Partikeldagarna2011,
Chalmers, Göteborg, Oct 18, 2011

Belle II

Belle-II: status and prospects

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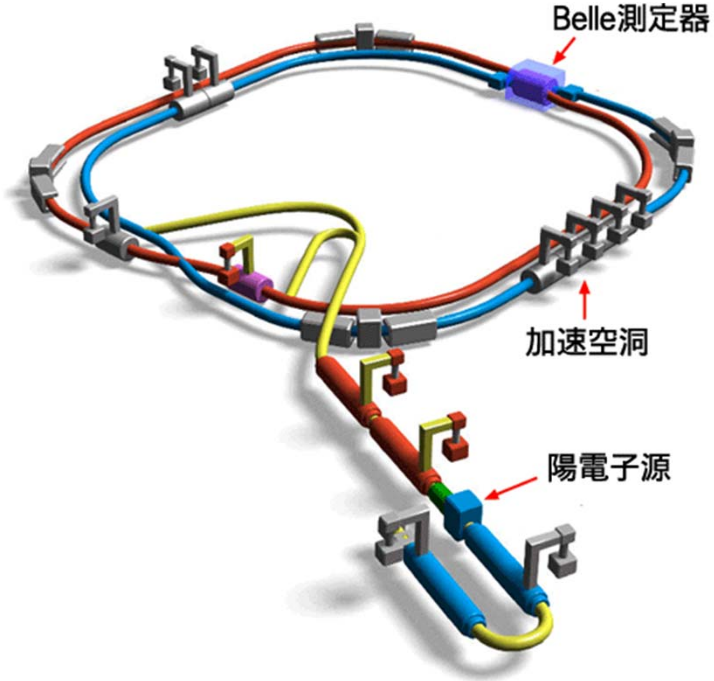
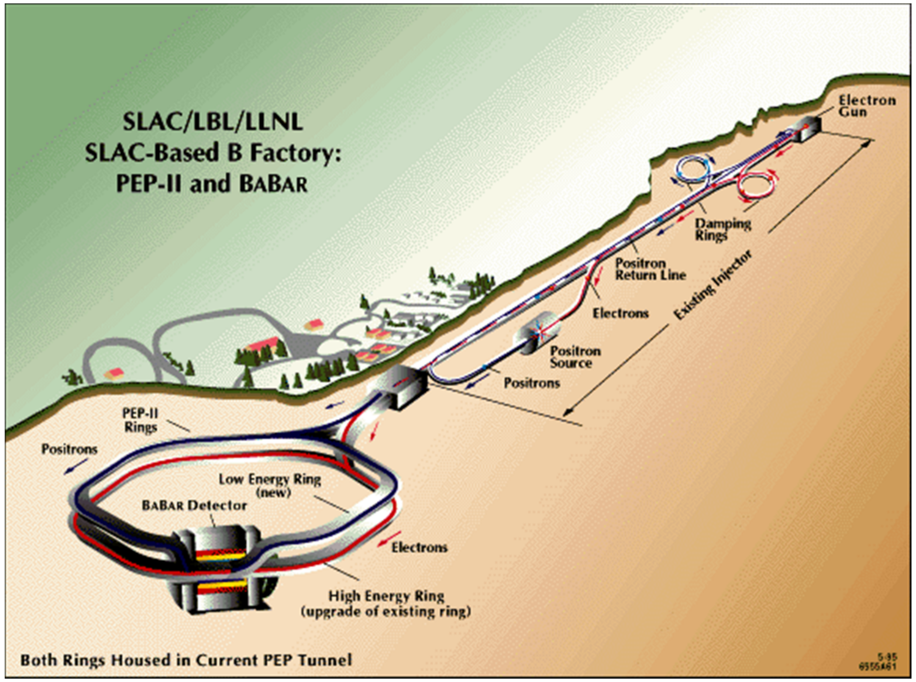
Contents

- Physics case for a super B factory
- Accellerator upgrade → SuperKEKB
- Detector upgrade → Belle-II
- Status and outlook

Asymmetric B factories





$\sqrt{s}=10.58$ GeV

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

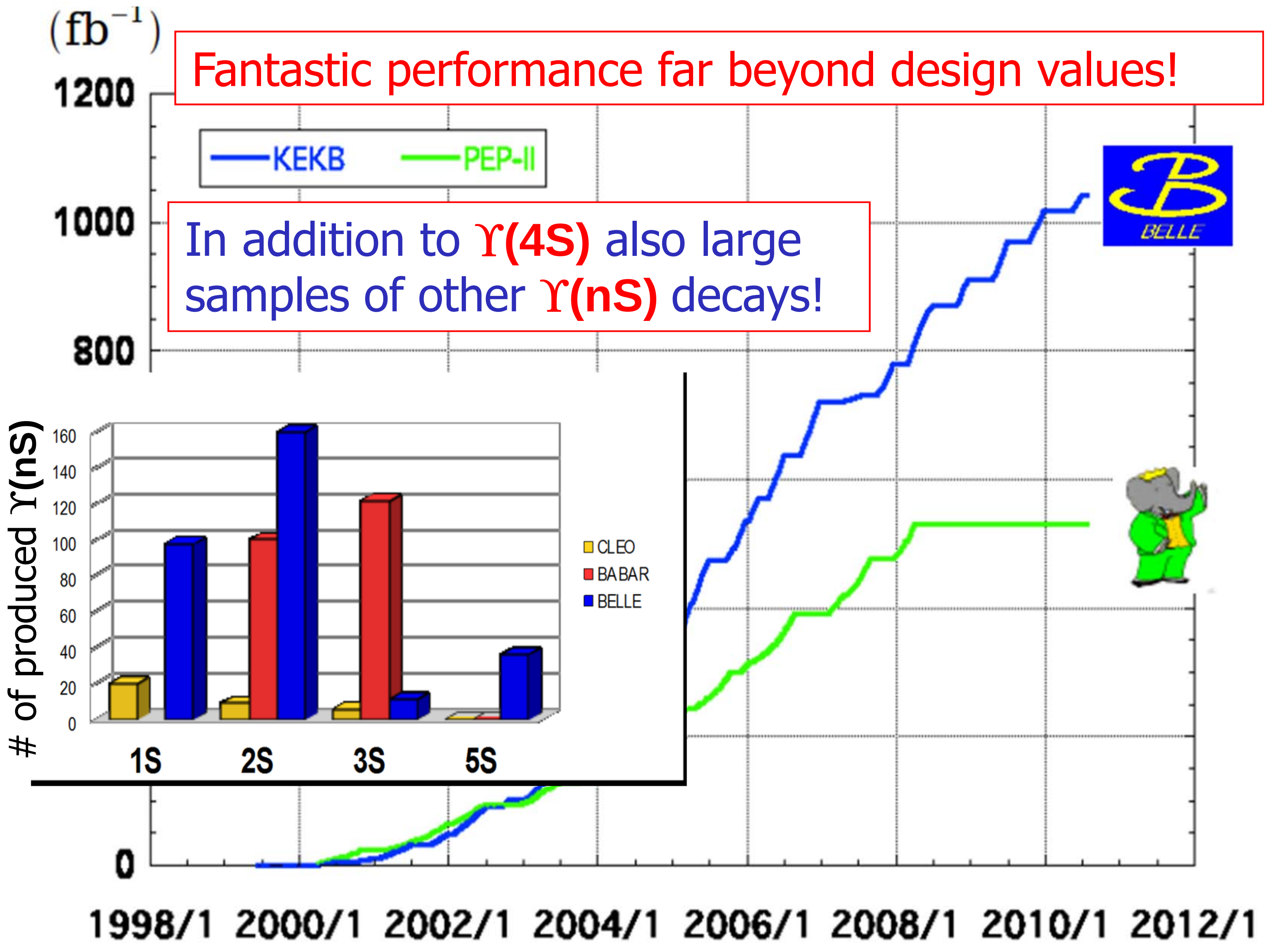
$\Upsilon(4s) \rightarrow B\,\bar{B}$

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

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

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

Integrated luminosity at B factories



$> 1\ ab^{-1}$

On resonance:

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

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

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

$\Upsilon(2S)$: 25 fb^{-1}

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

Off reson./scan:

$\sim 100\ fb^{-1}$

$\sim 550\ fb^{-1}$

On resonance:

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

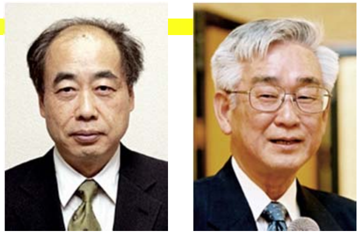
$\Upsilon(3S)$: 30 fb^{-1}

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

Off resonance:

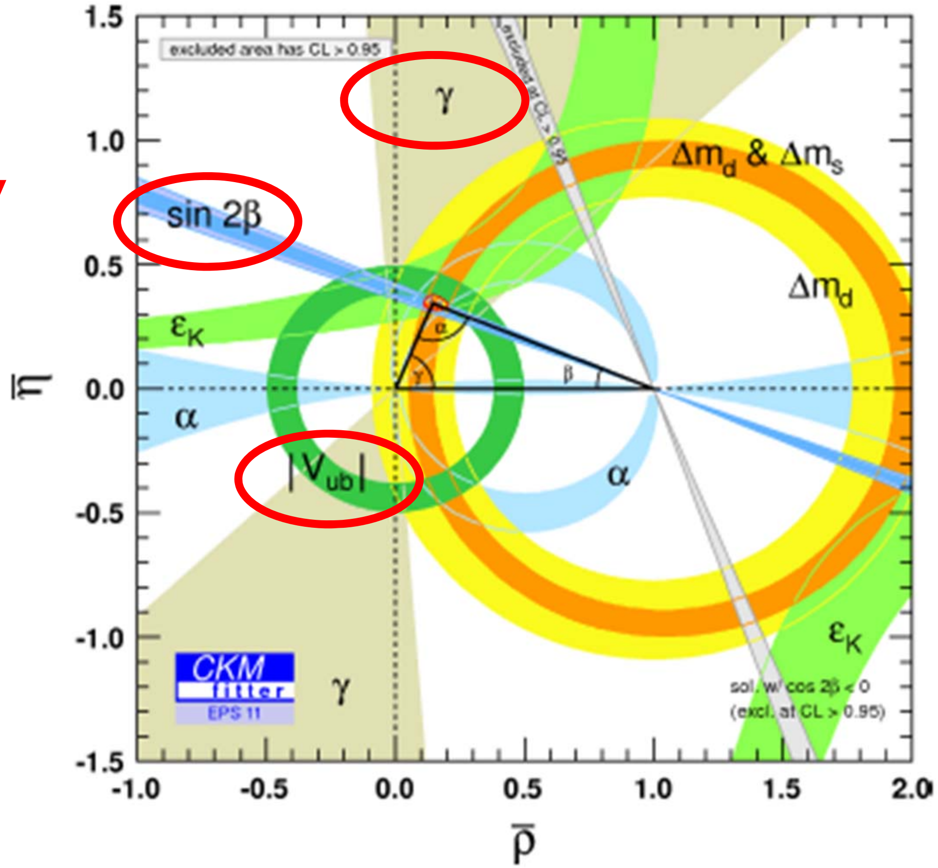
$\sim 54\ fb^{-1}$

Unitarity triangle – new/final measurements



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

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



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

CKM matrix

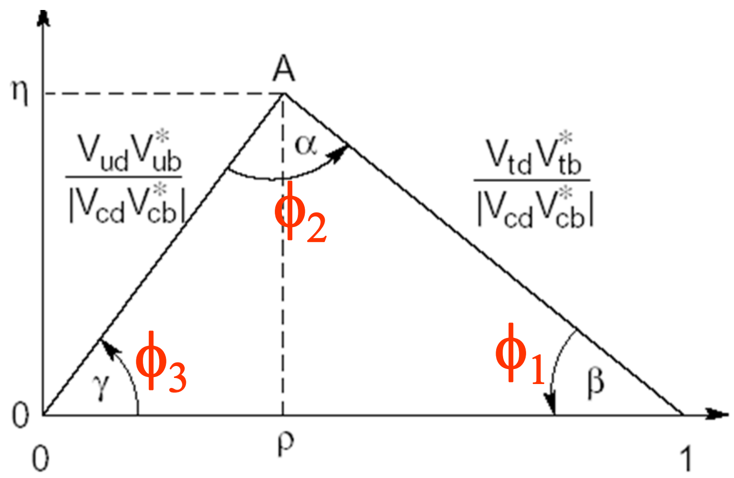
Wolfenstein parametrisation: expand in the parameter λ (=sinθ$_c$=0.22)

A, ρ and η: all of order one

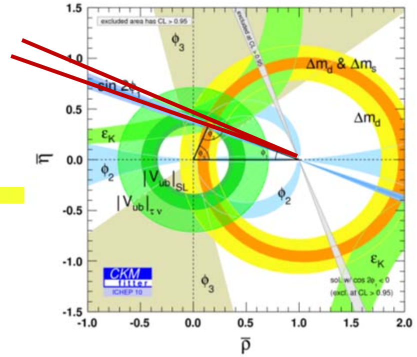
$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Unitarity condition:

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



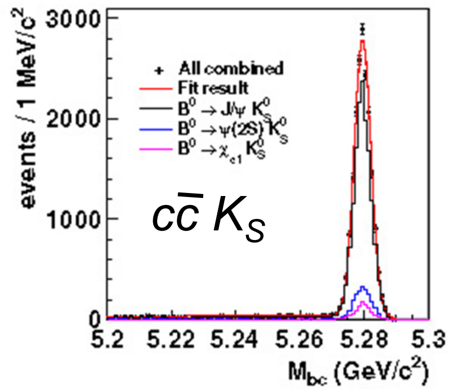
Final measurement of $\sin 2\phi_1$ (=$\sin 2\beta$)



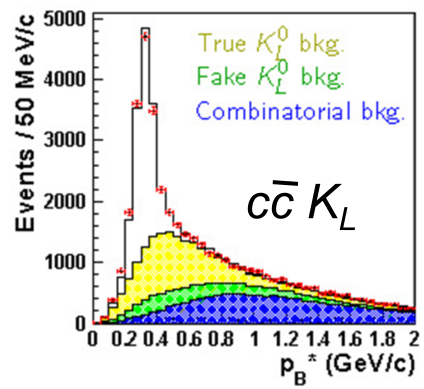
Belle, preliminary, 710 fb^{-1}

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

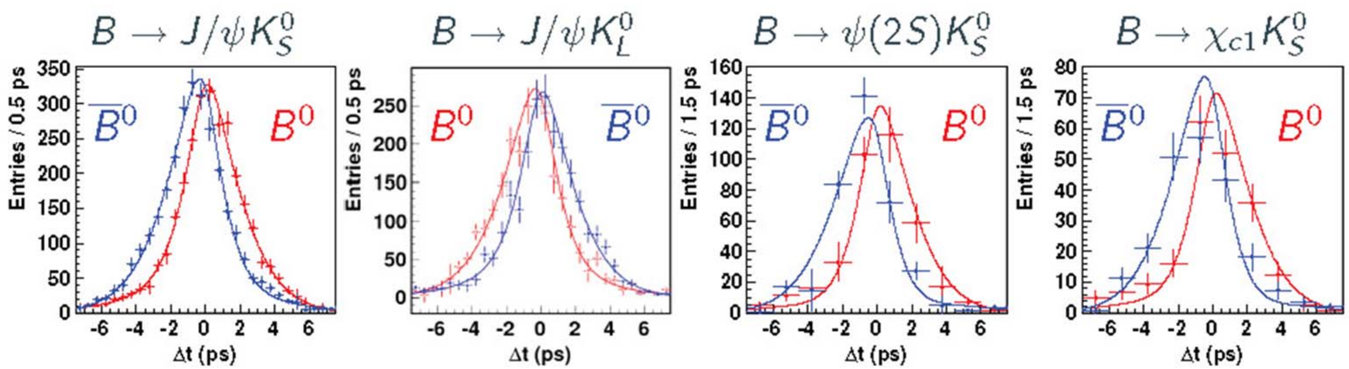
Improved tracking, more data
(50% more statistics than last result with 480 fb^{-1});
$c\bar{c}$ = J/ψ, $\psi(2S)$, χ_{c1} → 25k events



for K_L only cluster (direction) in ECL, KLM;
missing info from kinematic constraints;



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



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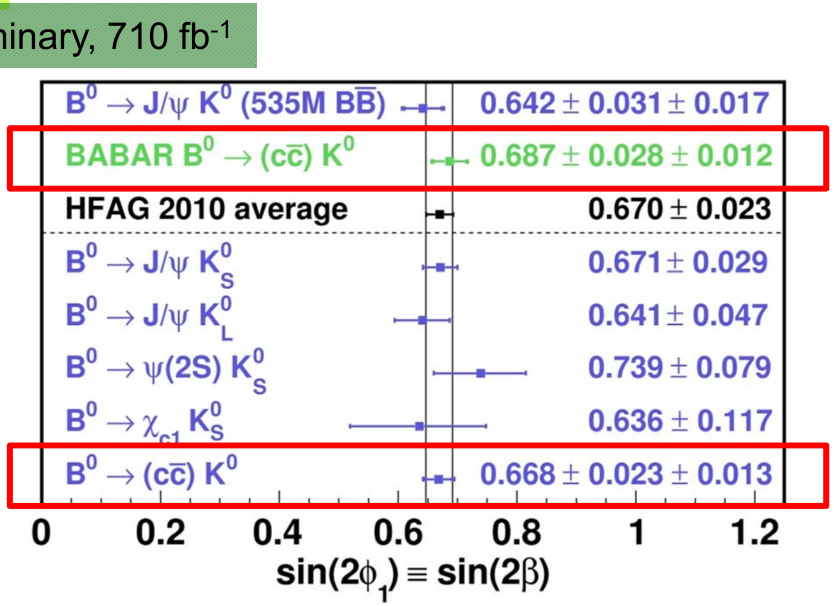
Final measurement of $\sin 2\phi_1$ (=$\sin 2\beta$)

ϕ_1 from $B^0 \to c\overline{c}\, K^0$

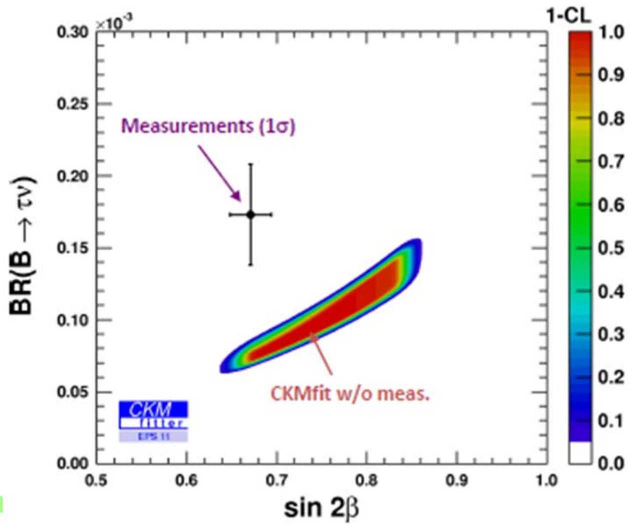


Final result (preliminary) from Belle:

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

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



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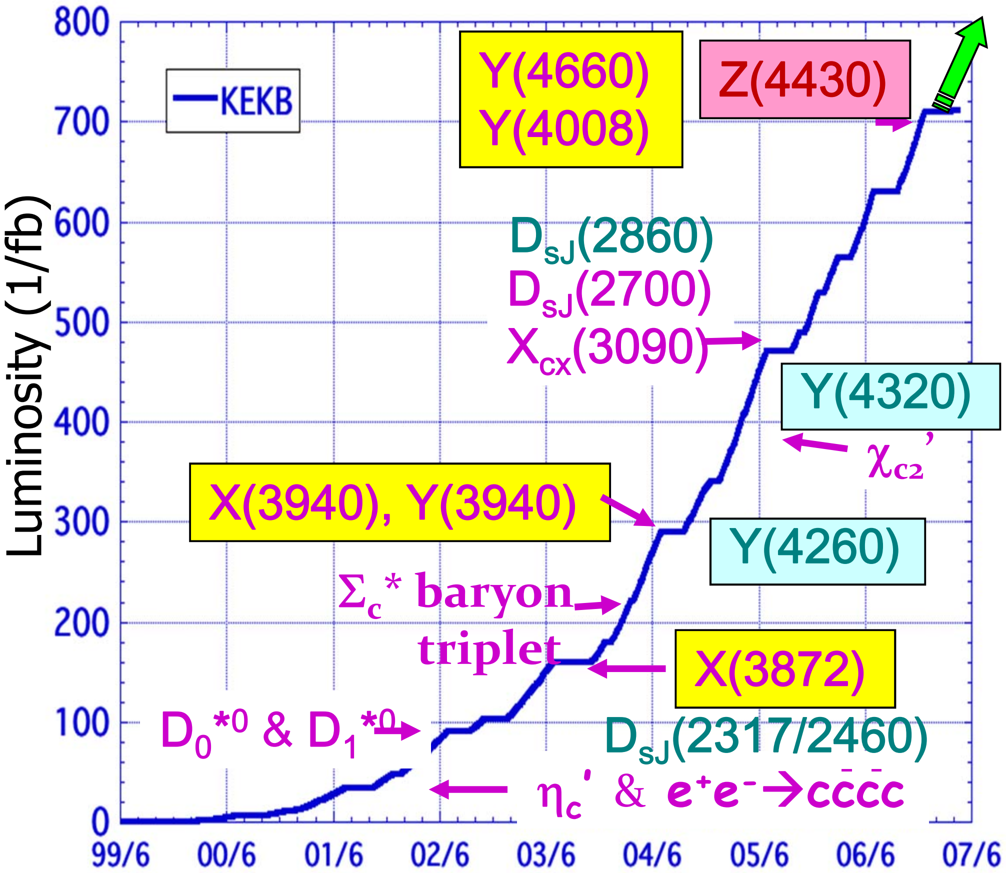
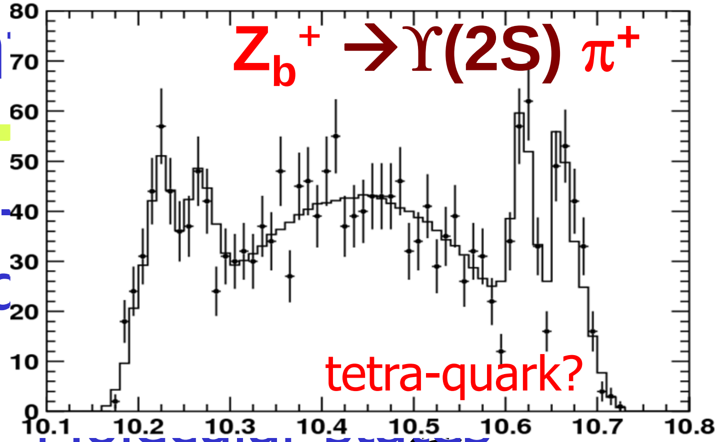
B factories: a success story

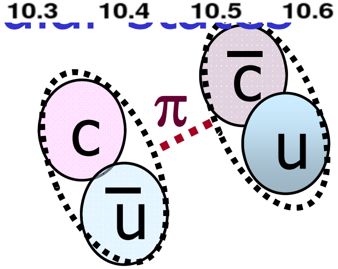
- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., $B \to \tau\nu$, $D\tau\nu$)
- $b \to s$ transitions: probe for new sources of CPV and constraints from the $b \to s\gamma$ branching fraction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

New hadrons a

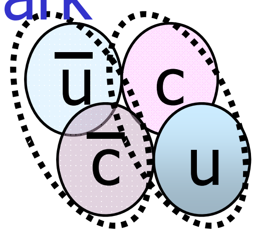
Discoveries of many new hadrons at B-
light on a new class of hadrons beyonc



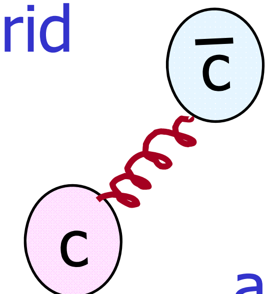




Tetra-quark



Hybrid



and more...

What next?

B factories → is SM with CKM right?

