Heavy Flavors II

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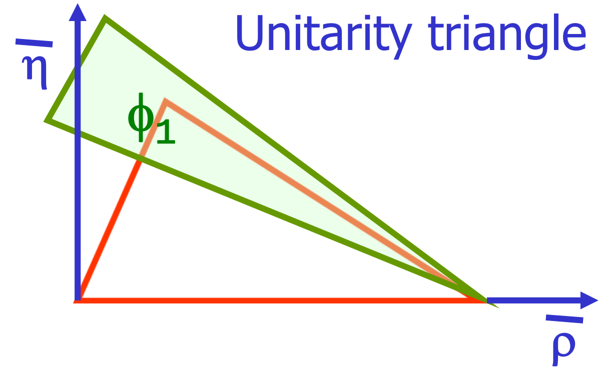
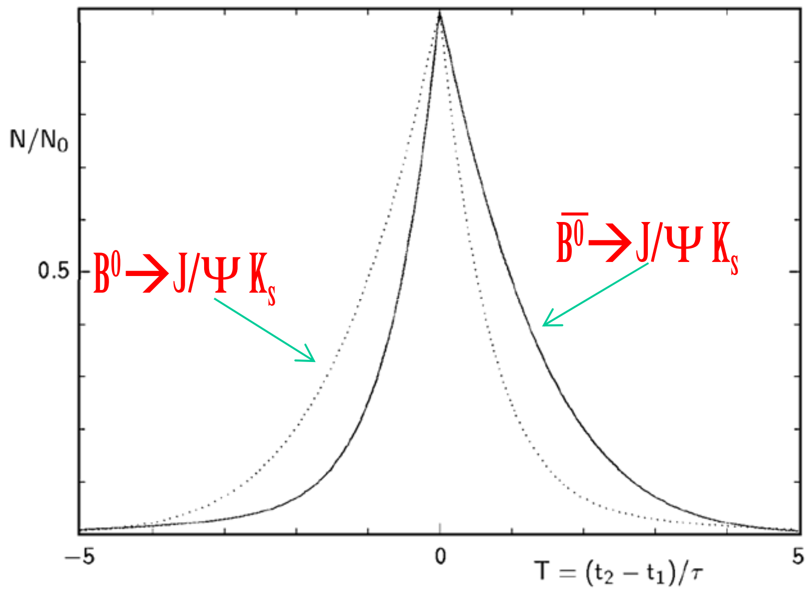
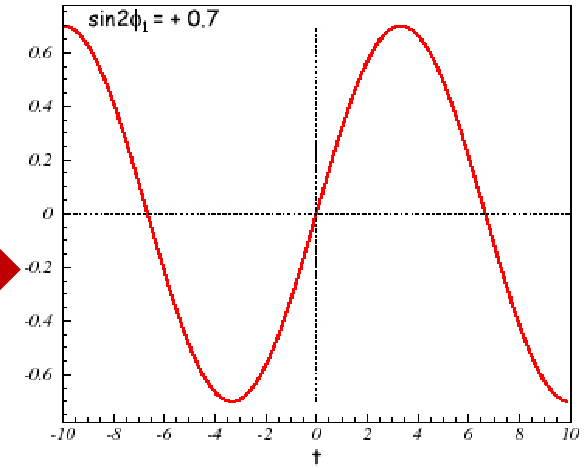
Reminder from Lecture 1: How to measure ϕ_1?



To measure the angle ϕ_1 of the unitarity triangle, we have to measure the time dependence of the difference in $B^0 \to J/\Psi\, K_s$ and $\bar{B}^0 \to J/\Psi\, K_s$ decays



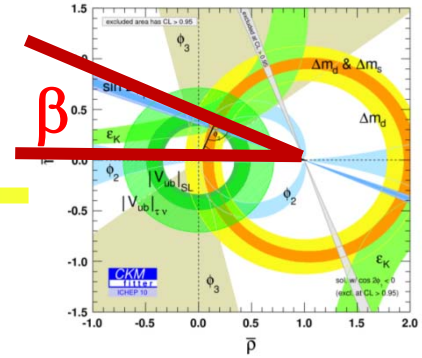


$$a_{f_{CP}} = -\frac{\Gamma(\overline{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\overline{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})}$$

Time dependent decay rate difference - CP asymmetry:

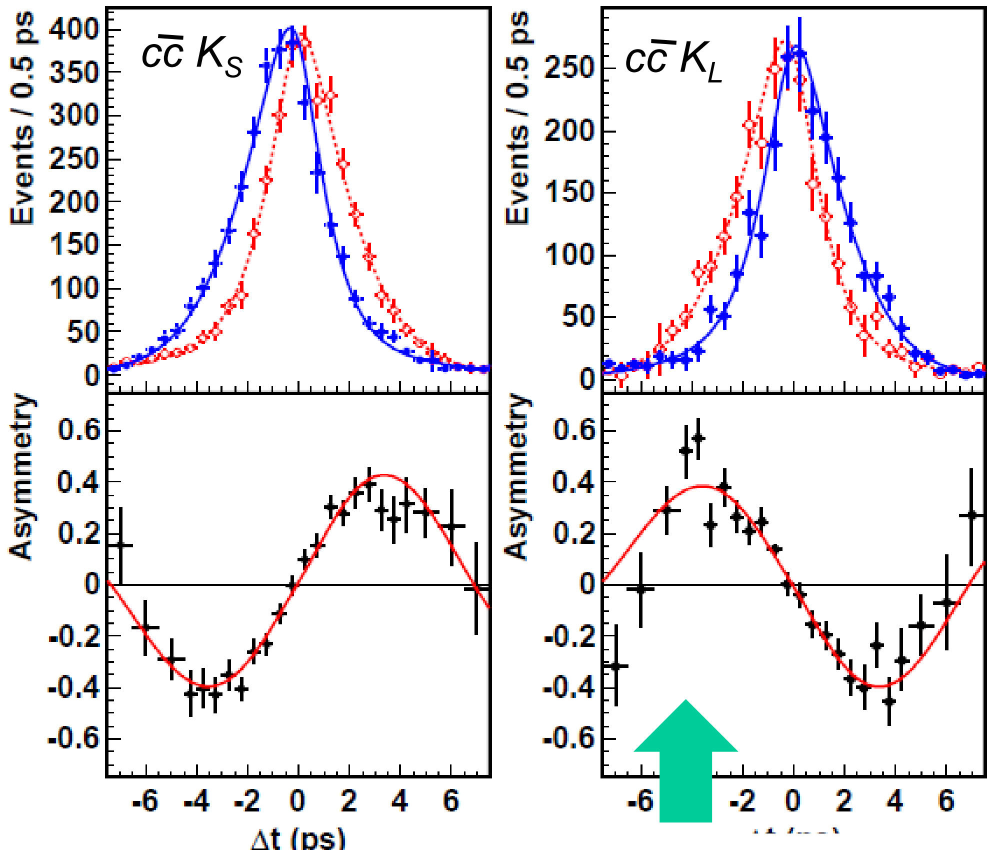
$$a_{f_{CP}} = -\mathrm{Im}(\lambda_{f_{CP}})\sin(\Delta m t) = \sin 2\phi_1 \sin(\Delta m t)$$

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



ϕ_1 from CP violation measurements in $B^0 \to J/\psi K^0$

$$a_{f_{CP}} = -\mathrm{Im}(\lambda_{f_{CP}})\sin(\Delta m t) = \sin 2\phi_1 \sin(\Delta m t)$$



Opposite CP → sine wave with a flipped sign

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

Belle:	0.668 ± 0.023 ± 0.012
BaBar:	0.687 ± 0.028 ± 0.012

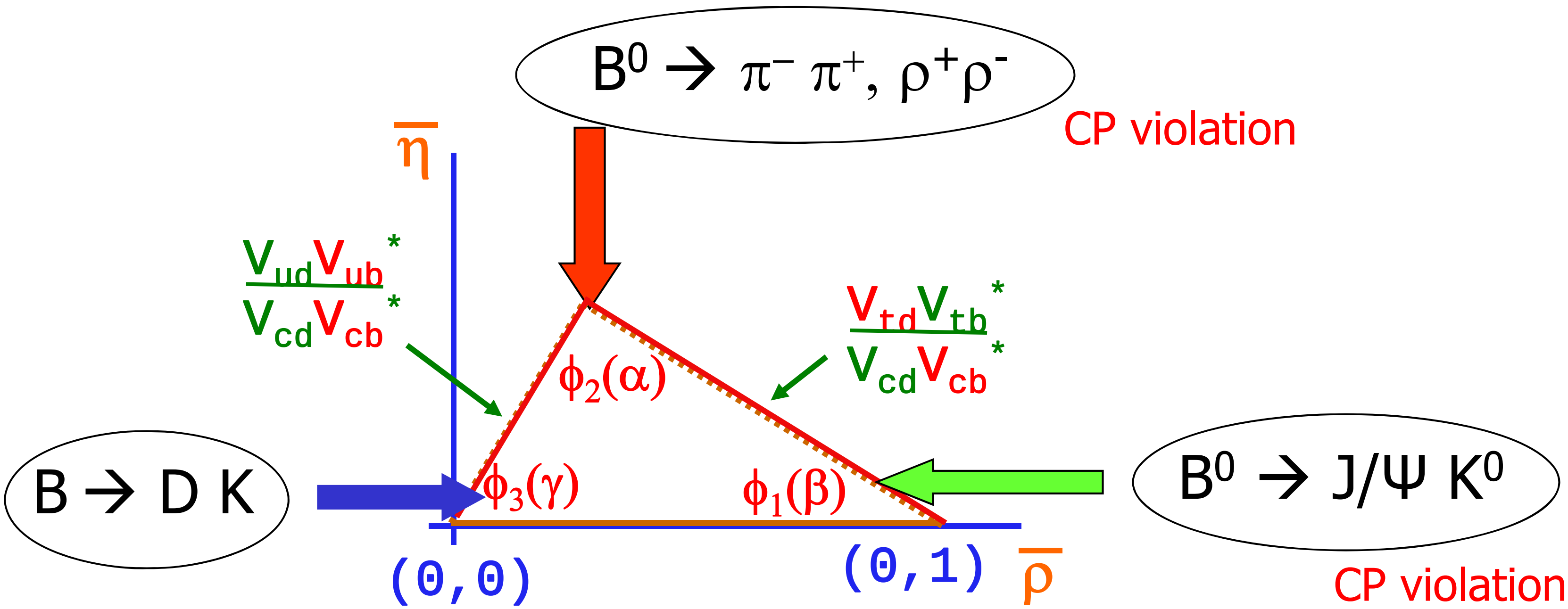
Belle, PRL 108, 171802 (2012)

BaBar, PRD 79, 072009 (2009)

with a single experiment precision of ~4%!

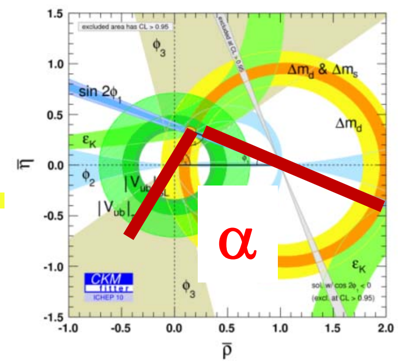
$\phi_1 = \beta = (21.4 \pm 0.8)^0$

Unitarity triangle: consistency checks



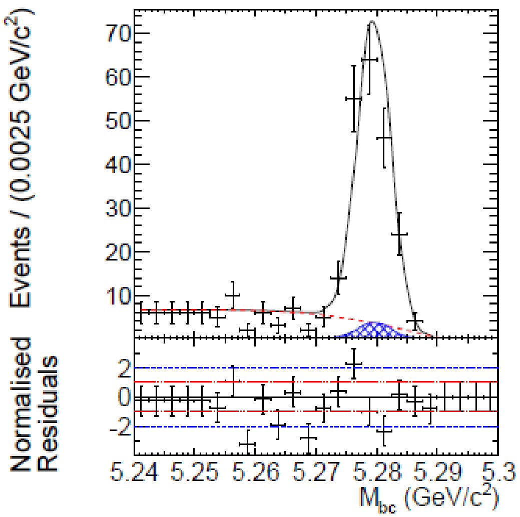
Consistency check of the unitarity triangle: precisely measure
- angles (through CP violation)
- sides (b→u and b→c rates) and B mixing

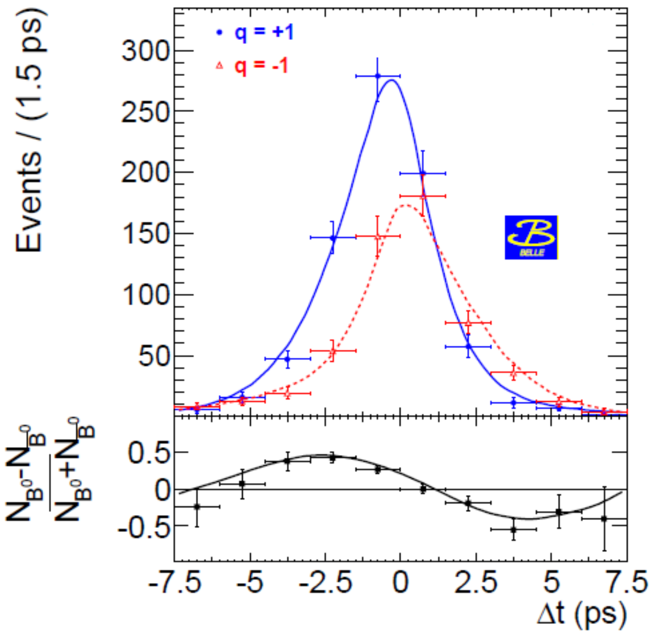
Final measurement of ϕ_2 (α) in B → $\pi^+\pi^-$ decays



ϕ_2 from CP violation measurements in $B^0 \to \pi^+\pi^-$

Belle, 710 fb^{-1}
PRD **88**, 092003 (2013)





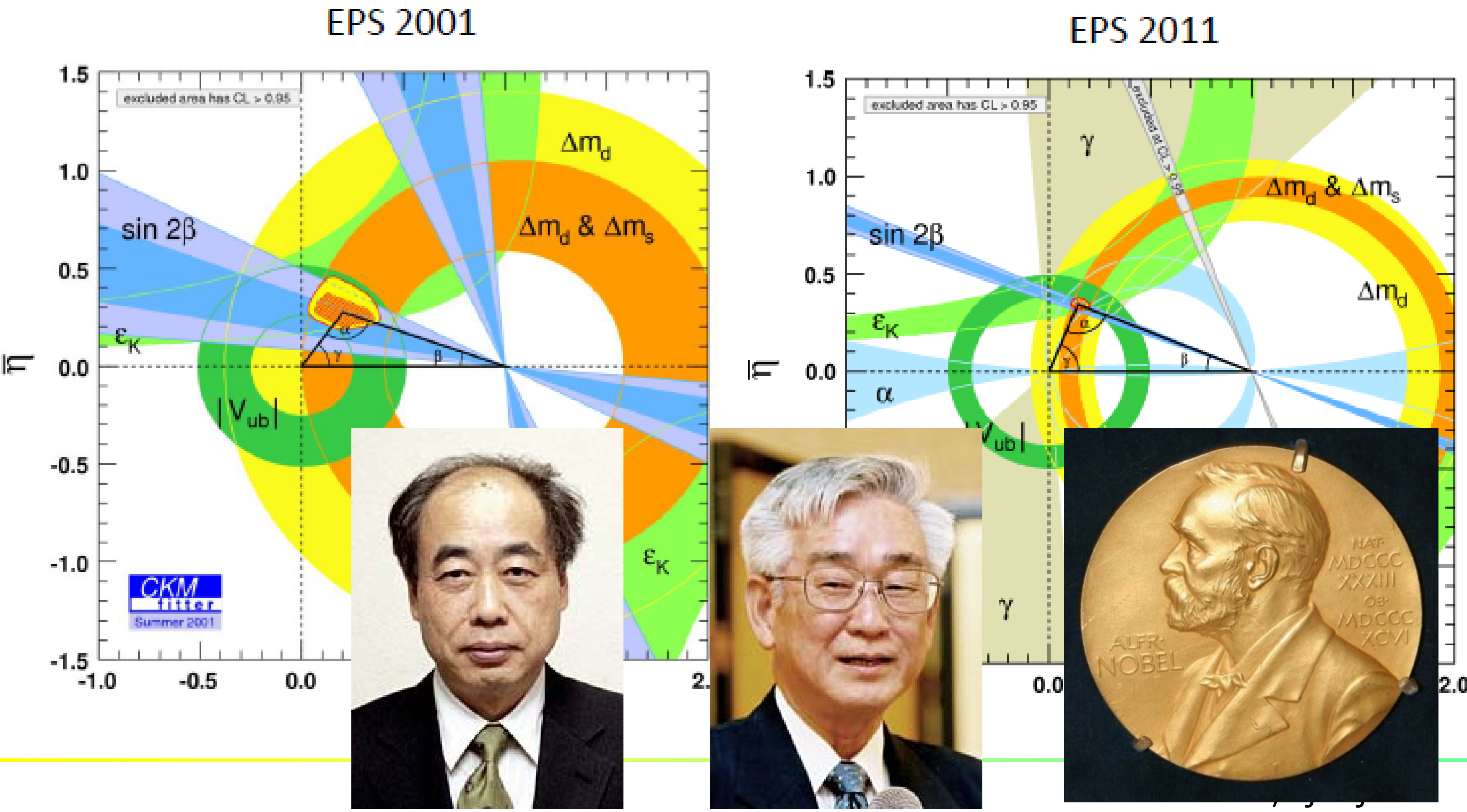
$$a_{f_{CP}} = C\cos(\Delta m t) + S\sin(\Delta m t)$$

Belle:
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

Summary of lecture 1: CP violation in the B system

B factories: CP violation in the B system: from the discovery (2001) to a precision measurement (2011) → remarkable agreement with KM prediction!

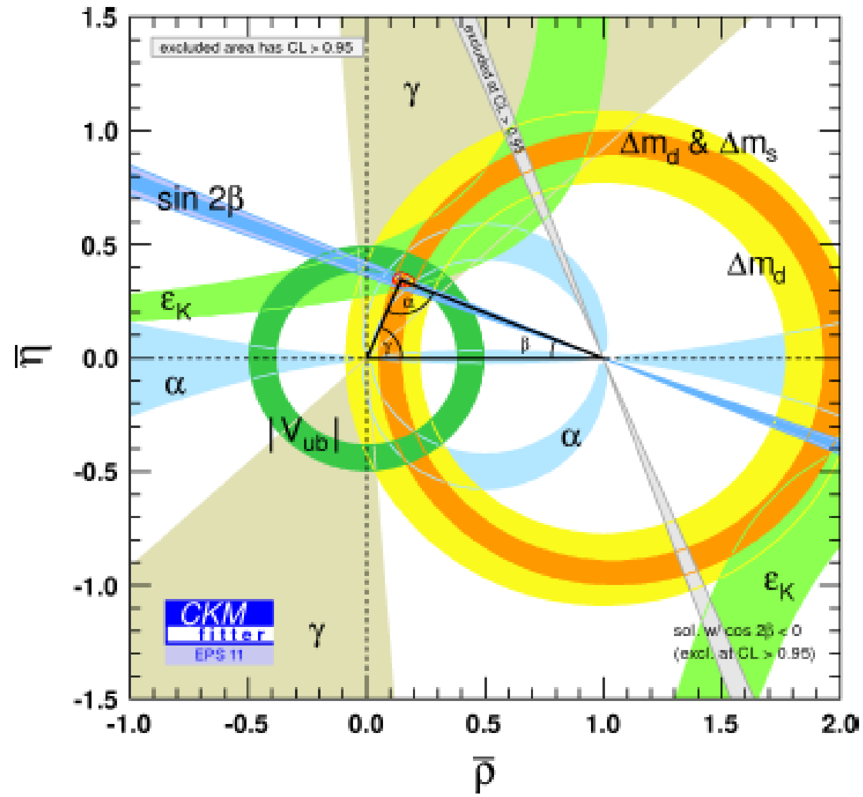


Contents, this lecture

- Flavor physics: introduction, with a little bit of history
- Flavor physics at B factories: CP violation
- **Flavor physics at B factories: rare decays and searches for NP effects**
- **Super B factory**
- Flavor physics at hadron machines: history, LHCb and LHCb upgrade

The unitarity triangle – new/final measurements

Constraints from measurements of angles and sides of the unitarity triangle → remarkable agreement, but contributions of New Physics could be as high as 10-20%

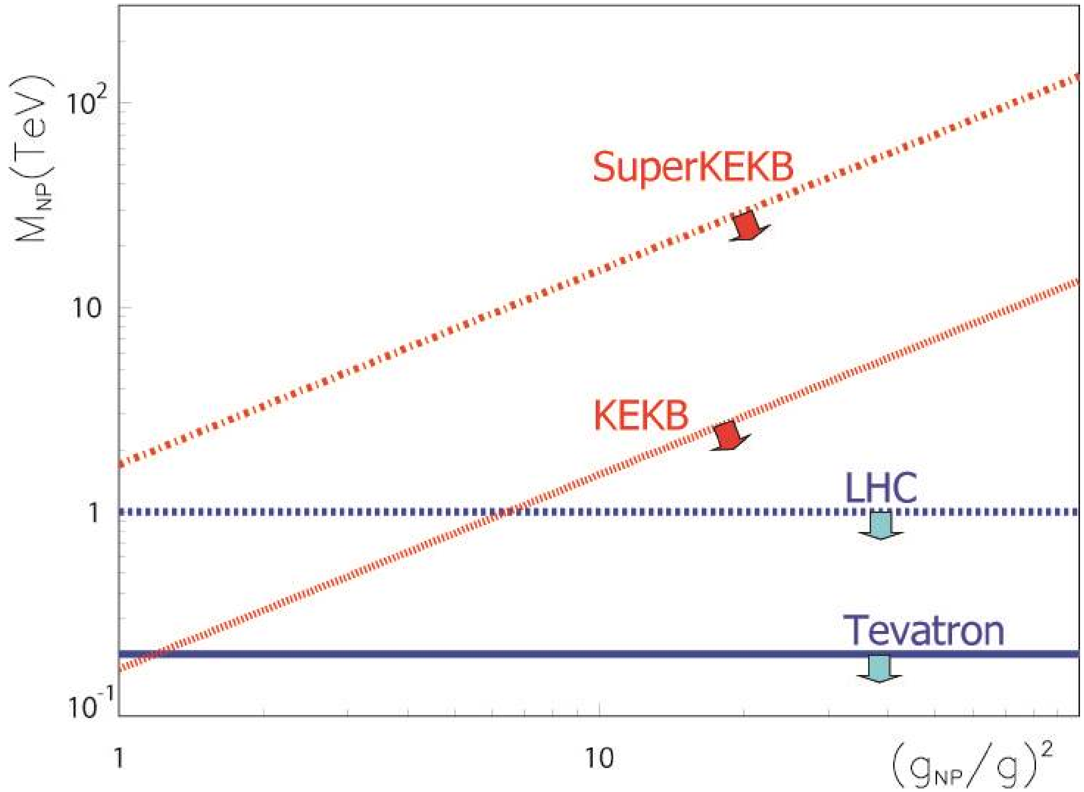


→investigate possible NP phenomena with precise measurements

→Intensity frontier

Intensity Frontier vs Energy Frontier

Reach in mass of New Physics particles



New Physics coupling vs standard model

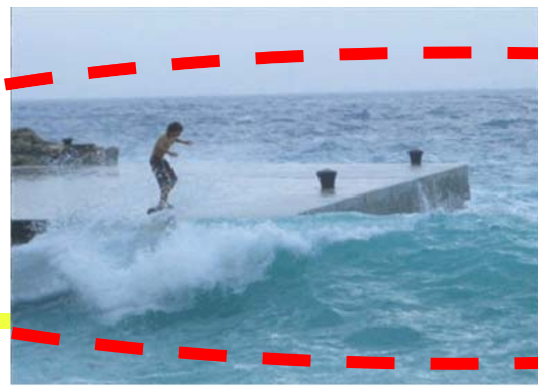
→ A very interesting complementarity of the two approaches

→see also lectures by Maxym Titov

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

It worked already many times!

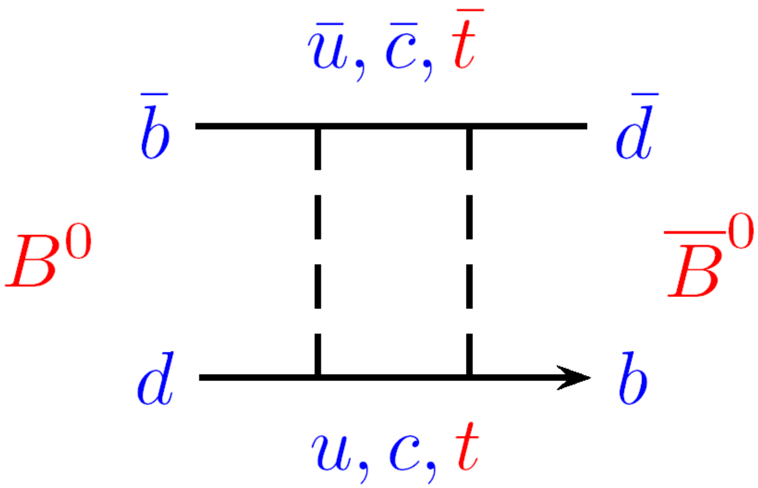
- The smallness of $K_L \to \mu^+\mu^-$ → GIM mechanism →need one more quark – c
- K^0 – anti-K^0 mixing frequency Δm_K → estimate the charm quark mass
- Mixing in the B^0 system: large mixing rate → high top mass; top quark has only been discovered seven years later!
- CP violation in K decays (1964) → KM mechanism (1973) → need three more quarks, discovered later in 1974, 1977, 1995

→discussed in Lecture 1

→discussed in lectures by Maxym Titov

New particles in loops

Mixing in the B^0 system: large mixing rate → high top mass; top quark has only been discovered seven years later!



