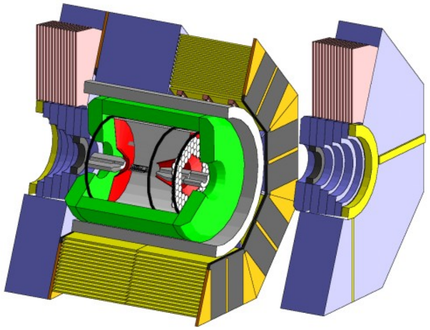


Belle II Project

The 17th KEKB Accelerator Review Committee

Feb 20, 2012

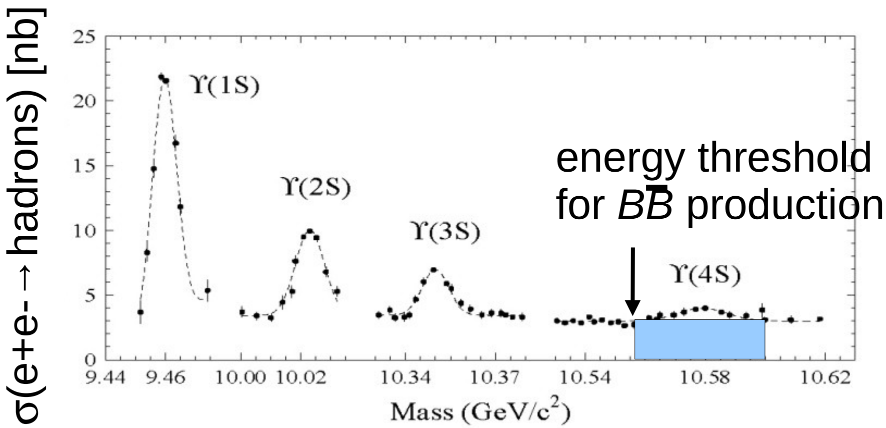
Karim Trabelsi (IPNS, KEK)

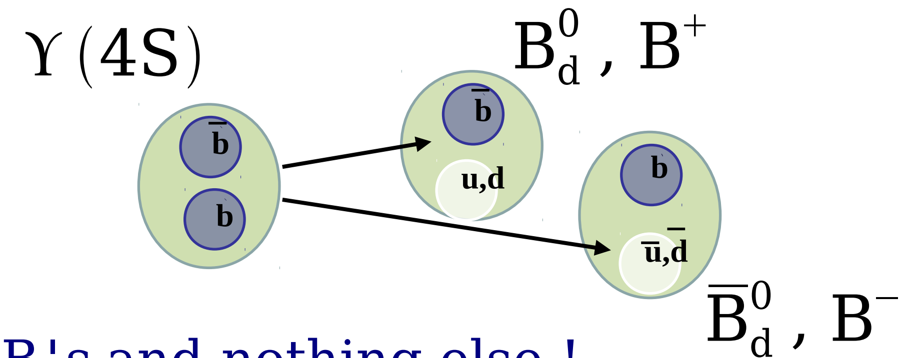
on behalf of

The Belle II Collaboration

~ 400 physicists from 65 institutes in 17 countries

B-factory is...





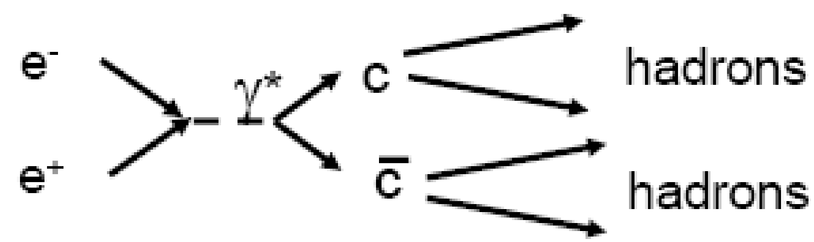
- 2 B's and nothing else !
- 2 B mesons are created simultaneously in a L=1 coherent state
  ⇒ before first decay, the final states contains a B and a $\bar{B}$

''on resonance'' production

$$e^+e^- \to \Upsilon(4S) \to B_d^0\bar{B}_d^0,\ B^+B^-$$

$$\sigma(e^+e^- \to B\bar{B}) \simeq 1.1\ \text{nb}\ (\sim 10^9\ B\bar{B}\ \text{pairs})$$

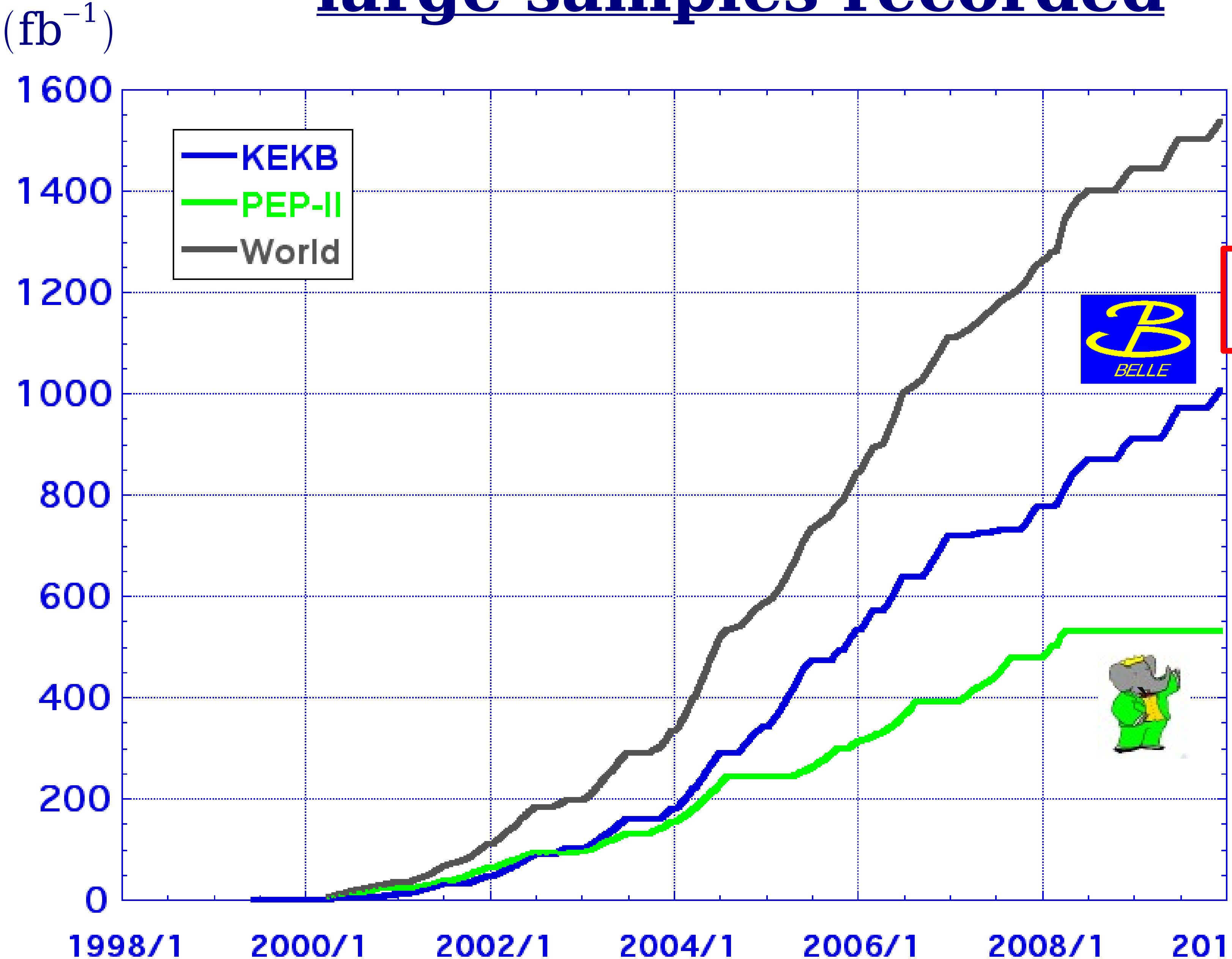
''continuum'' production



$$\sigma(e^+e^- \to c\bar{c}) \simeq 1.3\ \text{nb}\ (\sim 1.3\times 10^9\ X_c\bar{Y}_c\ \text{pairs})$$

ττ production also !

large samples recorded



> 1 ab^{-1}

On resonance:

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

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

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

$\Upsilon(2S)$: 24 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}

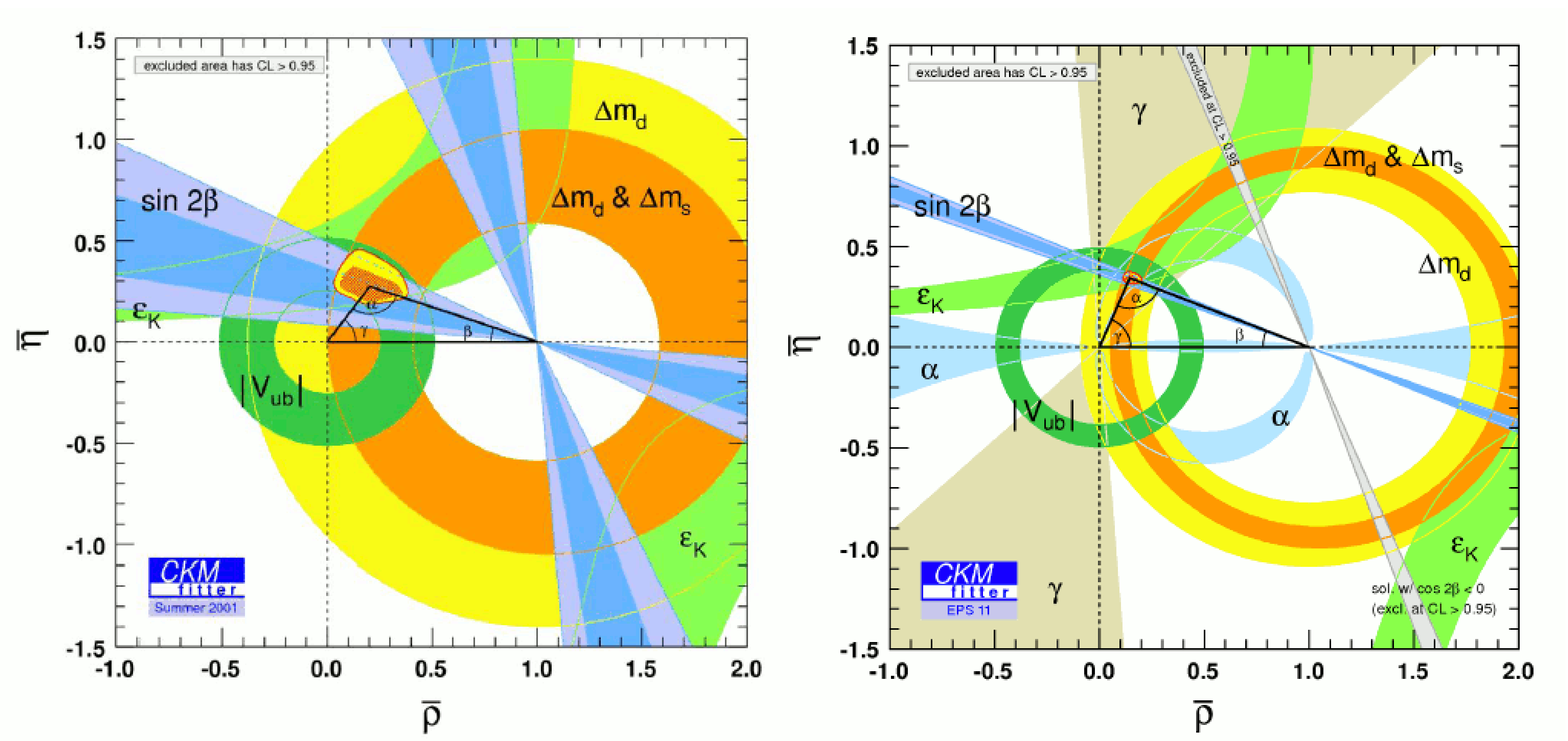
Off resonance:

$\sim$ 54 fb^{-1}

$\sim$770 M $B\bar{B}$ for Belle, $\sim$ 470 M $B\bar{B}$ for BaBar

$\sim$14M B_s also! ($\Upsilon(5S)$ runs)

from EPS 2001…   …to EPS 2011



⇒ clear impact on B-factories !

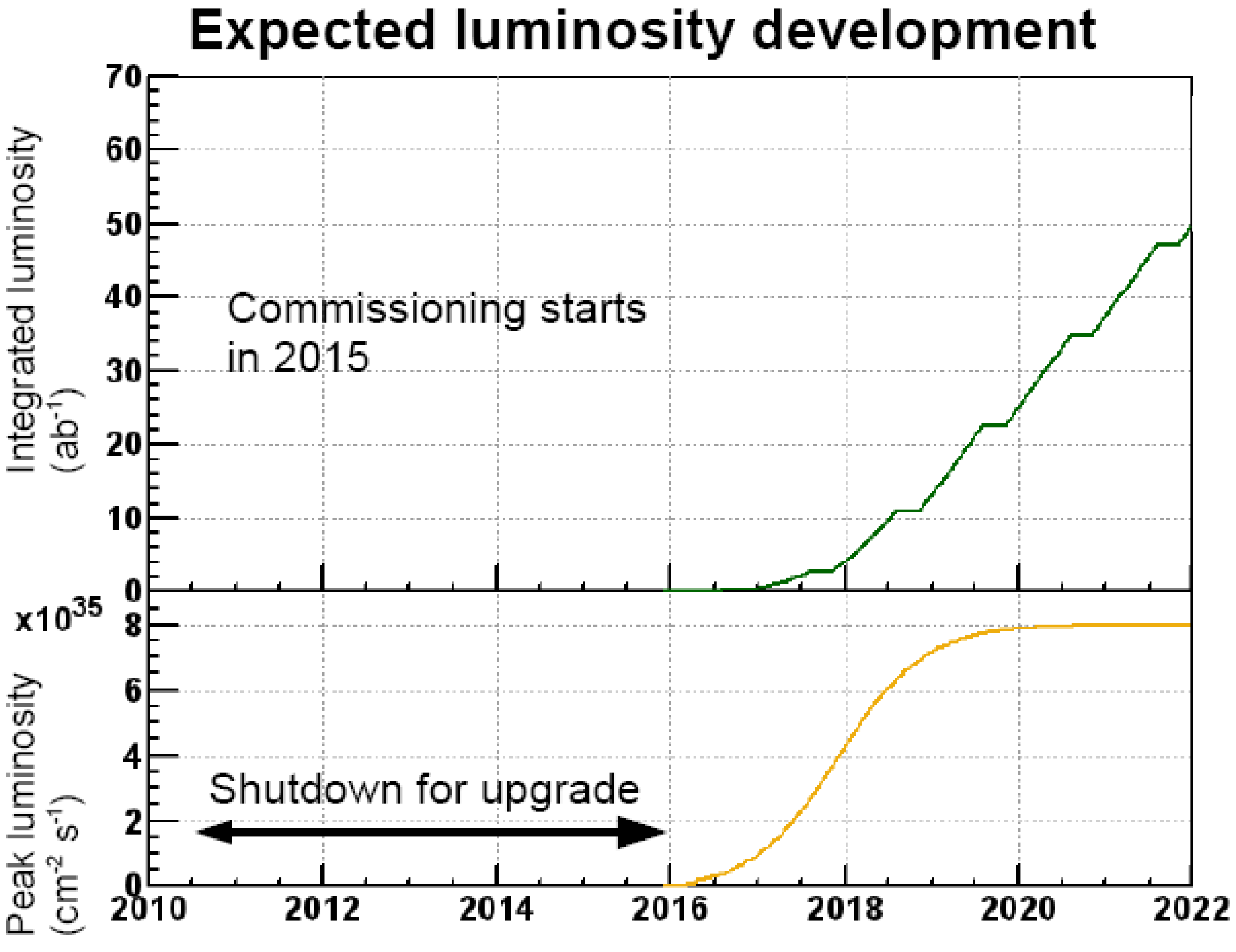
from confirmation of the SM to search of NP !

and then... Super B factories !

$\Rightarrow$ physics with $O(10^{10})$ B, τ, D....

