Aspects of Particle Physics today

July 7 , 2022

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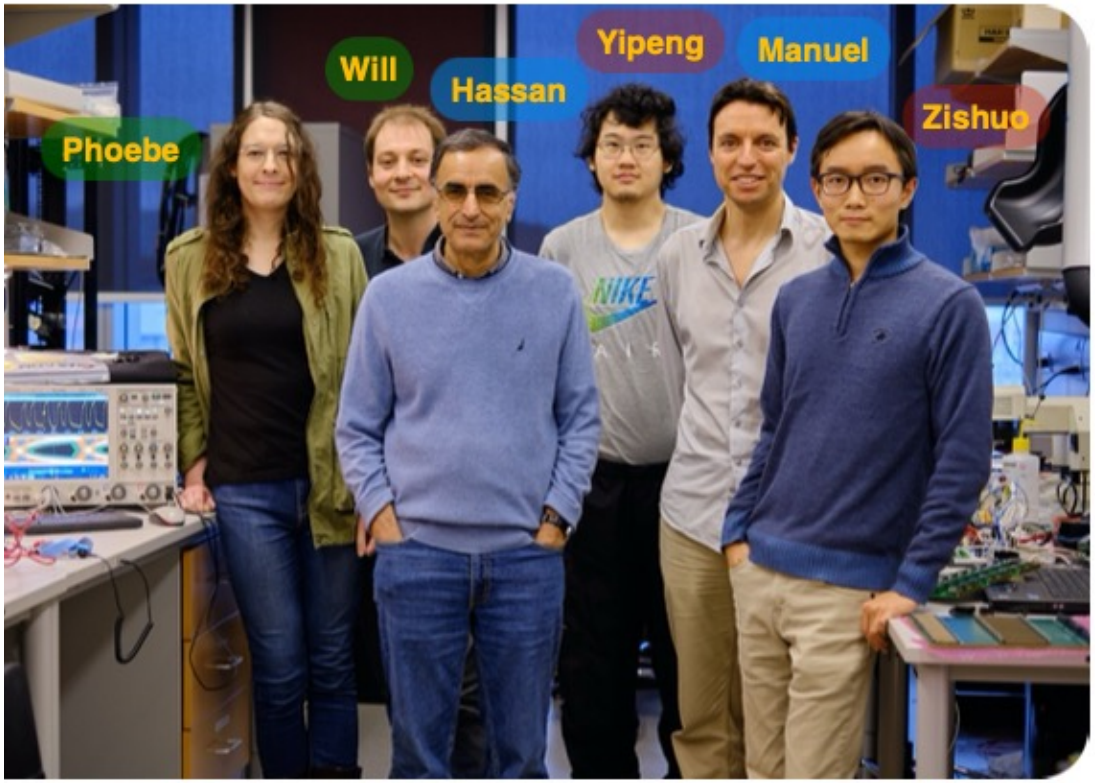
UMD Flavor & CP Violation Group



Standard Model:

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

Credit: J. W. Stewart

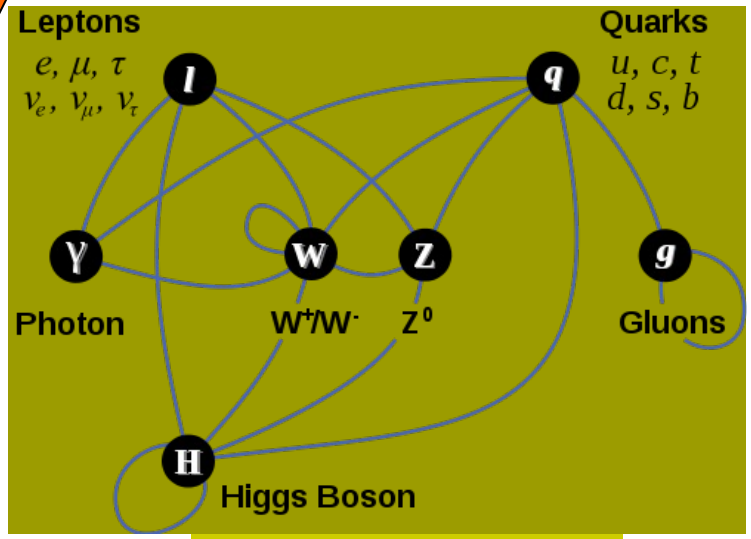
Three Generations of Matter (Fermions)

	I	II	III	
mass →	2,4 MeV	1,27 GeV	171,2 GeV	0
charge →	⅔	⅔	⅔	0
spin →	½	½	½	1
name →	u up	c charm	t top	γ photon
Quarks	4,8 MeV, -⅓, ½, d down	104 MeV, -⅓, ½, s strange	4,2 GeV, -⅓, ½, b bottom	0, 0, 1, g gluon
Leptons	<2,2 eV, 0, ½, ν_e electron neutrino	<0,17 MeV, 0, ½, ν_μ muon neutrino	<15,5 MeV, 0, ½, ν_τ tau neutrino	91,2 GeV, 0, 1, Z^0 Z boson
	0,511 MeV, -1, ½, e electron	105,7 MeV, -1, ½, μ muon	1,777 GeV, -1, ½, τ tau	80,4 GeV, ±1, 1, $W^\pm$ W boson

Gauge Bosons

Higgs

Interactions



+ Gravity

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

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

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

Some history: the birth of Anti-Matter

1928 Dirac's relativistic quantum theory

PAUL A. M. DIRAC

Theory of electrons and positrons

Nobel Lecture, December 12, 1933

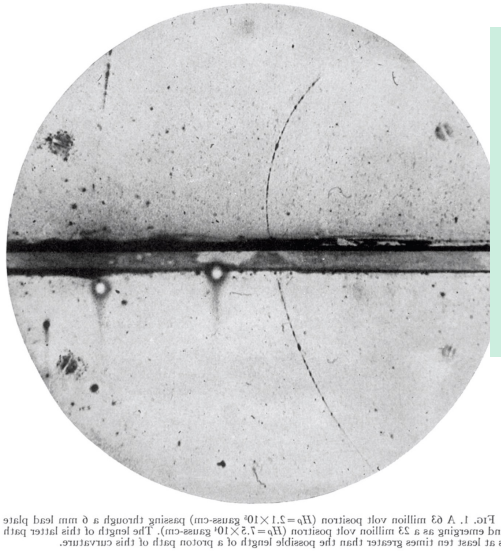
. . .

