NOBEL SYMPOSIA

**Nobel Symposium on LHC results, Krusenberg, May 13-17, 2013**

# Flavour physics at B factories: status and outlook


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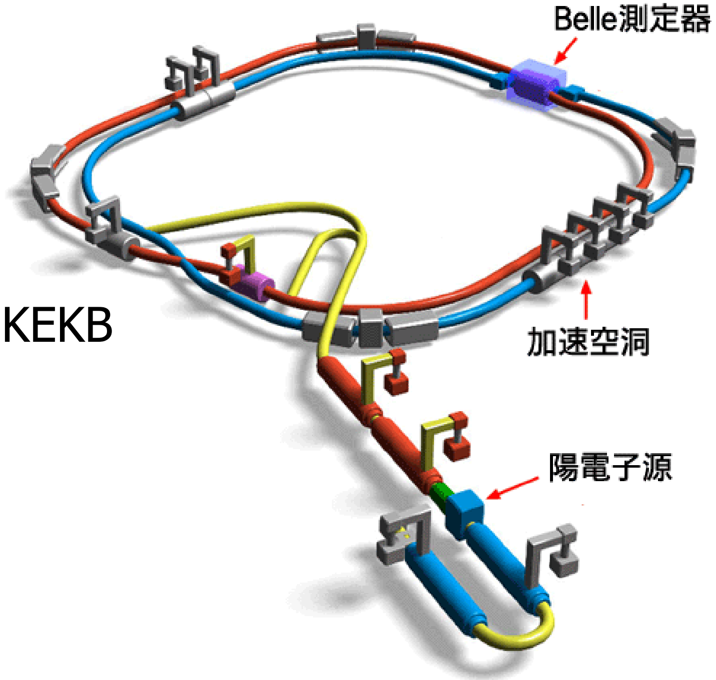
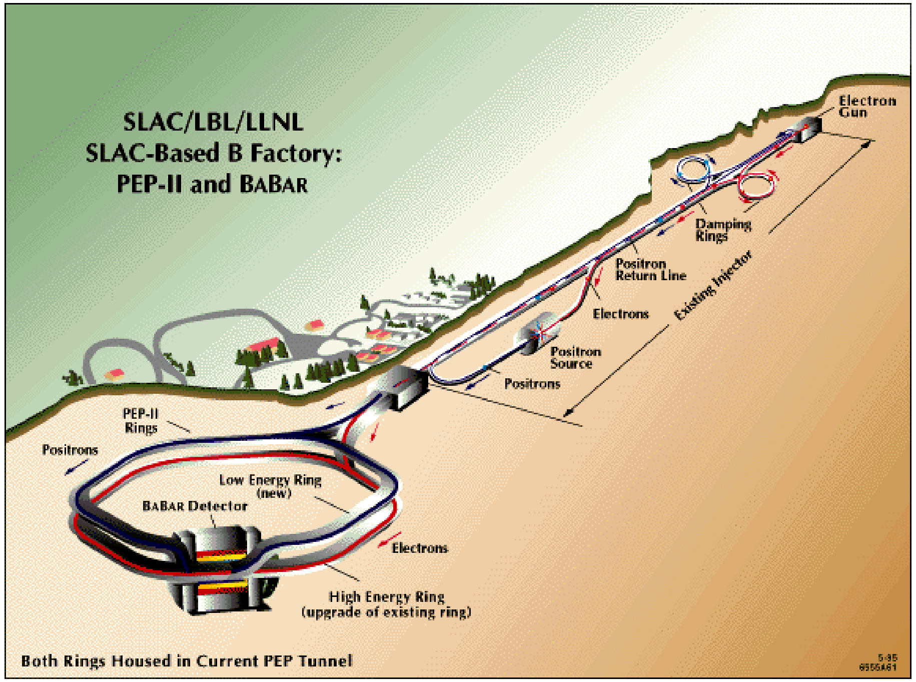
# Contents

- Introduction with a little bit of history
- B factories: recent results
- Super B factory: status and outlook
- Summary and the three questions

# Flavour physics at the luminosity frontier with asymmetric B factories




$\sqrt{s}=10.58$ GeV

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

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

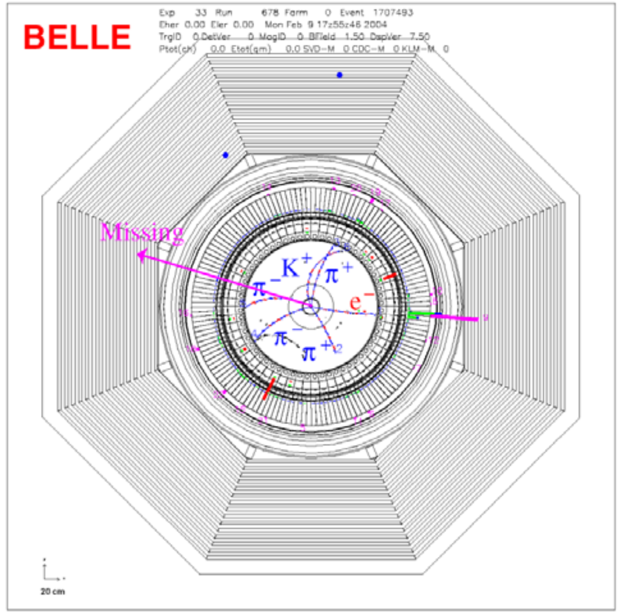
$\Delta z \sim c\beta\gamma\tau_B \sim 200\mu m$

| | | | |
|---|---|---|---|
| BaBar | $p(e^-)=9$ GeV | $p(e^+)=3.1$ GeV | $\beta\gamma=0.56$ |
| Belle | $p(e^-)=8$ GeV | $p(e^+)=3.5$ GeV | $\beta\gamma=0.42$ |

To a large degree shaped flavour physics in the previous decade

# Advantages of B factories in the LHC era

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




Unique capabilities of B factories:

→ Exactly two B mesons produced (at $\Upsilon(4S)$)

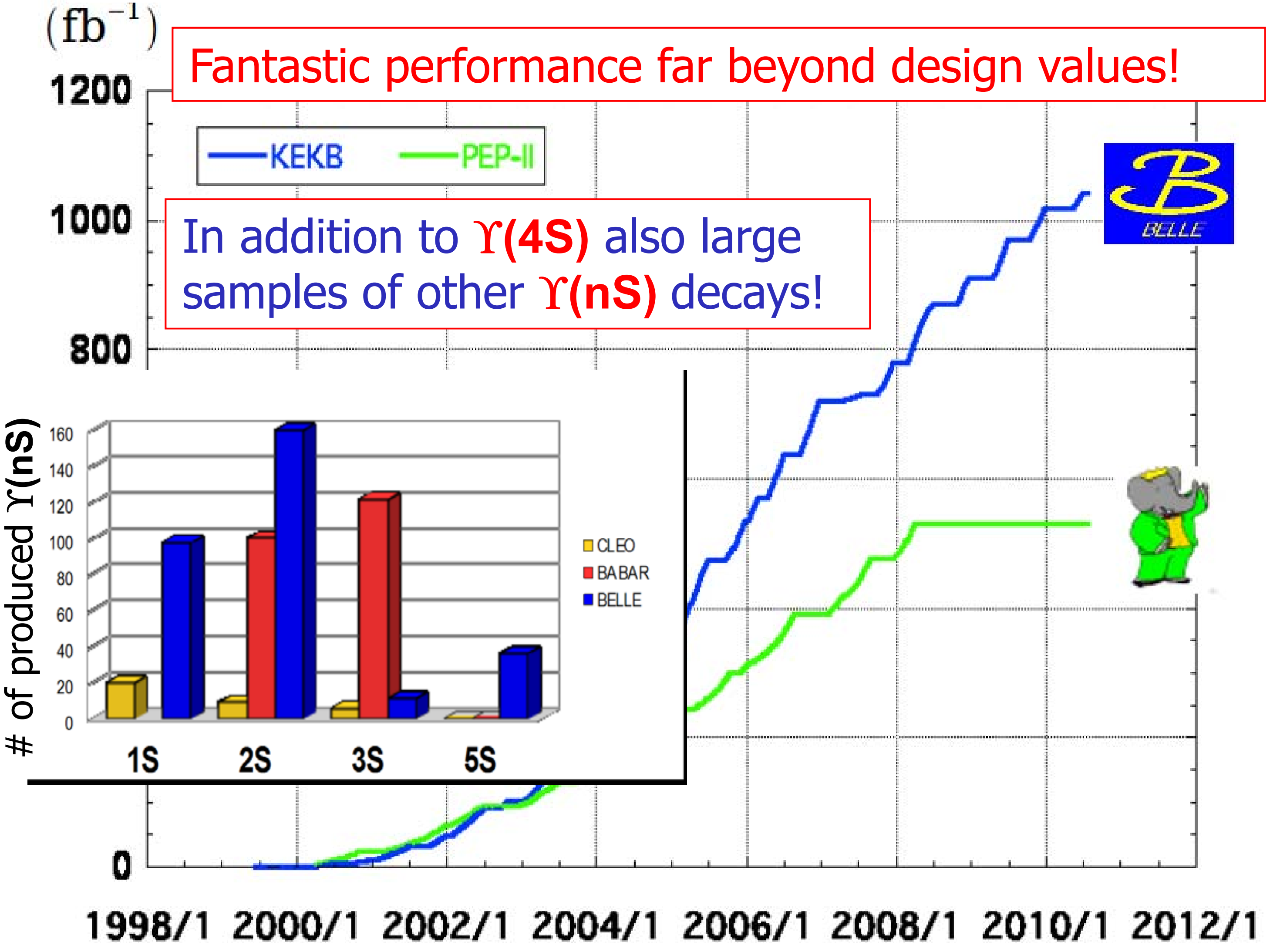
→ High flavour tagging efficiency

→ Detection of gammas, $\pi^0$s, $K_L$s

→ Very clean detector environment (can observe decays with several neutrinos in the final state!)

→ Well understood apparatus, with known systematics, checked on control channels

# 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 $fb^{-1}$

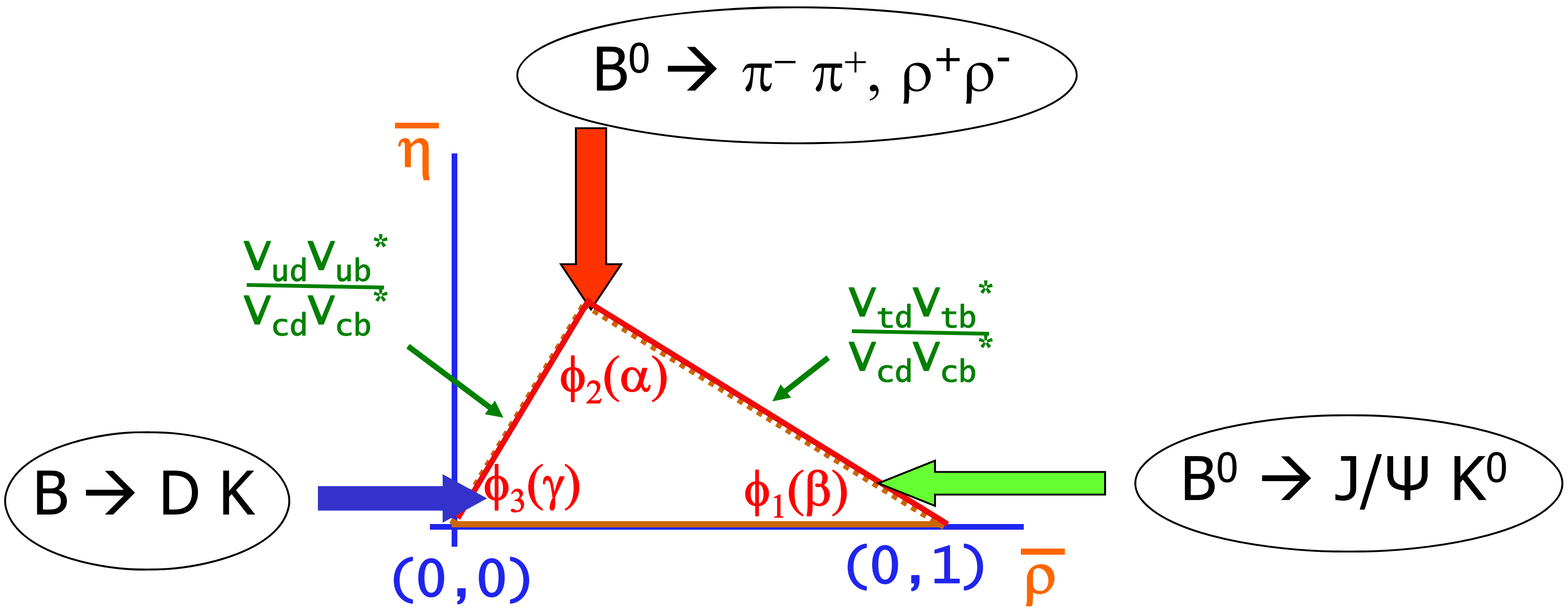
$\Upsilon(3S)$: 30 $fb^{-1}$

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

**Off resonance:**

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

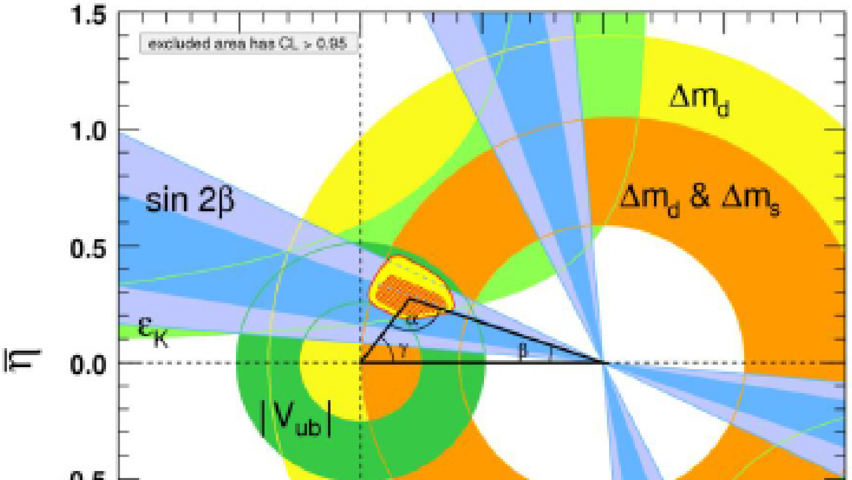
# CP violation in the B system and unitarity triangle



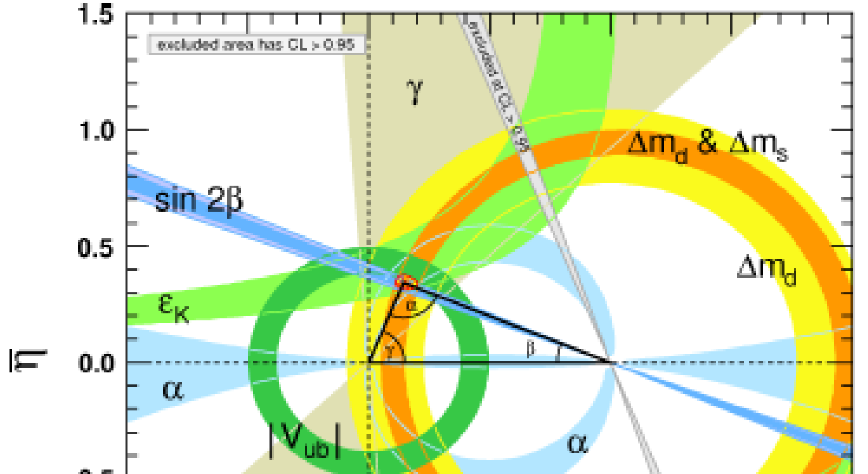
# B factories: CP violation in the B system

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

EPS 2001



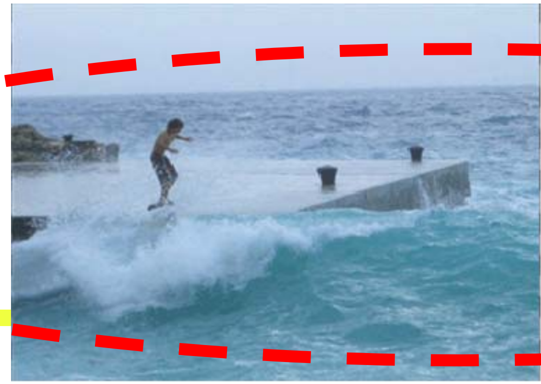

EPS 2011




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

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

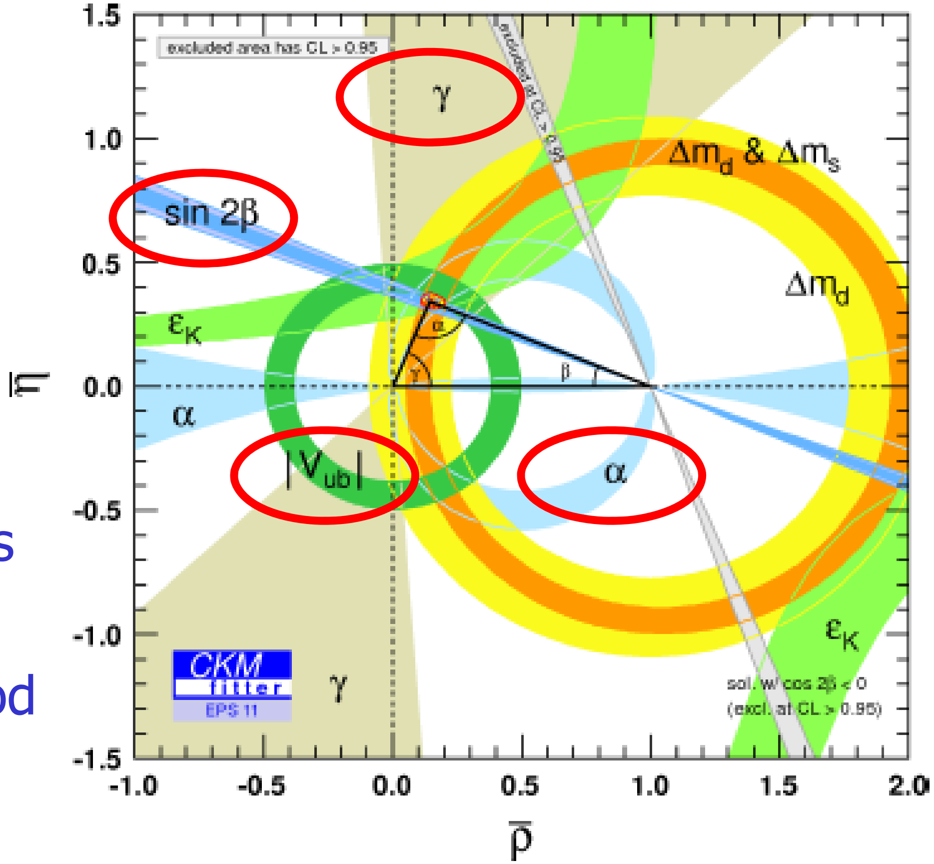
**Energy frontier (LHC)**



**Luminosity frontier - (super) B factories**

# The unitarity triangle – new/final measurements

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




Recent results:

