A New Era of Flavor Physics: Belle II and the SuperKEKB Project

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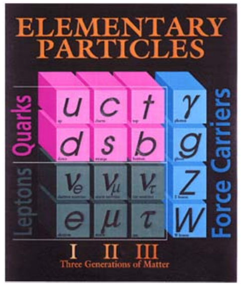
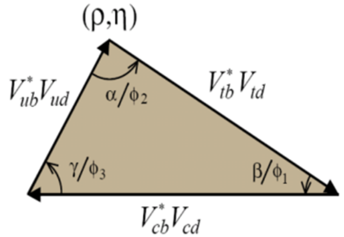
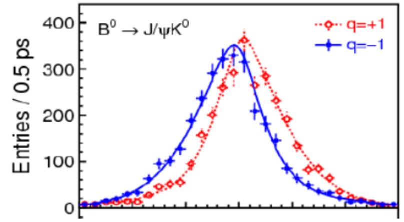
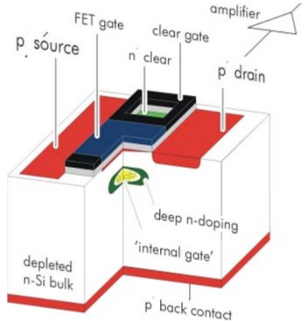
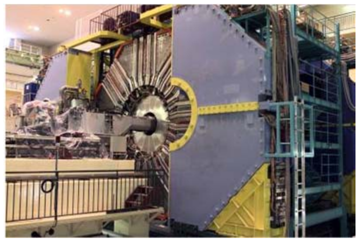
- Why is Flavor Physics Interesting ?
- The CKM matrix and the Unitarity Triangle
- Measurements on the CKM Matrix Elements
- Why go beyond ?
- SuperKEKB and Belle II



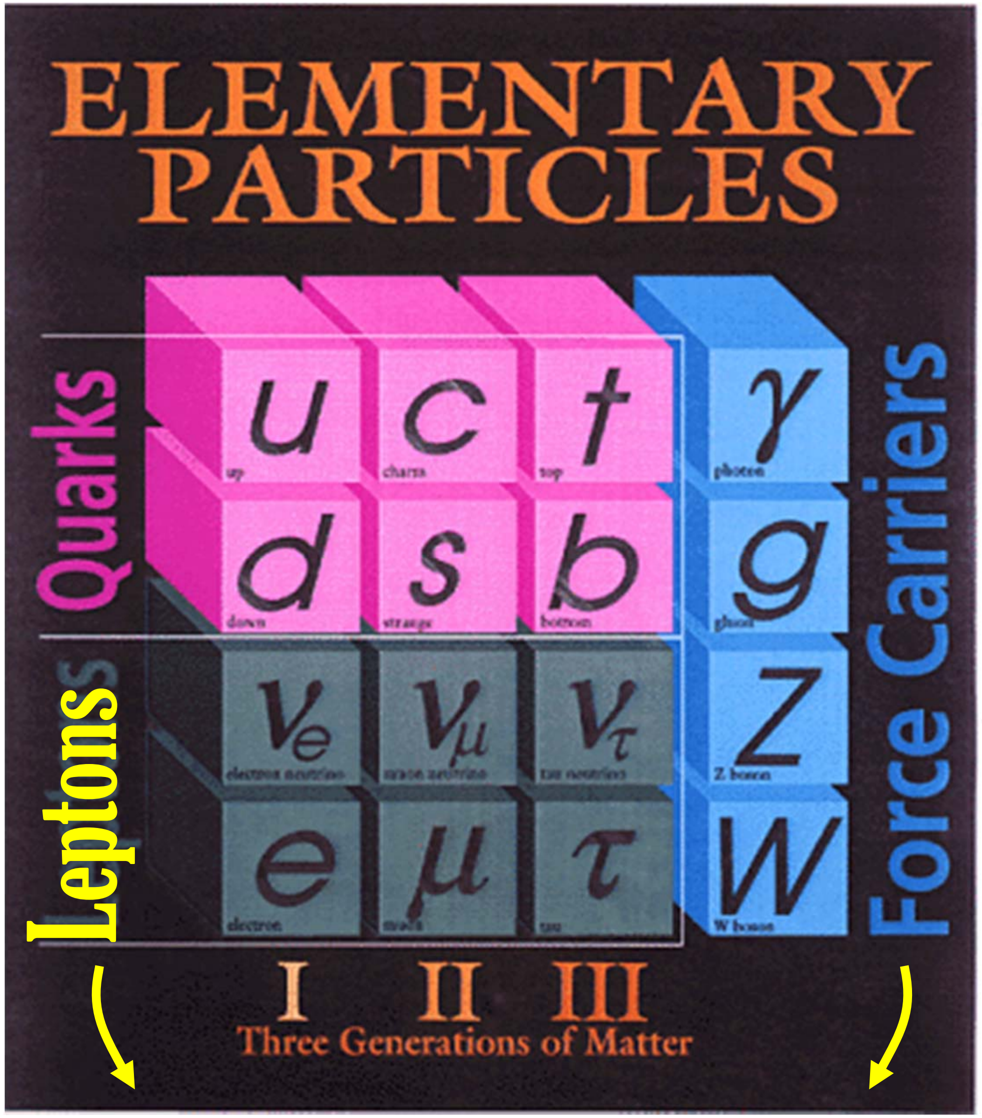








Particles in the Standard Model (SM)



uud ..., or $u\bar{d}$ ...

electr. charge		electr. charge	Mass of particles (in GeV):			
+2/3		0	0.005	1.4	175	0
-1/3		0	0.006	0.3	4.5	0
0		0	>0	>0	>0	91
-1		± 1	0.0005	0.1	1.8	80

„particles“:
Spin 1/2
(fermions)

„fields“:
Spin 1
(bosons)

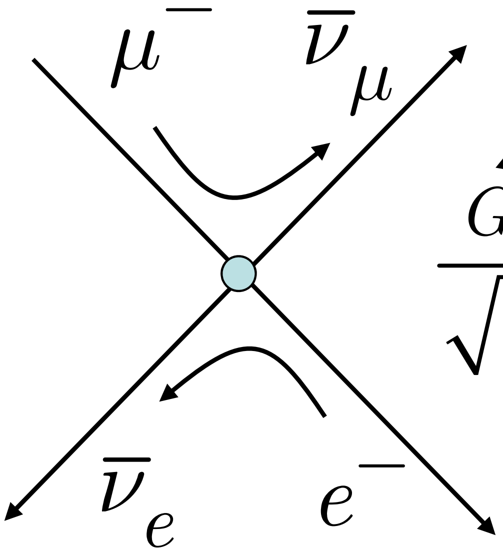
only one
particle missing: *H*

the Higgs

Transformations between Fermions

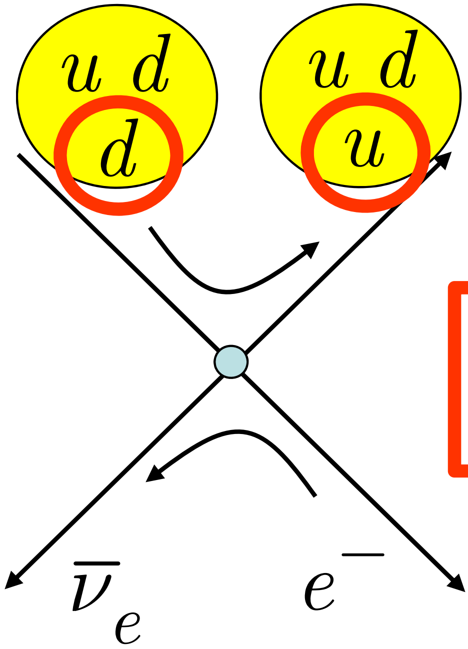
Changing "flavor" by **Universal Weak Interactions**

$$\mu^- \to \nu_\mu e^- \bar{\nu}_e \qquad\qquad n \to p e^- \bar{\nu}_e$$



Fermi's constant

$$\frac{G}{\sqrt{2}} = \frac{\alpha}{8\left(\sin\theta_W M_W\right)^2}$$

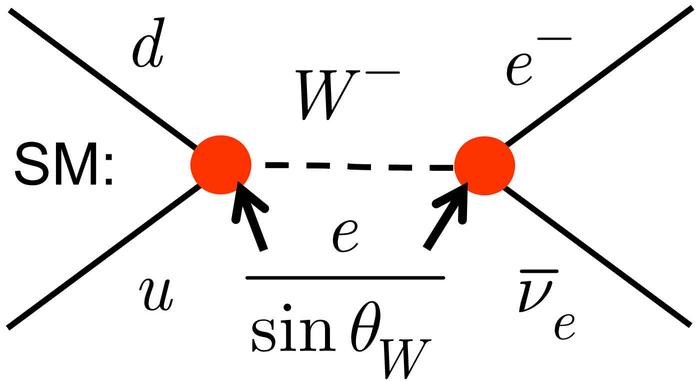


$$\boxed{\cos\theta_C}$$

Cabibbo-anlge

Electroweak Unification within Standard Model (SM): coupling strength basically as in electromagnetism

SM:

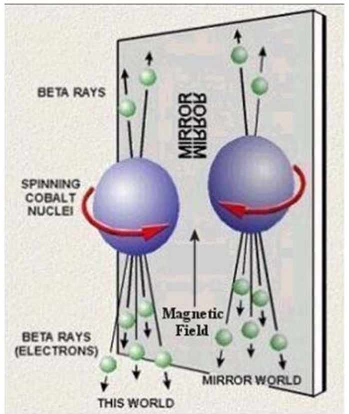


„weak" because of propagator

Surprising Discoveries in Weak Interactions of Quarks


T.D. Lee

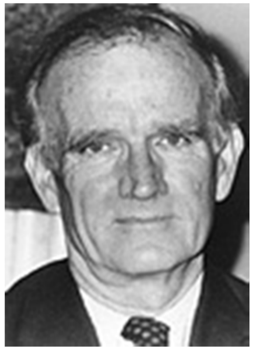

C.N. Yang

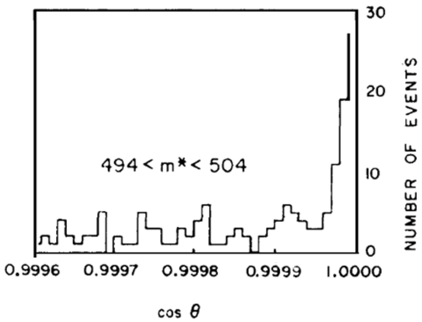


P violated maximally in weak interactions

1957


J. Cronin


V. Fitch

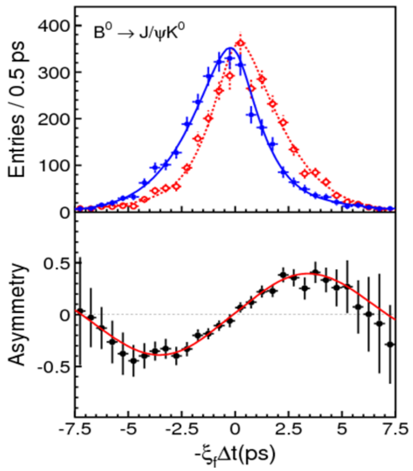


Small CP violation in neutral K system

1980


M. Kobayashi


T. Maskawa

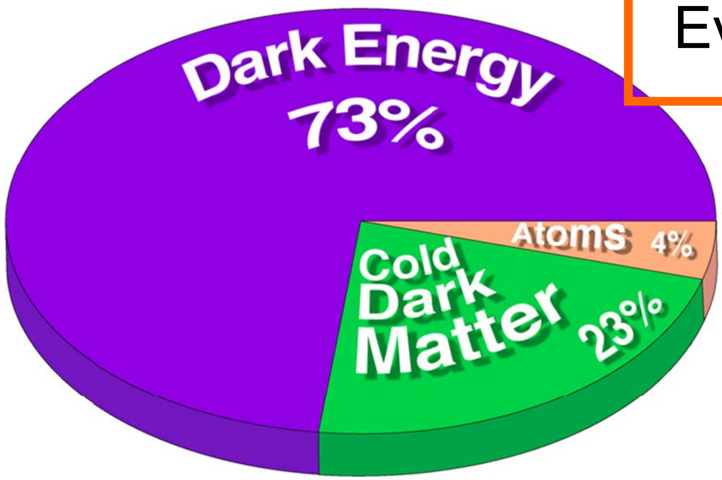


O(1) CP violation and 3 generations of quarks

2008

Why is CP Violation Interesting ?

The Standard Model $SU_3 \times SU_2 \times U_1$ (SM) describes all data so far
yet: cannot be the correct theory, SM only a „low energy“ approximation



Evidence for Physics beyond the Standard Model:

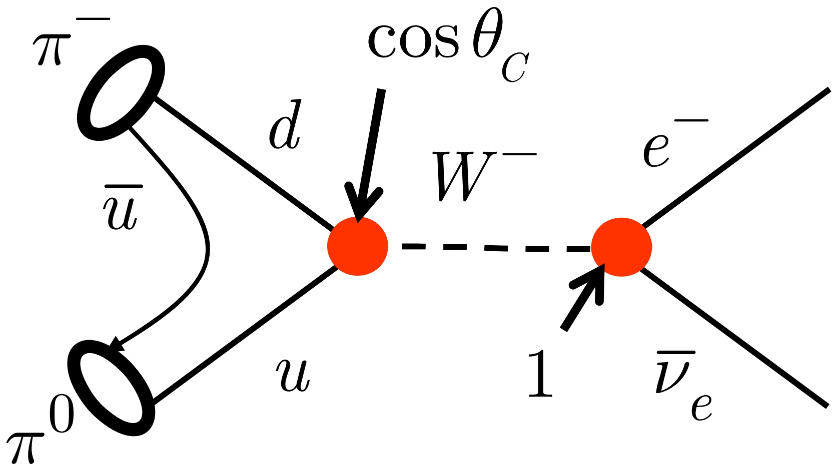
- Dark Matter exists
  (only 4% of the Universe accounted for by SM)
- Neutrinos have mass (Dirac, Majorana?)
- Baryon Asymmetry in the Universe is
  much too large (by 10 orders of magnitude)

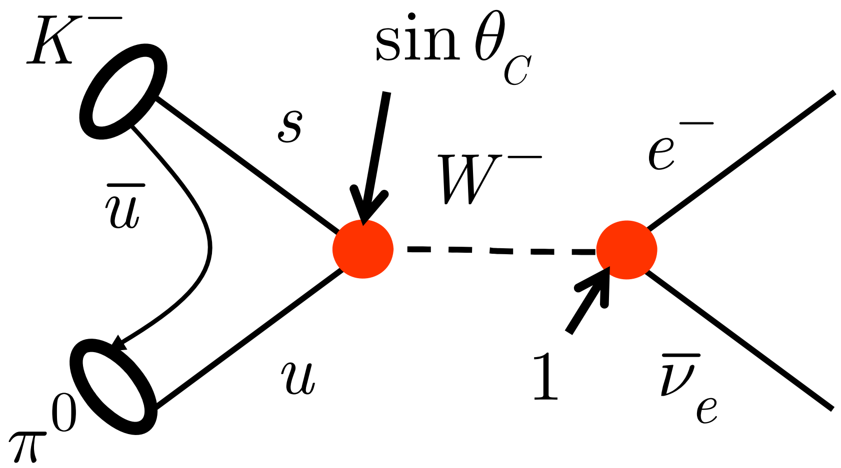
need
very high energy
(LHC) or
v. high precision
(SuperB factories)

At least two of them have to do with CP Violation

$\not{CP}$: One of the so-called Sakharov-conditions

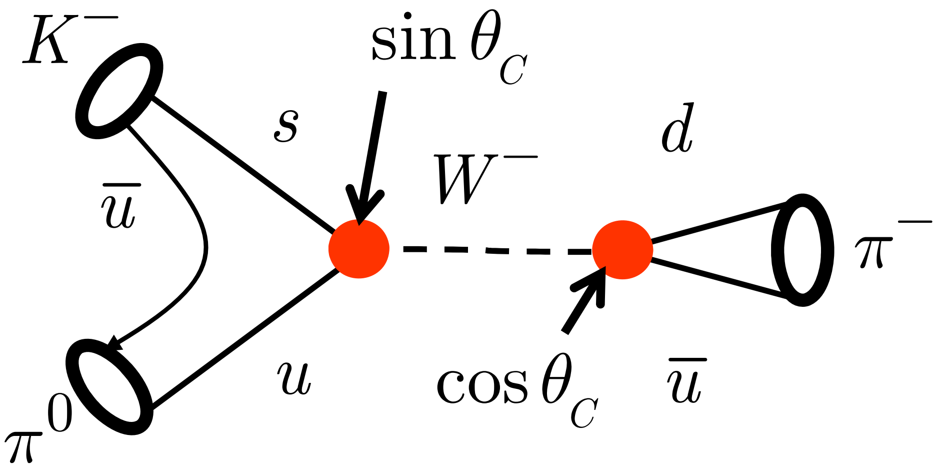
Changing Flavor …



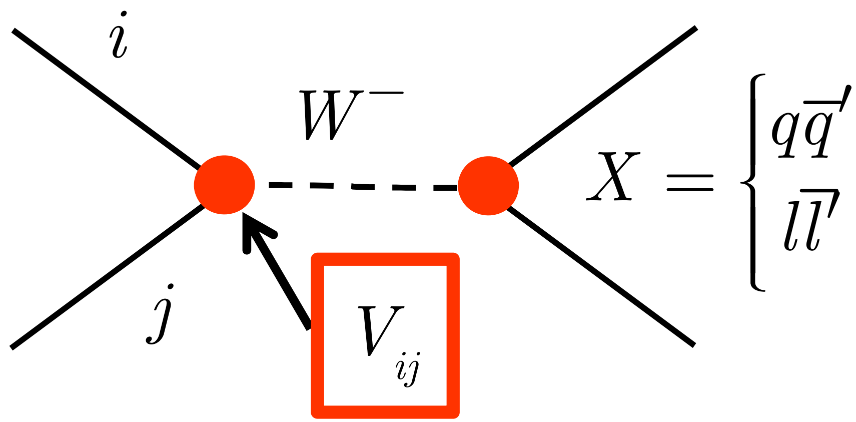


$\pi^- \to \pi^0 e^- \overline{\nu}_e$ semi-leptonic decays $K^- \to \pi^0 e^- \overline{\nu}_e$

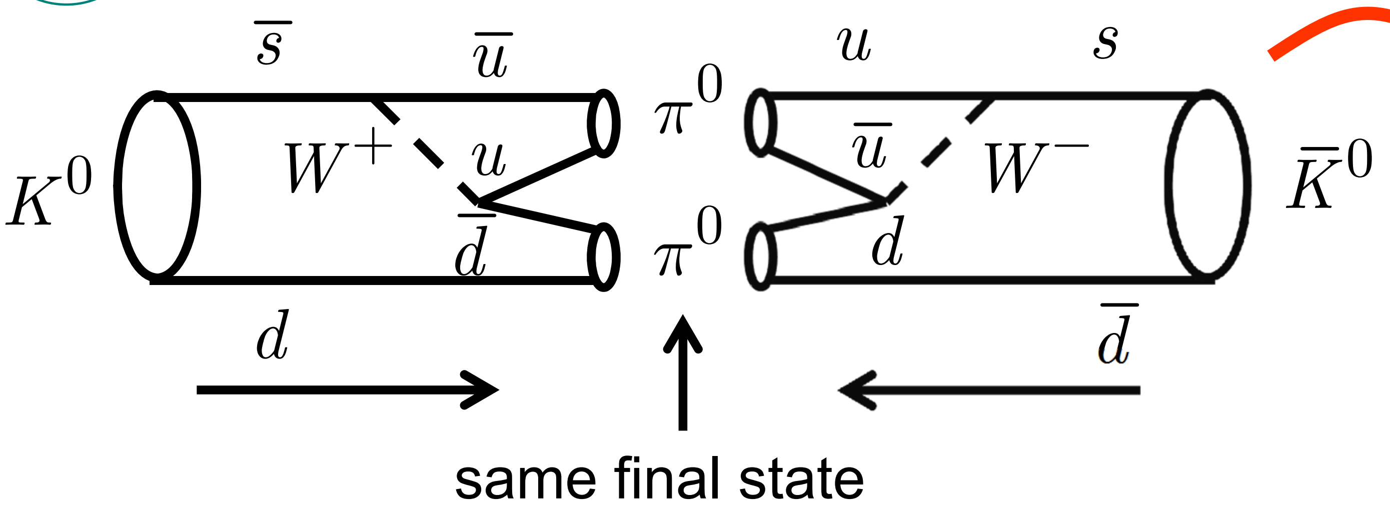
purely hadronic decays, e.g.

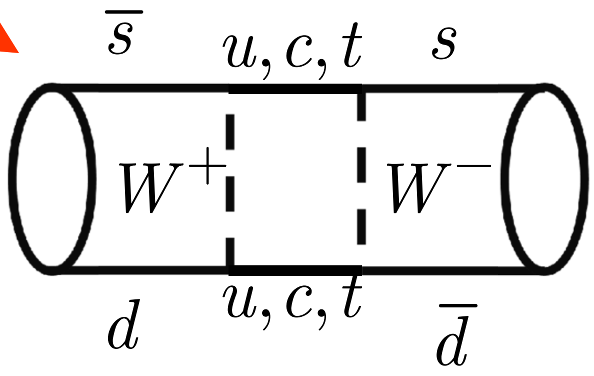


general flavor change:



Matter-Antimatter Oscillations





„box diagram“

$$\boxed{\left\langle \bar{K}^0 \middle| K^0 \right\rangle \neq 0}$$

time-dependent Schrödinger equation:

$$i\frac{\partial}{\partial t}\begin{pmatrix} K^0(t) \\ \bar{K}^0(t) \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}\begin{pmatrix} K^0(t) \\ \bar{K}^0(t) \end{pmatrix}$$

Mass eigenstates:

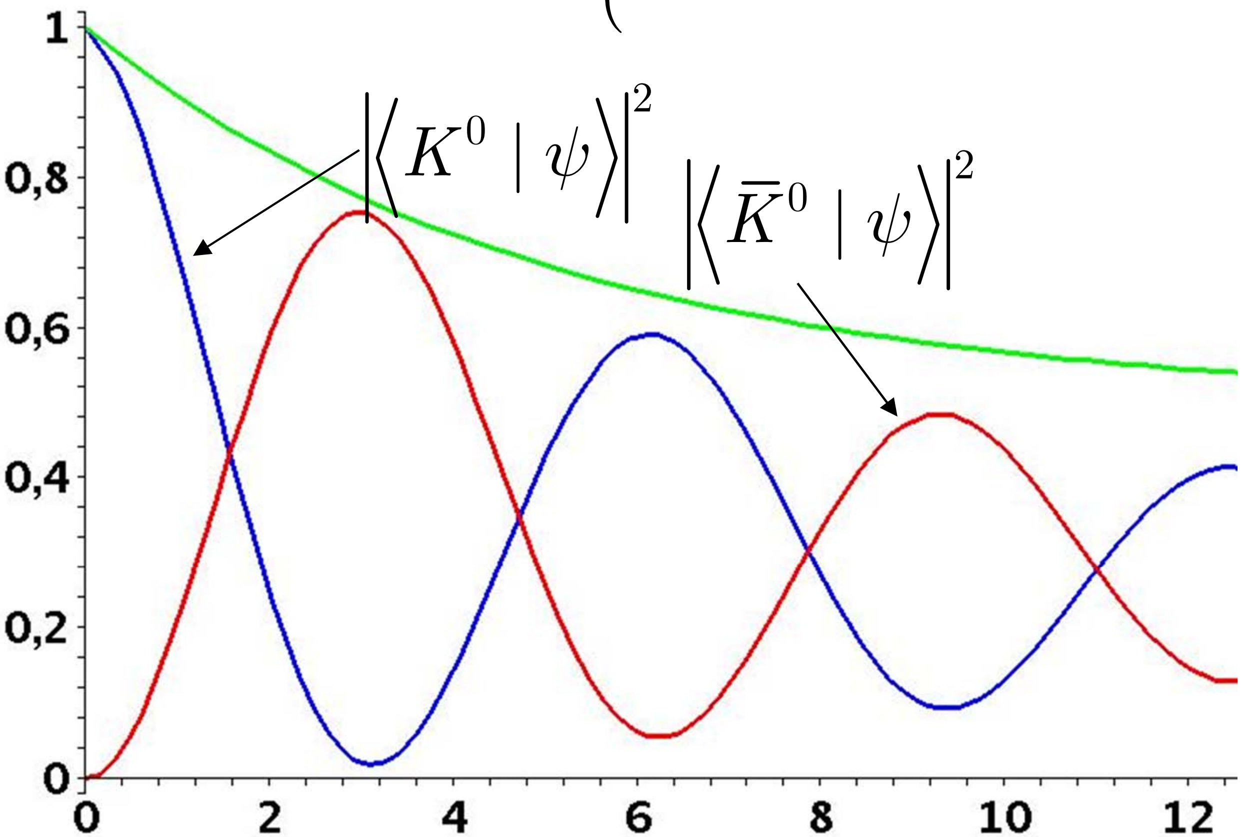
$$\left|K_S\right\rangle = \left|K^0\right\rangle + \left|\bar{K}^0\right\rangle \;:CP = +1 \qquad \left\langle K^0 \middle| \psi \right\rangle = a\left(e^{-i\tilde{M}_S t} + e^{-i\tilde{M}_L t}\right)$$

$$\left|K_L\right\rangle = \left|K^0\right\rangle - \left|\bar{K}^0\right\rangle \;:CP = -1 \qquad \left\langle \bar{K}^0 \middle| \psi \right\rangle = a\left(e^{-i\tilde{M}_S t} - e^{-i\tilde{M}_L t}\right)$$

Matter-Antimatter Oscillations

$$\tilde{M}_{S,L} = m_{S,L} - \frac{i}{2}\Gamma_{S,L} \qquad \Delta m = 3.4\times 10^{-12}\ \mathrm{MeV}$$

$$\left|\left\langle K^0 \mid \psi\right\rangle\right|^2 = a^2\left(e^{-i\Gamma_S t} + e^{-i\Gamma_L t} + e^{-i\frac{\Gamma_S+\Gamma_L}{2}t}\, 2\cos\Delta m t\right)$$



units of lifetime $\tau(K^0)$

$CP = +1:$

$K_S \to \pi\pi,$

$\tau = 0.9\times 10^{-10} s$

$CP = -1$

$K_L \to \pi\pi\pi,$

$\tau = 5\times 10^{-8} s$

(similar for D and B mesons)

Discovery of CP Violation in the Neutral Kaon System

- 2 particles with same mass but different parity („θ - τ“ puzzle)

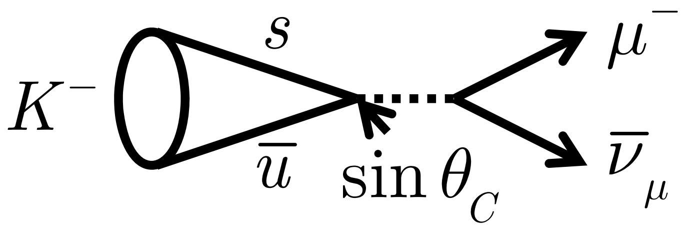
$$\theta^- \rightarrow \pi^- \pi^0 \qquad P = +1$$
$$\tau^- \rightarrow \pi^- \pi^+ \pi^- \qquad P = -1$$

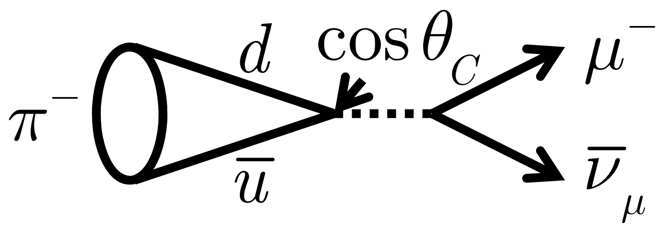
$$\boxed{\theta^- \equiv \tau^- \equiv K^-}$$

Lee & Yang

- „Strange particles“:

$$\frac{\Gamma(K^- \rightarrow \mu^- \nu_\mu)}{\Gamma(\pi^- \rightarrow \mu^- \nu_\mu)} \left(\frac{PS(\pi)}{PS(K)} \right) \ll 1$$





θ_C : Cabibbo angle

- CP violating decay of neutral kaons

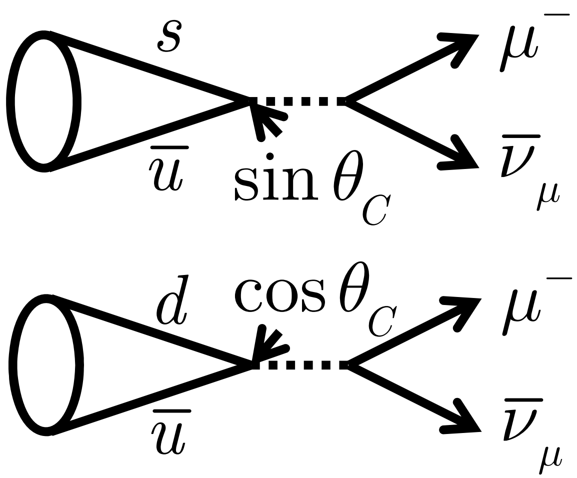
$$K^0, \bar{K}^0 (K_S) \rightarrow \pi\pi \qquad CP(\pi\pi) = +1$$
$$K^0, \bar{K}^0 (K_L) \rightarrow \pi\pi\pi \qquad CP(\pi\pi\pi) = -1$$

$$K_L \rightarrow \pi\pi$$
with 0.2 % prob.

Cronin & Fitch

The Origin of CP Violation in the SM

$$\begin{pmatrix} d' \\ s' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} \\ V_{cd} & V_{cs} \end{pmatrix} \begin{pmatrix} d \\ s \end{pmatrix}$$



Matrix V is unitary

$$d' = \quad d\cos\theta_C + s\sin\theta_C$$
$$s' = -d\sin\theta_C + s\cos\theta_C$$

CP violation from Quark Mixing:
Extension of the Cabibbo-Matrix!

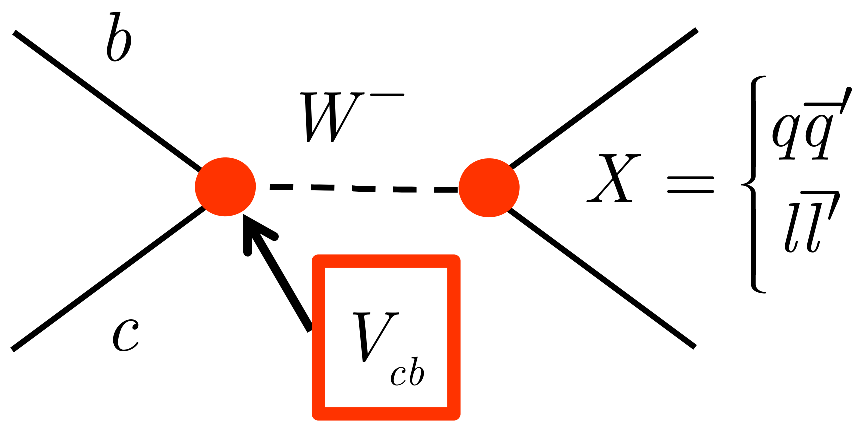
Mathematical reason: Matrix must have complex elements, only possible via n x n matrix with n > 2

Theory formulated in 1973 by Kobayashi & Maskawa
(Charm-, Bottom- and Top-Quark were not discovered yet!)

b-quark experiments have established the theory of K&M !

