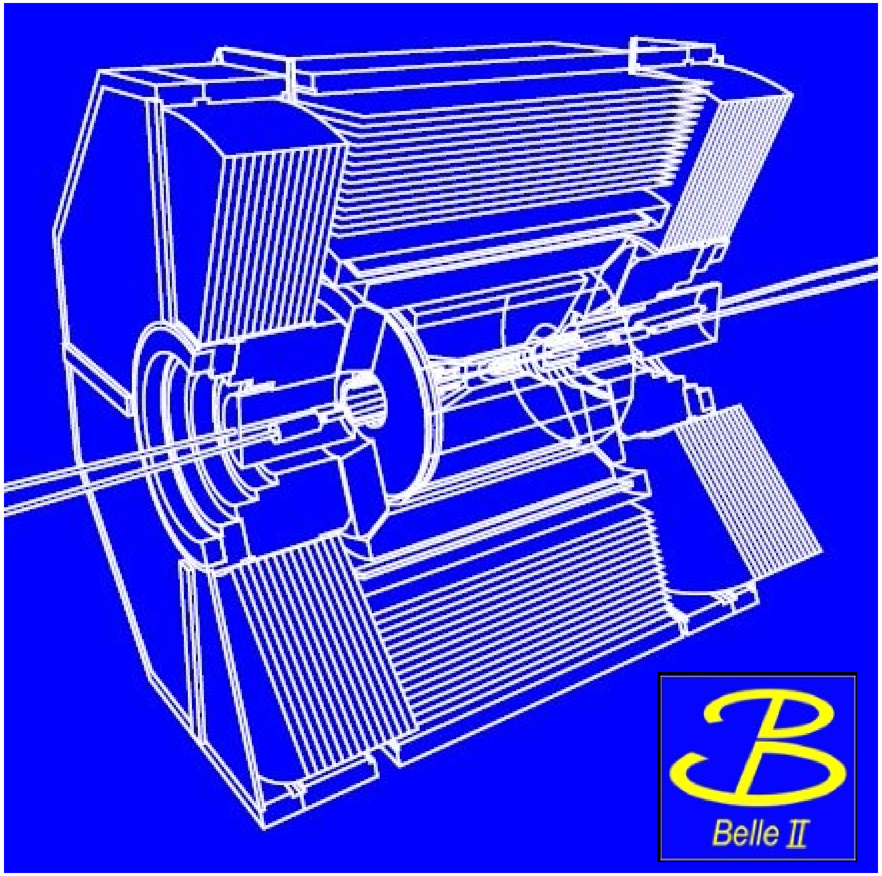
Quick overview of physics at Belle II



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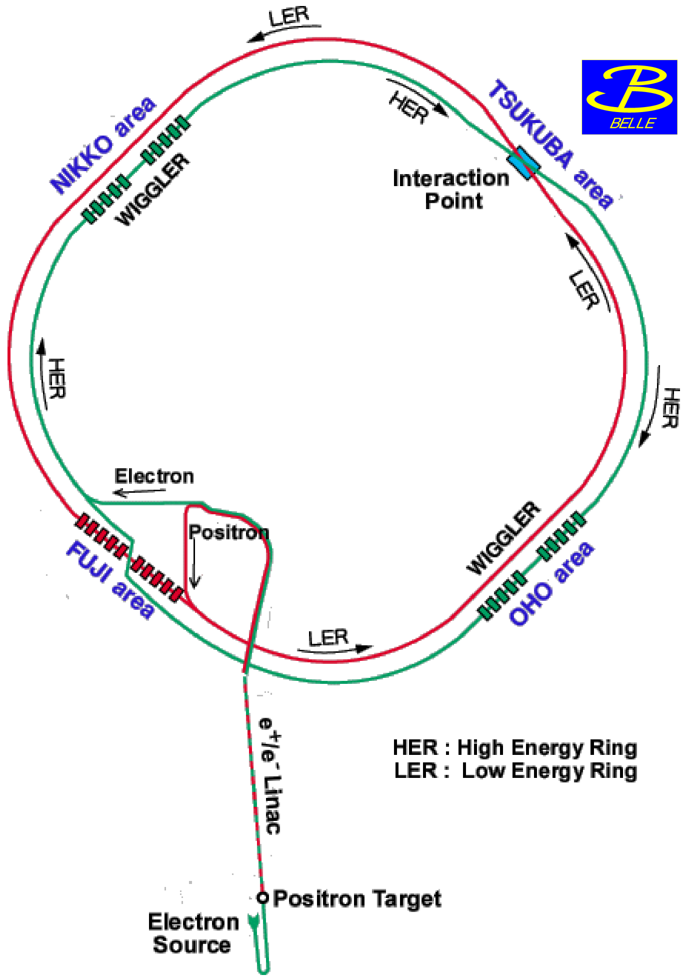
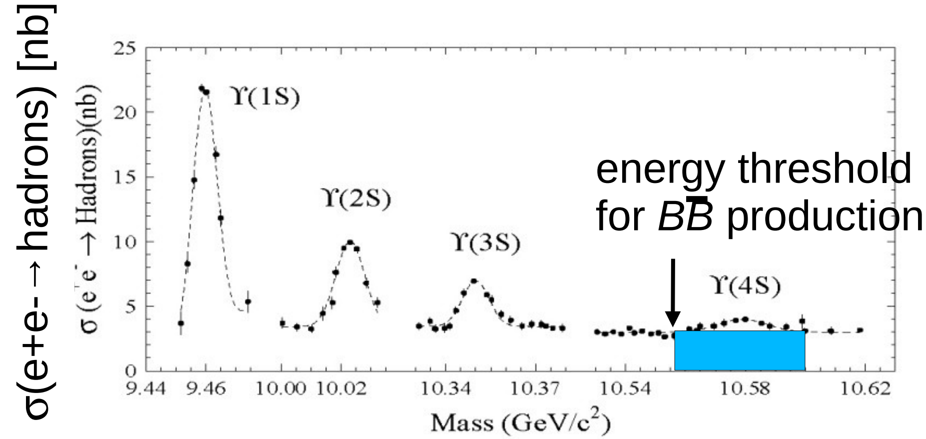
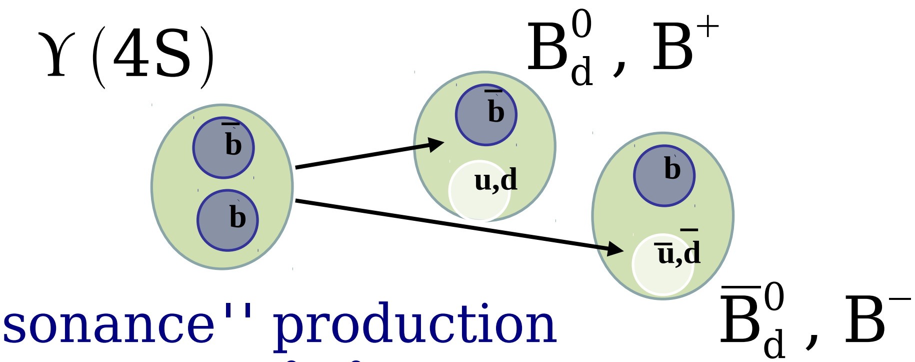
Belle = B-factory







"on resonance" production

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

- 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 $\bar{B}$

"continuum" production

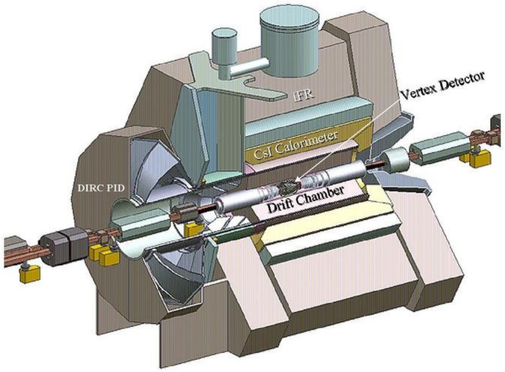
$$\sigma(e^+e^- \to c\bar{c}) \simeq 1.3 \text{ nb } (\sim 1.3\times10^9\ X_c\bar{Y}_c \text{ pairs})$$

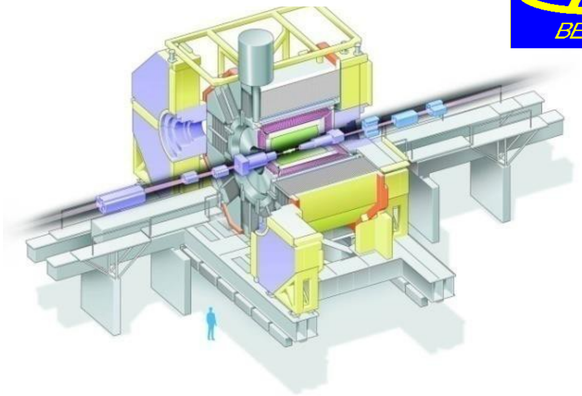
$\tau\tau$ production also !

