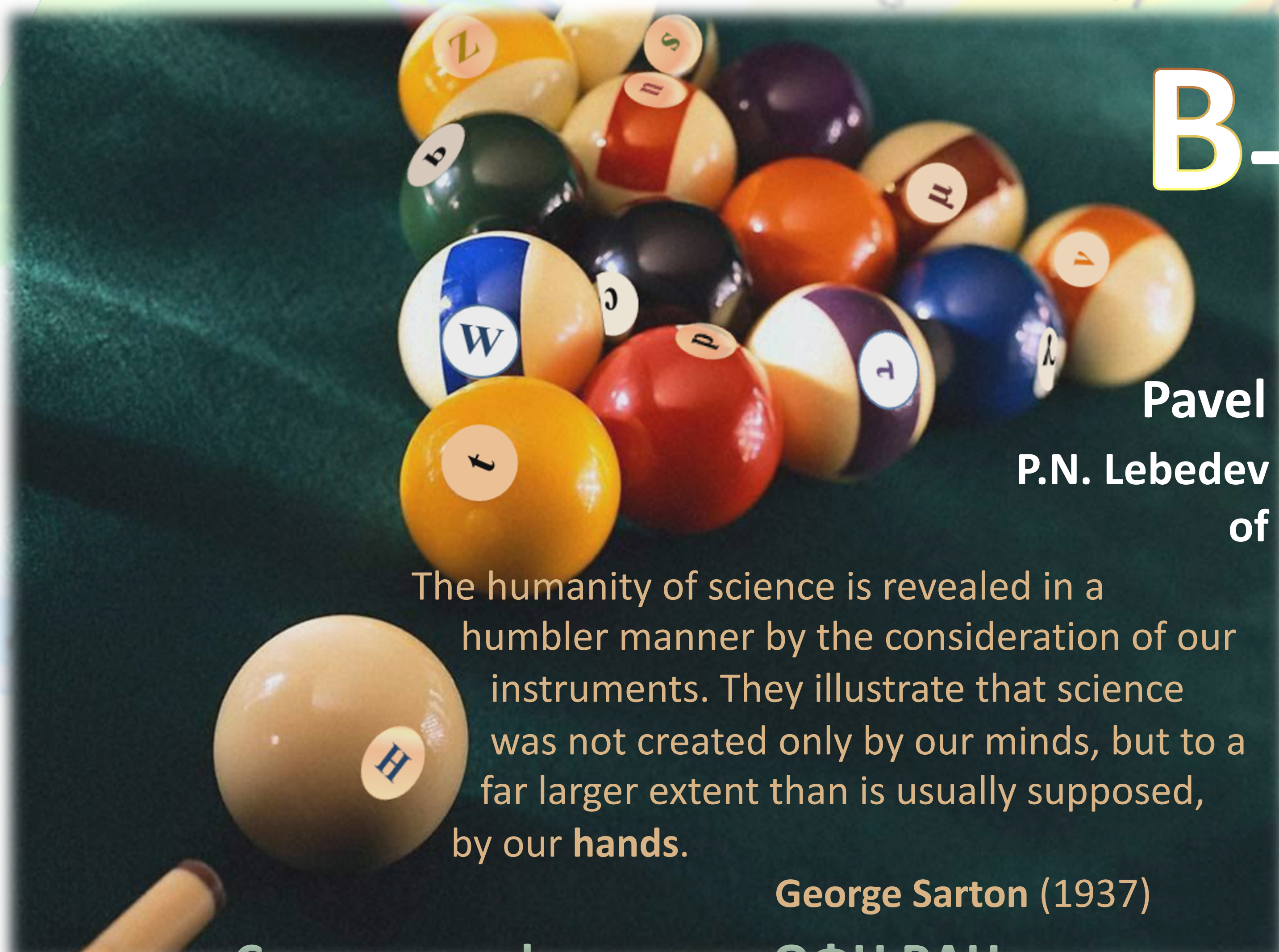
B-factories

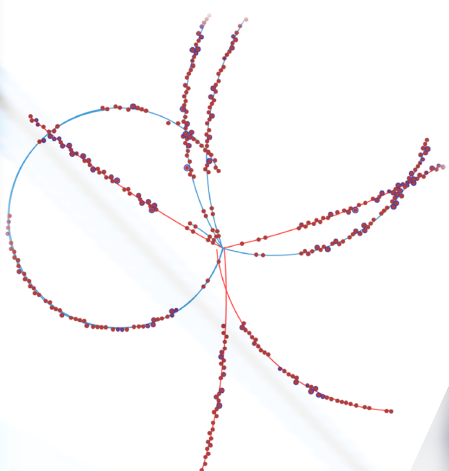
Pavel Pakhlov

P.N. Lebedev Physical Institute of RAS



The humanity of science is revealed in a humbler manner by the consideration of our instruments. They illustrate that science was not created only by our minds, but to a far larger extent than is usually supposed, by our **hands**.

George Sarton (1937)



Сессия-конференция ОФН РАН

Академгородок, март 2020

preHistory: era before beauty birth

FLAVOR PHYSICS:

At first there was strange (and muons) (since 1940th)

And strange behaved weirdly: violated everything – P, C and then CP (1956-1963)

And Sakharov behold this and said that this was good (1967)

****

… and there was evening, and there was morning…

Weinberg and Salam set the law… (1967)

Glashow, Iliopoulus and Maiani sacredly respected the law and made charm, (1970)

(and Glashow said that if nobody would find charm, then he would eat his hat)

****

… and there was evening, and there was morning…

Kobayashi and Maskawa said “Let the quarks sector teems with more creatures…” (1972)

… and Ting and Richter found charm to save Glashow’s hat and stomach (1973)

… but nobody heard Kobayashi and Maskawa … until τ-lepton was discovered (1975)

… and Lederman found beauty (1976)

preHistory: beauty birth

Lederman observed Υ(1S) (1976) and theorists started to discuss B-mesons

Pais and Treiman said there is CP violation in heavy quark decays, but alas, it is tiny (1975)

Ellis, Gaillard, Nanopoulos, Rudaz proved the top mass 5 < m_t < 65 GeV (1977)

… and made the greatest contribution to B-factories! (PEP 1980, TRISTAN 1986)

****

… and there was evening, and there was morning…

Bander, Silverman, Soni suggested to search for direct CP violation in B+ (1979)

Carter & Sanda said that indirect CP violation in B^0 can be as large as 10% (1980)

****

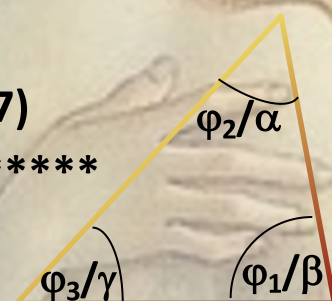
$$B^0 \to f_{\text{common}} \leftarrow \overline{B}^0$$

… and there was evening, and there was morning…

Discovery of Υ(4S) (1980), ~~→ BB~~* (1981), long life of B mesons (1983)

B-Bbar mixing (1986)

Rosner & Sanda: Unitarity triangle (1987)

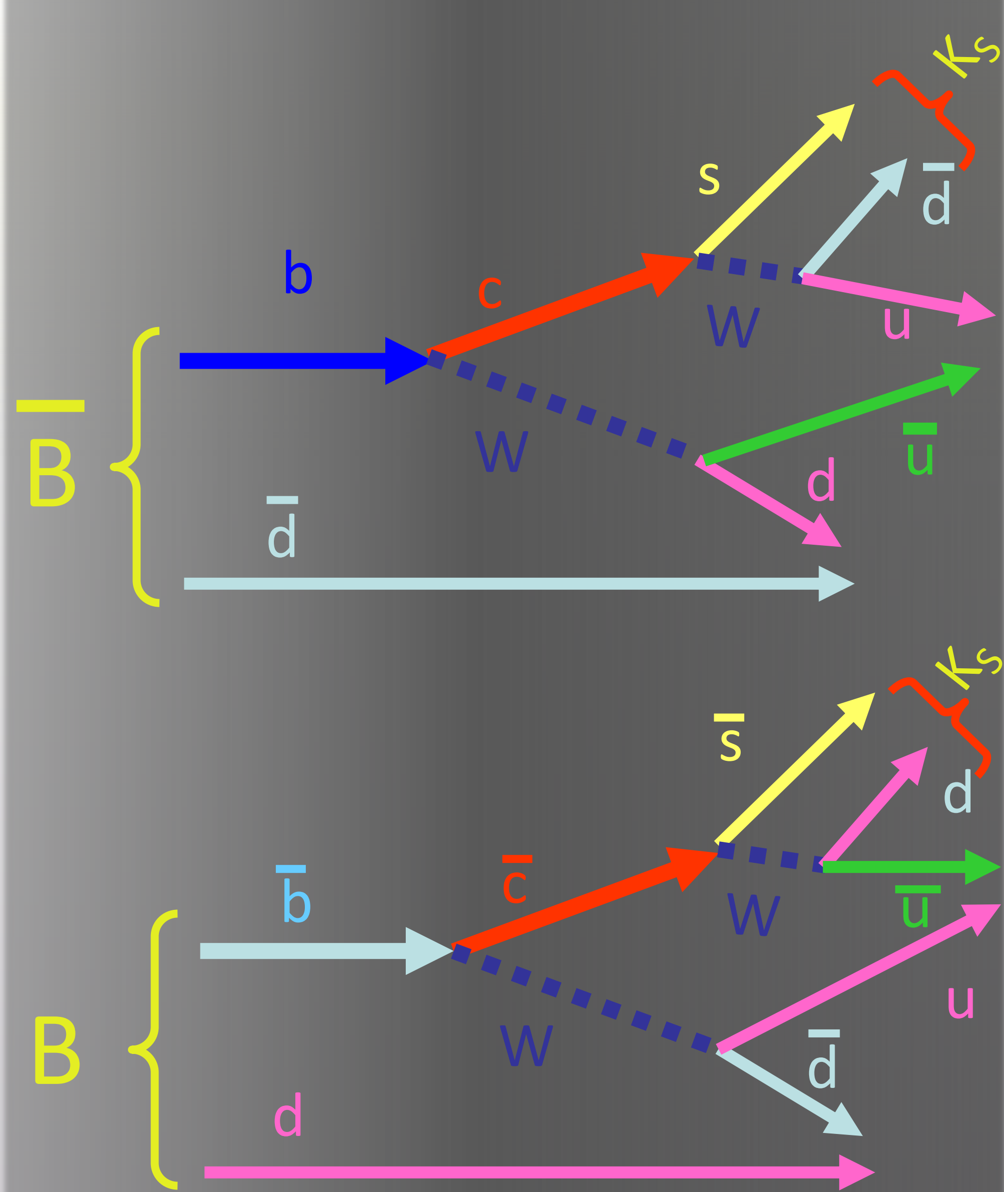


****

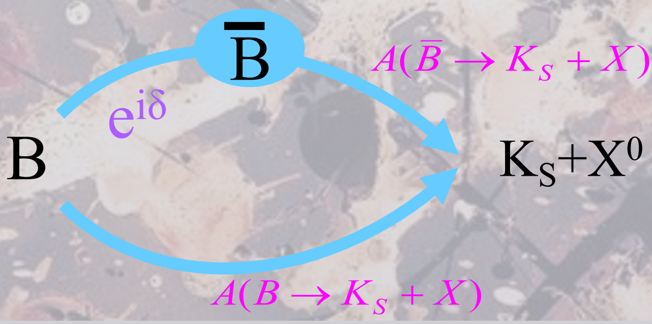
… and there was evening, and there was morning…

b $\to$ u (1991), b $\to$ sγ (1995), b $\to$ sg (1997),

Carter-Sanda idea



In 1980 nobody could think of golden mode ($J/\psi\ K^0_S$). But Carter & Sanda realized that two succeeding CKM-favored W emitions may result in (almost, up to s-d replacement) same quark configuration. s-d difference is hidden in K^0_S. Thus, both B^0 and B^0-bar decay into the indistinguishable final state (even if intermediate states D^0/D^0-bar are different). They estimated the CP violation effect may be as large as 10% (obviously, they pulled the effect up), but the Nature is very generous: in reality the effect is ~100%.



Why do we need asymmetric e^+e^- collider?

The source of B mesons is the Υ(4S), which has $J^{PC} = 1^{--}$.
The Υ(4S) decays to two bosons with $J^P = 0^-$.
Quantum Mechanics (application of the Einstein-Rosen-Podolsky effect) tells us that for a C = –1 initial state (Y(4S)) the rate asymmetry:

$$A = \frac{N_{(B_1 \to f_{CP})(\bar{B}_2 \to \bar{f}_{fl})} - N_{(B_1 \to f_{CP})(B_2 \to f_{fl})}}{N_{(B_1 \to f_{CP})(\bar{B}_2 \to \bar{f}_{fl})} + N_{(B_1 \to f_{CP})(B_2 \to f_{fl})}} = 0$$

However, if we measure the time dependence of A we find:

$$A(t_1,t_2) = \frac{N(t_1,t_2)_{(B_1 \to f_{CP})(\bar{B}_2 \to \bar{f}_{fl})} - N(t_1,t_2)_{(B_1 \to f_{CP})(B_2 \to f_{fl})}}{N(t_1,t_2)_{(B_1 \to f_{CP})(\bar{B}_2 \to \bar{f}_{fl})} + N(t_1,t_2)_{(B_1 \to f_{CP})(B_2 \to f_{fl})}} \propto \sin 2\phi_{CP}$$

Need to measure the time dependence of decays to "see" CP violation using the B's produced at the Υ(4S).