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.



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)

....

Stars of antimatter?
Galaxies of antimatter?

The view from Astrophysics

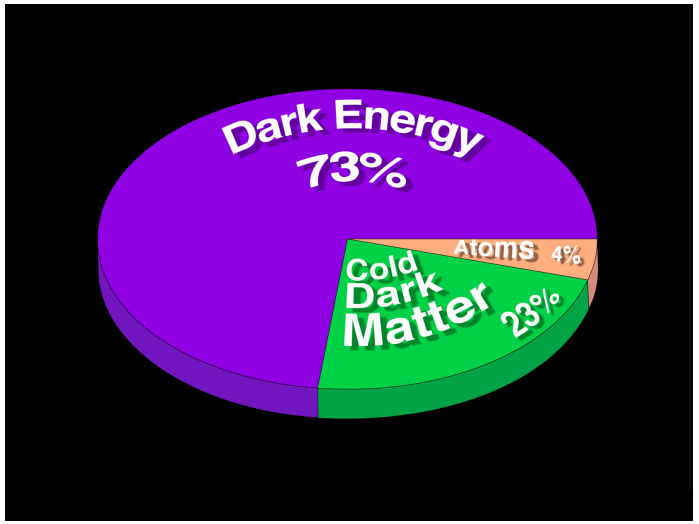
No evidence for any primary anti-matter in sky except those produced as secondary products in interactions of cosmic rays

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

So, what happened to all the anti-matter?

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

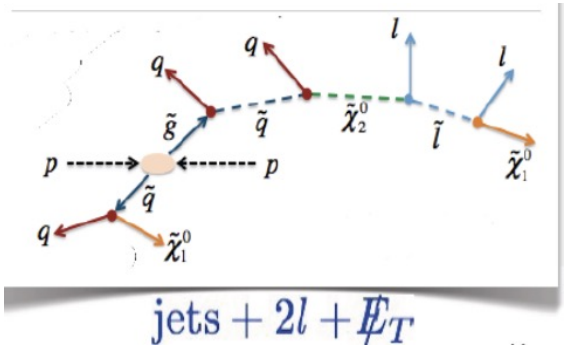
There must be other particles and forces than those in the Standard Model

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

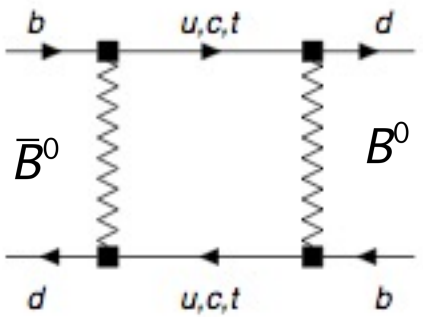
Finding these is the main goal of particle physics
&
why we use and need more powerful particle accelerators

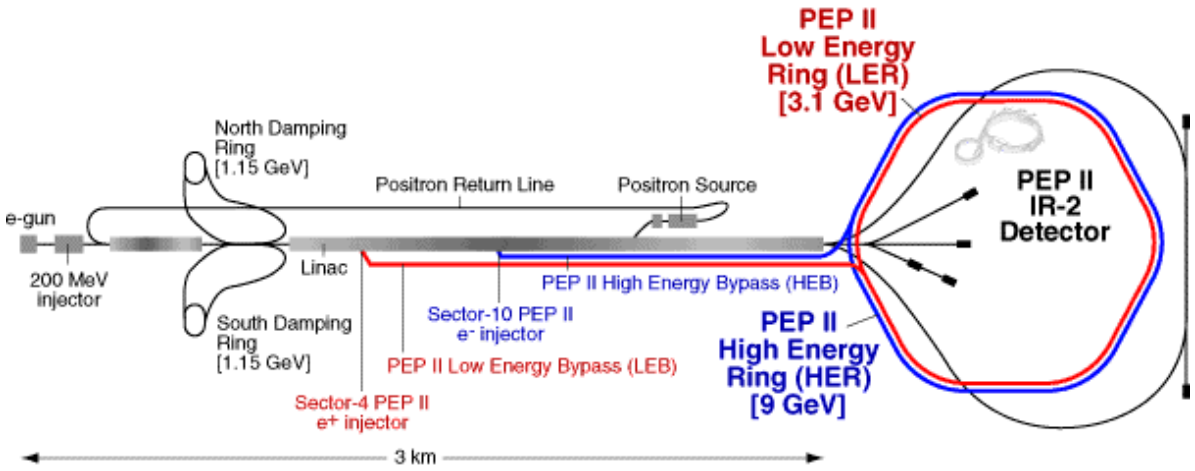
searches for new particles & interactions at LHC

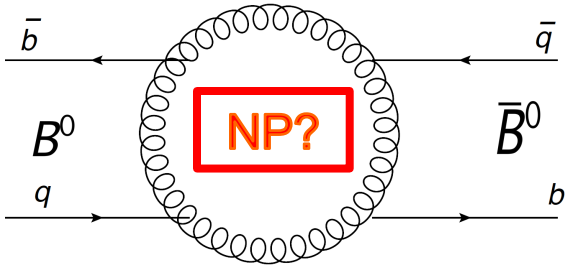
LHC Run-I yielded the Higgs
But no sign of NP particles yet
All eyes are on LHC Run II