Belle II

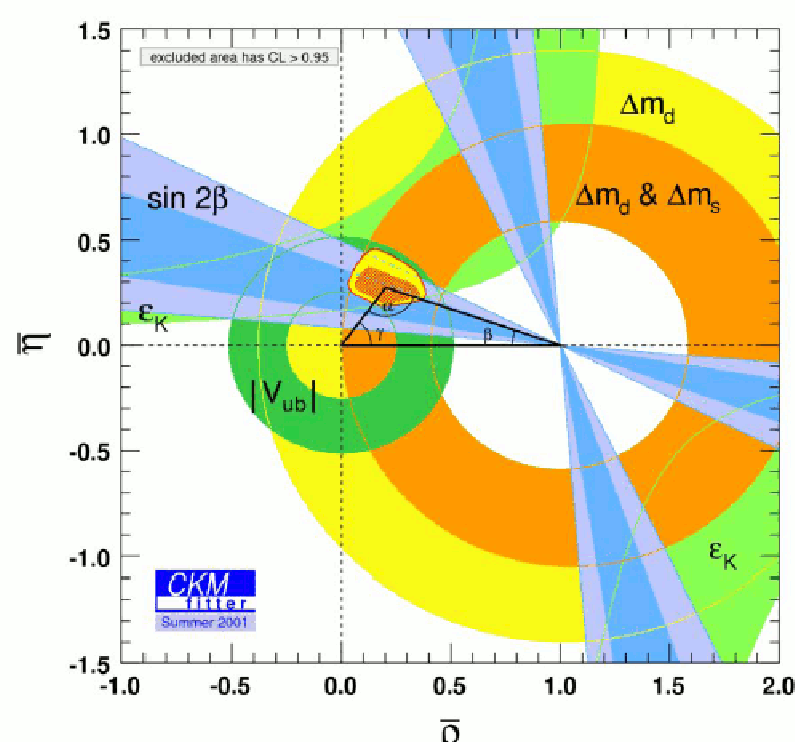
is an intensity frontier experiment built at Super-KEKB in Tsukuba, Japan

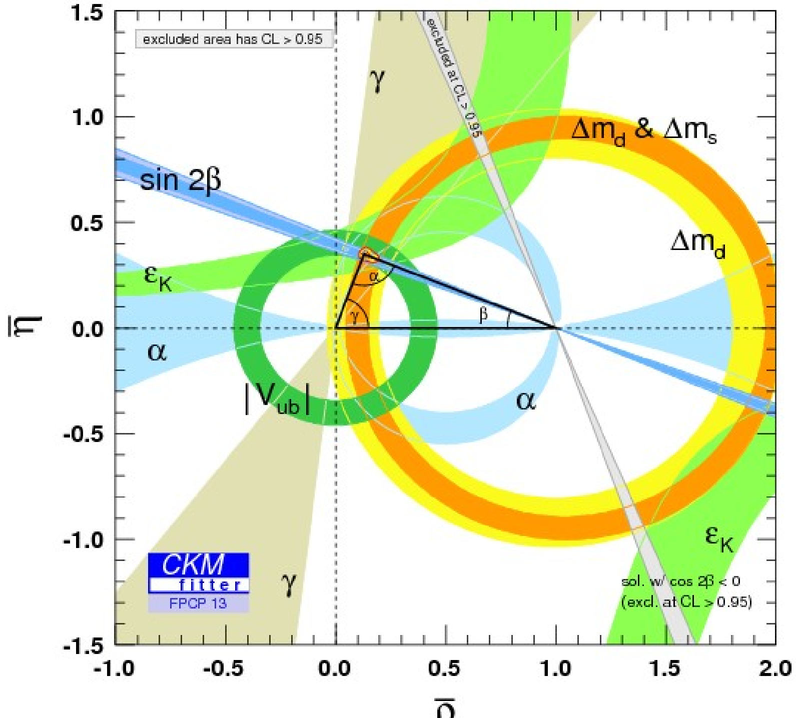
successor of extremely successfull B factories (BaBar and Belle)





from EPS 2001...

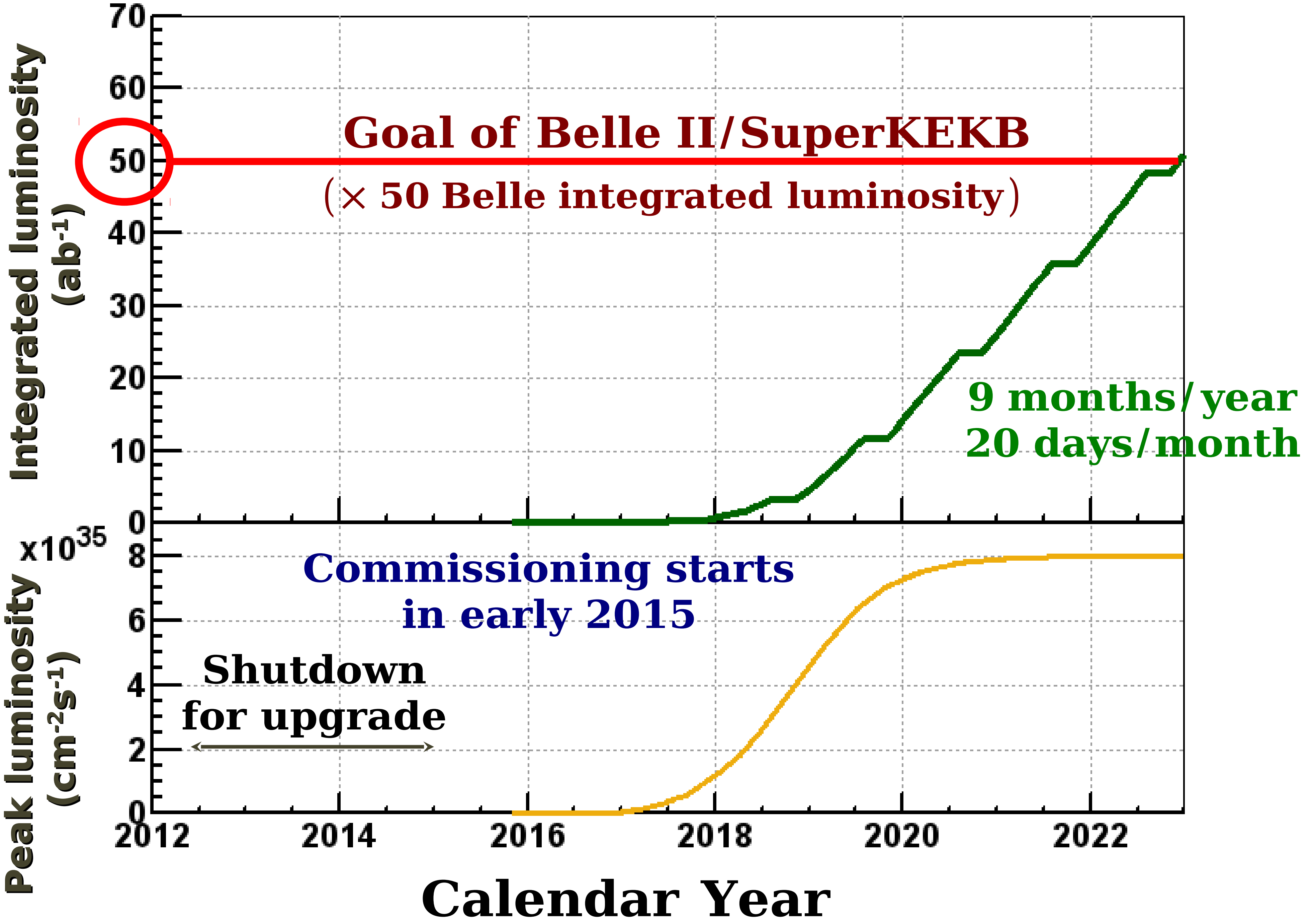




...to FPCP 2013

with current accuray deviations from SM still possible at o(10%)