B-meson's decay flight is only 20μm in Υ(4S) rest frame. No chance to measure such small distance with modern detectors…

⇒ this kills good idea?

No! just requires new idea:

Theory meets Experiment

Pier Oddone (1987) proposed the idea of asymmetric B-factory

TABLE 1.

Future $b\bar{b}$ factories and sweat shops. None of the luminosities shown in the Table have been achieved. Factors of two difference in luminosity are not significant.

E_{CM} GeV	Class	$E_1 \times E_2$ GeV × GeV	$\sigma_{b\bar{b}}$	Peak L proposed $cm^{-2}sec^{-1}$	$b\bar{b}$ events/yr 10^7 sec @ peak L	References
$\Upsilon(4S)$	CM RING	5 × 5	1 nb	5×10^{32}	$5 \cdot 10^6$	*SIN Proposal*[1]
	CM LINEAR	5 × 5		10^{33}	10^7	*Amaldi & Coignet*[2]
	BOOSTED LINEAR	2 × 12.5		5×10^{32}	$5 \cdot 10^6$	*Sessler & Wurtele*[3]
	BOOSTED RING	2 × 12.5		5×10^{32}	$5 \cdot 10^6$	*Oddone*[4]
Continuum 20 GeV	RING		0.1 nb	5×10^{33}	$5 \cdot 10^6$	*Bloom*[5]
	LINEAR			10^{34}	10^7	*Amaldi & Coignet*[2]
Z^0	LINEAR SLC	45 × 45	5 nb	5×10^{30}	$2.5 \cdot 10^5$	*SLC Study*[6]
	LEP	45 × 45		2×10^{31}	$8 \cdot 10^5$	*LEP Study*[7]
	RING IMAGINARY	45 × 45		5×10^{33}	$2.5 \cdot 10^8$	

DETECTOR CONSIDERATIONS

P. Oddone
Lawrence Berkeley Laboratory

1 INTRODUCTION

This short note is drawn in large part from the joint deliberations of the detector and physics groups at this workshop. There were many "full time" and "part time" members, among them C. Adolphsen, P. Avery, I. Bigi, E. Bloom, C. Buchanan, G. Coignet, H. Harari, W. Hofmann, N. Lockyer, I. Peruzzi, M. Piccolo, T. Sanda, P. Schlein, A. Soni, D. Stork, S. Weseler, H. Yamamoto, and T. Ypsilantis. In our deliberations we tried to under-

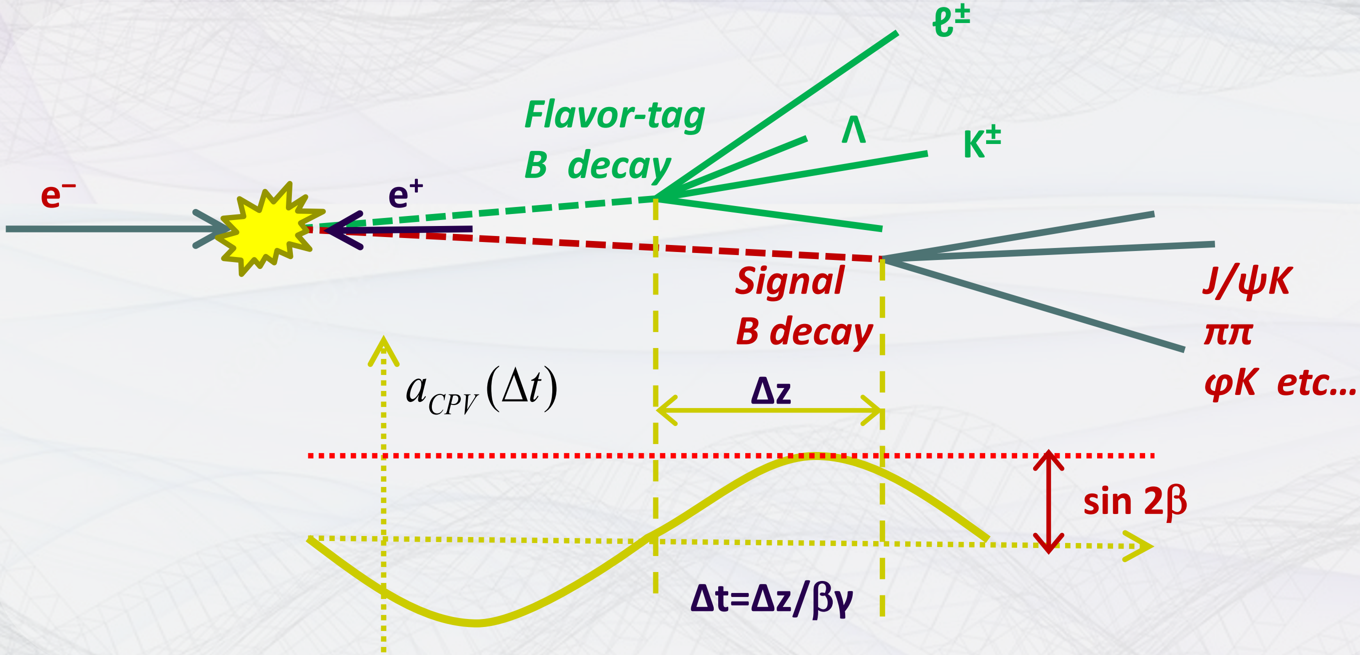
The idea of an Asymmetric B-Factory can be realized relatively economically at SLAC, where a powerful injector, an existing tunnel, and a ring of magnets suitable for the high energy ring already exist. The requirements for the accelerator are,

From Sanda's memories: "I went to KEK. People said that Oddone's idea is crazy and that the beam will blow up!

Measurement of CPV at B-factories

CPV asymmetry in the time-dependent rates for initial $B/\overline{B}$

$$a_{CPV}(\Delta t) = \frac{\Gamma_{\overline{B}\to\bar{f}}(\Delta t) - \Gamma_{B\to f}(\Delta t)}{\Gamma_{\overline{B}\to\bar{f}}(\Delta t) + \Gamma_{B\to f}(\Delta t)} = S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)$$



S **– parameter of indirect CP violation**
C **– direct CP violation parameter (non vanishing even after integration over Δt)**

For $f = \bar{f} = J/\psi K_S^0$
$S = \sin 2\beta; \quad C = 0$

Important:

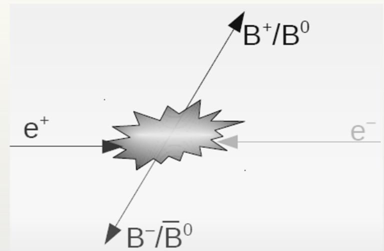
is provided by charged tracks from the second B ← **Flavor tagging**

β and γ are known from beam energies

Δt resolution is dominated by the resolution of z_{tag} – the tagging B-vertex (due to secondary tracks from D-decays) ← **Both B-vertex finding**

