Very forward region in Belle: physics impact and opportunities

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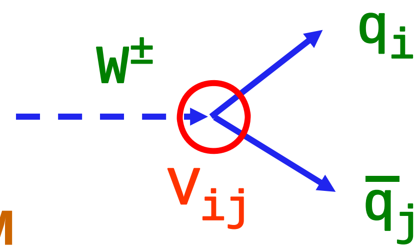
Contents

- Belle: highlights and plans
- Processes with missing particles
- Impact of instrumenting the forward region
- Summary

B factory physics program

B factory main task: **measure CP violation in the system of B mesons**

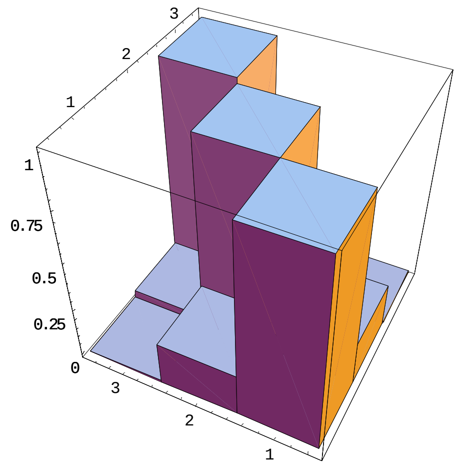
specifically: various measurements of complex elements of Cabbibo-Kobayashi-Maskawa matrix



CKM matrix is unitary

deviations could signal processes not included in SM

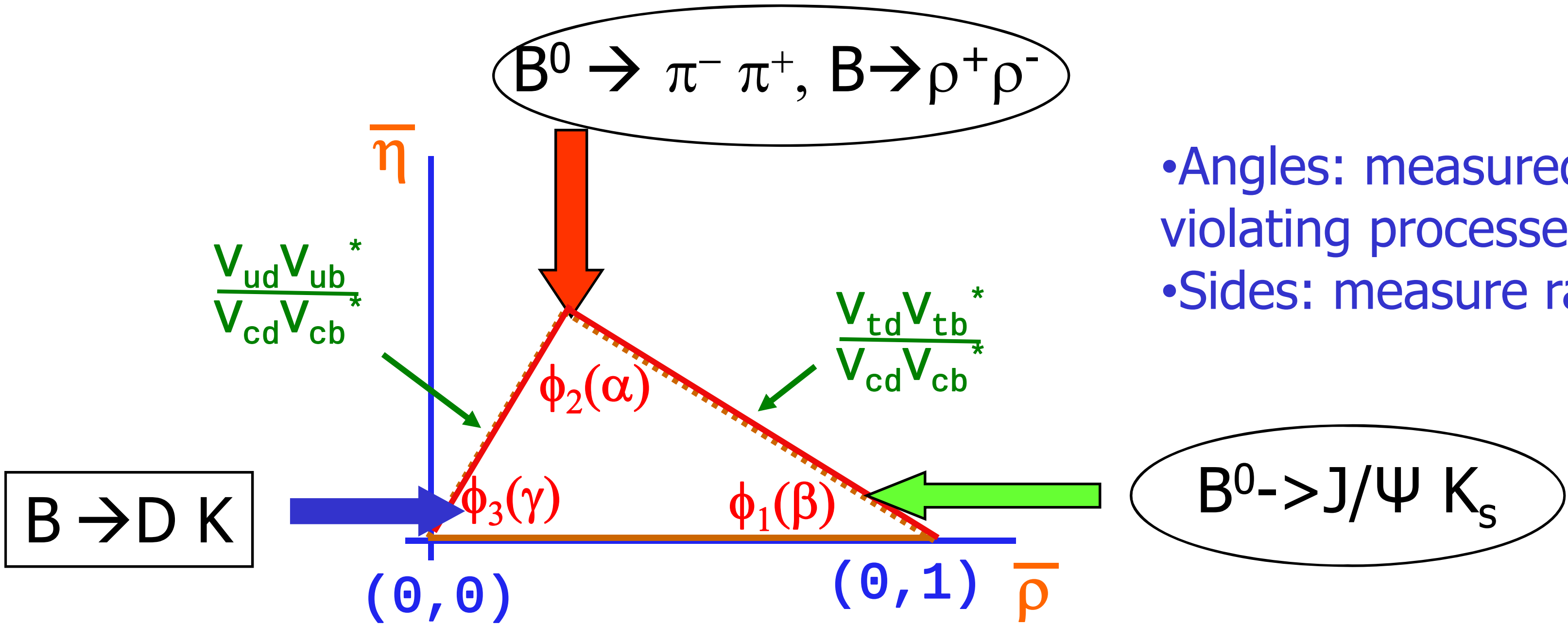
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$



Unitarity triangle

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

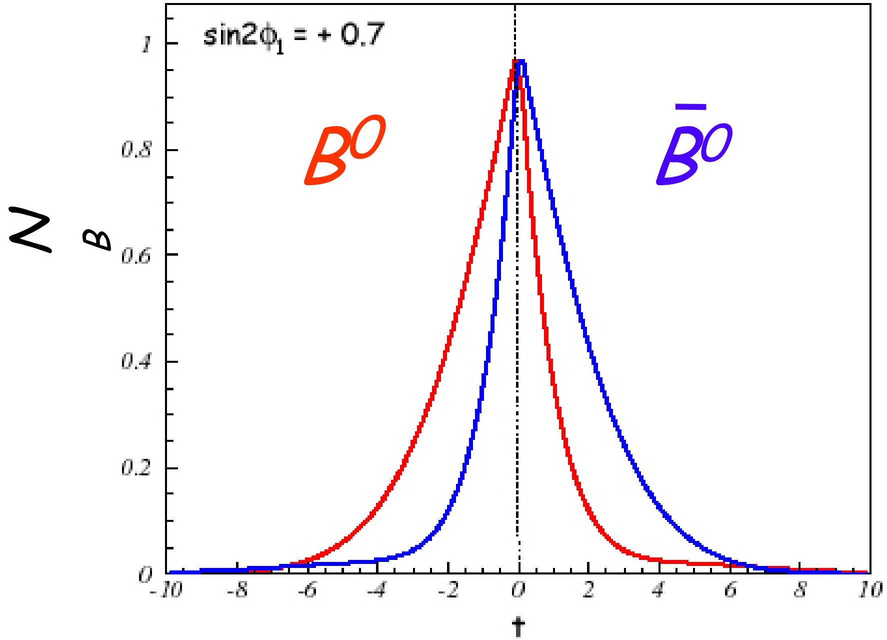
→Triangle in the complex plane

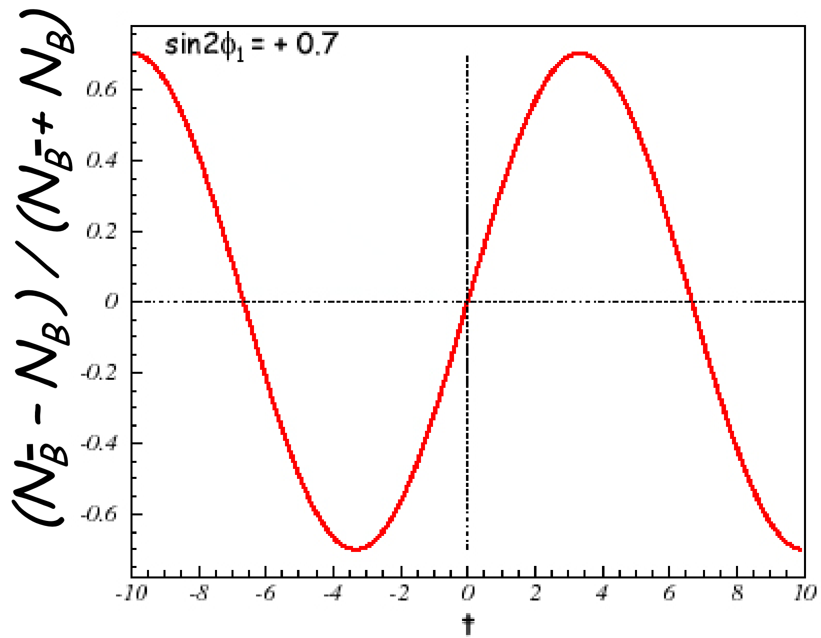


- Angles: measured in CP violating processes
- Sides: measure rates

Big Questions: *Are determinations of* ***angles*** *consistent with determinations of the* ***sides*** *of the triangle? Are angle determinations from* ***loop*** *and* ***tree*** *decays consistent?*

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

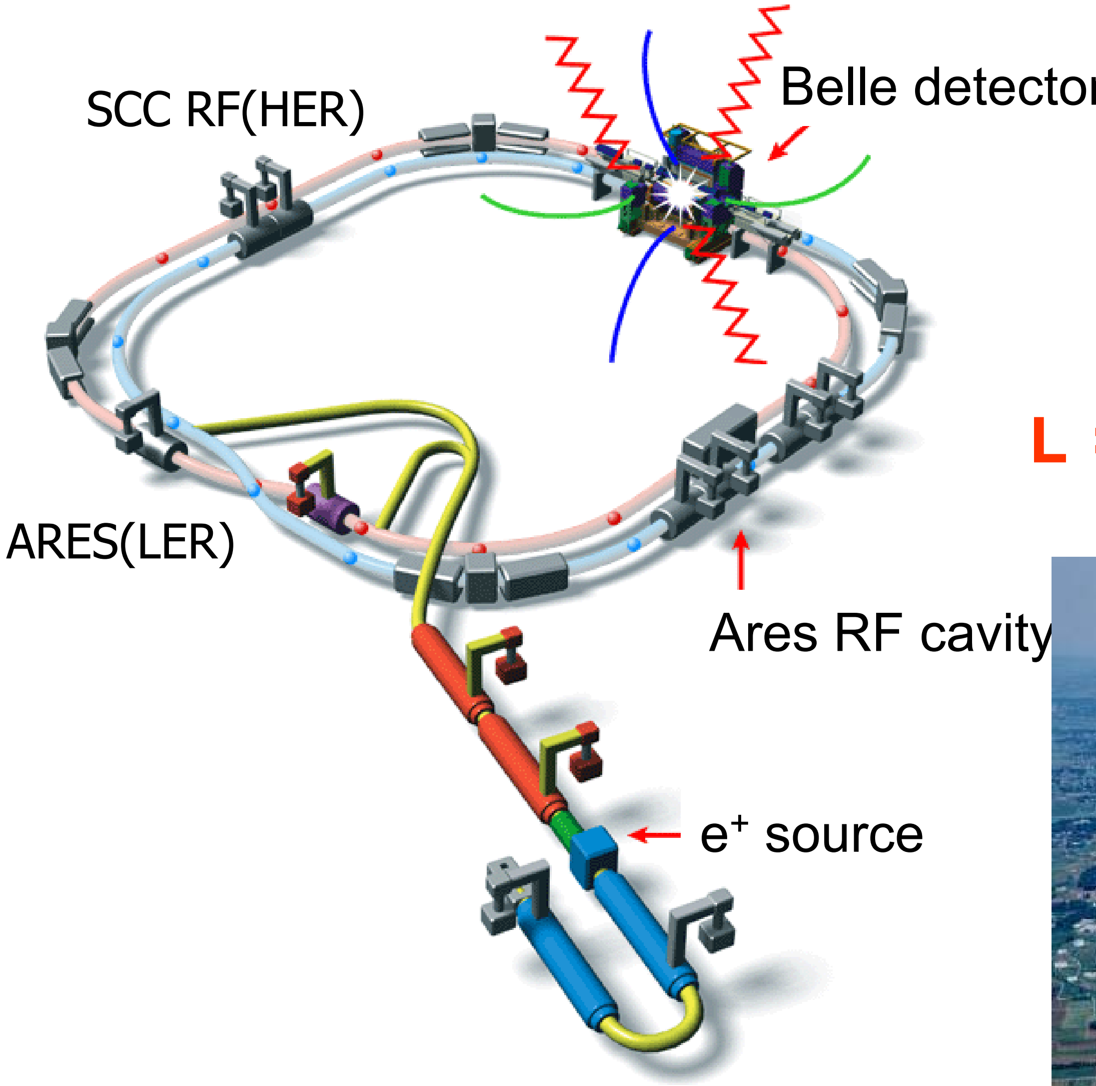




$$A_{CP}(t)=\frac{\Gamma(\overline{B}^{0}(t)\to f_{CP})-\Gamma(B^{0}(t)\to f_{CP})}{\Gamma(\overline{B}^{0}(t)\to f_{CP})+\Gamma(B^{0}(t)\to f_{CP})}=-\xi_f \sin 2\phi_1 \sin\Delta m_B t$$

