Prospects of SuperKEKB and Belle-II

Peter Križan

University of Ljubljana and J. Stefan Institute

Prospects on Current & Future Collider Physics

WCU opening ceremony, Daegu, Sept. 25, 2009

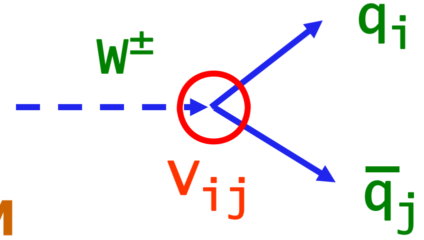
Contents

- Highlights from Belle
- Physics case for a Super B factory
- Accellerator upgrade → SuperKEKB
- Detector upgrade → Belle-II
- Summary

B factory physics program

B factory main task: measure CP violation in the system of B mesons

specifically: various measurements of complex elements of Cabbibo-Kobayashi-Maskawa matrix

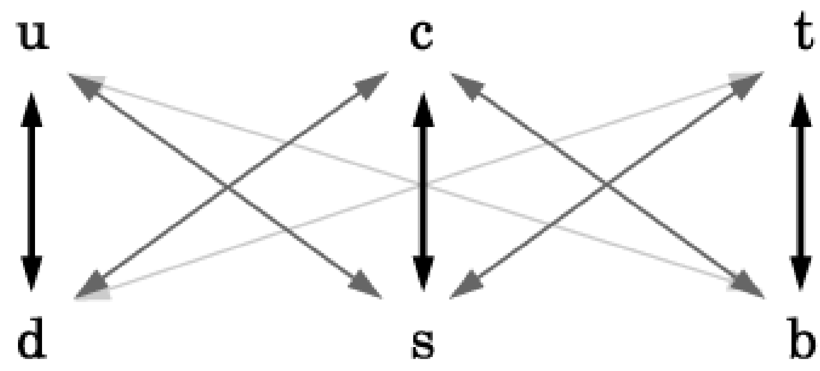


CKM matrix is unitary

deviations could signal processes not included in SM

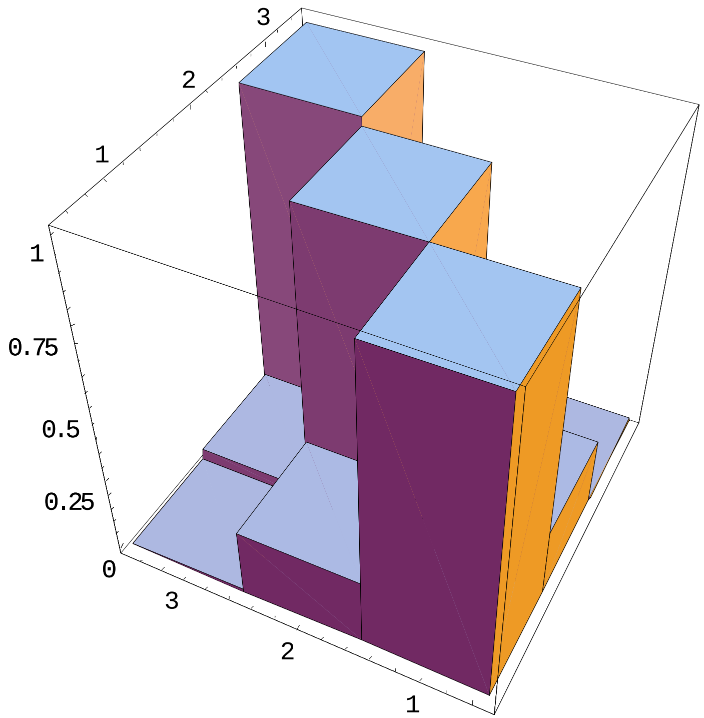
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

CKM matrix

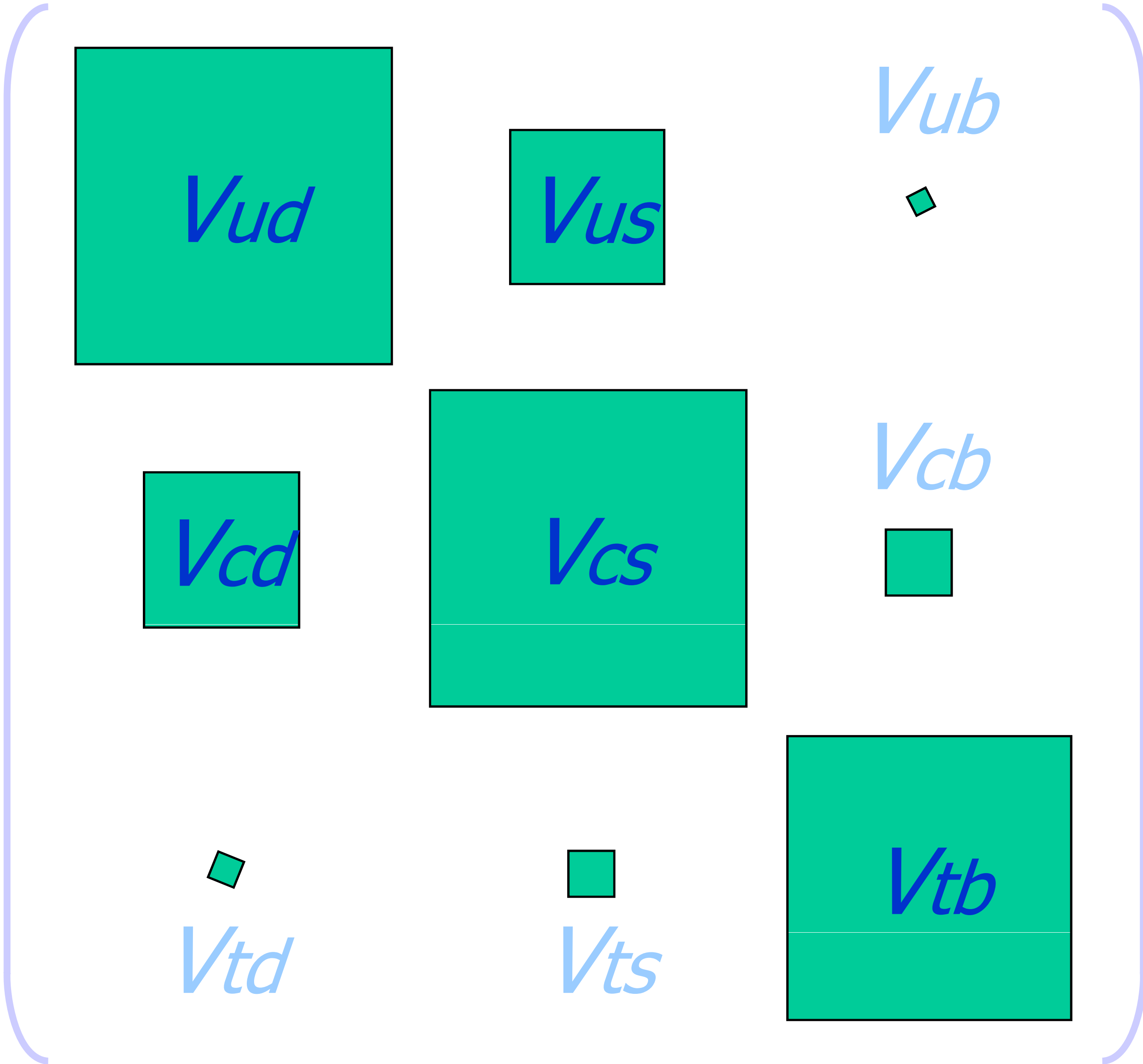


Transitions between members of the same family more probable (=thicker lines) than others

→CKM: almost a diagonal matrix, but not completely →



→CKM: almost real, but not completely!



CKM matrix

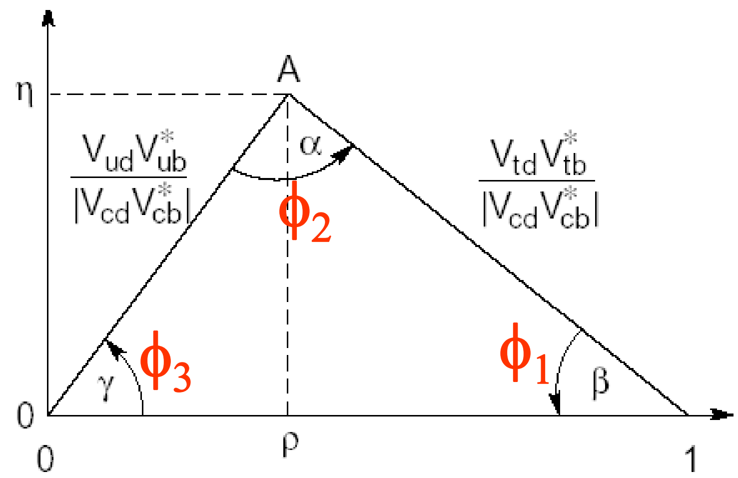
Wolfenstein parametrisation: expand in the parameter λ ($=\sin\theta_c=0.22$)

A, ρ and η: all of order one

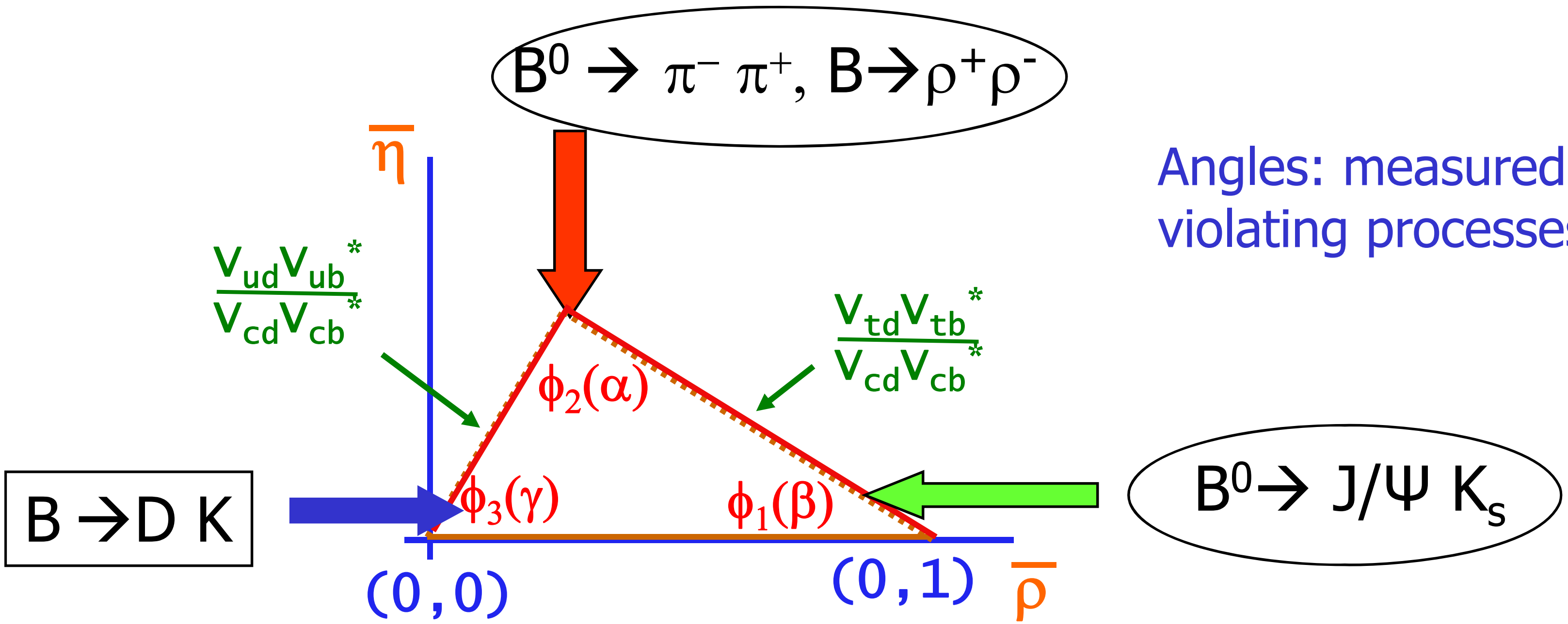
$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Unitarity condition:

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



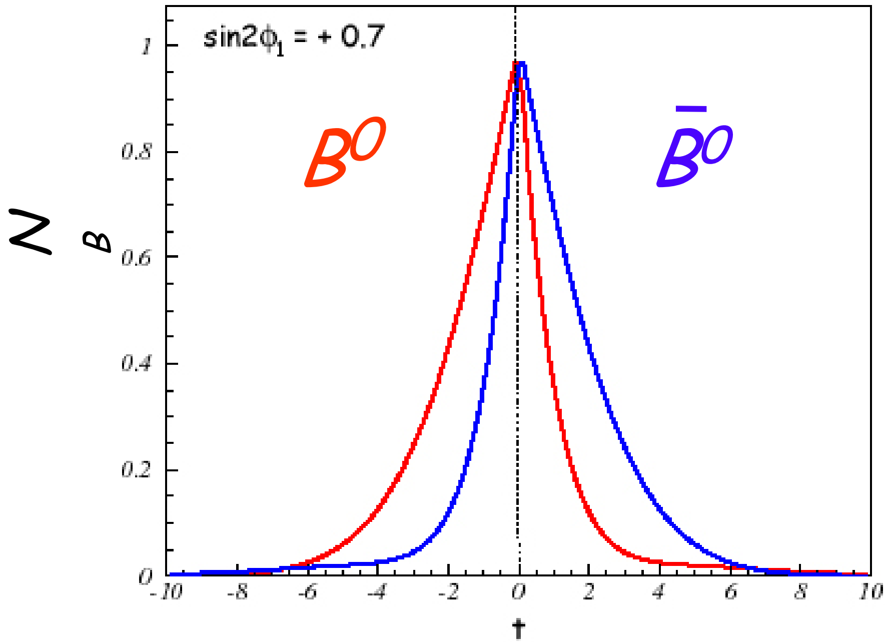
Three Angles: (ϕ_1,ϕ_2,ϕ_3) or (β, α, γ)

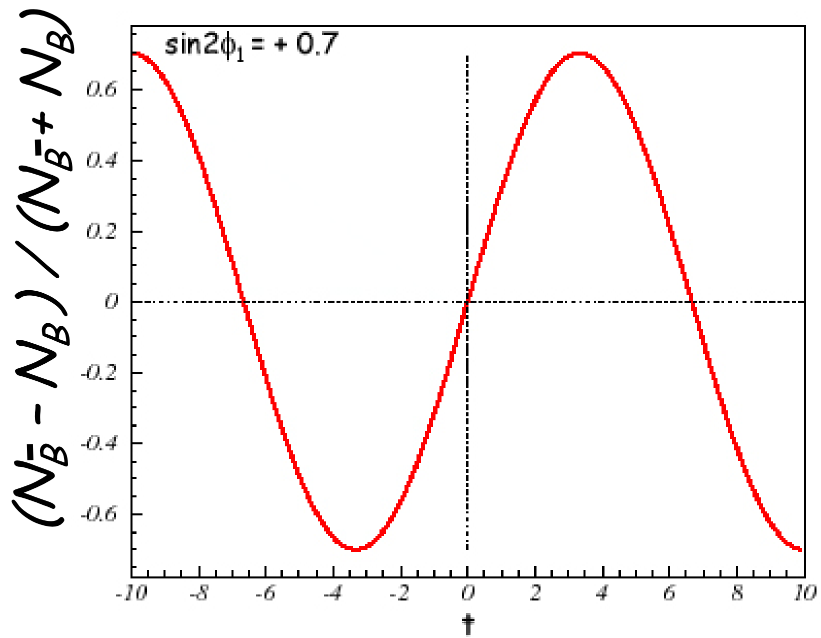


Angles: measured in CP violating processes

Big Questions: *Are determinations of* ***angles*** *consistent with determinations of the* ***sides*** *of the triangle? Are angle determinations from loop and tree decays consistent?*

CP Violation in B decays to CP eigenstates f_{CP}

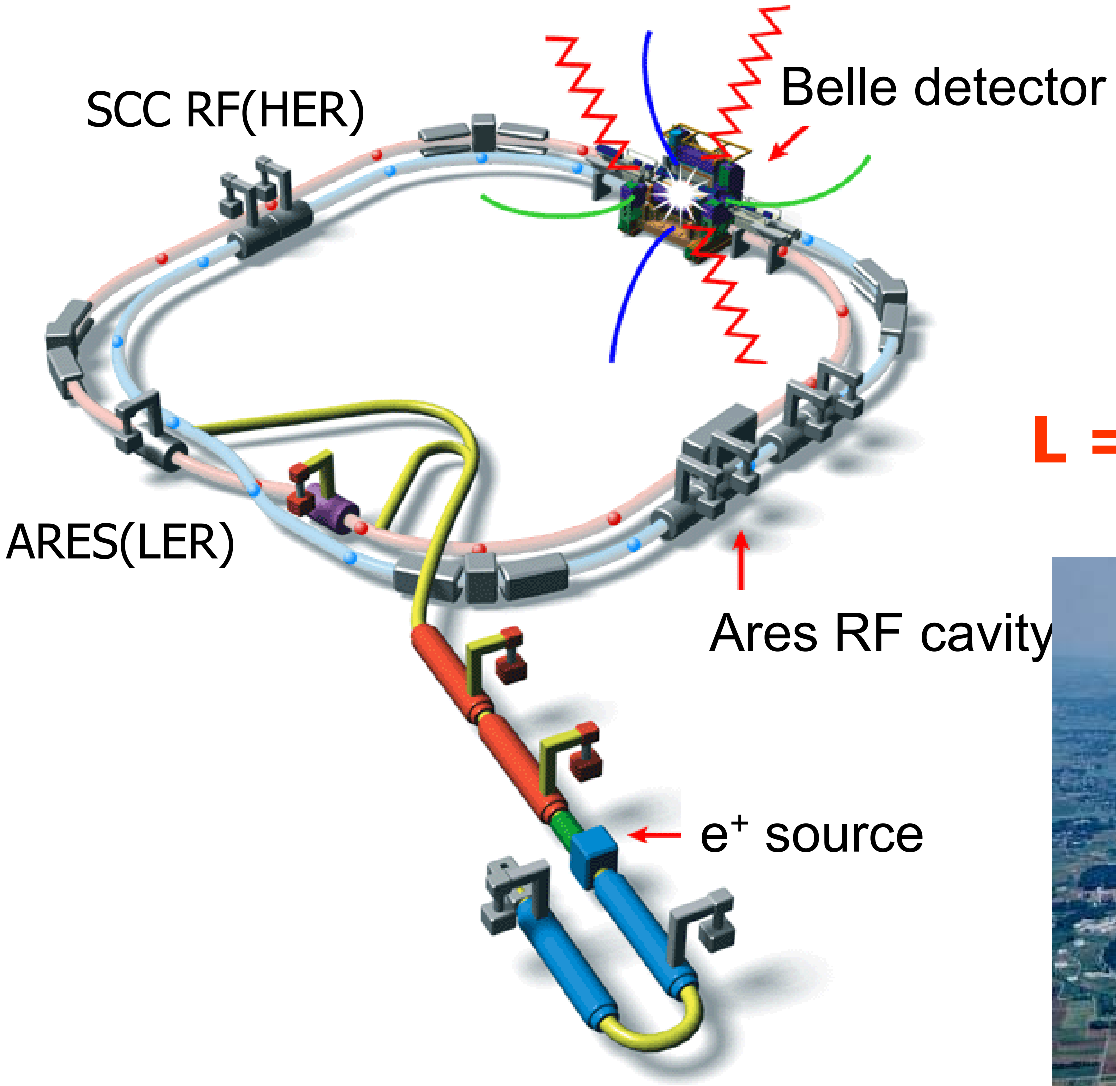




$$A_{CP}(t)=\frac{\Gamma(\overline{B}^0(t)\to f_{CP})-\Gamma(B^0(t)\to f_{CP})}{\Gamma(\overline{B}^0(t)\to f_{CP})+\Gamma(B^0(t)\to f_{CP})}=-\xi_f\sin2\phi_1\sin\Delta m_B t$$

$\xi_f = \pm1$ for $CP = \pm1$

The KEKB Collider

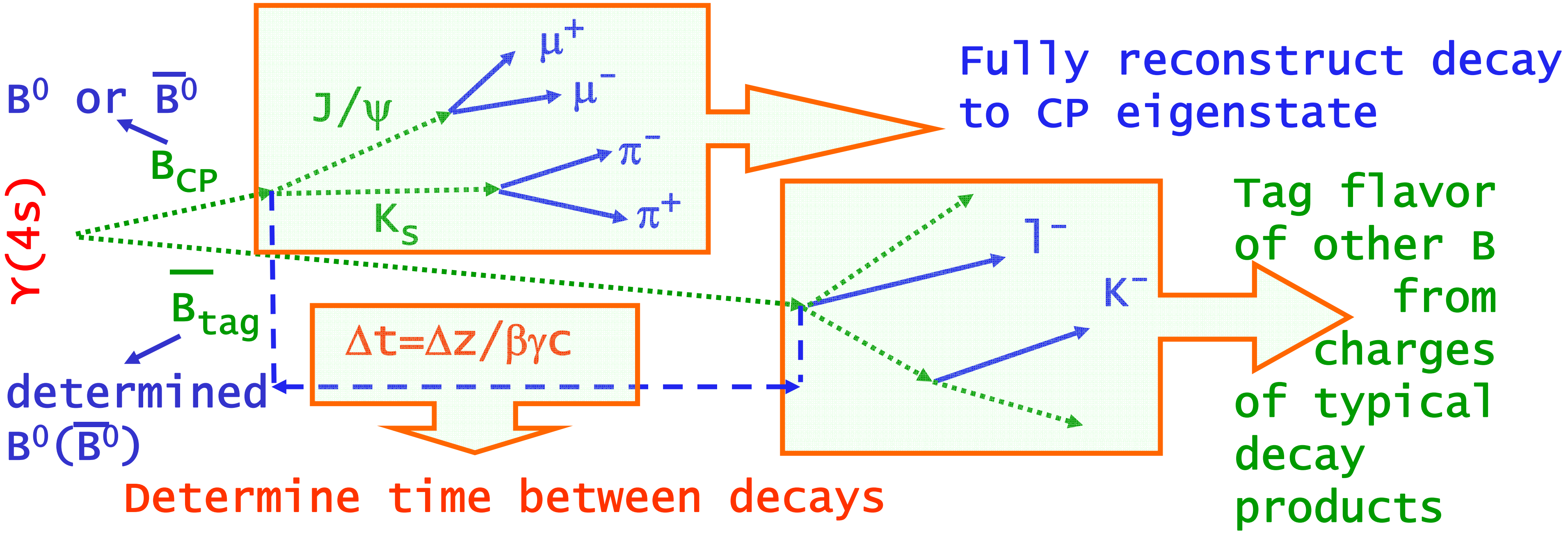


8 x 3.5 GeV
22mrad crossing angle

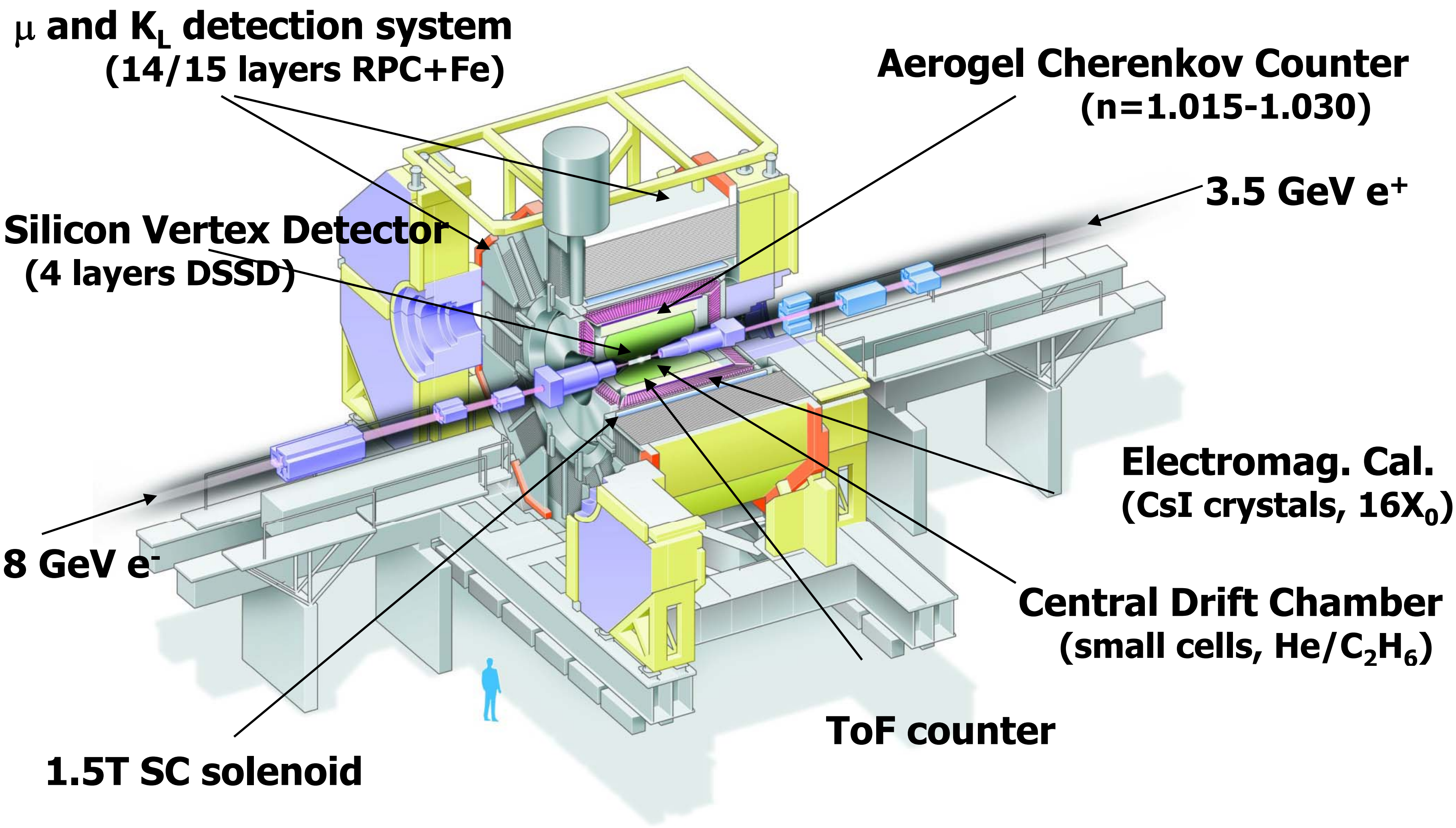
World record:

L = 2.1 x 10^{34}/cm^2/sec

Principle of measurement



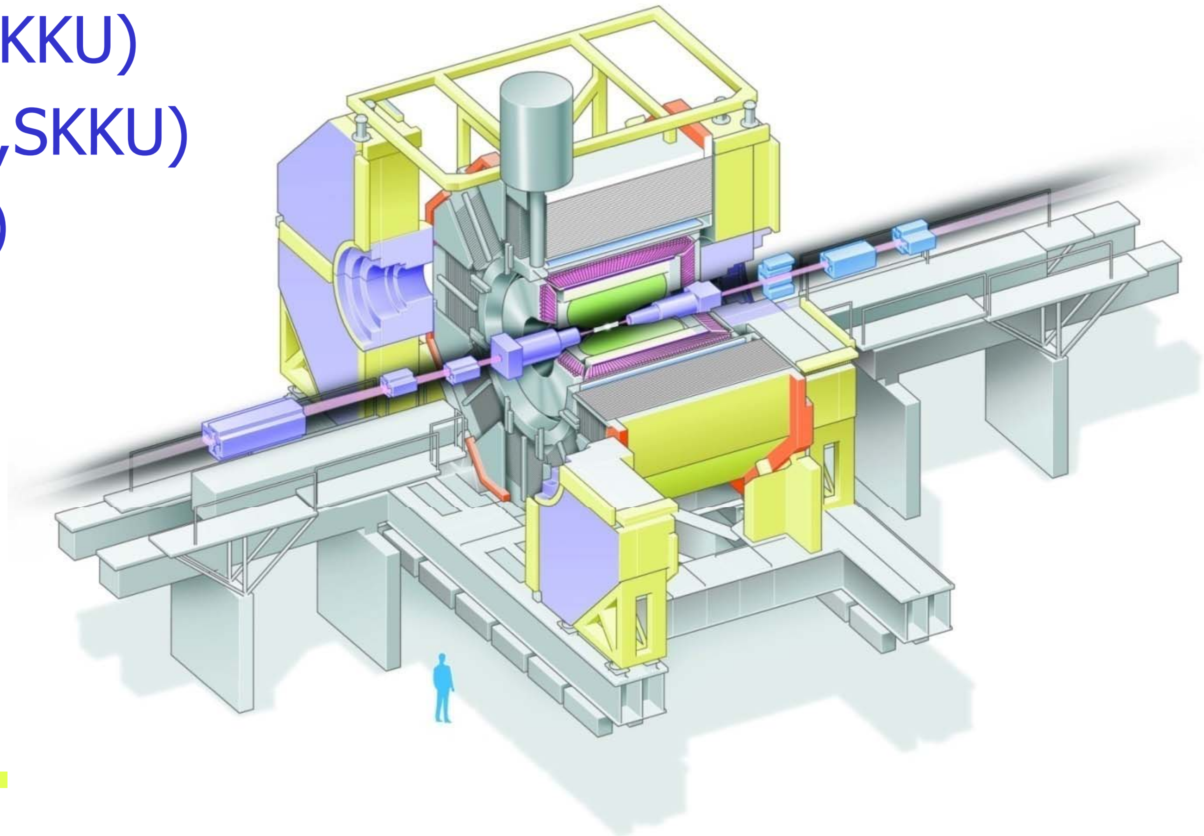
Belle spectrometer at KEK-B



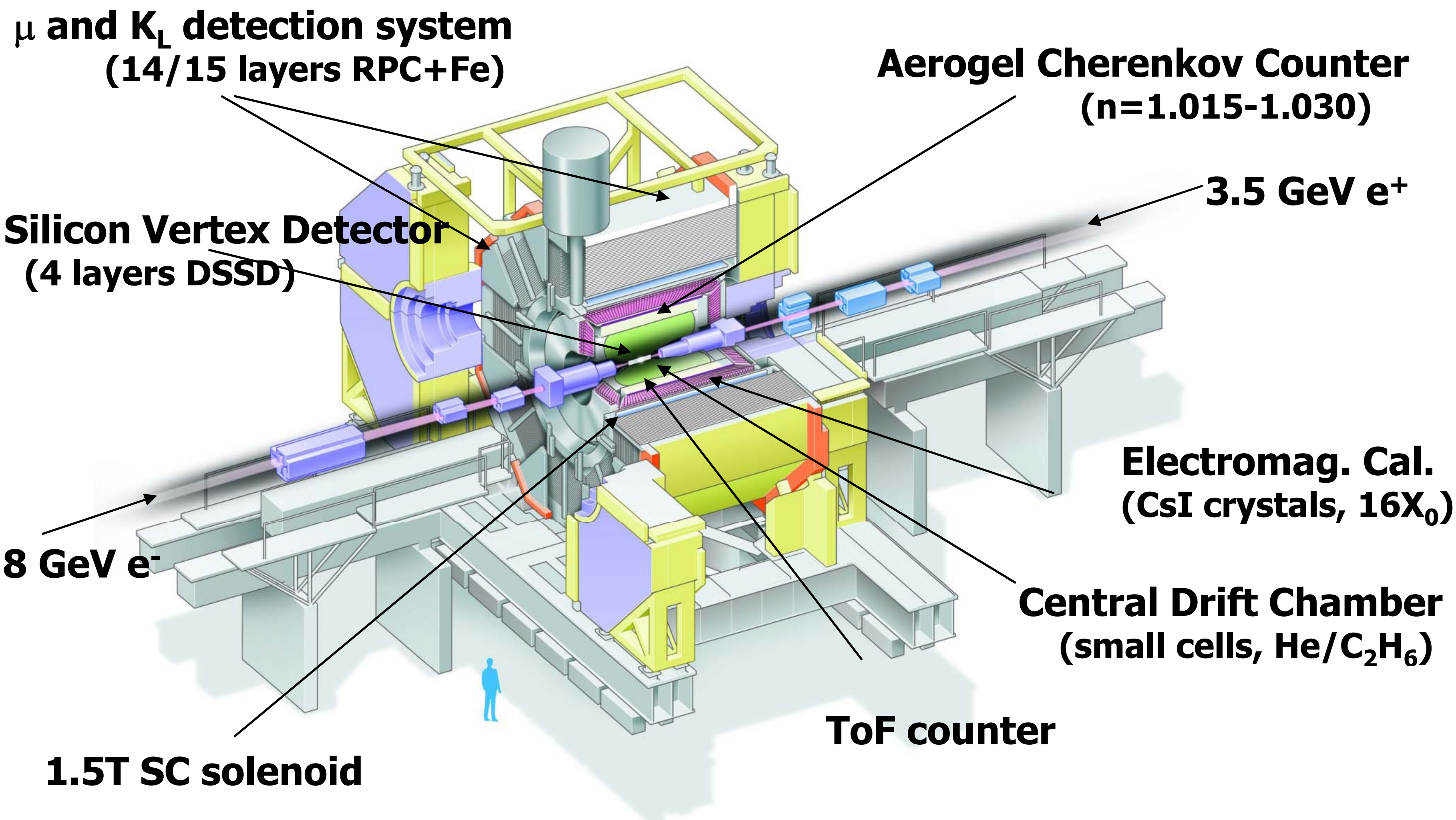
Super KEKB Quest for BSM

Korean contribution to the Belle spectrometer

- Major role in ECL construction (SNU,YU)
- ECL trigger/software (Hanyang,SNU,YU)
- EID software development(YU)
- TOF calibration (SKKU)
- DAQ upgrade (KU,SKKU)
- GDL upgrade (KU)
- SVD (KNU)