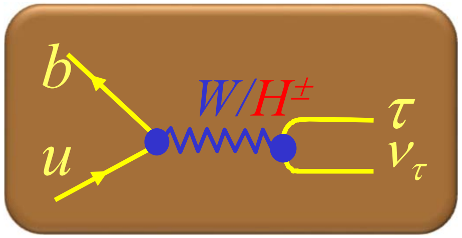
$$\Delta m \propto$$

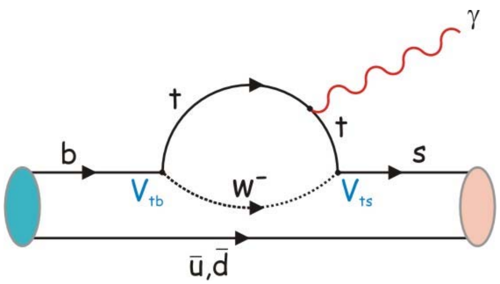
$$|V_{tb}^* \, V_{td}|^2 m_t^2 \;\propto\; \lambda^6 m_t^2$$

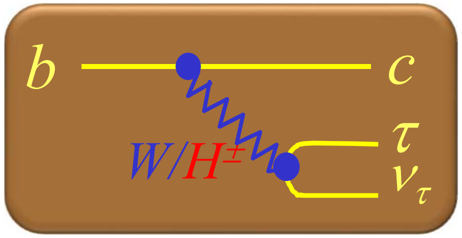
$$|V_{cb}^* \, V_{cd}|^2 m_c^2 \;\propto\; \lambda^6 m_c^2$$

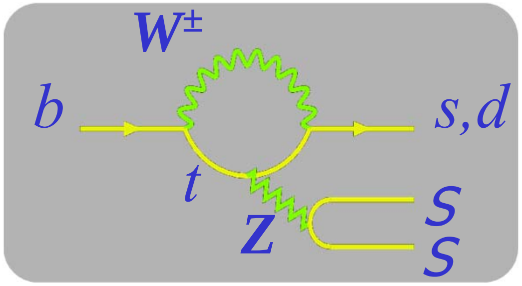
Experiment at 10 GeV E(cms), particle in the loop 170 GeV

Rare B decays





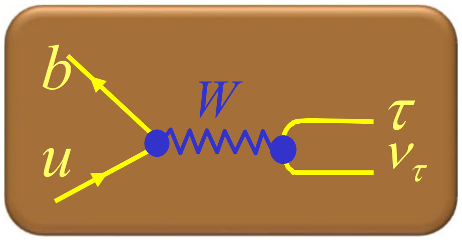




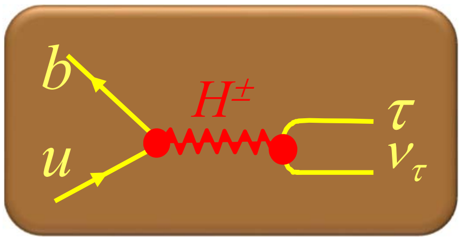
Search for effects of new particles and interactions

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

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



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



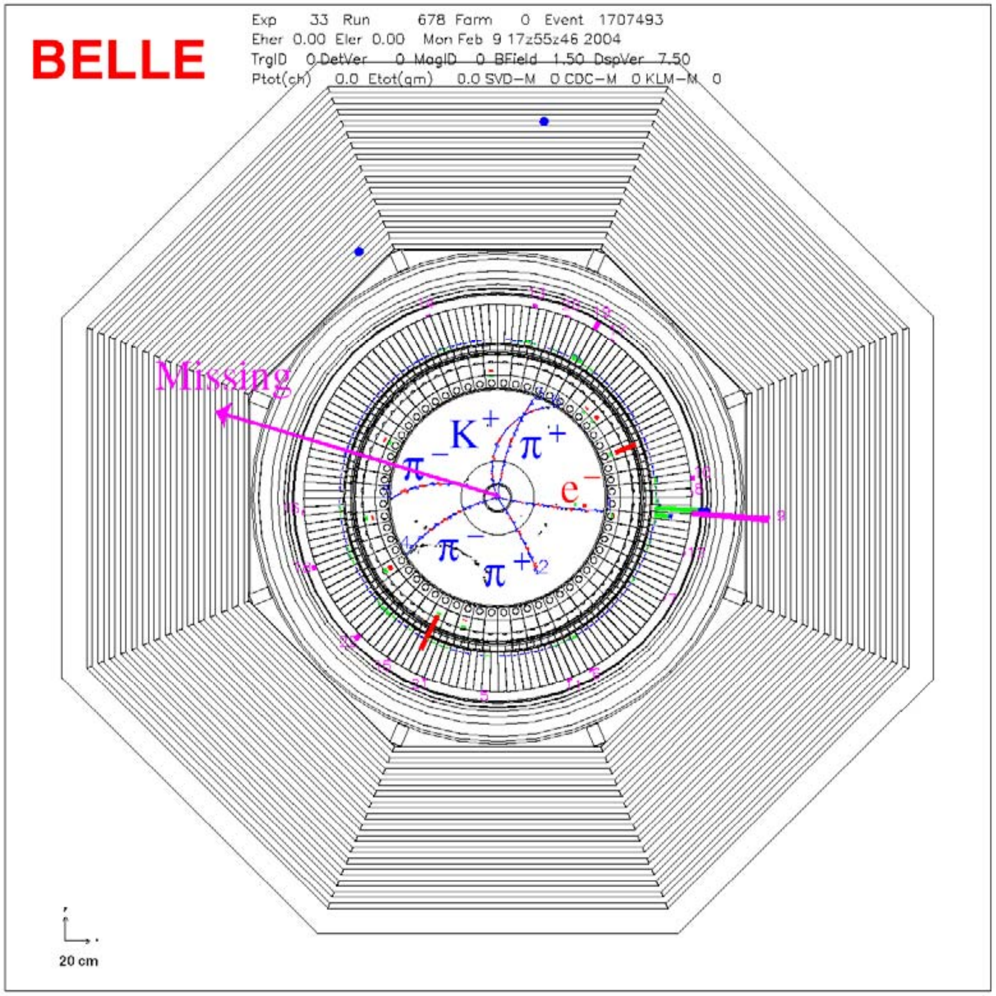
In some supersymmetric extension it can also proceed via a charged Higgs

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.

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

Example of a $B^- \to \tau^- \nu_\tau$ decay as measured at Belle

$$
\begin{aligned}
B^+ &\to D^0 \pi^+ \\
&\qquad (\to K \pi^- \pi^+ \pi^-) \\
B^- &\to \tau (\to e \nu \bar{\nu}) \nu
\end{aligned}
$$



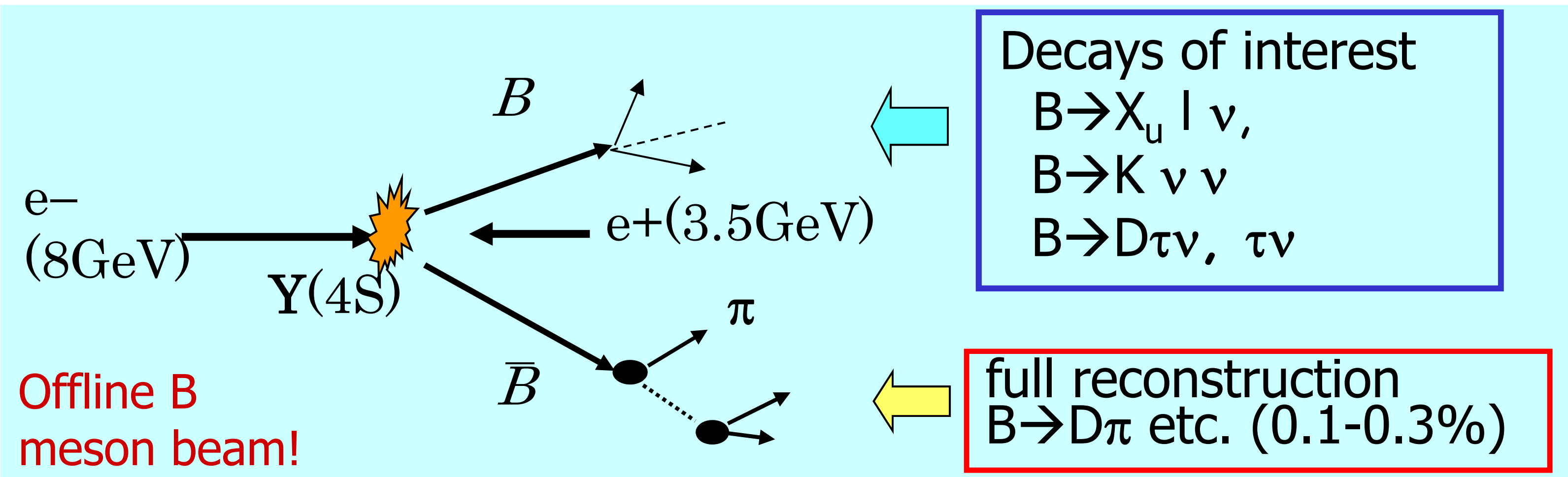
Tough to tackle experimentally: three neutrinos in the final state and only one charged particle from the B decay.

Can be carried out at B factories! →

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 Υ(4S) decays)



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

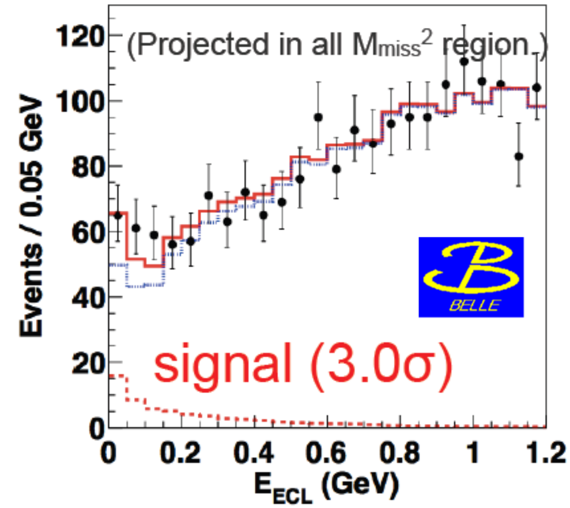
→unique feature at B factories

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

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 $E_{ECL} = 0$

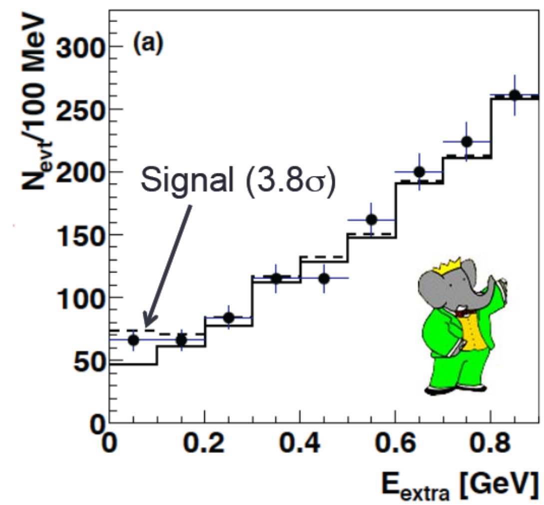


Belle $Br(B \to \tau\nu) = [0.72\ ^{+0.27}_{-0.25} \pm 0.11] \times 10^{-4}$

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)

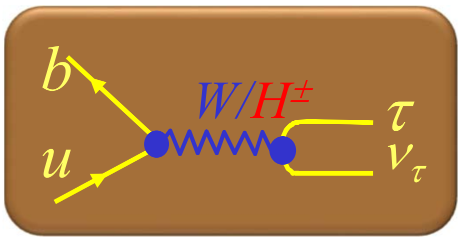


All measurements combined

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

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

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



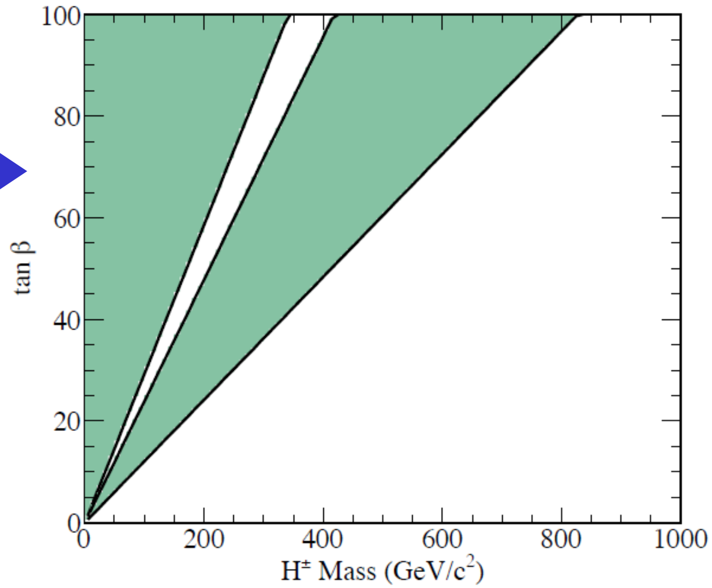
Measured value

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

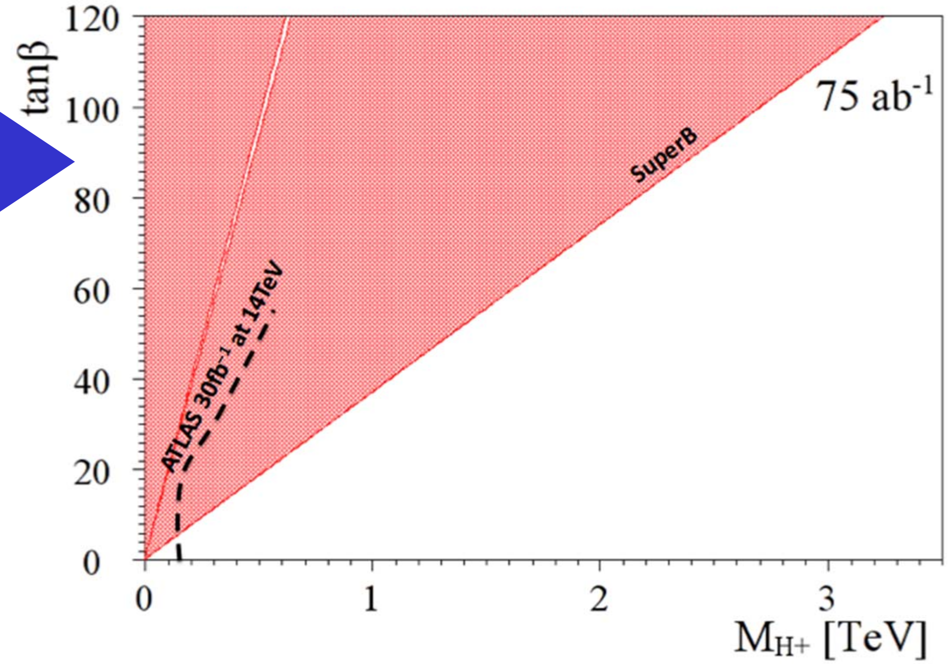
→ limit on charged Higgs mass vs. tanβ

(for type II 2HDM)

B factories: Exclusion plot

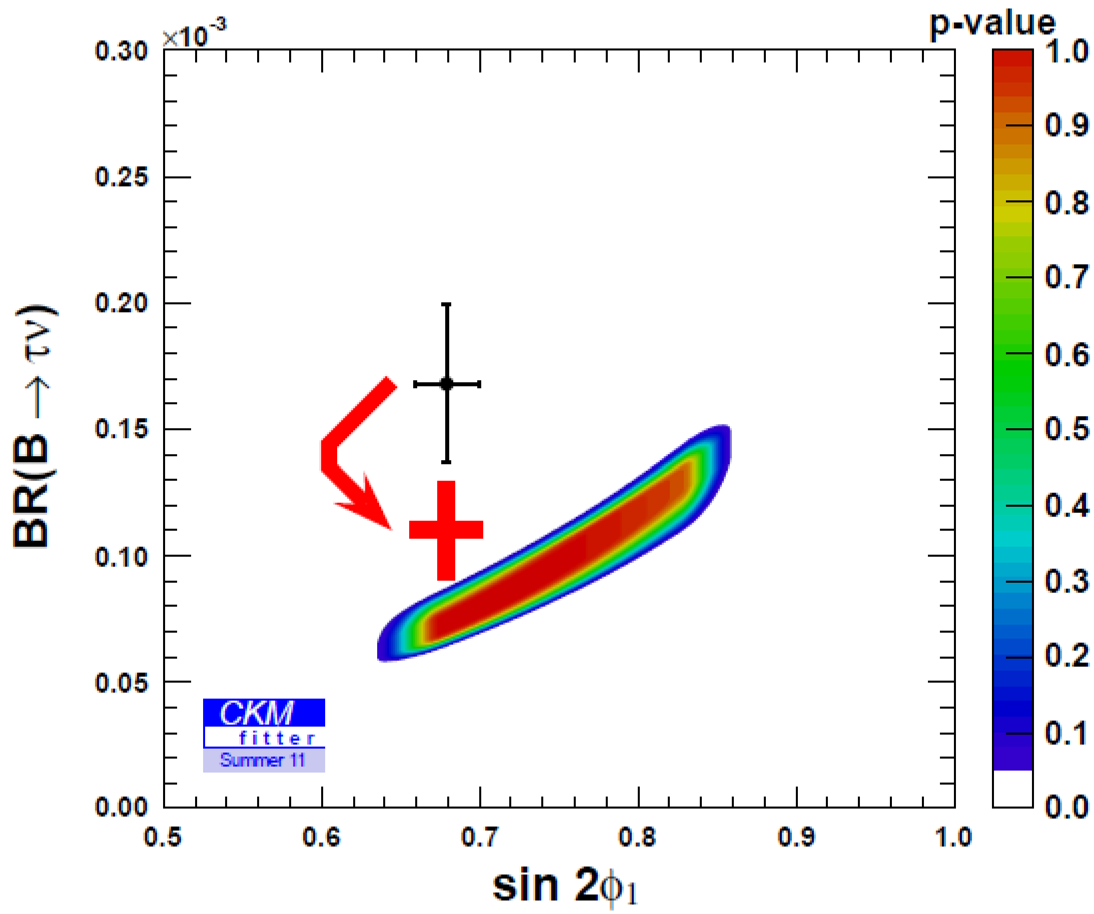


Super B factory: Discovery plot: very much competitive with LHC!



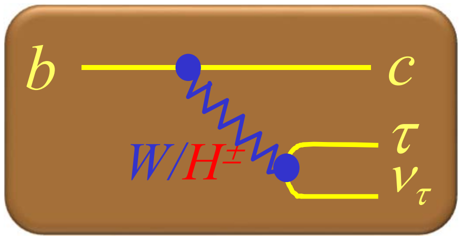
sin$2\phi_1$ (=sin2β) vs. $\mathcal{B}(B\to \tau\nu)$

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



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

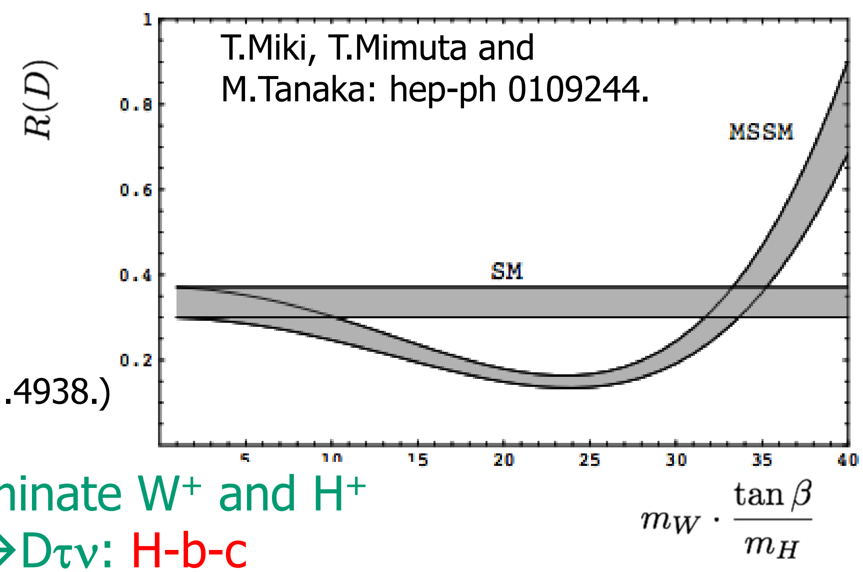
Semileptonic decay sensitive to charged Higgs



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

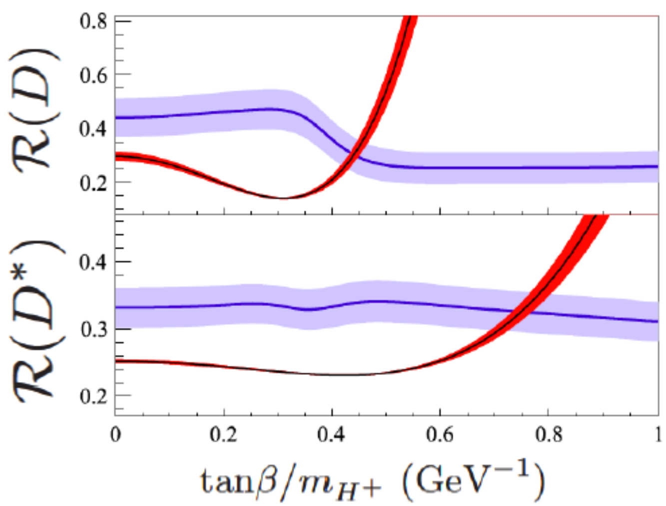
$$\mathcal{R}(D)_{\rm exp} = 0.440 \pm 0.072 \quad \mathcal{R}(D^*)_{\rm exp} = 0.332 \pm 0.030$$

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

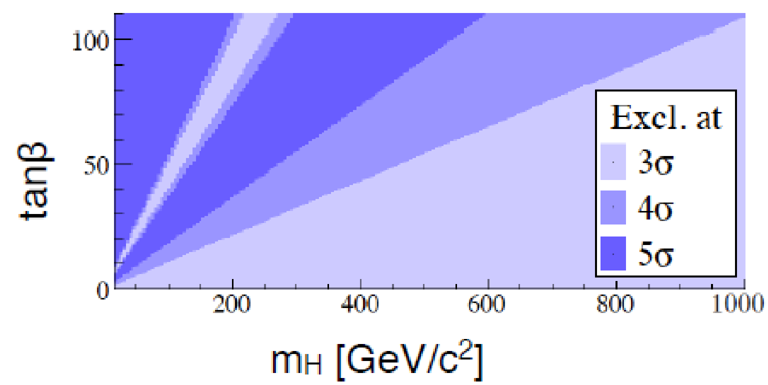
$$\mathcal{R}(D)_{\rm SM} = 0.297 \pm 0.017 \quad \mathcal{R}(D^*)_{\rm SM} = 0.252 \pm 0.003$$

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

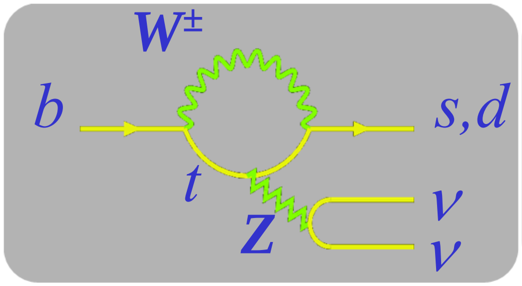
More discussion of the implications: BaBar, Phys. Rev. Lett. 109, 101802 (2012)

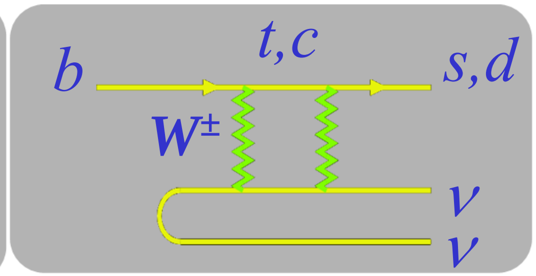
$B \to K^{(*)}\nu\bar{\nu}$

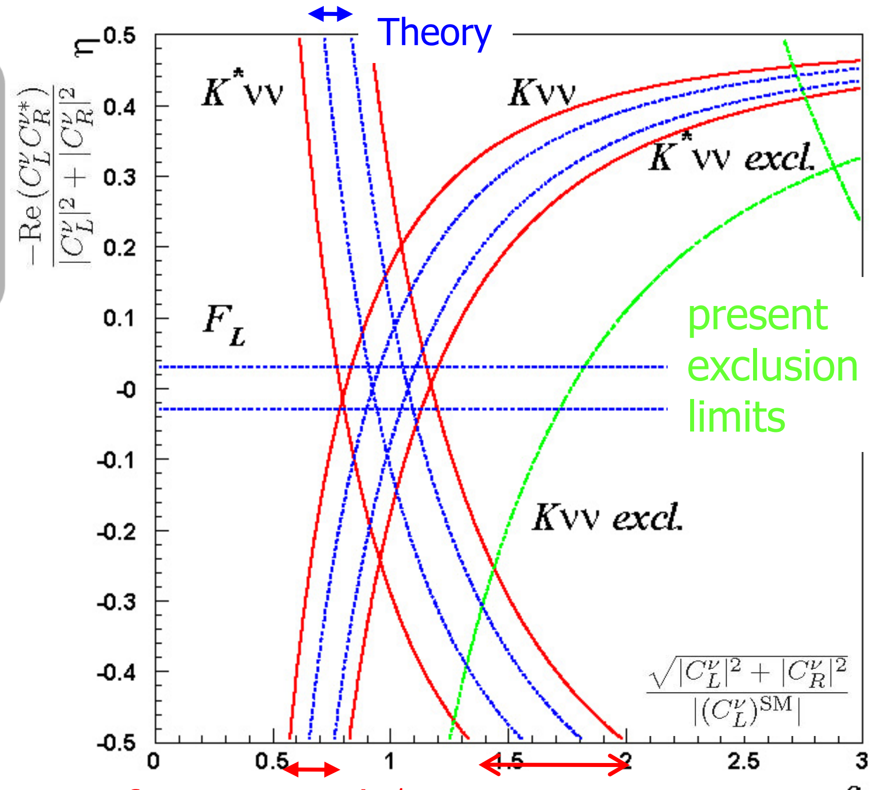
arXiv:1002.5012

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

SM: penguin + box diagrams







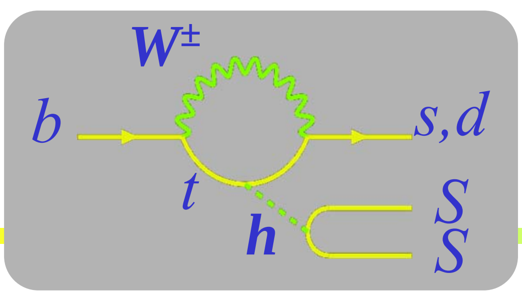
super B factory, 50 ab^{-1}

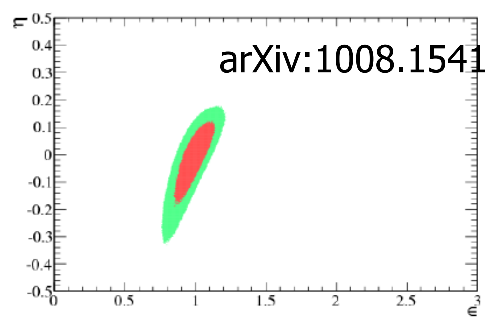
$B \to K\nu\nu$, $\mathcal{B} \sim 4{\cdot}10^{-6}$

