Aspects of Particle Physics today

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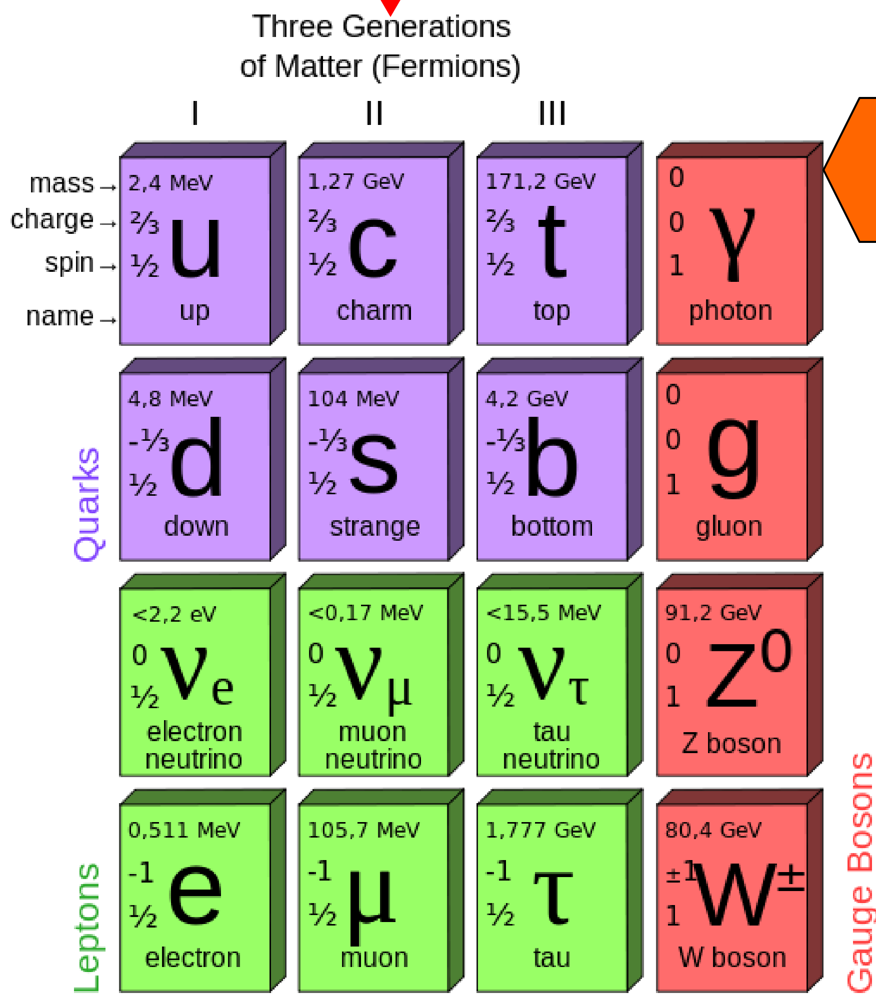
Standard Model in a Nutshell

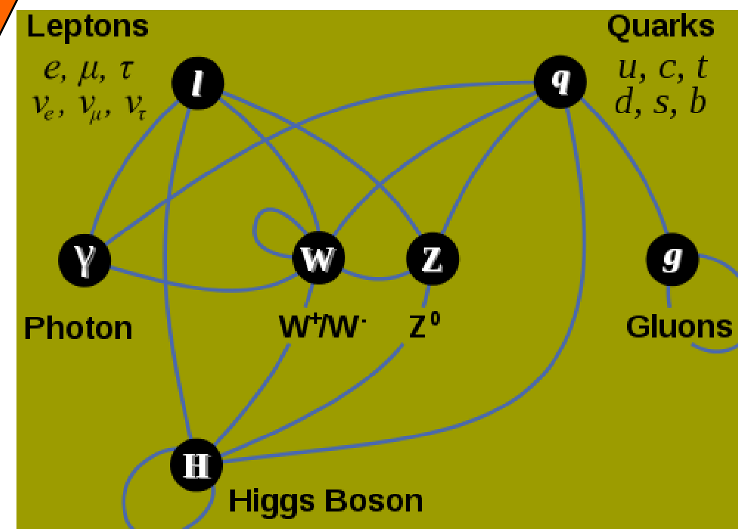
What we have learned so far
on basic structure of matter?

