b- и c-фабрики… что нового они нам дадут?

П. Пахлов

Международная лаборатория физики элементарных частиц, МИЭМ ВШЭ

Рабочее совещание ОИЯИ — НИУ ВШЭ

Дубна, 14 июня 2024

Physics before the SM

Three interactions are studied carefully and could be described theoretically:

- Strong – pion (other meson) exchange provides a good (at least qualitatively) description;
- Weak – 4-fermion interaction can precisely describe beta-decays, decays of muon, pion, others with a precision limited by strong corrections.
- Electromagnetic – fantastically precise theory which is confirmed at ~10^{-10} level.

Problems:

- while different kind of interactions looks physically similar, their theories are too different;
- there was no rationale for theories of weak and strong interactions: they were just cobbled together to fit
- weak interaction has unremovable infinities, in strong perturbation theory is inapplicable;

Building SM

- Use QED as an example to follow of a successful theory
- Yang-Mills theory as a mathematical background
- Heizenberg's idea of isospin as a good hint of approaching to YM theory

We can only guess in hindsight that everything was already in our hands in early 50th . In fact, it took another 15 years to overcome a large number of obstacles before success.

50th in Physics: "it was a time of frustration and confusion. The success of quantum electrodynamics in the late 1940s had produced a boom in elementary particle theory, and then the market crashed."

S. Weinberg

the SM

- three interactions are unified based on a common principle: gauge invariance
- accommodated fermions quite elegantly, when only the single fermion generation was known (strange quark, muon and muon neutrino were considered as a mistake of Nature:

"These particles resemble the rough sketches, which the Creator has thrown out as unsuccessful, and which we with our sophisticated equipment dug in his wastebasket."

- the main prediction (existence of neutral weak currents) confirmed
- renormalizability proved

All previous problems seem solved, and a great theory has been created!

One can crack open the champagne and celebrate

But then, together with success in testing, comes disillusionment. New phenomena (more quark generations, neutrino mixing) inflated SM to a clumsy monster, while some new observations (dark matter & energy, early Universe inflation) didn't find their place in the theory… Some intrinsic problems still not solved: strong CP problem, fine tuning, ultraviolet divergencies. Strong interaction though based on the same principle still stands alone, but even worse with gravity: it can't stand even nearby with SM.

SM hasn't answered many old questions, but raised new ones:

- Why is gauge symmetry group the way it is?
- Why are there so many different fermions?
- What is responsible for their organization into generations?
- Why are there 3 (nor 2, neither 37) generations each of quarks and leptons?
- Why are there flavor symmetries?
- What breaks the flavor symmetries?
- What causes matter – antimatter asymmetry?

Physics after the SM

Mentally we have already stepped over the Standard model and are thinking about the next theory, although we have absolutely no idea how it looks like.

- a pressing question for experiment: Where can this new unknown theory be revealed?

Seems like a stupid idea: how to search for something that you don’t know how it looks like.

Since ancient times, we have used only two ways to search for something new:

- to go there I don’t know where (energy frontier experiments)
- stupidly walk forward, and then wherever your feet take you... you’ll find a thread... (precision frontier experiments)

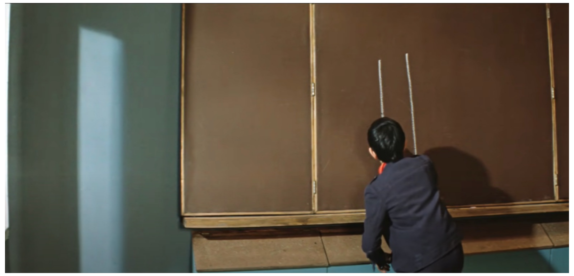
Heavy flavour Physics at LHC era?

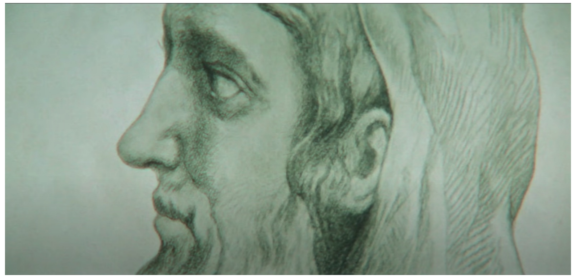
Few years ago we dreamed about NEW rich phenomenology at the energy frontier, new puzzles and ideas, that follow from LHC new observations. LHC has brought yet only the Higgs boson but nothing else.

