The latest and greatest in High Energy Physics

Presented to
SMU QuarkNet Workshop
by
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References

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4. http://webcast.cern.ch/home/pages/archive_cds.php
5. http://www.fcp01.vanderbilt.edu/schedules/neutrinos.html
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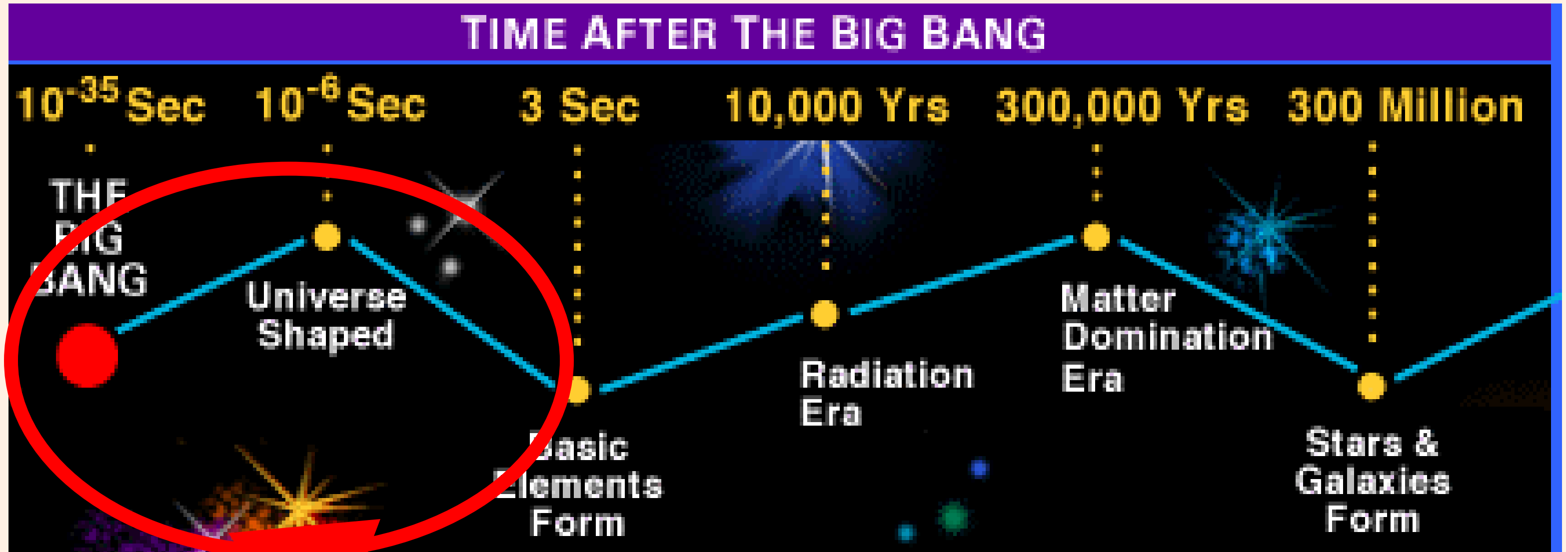
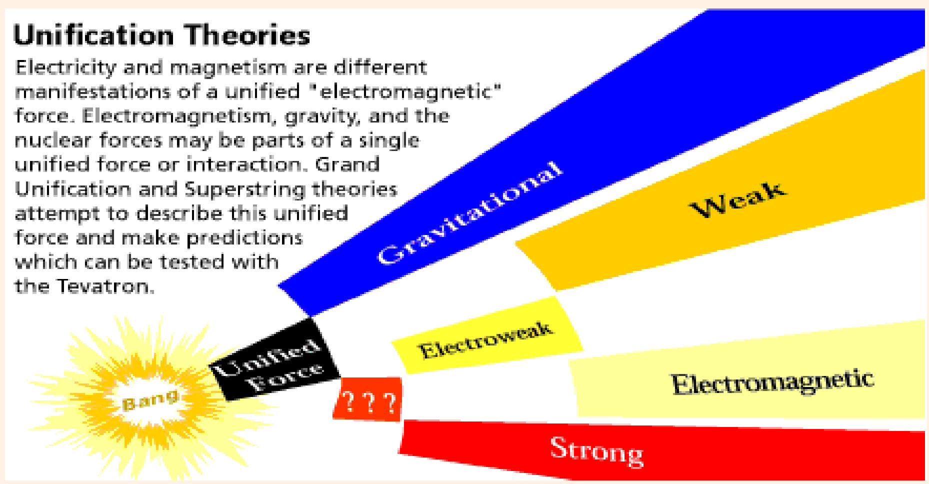
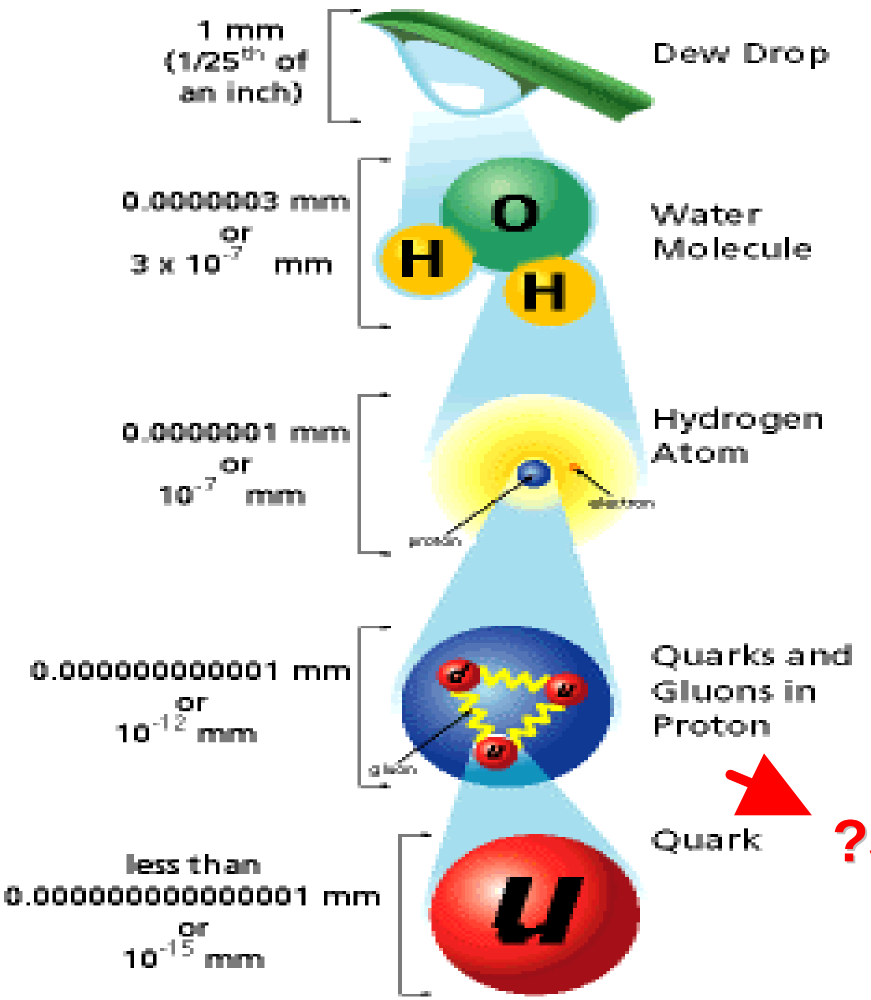
8. http://www.bnl.gov/RHIC/heavy_ion.html


TIME AFTER THE BIG BANG
10-35 Sec
10-6 Sec
3 Sec
10,000 Yrs
300,000 Yrs
300 Million
THE BIG BANG
Universe Shaped
Basic Elements Form
Radiation Era
Matter Domination Era
Stars & Galaxies Form


Unification Theories
Electricity and magnetism are different manifestations of a unified "electromagnetic" force. Electromagnetism, gravity, and the nuclear forces may be parts of a single unified force or interaction. Grand Unification and Superstring theories attempt to describe this unified force and make predictions which can be tested with the Tevatron.
Gravitational
Weak
Electroweak
Electromagnetic
Strong
Unified Force
???
Bang

A long way down...



- High Energy Physics is concerned with the lowest level (most fundamental) aspects of Nature
- Main goal is to find the underlying theory from which all observed physical phenomena follows (at least in principle)

?Supersymmetry

...

?Superstrings (1.6x10^{-32} mm)

Standard Model of elementary particles

- **Fermions (matter)**
- **Bosons (forces)**
- **Almost all particles observed**
  - **t quark in 1995 (m_t=175GeV)**
  - **n_τ** neutrino in 1999
- **Higgs particle**
  - **electroweak symmetry breaking**
  - **m_h>114 GeV @ 95% CL**

Physical laws & symmetries

Symmetry (Greek)= same measure

Any physics law can be expressed as a particular symmetry (= independence from certain parameters)

Example:
Conservation of energy follows from the independence of physical laws from time (symmetry with respect to translations in time)

High Energy Physics tries to explain the most fundamental symmetries of nature

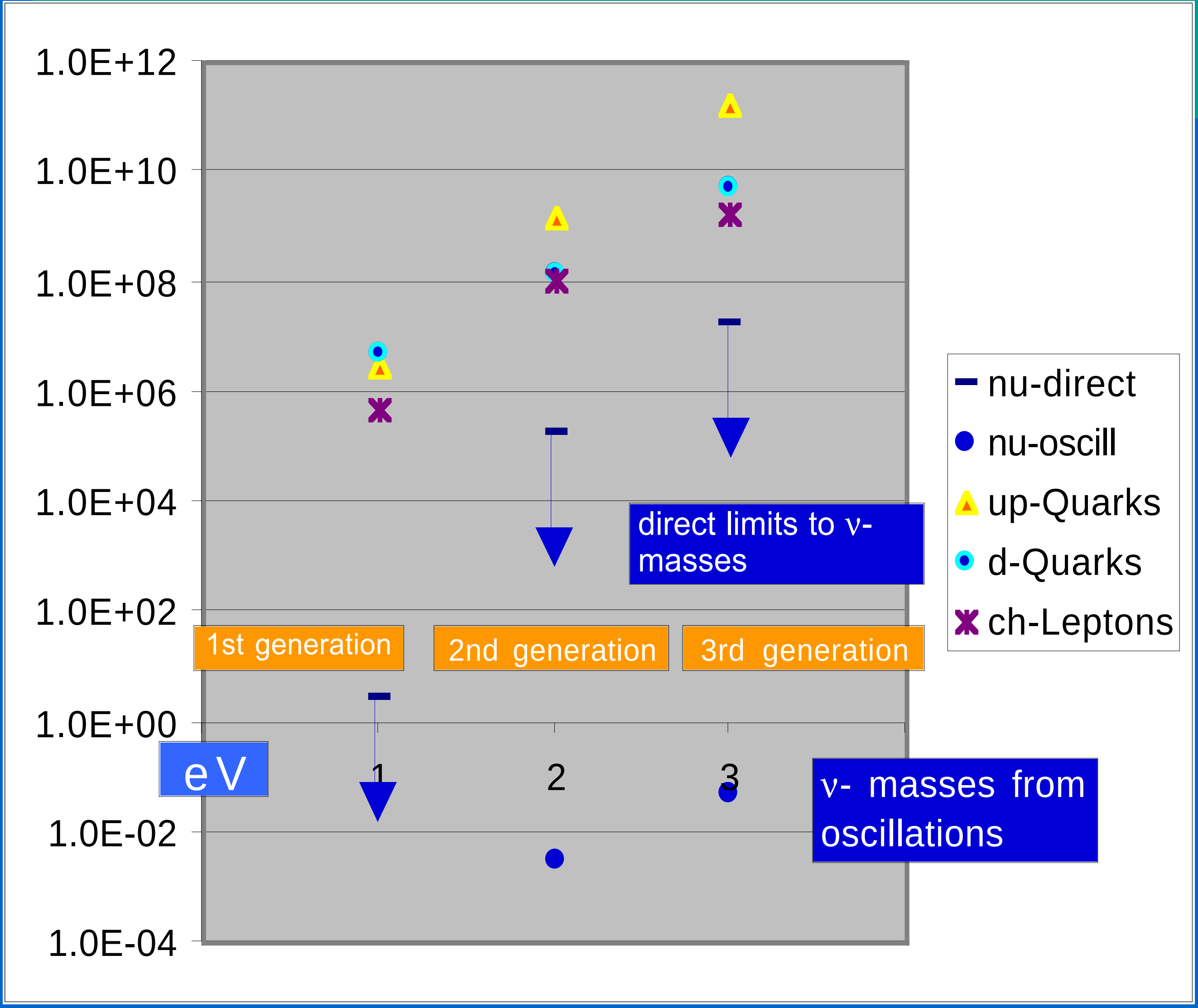
The hard part is to explain how symmetries break

Symmetry= Ability to predict

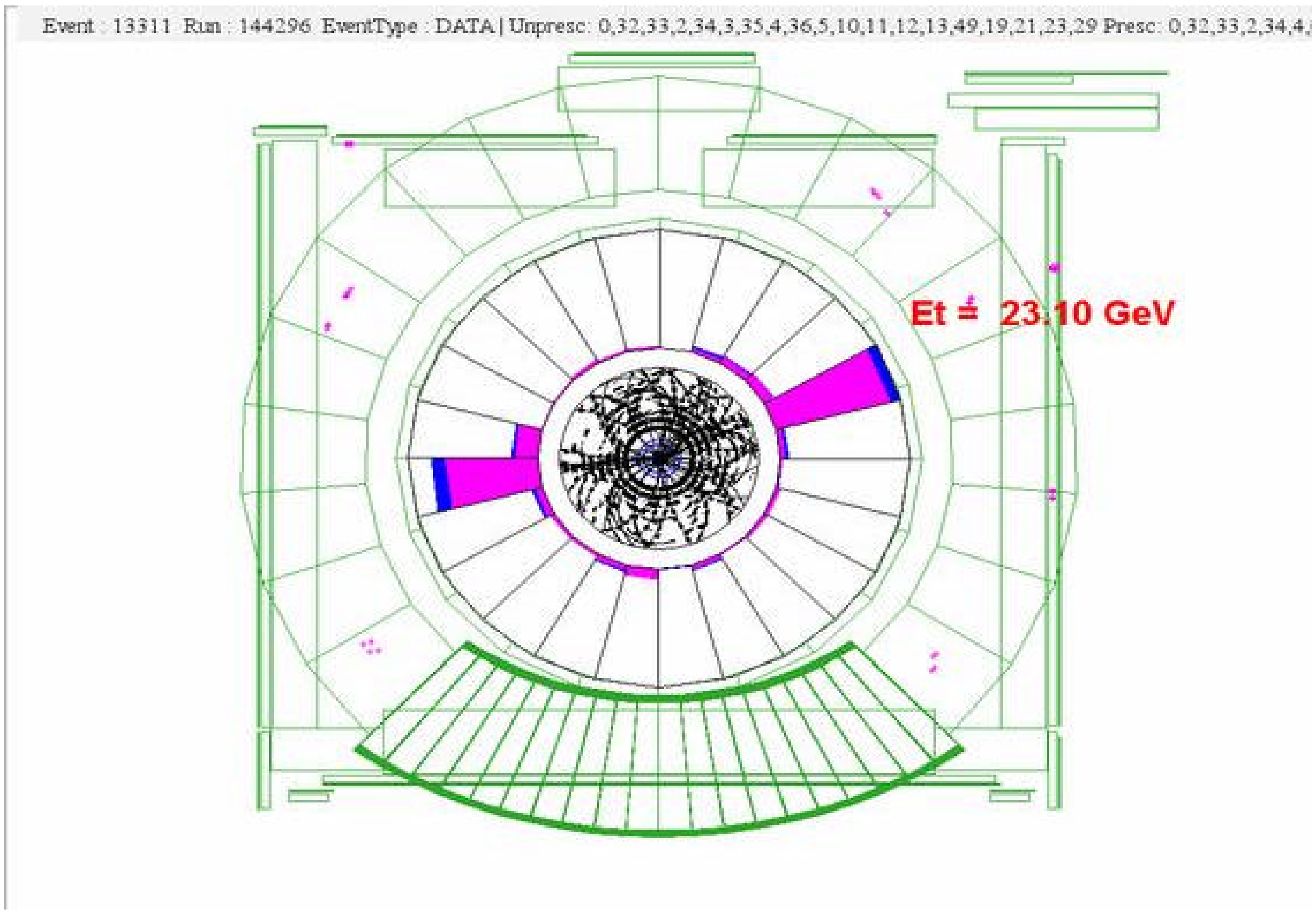
In the real picture, Symmetry is wonderfully broken

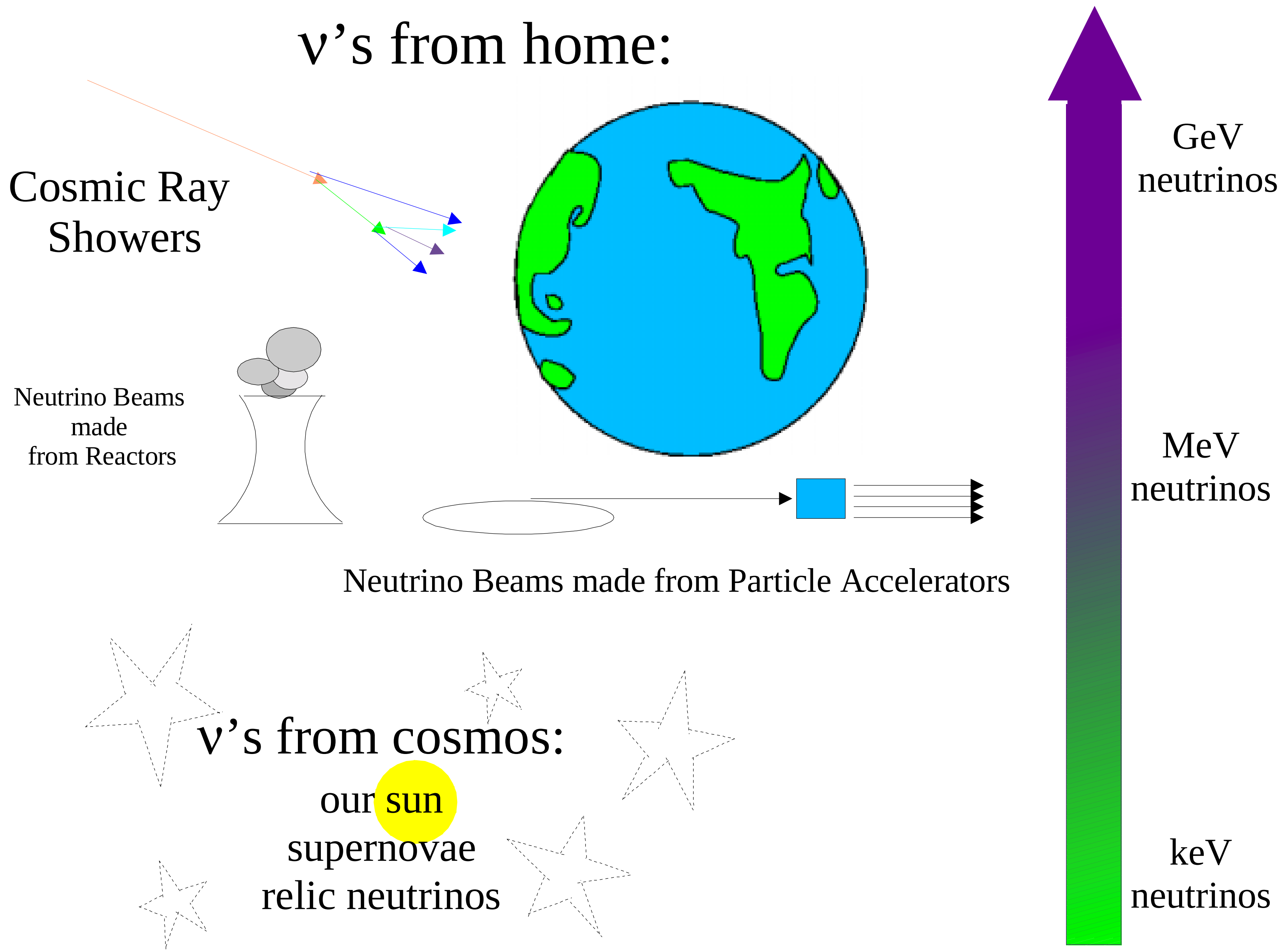
Piero della Francesca: Polittico della Misericordia

The spectrum of elementary constituents



Evidence for Massive Neutrinos




ν's from home:
Cosmic Ray
Showers
Neutrino Beams
made
from Reactors
Neutrino Beams made from Particle Accelerators
ν's from cosmos:
our sun
supernovae
relic neutrinos
GeV
neutrinos
MeV
neutrinos
keV
neutrinos

What makes neutrinos so interesting, anyway?

Neutrino **mass** has big implications for the Standard Model

- MNS matrix$\rightarrow$ not diagonal dominant
- CP and CPT violation
- sterile neutrinos
  - do not interact weakly −− mix with standard ν's

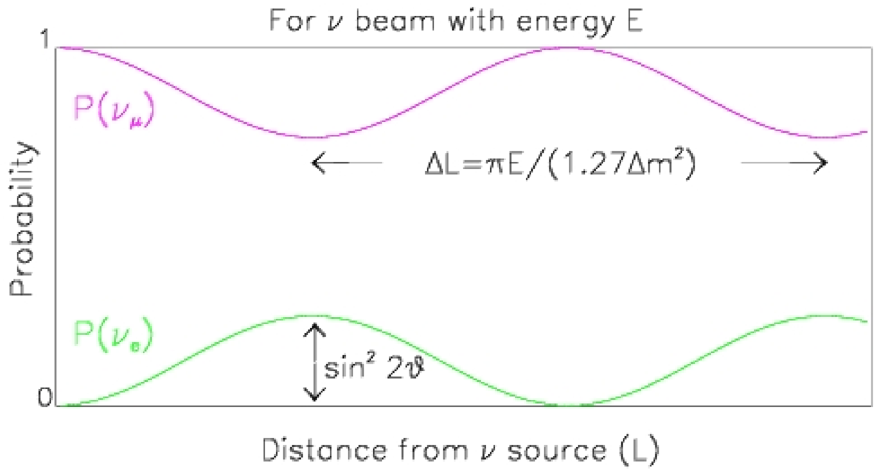
................and big implications for the universe

- supernovae neutrino bursts
- structure formation of galaxies(HDM)
- leptogenesis $\rightarrow$ baryon asymmetry

Neutrino **properties**: new interactions, magnetic moments, etc.

$\longrightarrow$ which beyond−the−Standard Model theory?