Credit: J. W. Stewart



Higgs

Interactions



+ Gravity

There is also a "mirror" picture
Anti-Matter

For every particle there exits an antiparticle counterpart
(same mass and lifetime , but opposite quantum numbers)

$$e^- \Leftrightarrow e^+ \qquad \nu \Leftrightarrow \bar{\nu} \;\; (?)$$

$$p \Leftrightarrow \bar{p} \qquad \pi^+ \Leftrightarrow \pi^-$$

$$n \Leftrightarrow \bar{n} \qquad \pi^0 \Leftrightarrow \pi^0$$

$$\gamma \Leftrightarrow \gamma \qquad ..$$

CPT invariance

$$m(a) = m(\bar{a})$$

$$\tau(a) = \tau(\bar{a})$$

CPT invariance: A mirror world, where all particles are replaced by their antiparticles and time runs backward, is governed by the same laws as ours

A very brief history of Anti-Matter

1928 Dirac's relativistic quantum theory

PAUL A. M. DIRAC

Theory of electrons and positrons

Nobel Lecture, December 12, 1933

. . .

The theory of electrons and positrons which I have just outlined is a self-consistent theory which fits the experimental facts so far as is yet known. One would like to have an equally satisfactory theory for protons. One might perhaps think that the same theory could be applied to protons. This would require the possibility of existence of negatively charged protons forming a mirror-image of the usual positively charged ones.

. . .

In any case I think it is probable that negative protons can exist, since as far as the theory is yet definite, there is a complete and perfect symmetry between positive and negative electric charge, and if this symmetry is really fundamental in nature, it must be possible to reverse the charge on any kind of particle. The negative protons would of course be much harder to produce experimentally, since a much larger energy would be required, corresponding to the larger mass.

If we accept the view of complete symmetry between positive and negative electric charge so far as concerns the fundamental laws of Nature, we must regard it rather as an accident that the Earth (and presumably the whole solar system), contains a preponderance of negative electrons and positive protons. It is quite possible that for some of the stars it is the other way about, these stars being built up mainly of positrons and negative protons. In fact, there may be half the stars of each kind. The two kinds of stars would both show exactly the same spectra, and there would be no way of distinguishing them by present astronomical methods.

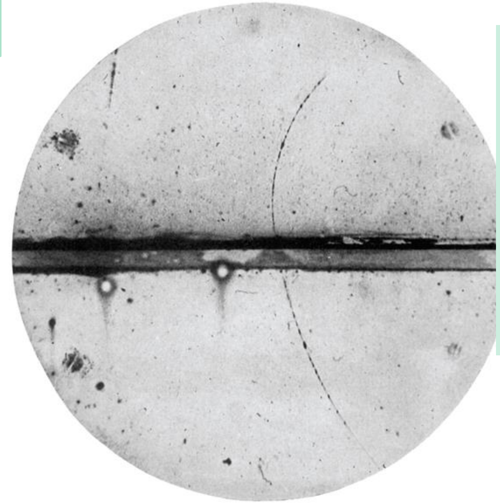


FIG. 1. A 63 million volt positron ($H\rho = 2.1\times10^5$ gauss-cm) passing through a 6 mm lead plate

1932: Carl Anderson
positive electrons in cosmic rays

Blackett & Occhialini
$\gamma \rightarrow e^+e^-$

Anti-proton at Bevatron, (1955)
Anti-Neutron at Bevatron (1960)
Anti-Deutron PS/CERN, AGS/BNL(1965)
Anti-Hydrogen (p-, e+) LEAR/CERN(1995)

$\bar{H}$: $f_{\text{d-d}}$ (Laser driven 1s-2s transition)
2,466,061,103,079.4(5.4)kHz

H: $f_{\text{d-d}}$ =
2,466,061,103,080.3(0.6)kHz

....

Stars of antimatter?
Galaxies of antimatter?