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

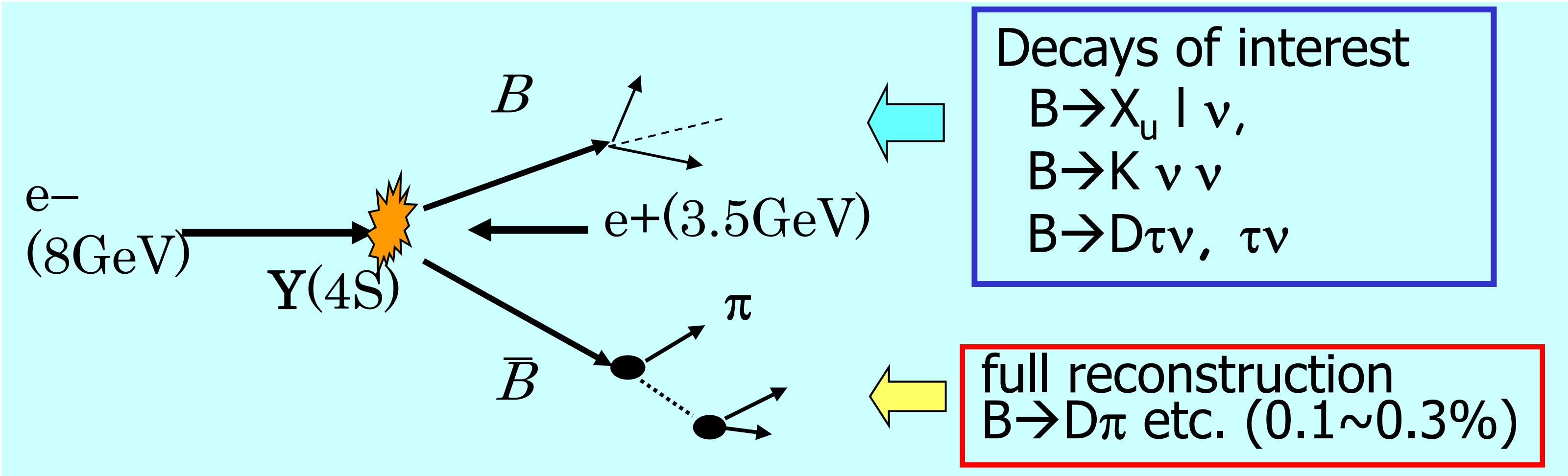
→ Need much more data (two orders!) because the SM worked so well until now → Super B factory

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

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

Full Reconstruction Method

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

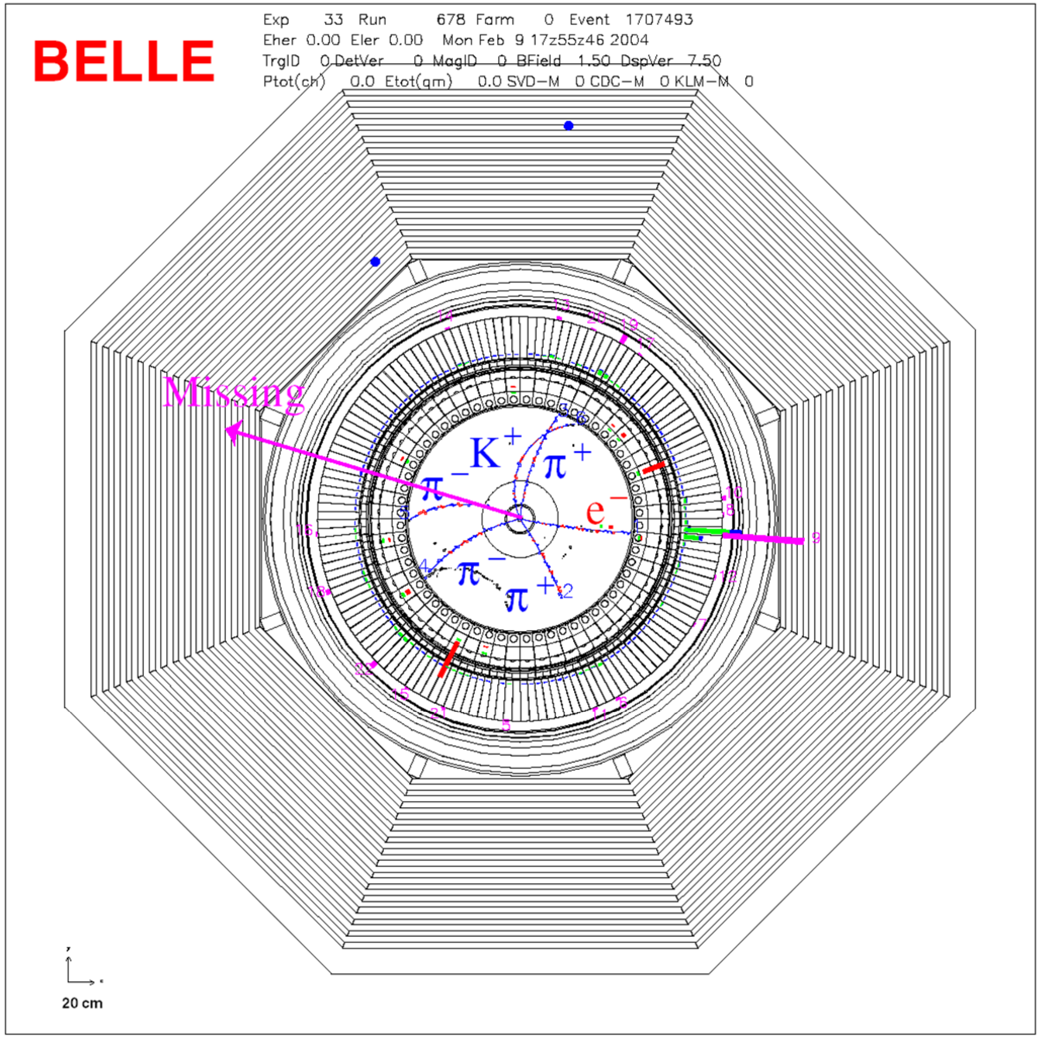


→ Offline B meson beam!

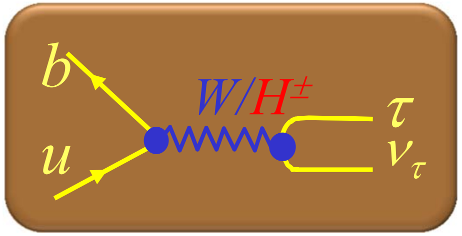
Powerful tool for B decays with neutrinos

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

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

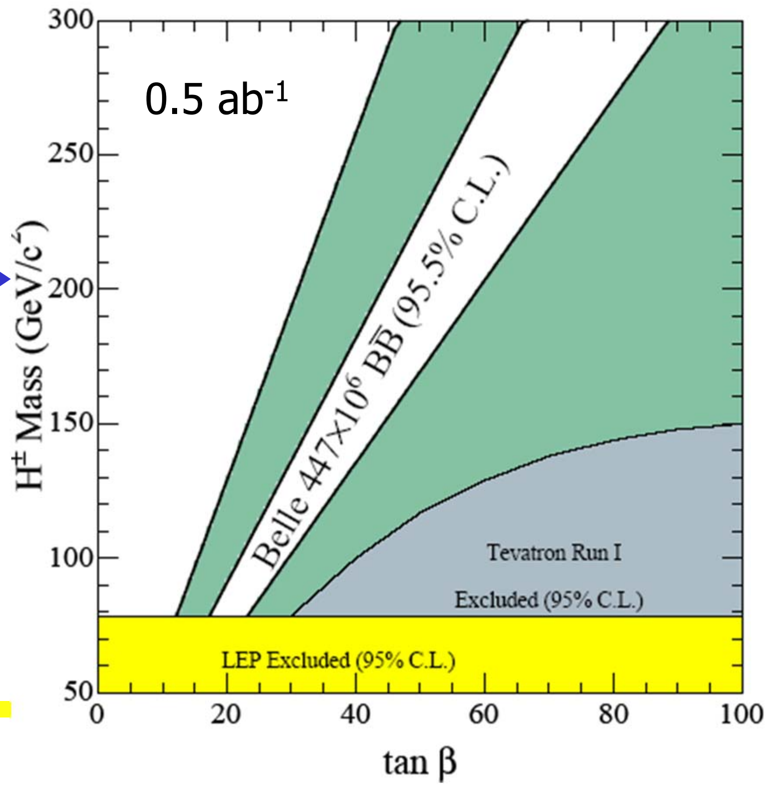


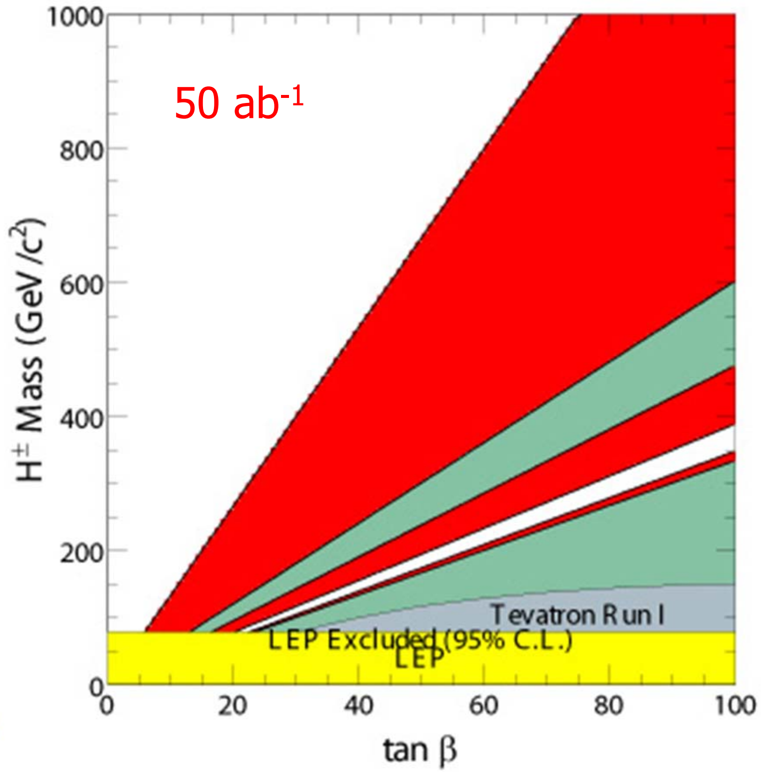
Charged Higgs limits from $B^- \rightarrow \tau^- \nu_\tau$



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

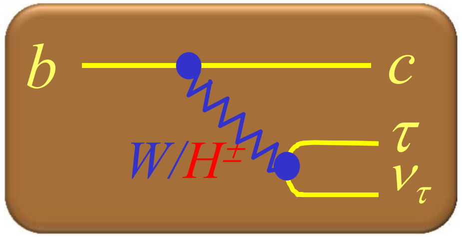
→ limit on charged Higgs mass vs. tanβ





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

Semileptonic decay sensitive to charged Higgs



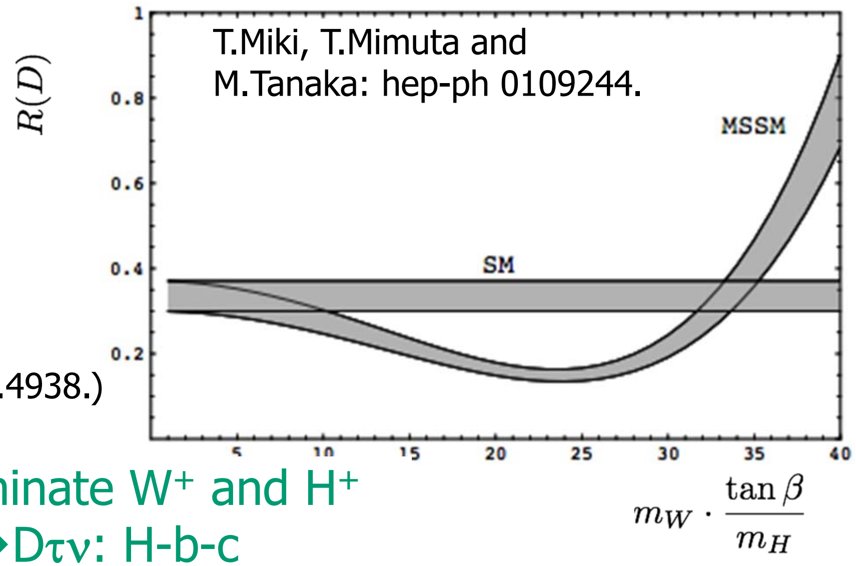
Ratio of τ to μ,e could be reduced/enhanced significantly

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

Complementary and competitive with B→τν

1. Smaller theoretical uncertainty of R(D)
   (For B→τν,
   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→τ ν: H-b-u, B→Dτν: H-b-c
   (LHC experiments sensitive to H-b-t)

Advantage of B factories!

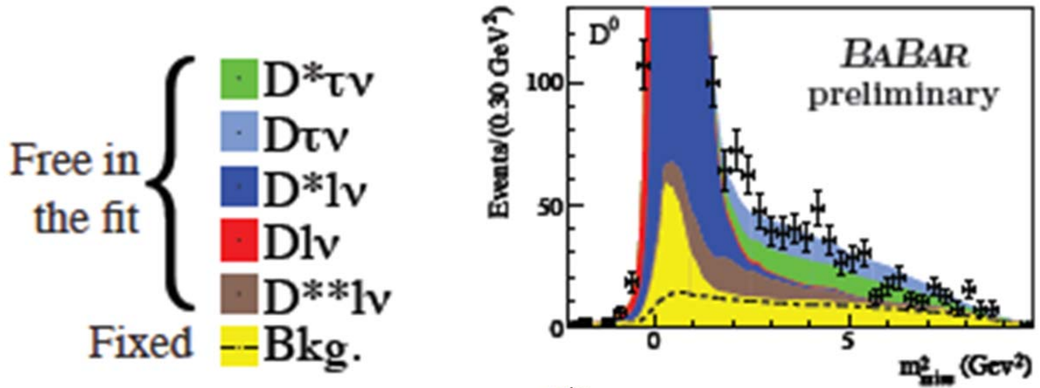
First observation of B → $D^{*-}\tau\nu$ by Belle (2007) → PRL 99, 191807 (2007)

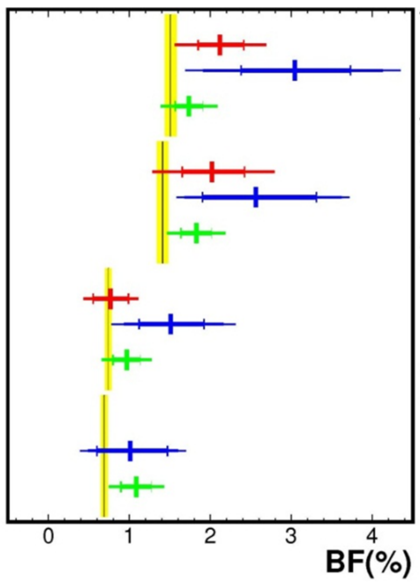
B → $D^{(*)}\tau\nu$ decays

→talk by M. Franco Sevilla

This summer: First 5σ observation of B → $D\tau\nu$ decays

Exclusive hadron tag data





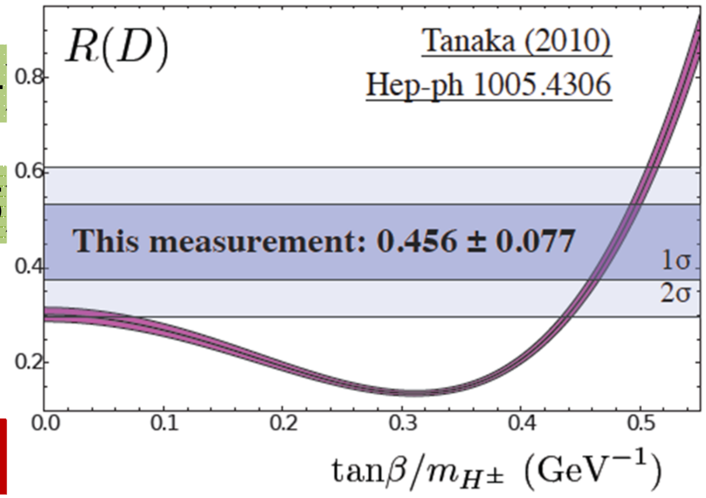
$B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$ (1.73±0.17±0.18)%

$B^0 \to D^{*-}\tau^+\nu_\tau$ (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 then SM predictions →



Belle inclusive tag, Belle exclusive tag, Babar excusive tag (this conference) compared to the SM prediction

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

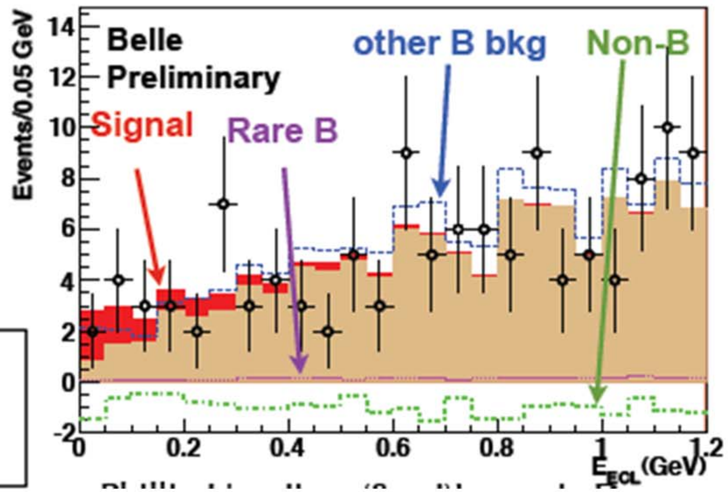
$B \to \nu\,\nu$ similar as $B \to \mu\,\mu$ a very sensitive channel to NP contributions

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.



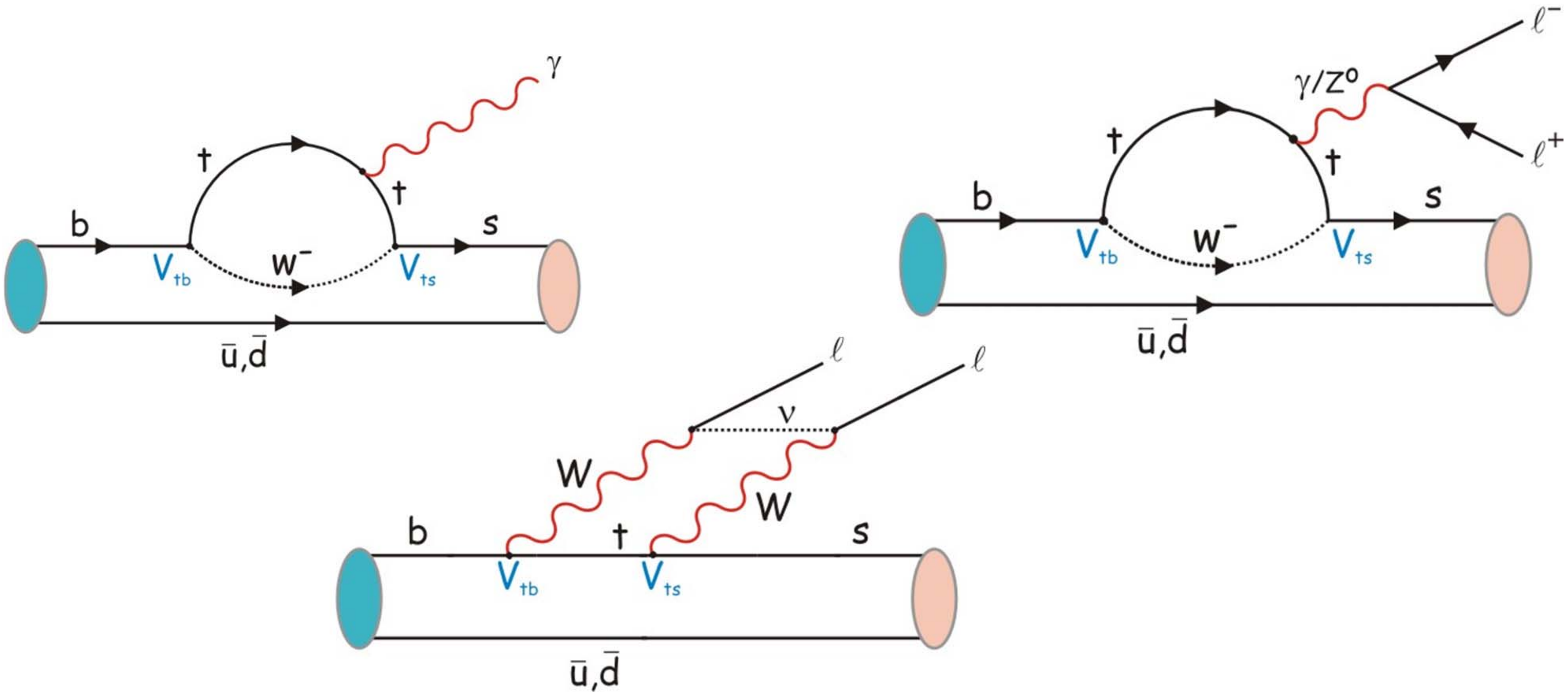
90% C.L. BR < 1.3×10^{-4}

Belle Preliminary 657M BBbar

c.f. (Babar) BR < 2.2×10^{-4}

Why FCNC decays?

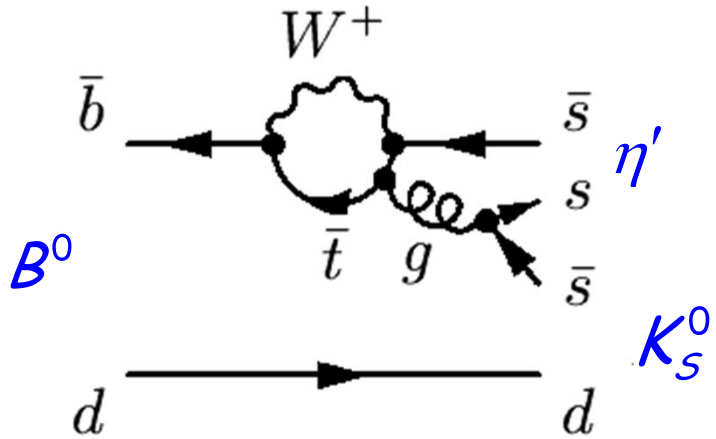
Flavour changing neutral current (FCNC) processes (like b→s, b→d) are fobidden at the tree level in the Standard Model. Proceed only at low rate via higher-order loop diagrams. Ideal place to search for new physics.



How can New Physics contribute to b→s?