2 Super B Factories projects: SuperB (in Italy) and SuperKEKB/Belle II (in Japan)

$50\ ab^{-1}$ by 2022 = $50 \times$ present

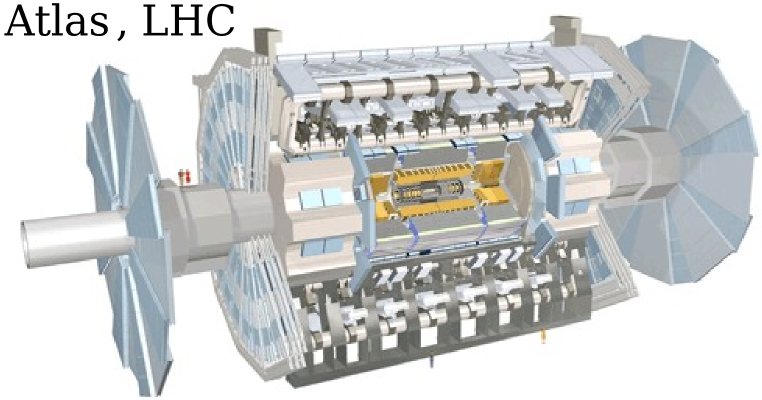


High Energy/High intensity (2 complementary approaches)

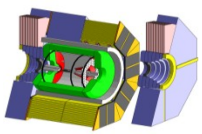
high energy frontier

high intensity frontier

Atlas, LHC



Belle II, SuperKEKB



Search for production of unknown particles at highest achievable energies

LHC

Search for effect of unknown particles on processes very rare within the SM

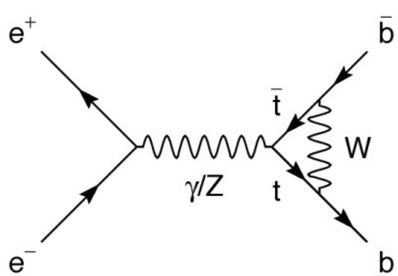
SuperKEKB

example of top quark discovery

predicted through the measurement of B_d^0-$\overline{B}_d^0$ oscillations

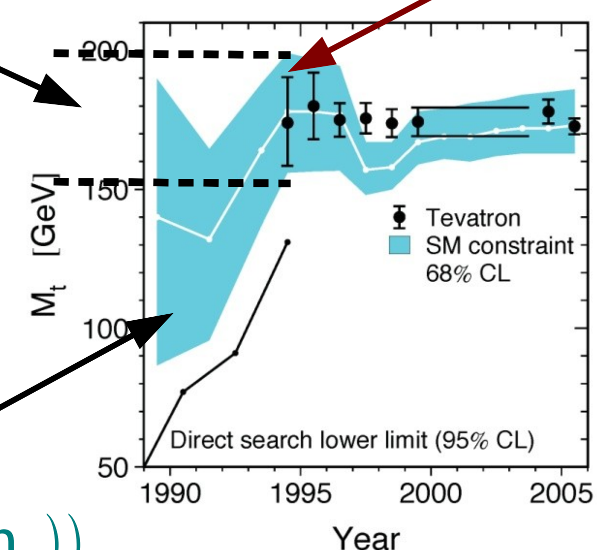
also influences $B(Z \to b\,\overline{b})$, precisely measured at LEP

precise measurements can yield evidence of NP even if not observed directly



just before discovery, we knew it should be here

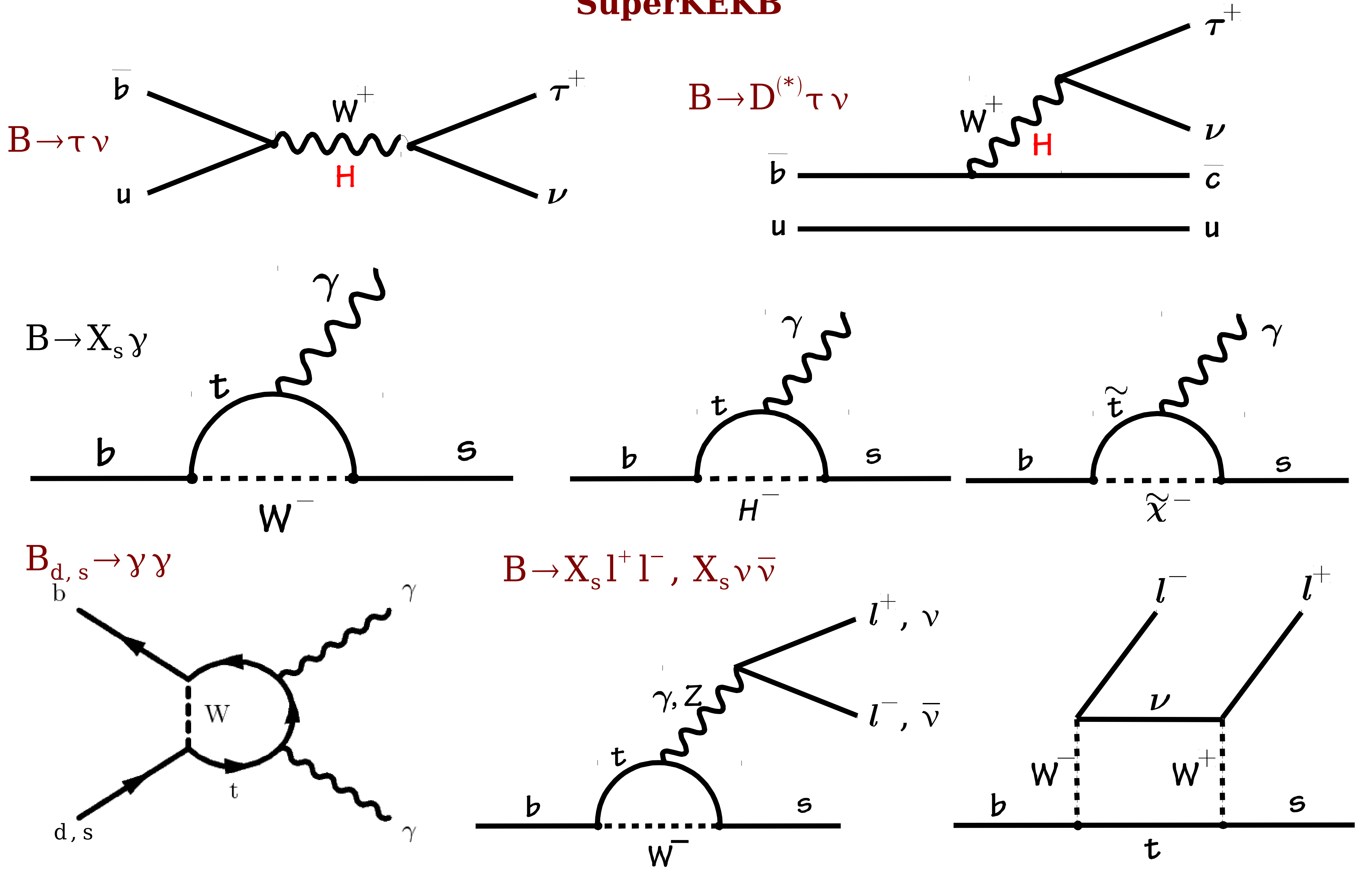
...and it appeared here CDF, PRL 74, 2626 (1995)



m_t from $B(Z \to b\,\overline{b}(m_t))$

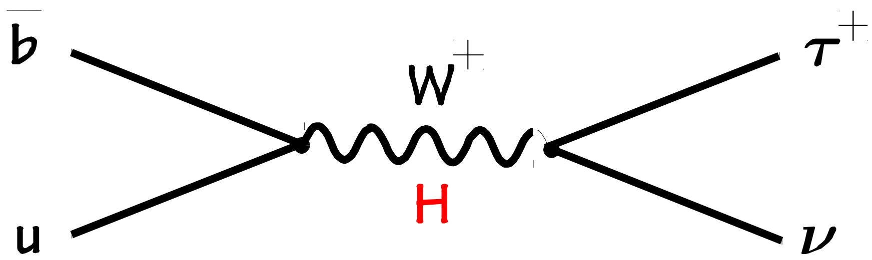
Search for effect of unknown particles
on processes very rare within the SM

SuperKEKB



Look for deviation from the SM predictions...

$B \to \tau\nu$



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

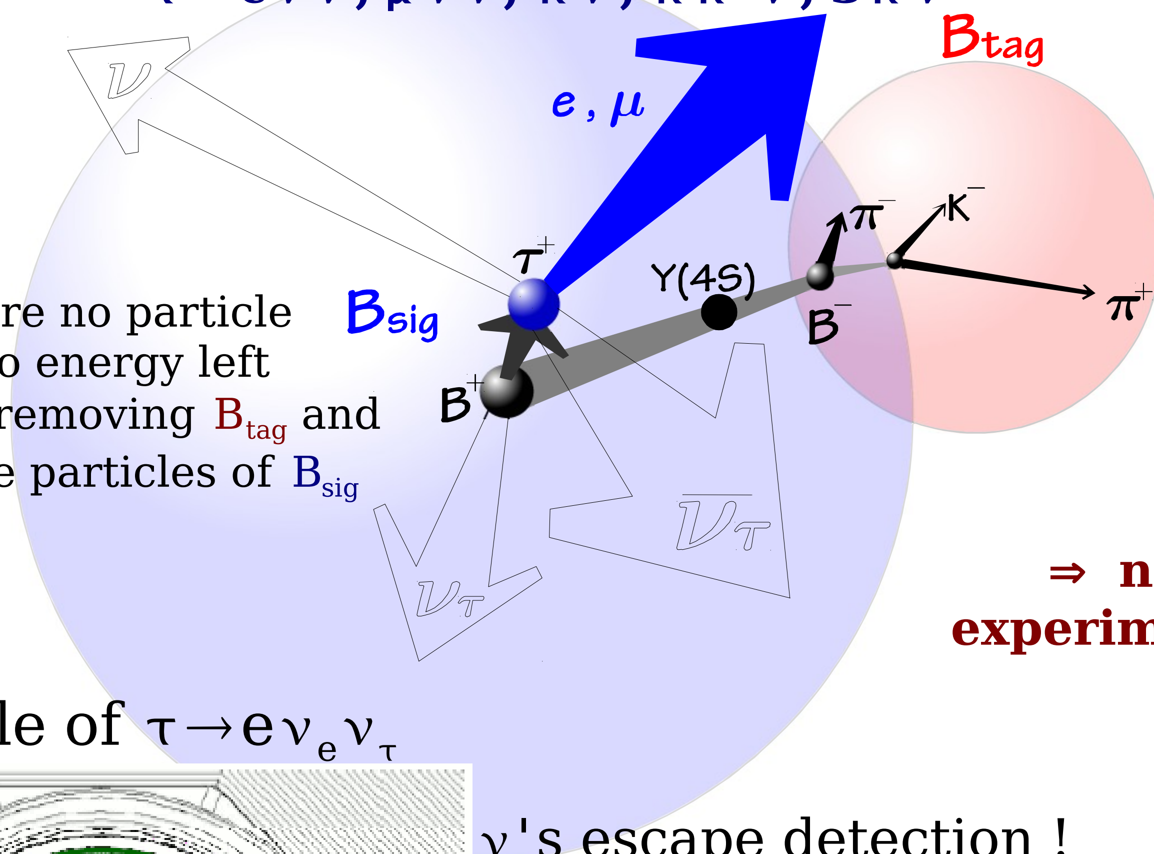
$$\text{2HDM (type II)}: \mathcal{B}(B^+ \to \tau^+ \nu) = \mathcal{B}_{SM} \times \left(1 - \frac{m_B^2}{m_{H^+}^2}\tan^2\beta\right)^2$$

uncertainties from f_B and $|V_{ub}|$ can be reduced to B_B
and other CKM uncertainties by combining with precise Δm_d
$\tan\beta$: free parameter of Minimal Supersymmetric Standard Model (MSSM)

Event reconstruction in $B \to \tau \nu$

$B_{sig} \to \tau \nu$ (70 % of all τ decays)

$\tau \to e \nu \nu\, , \mu \nu \nu\, , \pi \nu\, , \pi \pi^0 \nu\, , 3\pi \nu$



Require no particle and no energy left after removing B_{tag} and visible particles of B_{sig}

hadronic tag

$B \to D^{(*)}\pi\, , D^{(*)}$rho....

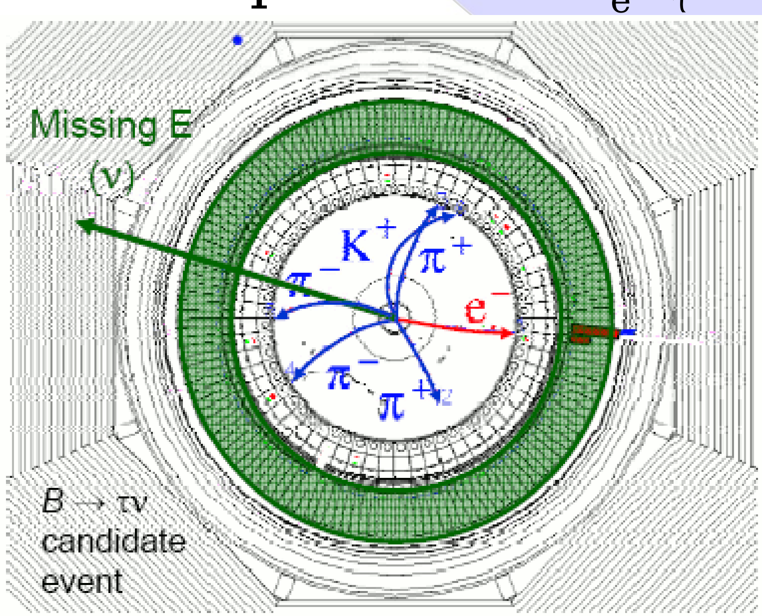
$\epsilon \sim 0.2\,\%$

semileptonic tag

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

⇒ not possible in other experiments (hadron colliders)

example of $\tau \to e \nu_e \nu_\tau$



ν's escape detection !

full reconstruct B_{tag}

$(K^+ \pi^- \pi^+ \pi^- \pi^+)$

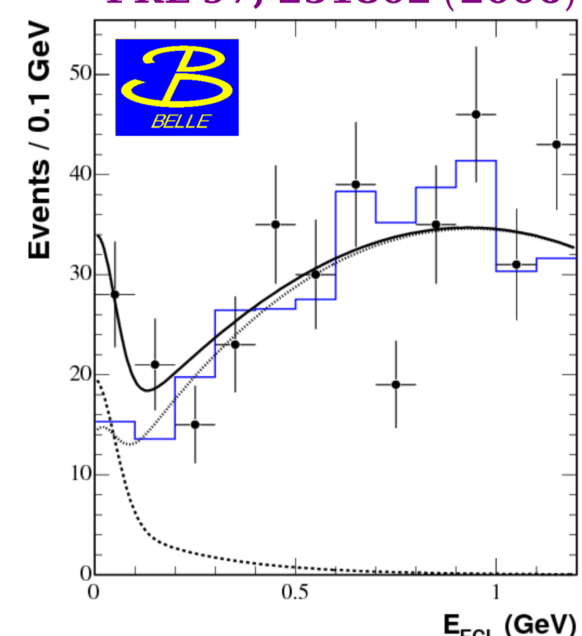
search for tracks from $B_{sig} \to \tau \nu$

(e^-)

no additional energy in EM calorimeter (from π^0 , γ , ...)

⇒ signal at $E_{ECL} \sim 0$

PRL 97, 251802 (2006)



$B^+ \to \tau^+ \nu$ results

World average: $\mathcal{B}(B^+ \to \tau^+ \nu) = (1.68 \pm 0.31) \times 10^{-4}$

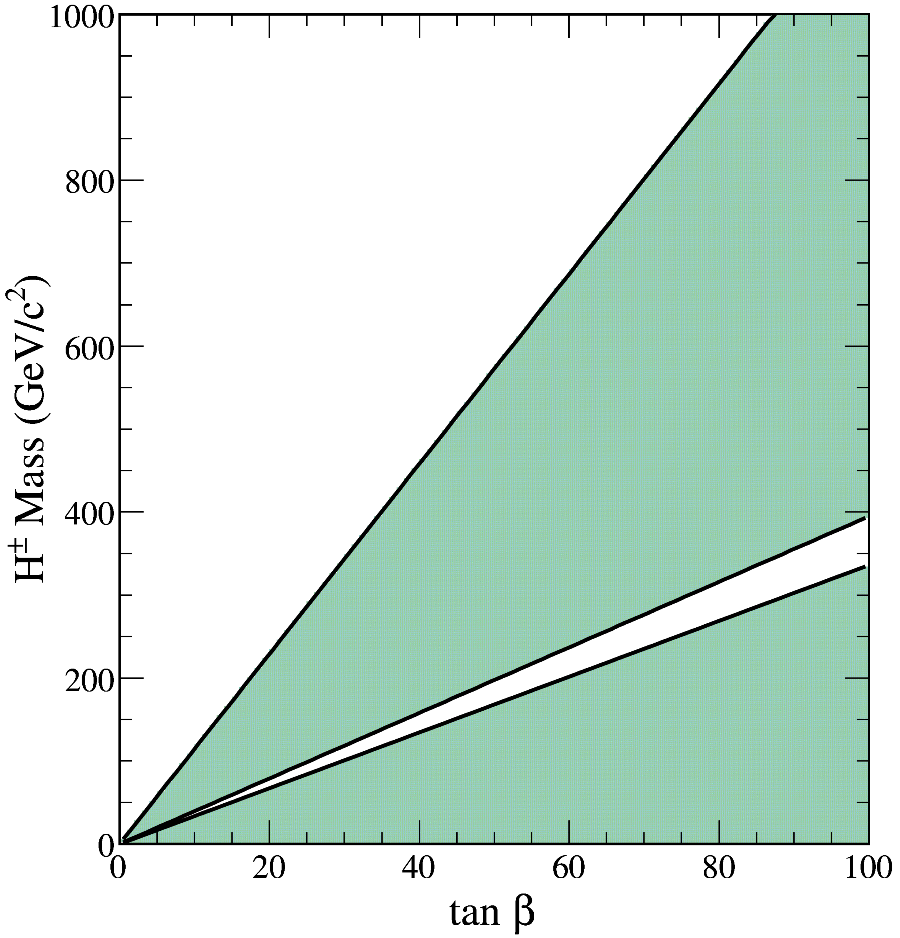
$\mathcal{B}_{SM}(B^+ \to \tau^+ \nu) = (1.20 \pm 0.25) \times 10^{-4}$
using f_B (HPQCD), $|V_{ub}|$ (HFAG)