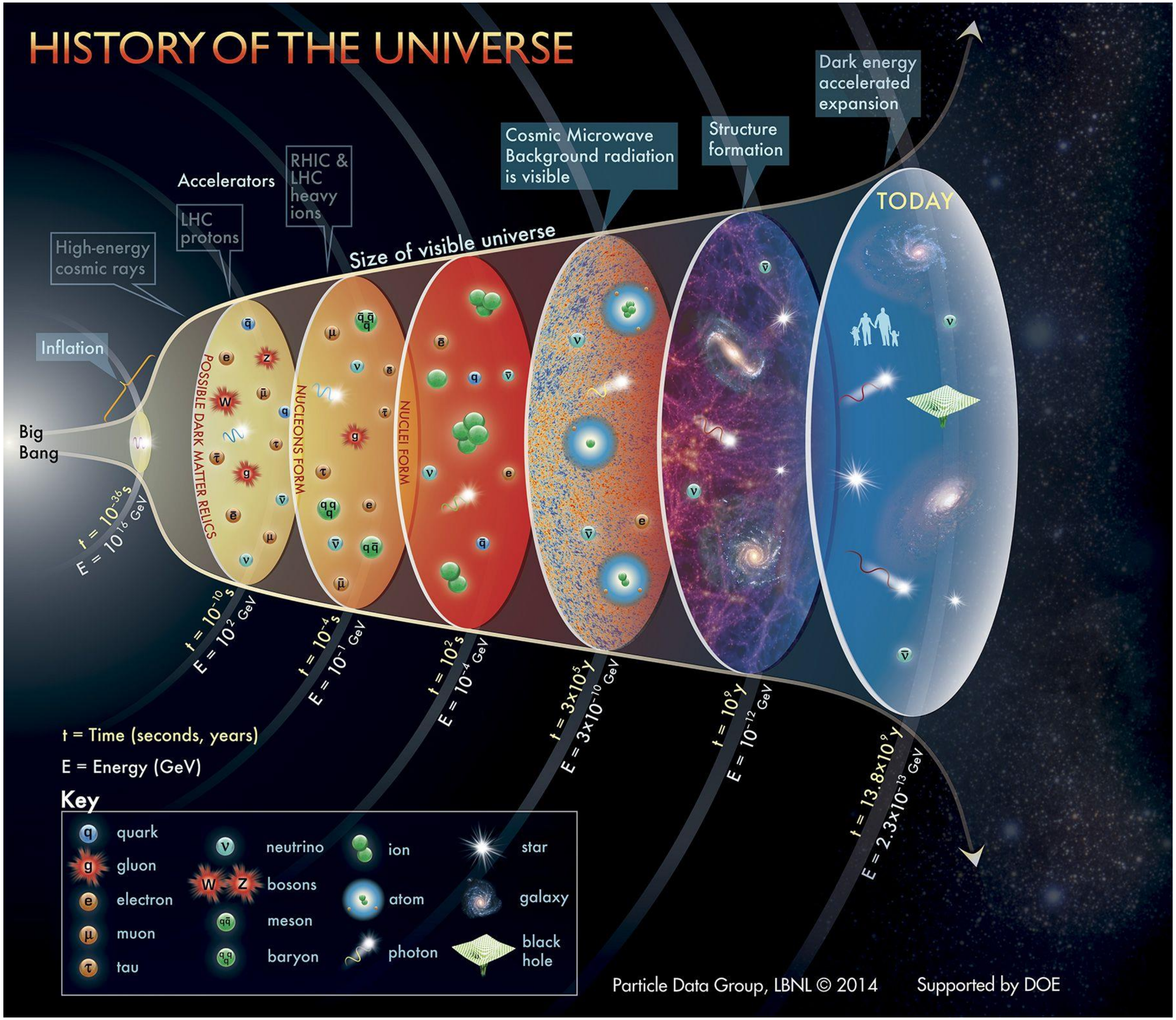
The view from Astrophysics

No evidence for any primary anti-matter in sky except those produced as secondary products in interactions of cosmic rays

$$\bar{p}/_{p} = 10^{-4}$$

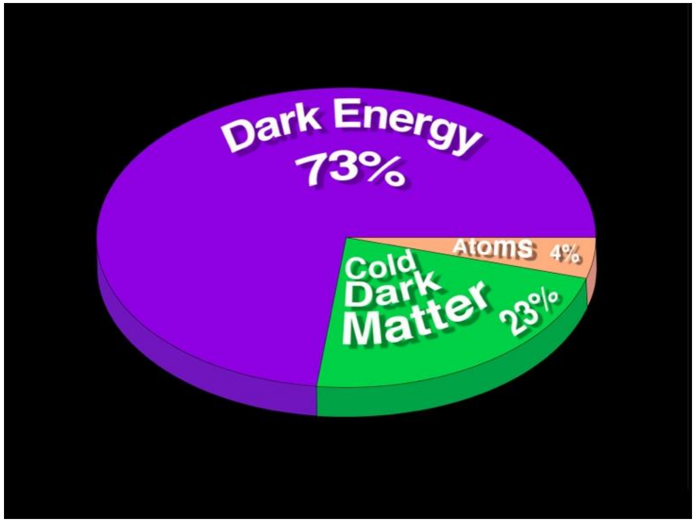
So, what happened to all the anti-matter?