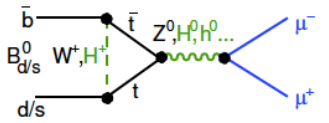


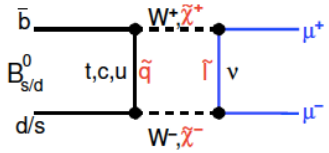
Search for their quantum imprints

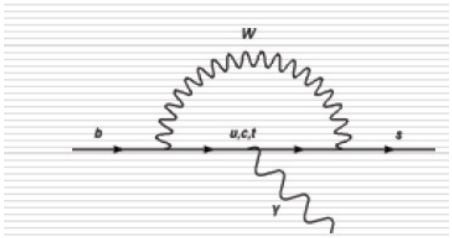


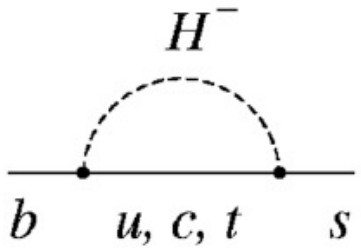








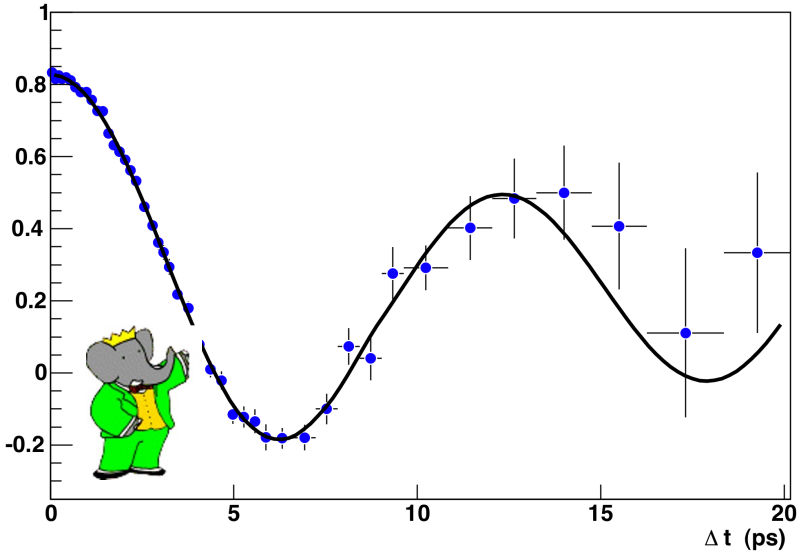




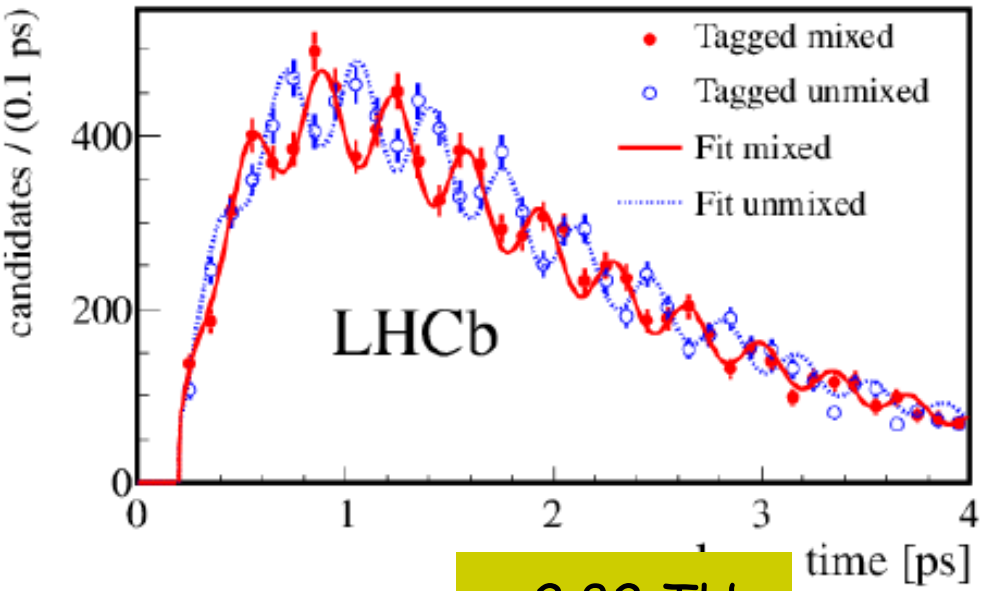
$B^0 \Leftrightarrow \bar{B}^0$ oscillation Today

Time evolution of a state prepared as B^0

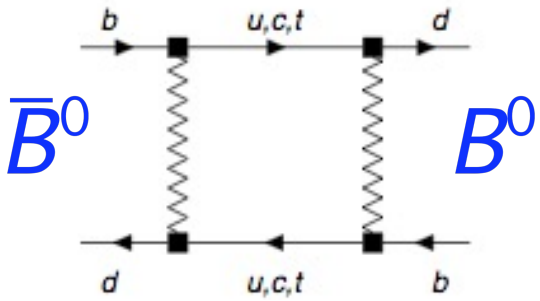
$B_d^0(\bar{b}d) \Leftrightarrow \bar{B}_d^0(b\bar{d})$



$B_s^0(\bar{b}s) \Leftrightarrow \bar{B}_s^0(b\bar{s})$



~81 GHz
$\propto m_t^2 \, |V_{tb}^* V_{td}|^2$

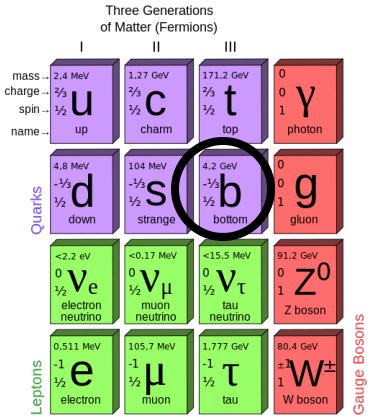


~2.82 THz
$\propto m_t^2 \, |V_{tb}^* V_{ts}|^2$

So, what's our work on?

Briefly:

Since 1981-been using the "b quark" to try to uncover some of these mysteries:



