Seminar, Birmingham University, Dec 14, 2011

From Belle to Belle II

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Contents

- Highlights from B factories (+ a little bit of history)
- Physics case for a super B factory
- Accellerator and detector upgrade → SuperKEKB + Belle-II
- Status and outlook

A little bit of history...

CP violation: difference in the properties of particles and their anti-particles – first observed in 1964 in the decays of neutral kaons.

M. Kobayashi and T. Maskawa (1973): CP violation in the Standard model – related to the weak interaction quark transition matrix

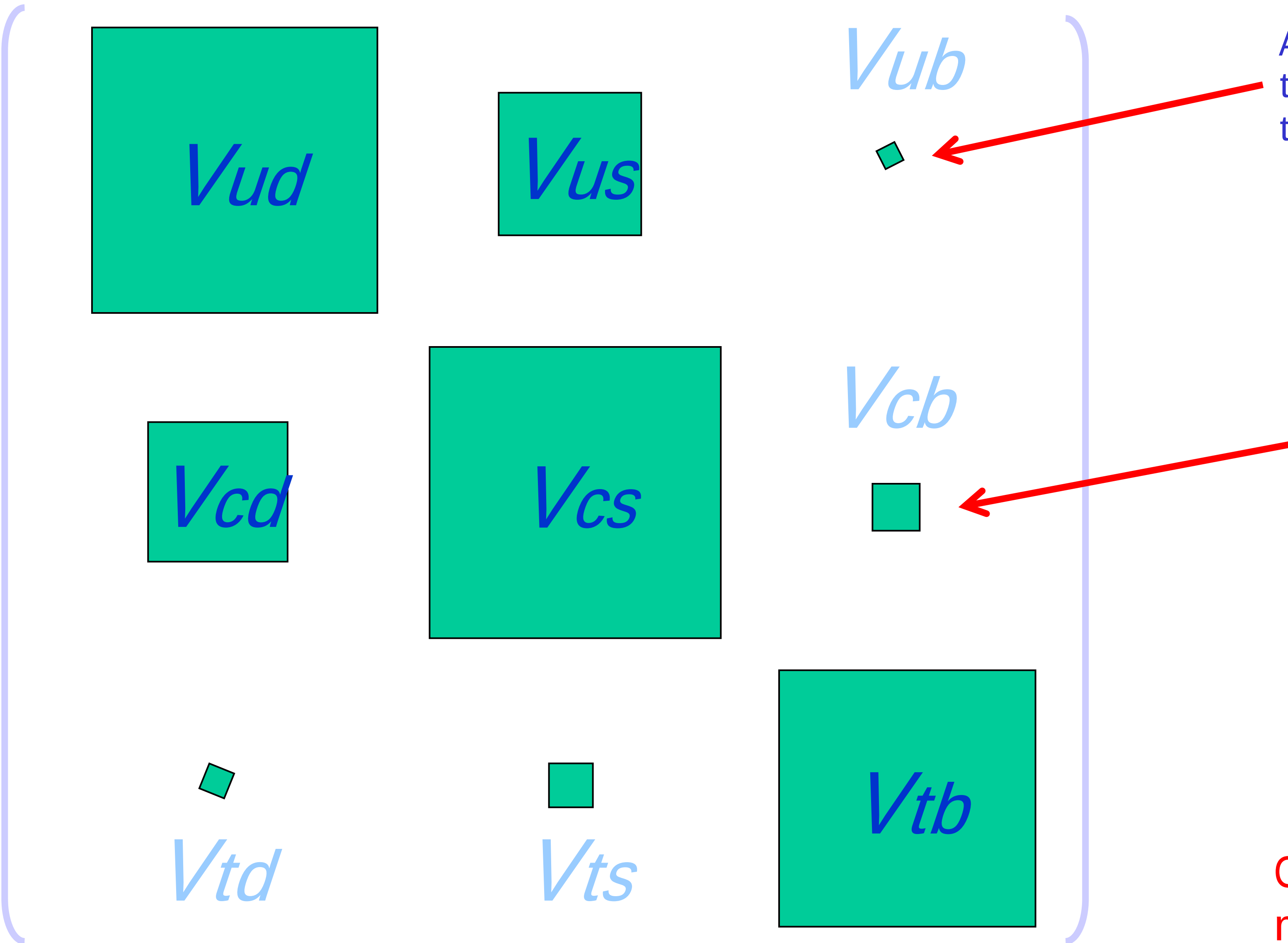
Their theory was formulated at a time when three quarks were known – and they requested the existence of three more!

The last missing quark was found in 1994.

… and in 2001 two experiments – Belle and BaBar at two powerfull accelerators (B factories) - have further investigated CP violation and have indeed proven that it is tightly connected to the quark transition matrix

CKM - Cabibbo-Kobayashi-Maskawa (quark transition) matrix:

almost real and diagonal, but not completely!



Amplitude for the b → u transition

Amplitude for the b → c transition

CKM: unitary matrix

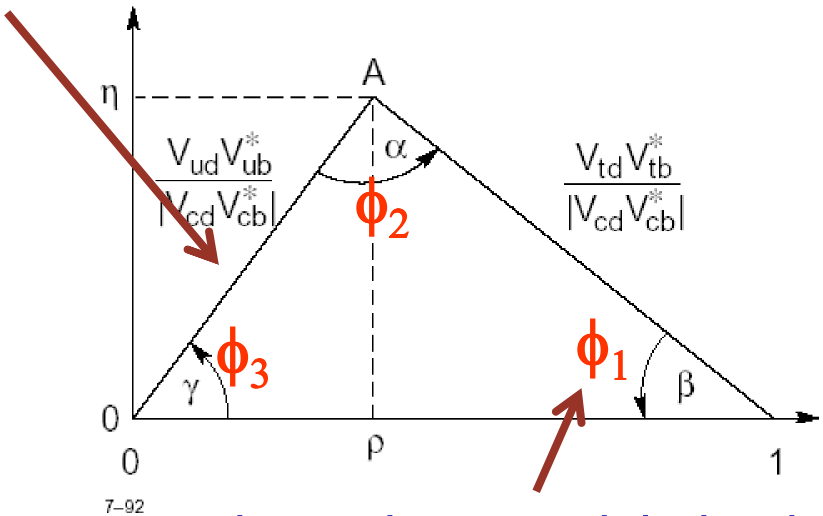
CKM matrix: determines charged weak interaction of quarks

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

A, ρ and η: all of order one

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

determines probability of b→u transitions



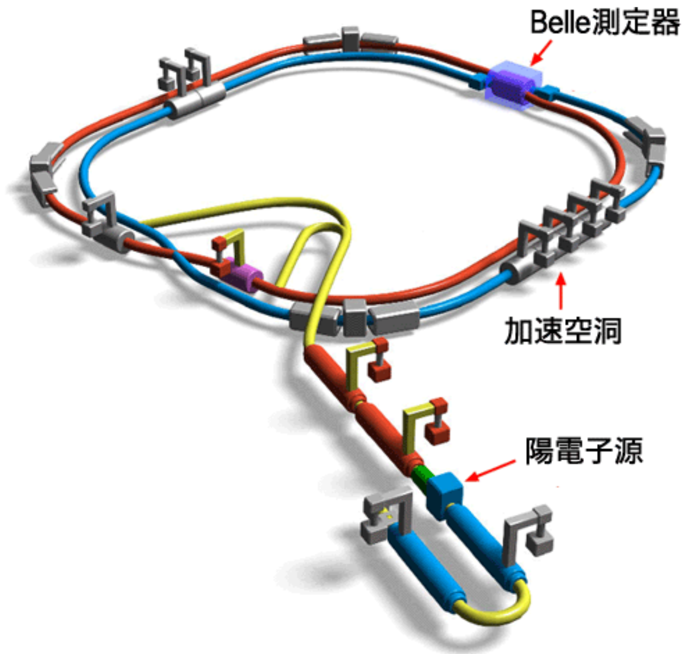
determines CP violation in B→J/ψ K_S decays

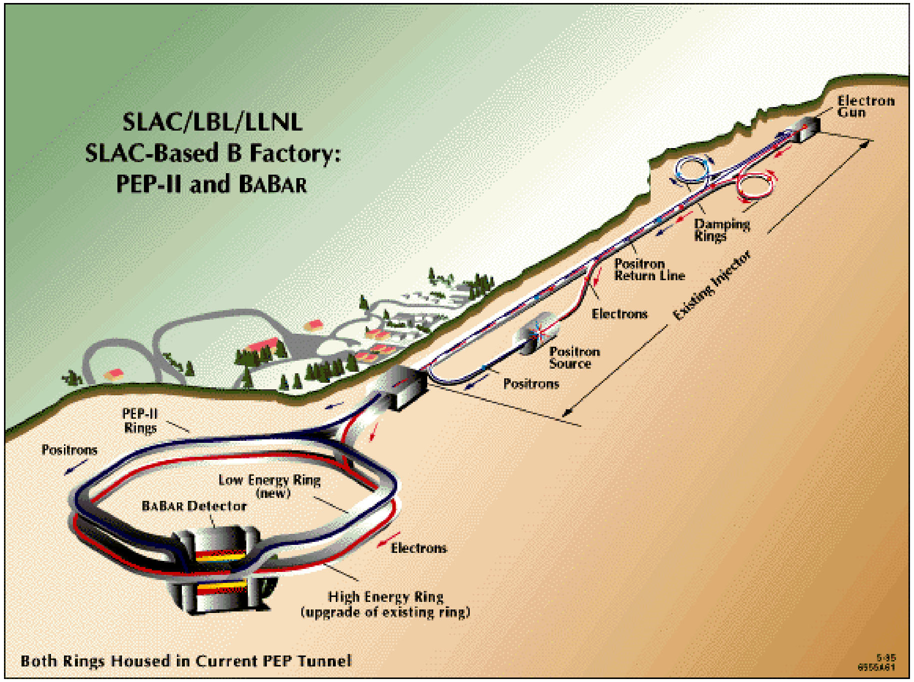
Unitarity condition:

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

Goal: measure sides and angles in several different ways, check consistency →

Asymmetric B factories





$\sqrt{s}$=10.58 GeV

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

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

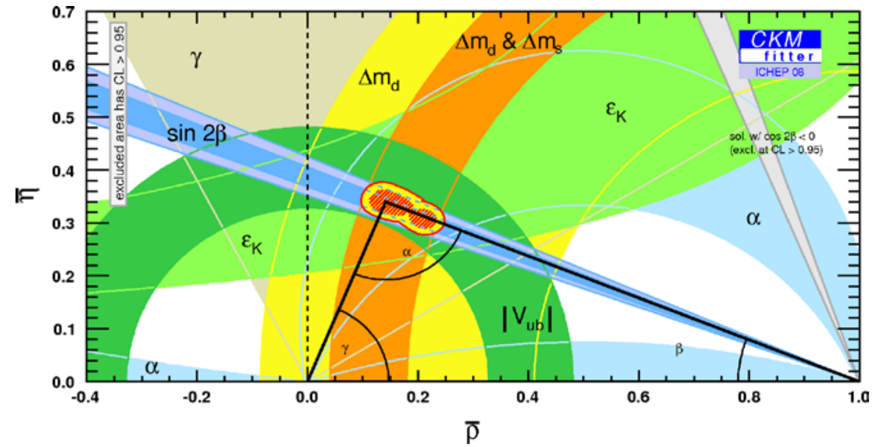
$\Delta z \sim c\beta\gamma\tau_B$
$\sim 200\mu m$

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

KM's bold idea verified by experiment

Relations between parameters as expected in the Standard model →

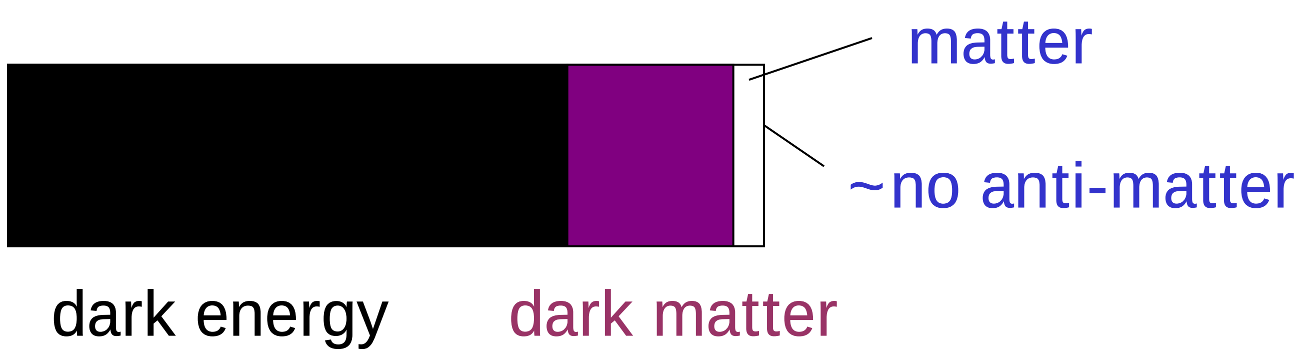


Nobel prize 2008!

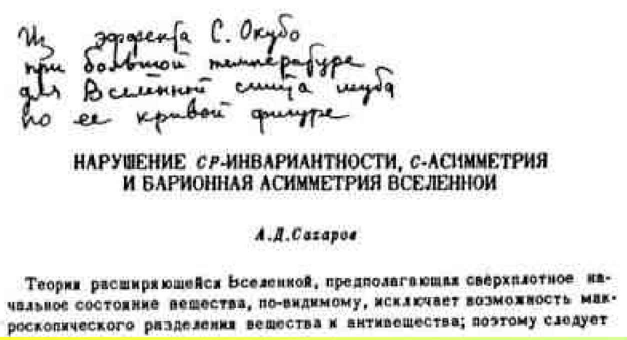
→ With essential experimental confirmations by BaBar and Belle! (explicitly noted in the Nobel Prize citation)

The KM scheme is now part of the Standard Model of Particle Physics

- However, the CP violation of the KM mechanism is too small to account for the asymmetry between matter and anti-matter in the Universe (falls short by 10 orders of magnitude !)
- SM does not contain the fourth fundamental interaction, gravitation
- Most of the Universe is made of stuff we do not understand...



Are we done ? (Didn't the B factories accomplish their mission, recognized by the 2008 Nobel Prize in Physics ?)



Из эффекта С. Окубо
при большой температуре
для Вселенной сшита шуба
по ее кривой фигуре

НАРУШЕНИЕ CP-ИНВАРИАНТНОСТИ, C-АСИММЕТРИЯ
И БАРИОННАЯ АСИММЕТРИЯ ВСЕЛЕННОЙ

А.Д.Сахаров

Теория расширяющейся Вселенной, предполагающая сверхплотное начальное состояние вещества, по-видимому, исключает возможность макроскопического разделения вещества и антивещества; поэтому следует

Matter - anti-matter asymmetry of the Universe: KM (Kobayashi-Maskawa) mechanism still short by 10 orders of magnitude !!!

Two frontiers

Two complementary approaches to study shortcomings of the Standard Model and to search for the so far unobserved processes and particles (so called New Physics, NP). These are the **energy frontier** and the **intensity frontier** .

Energy frontier : direct search for production of unknown particles at the highest achievable energies.

Intensity frontier : search for rare processes, deviations between theory predictions and experiments with the ultimate precision.

→for this kind of studies, one has to investigate a very large number of reactions events → need accelerators with ultimate **intensity** (= luminosity)

Comparison of **energy** /**intensity** frontiers

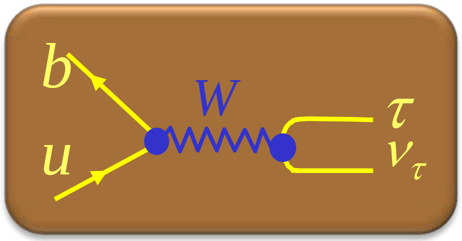
To observe a large ship far away one can either use **strong binoculars** or observe **carefully the direction and the speed of waves** produced by the vessel.

Energy frontier (LHC)

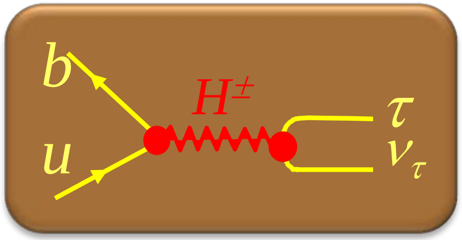
Luminosity frontier (Belle and Belle II)

An example: Hunting the charged Higgs in the decay $B^- \rightarrow \tau^- \nu_\tau$

In addition to the Standard Model Higgs to be discovered at the LHC, in New Physics (e.g., in supersymmetric theories) there could also be a charged Higgs.



The rare decay $B^- \rightarrow \tau^- \nu_\tau$ is in SM mediated by the W boson

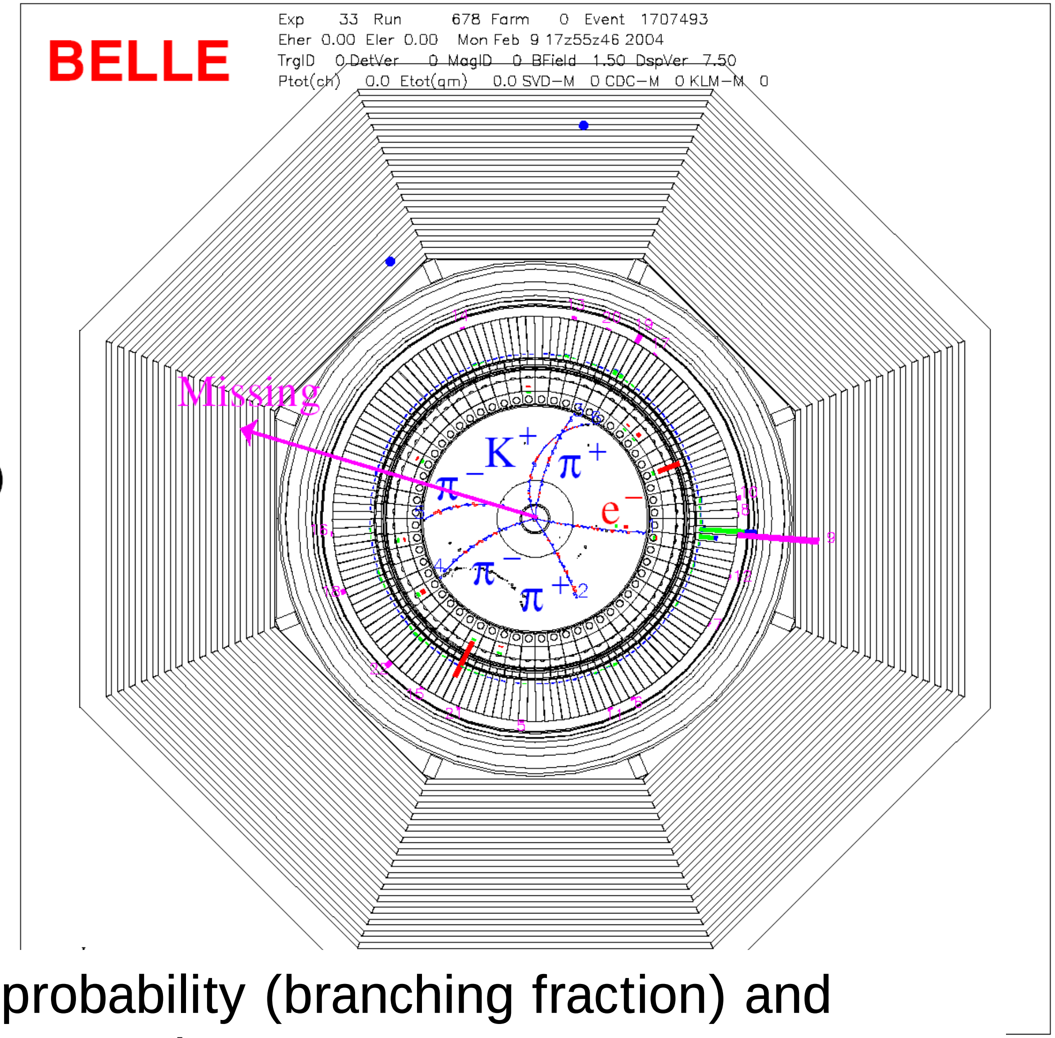


In some supersymmetric extensions it can also proceed via a charged Higgs

The charged Higgs would influence the decay of a B meson to a tau lepton and its neutrino, and modify the probability for this decay.

