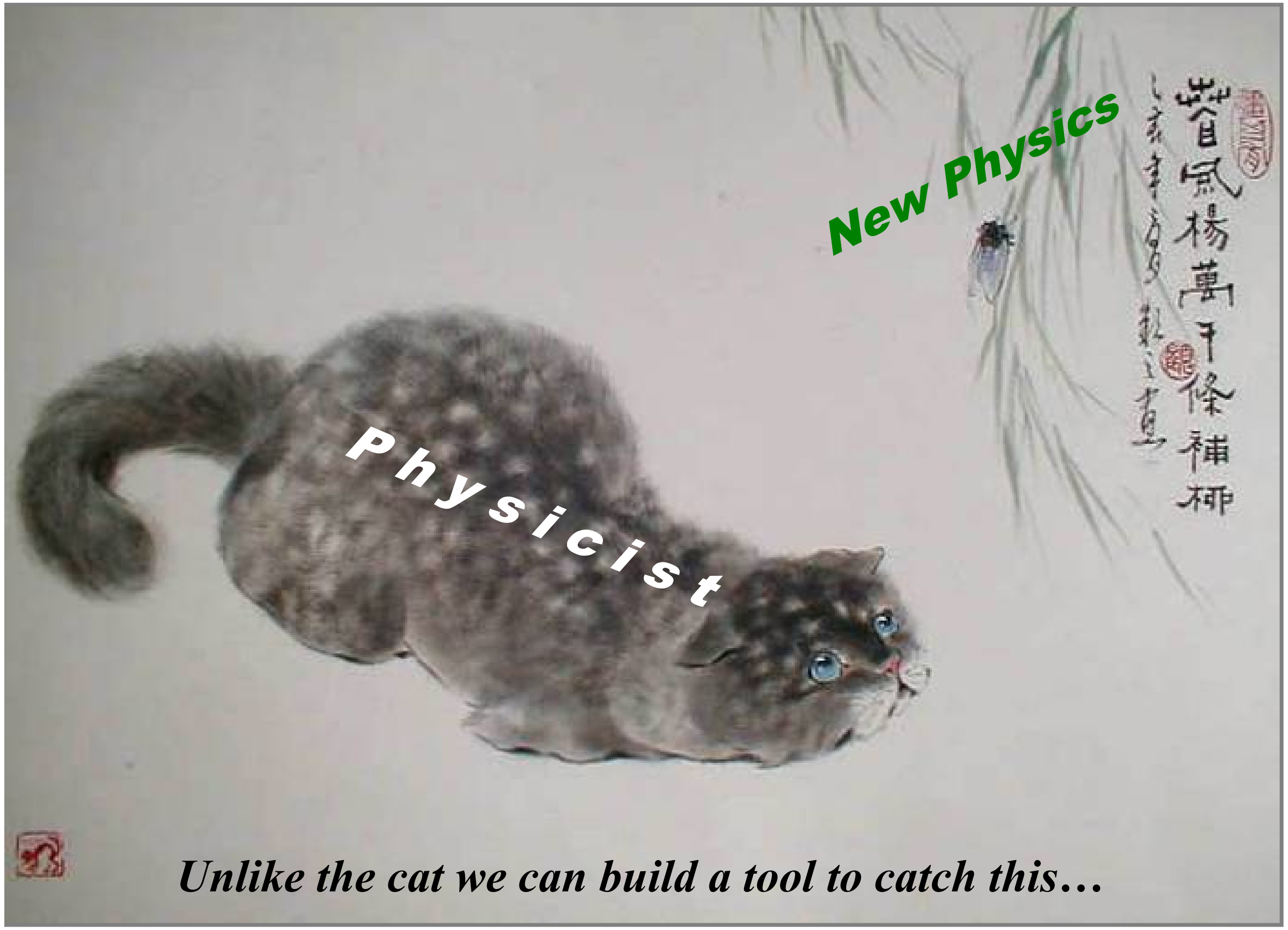
Belle-2 experiment at SuperKEKB

Super KEKB
Quest for BSM

Pavel Pakhlov

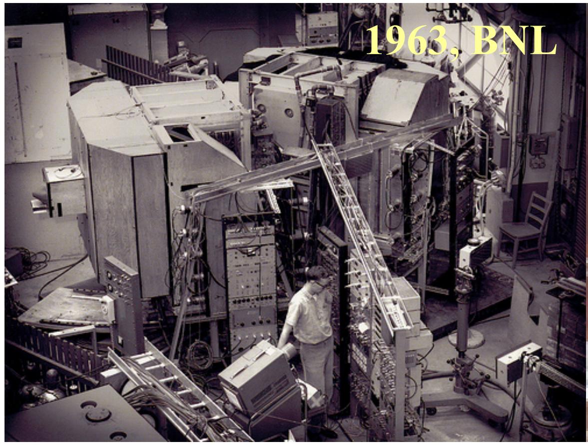
ITEP, Moscow

For the Belle/Belle-2 Collaborations

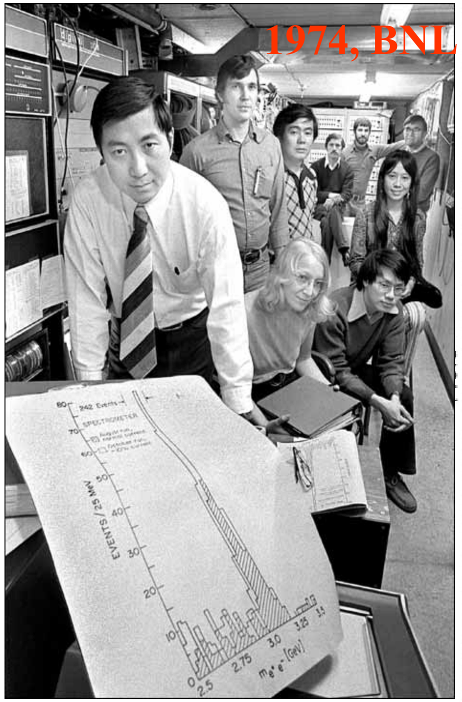


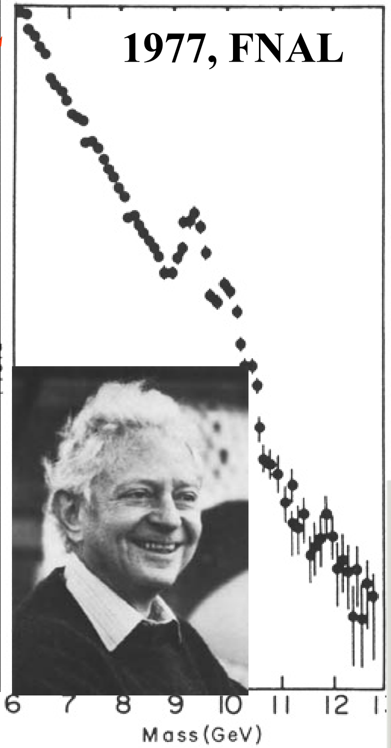
PHIPSI 09 IHEP, Beijing

46 years of living in a CP asymmetric world

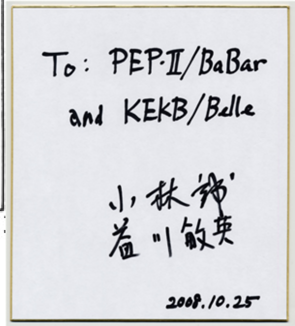


1963 CP violation in K^0 system
1967 Necessity of CPV for Universe
1973 6-quark model
1974 charm quark
1977 beauty quark
1980 large indirect CP violation predicted in B sector
1987 large BB-mixing + large V_{ub}
1995 top quark
2001 …





"… As late as *2001*, the two particle detectors BaBar at Stanford, USA, and Belle at Tsukuba, Japan, both detected broken symmetries independently of each other. The results were exactly as Kobayashi and Maskawa had predicted almost three decades earlier."