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

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

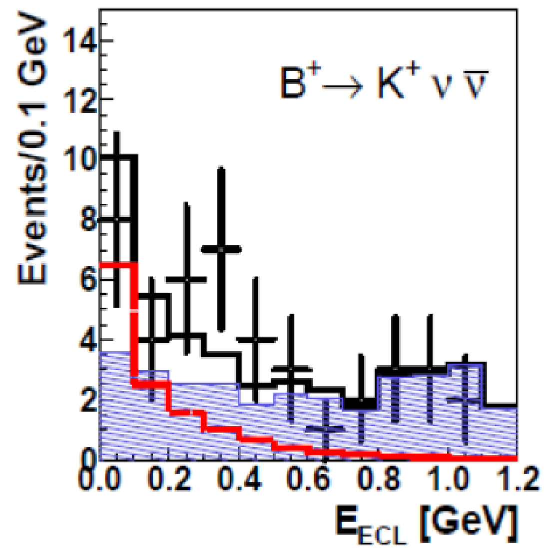
from, e.g.,





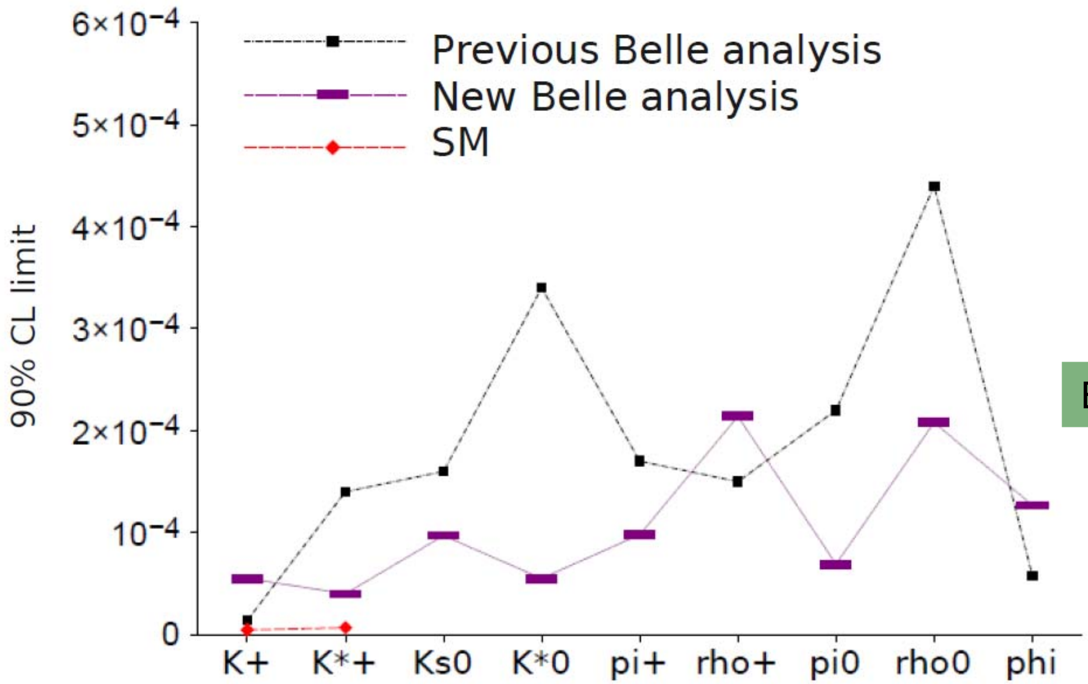
$B \to h\nu\bar{\nu}$ decays

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



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

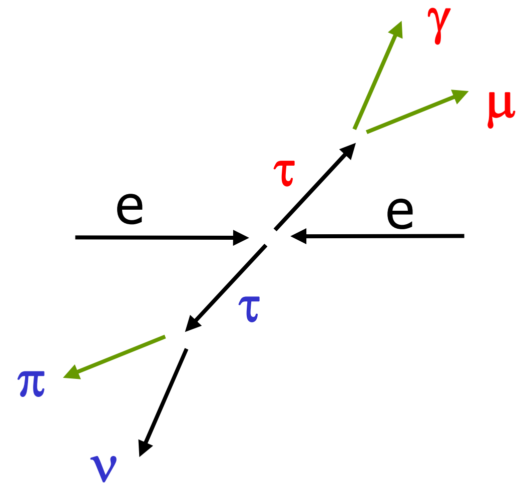
Present status: recent update from Belle



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

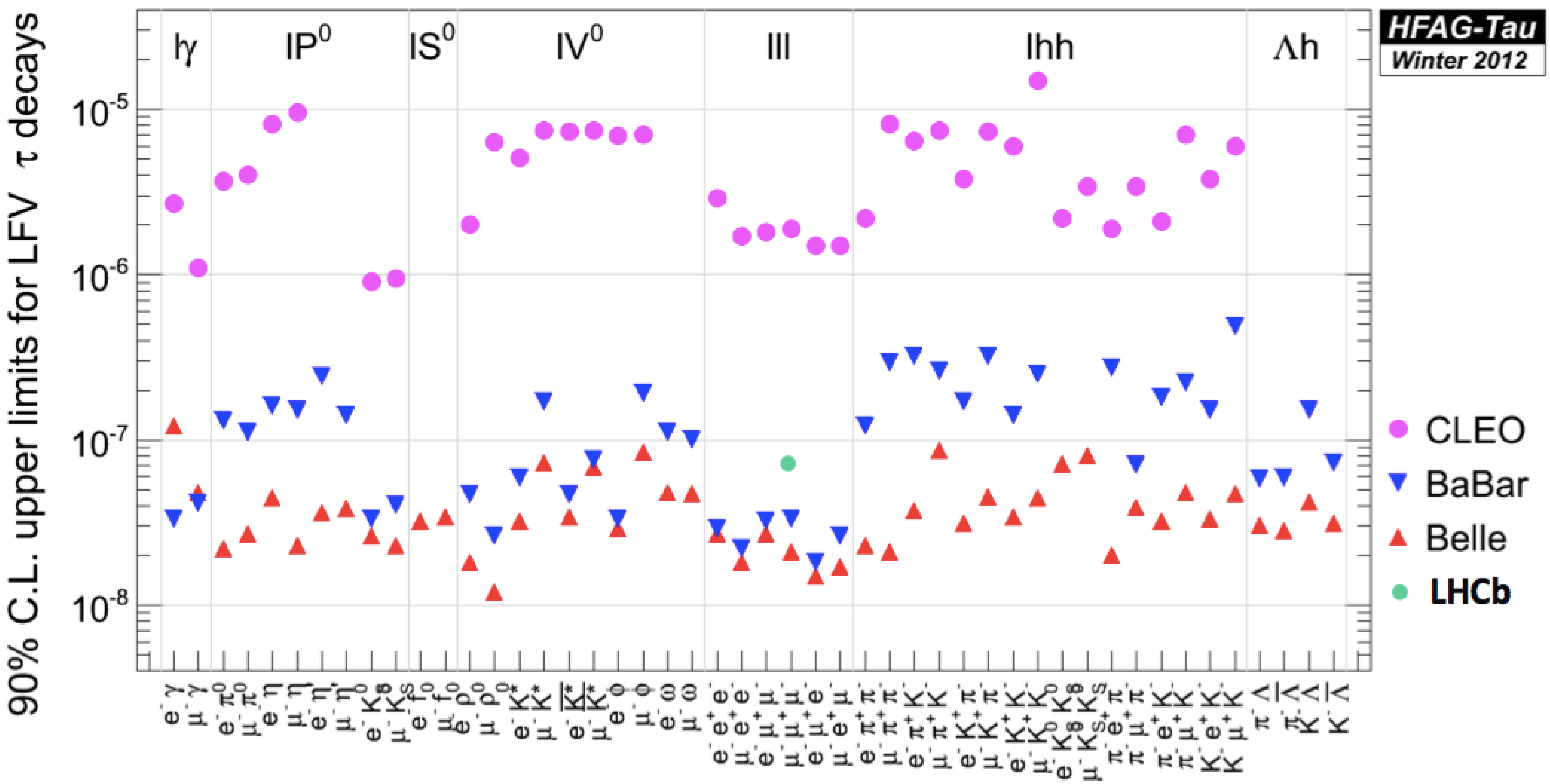
Rare τ decays

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



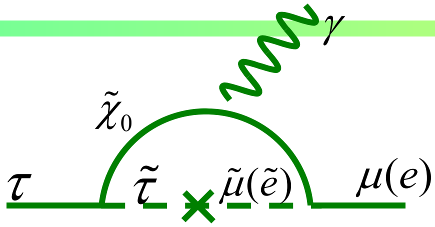
LFV in tau decays: present status

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



LFV and New Physics

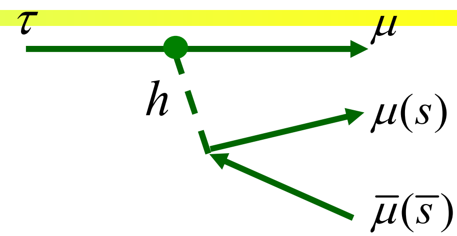
$\tau \rightarrow l\gamma$



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

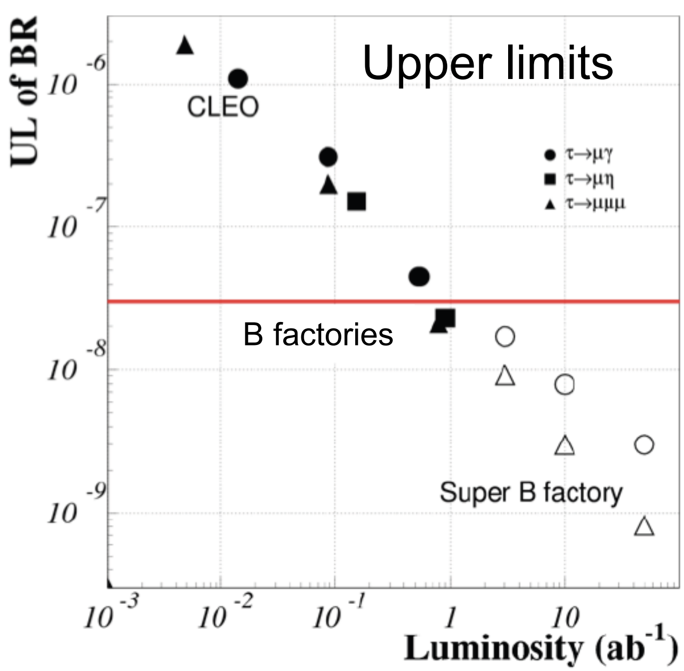
$$Br(\tau \rightarrow \mu\gamma) \simeq 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}}\right)\left(\frac{1\,TeV}{m_{SUSY}}\right)^4 \tan^2\beta$$

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



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

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



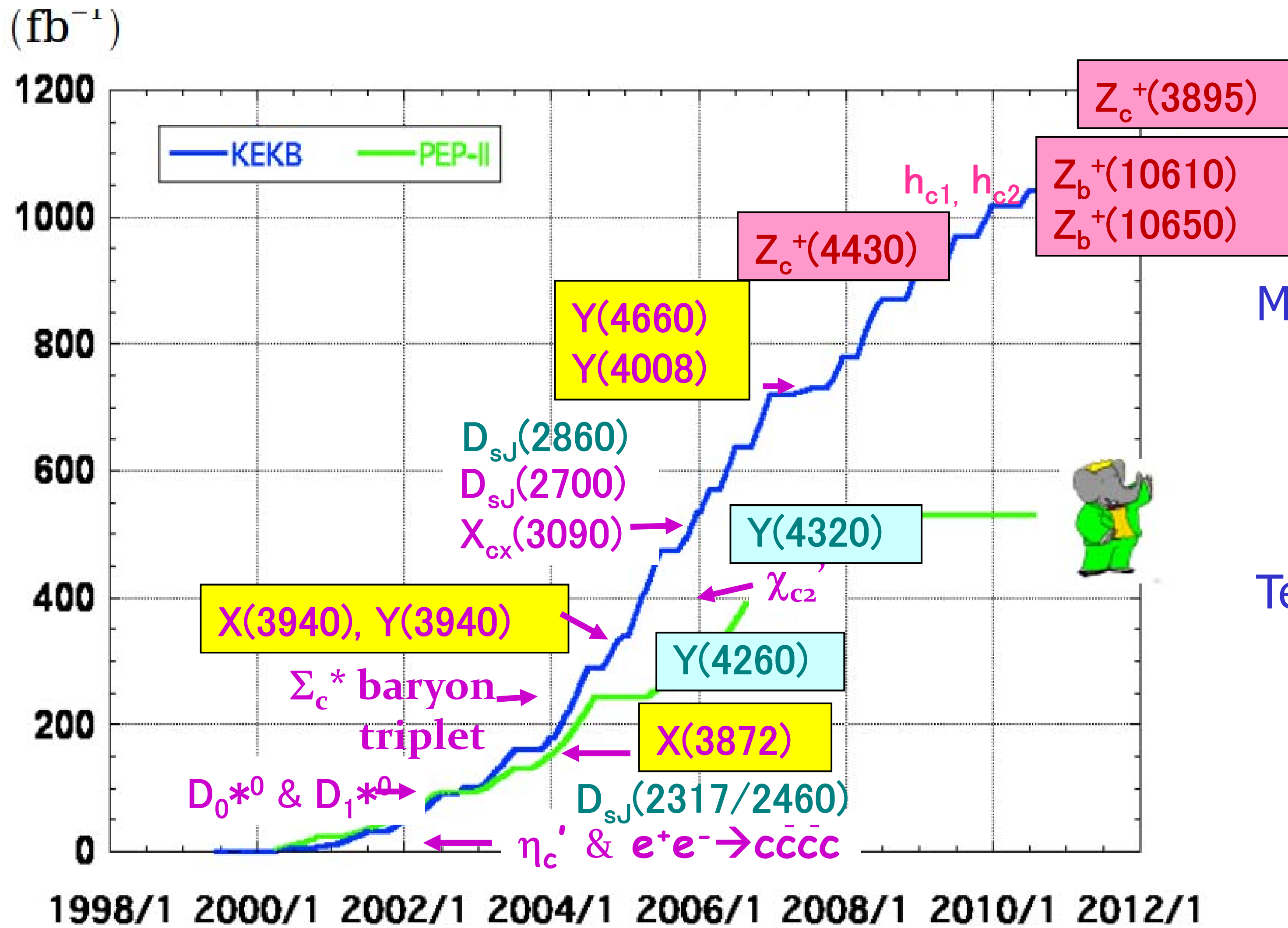
Integ. Lum.(ab^{-1})

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}

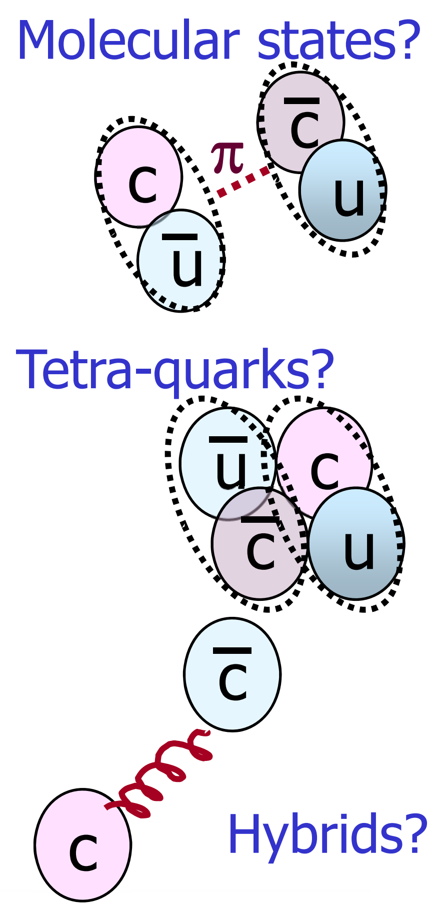
B factories: a success story

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

New hadrons at B-factories



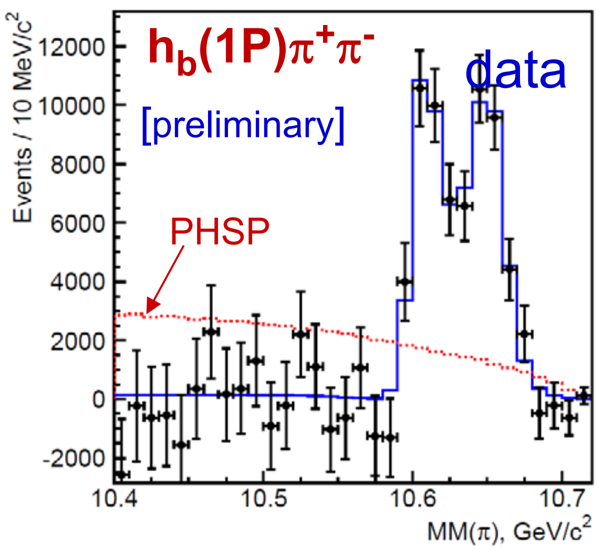
Coloured boxes: exotic candidates



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

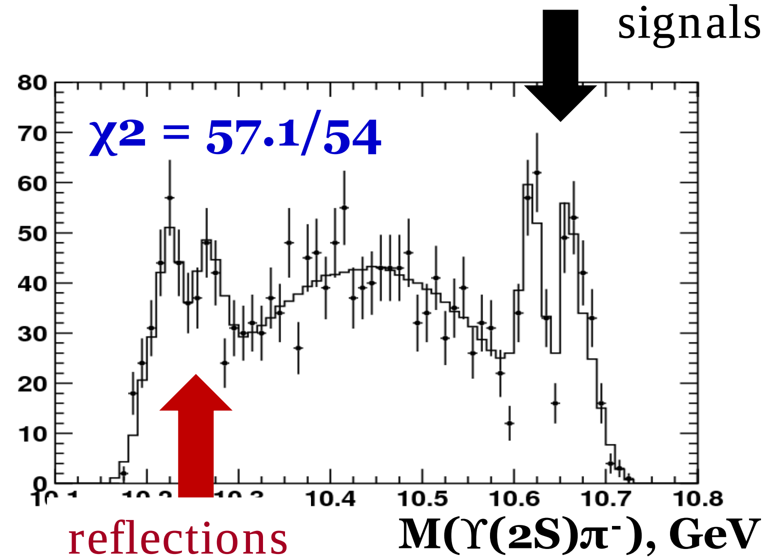
Look at $M(h_b\pi^+) = MM(\pi^-)$

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



Exclusive searches:

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



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

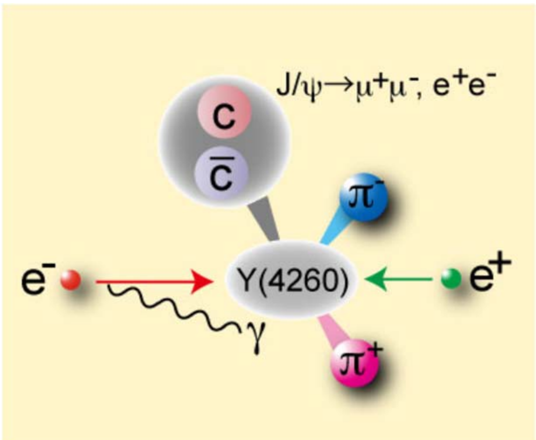
$Z_b(10650)$ M = 10653.3 ± 1.5 MeV
Γ = 14.0 ± 2.8 MeV

Seen in 5 different final states, parameters are consistent

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

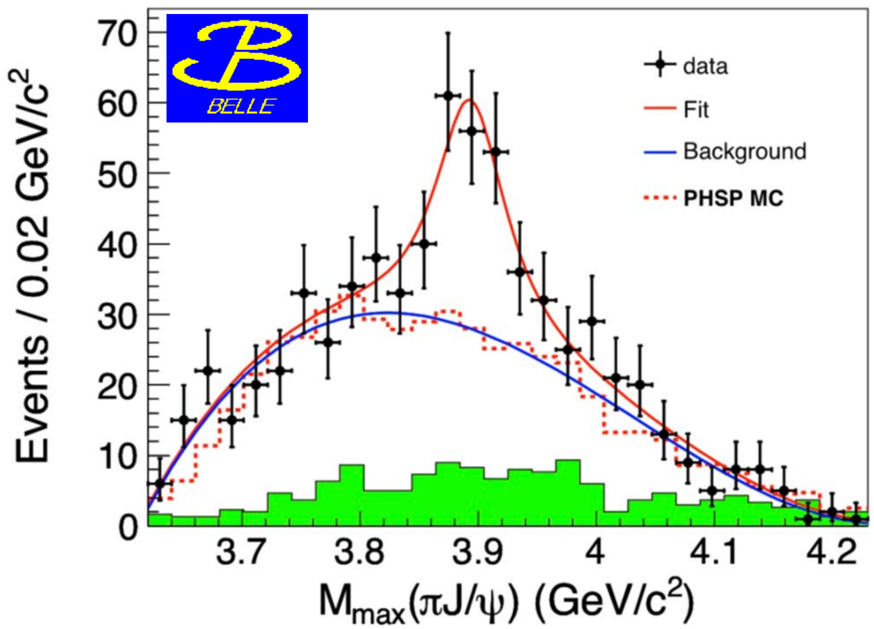
→ What is the nature of Z_b^+? Molecules, tetraquarks, cusps, ... ?

Charged charmonium in Y(4260) → $J/\psi\ \pi^+ \pi^-$



Y(4260) produced via ISR
(Initial State Radiation)

Look for a resonance in $J/\psi\ \pi^+$



Found! → $Z_c^+(3895)$

Observed also by BES III.
They also recently found a peak in $(DD^*)^+$ at 3885 MeV
PRL110, 252001 (2013)
PRL112, 022001 (2014)

PRL110, 252002 (2013)

very similar to
$\Upsilon(5S) \rightarrow Z_b^+\ \pi^- \rightarrow \Upsilon(1s)\ \pi^+ \pi^-$

What next?

Next generation: Super B factories → Looking for NP

→ Need much more data (almost two orders!)