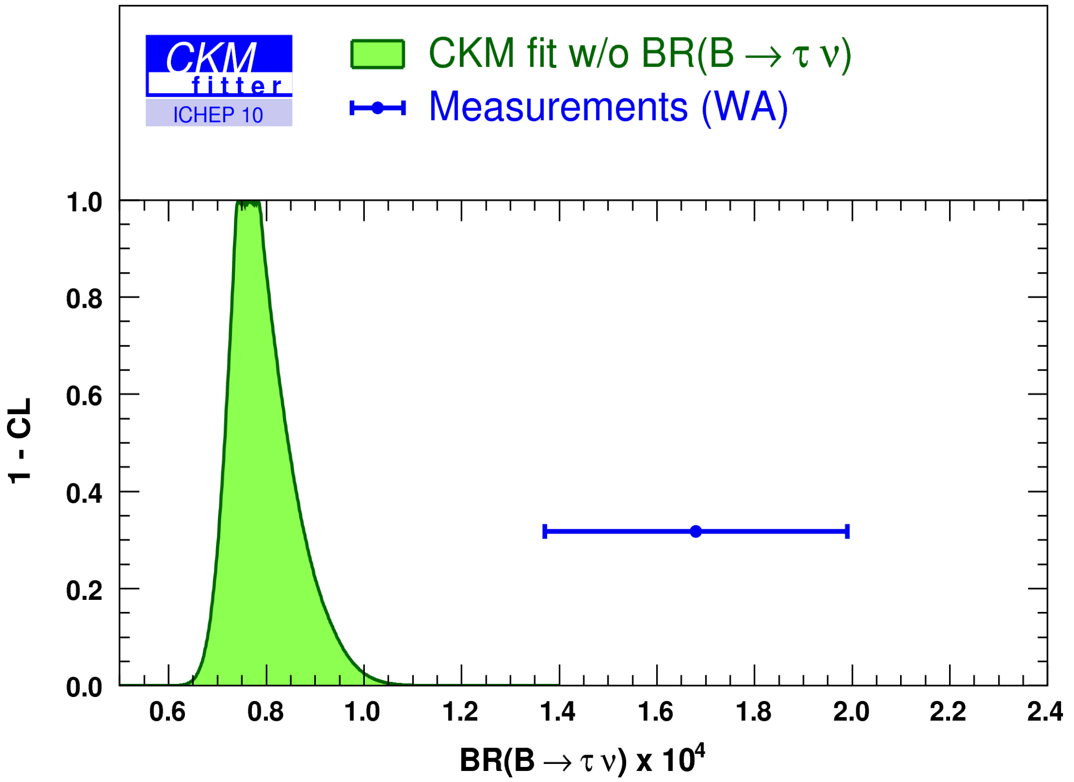
2HDM (type II):

$$\mathcal{B}(B^+ \to \tau^+ \nu) = \mathcal{B}_{SM} \times \left(1 - \frac{m_B^2}{m_{H^+}^2} \tan^2\beta\right)^2$$

CKMfitter: $\mathcal{B}_{SM}(B^+ \to \tau^+ \nu) = (0.76^{+0.11}_{-0.06}) \times 10^{-4}$

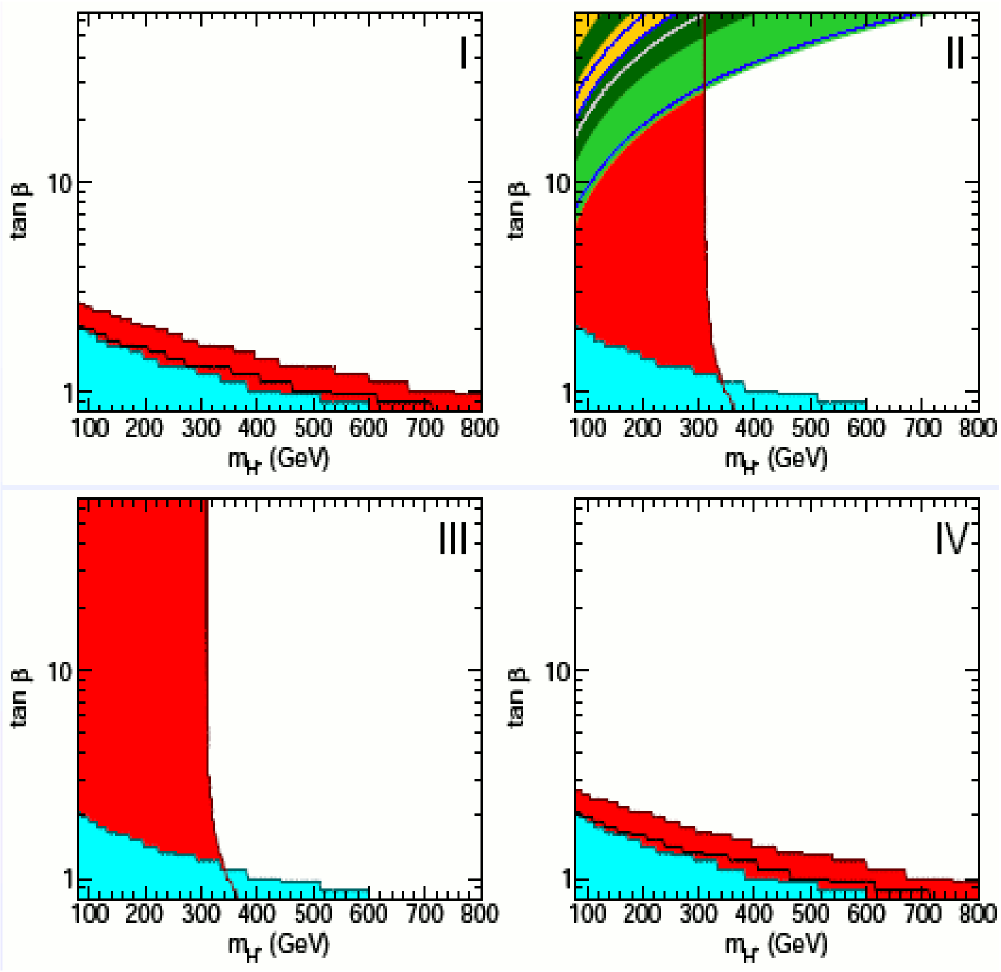
2.8σ difference





Combined charged Higgs bound from B-factories

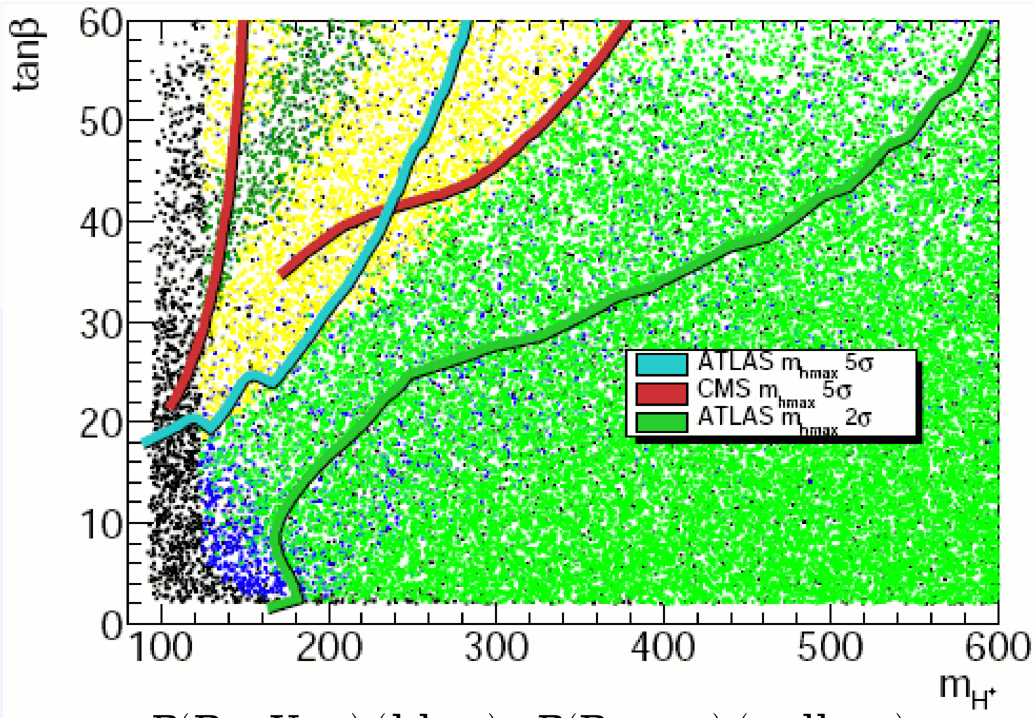
2HDM (Type I - IV)



$B(B \to X_s \gamma)$ (red), $B(B \to \tau \nu)$ (blue)
$B(B \to D \tau \nu)$ (yellow)

F.Mahmoudi and O.Stal
PRD81, 035016 (2010)

NUHM scenario
(non-universal Higgs mass models)

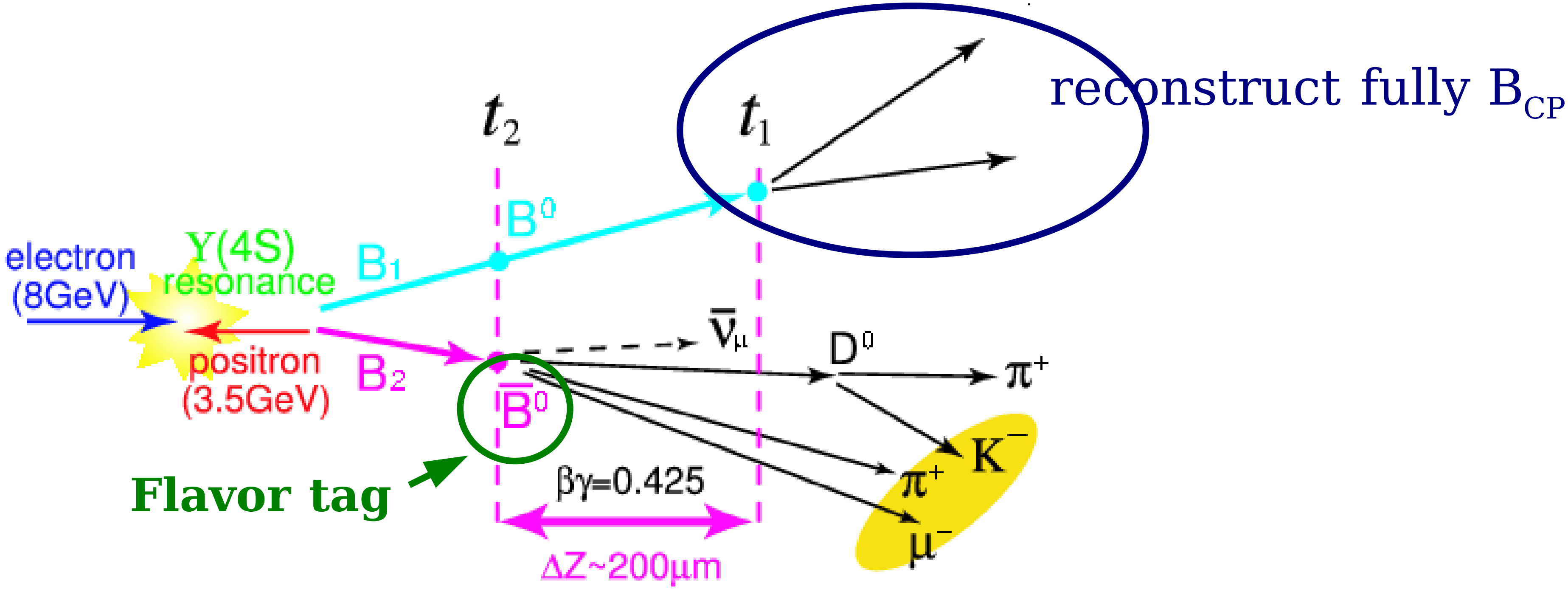


$B(B \to X_s \gamma)$ (blue), $B(B \to \tau \nu)$ (yellow)
$B(B \to D \tau \nu)$ (dark green), allowed region (green)

D.Eriksson et al
JHEP, 0811 (2008)

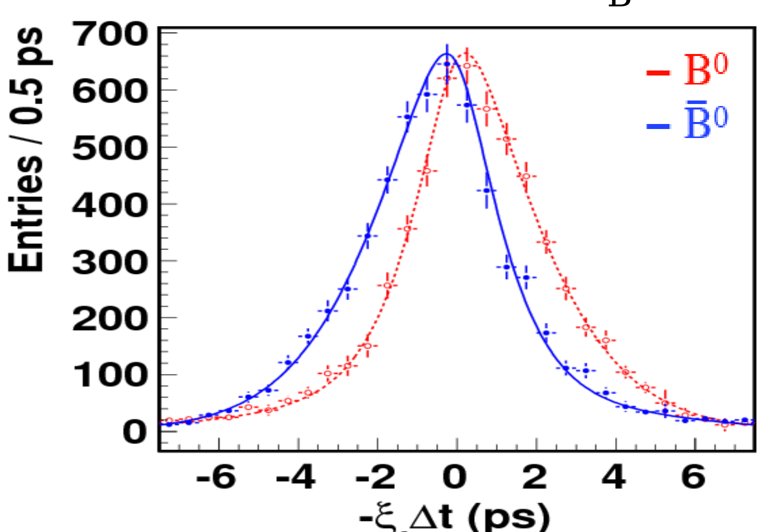
see also: U.Haisch et al (arXiv:0805.2141), O.Deschamps et al (arXiv:0907.5135)...

Measuring the CP parameters **S** and **A**



$\Delta z \sim c\beta\gamma\Delta t$

$$\frac{dP_{sig}}{dt}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}\left(1 + q\left(S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)\right)\right)$$

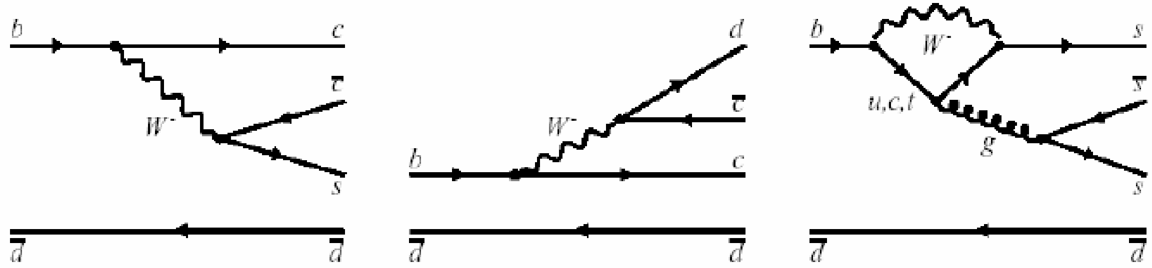


$$\sin 2\phi_1 = 0.668 \pm 0.023 \pm 0.013$$

$$A = 0.007 \pm 0.016 \pm 0.013$$

- World's most precise measurement
- anchor point of the SM

ϕ_1 with $b \to s$ penguins



$J/\psi K_S^0, \psi(2S) K_S^0, \chi_{c1} K_S^0,$
$\eta_c K_S^0, J/\psi K_L^0,$
$J/\psi K^{*0} (K^{*0} \to K_S^0 \pi^0)$

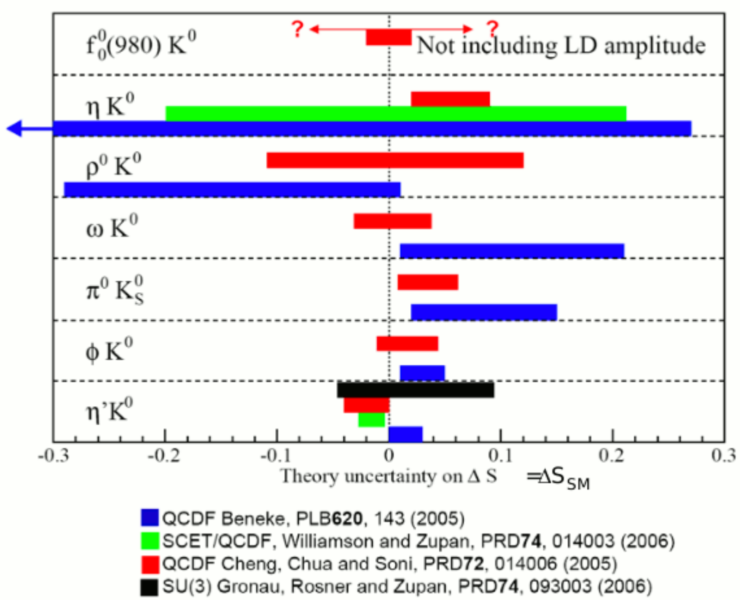
$D^{*+} D^-, D^+ D^-$
$J/\psi \pi^0, D^{*+} D^{*-}$

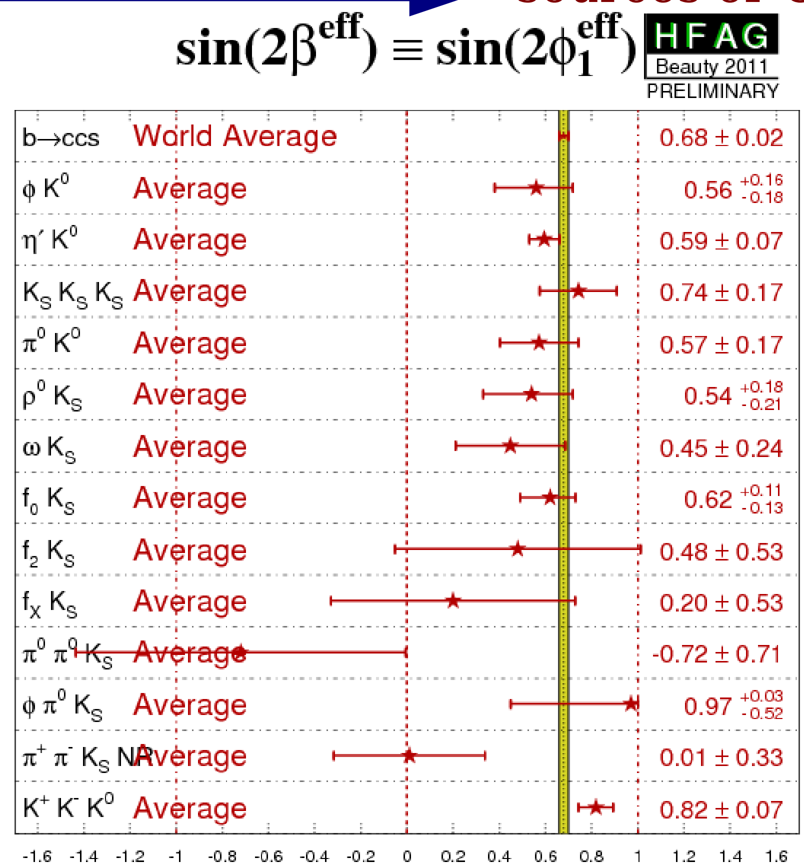
$\phi K^0, K^+ K^- K_S^0,$
$K_S^0 K_S^0 K_S^0, \eta' K^0, K_S^0 \pi^0,$
$\omega K_S^0, f_0(980) K_S^0$

increasing tree diagram amplitude

increasing sensitivity to new physics

possible new sources of CPV ?