Missing Energy Decays: $B^- \to \tau^- \nu_\tau$

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



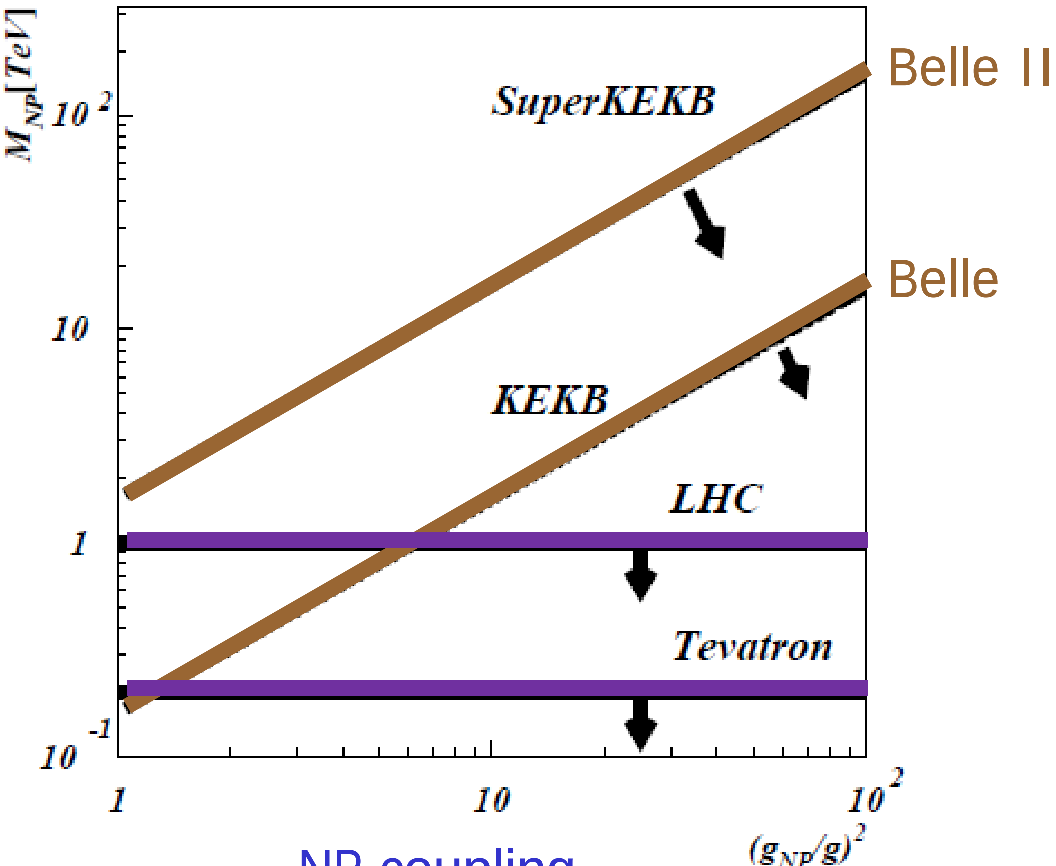
By measuring the decay probability (branching fraction) and comparing it to the SM expectation:

→ Properties of the charged Higgs (e.g. its mass)

New Physics reach

energy frontier vs. **intensity frontier**

NP mass scale (TeV)

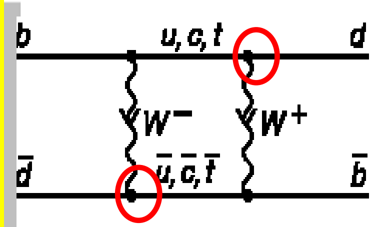


NP coupling

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



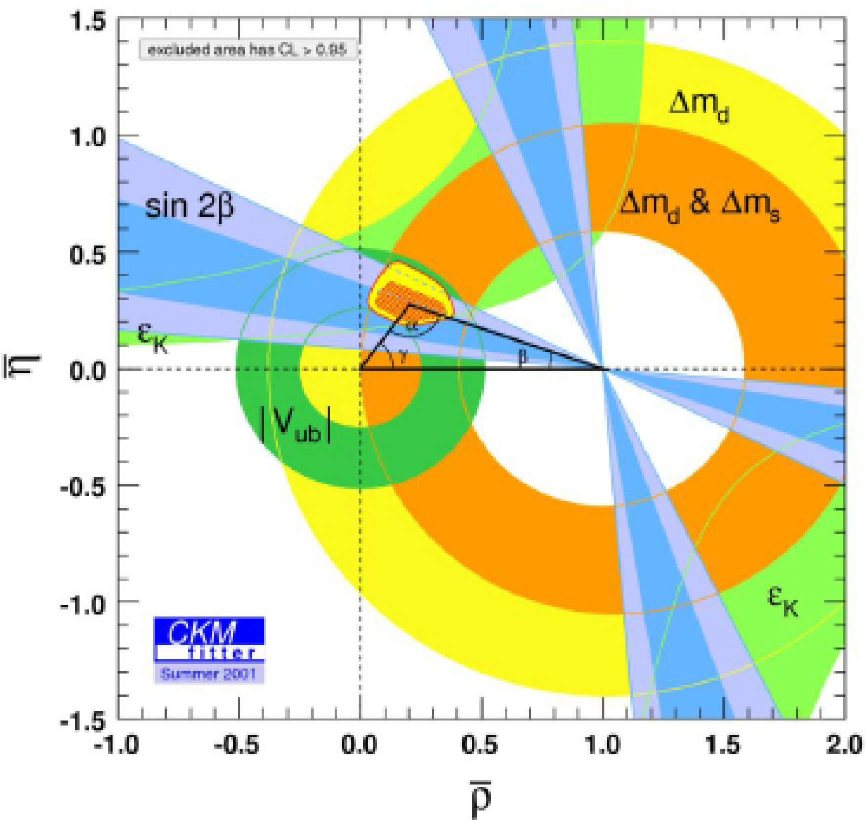
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

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

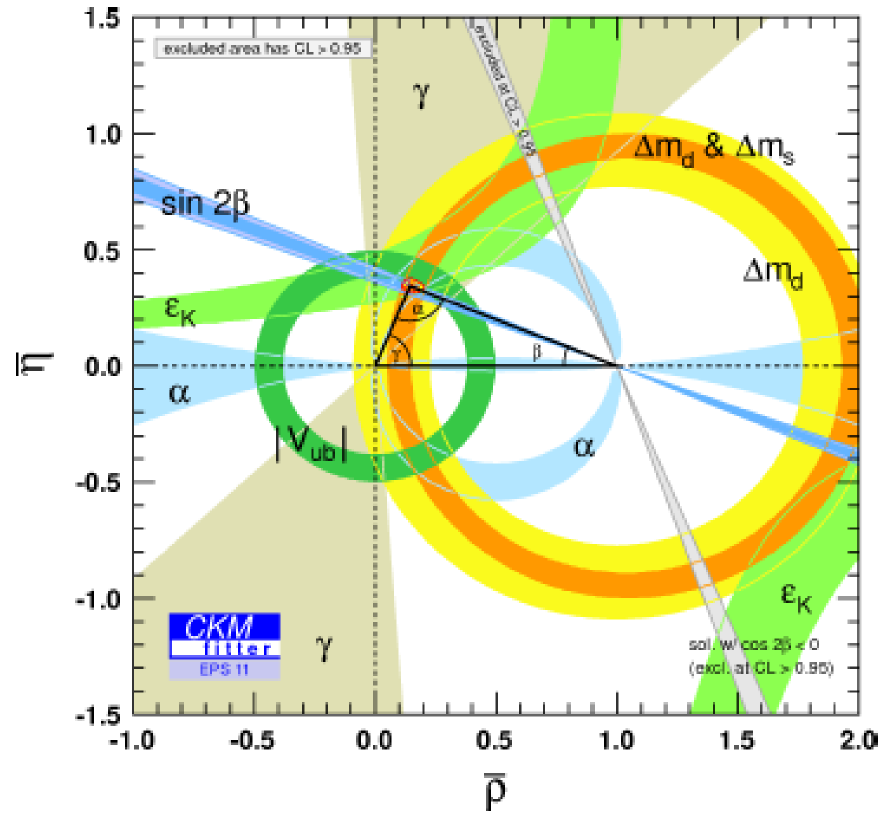
Unitarity triangle – 2011 vs 2001

CP violation in the B system: from the discovery (2001) to a precision measurement (2011).

EPS 2001



EPS 2011



Unitarity triangle – new measurements

Constraints from measurements of angles and sides of the unitarity triangle → Remarkable agreement, but still 10-20% NP allowed

→ search for New Physics!

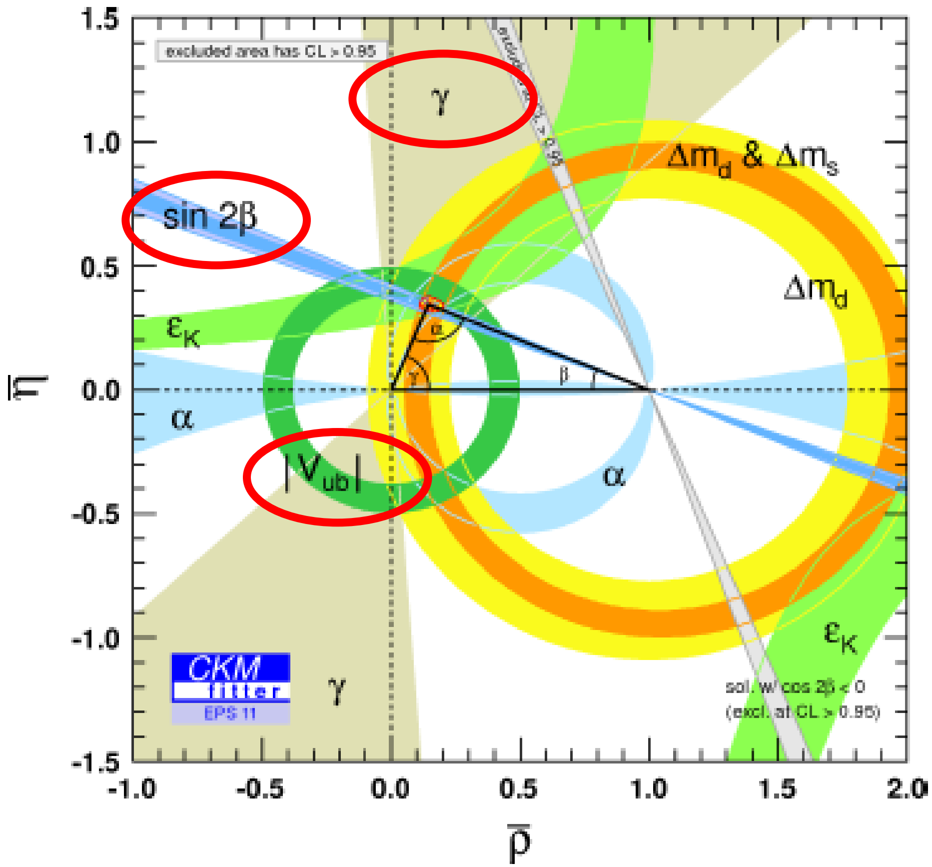
This summer:

Unitarity triangle:

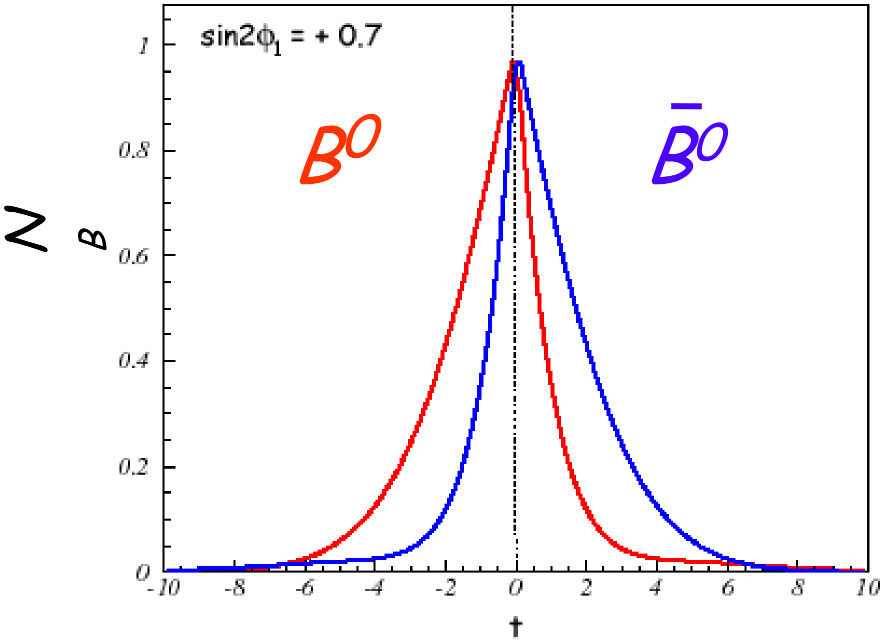
→ $\sin 2\phi_1$ (=$\sin 2\beta$) : final measurement from Belle

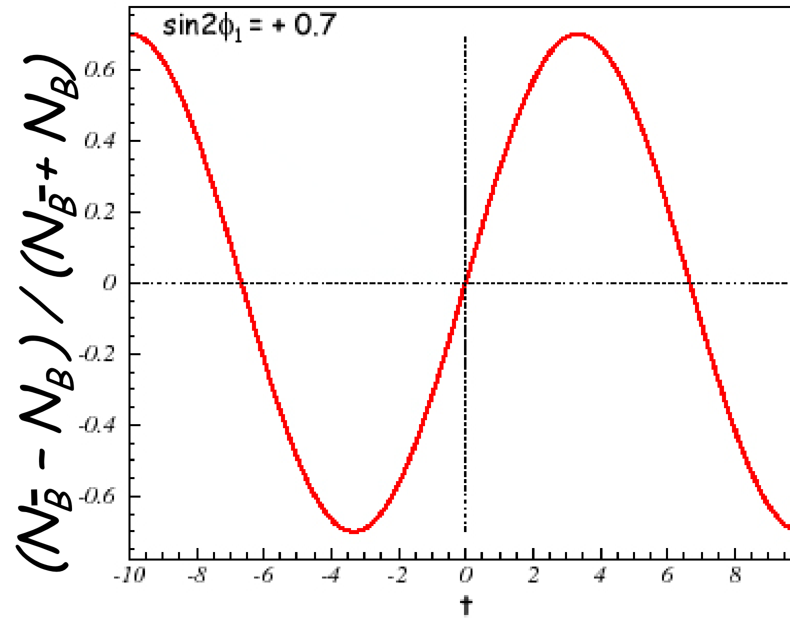
→ ϕ_3 (=γ) new model-independent method

→ $|V_{ub}|$ from exclusive and inclusive semileptonic decays



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

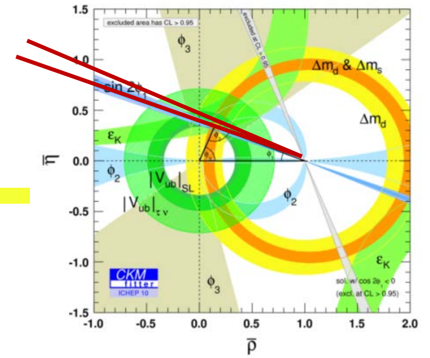




$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\overline{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} = S \sin \Delta m_B t + A \cos \Delta m_B t$$

- $B^0 \to J/\psi K^0$ in SM: S=sin2ϕ_1 (=sin2β), A=0

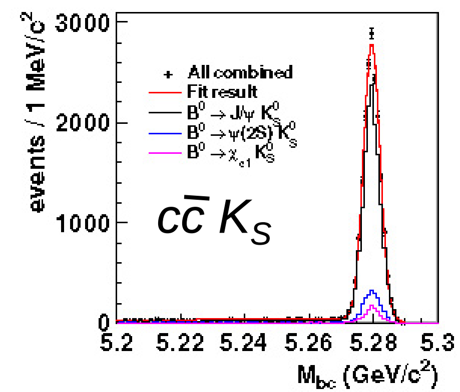
Final measurement of $\sin2\phi_1$ (=$\sin2\beta$)



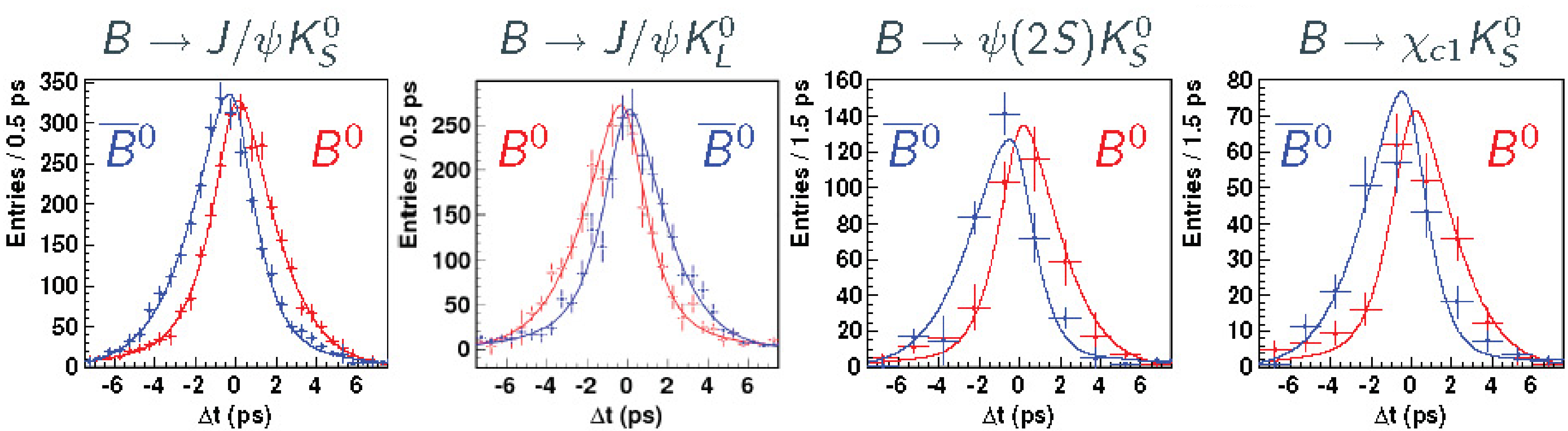
Belle, preliminary, 710 fb^{-1}

ϕ_1 from CP violation
measurements in $B^0 \rightarrow c\bar{c}\,K^0$

Improved tracking, more data
(50% more statistics than last result with 480 fb^{-1});
$c\bar{c}$ = J/ψ, $\psi(2S)$, χ_{c1} → 25k events



detector effects: wrong tagging, finite Δt resolution,
determined using control data samples



Final measurement of $\sin 2\phi_1$ (=$\sin 2\beta$)

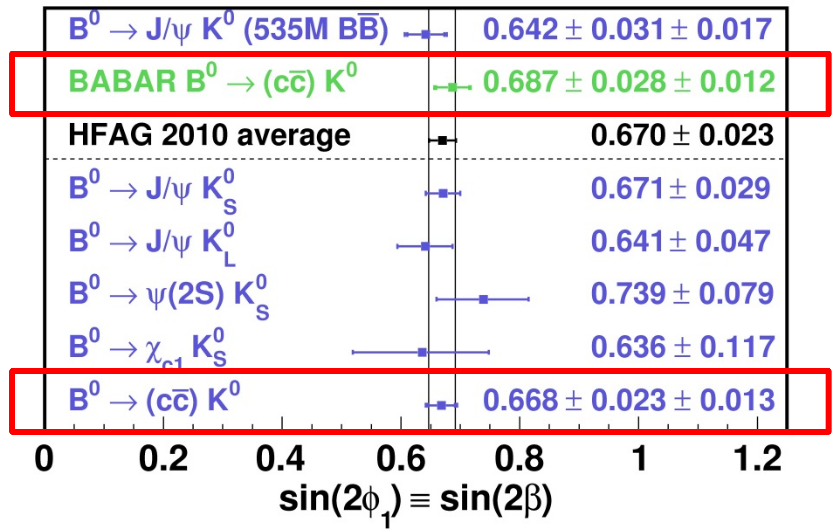
ϕ_1 from $B^0 \to c\bar{c}\, K^0$

Final result (preliminary) from Belle:

S= 0.668 ± 0.023 ± 0.013
A= 0.007 ± 0.016 ± 0.013

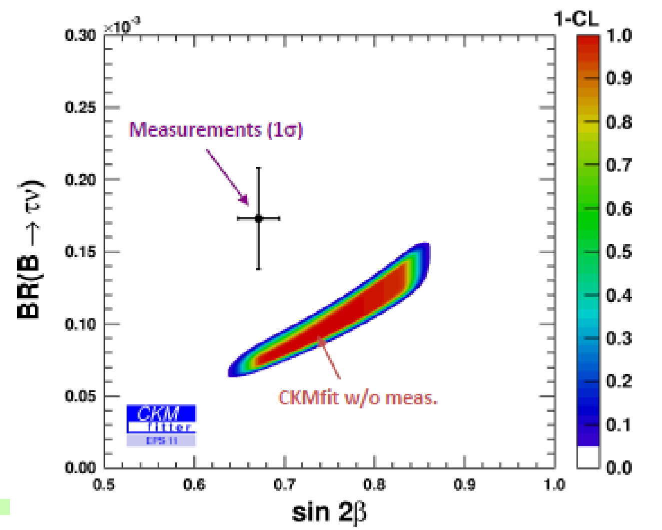
(SM: $S=\sin 2\phi_1$ (=$\sin 2\beta$), A=0)

Belle, preliminary, 710 fb^{-1}



Still statistics limited, part of the syst. is statistics dominated!

Tension between $\mathcal{B}(B\to \tau\nu)$ and $\sin 2\phi_1$ (~2.5 σ) remains



CP violation in B → D^+D^- and $D^{*+}D^{*-}$

SM: $b \to c\bar{c}d$, $S = \sin 2\phi_1$ ($= \sin 2\beta$), $A = 0$

B → D^+D^-

Belle preliminary

$$S = -1.06 \pm 0.18 \pm 0.07$$

$$A = +0.43 \pm 0.16 \pm 0.04$$

772 x 10^6 $B\bar{B}$ pairs

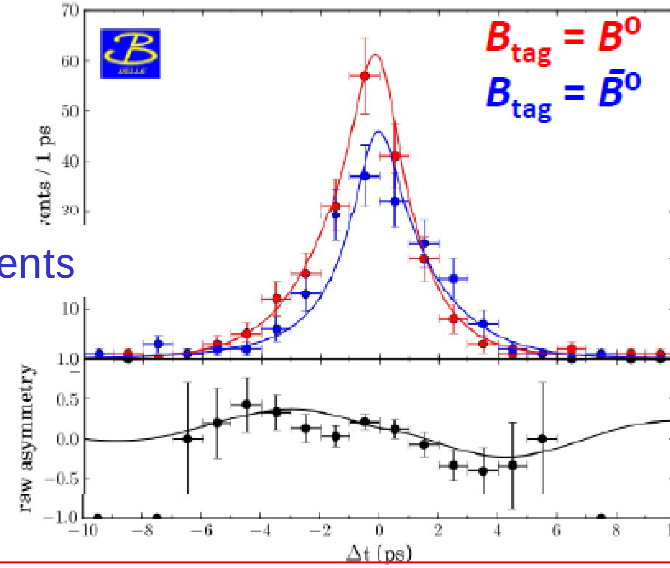
$B^0 \to (K^-\pi^+\pi^+)(K^+\pi^-\pi^-)$, $(K^-\pi^+\pi^+)(K_S\pi^0)$+c.c.

Previous measurement (535x10^6 $B\bar{B}$ pairs):

$$S = -1.13 \pm 0.37 \pm 0.09,$$

$$A = +0.91 \pm 0.23 \pm 0.06$$

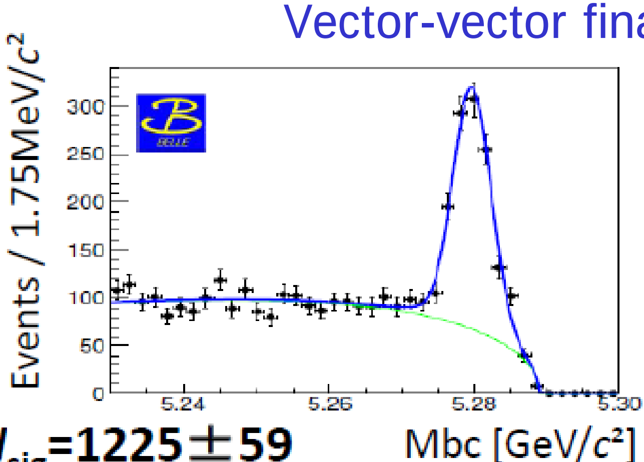
320 events



→ Large CP violation effects in many places in B decays!

B→$D^{*+}D^{*-}$

Vector-vector final state, need angular analysis for CPV measurement



N_{sig}=1225±59

1225 events, >2x increase in yield vs the 2009 paper

$$S = -0.79 \pm 0.13 \pm 0.03$$

$$A = +0.15 \pm 0.08 \pm 0.02$$

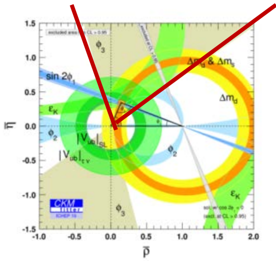
$$R_0 = 0.63 \pm 0.03 \pm 0.01$$

$$R_\perp = 0.14 \pm 0.02 \pm 0.01$$

772 x 10^6 $B\bar{B}$ pairs

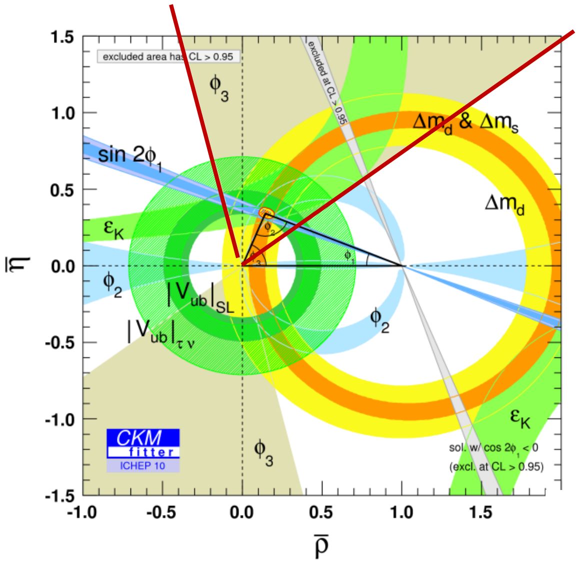
Belle preliminary

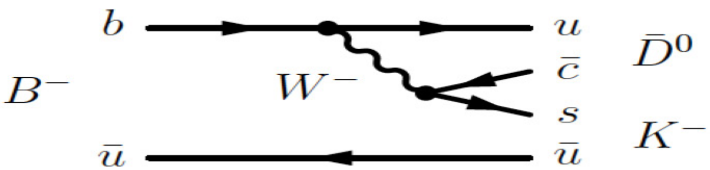
ϕ_3 (=γ) with Dalitz analysis



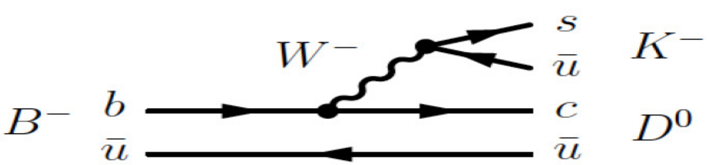
Dalitz method:

The best way to measure ϕ_3





Color+CKM suppressed



Favored

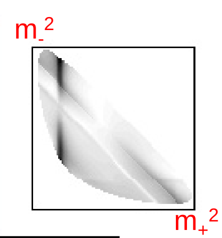
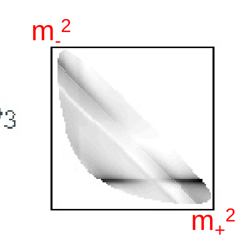
Giri et al., PRD68, 054018 (2003)
Bondar et al.