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta \sin^2(1.27\Delta m^2 L/E)$$

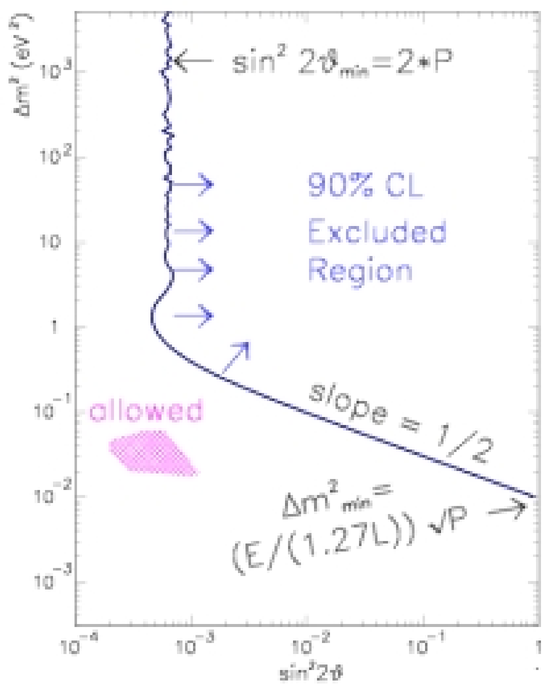


ν_μ disappearance

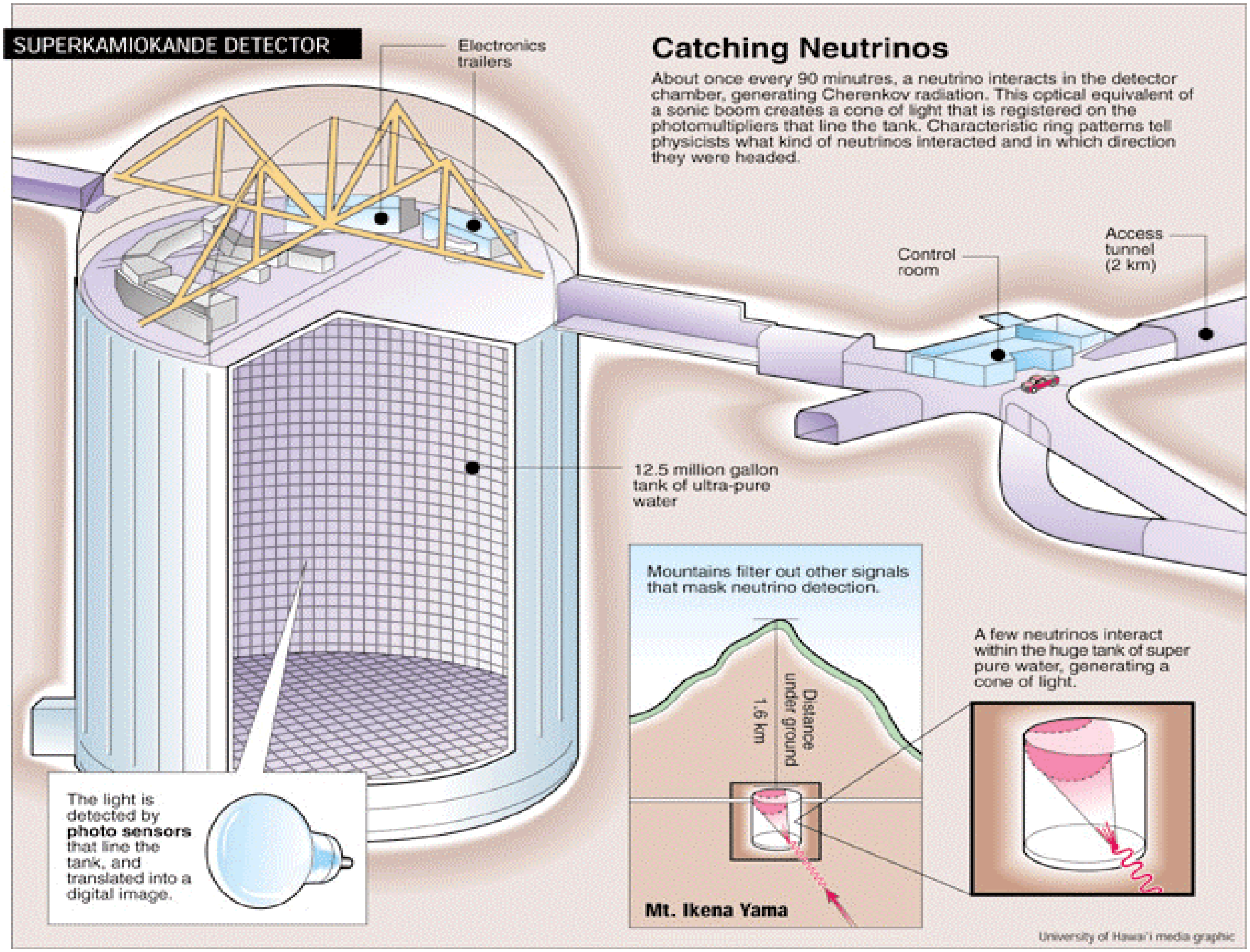
ν_e appearance

Oscillation Probability depends on:

- Two fundamental parameters
  - Δm^2
  - $\sin^2 2\theta$
- Two experimental parameters
  - L: distance from neutrino source to detector
  - E: Neutrino energy

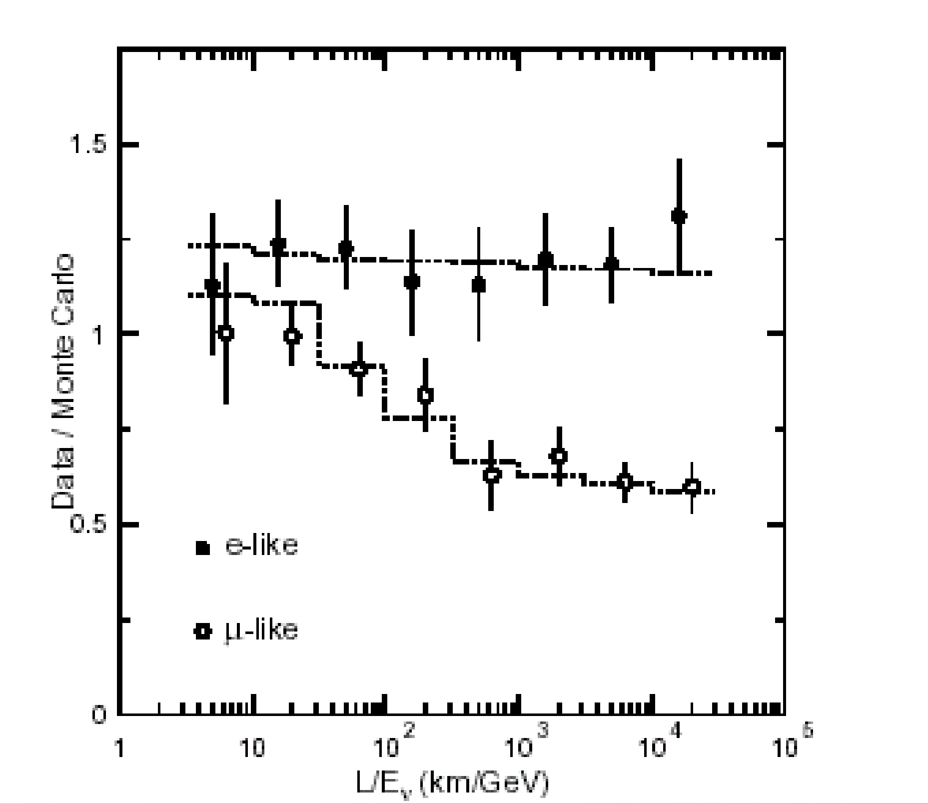


Super Kamiokande



neutrino oscillations

with this plot from SuperK in 1998, everybody started believing in atmospheric ν oscillations

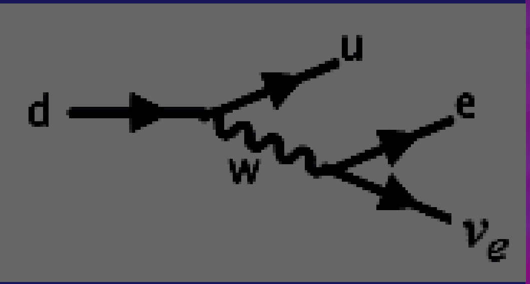


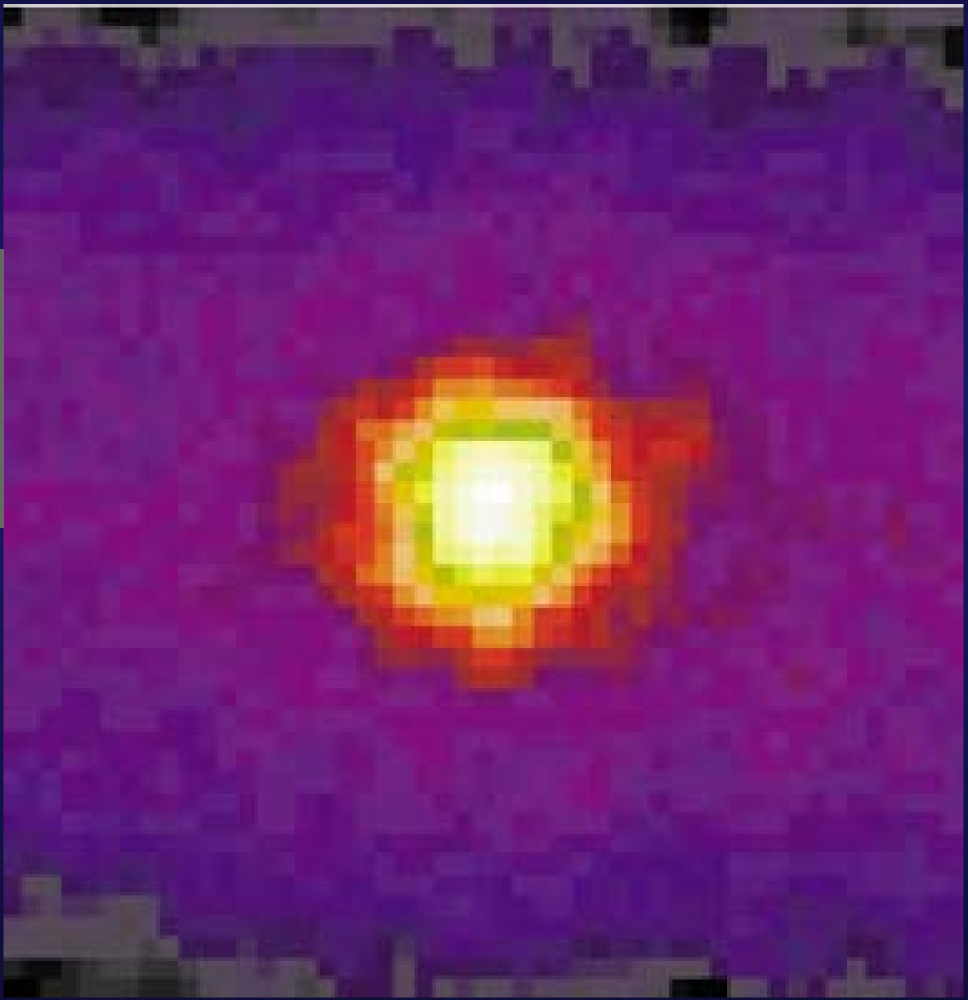
neutrino oscillations

but the situation with solar neutrino oscillations was more confused…

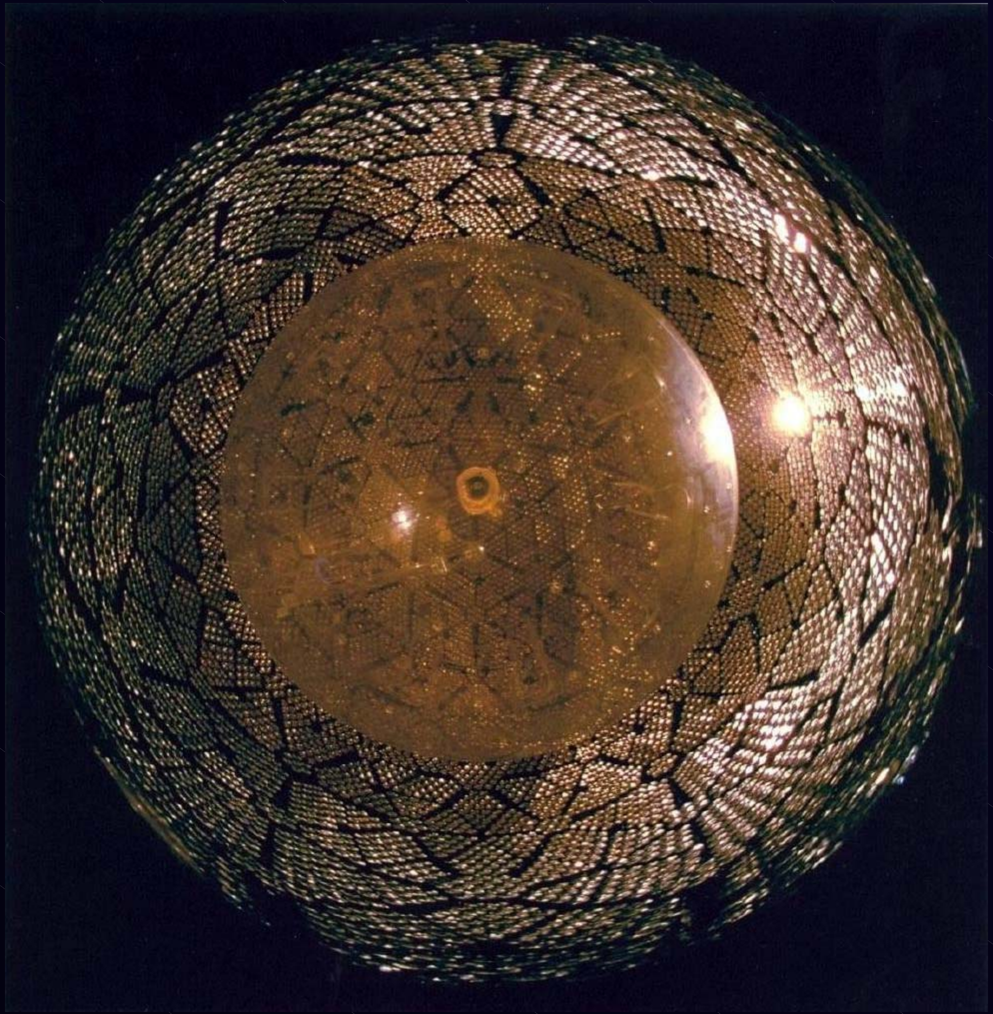
and the LSND result was even less convincing.

solar neutrinos





New results from SNO



- direct evidence for flavor conversion of solar ν's
- observation of day/night effect

ν Reactions in SNO

CC $\nu_e + d \Rightarrow p + p + e^-$

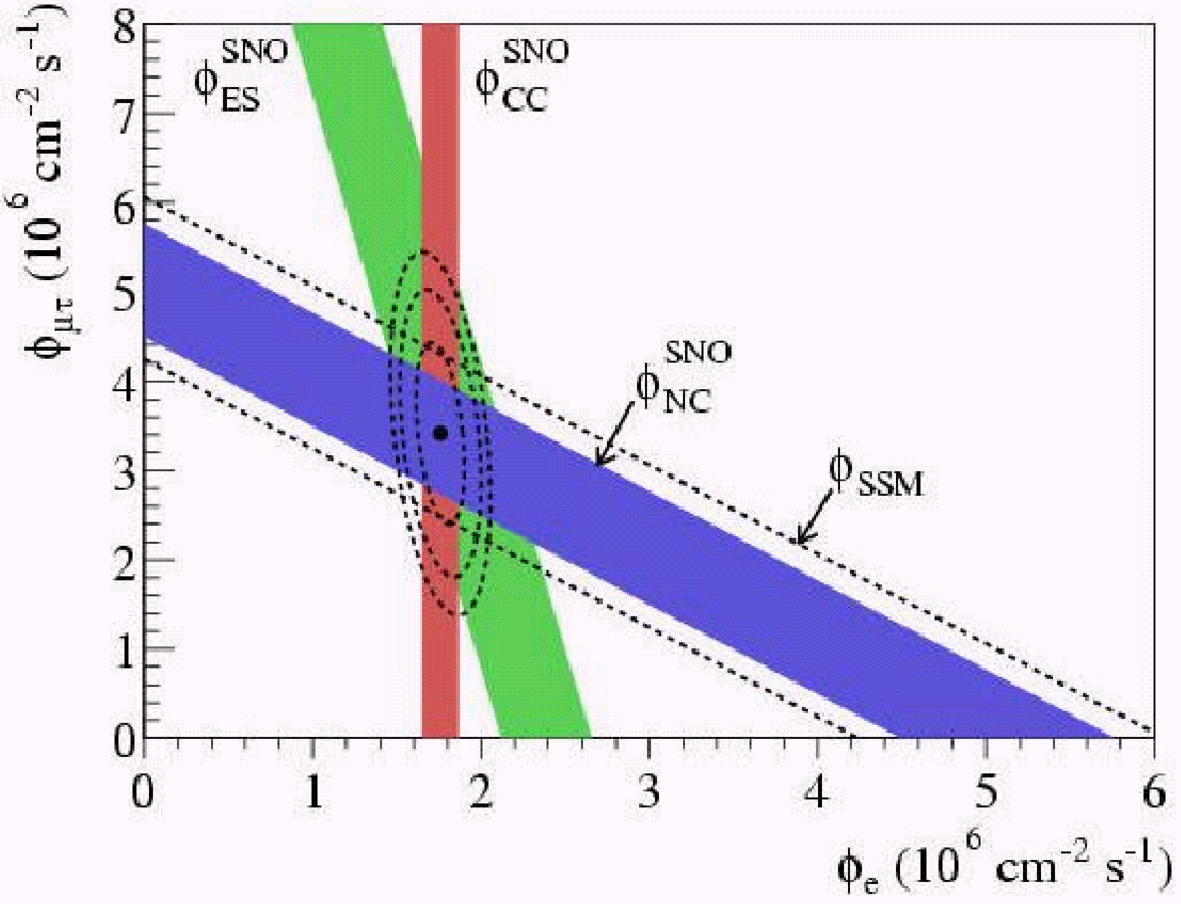
- Good measurement of ν_e energy spectrum
- Weak directional sensitivity $\propto$ 1-1/3cos(θ)
- ν_e only.

NC $\nu_x + d \Rightarrow p + n + \nu_x$

- Equal cross section for all ν types
- Measure total ^8B ν flux from the sun.

ES $\nu_x + e^- \Rightarrow \nu_x + e^-$

- Low Statistics
- Mainly sensitive to ν_e, some sensitivity to ν_μ and ν_τ
- Strong directional sensitivity



ϕ_{ES}^{SNO}
ϕ_{CC}^{SNO}
ϕ_{NC}^{SNO}
ϕ_{SSM}
$\phi_{\mu\tau}$ (10^6 cm^{-2} s^{-1})
ϕ_e (10^6 cm^{-2} s^{-1})
0
1
2
3
4
5
6
7
8

Shape Constrained Neutrino Fluxes

Signal Extraction in Φ_{CC}, Φ_{NC}, Φ_{ES}. $E_{Theshold} > 5$ MeV

$\Phi_{cc}(\nu_e) = 1.76^{+0.06}_{-0.05}$ (stat.) $^{+0.09}_{-0.09}$ (syst.) $\times 10^6\ cm^{-2}s^{-1}$

$\Phi_{es}(\nu_x) = 2.39^{+0.24}_{-0.23}$ (stat.) $^{+0.12}_{-0.12}$ (syst.) $\times 10^6\ cm^{-2}s^{-1}$

$\Phi_{nc}(\nu_x) = 5.09^{+0.44}_{-0.43}$ (stat.) $^{+0.46}_{-0.43}$ (syst.) $\times 10^6\ cm^{-2}s^{-1}$

Signal Extraction in Φ_e, $\Phi_{\mu\tau}$.

$\Phi_e = 1.76^{+0.05}_{-0.05}$ (stat.) $^{+0.09}_{-0.09}$ (syst.) $\times 10^6\ cm^{-2}s^{-1}$

$\Phi_{\mu\tau} = 3.41^{+0.45}_{-0.45}$ (stat.) $^{+0.48}_{-0.45}$ (syst.) $\times 10^6\ cm^{-2}s^{-1}$

Purely sterile oscillations excluded at 5.4 σ

are we converging on a

STANDARD MODEL of ν oscillations?

NO

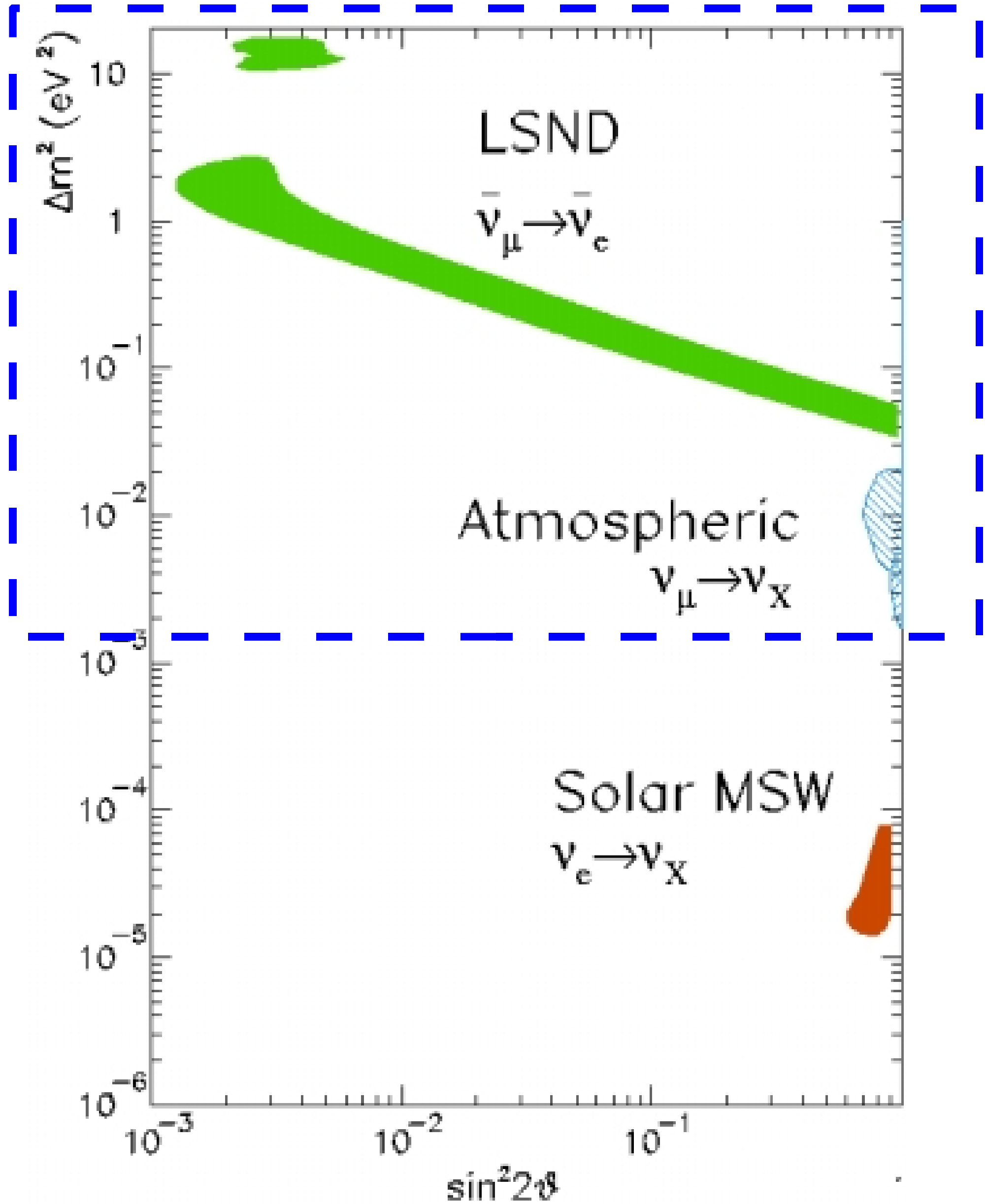
Neutrino Oscillation Signals

3 independent Δm^2!

↓

too many for the three standard model neutrinos!

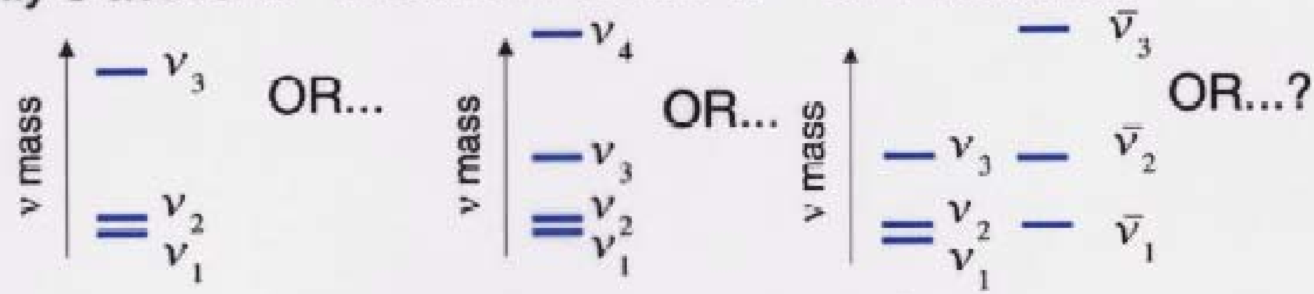
Terrestrial neutrino experiments at medium and high Δm^2



is the LSND result correct?

With the latest results on solar, atmospheric, and accelerator ν–oscillation searches (3 Δm^2s), we have an interesting situation:

Only 3 active ν: 3 active+1 sterile ν: CPT violation:



Only 3 active ν	3 active+1 sterile ν	CPT violation
solar: $\nu_e \rightarrow \nu_\mu$	*solar:* $\nu_e \rightarrow \nu_\mu, \nu_\tau$	*solar:* $\nu_e \rightarrow \nu_\mu$
atmos: $\nu_\mu \rightarrow \nu_e, \nu_\tau$	*atmos:* $\nu_\mu \rightarrow \nu_\tau$	*atmos:* $\nu_\mu \rightarrow \nu_\tau$
LSND: $\bar{\nu}_\mu \rightarrow \bar{\nu}_\tau \rightarrow \bar{\nu}_e$	*LSND:* $\bar{\nu}_\mu \rightarrow \bar{\nu}_s \rightarrow \bar{\nu}_\mu$	*LSND:* $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
– not a good fit to data	– possible(?)	– possible(?)

Need to definitively check the LSND result!

Rex Tayloe, Indiana U.
Neutrino 2002, 5/02

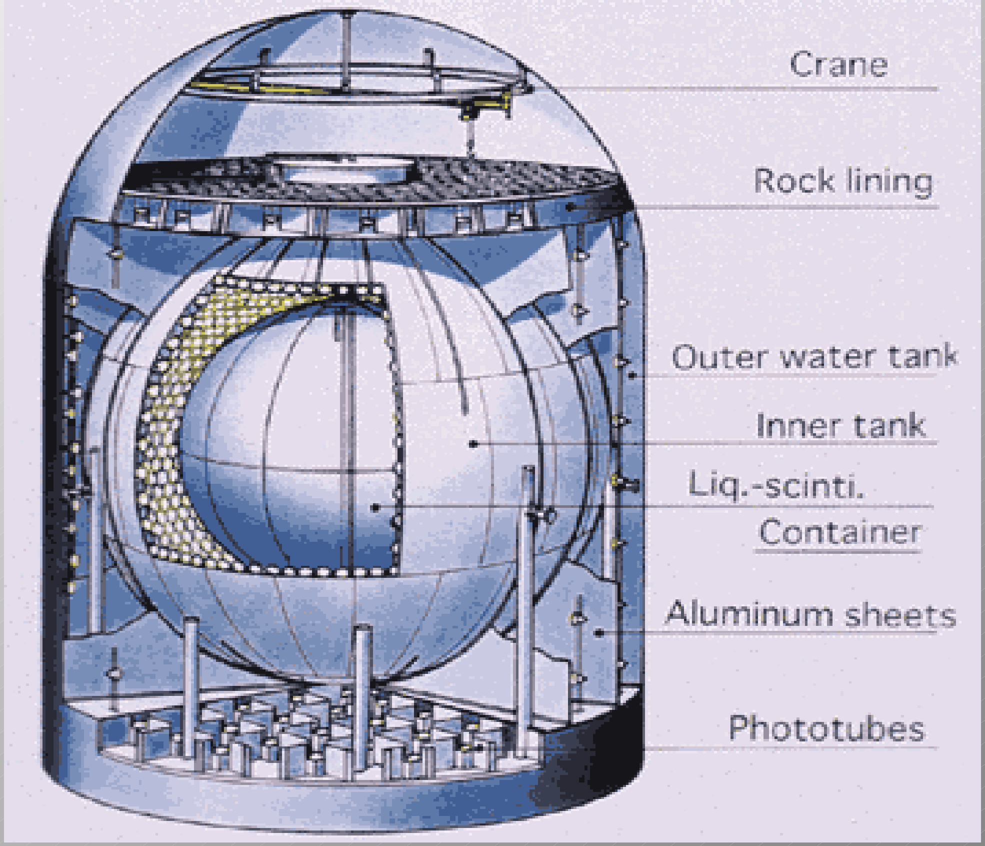
miniBooNE:

Goal: to definitively test the LSND signal.
First, with a
$\nu_\mu \rightarrow \nu_e$ appearance search.
Then, with a
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance search.
Then, if a signal is seen, with a 2nd detector.