e^+e^- asymmetric B-factories

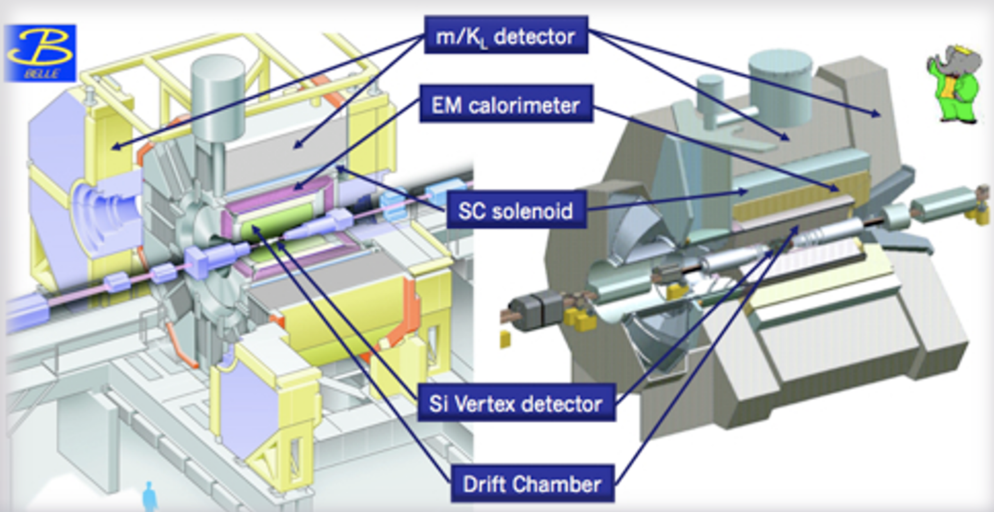
world highest luminosities

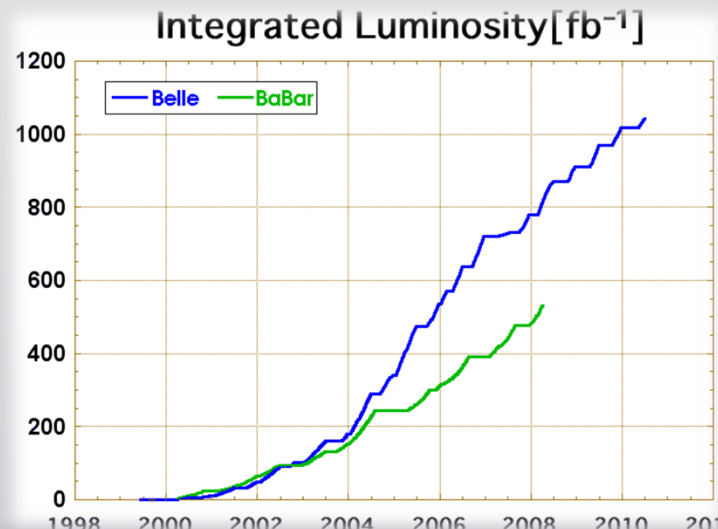


Completed data taking on June, 2010

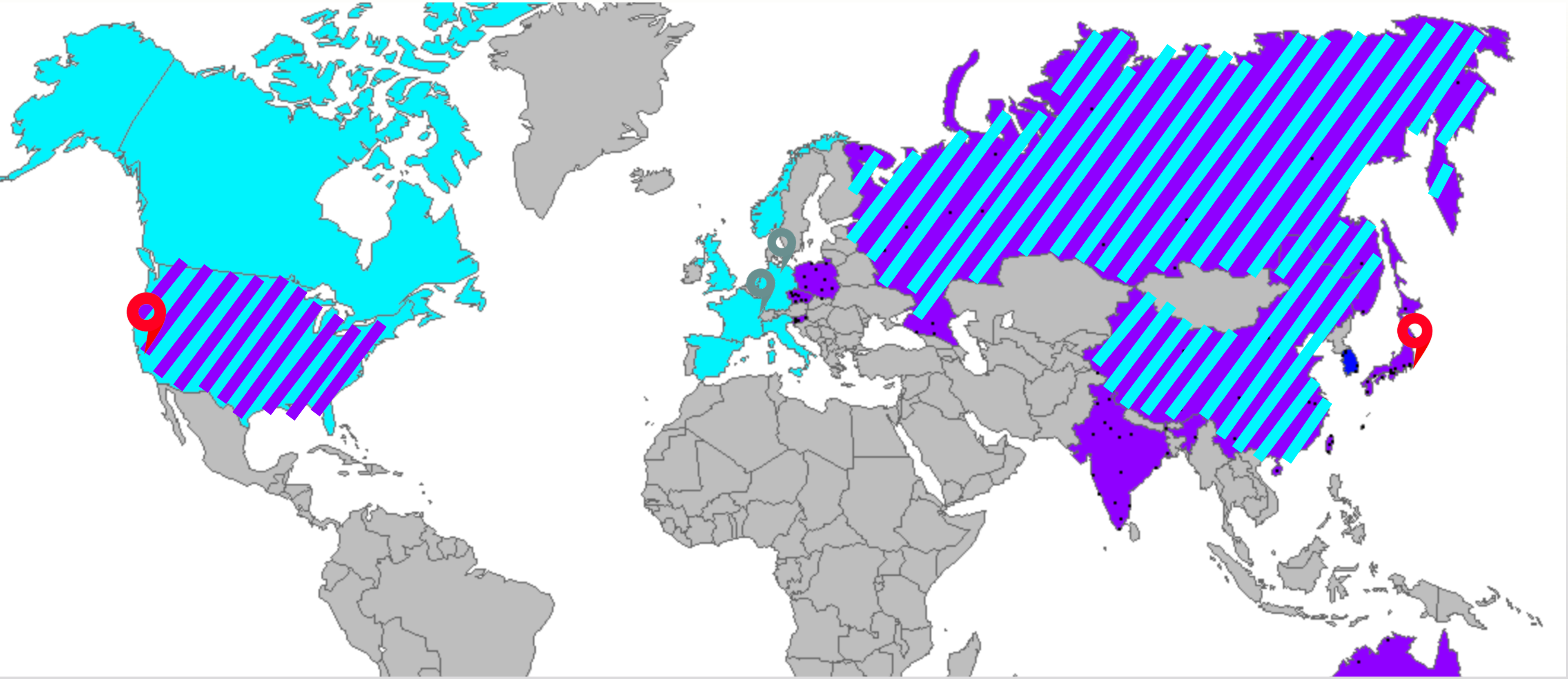
to start SuperKEKB/Belle II upgrade

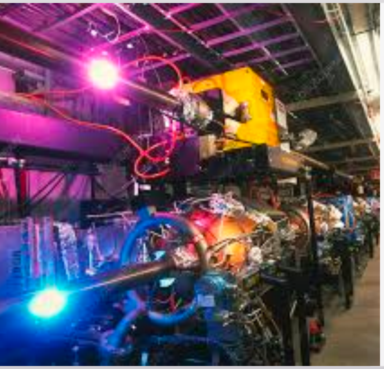
Stopped in 2008

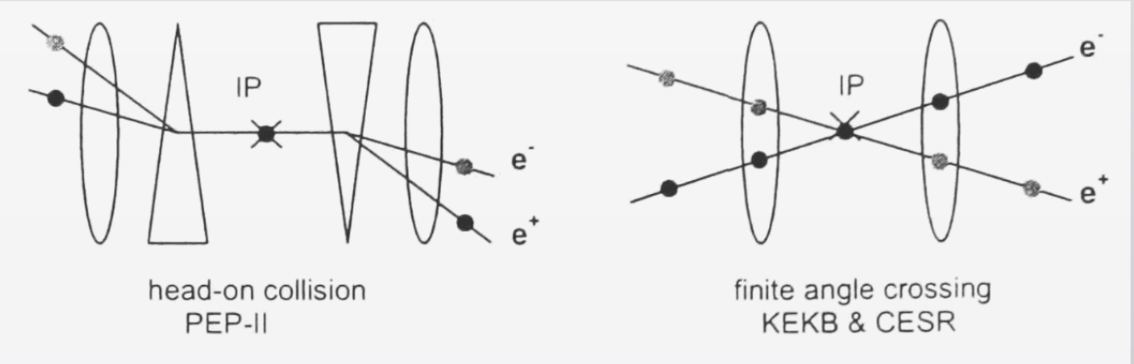




B-factories divided the world







KEK/SLAC comparison

Table 1 Main parameters of KEKB and PEP-II

	KEKB	PEP-II
Energy E_-/E_+ (GeV)	8.0/3.5	9.0/3.1
Circumference (m)	3016	2199
Luminosity ($10^{33}cm^{-2}s^{-1}$)	10	3
Beam-beam parameter ξ_x/ξ_y	0.039/0.052	0.03/0.03
β_x^*/β_y^* at IP (cm)	33/1.0	67/2.0 (HER) 50/1.5 (LER)
σ_x^*/σ_y^* at IP (μm)	90/1.9	220/6.8
Stored current I_-/I_+	1.1/2.6	0.99/2.14
Number of bunches	5000	1658
Bunch spacing (cm)	59	124
Crossing	±11 mrad	Head-on

all technical aspects of both accelerator and detector are realistic, but 100-fold jump in luminosity is challenging

Table 2 History of KEKB and PEP-II

	PEP-II	KEKB
Start of construction	Nov. 1993	April 1994
First stored HER beam	June 16, 1997	Dec. 13, 1998
First stored LER beam	July 16, 1998	Jan. 12, 1999
First beam collisions	July 23, 1998	Feb. 5, 1999
Detector installed	May 10, 1999 BaBar	May 24, 1999 BELLE
First detected events	May 26, 1999	June 1, 1999
Max. luminosity observed by November 30,1999	$1.43 \times 10^{33}cm^{-2}s^{-1}$	$0.52 \times 10^{33}cm^{-2}s^{-1}$

Fantastic: the construction took 6 years, but two projects started simultaneously: 1 week difference (0.2% accuracy)

SM: successes and failures

The SM successes:

***All particles** have been observed*

***All symmetries** have been confirmed and*

*The **mechanism of symmetry breaking** is established*

***All parameters** have been measured*

*Essentially **all experimental measurements** are consistent with the SM predictions*

BUT in the same time a lot of intrinsic problems

Inconsistencies at high energies (rad. corrections, UV divergences, Landau pole)

Still no unification of strong and electroweak interactions

Large number of free parameters

CP-violation is not completely understood

Flavor mixing and the number of generations is arbitrary

The origin of the mass spectrum in unclear

Most of open questions are addressed to the flavor sector

Flavor physics in the SM …

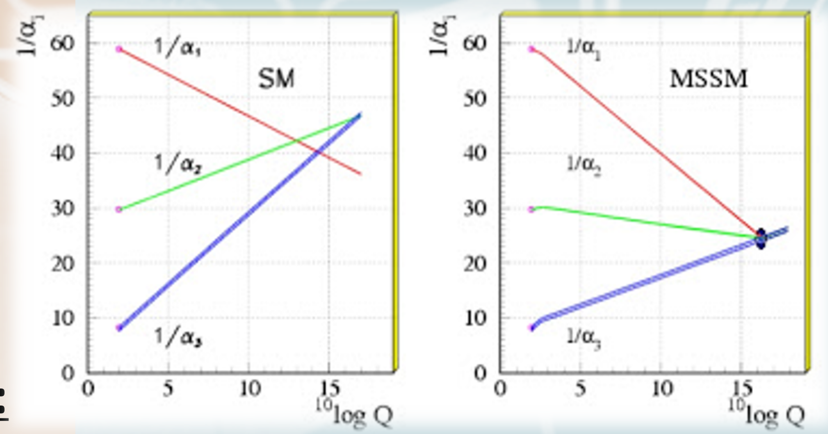
bosonic sector of the SM:

$$@1\text{GeV}: g' \sim 0.3, \quad g \sim 0.6, \quad g_s \sim 0.6, \quad \lambda \sim 1$$

5 free parameters:

one defines the scale

+ 4 dimensionless coupling constants



Ideally, we have to accept one scale parameter, and expect that dimensionless parameters are some geometrical constants; there is a hint that gauge constants are related to each other...

fermionic (flavor) sector (without neutrino):

3 Yukawa constants for charged leptons:

6 Yukawa constants for quarks

4 quark-mixing parameters

$$Y_t \sim 10^0, \quad Y_b \sim 10^{-2}, Y_c \sim 10^{-2},$$
$$Y_s \sim 10^{-3}, Y_u \sim 10^{-5}, Y_d \sim 10^{-5},$$
$$Y_\tau \sim 10^{-2}, Y_\mu \sim 10^{-3}, Y_e \sim 10^{-6},$$
$$|V_{ud}| \sim 1, |V_{us}| \sim 0.2, |V_{cb}| \sim 0.04,$$
$$|V_{ub}| \sim 0.004, \delta_{KM} \sim 1$$

This is a really miraculous part of the SM.
There is no idea

- **why do we have many (3) generations?**
- **why are these 13 constants such as they are?**
- **why is there a hierarchy & smallness structure?**
- **why is the mixing matrix almost unit, but not exactly?**

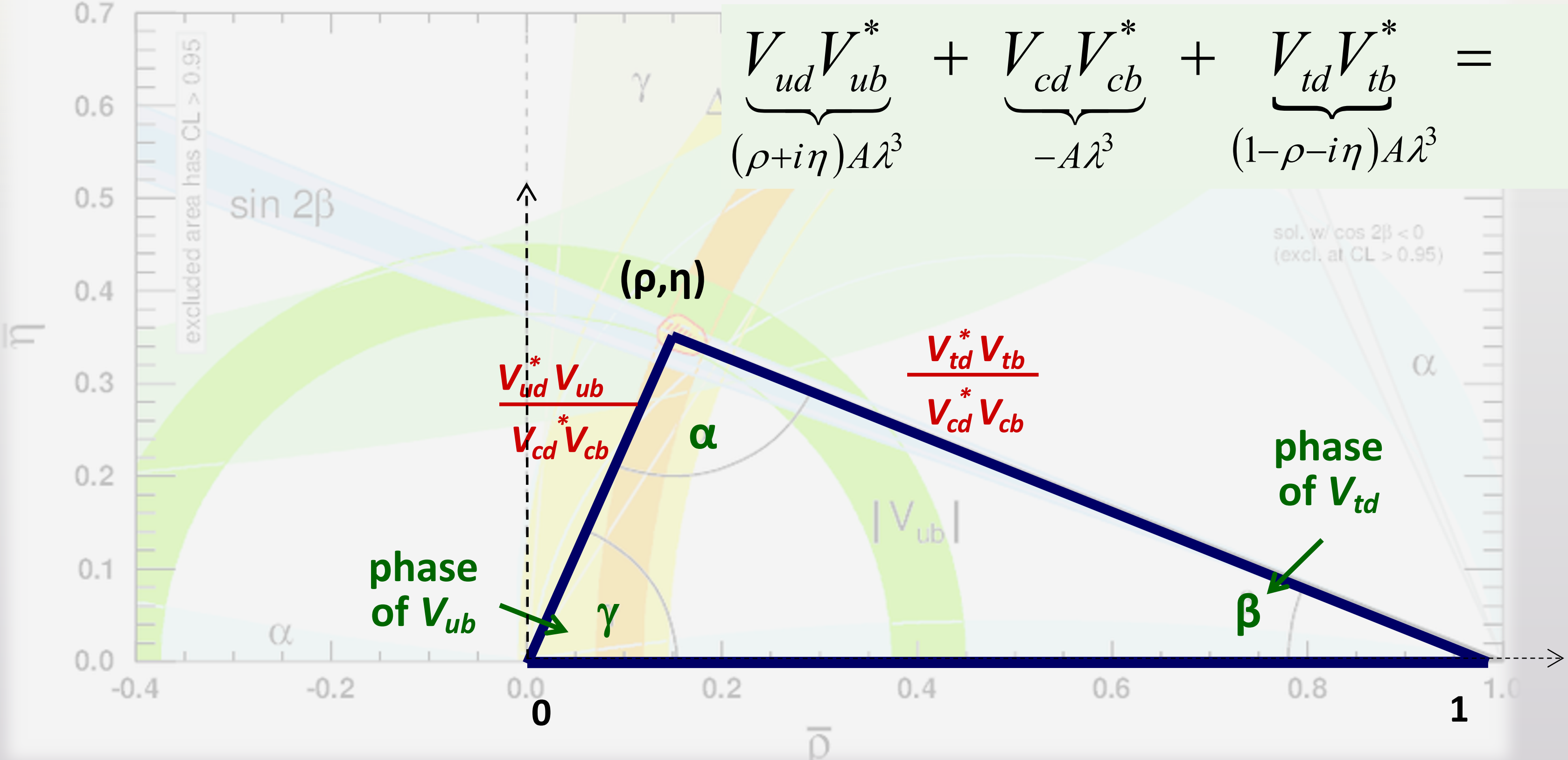
All these "W*hys?*": The SM flavor puzzle

Search for New Physics in CP violation

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

$$V^{\dagger}_{\mathrm{CKM}} \cdot V_{CKM} = V_{CKM} \cdot V^{\dagger}_{\mathrm{CKM}} = 1$$

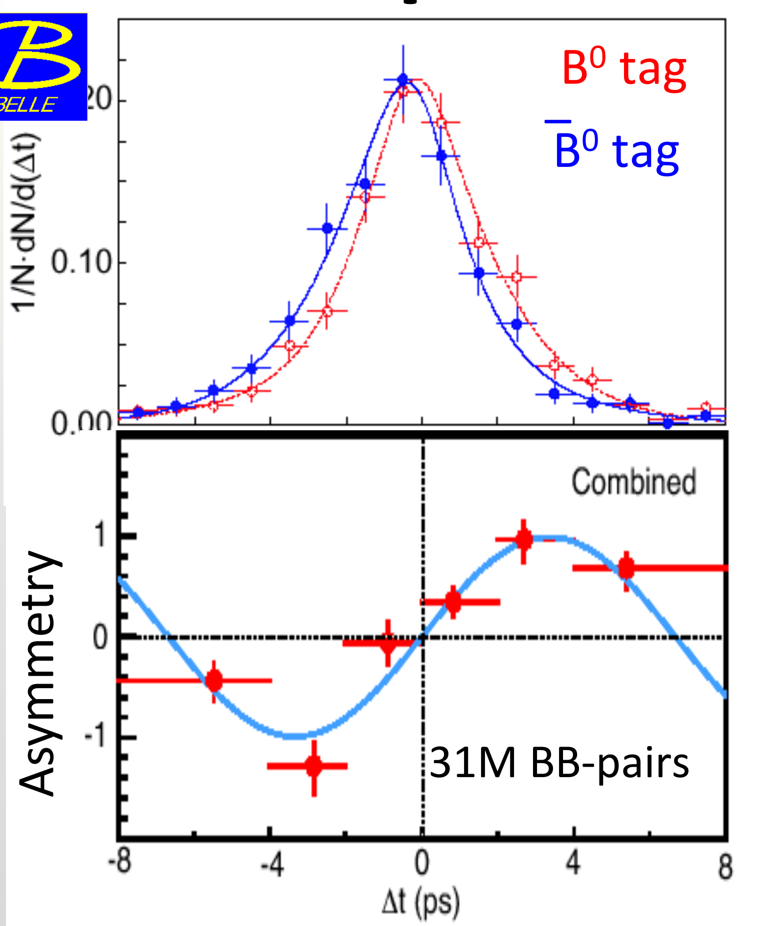
$$\underbrace{V_{ud}V^*_{ub}}_{(\rho+i\eta)A\lambda^3} + \underbrace{V_{cd}V^*_{cb}}_{-A\lambda^3} + \underbrace{V_{td}V^*_{tb}}_{(1-\rho-i\eta)A\lambda^3} = 0$$