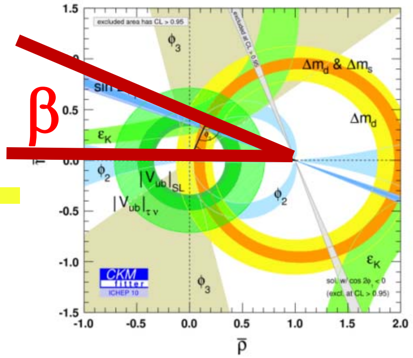
→ $\sin 2\phi_1$ (=$\sin 2\beta$): final measurements

→ $\phi_2$ (=$\alpha$): final measurements

→ $\phi_3$ (=$\gamma$): new model-independ. method

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

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

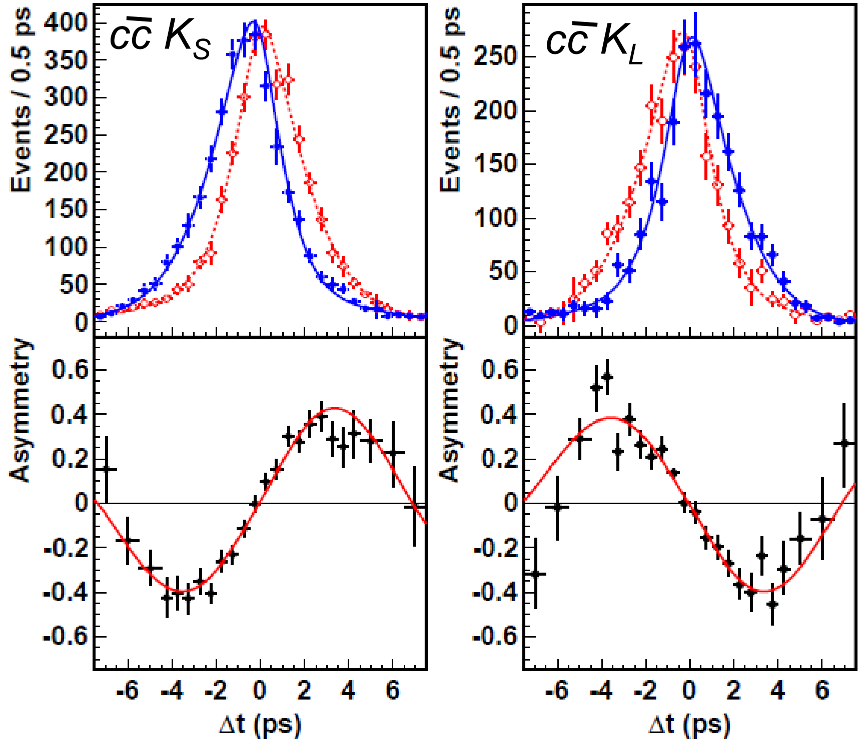


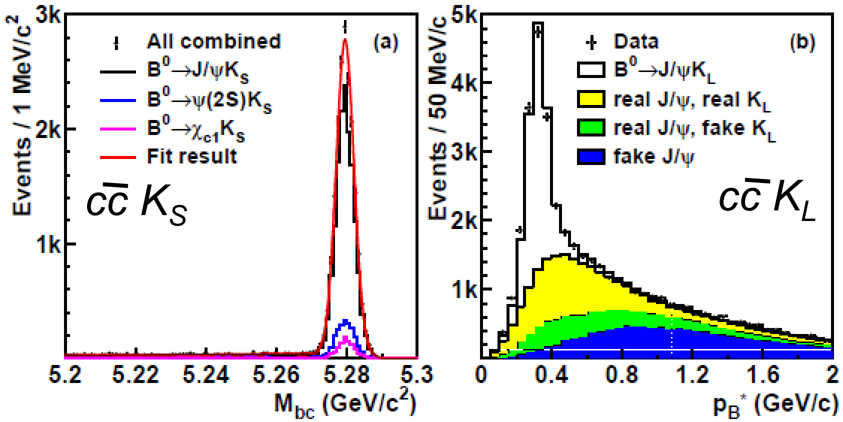

## $\phi_1$ from CP violation measurements in $B^0 \to c\bar{c}\, K^0$

Final measurement: with improved tracking, more data, improved systematics (50% more statistics than last result with 492 $fb^{-1}$);

$cc = J/\psi,\ \psi(2S),\ \chi_{c1}$ → 25k events

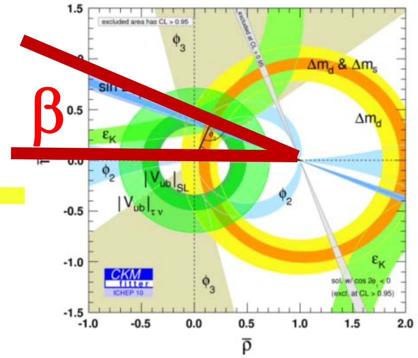
Detector effects: wrong tagging, finite $\Delta t$ resolution → determined using control data samples




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

# Final measurements of $\sin 2\phi_1$ (=$\sin 2\beta$)




## $\phi_1$ from $B^0 \to c\bar{c}\, K^0$

Final results for $\sin 2\phi_1$

| | |
|---|---|
| Belle: | $0.668 \pm 0.023 \pm 0.012$ |
| BaBar: | $0.687 \pm 0.028 \pm 0.012$ |

Belle, PRL 108, 171802 (2012)

BaBar, PRD 79, 072009 (2009)

with a single experiment precision of ~4%!

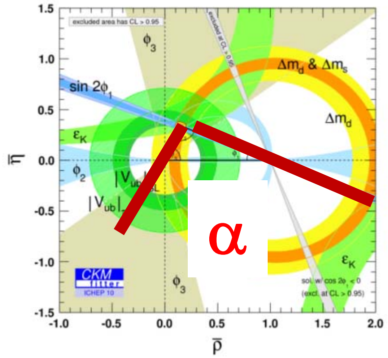
Comparison with LHCb:

•The power of tagging at B factories: 33% vs ~2-3% at LHCb

•LHCb: with 8k tagged $B_d \to J/\psi K_S$ events from 1/fb measured
$\sin 2\beta = 0.73 \pm 0.07(\text{stat.}) \pm 0.04(\text{syst.})$

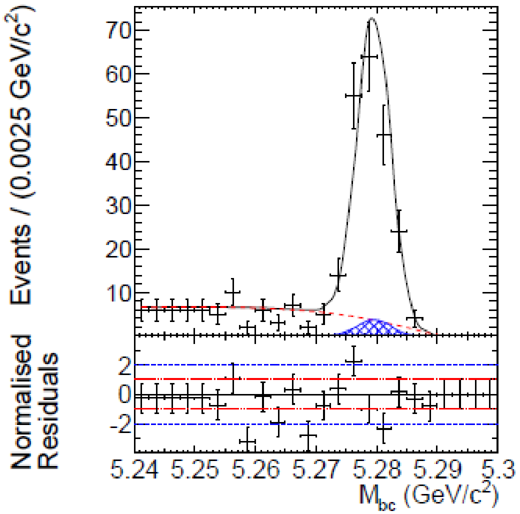
•Uncertainties at B factories - e.g., Belle final result
$\sin 2\beta = 0.668 \pm 0.023(\text{stat.}) \pm 0.012(\text{syst.})$ - are 3x smaller than at LHCb

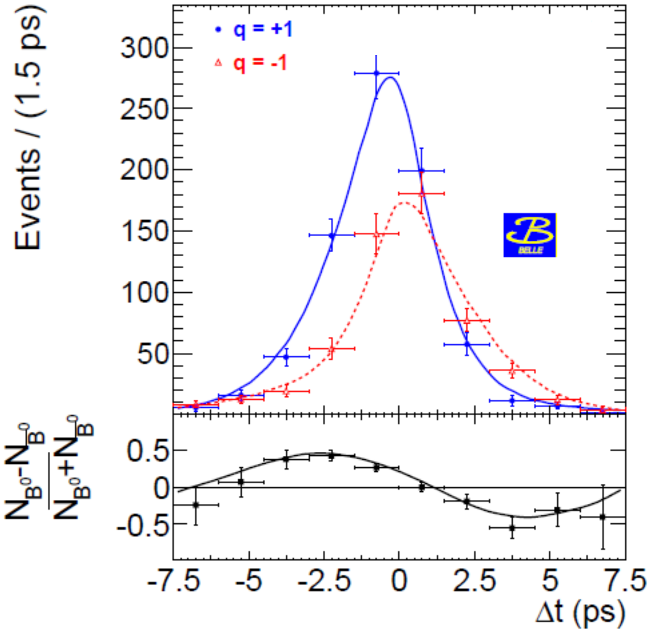
# Final measurement of $\phi_2$ ($\alpha$) in B $\rightarrow \pi^+\pi^-$ decays




## $\phi_2$ from CP violation measurements in $B^0 \rightarrow \pi^+\pi^-$

Belle, 710 $fb^{-1}$
arXiv:1302.0551
(submitted to PRD)



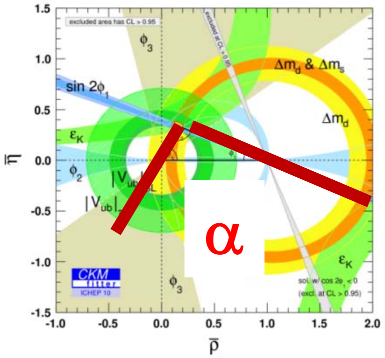




$$a_{f_{CP}} = C\cos(\Delta m t) + S\sin(\Delta m t)$$

Belle, this measurement:
S = −0.64 ± 0.08 ± 0.03
C = −0.33 ± 0.06 ± 0.03

BaBar:
S = −0.68 ± 0.10 ± 0.03
C = −0.25 ± 0.08 ± 0.02

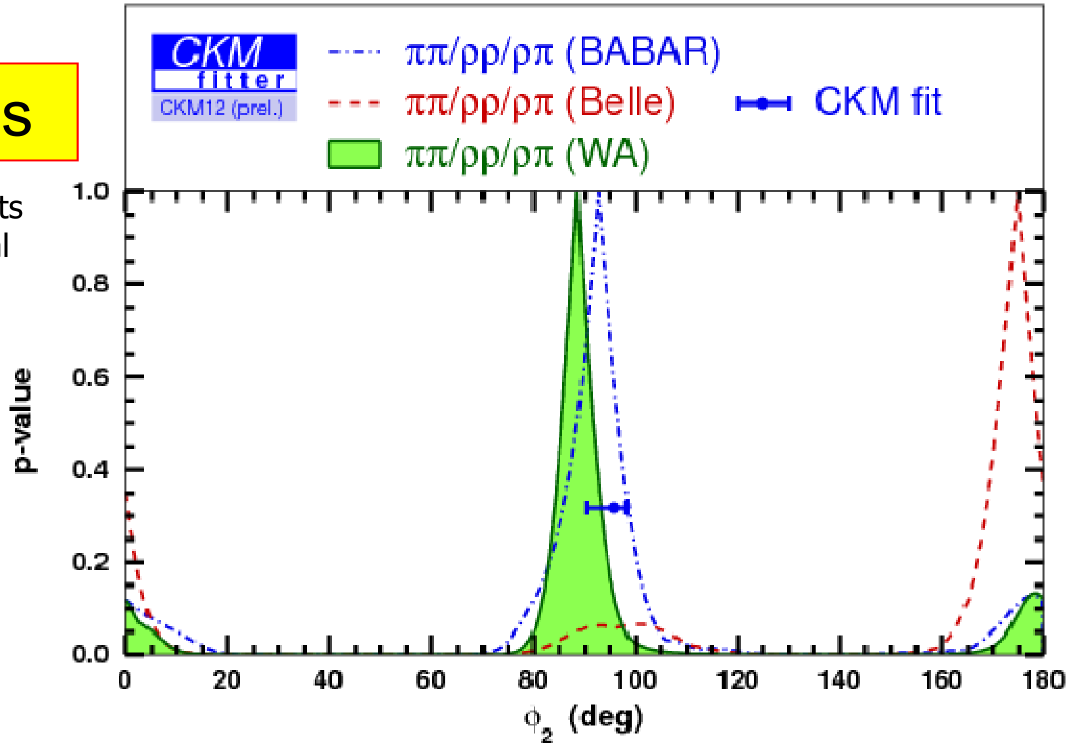
# Improved measurement of $\phi_2\ (\alpha)$ in $B \rightarrow \pi\pi, \rho\rho, \rho\pi$ decays




*$\phi_2\ (\alpha)$* from CP violation and branching fraction measurements in $B \rightarrow \pi\pi, \rho\rho, \rho\pi$

$\phi_2 = \alpha = (85.4^{+4.0}_{-3.8})$ degrees

http://ckmfitter.in2p3.fr/www/results/plots_fpcp13/ckm_res_fpcp13.html



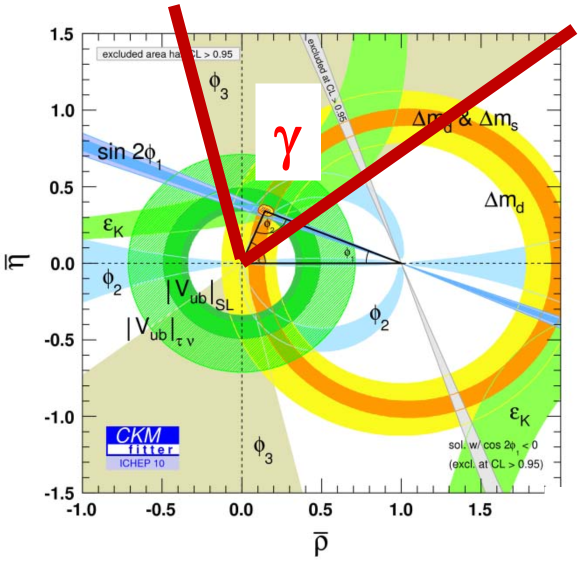

Still to be updated for the final version: new results expected from Belle on $\rho^+\rho^-$, $\rho\pi$; a new $\rho\pi$, analysis published by BaBar →PRD88, 012003 (2013).

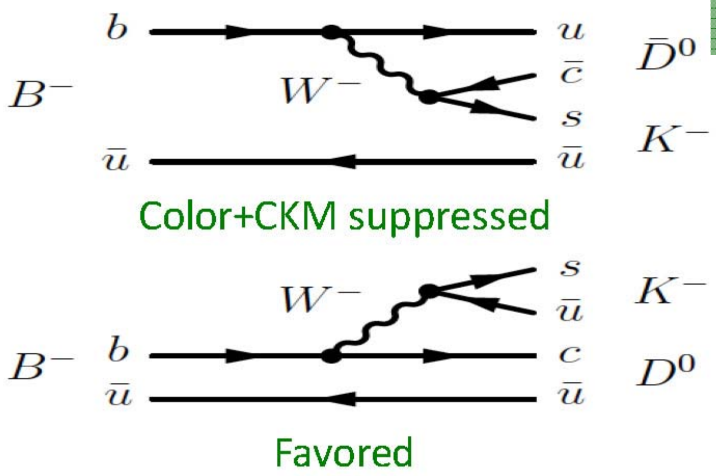
# $\phi_3$ (=$\gamma$) with Dalitz analysis

A. Giri et al., PRD68, 054018 (2003)
A. Bondar et al (Belle), Proc. BINP Meeting on Dalitz Analyses, 2002

GGSZ method:

The best way to measure $\phi_3$

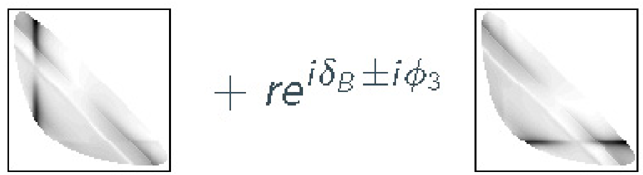



$\overset{(-)}{D^0} \rightarrow K_S\pi^+\pi^-$

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

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

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

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

$\phi_3$=(78 ± 12 ± 4 ± 9)°

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

$\phi_3$=(68 ± 14 ± 4 ± 3)°

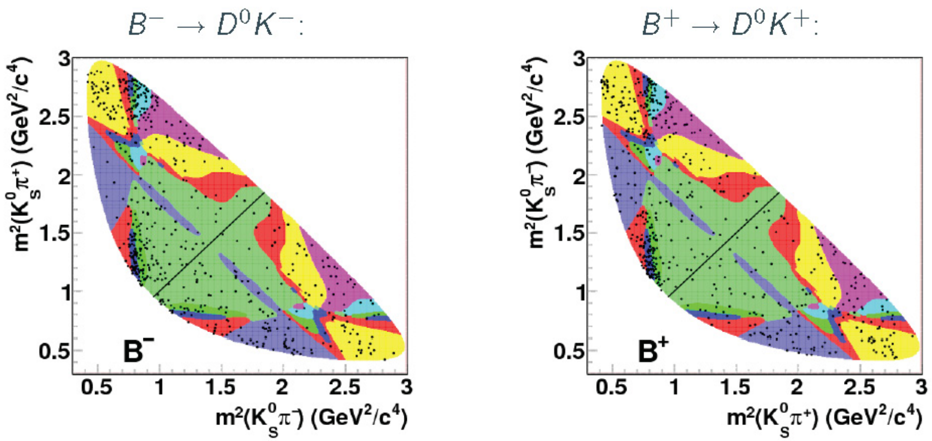
BaBar, PRL 105, 121801, (2010)