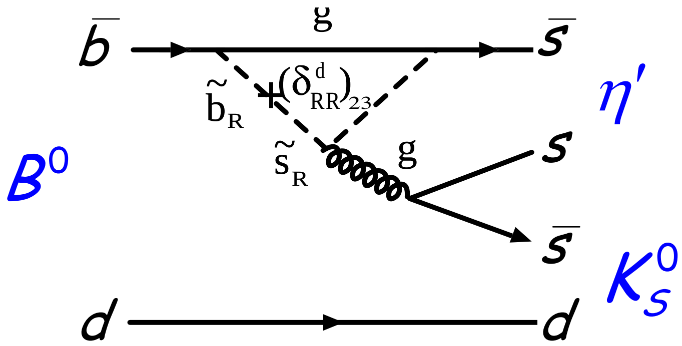
For example in the process:

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



Ordinary penguin diagram with a t quark in the loop

Diagram with supersymmetric particles

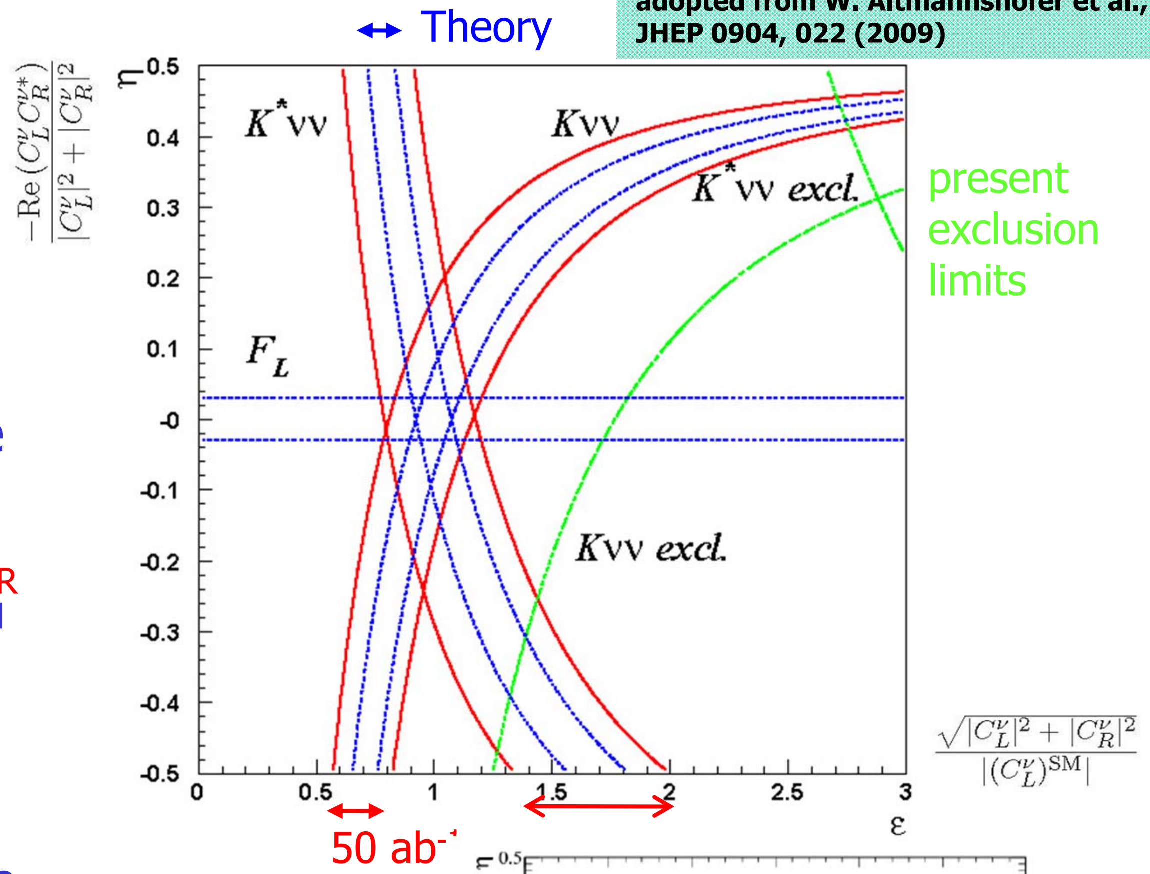


$B \to K^{(*)}\nu\nu$

arXiv:1002.5012

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

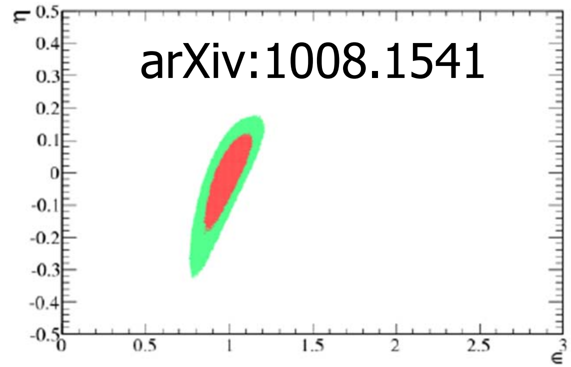
$B \to K\nu\nu$, $\mathcal{B} \sim 4 \cdot 10^{-6}$
$B \to K^*\nu\nu$, $\mathcal{B} \sim 6.8 \cdot 10^{-6}$



SM: penguin+box

Look for departure from the expected value → information on couplings C^ν_R and C^ν_L compared to $(C^\nu_L)^{SM}$

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



not possible @ LHCb

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

nature International weekly journal of science

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

LETTERS

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

The Belle Collaboration*

CP asymmetry

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

Difference between B^+ and B^0 decays

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

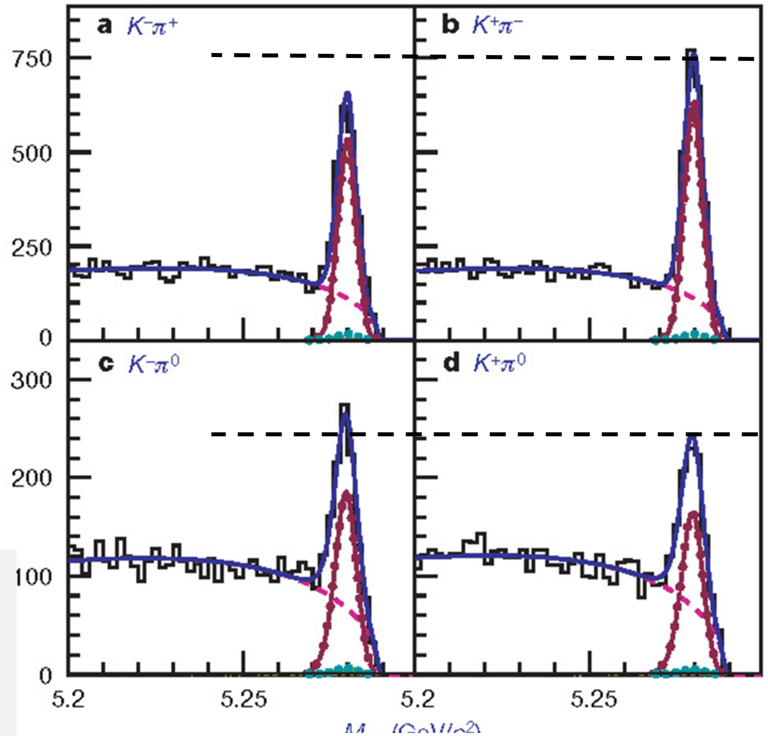
Measure:

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

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

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

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

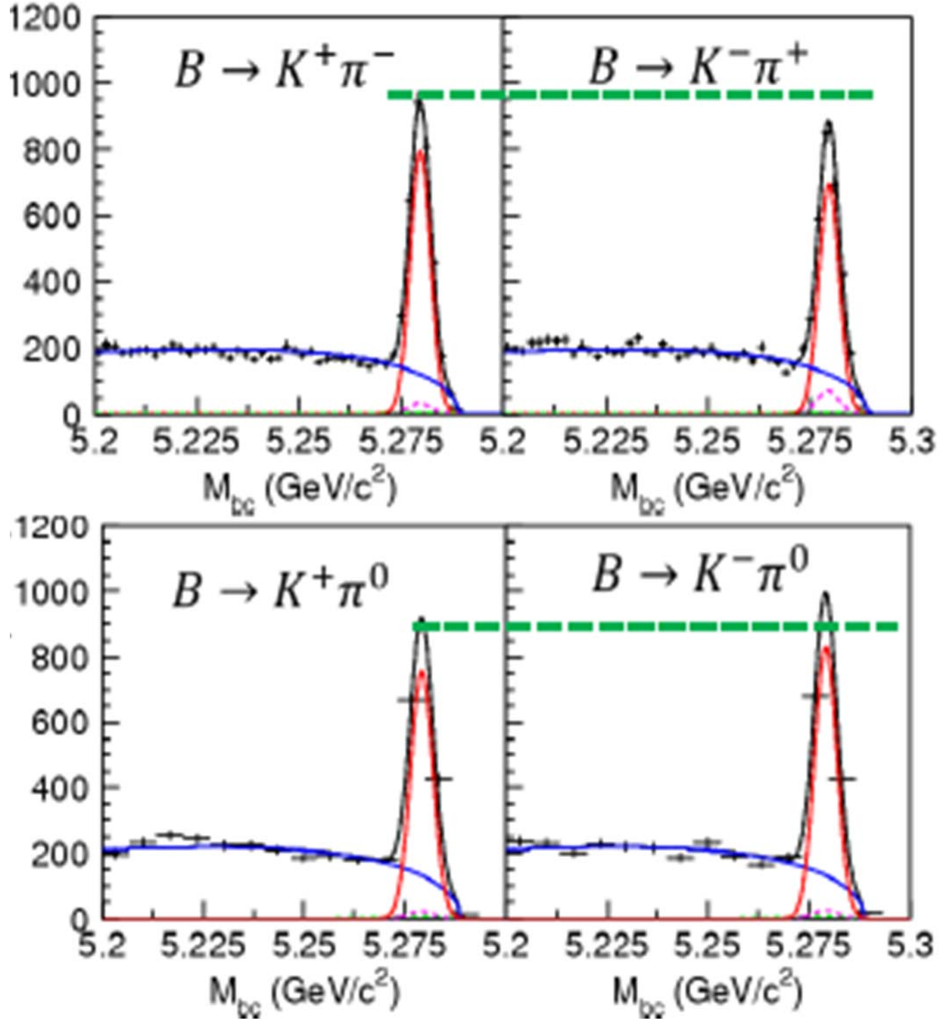


~1 in 10^5 B mesons decays in this decay mode

Belle, Nature 452, 332 (2008)

Direct CP violation difference in $B \to K^+\pi^-$ and $K^+\pi^0$

Update 2011, preliminary



$\Delta A_{K\pi} = A_{CP}(K\pi^0) - A_{CP}(K\pi)$

Update the 2008 result with the full data set and improved reconstruction - ~2x more data

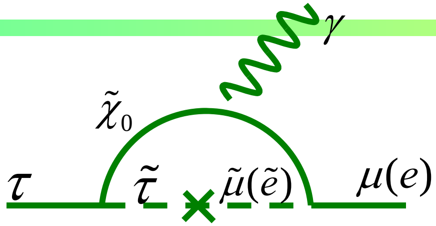
$$A_{cp}(K^{\pm}\pi^0) = +0.043 \pm 0.024 \pm 0.002$$
$$A_{cp}(K^{\pm}\pi^{\mp}) = -0.069 \pm 0.014 \pm 0.007$$

Belle preliminary:

$$\Delta A_{K\pi} = +0.112 \pm 0.028 \;@4\sigma$$

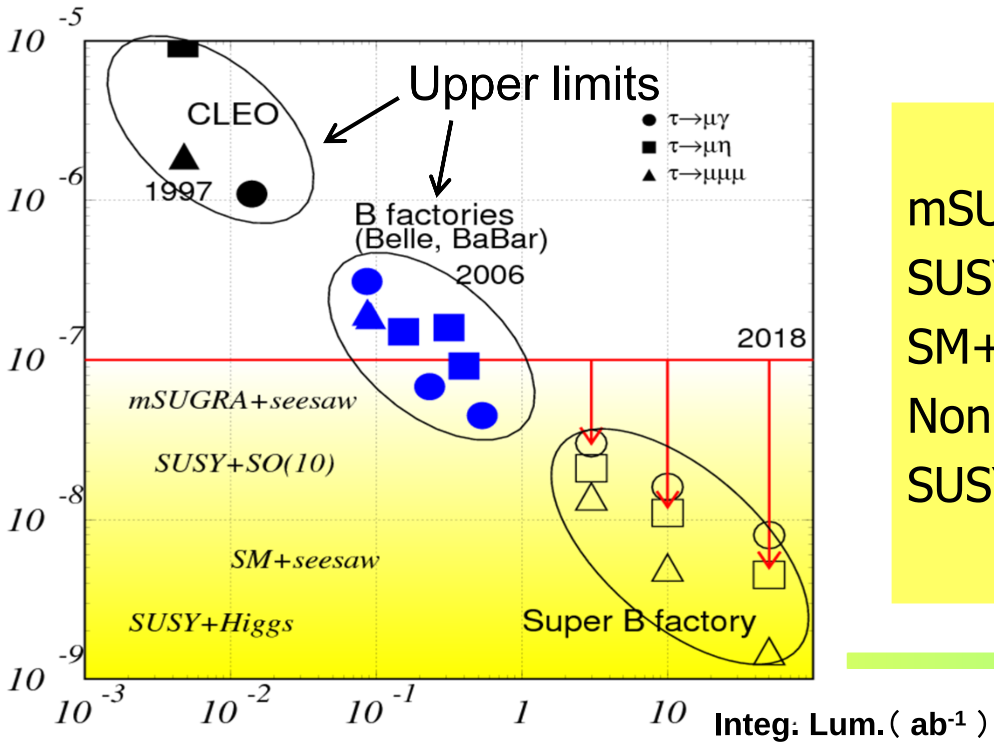
LFV and New Physics

τ→lγ

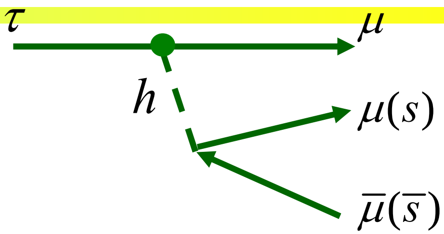


- SUSY + Seasaw $(m^2_{\tilde{l}})_{23(13)}$
- Large LFV Br(τ→μγ)=O($10^{-7\sim9}$)

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



τ→3l,lη



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

$$Br(\tau \to 3\mu) = 4\times10^{-7}\times\left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}}\right)\left(\frac{\tan\beta}{60}\right)^6\left(\frac{100GeV}{m_A}\right)^4$$

model	Br(τ→μγ)	Br(τ→lll)
mSUGRA+seesaw	10^{-7}	10^{-9}
SUSY+SO(10)	10^{-8}	10^{-10}
SM+seesaw	10^{-9}	10^{-10}
Non-Universal Z’	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-7}

B Physics @ Υ(4S)

Observable	B Factories ($2\ \mathrm{ab}^{-1}$)	Super$B$ ($75\ \mathrm{ab}^{-1}$)
$\sin(2\beta)$ $(J/\psi K^0)$	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 ($2\ \mathrm{ab}^{-1}$)	Super$B$ ($75\ \mathrm{ab}^{-1}$)
$\lvert V_{cb}\rvert$ (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%
$\mathcal{B}(B\to K\nu\bar\nu)$	visible	20%
$\mathcal{B}(B\to\pi\nu\bar\nu)$	–	possible

Charm mixing and CP

Mode	Observable	$\Upsilon(4S)$ ($75\ \mathrm{ab}^{-1}$)	$\psi(3770)$ ($300\ \mathrm{fb}^{-1}$)
$D^0\to K^+\pi^-$	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}
$D^+\to\pi^-e^+e^+,\ D^+\to K^-e^+e^+$	1×10^{-8}
$D^+\to\pi^-\mu^+\mu^+,\ D^+\to K^-\mu^+\mu^+$	1×10^{-8}
$D^+\to\pi^-e^\pm\mu^\mp,\ D^+\to K^-e^\pm\mu^\mp$	1×10^{-8}

τ Physics

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

B_s Physics @ Υ(5S)

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

M. Giorgi, ICHEP2010

Physics at a Super B Factory

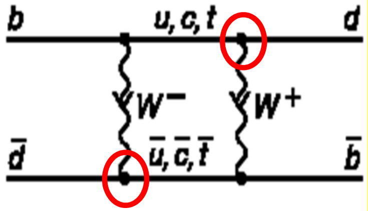
- There is a good chance to see new phenomena;
  - **CPV in B decays from the new physics (non KM).**
  - **Lepton flavor violations in τ decays.**
- They will help to diagnose (if found) or constrain (if not found) new physics models.
- $B \rightarrow \tau\nu$, $D\tau\nu$ can probe the charged Higgs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

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

Super B Factory Motivation 2

- Lessons from history: the top quark

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



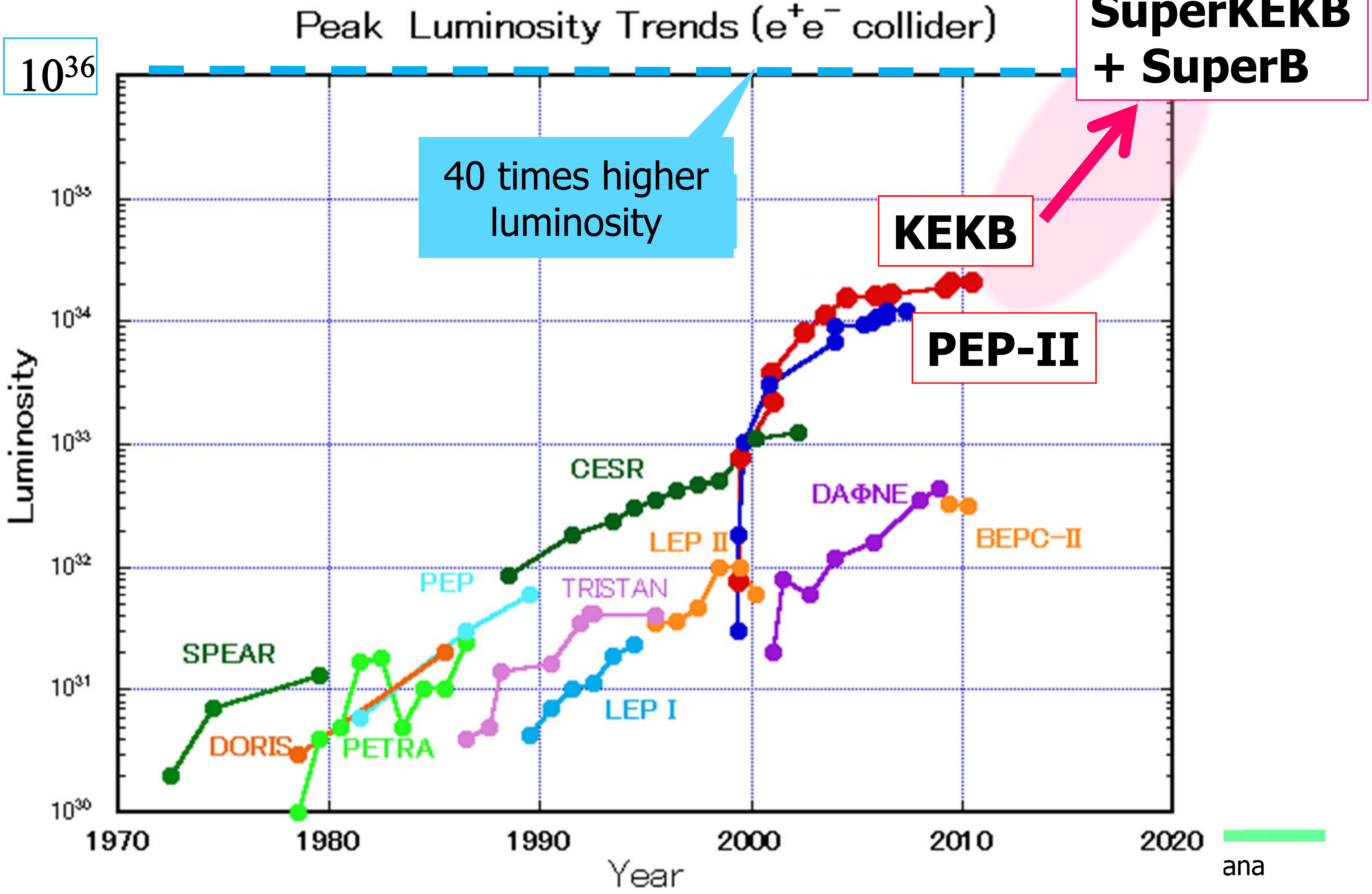
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

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

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

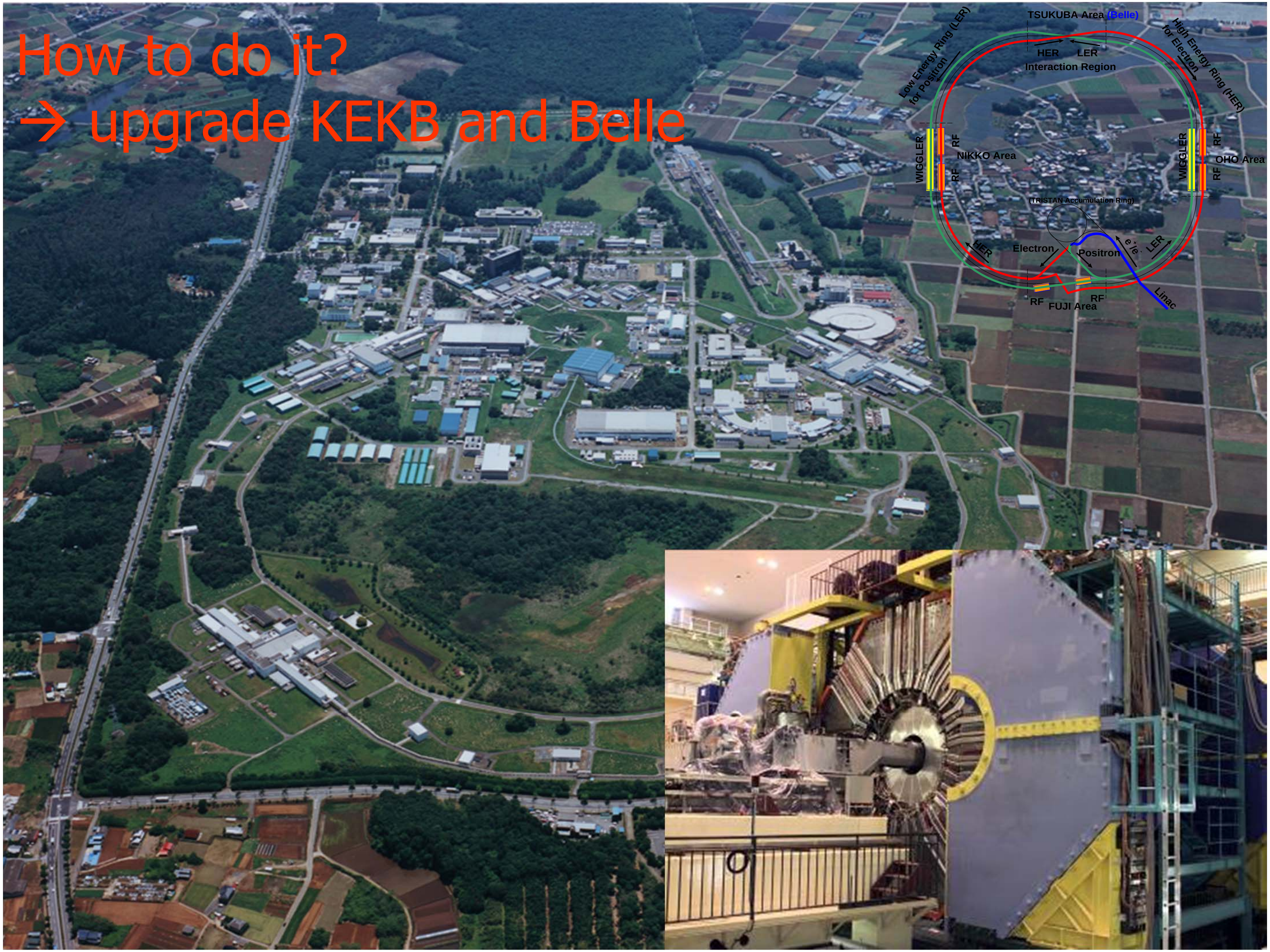
Accelerator

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

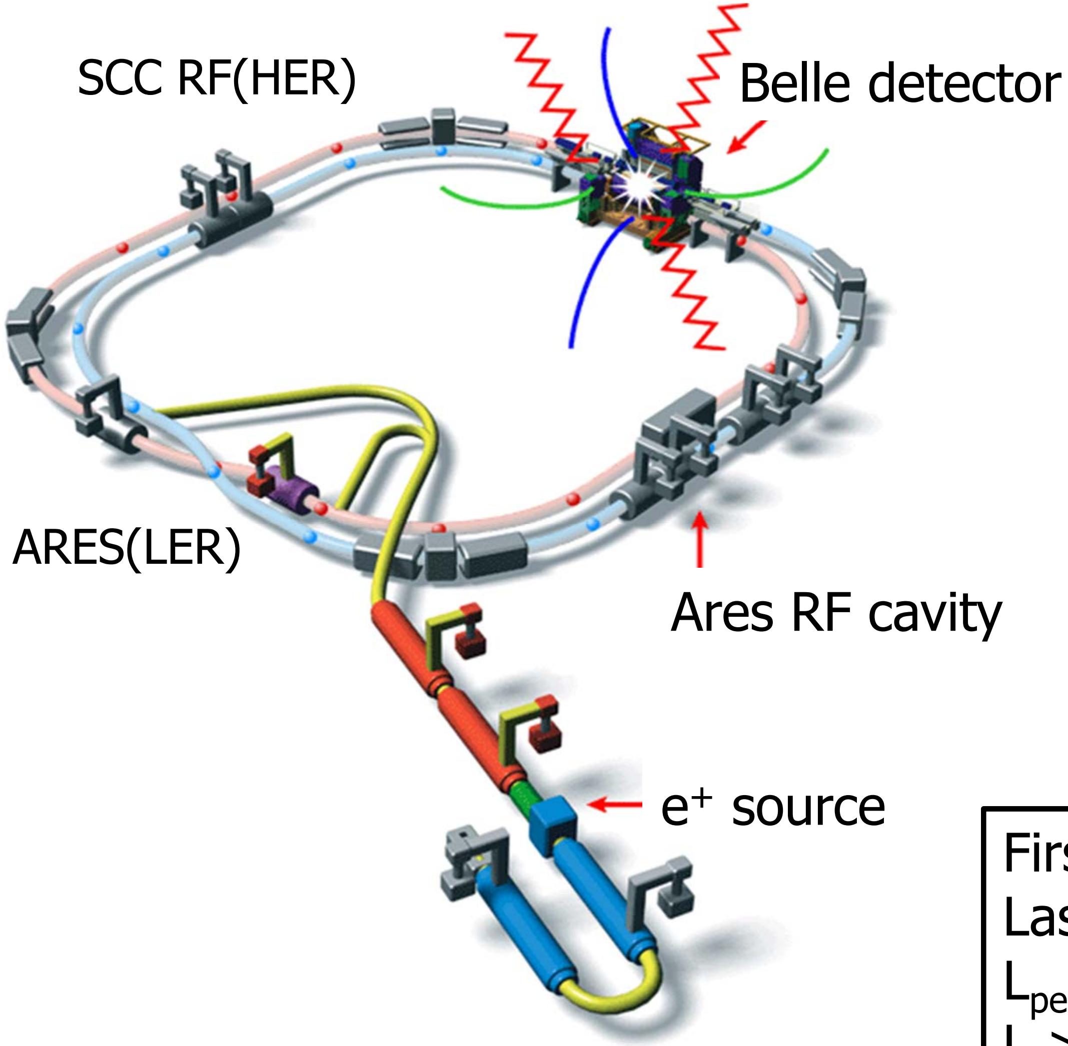


ana

How to do it?
→ upgrade KEKB and Belle



The KEKB Collider & Belle Detector



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

Peak luminosity (WR!) :

