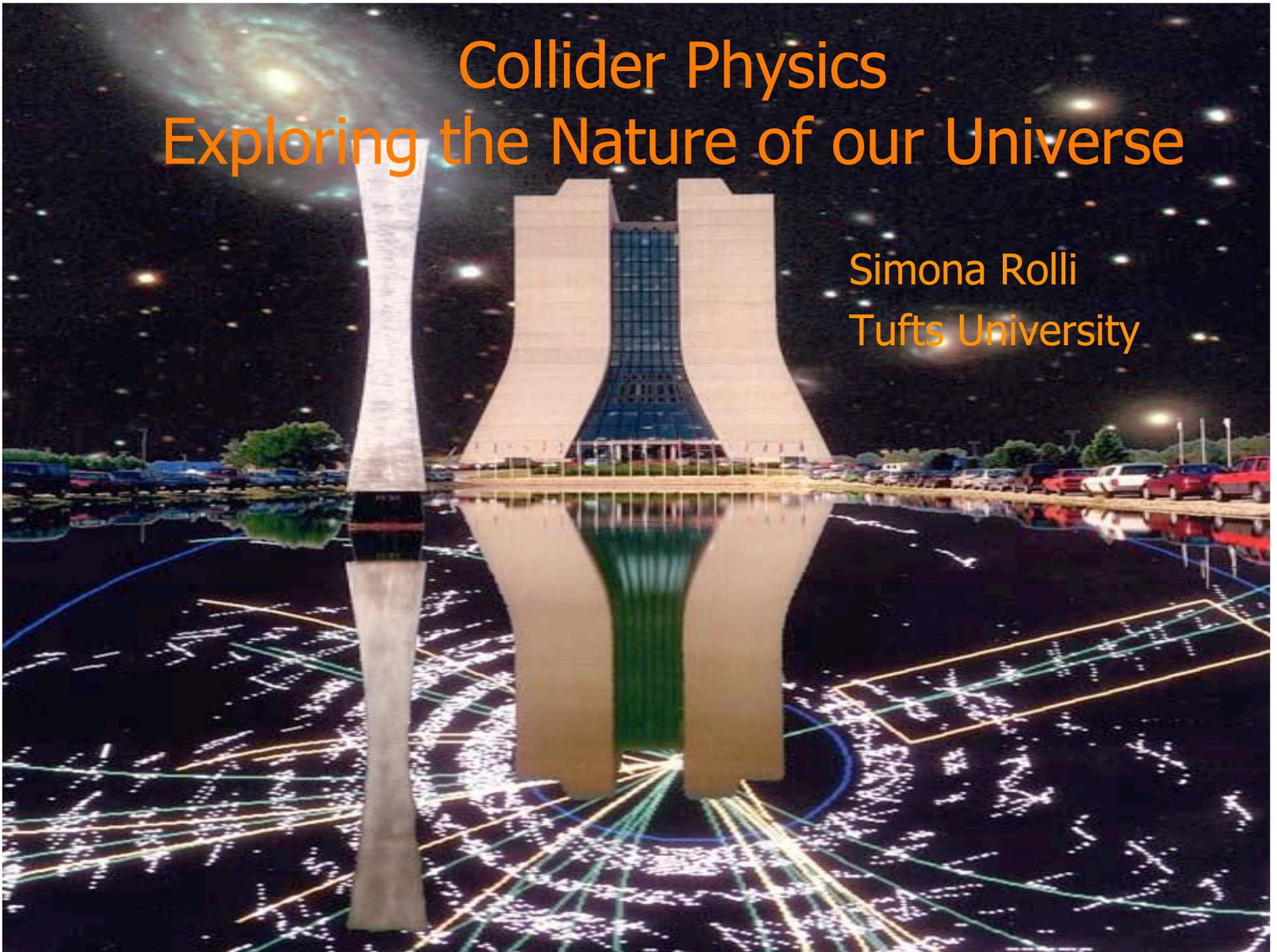


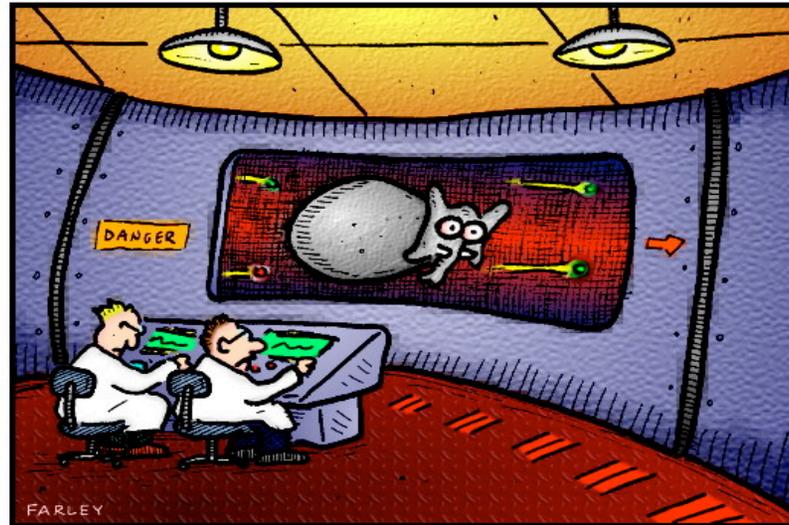
Collider Physics

Exploring the Nature of our Universe

Simona Rolli
Tufts University



Introduction



Deep within the atomic supercollider, the search continues for the elusive elephantino.

A (small) community of scientists is building more and more powerful machines to explore the intimate nature of matter and answer some of the fundamental questions about our Universe

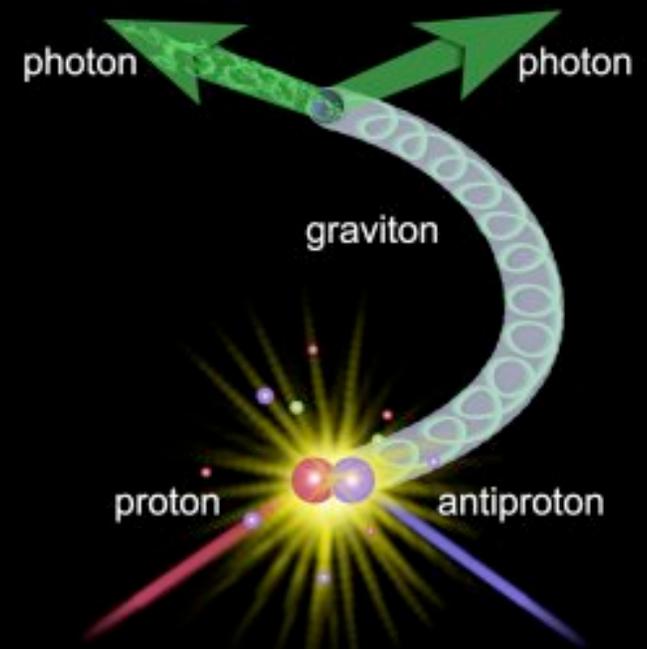
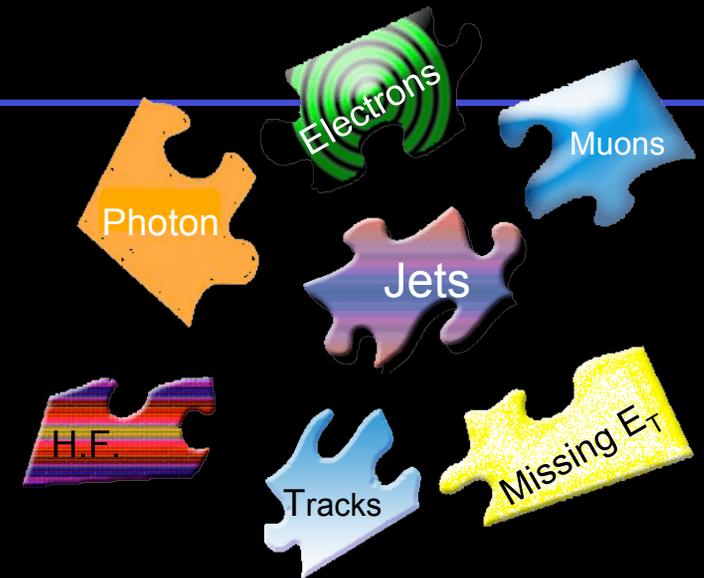
Particle Physics has evolved from small laboratory experiments to world-wide enterprises lasting several years and involving several thousand people per experiment

Not all the questions have received an answer yet.

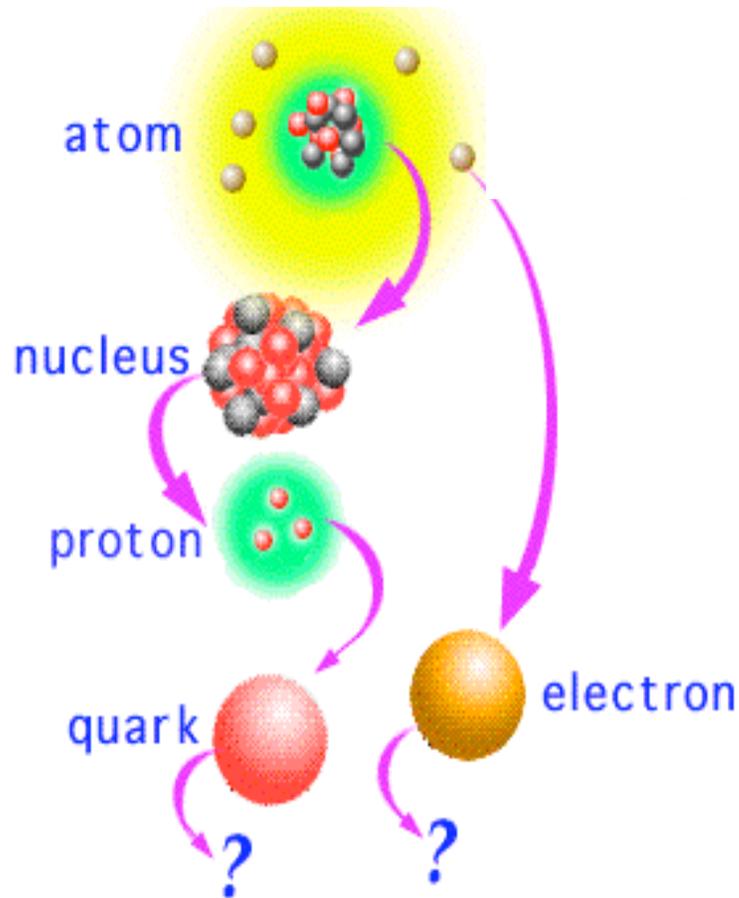
The search is still on.....

Outline of the talk

- **What is the Universe made of ?**
 - **The Standard Model of particle physics**
- **The Experimental Apparatus**
 - **The Collider**
 - **The detectors**
 - **From 540 GeV to 14 TeV in 30 years**
- **Physics Processes and their Signatures**
 - **From W/Z to the Top quark and Beyond**
 - **From the SppS to the Tevatron**
 - **Current status**
 - **The future: LHC**
 - **What to expect**



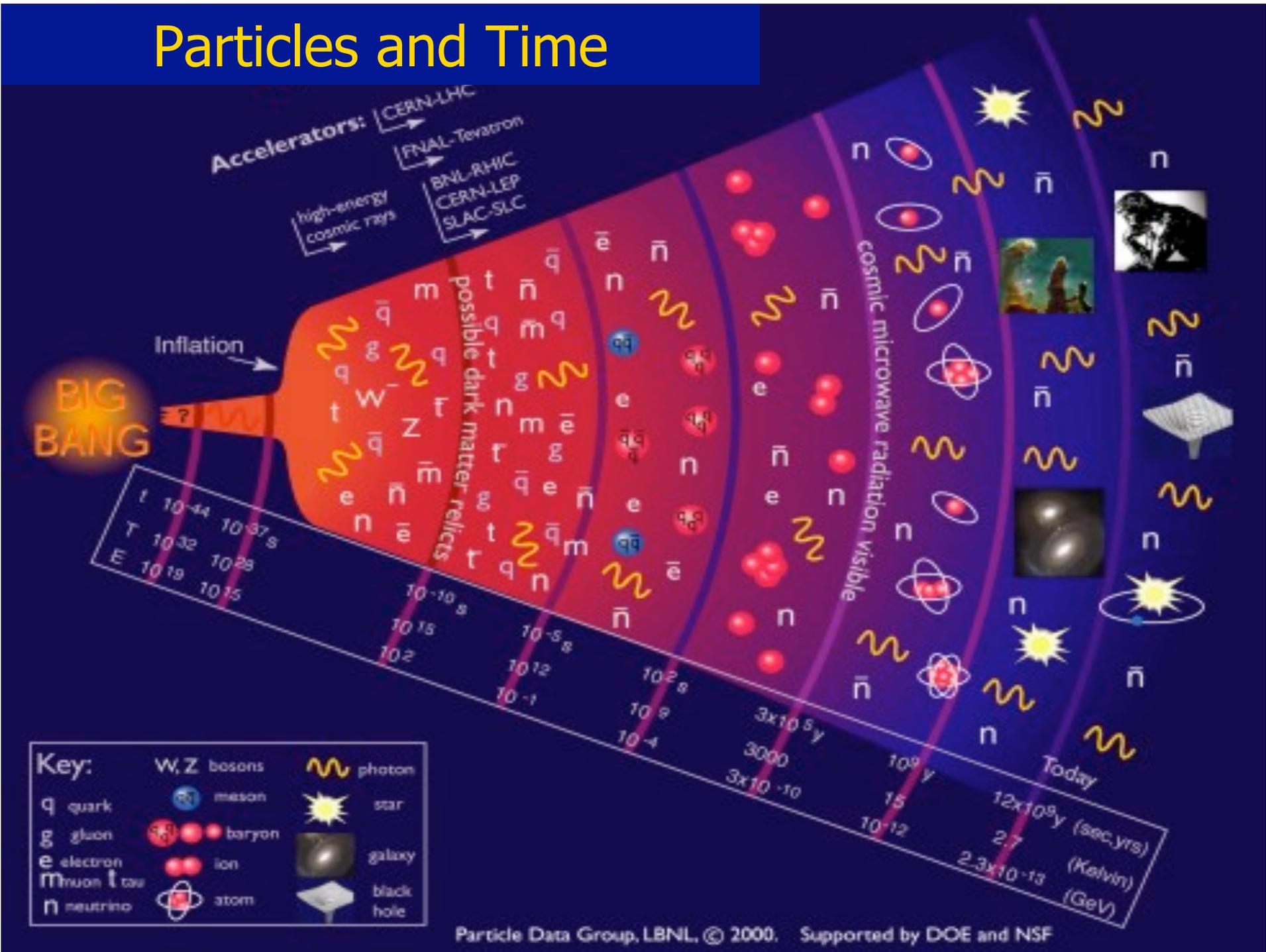
What is the Universe made of?



- Everything we see is made of molecules or chains of atoms
- Atoms contain a nucleus surrounded by electrons
- In the nucleus there are protons and neutrons
- Proton and neutrons are bound states of quarks and gluons

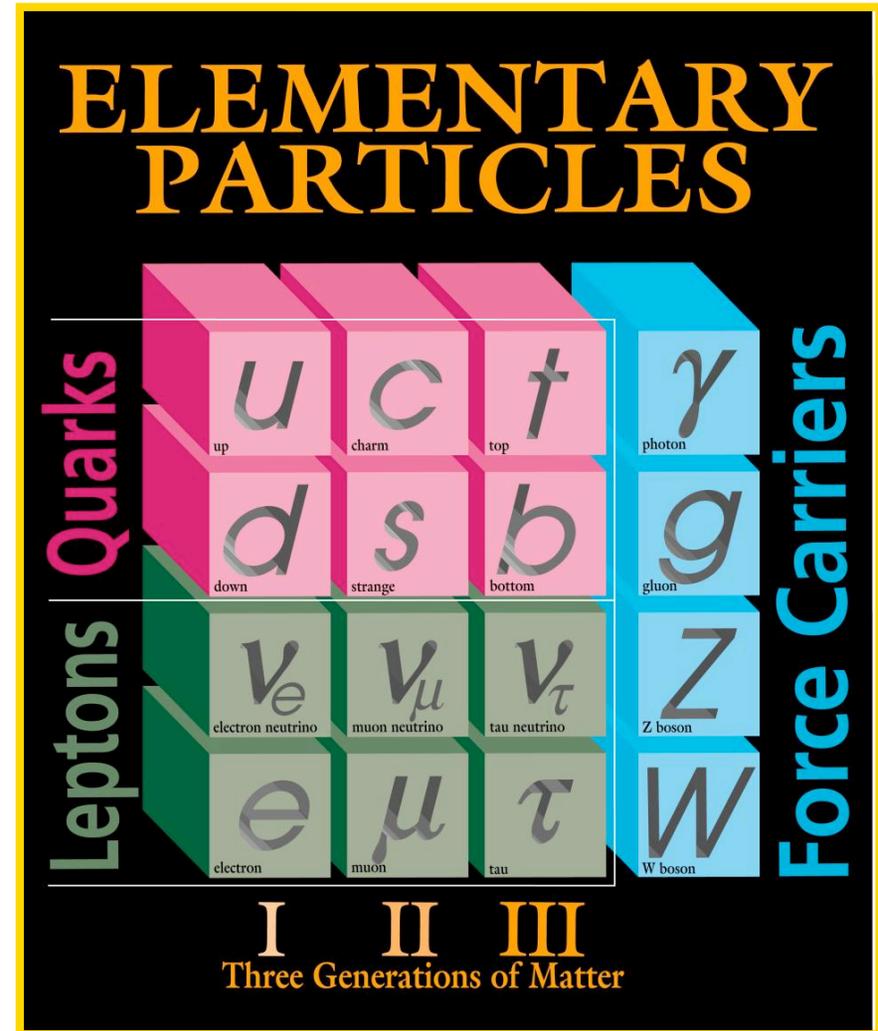
- When we look closer we find an amazing world of particles and interactions and we travel back in time.....