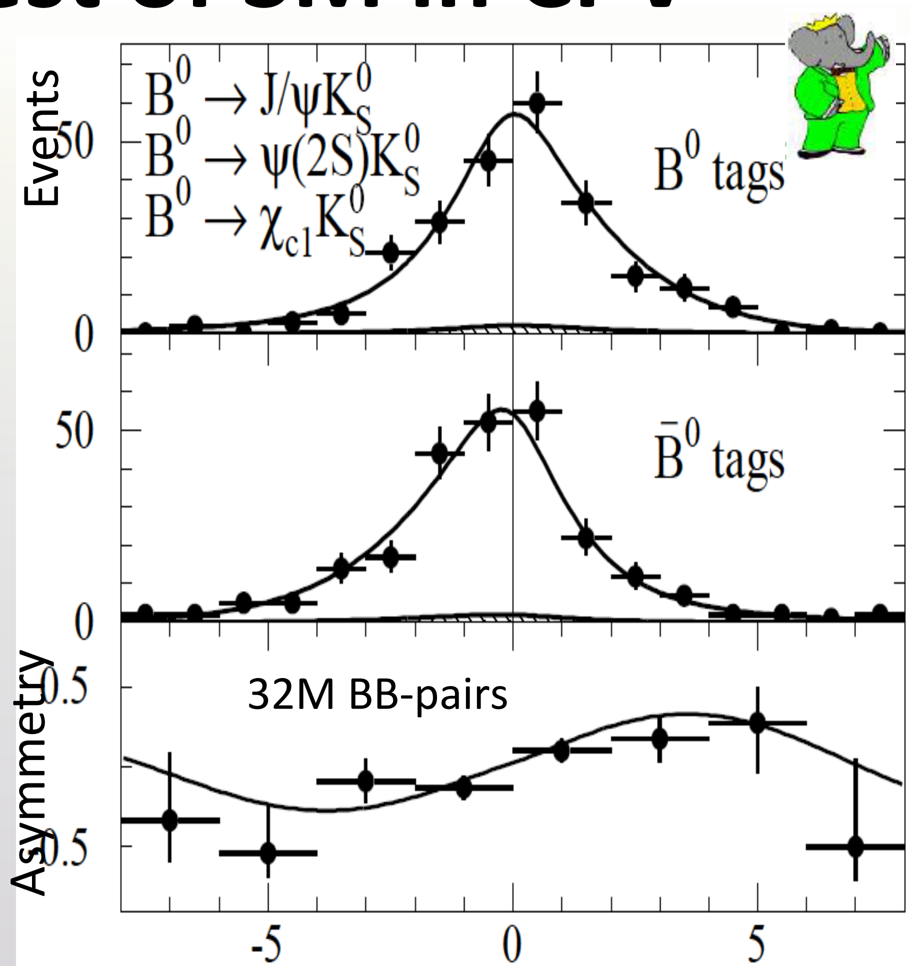
Consistency of Unitarity triangle = probe for NP at *O*(1TeV)

- UT Sides from Br's
- UT angles from CP violation

First quantative test of SM in CPV



[PRL 87,091802(2001)]



[PRL 87,091801(2001)]

$\sin 2\beta = 0.99 \pm 0.14 \pm 0.06$

$\sin 2\beta = 0.59 \pm 0.14 \pm 0.05$

Нарушение CP в B-мезонах на территории РФ утверждено государственным органом с 2003 года

соответствующее положение будет внесено в 67 статью Конституции

Д. 15.05.2003 - 1232/05

71:04-1/143

Российская академия наук

Сибирское отделение

Институт ядерной физики имени Г.И.Будкера

Президиум ВАК России

решение от "23" 05 2003 № 220/67

присудил ученую степень ДОКТОРА

физ.-мат. наук

Начальник управ. ВАК России

Бондарев Александр Евгеньевич

На правах рукописи

Изучение нарушения *CP* четности в распадах *B* мезонов в эксперименте Belle

Специальность 01.04.16 – физика ядра и элементарных частиц

Диссертация на соискание ученой степени доктора физико - математических наук

ЗДОРОВ

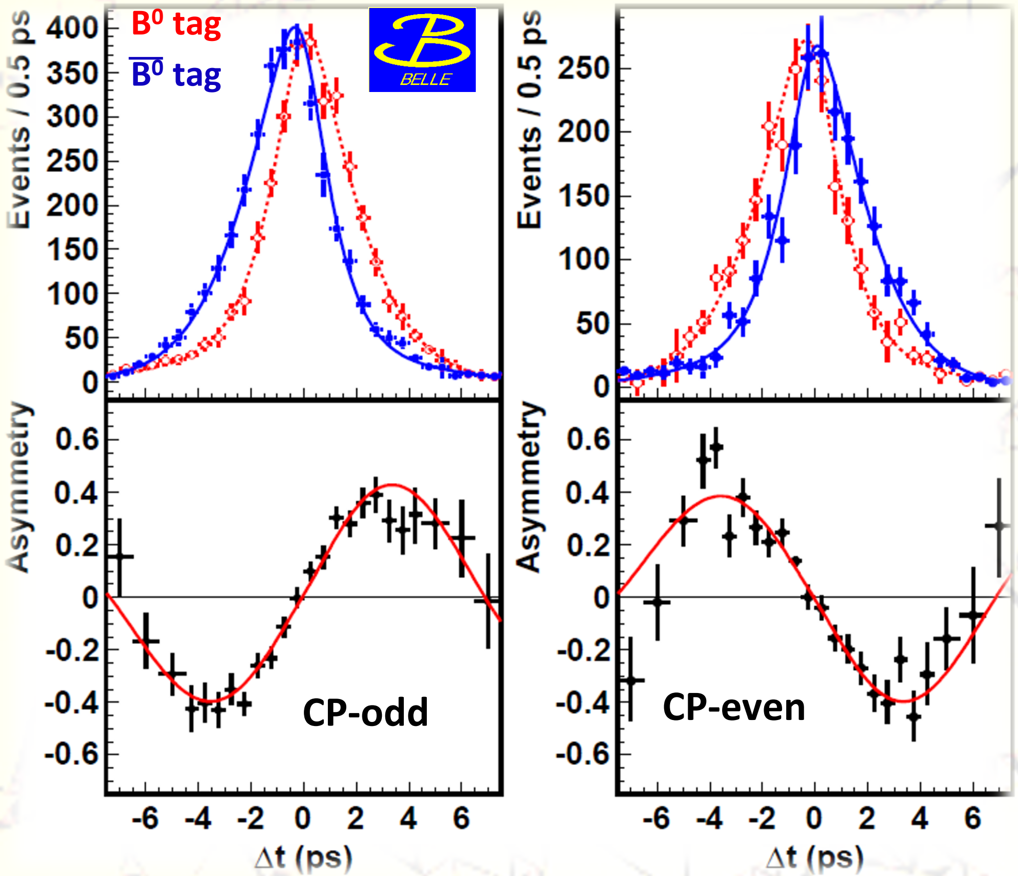
ОПЛАЧЕНО

СОВЕРШЕННО СЕКРЕТНО

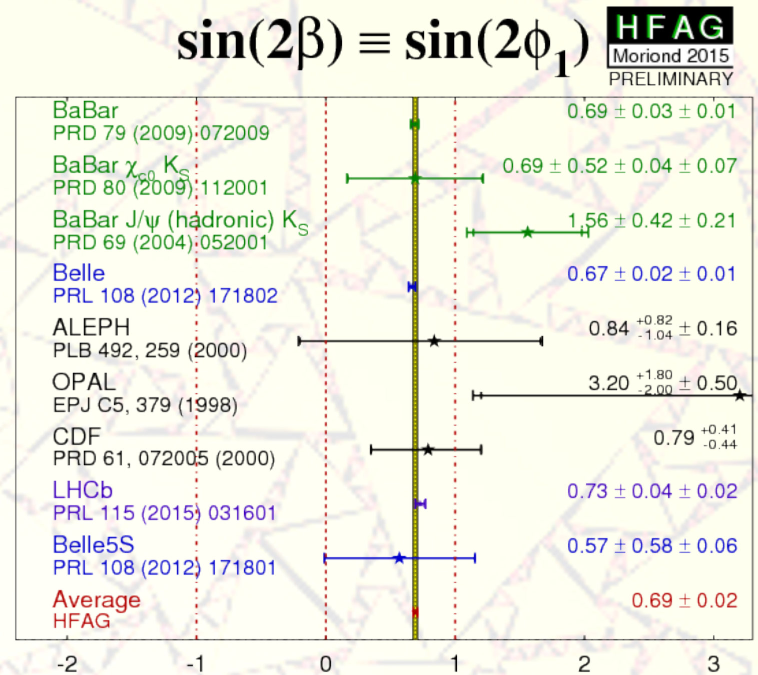
НОВОСИБИРСК – 2003

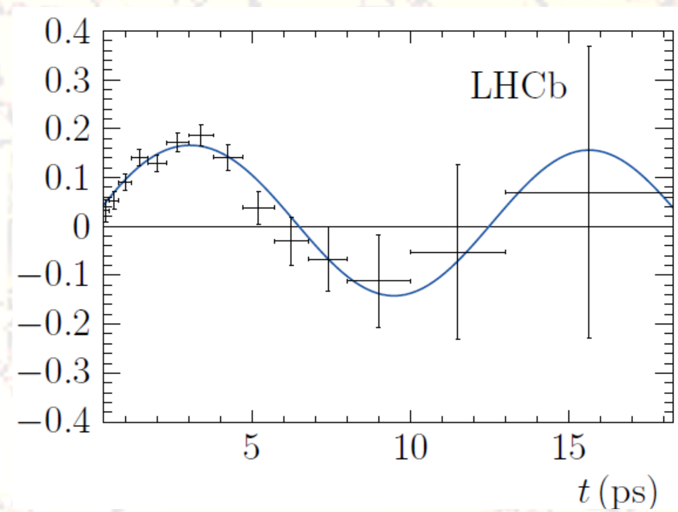
Precise measurement of sin(2β) in $B^0 \to ccK^0$

Belle 2012 (0.8 ab^{-1}): $B \to ccK^0_S$ & $B \to J/\psi K^0_L$



PRL 108 171208 (2012)

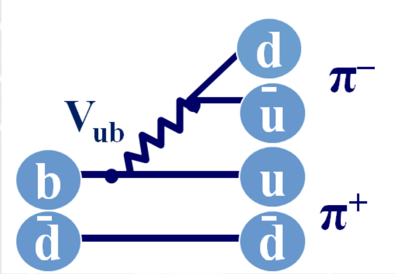




$\sin(2\beta) = 0.667 \pm 0.023 \pm 0.012$ (0.9°)

$A_f = 0.006 \pm 0.016 \pm 0.012$

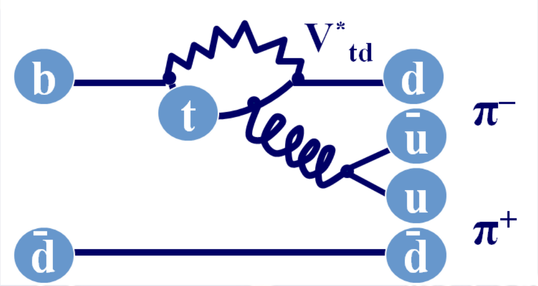
α measurements



$B^0 \to \pi\pi$
$B^0 \to \rho\rho$
$B^0 \to \rho\pi$

The decay amplitudes $B \to \pi^+\pi^-(\rho^+\rho^-)$ include:
- tree term $T \sim V_{ub}^* V_{ud}$ (dominant)
- penguin term $P \sim V_{tb}^* V_{td}$ (suppressed, but not small)

Parameter S of indirect CPV related to effective $\alpha(\alpha_{eff})$ shifted by extra angle



$$S = \sin 2\alpha + 2r\cos\delta\sin(\alpha+\beta)\cos 2\alpha + O(r^2)$$

δ – the relative strong phase between T and P amplitudes
$r < 1$ – ratio of P to T amplitude

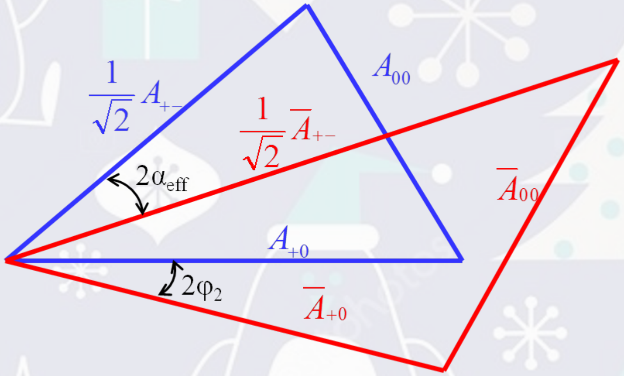
To extract α additional inputs required

$$S = \sqrt{1-C^2}\sin(2\alpha_{eff}) \qquad \alpha_{eff} = \alpha + \theta$$

The cleanest method is isospin analysis (Gronau and London)
We need to measure all 6 BR's of B^0 and B^+ to $\pi\pi$ decays: $\pi^+\pi^-$, $\pi^0\pi^0$, $\pi^+\pi^0$
Need neutral modes!