2.1×10^{34} $cm^{-2}s^{-1}$

=2x design value

First physics run on June 2, 1999
Last physics run on June 30, 2010
$L_{peak} = 2.1\text{x}10^{34}/cm^2/s$
$L > 1ab^{-1}$

The last beam abort of KEKB on June 30, 2010

→ Can start construction of SuperKEKB and Belle II

Strategies for increasing luminosity

Beam-beam parameter

Beam current

Lorentz factor

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

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

Classical electron radius

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

Vertical beta function@IP

(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y

"Nano-Beam" scheme

Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB

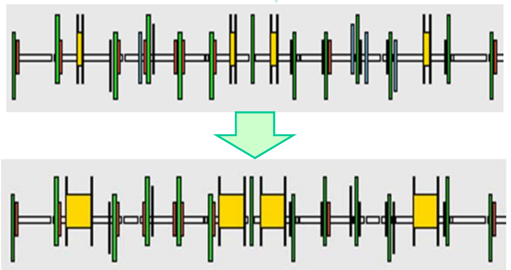
Machine design parameters

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

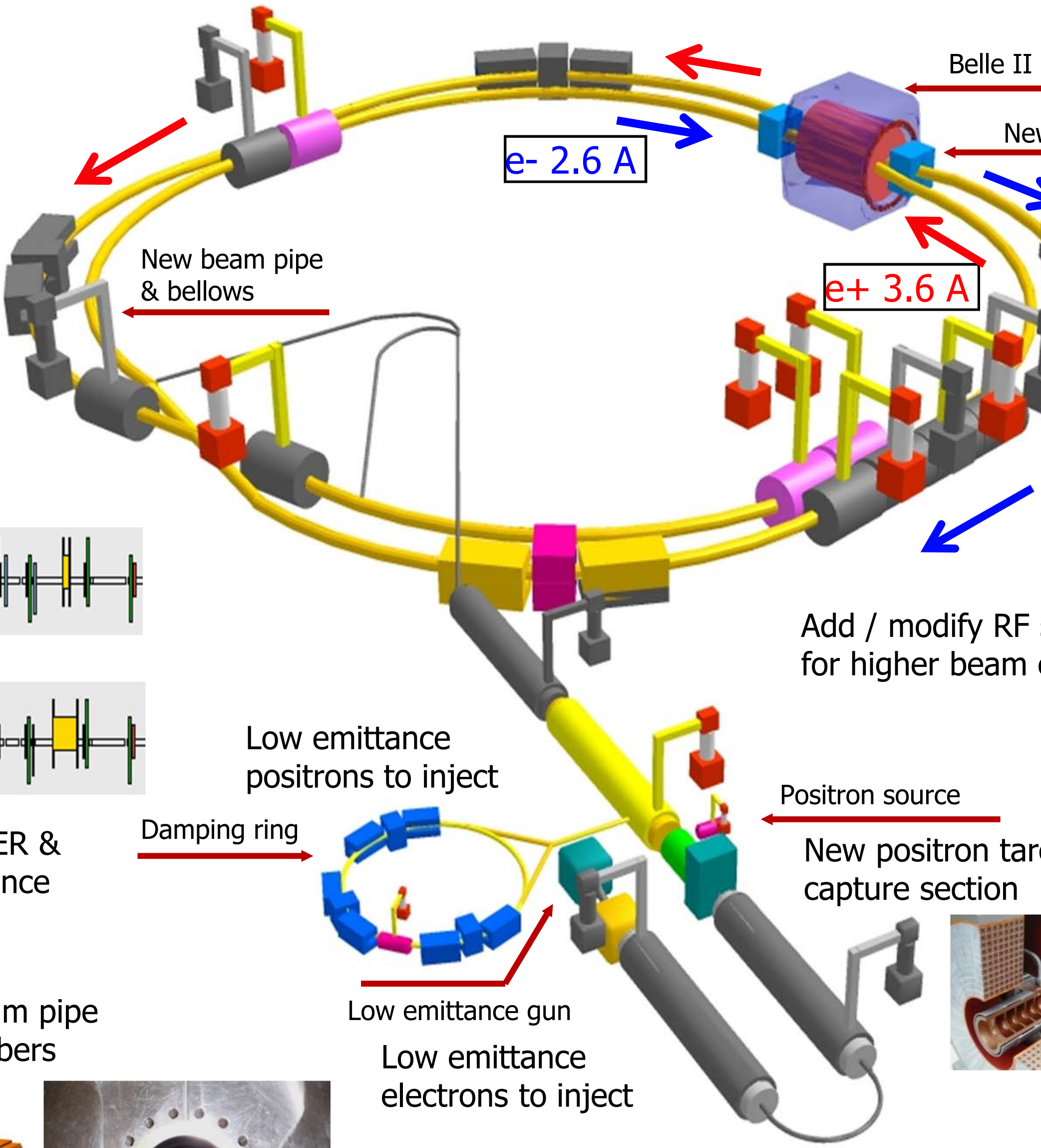
- **Small beam size & high current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem of LER short lifetime

KEKB to SuperKEKB

Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

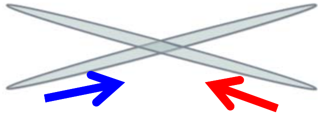


Belle II

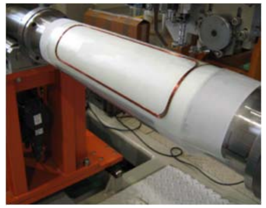
New IR

New beam pipe & bellows

Colliding bunches



New superconducting /permanent final focusing quads near the IP



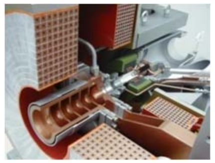
Add / modify RF systems for higher beam current

Low emittance positrons to inject

Positron source

Damping ring

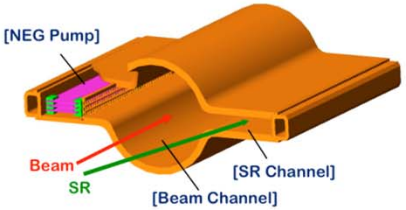
New positron target / capture section

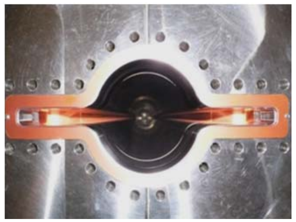


Low emittance gun

Low emittance electrons to inject

TiN-coated beam pipe with antechambers





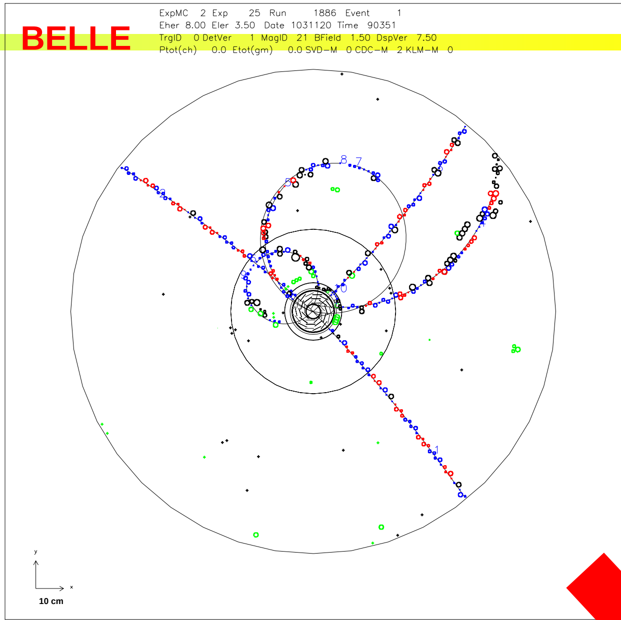
To get x40 higher luminosity

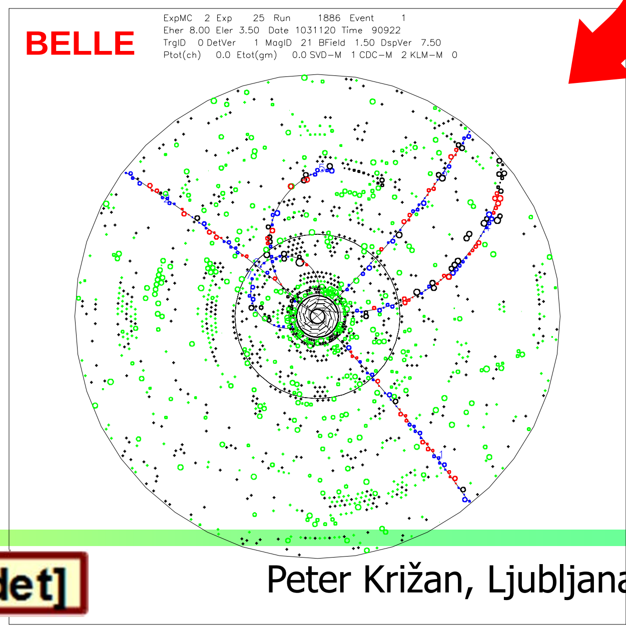
Detector

Requirements for the Belle II detector

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

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

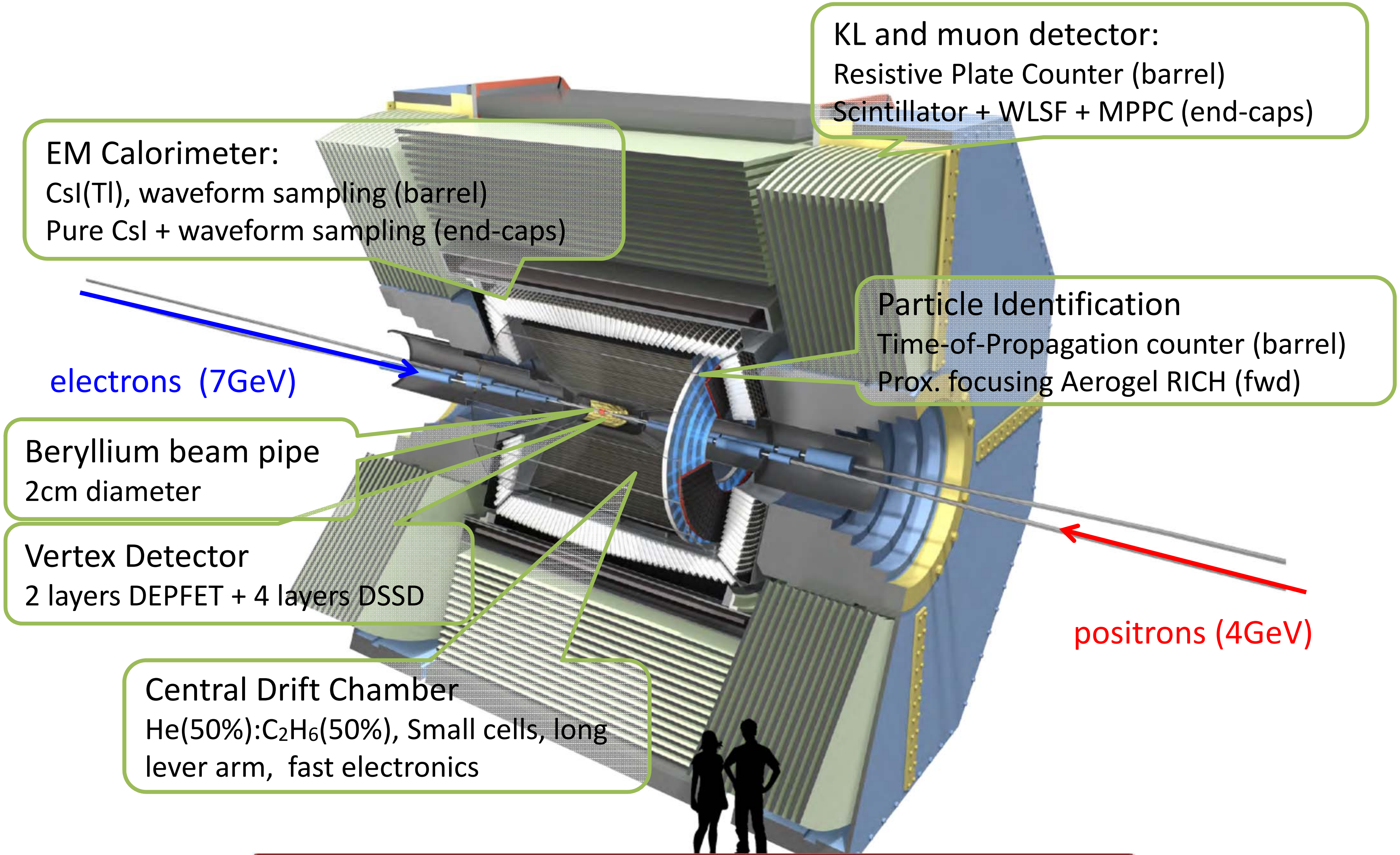




Solutions:
- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter crystals
- Faster readout electronics and computing system.

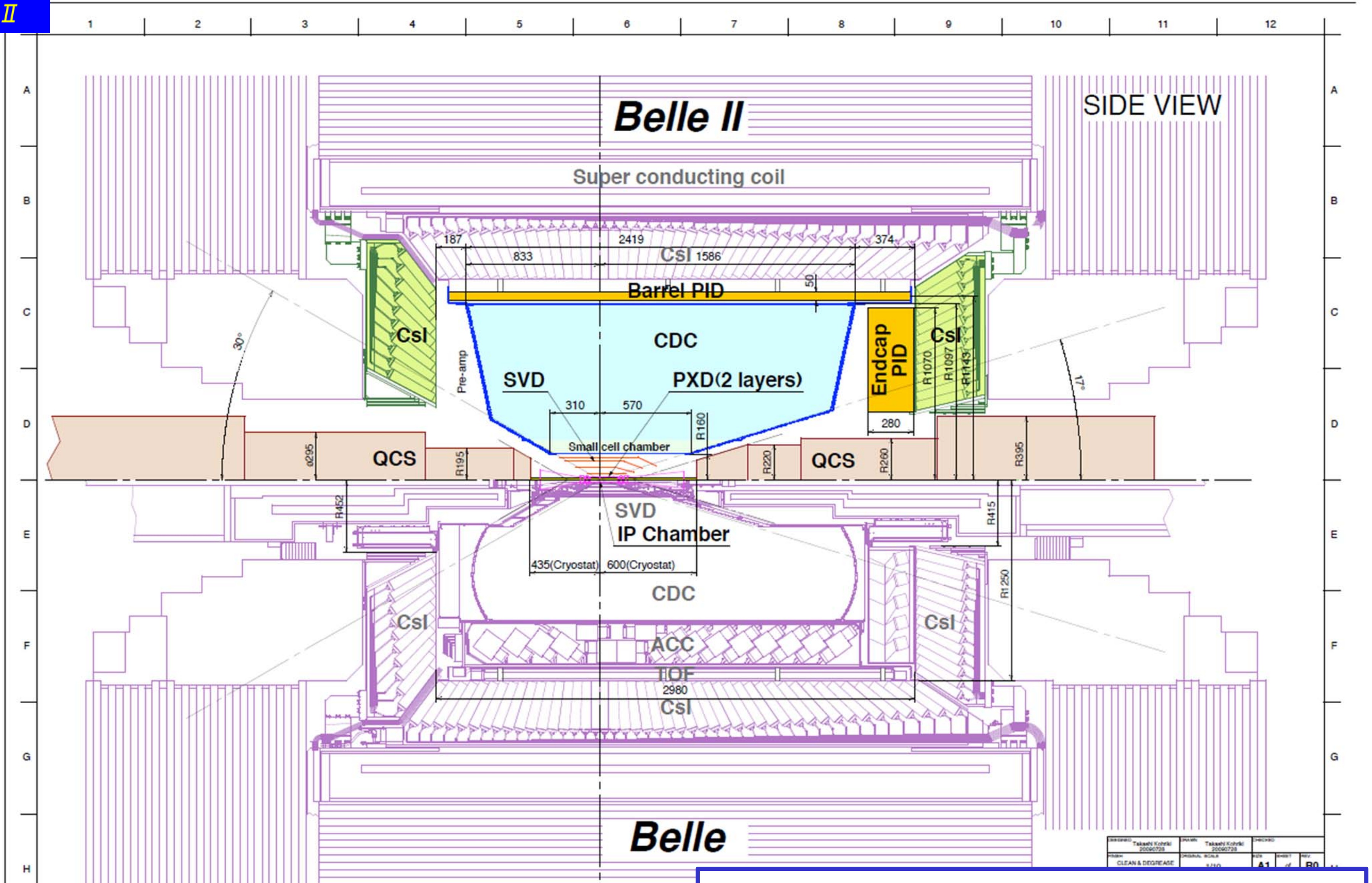
TDR published arXiv:1011.0352v1 [physics.ins-det]

Belle II Detector



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

Belle II (top) compared with Belle (bottom)

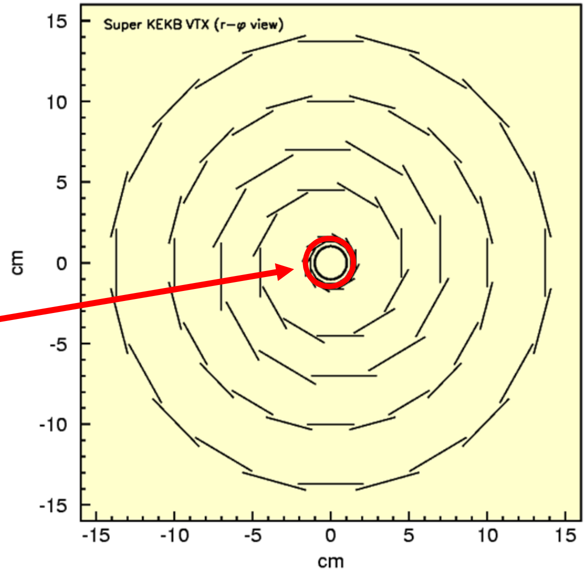


SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm

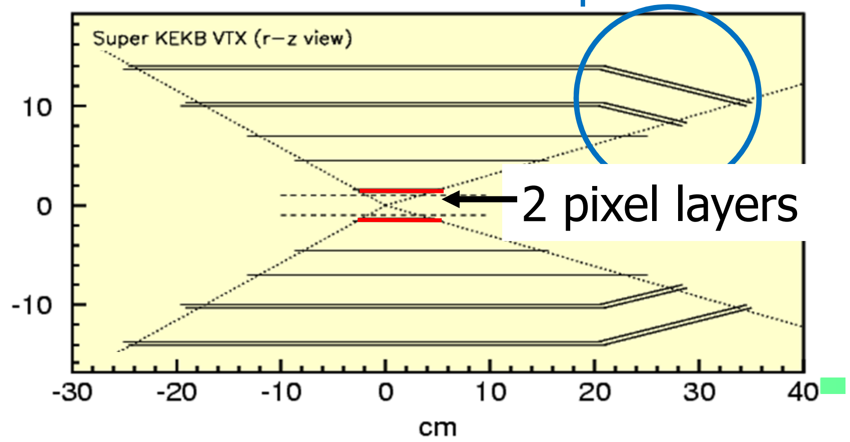
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

Vertex detector upgrade: PXD+SVD

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

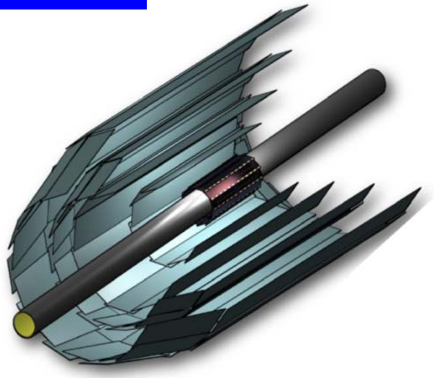


Slanted layers to keep the acceptance

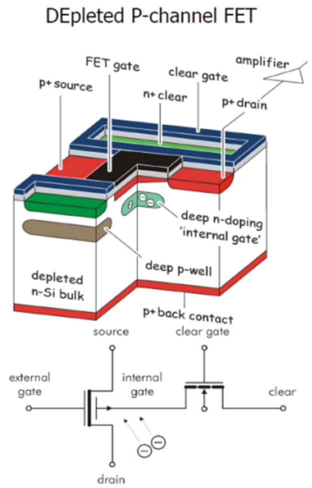


Vertex Detector

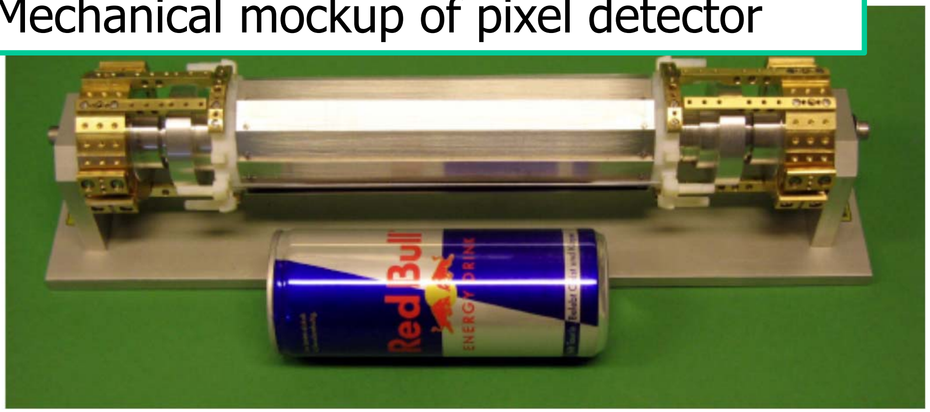
DEPFET:
http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome

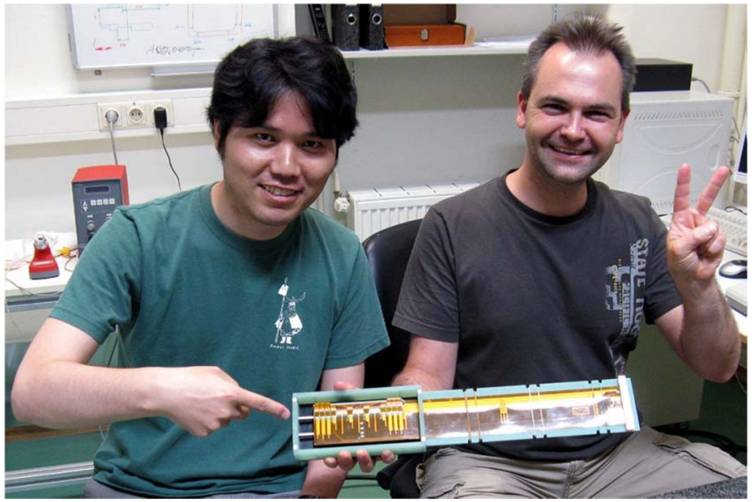


Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**

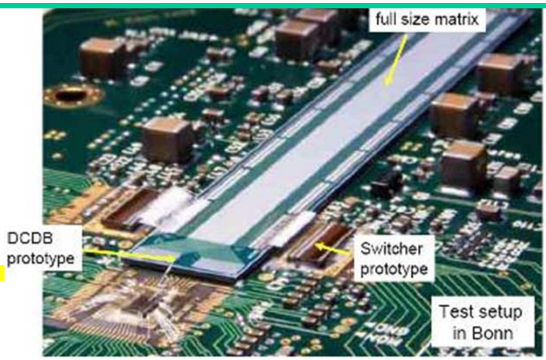


Mechanical mockup of pixel detector





Prototype DEPFET pixel sensor and readout

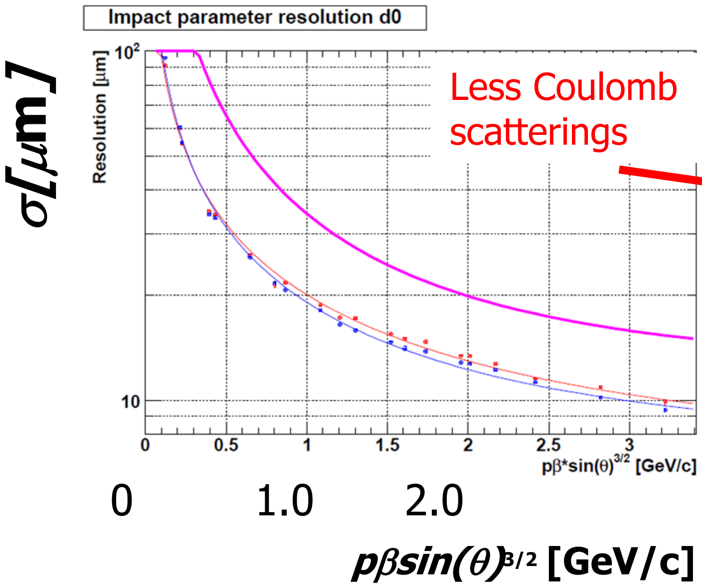


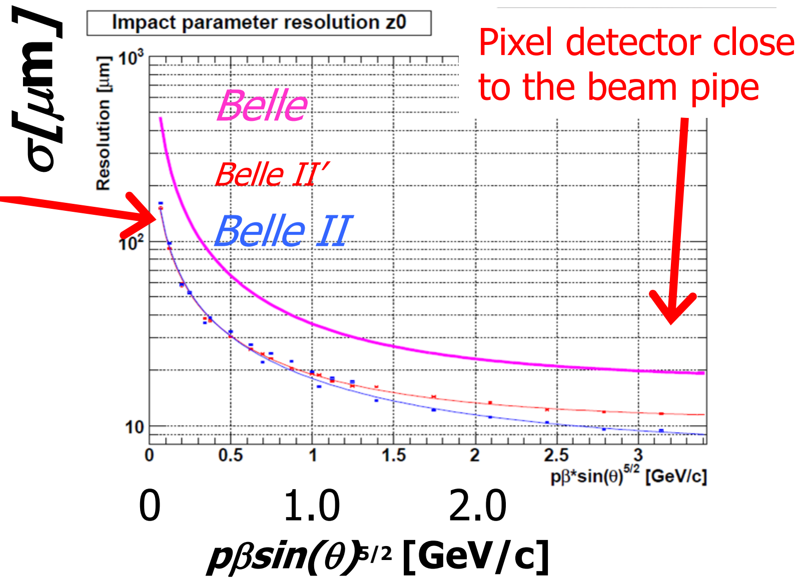
A prototype ladder using the first 6 inch DSSD from Hamamatsu has been assembled and tested.