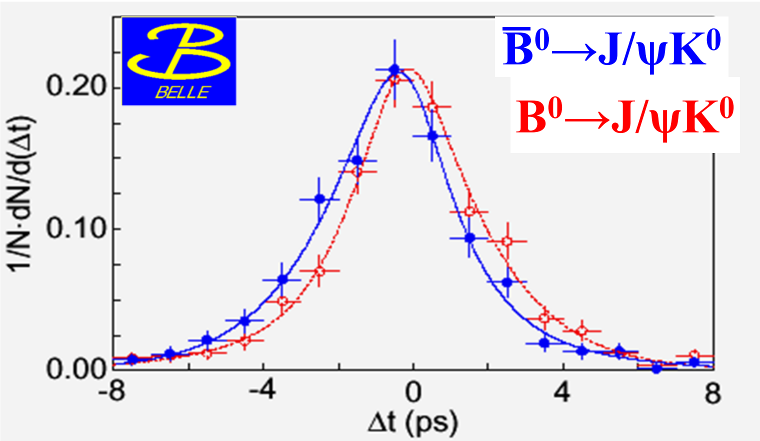


CP violation in B sector

From the discovery of *CP* violation in $B \rightarrow J/\psi K^0$ in 2001 ...

Babar 2001: $\sin(2\varphi_1) = 0.59 \pm 0.14 \pm 0.05$

Belle 2001: $\sin(2\varphi_1) = 0.99 \pm 0.14 \pm 0.06$



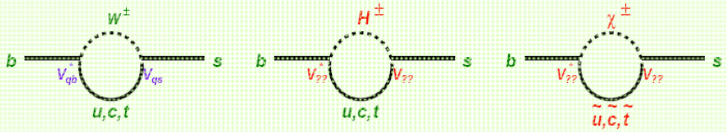
... to

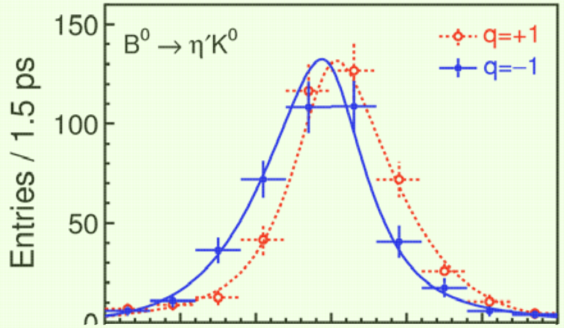
- **precise measurement of CPV parameter in $B \rightarrow (c\bar{c}) K^0$ (HFAG'09)**

WA 2009: $\sin(2\varphi_1) = 0.670 \pm 0.023$

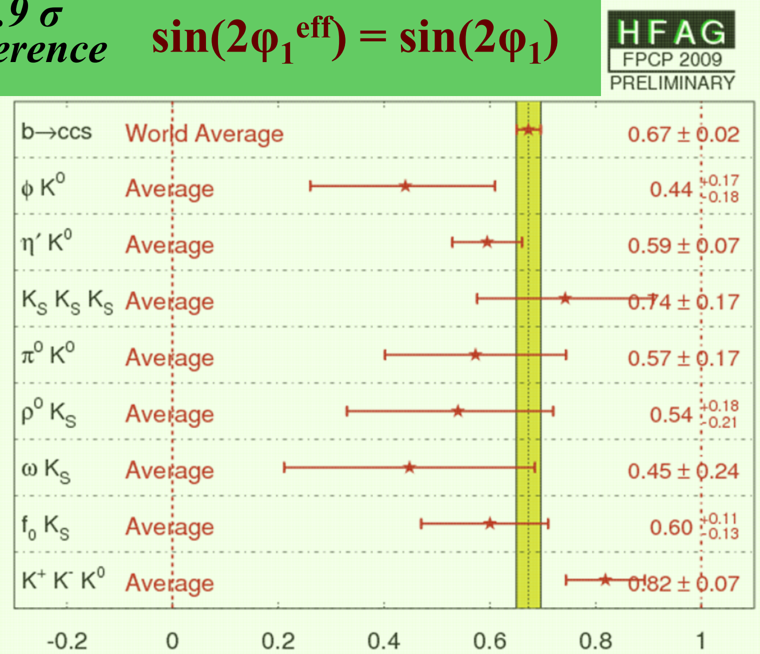
- **observation of direct *CP* violation**
- **observation of *CP* violation in charged B**
- **dozen B-decay channels with I*CP* violation: the most intriguing are the penguin modes**

penguin loops may involve New Particles with different CP-violating phase



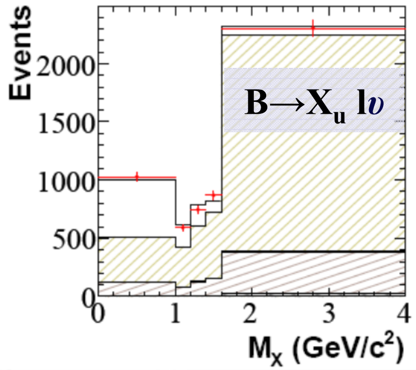


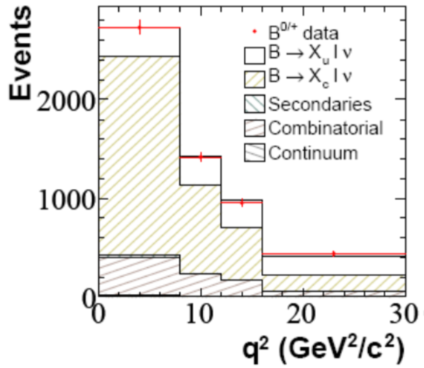
1.9 σ difference **$\sin(2\varphi_1^{eff}) = \sin(2\varphi_1)$**

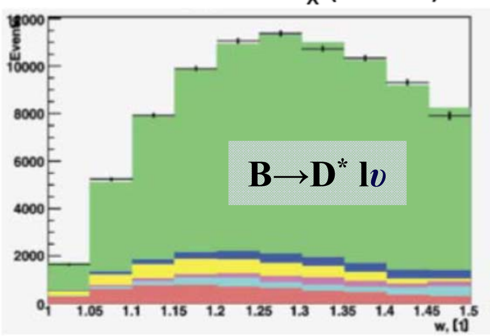


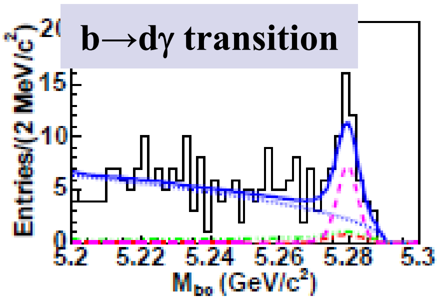
From CPV observation to precise KM test

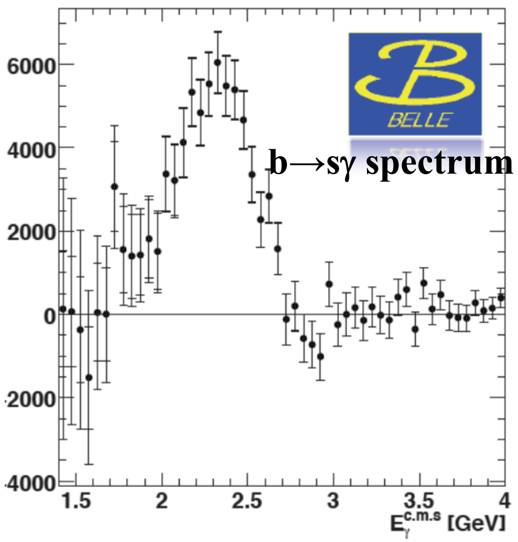
- Angle $\varphi_1(\beta)$ is measured with 1^o accuracy; angles $\varphi_2(\alpha)$ and $\varphi_3(\gamma) \sim 5\text{-}15^o$ accuracy
- Accuracies for $V_{cb} \sim 3\%$; $V_{ub} \sim 10\%$; $V_{td} \sim 7\%$; $V_{ts} \sim 6\%$; $V_{td}/V_{ts} \sim 3\%$ (Δm_s)