# $\phi_3$ (=$\gamma$) from model-independent/binned Dalitz method

GGSZ 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

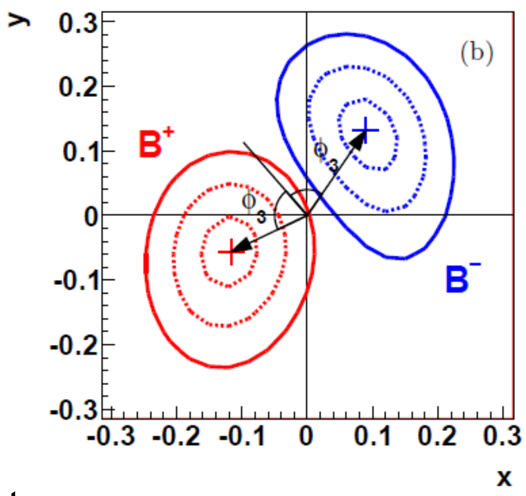
Belle, 710 fb$^{-1}$, Phys. Rev. D85 (2012) 112014

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

$\phi_3$=(77.3 ± 15 ± 4.1 ± 4.3)$^o$

from $c_i$, $s_i$ (statist.!)

to be reduced with BESIII data



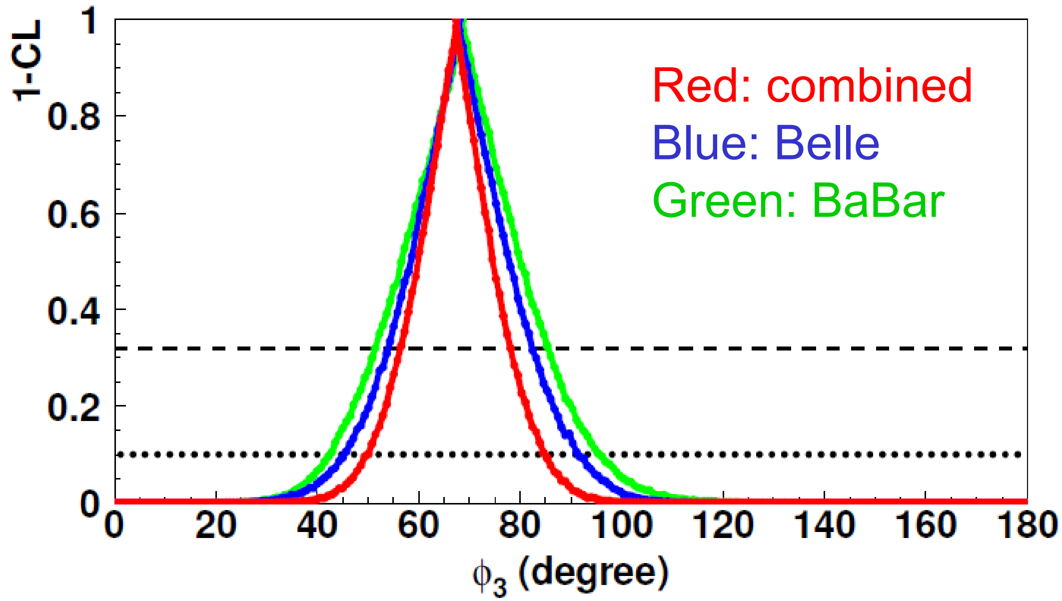

New method pioneered by Belle, very important for large event samples at LHCb and super B factory

# $\phi_3$ measurement

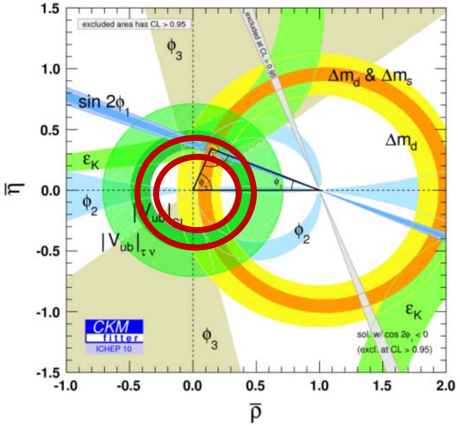
Combined $\phi_3$ value:

$\phi_3$ =(67 ± 11) degrees

Note that at B factories the measurement of $\phi_3$ finally turned out to be much better than expected!



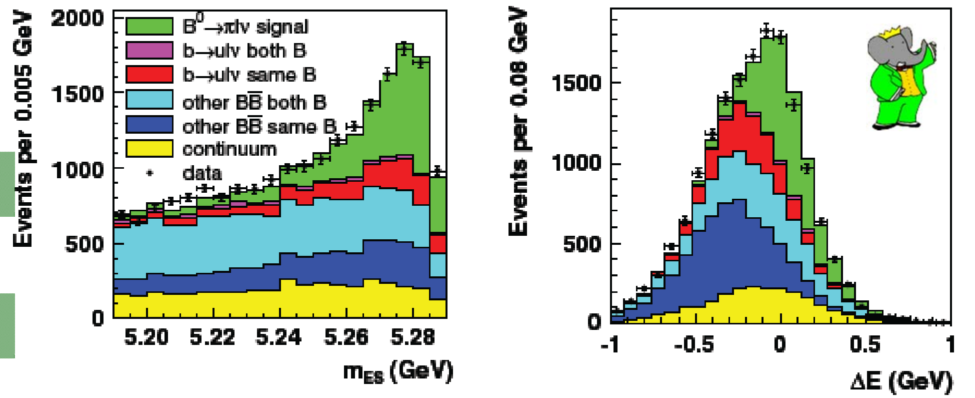

This is not the last word from B factories, analyses still to be finalized...




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

Yield: 2d fit in $M_{bc}=M_{ES}$ and $\Delta E$, bins of $q^2$

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




$\mathcal{B}=(1.41\pm0.05\pm0.07)\cdot10^{-4}$ untagged

BaBar, PRD83, 032007 (2011)

$\mathcal{B}=(1.42\pm0.05\pm0.07)\cdot10^{-4}$ untagged loose neutrino

BaBar, PRD83, 052011 (2011)

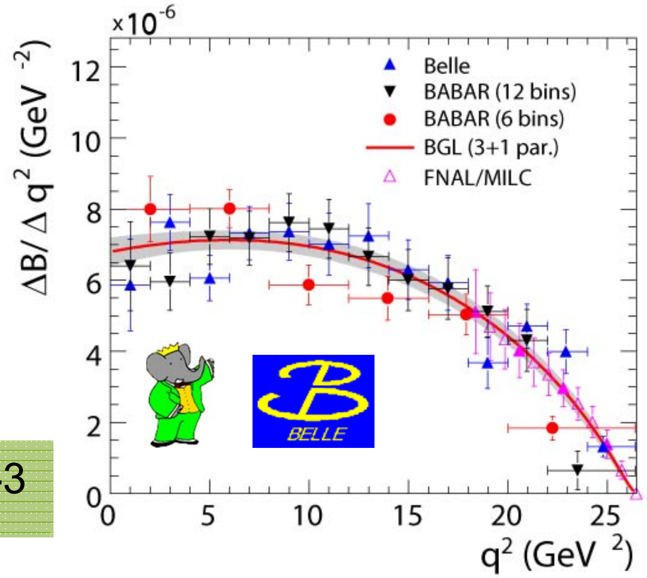
$\mathcal{B}=(1.49\pm0.04\pm0.07)\cdot10^{-4}$ untagged

Belle, PRD83, 071101 (2011)

$\mathcal{B}=(1.49\pm0.09\pm0.07)\cdot10^{-4}$ hadron tag

Belle, PRD88, 032005 (2013)

$|V_{ub}|$ extraction: fit data + LQCD points in $q^2=(p_\ell+p_\nu)^2=(p_B-p_\pi)^2$




Belle + BaBar + FNAL/MILC

$|V_{ub}| = (3.23 \pm 0.30)\cdot10^{-3}$

# $|V_{ub}|$ from inclusive decays $B \to X_u \ell^+ \nu$

The other possibility: inclusive b→u measurement by measuring

- lepton spectrum in semileptonic $b \to u \ell^+ \nu$ decays, or by using
- tagged events (e.g. fully reconstruct one of the B's, and then measure the rate vs mass of the hadronic system $X_u$)

Inclusive decays

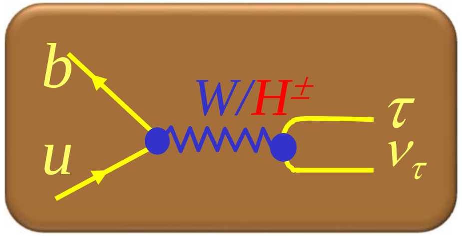
$$|V_{ub}| = (4.42 \pm 0.20\,(\mathrm{exp}) \pm 0.15(\mathrm{th}))\cdot 10^{-3}$$

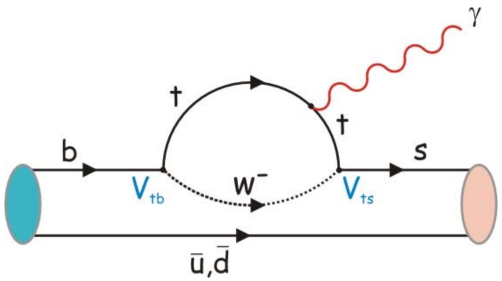
vs exclusive decays

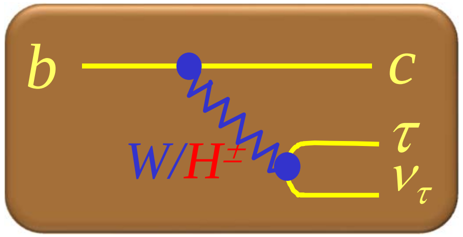
$$|V_{ub}| = (3.23 \pm 0.30)\cdot 10^{-3}$$

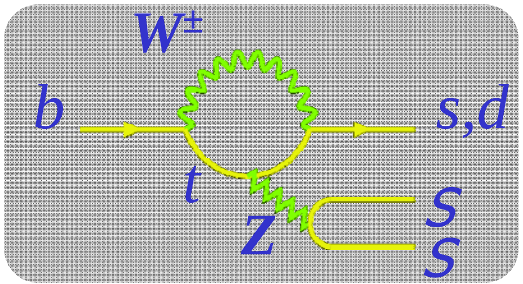
→ Tension between inclusive and exclusive decays is still there - and not understood

# Rare B decays



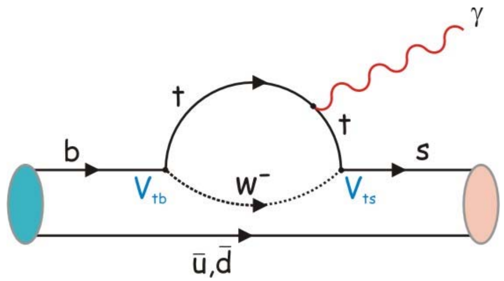



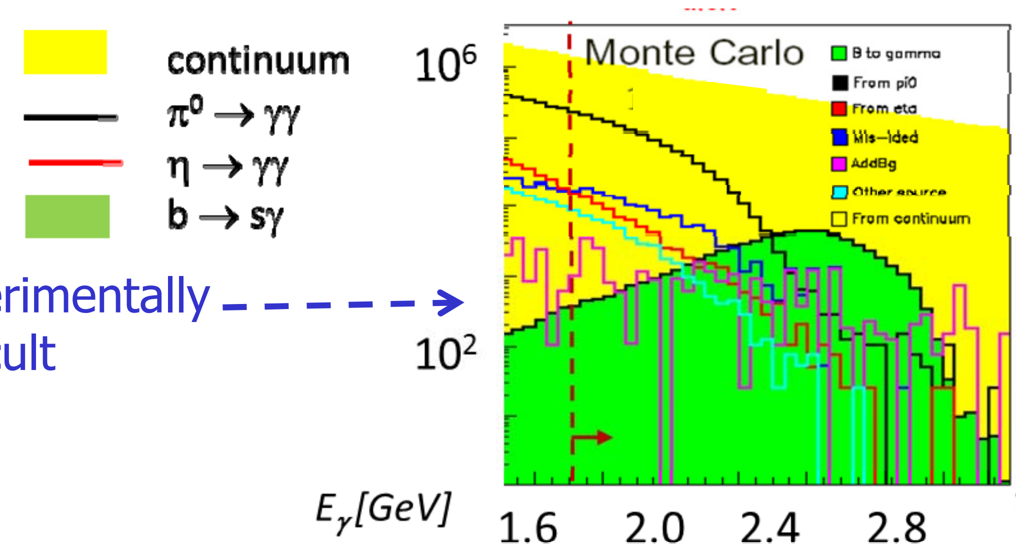
# $B \to X_s\gamma$ inclusive

Advantage of B factories!




Radiative decay sensitive to charged Higgs

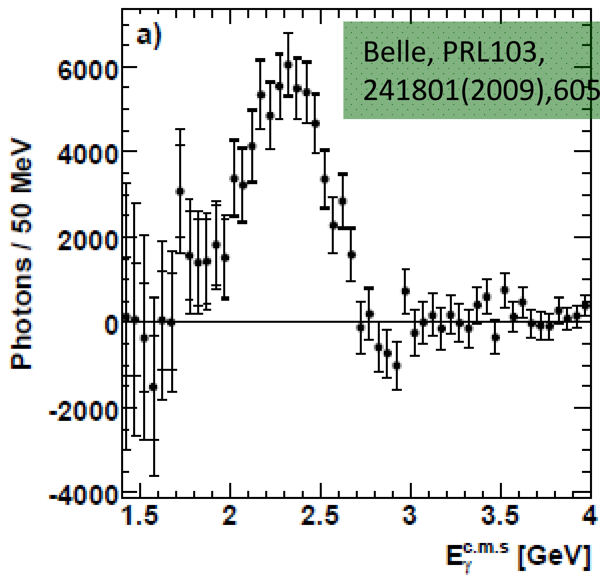
Experimentally difficult




Experiment: measure low $E_\gamma$
$\Rightarrow$ huge bkg. $\Rightarrow E_\gamma > E_{cut}$

Theory:
parameter extraction from partial Br($E_\gamma > E_{cut}$) $\Rightarrow$ extrapolation needed;

Only $\gamma$ on signal side reconstructed
Improve S/B by tagging the other B




Belle, PRL103, 241801(2009),605 fb[-1]

$$\mathcal{B}(B \to X_s\gamma; 1.7\,GeV < E_\gamma < 2.8\,GeV) = (3.47 \pm 0.15 \pm 0.40)\cdot 10^{-4}$$

# $B \to X_s\gamma$ inclusive

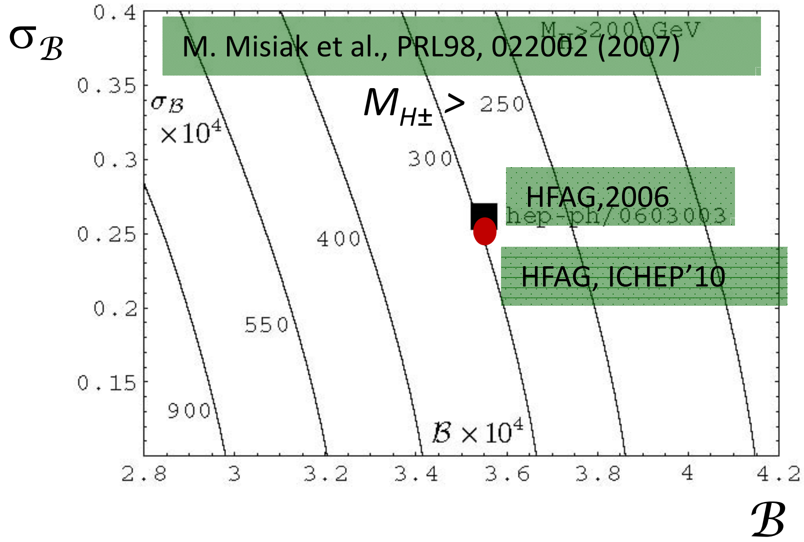
Branching fraction, world average

HFAG, ICHEP'10

$$\mathcal{B}(B \to X_s\gamma; E_\gamma > 1.6\ GeV) =$$
$$= (3.55 \pm 0.24(stat. + syst.) \pm 0.09(shape\ f.) \cdot 10^{-4}$$

Decay rate sensitive to charged Higgs

→ tight constraints on models of new physics, two-Higgs-doublet model II mass limit at ~300 GeV/c$^2$




Measurements systematics dominated

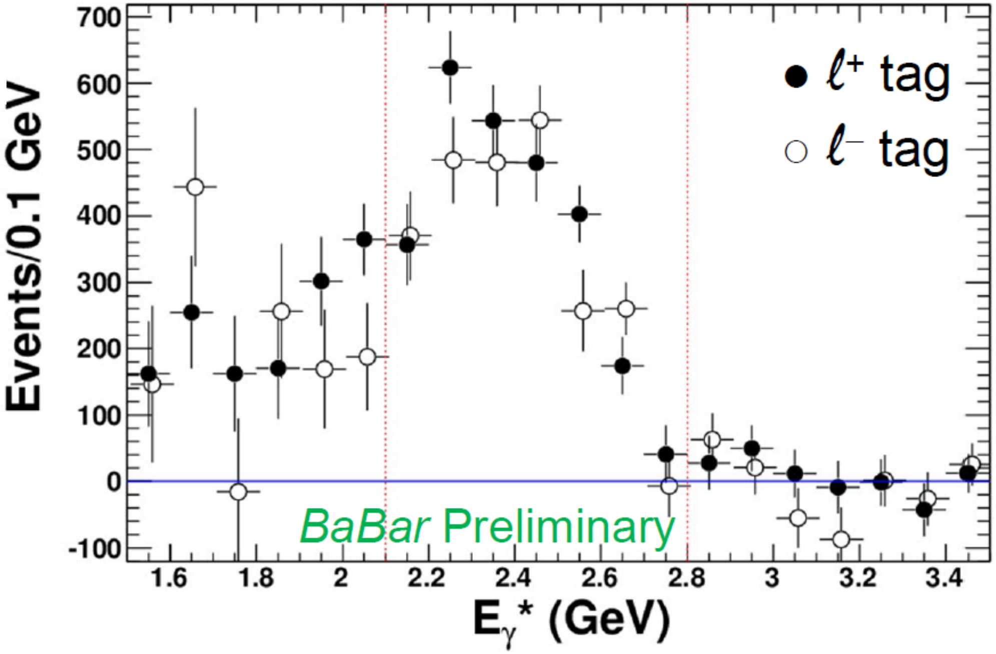
Systematics can be reduced by stronger tagging (e.g. full reconstruction of the other B) on the account of stat. uncertainty
⇒ need a larger sample → Super B factory

# Search for direct CP violation in $B \rightarrow X_{s+d}\gamma$ decays

$$A_{CP} = \frac{\Gamma(B \rightarrow X_{s+d}\gamma) - \Gamma(\overline{B} \rightarrow X_{\bar{s}+\bar{d}}\gamma)}{\Gamma(B \rightarrow X_{s+d}\gamma) + \Gamma(\overline{B} \rightarrow X_{\bar{s}+\bar{d}}\gamma)} \simeq 0$$

Benzke, Lee, Neubert, Paz, PRL 106, 141801 (2011)

Events separated by charge of lepton




- Inclusive analysis with lepton tag (tags B flavour and reduces background)
- Energy range (2.1<E<2.8 GeV) chosen to minimize total error (stat+syst).

