Status of Belle II

FPCP
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University of Ljubljana/Jožef Stefan Institute
Belle/Belle II Collaboration

University of Ljubljana
"Jožef Stefan" Institute
Belle II

Introduction

E_{miss} measurements
(with comments on the upgrade)

Inclusive decays
(with comments on the upgrade)

Neutral final states
(with comments on the upgrade)

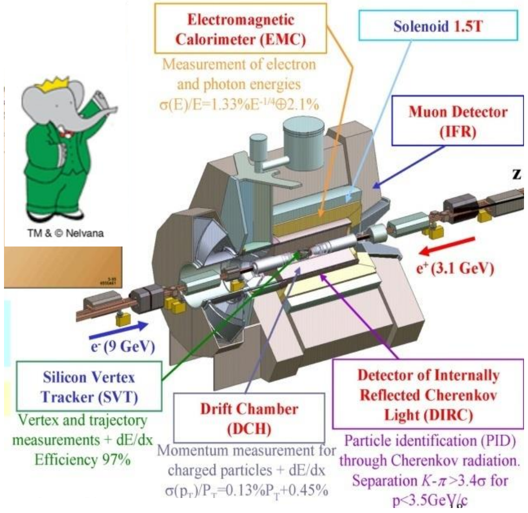
Summary

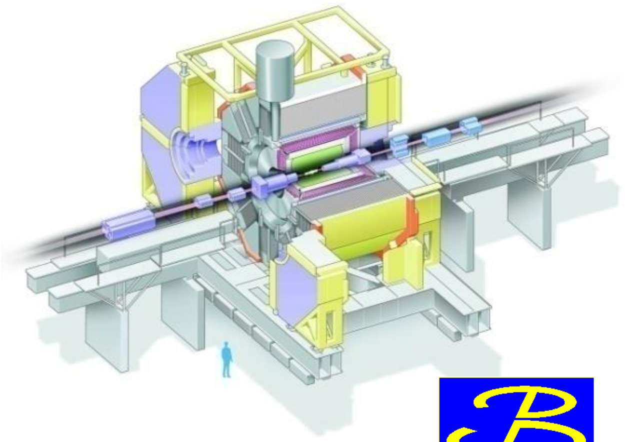
Introduction

Belle II

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

successor of extremely successfull B factories (Belle & BaBar)





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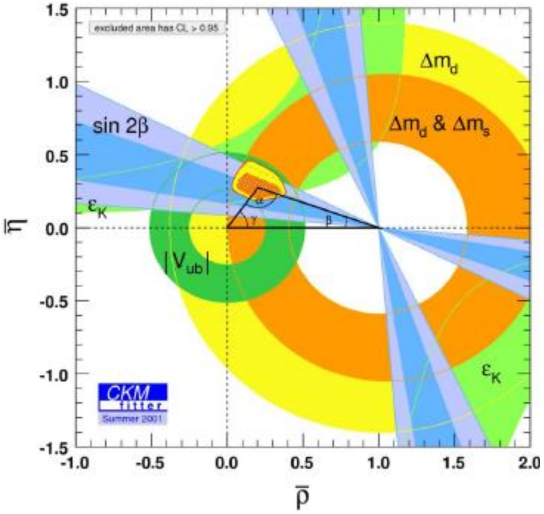
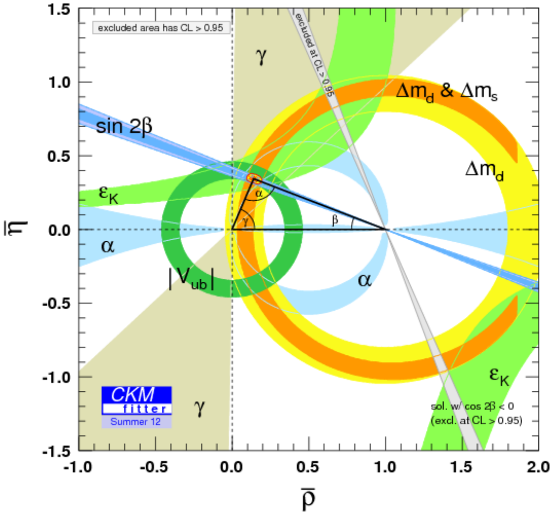
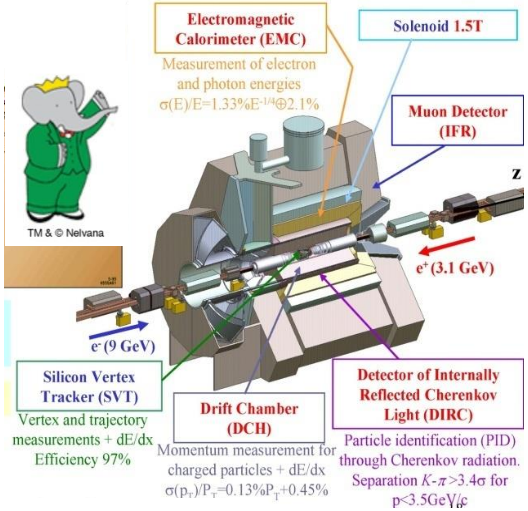
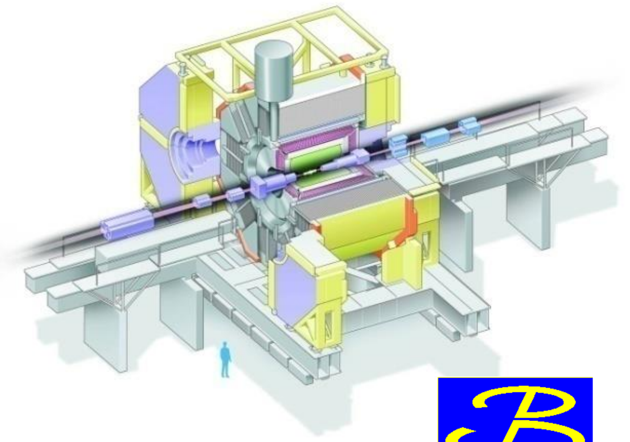
2001



2012







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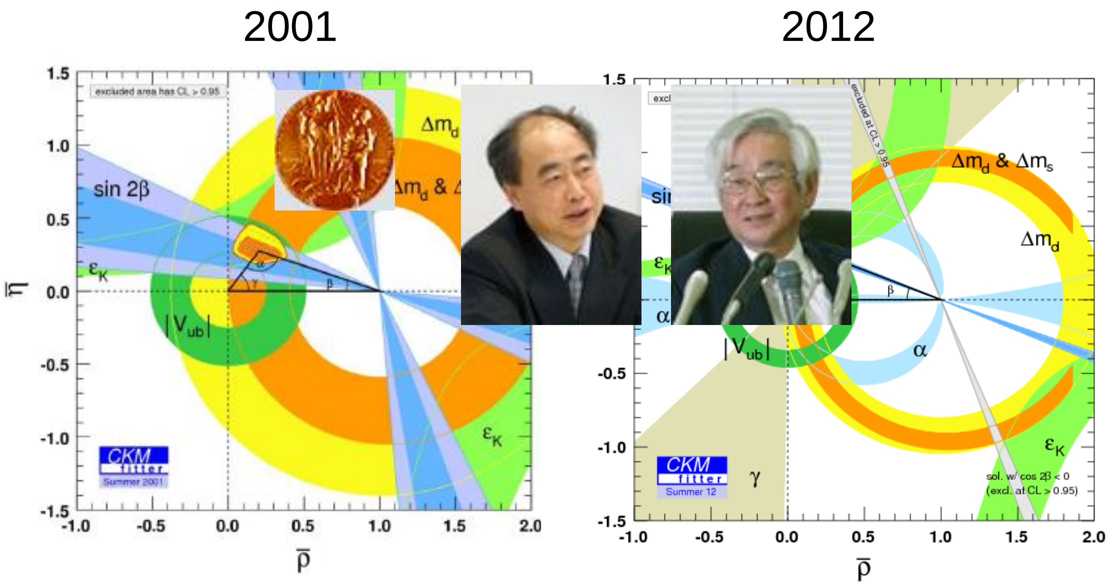

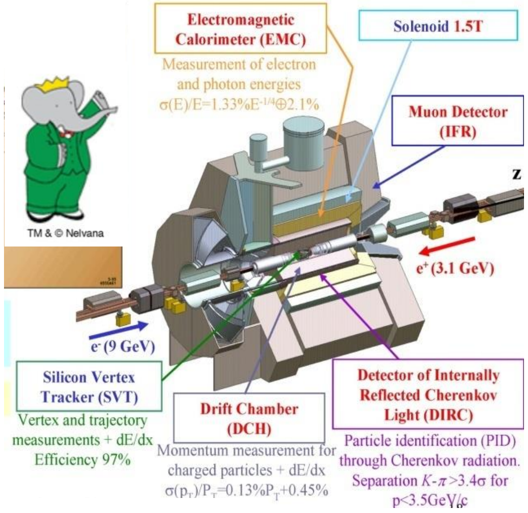

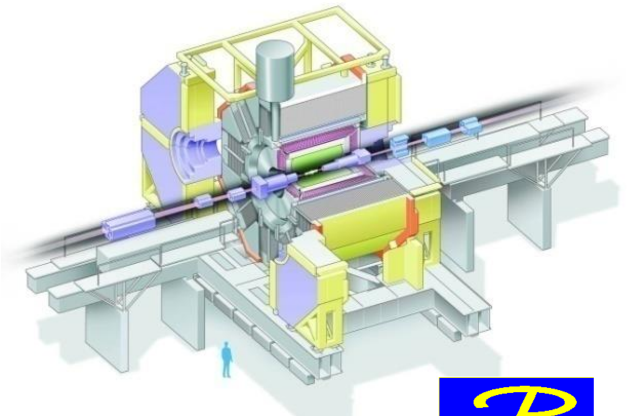

With current accuracy deviations from SM still possible at $\mathcal{O}(10\%)$

Quest for NP.....

...continues
Intensity frontier

B Factories (**BF**) → Super B Factory (**SBF**)

- $\sigma \propto 1/\sqrt{N} \Rightarrow \mathcal{O}(10^2)$ higher luminosity

- complementarity to other intensity frontiers experiments (LHCb, BES III, ...);

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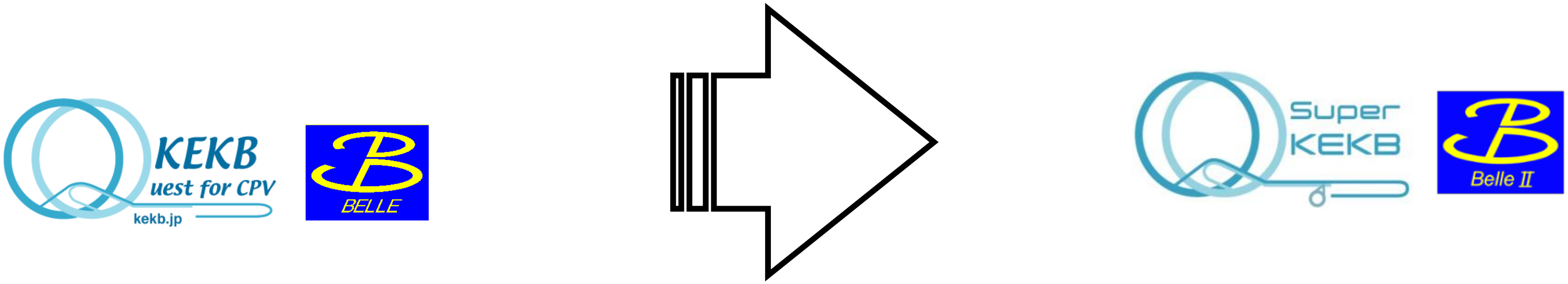

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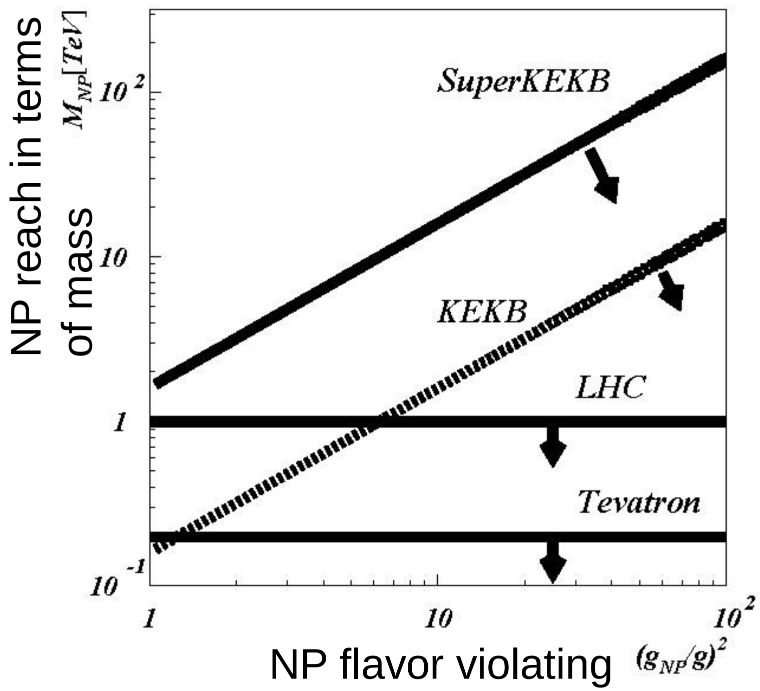

NP reach in terms of mass

NP flavor violating couplings(~1 in MFV)

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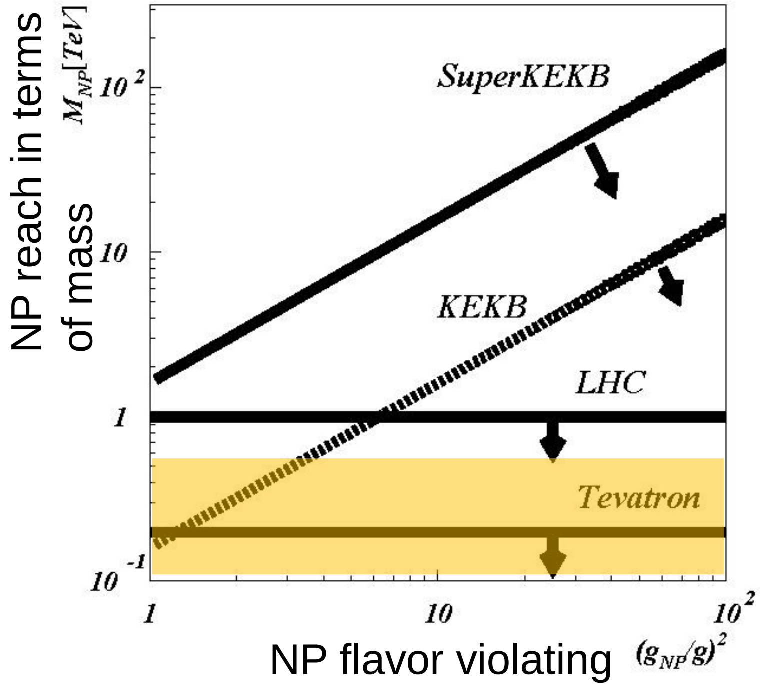

NP flavor violating couplings(~1 in MFV)

KEKB uest for CPV kekb.jp

BELLE

Super KEKB

Belle II

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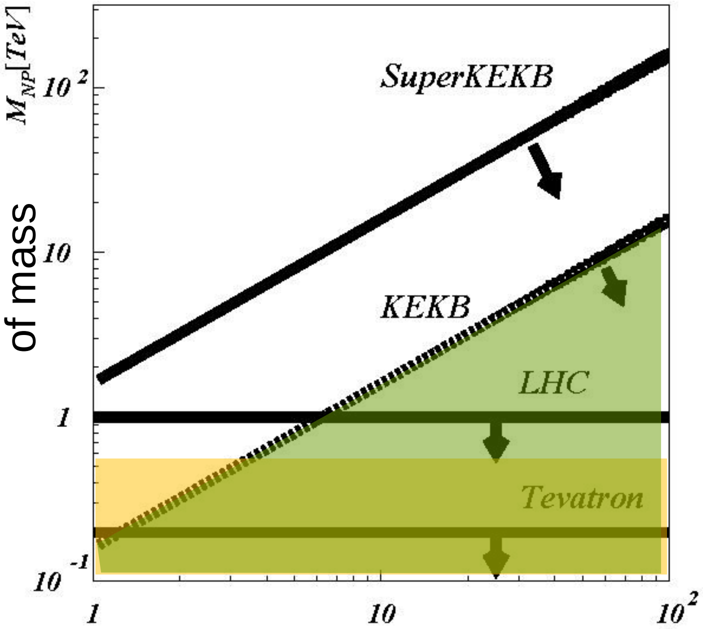

