Experimental Particles Physics:

Search for the Origin of Mass and Matter

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Johns Hopkins University

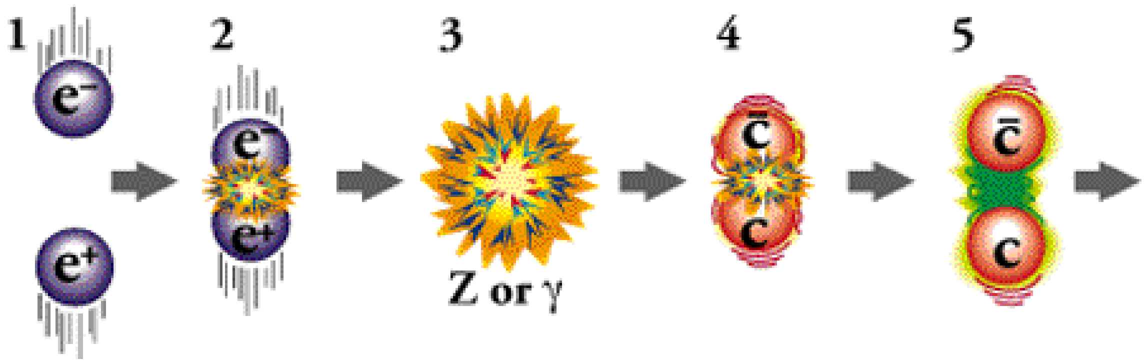
March 27, 2006

Graduate Student Seminar

OUTLINE

Experimental High Energy Physics Group at Jonns Hopkins

- Who we are
- What we are doing
- Why we are doing this
- How we do this
- Where you can contribute



Experimental High Energy Physics Group

- Experimental HEP faculty at JHU:

Bruce Barnett (CDF and CMS)

Barry Blumenfeld (CDF and CMS)

Chih-Yung Chien (CMS)

Andrei Gritsan (BaBar and CMS)

Petar Maksimovic (CDF and CMS)

Morris Swartz (CMS)

  – CDF experiment at proton-antiproton collider at Fermilab
  – BaBar experiment at electron-positron collider at Stanford
  – CMS near-future experiment at proton-proton collider in Europe

Experimental High Energy Physics Group

- Postdoctoral researchers:

  Satyajit Behari (CDF, at Fermilab)

  Zijin Guo (BaBar, in Bloomberg)

  Dongwook Kim (CMS, at Fermilab)

- Graduate students:

  Yanyan Gao (BaBar, in Bloomberg)

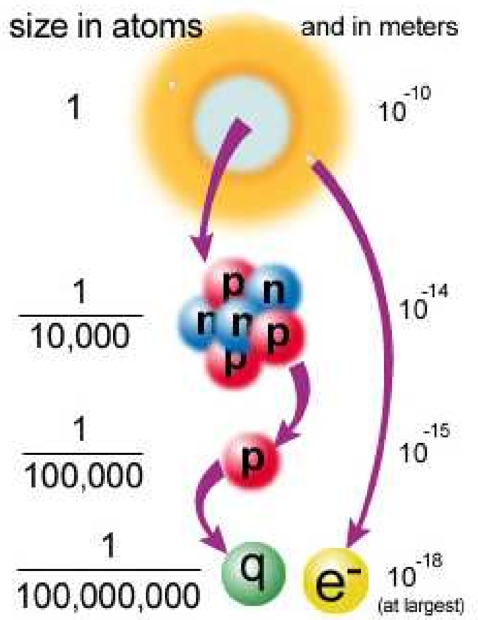
  Mark Mathis (CDF, in Bloomberg)

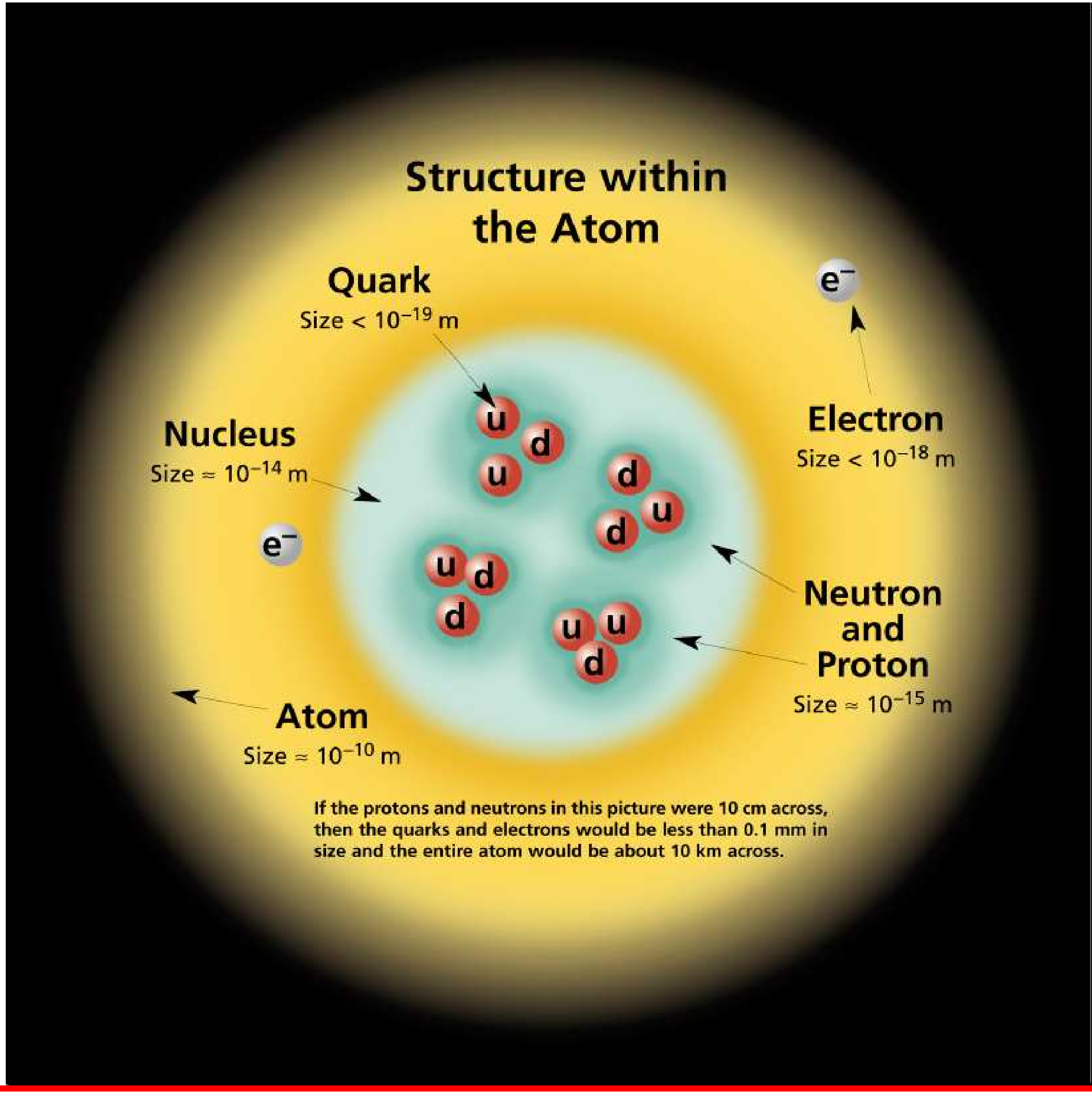
  Reid Mumford (CDF, at Fermilab)

  Jennifer Pursley (CDF, at Fermilab)

- expect new people to join

What We Know about Matter





Study the Standard Model of Matter

- Fermions (spin$=\frac{\hbar}{2}$) $\Rightarrow$ occupy space and constitute matter

matter		anti-matter	
quarks	leptons	anti-quarks	anti-leptons

$$\begin{pmatrix} d \\ s \\ b \end{pmatrix} \begin{pmatrix} u \\ c \\ t \end{pmatrix} \begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix} \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} \qquad \begin{pmatrix} \bar{d} \\ \bar{s} \\ \bar{b} \end{pmatrix} \begin{pmatrix} \bar{u} \\ \bar{c} \\ \bar{t} \end{pmatrix} \begin{pmatrix} \bar{e} \\ \bar{\mu} \\ \bar{\tau} \end{pmatrix} \begin{pmatrix} \bar{\nu}_e \\ \bar{\nu}_\mu \\ \bar{\nu}_\tau \end{pmatrix}$$

-e/3 2e/3 -e 0 Q e/3 -2e/3 e 0

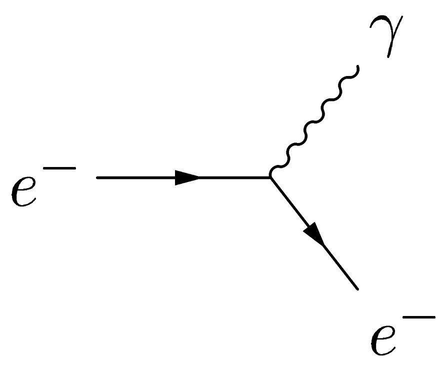
- "Forces" (bosons mediate interactions):

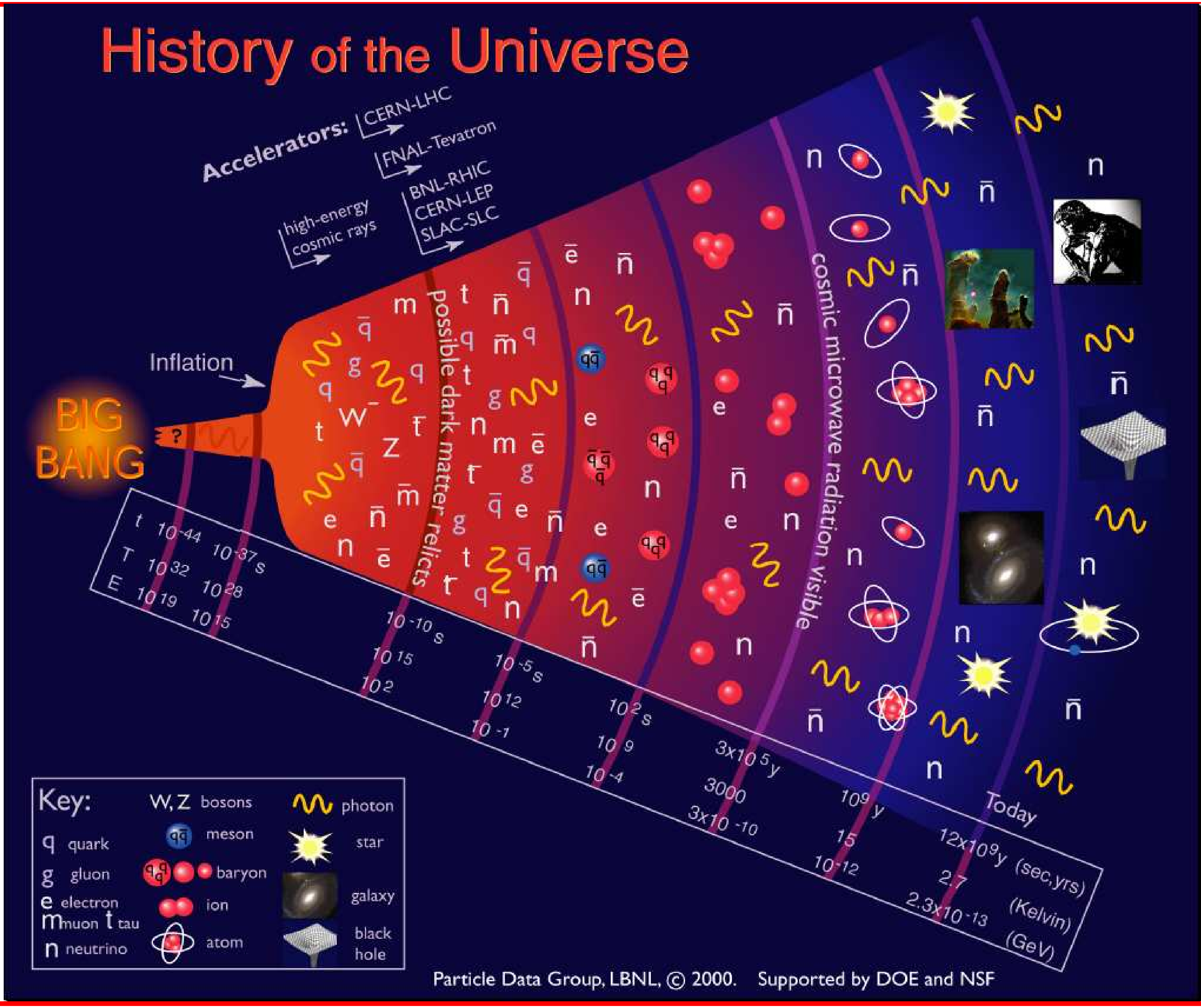
Electromagnetic (γ)