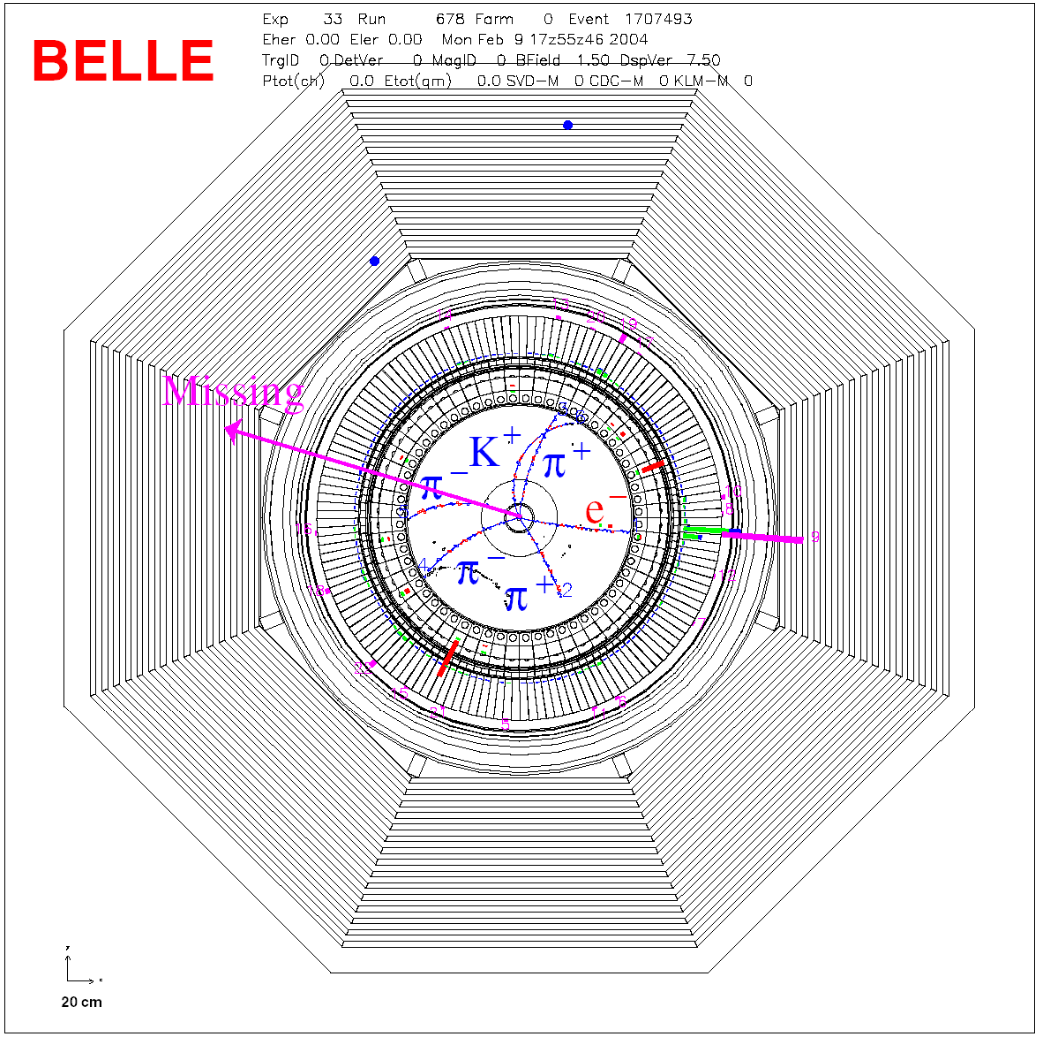
$A_{CP}$ = 0.057 ± 0.060(stat) ± 0.018(syst)

BaBar, Phys. Rev. Lett. 109, 191801 (2012)

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

Example of a missing energy decay

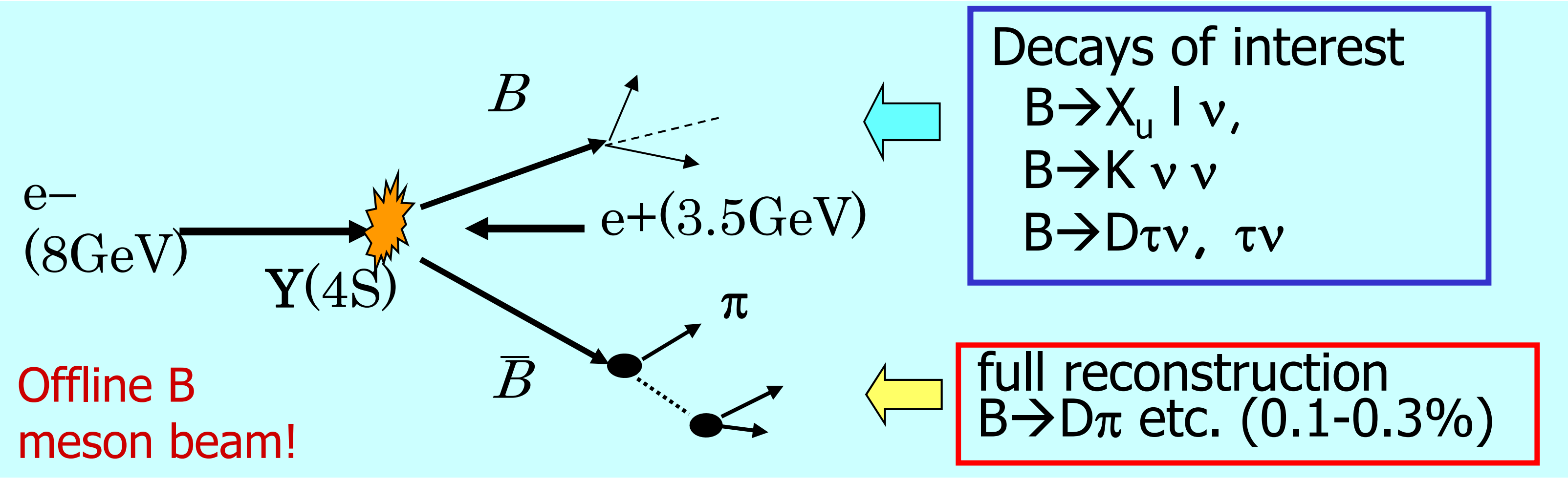
$$B^+ \rightarrow D^0 \pi^+$$
$$(\rightarrow K\pi^-\pi^+\pi^-)$$
$$B^- \rightarrow \tau(\rightarrow e\nu\bar{\nu})\nu$$



# Full reconstruction tagging

Idea: fully reconstruct one of the B's to tag B flavor/charge, determine its momentum, and exclude decay products of this B from further analysis

(exactly two B's produced in $\Upsilon(4S)$ decays)




Powerful tool for B decays with neutrinos, used in several analyses in this talk

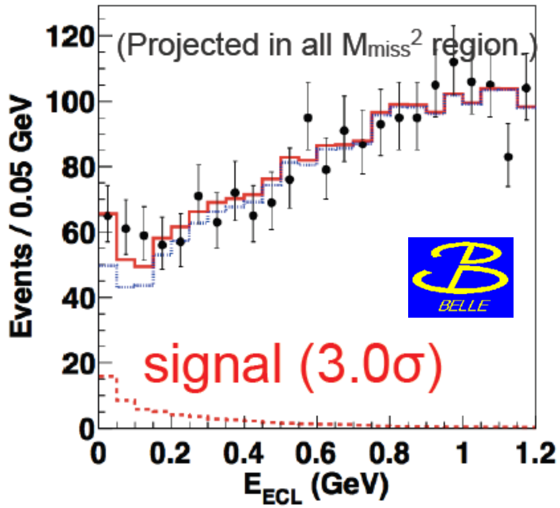
→unique feature at B factories

# $B^- \to \tau^- \nu_\tau$

Method: tag one B with full reconstruction, look for the $B^- \to \tau^- \nu_\tau$ in the rest of the event.

Main discriminating variable on the signal side: remaining energy in the calorimeter, not associated with any charged track or photon

→ Signal at $E_{ECL} = 0$

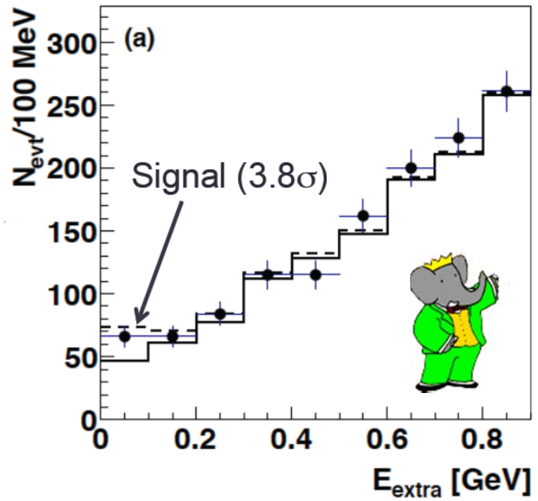



Belle $$Br(B \to \tau\nu) = [0.72\ ^{+0.27}_{-0.25} \pm 0.11] \times 10^{-4}$$

PRL 110, 131801 (2013)

BaBar $$Br(B \to \tau\nu) = [1.83\ ^{+0.53}_{-0.49} \pm 0.24] \times 10^{-4}$$

Phys. Rev. D 88, 031102(R) (2013)

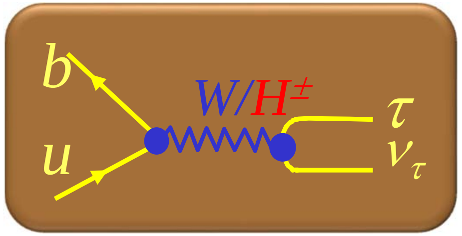



All measurements combined

$$BF(B \to \tau\nu) = (1.15 \pm 0.23) \cdot 10^{-4}$$

$$r_H = \frac{BF(B \to \tau\nu)_{meas}}{BF(B \to \tau\nu)_{SM}} = 1.14 \pm 0.40$$

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



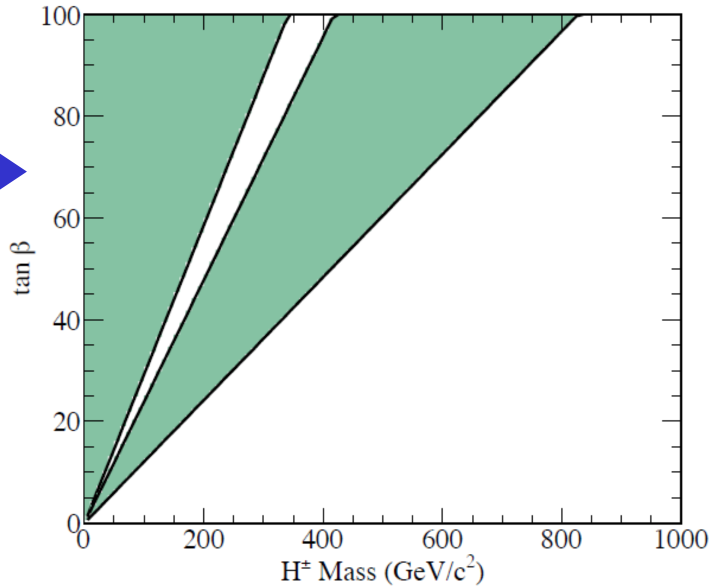

Measured value

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

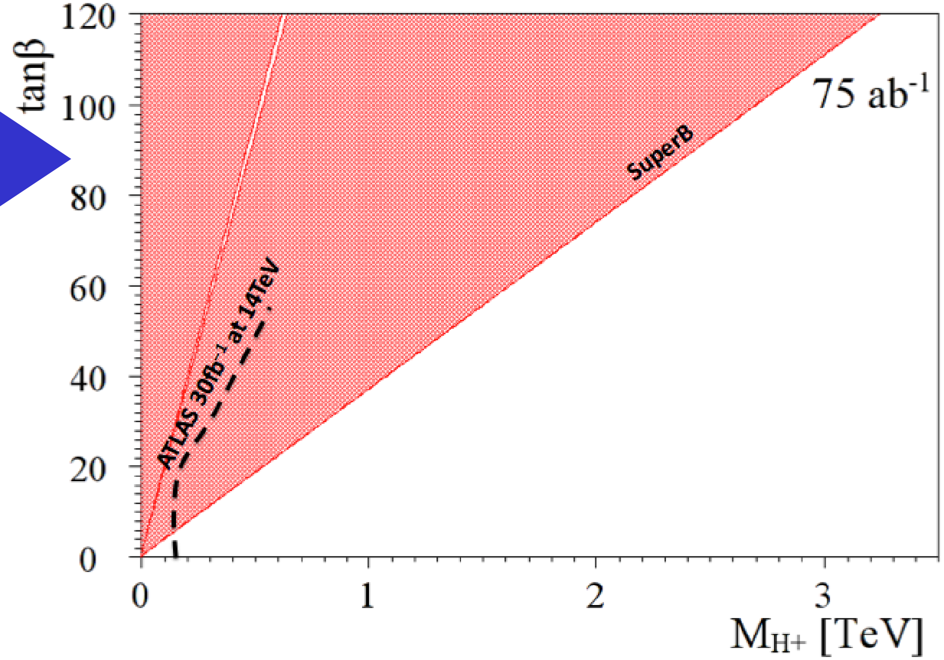
→ limit on charged Higgs mass vs. tanβ

(for type II 2HDM)

B factories: Exclusion plot

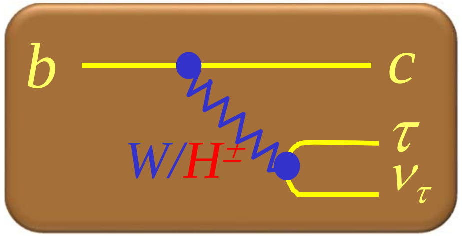



Super B factory: Discovery plot: very much competitive with LHC!



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

## Semileptonic decay sensitive to charged Higgs




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

Kamenik, Mescia arXiv:0802.3790

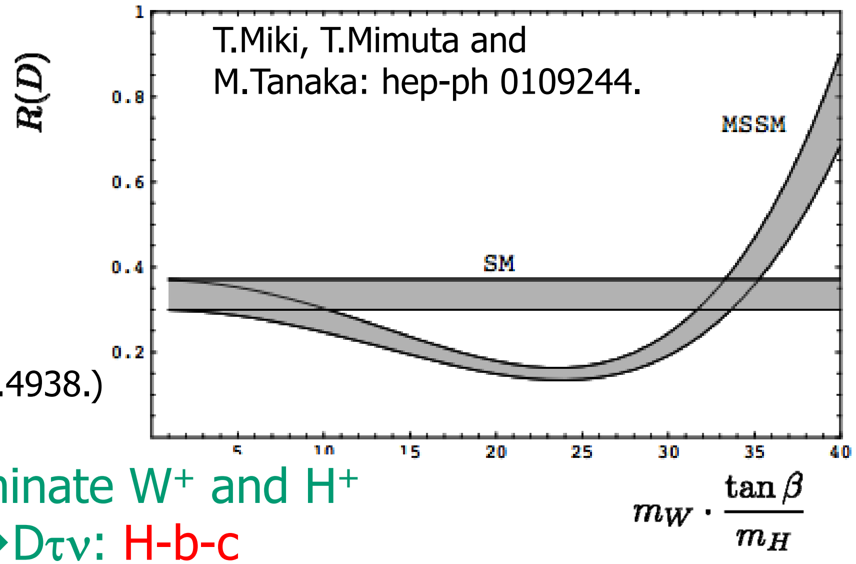
$$R(D) \equiv \frac{\mathcal{B}(B \to D\tau\nu)}{\mathcal{B}(B \to D\ell\nu)}$$

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)

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

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

Exclusive hadron tag data

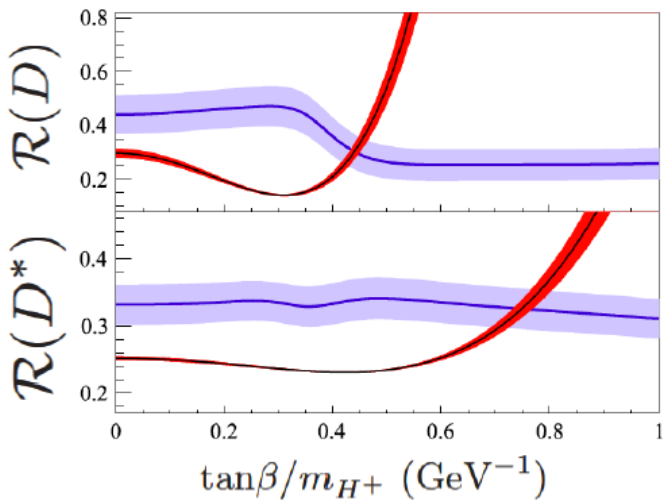
$$\mathcal{R}(D)_{\rm exp} = 0.440 \pm 0.072 \qquad \mathcal{R}(D^*)_{\rm exp} = 0.332 \pm 0.030$$

$\updownarrow$ 2.0σ $\qquad\qquad$ $\updownarrow$ 2.7σ

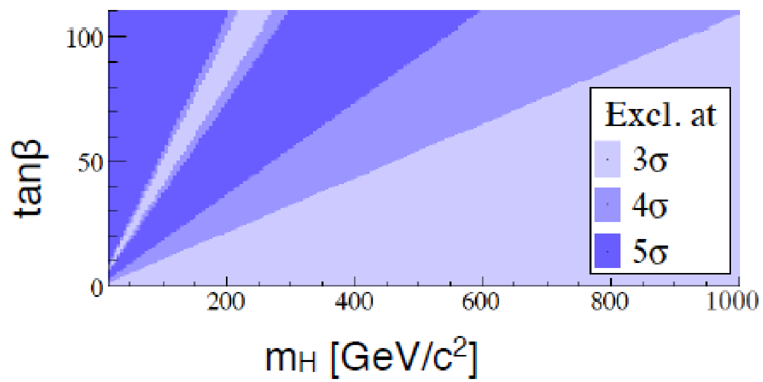
$$\mathcal{R}(D)_{\rm SM} = 0.297 \pm 0.017 \qquad \mathcal{R}(D^*)_{\rm SM} = 0.252 \pm 0.003$$

*SM expectations in S. Fajfer, J. Kamenik, I. Nisandzic, PRD 85, 094025 (2012).*

→ Combined result: 3σ away from SM.