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

The KEKB collider



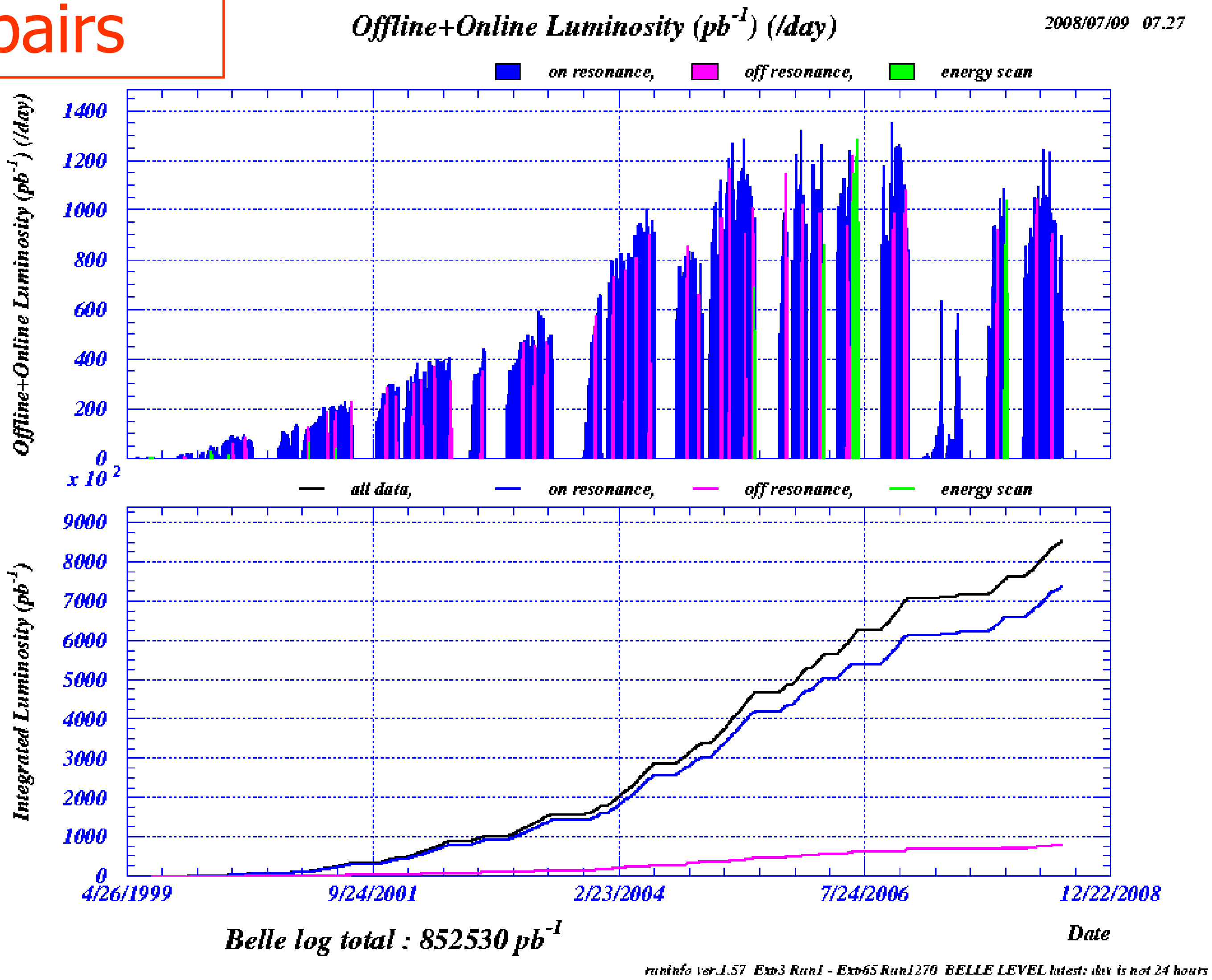
8 x 3.5 GeV
22mrad crossing angle

World record:

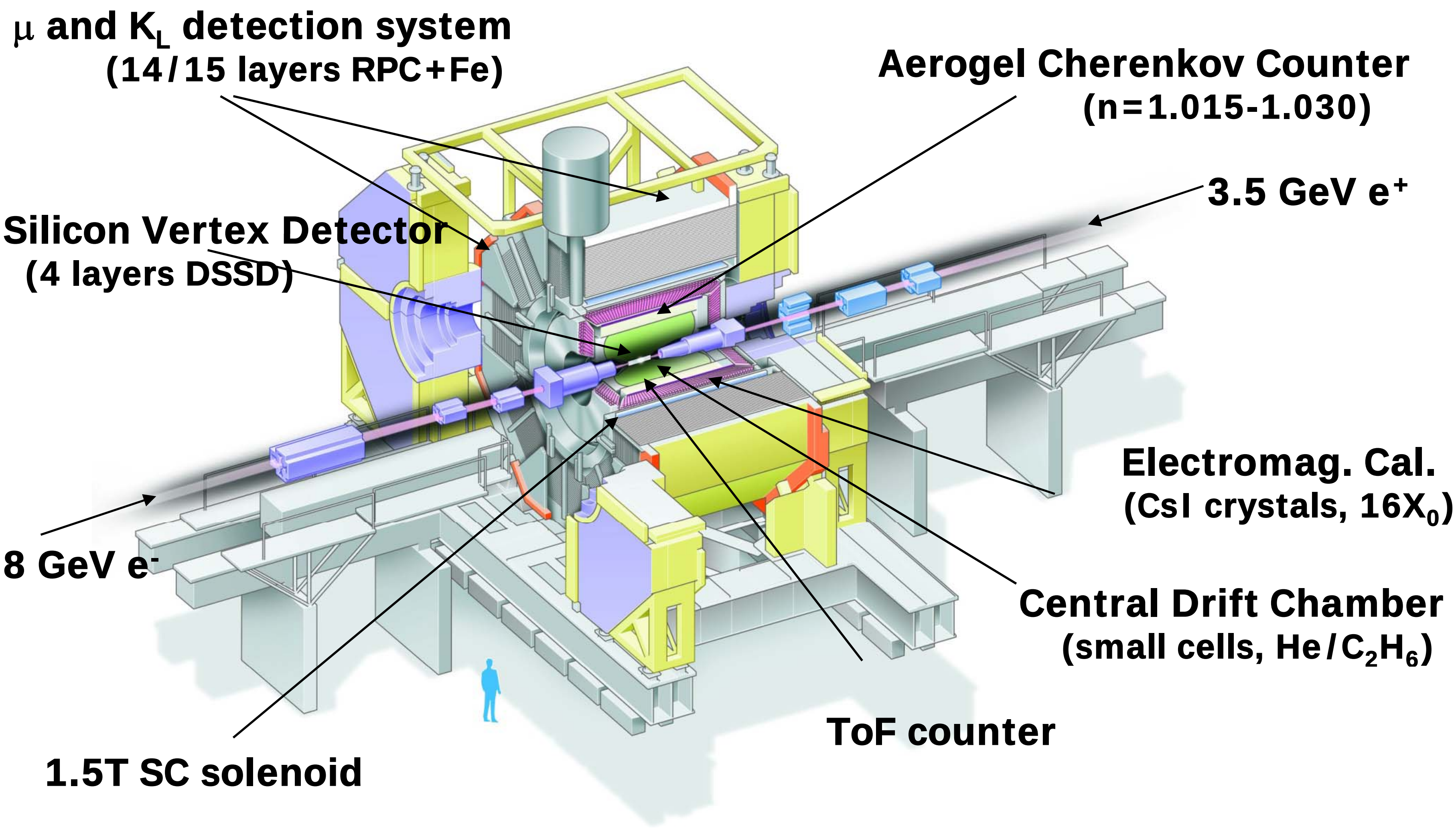
$L = 1.7 \times 10^{34} / cm^2 / sec$

KEKB collider: luminosity record

Accumulated 852 fb^{-1}
→ ~900 M BB-pairs

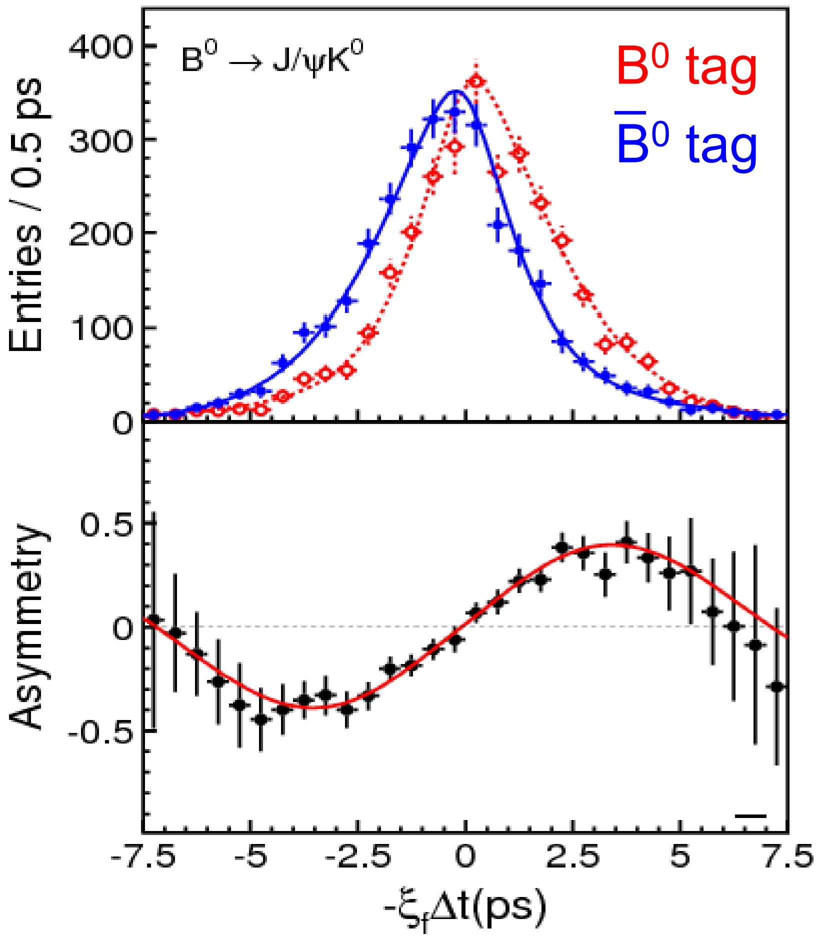


Belle spectrometer at KEK-B



CP violation in the B system

CP violation in B system: from the discovery in $B^0 \to J/\Psi\ K_s$ decays (2001) to a precision measurement (2006)



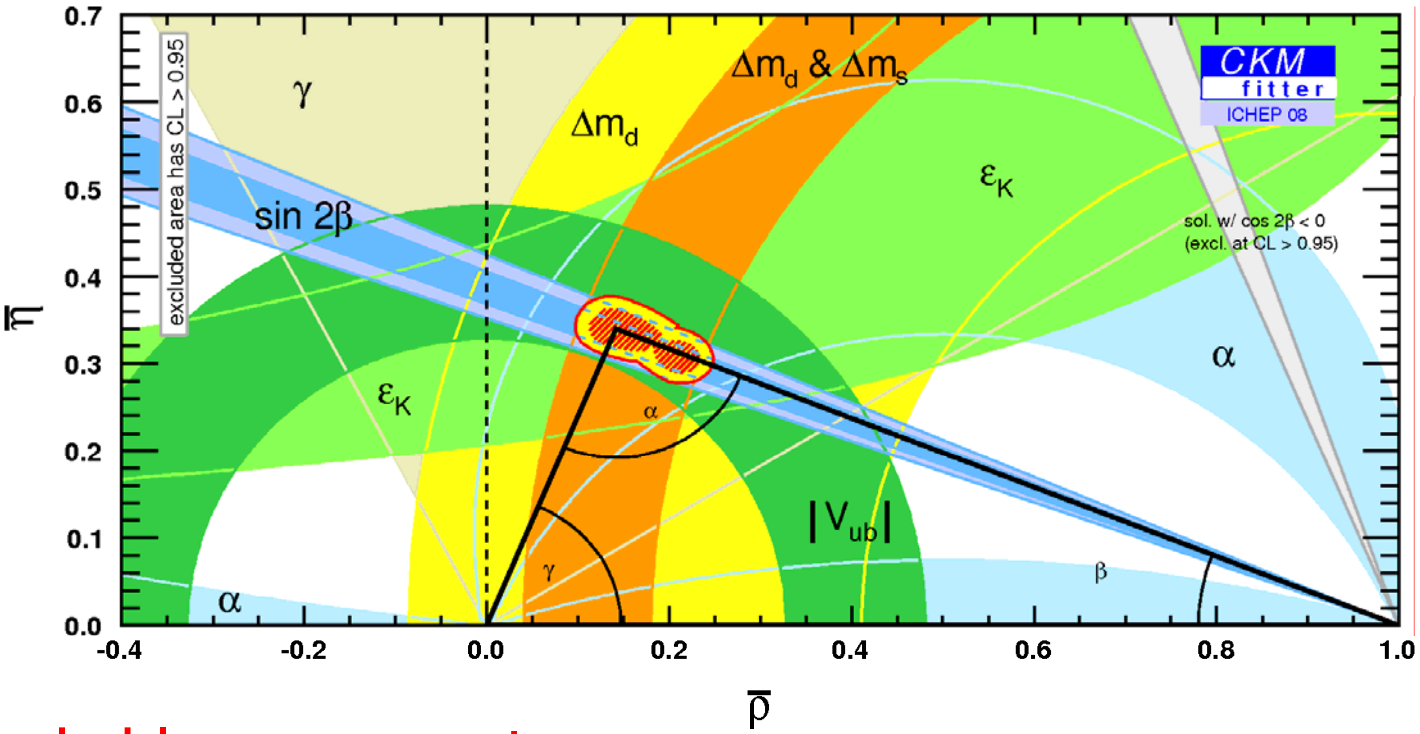
$\sin 2\phi_1 = \sin 2\beta$ from $b \to c\bar{c}s$

535 M $B\overline{B}$ pairs

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

All measurements combined...