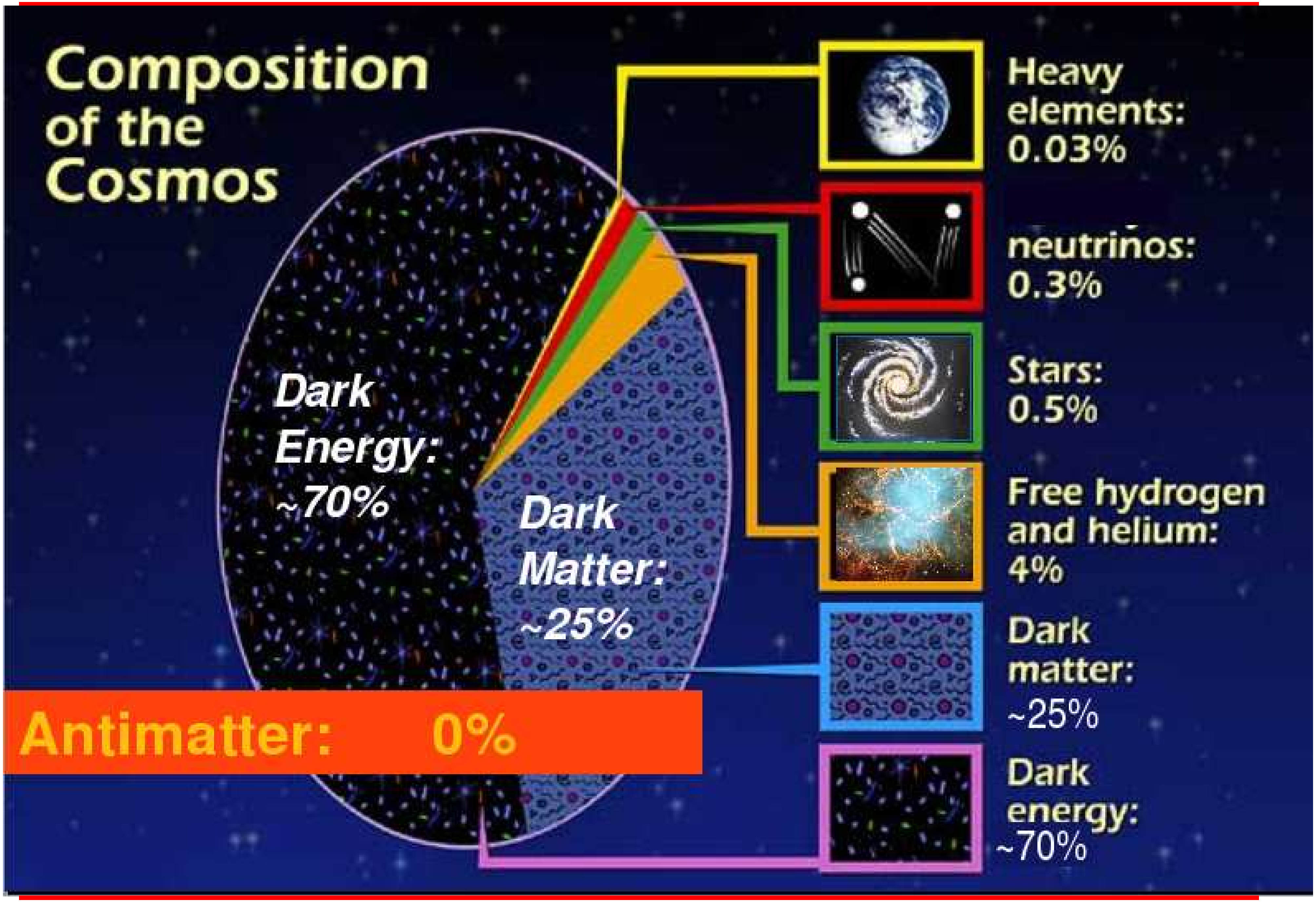
Weak (Z^0, $W^\pm$)

Strong (gluons)

Gravity (not in model yet...)

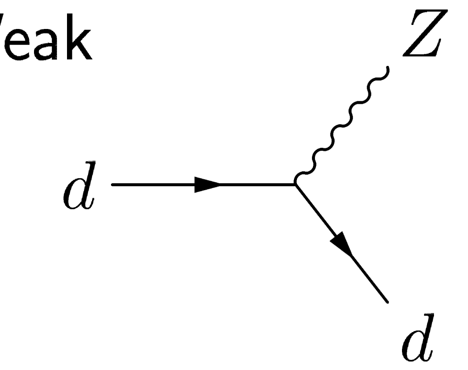



History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relics
cosmic microwave radiation visible
t 10-44 10-37 s
T 10 32 10 28
E 10 19 10 15
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 y
15
10-12
Today
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W,Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

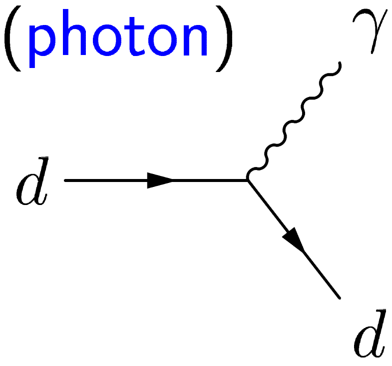

Composition of the Cosmos
Dark Energy: ~70%
Dark Matter: ~25%
Heavy elements: 0.03%
neutrinos: 0.3%
Stars: 0.5%
Free hydrogen and helium: 4%
Dark matter: ~25%
Dark energy: ~70%
Antimatter: 0%

Standard Model of Interactions

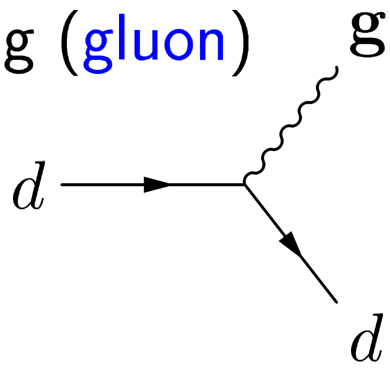
- Weak

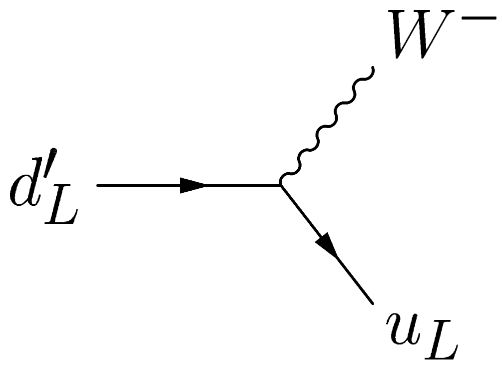


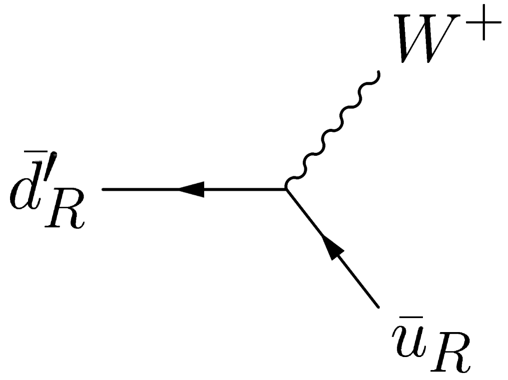
- EM (photon)



- Strong (gluon)







- Weak interactions are special:

  (1) change of quark "flavor" (e.g. $b \to u$)

  $$|d'\rangle = V_{ud} \cdot |d\rangle + V_{us} \cdot |s\rangle + V_{ub} \cdot |b\rangle$$

  (2) couple "left-handed" fermions

  helicity λ = spin·direction $= -\frac{1}{2}$

- Violate Charge and Parity symmetry

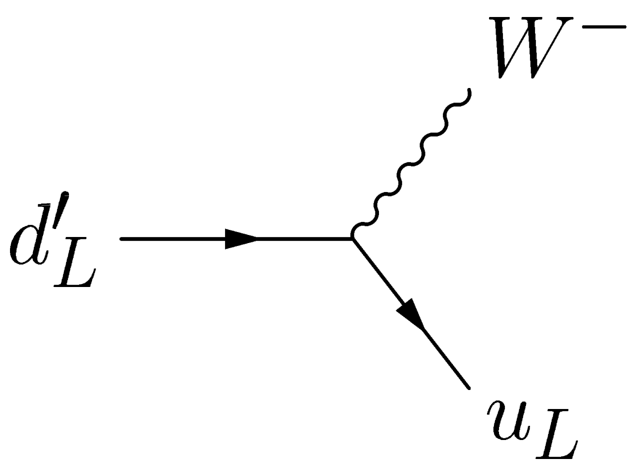
  might violate CP (?)

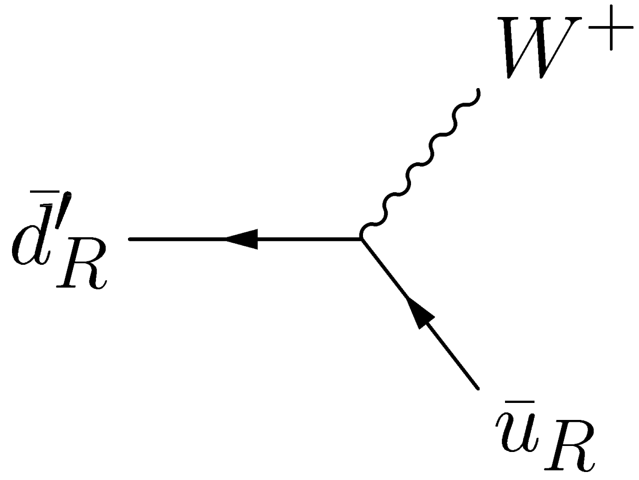
Fundamental Symmetries

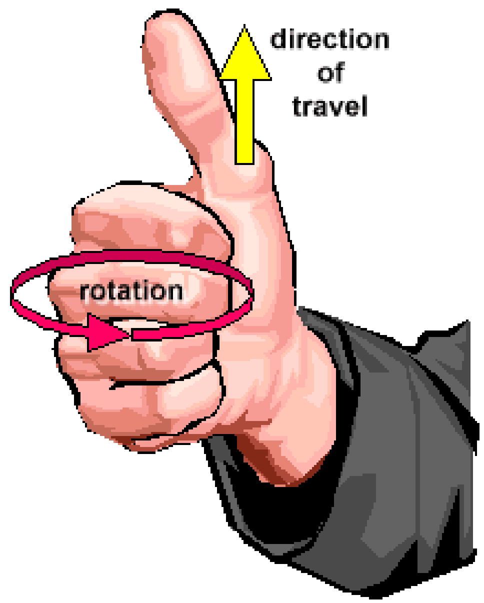
- Symmetries $\Rightarrow$ conservation laws