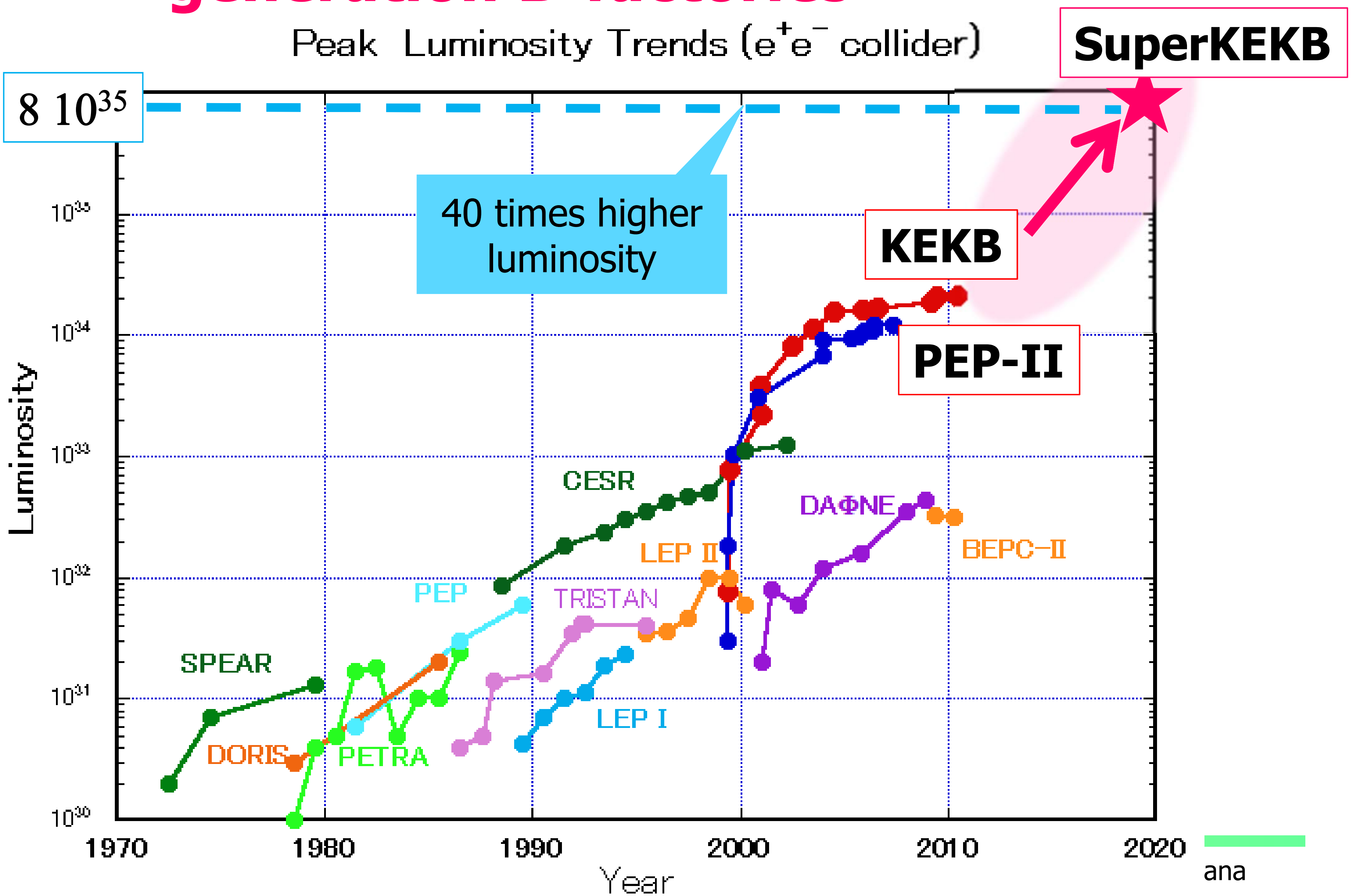
However: it will be a different world in two years, there is a hard competition from LHCb and BESIII

Still, a e^+e^- machine 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)

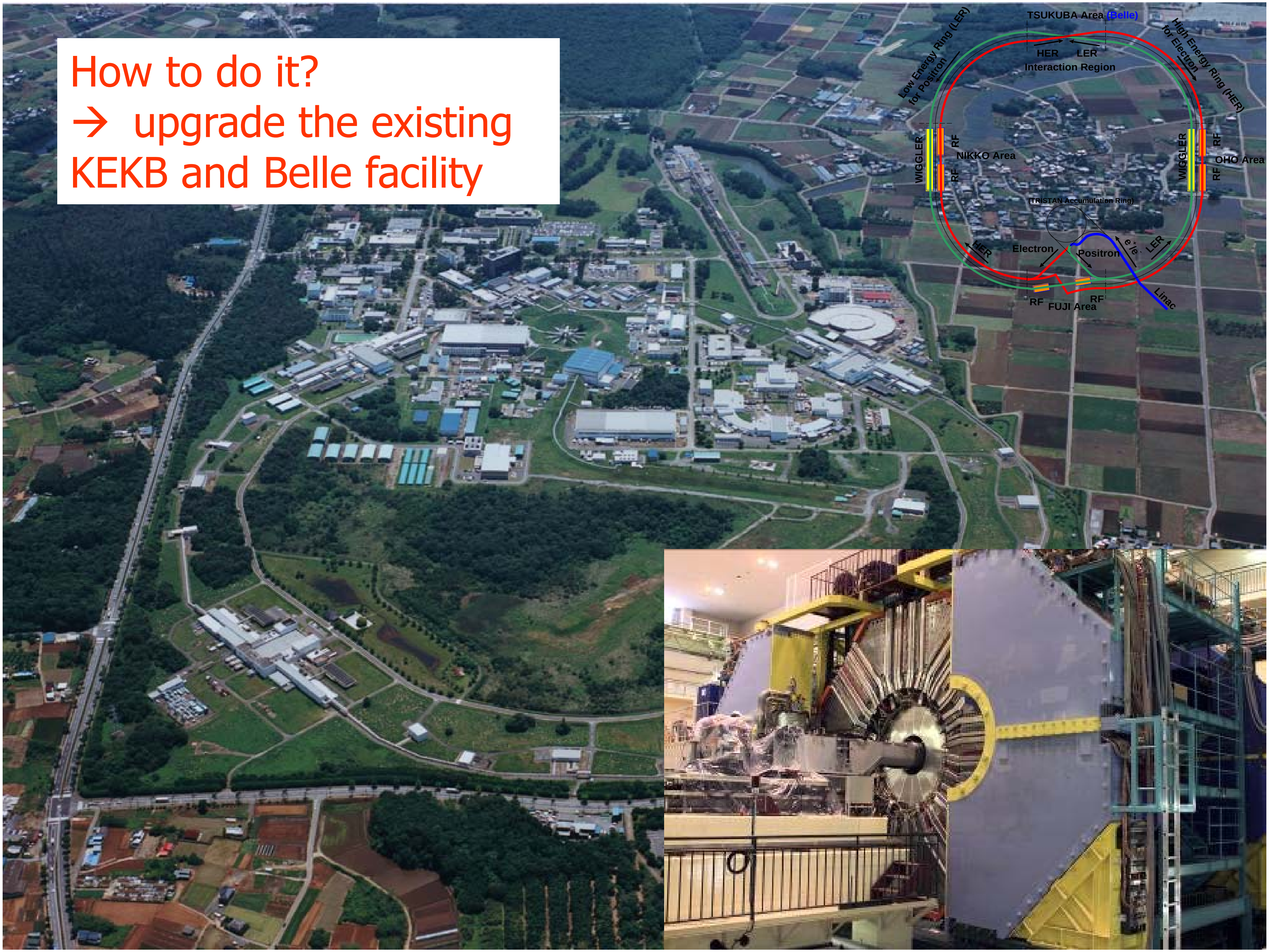
→ SuperB Progress Reports: Physics, arXiv:1008.1541 (SuperB)

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



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

← **"Nano-Beam" scheme**

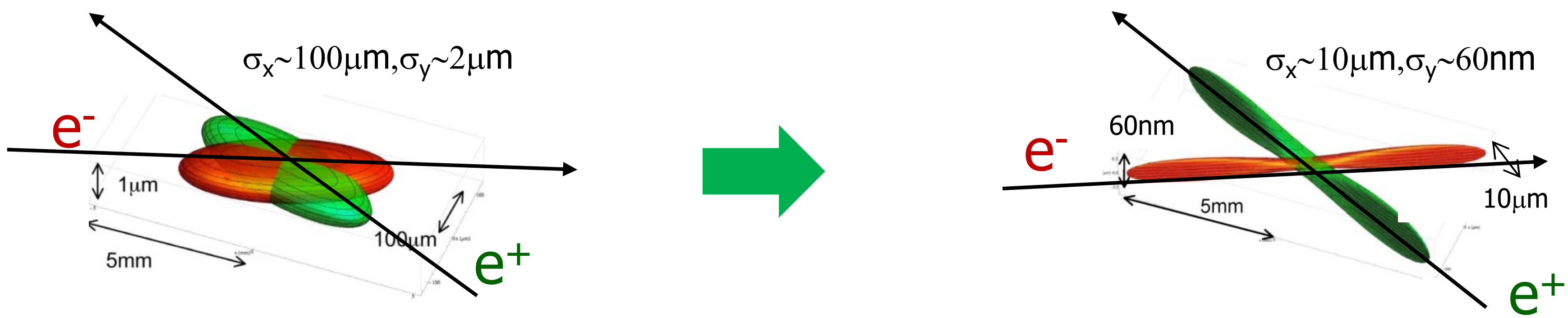
Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB

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?

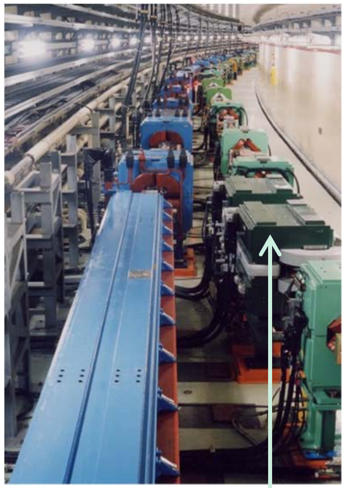
In KEKB, colliding electron and positron beams were already much thinner than a human hair...



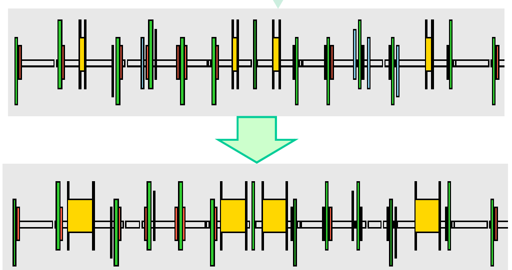
... For a 40x increase in intensity you have to make the beam as thin as a few x100 atomic layers!

→Profiting from ILC R+D, lectures by M. Titov

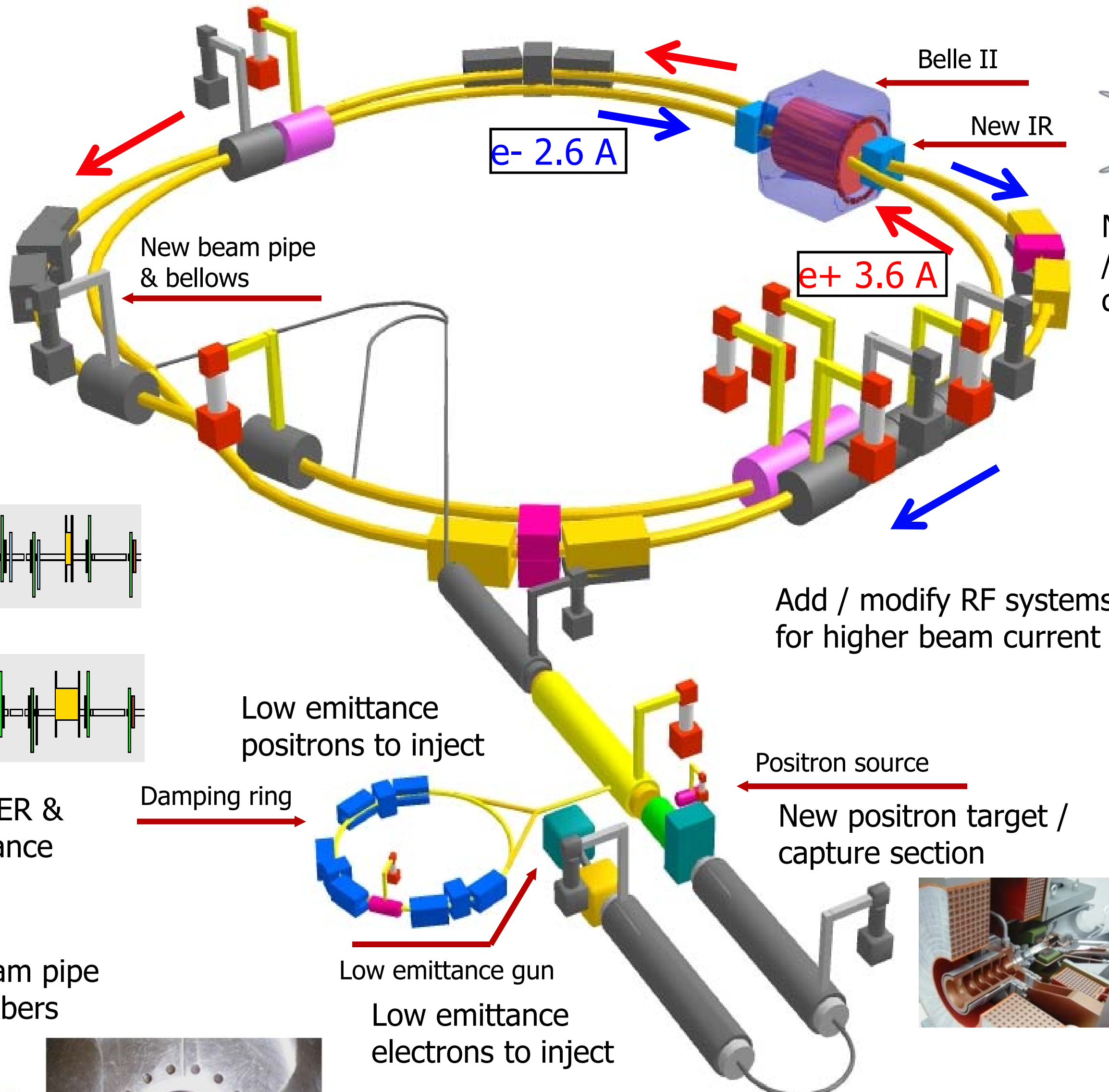
KEKB → SuperKEKB



Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance



Belle II

New IR

New beam pipe & bellows

Low emittance positrons to inject

Damping ring

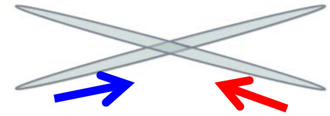
Low emittance gun

Low emittance electrons to inject

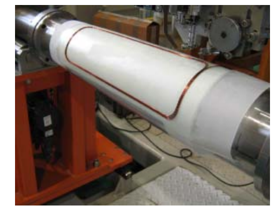
Positron source

New positron target / capture section

Colliding bunches

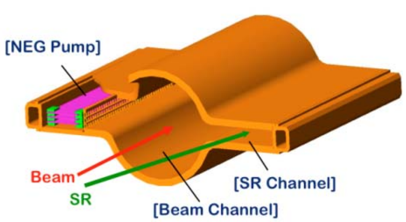


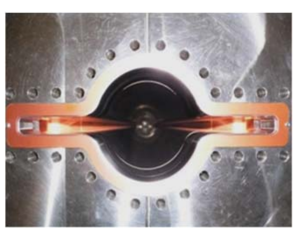
New superconducting /permanent final focusing quads near the IP



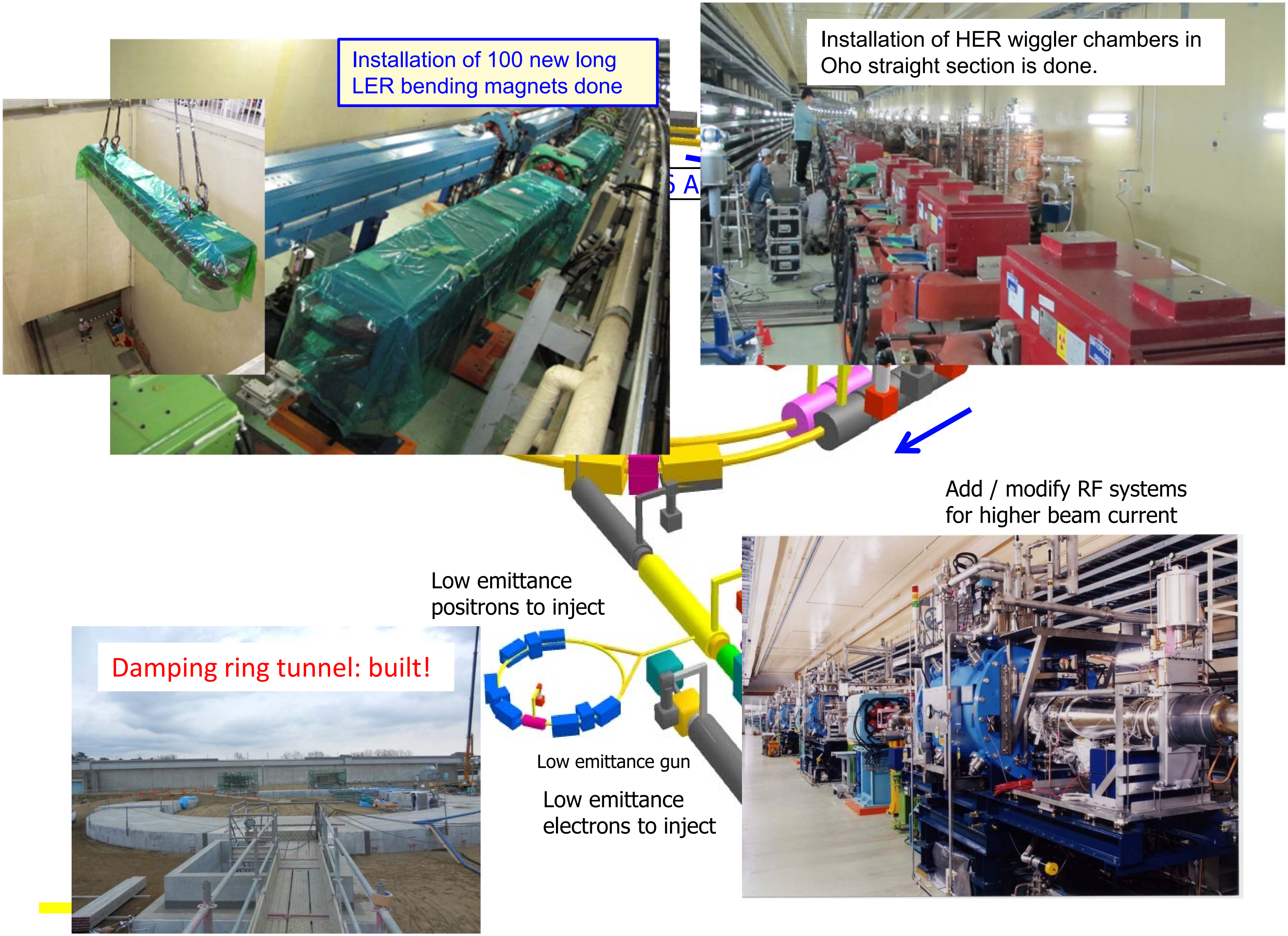
Add / modify RF systems for higher beam current

TiN-coated beam pipe with antechambers





To get x40 higher luminosity

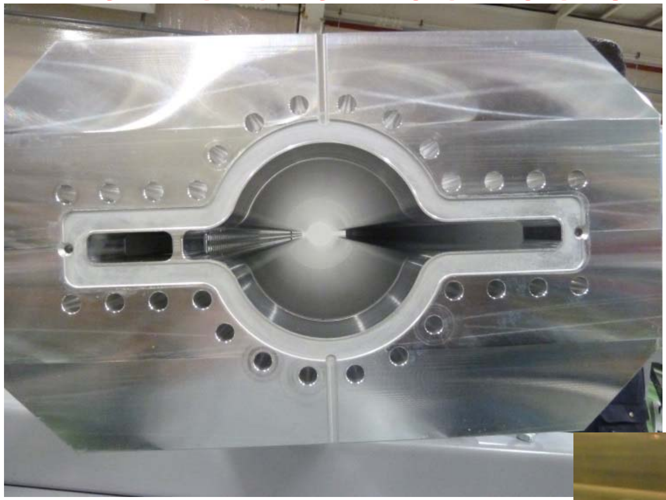

Installation of 100 new long LER bending magnets done
Installation of HER wiggler chambers in Oho straight section is done.
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Damping ring tunnel: built!
Low emittance gun
Low emittance electrons to inject

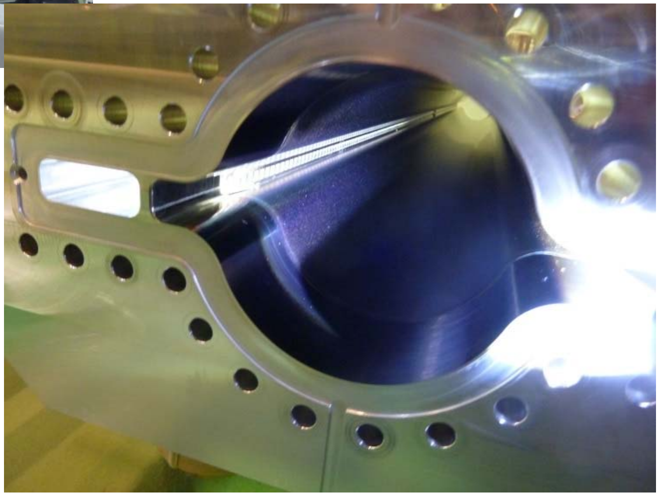
Entirely new LER beam pipe with ante-chamber and Ti-N coating

Beam pipe is made of aluminum.

Fabrication of the LER arc beam pipe section is completed

Al ante-chamber before coating





After TiN coating before baking

After baking

All 100 4 m long dipole magnets have been successfully installed in the low energy ring (LER)!

Three magnets per day !

Installing the 4 m long LER dipole **over** the 6 m long HER dipole (remains in place).

Magnet installation

field measurement

Installation of 100 new LER bending magnets done

move into tunnel

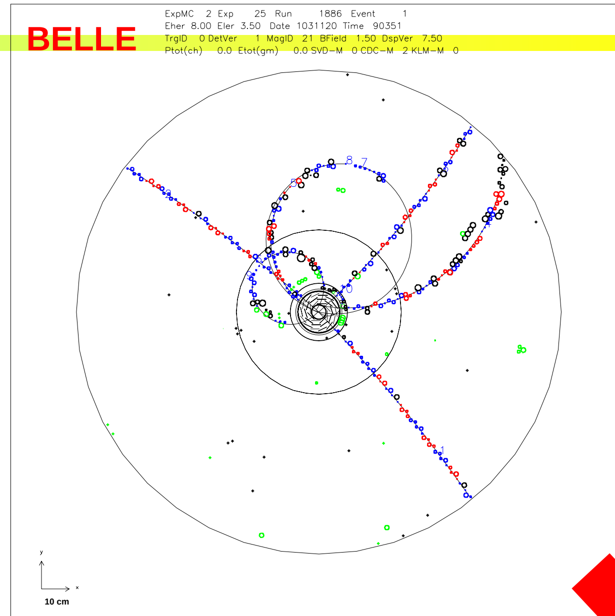
carry on an air-pallet

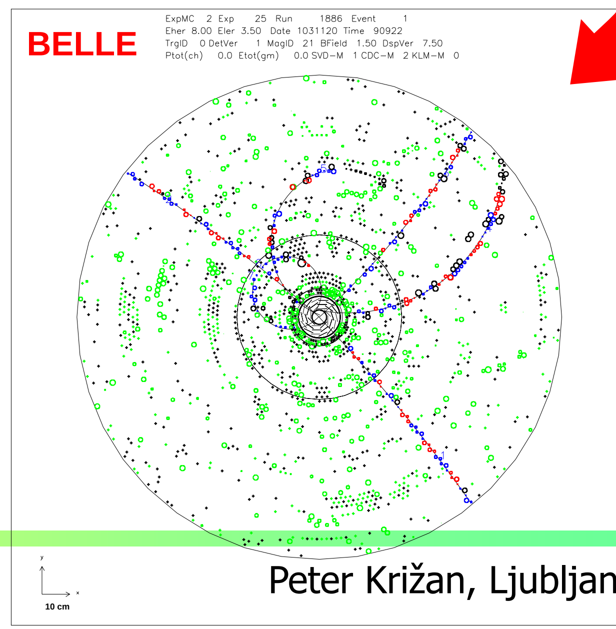
carry over existing HER dipole

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 ← $s\mu\mu$ recon. eff.
  - hermeticity ← ν “reconstruction”



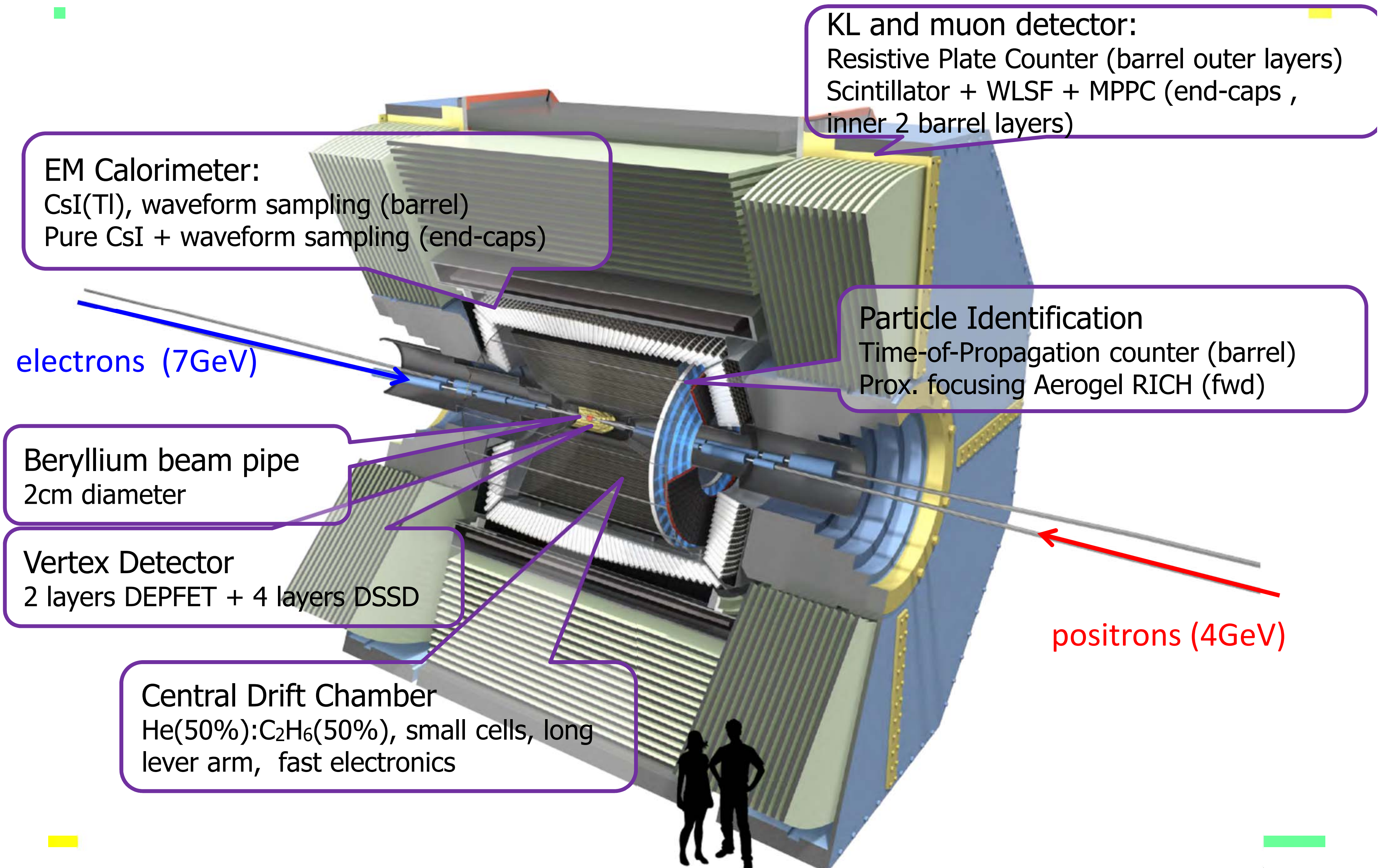


Solutions:

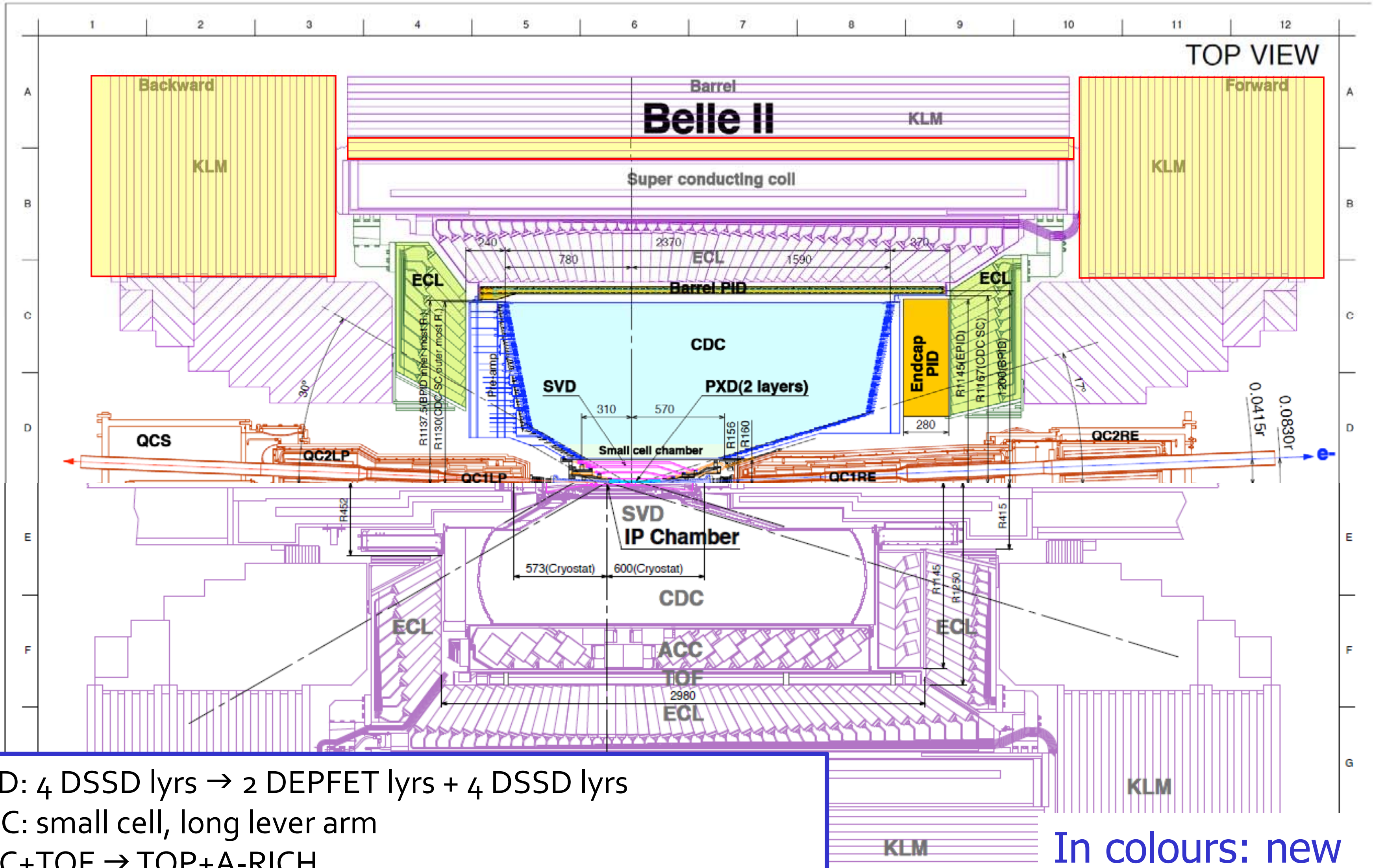
- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter crystals
- Faster readout electronics and computing system.