focusing on

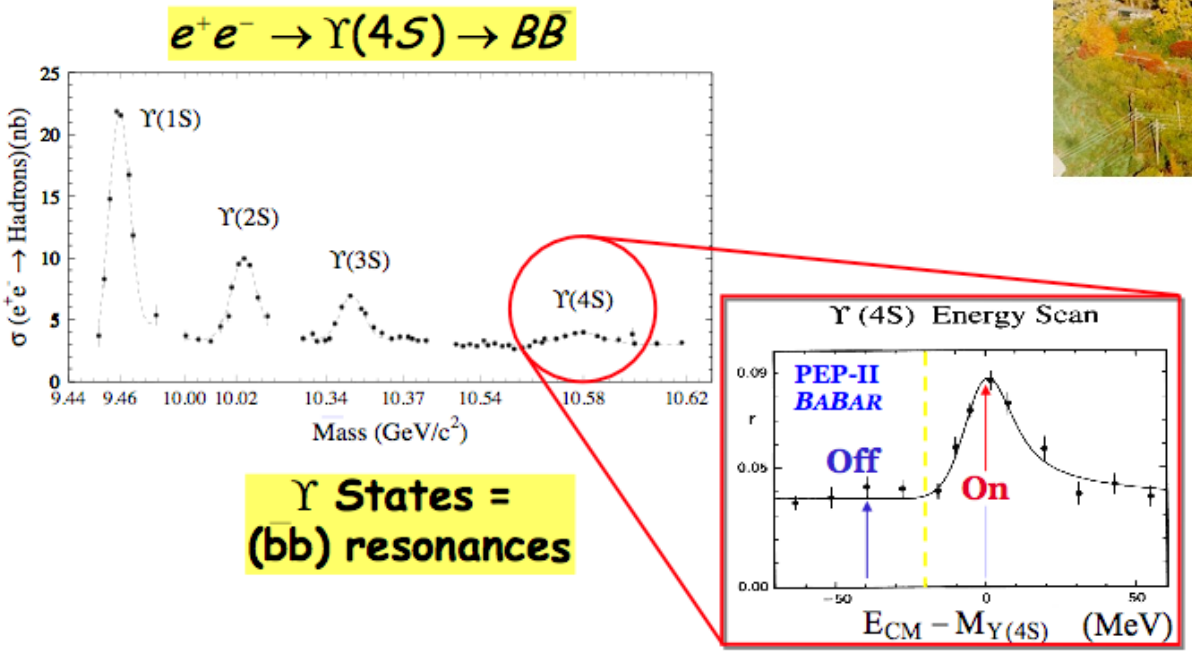
the matter-antimatter imbalance mystery

The setting for the "b-quark probe" in 1981

Cornell Electron Positron Collider

Produce
matter and antimatter in pair

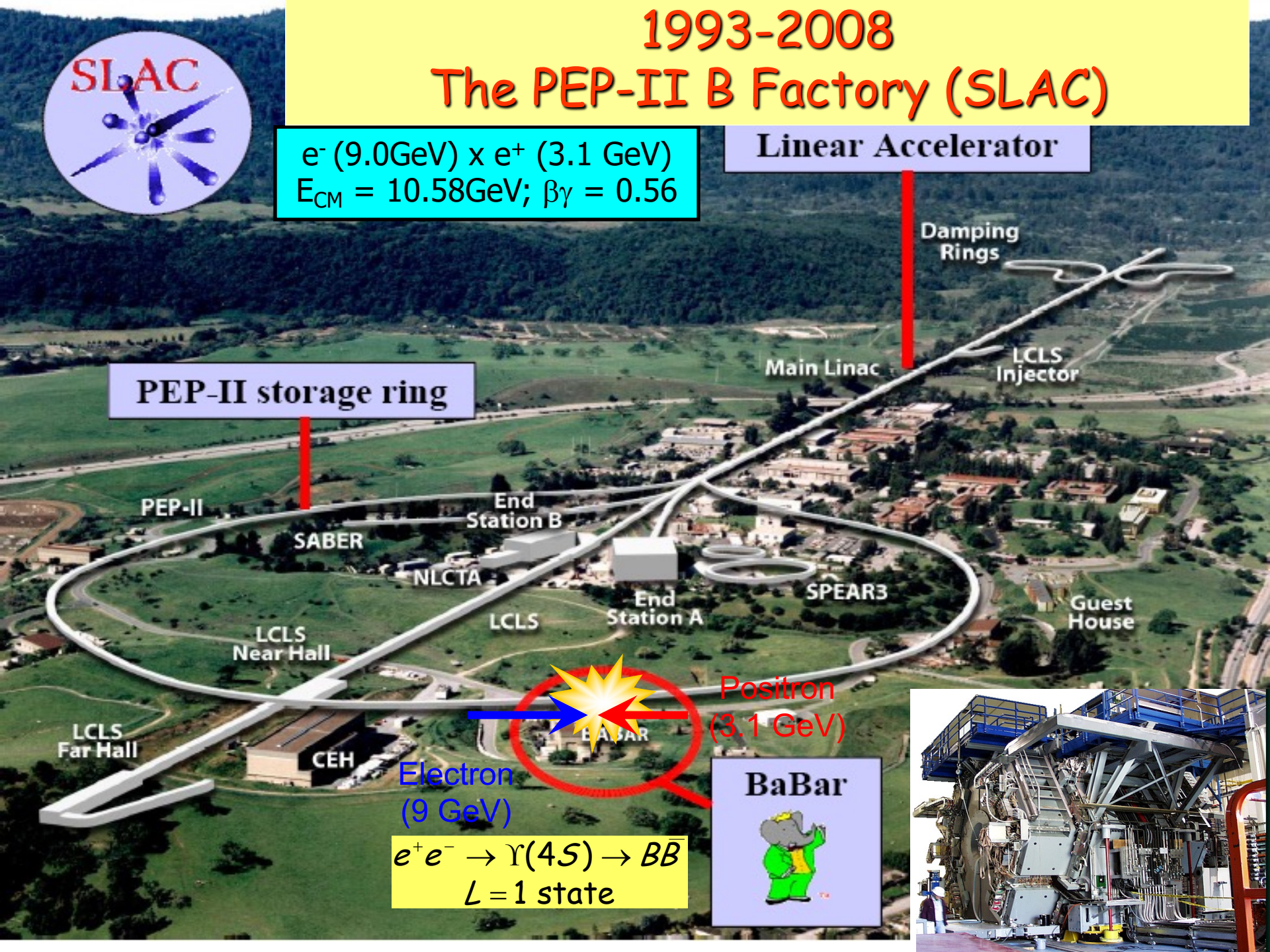
e+ e- →B meson + anti-B-meson
record & study their properties



