Belle-II and SuperKEKB

Peter Križan

University of Ljubljana and J. Stefan Institute

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University of Ljubljana

"Jožef Stefan" Institute

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- Accellerator upgrade → SuperKEKB
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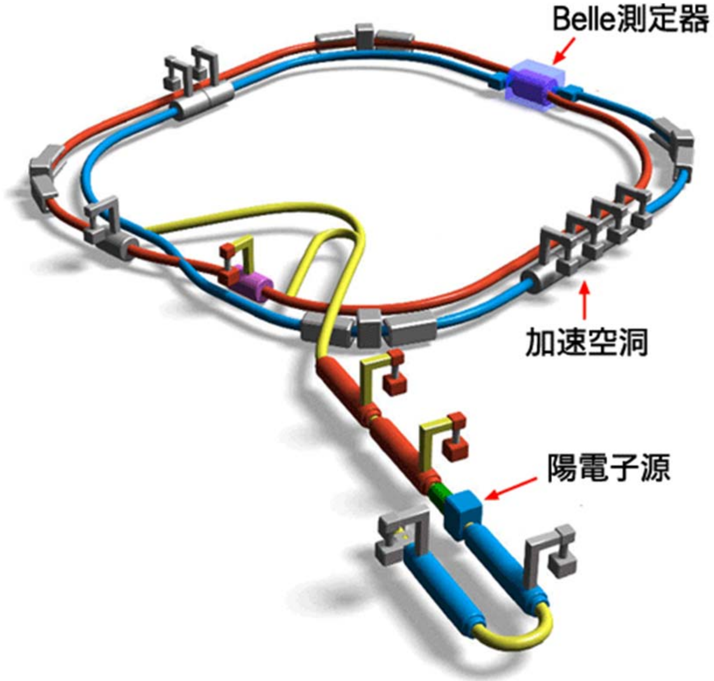
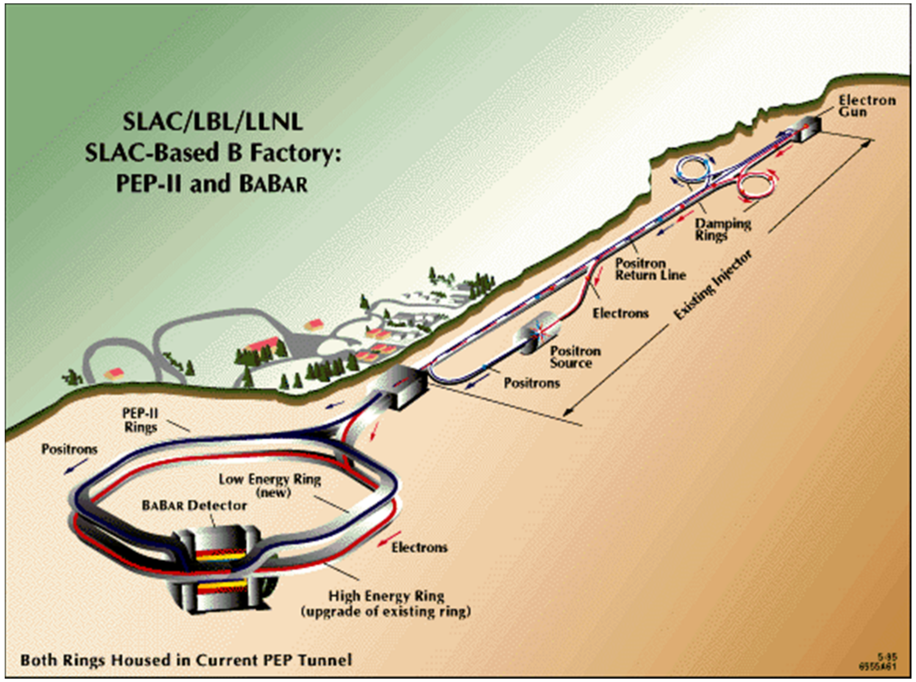
Asymmetric B factories





$\sqrt{s}$=10.58 GeV

$e^+ \rightarrow \Upsilon(4s) \leftarrow e^-$

$\Upsilon(4s) \rightarrow B\,\bar{B}$

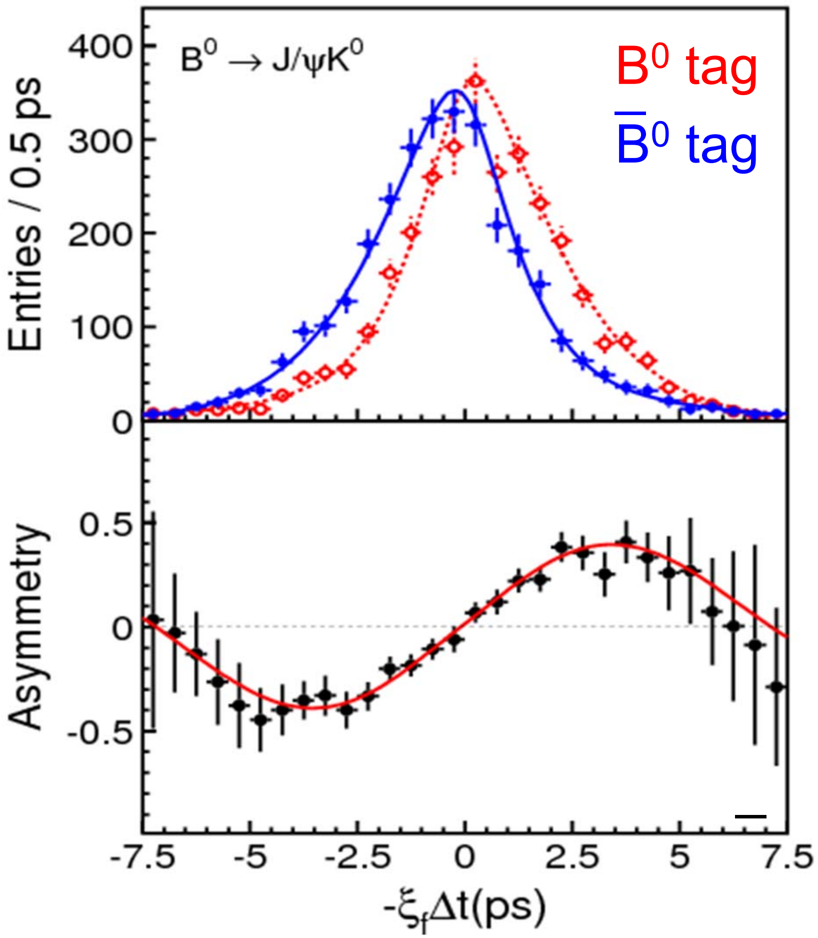
$\Delta z \sim c\beta\gamma\tau_B$
$\sim 200\mu m$

BaBar p(e^-)=9 GeV p(e^+)=3.1 GeV $\beta\gamma$=0.56

Belle p(e^-)=8 GeV p(e^+)=3.5 GeV $\beta\gamma$=0.42

Main motivation for B factories: measure CP violation in the B system

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

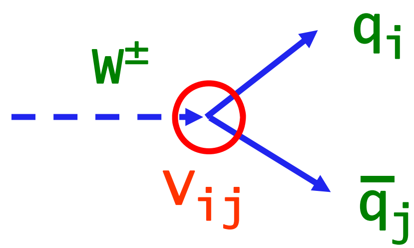


sin2ϕ_1/sin2β from b→ccs

535 M $B\overline{B}$ pairs

sin2ϕ_1= 0.642 ±0.031 (stat) ±0.017 (syst)

CP violation in the Standard model – related to the quark transition matrix

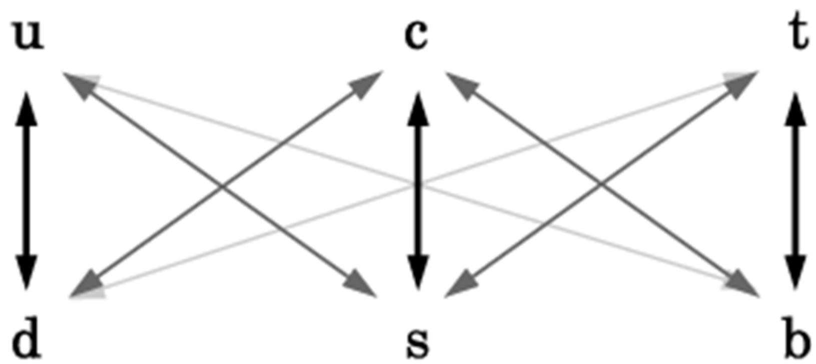


Cabbibo-Kobayashi-Maskawa matrix

CKM matrix is unitary in SM

deviations could signal processes not included in SM

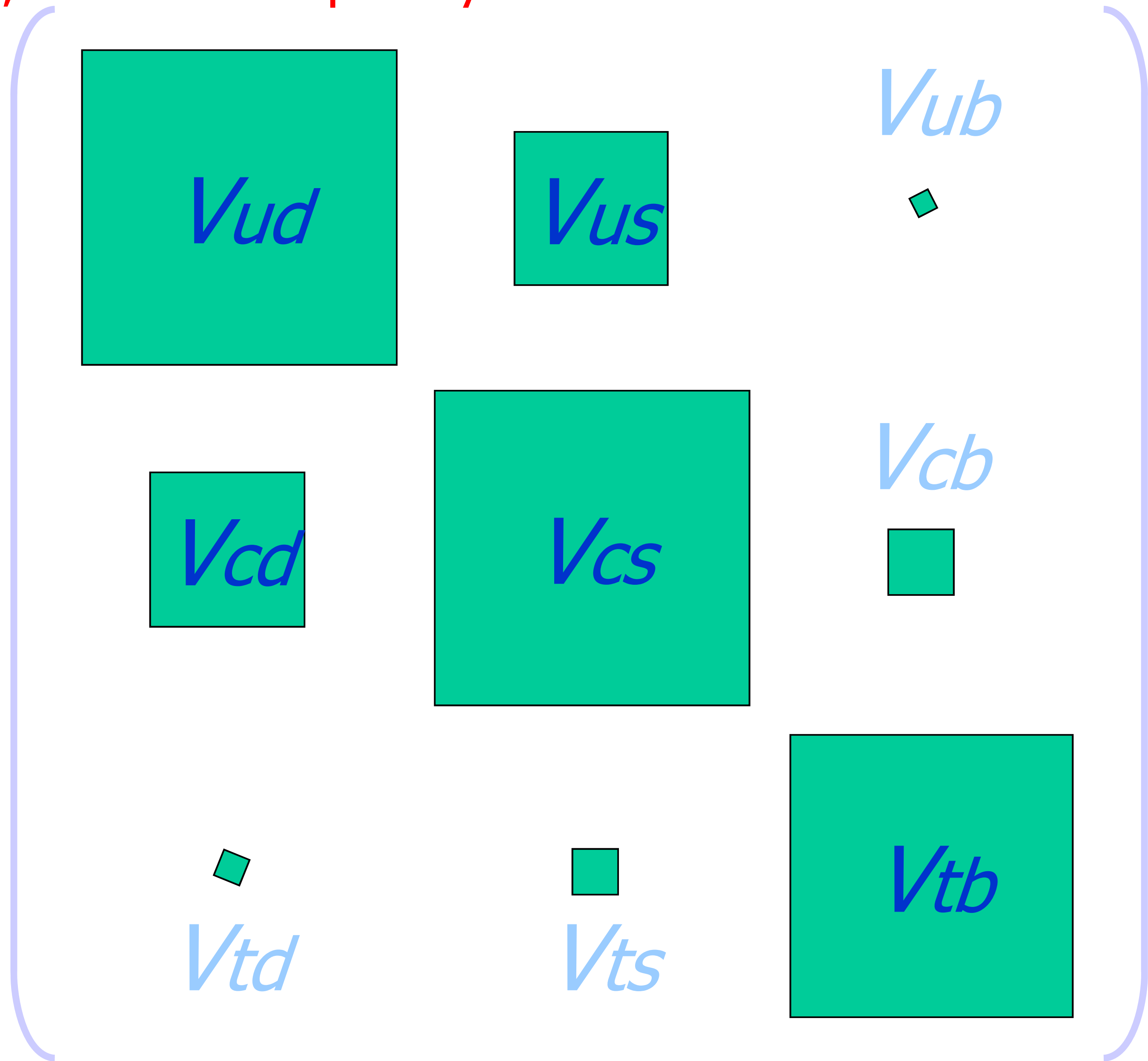
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



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

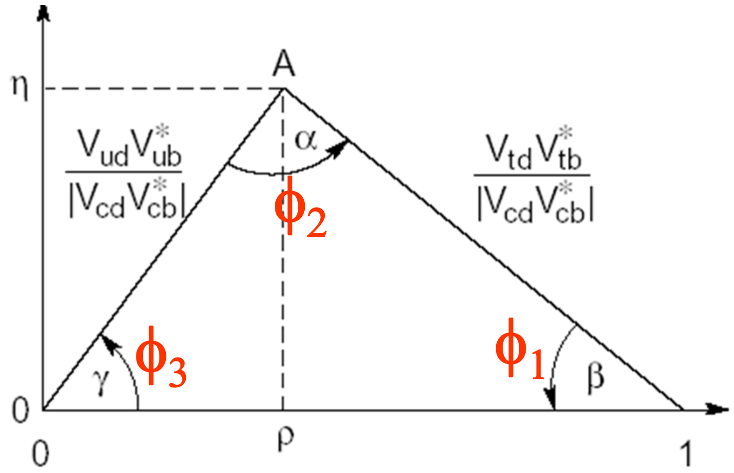
Wolfenstein parametrisation: expand in the parameter λ (=$\sin\theta_c$=0.22)

A, ρ and η: all of order one

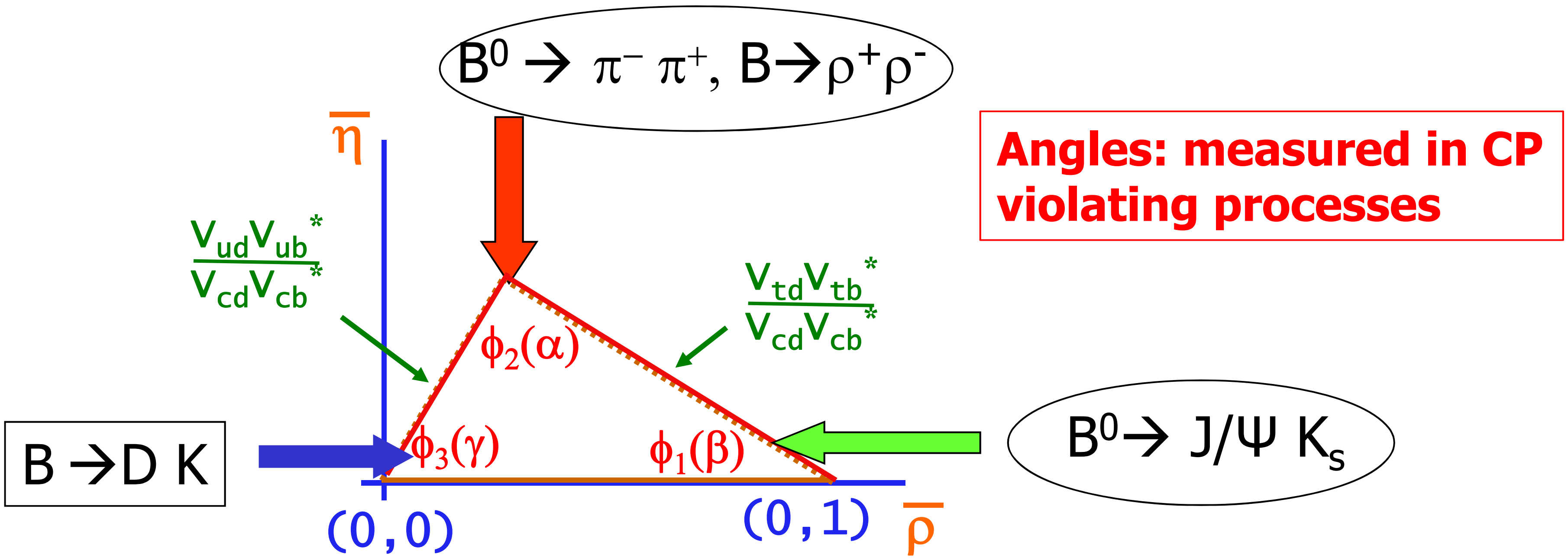
$$V = \begin{pmatrix} 1-\dfrac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\dfrac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Unitarity condition:

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

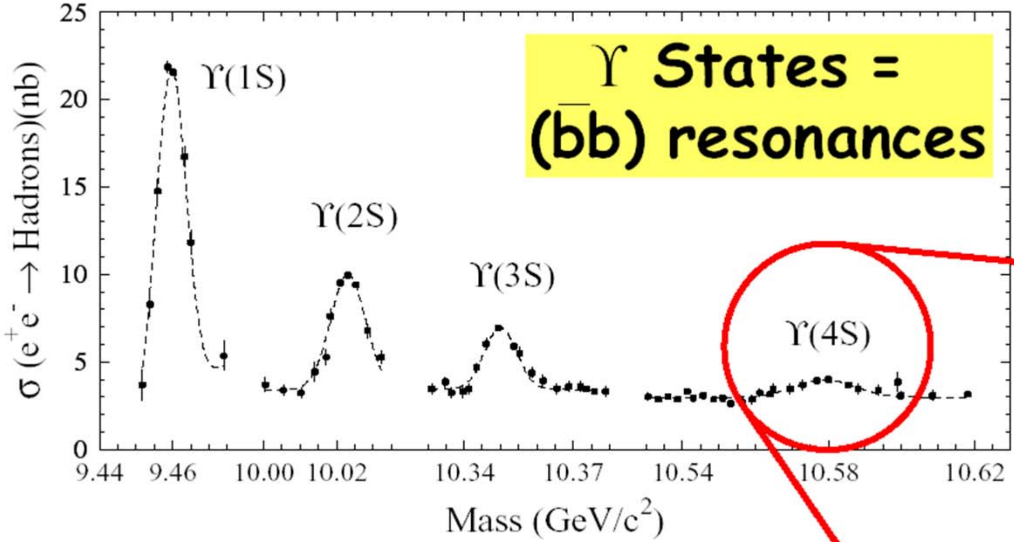


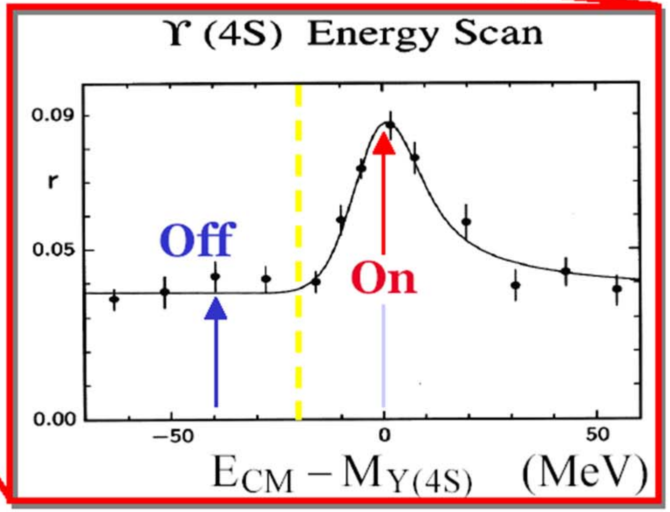
Three Angles: (ϕ_1,ϕ_2,ϕ_3) or (β, α, γ)



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

B meson production at Υ(4s)





Cross Sections at $\Upsilon(4S)$:

$b\bar{b} \sim 1.1$ nb

$c\bar{c} \sim 1.3$ nb

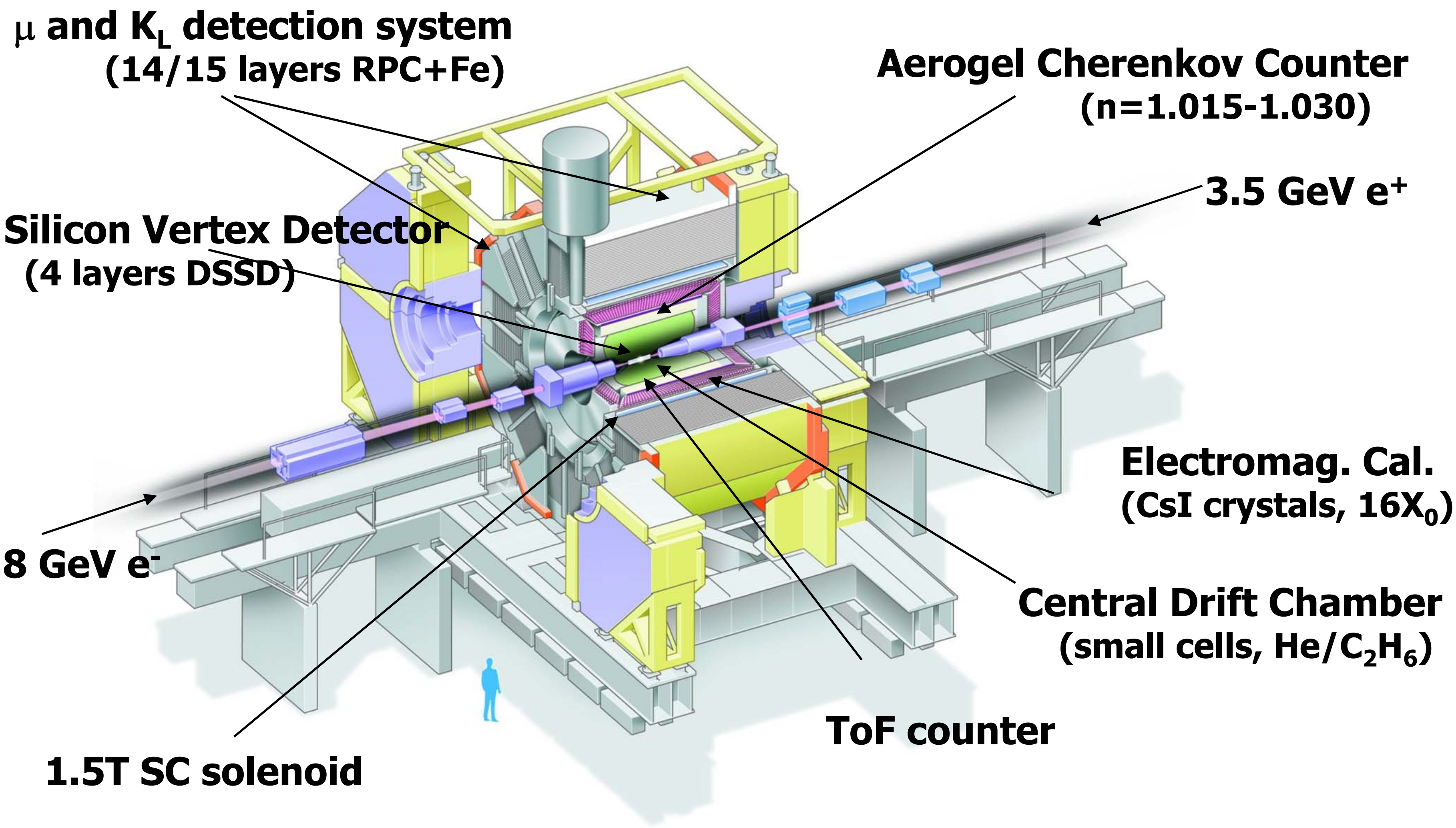
$d\bar{d}, s\bar{s} \sim 0.3$ nb

$u\bar{u} \sim 1.4$ nb

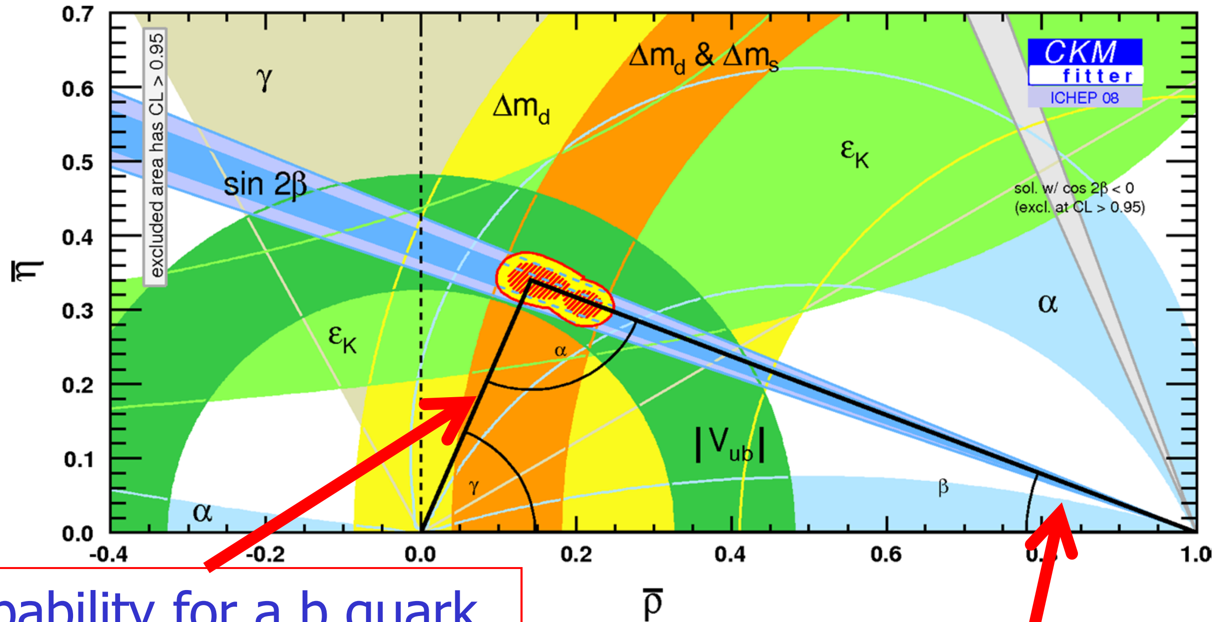
$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$$
$$L = 1 \text{ state}$$

Big advantage: low background

Belle spectrometer at KEK-B



All measurements combined...