Particles and Time



The Standard Model of Particle Physics

- The Standard Model describes the fundamental particles and the interactions between them
- **Leptons** like electrons are believed to be fundamental
- Hadrons are composite states of **quarks** and **gluons**;
 - Baryons (three quarks like protons and neutrons)
 - Mesons (a quark and one anti-quark)
- **Force carriers** are particles responsible for the interactions
- **Collider experiments can identify all types of particles**



Timeline of Particle Discoveries

1895 The **electron** is discovered, except electrons are called **cathode rays** by their discoverer.

1896 **X rays** and other forms of radioactivity are observed

1899 **Alpha particles** are discovered, and later shown to be helium nuclei consisting of two neutrons and two protons.

1911 Nuclear model of **atom** with heavy nucleus in the middle and light electrons orbiting around it, is proposed, and becomes accepted.

1911 **Electron charge** measured in an oil drop experiment indicates that all electrons carry the same electric charge.

1932 The **neutron** directly observed in an experiment for first time.

1932 The **positron**, predicted by a theorist in 1928, is discovered.

1934 Radioactive **nuclei** produced in the laboratory.

1937 The **muon**, a charged lepton like the electron only heavier and hence unstable, is discovered.

1947 Two **charged pi mesons**, with positive and negative charge, are discovered.

1950 The **neutral pi meson** is discovered.

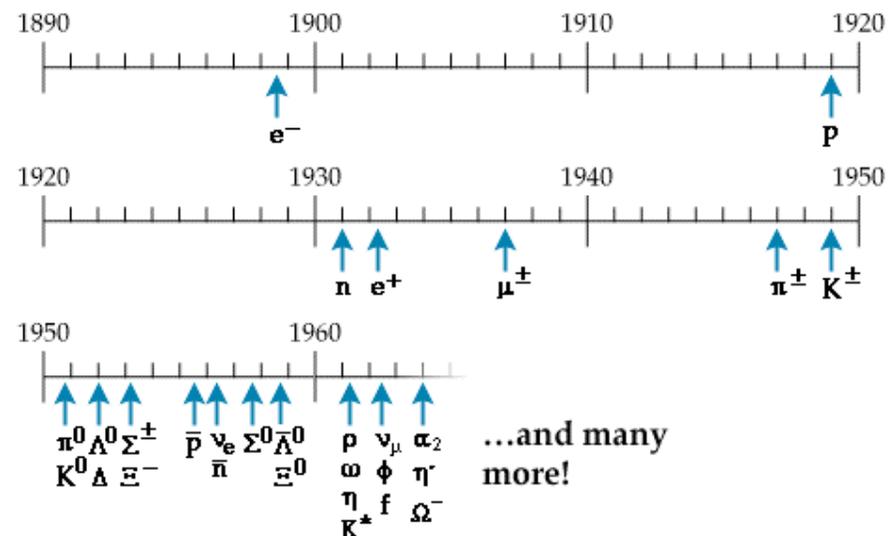
1953 The **lambda baryon** and **K meson** are discovered.

1956 The **electron neutrino**, predicted by theory in 1930, is confirmed to exist.

1950s-1960s Lots of **baryons** and **mesons** being discovered, and their properties occur in regular patterns that look as if baryons and mesons are made of smaller building blocks. Physicists exhibit a tendency to name new particles after letters in the Greek alphabet.

1961 The **muon neutrino** is discovered and shown to be a different particle from the electron neutrino..

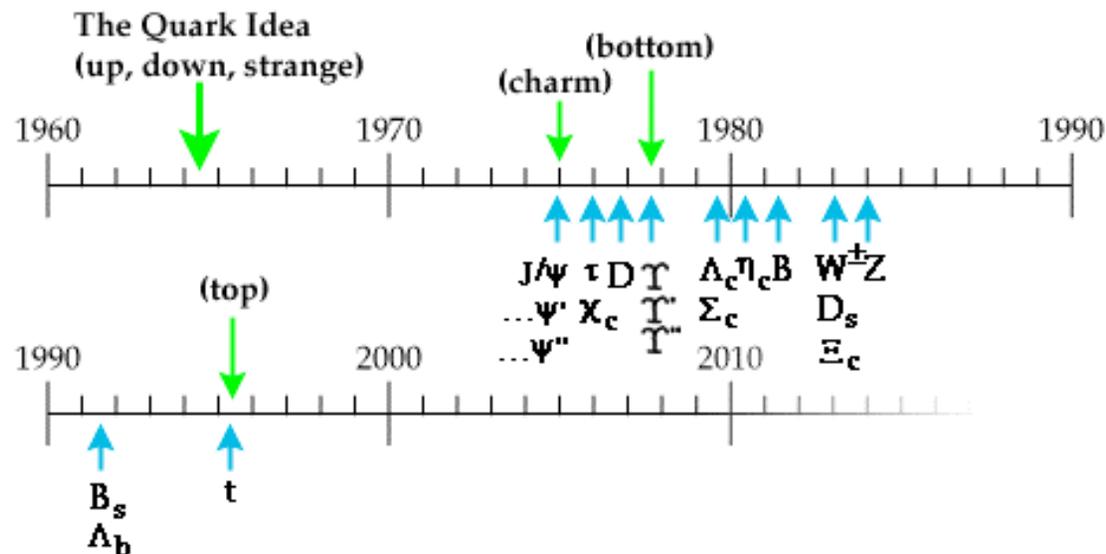
1963 **Quark** theory postulates that protons are made of smaller particles that carry charges that come in thirds of the electron charge. The three flavors of quarks are given names: **up**, **down** and **strange**.



Timeline of Particle Discoveries

- 1970s** Deep inelastic scattering and other experiments reveal more of the quark structure inside protons and other hadrons.
- 1974** A fourth flavor of quark, named **charm**, is detected in a newly discovered meson called the **J** (aka the **yor Psi**).
- 1975** The **tau lepton** is discovered, making a triplet of charged leptons with the electron and muon, leading to predictions of a **tau neutrino** to accompany the electron neutrino and the muon neutrino.
- 1979** A fifth flavor of quark, named **bottom**, is detected in the newly discovered Upsilon meson. This pattern leads particle physicists to believe they will find a sixth and final flavor of quark some day. This predicted last flavor of quark is called **top**.
- 1983** The massive gauge bosons that carry the weak nuclear force, called the **W^+, W^-** and **Z^0** , are discovered and the Standard Model of Particle Physics is confirmed.

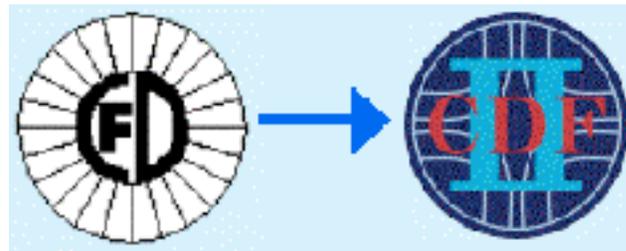
- 1989** The lifetime of the **Z^0** weak nuclear gauge boson is measured, and agrees precisely with there being exactly three kinds of neutrinos, and no more.
- 1995** The **top quark** is finally directly observed and measured, confirming the predictions of theorists that there are six flavors of quarks, as described in the Standard Model.
- Future** The search goes on for the **Higgs boson** (the only particle predicted by the Standard Model that hasn't been seen yet), for **supersymmetric particles** predicted by string theory, for proton decay and for **magnetic monopoles** predicted by Grand Unified Theories, and **new kinds of exotic unpredicted particles** is ongoing. Perhaps in a few years there will be some more interesting entries for this page. Come back later and see.



The Thrill of Discovery: A Brief History of CDF

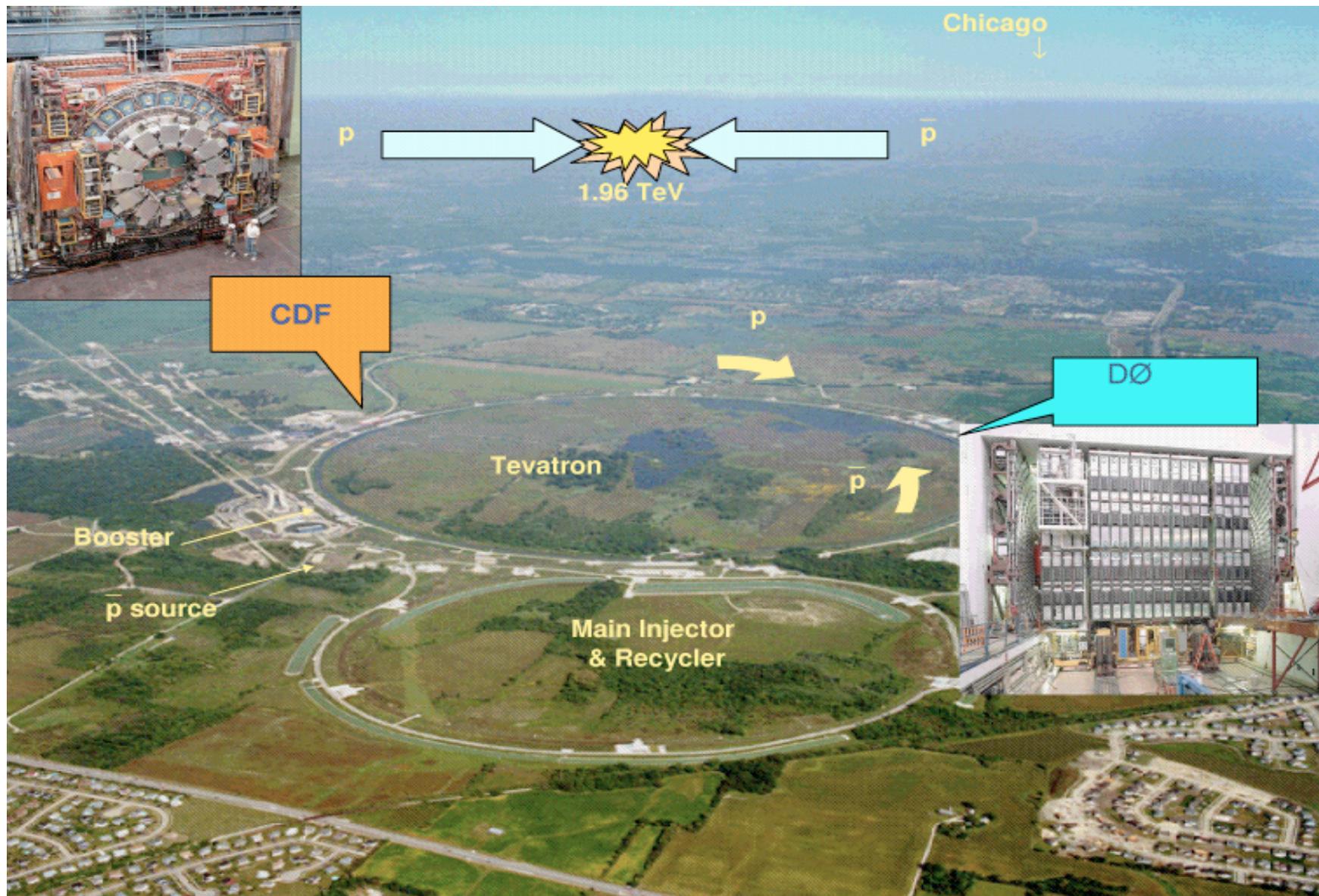
- **1985**: First collisions with partial detector
- **1987**: Core detector in place. Jet Physics
- **1988-89**: "Run 0" 4x the expected data, seen lots of W/Z's
- **1992-1995** : "Run I" -added silicon detector. Top quark discovered!

- **2001**: Run II era begins with essentially a new detector, higher collisions energy and more data.
- **2004**: First Run II physics papers published
- **2007**: trying to catch the Higgs

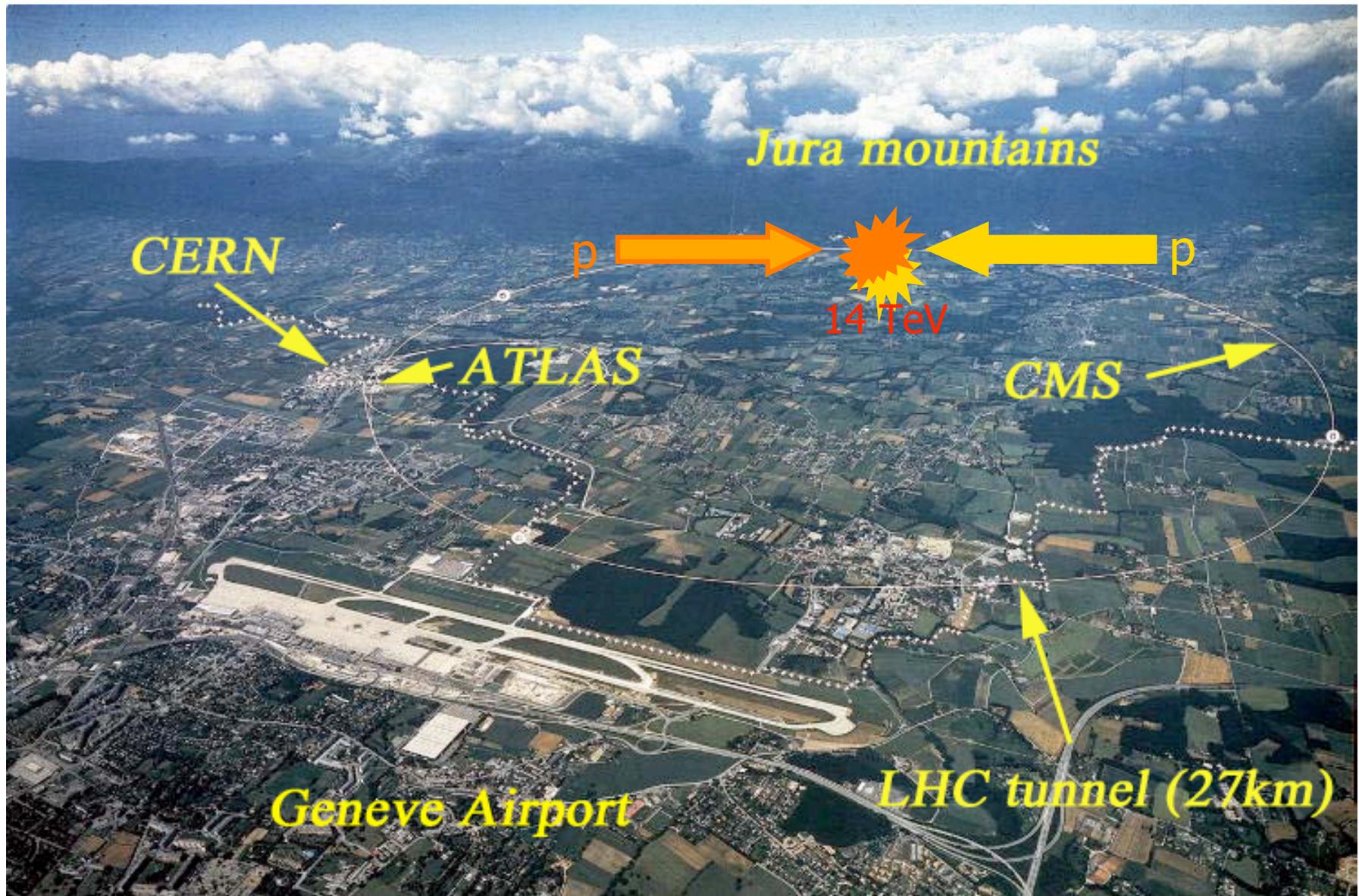


**12 countries, 59 institutions
706 physicists**

The Experimental Apparatus: Fermilab



The Experimental Apparatus: CERN



The Accelerator Chain (Fermilab)

At Fermilab, we start by accelerating protons in the C-W (750 KeV) to the Linac and Booster (up to 8 GeV)

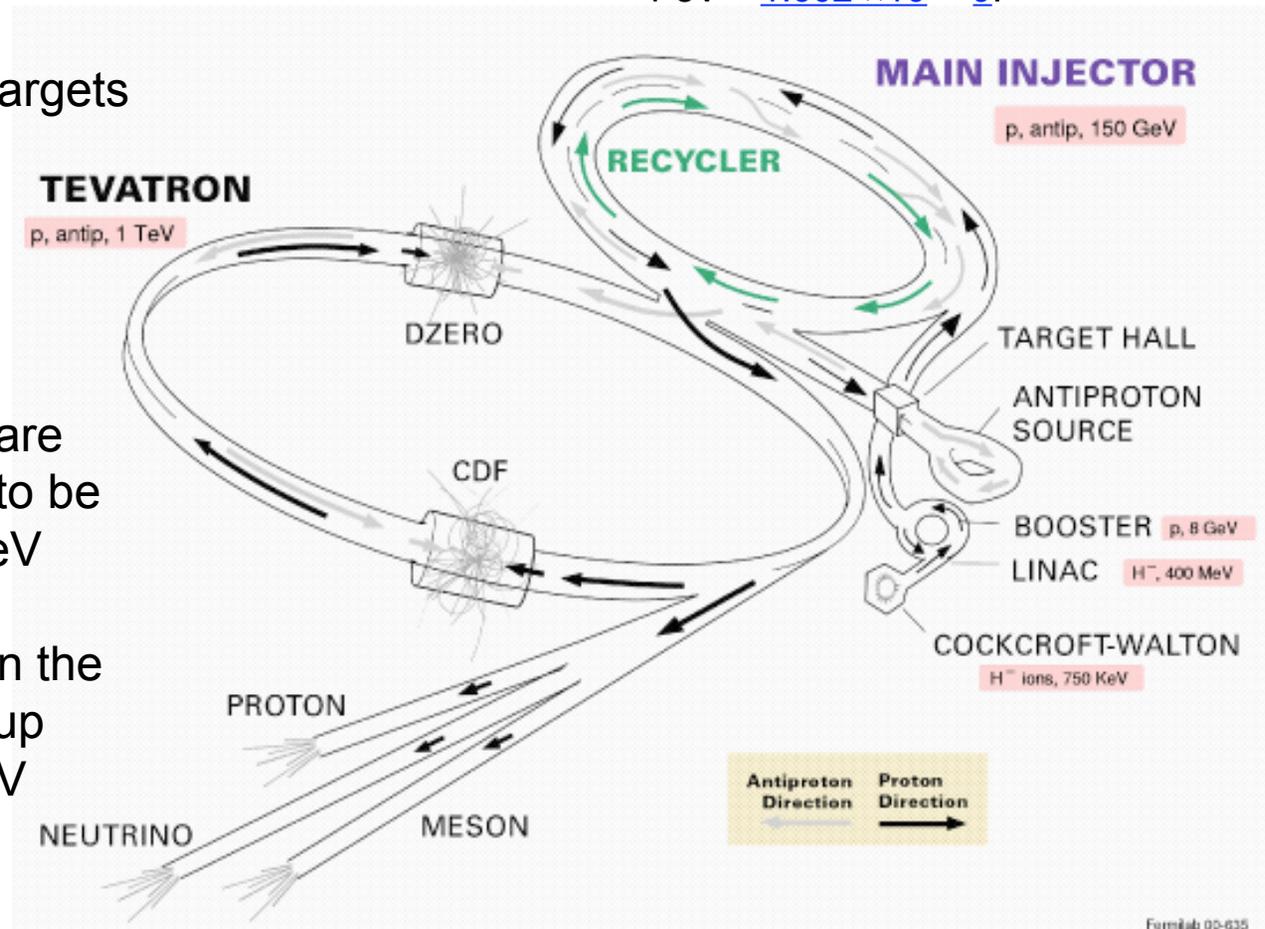
Some protons hit (gold) targets to make antiprotons

Antiprotons are stored (precious!)

