Belle and SuperBelle

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Contents

- Highlights from Belle
- Physics case for the Super B factories
- Accellerator and detector upgrade
- Summary

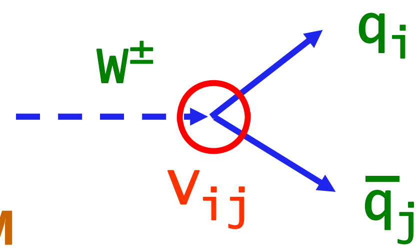
'SuperBelle' → since this Tuesday officially Belle II

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

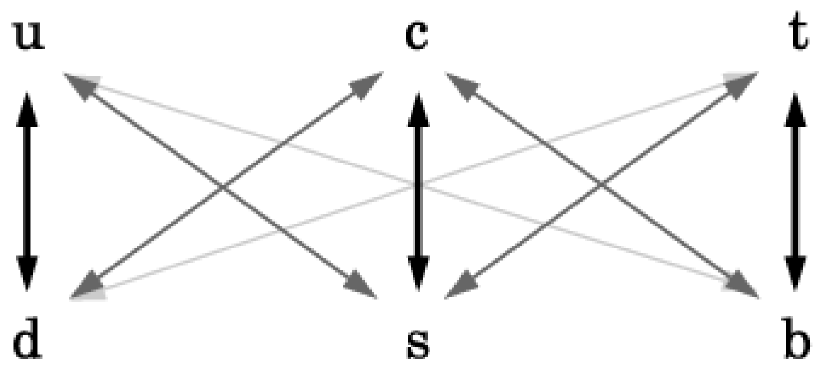
CKM matrix is unitary



deviations could signal processes not included in SM

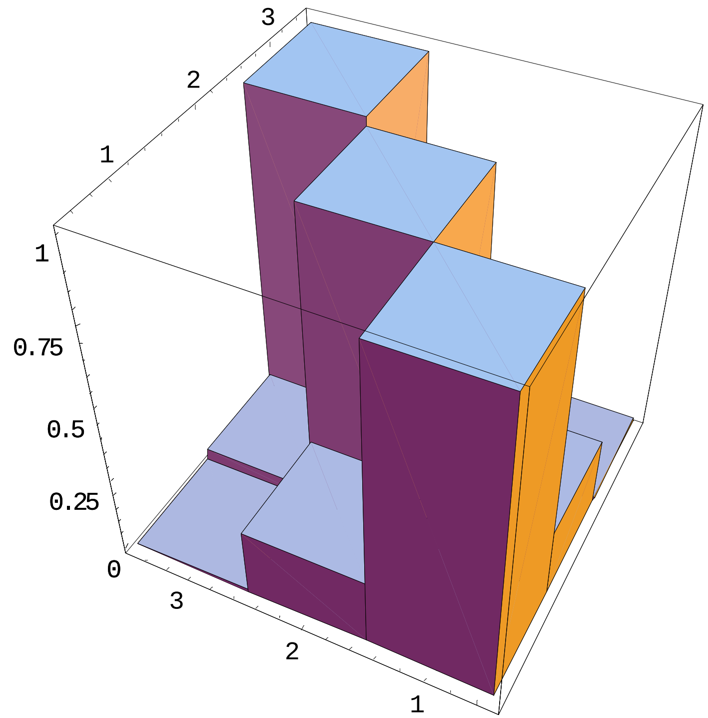
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

CKM matrix



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

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

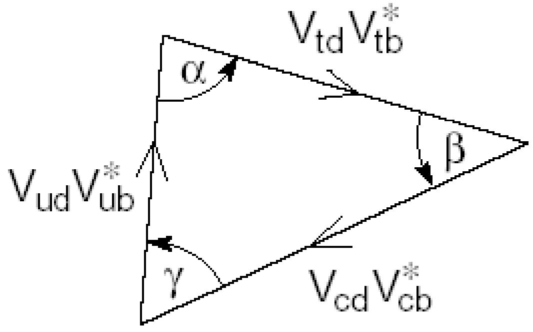


→CKM: almost real, but not completely...

Unitarity triangle

Unitarity condition:

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



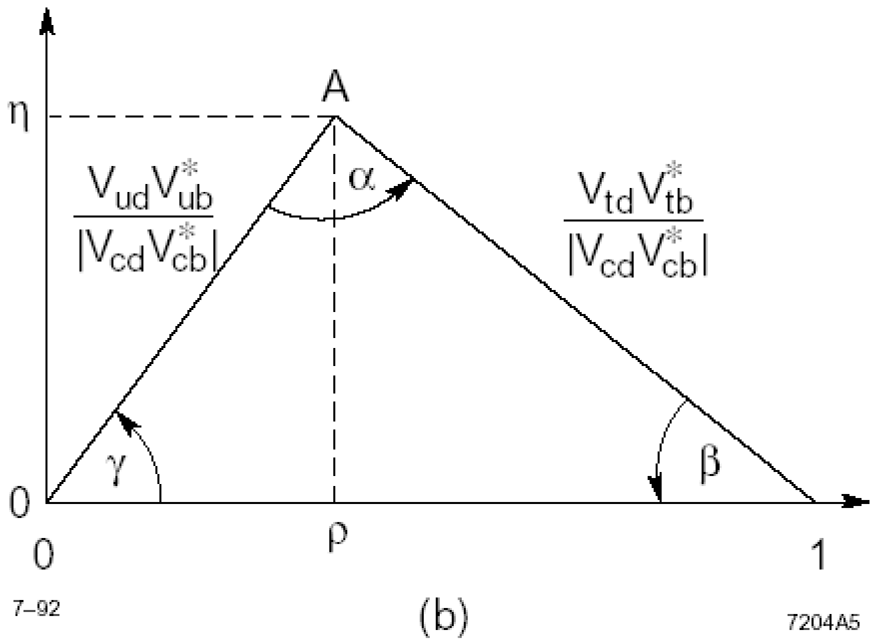
(a)

Another notation:

$\phi_1=\beta$

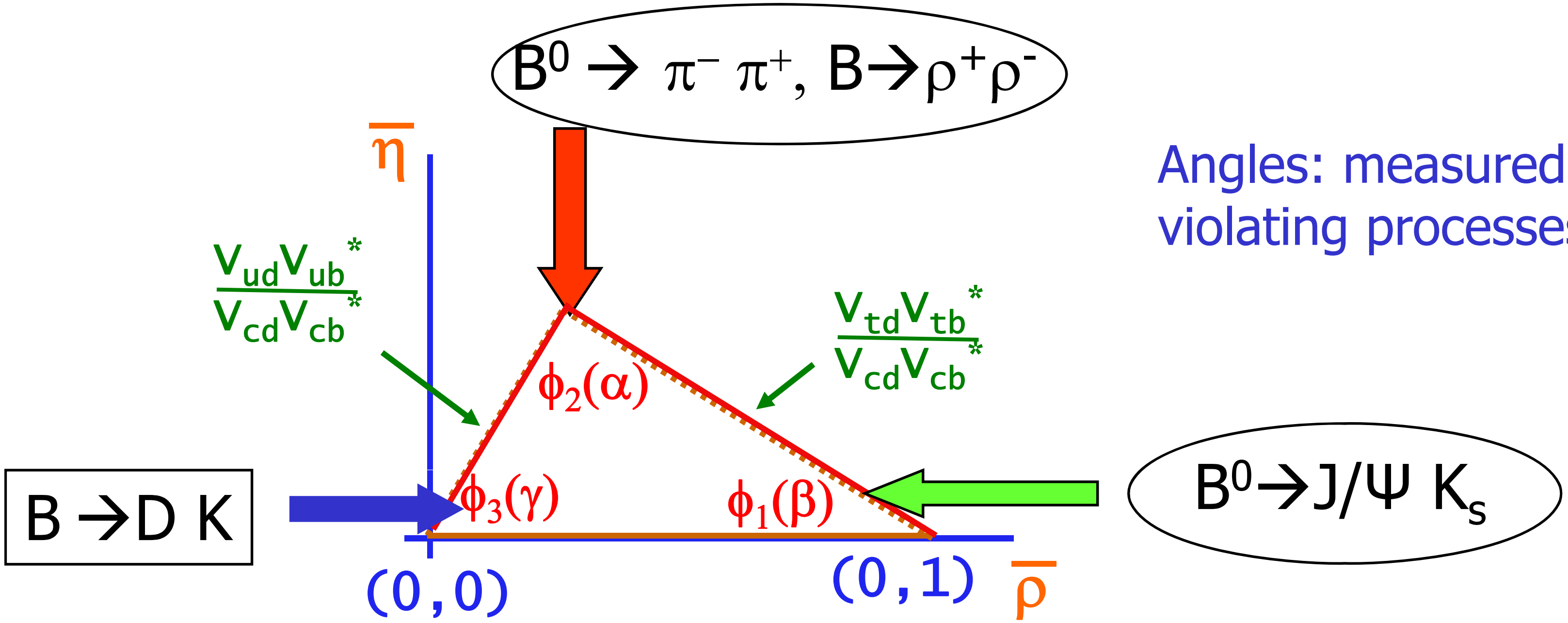
$\phi_2=\alpha$

$\phi_3=\gamma$



(b)

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

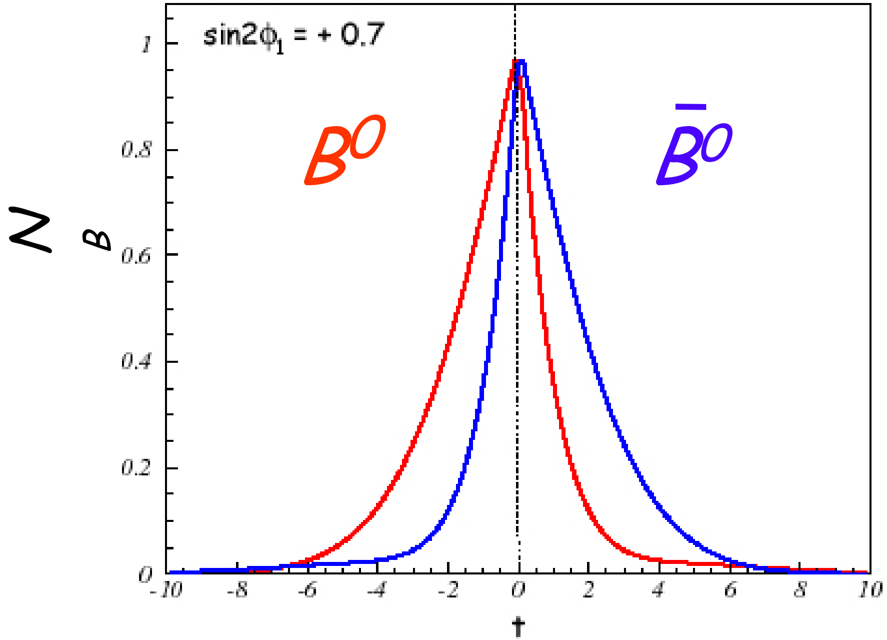


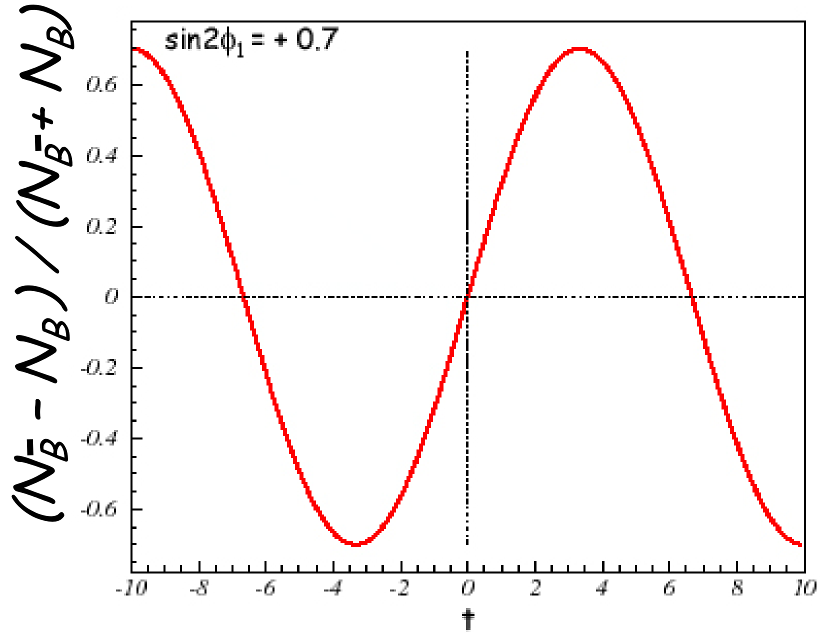
Angles: measured in CP violating processes

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}

example: $B^0 \rightarrow J/\Psi\ K_s$

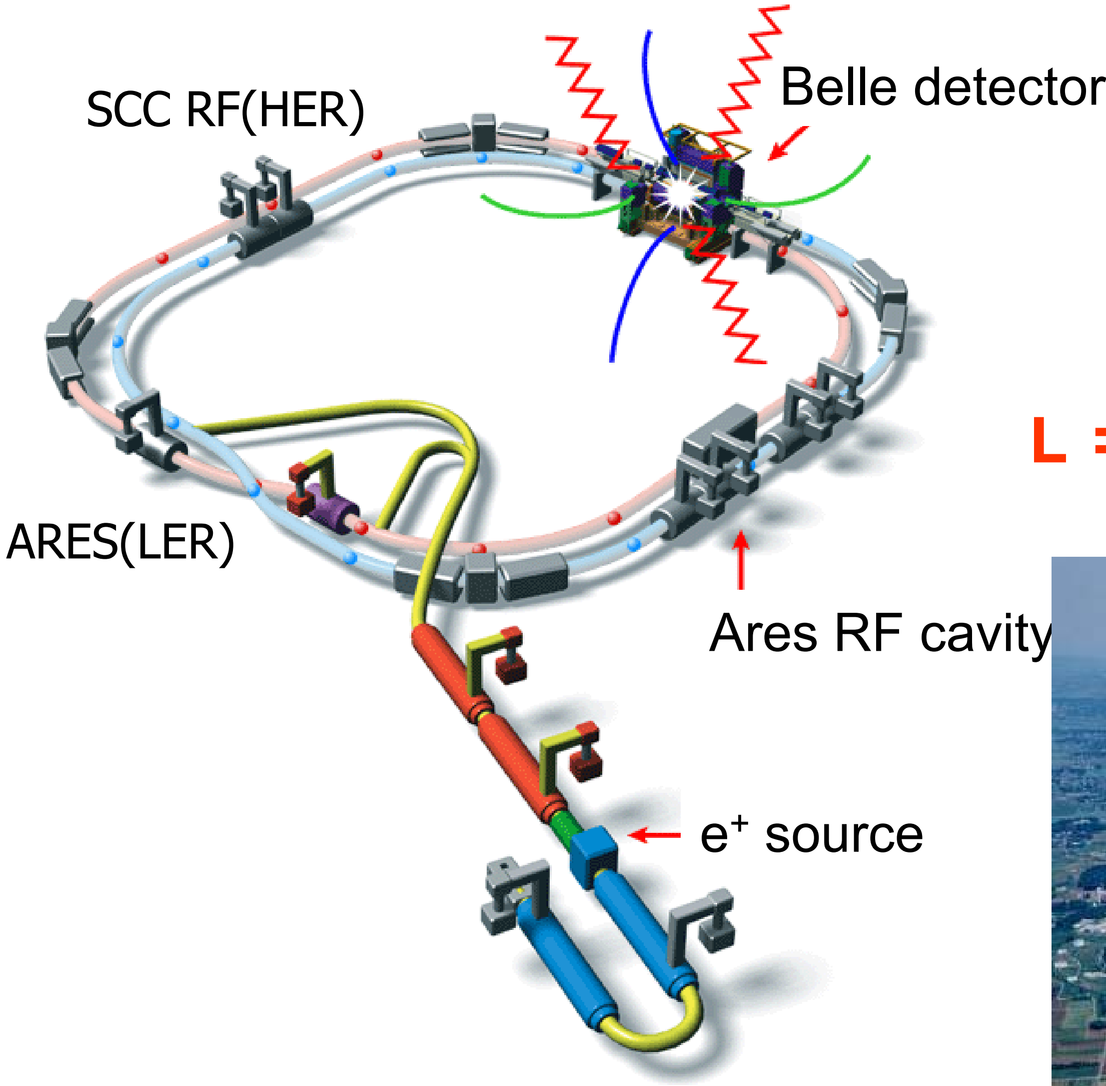




$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0(t) \rightarrow f_{CP}) - \Gamma(B^0(t) \rightarrow f_{CP})}{\Gamma(\overline{B}^0(t) \rightarrow f_{CP}) + \Gamma(B^0(t) \rightarrow f_{CP})} = -\xi_f \sin 2\phi_1 \sin \Delta m_B t$$

$\xi_f = \pm 1$ *for* $CP = \pm 1$

The KEKB Collider

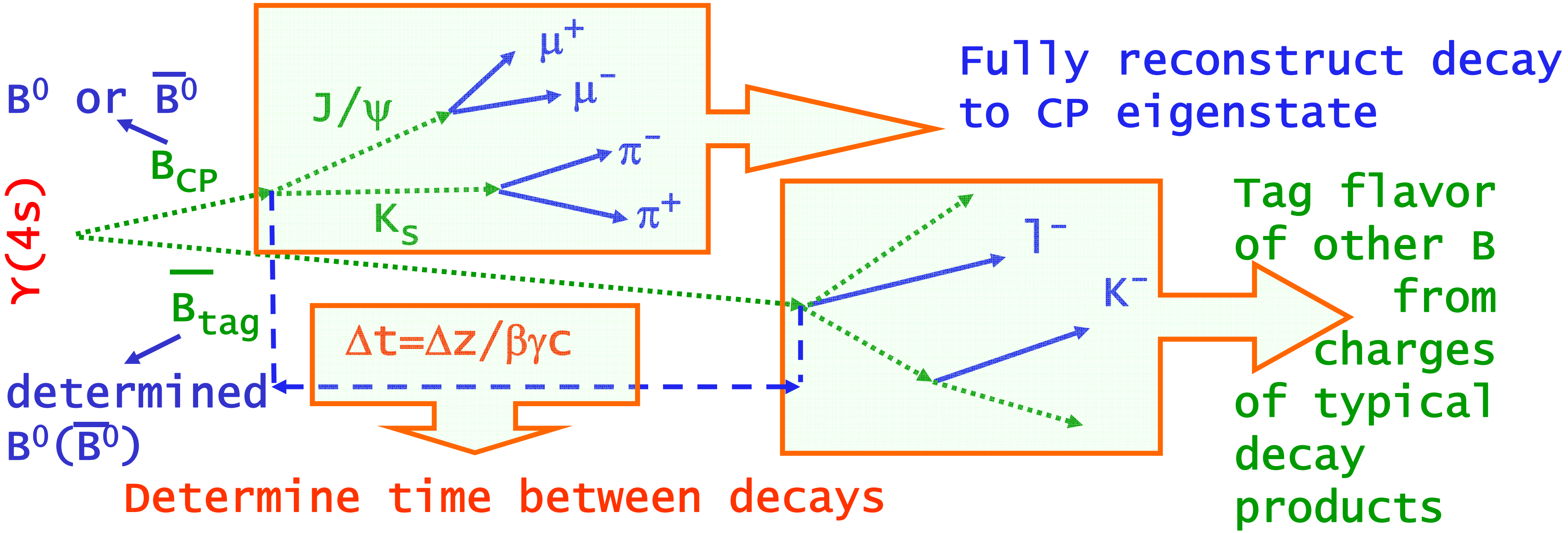


8 x 3.5 GeV
22mrad crossing angle

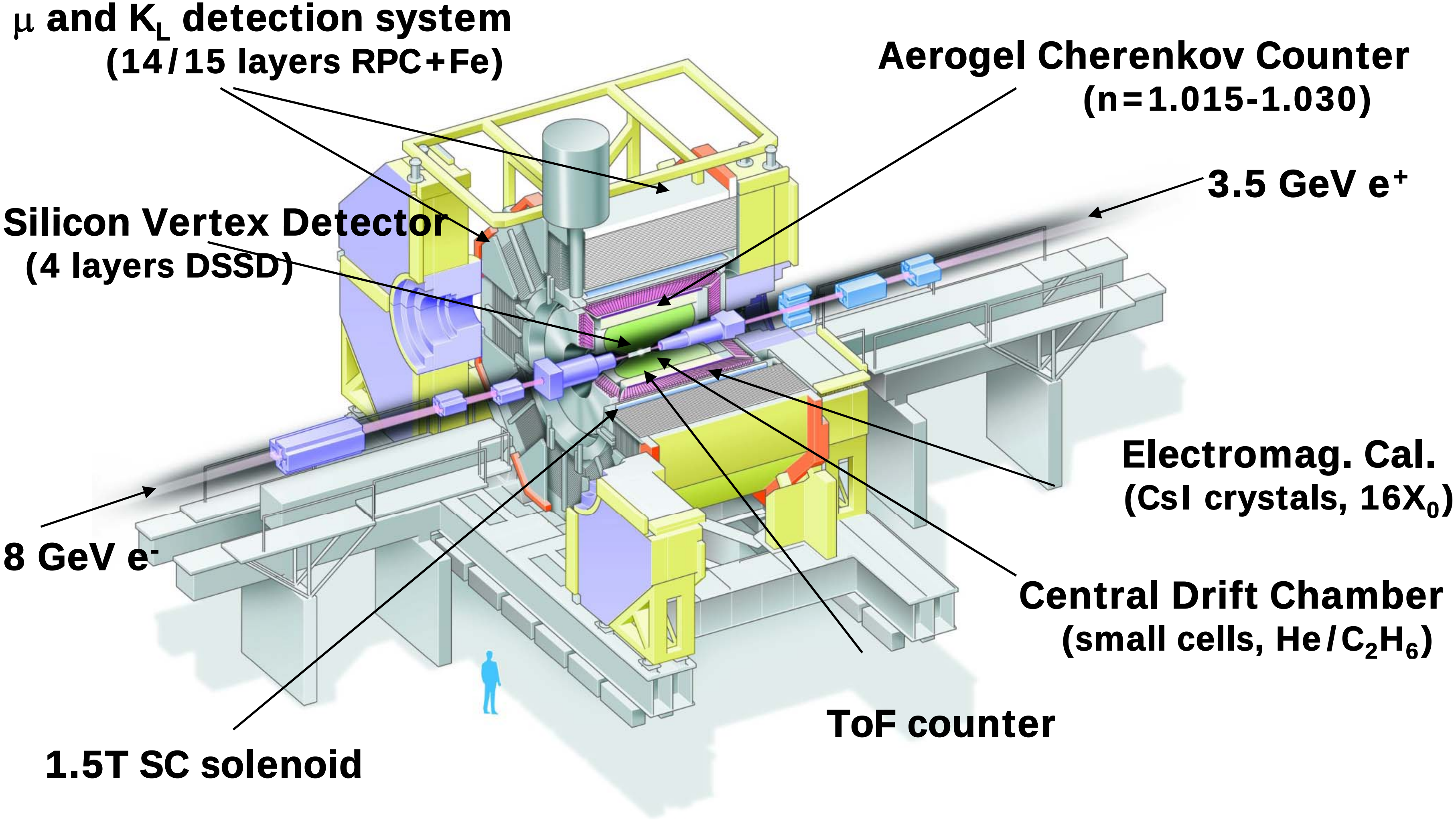
World record:

L = 1.96 x 10^{34}/cm^2/sec

Principle of measurement



Belle spectrometer at KEK-B



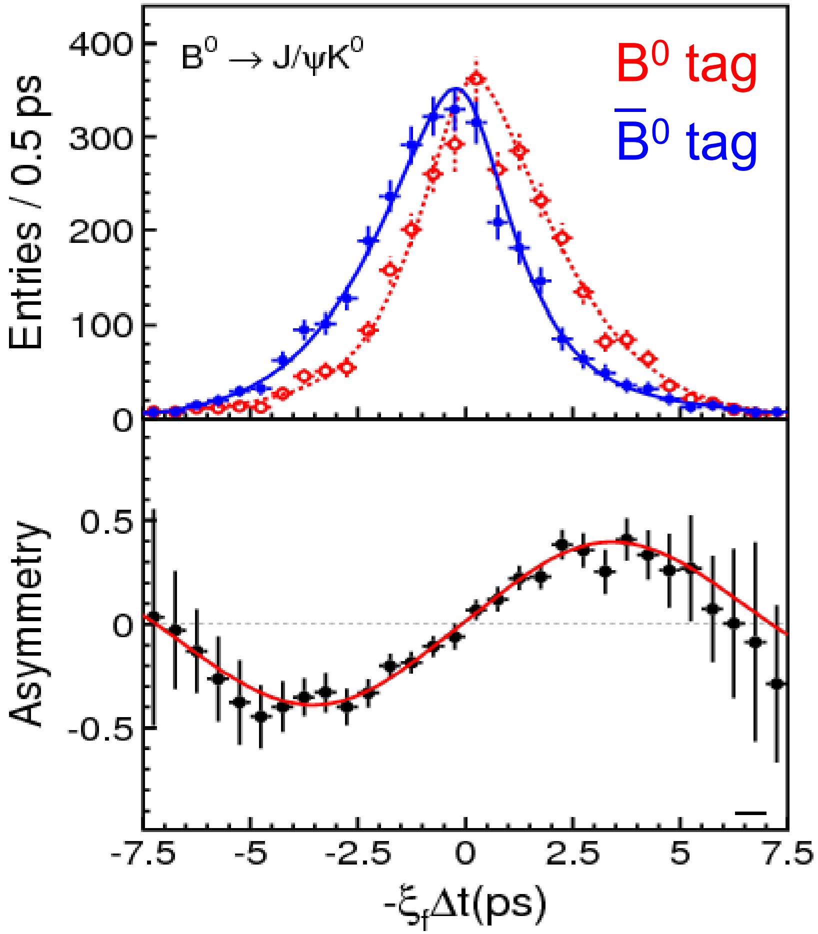
+ an extremely well operating KEK-B collider →

CP violation in the B system

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

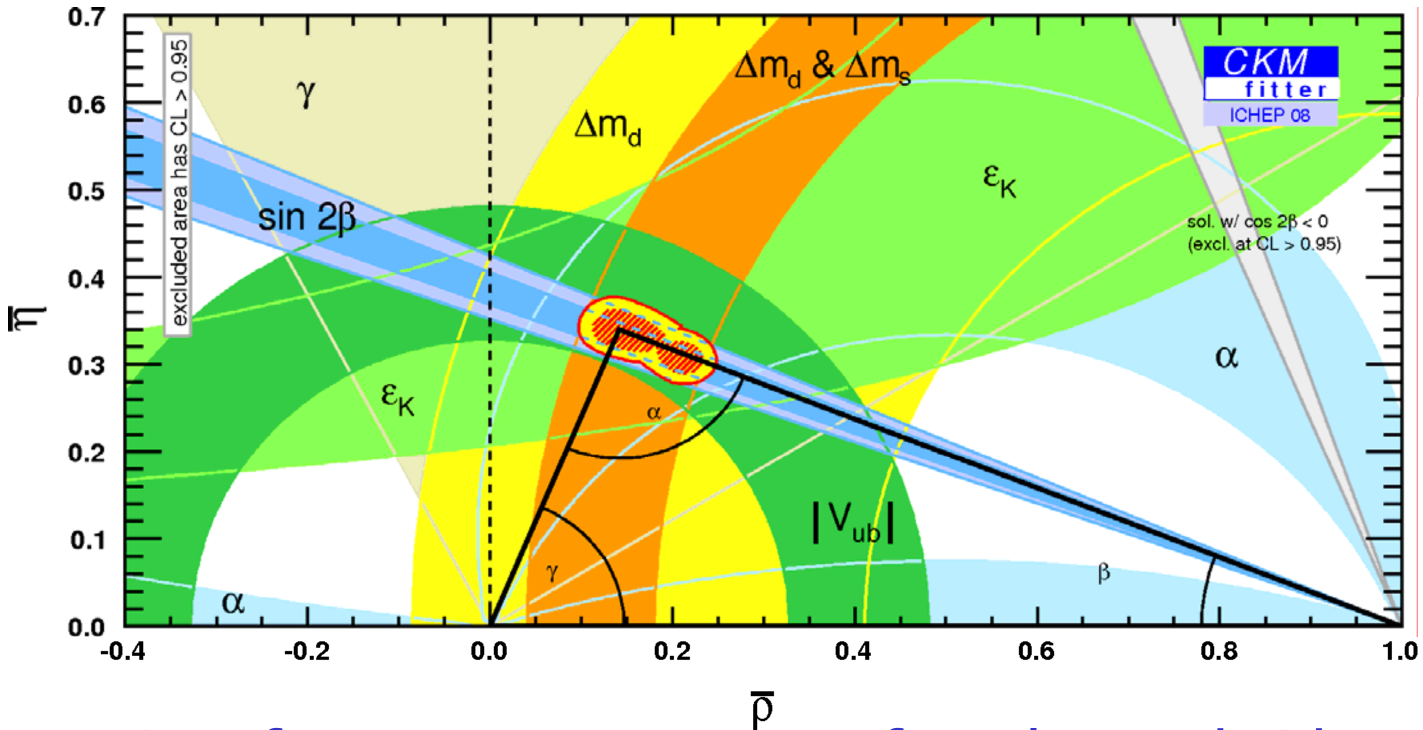
$\sin 2\phi_1 = \sin 2\beta$ from $b \rightarrow c\bar{c}s$

535 M $B\bar{B}$ pairs



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

All measurements combined...

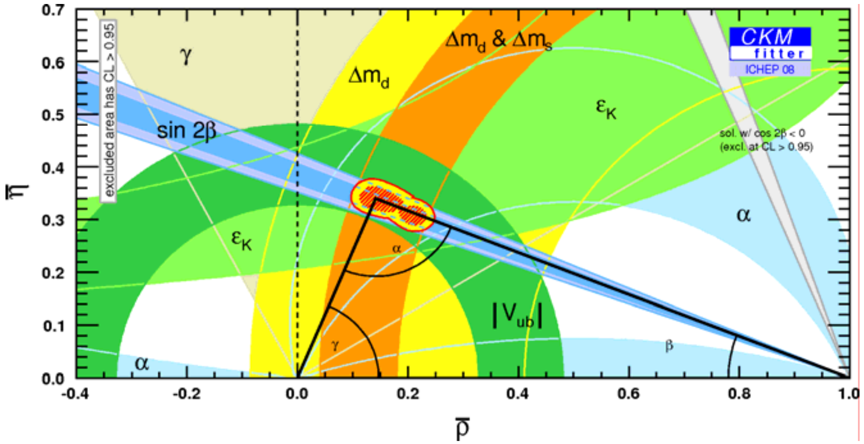


Contraints from measurements of angles and sides of the unitarity triangle

→ Remarkable agreement

Consistent picture

Relations between parameters as expected in the Standard model →



➡ Nobel prize 2008!

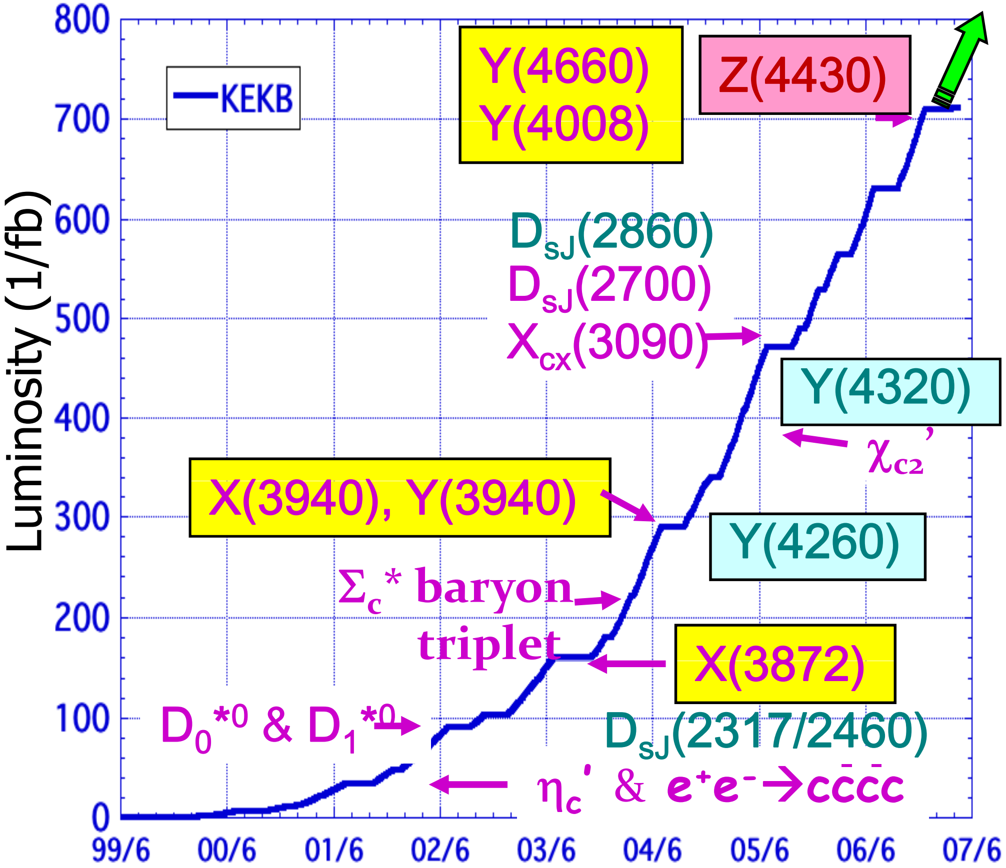
Also for us a good reason to celebrate...