SuperKEKB luminosity projection



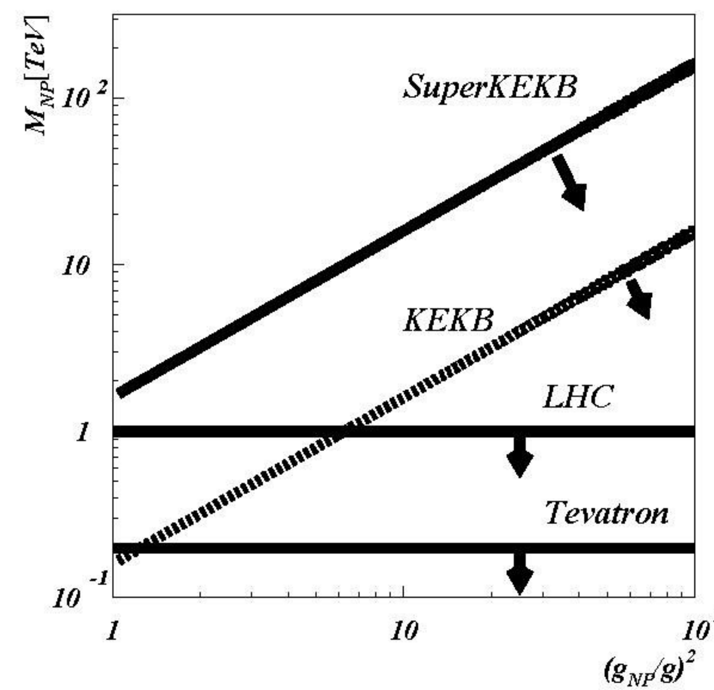
Quest for NP... continues

Intensity frontier front: $o(10^2)$ higher luminosity

B Factories → Super B Factory

- complementarity to other intensity frontiers experiments (LHCb, BES III...)
- accurate theoretical predictions to compare to
  - theory uncertainty matches the expected exp. precision
  - theory uncertainty will match the expected exp. precision with expected progress in LQCD

Illustrative reach of NP searches



NP flavour violating coupling (~ 1 in MFV) accurate theoretical predictions to compare to

theory uncertainty matches the expected exp. precision

theory uncertainty will match the expected exp. precision with expected progress in LQCD

(here LHCb means LHCb upgrade)

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\lvert V_{us}\rvert$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\lvert V_{cb}\rvert$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\lvert V_{ub}\rvert$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K_S^0]$	***	$8 \cdot 10^{-3}$	Belle II/LHCb (*)
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	Belle II / LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K_S^0\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A_{SL}^d	***	0.001	LHCb
A_{SL}^s	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $A_{FB}(B \to K^*\mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\lvert q/p\rvert_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

(*) flavor tagging

(adopted from G.Isidori et al, Ann. Rev. Nucl. Part. Sci. 60, 355 (2010))

Methods and processes where BF can provide important insight into NP complementary to other experiments:

E_{miss}:

$\mathcal{B}(B \to \tau\nu)$, $\mathcal{B}(B \to D^{(*)}\tau\nu)$, $\mathcal{B}(K^{(*)}\nu\bar{\nu})$, ...

Inclusive:

$\mathcal{B}(B \to s\gamma)$, $A_{CP}(B \to s\gamma)$, $\mathcal{B}(B \to s\,l\,l)$, ...

Neutrals:

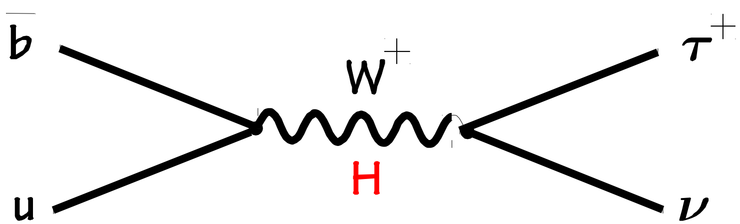
$S(B \to K_S\pi^0\gamma)$, $S(B \to \eta' K_S)$, $S(B \to K_S K_S K_S)$, $\mathcal{B}(\tau \to \mu\gamma)$, $\mathcal{B}(B_s \to \gamma\gamma)$, ...

Detailed description of physics program at SBF in

Physics at Super B Factory
A.G. Akeroyd et al, arXiv:1002.5012

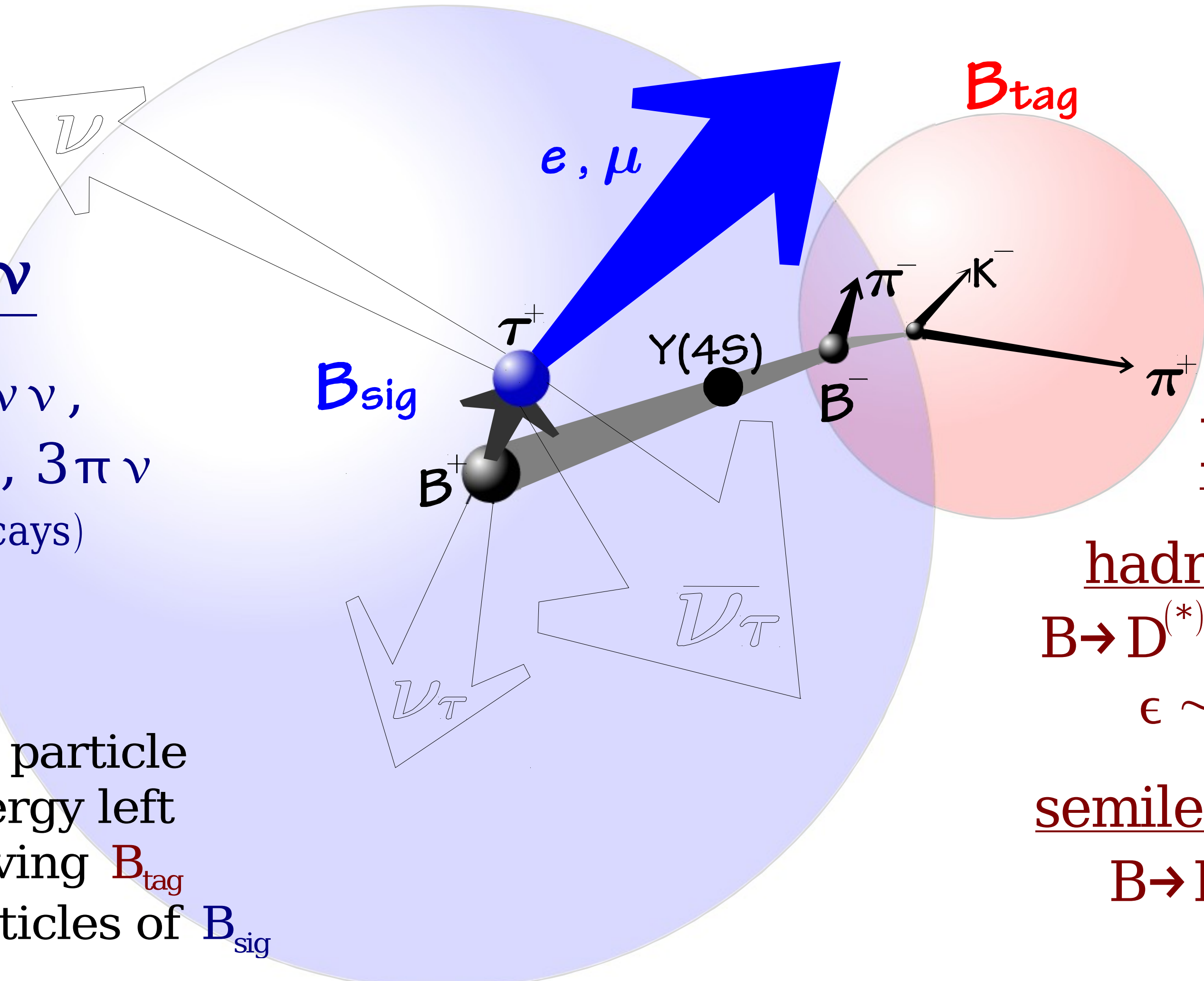
SuperB Progress Reports, Physics
B. O'Leary et al, arXiv:1008.1511