Constraints from measurements of angles and sides of the unitarity triangle →



→ Remarkable agreement

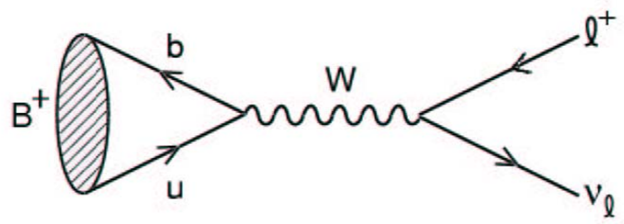
(appart from a small inconsistency in V_{ub})

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., $B \to \tau\nu$, $D\tau\nu$) by fully reconstructing the other B meson
- Observation of D mixing
- CP violation in $b \to s$ transitions: probe for new sources of CPV
- Forward-backward asymmetry (A_{FB}) in $b \to s l^+ l^-$ has become a powerfull tool to search for physics beyond SM.
- Observation of new hadrons

Purely leptonic decay B→τ ν

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



- Branching fraction

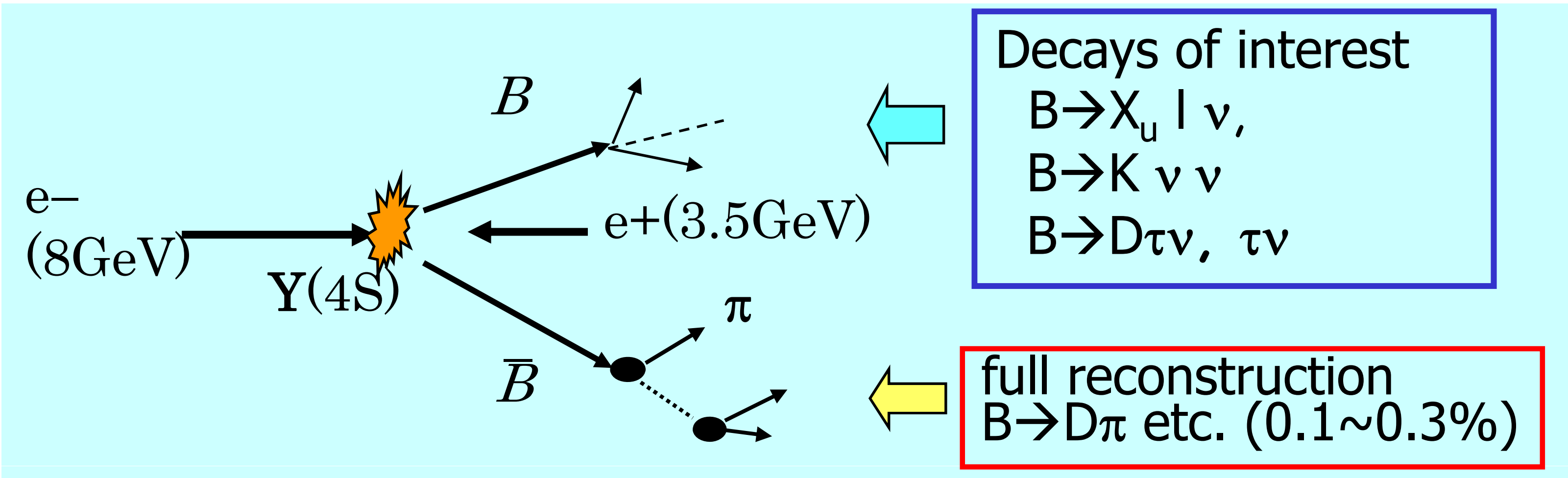
$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

- Provide information of $f_B|V_{ub}|$
  - $|V_{ub}|$ from $B \to X_u\, l\, \nu$ ➡ f_B ⟺ cf) Lattice
  - $Br(B\to\tau\nu)/\Delta m_d$ ➡ $|V_{ub}| / |V_{td}|$

- Limits on charged Higgs

Full Reconstruction Method

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

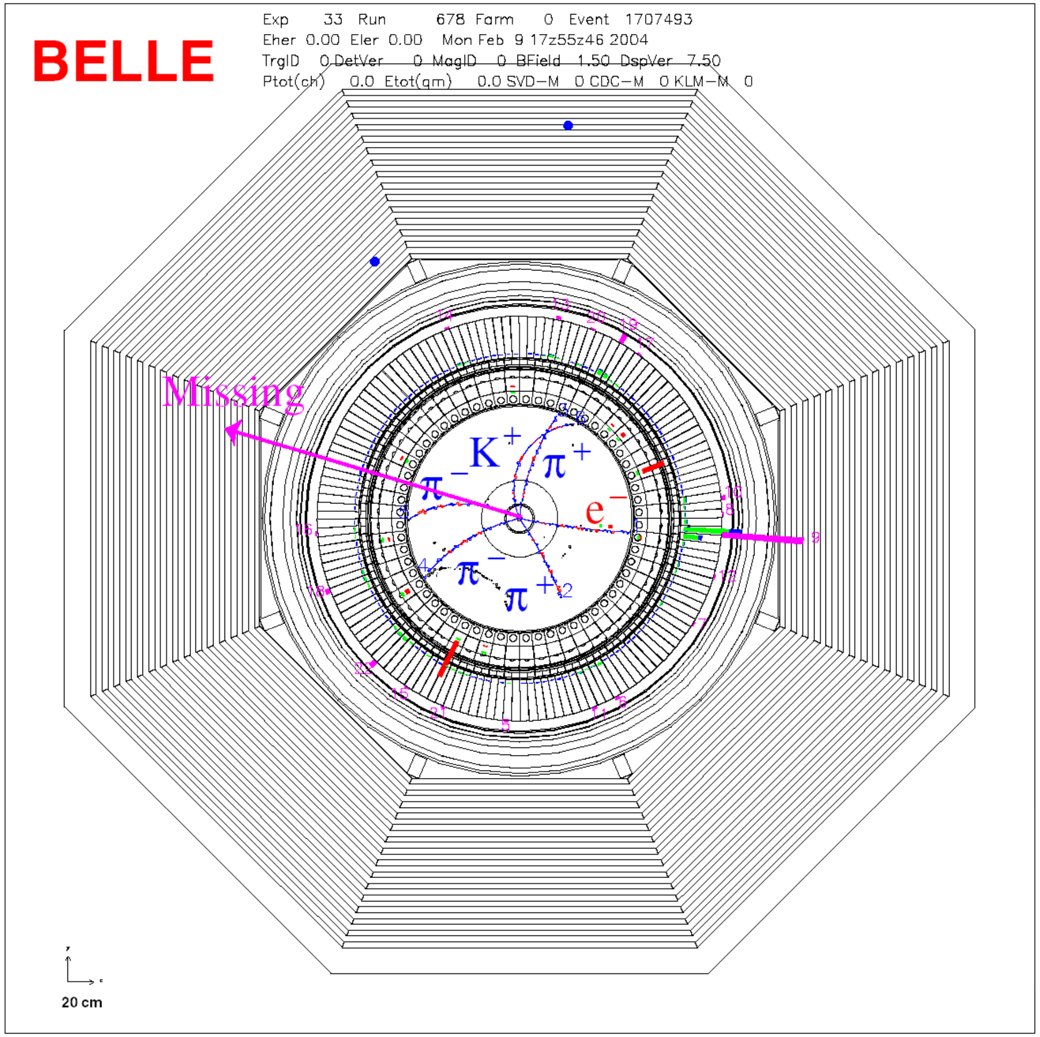


→ Offline B meson beam!

Powerful tool for B decays with neutrinos

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

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



$B \to \tau \nu$

τ decay modes

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

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

- Cover 81% of τ decays
- Efficiency 15.8%

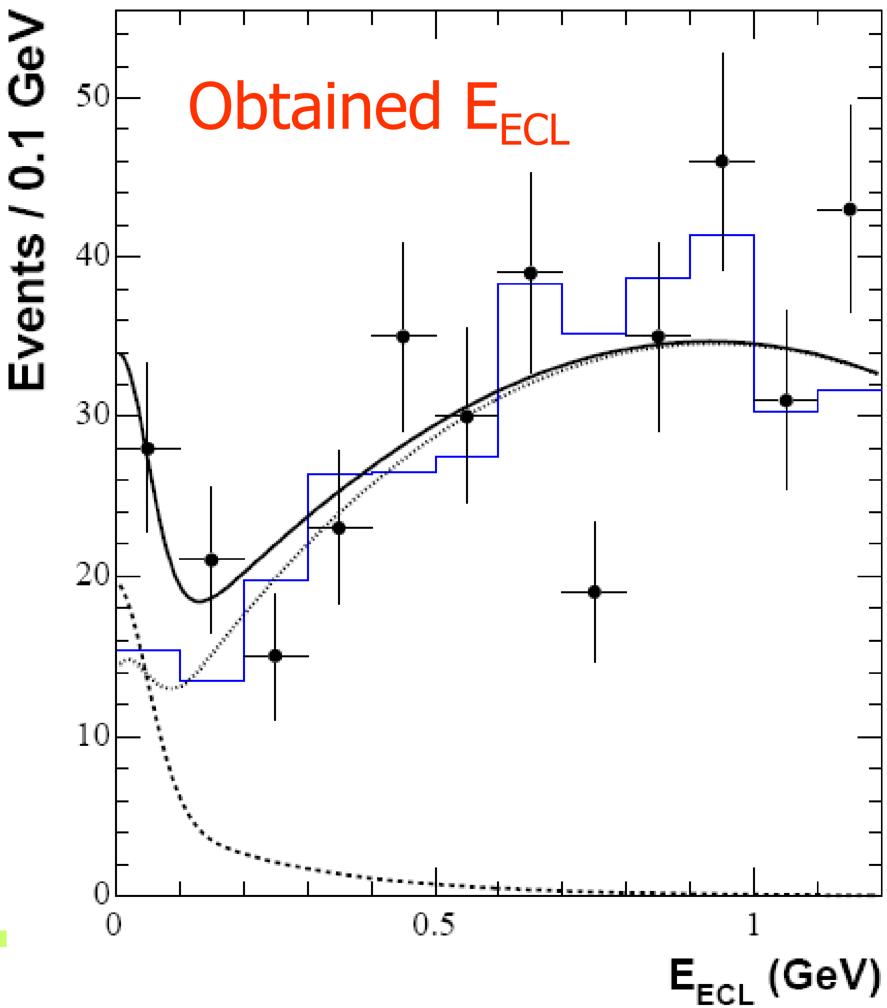
Event selection

- Main discriminant: extra neutral ECL energy

Fit to $E_{residual}$ → $17.2^{+5.3}_{-4.7}$ signal events.

→3.5σ significance including systematics

PRL,



$B \to \tau \nu_\tau$

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

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

→ Product of B meson decay constant f_B and CKM matrix element $|V_{ub}|$

$$f_B \times V_{ub} = \left(10.1^{+1.6+1.3}_{-1.4-1.4}\right) \times 10^{-4}\, GeV$$

Using $|V_{ub}| = (4.39 \pm 0.33) \times 10^{-3}$ from HFAG

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

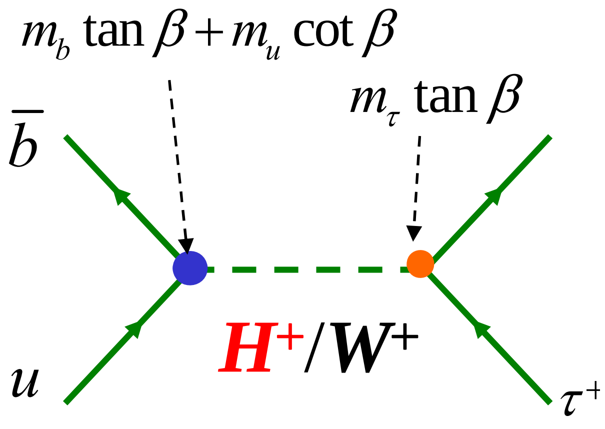
15% 15% = 13%(exp.) + 8%(V_{ub})

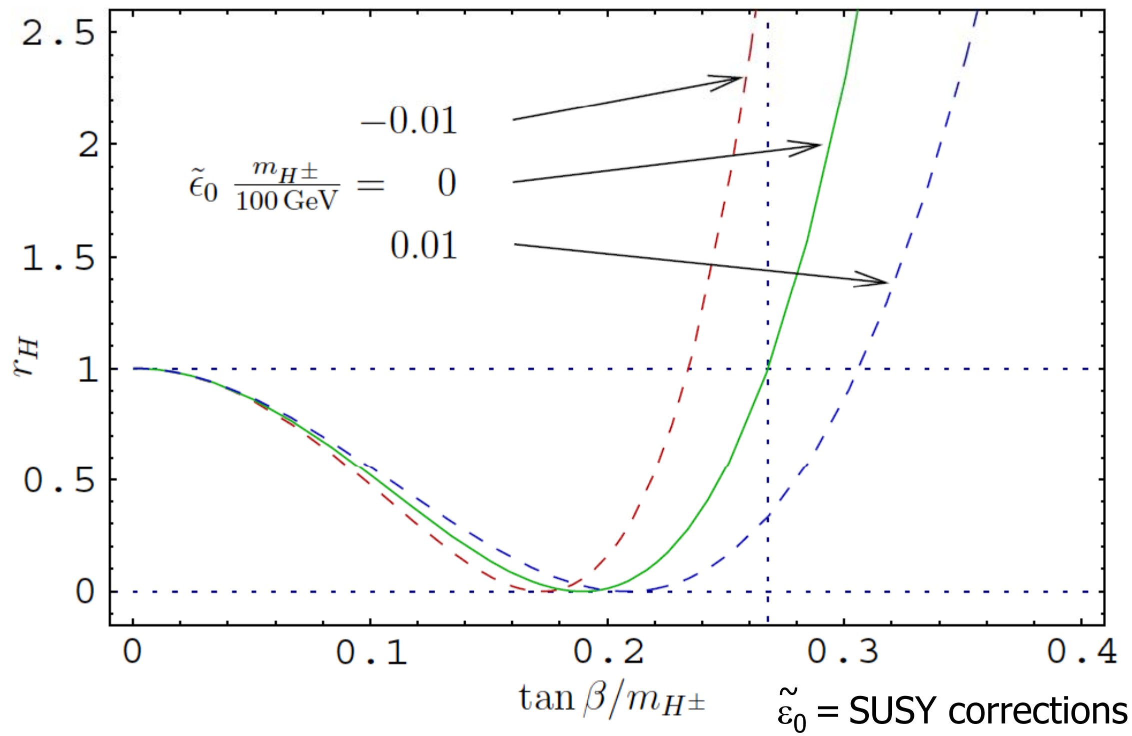
First measurement of f_B!