Protons and antiprotons are sent to the main injector to be accelerated up to 150 GeV

They finally get injected in the Tevatron, which ramps up the beam energy to 1 TeV

An **electronvolt** (symbol: eV) is the amount of [energy](#) gained by a single unbound [electron](#) when it falls through an electrostatic potential difference of one [volt](#). Very small amount of energy: $1 \text{ eV} \approx 1.602 \times 10^{-19} \text{ J}$.



A small digression on Luminosity

The event rate \mathcal{R} in a collider is proportional to the interaction cross section σ_{int}
The factor of proportionality is called instantaneous Luminosity \mathcal{L}

$$\mathcal{R} = \sigma \times \mathcal{L}$$

The instantaneous luminosity depends on
the **number of bunches** n_1 and n_2 of particles colliding,
their **frequency** f and the gaussian beam profiles $\sigma_x \sigma_y$

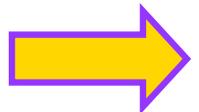
$$\mathcal{L} = f n_1 n_2 / 4\pi \sigma_x \sigma_y$$

Typical values for past, present and future colliders:

- SppS: $10^{27-28} \text{ cm}^{-2}\text{s}^{-1}$
- TeVatron: $10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- LHC: $10^{33-34} \text{ cm}^{-2}\text{s}^{-1}$

$$1 \text{ picobarn (pb)} = 10^{-36} \text{ cm}^2$$

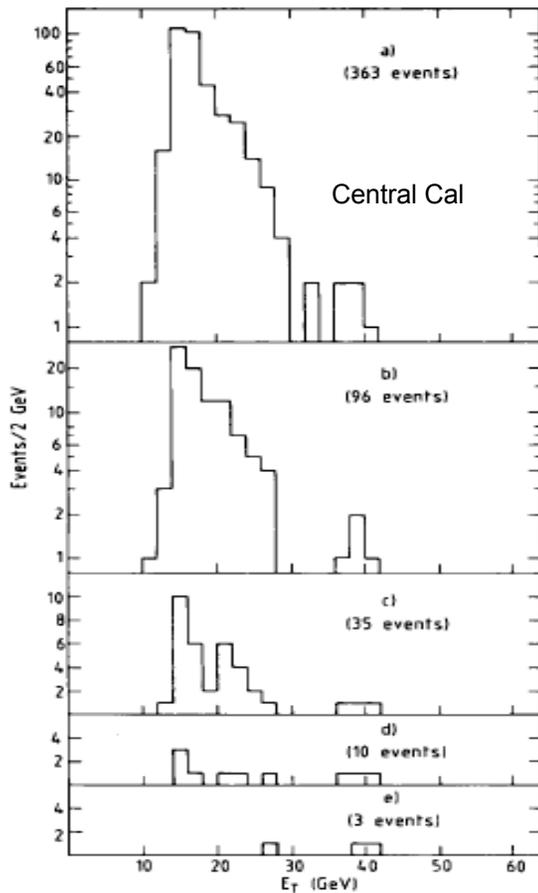
The real important quantity is
the integrated Luminosity,
expressed in units inverse
to the cross section, pb^{-1} , fb^{-1} .
It tells us the number of events we
can see during the lifetime of the
experiment!



The discovery of the IVB (CERN 1983)

Proton-antiproton collisions at $\sqrt{s} = 540\text{GeV}$ $\sim 20\text{ nb}^{-1}$

Search for W bosons at UA2
4 events!



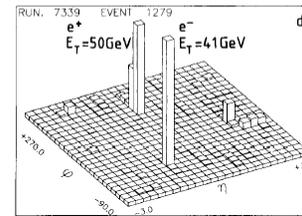
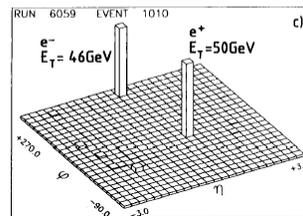
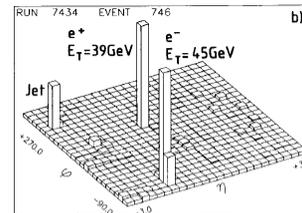
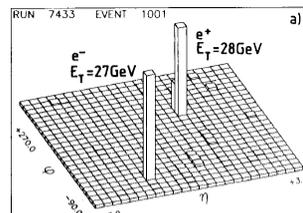
$$m_{W^\pm} = 82.1 \pm 1.7 \text{ GeV}$$

$$m_{Z^0} = 93.0 \pm 1.7 \text{ GeV}$$

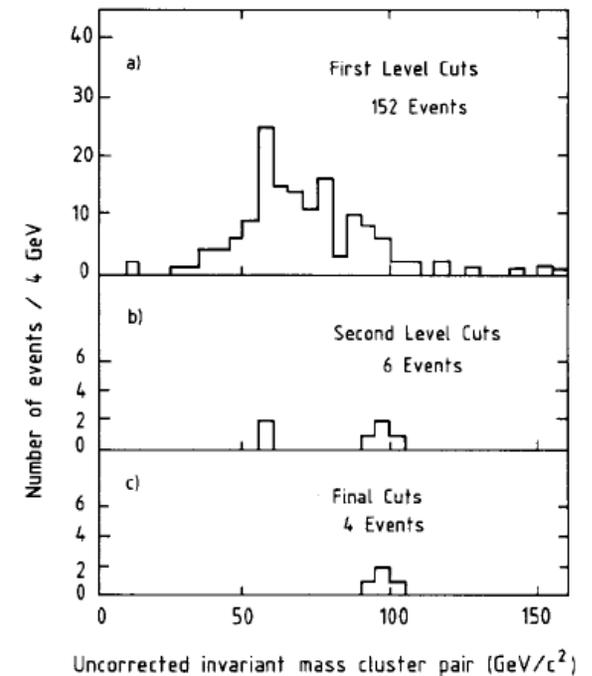
Current values (Particle Data Group 2006):

$$m_{W^\pm} = 80.403 \pm 0.029 \text{ GeV}$$

$$m_{Z^0} = 91.1876 \pm 0.0021 \text{ GeV}$$

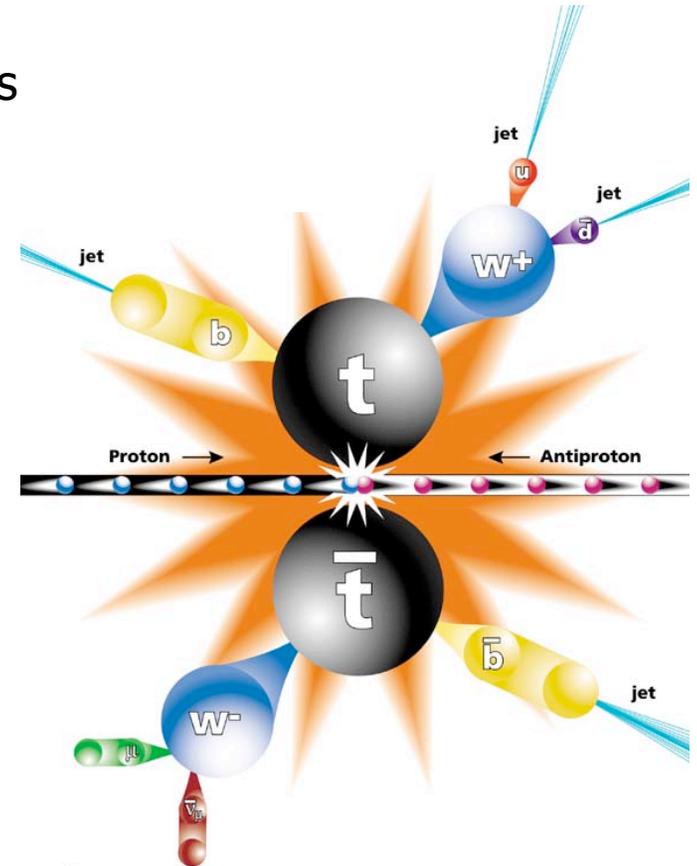


Search for Z bosons at UA1
4 events!



Proton-(Anti)proton Collisions

- Collisions:
 - At high energies we go inside the protons and antiprotons where we collide the internal quarks and gluons
- $E = mc^2$
 - Energy and mass are equivalent. With lots of energy we can produce lots of particles
 - 0.54 -0.63 TeV (SppS)
 - 1.8 -1.96 TeV (TeVatron)
 - 14 TeV (LHC)
- Production
 - In the collision process we can produce several types of particles and study their properties
- Decay
 - Some particles decay and the study of their daughters gives us insight on the nature of the interactions

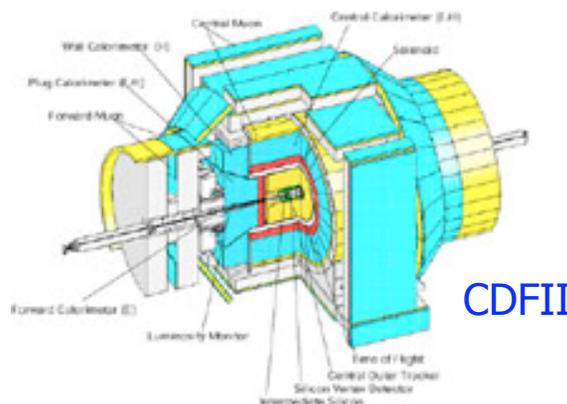
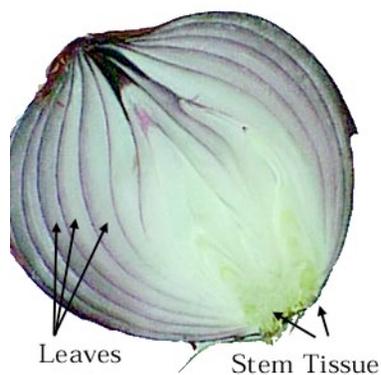


The Detector

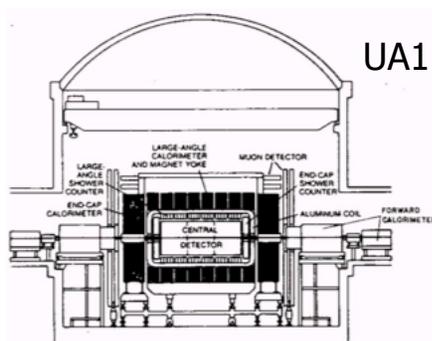
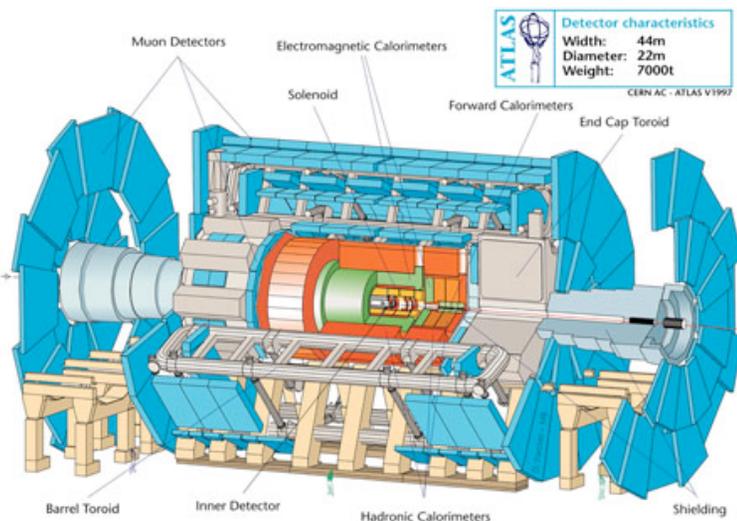
The Experiment studies *interesting* collisions between protons and antiprotons

- events of interest are selected (trigger)
- the interaction of particle and matter is used to identify the physics objects

a multipurpose detector is like a large onion....



CDFII



UA1

Charged particles leave tracks in a magnetic field (inner layer)

Most particles energies are absorbed by calorimeters (intermediate layers)

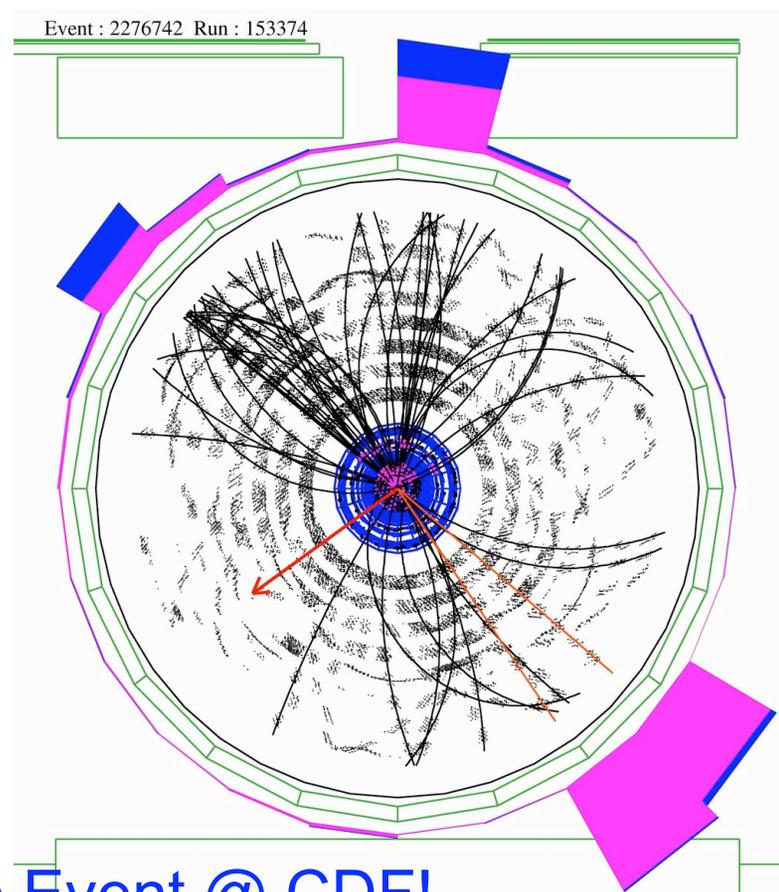
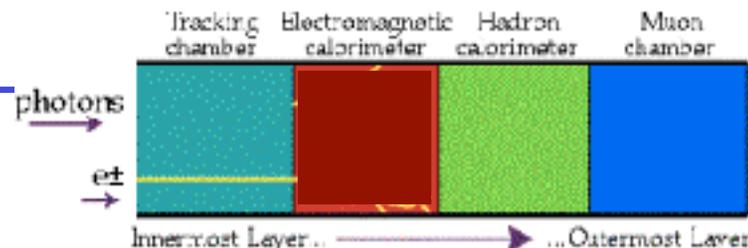
MIP's interact with the the most outside layers (muon chambers)