Dec. 1997:
Proposal submitted
June 2002:
experiment begins

KamLAND is looking for LMA “solar” oscillations in reactor *antineutrinos*.

In CPT violating scenario, KamLAND does not see oscillations!



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Has time run out on Einstein's theory?

Atomic clocks on the space station might reveal truth

June 5, 2002 Posted: 11:42 AM EDT (1542 GMT)

By Eleni Berger
CNN

(CNN) -- Experiments with high-precision clocks in space could help shed light on whether Einstein's theory of relativity is ... well, relative.

"I don't think it's really possible to throw Einstein's theory out entirely, because it certainly holds to a fantastic degree of precision," says Dr. Alan Kostelecky, professor of physics at Indiana University in Bloomington. "The question is whether at very small scales you would need to adjust the theory to account for adjustments in space-time."

SAVE THIS
PRINT THIS
MOST POPULAR

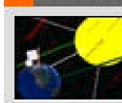
Atomic clocks that are scheduled to be placed on the international space station within the next few years could help researchers find out -- if station crews perform the tests Kostelecky and his colleagues are proposing.

Einstein's Special Theory of Relativity postulates that the laws of physics and the speed of light are always the same to an observer moving at a constant speed. That means a coin will always fall straight down, whether you drop it while standing still or while inside a moving vehicle.

Likewise, a clock on its side will tick at the same rate as a clock that is upright -- at least it will on earth.

But newer theories involving gravity and particle physics have led some scientists to speculate that Einstein's idea may not hold true in space.

EXTRA INFORMATION



Click here to see an animation of the proposed experiments

Precision in time and space

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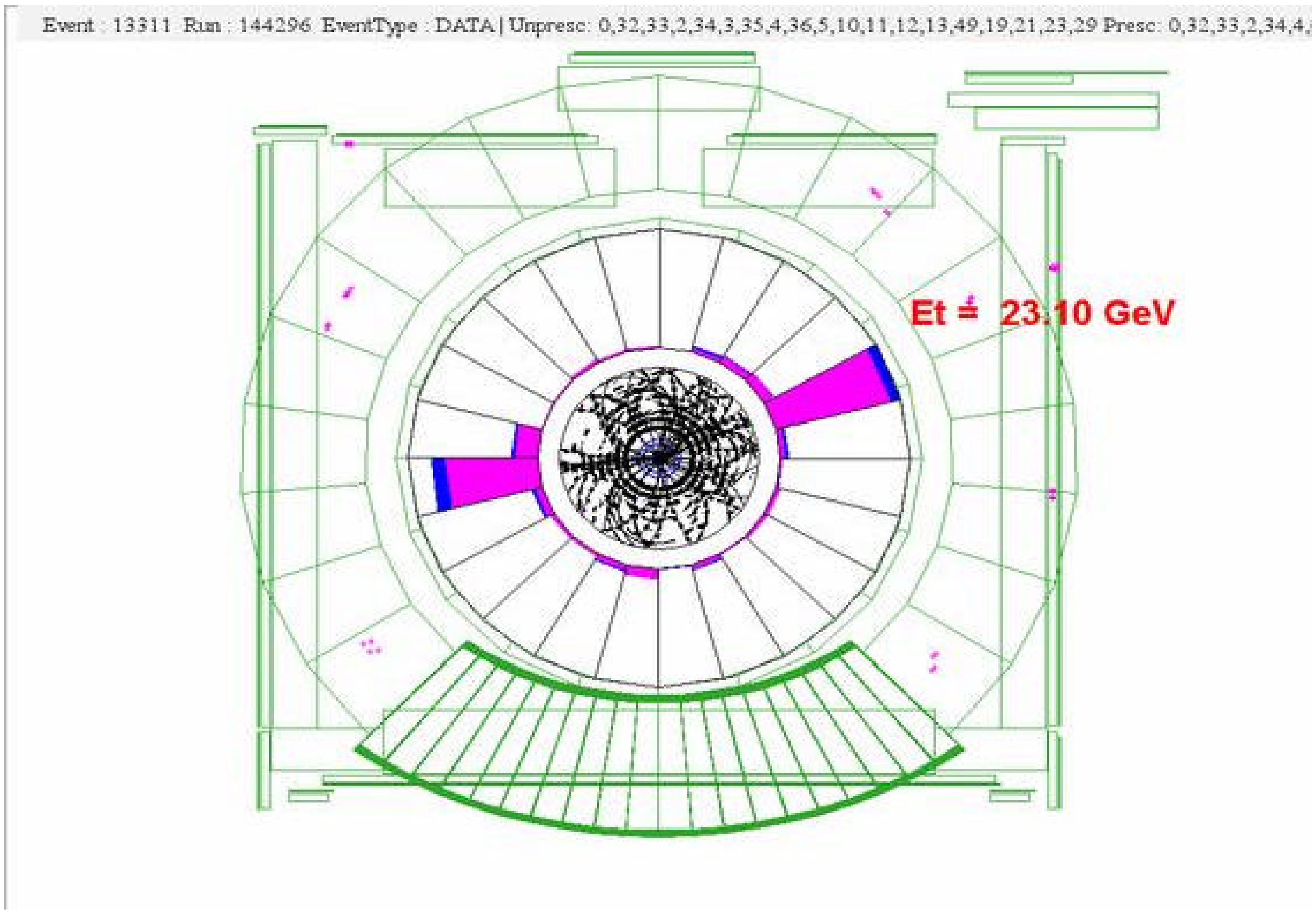
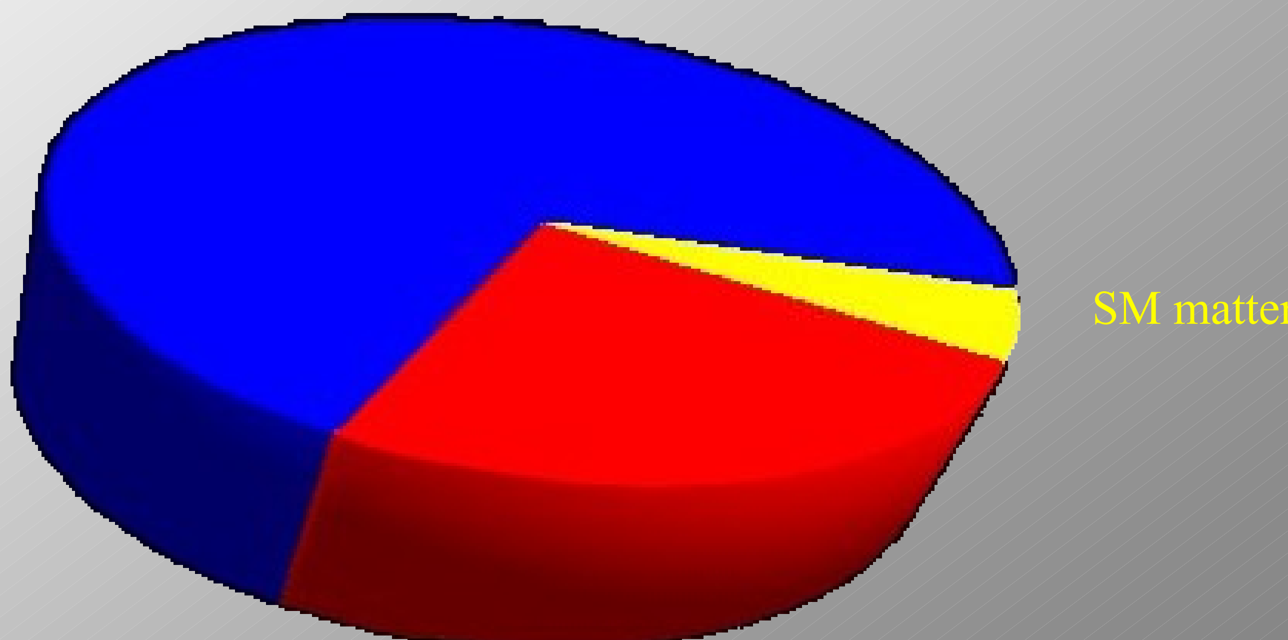
Evidence for
Dark Energy

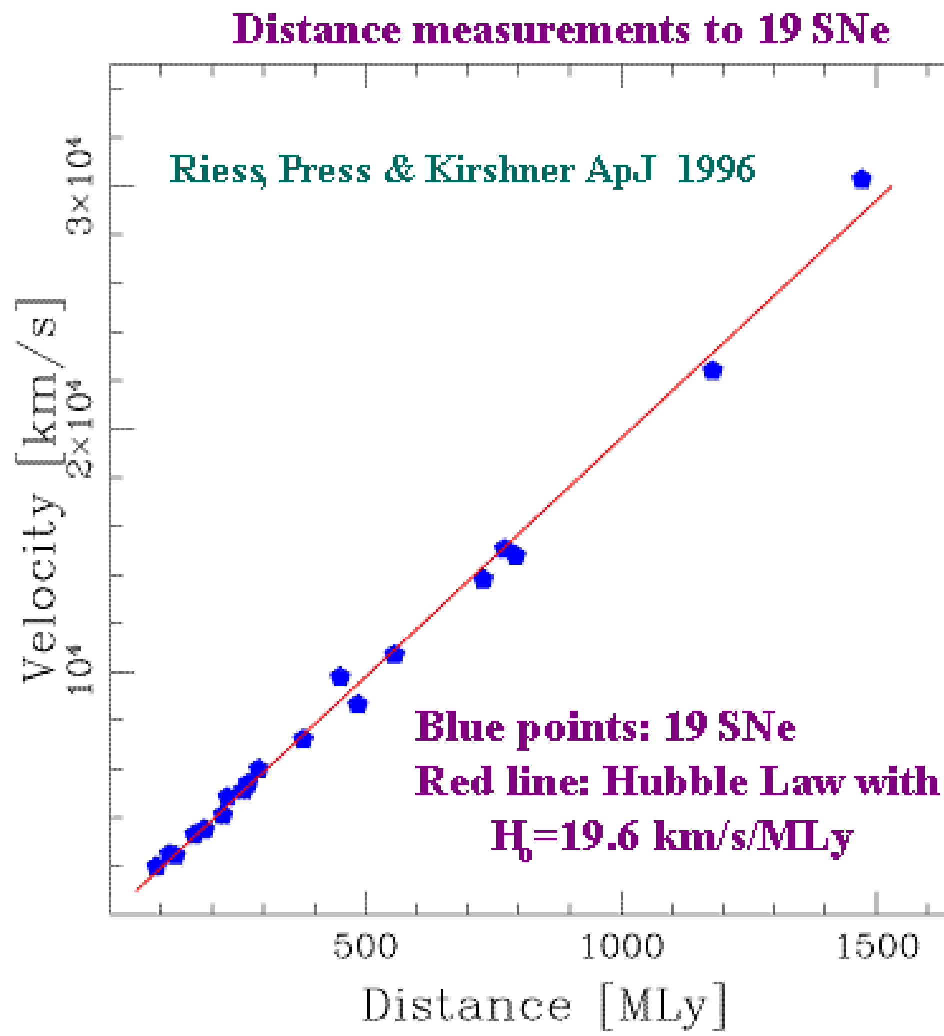


what else does the Standard Model <u>not</u> explain ?

95% of the Universe!



Type Ia Supernovae Measurements



Type Ia supernovae and every other distance indicator used provides results consistent with the Hubble Law: other galaxies are receding from us, and their recession velocities are proportional to their distances, in other words, the farther away the galaxy, the faster it travels away from us.

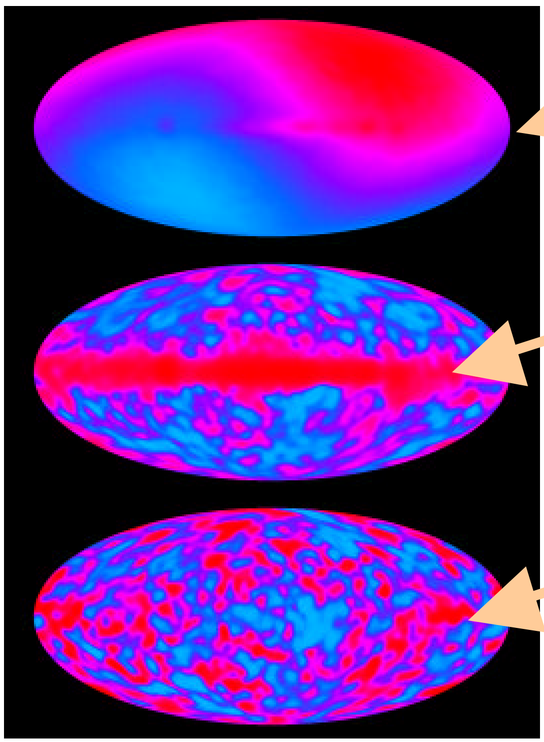
$$v_r = H_o d$$

COBE

Anisotropy of Cosmic Microwave Background (CMB)

CMB is isotropic and homogenous to a high degree; its average temperature is

$$T = 2.725 \pm 0.002 \text{ K}$$



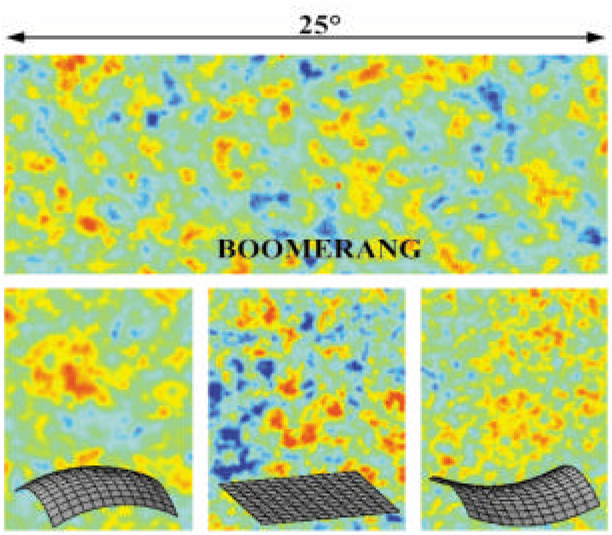
Dipole contribution due to Sun motion

Milky way radiation

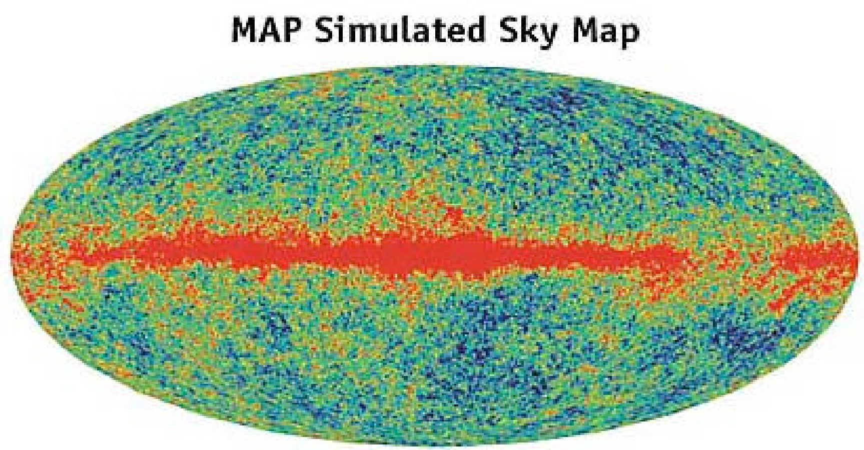
"Standing waves" sensitive to the large-scale structure of the Universe with the amplitude

$$D\,T = 0.000\ 003\,K$$

Boomerang (1998)



MAP (launched 2001)



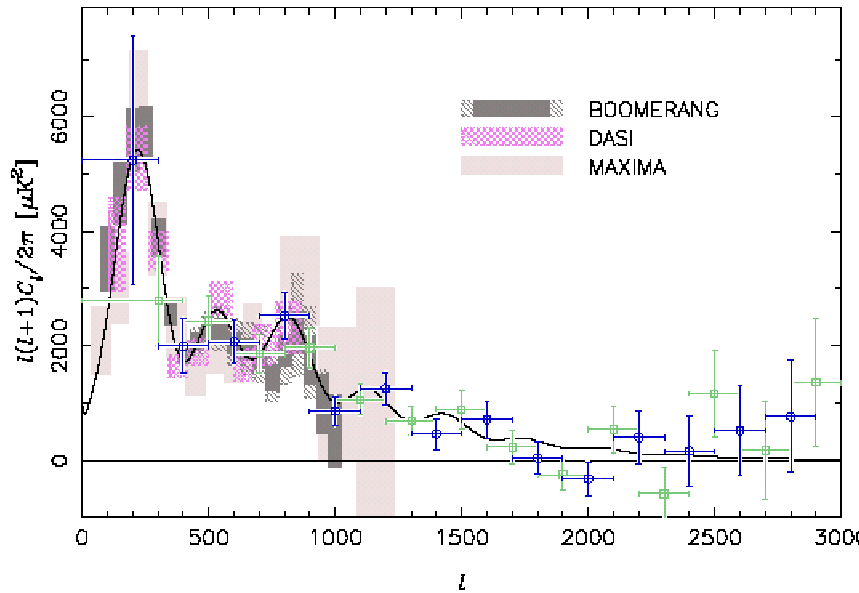
Wonderful angular resolution!

large-scale structure of spacetime

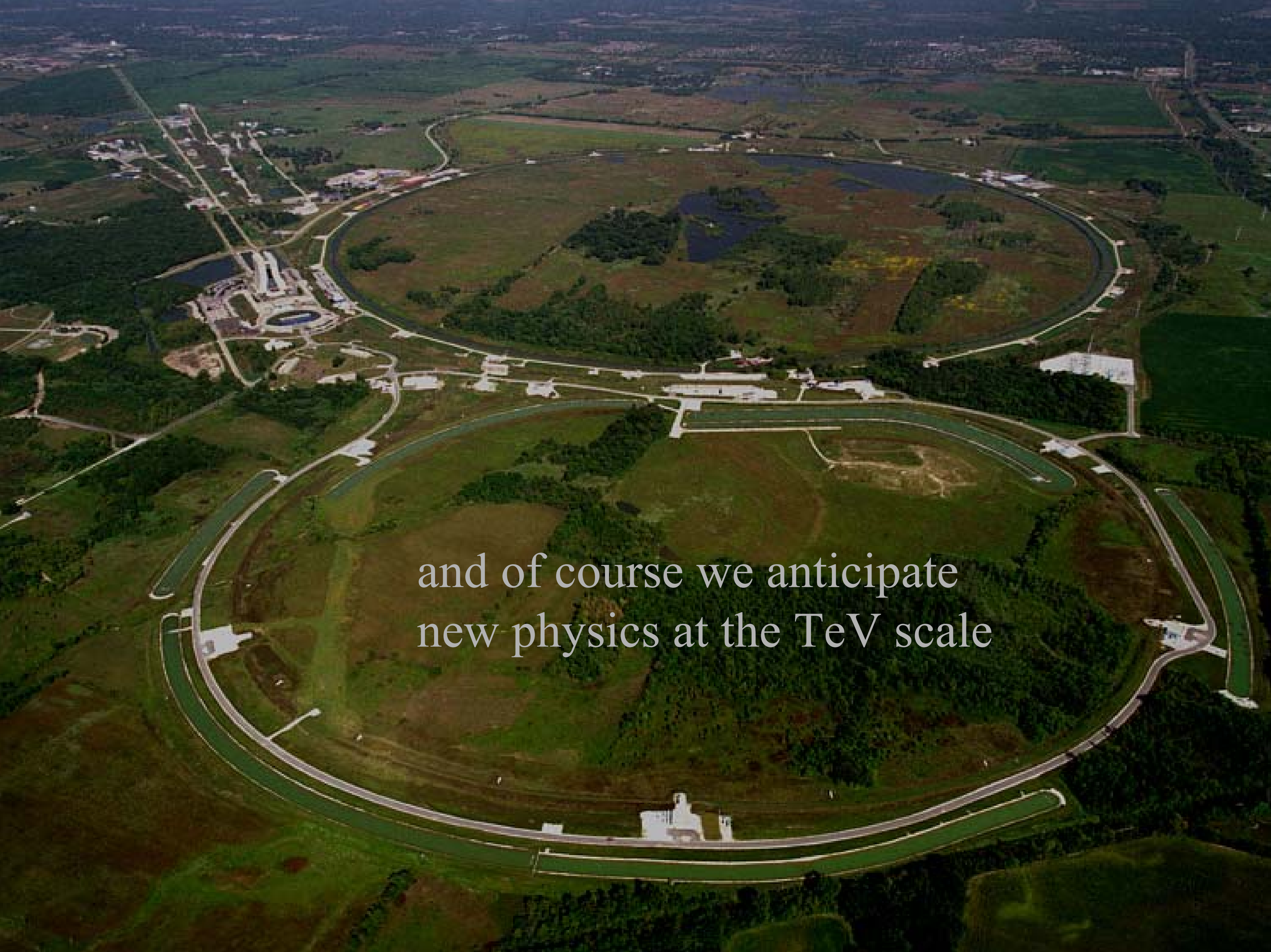
talk by Max Tegmark

We are getting lots of information about the cosmological parameters!

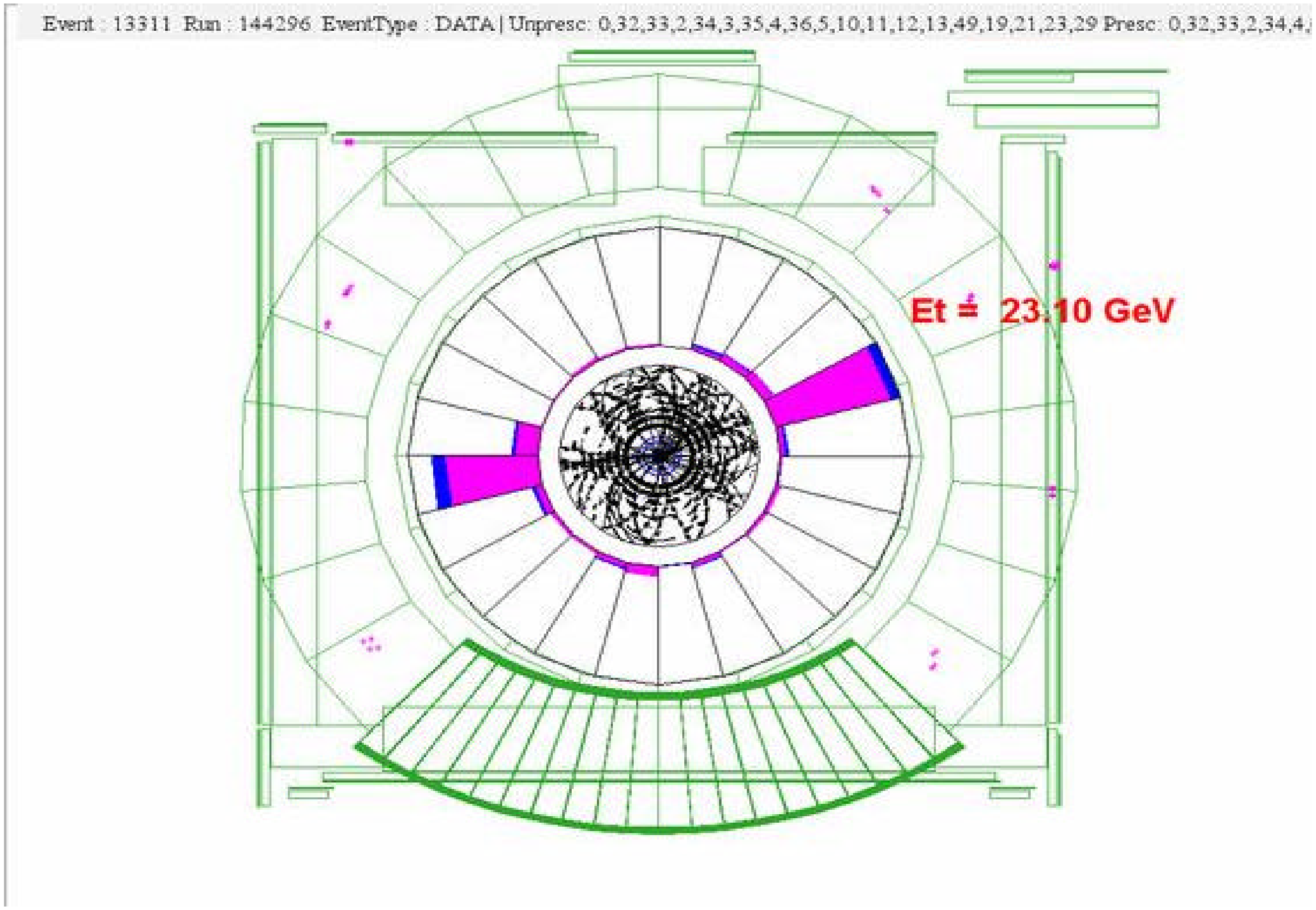
Biggest discovery in cosmology of past 5 years: real error bars!