Υ States =
(bb) resonances

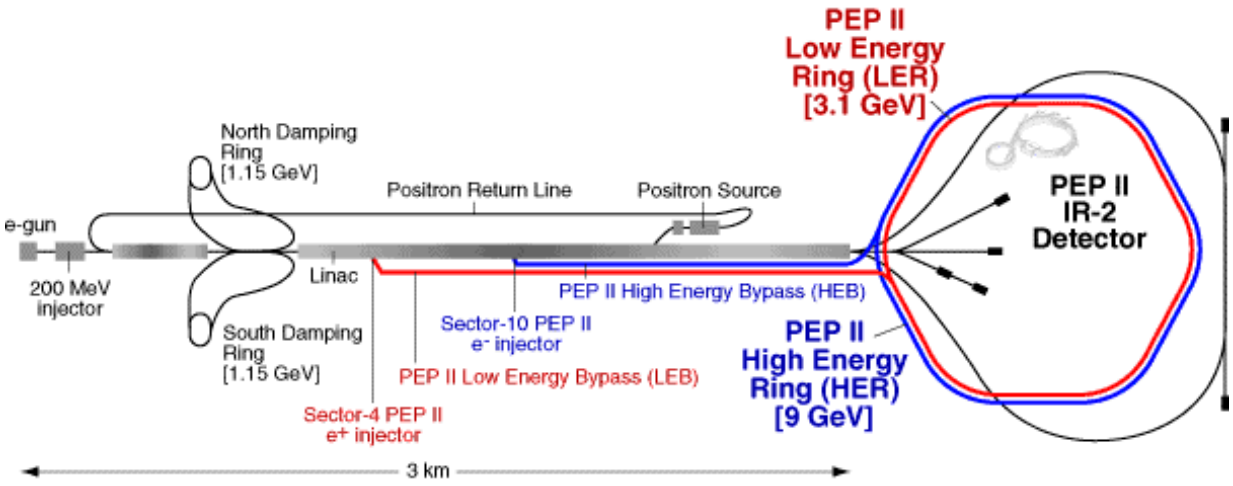
1993-2008
The PEP-II B Factory (SLAC)

e^- (9.0GeV) x e^+ (3.1 GeV)
E_{CM} = 10.58GeV; $\beta\gamma$ = 0.56

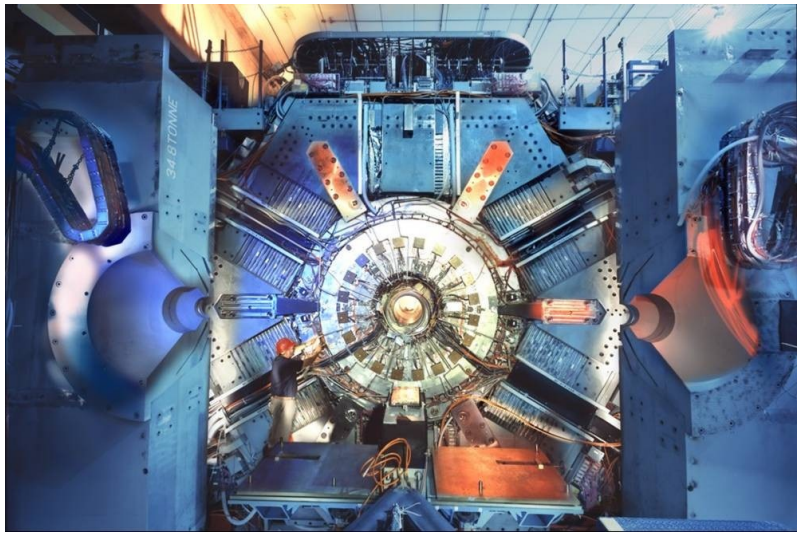


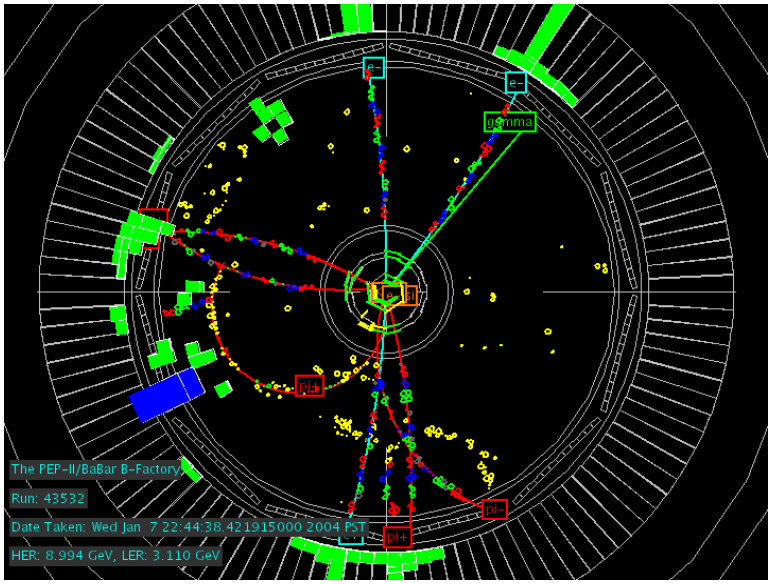
$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
$L = 1$ state