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

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

Charged Higgs contribution to B→τ ν





$\tilde{\varepsilon}_0$ = SUSY corrections to b Yukawa coupling

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\rm SM} \times r_H,$$

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

The interference is destructive in 2HDM (type II). $B > B_{SM}$ implies that H^+ contribution dominates

Phys. Rev. D **48**, 2342 (1993)

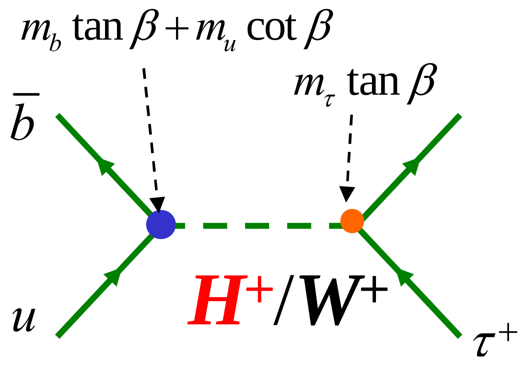
SM: B (B→τν)= ($0.78 ^{+0.09}_{-0.13}$) x 10^{-4} (CKM fitter 2008 prediction)

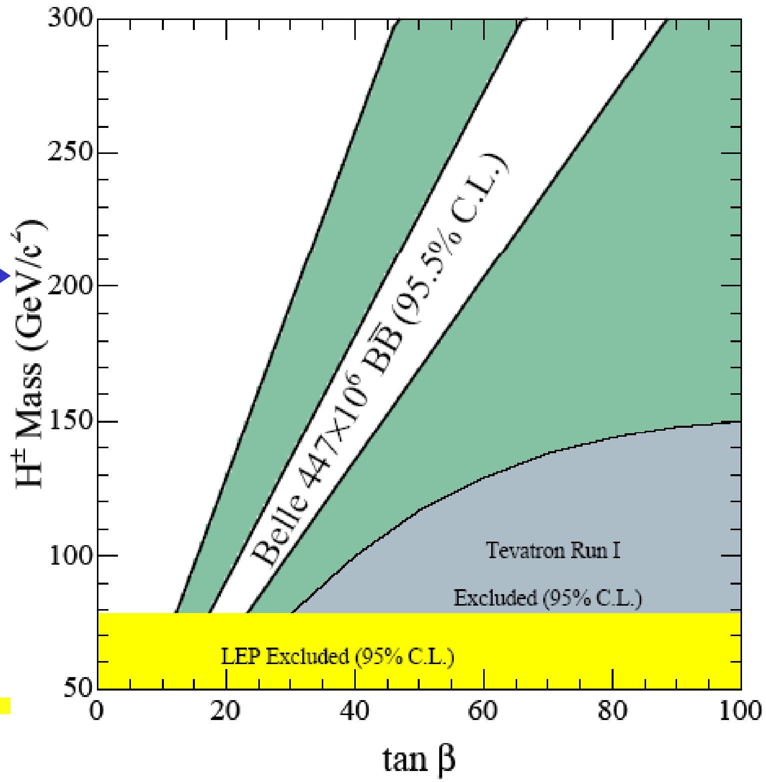
Charged Higgs limits from $B^- \to \tau^- \nu_\tau$

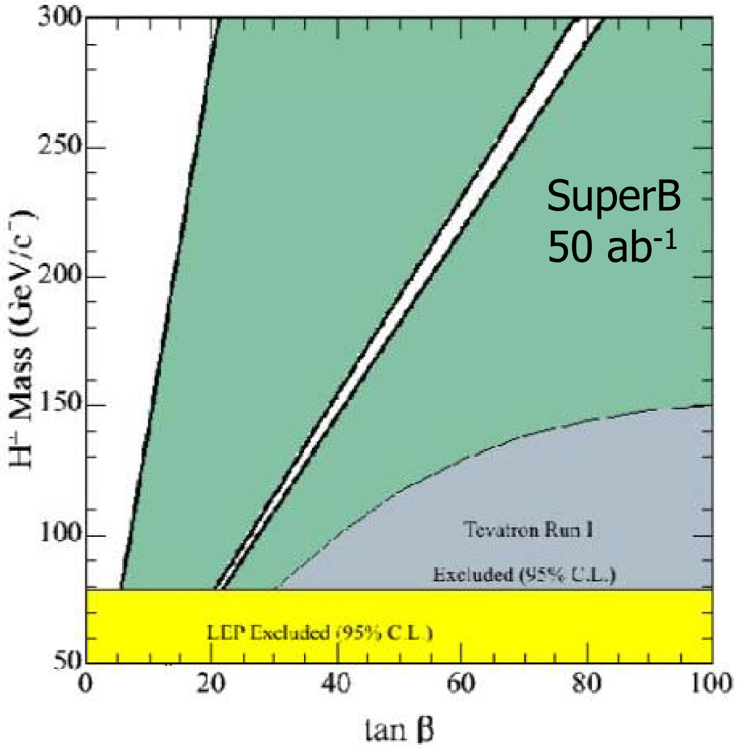
If the theoretical prediction is taken for $\mathbf{f_B}$

→ limit on charged Higgs mass vs. tanβ

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







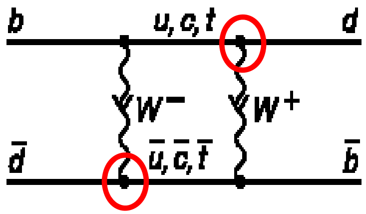
Physics at a Super B Factory

- There is a good chance to see new phenomena;
  - **CPV in B decays from the new physics (non KM).**
  - **Lepton flavor violations in τ decays.**
- They will help to diagnose (if found) or constraint (if not found) new physics models.
- Even in the worst case scenario (such as MFV), $B\rightarrow\tau\nu$, $D\tau\nu$ 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 an unique way to search for the TeV scale physics.

Super B Factory Motivation 2

- A lesson from history: the top quark

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



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

- There are many more topics: CPV in charm, new hadrons, searches for light dark matter, ...

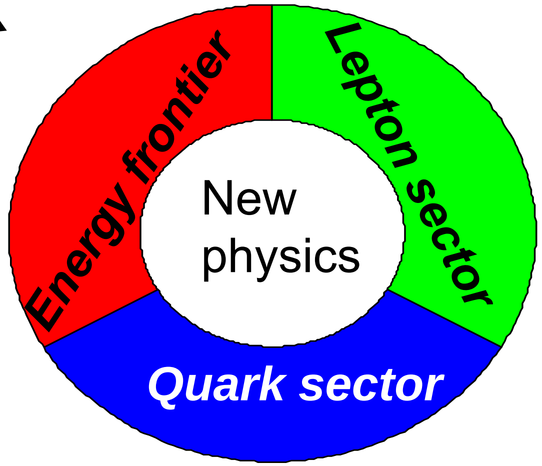
Super B factory: an important part of a broad unbiased approach to New Physics

ν experiments, g_μ-2, $\mu \rightarrow e\gamma$, etc.

LHC, ILC

Mass spectrum, interactions

ν mass and mixing, CPV, and LFV

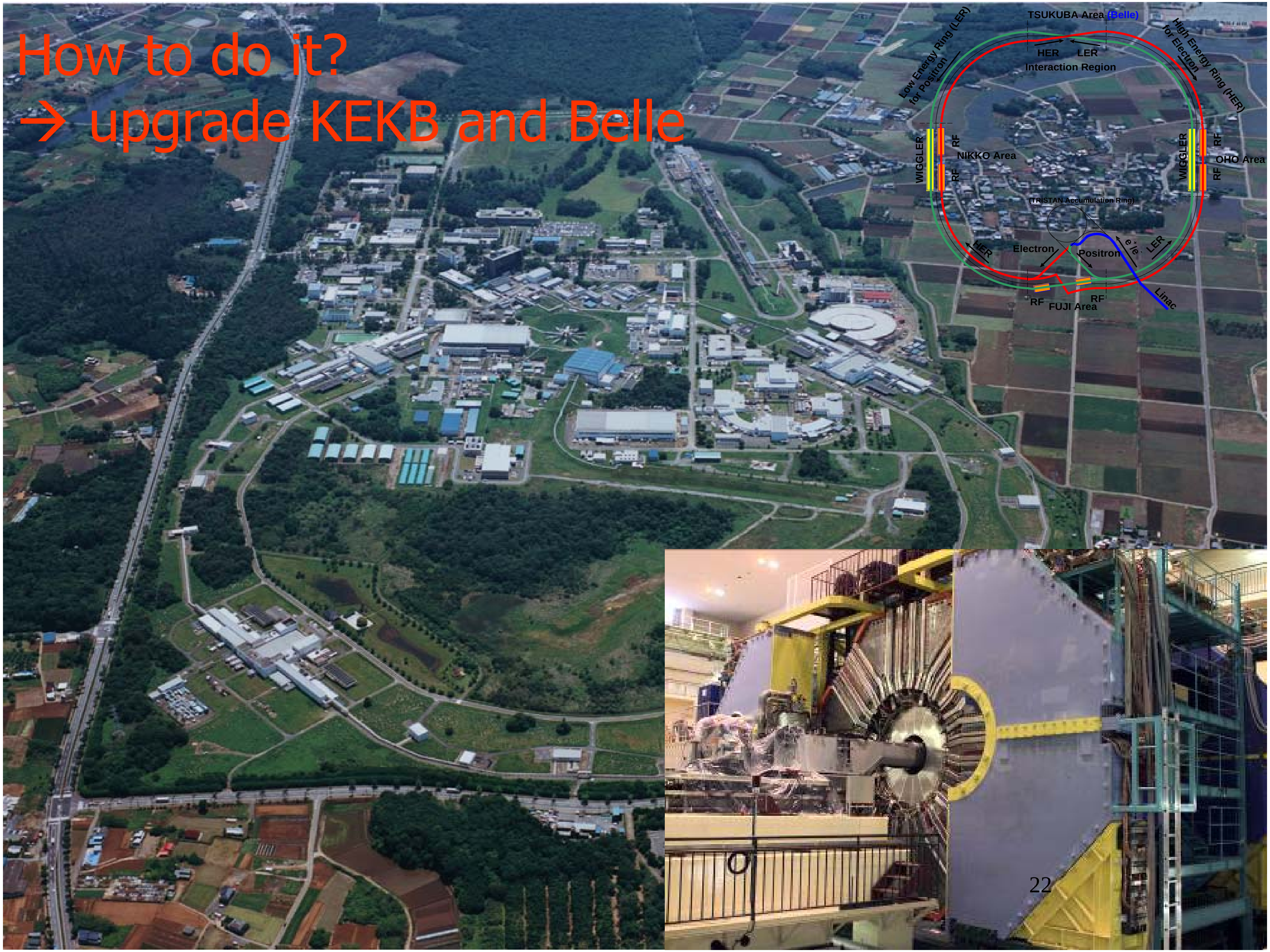


τ LFV, τ CPV

Flavor mixing, CP phases

Super B factory, LHCb, *K* experiments…

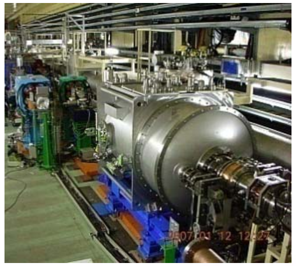
How to do it?
→ upgrade KEKB and Belle

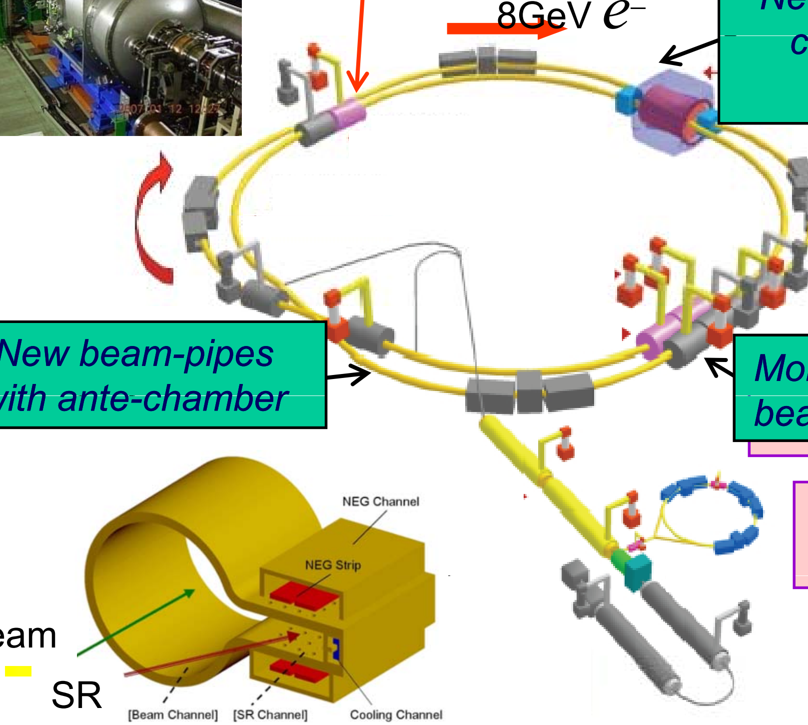


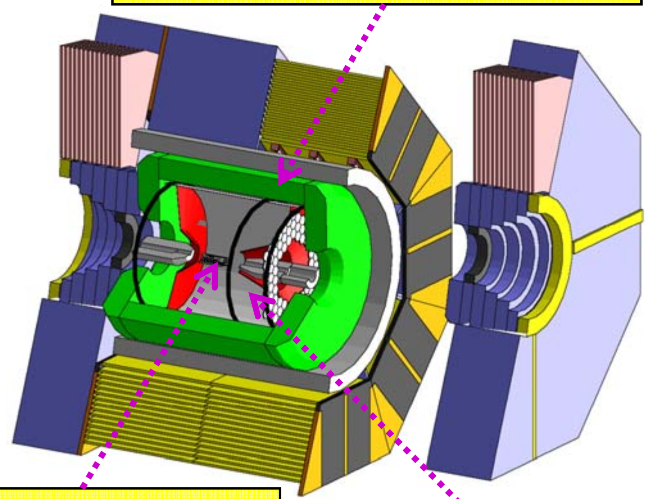
KEKB Upgrade Plan : Super-B Factory at KEK