Belle spectrometer at KEK-B



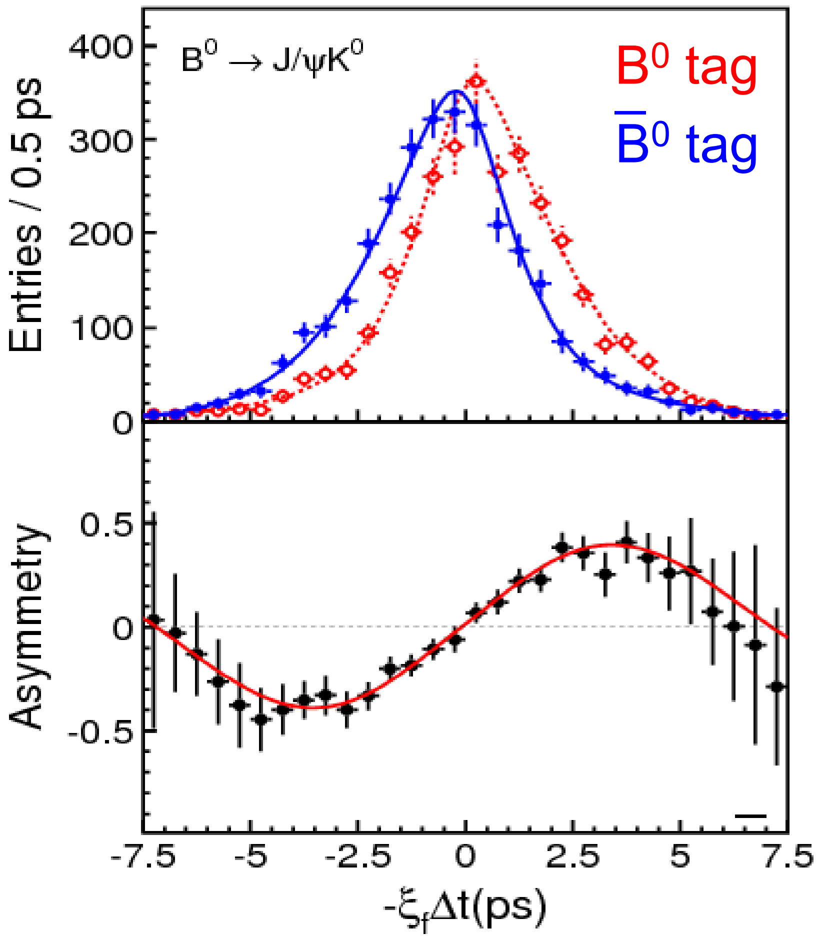
+ an extremely well operating KEK-B collider →

CP violation in the B system

CP violation in B system: from the discovery (2001) to a precision measurement (2006)

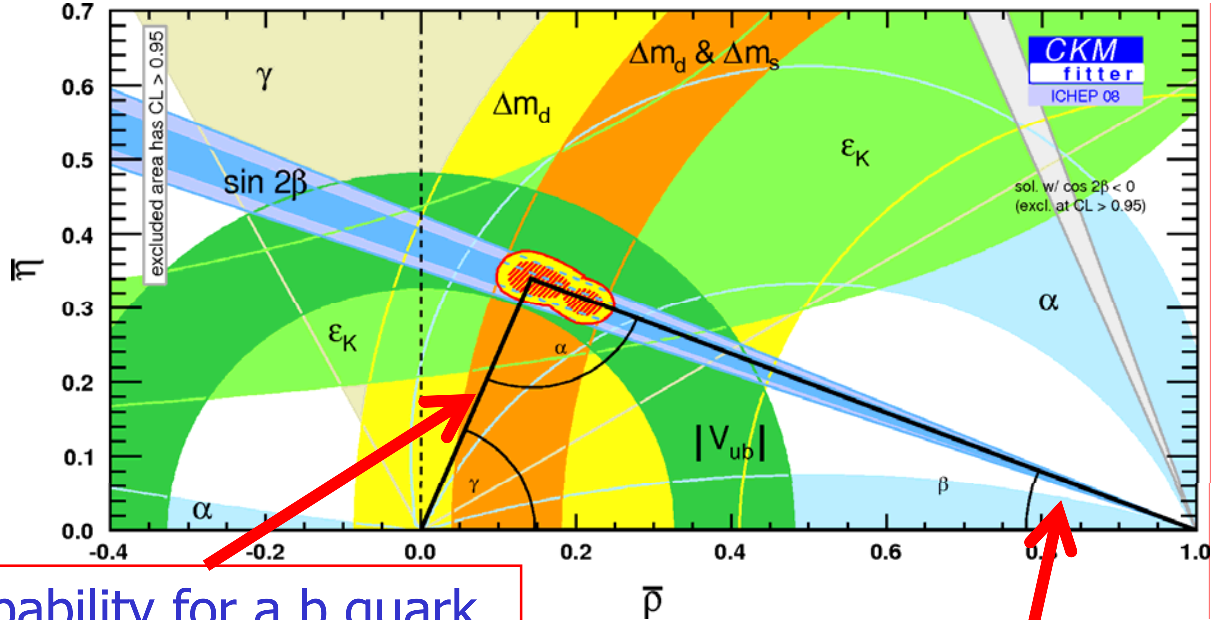
$\sin 2\phi_1 = \sin 2\beta$ from $b \to c\bar{c}s$

535 M $B\bar{B}$ pairs



$\sin 2\phi_1$= 0.642 ±0.031 (stat) ±0.017 (syst)

All measurements combined...



Probability for a b quark to turn into a u quark → determines the length of the side $\mathbf{V_{ub}}$

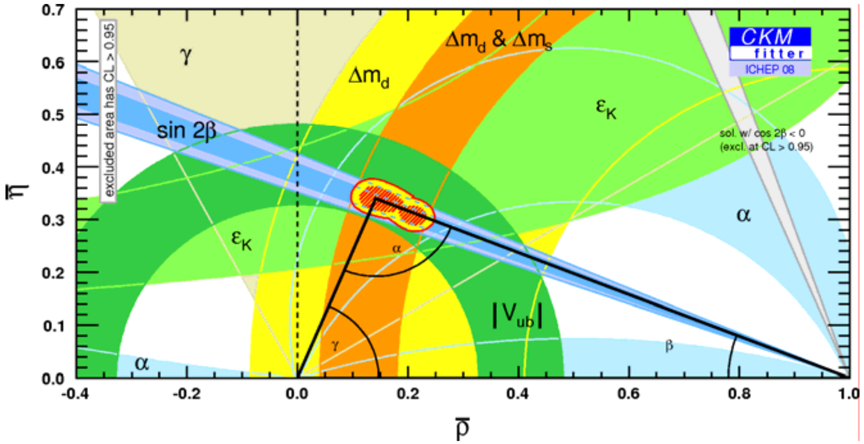
CP asymmetry oscilation amplitude → angle $\phi_1 = \beta$

Constraints from measurements of angles and sides of the unitarity triangle

→ Remarkable agreement

Consistent picture

Relations between parameters as expected in the Standard model →



→ Nobel prize 2008!

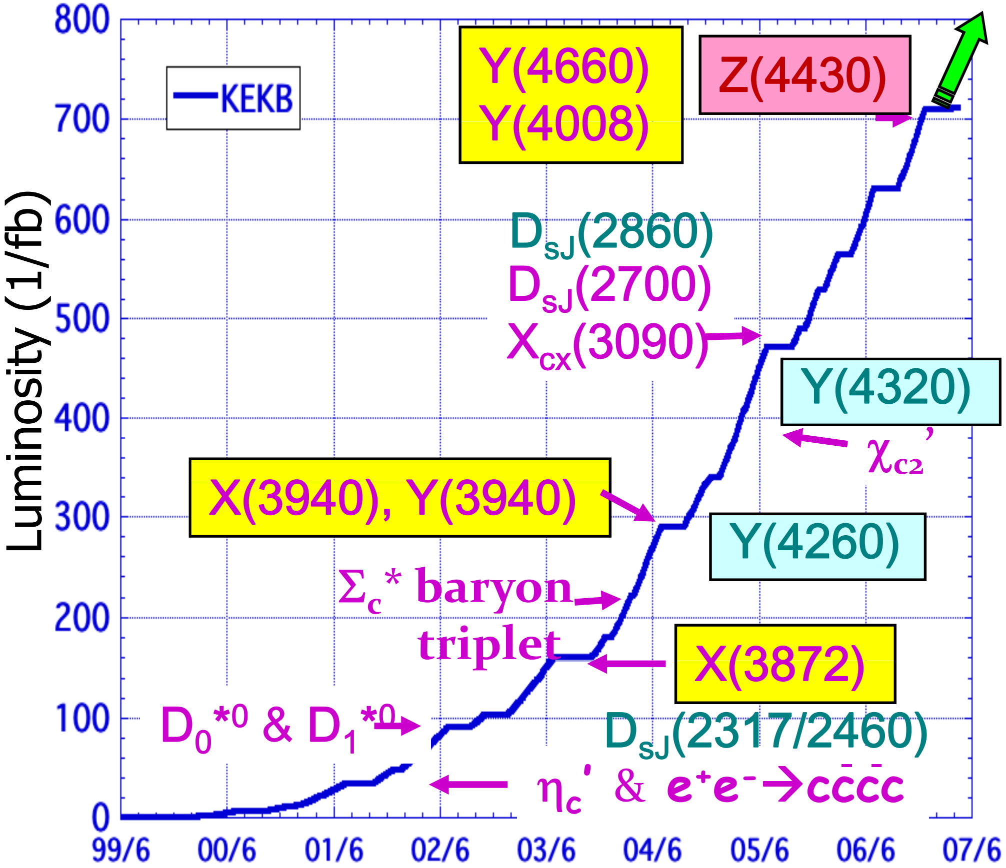

Also for us a good reason to celebrate...

B factories: a success story

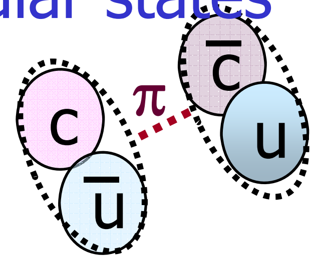
- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., $B\rightarrow\tau\nu$, $D\tau\nu$) by fully reconstructing the other B meson
- Observation of D mixing
- CP violation in $b\rightarrow s$ transitions: probe for new sources if CPV
- Forward-backward asymmetry (A_{FB}) in $b\rightarrow sl^+l^-$ has become a powerfull tool to search for physics beyond SM.
- Observation of new hadrons

New hadrons at B-factories

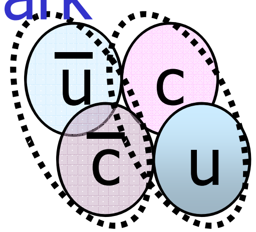
Discoveries of many new hadrons at B-factories have shed light on a new class of hadrons beyond the ordinary mesons.



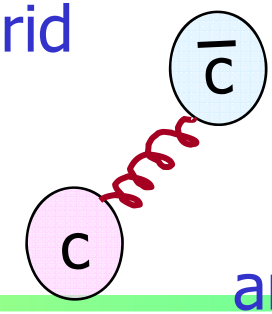
Molecular states



Tetra-quark



Hybrid



and more...

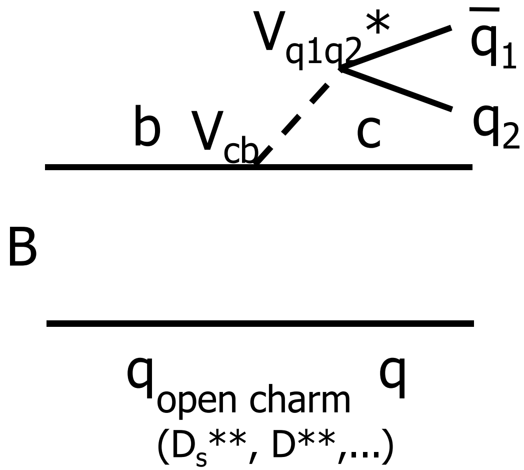
Spectroscopy @ B-factories

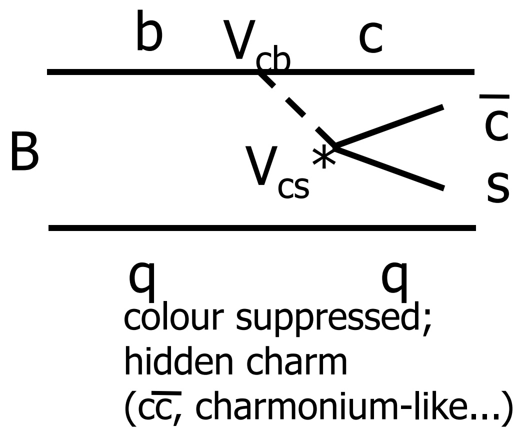
Production
@ B-factories
open and hidden charm;
clean exp. environment;

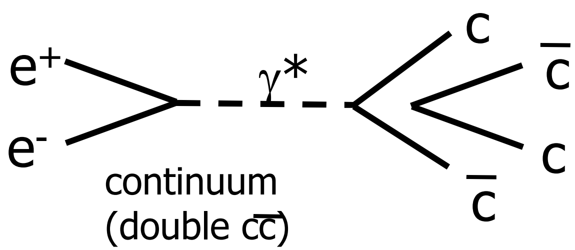
various methods related to different prod. mechanisms;

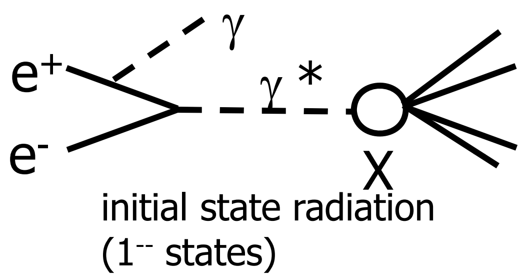
rich harvest of previously unknown states at B-factories;

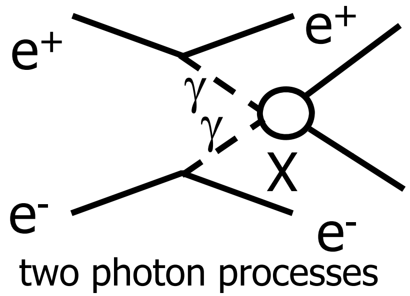
spectroscopy:
tests of QCD, bounding q's and g's in hadrons











Spectroscopy

Exotic states

- states other than $q_1\bar{q}_2$, $q_1q_2q_3$ not forbidden in SM;
- exotic J^{PC} (e.g. 0^{+-}, 1^{-+}, 2^{+-},... forbidden for $q\bar{q}$);
- exotic decay modes (not possible from $q\bar{q}$);
- strange properties (widths,...);

- pentaquarks: $q_1\bar{q}_2q_3q_4q_5$;
- hybrids: $c\bar{c}$ + g's;
- tetraquarks: diquark-antidiquark, $[\bar{c}\bar{q}][cq]$
- molecules: $M(\bar{c}q)M(c\bar{q})$, loosely bound mesons

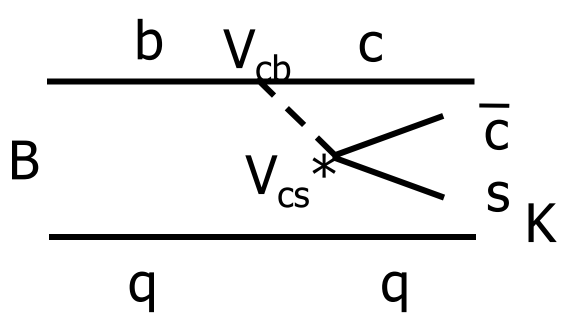
Spectroscopy

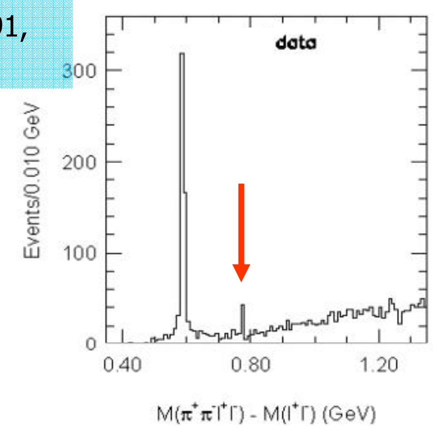
- X(3872)
  observed in B decays,
  B →(J/ψ ππ)K;
  charmonium-like;

  well established state;

$$M_{X(3872)} = 3871.2 \pm 0.5\ MeV$$
$$M_{X(3872)} - M_{D^{*0}} - M_{D^0} = -0.6 \pm 0.6\ MeV$$
$$\Gamma < 2.3\ MeV$$

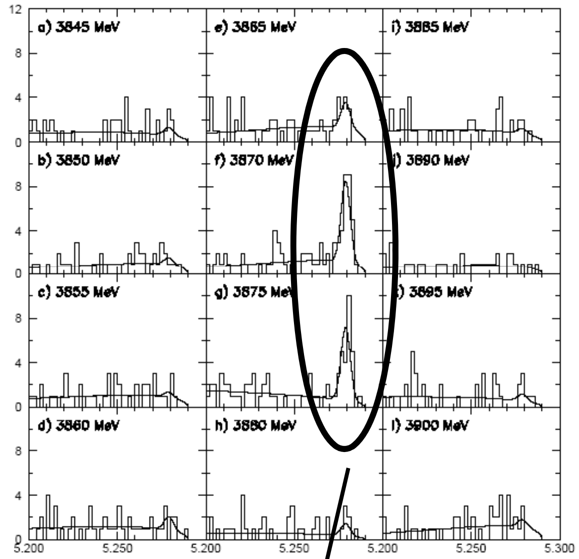
S.K. Choi, S.L. Olsen et al, Belle, PRL 91, 262001 (2003), 140fb^{-1}

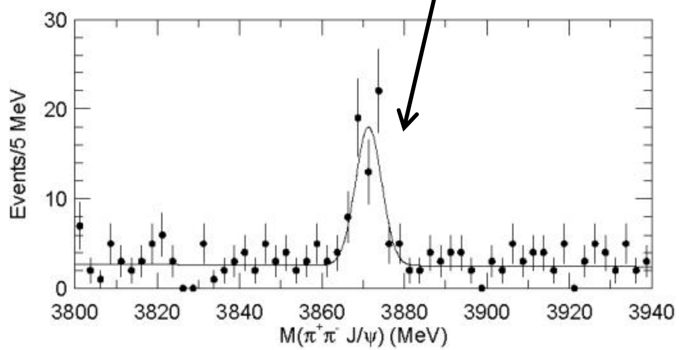


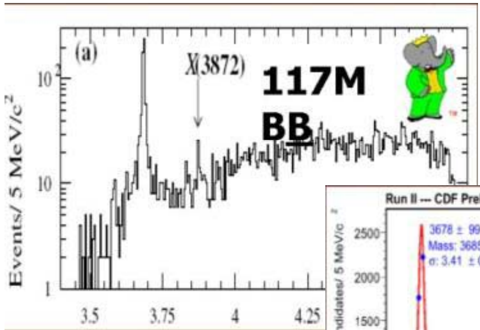


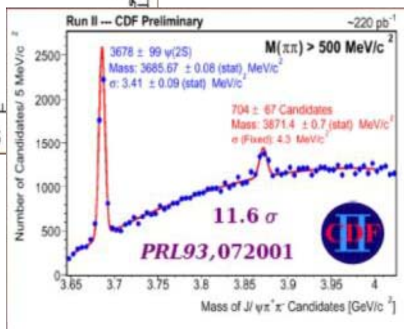
M_{bc} in 5 MeV bins of $M(\pi^+\pi^- J/\psi)$

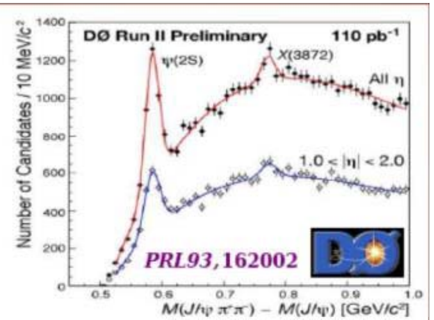
Belle, hep-ex/0505038, 250fb^{-1}











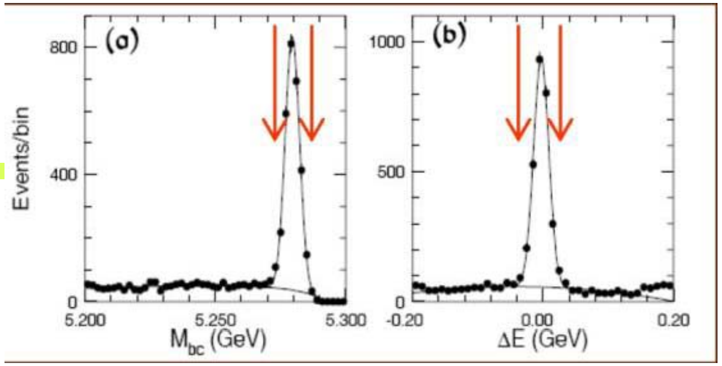
- The nature of X(3872) still not understood

Spectroscopy

- $Z^+(4430)$

  Belle, PRL100, 142001 (2008), 605 fb^{-1}

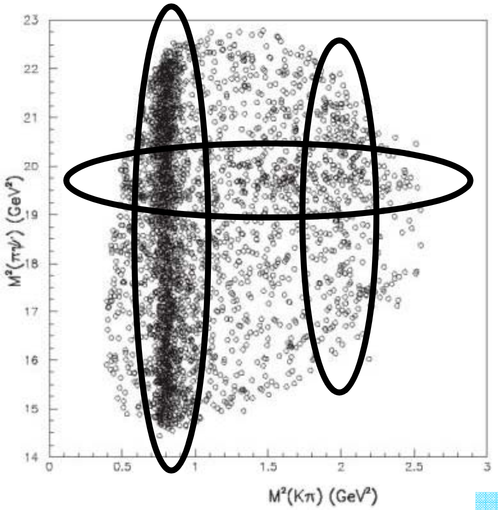
  $B \to (\psi'\pi^+)K$;
  $\psi' \to \ell\ell$, $J/\psi\pi\pi$;

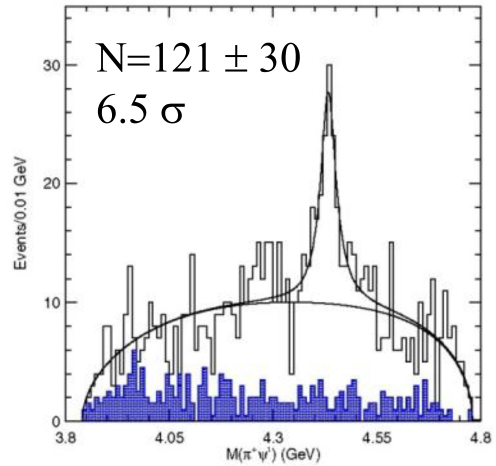


  Dalitz plot;
  K* veto;

  $\Rightarrow M(\psi'\pi^+)$;
  fit: BW + phase space;

$$M(Z) = (4433 \pm 4 \pm 2)\ MeV$$
$$\Gamma(Z) = (45 \pm^{18}_{13} \pm^{30}_{13})\ MeV$$





  signal stable in subsamples, w.r.t. K* veto, etc.;

  known S-, P- and D-wave $K\pi$ resonances tried, cannot reproduce the peak;
  first charged charmonium-like resonance;

possibilities:
tetraquark, radial excitation of $X^+(3872)$ ($J^P=1^+$; neutral partner?);
$D^*D_1(2420)$ threshold effect;
$D^*D_1(2420)$ molecule ($J^P=0^-,1^-,2^-$;decays to $D^*D^*\pi$?)

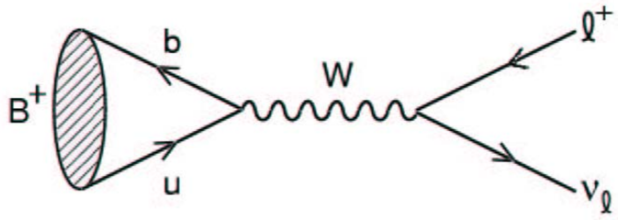
L.Maiani et al., arxiv:0708.3997
J. Rosner, PRD74, 114002 (2007)
C. Meng et al., arxiv:0708.4222

Korean contributions to this success story

- Discovery of X(3872), Y(3940), $Z(4430)^+$ by S.K.Choi (Gyeongsang) & S.Olsen (SNU)
- Evidence of $B^0 \rightarrow \pi^0 \pi^0$ by S.H.Lee (SNU)
- $B^0 \rightarrow J/\psi\ \pi^0$ tcpv by S.E.Lee (SNU)
- $B^+ \rightarrow K_1(1270)\ \gamma$ by H.Y.Yang (SNU)
- $B \rightarrow K^{*0} \rho^0$ by S.H.Kyeong (Yonsei)
- $D_s \rightarrow K^+K^-\pi^+$ DCSD by B.R.Ko and E. Won (Korea)

Purely leptonic decay B→τ ν

- Challenge: B decay with at least two neutrinos
- Proceeds via W annihilation in the SM.



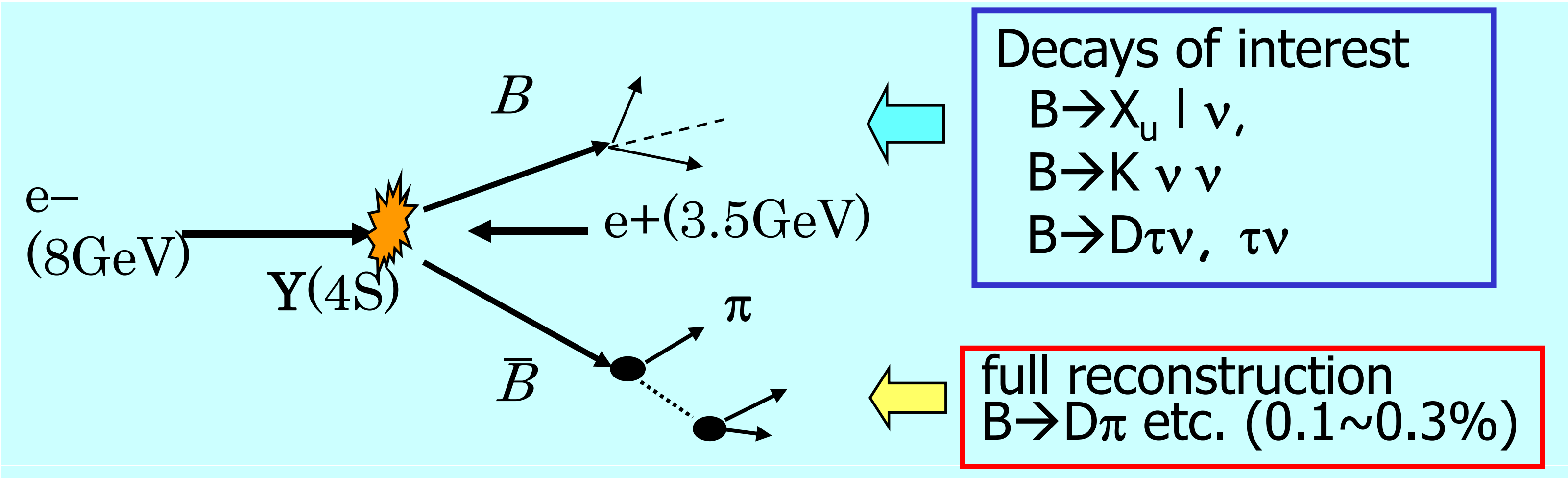
- Branching fraction

$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

- Provide information of $f_B|V_{ub}|$
  - $|V_{ub}|$ from $B \to X_u l \nu$ → f_B ⟺ cf) Lattice
  - $Br(B \to \tau\nu)/\Delta m_d$ → $|V_{ub}| / |V_{td}|$
- Limits on charged Higgs

Full Reconstruction Method

- Fully reconstruct one of the B's to
  - Tag B flavor/charge
  - Determine B momentum
  - Exclude decay products of one B from further analysis

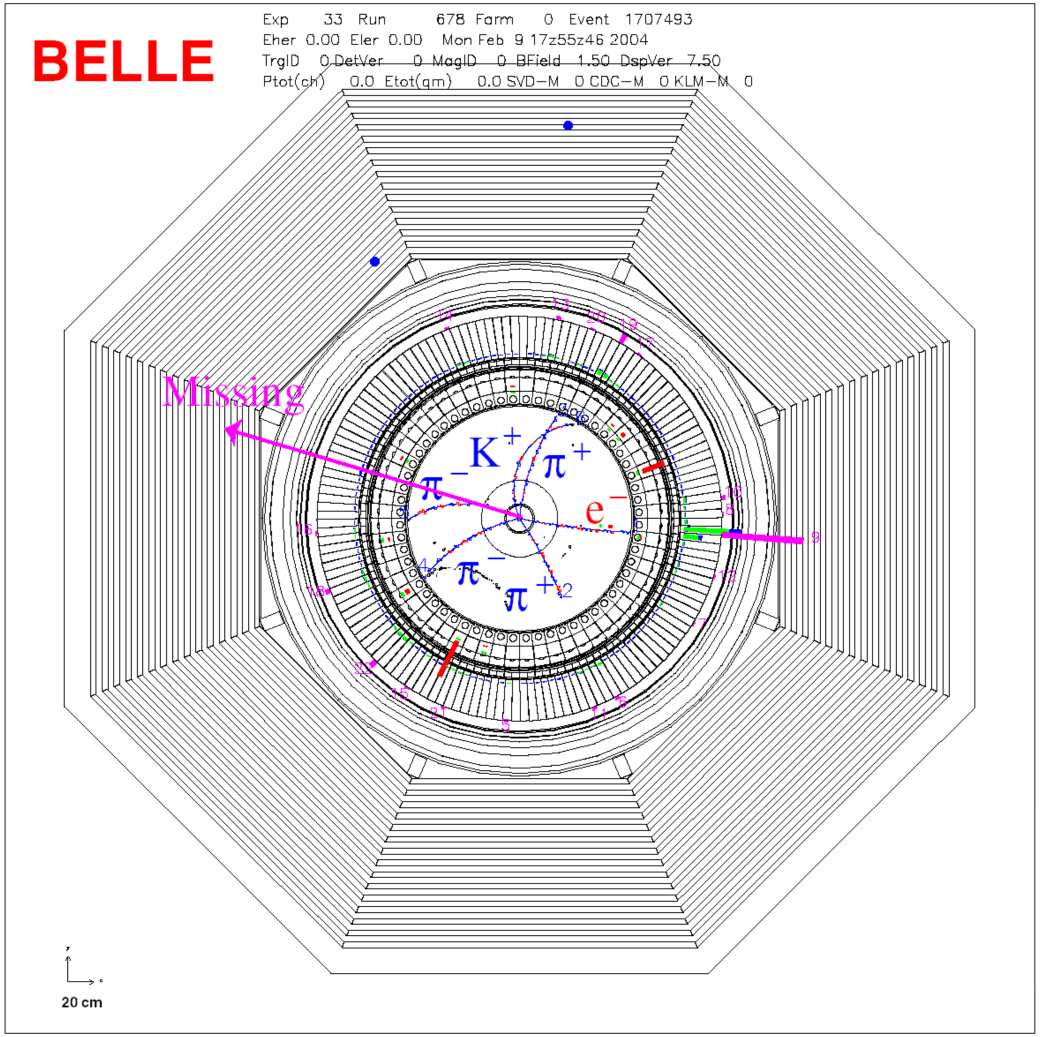


→ Offline B meson beam!