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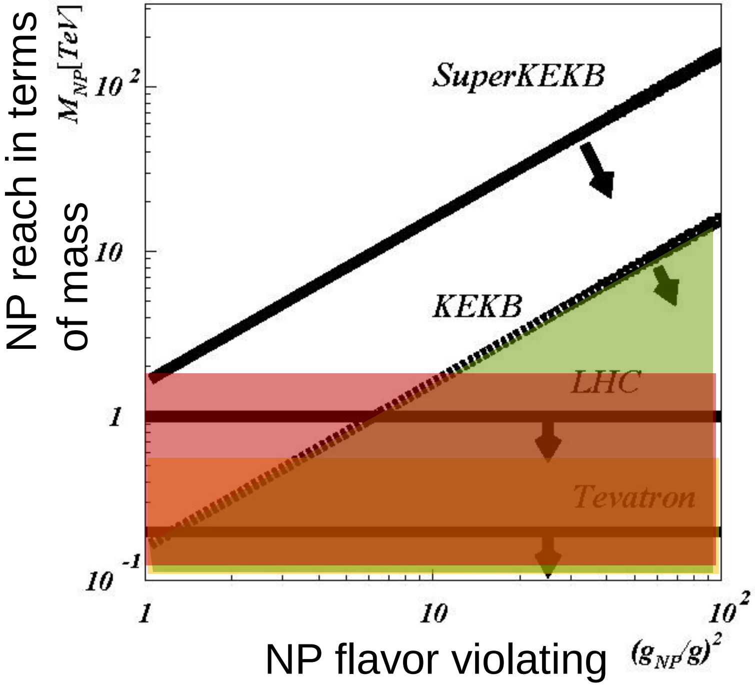

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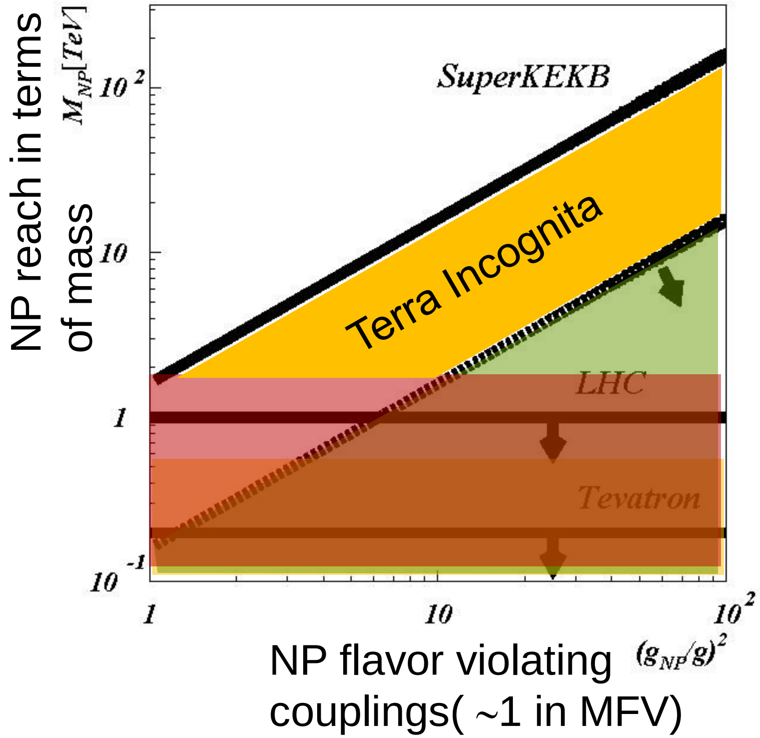

SuperKEKB

Nano beams design (P. Raimondi)

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{y\pm}}{\beta_{y\pm}^*}\frac{R_L}{R_{\xi_y}}$$

β^*: beta-function (trajectories envelope) at IP
ξ_y: beam-beam parameter

small β_y^*
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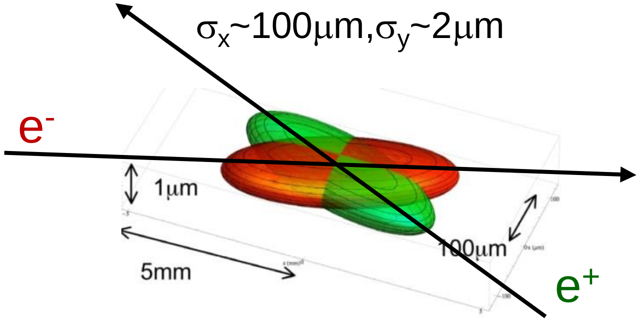

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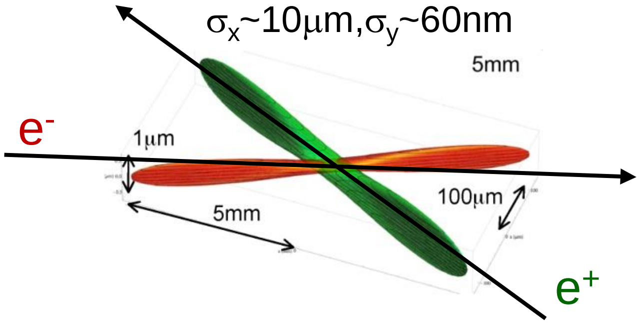

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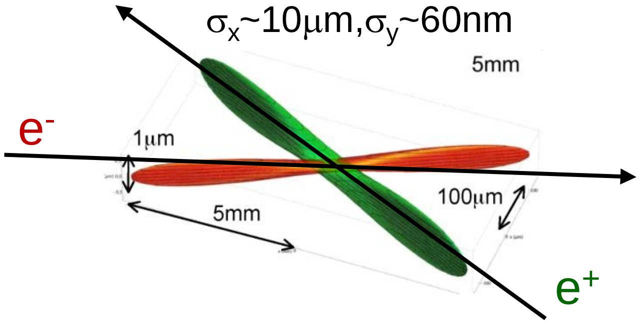

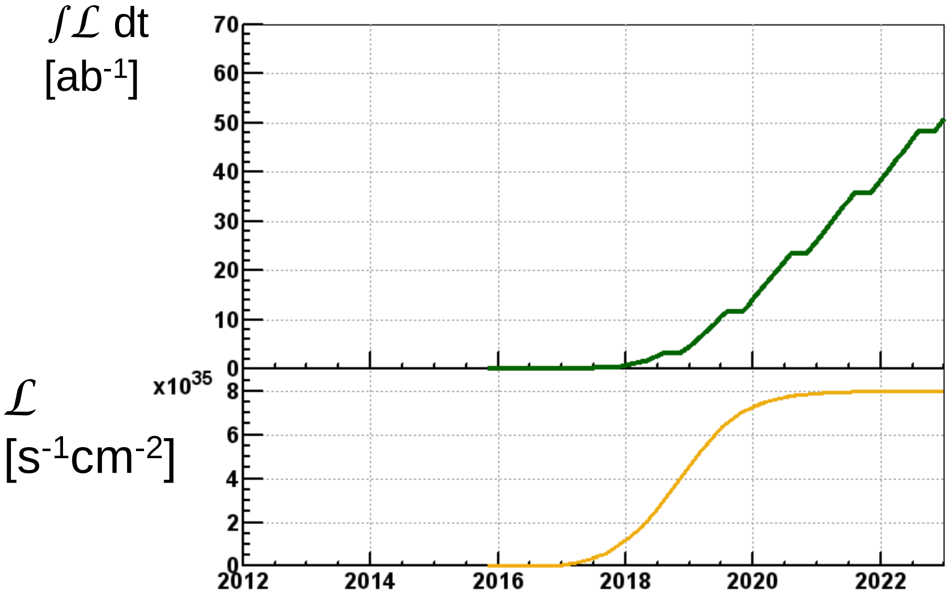

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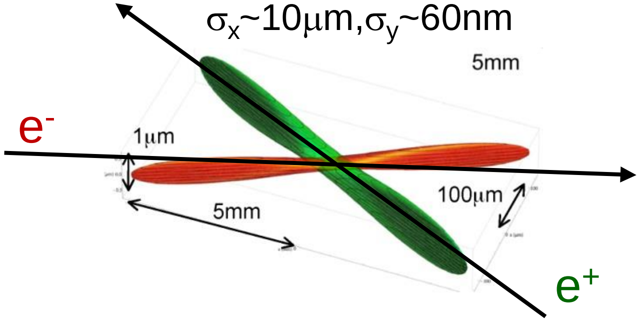

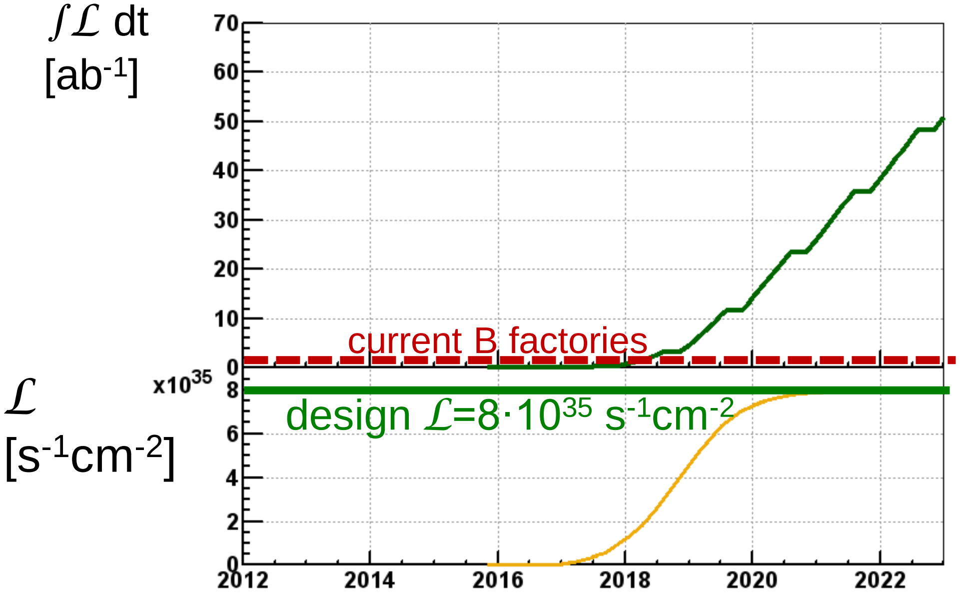

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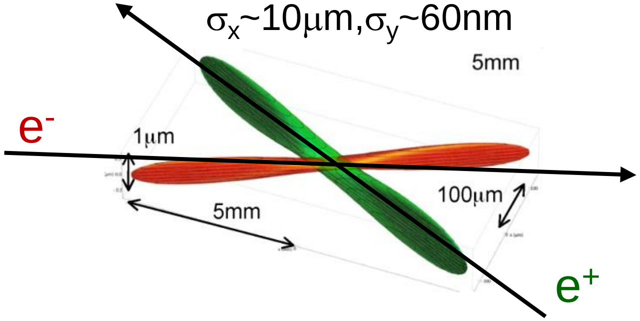

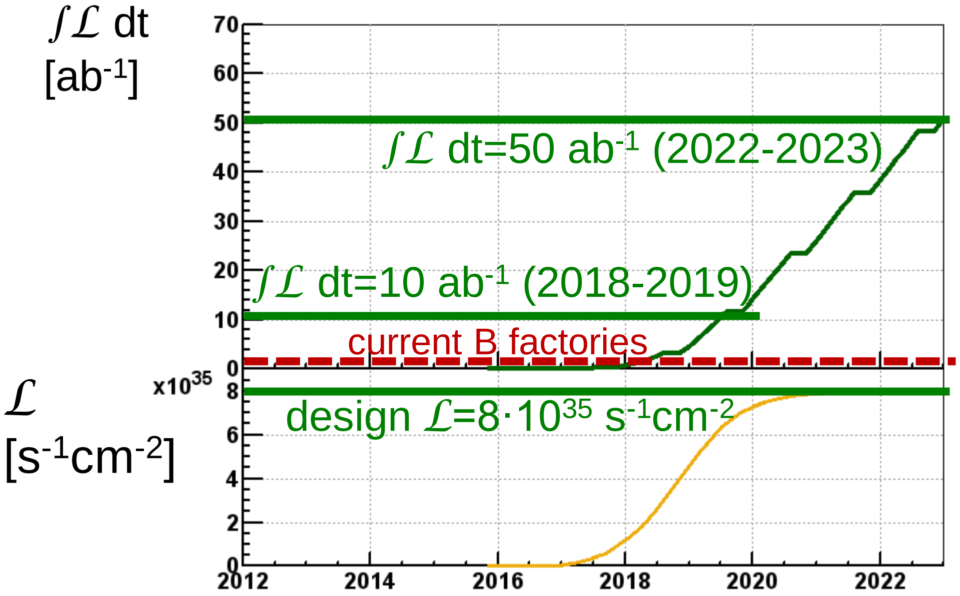

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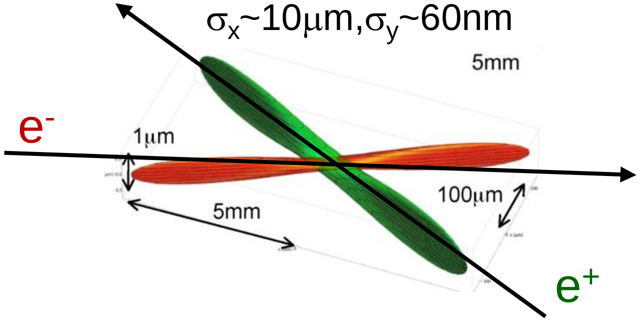
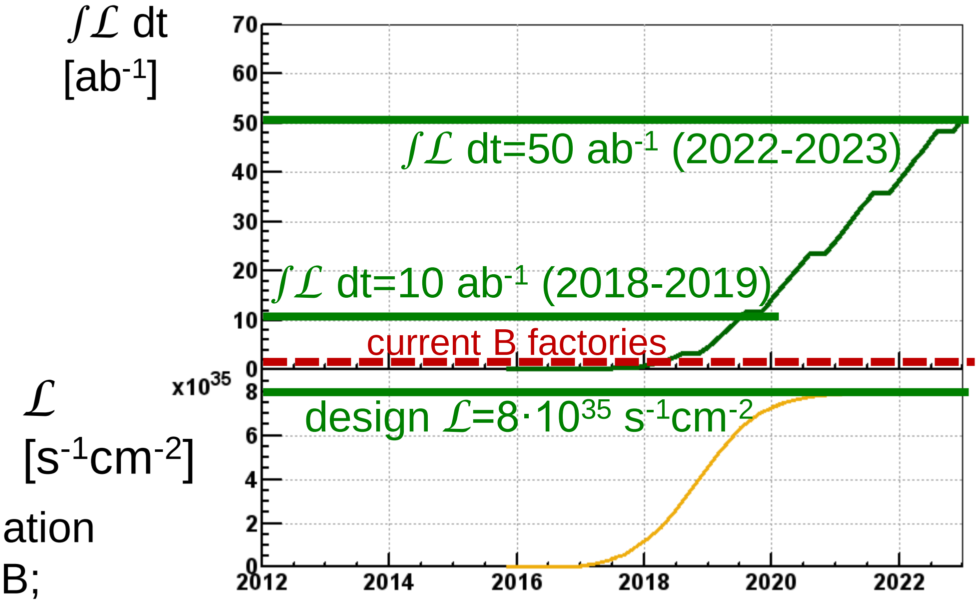


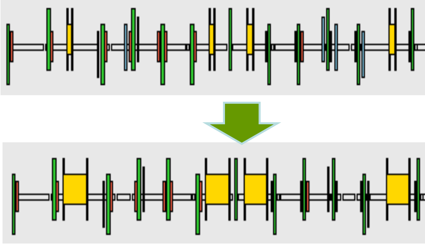


magnet installation for SuperKEKB;