Intimate Connection of Particle Physics to the History of the Universe



Standard Model has been astonishingly successful

But the picture seems incomplete



- No Dark Matter candidate
- Nothing on Dark energy
- Not able to account for the observed Matter-Antimatter imbalance in universe

The picture seems incomplete

There must be other particles and forces than those in the Standard Model

New Symmetries & Forces ?
(e.g. Supersymmetry)
Extra Dimensions ?
....

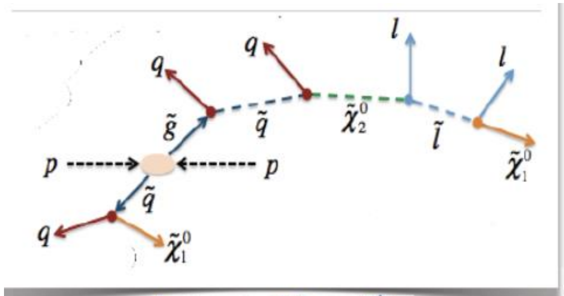
Finding these is the main goal of particle physics
&
why we use and need more powerful particle accelerators

Searches for new particles & interactions at LHC

Studies at LHC yielded the Higgs

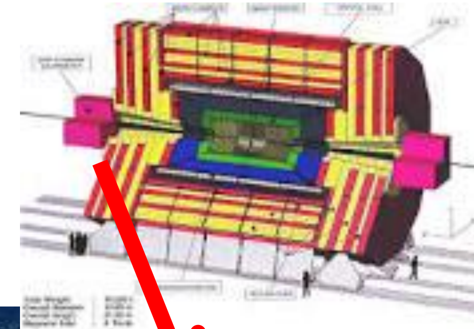
But no sign of NP particles yet

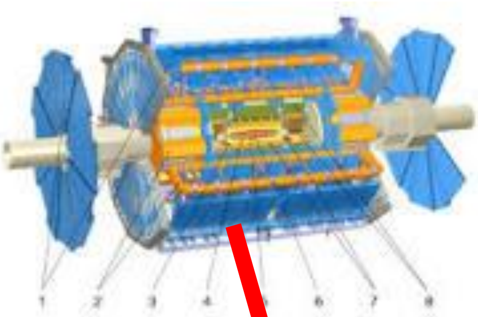
All eyes are still are on LHC

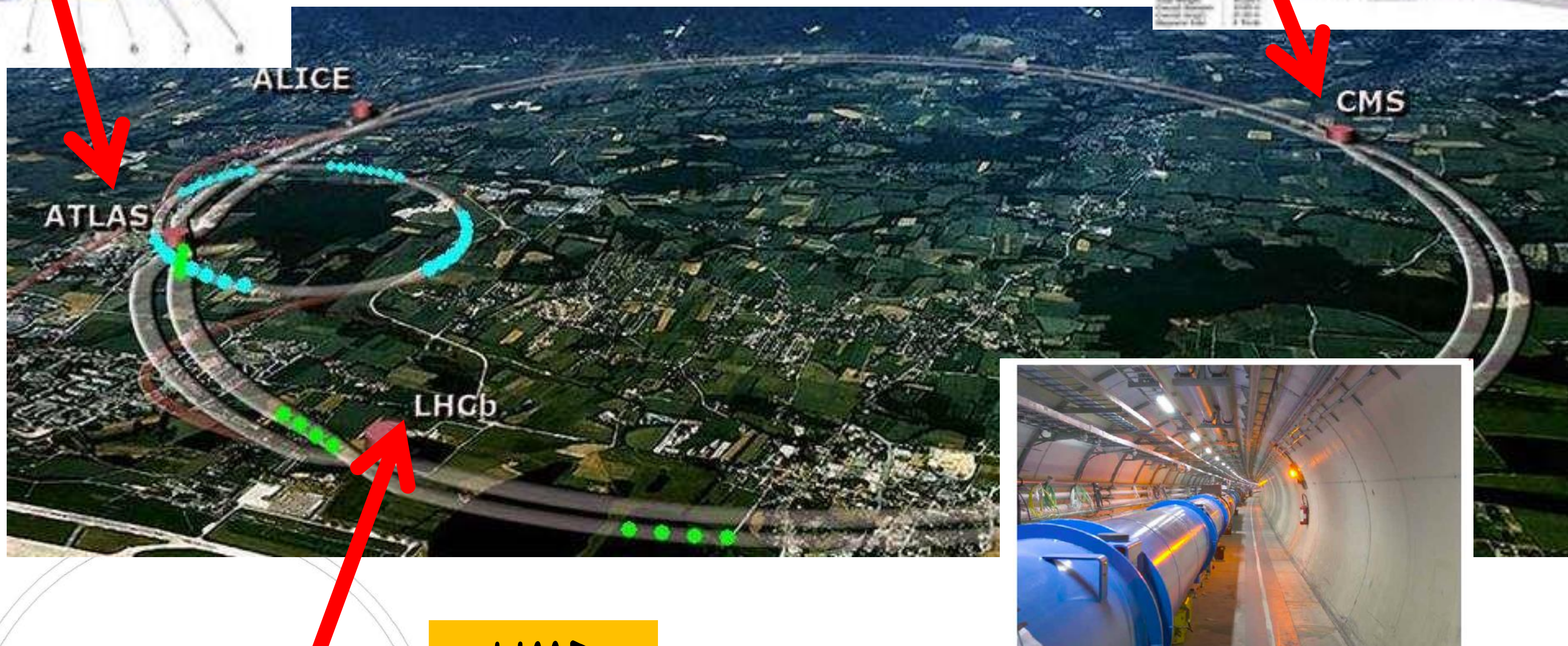


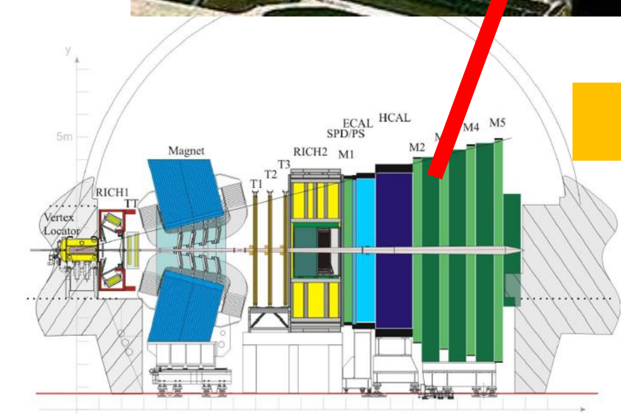
$\text{jets} + 2l + \not{E}_T$

UMD



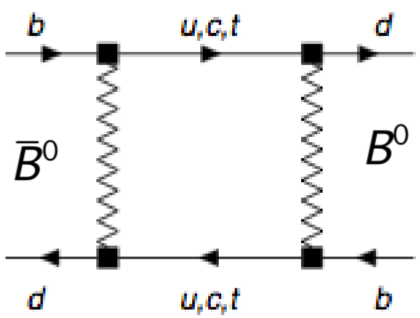


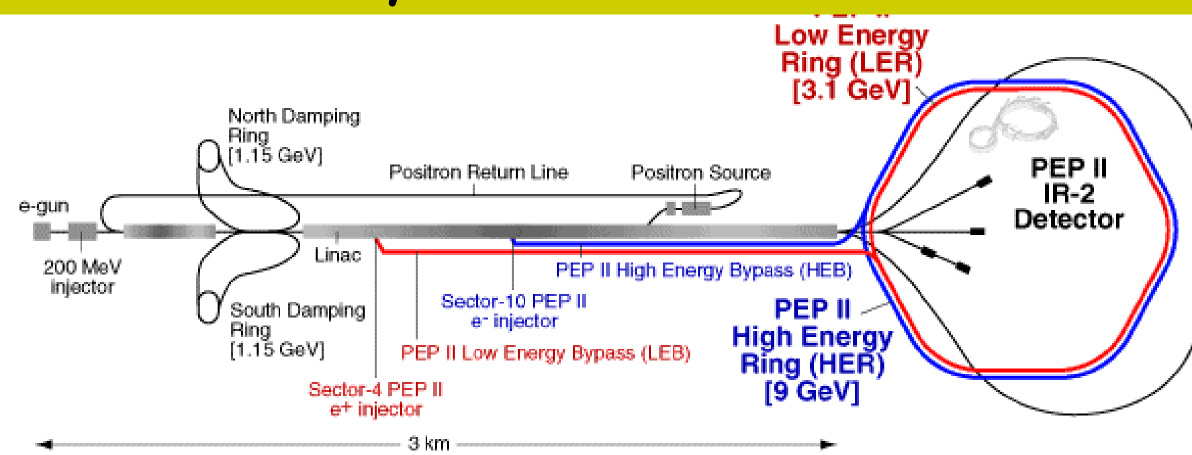

ALICE
CMS
ATLAS
LHCb

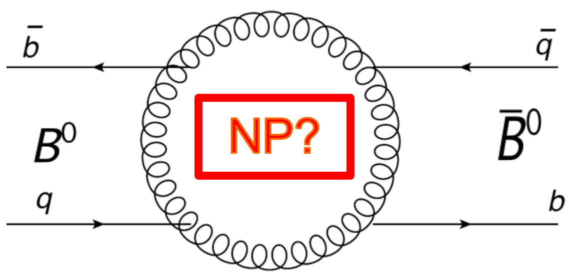

Vertex
Locator
RICH1
TT
Magnet
T1
T2
T3
RICH2
SPD/PS
ECAL
HCAL
M1
M2
M4
M5
5m

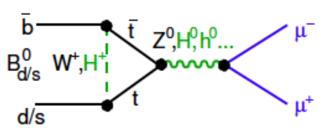
UMD

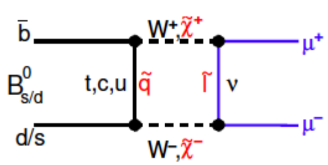
Another Path: Search for the quantum imprints of New Physics