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

Belle II Detector



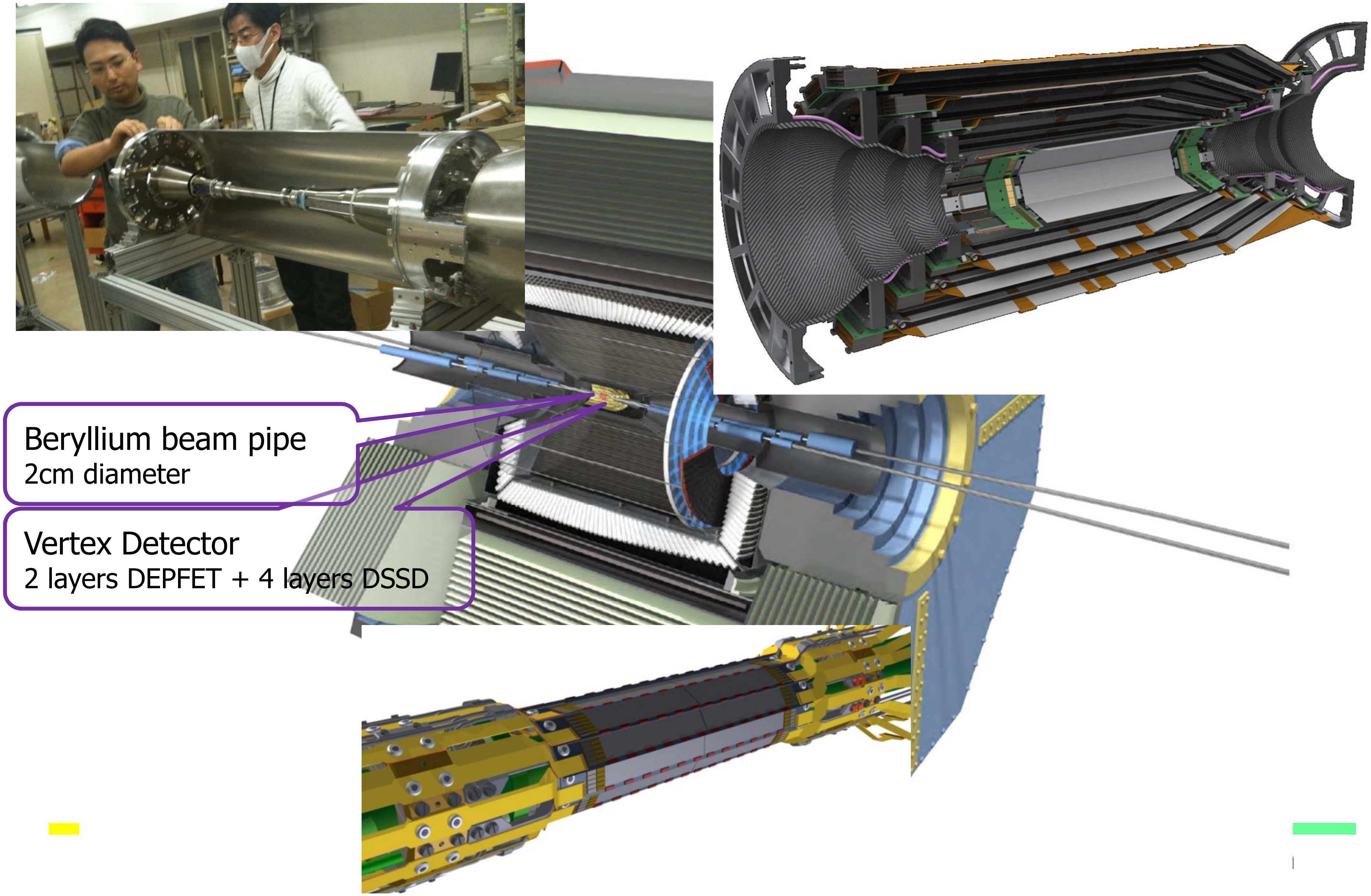
Belle II Detector (in comparison with Belle)



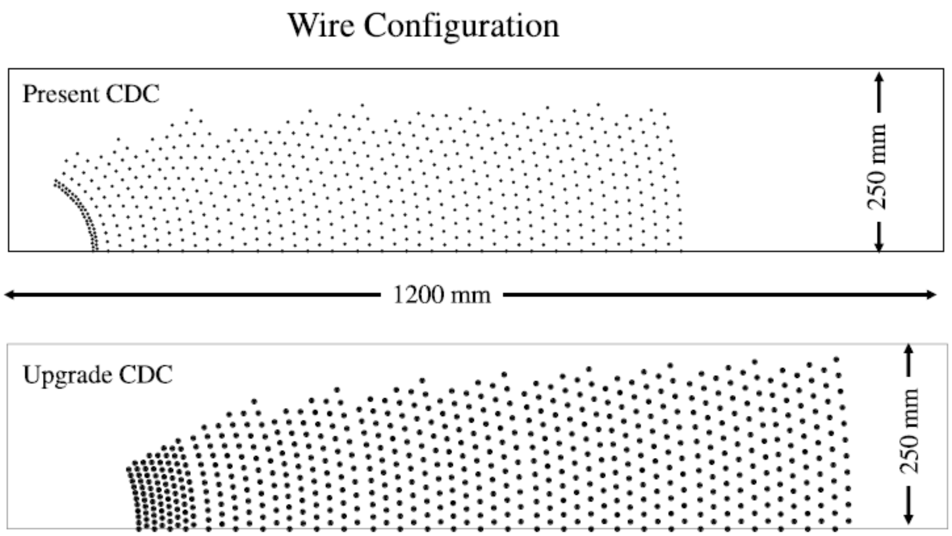
SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

In colours: new components

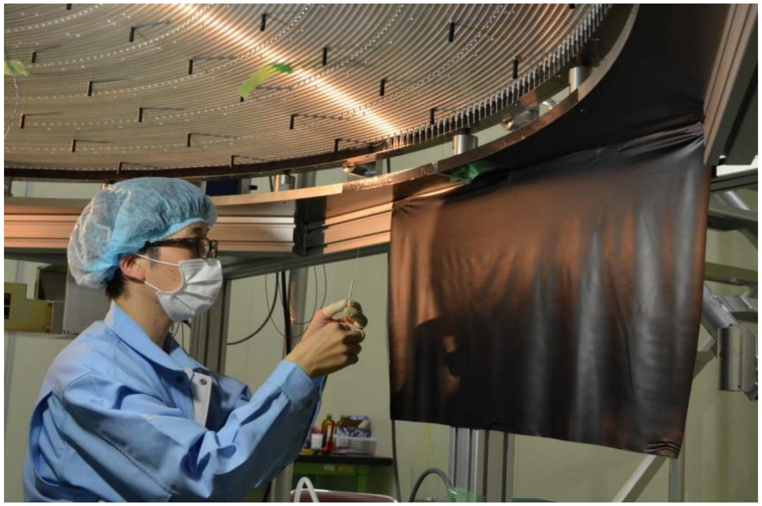
Belle II Detector – vertex region



Belle II CDC



Much bigger than in Belle!



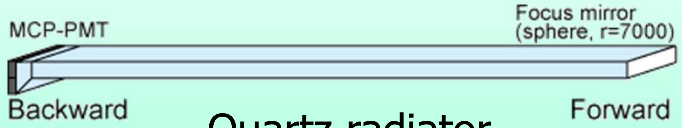
Wire stringing in a clean room

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

- Finished!

Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



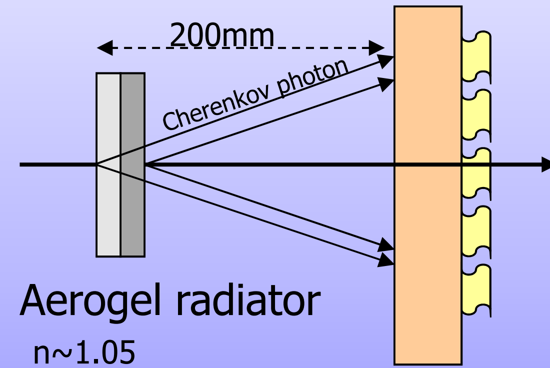
Quartz radiator

Focusing mirror

Small expansion block

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

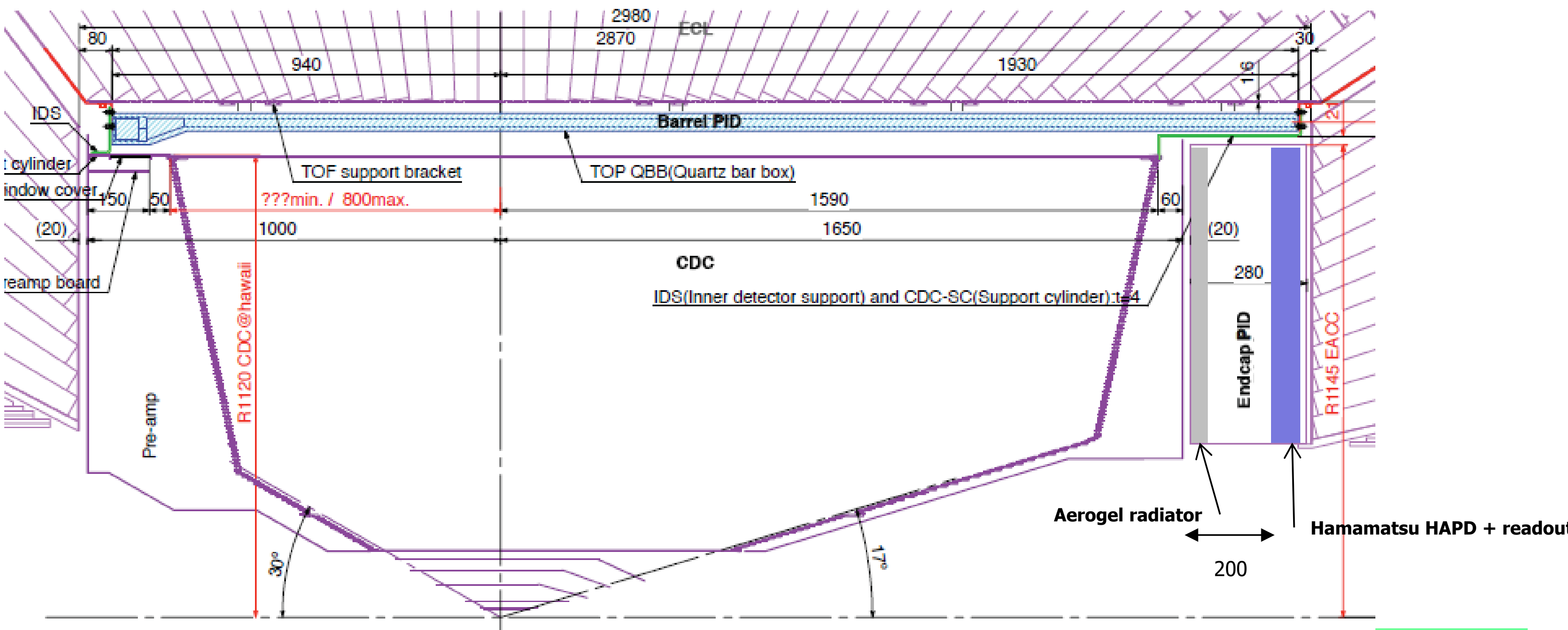
Endcap PID: Aerogel RICH (ARICH)



Aerogel radiator

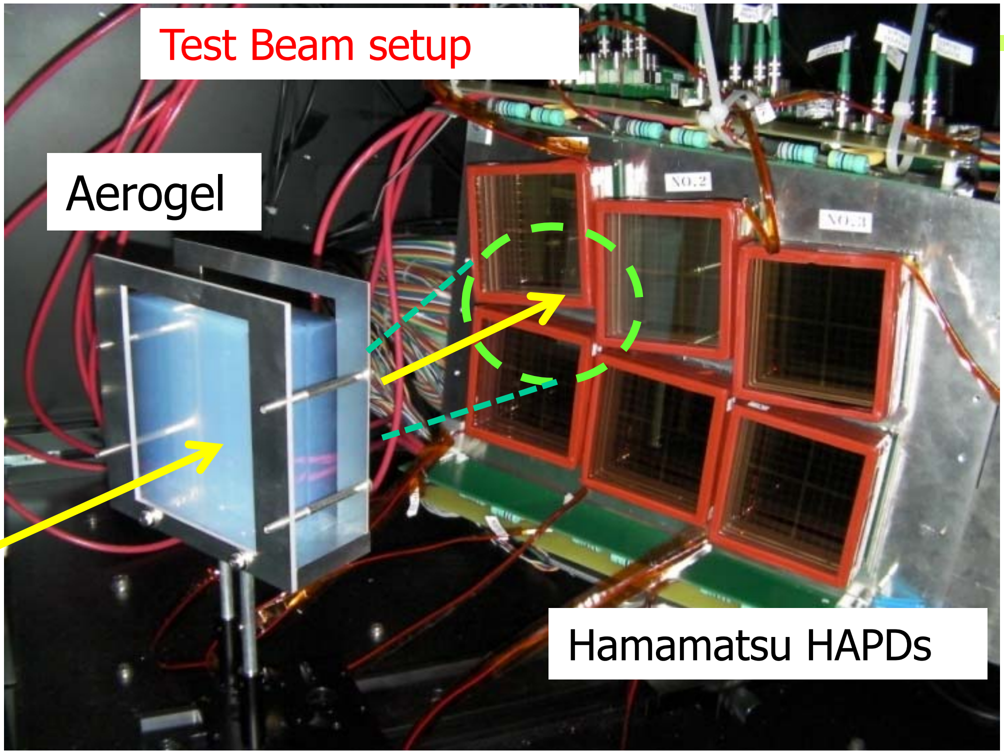
n~1.05

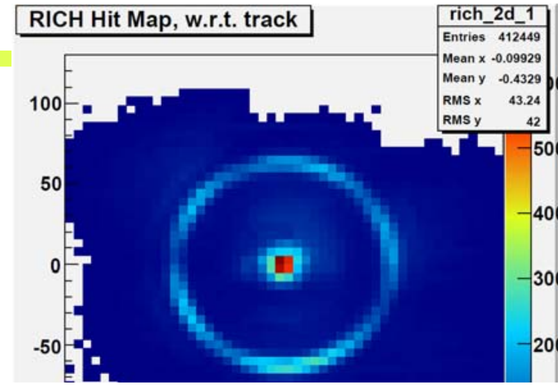
Hamamatsu HAPD



Peter Križan, Ljubljana

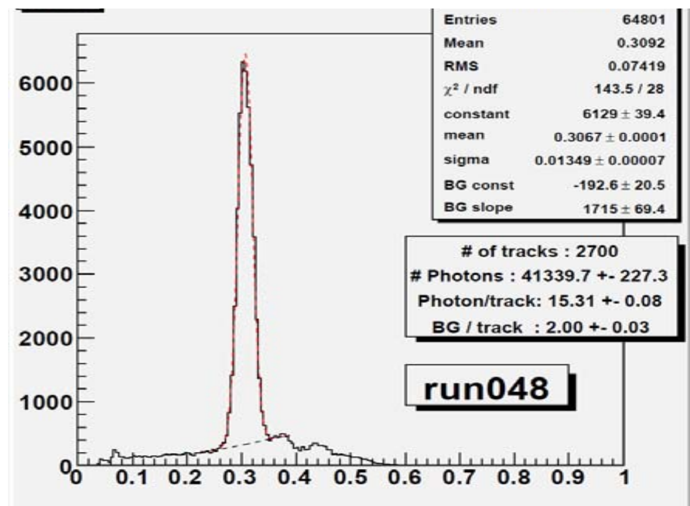
Aerogel RICH (endcap PID)





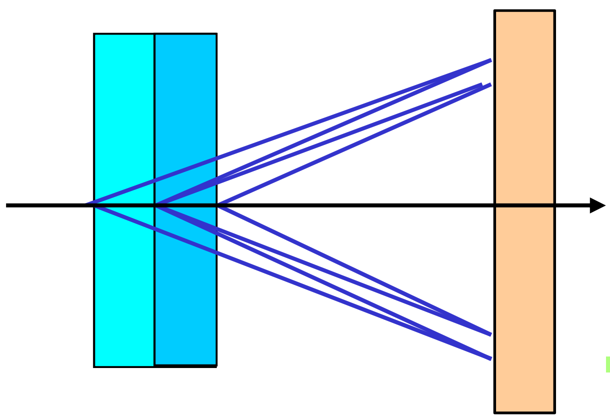
Clear Cherenkov image observed

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 !

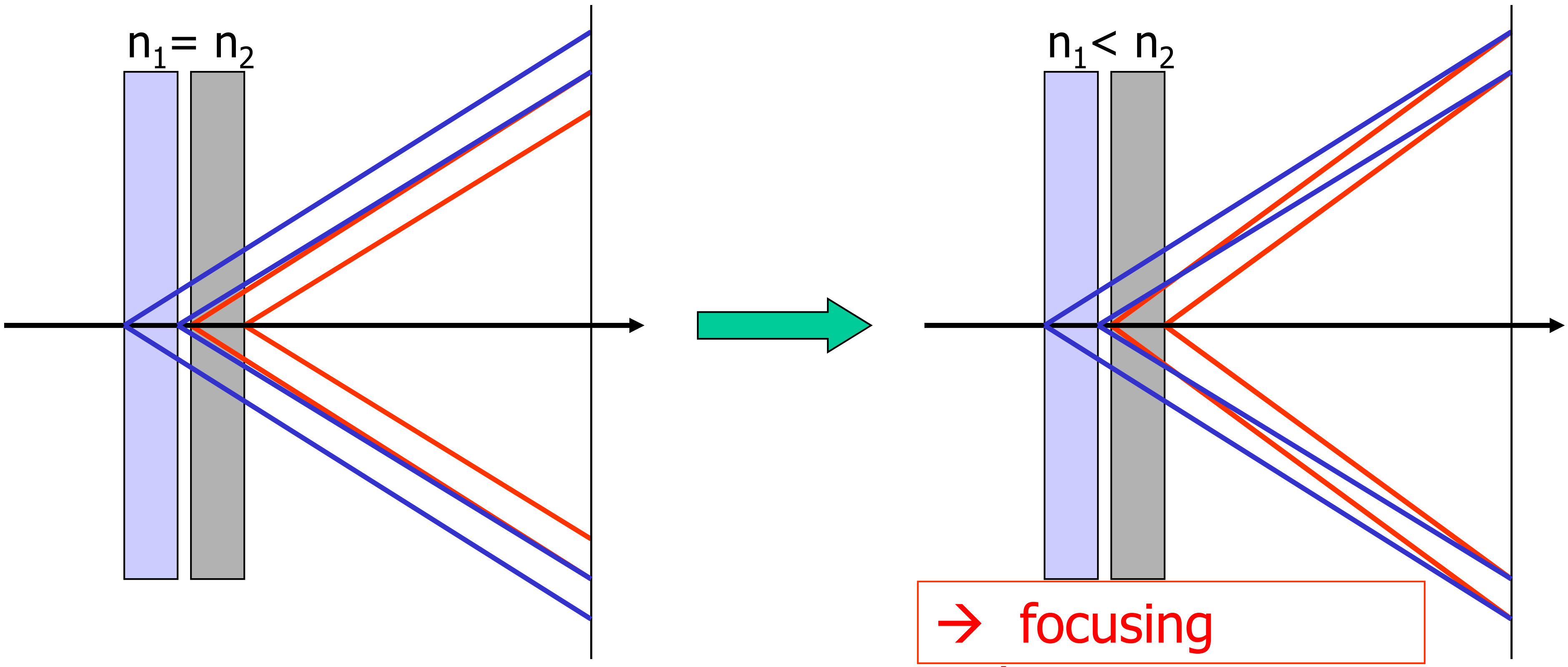
Peter Križan, Ljubljana

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

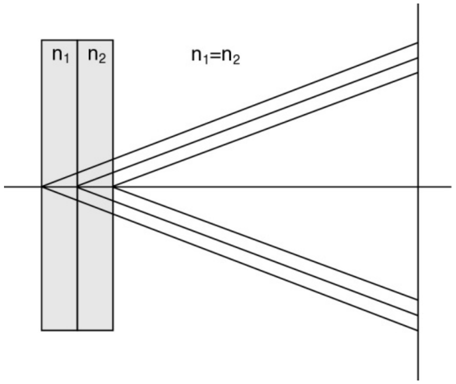


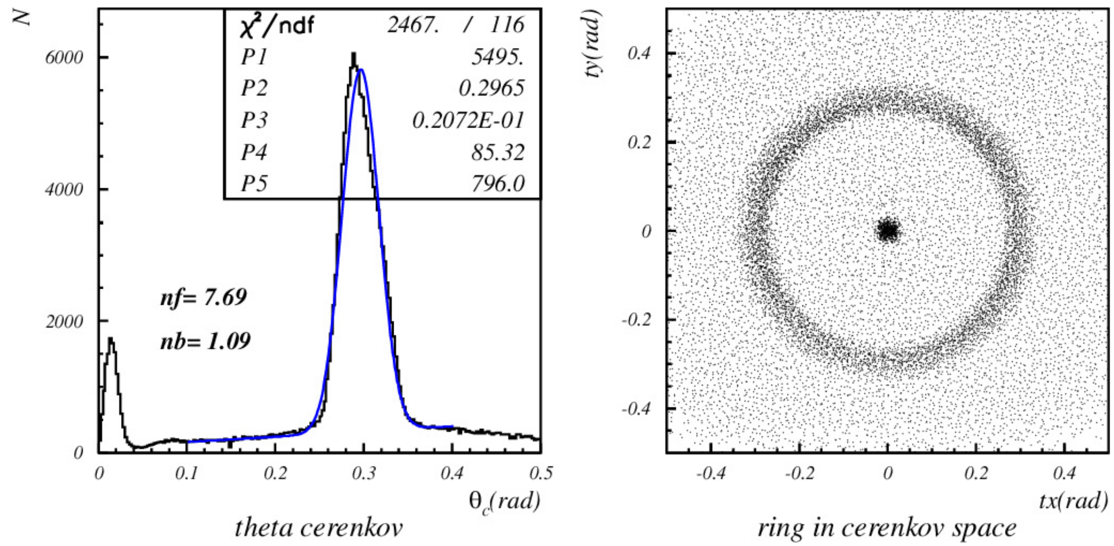
Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

Focusing configuration – data

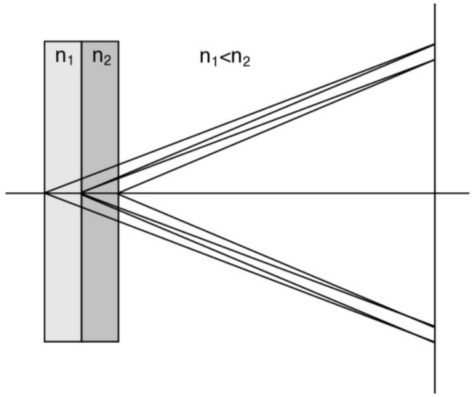
Increases the number of photons without degrading the resolution