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

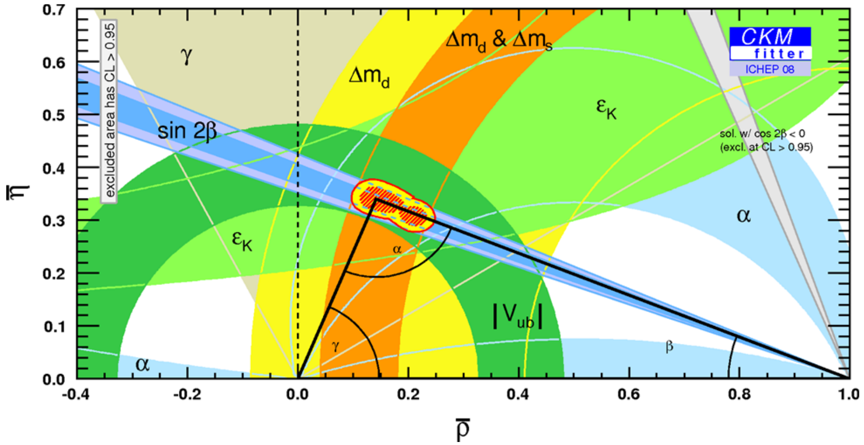
CP asymmetry oscilation amplitude → angle $\phi_1 = \beta$

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!

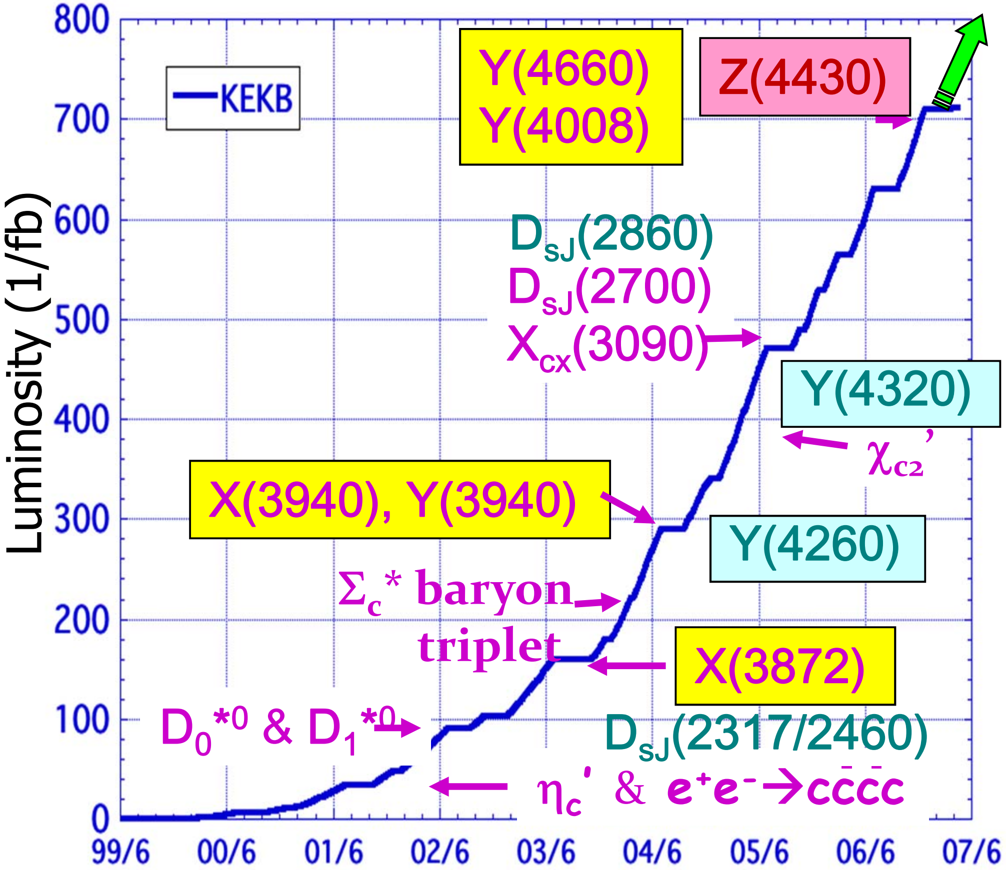
→ With essential confirmations BaBar and Belle!

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., $B \to \tau\nu$, $D\tau\nu$)
- $b \to s$ transitions: probe for new sources of CPV and constraints from the $b \to s\gamma$ branching fraction
- Forward-backward asymmetry (A_{FB}) in $b \to s l^+ l^-$ has become a powerfull tool to search for physics beyond SM.
- Observation of D mixing
- Searches for rare τ decays
- Observation of new hadrons

New hadrons at B-factories

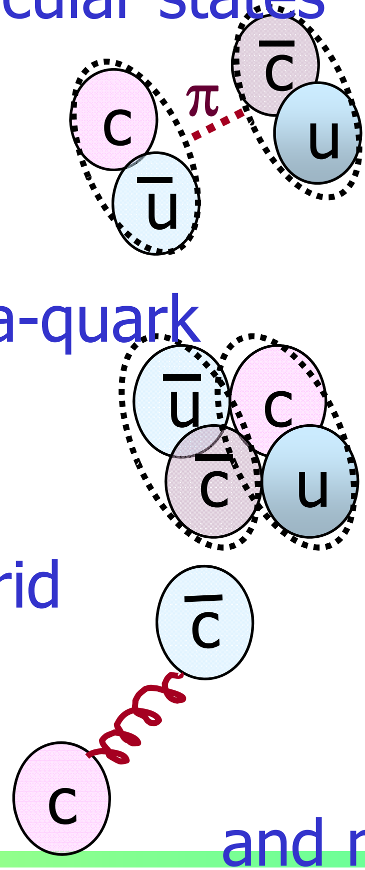
Discoveries of many new hadrons at B-factories have shed light on a new class of hadrons beyond the ordinary mesons.



Molecular states

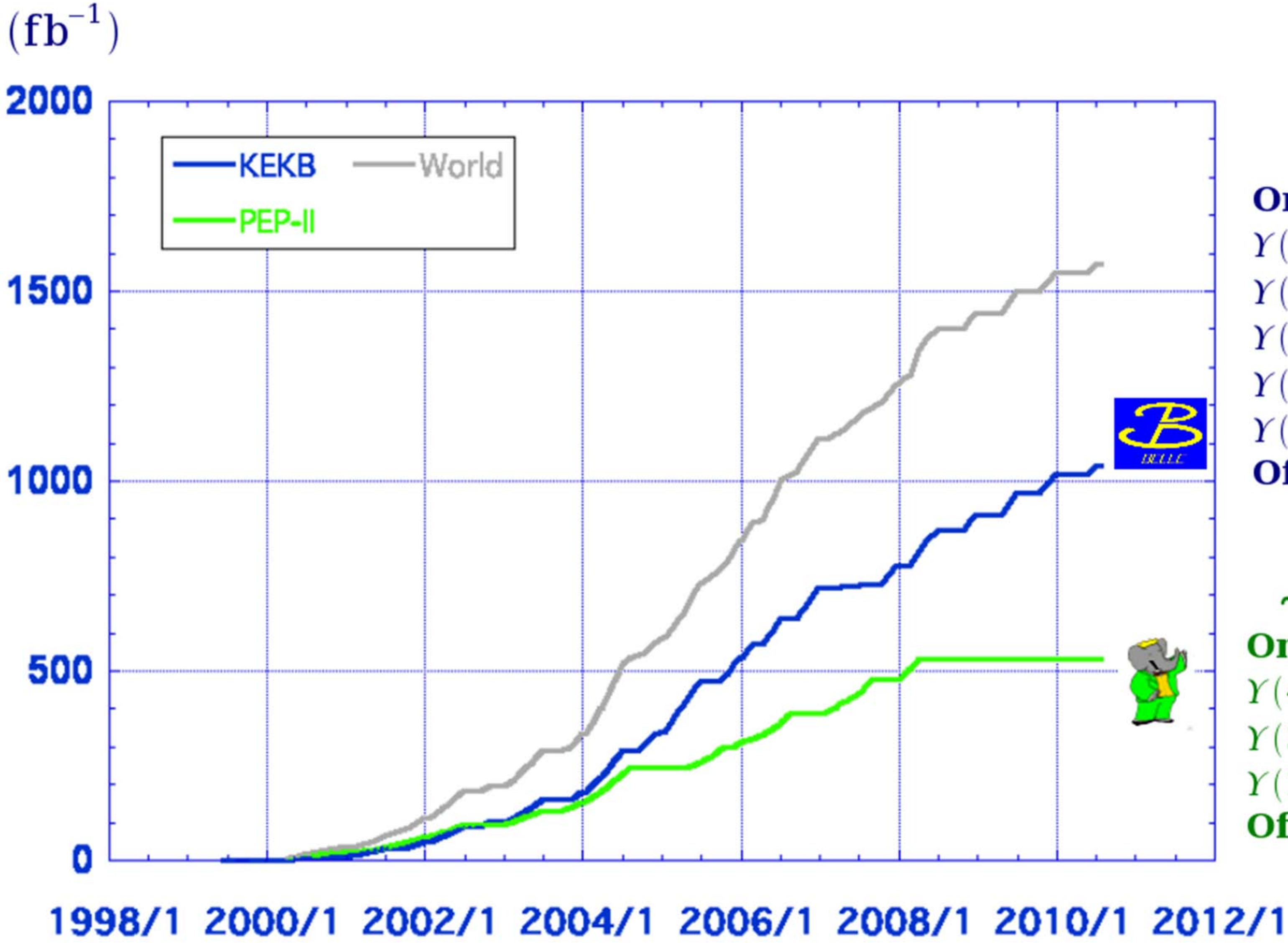
Tetra-quark

Hybrid



and more...

Luminosity at B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

~100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

~54 fb^{-1}

Fantastic performance much beyond design values!

What next?

B factories → is SM with CKM right?

Next generation: Super B factories → in which way is the SM wrong?

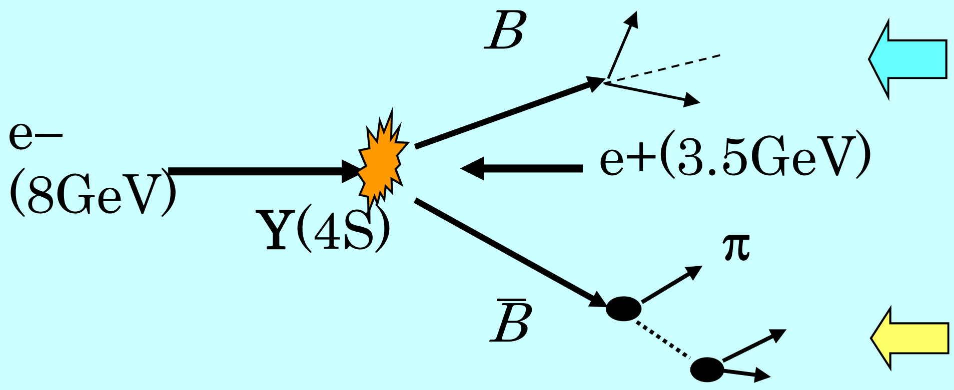
→ Need much more data (two orders!) because the SM worked so well until now → Super B factory

However: it will be a different world in four years, there will be serious competition from LHCb and BESIII

Still, e^+e^- machines running at (or near) Υ(4s) will have considerable advantages in several classes of measurements, and will be complementary in many more

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



Decays of interest
$B \to X_u \, l \, \nu$,
$B \to K \, \nu \, \nu$
$B \to D\tau\nu$, $\tau\nu$

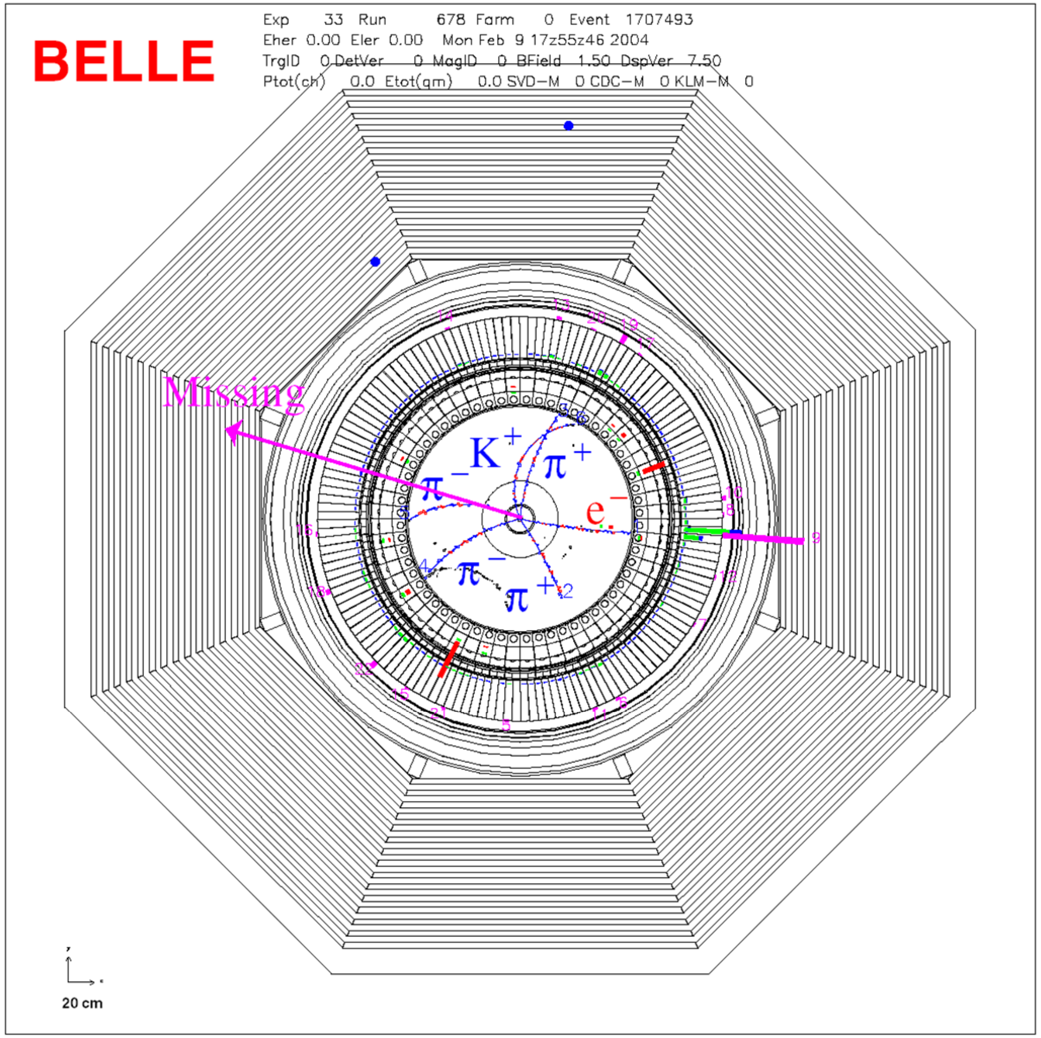
full reconstruction
$B \to D\pi$ etc. (0.1~0.3%)

→ Offline B meson beam!

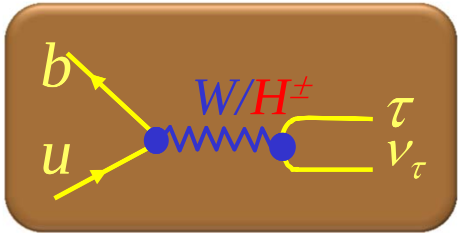
Powerful tool for B decays with neutrinos

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

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

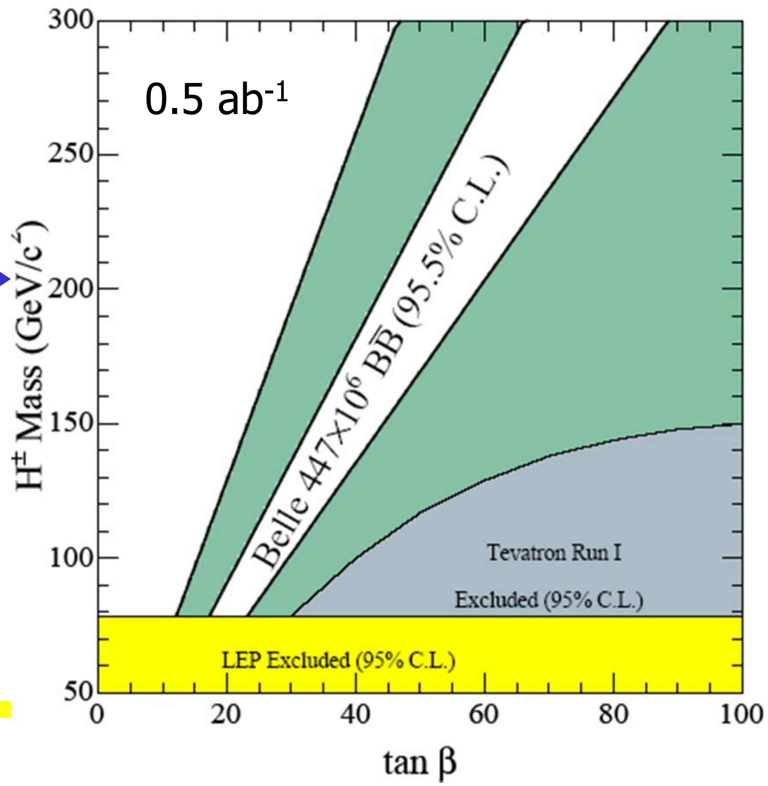


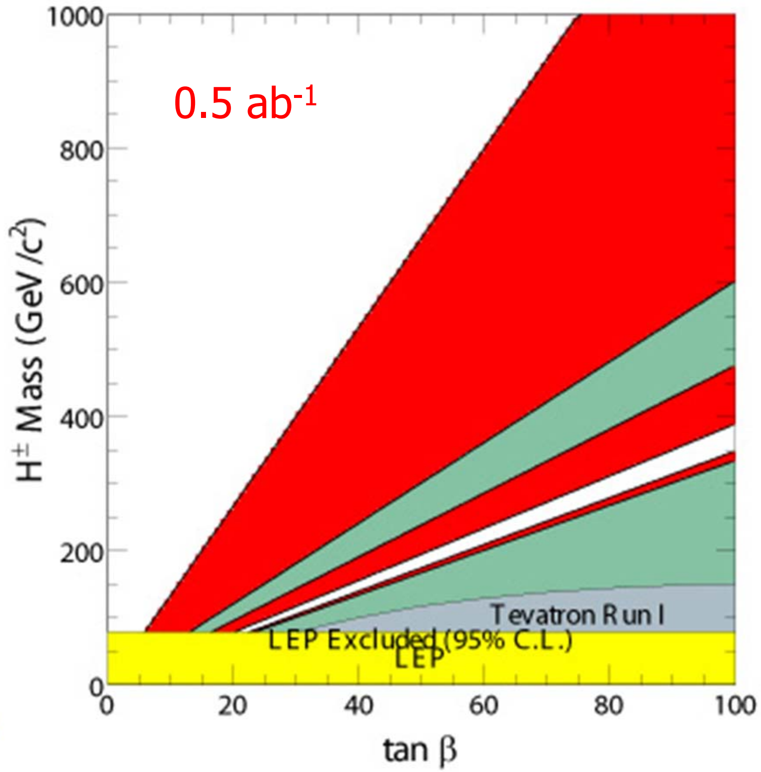
Charged Higgs limits from $B^- \to \tau^- \nu_\tau$



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

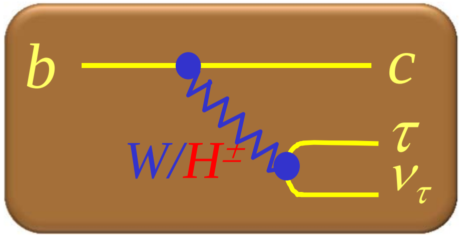
→ limit on charged Higgs mass vs. tanβ





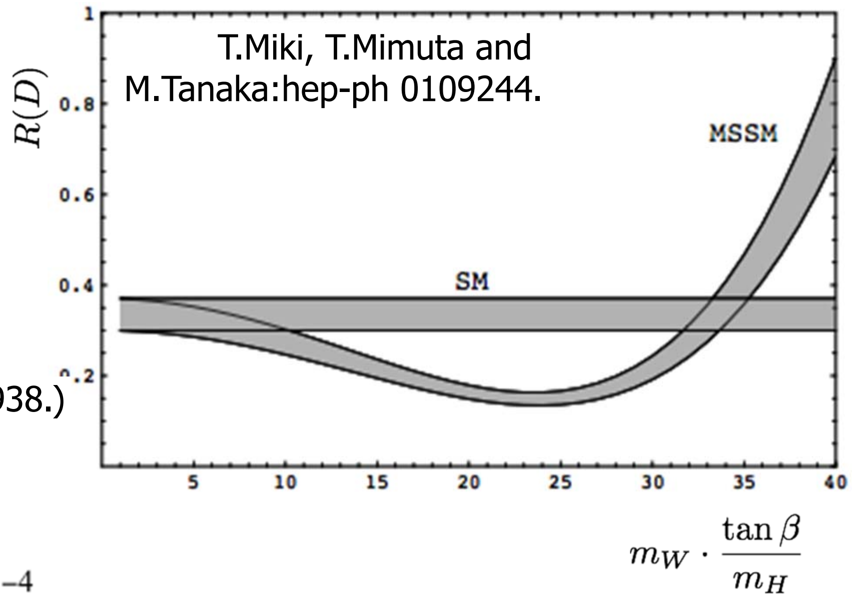
B→D$^{(*)}$τν

Semileptonic decay sensitive to charged Higgs



Ratio of τ to μ,e could be reduced/enhanced significantly

$$R(D) \equiv \frac{\mathcal{B}(B \to D\tau\nu)}{\mathcal{B}(B \to D\ell\nu)}$$



Compared to B→τν

1.Smaller theoretical uncertainty of R(D)

(For B→τν,
There is O(10%) f_B uncertainty from lattice QCD)

2.Large expected Br (Ulrich Nierste arXiv:0801.4938.)