- *Asymmetric energy e^+e^- collider at $E_{CM}=m(\Upsilon(4S))$ to be realized by upgrading the existing KEKB collider.*
- *Initial target:* *10×higher luminosity* $\cong 2\times10^{35}$/cm²/sec → 2×10^{9} $B\bar{B}$ *and* $\tau^+\tau^-$ *per yr.*

  after 3 year shutdown
- *Final goal:* $L=8\times10^{35}$/cm²/sec *and* $\int L\,dt$ = 50 ab^{-1}





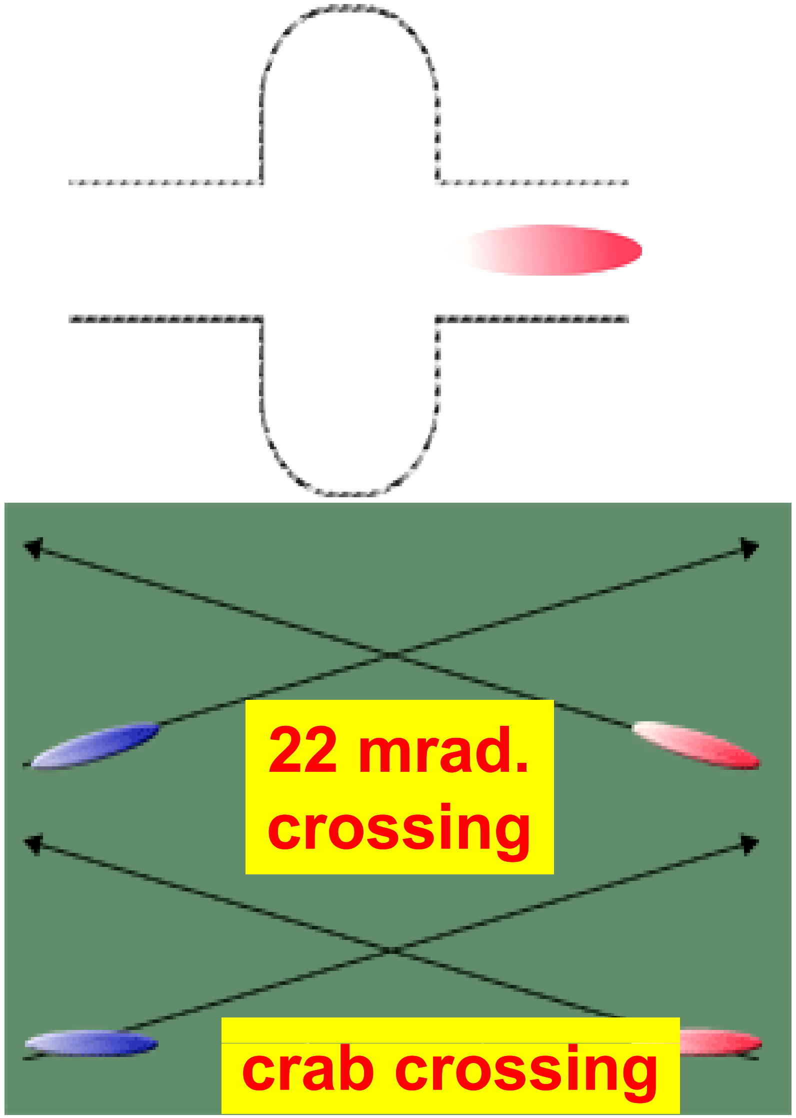


Luminosity gain and upgrade items (preliminary)

3 years shutdown

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

Crab cavity commissioning

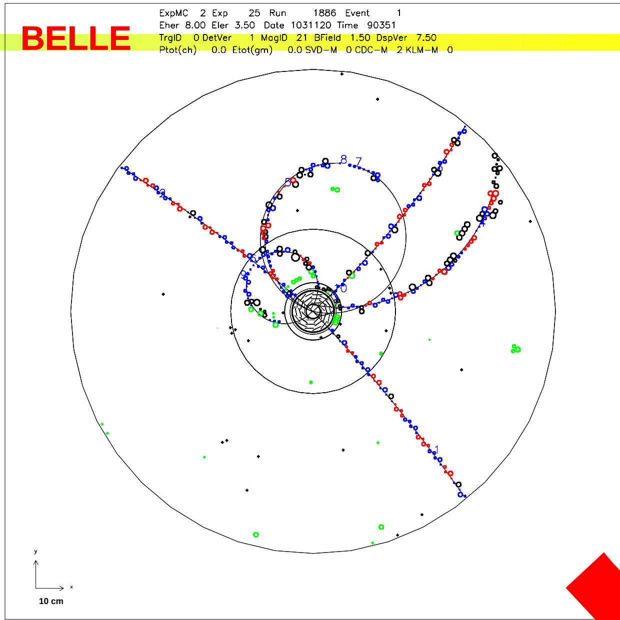


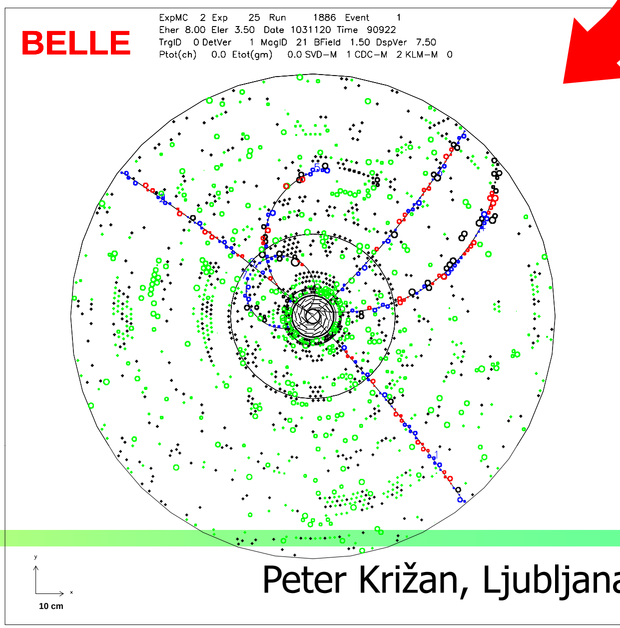
Installed in the KEKB tunnel
(February 2007)

Requirements for the Super B detector

Critical issues at L= 4 x 10^{35}/cm^2/sec

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

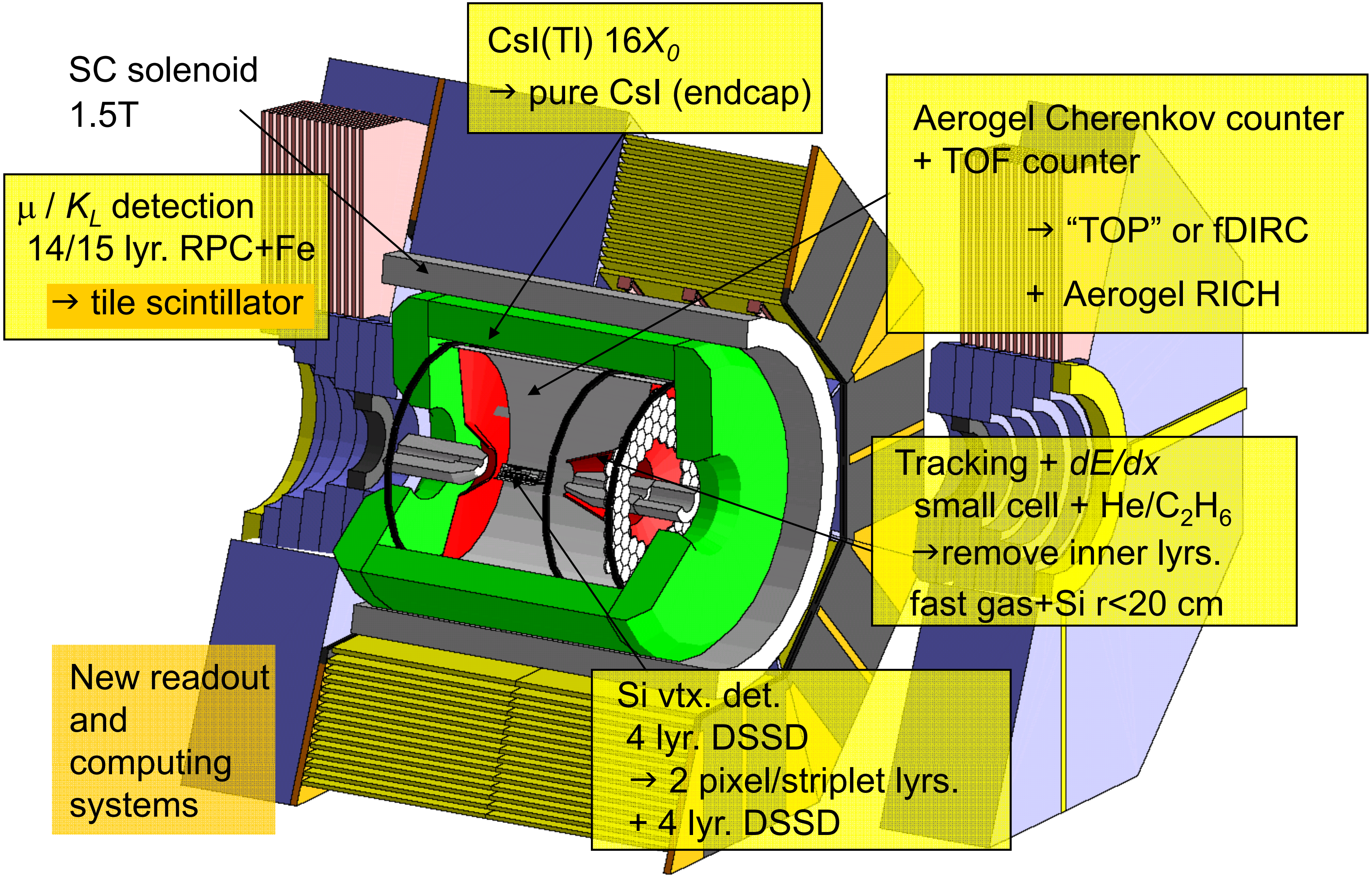




Possible solution:

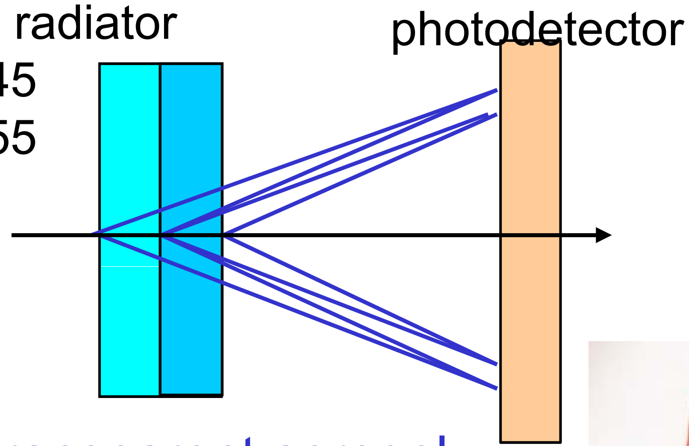
- Replace inner layers of the vertex detector with a silicon striplet or pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter by pure CsI.
- Faster readout electronics and computing system.

Belle upgrade for the Super B factory



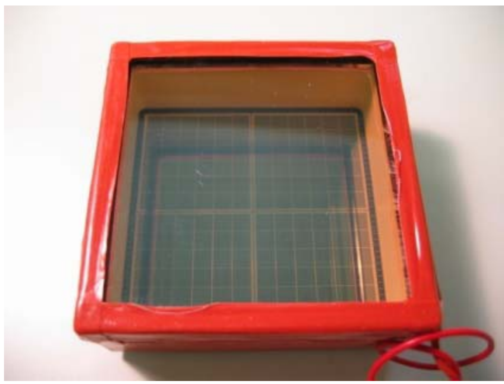
An example of upgrade issues: aerogel RICH as a PID device

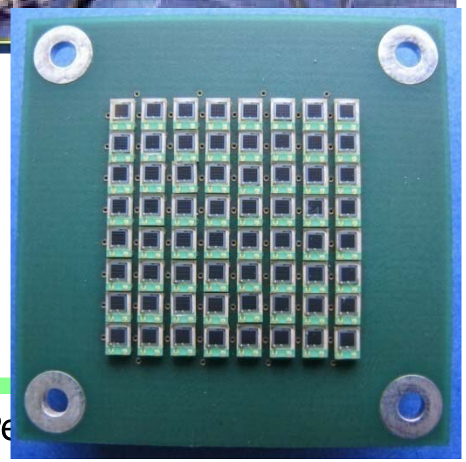
- Proximity focusing RICH with aerogel radiator, with multiple layers with different indices → 'focusing' radiator



Multi-pixel photodetector to measure single photon positions in B=1.5T
→ HAPD or MCP-PMT or SiPM

Highly transparent aerogel :
Λ_t > 40mm (λ=400nm)





Studies with missing energy

- The studies associated with missing energies are potentially hot physics topics in the super *B*-factory era:
  - *B* decays with neutrinos (e.g. $B \to K(*)\nu\nu$, $B \to \tau\nu$, $B \to D(*)l\nu$, etc.)
  - Dark matter related searches (e.g. $\Upsilon(1S) \to$ nothing.)

- Requirements for the analyses:
  - Large data set & a high luminosity machine.
    - ⇨ Since the reconstruction efficiencies are very small (<<0.1%).
  - A clean environment.
    - → In order to keep background level low.