Powerful tool for B decays with neutrinos

Event candidate $B^- \rightarrow \tau^- \nu_\tau$

$$B^+ \to D^0\pi^+$$
$$(\to K\pi^-\pi^+\pi^-)$$
$$B^- \to \tau(\to e\nu\bar{\nu})\nu$$



$B \to \tau\ \nu$

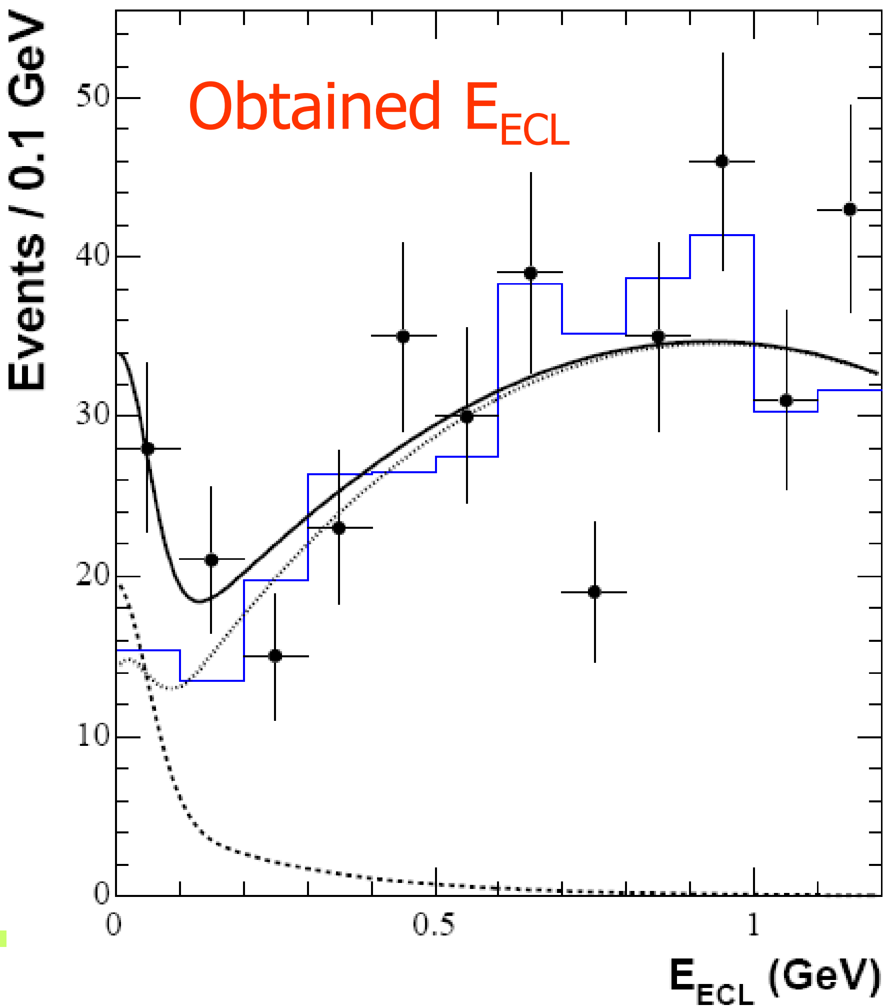
Submitted to PRL, hep-ex/0604018

τ decay modes

$$\tau^- \to \mu^- \nu \bar{\nu}, e^- \nu \bar{\nu}$$

$$\tau^- \to \pi^- \nu, \pi^- \pi^0 \nu, \pi^- \pi^+ \pi^- \nu$$

- Cover 81% of τ decays
- Efficiency 15.8%



Event selection

- Main discriminant: extra neutral ECL energy

Fit to $E_{residual}$ → $17.2^{+5.3}_{-4.7}$ signal events.

→3.5σ significance including systematics

$B \to \tau \nu_\tau$

$$BF(B^+ \to \tau^+ \nu_\tau) = (1.79^{+0.56+0.46}_{-0.49-0.51}) \times 10^{-4}$$

$$\Gamma^{SM}(B^+ \to \ell^+ \nu) = \frac{G_F^2}{8\pi} |V_{ub}|^2 f_B^2 m_B m_\ell^2 \left(1 - \frac{m_\ell^2}{m_B^2}\right)$$

→ Product of B meson decay constant f_B and CKM matrix element $|V_{ub}|$

$$f_B \times V_{ub} = \left(10.1^{+1.6+1.3}_{-1.4-1.4}\right) \times 10^{-4}\, GeV$$

Using $|V_{ub}| = (4.39 \pm 0.33) \times 10^{-3}$ from HFAG

$$f_B = 229^{+36+34}_{-31-37}\, MeV$$

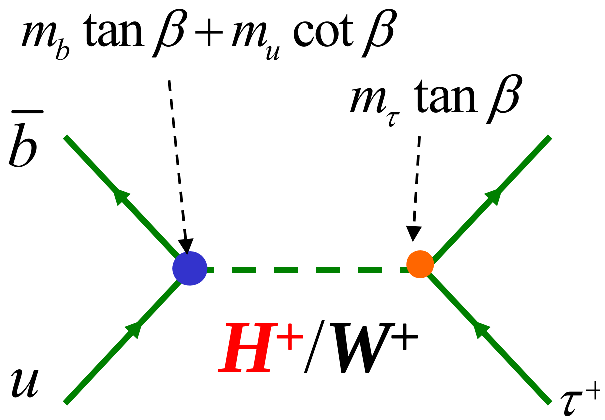
15%   15% = 13%(exp.) + 8%(V_{ub})

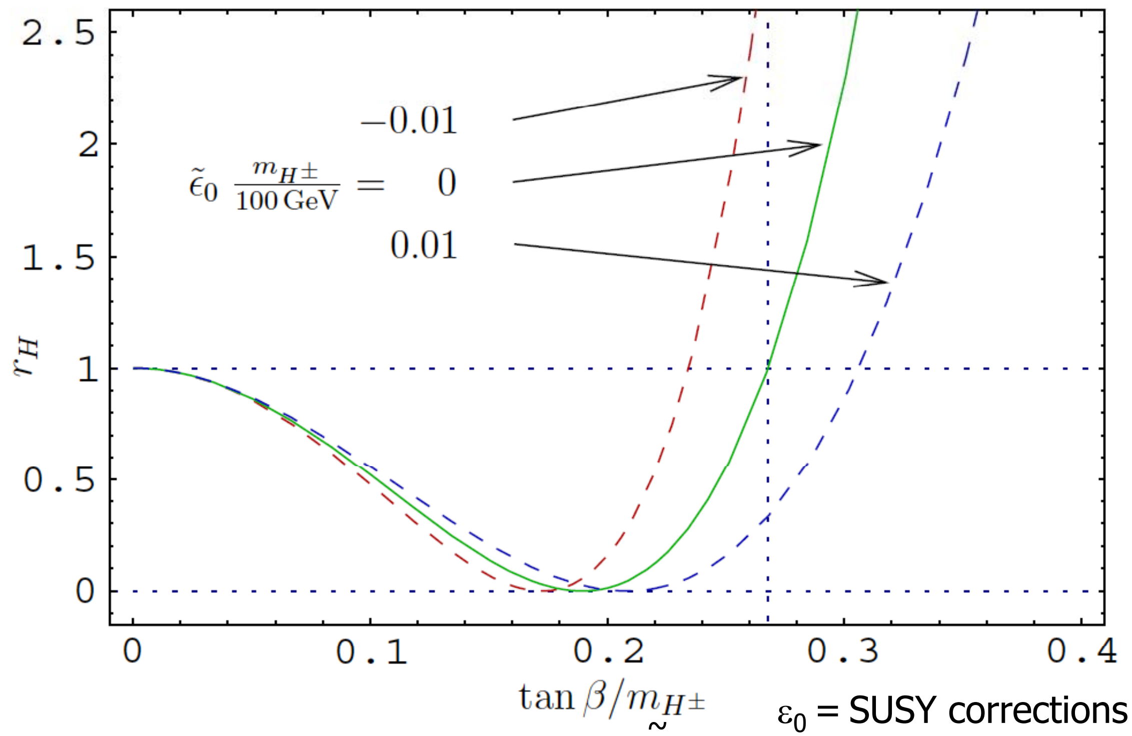
First measurement of f_B!

$f_B = (216 \pm 22)$ MeV from unquenched lattice calculation

[HPQCD, Phys. Rev. Lett. 95, 212001 (2005)]

Charged Higgs contribution to $B \to \tau \nu$





ε_0 = SUSY corrections to b Yukawa coupling

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\rm SM} \times r_H,$$

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

The interference is destructive in 2HDM (type II). $B > B_{SM}$ implies that H^+ contribution dominates

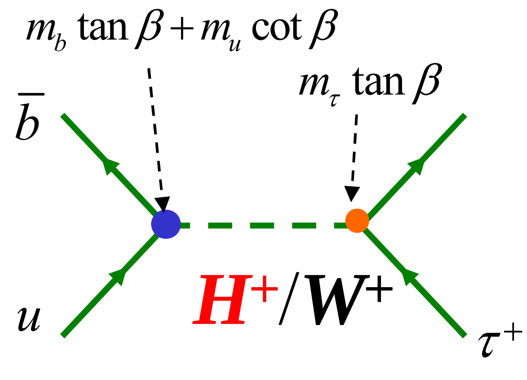
Phys. Rev. D **48**, 2342 (1993)

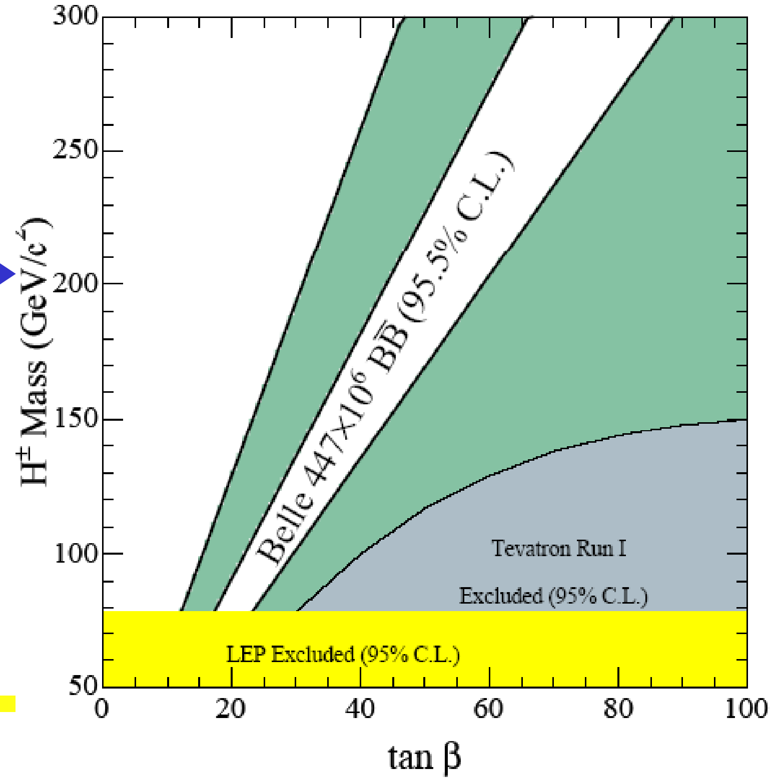
SM: $\mathcal{B}(B\to\tau\nu) = (0.78\ ^{+0.09}_{-0.13}) \times 10^{-4}$ (CKM fitter 2008 prediction)

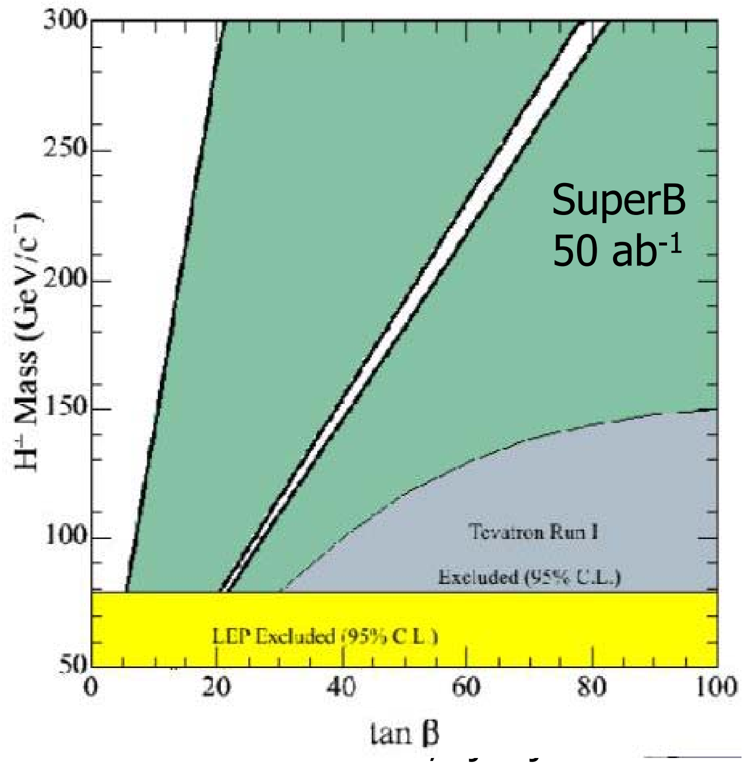
Charged Higgs limits from $B^- \to \tau^- \nu_\tau$

If the theoretical prediction is taken for $\mathbf{f_B}$
→ limit on charged Higgs mass vs. tanβ

$$r_H = \frac{BF(B \to \tau\nu)}{BF(B \to \tau\nu)_{SM}} = \left(1 - \frac{m_B^2}{m_H^2} \tan^2\beta\right)^2$$







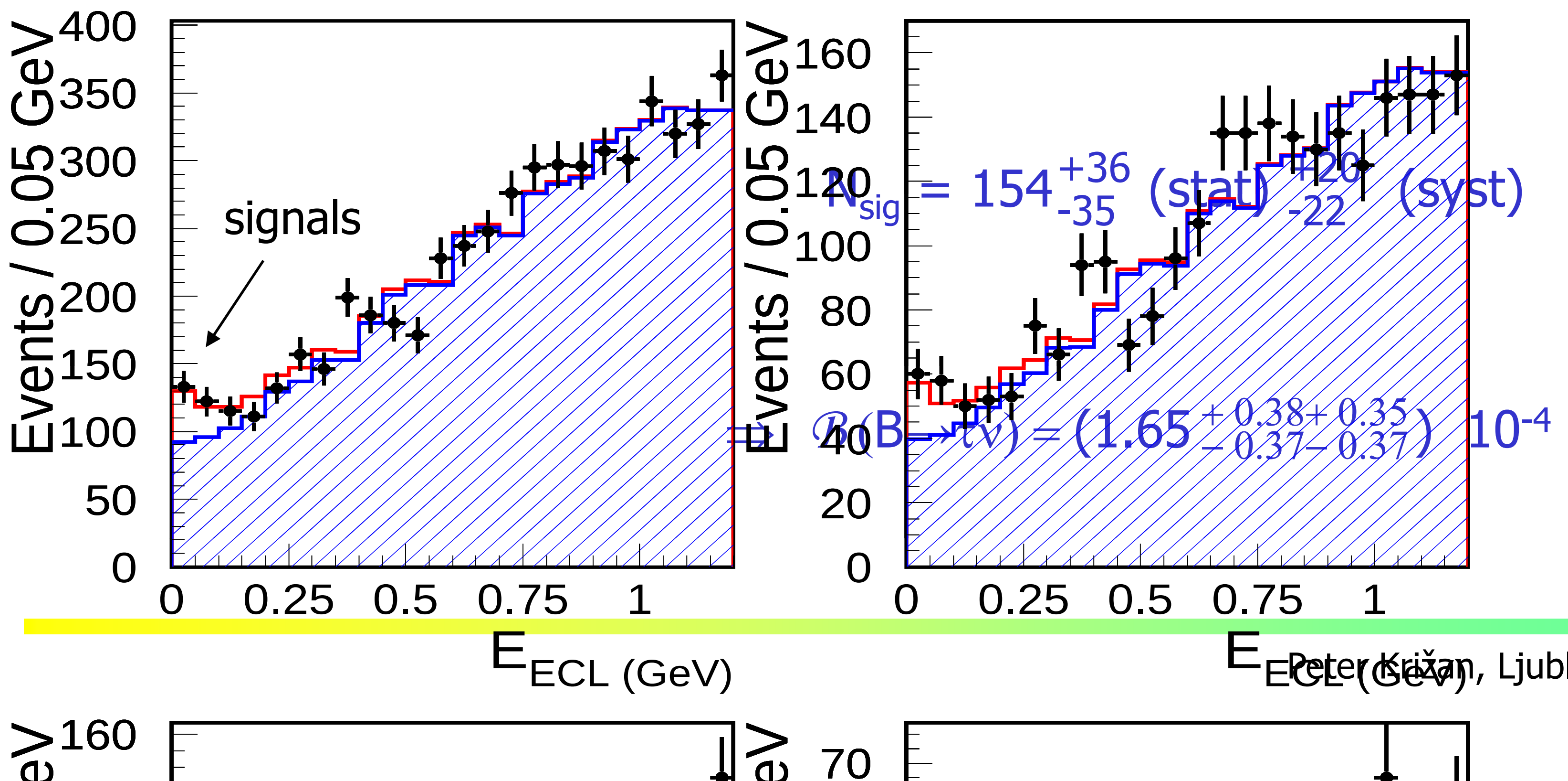
$B^+ \to \tau^+ \nu$ with the semileptonic tag

Method: Tag B on one side with the semileptonic decay B → $D^{(*)}$ l ν

→ Neutrino not reconstructed in the tagging B decay sequence → more background than in fully reconstructed hadronic decays, but higher efficiency → more signal events

Again look for τ signature with "extra" energy in the ECAL

657 M $B\bar{B}$ with $D^{(*)}$l ν tag



$N_{sig} = 154^{+36}_{-35}$ (stat) $^{+20}_{-22}$ (syst)

$\mathcal{B}(B \to \tau\nu) = (1.65^{+0.38+0.35}_{-0.37-0.37})\ 10^{-4}$

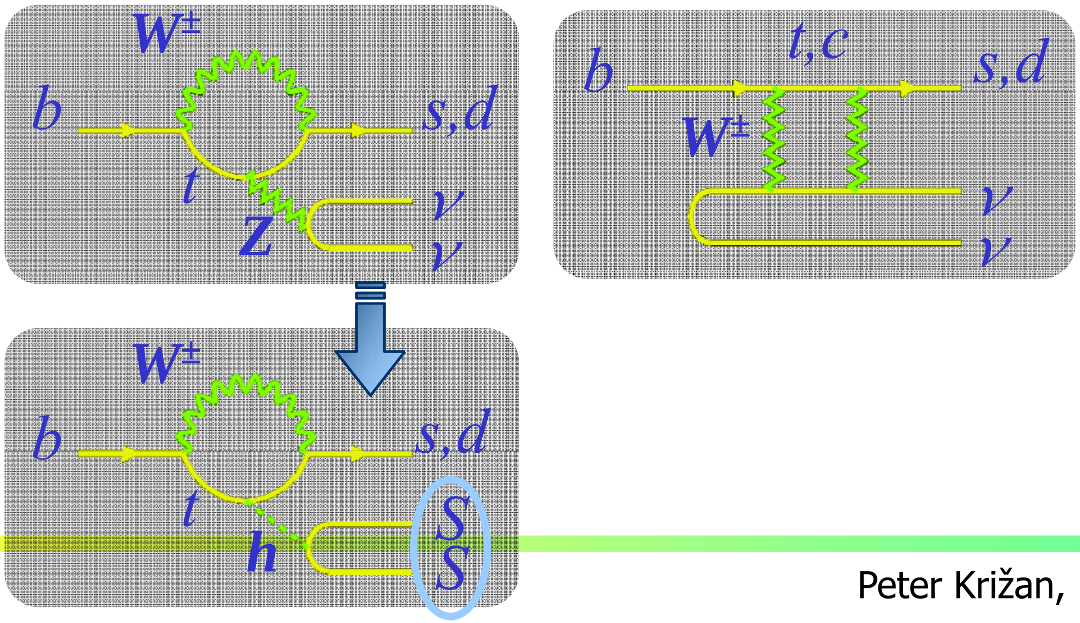
$B \to K^{(*)}\nu\nu$

$B \to K^{(*)}\nu\nu$ is a particularly interesting and challenging mode (with $B \to \tau\nu$ as a small background), theoretically clean

Experimental signature: $B \to K$ + nothing

The "nothing" can also be a pair of light dark matter particles with mass of order 1 GeV. Direct dark-matter searches cannot see the M<10 GeV region.

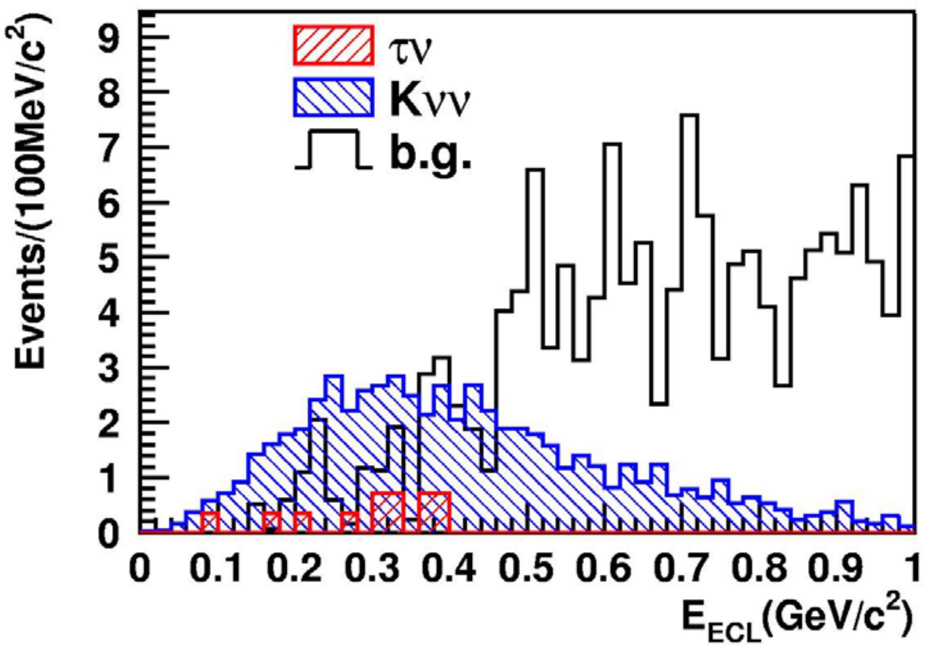
SM prediction for $B^+ \to K^+\nu\nu$: $(3.8^{+1.2}_{-0.6}) \times 10^{-6}$



$B^- \rightarrow K^- \nu \nu$ prospects

MC extrapolation to 50 ab^{-1}

5σ Observation of $B^\pm \rightarrow K^\pm \nu \nu$



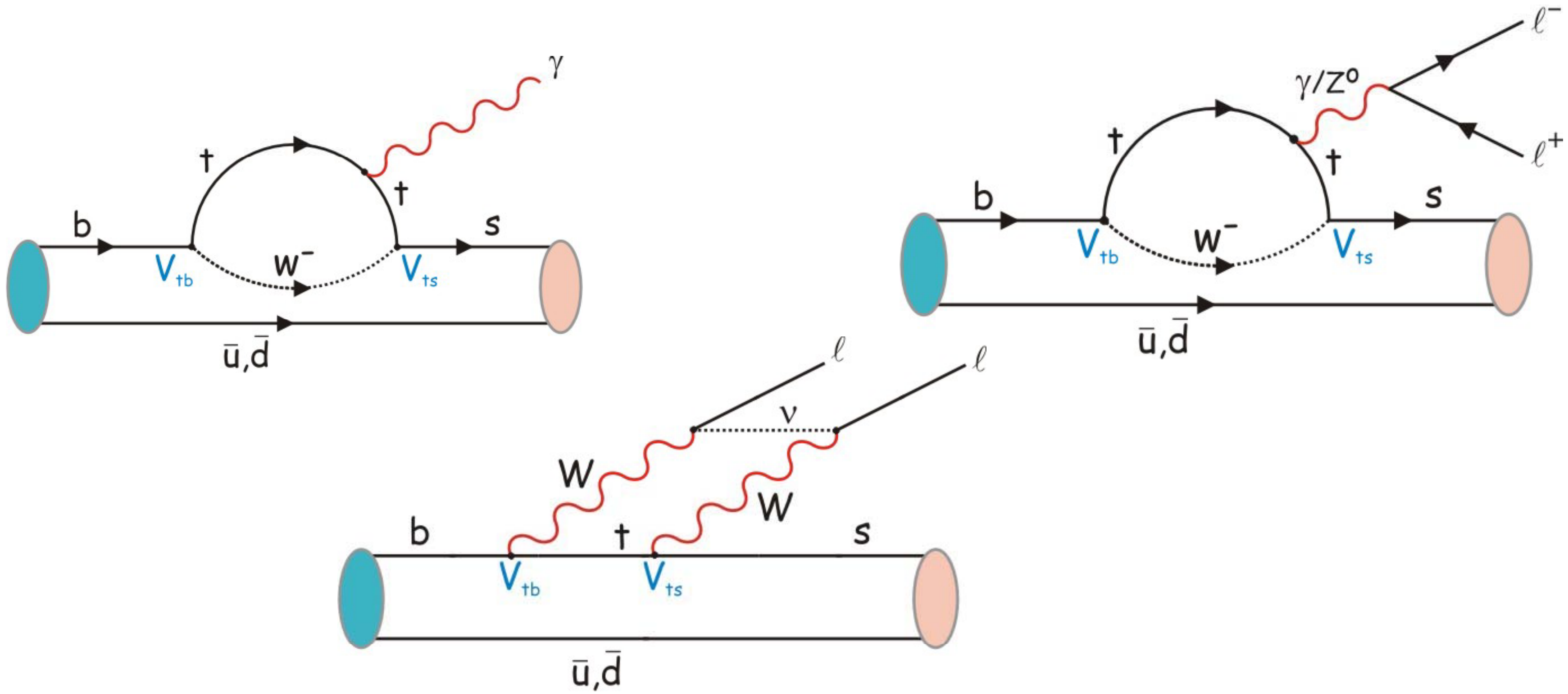
Extra EM calorimeter energy

SM prediction:
G.Buchalla, G.Hiller, G.Isidori
(PRD 63 014015)

$B \rightarrow \tau\nu$ analysis is a proof that such a one prong decay can be studied at a B factory

Why FCNC decays?

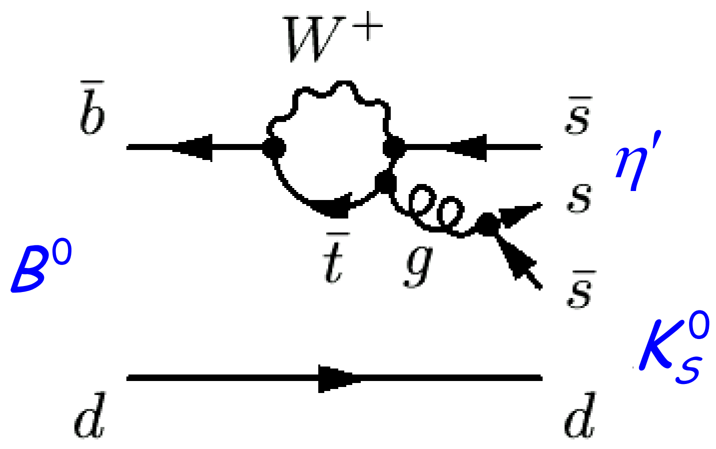
Flavour changing neutral current (FCNC) processes (like $b \to s$, $b \to d$) are fobidden at the tree level in the Standard Model. Proceed only at low rate via higher-order loop diagrams. Ideal place to search for new physics.



How can New Physics contribute to b→s?

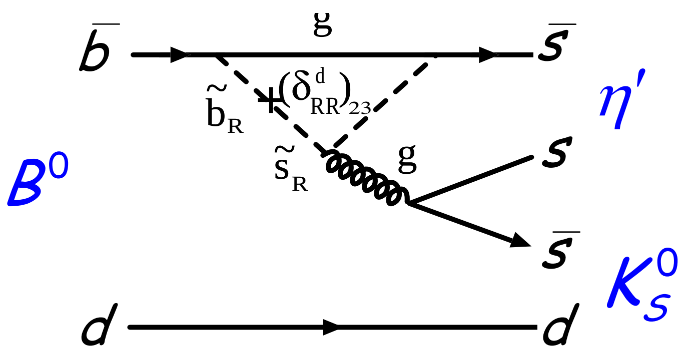
For example in the process:

$B^0 \to \eta' K^0$



Ordinary penguin diagram with a t quark in the loop

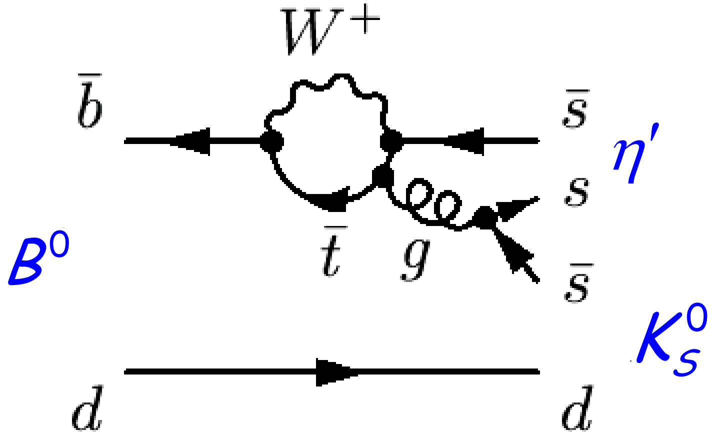
Diagram with supersymmetric particles



Searching for new physics phases in CP violation measurements in b→s decays

Prediction in SM:

$B^0 \to \eta' K^0$



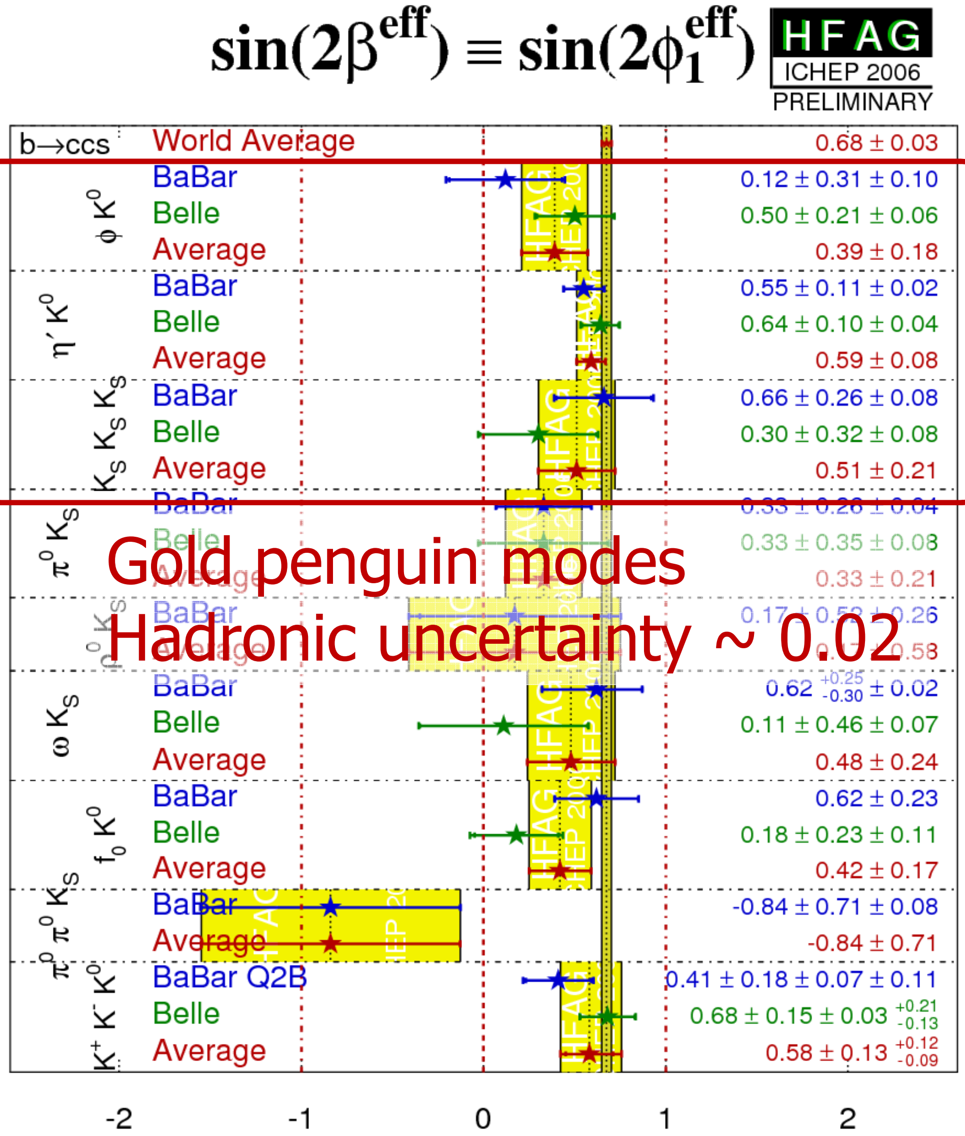
$$a_f = -\mathrm{Im}(\lambda_f)\sin(\Delta m t)$$

$$\mathrm{Im}(\lambda_f) = \xi_f \sin 2\phi_1$$

The same value as in the decay $B^0 \to J/\psi\ K_S$!