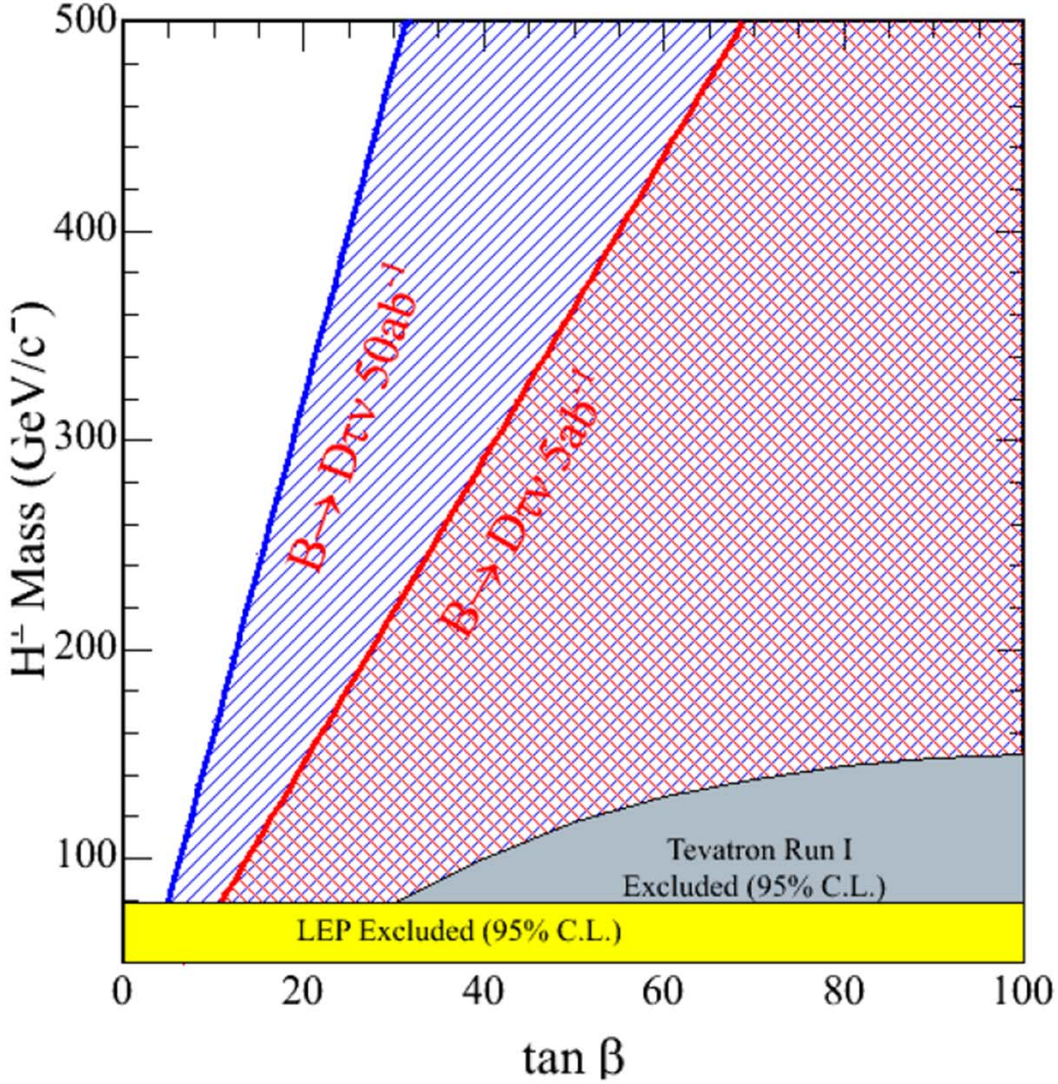
$$\mathcal{B}(B^- \to D^0\tau^-\bar{\nu}_\tau)^{SM} = (0.71 \pm 0.09)\%$$
$$\mathcal{B}(\bar{B}^0 \to D^+\tau^-\bar{\nu}_\tau)^{SM} = (0.66 \pm 0.08)\%$$
$$\mathcal{B}(B \to \tau\nu) = [1.65^{+0.38}_{-0.37}(stat)^{+0.35}_{-0.37}(syst)] \times 10^{-4}$$

3. Differential distributions can be used to discriminate W^+ and H^+

4. Sensitive to different vertex B→τ ν: H-b-u, B→Dτν: H-b-c
(LHC experiments sensitive to H-b-t)

B→Dτν

Exclusion plots for
$\tan\beta$ and H^+ mass
for 5ab^{-1} and 50ab^{-1}



B→D$^*\tau\nu$ – similar constraints on H$^+$

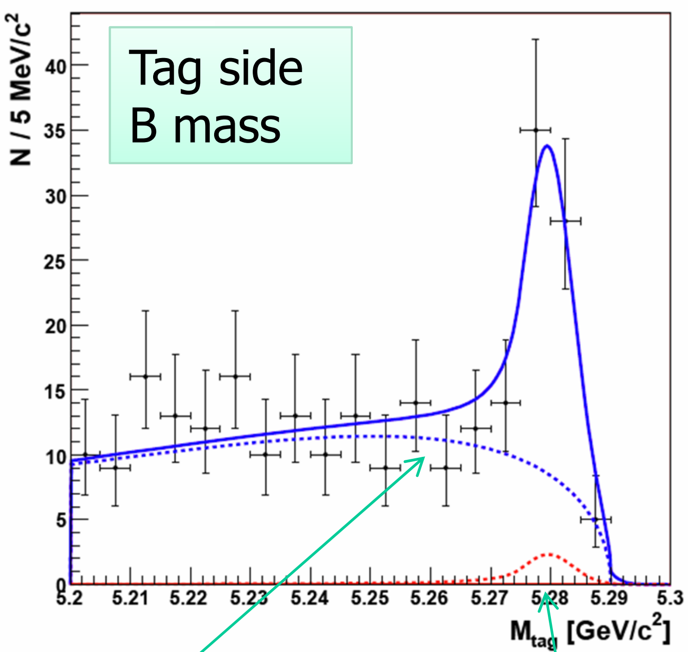
[PRL 99, 191807 (2007)]

FIRST OBSERVATION - 2007

$$BF(B^0 \to D^{*-}\tau^+\nu_\tau) = (\mathbf{2.02}\,^{+0.40}_{-0.37}(stat) \pm 0.37(syst)) \times \mathbf{10}^{-2}$$

535M $B\bar{B}$

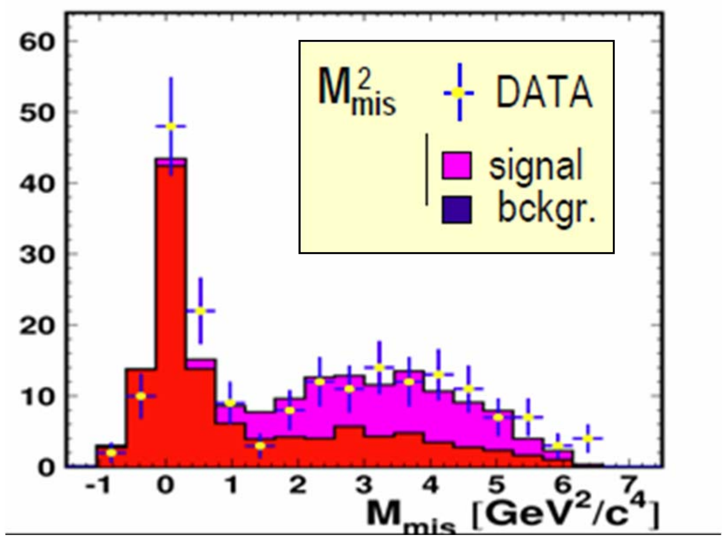
SIGNAL YIELD $N_s = 60\,^{+12}_{-11}$ **6.7σ (5.2σ with syst.)**



combinatorial background

peaking background (D*eν)

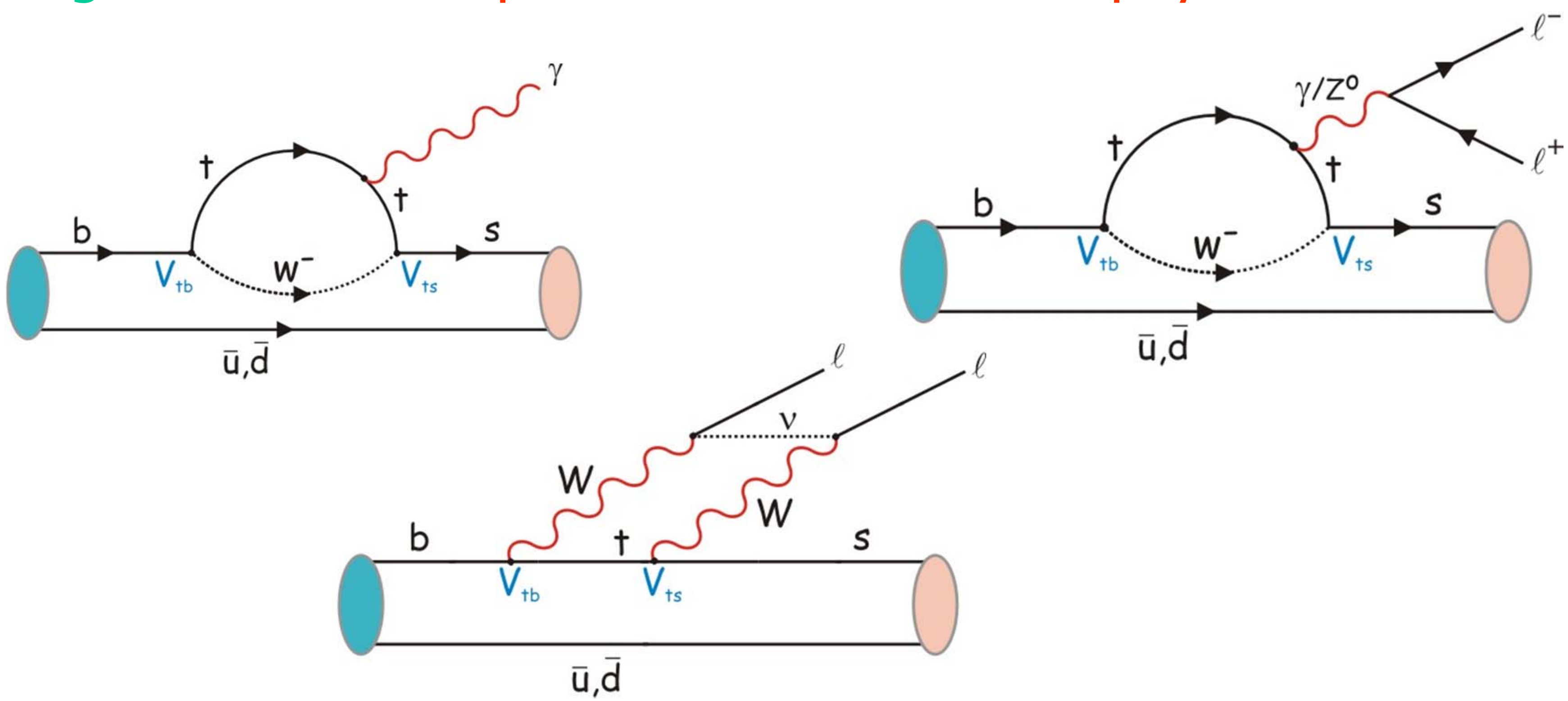
$$M_{mis}^2 = (E_b - E_{D^{(*)}} - E_{l/h})^2 - (-\vec{p}_{tag} - \vec{p}_{D^{(*)}} - \vec{p}_{l/h})^2$$



Recent update: CKM2010, A. Bozek

Why FCNC decays?

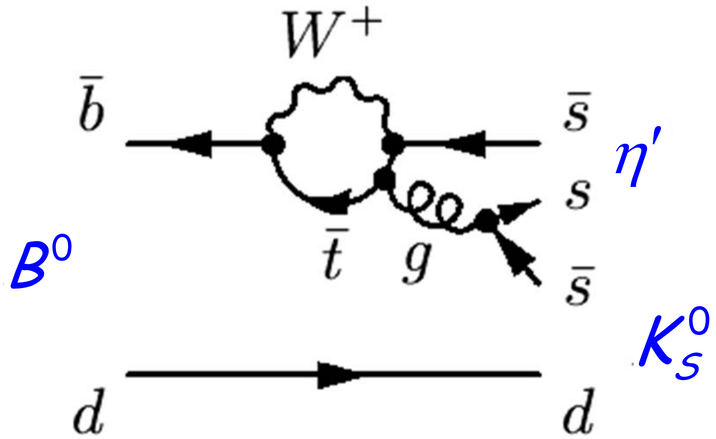
Flavour changing neutral current (FCNC) processes (like b→s, b→d) are fobidden at the tree level in the Standard Model. Proceed only at low rate via higher-order loop diagrams. Ideal place to search for new physics.



How can New Physics contribute to b→s?

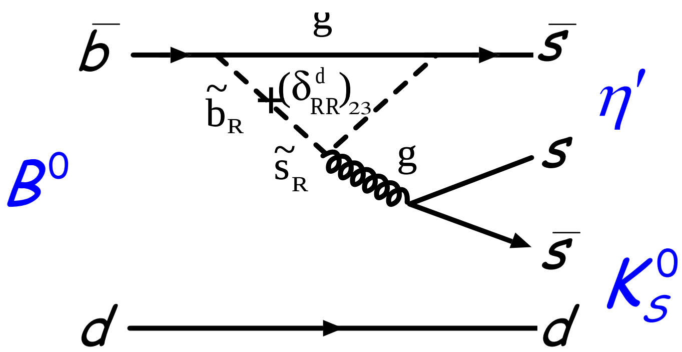
For example in the process:

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



Ordinary penguin diagram with a t quark in the loop

Diagram with supersymmetric particles



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

arXiv:1002.5012

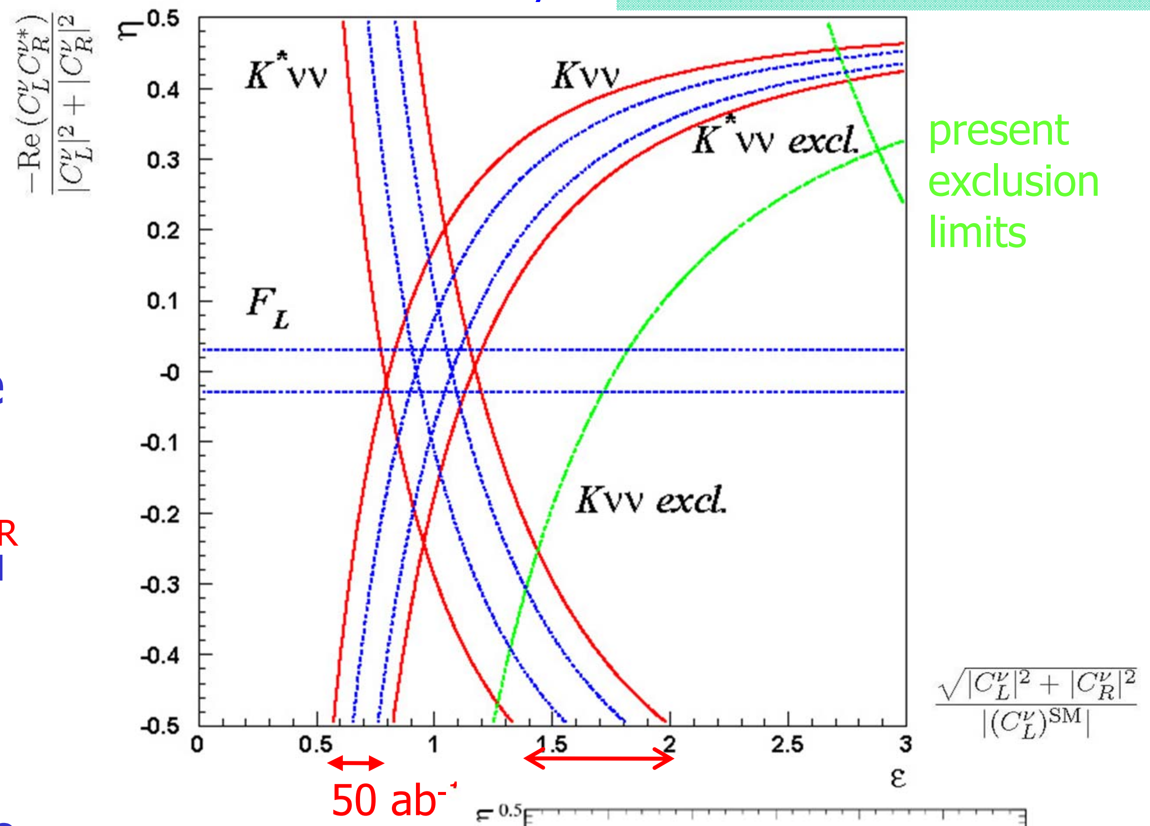
adopted from W. Altmannshofer et al., JHEP 0904, 022 (2009)

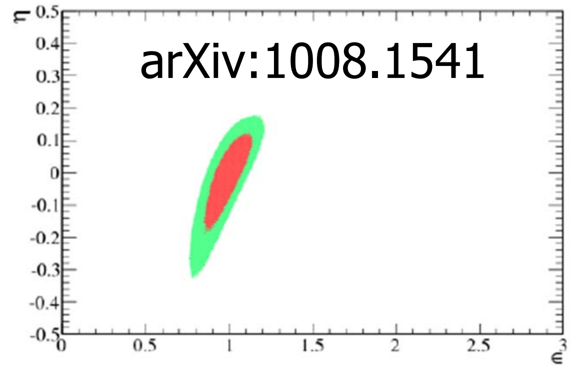
$B \to K\nu\nu$, $\mathcal{B} \sim 4{\cdot}10^{-6}$
$B \to K^*\nu\nu$, $\mathcal{B} \sim 6.8{\cdot}10^{-6}$

SM: penguin+box

Look for departure from the expected value → information on couplings C^{ν}_{R} and C^{ν}_{L} compared to $(C^{\nu}_{L})^{SM}$

Again: fully reconstruct one of the B mesons, look for signal (+nothing else) in the rest of the event.





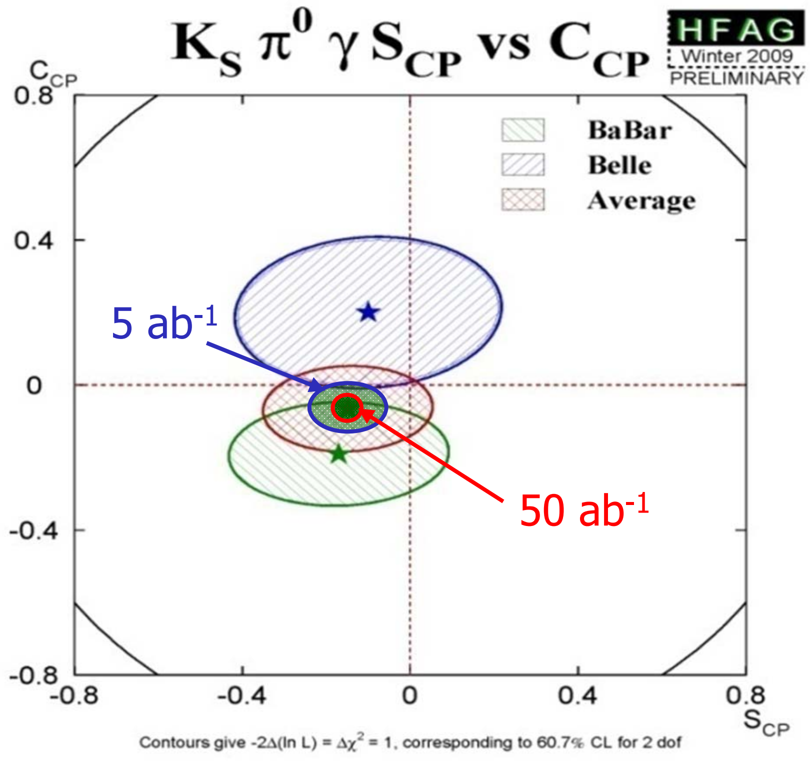
not possible @ LHCb

CP violation in $B \to K_S \pi^0 \gamma$

CP violation in $B \to K_S \pi^0 \gamma$ decays:
Search for right-handed currents

$B \to K^* \gamma$, $\mathcal{B} \sim 4.0 \cdot 10^{-5}$

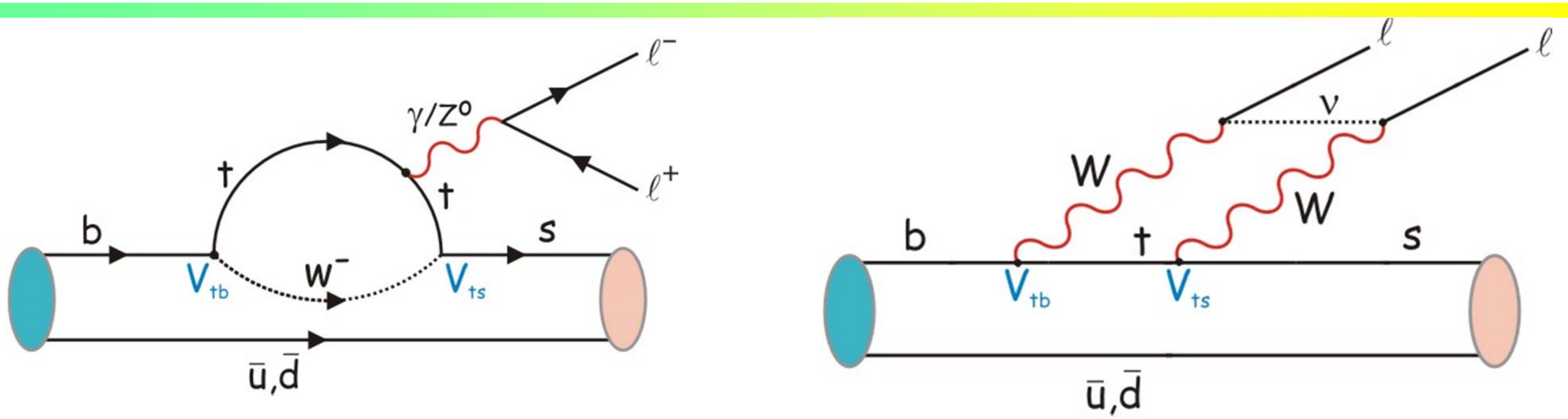
$\delta S \sim 0.2$ (present)
→ ~a few % at 50 ab^{-1}



adopted from HFAG

not possible @ LHCb

Another FCNC decay: B → K^* l^+ l^-



b → s l^+l^- was first measured in B → K l^+l^- by Belle (2001).