Charge + Parity (mirror) transformation

Matter $\Longleftrightarrow$ Antimatter



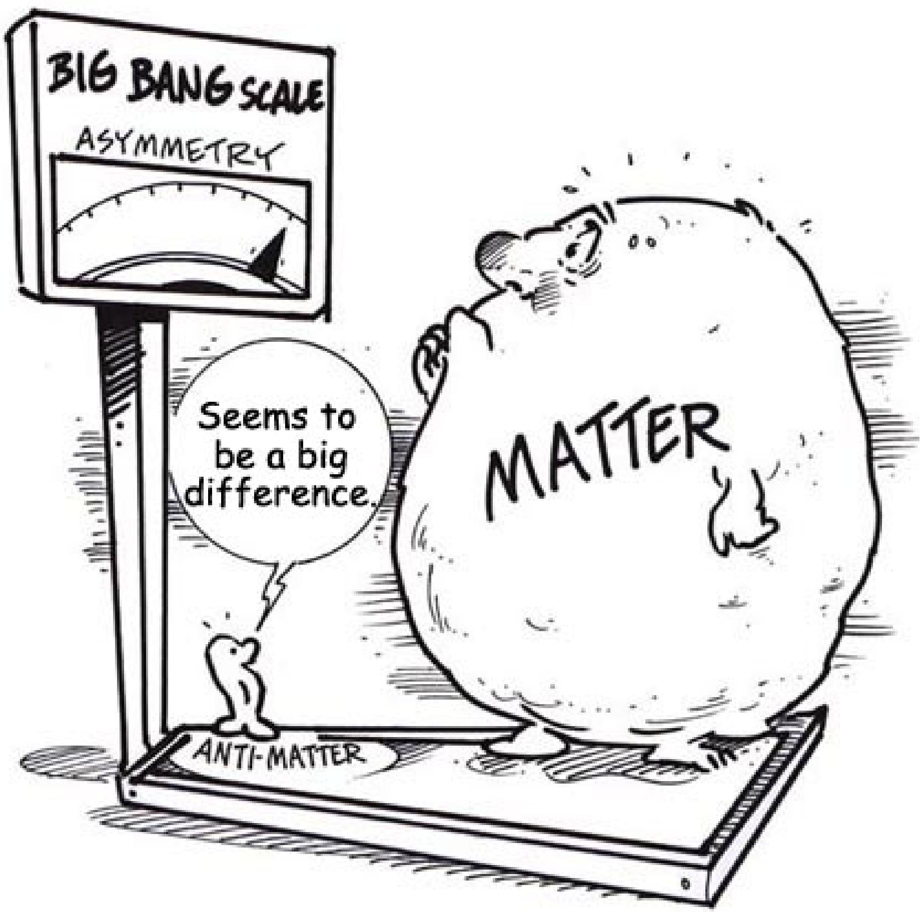




- CP asymmetry $\Longleftrightarrow$ matter and antimatter difference

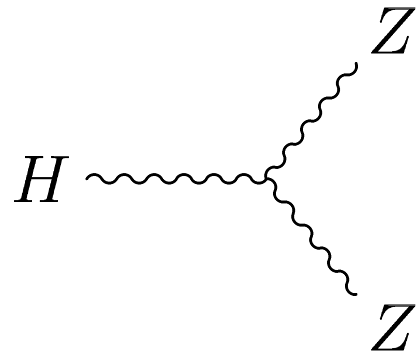
Look Beyond the "Standard Model"

- Why does MATTER dominate (Sakharov):
  - CP-asymmetry
  - baryon non-conservation
  - non-equilibrium



- Need something beyond the SM
  - large CP-asymmetry
  - dark matter ...
  - Higgs and mass hierarchy problem

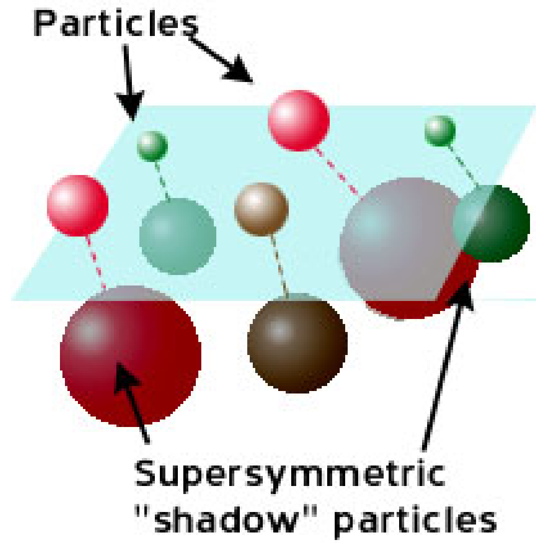
Higgs Particle and "New Physics"



- "Naive" Standard Model $\Rightarrow$ massless particles

  Higgs mechanism (math operation) $\Rightarrow$ masses

  expect Higgs particle (heavy)



- Divergent Higgs mass

  $\Rightarrow$ cancellation with superpartners

- New Models (e.g. SUperSYmmetry)

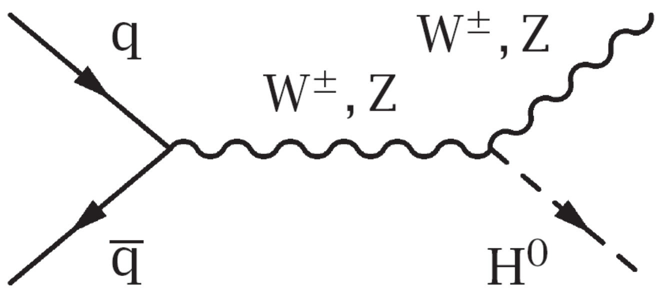
quarks (spin=$\frac{1}{2}$) $\begin{pmatrix} d \\ s \\ b \end{pmatrix} \begin{pmatrix} u \\ c \\ t \end{pmatrix}$ heavy $\rightarrow$ s$\tilde{\text{q}}$uarks (spin=0) $\begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix} \begin{pmatrix} \tilde{u} \\ \tilde{c} \\ \tilde{t} \end{pmatrix}$

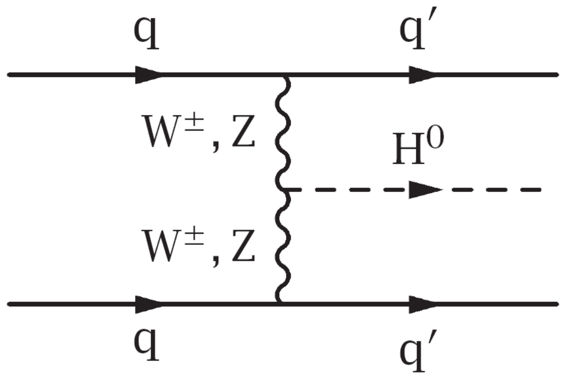
bosons (spin=$1/0$) $W, Z/H$ $\tilde{\chi}_i^0, \tilde{\chi}_i^\pm$ (spin=$\frac{1}{2}$) (dark matter?)

Access to New Particles

- Brute force: new particles at highest energy (e.g. CMS, CDF)

  (exceed current $E = mc^2 \sim 100$ GeV)

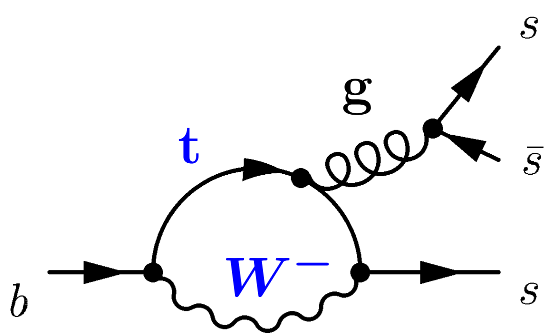


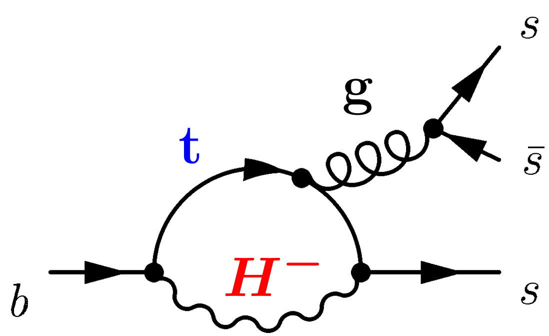


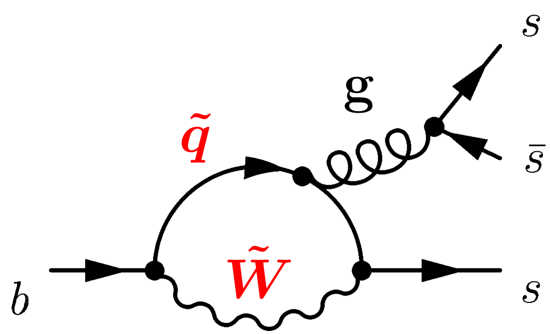
- Virtual production: $\Delta E \Delta t \sim \hbar$ (e.g. BABAR and CDF)