Matrix Elements Involving *b* Quarks

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix}$$



- naïve expectation: $V_{cb} \approx V_{cd} = V_{us}$ e.g. $B \to Dl\nu$
- big surprise: *B* mesons live much too long $\quad \tau(B) = 1.5\ \mathrm{ps}$
- $$\tau(B) = \tau(\mu)\left(\frac{m_\mu}{m_b}\right)^5 \frac{1}{9\left|V_{cb}\right|^2}$$

B meson lifetime

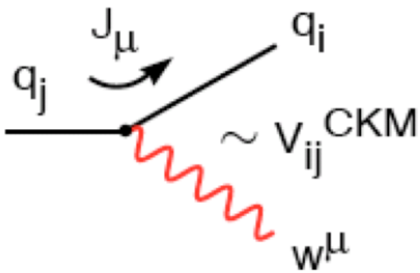
$2 \times 3 + 3$

quark families, color

lepton families

$$\boxed{\left|V_{cb}\right| \approx \frac{1}{30} = O(\sin^2\theta_C)}$$

The CKM Matrix and the Unitarity Triangle(s)



weak decays of hadrons (quarks change flavor)
are described in the SM by the (unitary) CKM matrix

Cabibbo, Kobayashi, Maskawa $\quad \lambda = \sin\theta_C$

$$V^{\mathrm{CKM}} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

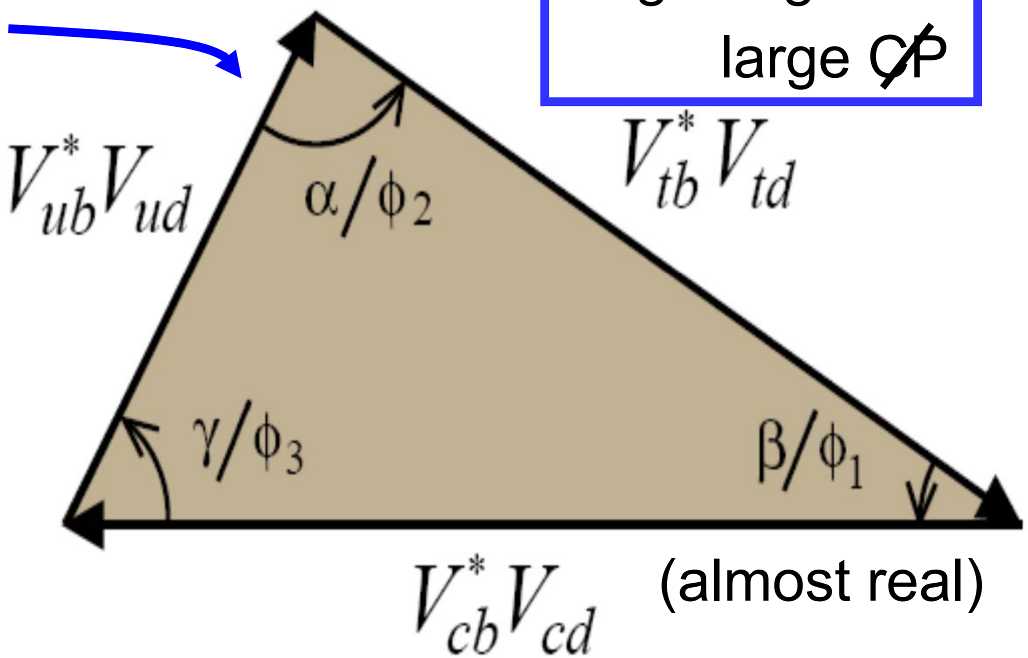
large angles = large ~~CP~~

$$\boxed{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}$$

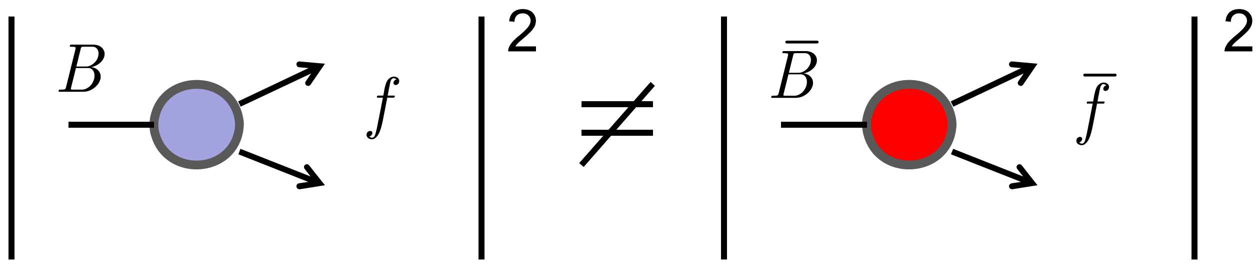
Triangle for B mesons

$$\boxed{V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* = 0}$$

Triangle for K mesons



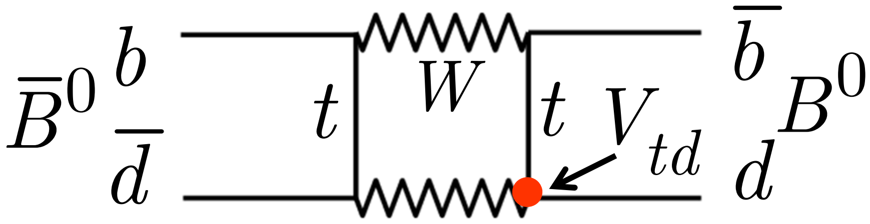
Types of CP Violation in the B-System



direct
CP violation

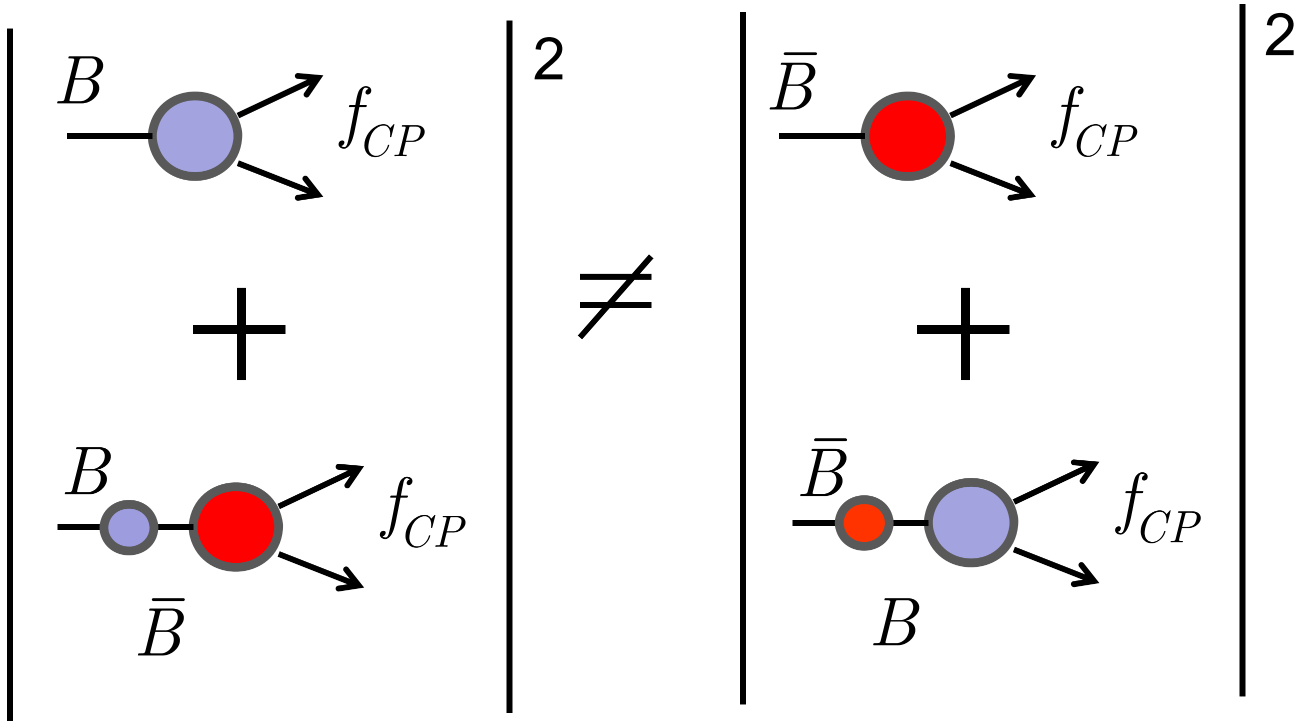
(charged and
neutral B mesons)

„mixing“:



$$B_L = pB^0 + q\bar{B}^0$$

$$B_H = pB^0 - q\bar{B}^0$$



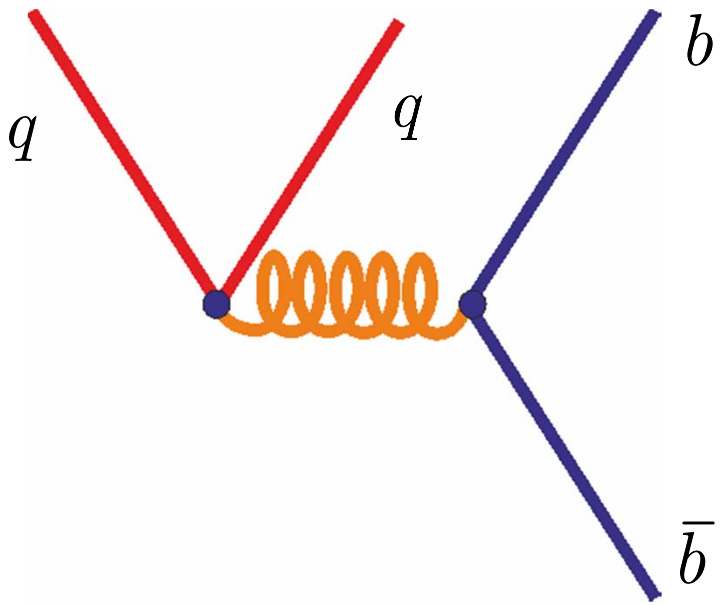
$$\Delta m = M(B_H) - M(B_L)$$
$$= 3.3 \times 10^{-10} \text{ MeV}$$

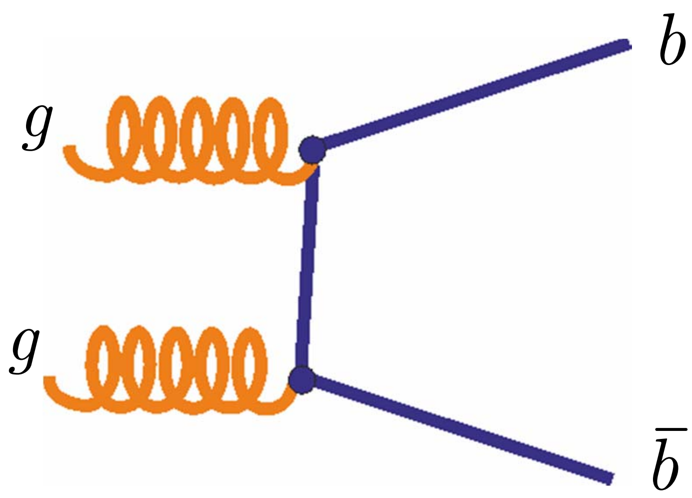
mixing-induced
CP violation

(only
neutral B mesons)

Production Mechanisms of B-Mesons

B-mesons can be (easily) produced in pairs via the Strong Interaction:



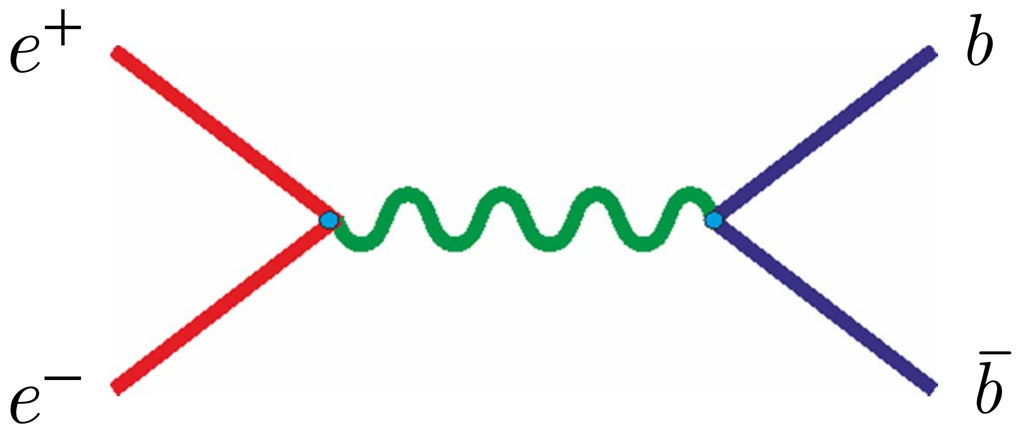


LHC:

ATLAS,
CMS,

LHCb

… or the Electromagnetic Interaction:



(Super) B Factories:

KEK (Belle)
PEP II (BaBar)

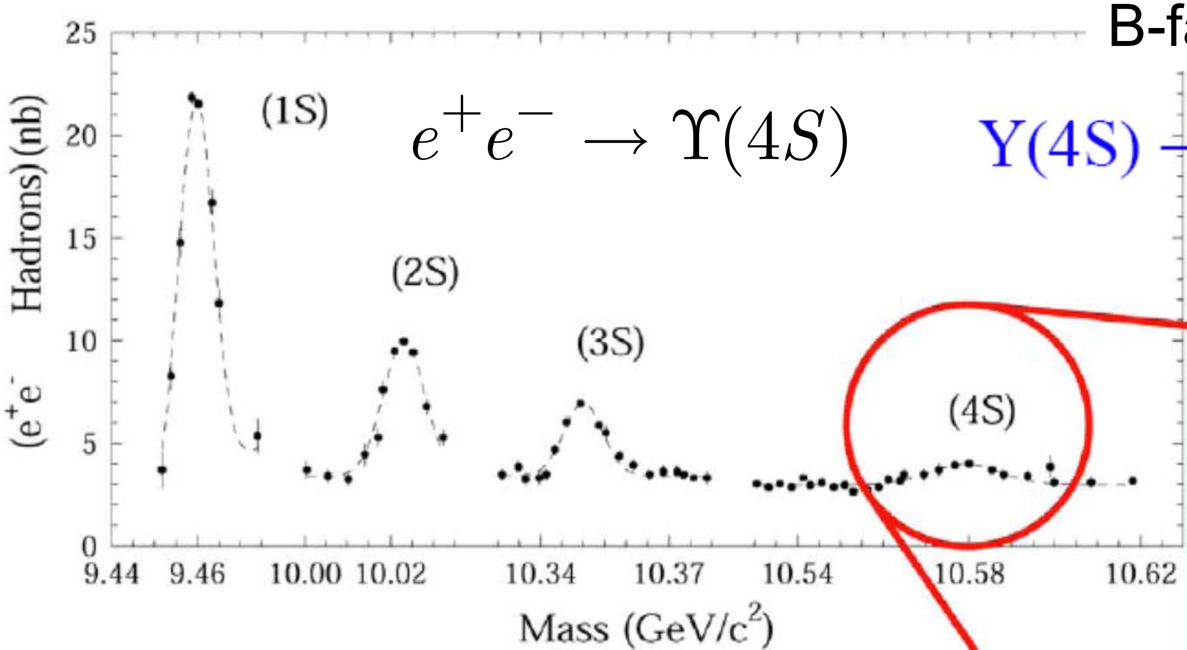
Belle II @ SuperKEKB
SuperB

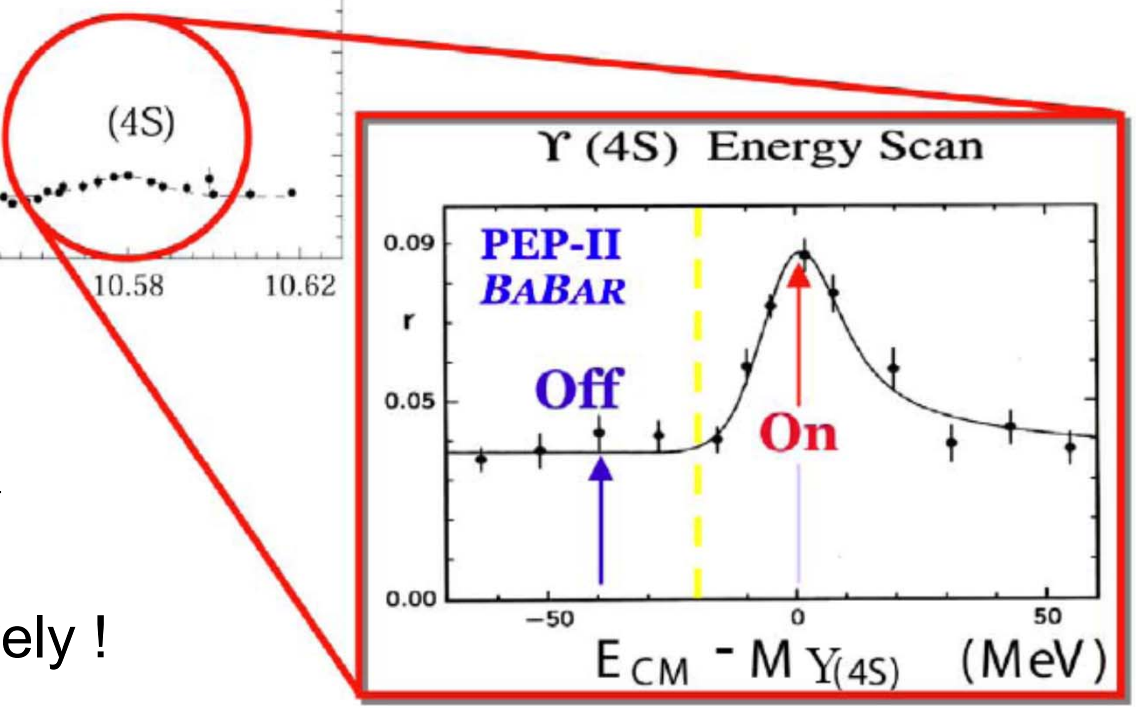
Where do we Measure?

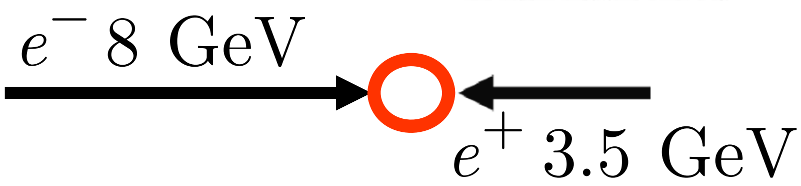
B-factories at KEK and SLAC

$$e^+e^- \to \Upsilon(4S)$$

$\Upsilon(4S) \to B^0\bar{B}^0$ (50%), B^+B^- (50%)







B-mesons are produced exclusively !

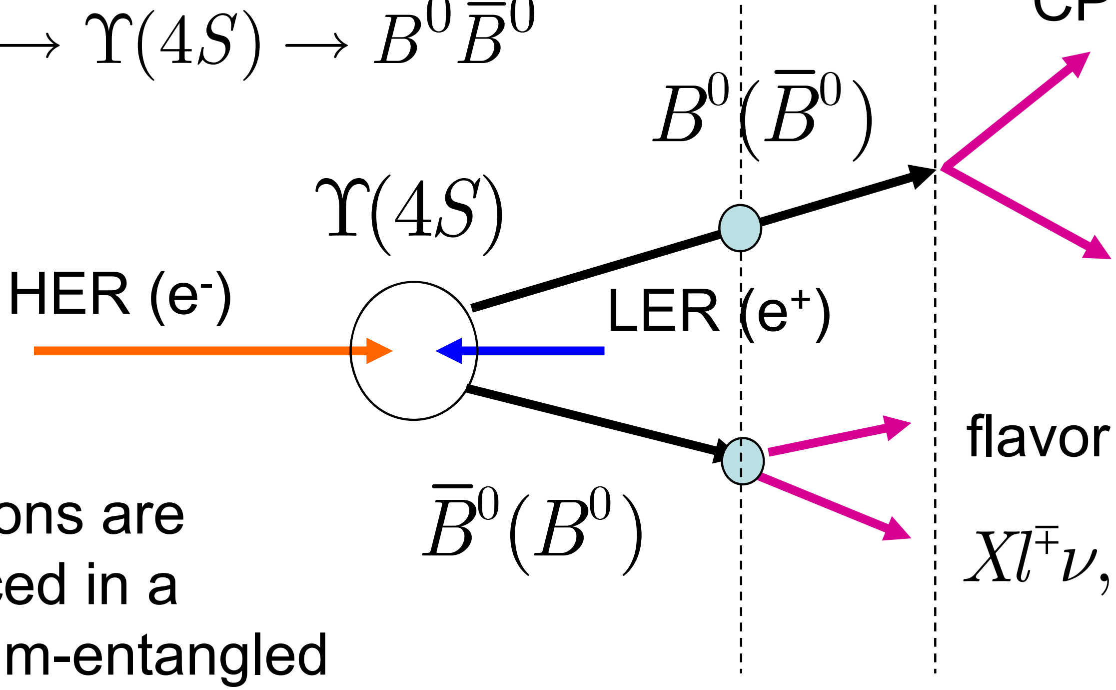
Beam energies are asymmetric:
both B's have the same Lorentz boost,
fly parallel in the lab system

Flavor of the CP decay of one B determined by the other B

The $\cancel{CP}$ Observables: What do we measure?

B-Mesons: $\left|B^0\right\rangle = \left|\bar{b}d\right\rangle \quad \left|B^+\right\rangle = \left|\bar{b}u\right\rangle$

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^0\bar{B}^0$$



some state $f(\bar{f})$ or CP eigenstate, e.g.

$J/\psi K_S$ $CP = -1$ the „Golden" channel

flavor eigenstate

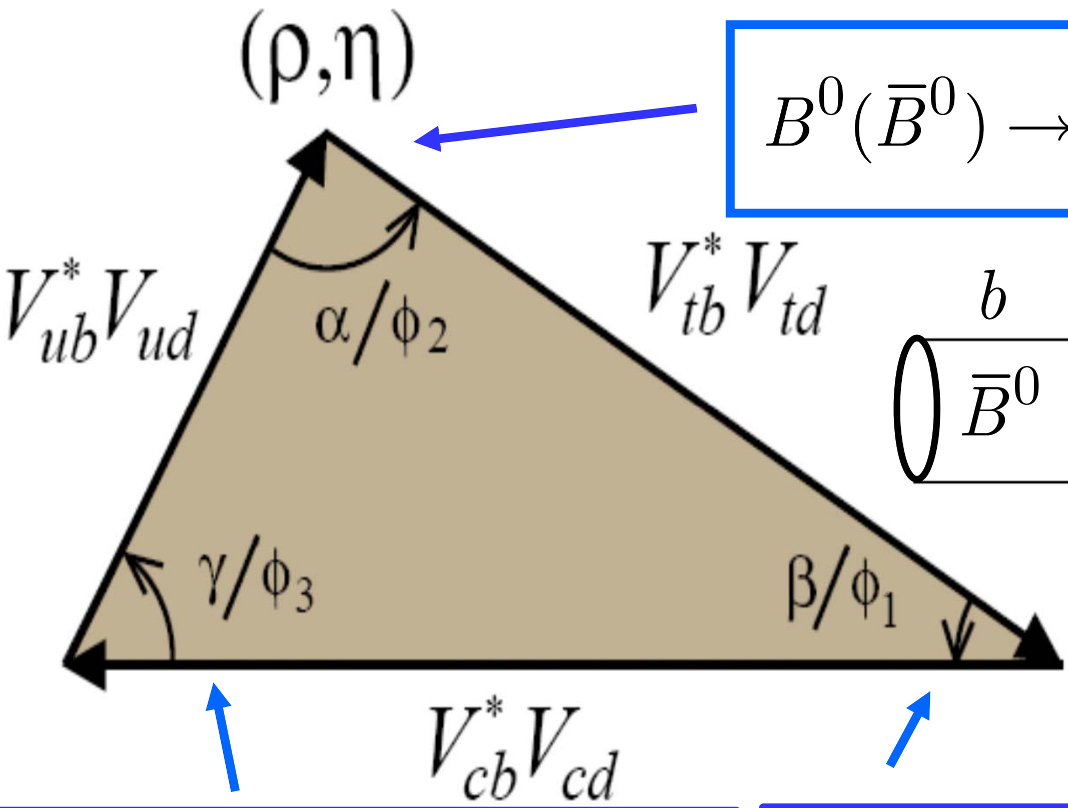
$Xl^{\mp}\nu, D^{*\pm}X$ „flavor tagging"

B mesons are produced in a quantum-entangled state !

$$\Delta z = \beta\gamma c \Delta t$$

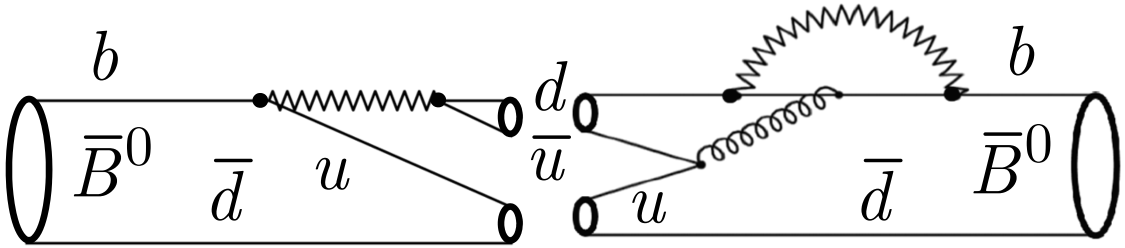
Asymmetric beam energies: translate decay time to decay length

Measuring the Angles Φ_2, Φ_1, Φ_3 (α, β, γ)



$$B^0(\overline{B}^0) \rightarrow \pi\pi, \rho\rho, \rho\pi, a_1\pi$$

$Br \sim 10^{-6}$



T ~ P

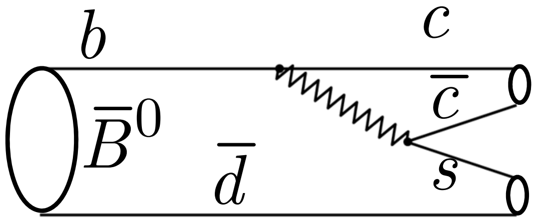
Tree (T) or Penguin (P) dominates

$Br \sim 10^{-4}$

$$B^+(B^-) \rightarrow D\,K, D^*\pi$$
$$B^0(\overline{B}^0) \rightarrow K\pi$$

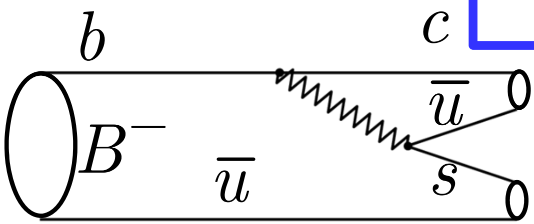
$$B^0(\overline{B}^0) \rightarrow J/\psi\, K_{S,L}$$
$$\rightarrow \phi\, K_{S,L}$$

....

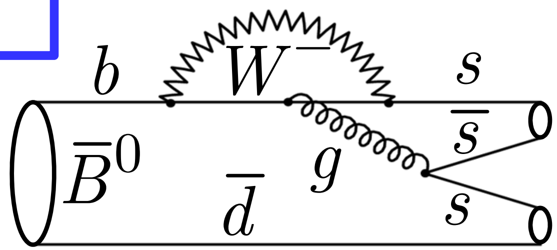


T

$Br \sim 10^{-5}$



T (only)



P

Mixing-Induced CP Asymmetry

Def: $A(B^0 \to \psi) \equiv A \qquad A(\bar{B}^0 \to \psi) \equiv \bar{A}$

CP eigenstate

$$\lambda_\psi \equiv \frac{q}{p}\frac{\bar{A}_\psi}{A_\psi} \approx e^{-2i\phi_1}$$

$$\mathcal{A}_{CP}(\psi,\Delta t) = \frac{N(\bar{B}^0 \to \psi;t) - N(B^0 \to \psi;t')}{N(\bar{B}^0 \to \psi;t) + N(B^0 \to \psi;t')}$$

$$= \left[\underbrace{\frac{1-\left|\lambda_\psi\right|^2}{1+\left|\lambda_\psi\right|^2}}_{A}\cos\Delta m\Delta t + \underbrace{\frac{2\,\mathrm{Im}(\lambda_\psi)}{1+\left|\lambda_\psi\right|^2}}_{S}\sin\Delta m\Delta t\right]$$

$$\Delta t = t - t'$$

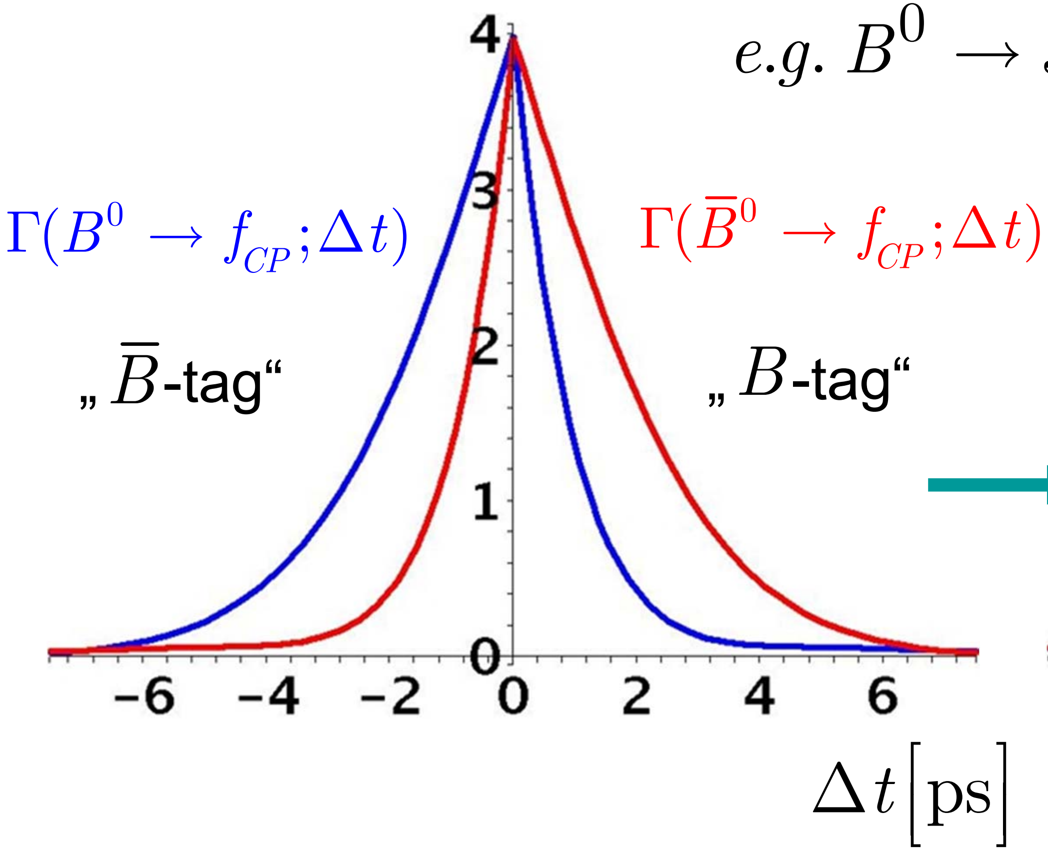
A Direct CP-Violation

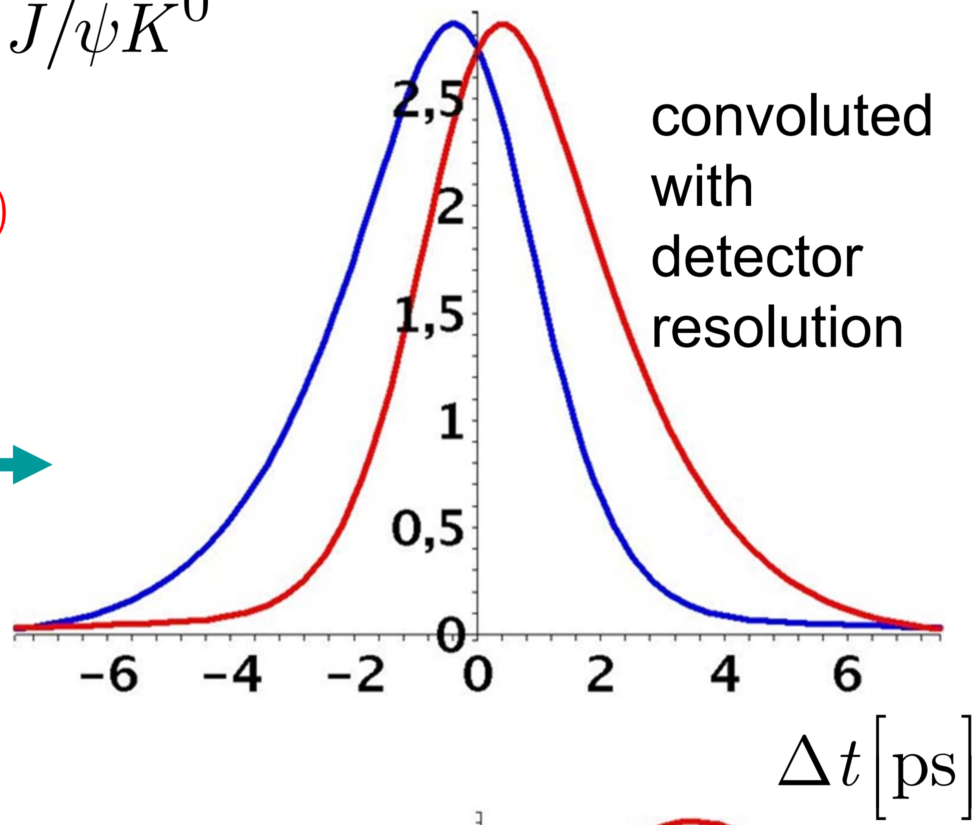
S CP-Violation via Mixing and Decay („mixing-induced“ CP violation)

$$\boxed{\begin{array}{l} J/\psi K_S : \\ \lambda_\psi = e^{-i2\phi_1} \end{array}}$$