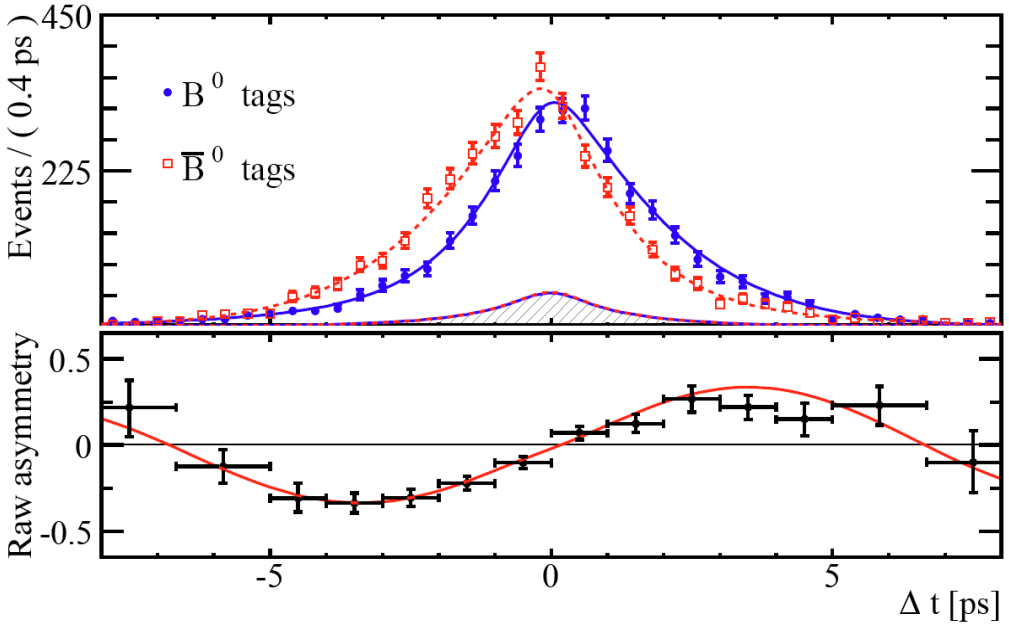
The e+e- B Factory at SLAC



Collected a billion events
of B & anti-B mesons pairs







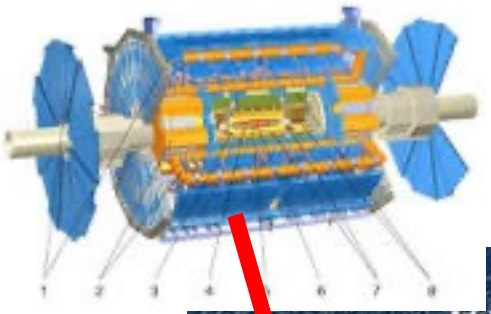
Results from a billion events

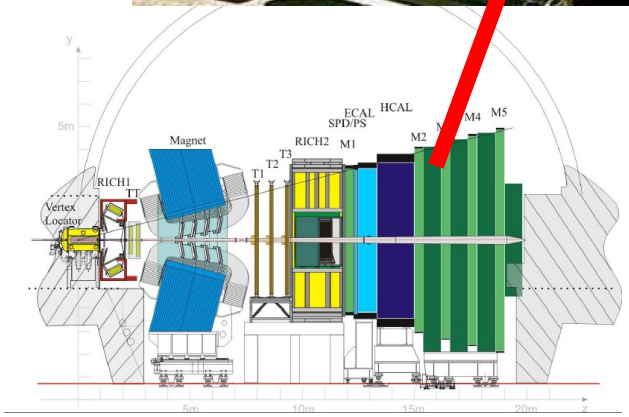
Time evolution of
B mesons & anti-B mesons

Our results found significant asymmetry between matter and antimatter – at expected level from Standard Model
(2008 Nobel prize went to Kobayashi & Maskawa for predictions)

But this is not enough to explain the imbalance in universe, so the search goes on.

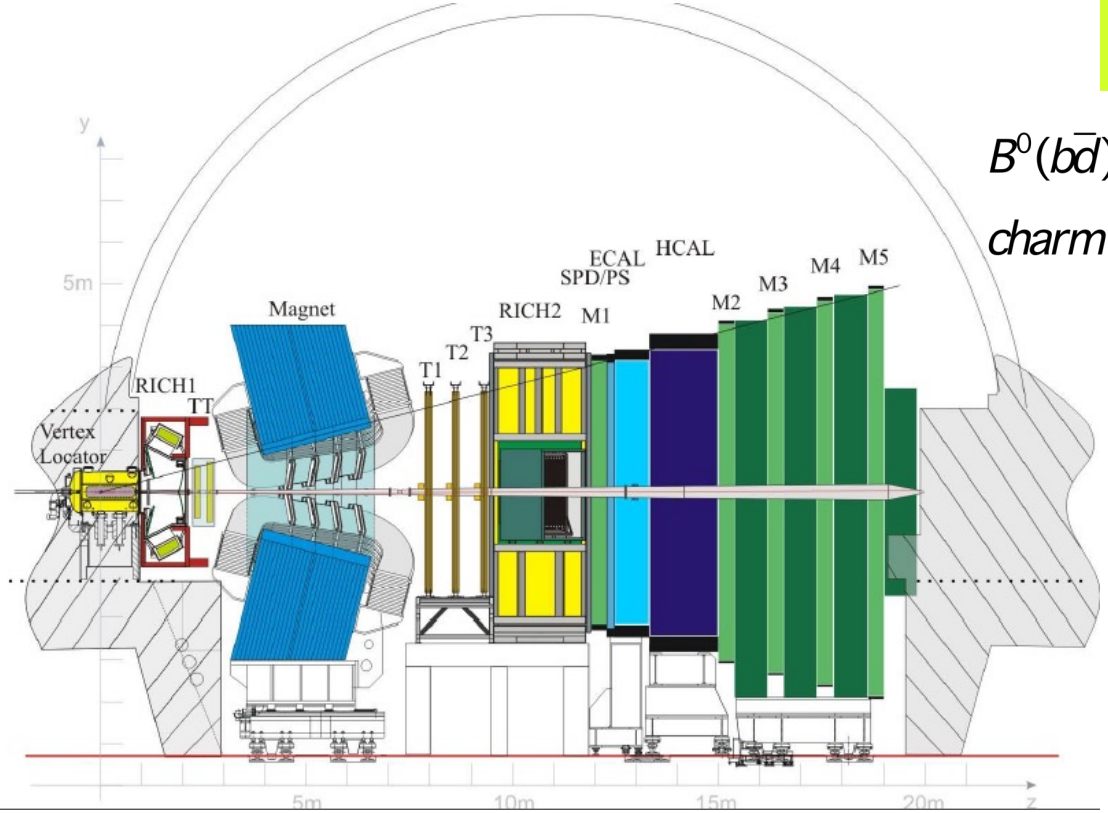
2012-now
At Large Hadron Collider (LHC)
LHCb experiment