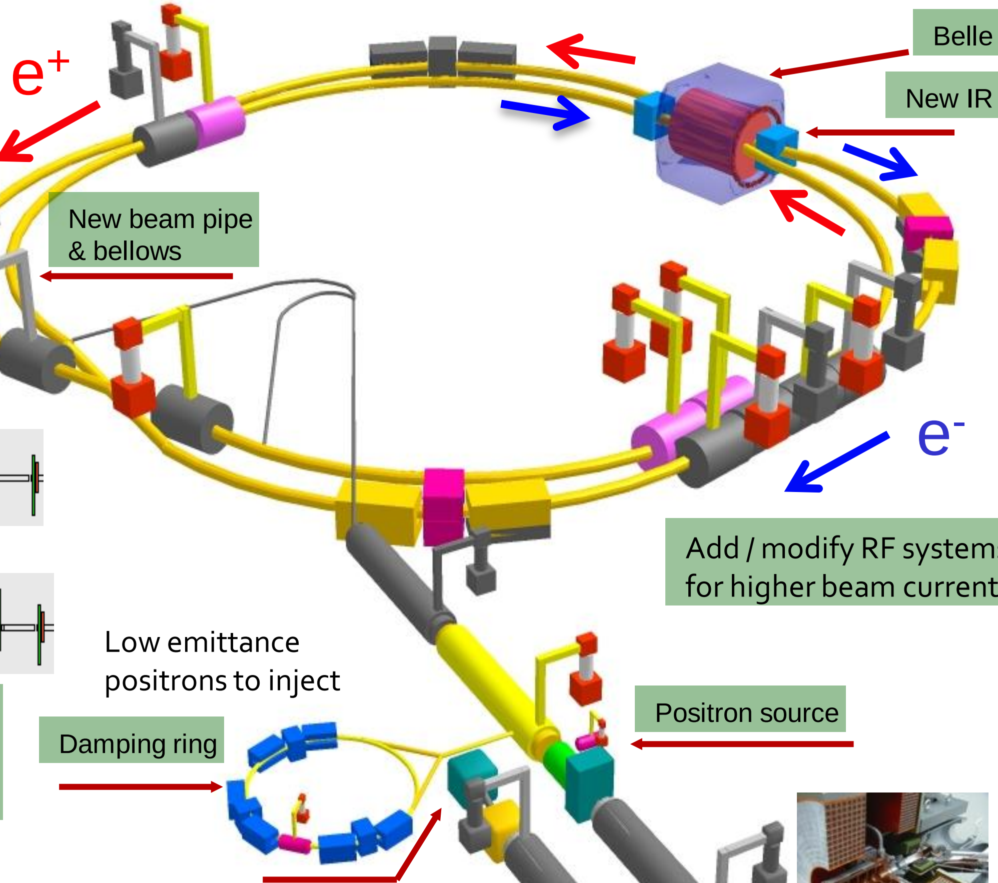
Being built on schedule

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

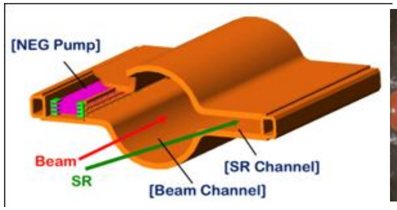
Low emittance electrons to inject

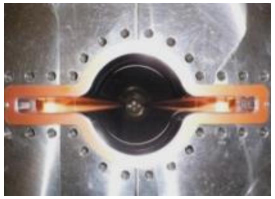
Positron source

New positron target / capture section

New superconducting /permanent final focusing quads near the IP

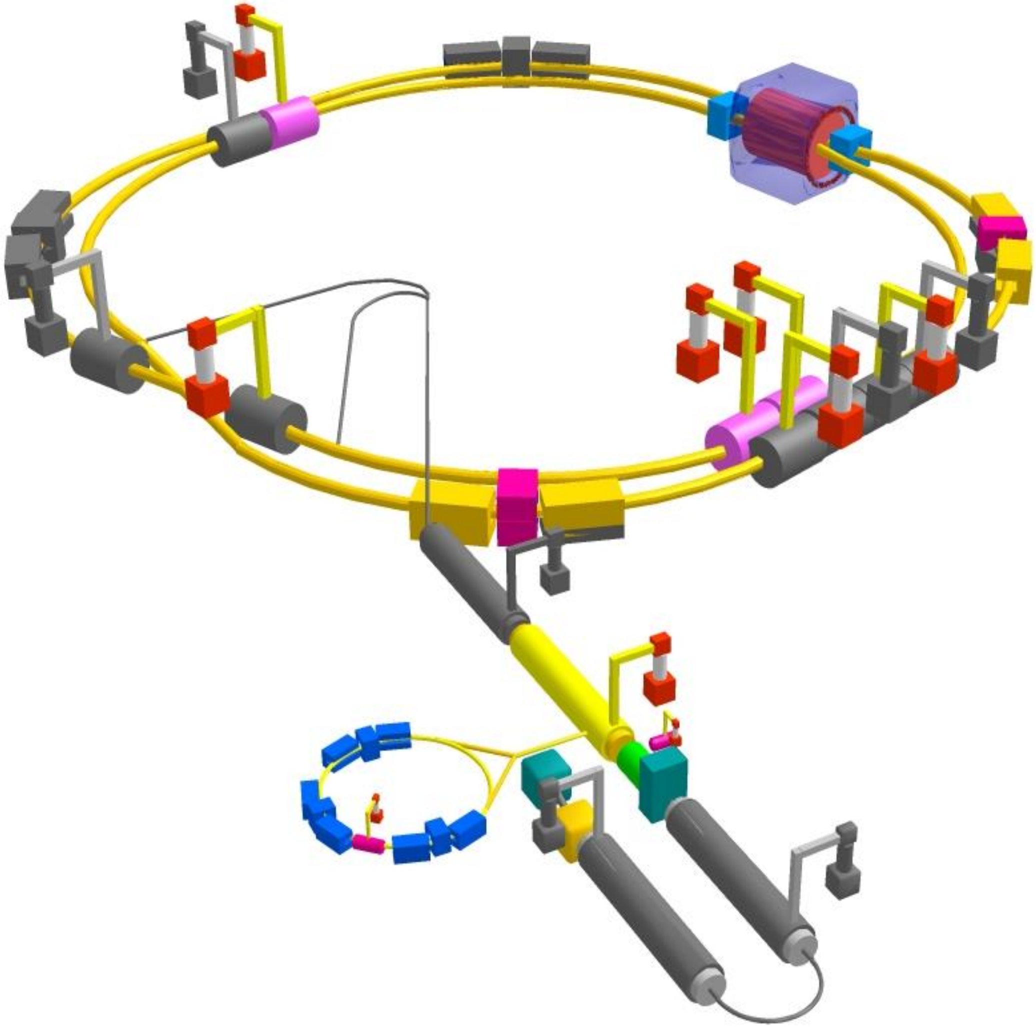
Add / modify RF systems for higher beam current





TiN-coated beam pipe with antechambers

Introduction



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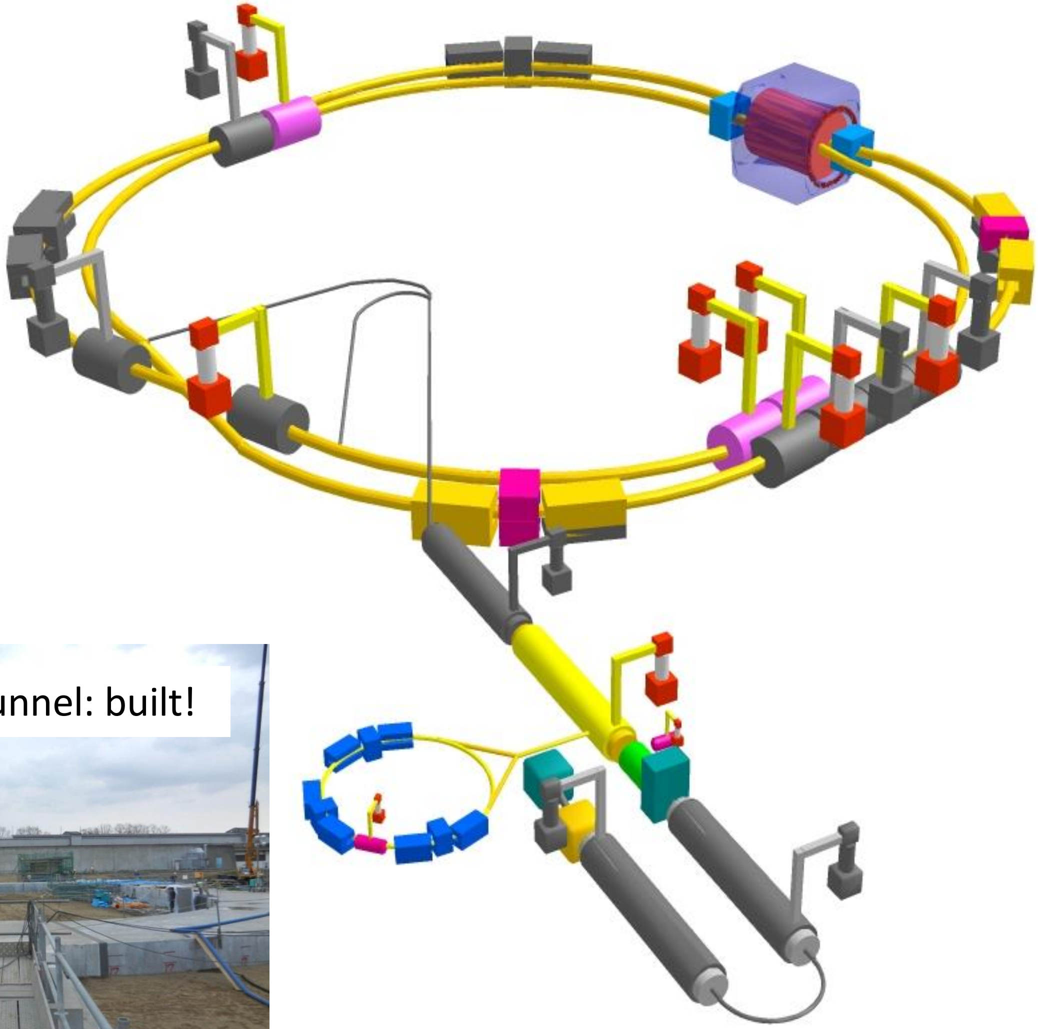

Damping ring tunnel: built!

Introduction

Installation of 100 new long LER bending magnets done

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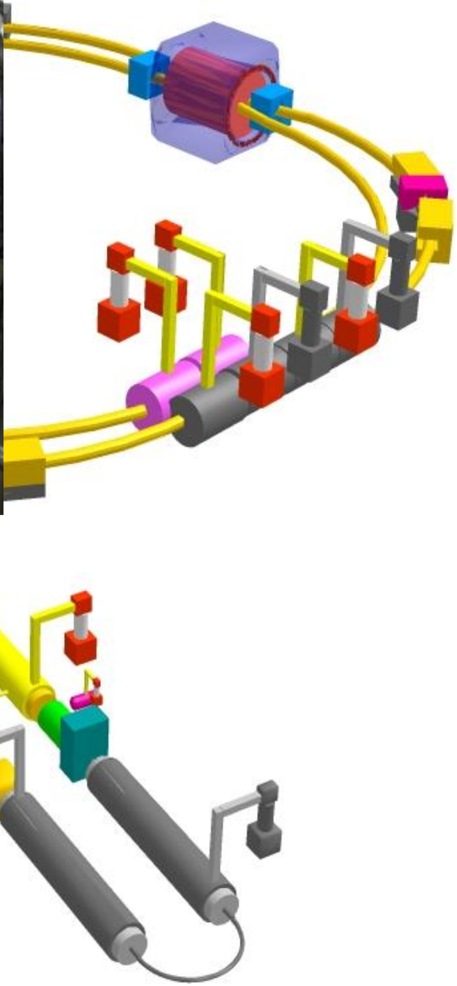

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Installation of HER wiggler chambers in Oho straight section is done.

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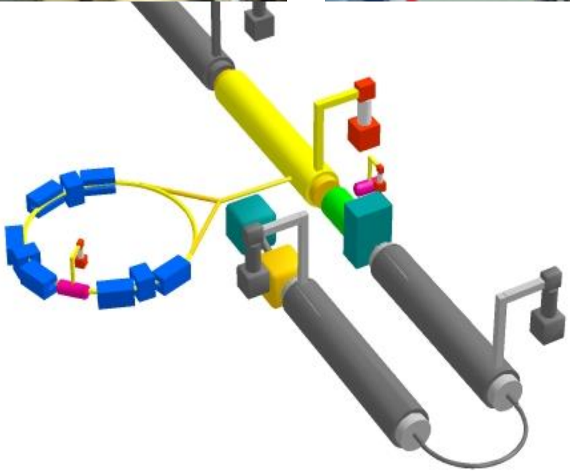

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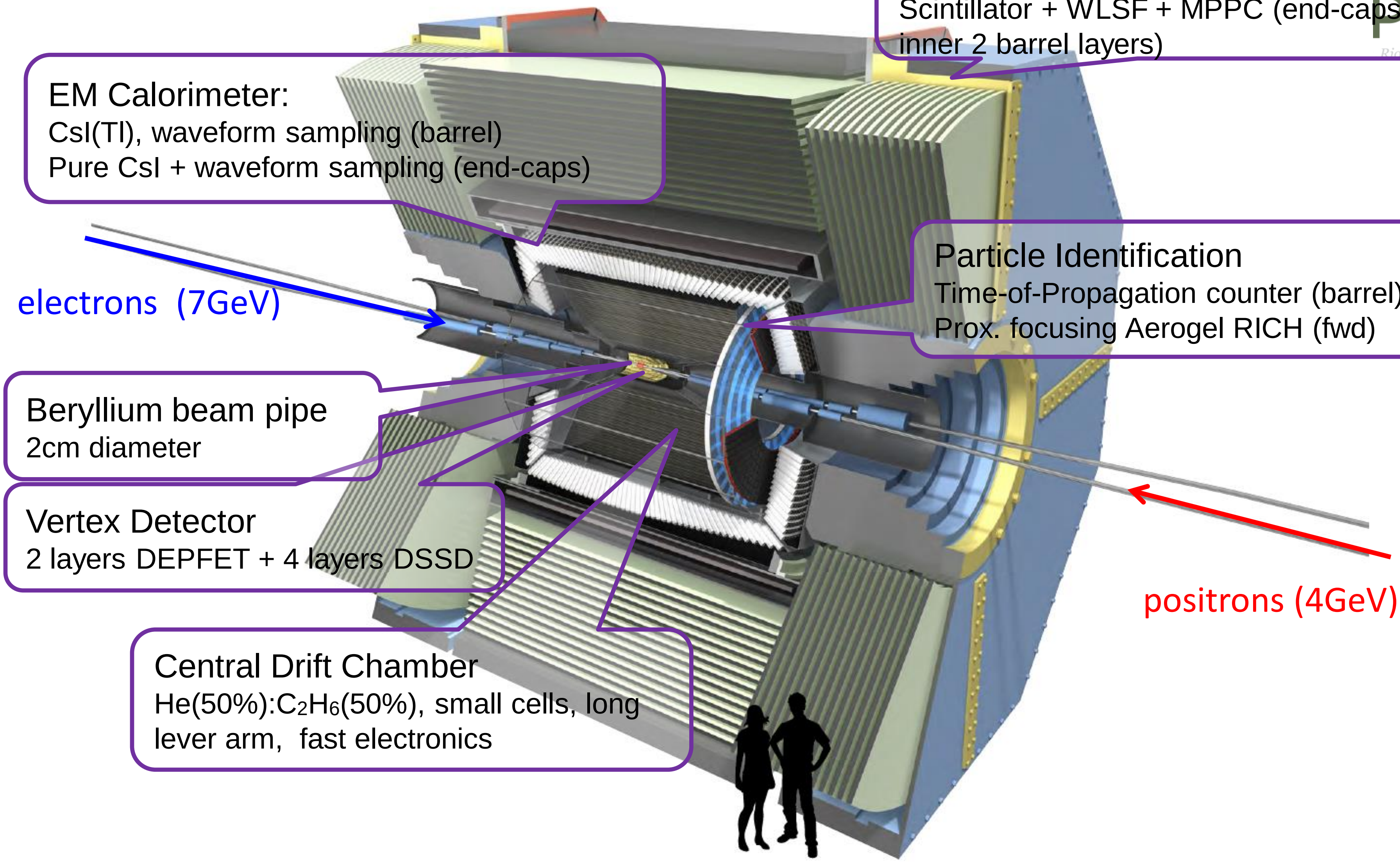

KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps , inner 2 barrel layers)

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

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

Central Drift Chamber
He(50%):C_2H_6(50%), small cells, long lever arm, fast electronics

