Flavour Physics Workshop,
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Physics at Belle II

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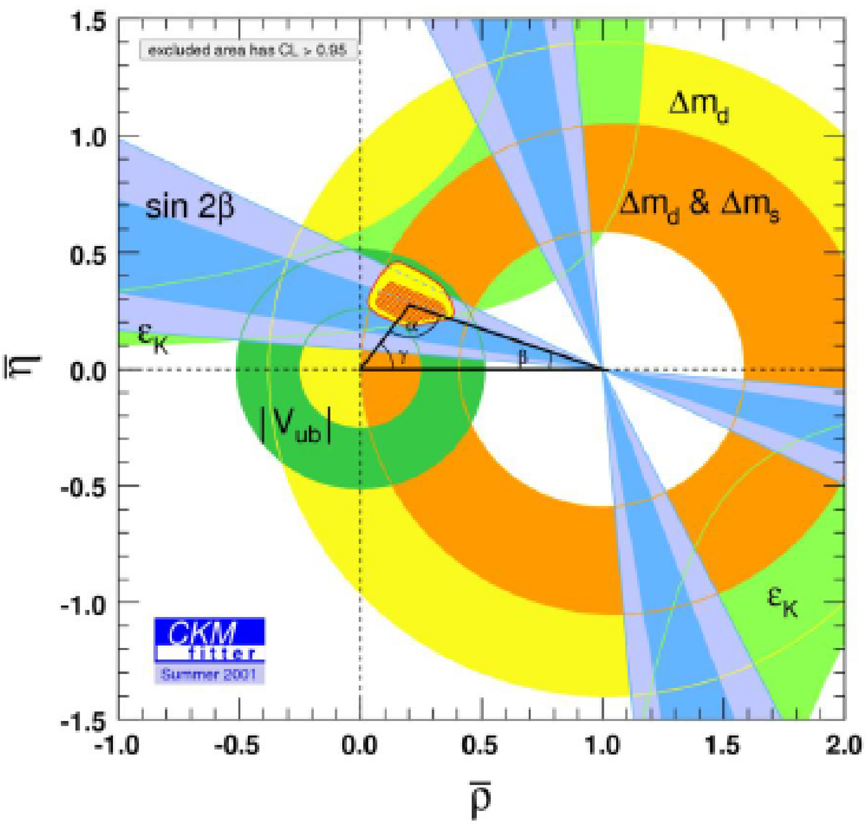
Contents

- Highlights from B factories
- Physics case for a super B factory
- Accellerator and detector upgrade → SuperKEKB + Belle-II
- Status and outlook

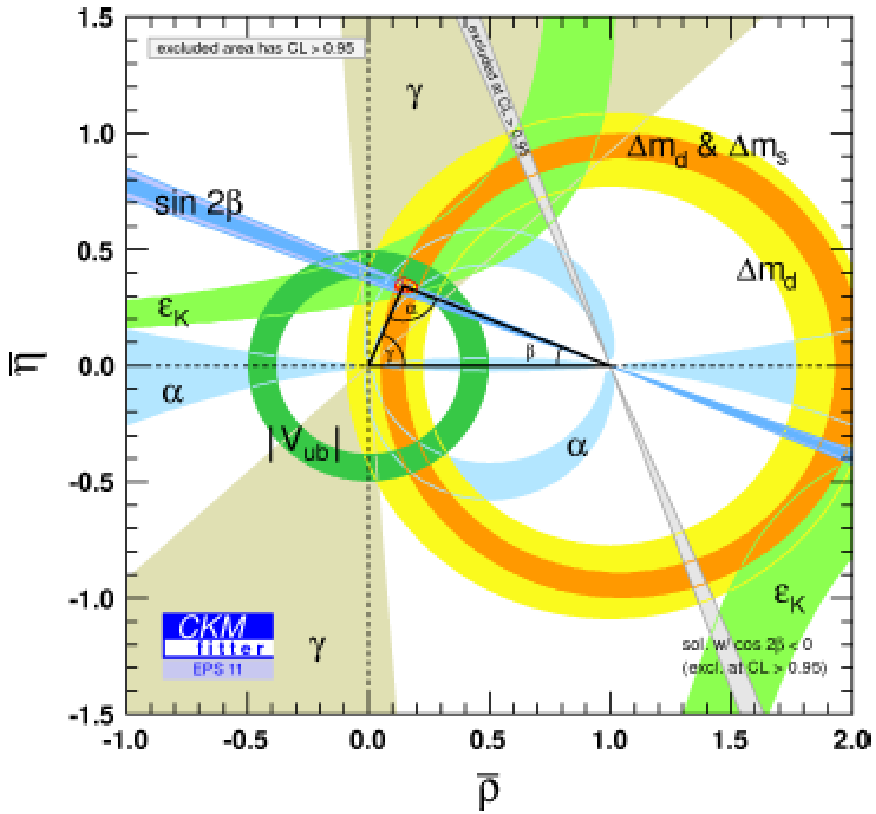
Unitarity triangle – 2011 vs 2001

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

EPS 2001



EPS 2011



Unitarity triangle – recent measurements

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

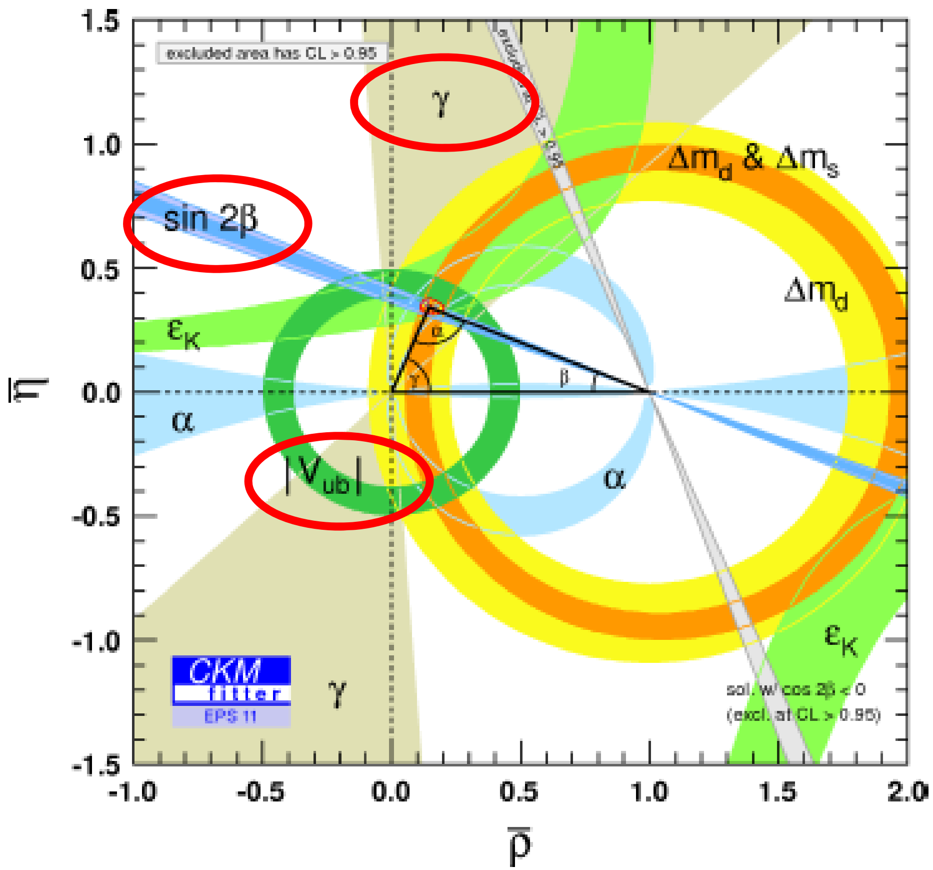
Last summer :

Unitarity triangle:

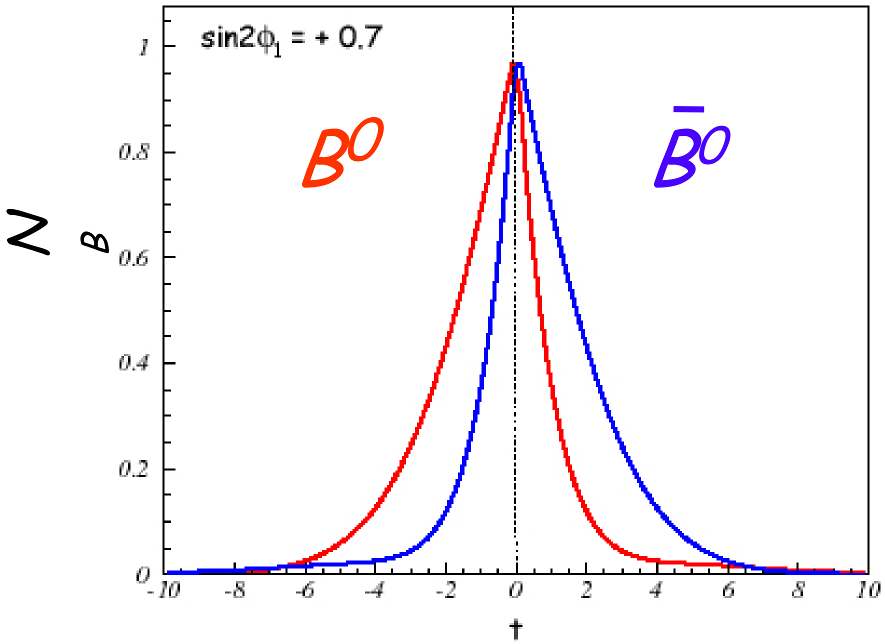
→ $\sin 2\phi_1$ (=$\sin 2\beta$) : final measurement from Belle

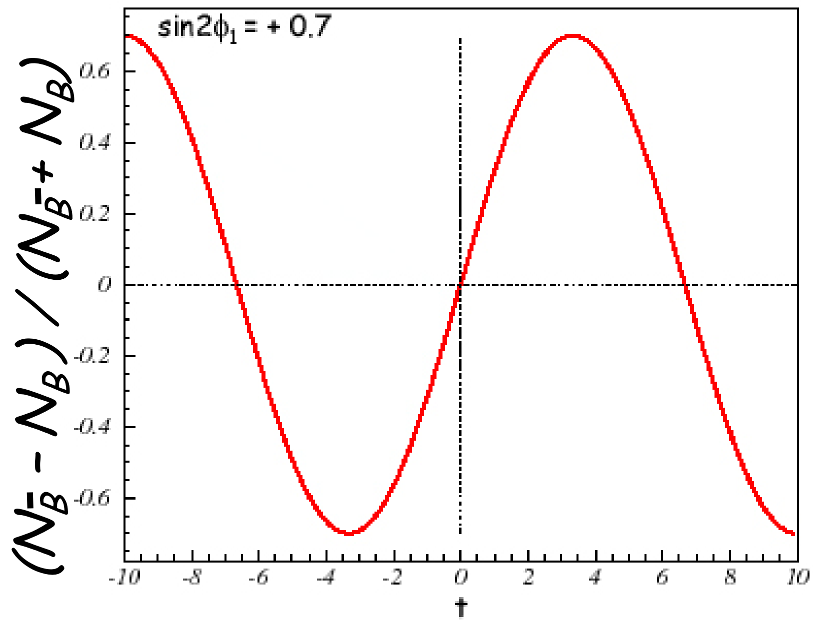
→ ϕ_3 (=γ) new model-independent method

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



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

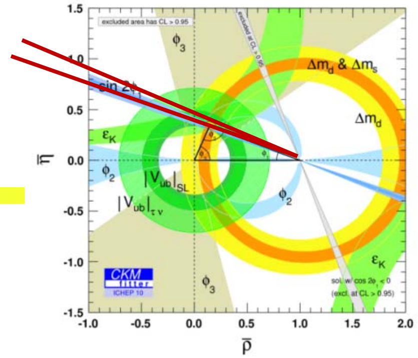




$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\overline{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} = S \sin \Delta m_B t + A \cos \Delta m_B t$$

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

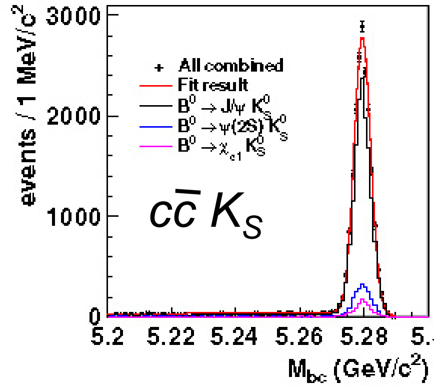
Final measurement of $\sin 2\phi_1$ (=$\sin 2\beta$)



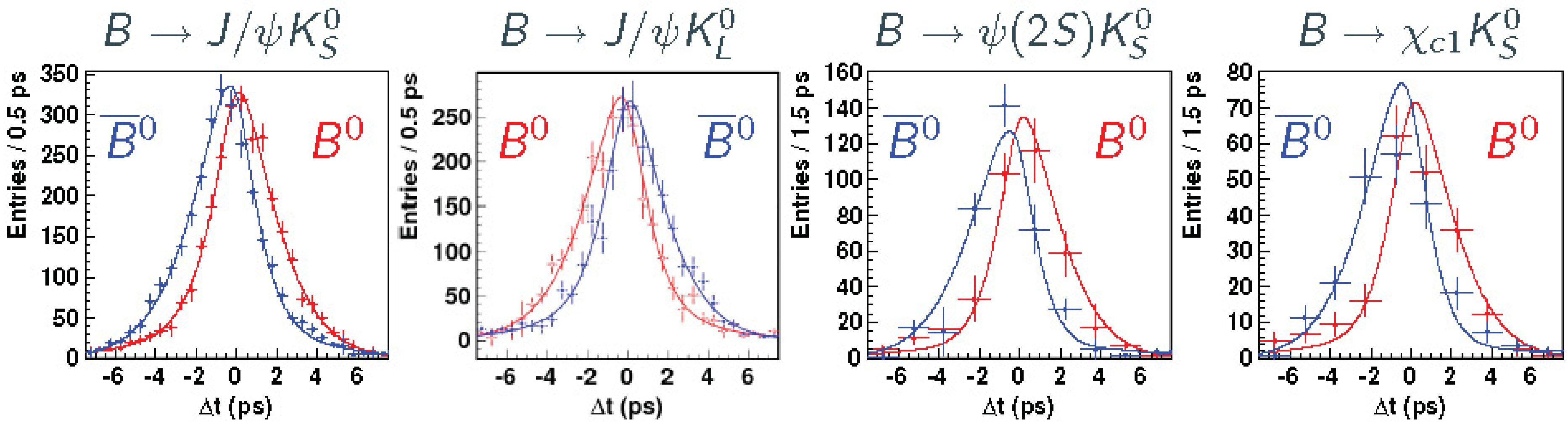
Belle, 710 fb^{-1}
PRL 108, 171802 (2012)

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

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 $\sin 2\phi_1$ (=$\sin 2\beta$)

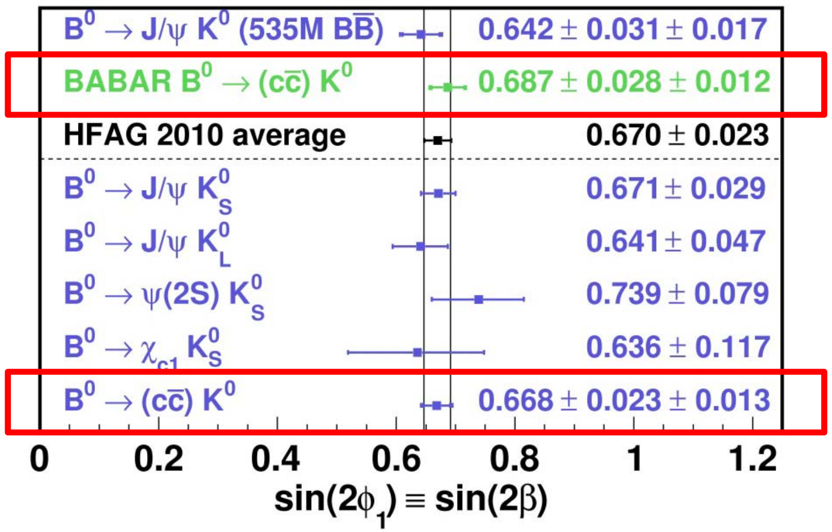
ϕ_1 from $B^0 \to c\bar{c}\, K^0$

Final result from Belle:

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

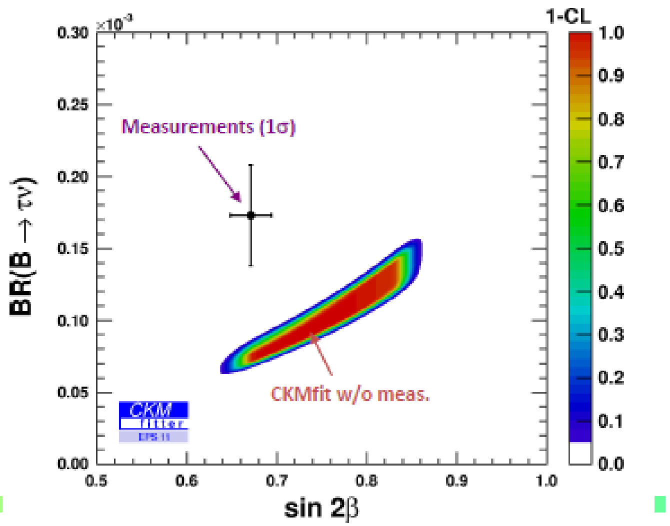
(SM: $S=\sin 2\phi_1$ (=$\sin 2\beta$), $A=0$)

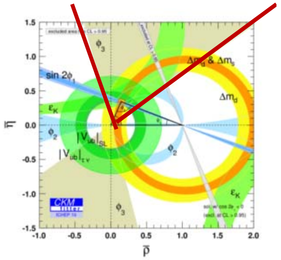
Belle, 710 fb^{-1} PRL 108, 171802 (2012)



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

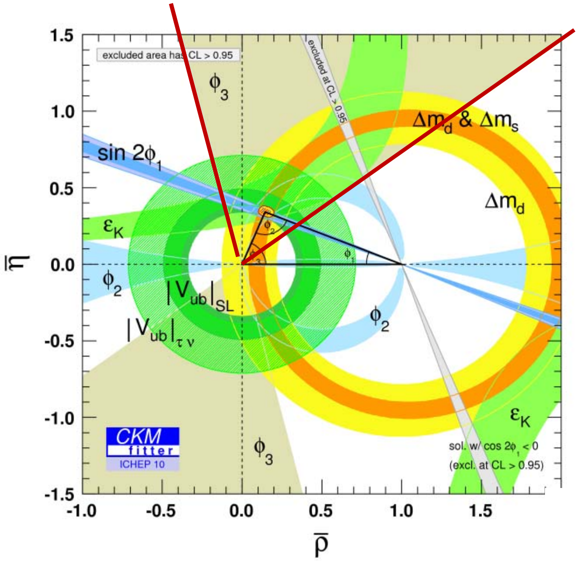


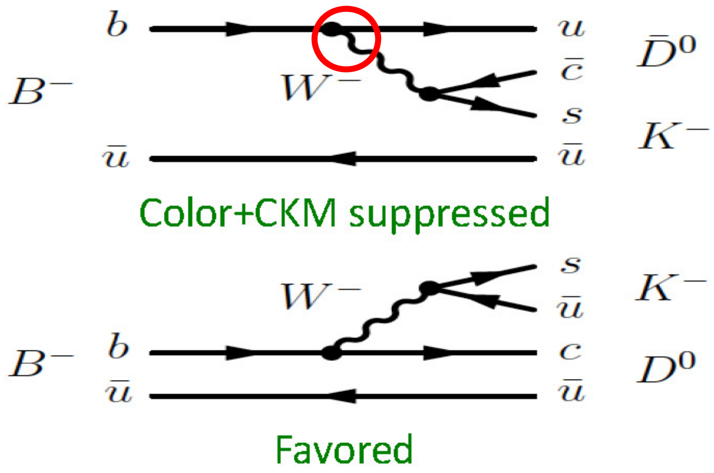


ϕ_3 (=γ) with Dalitz analysis

Dalitz method:

The best way to measure ϕ_3





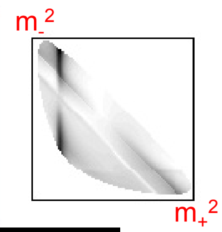
Giri et al., PRD68, 054018 (2003)
Bondar et al.