Time-Dependent CP-Asymmetries

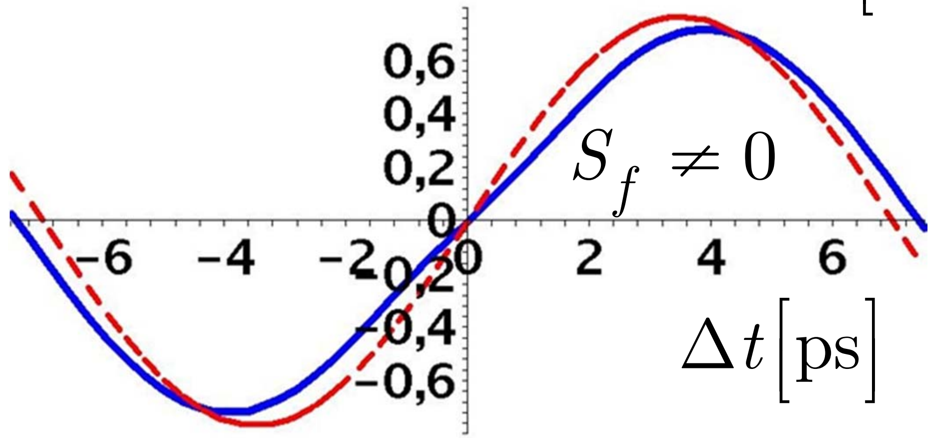
$e.g.\ B^0 \to J/\psi K^0$





convoluted with detector resolution

$$\mathcal{A}_{CP}(\Delta t) = \frac{N(\overline{B}^0,t) - N(B^0,t')}{N(\overline{B}^0,t) + N(B^0,t')}$$
$$= A_f \cos \Delta m \Delta t + S_f \sin \Delta m \Delta t$$



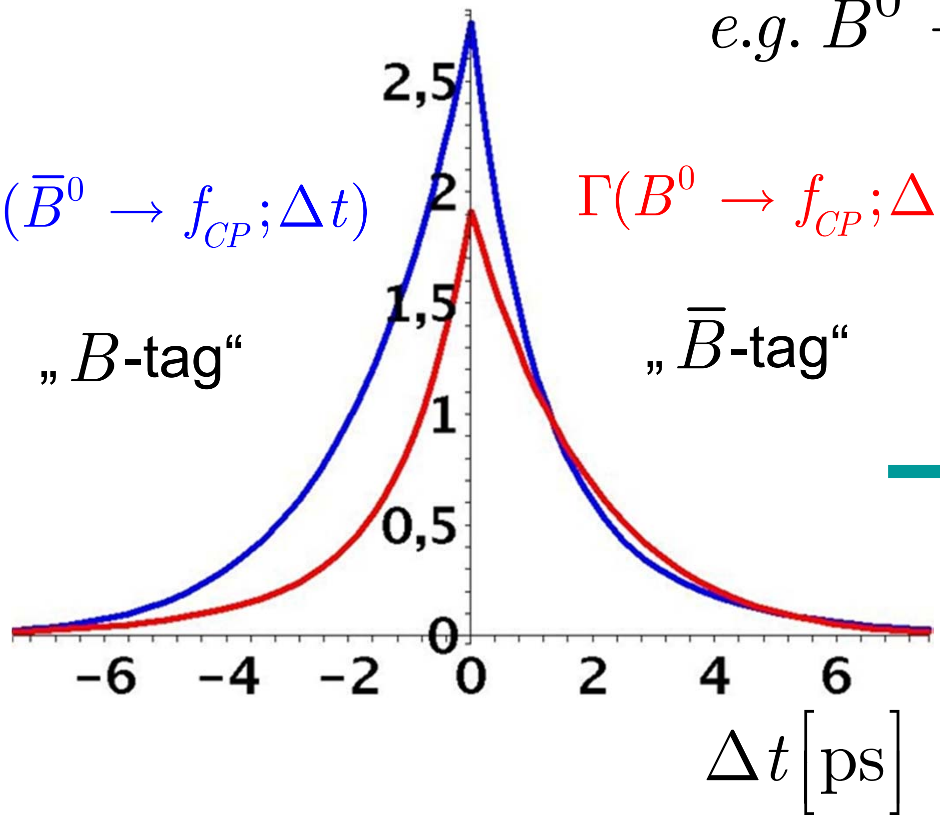
No direct CP violation: $A_f = 0$

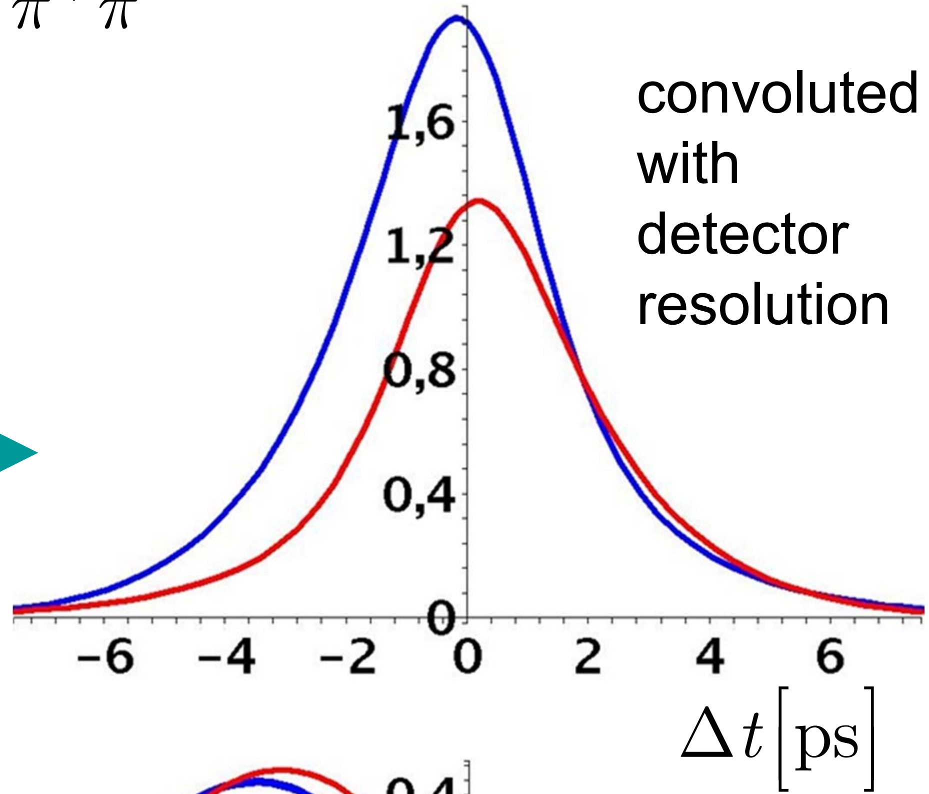
Time-Dependent CP-Asymmetries

$e.g.\ B^0 \to \pi^+\pi^-$

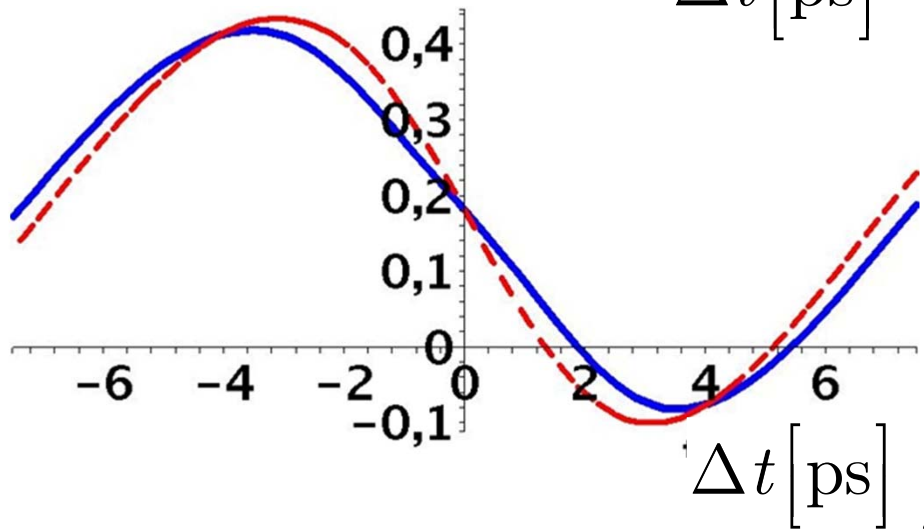
$\Gamma(\bar{B}^0 \to f_{CP};\Delta t)$ $\Gamma(B^0 \to f_{CP};\Delta t)$

„B-tag“ „$\bar{B}$-tag“





convoluted with detector resolution

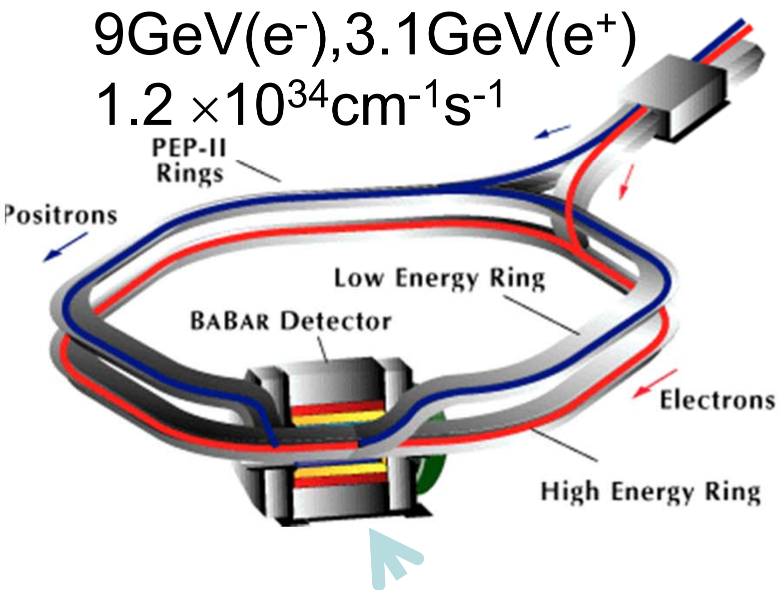


$$\mathcal{A}_{CP}(\Delta t) = \frac{N(\bar{B}^0,t) - N(B^0,t')}{N(\bar{B}^0,t) + N(B^0,t')}$$
$$= A_f \cos\Delta m\Delta t + S_f \sin\Delta m\Delta t$$

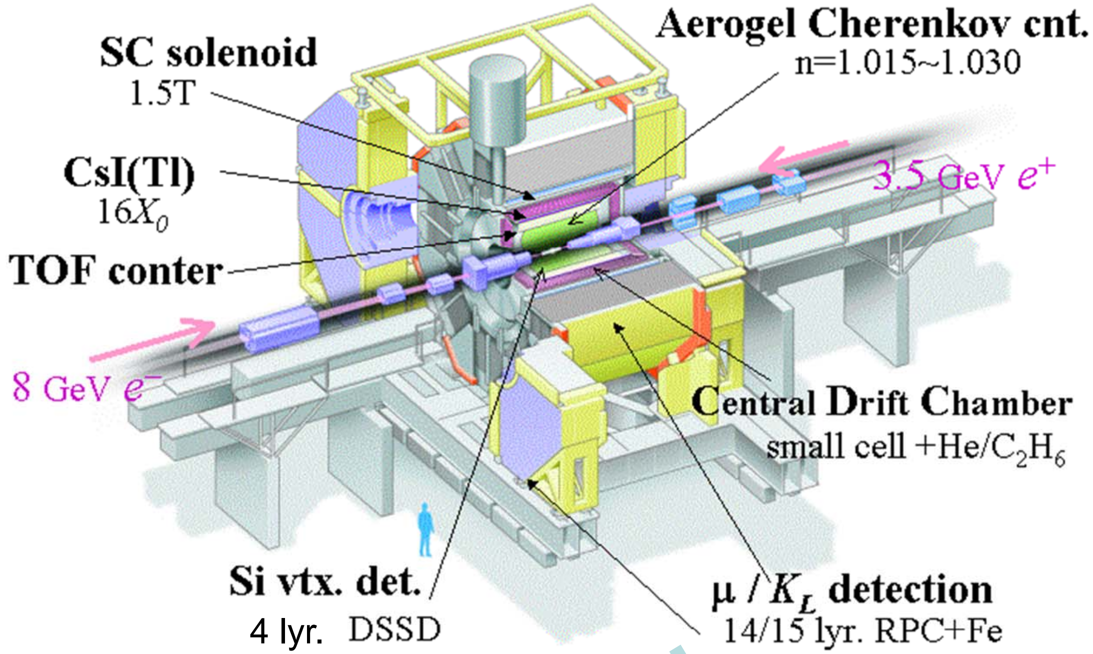
Direct CP violation: $A_f \neq 0$

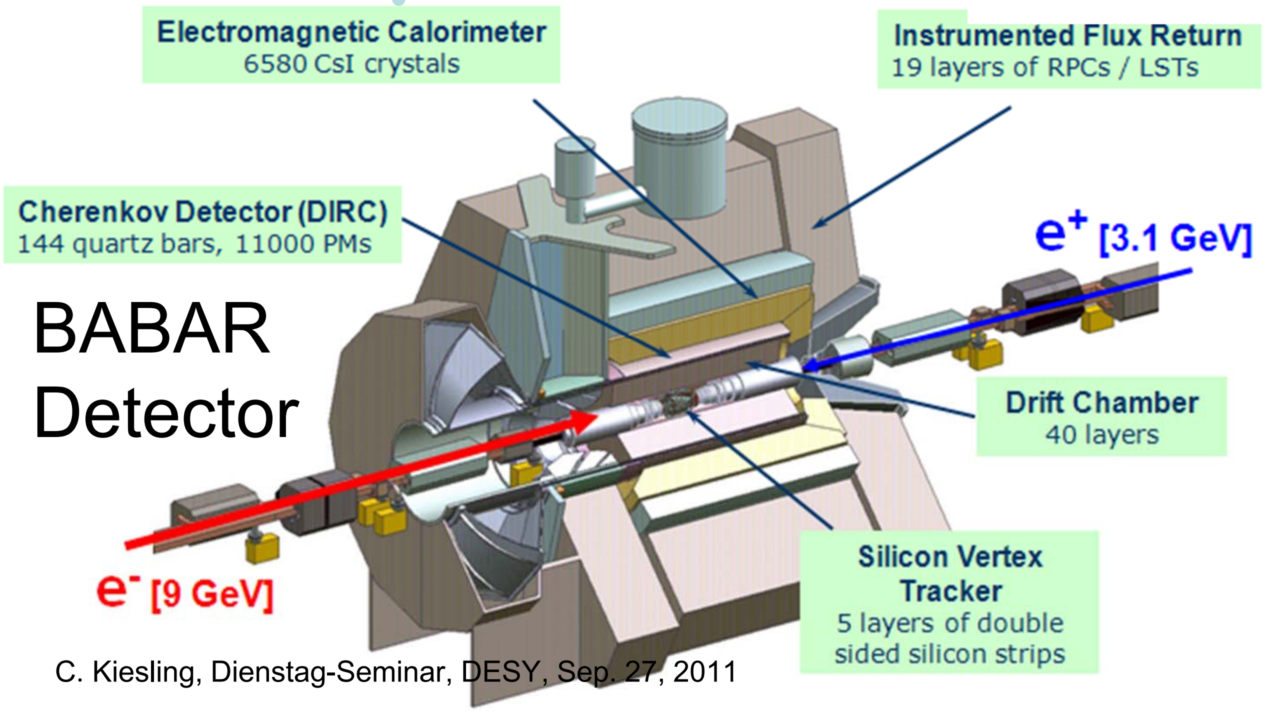
B-Factories

PEP-II
$9GeV(e^-), 3.1GeV(e^+)$
$1.2 \times 10^{34} cm^{-1}s^{-1}$

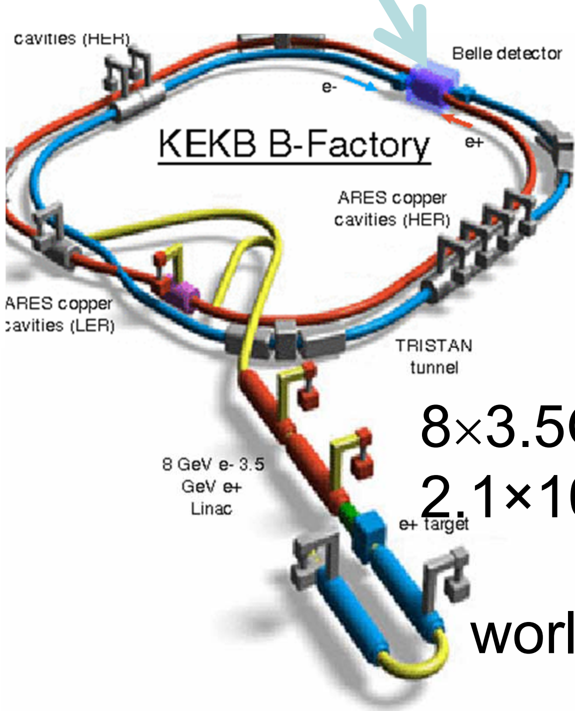


Belle Detector





BABAR
Detector

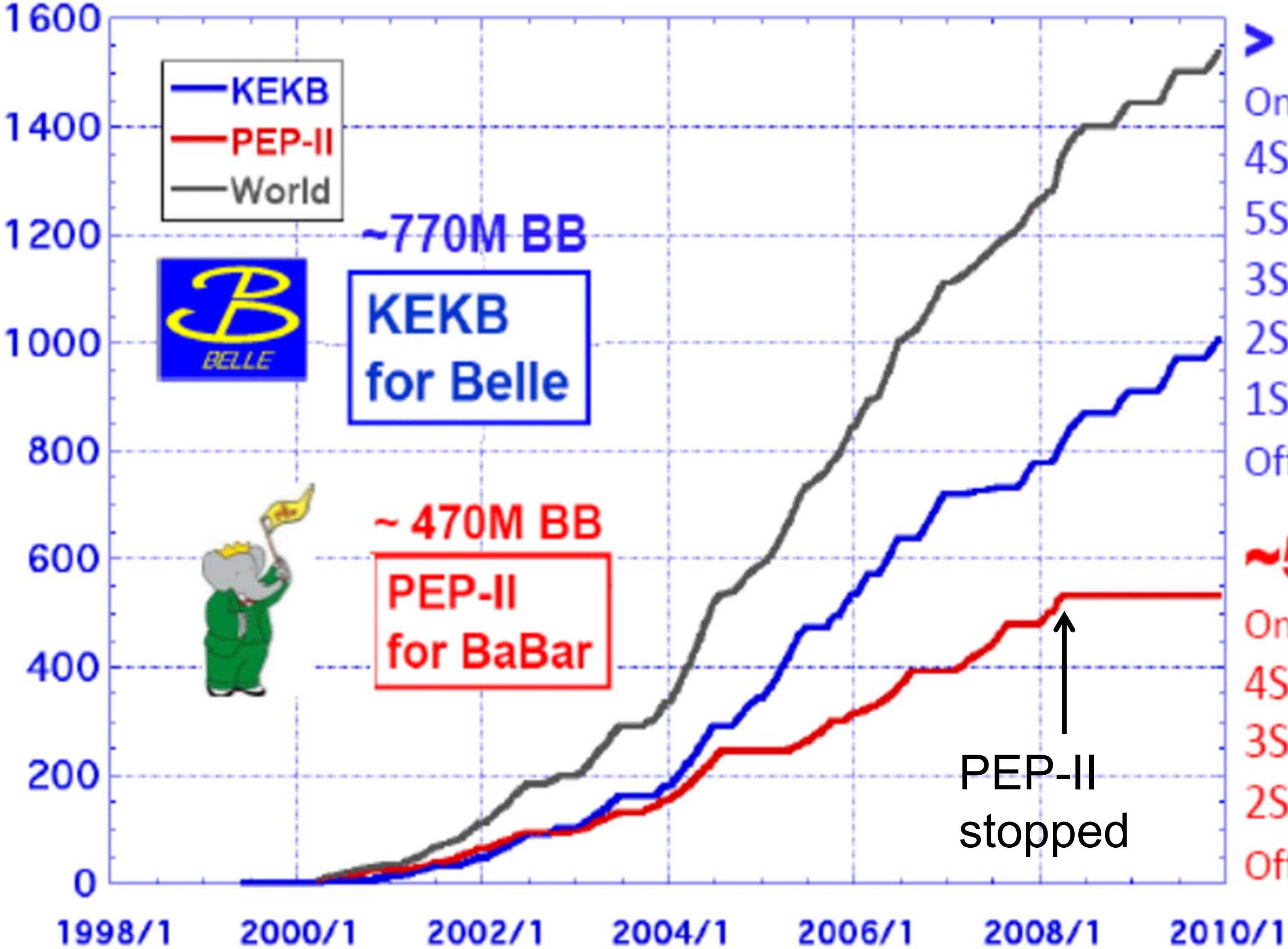


$8 \times 3.5GeV$
$2.1 \times 10^{34} cm^{-2}s^{-1}$

world record !

Luminosity accumulated at Present B-Factories

30.6.2010: KEKB stopped



> 1.0 ab^{-1}

On-resonance samples:

4S: 711 fb^{-1}

5S: 121 fb^{-1}

3S: 3.0 fb^{-1}

2S: 24 fb^{-1}

1S: 5.7 fb^{-1}

Off-resonance: 87 fb^{-1}

~553 fb^{-1}

On-resonance samples:

4S: 433 fb^{-1}

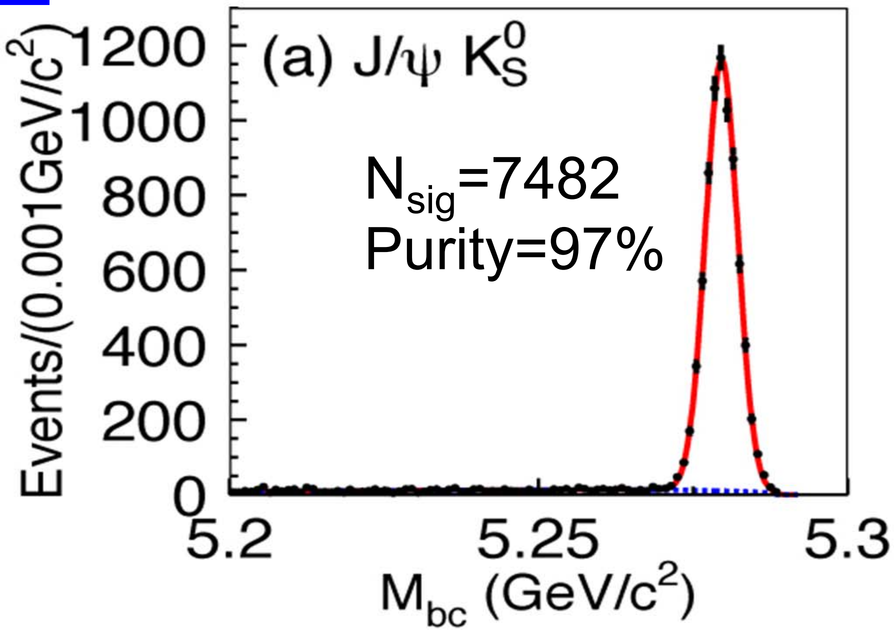
3S: 30 fb^{-1}

2S: 14 fb^{-1}

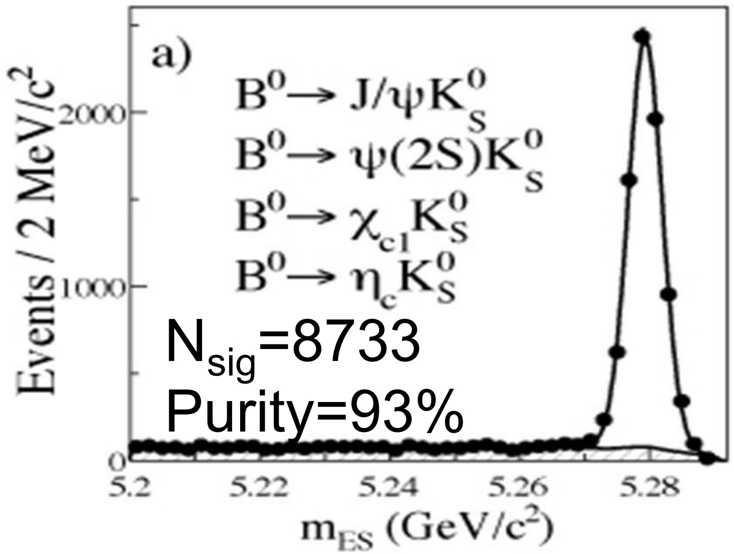
Off-resonance: 54 fb^{-1}

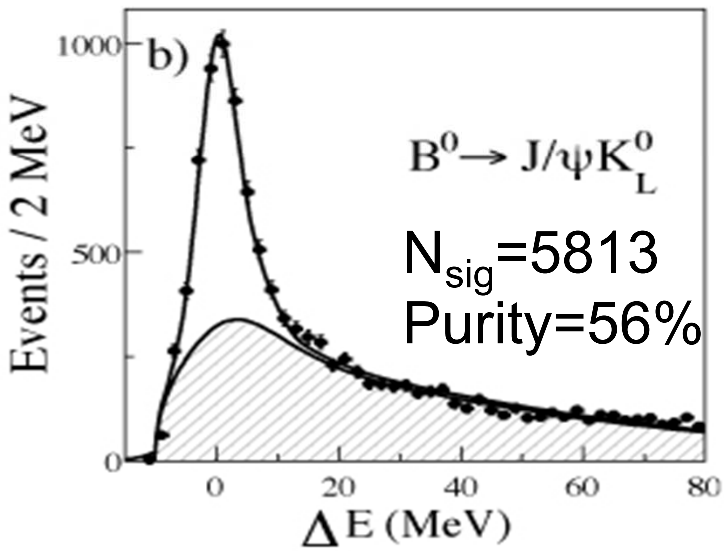
Measurement of ϕ_1 (β) in Charmonium K^0 modes

535M$B\bar{B}$



465M$B\bar{B}$





E_B - $E_{CM}/2$

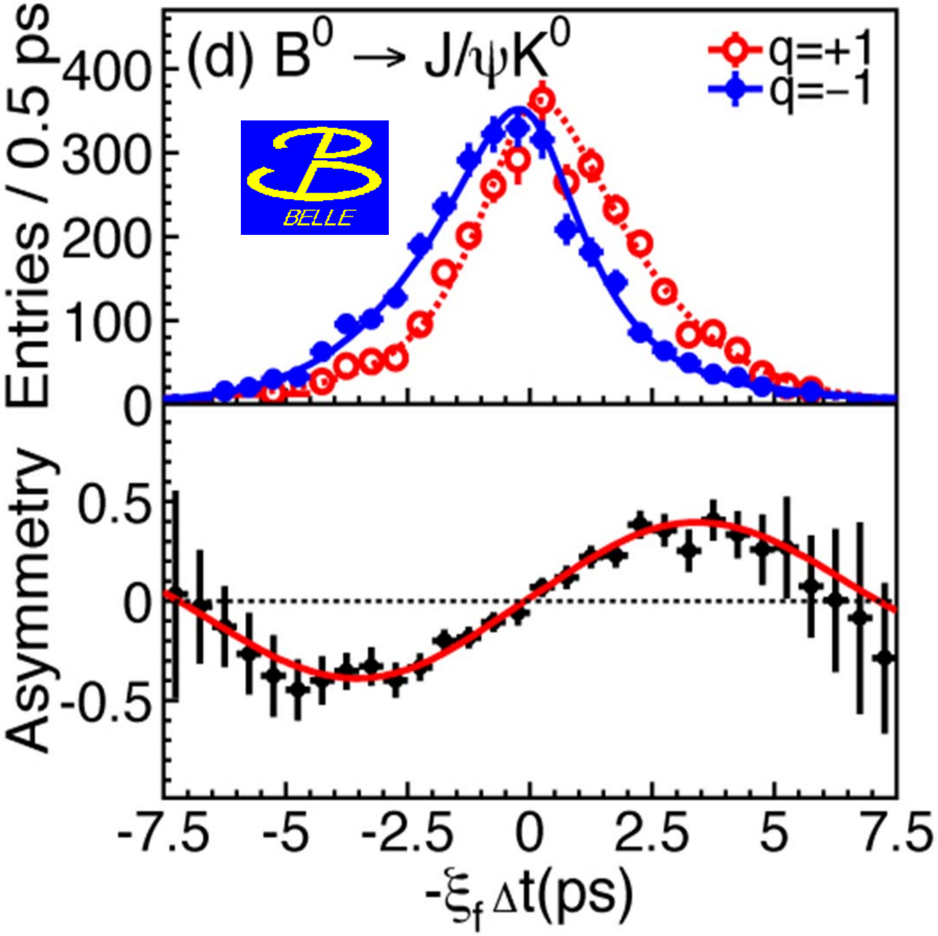
Signal extraction:

reconstruct desired final state using

$$M_{bc} = \sqrt{\left(E^*_{beam}\right)^2 - \left(p^*_{B^0}\right)^2}$$

$$\Delta E = E^*_{B^0} - E^*_{beam}$$

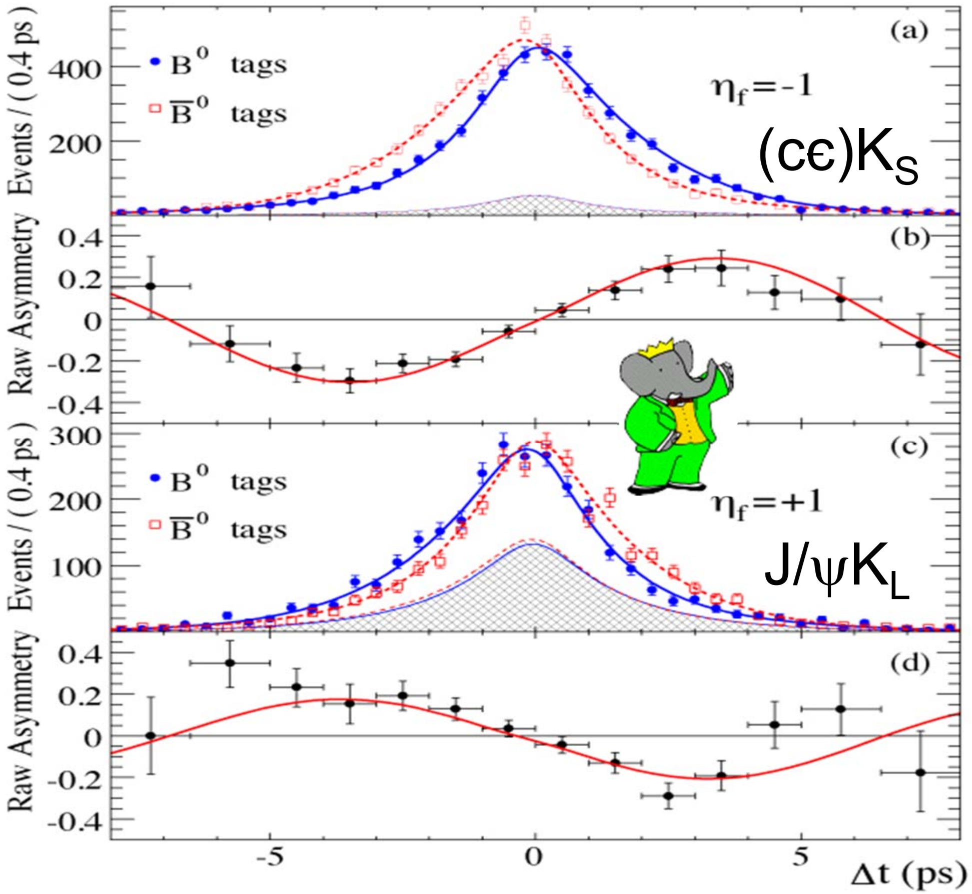
Measurement of ϕ_1 (β) in Charmonium K^0 modes