B factories: a success story

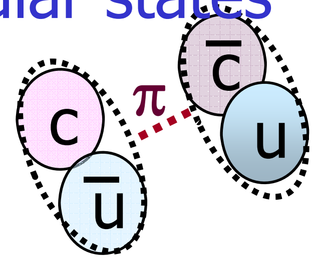
- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., $B \rightarrow \tau\nu$, $D\tau\nu$) by fully reconstructing the other B meson
- Observation of D mixing
- CP violation in $b \rightarrow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

New hadrons at B-factories

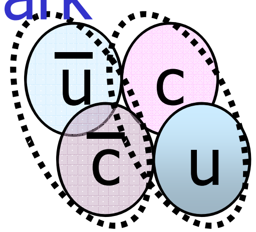
Discoveries of many new hadrons at B-factories have shed light on a new class of hadrons beyond the ordinary mesons.



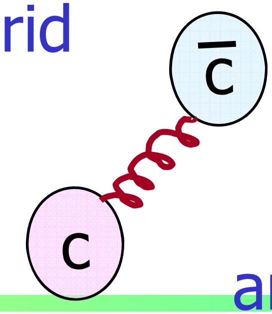
Molecular states



Tetra-quark



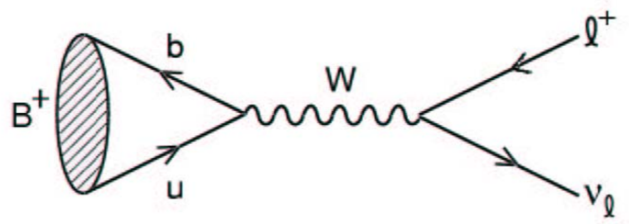
Hybrid



and more...

Purely leptonic decay $B \to \tau\, \nu$

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



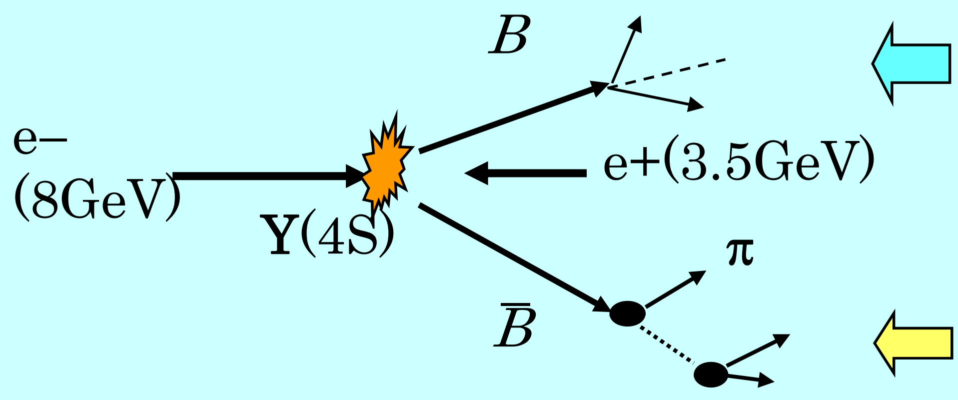
- Branching fraction

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

- 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



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%)

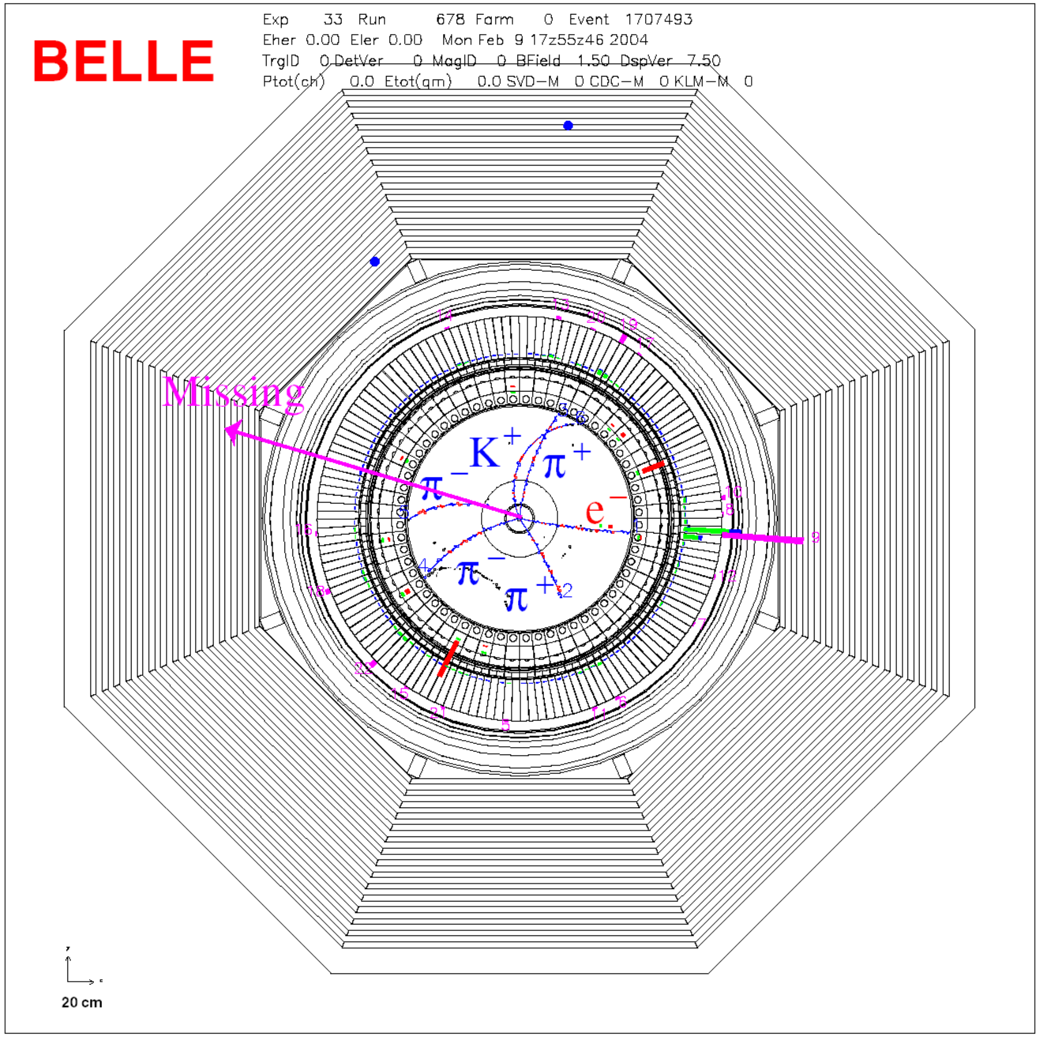
→ Offline B meson beam!

Powerful tool for B decays with several neutrinos

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

$$B^+ \rightarrow D^0 \pi^+ \quad (\rightarrow K\pi^-\pi^+\pi^-)$$

$$B^- \rightarrow \tau(\rightarrow e\nu\bar{\nu})\nu$$



B→τ ν

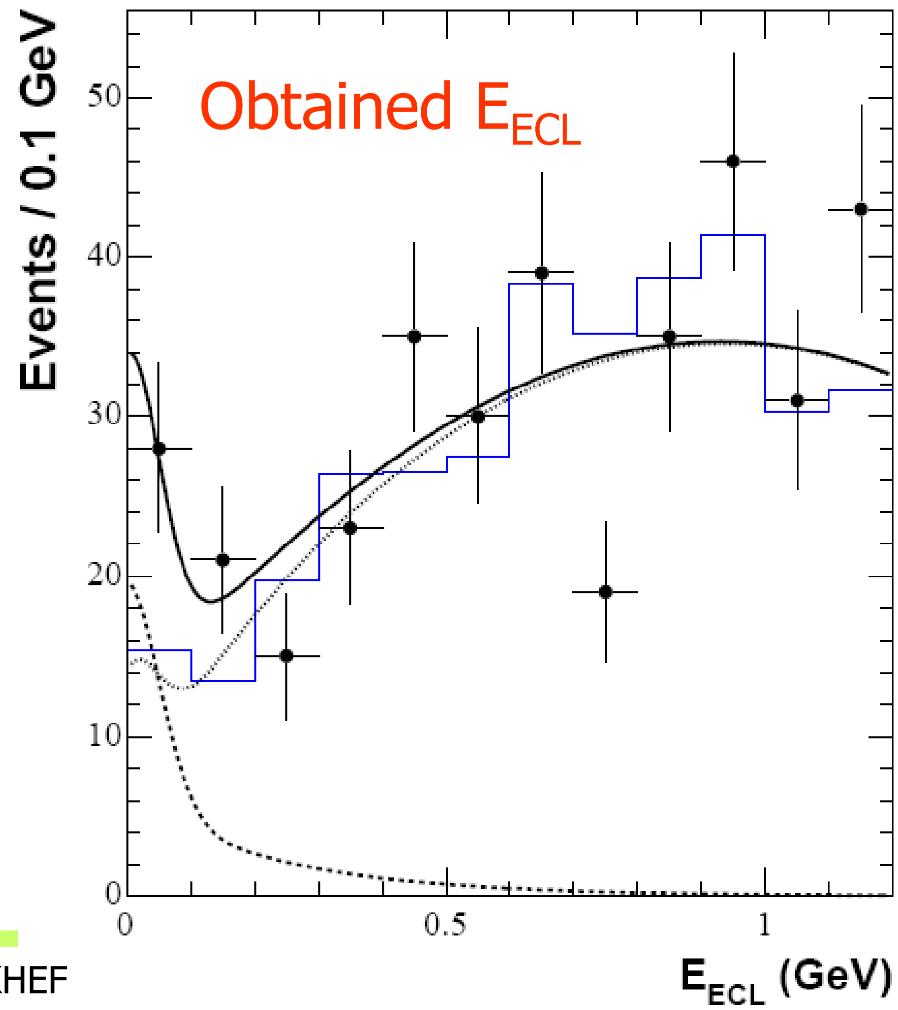
τ decay modes

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

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

- Cover 81% of τ decays
- Efficiency 15.8%

Phys. Rev. Lett. 97, 251802 (2006)



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

Super KEKB Quest for BSM

B → τ ν_τ

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

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

→ 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

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

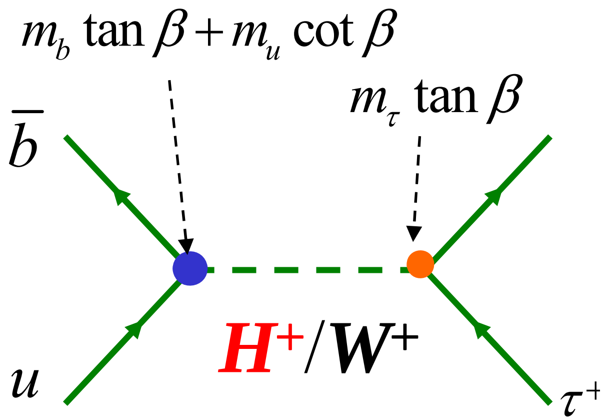
15% 15% = 13%(exp.) + 8%(V_{ub})

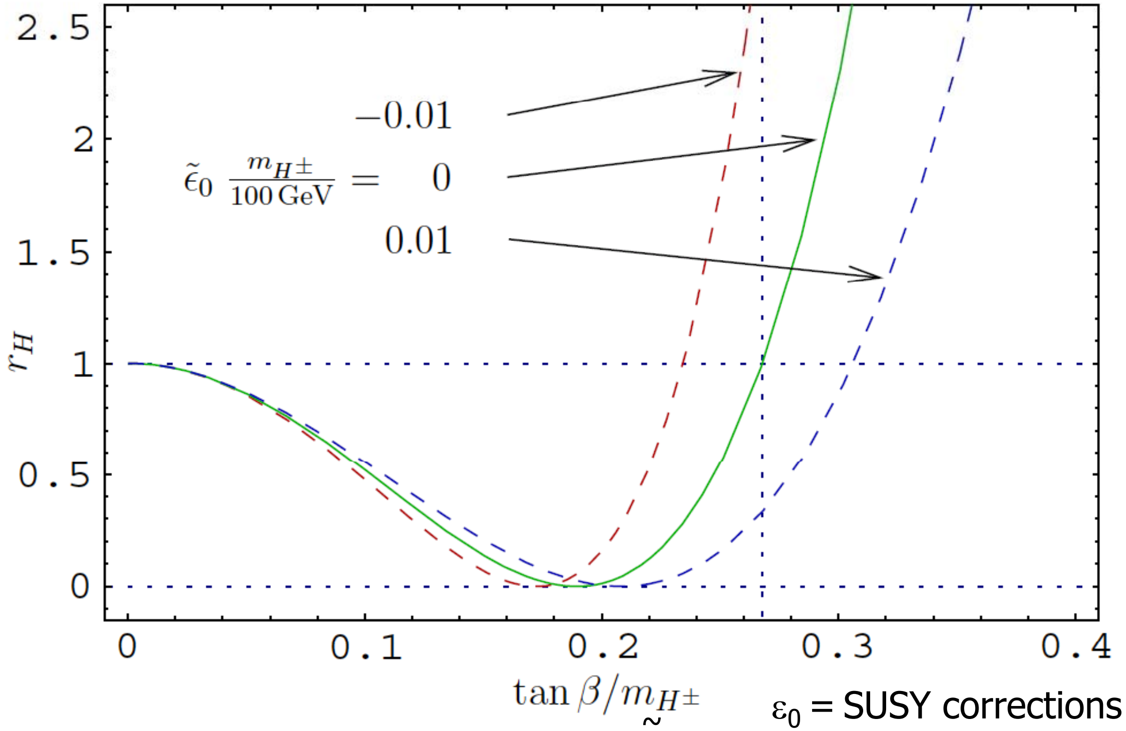
First measurement of f_B!

f_B = (216 ± 22) MeV from unquenched lattice calculation

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

Charged Higgs contribution to B→τ ν





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)

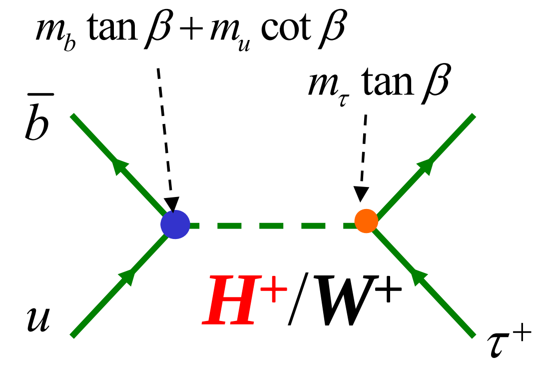
SM: B (B→τν)= ($0.78^{+0.09}_{-0.13}$) x 10^{-4} (CKM fitter 2008 prediction)

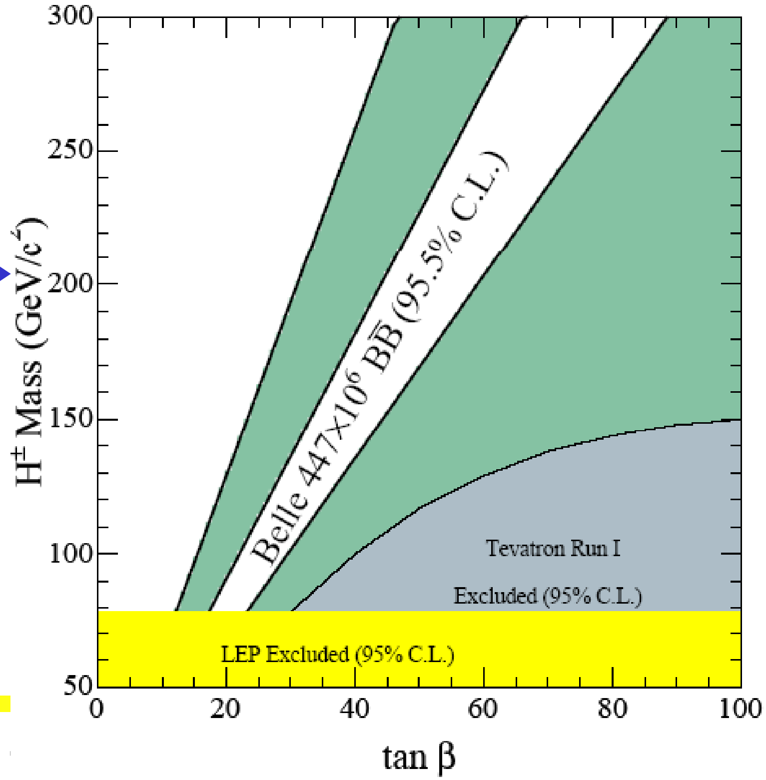
Charged Higgs limits from $B^- \rightarrow \tau^- \nu_\tau$

If the theoretical prediction is taken for f_B

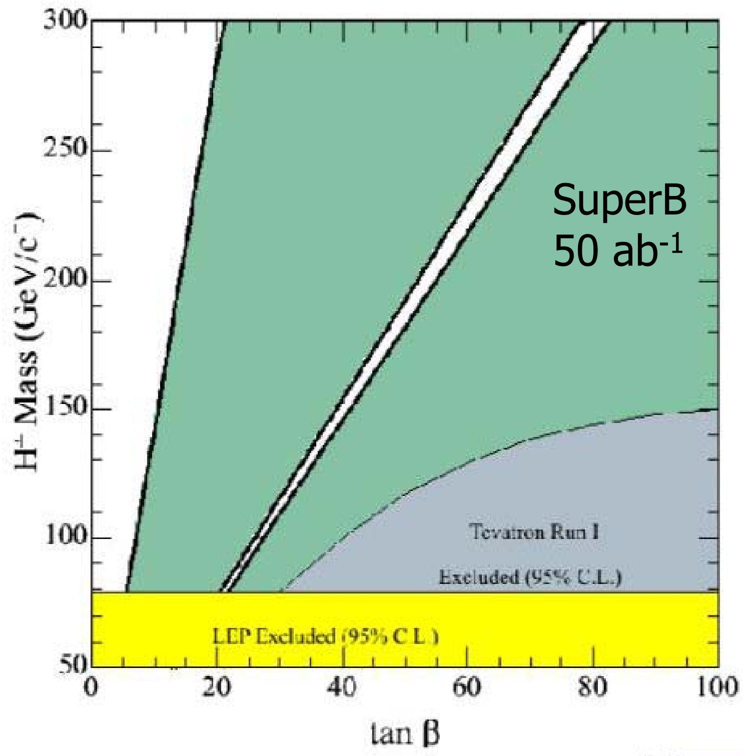
→ limit on charged Higgs mass vs. tanβ

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





EF



New Belle result on $B^+ \to \tau^+ \nu$

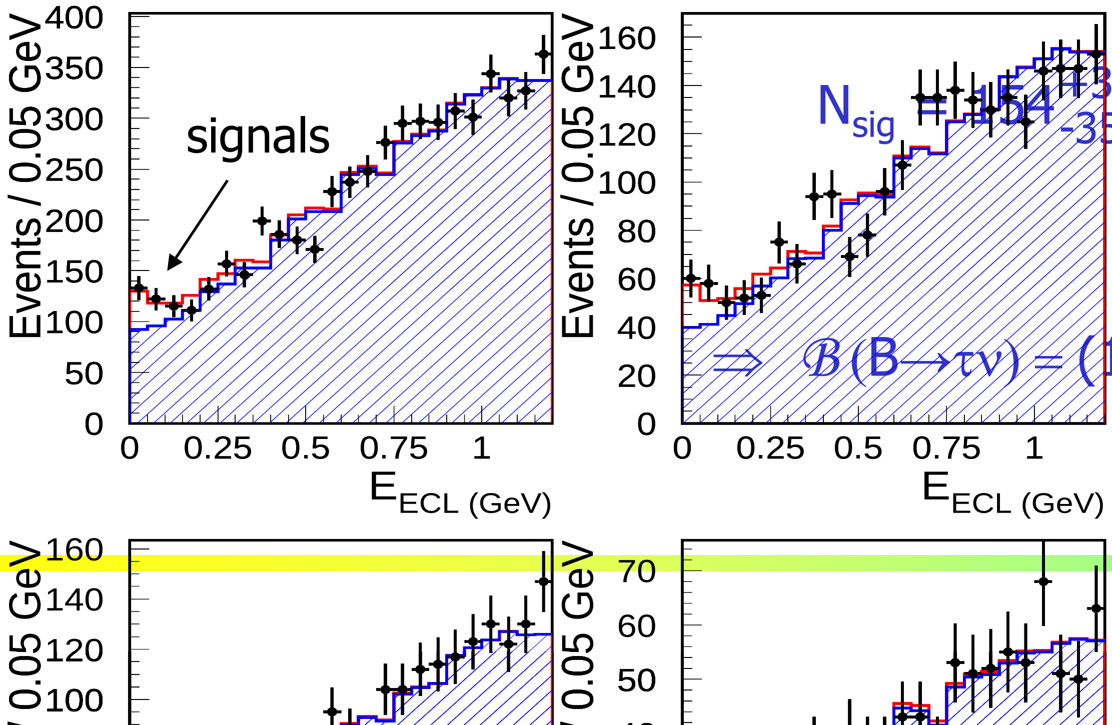
Method: Tag B on one side with the semileptonic decay B → $D^{(*)}$ l ν

→ Neutrino not reconstructed in the tagging B decay sequence → more background than in fully reconstructed hadronic decays

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

NEW with 3.8σ

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



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

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

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

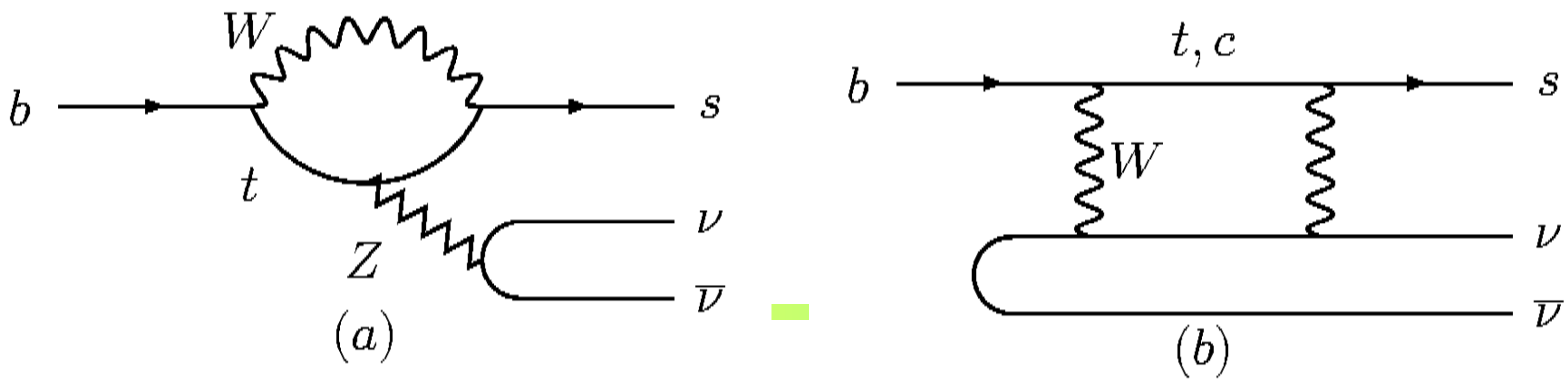
$B \to K^{(*)}\nu\nu$ is a particularly interesting and challenging mode (with $B \to \tau\nu$ as a small background), theoretically clean

Experimental signature: $B \to K$ + nothing

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

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

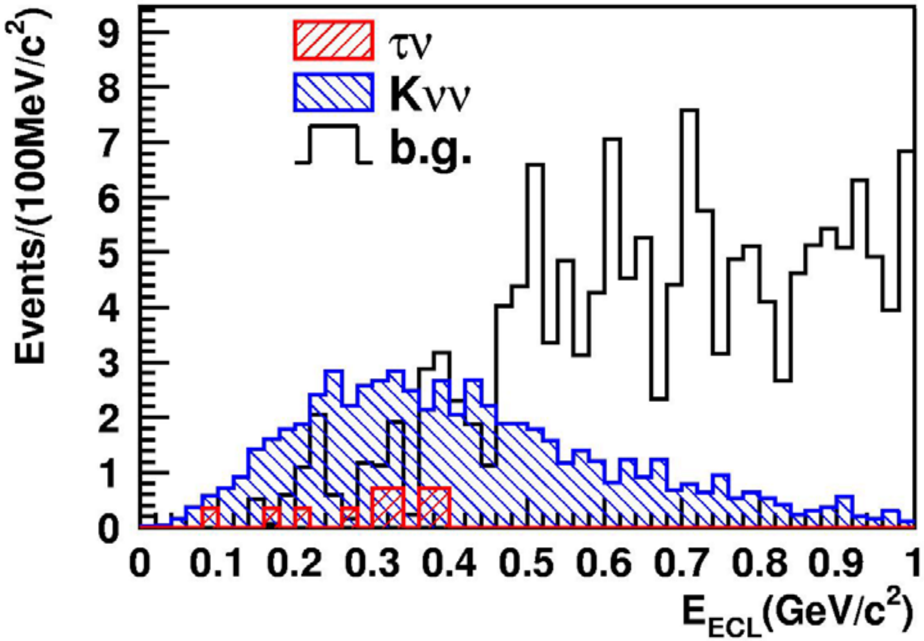
$B \to \tau\nu$ analysis is a proof that such a one prong decay can be studied at a B factory



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

MC extrapolation to 50 ab^{-1}

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



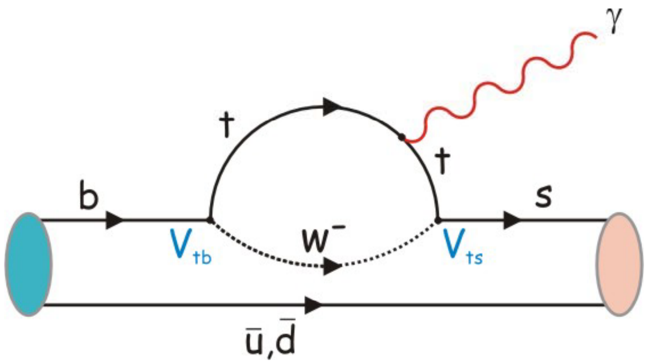
Extra EM calorimeter energy

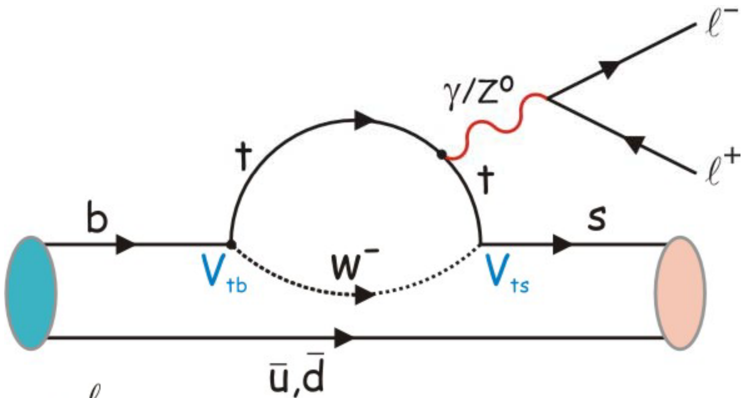
Fig. from SuperKEKB LoI

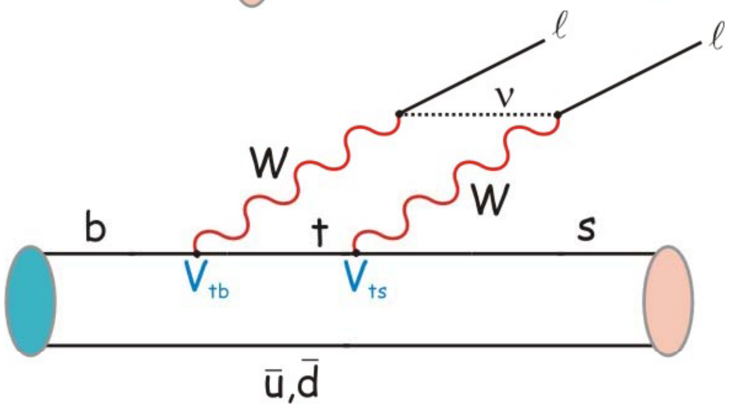
SM prediction:
G.Buchalla, G.Hiller, G.Isidori
(PRD 63 014015)

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.



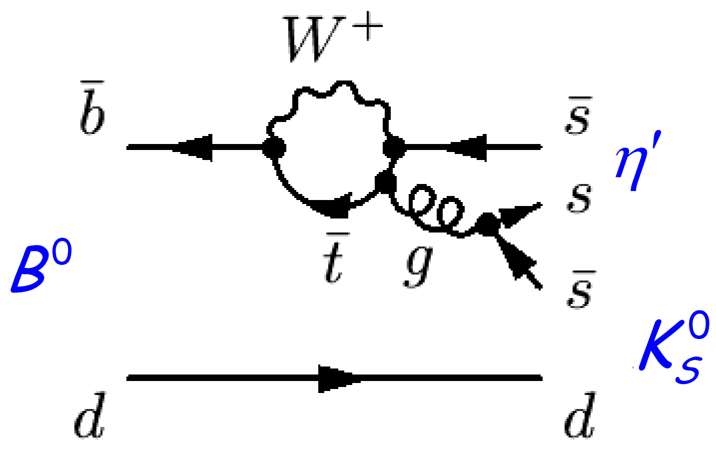




How can New Physics contribute to b→s?