Flavour physics is a chance to find underground life (burrows under the palm tree)

Let's imagine we are checking the Euclidean geometry

We can try to draw a straight line to infinity and check whether it will intersect a parallel one

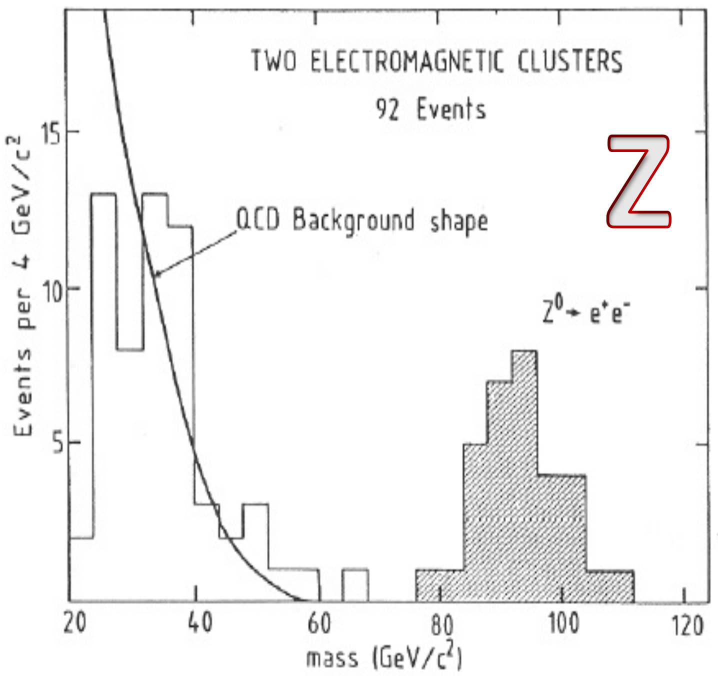


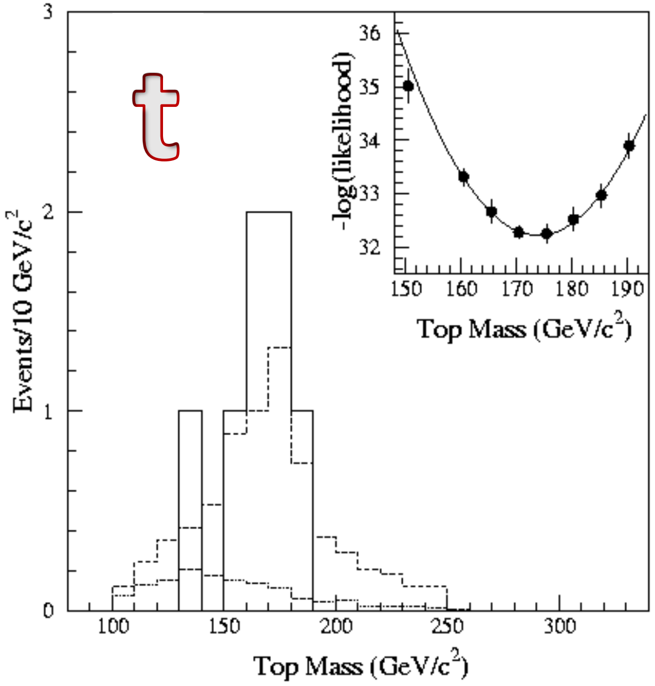


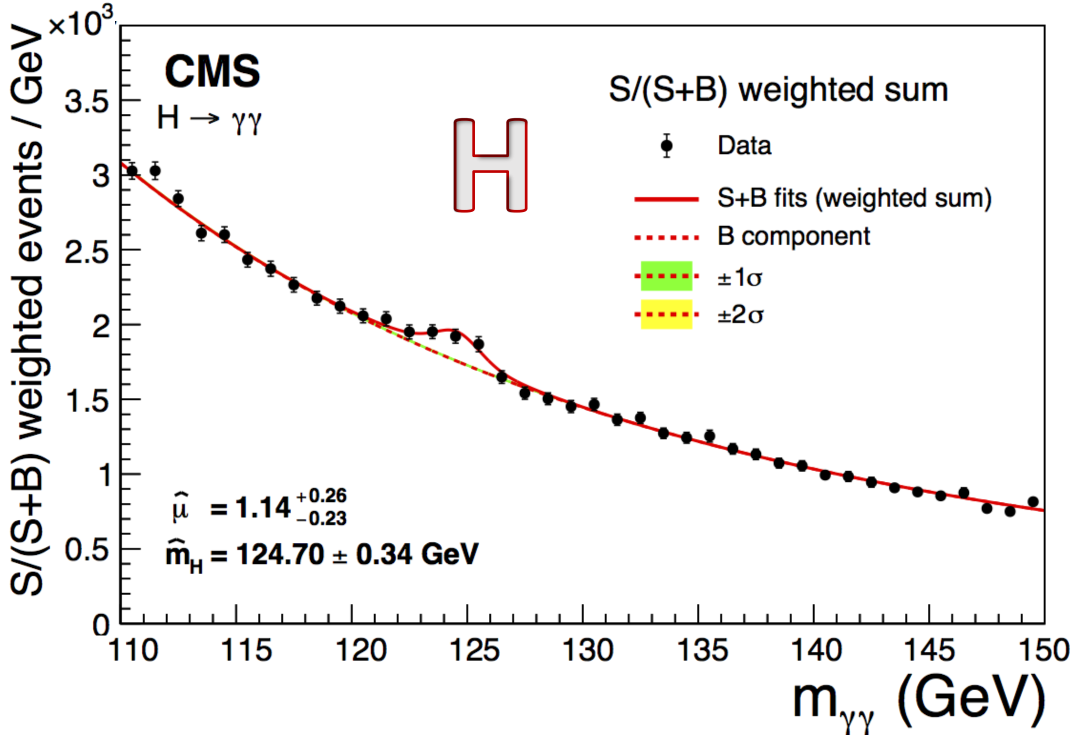
Another way is to draw a circle, to measure its length and check how it is related to π