This is only true if there are no other particles in the loop! In general the parameter can assume a different value $\sin 2\phi_1^{eff}$

Search for NP: $b \to s q\bar{q}$



Gold penguin modes

Hadronic uncertainty ~ 0.02

ICHEP08

BaBar
Belle
Naïve average

ϕK^0:
- 0.26±0.25±0.04
- 0.67± $^{0.25}_{0.27}$ ±0.07
- 0.45±0.18

$\eta' K^0$:
- 0.57±0.08±0.02
- 0.64±0.10±0.04
- 0.60±0.07

$K_S K_S K_S$:
- 0.71±0.24±0.04
- 0.30±0.32±0.08
- 0.57±0.20

Need much more data to clarify the issue

A difference in the direct violation of CP symmetry in B^+ and B^0 decays


nature International weekly journal of science

nature Vol 452|20 March 2008|doi:10.1038/nature06827

LETTERS

Difference in direct charge-parity violation between charged and neutral *B* meson decays

The Belle Collaboration*

CP asymmetry

$$\mathcal{A}_f = \frac{N(\overline{B} \to \overline{f}) - N(B \to f)}{N(\overline{B} \to \overline{f}) + N(B \to f)}$$

Difference between B^+ and B^0 decays

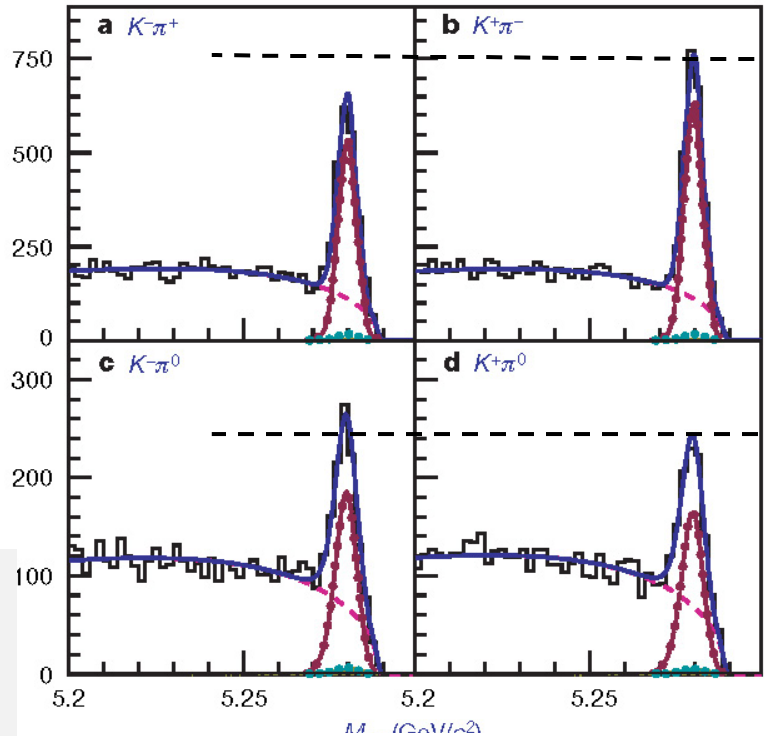
In SM expect $\mathcal{A}_{K^\pm\pi^\mp} \approx \mathcal{A}_{K^\pm\pi^0}$

Measure:

$$\mathcal{A}_{K^\pm\pi^\mp} = -0.094 \pm 0.018 \pm 0.008$$

$$\mathcal{A}_{K^\pm\pi^0} = +0.07 \pm 0.03 \pm 0.01$$

$$\Delta\mathcal{A} = +0.164 \pm 0.037$$



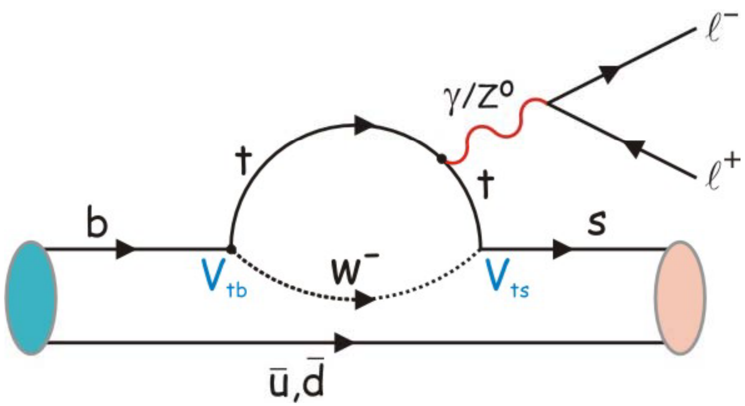
A problem for a SM explanation (in particular when combined with other measurements)

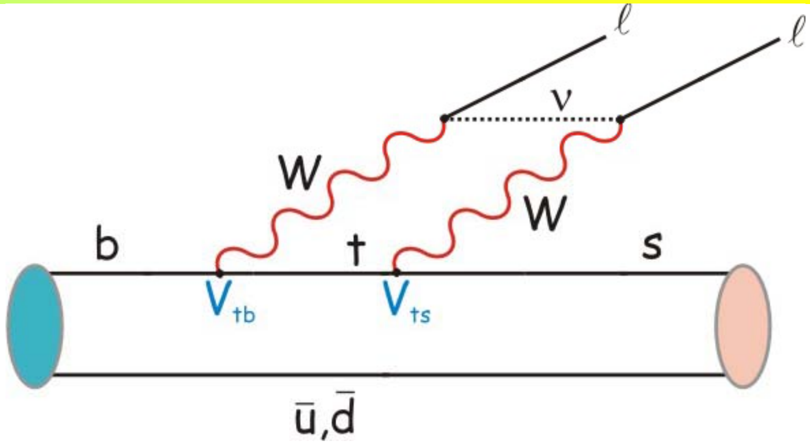
A hint for new sources of CP violation?

~1 in 10^5 B mesons decays in this decay mode

Belle, Nature 452, 332 (2008)

Another FCNC decay: $B \to K^* l^+ l^-$





$b \to s\, l^+l^-$ was first measured in $B \to K\, l^+l^-$ by Belle (2001).

Important for further searches for the physics beyond SM

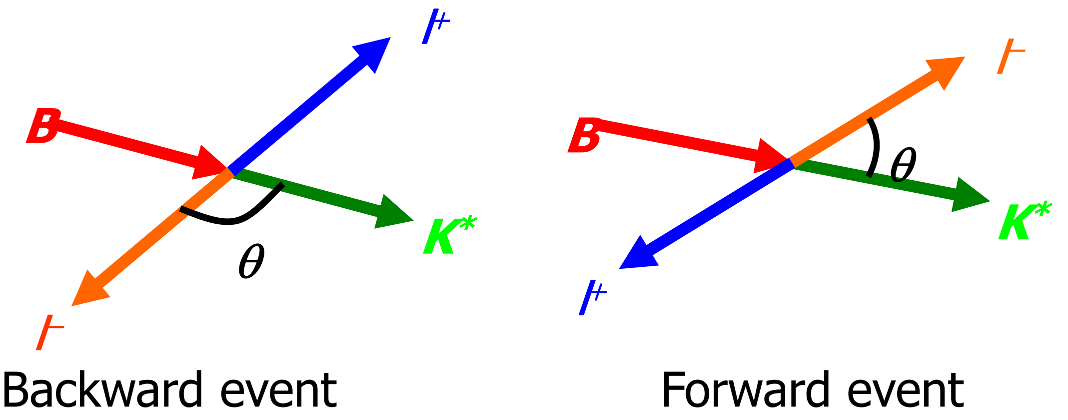
Particularly sensitive: backward-forward asymmetry in $K^* l^+l$

$$A_{FB} \propto \Re\left[C_{10}^*\left(sC_9^{eff}(s)+r(s)C_7\right)\right]$$

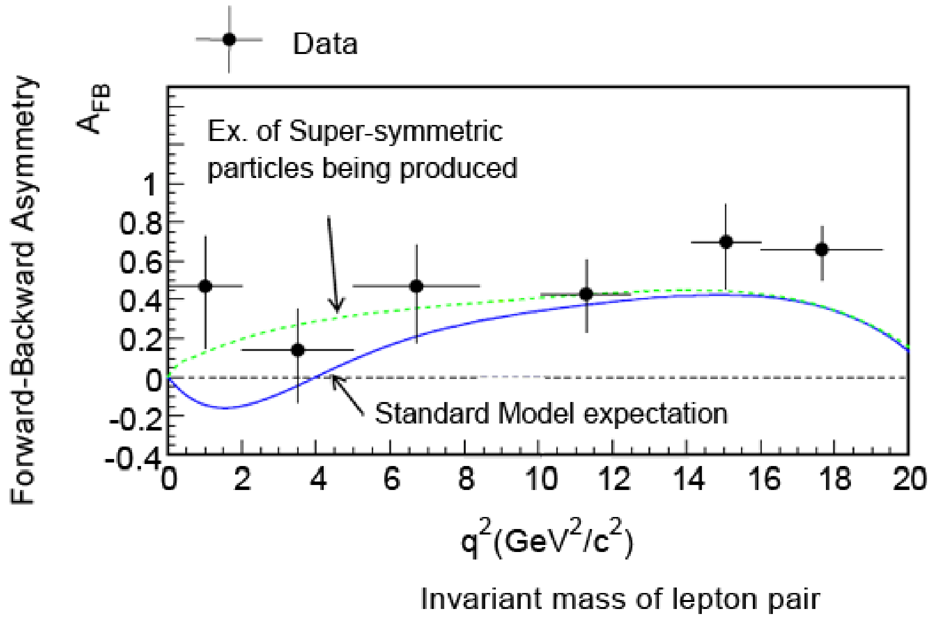
C_i : Wilson coefficients, abs. value of C_7 from $b \to s\gamma$

s=lepton pair mass squared

Backward-forward asymmetry in $K^* l^+l$

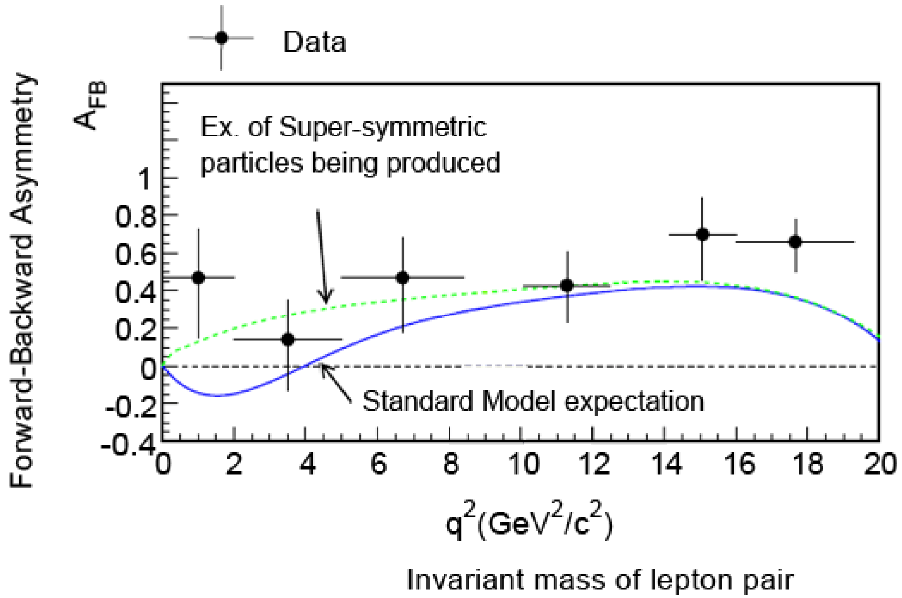


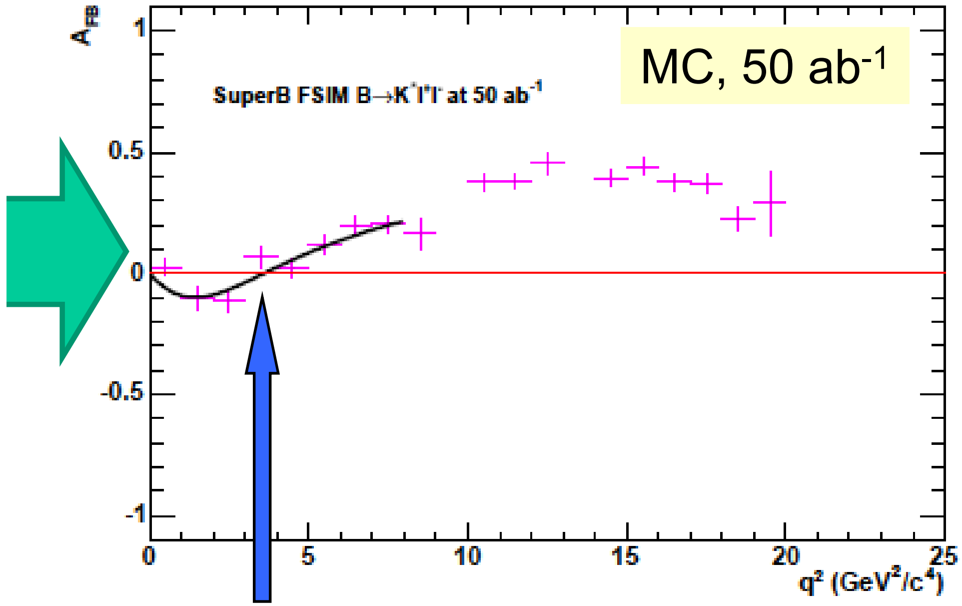
[γ^* and Z^* contributions in $B \rightarrow K^* l\, l$ interfere and give rise to forward-backward asymmetries c.f. $e^+e^- \rightarrow \mu^+ \mu^-$]



$$A_{FB} \propto \Re\left[C_{10}^* \left(s C_9^{eff}(s) + r(s) C_7 \right) \right]$$

$A_{FB}(B \to K^* l^+ l^-)[q^2]$ at a Super B Factory





- Zero-crossing q^2 for A_{FB} will be determined with a 5% error with $50 ab^{-1}$.

Strong competition from LHCb and ATLAS/CMS

D^0 mixing in K^+K^-, $\pi^+\pi^-$

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

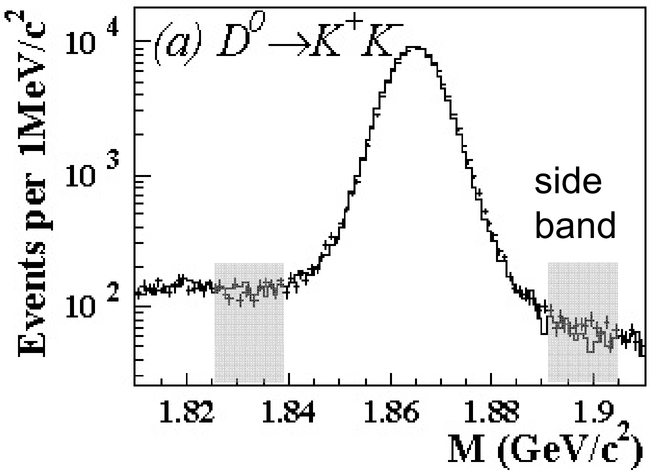
CP even final state;
in the limit of no CPV: CP|D$_1$> = |D$_1$>
⇒ measure $1/\Gamma_1$

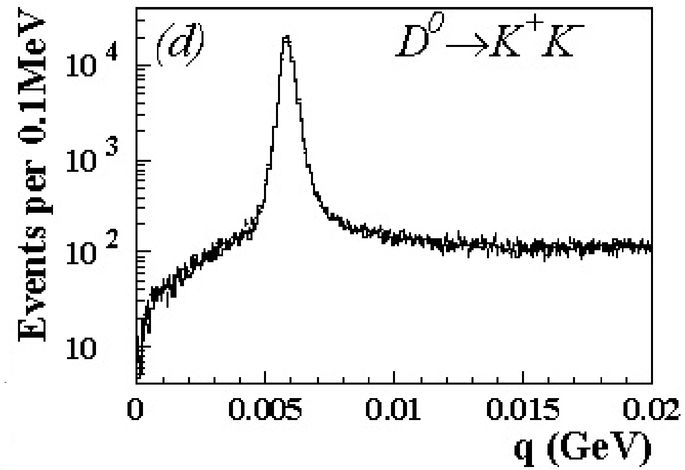
$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$$

$$y_{CP} \equiv \frac{\tau(K^-\pi^+)}{\tau(K^-K^+)} - 1 = y\cos\varphi - \frac{1}{2}A_M x \sin\varphi = \underset{no\ CPV}{=} y$$

S. Bergman et al., PLB486, 418 (2000)

A_M, ϕ: CPV in mixing and interference





Signal: $D^0 \to K^+K^- / \pi^+\pi^-$ from D^*

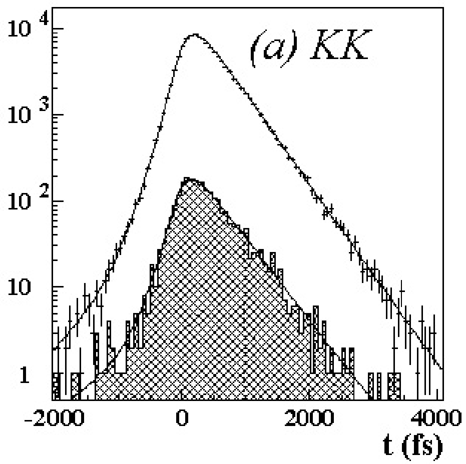
M, Q, σ_t selection optimized in MC

	K^+K^-	$K^-\pi^+$	$\pi^+\pi^-$
N_{sig}	111×10^3	1.22×10^6	49×10^3
purity	98%	99%	92%

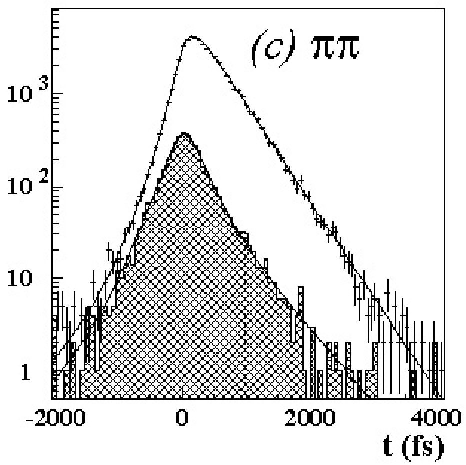
PRL 98, 211803 (2007), 540fb^{-1}

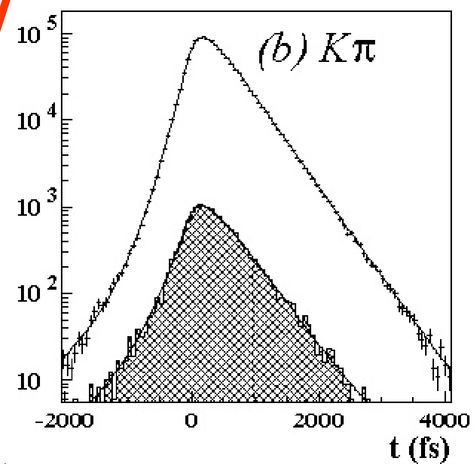
D^0 mixing in K^+K^-, $\pi^+\pi^-$

Decay time distributions for KK, $\pi\pi$, $K\pi$



+

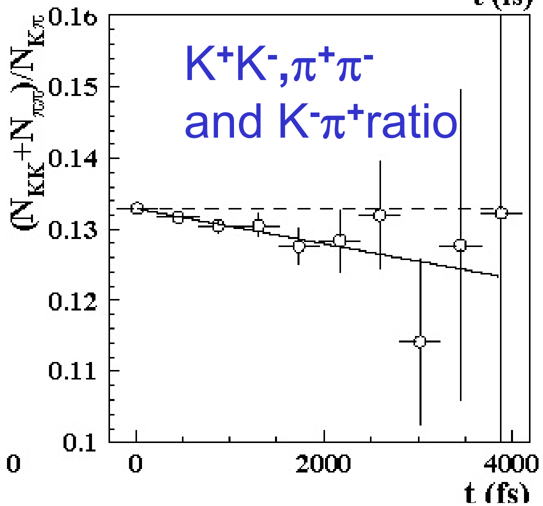




Difference of lifetimes visually observable

in the ratio of the distributions →

Real fit:



$y_{CP} = (1.31 \pm 0.32 \pm 0.25)$ %

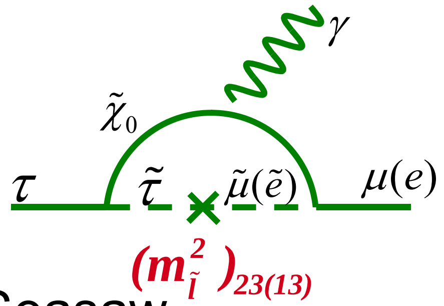
evidence for D^0 mixing

(regardless of possible CPV)

→y_{CP} is on the high side of SM expectations

LFV and New Physics

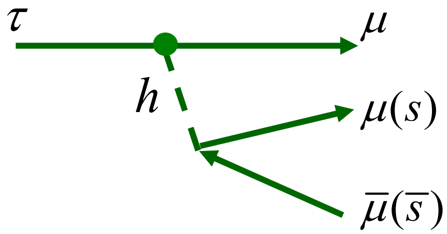
$\tau \to l\gamma$



- SUSY + Seasaw
- Large LFV $Br(\tau \to \mu\gamma) = O(10^{-7\sim 9})$

$$Br(\tau \to \mu\gamma) \simeq 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{1\,TeV}{m_{SUSY}} \right)^4 \tan^2\beta$$

$\tau \to 3l, l\eta$



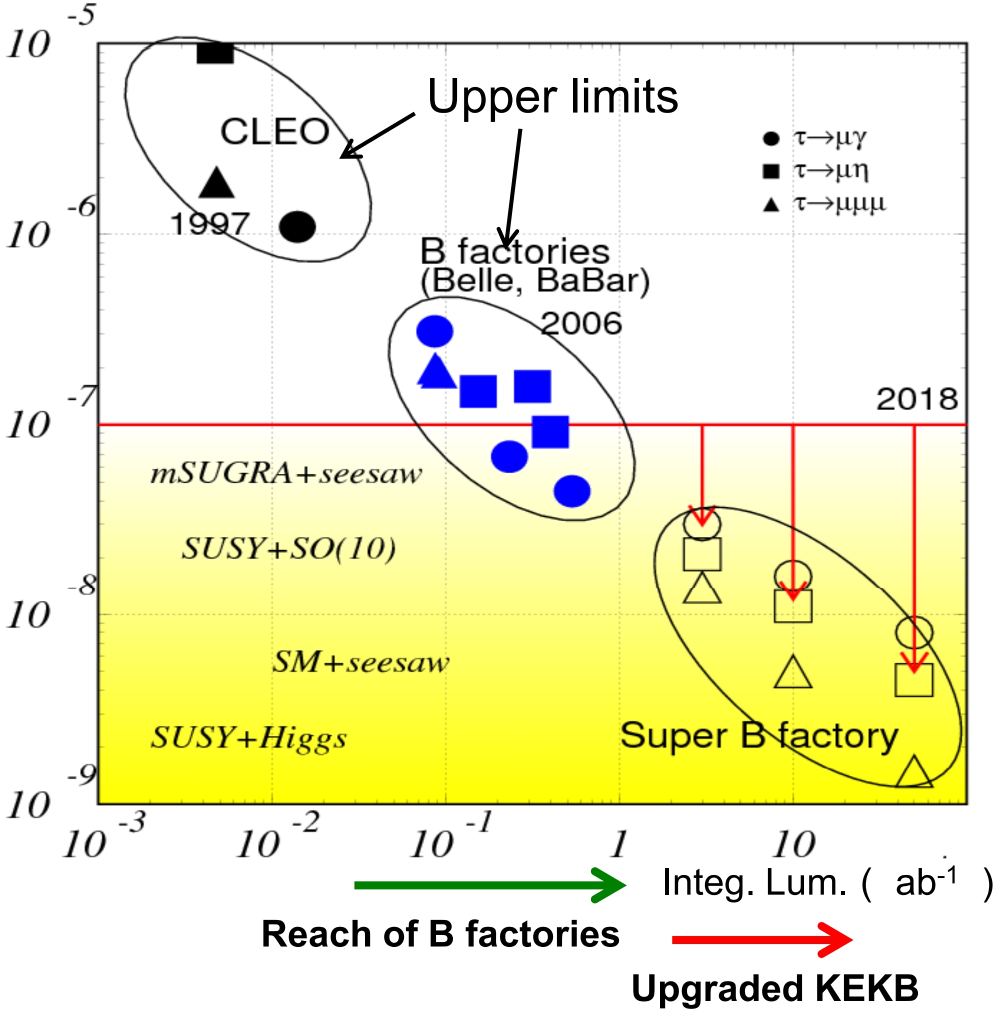
- Neutral Higgs mediated decay.
- Important when MSUSY >> EW scale.

$$Br(\tau \to 3\mu) = 4 \times 10^{-7} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{\tan\beta}{60} \right)^6 \left(\frac{100GeV}{m_A} \right)^4$$

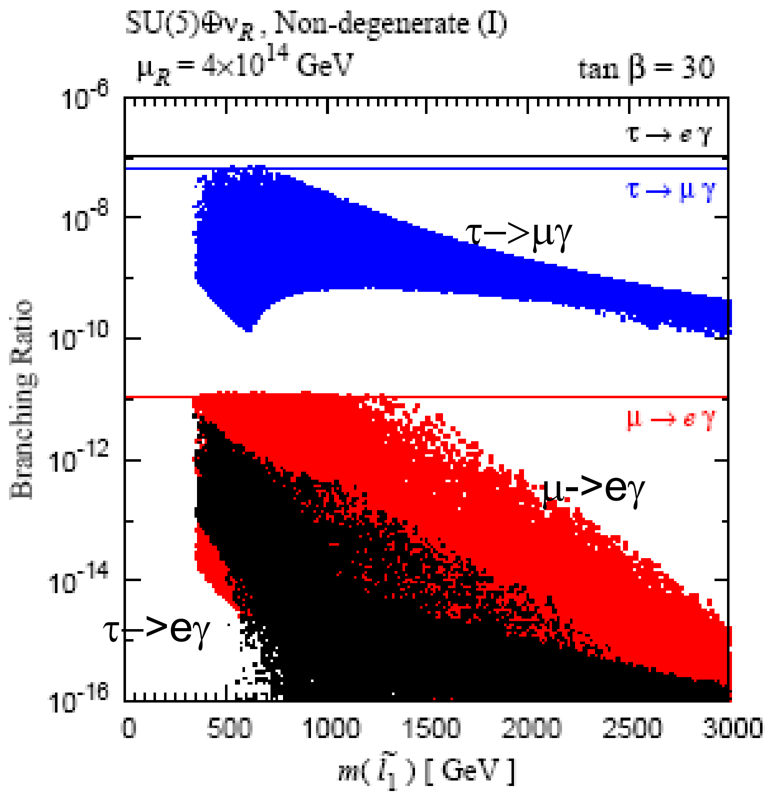
model	$Br(\tau \to \mu\gamma)$	$Br(\tau \to lll)$
mSUGRA+seesaw	10^{-7}	10^{-9}
SUSY+SO(10)	10^{-8}	10^{-10}
SM+seesaw	10^{-9}	10^{-10}
Non-Universal Z'	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-7}

Precision measurements of τ decays

LF violating τ decay?



Theoretical predictions compared to present experimental limits



T.Goto et al., 2007

Physics at a Super B Factory

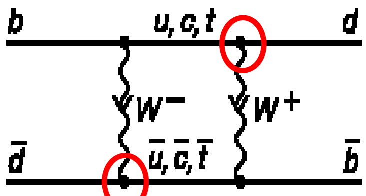
- There is a good chance to see new phenomena;
  - **CPV in B decays from the new physics (non KM).**
  - **Lepton flavor violations in τ decays.**
- They will help to diagnose (if found) or constraint (if not found) new physics models.
- Even in the worst case scenario (such as MFV), $B \to \tau\nu$, $D\tau\nu$ can probe the charged Higgs in large tanβ region.
- **Physics motivation is independent of LHC**.
  - If LHC finds NP, precision flavour physics is compulsory.
  - If LHC finds no NP, high statistics B/τ decays would be an unique way to search for the TeV scale physics.

Super B Factory Motivation 2

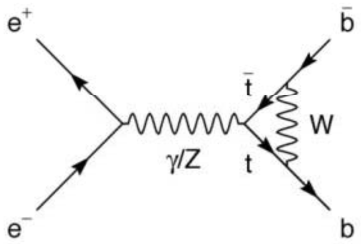
- There are many more topics: CPV in charm, new hadrons, …

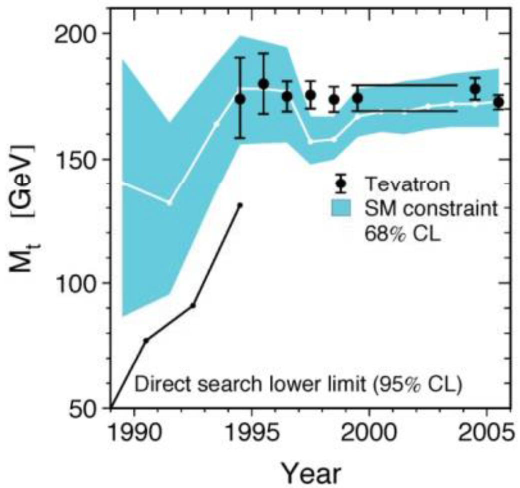
- Lessons from history: the top quark

<u>Physics of top quark</u>
First estimate of mass: BB mixing → ARGUS
Direct production, Mass, width etc. → CDF/D0
Off-diagonal couplings, phase → BaBar/Belle