Standard Model

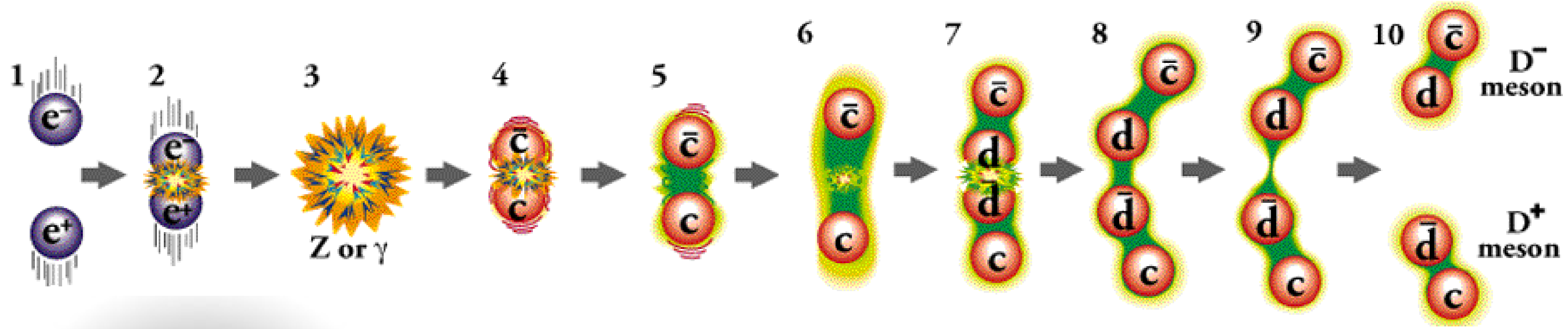
new particles in loops

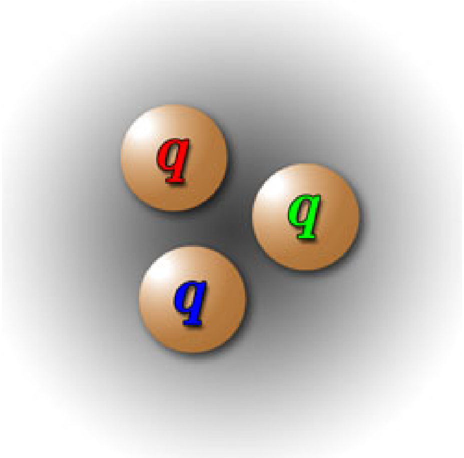


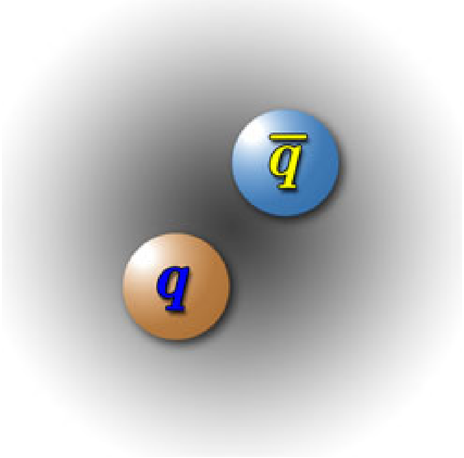


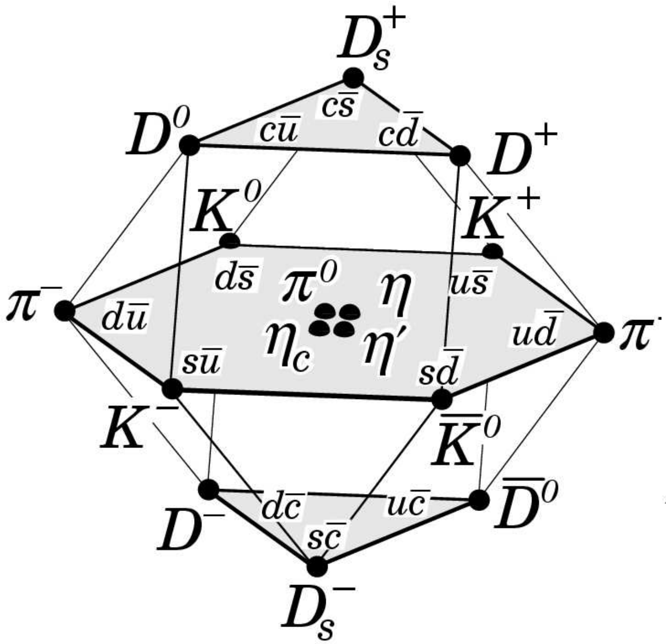


Bound Quarks: Mesons and Baryons

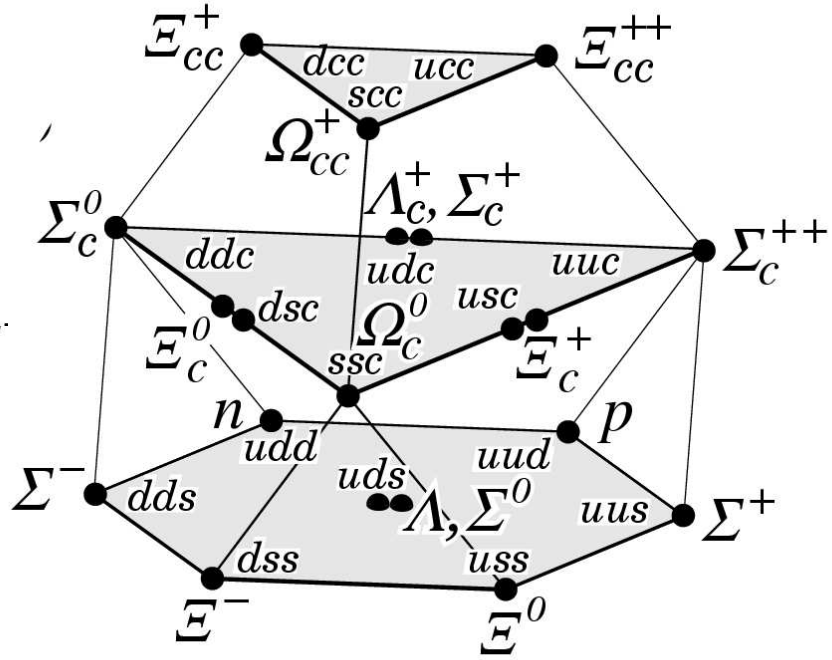






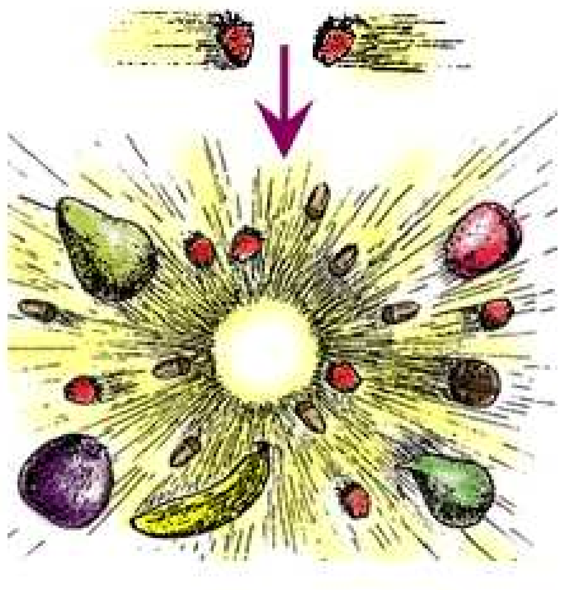


mesons



baryons

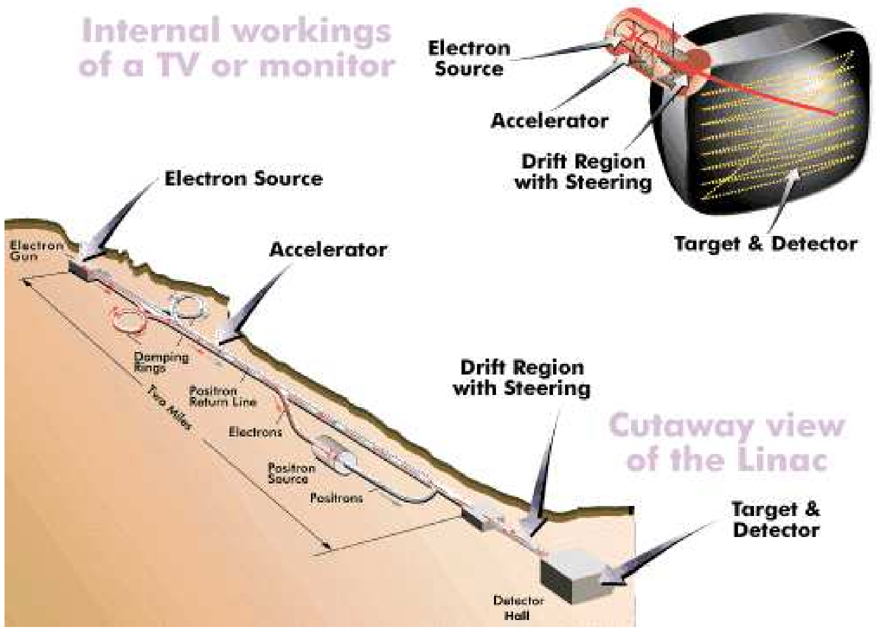