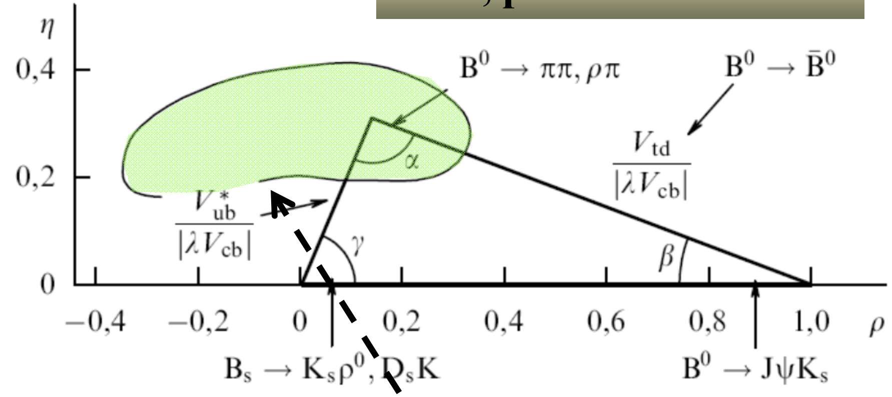






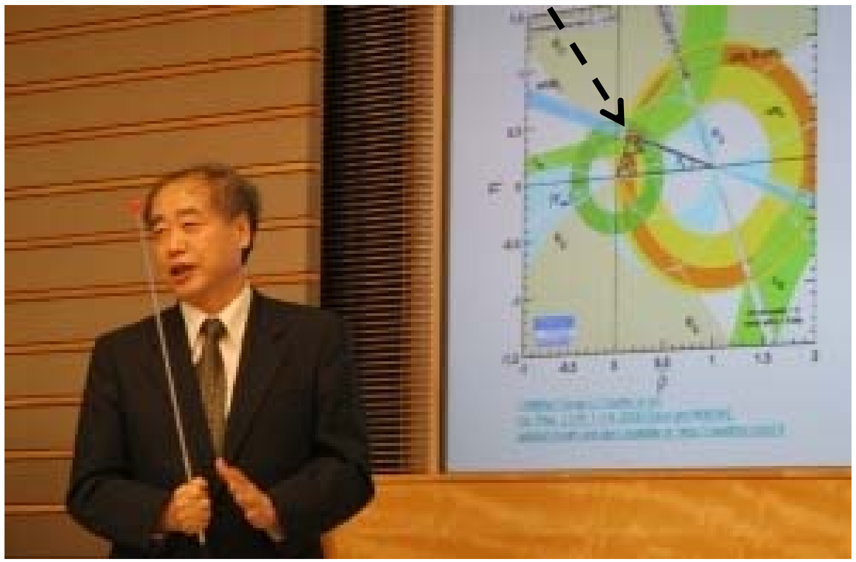


1995, pre B-factories era



The allowed area for upper apex is squeezed by almost 2 orders of magnitude

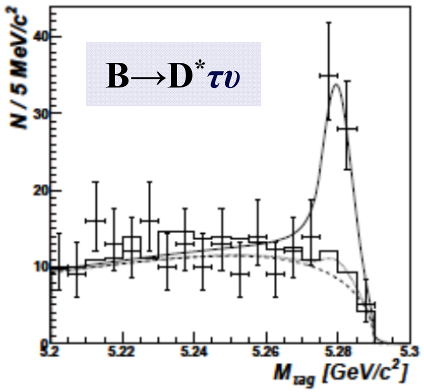
Belle & BaBar + Tevatron + huge contribution from theory



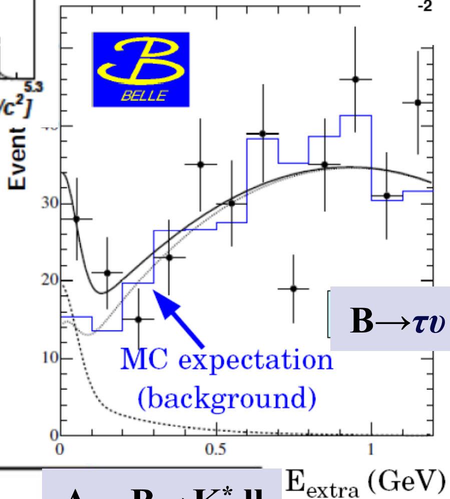
Many other highlights…

Constrains on NP

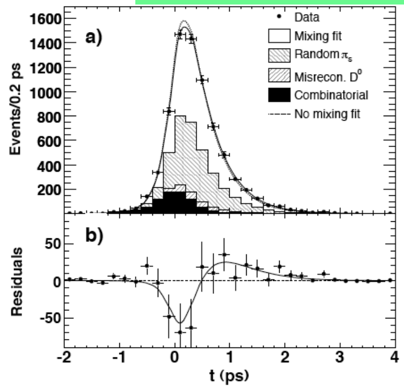
B→D$^*\tau\upsilon$

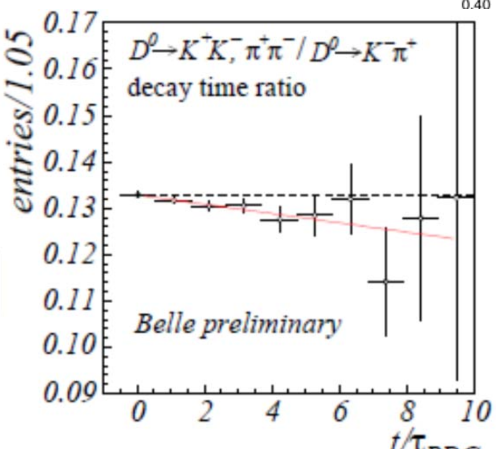


B→$\tau\upsilon$



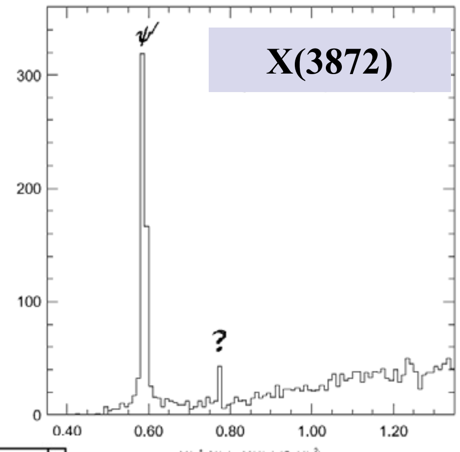
D^0 D^0 mixing



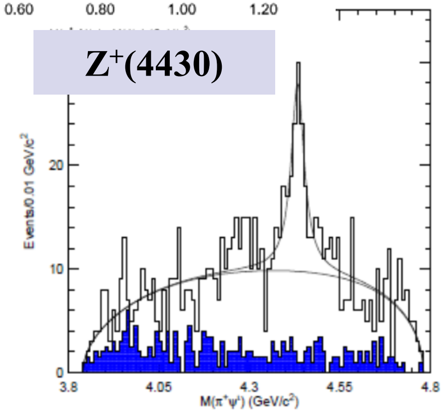


Many new resonances

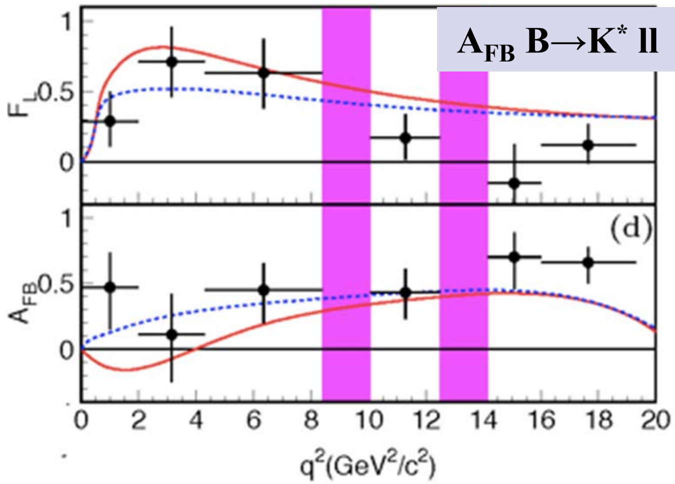
X(3872)