$\overset{(-)}{D^0} \rightarrow K_S\pi^+\pi^-$

$m_+ = m(K_S\pi^+)$
$m_- = m(K_S\pi^-)$

3-body $D^0 \rightarrow K_S\pi^+\pi^-$ Dalitz amplitude

$$|M_\pm(m_+^2, m_-^2)|^2 = |f_D(m_+^2, m_-^2) + re^{i\delta_B \pm i\phi_3} f_D(m_-^2, m_+^2)|^2$$

$$= \Bigg|$$  $$+ re^{i\delta_B \pm i\phi_3}$$  $$\Bigg|^2$$

model dependent description of f_D using continuum D* data ⇒ systematic uncertainty

ϕ_3=(78 ± 12 ± 4 ± 9)^o

ϕ_3=(68 ± 14 ± 4 ± 3)^o

Belle, PRD81, 112002, (2010), 605 fb^{-1}

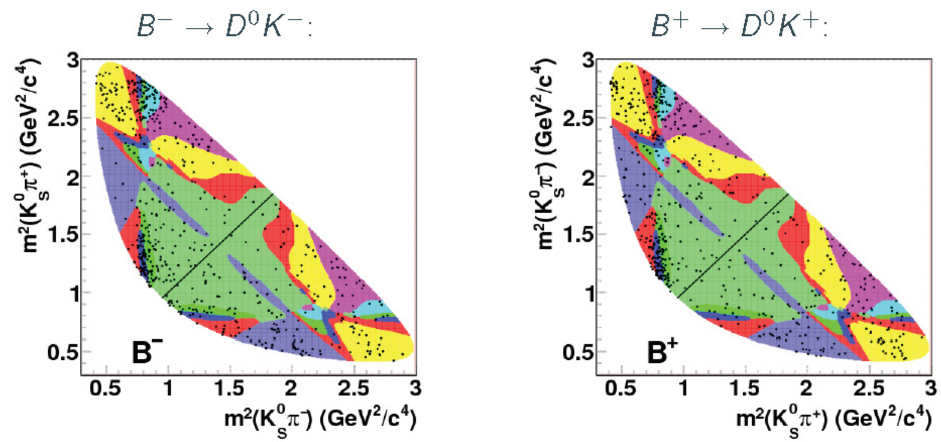
BaBar, PRL 105, 121801, (2010)

ϕ_3 (=γ) from model-independent/binned Dalitz method

Dalitz method: How to avoid the model dependence?
→ Suitably subdivide the Dalitz space into bins

$$M_i^{\pm} = h\{K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_{\pm} c_i + y_{\pm} s_i)\}$$

$$x_{\pm} = r_B \cos(\delta_B \pm \phi_3) \quad y_{\pm} = r_B \sin(\delta_B \pm \phi_3)$$



M_i: # B decays in bins of D Dalitz plane, K_i: # D^0 ($\overline{D^0}$) decays in bins of D Dalitz plane ($D^* \to D\pi$), c_i, s_i: strong ph. difference between symm. Dalitz points ← Cleo, PRD82, 112006 (2010)

Belle, 710 fb^{-1}
arXiv:1106.4046

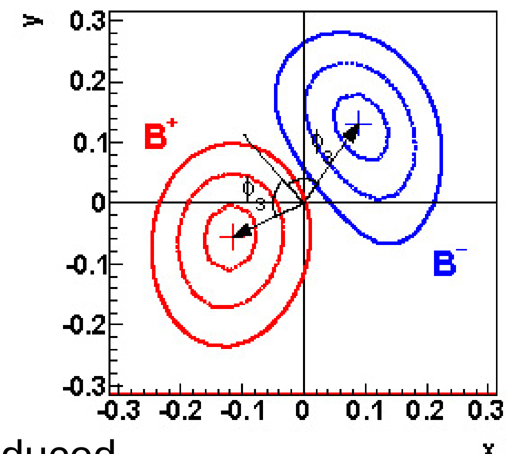
Use only DK
N_{sig} = 1176 ± 43

4-dim fit for signal yield (ΔE, M_{bc}, cosθ_{thrust}, $\mathcal{F}$);

ϕ_3=(77 ± 15 ± 4 ± 4)^o

from c_i, s_i (statist.!)

to be reduced with BESIII data



Important method upgrade for large event samples at LHCb and super B factories

ϕ_3 with the ADS method

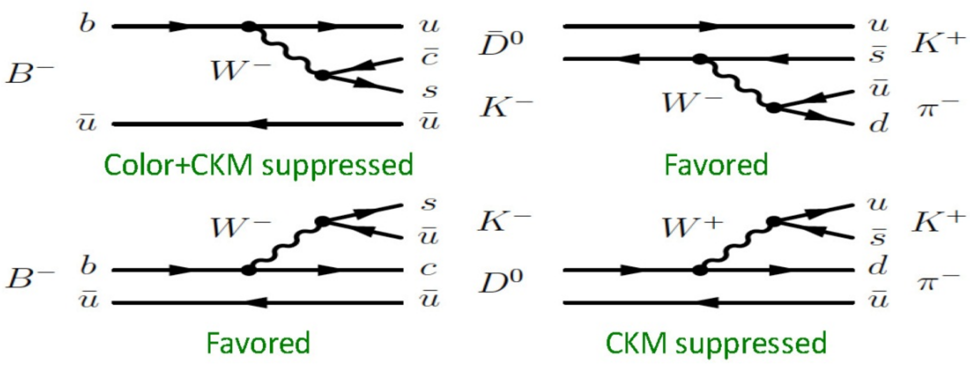
D. Atwood, I. Dunietz, A. Soni, PRL78, 3257 (1997)

$B^- \to [K^+\pi^-]_D K^-$ compared to
$B^- \to [K^-\pi^+]_D K^-$

$$\mathcal{R}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]_D K^-) + \mathcal{B}([K^-\pi^+]_D K^+)}{\mathcal{B}([K^-\pi^+]_D K^-) + \mathcal{B}([K^+\pi^-]_D K^+)}$$

$$\mathcal{A}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]_D K^-) - \mathcal{B}([K^-\pi^+]_D K^+)}{\mathcal{B}([K^+\pi^-]_D K^-) + \mathcal{B}([K^-\pi^+]_D K^+)}$$

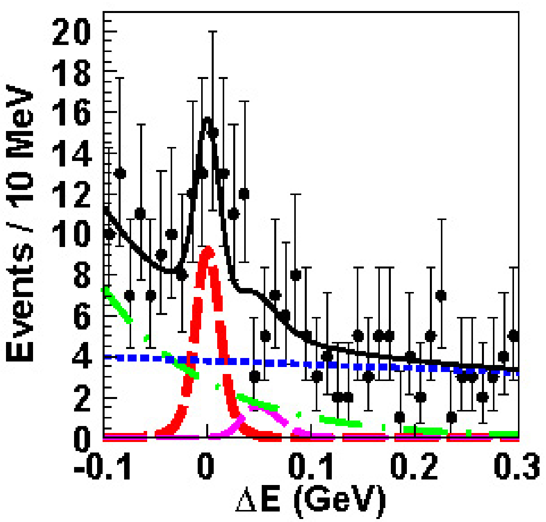
using additional input on r_B, r_D, ϕ_3 can be extracted in a model independ. manner



$$\mathcal{R}_{DK} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\phi_3,$$

$$\mathcal{A}_{DK} = 2r_B r_D \sin(\delta_B + \delta_D)\sin\phi_3/\mathcal{R}_{DK},$$

Breakthrough 2011: first evidence of the CKM supressed mode



$B^- \to [K^+\pi^-]_D K^-$
N_{sig}=56 ±15, 4.1 σ sign.,

$R_{DK}=(1.63\,^{+0.44}_{-0.41}\,^{+0.07}_{-0.13})\cdot 10^{-2}$
$A_{DK}= -0.39\,^{+0.26}_{-0.28}\,^{+0.04}_{-0.03}$

Belle, PRL 106, 231803 (2011)
arXiv:1103:5951, 710 fb^{-1}

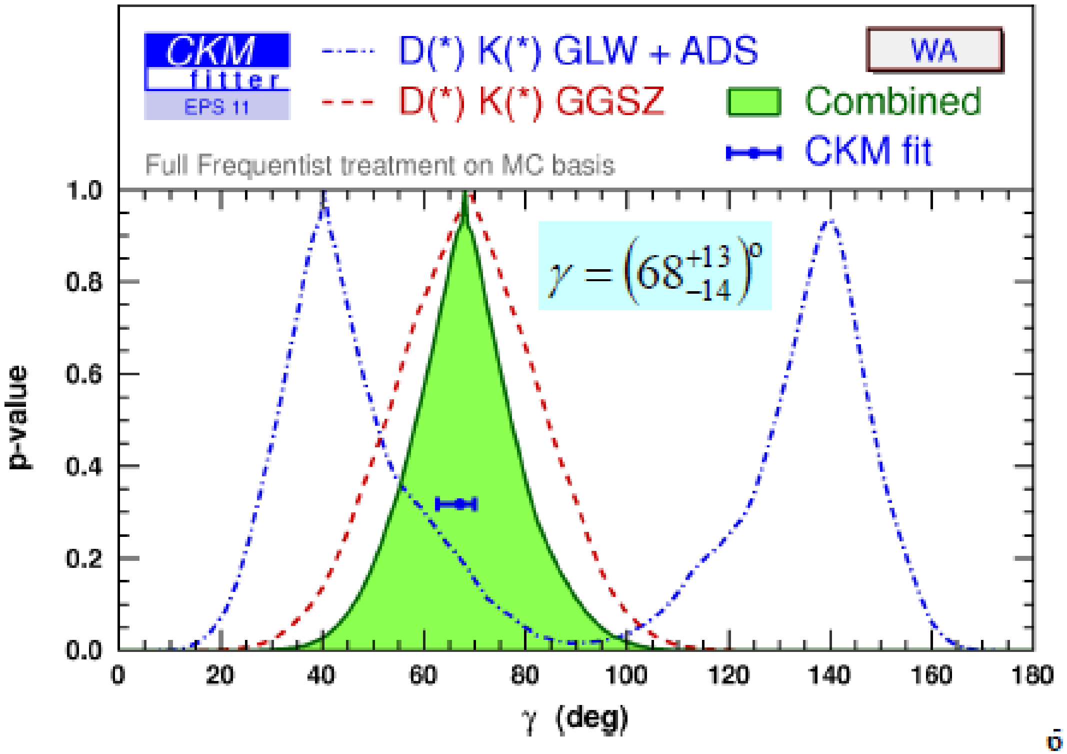
ϕ_3 measurement

Combined ϕ_3 value:

$\phi_3 = (68\ ^{+13}_{-14})$ degrees

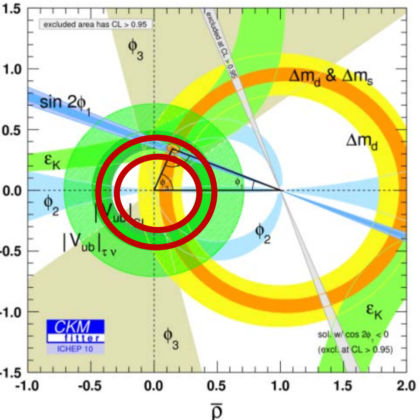
Note that B factories were not built to measure ϕ_3

It turned out much better than planned!



This is not the last word from B factories, analyses still to be finalized...

$|V_{ub}|$ from $B^0 \to \pi^- \ell^+ \nu$ exclusive decays



Yield: 2d fit in M_{bc}=M_{ES} and ΔE, bins of q^2

$$m_{bc} = \sqrt{E_{\text{beam}}^2 - |\vec{p_\pi} + \vec{p_\ell} + \vec{p_\nu}|^2}$$
$$\Delta E = E_{\text{beam}} - (E_\pi + E_\ell + E_\nu)$$

$\mathcal{B}$=(1.41±0.05±0.07)·10^{-4}

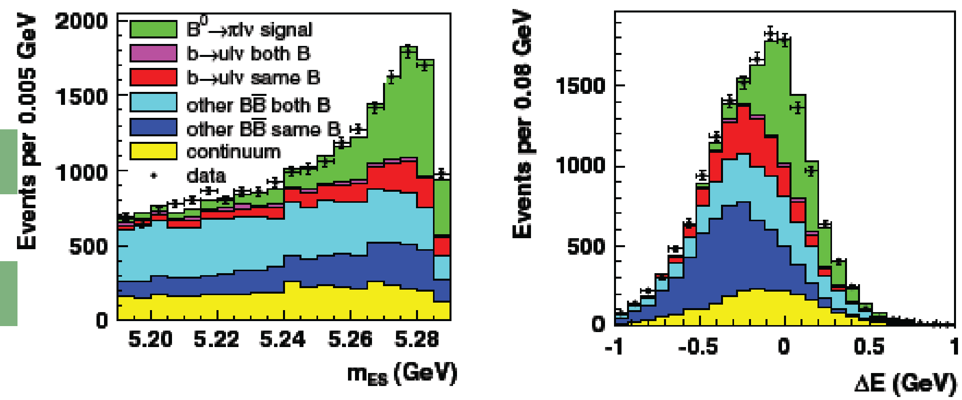
BaBar, PRD83, 032007 (2011)

$\mathcal{B}$=(1.42±0.05±0.07)·10^{-4}

BaBar, PRD83, 052011 (2011)

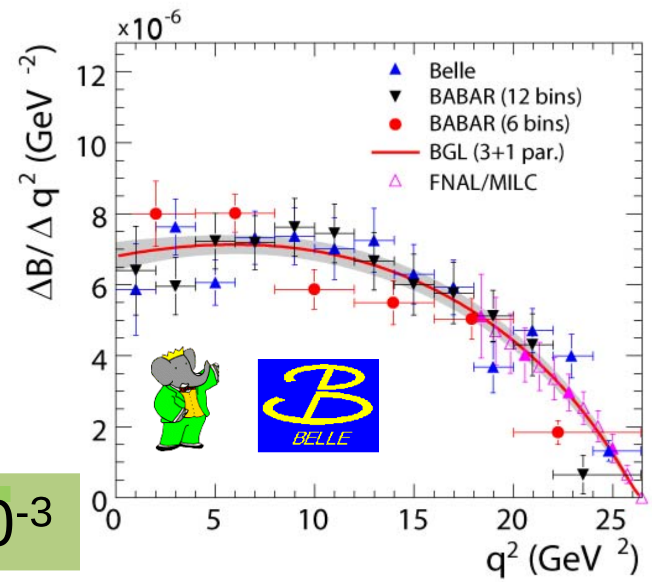
$\mathcal{B}$=(1.49±0.04±0.07)·10^{-4}

Belle, arXiv:1012:0090



$|V_{ub}|$ extraction: fit data + LQCD points in

$$q^2 = (p_\ell + p_\nu)^2 = (p_B - p_\pi)^2$$



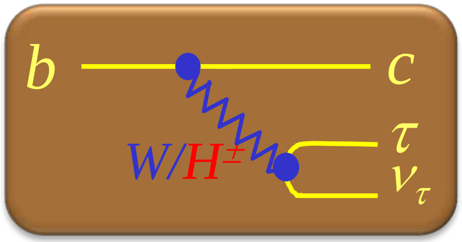
BaBar + FNAL/MILC $|V_{ub}|$ = (3.13±0.12±0.28)·10^{-3}

Belle + FNAL/MILC $|V_{ub}|$ = (3.43±0.33)·10^{-3}

Belle + BaBar + FNAL/MILC $|V_{ub}|$ = (3.26 ± 0.30)·10^{-3}

$B \to D^{(*)}\tau\nu$

Semileptonic decay sensitive to charged Higgs



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

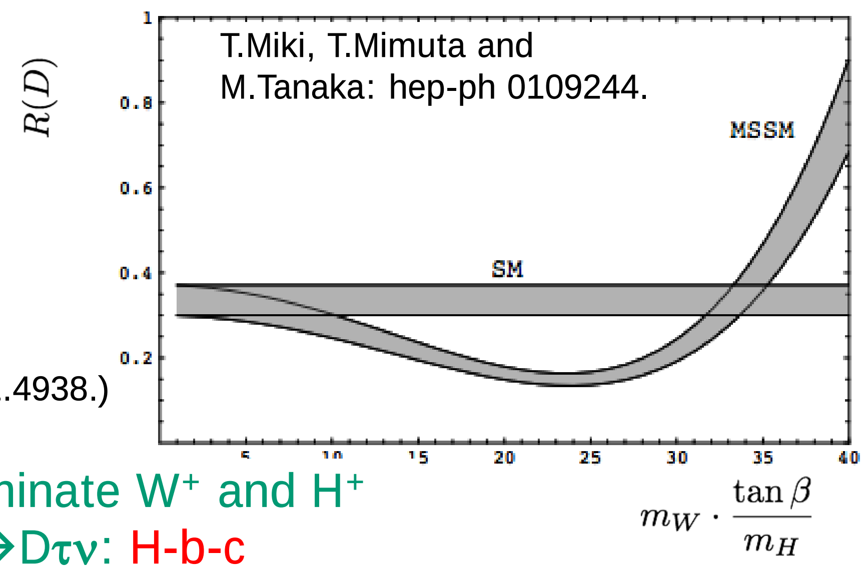
$$R(D) \equiv \frac{\mathcal{B}(B \to D\tau\nu)}{\mathcal{B}(B \to D\ell\nu)}$$

Complementary and competitive with $B \to \tau\nu$

1.Smaller theoretical uncertainty of R(D)

(For $B \to \tau\nu$,
There is O(10%) f_B uncertainty from lattice QCD)

2.Large Brs (~1%) in SM (Ulrich Nierste arXiv:0801.4938.)



3. Differential distributions can be used to discriminate W^+ and H^+
4. Sensitive to different vertex $B \to \tau\nu$: H-b-u, $B \to D\tau\nu$: H-b-c
(LHC experiments sensitive to H-b-t)

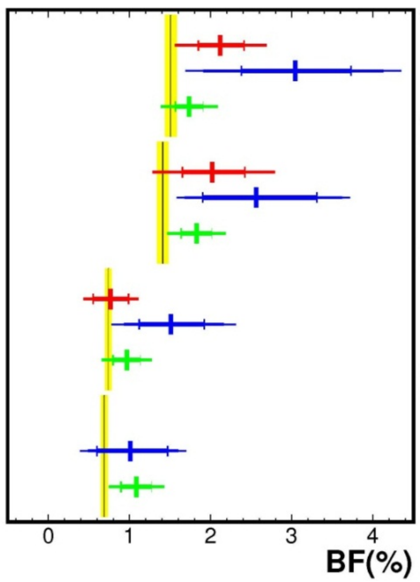
Advantage of B factories!

First observation of $B \to D^{*-}\tau\nu$ by Belle (2007) → PRL 99, 191807 (2007)

B → D$^{(*)}$ τν decays

This summer: First 5σ observation (BaBar) of B → Dτν decays (exclusive hadron tag data)

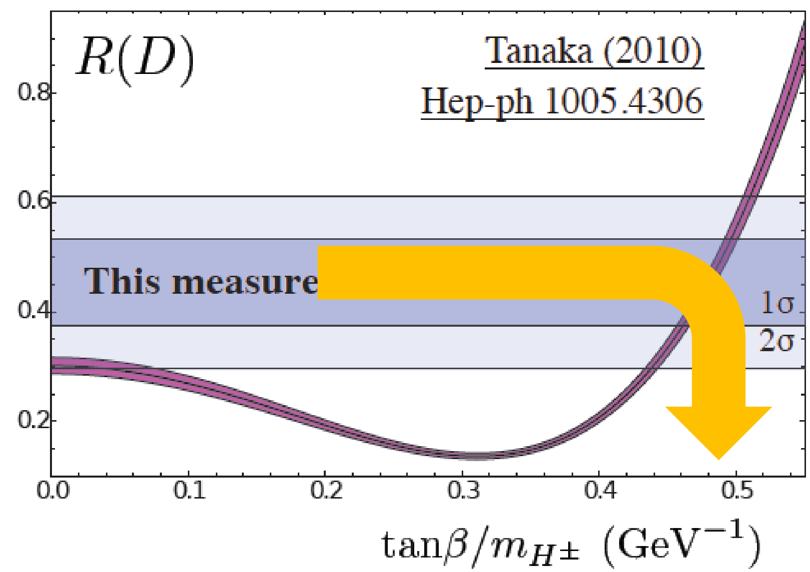
Belle inclusive tag,
Belle exclusive tag,
Babar excusive tag (summer 2011)
compared to the
SM prediction



$B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$	(1.73±0.17±0.18)%
$B^0 \to D^{*-}\tau^+\nu_\tau$	(1.82±0.19±0.17)%
$B^+ \to \overline{D}^0\tau^+\nu_\tau$	(0.96±0.17±0.14)%
$B^0 \to D^-\tau^+\nu_\tau$	(1.08±0.19±0.15)%

All values higher than SM predictions →

→ A very interesting limit on charged Higgs

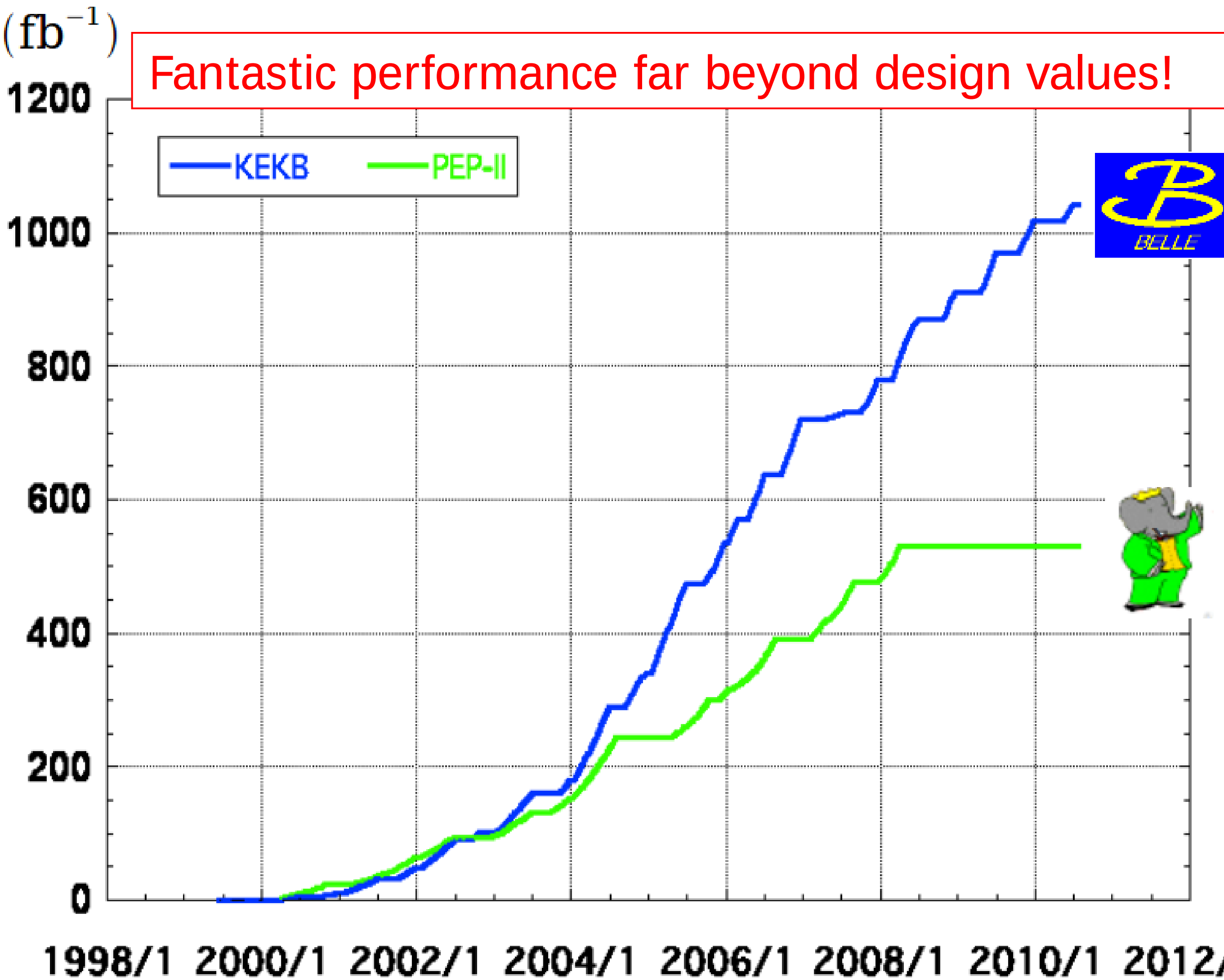


B factories: a success story

- 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

Integrated luminosity at B factories

Fantastic performance far beyond design values!