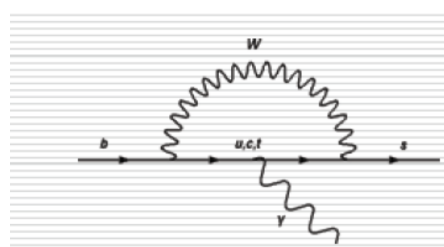


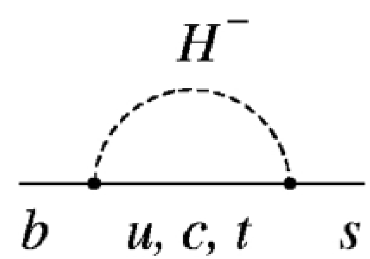








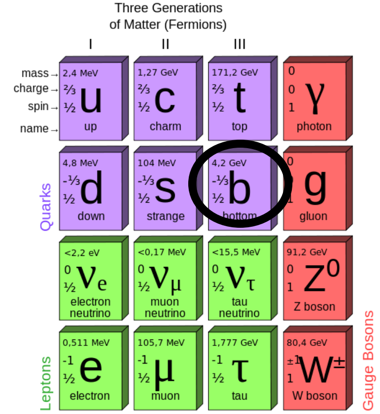




A key focus of this Group at UMD

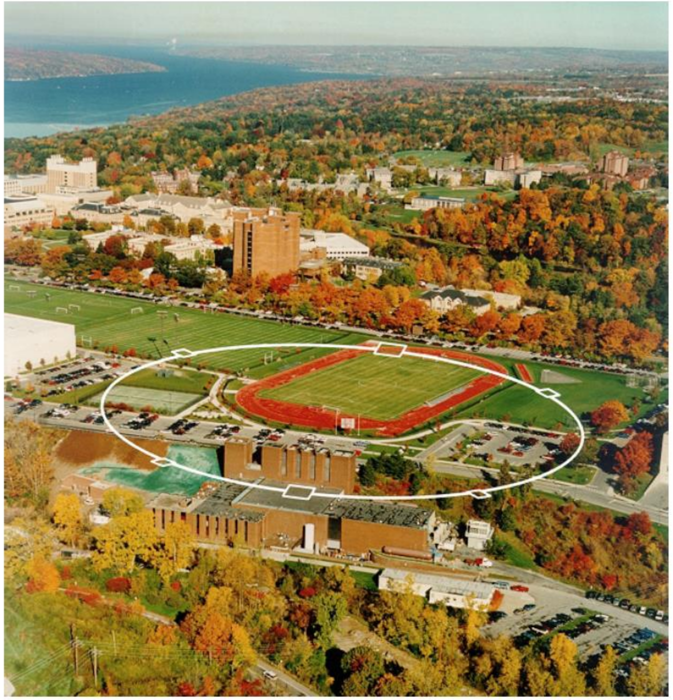
Flavor Physics and CP Violation

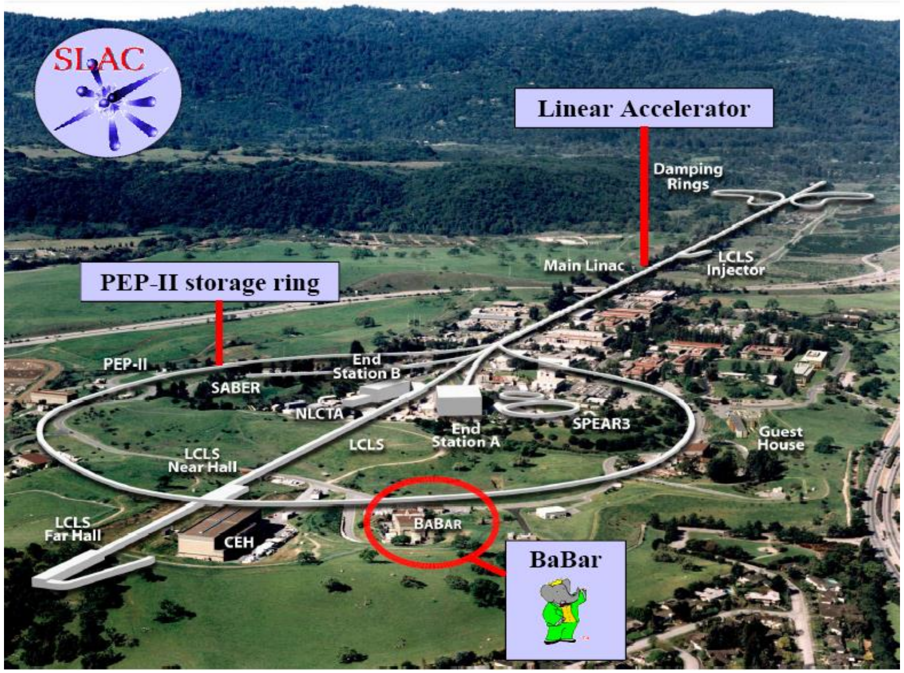