Previous experience

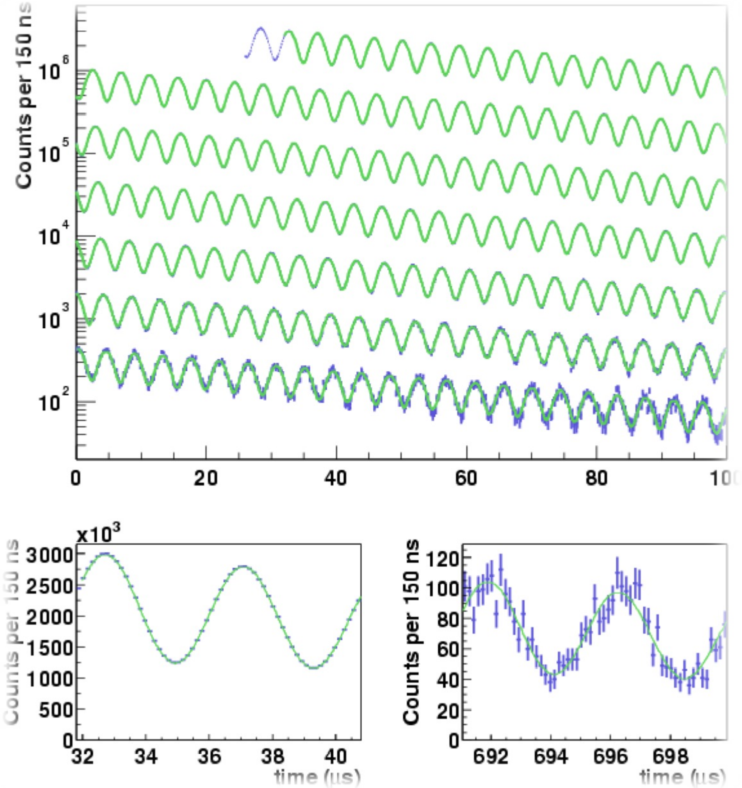
Experiments at high energies are indeed very useful. They allow to measure parameters that were not known. But there has not yet been a single case where something new was discovered at energy frontier experiments, that was not foreseen in advance. Existence of c-, b-, t-quarks, W, Z and Higgs bosons were inevitably proven by low energy precise experiments.