Priors	Ω_{tot}	n_s	$\Omega_b h^2$	$\Omega_{cdm} h^2$	Ω_Λ	Ω_m	Ω_b	h	Age	τ_c
wk-h	$1.05^{0.05}_{0.05}$	$1.02^{0.06}_{0.07}$	$0.023^{0.003}_{0.003}$	$0.13^{0.03}_{0.02}$	$0.54^{0.12}_{0.13}$	$0.52^{0.15}_{0.15}$	$0.080^{0.023}_{0.023}$	$0.55^{0.09}_{0.09}$	$15.0^{1.1}_{1.1}$	$0.16^{0.18}_{0.13}$
wk-h+LSS	$1.03^{0.03}_{0.04}$	$1.00^{0.06}_{0.06}$	$0.023^{0.003}_{0.003}$	$0.12^{0.02}_{0.02}$	$0.61^{0.09}_{0.10}$	$0.42^{0.12}_{0.12}$	$0.067^{0.013}_{0.013}$	$0.60^{0.09}_{0.09}$	$14.7^{1.2}_{1.2}$	$0.09^{0.12}_{0.07}$
wk-h+SN	$1.01^{0.04}_{0.03}$	$1.03^{0.06}_{0.06}$	$0.024^{0.003}_{0.003}$	$0.12^{0.02}_{0.02}$	$0.68^{0.06}_{0.07}$	$0.33^{0.07}_{0.07}$	$0.055^{0.014}_{0.014}$	$0.67^{0.07}_{0.07}$	$13.9^{1.0}_{1.0}$	$0.14^{0.17}_{0.11}$
wk-h+LSS+SN	$1.00^{0.03}_{0.02}$	$1.03^{0.06}_{0.06}$	$0.024^{0.003}_{0.003}$	$0.12^{0.02}_{0.02}$	$0.69^{0.04}_{0.06}$	$0.32^{0.06}_{0.06}$	$0.052^{0.011}_{0.011}$	$0.68^{0.06}_{0.06}$	$13.8^{0.9}_{0.9}$	$0.13^{0.14}_{0.10}$


and of course we anticipate
new physics at the TeV scale

Waiting for
New Discoveries
at
New Colliders

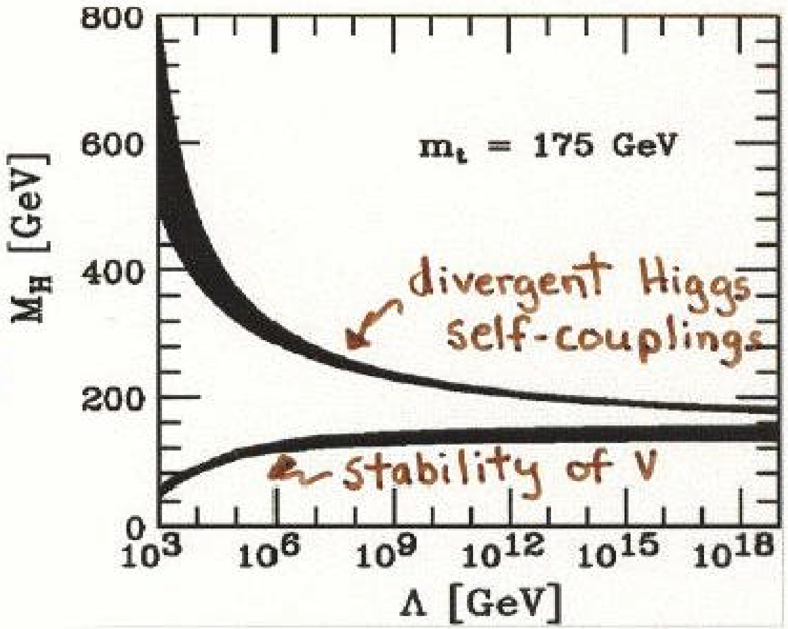


New Physics Exists! But, at what scale?

1) Weakly-coupled SM

- $\Lambda_{NP} < M_{GUT}$ for most values of m_h
- EWSB stability crisis

New Physics must appear by few TeV!



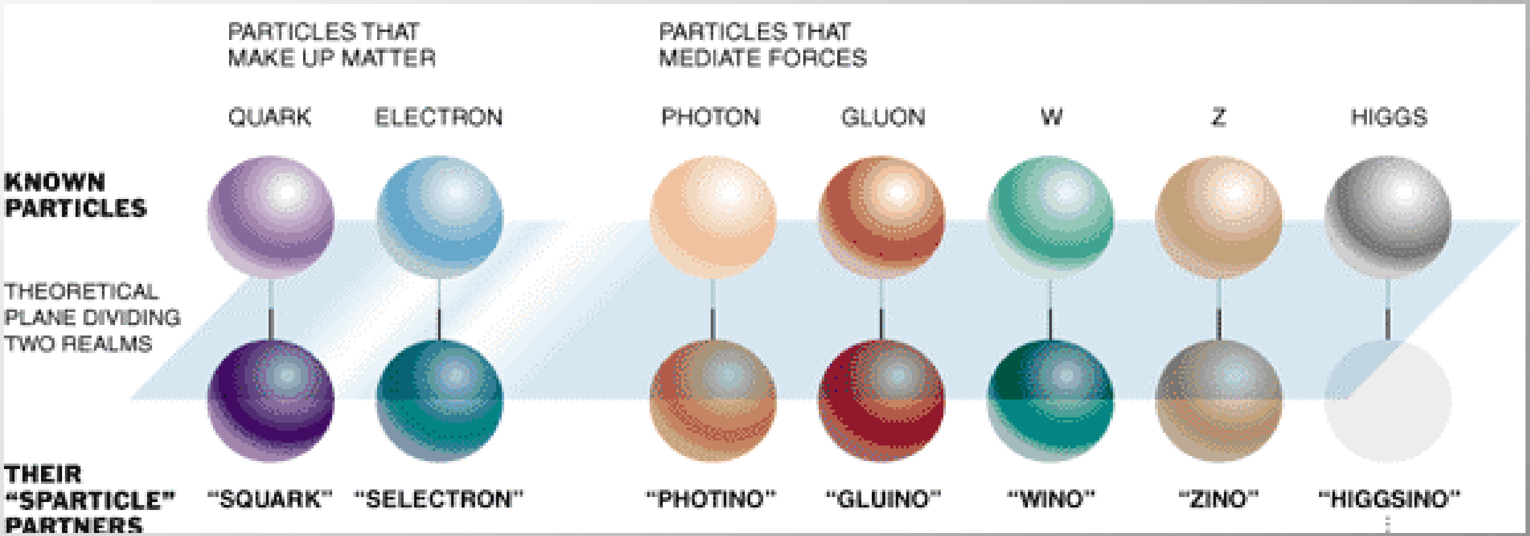
2) Strongly-coupled SM

WW scattering unitarized at scale of few TeV

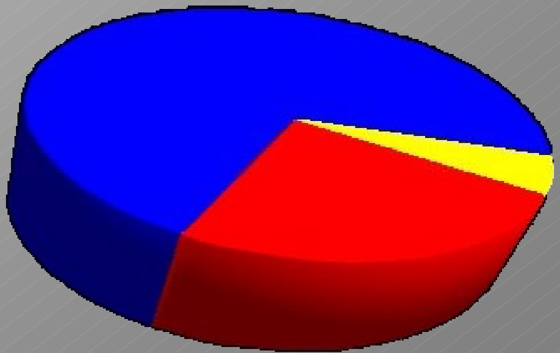
Expect New Physics at the TeV scale !!

supersymmetry

fermions  **bosons**



- none of the sparticles have been discovered yet
- most of the **dark matter** in the universe maybe the lightest sparticle



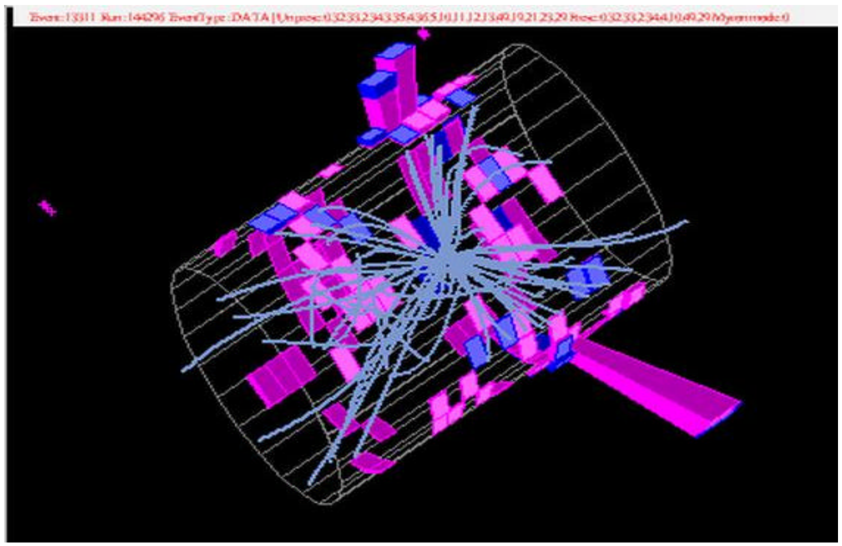
SUSY and extra dimensions at hadron colliders

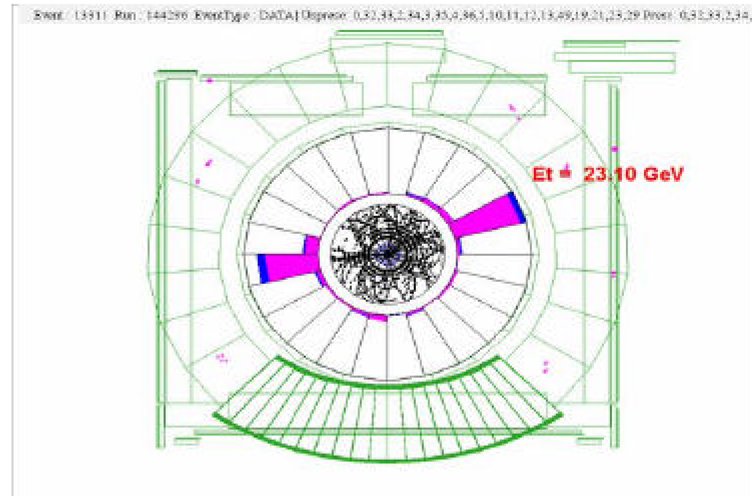
talk by Dave Stuart

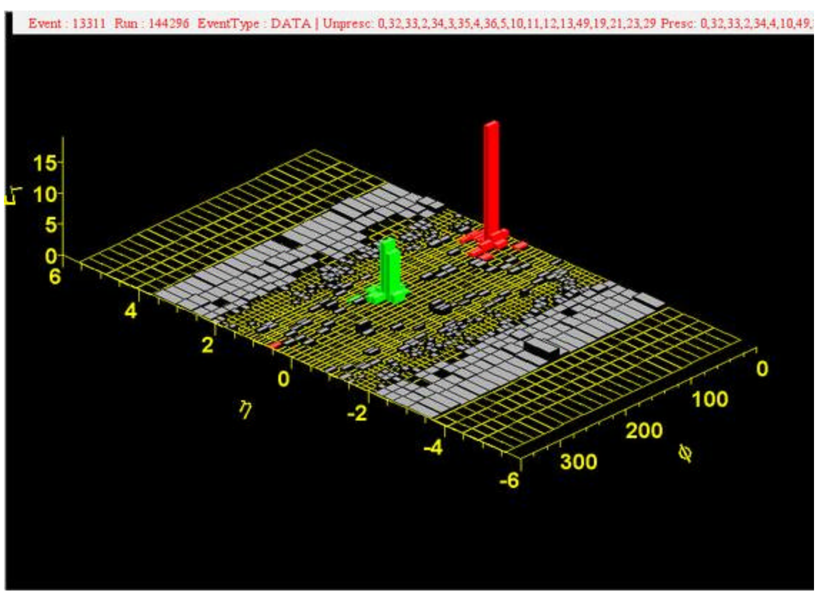
- Tevatron and LHC are our energy frontier colliders for at least a dozen years

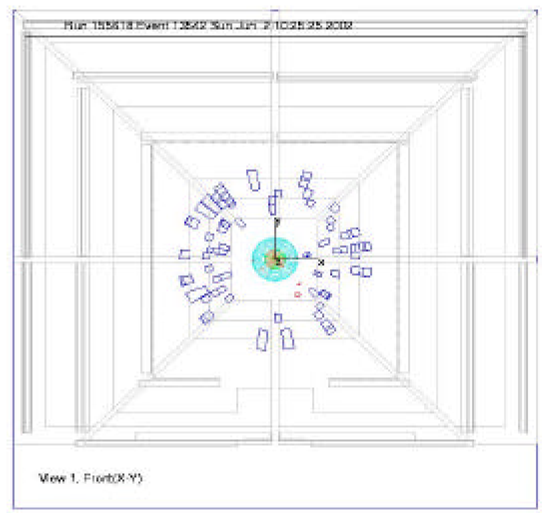
- If you don't understand QCD and EW backgrounds as seen in your detector, you are likely to miss the new physics!

Tevatron Run II takes off now



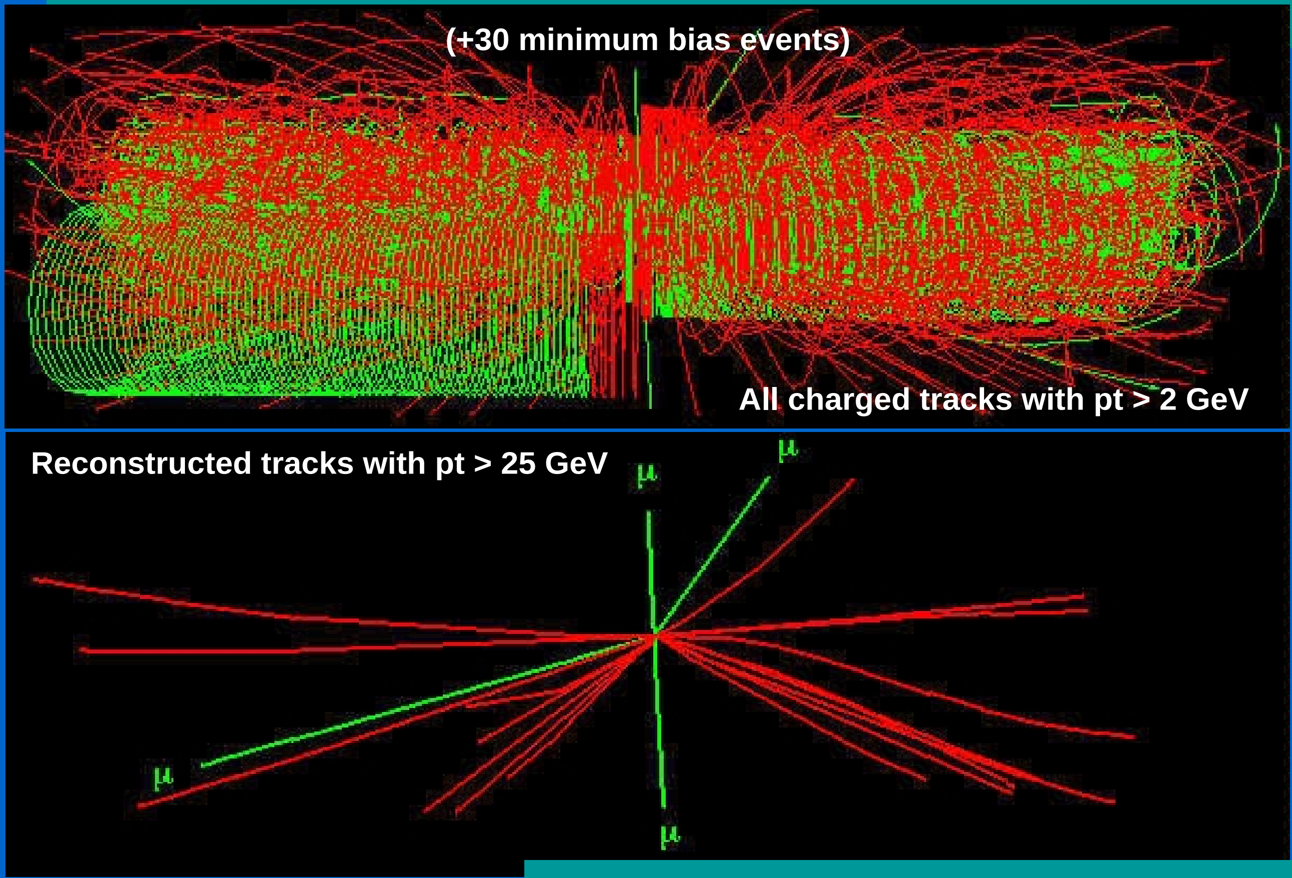






Live events from http://www.fnal.gov

Computing in LHC experiments



Higgs decay in 4 muons
1 in 10 ^{13} events

The data transmitted in ONE SECOND of LHC running

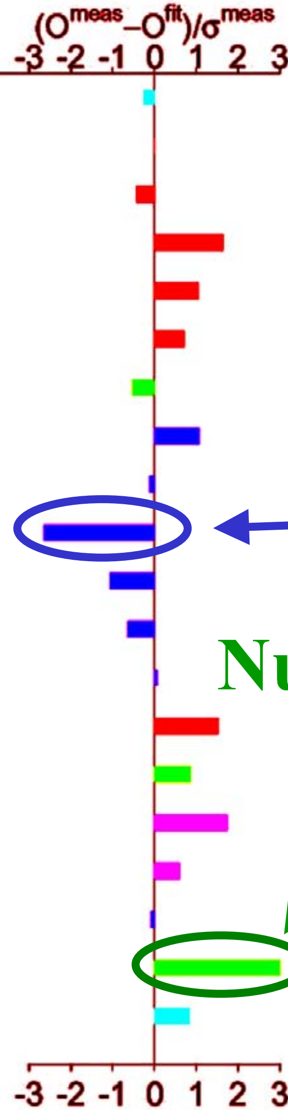
is equivalent to:

the information exchanged by WORLD TELECOM (≈ 100 million phone calls)

Status of Standard Model 2002

EWWG Winter 2002

	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.27
m_Z [GeV]	91.1875 ± 0.0021	.01
Γ_Z [GeV]	2.4952 ± 0.0023	-.42
σ^0_{had} [nb]	41.540 ± 0.037	1.63
R_l	20.767 ± 0.025	1.05
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.70
$A_l(P_\tau)$	0.1465 ± 0.0033	-.53
R_b	0.21646 ± 0.00065	1.06
R_c	0.1719 ± 0.0031	-.11
$A^{0,b}_{fb}$	0.0994 ± 0.0017	-2.64
$A^{0,c}_{fb}$	0.0707 ± 0.0034	-1.05
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.06
A_l(SLD)	0.1513 ± 0.0021	1.50
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.86
m_W [GeV]	80.451 ± 0.033	1.73
Γ_W [GeV]	2.134 ± 0.069	.59
m_t [GeV]	174.3 ± 5.1	-.08
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	3.00
Q_W(Cs)	-72.39 ± 0.59	.84