Electronics to read out each subsystem

Computers to record and analyze data

Tracks

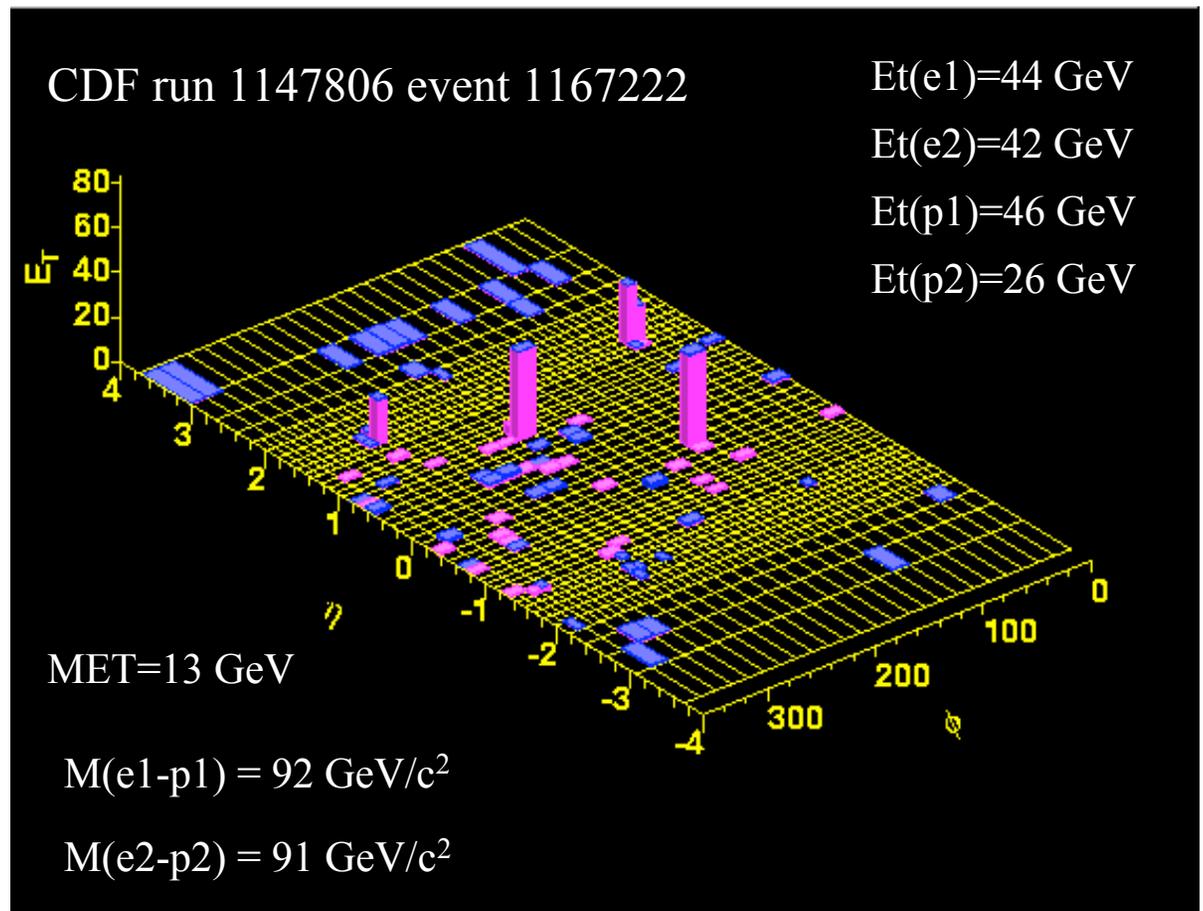
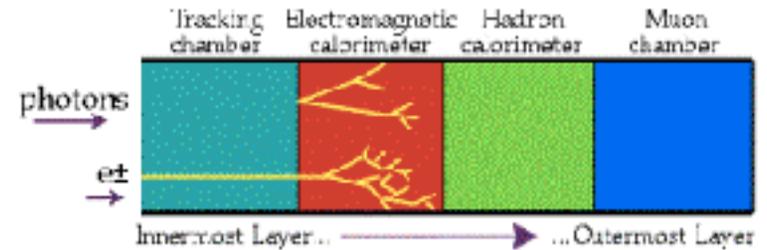
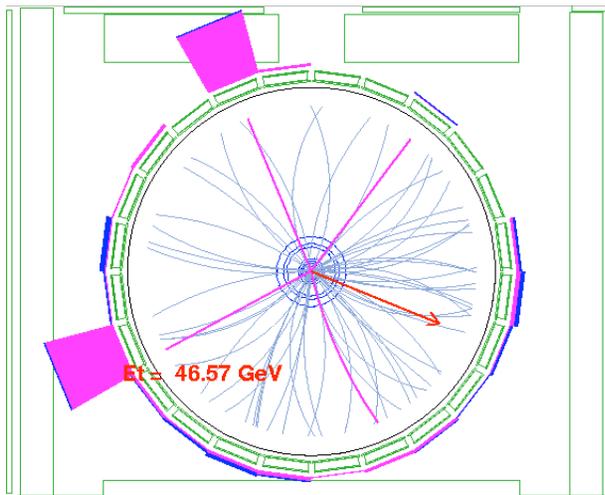
- Charged particles bend in the magnetic field
- Ions and e's knocked off gas molecules drift to the wires giving electronic signals (**drift chambers**)
- **Hit patterns** can be recognized as **tracks**
- The higher the energy (momentum) the straighter is the track
- Beside momentum, tracks give information about the collision point



A Top Event @ CDF!

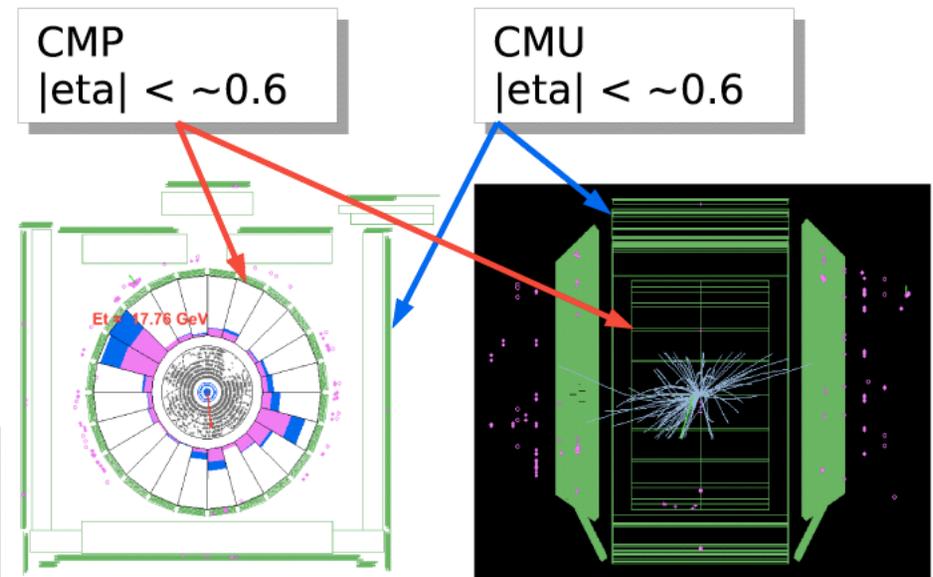
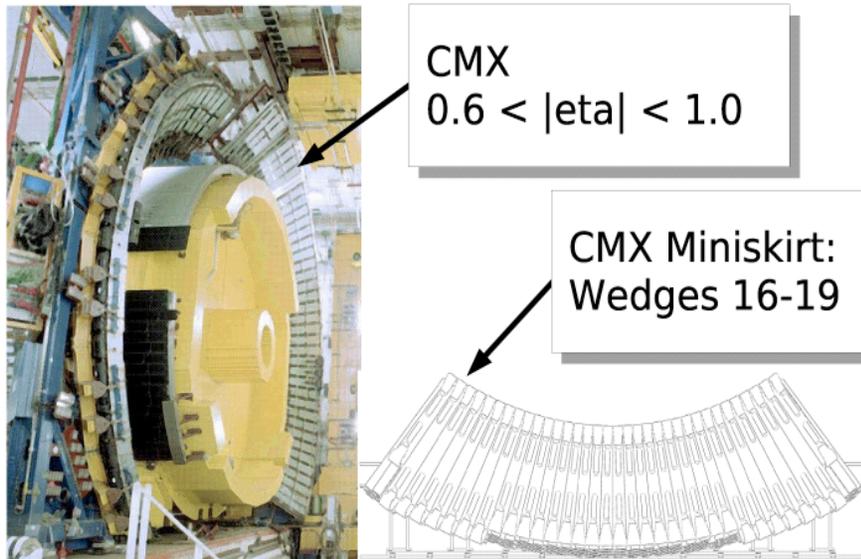
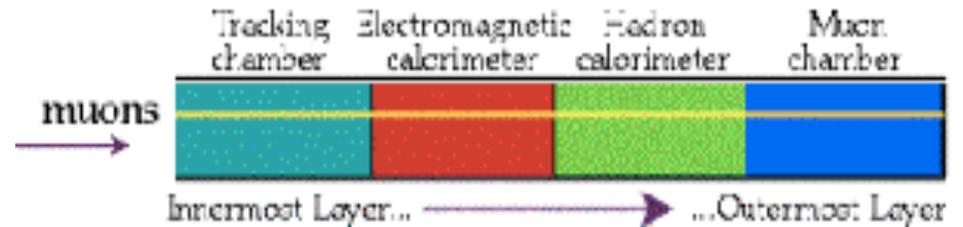
Electrons and Photons

- Electrons and Photons get easily absorbed by the calorimeter (energy deposit)
- Tracking association gives the ability to identify a charged particle: the electron.



Muons

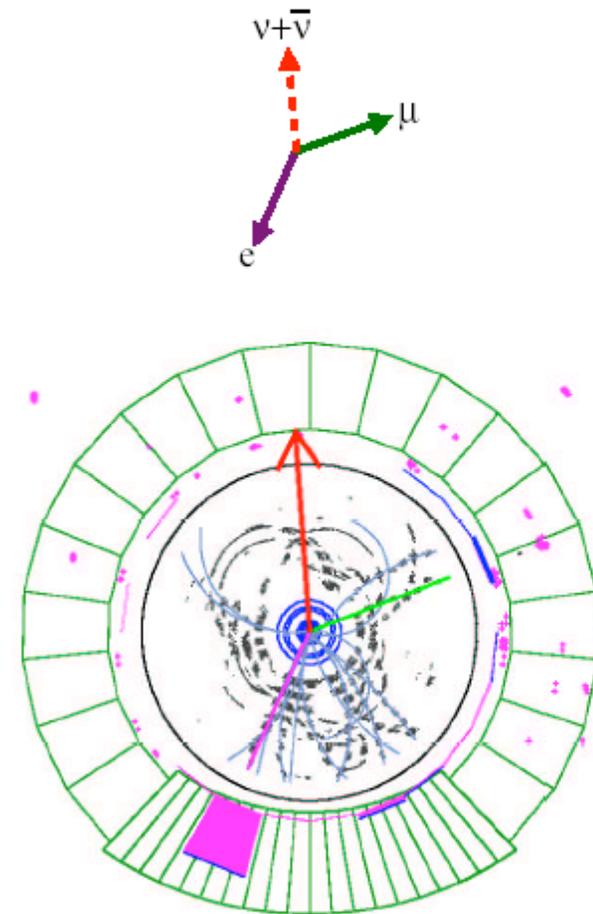
- Muons can penetrate lots of material before getting absorbed.
- Easily identified as coincidence between tracks and hits in the outer layer muon chambers: MIP



CDF Muon System

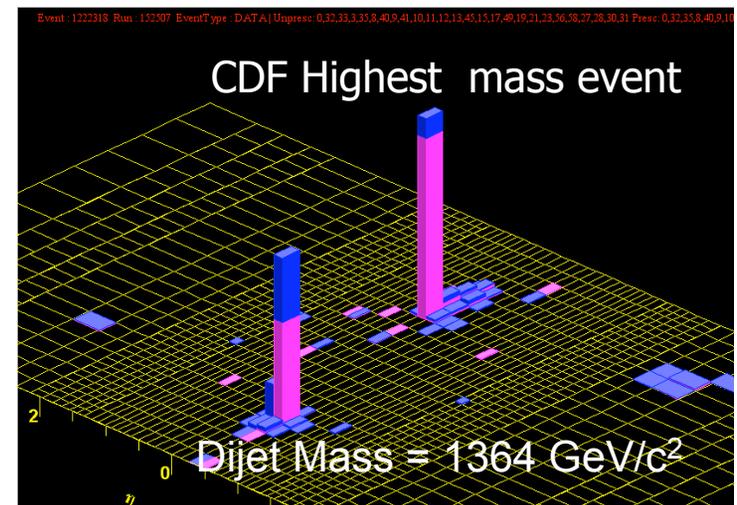
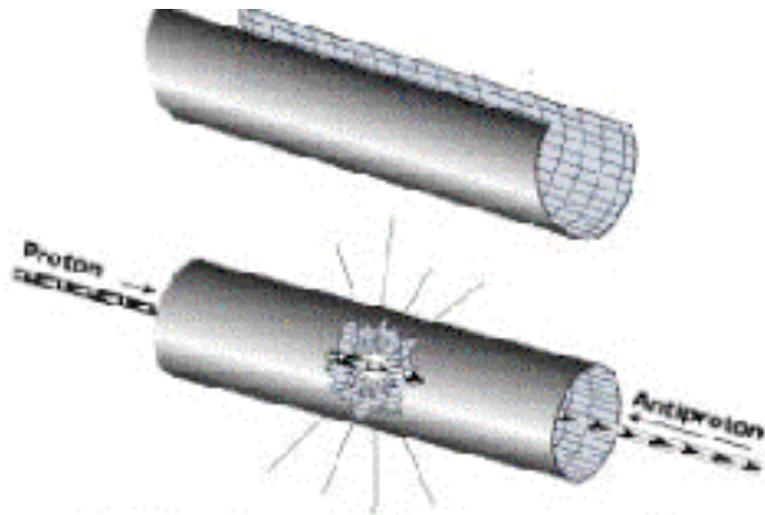
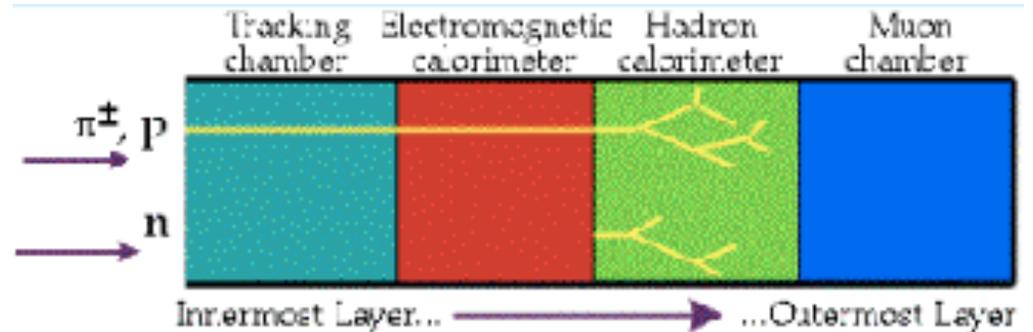
Neutrinos

- Neutrinos rarely interact at all.
 - Since they have no charge, there is no track associated to them.
 - They don't leave energy in the calorimeter
 - They leave the detector undisturbed...
- The presence of the neutrino is inferred by its absence!
- We deduce the presence of neutrinos by calculating the missing energy to the total energy of the event.



Jets

- A quark or gluon flying out of the interaction point will generate lots of hadrons moving in the same general direction: a jet.

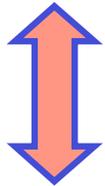


Signatures and Physics Objects



■ Physics Objects

- Tracks
- Jets
- Electron
- Photons
- Neutrinos
- Muons



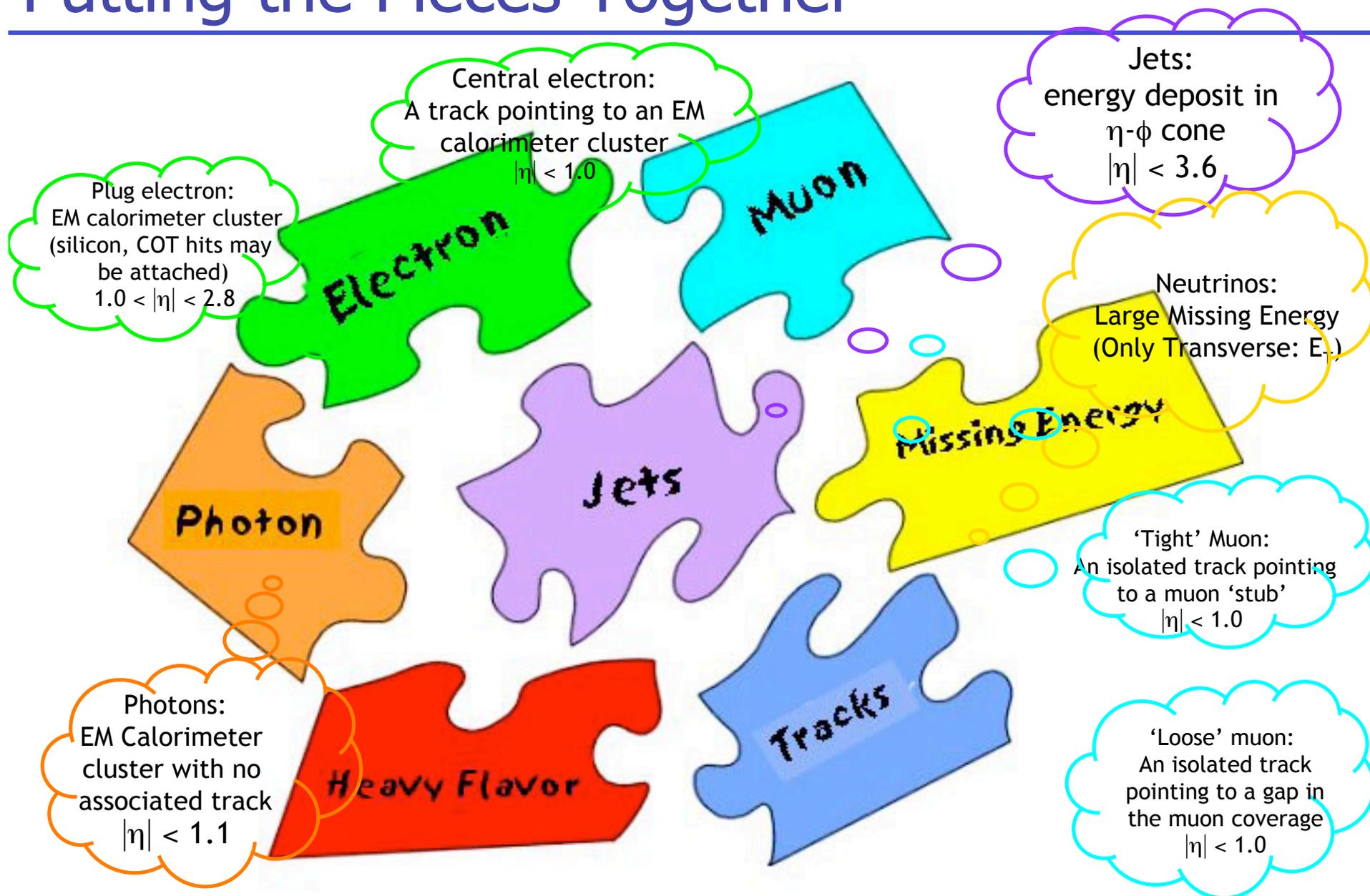
■ Detector Components

- Tracking system
 - COT
 - Silicon detector
- Calorimeters
- Muon Chambers

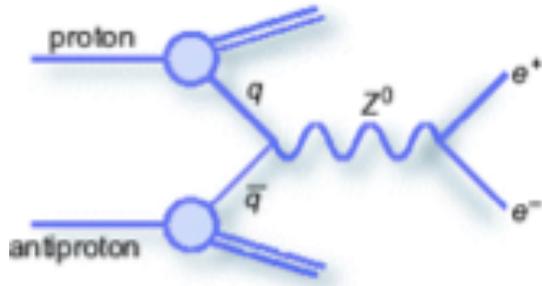
We study physics processes organizing them by their signature