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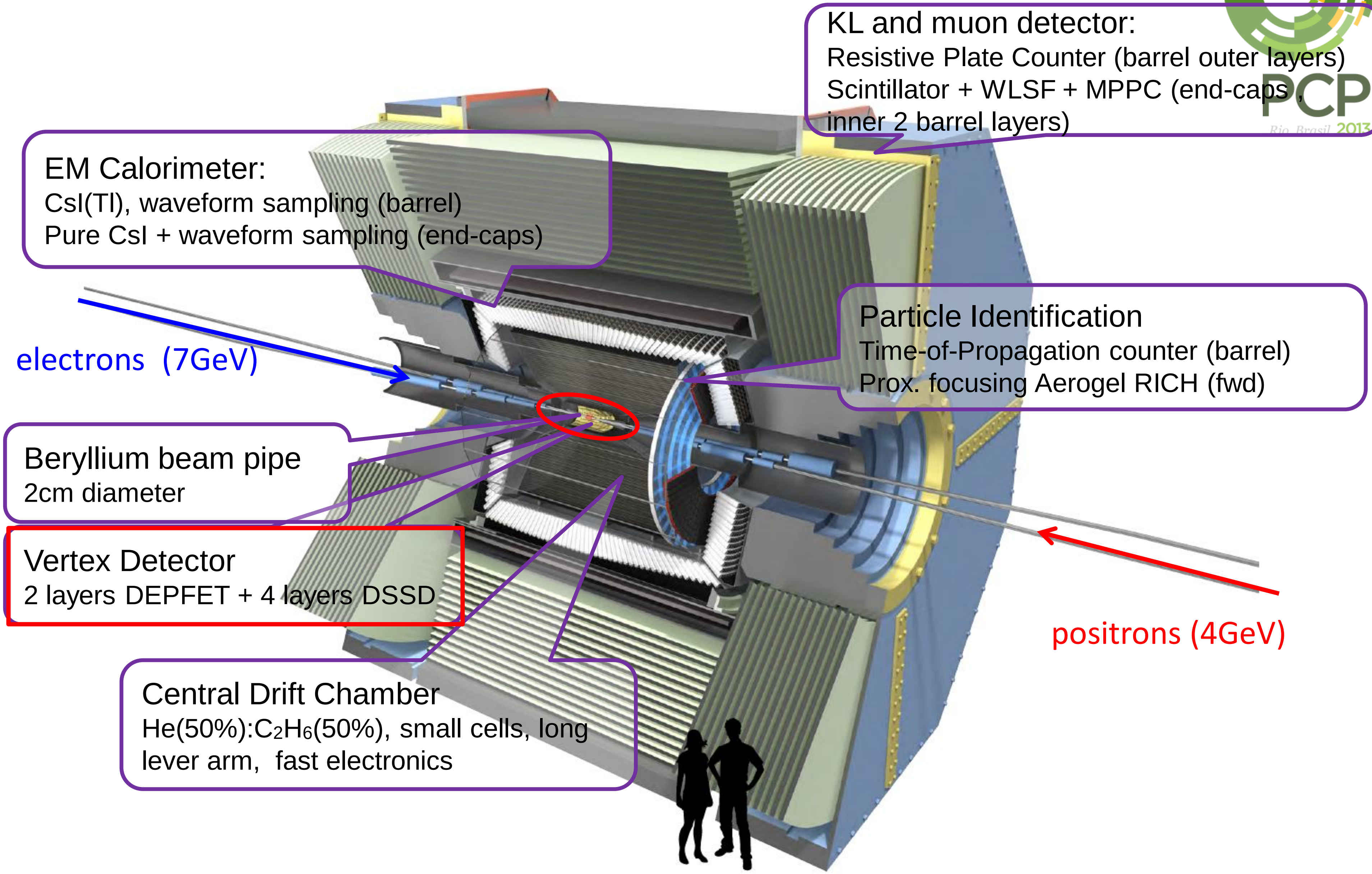

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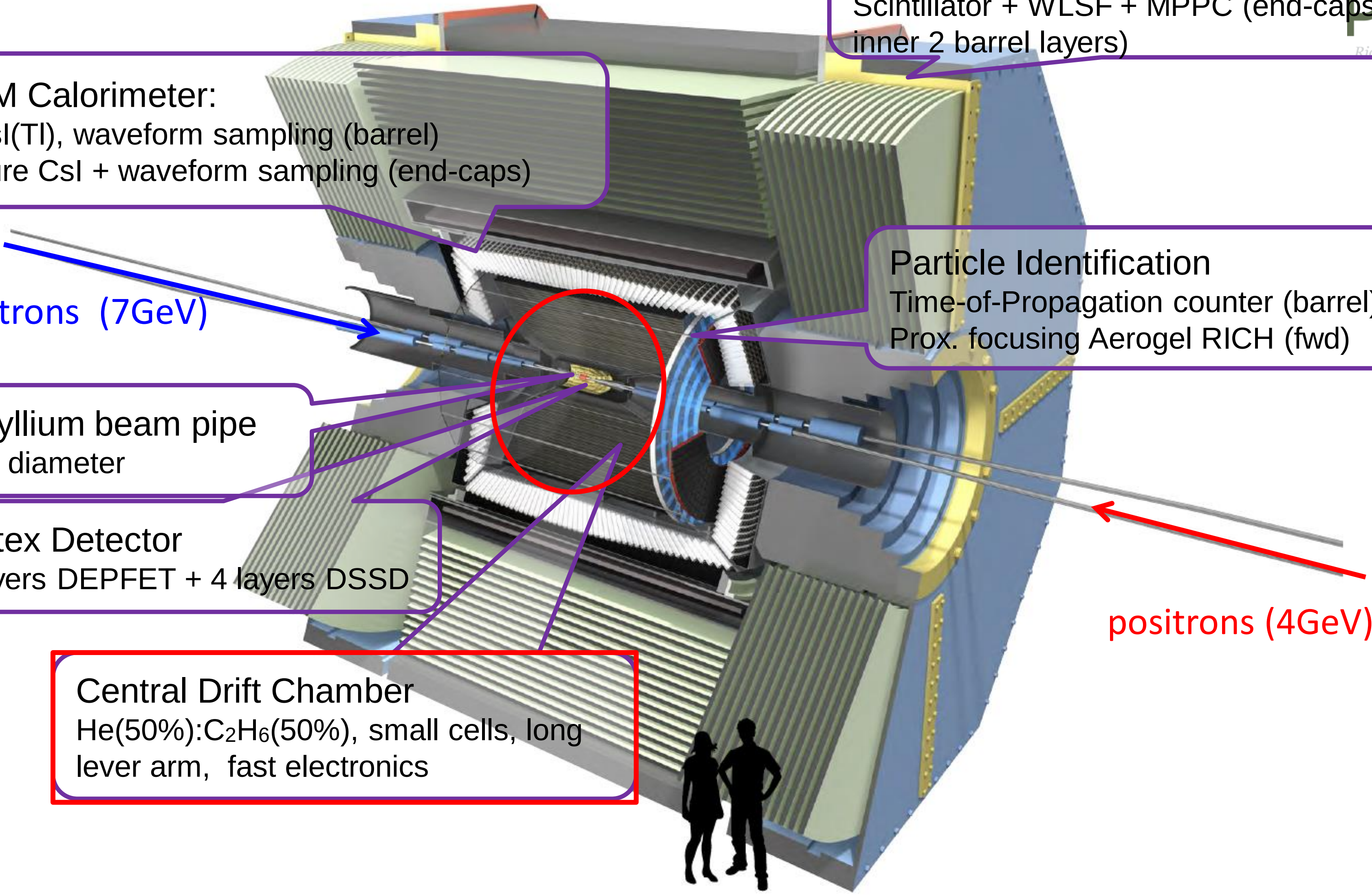

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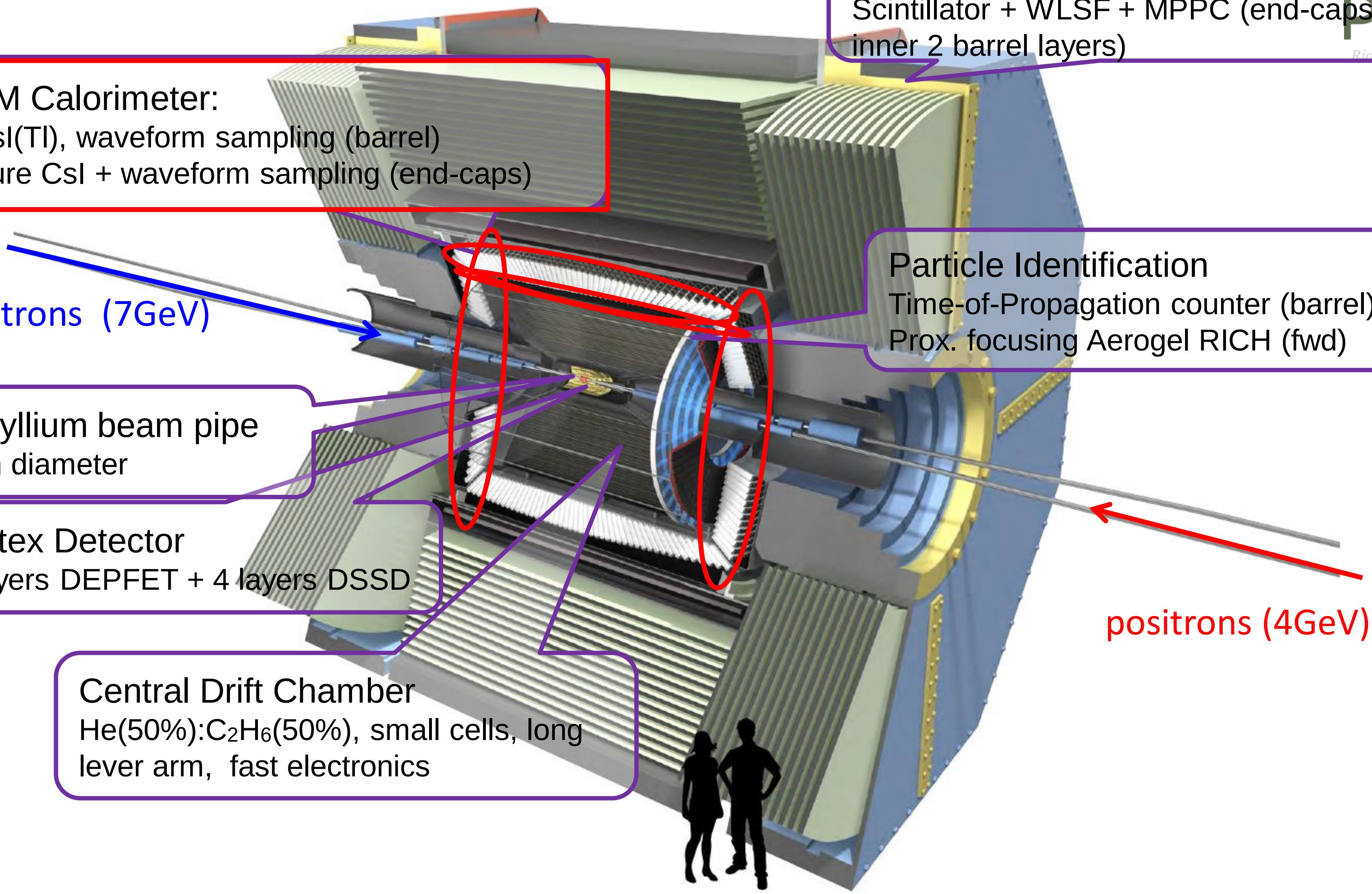

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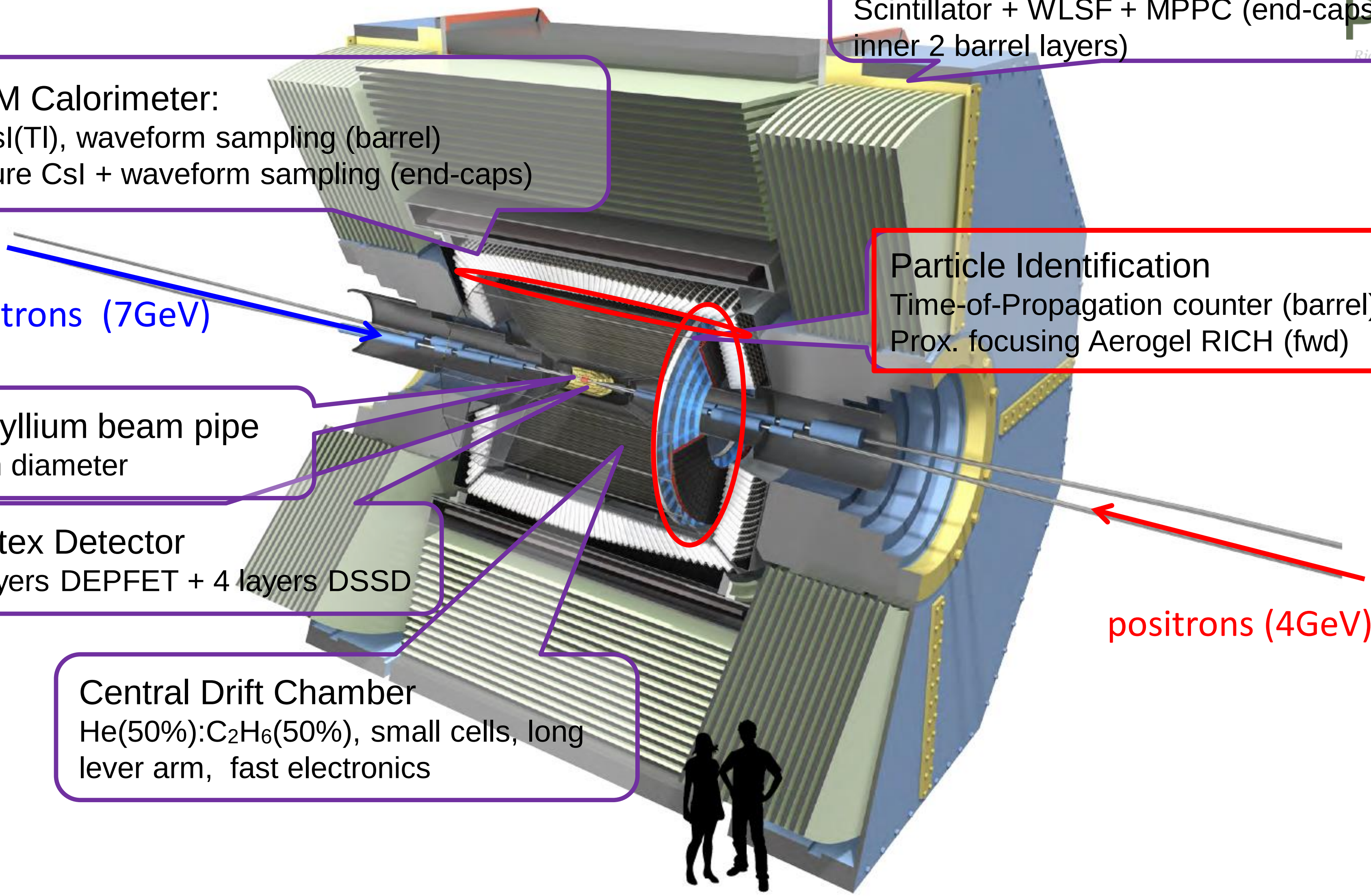

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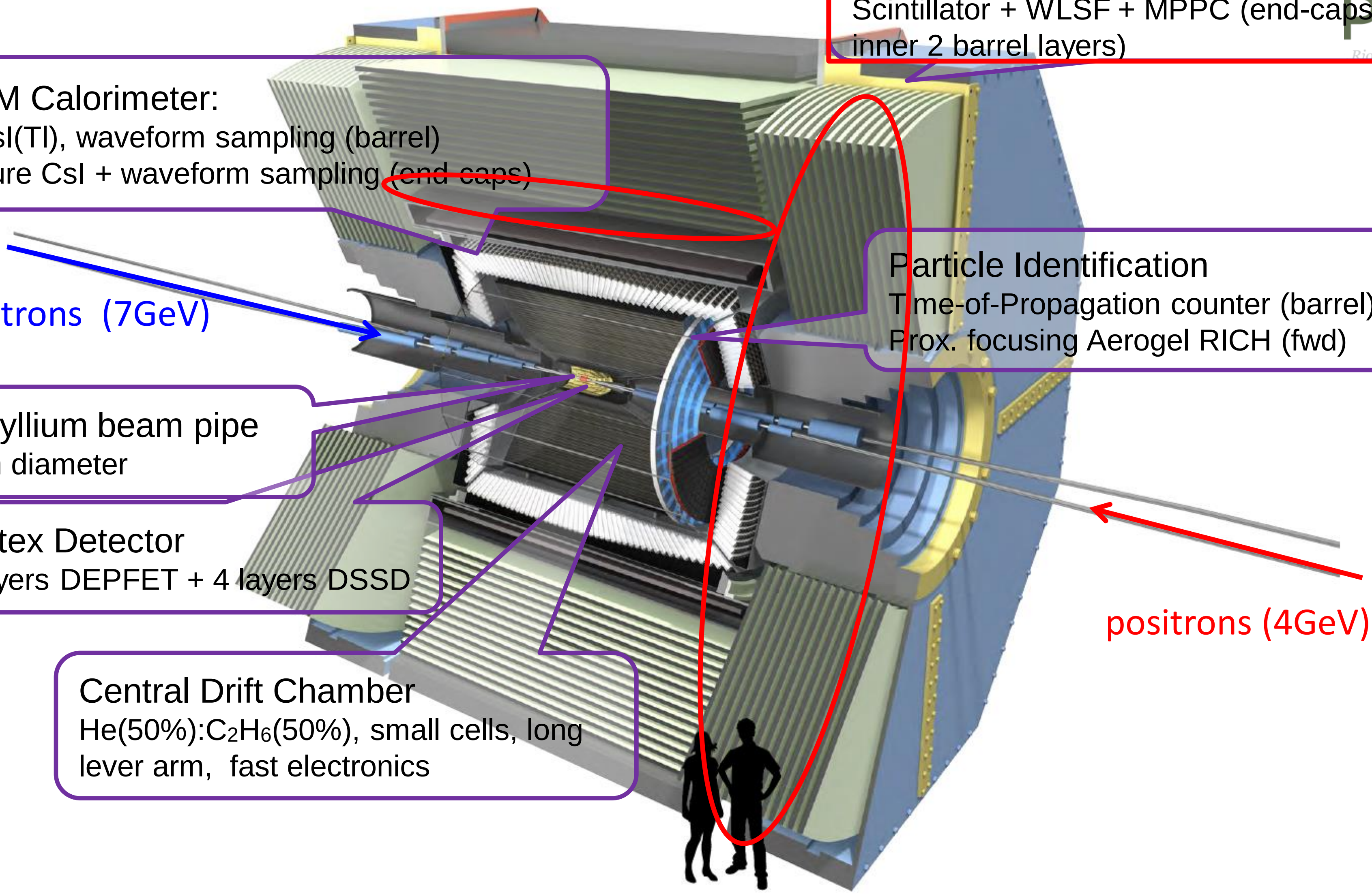

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Methods and processes where (S)BF can provide important insight into NP complementary to other experiments:

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$\mathcal{B}(B \to \tau\nu)$, $\mathcal{B}(B \to X_c\tau\nu)$, $\mathcal{B}(B \to h\nu\nu)$,...