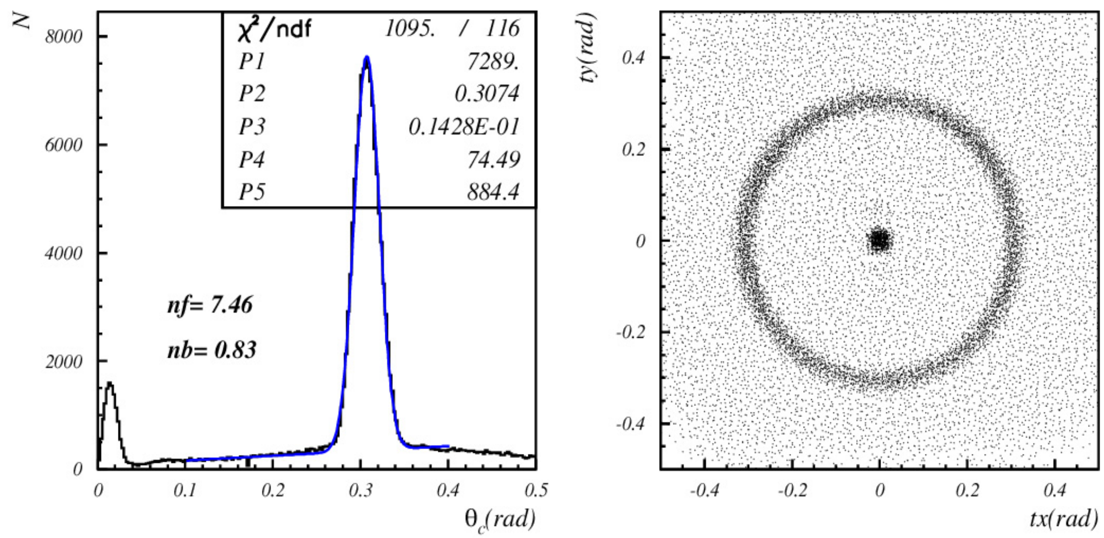
4cm aerogel single index





2+2cm aerogel

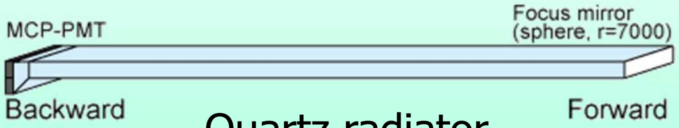




→NIM A548 (2005) 383

Cherenkov detectors

Barrel PID: Time of Propagation Counter (TOP)



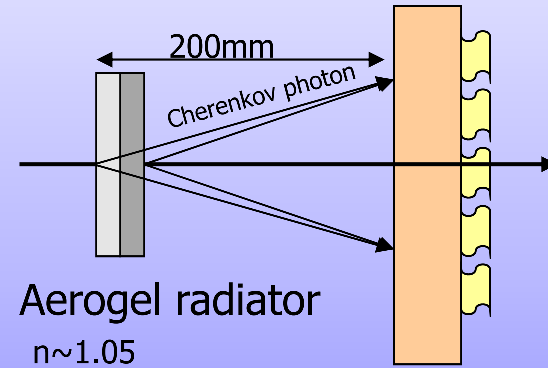
Quartz radiator

Focusing mirror

Small expansion block

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

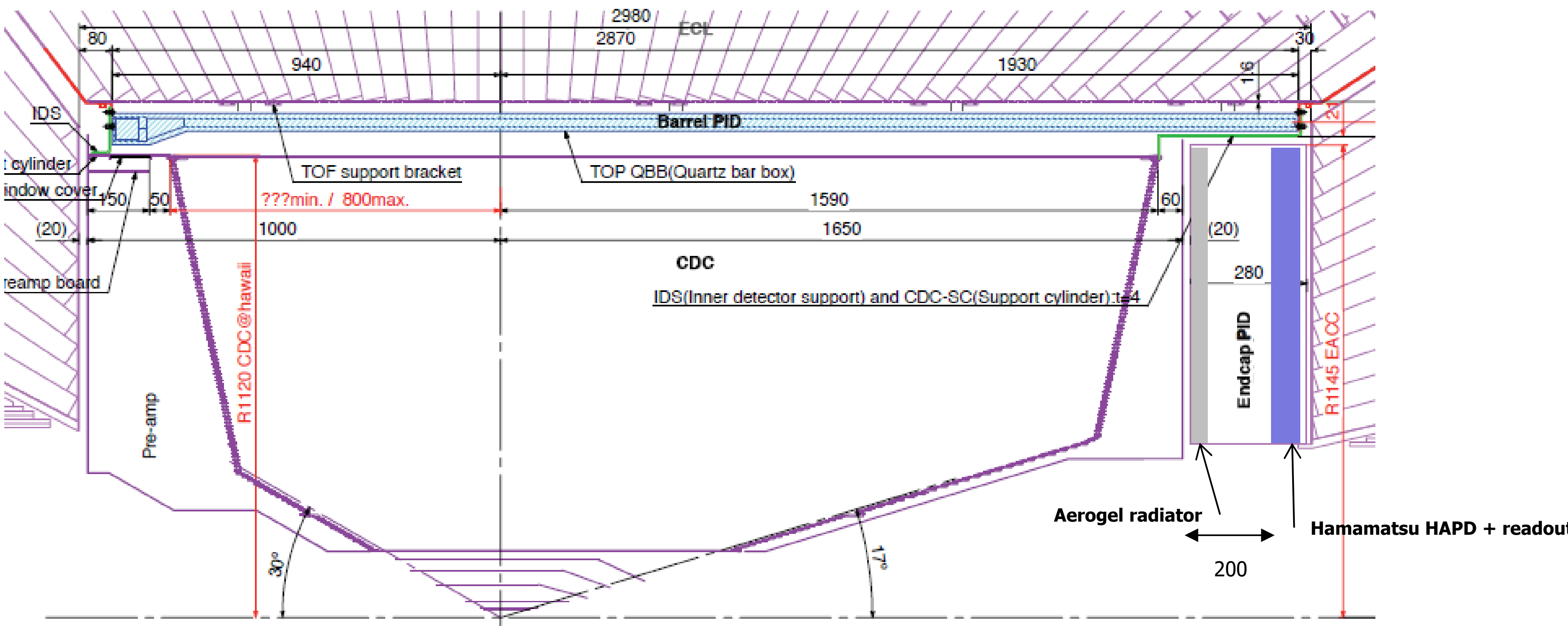
Endcap PID: Aerogel RICH (ARICH)



Aerogel radiator

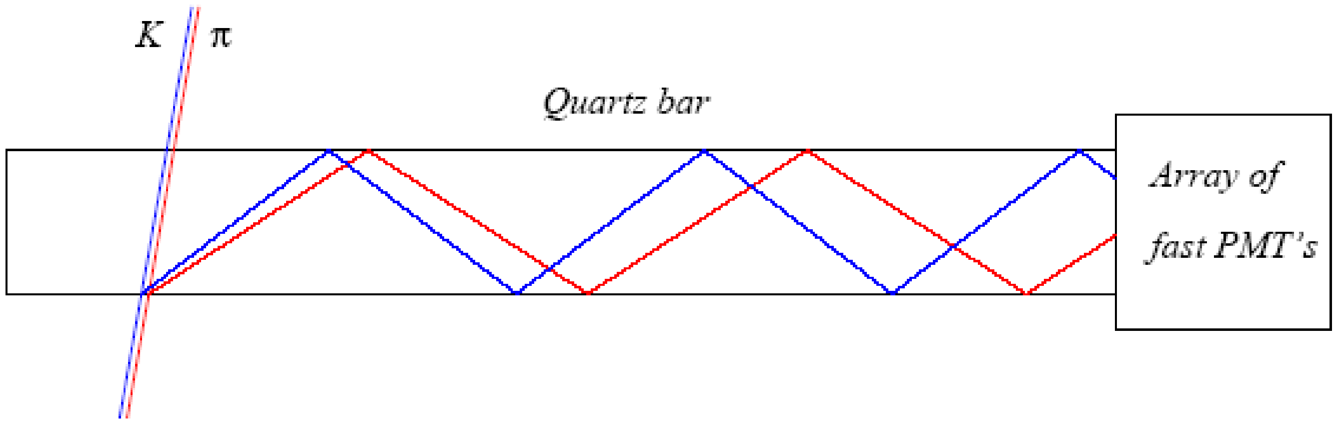
n~1.05

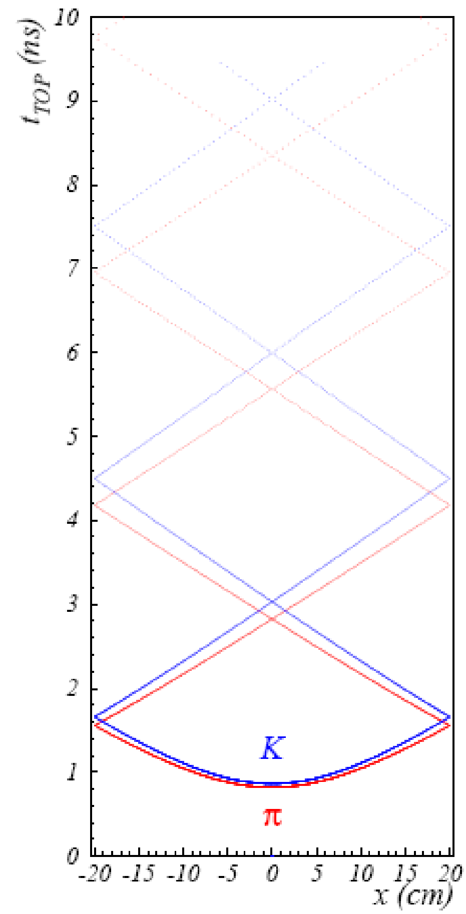
Hamamatsu HAPD
+ new ASIC



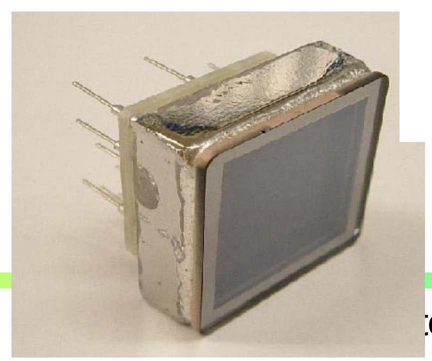
Peter Križan, Ljubljana

Belle II Barrel PID: Time of propagation (TOP) counter



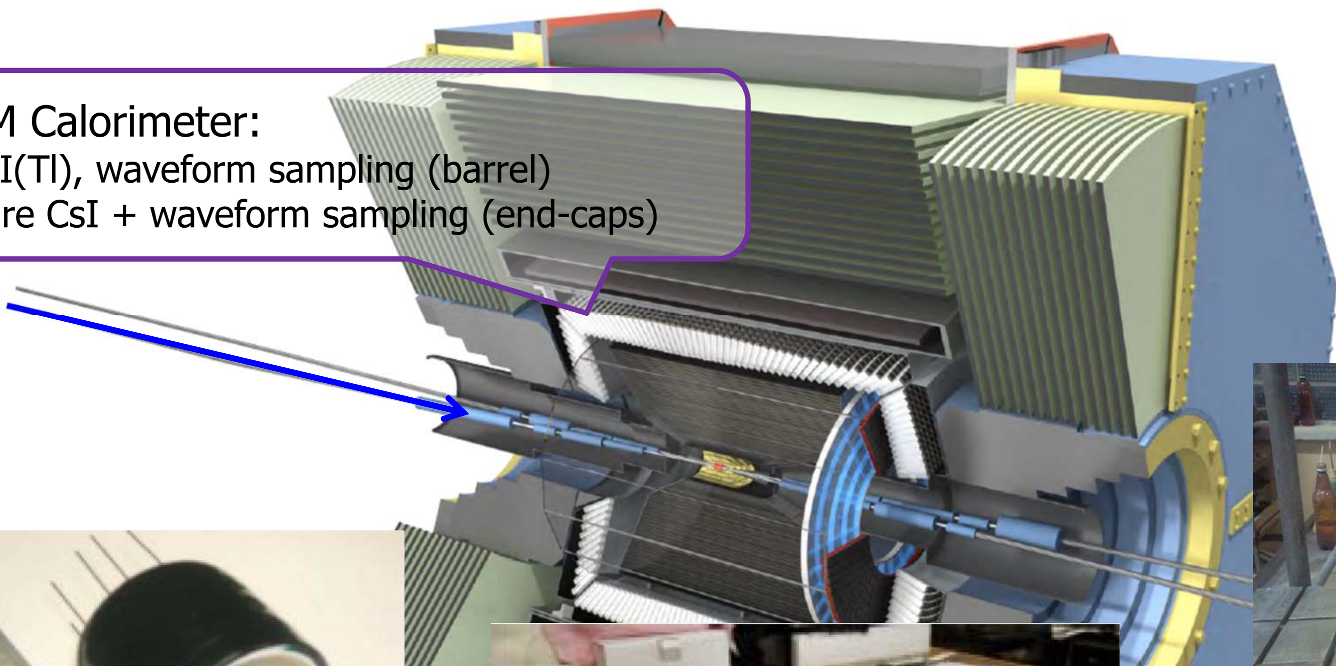


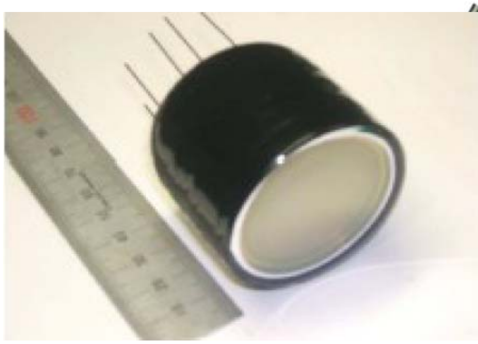
- Cherenkov ring imaging with precise time measurement.
- Uses internal reflection of Cherenkov ring images from quartz like the BaBar DIRC.
- Reconstruct Cherenkov angle from two hit coordinates and the time of propagation of the photon
  - Quartz radiator (2cm thick)
  - Photon detector (MCP-PMT)
    - Excellent time resolution ~ 40 ps
    - Single photon sensitivity in 1.5



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

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

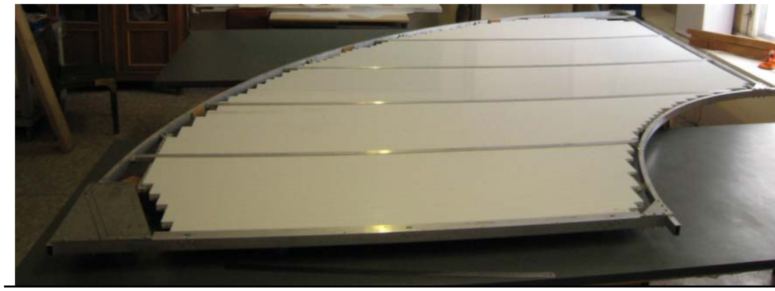


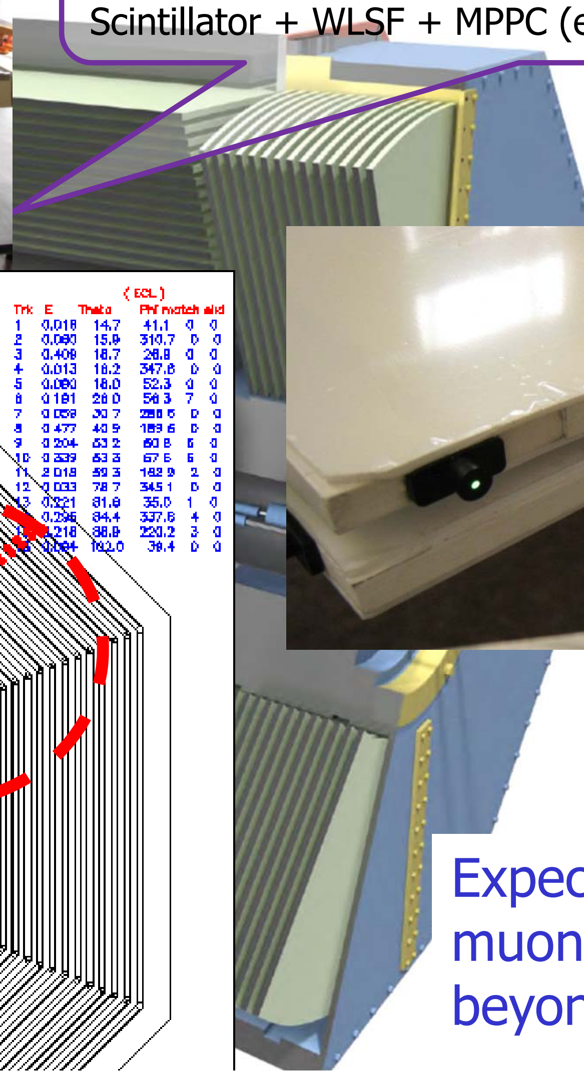


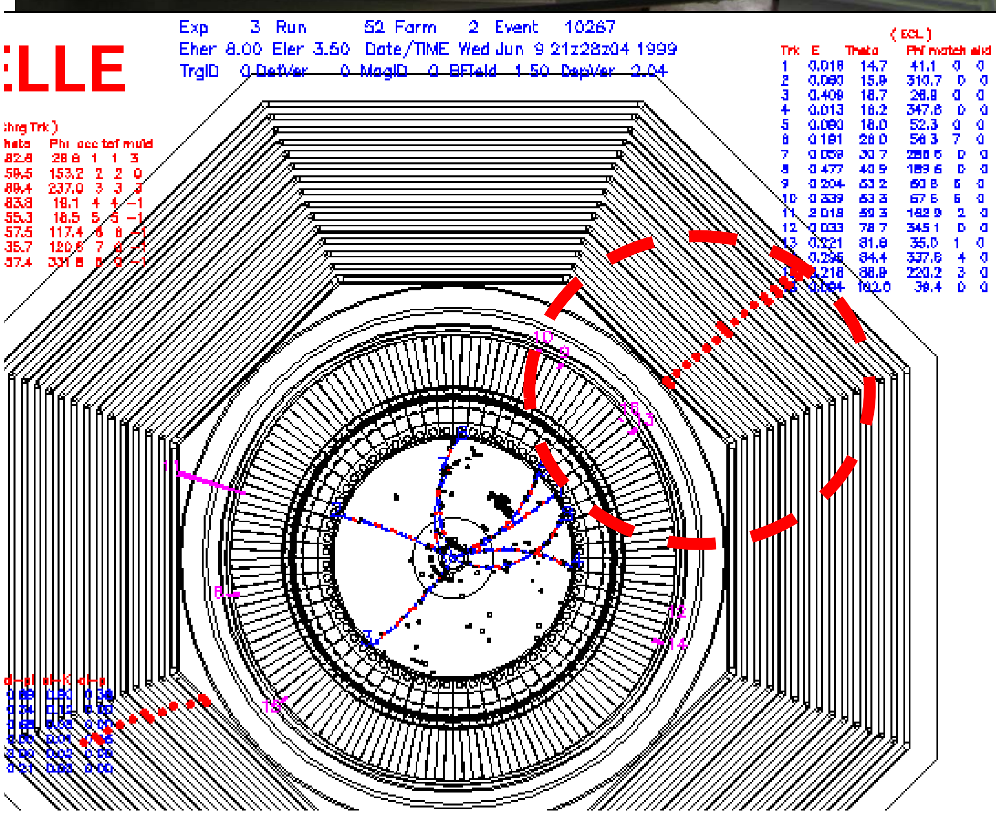
Upgrade to pure CsI: a major collaborative effort of Russia, Japan, Canada, Italy, Ukraine

Detection of muons and K_Ls: a sizable part of the present RPC system have to be replaced to handle higher backgrounds (mainly from neutrons).

K_L and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps + barrel 2 inner layers)



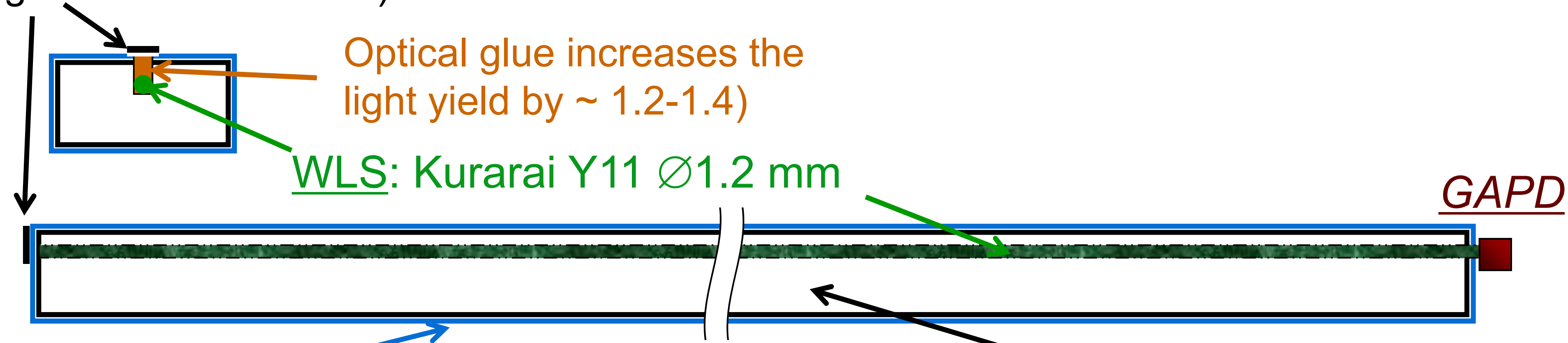




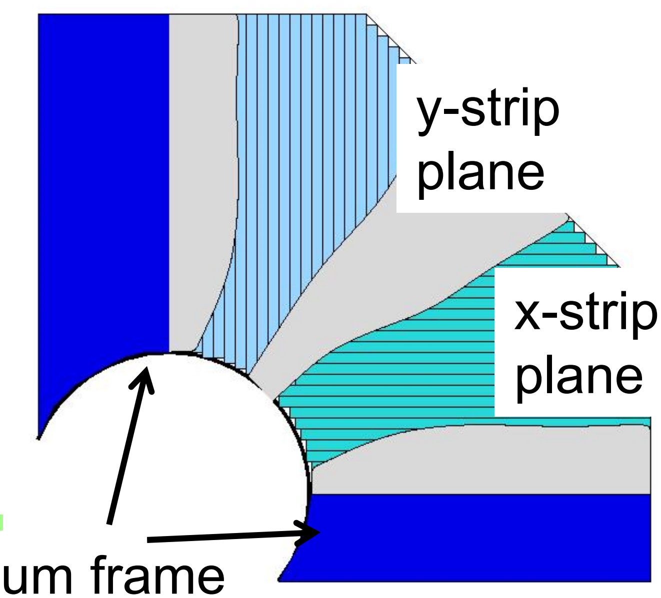
Expected to improve K_L and muon detection efficiency beyond Belle performance.

Muon detection system upgrade

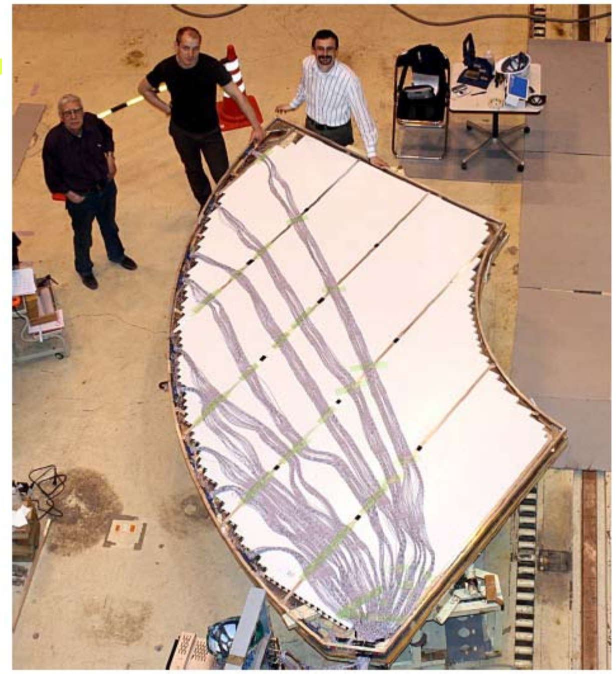
Scintillator-based KLM (endcap and 2 barrel layers)



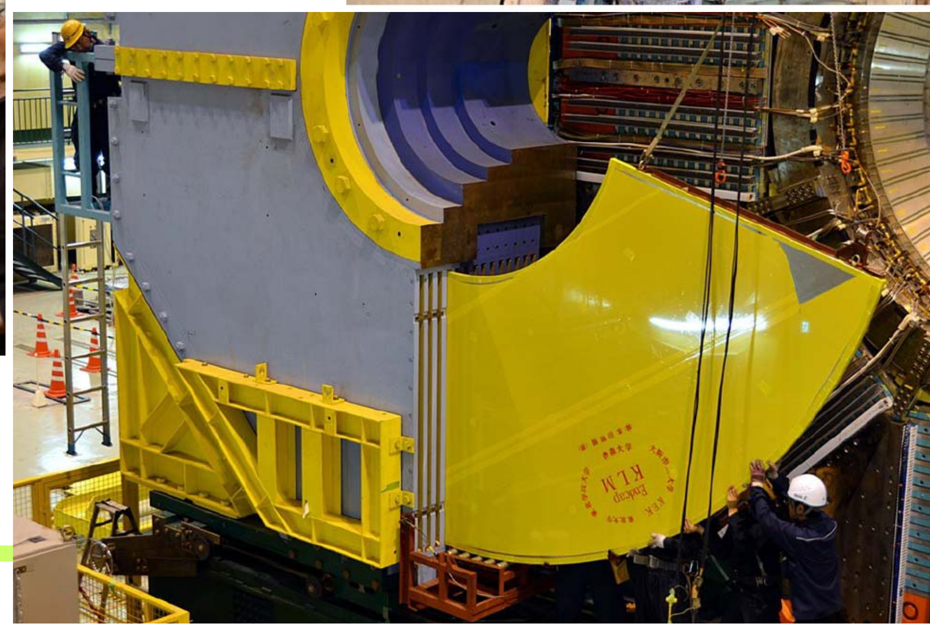
- Two independent (x and y) layers in one superlayer made of orthogonal strips with WLS read out
- Photo-detector = SiPM (avalanche photodiode in Geiger mode)
- ~120 strips in one 90º sector (max L=280cm, w=25mm)
- ~30000 read out channels
- Geometrical acceptance > 99%



Muon detection system upgrade



Scintillator-based KLM:
•design and construction of modules at ITEP, Moscow
•installation of final modules in the Belle II detector – the first Belle II component to be ready!



The Belle II Collaboration

A very strong group of ~600 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 in 2011
- Non-Japanese funding agencies have also allocated sizable funds for the upgrade of the detector.