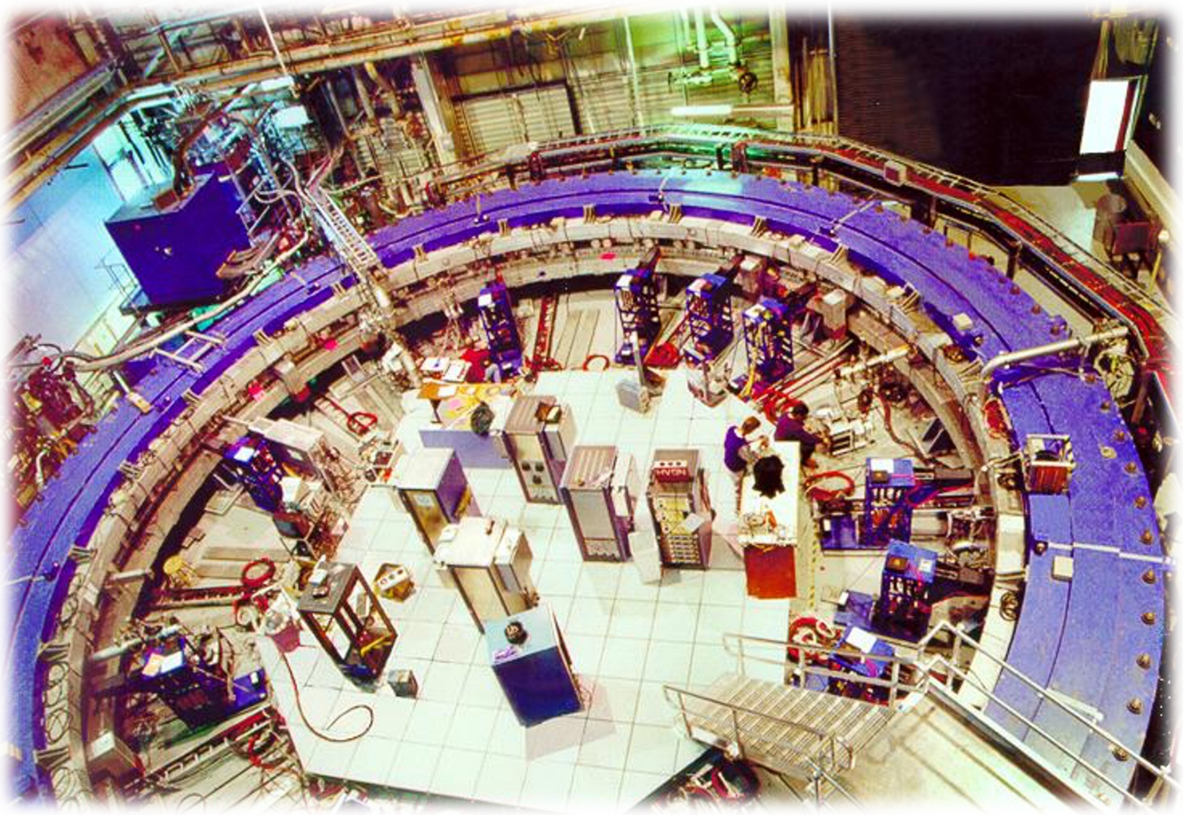




Muon g-2 experiments



The main problem with such an experiment is that a large collaboration has been measuring one number for many years… Then they achieve fantastic precision (~10^{-11}), BUT…



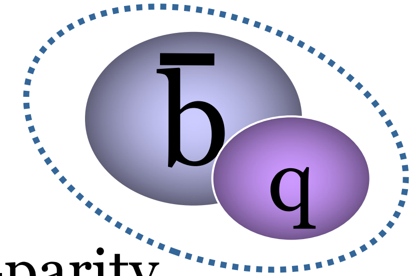
the conclusion depends on other people, who decide what this number should be equal to.

It depends on this whether we see or do not see something new. Unfortunately, these people periodically change the desired value back and forth.