Producing New Matter

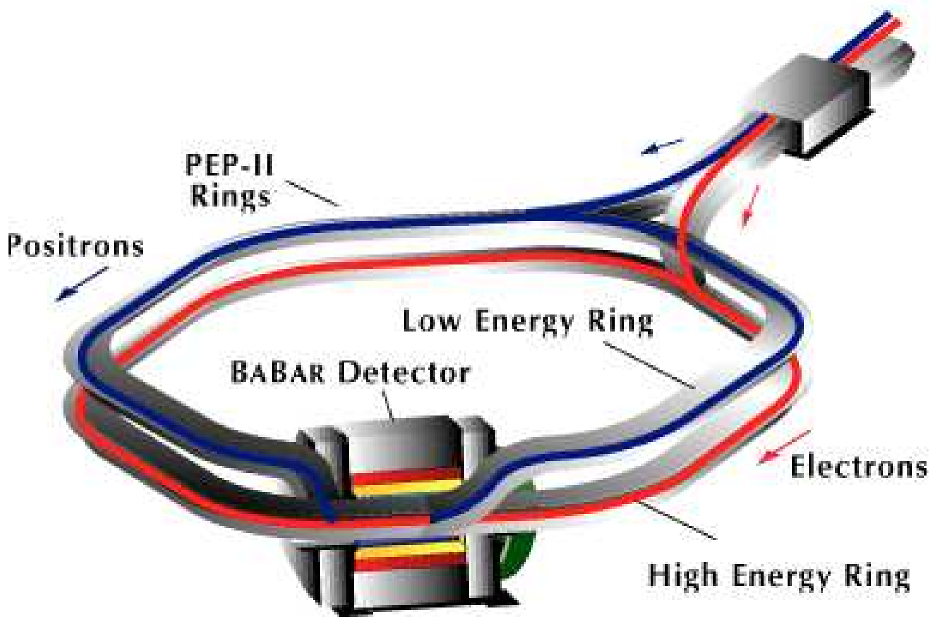


Smash at high energy

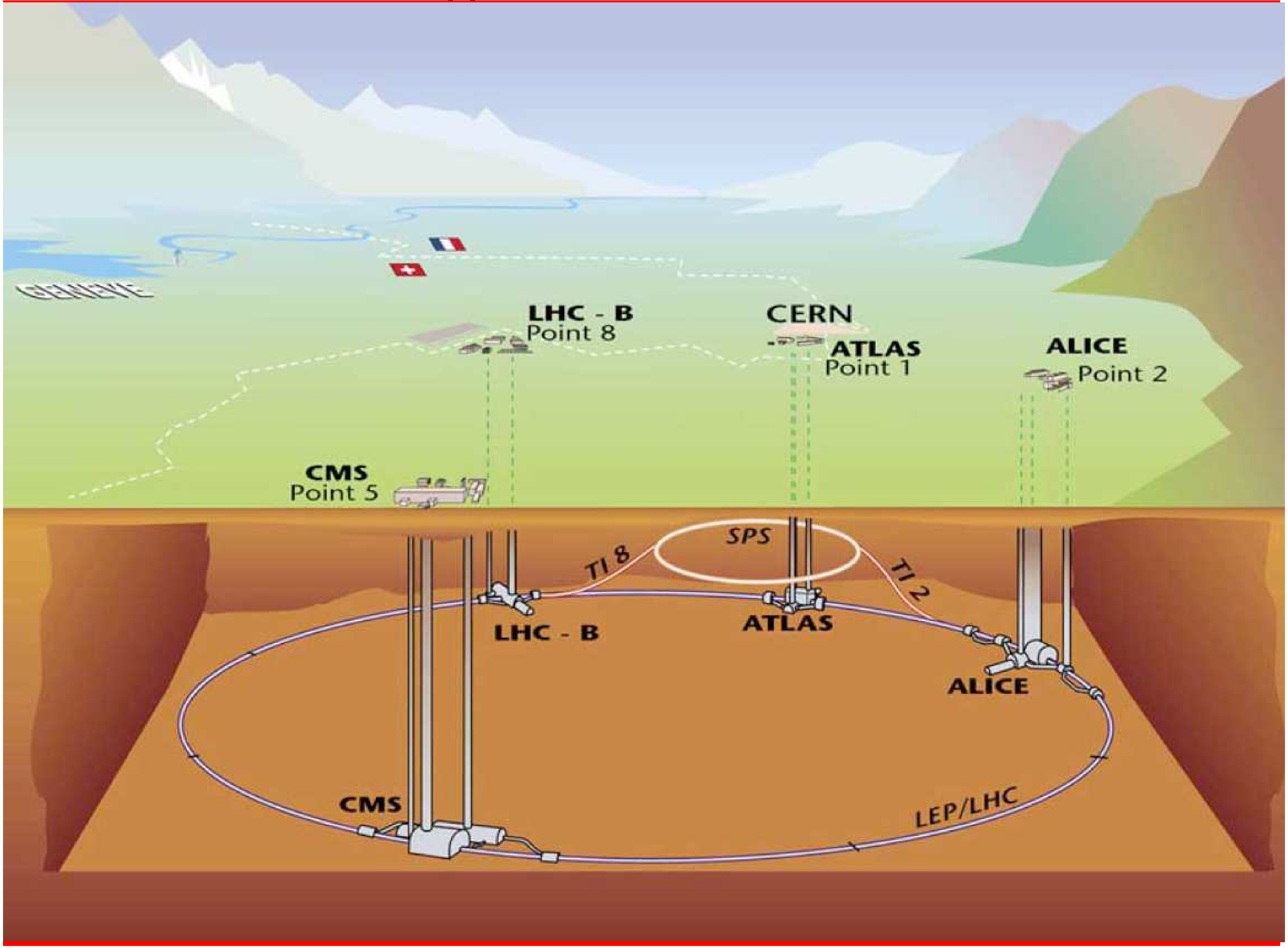
$$E = mc^2$$

Stanford Linear Accelerator Center





Producing New Matter: Near Future

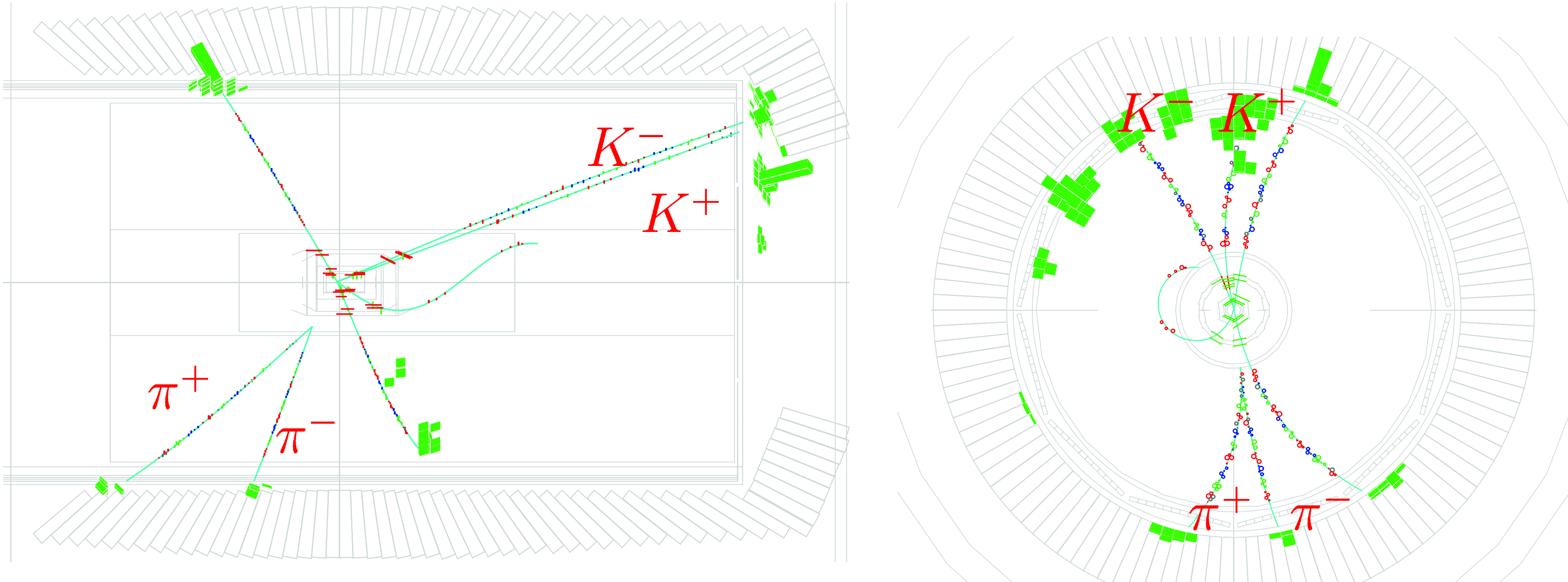


Detecting Particles

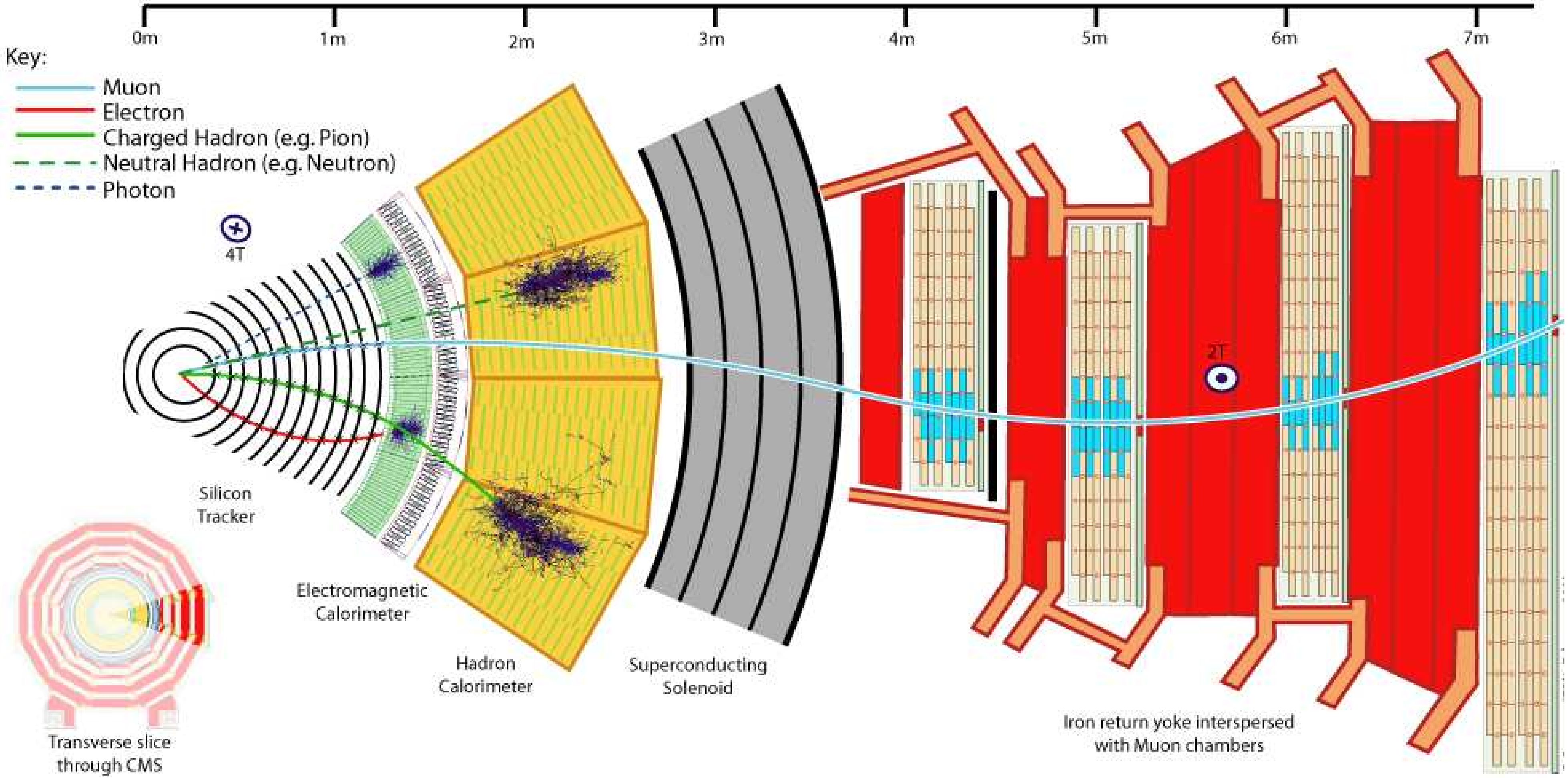
- Example: B meson decay products on BABAR at SLAC