- Leptons-only final states
 - SM and BSM
- ... + Missing Energy and Photons
 - W production
- ... + Jets and heavy flavors
 - Leptoquarks
 - Top quark

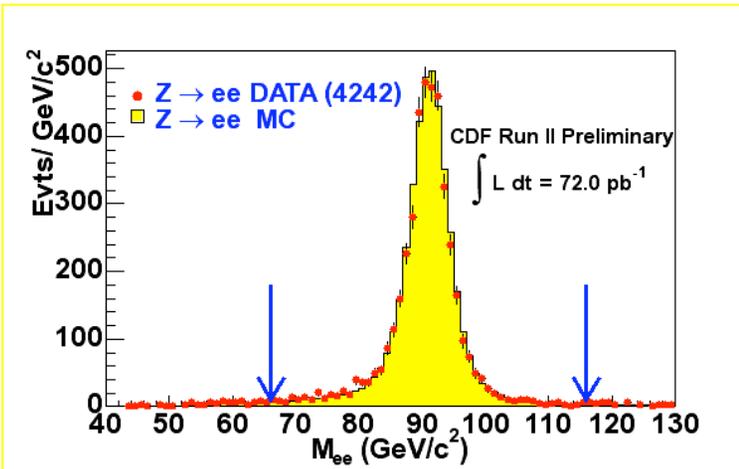
Putting the Pieces Together



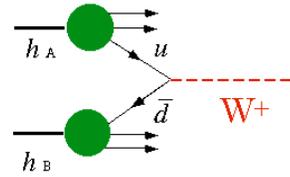
Vector Bosons Production at CDF



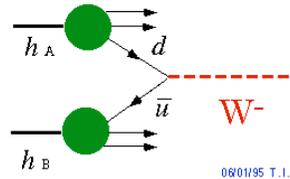
The Standard Candles



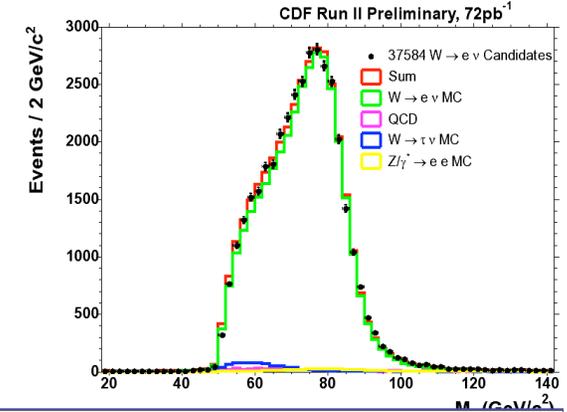
W+ Production



W- Production



Transverse Mass - W to ev



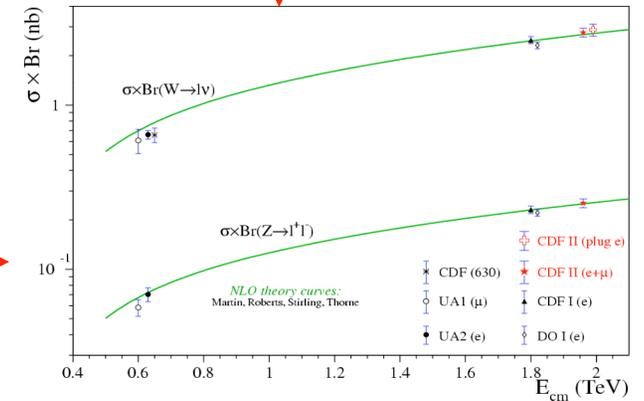
$$\sigma \cdot \text{BR}(p\bar{p} \rightarrow W \rightarrow e\nu) = 2782 \pm 14(\text{stat})_{-56}^{+61}(\text{syst}) \pm 167(\text{lum}) \text{ pb}$$

$$\sigma \cdot \text{BR}(p\bar{p} \rightarrow W \rightarrow \mu\nu) = 2772 \pm 16(\text{stat})_{-60}^{+64}(\text{syst}) \pm 166(\text{lum}) \text{ pb}$$

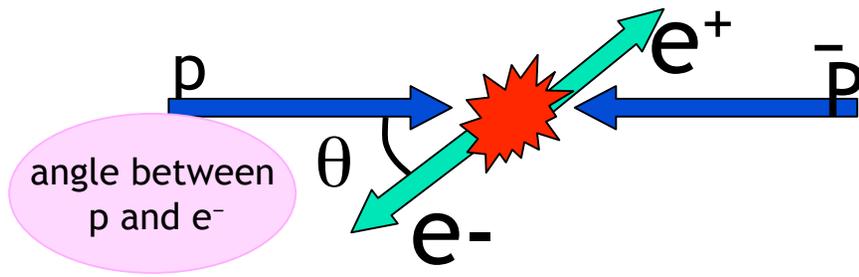
In agreement with previous measurements and theory prediction

$$\sigma \times \text{BR}(Z \rightarrow ee) = 255.2 \pm 3.9(\text{stat}) \pm 5.5(\text{syst}) \pm 15.3(\text{lum}) \text{ pb}$$

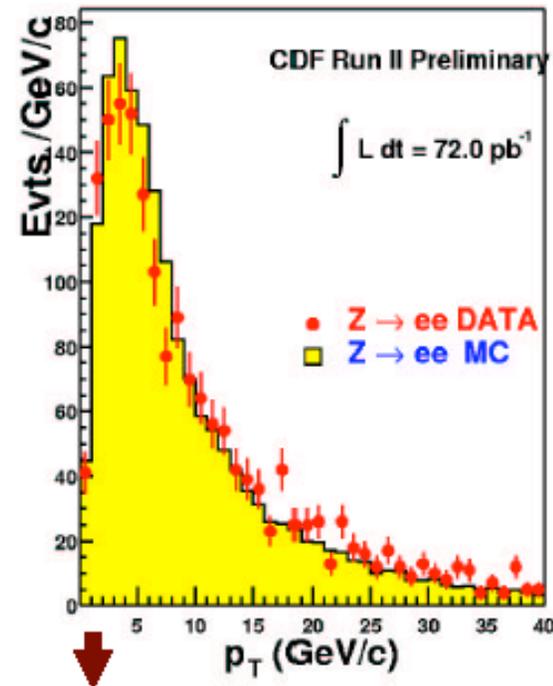
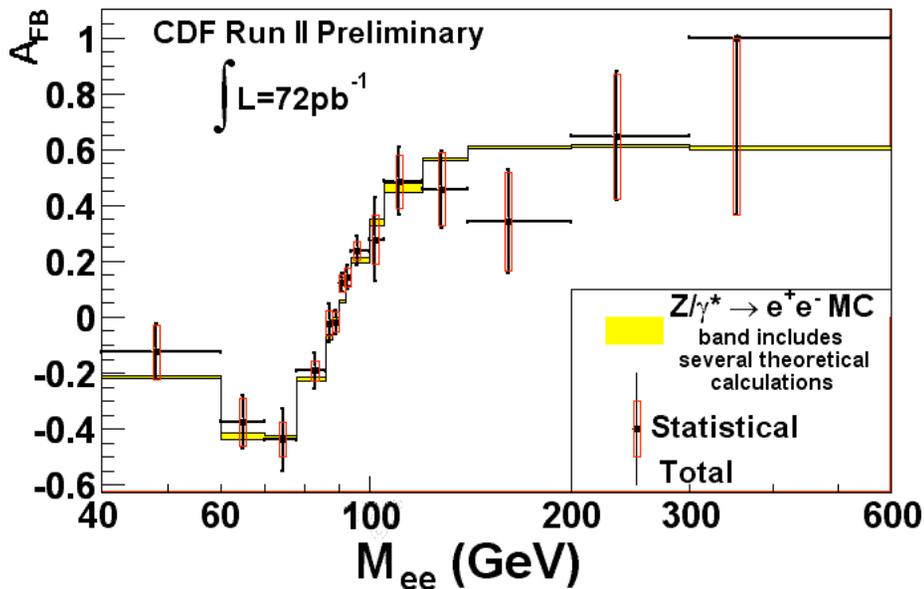
$$\sigma \times \text{BR}(Z \rightarrow \mu\mu) = 248.9 \pm 5.9(\text{stat})_{-6.2}^{+7.0}(\text{syst}) \pm 14.9(\text{lum}) \text{ pb}$$



Drell-Yan Measurements at CDF



$$A_{fb} = \frac{\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)}{\sigma(\cos\theta > 0) + \sigma(\cos\theta < 0)}$$



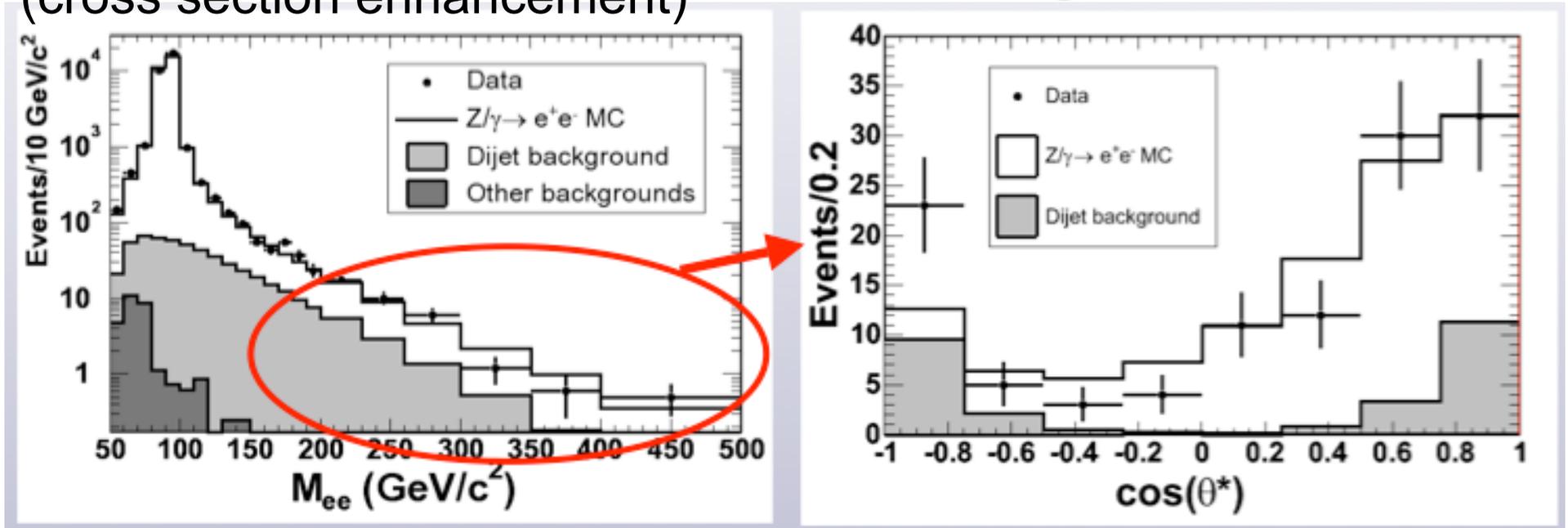
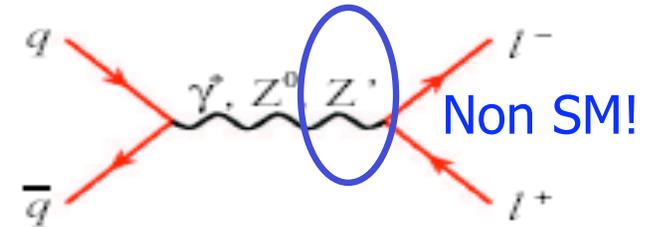
* Production properties : eventually feed into precision measurements (M_W)

* $|\eta^e| < 3.0$: using full detector coverage
 * extract quark, lepton couplings & $\sin^2\theta_w$
 * sensitive to new physics

Searches for BSM using dilepton final states



Anomalous production of Z' could be seen in the dilepton mass and $\cos\theta^*$ distributions (cross section enhancement)



Search for Z' using the $m_{ee} > 200 \text{ GeV}/c^2$ region (448 pb^{-1})

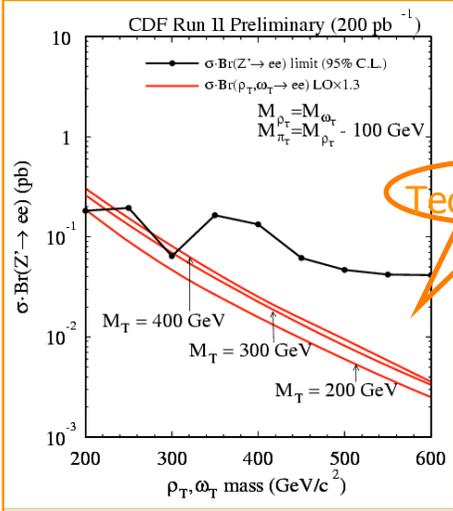
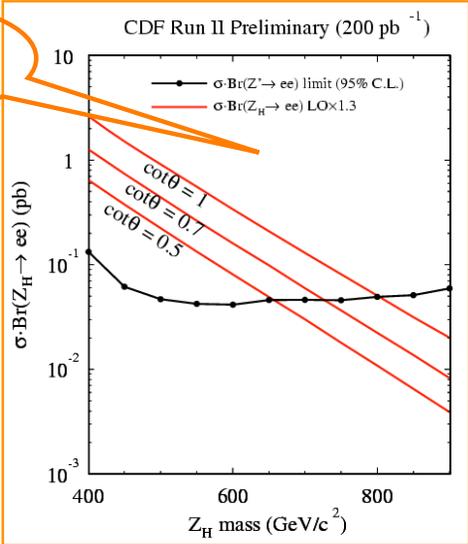
Source	$Z/\gamma^* \rightarrow e^+e^-$	Dijet	Diboson	Total SM	Observed
Events	80.0 ± 8.0	28^{+14}_{-17}	6.8 ± 1.4	115^{+16}_{-19}	120

Searches in dileptons at CDF



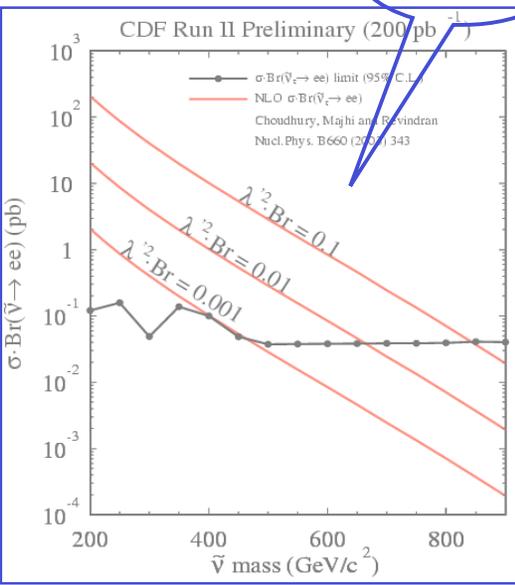
Calculate the acceptances for resonant states for 3 different spin assumption (0,1,2)

Little Higgs

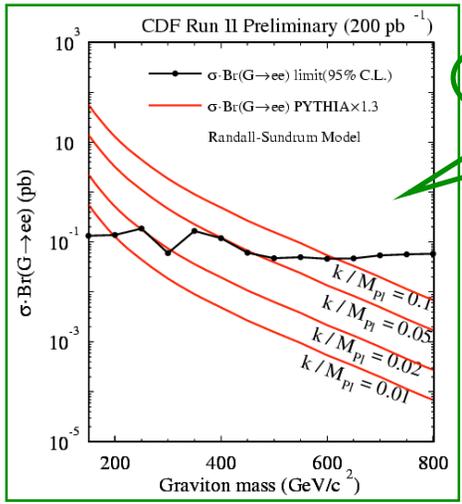


Technicolor

SUSY



Extra-Dimensions



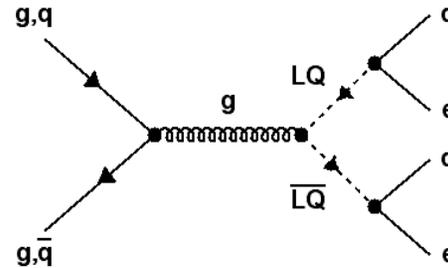
- Randall-Sundrum graviton model
4-dimensional metric multiplied by *warp* factor exponentially changing with the additional dimension
Generating a large hierarchy does not require a large r_c
- The coupling of individual KK states to matter is set by the weak scale (parameters: M_G and k/M_{Pl} [anck])
KK states can be observed as spin 2 resonances

More complex signatures:

Leptoquarks

Leptoquarks (LQ) are hypothetical particles which appear in many SM extensions to explain **symmetry between leptons and quarks**

- SU(5) GUT model
 - superstring-inspired models
 - 'colour' SU(4) Pati-Salam model
 - composite models
 - Technicolor
- They couple to leptons and quarks of the same generation
 - Decay is governed by $\text{Br}(\text{LQ} \rightarrow q\bar{l})$