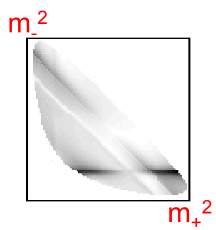
$\overset{(-)}{D^0} \rightarrow K_S\pi^+\pi^-$

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

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

$$= \left| \quad + re^{i\delta_B \pm i\phi_3} \quad \right|^2$$





model dependent description of f_D using continuum D* data $\Rightarrow$ systematic uncertainty

ϕ_3=(78 ± 12 ± 4 ± 9)°

ϕ_3=(68 ± 14 ± 4 ± 3)°

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

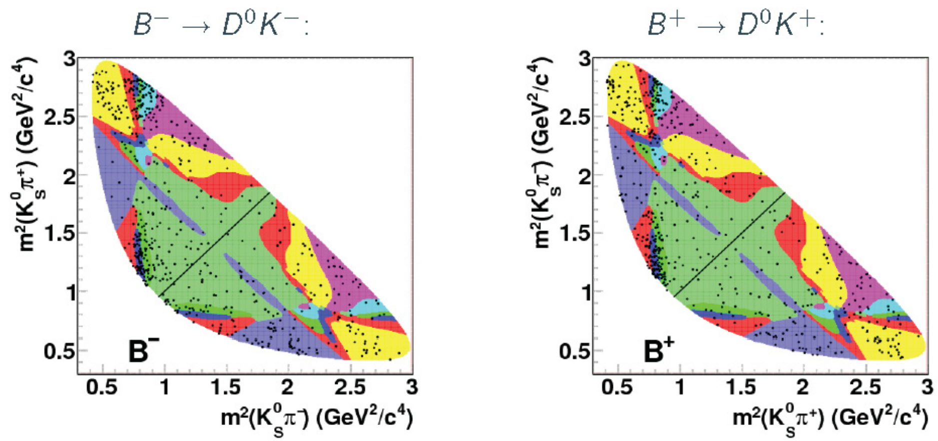
BaBar, PRL 105, 121801, (2010)

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)

Use only DK
N_{sig} = 1176 ± 43

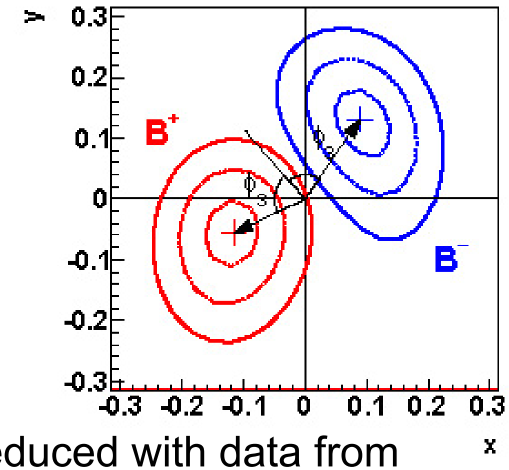
Belle, 710 fb^{-1}
arXiv:1106.4046

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

ϕ_3=(77 ± 15 ± 4 ± 4)°

from c_i, s_i (statist.!)

to be reduced with data from BESIII and super B factories



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

ϕ_3 with the ADS method

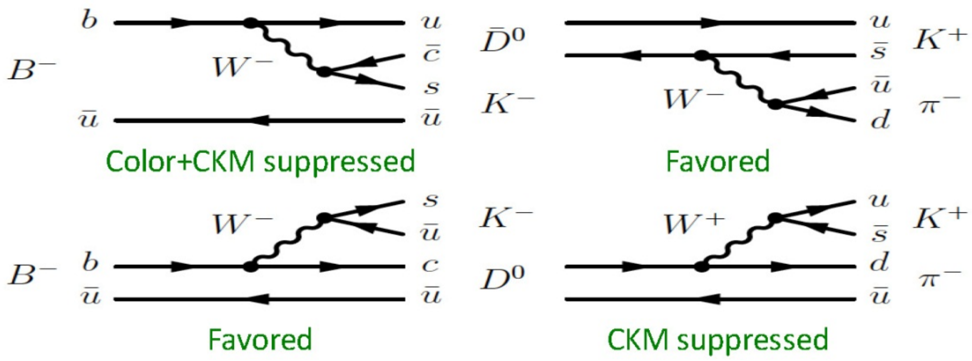
D. Atwood, I. Dunietz, A. Soni, PRL78, 3257 (1997)

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

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

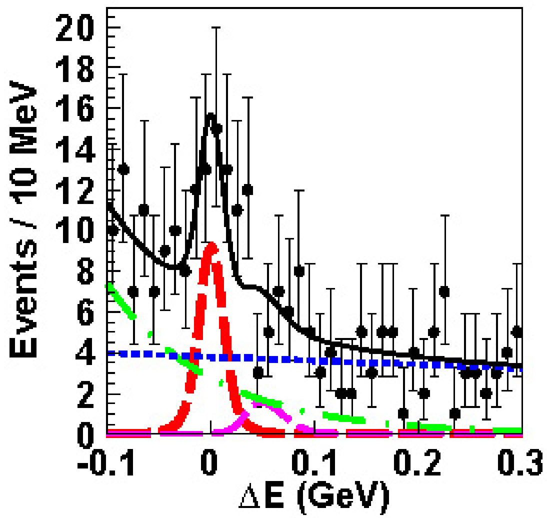
$$\mathcal{A}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]_D K^-) - \mathcal{B}([K^-\pi^+]_D K^+)}{\mathcal{B}([K^+\pi^-]_D K^-) + \mathcal{B}([K^-\pi^+]_D K^+)}$$

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



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

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}

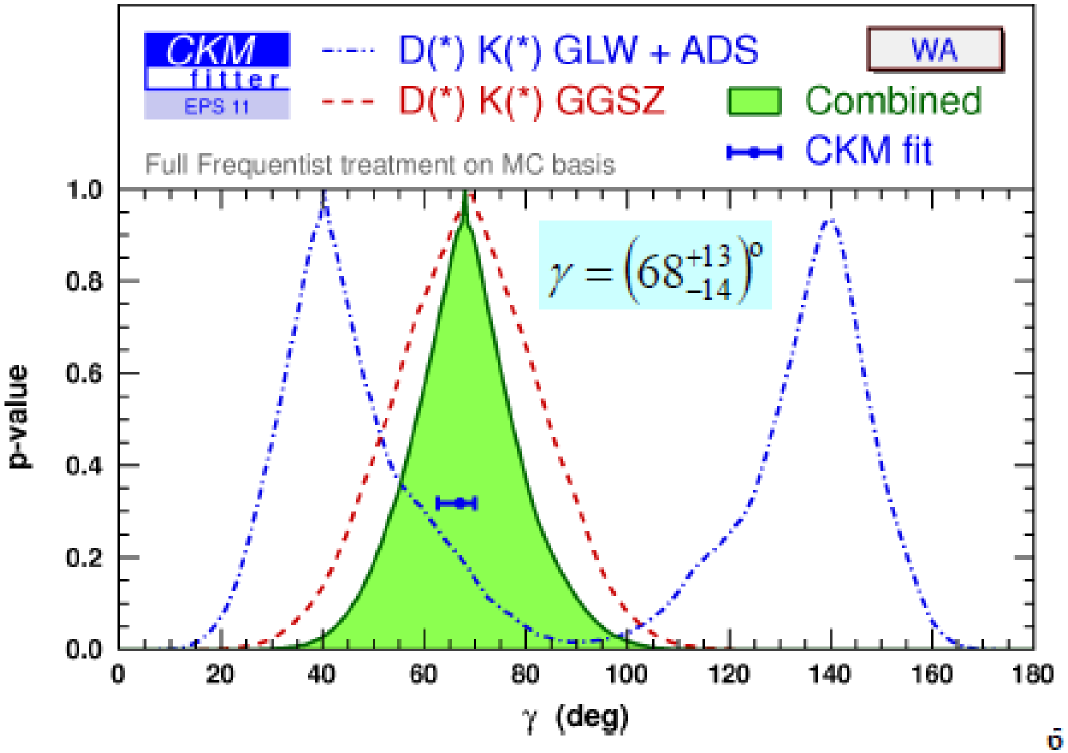
ϕ_3 measurement

Combined ϕ_3 value:

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

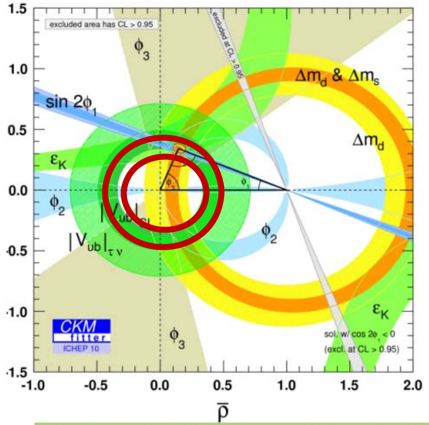
Note that B factories were not built to measure ϕ_3

It turned out much better than planned!



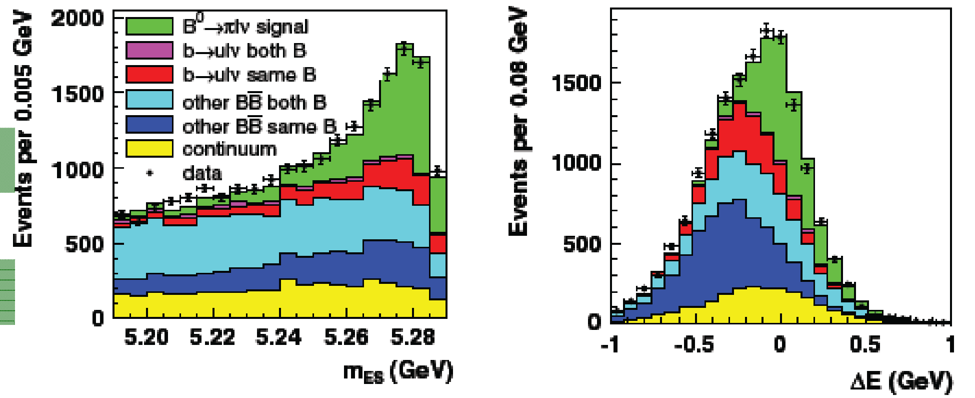
This is not the last word from B factories, analyses still to be finalized...

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



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

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



$\mathcal{B}$=(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

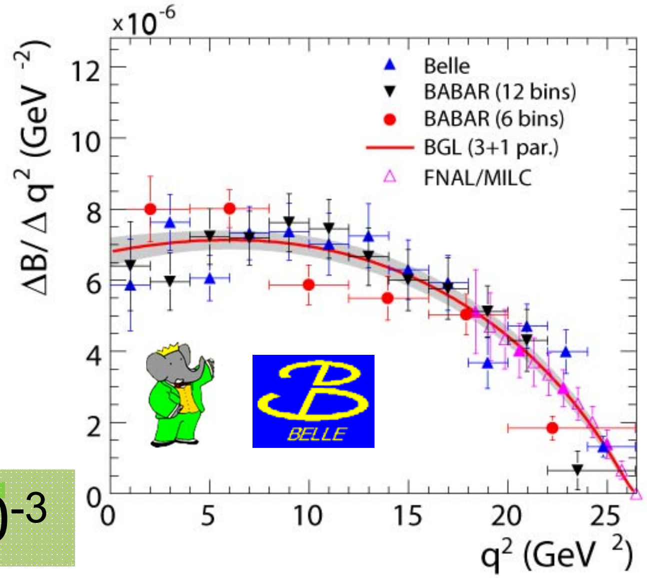
$|V_{ub}|$ extraction: fit data + LQCD points in

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

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

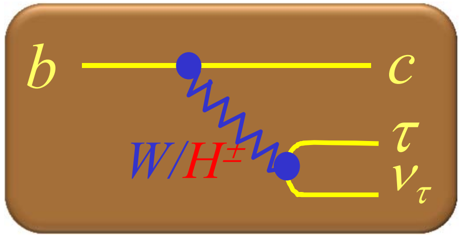
Belle + FNAL/MILC $|V_{ub}|$ = (3.43±0.33)·10^{-3}

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

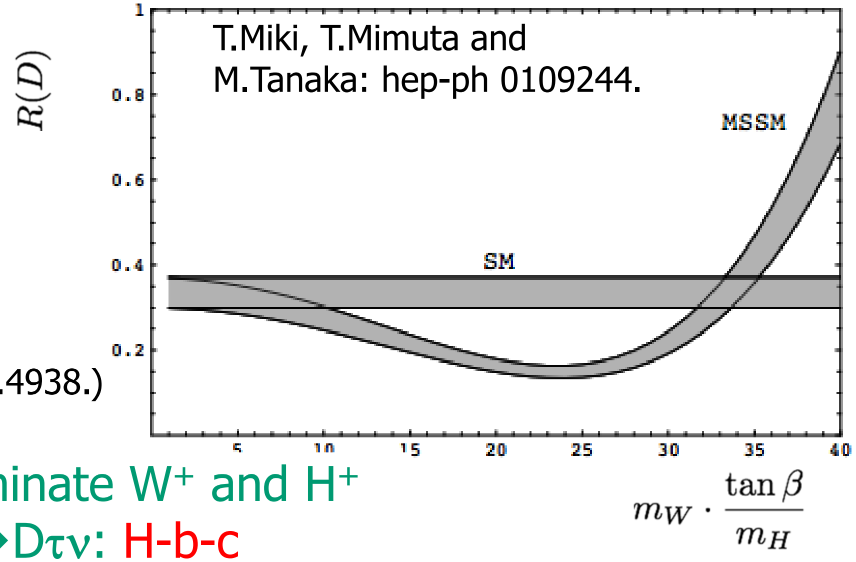
$$R(D) \equiv \frac{\mathcal{B}(B \to D\tau\nu)}{\mathcal{B}(B \to D\ell\nu)}$$

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)

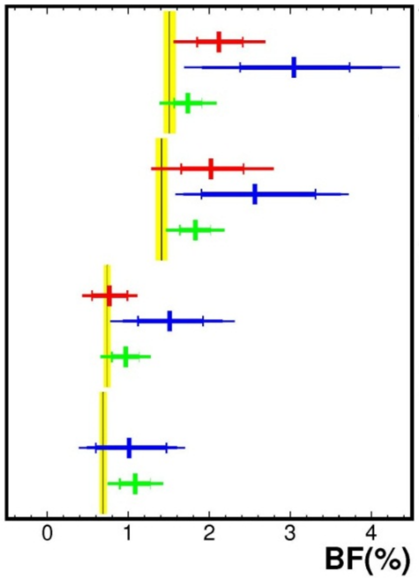
Advantage of B factories!

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

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

EPS HEP 2011: First 5σ observation (BaBar) of $B \rightarrow D\tau\nu$ decays (exclusive hadron tag data)

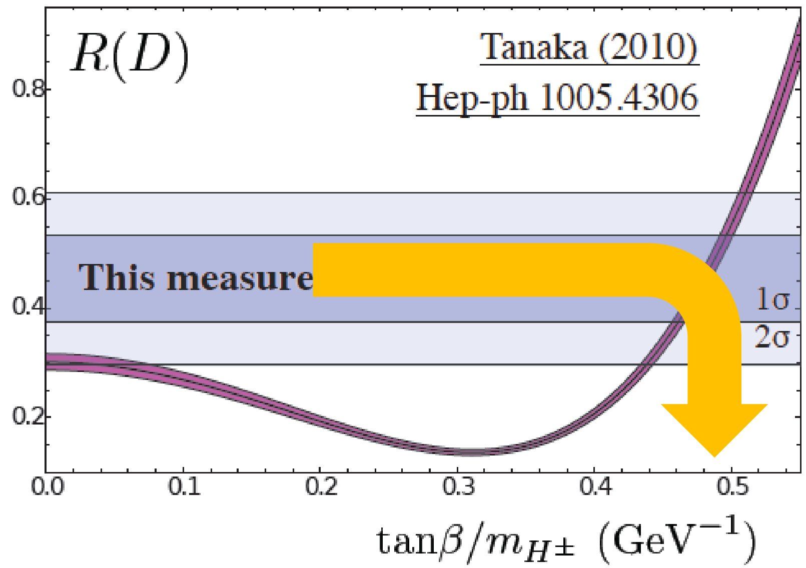
Belle inclusive tag,
Belle exclusive tag,
Babar excusive tag (summer 2011)
compared to the
SM prediction



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

All values higher than SM predictions →

→ A very interesting limit on charged Higgs



For an update of the result see Guy Wormser's slides this morning

Leptonic decays of charmed mesons $D_s \to \mu\nu, \tau\nu$

Again make use of the hermeticity of the aparatus!

$$e^+e^- \to c\bar{c} \to \overline{D}_{\rm tag} K X_{\rm frag} D_s^{*+}$$

Recoil method in charm events:

- Reconstruct D_{tag} to tag charm, kaon to tag strangeness
- Additional light mesons (X_{frag}) can be produced in the fragmentation process (π, $\pi\pi$, ...)

2 step reconstruction:

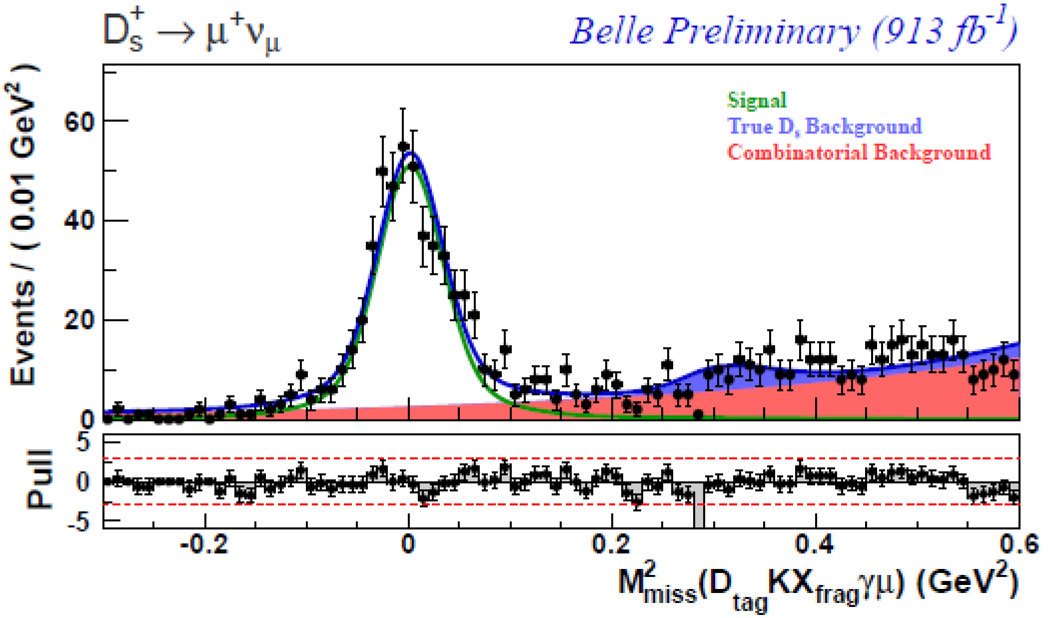
- Inclusive reconstruction of D_s mesons for normalization (without any requirements upon D_s decay products)
- Within the inclusive D_s sample search for D_s decays
  - $D_s \to \mu\nu$: peak at $m_\nu^2 = 0$ in $M^2_{\rm miss}(D_{\rm tag} K X_{\rm frag} \gamma \mu)$
  - $D_s \to \tau\nu$: peak towards 0 in extra energy in calorimeter

$D_s^+ \to \mu^+\nu_\mu$

Fit to the missing mass squared – $M^2_{\rm miss}(D_{\rm tag}KX_{\rm frag}\gamma\mu^\pm)$

Selection:

- $M_{\rm miss}(D_{\rm tag}KX_{\rm frag}\gamma)$ signal region
- 1 charged track pointing to the IP
- passing muon PID requirements



$$N^{\rm excl}_{D_s\to\mu\nu} = 489 \pm 26$$

Belle preliminary @ 913 fb^{-1}

$$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (0.528 \pm 0.028({\rm stat.}) \pm 0.019({\rm syst.}))\%$$

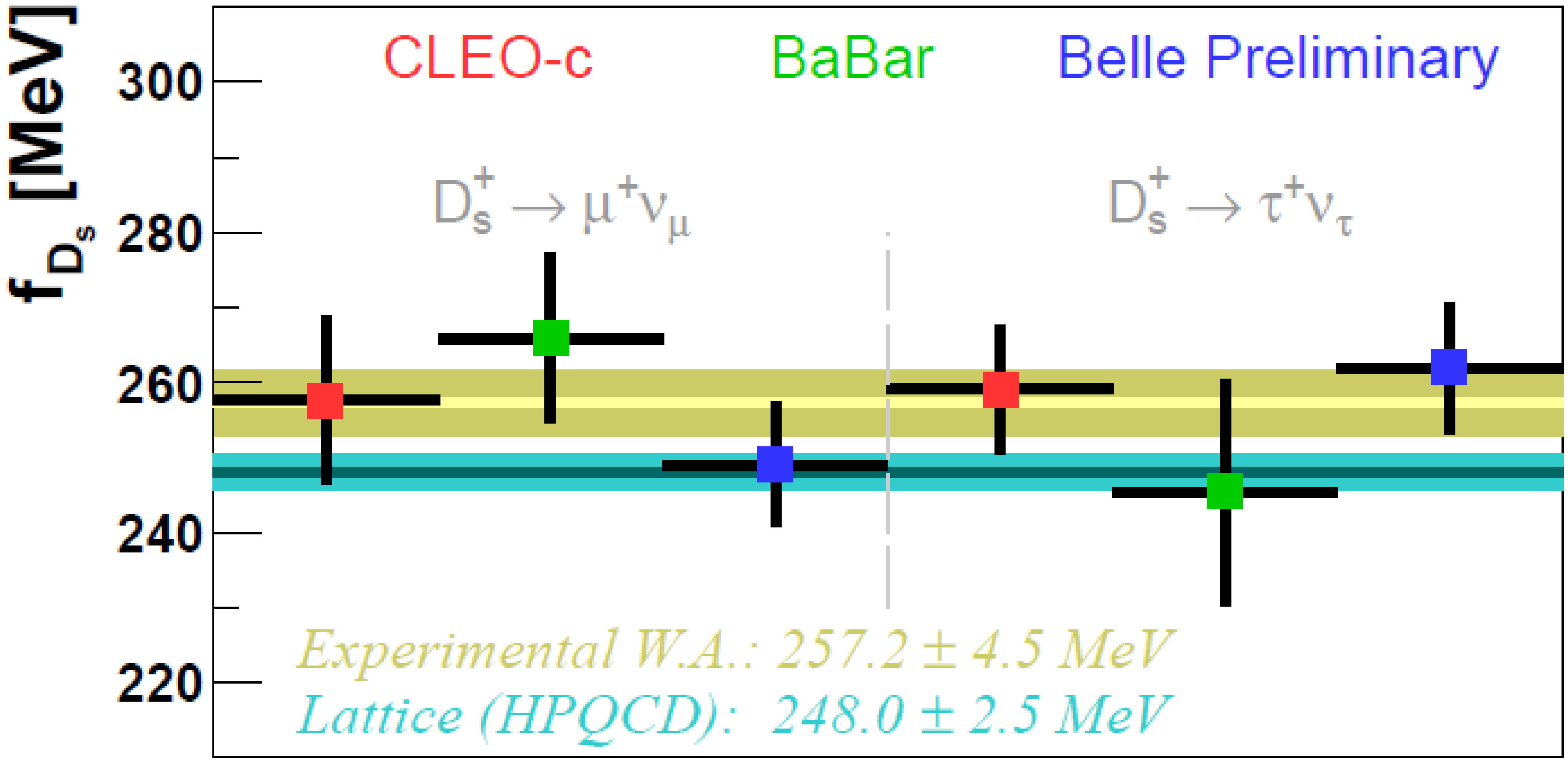
Most precise measurement up to date.