Z$^+$(4430)

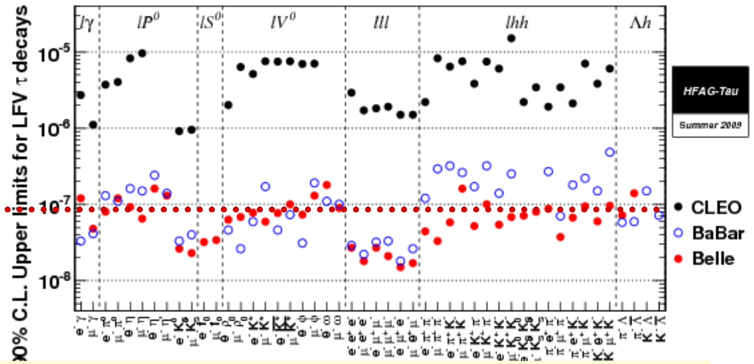


A$_{FB}$ B→K* ll



LFV in τ-decays

UL ~ 10^{-7}



demonstrate a very broad B-factory program

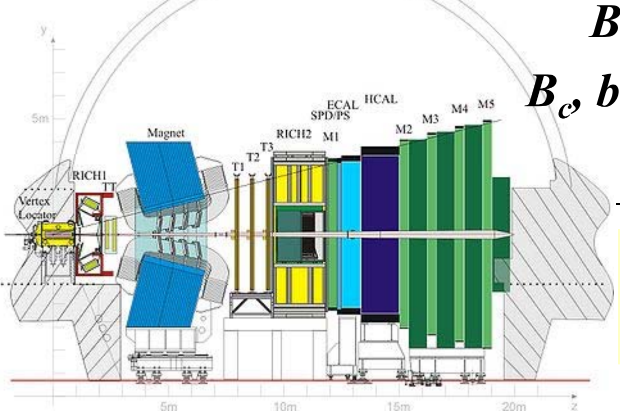
KM mechanism confirmed and (all?) Nobel prises received.

Shouldn’t we relax now?

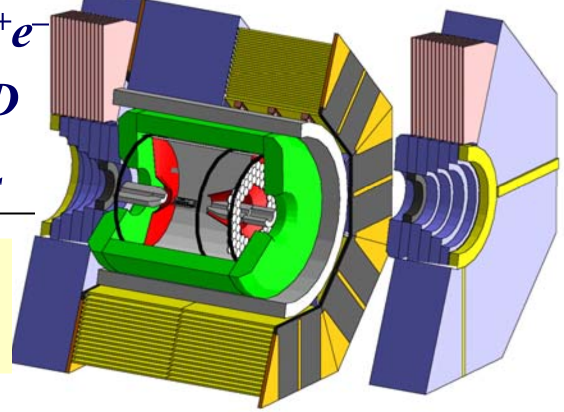
Future of flavour physics

- **Physics beyond the Standard Model must exist. New Physics is required to supply Dark Matter, to add CP violation for cosmology, to cut off UV divergencies…**
- **If the LHC finds New Physics at the TeV scale,**
  - **its flavor structure must be examined experimentally. TeV-particles should reveal in B, D and tau-decays. A super B factory is the best tool for this purpose.**
- **If the LHC finds nothing but a SM-like Higgs,**
  - **searching for deviations from the SM in flavour physics will be almost the last chance to find New Physics in the next decade. Alternatively, even the ULs constrain NP at energy scales inaccessible to energy frontier experiments.**

LHCb advantageous in	**e^+e^- advantageous in**
CPV in $B \to J/\psi\, K_S$	*CPV in $b \to sss$, sqq*
Direct CPV in $B \to K^{*0}\gamma$	*Indirect CPV in $B \to K_S \pi^0 \gamma$*
Time-dependent B_s studies	*Missing E modes: $B \to K\upsilon\upsilon$, $\tau\upsilon$, $D^{(*)}\tau\upsilon$*
$B_s \to \mu^+\mu^-$	*Inclusive $b \to s\, \mu^+\mu^-$, $s\, e^+e^-$*
B_c, b-baryons	*DD mixing and CPV in D*
	LFV in $\tau\to\mu\gamma$ and others



SuperB factories and LHCb are complementary to each other



Two super B-factory projects

are prolongation of the successful B-factories

KEKB/Belle

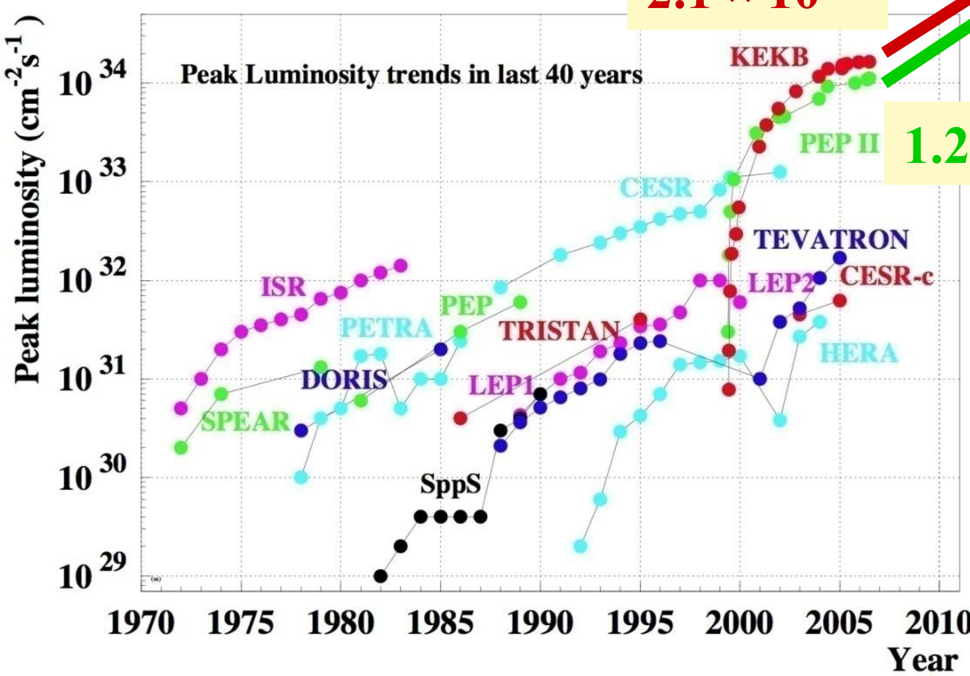
PEP-II/BaBar

8 × 10^{35}

2.1 × 10^{34}

10 × 10^{35}

1.2 × 10^{34}



D. Hitlin's talk

SuperKEKB/Belle2

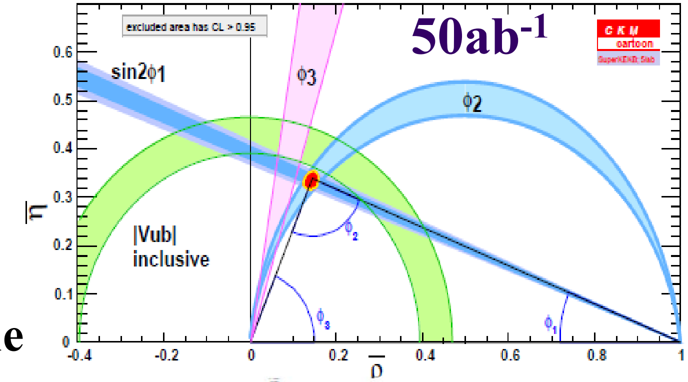
SuperB

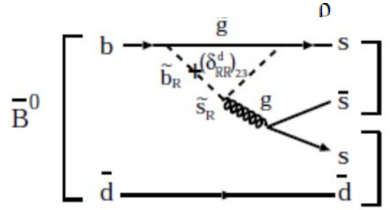
Physics reach with 50 ab^{-1} (~ 5 years with 8×10^{35}/cm^2/s)