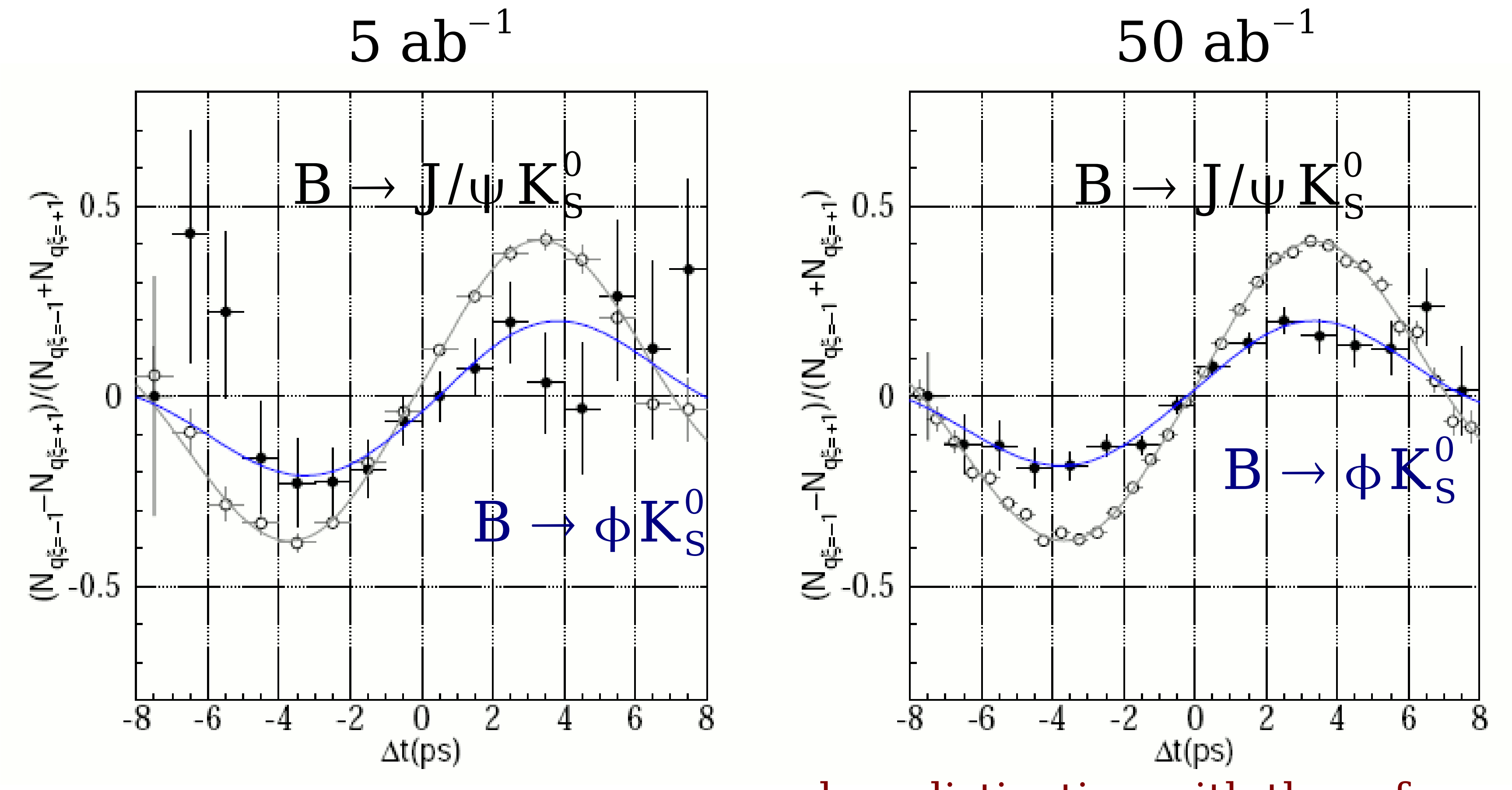




More statistics crucial
for mode-by-mode studies

$B \to \phi K_S^0$ time-dependent CPV

(input values $S_{\phi K_S^0} = +0.39$, $A_{\phi K_S^0} = 0$)

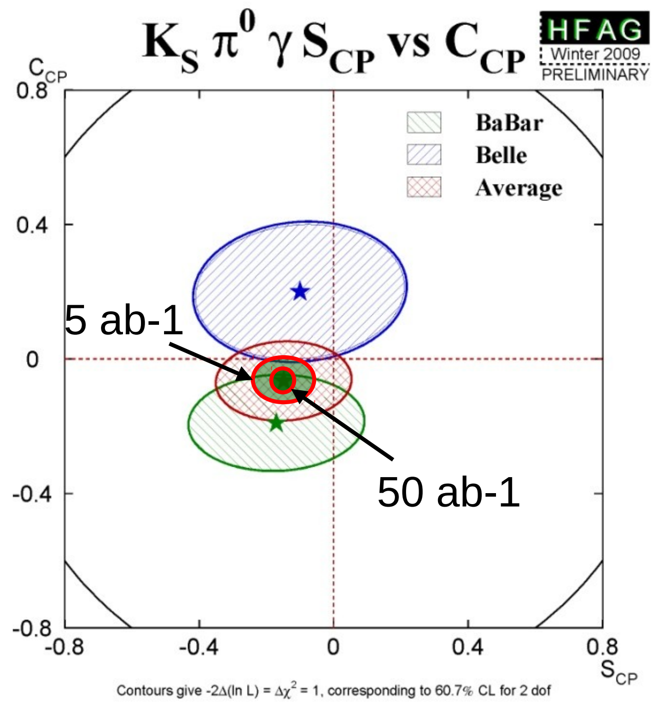


clear distinction with the reference mode

$B \to K^* \gamma$ time-dependent CPV

In SM mainly $B^0 \to K_S^0 \pi^0 \gamma_R$ and $\overline{B}^0 \to K_S^0 \pi^0 \gamma_L$

$K_S^0 \pi^0 \gamma$ is like an effective flavor eigenstate, and mixing-induced CP violation is expected to be small $S \sim -2(m_s/m_b)\sin(2\phi_1)$



Left-Right Symmetric Models:

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

[D.Atwood et al., PRL 79, 185 (1997)]

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

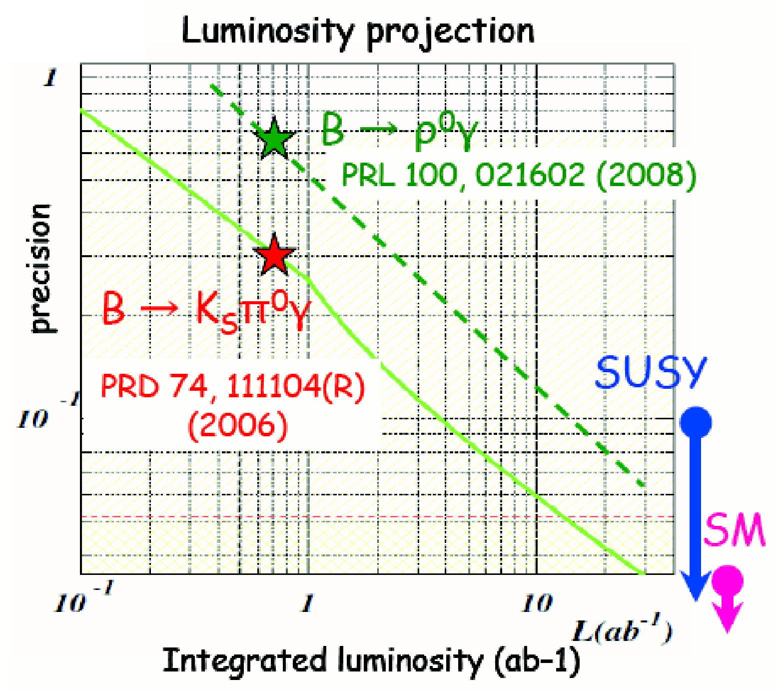
$$A_{CP}^{K_S\pi^0\gamma} = 0.07 \pm 0.12$$

[HFAG, Winter 09]

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

$$= 0.03 \text{ @ } 50\ ab^{-1}$$

($\sim$ SM prediction)



...and many more modes...

$o(10^2)$ higher luminosity

complementarity to other experiments (LHCb, BES)

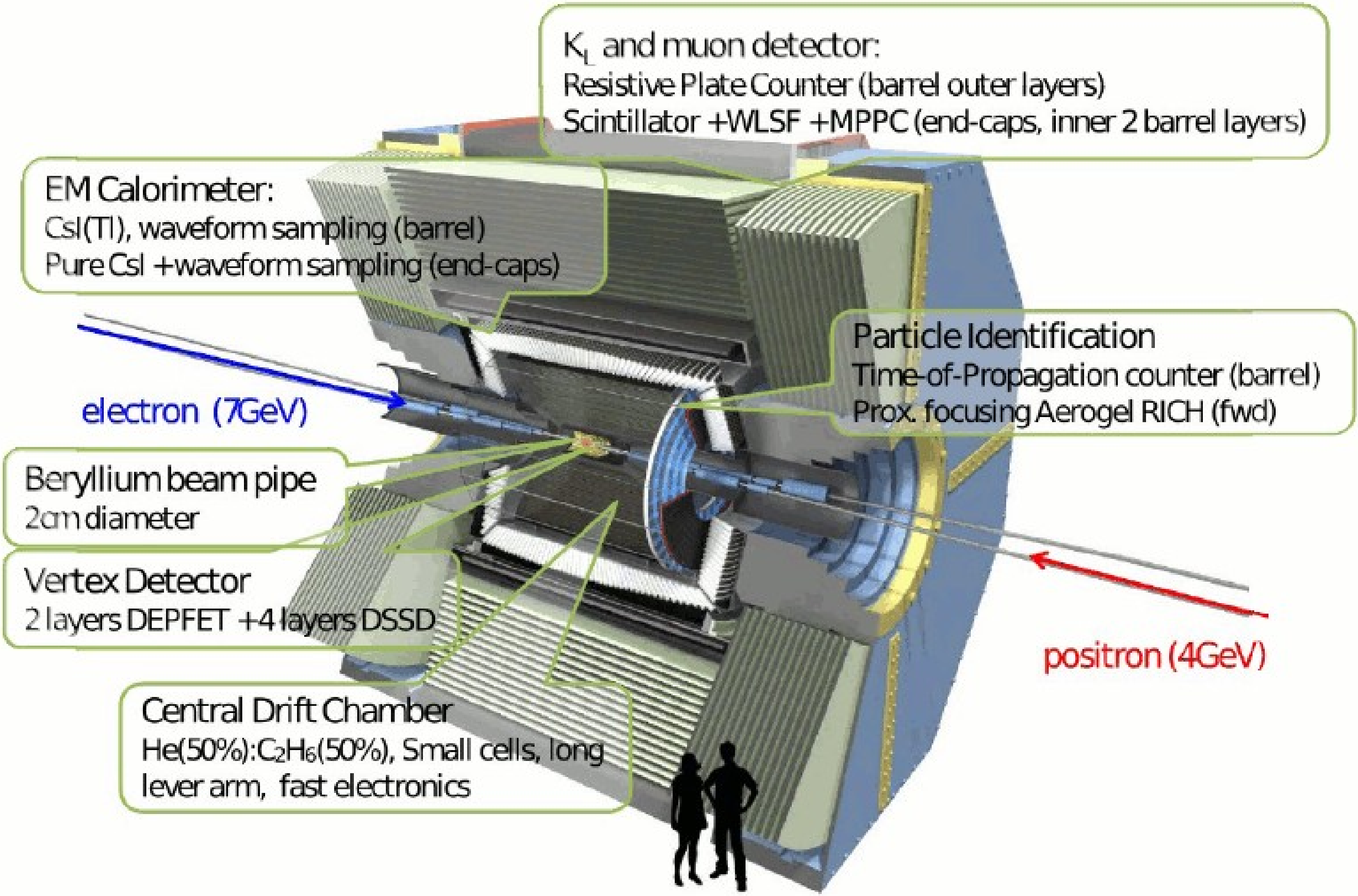
→ (red) theory uncertainty matches the expected exp. precision

→ (blue) theory uncertainty will match the expected exp. precision with expected progress in LQCD

Observable	SM prediction	Theory error	Present result	Future error	Future Facility
$\|V_{us}\|$ $[K \to \pi \ell \nu]$	input	$0.5\% \to 0.1\%_{\rm Latt}$	0.2246 ± 0.0012	0.1%	K factory
$\|V_{cb}\|$ $[B \to X_c \ell \nu]$	input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super-B
$\|V_{ub}\|$ $[B \to \pi \ell \nu]$	input	$10\% \to 5\%_{\rm Latt}$	$(3.38 \pm 0.36) \times 10^{-3}$	4%	Super-B
γ $[B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	3°	LHCb
$S_{B_d \to \psi K}$	$\sin(2\beta)$	$\lesssim 0.01$	0.671 ± 0.023	0.01	LHCb
$S_{B_s \to \psi \phi}$	0.036	$\lesssim 0.01$	$0.81^{+0.12}_{-0.32}$	0.01	LHCb
$S_{B_d \to \phi K}$	$\sin(2\beta)$	$\lesssim 0.05$	0.44 ± 0.18	0.1	LHCb
$S_{B_s \to \phi \phi}$	0.036	$\lesssim 0.05$	—	0.05	LHCb
$S_{B_d \to K^* \gamma}$	few $\times 0.01$	0.01	-0.16 ± 0.22	0.03	Super-B
$S_{B_s \to \phi \gamma}$	few $\times 0.01$	0.01	—	0.05	LHCb
$A^d_{\rm SL}$	-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
$A^s_{\rm SL}$	2×10^{-5}	$< 10^{-5}$	$(1.6 \pm 8.5) \times 10^{-3}$	10^{-3}	LHCb
$A_{CP}(b \to s\gamma)$	< 0.01	< 0.01	-0.012 ± 0.028	0.005	Super-B
$\mathcal{B}(B \to \tau \nu)$	1×10^{-4}	$20\% \to 5\%_{\rm Latt}$	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super-B
$\mathcal{B}(B \to \mu \nu)$	4×10^{-7}	$20\% \to 5\%_{\rm Latt}$	$< 1.3 \times 10^{-6}$	6%	Super-B
$\mathcal{B}(B_s \to \mu^+ \mu^-)$	3×10^{-9}	$20\% \to 5\%_{\rm Latt}$	$< 5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \to \mu^+ \mu^-)$	1×10^{-10}	$20\% \to 5\%_{\rm Latt}$	$< 1.5 \times 10^{-8}$	[?]	LHCb
$A_{\rm FB}(B \to K^* \mu^+ \mu^-)_{q_0^2}$	0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \to K \nu \bar{\nu}$	4×10^{-6}	$20\% \to 10\%_{\rm Latt}$	$< 1.4 \times 10^{-5}$	20%	Super-B
$\|q/p\|_{D-\rm mixing}$	1	$< 10^{-3}$	$(0.86^{+0.18}_{-0.15})$	0.03	Super-B
ϕ_D	0	$< 10^{-3}$	$(9.6^{+8.3}_{-9.5})^\circ$	2°	Super-B
$\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$	8.5×10^{-11}	8%	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	10%	K factory
$\mathcal{B}(K_L \to \pi^0 \nu \bar{\nu})$	2.6×10^{-11}	10%	$< 2.6 \times 10^{-8}$	[?]	K factory
$R^{(e/\mu)}(K \to \pi \ell \nu)$	2.477×10^{-5}	0.04%	$(2.498 \pm 0.014) \times 10^{-5}$	0.1%	K factory
$\mathcal{B}(t \to c Z, \gamma)$	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-13})$	$< 0.6 \times 10^{-2}$	$\mathcal{O}(10^{-5})$	LHC (100 fb^{-1})

Isidori, Nir, Perez, 1002.0900

The Belle II detector



Features required: hermeticity, low mom recon, better K_S efficiency, improved π/K separation, π^0/γ efficiency, etc...