Extract f_{Ds} :

$$f_{D_s} = \frac{1}{G_F m_\ell \left(1 - \frac{m_\ell^2}{M_{D_s}^2}\right)|V_{cs}|}\sqrt{\frac{8\pi\mathcal{B}(D_s \to \ell\nu_\ell)}{M_{D_s}\tau_{D_s}}}$$

f_{D_s} Comparison

Average of CLEO-c [PRD80,112004(2009)], BaBar [PRD82,091103(2010)] and Belle Preliminary.



Average of experimental determinations is consistent within 1.8σ with most precise lattice QCD calculation by HPQCD.

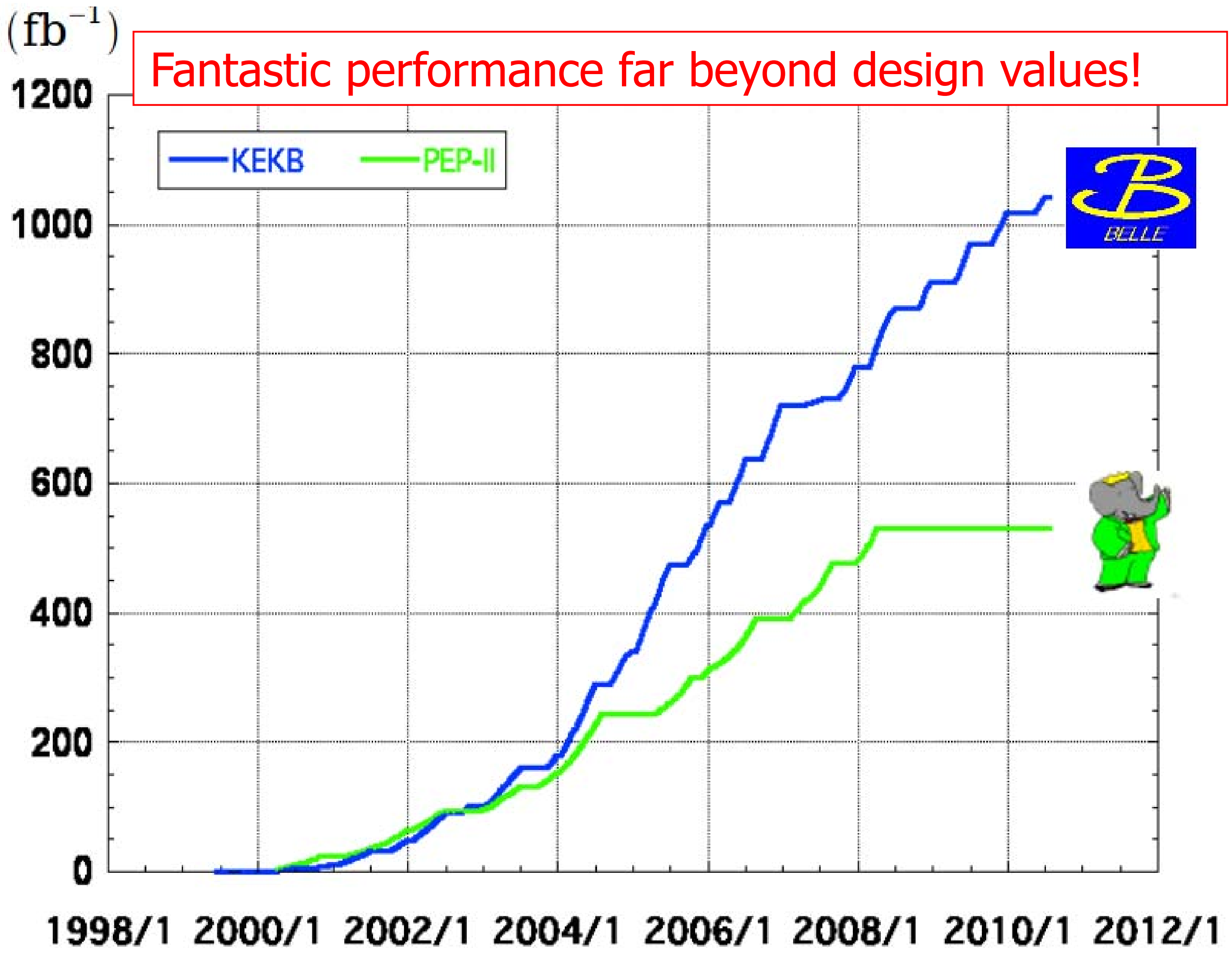
Need further lattice QCD results with comparable precision to confirm the calculation by HPQCD.

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:

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

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

On resonance:

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

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

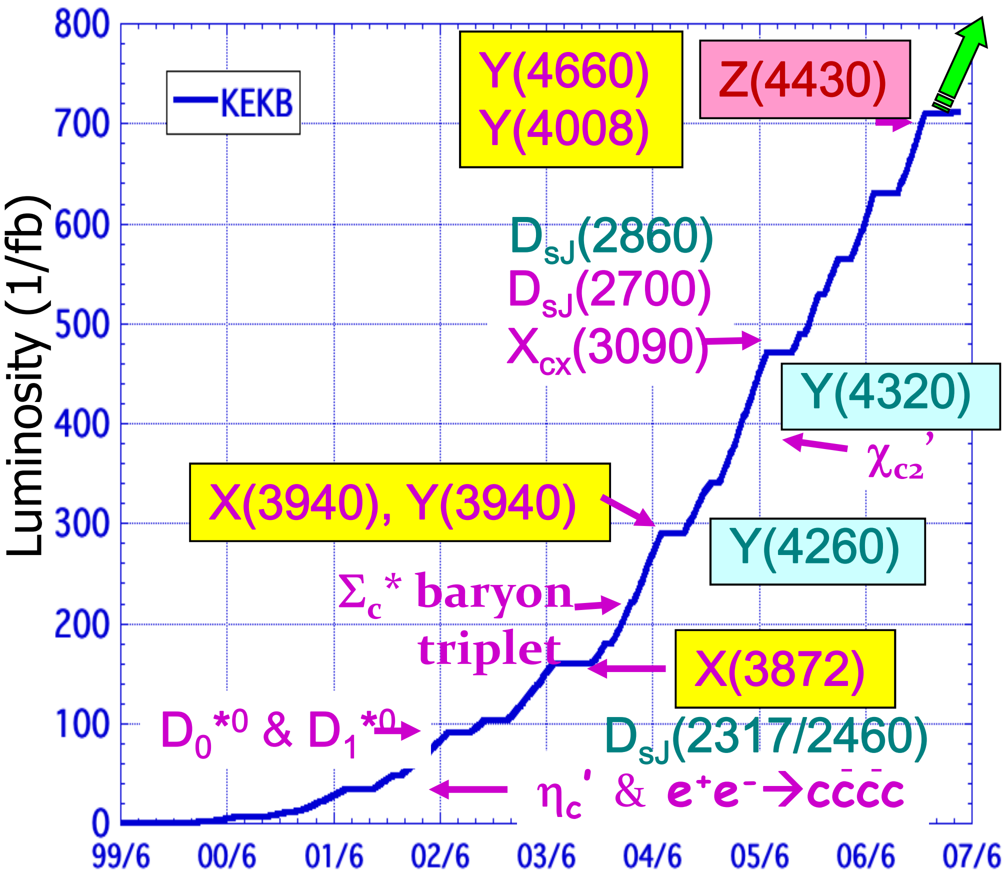
$\Upsilon(2S)$: 14 fb^{-1}

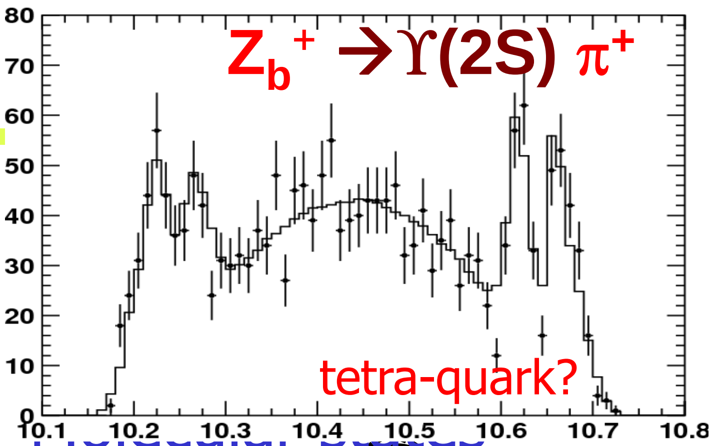
Off resonance:

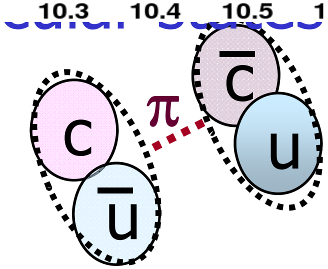
$\sim 54\ fb^{-1}$

New hadrons at B-factories

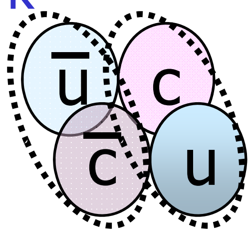
Discoveries of many new hadrons at B-factories
class of hadrons beyond the ordinary mesons.



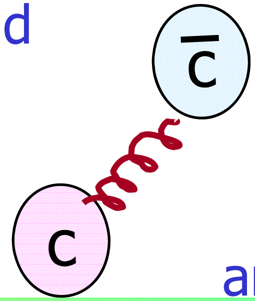




Tetra-quark



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?

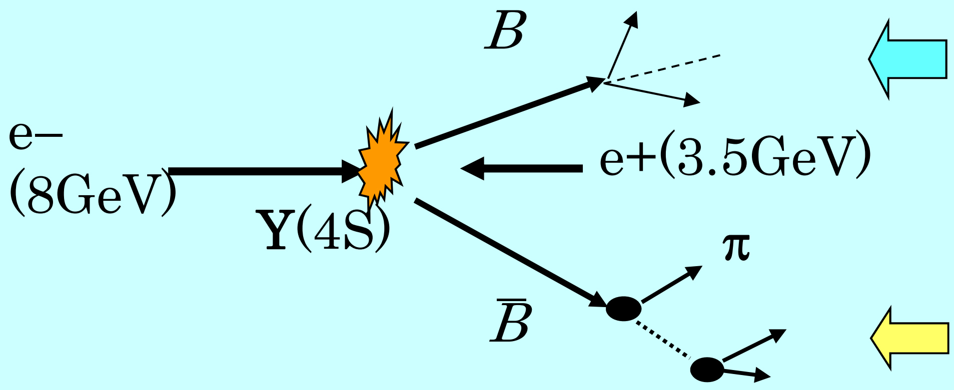
→ Need much more data (two orders!) because the SM worked so well until now → Super B factory

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) Υ(4s) will have considerable advantages in several classes of measurements, and will be complementary in many more

Full Reconstruction Method

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



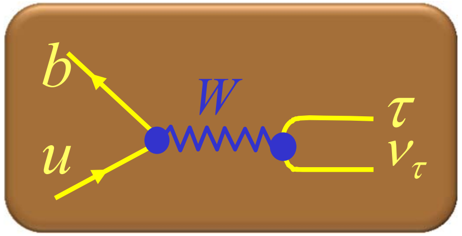
Decays of interest
$B \rightarrow X_u\, l\, \nu$,
$B \rightarrow K\, \nu\, \nu$
$B \rightarrow D\tau\nu$, $\tau\nu$

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

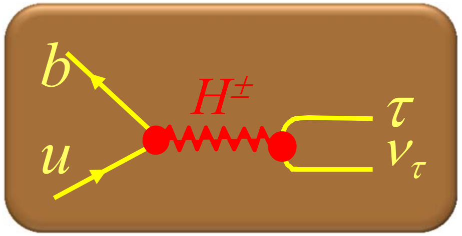
→ Offline B meson beam!

Powerful tool for B decays with neutrinos

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



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

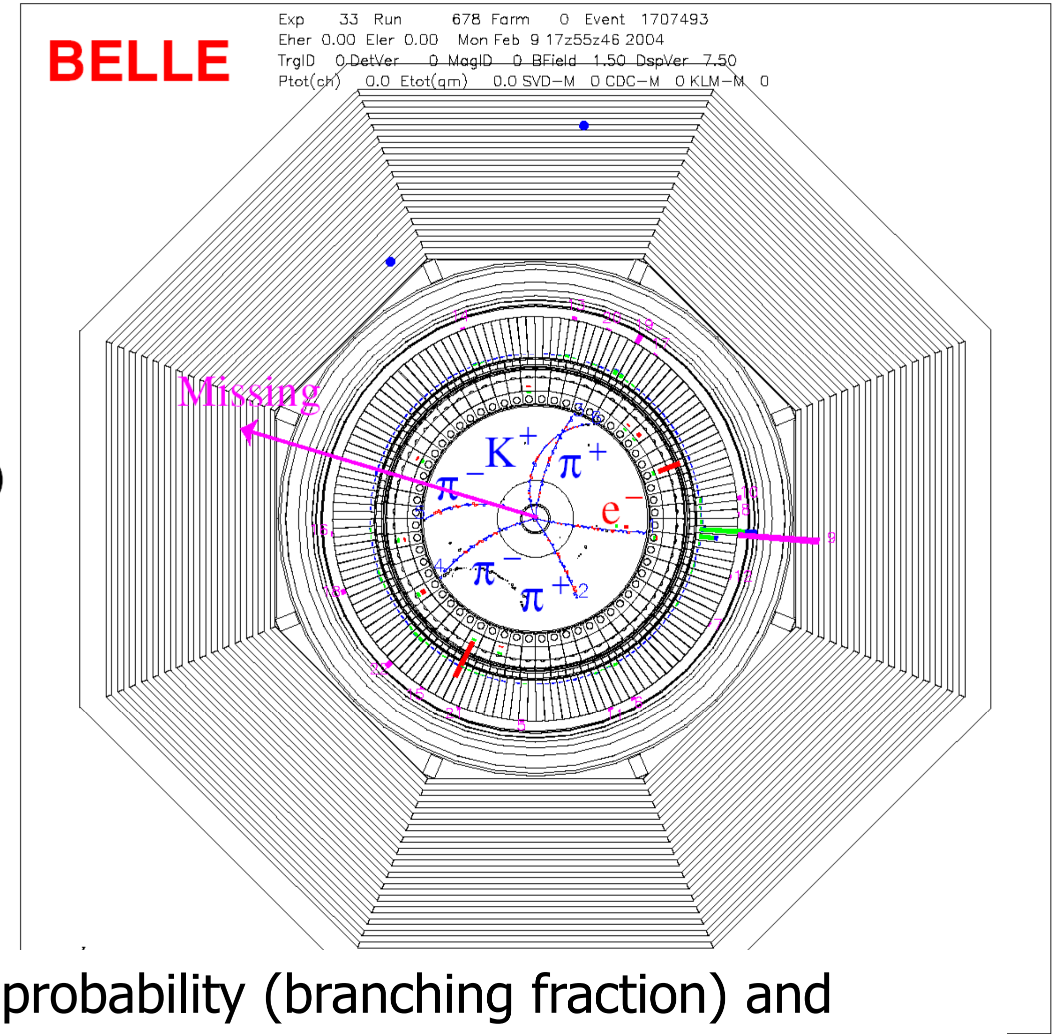


In some supersymmetric extensions it can also proceed via a charged Higgs

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: $B^- \rightarrow \tau^- \nu_\tau$

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



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

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

$B \rightarrow \nu\,\nu$ decay

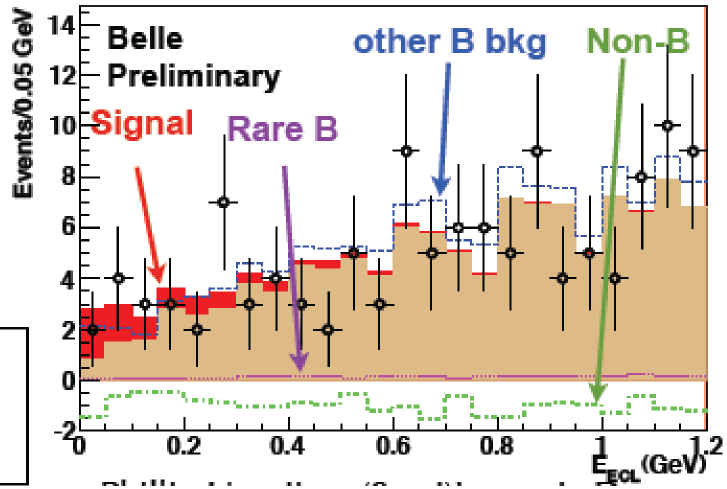
$B \rightarrow \nu\,\nu$ similar as $B \rightarrow \mu\,\mu$ a very sensitive channel to NP contributions

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

$\rightarrow$ 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.