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Inclusive:

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

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Neutrals:

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

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

E_{miss}:
$\mathcal{B}(B \to \tau\nu)$, $\mathcal{B}(B \to X_c\tau\nu)$, $\mathcal{B}(B \to h\nu\nu)$,...

Inclusive:
$\mathcal{B}(B \to s\gamma)$, $A_{CP}(B \to s\gamma)$, $\mathcal{B}(B \to s\ell\ell)$, ...

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:

A.G. Akeroyd et al., arXiv: 1002.5012 ~ 300 pages

Physics at Super B Factory

Belle II

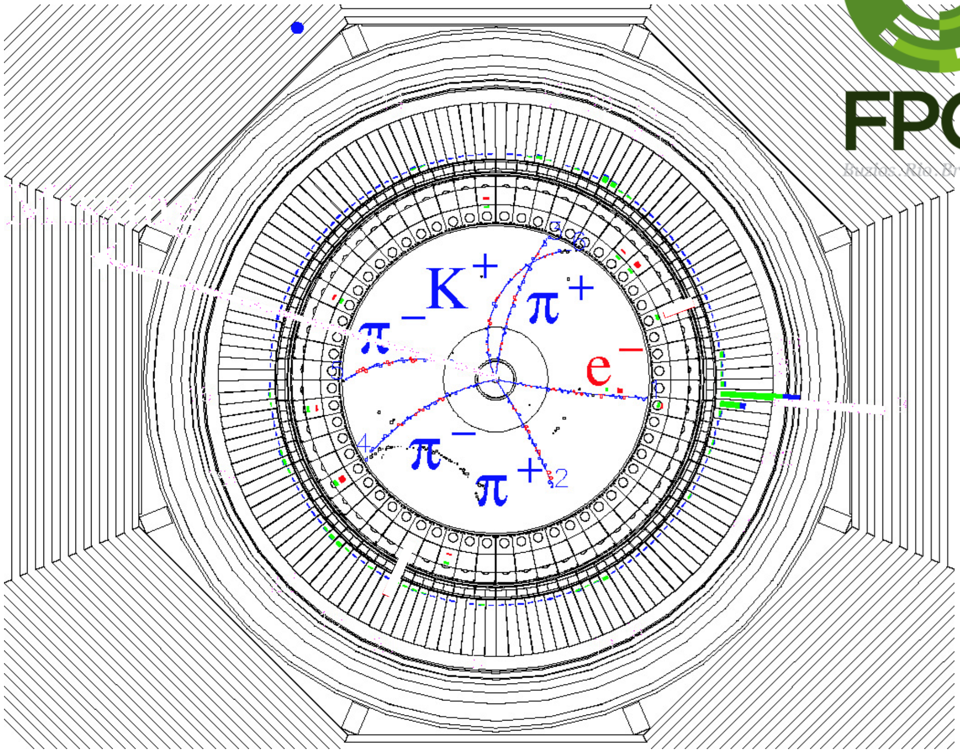
B. O'Leary et al., arXiv: 1008.1541 ~ 100 pages

SuperB

Super$B$
Progress Reports
Physics

Missing energy

$B \to \tau\nu,\ h\nu\nu, \ldots$

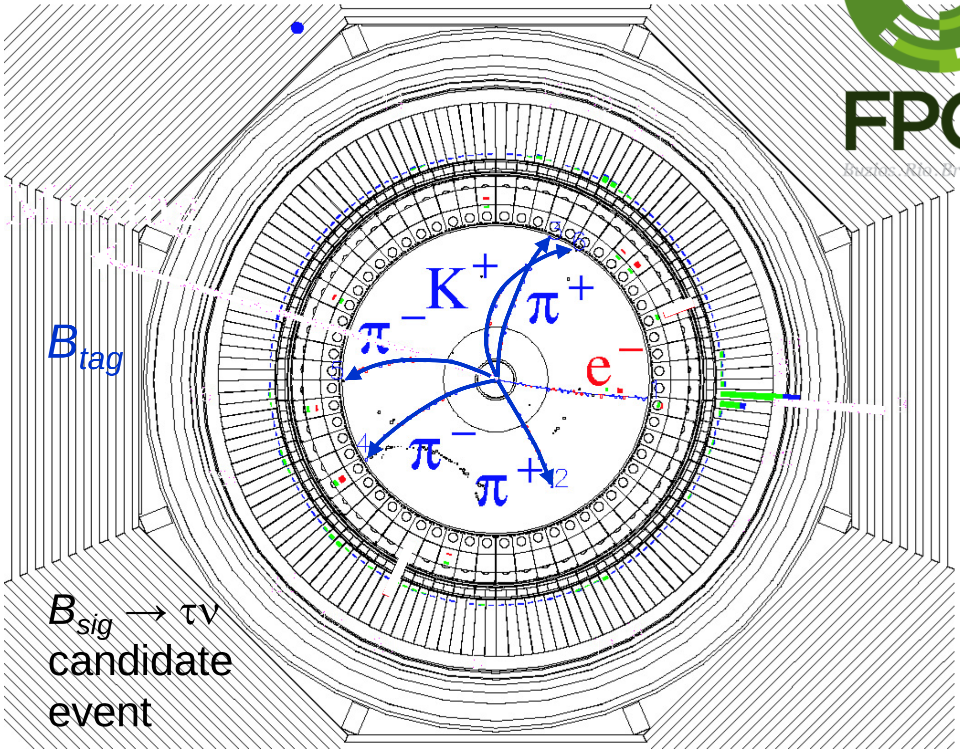


fully (partially) reconstruct B_{tag};
reconstruct *h* from $B_{sig} \to h\nu\nu$ or
$B_{sig} \to \tau(\to h\nu)\nu$;
no additional energy in EM calorim.;
signal at E_{ECL}~0;

Missing energy

$B \to \tau\nu,\ h\nu\nu,\ \dots$

fully (partially) reconstruct B_{tag};
reconstruct h from $B_{sig} \to h\nu\nu$ or
$B_{sig} \to \tau(\to h\nu)\nu$;
no additional energy in EM calorim.;
signal at E_{ECL}~0;



B_{tag}

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

Missing energy

$B \rightarrow \tau\nu,\ h\nu\nu, \ldots$

fully (partially) reconstruct B_{tag};
reconstruct h from $B_{sig} \rightarrow h\nu\nu$ or $B_{sig} \rightarrow \tau(\rightarrow h\nu)\nu$;
no additional energy in EM calorim.;
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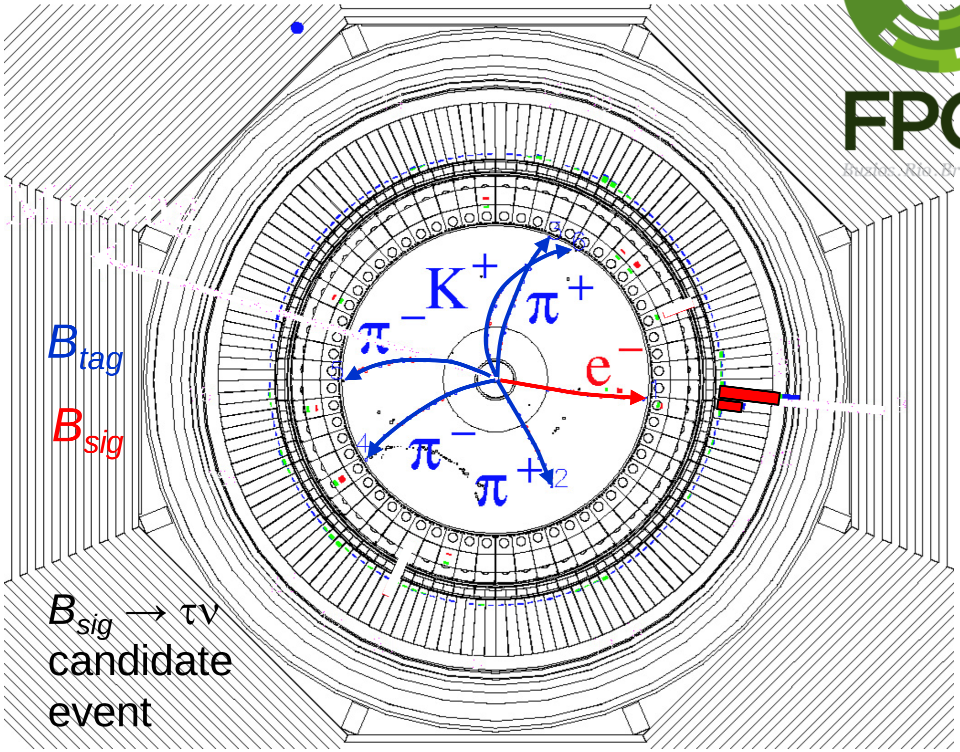

$B_{sig} \rightarrow \tau\nu$ candidate event

Missing energy

$B \to \tau\nu,\ h\nu\nu, \ldots$

fully (partially) reconstruct B_{tag};
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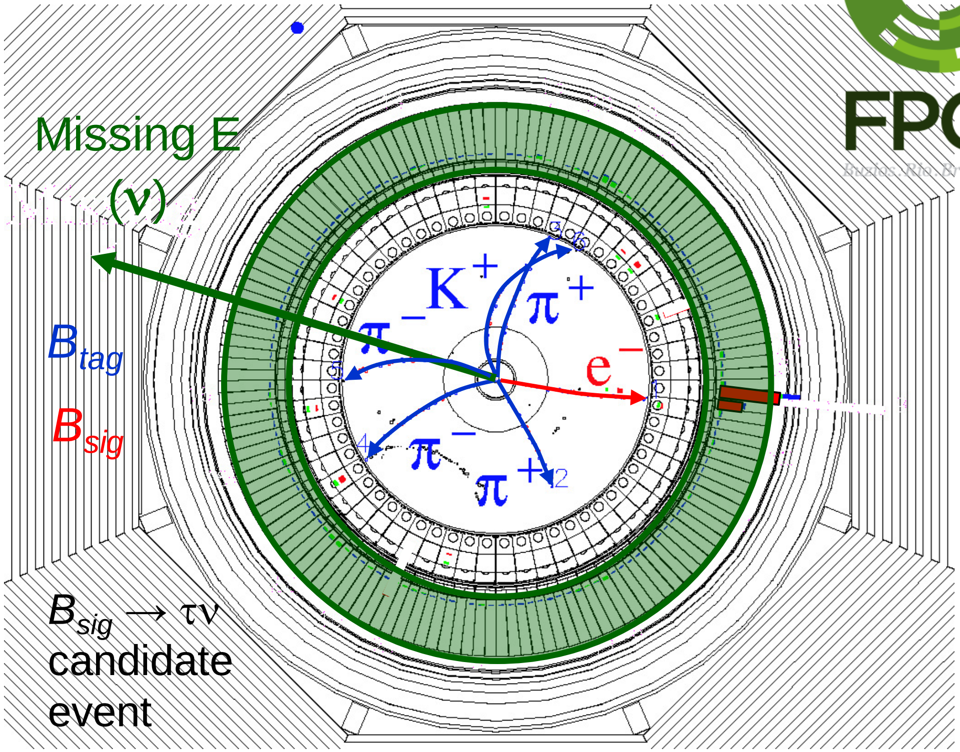

$B_{sig} \to \tau\nu$ candidate event

Missing energy

$B \to \tau\nu,\ h\nu\nu, \ldots$

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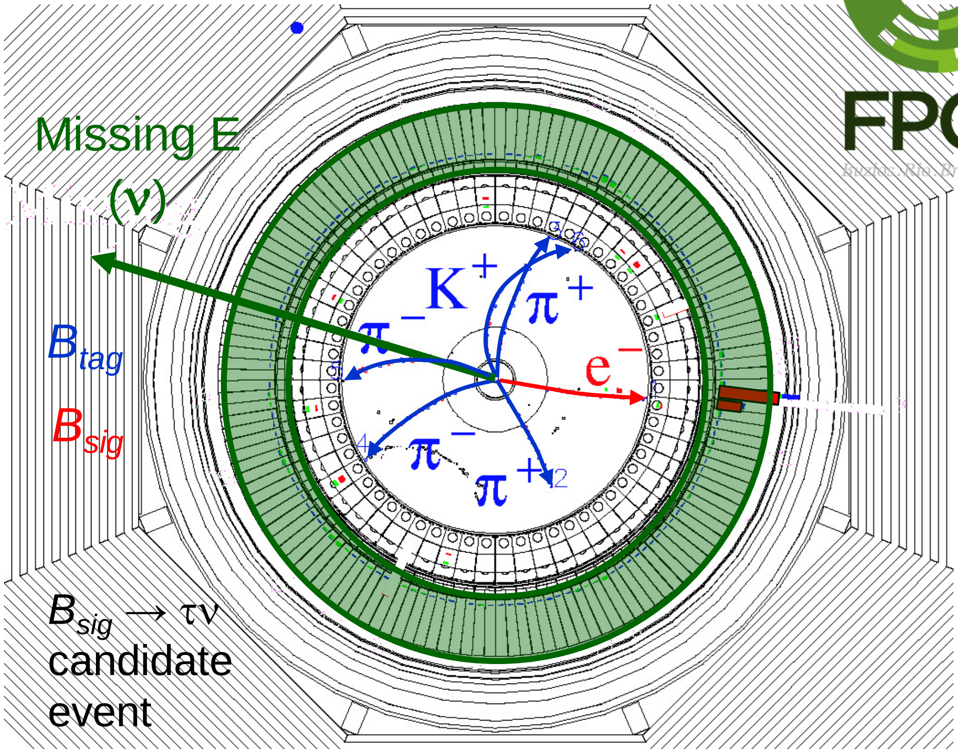
$B_{sig} \to \tau(\to h\nu)\nu$;
no additional energy in EM calorim.;
signal at E_{ECL}~0;

B_{tag} full reconstruction (NeuroBayes)



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

Missing energy

$B \to \tau\nu, h\nu\nu, \ldots$

fully (partially) reconstruct B_{tag};
reconstruct h from $B_{sig} \to h\nu\nu$ or
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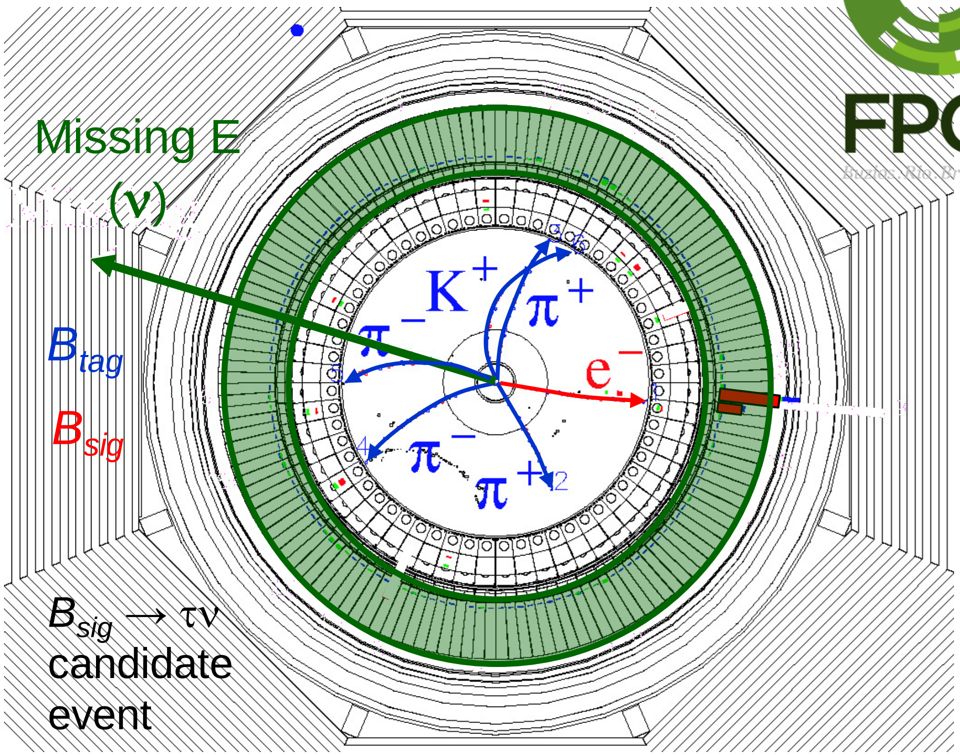
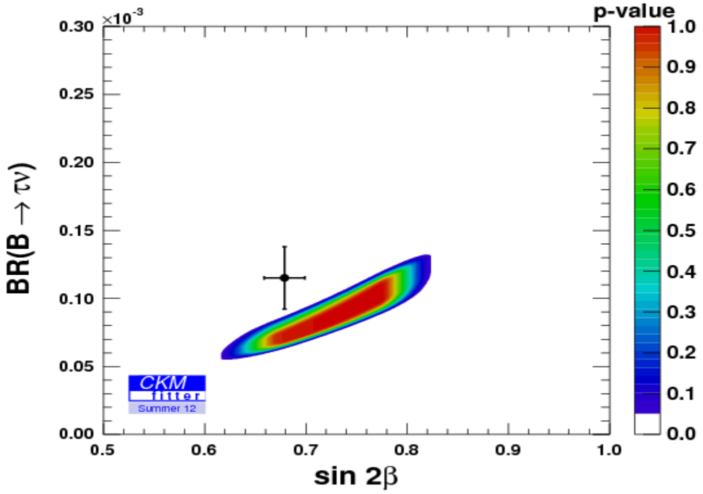