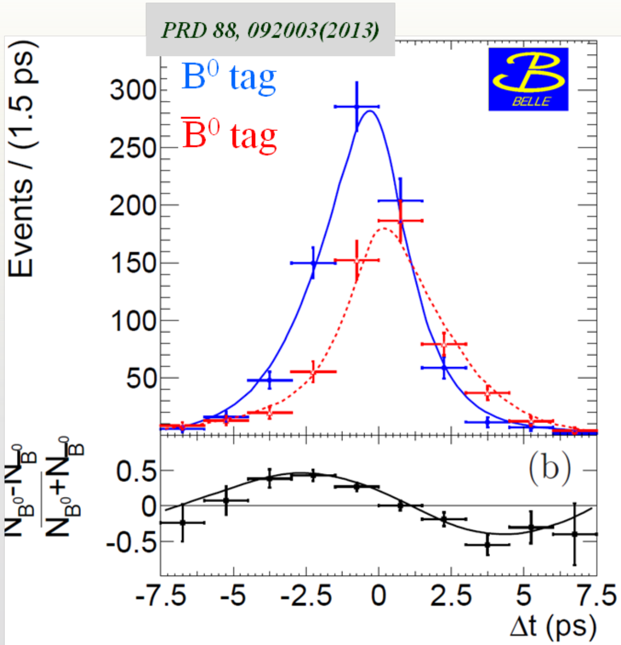
$$A_{+-} + \sqrt{2}\,A_{00} = \sqrt{2}\,A_{+0}$$
$$\overline{A}_{+-} + \sqrt{2}\,\overline{A}_{00} = \sqrt{2}\,\overline{A}_{+0}$$

$$A_{+-} = A(B^0 \to \pi^+\pi^-) = e^{-i\alpha}\,T^{+-} + P$$
$$\sqrt{2}\,A_{00} = \sqrt{2}\,A(B^0 \to \pi^0\pi^0) = e^{-i\alpha}\,T^{00} + P$$
$$\sqrt{2}\,A_{+0} = \sqrt{2}\,A(B^+ \to \pi^+\pi^0) = e^{-i\alpha}\,(T^{00} + T^{+-})$$



Isospin triangles

α: experimental results

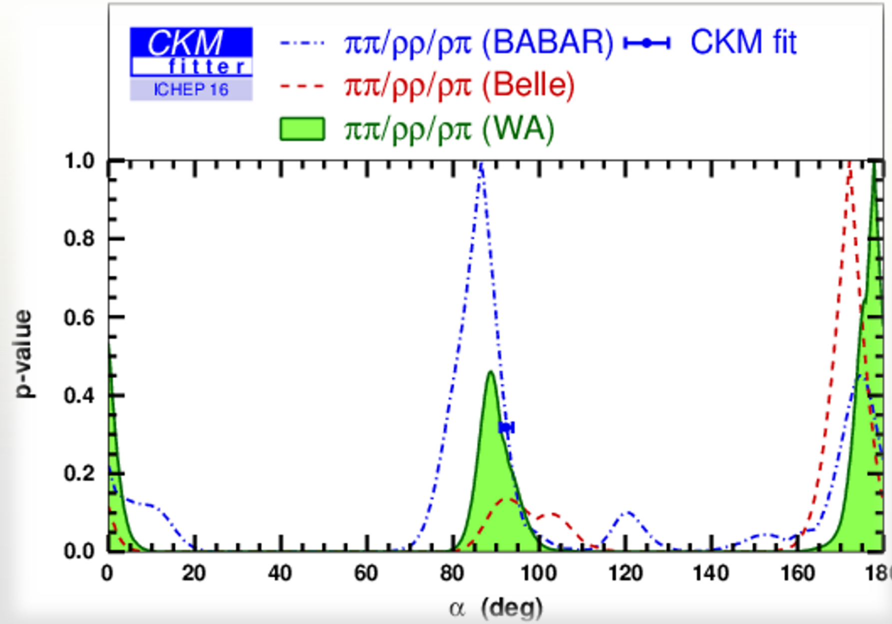


$B^0 \to \rho^0\rho^0$

- angular analysis
- purely CP=+1 final state
- small Br, small penguin contribution

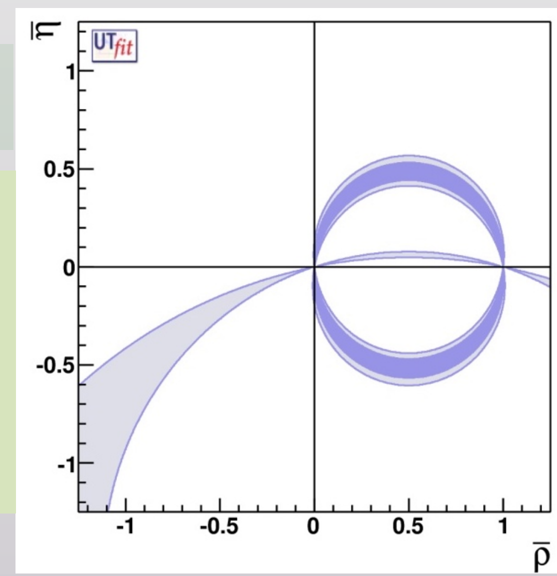
$B^0 \to \rho^\pm\pi^\pm$

not CP eigenstate, but B^0 can decay to both $\rho^+\pi^-$ and $\rho^-\pi^+$



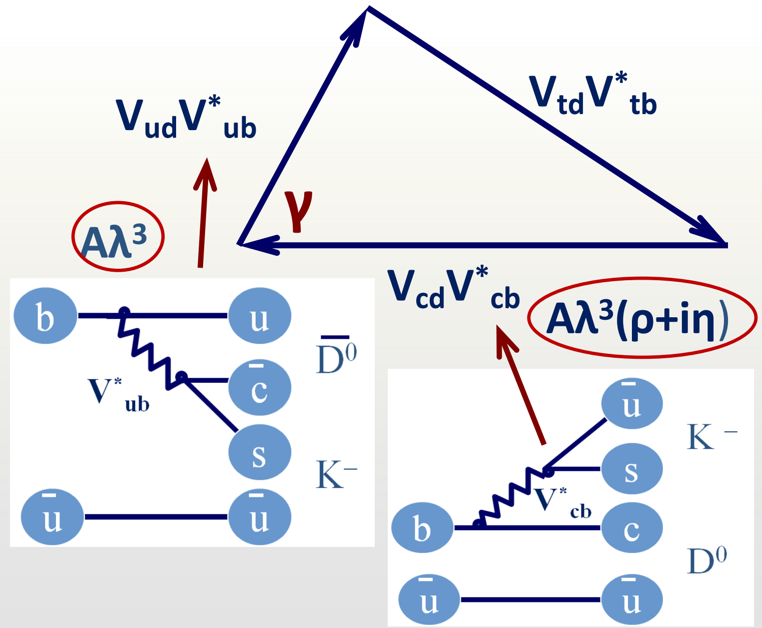
$$\alpha_{WA} = (88.8^{+2.3}_{-2.3})^\circ \bigcup (177.8^{+3.7}_{-4.9})^\circ$$

- Complicated analysis (especially for $\rho^0\rho^0$)
  - method was checked many times by Belle & BaBar
  - Belle & BaBar consistent results
- Statistics limited (not systematic)
- **B factories only** (a lot of neutrals in the final states)



Direct CPV and angle γ

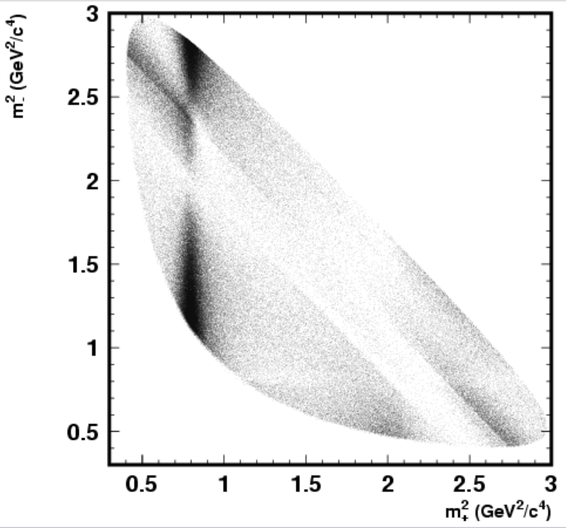
B→DK: the angle between two amplitudes is really γ, but the final states are different $D^0 \neq \overline{D^0}$



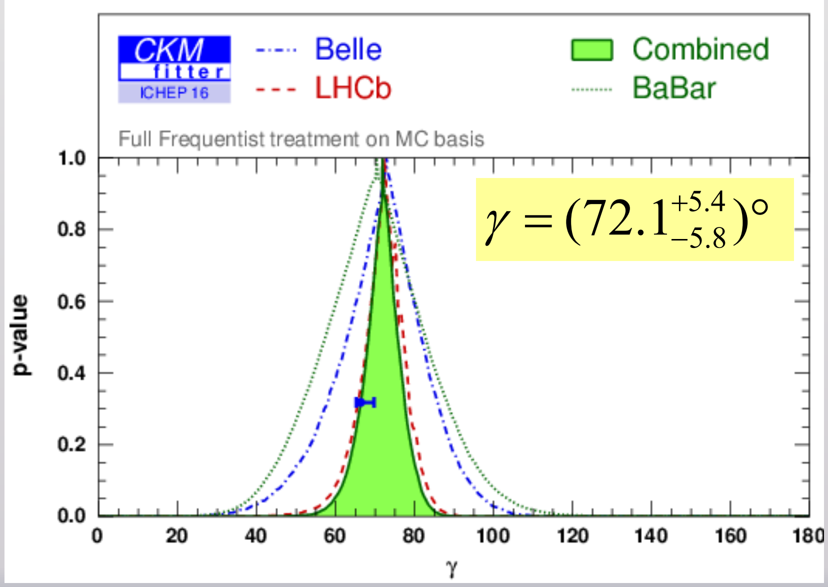
- **GLW method: use D^0 decays into two-body CP eigenstates, *e.g.* $D^0 \to K^+ K^-$**
- **GGSZ/Belle method: Dalitz analysis of 3-body final state, *e.g.* $D^0 \to K_S^0 \pi^+ \pi^-$**

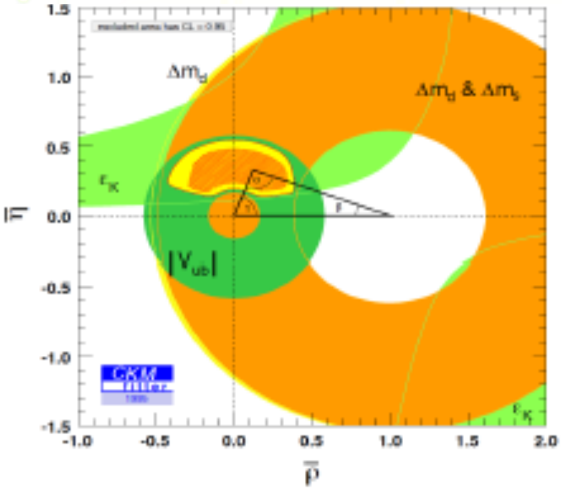
Measure B^+/B^- asymmetry across Dalitz plot

$$A_\pm = f\left(m_+^2, m_-^2\right) + r_B e^{\pm i\gamma} e^{i\delta} f\left(m_-^2, m_+^2\right)$$

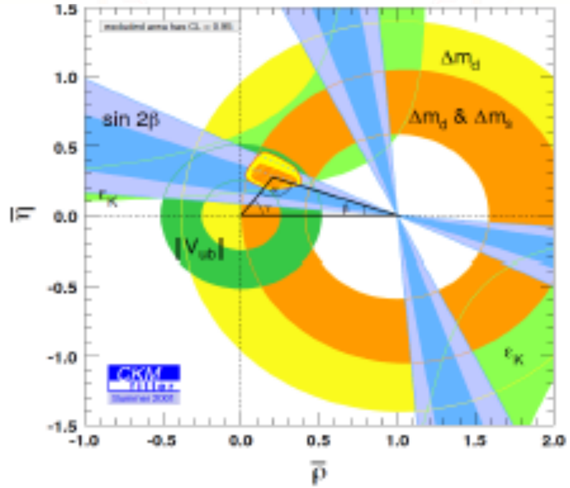


The accuracy of present measurements is limited by statistics. The systematic and model uncertainties are much smaller.