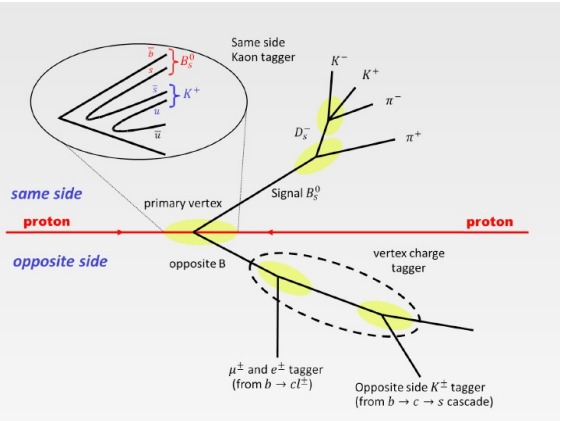
The LHCb Experiment

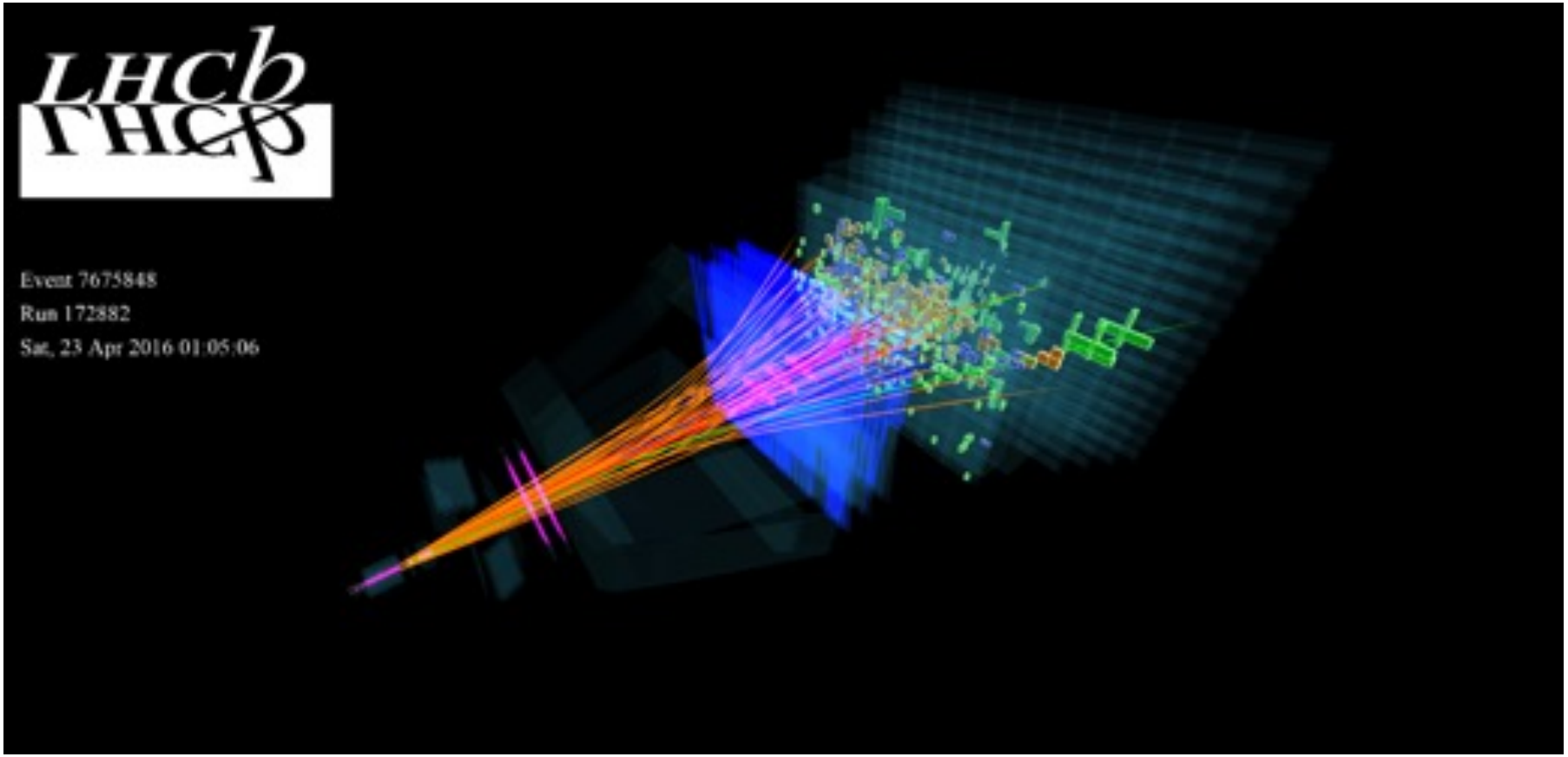
σ_{inel}~70-80 mb
$\sigma_{b\bar{b}}$~500 μb (14 TeV)