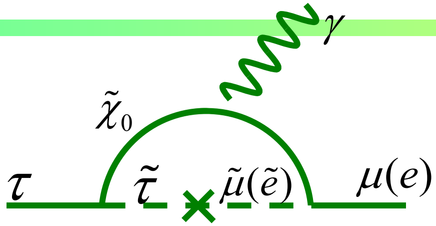
90% C.L. BR < 1.3 x 10^{-4}

Belle Preliminary 657M BBbar

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

LFV and New Physics

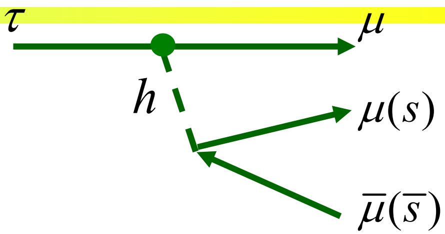
$\tau \to l\gamma$



- SUSY + Seasaw $(m^2_{\tilde{l}})_{23(13)}$
- Large LFV $Br(\tau \to \mu\gamma) = O(10^{-7\sim9})$

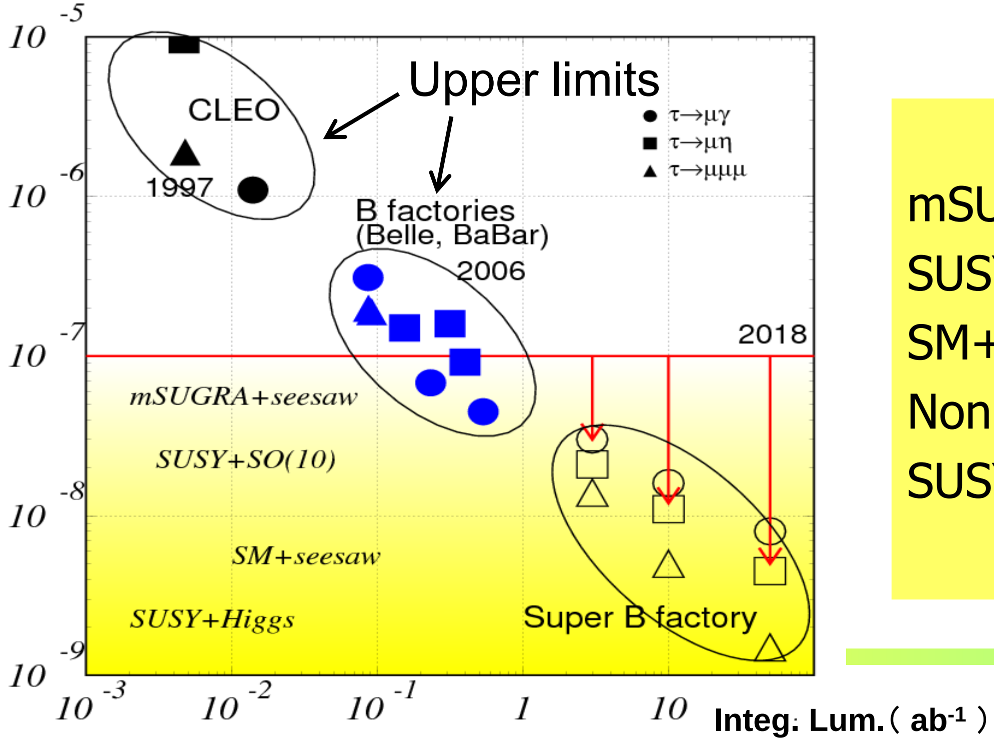
$$Br(\tau \to \mu\gamma) \cong 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}}\right)\left(\frac{1\,TeV}{m_{SUSY}}\right)^4 \tan^2\beta$$

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



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

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



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

Physics sensitivity at Belle II

Observable	Belle 2006	SuperKEKB		†LHCb	
	(~0.5 ab^{-1})	(5 ab^{-1})	(50 ab^{-1})	(2 fb^{-1})	(10 fb^{-1})
Leptonic/semileptonic B decays					
$\mathcal{B}(B^+ \to \tau^+\nu)$	3.5σ	10%	3%	-	-
$\mathcal{B}(B^+ \to \mu^+\nu)$	†† $< 2.4\mathcal{B}_{SM}$	4.3 ab^{-1} for 5σ discovery		-	-
$\mathcal{B}(B^+ \to D\tau\nu)$	-	8%	3%	-	-
$\mathcal{B}(B^0 \to D\tau\nu)$	-	30%	10%	-	-
LFV in τ decays (U.L. at 90% C.L.)					
$\mathcal{B}(\tau \to \mu\gamma)$ [10^{-9}]	45	10	5	-	-
$\mathcal{B}(\tau \to \mu\eta)$ [10^{-9}]	65	5	2	-	-
$\mathcal{B}(\tau \to \mu\mu\mu)$ [10^{-9}]	21	3	1	-	-
Unitarity triangle parameters					
$\sin 2\phi_1$	0.026	0.016	0.012	~0.02	~0.01
ϕ_2 ($\pi\pi$)	11°	10°	3°	-	-
ϕ_2 ($\rho\pi$)	$68° < \phi_2 < 95°$	3°	1.5°	10°	4.5°
ϕ_2 ($\rho\rho$)	$62° < \phi_2 < 107°$	3°	1.5°	-	-
ϕ_2 (combined)		2°	$\lesssim 1°$	10°	4.5°
ϕ_3 ($D^{(*)}K^{(*)}$) (Dalitz mod. ind.)	20°	7°	2°	8°	
ϕ_3 ($DK^{(*)}$) (ADS+GLW)	-	16°	5°	5-15°	
ϕ_3 ($D^{(*)}\pi$)	-	18°	6°		
ϕ_3 (combined)		6°	1.5°	4.2°	2.4°
$\|V_{ub}\|$ (inclusive)	6%	5%	3%	-	-
$\|V_{ub}\|$ (exclusive)	15%	12% (LQCD)	5% (LQCD)	-	-
$\bar{\rho}$	20.0%		3.4%		
$\bar{\eta}$	15.7%		1.7%		

Physics sensitivity at Belle II

Observable	Belle 2006	SuperKEKB		†LHCb	
	(~0.5 ab^{-1})	(5 ab^{-1})	(50 ab^{-1})	(2 fb^{-1})	(10 fb^{-1})
Hadronic $b \to s$ transitions					
$\Delta\mathcal{S}_{\phi K^0}$	0.22	0.073	0.029		0.14
$\Delta\mathcal{S}_{\eta' K^0}$	0.11	0.038	0.020		
$\Delta\mathcal{S}_{K^0_S K^0_S K^0_S}$	0.33	0.105	0.037	-	-
$\Delta\mathcal{A}_{\pi^0 K^0_S}$	0.15	0.072	0.042	-	-
$\mathcal{A}_{\phi\phi K^+}$	0.17	0.05	0.014		
$\phi_1^{eff}(\phi K_S)$ Dalitz		3.3°	1.5°		
Radiative/electroweak $b \to s$ transitions					
$\mathcal{S}_{K^0_S \pi^0 \gamma}$	0.32	0.10	0.03	-	-
$\mathcal{B}(B \to X_s \gamma)$	13%	7%	6%	-	-
$A_{CP}(B \to X_s \gamma)$	0.058	0.01	0.005	-	-
C_9 from $A_{FB}(B \to K^* \ell^+ \ell^-)$	-	11%	4%		
C_{10} from $A_{FB}(B \to K^* \ell^+ \ell^-)$	-	13%	4%		
C_7/C_9 from $A_{FB}(B \to K^* \ell^+ \ell^-)$	-		5%		7%
R_K		0.07	0.02		0.043
$\mathcal{B}(B^+ \to K^+ \nu\nu)$	†† $< 3\ \mathcal{B}_{SM}$		30%	-	-
$\mathcal{B}(B^0 \to K^{*0} \nu\bar{\nu})$	†† $< 40\ \mathcal{B}_{SM}$		35%	-	-
Radiative/electroweak $b \to d$ transitions					
$\mathcal{S}_{\rho\gamma}$	-	0.3	0.15		
$\mathcal{B}(B \to X_d \gamma)$	-	24% (syst.)		-	-

Physics reach with 50 ab^{-1}: Physics at Super B Factory (Belle II authors + guests) hep-ex arXiv:1002.5012

More examples...

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

arXiv:1002.5012

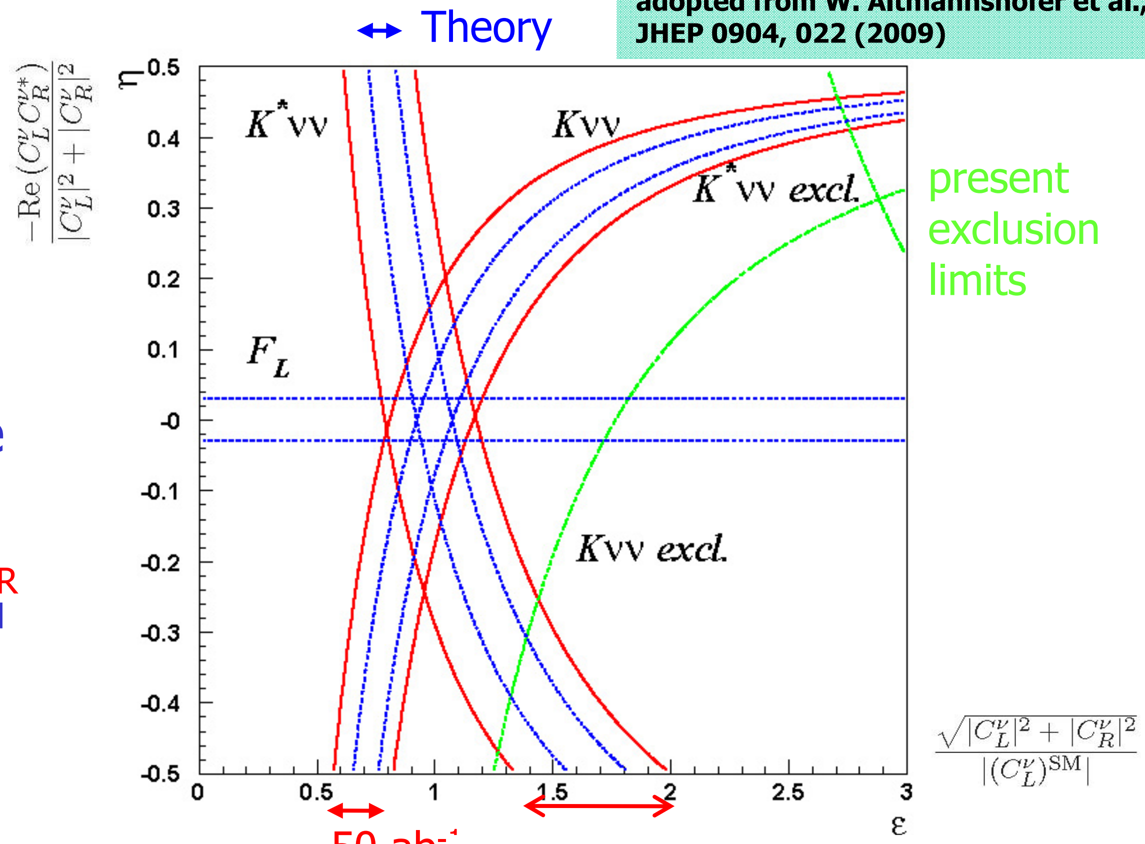
adopted from W. Altmannshofer et al., JHEP 0904, 022 (2009)

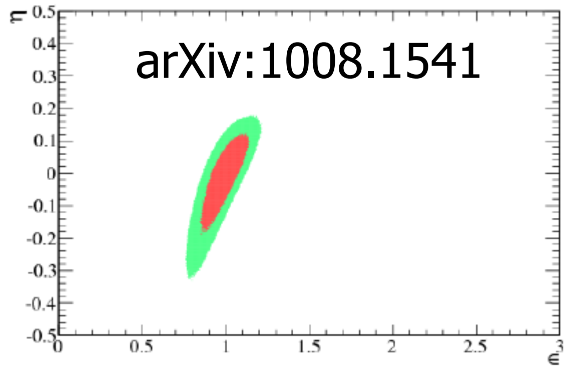
$B \to K\nu\nu$, $\mathcal{B} \sim 4\cdot10^{-6}$
$B \to K^*\nu\nu$, $\mathcal{B} \sim 6.8\cdot10^{-6}$

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.





More examples...

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

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

t-dependent CPV

SM:

$S_{CP}^{K^*\gamma} \sim -(2m_s/m_b)\sin 2\phi_1 \sim -0.04$

Left-Right Symmetric Models:

$S_{CP}^{K^*\gamma} \sim 0.67 \cos 2\phi_1 \sim 0.5$

D. Atwood et al., PRL79, 185 (1997)
B. Grinstein et al., PRD71, 011504 (2005)

$S_{CP}^{Ks\pi 0\gamma} = -0.15 \pm 0.20$

$A_{CP}^{Ks\pi 0\gamma} = -0.07 \pm 0.12$

HFAG, Summer'11

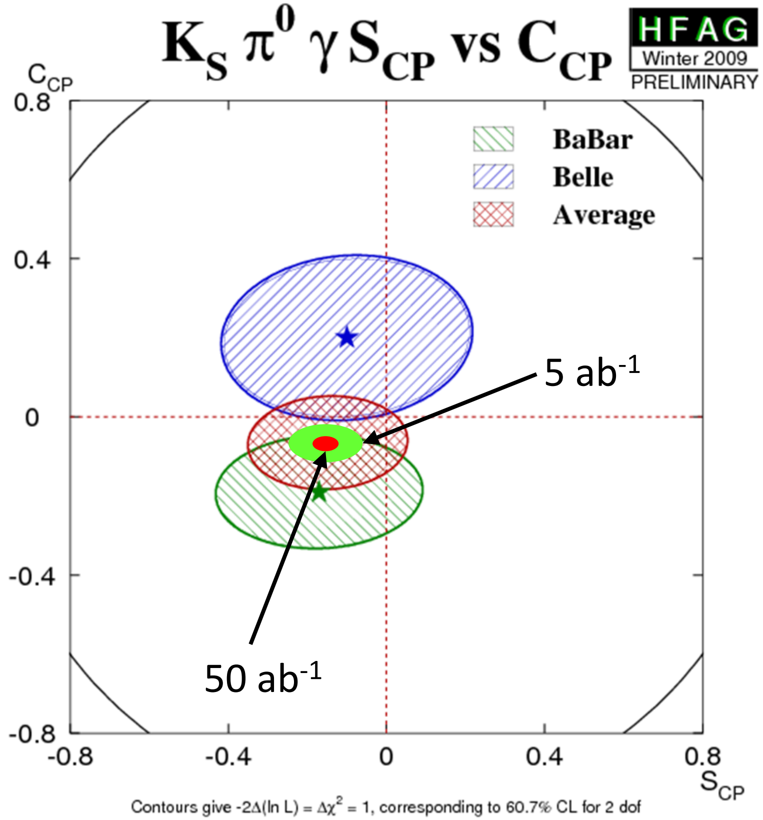
$\sigma(S_{CP}^{Ks\pi 0\gamma}) = 0.09$ @ 5 ab^{-1}

0.03 @ 50 ab^{-1}

(~SM prediction)

t-dependent decays rate of $B \to f_{CP}$;
S and A: CP violating parameters

$$P(B^0 \to f;\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}[1 + S_{CP}^f \sin(\Delta m \Delta t) + A_{CP}^f \cos(\Delta m \Delta t)]$$



Complementarity

Super B Factories/LHC

one example:

LHC: search for $H^{\pm}$ (MSSM);

$H^{\pm} \to tb,\ t \to b\ell\nu$

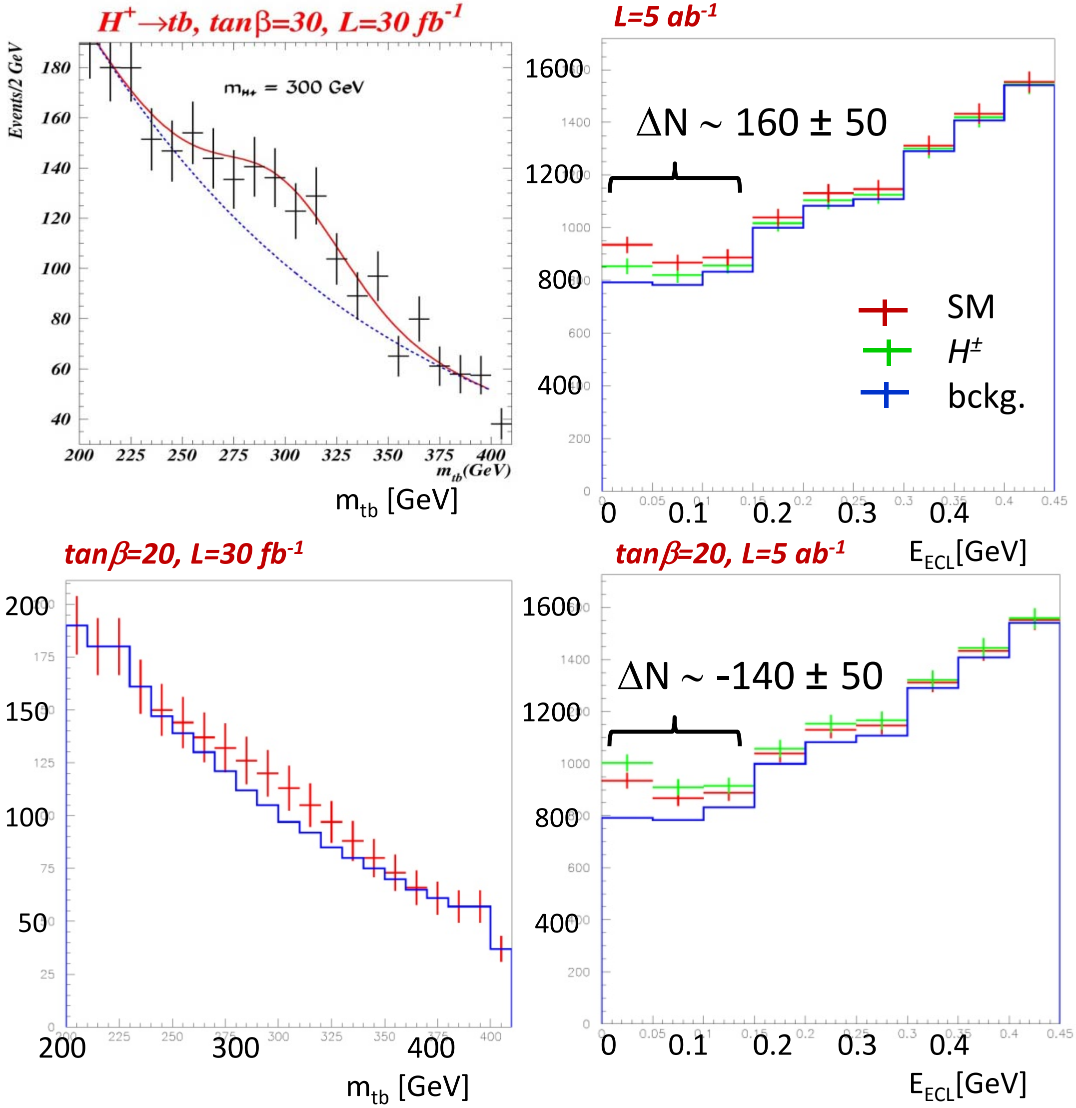
signal of $H^{\pm}$ with m_H=300 GeV/c^2 and $\tan\beta$=30;

Super B factories: verification if signal indeed from $H^{\pm}$: contribution of $H^{\pm}$ to $\mathcal{B}(B \to \tau\nu)$