- **Which physics will we do at Super B-factories?**

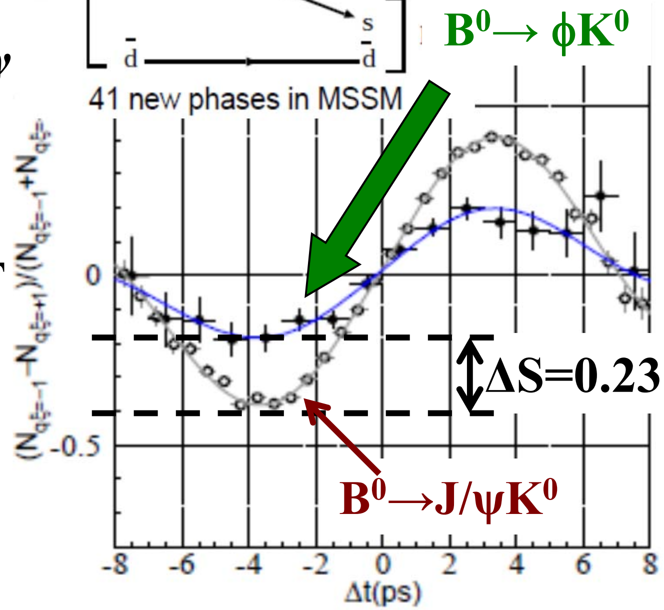
Basically the same we did at B-factories:

- **Measure UT (angles & sides) *with much better precision*. If new phases contribute to any measurable → inconsistency of UT.**
- **CPV in *b → sqq vs b → ccs:* Extra new phases in the penguin loop makes CPV parameters different. Typical accuracy in ΔS σ ≈ 0.02 – 0.03 for B → K^0 ϕ (K^0 η').**
- **search for CPV in radiative decays *B → $K^{*0}(K_S^0\,\pi^0)\,\gamma$* is a test of right-handed current in the penguin loop (CPV ≠ 0).**
- **Rare decays *b → sg(γ)*, B → *τν*. Even Br's constrain mass of NP (provided CKM matrix elements and FF are known precisely).**
- **Electro-weak penguins *b → sμμ, see, sνν:* Br's, Q^2 - distribution, FB asymmetry are sensitive to NP**
- **+ many new decay channels hardly / not seen with the present statistics.**
- **+ New ideas.**





41 new phases in MSSM



Not technical updates of the previous analyses:
need to reduce model dependence and systematic uncertainties

Physics of beauty requires beautiful environments
Ski resort 80 km
Sightseeing 80km
Pacific ocean 50km
Spa resort 120 km
Restaurant 2km
Tsukuba is nice place to study charm and beauty

How to get high luminosity

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

Lorentz factor

Beam current

Beam-Beam parameter

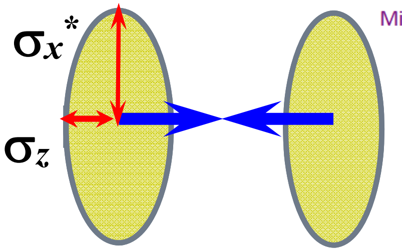
Geometrical reduction factors (crossing angle, hourglass effect)

Beam aspect ratio at IP

Vertical beta function at IP

Minimum value is limited by hourglass effect

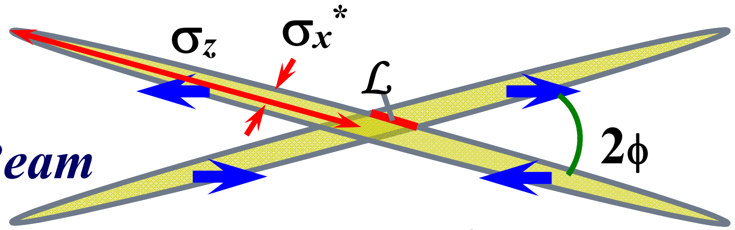
- ❖ Target luminosity: $8\times10^{35}/cm^2/s$
- ❖ Continuous injection (succesful experience of KEKB operation)
- ❖ Constraint: to save money use existing KEKB components as much as possible



Two options:

High Current

Nano-Beam



Half crossing angle: ϕ~30mrad

Slightly smaller β_y^*

6.5(LER)/5.9(HER) → 3.0/6.0

Significantly increase beam currents

1.8A(LER)/1.45A(HER) → 9.4A/4.1A

Increase ξ_y

0.1(LER)/0.06(HER) → 0.3 or more

Developement of the LoI design for SuperKEKB (2004)

Much smaller β_y^*

6.5(LER)/5.9(HER) → 0.21/0.37

Slightly increase beam currents

1.8A(LER)/1.45A(HER) → 3.6A/2.1A

Keep ξ_y

0.1(LER)/0.06(HER) → 0.09/0.09

Proposed by P. Raimondi et al. for use at Italian Super B Factory; Now considered also for SuperKEKB