$B_{sig} \to \tau\nu$
candidate
event



Missing energy

$B \to \tau\nu, h\nu\nu, \ldots$

fully (partially) reconstruct B_{tag};
reconstruct h from $B_{sig} \to h\nu\nu$ or
$B_{sig} \to \tau(\to h\nu)\nu$;
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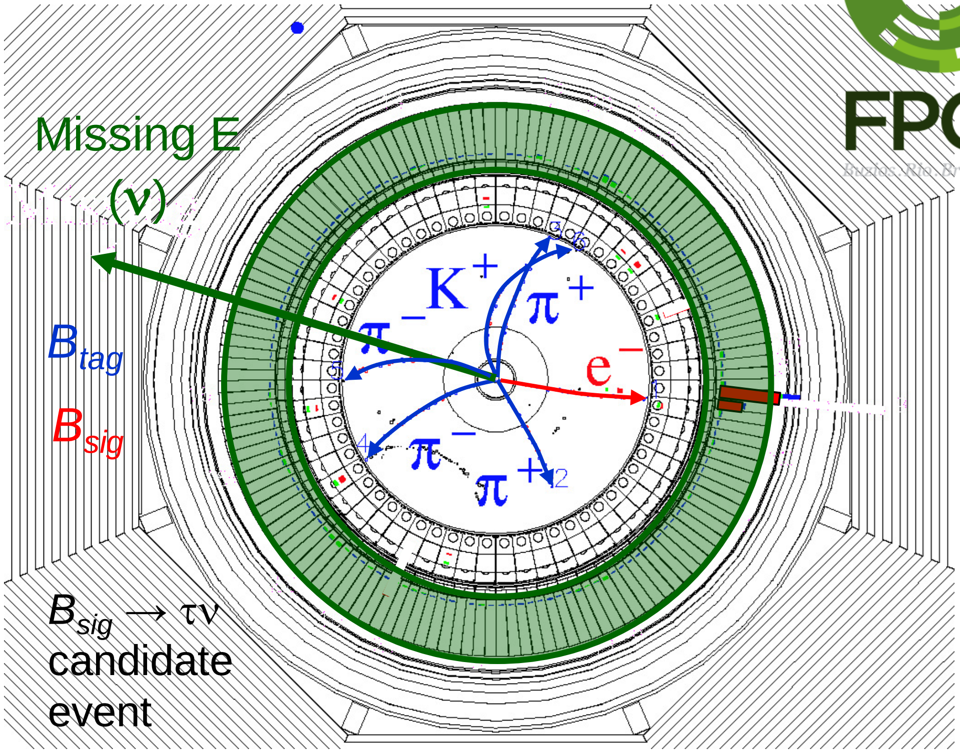
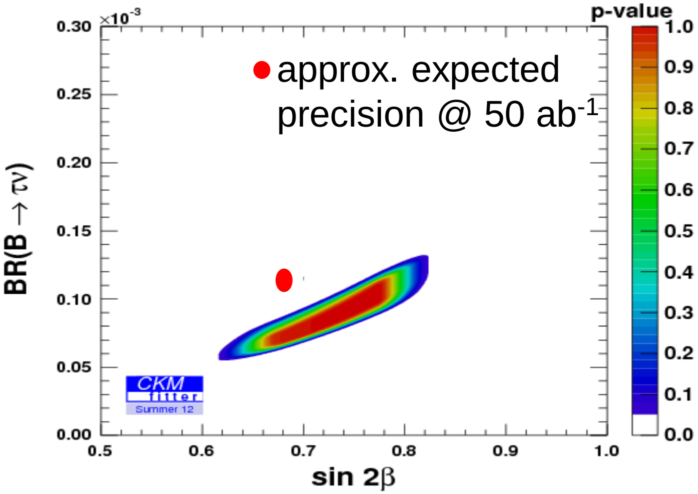
B_{tag} full reconstruction (NeuroBayes)



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

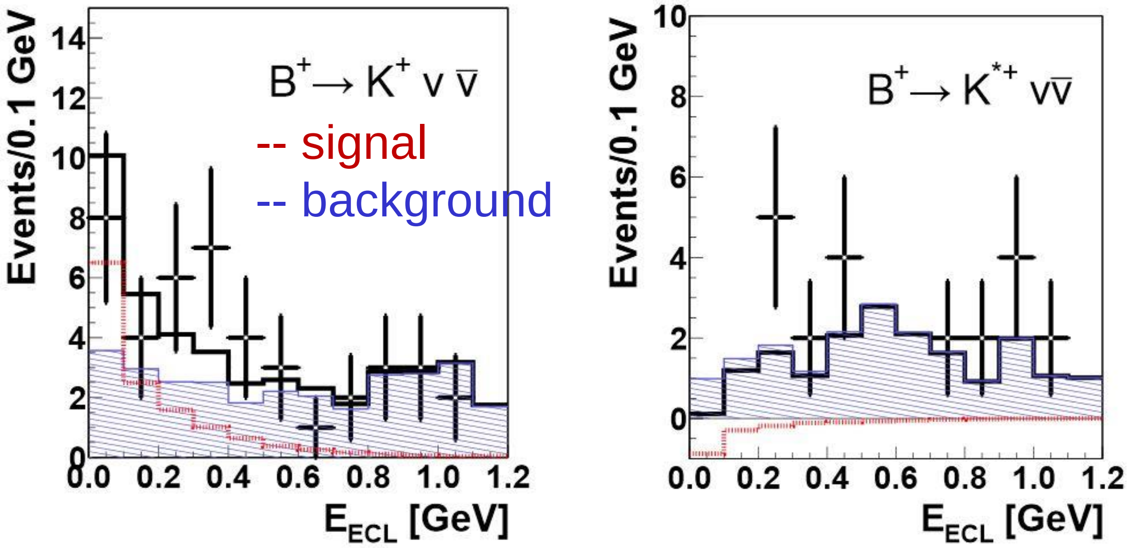


● approx. expected precision @ 50 ab^{-1}

Missing energy

Belle preliminary, arXiv:1303.3719, 711 fb^{-1}

$$B \to h \nu \nu$$

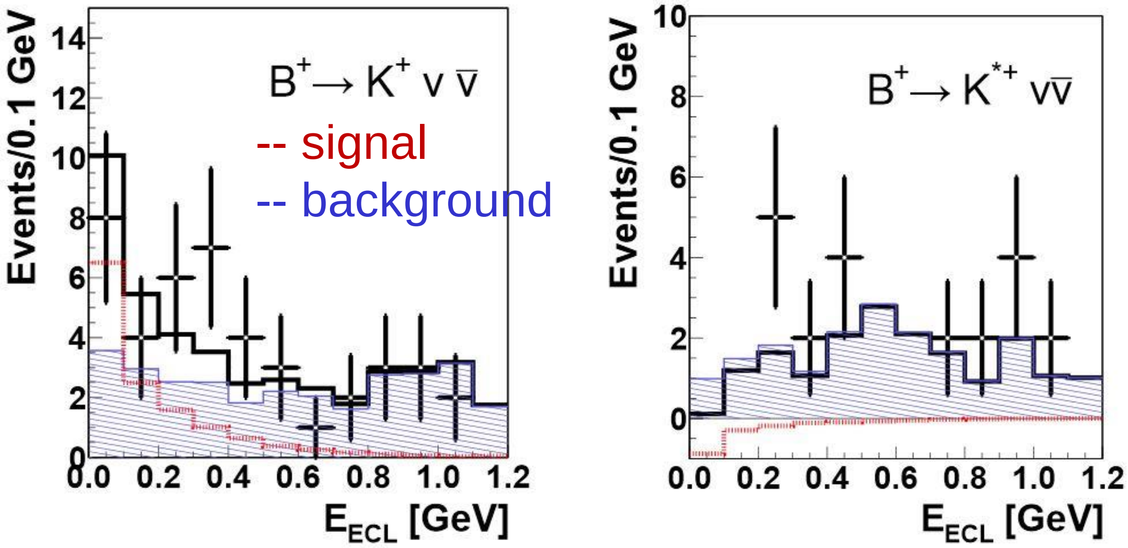


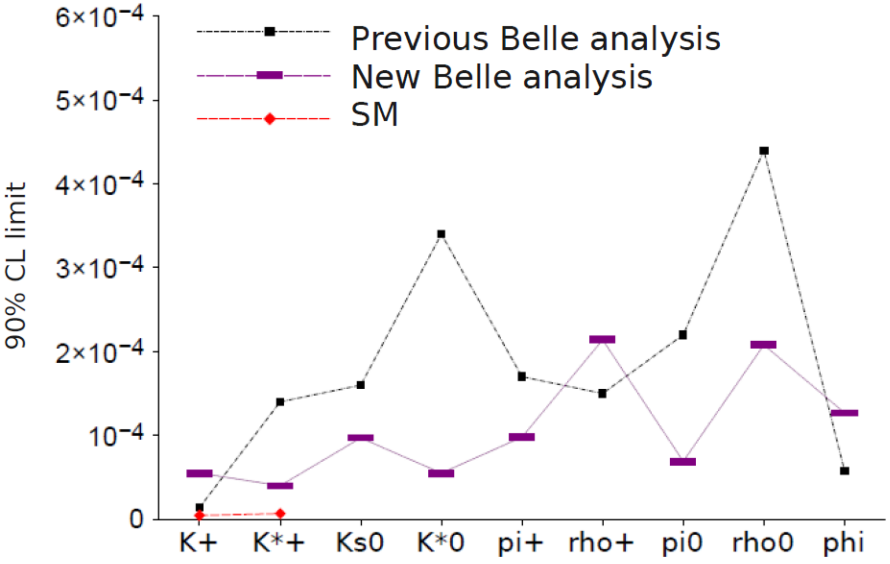
-- signal
-- background

Missing energy

Belle preliminary, arXiv:1303.3719, 711 fb^{-1}

$$B \to h\nu\nu$$





Missing energy

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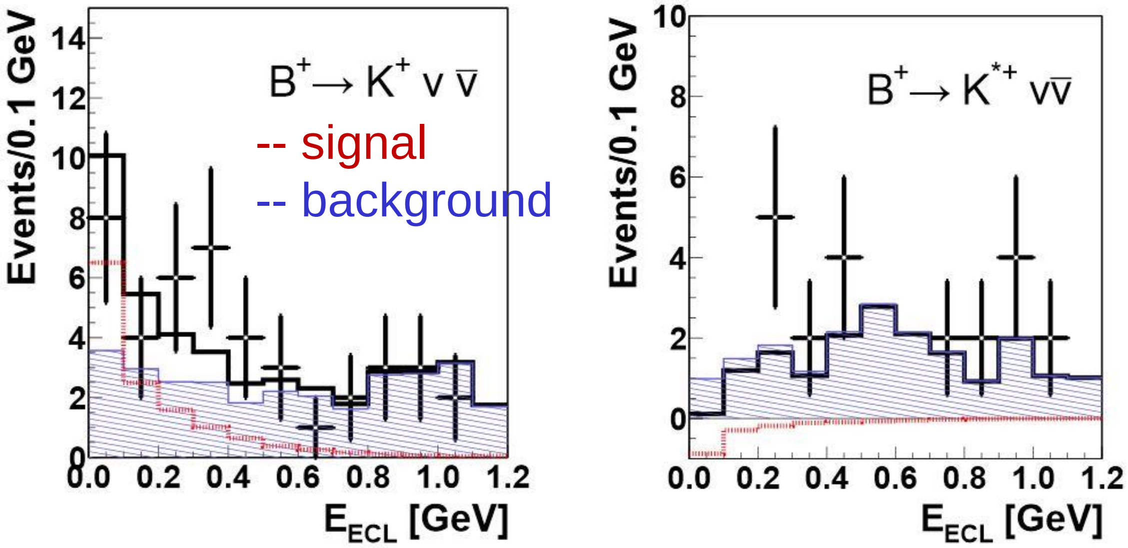
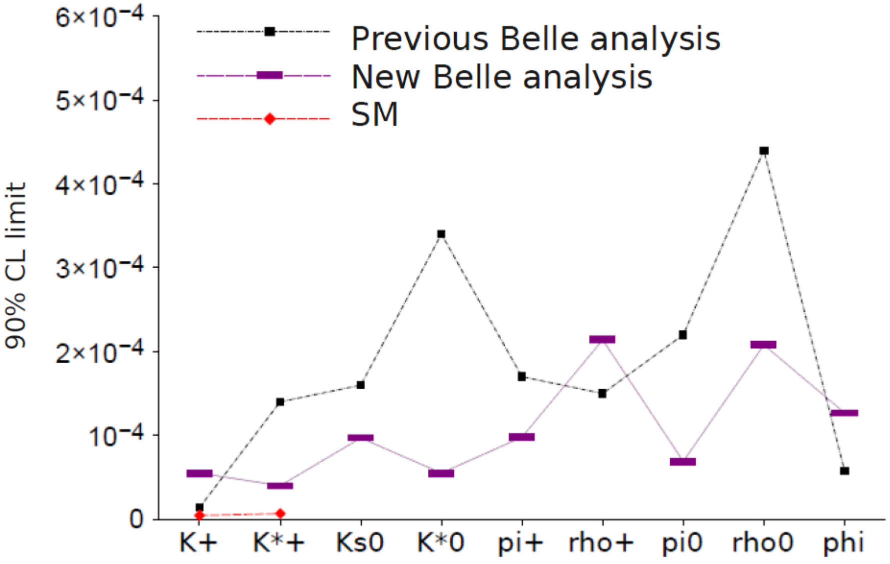
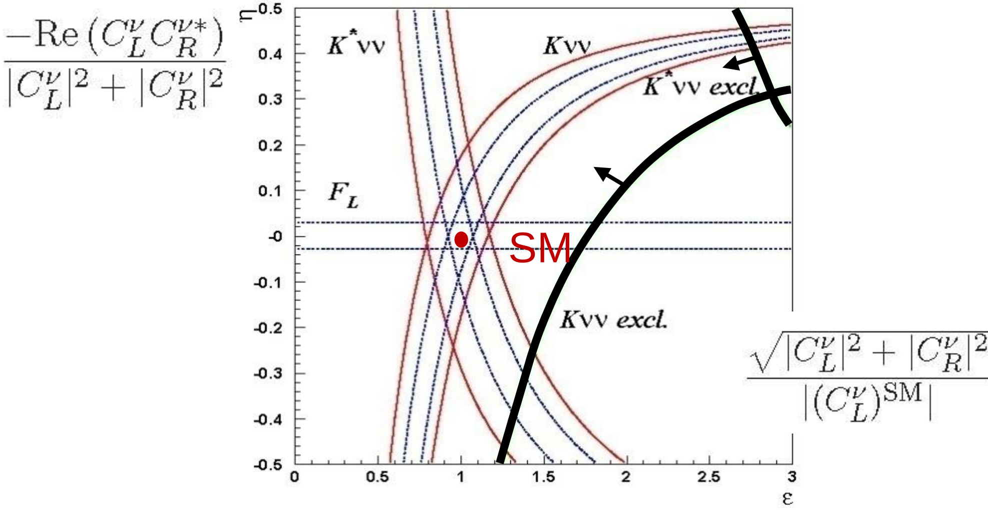
$B \to h \nu\nu$