$A^{0,b}_{fb}$

NuTeV

Largest Pulls in Standard Model Electroweak Fit

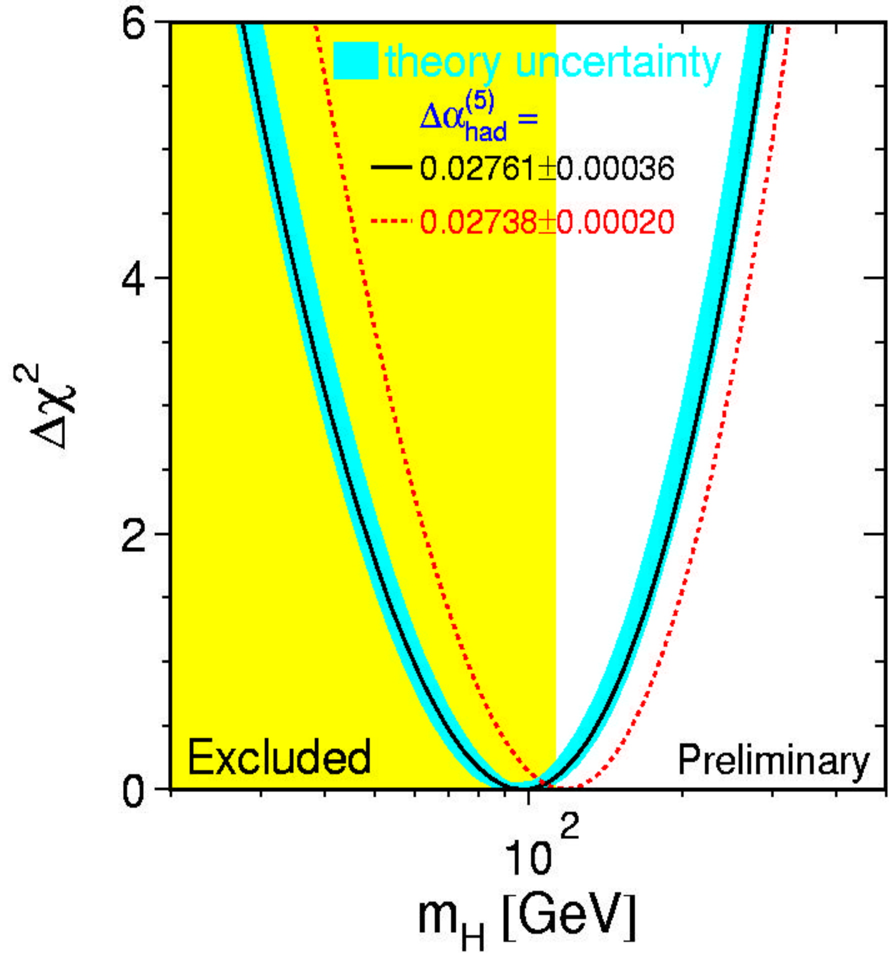
Probability of χ^2 fit $\approx$ 1.7 %

Probability of χ^2 fit (without NuTeV) $\approx$ 14 %

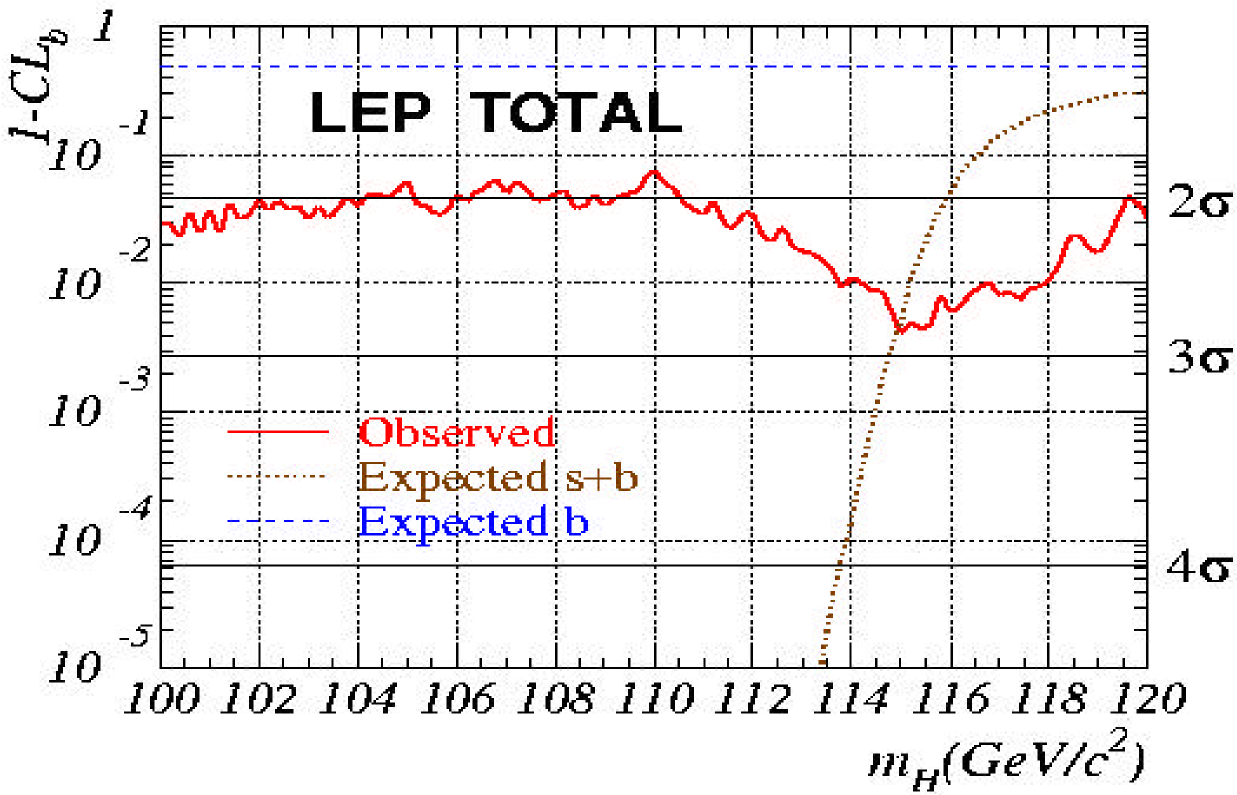
+ Møller scattering

Higgs mass from Standard Model fit

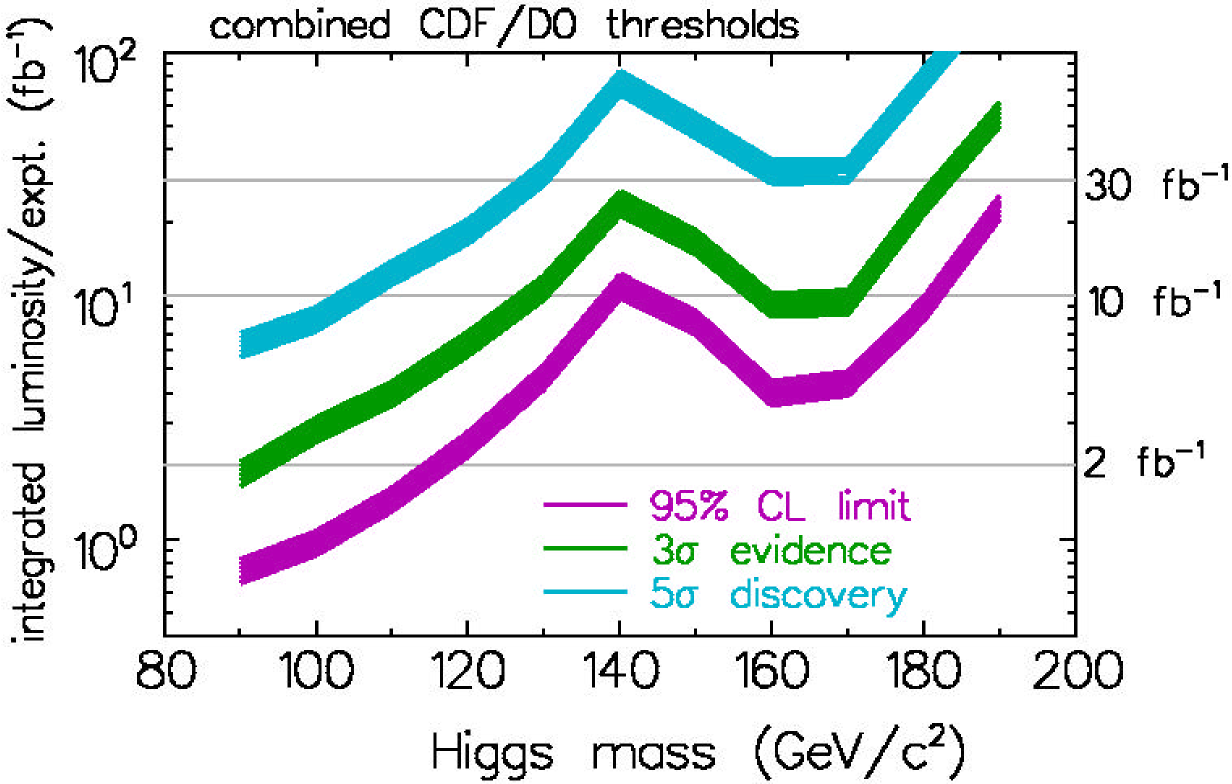
- Winter 2001 result
- $m_H = 98^{+58}_{-38}$ GeV
- $m_H < 212$ GeV (95 % CL)
- Direct search :
- $m_H > 113.5$ GeV (95 % CL) (November LEPC)
- Fits using ZFITTER, TOPAZ0



Maybe a hint of Higgs...

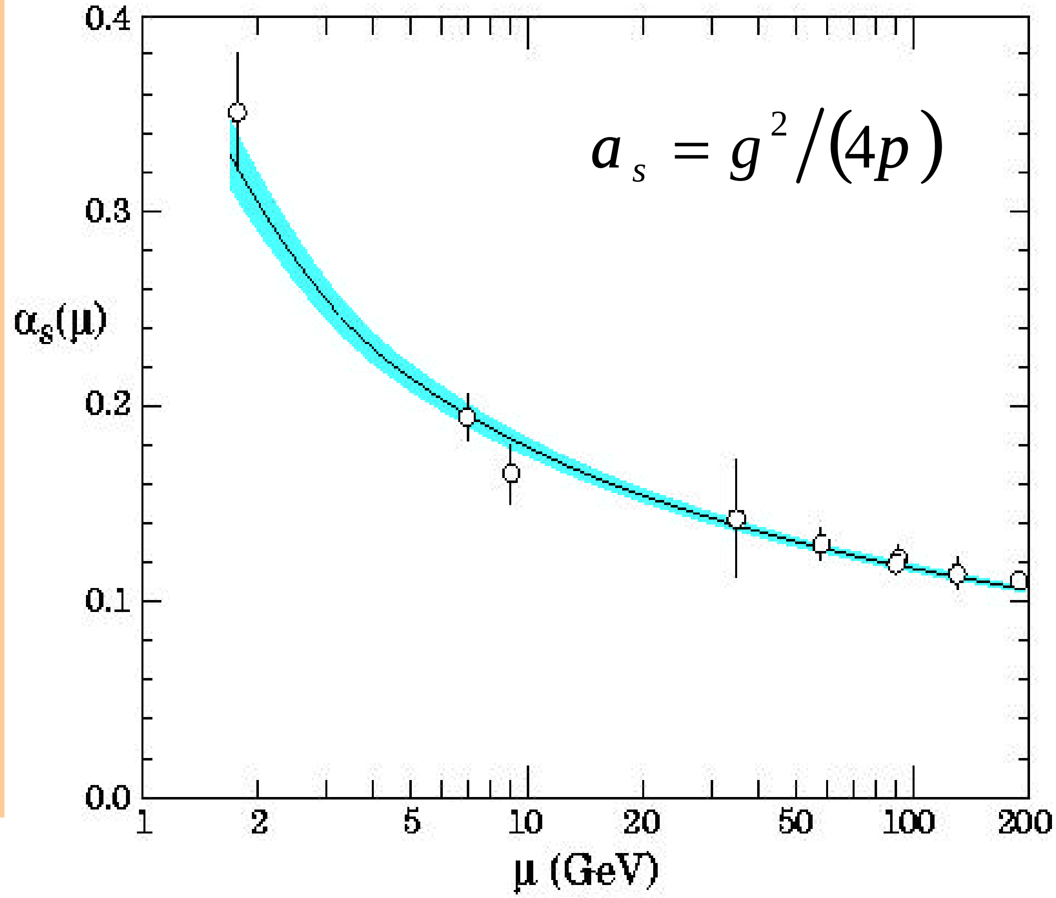


Higgs Discovery Potential at Tevatron Run II



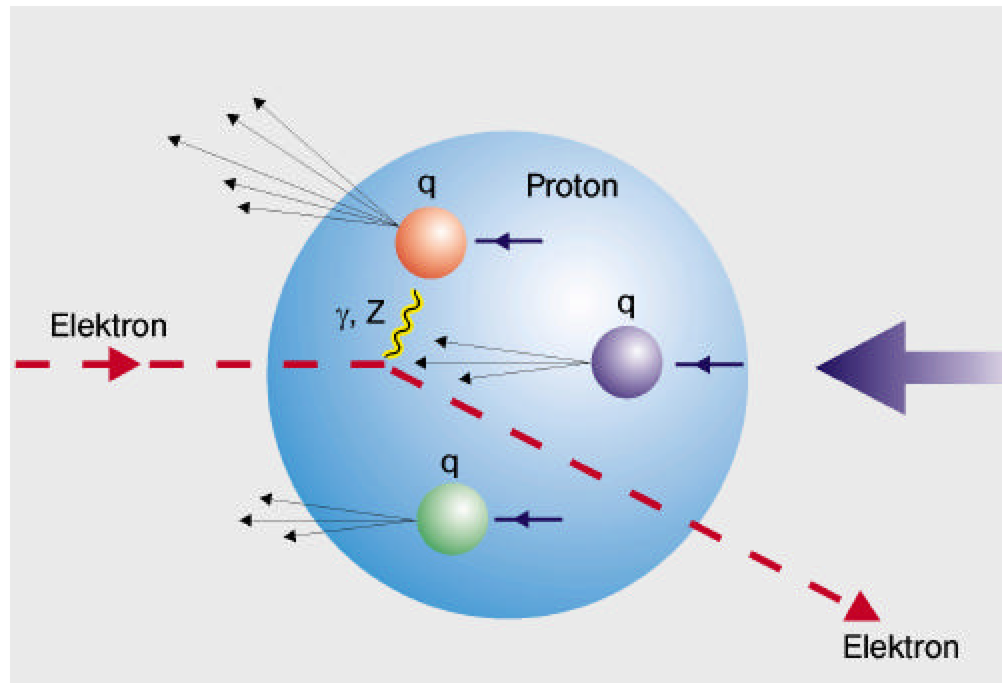
Perturbation Theory in Strong Interactions

- QCD enjoys the property that the coupling strength decreases as the energy increases
- Known as *asymptotic freedom*
- Means we can use perturbation theory
- There is a simple diagrammatic technique called *Feynman diagrams*



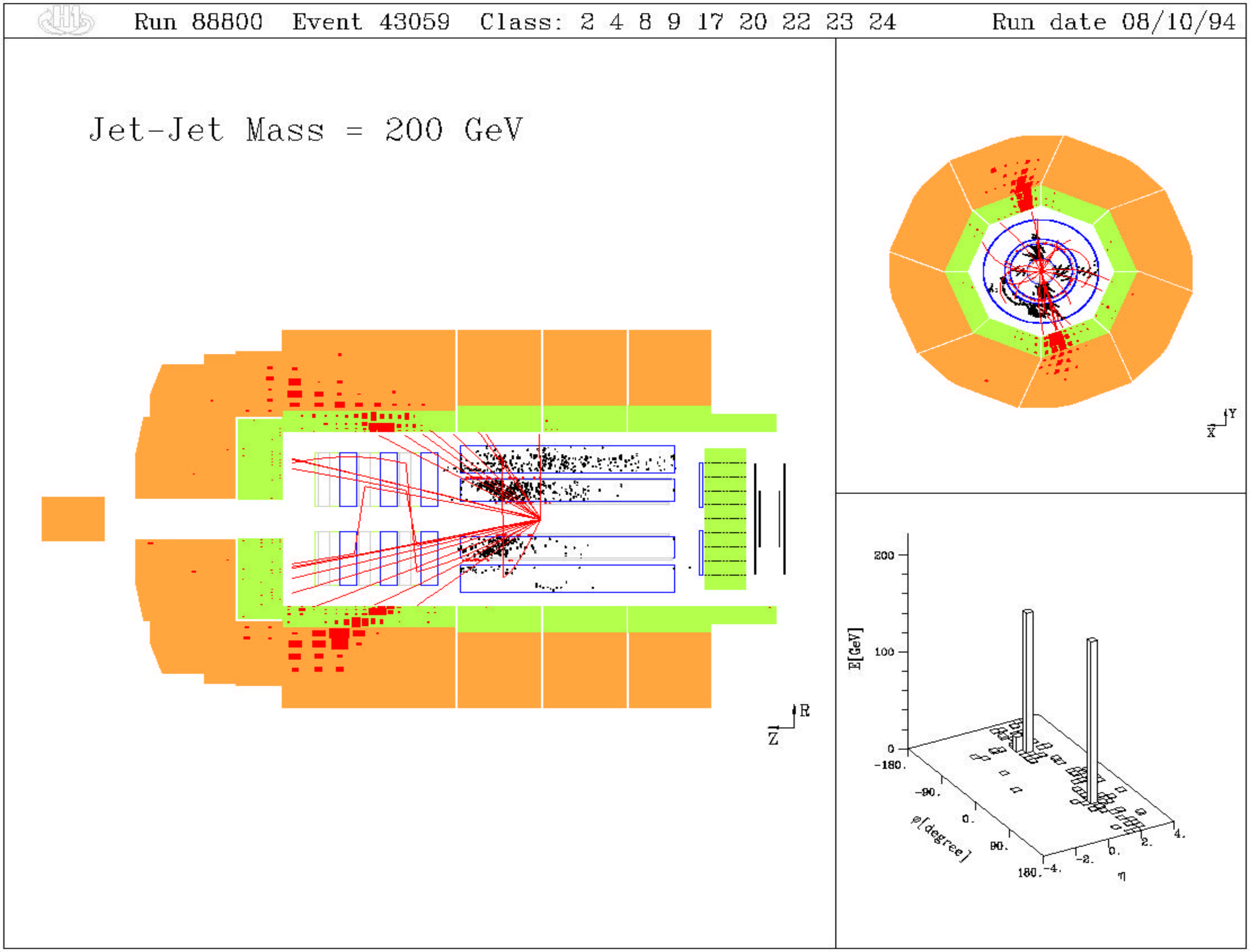
Electron-proton scattering

- Canonical testing ground for QCD is ep scattering
- Early ep scattering experiments lead to discovery of quarks (1990 Nobel Prize)
- State-of-the-art ep facility is in Hamburg, Germany at DESY
- Machine is called HERA



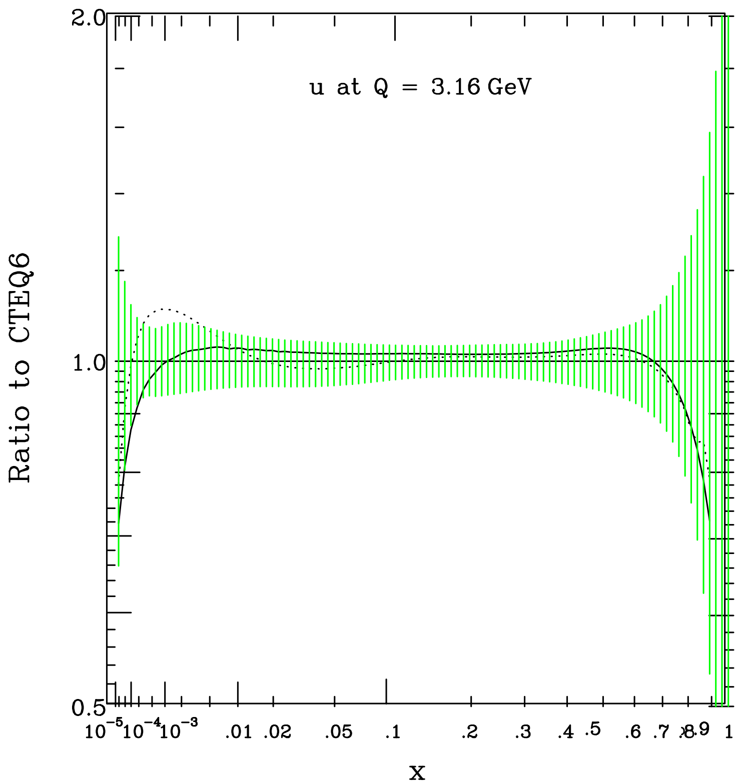
O
HERA
N
S
W
PETRA

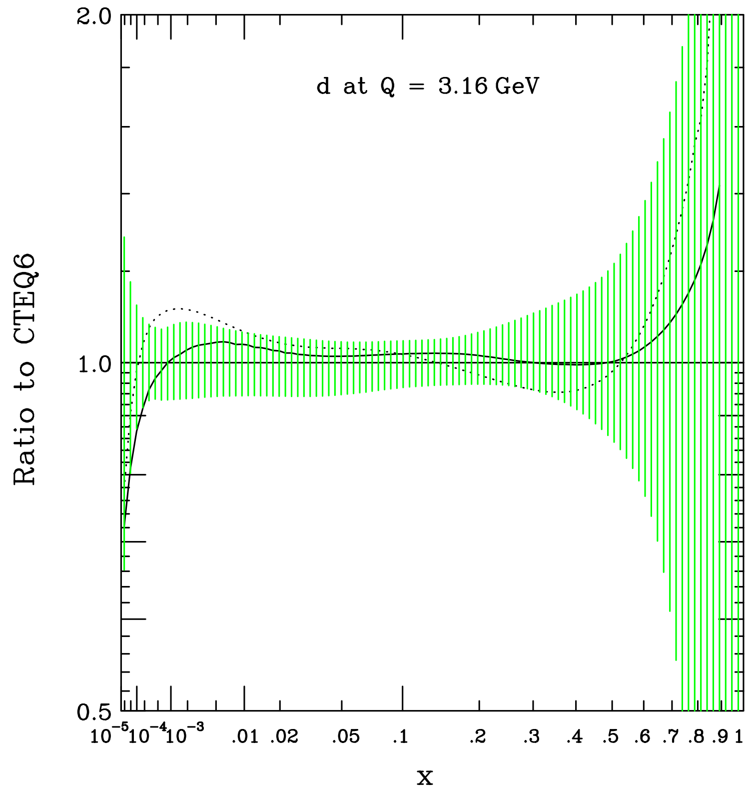
Dijet event



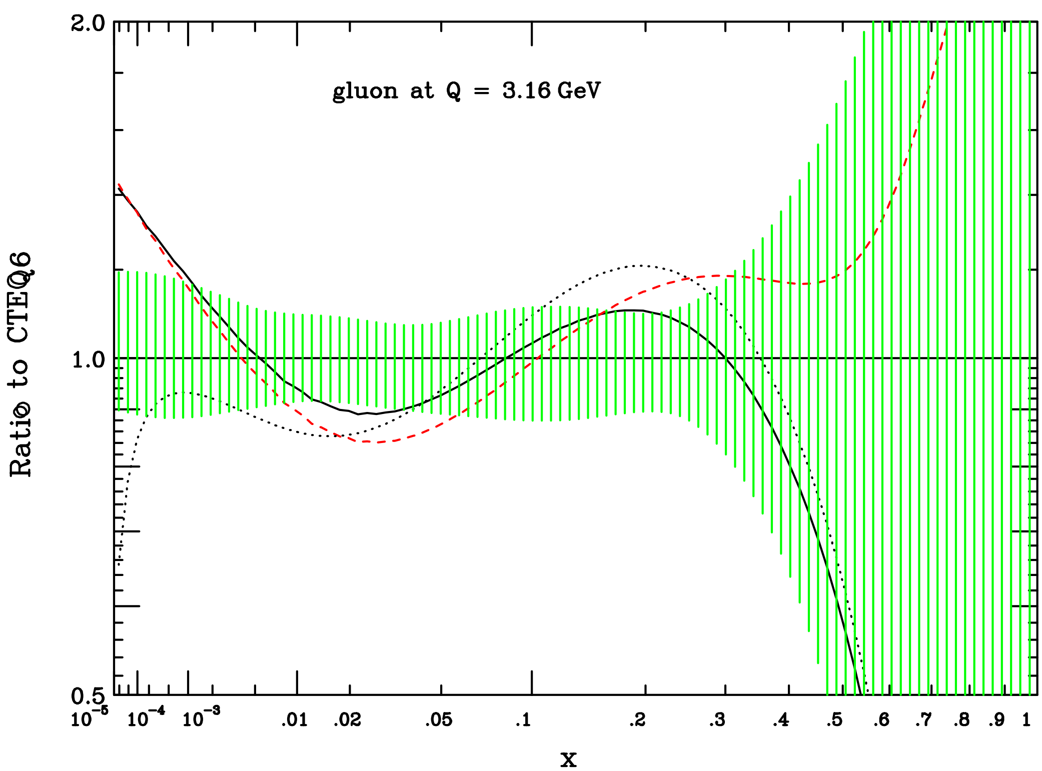
Run 88800 Event 43059 Class: 2 4 8 9 17 20 22 23 24 Run date 08/10/94
Jet-Jet Mass = 200 GeV
R
Z
Y
X
200
100
0
E[GeV]
-180.
-90.
0.
90.
180.
φ[degree]
-4.
-2.
0.
2.
4.
η

Uncertainties of PDF's :

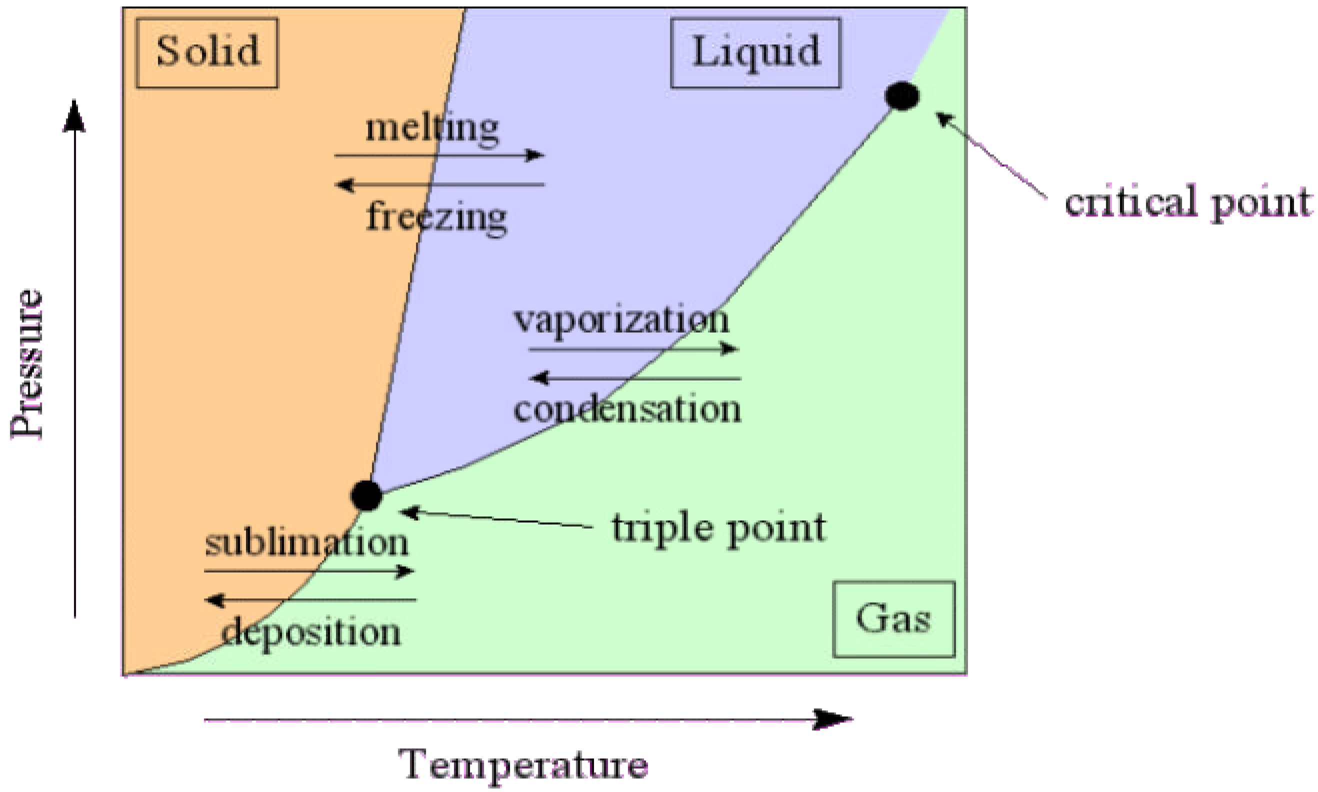


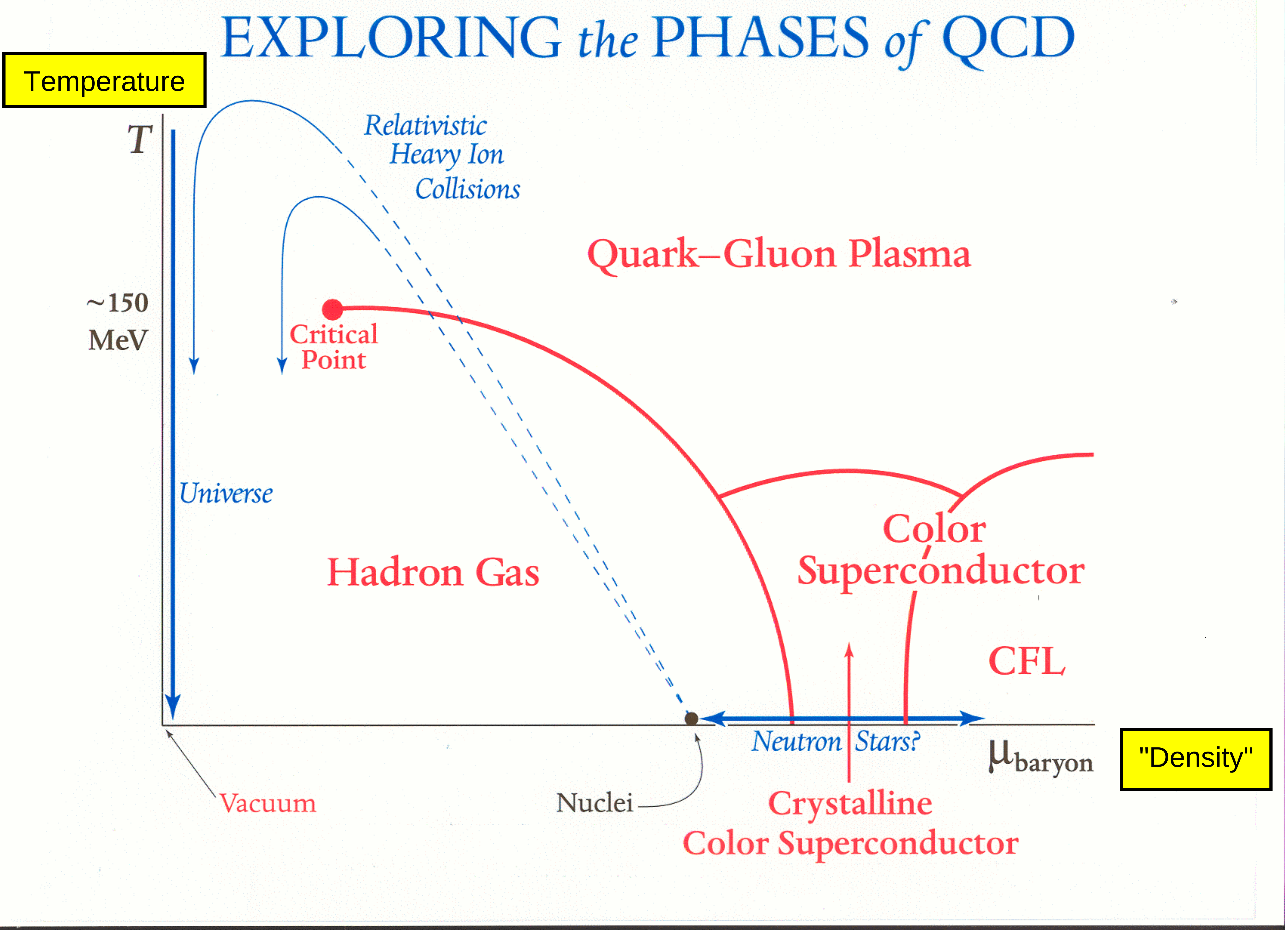


Gluon : better constrained now by DIS and jet data



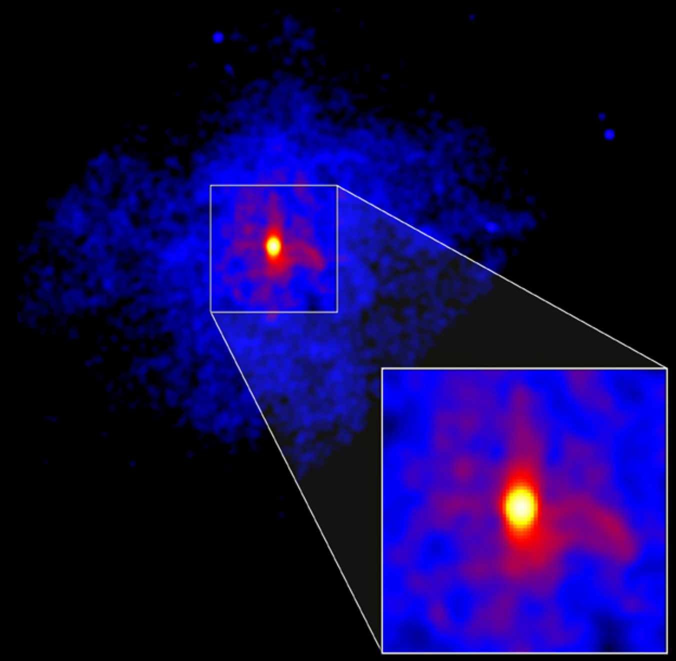
The phase diagram of water




EXPLORING the PHASES of QCD
Temperature
T
~150 MeV
Relativistic Heavy Ion Collisions
Quark–Gluon Plasma
Critical Point
Universe
Hadron Gas
Color Superconductor
CFL
Neutron Stars?
μ_{baryon}
"Density"
Vacuum
Nuclei
Crystalline Color Superconductor

Quark Stars?