Blue: this result, red: Type-II 2HDM.

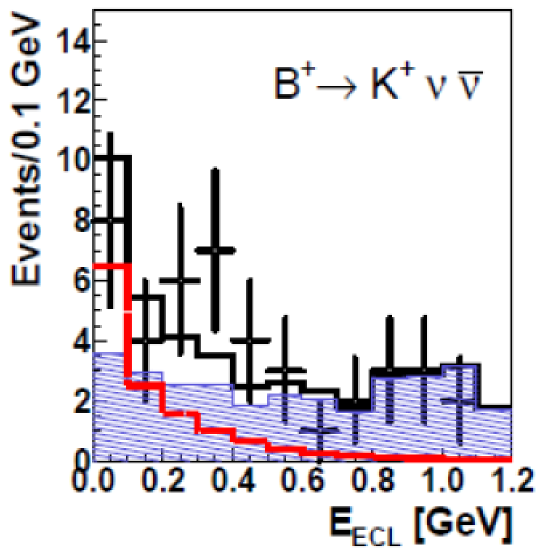



→ Combined result: Type II 2HDM excluded at 99.8% C.L. for any values of tanβ and charged Higgs mass

More discussion of the implications: BaBar, Phys. Rev. Lett. 109, 101802 (2012)

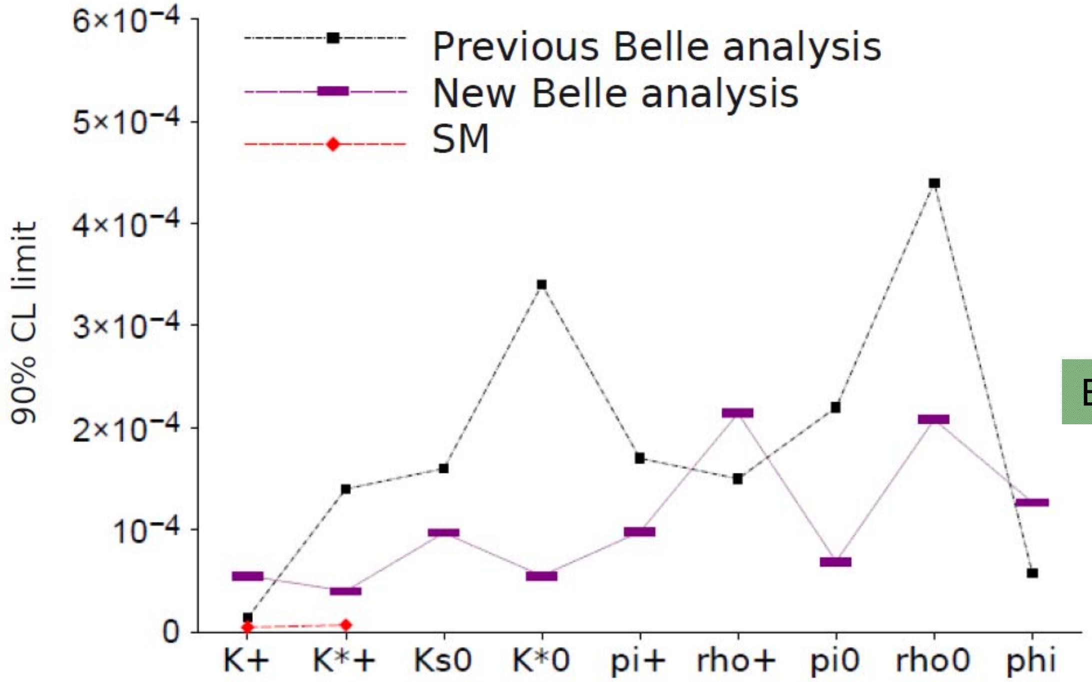
# $B \to h\nu\bar{\nu}$ decays

Method: again tag one B with full reconstruction, search for signal in the remaining energy in the calorimeter, at $E_{ECL} = 0$




$$N_{Sig} = 13.3^{+7.4}_{-6.6}(stat) \pm 2.3(syst)$$
$$S_{stat+syst} = 2.0\sigma$$

Present status: recent update from Belle



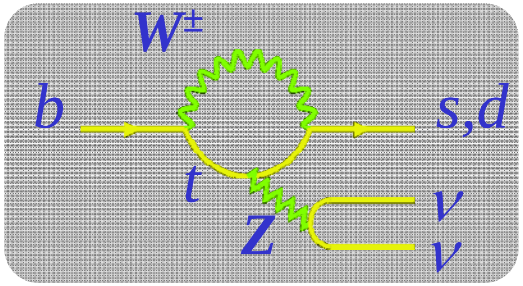

Belle, Phys. Rev. D 87, 111103(R) (2013)

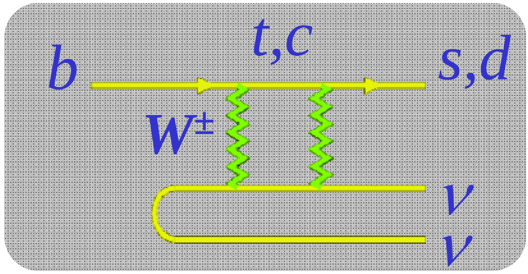
# $B \to K^{(*)}\nu\bar{\nu}$

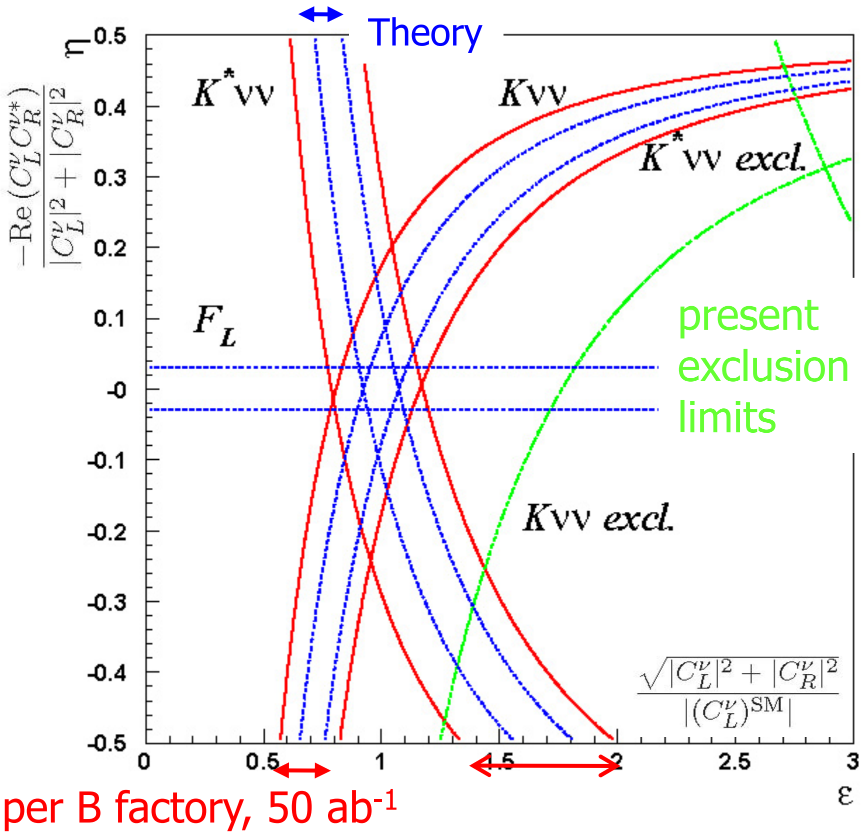
arXiv:1002.5012

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

SM: penguin + box diagrams



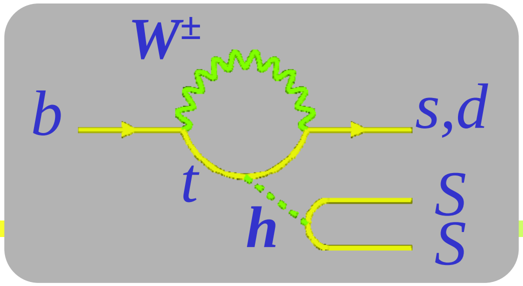



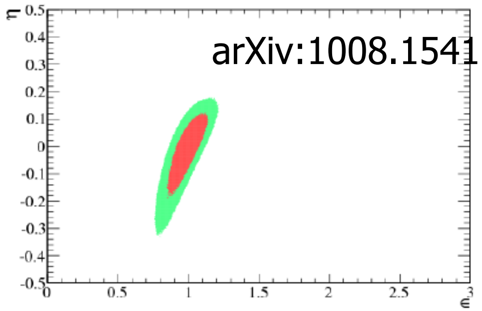




$B \to K\nu\nu$, $\mathcal{B} \sim 4{\cdot}10^{-6}$
$B \to K^*\nu\nu$, $\mathcal{B} \sim 6.8{\cdot}10^{-6}$

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

from, e.g.,



# Charm and $\tau$ physics

B factories = charm and $\tau$ factories

Charm and $\tau$ can be found in any "Y(nS) samples"

→ the integrated luminosity of the samples used for charm and $\tau$ studies is larger than for the B physics studies (Belle ~ 1 $ab^{-1}$, BaBar ~0.550 $ab^{-1}$)

→ This will of course remain true for the super B factory

A few examples of the strengths of B factories:

- CP violation in charm at B factories (and super B factories) →can measure CPV separately in individual decay channels, $\pi^+\pi^-$, $K^+K^-$, $K_S\,\pi$ ,...
- $D\bar{D}$ pairs produced with very few light hadrons
- Full reconstruction of events →

# Rare charm decays: tag with the other D

Again make use of the hermeticity of the apparatus!

Example: leptonic decays of $D_s$

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

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 ($\pi$, $\pi\pi$, …)

2 step reconstruction:

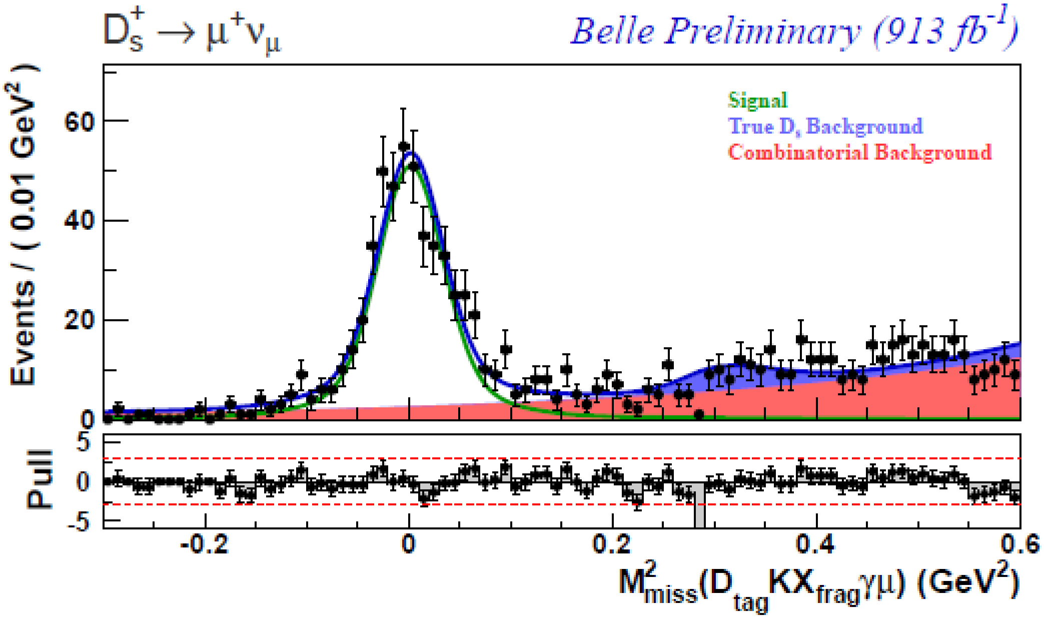
- Inclusive reconstruction of $D_s$ mesons for normalization (without any requirements upon $D_s$ decay products)
- Within the inclusive $D_s$ sample search for $D_s$ decays
  - $D_s \to \mu\nu$: peak at $m_\nu^2 = 0$ in $M^2_{\rm miss}(D_{\rm tag} K X_{\rm frag} \gamma \mu)$
  - $D_s \to \tau\nu$: peak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

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

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

Selection:

- $M_{\rm miss}(D_{\rm tag} K X_{\rm frag} \gamma)$ 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, arxiv:1301.7218

**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.

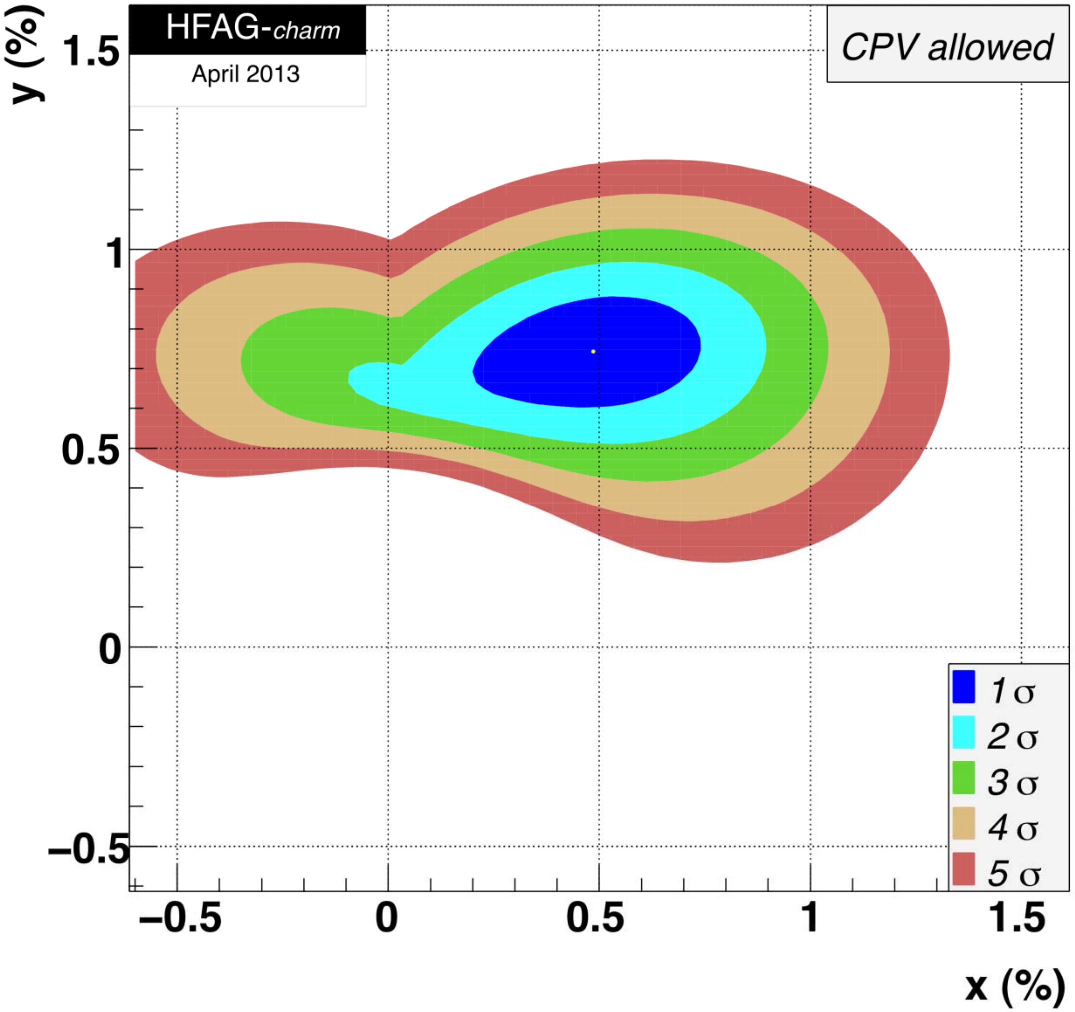


Extract $f_{Ds}$ :

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

# Charm: last but not least…

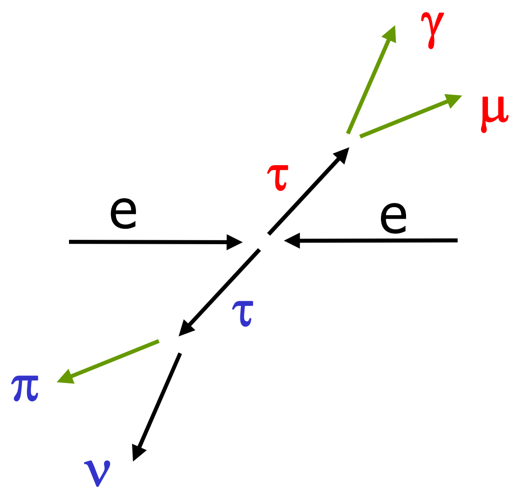
D mixing was discovered at Belle and BaBar…




… and there remains a lot for us to do in the era of super B factories.