> 1 ab^{-1}

On resonance:

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

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

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

$\Upsilon(2S)$: 25 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}

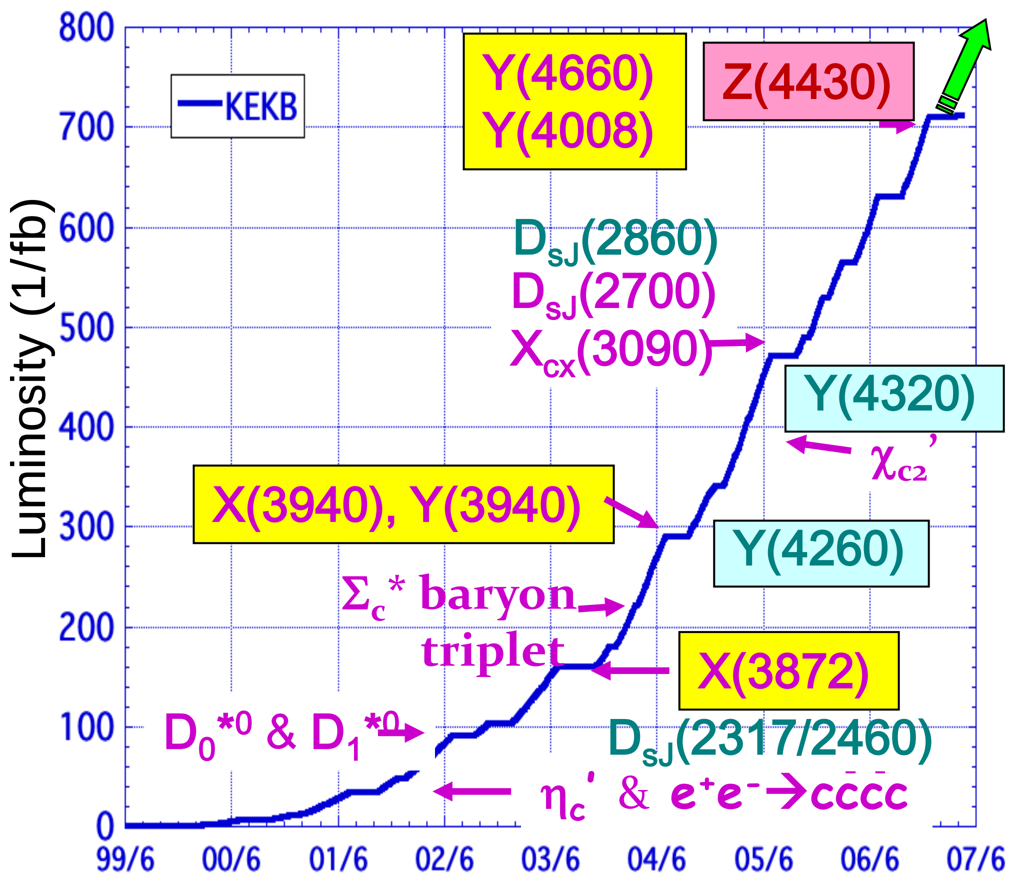
$\Upsilon(2S)$: 14 fb^{-1}

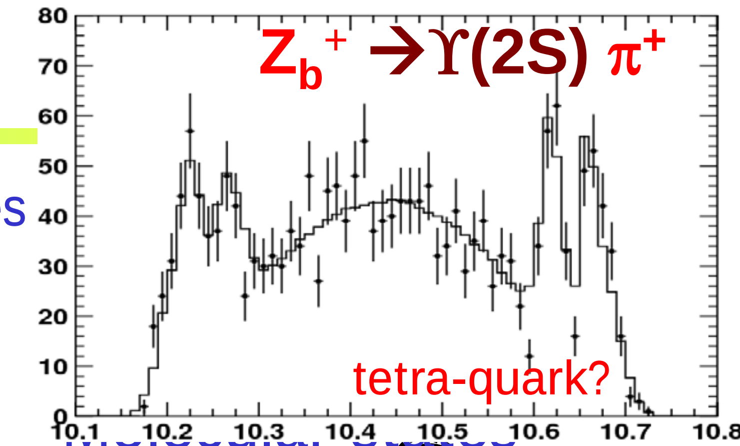
Off resonance:

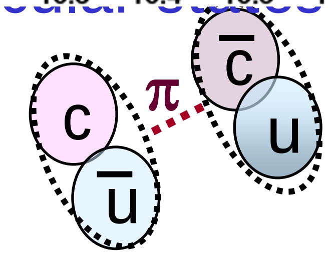
~ 54 fb^{-1}

New hadrons at B-factories

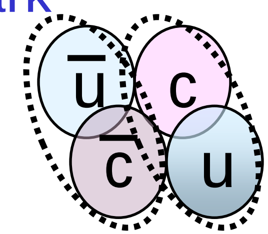
Discoveries of many new hadrons at B-factories
class of hadrons beyond the ordinary mesons.



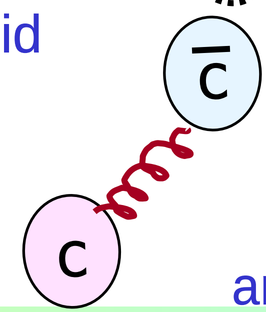




Tetra-quark



Hybrid



and more...

What next?

B factories → is SM with the KM scheme 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) Y(4s) will have considerable advantages in several classes of measurements, and will be complementary in many more

B Physics @ Υ(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})
$\lvert V_{cb}\rvert$ (exclusive)	4% (∗)	1.0% (∗)
$\lvert V_{cb}\rvert$ (inclusive)	1% (∗)	0.5% (∗)
$\lvert V_{ub}\rvert$ (exclusive)	8% (∗)	3.0% (∗)
$\lvert V_{ub}\rvert$ (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%
$\mathcal{B}(B\to K\nu\overline{\nu})$	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}	
	$\lvert q/p\rvert$	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}

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}

B$_s$ Physics @ Υ(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_{SL}	0.006	0.004

Physics reach with 50 ab^{-1} (75 ab^{-1}):

Physics at Super B Factory (Belle II authors + guests)

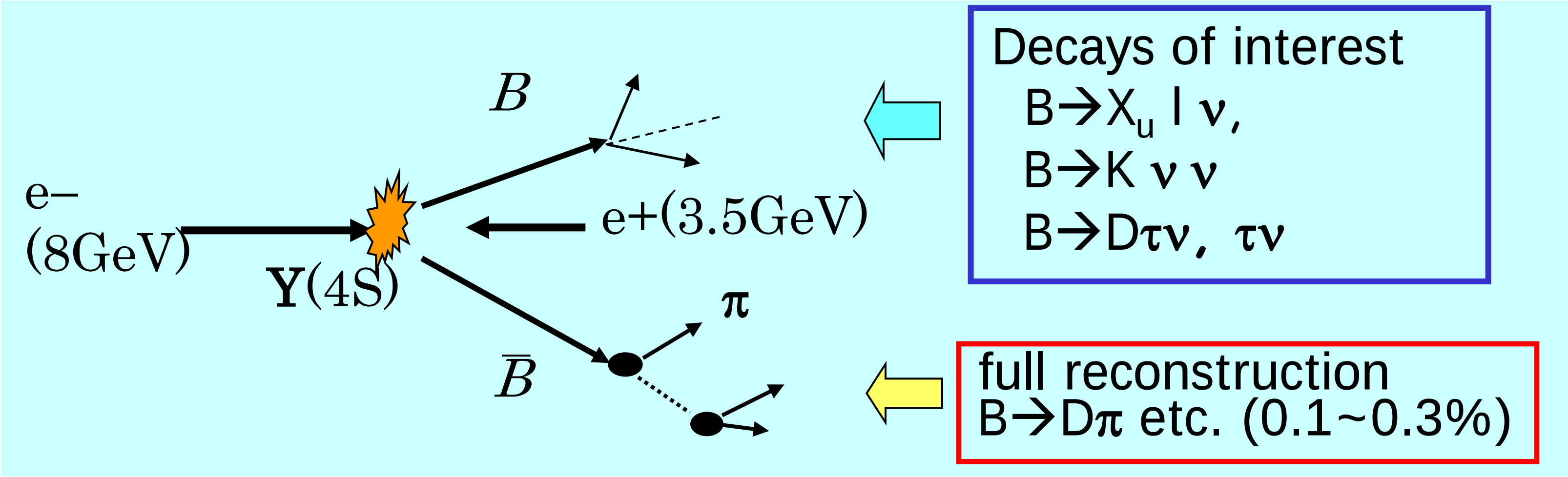
hep-ex > arXiv:1002.5012

SuperB Progress Reports: Physics (SuperB authors + guests)

hep-ex > arXiv:1008.1541

Full Reconstruction Method

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



→ Offline B meson beam!

Powerful tool for B decays with neutrinos

$B \to \nu\,\nu$ decay

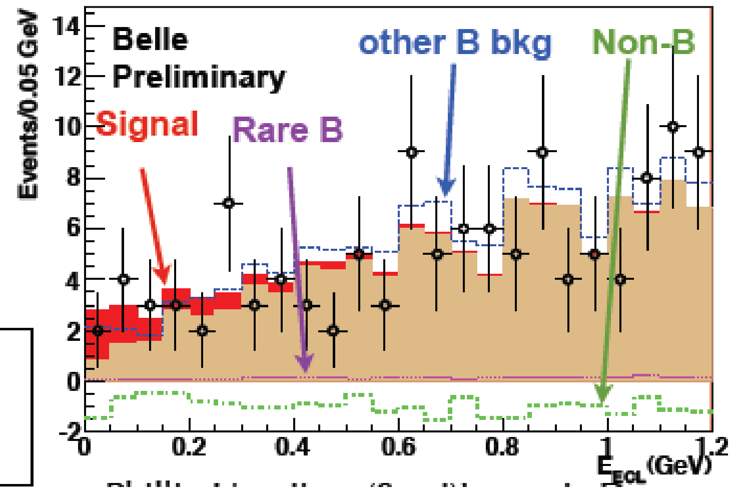
$B \to \nu\,\nu$ similar as $B \to \mu\,\mu$ a very sensitive channel to NP contributions

Even more strongly helicity suppressed by $\sim(m_\nu/m_B)^2$

$\to$ Any signal = NP

Unique feature at B factories: use tagged sample with fully reconstructed B decays on one side, require no signal from the other B.

Use rest energy in the calorimeter and angular distribution as the fit variables.



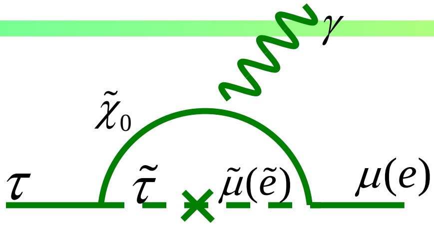
90% C.L. BR < 1.3 x 10^{-4}

Belle Preliminary 657M BBbar

c.f. (Babar) BR < 2.2 x 10^{-4}

LFV and New Physics

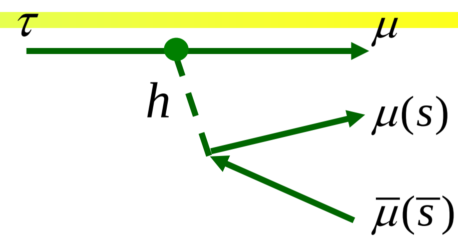
$\tau \to l\gamma$



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

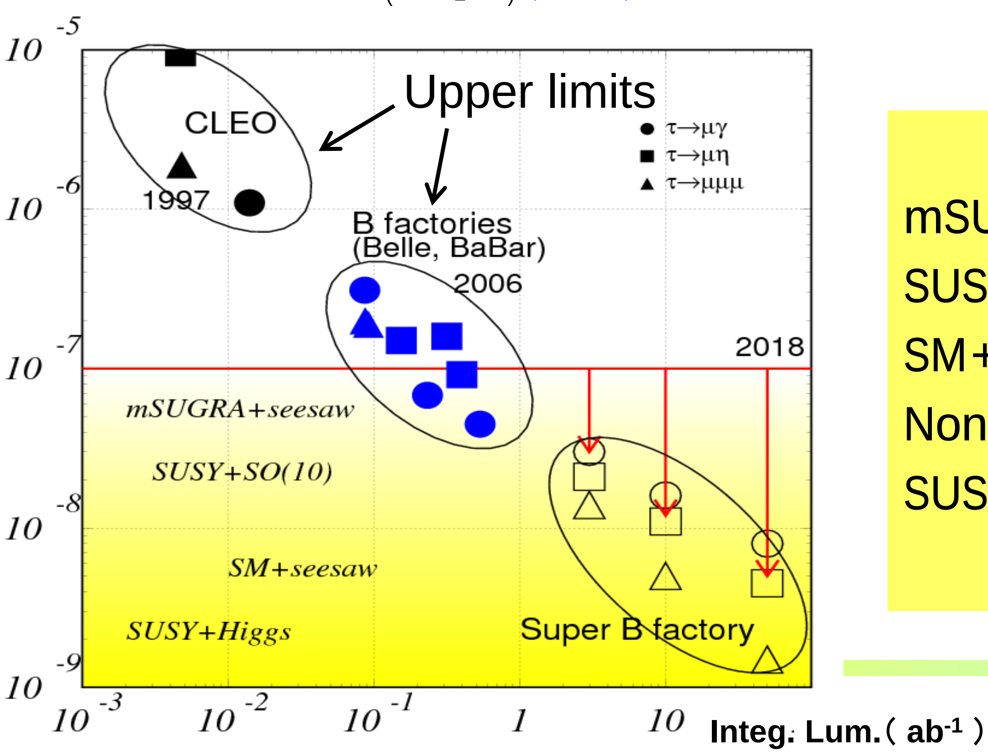
$$Br(\tau \to \mu\gamma) \simeq 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}}\right)\left(\frac{1\,TeV}{m_{SUSY}}\right)^4 \tan^2\beta$$

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



- Neutral Higgs mediated decay.
- Important when M_{SUSY} >> EW scale.

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

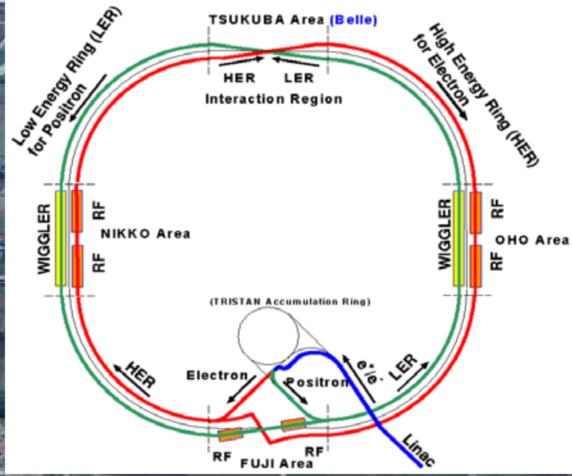


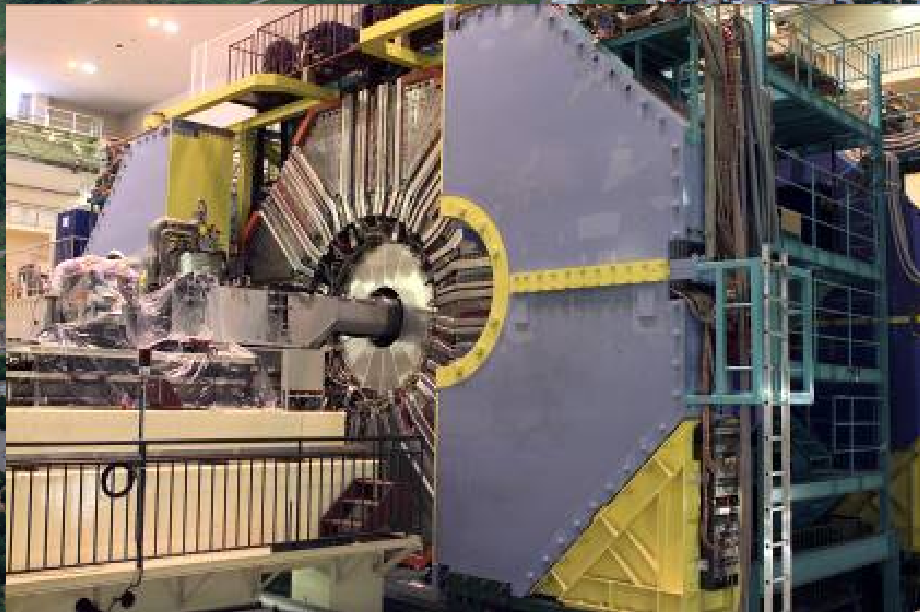
model	$Br(\tau \to \mu\gamma)$	$Br(\tau \to lll)$
mSUGRA+seesaw	10^{-7}	10^{-9}
SUSY+SO(10)	10^{-8} 10^{-10}	
SM+seesaw	10^{-9}	10^{-10}
Non-Universal Z'	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-7}

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 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 a unique way to search for the >TeV scale physics (=TeV scale in case of MFV).

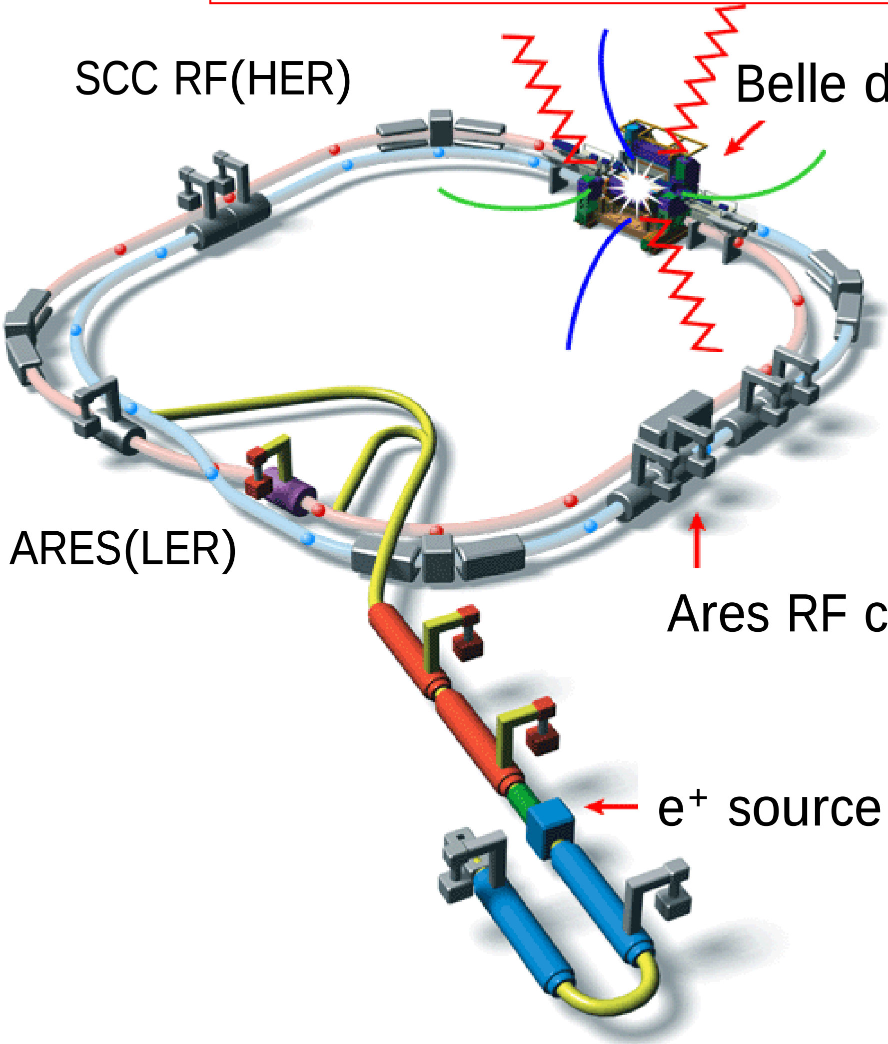
How to do it?
→ upgrade KEKB and Belle





The KEKB Collider

Fantastic performance far beyond design values!



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

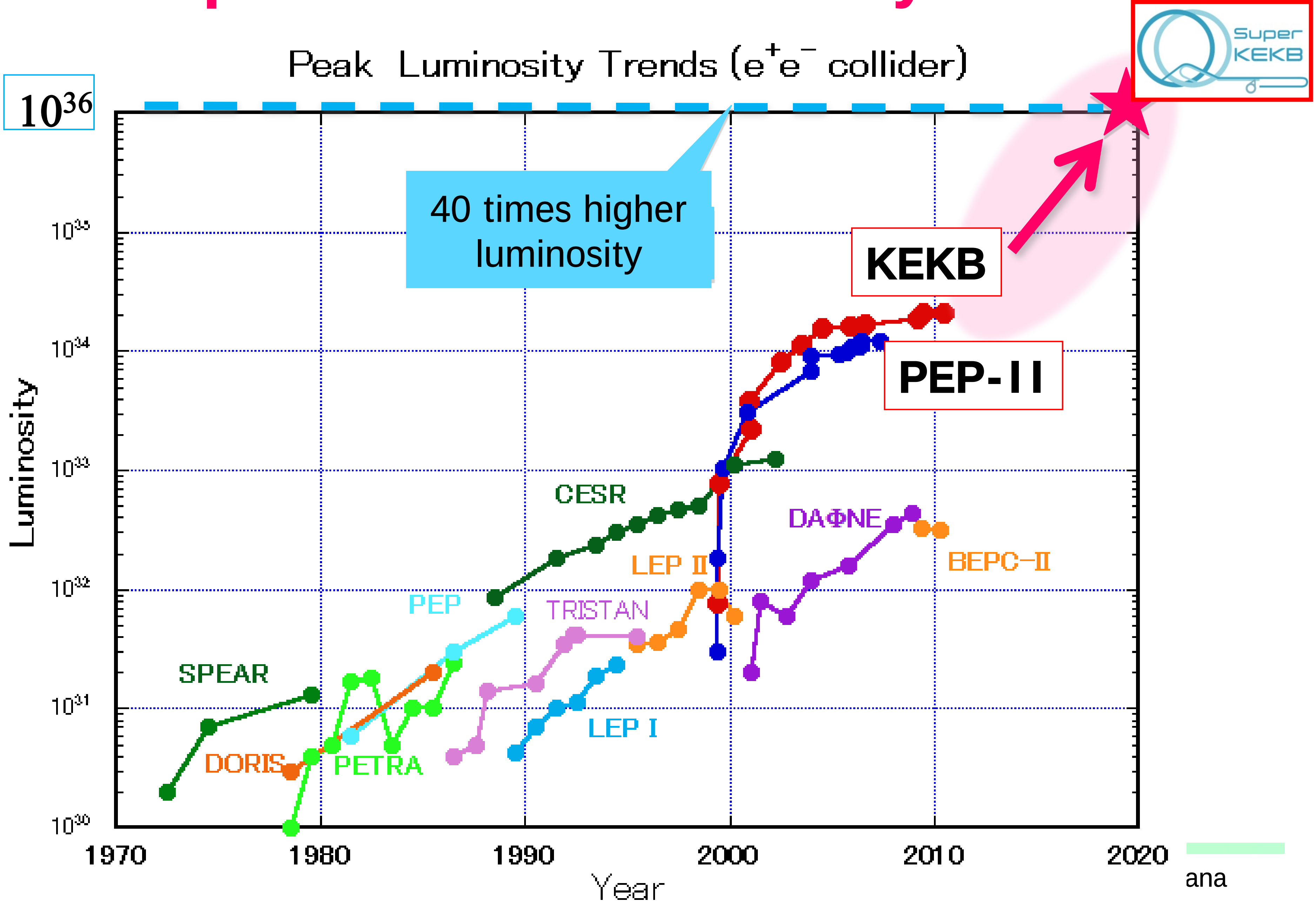
Peak luminosity (WR!) :

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} = $2.1\times10^{34}/cm^2/s$
L > $1ab^{-1}$

SuperKEKB is the intensity frontier



ana

How to increase the luminosity?