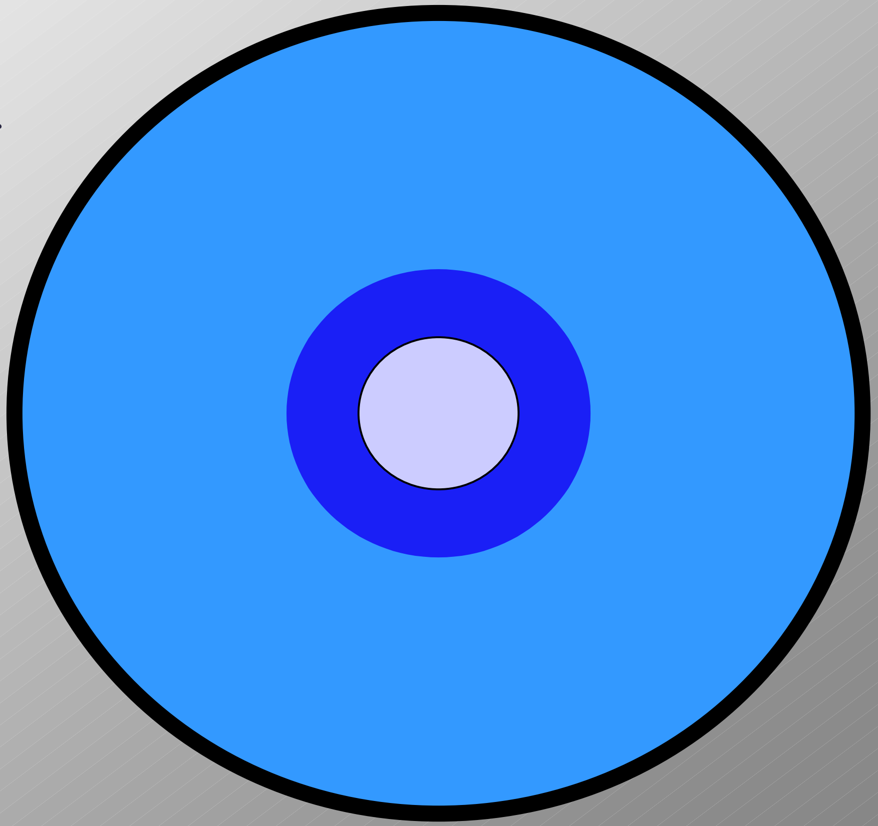
→ not yet!



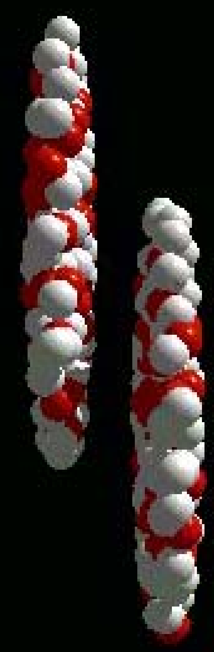
Chandra and HST neutron star images

a real neutron star?

- outer crust
- superfluid nuclear matter
- crystalline CS quark matter
- transparent CFL quark matter

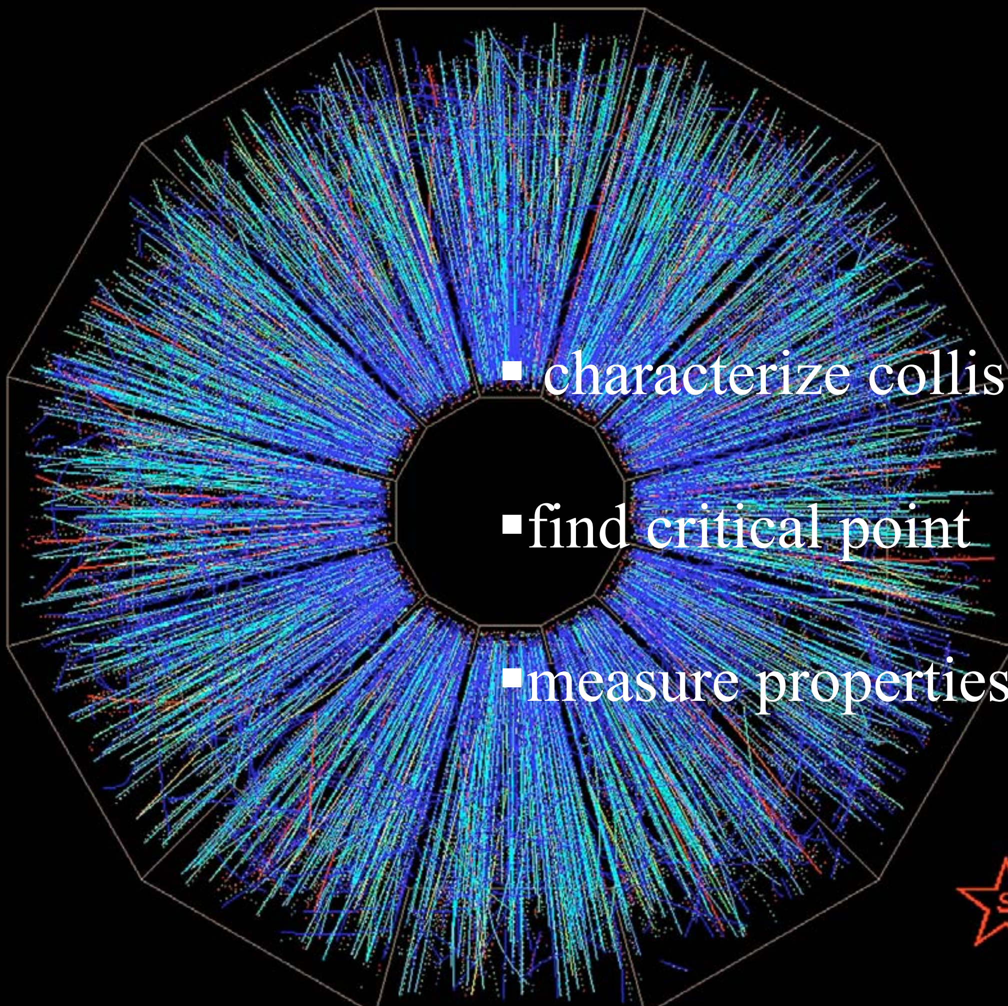


Hot quark matter at RHIC



hot = 2 trillion degrees K

RHIC physics agenda



- characterize collision at freezeout
- find critical point
- measure properties of quark-gluon plasma

RHIC results: particle ratios

Phobos preliminary

In an equilibrium system, two parameters are sufficient to predict the "chemical" mix:

(# pions) / (# protons)
(# kaons) / (# pions)
(# anti-protons)/(# protons)
et cetera.

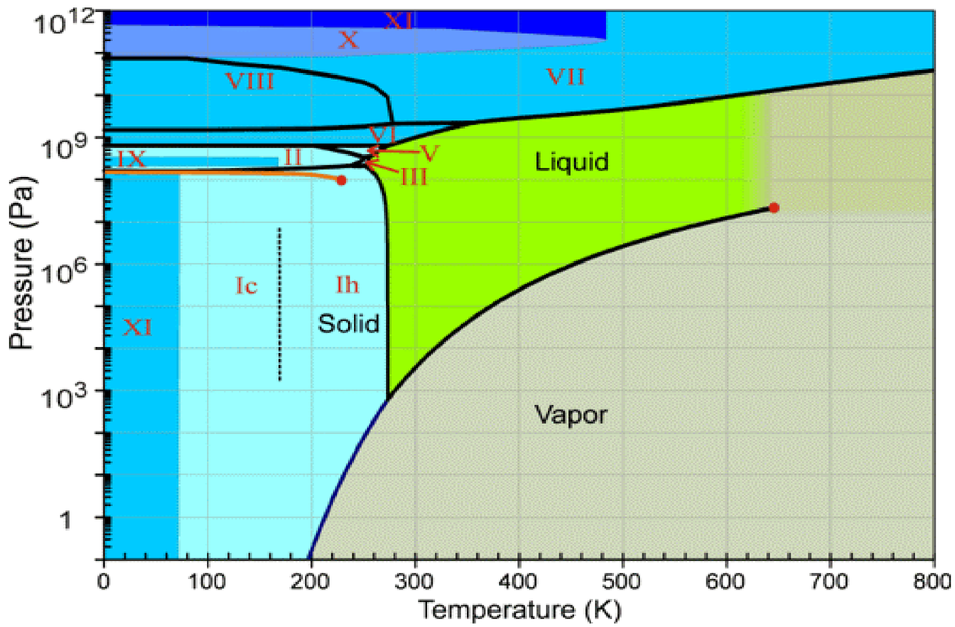
$$\frac{\pi^-}{\pi^+} = 1.025 \pm 0.006(stat) \pm 0.020(sys)$$

$$\frac{K^-}{K^+} = 0.95 \pm 0.03(stat) \pm 0.04(sys)$$

$$\frac{\bar{p}}{p} = 0.74 \pm 0.02(stat) \pm 0.03(sys)$$

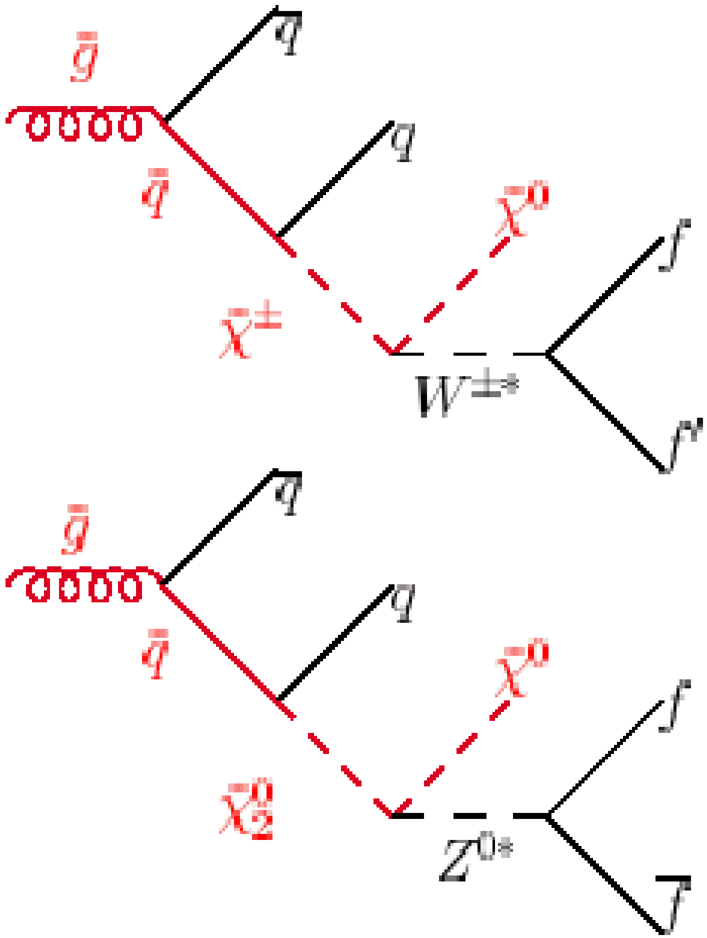
→ **Temperature (T)**
and "net amount of matter" (μ_B)

The phase diagram of water II



Ice polymorph	Density,[a] g cm^{-3}	Protons	Crystal	Symmetry	Dielectric, e_s	Notes
Ih, **Hexagonal ice**	0.92	disordered	Hexagonal	one C_6	97.5	
Ic, **Cubic ice**	0.92	disordered	Cubic	four C_3		
Low density amorphous ice[b]	0.94	disordered	Non-crystalline			may be mixtures of several types
High density amorphous ice[c]	1.17	disordered	Non-crystalline			may be mixtures of several types
II, **Ice-two**	1.17	ordered	Rhombohedral	one C_3	3.66	
III, **Ice-three**	1.14	disordered	Tetragonal	one C_4	117	protons may be partially ordered
IV, Ice-four	1.27	disordered	Rhombohedral	one C_3		metastable in ice V phase space
V, Ice-five	1.23	disordered	Monoclinic	one C_2	144	protons may be partially ordered
VI, Ice-six	1.31	disordered	Tetragonal[d]	one C_4	193	protons can be partly ordered
VII, Ice-seven	1.50	disordered	Cubic[d]	four C_3		two interpenetrating ice Ic frameworks
VIII, Ice-eight	1.46	ordered	Tetragonal[d]	one C_4		low temperature form of ice VII
IX, Ice-nine	1.16	ordered	Tetragonal	one C_4	3.74	low temperature form of ice III
X, Ice-ten	2.51	symmetric	Cubic[d]	four C_3		symmetric proton form of ice VII
XI, **Ice-eleven**	0.92	ordered	Orthorhombic	three C_2		low temperature form of ice Ih
XI, Ice-eleven	>2.51	symmetric	Hexagonal[d]	distorted		Found in simulations only
XII, Ice-twelve	1.29	disordered	Tetragonal	one C_4		metastable in ice V phase space

$\tilde{q}$ and $\tilde{g}$ searches at the Tevatron



Several signatures:

- Dileptons + jets + $\not{E}_T$

  CDF, PRL **87**, 251803 (2001)

  D0, PRD-RC **63**, 091102 (2001)

- Multijets + $\not{E}_T$

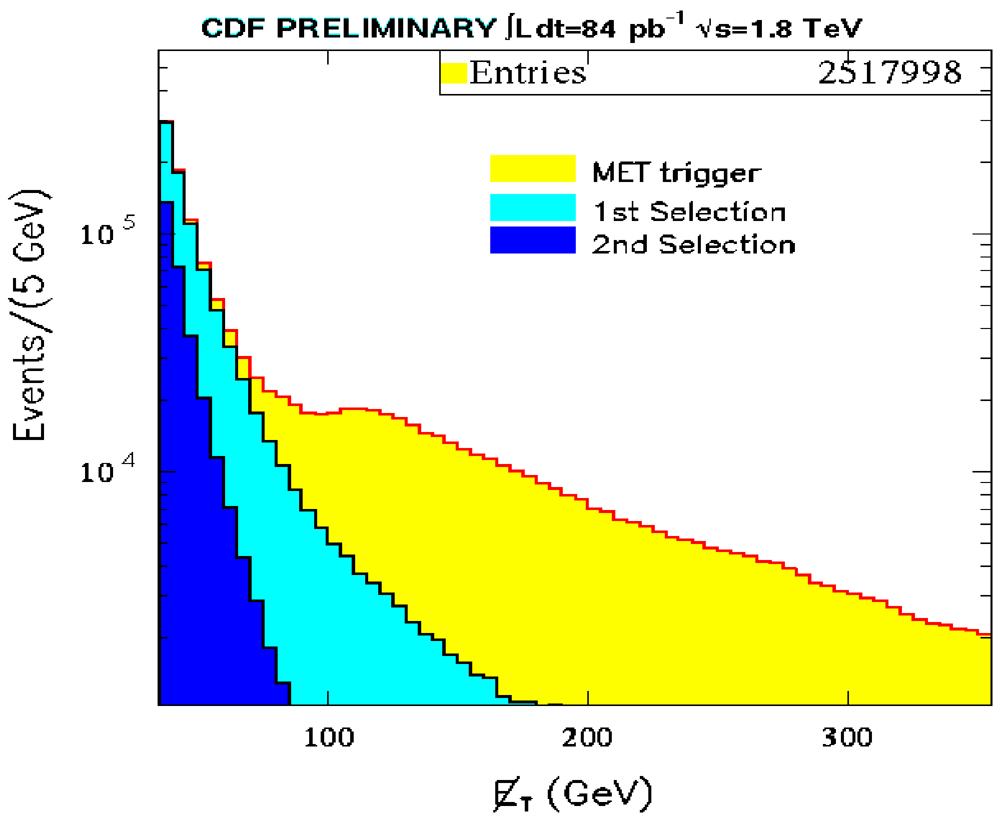
  CDF, PRL **88**, 041801 (2002)

  D0, PRL **83**, 4937 (1999)

- $e^\pm$ + jets + $\not{E}_T$

  D0, hep-ex/0205002

$\not{E}_T$ + jets search



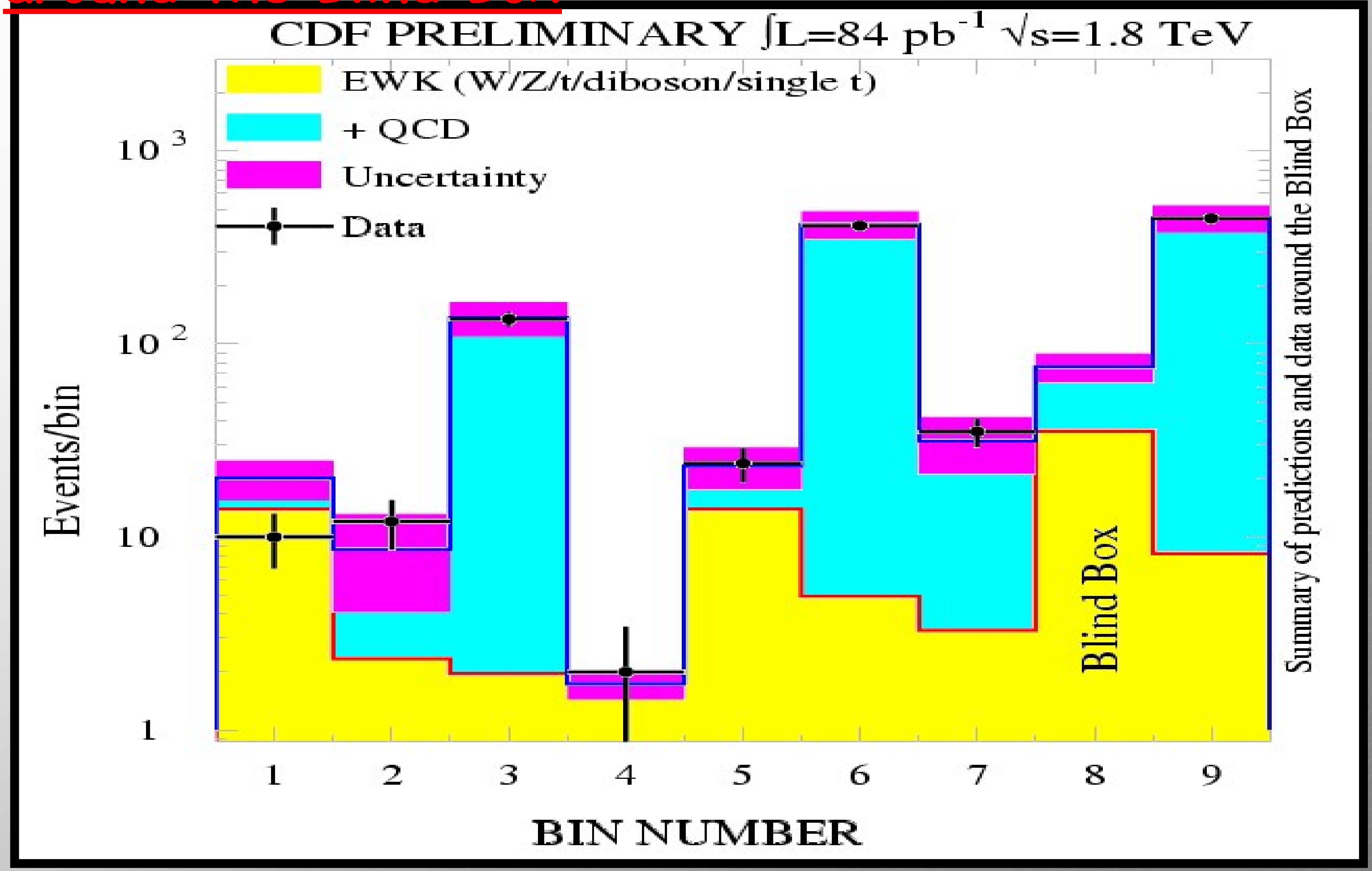
MISSING ENERGY + MULTIJET STANDARD MODEL COMPONENT

- $Z(\to ll) + \text{jets}$
- $W(\to l\nu) + \text{jets}$
- $t\bar{t}$, single top
- Diboson
- QCD multijet