Important for further searches for the physics beyond SM

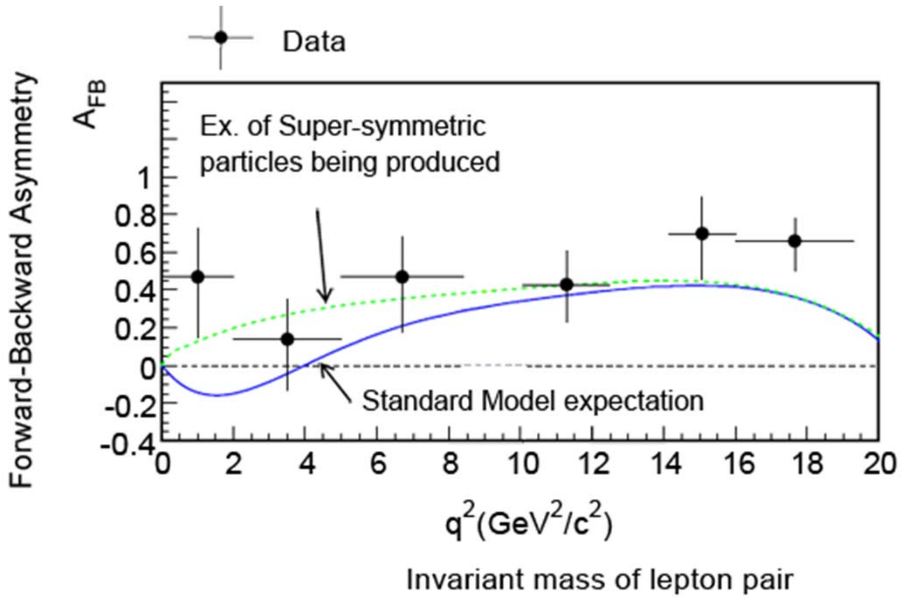
Particularly sensitive: backward-forward asymmetry in K^* l^+l

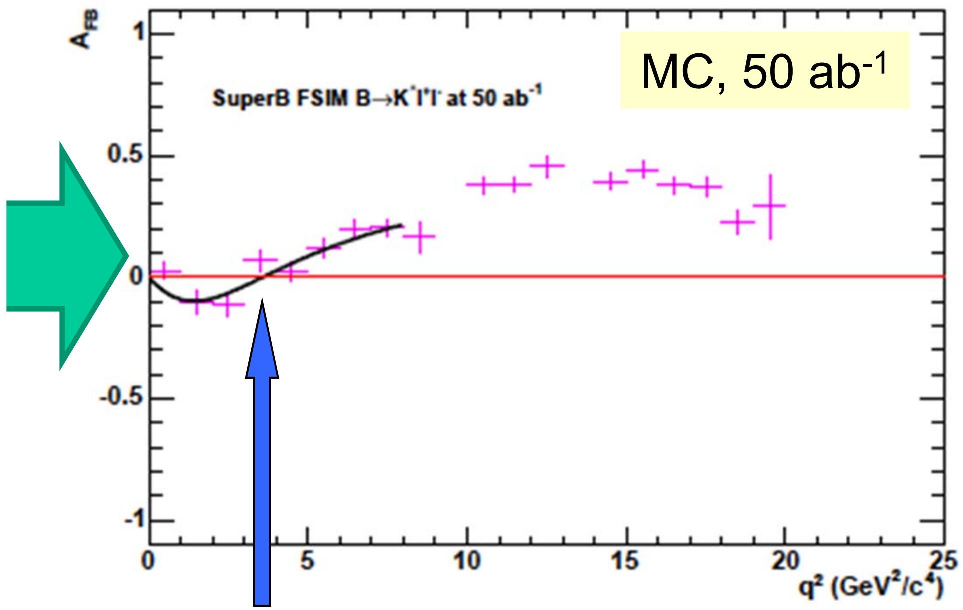
$$A_{FB} \propto \Re\left[C_{10}^* \left(s C_9^{eff}(s) + r(s) C_7 \right) \right]$$

C_i : Wilson coefficients, abs. value of C_7 from b→sγ

s=lepton pair mass squared

$A_{FB}(B \rightarrow K^* l^+ l^-)[q^2]$





Data: very interesting!

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

Strong competition from LHCb and ATLAS/CMS

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

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:

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

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

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

A problem for a SM explanation
(in particular when combined with other measurements)
A hint for new sources of CP violation?

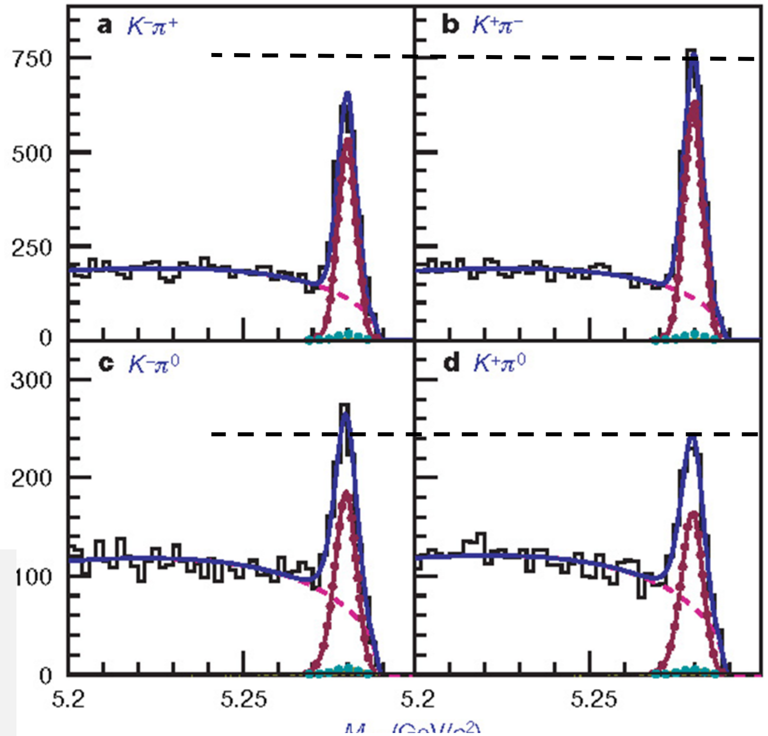

nature International weekly journal of science

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*

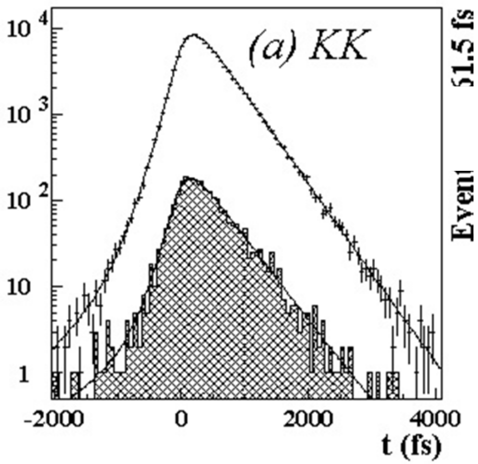


~1 in 10^5 B mesons decays in this decay mode

Belle, Nature 452, 332 (2008)

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

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



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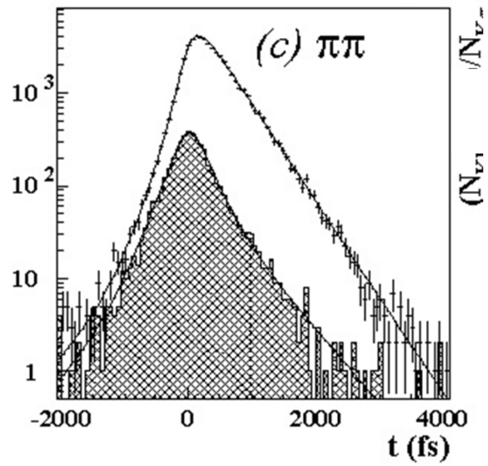
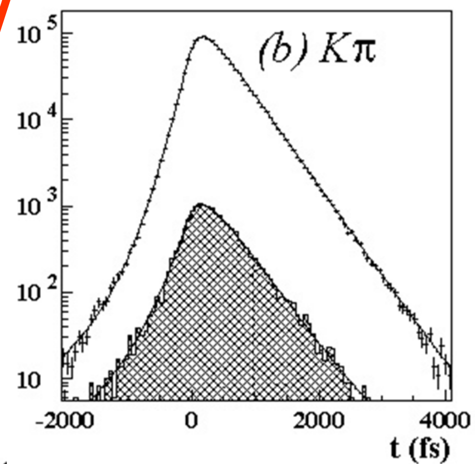
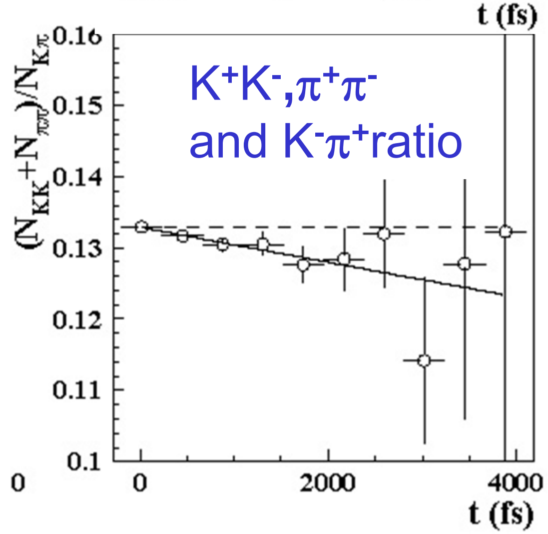




Difference of lifetimes visually observable in the ratio of the distributions →



Real fit:

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

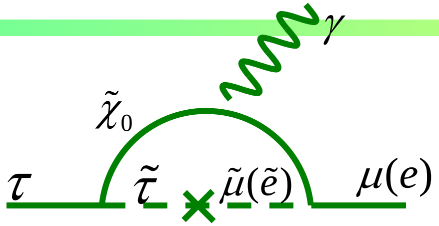
→ Observation of D mixing!

→ on a high side of SM predictions

CP violation in the D system would be a clear sign of new physics

LFV and New Physics

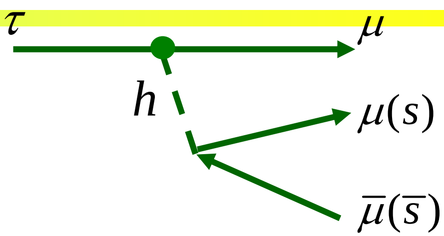
$\tau \to l\gamma$



- SUSY + Seasaw $(m^2_{\tilde{l}})_{23(13)}$
- Large LFV $Br(\tau \to \mu\gamma) = O(10^{-7\sim 9})$

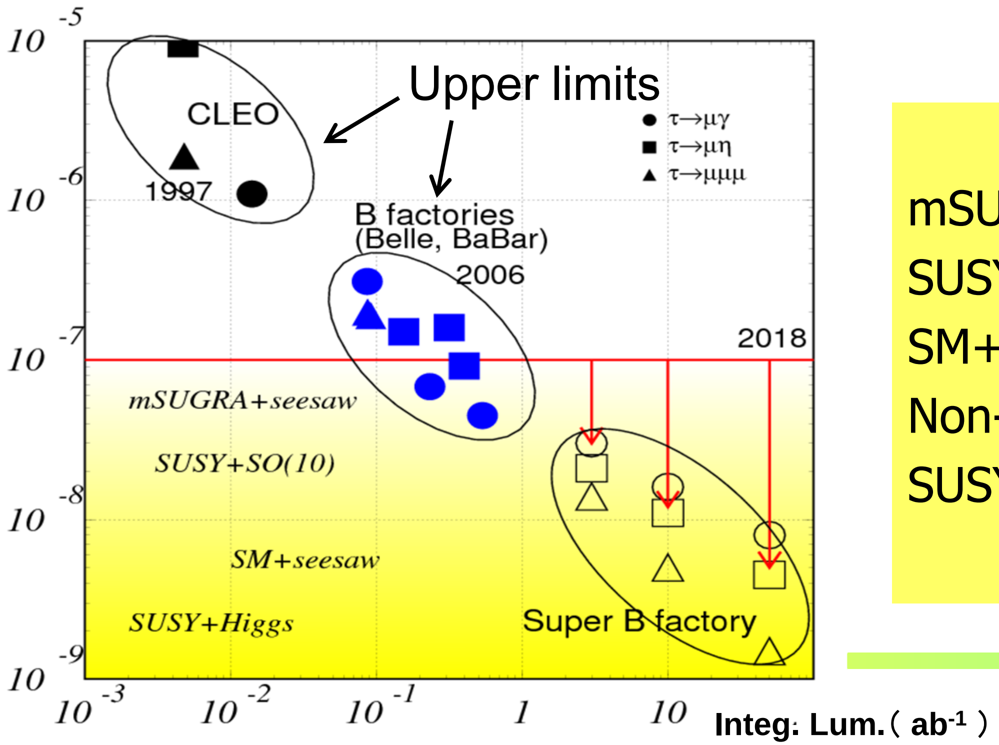
$$Br(\tau \to \mu\gamma) \simeq 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}}\right)\left(\frac{1\,TeV}{m_{SUSY}}\right)^4 \tan^2\beta$$

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



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

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



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}

B Physics @ Y(4S)

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi \pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K^0_S K^0_S K^0_S)$	0.15	0.02 (∗)
$S(K^0_S \pi^0)$	0.15	0.02 (∗)
$S(\omega K^0_S)$	0.17	0.03 (∗)
$S(f_0 K^0_S)$	0.12	0.02 (∗)
γ $(B \to DK, D \to CP$ eigenstates$)$	$\sim 15°$	2.5°
γ $(B \to DK, D \to$ suppressed states$)$	$\sim 12°$	2.0°
γ $(B \to DK, D \to$ multibody states$)$	$\sim 9°$	1.5°
γ $(B \to DK$, combined$)$	$\sim 6°$	1–2°
α $(B \to \pi\pi)$	$\sim 16°$	3°
α $(B \to \rho\rho)$	$\sim 7°$	1–2° (∗)
α $(B \to \rho\pi)$	$\sim 12°$	2°
α (combined)	$\sim 6°$	1–2° (∗)
$2\beta+\gamma$ $(D^{(*)\pm}\pi^\mp, D^\pm K^0_S \pi^\mp)$	20°	5°

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\|V_{cb}\|$ (exclusive)	4% (∗)	1.0% (∗)
$\|V_{cb}\|$ (inclusive)	1% (∗)	0.5% (∗)
$\|V_{ub}\|$ (exclusive)	8% (∗)	3.0% (∗)
$\|V_{ub}\|$ (inclusive)	8% (∗)	2.0% (∗)
$\mathcal{B}(B \to \tau\nu)$	20%	4% (†)
$\mathcal{B}(B \to \mu\nu)$	visible	5%
$\mathcal{B}(B \to D\tau\nu)$	10%	2%
$\mathcal{B}(B \to \rho\gamma)$	15%	3% (†)
$\mathcal{B}(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († ∗)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K^0_S\pi^0\gamma)$	0.15	0.02 (∗)
$S(\rho^0\gamma)$	possible	0.10
$A_{CP}(B \to K^*\ell\ell)$	7%	1%
$A^{FB}(B \to K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \to X_s\ell\ell)s_0$	35%	5%
$\mathcal{B}(B \to K\nu\bar{\nu})$	visible	20%
$\mathcal{B}(B \to \pi\nu\bar{\nu})$	–	possible

Charm mixing and CP

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}	
$D^0 \to K^0_S\pi^+\pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$\|q/p\|$	3×10^{-2}	
	ϕ	$2°$	
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2)\times10^{-5}$
	y		$(1-2)\times10^{-3}$
	$\cos\delta$		$(0.01-0.02)$

Charm FCNC

	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_S e^+e^-$, $D^0 \to K^0_S\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_S e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^-e^+e^+$, $D^+ \to K^-e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^-e^\pm\mu^\mp$, $D^+ \to K^-e^\pm\mu^\mp$	1×10^{-8}

τ Physics

	Sensitivity
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K^0_S)$	2×10^{-10}

B_s Physics @ Y(5S)

Observable	Error with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	20°	8°
$A^s_{\rm SL}$	0.006	0.004
$A_{\rm CH}$	0.004	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	$< 8\times10^{-9}$
$\|V_{td}/V_{ts}\|$	0.08	0.017
$\mathcal{B}(B_s \to \gamma\gamma)$	38%	7%
β_s from $J/\psi\phi$	10°	3°
β_s from $B_s \to K^0\bar{K}^0$	24°	11°

M. Giorgi, ICHEP2010

Physics at a Super B Factory

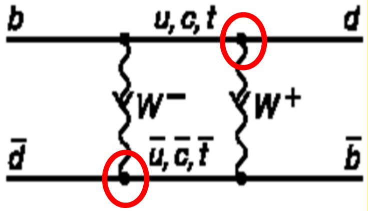
- There is a good chance to see new phenomena;
  - **CPV in B decays from the new physics (non KM).**
  - **Lepton flavor violations in τ decays.**
- They will help to diagnose (if found) or constrain (if not found) new physics models.
- $B \rightarrow \tau\nu$, $D\tau\nu$ can probe the charged Higgs in large $\tan\beta$ 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 a unique way to search for the >TeV scale physics (=TeV scale in case of MFV).

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

Super B Factory Motivation 2

- 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



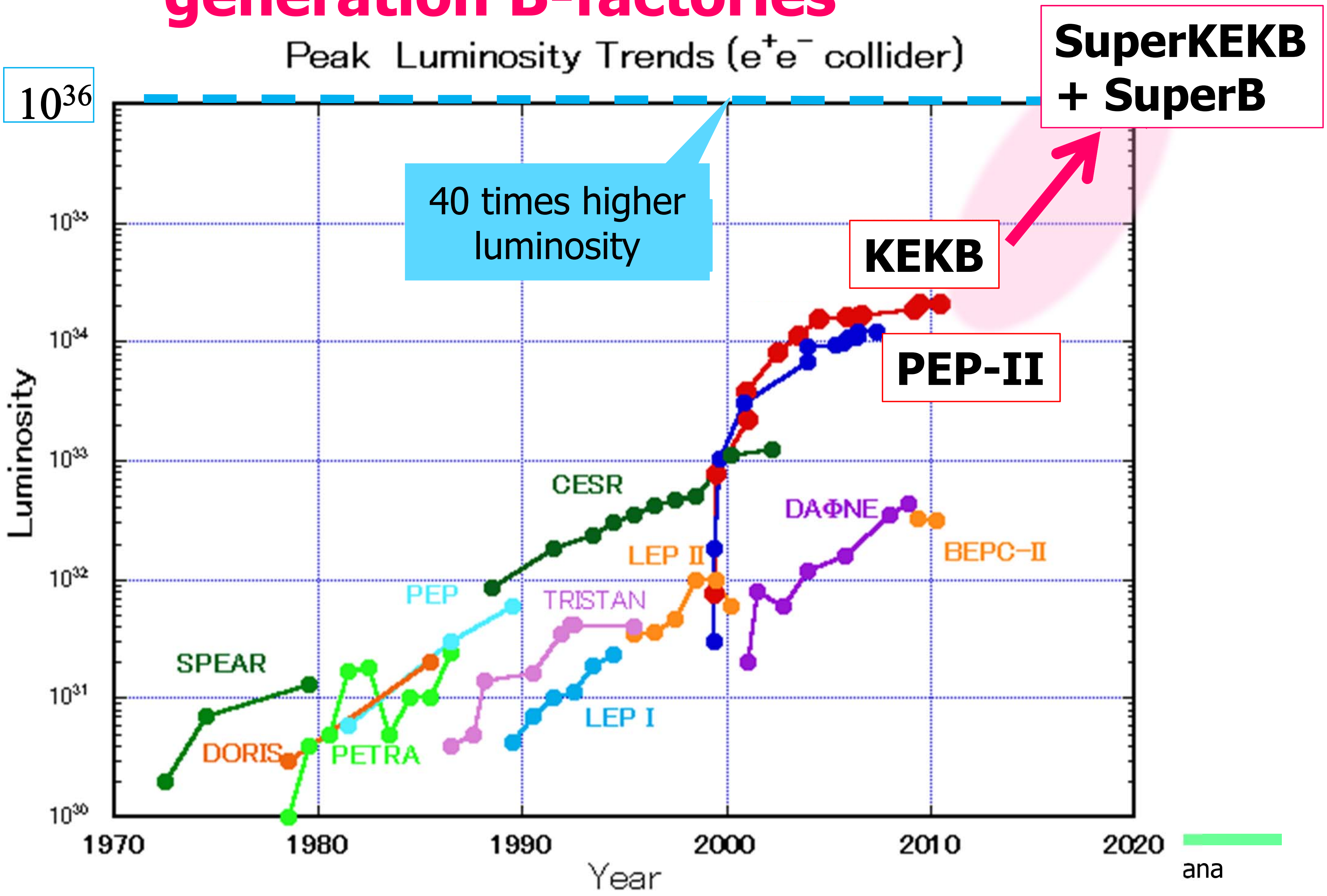
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- Even before that: prediction of charm quark from the GIM mechanism, and its mass from K^0 mixing