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

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^*
(2) Increase beam currents
(3) Increase ξ_y

"Nano-Beam" scheme

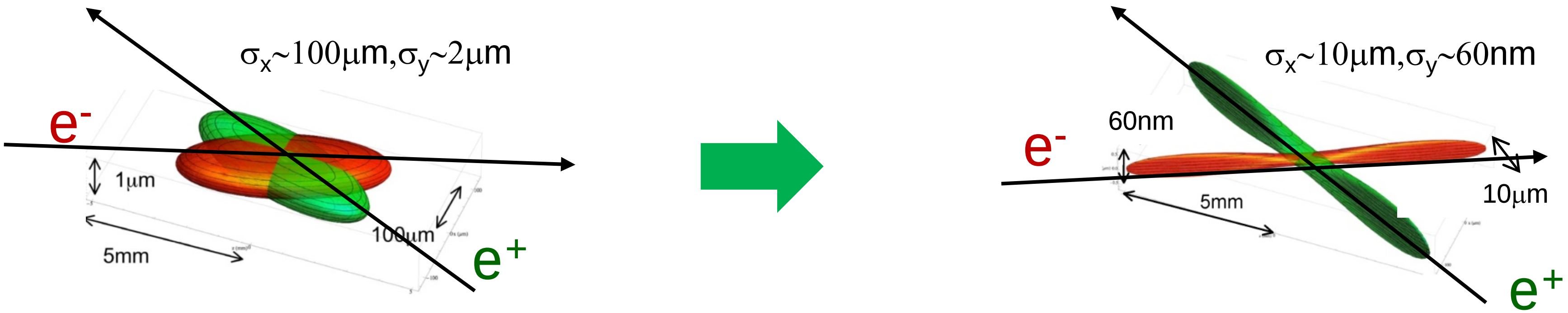
Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB – 'spin-off' from LC studies

How big is a nano-beam ?

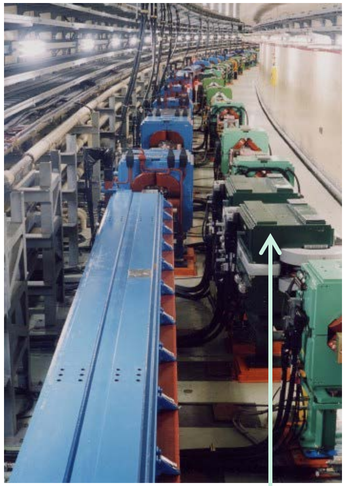
How to go from an excellent accelerator with world record performance – KEKB – to a 40x times better, more intense facility?

In KEKB, colliding electron and positron beams are much thinner than the human hair...

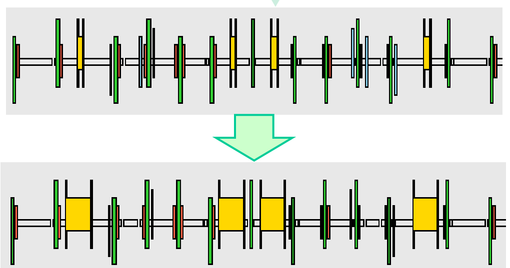


… For a 40x increase in intensity you have to make the beam as thin as a few 100 atomic layers!

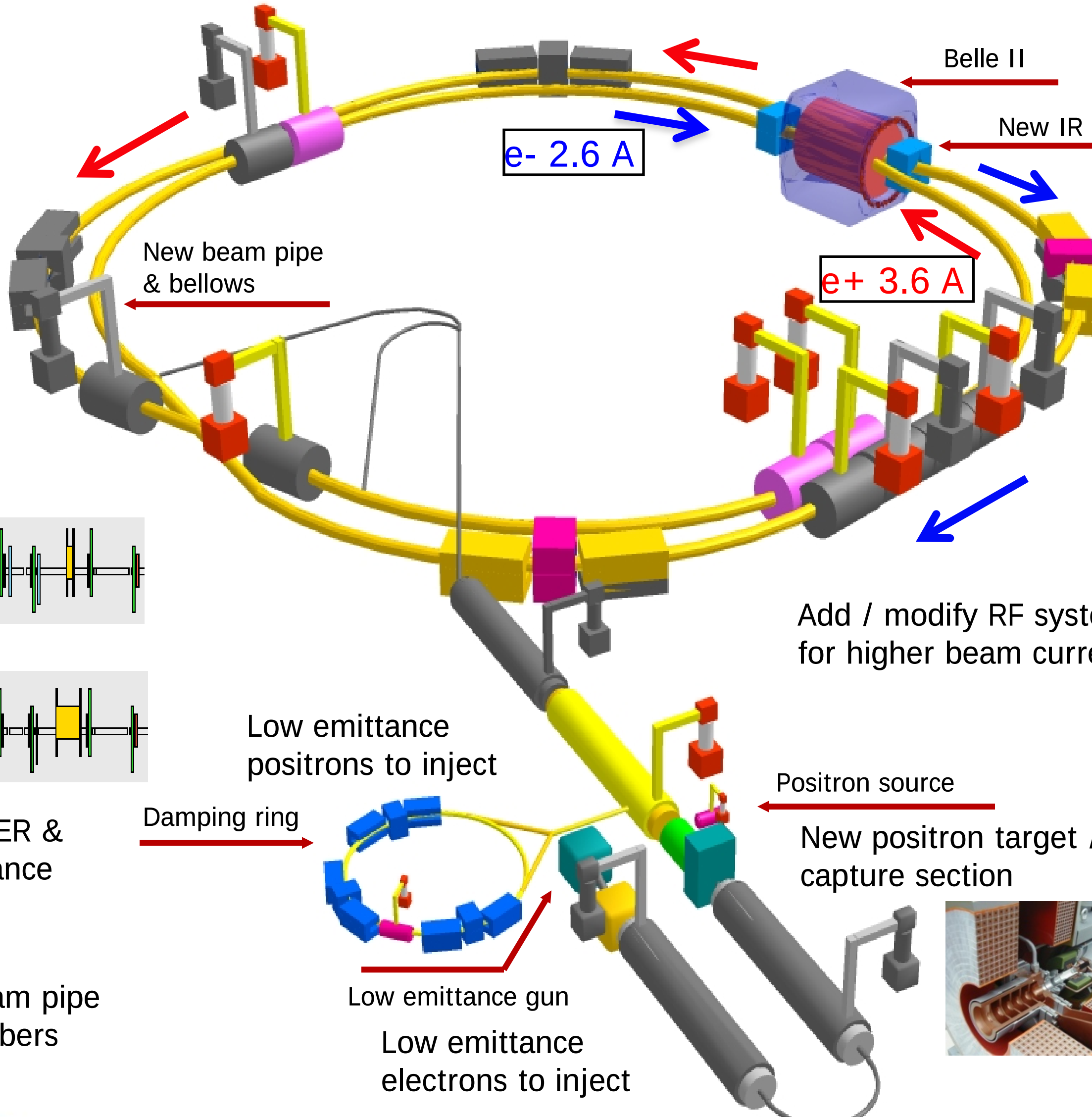
KEKB to SuperKEKB



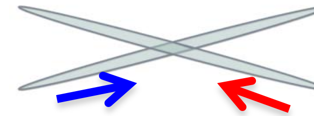
Replace short dipoles with longer ones (LER)



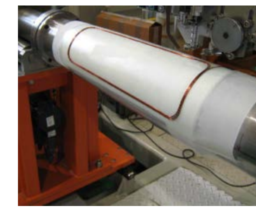
Redesign the lattices of HER & LER to squeeze the emittance



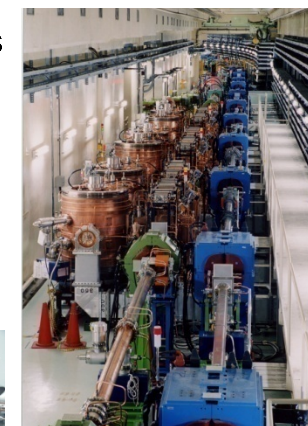
Colliding bunches



New superconducting /permanent final focusing quads near the IP

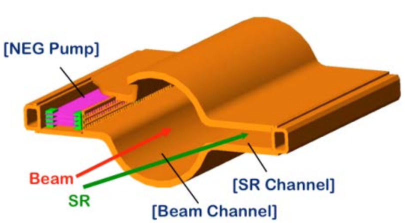


Add / modify RF systems for higher beam current



New positron target / capture section

TiN-coated beam pipe with antechambers

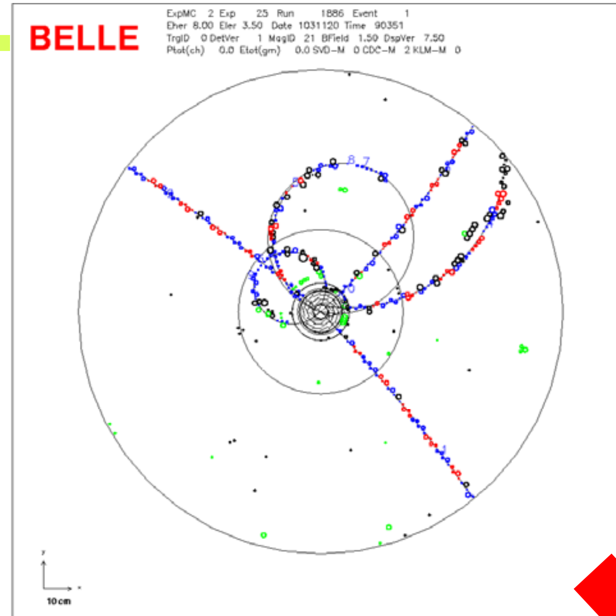


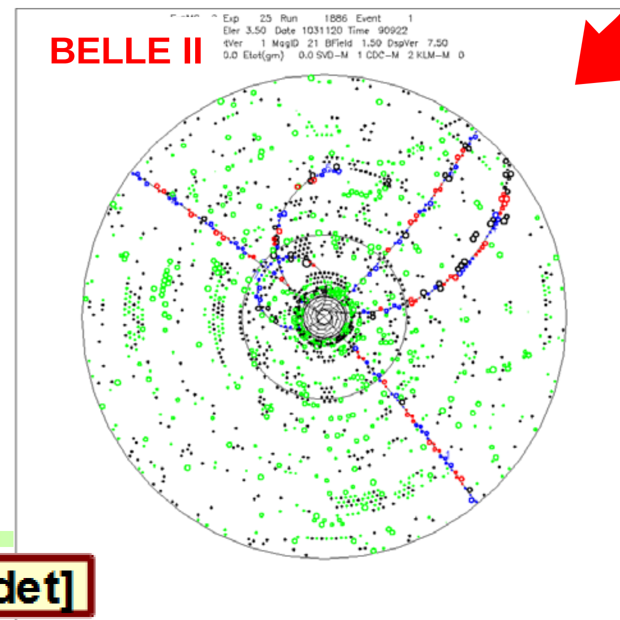
To get x40 higher interaction rate

Need to build a new detector to handle higher backgrounds

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

- **Higher background ($\times$10-20)**
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM
- **Higher event rate ($\times$10)**
  - higher rate trigger, DAQ and computing
- **Require special features**
  - low p μ identification $\leftarrow$ $s\mu\mu$ recon. eff.
  - hermeticity $\leftarrow$ ν “reconstruction”

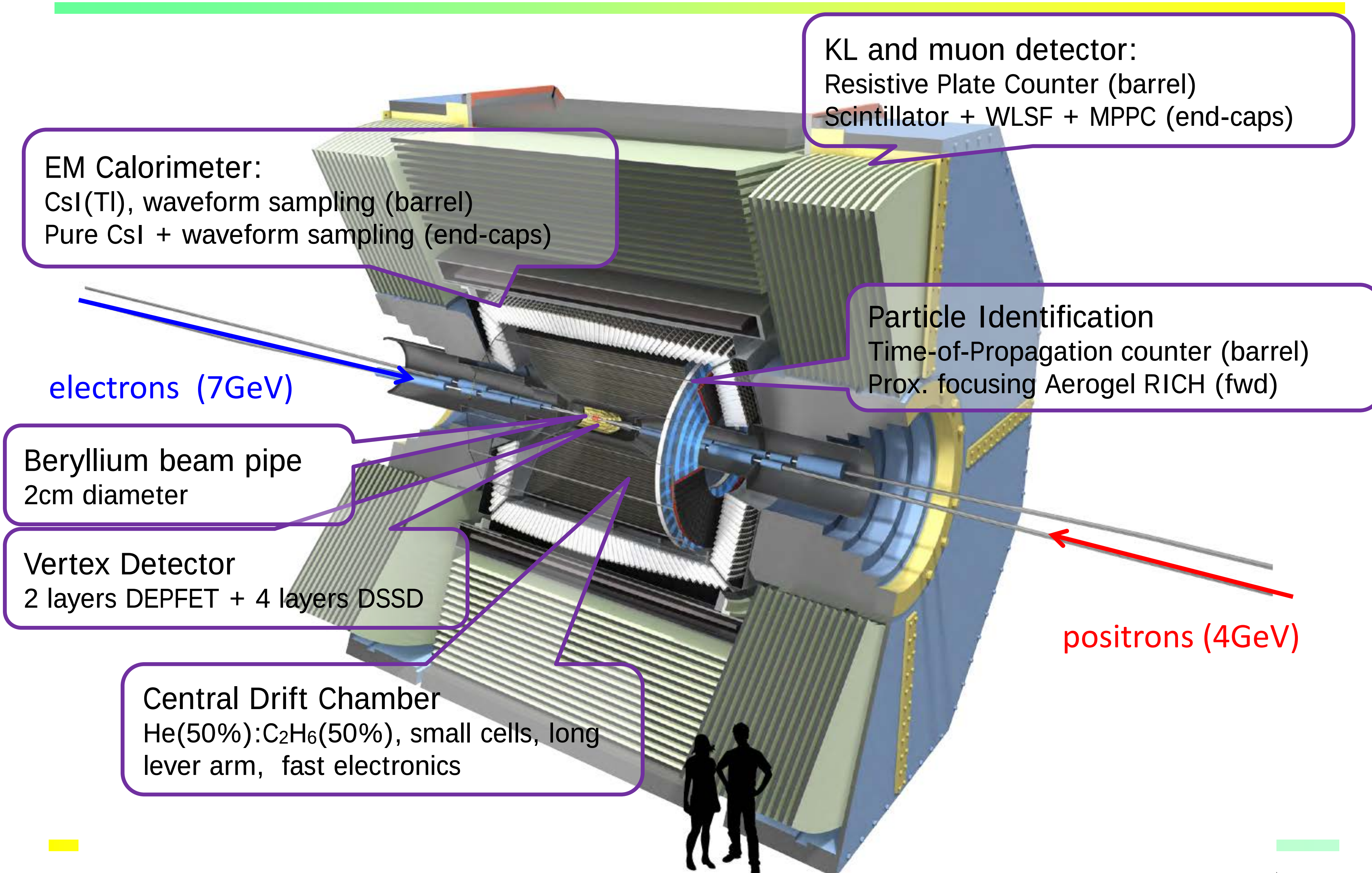




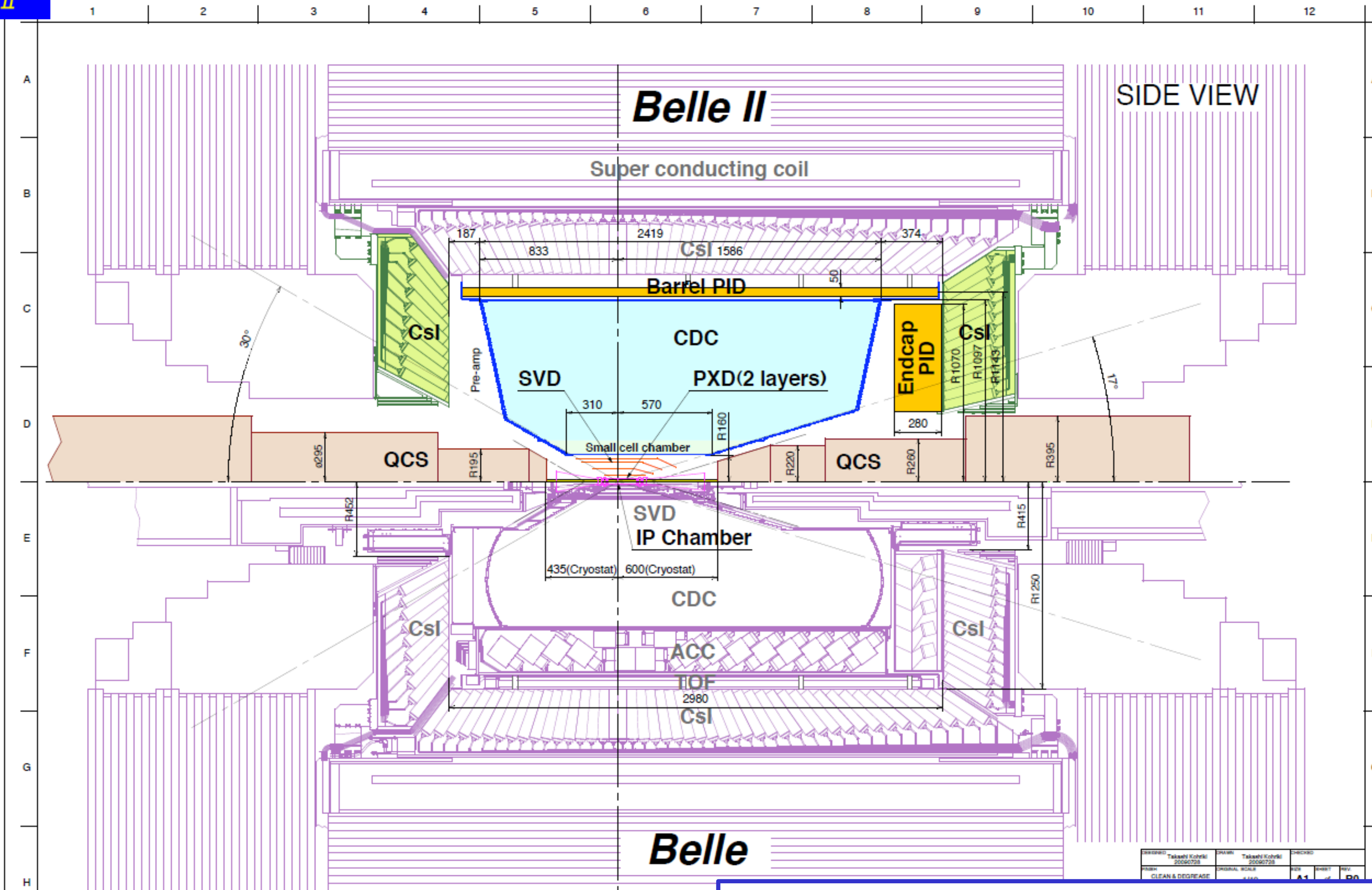
Have to employ and develop new technologies to make such an apparatus work! →

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

Belle II Detector



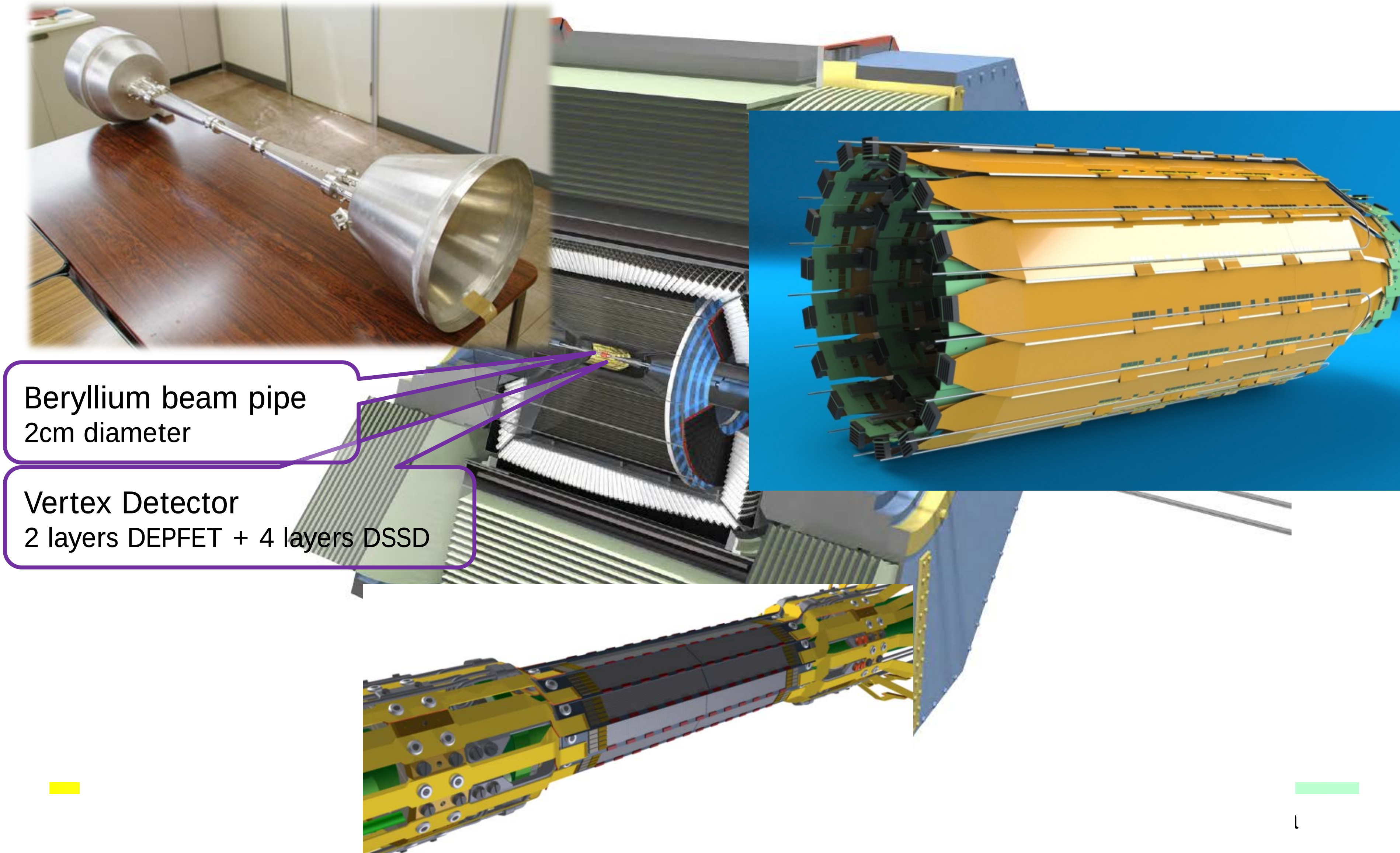
Belle II (top) compared with Belle (bottom)



SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm

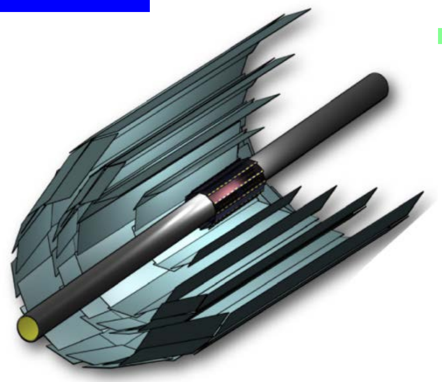
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

Belle II Detector – vertex region



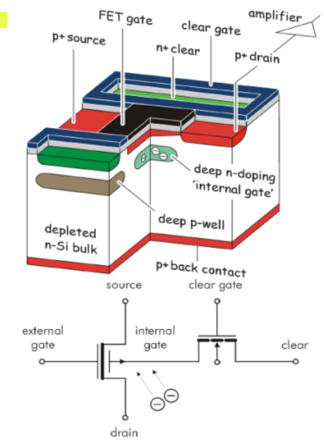
Vertex Detector

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

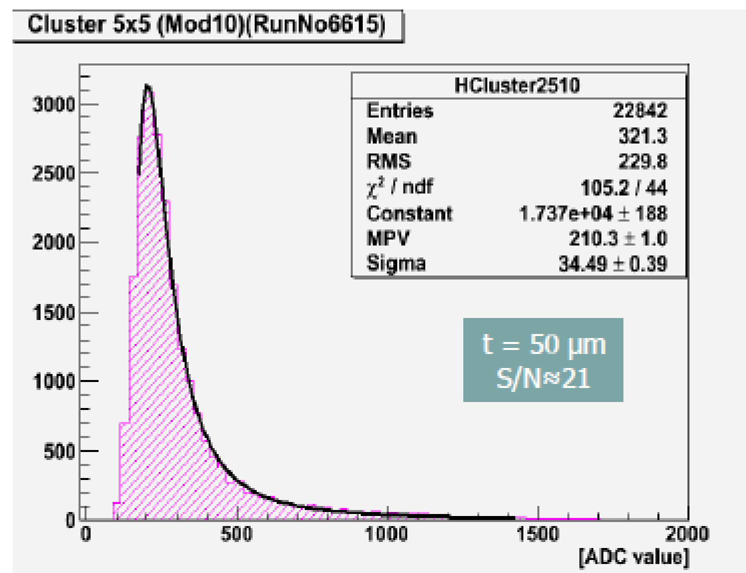


Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**

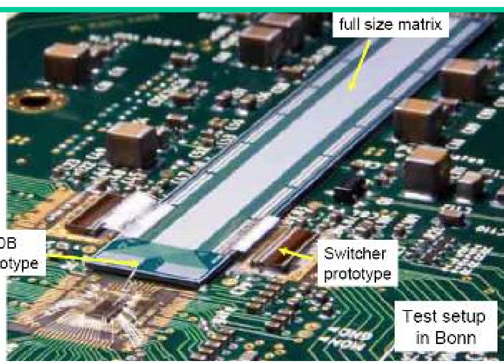
DEpleted P-channel FET



Mechanical mockup of pixel detector



Prototype DEPFET pixel sensor and readout

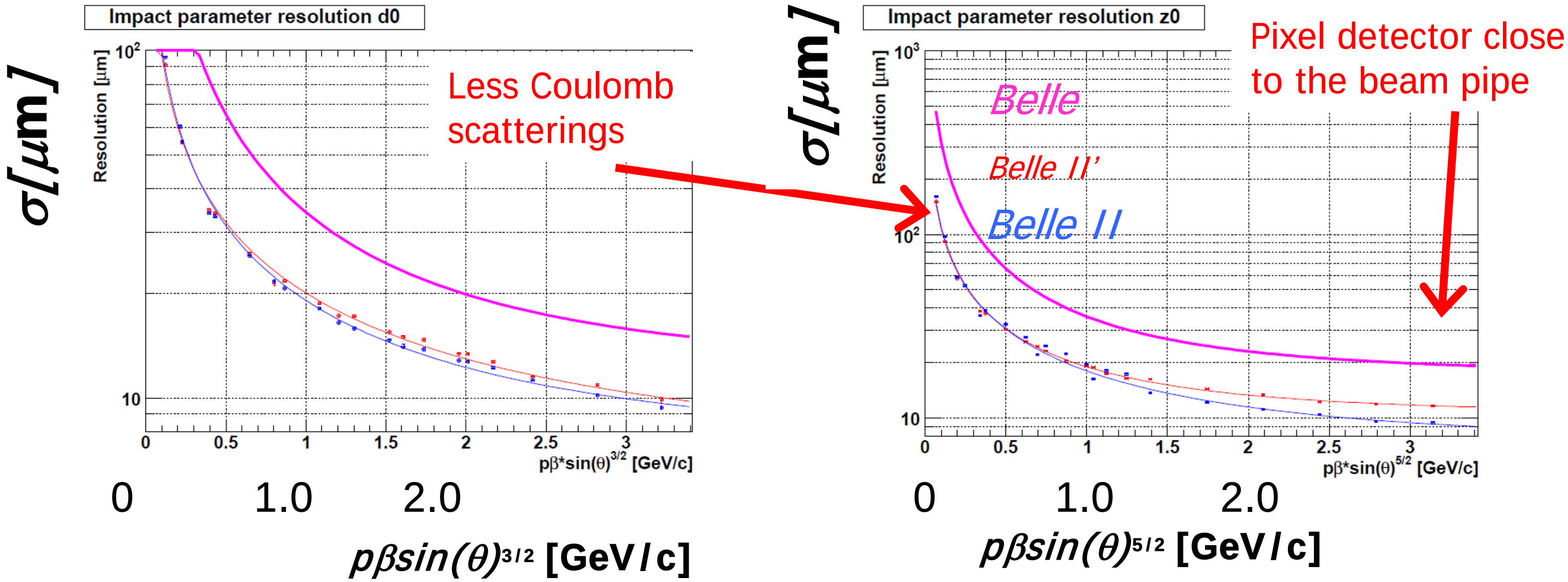


DEPFET sensor: very good S/N

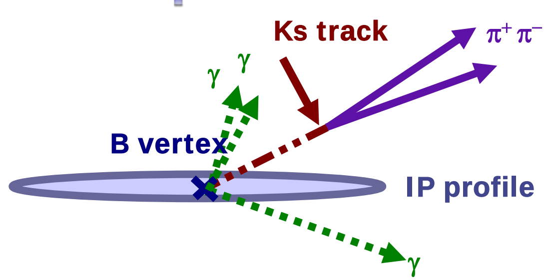
Expected performance

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

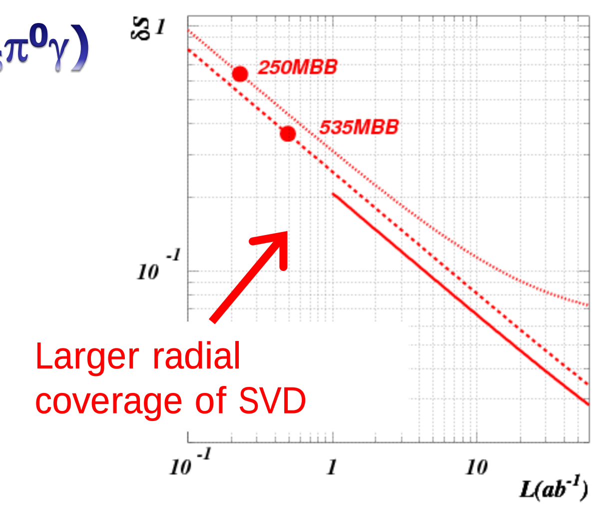
Significant improvement in IP resolution!



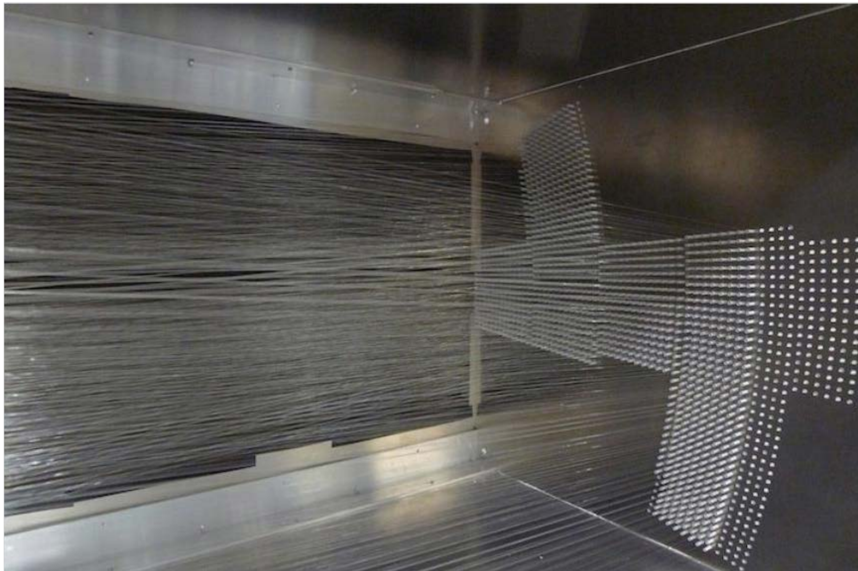
Significant improvement in $\delta S(K_S\pi^0\gamma)$

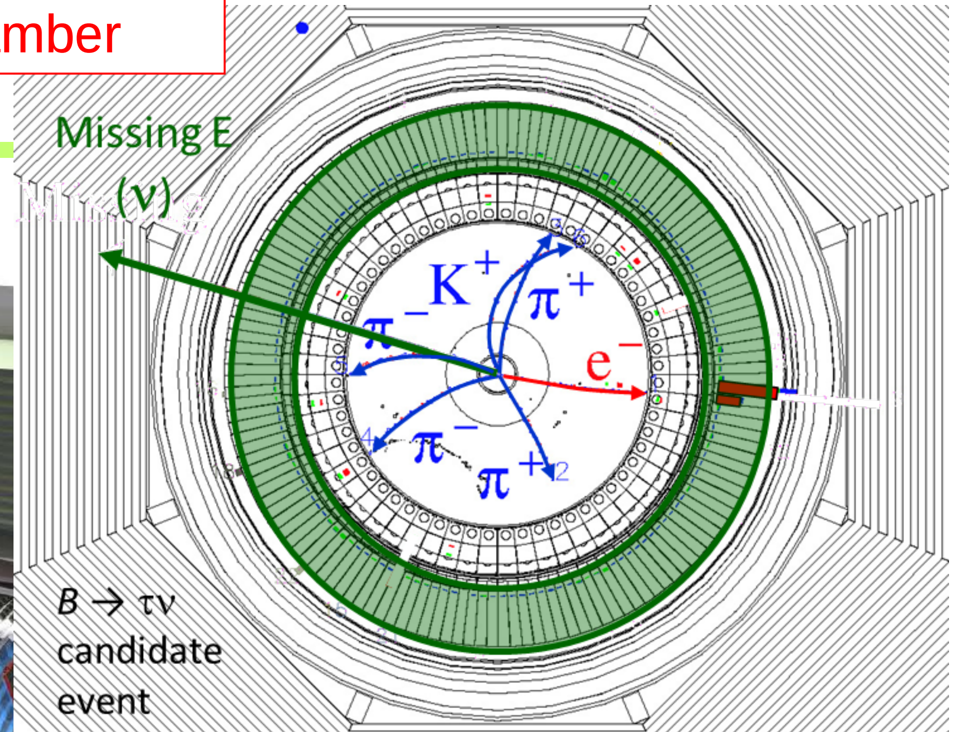


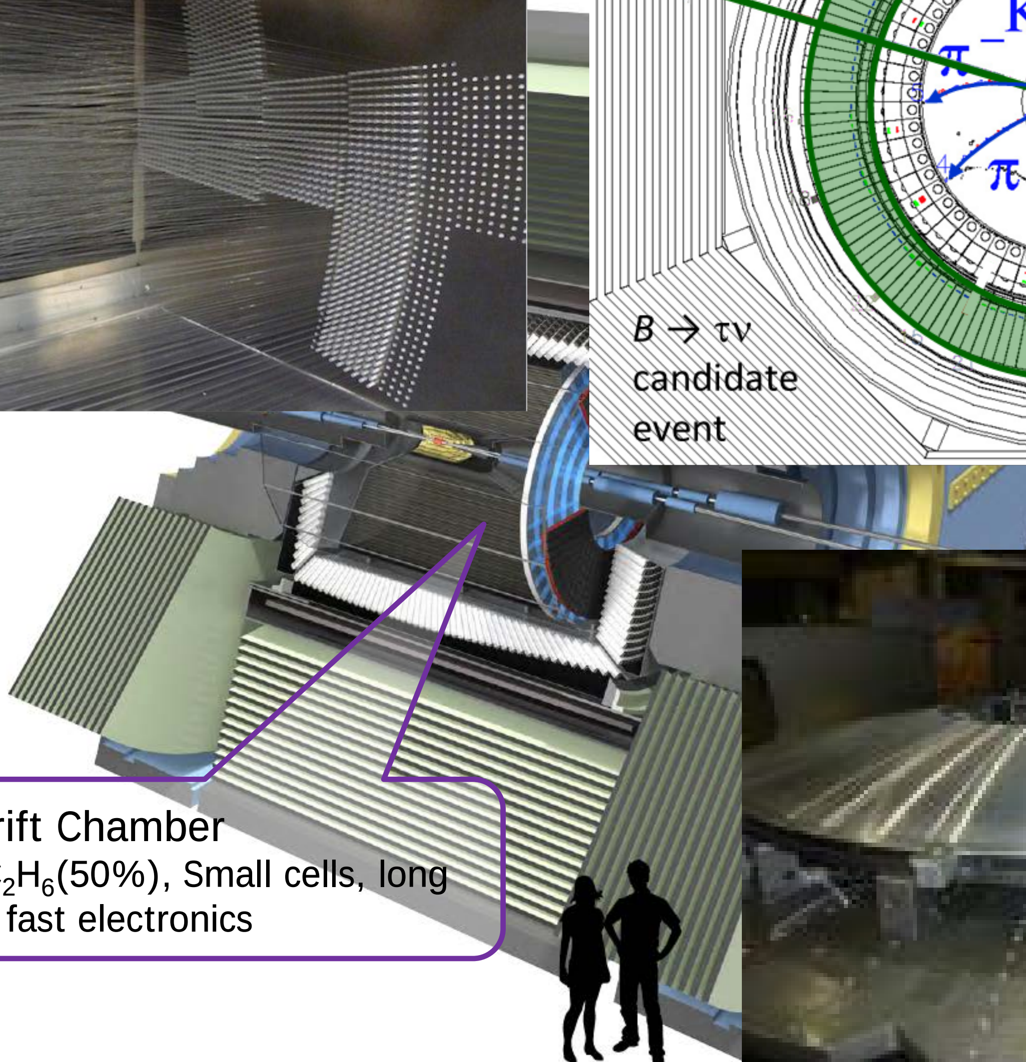
B decay point reconstruction with K_S trajectory



Main tracking device: small cell drift chamber



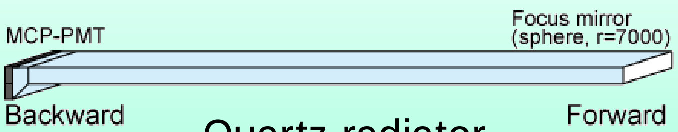




Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



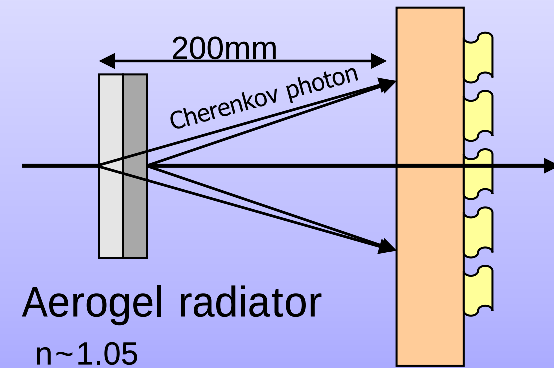
Quartz radiator

Focusing mirror

Small expansion block

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

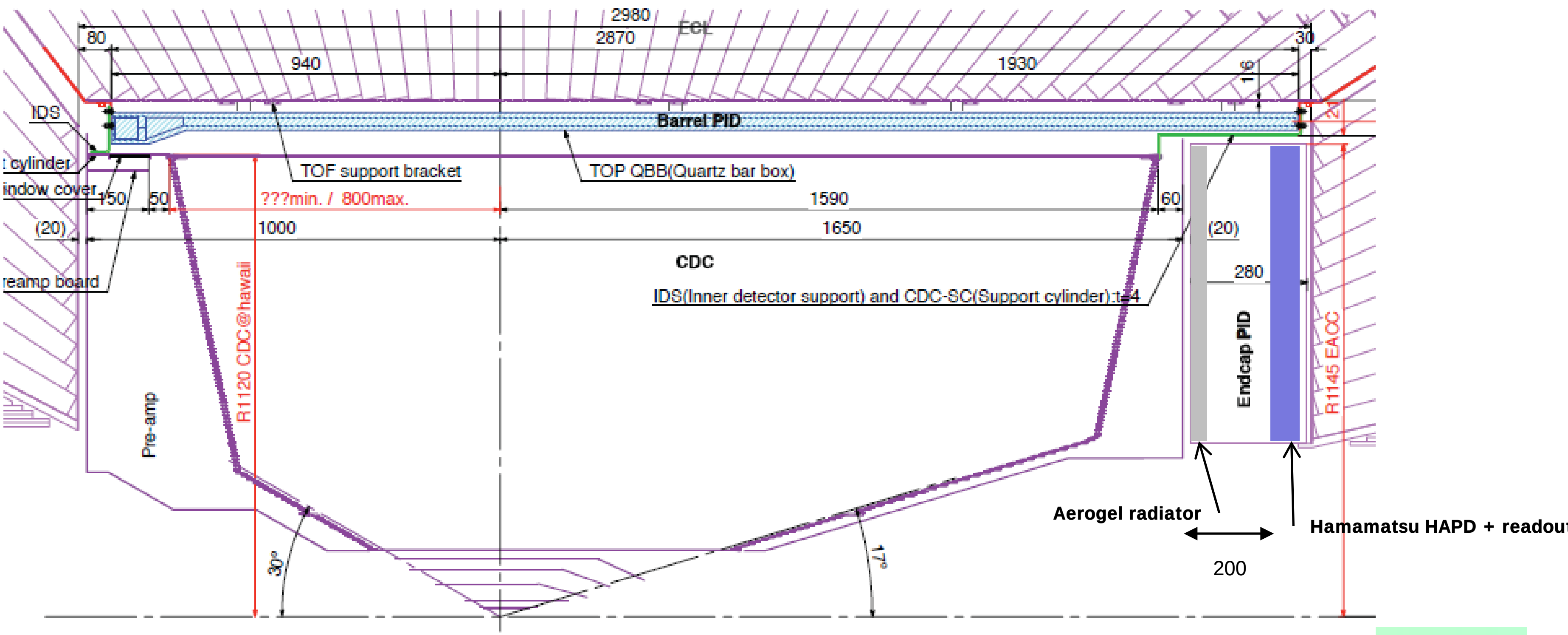
Endcap PID: Aerogel RICH (ARICH)



Aerogel radiator

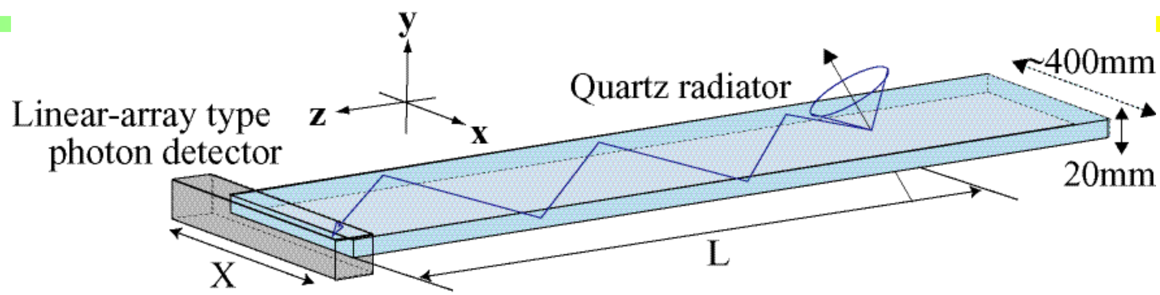
n~1.05

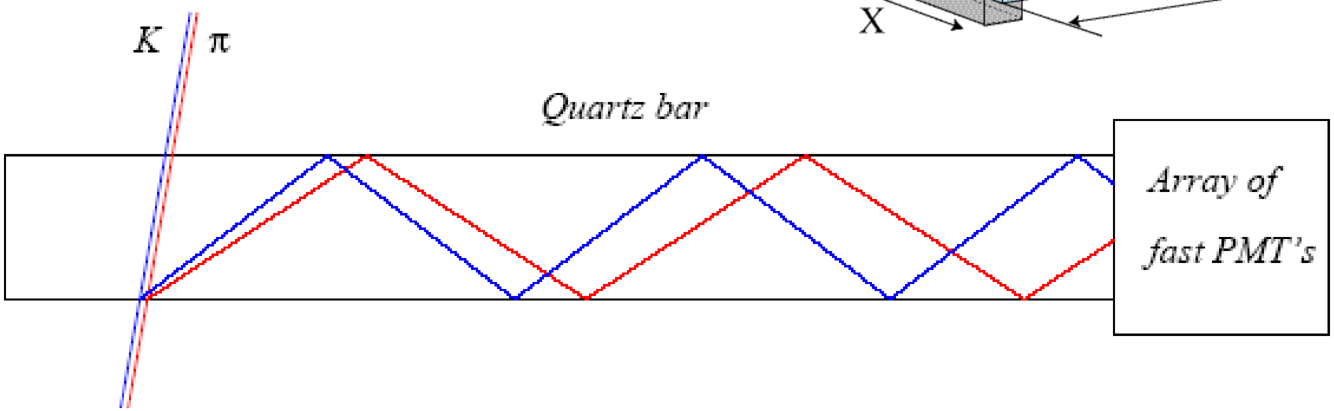
Hamamatsu HAPD
+ new ASIC



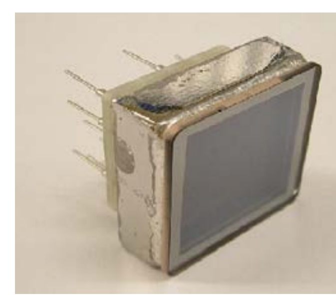
Peter Križan, Ljubljana

Barrel PID: Time of propagation (TOP) counter

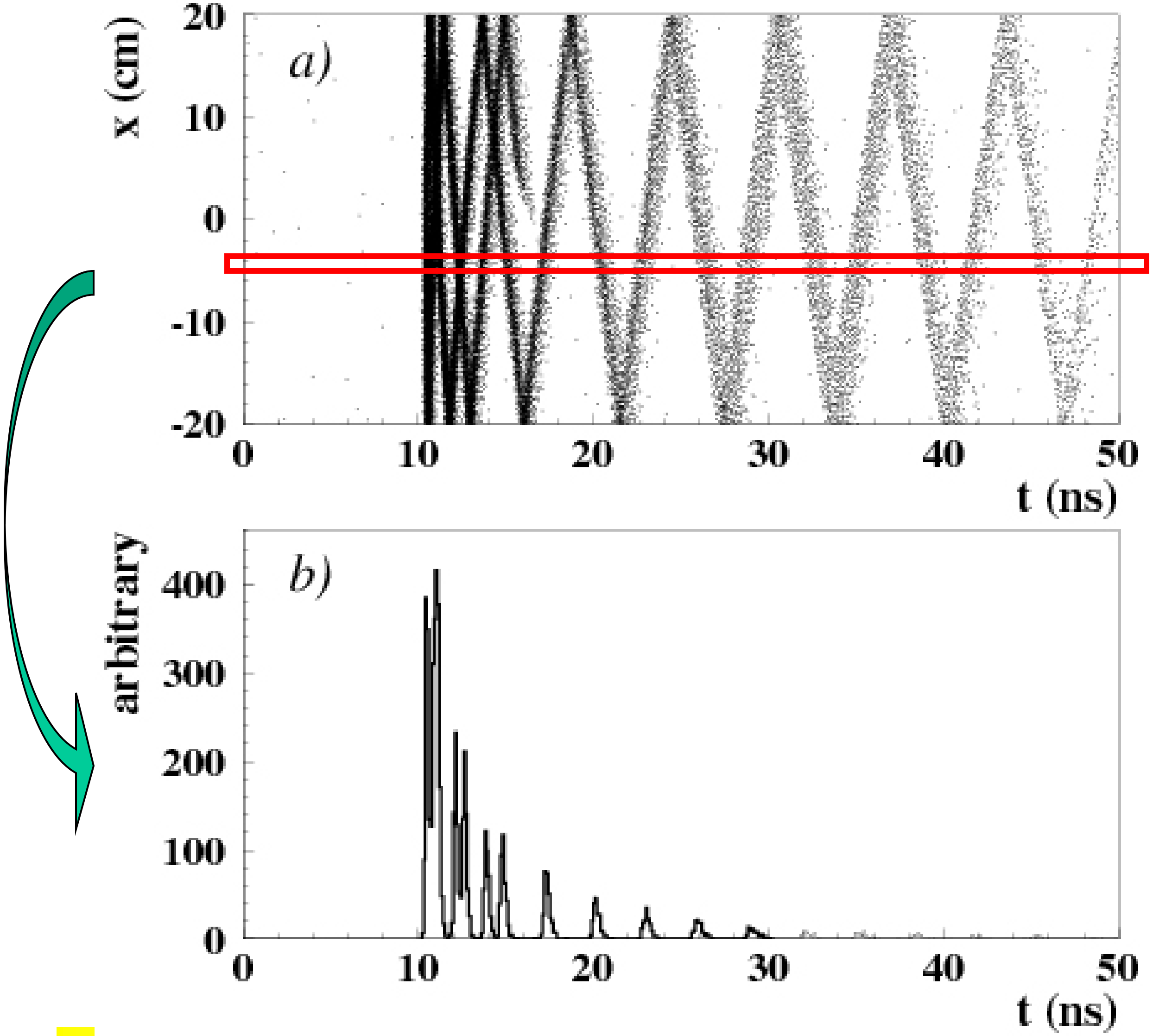




- Cherenkov ring imaging with precise time measurement.
- Use 2cm thick quartz bars – similar to BaBar DIRC counter.
- Reconstruct Cherenkov angle from two hit coordinates and the time of propagation of the photon
  - Quartz radiator (2cm)
  - Photon detector (MCP-PMT)
    - Good time resolution ~ 40 ps
    - Single photon sensitivity in 1.5