Decision expected in 2009

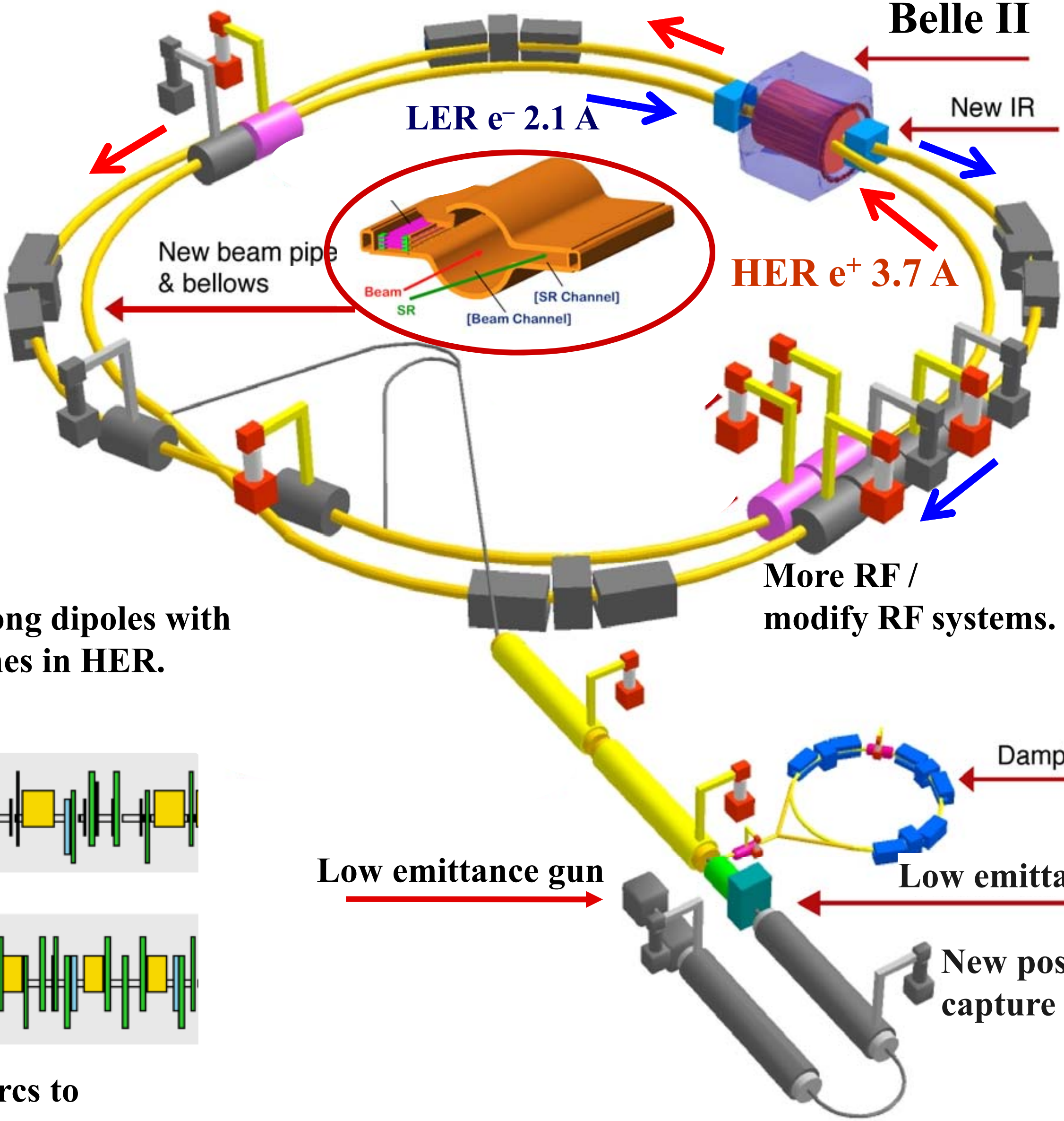
Comparison of parameters

Low Energy ring / High Energy ring	KEKB design	KEKB achieved (with crab)	SuperKEKB High-Current	SuperKEKB Nano-Beam
β_y^* (mm)	10 / 10	6.5 / 5.9 (5.9 / 5.9)	3 / 6	0.26 / 0.26
ε_x (nm)	18 / 18	18(15) / 24	24 / 18	2.8 / 2.0
σ_y(μm)	1.9	1.1	0.85 / 0.73	0.084 / 0.072
ξ_y	0.052	0.108 / 0.056 (0.101 / 0.096)	0.3 / 0.51	0.08 / 0.08
σ_z (mm)	4	~ 7	5 / 3	5 / 5
I_{beam} (A)	2.6 / 1.1	1.8 / 1.45 (1.62 / 1.15)	9.4 / 4.1	3.6 / 2.1
$N_{bunches}$	5000	~ 1500	5000	~ 2000
Luminosity (10^{34} cm^{-2} s^{-1})	1	1.76 (2.08)	53	80

Preliminary

Also consider smaller boost: E_{HER}/E_{LER} KEKB 8GeV/3.5GeV → SuperKEKB 7GeV/4GeV
easier for accelerator people; not very critical for physics

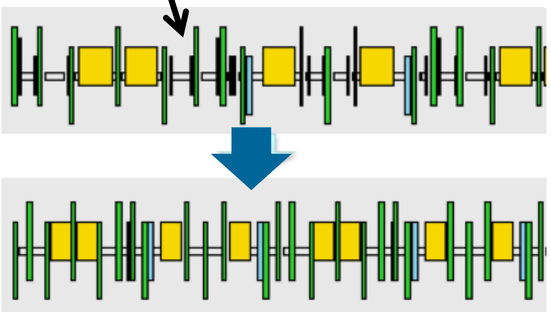
KEKB upgrade → SuperKEKB(nano-beam)



Two separate focusing quads/each 2 beams closer to IP; Superconducting / permanent magnets

More RF / modify RF systems.

Replace long dipoles with shorter ones in HER.



Redesign the HER arcs to reduce the emitance.

Low emittance gun

Low emittance positrons

New positron target / capture section

Detector upgrade

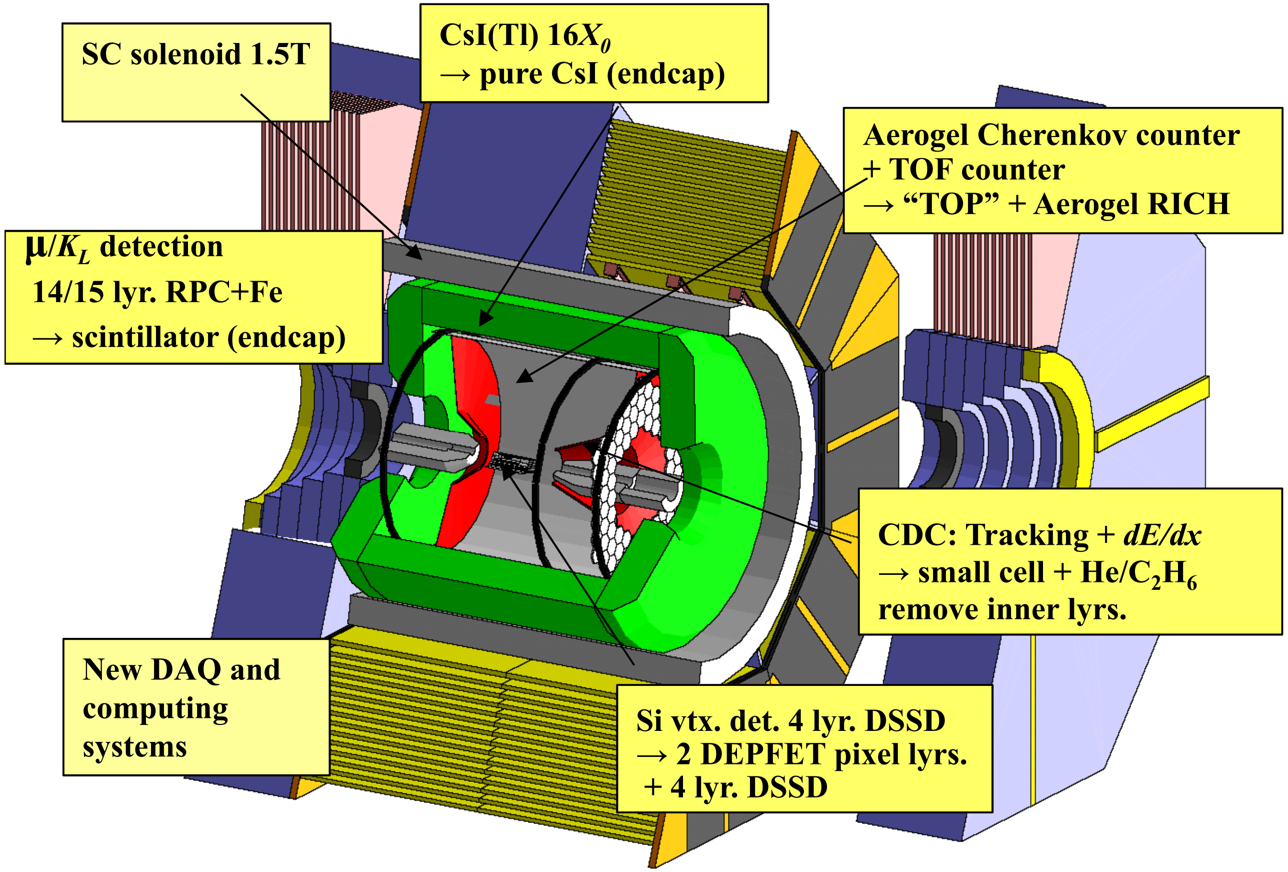
Critical issues at $L = 8 \times 10^{35}/cm^2/sec$