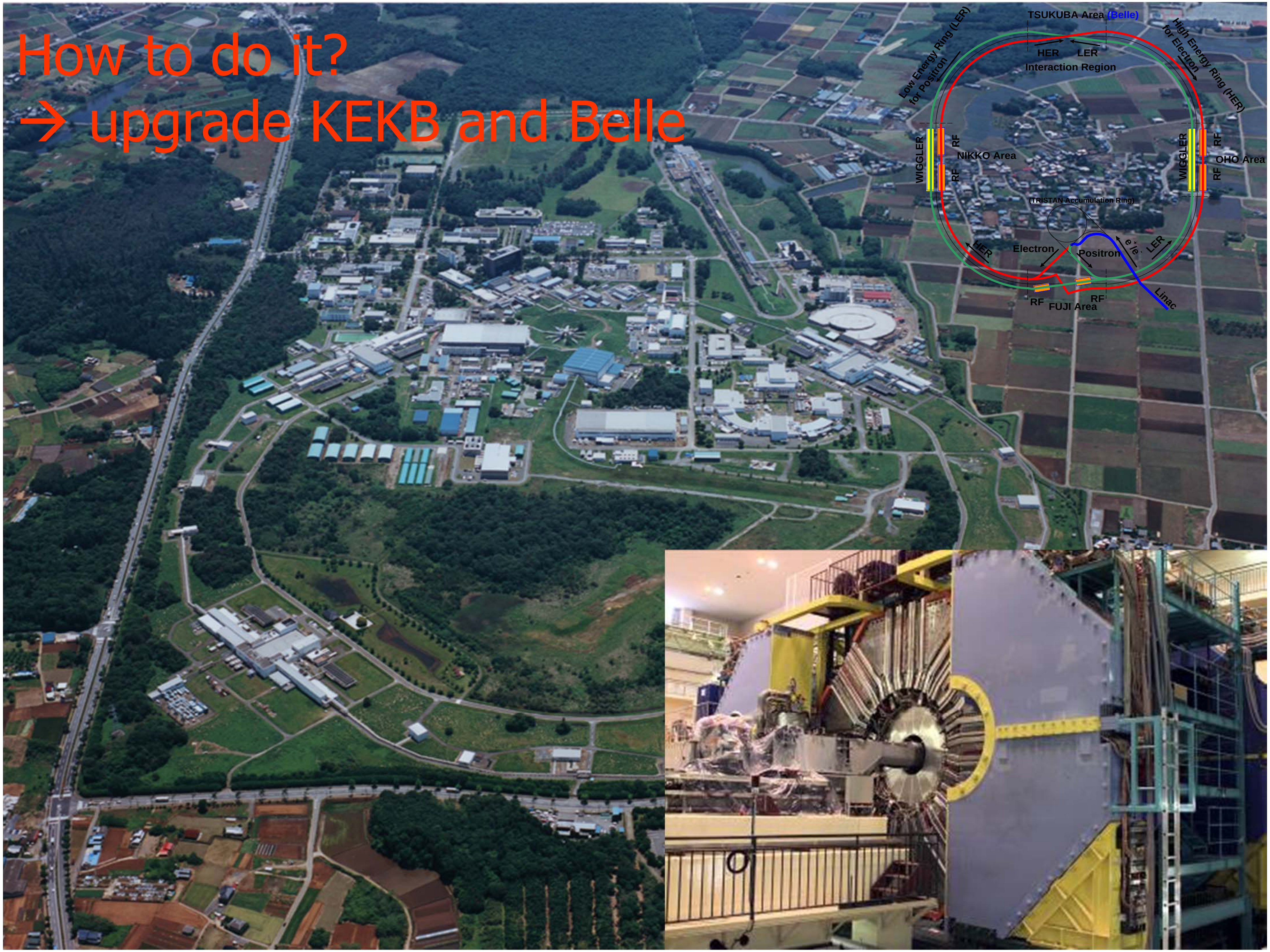
Recent update of the physics reach with 50 ab^{-1} (75 ab^{-1}):
Physics at Super B Factory (Belle II authors + guests)
hep-ex > arXiv:1002.5012
SuperB Progress Reports: Physics (SuperB authors + guests)
hep-ex > arXiv:1008.1541

Accelerator

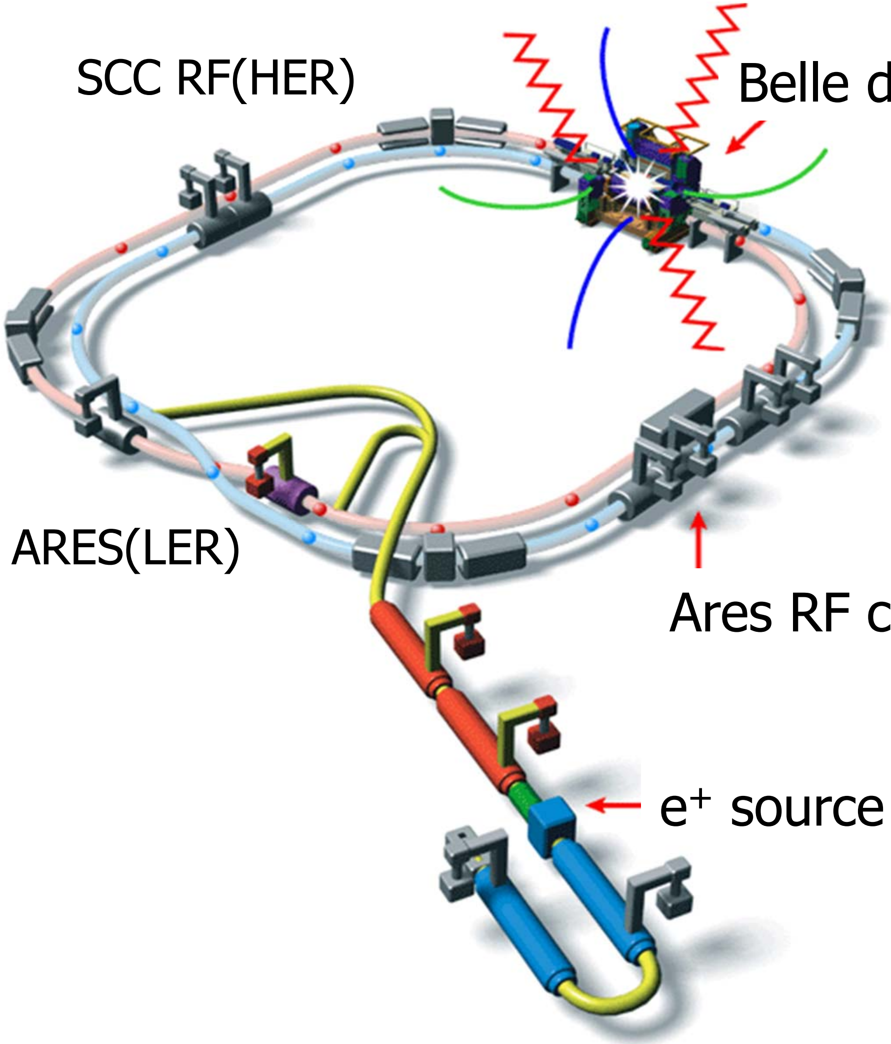
Need O(100x) more data →Next generation B-factories



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 x 10^{34} cm^{-2}s^{-1}

=2x design value

First physics run on June 2, 1999
Last physics run on June 30, 2010
L_{peak} = 2.1x10^{34}/cm^2/s
L > 1ab^{-1}

The last beam abort of KEKB on June 30, 2010

→ Can start construction of SuperKEKB and Belle II

Strategies for increasing luminosity

Beam-beam parameter

Lorentz factor

Beam current

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

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

(1) Smaller β_y^*
(2) Increase beam currents
(3) Increase ξ_y

"Nano-Beam" scheme

Collision with very small spot-size beams

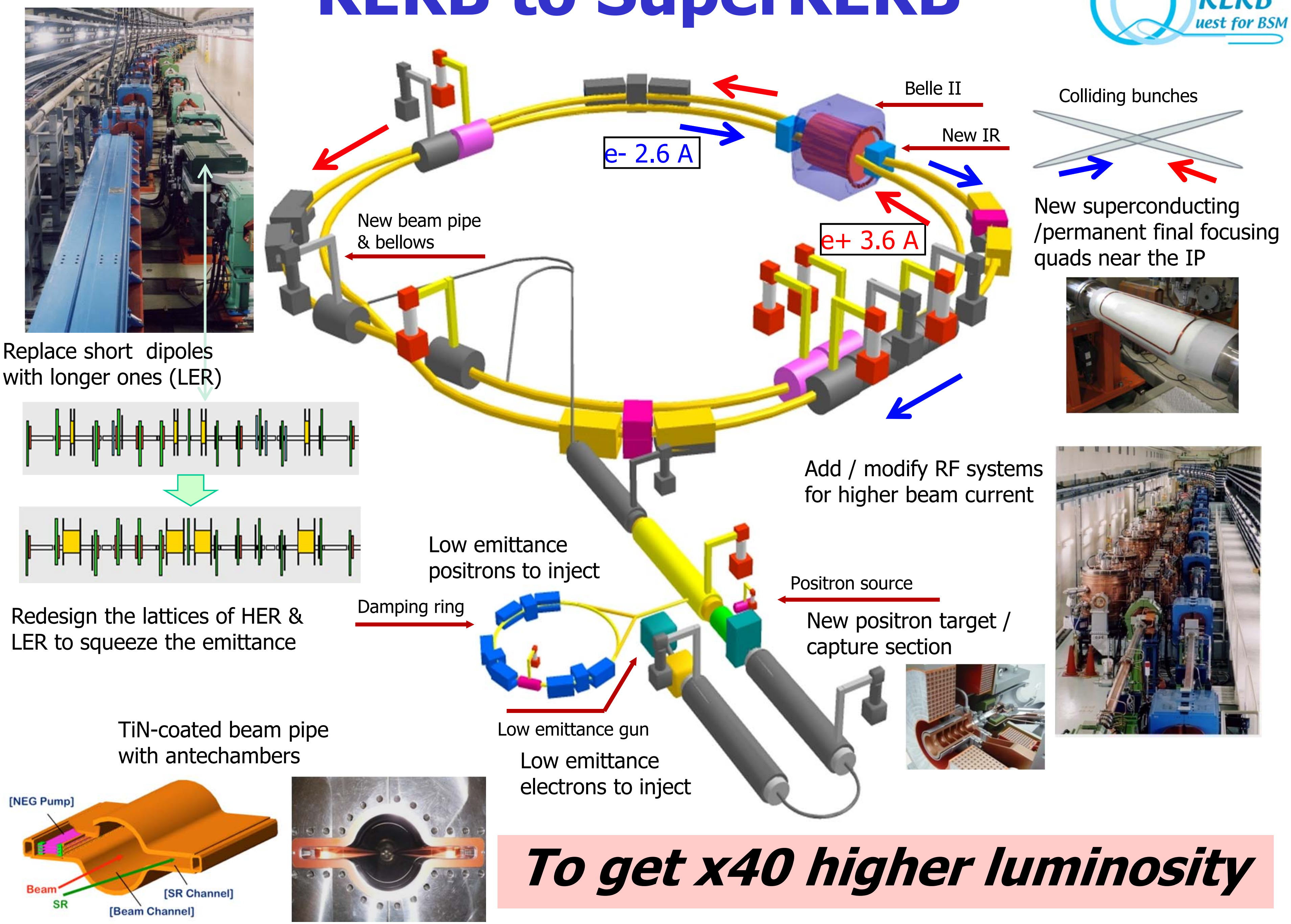
Invented by Pantaleo Raimondi for SuperB

Machine design parameters

parameters		KEKB LER	KEKB HER	**SuperKEKB** LER	**SuperKEKB** HER	units
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.3-4.6	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.31	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0886	0.0830	
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**

- **Small beam size & high current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem of LER short lifetime

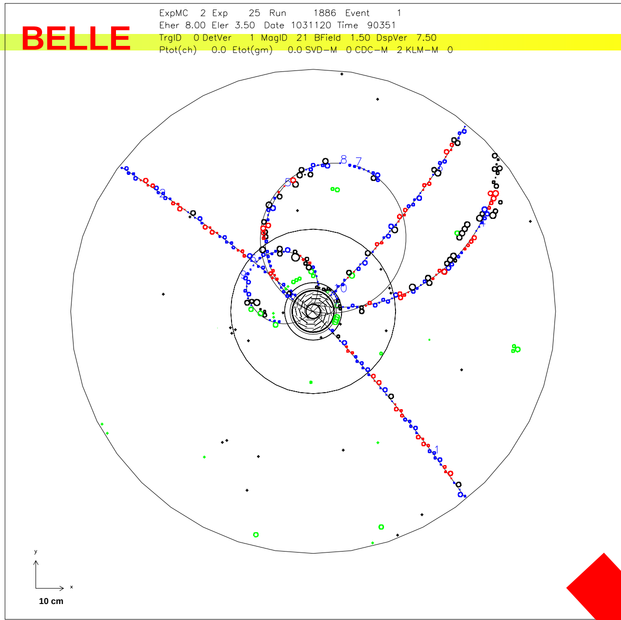
KEKB to SuperKEKB



To get x40 higher luminosity

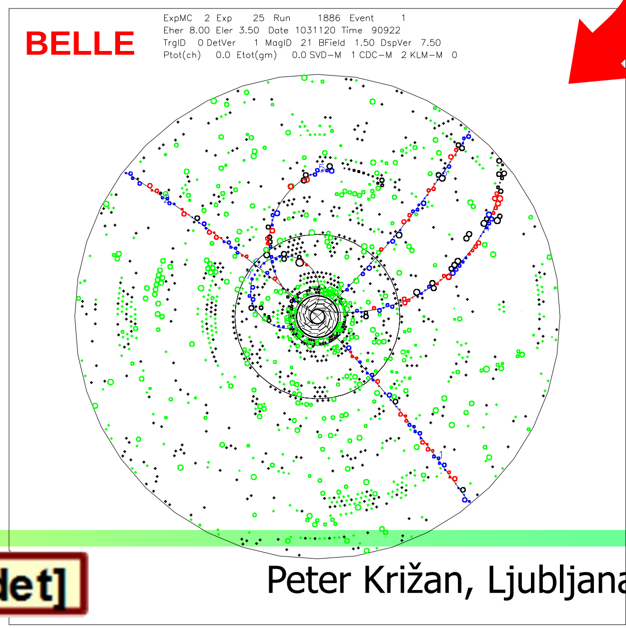
Detector

Requirements for the Belle II detector



Critical issues at L= 8 x 10^{35}/cm^2/sec

- **Higher background (×10-20)**
  - 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”

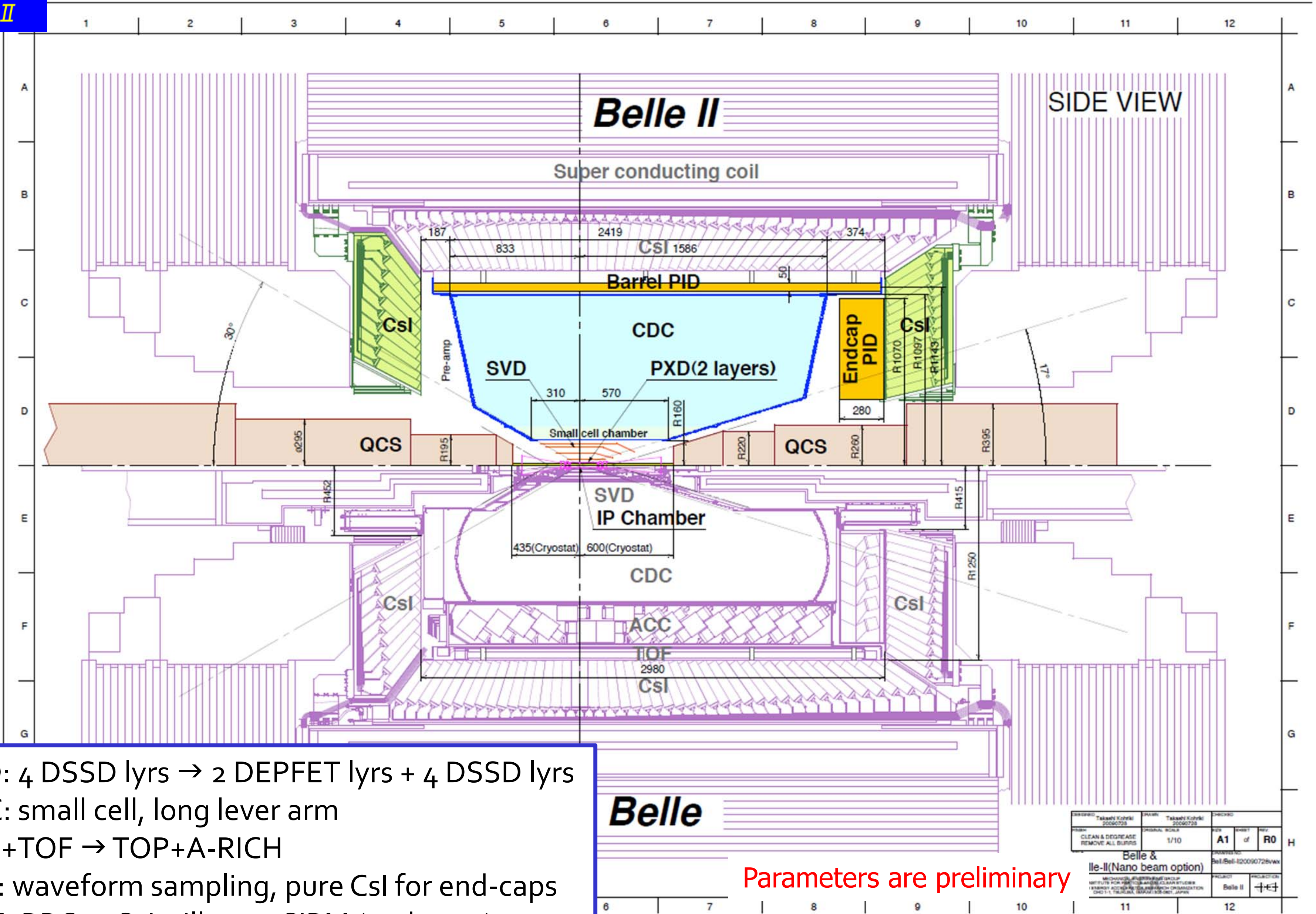


Solutions:

- Replace inner layers of the vertex detector with a 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.

TDR published arXiv:1011.0352v1 [physics.ins-det]

Belle II in comparison with Belle

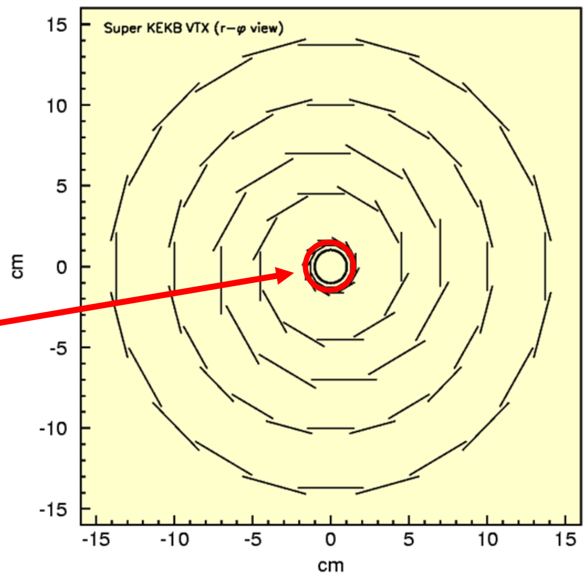


SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

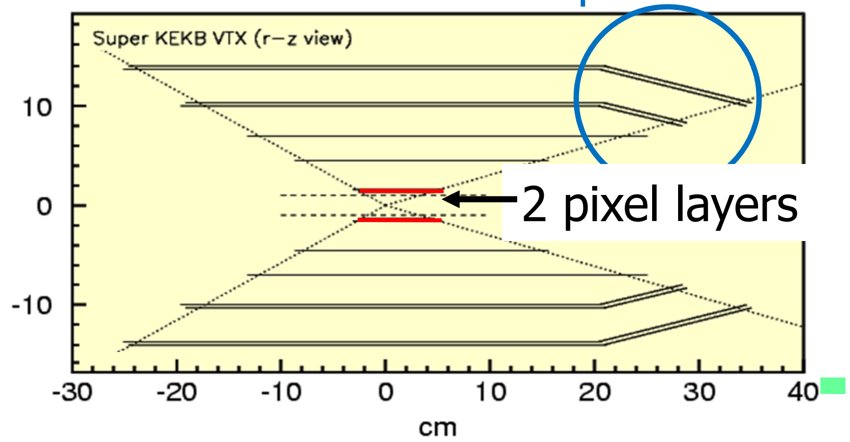
Parameters are preliminary

Vertex detector upgrade: PXD+SVD

- Configuration: 4 layers → 6 layers (outer radius = 8cm→14cm)
  - More robust tracking
  - Higher Ks vertex reconstr. efficiency
- Inner radius: 1.5cm → 1.3cm
  - Better vertex resolution
- Sensors of the two innermost layers L1+L2: DEPFET Pixel sensors →PXD
- Layers 3-6: normal double sided Si detector (DSSD) →SVD
- Strip readout chip: VA1TA → APV25
  - Reduction of occupancy coming from beam background.
  - Pipeline readout to reduce dead time.