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

Atlas, reconstructed $H^{\pm}$ mass

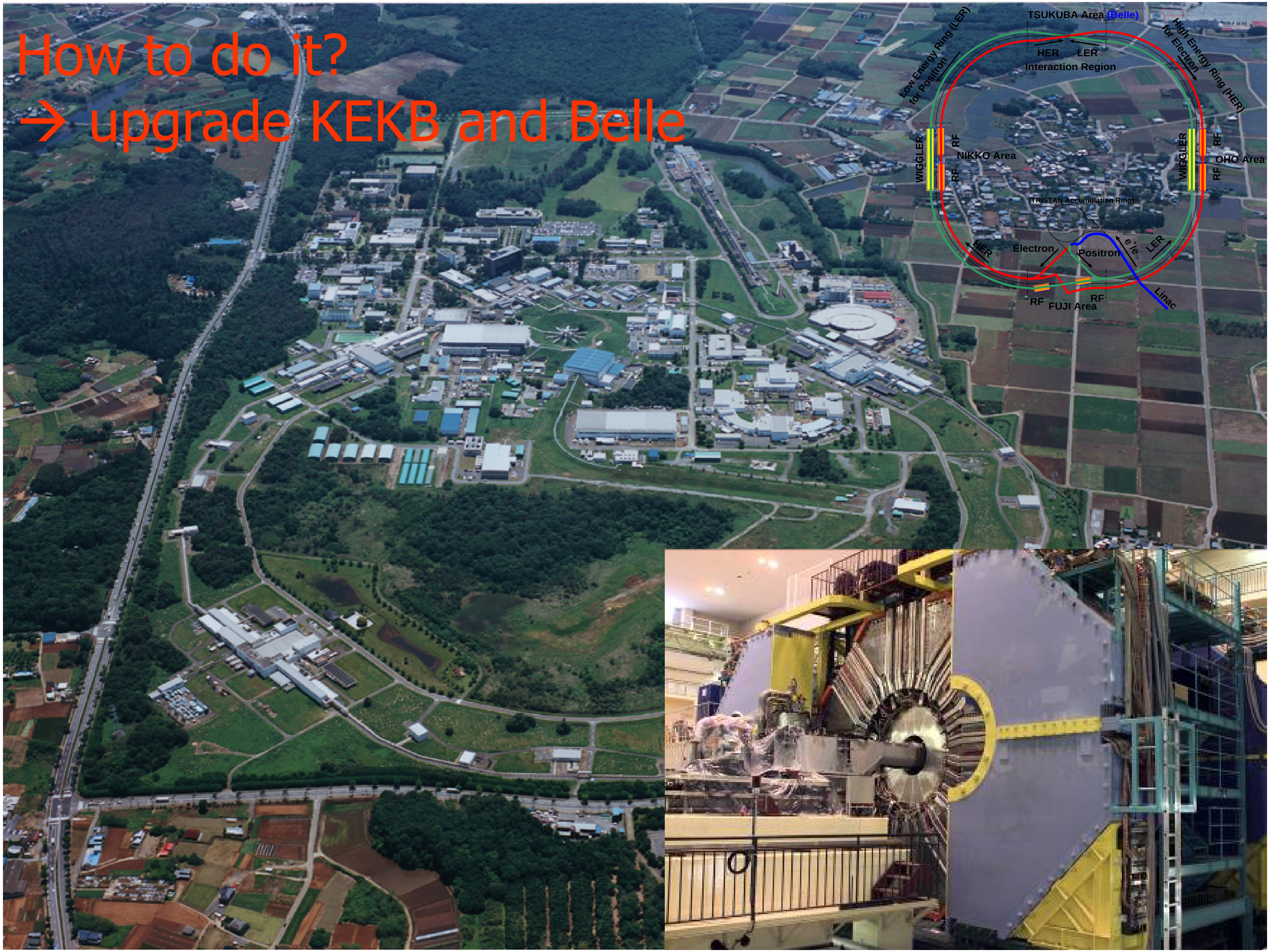
Belle II, E_{ECL} in $B \to \tau\nu$



Physics at a Super B Factory

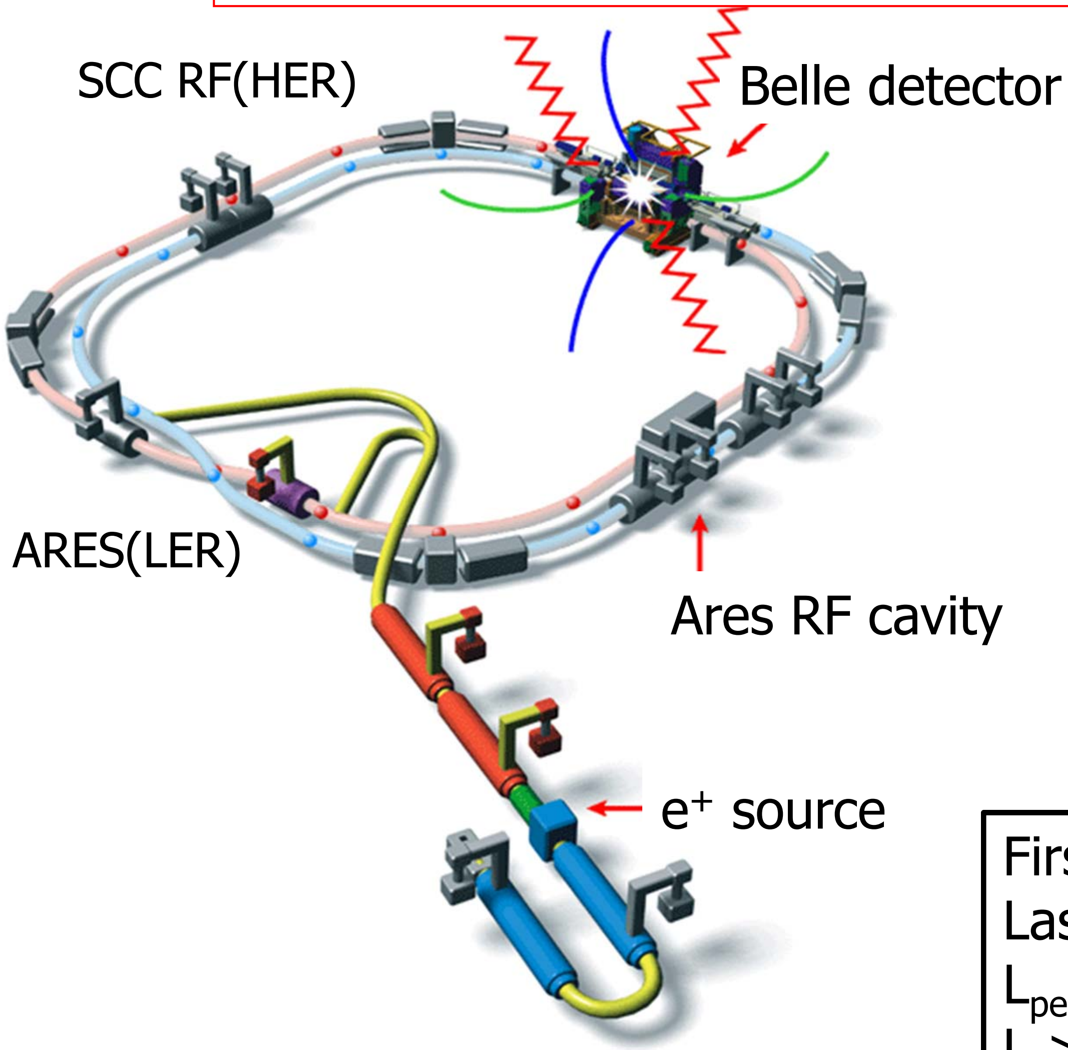
- There is a good chance to see new phenomena;
  - **CPV in B decays from the new physics (non KM).**
  - **Lepton flavor violations in τ decays.**
- They will help to diagnose (if found) or constrain (if not found) new physics models.
- $B \rightarrow \tau\nu$, $D\tau\nu$ can probe the charged Higgs 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

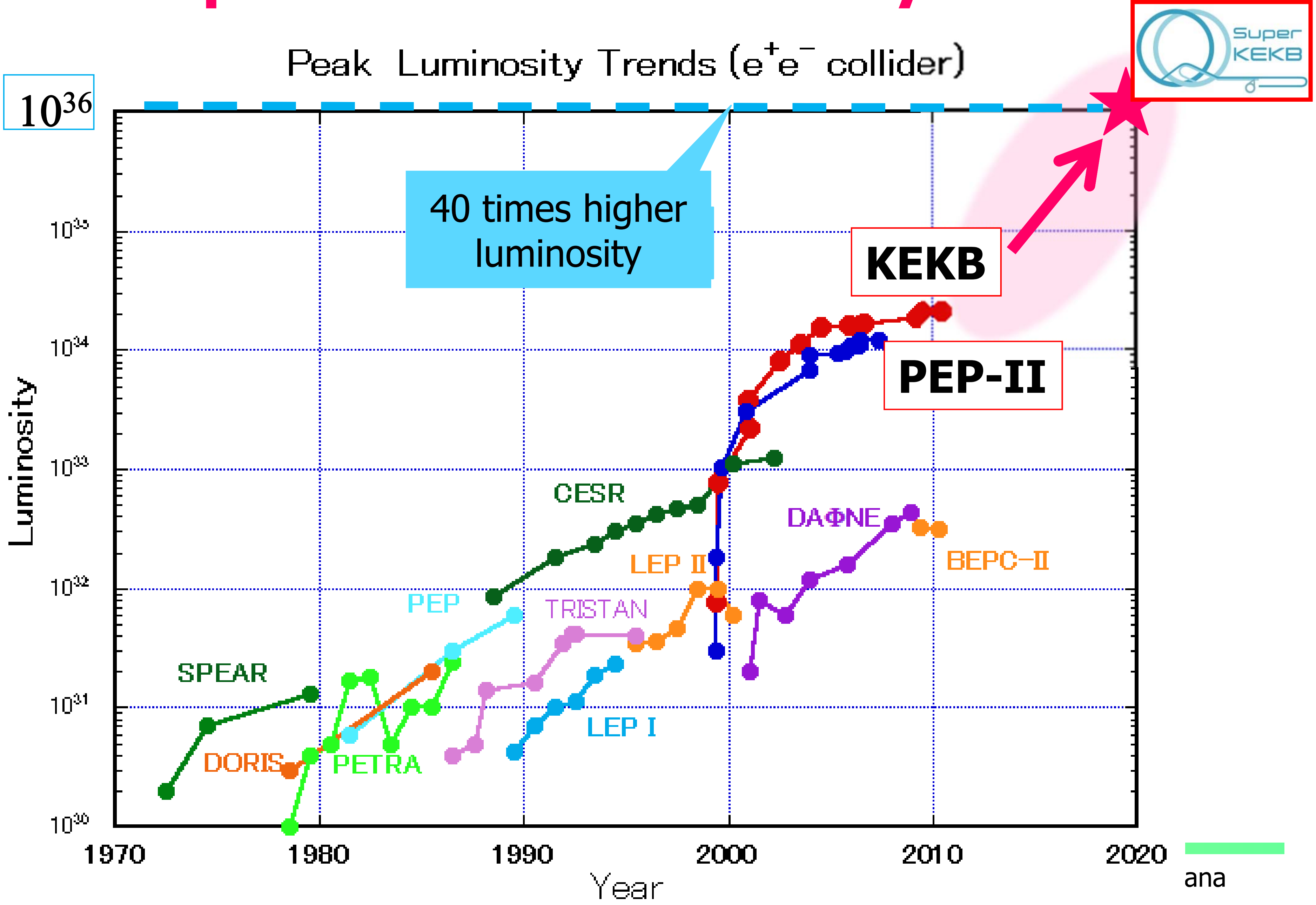
Peak luminosity (WR!) :

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} = 2.1x10^{34}/cm^2/s
L > 1ab^{-1}

SuperKEKB is the intensity frontier



How to increase the luminosity?

Beam-beam parameter

Lorentz factor

Beam current

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

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

Classical electron radius

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

Vertical beta function@IP

(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y

"Nano-Beam" scheme

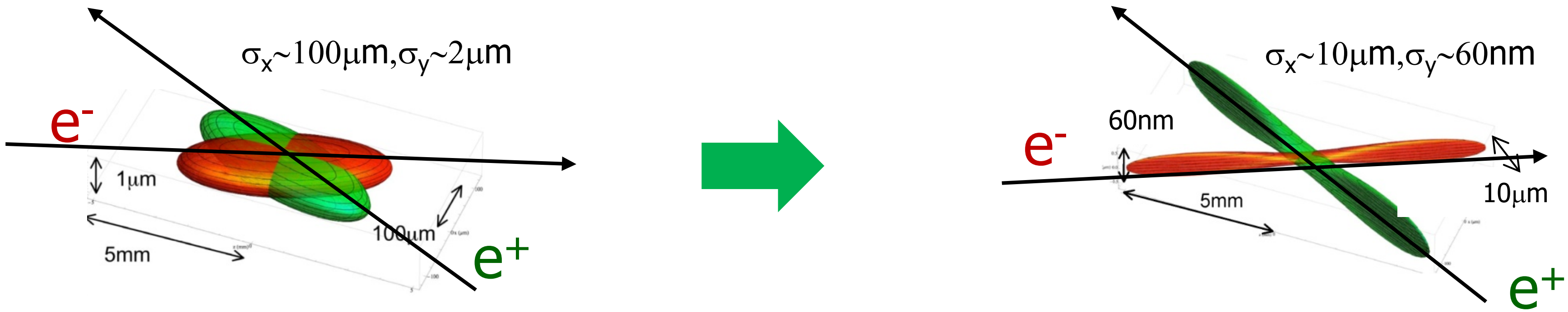
Collision with very small spot-size beams

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 x 100 atomic layers!

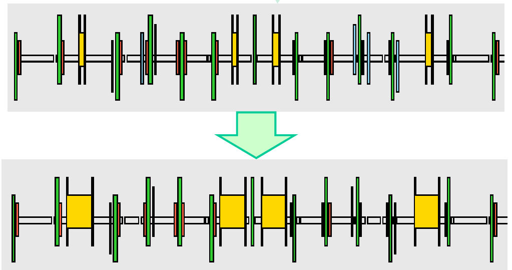
Machine design parameters

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	5.0	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 short lifetime for LER

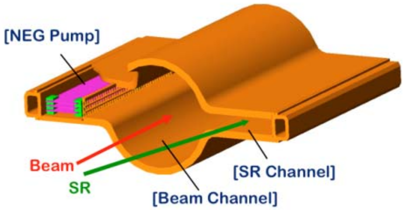
KEKB to SuperKEKB

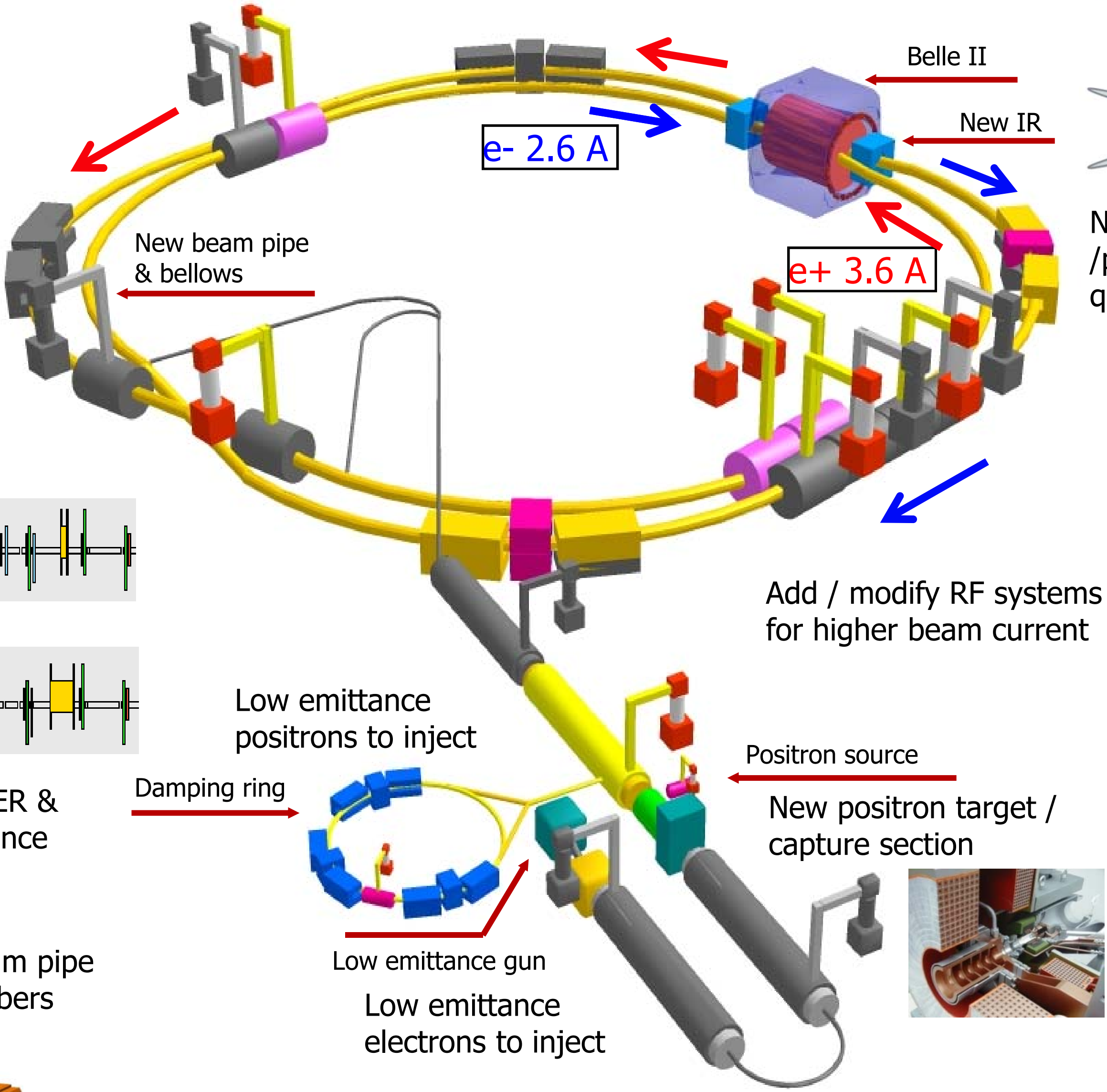
Replace short dipoles with longer ones (LER)



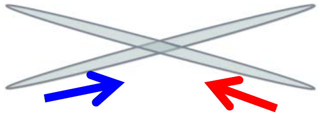
Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers

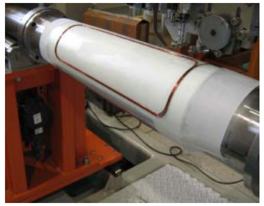




Colliding bunches



New superconducting /permanent final focusing quads near the IP



Add / modify RF systems for higher beam current

New positron target / capture section

To get x40 higher interaction rate

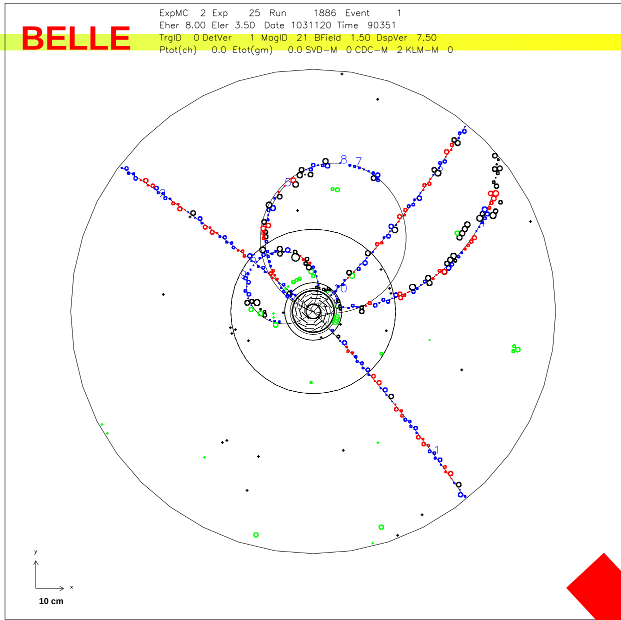
1st installation of the SuperKEKB magnet on Feb. 7 2012.

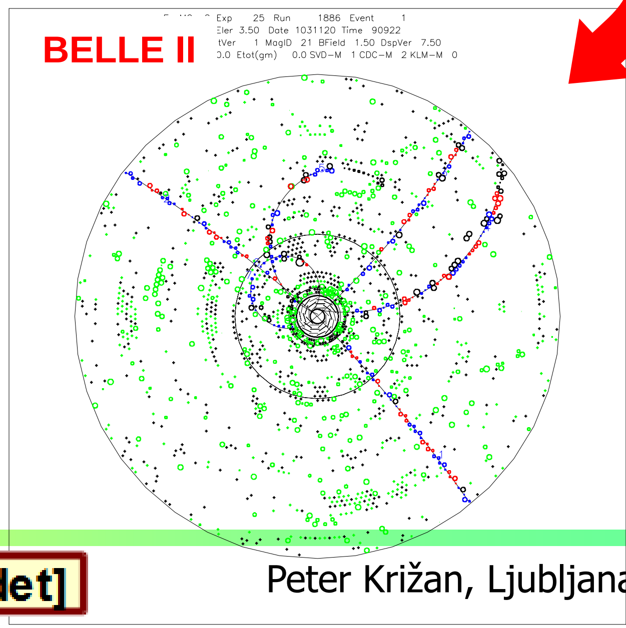
- The main purpose of this installation was to debug the tools and methods for installing the 4 m LER dipole over the 6 m HER dipole (remain in place).
- Installed 2 dipole magnets. The rest of the LER dipoles are scheduled to be installed this year.