Expected performance

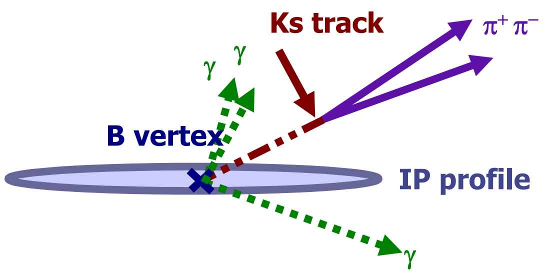
$$\sigma = a + \frac{b}{p\beta \sin^{\nu}\theta}$$

Significant improvement in IP resolution!

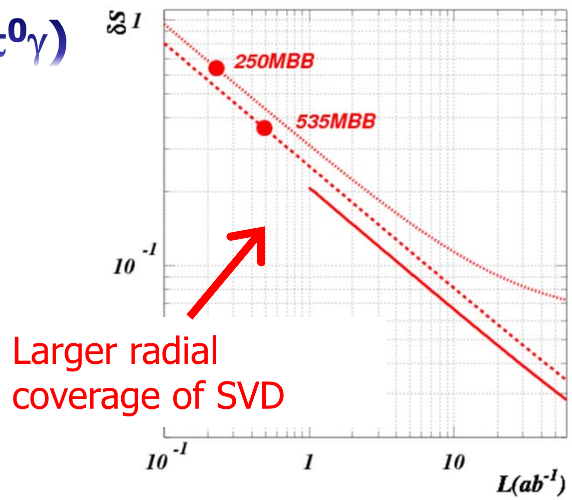




Significant improvement in $\delta S(K_S\pi^0\gamma)$

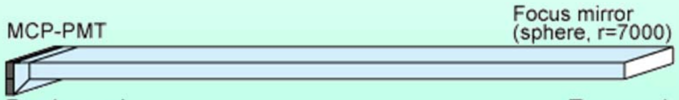


B decay point reconstruction with K_S trajectory



Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



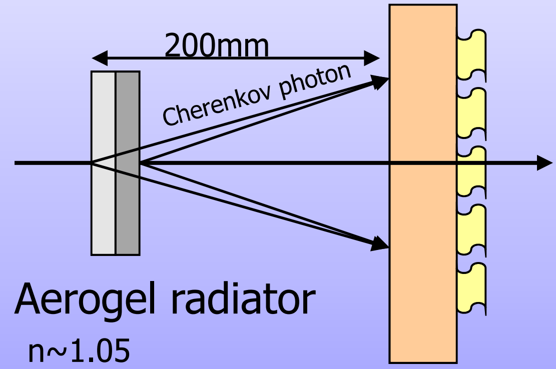
Quartz radiator

Focusing mirror

Small expansion block

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

Endcap PID: Aerogel RICH (ARICH)

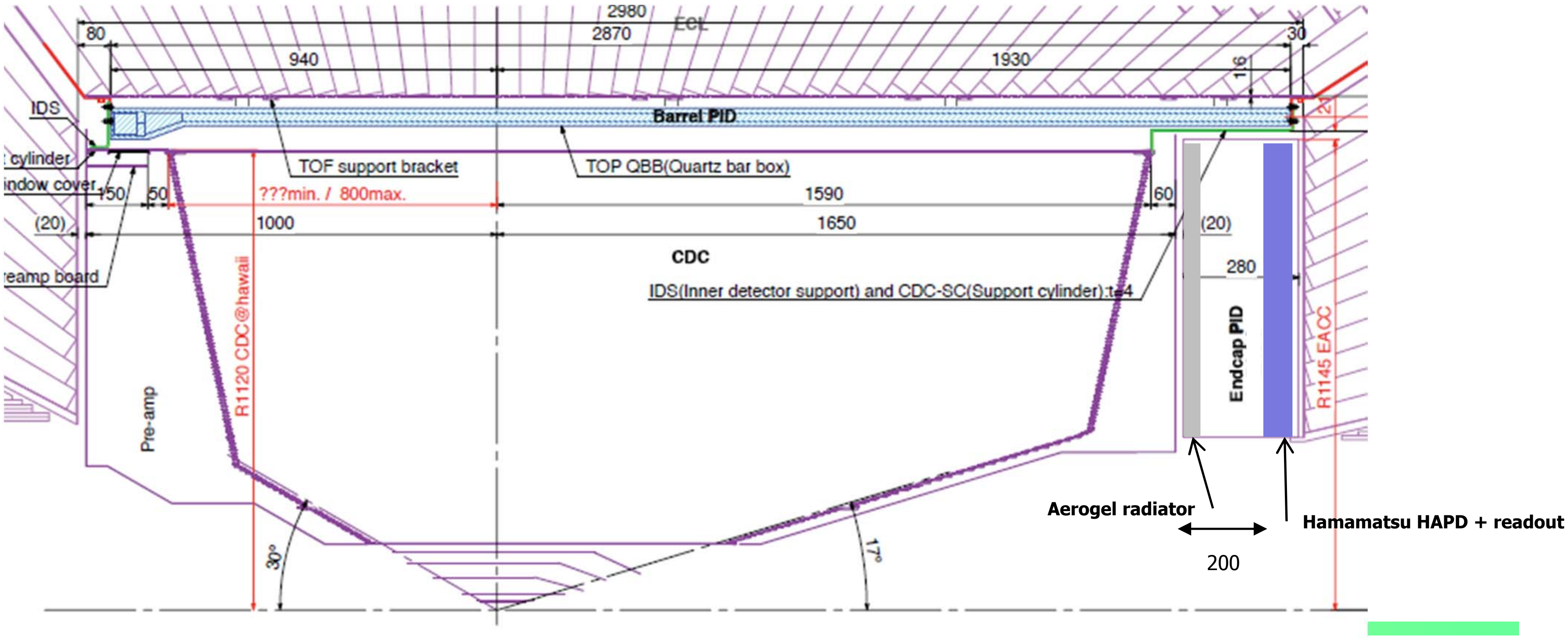


Aerogel radiator

n~1.05

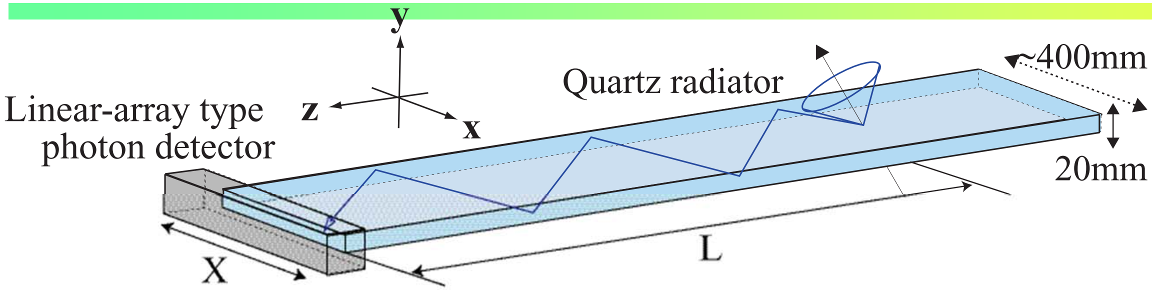
Hamamatsu HAPD

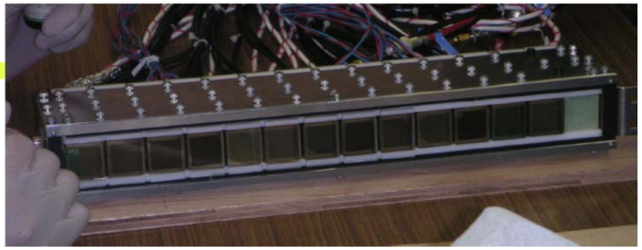
+ new ASIC



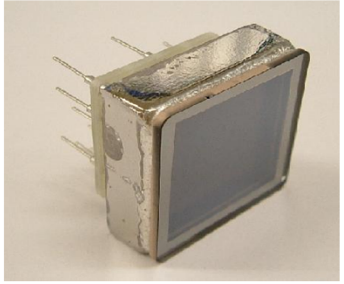
Peter Križan, Ljubljana

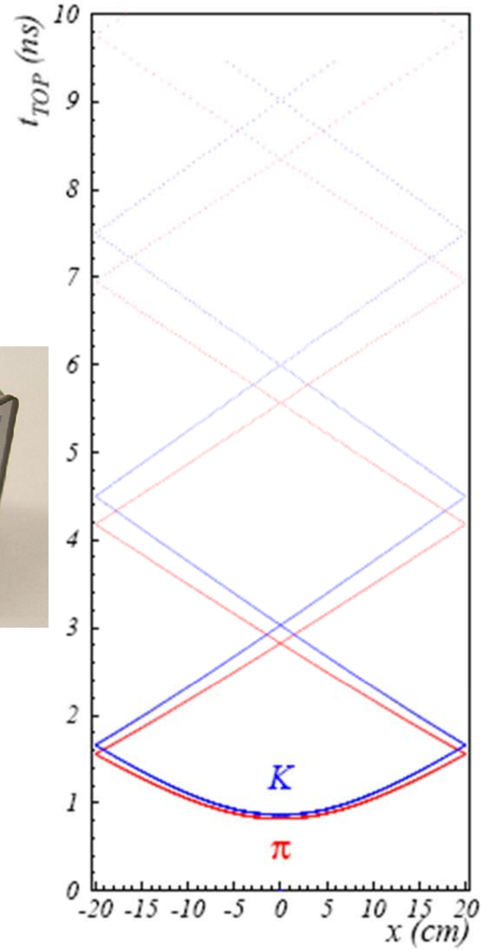
Barrel PID: Time of propagation (TOP) counter

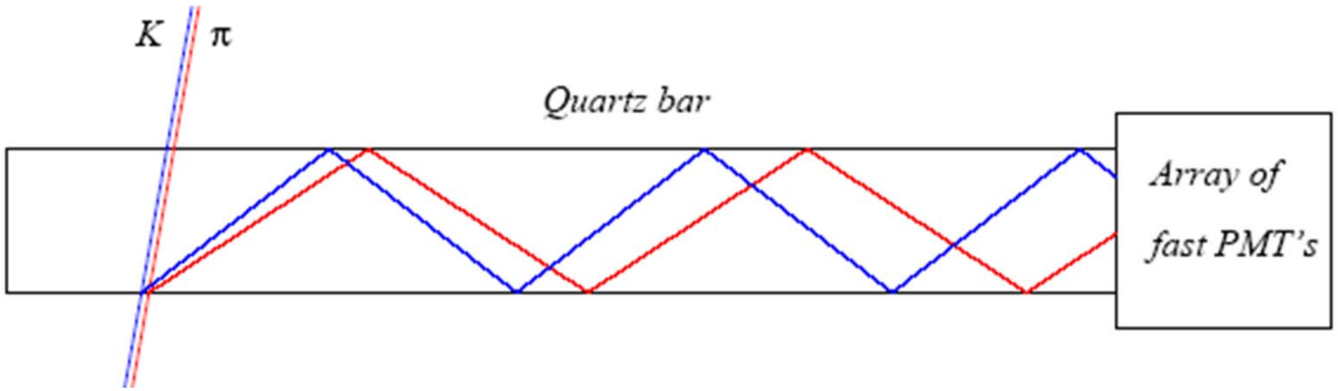




- Cherenkov ring imaging with precise time measurement.
- Reconstruct angle from two coordinates and the time of propagation of the photon
  - Quartz radiator (2cm)
  - Photon detector (MCP-PMT)
    - Good time resolution ~ 40 ps
    - Single photon sensitivity in 1.5







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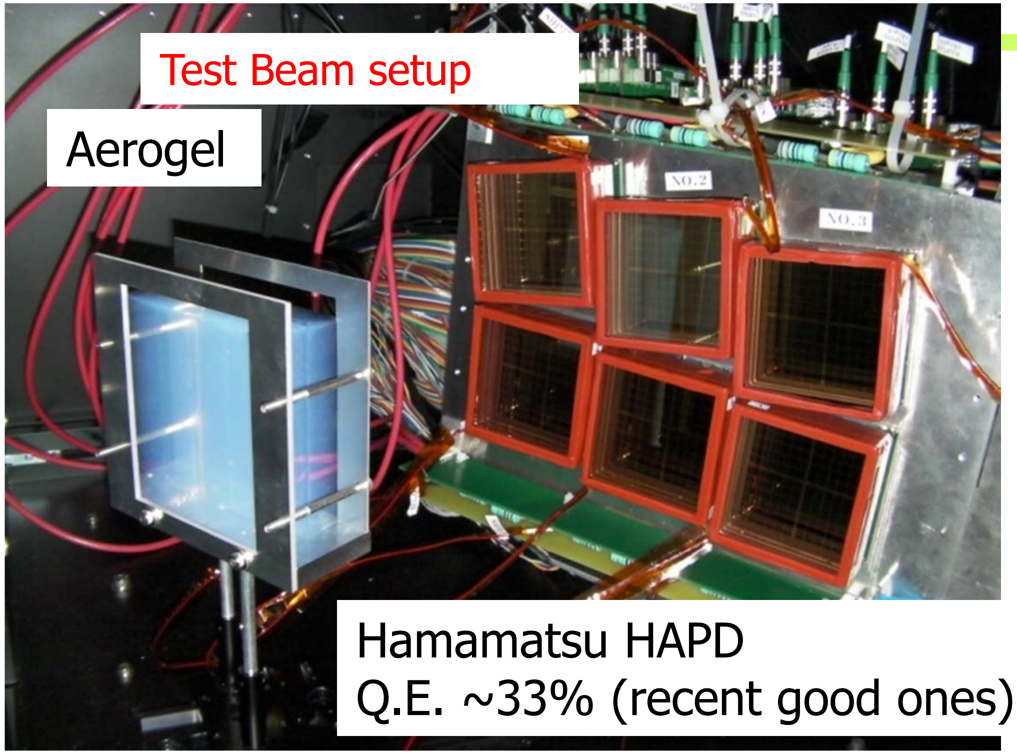
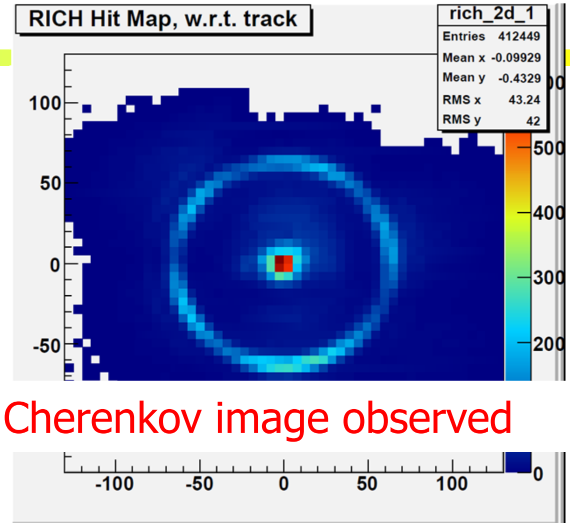
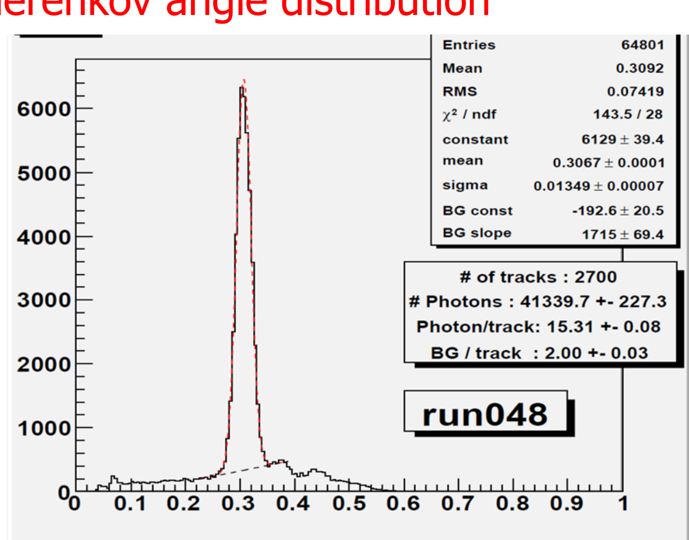
Aerogel RICH (endcap PID)





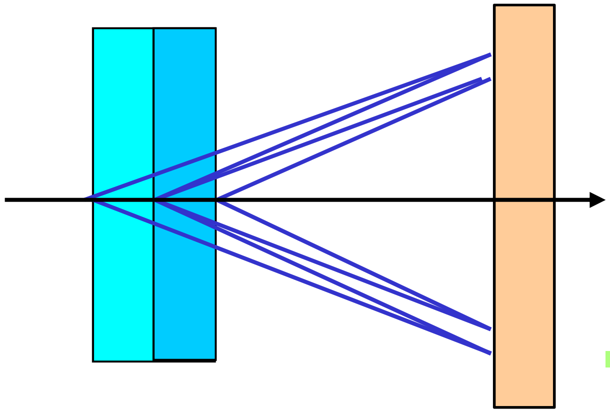
Clear Cherenkov image observed

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.



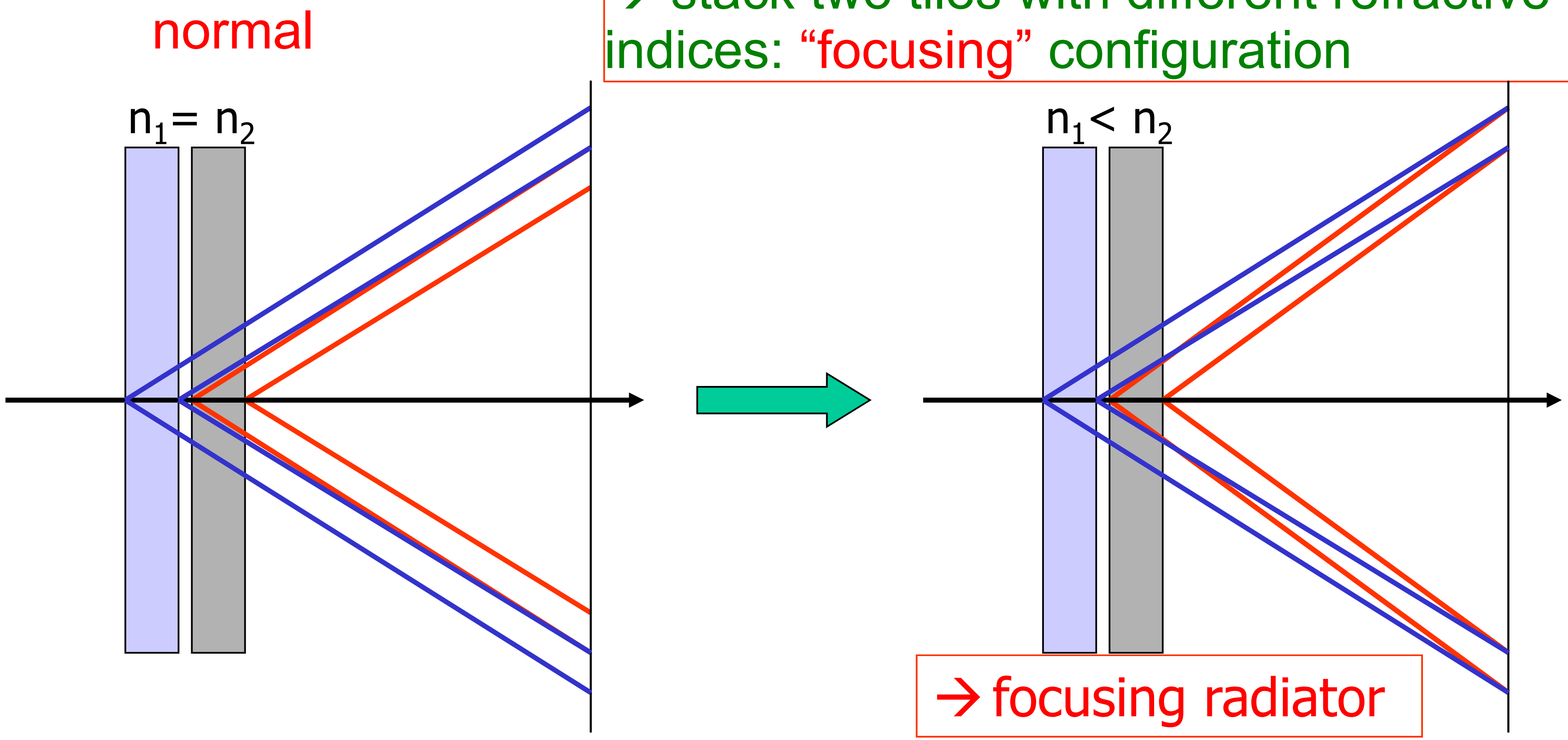
6.6 σ π/K at 4GeV/c !