$\sin 2\phi_1 = 0.642 \pm 0.031 \pm 0.017$

$A_f = 0.018 \pm 0.021 \pm 0.014$

PRL98,031802(2007)



$\sin 2\phi_1 = 0.687 \pm 0.028 \pm 0.012$

$A_f = -0.024 \pm 0.020 \pm 0.016$

PRD79,072009(2009)

Comparison Tree and Penguins for ϕ_1 (β)

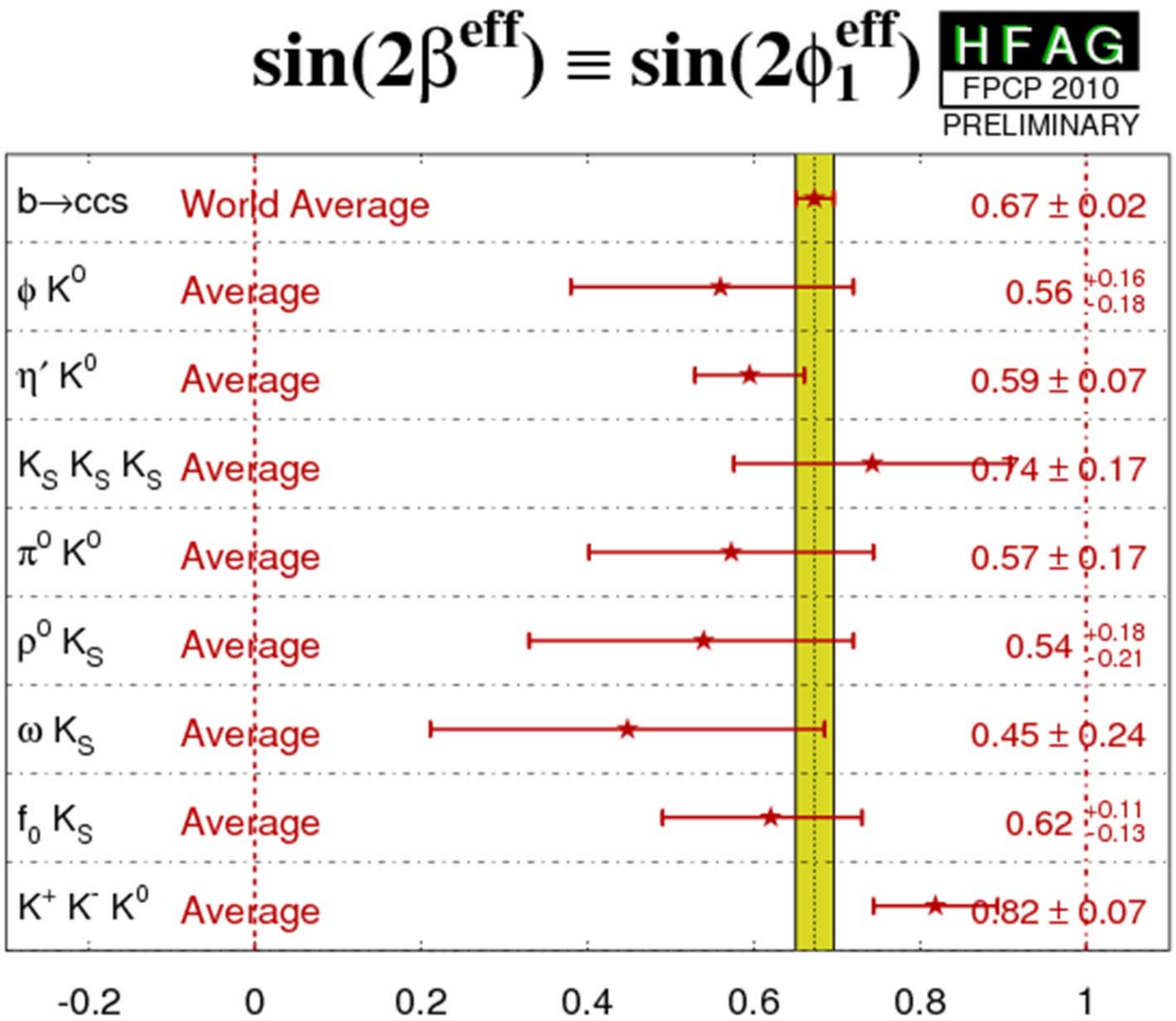
$b \longrightarrow c\bar{c}s$ tree

$b \longrightarrow sq\bar{q}$ penguins

penguins from 2-body decays

penguins from Dalitz plot analysis

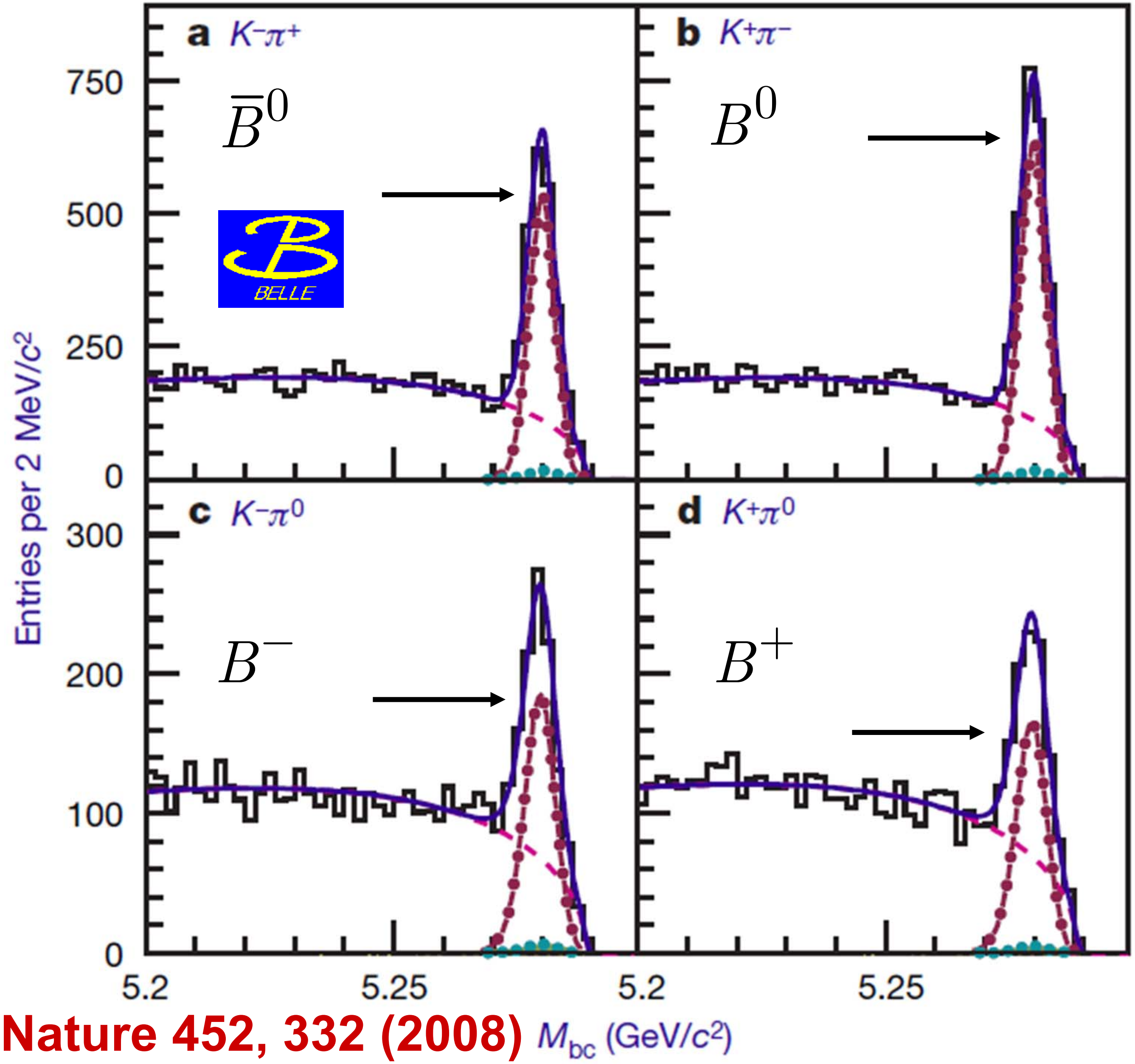
only small contr. from T -> „eff.“



ϕ_1 from tree and penguins consistent

note: Theory would favor $\phi_1^{eff} > \phi_1$

Another Puzzle: Direct CP Violation in $B \to K\pi$



Nature 452, 332 (2008)

$A_{CP}(K^+\pi^-) < 0$

WA: -0.098 ± 0.012

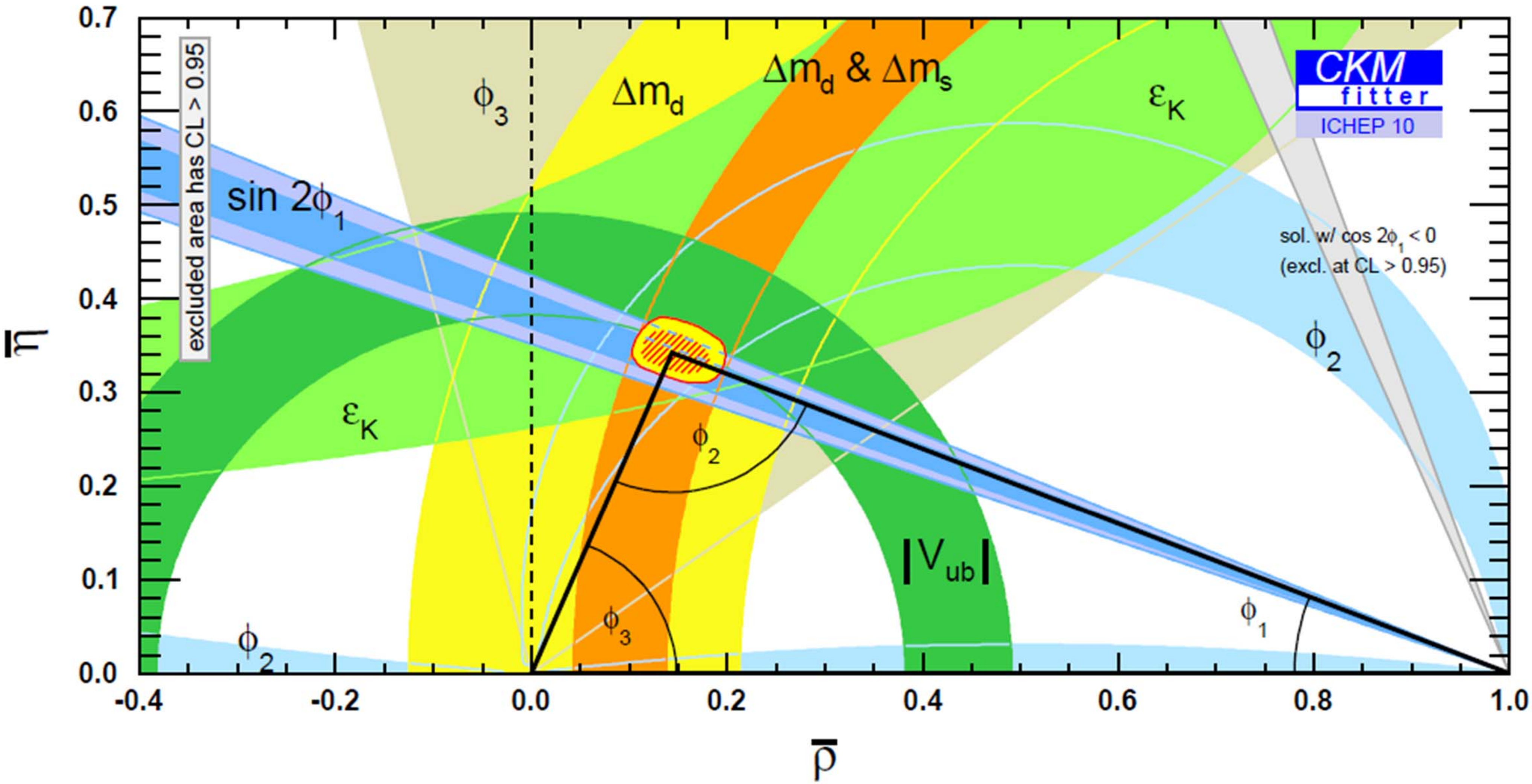
$A_{CP}(K^+\pi^0) > 0$

WA: $+0.050 \pm 0.025$

should be equal !

- Large color-suppressed tree amplitude?
- Enhanced EW penguin?
- New Physics?

The Unitarity Triangle in 2011



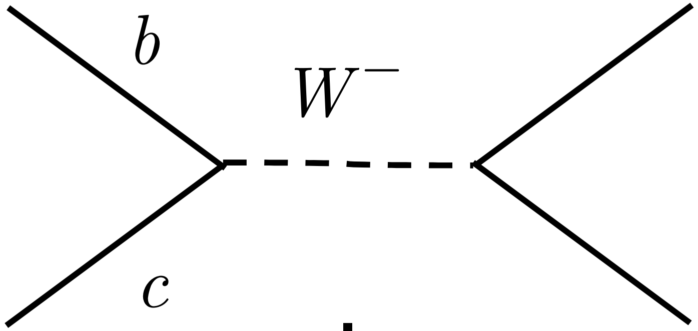
Generally consistent with SM, but some „tensions“ exist …

How do we see the New Physics ?

Tree level effects (FCCC)

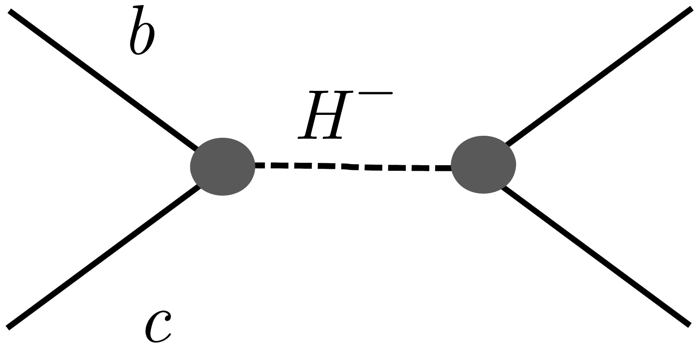
Quantum loop effects (FCNC)

SM

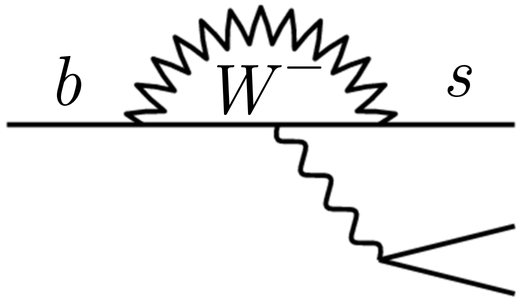


+

NP



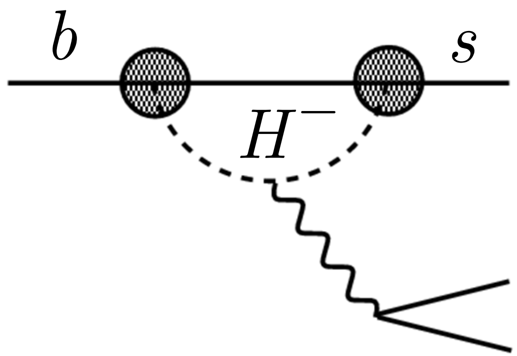
SM



„Penguins“

+

NP

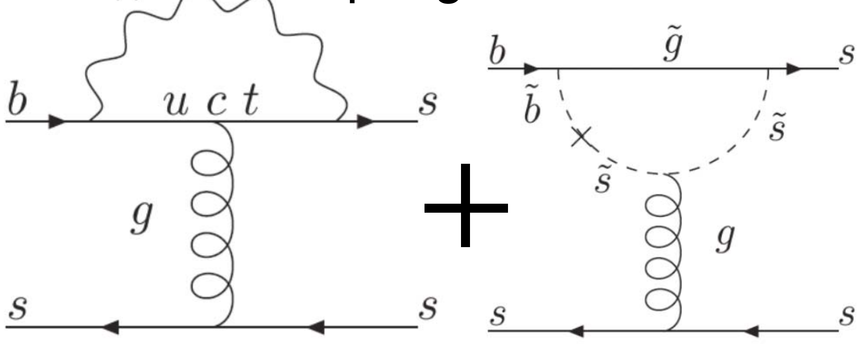


CP violation beyond the SM

If triangle „does not close“ → **New Physics** ← unexpectedly „large“ branching fractions

New Physics at the Loop Level ....

„penguins“



SM NP

Rare Decays of *B* mesons:

	SM pred.
$B \to X_{s,d}\gamma$	$\mathcal{O}\left(10^{-4}\right)$
$B \to X_{s,d} l^+ l^-$	$\mathcal{O}\left(10^{-6}\right)$
$B \to X_d \nu\overline{\nu}$	$\mathcal{O}\left(10^{-6}\right)$
$B \to l^+ l^-$	$\mathcal{O}\left(10^{-10}\right)$

NP in CPV asymmetries:

$$B \to J/\psi K_S \longleftrightarrow B \to \phi K_S$$

Principle:

Deviation of observable from the SM prediction signals NP

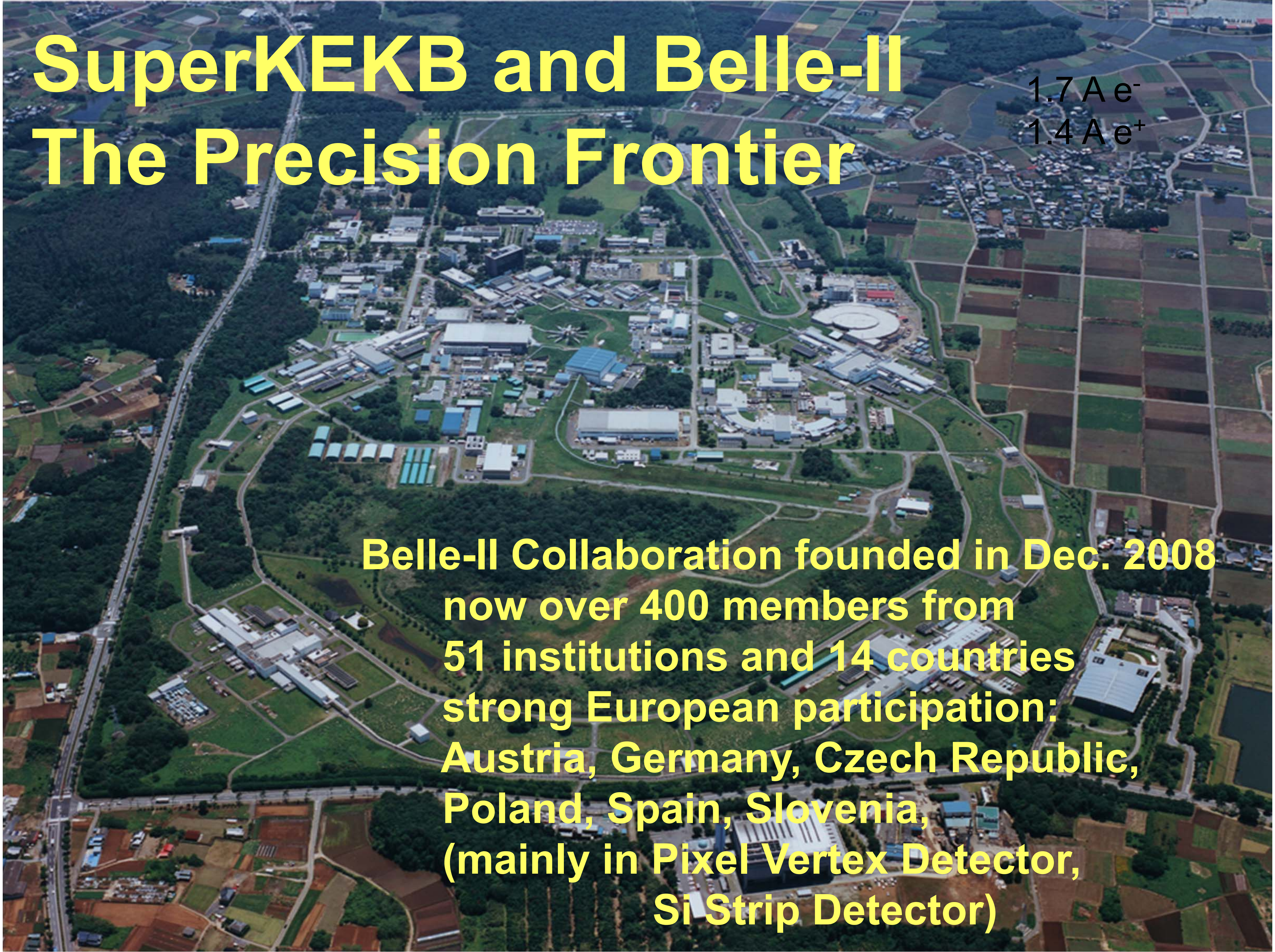
virtual particles in the loop reveal their existence $\longrightarrow \Lambda_{NP}$

leptons:

$$\left.\begin{array}{l} \tau \to \mu\gamma \\ \tau \to \mu\mu\mu \\ \tau \to \mu\eta \end{array}\right\}$$ NP could make these decays possible

need precision (statistics) to challenge the SM

SuperKEKB and Belle-II
The Precision Frontier



Belle-II Collaboration founded in Dec. 2008

now over 400 members from
51 institutions and 14 countries
strong European participation:
Austria, Germany, Czech Republic,
Poland, Spain, Slovenia,
(mainly in Pixel Vertex Detector,
Si Strip Detector)

Strategies for High Luminosity @ Super BF's

$$\mathcal{L} = \frac{N_+ N_- f}{4\pi\sigma_x\sigma_y} R$$

basic formula for the (instantaneous) luminosity

Accelerator physicists usually like this one better:

stored current

tune shift

$$\mathcal{L} = \frac{\gamma_+}{2er_e}\left(1 + \frac{\sigma_y}{\sigma_x}\right)\left(\frac{I_+\xi_{y,+}}{\beta_y}\right)\left(\frac{R}{R_{\xi_y}}\right)$$

vertical beta function at IP

$R_{,\xi}$: reduction factors (geometrical)

$\sigma_{x,y}$: beam spot size at IP

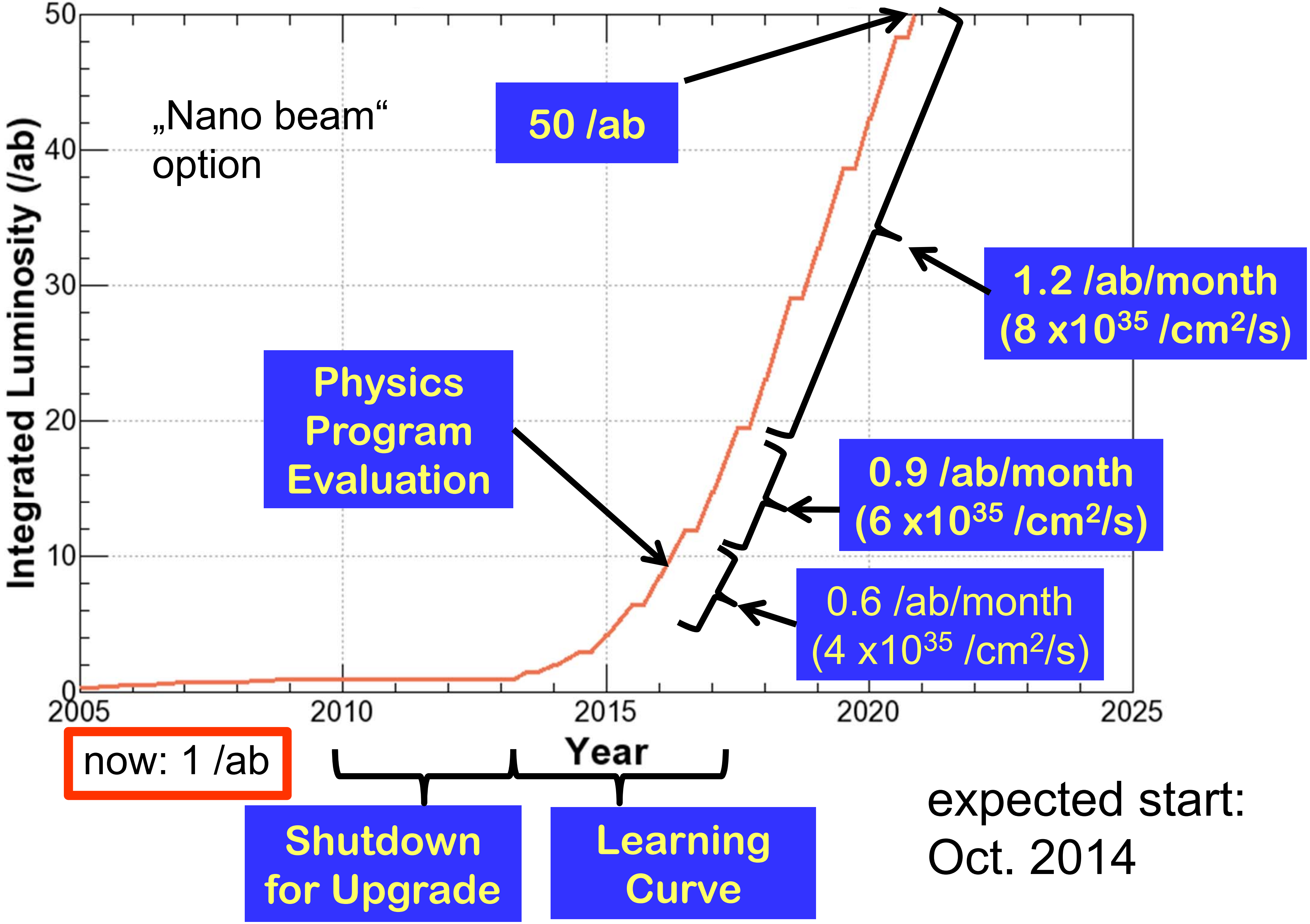
beam-beam parameter (or tune shift)

$$\xi_{y,+} = \frac{r_e}{2\pi\gamma_+}\left(\frac{\beta_y N_-}{\sigma_x\left(\sigma_x + \sigma_y\right)}\right) R_{\xi_y}$$

$$\boxed{\sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y}}}$$

beam emittance (need damping ring(s))

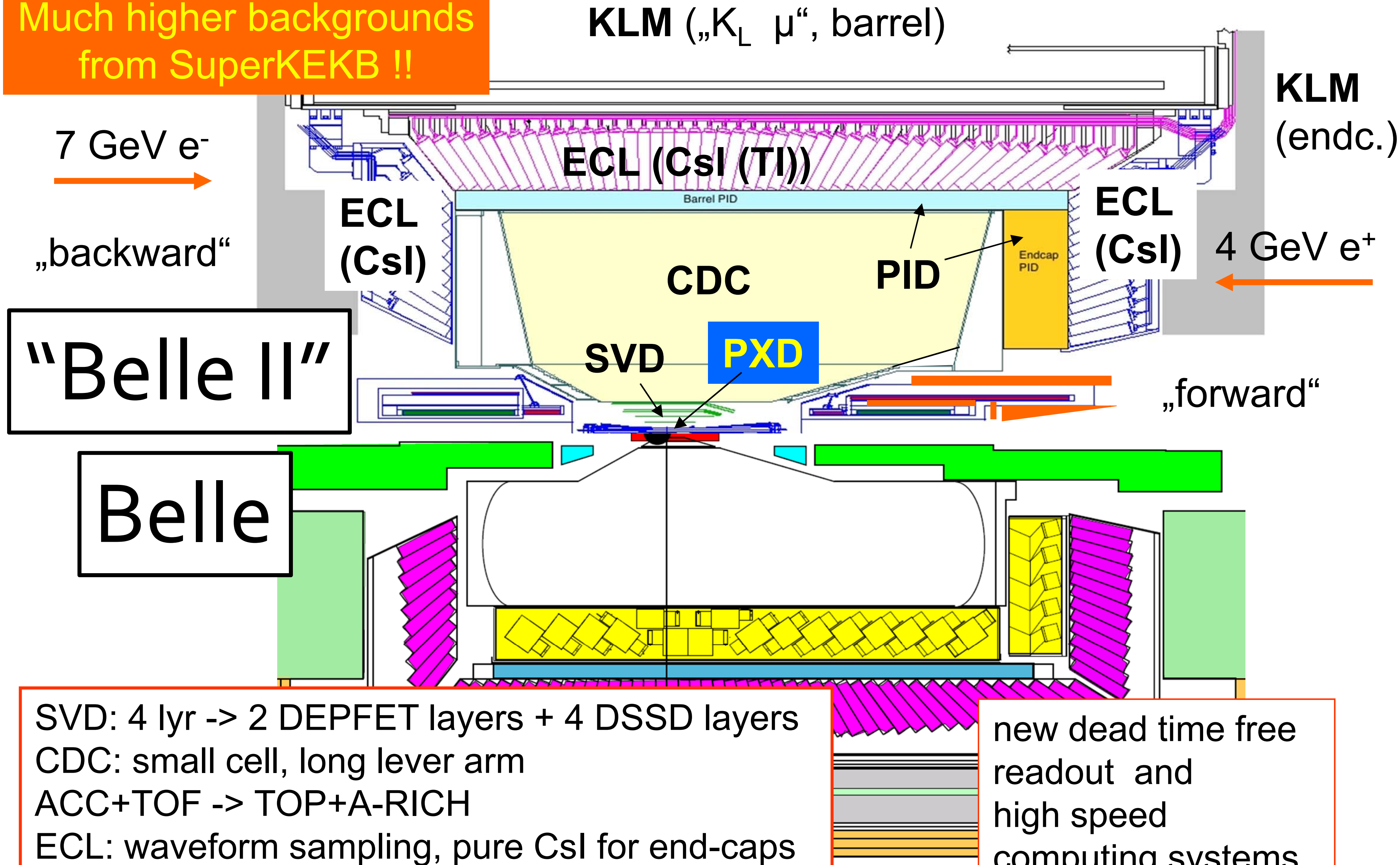
Expected Luminosity Development



expected start:
Oct. 2014

Detector for SuperKEKB: Belle II

Much higher backgrounds from SuperKEKB !!