Need to build a new detector to handle higher backgrounds

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”

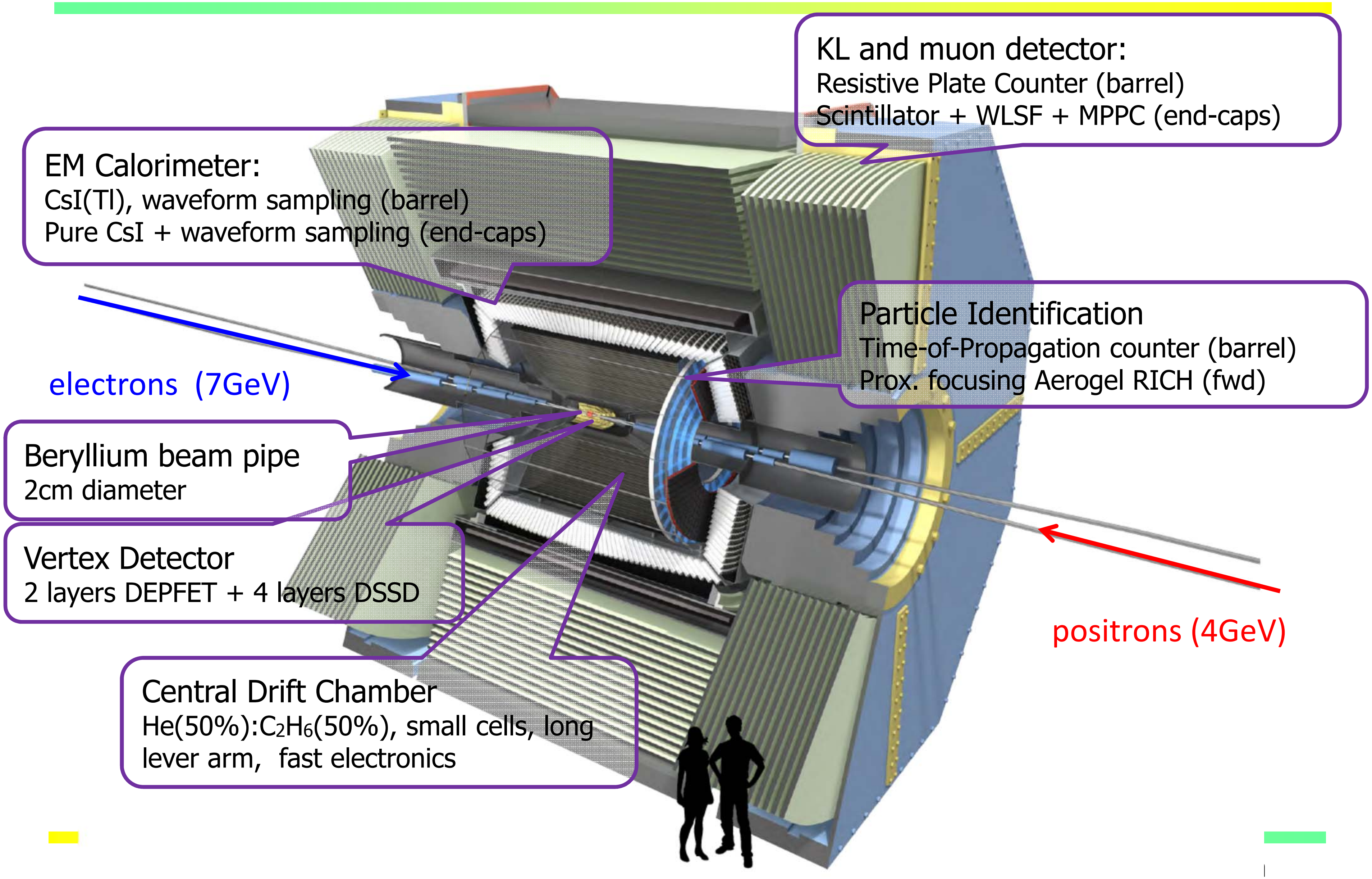




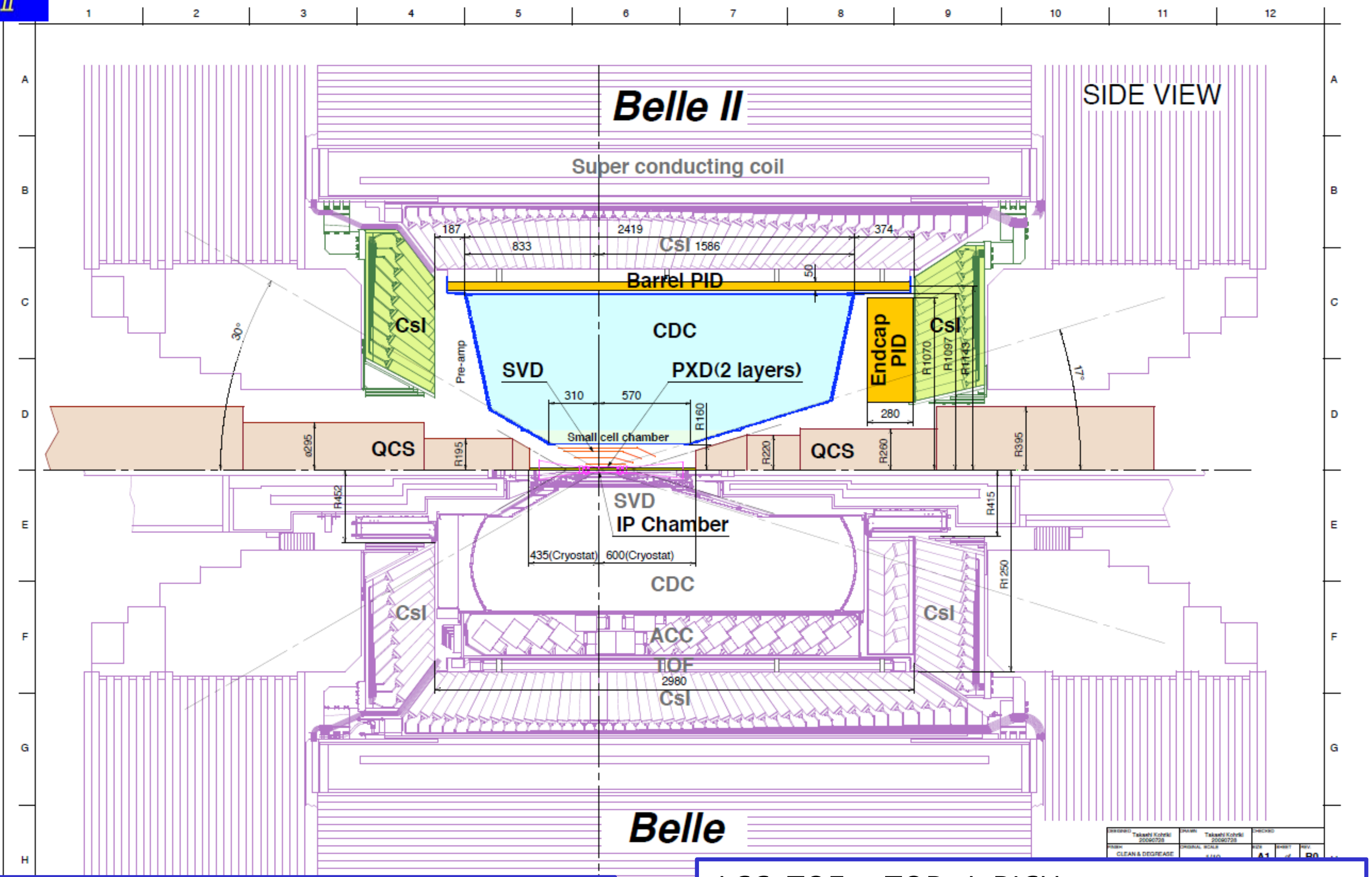
Have to employ and develop new technologies to make such an apparatus work! →

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

Belle II Detector



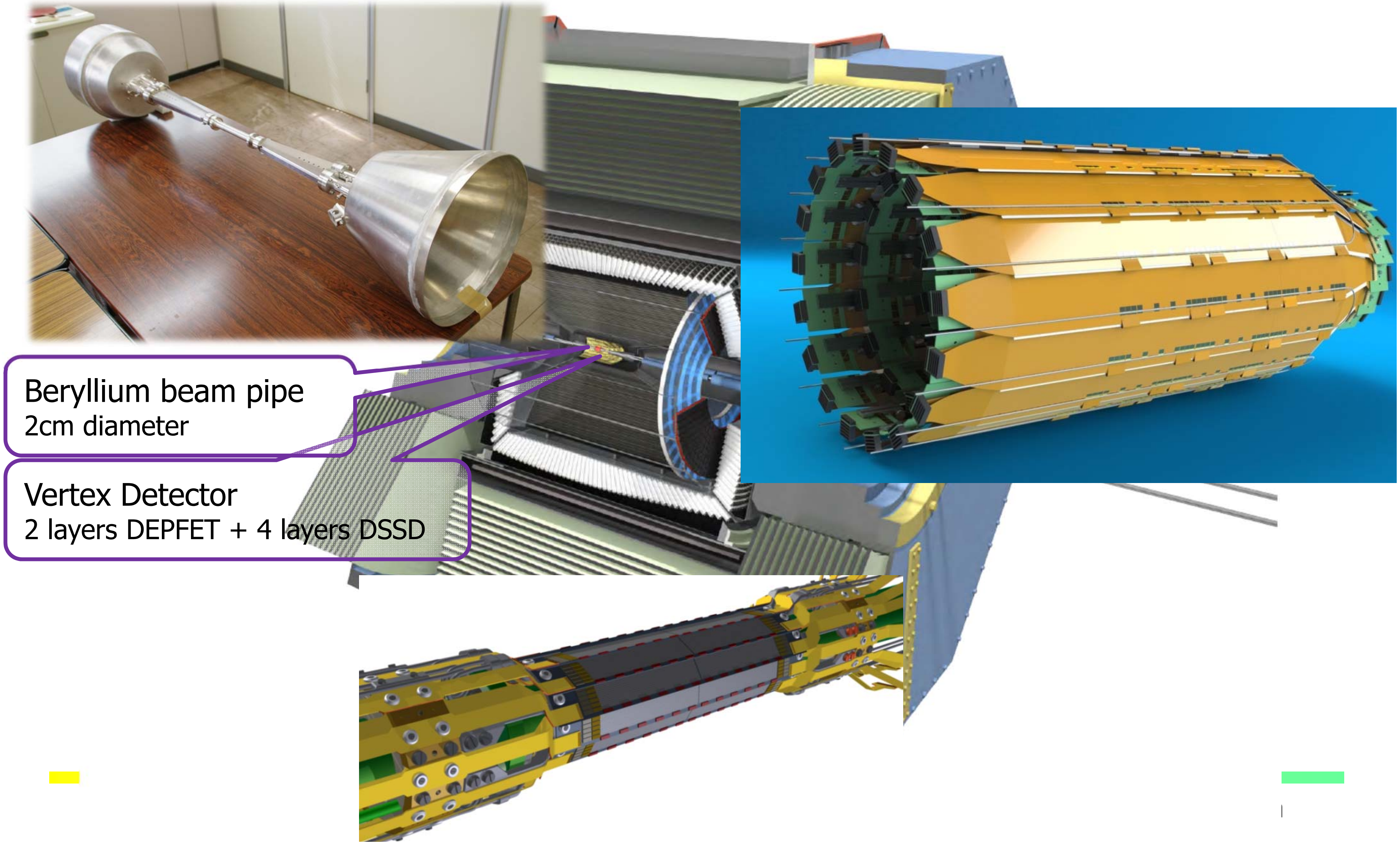
Belle II (top) compared with Belle (bottom)



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

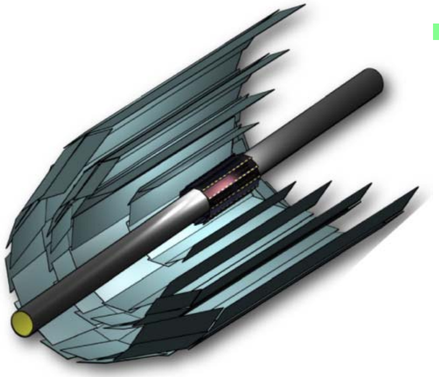
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

Belle II Detector – vertex region

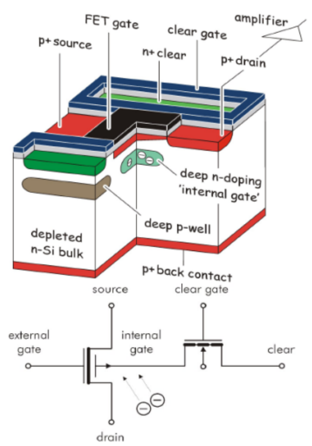


Vertex Detector

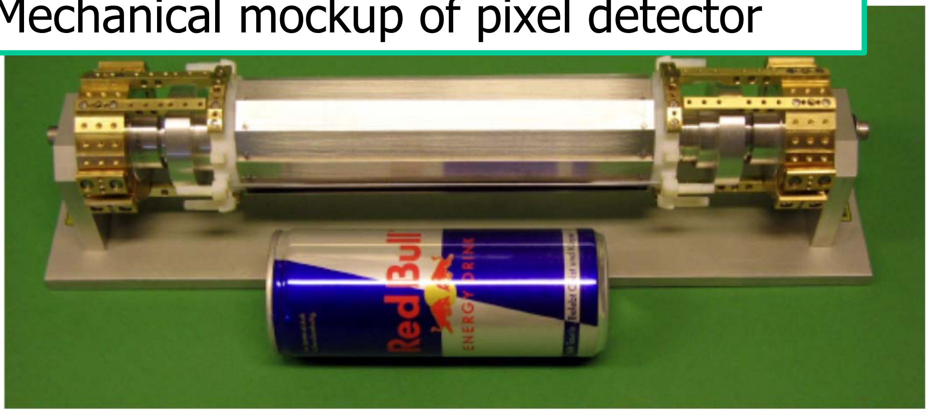
DEPFET:
http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome

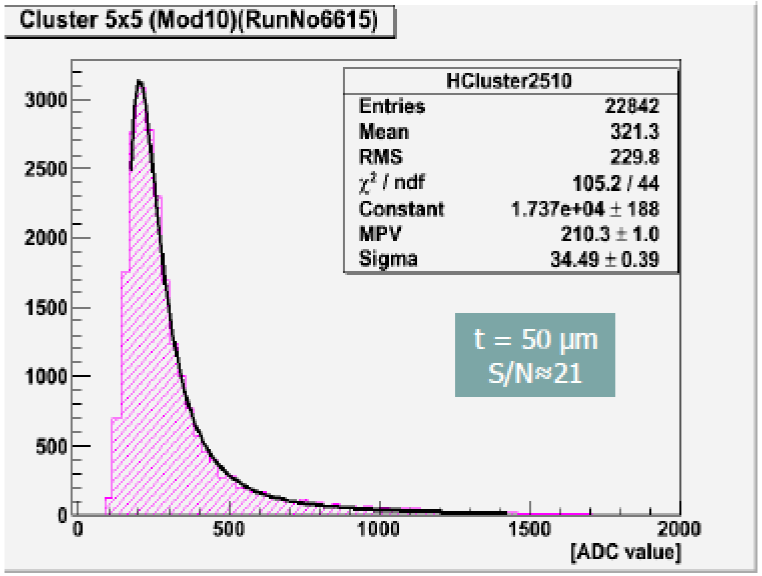


Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**

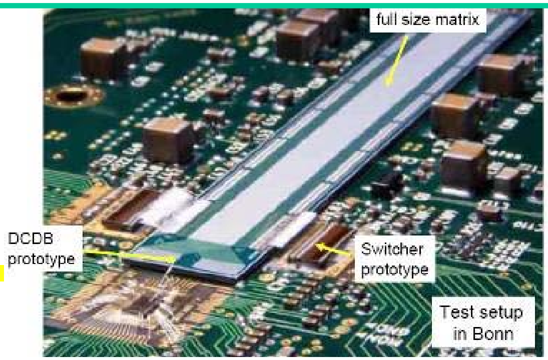


Mechanical mockup of pixel detector





Prototype DEPFET pixel sensor and readout



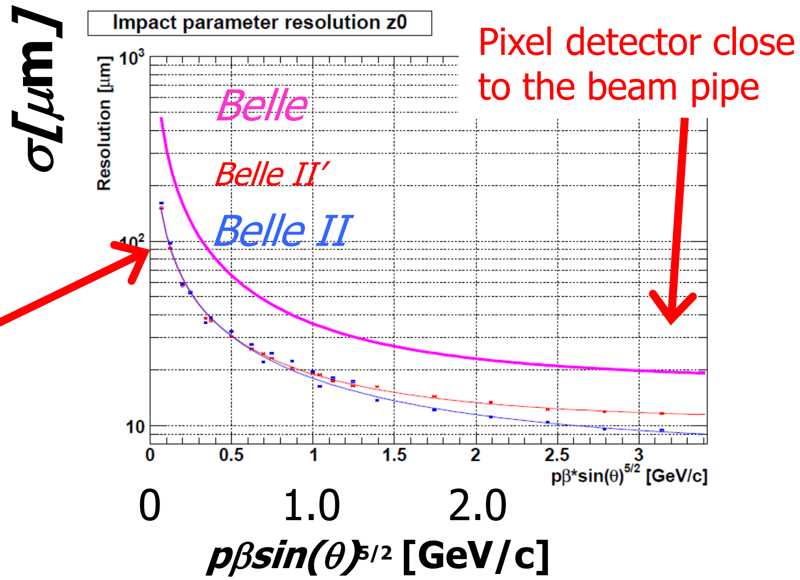
DEPFET sensor: very good S/N

Important contribution from Valencia!

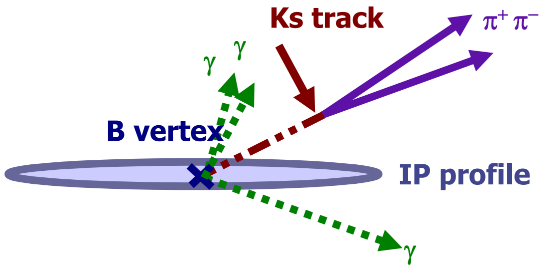
Expected performance

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

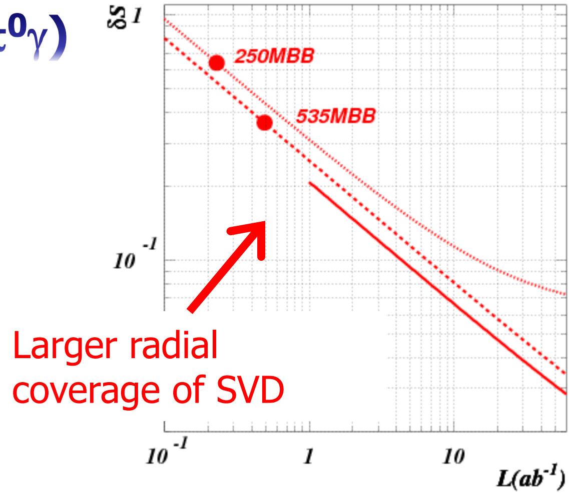
Significant improvement in vertex resolution!



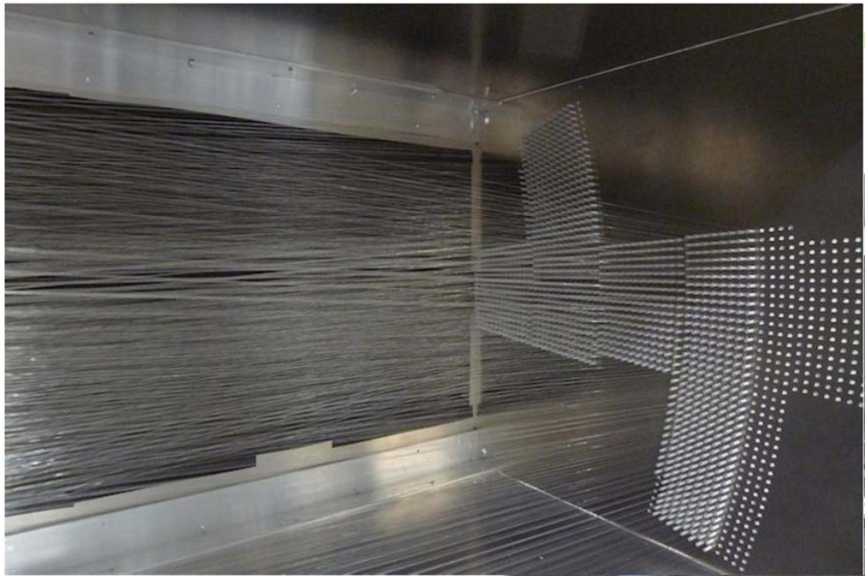
Significant improvement in $\delta S(K_S\pi^0\gamma)$