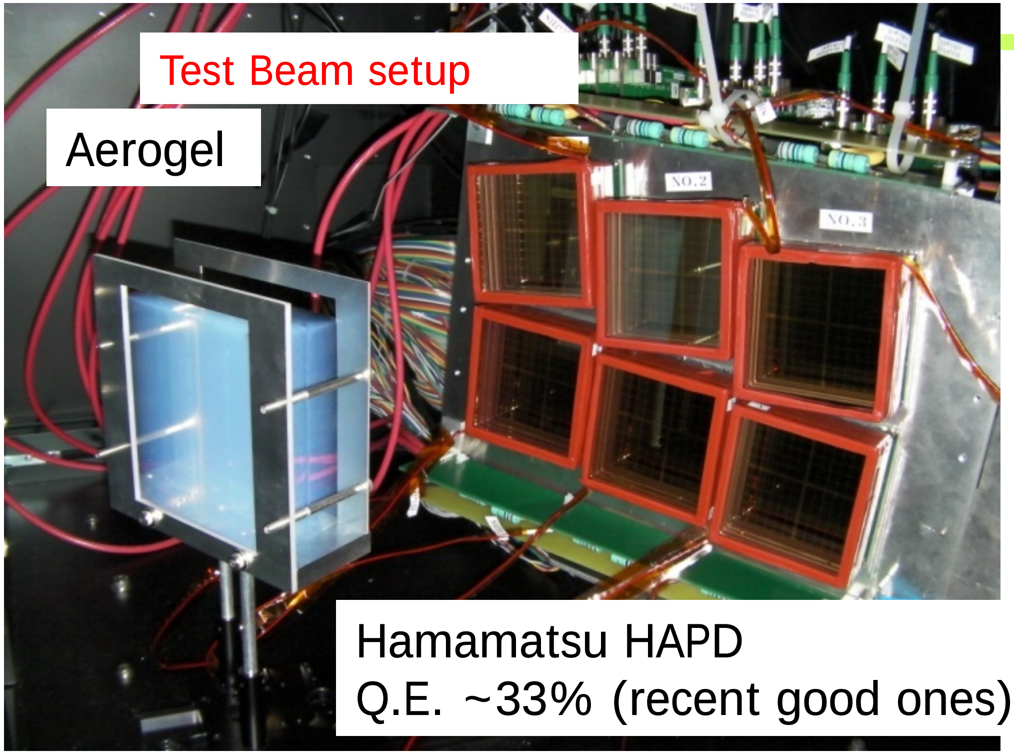
TOP image

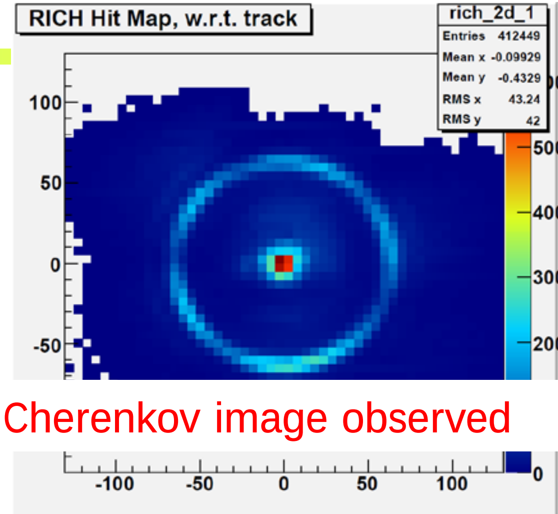


Pattern in the coordinate-time space ('ring') of a pion hitting a quartz bar with ~80 MAPMT channels

Time distribution of signals recorded by one of the PMT channels: different for π and K (~shifted in time)

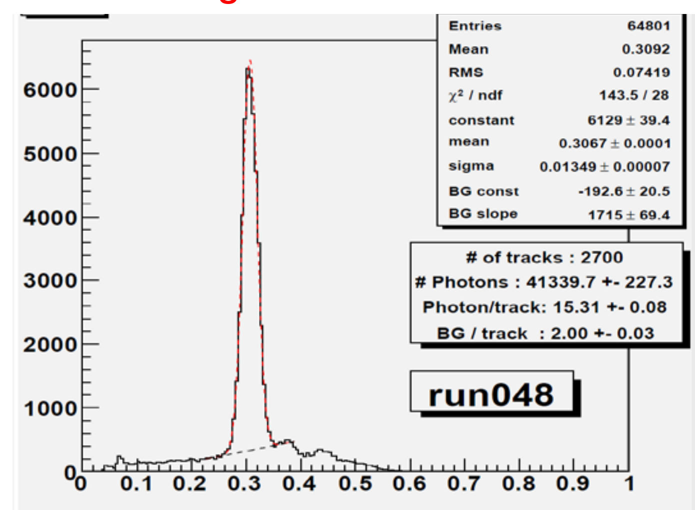
Aerogel RICH (endcap PID)



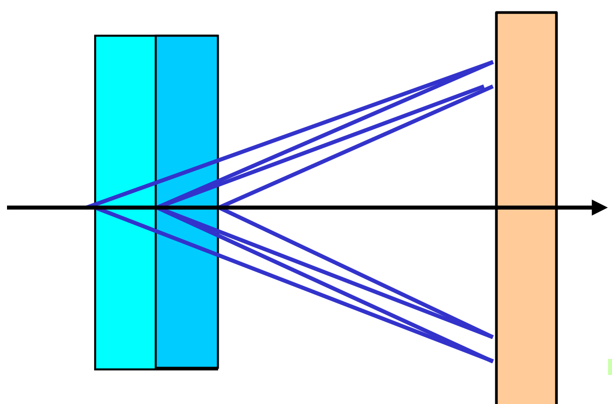


Clear Cherenkov image observed

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 !

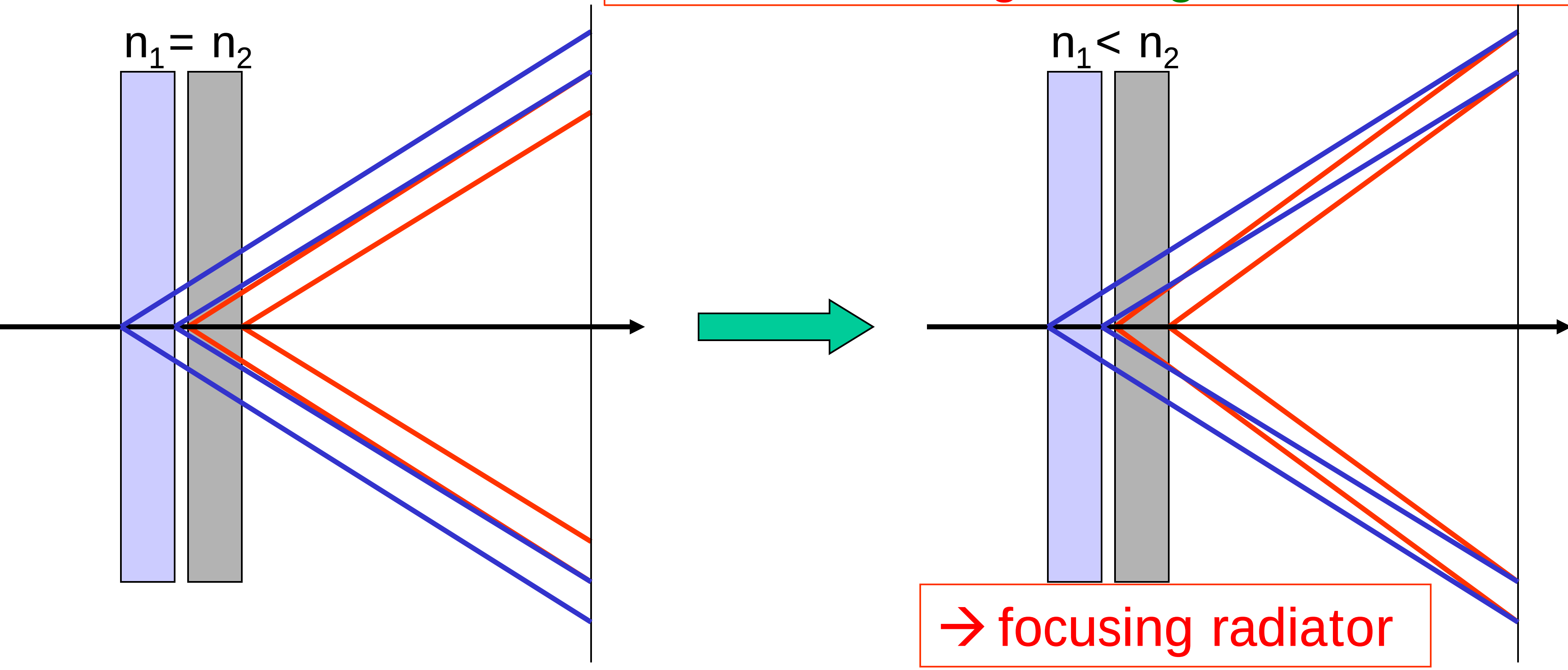
Peter Križan, Ljubljana

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

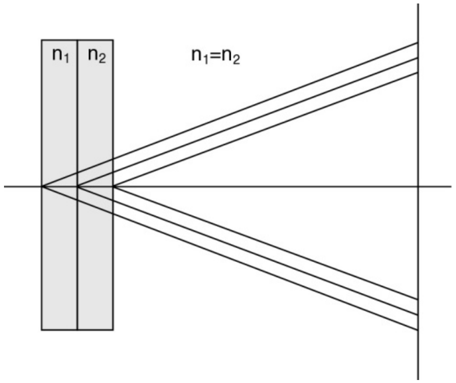


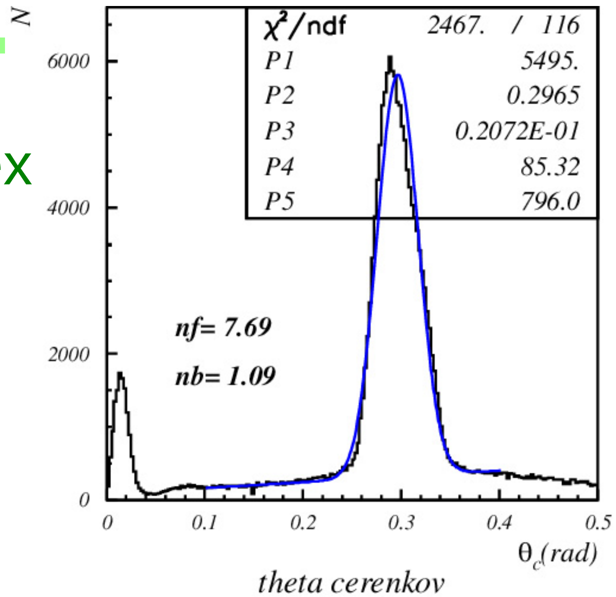
→ focusing radiator

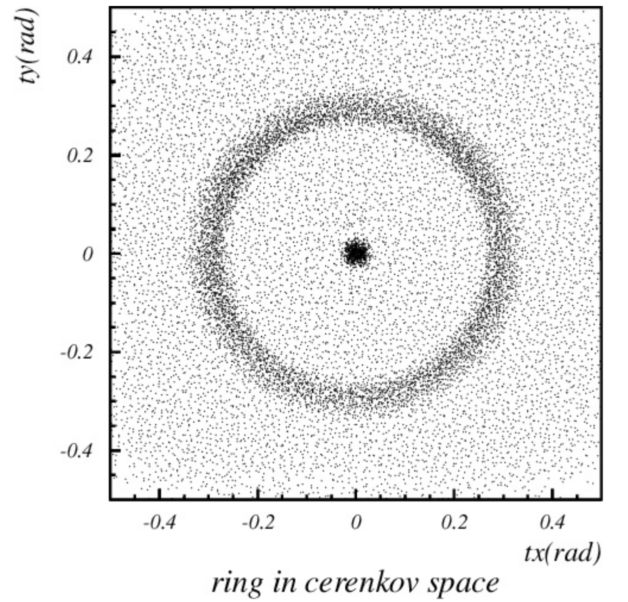
Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

Focusing configuration – data

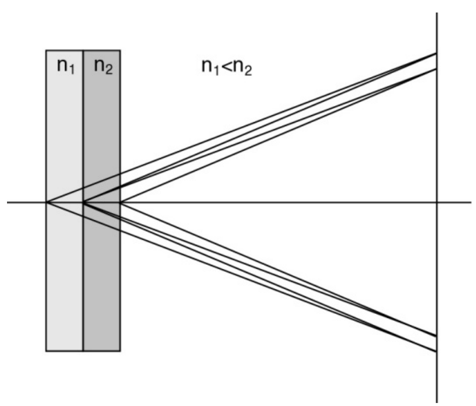
4cm aerogel single index

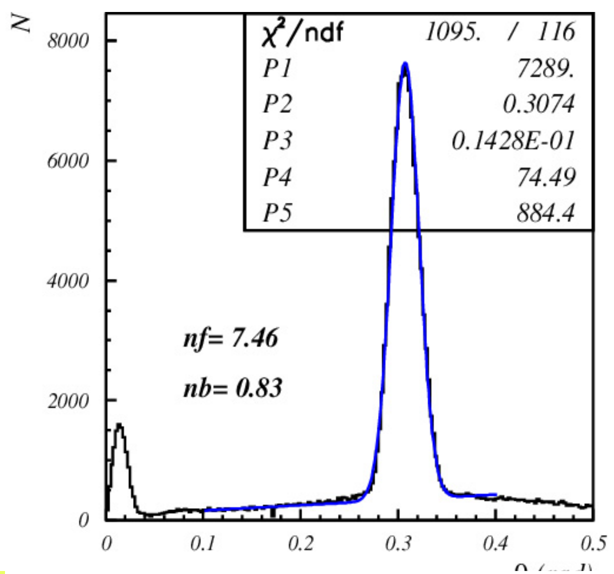


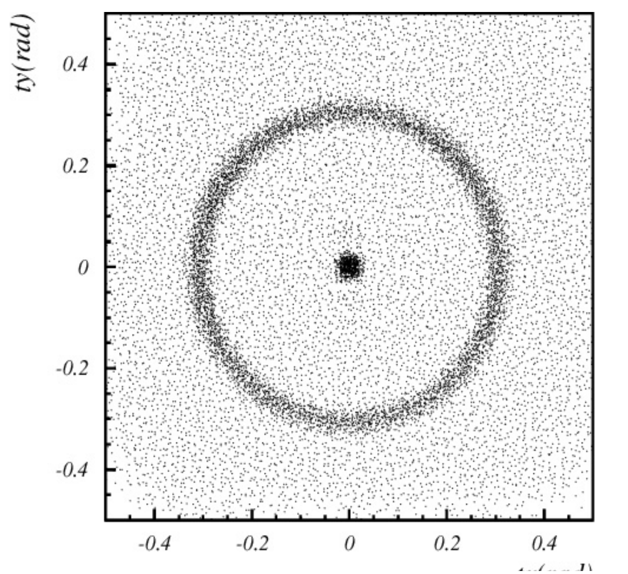




2+2cm aerogel



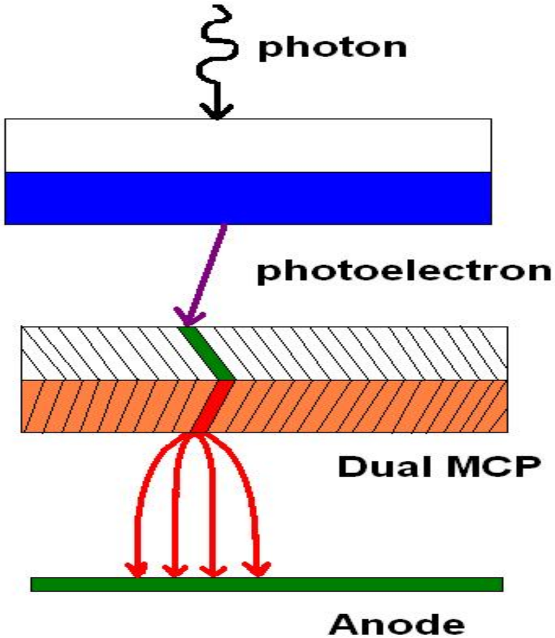


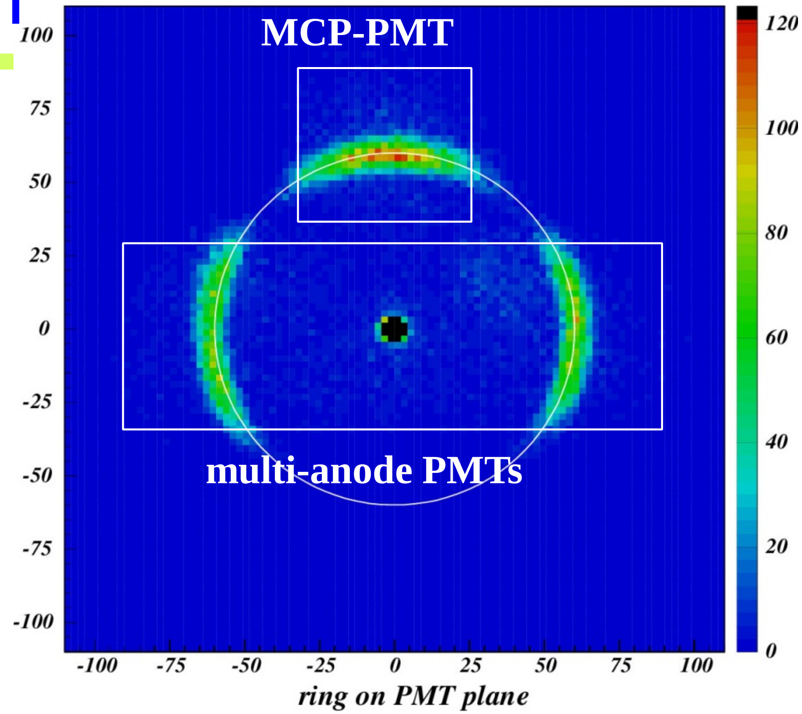


→NIM A548 (2005) 383

Fallback solution: BURLE/Photonis MCP-PMT

Photonis (BURLE) 85011 microchannel plate (MCP) PMT: multi-anode PMT with two MCP steps

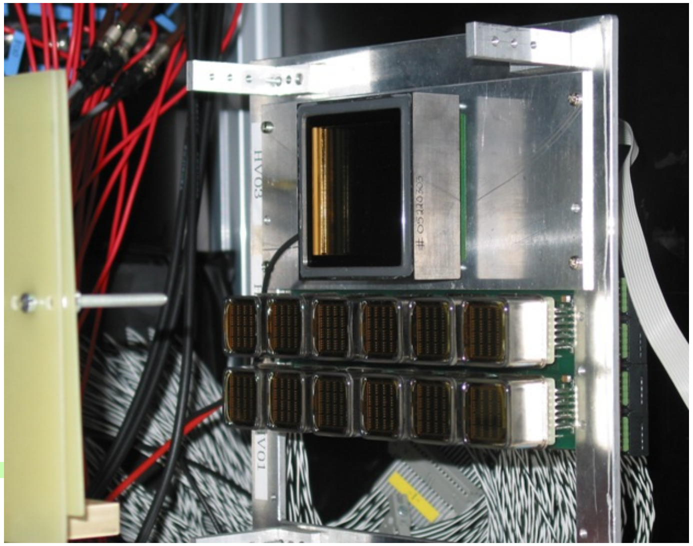




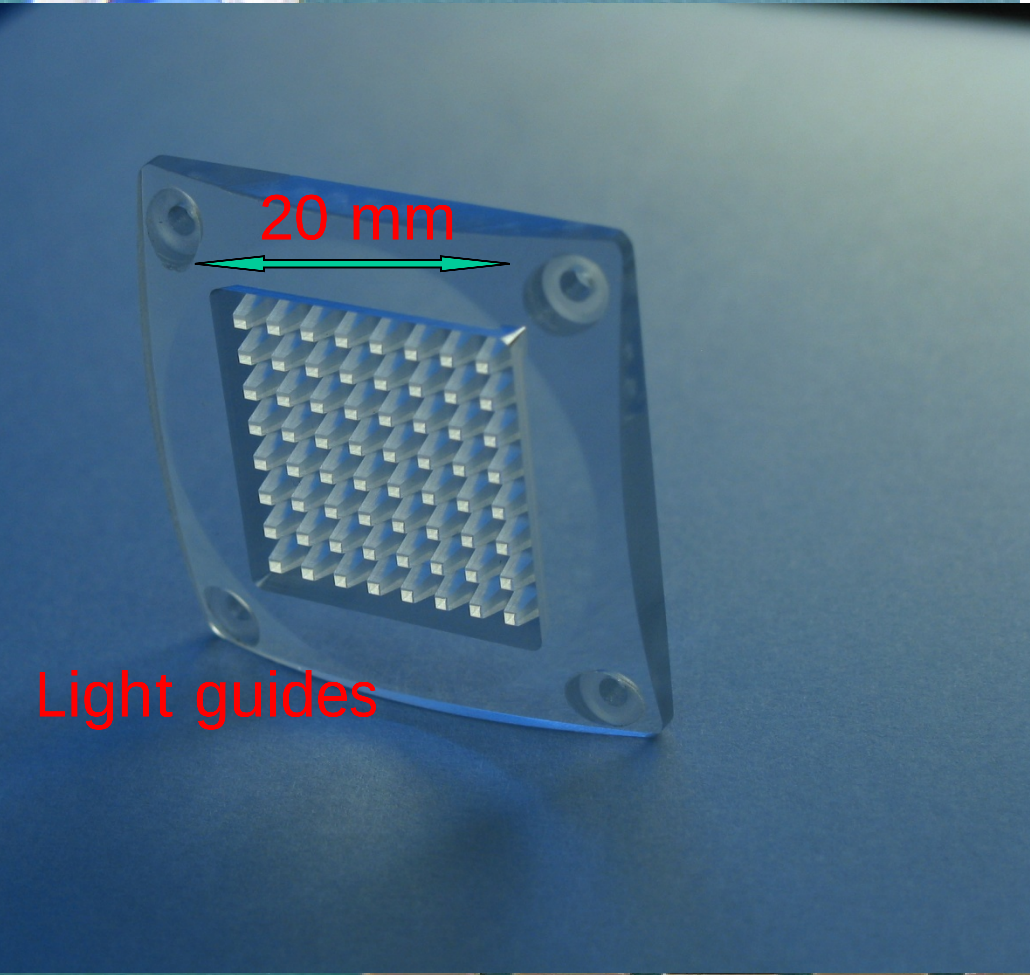
→good performance in beam and bench tests, NIMA567 (2006) 124