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



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

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



$B_{sig} \to \tau\nu$

$\tau \to e\nu\nu$, $\mu\nu\nu$,
$\tau \to \pi\nu$, $\pi\pi^0\nu$, $3\pi\nu$
(70 % of all τ decays)

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

B_{tag}

hadronic tag
$B \to D^{(*)}\pi$, $D^{(*)}\rho$ ....
$\epsilon \sim 0.3\,\%$

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

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

fully (partially) reconstruct B_{tag}

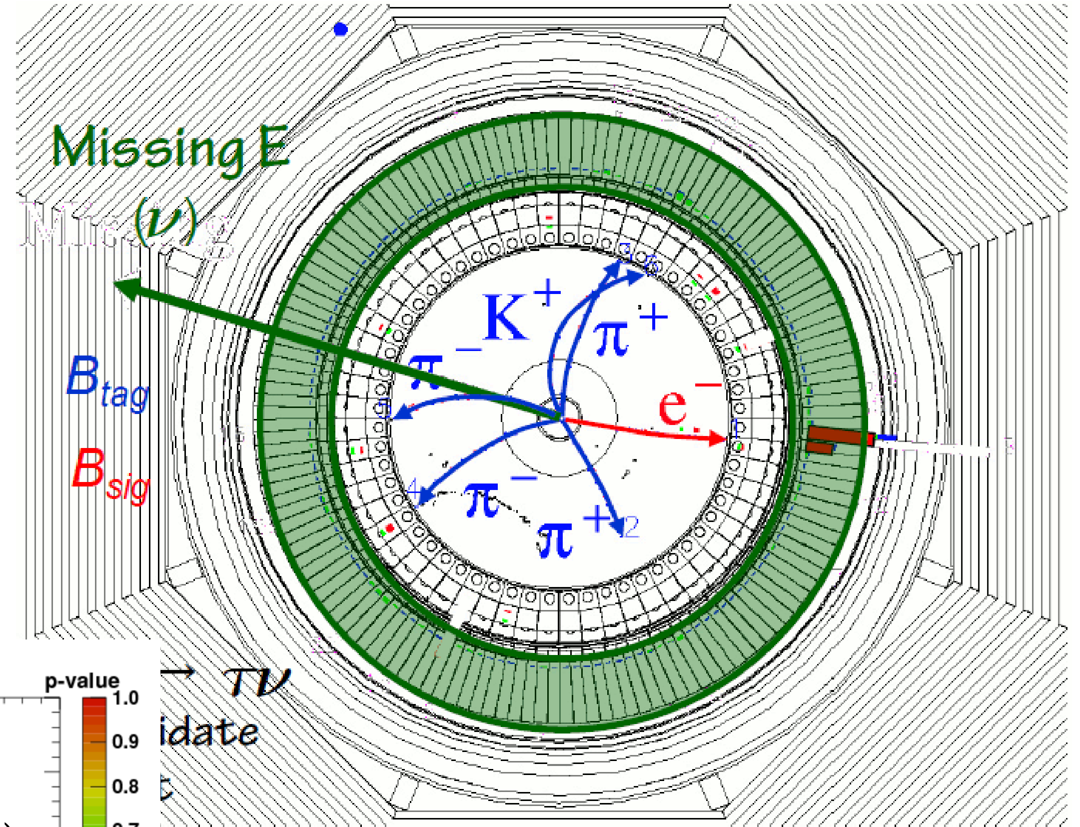
B_{tag} full reconstruction: hadronic tag

reconstruct h from $B_{sig} \to \tau\nu$ or

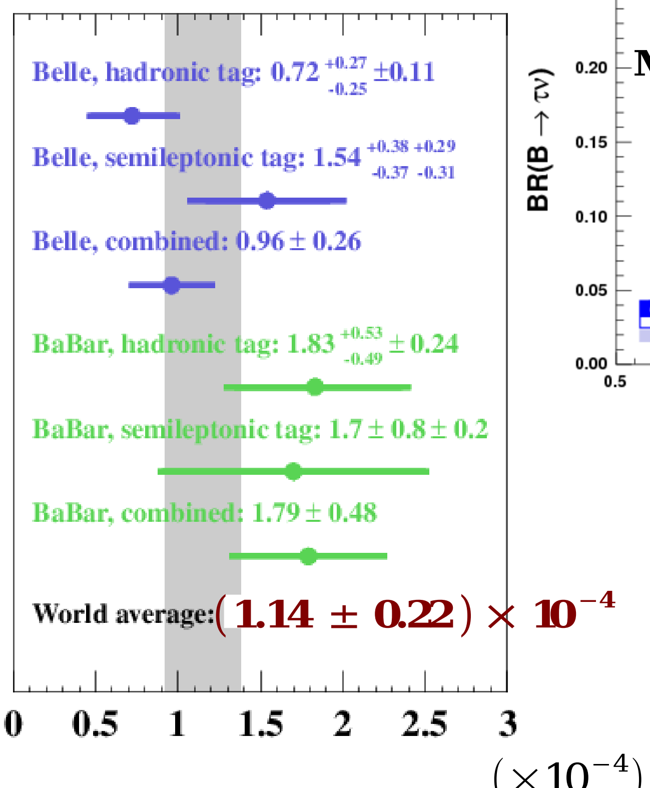
$B_{sig} \to h\nu\bar{\nu}$

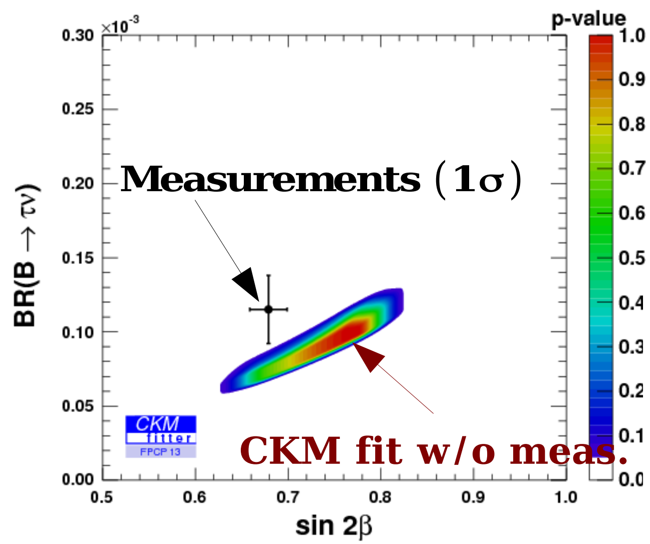
no additional energy in EM calorim.