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

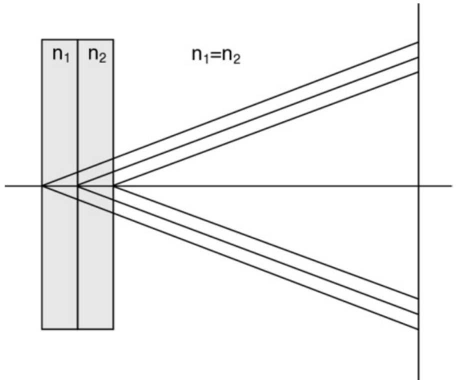


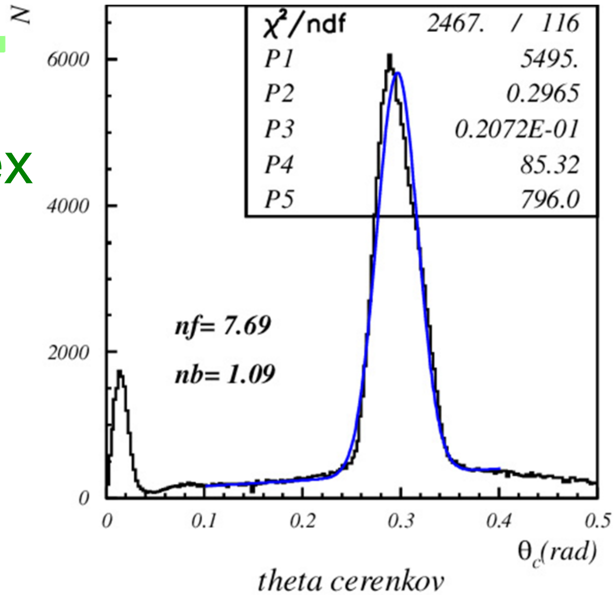
→ focusing radiator

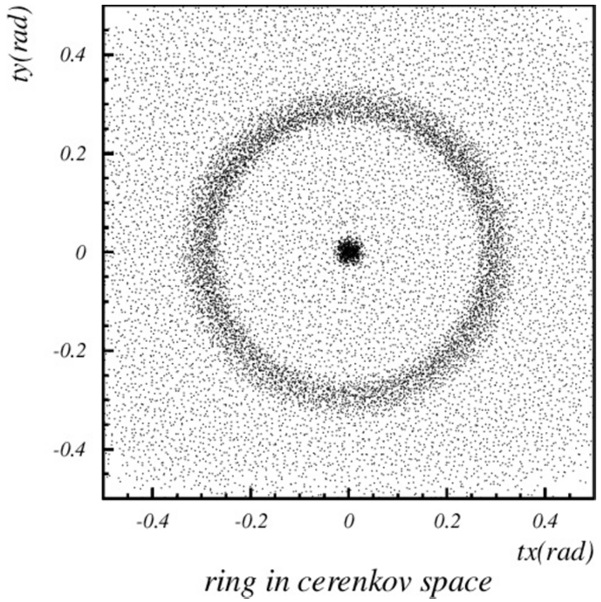
Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

Focusing configuration – data

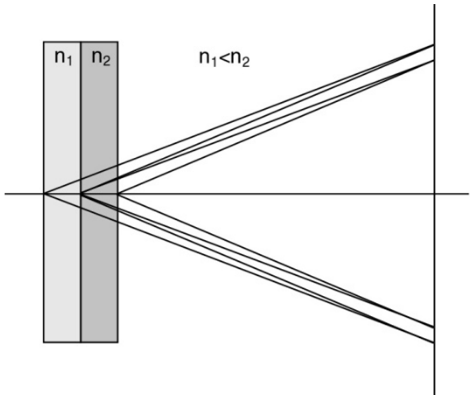
4cm aerogel single index

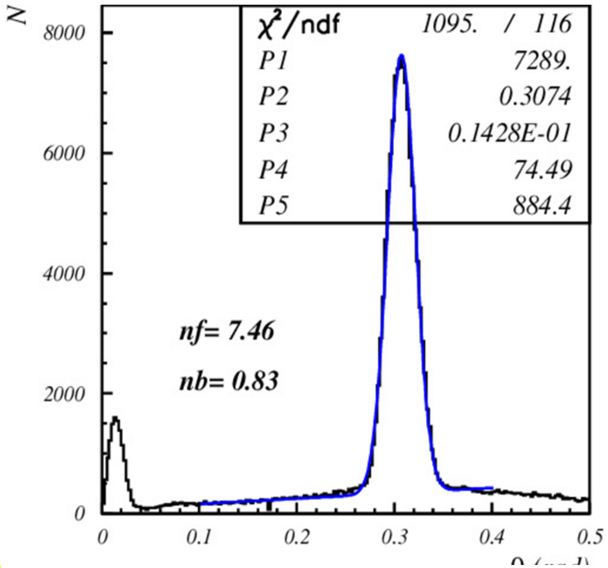


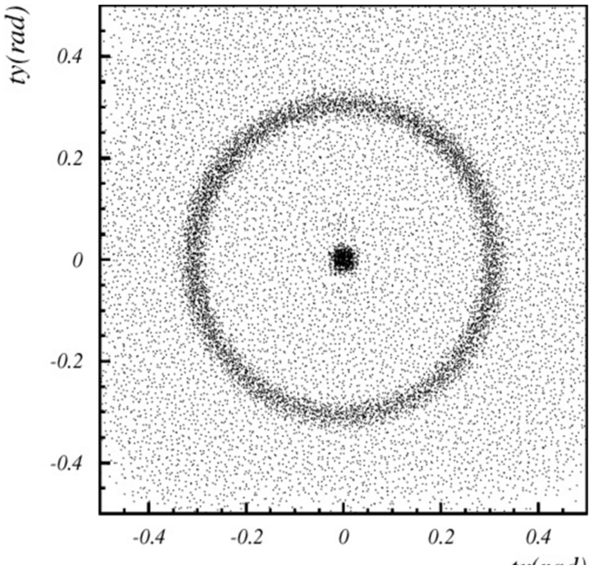




2+2cm aerogel



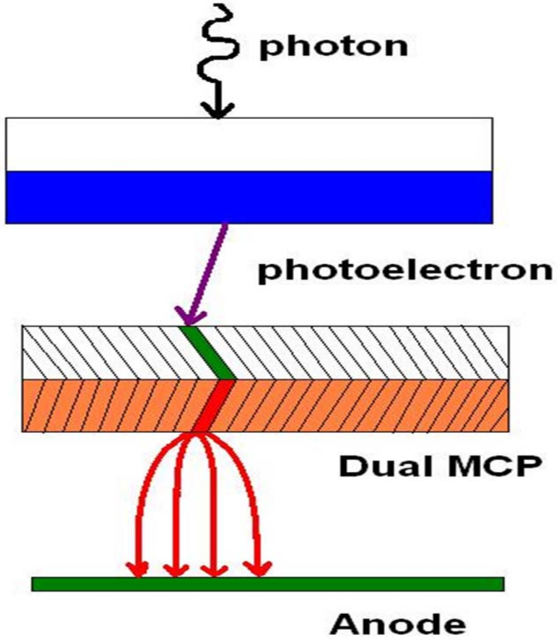


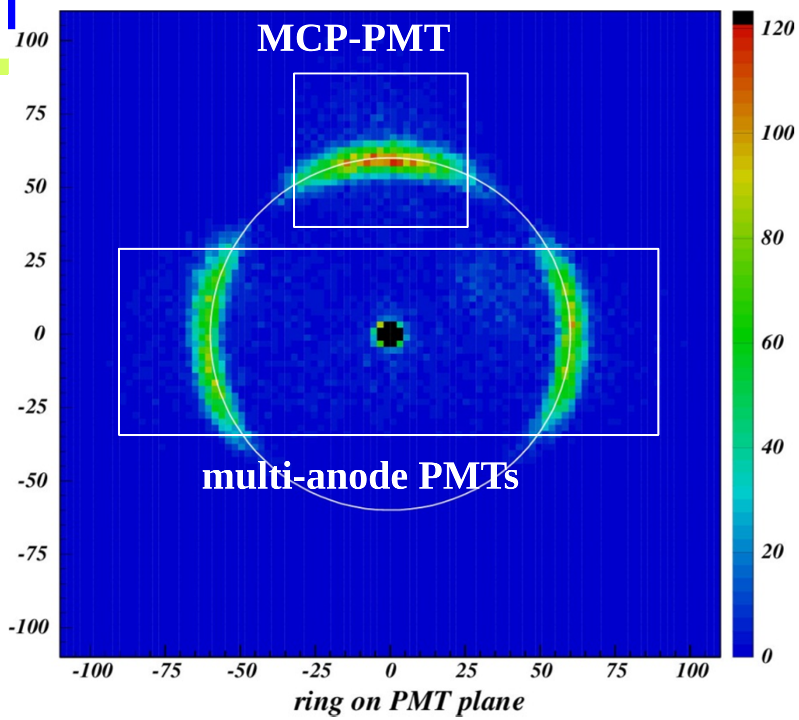


→NIM A548 (2005) 383

Fallback solution: BURLE/Photonis MCP-PMT

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

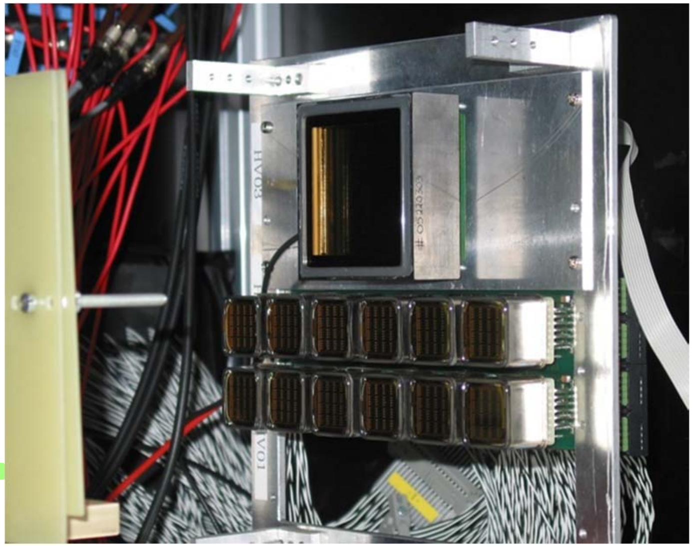




→good performance in beam and bench tests, NIMA567 (2006) 124

→ very fast (<40 ps)

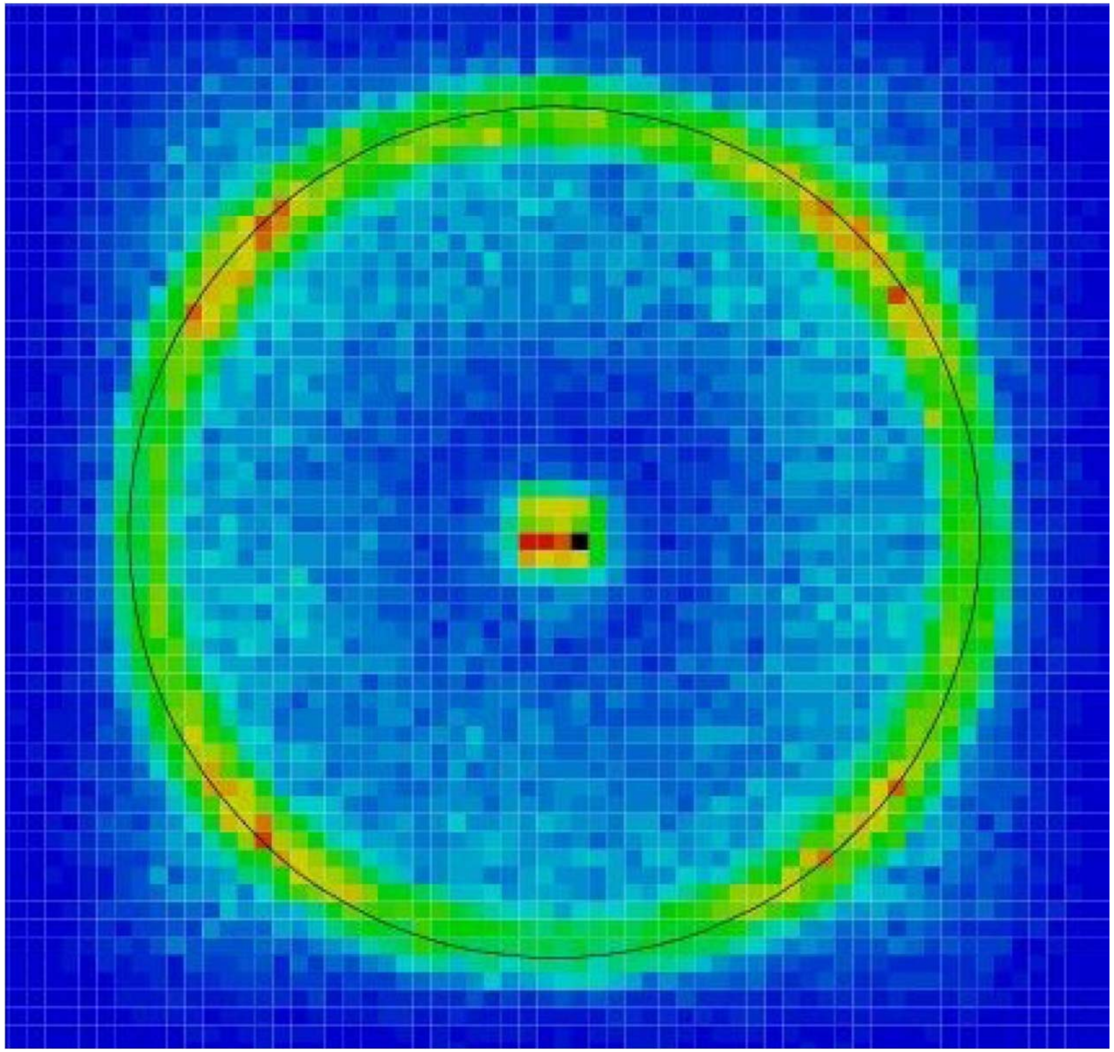
→ ageing?



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



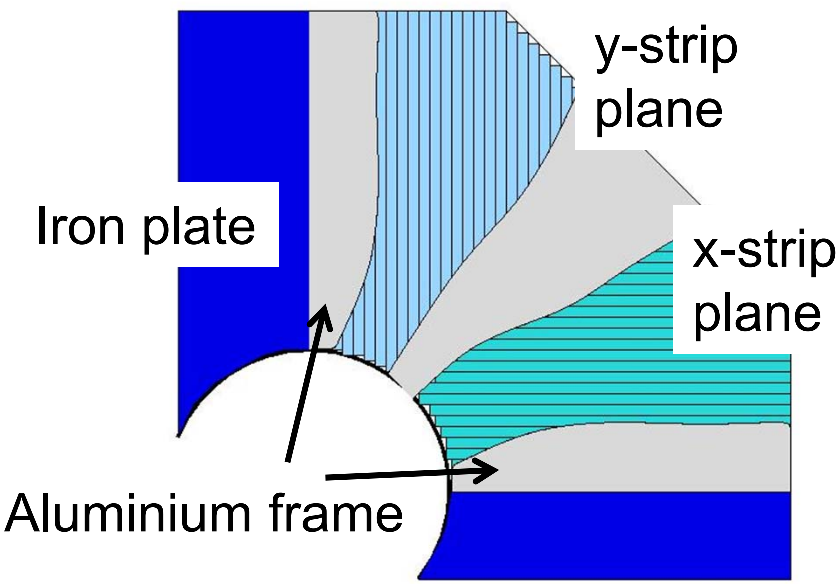
First successful use of SiPMs as single photon detectors in a RICH counter!

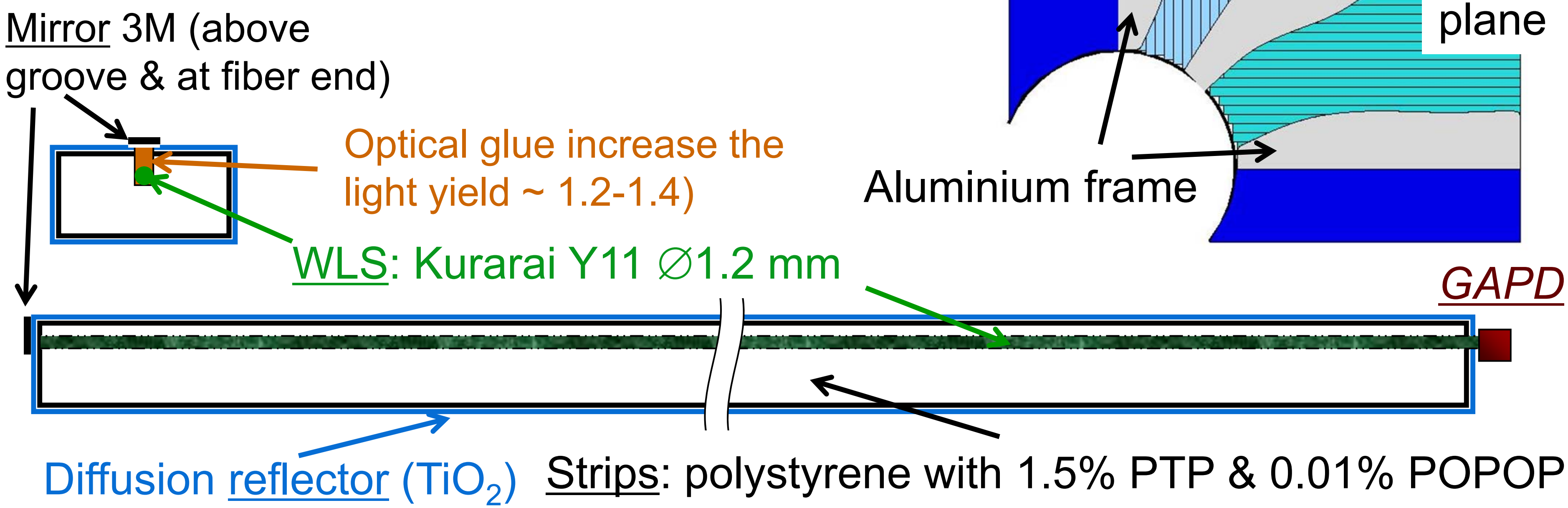
NIM A594 (2008) 13

KLM upgrade in the endcaps

Scintillator-based KLM (endcap)

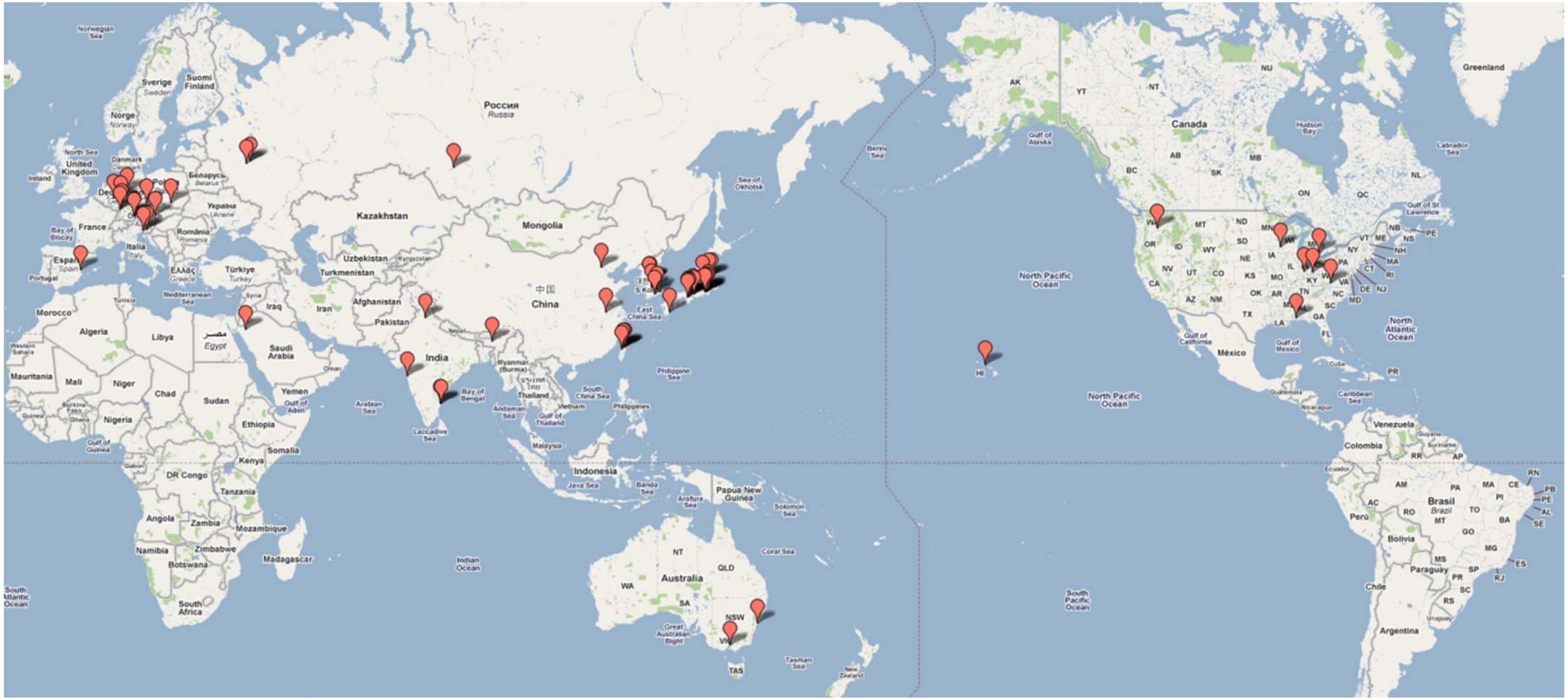
- Two independent (x and y) layers in one superlayer made of orthogonal strips with WLS read out
- Photo-detector = avalanche photodiode in Geiger mode (SiPM)
- ~120 strips in one 90º sector
  (max L=280cm, w=25mm)
- ~30000 read out channels
- Geometrical acceptance > 99%





Status of the project

Belle II Collaboration



15 countries/regions, ~60 institutions, ~400 collaborators

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:

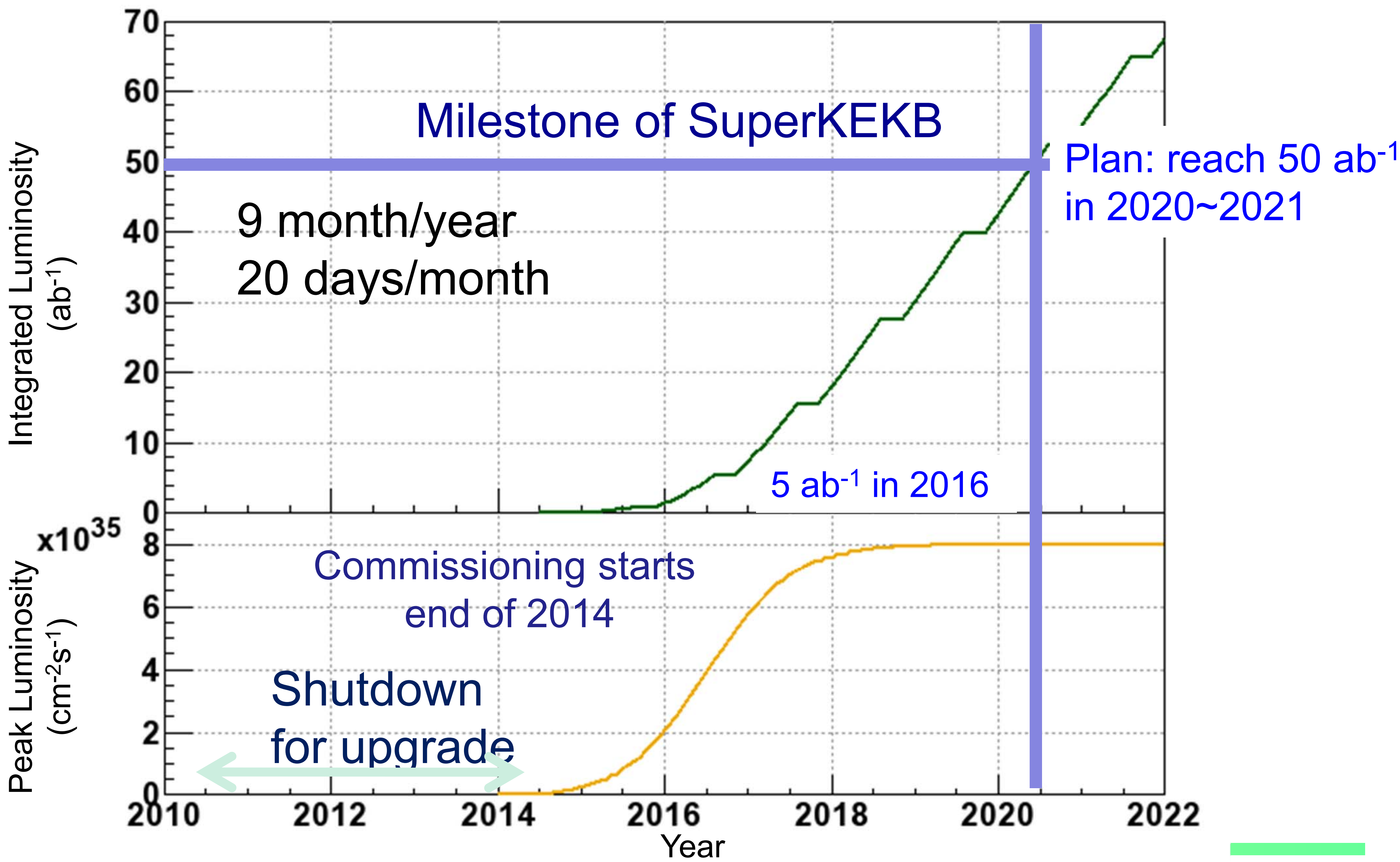
- KEKB stopped operation in July 2010, and the low energy ring was to a large extent disassembled
- Belle was rolled out to the parking position in December 2010.

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.