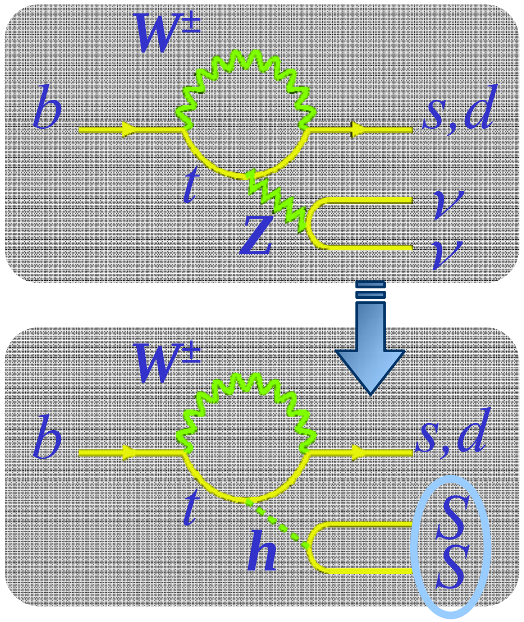
- Detector design target:

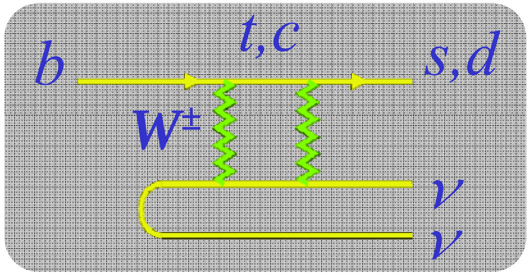
  Large acceptance and high detection efficiencies

Benchmark mode: $B \to K(*)\nu\nu$

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

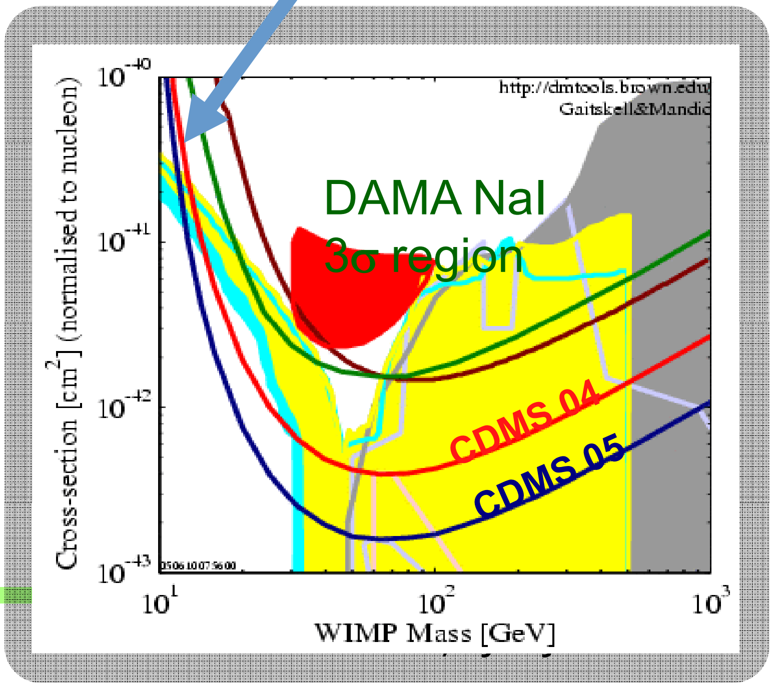
- Proceed through electroweak penguin + box diagram.
- Sensitive to New Physics in the loop diagram.
- Theoretically clean: no long distance contributions.
- May be sensitive to light dark matter (C. Bird, PRL 93, 201803 (2004))





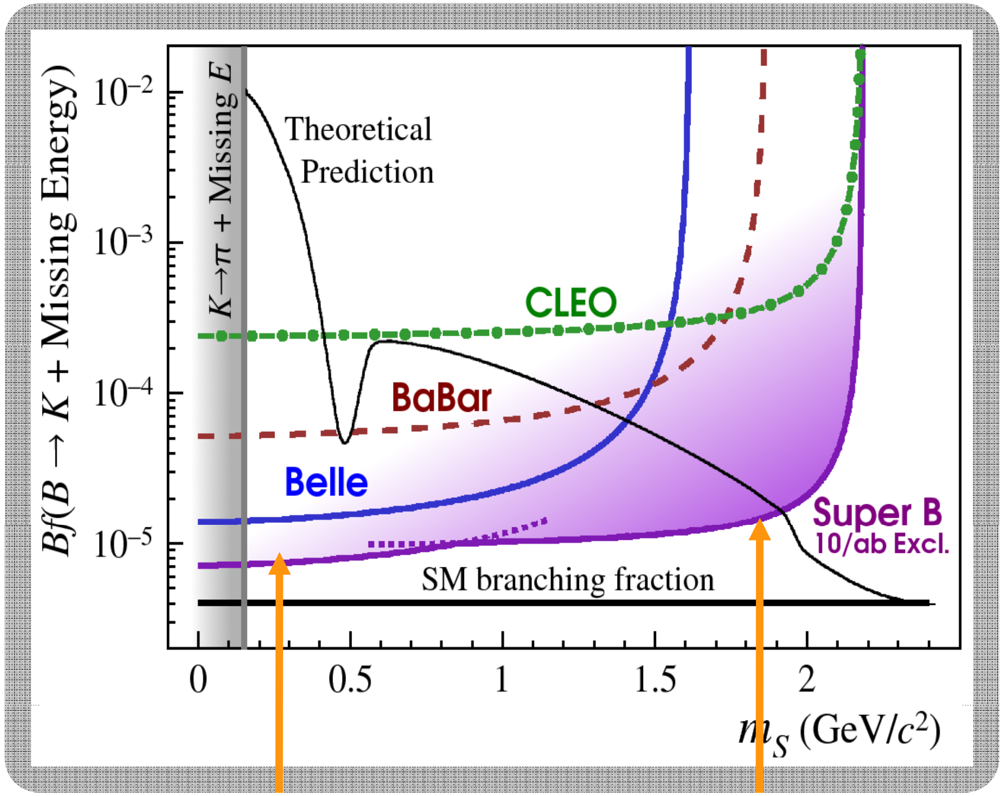
$b \to s$ + Missing E may be enhanced by this extra diagram.

No sensitivity to light dark matter (M<10 GeV) in direct searches



$B \to K^{(*)} \nu\nu$: prospects for 10/ab

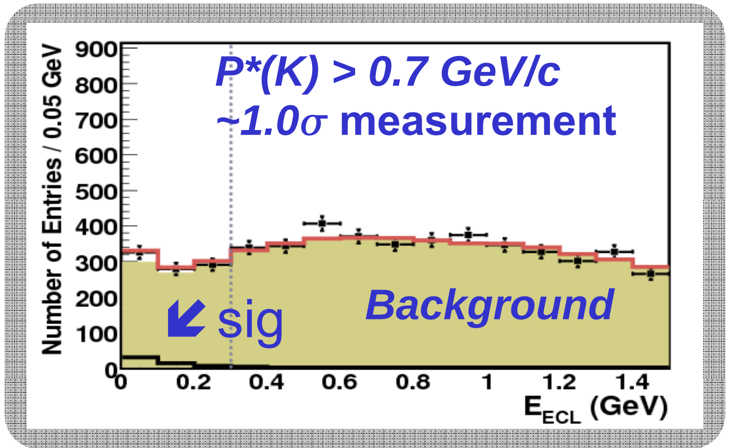
- Assuming no changes in the analysis & detector:

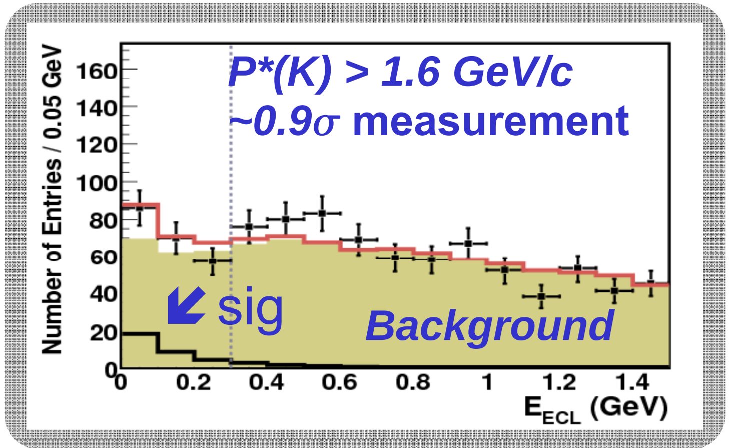


with the same $P^*(K)$ threshold (1.6 GeV)

with a lower $P^*(K)$ threshold (0.7 GeV)

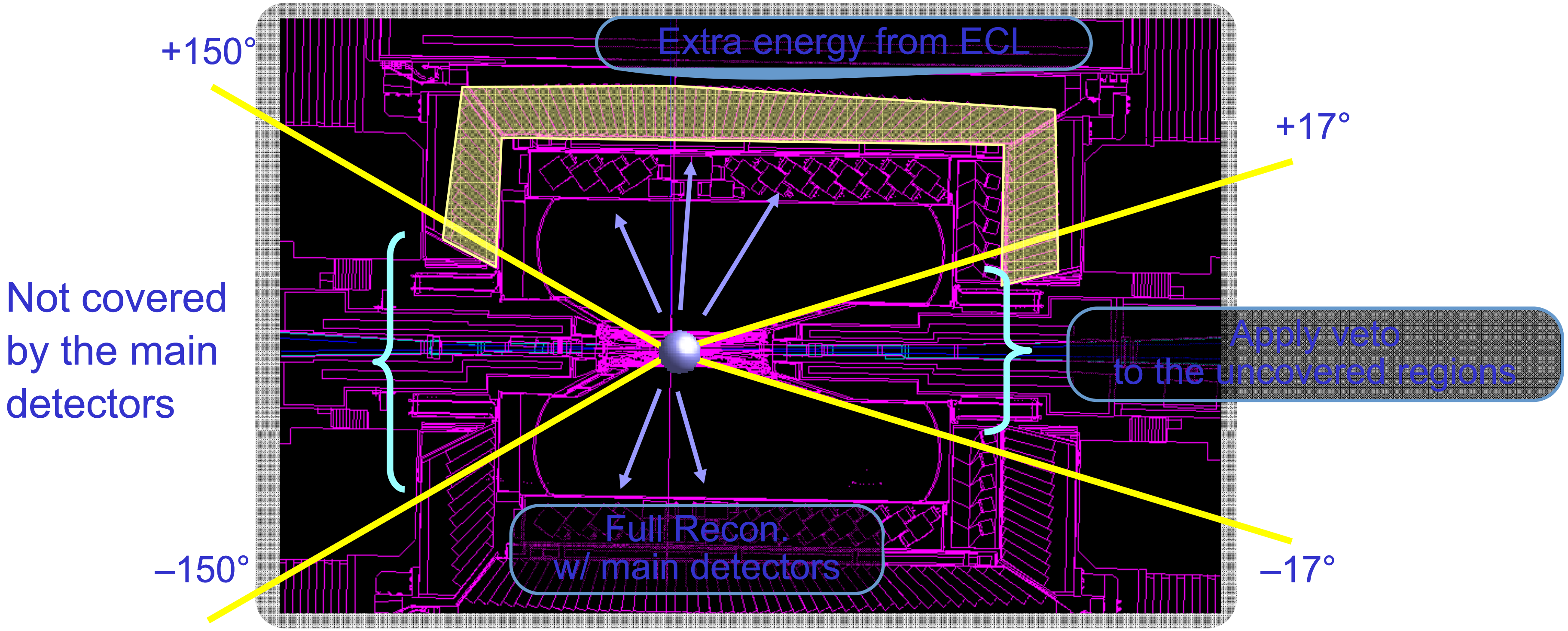
Toy MC results:





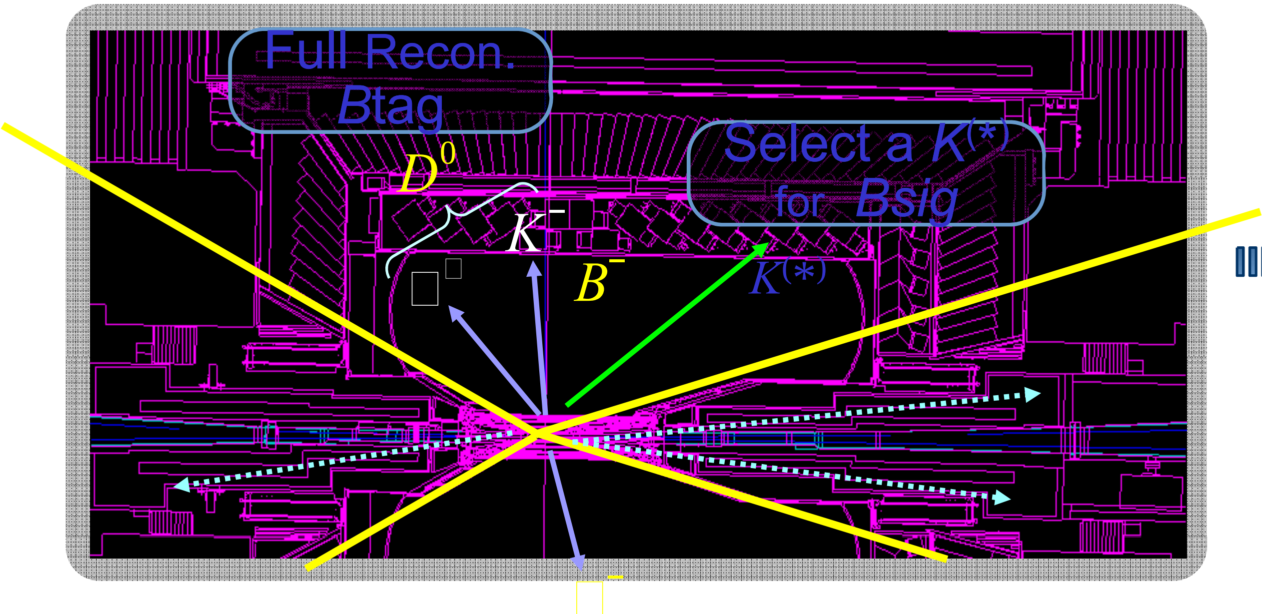
$B \to K^{(*)} \nu\nu$ with a Super Forward Detector

- Minimum hypothesis:
  A super forward detector without precise tracking or energy resolution. *(No direct contribution to the full-reconstruction part)*
- Treat as a veto detector covering small and large angles.