signal at $E_{ECL} \sim 0$

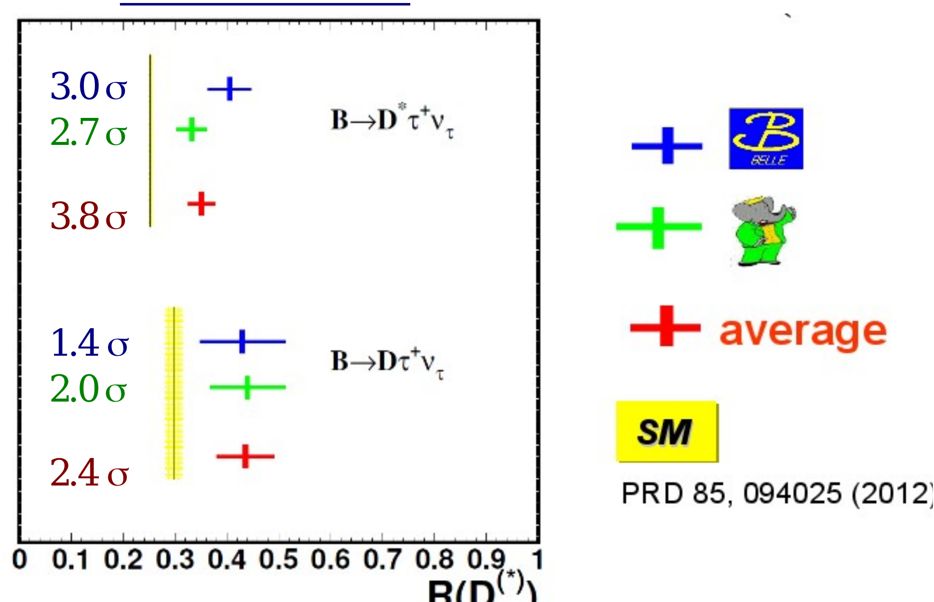


$B \to \tau\nu$



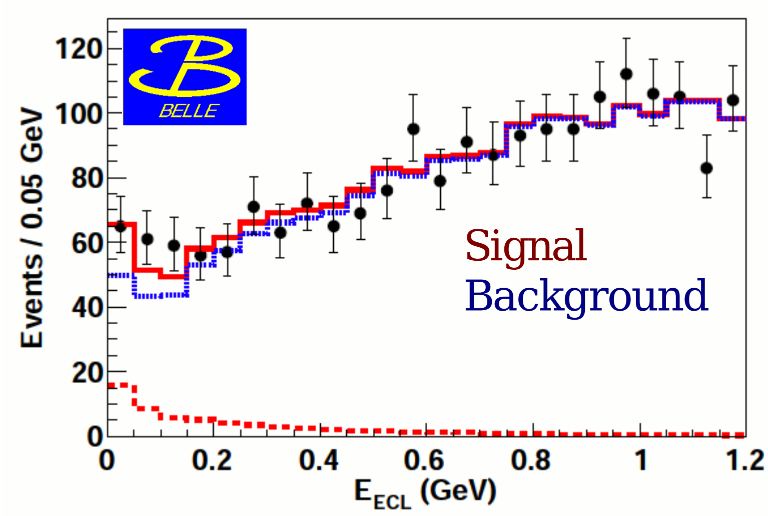


$B \to D^{(*)}\tau\nu$



PRD 85, 094025 (2012)

Missing energy modes...



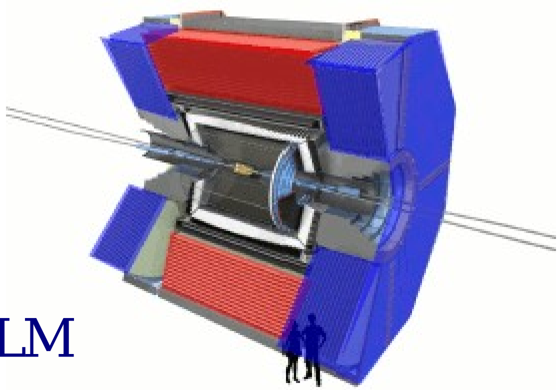
peaking background from K_L :

better K_L efficiency in KLM

better background rejection in ECL/KLM

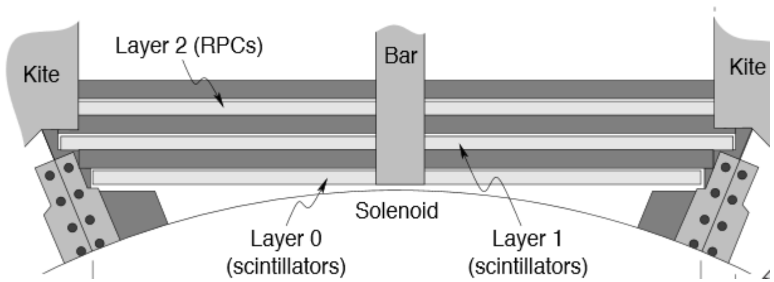
ECL: new electronics, better suppression of bckg

KLM



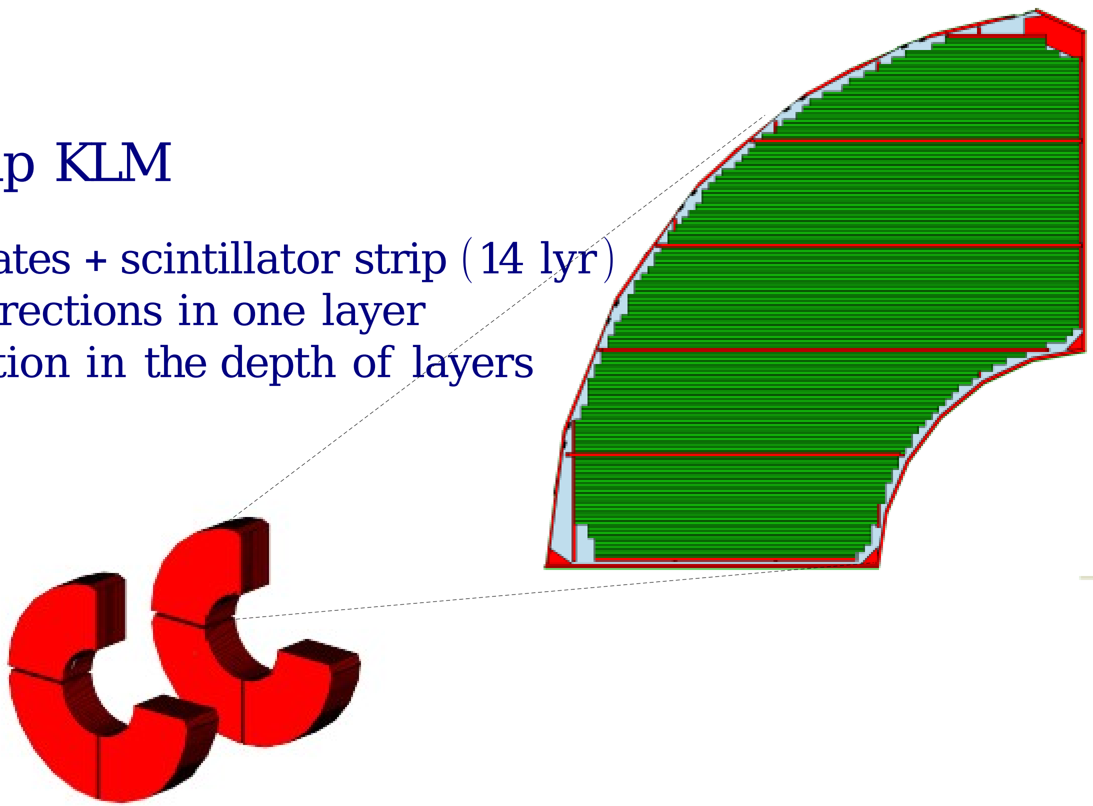
Barrel KLM

Iron plates (14 lyr)
inner 2 layers: scintillators
other layers (13 lyr): RPC (same as Belle)



Endcap KLM

Iron plates + scintillator strip (14 lyr)
X−Y directions in one layer
Z direction in the depth of layers