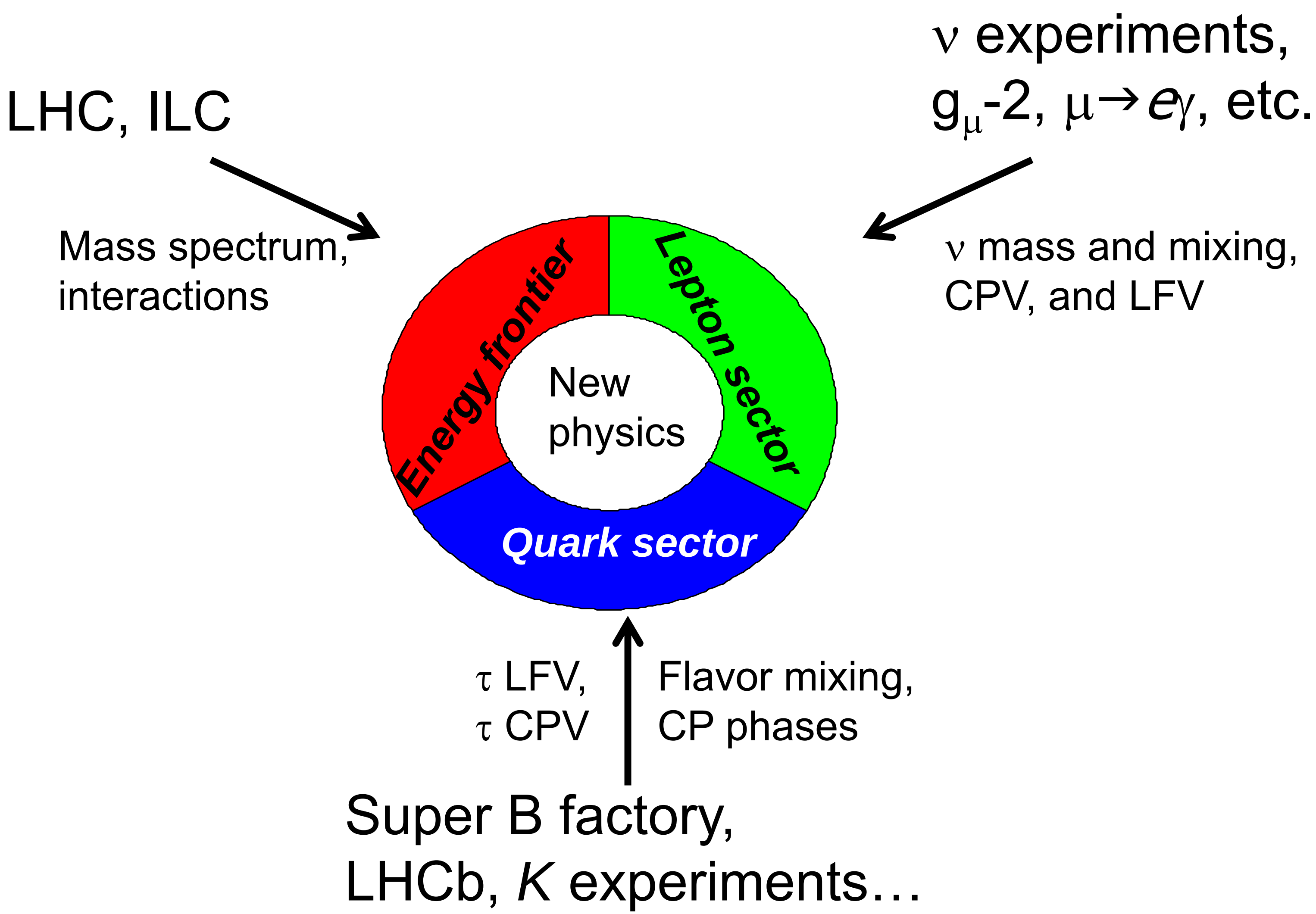


$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

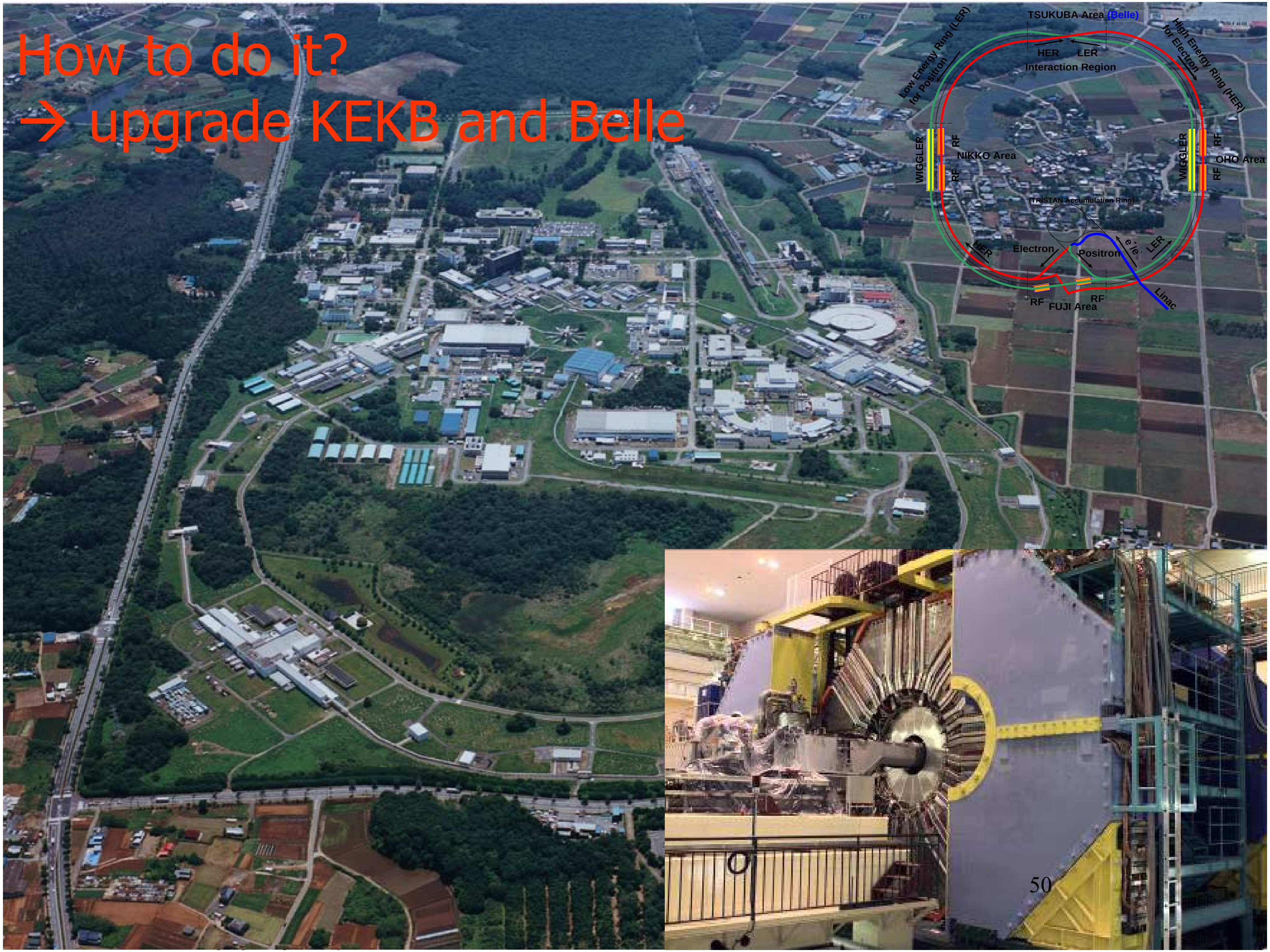




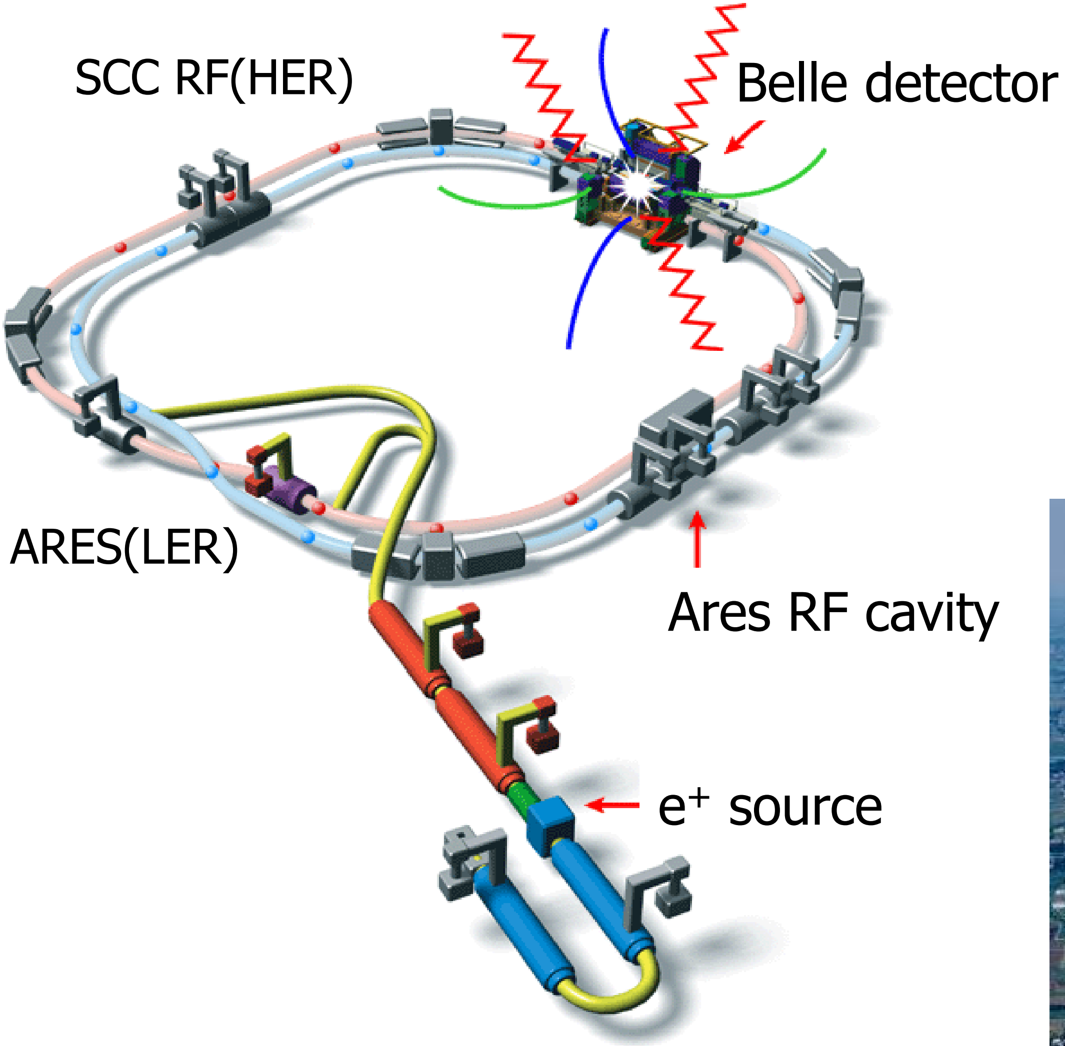
Super B factory: an important part of a broad unbiased approach to New Physics



How to do it?
→ upgrade KEKB and Belle



The KEKB Collider & Belle Detector



- e^- (8 GeV) on e^+(3.5 GeV)
  - $\sqrt{s} \approx m_{\Upsilon(4S)}$
  - Lorentz boost: $\beta\gamma$=0.425
- 22 mrad crossing angle
- Operating since 1999

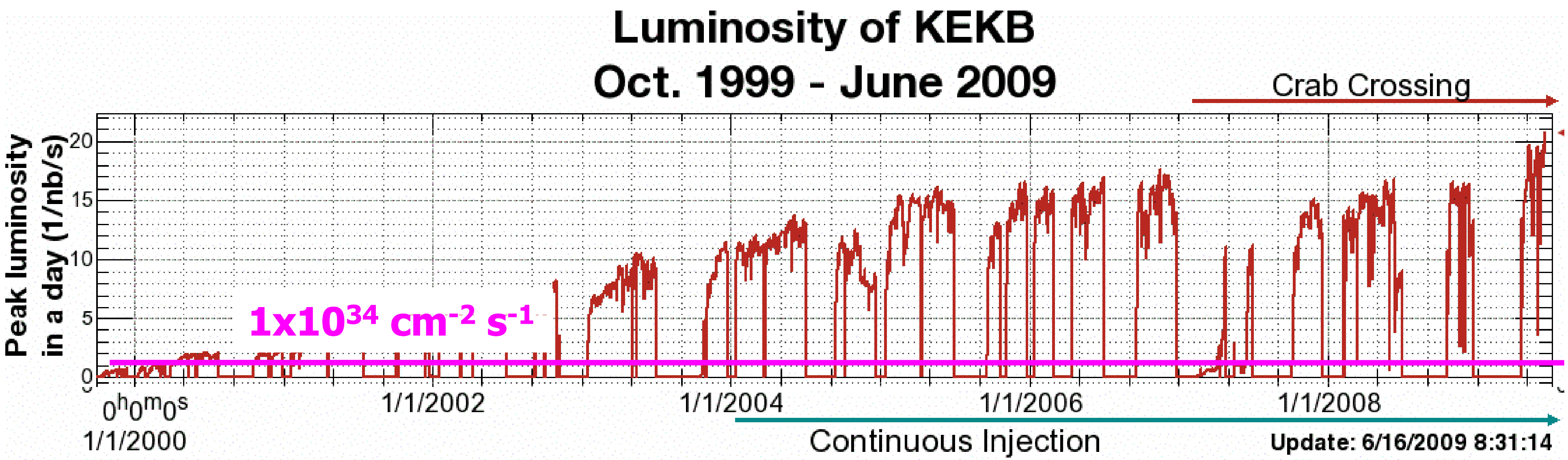
Peak luminosity (WR!) :

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

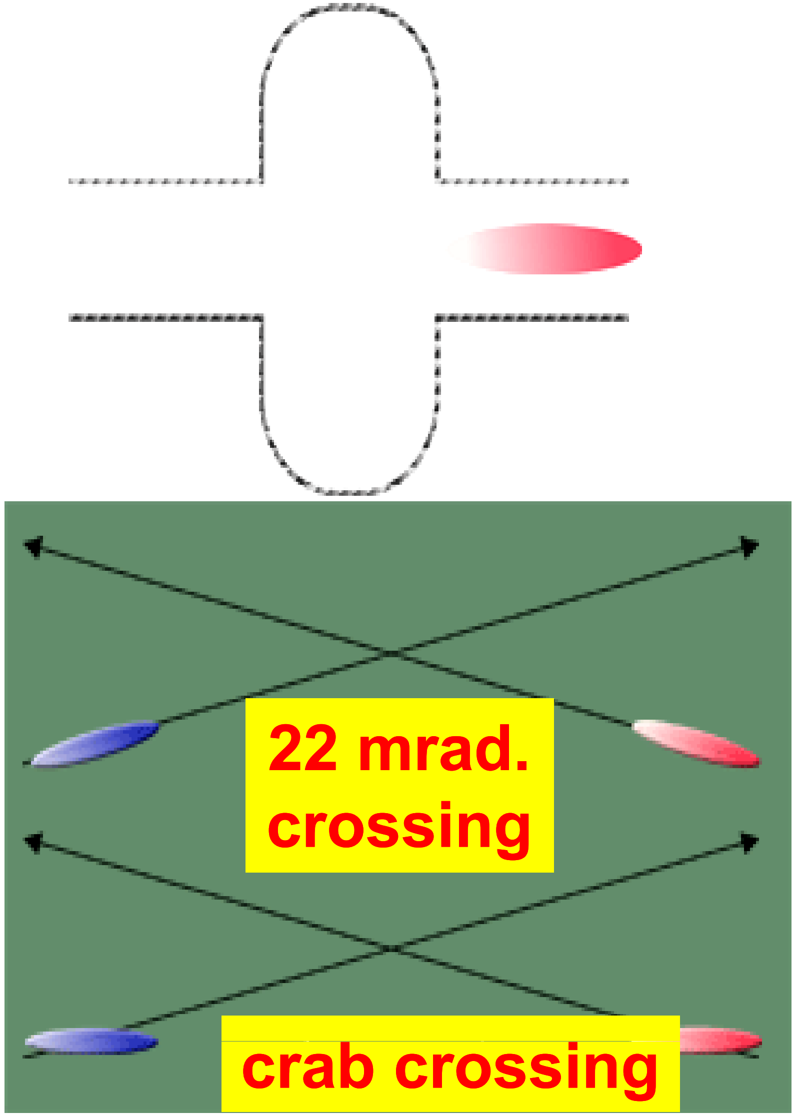
The KEKB Performance

Luminosity Records:

- **Peak L = 2.1x10^{34} cm^{-2} s^{-1}** (2x the design value)
- **Daily ∫Ldt = 1.5 fb^{-1}** (2.5 x the design value)
- **Total ∫Ldt ~ 950 fb^{-1}** (as of July 2009)

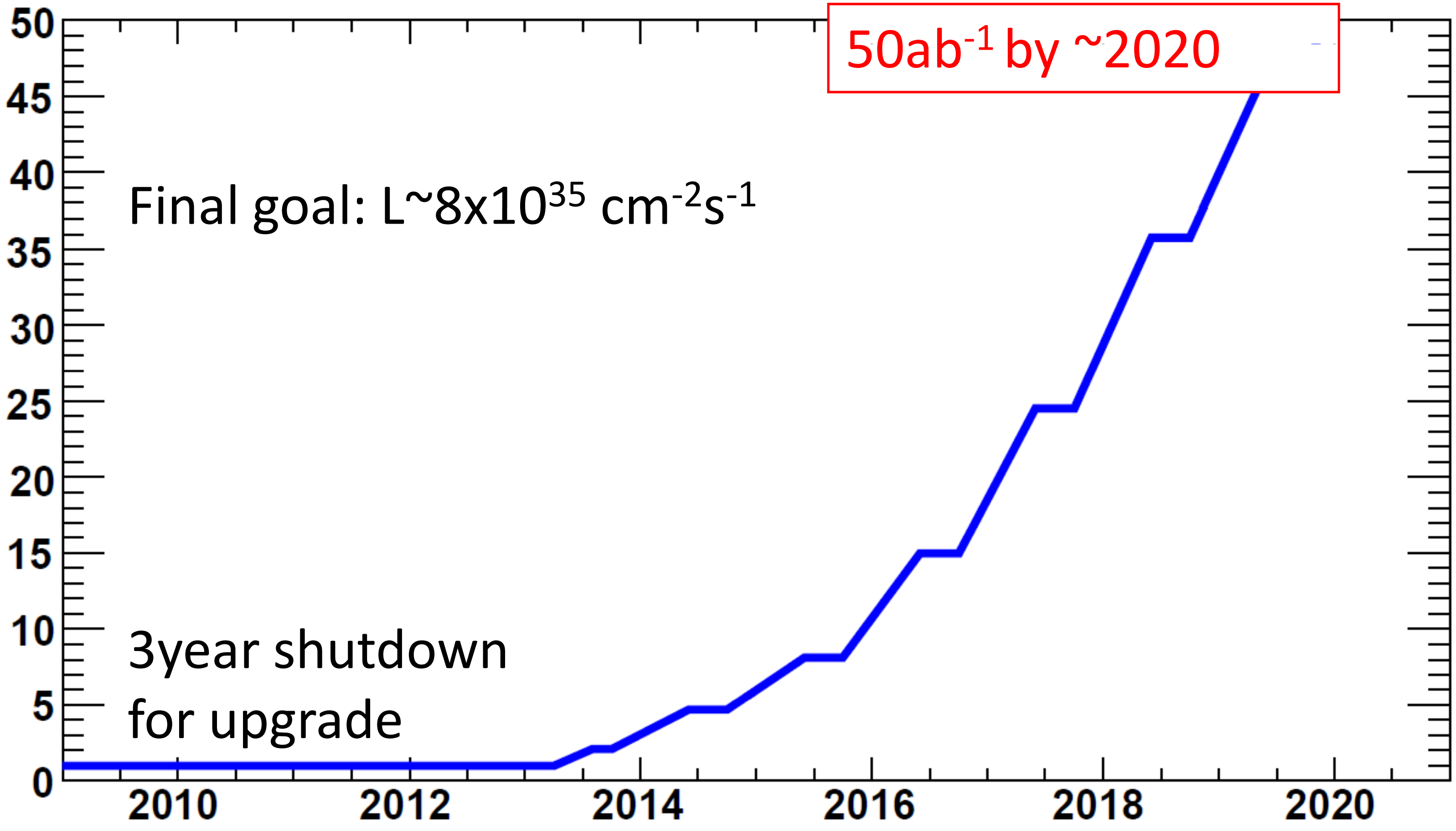


Crab cavity commissioning



Installed in the KEKB tunnel
(February 2007)

Luminosity Prospects



Strategies for Increasing Luminosity

Beam-beam parameter

Lorentz factor

Beam current

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

Lumi. reduction factor (crossing angle)& Tune shift reduction factor (hour glass effect) 0.8 ~ 1 (short bunch)

Classical electron radius

Beam size ratio@IP 1 ~ 2 % (flat beam)

Vertical beta function@IP

High-Current Option

(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y

Nano-Beam Option

Luminosity: Two Options

High Current	Nano-Beam
Slightly smaller β_y^*	Smaller β_y^*
6.5(LER)/5.9(HER)→ 3.0/6.0	6.5(LER)/5.9(HER)→ 0.21/0.37
Increase beam currents	Slightly increase beam currents
1.8A(LER)/1.45A(HER) → 9.4A/4.1A	1.8A(LER)/1.45A(HER) → 3.6A/2.1A
	Close to original KEK design
Increase ξ_y	Keep ξ_y
0.1(LER)/0.06(HER) → 0.3 or more	0.1(LER)/0.06(HER) → 0.09/0.09
Evolution of design in original Letter of Intent (LoI) for SuperKEKB (2004)	Proposed by P. Raimondi et al., along with Crab Waist, for use at the SuperB in Frascati

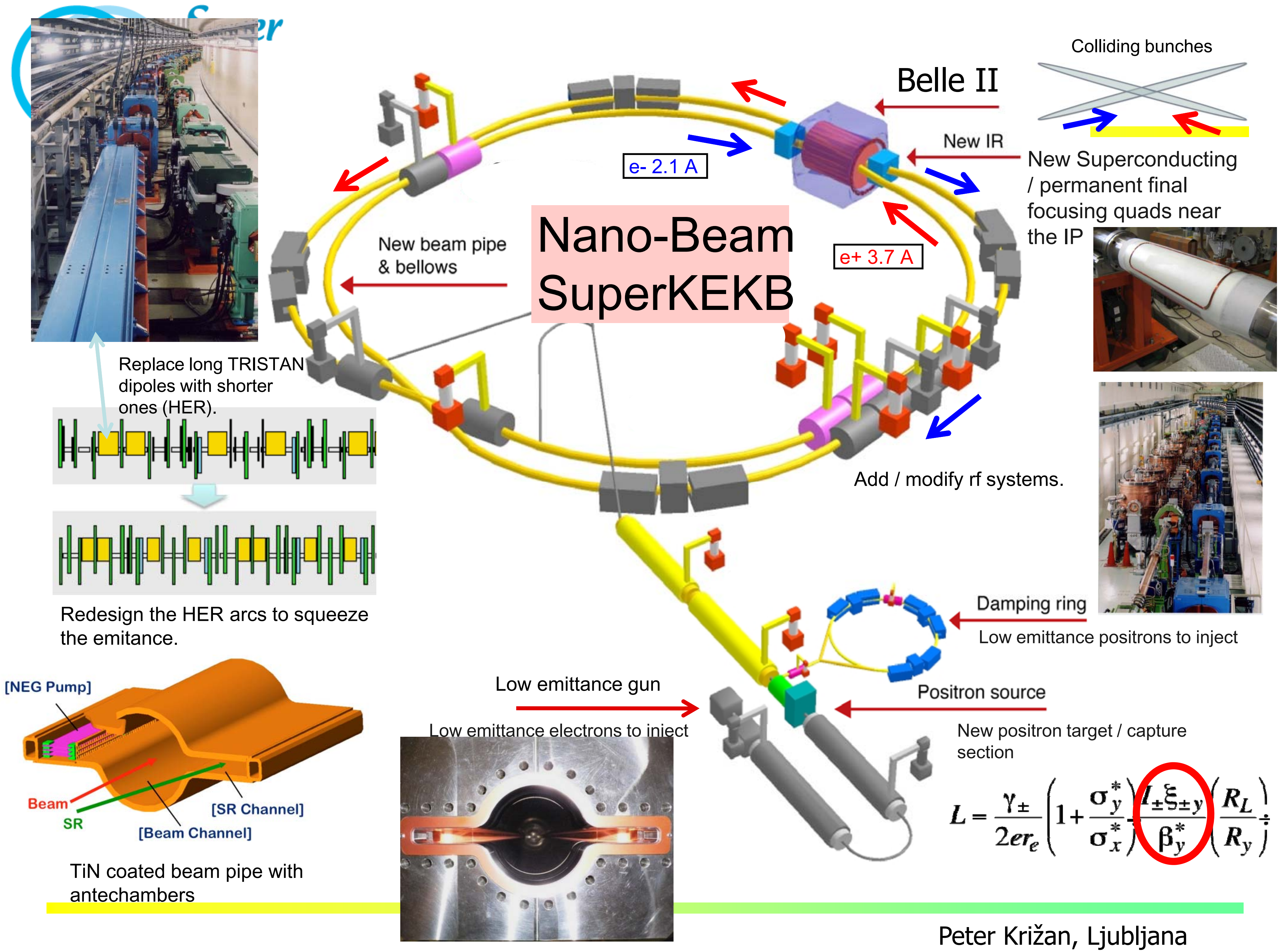
Decision expected by the end of 2009

Comparison of Parameters

Preliminary

	KEKB Design	KEKB Achieved (): with crab	SuperKEKB High-Current Option	SuperKEKB Nano-Beam Scheme
β_y^* (mm)(LER/HER)	10/10	6.5/5.9 (5.9/5.9)	3/6	0.24/0.37
ε_x (nm)	18/18	18(15)/24	24/18	2.8/2.0
κ(%)	1	0.8-1	1/0.5	1.0/0.7
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	0.09/0.09
σ_z (mm)	4	~ 7	5(LER)/3(HER)	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	2119
Luminosity (10^{34} cm^{-2} s^{-1})	1	1.76 (2.08)	53	80

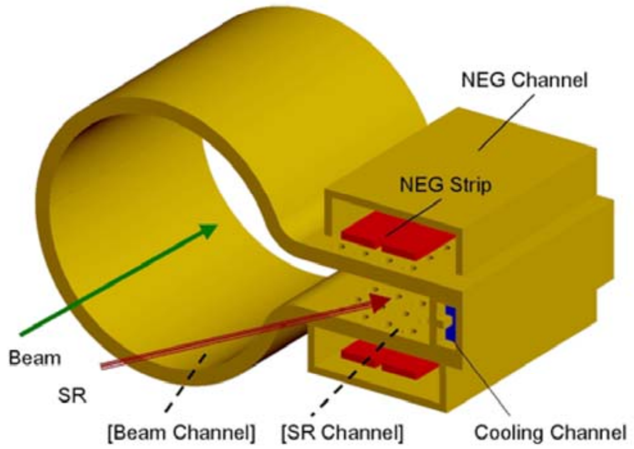
High Current Option includes crab crossing and travelling focus.

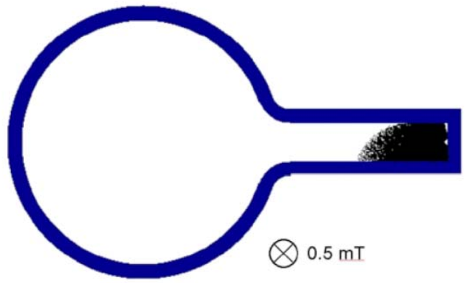


$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

Super-KEKB (cont'd)

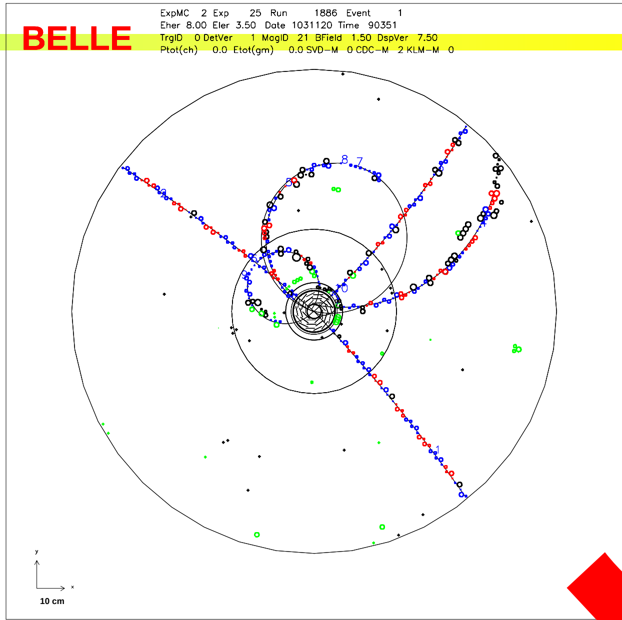
- Ante-chamber /solenoid for reduction of electron clouds





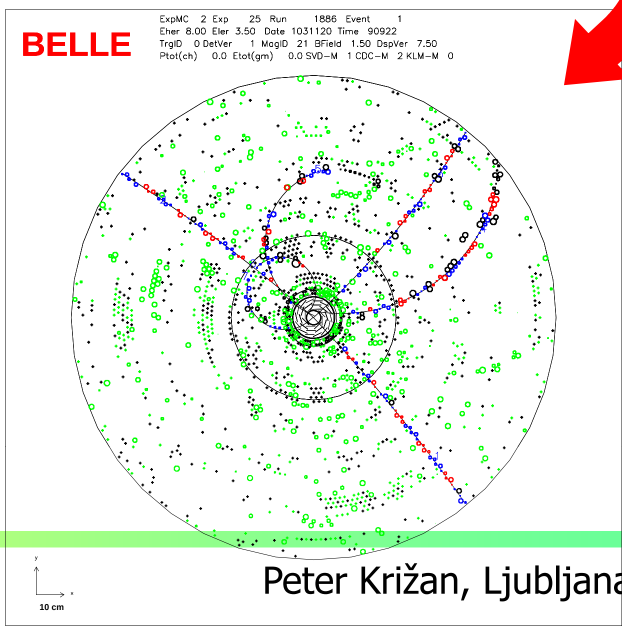
Ante-chamber
with solenoid field

Requirements for the Super B detector



Critical issues at L= 4 x 10^{35}/cm^2/sec

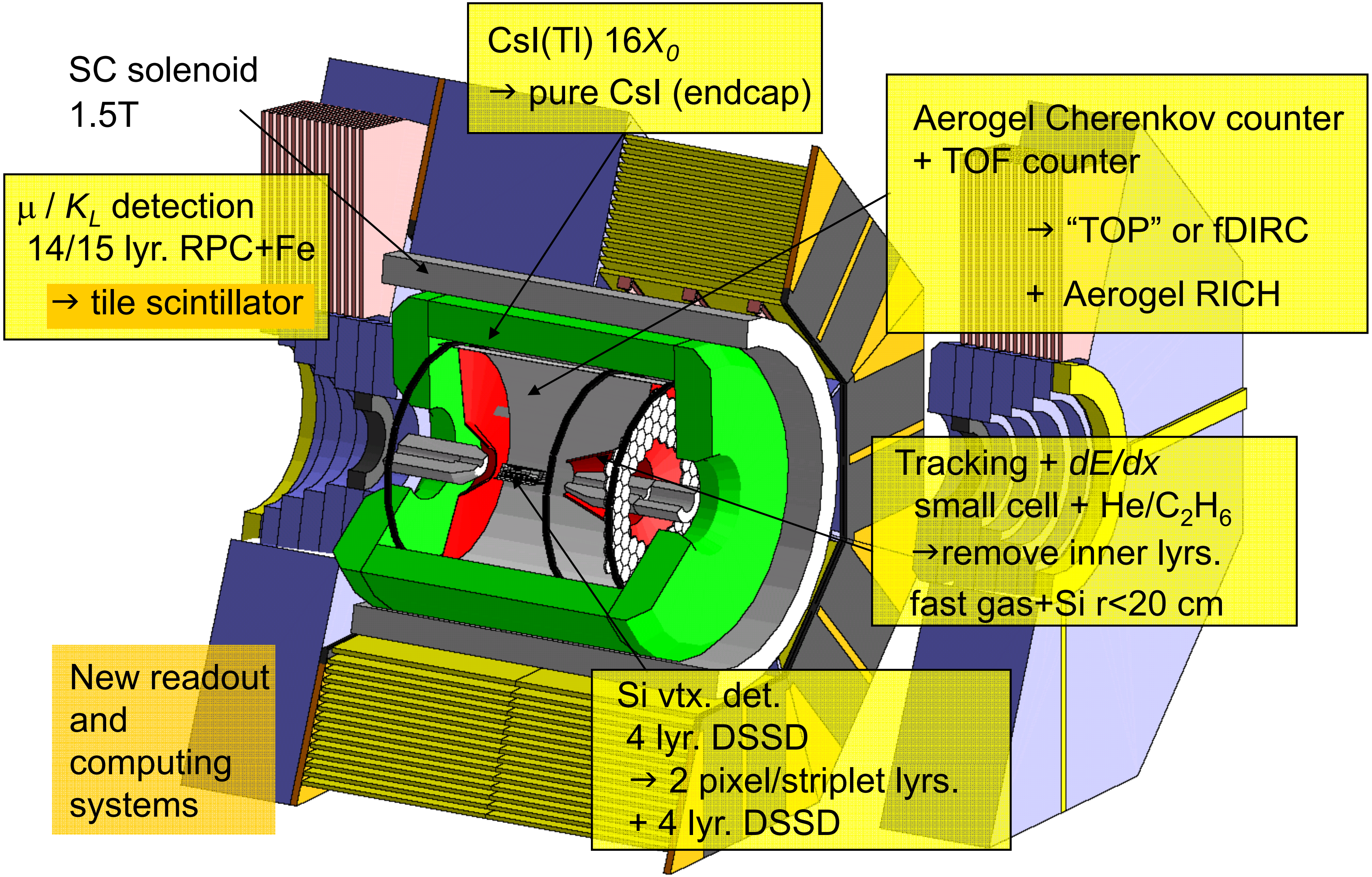
- **Higher background (×20)**
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM
- **Higher event rate (×10)**
  - higher rate trigger, DAQ and computing
- **Require special features**
  - low *p* μ identification ← sμμ recon. eff.
  - hermeticity ← ν "reconstruction"



Possible solution:

- Replace inner layers of the vertex detector with a silicon striplet or pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter crystals
- Faster readout electronics and computing system.