1 st Generation	2 nd Generation	3 rd Generation
$\text{LQ } \bar{\text{LQ}} \rightarrow e^+ e^- q \bar{q}$	$\text{LQ } \bar{\text{LQ}} \rightarrow \mu^+ \mu^- q \bar{q}$	$\text{LQ } \bar{\text{LQ}} \rightarrow \tau^+ \tau^- q \bar{q}$
$\text{LQ } \bar{\text{LQ}} \rightarrow e^\pm \nu_e q_i \bar{q}_i$	$\text{LQ } \bar{\text{LQ}} \rightarrow \mu^\pm \nu_\mu q_i \bar{q}_i$	$\text{LQ } \bar{\text{LQ}} \rightarrow \tau^\pm \nu_\tau q_i \bar{q}_i$
$\text{LQ } \bar{\text{LQ}} \rightarrow \nu_e \nu_e q \bar{q}$	$\text{LQ } \bar{\text{LQ}} \rightarrow \nu_\mu \nu_\mu q \bar{q}$	$\text{LQ } \bar{\text{LQ}} \rightarrow \nu_\tau \nu_\tau q \bar{q}$

Signature

$$\begin{aligned} \text{LQ LQ} &\rightarrow \text{llqq} \\ \text{LQ LQ} &\rightarrow \text{lvqq} \\ \text{LQ LQ} &\rightarrow \text{vvqq} \end{aligned}$$

2 leptons+2jets
1 lepton+MET+2jets
MET+2jets

$$\begin{aligned} \text{BR} &= \beta^2 \\ \text{BR} &= 2\beta(1-\beta) \\ \text{BR} &= (1-\beta)^2 \end{aligned}$$

Search for Leptoquarks at CDF



Signature: dilepton + jets, lepton + jets + MET, MET + jets

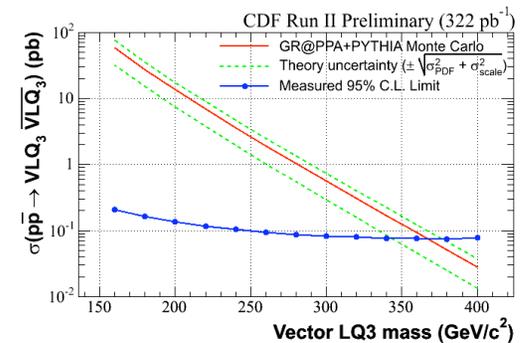
Analysis: counting experiment

A series of cuts is applied in sequence with the goal of reducing the background (W/Z + jets and top) enhancing the signal retention

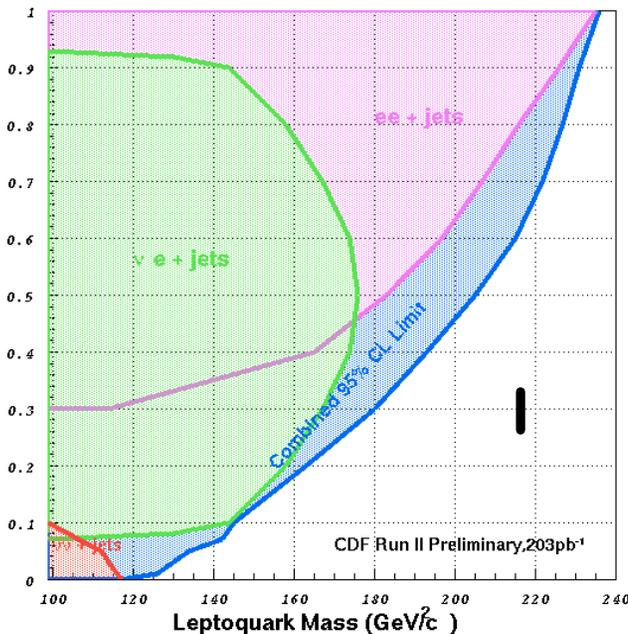
Cuts are optimized to give the maximum S/B

Final number of events are compared with SM expectation

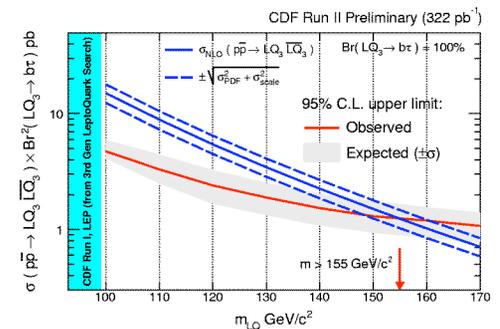
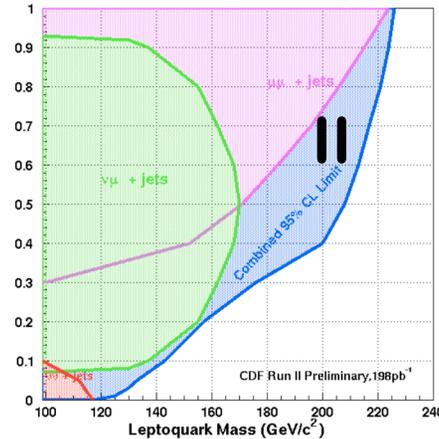
No excess -> limits on production cross section



Search For First Generation Scalar Leptoquarks

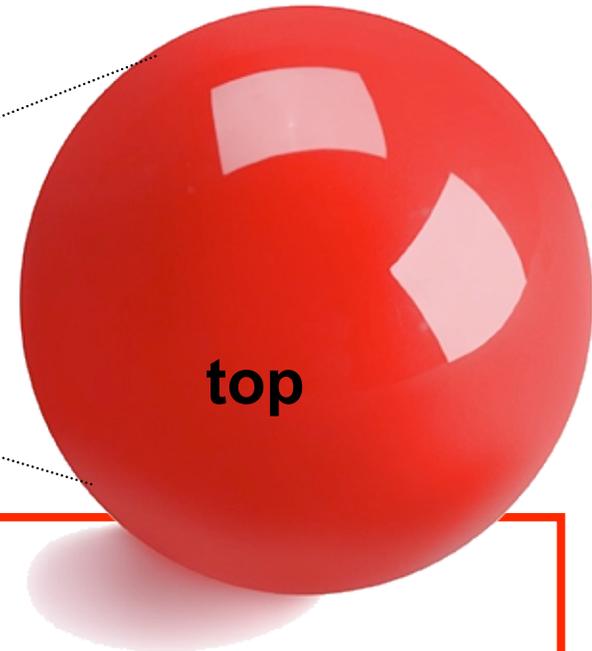
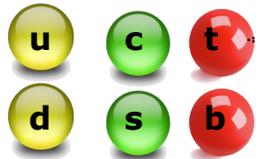


Search For Second Generation Scalar Leptoquarks



More complex signatures: The Top Quark

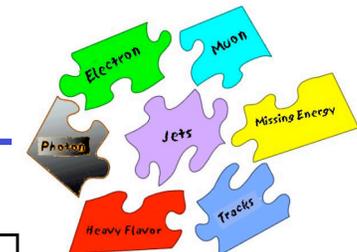
Discovered in 1995 at the TeVatron,
flurry of measurements still ongoing
We still don't know all about it



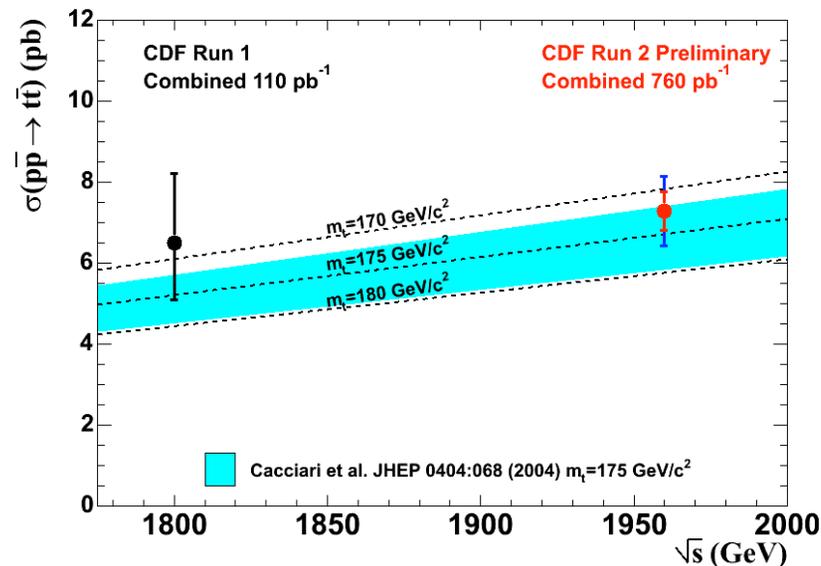
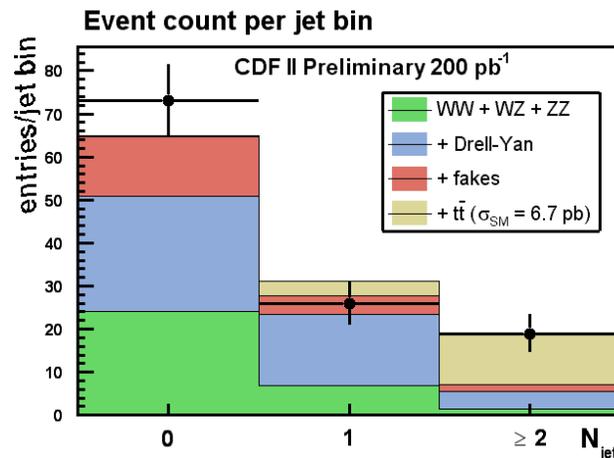
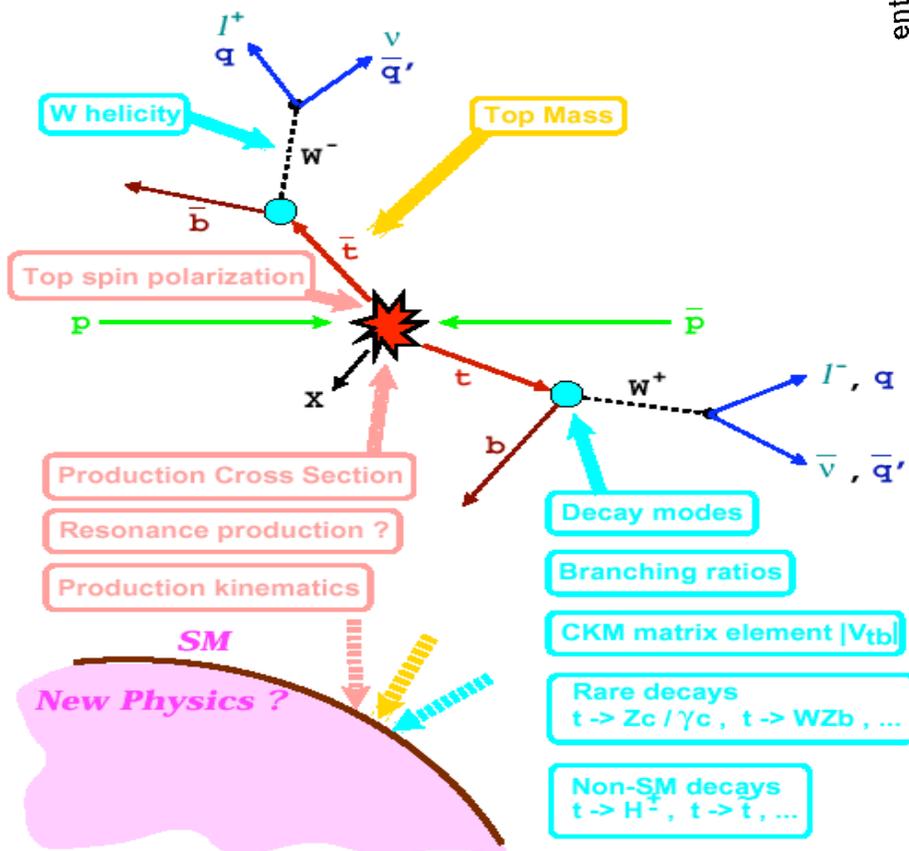
- Mass	Precision <2%
- Top width ~ 1.5 GeV	?
- Electric charge $\frac{2}{3}$	-4/3 excluded @ 94% C.L. (preliminary)
- Spin $\frac{1}{2}$	Not really tested – spin correlations
- BR($t \rightarrow Wb$) $\sim 100\%$	At 20% level in 3 generations case
	FCNC: probed at the 10% level
- Production mechanisms	Single Top : just observed

The LHC will offer opportunity for further testing
and precision measurements

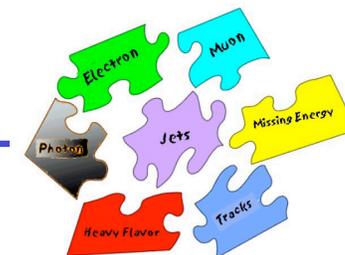
Top Quark at the TeVatron



Complex final state including leptons, missing energy, jets and heavy flavors



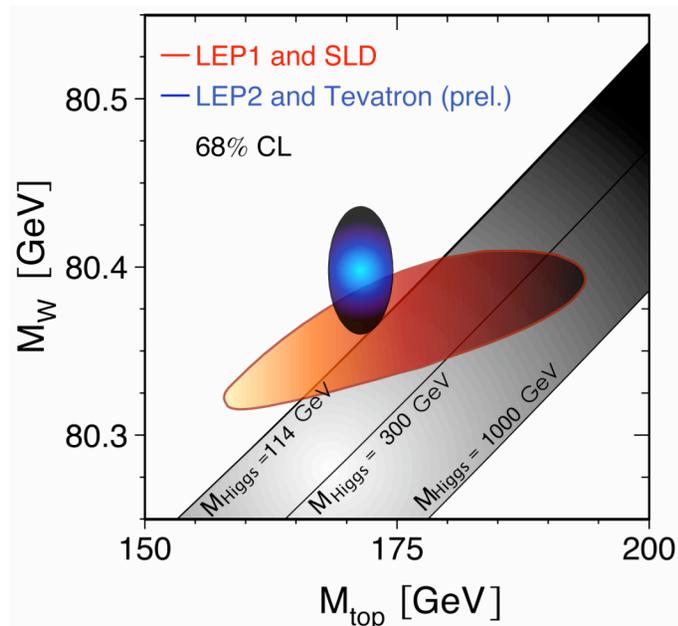
Top Quark at the TeVatron: mass



- The Top Quark Mass is a fundamental parameter of the Standard Model
 - Only fermion with mass near electroweak scale
- Correlated to other SM parameters via electroweak corrections

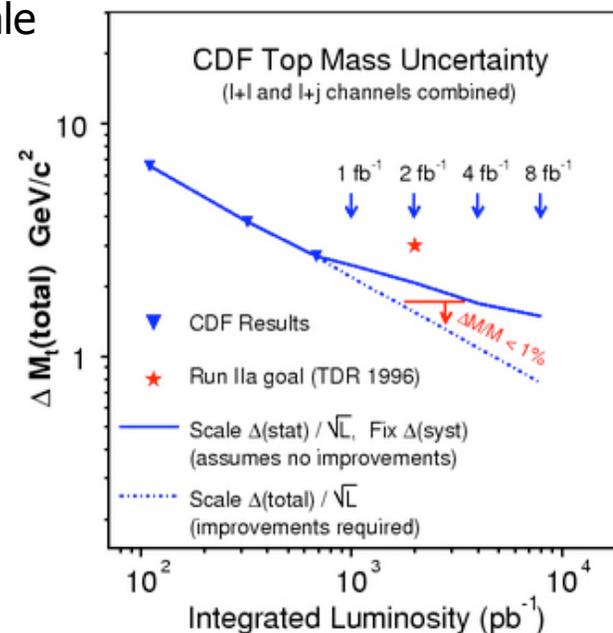
A precise measurement provides stringent SM test

- Constrains the mass of the Higgs Boson



- Its measurement presents various challenges

- Missing neutrinos
- Additional jets from ISR/FSR
- Jet energy scale

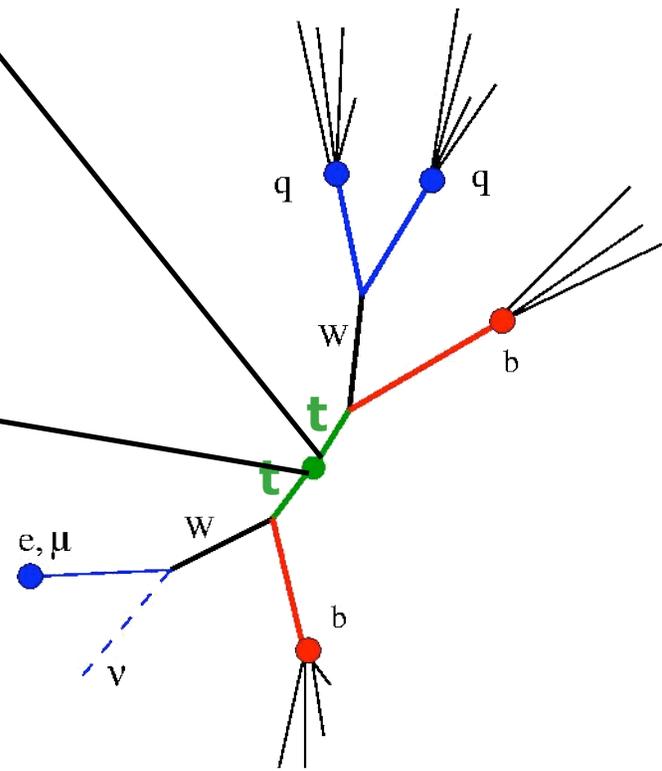
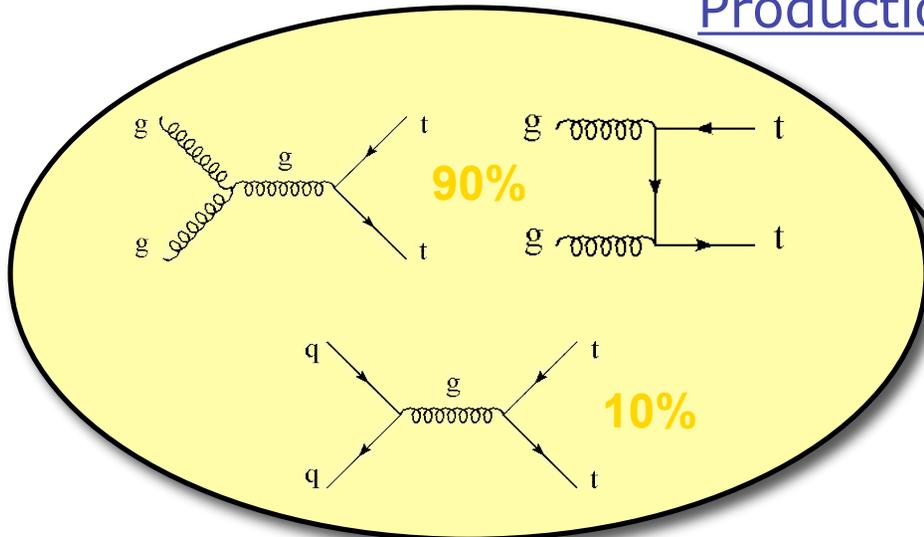