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

time-dependent CPV

time-dependent decays rate of $B \to f_{CP}$

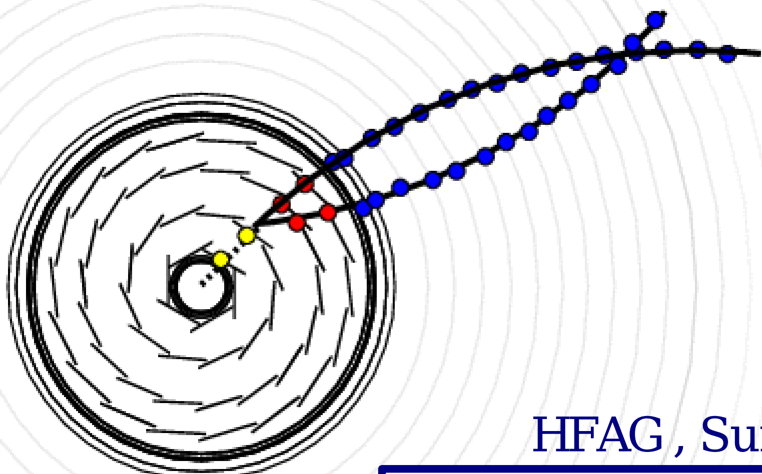
S and A: CP violating parameters

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

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

$$\text{Left-Right Symmetric Models: } S_{CP}^{K^*\gamma} \sim 0.5$$

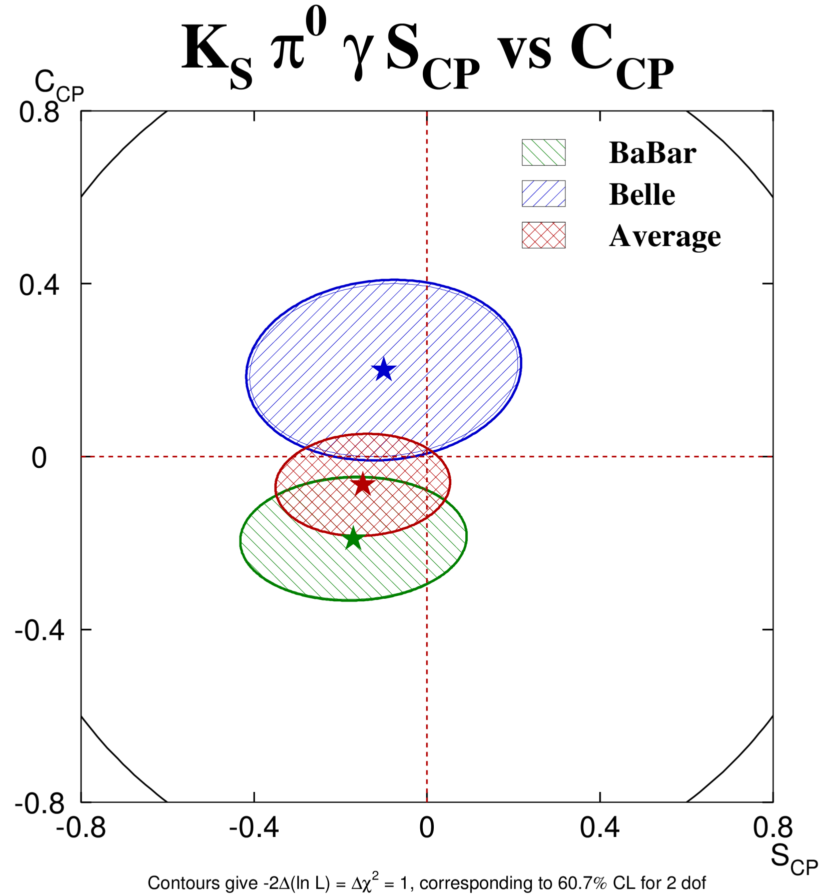
[D. Atwood et al, PRL 79, 185 (1997)]



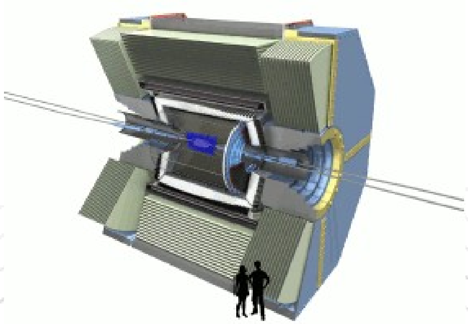
HFAG, Summer 2013

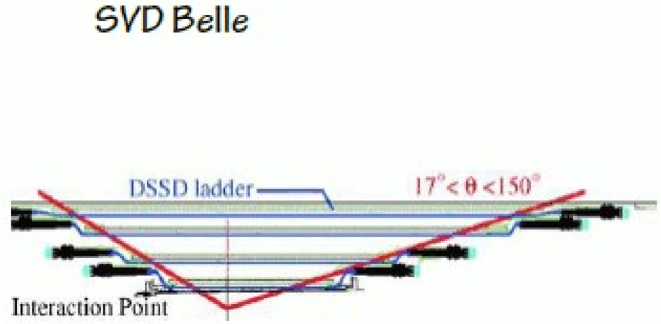
$$S_{CP}^{K_S\pi^0\gamma} = -0.15 \pm 0.20$$
$$A_{CP}^{K_S\pi^0\gamma} = -0.07 \pm 0.12$$

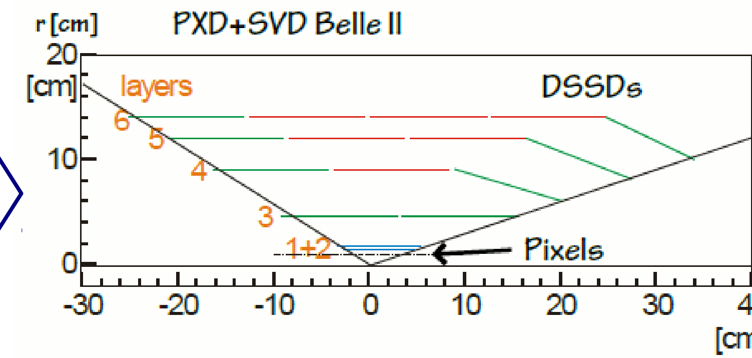
$$\sigma(S_{CP}^{K_S\pi^0\gamma}) = 0.09 \text{ @ } 5\,ab^{-1}$$
$$= 0.03 \text{ @ } 50\,ab^{-1}$$



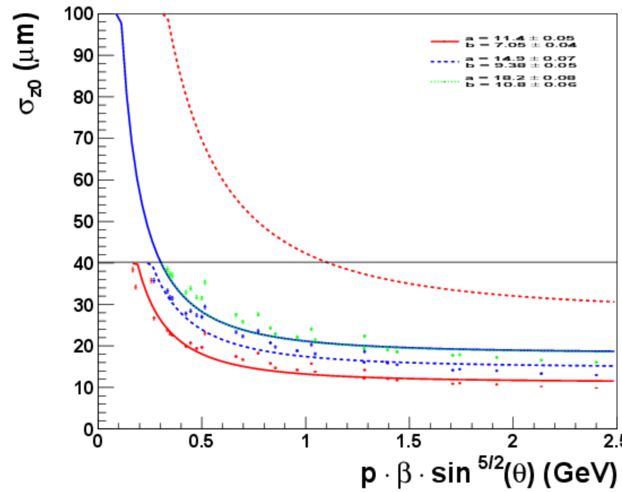
PXD / SVD

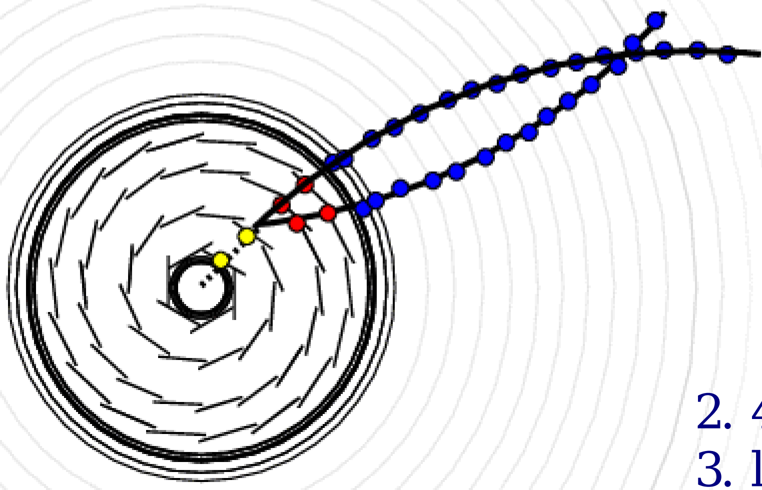




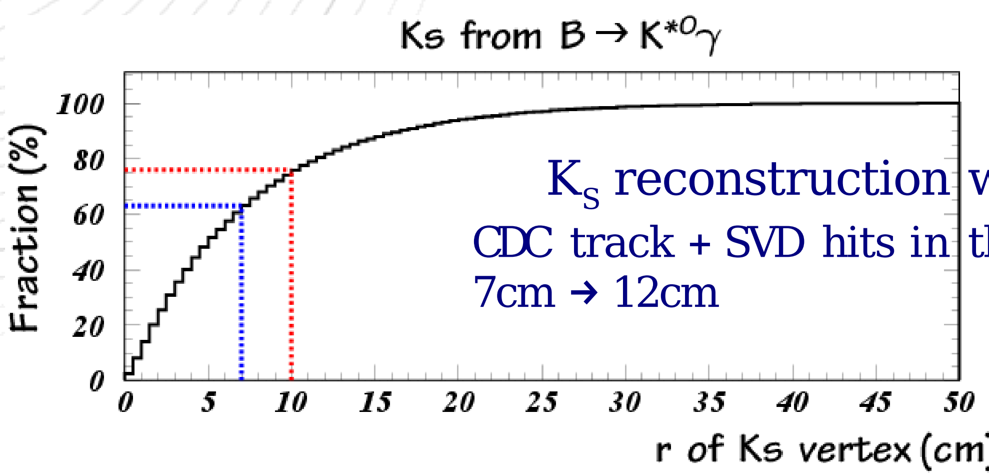


1. smaller radius beam pipe (1.5 cm → 1.0 cm)