Belle Upgrade for Super-B

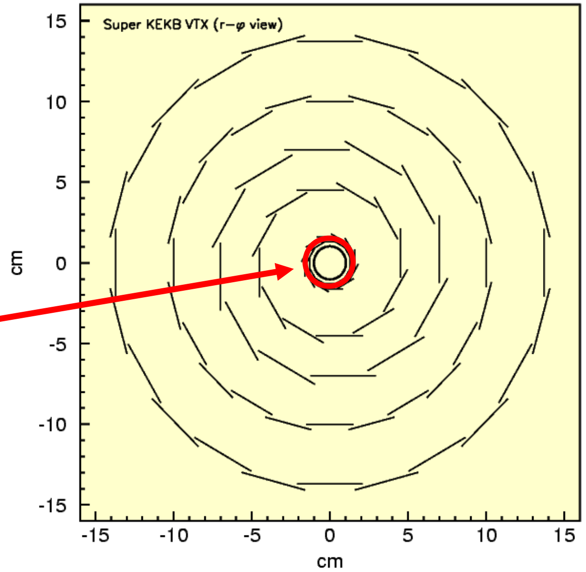


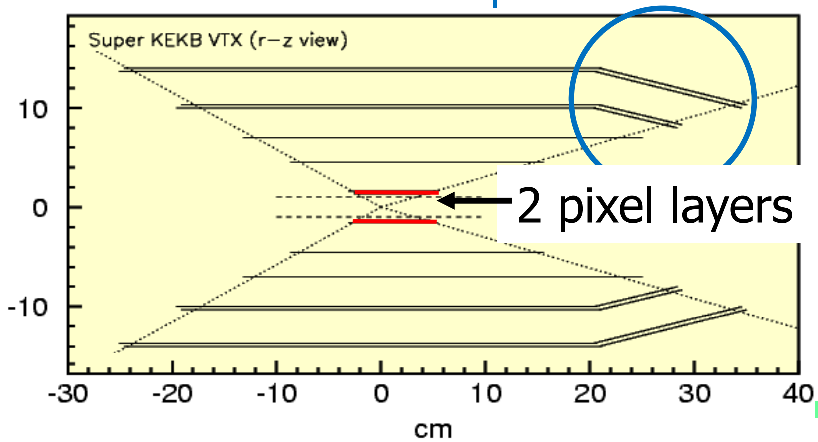
PXD+SVD Upgrade

- Sensors of the innermost layer:

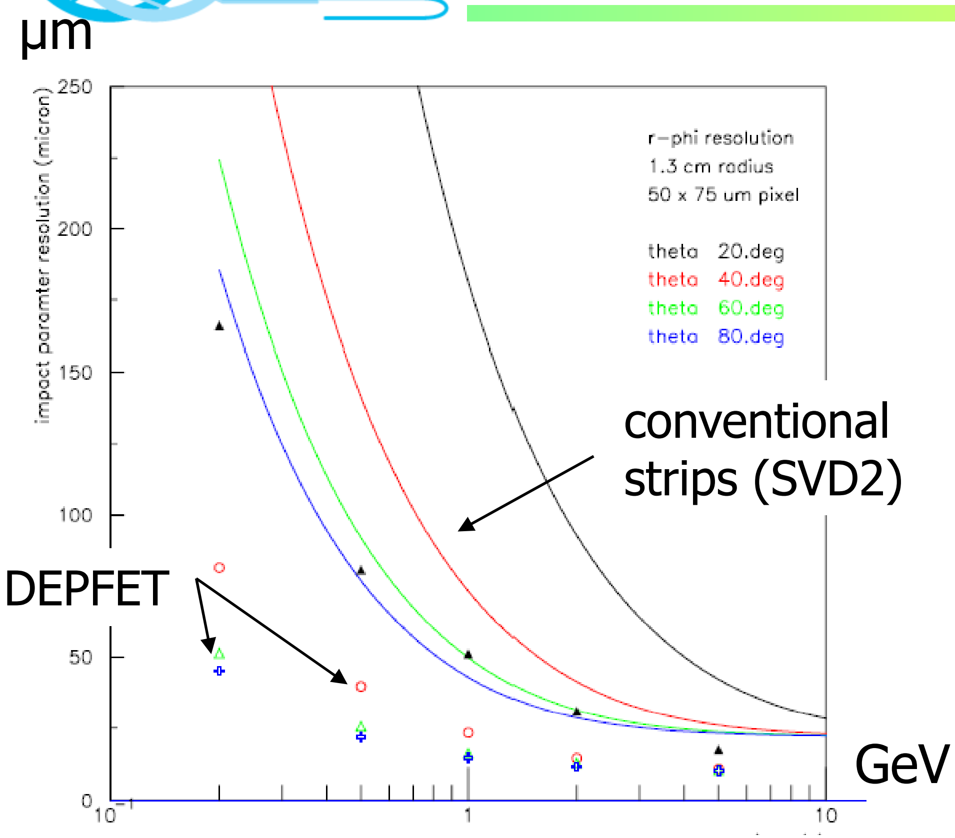
  Normal double sided Si detector (DSSD) → DEPFET Pixel sensors

- Configuration: 4 layers → 6 layers (outer radius = 8cm→14cm)
  - More robust tracking
  - Higher Ks vertex reconstruction efficiency
- Inner radius: 1.5cm → 1.3cm
  - Better vertex resolution
- Strip Readout chip: VA1TA → APV25
  - Reduction of occupancy coming from beam background.
  - Pipeline readout to reduce dead time.





DEPFET Performance



Impact parameter resolution (dots: DEPFET)

Very preliminary
(single tracks, no background)

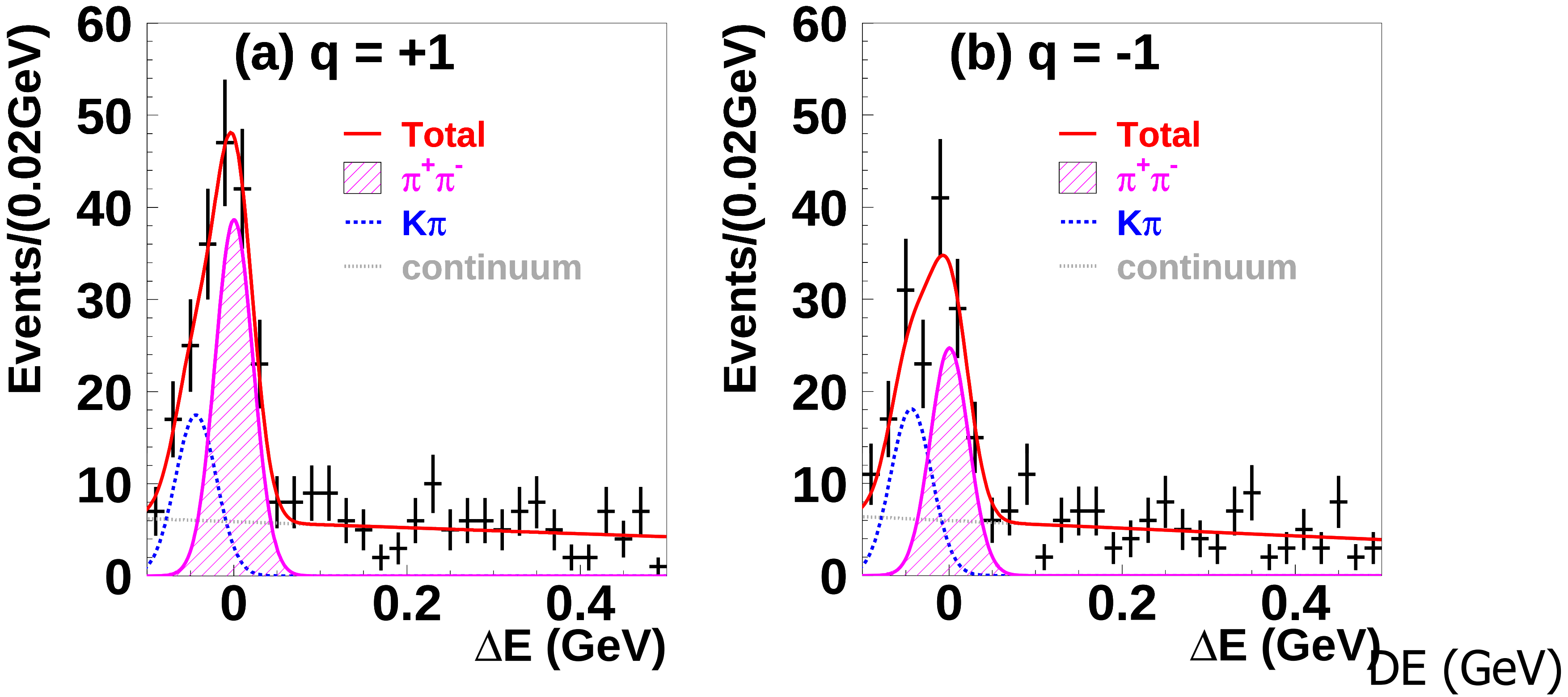
DEPFET:
- L1 1.3 cm (32µm x 50µm)
- L2 1.6 cm (32µm x 50µm)
- thickness: 50µm, noise 100e

DSSD L3/L4/L5/L6: 4.5/7.0/10/13.8cm (50µm x 75µm) thickness 300µm, noise 1600e beam pipe radius: 1cm (Be with 10mm Au layer)

Substantial improvement compared to Belle SVD2

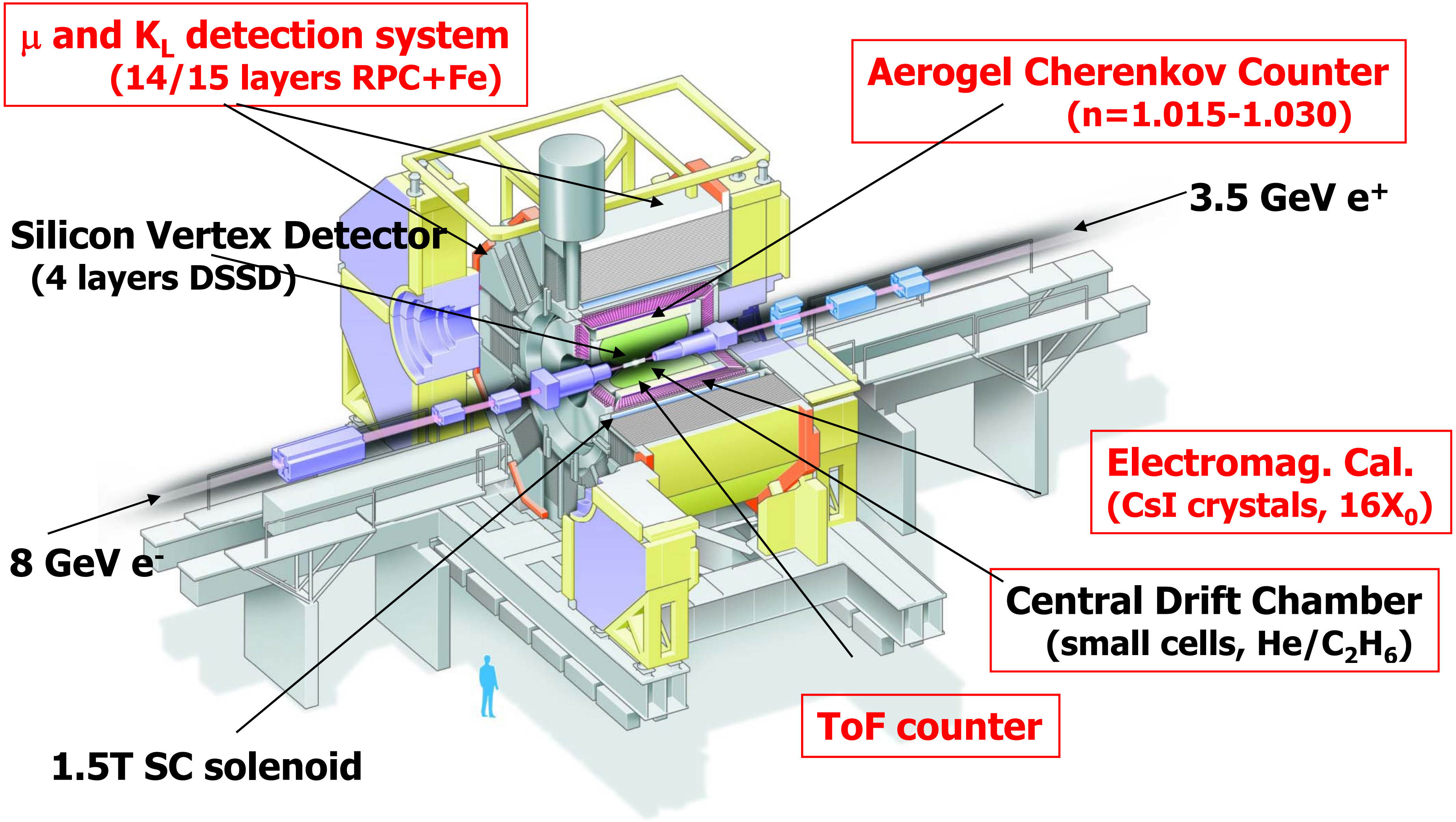
Why excellent particle identification?

Example B→ππ decays: B→πK rate 10x bigger than B→ππ!

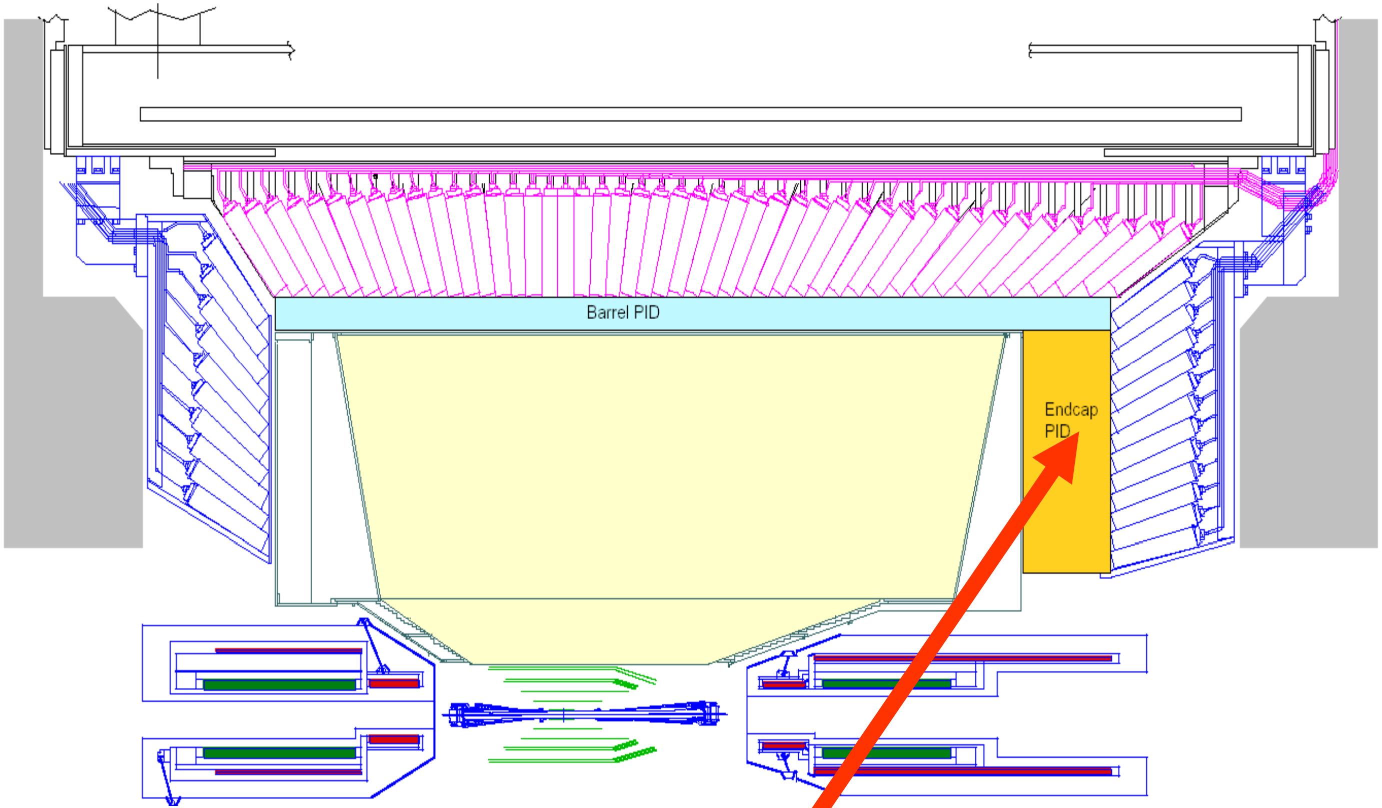


→ We would see no CP effect without excellent PID!

Particle identification systems in Belle



Belle upgrade – side view



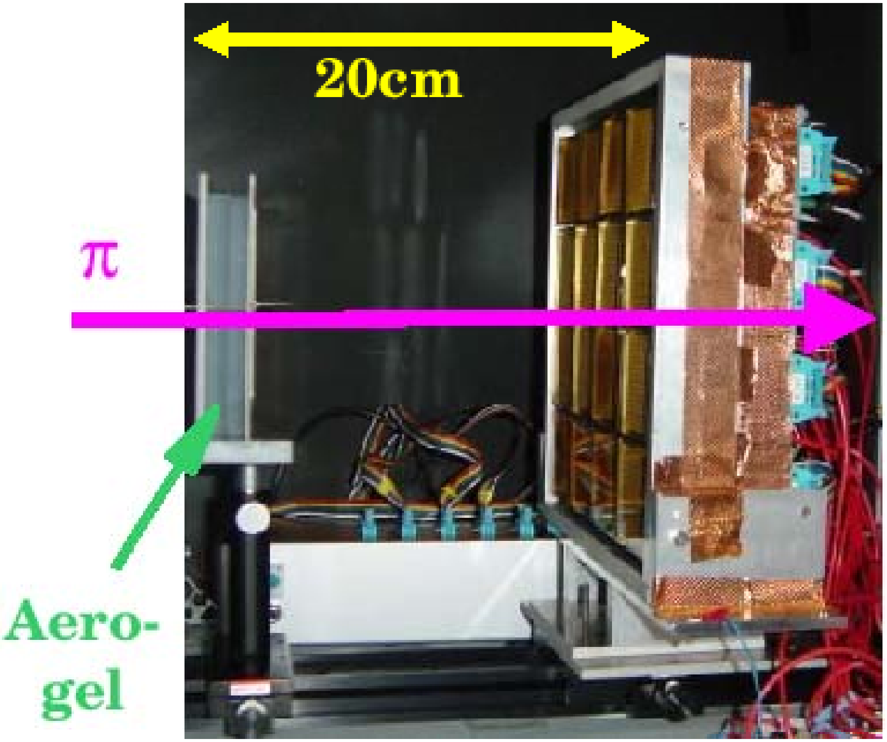
Two new particle ID devices, both RICHes:

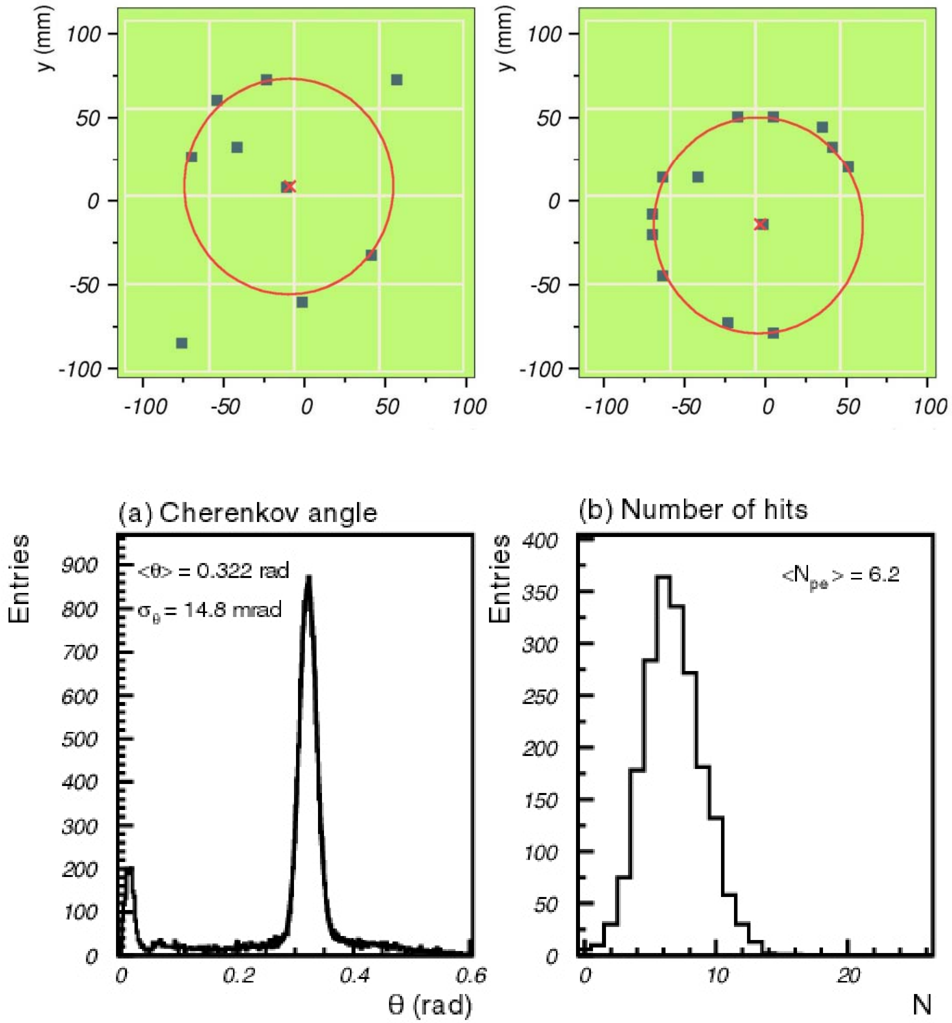
Barrel: TOP or focusing DIRC

Endcap: proximity focusing RICH

Beam tests

Clear rings, little background



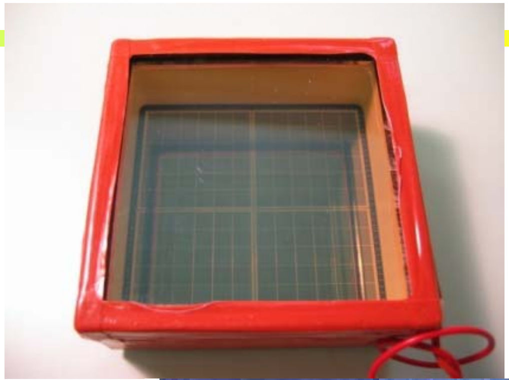


Photon detector: array of 16 H8500 PMTs

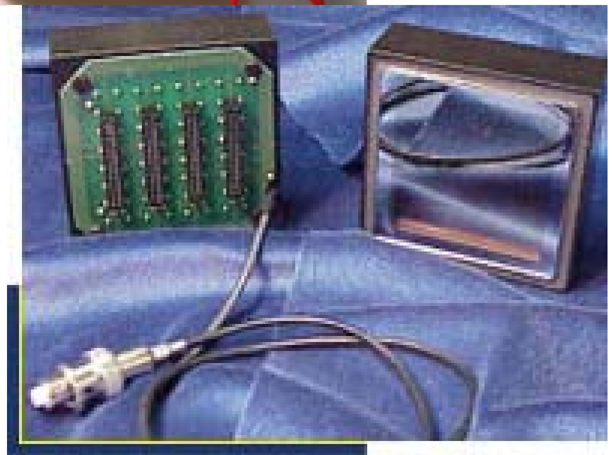
Single photon detecors for the Aerogel RICH

Main challenge: R+D of a photon detector for operation in high magnetic fields (1.5 T).

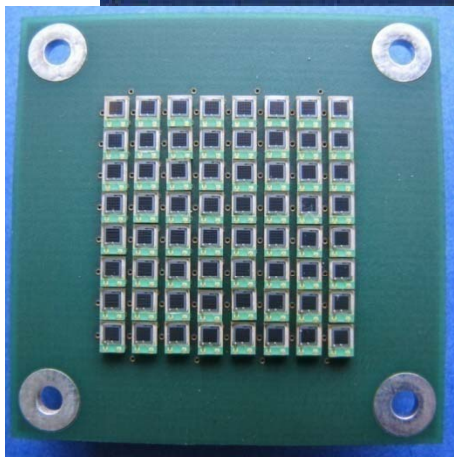
Candidates:



•HAPD: development with HPK

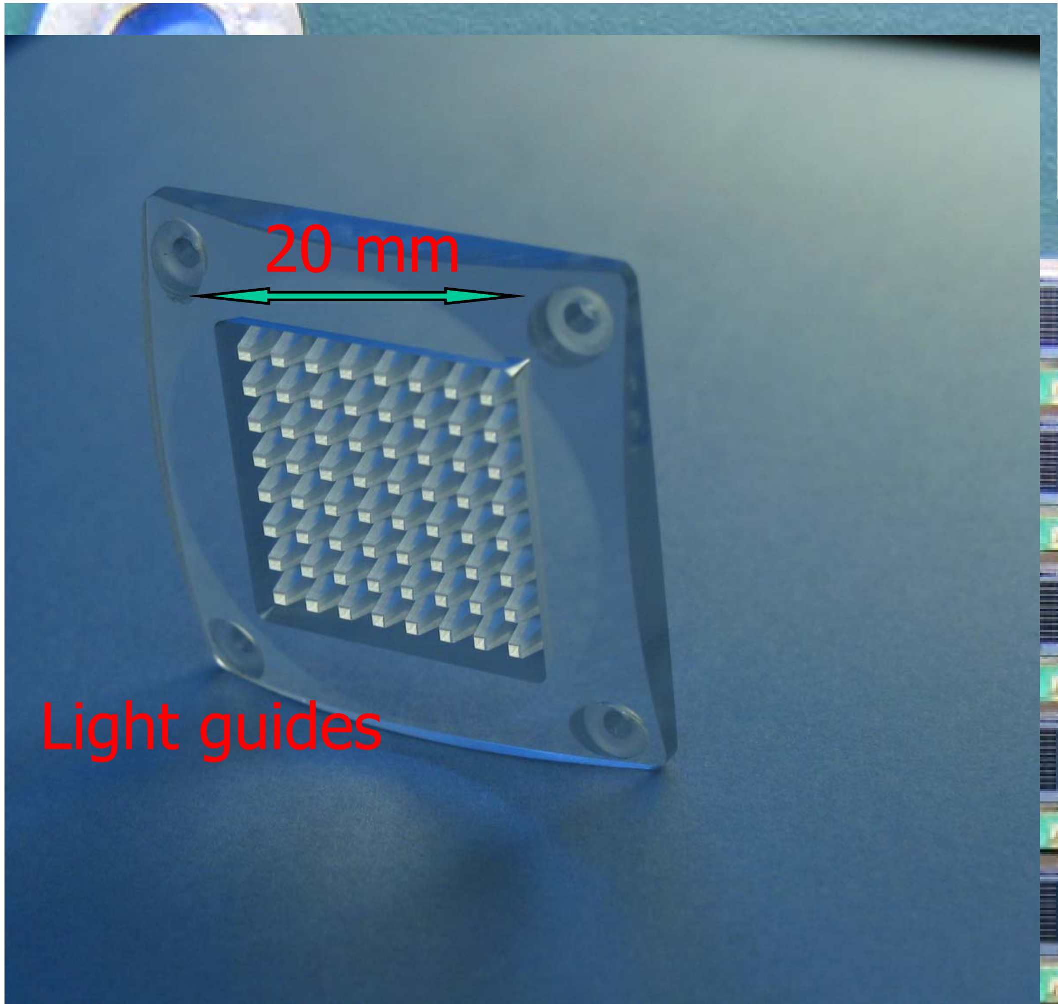


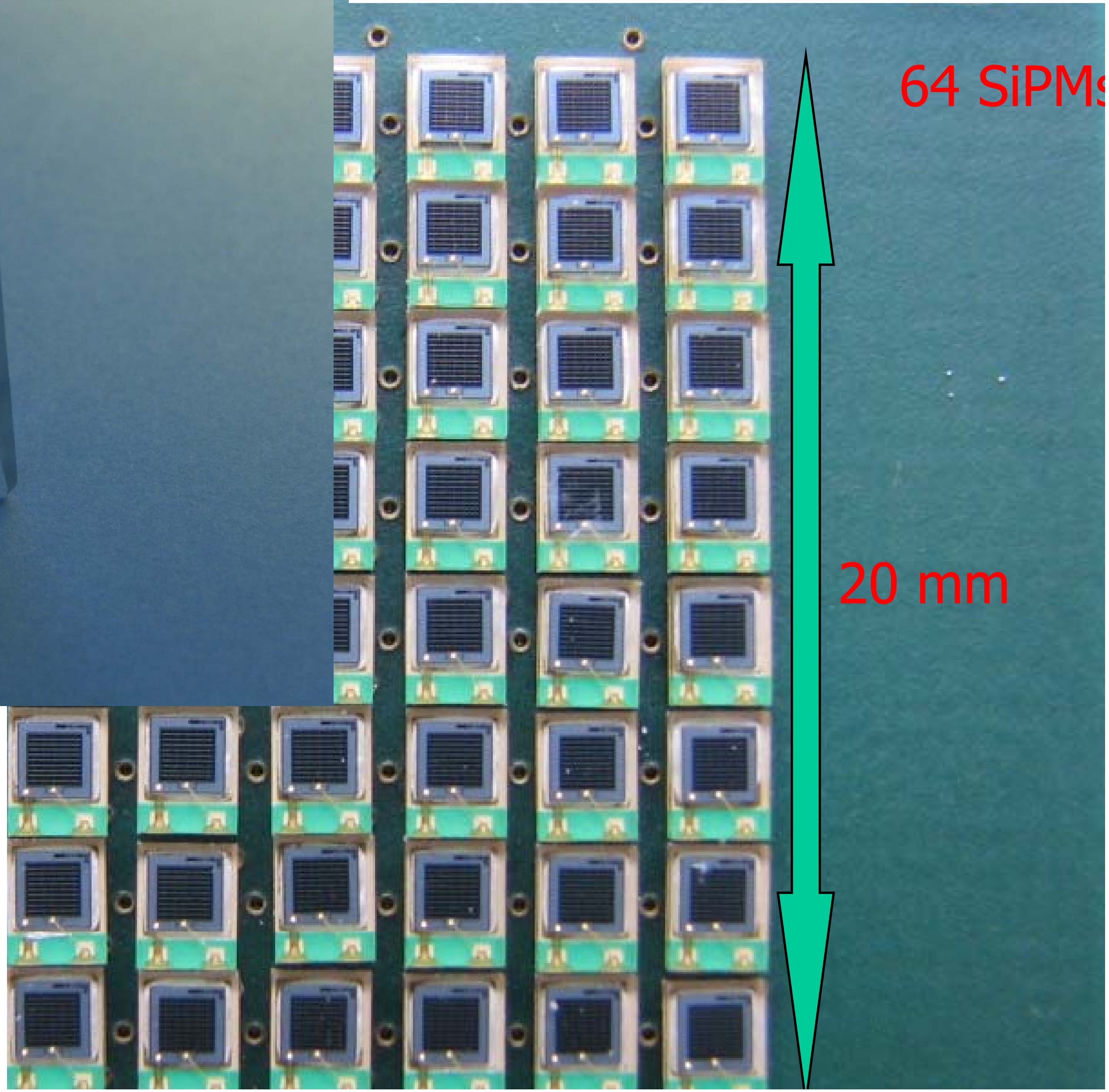
•MCP PMT by Photonis: excellent timing, could be also used as a TOF counter

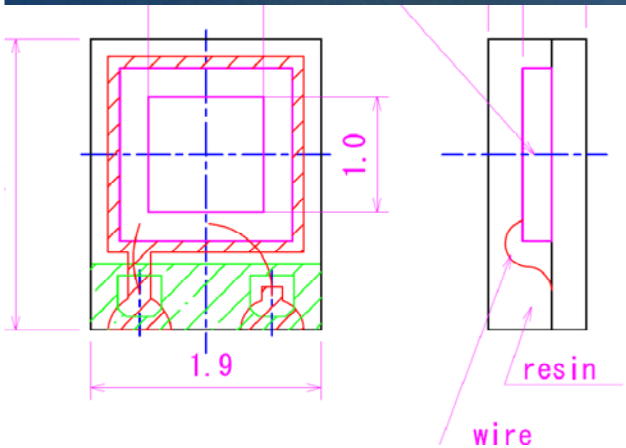


•SiPMs (G-PAD): easy to handle, but never before used for single photon detection (high dark count rate with single photon pulse height) → use a narrow time window and light concentrators

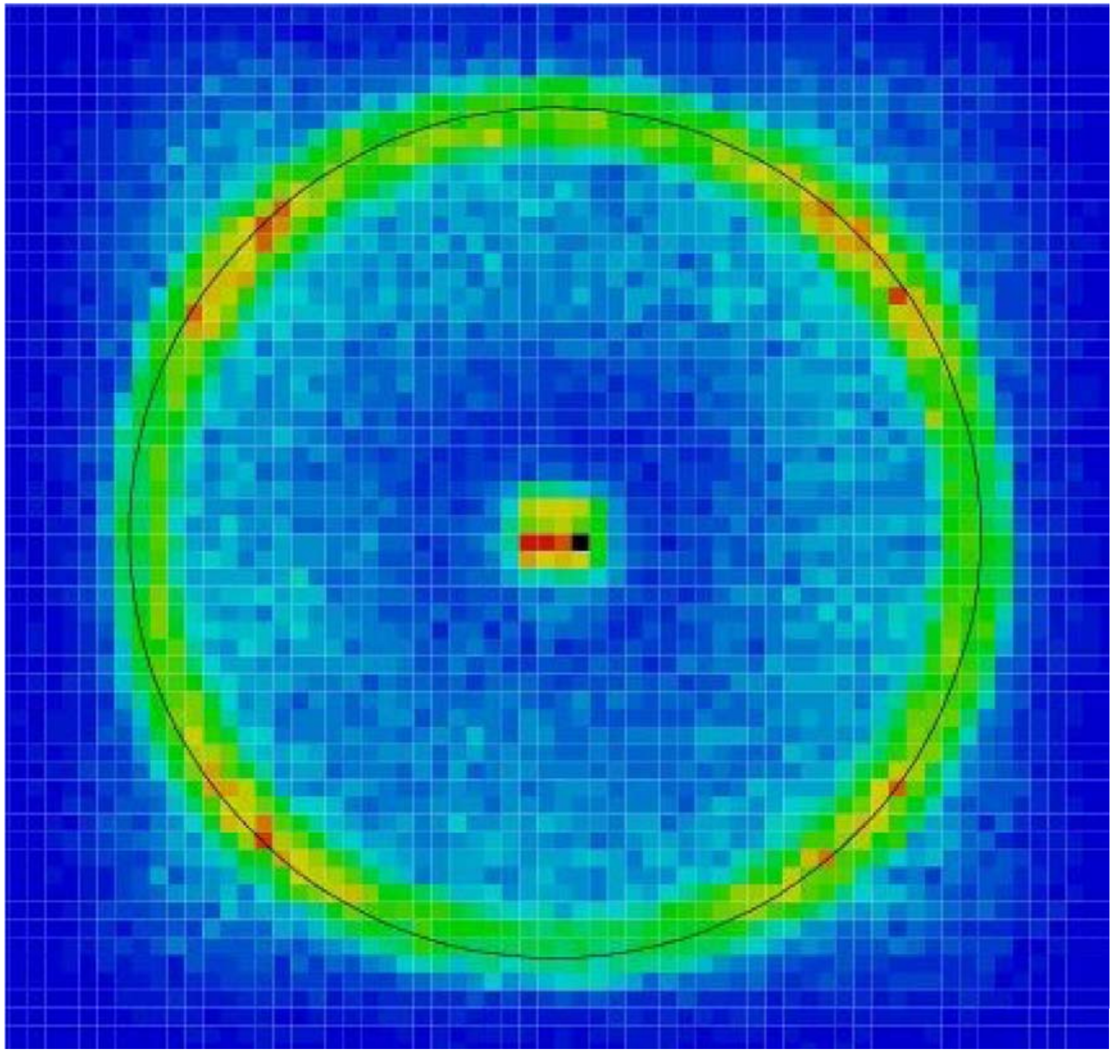
Photon detector for the beam test







Cherenkov ring with SiPMs

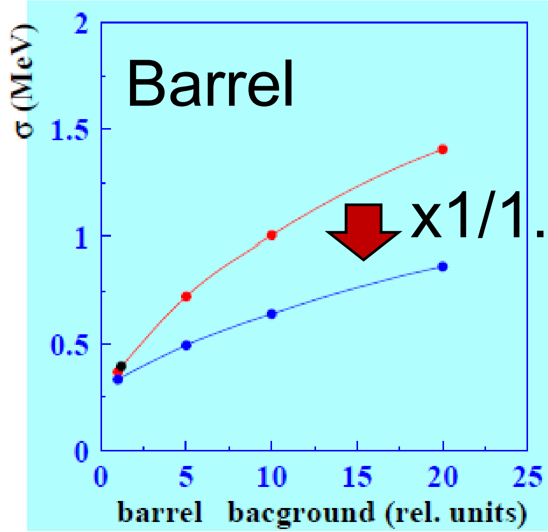


First successful use of SiPMs as single photon detectors in a RICH counter!