B-mesons

What are B mesons?

name	quarks	charge	mass (GeV)	lifetime (10^{-12}s)
B_d^0 or B^0	$\bar{b}d$	0	5.2796	1.519
B_u^+ or B^+	$\bar{b}u$	+1	5.2793	1.641
B_s^0	$\bar{b}s$	0	5.3668	1.463
B_c^+	$\bar{b}c$	+1	6.277	0.45



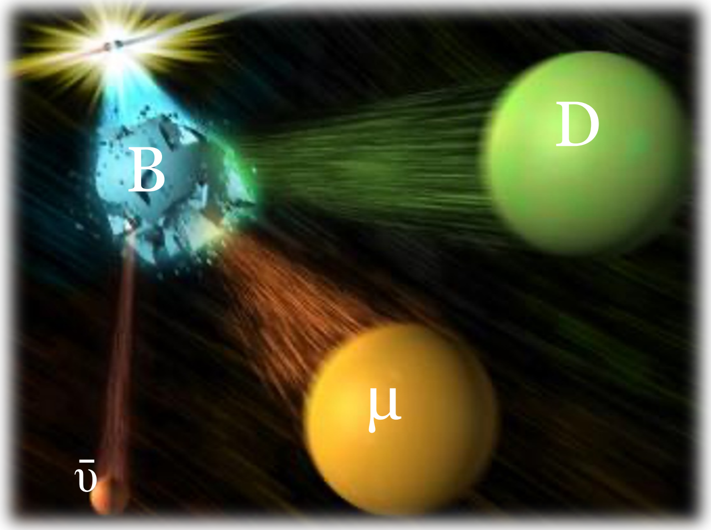
Spin-parity
$J^P = 0^-$

How are they produced?

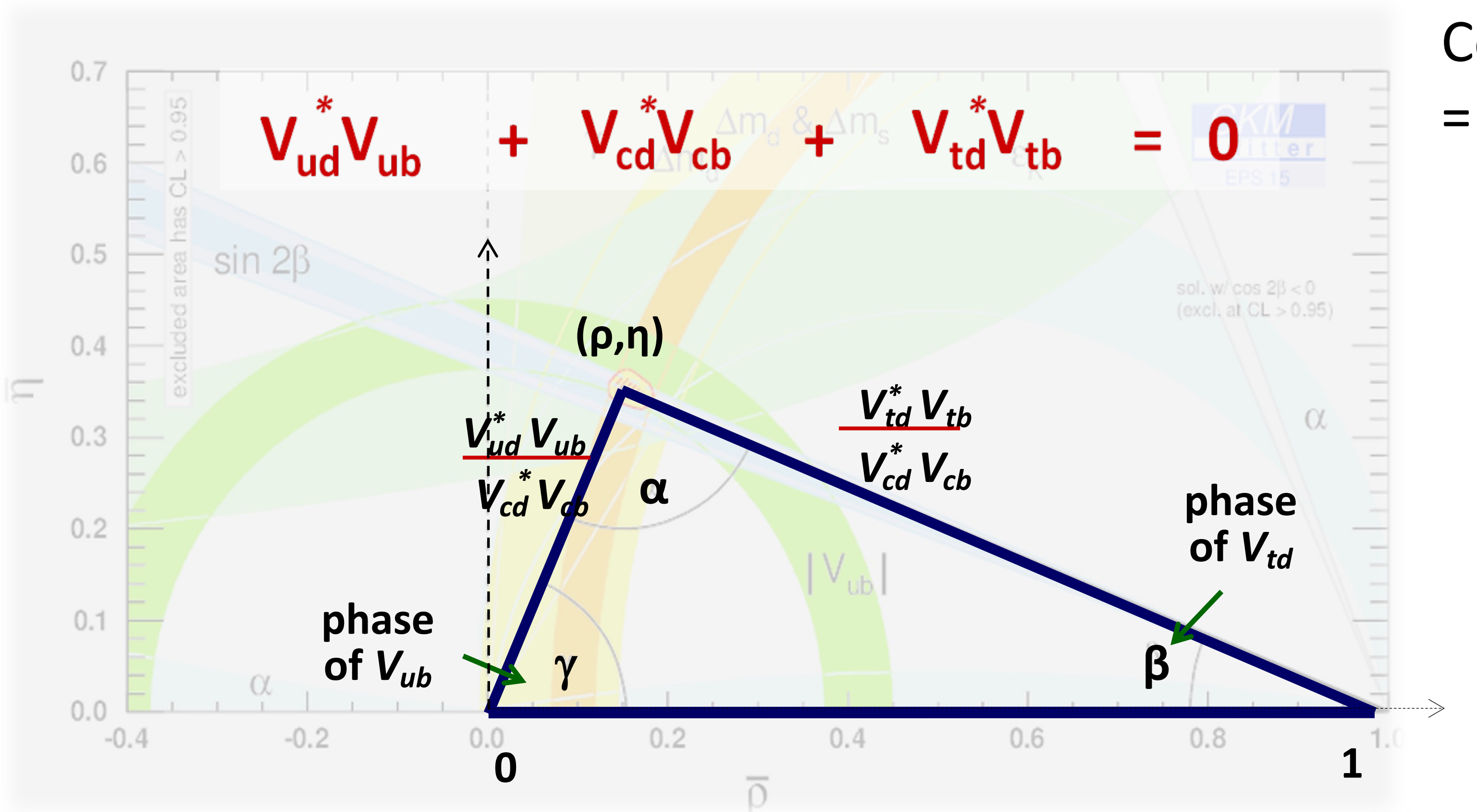
- $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ is the cleanest process (large $B\bar{B}$ /other cross section; no extra particles; quantum correlations)
- also at hadron machines: $pp \to B + \bar{B} +$ anything