2. 4 DSSD layers → 2 pixel layers + 4 DSSD layers
3. larger radius outermost layer (8.8 cm → 14 cm)

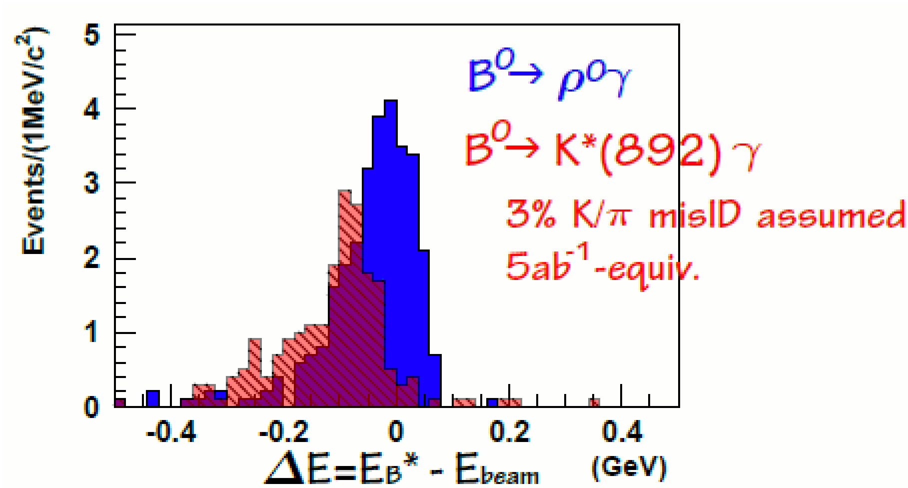


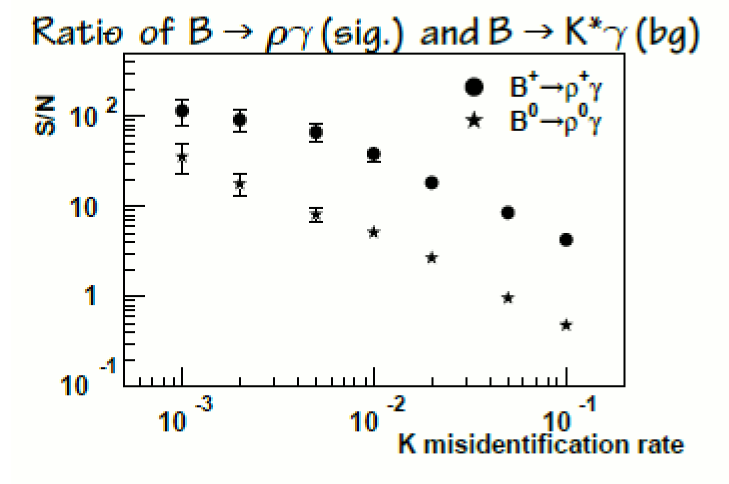
K_S reconstruction with PXD/SVD: $K^{*0}\gamma$ TCPV

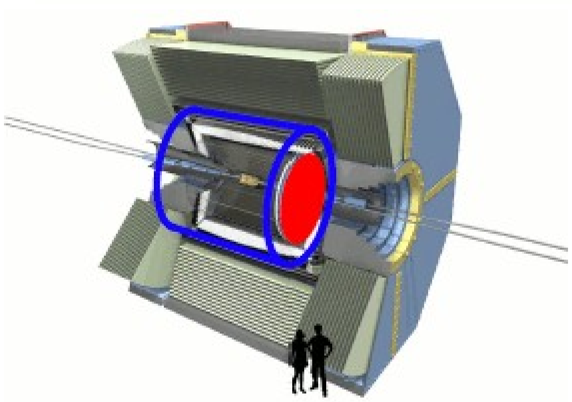
CDC track + SVD hits in the 1st and 2nd outermost layers