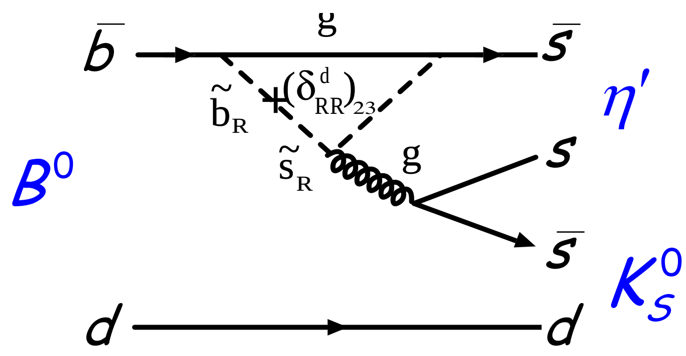
For example in the process:

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



Ordinary penguin diagram with a t quark in the loop

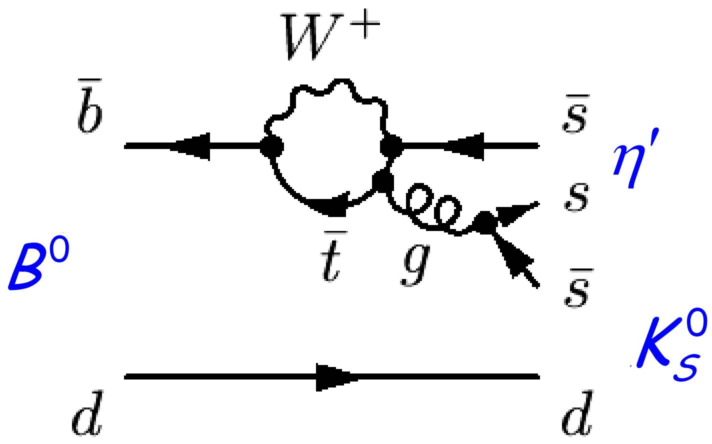
Diagram with supersymmetric particles



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

Prediction in SM:

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



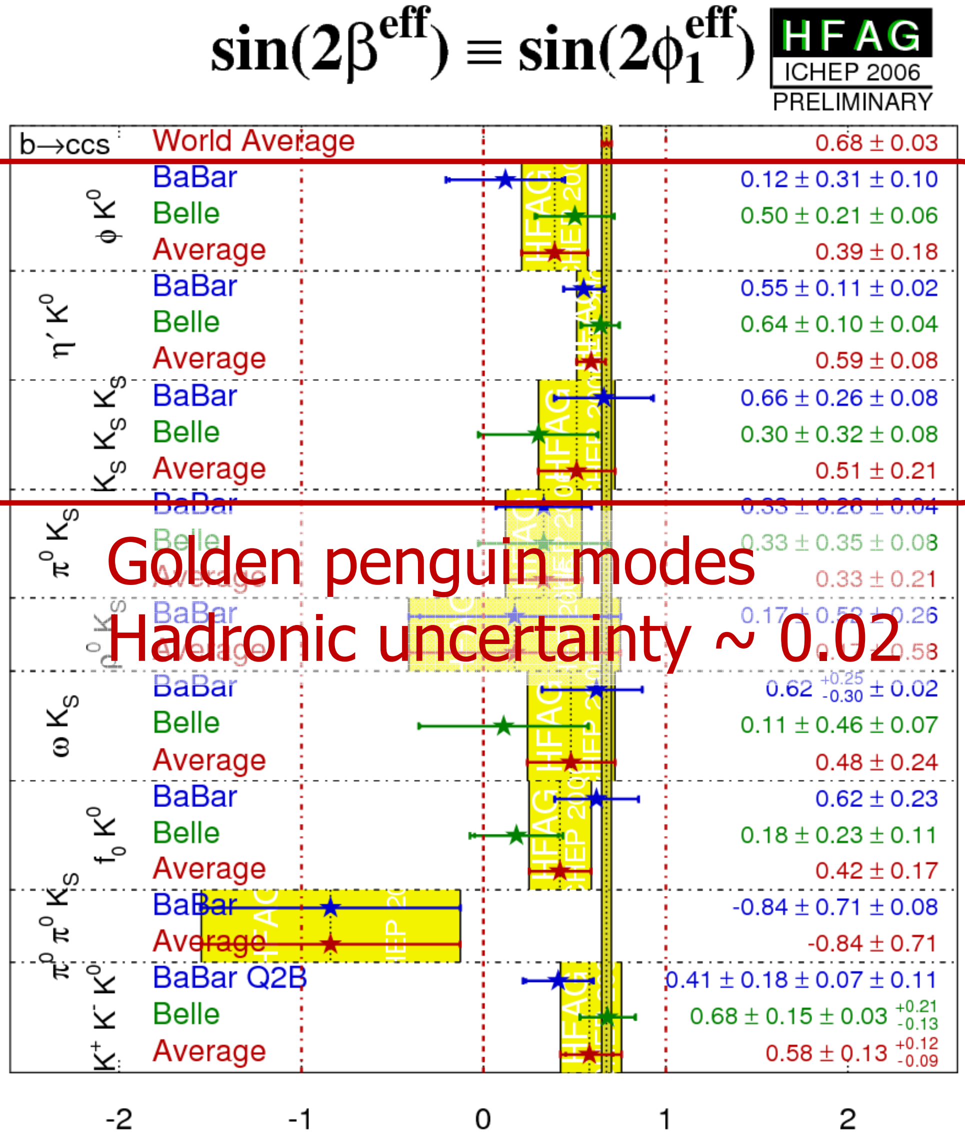
$$a_f = -\text{Im}(\lambda_f)\sin(\Delta m t)$$

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

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 $\sin 2\phi_1^{\text{eff}}$

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



Golden penguin modes

Hadronic uncertainty ~ 0.02

ICHEP08

BaBar
Belle
Naïve average

$0.26 \pm 0.25 \pm 0.04$
$0.67 \pm {}^{0.25}_{0.27} \pm 0.07$
0.45 ± 0.18

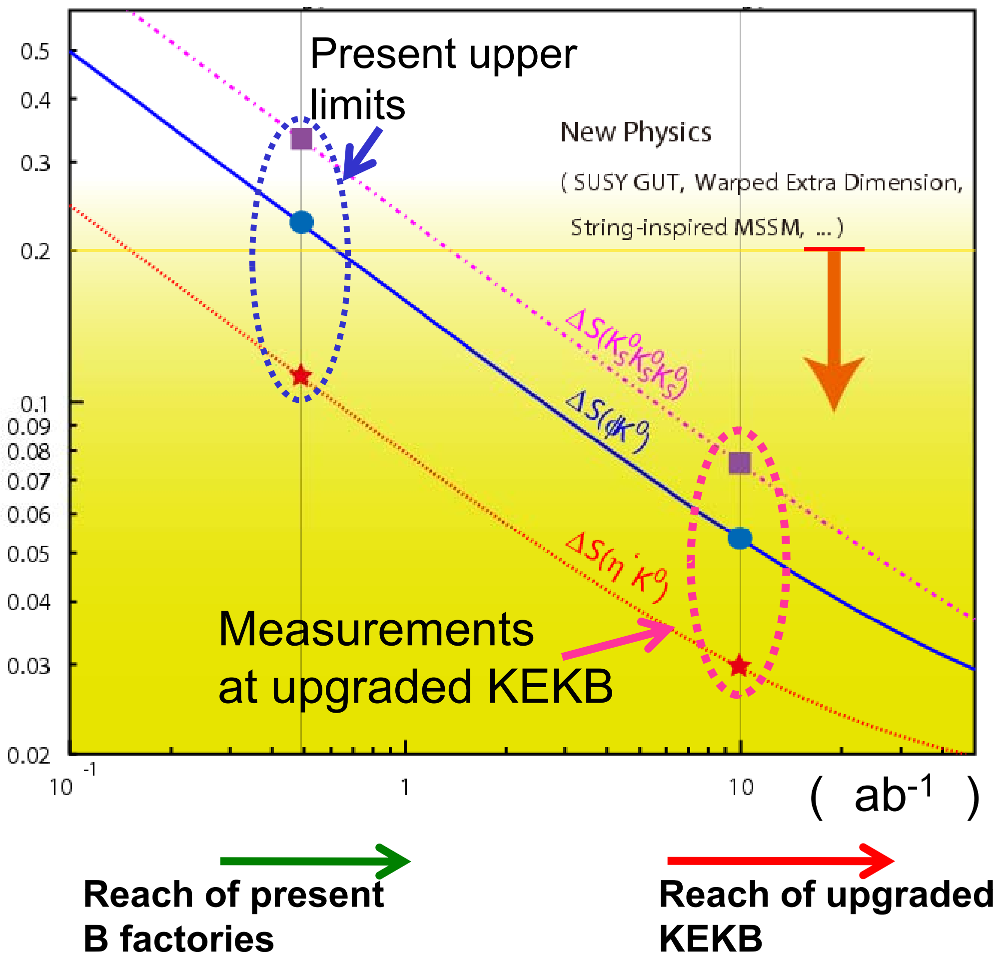
$0.57 \pm 0.08 \pm 0.02$
$0.64 \pm 0.10 \pm 0.04$
0.60 ± 0.07

$0.71 \pm 0.24 \pm 0.04$
$0.30 \pm 0.32 \pm 0.08$
0.57 ± 0.20

Need much more data to clarify the issue

Searches for new sources of quark mixing and CP violation

CP asymmetries of penguin dominated B decays



Deviation from SM

↓

New source of CP violation

↓

Relevant to baryogenesis?

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

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

Difference between B^+ and B^0 decays

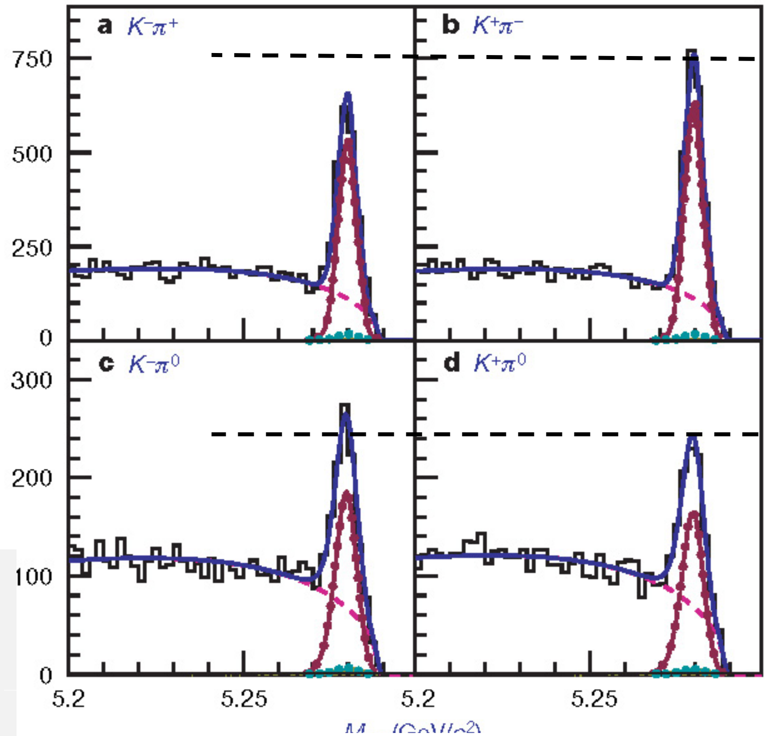
In SM expect $\mathcal{A}_{K^\pm\pi^\mp} \approx \mathcal{A}_{K^\pm\pi^0}$

Measure:

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

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

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

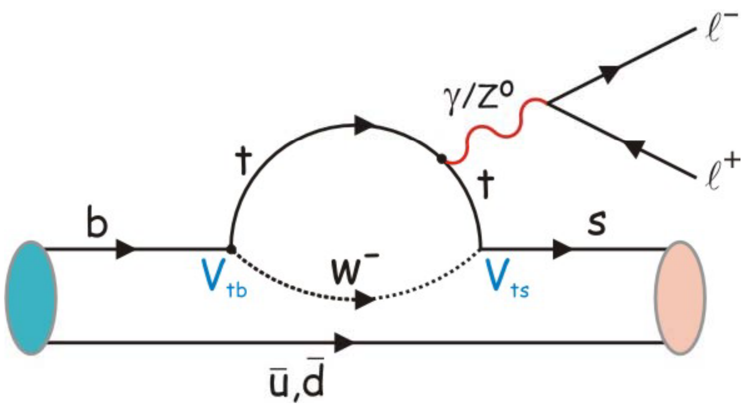


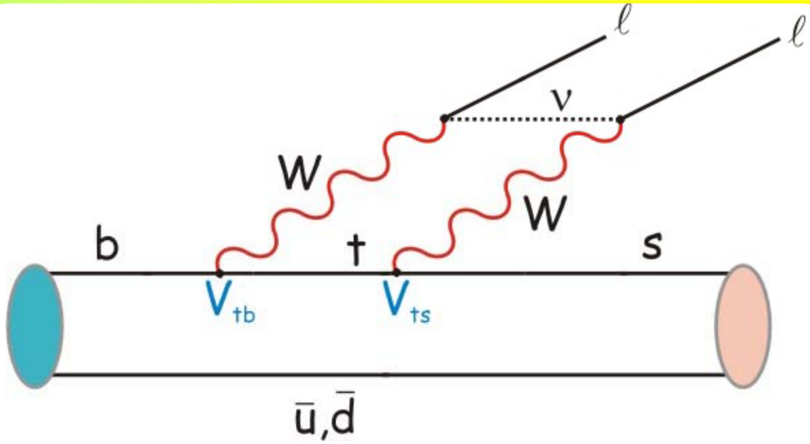
A problem for a SM explanation
(in particular when combined with other measurements)
A hint for new sources of CP violation?

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

Belle, Nature 452, 332 (2008)

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





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

Important for further searches for physics beyond the SM

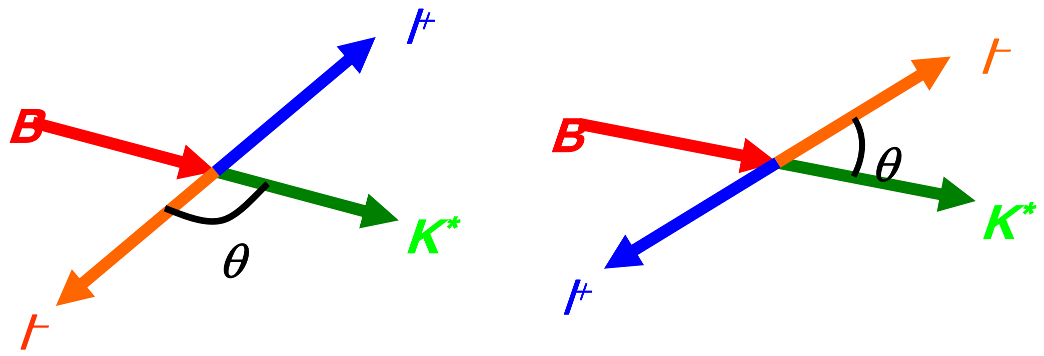
Particularly sensitive: backward-forward asymmetry in $K^*\ l^+l$

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

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

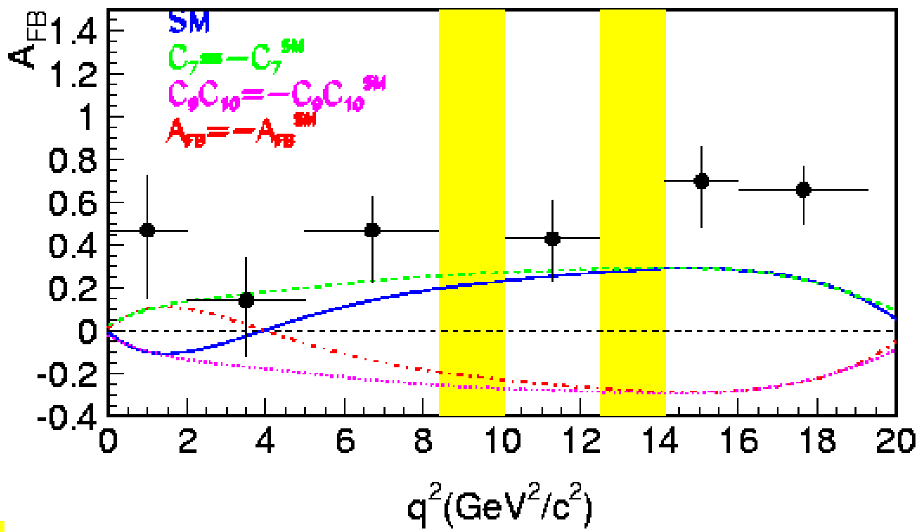
s=lepton pair mass squared

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



Backward event | Forward event

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

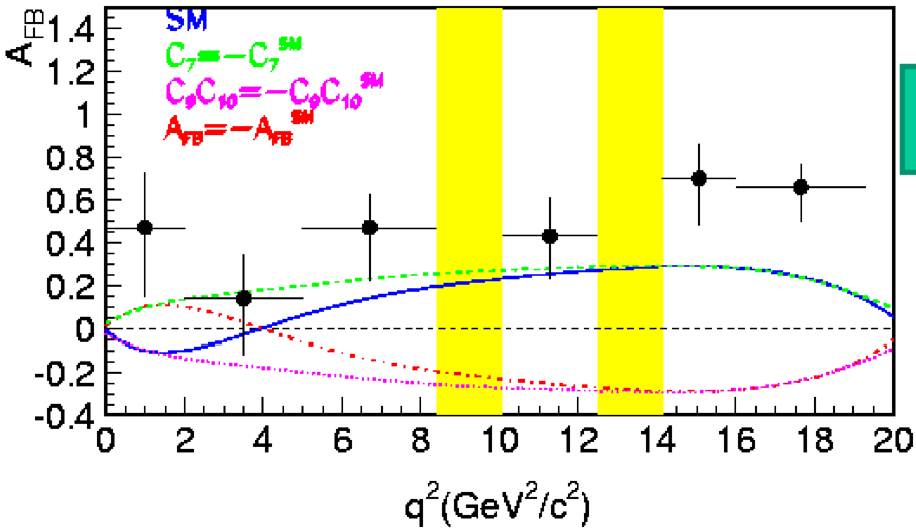


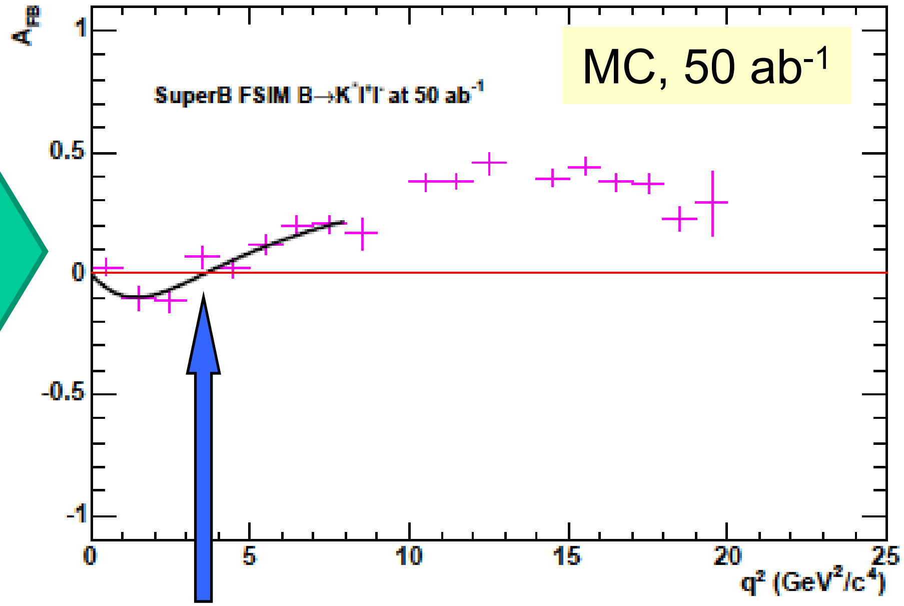
657 M BB

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

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

657 M BB





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

Strong competition from LHCb and ATLAS/CMS

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

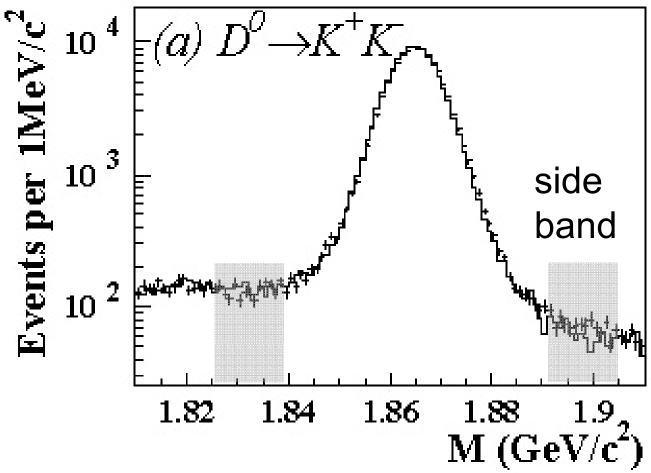
Two mixing parameters:

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

$x=\Delta m/\Gamma$ $\quad$ $y=\Delta\Gamma/2\Gamma$

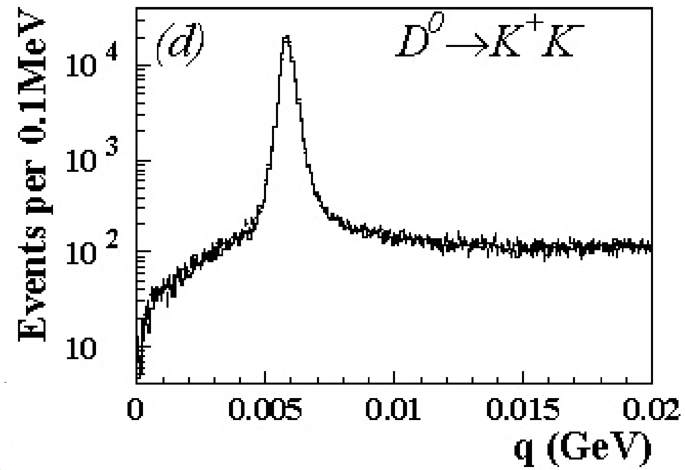
$D^0 \to K^+K^- / \pi^+\pi^-$: CP even final state;
in the limit of no CPV: $CP|D_1\rangle = |D_1\rangle$
$\Rightarrow$ measure $1/\Gamma_1$

$$y_{CP} \equiv \frac{\tau(K^-\pi^+)}{\tau(K^-K^+)} - 1 \underset{no\,CPV}{=} y$$



Signal: $D^0 \to K^+K^- / \pi^+\pi^-$ from D^*
M, Q, σ_t selection optimized in MC

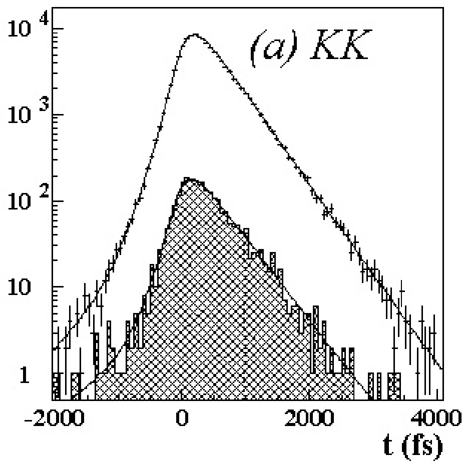
	K^+K^-	$K^-\pi^+$	$\pi^+\pi^-$
N_{sig}	111×10^3	1.22×10^6	49×10^3
purity	98%	99%	92%



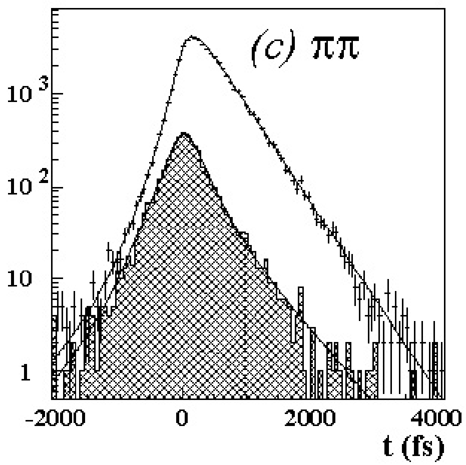
PRL 98, 211803 (2007), $540 fb^{-1}$

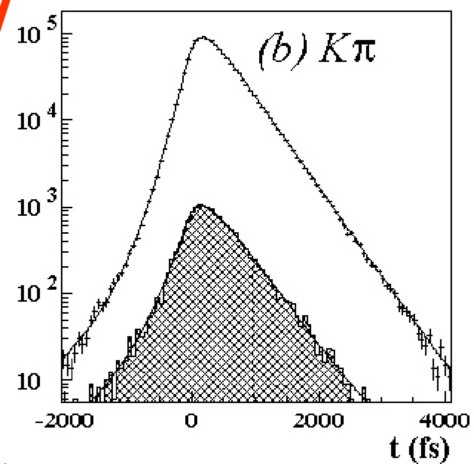
D^0 mixing in K^+K^-, $\pi^+\pi^-$

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

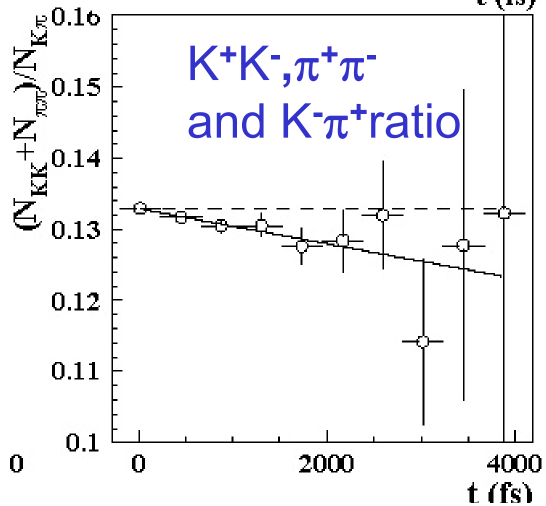


+





Difference of lifetimes
visually observable
in the ratio of the distributions →
Real fit:



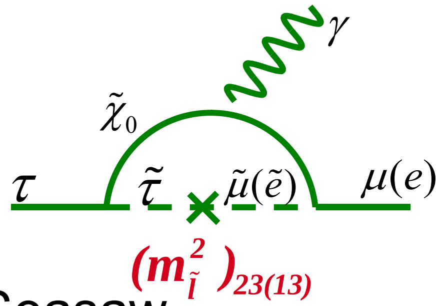
y_{CP} = (1.31 ± 0.32 ± 0.25) %

evidence for D^0 mixing
(regardless of possible CPV)

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

LFV and New Physics

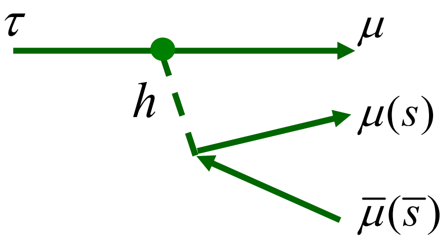
$\tau \rightarrow l\gamma$



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

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

$\tau \rightarrow 3l, l\eta$



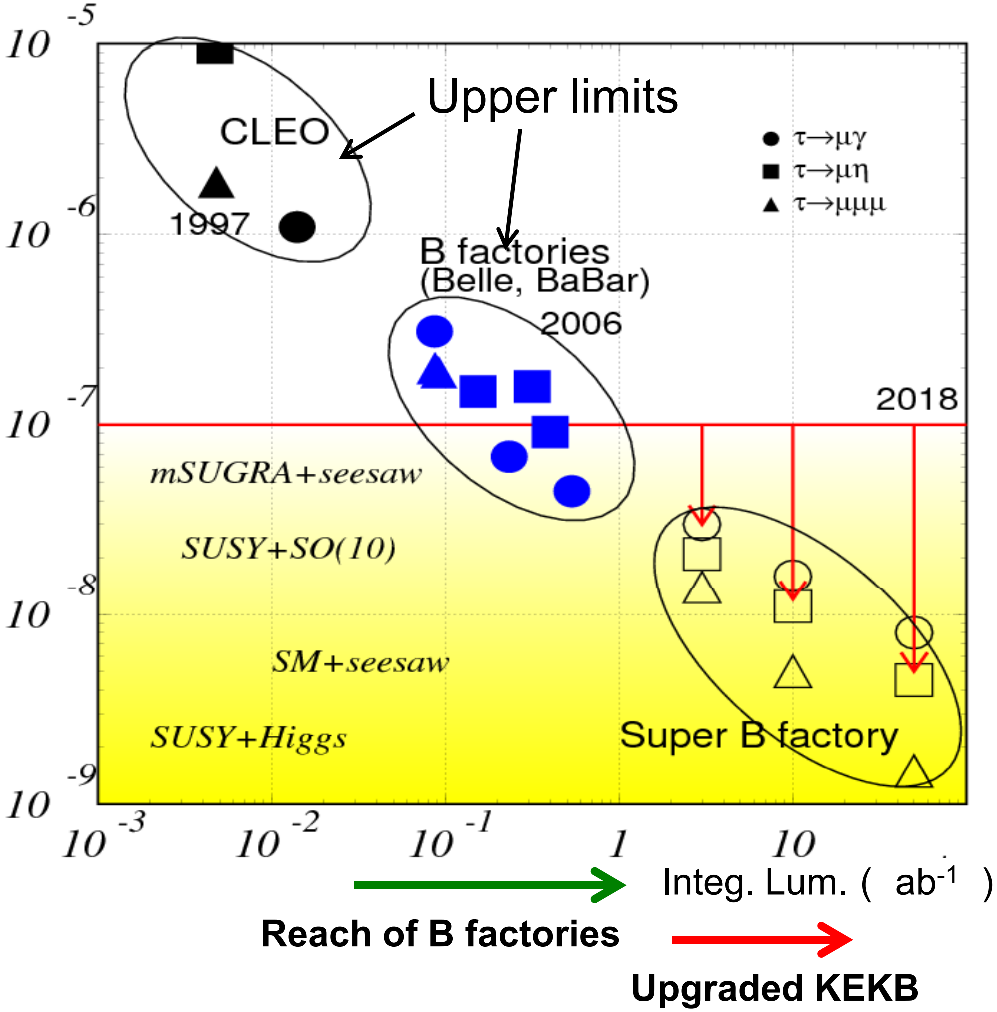
- Neutral Higgs mediated decay.
- Important when MSUSY >> EW scale.

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

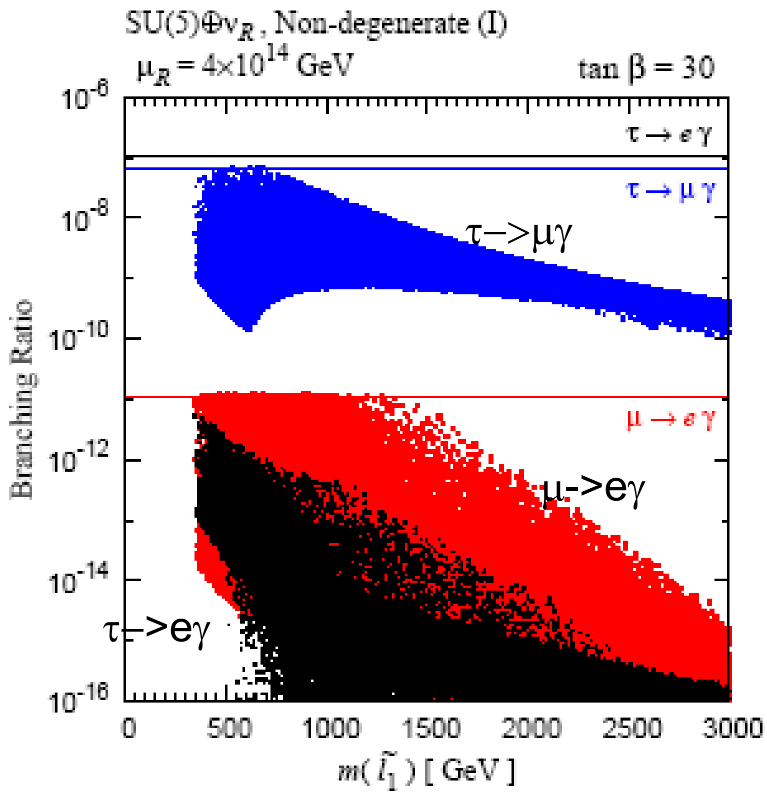
model	$Br(\tau \rightarrow \mu\gamma)$	$Br(\tau \rightarrow lll)$
mSUGRA+seesaw	10^{-7}	10^{-9}
SUSY+SO(10)	10^{-8}	10^{-10}
SM+seesaw	10^{-9}	10^{-10}
Non-Universal Z'	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-7}

Precision measurements of τ decays

LF violating τ decay?



Theoretical predictions compared to present experimental limits



T.Goto et al., 2007

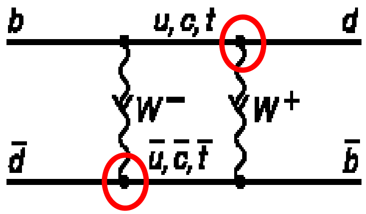
Physics at a Super B Factory

- 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

- A lesson from history: the top quark

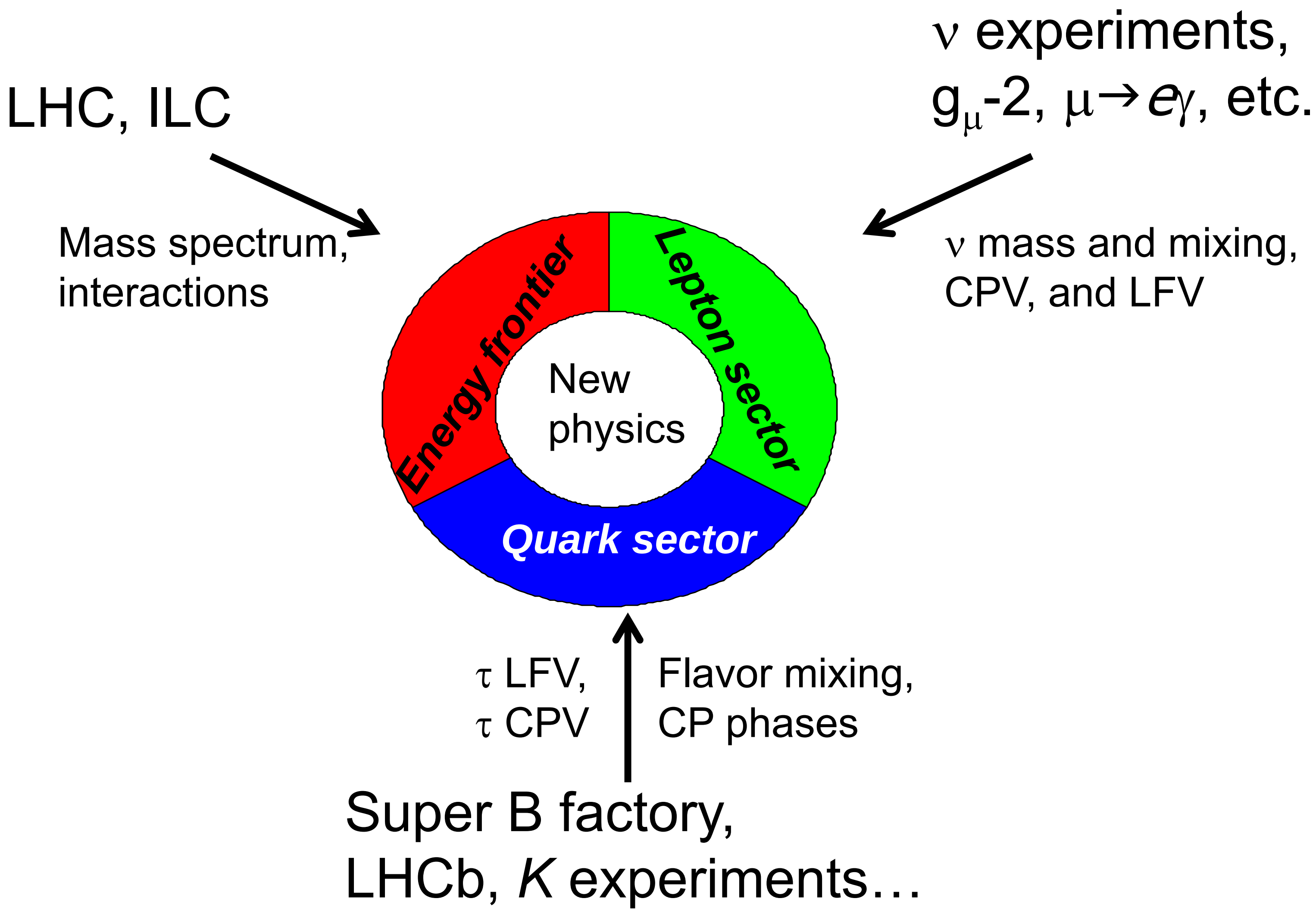
<u>Physics of top quark</u>
First estimate of mass: BB mixing → ARGUS
Direct production, Mass, width etc. → CDF/D0
Off-diagonal couplings, phase → BaBar/Belle