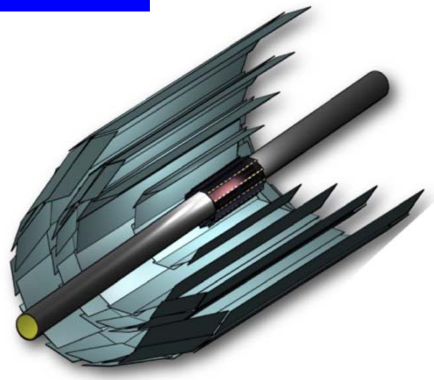


Slanted layers to keep the acceptance



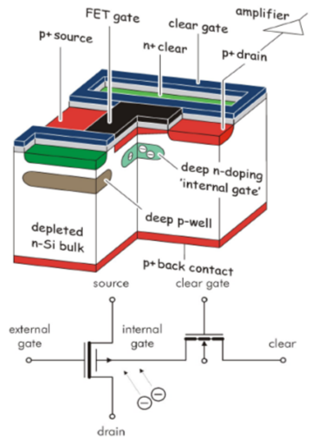
Vertex Detector

DEPFET:
http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome

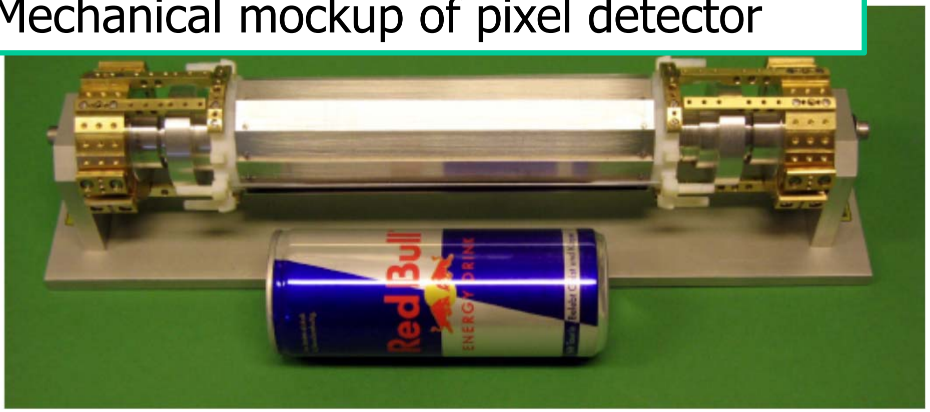


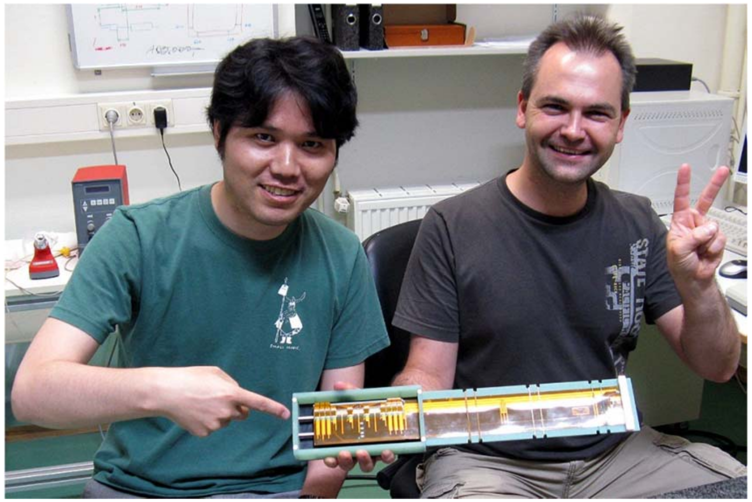
Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**

DEpleted P-channel FET

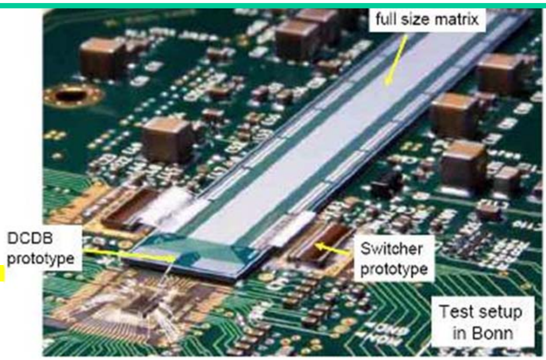


Mechanical mockup of pixel detector





Prototype DEPFET pixel sensor and readout

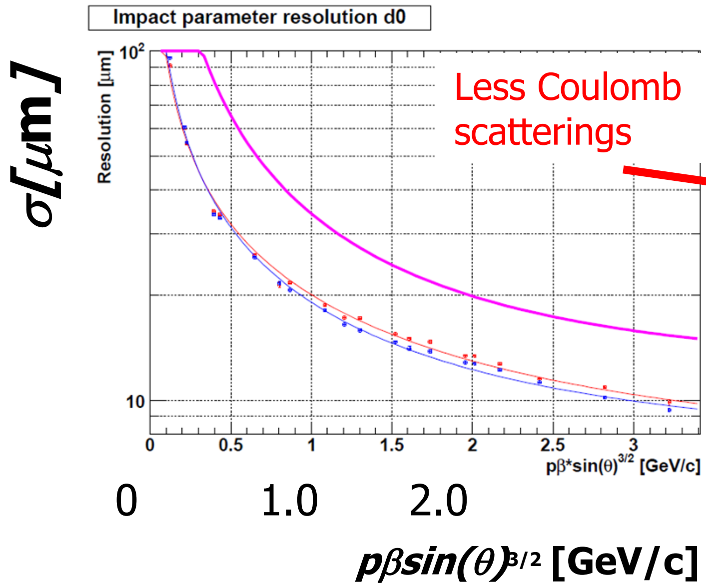


A prototype ladder using the first 6 inch DSSD from Hamamatsu has been assembled and tested.

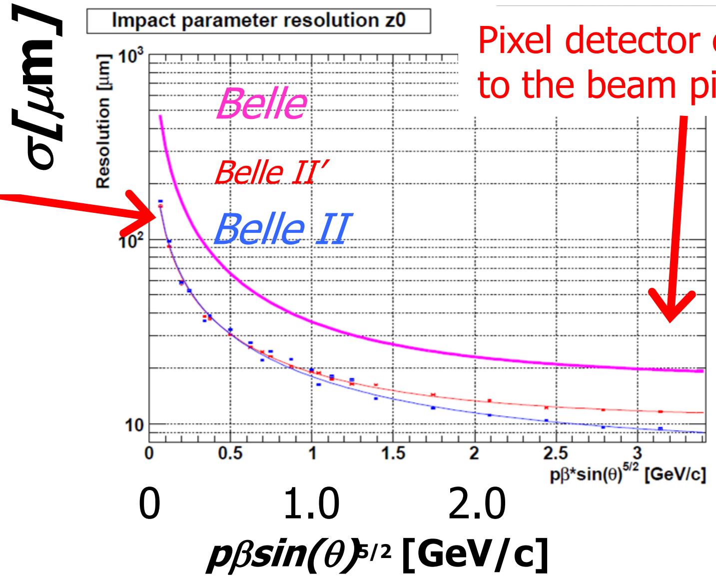
Expected performance

$$\sigma = a + \frac{b}{p\beta \sin^{\nu}\theta}$$

Significant improvement in IP resolution!

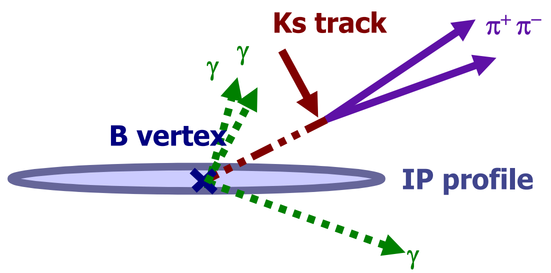


Less Coulomb scatterings

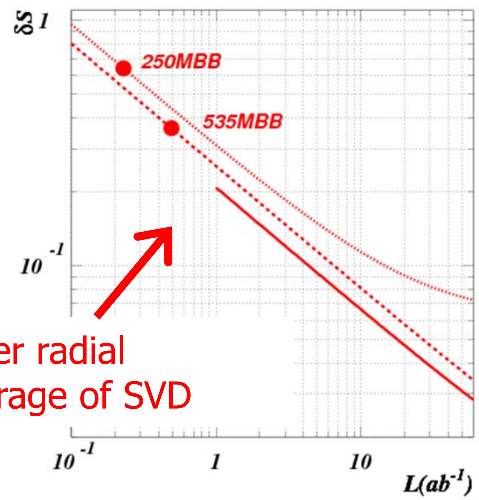


Pixel detector close to the beam pipe

Significant improvement in $\delta S(K_S\pi^0\gamma)$



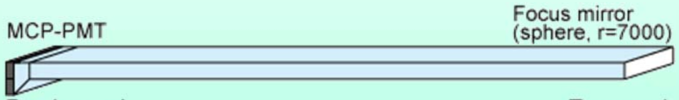
B decay point reconstruction with K_S trajectory



Larger radial coverage of SVD

Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



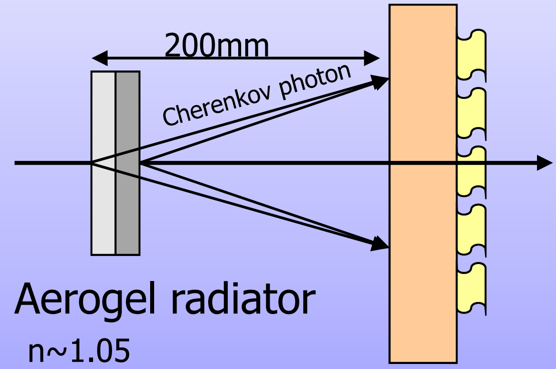
Quartz radiator

Focusing mirror

Small expansion block

Hamamatsu MCP-PMT (measure t, x and y)

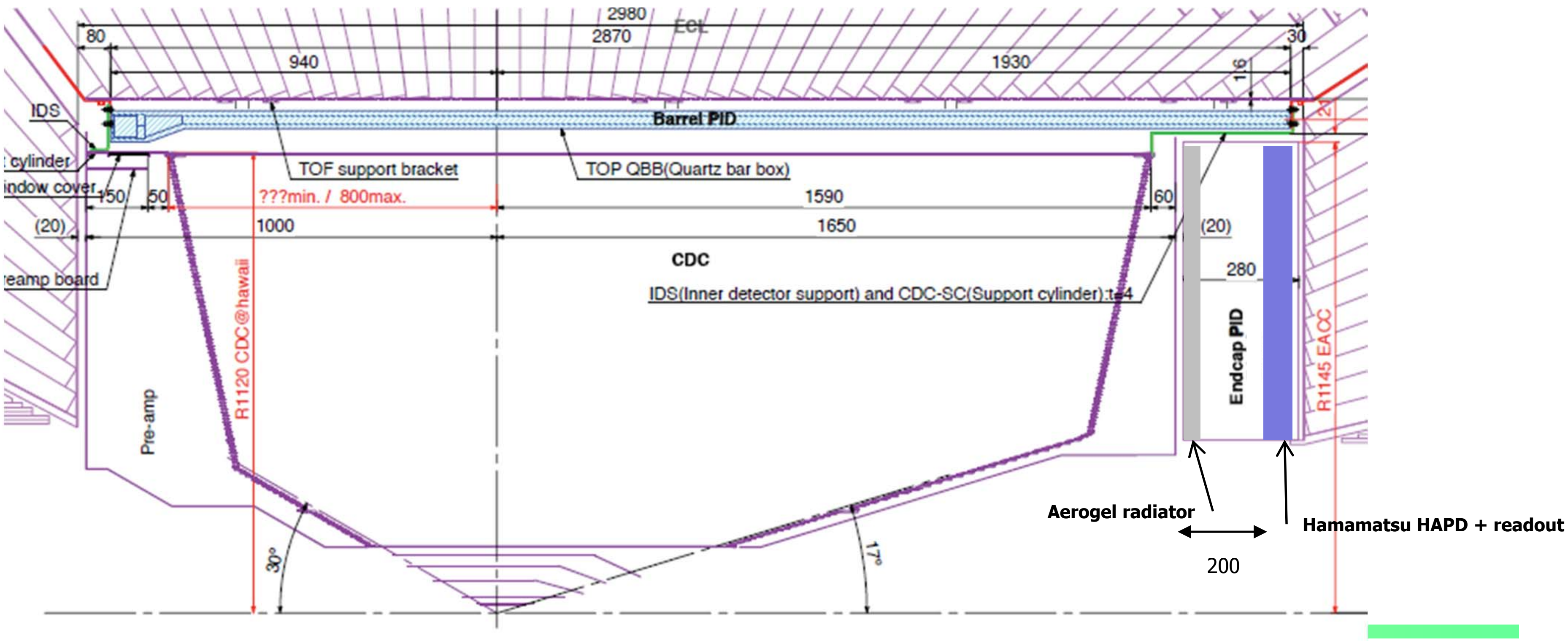
Endcap PID: Aerogel RICH (ARICH)



Aerogel radiator

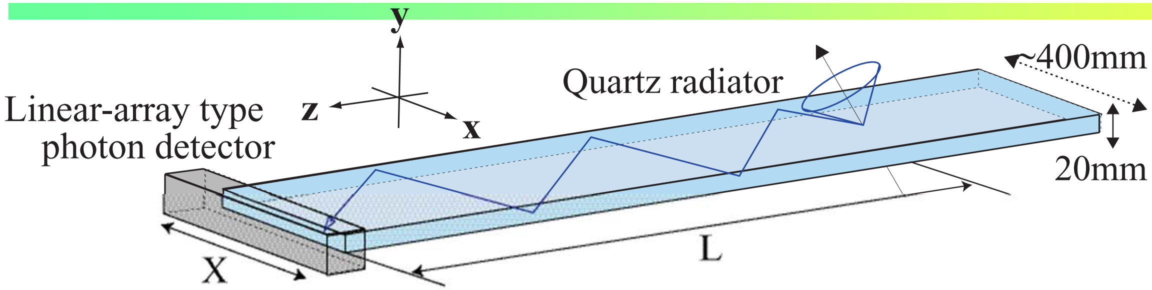
n~1.05

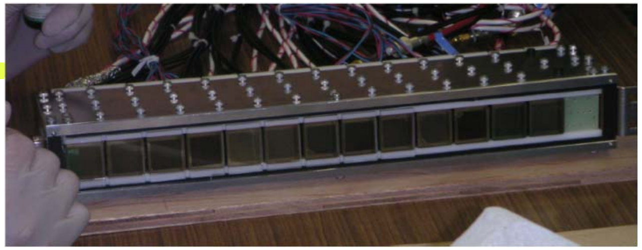
Hamamatsu HAPD
+ new ASIC



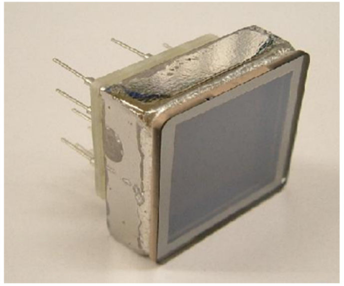
Peter Križan, Ljubljana

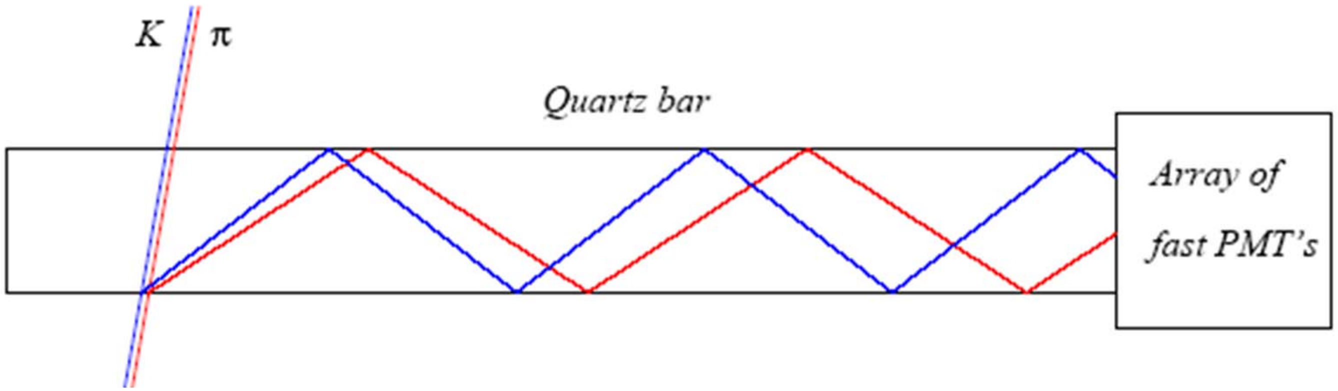
Barrel PID: Time of propagation (TOP) counter

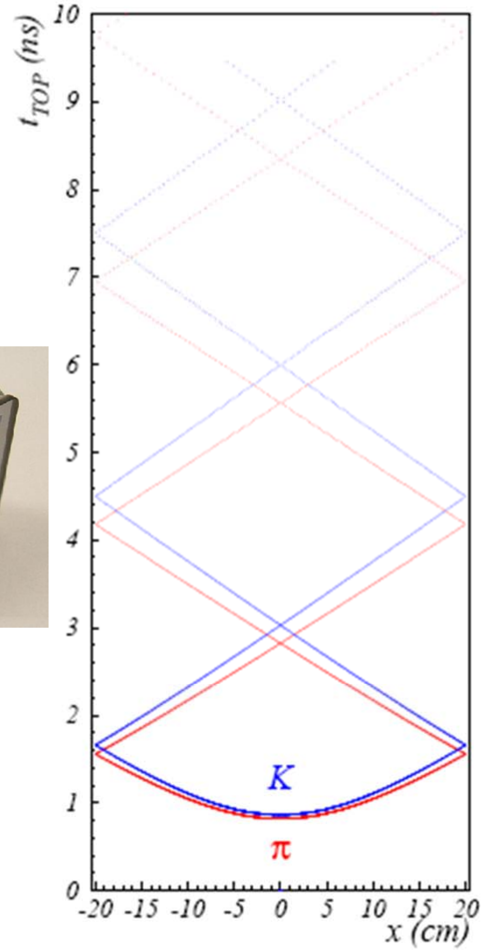




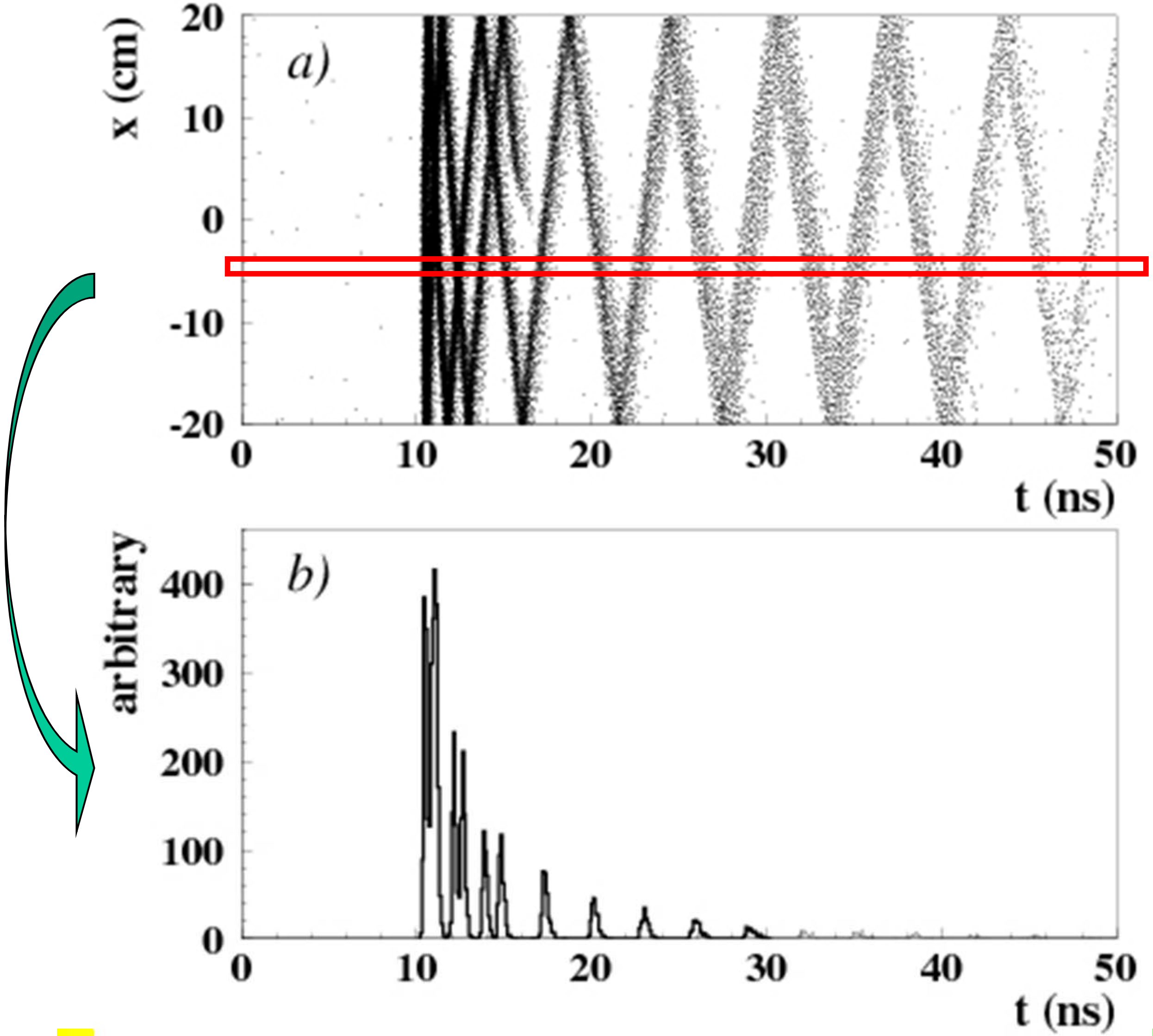
- Cherenkov ring imaging with precise time measurement.
- Reconstruct angle from two coordinates and the time of propagation of the photon
  - Quartz radiator (2cm)
  - Photon detector (MCP-PMT)
    - Good time resolution ~ 40 ps
    - Single photon sensitivity in 1.5







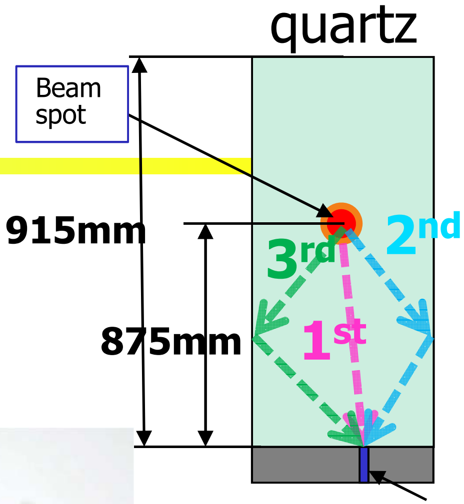
TOP image



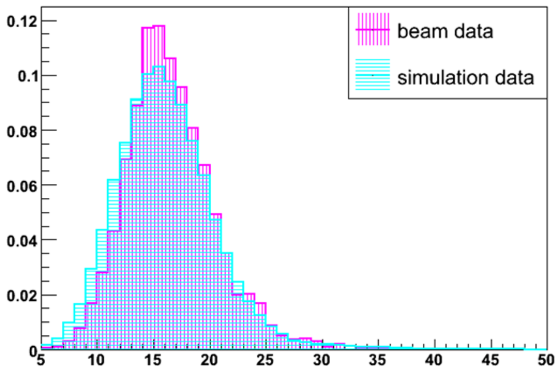
Pattern in the coordinate-time space ('ring') of a pion hitting a quartz bar with ~80 MAPMT channels

Time distribution of signals recorded by one of the PMT channels: different for π and K