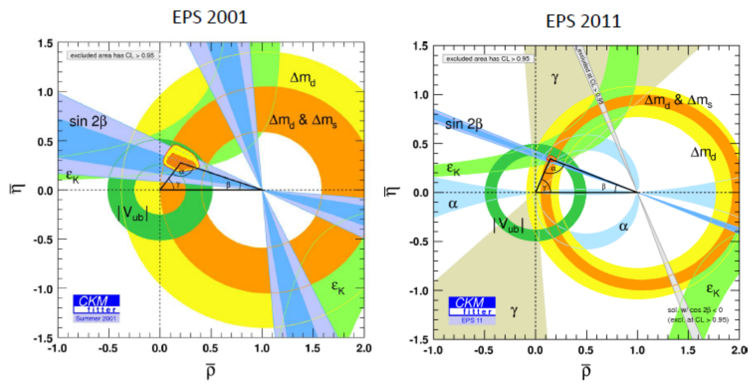
SuperKEKB and Belle II construction proceeding, nearly on schedule.

Commissioning start delayed by 12 months from original plan, now scheduled for January 2016.

First data taking (no vertex detector): in autumn 2017

First data taking (with vertex detector): in autumn 2018

Summary

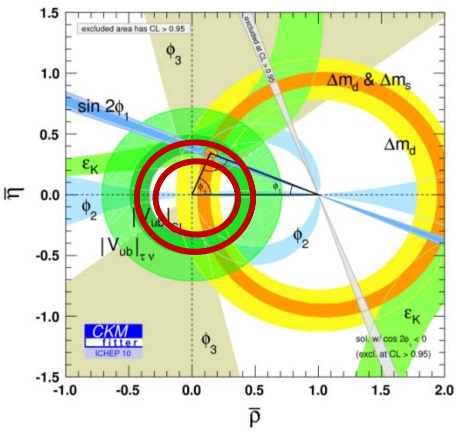


- B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of the performance, achieving and surpassing design perfomance
- Next generation: intensity frontier experiment, look for New Physics effects
- Super B factory at KEK under construction 2010-16 → SuperKEKB+Belle II, L x40, construction at full speed
- Expect a new, exciting era of discoveries, complementary to the LHC

Tomorrow:

- Flavor physics: introduction, with a little bit of history
- Flavor physics at B factories: CP violation
- Flavor physics at B factories: rare decays and searches for NP effects
- Super B factory
- **Flavor physics at hadron machines: history, LHCb and LHCb upgrade**

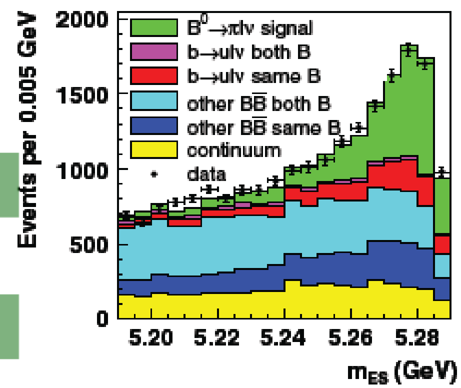
Additional slides

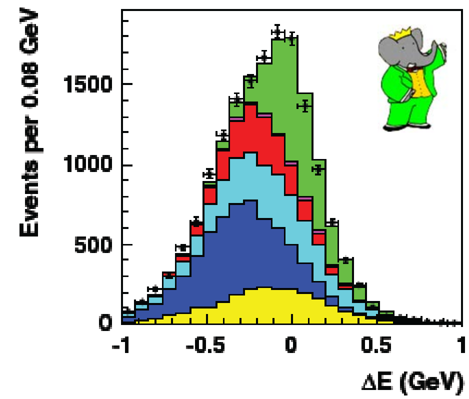


$|V_{ub}|$ from $B^0 \rightarrow \pi^- \ell^+ \nu$ exclusive decays

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

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



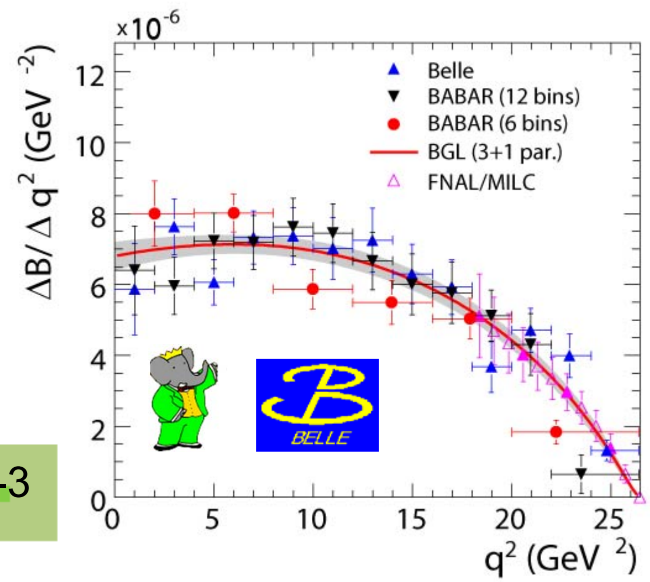


$\mathcal{B}$=(1.41±0.05±0.07)·10^{-4} untagged
BaBar, PRD83, 032007 (2011)

$\mathcal{B}$=(1.42±0.05±0.07)·10^{-4} untagged loose neutrino
BaBar, PRD83, 052011 (2011)

$\mathcal{B}$=(1.49±0.04±0.07)·10^{-4} untagged
Belle, PRD83, 071101 (2011)

$\mathcal{B}$=(1.49±0.09±0.07)·10^{-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 ± 0.30)·10^{-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

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

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

ϕ_2 $B \to \rho\rho$

ϕ_2 from isospin analysis (longitudinal polarization)

- constraints using Belle results only

$\phi_2 = (84.9 \pm 13.5)^\circ$

$\Delta\phi_2 = (0.0 \pm 10.4)^\circ$

$\Rightarrow$ Belle needs updates on

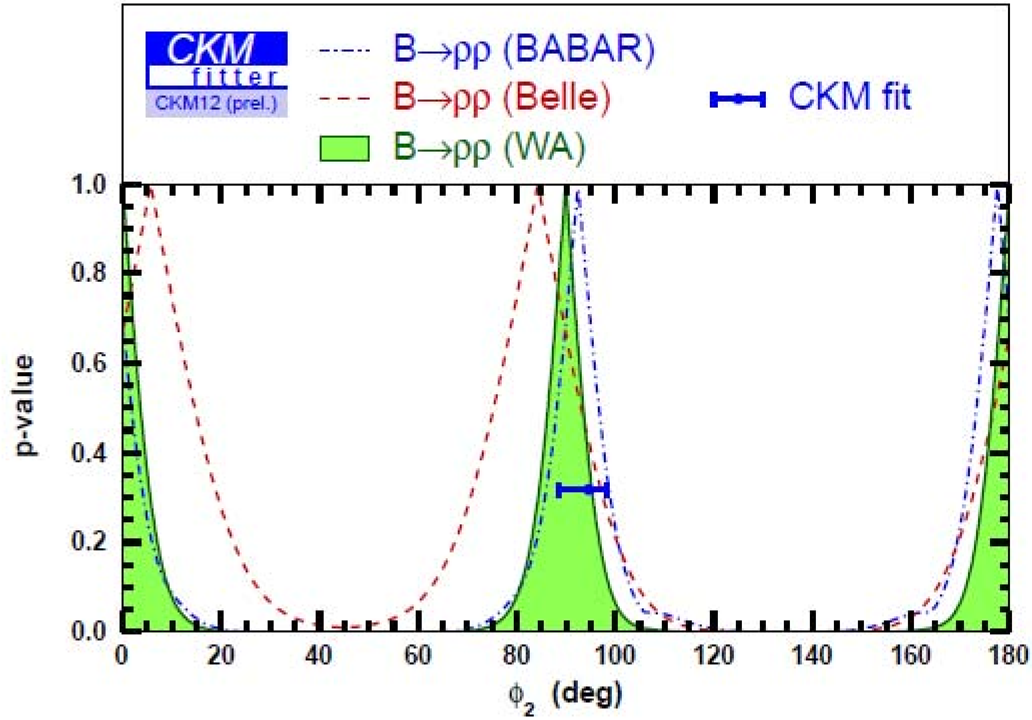
- $B^0 \to \rho^+\rho^-$

$\mathcal{B}, f_L$ from 275M $B\bar{B}$ (*PRL***96***, 171801 (2006)*)

$\not{C}\not{P}$ from 535M $B\bar{B}$ (*PRD***76***, 011104 (2007)*)

- $B^\pm \to \rho^\pm\rho^0$

85M $B\bar{B}$ (*PRL***91***, 221801 (2006)*)

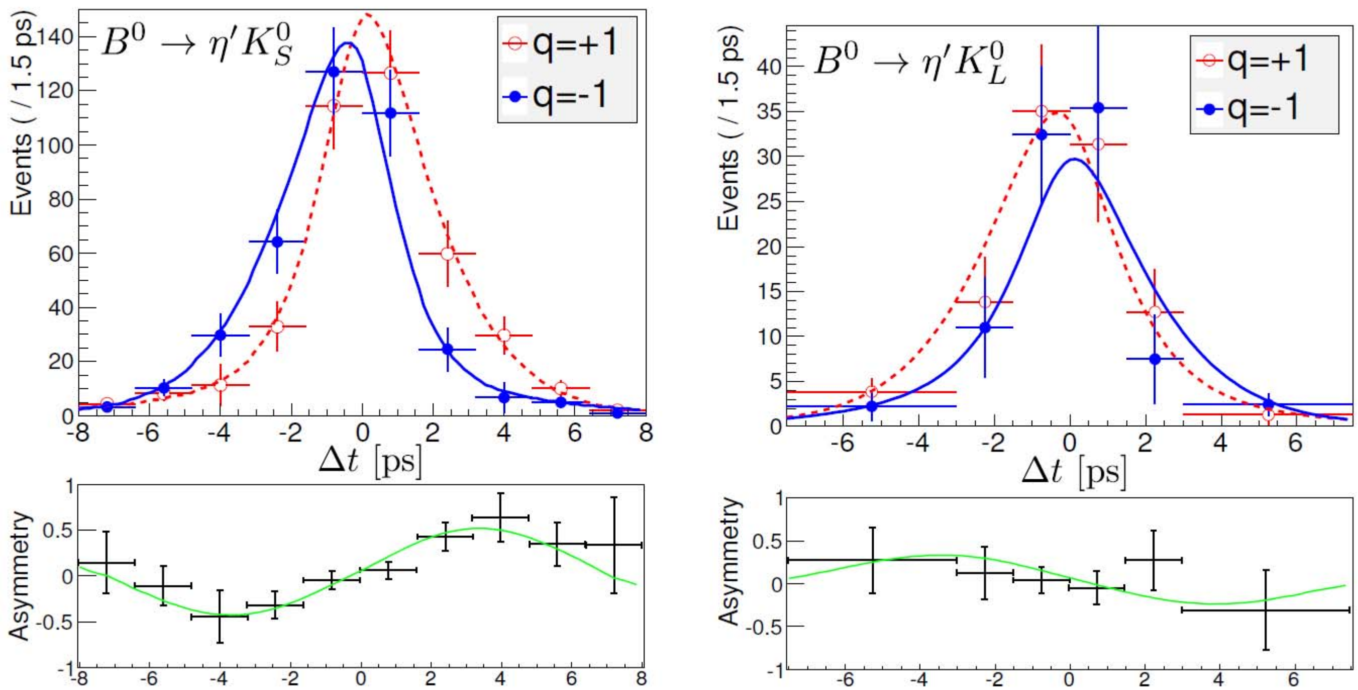


W.A.: $\phi_2 = (89.9^{+5.4}_{-5.3})^\circ$

[prospect for Belle2 $\phi_2^{\rho\rho} = (X \pm 3)^\circ$]

CP violation in penguin dominated b → qqs transitions

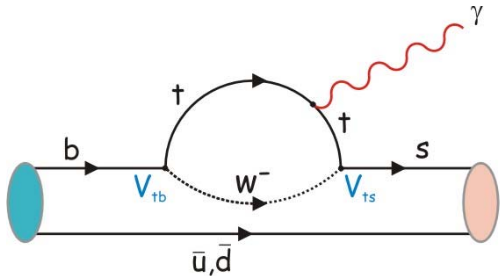
CP violation given by the same parameter sin2ϕ1 as in J/ψ K decays



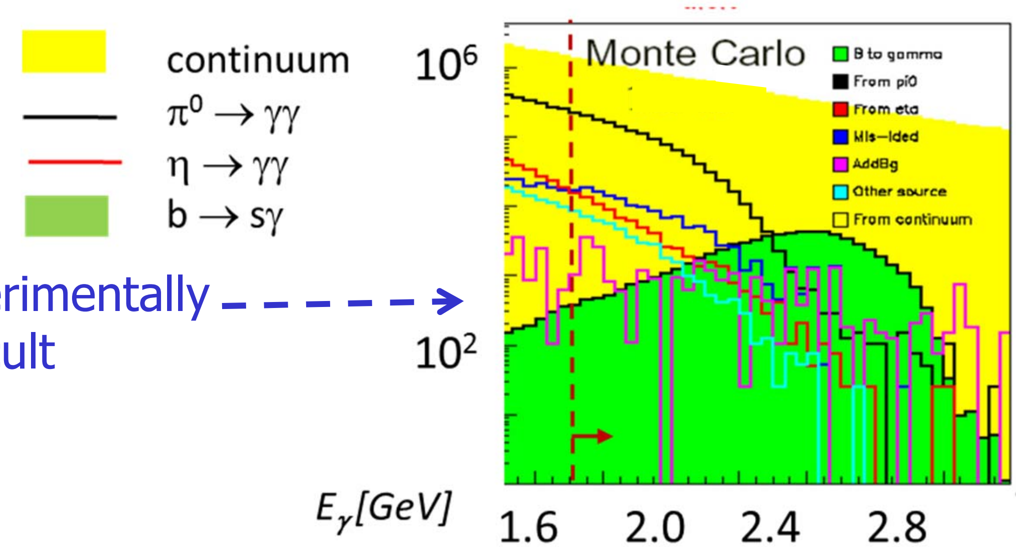
Decay mode	$-\xi_f \mathcal{S}_f$	$\mathcal{A}_f$
η' K_S^0	$+0.71 \pm 0.07$	$+0.02 \pm 0.05$
η' K_L^0	$+0.46 \pm 0.21$	$+0.09 \pm 0.14$
η' K^0	$+0.68 \pm 0.07 \pm 0.03$	$+0.03 \pm 0.05 \pm 0.04$

$B \to X_s\gamma$ inclusive

Advantage of B factories!



Radiative decay sensitive to charged Higgs

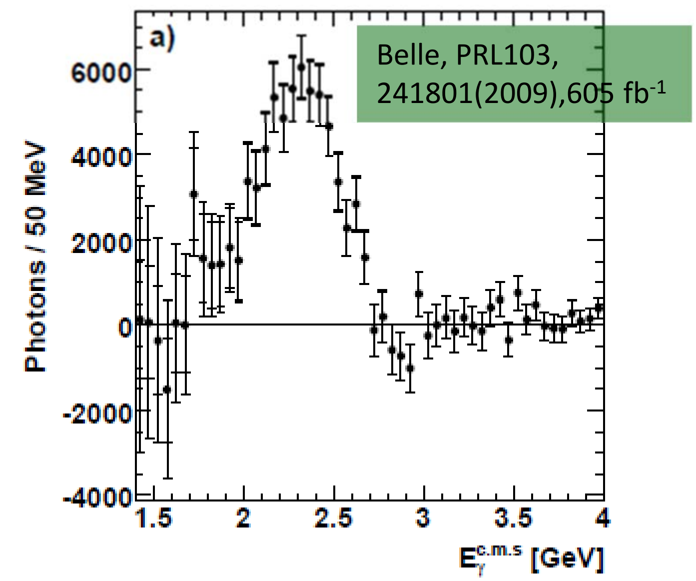


Experimentally difficult

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

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

Only γ on signal side reconstructed
Improve S/B by tagging the other B



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

$B \to X_s\gamma$ inclusive

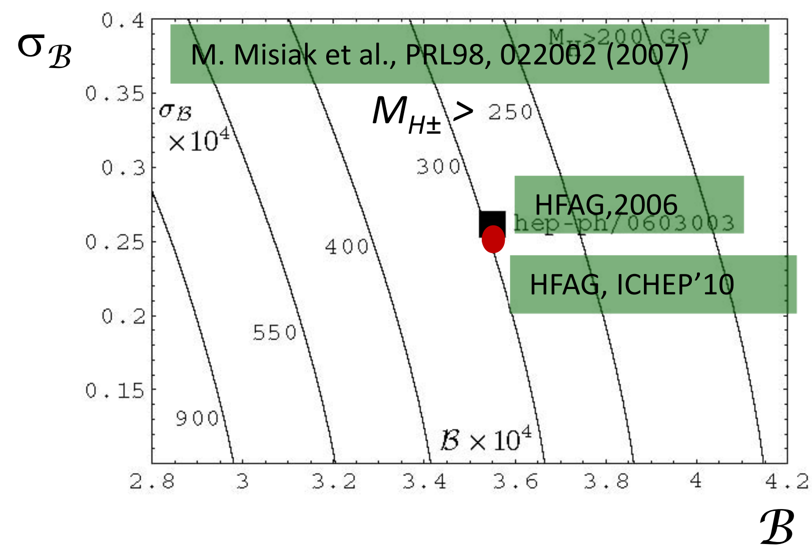
Branching fraction, world average

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

HFAG, ICHEP'10

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
$\Rightarrow$ need a larger sample → Super B factory

B $\to X_s\gamma$, semi-inclusive

Sum of 38 exclusive channels

Mode ID	Final State	Mode ID	Final State
1	$K^+\pi^-$	20	$K^0_S\pi^+\pi^0\pi^0$
2	$K^0_S\pi^+$	21	$K^+\pi^+\pi^-\pi^0\pi^0$
3	$K^+\pi^0$	22	$K^0_S\pi^+\pi^-\pi^0\pi^0$
4	$K^0_S\pi^0$	23	$K^+\eta$
5	$K^+\pi^+\pi^-$	24	$K^0_S\eta$
6	$K^0_S\pi^+\pi^-$	25	$K^+\eta\pi^-$
7	$K^+\pi^+\pi^0$	26	$K^0_S\eta\pi^+$
8	$K^0_S\pi^+\pi^0$	27	$K^+\eta\pi^0$
9	$K^+\pi^+\pi^-\pi^-$	28	$K^0_S\eta\pi^0$
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11	$K^+\pi^+\pi^-\pi^0$	30	$K^0_S\eta\pi^+\pi^-$
12	$K^0_S\pi^+\pi^-\pi^0$	31	$K^+\eta\pi^-\pi^0$
13	$K^+\pi^+\pi^+\pi^-\pi^-$	32	$K^0_S\eta\pi^+\pi^0$
14	$K^0_S\pi^+\pi^+\pi^-\pi^-$	33	$K^+K^+K^-$
15	$K^+\pi^+\pi^-\pi^-\pi^0$	34	$K^+K^-K^0_S$
16	$K^0_S\pi^+\pi^+\pi^-\pi^0$	35	$K^+K^+K^-\pi^-$
17	$K^+\pi^0\pi^0$	36	$K^+K^-K^0_S\pi^+$
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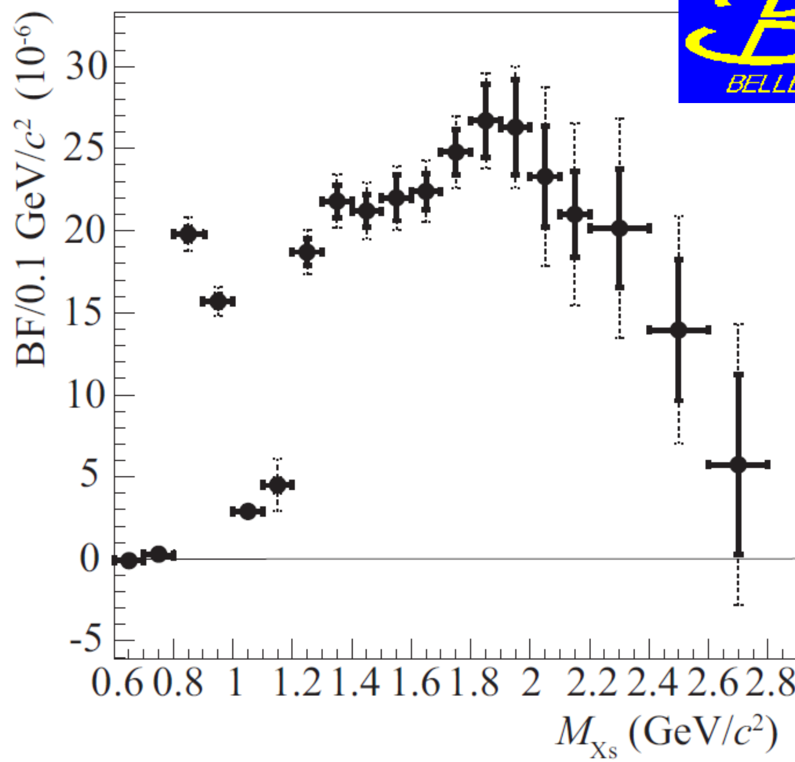

Branching fraction,
(corresponding to a minimum photon energy of 1.9 GeV)

$$\mathcal{B}(B \to X_s\gamma; M_{Xs} < 2.8 GeV/c^2) =$$
$$= (3.51 \pm 0.17(stat.) \pm 0.33(syst)) \cdot 10^{-4}$$

To be submitted to PRD

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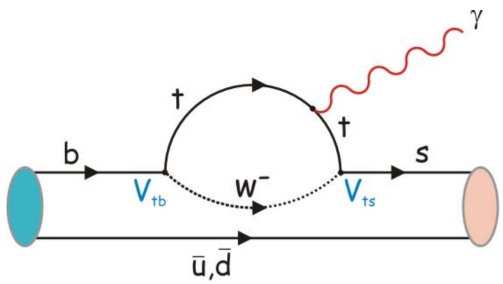

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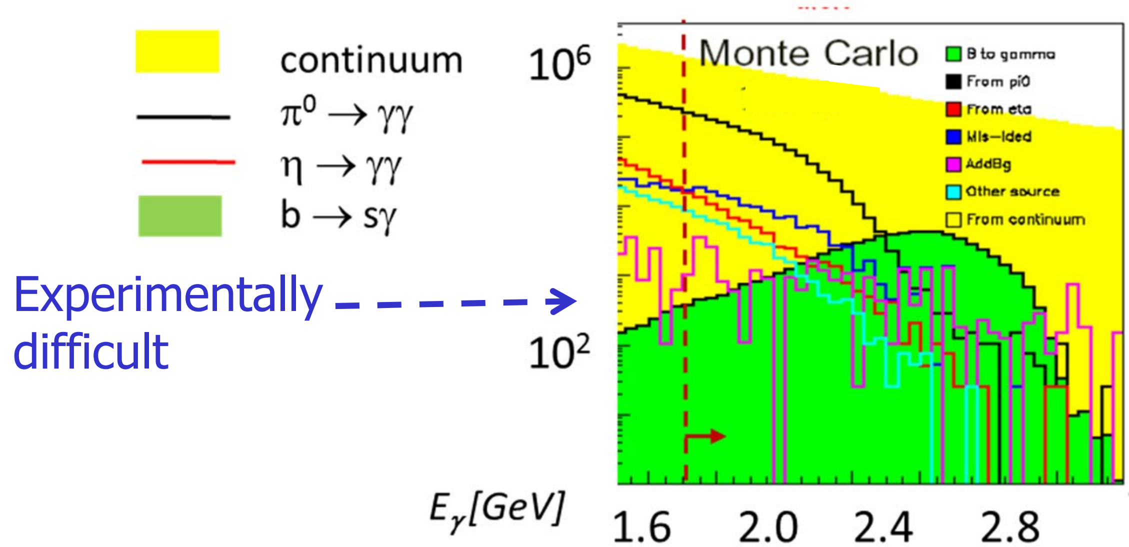

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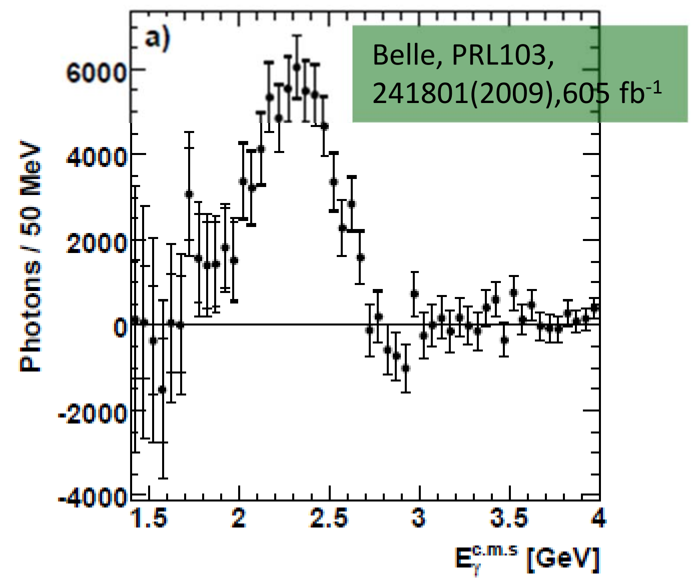

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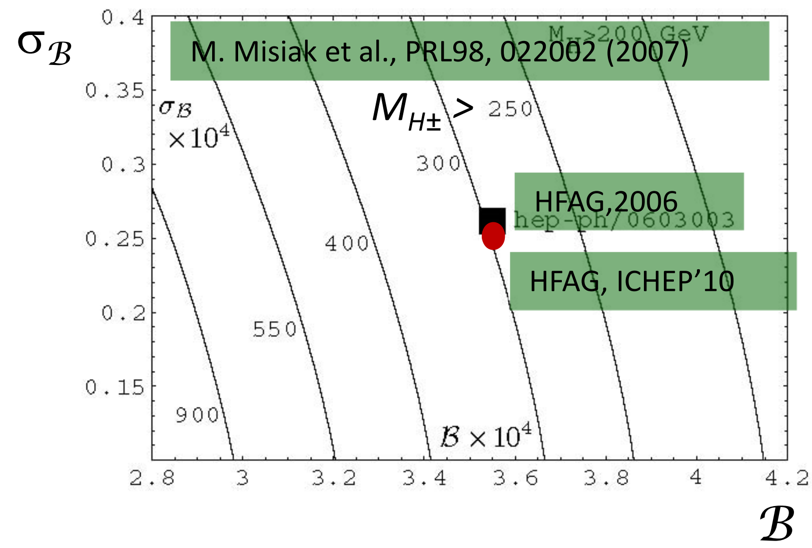