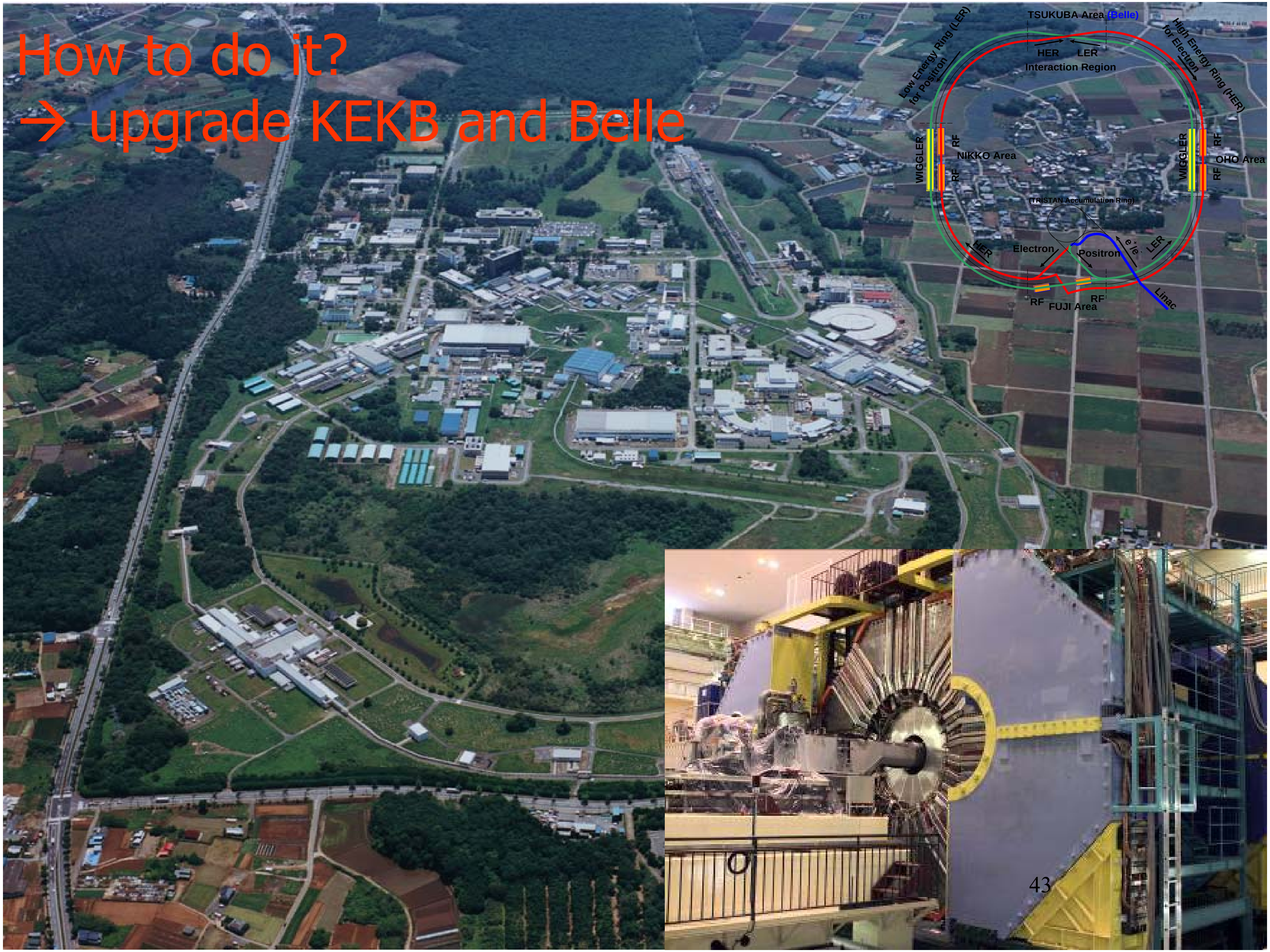
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

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

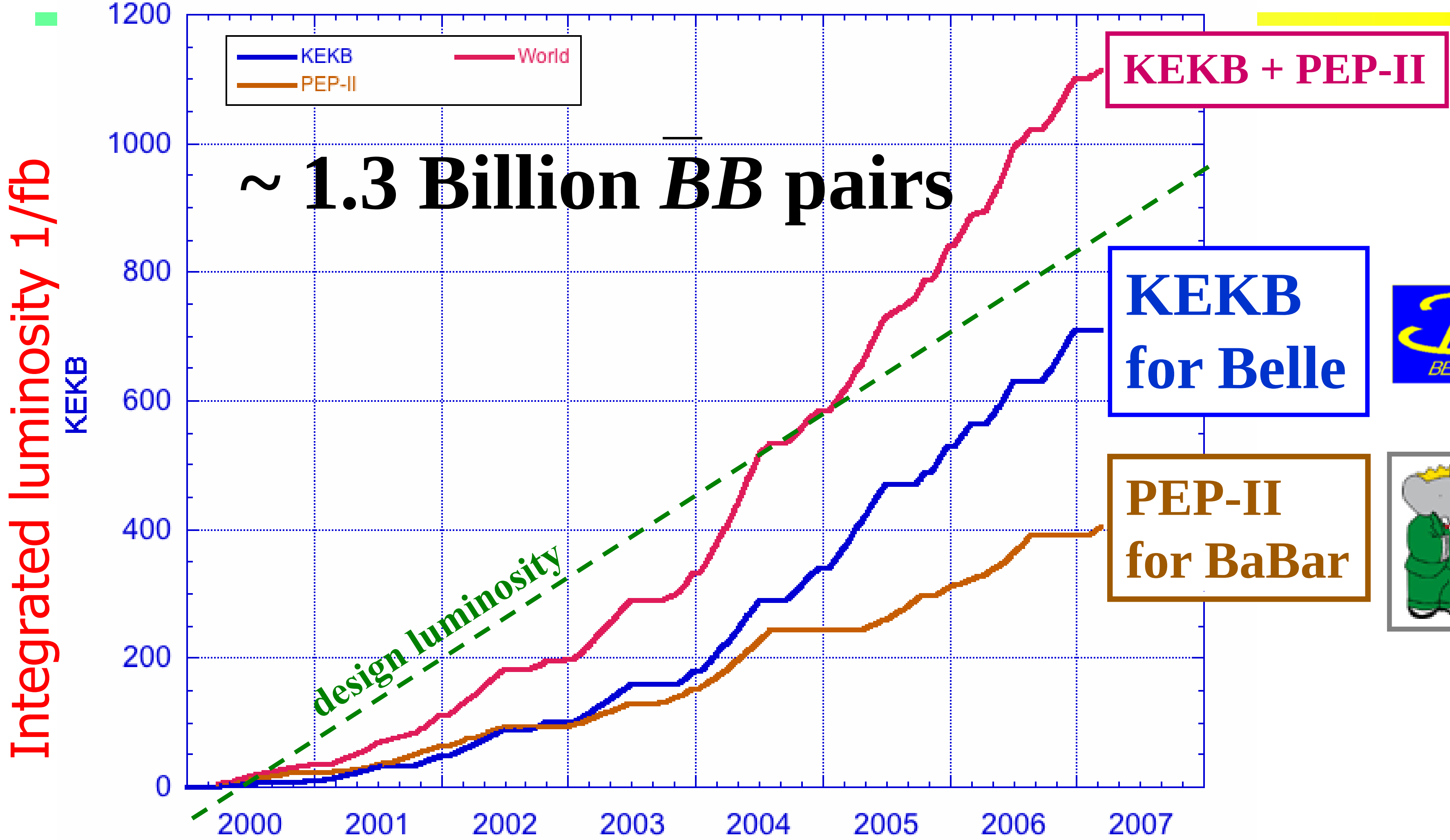
Super B factory: an important part of a broad unbiased approach to New Physics

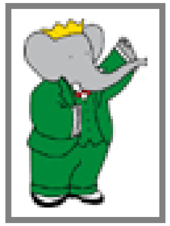


How to do it?
→ upgrade KEKB and Belle



Track Record

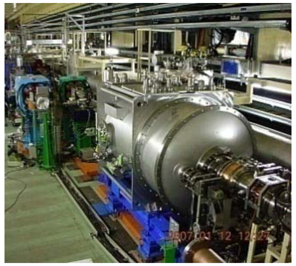


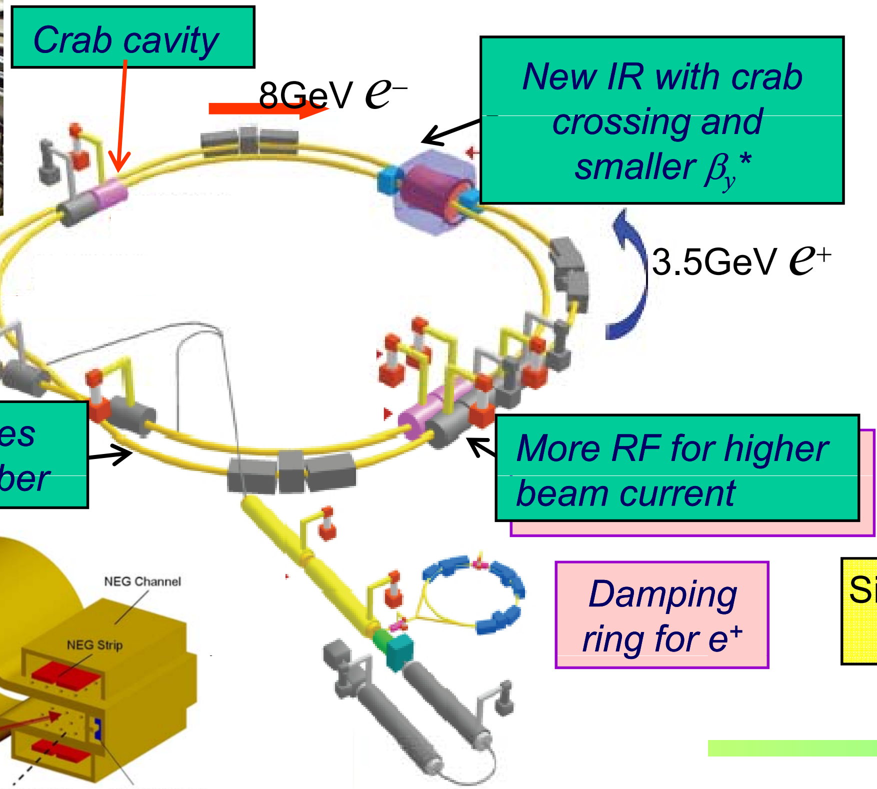


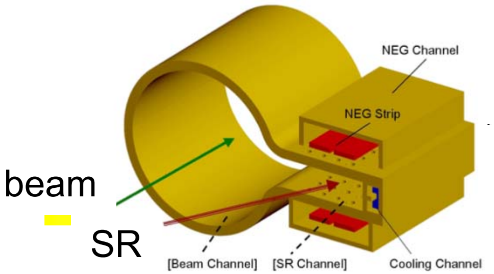
L_{peak} (KEKB) = 1.96 x 10^{34}/cm^2/sec (design 1.0)

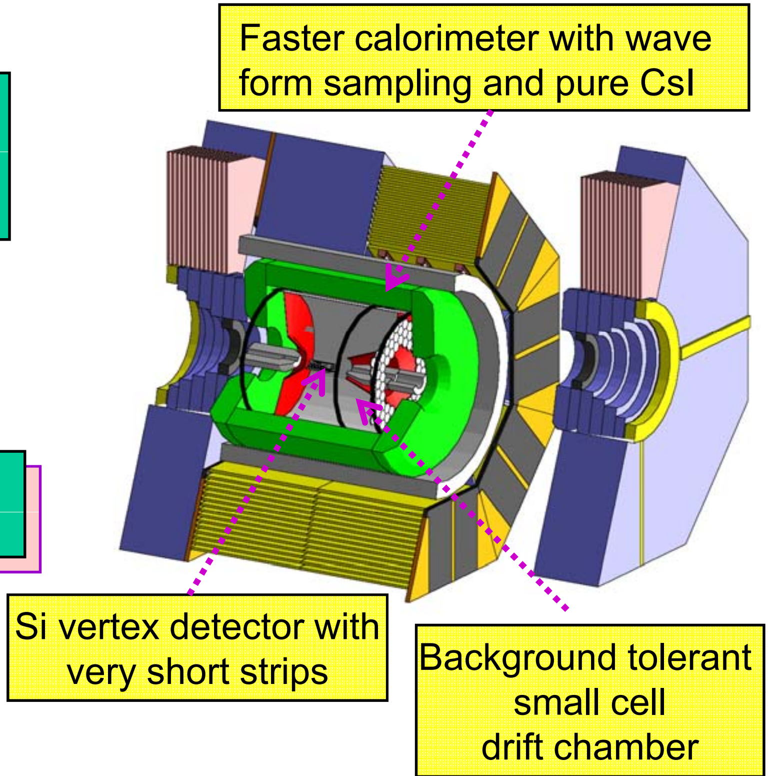
KEKB Upgrade Plan : Super-B Factory at KEK

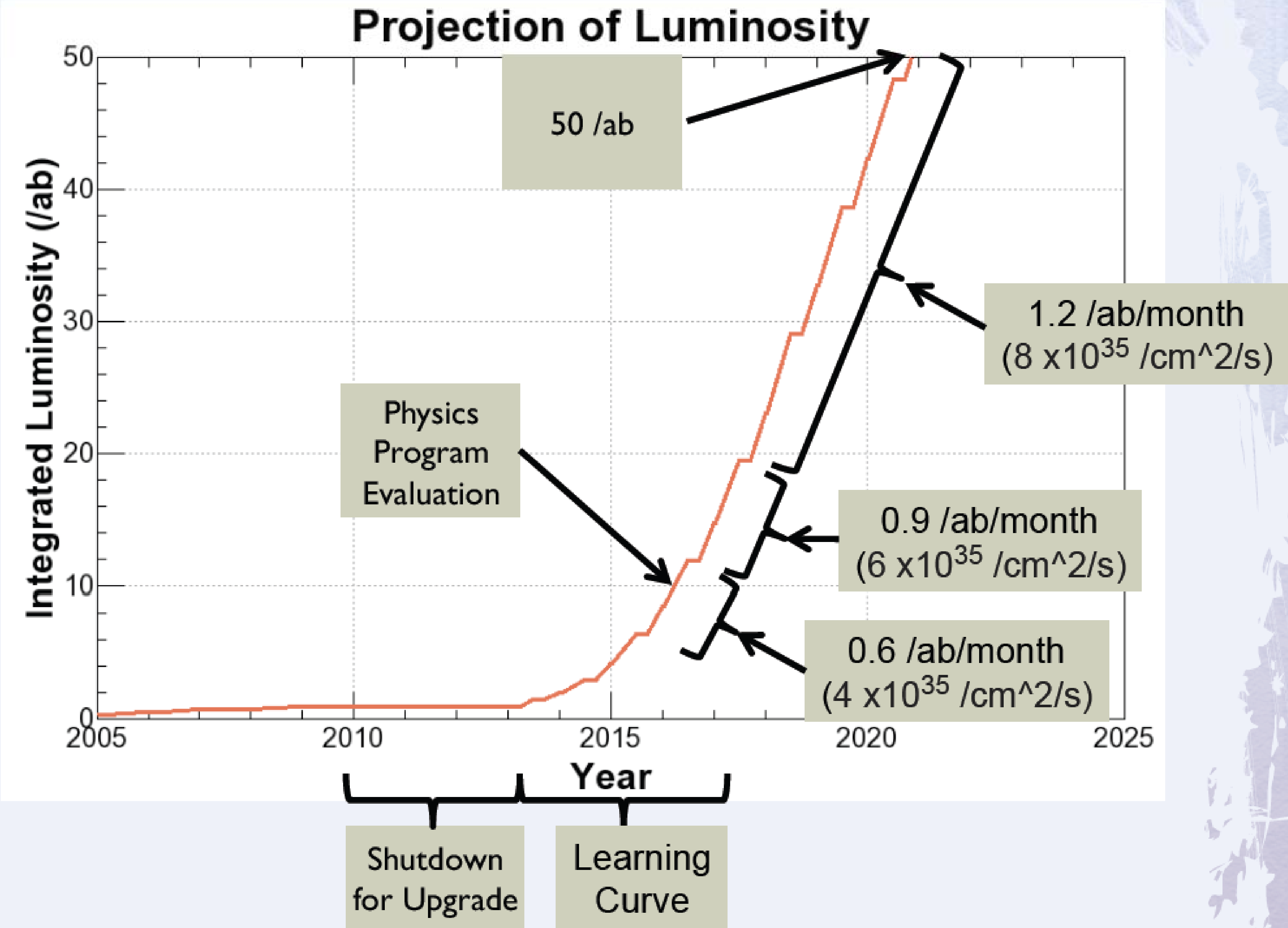
- *Asymmetric energy e^+e^- collider at $E_{CM}=m(\Upsilon(4S))$ to be realized by upgrading the existing KEKB collider.*
- *Initial target:* *10×higher luminosity* $\cong 2\times10^{35}$/cm²/sec after 3 year shutdown
  $\rightarrow 2\times10^{9}\ B\bar{B}$ *and* $\tau^+\tau^-$ *per yr.*
- *Final goal:* $L=8\times10^{35}$/cm²/sec *and* $\int L\,dt = 50\ ab^{-1}$











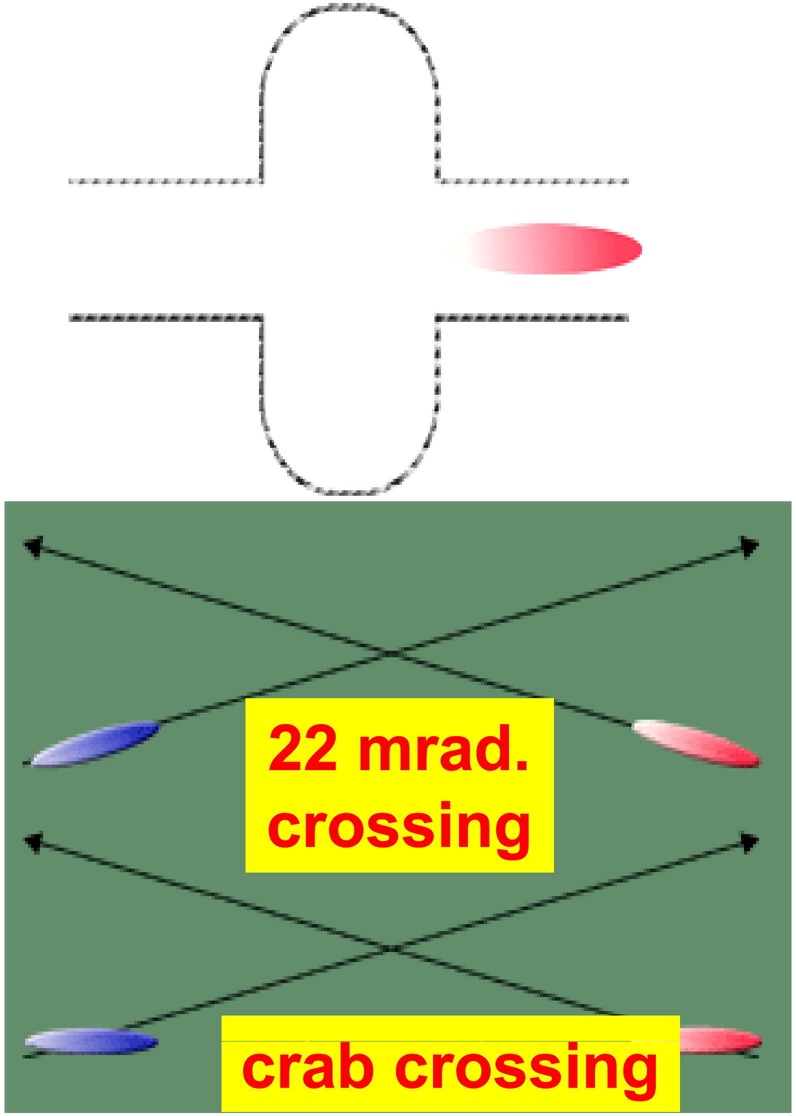
Projection of Luminosity
Integrated Luminosity (/ab)
0
10
20
30
40
50
2005
2010
2015
2020
2025
Year
50 /ab
Physics Program Evaluation
1.2 /ab/month
(8 x10^35 /cm^2/s)
0.9 /ab/month
(6 x10^35 /cm^2/s)
0.6 /ab/month
(4 x10^35 /cm^2/s)
Shutdown for Upgrade
Learning Curve

Luminosity gain and upgrade items (preliminary)

3 years shutdown

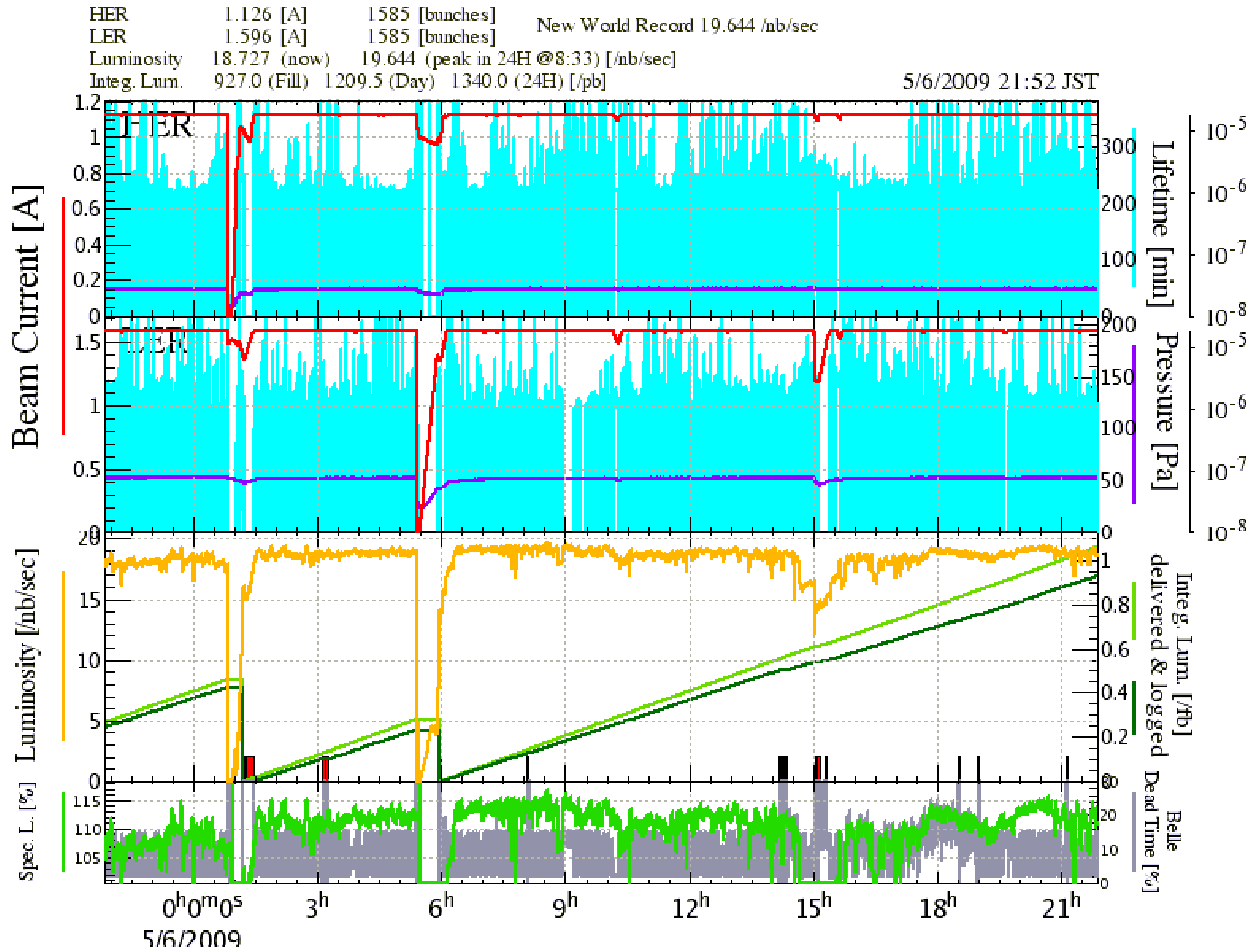
Item	Gain	Purpose
beam pipe	x 1.5	high current, short bunch, electron cloud
IR($\beta^*_{x/y}$=20cm/3 mm)	x 1.5	small beam size at IP
low emittance(12 nm) & $\nu_x \rightarrow 0.5$	x 1.3	mitigate nonlinear effects with beam-beam
crab crossing	x 2	mitigate nonlinear effects with beam-beam
RF/infrastructure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

Crab cavity commissioning



Installed in the KEKB tunnel
(February 2007)

Crab cavity commissioning: finally success, new world record 1.96 10^{34} cm^{-2} s^{-1}



Design Options: high current or nano-beam

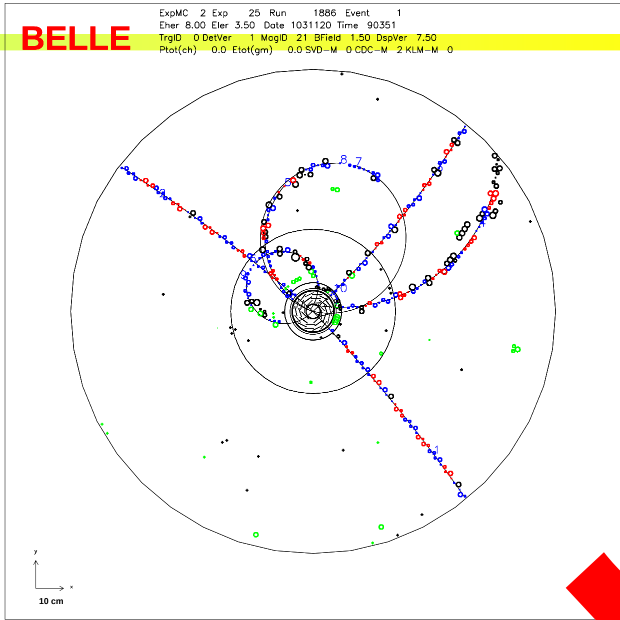
	KEKB Design	KEKB Achieved (): with crab	SuperKEKB High-Current Option	SuperKEKB Nano-Beam Option
β_y^* (mm)(LER/HER)	10/10	6.5/5.9 (5.9/5.9)	3/6	0.22/0.22
ε_x (nm)	18/18	18(15)/24	24/18	1/1
σ_y(μm)	1.9	1.1	0.85/0.73	**0.034/0.044**
ξ_y	0.052	0.108/0.056 (0.101/0.096)	**0.3/0.51**	0.07/0.07
σ_z (mm)	4	~ 7	5(LER)/3(HER)	6
I_{beam} (A)	2.6/1.1	**1.8/1.45** (1.6/1.1)	**9.4/4.1**	**2.96/1.70**
$N_{bunches}$	5000	~1600	5000	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	1.76 (1.93)	53	80

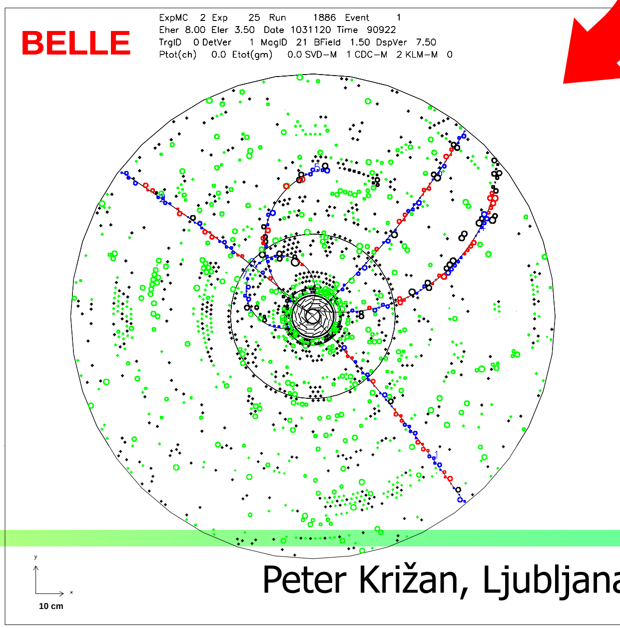
Nano-beam scheme: proposed by P. Raimondi et al., for use at the Frascati Super B Factory.

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”

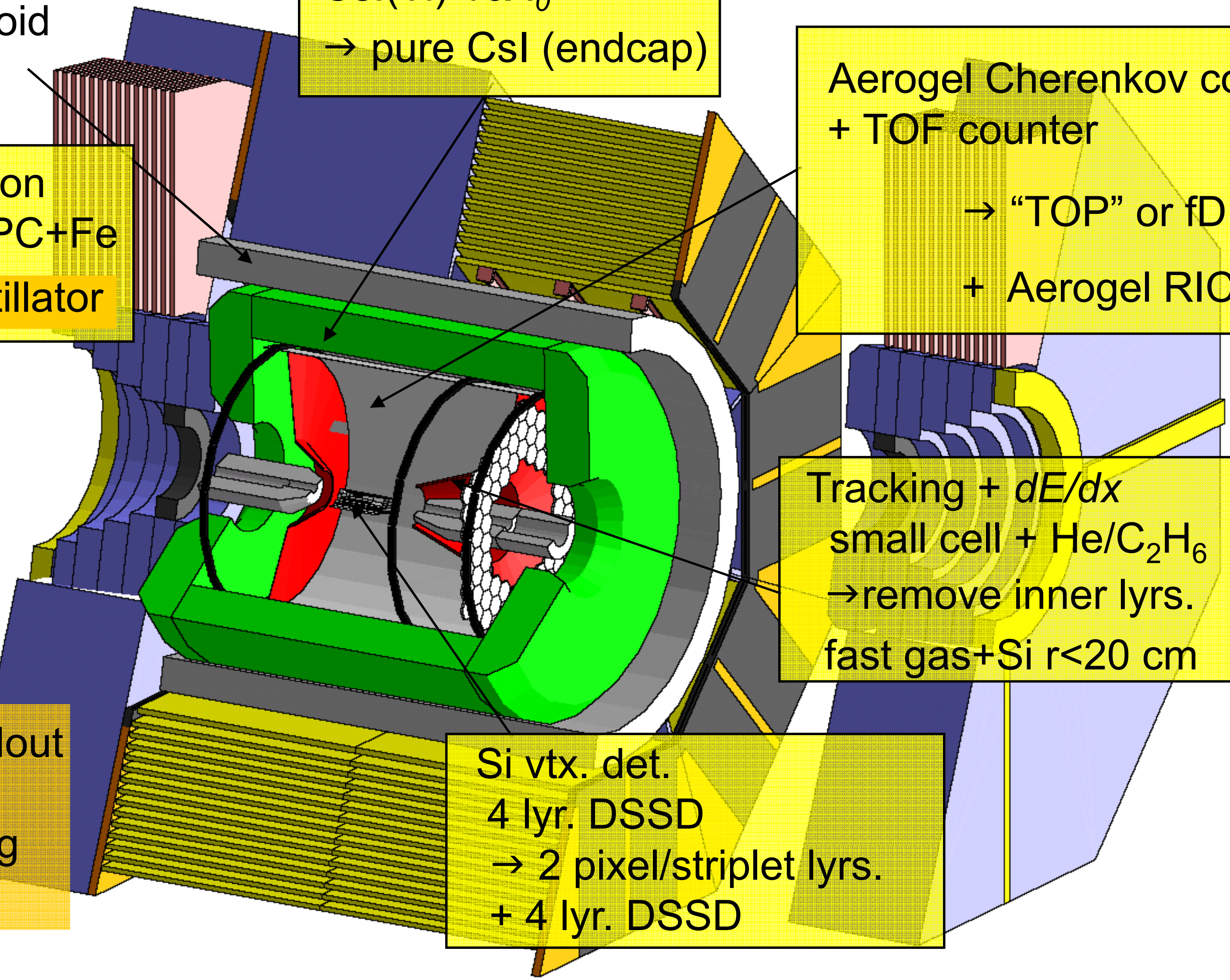




Possible solution:

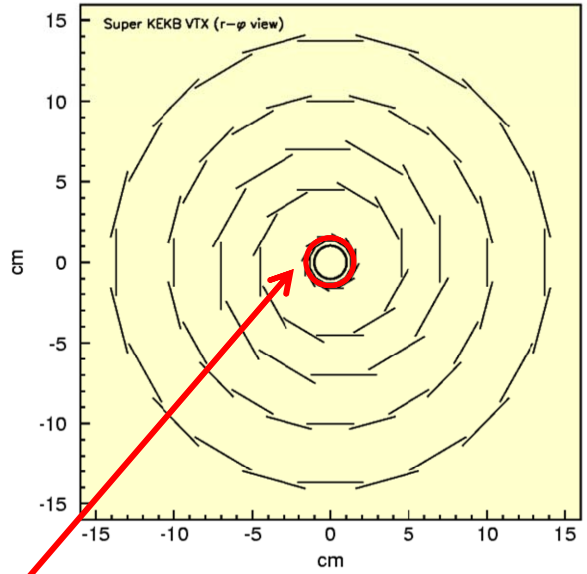
- Replace inner layers of the vertex detector with a silicon striplet or pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter by pure CsI.
- Faster readout electronics and computing system.