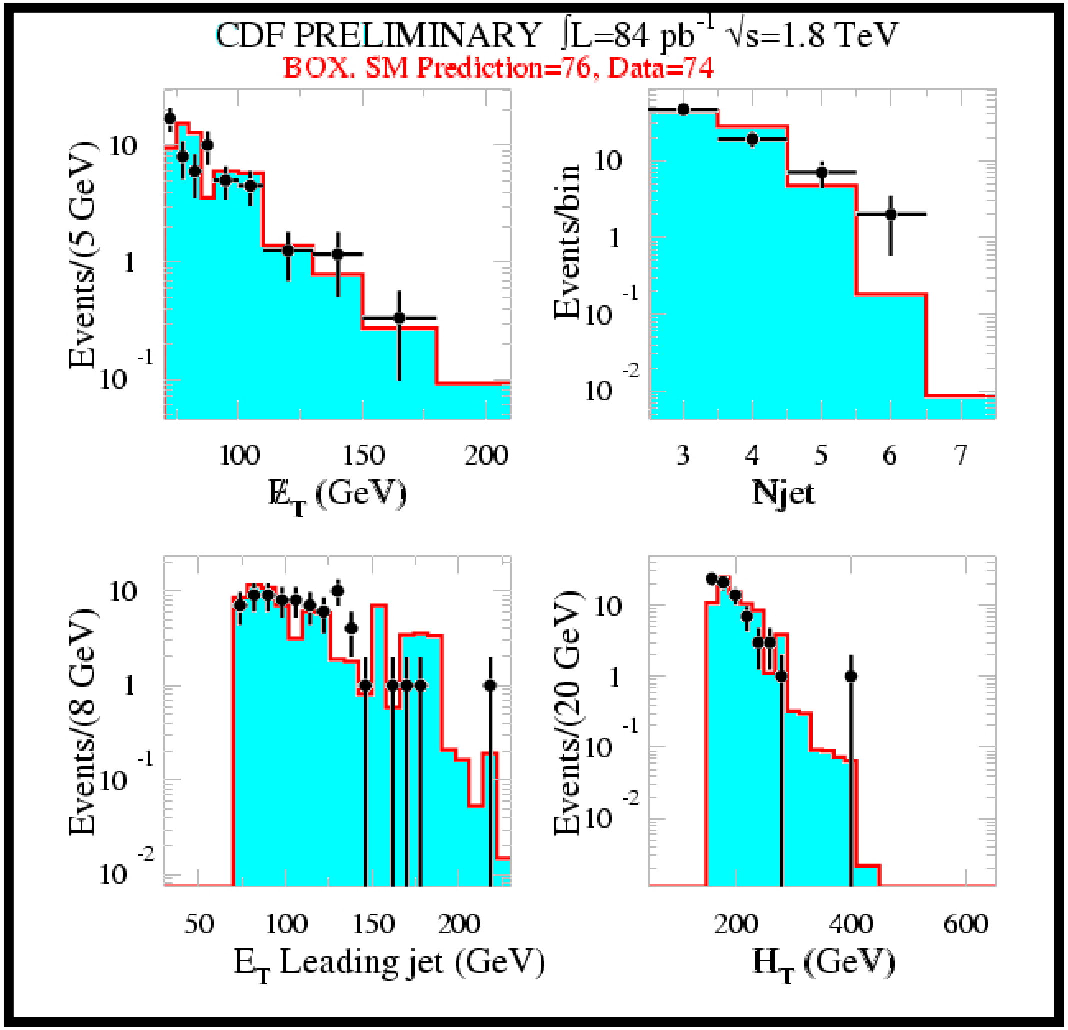
EWK

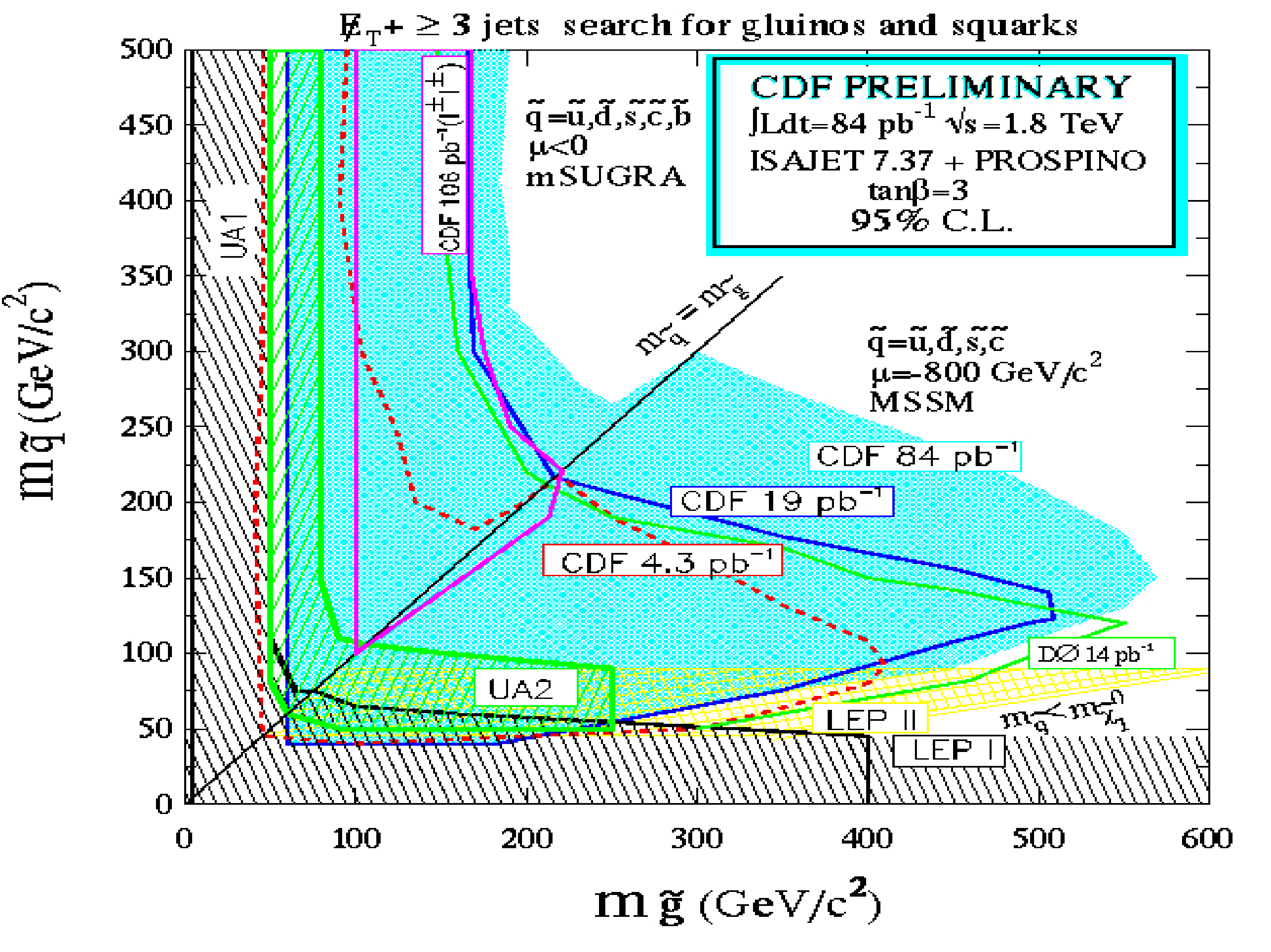
Note: The missing energy is a QCD sample

Comparisons SM predictions-Data around the Blind Box



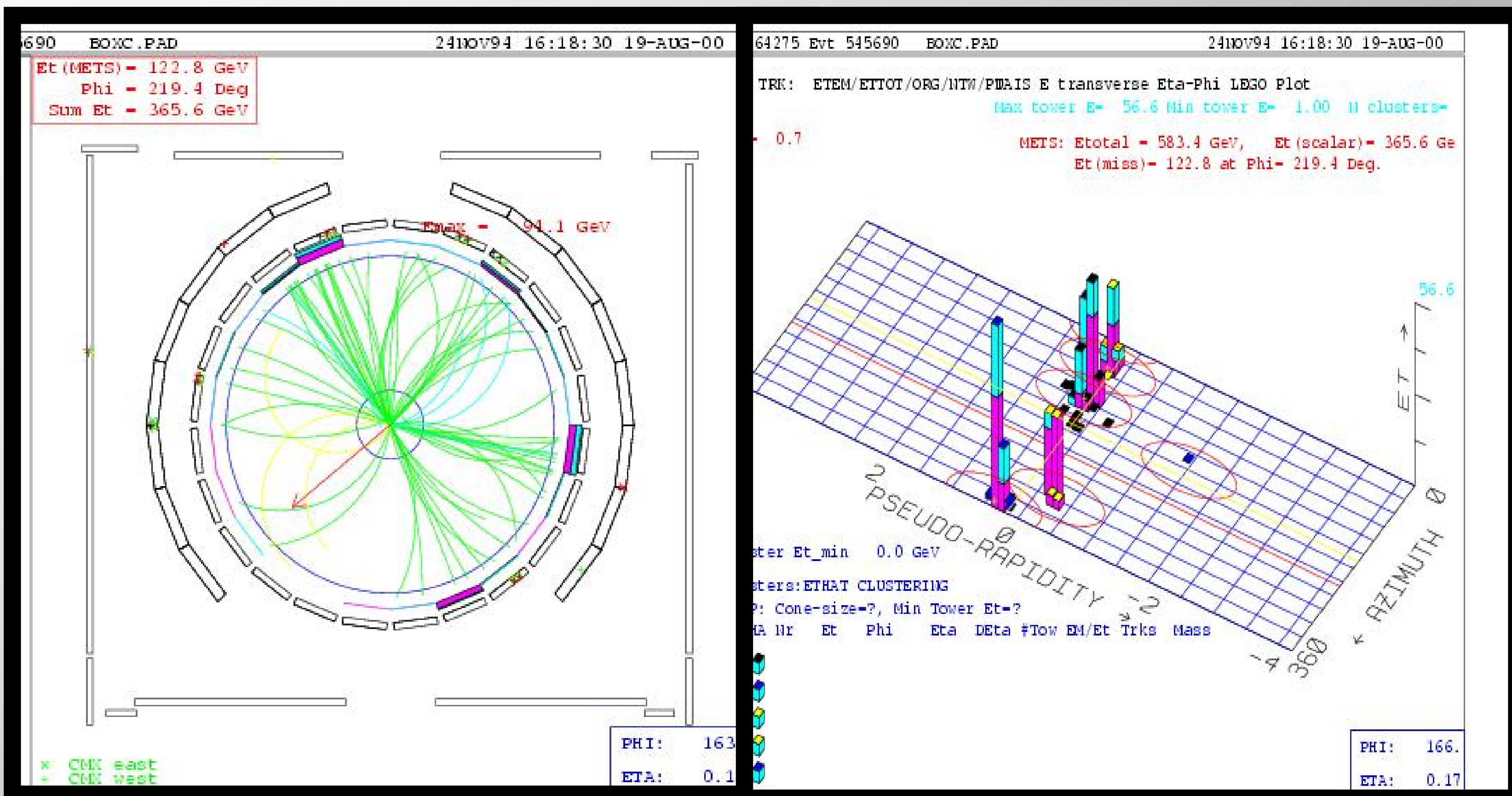
$\not\!\!E_T$ + jets search





$\not E_T + \geq 3$ jets search for gluinos and squarks
CDF PRELIMINARY
∫Ldt=84 pb^{-1} √s=1.8 TeV
ISAJET 7.37 + PROSPINO
tanβ=3
95% C.L.
$\tilde{q}=\tilde{u},\tilde{d},\tilde{s},\tilde{c},\tilde{b}$
μ<0
mSUGRA
CDF 106 pb^{-1}($l^{\pm}l^{\pm}$)
UA1
$m_{\tilde{q}} = m_{\tilde{g}}$
$\tilde{q}=\tilde{u},\tilde{d},\tilde{s},\tilde{c}$
μ=-800 GeV/c^2
MSSM
CDF 84 pb^{-1}
CDF 19 pb^{-1}
CDF 4.3 pb^{-1}
DØ 14 pb^{-1}
UA2
LEP II
LEP I
$m_{\tilde{q}} < m_{\tilde{\chi}_1^0}$
$m_{\tilde{q}}$ (GeV/c^2)
$m_{\tilde{g}}$ (GeV/c^2)
0
50
100
150
200
250
300
350
400
450
500
600

gluino candidate event



attacking the Big questions

- what is the dark matter?
- what is the structure of spacetime?

what is the dark matter?

• stable weakly interacting massive particles (WIMPS) are attractive CDM candidates

• for large portions of the parameter space of R-parity conserving SUSY models, the weakly interacting massive *neutralino* is the stable LSP

How do we test this?

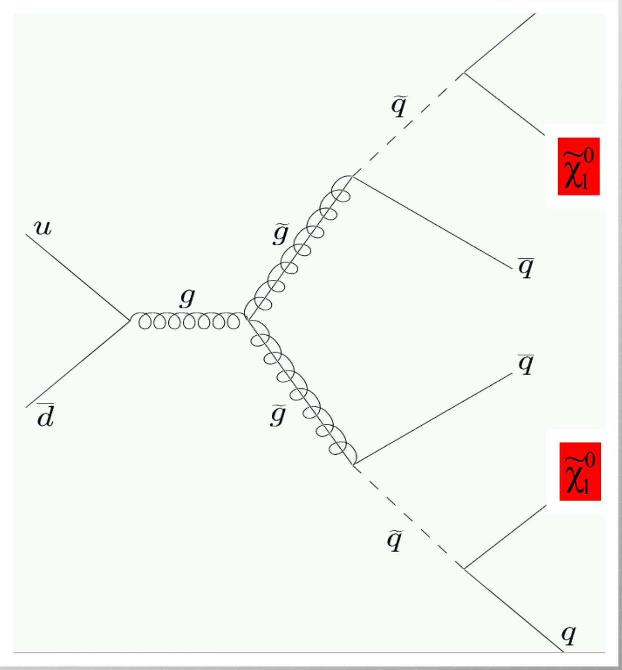
what is the dark matter?

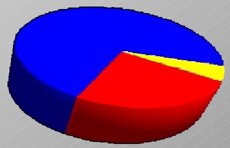
a 5-pronged attack:

- study DM distributions, clustering
- look for high energy gamma rays from neutralino annihilation in the cosmos
- look for high energy neutrinos from neutralino annihilation in the Sun
- detect DM particles coming from space
- **produce neutralinos in colliders!**

talks by J. Annis S. Asztalos, L. Baudis, P. Johansson, C. Kao, T. Okamoto

what is the dark matter?





Is this the
dark matter?

We will have a definitive answer within about 5 years!

what is the structure of spacetime?

Really many questions, all hard:

- large-scale structure of spacetime?
- microscopic structure of spacetime?
- extra dimensions of spacetime?
- quantum dynamics of spacetime?

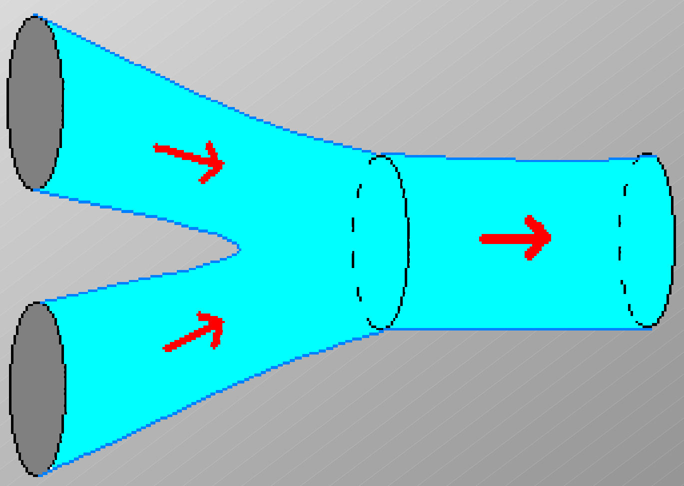
- microscopic structure of spacetime?
- extra dimensions of spacetime?
- quantum dynamics of spacetime?

strings

talk by Ashoke Sen

strings

- require 7 extra space dimensions
- and give us ways to hide them



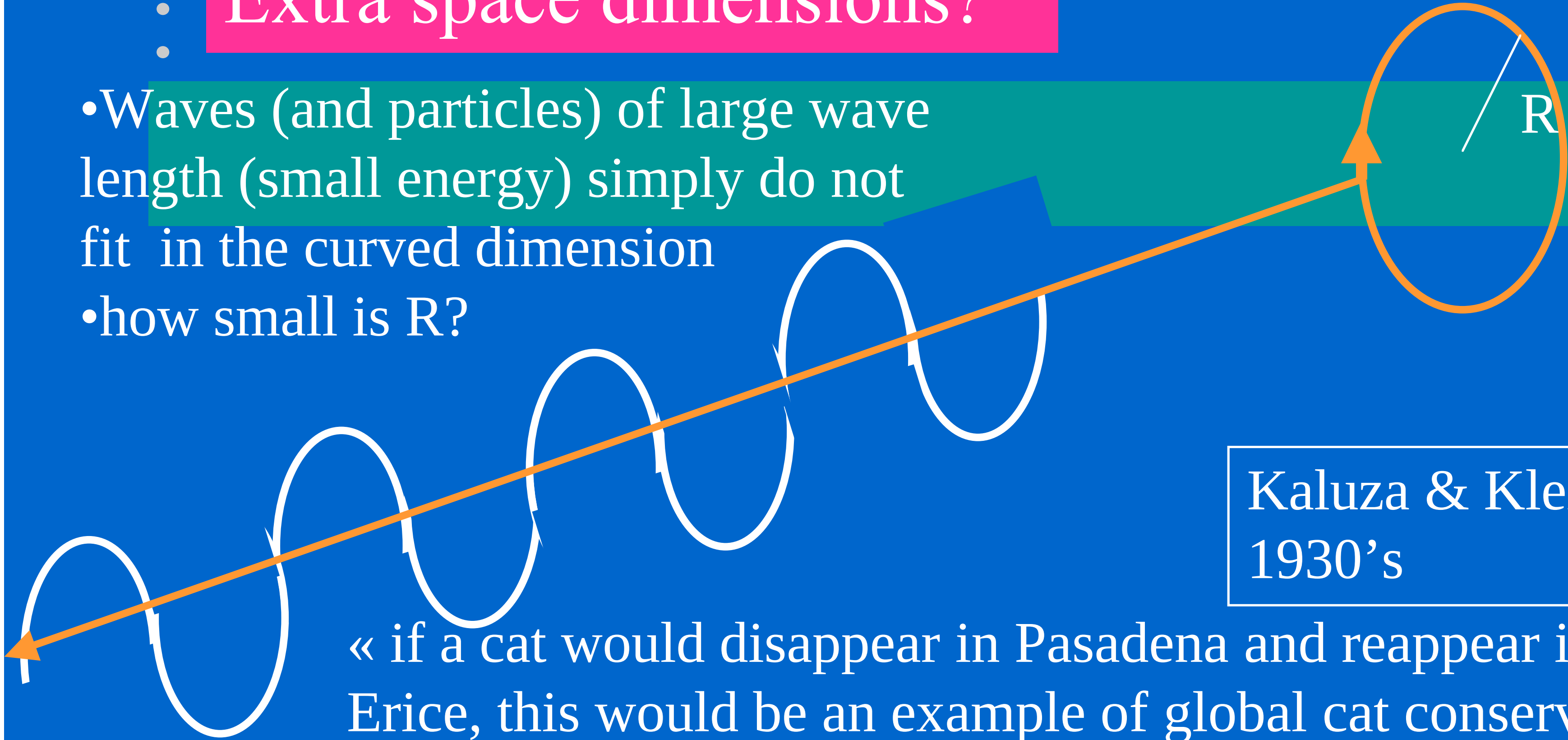
6 or 7 extra dimensions?

Experiments can actually discover them!

String theory demands extra dimensions.

Extra space dimensions?

- Waves (and particles) of large wave length (small energy) simply do not fit in the curved dimension
- how small is R?



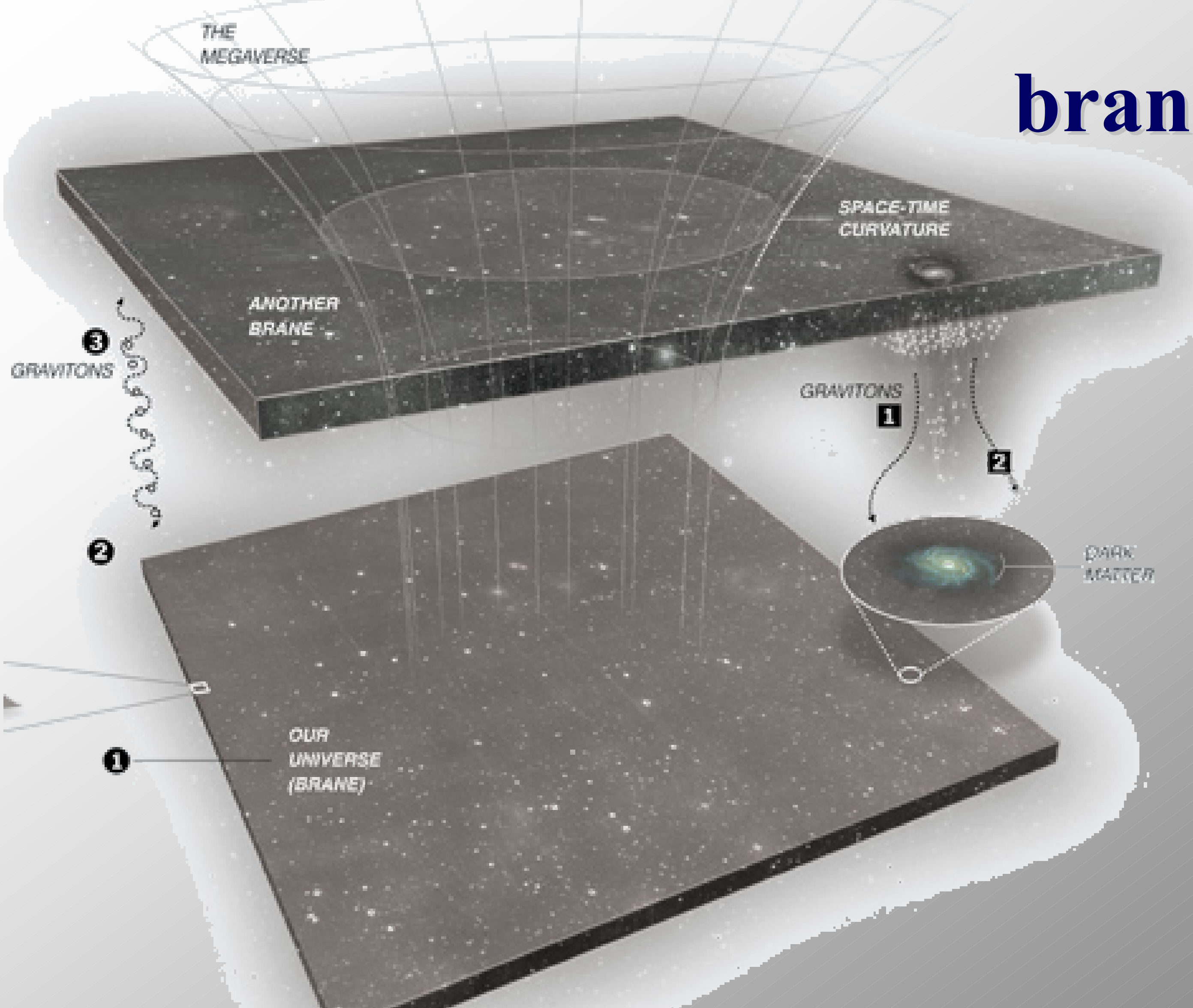
Kaluza & Klein
1930's

« if a cat would disappear in Pasadena and reappear in Erice, this would be an example of global cat conservation. This is not the way cats are conserved » (R.P. Feynman)

.... in 4 dimensions

Superstring theory not consistent in 4 dimensions
Extra curved dimensions required
Scale? $\approx 1/M_{Planck}$?

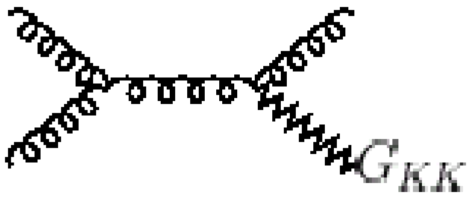
brane-worlds



Standard Model particles are trapped on a brane and can't move in the extra dimensions

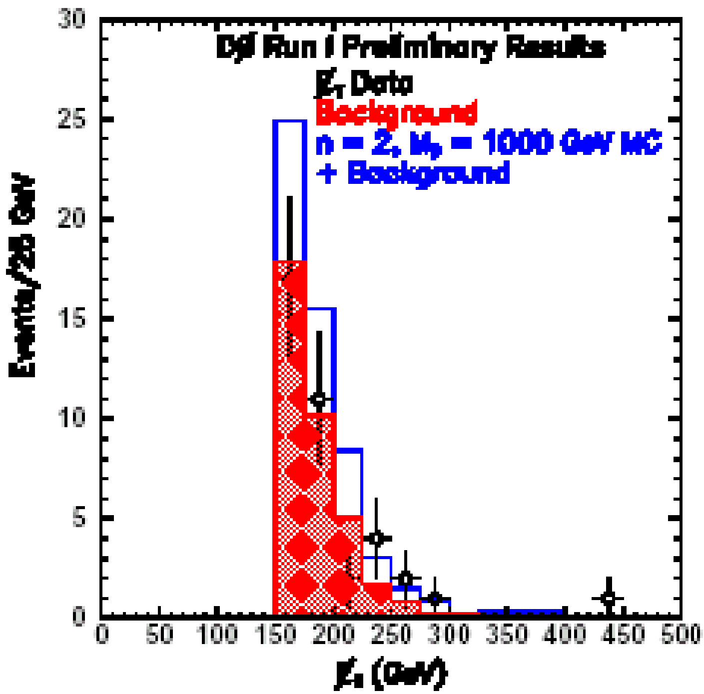
How do we look for graviton production (from large extra dimensions) at hadron colliders?