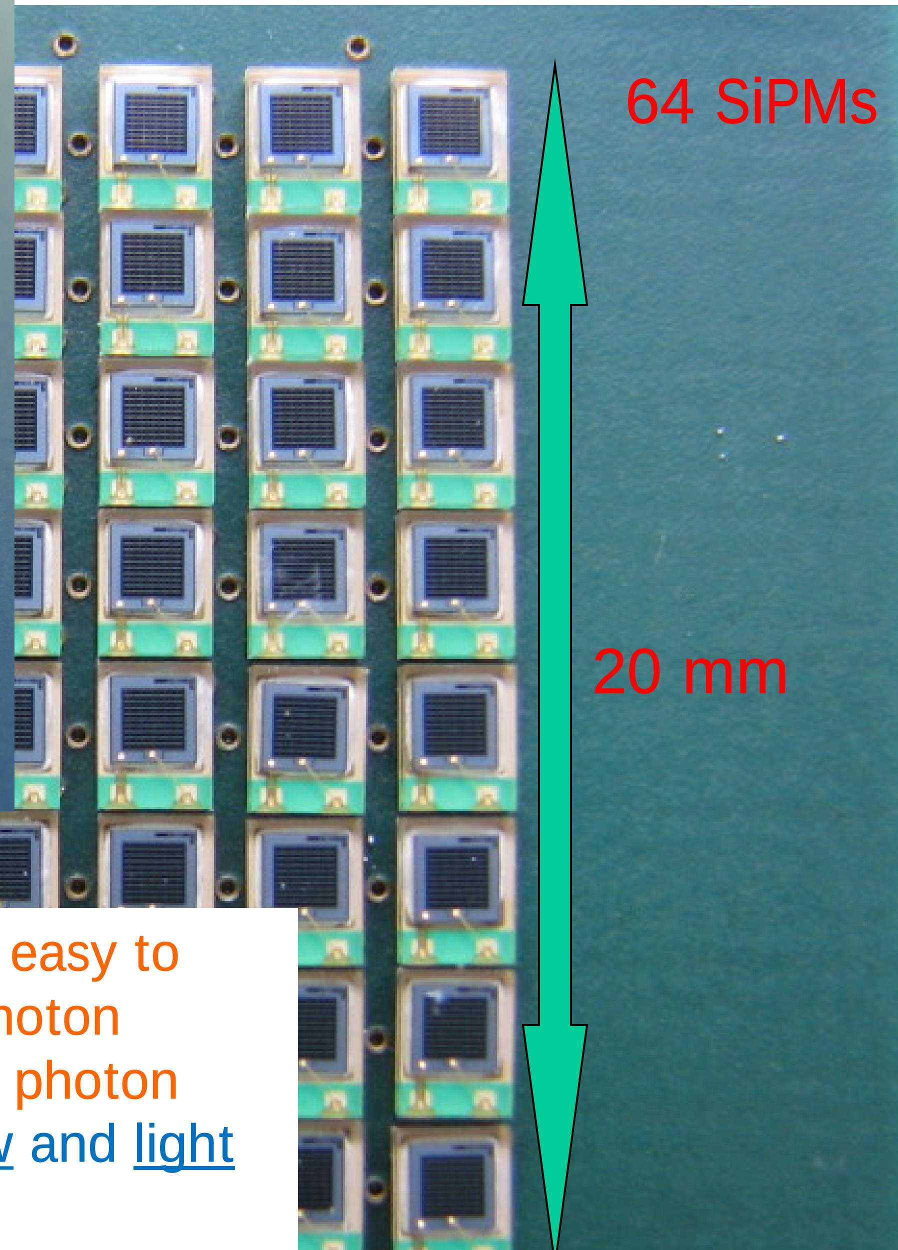
→ very fast (<40 ps)

→ ageing: test, not a problem



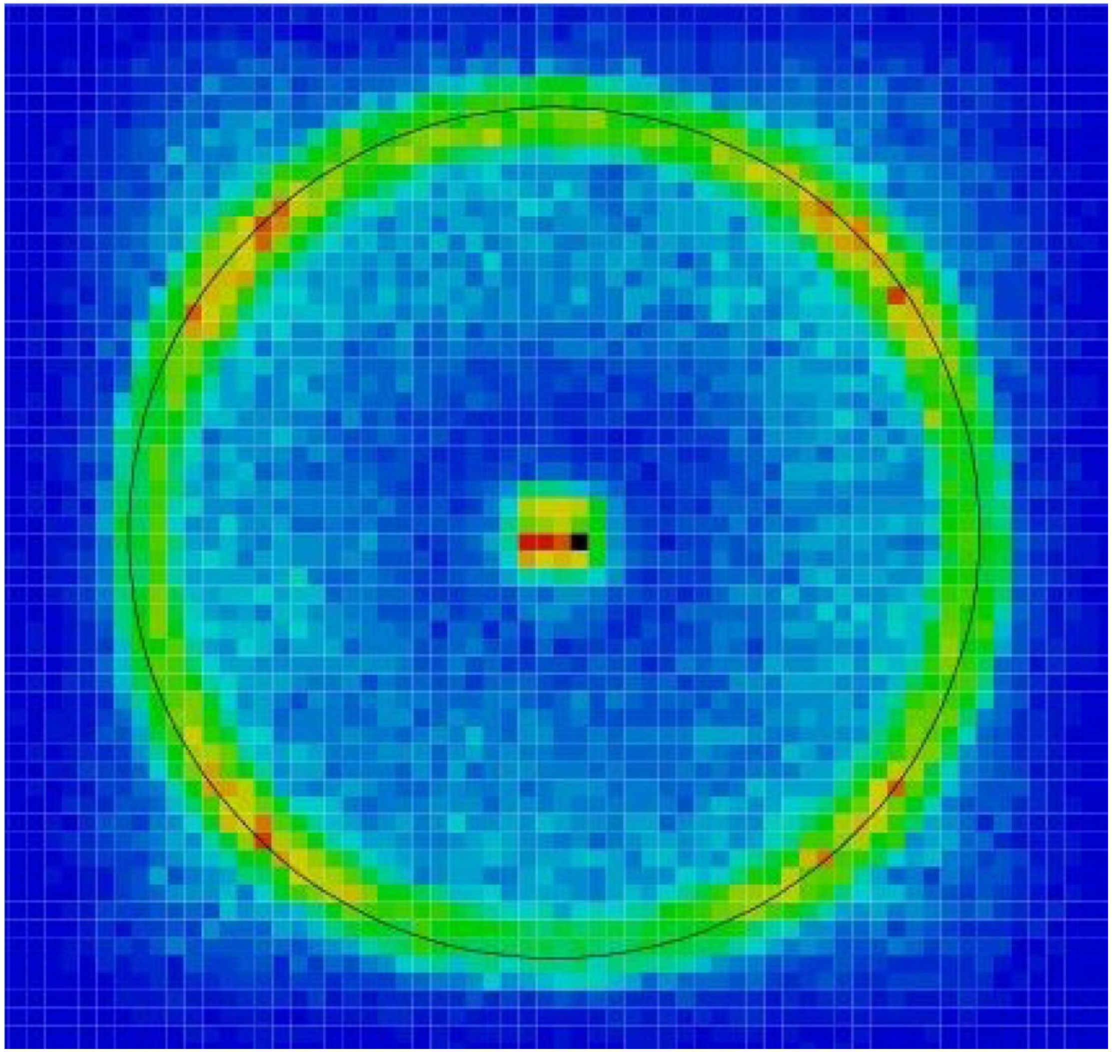
Another candidate: SiPM





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 narrow time window and light concentrators

Cherenkov ring with SiPMs

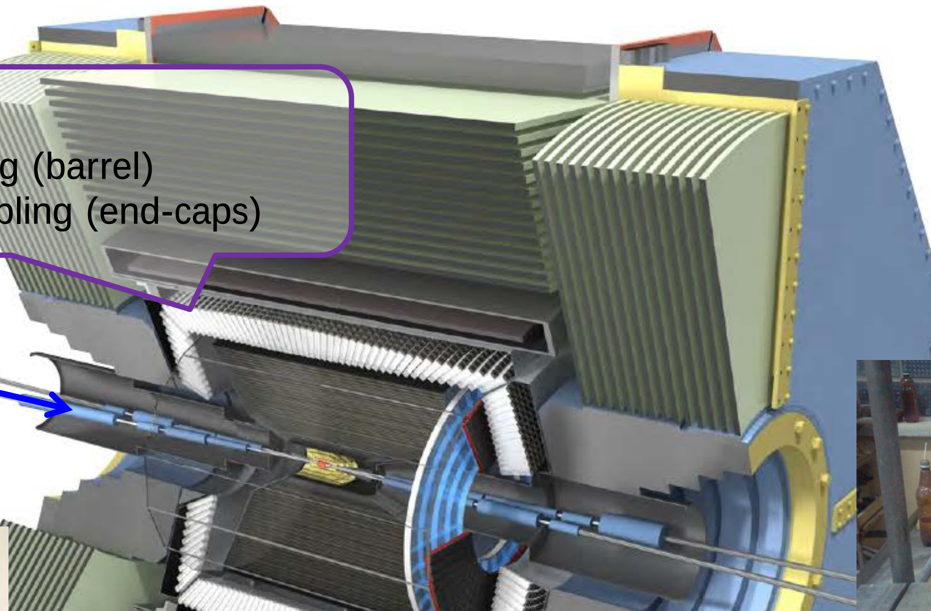


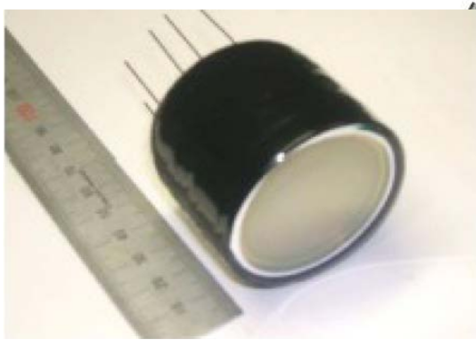
First successful use of SiPMs as single photon detectors in a RICH counter!

NIM A594 (2008) 13

EM calorimeter: upgrade need because of higher rates (electronics) and radiation load (endcap, CsI(Tl) → pure CsI)

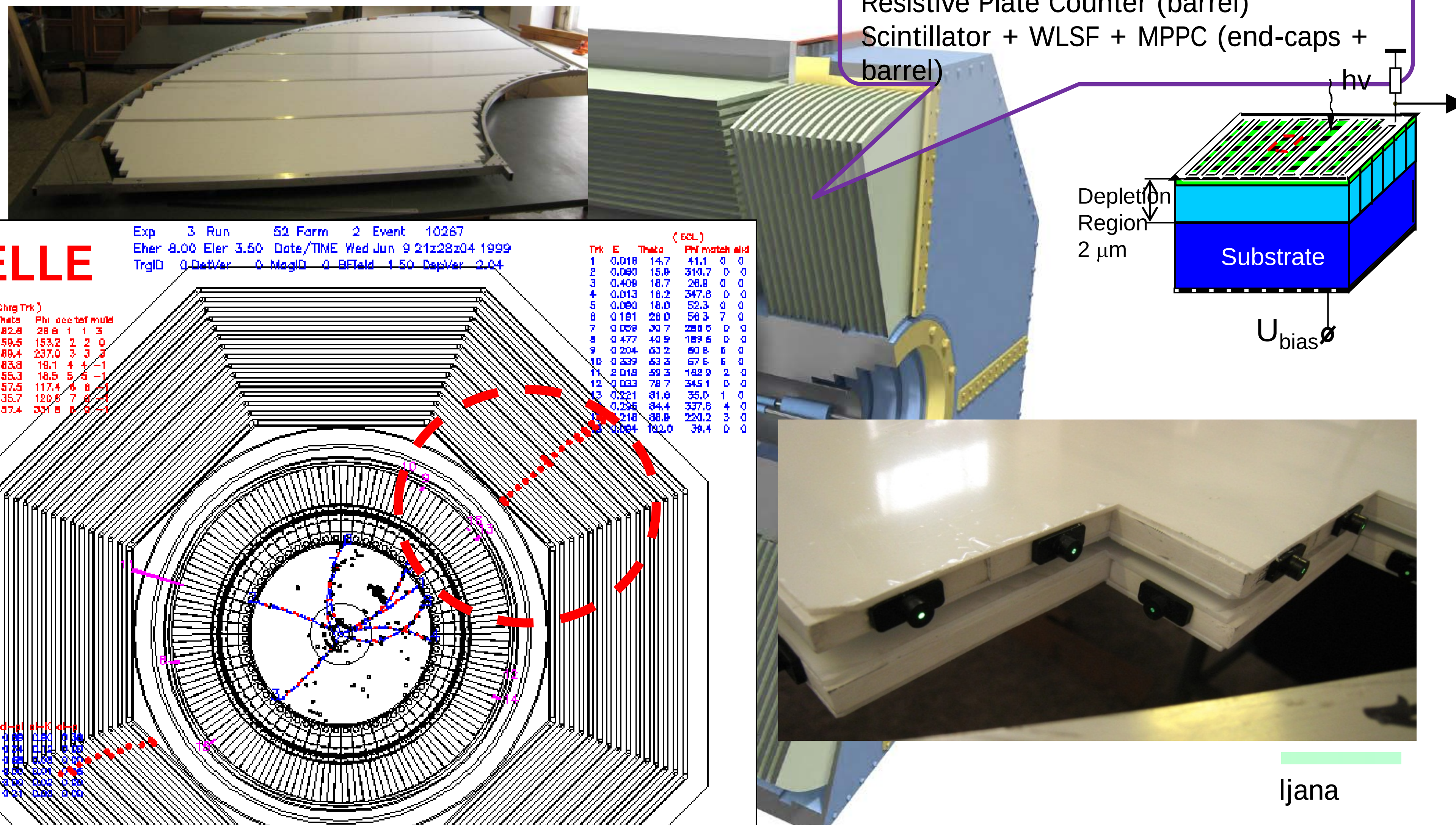
EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)





Detection of muons and KLs: parts of the present RPC system has to be replace because it cannot handle the high background rates (mainly neutrons)

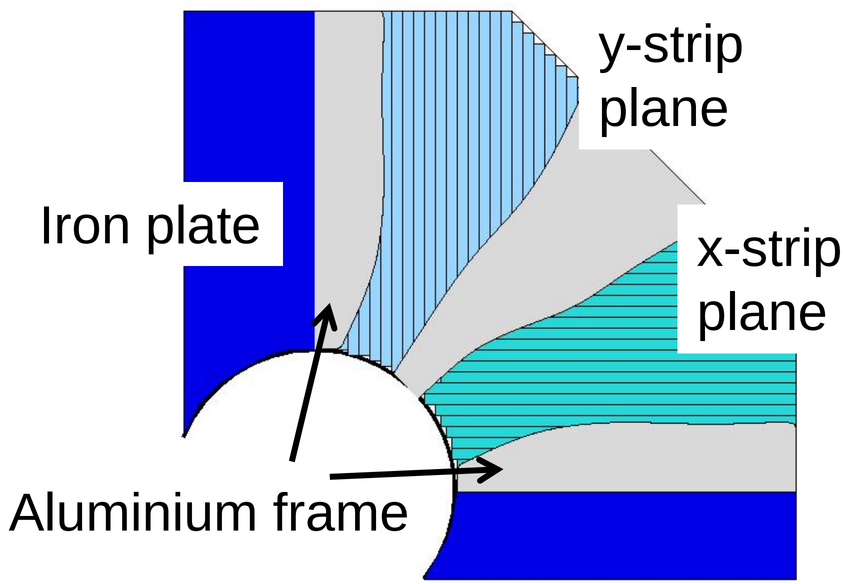
K_L and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps + barrel)

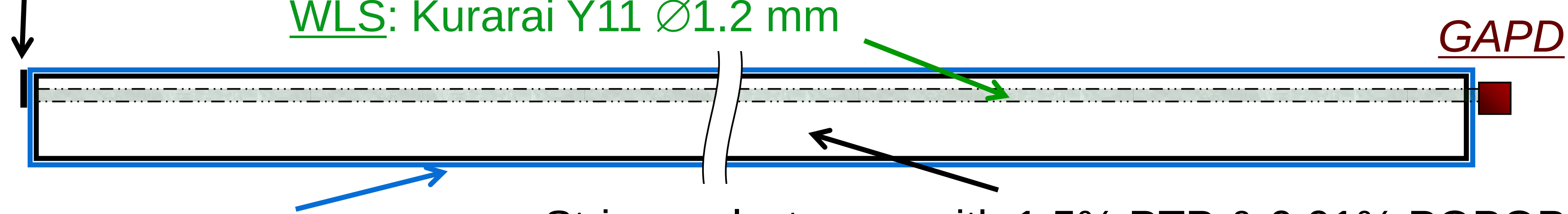


Muon detection system upgrade in the endcaps

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%





The Belle II Collaboration

A very strong group of ~400 highly motivated scientists!

European groups of Belle-II

•Austria: HEPHY (Vienna)
•Czech republic: Charles University (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
•Spain: Valencia

A sizeable fraction of the collaboration:

in total ~150 collaborators out of ~400!

SuperKEKB/Belle II Status

Funding

- ~100 MUS for machine -- Very Advanced Research Support Program (FY2010-2012)
- Full approval by the Japanese government in December 2010; the project is in the JFY2011 budget as approved by the Japanese Diet end of March 2011
- Most of non-Japanese funding agencies have also already allocated sizable funds for the upgrade of the detector.

→construction started in 2010!

KEKB/Belle status after the earthquake

Fortunately enough:

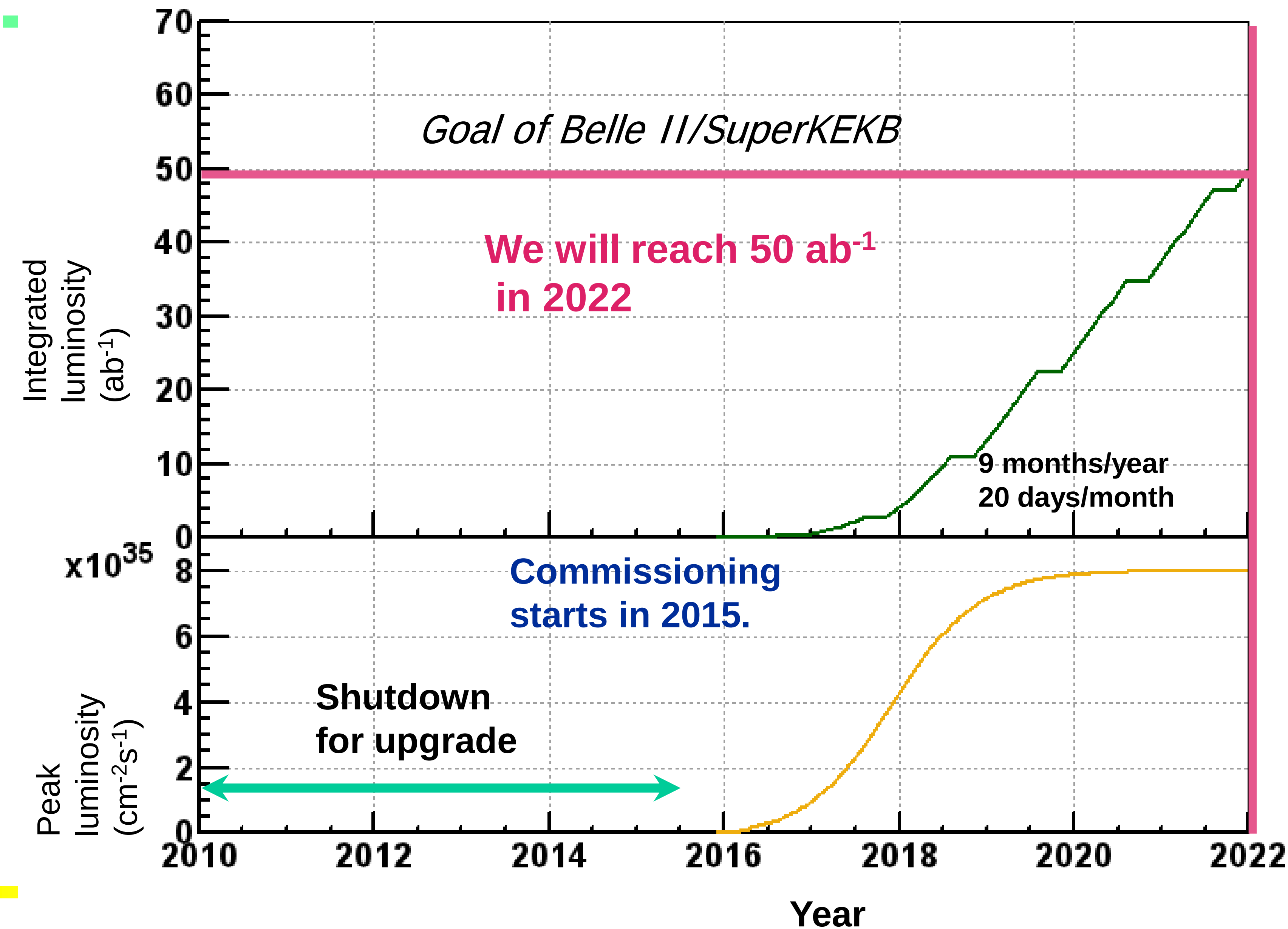
- KEKB stopped operation in July 2010, and the low energy ring was to a large extent disassembled
- Belle was rolled out to the parking position in December 2010.

The 1400 tons of Belle moved by ~6cm (most probably by 20cm in one direction, and 14cm back)…

We are checking the functionality of the Belle spectrometer (in particular the CsI calorimeter), so far all OK in LED and cosmic ray tests!

The lab has recovered from the earthquake, back to normal operation since early summer.

Schedule (Beam starts in Fall 2014)



Conclusion

- KEKB has proven to be an excellent tool for flavour physics, with reliable long term operation, breaking world records, and surpassing its design perfomance by a factor of two.
- Major upgrade at KEK in 2010-14 → SuperKEKB+Belle II, with 40x larger event rates, construction started
- Expect a new, exciting era of discoveries, complementary to the LHC

- There is a lot of work to do – I you are interested join us – it is a good group with excellent working atmosphere!