Belle Upgrade for Super-B

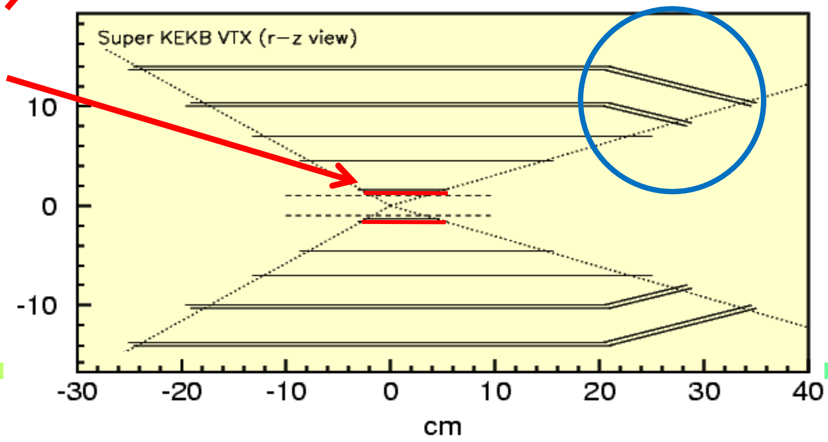


SVD Upgrade

- Configuration: 4 layers →6 layers (outer radius = 8cm→14cm)
  - More robust tracking
  - Higher Ks vertex reconstruction efficiency
- Inner radius: 1.5cm → 1.0cm
  - Better vertex resolution. Not on day 1.
- Readout chip: VA1TA→ APV25
  - Reduction of occupancy coming from beam background.
  - Pipeline readout to reduce dead time.
- Sensors of the innermost two layers: strips → DEPFET pixel sensors

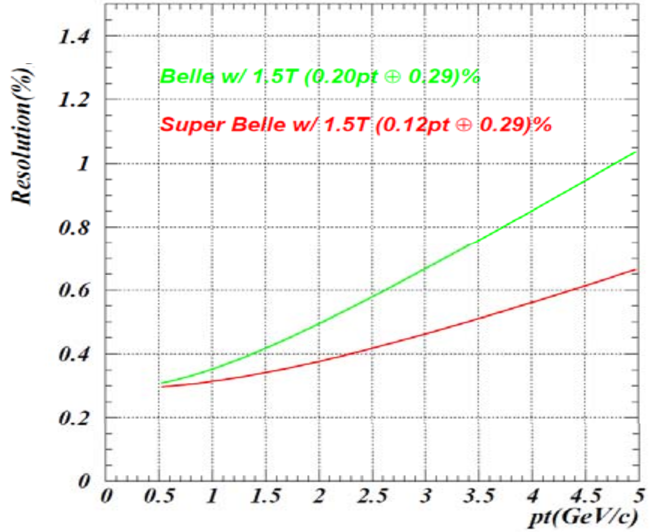


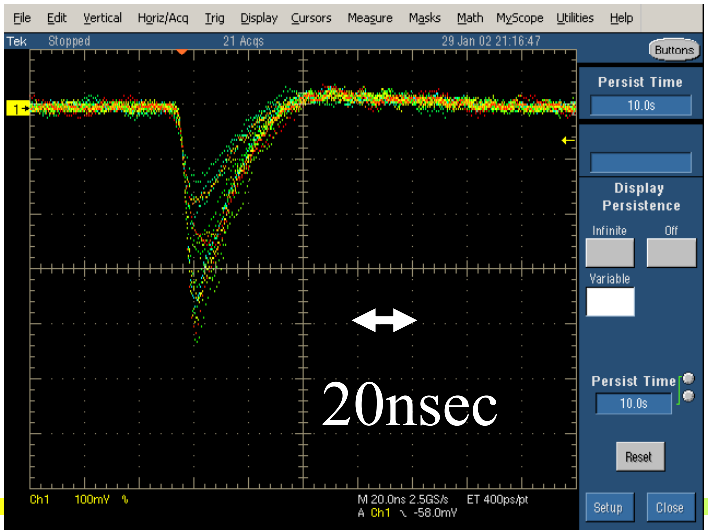
Slanted layer to keep the acceptance

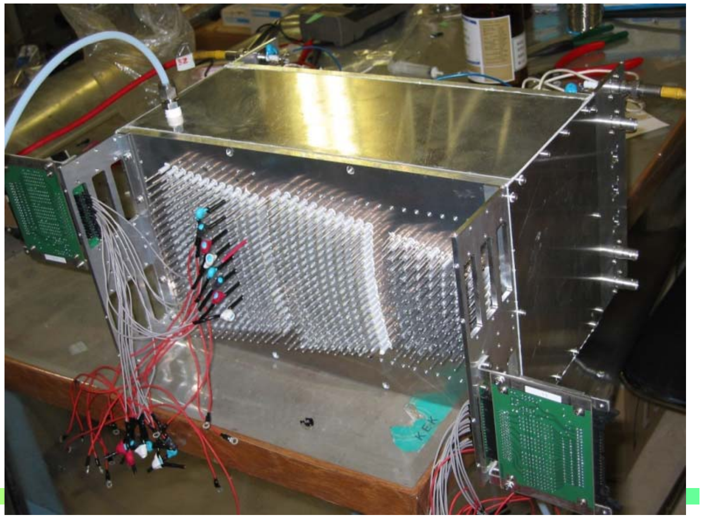


CDC Upgrade

- 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

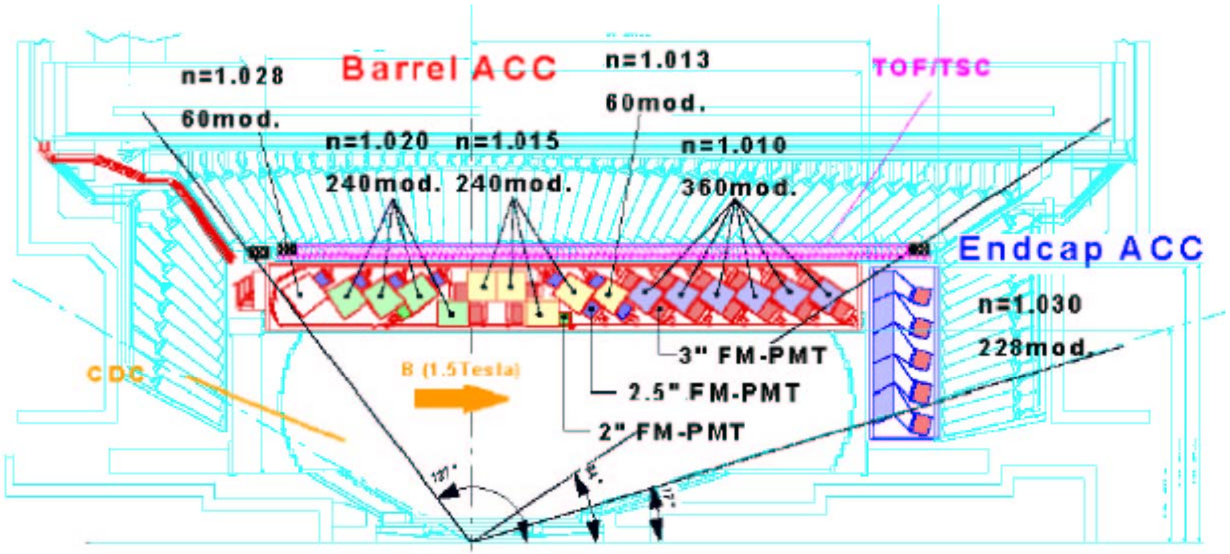




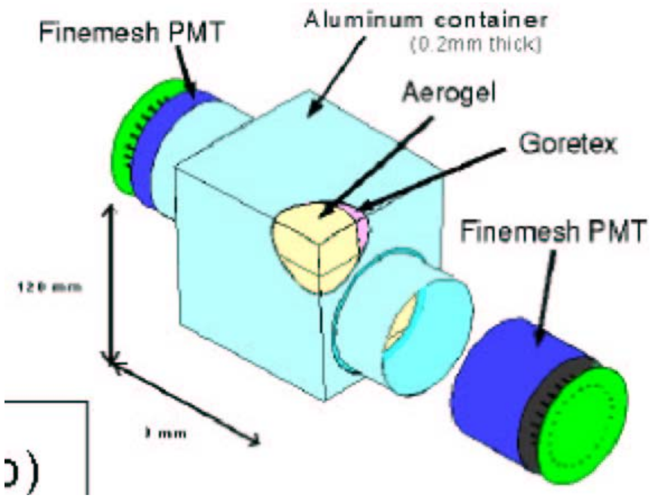


Present Belle PID: threshold Cherenkov counter - ACC (aerogel Cherenkov counter)

K (below threshold) vs. π (above) by properly choosing n for a given kinematic region (more energetic particles fly in the 'forward region')



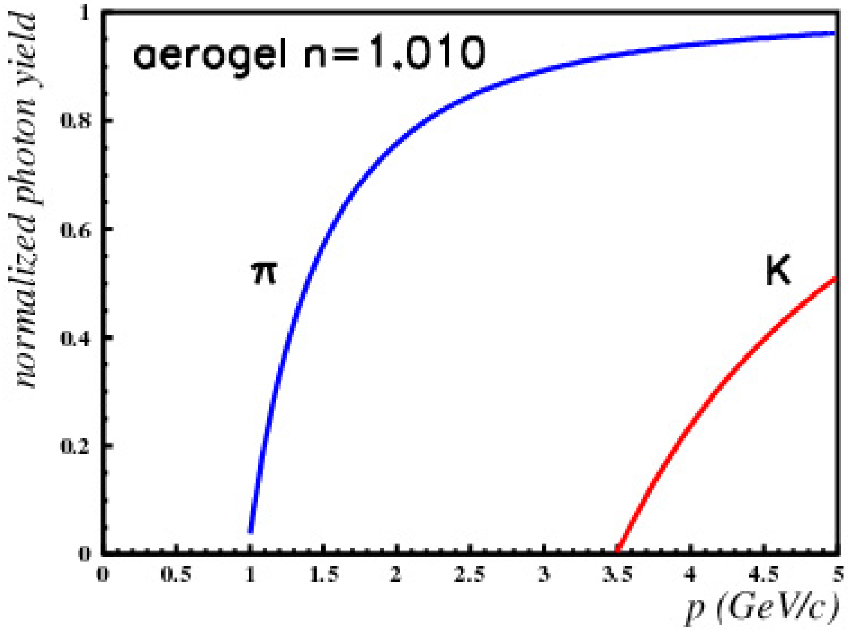
Detector unit: a block of aerogel and two fine-mesh PMTs



Fine-mesh PMT: works in high B fields

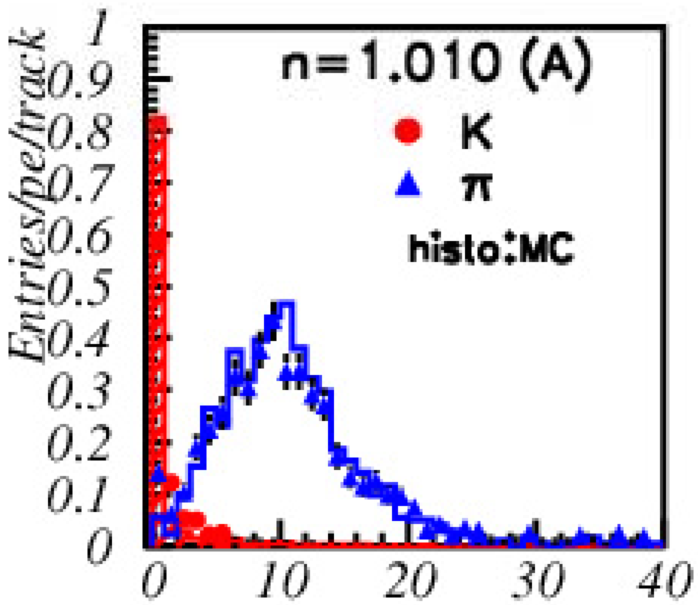
Belle ACC: threshold Cherenkov counter

expected yield vs p

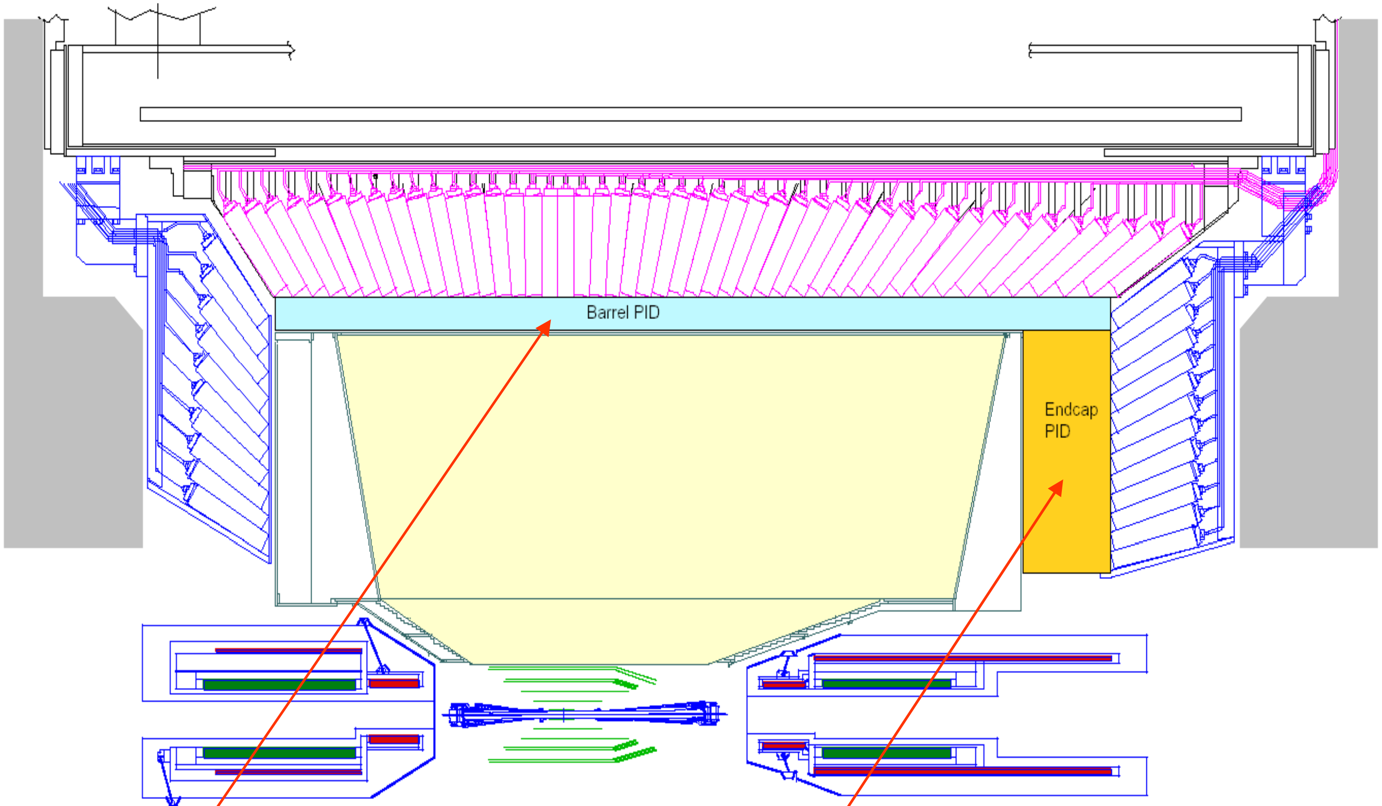


NIM A453 (2000) 321

yield for 2GeV<p<3.5GeV: expected and measured number of hits



Belle upgrade – side view

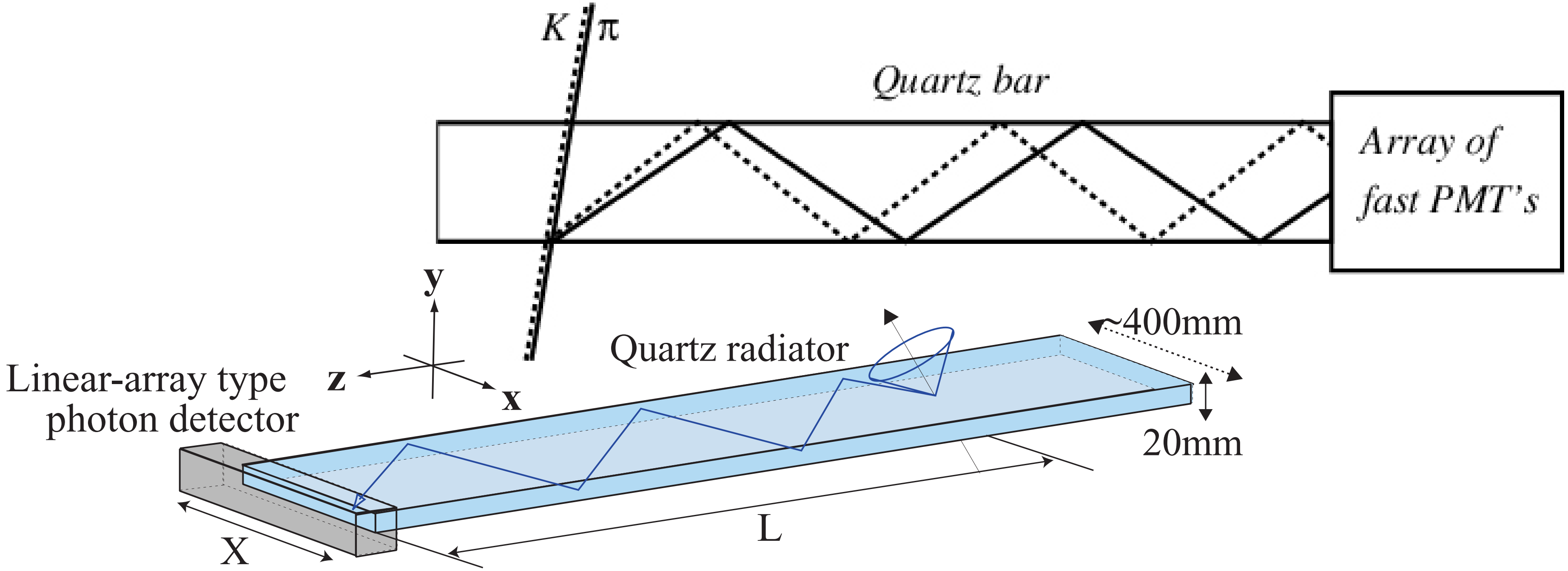


Two new particle ID devices, both RICHes:

Barrel: time-of-propagation (TOP) counter or focusing DIRC

Endcap: proximity focusing RICH

Time-Of-Propagation (TOP) counter



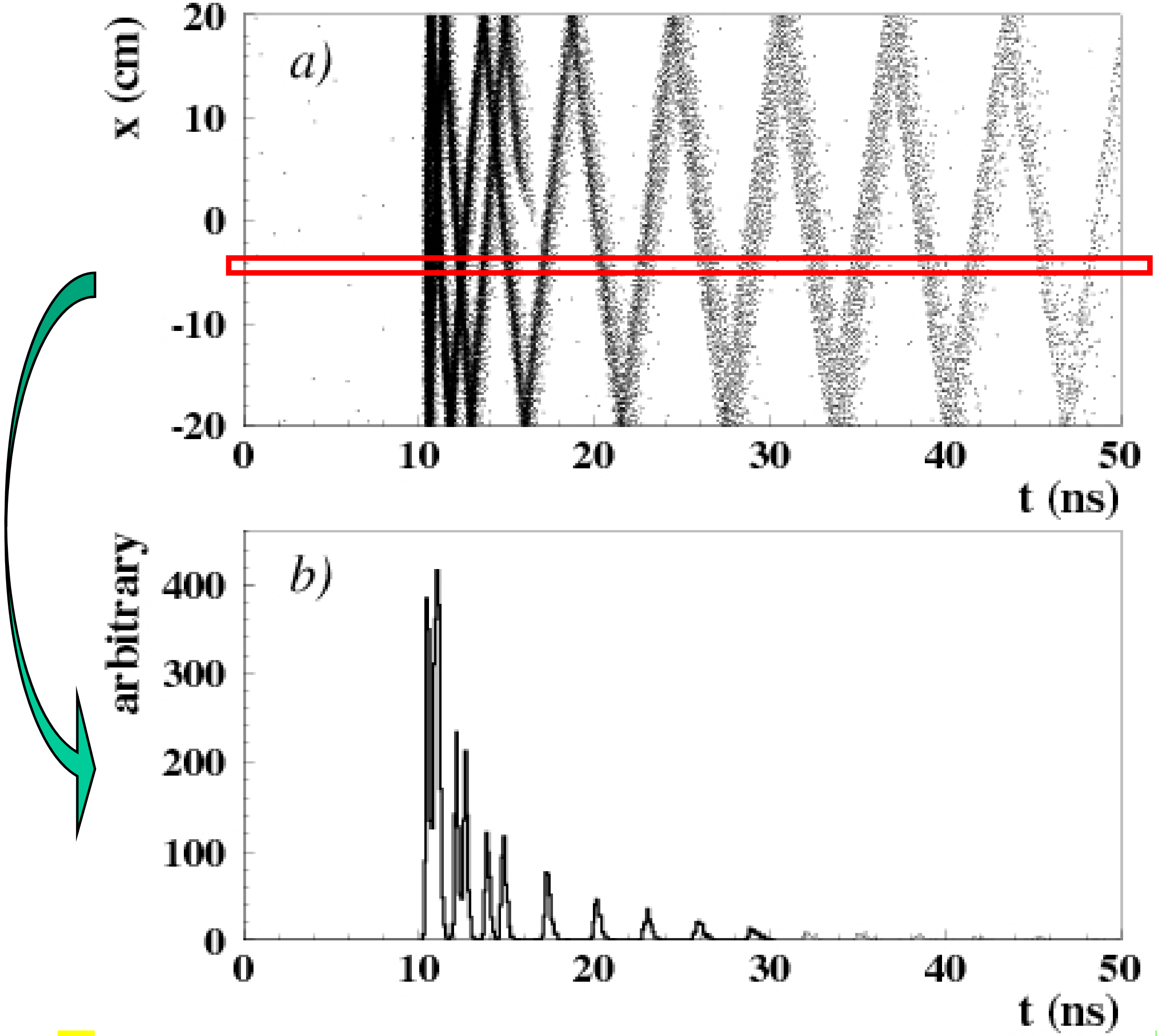
Similar to DIRC, but instead of two coordinates measure:

– One (or two coordinates) with a few mm precision

– Time-of-arrival

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

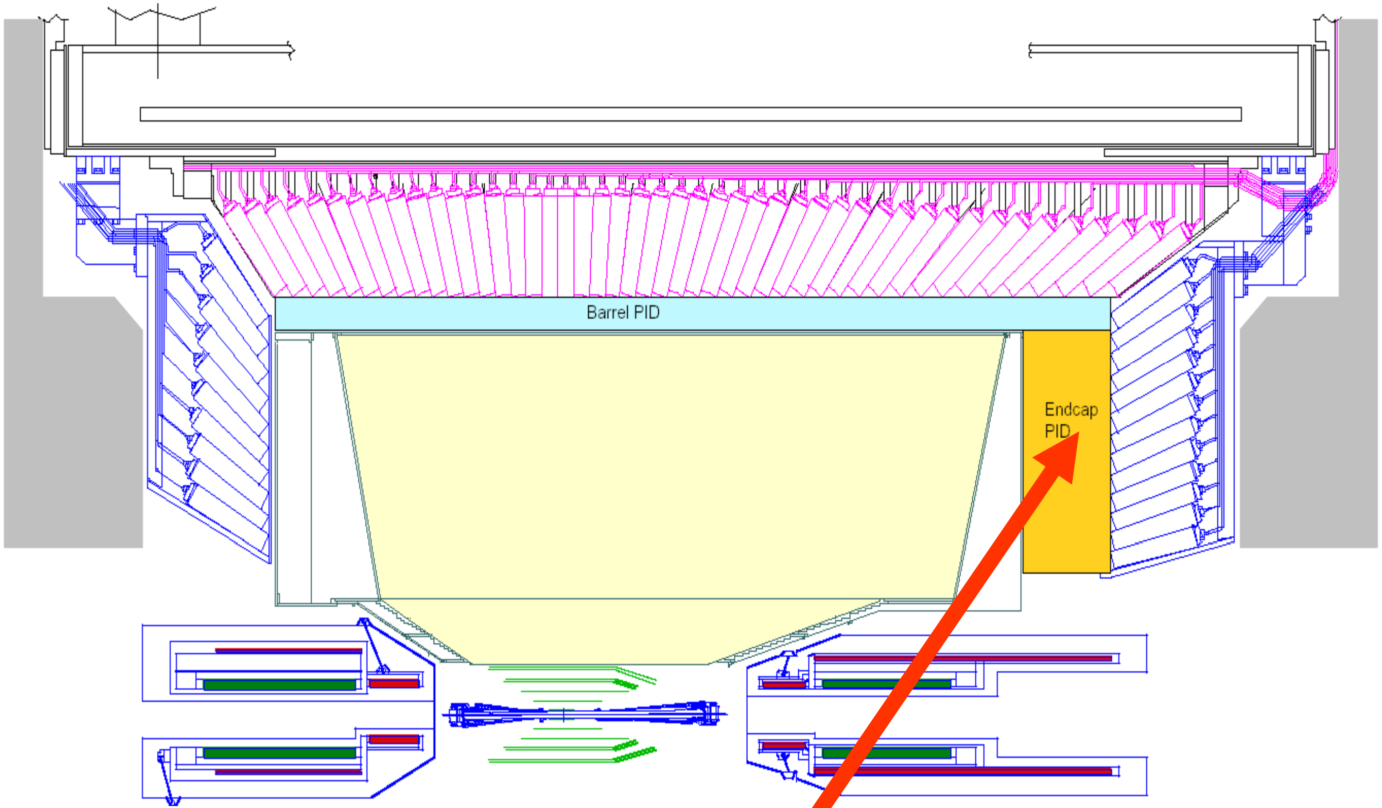
TOP image



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

Belle upgrade – side view

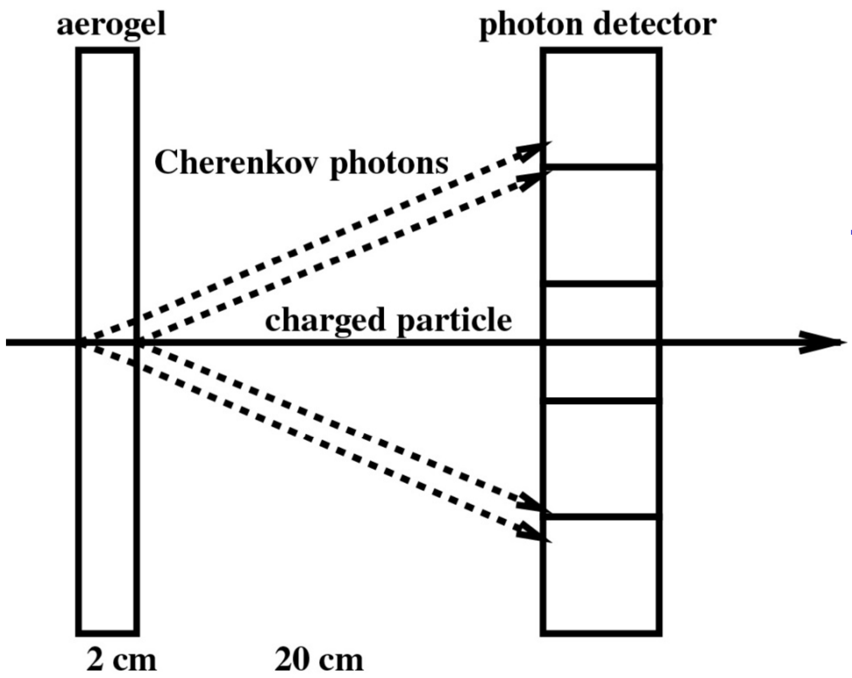


Two new particle ID devices, both RICHes:

Barrel: TOP or focusing DIRC

Endcap: proximity focusing RICH

Endcap: Proximity focusing RICH



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

For single photons: $\delta\theta_c$(meas.)=σ_0 ~ 14 mrad,
typical value for a 20mm thick radiator and 6mm PMT pad size

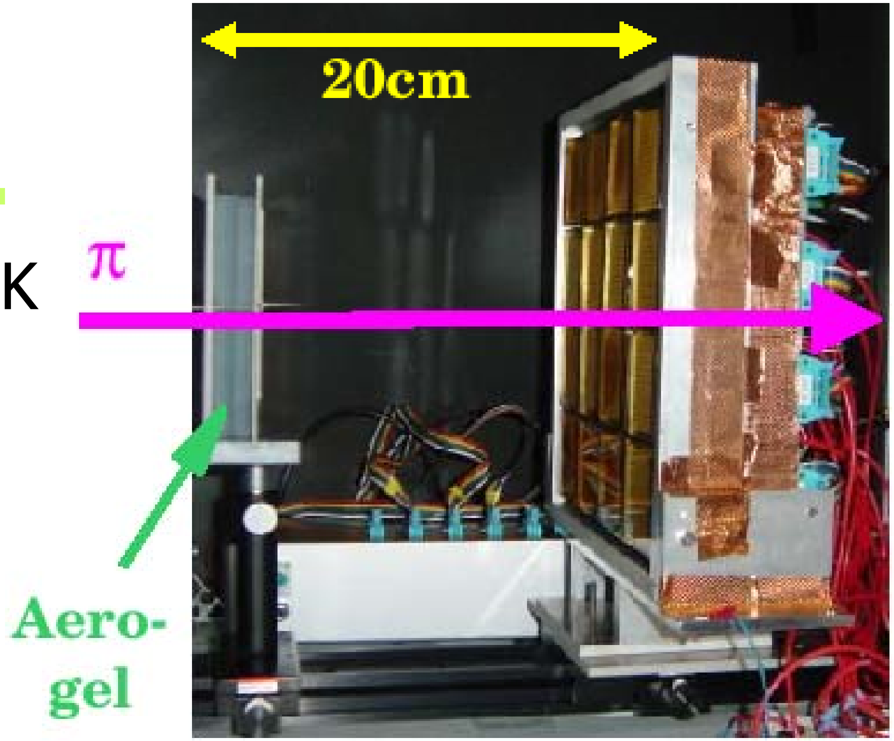
Per track: $$\sigma_{track} = \frac{\sigma_0}{\sqrt{N_{pe}}}$$

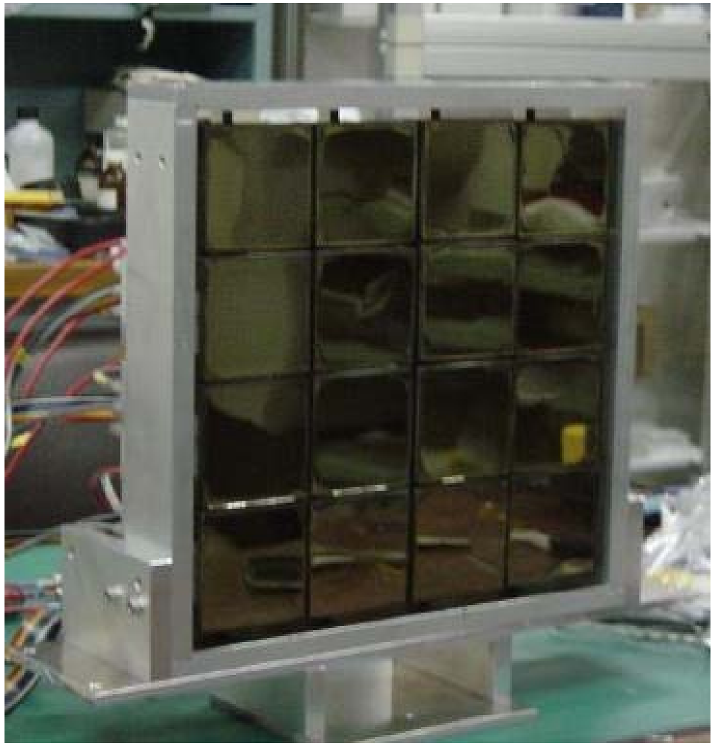
Separation: $[\theta_c(\pi) - \theta_c(K)]/\sigma_{track}$

→ 5σ separation with N_{pe}~10

Beam tests

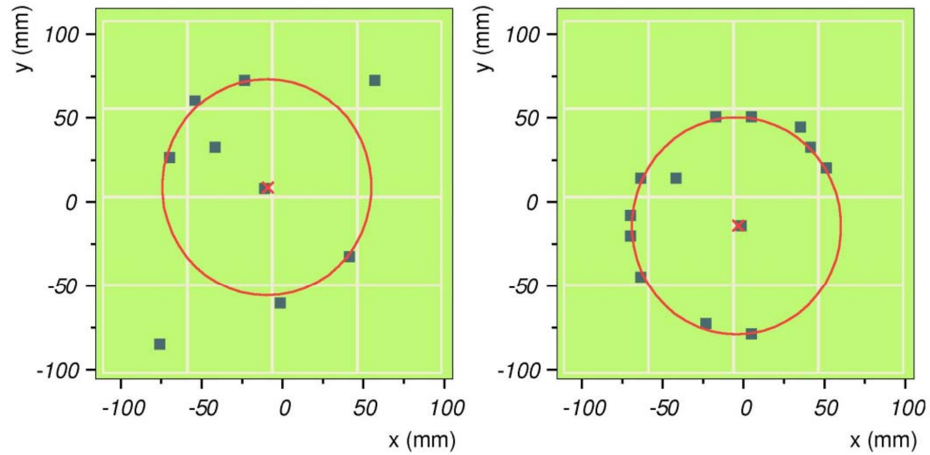
pion beam (π2) at KEK





Photon detector: array of 16 H8500 PMTs

Clear rings, little background

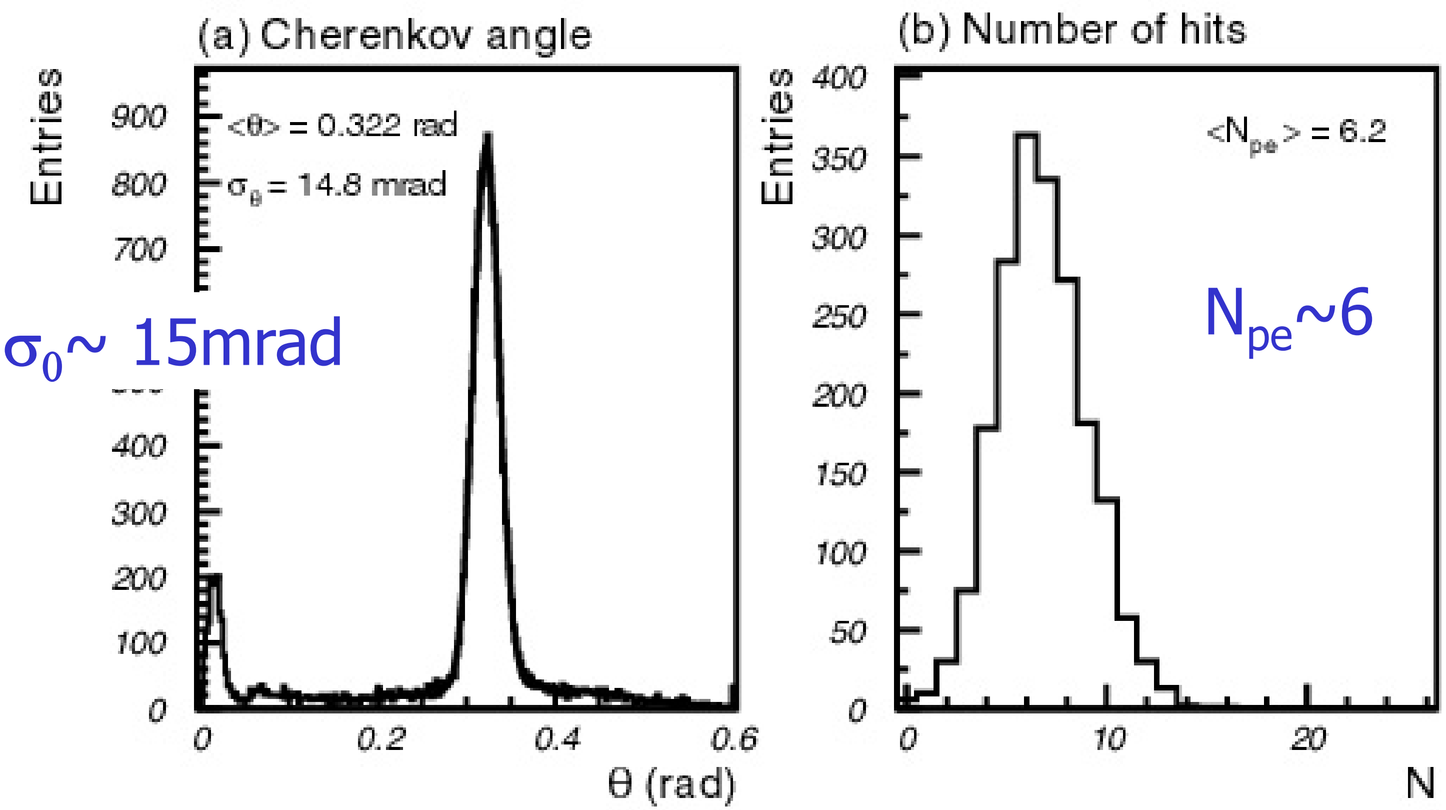


Beam test: Cherenkov angle resolution and number of photons

NIM A521(2004)367; NIM A553(2005)58

Beam test results with 2cm thick aerogel tiles:

>4σ K/π separation



$\sigma_0 \sim$ 15mrad

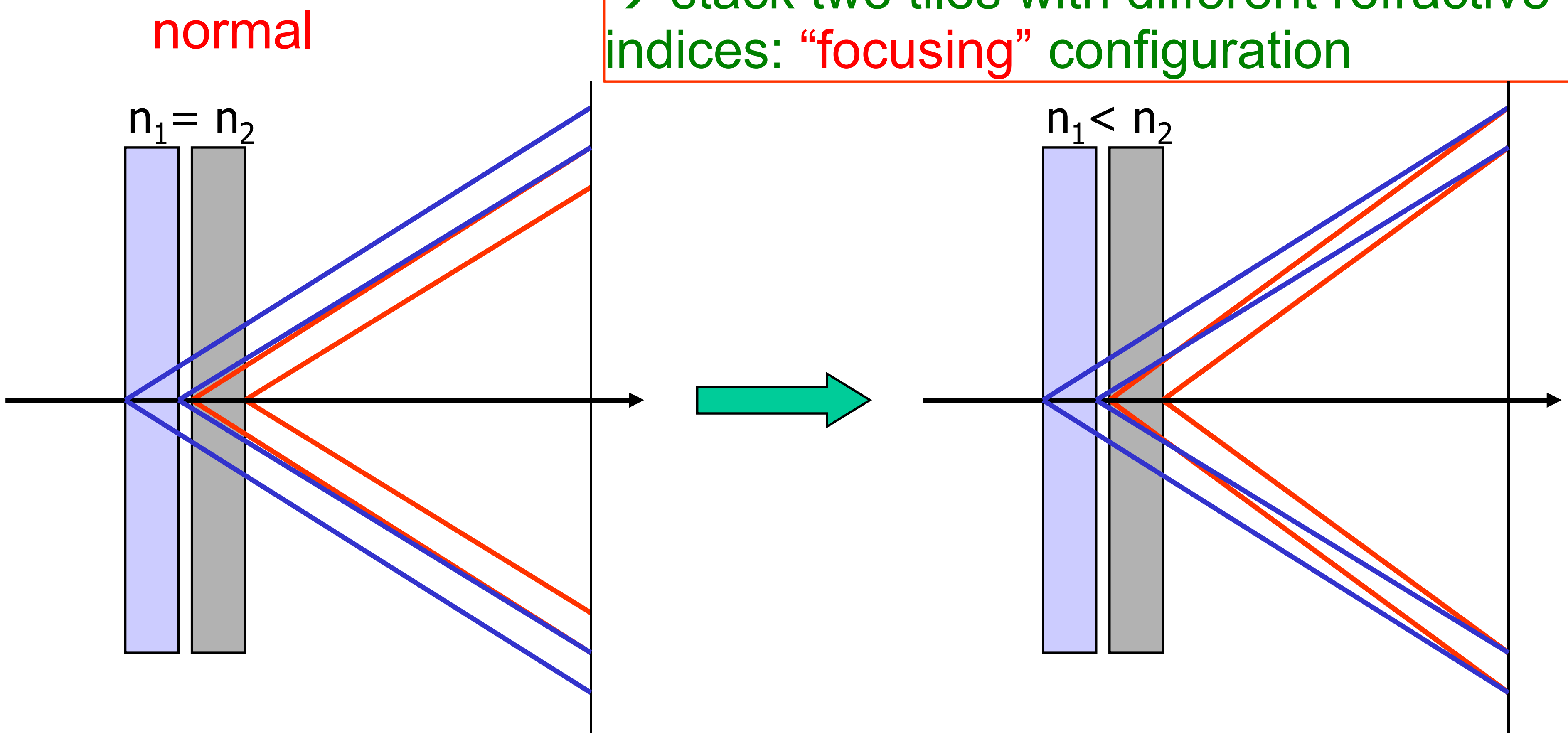
$N_{pe} \sim 6$

→ Number of photons has to be increased.

Radiator with multiple refractive indices

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

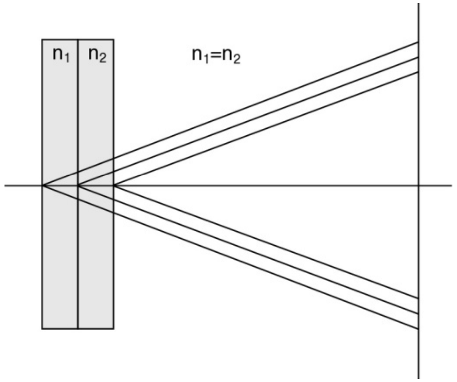
→ stack two tiles with different refractive indices: “focusing” configuration

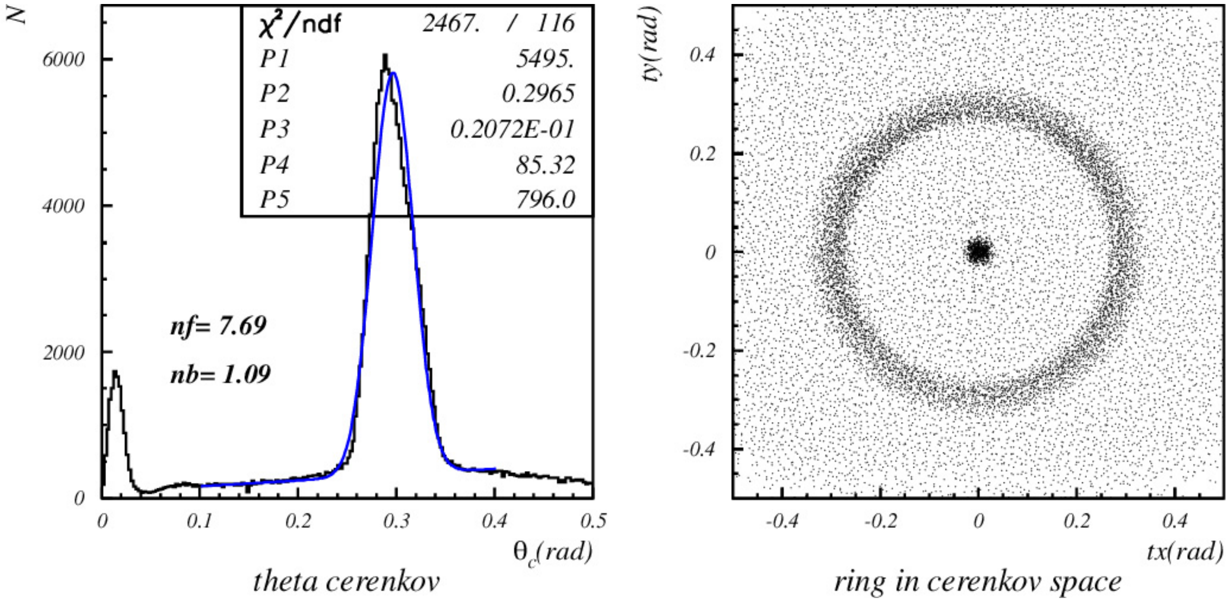


→ focusing radiator

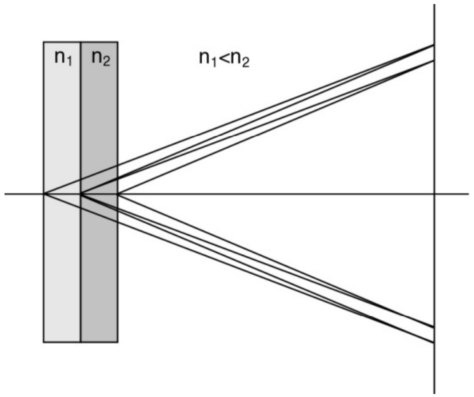
Focusing configuration – data

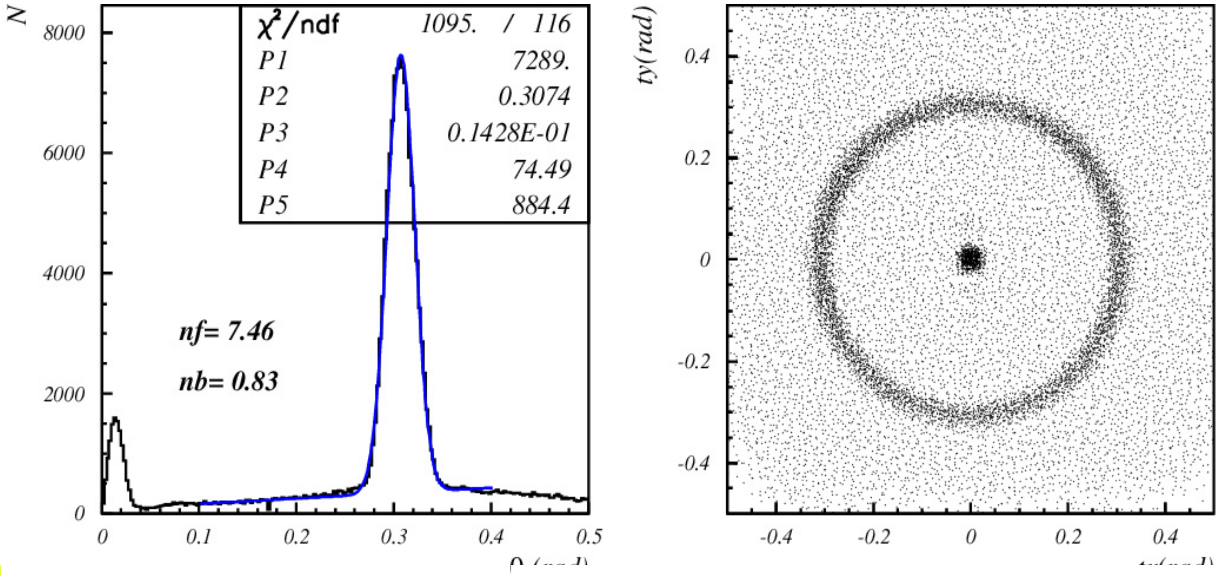
4cm aerogel single index





2+2cm aerogel



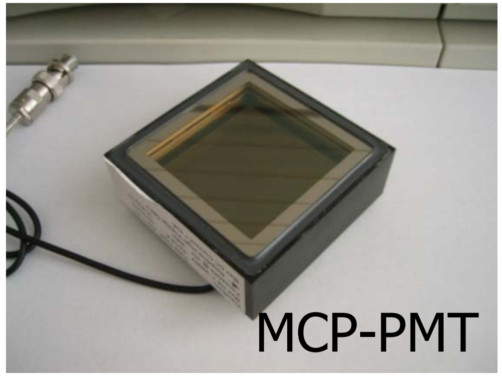


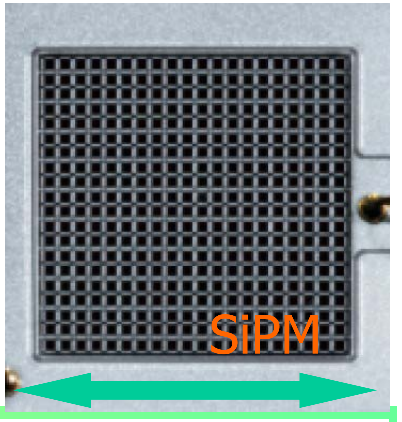
→NIM A548 (2005) 383

Photon detector options for 1.5T

- HAPD
  - Working samples, being tested on the bench and in the beam
  - Stability, ageing? Need more production R&D
- MCP-PMT
  - Excellent beam and bench performance
  - Good TTS for TOF information
    - <20ps TOF resolution (low momentum PID)
  - Need lifetime estimation
- SiPM (GAPD)
  - Good stability, enough gain and reasonable TTS
  - Need large effective area or light guide to make ~5x5mm^2 pads
  - Need gated readout because of high dark count (<~MHz)
  - Radiation hardness?

HAPD





1 mm

SiPM as photon detector?

Can we use SiPM (Geiger mode APD) as the photon detector in a RICH counter?

+immune to magnetic field

+high photon detection efficiency, single photon sensitivity

+easy to handle (thin, can be mounted on a PCB)

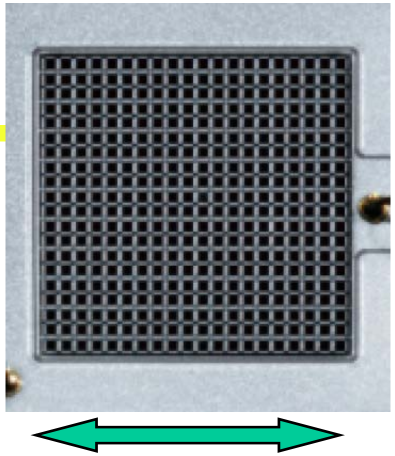
+potentially cheap (not yet...) silicon technology

+no high voltage

-very high dark count rate (100kHz – 1MHz) with <u>single photon pulse height</u>

-radiation hardness

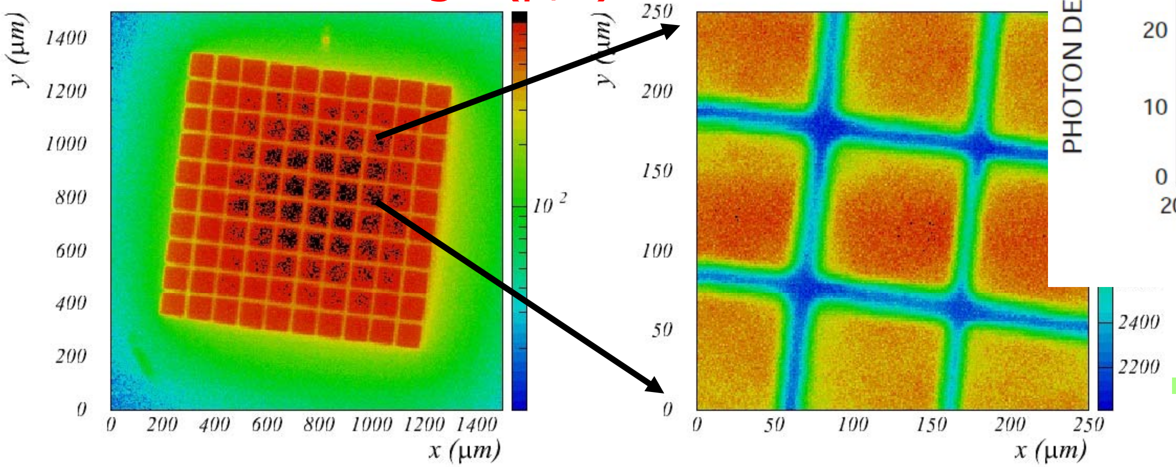
SiPMs as photon detectors?

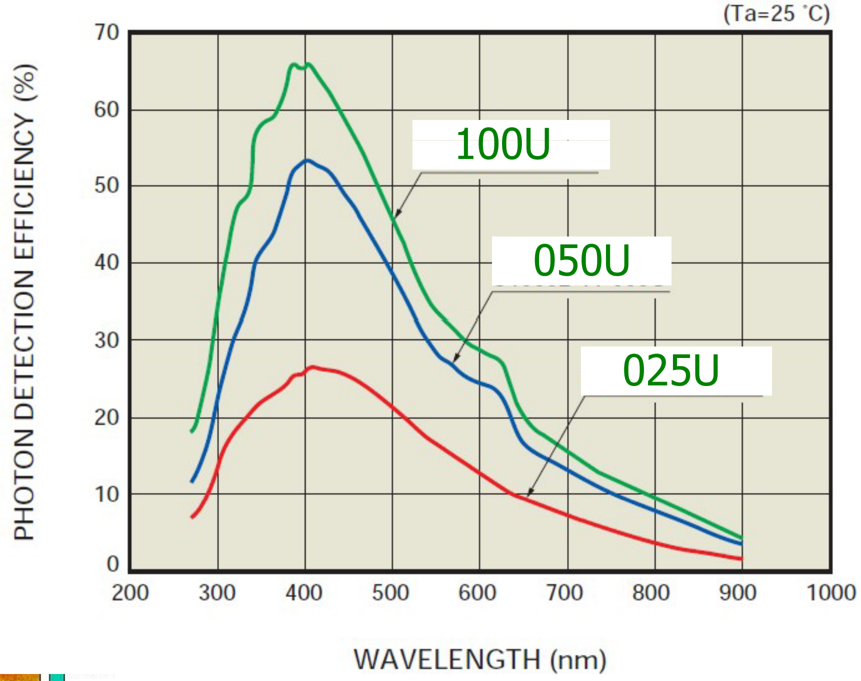


SiPM is an array of APDs operating in Geiger mode. Characteristics:

- low operation voltage ~ 10-100 V
- gain ~ 10^6
- peak PDE up to 65%(@400nm)

  PDE = QE x ε_{geiger} x ε_{geo}
- ε_{geo} – dead space between the cells
- time resolution ~ 100 ps
- works in high magnetic field
- dark counts ~ few 100 kHz/mm^2
- radiation damage (p,n)





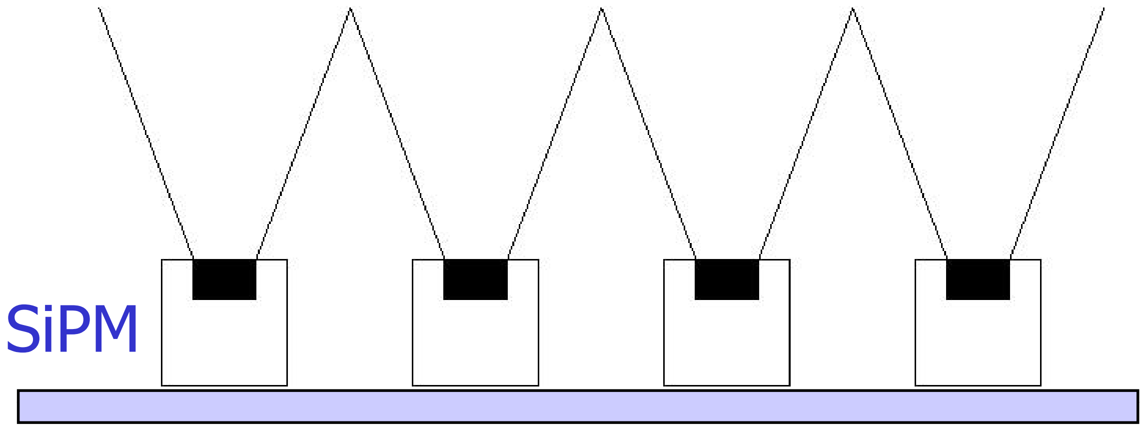
Hamamatsu MPPC: S10362-11

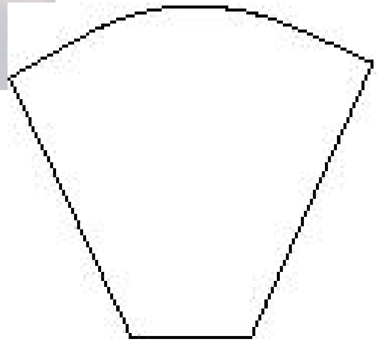
Can such a detector work?

Improve the signal to noise ratio:

- Reduce the noise by a narrow (<10ns) time window
- Increase the number of signal hits per single sensor by using light collectors and by adjusting the pad size to the ring thickness

E.g. light collector with reflective walls





or combine a lens and mirror walls

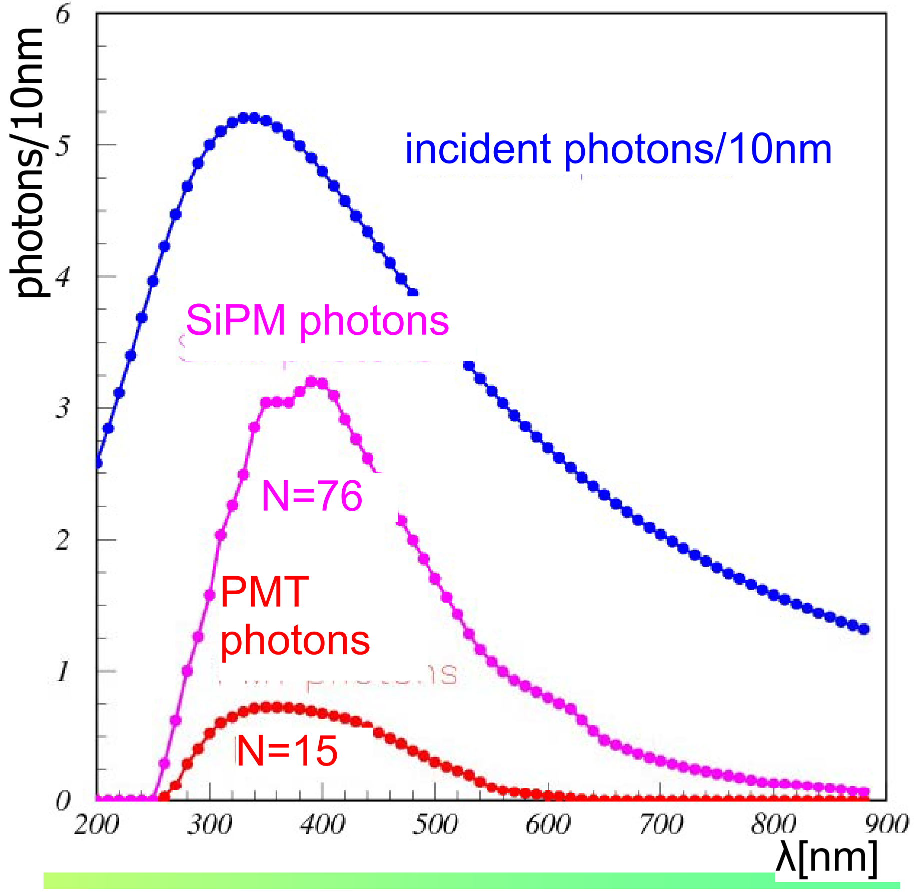
Expected number of photons for aerogel RICH

with multianode PMTs or SiPMs(100U), and
aerogel radiator: thickness 2.5 cm, n = 1.045
and transmission length (@400nm) 4 cm.

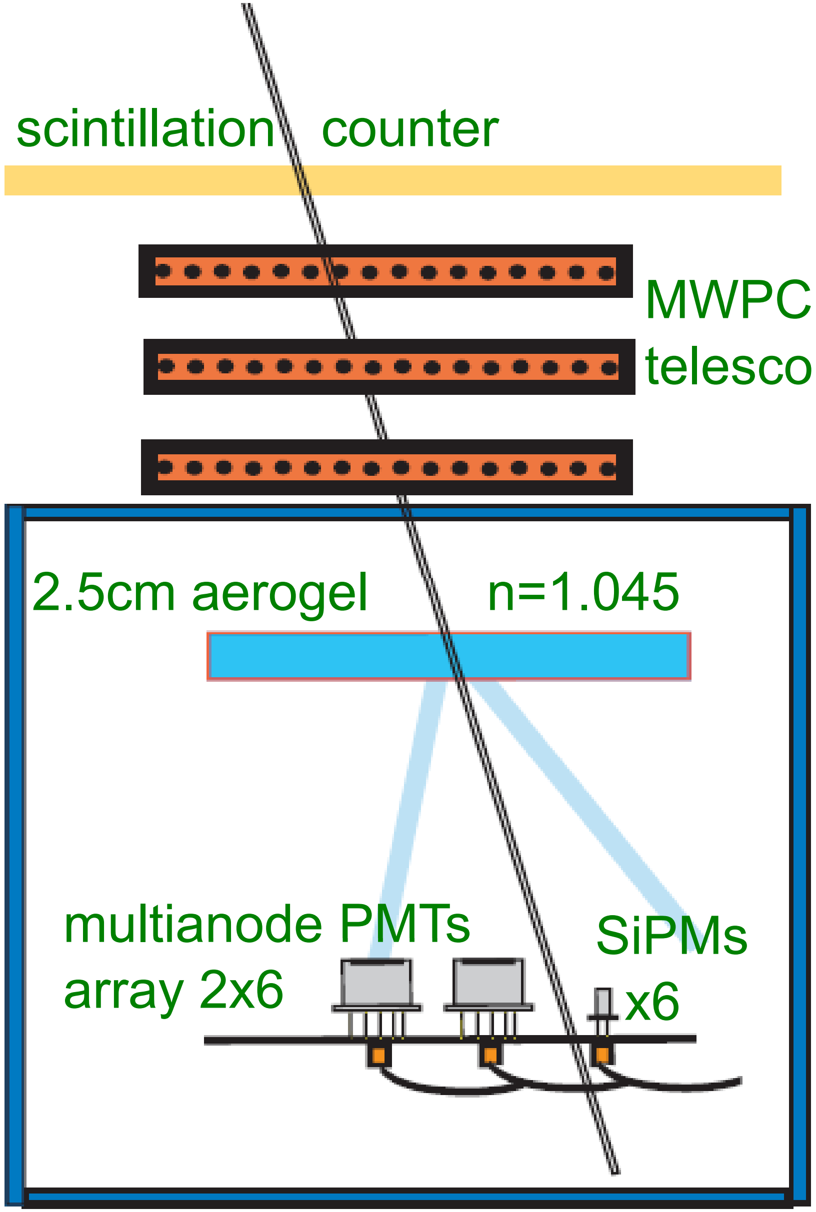
$N_{SiPM} / N_{PMT} \sim 5$

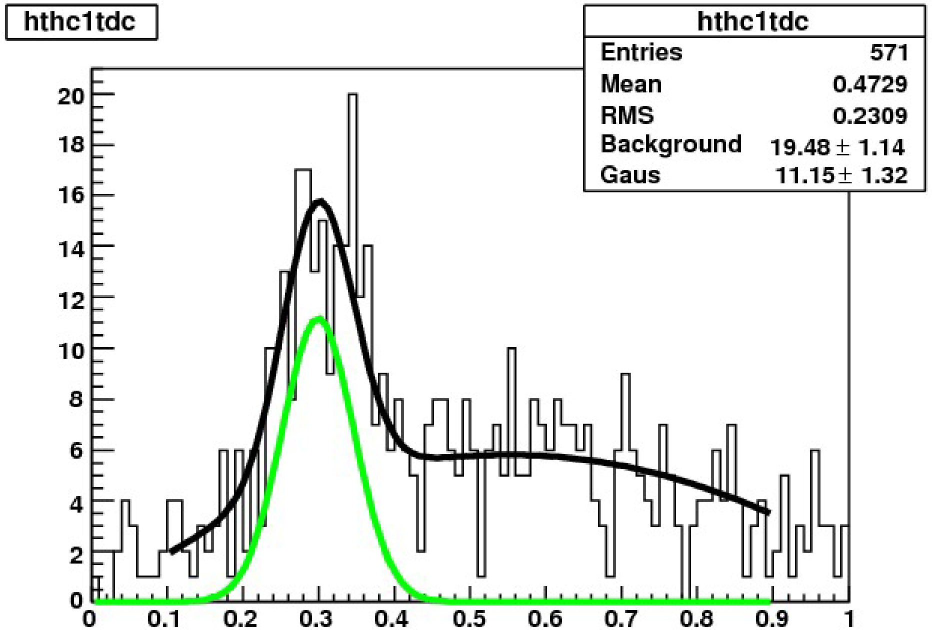
Assuming 100% detector active area

Never before tested in a RICH where we have to detect single photons. ← Dark counts have single photon pulse heights (rate 0.1-1 MHz)



Cosmic rays test setup





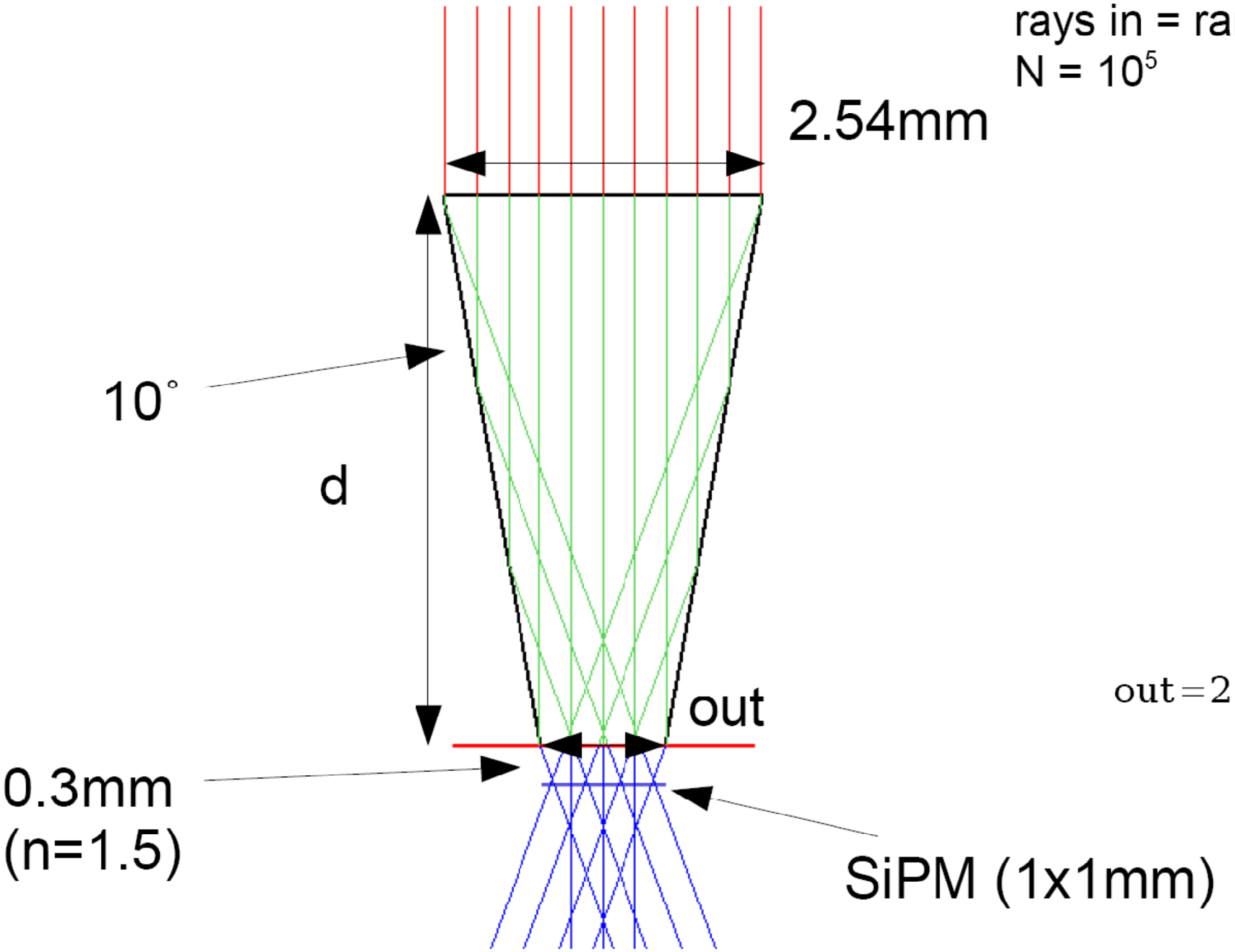
→First single Cherenkov photons observed with SiPMs