  e.g. $B^0 \to \phi K^0 \to (K^+K^-)(\pi^+\pi^-)$

- Different detector subsystems

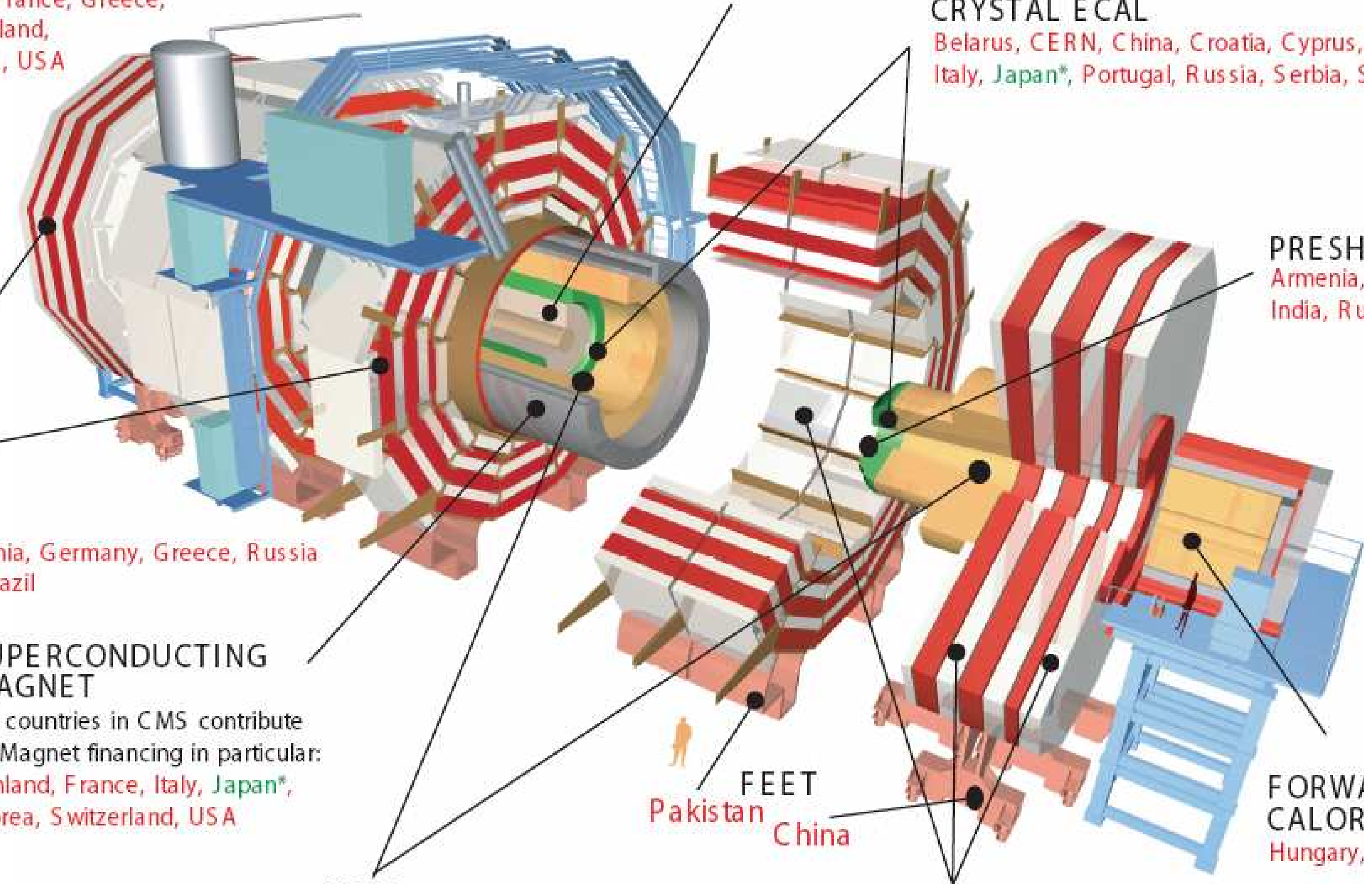


Detecting Particles at CMS



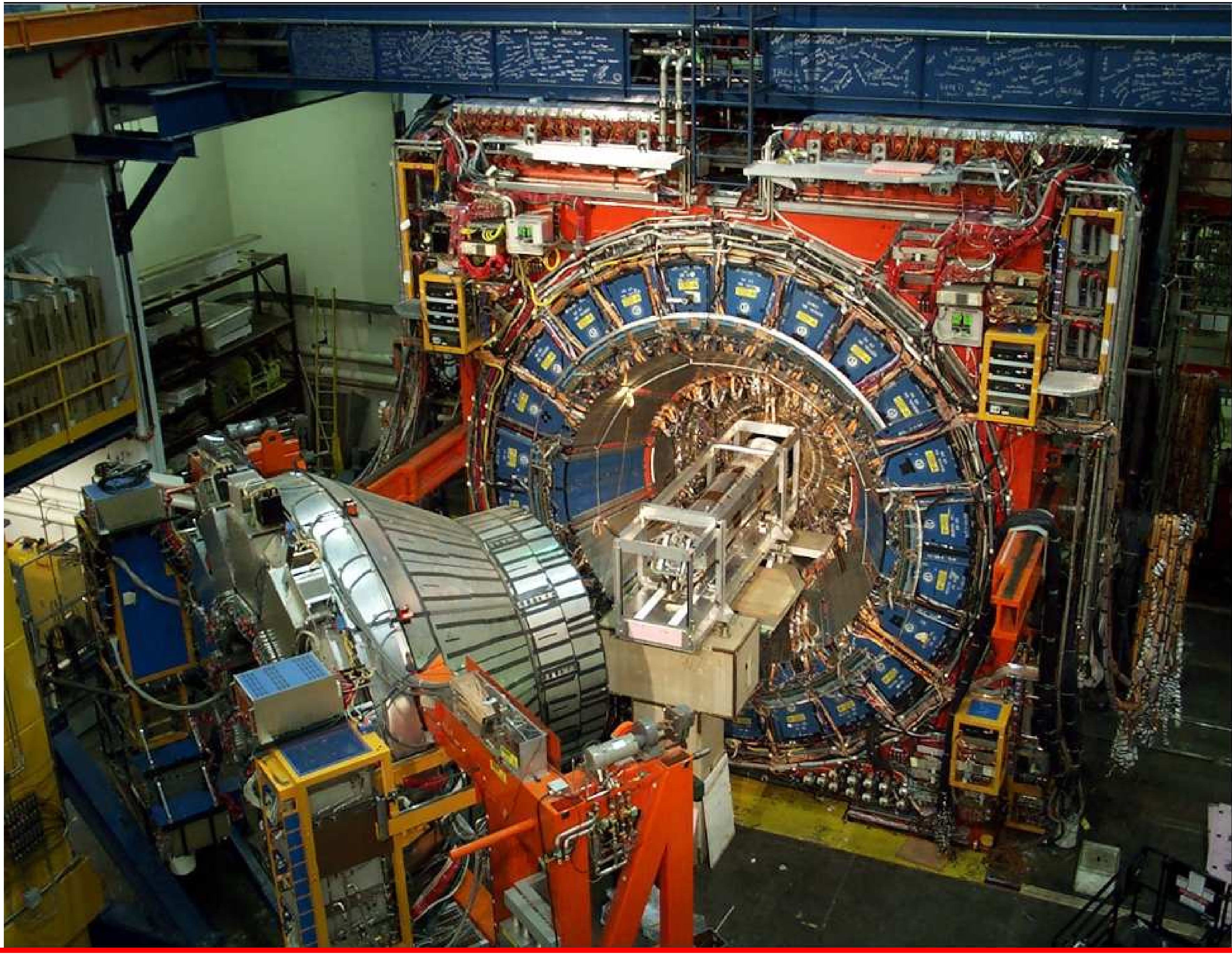
CMS Experiment

36 Nations, 160 Institutions, 2008 Scientists and Engineers (November 2003)

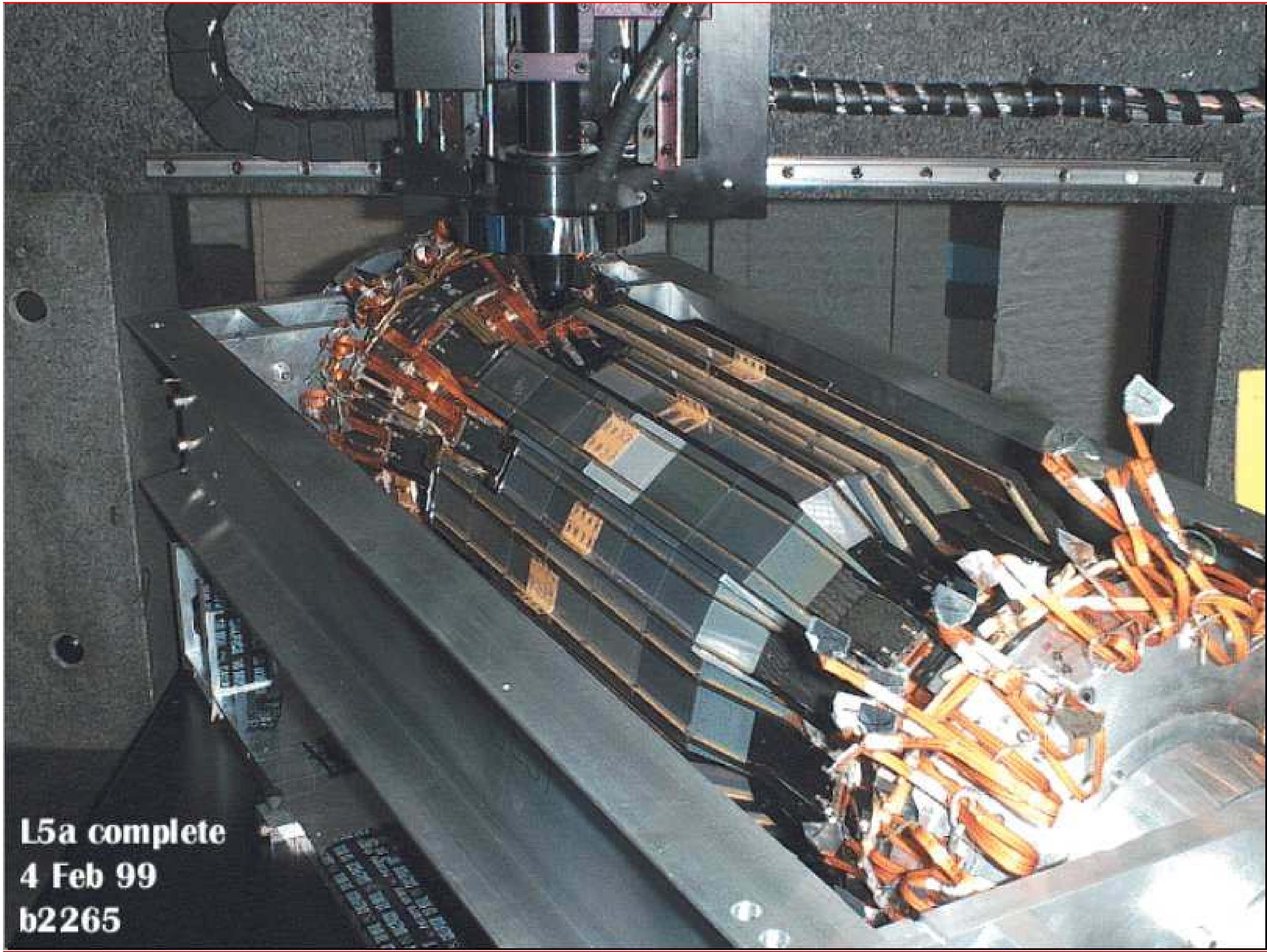


Total weight	:	12500 T
Overall diameter	:	15.0 m
Overall length	:	21.5 m
Magnetic field	:	4 Tesla

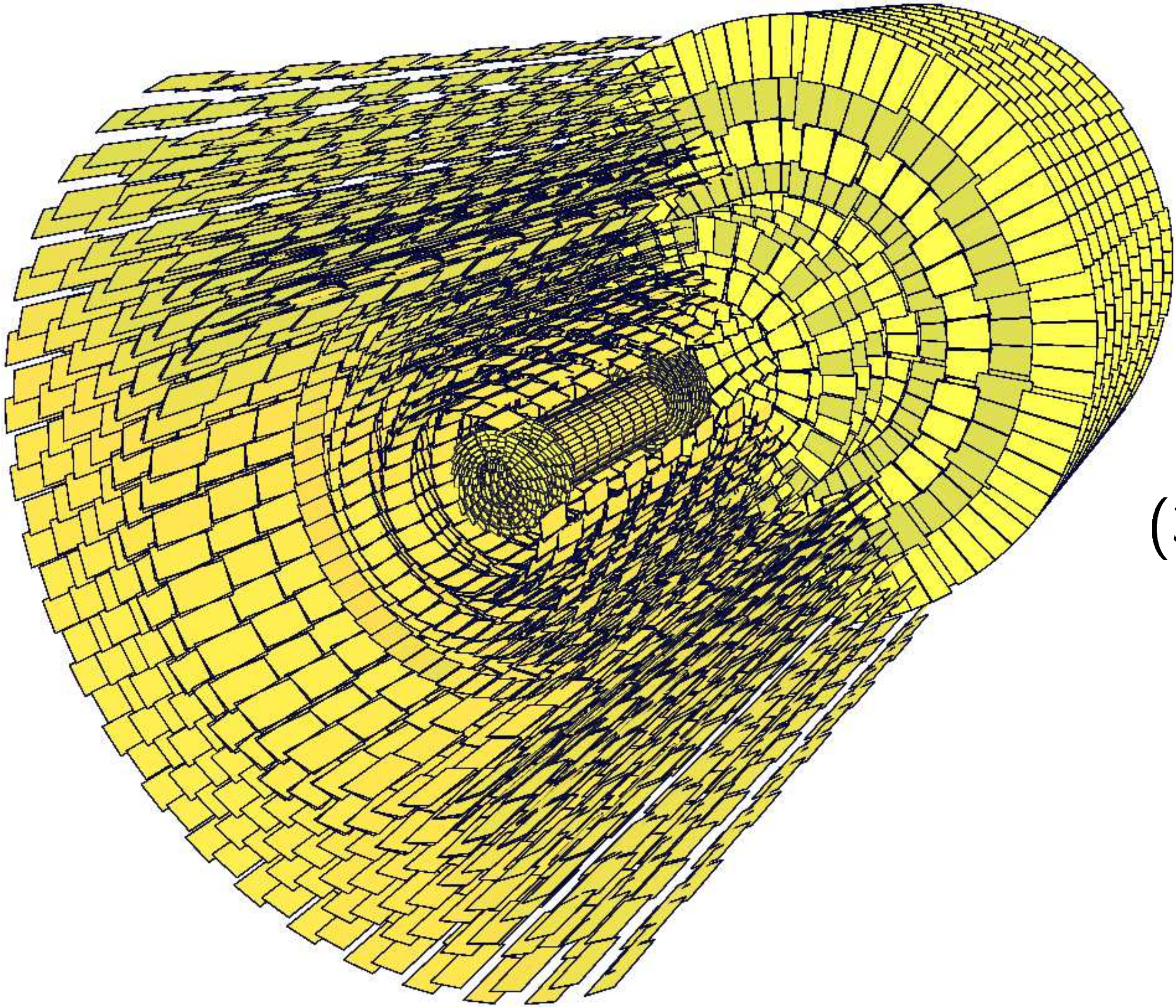
How It Looks: CDF Experiment



BaBar Silicon Vertex Detector Assembly



Modern Tracking Detectors

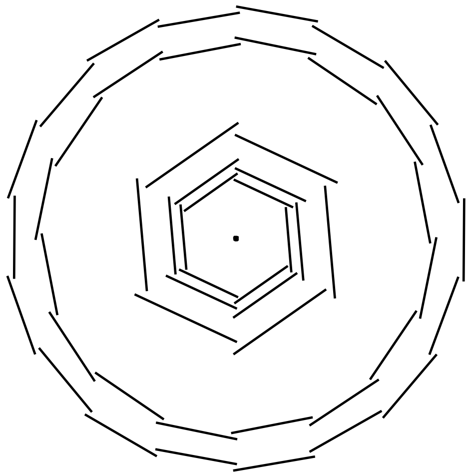


← CMS tracker

(>20,000 sensors)