SVD: 4 lyr -> 2 DEPFET layers + 4 DSSD layers
CDC: small cell, long lever arm
ACC+TOF -> TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC -> Scintillator +SiPM (end-caps)

new dead time free readout and high speed computing systems

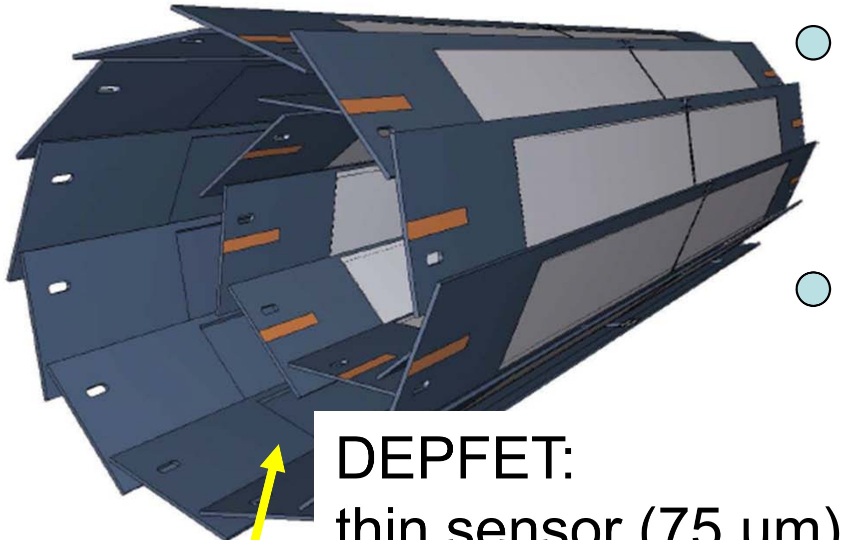
Silicon Tracking System @ Belle II

SuperKEKB: Nano beam option, 1 cm radius of beam pipe

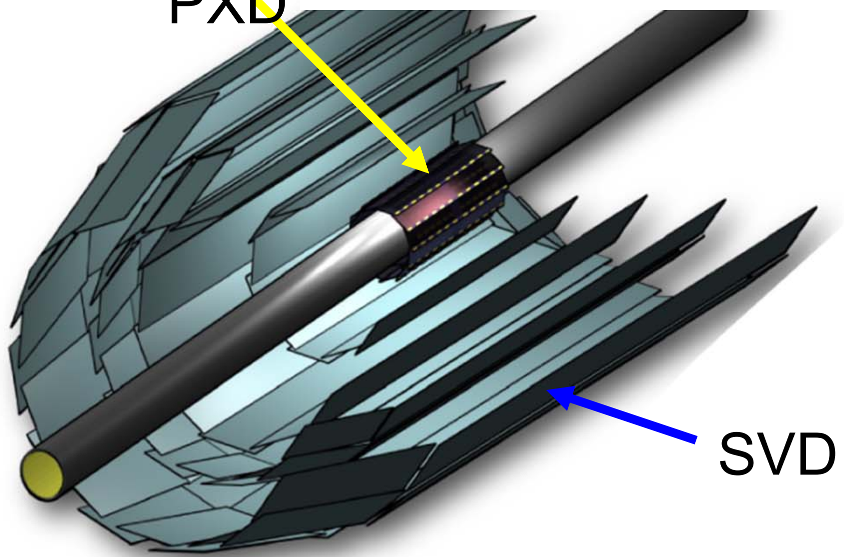
„PXD“

- 2 layer Si pixel detector (DEPFET technology)
  (R = 1.4, 2.2 cm) monolithic sensor
  thickness 75 µm (!), pixel size ~50 x 50 µm²

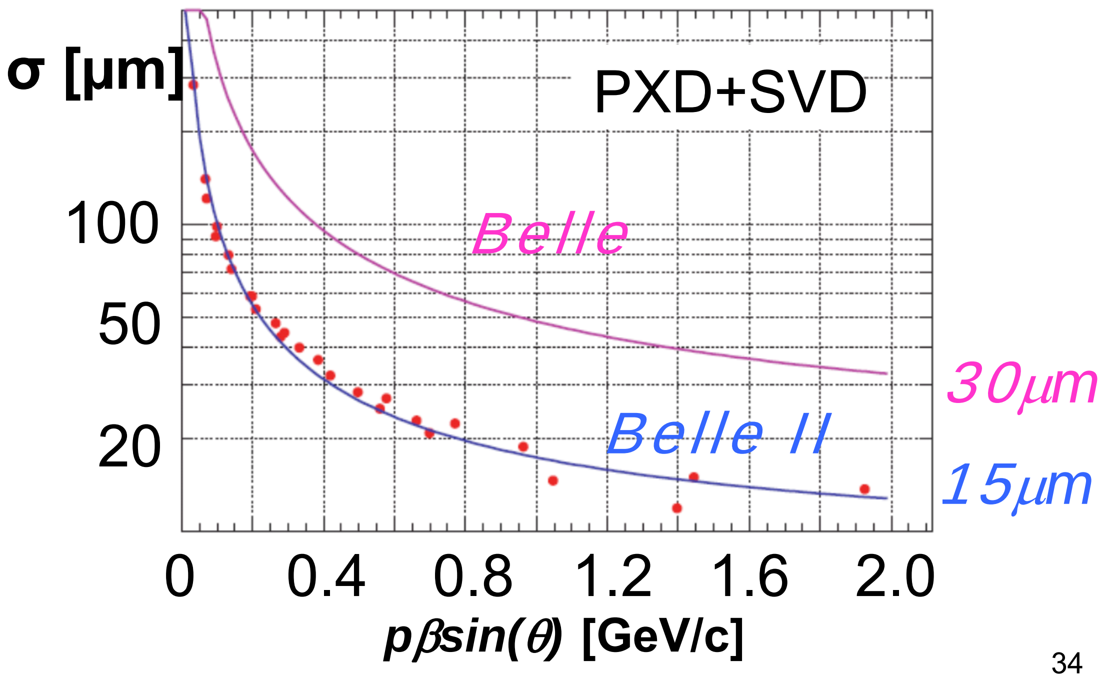
- 4 layer Si strip detector (DSSD) ← „SVD“
  (R = 3.8, 8.0, 11.5, 14.0 cm)



DEPFET:
thin sensor (75 µm)
unique worldwide



Significant improvement in z-vertex resolution



DEPFET Principle

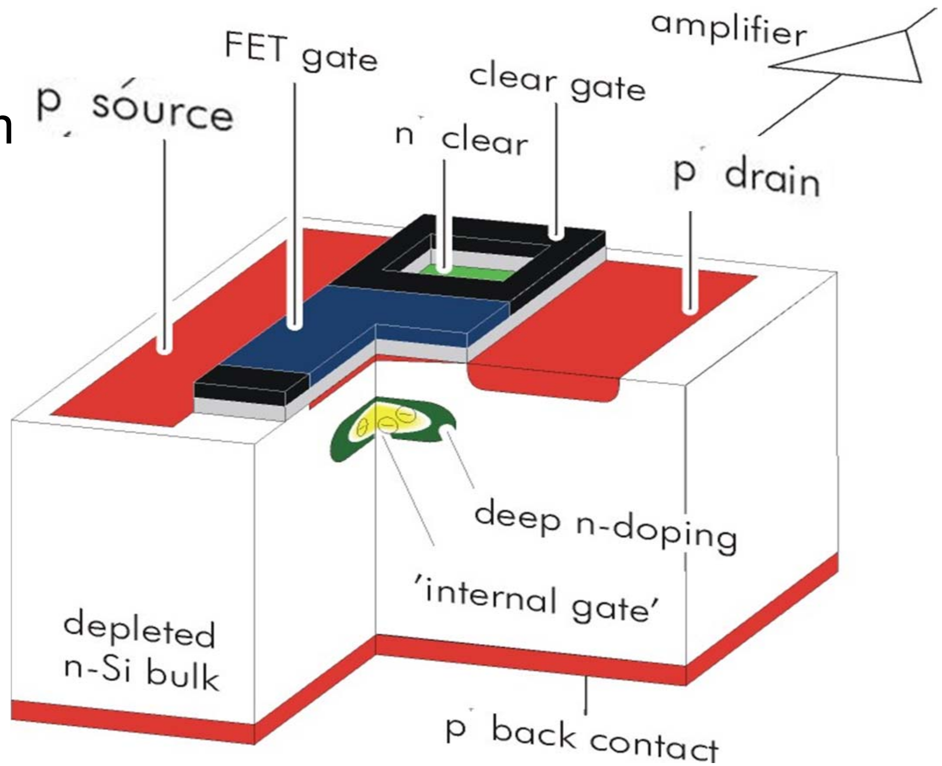
p-channel FET on a completely depleted bulk invented at MPI, produced at HLL

A deep n-implant creates a potential minimum for electrons under the gate ("internal gate")

Signal electrons accumulate in the internal gate and modulate the transistor current (g_q ~ 400 pA/e^-)

Accumulated charge can be removed by a clear contact ("reset")

Depleted p-channel FET



Fully depleted: → large signal, fast signal collection

Low capacitance, internal amplification → low noise

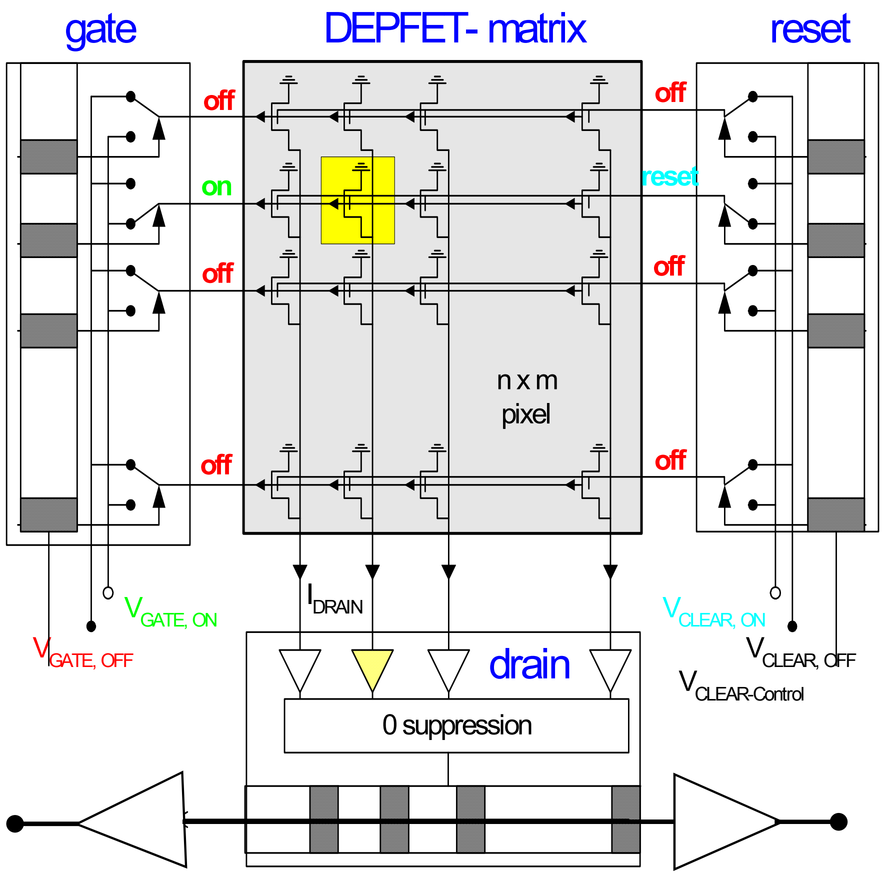
Transistor on only during readout: → low power

Array of DEPFETs

Row wise read-out

("rolling shutter mode")

- select row with external gate
  read current,
  clear internal gate,
  read current again
  → the difference is the signal



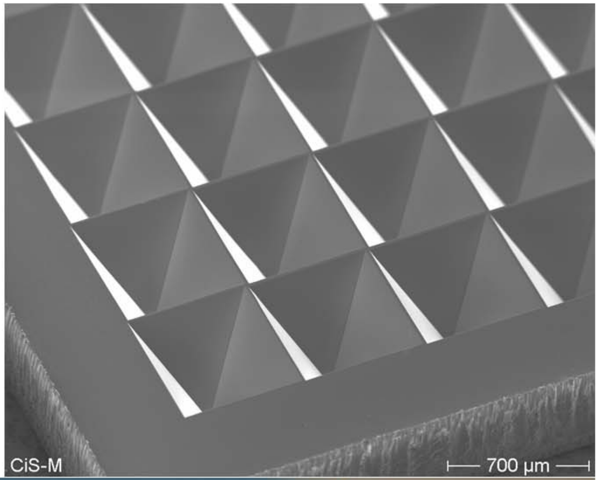
- readout time of entire PXD in 20 µs

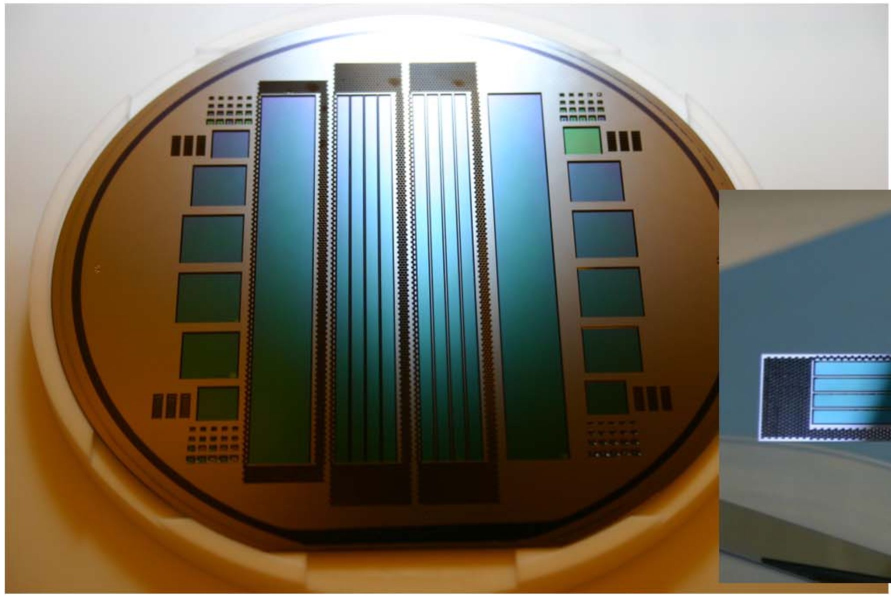
- three different auxiliary ASICs needed
  - → Switcher
  - → DCD (drain current digitizer)
  - → DHP (data handling processor)

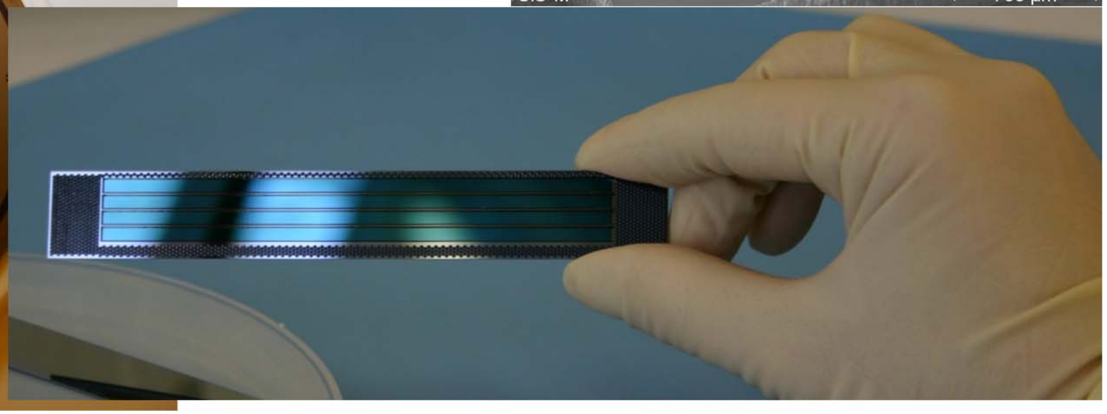
Thinning Technology

1. implant backside on sensor wafer
2. bond sensor wafer to handle wafer
3. thin sensor side to desired thickness
4. process DEPFETs on top
5. structure resist, etch backside up to oxide/implant

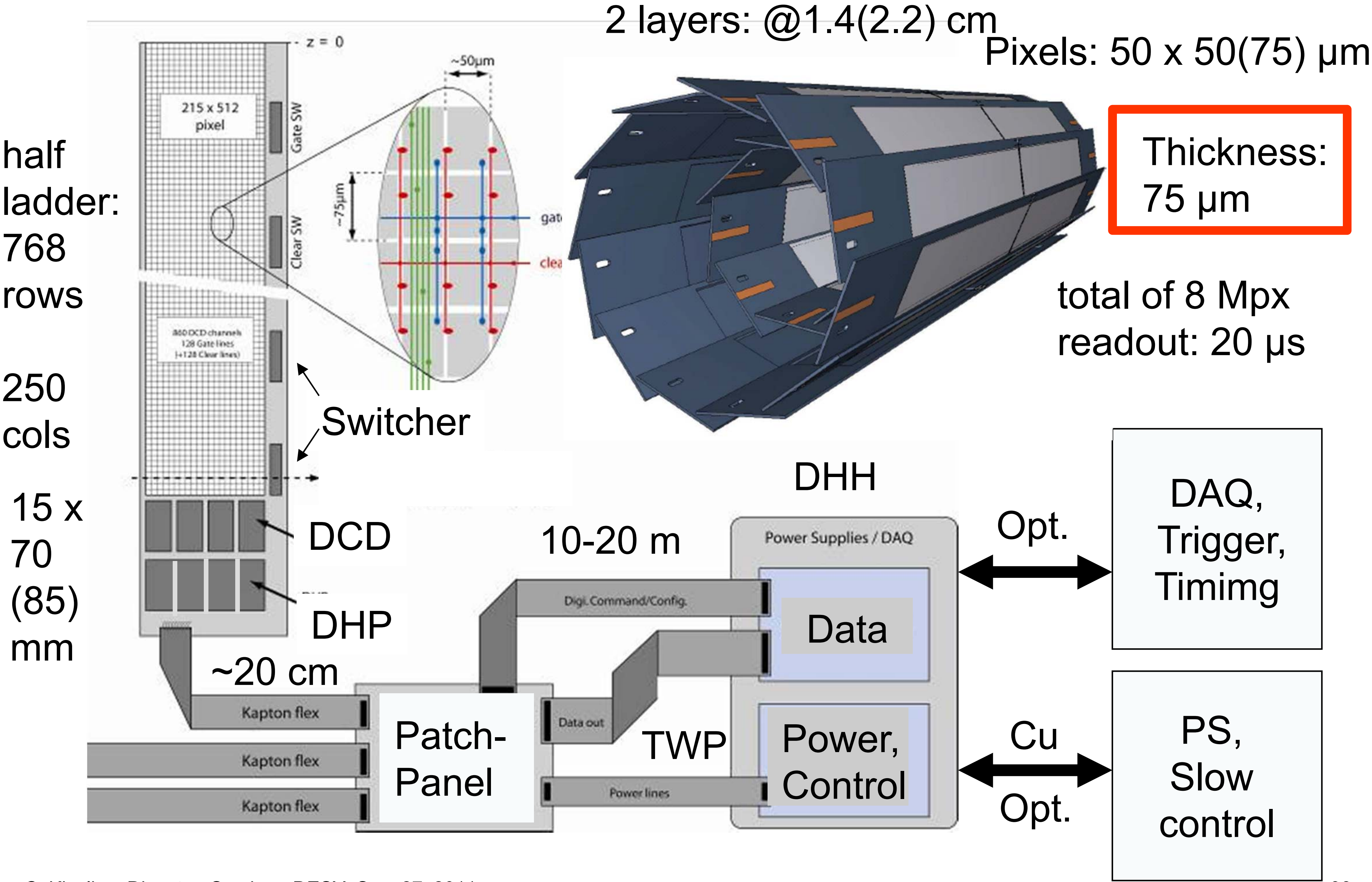
- Sensor wafer bonded on “handle” wafer.
- Rigid frame for handling and mechanical stiffness
- 50 μm thickness produced
- Samples of 10x1.3 cm^2 & frame of 1 & 2 mm width
- Electrical properties tested successfully (diodes)







PXD Project - Layout



Full-Size Mockup of the PXD

DEPFET-Collab. @ Belle II

Original Collaboration: DEPFET pixel detector @ ILC (since 2002)
now: Unite efforts to deliver a REAL PXD by end of 2014 for Belle II

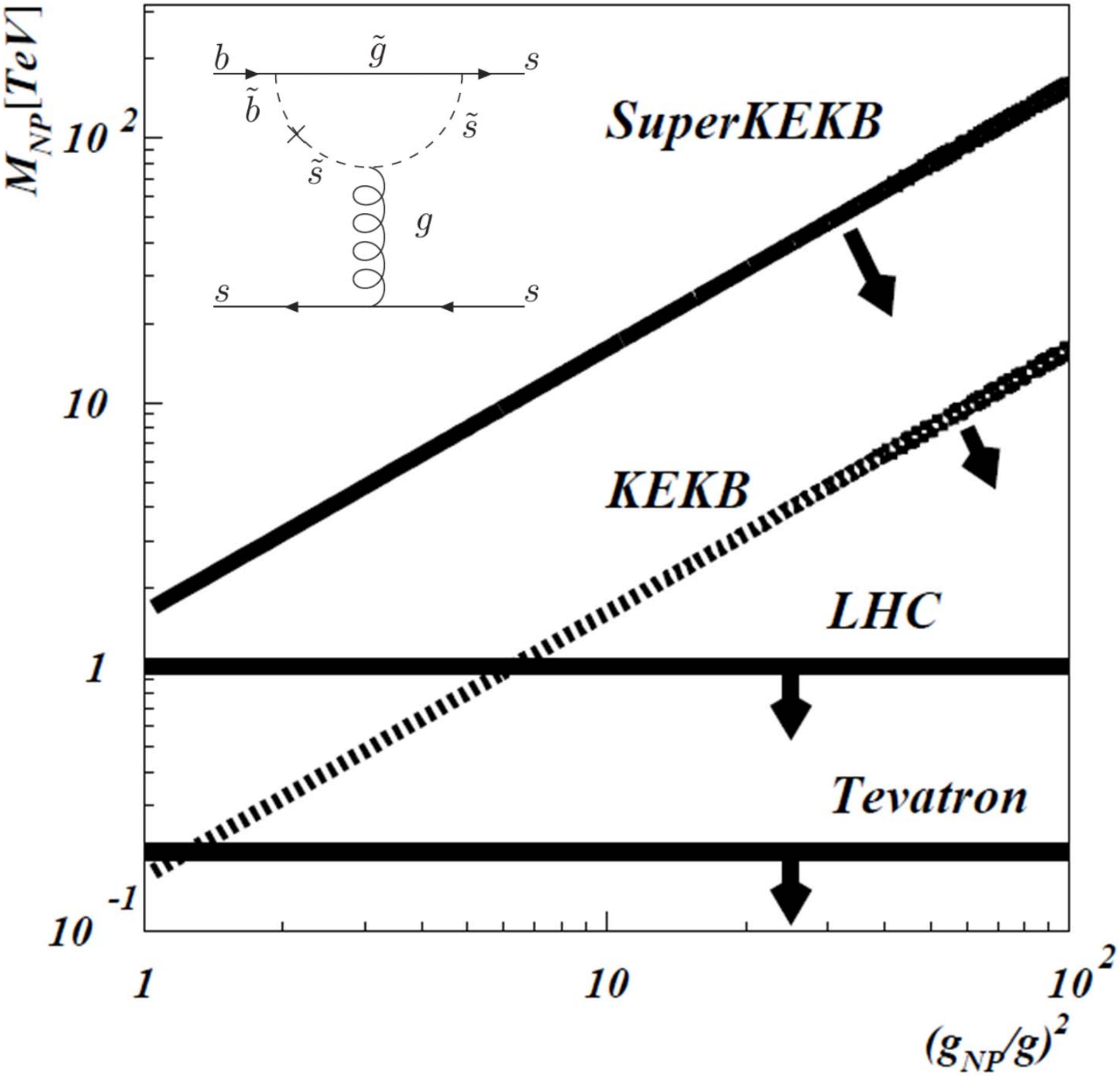
University of Barcelona, Spain
CNM, Barcelona, Spain
IHEP Beijing, China
DESY Hamburg (C. Niebuhr)
University of Bonn (N. Wermes, H. Krüger)
University of Heidelberg (P. Fischer, I. Peric)
University of Giessen (W. Kühn, S. Lange)
University of Göttingen (A. Frey)
University of Karlsruhe (T. Müller, M. Feindt)
IFJ PAN, Krakow, Poland
Ludw.-Max.-University, Munich (J. Schieck)
Max-Planck-Institute for Physics, Munich
Technical University, Munich (S. Paul)
Charles University, Prague, Czech Republic
IFCA Santander, Spain
IFIC, Valencia, Spain

DEPFET@Belle II

Management:

- Project Leader
  C. Kiesling (MPI)
- Technical Coord.
  H.-G. Moser (MPI)
- IB- Board
  Chair: Z. Dolezal (Prag)
- Integration Coordinator
  Shuji Tanaka (KEK)

Sensitivity to New Physics



Super Flavor Factories:

Indirect discovery of New Physics In quantum loops via high precision measurements, searching for deviations from the SM

complementary to the LHC

LHCb vs Super Flavor Factories

+ LHCb

large samples (but low efficiencies)

exclusive decays

B_s oscillations

B_c , bottom baryons

$B^0_{s,d} \to \mu\mu$

$B \to J/\psi K_S$

$D^0 \to K^+\pi^-, K^+K^-$

+ Super B Factories

all final states measurable,
esp. those with photons, neutrinos

+ inclusive decays

rare decays, such as

$B^+ \to l^+\nu, B^+ \to K^+\nu\overline{\nu}$

$b \to s\gamma, b \to sl^+l^-$

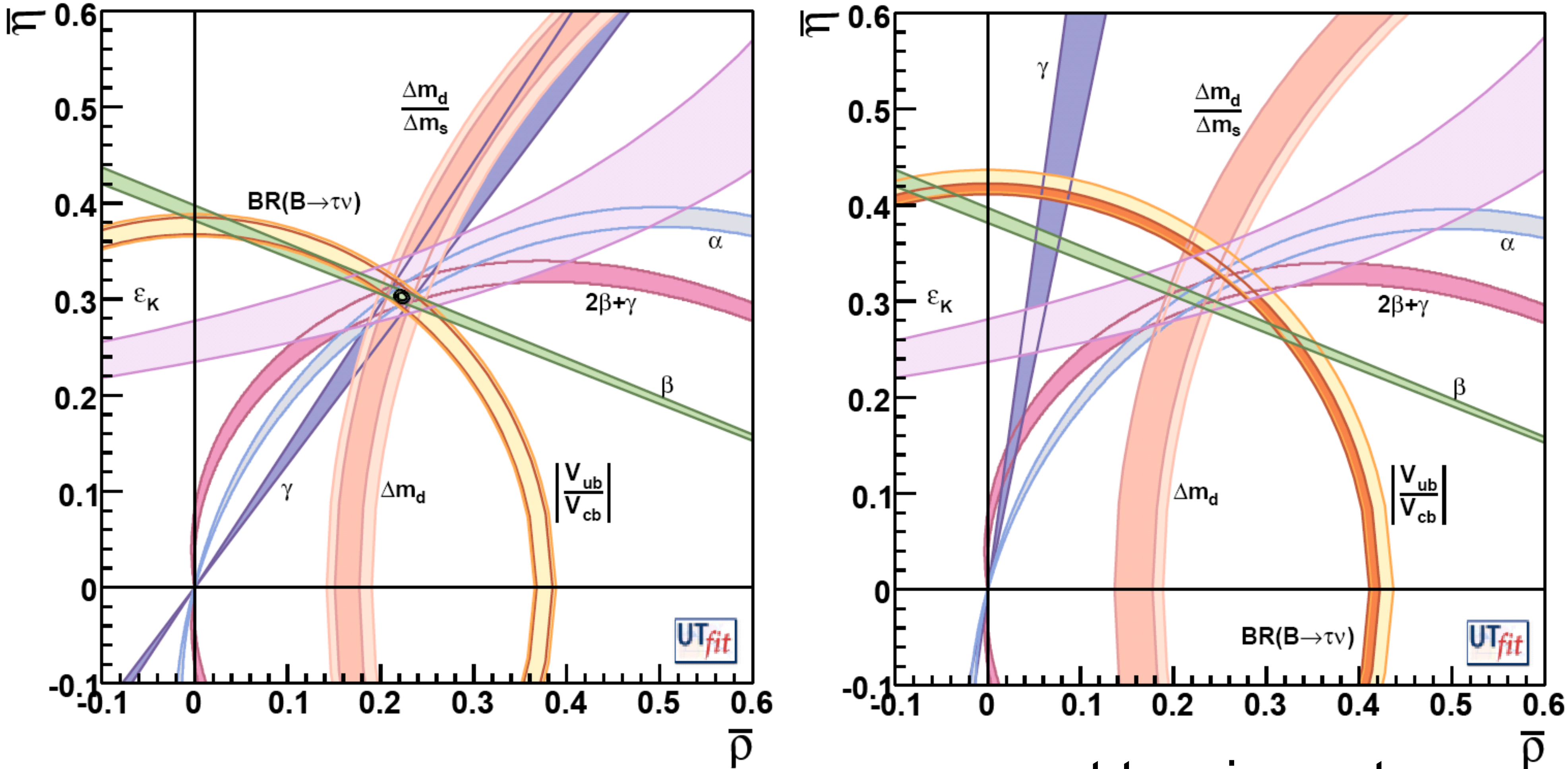
$B \to J/\psi\phi, \pi\pi, \rho\pi, \rho\rho, \pi\pi\pi$

$D^0\overline{D}^0$ mixing

LHCb and Super B Fact. will run concurrently. → largely complementary

The Unitarity Triangle in the year 2021

$$\int \mathcal{L} dt = 50\ \mathrm{ab}^{-1}$$



SM correct — present tensions stay …

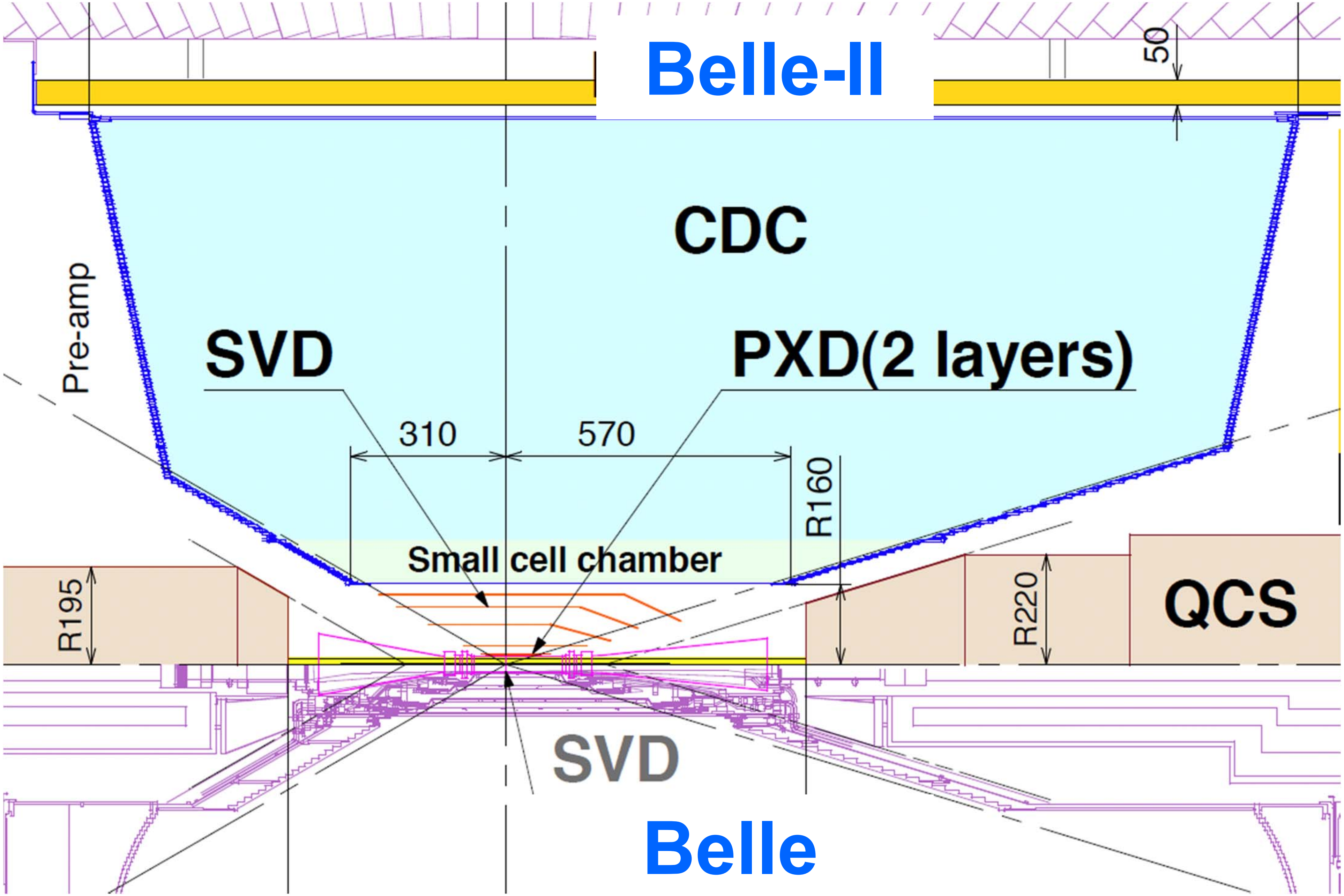
a nightmare … — … the dream !