Investigation of CP Violation (Matter-antimatter imbalance mystery) using b-quark particles



Cornell Electron Positron Collider

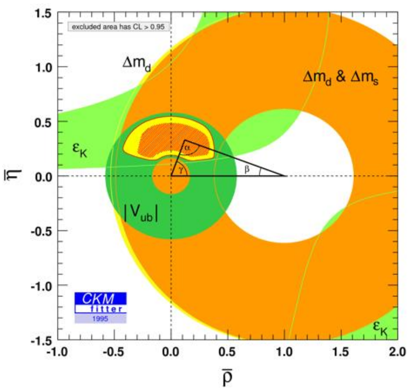
SLAC National Accelerator Center



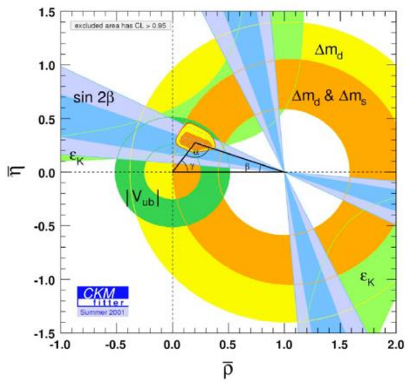


Flavor Physics and CP Violation
Evolution of Quark Mixing & CP Violation Parameters