Zero order study

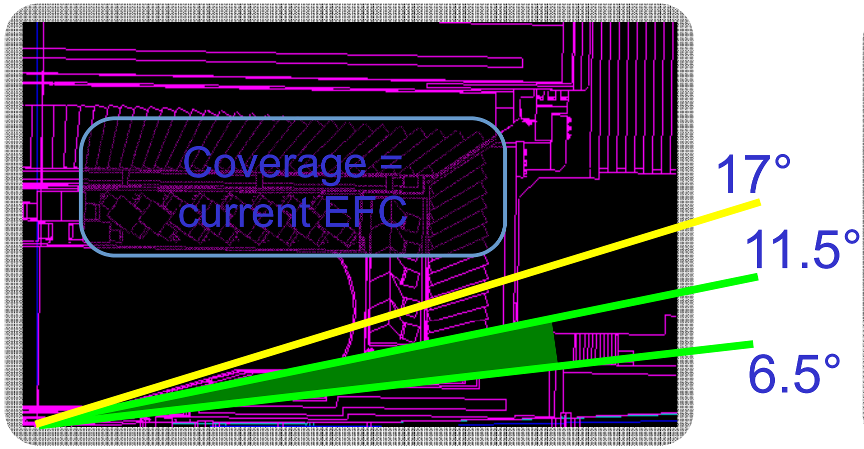
- MC simulation + reconstruction with current Belle detector.
- Guesstimate the extra background suppression power by applying veto to the generator particles in the uncovered region.

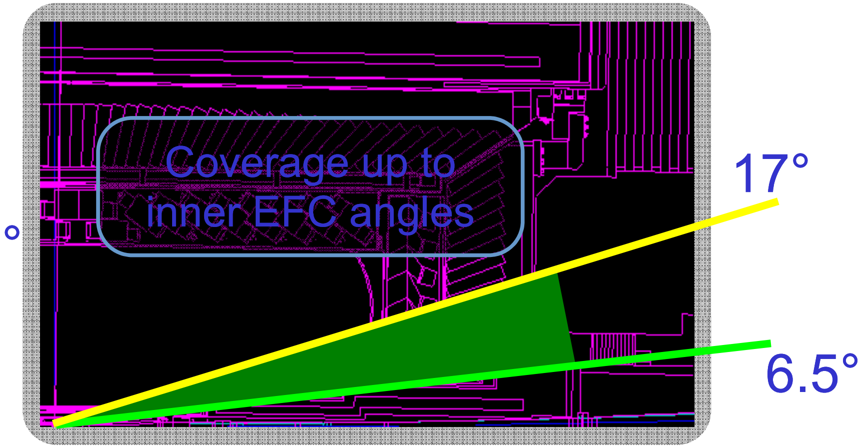


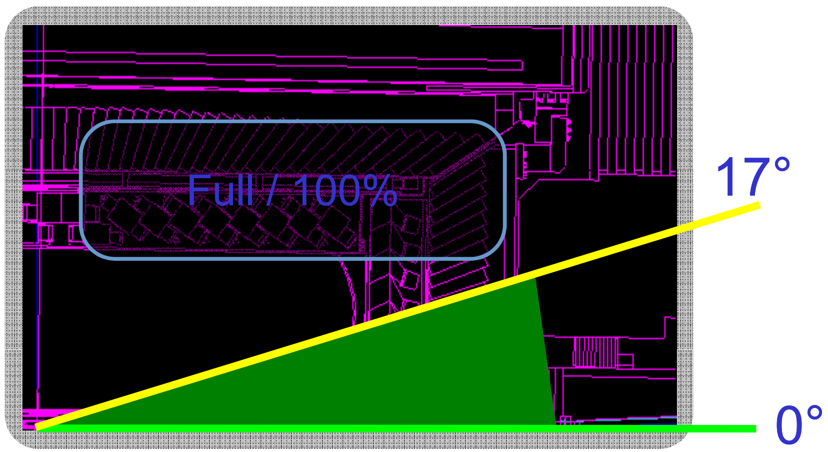
If a generated particle passed the "virtual" super forward detector

Drop the event

Configurations & assumptions







Detecting capability:

- Muon only.
- Charged tracks.
- Charged tracks + photon

Assuming a uniform 95% detecting efficiency

EFC = Extreme Forward Calorimeter in present Belle

Zero order study: results

- Extra background suppression power:

	Muons only	*Charged tracks*	*tracks + photons*
EFC Coverage	6%	21%	29%
Up to inner EFC angle	18%	51%	64%
100% Coverage	19%	55%	69%

- If we can reject all the charged tracks up to the coverage of inner EFC, we should be able to reject another **20-50%** of the background.

- We should do a real simulation instead of such counting studies, and take the new design of IR/KEKB into account.

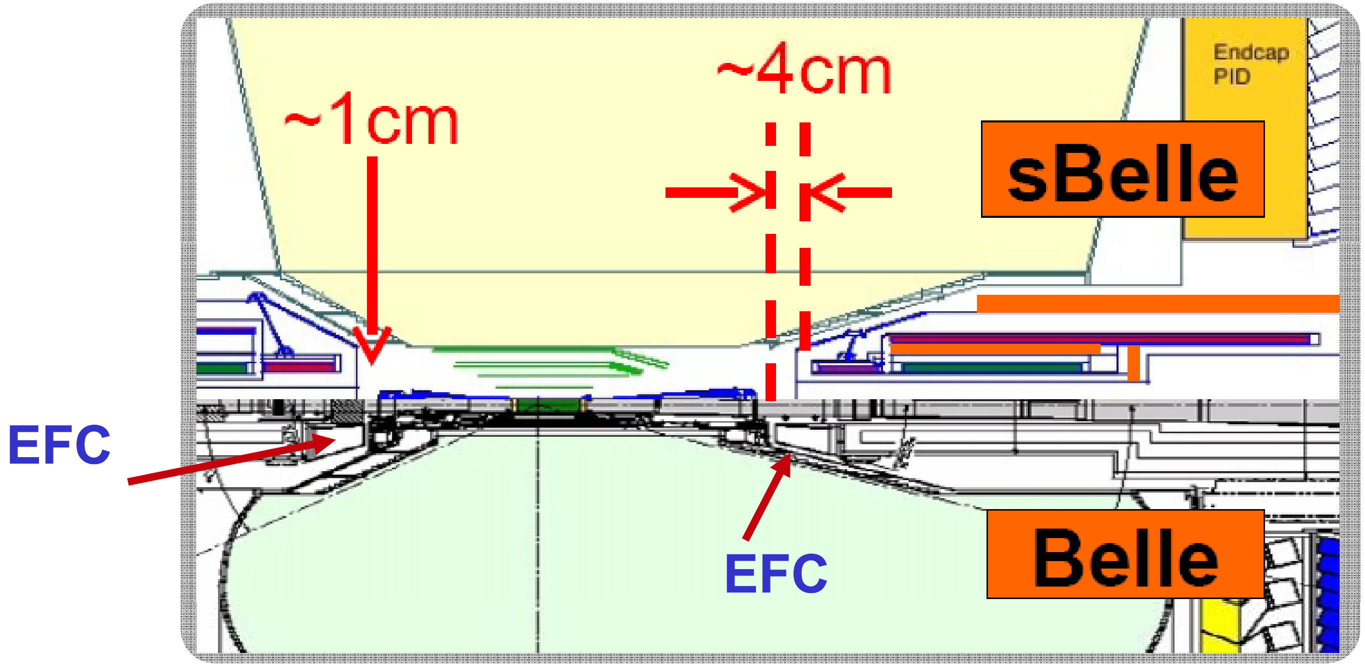
Extreme Forward Calorimeter → Super Forward Detector

First order study: Geant4 simulations

- Minimum hypothesis & target:
  A forward TRACKER for improving detector acceptance.
  (No direct contribution to the main analysis, but as a veto detector)

- Reject the prompt tracks from IP for the full-reconstruction analyses.

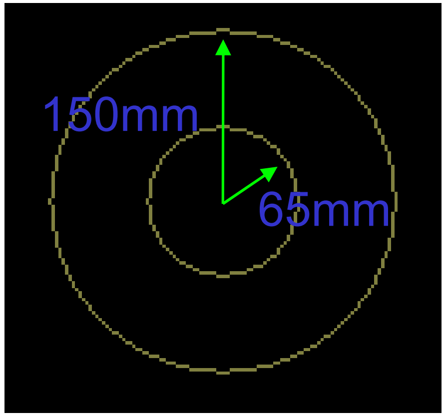
- No space so far, so we first have to show the capabilities of such a counter

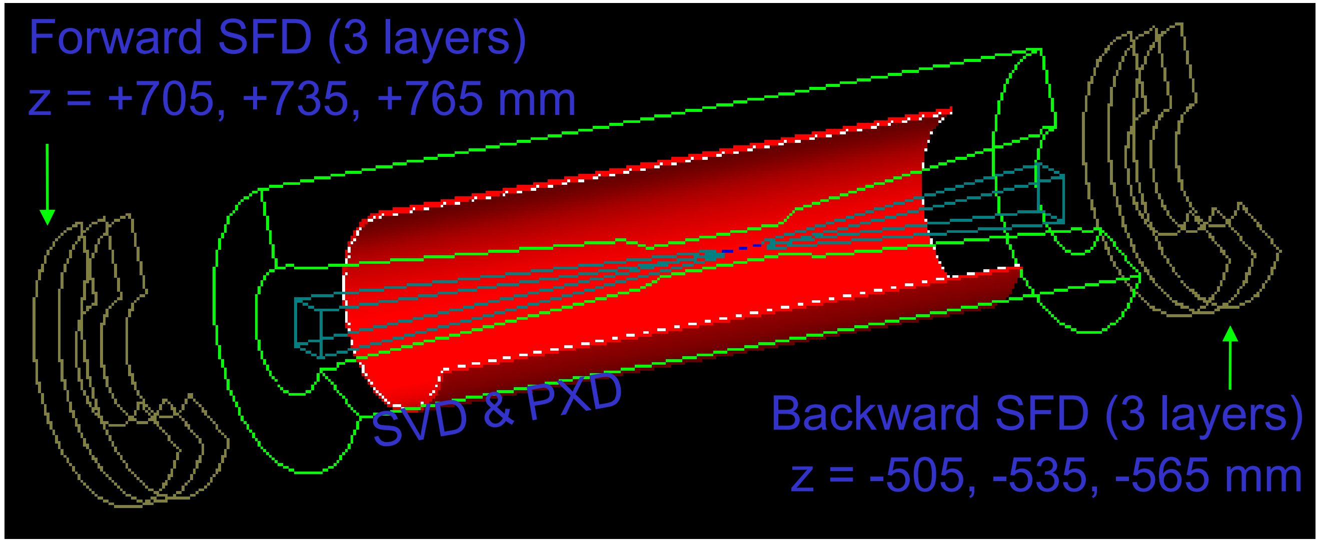


Preliminary geometry

- Build into Geant4 within the framework of Super Belle MC.
- Assuming a silicon pixel detector with large cells: 2mm x 2mm.

Sensor:

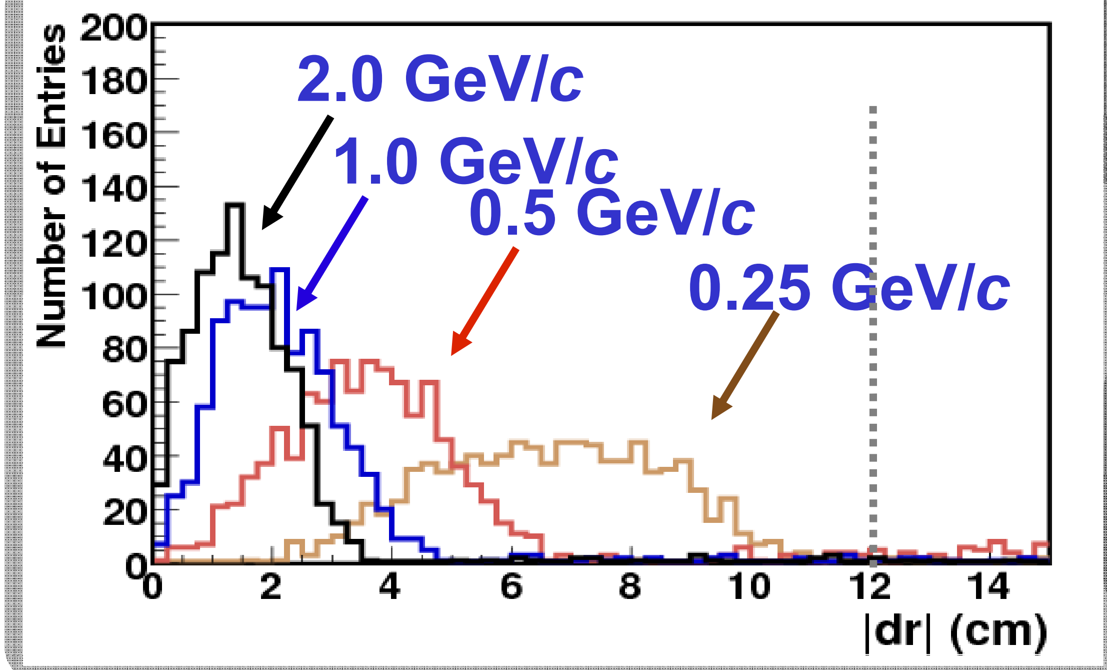


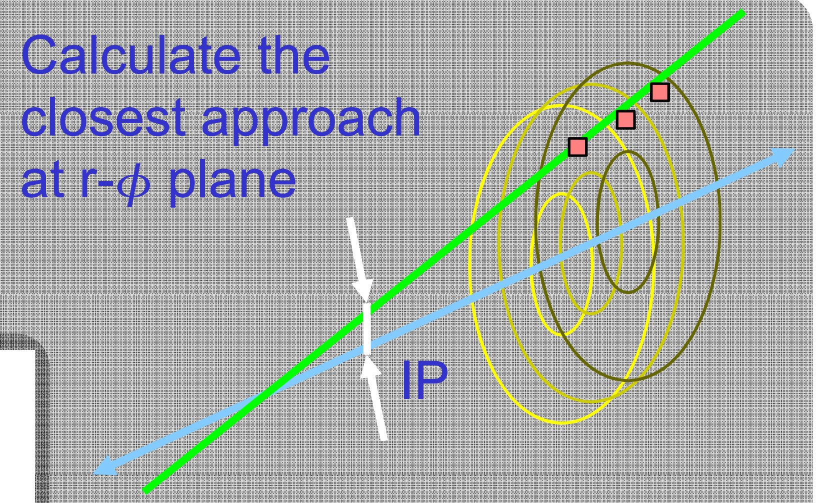


Coverage: FW (5.3°–11.1°), BW(165.1°–172.7°)