How are they decay?

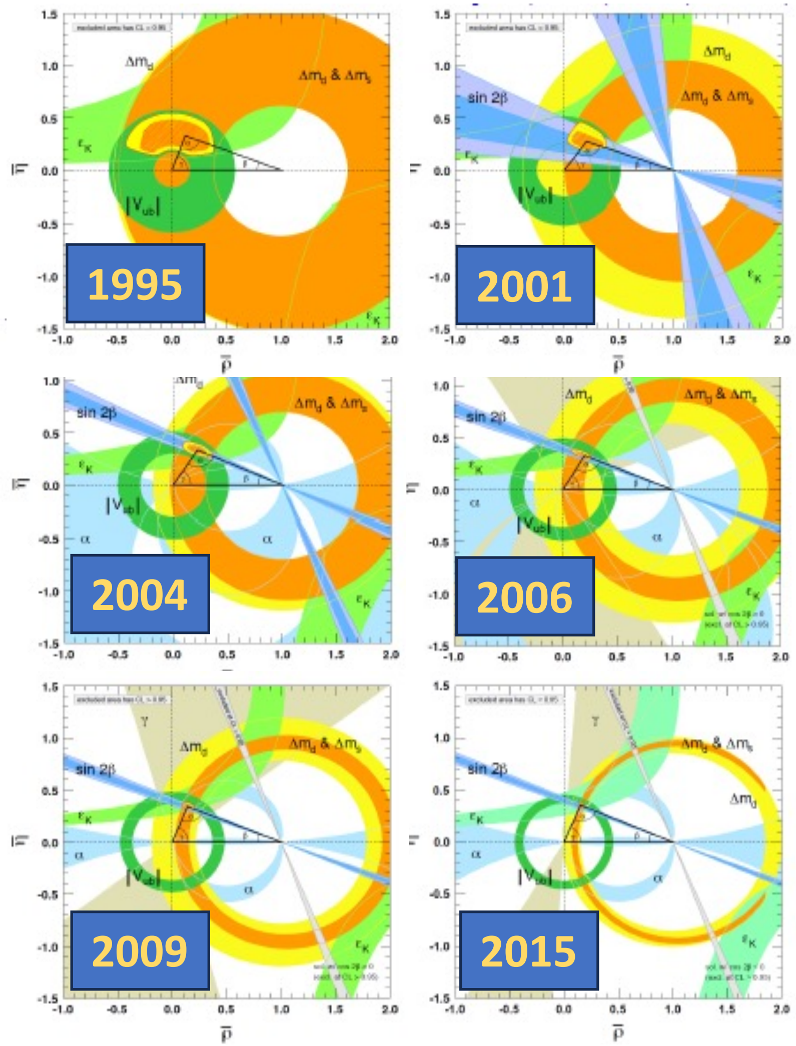
- usually to charm $b \to c$, e.g. $B \to D\mu\bar{\upsilon}, D^*\pi$, etc
- much rarely to light quarks $B \to \pi\pi$ ($\frac{|b\to c|^2}{|b\to u|^2} \sim 100$)