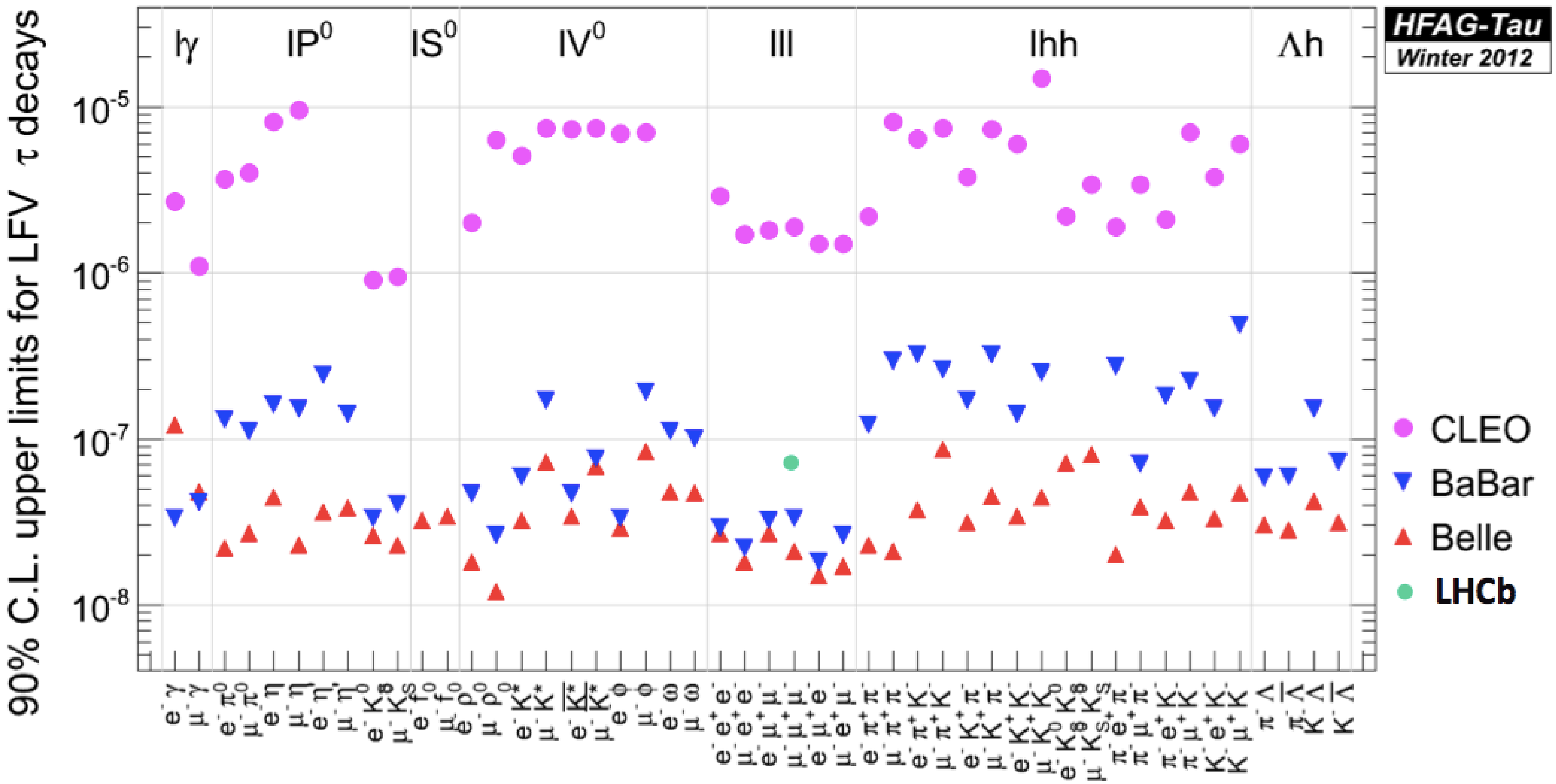
# Rare $\tau$ decays

Example: lepton flavour violating decay $\tau \rightarrow \mu\,\gamma$



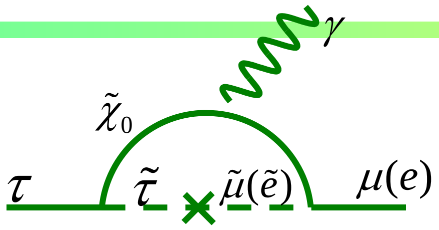
# LFV in tau decays: present status

Lepton flavour violation (LFV) in tau decays: would be a clear sign of new physics



# LFV and New Physics

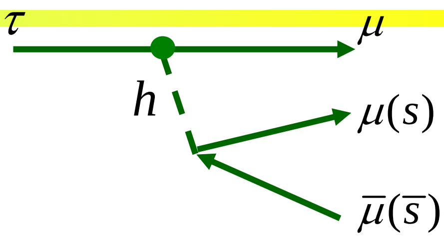
## $\tau \rightarrow l\gamma$




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

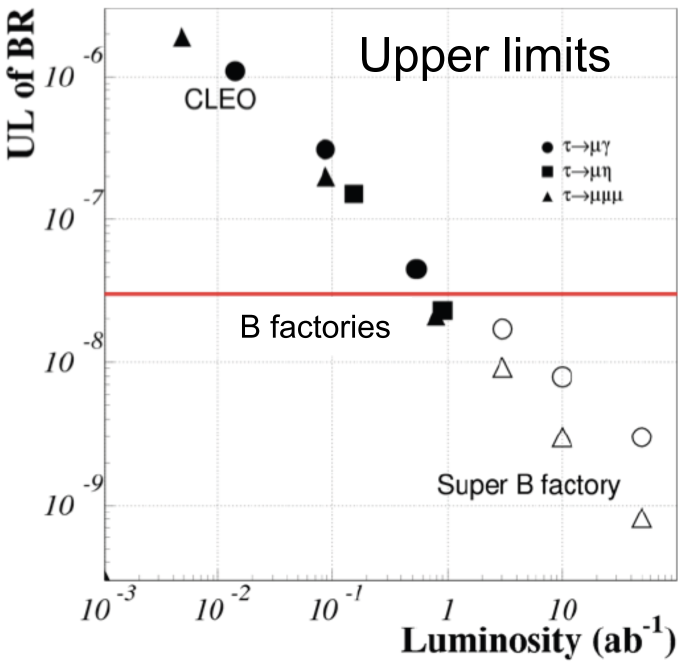
$$Br(\tau \rightarrow \mu\gamma) \simeq 10^{-6} \times \left( \frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left( \frac{1\,TeV}{m_{SUSY}} \right)^4 \tan^2\beta$$

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




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

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




Integ. Lum.( ab$^{-1}$ )

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

# 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 $b \to s l^+ l^-$
- Observation of D mixing
- Searches for rare $\tau$ decays
- Discovery of exotic hadrons including charged charmonium- and bottomonium-like states

B factories remain competitive in many measurements because of their unique capabilities.

# What next?

Next generation: Super B factories → Looking for NP

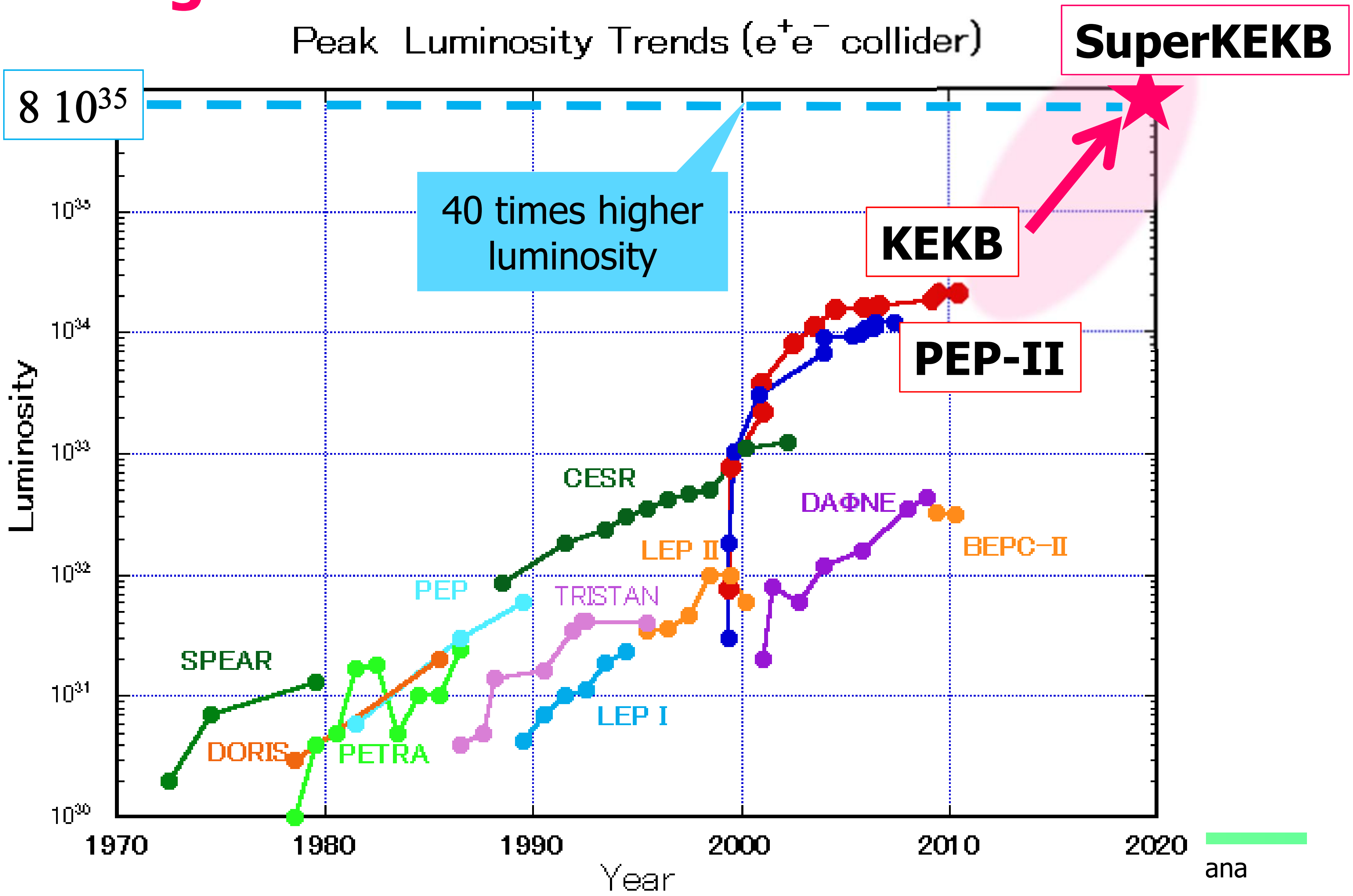
→ Need much more data (almost two orders!)

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

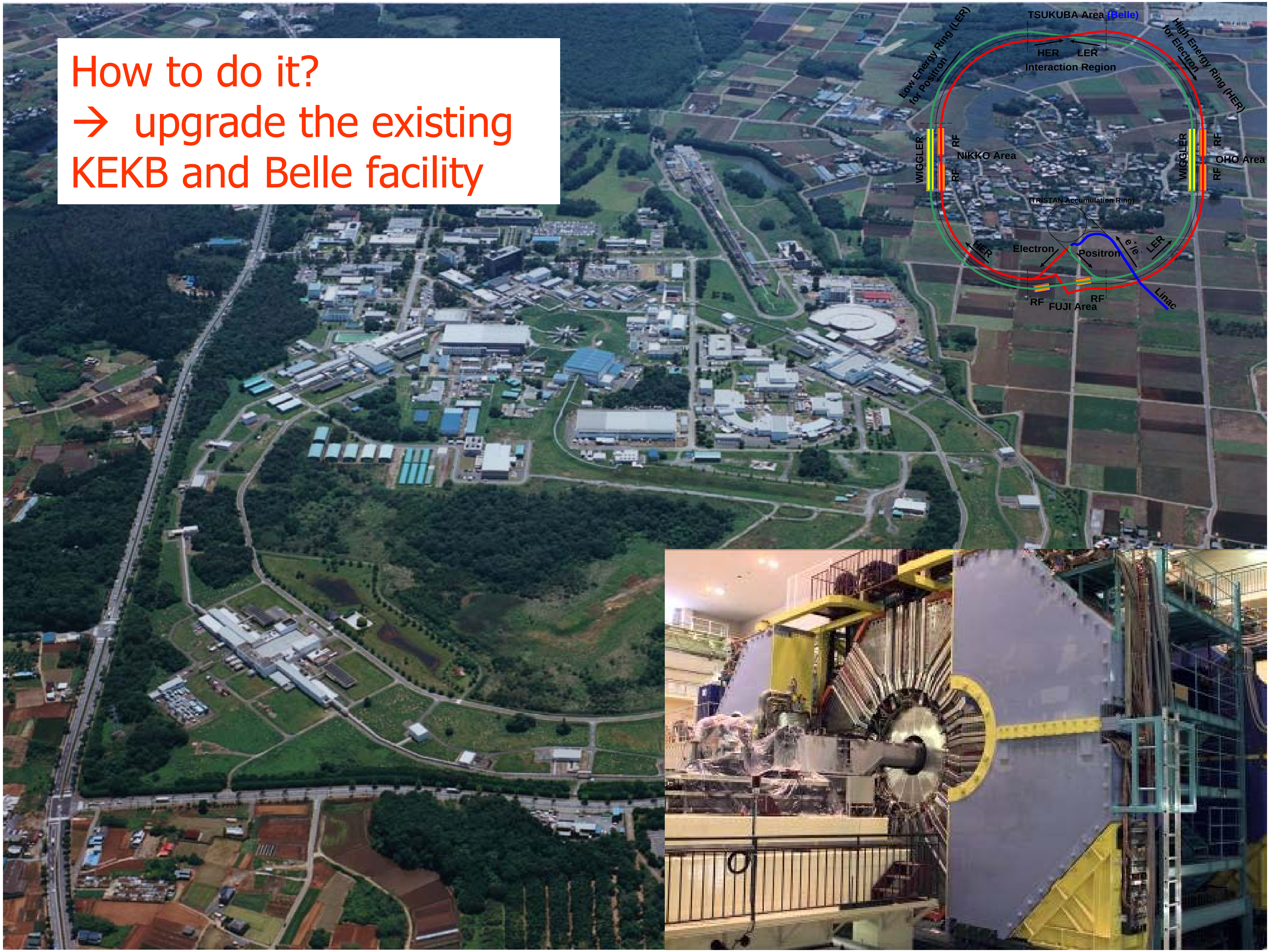
→ Physics at Super B Factory, arXiv:1002.5012 (Belle II)
→ SuperB Progress Reports: Physics, arXiv:1008.1541 (SuperB)

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




ana

How to do it?
→ upgrade the existing KEKB and Belle facility



# 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

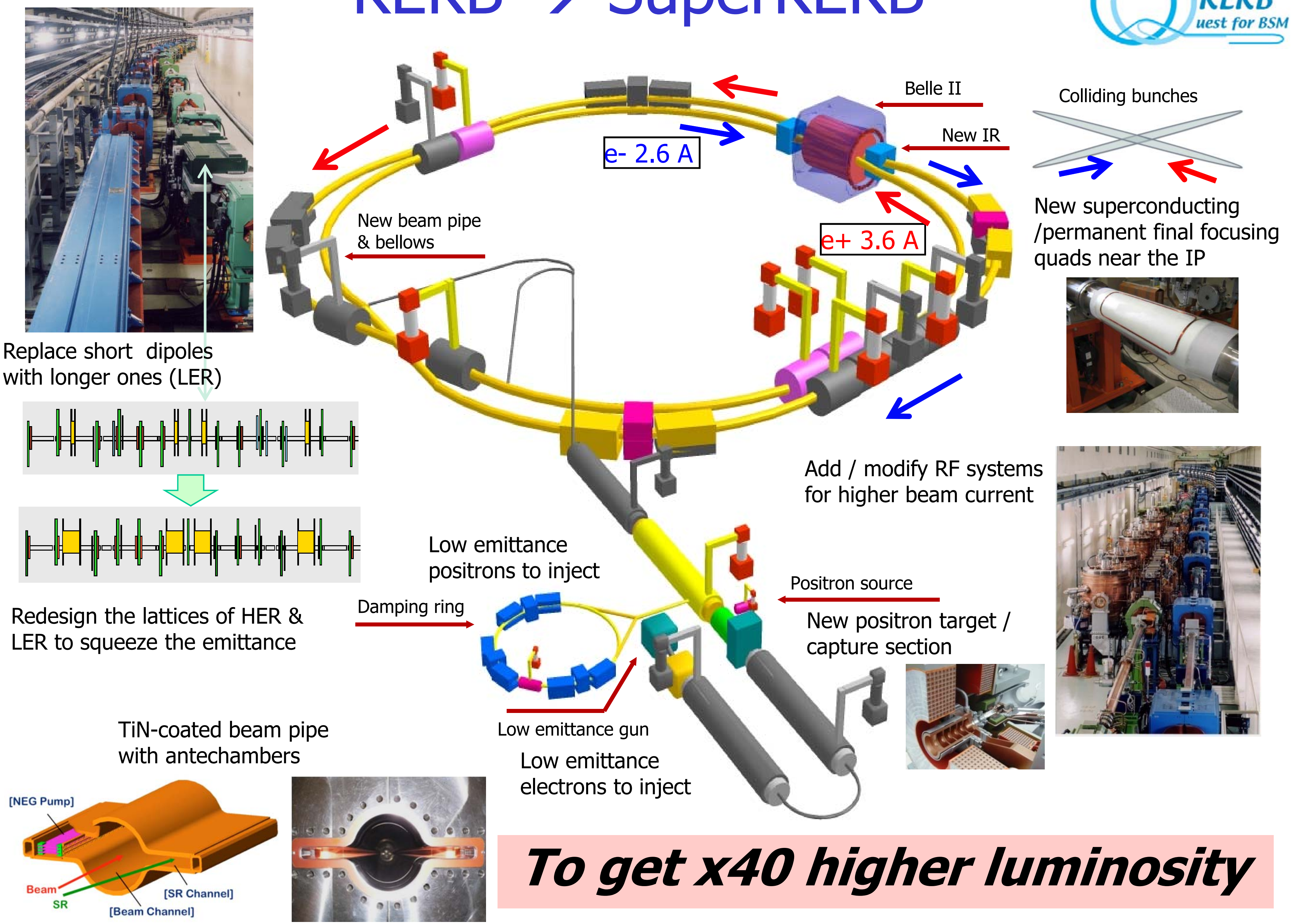
**(1) Smaller $\beta_y^*$**
**(2) Increase beam currents**
(3) Increase $\xi_y$