Luminosity upgrade projection



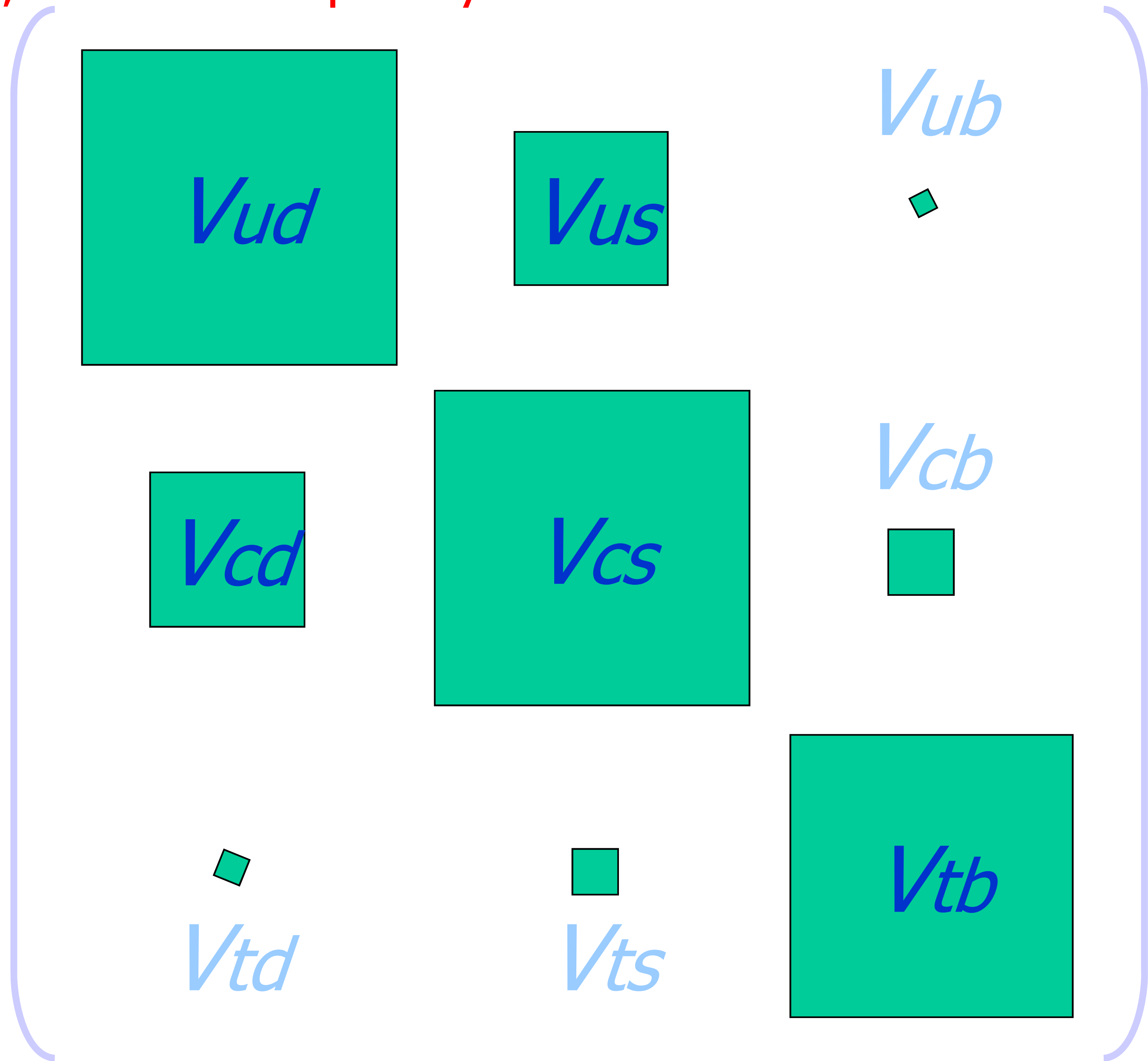
Summary

- B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of the performance, achieving and surpasing design perfomance
- Major upgrade at KEK in 2010-15 → SuperKEKB+Belle II, L x40, construction started
- Physics reach updates available
- Expect a new, exciting era of discoveries, complementary to the LHC
- Join if you can! A lot of interesting things still to be done...

Back-up slides

CKM: almost a diagonal matrix, but not completely

CKM: almost real, but not completely!



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

SM: b→ccd, S=sin2ϕ_1 (=sin2β), 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

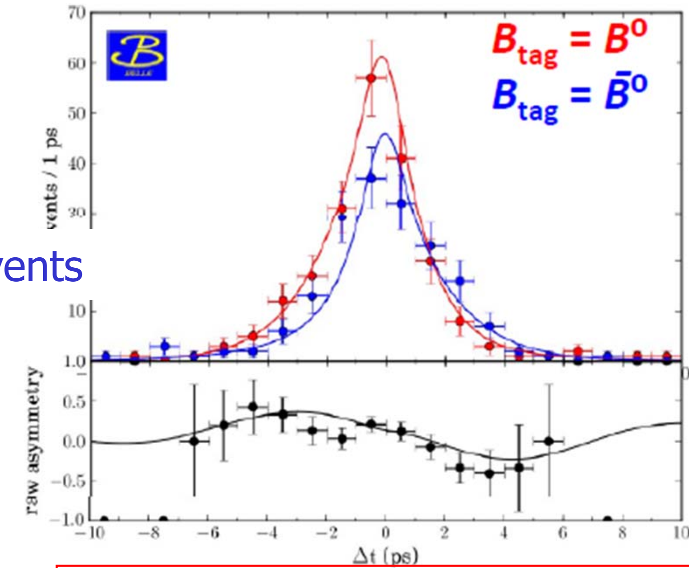
$B^0 \to (K^-\pi^+\pi^+)(K^+\pi^-\pi^-)$, $(K^-\pi^+\pi^+)(K_S\pi^0)$+c.c.

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

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

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

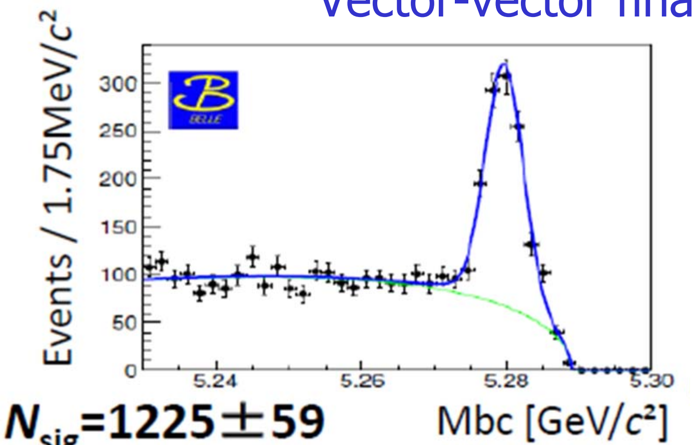
320 events



→ Large CP violation effects in many places!

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

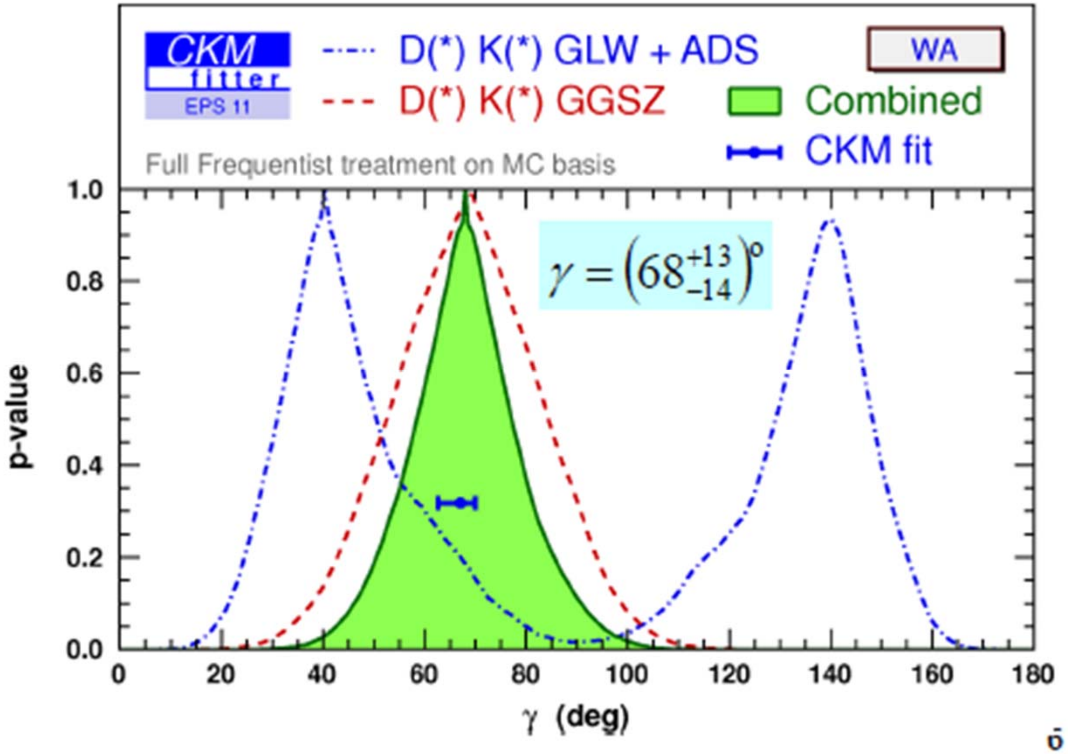
ϕ_3 measurement

Combined ϕ_3 value:

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

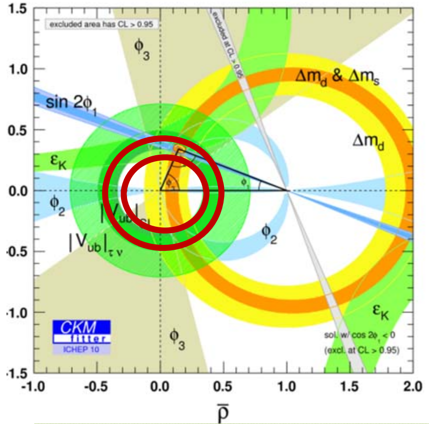
Note that B factories were not built to measure ϕ_3

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

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

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

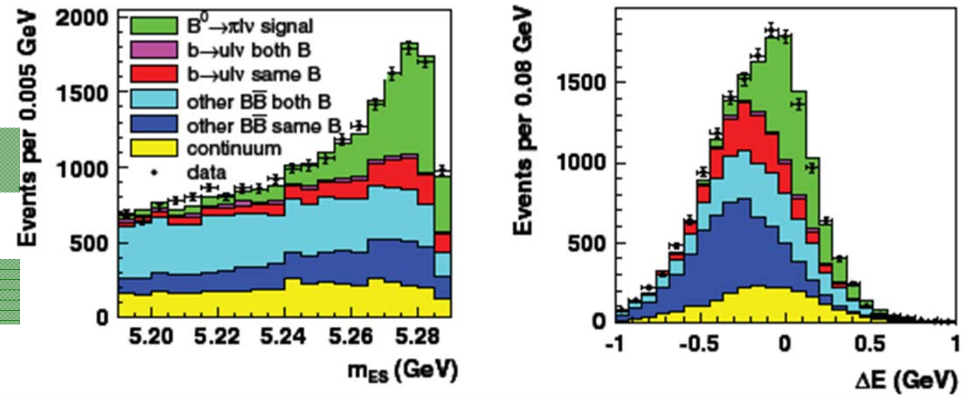
BaBar, PRD83, 032007 (2011)

$\mathcal{B}$=(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



→talks by P. Urquijo, M. Franco Sevilla

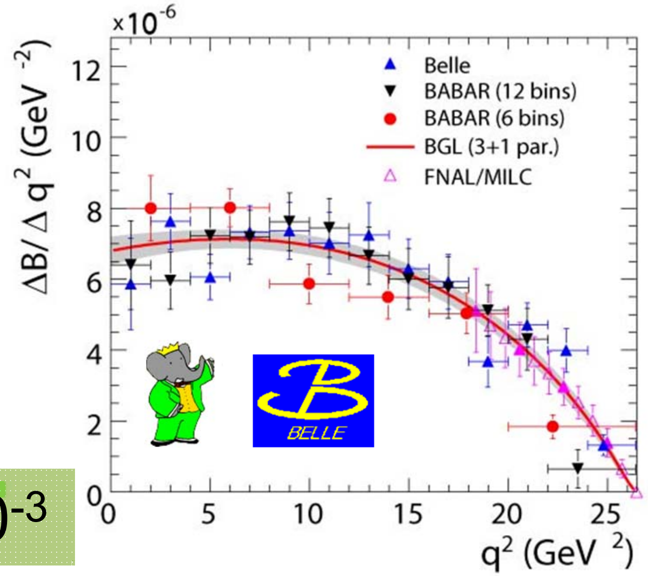
$|V_{ub}|$ extraction: fit data + LQCD points in

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

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

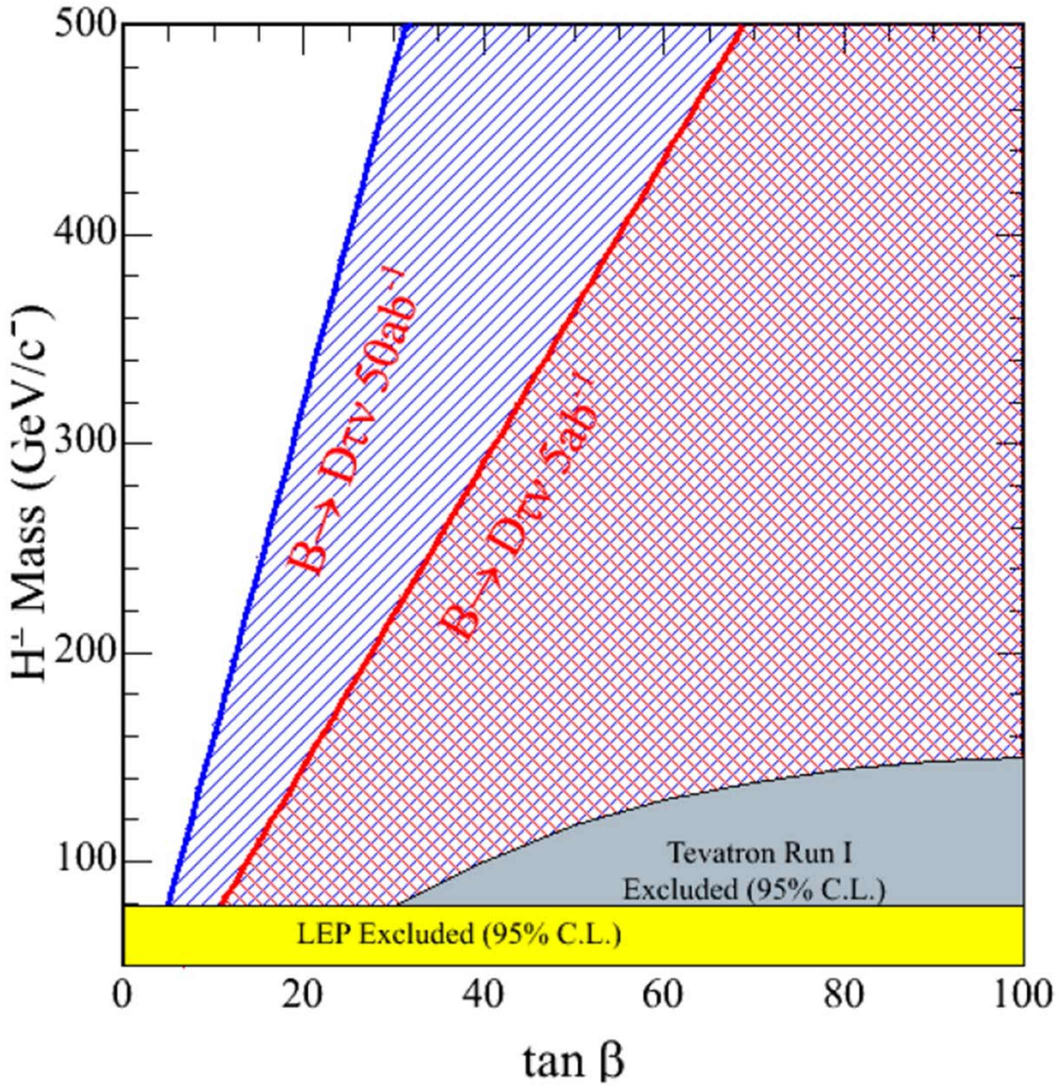
Belle + FNAL/MILC $|V_{ub}|$ = (3.43±0.33)·10^{-3}

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

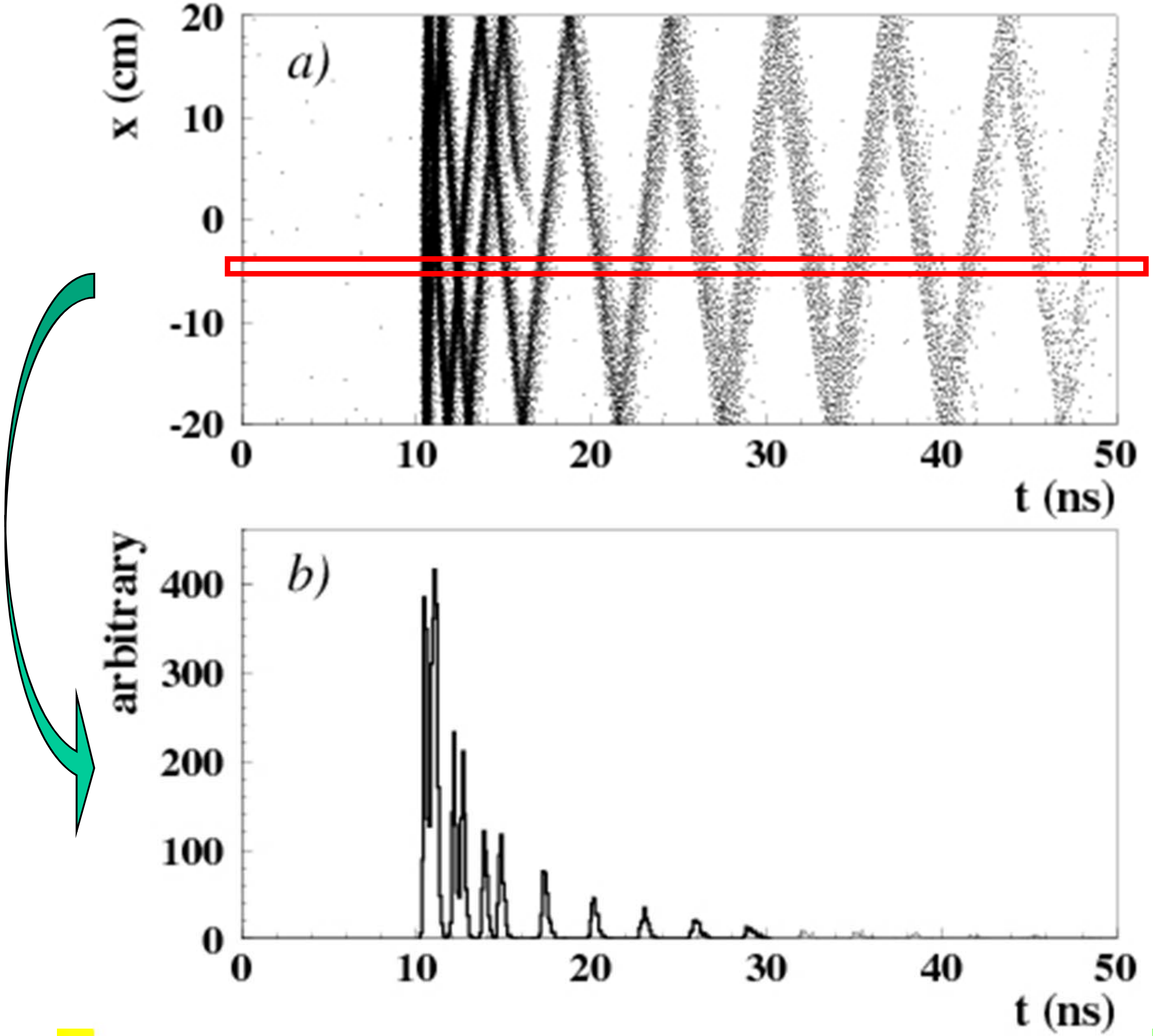


B→Dτν

Exclusion plots for
tanβ and H^+ mass
for 5ab^{-1} and 50ab^{-1}



TOP image

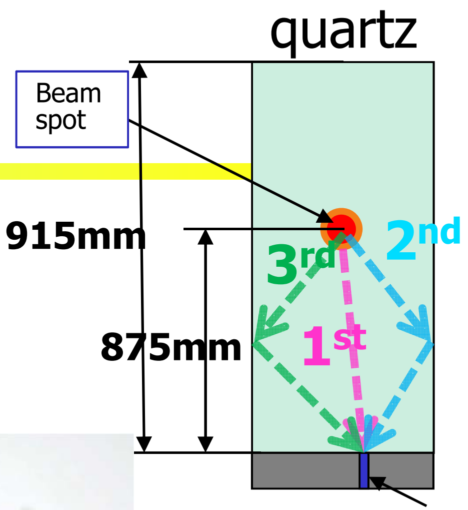


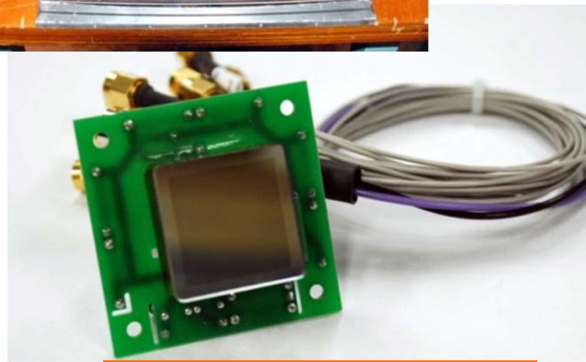
Pattern in the coordinate-time space ('ring') of a pion hitting a quartz bar with ~80 MAPMT channels

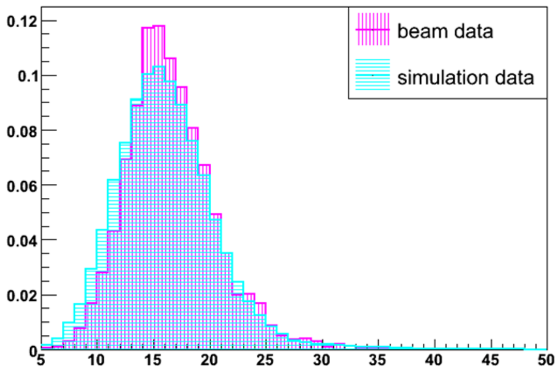
Time distribution of signals recorded by one of the PMT channels: different for π and K

TOP (Barrel PID)

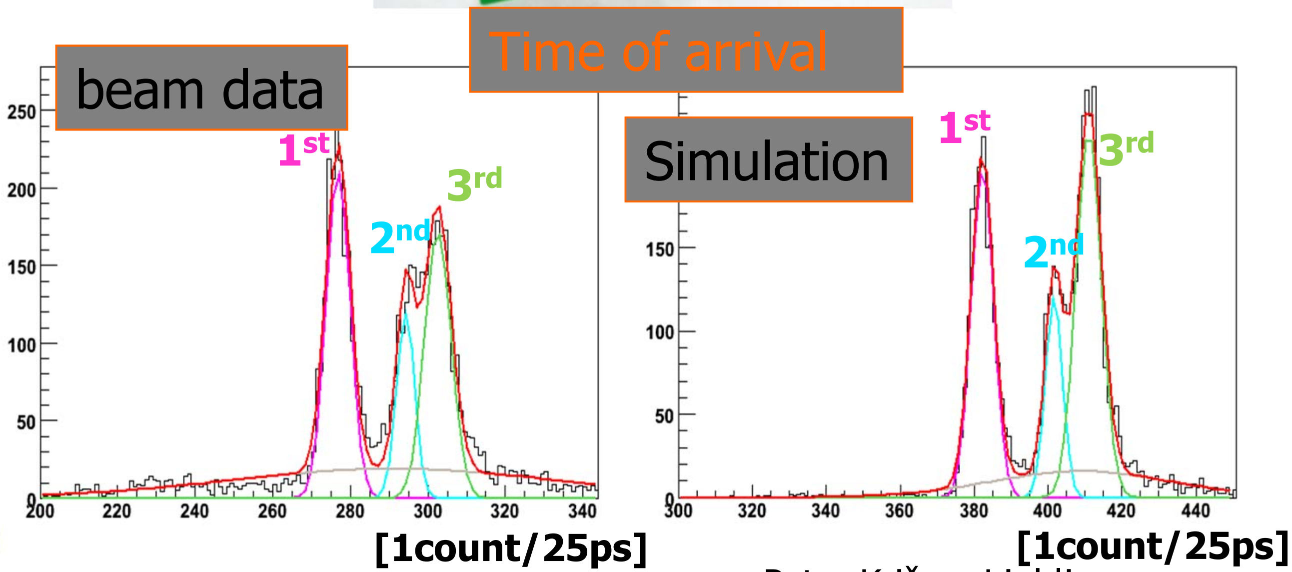
- Quartz radiator
  - 2.6m^L x 45cm^W x 2cm^T
  - Excellent surface accuracy
- MCP-PMT
  - Hamamatsu 16ch MCP-PMT
    - Good TTS (<35ps) & enough lifetime
    - Multialkali photo-cathode → SBA
- Beam test in 2009
  - # of photons consistent
  - Time resolution OK