B-physics: Search for New Physics in CP violation

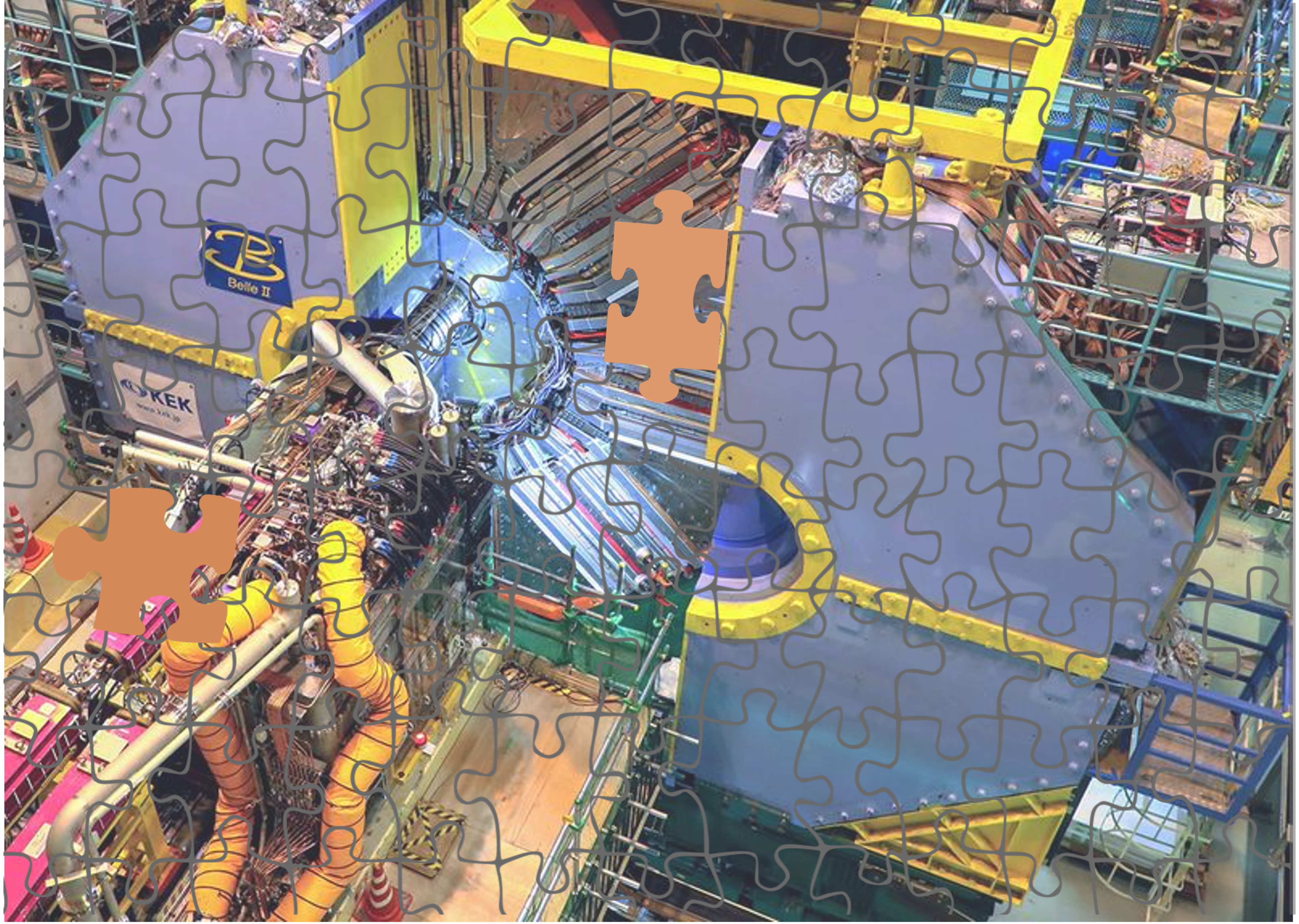


Consistency of Unitarity triangle
= probe for NP at O(1TeV)