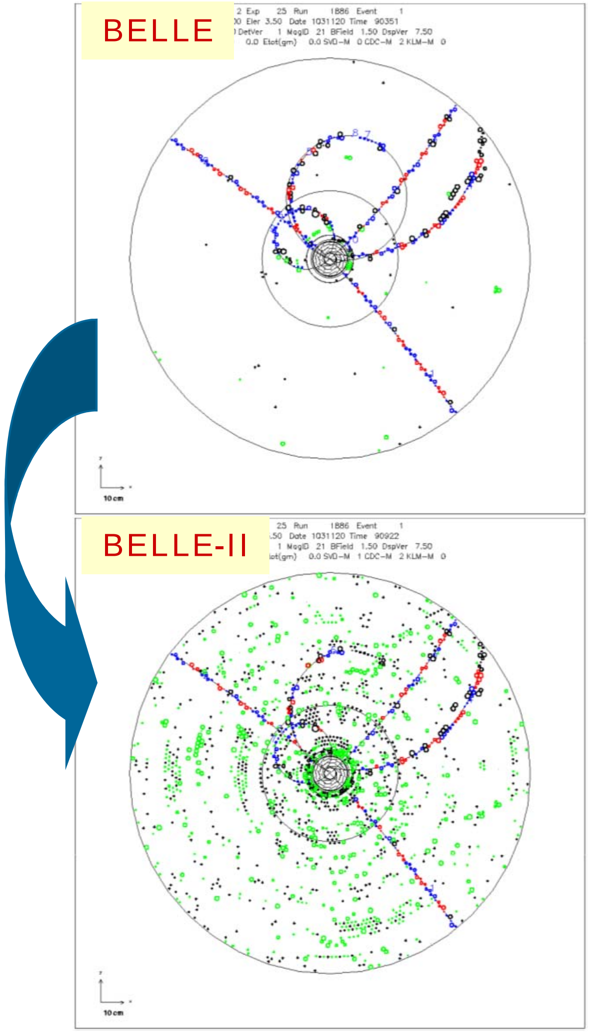
- ❖ **Higher event rate**
  - ❖ higher rate trigger, DAQ and computing

+

- ❖ **Improve performance**
  - ❖ try better PID options
  - ❖ low p μ identification for $b \to s\mu\mu$ efficiency
  - ❖ hermeticity → missing E "reconstruction"

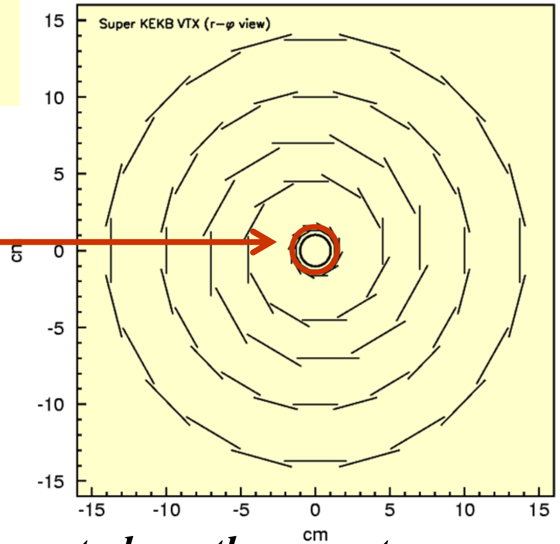
- ❖ **Higher background**
  - ❖ radiation damage and occupancies
  - ❖ fake hits and pile-up noise in the ECL



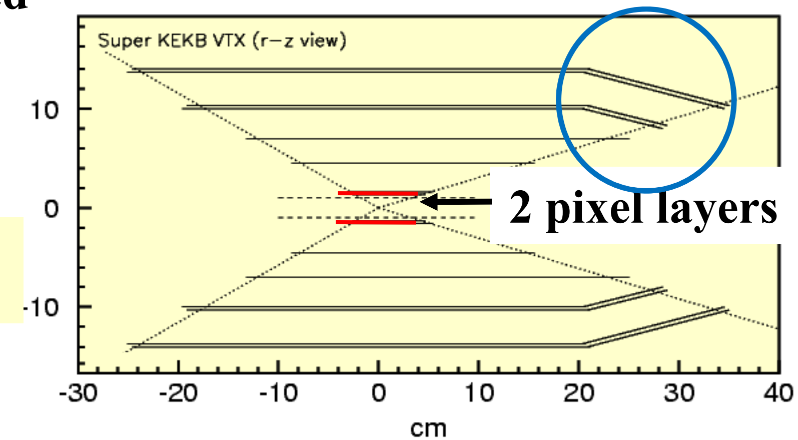


Vertex detector: PiXel Det+Si Vertex Detector

- **Sensors of the innermost layer: Normal double sided Si detector (DSSD) → DEPFET Pixel sensors (DEpleted P-channel FET)**
- **Add layers: 4 layers → 6 layers for more robust tracking**
- **Slightly decrease inner radius for better vertex resolution: 1.5 cm → 1.3 cm**
- **Increase outer radius to replace the most occupied Drift chamber layers: 8 cm→14 cm**
  - **Higher K_S vertex reconstruction efficiency**



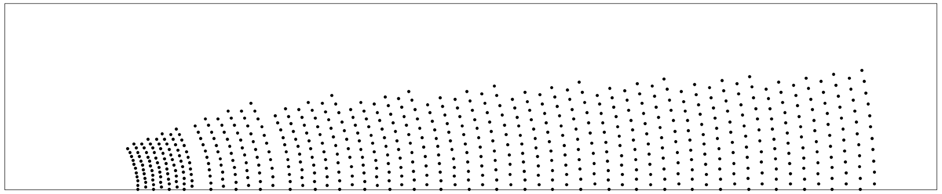
Slant layer to keep the acceptance



Tracking: New Central Drift Chamber

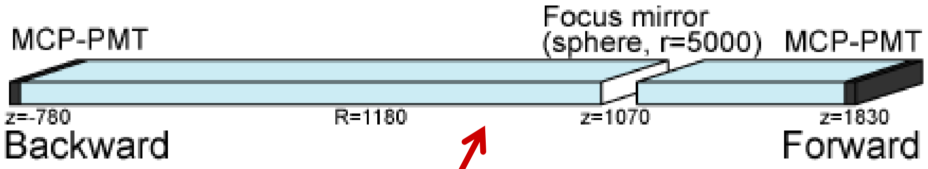
	Belle	Belle-II
Radius of inner boundary (mm)	77	160
Radius of outer boundary (mm)	880	1096
Number of layers	50	58
Number of total sense wires	8400	15104
Effective radius for dE/dx (mm)	752	928
Gas	He-C_2H_6	He-C_2H_6
Diameter of sense wire (mm)	30	30

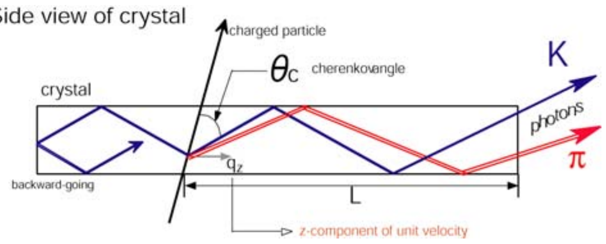
Smaller cell size in the innermost layers
More layers for dE/dx measurements