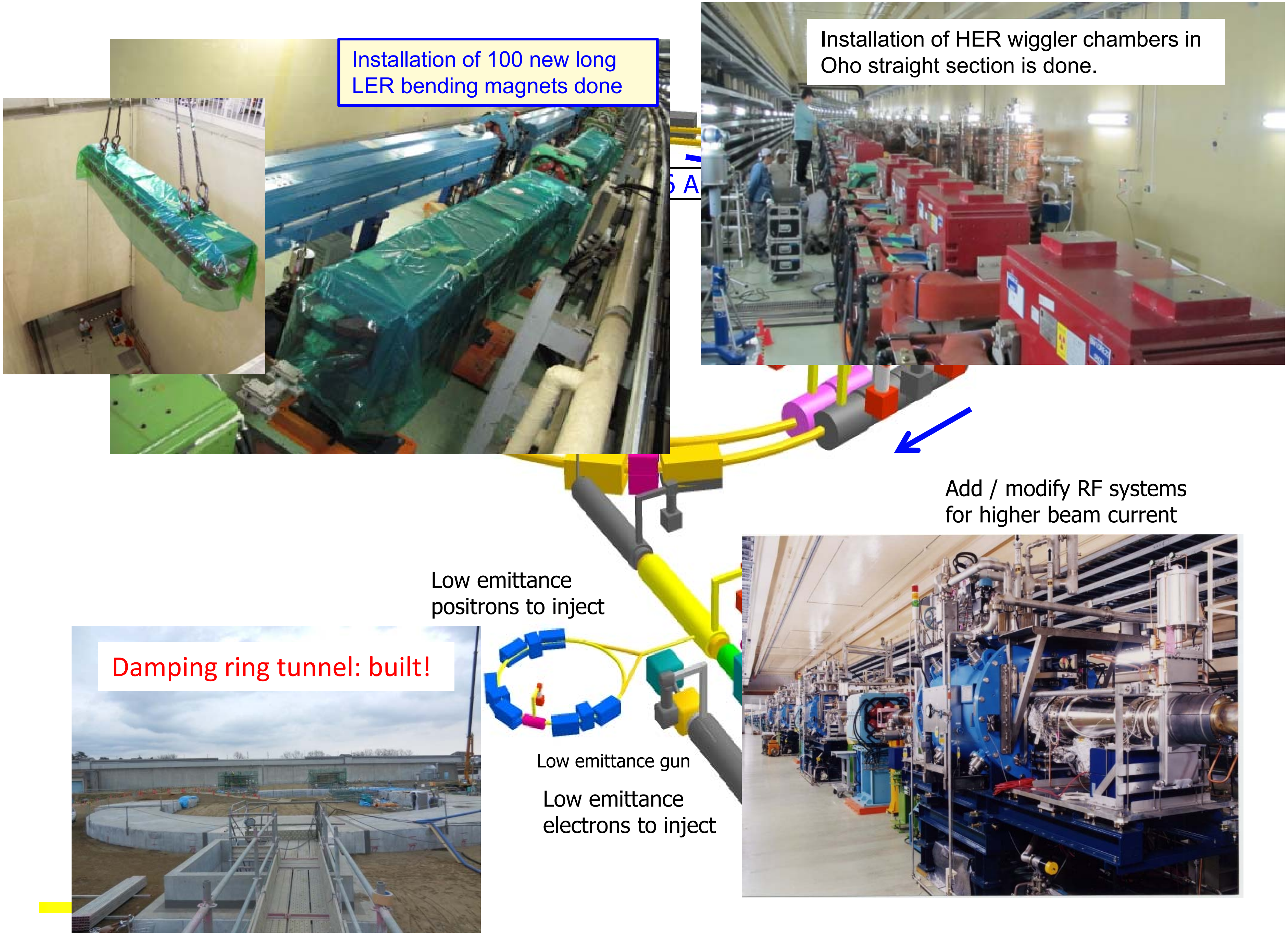
**"Nano-Beam" scheme**

***Collision with very small spot-size beams***

Invented by Pantaleo Raimondi for SuperB

# KEKB → SuperKEKB

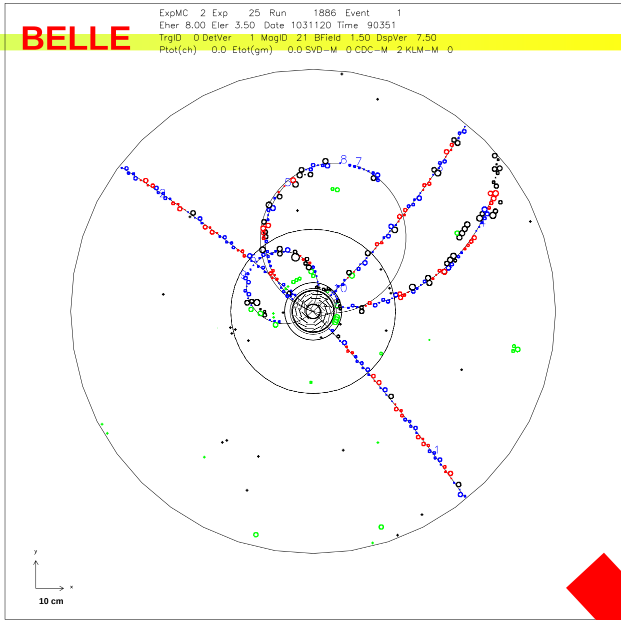


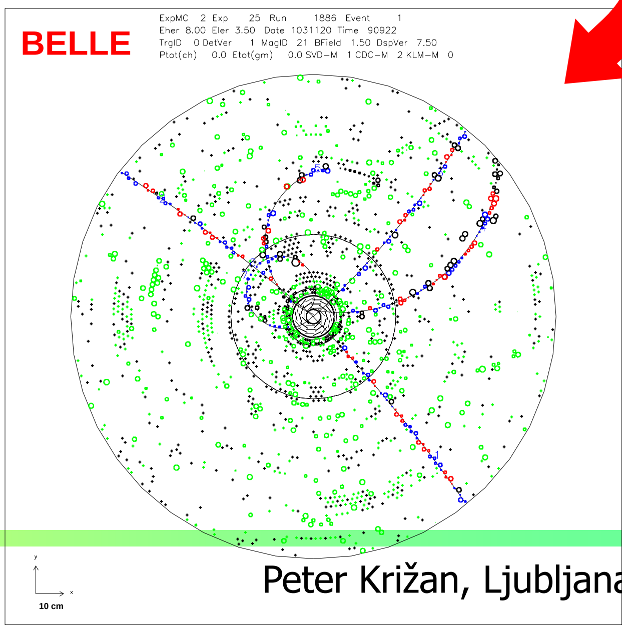

Installation of 100 new long LER bending magnets done
Installation of HER wiggler chambers in Oho straight section is done.
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Damping ring tunnel: built!
Low emittance gun
Low emittance electrons to inject

# 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"



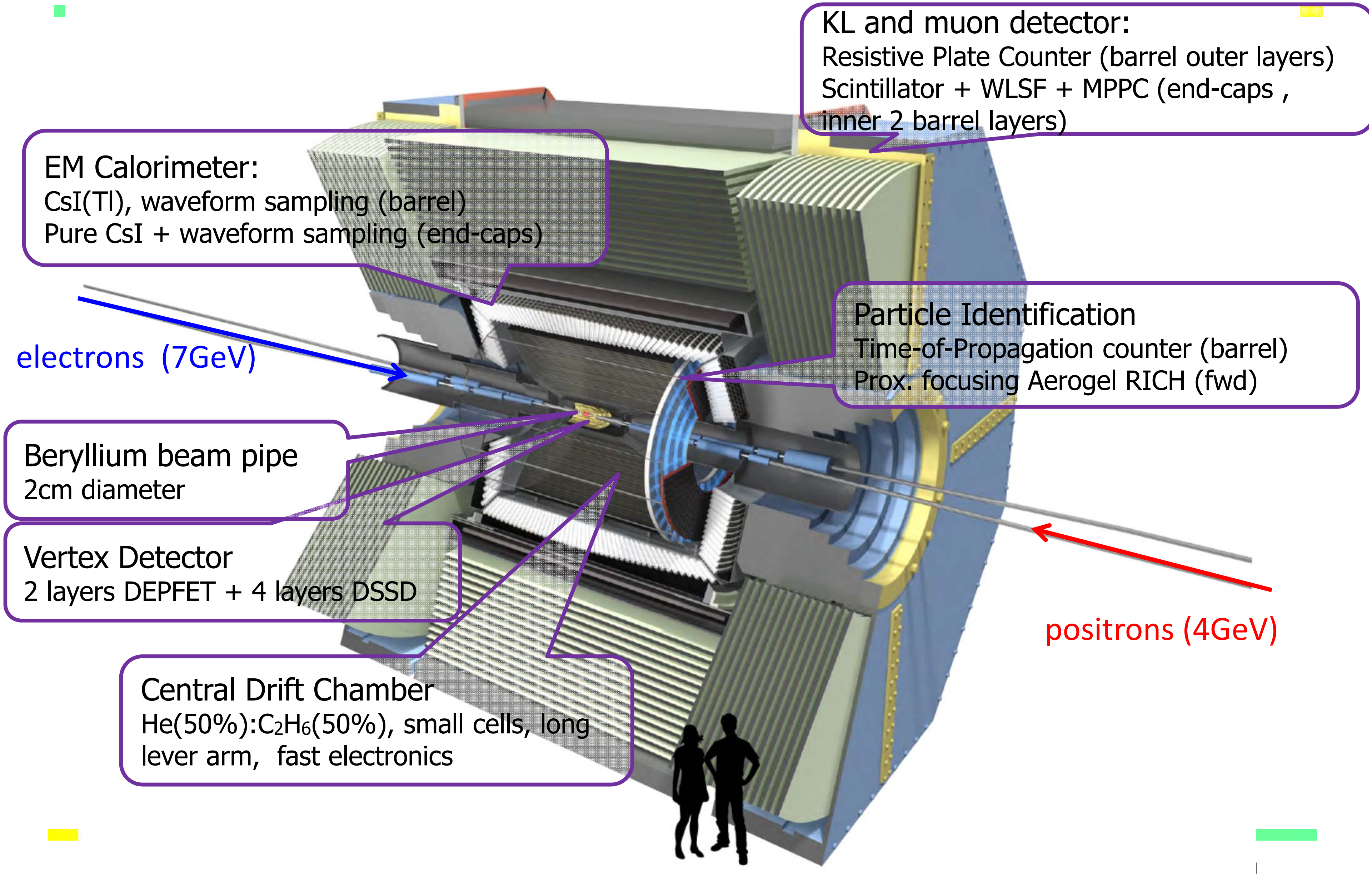




Solutions:

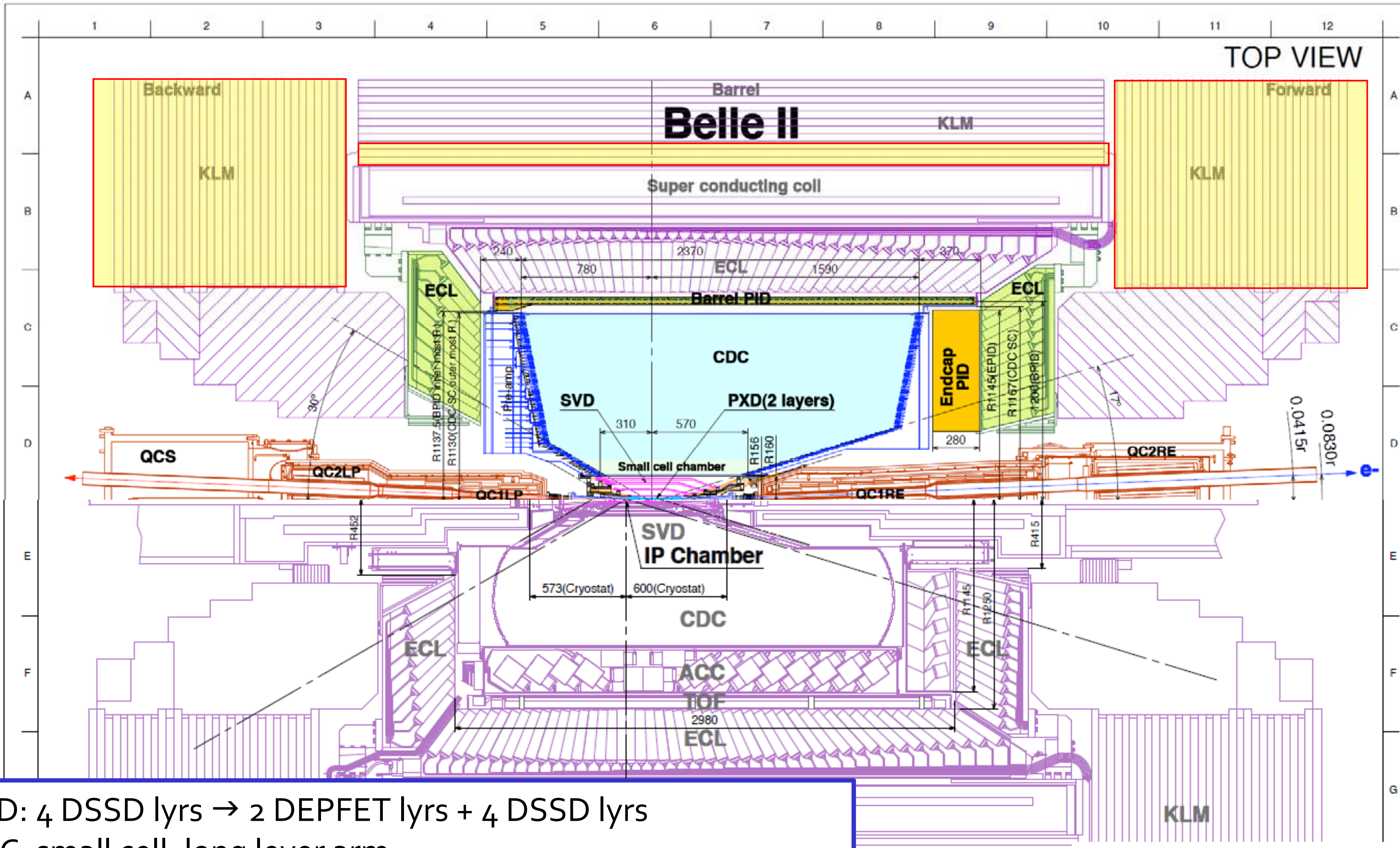
- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter crystals
- Faster readout electronics and computing system.

Belle II TDR, arxiv:1011.0352v1[physics.ins-det]

# Belle II Detector



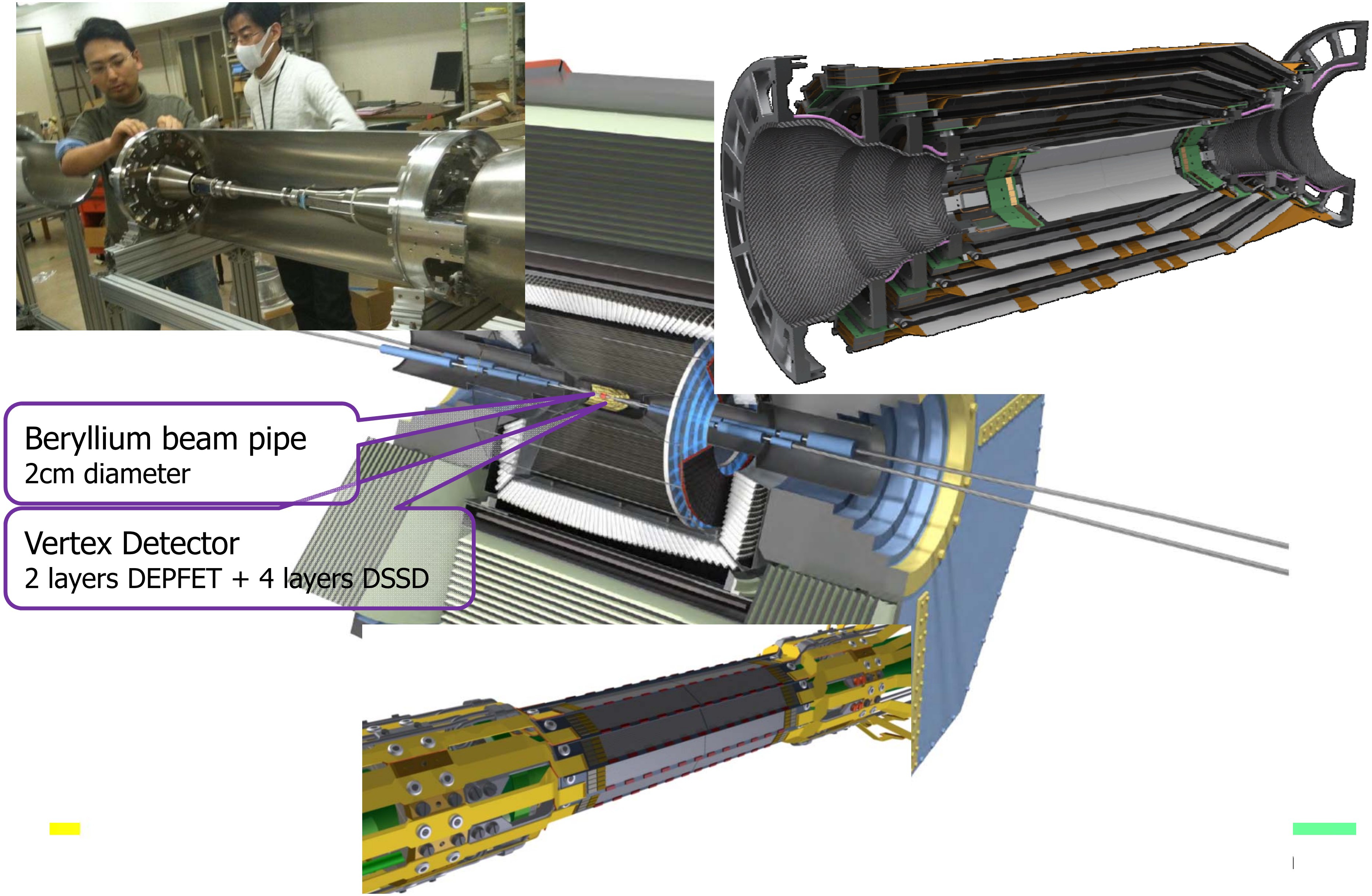
# Belle II Detector (in comparison with Belle)