# of photons

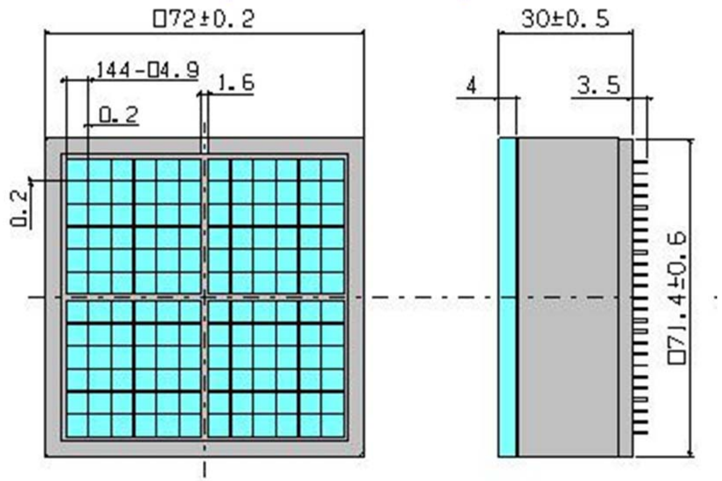


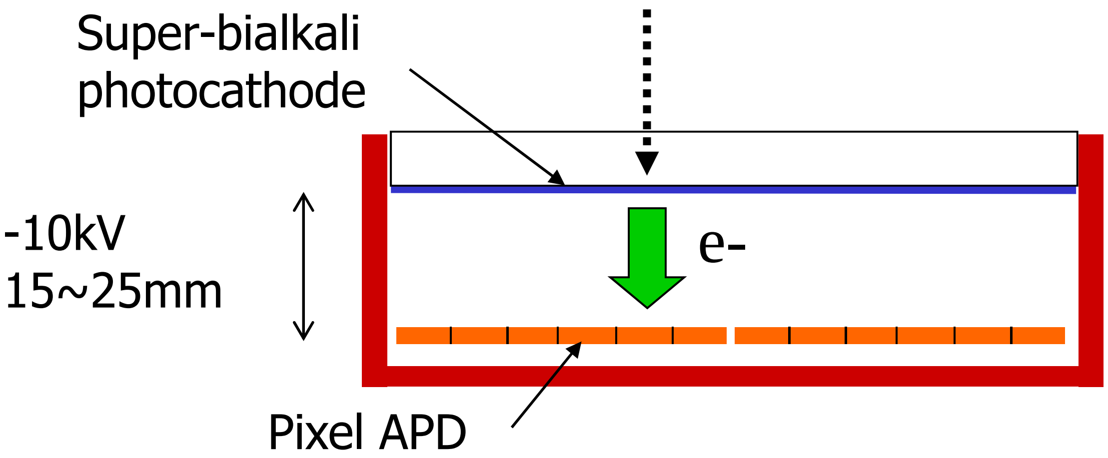
Peter Križan, Ljubljana

Photon detector for the aerogel RICH

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

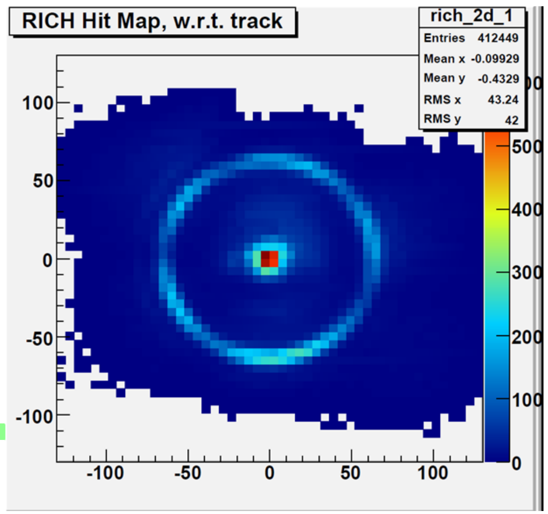
Baseline detector: large active area HAPD of the proximity focusing type





R&D project in collaboration with HPK.

Beam test results:
Cherenkov ring

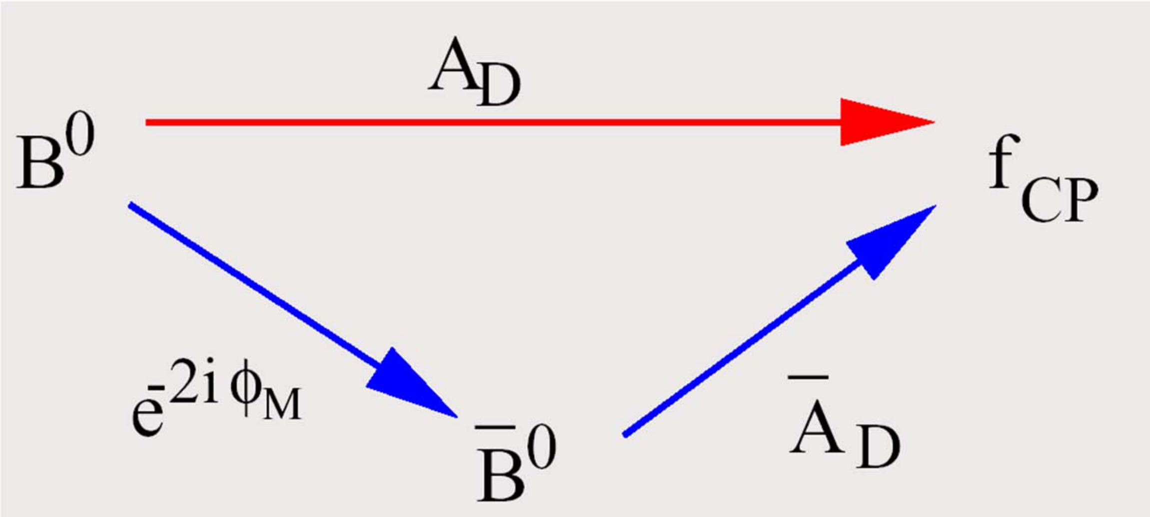


→ NIM A595 (2008) 180

CP violation in the interference between decays with and without mixing

CP violation in the interference between mixing and decay to a state accessible in both B^0 and anti-B^0 decays

For example: a CP eigenstate f_{CP} like $\pi^+ \pi^-$ or $J/\psi K_S$

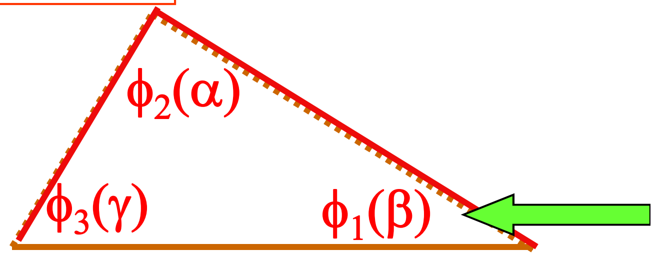


Decay rate asymmetry

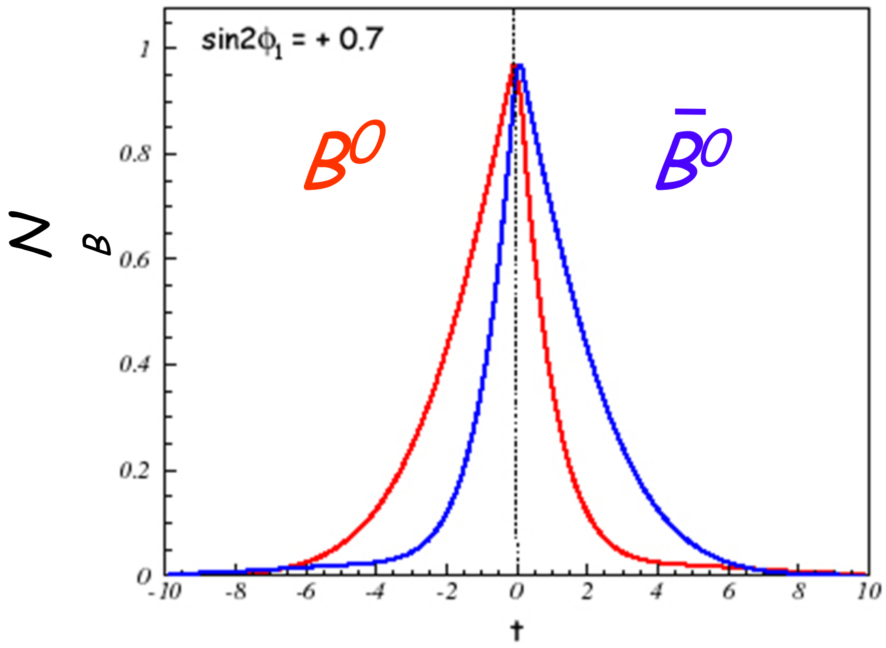
$$a_{f_{CP}} = -\mathrm{Im}(\lambda)\sin(\Delta m t)$$

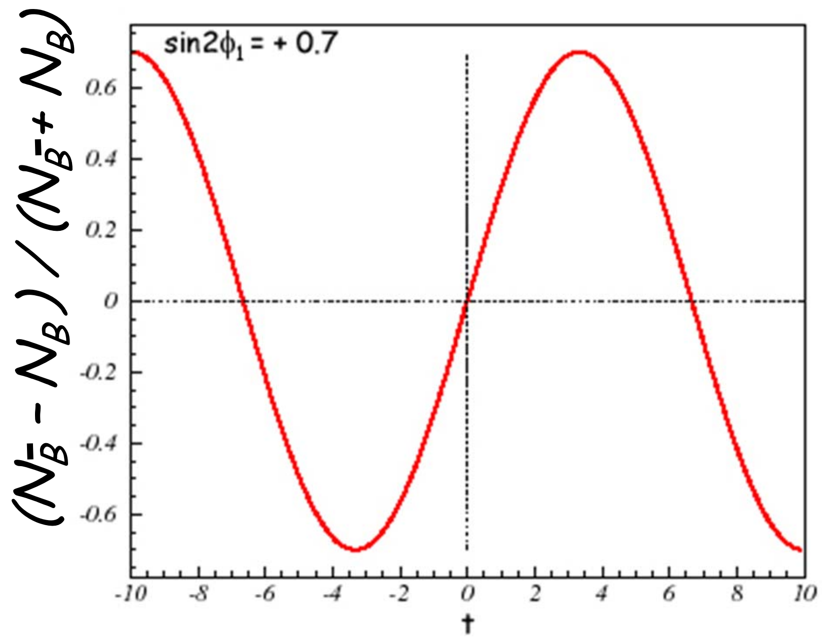
If $|\lambda| = 1$

For $J/\psi K_S$ $\quad \mathrm{Im}(\lambda) = \sin 2\phi_1$



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

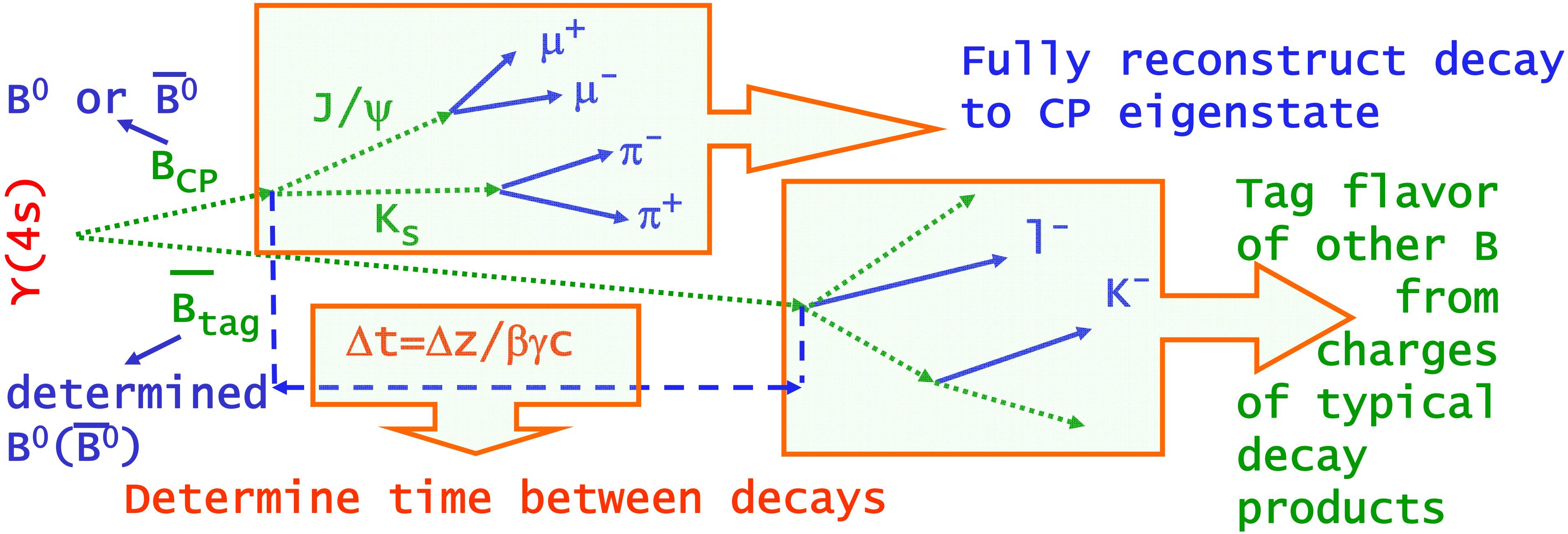




$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\overline{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} = -\xi_f \sin 2\phi_1 \sin \Delta m_B t$$

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

Principle of measurement



Search for $h_b(nP)$ in $\Upsilon(5S)$ decays

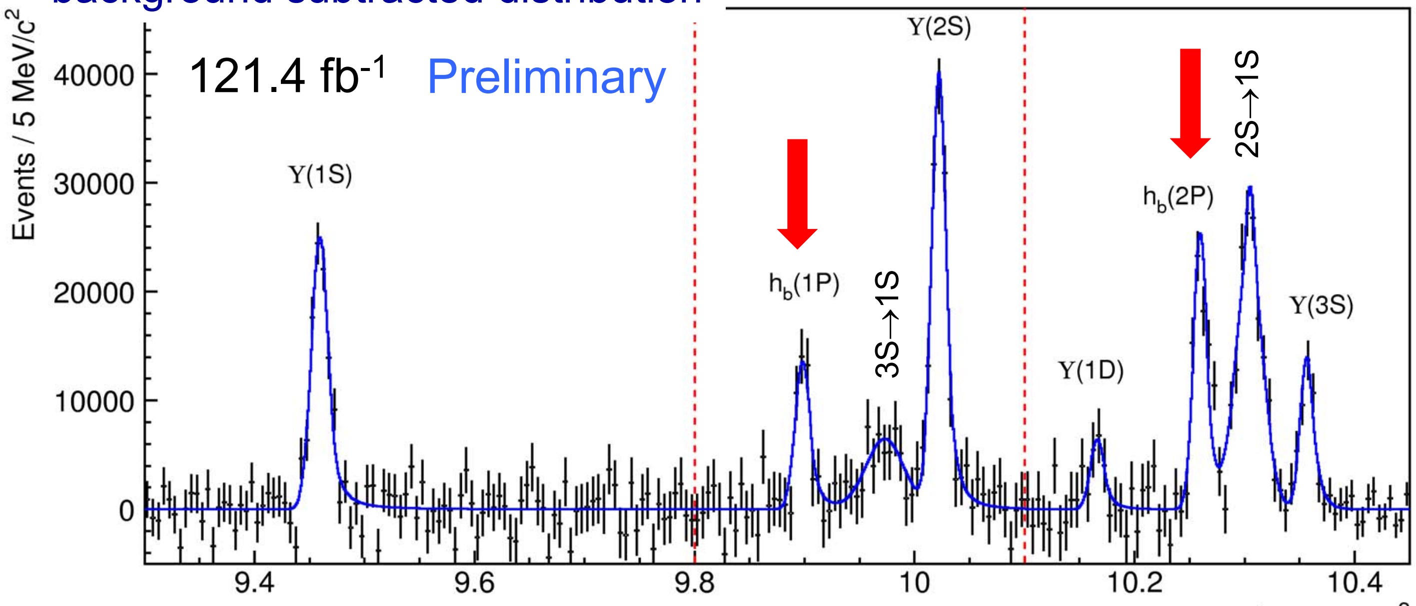
$h_b(nP)$: (bb), S=0, L=1, $J^{PC}=1^{+-}$

Evidence from BaBar $\Upsilon(3S) \rightarrow \pi^0 h_b(1P) \rightarrow \pi^0 \gamma \eta_b(1S)$ arXiv:1102.4565

Search for signal $\Upsilon(5S) \rightarrow h_b(nP)\, \pi^+\pi^-$ ← Only two charged pions used

$$M_{hb(nP)} = \sqrt{(P_{\Upsilon(5S)} - P_{\pi+\pi-})^2} \equiv MM(\pi+\pi-)$$

background subtracted distribution



Significance w/ systematics

$h_b(1P)$ 5.5σ

$h_b(2P)$ 11.2σ

arXiv:1103.3419

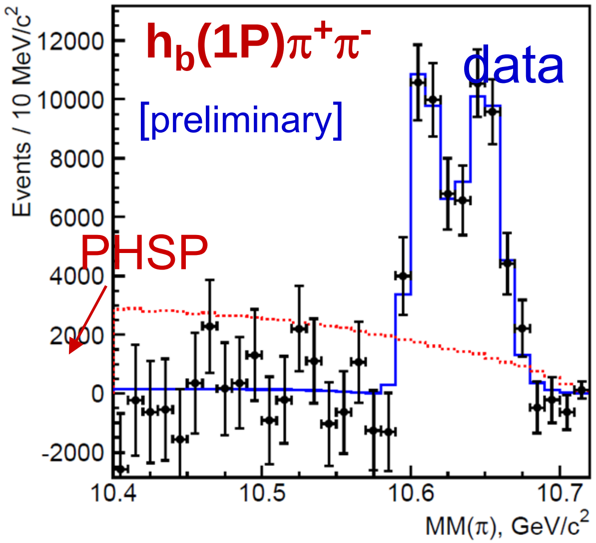
→talk by J. Wicht

h_b production is enhanced (despite of spin flip between Y(5S) and h_b)
→ the mechanism of production is exotic

Resonant substructure in $\Upsilon(5S) \to h_b(nP)\,\pi^+\pi^-$

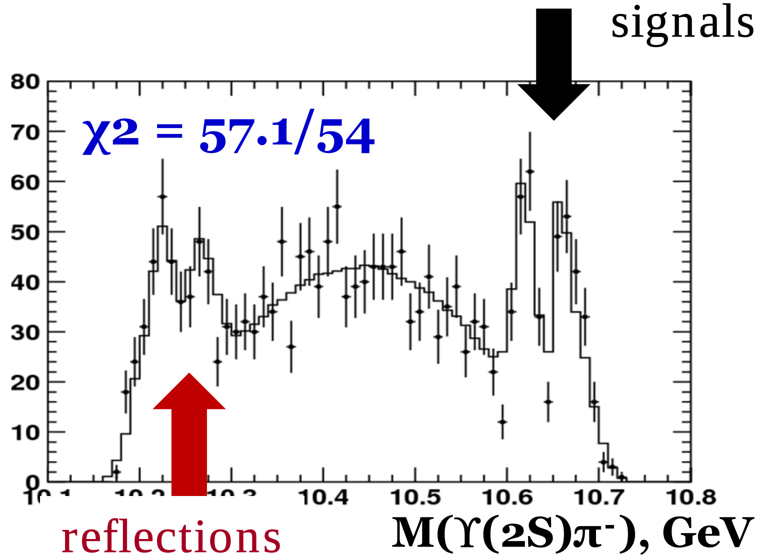
Look at $M(h_b\pi^+) = MM(\pi^-)$

measure $\Upsilon(5S)\to h_b\pi\pi$ yield in bins of $MM(\pi)$



Exclusive searches:

Observed in $\Upsilon(5S) \to$ **$\Upsilon(1S)$** π+π-, **$\Upsilon(2S)$** π+π- and **$\Upsilon(3S)$** π+π-



$Z_b(10610)$ M = 10608.1 ± 1.7 MeV
Γ = 15.5± 2.4 MeV

$Z_b(10650)$ M = 10653.3 ± 1.5 MeV
Γ = 14.0 ± 2.8 MeV

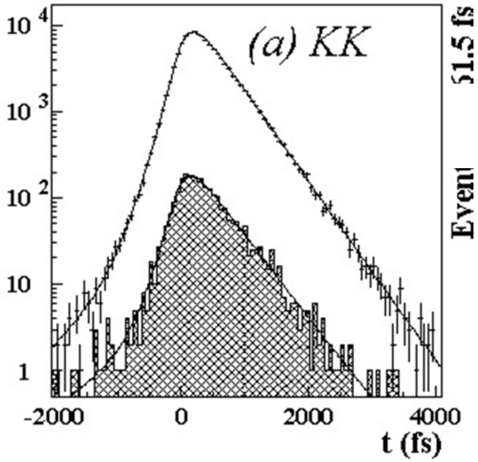
Seen in 5 different final states, parameters are consistent

$J^P=1^+$ in agreement with data; other J^P are disfavored

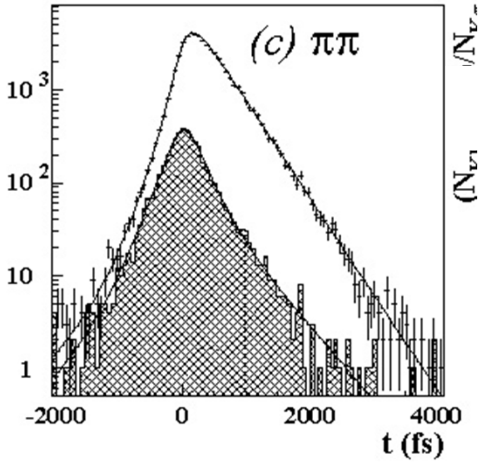
→ What is the nature of Z_b^+? Molecules, tetraquarks, cusps, ... ?

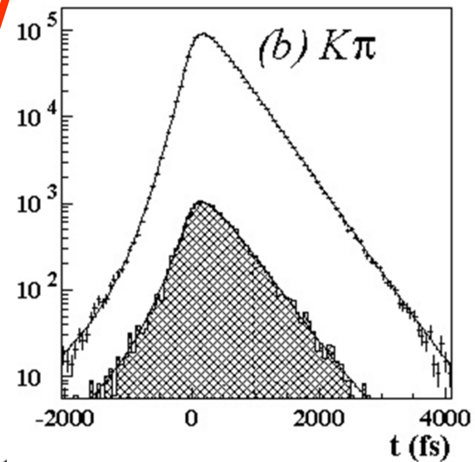
D^0 mixing in K^+K^-, $\pi^+\pi^-$

Decay time distributions for KK, ππ, Kπ



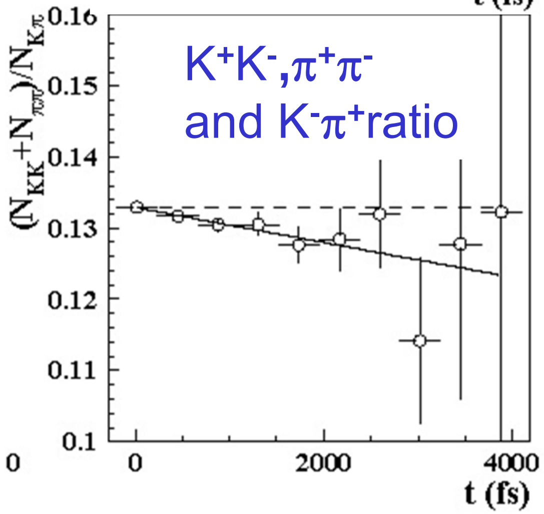
+





Difference of lifetimes visually observable

in the ratio of the distributions →



K^+K^-, $\pi^+\pi^-$ and $K^-\pi^+$ ratio

Real fit:

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

→ Observation of D mixing!

→ on a high side of SM predictions

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