Track finding: straight lines

- Input: single forward muon with p = 0.25, 0.5, 1.0, 2.0 GeV/c.
- Output: efficiency >95% (cut |dr|<12 cm)





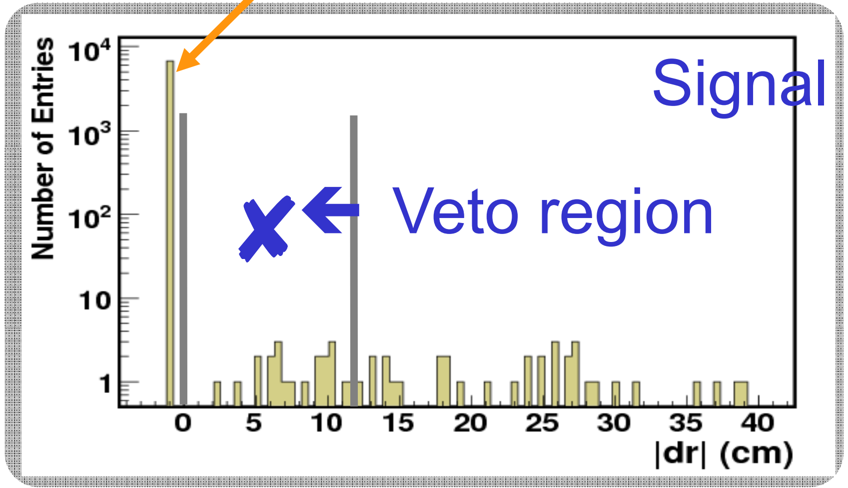
➔ *Seems to be OK.*

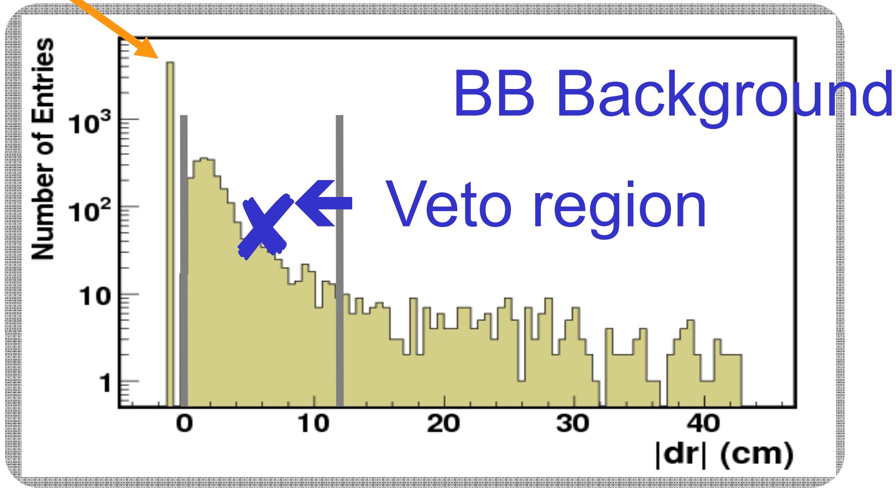
→ *check the performance on background suppression.*

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

- Veto events with one or more reconstructed tracks:

No tracks reconstructed





Signal efficiency: 99.7%

Background reduction: 31.5%

→Looks very promissing!

→More studies are required to arrive at a conclusive result, e.g. realistic material in front of the detector, supporting structure, shielding, etc.
→Exposure to radiation: under study

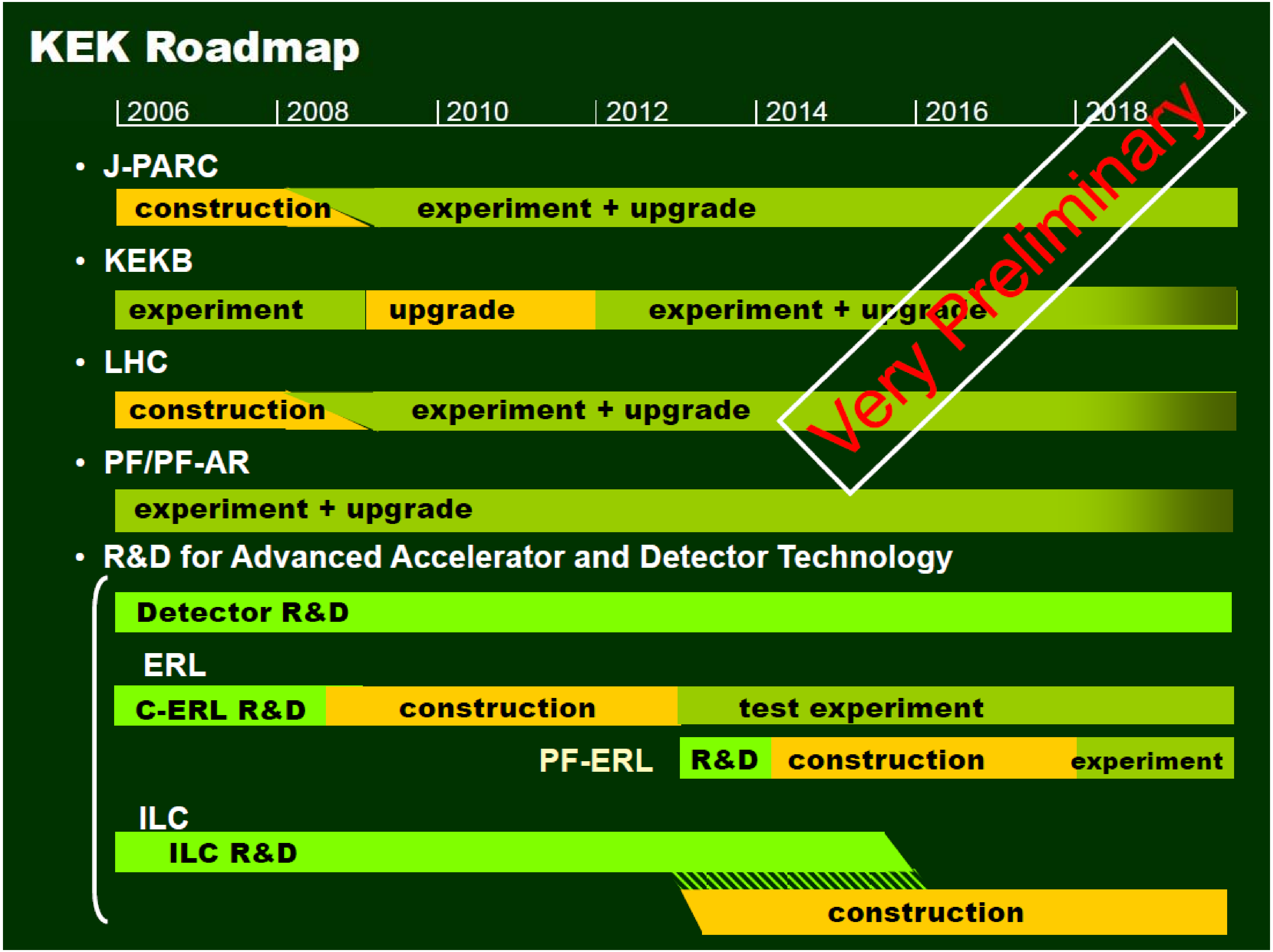
KEK's 5 year Roadmap

- Official 20 page report released on January 4, 2008 by director A. Suzuki and KEK management
- KEKB's upgrade to $2x10^{35}$ /cm^2/sec in 3+x years is *the central element in particle physics.* (Funding limited: Final goal is 8×10^{35} and an integrated luminosity of 50 ab^{-1})

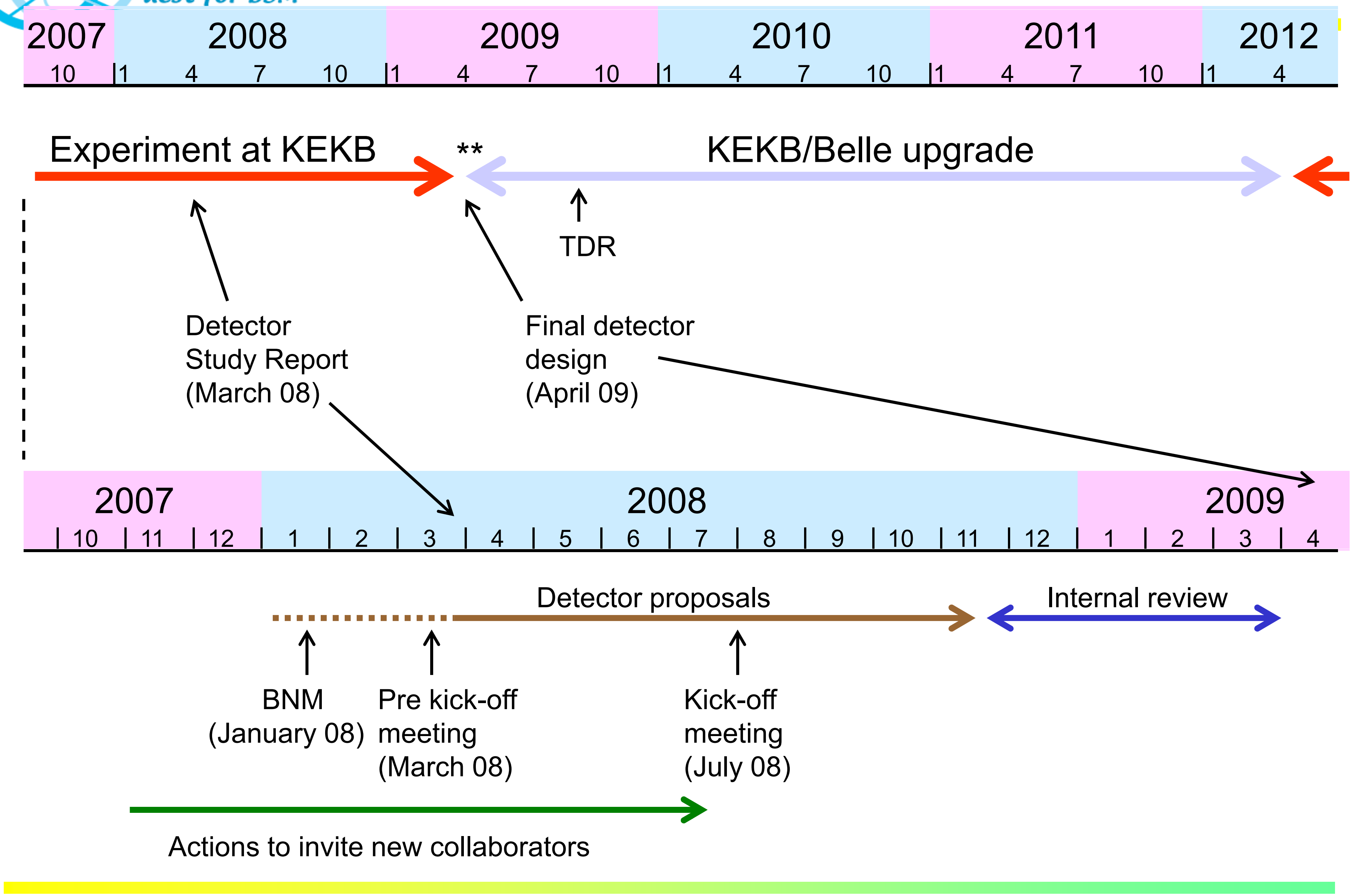
  →Recommended by the Roadmap Review Committee

  - Membership: Young Kee Kim, John Ellis, Rolf Heuer, Andrew Hutton, Jon Rosner, H. Takeda and reviewers from other fields

Super-Belle (and Super KEKB) is an open international project that covers the next two orders of magnitudes at the luminosity frontier. A special opportunity for high impact international collaboration


KEK Roadmap
2006
2008
2010
2012
2014
2016
2018
• J-PARC
construction
experiment + upgrade
• KEKB
experiment
upgrade
experiment + upgrade
• LHC
construction
experiment + upgrade
• PF/PF-AR
experiment + upgrade
• R&D for Advanced Accelerator and Detector Technology
Detector R&D
ERL
C-ERL R&D
construction
test experiment
PF-ERL
R&D
construction
experiment
ILC
ILC R&D
construction
Very Preliminary

Tight Schedule for the Super KEKB Collaboration



** Possible 6-month shift to the right

Summary

- B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of the performance.
- Major upgrade in 2009-12 → Super B factory, L x10 → x40
- Essentially a new project, all components have to be replaced, plans exist (LoI and baseline design), nothing is frozen...
- Missing energy studies have a high potential at the Super B factory (e.g. $B \to K(*)\nu\nu$, $B \to \tau\nu$, $B \to D(*)\tau\nu$, $\Upsilon(1S) \to$ nothing etc.)
- A preliminary configuration of the Super Forward Detector has been investigated: removed ~30% of the backgrounds from B decays. More detailed and careful studies should be carried out.
- Expect a new, exciting era of discoveries, complementary to LHC
- Do not miss the chance to be a part of it...