Tevatron July 2006 combination of CDF+D0 Run I+II results:
Top quark mass = 171.4 +/- 2.1 GeV

Top production at the LHC

Production: $\sigma_{tt}(\text{LHC}) \sim 830 \pm 100 \text{ pb}$

Cross section LHC = 100 x Tevatron
Background LHC = 10 x Tevatron



Decay

$c\bar{s}$	lepton + jets	tau + jets	all hadronic		
$u\bar{d}$					
τ	$\tau e/\tau \mu$	$\tau \tau$		tau + jets	
μ	dilepton	$\tau e/\tau \mu$	lepton + jets		
e					
	e^+	μ^+	τ^+	$u\bar{d}$	$c\bar{s}$

*L+jets (l=e,μ) is the Golden channel
→ 2.5 million events/year*

Top quark physics **with** b-tag at ATLAS

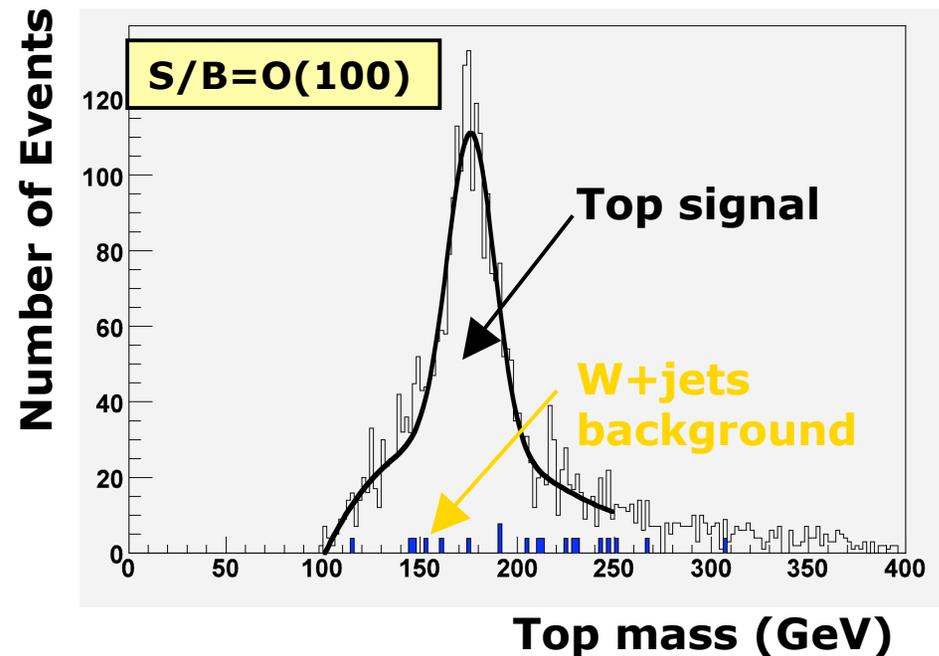
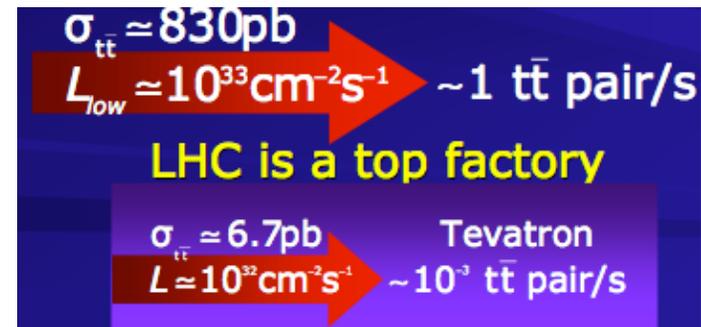


LHC is a top factory \rightarrow Seeing top is easy

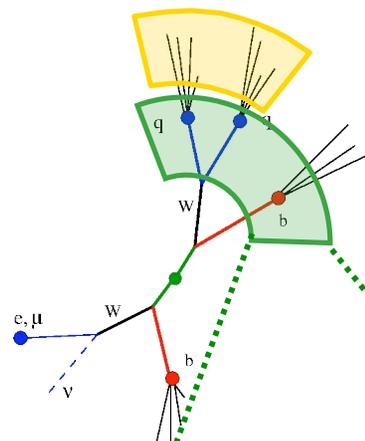
Selection: High P_T Lepton
 Large Missing E_T
 4 high- P_T jets (2 b-jets)

\rightarrow signal efficiency few %
 \rightarrow very small SM background

- 'Standard' Top physics at the LHC:
 - b-tag is important in selection
 - Most measurements limited by systematic uncertainties
- 'Early' top physics at the LHC:
 - Cross-section measurement ($\sim 20\%$)
 - Decay properties



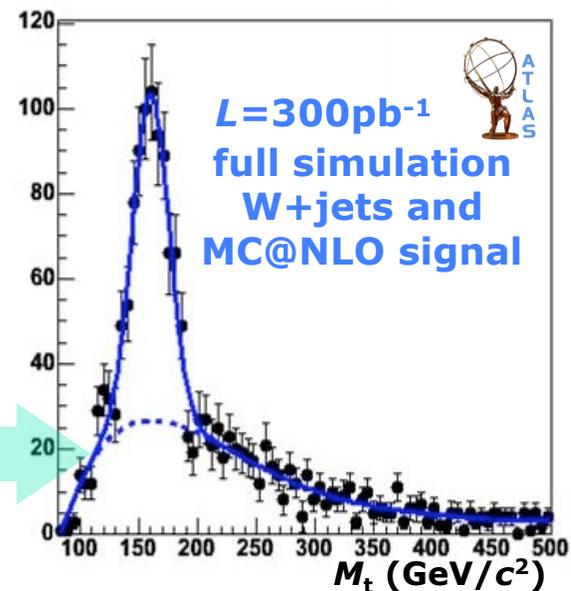
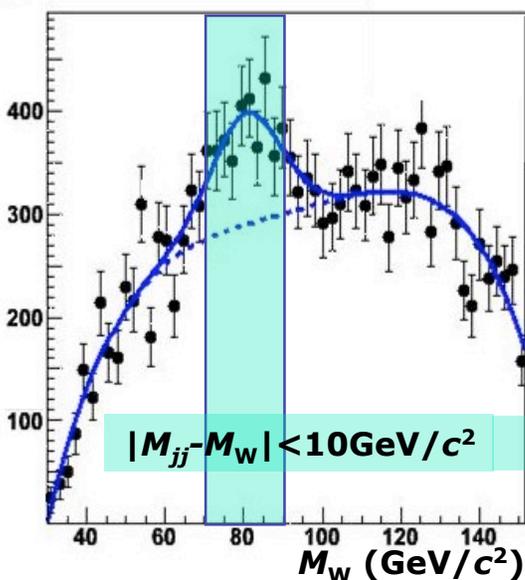
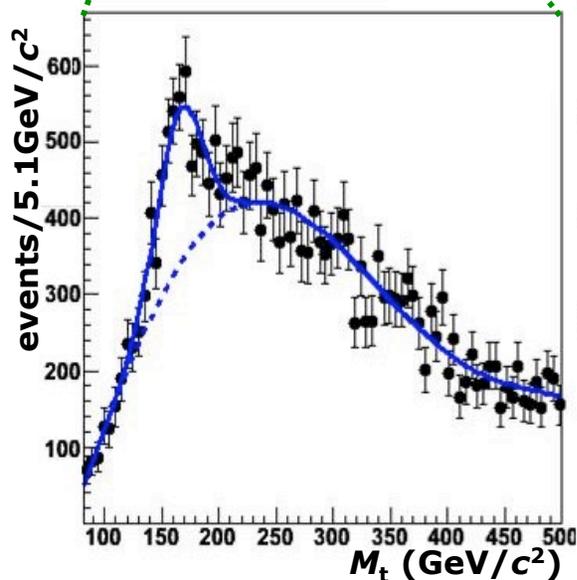
Top quark physics **without** b-tag (early phase)



Selection

- semileptonic top: $p_T(\text{lepton}) > 20 \text{ GeV}/c$, missing $E_T > 20 \text{ GeV}$
 - no b-tagging required
- hadronic top: $N_{jet} > 4$, $p_T(\text{jet}) > 40 \text{ GeV}/c$ (0.4 cone algorithm)
- 3 jets with highest vector-sum p_T identified as top
 - of these, 2 leading jets in 3-jet rest frame identified as W

A top peak can be seen without b-tag requirement



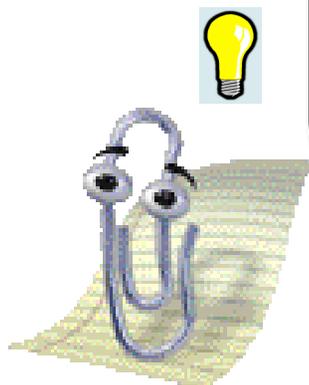
Top quark pair production as calibration tool

You can use production of top quark pairs to help calibrate LHC detectors in complex event-topologies

Yes

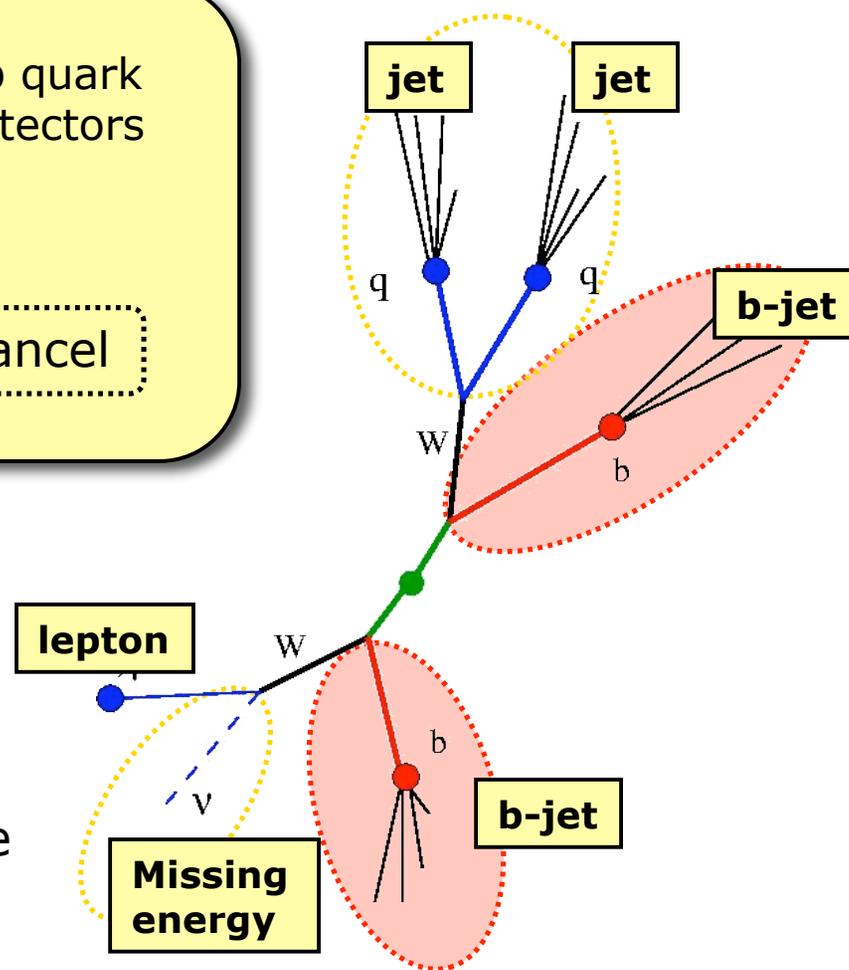
No

Cancel



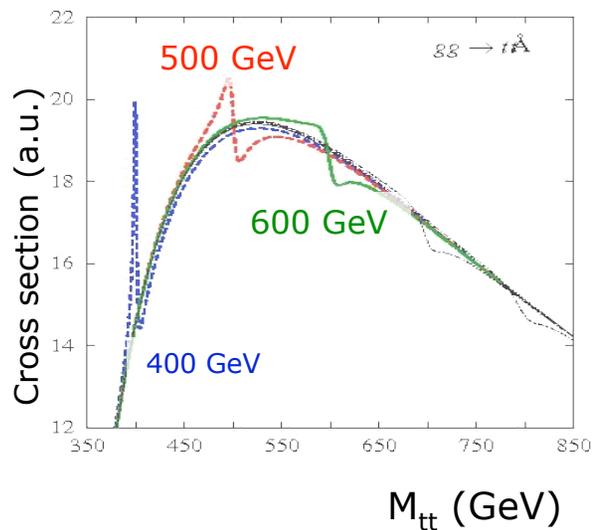
→ A candle for complex topologies:

- Calibrate light jet energy scale
- Calibrate missing E_T
- Obtain enriched b-jet sample
- Leptons and trigger



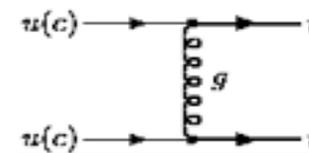
*Note candles: 2 W-bosons
2 top quarks*

A window to new physics ?

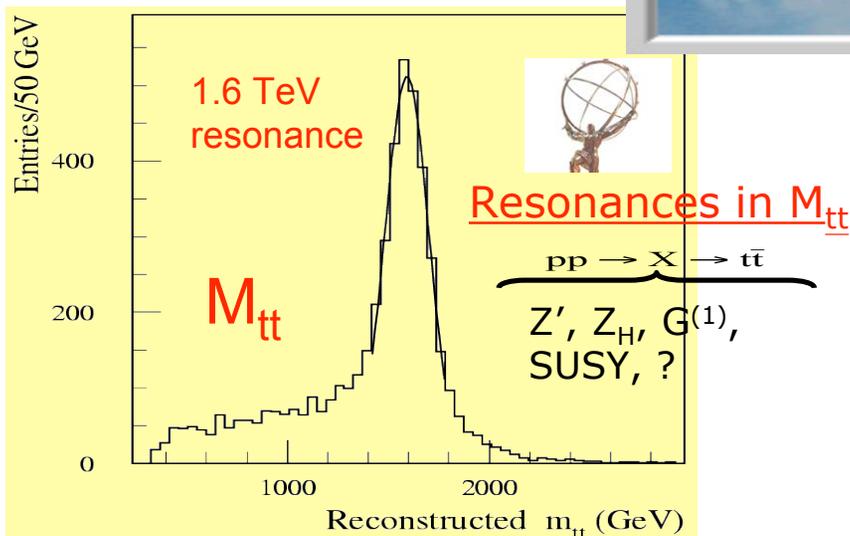


Structure in M_{tt}

Interference from MSSM Higgses H,A
 $\rightarrow tt$ (can be up to 6-7% effect)



Like-sign tt ?



FCNC decays: GIM suppressed in SM, can be enhanced in SM extensions

q=u,c	t \rightarrow Zq	t \rightarrow γ q	t \rightarrow gq
BR(L=10fb $^{-1}$)	3.4 \cdot 10 $^{-4}$	6.6 \cdot 10 $^{-5}$	1.4 \cdot 10 $^{-3}$
BR(L=100fb $^{-1}$)	6.5 \cdot 10 $^{-5}$	1.8 \cdot 10 $^{-5}$	4.3 \cdot 10 $^{-4}$

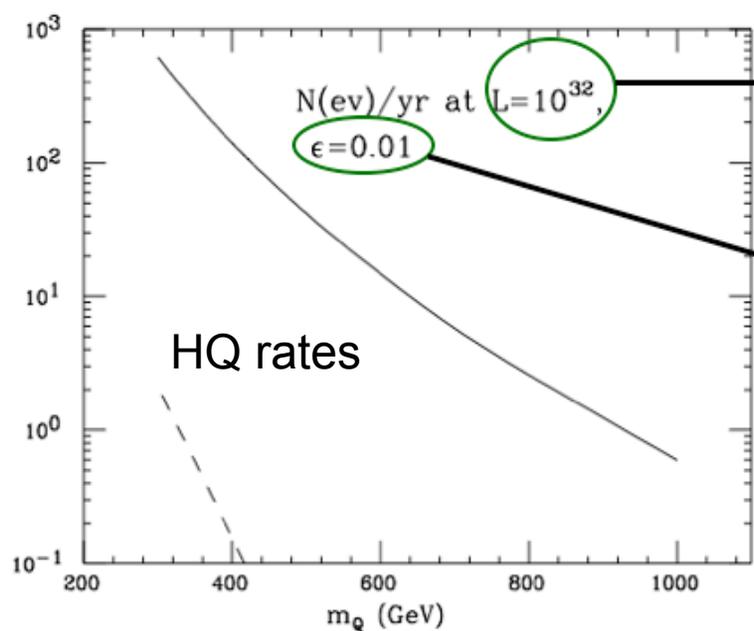
Toward the LHC

What to expect at the beginning?