Beam background

At SuperKEKB luminosity will increase by a **factor 40**
⇒ **background increases drastically**

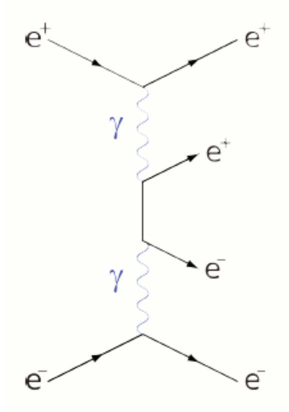
backgrounds (currently) identified at Belle II

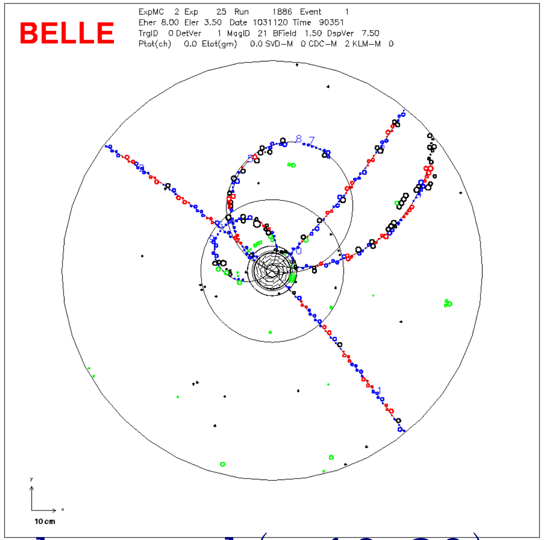
- Touschek scattering (intra-bunch scattering)
- Synchroton radiation
- Beam-gas scattering

Machine induced background

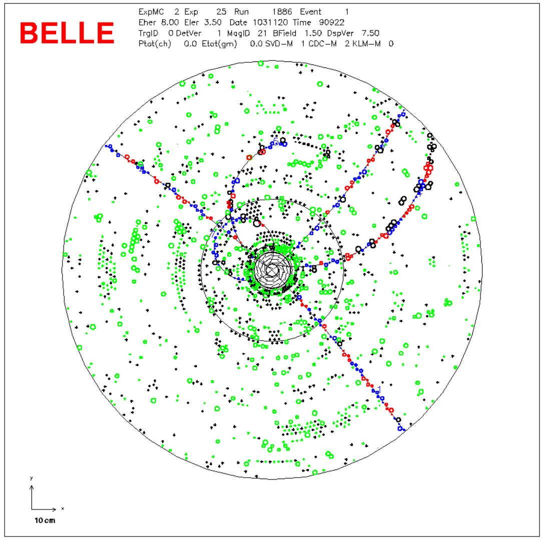
- Radiative Bhabha event: emitted γ
- Radiative Bhabha event: spent e^+/e^-
- 2-photon process event: $e^+e^- \to e^+e^-e^+e^-$

Luminosity dependent background



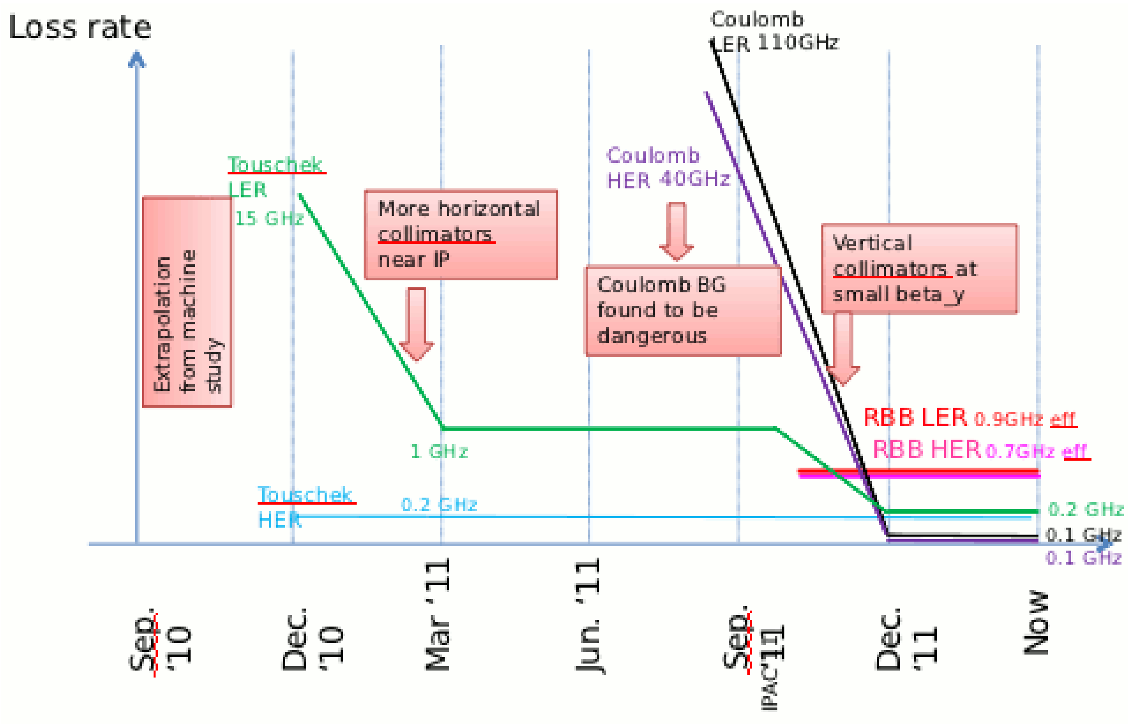


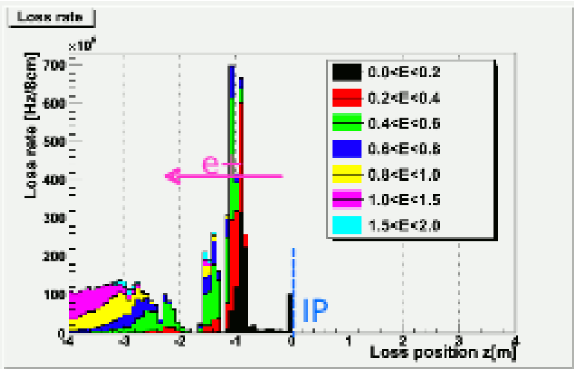
(× 10-20)

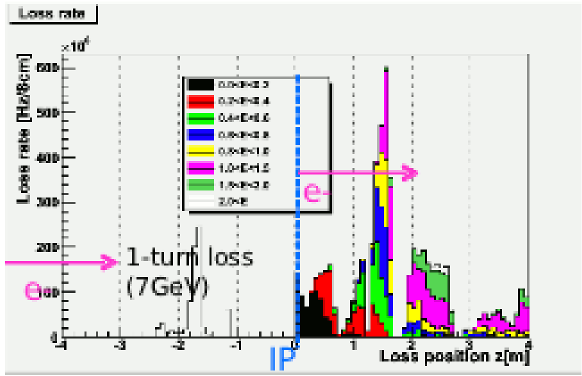


Higher background (× 10-20): radiation damage and occupancy
Higher event rate (× 10): higher rate trigger, DAQ and computing
Features required: hermeticity, low mom recon, better K_S efficiency, improved π/K separation, π^0 efficiency, etc...

Beam background



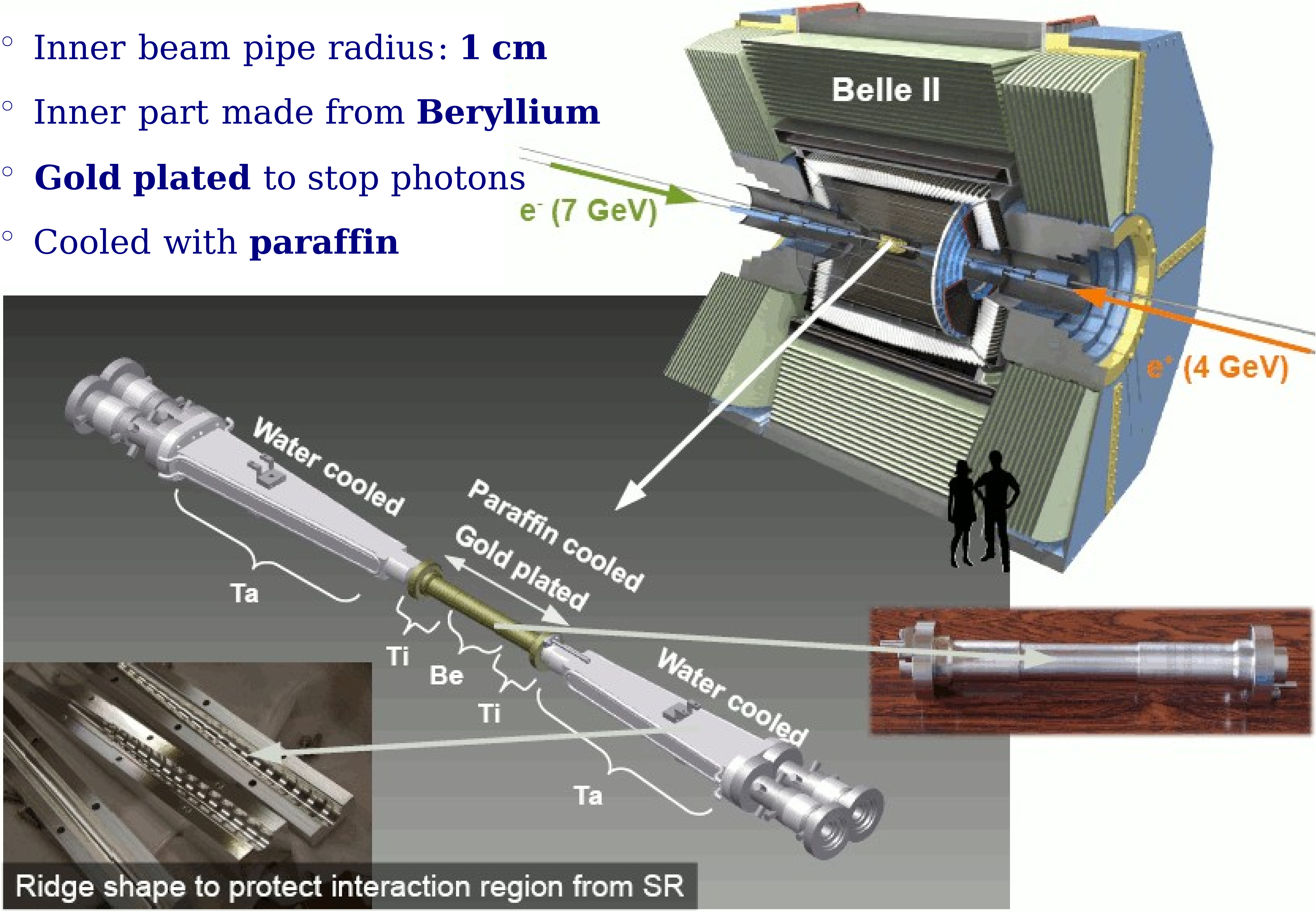




- Movable masks reduced Touschek and Coulomb backgrounds
- SuperB joint topical workshop on bakcgrounds (Feb 2012): (2 photon BG background estimations now agree)
- The main issue is now radiative Bhabha components hard to shield detector (TOP...) from the off-momentum e^-/e^+ (few cm thick W shield around final quads, magnetic shielding of the dipole leak field component)
- 2nd full simulation campaign (Feb.2012) to estimate detector response (Touschek/Beam-gas/Rad.Bhabha/2photon) (→ **H.Nakayama's talk**)

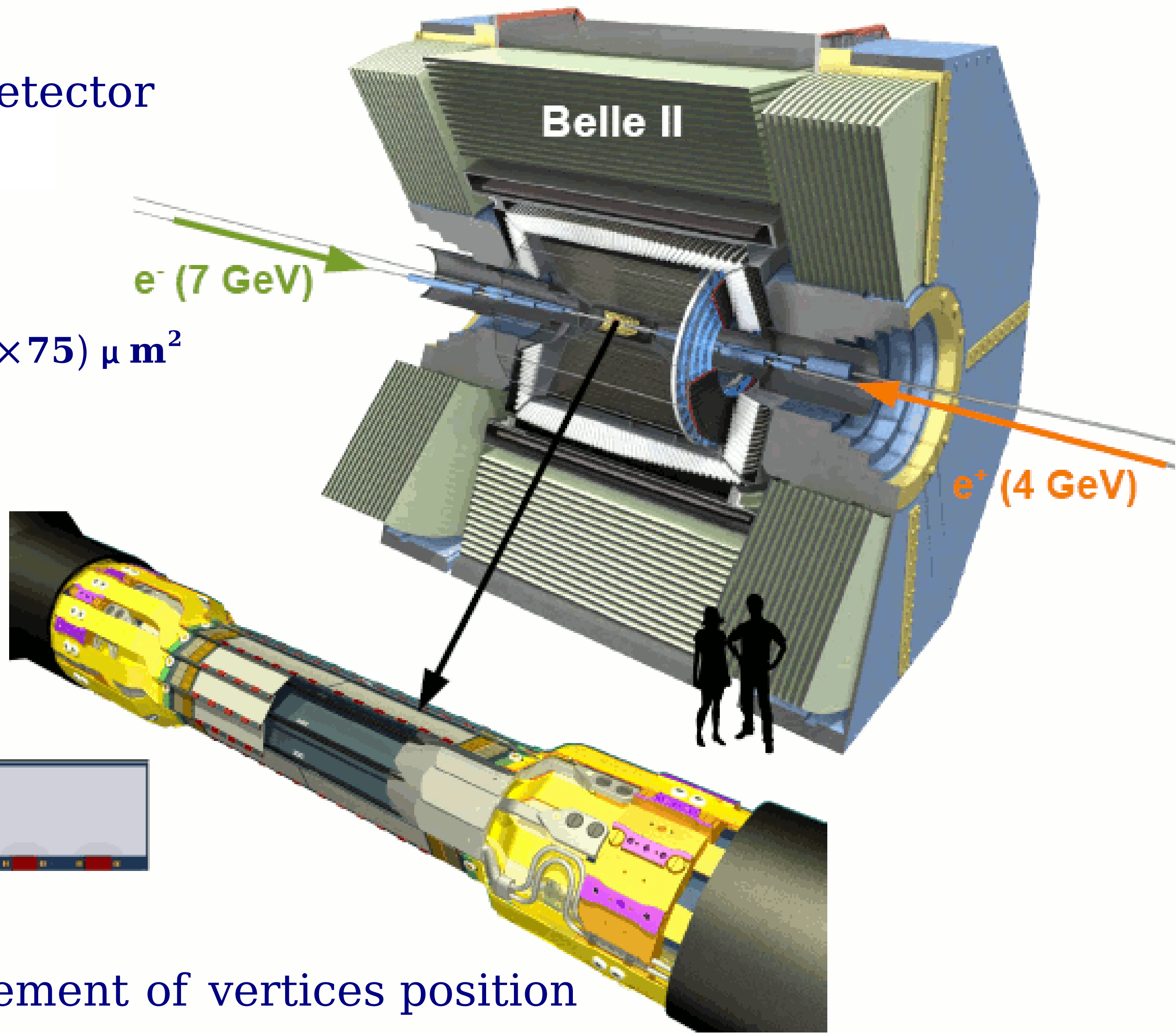
The Belle II detector – Interaction Region

- Inner beam pipe radius: **1 cm**
- Inner part made from **Beryllium**
- **Gold plated** to stop photons
- Cooled with **paraffin**



The Belle II detector – Pixel Vertex Detector

- **2 layer** silicon pixel detector
- **40** modules
- **Thickness 75 μm**
- Pixel size: **(50×50), (50×75) μm^2**
- **8 million** pixels
- readout time **20 μs**
- **DEPFET** technology