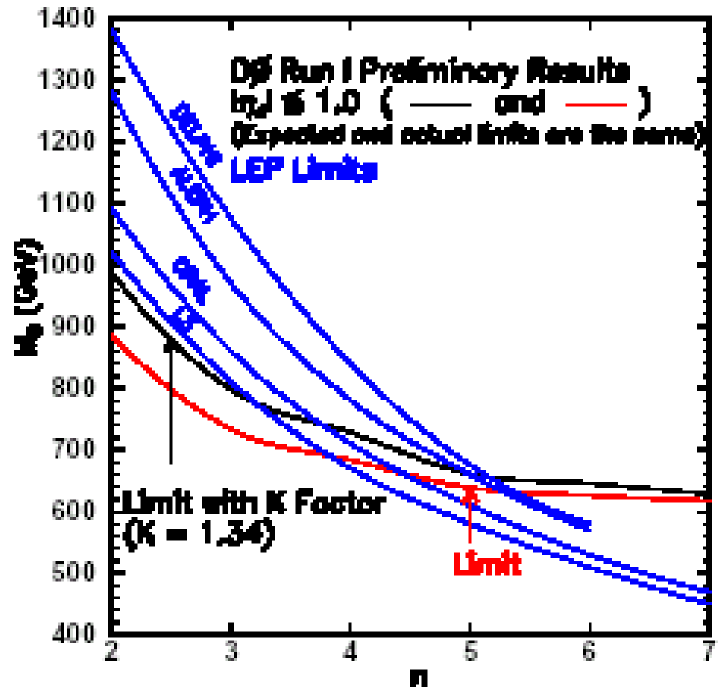
Gravitons at the Tevatron



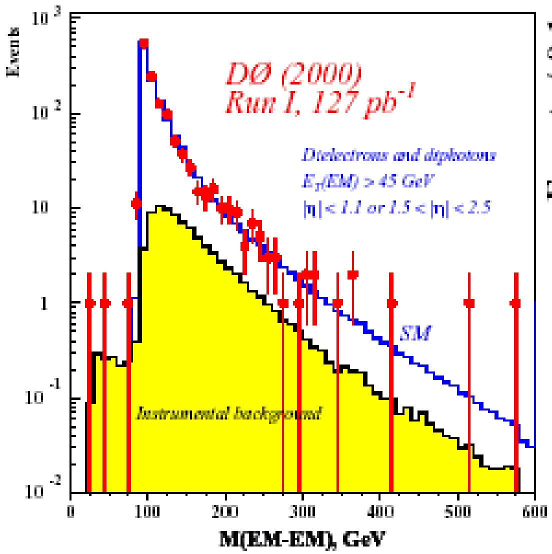
Bkgds	
W & Z	30.2 ± 6.4
QCD & cosmics	7.8 ± 7.1
Observed	38

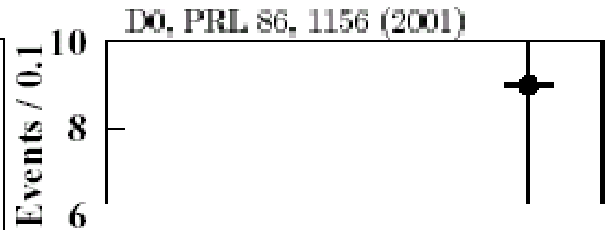
E_T^1 and $\not\!\!E_T > 150$ GeV, $E_T^2 < 50$ GeV





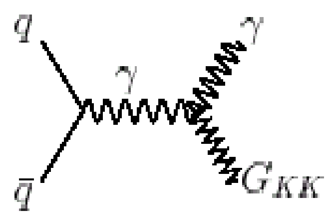
Extra dimension search in $\gamma\gamma$

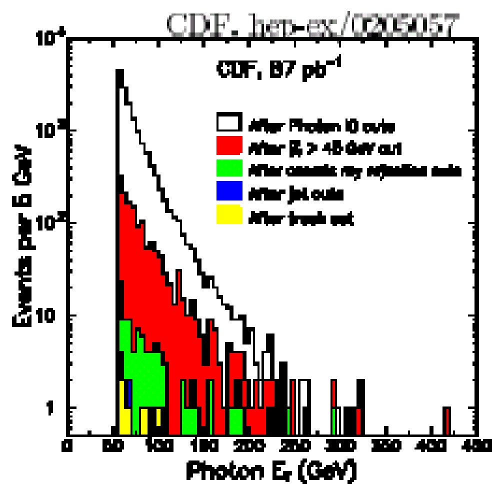




Limits: $M_s > 1.01$ TeV for $\lambda = -$

Gravitons at the Tevatron



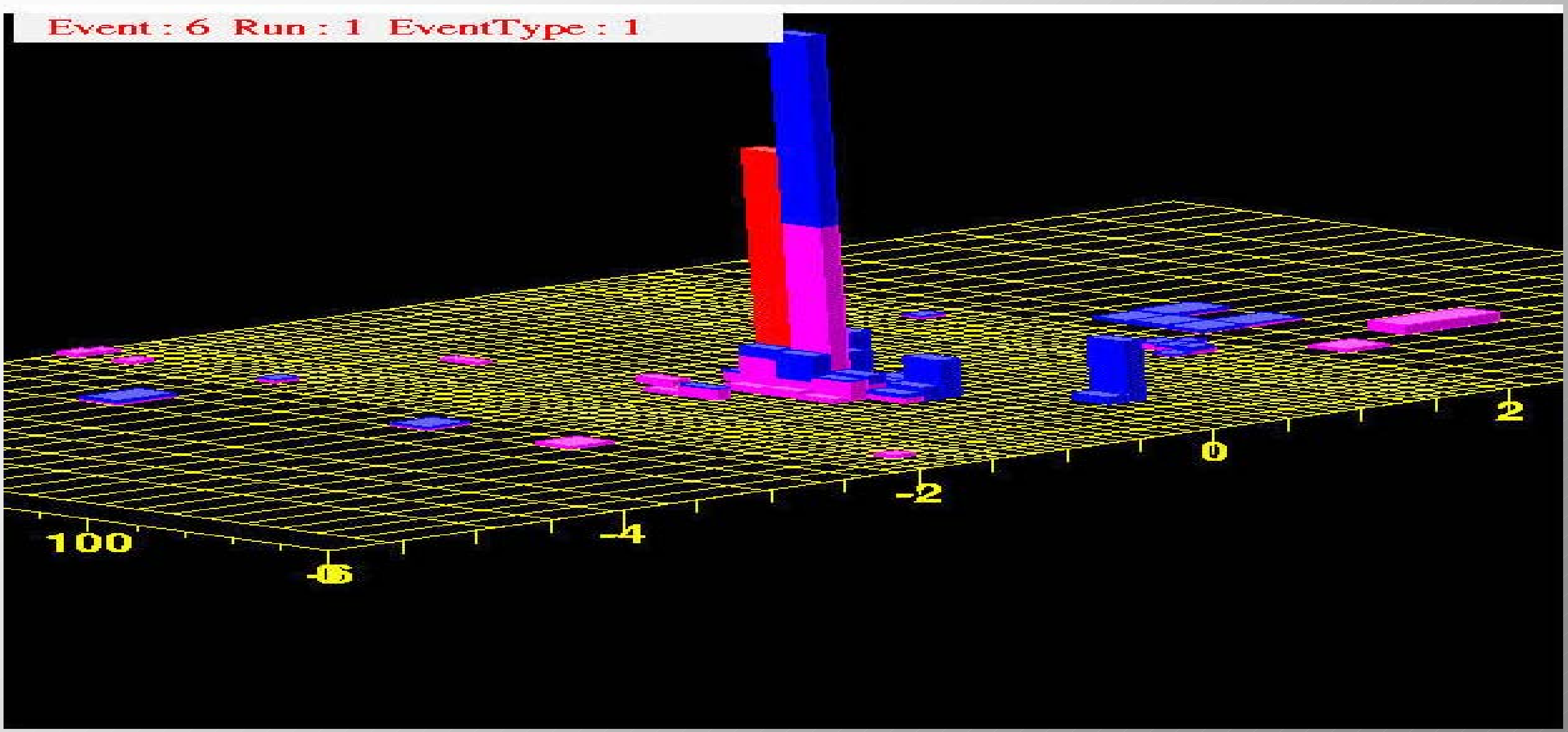


Background sources (note: numbers do not add due to rounding).

Cosmic rays	6.3 ± 2.0
$Z\gamma \to \nu\bar{\nu}\gamma$	3.2 ± 1.0
$W \to e\nu$	0.9 ± 0.1
Prompt diphotons	0.4 ± 0.1
$W\gamma$	0.3 ± 0.1
Total non-QCD background	11.0 ± 2.2
QCD background	0.9^{*}
Total observed	11

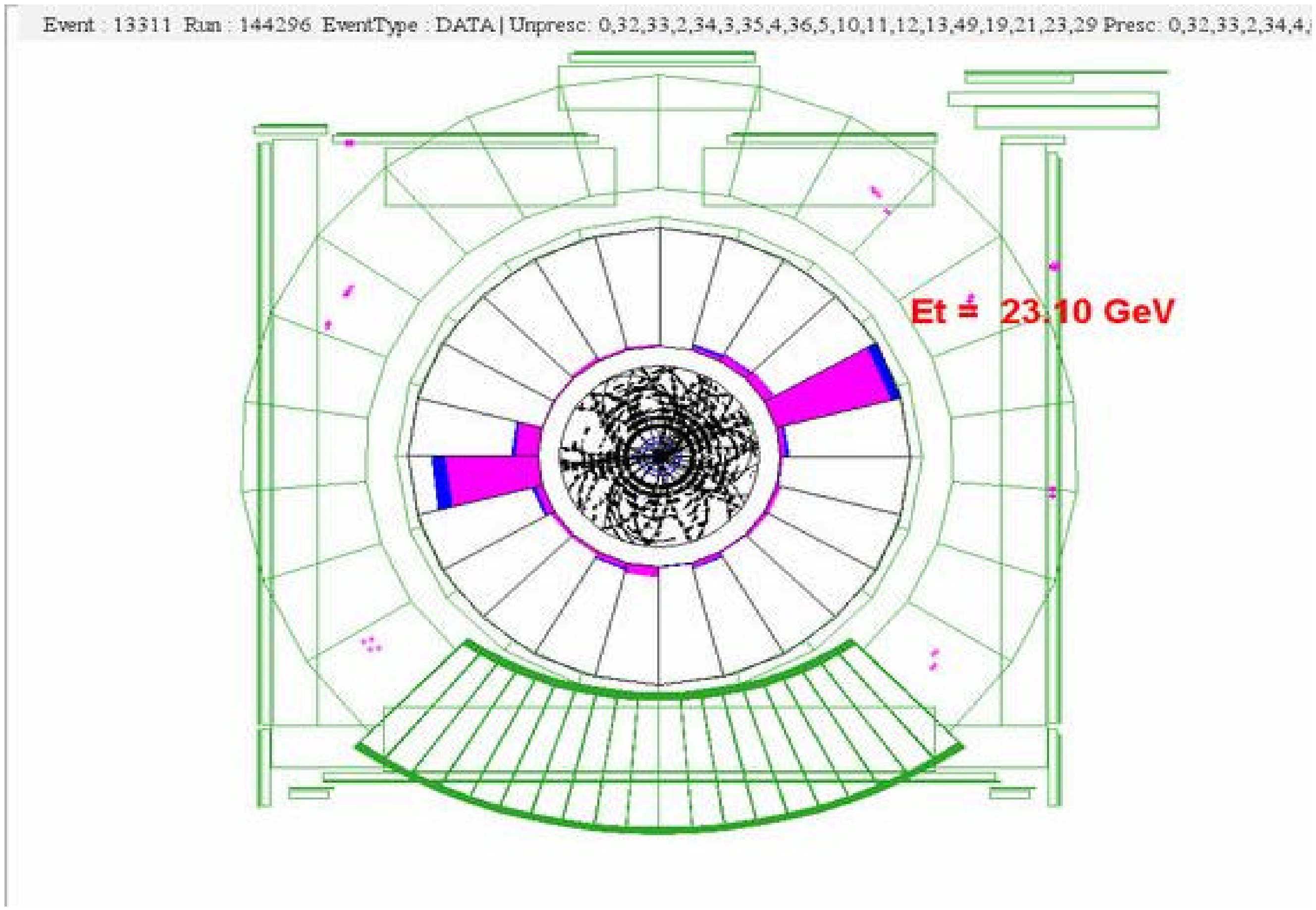
* Estimate. The uncertainty in this background is large, and this background is not considered when setting limits.

Limits
$M_D > 0.55$ TeV for n=4
$M_D > 0.58$ TeV for n=6
$M_D > 0.60$ TeV for n=8



Only qqbar->g G (PYTHIA 6.115 + graviton process), δ=6, M=1TeV, $\sqrt{s}$=2TeV, GEANT CDF preliminary RUNII simulation and display

Visions of Future



HEPAP Subpanel on Long Range Planning

- Process
- Recommendations
- Long Range Plan

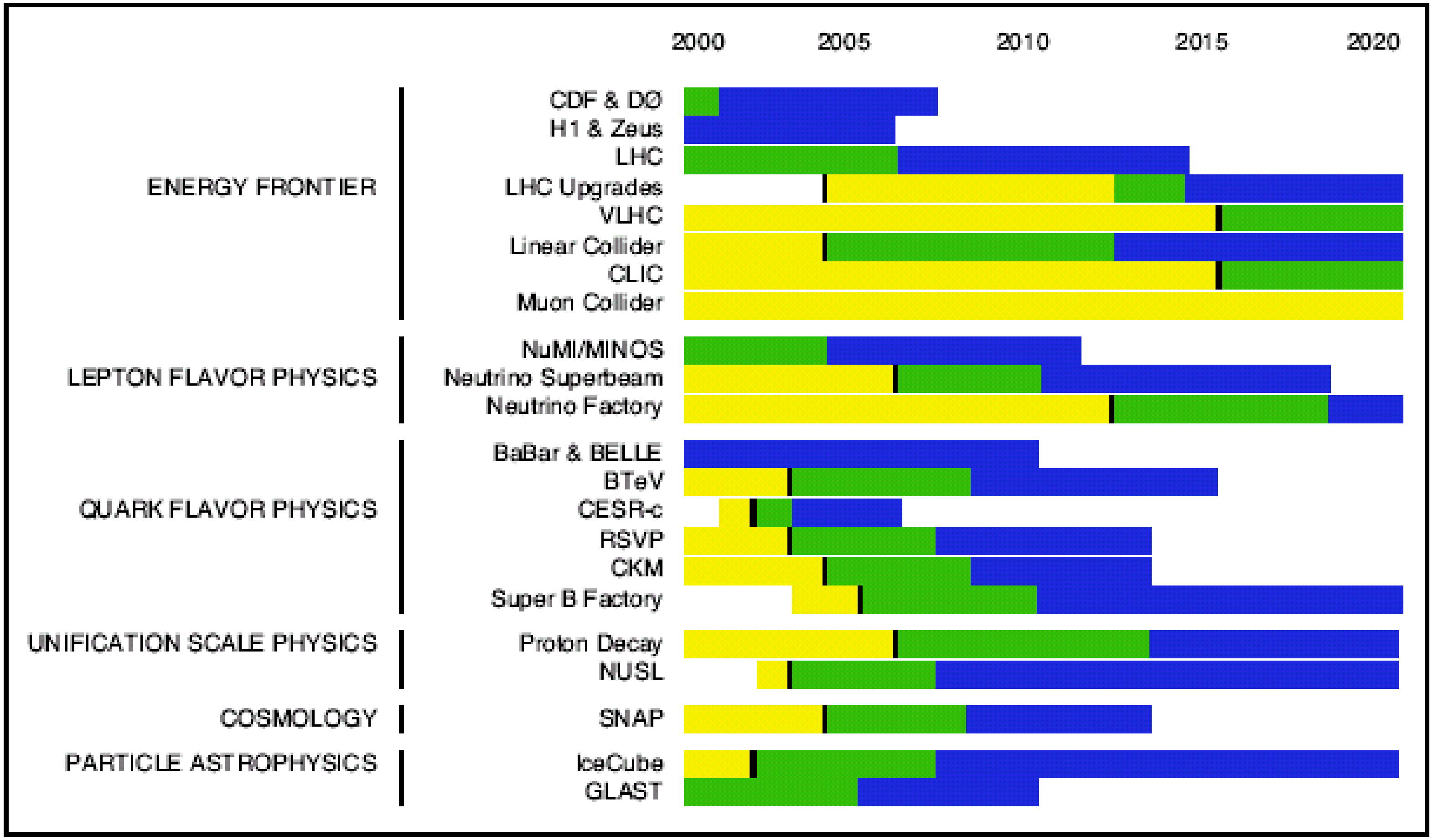
Web site: http://doe-hep.hep.net/lrp_panel/

Subpanel Membership

Jonathan Bagger - Johns Hopkins University (Co-Chair)
Barry Barish - California Institute of Technology (Co-Chair)

Paul Avery - University of Florida
Janet Conrad - Columbia University
Persis Drell - Cornell University
Glennys Farrar - New York University
Larry Gladney - Univ of Pennsylvania
Don Hartill - Cornell University
Norbert Holtkamp - Oak Ridge Natl Lab
George Kalmus - Rutherford Appleton Lab
Rocky Kolb - Fermilab
Joseph Lykken - Fermilab
William Marciano - Brookhaven Natl Lab
John Marriner - Fermilab
Jay Marx - Lawrence Berkeley National Lab
Kevin McFarland - University of Rochester
Hitoshi Murayama - Univ of Calif, Berkeley
Yorikiyo Nagashima - Osaka University
Rene Ong - Univ of Calif, Los Angeles
Tor Raubenheimer - SLAC
Abraham Seiden - Univ of Calif, Santa Cruz
Melvyn Shochet - University of Chicago
William Willis - Columbia University
Fred Gilman (Ex-Officio) - Carnegie Mellon
Glen Crawford (Executive Secretary) - DOE

The Particle Physics Roadmap



Not all projects illustrated on the roadmap can be pursued.

What is the Next Big Step?

Exploration of the TeV Scale

- This exploration requires the CERN LHC –
  - A proton-proton collider with an energy seven times that of the Tevatron.

- Together with a high-energy e+e- linear collider.
  - The LHC and a linear collider are both necessary to discover and understand the new physics at the TeV scale.
  - A coherent approach, exploiting the strengths of both machines, will maximize the scientific contributions of each.

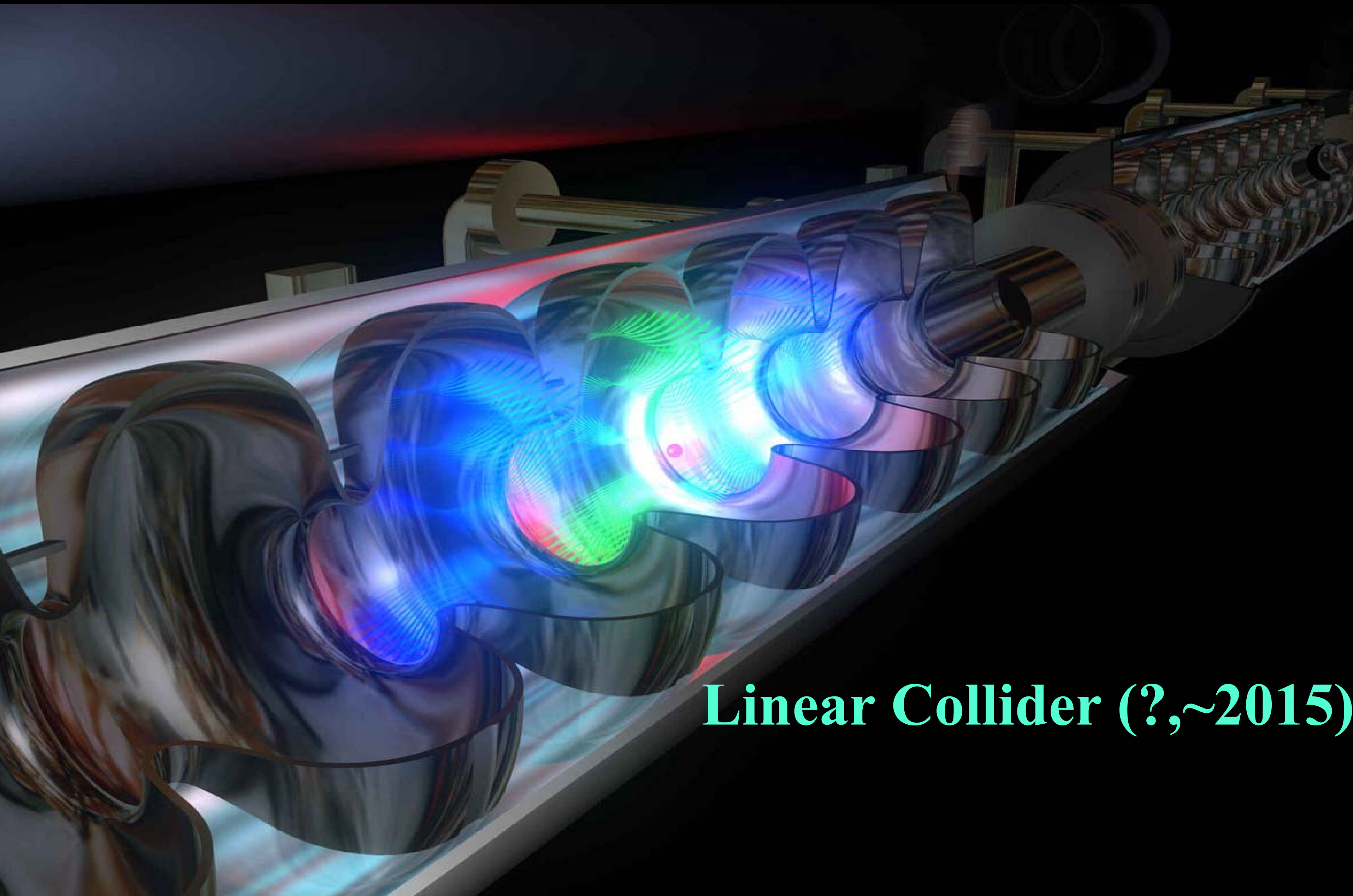
The centerpiece of our roadmap is the thorough exploration of the TeV scale.

new accelerators for new physics

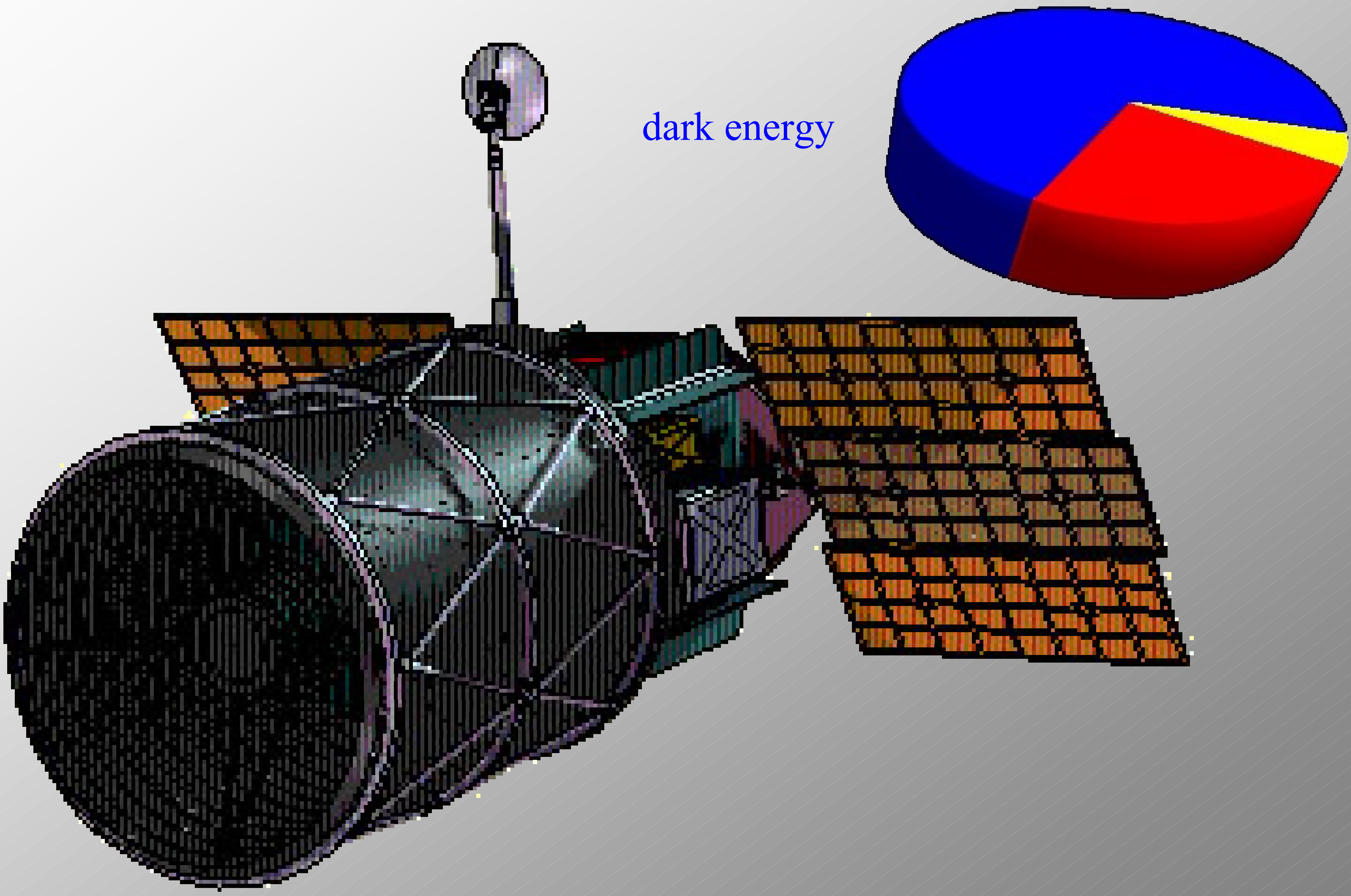
Large Hadron Collider (CERN, 2007)

ATLAS shaft and service cavern

new accelerators for new physics



underground and in the sky



SuperNova Acceleration Probe (SNAP)

the triple coincidence problem

How can it be that we are experiencing, *at the same time*,

- the Golden Age of flavor physics
- the Golden Age of cosmology
- the advent of the Higgs and the new physics of the TeV scale

Answer: particle physics is an amazingly vital field!