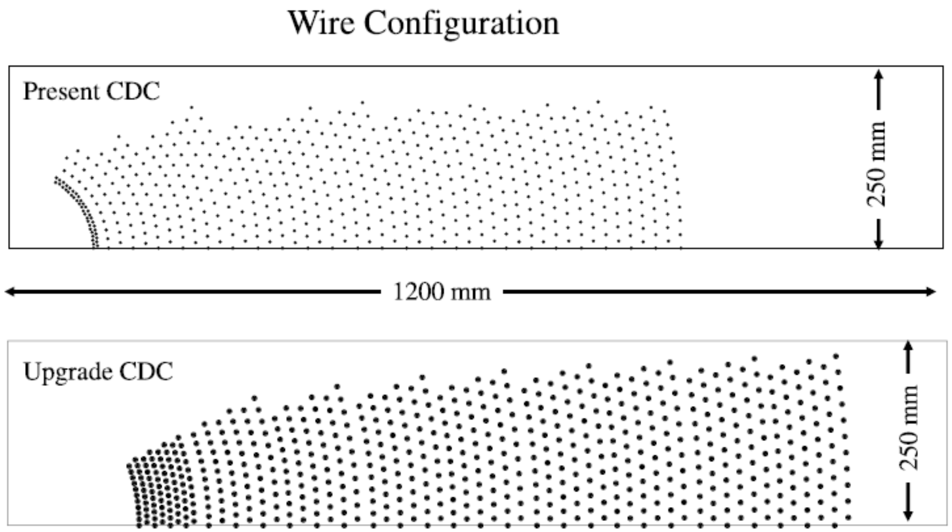

SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

In colours: new components

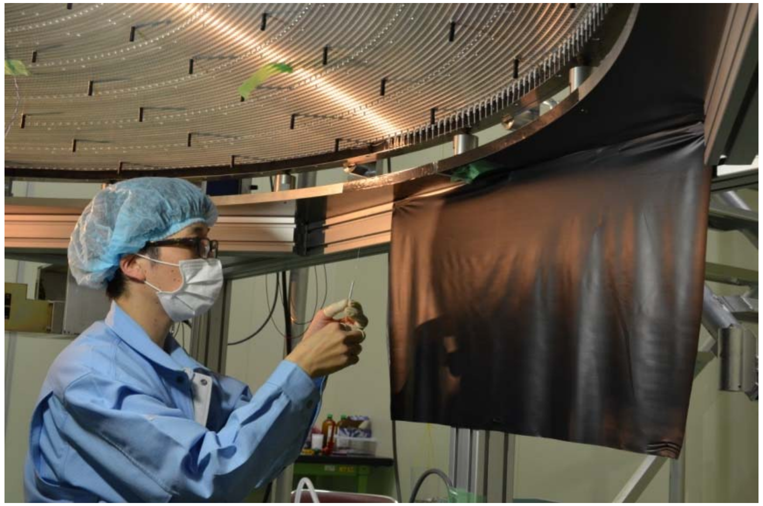
# Belle II Detector – vertex region



# Belle II CDC




Much bigger than in Belle!

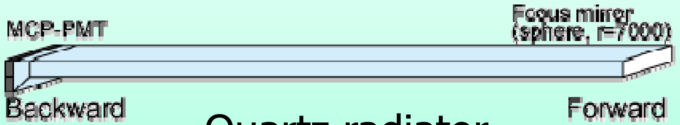


Wire stringing in a clean room

- thousands of wires,
- 1 year of work...

# Particle Identification Devices

## Barrel PID: Time of Propagation Counter (TOP)



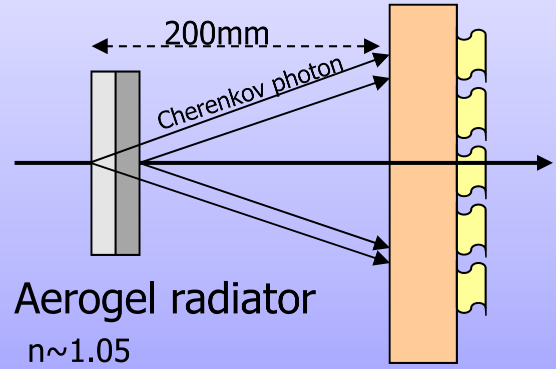

Quartz radiator

Focusing mirror

Small expansion block

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

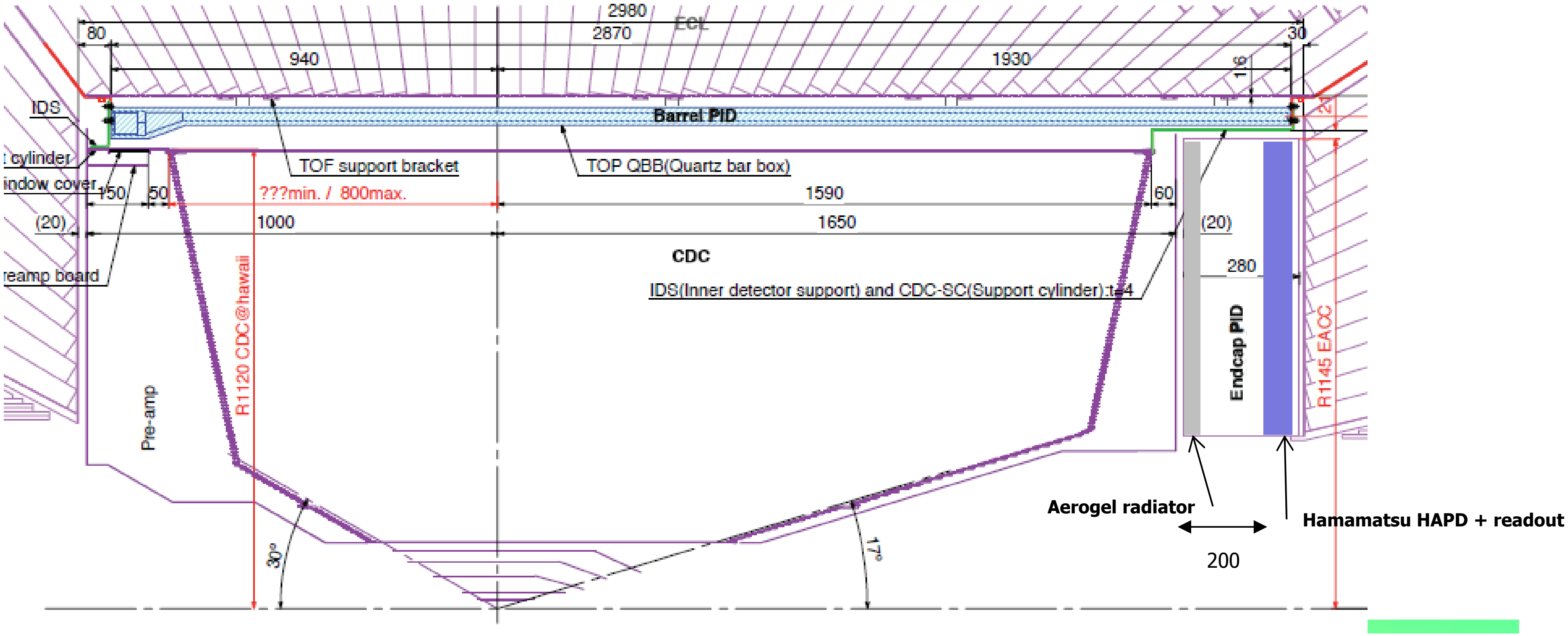
## Endcap PID: Aerogel RICH (ARICH)



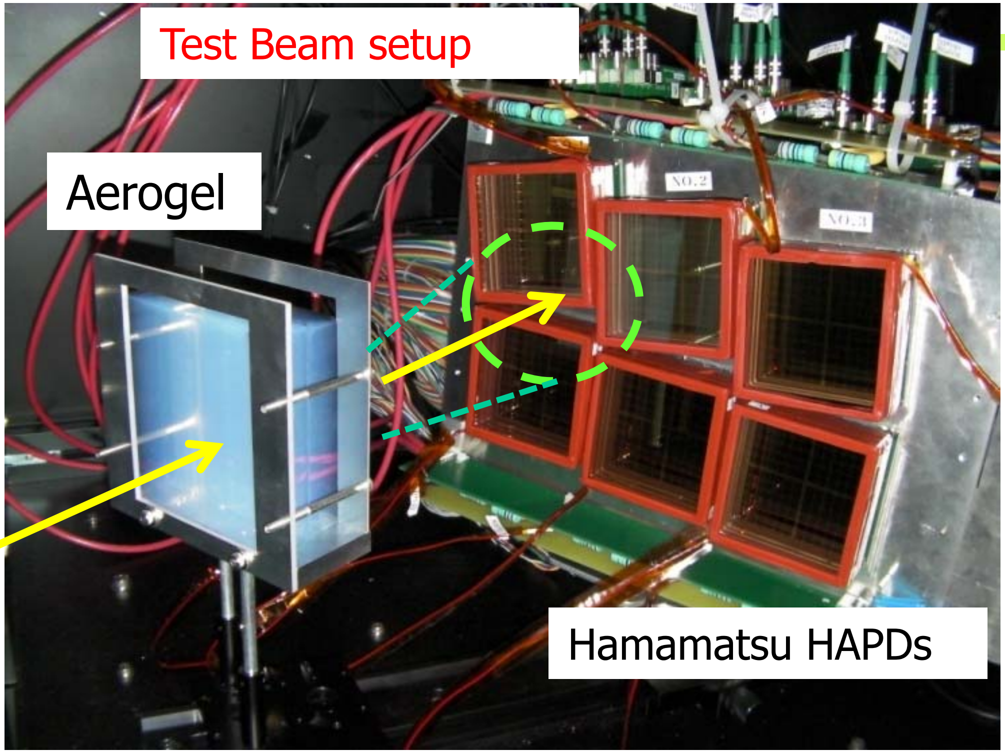

Aerogel radiator

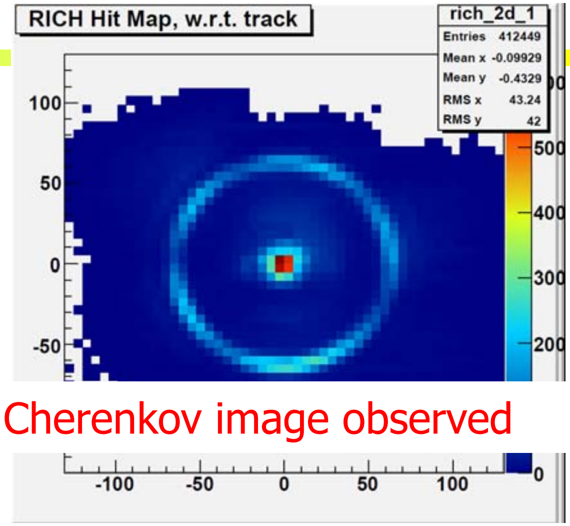
n~1.05

Hamamatsu HAPD



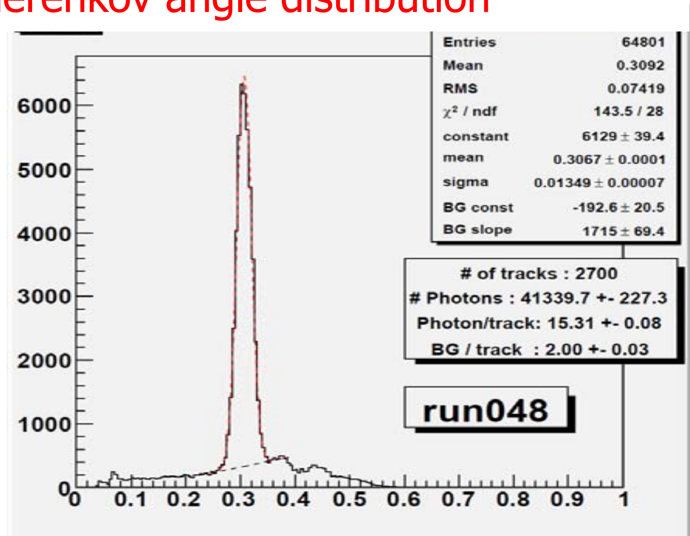
# Aerogel RICH (endcap PID)



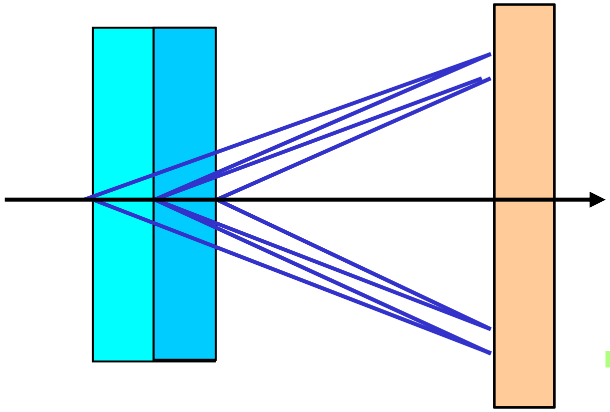




Clear Cherenkov image observed

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

# The Belle II Collaboration

A very strong group of ~480 highly motivated scientists!

# SuperKEKB/Belle II Status

Funding

- ~100 MUS for machine approved in 2009 -- 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.

Fortunately little damage during the March 2011 earthquake → no delay

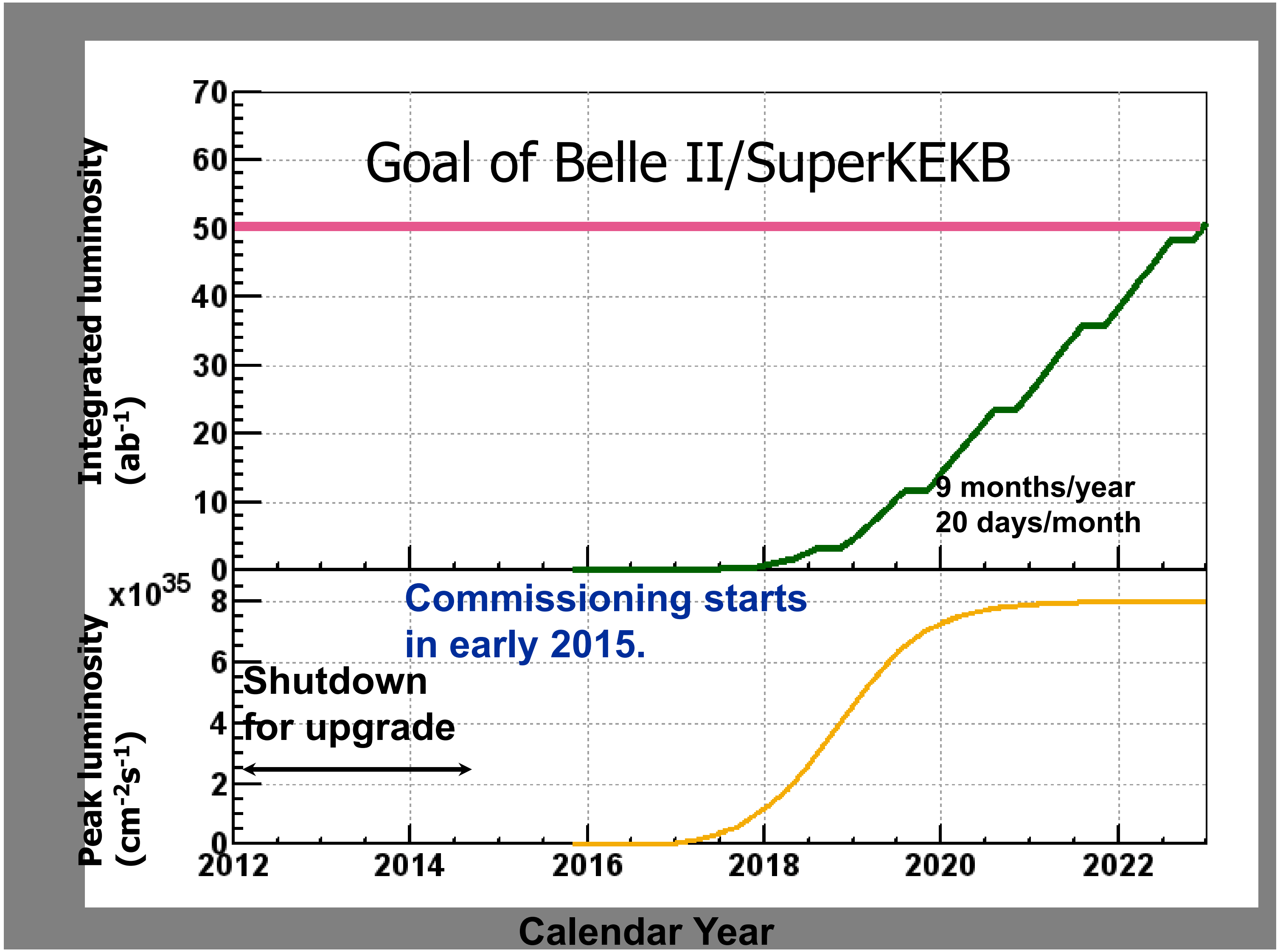


Ground breaking ceremony in November 2011

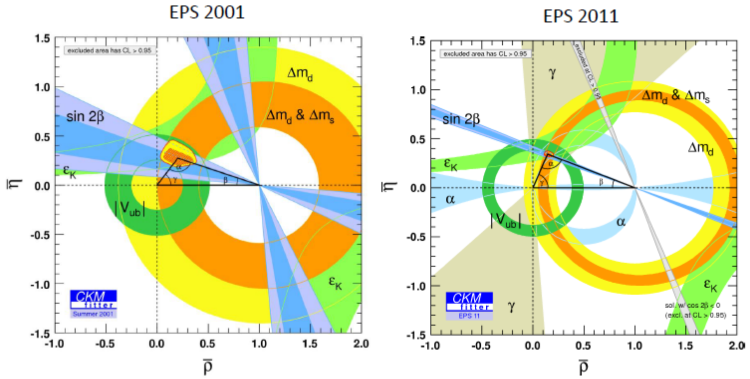
SuperKEKB and Belle II construction proceeds according to the schedule.

The Italian super B factory project SuperB was unfortunately canceled, some of the former SuperB collaborators have joined/will join Belle II.

# SuperKEKB luminosity 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 surpassing design perfomance
- Super B factory at KEK under construction 2010-15 → SuperKEKB+Belle II, L x40, construction at full speed – the biggest particle physics project under preparation
- Expect a new, exciting era of discoveries, complementary to the LHC