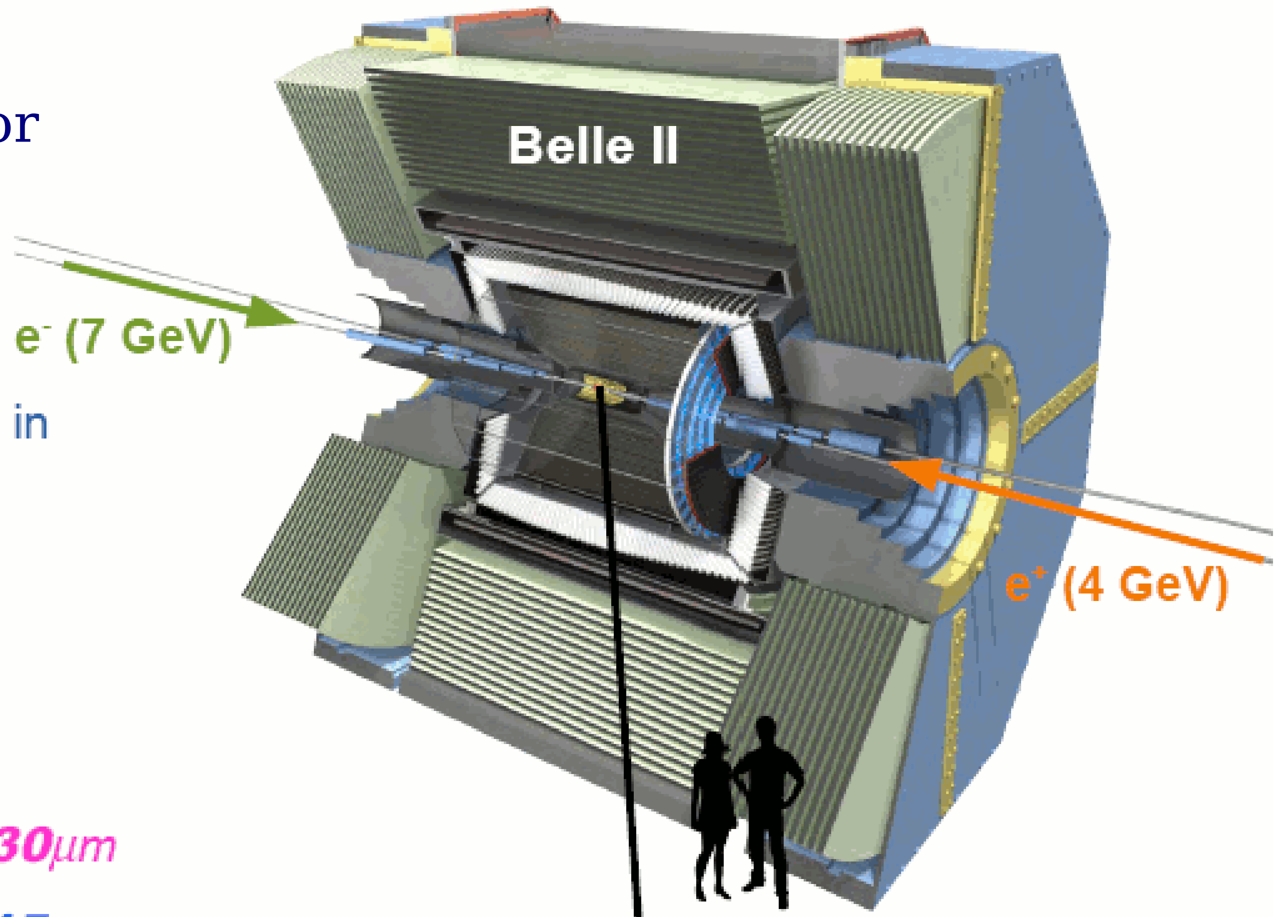


Allow a precise measurement of vertices position

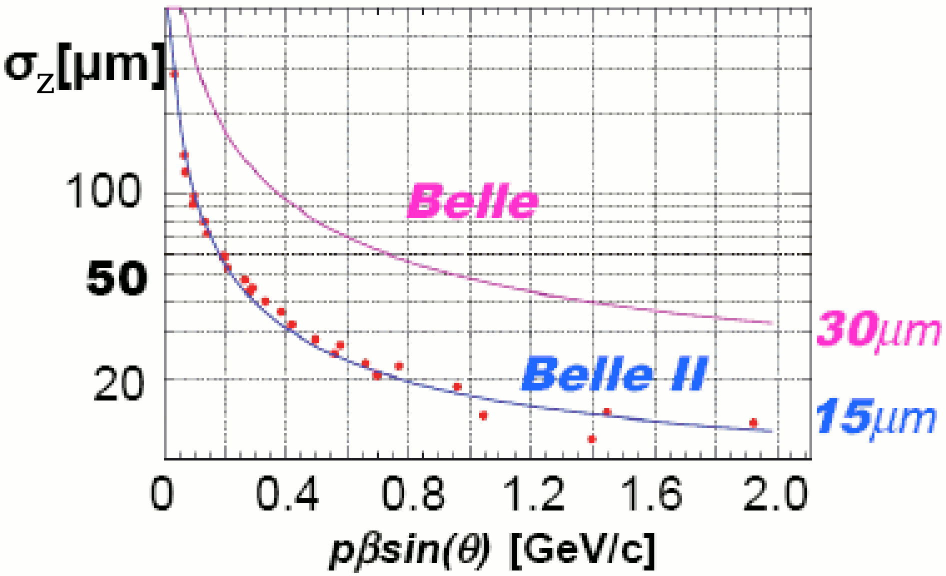
⇒ close to the IP: first layer radius **1.4 cm**, second layer **2.2 cm**
high background environment, strip detector unusable
PXD limit: 3%, studies show < 0.8%

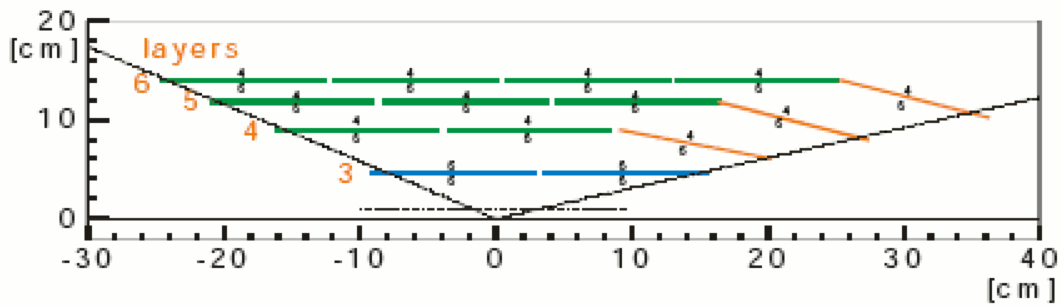
The Belle II detector – Silicon Vertex Detector

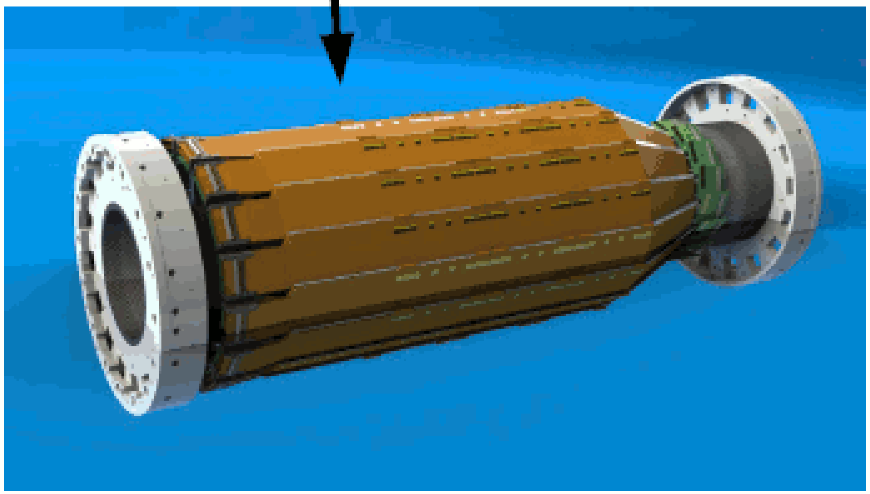
- **4 layer** silicon strip detector
- double sided strips



PXD + SVD: significant improvement in z-vertex resolution

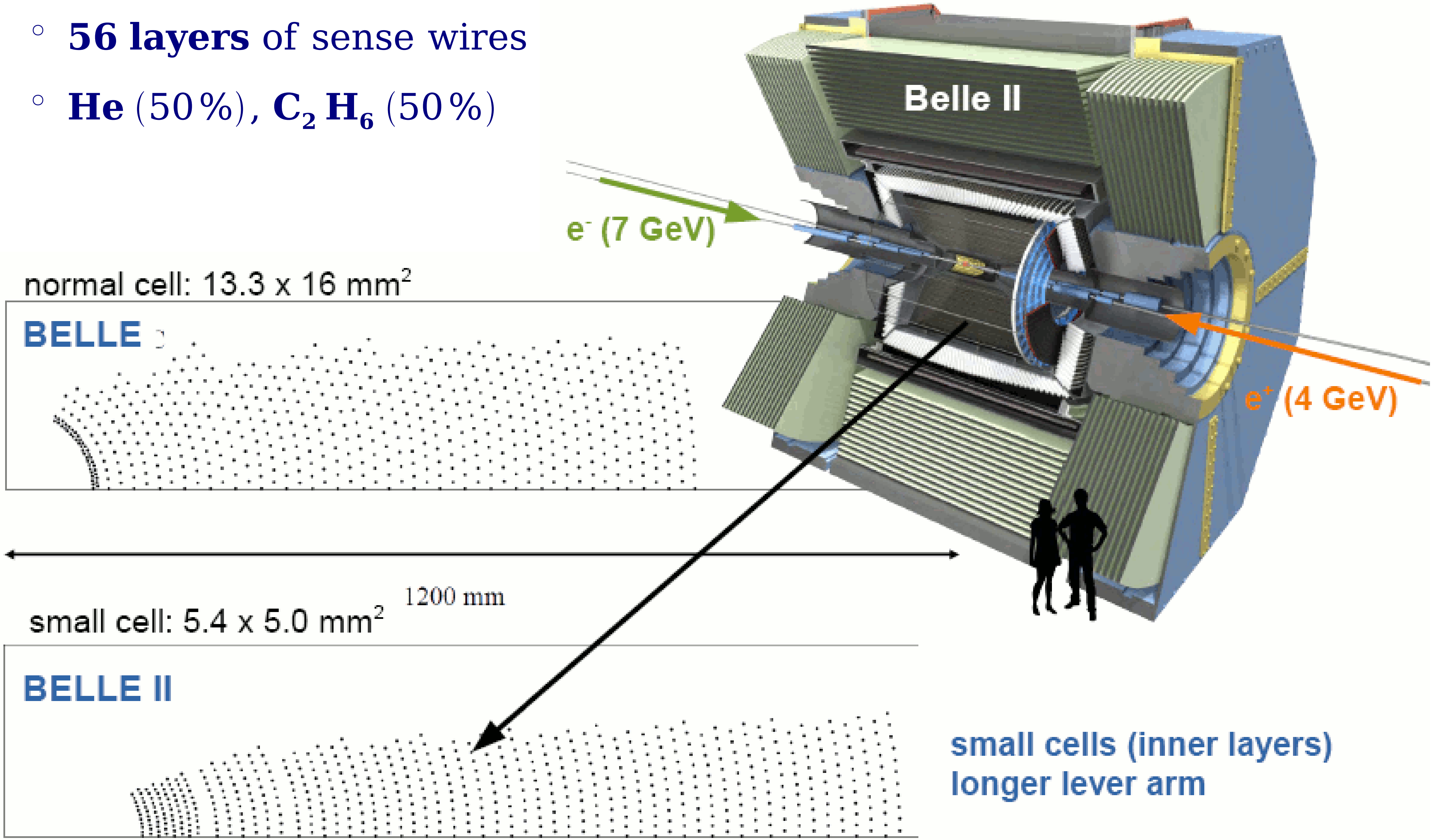






The Belle II detector – Central Drift Chamber

- **56 layers** of sense wires
- **He** (50%), $\mathbf{C_2H_6}$ (50%)

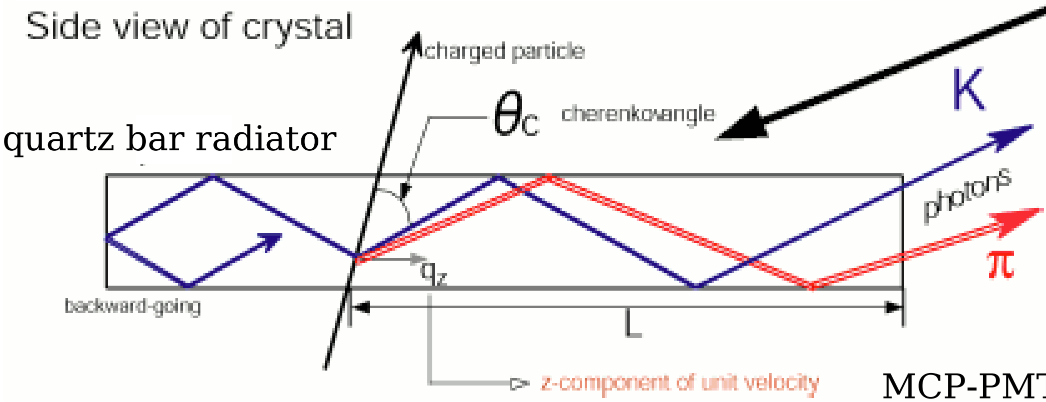


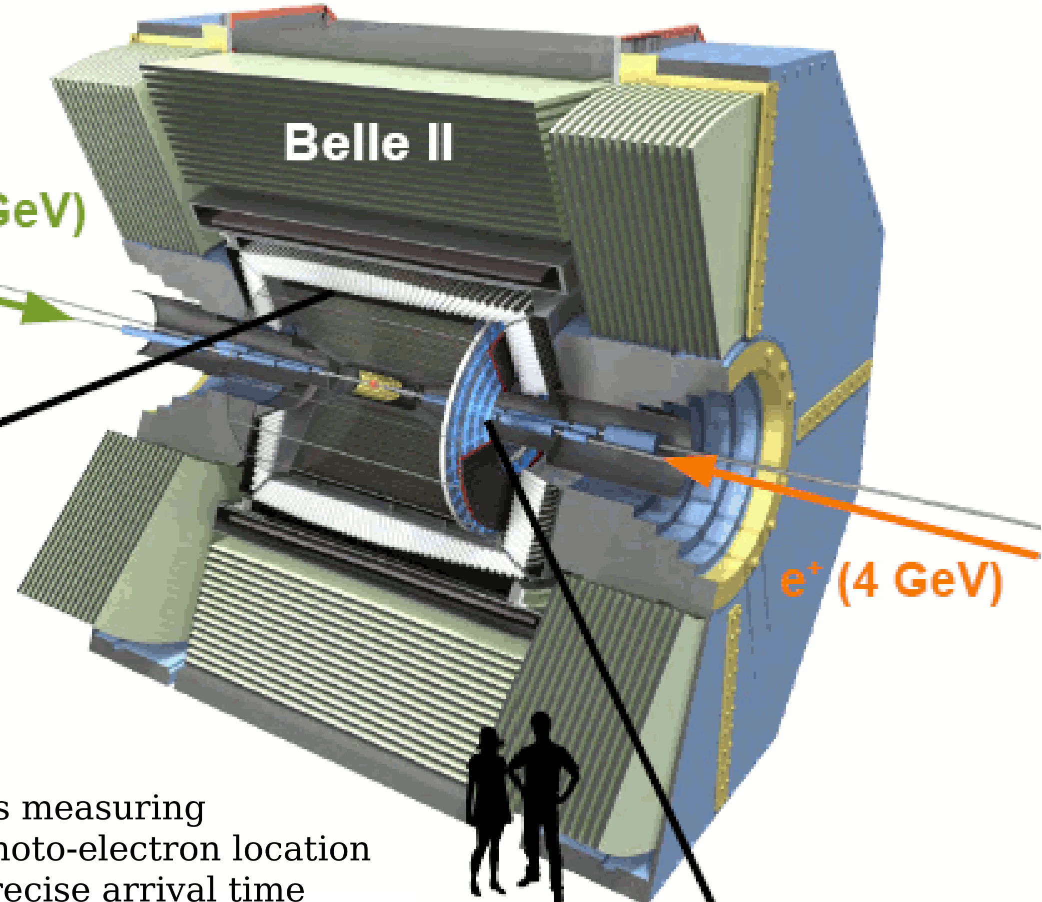
z-coordinate via standard stereo wire arrangement, charge division planned

The Belle II detector – Particle Identification

Time Of Propagation (TOP) Counter

- Barrel particle identification
- **3σ** K/π separation
- Separation by position and time
- Excellent time resolution **<~40 ps**