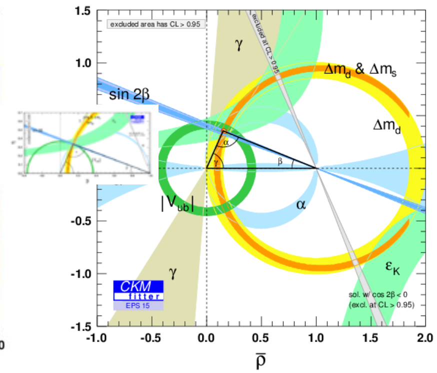
Last century



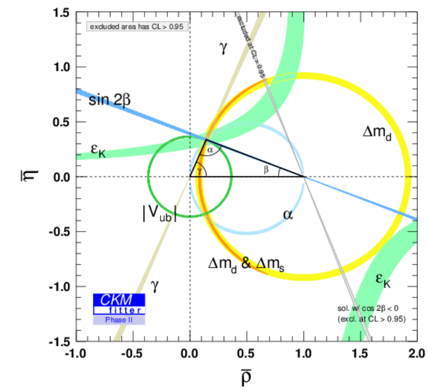
2001



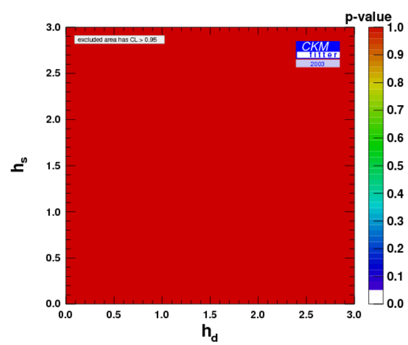
Today

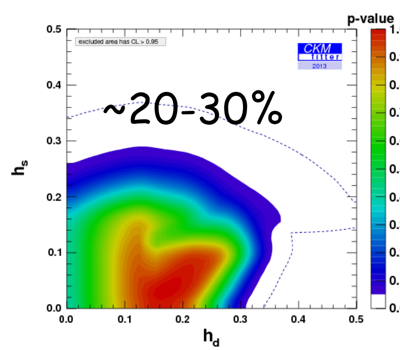


Towards O(1%) test of CKM



Constraint on NP/SM





Experimental Particle Physics at UMD

- Significant influx of physicists from Princeton in 1950's. John Toll played a major role.

- Accelerator based experimental Particle Physics program initiated by George Snow and Bob Glasser in Mid-1950's. Focused mostly on Bubble Chamber experiments. Important contributions to the studies of Strange particles and initials suggestions for charm quark
  - Soon, joined by Gus and Bice-Sechi Zorn, Phil Steinberg and Andris Skuja with focus on "counter" experiments

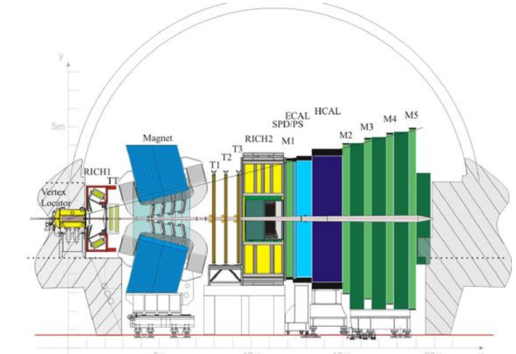
  - Performed experiments at Brookhaven National Lab, Fermilab, SLAC, DESY, Cornell, CERN. Leading roles in precision studies of Z and W at LEP(CERN), discovery of Top quark at Fermilab and discovery of CP violation in B decays at SLAC, Higgs discovery, search for Supersymmetry, Study of Lepton Flavor Universality and CP violation at LHC (CERN).

- Leading non-Accelerator program (Particle Astrophysics) established by Gaurang Yodh. Continued and significantly expanded by J. Goodman, G. Sullivan, K. Hoffman, B. Clark : Gamma ray and Neutrino observatories. Dark Matter search C. Hall and X. Ji

Some of the current research in Fundamental Physics at UMD

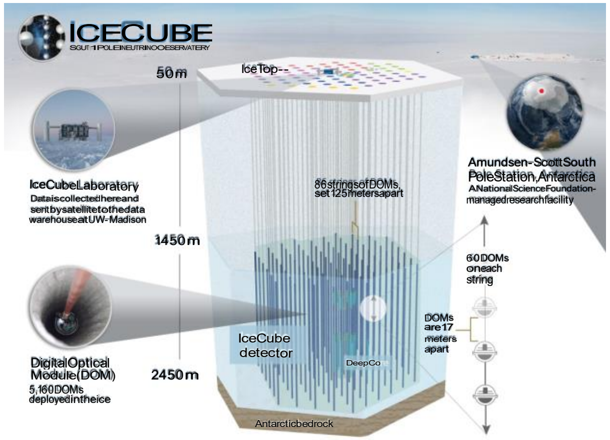
CMS Experiment at CERN

LHCb Experiment at CERN

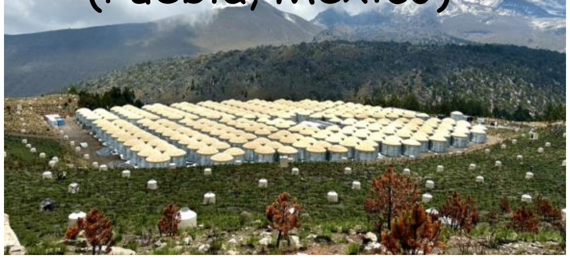


LIGO Interferometer Study of Gravitational Waves

High energy astrophysical Neutrino Observatory in Antarctica



HAWC Gamma Ray observatory (Puebla, Mexico)



Direct Search for Dark Matter with LZ experiment(Sanford, S.D.) & PandaX (China)