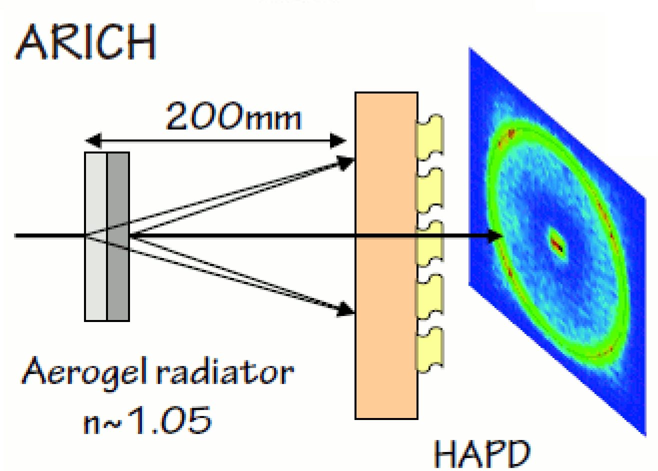
7cm → 12cm

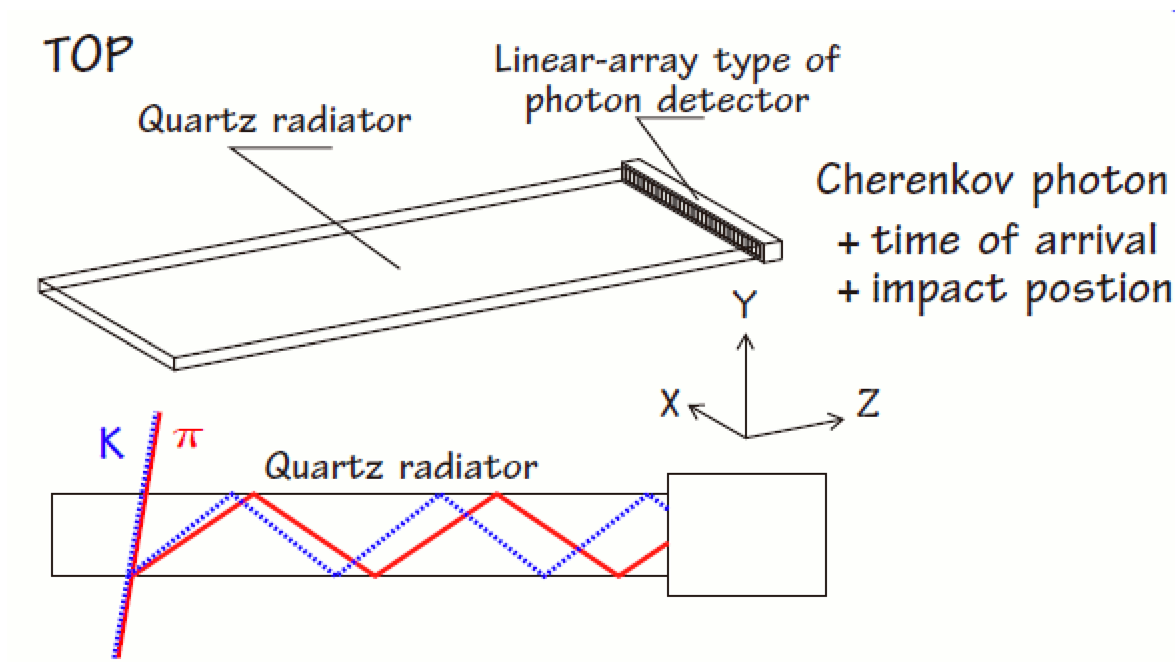
Inclusive : B→s(+d)γ, direct CPV









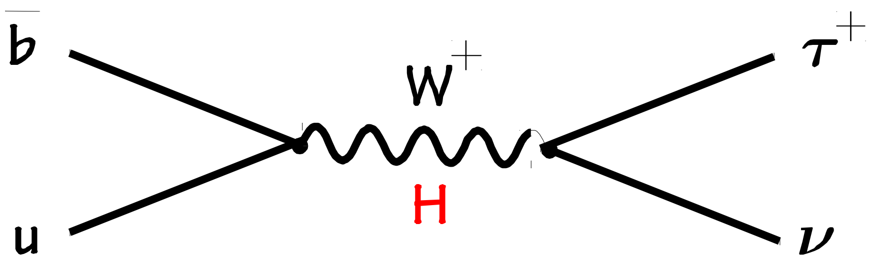


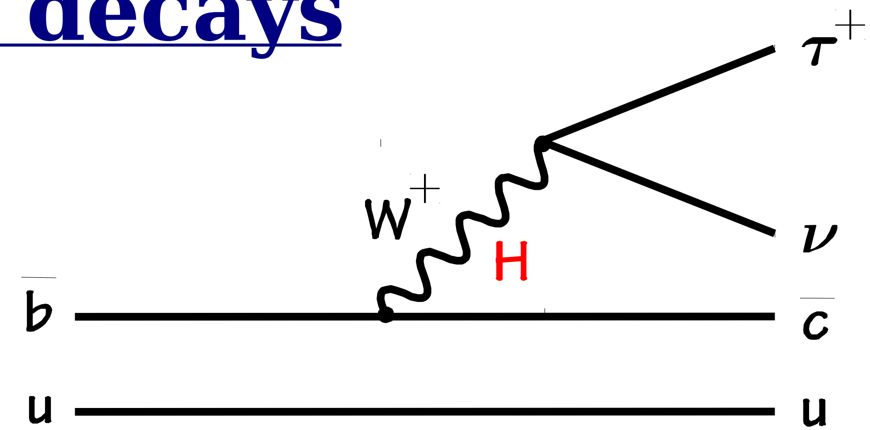
Conclusion

- Belle II: successor to B factories with $o(10^2)$ larger data sample
- search for NP at intensity frontier, complementary to energy frontier and other precision experiments
- physics benchmarks, methods, ... known from B factories, improve them (syst limited) for huge statistics
- Belle II and SuperKEKB well on track, physics runs scheduled for the end of 2016

Backup slides

Tauonic B decays





$B \to \tau \nu$

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

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

uncertainties from f_B and $|V_{ub}|$ can be reduced to B_B and other CKM uncertainties by combining with precise Δm_d

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

$$\text{2HDM (type II)}: \mathcal{B}(B \to D \tau^+ \nu) = G_F^2 \tau_B |V_{cb}|^2 f\left(F_V, F_S, \frac{m_B^2}{m_{H^+}^2}\tan^2\beta\right)$$

uncertainties from form factors F_V and F_S can be studied with $B \to D l \nu$ (more form factors in $B \to D^* \tau \nu$)

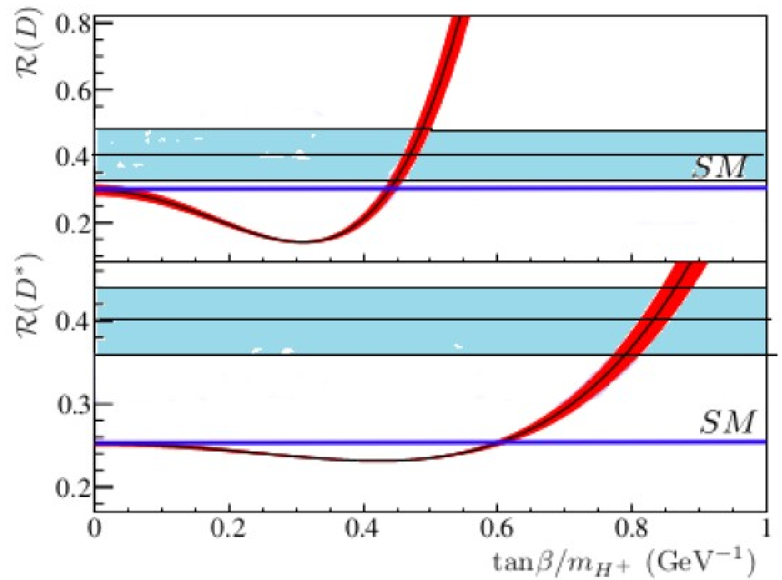
Results on $B \to D^{(*)} \tau \nu$

- Also sensitive to charged Higgs:
  - uncertainties related to $|V_{cb}|$ and hadronic effects cancel in ratios:

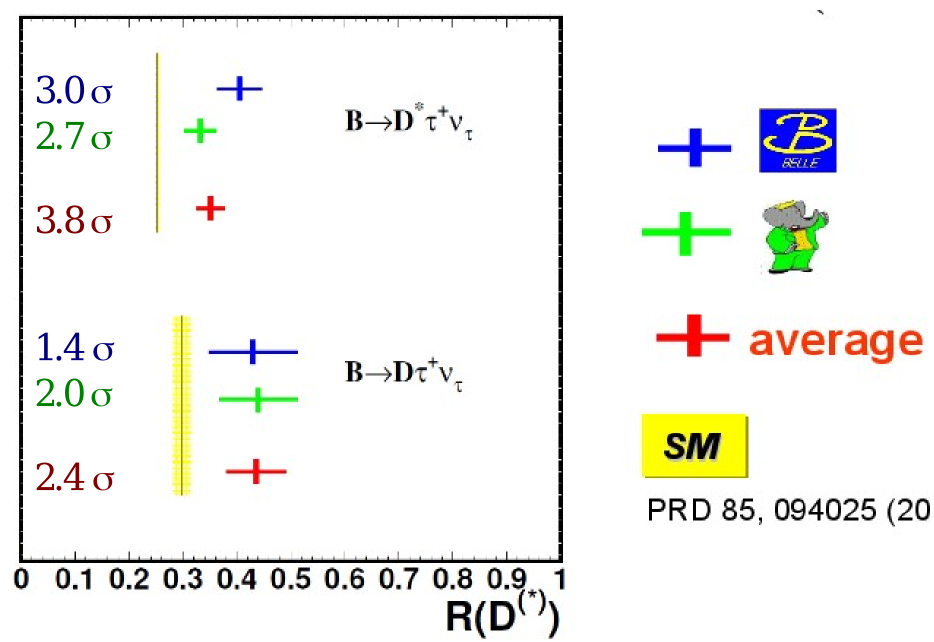
$$\mathcal{R}(D) = \frac{\mathcal{B}(\bar{B} \to D\tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D\ell^- \bar{\nu}_\ell)} \qquad \mathcal{R}(D^*) = \frac{\mathcal{B}(\bar{B} \to D^*\tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^*\ell^- \bar{\nu}_\ell)}$$

  - Standard Model expectations:

$$\mathcal{R}(D) \sim 0.3 \qquad \mathcal{R}(D^*) \sim 0.25$$



- Previous Belle measurements:
  - Inclusive tagging:
    * $B^0 \to D^{*-} \tau^+ \nu$ [PRL 99, 191807 (2007)]
    * $B^+ \to D^{(*)0} \tau^+ \nu$ [PRD 82, 072005 (2010)]
  - Exclusive tagging:
    * $B^0 \to D^{(*)-} \tau^+ \nu$
    * $B^+ \to D^{(*)0} \tau^+ \nu$ [arXiv:0910/4301]



PRD 85, 094025 (2012)

Combined for Belle/BaBar $R(D^{(*)})$: $4.8\,\sigma$

$\Rightarrow$ $R(D^{(*)})$ analysis for final Belle data set (had tag) underway

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

$\mathcal{B}(B \to K^{(*)} \nu \bar{\nu})$ can be measured
to $\pm 30\%$ with 50 ab^{-1}
limits on right-handed currents