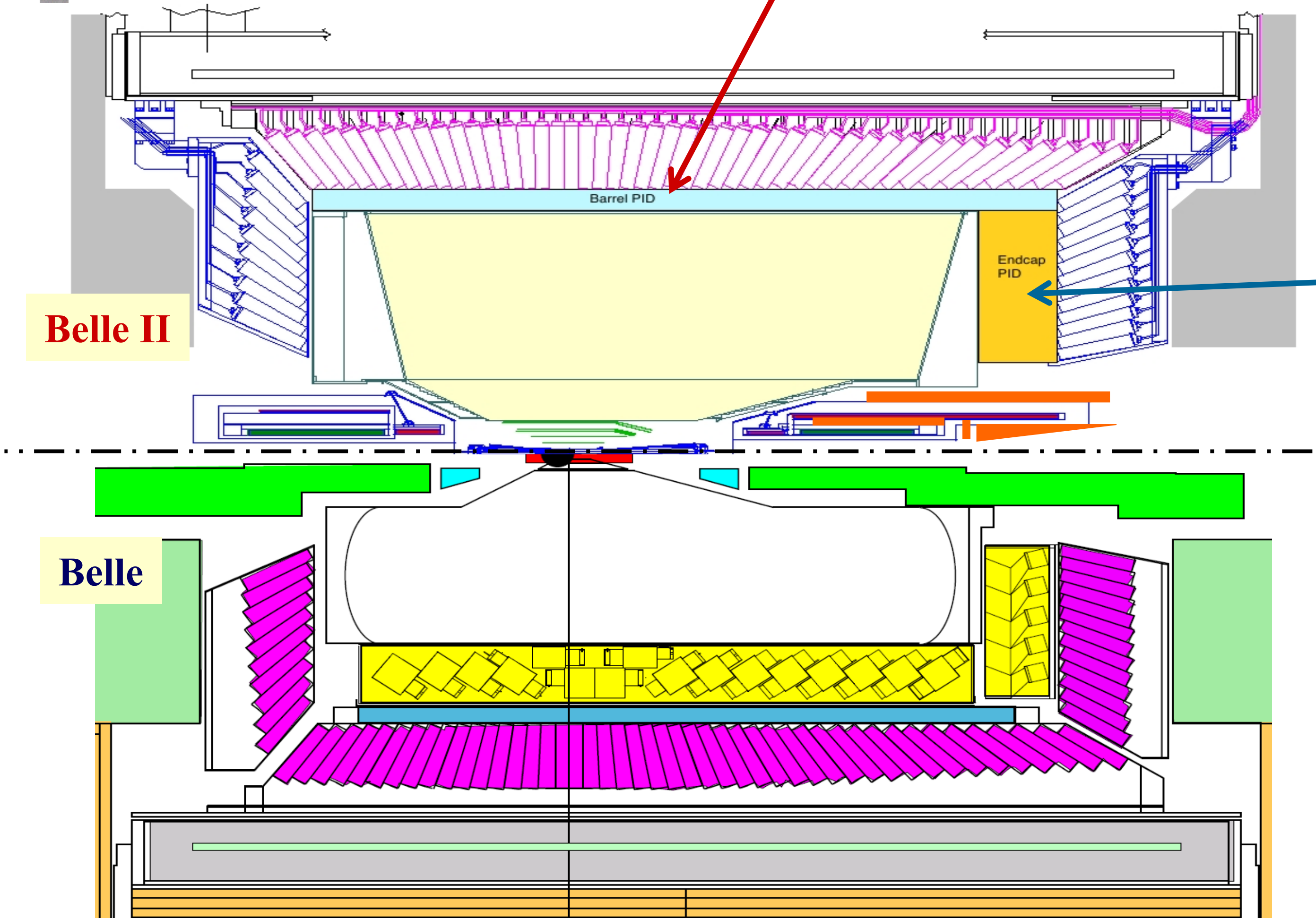


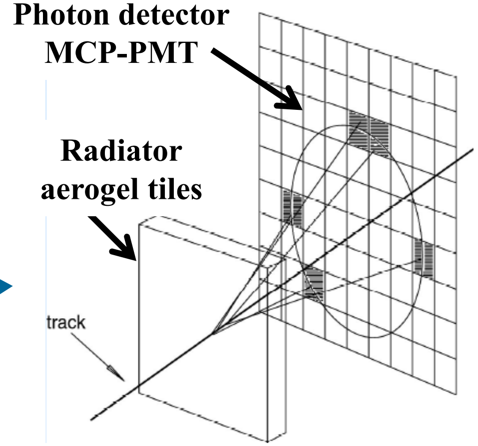
Particle ID: TOP (Barrel) & RICH(Forward Endcap)

Cherenkov ring in quartz bar: difference of propagation time for K/π is ~100ps

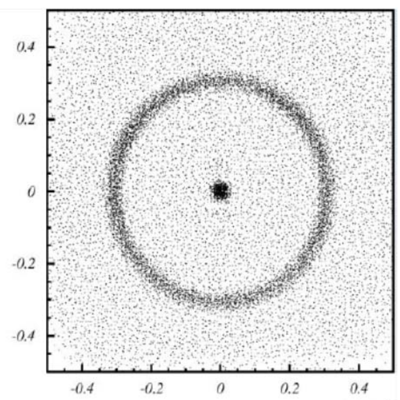








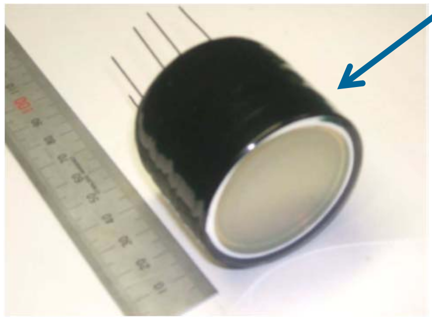
4σ K/π separation in 1-4GeV



Electromagnetic calorimeter and muon-KL detector

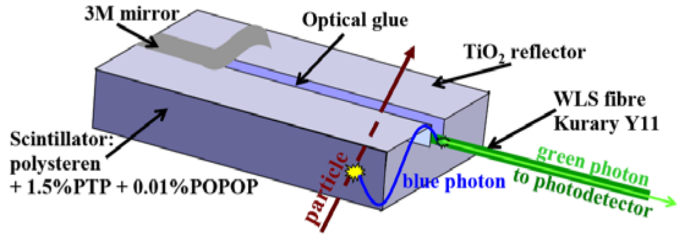
To keep Electromagnetic calorimeter resolution with pile up:

- ❖ **Barrel: Keep CsI(Tl) + improve read out**
- ❖ **Endcap: Replace with pure CsI (shorter decay time) + photopentode + faster read out**



To keep KLM efficiency:

- ❖ **Barrel: Keep RPC**
- ❖ **Endcap: Replace with scintillator strips + WLS read out by SiPM**



Organization

- ❖ **Belle II is a new international collaboration (Spokesperson Peter Križan, Ljubljana) with the most Belle members continuing with new project +**
  - ❖ **Many new collaborators from new institutes joined last two years**
  - ❖ **Open for new groups**
- ❖ **Current Status of the project:**
  - ❖ **SuperKEKB is a lab priority**
  - ❖ **The Japanese government has allocated in FY 2009 ~$32 M for R&D**
  - ❖ **KEK has submitted a budget request for FY 2010 and beyond of $350 M for construction; Funding in other countries on the way**
  - ❖ **TDR to be submitted by March 2010**
  - ❖ **Start data taking in 2013**

Summary

- **Thanks to B-factories CKM is firmly established as the main source of CP asymmetry in weak interaction.**
- **New sources of CP violation/ new physics coupled to flavour sector are anticipated by many models. With higher sensitivity we have a good chance to find them.**
- **In spite of new player (LHCb) in the field, higher luminosity e^+e^- machines remain competetive/complementory tool for studying flavour physics.**
- **Major upgrade of KEKB and Belle planned for 2009-2012**

to start doing exciting physics in 2013