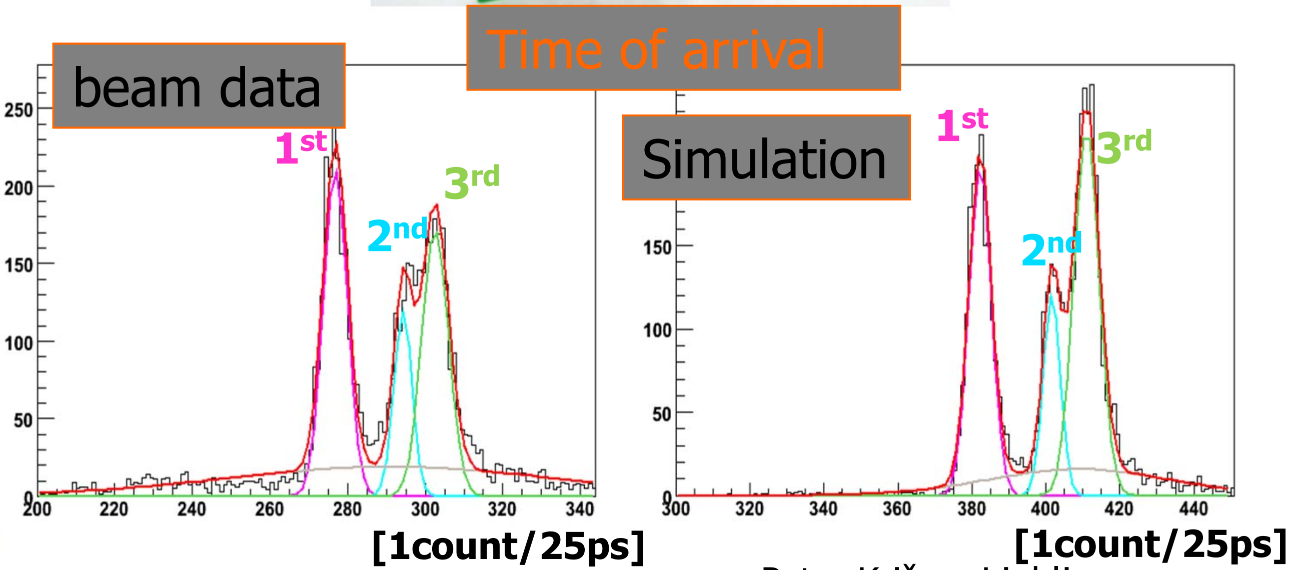
TOP (Barrel PID)



- Quartz radiator
  - 2.6m^{L} x 45cm^{W} x 2cm^{T}
  - Excellent surface accuracy
- MCP-PMT
  - Hamamatsu 16ch MCP-PMT
    - Good TTS (<35ps) & enough lifetime
    - Multialkali photo-cathode → SBA
- Beam test in 2009
  - # of photons consistent
  - Time resolution OK



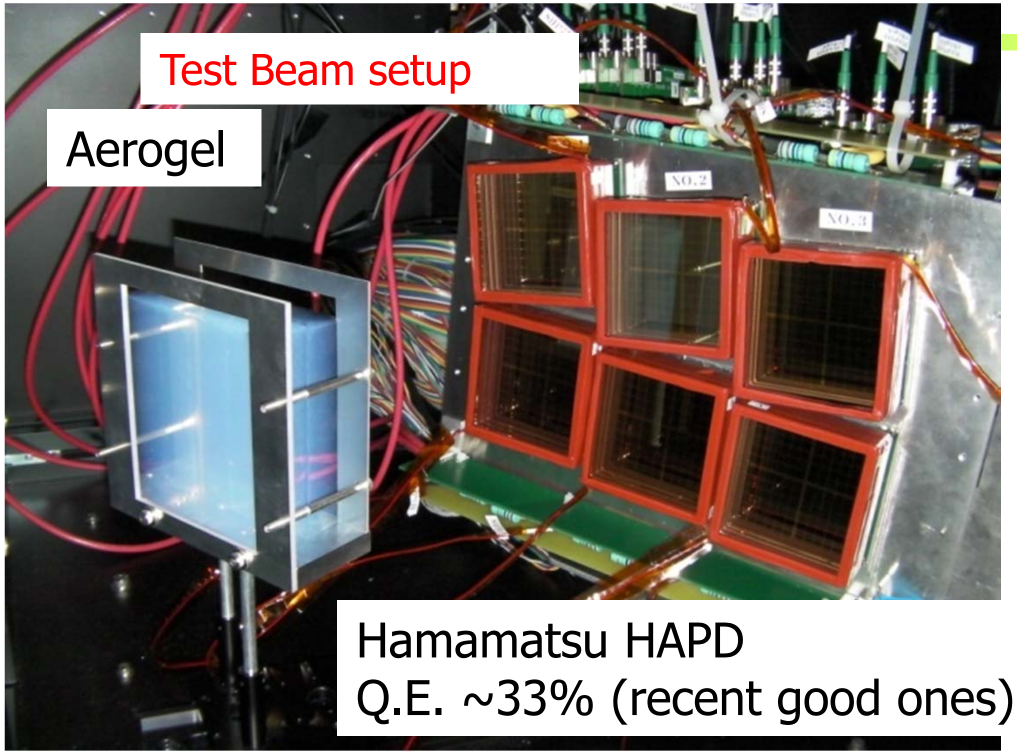
# of photons



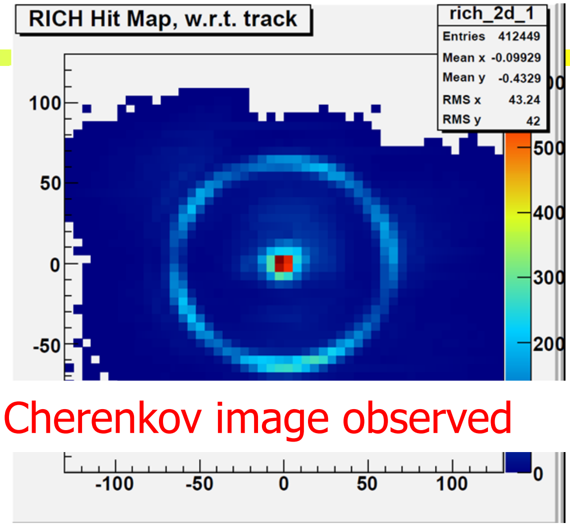
Aerogel RICH (endcap PID)

Test Beam setup

Aerogel

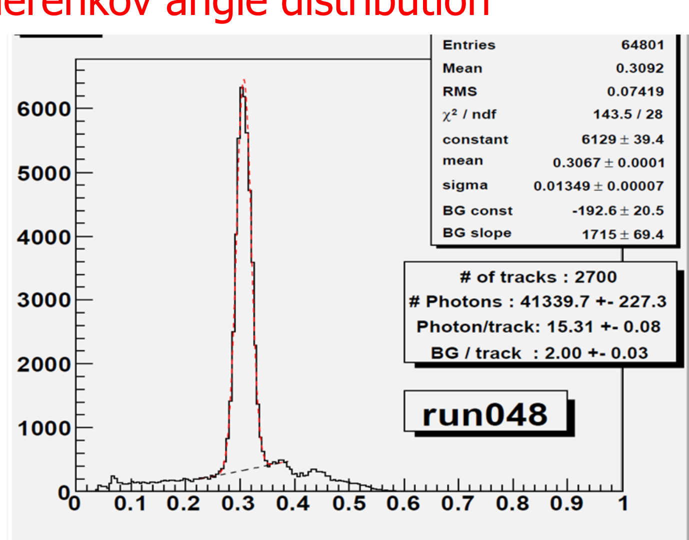


Hamamatsu HAPD
Q.E. ~33% (recent good ones)



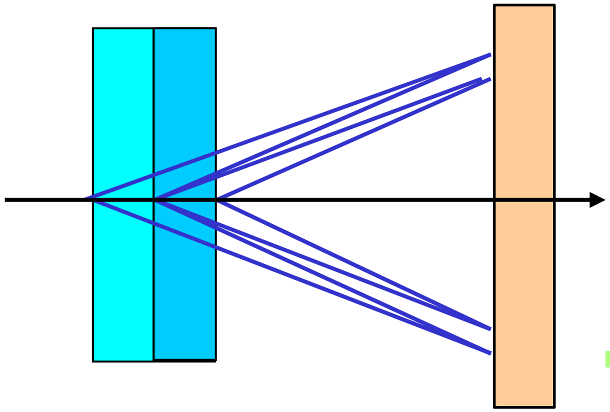
Clear Cherenkov image observed

Cherenkov angle distribution



RICH with a novel "focusing" radiator – a two layer radiator

Employ multiple layers with different refractive indices→ Cherenkov images from individual layers overlap on the photon detector.



6.6 σ π/K at 4GeV/c !

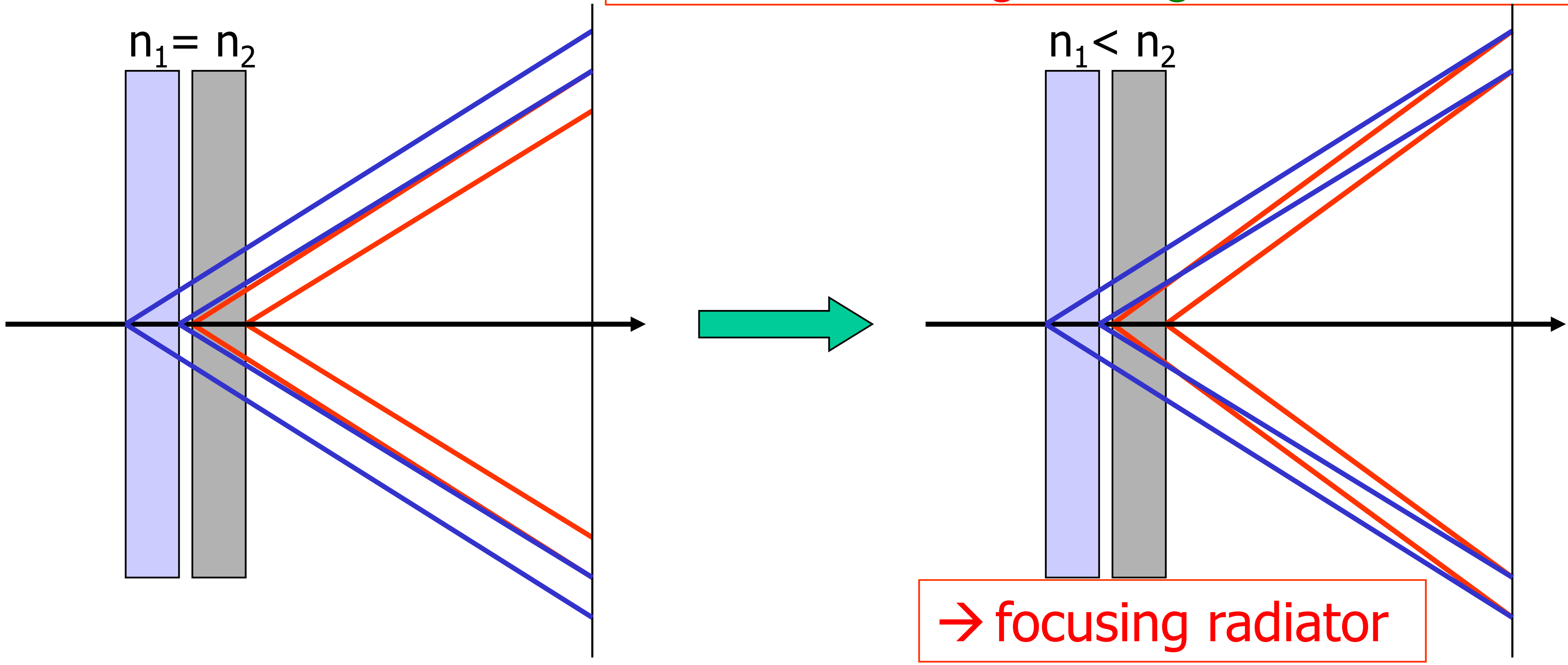
Peter Križan, Ljubljana

Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

→ stack two tiles with different refractive indices: “focusing” configuration

normal

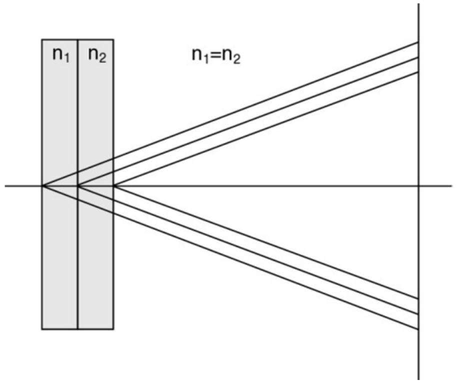


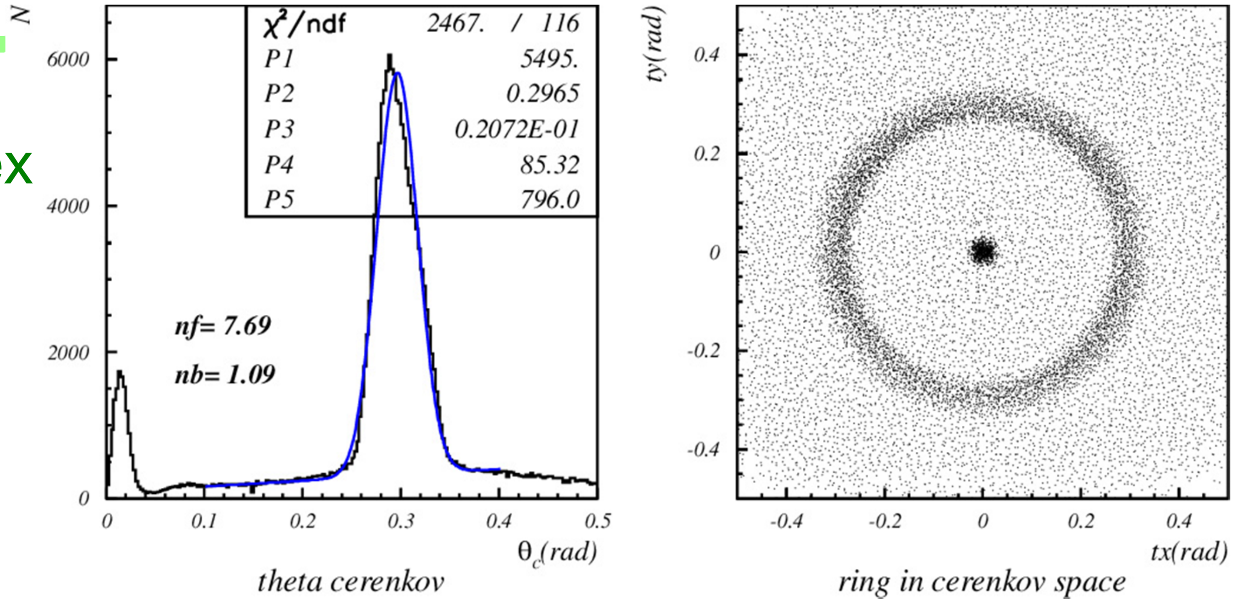
→ focusing radiator

Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

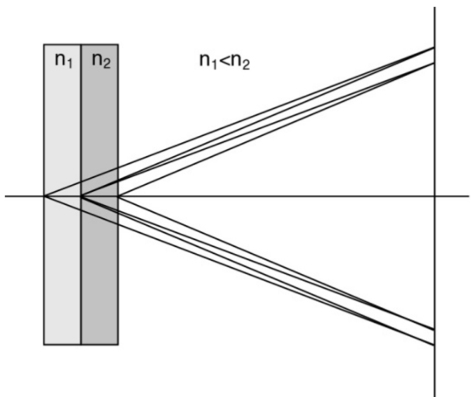
Focusing configuration – data

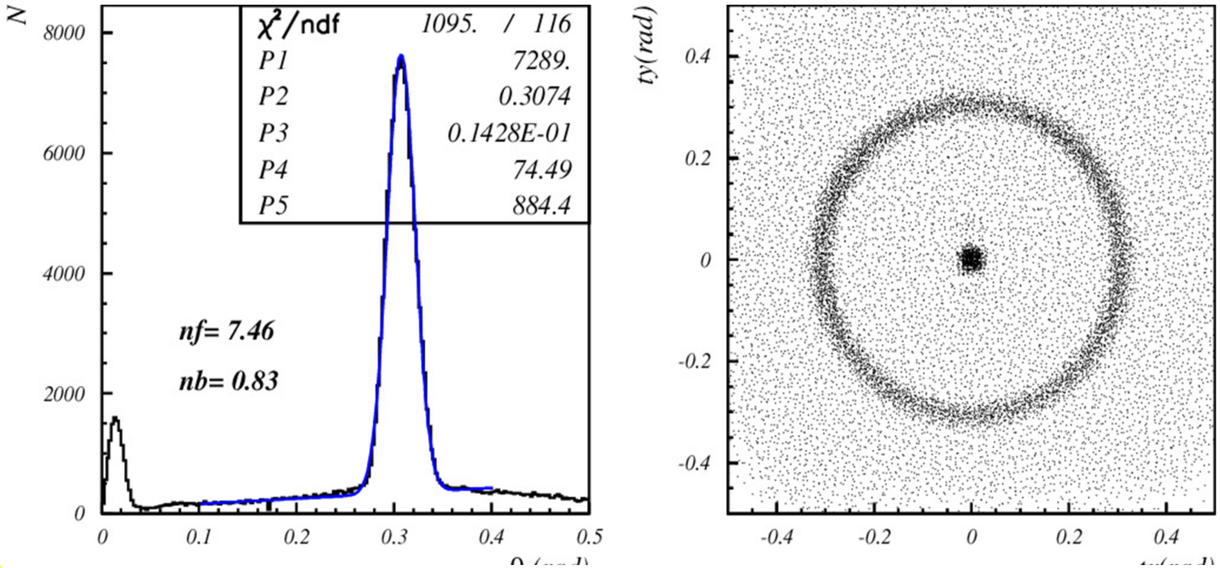
4cm aerogel single index





2+2cm aerogel



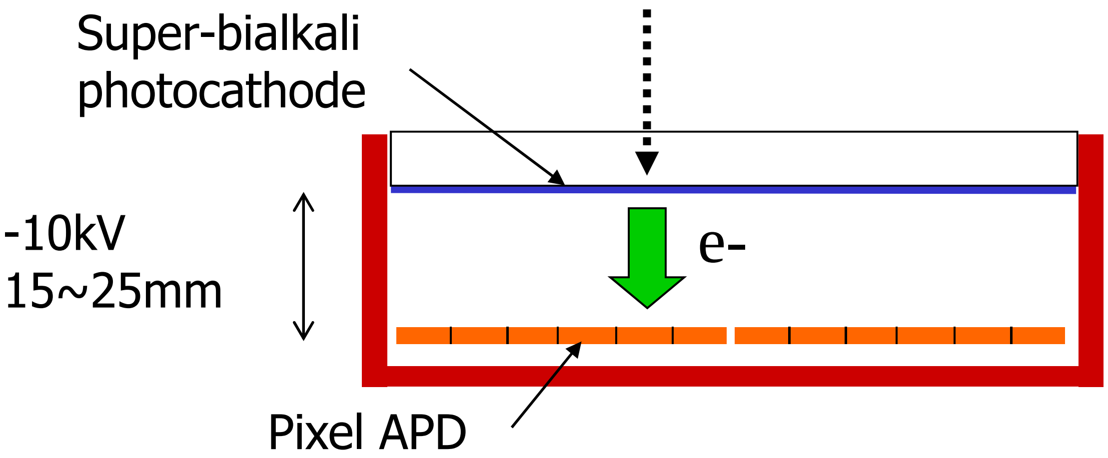


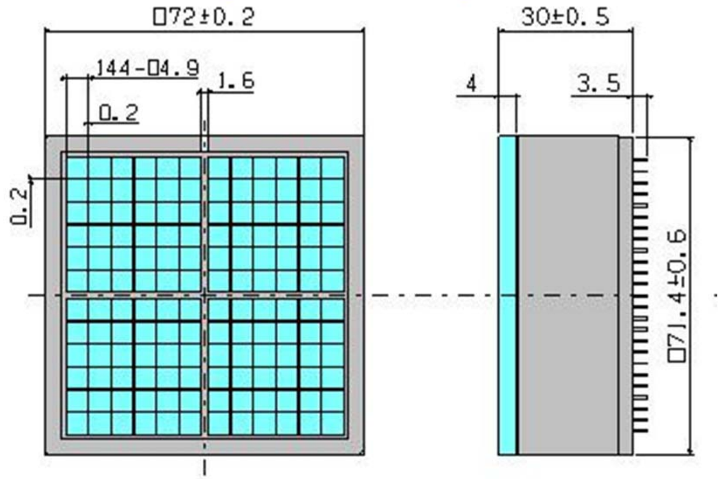
→NIM A548 (2005) 383

Photon detector for the aerogel RICH

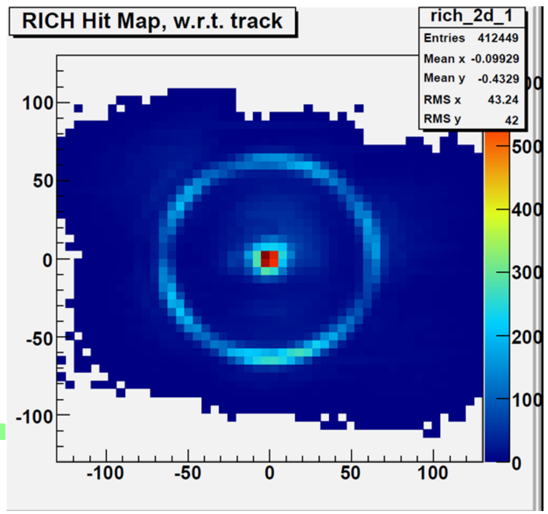
Need: Operation in a high magnetic field (1.5 T), pad size 5mm

Baseline detector: large active area HAPD of the proximity focusing type





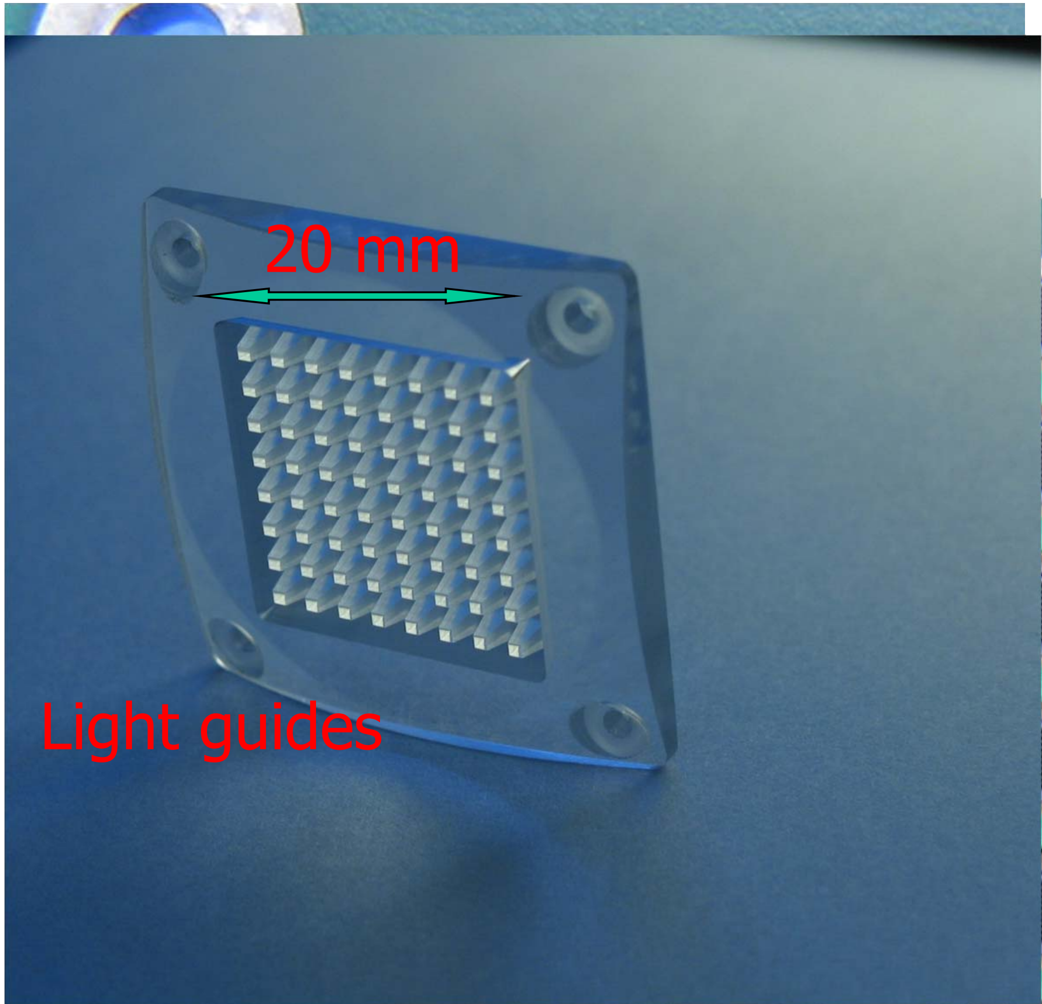
R&D project in collaboration with HPK.