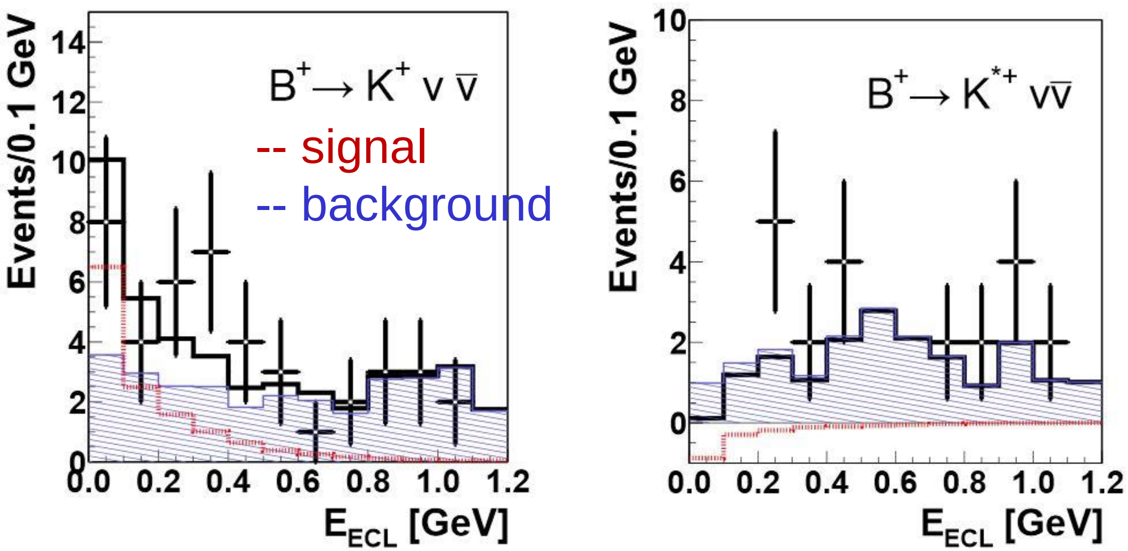
W. Altmannshofer et al., arXiv:0902.0160

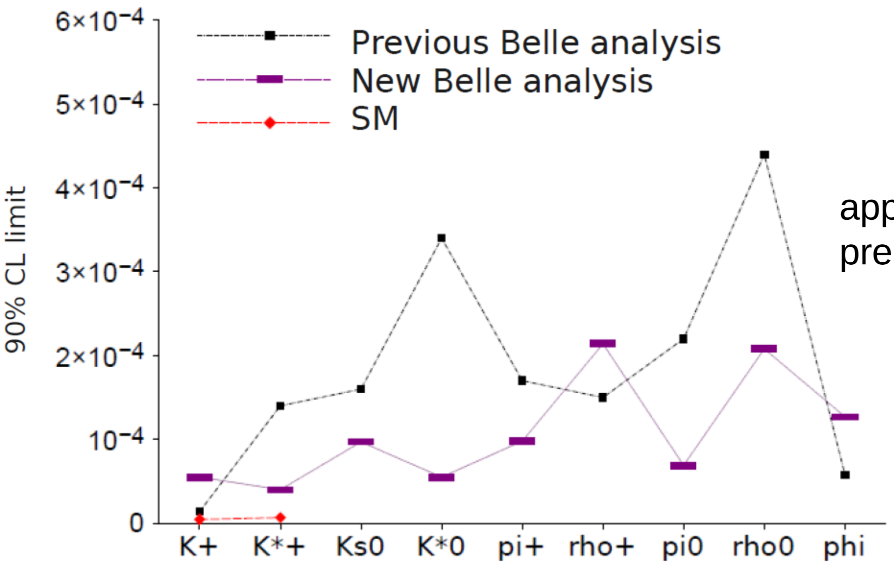
Missing energy

$B \to h \nu\nu$

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

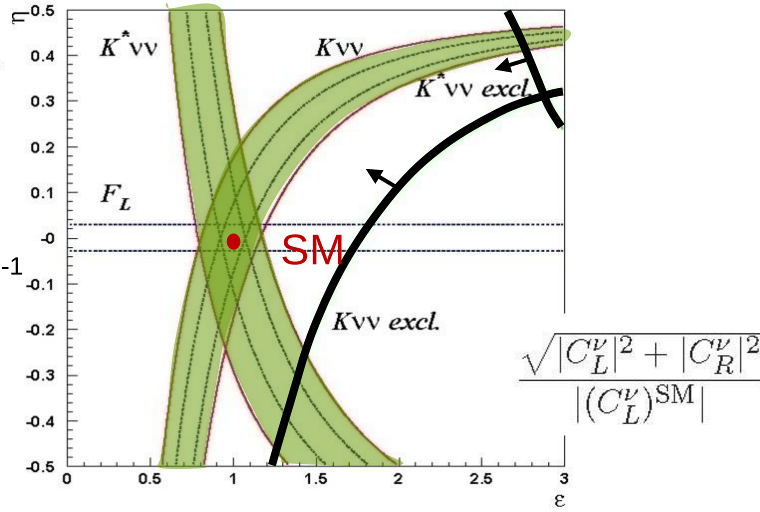
Belle preliminary, arXiv:1303.3719, 711 fb^{-1}





$$\eta = \frac{-\mathrm{Re}\,(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}$$

🟩 approx. expected precision @ 50 ab^{-1}

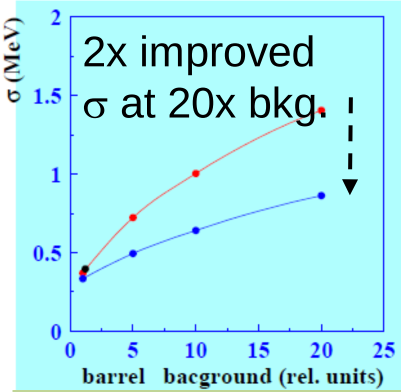


$$\varepsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{\mathrm{SM}}|}$$

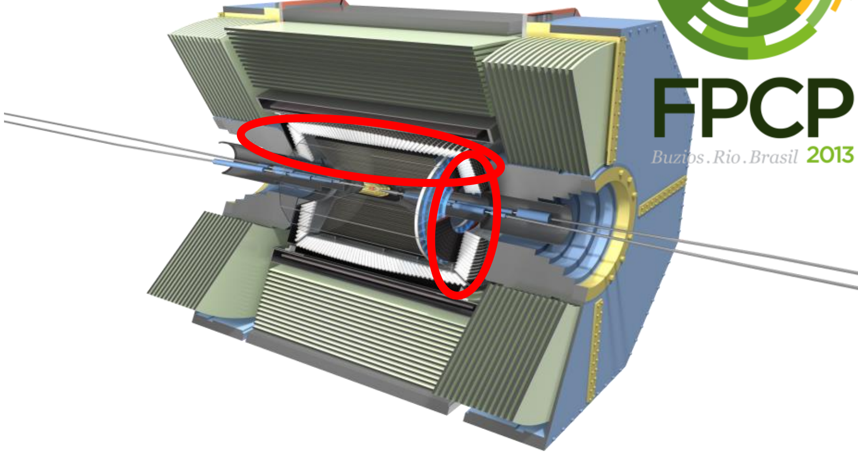
W. Altmannshofer et al., arXiv:0902.0160

Calorimeter

new electronics with
2MHz wave form sampling



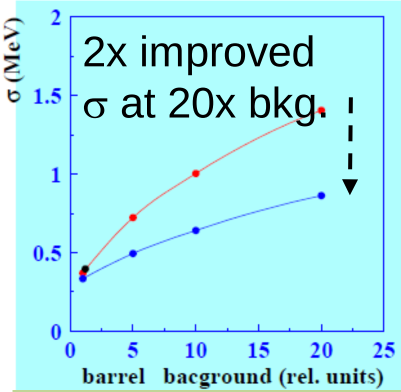
Better suppression of background



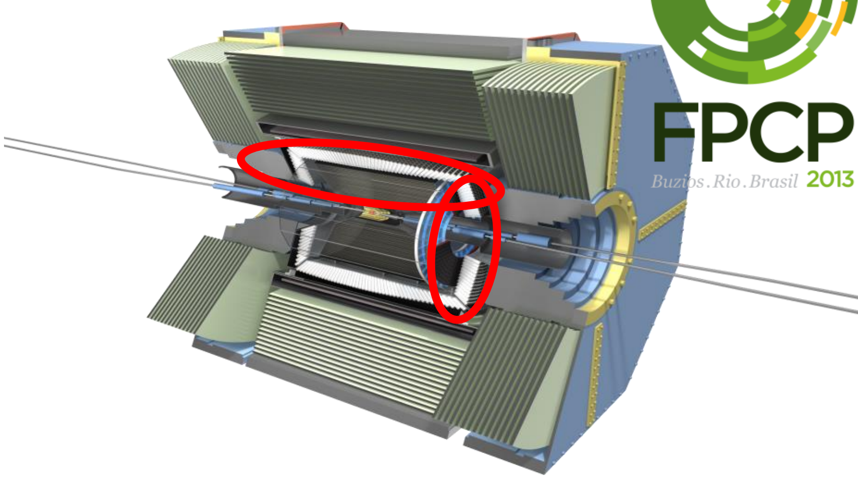
endcap: pure CsI crystals;
(considered for upgrade)

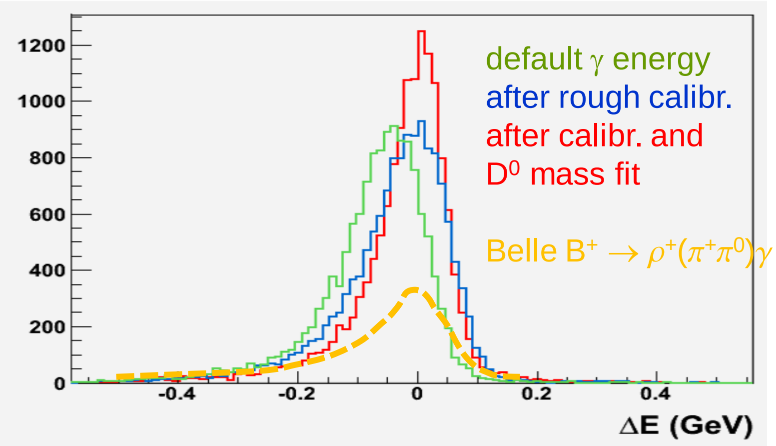
Calorimeter

new electronics with
2MHz wave form sampling



Better suppression of background

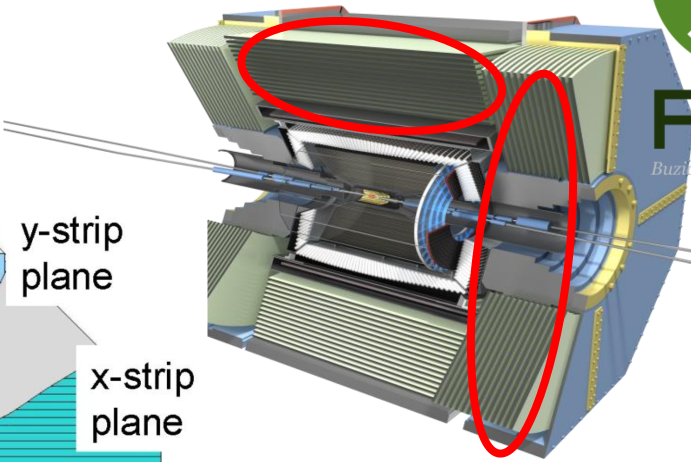




Belle II full simulation:
$B^0 \to D^0\pi^0$, $D^0 \to \pi^0\pi^0$,
$\pi^0 \to \gamma\gamma$
$\Delta E = E_B^* - E_{beam}$

verification and fine tuning
detector response

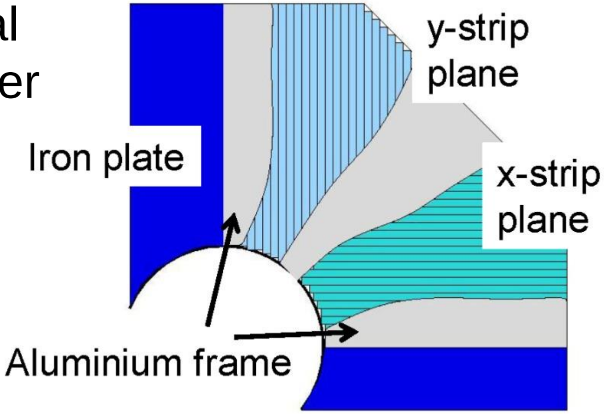
endcap: pure CsI crystals;
(considered for upgrade)



K_L and μ detector

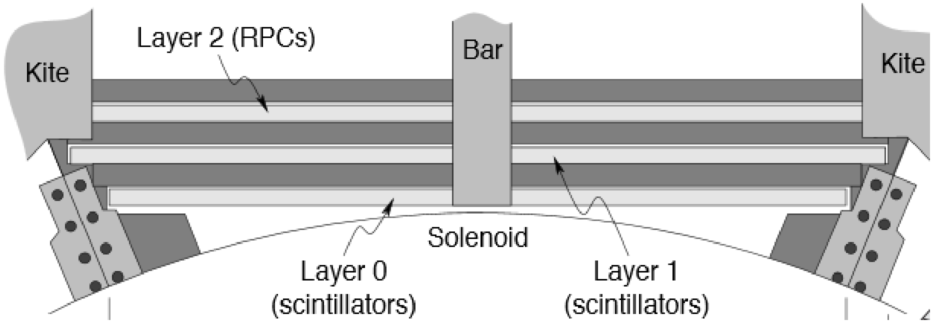
Endcaps:

- scintillators, two orthogonal directions in one super-layer
- avalanche photo-diode in Geiger mode (GAPD)



2 inner barrel layers:

- upgrade to scintilators

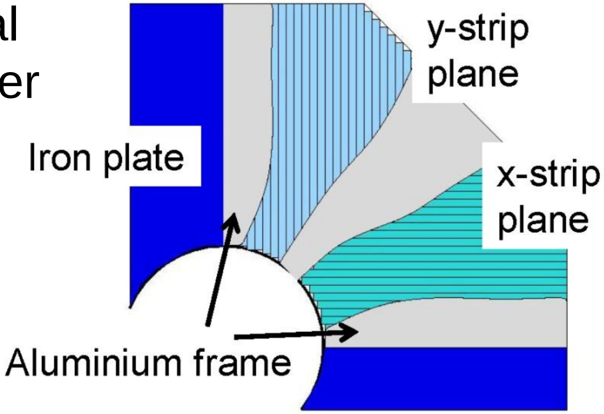


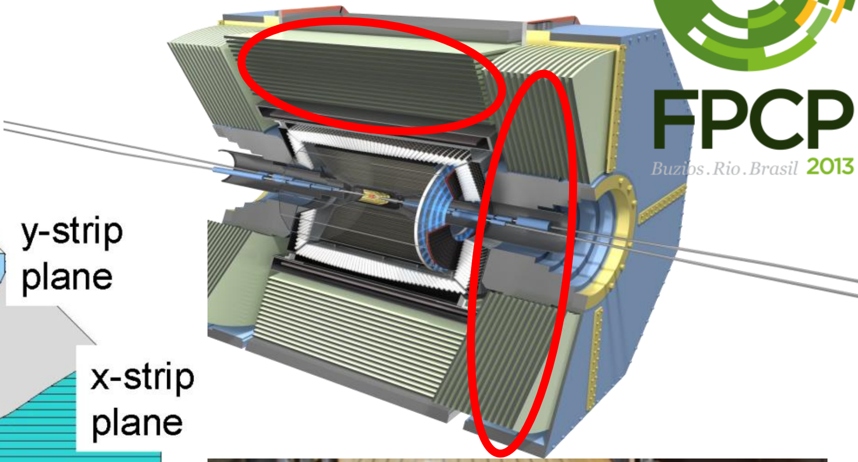
KLM

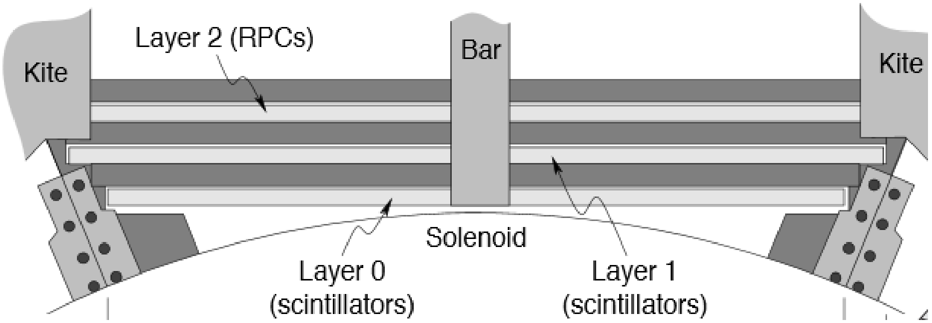
K_L and μ detector

Endcaps:
- scintillators, two orthogonal directions in one super-layer
- avalanche photo-diode in Geiger mode (GAPD)