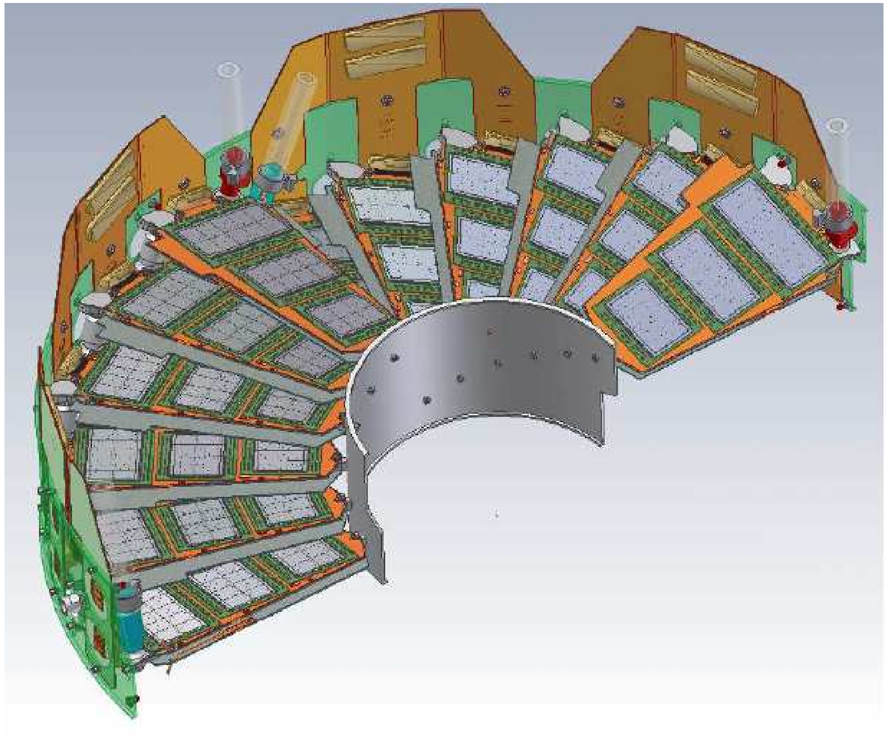
↓ BaBar silicon

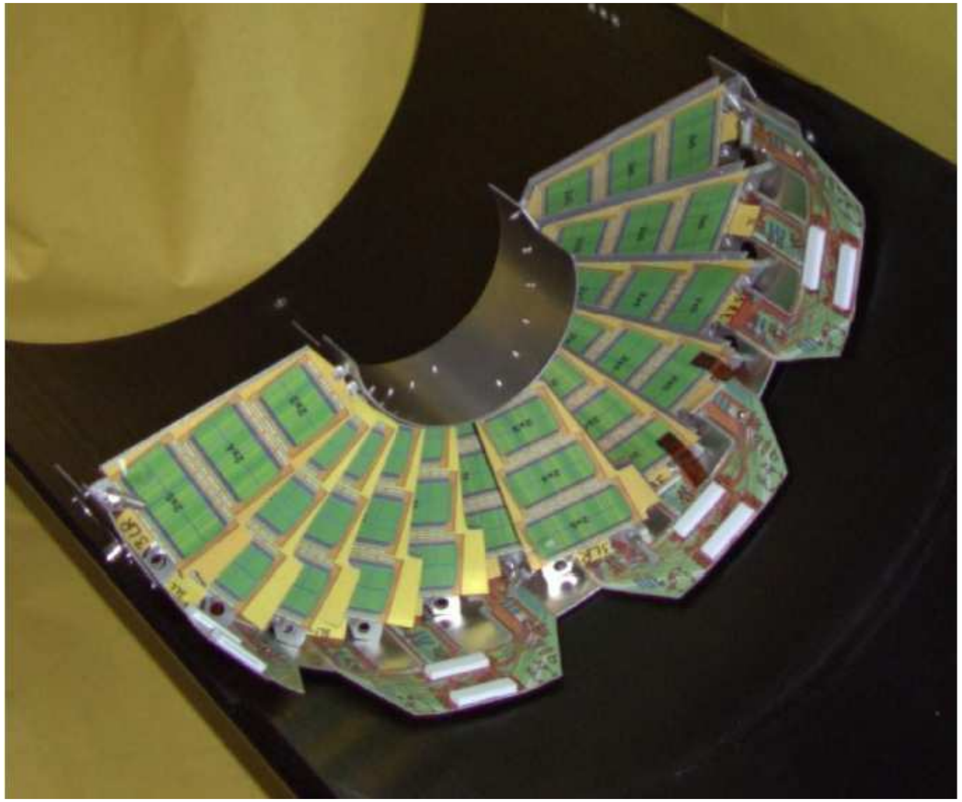
(340 sensors, R∼15cm)



Example: CMS Forward Pixel Detector

- CMS Forward Pixel (optical survey at Fermilab):
  - 3 or 4 sensors on a panel
  - 2 panels back-to-back in a blade = 7 sensors
  - 12 blades in a half-disk
  - half-disks in a cylinder,   cylinder in CMS



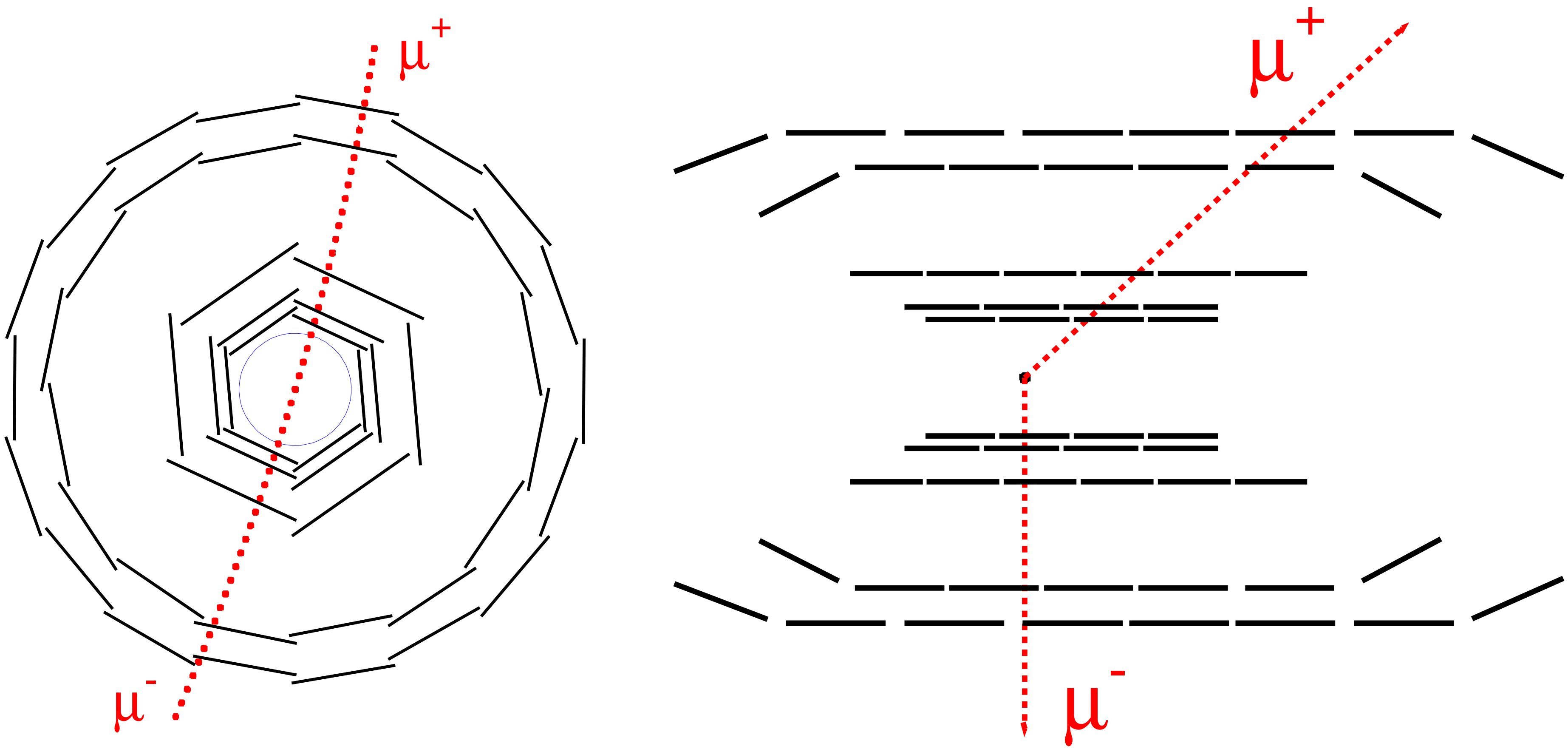


Need Good Vertex Resolution

- Silicon "alignment" with particle tracks

  crucial for precise particle detection: BABAR and CMS

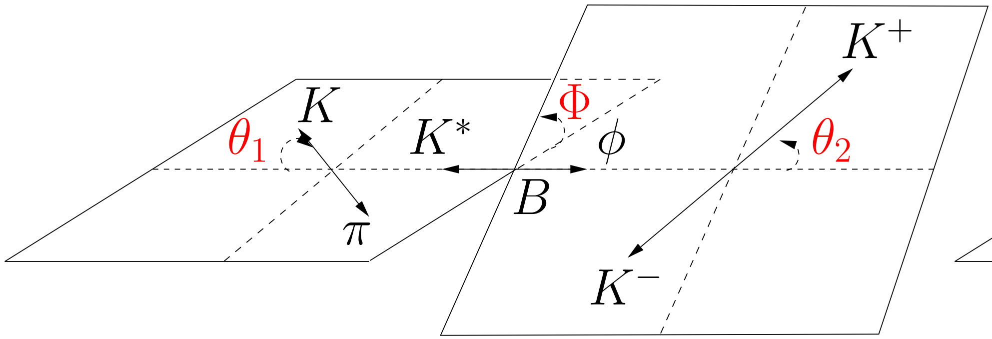
- Other technical aspects of detector operation