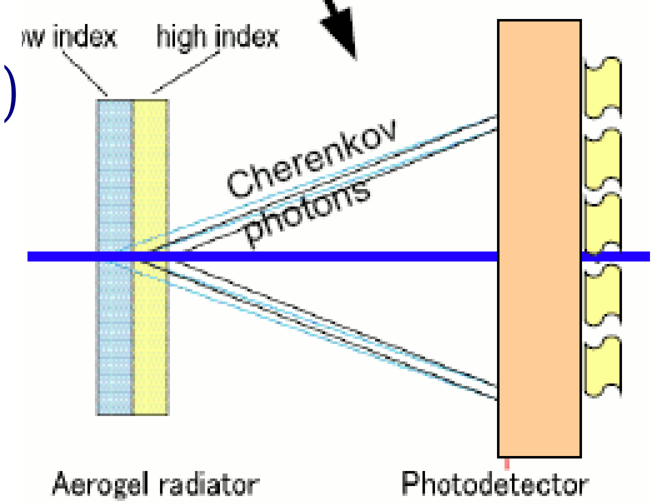




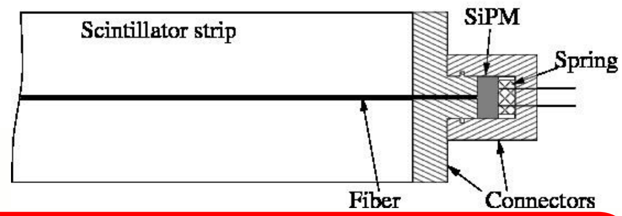
MCP-PMTs measuring
not only photo-electron location
but also precise arrival time

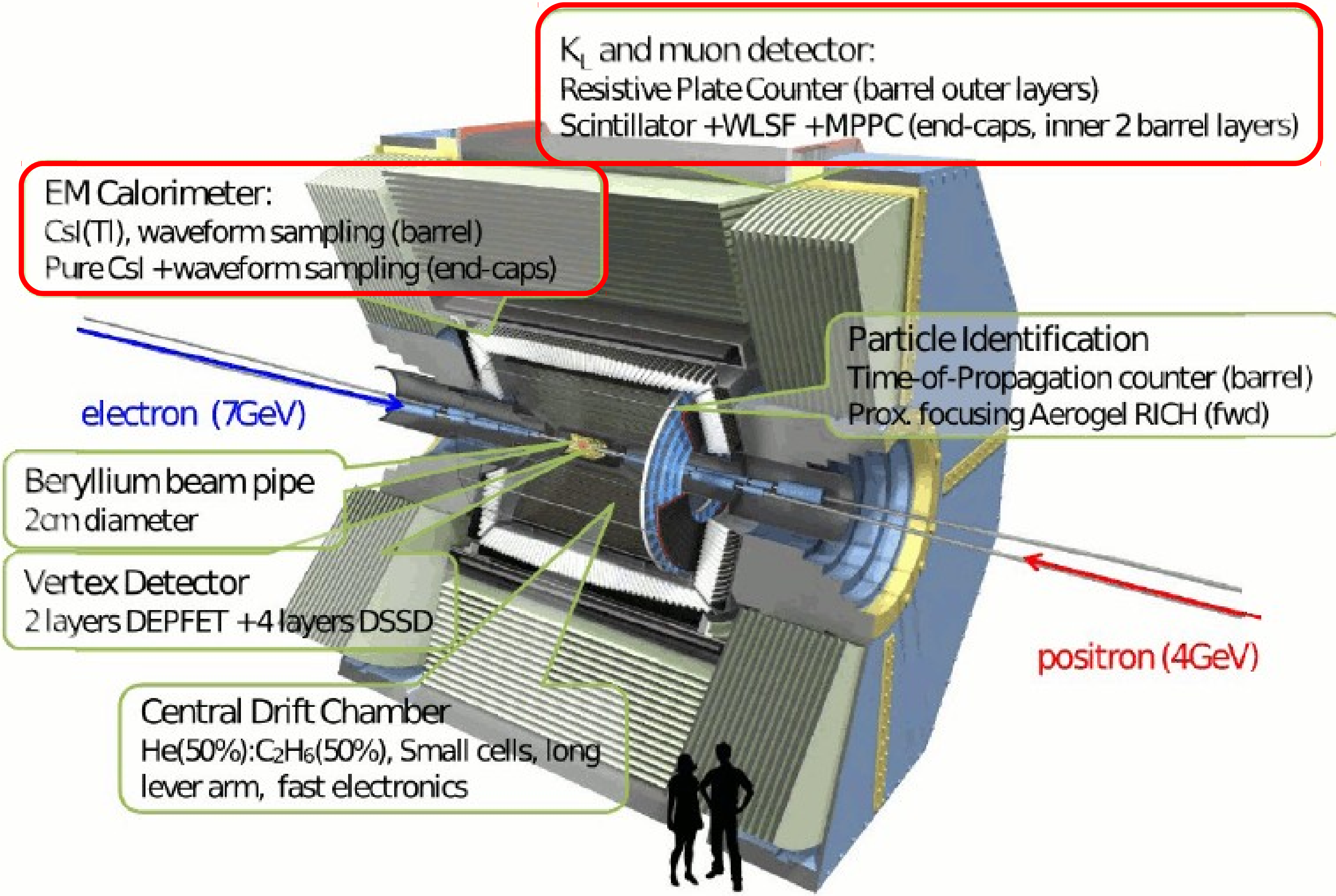
Aerogel Ring Imaging Cherenkov Counter (ARICH)

- Forward particle identification
- **Aerogel** is used as the **Cherenkov radiator**
- **4σ** K/π separation up to 4 GeV
- focusing due to different diffraction indices

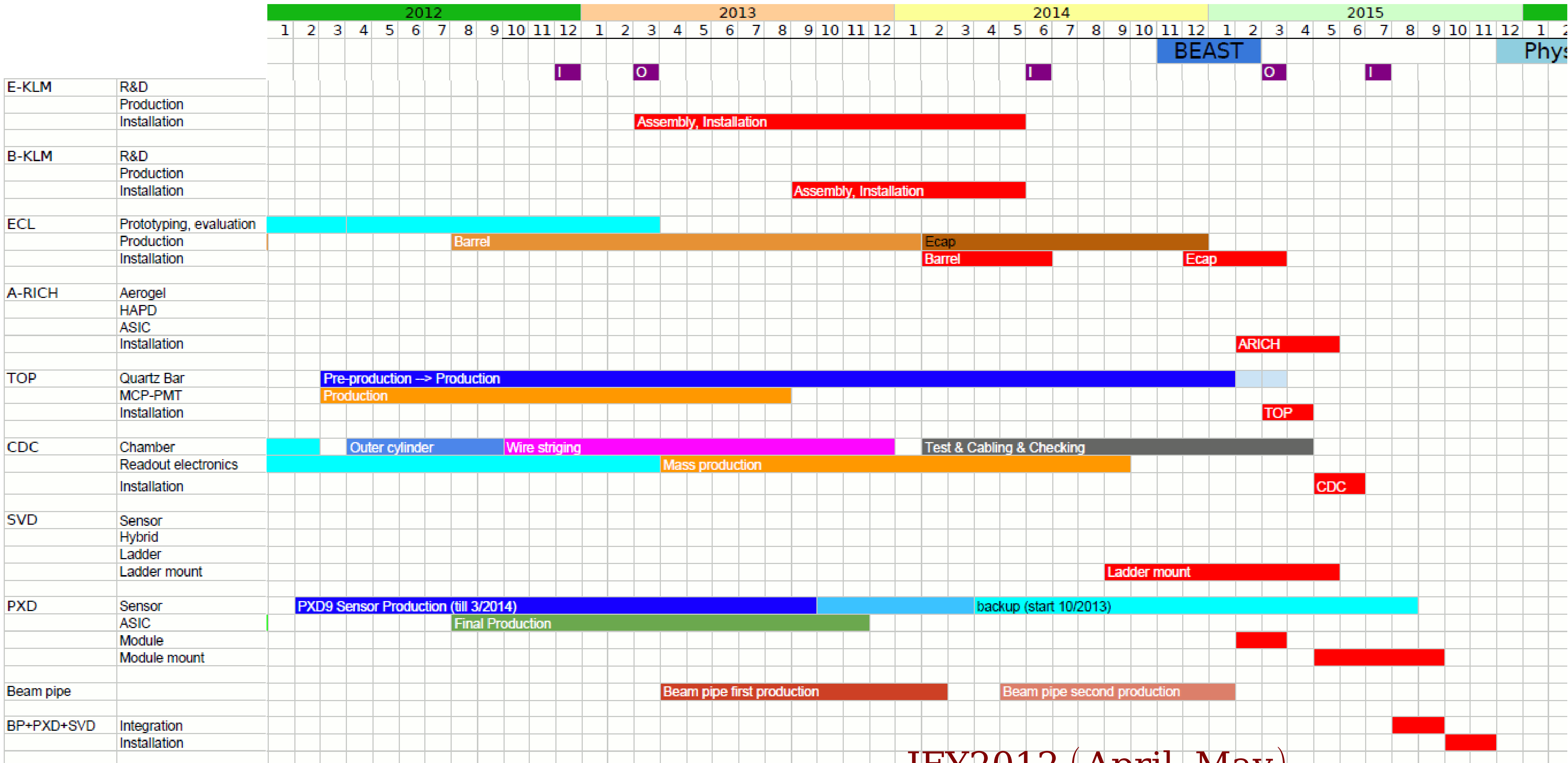


The Belle II detector





Construction Schedule of SuperKEKB/Belle II (Y.Ushiroda)



Feb. 2013: EKLM ready to start installation
Aug. 2013: BKLM ready to start installation
July 2014: Beam pipe 1 ready
August 2014: SVD ready to start ladder mount
Dec 2014: ECL ready to start installation
Jan 2015: TOP, ARICH ready to start installation
April 2015: CDC ready to start installation
July 2015: Beam pipe 2 ready
August 2015: PXD ready...

JFY2012 (April-May)

Belle rotation, Removal of cables

JFY2013

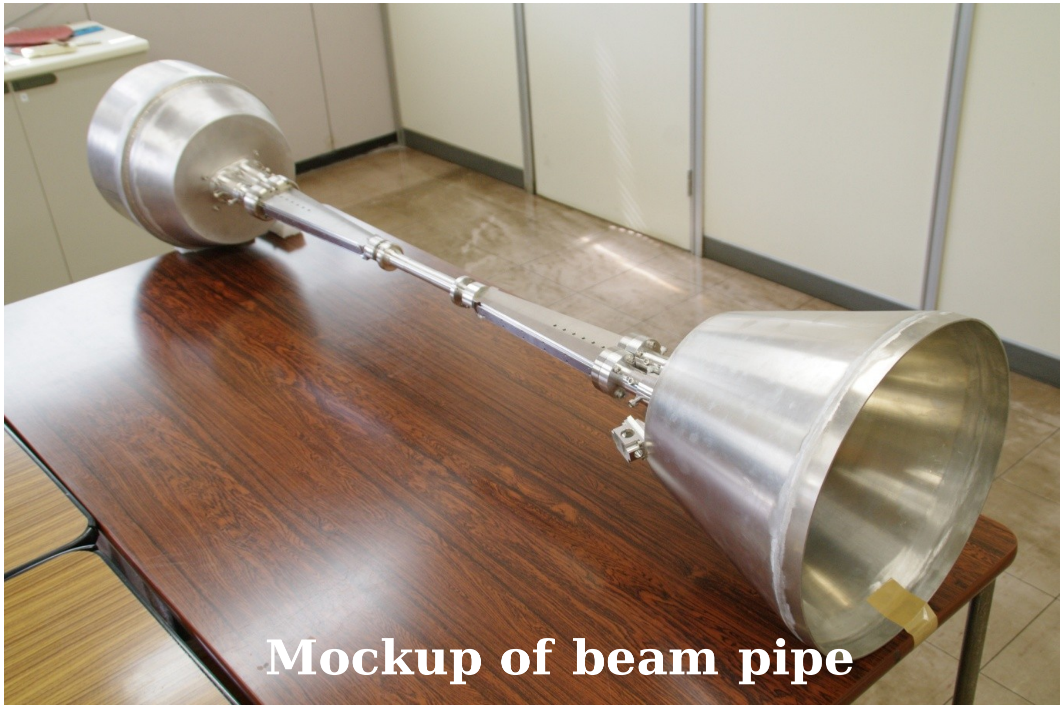
Installation of KLM starts

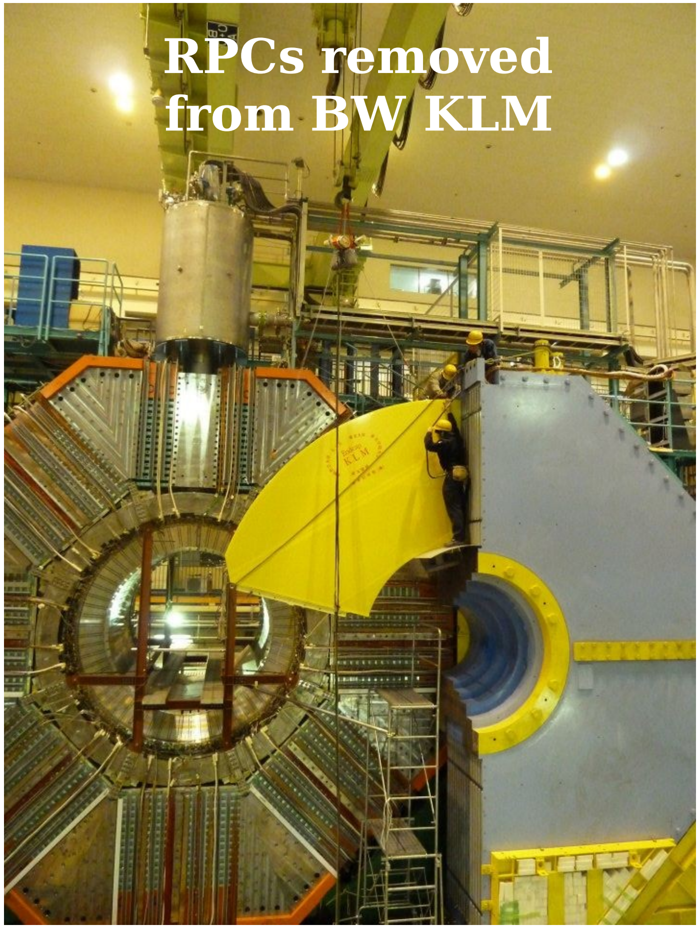
JFY2014

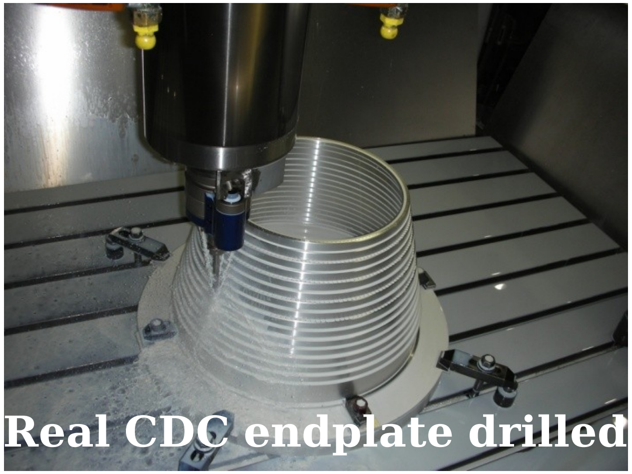
Machine operation starts
After machine commissioning,
inner detectors are installed
Physics run starts in end of CY 2015

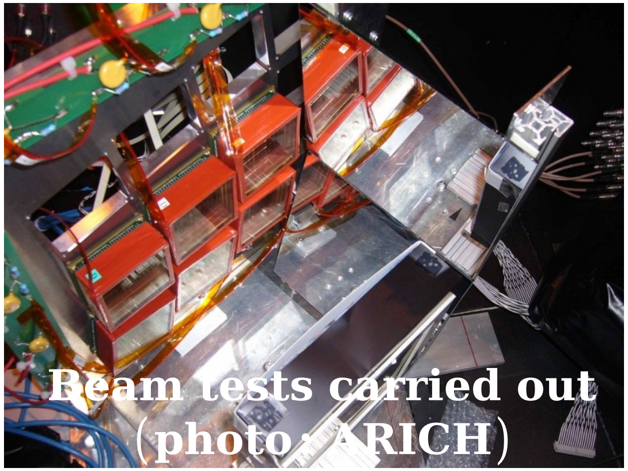
Detector Construction Status

(Y.Ushiroda)



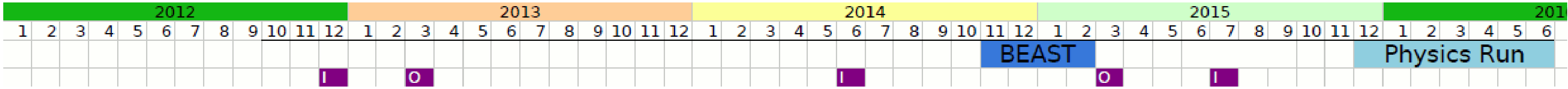






TOP beam test data (Dec 2011) under analysis → BPAC (Feb 25-26)

Beast II: Beam Exorcism for A STable experiment II



A background detector for the commissioning of the Belle II experiment

1. Determine whether it is safe to roll-in the detector
   measure instantaneous and integrated radiation dose
   test the beam abort systems