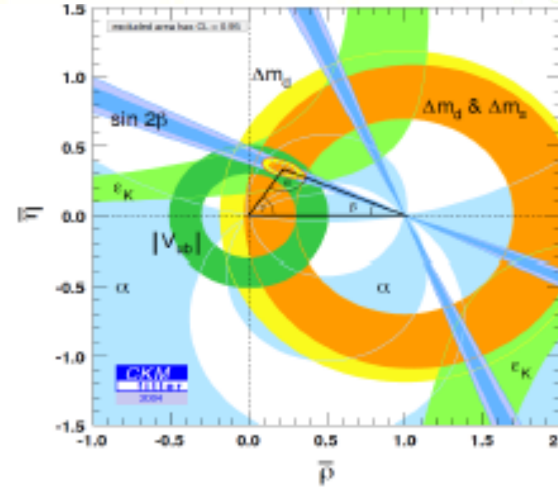




1995

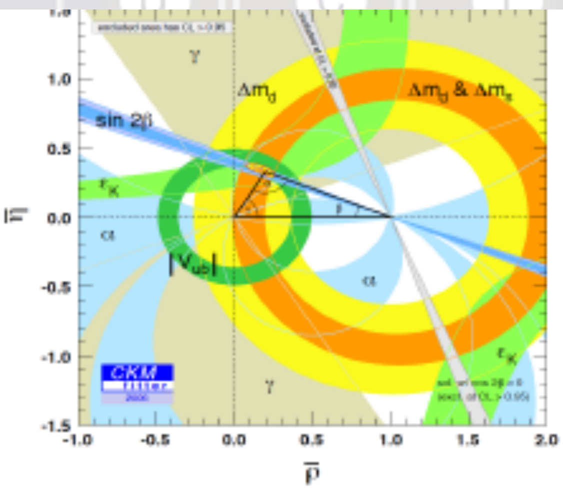


2001

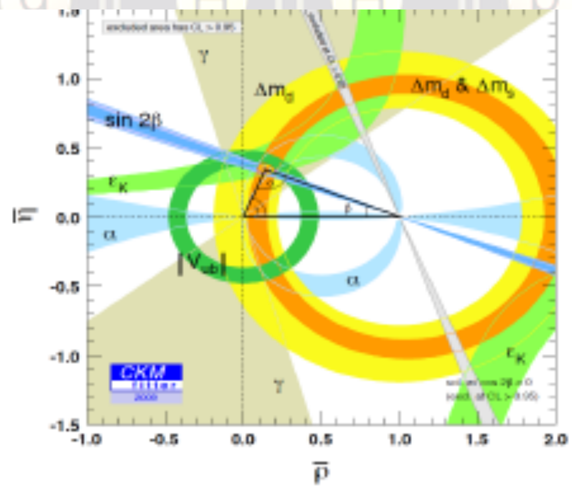


2004

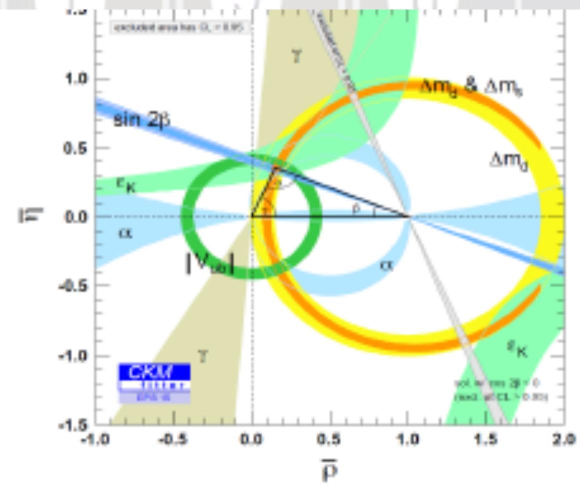
Unitarity triangle: two decades history



2006

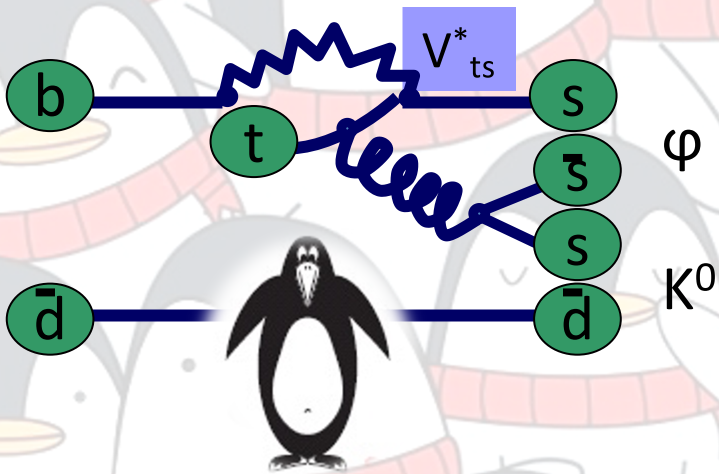


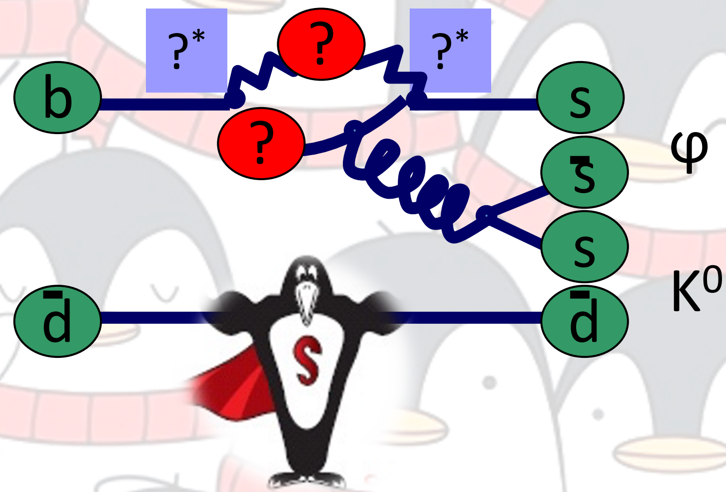
2009



2015

CP violation in hadronic penguin modes





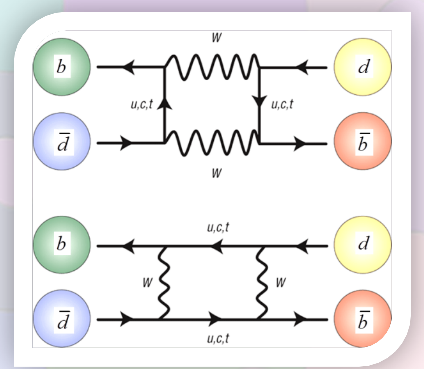
SM: No tree contribution!

indirect CP asymmetry should be ≡ sin2β, direct asymmetry ≡ 0

Theoretical uncertainty $\sin 2\beta^{eff} = \sin 2\beta + O(0.01\text{-}0.03)$ is much smaller than the current experimental errors!

NP: Any new heavy particles (*e.g.* SUSY) can enter loop (at the same order as SM) and change $\sin 2\beta^{eff}$

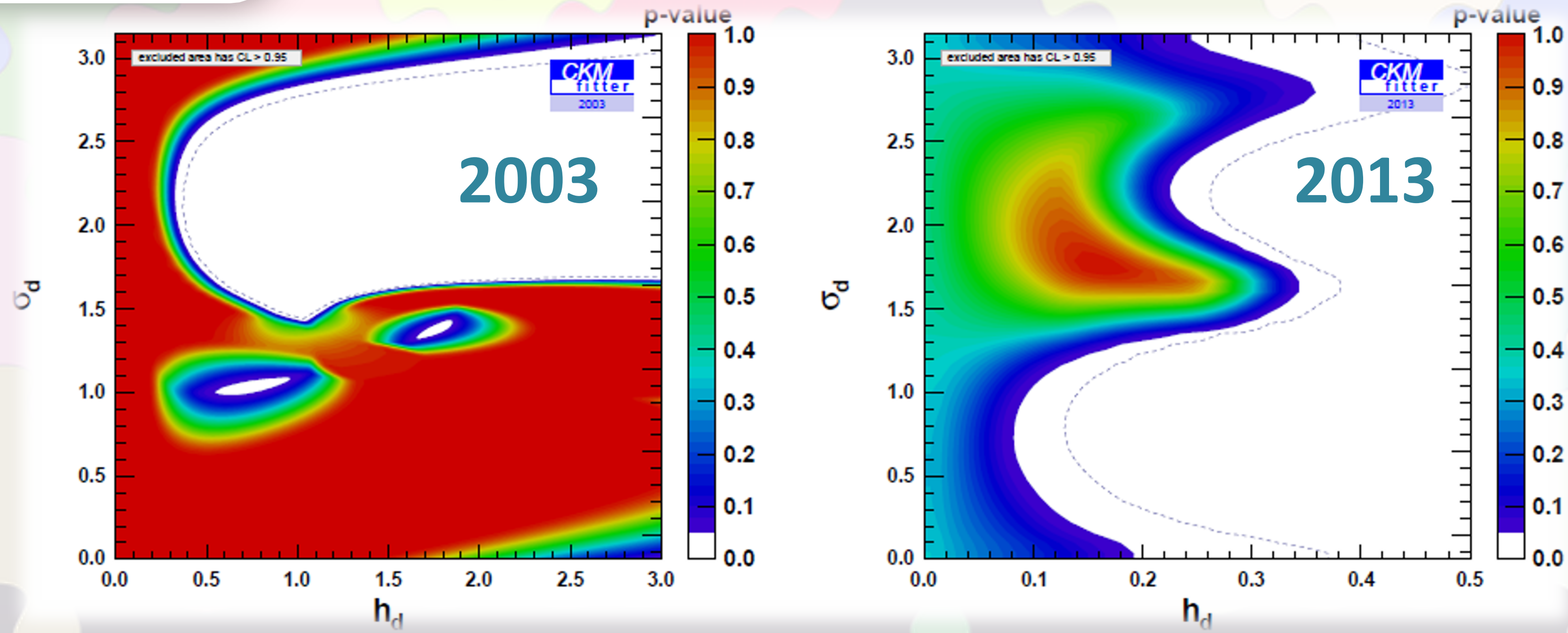
CP violation: enigmatic phenomenon & effective tool for New Physics searches



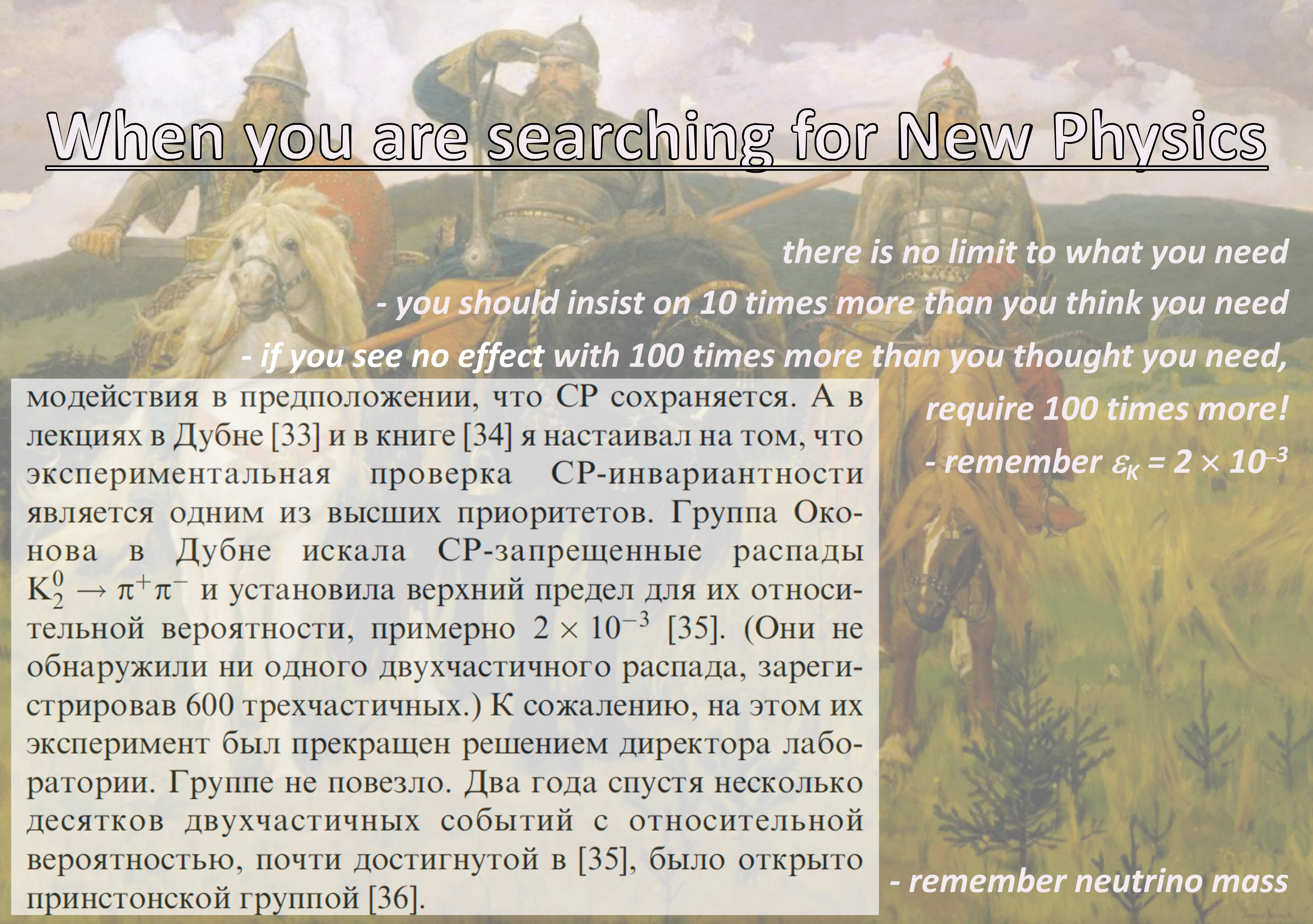
Before CP-studies at B-factories it was not known, if the SM is the main contributor to the B^0B^0-mixing

$$\Delta m_d = \Delta m_d^{SM} \times (1 + h_d e^{2i\sigma})$$

NP



To continue study, SUPER B FACTORY NEEDED



When you are searching for New Physics

there is no limit to what you need

- you should insist on 10 times more than you think you need

- if you see no effect with 100 times more than you thought you need, require 100 times more!