At the start of LHC, the situation will resemble much more that at the beginning of UA1/UA2:

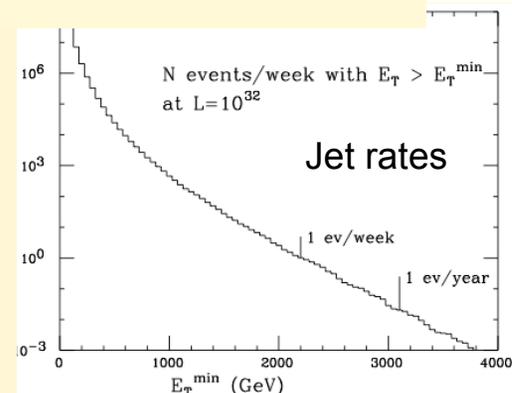
The phase-space for the Tevatron will have totally saturated the search boundary for most phenomena, at a level well below the LHC initial reach: seen from the LHC, the Tevatron will look like the ISR as seen from the SppS!

Rates 10^3 times larger in the region of asymptotic Tevatron reach



1% of L_{\max} for the LHC, (as in SppS and Tevatron early runs), close to L_{\max} for Tevatron

(assume a 1% signal efficiency)



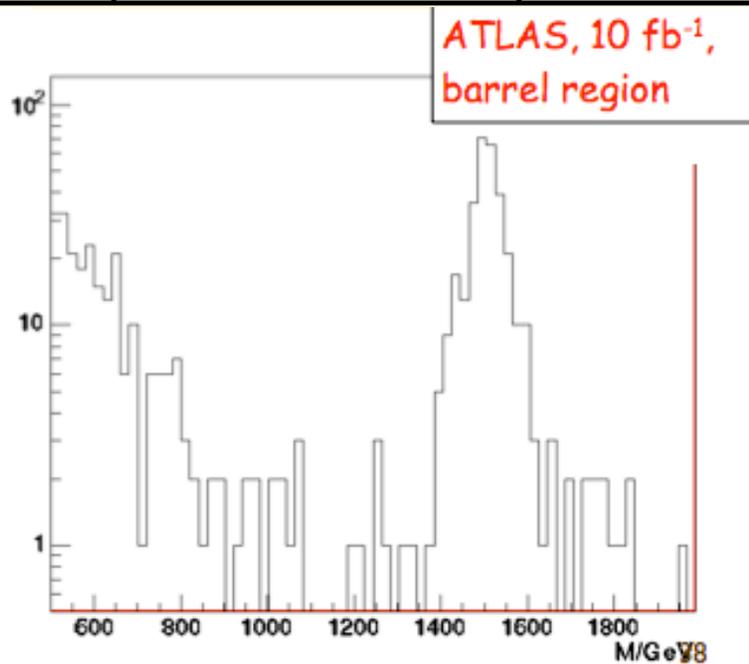
Examples of possible early discoveries

- An easy case : a new resonance decaying into e^+e^- , e.g. a Z' $\rightarrow ee$ of mass 1-2 TeV
- An intermediate case : SUSY
- A more difficult case : a light Higgs ($m \sim 115$ GeV)

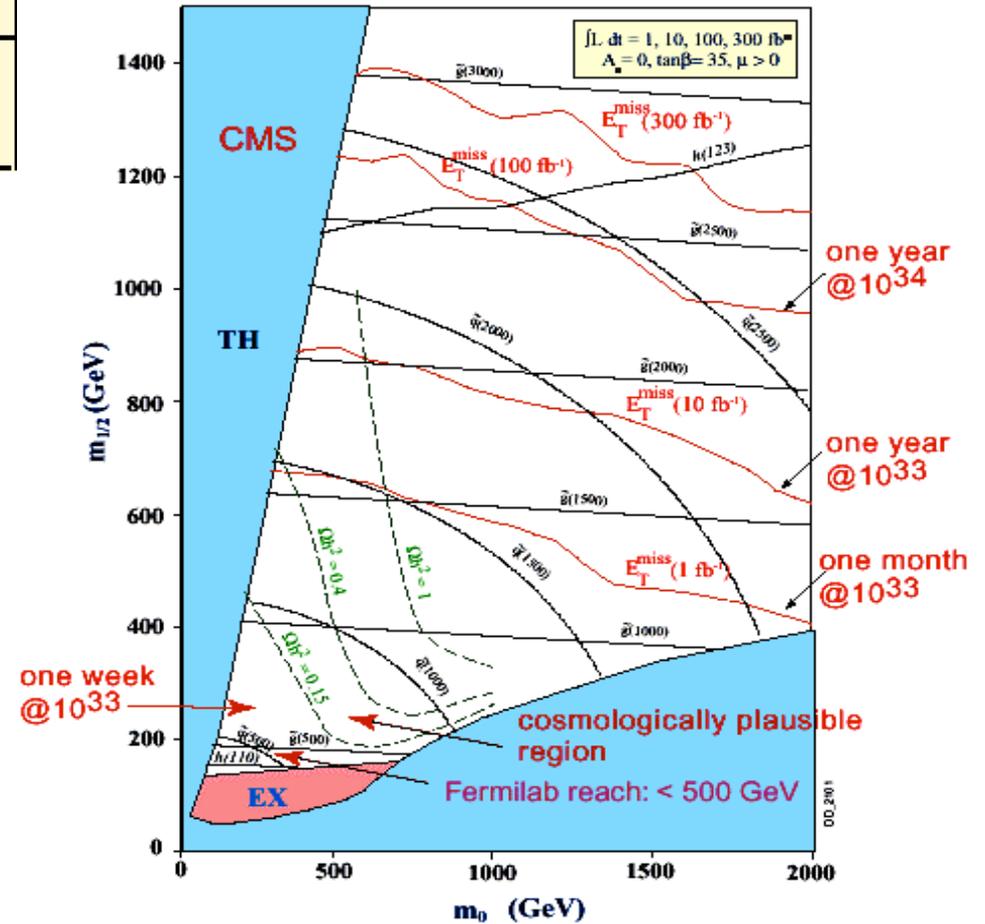
LHC: early discoveries?

$$Z' \rightarrow ee$$

Mass	Expected events for 10 fb ⁻¹ (after all cuts)	$\int L dt$ needed for discovery (corresponds to 10 observed evts)
1 TeV	~ 1600	~ 70 pb ⁻¹
1.5 TeV	~ 300	~ 300 pb ⁻¹
2 TeV	~ 70	~ 1.5 fb ⁻¹

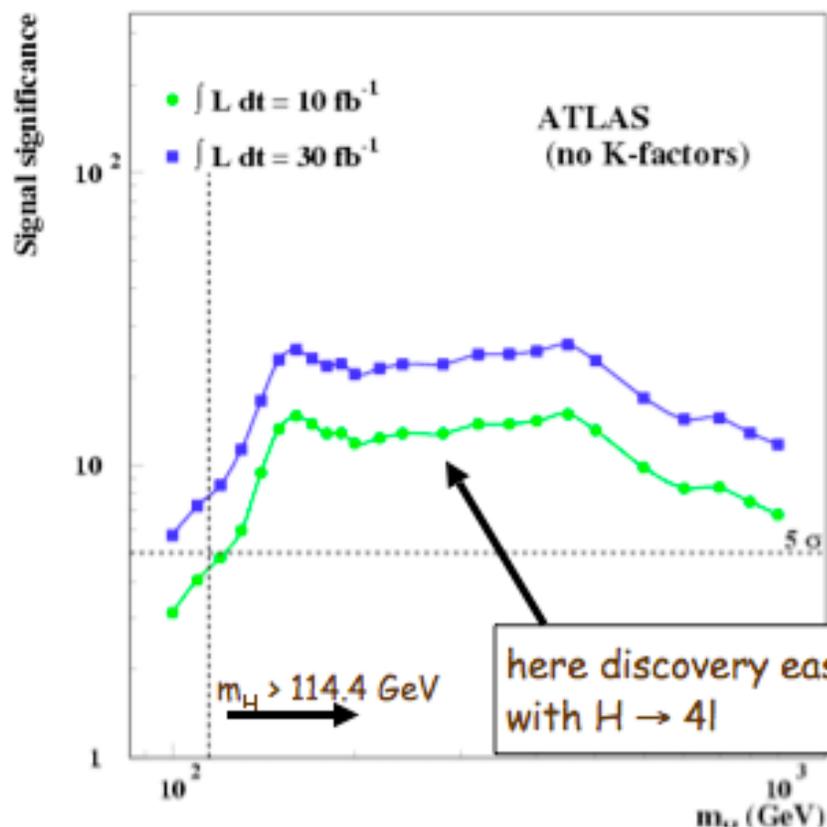


SUSY



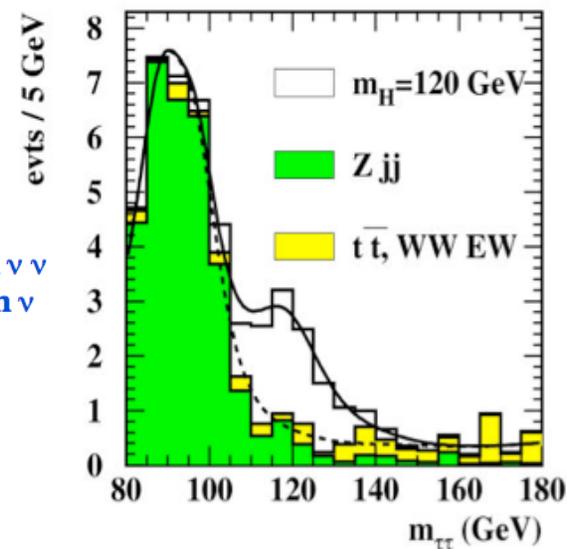
LHC: Higgs?

Higgs (115-130 GeV)



	$H \rightarrow \gamma\gamma$	$qqH \rightarrow qq\tau\tau$ ($ll+l$ -had)	$H \rightarrow 4\ell$	$qqH \rightarrow qqWW$
S	120	~ 8	~ 5	18
B	2500	~ 6	< 1	15
S/B	0.05		~ 5	~ 1
Sig.	2.4	~ 2.7	3.2	3.9

$qqH \rightarrow qq\tau\tau$
 $\rightarrow qq l\nu\nu l\nu\nu$
 $\rightarrow qq l\nu\nu h\nu$



Total S/\sqrt{B} for 10 fb^{-1} and complete detector: $\sim 6.5 \sigma$

Conclusions

Hadron Collider Physics is now more exciting than ever!

From the pioneer days of the SppS we have moved to the TeVatron , where we can make precision measurements for various processes.

Many of the results interplay nicely :
from testing the SM to searches for Exotica
... same signature, different physics

The LHC is about to start with great expectations.....



Stay Tuned!



ATLAS explores...

where quarks and gluons collide...

where forces unify...

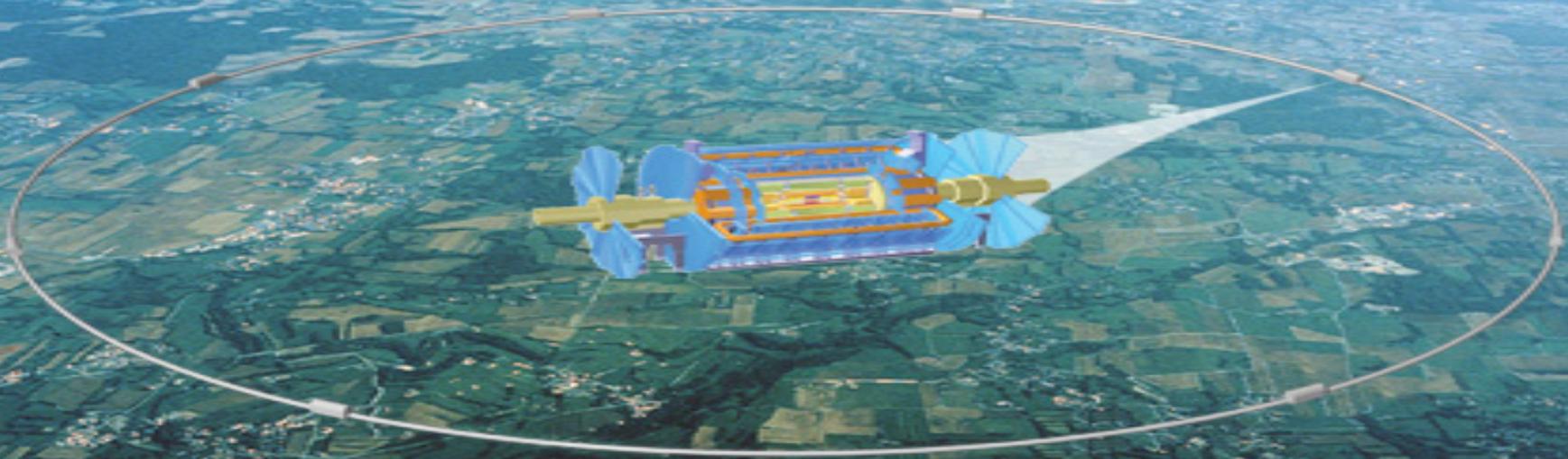
where extra dimensions may lurk...

where dark matter reigns...

to find the truly fundamental.

the ATLAS Experiment

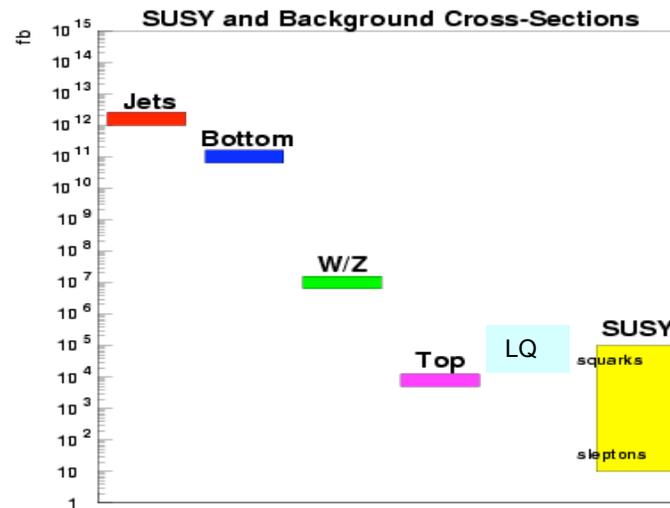
CERN Geneva, Switzerland



ATLAS is a particle physics experiment conducted by 34 nations at the CERN Laboratory in Geneva, Switzerland. It will explore the fundamental nature of matter and the basic forces that shape our universe. This poster is available from CERN. The ATLAS statue image is courtesy of NYCTourist.com

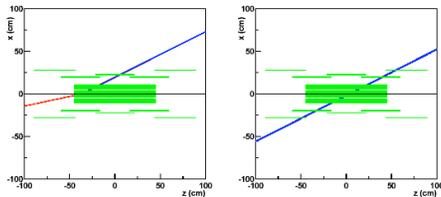
Backup Slides

Physics Processes Relative Cross Sections



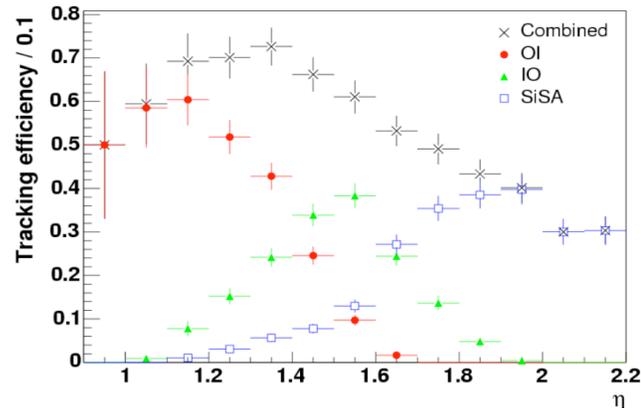
Efficiency and Acceptance

- Detectors are not perfect
 - hermetic
 - Components failure
 - Over time degradation
- Geometric acceptance
 - Less than 4π coverage
 - Certain components only extend up to certain angles
 - Silicon tracking



$$\eta = -\ln\left[\tan\left(\frac{1}{2}\theta\right)\right]$$

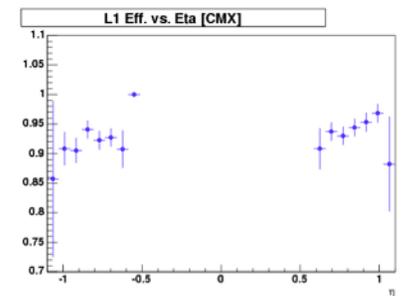
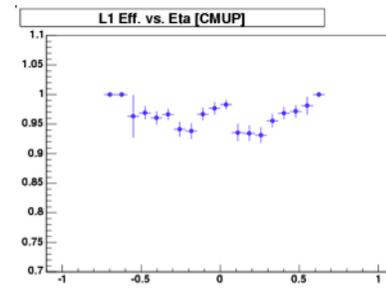
Tracking Efficiency



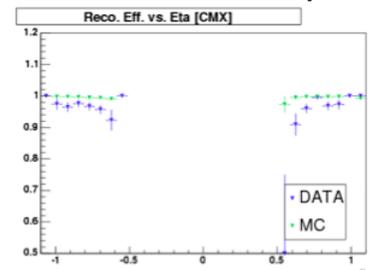
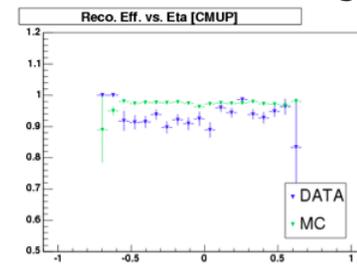
- Detection Efficiency
 - Trigger
 - Reconstruction
 - Identification



$$\mathcal{R} = \sigma \times \mathcal{L} \times \varepsilon$$



Muon Trigger and Reco Efficiency



TeVatron Top Mass, March 2007