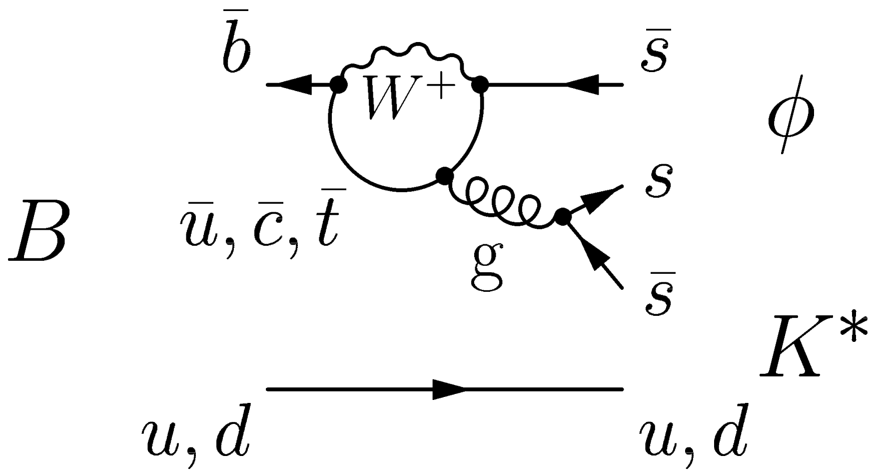


What We Study

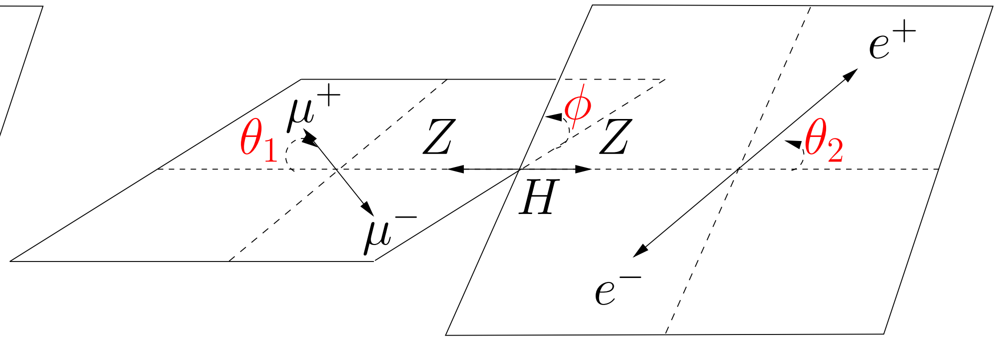
- Analysis of decay products:

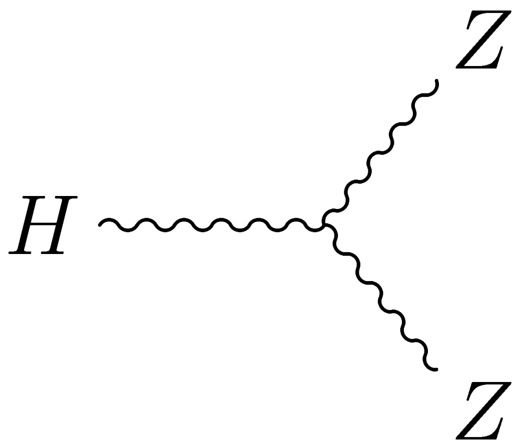
at BABAR





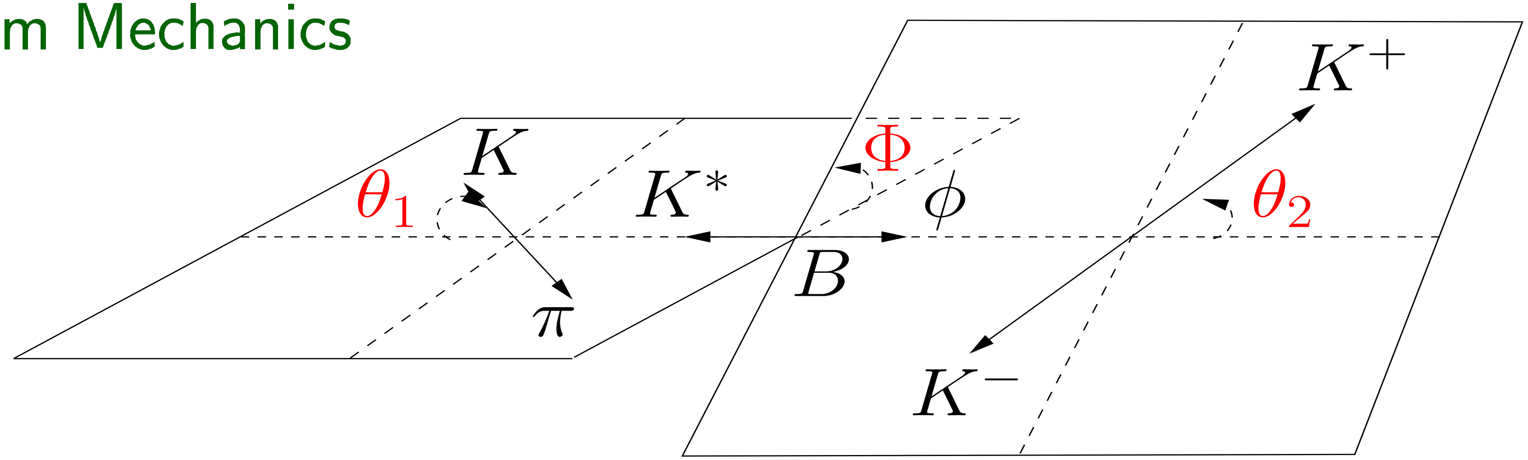
at CMS





Example: Angular Measurements

- Quantum Mechanics



(•) measure amplitudes from their angular dependence:

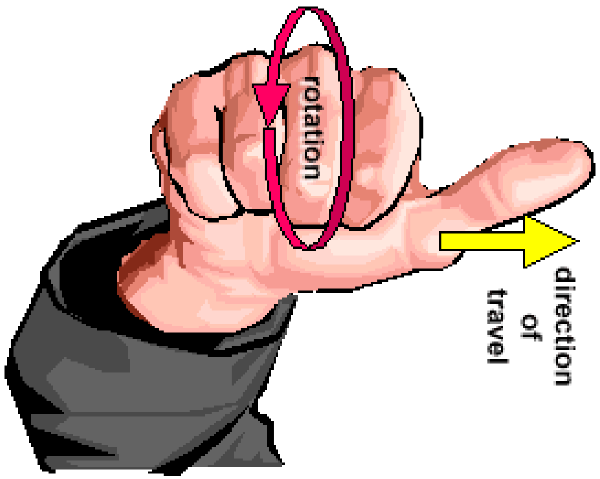
$$\frac{d^3\Gamma}{d\cos\theta_1 d\cos\theta_2 d\Phi} \propto \left| \sum_{m=-1,0,1} A_m \times Y_{1,m}(\theta_1, 0) \times Y_{1,-m}(\pi - \theta_2, -\Phi) \right|^2$$

$$\propto \left\{ \frac{1}{4} \boxed{\overset{\text{transverse}}{\sin^2\theta_1 \sin^2\theta_2 \left(|A_{+1}|^2 + |A_{-1}|^2\right)}} + \boxed{\overset{\text{longitudinal}}{\cos^2\theta_1 \cos^2\theta_2 |A_0|^2}} \right.$$

$$+\frac{1}{2}\sin^2\theta_1 \sin^2\theta_2 \left[\cos 2\Phi \,\mathrm{Re}(A_{+1}A^*_{-1}) - \sin 2\Phi \,\mathrm{Im}(A_{+1}A^*_{-1})\right]$$

$$\left. +\frac{1}{4}\sin 2\theta_1 \sin 2\theta_2 \left[\cos\Phi \,\mathrm{Re}\,(A_{+1}A^*_0 + A_{-1}A^*_0) - \sin\Phi \,\mathrm{Im}\,(A_{+1}A^*_0 - A_{-1}A^*_0)\right] \right\}$$

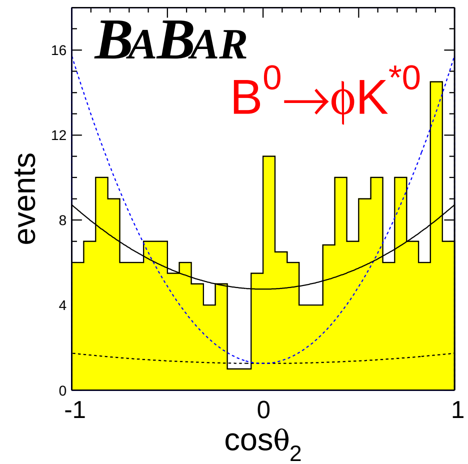
Example: Polarization Puzzle



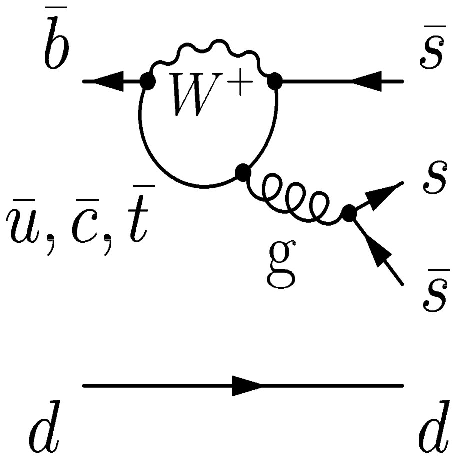
Polarization in $B \to \phi K^*$

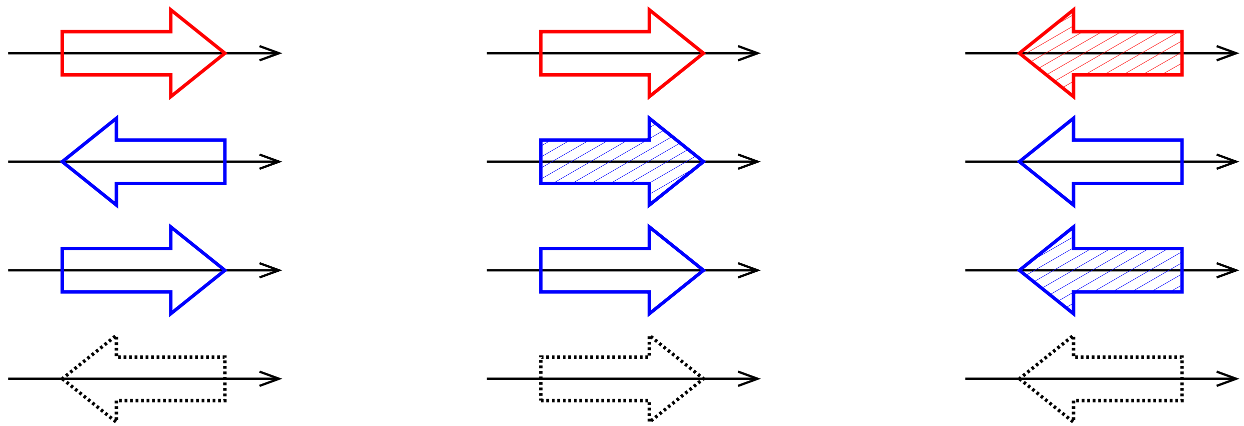
expected: $A_0 \gg A_+ \gg A_-$

measured: $A_0 \sim A_\pm$



$A_0 \sim 1 \quad \gg \quad A_+ \sim \frac{m_V}{m_B} \quad \gg \quad A_- \sim \frac{{m_V}^2}{{m_B}^2}$





Summary

- Origin of Matter and Mass:
  - Why do we have matter and no antimatter (CP violation) ?
  - Can we produce dark matter in laboratory ?
  - What is the origin of mass (Higgs)?
- On-going collider program at JHU:
  - CDF experiment at proton-antiproton collider at Fermilab
  - BABAR experiment at electron-positron collider at Stanford
  - CMS new frontier in 2007-2008
- Various projects:
  - silicon detectors: calibration, alignment, operation, simulation
  - data analysis: simulation, computer reconstruction, results

More information (and some graphics in this talk) on particle physics:

http://particleadventure.org/particleadventure/

http://pdg.lbl.gov/

http://www2.slac.stanford.edu/vvc/

http://public.web.cern.ch/Public/Welcome.html

http://www.fnal.gov/