- remember $\varepsilon_K = 2 \times 10^{-3}$

- remember neutrino mass

модействия в предположении, что CP сохраняется. А в лекциях в Дубне [33] и в книге [34] я настаивал на том, что экспериментальная проверка CP-инвариантности является одним из высших приоритетов. Группа Оконова в Дубне искала CP-запрещенные распады $K_2^0 \to \pi^+\pi^-$ и установила верхний предел для их относительной вероятности, примерно 2×10^{-3} [35]. (Они не обнаружили ни одного двухчастичного распада, зарегистрировав 600 трехчастичных.) К сожалению, на этом их эксперимент был прекращен решением директора лаборатории. Группе не повезло. Два года спустя несколько десятков двухчастичных событий с относительной вероятностью, почти достигнутой в [35], было открыто принстонской группой [36].

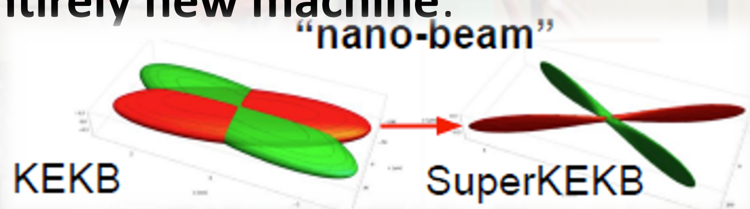
KEKB upgrade → SuperKEKB(nano-beam)

Parameter	KEKB Design	KEKB Achieved	SuperKEKB Design
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	0.27/0.30
β_x^* (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\frac{\varepsilon_y}{\varepsilon_x}$ (%)	1	0.85/0.64	0.27/0.24
σ_y (μm)	1.9	0.94 → 1/20	0.048/0.062
ξ_y	0.052	0.129/0.090	0.09/0.081
σ_z (mm)	4	6/7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19 → x2	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity ($10^{34} cm^{-2} s^{-1}$)	1.0	2.11 → x40	80

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{y\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_{y\pm}}}\right)$$

SuperKEKB is built in tunnel of KEKB but is almost entirely new machine:

- **× 20 smaller beam focus at interaction region**
- **Twice higher beam current**
- **First beam in 2016 → first collision in April 2018**

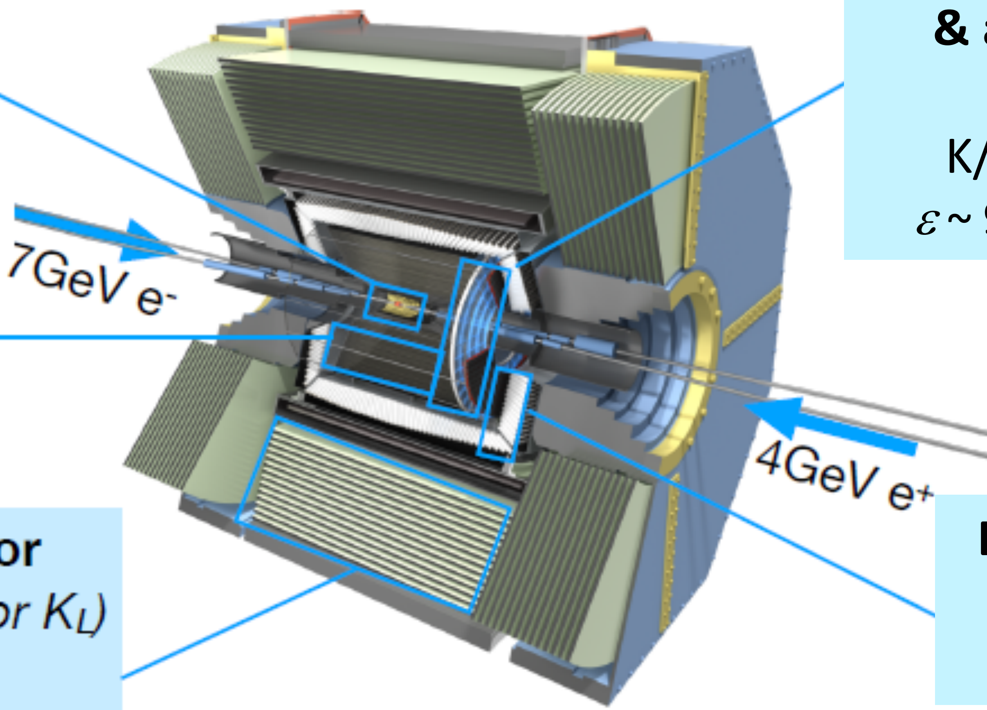


The Belle II detector

Vertex detector
Tracking
$\sigma_{z0} \sim 15\ \mu m$
(2x better than Belle)

Drift chamber
Tracking
$\sigma_{r\phi} \sim 100\ \mu m$
$\sigma_{dE/dx} \sim 5\%$

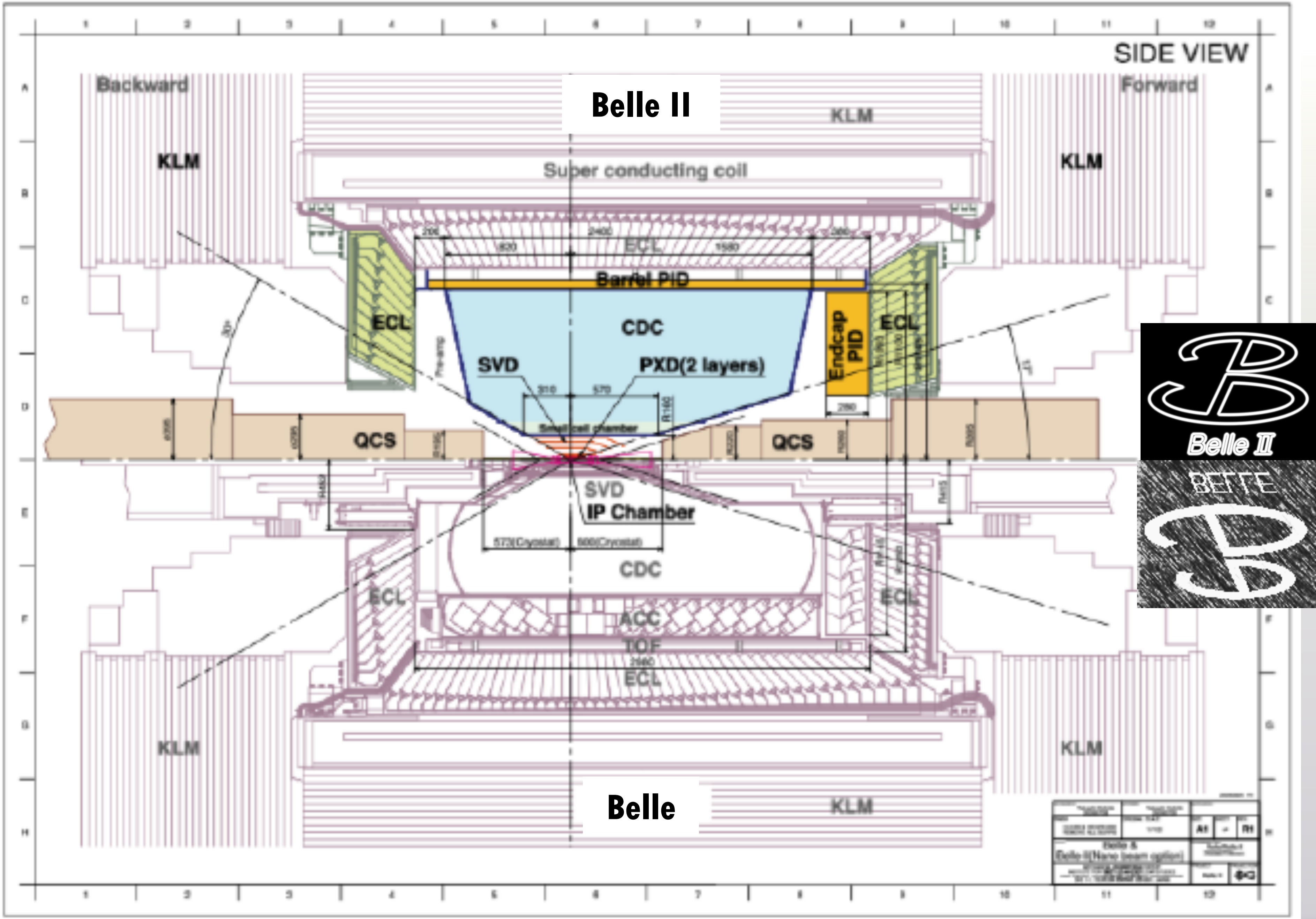
K_L and Muon detector
$\Delta\phi = \Delta\theta \sim$ 10-20 *mrad (for K_L)*
μ/π separation:
$\varepsilon \sim 90\%$ @ 1.5% fake



Time of propagation & aerogel RICH detectors
K/π separation
$\varepsilon \sim 90\%$ @ 5% fake

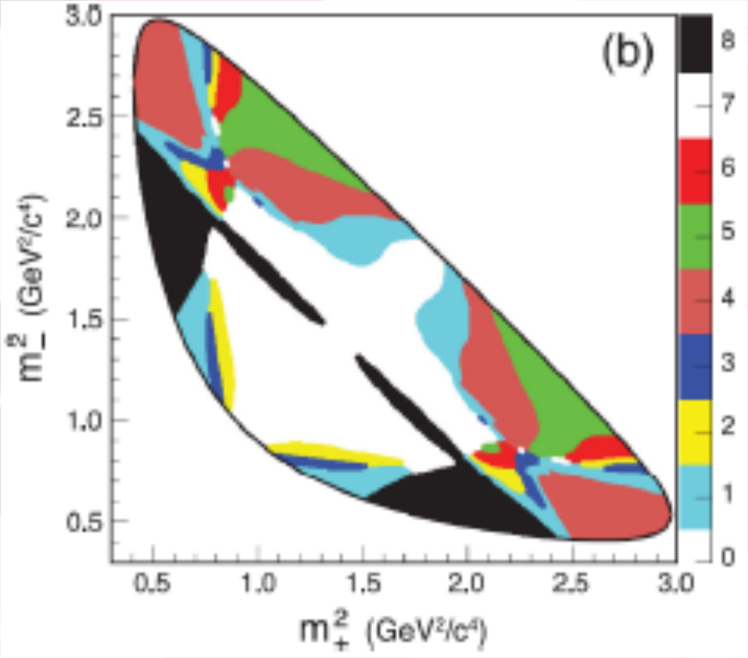
EM Calorimeter
σE/E ~ 2% @
E =1 GeV

Belle II is an upgrade of the Belle detector: capable to work at much higher background environment
Highlights. <u>*Vertex:*</u> 2 layers of pixels, 4 layers of DS Si strips with extended coverage, <u>*Drift chamber:*</u> smaller cell size + longer lever arm, <u>*PID:*</u> new TOP + ARICH


SIDE VIEW
Backward
Forward
Belle II
KLM
KLM
KLM
Super conducting coil
ECL
Barrel PID
ECL
CDC
Endcap PID
ECL
SVD
PXD(2 layers)
Small cell chamber
QCS
QCS
SVD
IP Chamber
CDC
ECL
ECL
ACC
TOF
ECL
KLM
KLM
Belle
KLM

γ at Belle II and LHCb

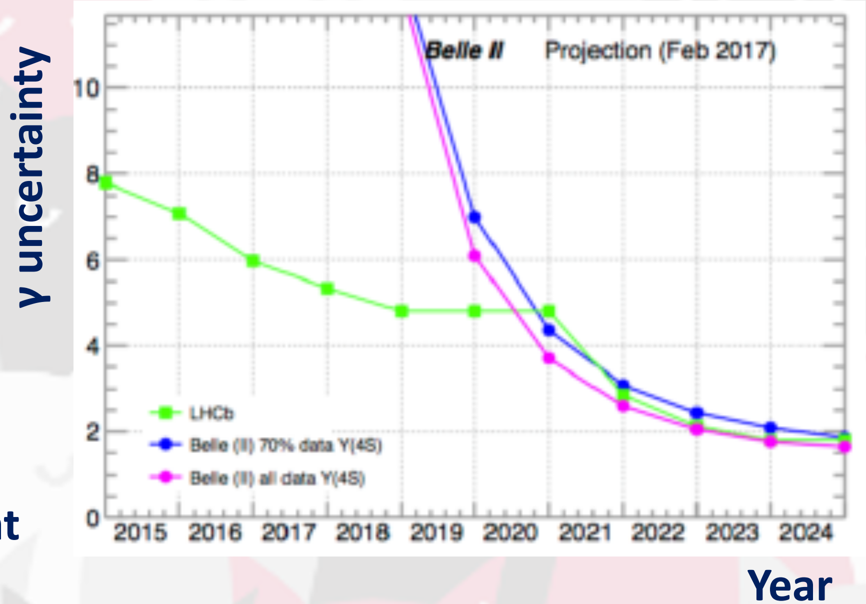
Continue in future with these two methods. But model uncertainties will become critical for Dalitz method with more data and reduced statistical errors. Propose to use $D^0 \to K_S{}^0 \pi^+ \pi^-$ binned plot from CP tagged data at charm-factory. Tried with CLEO data.