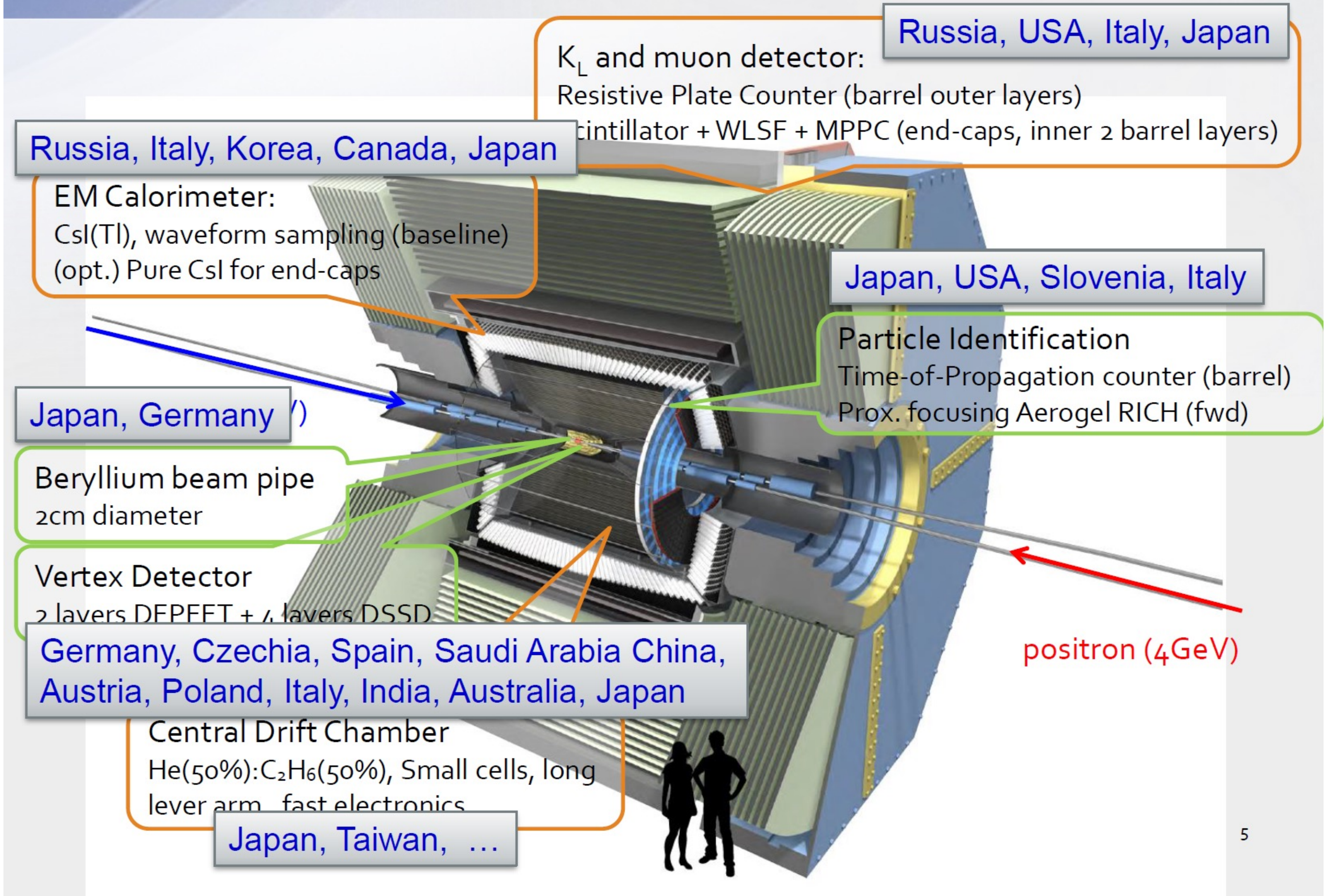


The strategy is similar:

we measure not a single number but many fundamental ones and then compare them not with theory but check their consistency with each other.


Belle II
KEK

Belle II Detector



Summary

The current era is the most exciting one in beauty and charm physics for many decades. Neutral mixing and CP-violation in charm, long feared to be too small for experimental study, are now observed, and the next goals are firmly in sight. The most urgent tasks are to establish whether the parameter x, and hence the mass splitting in the neutral charm system, is of a similar magnitude to y, or instead vanishing; to make further measurements of direct CP-violation, in particular those that will help elucidate whether the size of A_{CP} is compatible with SM expectations; and finally to intensify the search for CP-violation associated with $D^0 - \overline{D}^0$ oscillations.