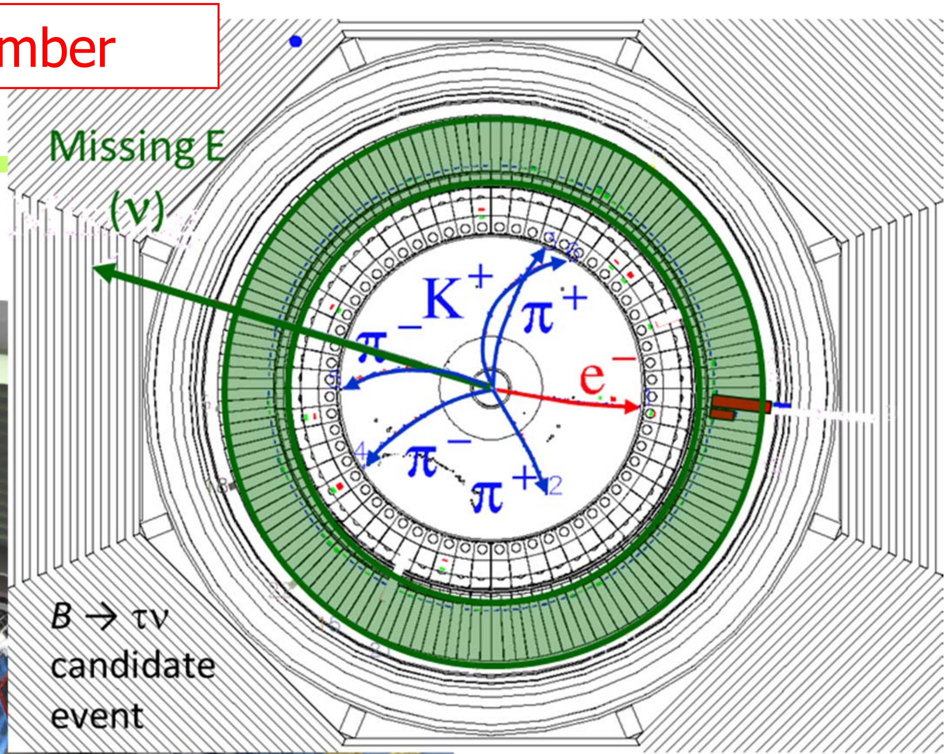


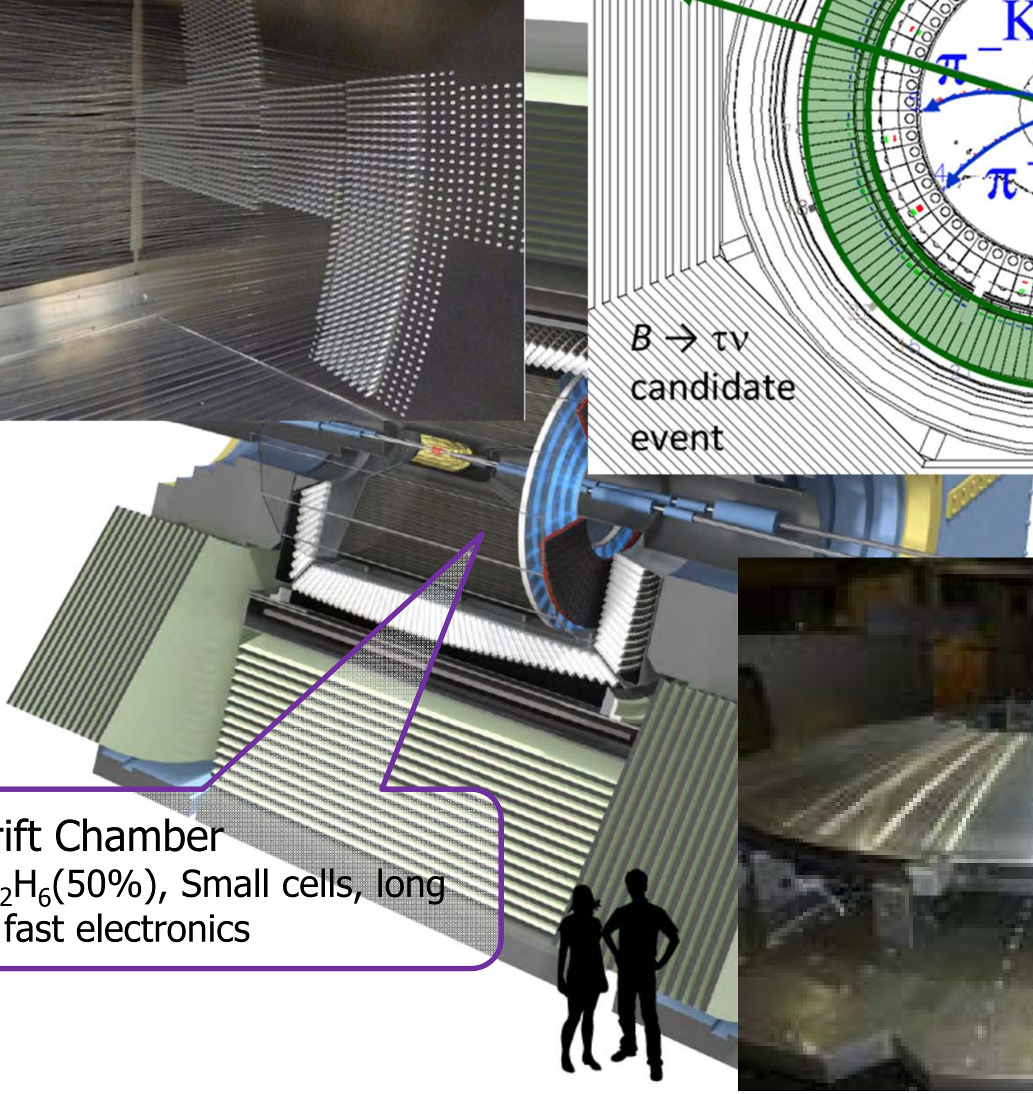
B decay point reconstruction with K_S trajectory



Main tracking device: small cell drift chamber

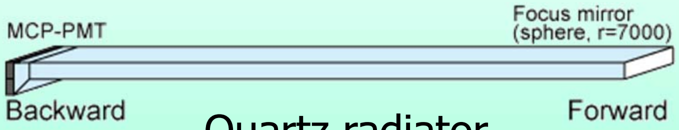






Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



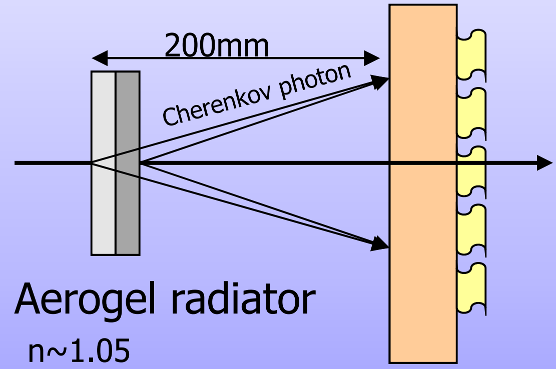
Quartz radiator

Focusing mirror

Small expansion block

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

Endcap PID: Aerogel RICH (ARICH)

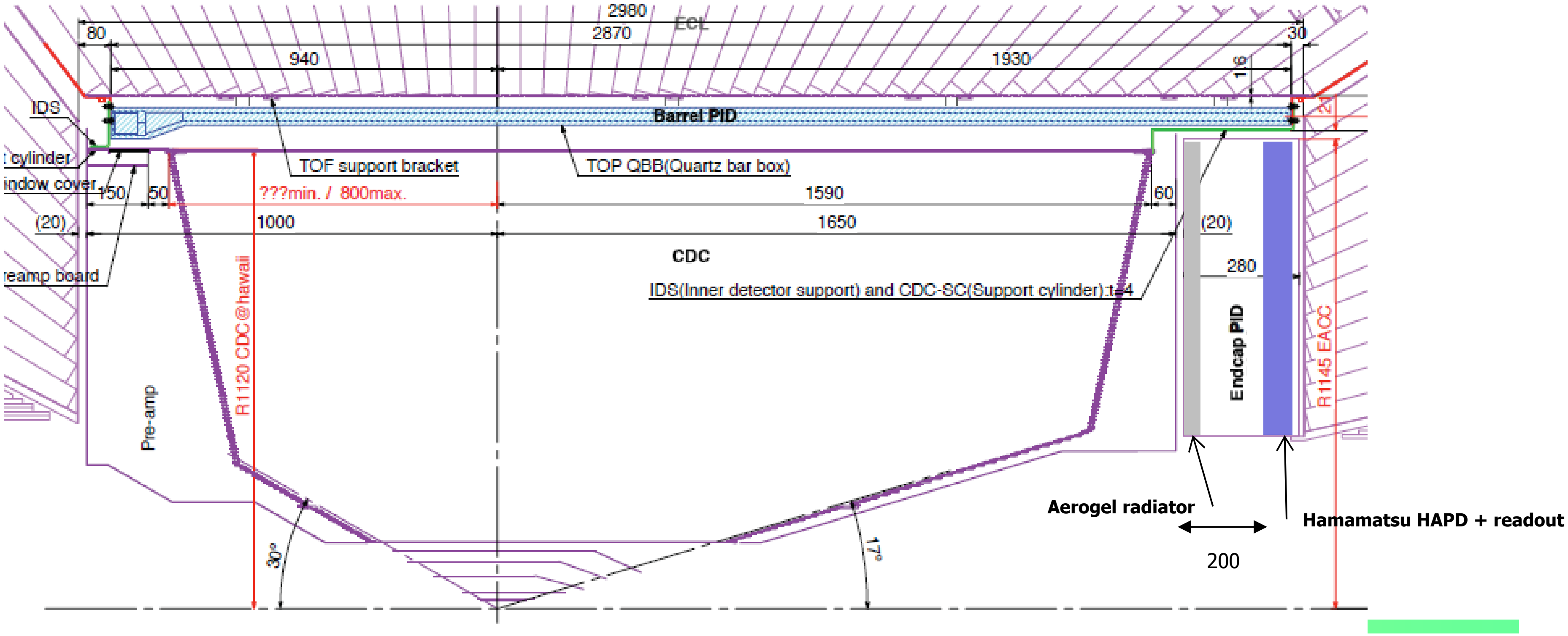


Aerogel radiator

n~1.05

Hamamatsu HAPD

+ new ASIC



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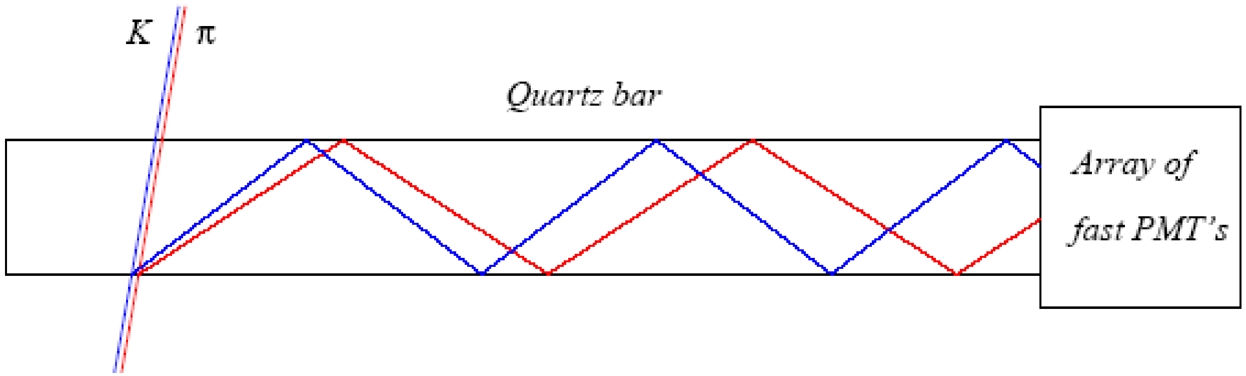
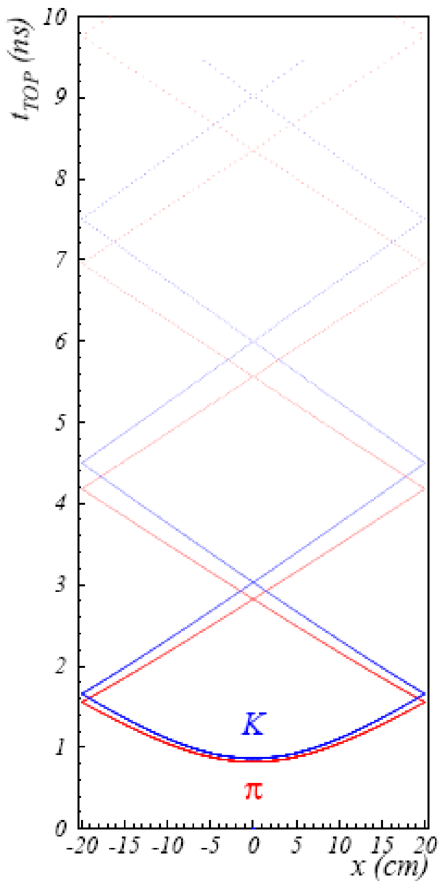
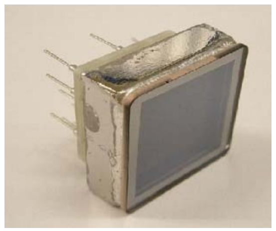
Barrel PID: Time of propagation (TOP) counter

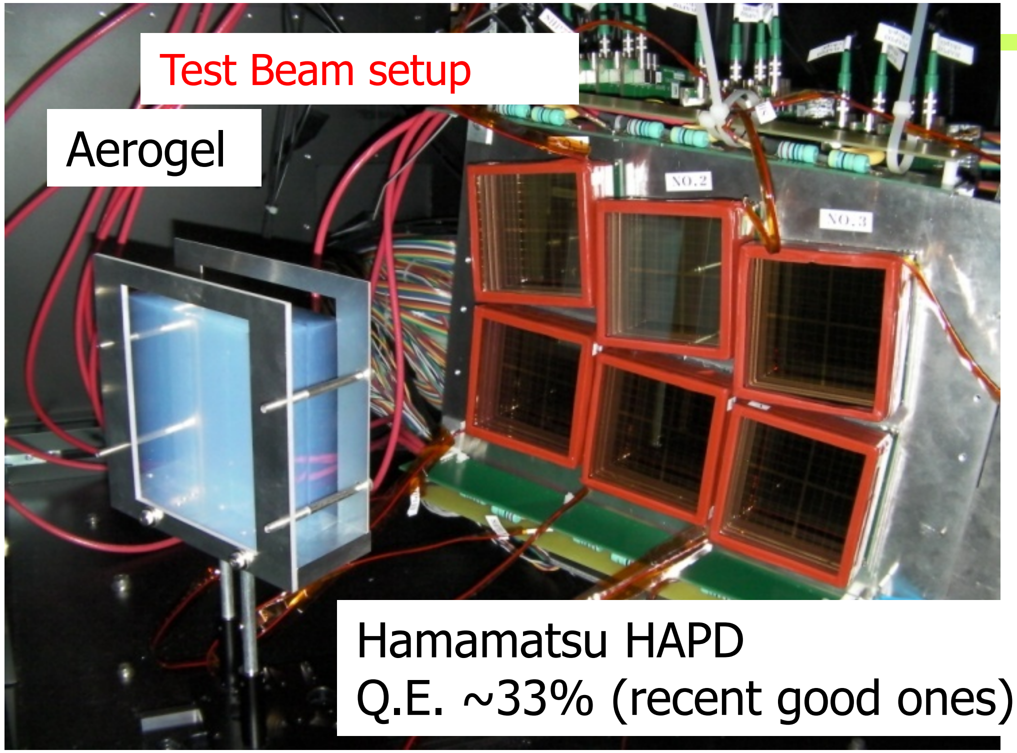


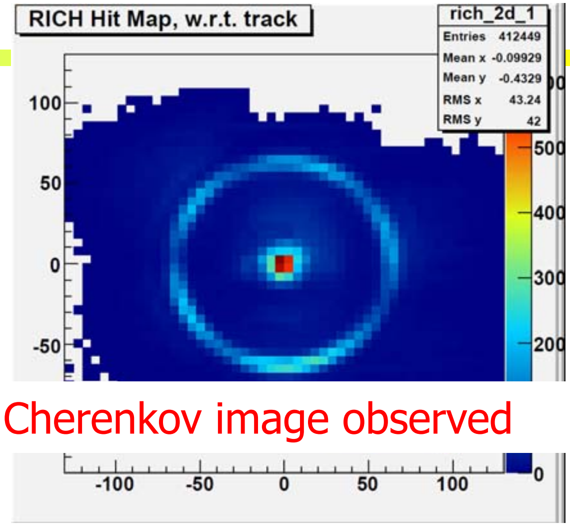


- Cherenkov ring imaging with precise time measurement.
- Use 2cm thick quartz bars – similar to BaBar DIRC counter.
- Reconstruct Cherenkov angle from two hit coordinates and the time of propagation of the photon
  - Quartz radiator (2cm)
  - Photon detector (MCP-PMT)
    - Good time resolution ~ 40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



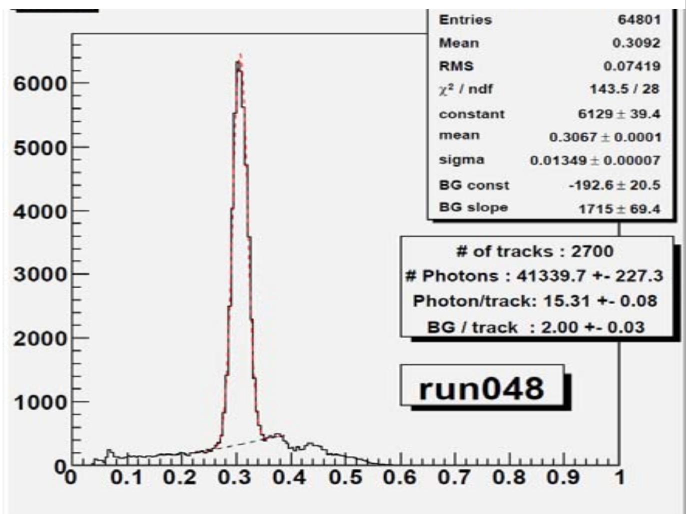
Aerogel RICH (endcap PID)





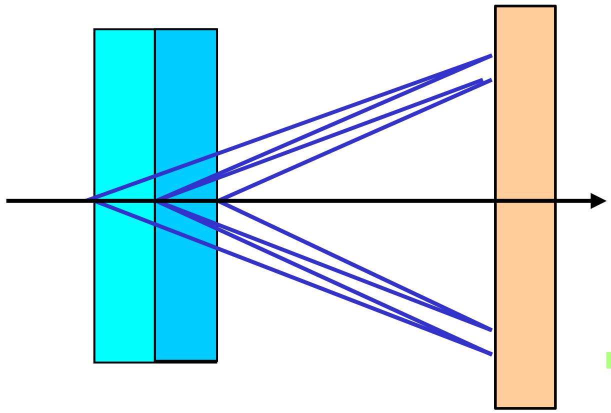
Clear Cherenkov image observed

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 !

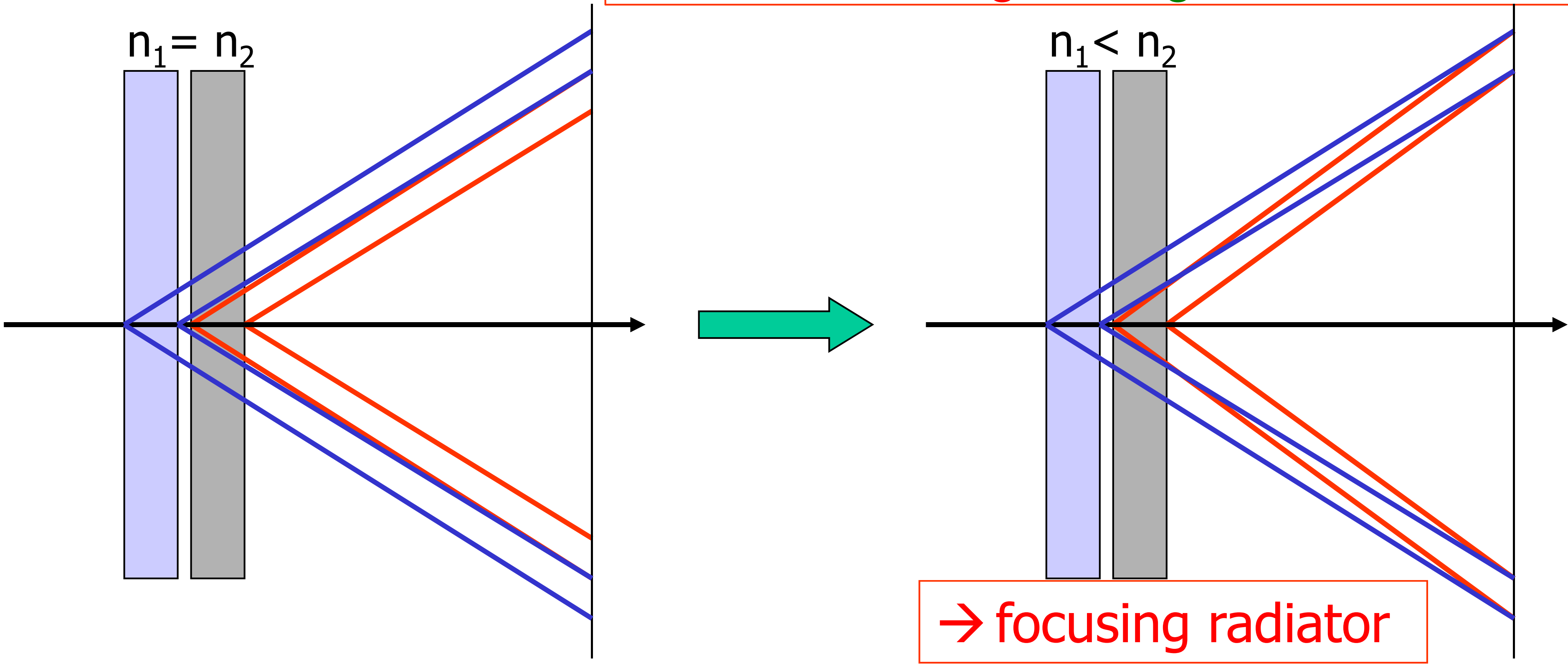
Peter Križan, Ljubljana

Radiator with multiple refractive indices

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

normal

→ stack two tiles with different refractive indices: "focusing" configuration

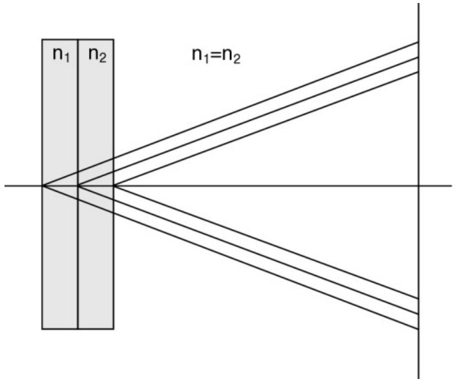


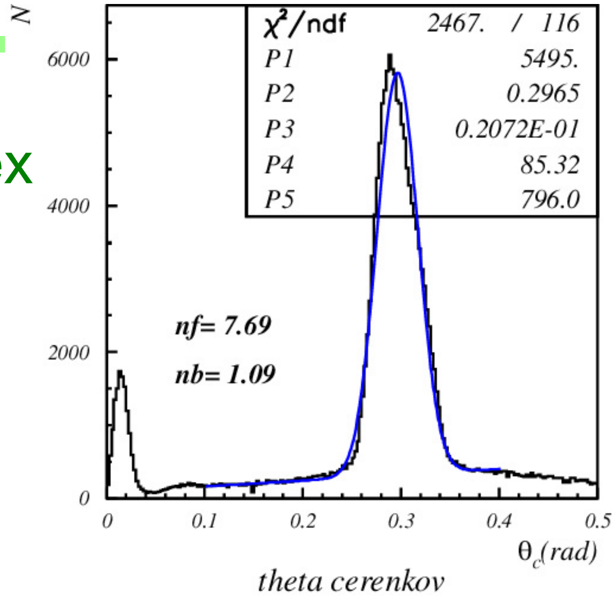
→ focusing radiator

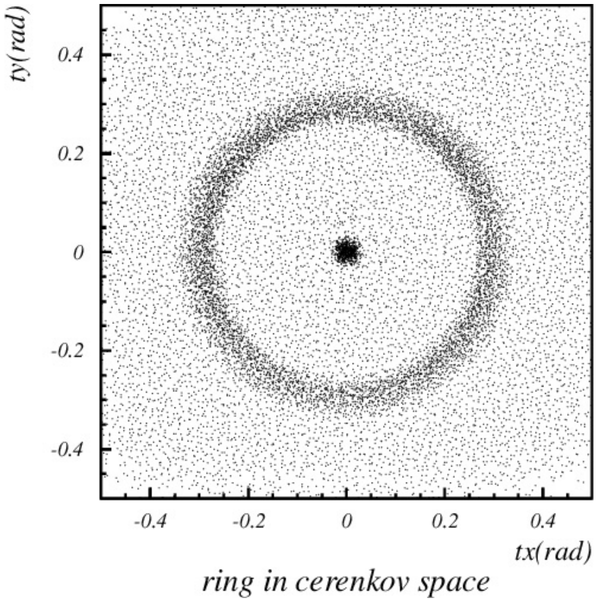
Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