Conclusions

- „New Physics“ needed to explain the observed matter-antimatter asymmetry → new sources of CP violation
- Present mesurements of the fundamental (?) parameters of the CKM matrix show some „tensions“
- A new generation of B factories with O(50) times the present luminosity planned to search for NP, complementary to the LHC
- At KEK (Japan), the SuperKEKB project is well under way: Strong contribution from Europe (pixel vertex detector)
- Plan to have machine and detector ready for data taking in 2015
- Excellent prospects for high precision flavor physics during this decade

Backup

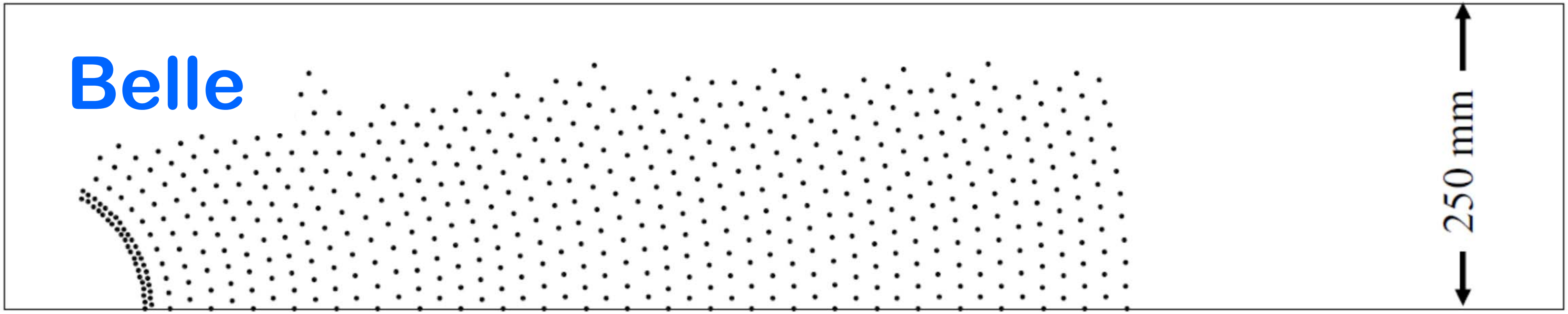
New Tracking System for Belle-II



New Central Drift Chamber (CDC)

	Belle	Belle-II
Radius of inner boundary (mm)	77	160
Radius of outer boundary (mm)	880	1096
Radius of inner most sense wire (mm)	88	168
Radius of outer most sense wire (mm)	863	1082
Number of layers	50	58
Number of total sense wires	8400	15104
Effective radius of dE/dx measurement (mm)	752	928
Gas	He-C_2H_6	He-C_2H_6
Diameter of sense wire (μm)	30	30

New Central Drift Chamber (CDC)

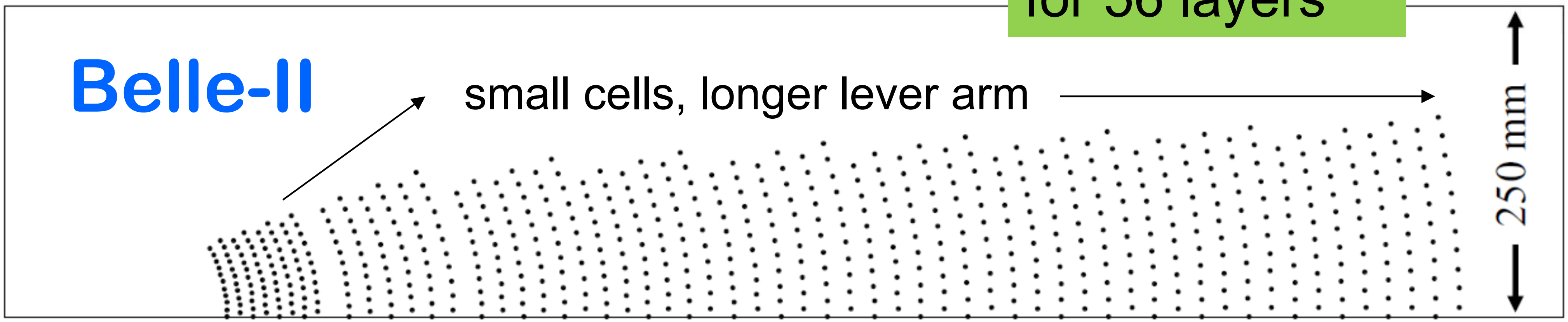


normal cell: 13.3 x 16 mm^2

small cell: 5.4 x 5.0 mm^2

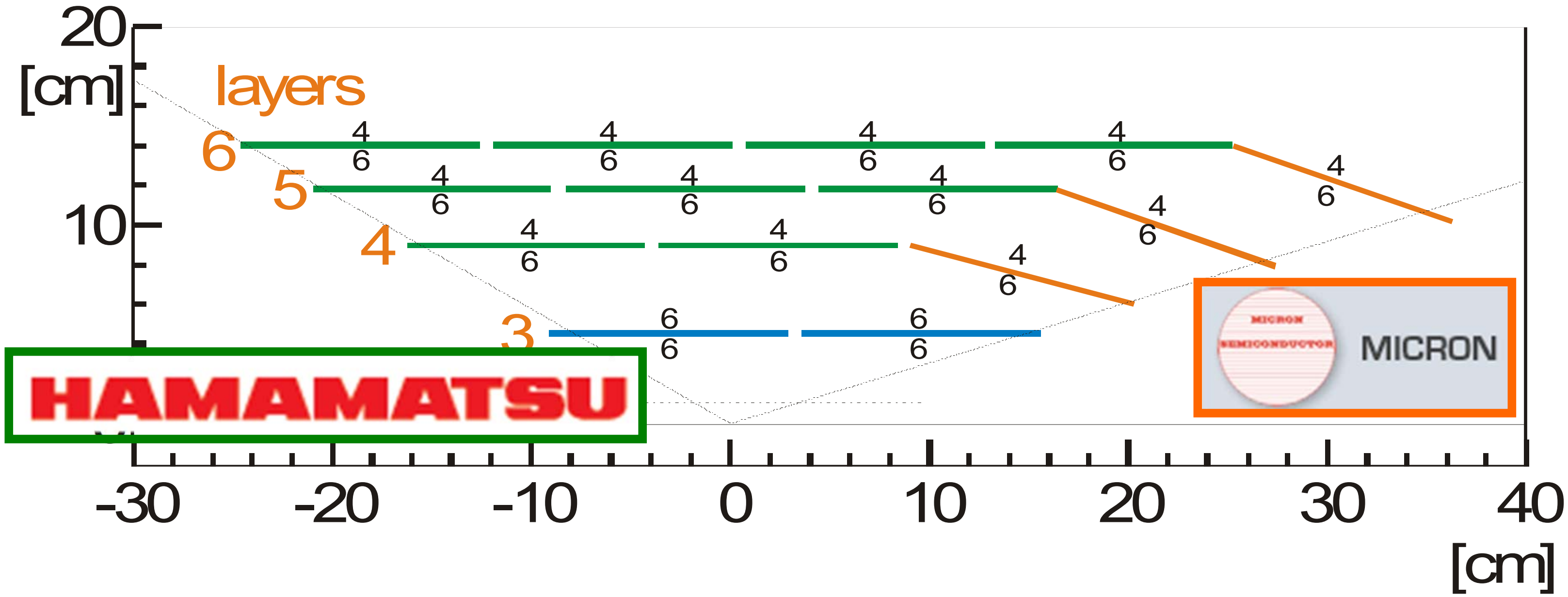
1200 mm

dE/dx: 4.8%
for 56 layers



z-coordinate via standard stereo wire arrangement, charge division planned

New Si System for Belle-II : SuperSVD



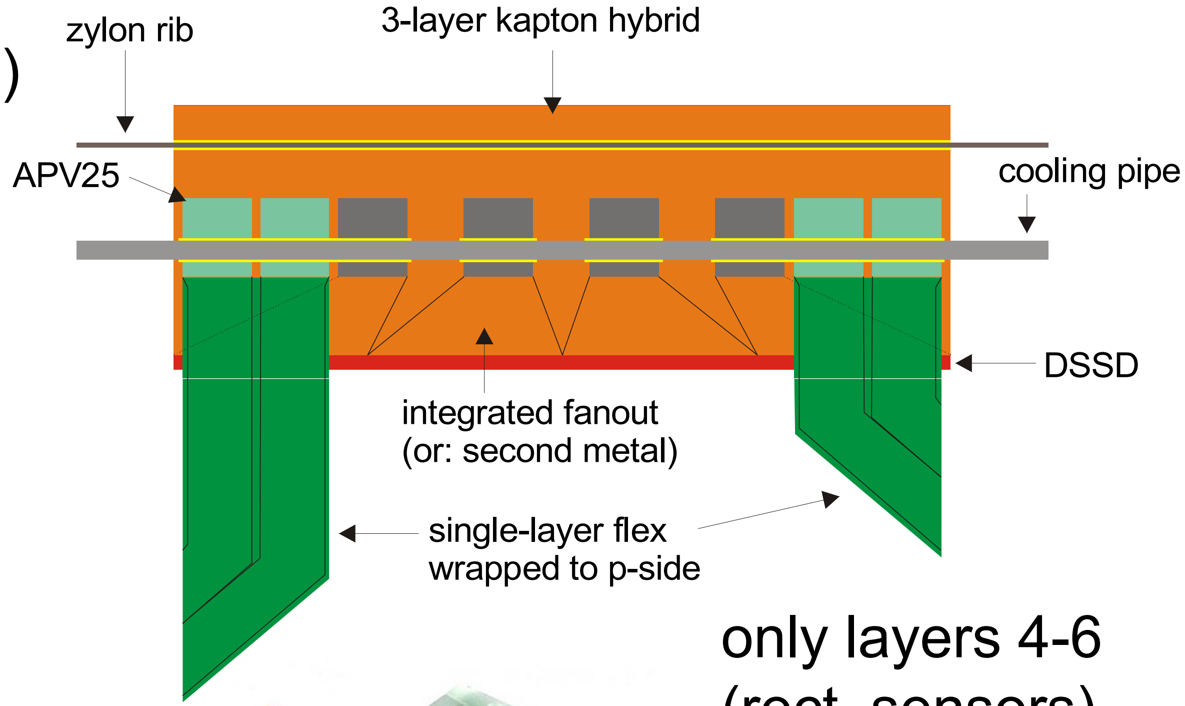
300 μm DSSD

Pitch:
50/160 μm (rect.)
50-75/160 μm (wedge)

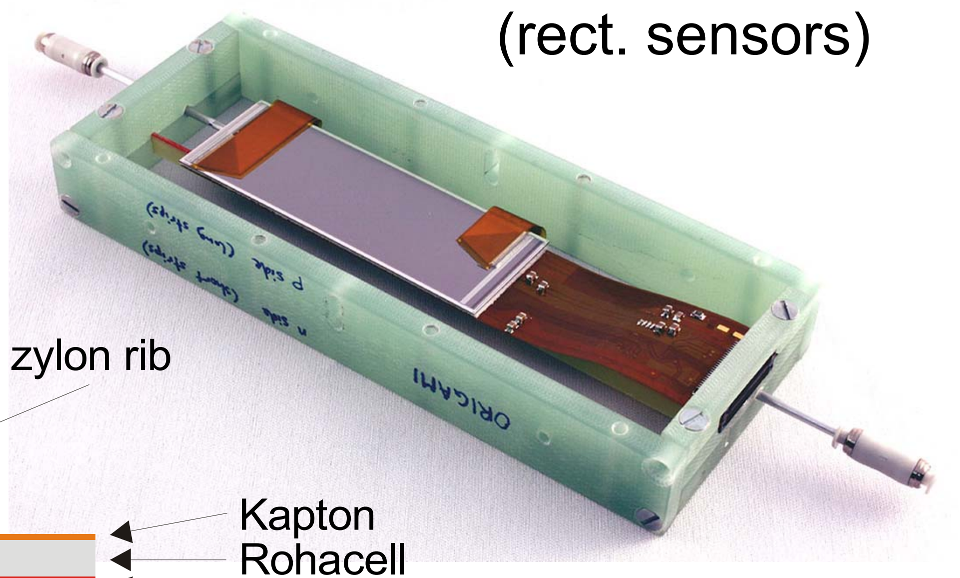
Layer	# Ladders	Rect. Sensors [50μm]	Rect. Sensors [75μm]	Wedge Sensors	APVs
6	17	0	68	17	850
5	14	0	42	14	560
4	10	0	20	10	300
3	8	16	0	0	192
Sum:	**49**	**16**	**130**	**41**	**1902**

Chip on Sensor: The Origami Concept (SVD)

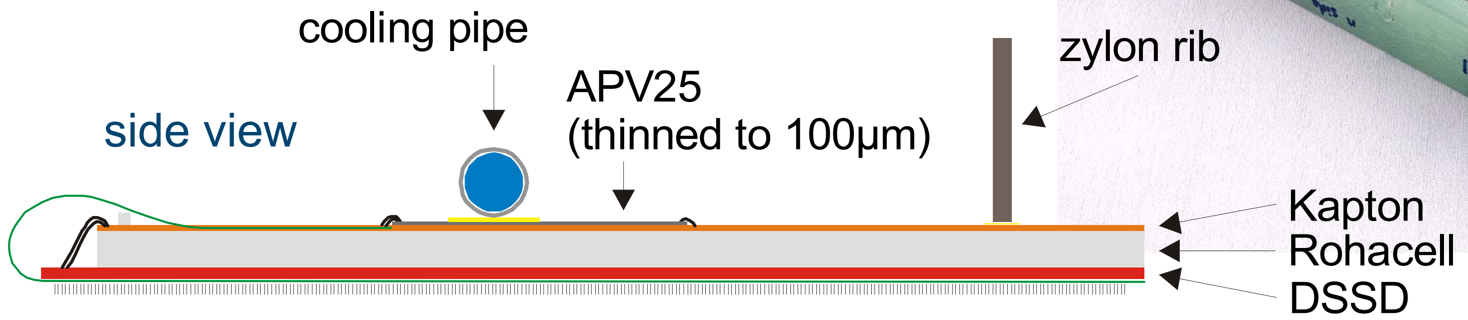
- Thinned readout chips (APV25) on sensor
- Strips of bottom side are connected by flex fanouts wrapped around the edge
- All readout chips are aligned → single cooling pipe
- Shortest possible connections → high signal-to-noise ratio



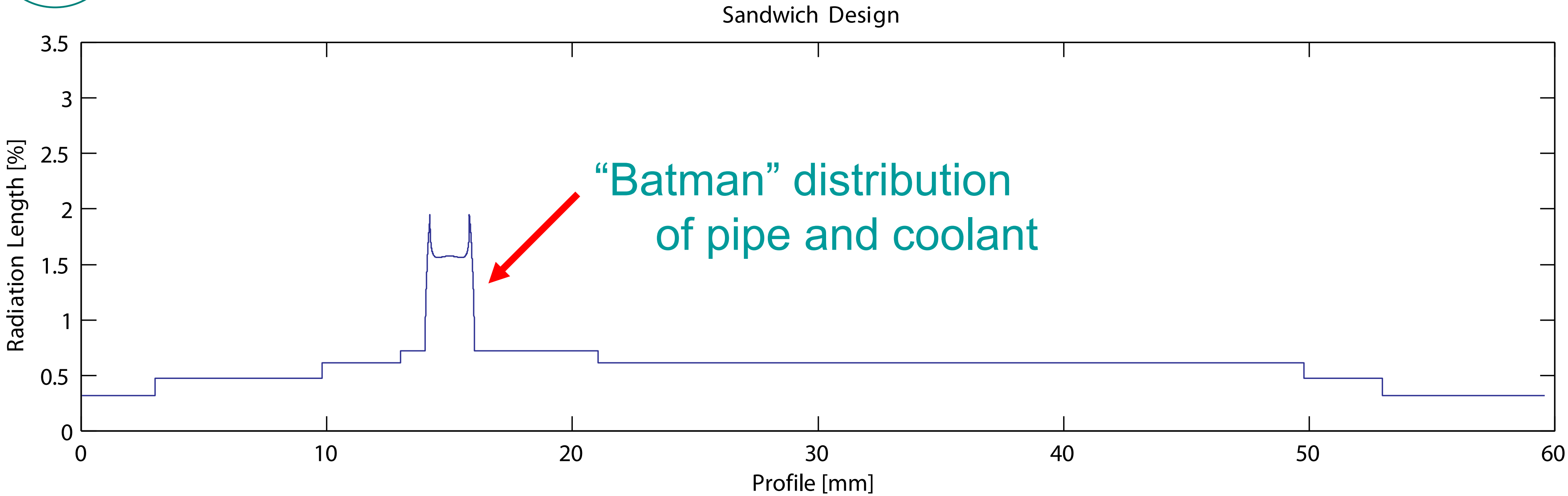
only layers 4-6
(rect. sensors)

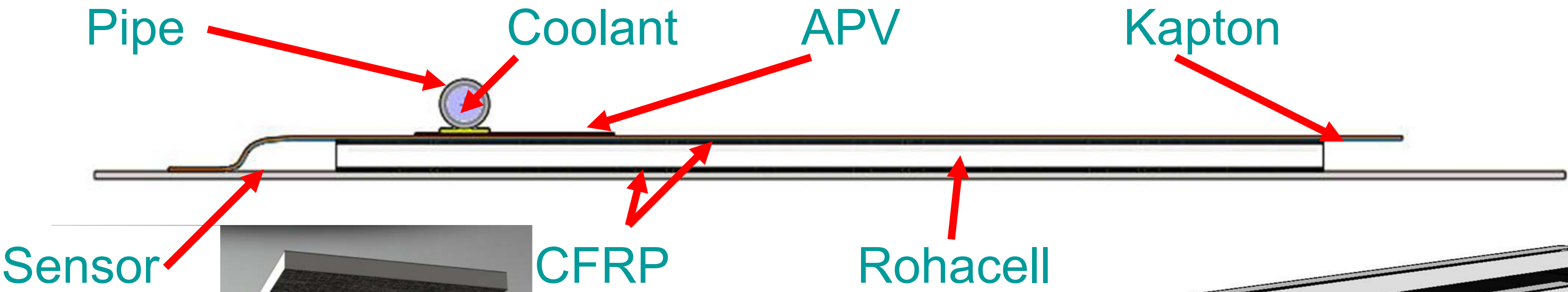


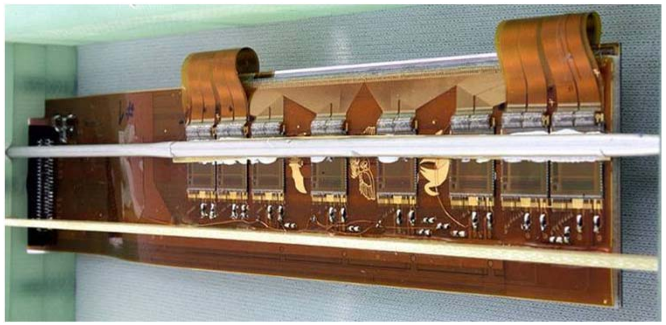
Total material budget: 0.6% X_0
(cf. 0.48% for conventional readout)

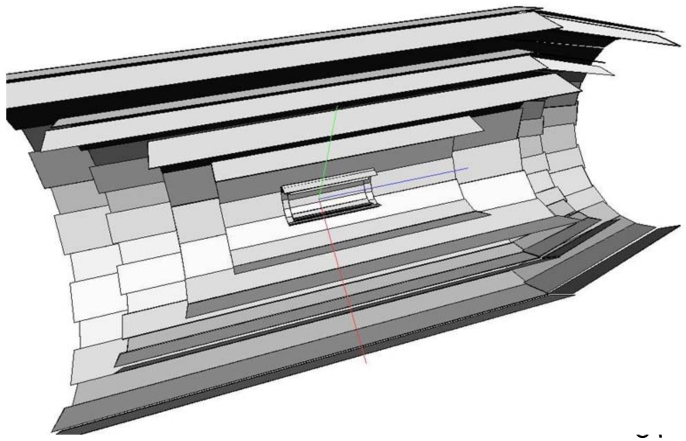


SVD Mechanics and Material Budget

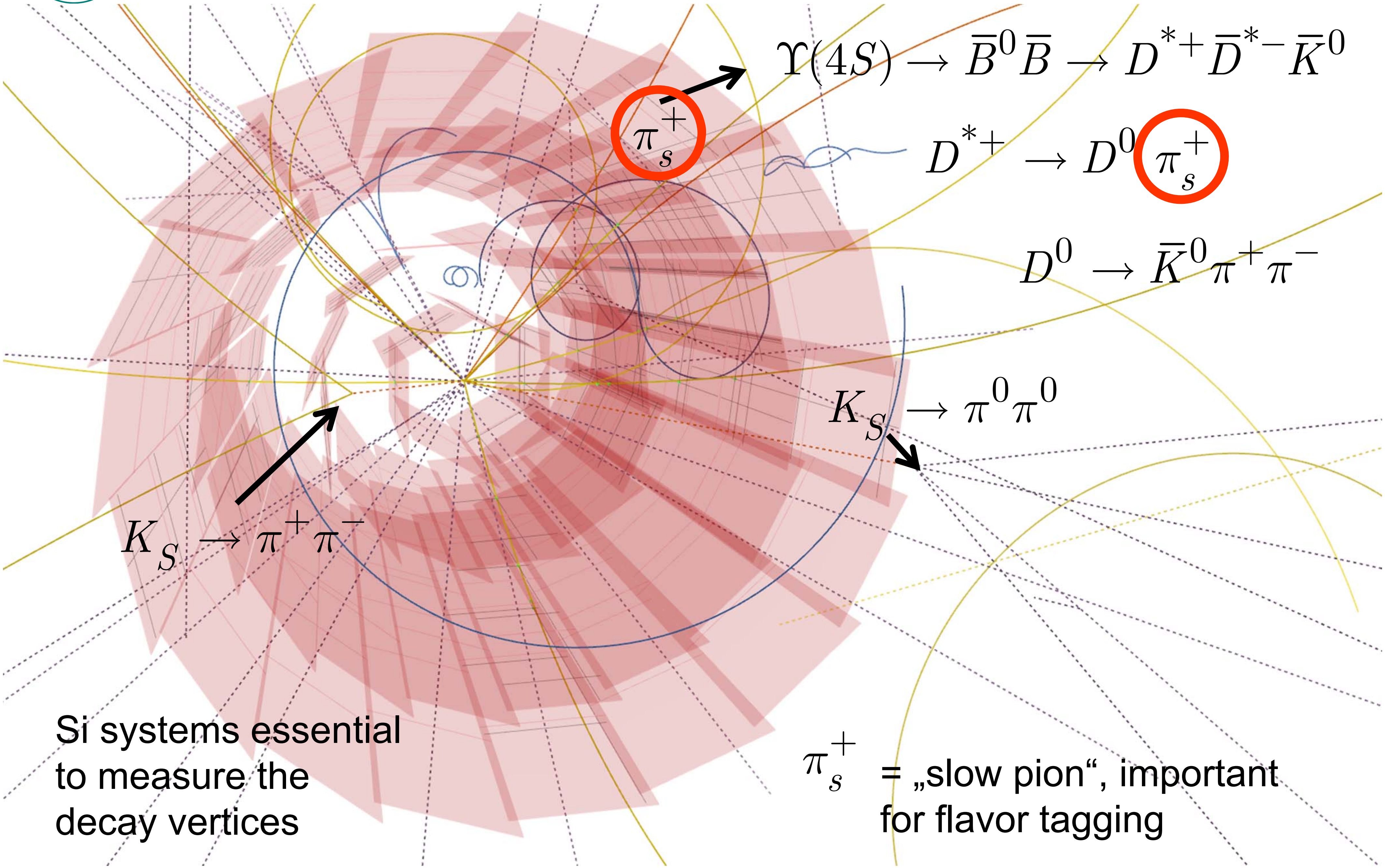








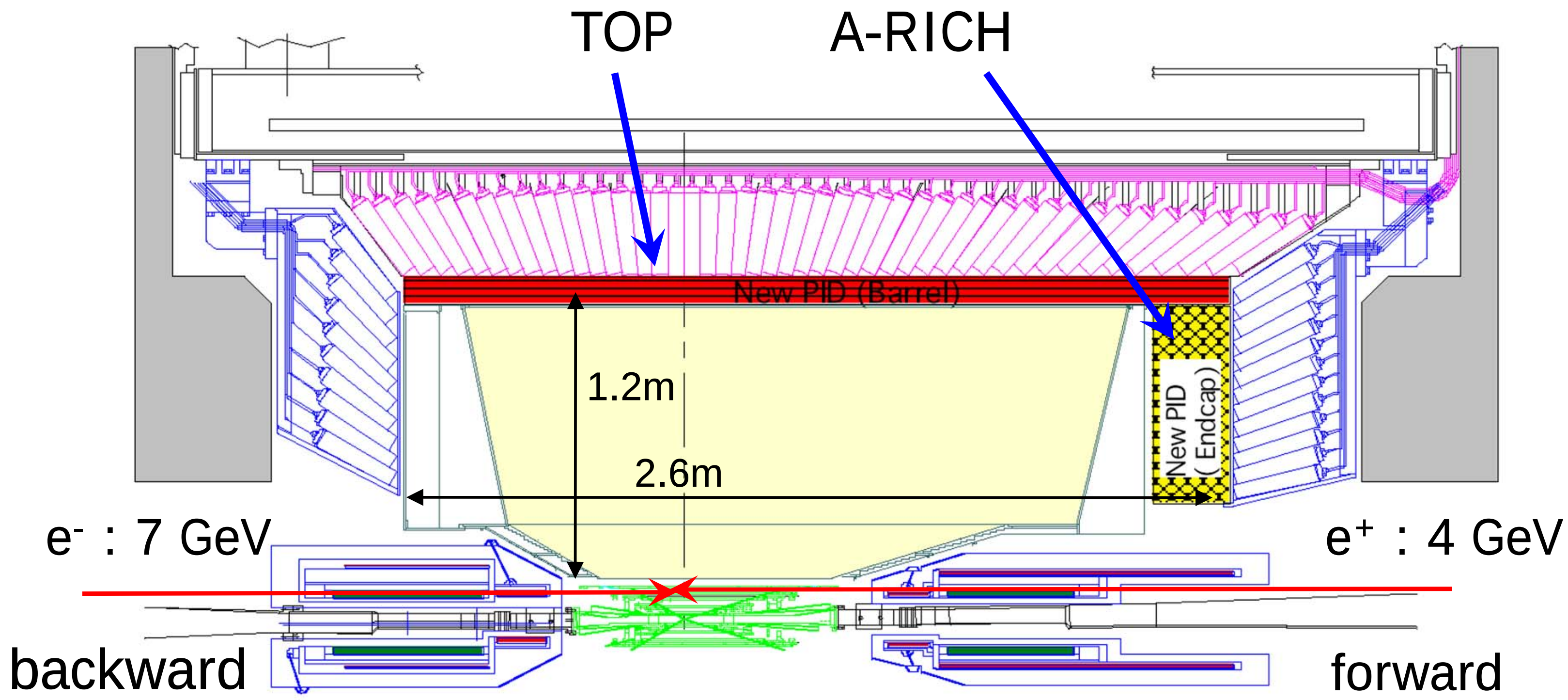
An Event in the Silicon Tracking System (Belle)



Si systems essential to measure the decay vertices

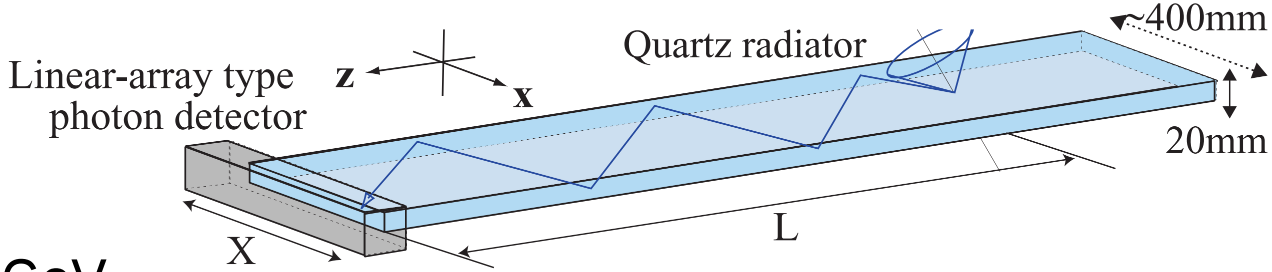
π_s^+ = „slow pion“, important for flavor tagging

Upgrade: Particle Identification



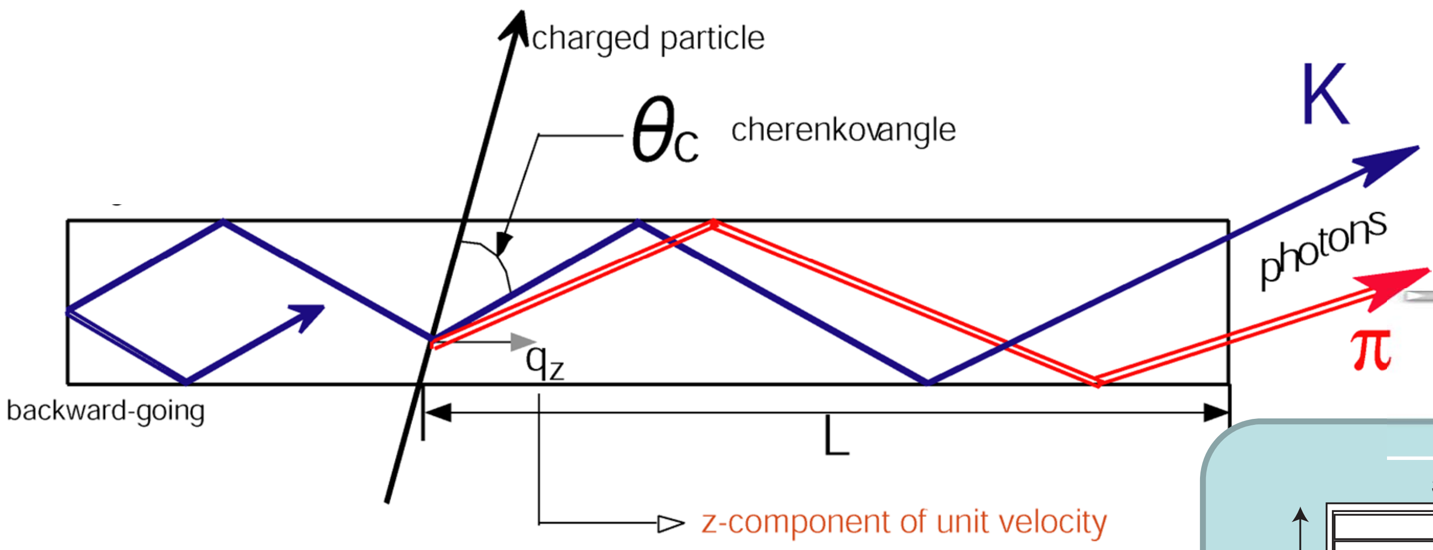
Goal:

3σ K/pi separation (barrel)
4σ K/pi separation up to 4 GeV (end caps)