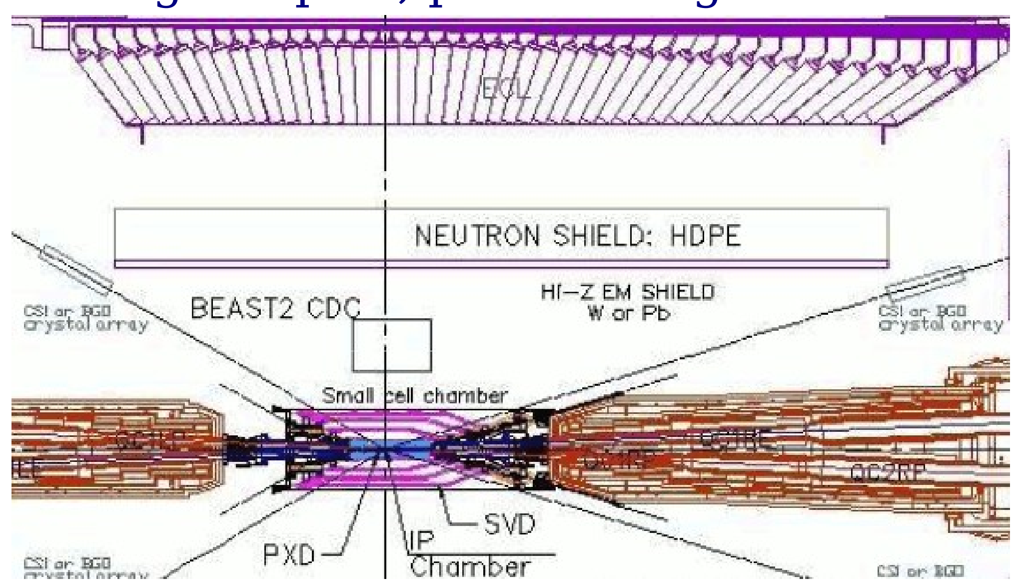
2. SuperKEKB machine needs real time measurements of luminosity and backgrounds during beam commissioning (tuning of beam optics and moveable mask positions)

3. Detailed understanding of beam background sources needed to validate the simulations

Group and discussion started at November 2011, biweekly meetings

Define BEAST II, preparing Conceptual Design Report, possible ingredients:

- Non-magnetic support structure
- PXD/SVD modules
- CDC prototype
- BGO crystals for lumi monitoring
- Diodes, radFETs, diamonds
- microTPC
  (neutron detection, xrays, tracks)

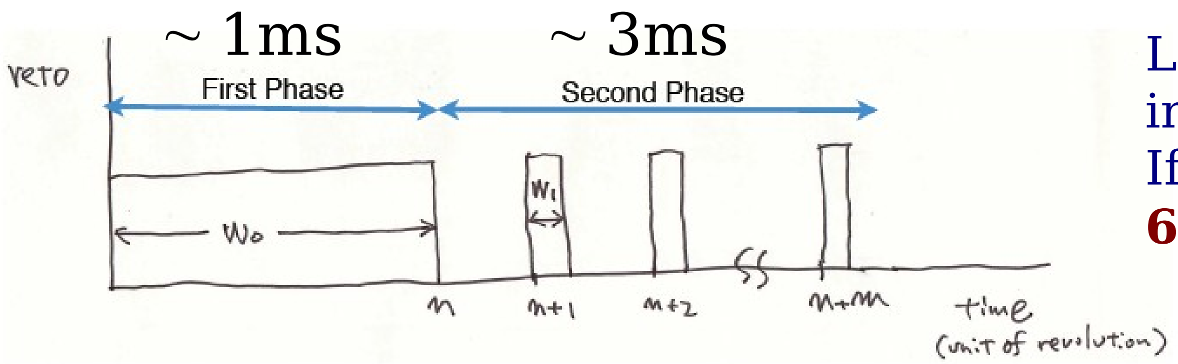


Machine-detector issues (Y.Ushiroda)

- **Beam Energy Asymmetry:**
  - Agreed with (7×4) GeV as requested by machine
- **Solenoid Axis:**
  - Agreed to be bisector of beams; will rotate Belle in JFY2012
- **Space requirement in exp. hall:**
  - Offer the prime real estate for QCS related equipments.
- **Solenoid for machine commissioning:**
  - Agreed to serve; but crucial for detector construction schedule
  - Hope machine live with a dummy solenoid instead of Belle's solenoid
- **Injection veto:**
  - Efforts from both sides necessary (next slide)
- **Beam Background**
  - Radiative Bhabha remains crucial
  - Reduce dipole leakage field, or add shield around QCS

Injection veto

(Y.Ushiroda)



Level 1 trigger is blocked after injection because BG is too high
If n = 100, W1=1μs and m=300
6.5% dead-time @ 50Hz injection

- **Two phases**
  - **First phase : veto n turns completely**
    W0 = n * 10 usec
    n = 10〜100
  - **Second phase : veto periodically**
    W1 = 〜1 usec
    m 〜 300
  - **Three parameters (n, m, W1) : SKEKB dependence**

DEPFET pixel detector integrates data for 20μs = 2 revolutions of noisy bunches
Pixels are all exposed till the end of 2nd phase (4ms)
→ **20% dead-time @ 50Hz injection**

Trying to increase frame rate (20μs→5μs)
but still 10% dead-time @ 50Hz injection

''Any idea to reduce injection repetition rate (by reinforcing injectors?) to achieve quiet injection, fast background damping is welcome. Meanwhile, we seek for possible improvement in the device.''

Conclusion

$\sim 10^2 \times$ luminosity will probe significantly into $>$ 1 TeV mass scale

precision CKM, CP, lepton universitality, LFV...

Rich physics program at SuperKEKB/Belle II

complementary to LHC in sensitivity

Belle II detector expected to have similar or better performance than Belle even under higher beam background

Schedule is still very tight but no major problem until now

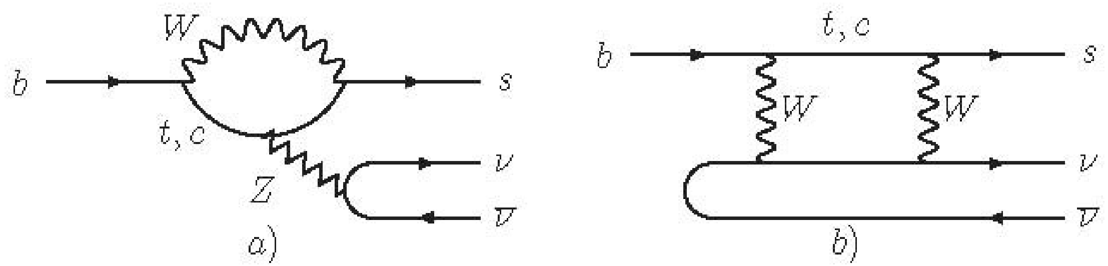
$\Rightarrow$ **Physics run starts in end of 2015**

Backup slides

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

$B_{sig}\ B_{tag} \to (h \nu \bar{\nu})\ (X l \nu)$ semil. tag

$\to (h \nu \bar{\nu})\ (X)$ hadronic tag



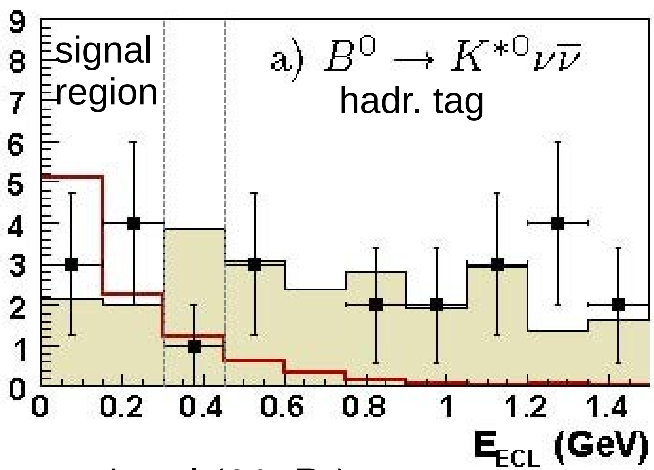
fully (partially) reconstruct B_{tag}

reconstruct h from $B_{sig} \to h \nu \bar{\nu}$

no additional energy in EM calorim.

(signal at $E_{ECL} \sim 0$)

PRL 99, 221802 (2007), 490 fb^{-1}



-- exp. signal (20xBr)

exp. bkg. (scaled to sideband)

$\int L\,dt = 50\ ab^{-1}$

semil. + hadr. tag (improved):

$N_{sig} \sim 240$, $N_{bkg} \sim 4600$

$Br(B^0 \to K^{*0} \nu \bar{\nu})$ can be measured to $\pm 30\%$

similar precision for $Br(B^0 \to K_S \nu \bar{\nu})$

$N_{bkg}^{exp} = 4.2 \pm 1.4 \quad \Rightarrow \quad Br(K^{*0} \nu \bar{\nu}) < 3.4 \times 10^{-4}$ @ 90% C.L.

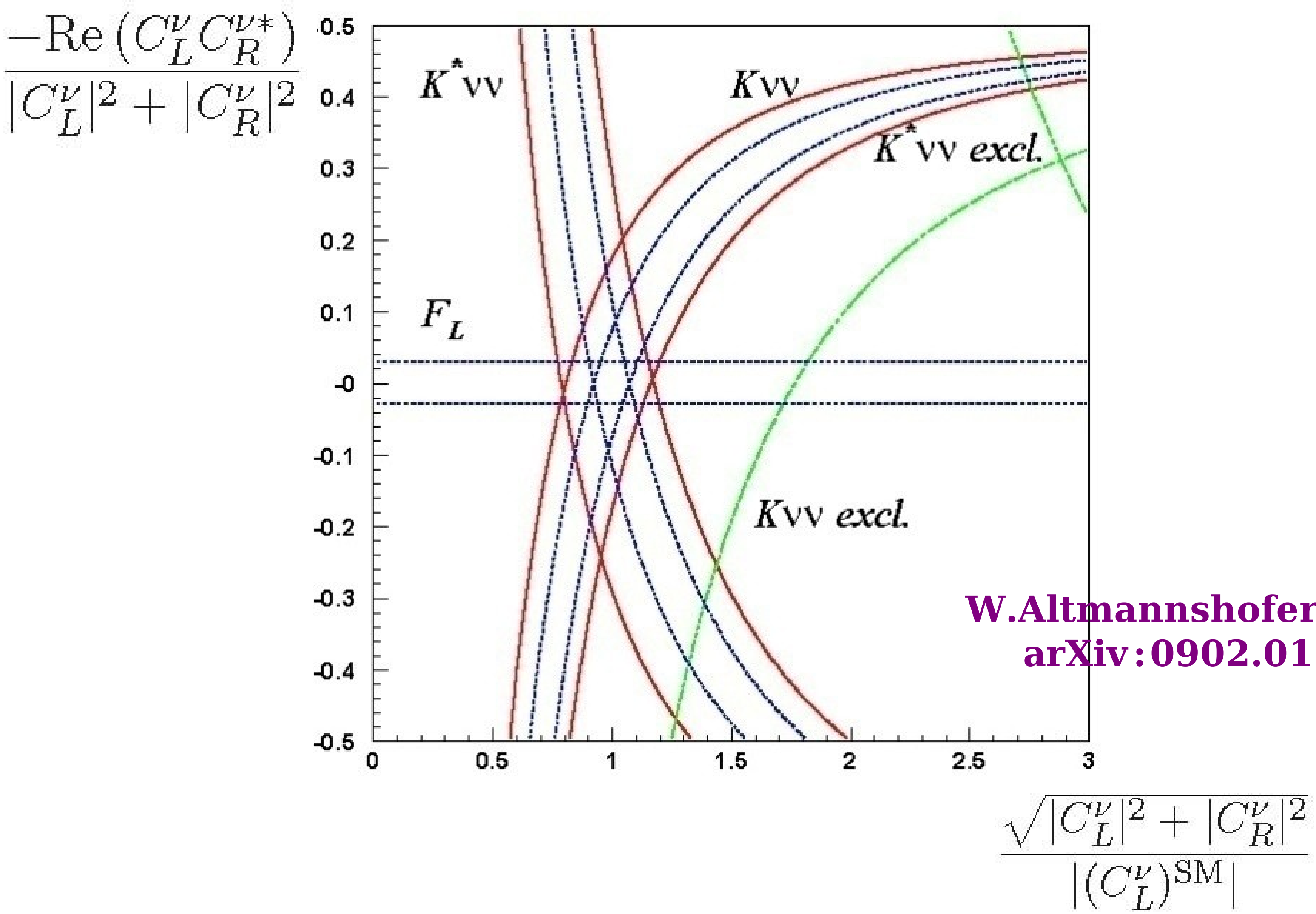
($N_{sig}^{exp} = 0.34$, $Br(B^0 \to K^{*0} \nu \bar{\nu}) = 1.3 \times 10^{-5}$)

G.Buchalla et al, PRD 63, 014015 (2001)

[similarly for $K^+ \nu \bar{\nu}$]

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

model independent way including a possible contribution of the NP right-handed currents parametrized by the Wilson coefficient C_R^{ν} (in addition to the SM coefficient C_L^{ν})



W.Altmannshofer et al
arXiv:0902.0160

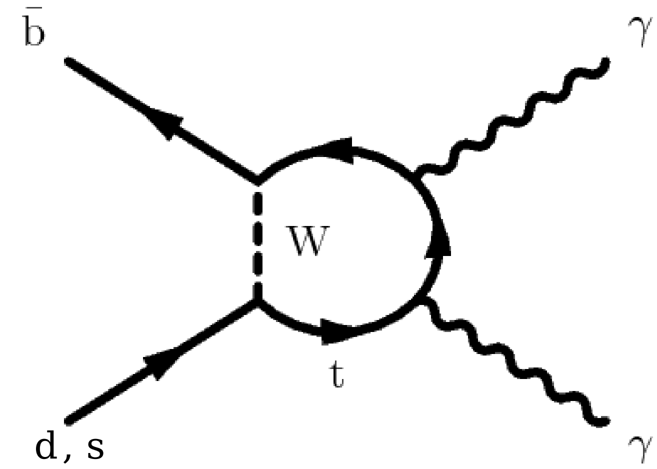
$B_{d,s} \to \gamma\gamma$

$B_{SM}(B_d \to \gamma\gamma) \sim 3\times10^{-8}$

Bosch and Buchalla

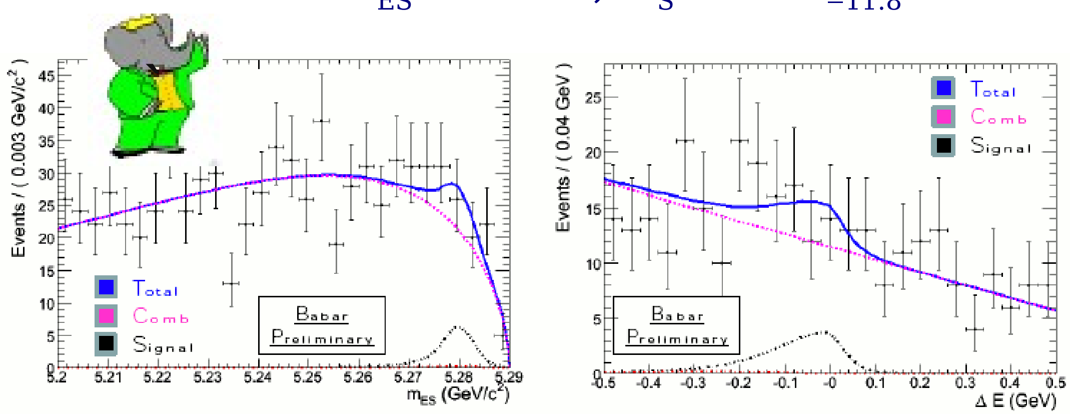
JHEP 0208:054 (2002)

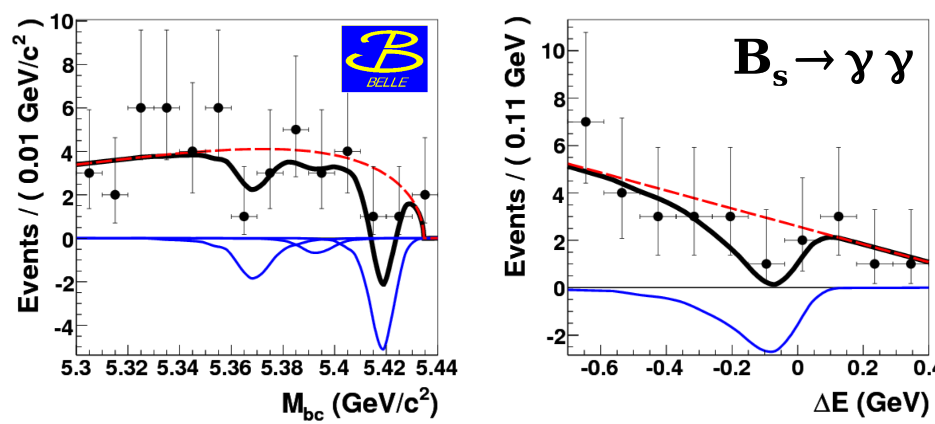
$B_{SM}(B_s \to \gamma\gamma) \sim 1\times10^{-6}$



after continuum background rejection and π^0, η vetoes

2d fit to m_{ES} and ΔE, $N_S = 21.3^{+12.8}_{-11.8} \pm 1.4$





$B(B^0 \to \gamma\gamma) < 3.2\times10^{-7}$ @ 90% C.L.

$B(B_s \to \gamma\gamma) < 8.7\times10^{-6}$ @ 90% C.L.

$B(B^0 \to \gamma\gamma) < 6.1\times10^{-7}$ @ 90% C.L.

(using 104 fb^{-1}) [PRD73, 051107 (2006)]

(using 23 fb^{-1}) PRL 100, 121801 (2008)