NIM A594 (2008) 13

Increase light yield → light guides

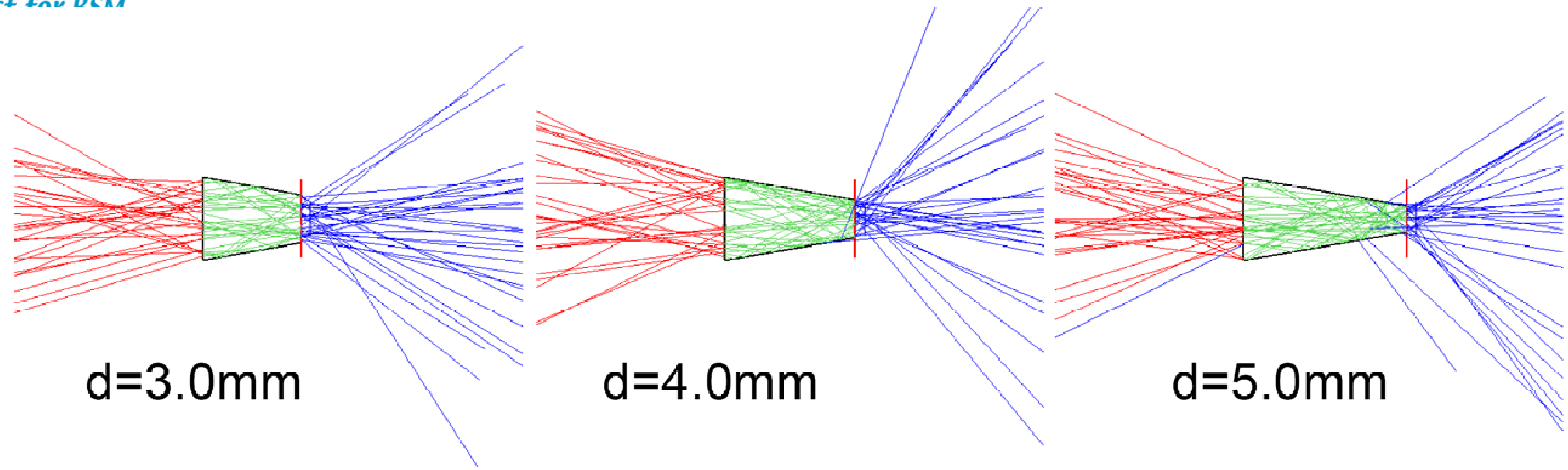
Light Guide Acceptance / (d and out)

rays in = random isotropic 0-30°
N = 10^5

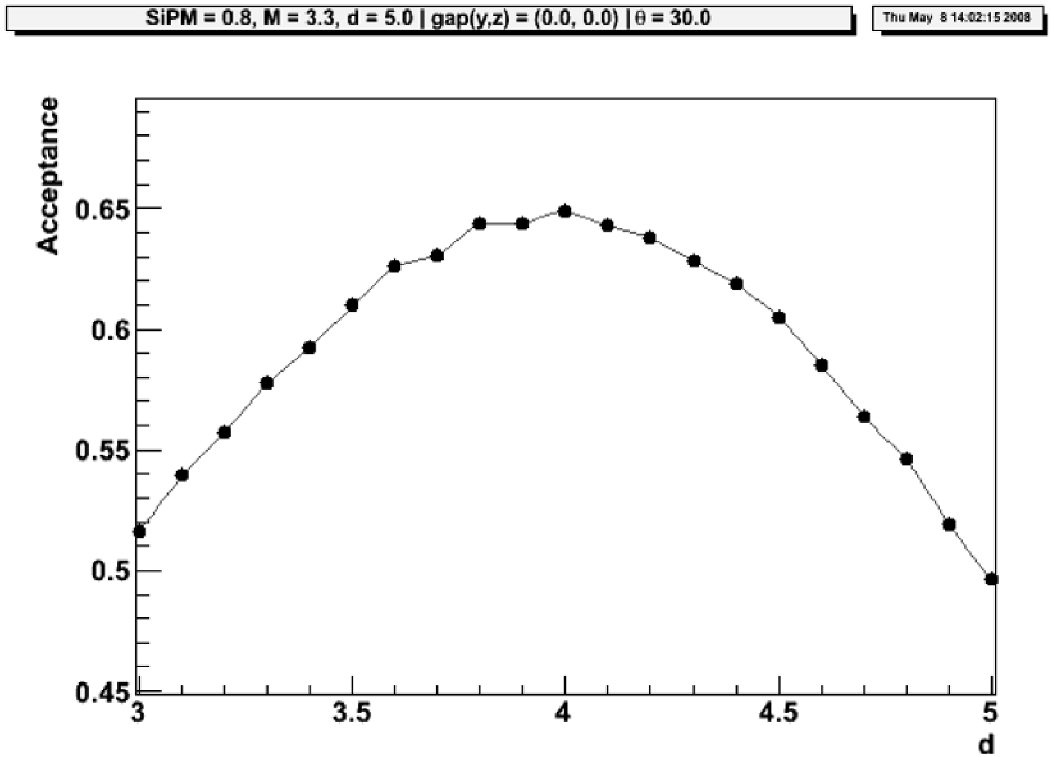


$$out = 2.54mm - 2*d*\tan(10^\circ)$$

Light guide geometry optimisation

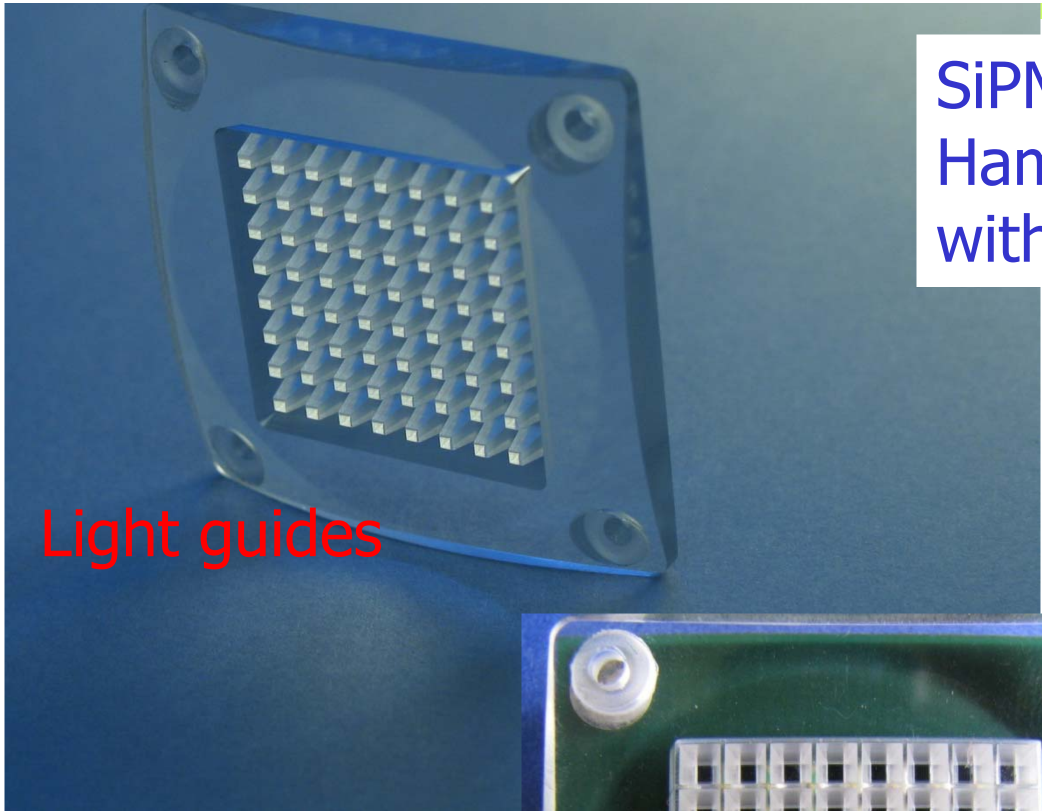


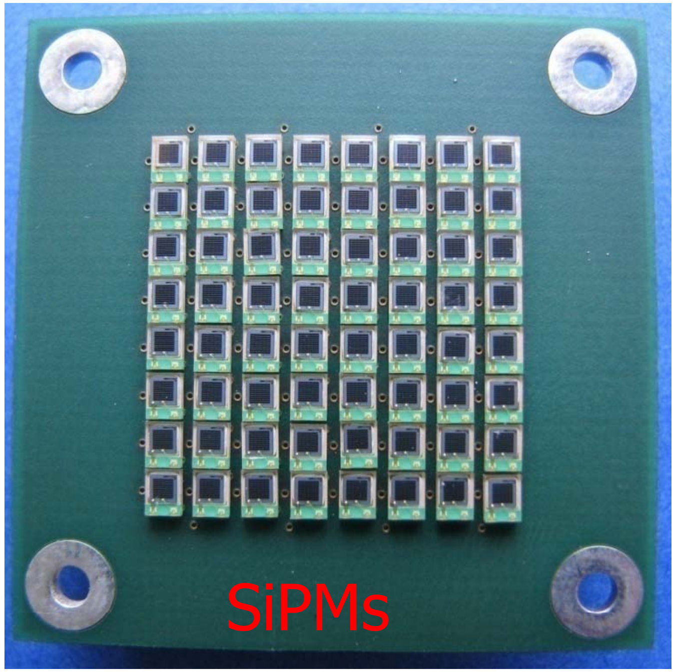
d (mm)	out (mm)	accept. (%)
3.0	1.48	51.6
3.1	1.45	54.0
3.2	1.41	55.7
3.3	1.38	57.8
3.4	1.34	59.2
3.5	1.31	61.0
3.6	1.27	62.6
3.7	1.24	63.1
3.8	1.20	64.4
3.9	1.16	64.4
4.0	**1.13**	**64.9**
4.1	1.09	64.3
4.2	1.06	63.8
4.3	1.02	62.8
4.4	0.99	61.8
4.5	0.95	60.5
4.6	0.92	58.5
4.7	0.88	56.4
4.8	0.85	54.6
4.9	0.81	51.9



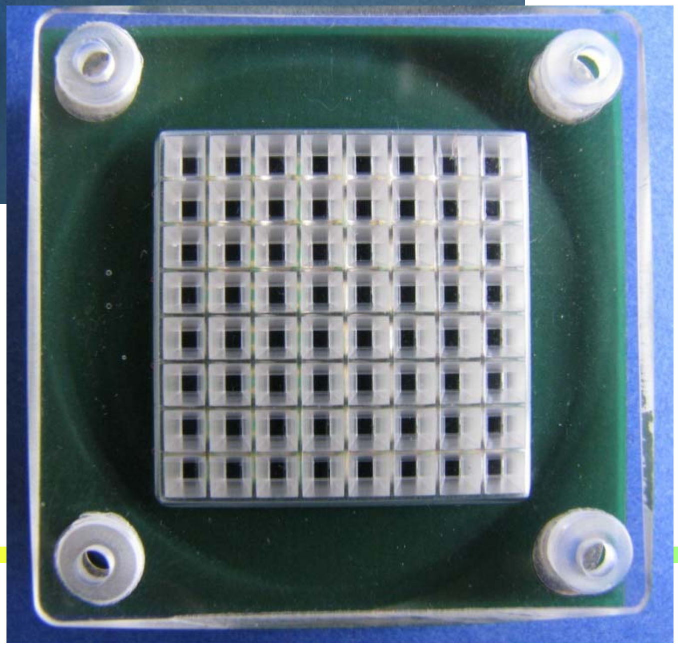
Detector module for beam tests at CERN

SiPMs: array of 8x8 SMD mount Hamamatsu S10362-11-100P with 0.3mm protective layer



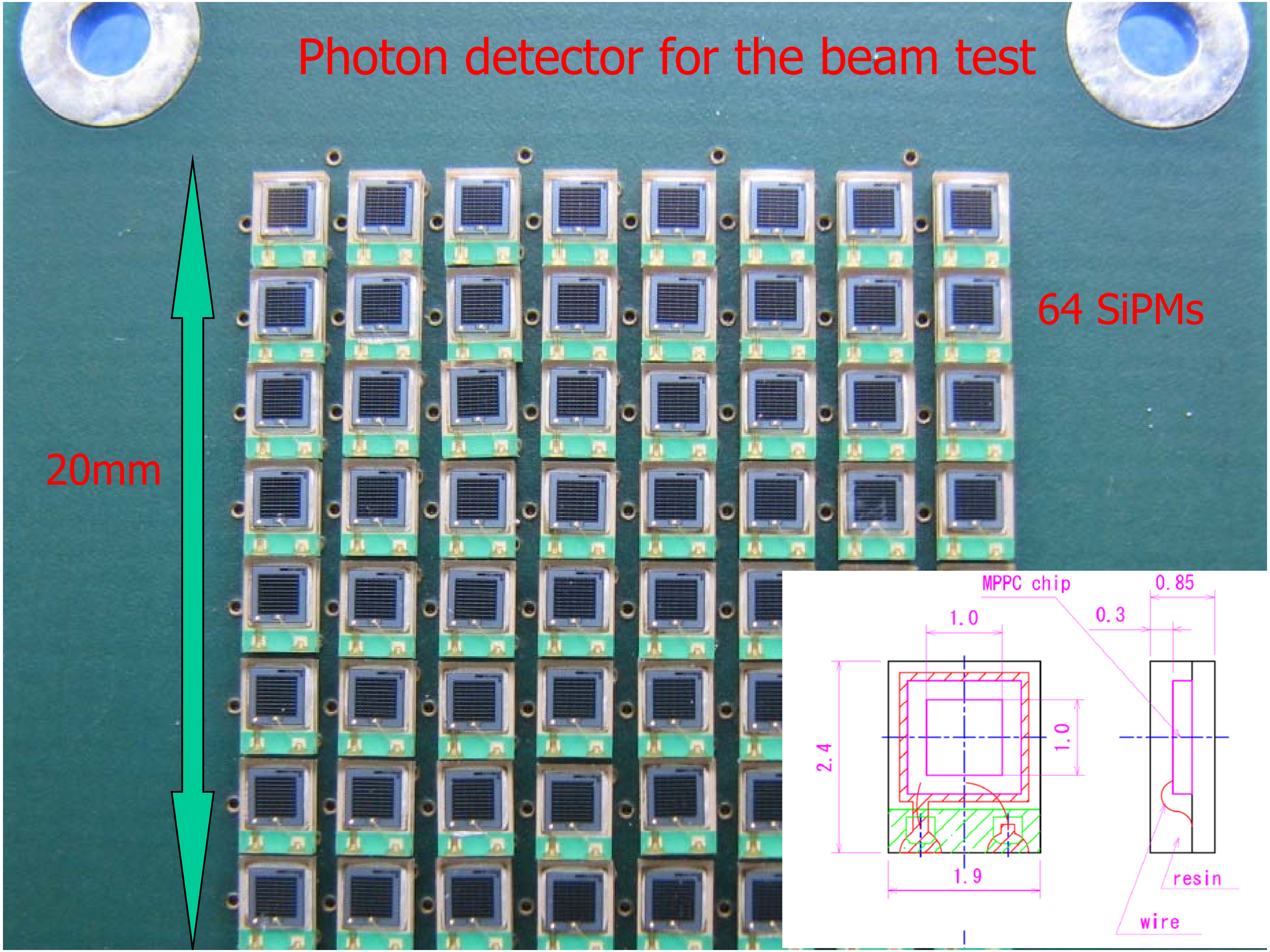


2cm



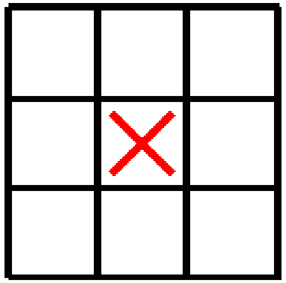
SiPMs + light guides

Photon detector for the beam test

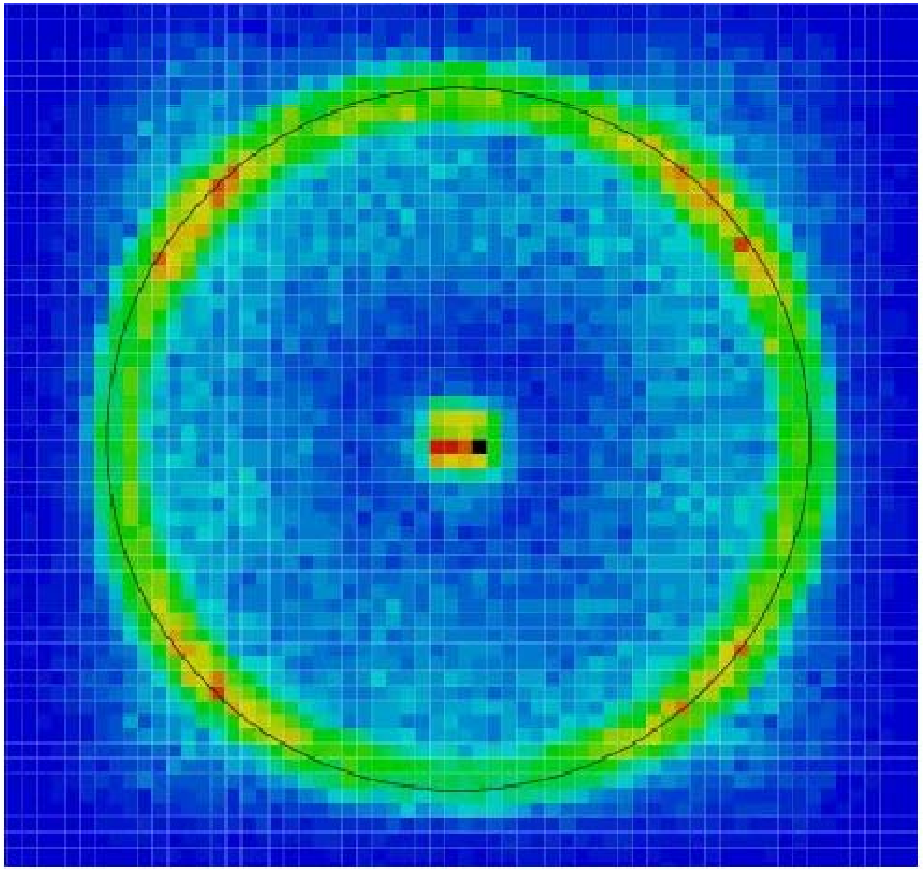


Ring images

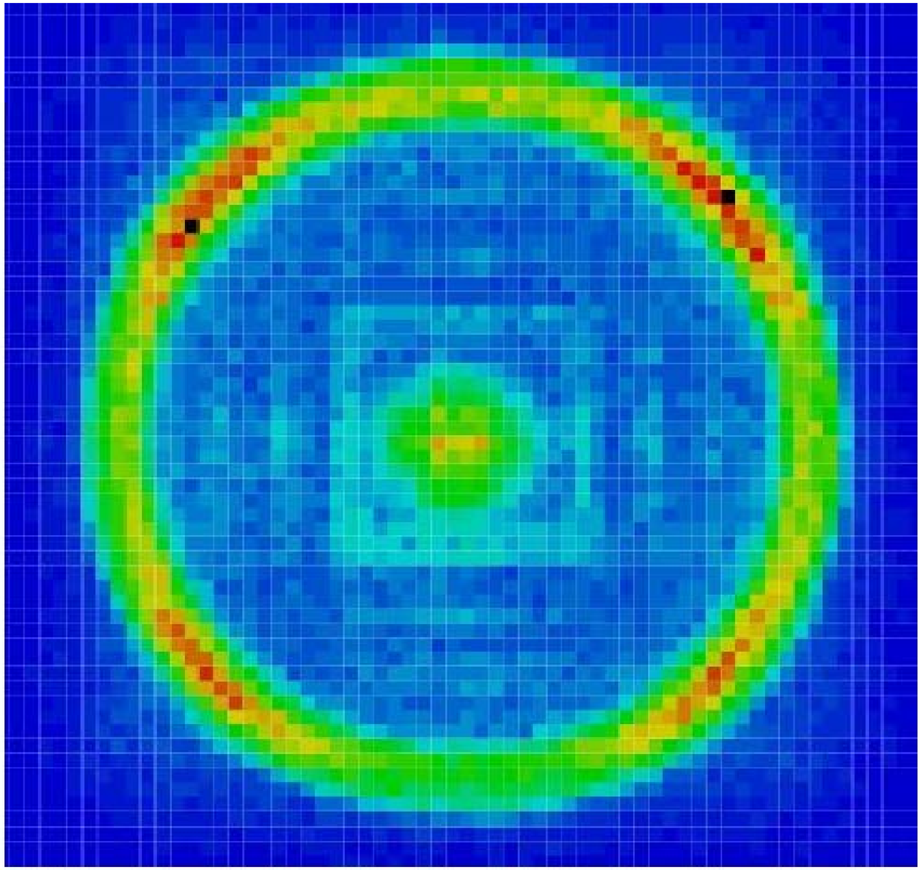
- module was moved to 9 positions to cover the ring area
- these plots show only superposition of 8 positions (central position is not included)



w/o light guides

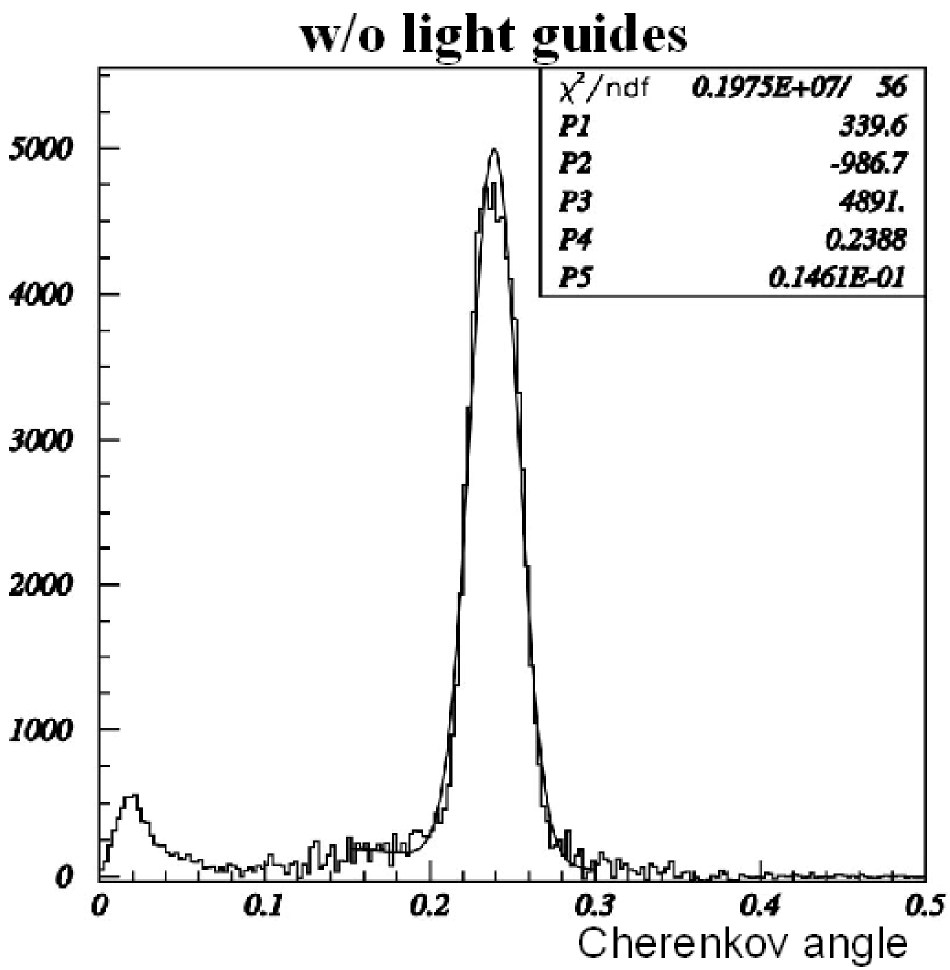


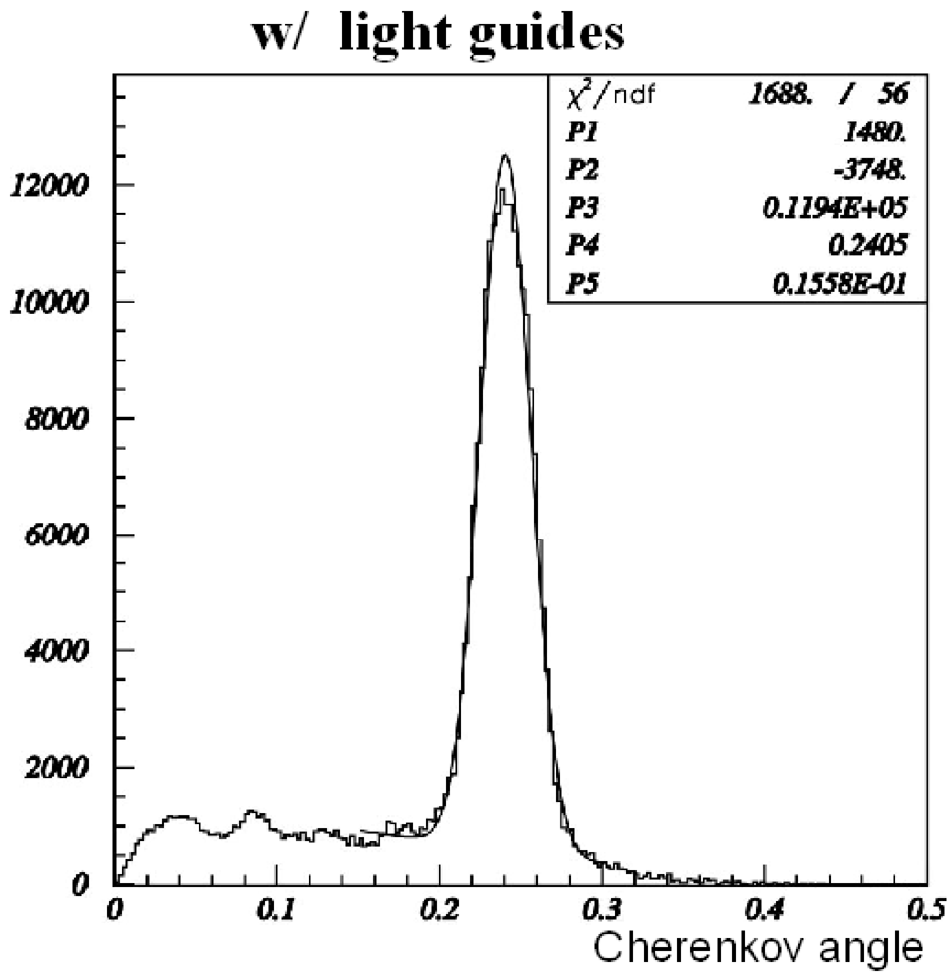
w/ light guides



Cherenkov angle distributions

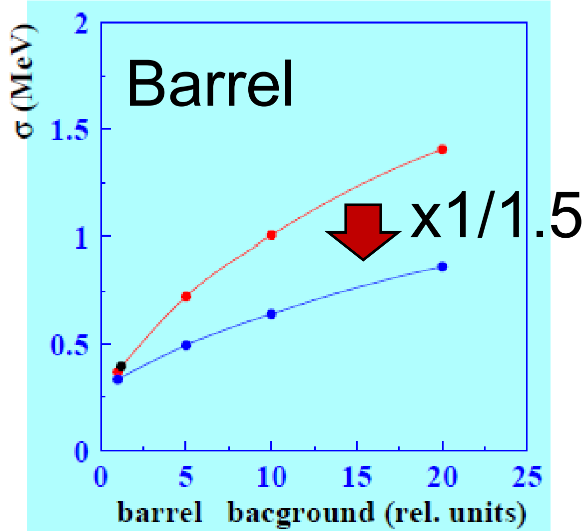
- background subtracted distributions
- ratio of detected photons w/ and w/o: ~ 2.3
- resolution within expectations (14.5mrad)





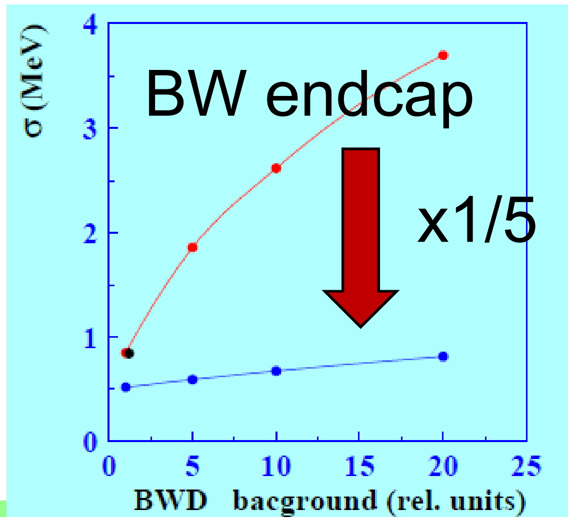
ECL Upgrade

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



- Barrel:
  0.5μs shaping + 2MHz w.f. sampling.
- Endcap:
  pure CsI + photopentods
  30ns shaping + 43MHz w.f. sampling

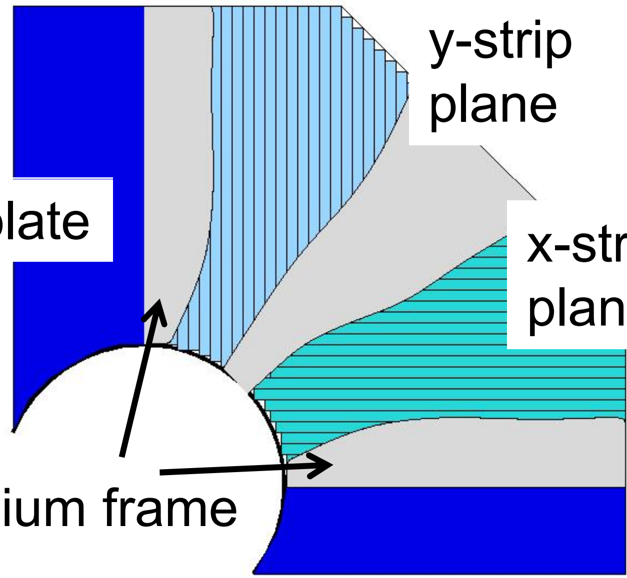
Pure CsI & photopentods

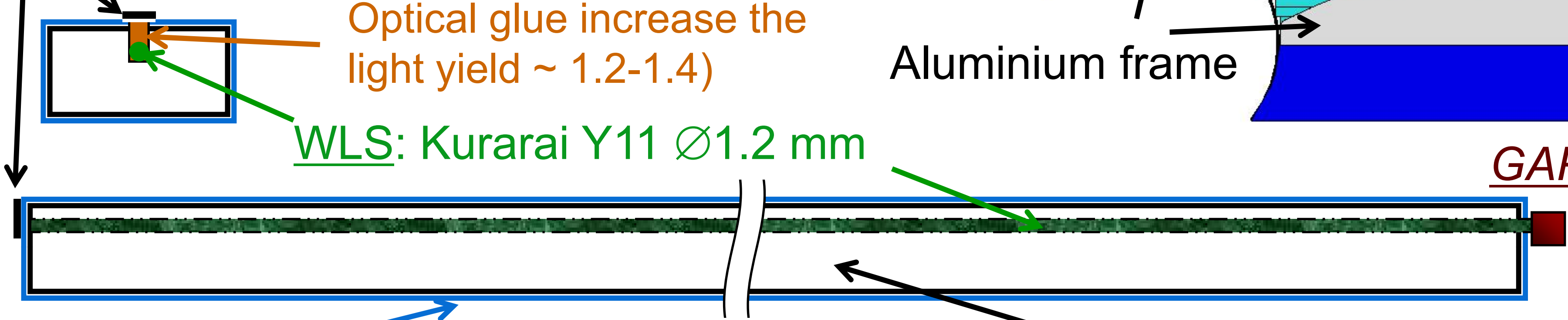


KLM upgrade

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%





KEK's 5 year Roadmap

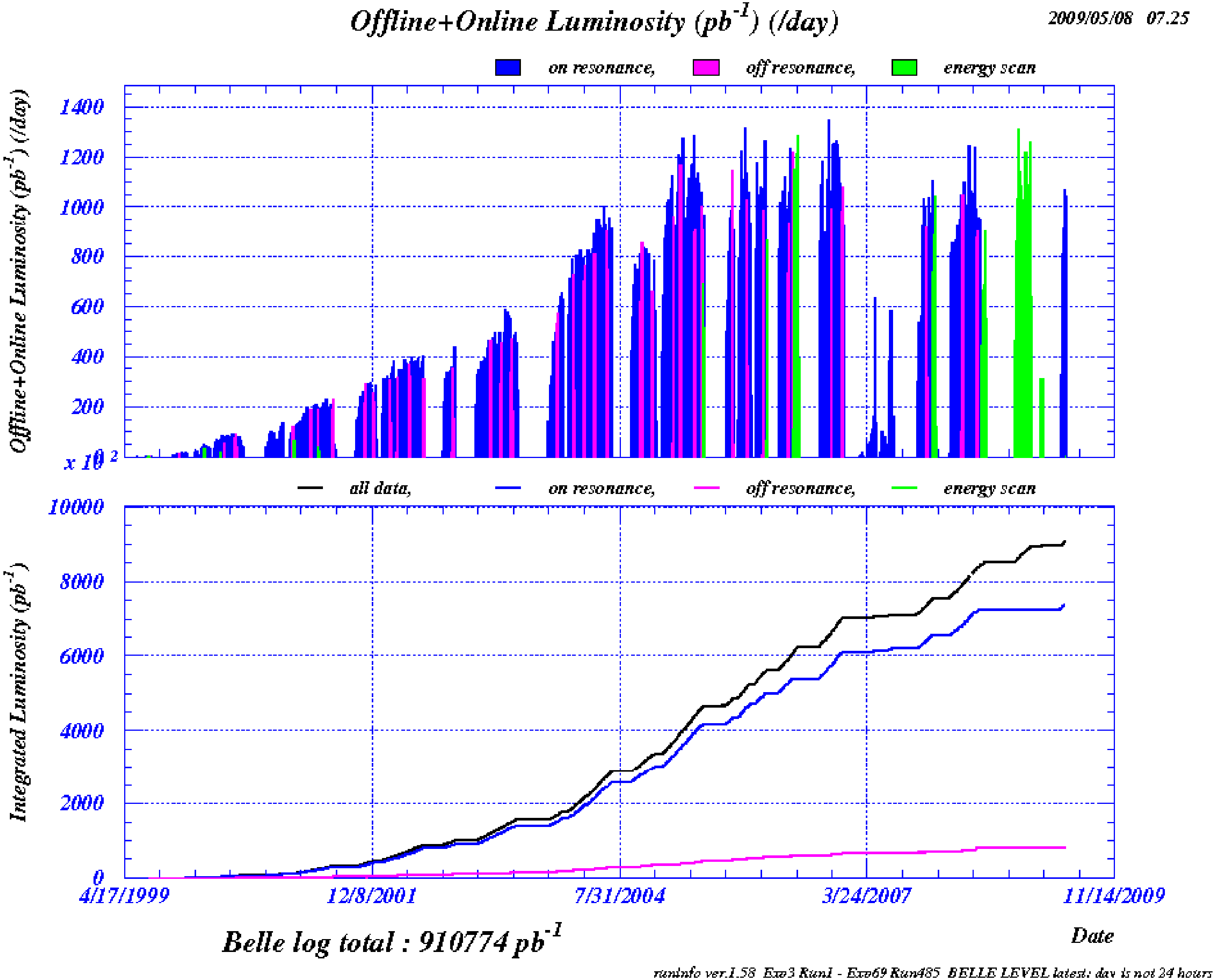
- Official 20 page report released in January 2008 by director A. Suzuki and KEK management
- KEKB's upgrade is the central element in particle physics, with a final goal luminosity of 8 x 10^{35} $cm^{-2}s^{-1}$, and an integrated luminosity of 50 ab^{-1}
- The project is currently being evaluated by the Japanese Ministry of Science and Higher Education (MEXT)