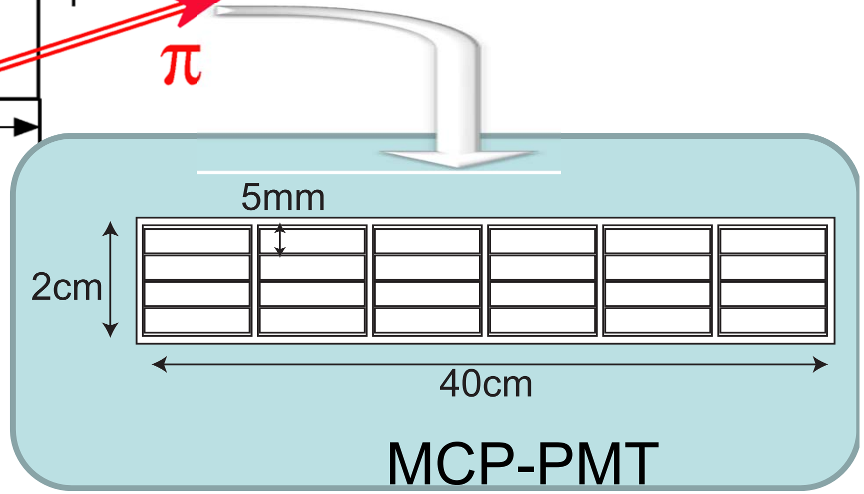


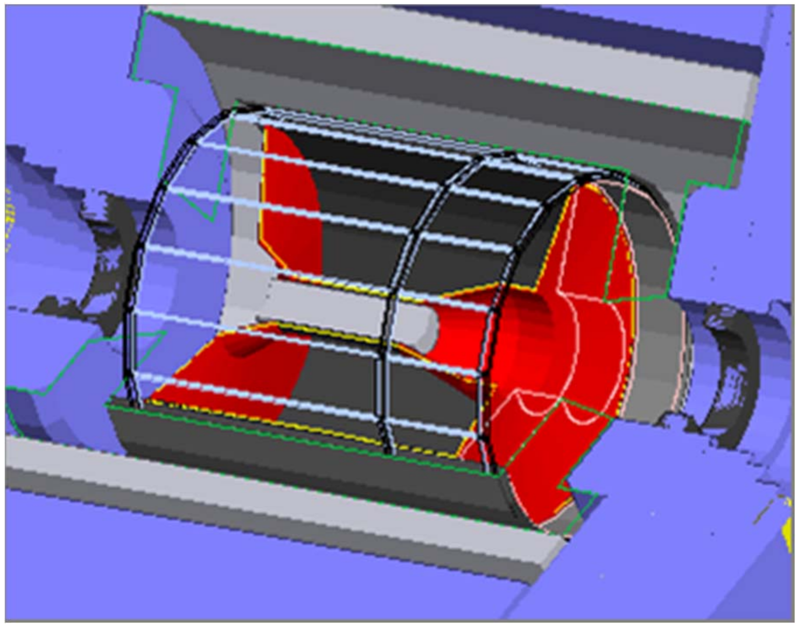
TOP: time of propagation

Baseline Design for Barrel PID (TOP)



TOP =
Time of Propagation





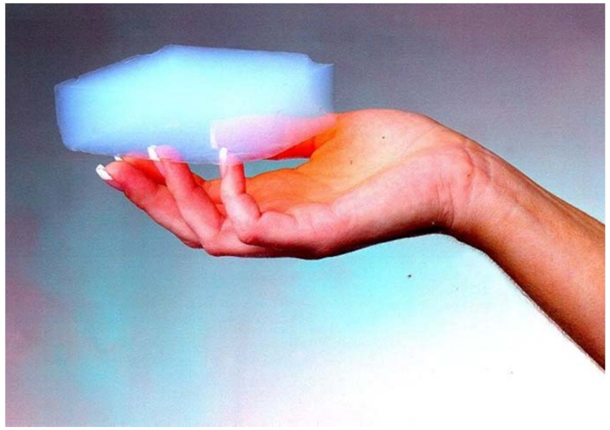
Ring imaging with :

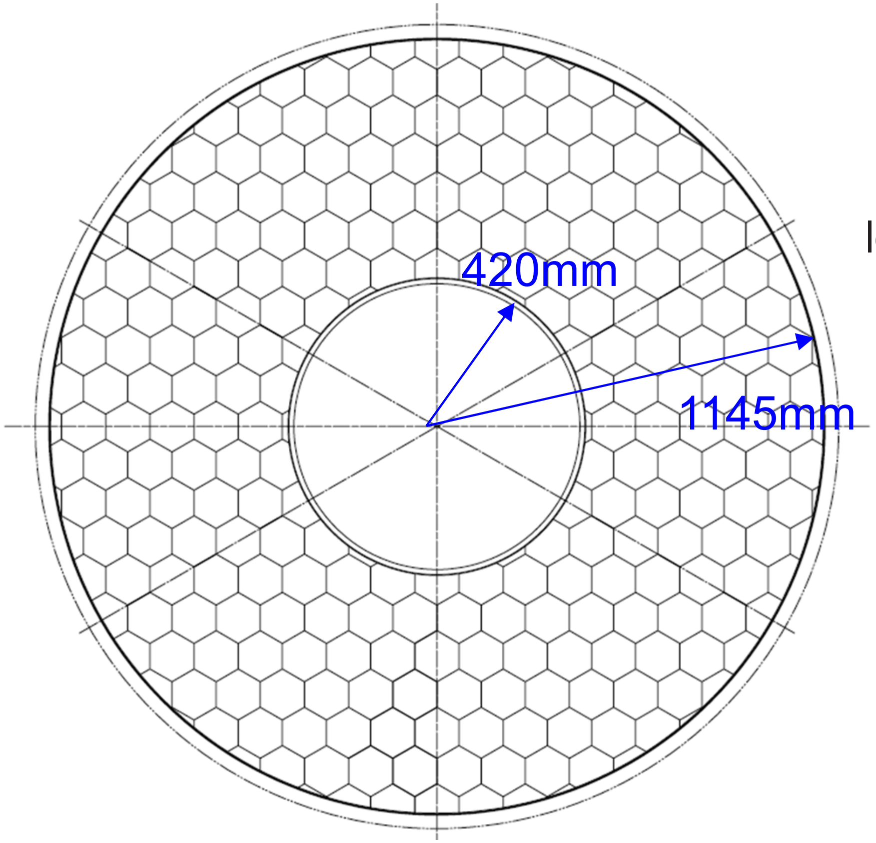
- One coordinate with a few mm precision
- Time-of-arrival

→ Excellent time resolution < ~40ps
required for single photon in 1.5T B field

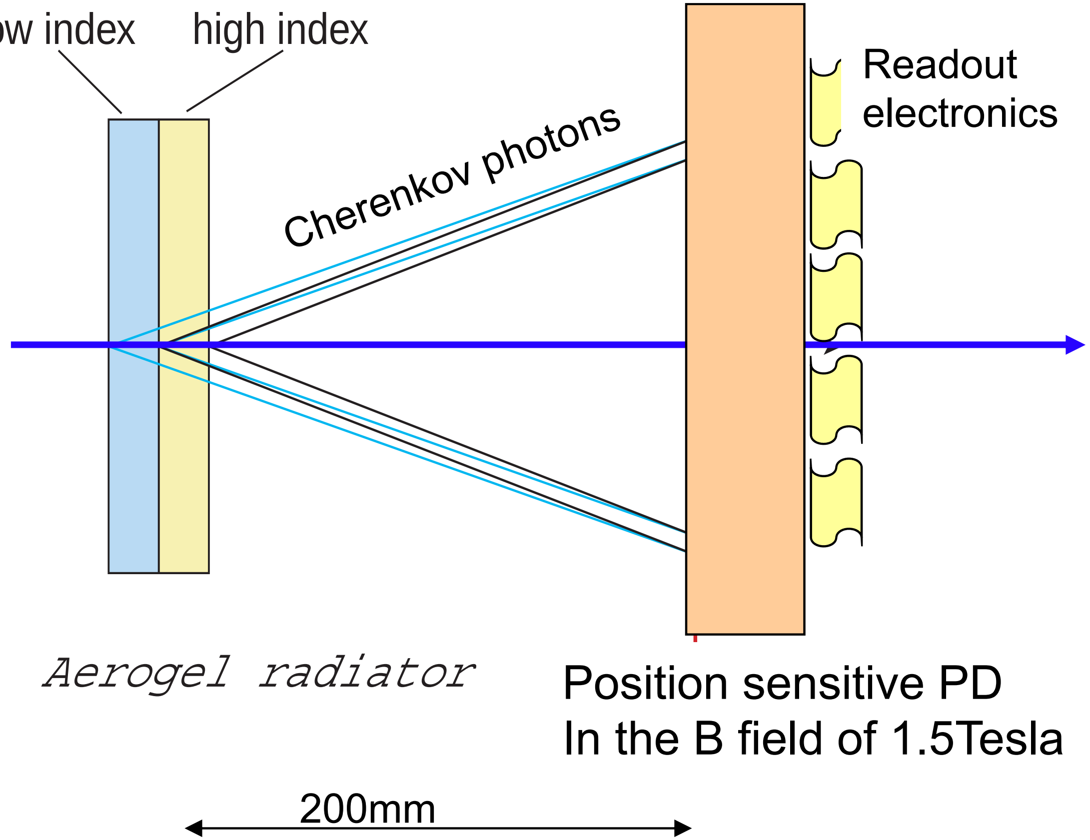
Baseline Design for Endcap PID (A-RICH)

Proximity focusing RICH with silica aerogel as Cherenkov radiator for new Belle forward PID

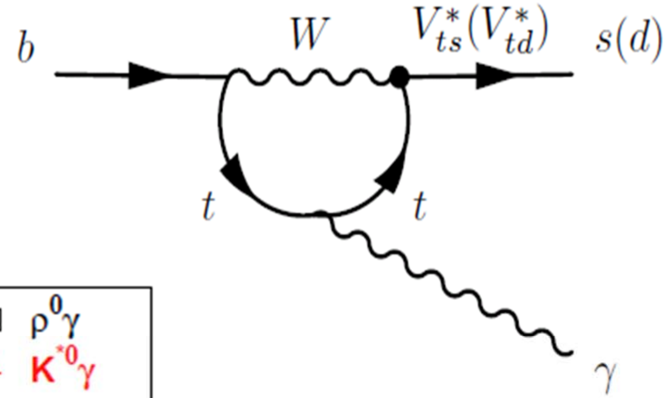




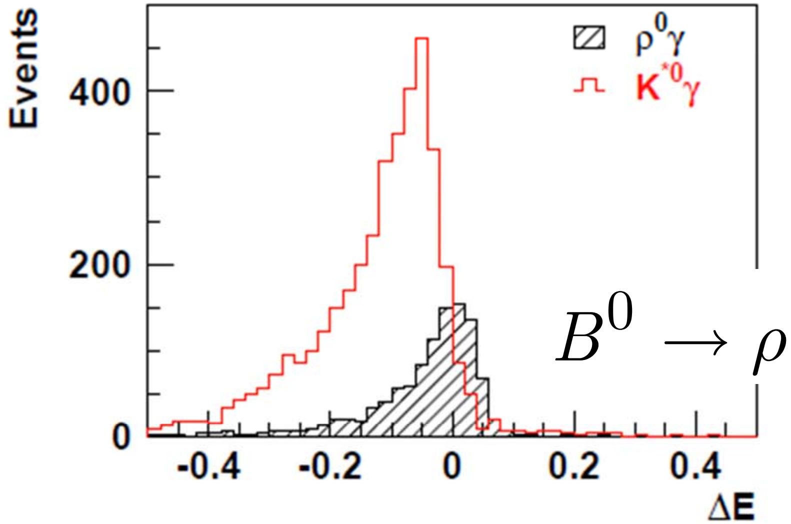
x-y view of forward end-cap



PID Improvement in Belle-II

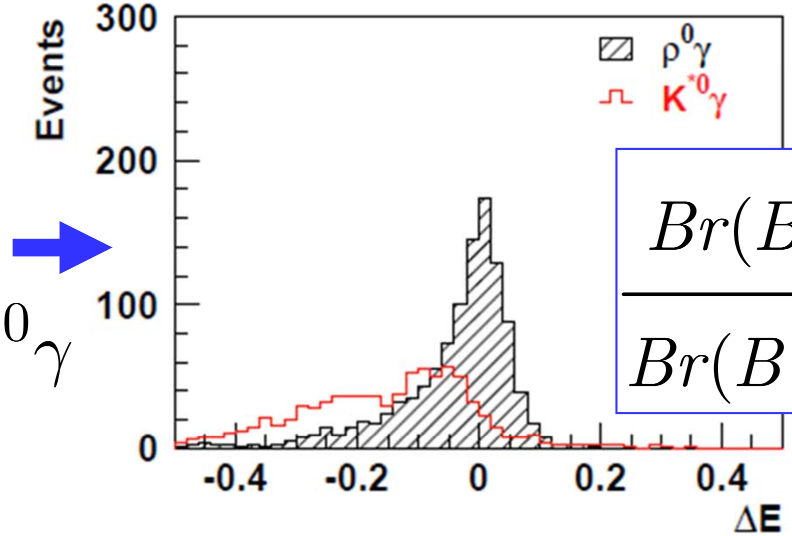


Present Belle PID



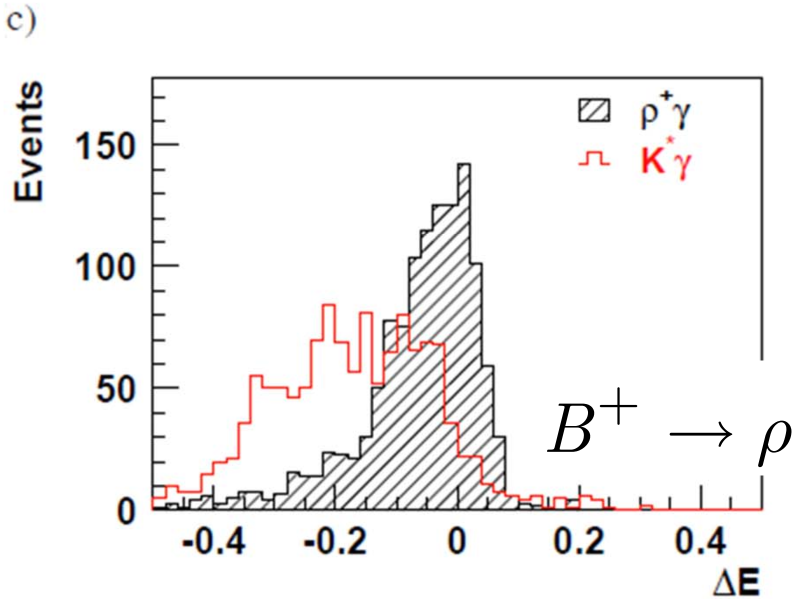
$$B^0 \to \rho^0 \gamma$$

Belle II PID

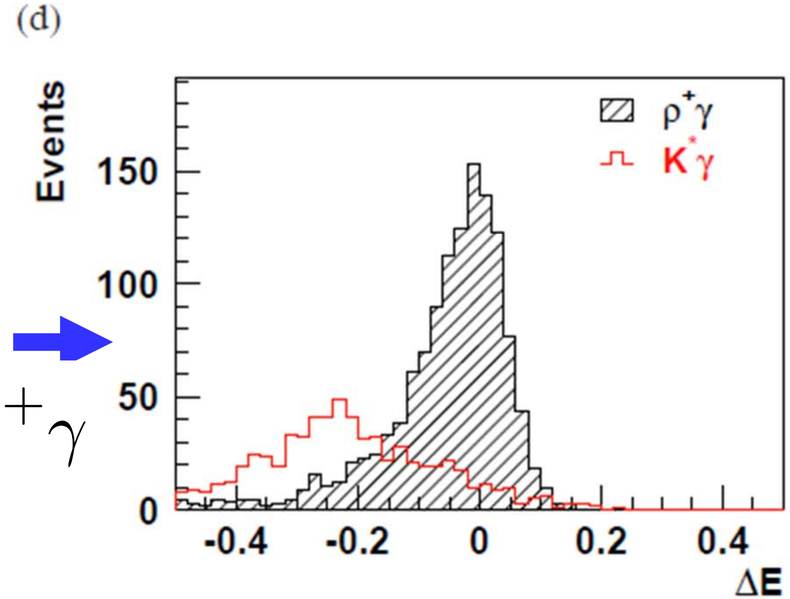


$$\frac{Br(B \to \rho\,\gamma)}{Br(B \to K^*\gamma)} \sim \left|\frac{V_{td}}{V_{ts}}\right|^2$$

$(\sim 1/40)$



$$B^+ \to \rho^+ \gamma$$



$B \to \rho\gamma$

difficult because of dominating

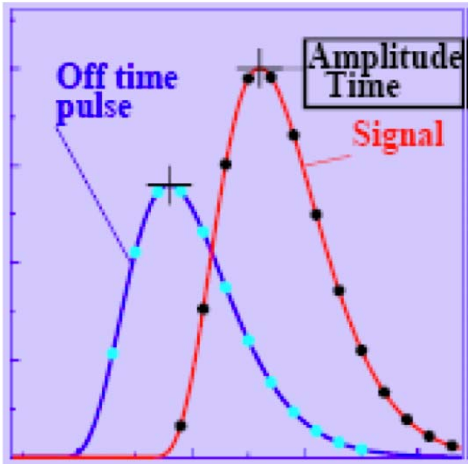
$K^*\gamma$

(Background from K's misident. as π's)

Calorimeter Upgrade (ECL)

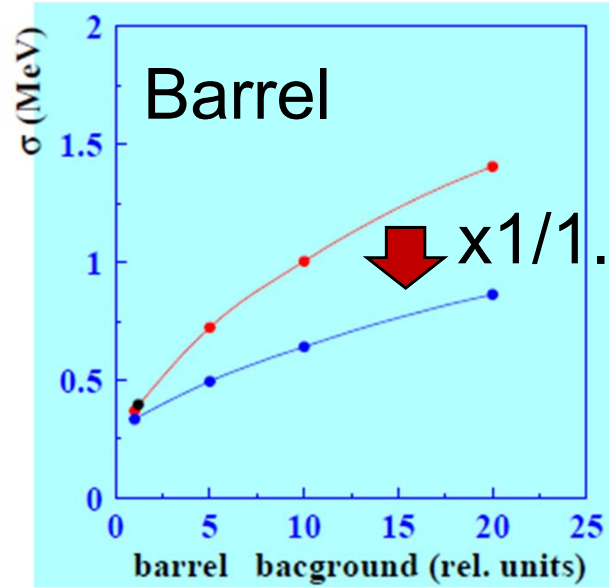
- Increase of dark current due to neutron flux
- Fake clusters & pile-up noise

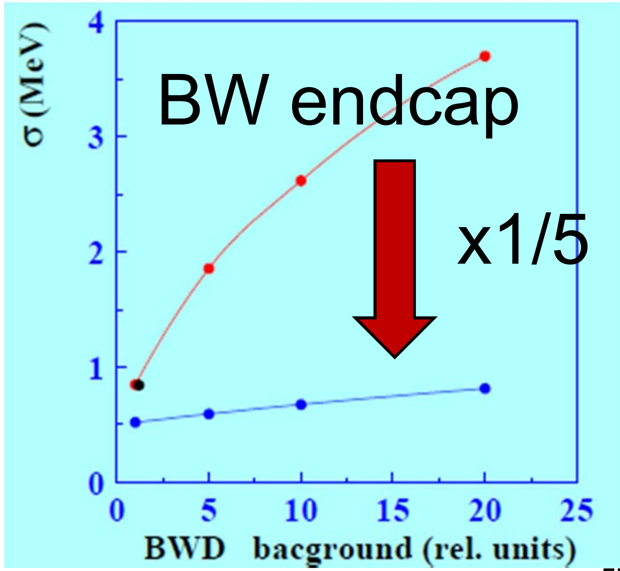
- Barrel:
  500 ns shaping + 2MHz w.f. sampling.
- Endcap:
  rad. hard crystals with short decay time (e.g. pure CsI) + photopentodes
  30ns shaping + 43MHz w.f. sampling



FADC: 16 samples

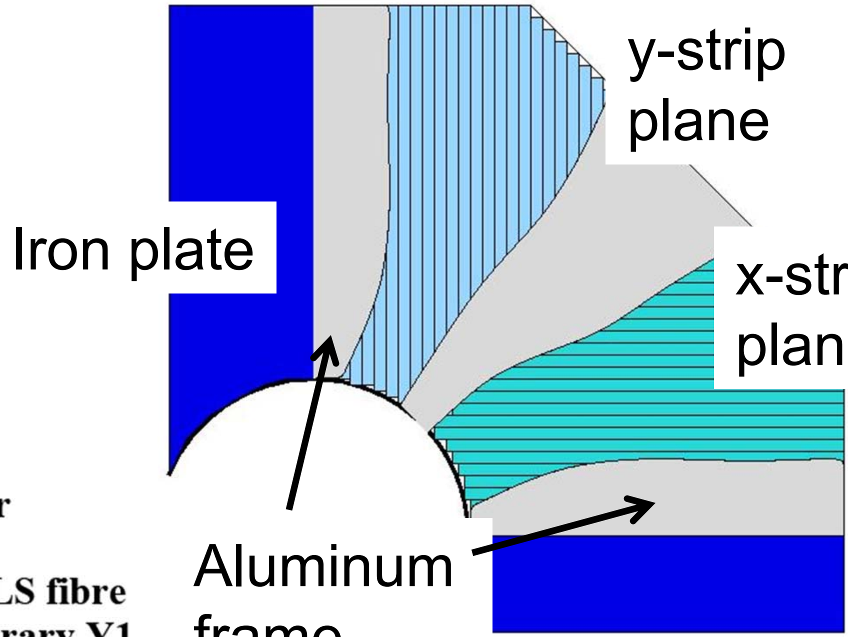
Pileup Reduction:

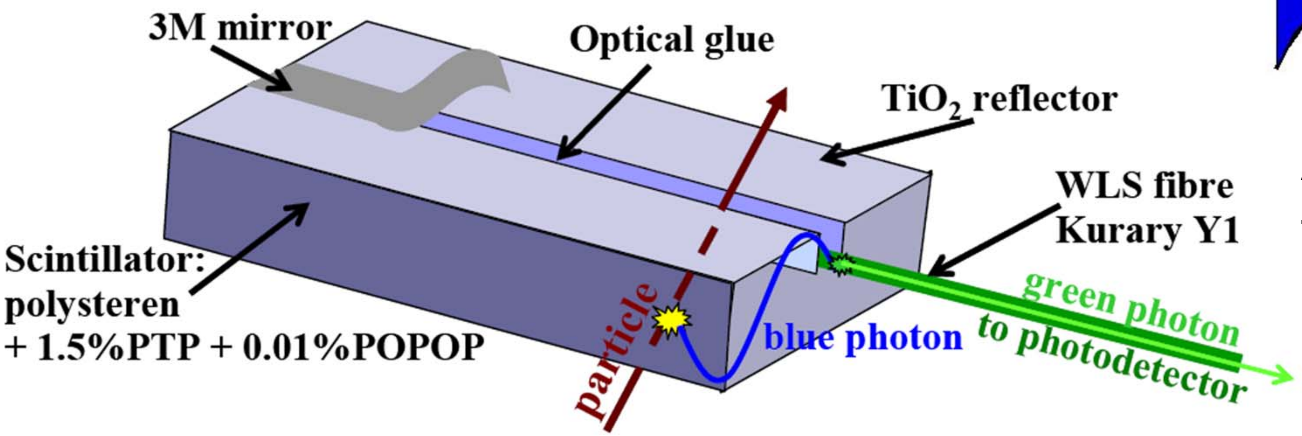




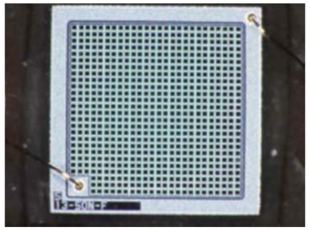
Upgrade of KLM (Endcaps)

- Two independent (x and y) layers in one superlayer made of orthogonal scintillator strips with WLS read out
- Photo-detector: avalanche photodiode in Geiger mode (SiPM)
- ~120 strips in one 90º sector
  (max L=280cm, w=25mm)
- ~30000 read out channels
- Geometrical acceptance > 99%



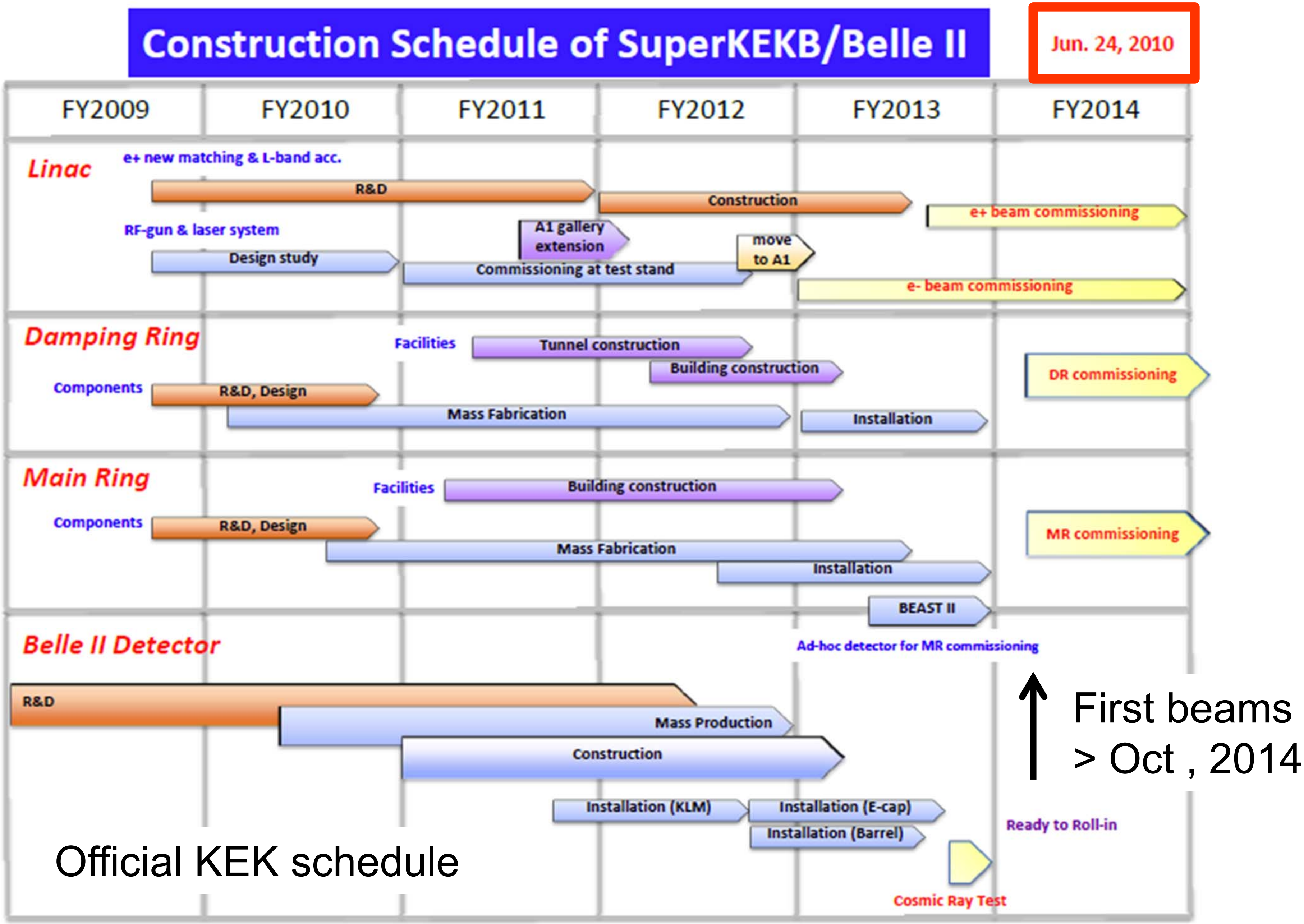


676 pixels (20x20μm^2)



SiPM, e.g.
Hamamatsu
1.3x1.3 mm^2

Schedule for SuperKEKB and Belle II



Moduli of the CKM Matrix Elements

general recipe: measure lifetimes, decay widths, branching ratios

- $\left|V_{ud}\right|$ e.g. neutron lifetime, super-allowed nuclear beta decays:

  $$\left|V_{ud}\right| = 0.97425 \pm 0.00022$$

- $\left|V_{us}\right|$ ratio of decay branching ratios, e.g. $K \to \mu\nu,\ \pi \to \mu\nu$

  $$\left|V_{us}\right| = 0.2252 \pm 0.0009$$

- $\left|V_{cd}\right|$ decay branching ratios, e.g. $D \to Kl\nu,\ \pi l\nu$

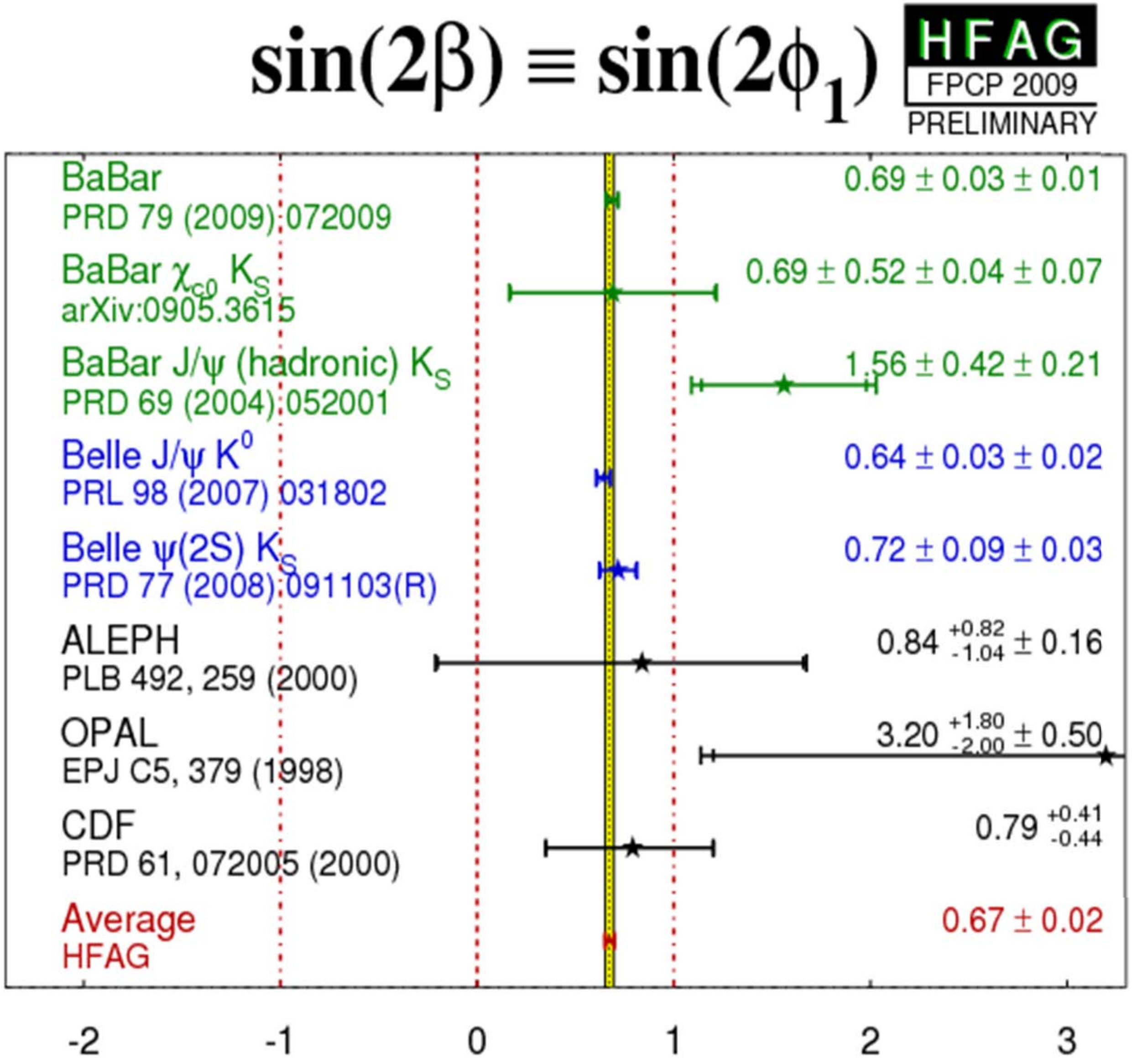
  $$\left|V_{cd}\right| = 0.230 \pm 0.011$$