Extrapolation is done assuming BESIII data at ψ(3770) is ~ 10/fb

Sensitivity of Belle II and LHCb upgrade

	LHCb	Belle II
B→DK with D→hh	1.3°	2.0°
B→DK with $D\to K_S{}^0\pi\pi$	1.9°	2.0°
Total	**1.1°**	**1.5°**
Time dependent $B_s \to D_s K$	2.4°	

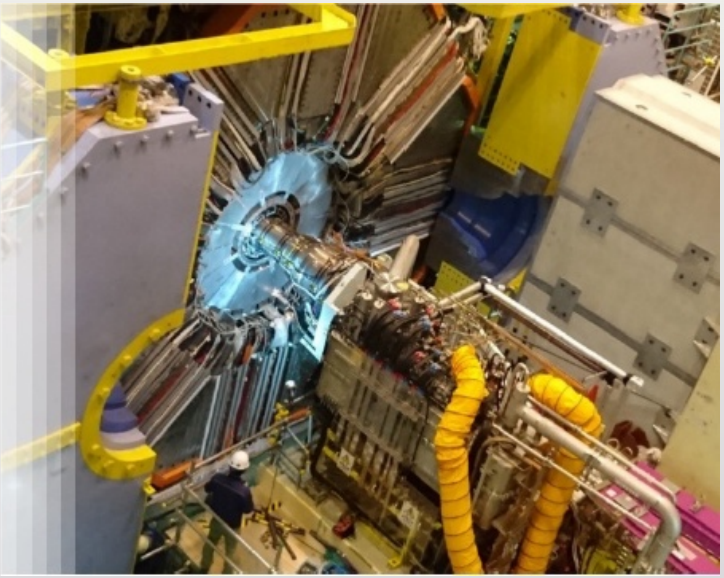


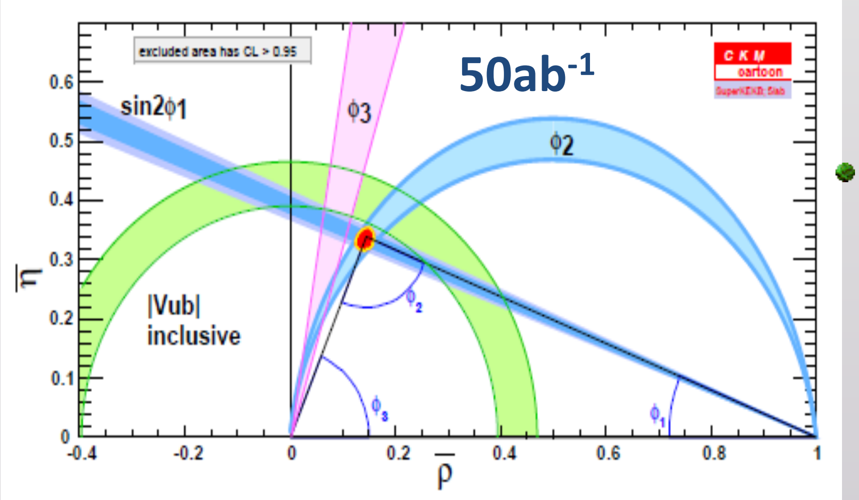
Summary I

Physics beyond the Standard Model has successfully avoided detection up to now. But we are sure it is somewhere nearby.

Up to now the sensitivity of Flavor experiments to New Physics amplitude was ~10% of those from the SM; in 5-10 years it will be improved by an order of magnitude.

- **Rich physics program for Belle II**
- **Belle II is healthy and started data taking in 2018**
- **Belle II goal of 50/ab will provide great sensitivity and complimentarity to LHCb information in many areas of flavor, CPV and related fields**





- **We hope to observe something like THIS in 5-7 years**

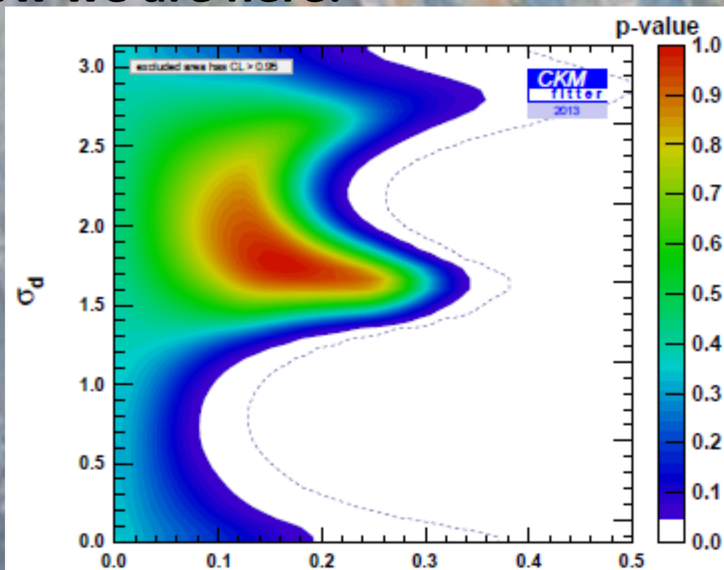
UT 2014		Belle II
α	4° (WA)	1°
β	0.8° (WA)	0.2°
γ	8.5° (WA) 14°(Belle)	1-1.5°

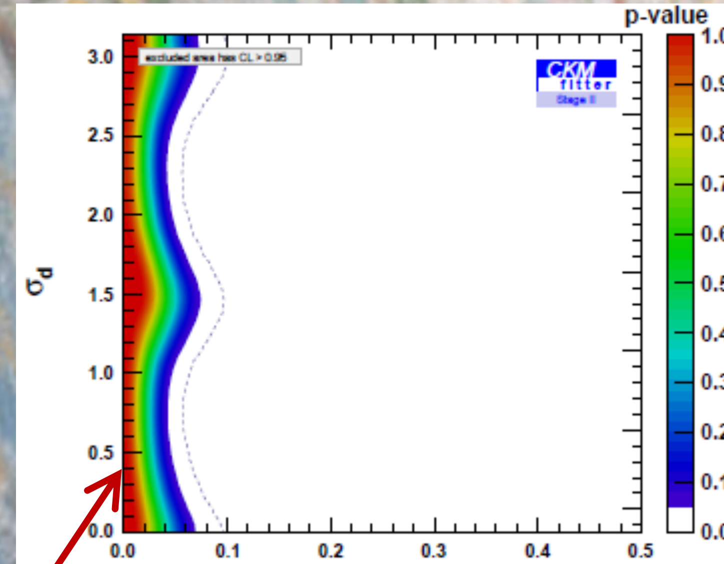
Summary II

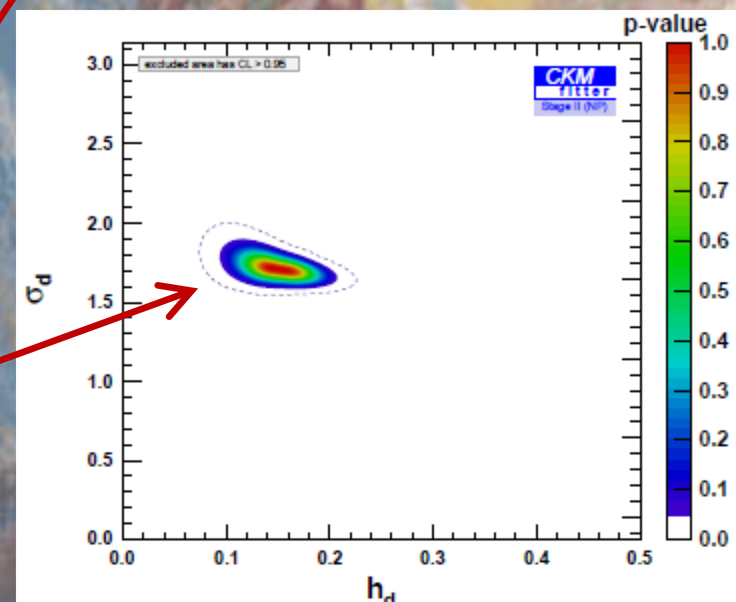
$$\Delta m_d = \Delta m_d^{SM} \times (1 + h_d e^{2i\sigma})$$

← **NP**

Now we are here:







Two scenarios:

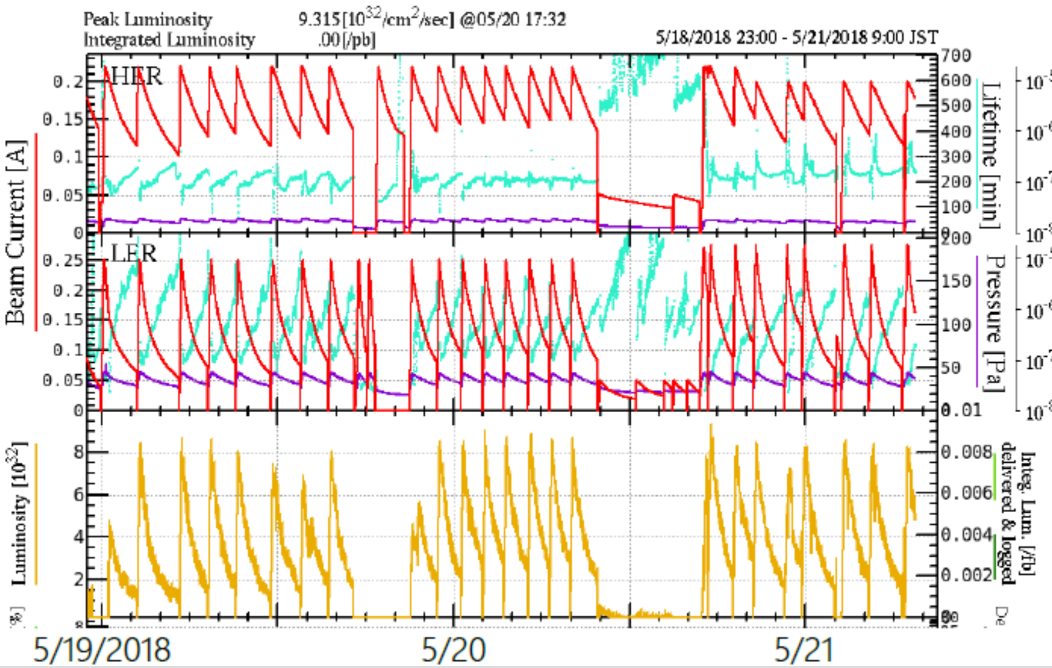
- **Improve UL by a factor of 5-10**
- **or observe something new!**

Summary III

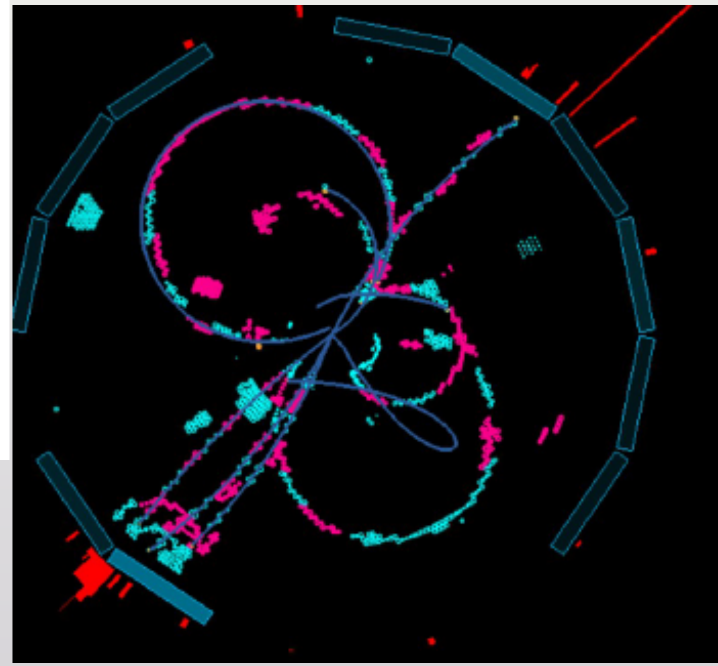
Belle II + SuperKEKB have successfully started operation

Y. Ohnishi, Y. Funakoshi

L_{peak} = 9.3 x 10^{32} /cm^2/s @ 5/20/2018



From January 2019 -- phase III:
add vertex detector (Belle II full set) and perform long run for CP violation studies



... the first hadronic event recorded at Belle II!

T H A N K   Y O U !