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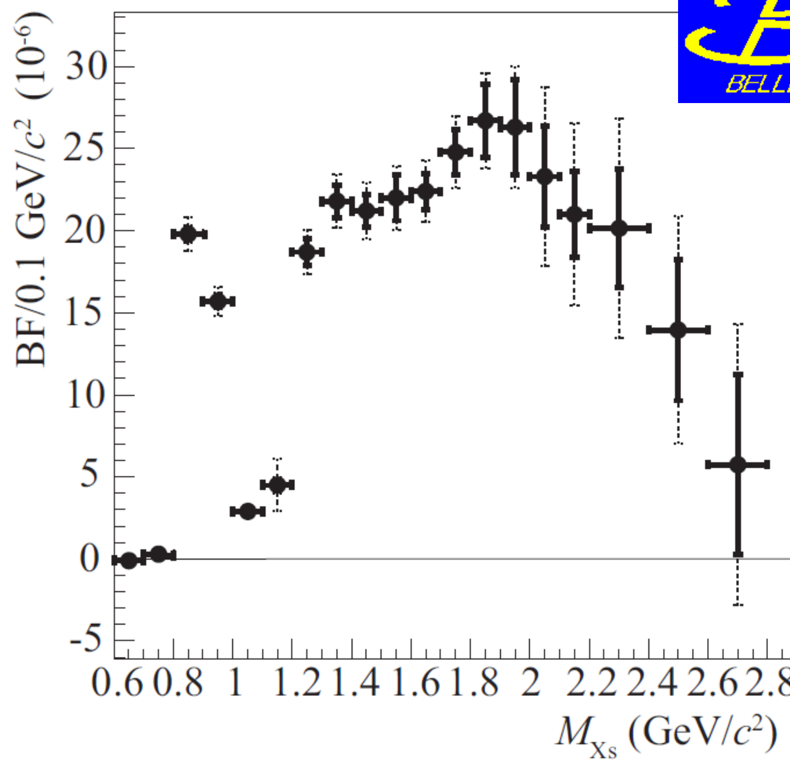

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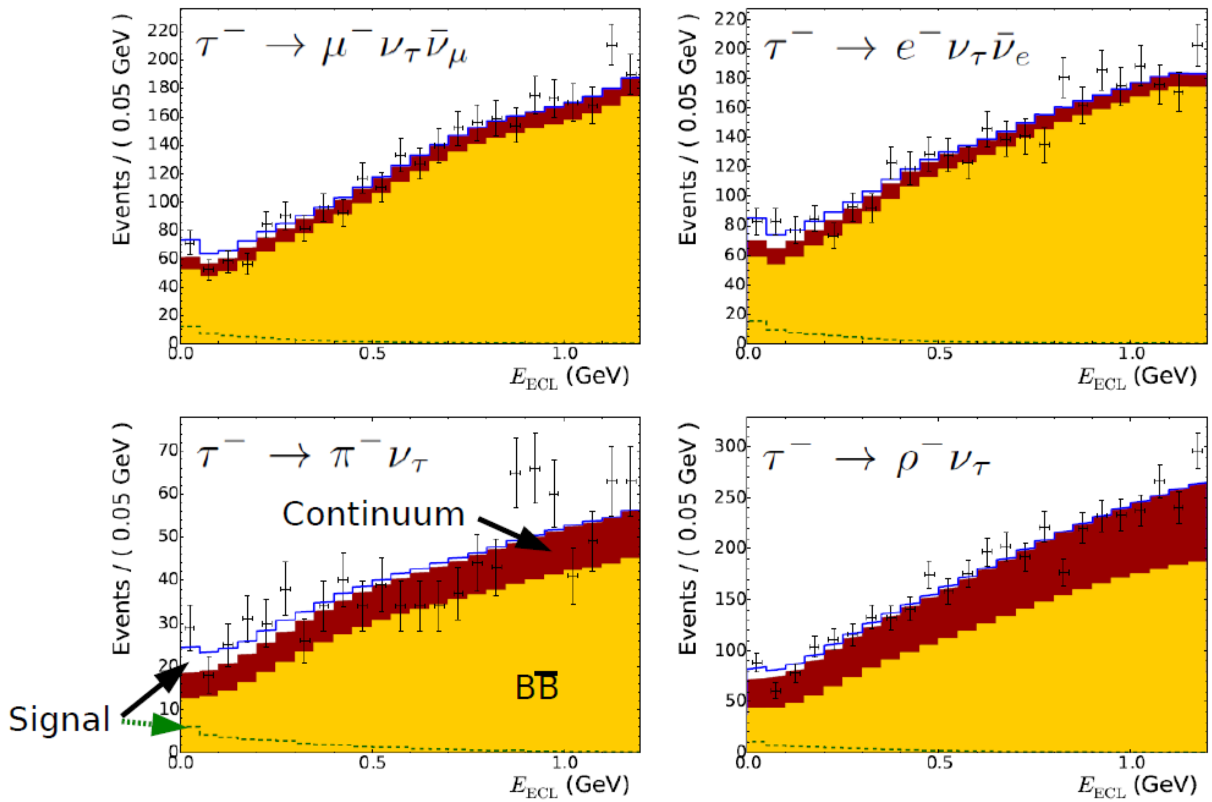
To be submitted to PRD

Belle update $B^- \to \tau^- \nu_\tau$

Method: tag with a semileptonic B decay, look for the $B^- \to \tau^- \nu_\tau$ in the rest of the event.

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

→ Signal at $E_{ECL} = 0$



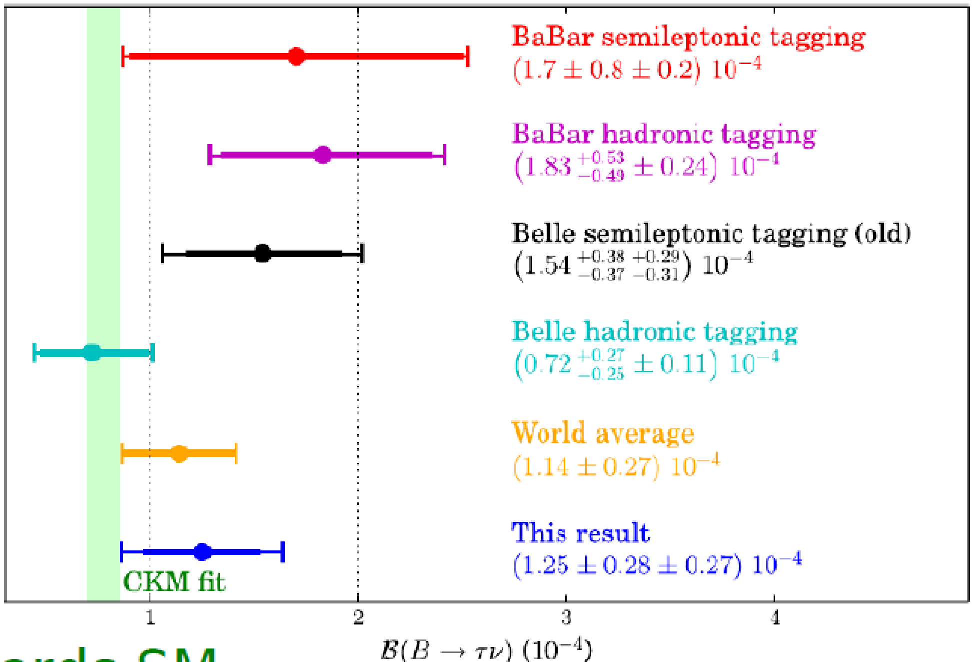
Belle update $B^- \to \tau^- \nu_\tau$, tag with a semileptonic B

Belle-CONF-1401

- $\mathcal{B}(B \to \tau\nu) = [1.25 \pm 0.28\ (\text{stat}) \pm 0.27\ (\text{syst})] \times 10^{-4}$
- Signal significance of 3.4σ including systematics

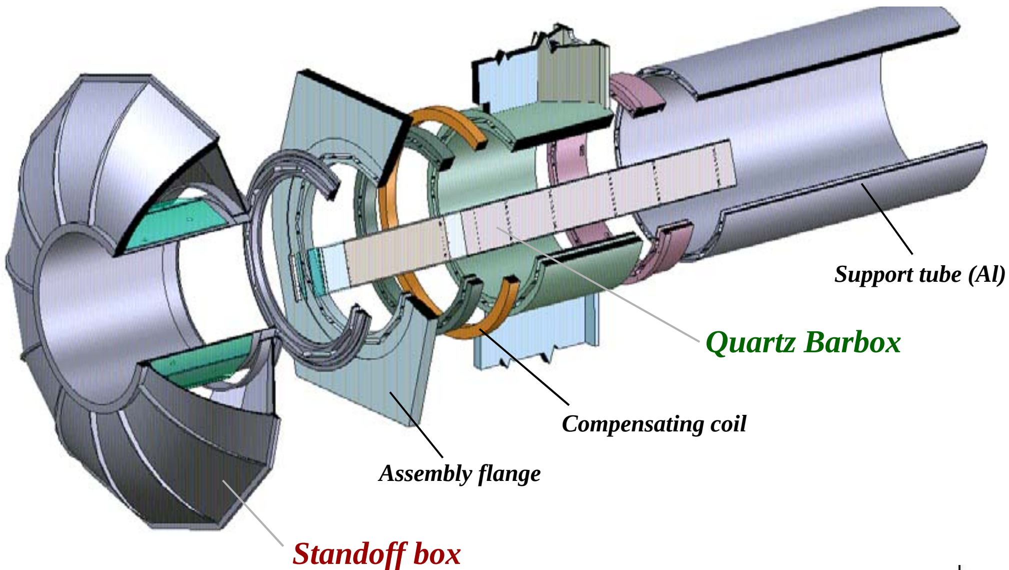
Decay Mode	N_{sig}	$\mathcal{B}(10^{-4})$
$\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$	13±21	0.34±0.55
$\tau^- \to e^- \nu_\tau \bar{\nu}_e$	47±25	0.90±0.47
$\tau^- \to \pi^- \nu_\tau$	57±21	1.82±0.68
$\tau^- \to \rho^- \nu_\tau$	119±33	2.16±0.60
Combined	222±50	1.25±0.28

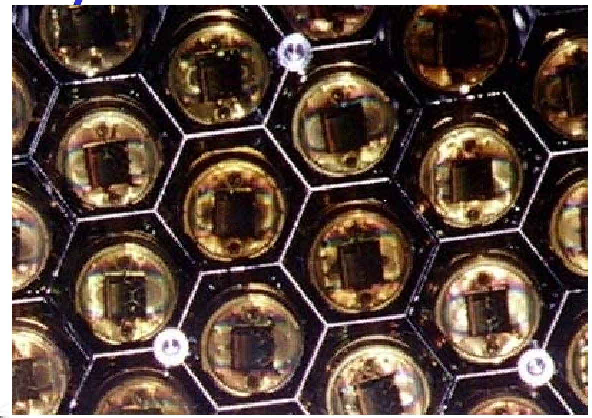
statistical errors only

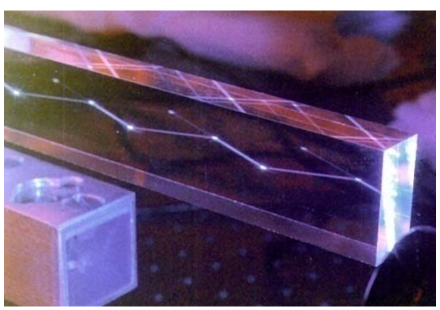


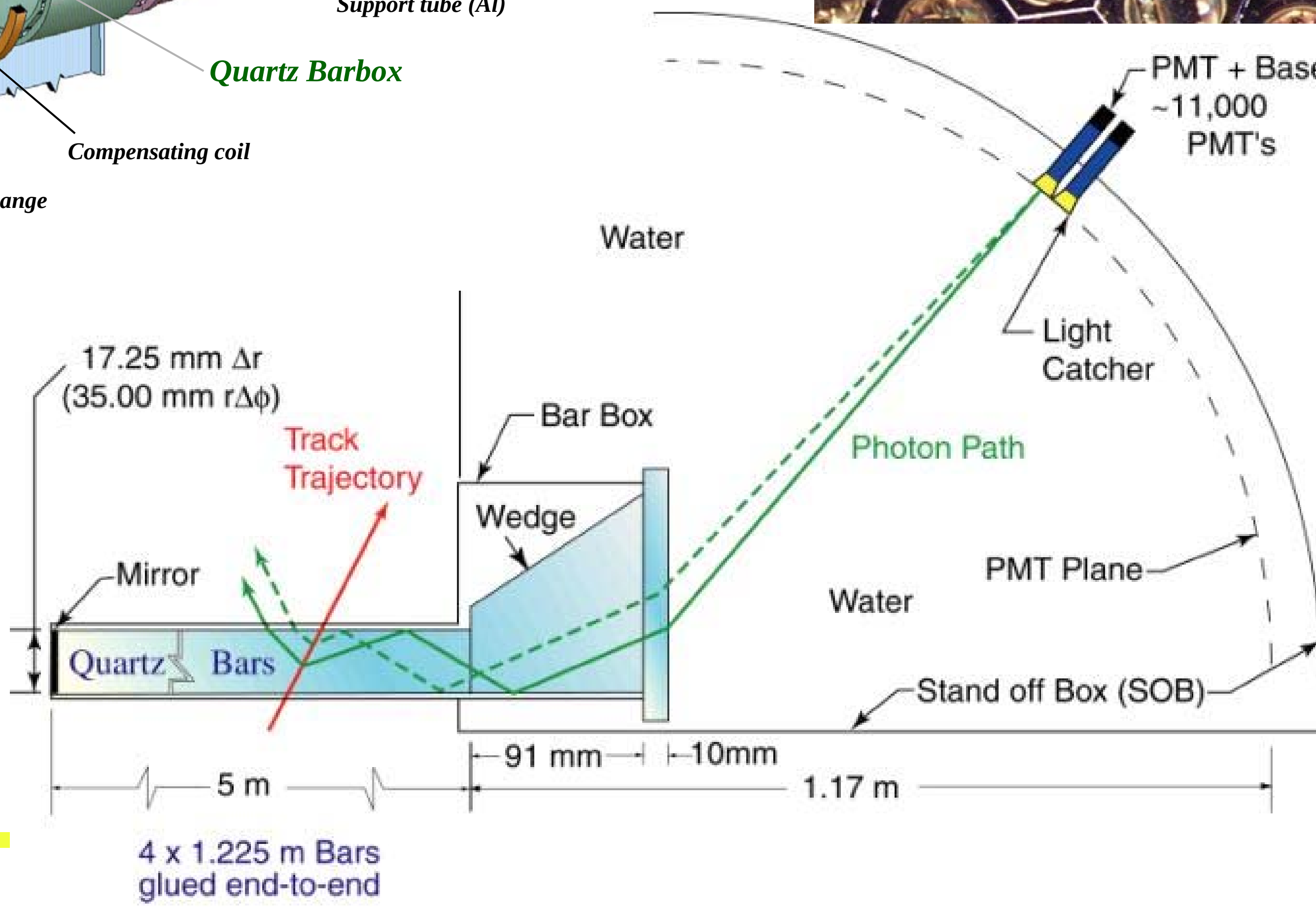
- Consistent results among tau channels
- Central value shifted towards SM
- Combination with Belle hadronic tag result in progress

DIRC (@BaBar) - detector of internally reflected Cherenkov light

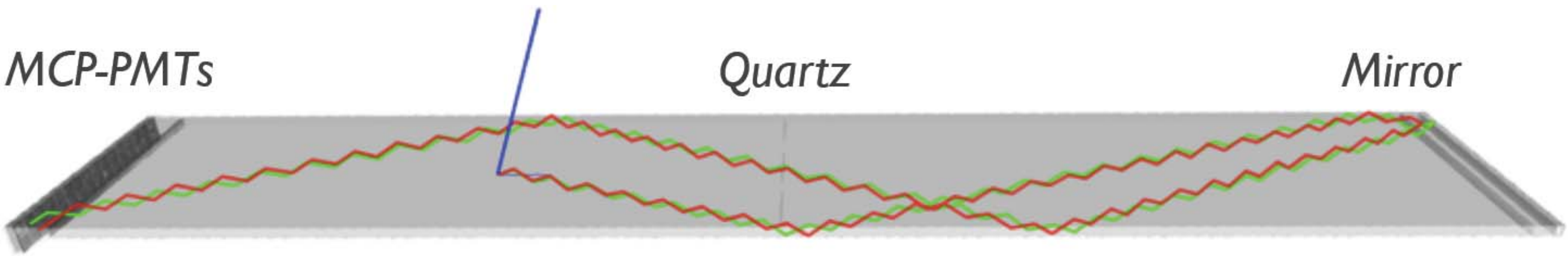




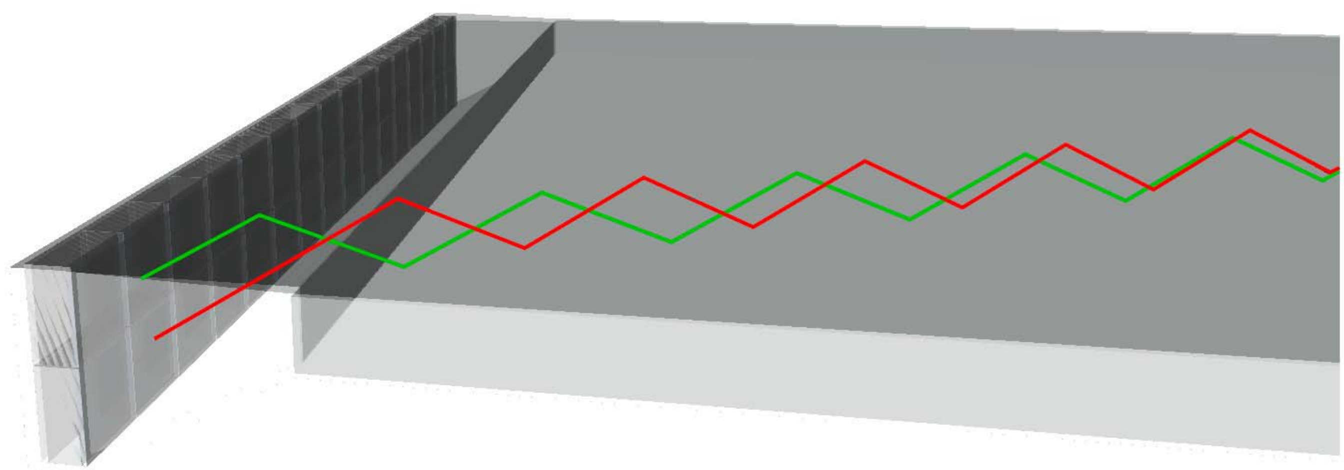




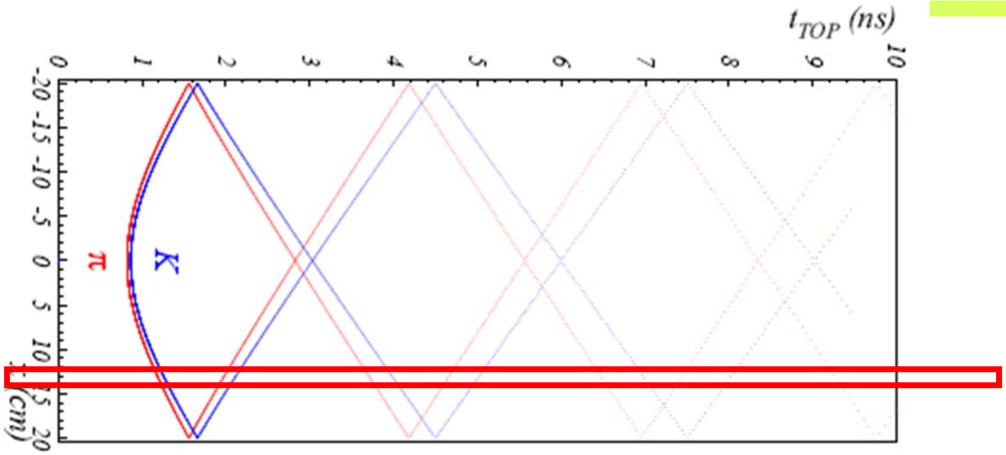
Barrel PID: Time of propagation (TOP) counter



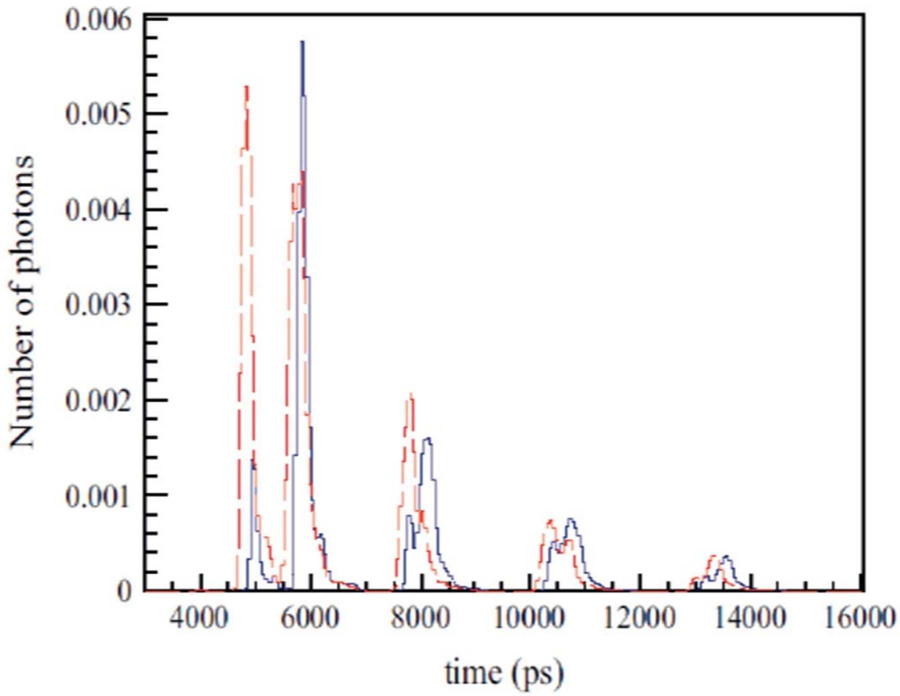
Example of Cherenkov-photon paths for 2 GeV/c $\pi^{\pm}$ and $K^{\pm}$.



TOP image



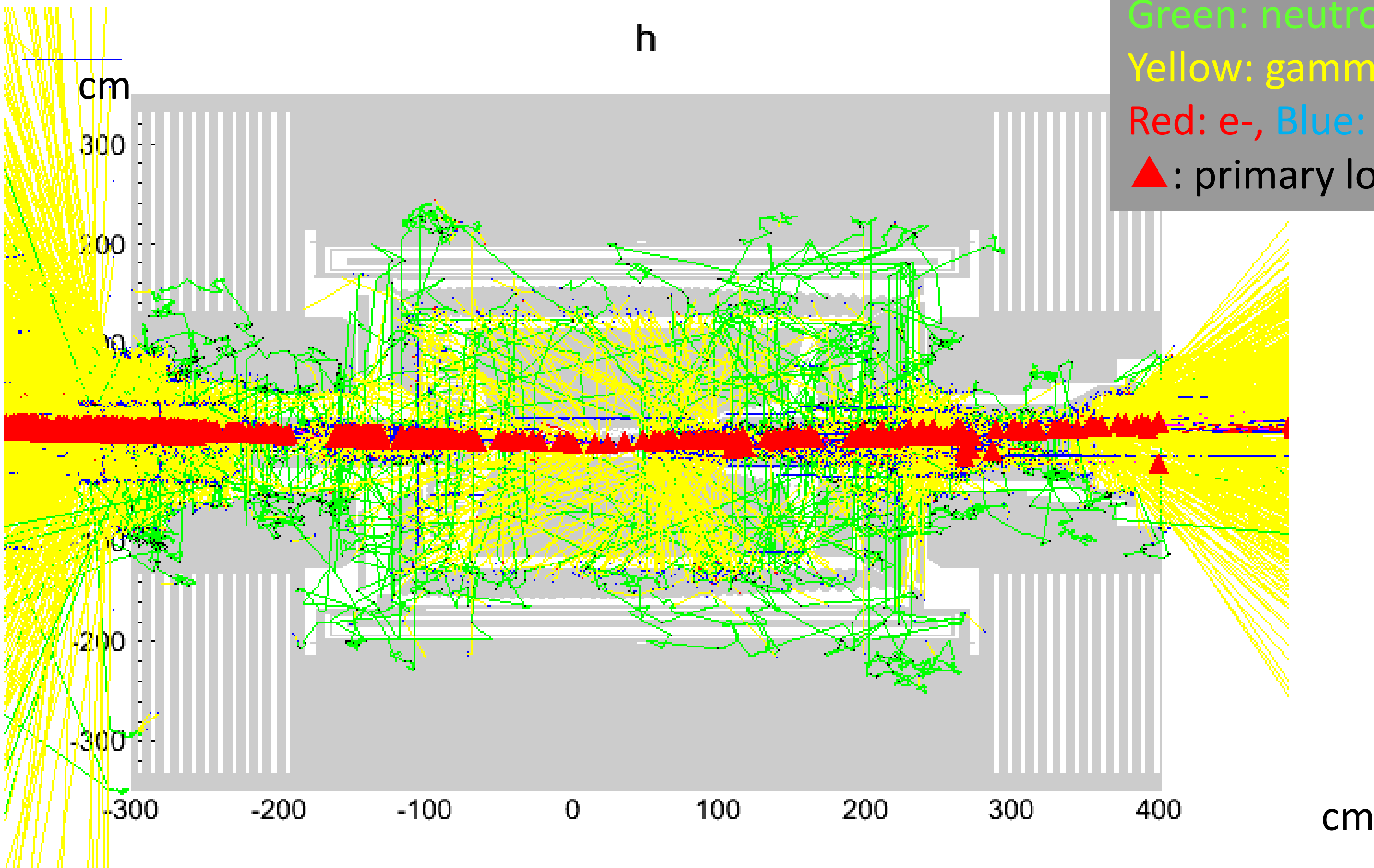
Pattern in the coordinate-time space ('ring') of a pion hitting a quartz bar with ~80 MAPMT channels



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

Background event display

100ns, shown E>1MeV
Green: neutrons
Yellow: gammas
Red: e-, Blue: e+
▲: primary loss position



Neutrons: background hits in the muon and KL detection system (KLM) → reduce the efficiency of muon and KL detection → replace RPCs in the endcaps and 2 barrel layers.