- $\left|V_{cs}\right|$ decay branching ratios, e.g. $D_s \to l\nu$

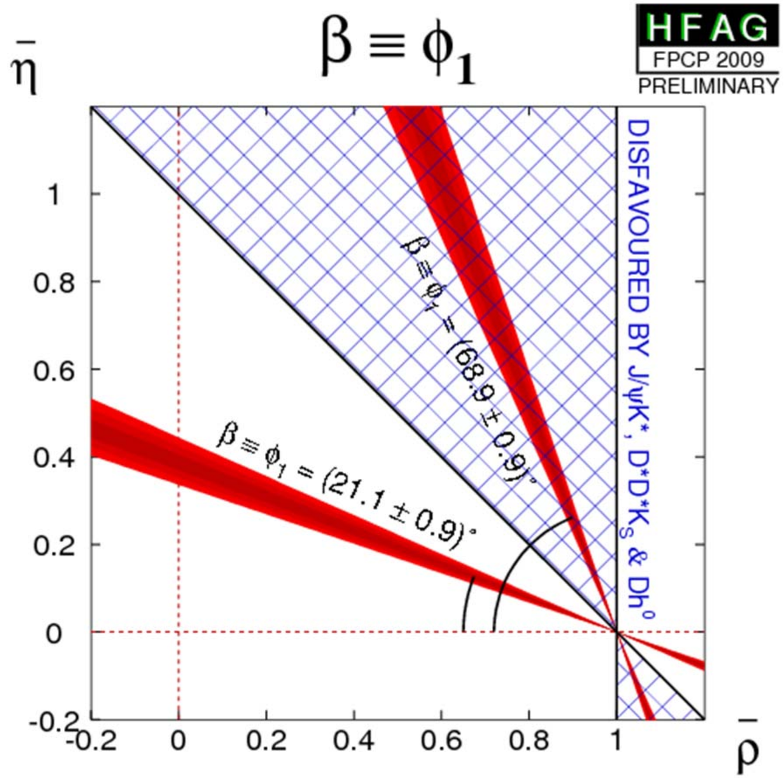
  $$\left|V_{cs}\right| = 1.023 \pm 0.036$$

$$\begin{pmatrix} u \\ d \end{pmatrix} \qquad \begin{pmatrix} c \\ s \end{pmatrix}$$

Measurement of ϕ_1 (β) in Charmonium K^0 modes



good agreement between experiments

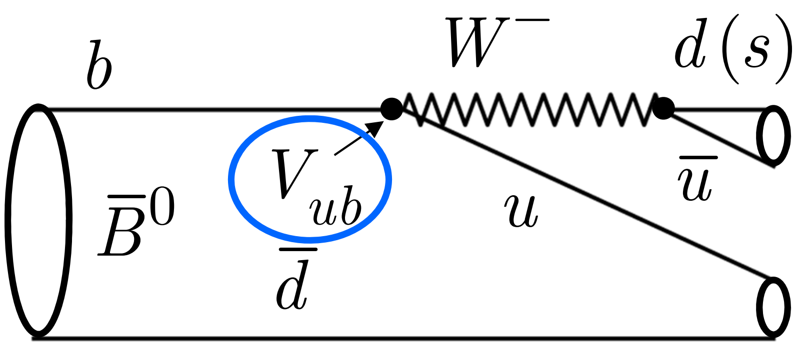


ambiguity can be lifted by additional decay channels, e.g.

$$B \to Dh$$

How to Measure α (Φ_2)

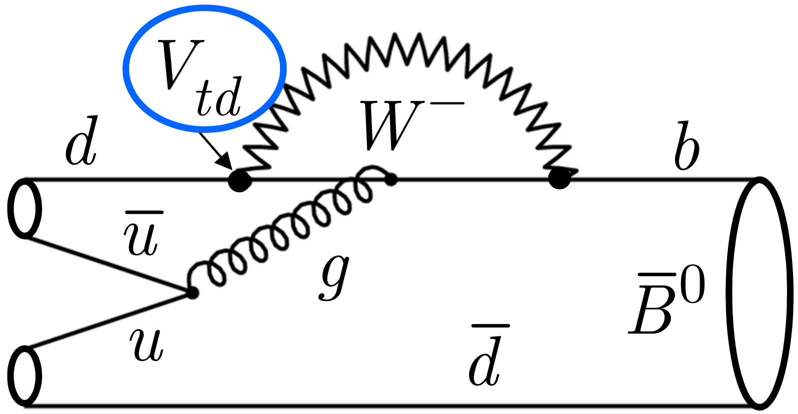
$$b \longrightarrow u\bar{u}d$$



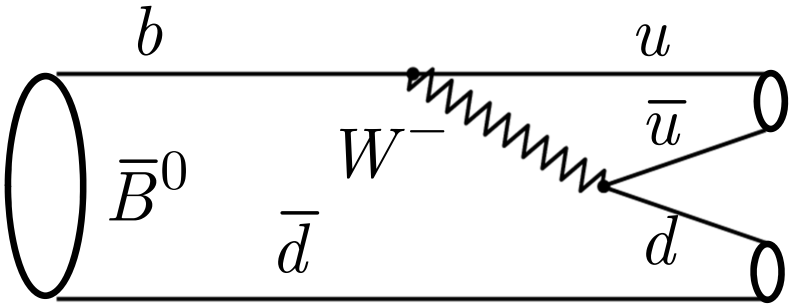
T

π^-, ρ^-, π^-

π^+, ρ^+, a_1^+



P



π^0, ρ^0

π^0, ρ^0

color-suppressed (~1/9)

T ~ P

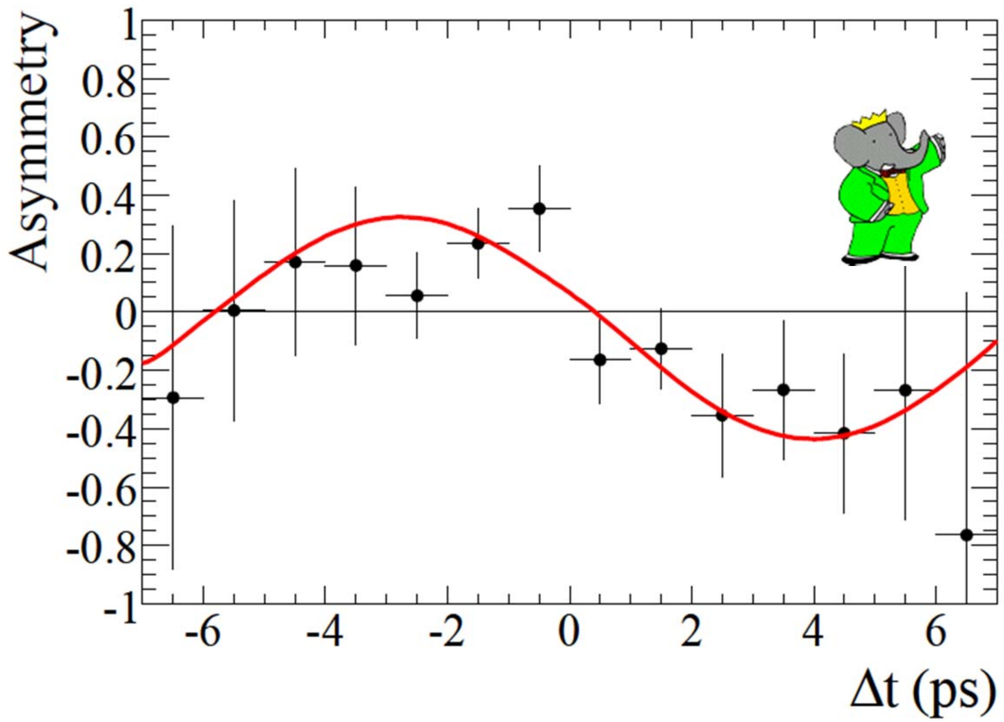
potentially large

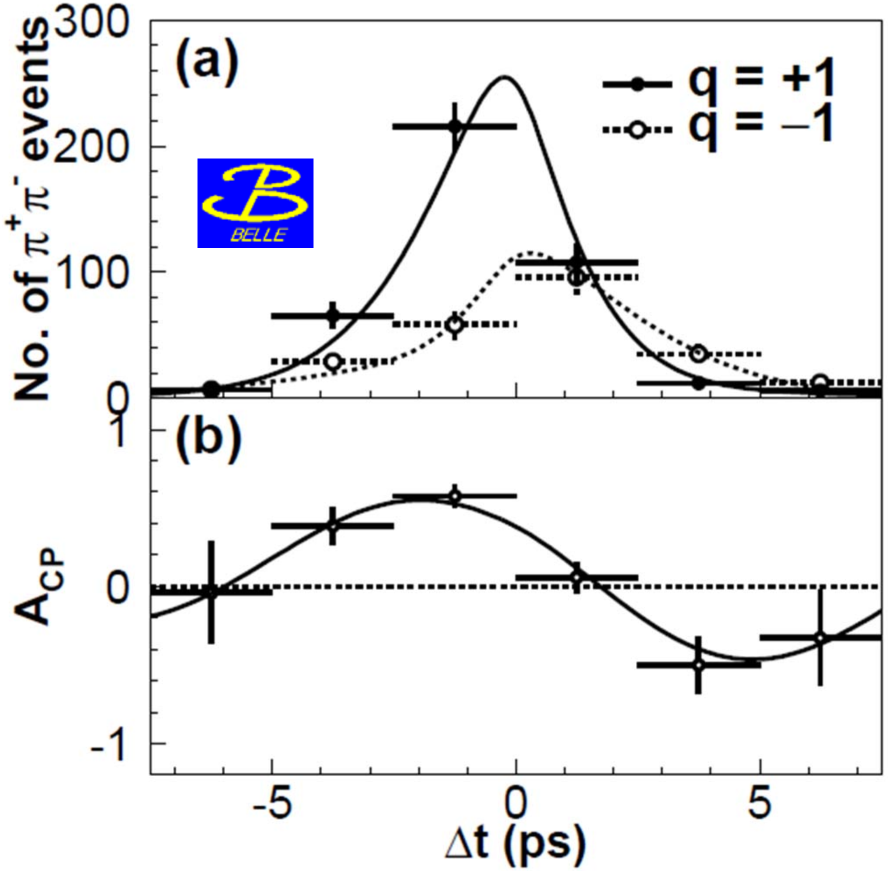
$$B^0 \rightarrow \pi^+\pi^-$$
$$\rightarrow \rho^+\rho^-$$
$$\rightarrow \rho^0\rho^0$$
$$\rightarrow a_1\pi$$

$$S_{CP} = \sqrt{1 - A_{CP}^2}\,\sin(2\phi_2 - 2\Delta\phi_2)$$
$$= \sqrt{1 - A_{CP}^2}\,\sin 2\phi_2^{eff}$$

contribution from strong phases

$B^0 \to \pi^+\pi^-$ direct and mixing-induced CP asymmetry





BaBar

arXiv:0807.4226 (2008)

467 million $B^0\bar{B}^0$ pairs

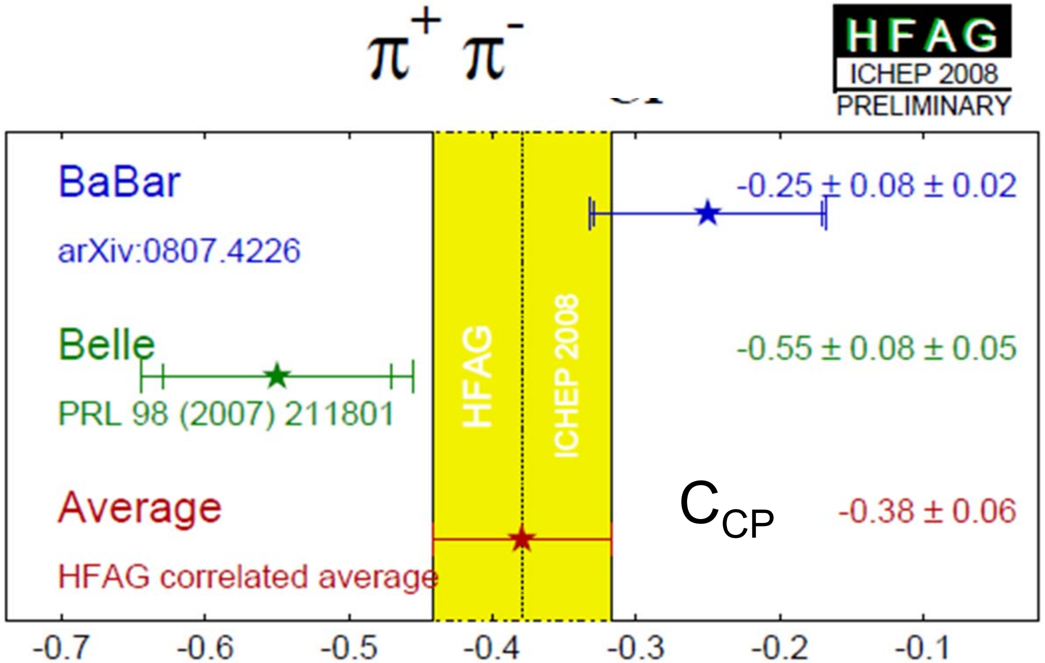
$A(\Delta t) \equiv (N_{B^0} - N_{\bar{B}^0})/(N_{B^0} + N_{\bar{B}^0})$

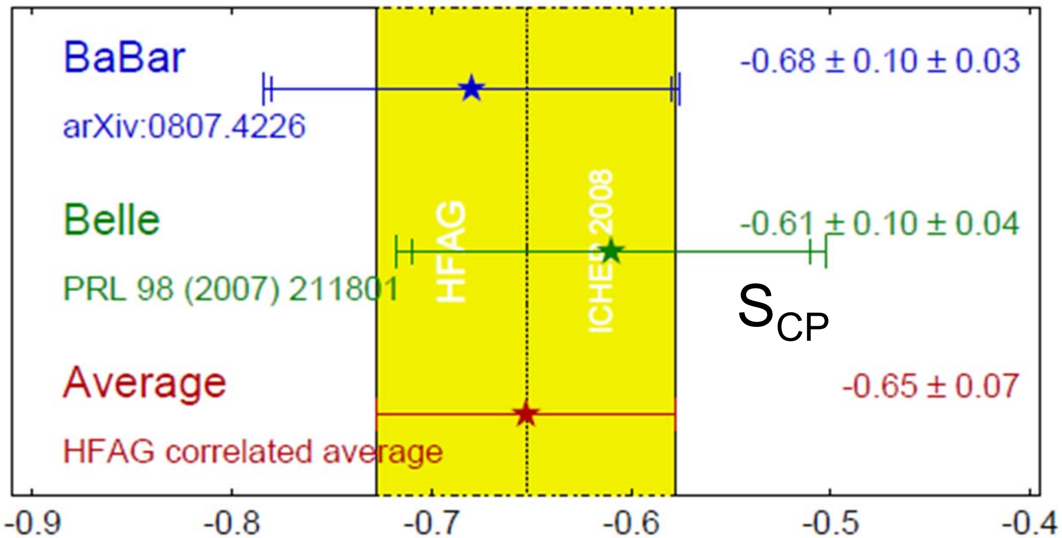
PRL **98**, 211801 (2007)

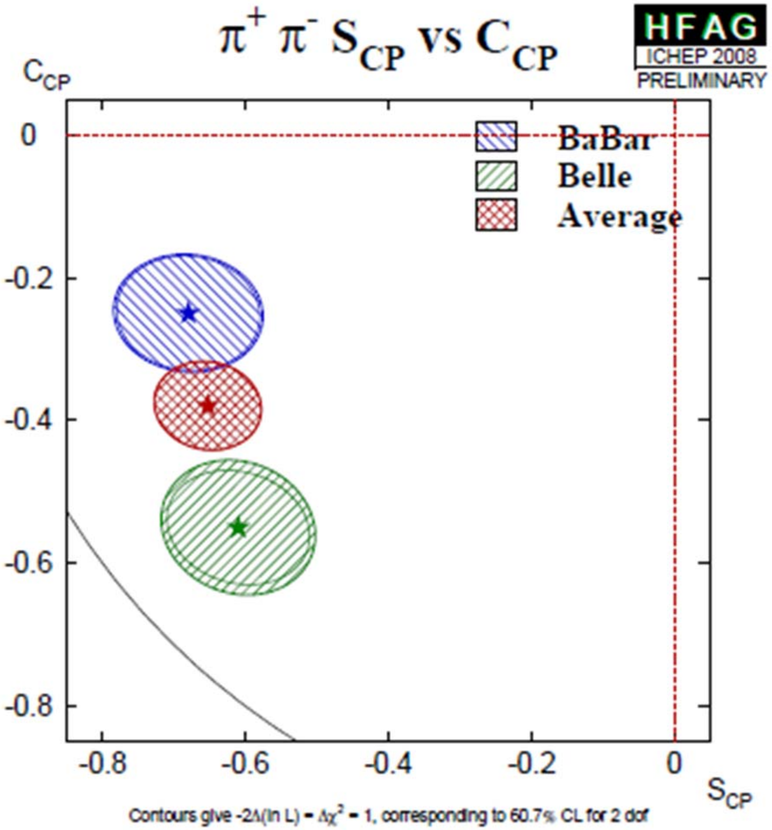
535 million $B^0\bar{B}^0$ pairs

Δt distribution and asymmetry

Measurements of α (Φ_2) $B^0 \to \pi^+\pi^-$



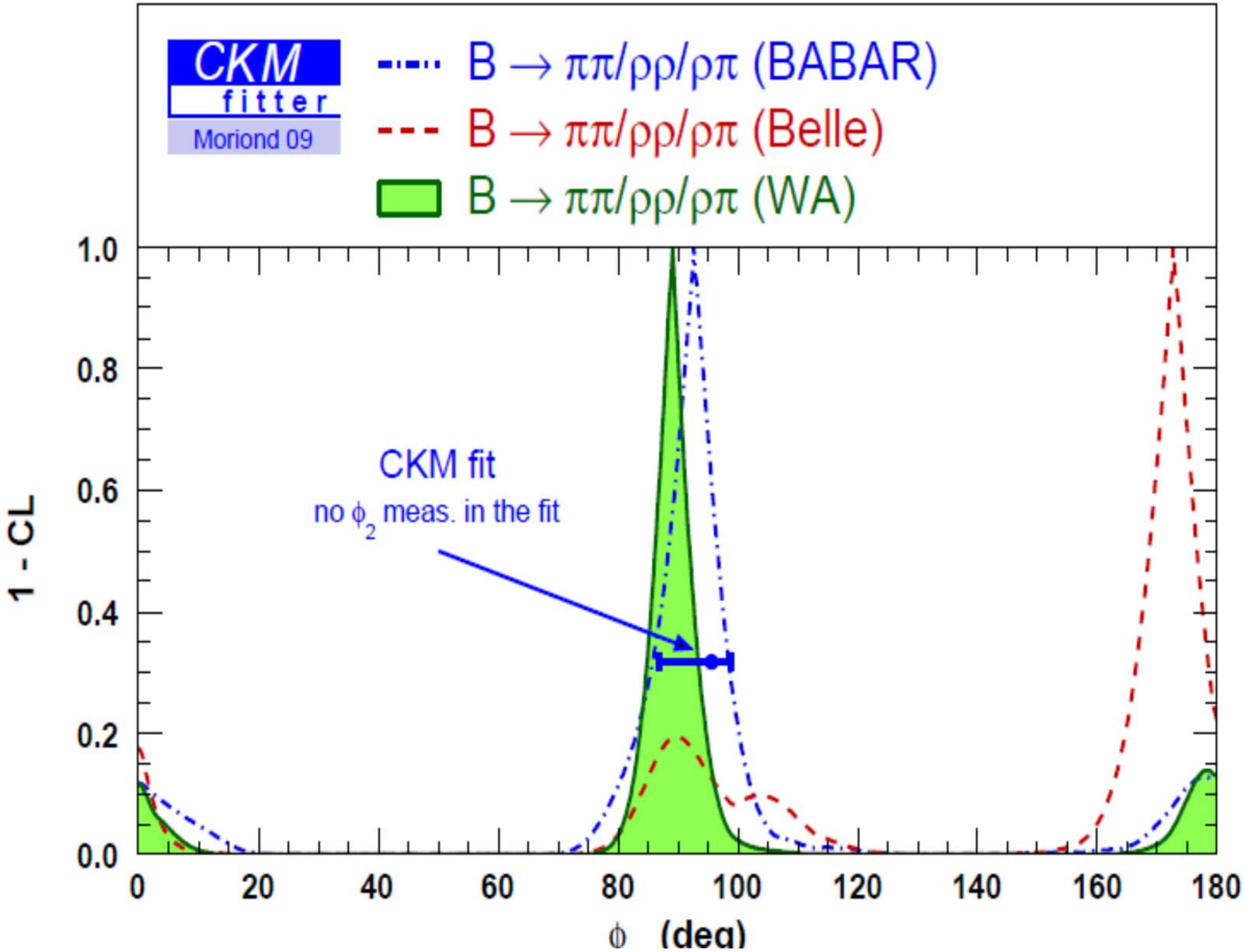




$C_{CP} = -A_{CP}$

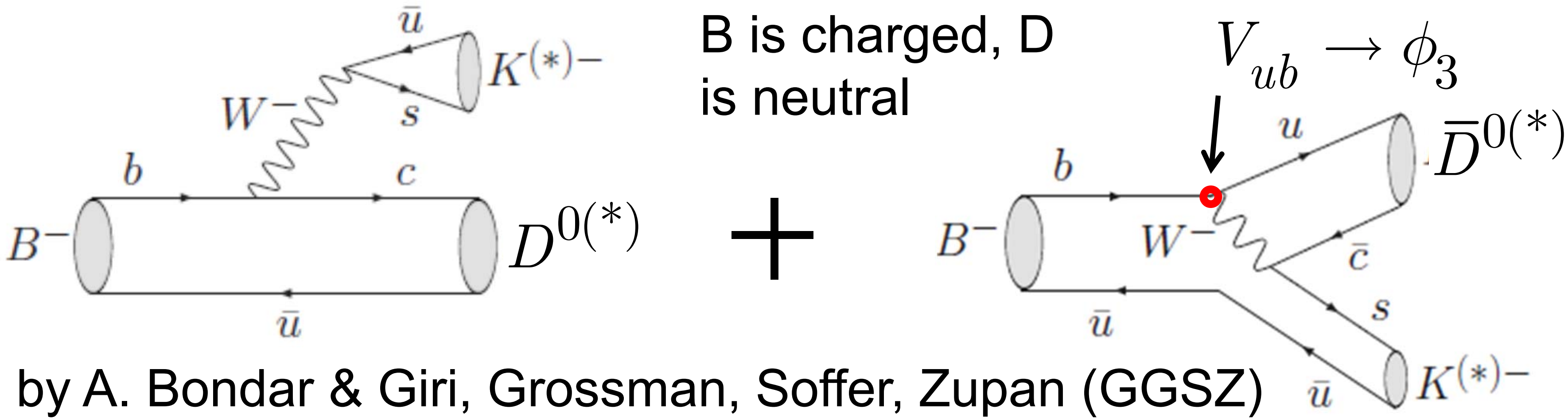
1.9 σ difference between BaBar and Belle

Status of ϕ_2 (α)



$$\phi_2 = \left(89.0^{+4.4}_{-4.2}\right)^\circ$$

Direct CP Violation and Measurement of ϕ_3 (γ)



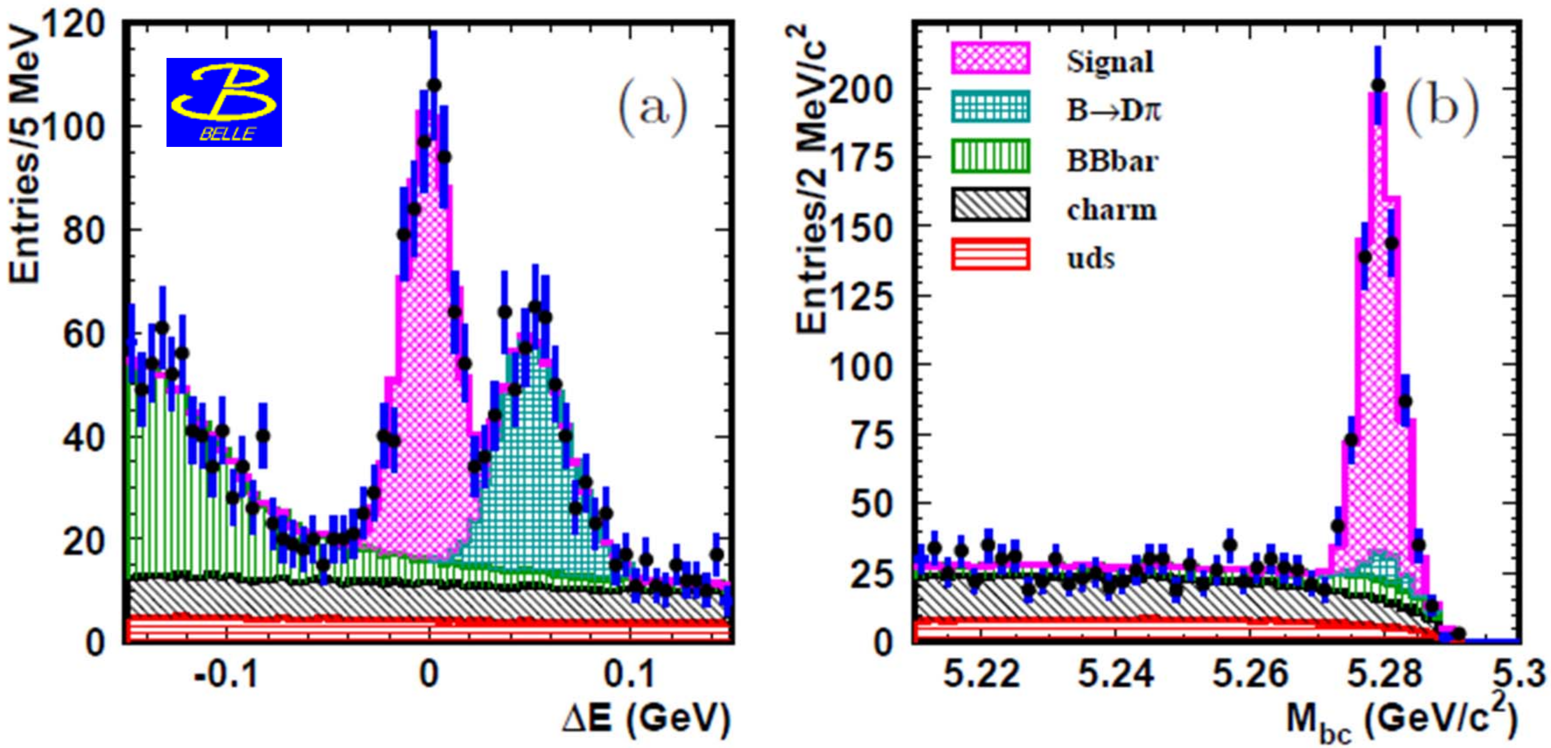
B is charged, D is neutral

method by A. Bondar & Giri, Grossman, Soffer, Zupan (GGSZ)

$$B^- \rightarrow DK^-$$

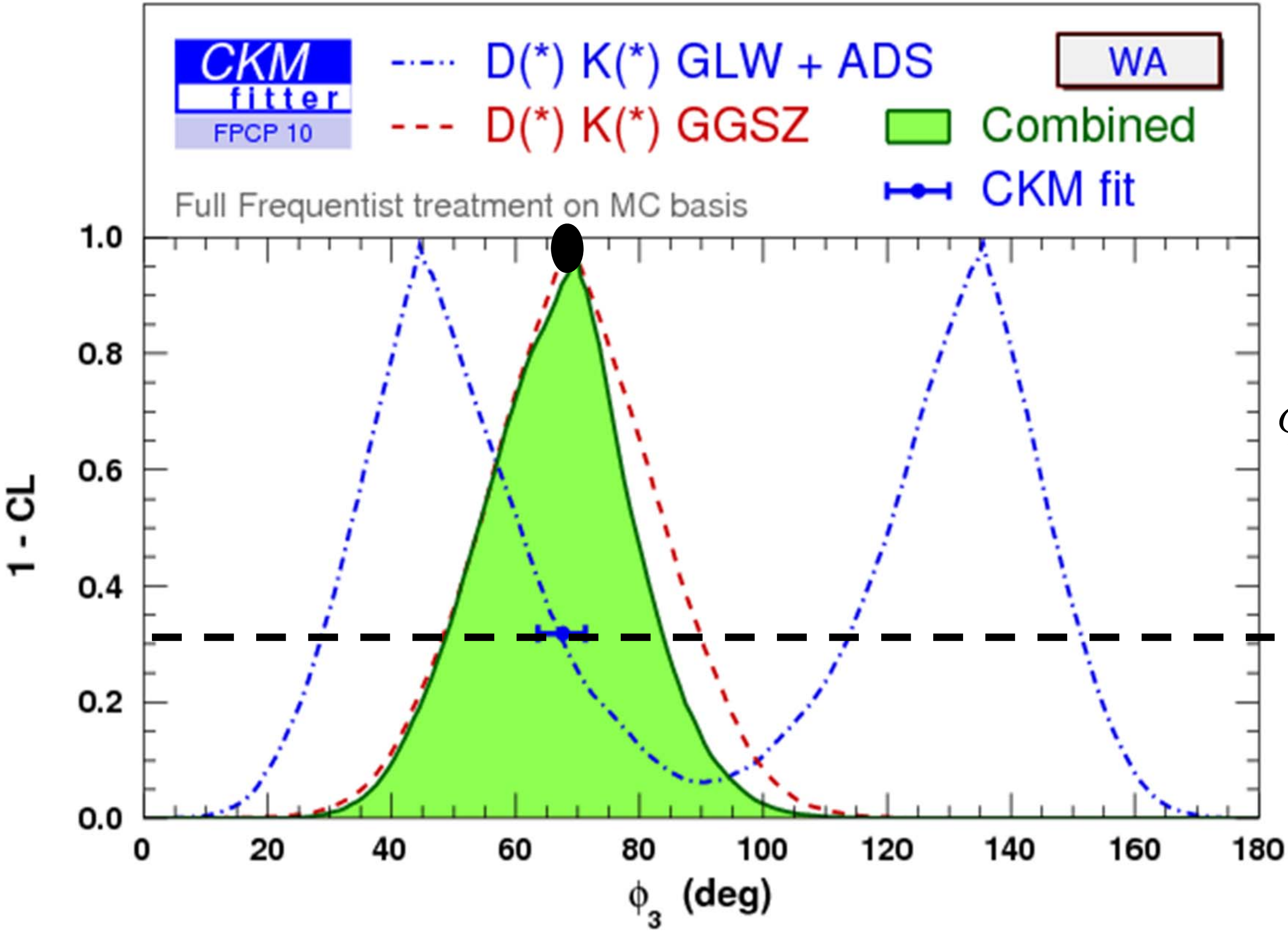
$$D \rightarrow K_S \pi^+ \pi^-$$

Dalitz plot analysis



PRD 81 (2010) 112002

Status of ϕ_3 (γ)



$$\phi_3 = \left(70^{+14}_{-21}\right)^\circ$$

The Flavor Transition Matrix

$$\underbrace{\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}}_{\text{flavor eigenstates}} \longrightarrow \begin{pmatrix} u \\ d' = V_{ud}d + V_{us}s + V_{ub}b \end{pmatrix}$$

mass eigenstate

(similar for 2nd and 3rd family)

mass $\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$ flavor

$$\boxed{\begin{aligned} |V_{ud}| &\approx \cos\theta_C \\ |V_{us}| &\approx \sin\theta_C \end{aligned}}$$

Cabibbo-Kobayashi-Maskawa (CKM) Matrix