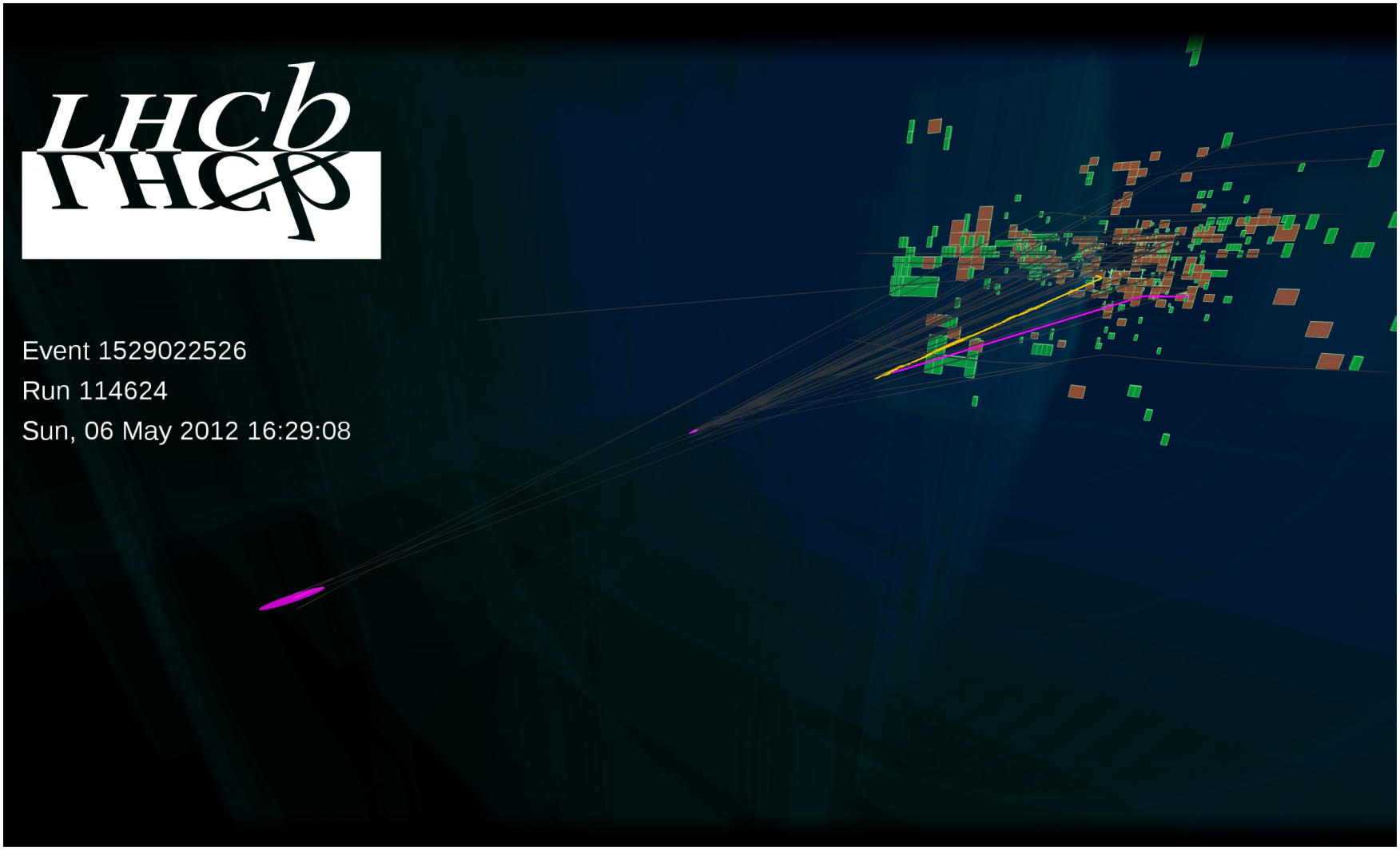


$B^0(b\bar{d})$ $B^-(b\bar{u})$ $B_s^0(b\bar{s})$ $B_c(b\bar{c})$ $b-$ baryons

$charm-$ hadrons,..




LHCb
Event 7675848
Run 172882
Sat, 23 Apr 2016 01:05:06


LHCb
Event 1529022526
Run 114624
Sun, 06 May 2012 16:29:08

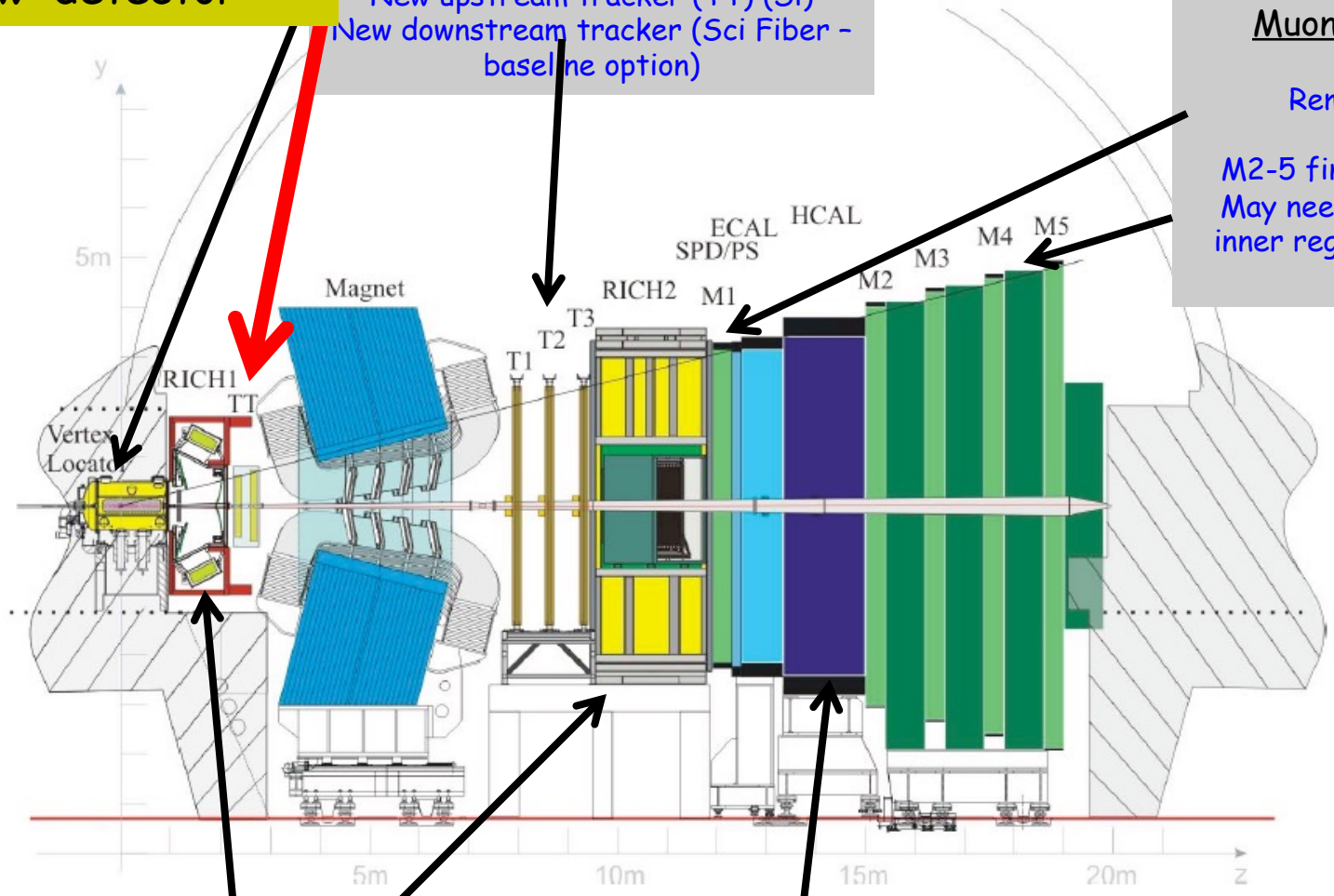
Now working towards developing a largely new detector

Tracking system:
New VELO (Si strip → Pixel)
New upstream tracker (TT) (Si)
New downstream tracker (Sci Fiber – baseline option)

Muon System:

Remove M1

M2-5 fine for 1×10^{33}
May need upgrade of inner region at 2×10^{33}



RICH 1 & RICH 2
HPD→ MaPMT
New 40 MHz R/O
RICH1: new optics
remove aerogel

Calorimeter:
New 40 MHz R/O
Lower PMT gain to reduce anode current
Remove SPD & PS

Early days of designing the Upstream tracker at our UMD labs