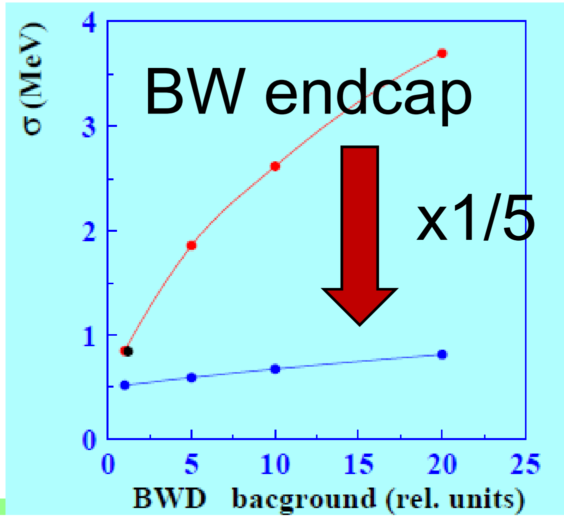
NIM A594 (2008) 13

Calorimeter (ECL) Upgrade

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



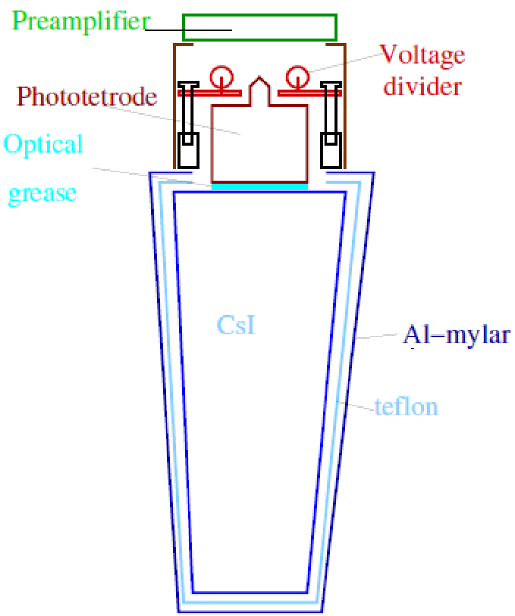
- Barrel:
  0.5μs shaping + 2MHz w.f. sampling.
- Endcap:
  rad. hard crystals with short decay time (e.g. pure CsI) + photopentodes
  30ns shaping + 43MHz w.f. sampling

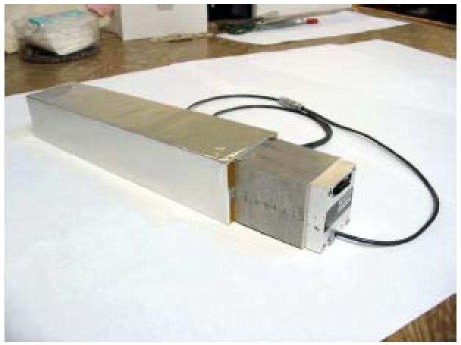


Pure CsI & photopentodes

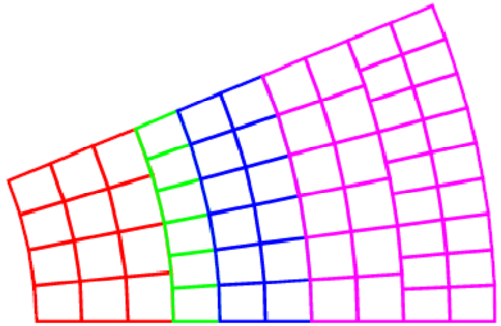
Possible endcap upgrade scenarios

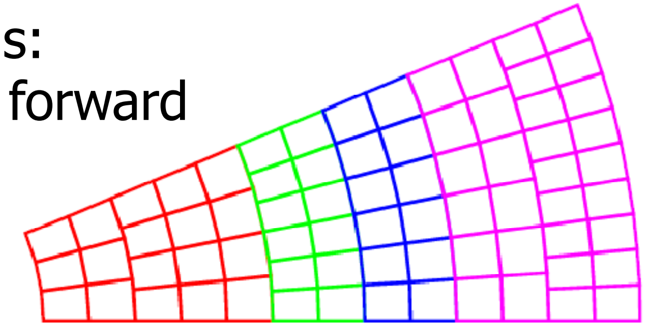
- Waveform sampling & fitting
- CsI(Tl) → pure CsI for end caps





Various scenarios of a partial replacement with rad. hard crystals:





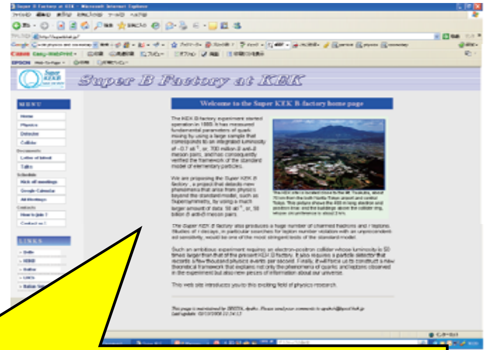
- 480 (red only)
- 768 (+green)
- 1152 (+blue)
- 2112 (+pink)

Project Status

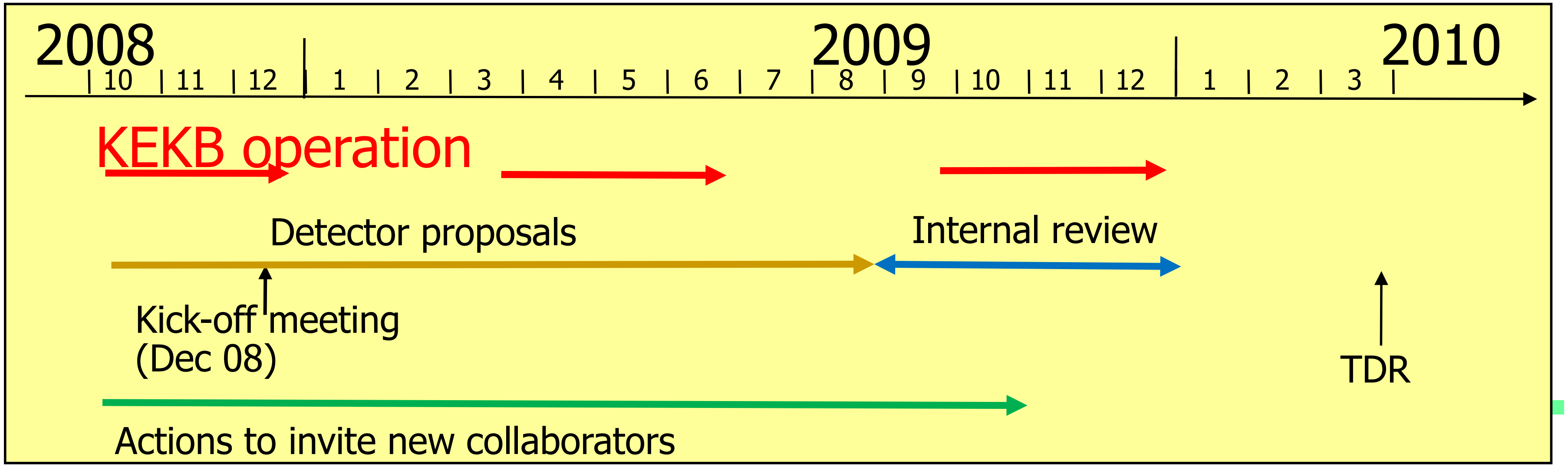
- SuperKEKB is the lab priority.
- The Japanese government has allocated 32 oku-yen ($32 M, €23 M) for upgrade R&D in FY 2009, as a part of its economic stimulus package.
- KEK has submitted a budget request for FY 2010 and beyond of $350 M for construction.
- We are proceeding with R&D while awaiting approval of the construction budget request.

New Collaboration (Belle II)

- Belle II is a new international collaboration.
  - Regular collaboration meetings (next 18-19 Nov 2009)
- Near-term plan
  - Detector study report has been completed.
  - Detector proposals (by Dec. 2009).
  - TDR by March 2010



Belle II webpage
http://superb.kek.jp/
Mailing list subscription is available.



Korean participation in Belle-II

Most of Korean Belle institutions will continue to work on Belle-II

Newcomers: KISTI with computing resources

The Korean groups in Belle-II are planning to make a significant contribution to the upgraded spectrometer

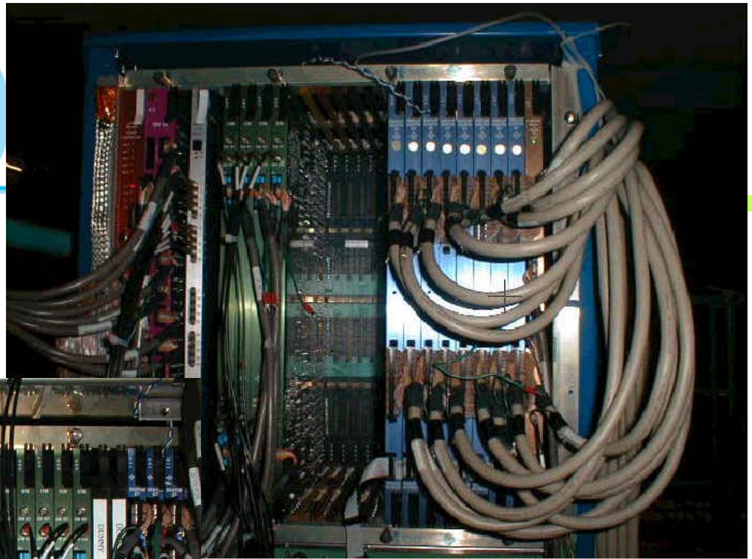
- Subject to funding situation in Korea

Summary

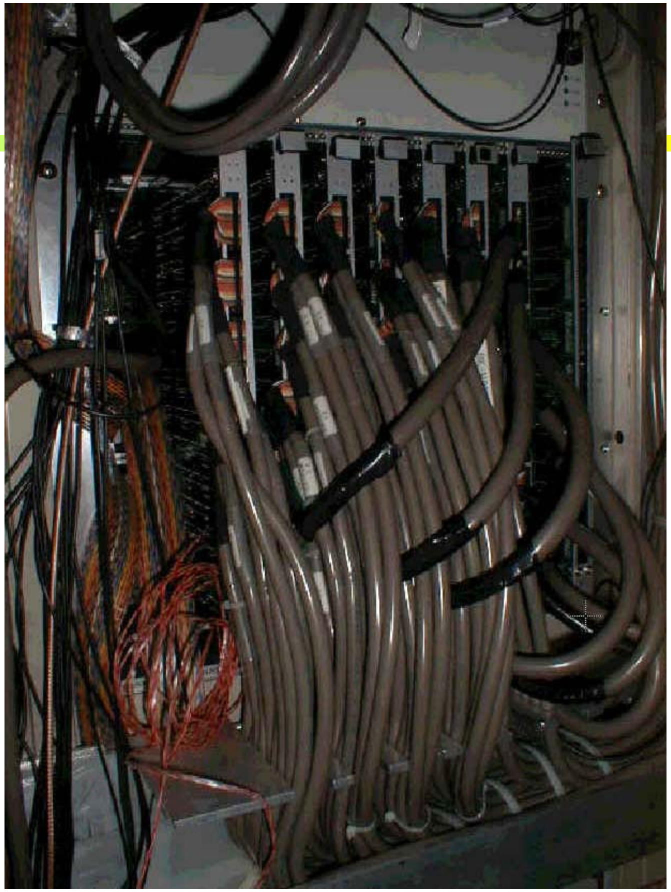
- B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of the performance.
- Major upgrade in 2009-12 → Super B factory, L x10 → x40
- Essentially a new project, all components have to be replaced, nothing is frozen...
- A physics reach update is being prepared – to be made public soon
- Expect a new, exciting era of discoveries, complementary to LHC
- Do not miss the opportunity to be a part of it!

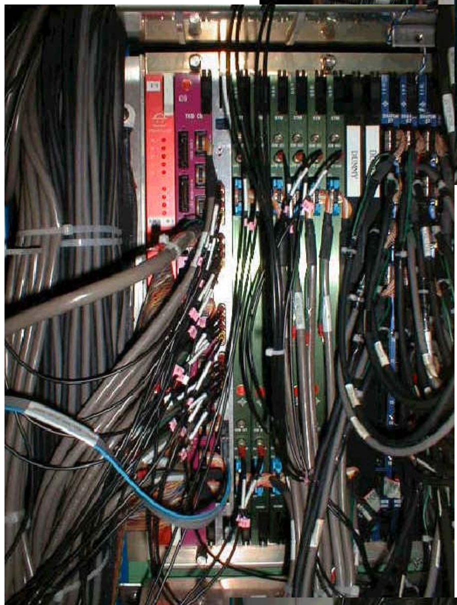
Additional slides

STM



CCM

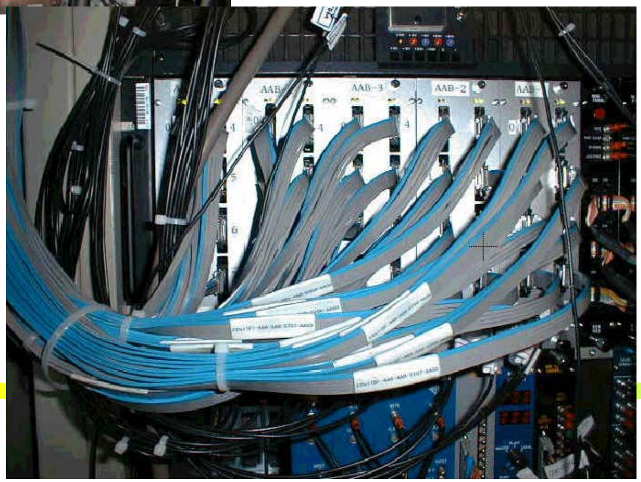


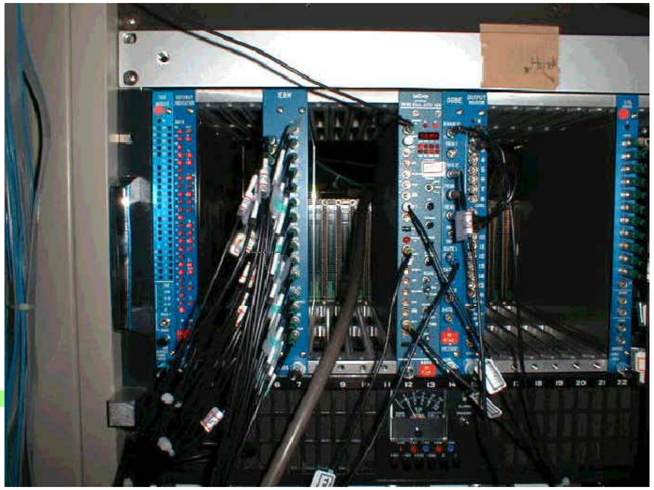


AAA

EBM

AAB

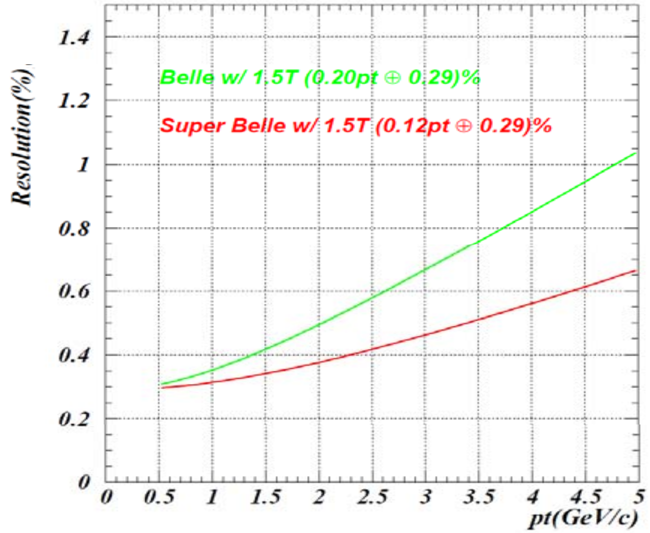


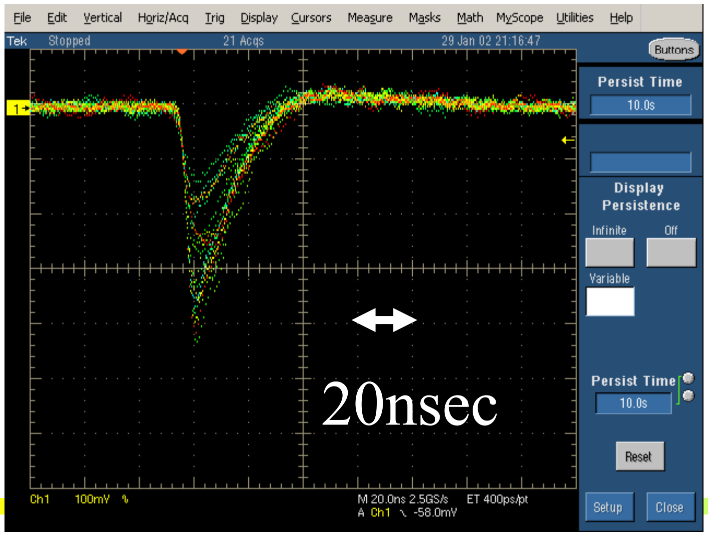


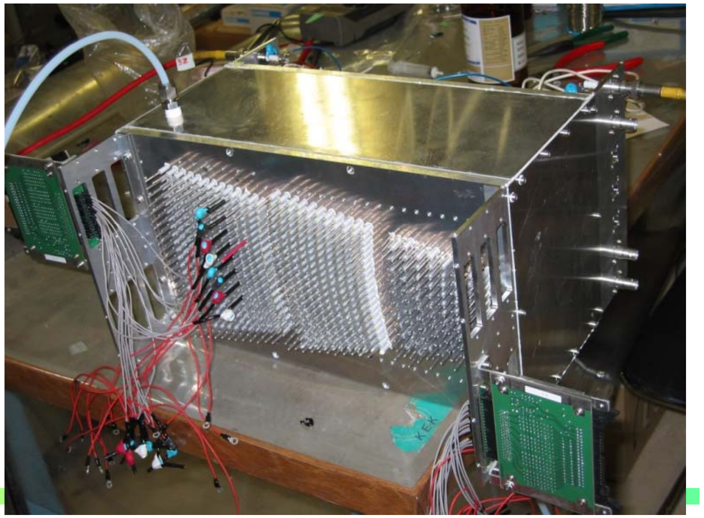
CDC Upgrade

- Larger outer radius: 752mm →978mm
  - Longer lever arm → better Pt reso.
  - More samplings → better dE/dx reso.
- Smaller cell size:

  12mm, 64cells → 8mm, 160cells
  - Improved background tolerance
- New ASD with fast shaping







DEPFET Principle

p-channel FET on a completely depleted bulk

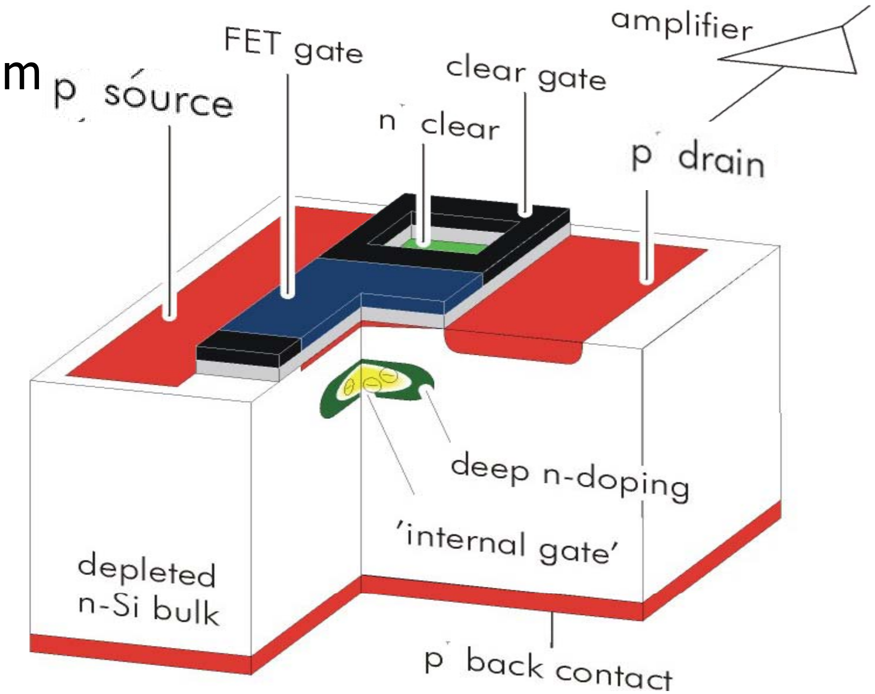
A deep n-implant creates a potential minimum for electrons under the gate ("internal gate")

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")

Invented in MPI Munich

Depleted p-channel FET



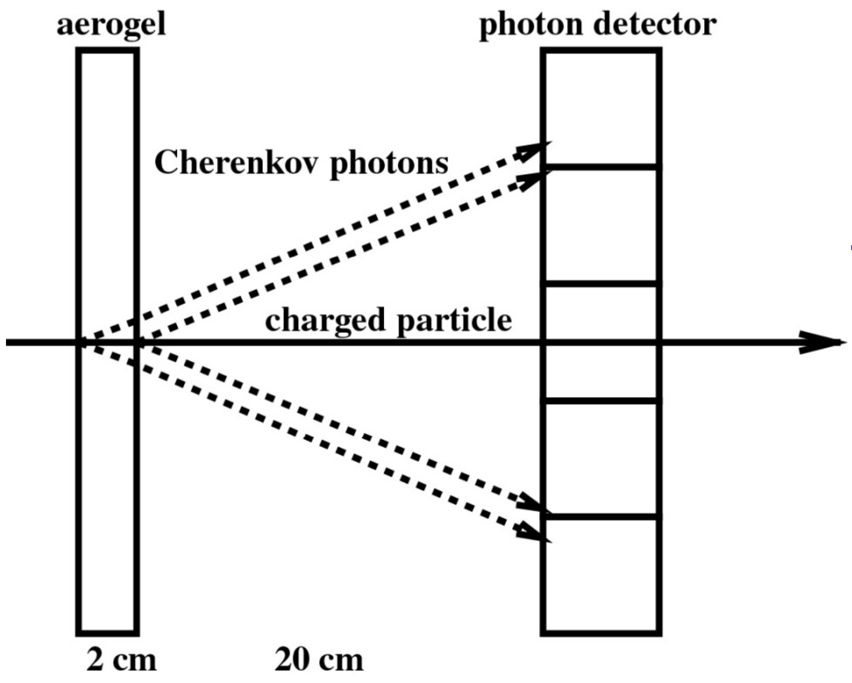
Fully depleted:
→ large signal, fast signal collection

Transistor on only during readout: low power

Low capacitance, internal amplification → low noise

Complete clear → no reset noise

Endcap: Proximity focusing RICH



K/π separation at 4 GeV/c:
$\theta_c(\pi) \sim 308$ mrad (n = 1.05)
$\theta_c(\pi) - \theta_c(K) \sim 23$ mrad

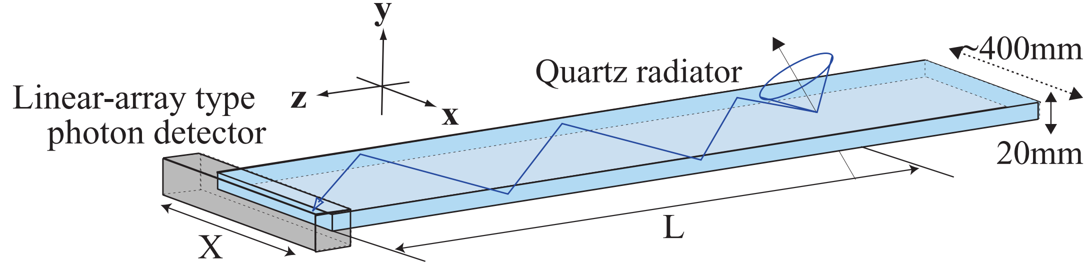
For single photons:
$\delta\theta_c$(meas.)$=\sigma_0 \sim 14$ mrad,
typical value for a 20mm thick radiator and 6mm PMT pad size

Per track: $$\sigma_{track} = \frac{\sigma_0}{\sqrt{N_{pe}}}$$

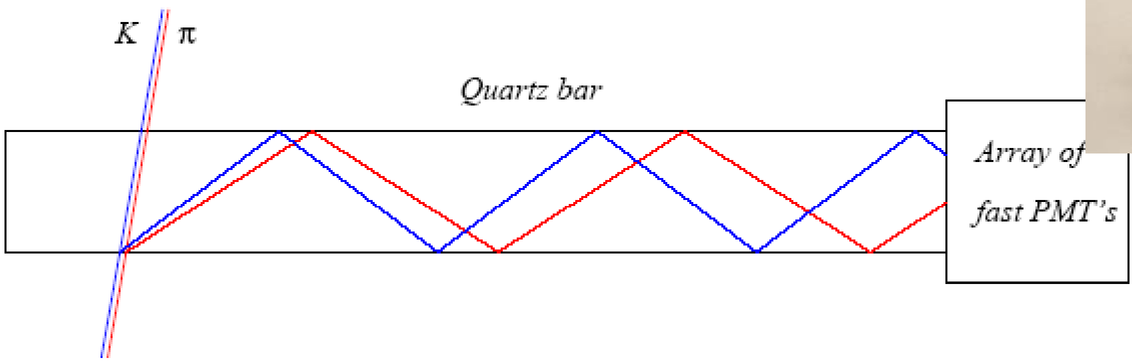
Separation: $[\theta_c(\pi) - \theta_c(K)]/\sigma_{track}$

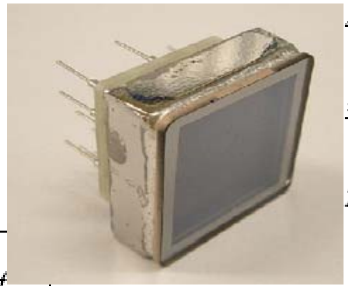
→ 5σ separation with $N_{pe} \sim 10$

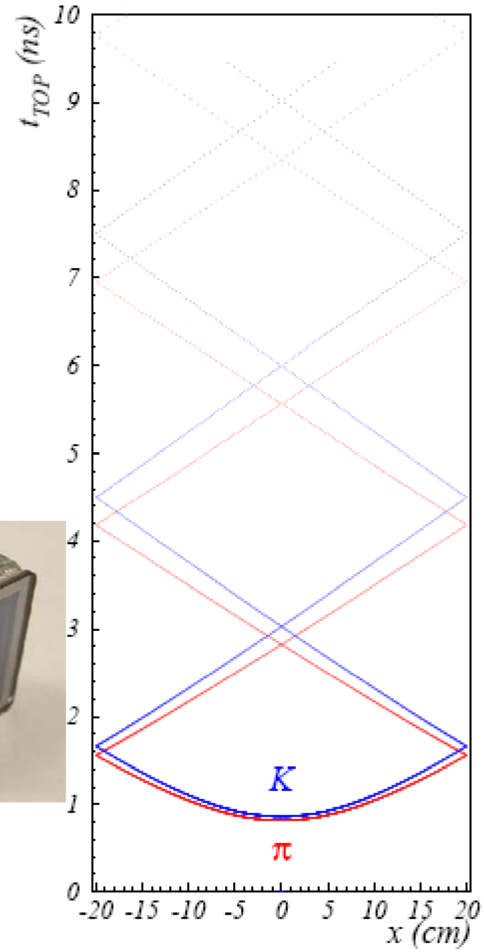
Barrel PID: Time of propagation (TOP) counter



- Cherenkov ring imaging with precise time measurement.
- Reconstruct angle from one coordinate and the time of propagation of the photon
  - Quartz radiator (2cm)
  - Photon detector (MCP-PMT)
    - Good time resolution < ~ 40 ps
    - Single photon sensitive in 1.5 T







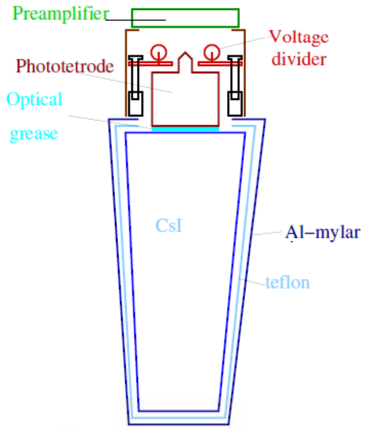
Calorimeter (ECL) upgrade

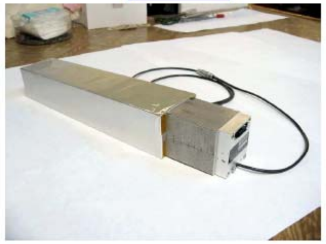
End caps

Background is the biggest issue → Faster crystal CsI(Tl) $\tau \sim 1\mu s$ → pure CsI $\tau \sim 30ns$ → Small light yield UV → PMT

Barrel

Background is the biggest issue, but not as bad as end caps → Waveform sampling & fitting

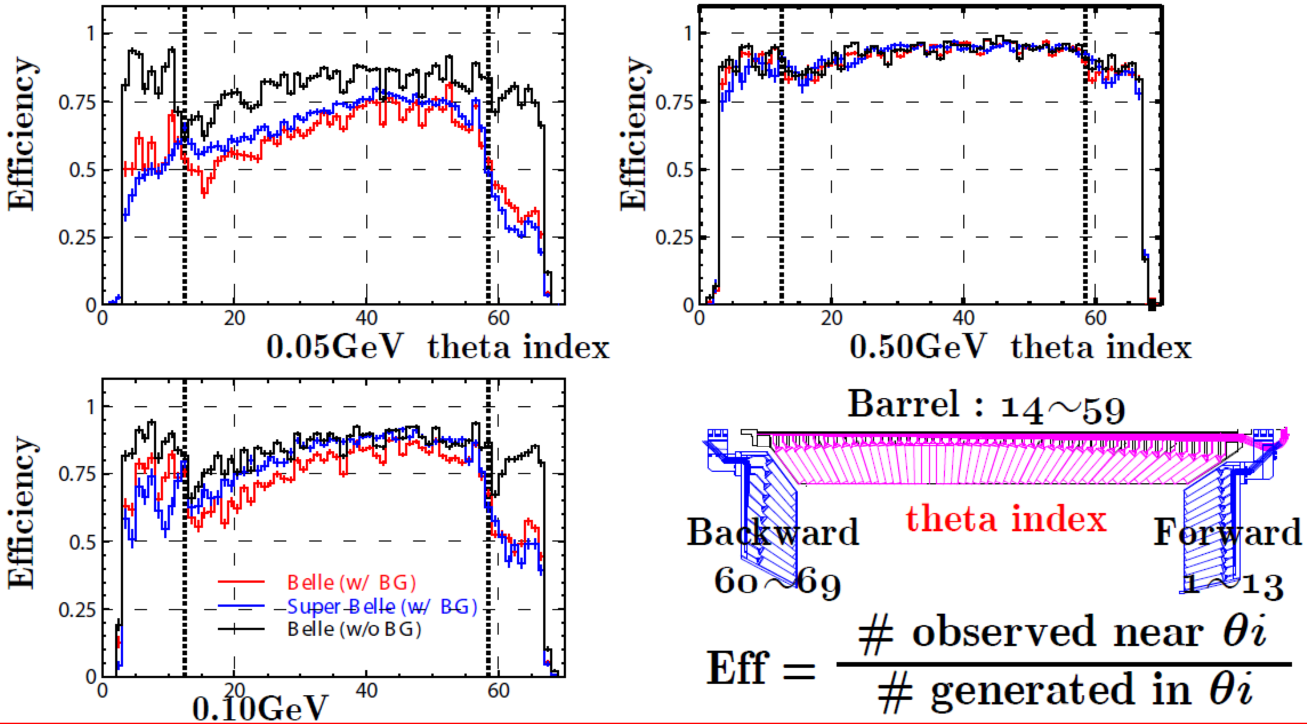




Free bonus: Reduced material in front of ECL due to PID upgrade

ECL: Effect of material in front

γ efficiency



$$\mathrm{Eff} = \frac{\#\ \text{observed near}\ \theta i}{\#\ \text{generated in}\ \theta i}$$

Removal of ACC helps. No big worry

Pure CsI crystals

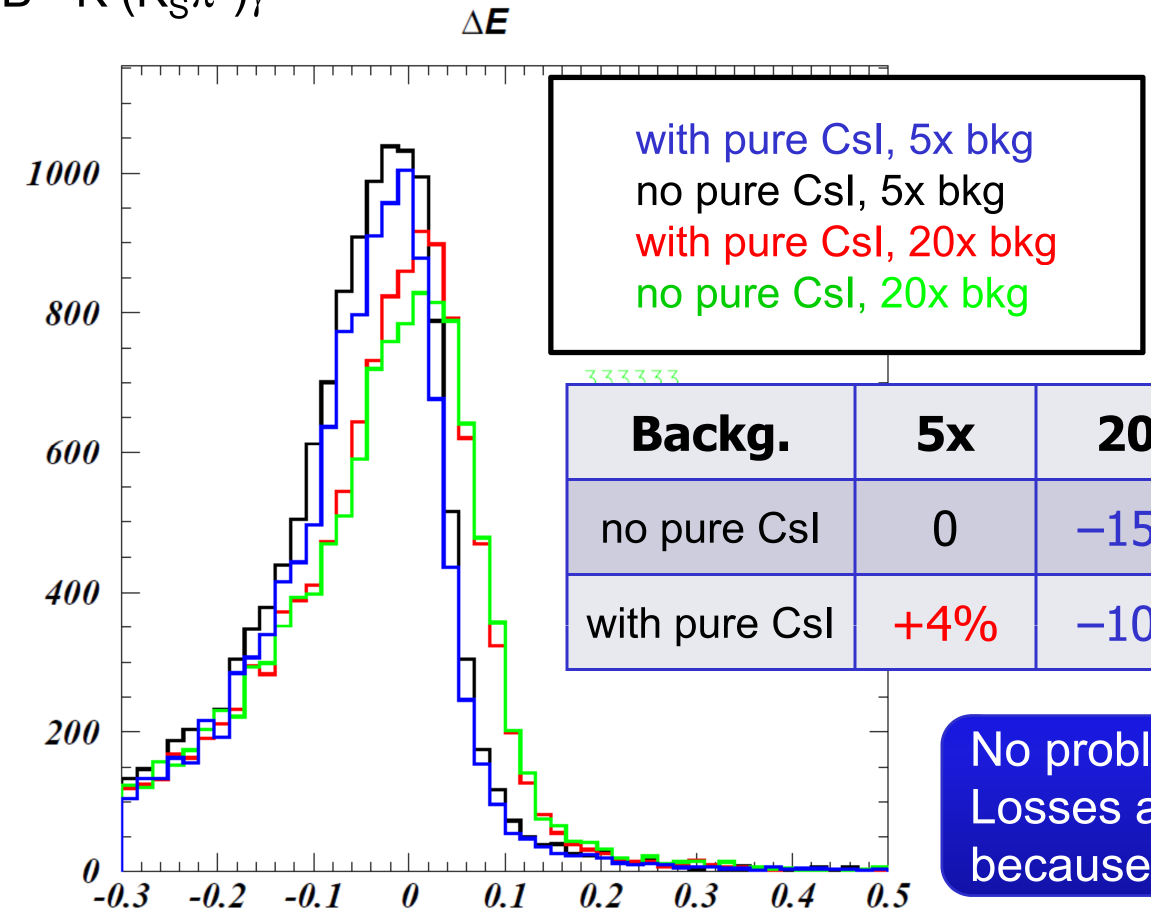
MC study of the impact of using pure CsI on the sample of fully reconstructed B mesons:

- Full backward and forward endcap (2112 crystals): eff +5%, background –7%
- Visible effect if >1000 replaced crystals

Need MC studies of the effect also on other channels.