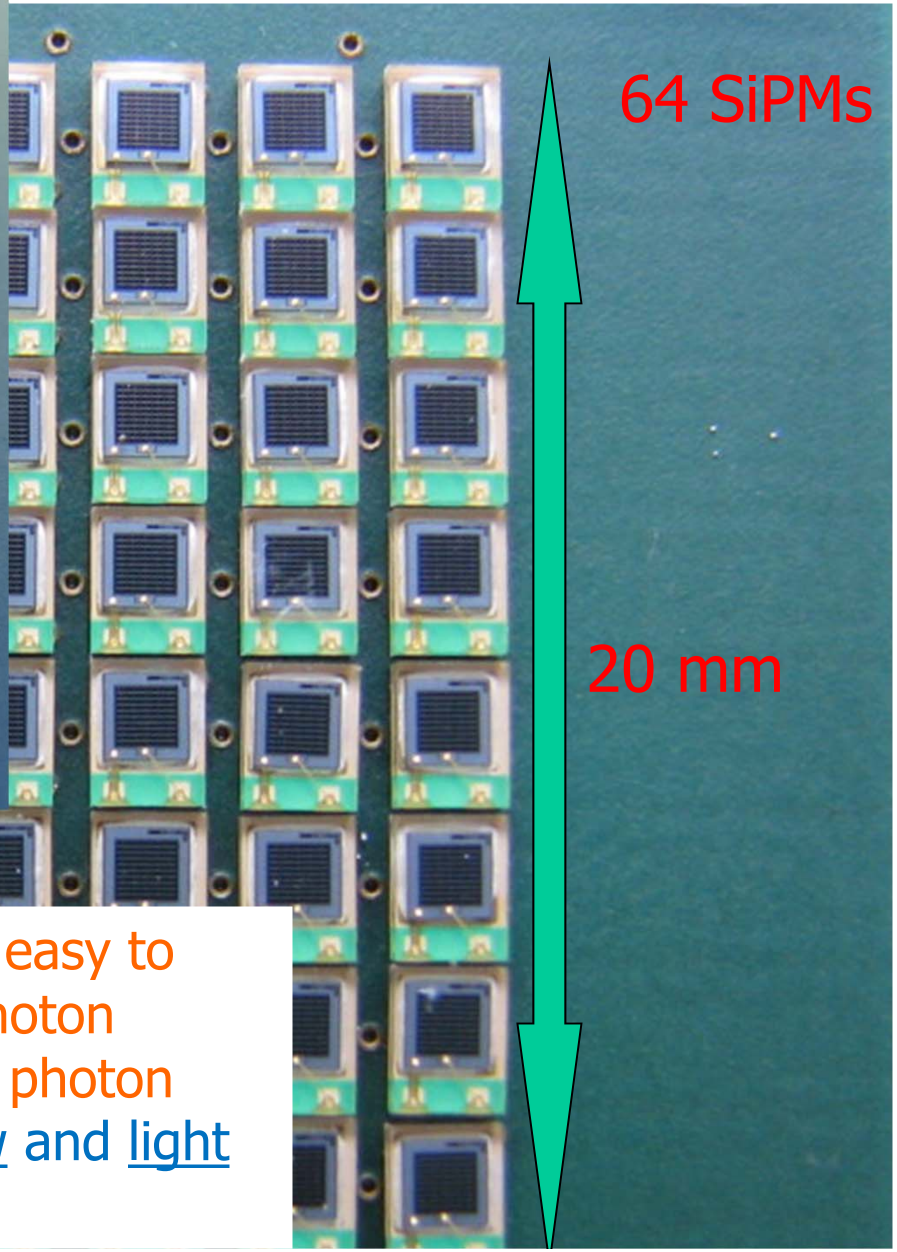


Beam test results: Cherenkov ring

→ NIM A595 (2008) 180

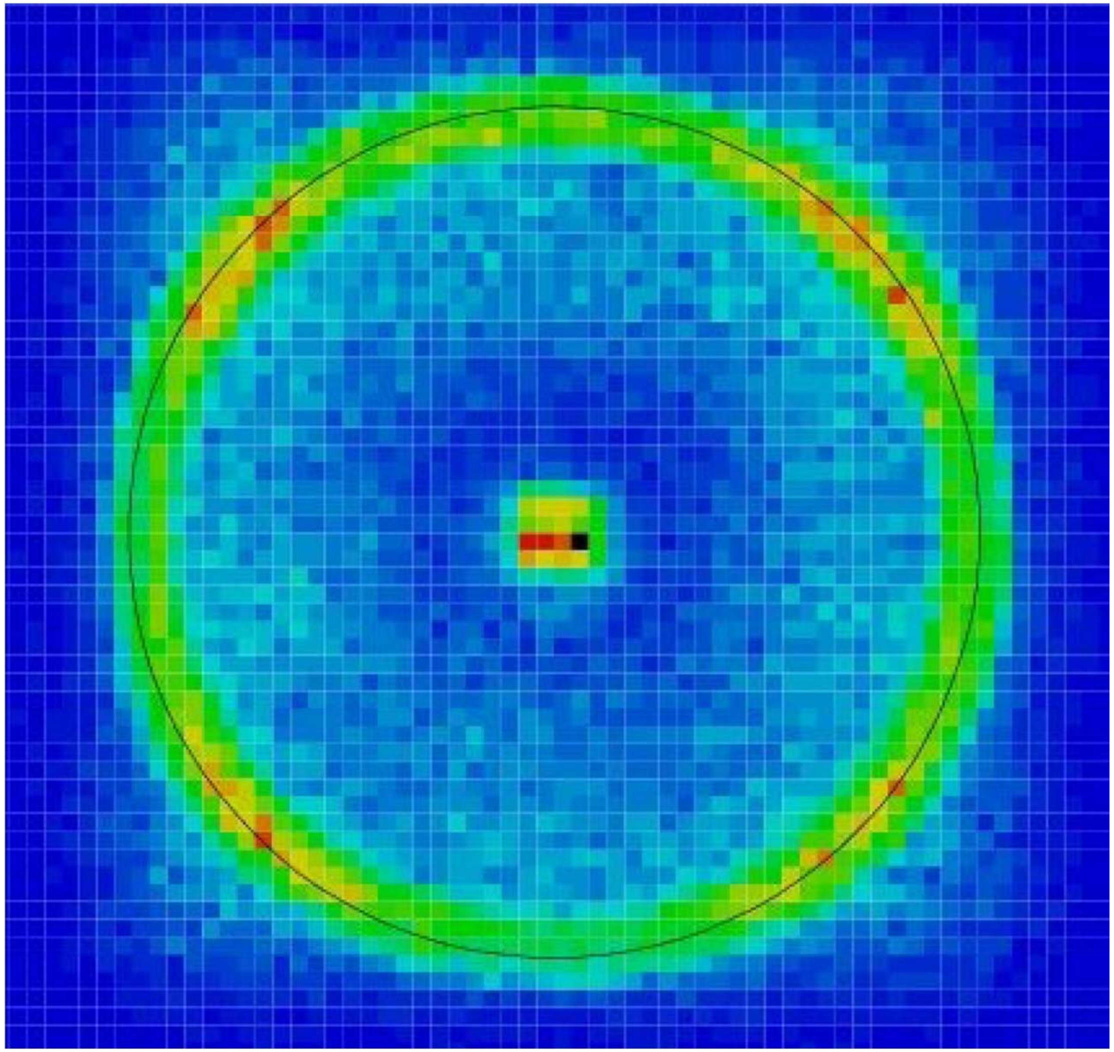
Another candidate: SiPM





Another sensor candidate: 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 <u>narrow time window</u> and <u>light concentrators</u>

Cherenkov ring with SiPMs



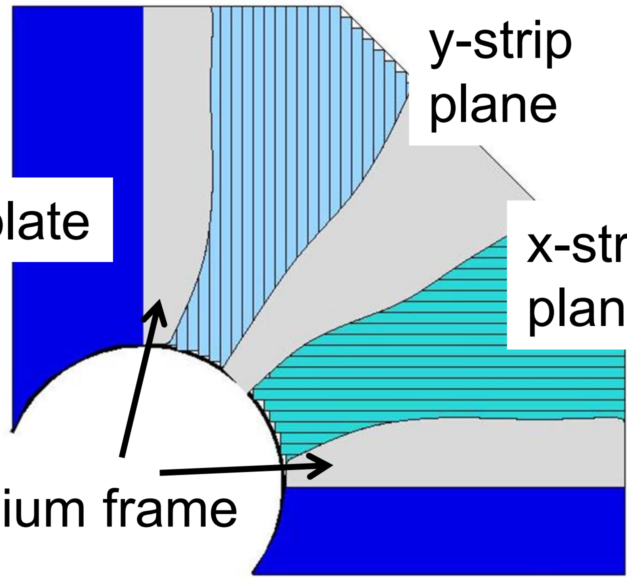
First successful use of SiPMs as single photon detectors in a RICH counter!

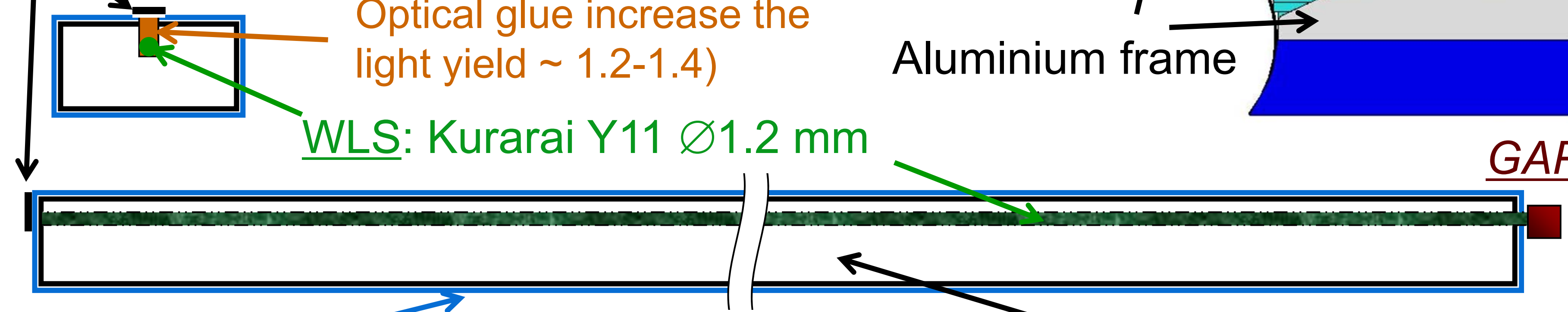
NIM A594 (2008) 13

KLM upgrade in the endcaps

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%





Status of the project

Belle II Collaboration

13 countries/regions, 54 institutes

300 collaborators,
>100 from Europe

European groups of Belle-II

- Austria: HEPHY (Vienna)
- Czech republic: Charles University in Prague
- Germany: U. Bonn, U. Giessen, U. Goettingen, U. Heidelberg, KIT Karlsruhe, LMU Munich, MPI Munich, TU Munich
- Poland: INP Krakow
- Russia: ITEP (Moscow), BINP (Novosibirsk), IHEP (Protvino)
- Slovenia: J. Stefan Institute (Ljubljana), U. Ljubljana, U. Maribor and U. Nova Gorica

A sizeable fraction of the collaboration: in total >100 collaborators out of ~300!

SuperKEKB/Belle II funding Status

KEKB upgrade has been approved

- 5.8 oku yen (~MUSD) for Damping Ring (FY2010)
- 100 oku yen for machine -- Very Advanced Research Support Program (FY2010-2012)

- Continue efforts to obtain additional funds to complete construction as scheduled – getting very good signs from the government: green light from the cabinet!

Several non-Japanese funding agencies have already allocated sizable funds for the upgrade.

→construction started!

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Press Release

大学共同利用機関法人 KEK 高エネルギー加速器研究機構

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last update: 10/06/23

Press Release

KEKB upgrade plan has been approved

June 23, 2010
High Energy Accelerator Research Organization (KEK)

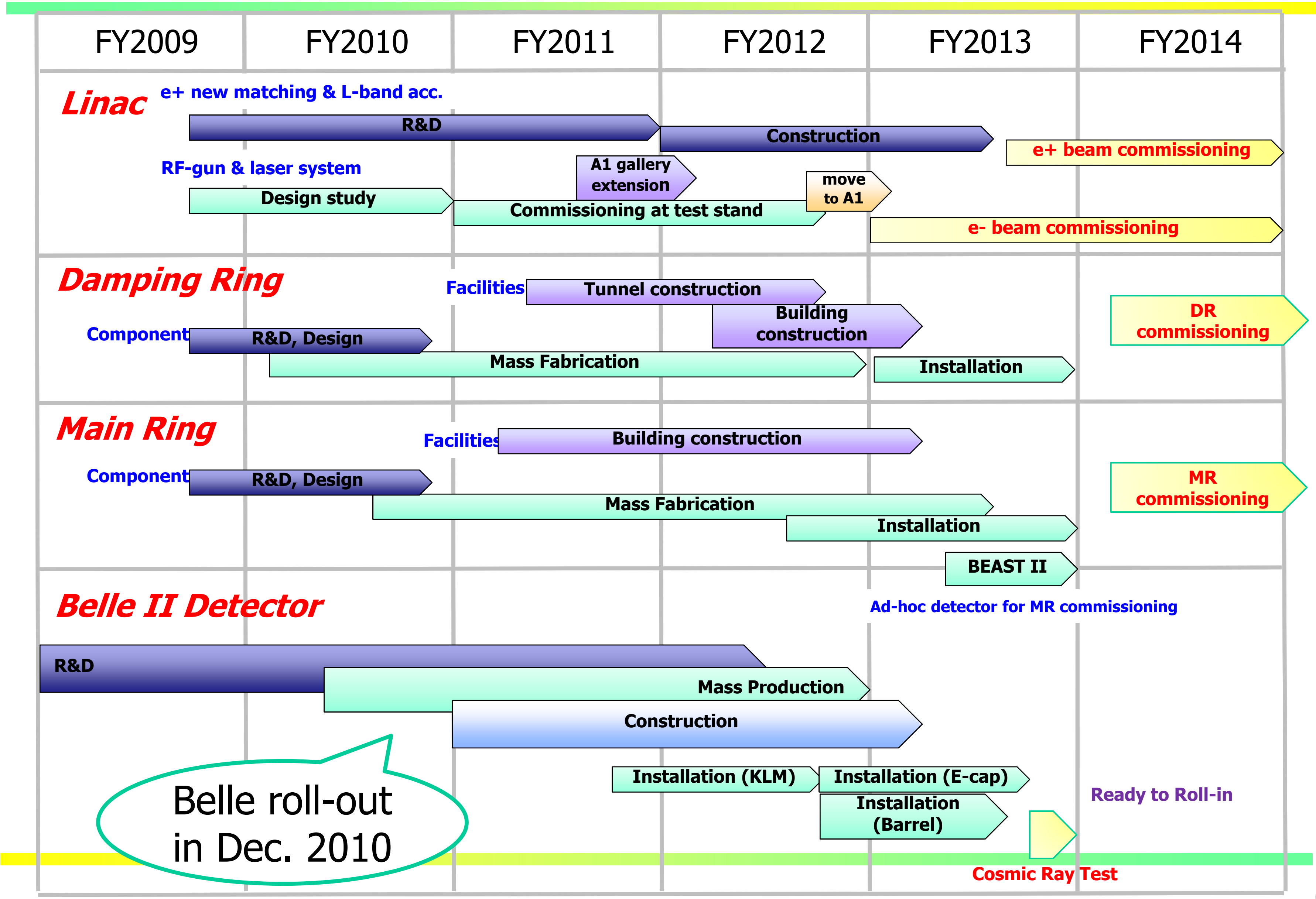
The MEXT, the Japanese Ministry that supervises KEK, has announced that it will appropriate a budget of 100 oku-yen (approx $110M) over the next three years starting this Japanese fiscal year (JFY2010) for the high performance upgrade program of KEKB. This is part of the measures taken under the new "Very Advanced Research Support Program" of the Japanese government.

"We are delighted to hear this news," says Masanori Yamauchi, former spokesperson for the Belle experiment and currently a deputy director of the Institute of Particle and Nuclear Studies of KEK. "This three- year upgrade plan allows the Belle experiment to study the physics from decays of heavy flavor particles with an unprecedented precision. It means that KEK in Japan is launching a renewed research program in search for new physics by using a technique which is complementary to what is employed at LHC at CERN."

[Media Contact] Youhei Morita,
Head of Public Relations Office, KEK
tel. +81-29-879-6047

Construction Schedule of SuperKEKB/Belle II

Jun. 24, 2010

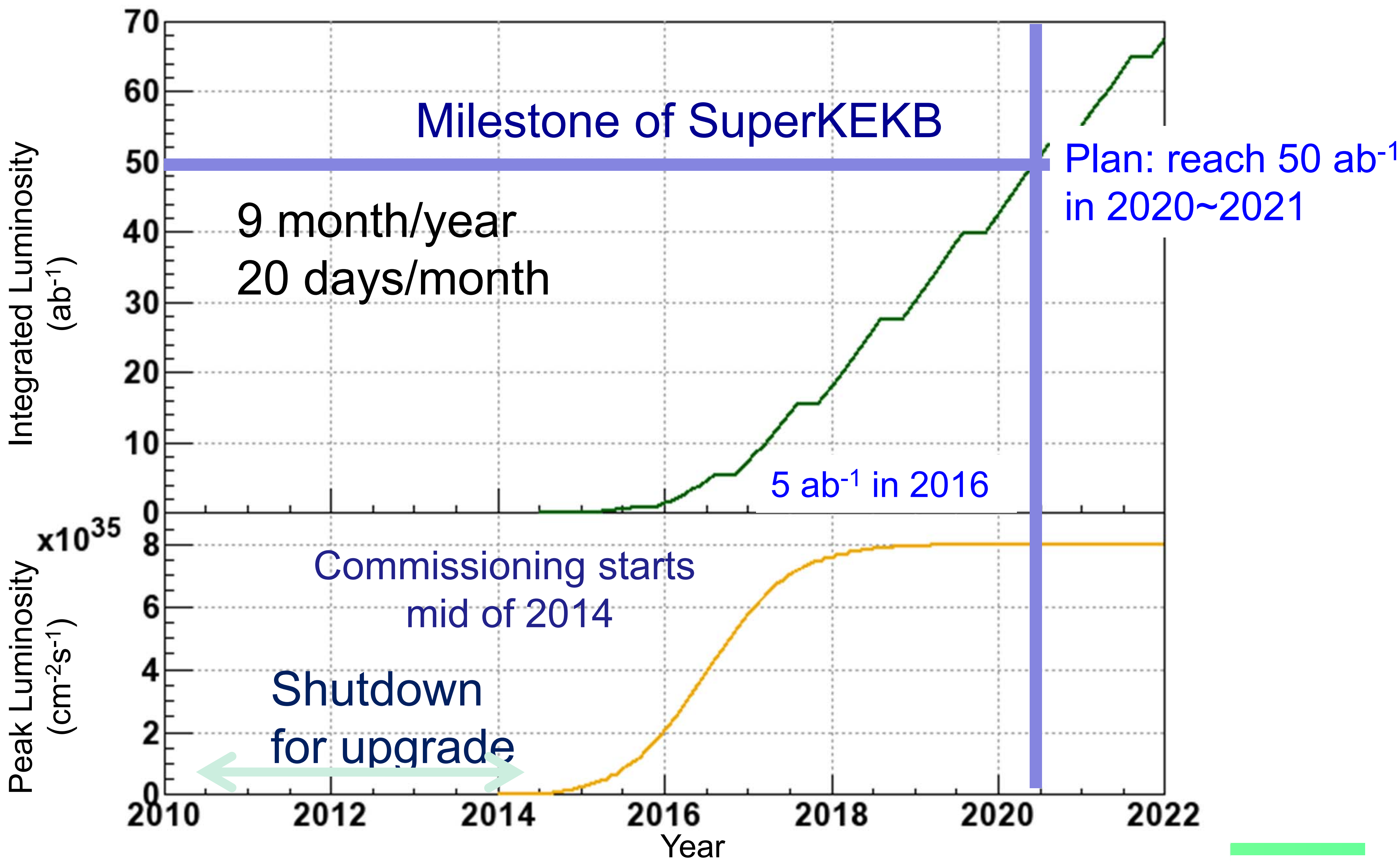


Early November:
taking out the SVD2
– vertex detector

In the meantime:
also central drift
chamber is out

Belle has been rolled out in December to the parking position in the Tsukuba hall – waiting for the assembly to start...

Luminosity upgrade projection



Summary

- B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of the performance, achieving and surpasing design perfomance
- Major upgrade at KEK in 2010-14 → SuperKEKB+Belle II, L x40, construction started
- Physics reach updates available
- Expect a new, exciting era of discoveries, complementary to the LHC