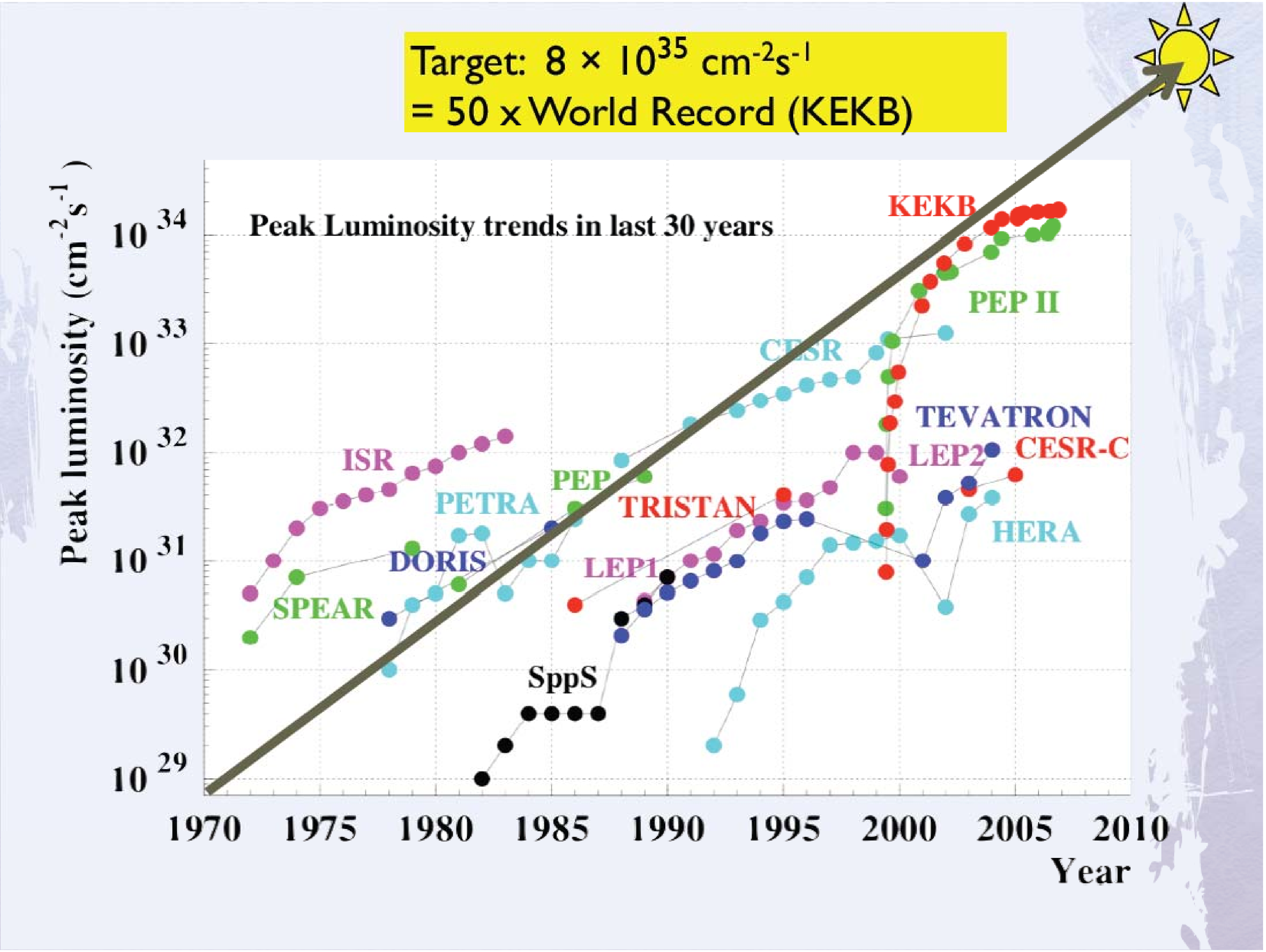
Belle-II (and SuperKEKB) is an open international project that covers the next two orders of magnitudes at the luminosity frontier - a very good opportunity for high impact international collaboration.

Summary

- B factories have proven to be an excellent tool for flavour physics
- 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, most of things are not yet frozen...
- Expect a new, exciting era of discoveries, complementary to LHC
- Do not miss the chance to be part of it...

Additional slides


Offline+Online Luminosity (pb-1) (/day)
2009/05/08 07.25
on resonance,
off resonance,
energy scan
Offline+Online Luminosity (pb-1) (/day)
1400
1200
1000
800
600
400
200
0
x 10 2
all data,
on resonance,
off resonance,
energy scan
10000
8000
6000
4000
2000
0
Integrated Luminosity (pb-1)
4/17/1999
12/8/2001
7/31/2004
3/24/2007
11/14/2009
Date
Belle log total : 910774 pb-1
runinfo ver.1.58 Exp3 Run1 - Exp69 Run485 BELLE LEVEL latest: day is not 24 hours



Target: 8 × 10^35 cm^-2s^-1
= 50 x World Record (KEKB)
Peak Luminosity trends in last 30 years
Peak luminosity (cm^-2 s^-1)
10^34
10^33
10^32
10^31
10^30
10^29
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
KEKB
PEP II
CESR
TEVATRON
CESR-C
LEP2
HERA
ISR
PETRA
PEP
TRISTAN
DORIS
LEP1
SPEAR
SppS

Strategy: Nano-Beam Option

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

Lorentz factor

Beam current

Beam-beam parameter

Classical electron radius

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

Vertical beta function@IP

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

(1) Smaller β_y^*

- 6.5(LER)/5.9(HER) mm→0.22/0.22 mm

(2)Increase beam currents

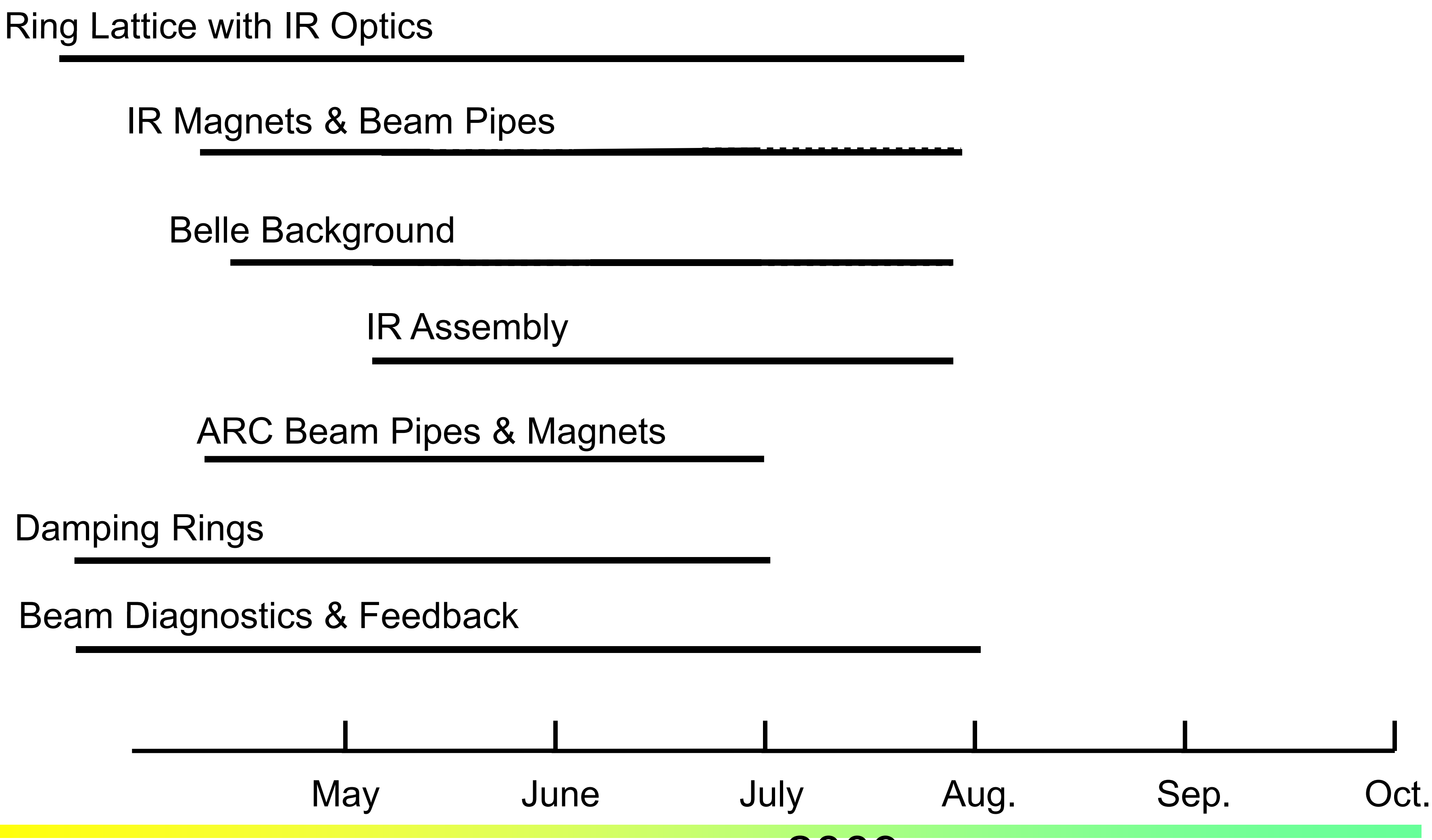
- 1.7 A (LER) / 1.4 A (HER) → 2.96 A (LER) / 1.5 A (HER)
  - Close to original KEKB design

~~(3) Increase ξ_y~~

- 0.1(LER)/0.06(HER) → 0.07/0.07

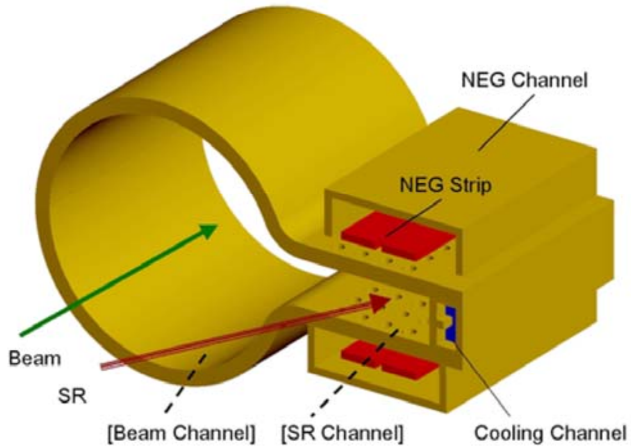
Proposed by P. Raimondi et al., along with Crab Waist, for use at Italian Super B Factory

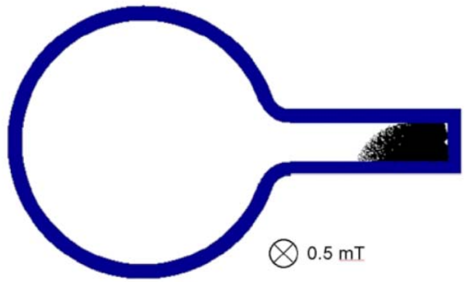
Preliminary Time Table for Nano-Beam Option Evaluation



Super-KEKB (cont'd)

- Ante-chamber /solenoid for reduction of electron clouds

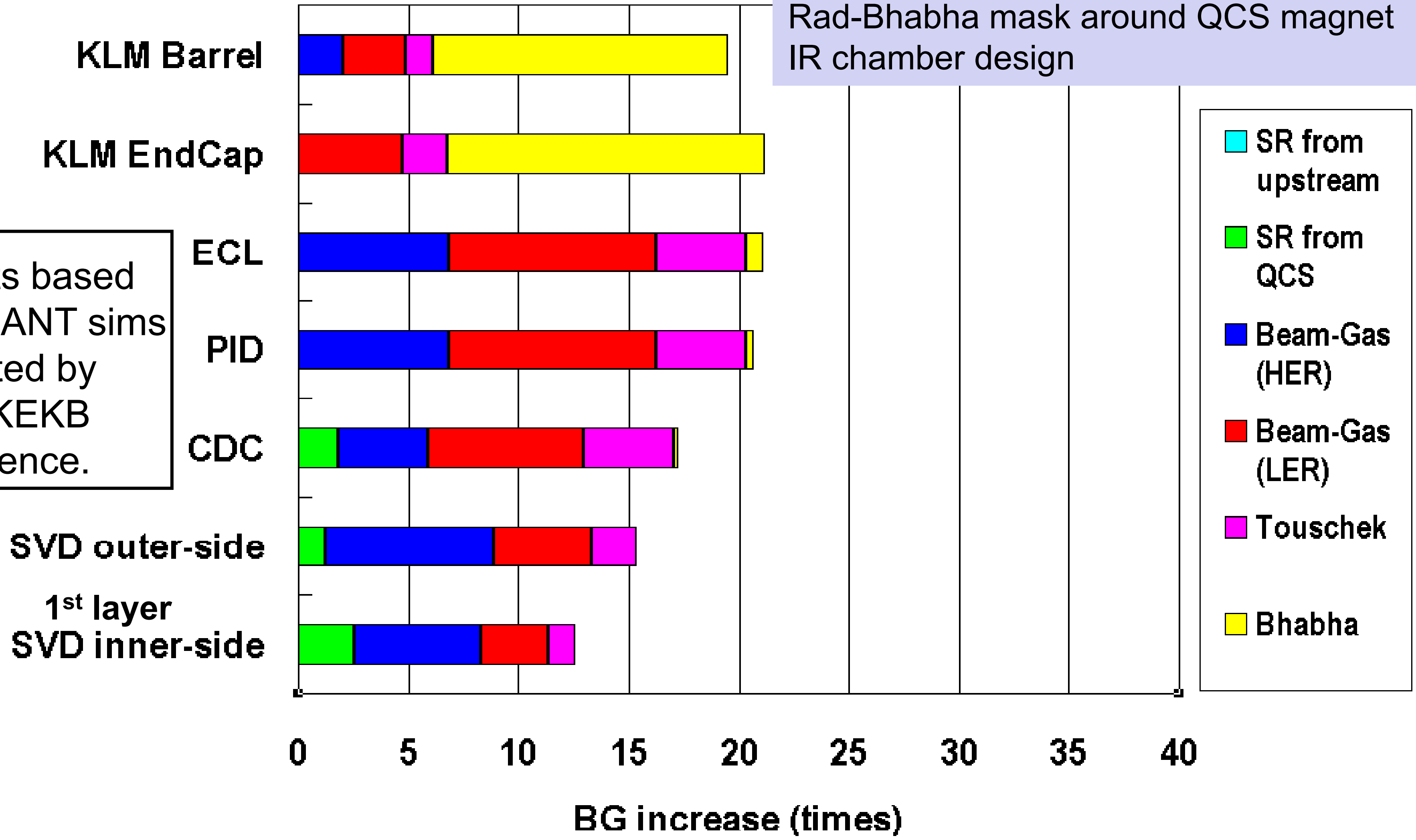




Beam Background (after 1st optimization)

Rad-Bhabha mask around QCS magnet
IR chamber design

Results based on GEANT sims validated by Belle/KEKB experience.



Conservative, robust detector should handle up to 20 times more background

Model-indep. check of NP

- A_{cp} (Kπ) sum rule

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

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

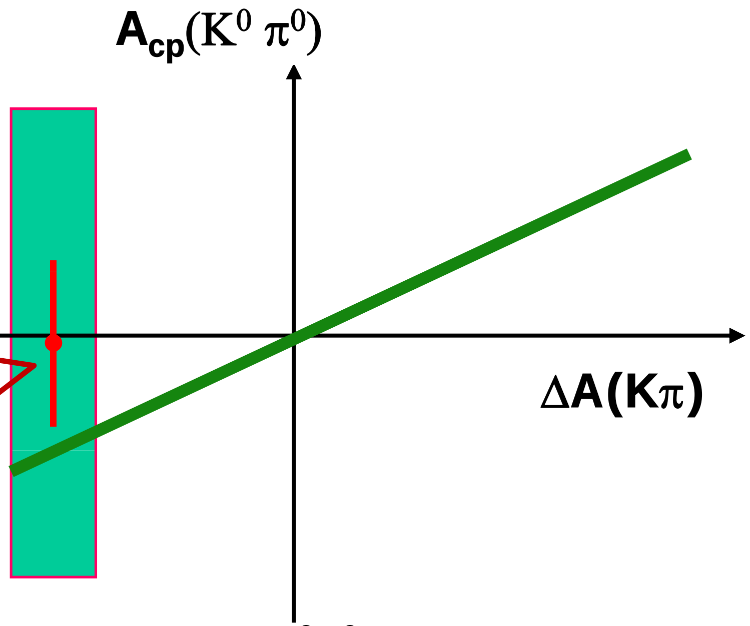
$$\mathcal{A}_{CP}(K^+\pi^-)+\mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}=\mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}+\mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

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

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

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

HFAG AVG: -0.01 ± 0.10



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

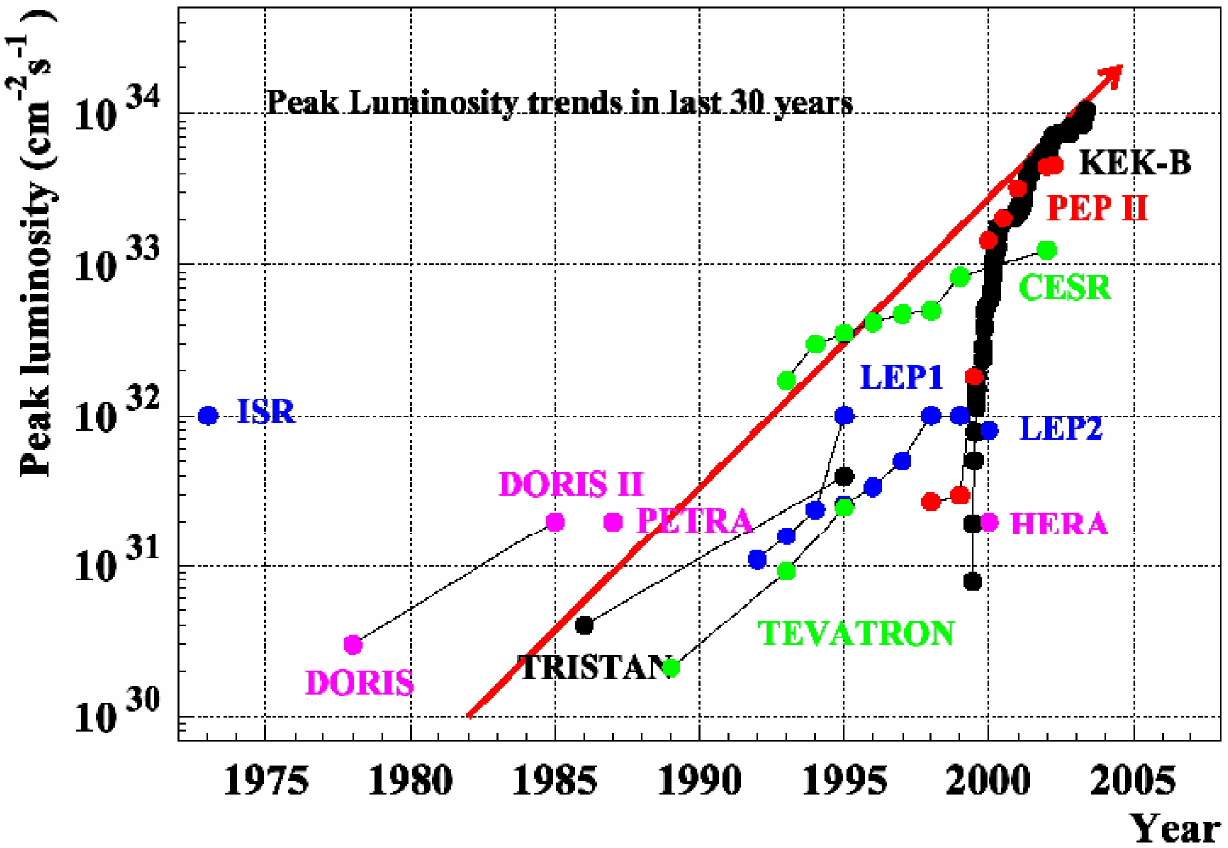
$$\Gamma^{SM}(B^+ \to \ell_1^+ \nu) / \Gamma^{SM}(B^+ \to \ell_2^+ \nu) = \frac{m_{l1}^2}{m_{l2}^2} \frac{(1 - m_{l1}^2 / m_B^2)^2}{(1 - m_{l2}^2 / m_B^2)^2}$$

Comparison with LHCb

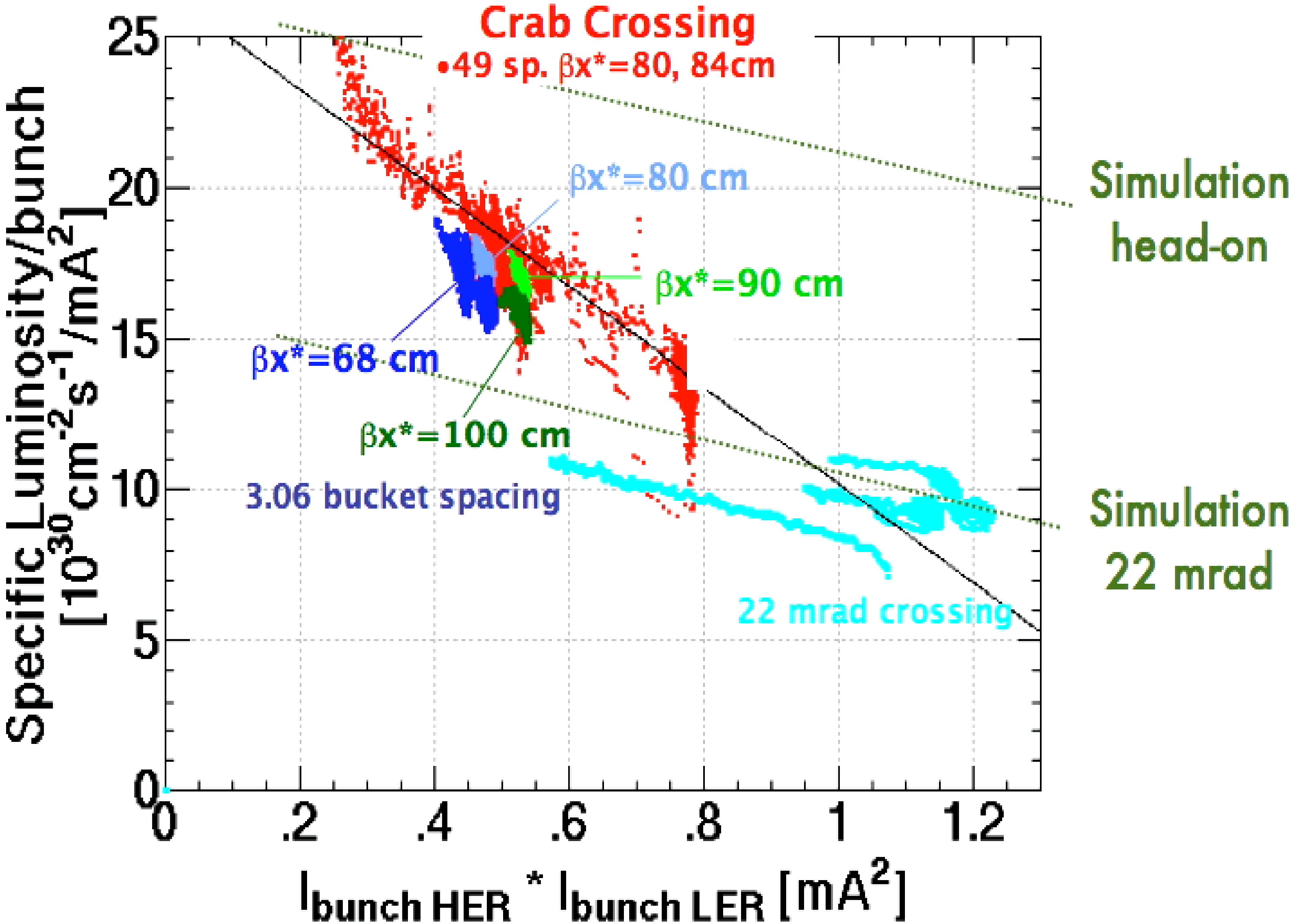
e^+e^- has advantages in…	LHCb has advantages in…
CPV in $B\to\phi K_S$, $\eta' K_S$,…	CPV in $B\to J/\psi K_S$
CPV in $B\to K_S\pi^0\gamma$	Most of B decays not including ν or γ
$B\to K\nu\nu$, $\tau\nu$, $D^{(*)}\tau\nu$	Time dependent measurements of B_S
Inclusive $b\to s\mu\mu$, *see*	$B_{(s,d)}\to\mu\mu$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

Complementary!!

Luminosity and accelerators vs time



Crab cavity commissioning



Rare decays - prospects

- Radiative, electroweak and tauonic B decays are of great importance to probe new physics.

- We are starting to measure B→ $\tau\nu$, $K\nu\nu$, $D\tau\nu$, $A_{FB}(K^*ll)$, $A_{CP}(K\pi^0\gamma)$ etc. at the current B factories.

  →Hot topics in the coming years !

- For precise measurements, we need a Super-B factory!

→Observe $K^{(*)}\nu\nu$, zero crossing in A_{FB}, $D^{(*)}\tau\nu$

→ Expected precision ($5ab^{-1}$→$50ab^{-1}$);

  - Br($\tau\nu$): 13%→7%
  - Br($D^{(*)}\tau\nu$): 7.9%→2.5%
  - q_0^2 of $A_{FB}(K^*ll)$: 11%→5%
  - $A_{CP}(K\pi^0\gamma)$ tCPV: 0.14→0.04

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

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

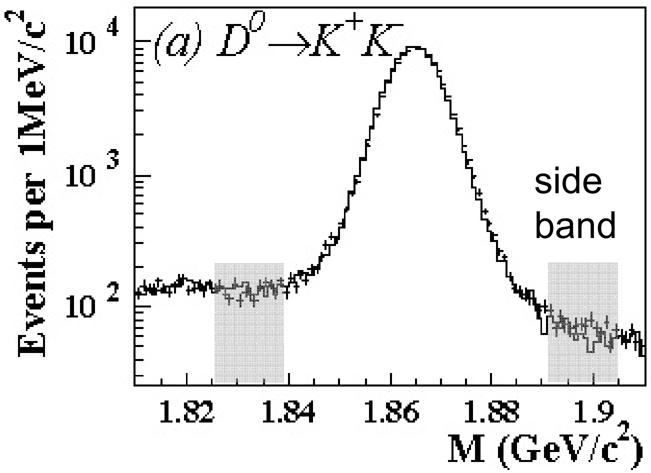
$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$$

CP even final state;
in the limit of no CPV: CP$|D_1\rangle = |D_1\rangle$
$\Rightarrow$ measure $1/\Gamma_1$

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

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

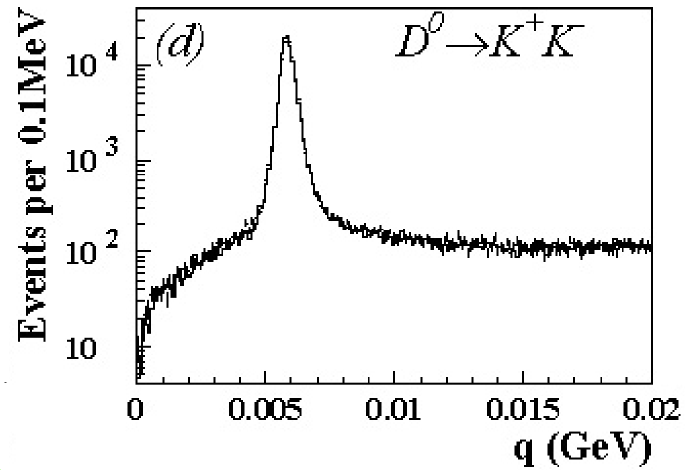
A_M, ϕ: CPV in mixing and interference



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%



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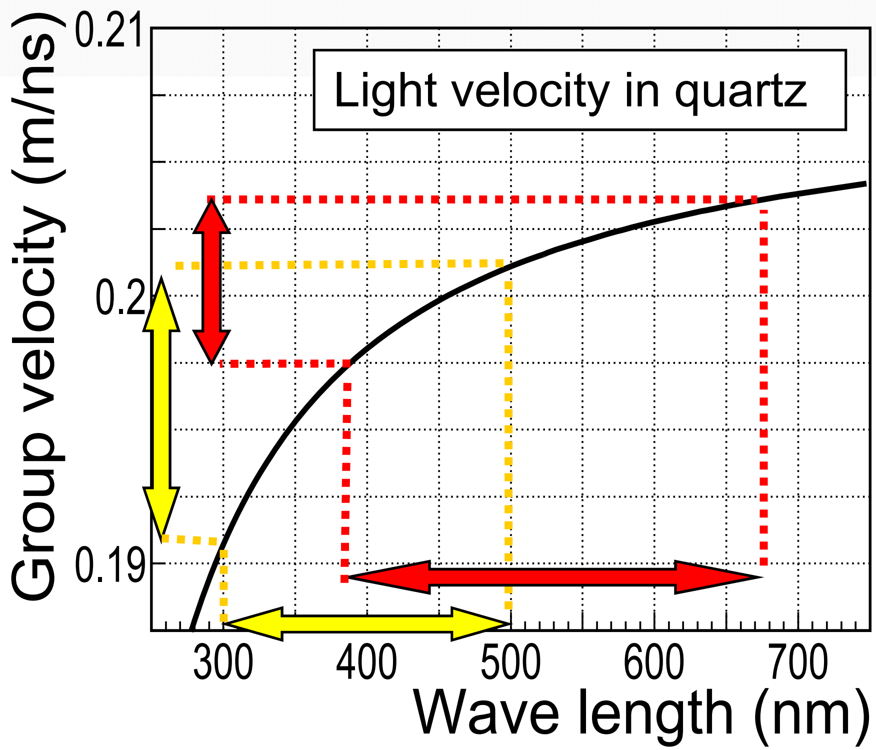
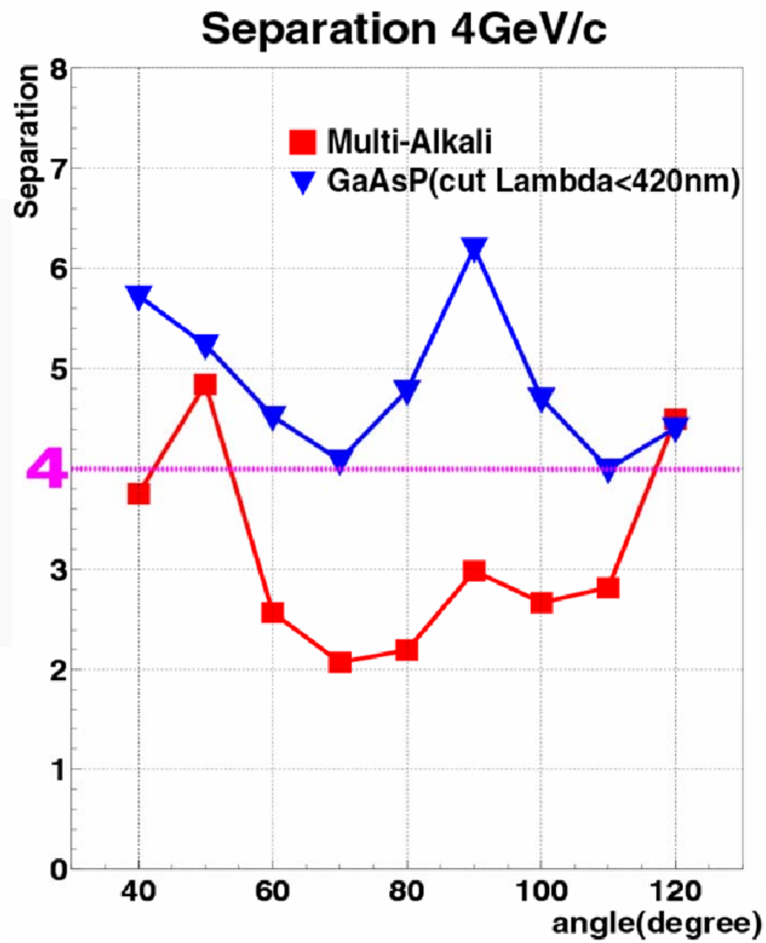
TOP counter MC

Expected performance with:

bi-alkali photocathode: <4σ p/K separation at 4GeV/c (← chromatic dispersion)





with GaAsP photocathode: >4σ π/K separation at 4GeV/c