Focusing configuration – data

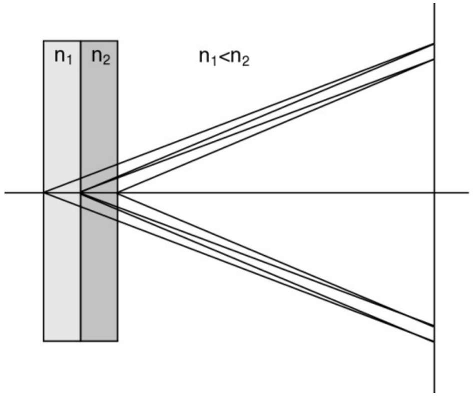
4cm aerogel single index

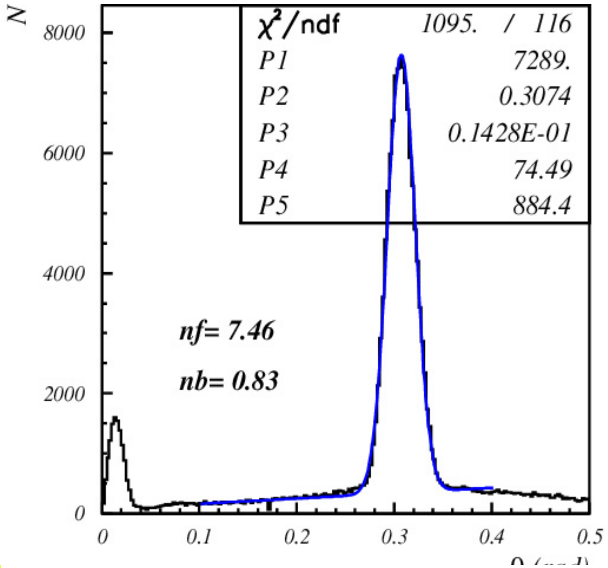


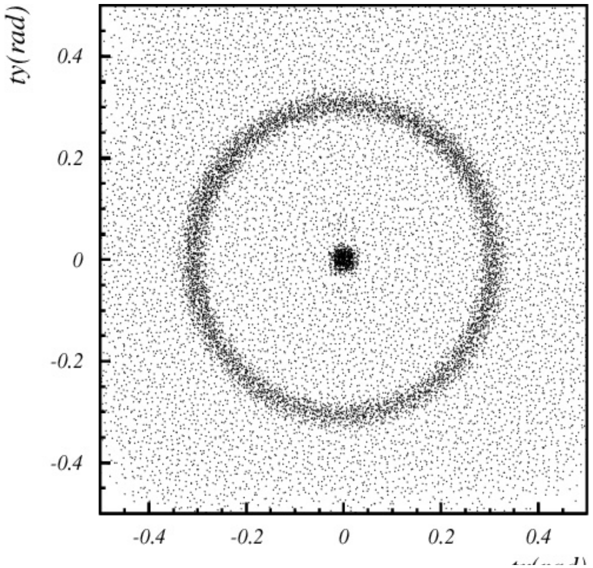




2+2cm aerogel



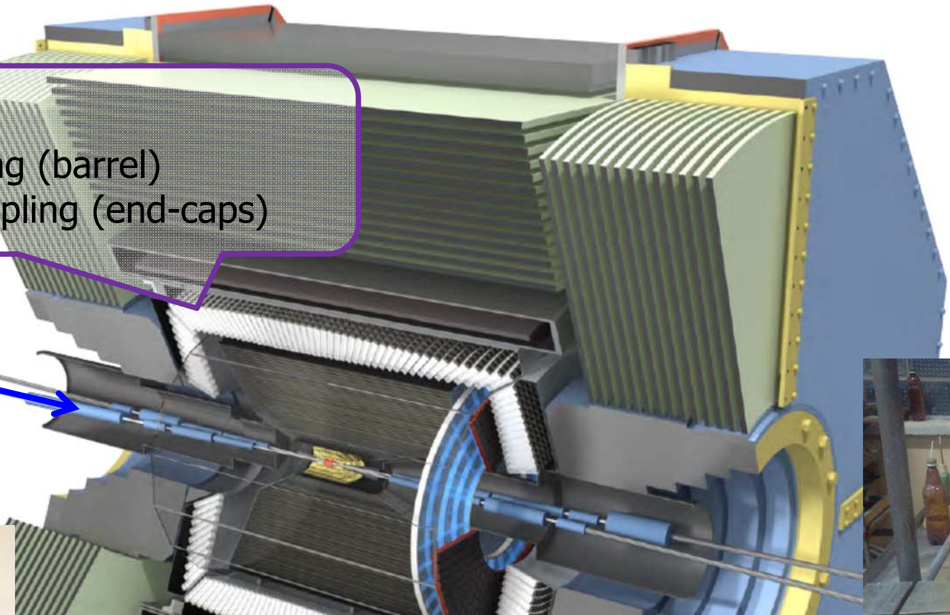


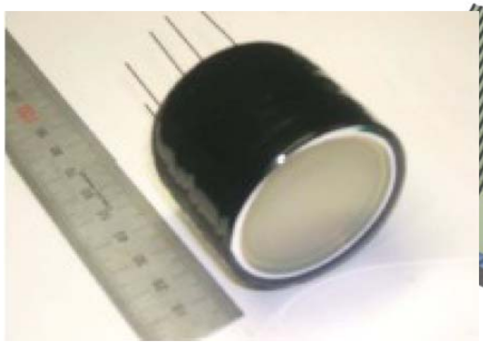


→NIM A548 (2005) 383

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

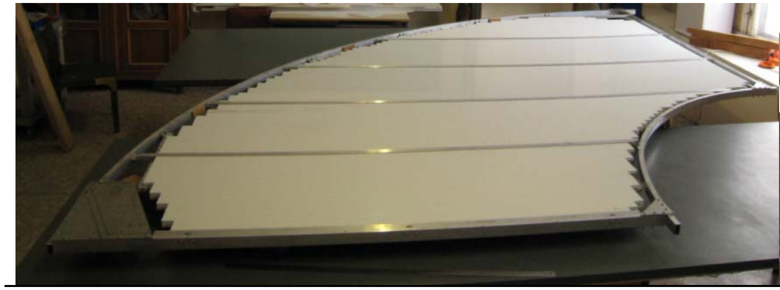
EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

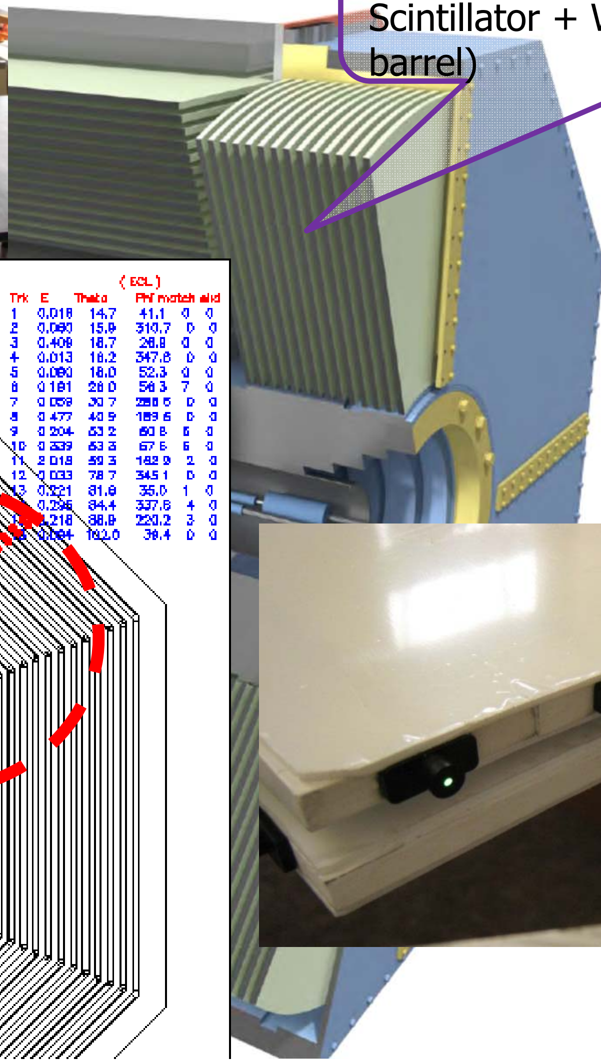


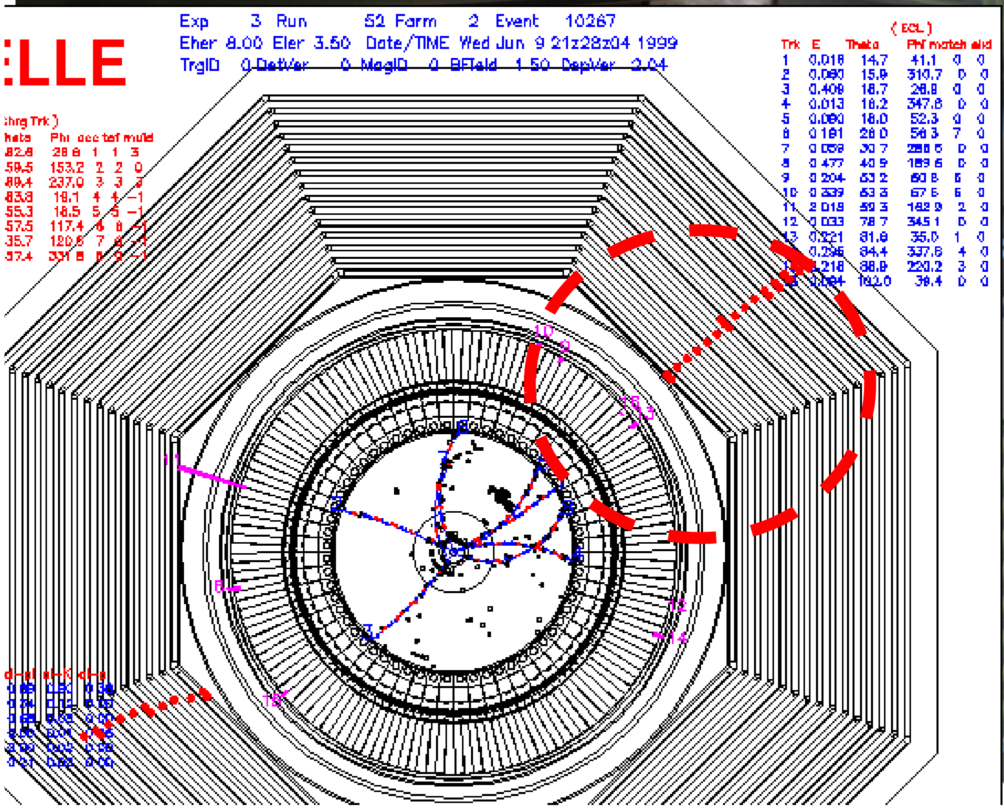


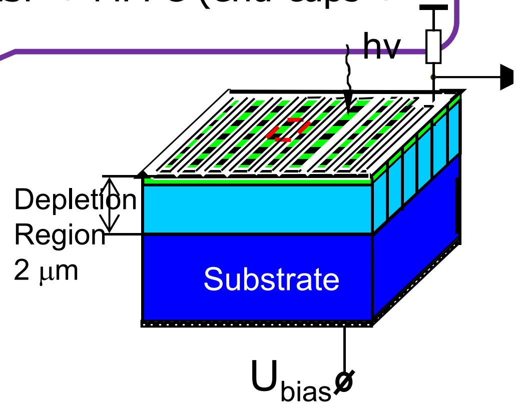
Detection of muons and KLs: parts of the present RPC system has to be replace because it cannot handle the high background rates (mainly neutrons)

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







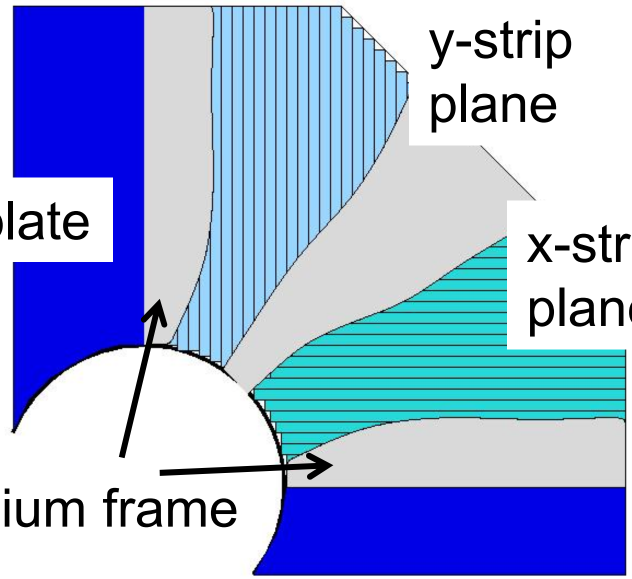


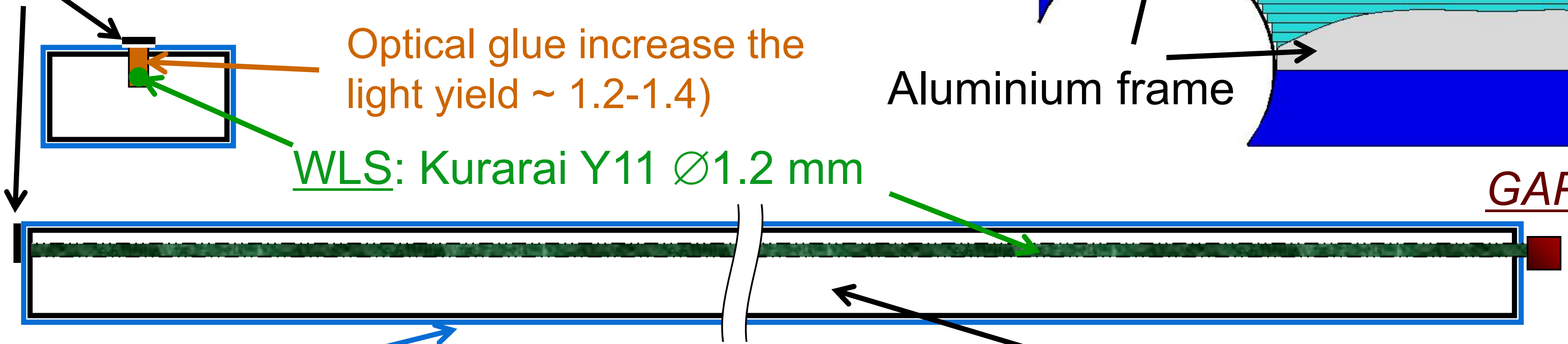
ljana

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 comes from Europe:
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 was finally 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:

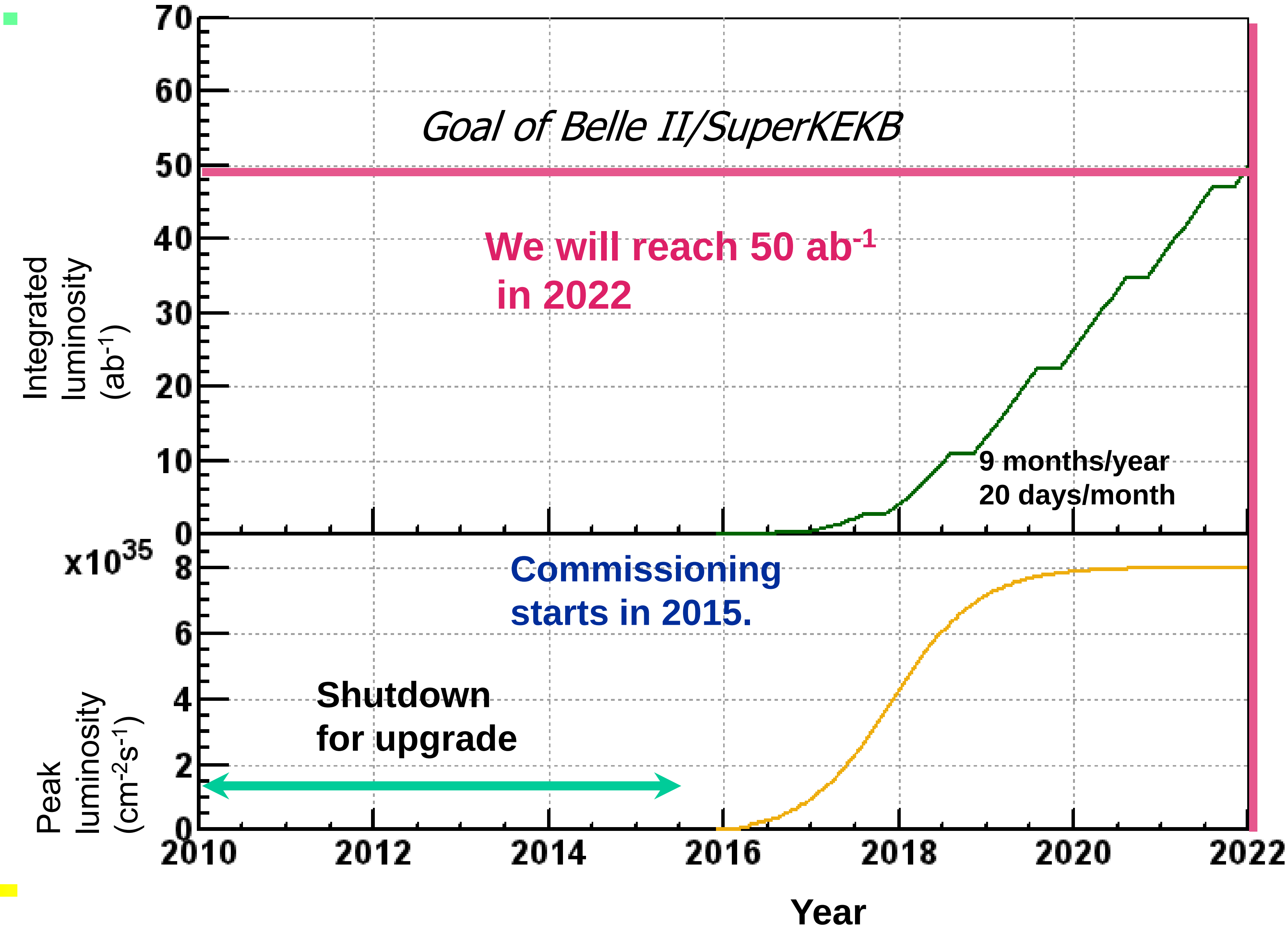
- KEKB stopped operation in July 2010, and the low energy ring was to a large extent disassembled
- Belle was rolled out to the parking position in December 2010.

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, good competition with SuperB and complementary to the LHC