Pure CsI – impact 2

$B \to K^*(K_S \pi^0)\gamma$



Backg.	5x	20x
no pure CsI	0	−15%
with pure CsI	+4%	−10%

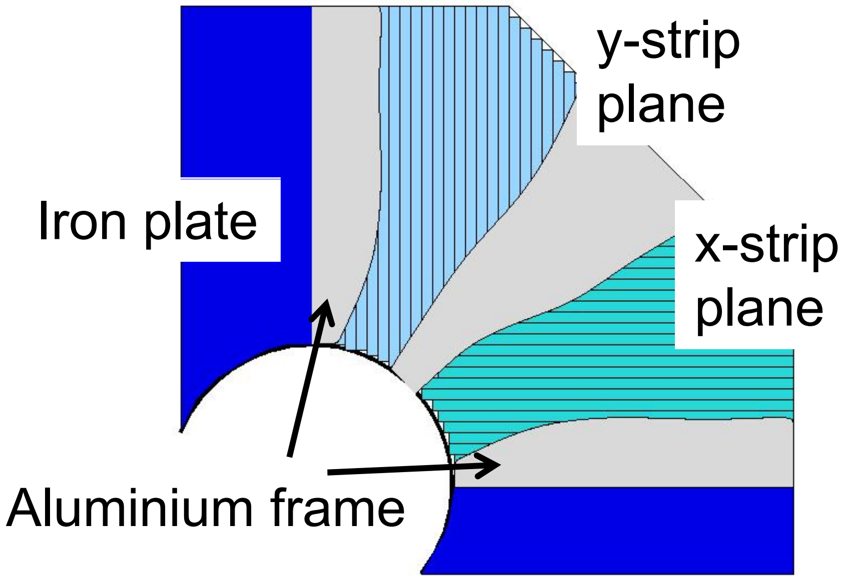
No problem with 5x background
Losses at 20x background
because of CsI(Tl) in barrel

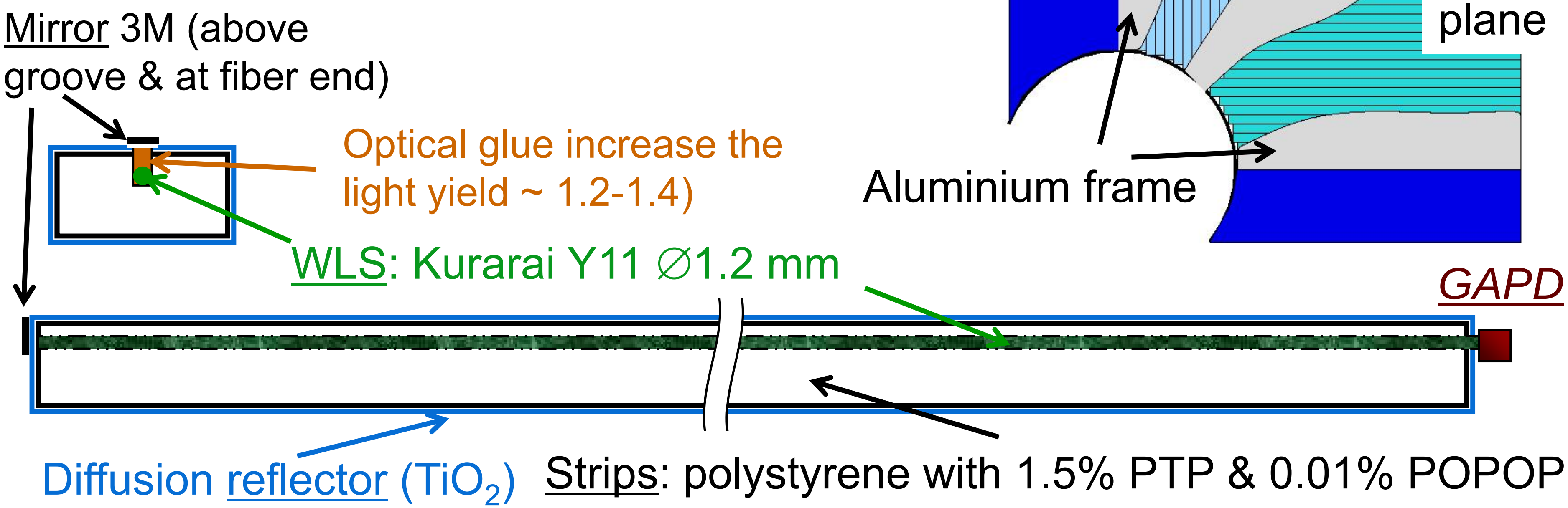
(*) Reduce material not taken into account for this study

KLM upgrade

Scintillator-based KLM (endcap)

- Two independent (x and y) layers in one superlayer made of orthogonal 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%





Model-indep. check of NP

- A_{cp} ($K\pi$) sum rule

M. Gronau, PLB 627, 82 (2005);

D. Atwood & A. Soni, Phys. Rev. D 58, 036005(1998).

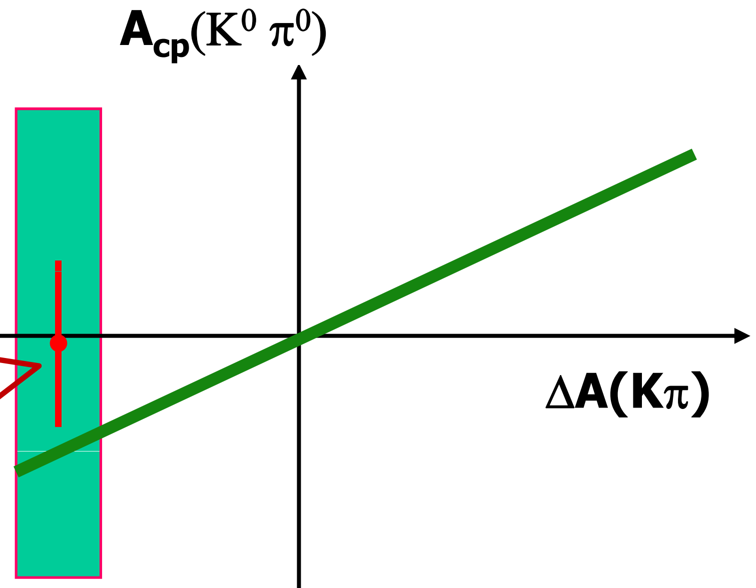
$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

$B^0 \to K^0\pi^0$ New

BaBar: $A = -0.13 \pm 0.13 \pm 0.03$

Belle: $A = +0.14 \pm 0.13 \pm 0.06$

HFAG AVG: -0.01 ± 0.10



Sum rule predicts $A_{cp}(K^0\pi^0) = -0.151 \pm 0.043$

Leptonic B decays

Phenomenology

additional Higgs doublet;

$\tan\beta = v_1/v_2$, ratio of vacuum expectation values;

$H^\pm$ coupling $\propto m_l$ $\Rightarrow$ same factor as helicity SM suppression

Type II Two Higgs Doublets Models (ϕ_1 gives masses to d-type and charged lepton; ϕ_2 gives masses to u-type; in Type I models ϕ_1 is decoupled and ϕ_2 generates all masses)

W.S.Hou, PRD48, 2342 (1993)

$$\Gamma(B^+ \to \tau^+\nu) = \Gamma^{SM}(B^+ \to \tau^+\nu)\cdot \underbrace{\left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2}_{independent\ of\ m_\tau}$$

if $\Gamma^{meas} > \Gamma^{SM} \Rightarrow H^\pm$ contribution dominant

$$\Gamma^{SM}(B^+ \to \ell^+\nu) = \frac{G_F^2}{8\pi}|V_{ub}|^2 f_B^2 m_B m_\ell^2 \left(1 - \frac{m_\ell^2}{m_B^2}\right)$$

ratio independent of $H^\pm$ contribution:

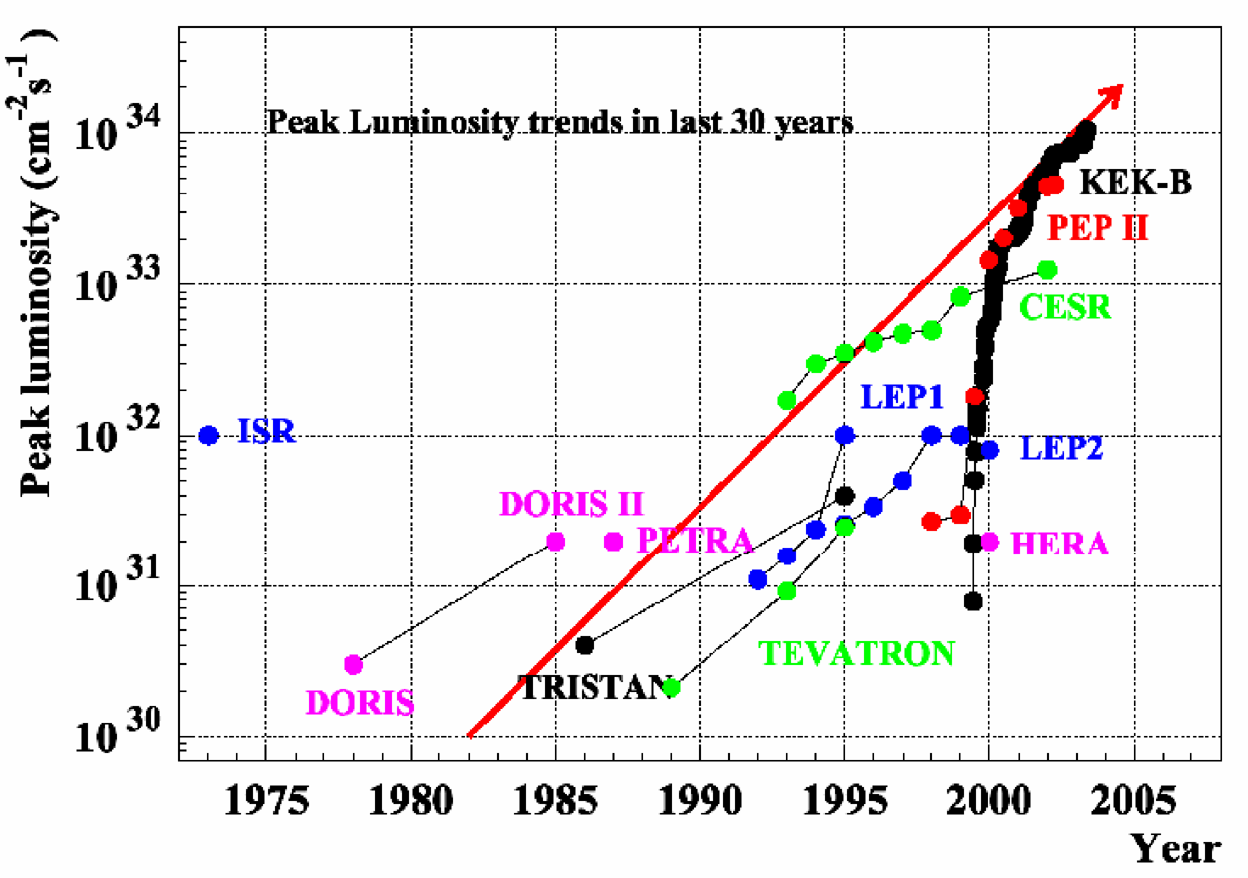
$$\Gamma^{SM}(B^+ \to \ell_1^+\nu)/\Gamma^{SM}(B^+ \to \ell_2^+\nu) = \frac{m_{l1}^2}{m_{l2}^2}\frac{(1-m_{l1}^2/m_B^2)^2}{(1-m_{l2}^2/m_B^2)^2}$$

Comparison with LHCb

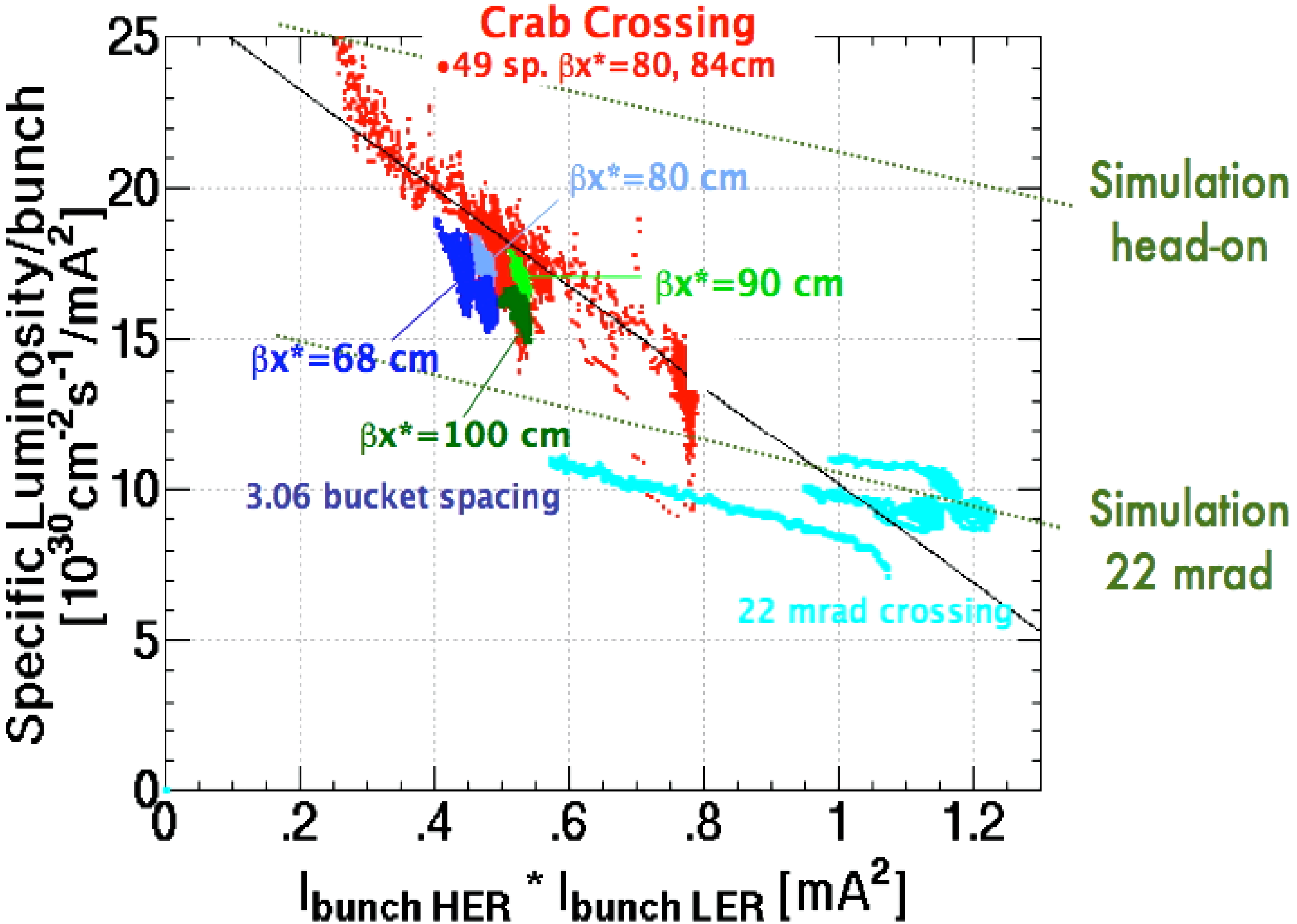
e^+e^- has advantages in…	LHCb has advantages in…
CPV in $B \to \phi K_S$, $\eta' K_S$,…	CPV in $B \to J/\psi K_S$
CPV in $B \to K_S \pi^0 \gamma$	Most of B decays not including ν or γ
$B \to K\nu\nu$, $\tau\nu$, $D^{(*)}\tau\nu$	Time dependent measurements of B_S
Inclusive $b \to s\mu\mu$, *see*	$B_{(s,d)} \to \mu\mu$
$\tau \to \mu\gamma$ and other LFV	B_c and bottomed baryons
$D^0\overline{D^0}$ mixing	

Complementary!!

Luminosity and accelerators vs time



Crab cavity commissioning



Luminosity gain and upgrade items (high current option)

3 years shutdown

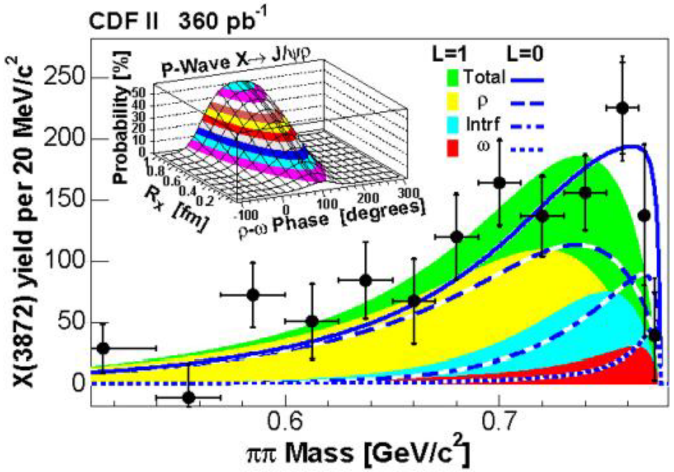
Item	Gain	Purpose
beam pipe	x 1.5	high current, short bunch, electron cloud
IR($\beta^*_{x/y}$=20cm/3 mm)	x 1.5	small beam size at IP
low emittance(12 nm) & $\nu_x \rightarrow 0.5$	x 1.3	mitigate nonlinear effects with beam-beam
crab crossing	x 2	mitigate nonlinear effects with beam-beam
RF/infrastructure	x 3	high current
DR/e^+ source	x 1.5	low β^* injection, improve e^+ injection
charge switch	x ?	electron cloud, lower e^+ current

Accellerator parameters

Parameter	Units	SuperB	Super-KEKB Old scheme	Super-KEKB Italian scheme
Energy	GeV	4x7	3.5x8	3.5x8
Luminosity	$10^{36}/cm^2/s$	1.0	0.5 to 0.8	0.8
Beam currents	A	2.0x2.0	9.4x4.1	3.8x2.2
$N_{bunches}$		2400	5000	2230
Ey* (L/H)	pm	7/4	240/90	34/11
Ex* (L/H)	nm	2.8/1.6	24/18	2.8/2
By* (L/H)	mm	0.21/0.37	3	0.21/0.37
Bx* (L/H)	cm	3.5/2.0	20	4.4/2.5
Sz (L/H)	mm	5/5	5/3	5/5
Crossing angle (full)	mrad	60	30 to 0	60
RF power (AC line)	MW	26	90	>50
Tune shifts (L/H)		0.125/0.125	0.3/0.51	0.081/0.081

Spectroscopy

CDF, PRL96, 102002 (2006), 360pb[-1]



X(3872)

properties

$$\frac{Br(X \to \gamma J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} = 0.14 \pm 0.05$$

C=+1;

Belle, hep-ex/0505037, 250fb[-1]

M(ππ) distrib., ρ-like;

$(c\bar{c}) \to J/\psi\rho$ isospin breaking;

4-quark states:

$$\left|c\bar{c}u\bar{u}\right\rangle =$$

$$= \frac{1}{\sqrt{2}}\left|c\bar{c}\right\rangle \left[\frac{1}{\sqrt{2}}\left(\left|u\bar{u}\right\rangle + \left|d\bar{d}\right\rangle\right) + \frac{1}{\sqrt{2}}\left(\left|u\bar{u}\right\rangle - \left|d\bar{d}\right\rangle\right)\right] =$$

$$= \frac{1}{\sqrt{2}}\left[\left|I=0\right\rangle + \left|I=1\right\rangle\right]$$

η_c'': ang. distr., M, G;

χ_{c0}': ang. distr., DD;

χ_{c1}': $\gamma J/\psi$

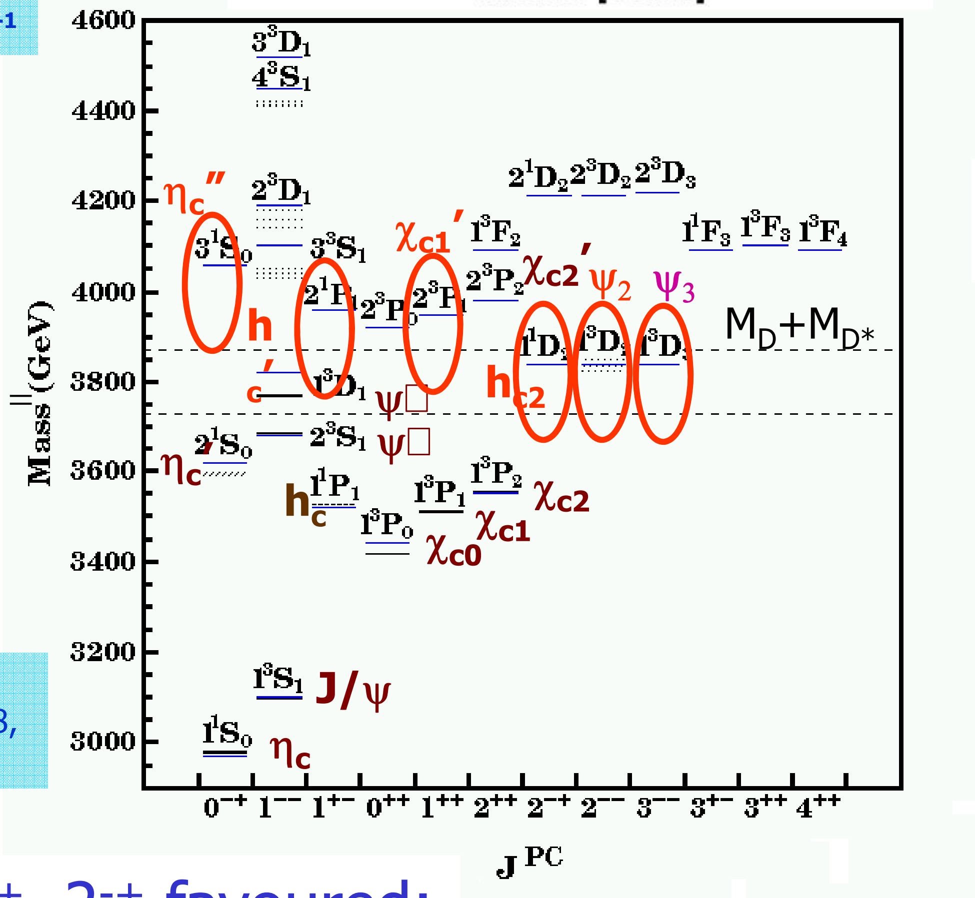
h_{c2}: $\pi\pi h_c$ dominant, DD*;

c_{c2}': DD*;

- no obvious $c\bar{c}$ candidate;

ang. distrib.:

Belle, hep-ex/0505038, 250fb[-1]



J^{PC}= 1^{++}, 2^{-+} favoured;

Spectroscopy

X(3872)

other possibilities

DD* molecule:
prod. from B^0 suppressed compared to B^+ (depending on model parameters);

$$\frac{Br(B^0 \to XK^0)}{Br(B^+ \to XK^+)} = 0.94 \pm 0.24 \pm 0.10$$

$$M(B^+ \to X) - M(B^0 \to X) = (0.22 \pm 0.90 \pm 0.27)\ MeV$$

Belle, BELLE-CONF-0711, 605 fb^{-1}

$$\frac{Br(B^0 \to XK^0)}{Br(B^+ \to XK^+)} = 0.41 \pm 0.24 \pm 0.05$$

$$M(B^+ \to X) - M(B^0 \to X) = (2.7 \pm 1.6 \pm 0.4)\ MeV$$

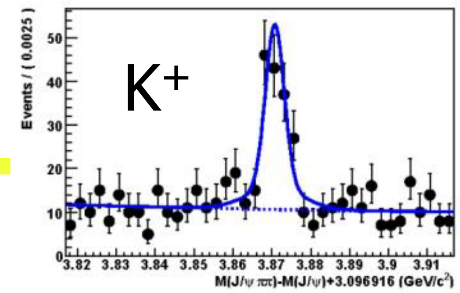
BaBar, PRD77, 111101 (2008), 413 fb^{-1}

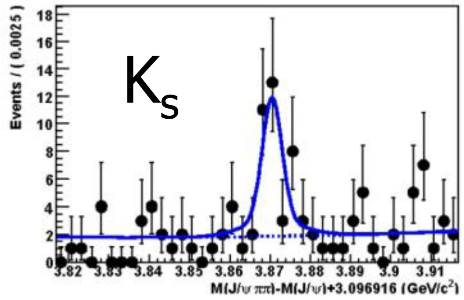
tetraquarks:

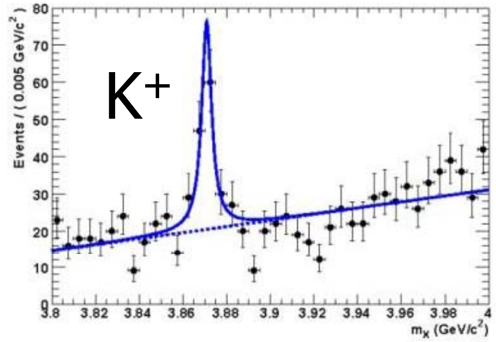
L. Maiani et al., PRD71, 014028 (2005)

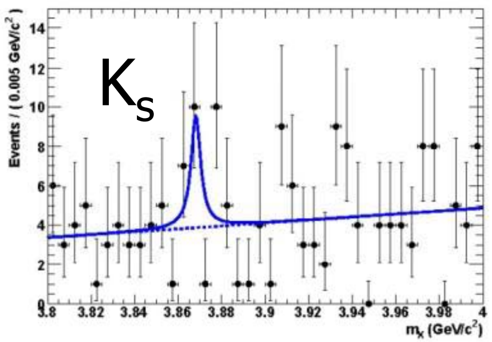
two mixed states, $[cu][\overline{cu}]$, $[cd][\overline{cd}]$;
one produced mainly in B^0, other in B^+ decays $\Rightarrow$ mass difference;
also charged X^+ $[cu][\overline{cd}]$, no evidence so far;

$M(J/\psi\pi\pi)$ for $B \to XK$









Spectroscopy

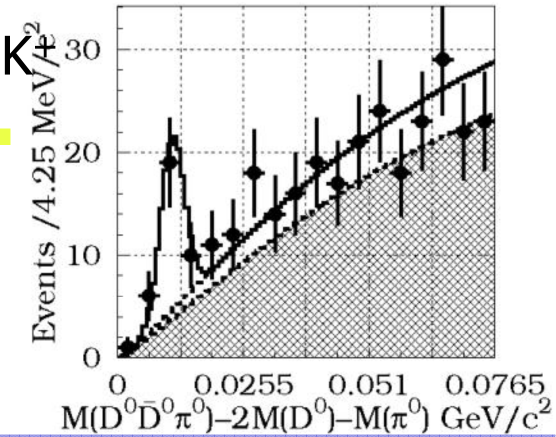
- X(3872)
  other possibilities

DD* molecule:
isospin breaking;
$J^{PC}=1^{++}$;
$J/\psi\pi\pi$ favoured over $DD\pi$;
R~0.1

E. Braten, M. Lu, PRD77, 014029 (2008);
see also E.S. Swanson, Phys. Rept. 429, 243 (2006) for review

Belle, PRL97, 162002 (2006), 414 fb^{-1}

$B^+ \to X(\overline{D}^0 D^0 \pi^0) K^+$



$$M_{X(3872)} = (3875.4 \pm 0.7 \pm {}^{0.4}_{1.7} \pm 0.9)\ MeV$$

last uncertainty: m_{D0};
main syst.: p^0 calibration and signal shape

Belle, PRL97, 162002 (2006), 414 fb^{-1}

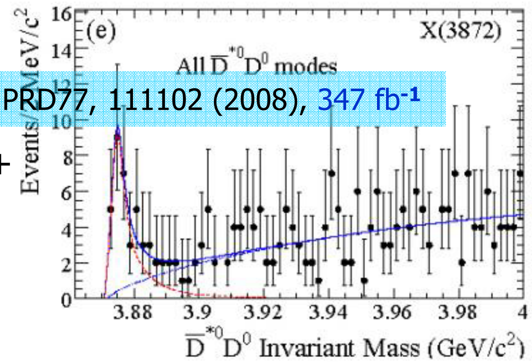
Belle, hep-ex/0505037, 250fb^{-1}

$$R = \frac{Br(X \to D^0 D^0 \pi^0)}{Br(X \to J/\psi\pi\pi)} = 10 \pm 4$$

J=2 decays to DD* suppressed by $(p^*)^{2L+1}$ with L=1,2;
1^{++} state favoured

BaBar, PRD77, 111102 (2008), 347 fb^{-1}

$B^+ \to X(\overline{D}^{*0} D^0) K^+$



$$M_{X(3872)} = (3875.1 \pm {}^{0.7}_{0.5} \pm 0.5)\ MeV$$