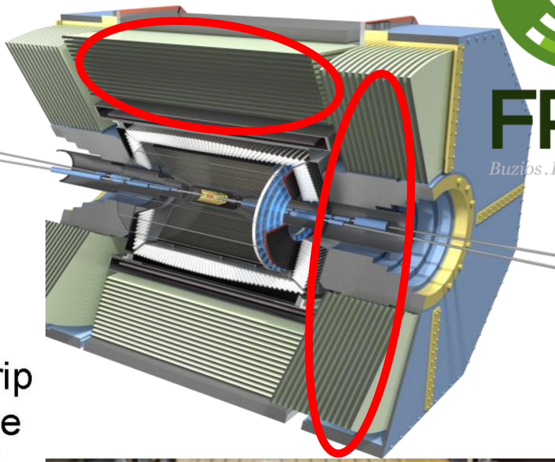
2 inner barrel layers:
- upgrade to scintilators







K_L and μ detector



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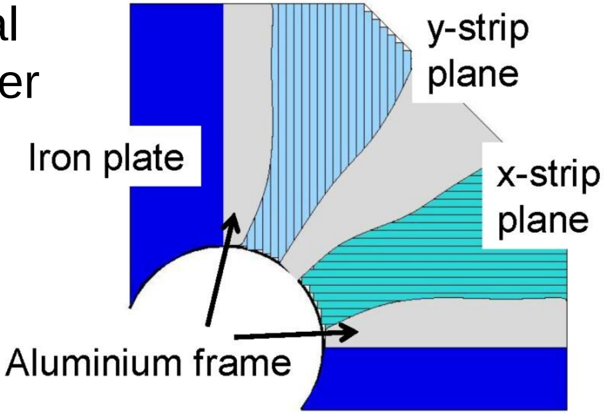

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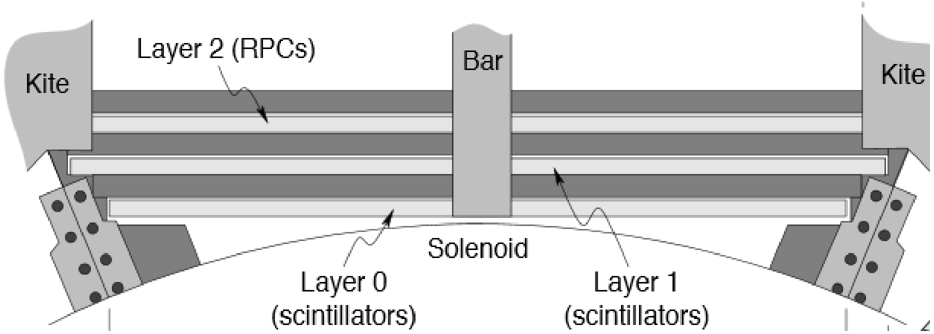

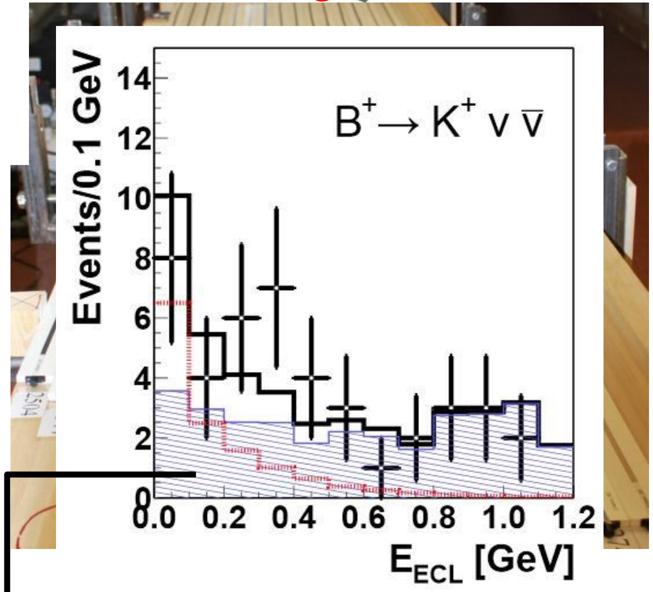

main backround from K_L's, better K_L efficiency better background rejection

Inclusive decays

B → sγ
direct CPV

Semi-inclusive, sum of many exclusive states:

BaBar, PRL101, 171804(2008),350 fb^{-1}

all flavor specific final states;

$$\begin{aligned}
B^- \rightarrow\ & K_S^0\pi^-\gamma, K^-\pi^0\gamma, K^-\pi^+\pi^-\gamma, K_S^0\pi^-\pi^0\gamma,\\
& K^-\pi^0\pi^0\gamma, K_S^0\pi^+\pi^-\pi^-\gamma, K^-\pi^+\pi^-\pi^0\gamma,\\
& K_S^0\pi^-\pi^0\pi^0\gamma, K^-\eta\gamma, K^+K^-K^-\gamma,\\
\overline{B}^0 \rightarrow\ & K^-\pi^+\gamma, K^-\pi^+\pi^0\gamma, K^-\pi^+\pi^-\pi^+\gamma, K^-\pi^+\pi^0\pi^0\gamma,\\
& K^-\pi^+\eta\gamma, K^+K^-K^-\pi^+\gamma,
\end{aligned}$$

Inclusive decays

$B \to s\gamma$
direct CPV

Semi-inclusive, sum of many exclusive states:

BaBar, PRL101, 171804(2008),350 fb^{-1}

all flavor specific final states;

$$
\begin{aligned}
B^- \;\rightarrow\;& K^0_S\pi^-\gamma, K^-\pi^0\gamma, K^-\pi^+\pi^-\gamma, K^0_S\pi^-\pi^0\gamma,\\
& K^-\pi^0\pi^0\gamma, K^0_S\pi^+\pi^-\pi^-\gamma, K^-\pi^+\pi^-\pi^0\gamma,\\
& K^0_S\pi^-\pi^0\pi^0\gamma, K^-\eta\gamma, K^+K^-K^-\gamma,\\
\overline{B}^0 \;\rightarrow\;& K^-\pi^+\gamma, K^-\pi^+\pi^0\gamma, K^-\pi^+\pi^-\pi^+\gamma, K^-\pi^+\pi^0\pi^0\gamma,\\
& K^-\pi^+\eta\gamma, K^+K^-K^-\pi^+\gamma,
\end{aligned}
$$

$$\frac{N_b - N_{\bar{b}}}{N_b + N_{\bar{b}}} = \langle D\rangle A_{CP} + \Delta D + A_{\det}$$

$\langle D\rangle$: average dilution due to flavour mistag, ~1

ΔD: difference between flavour mistag for b and $\bar{b}$, << 1

A_{det}: detector induced asymmetry

Inclusive decays

B → sγ direct CPV

Semi-inclusive, sum of many exclusive states:

BaBar, PRL101, 171804(2008),350 fb^{-1}

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$$
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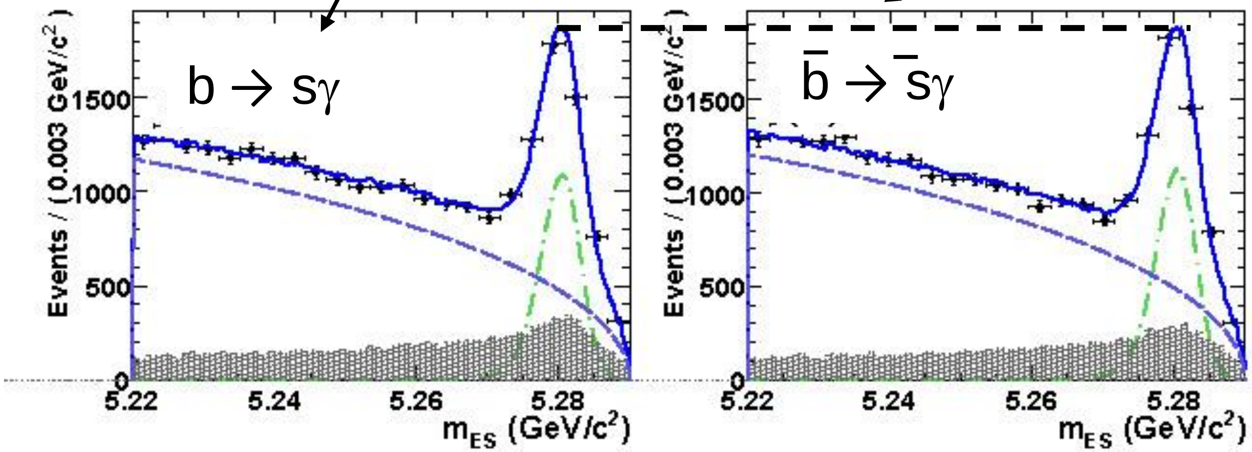
&\quad K_S^0\pi^-\pi^0\pi^0\gamma, K^-\eta\gamma, K^+K^-K^-\gamma,\\
\overline{B}^0 &\rightarrow K^-\pi^+\gamma, K^-\pi^+\pi^0\gamma, K^-\pi^+\pi^-\pi^+\gamma, K^-\pi^+\pi^0\pi^0\gamma,\\
&\quad K^-\pi^+\eta\gamma, K^+K^-K^-\pi^+\gamma,
\end{aligned}
$$

$$\frac{N_b - N_{\bar{b}}}{N_b + N_{\bar{b}}} = \langle D\rangle A_{CP} + \Delta D + A_{\det}$$



<D>: average dilution due to flavour mistag, ~1

ΔD: difference between flavour mistag for b and b̄, << 1

A$_{det}$: detector induced asymmetry

$$A_{CP} = (-0.8 \pm 2.9)\%$$

HFAG, Aug 2012

SM: A_{CP} ~ $(0.44\pm^{0.24}_{0.14})\%$

T. Hurth et al., Nucl.Phys. B704, 56 (2005)

Inclusive decays

B → sγ

direct CPV

Expectations

A_{det} = - 0.007 ± 0.005

A_{det}: careful study of K/π asymmetries in (p, θ_{lab}) using D decays or inclusive tracks from fragmentation;

Inclusive decays

B → sγ

direct CPV

Expectations

A_{det} = - 0.007 ± 0.005
A_{det}: careful study of K/π asymmetries in (p, θ_{lab}) using *D* decays or inclusive tracks from fragmentation;

lots of work on system., few 10^{-3} exp. sensitivity

LHCb, 5 fb^{-1} : $\sigma(S(\psi\phi))$ ~0.02

extrap. from 337 pb^{-1}: ±0.05
(syst. @ 337 pb^{-1} ± 0.07)

LHCb, arXiv:0912.4179

Inclusive decays

B → sγ
direct CPV
Expectations

A_{det} = - 0.007 ± 0.005
A_{det}: careful study of K/π asymmetries in (p, θ_{lab}) using *D* decays or inclusive tracks from fragmentation;

lots of work on system., few 10^{-3} exp. sensitivity

LHCb, 5 fb^{-1} : σ(S(ψϕ)) ~0.02

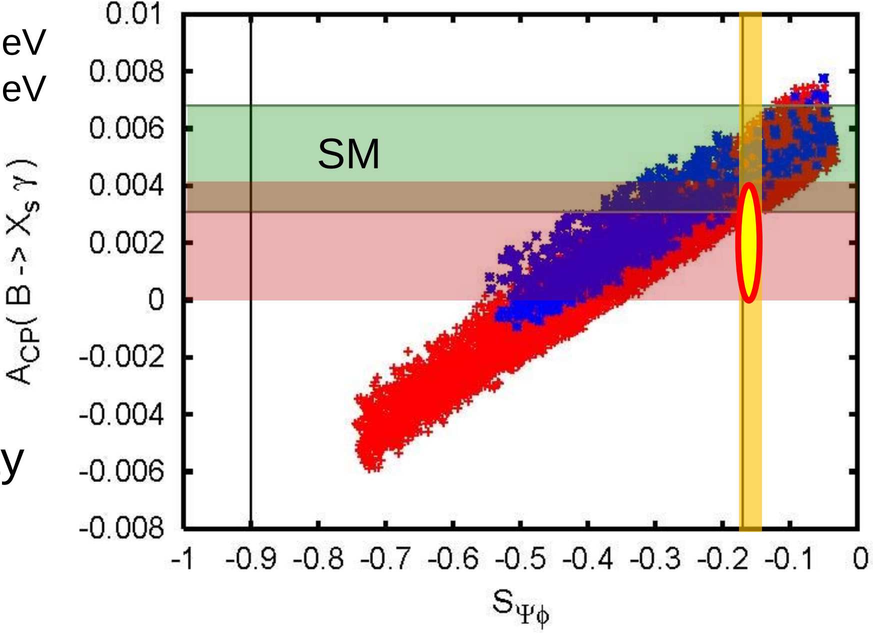
extrap. from 337 pb^{-1}: ±0.05
(syst. @ 337 pb^{-1} ± 0.07)

LHCb, arXiv:0912.4179

🟥 super B fact. sensitivity
🟨 LHCb sensitivity 5 fb^{-1}
○ example of overlap region

A. Soni et al., PRD82, 033009 (2010)

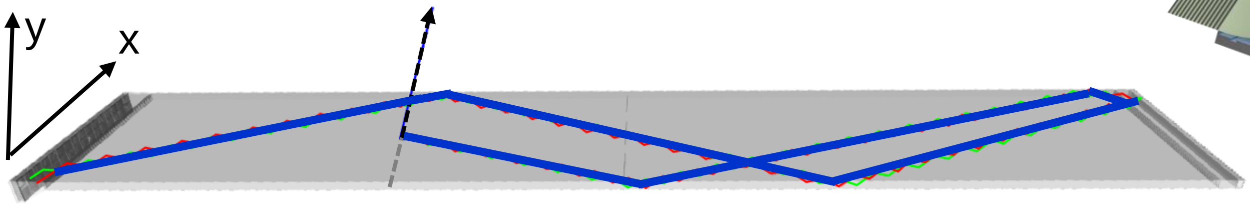
$M_{t'}$
● 400 GeV
● 600 GeV

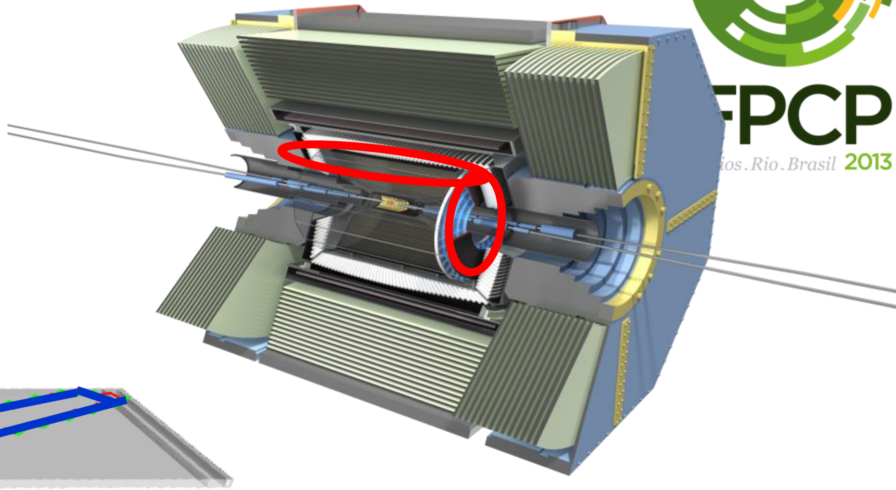


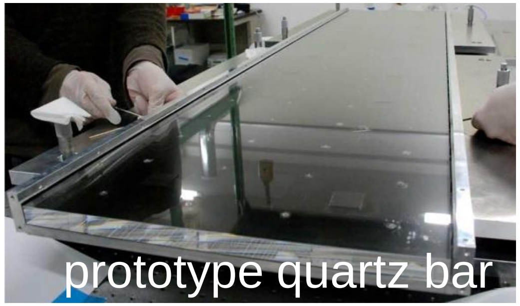
($M_{t'}$ >550 GeV from LHC)

Belle II / Inclusive $b \rightarrow s(+d)\gamma$

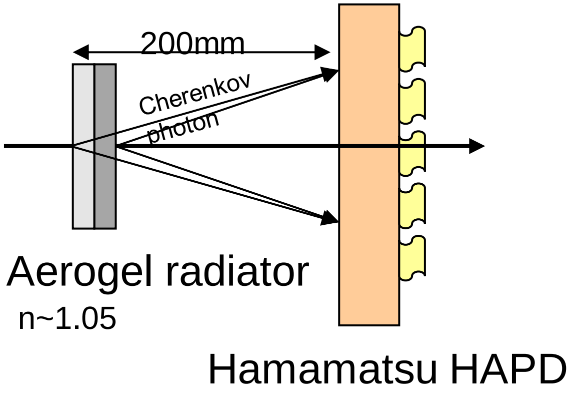
barrel: TOP detector
partial Cerenkov ring reconstruction
from x, y and t of propagation





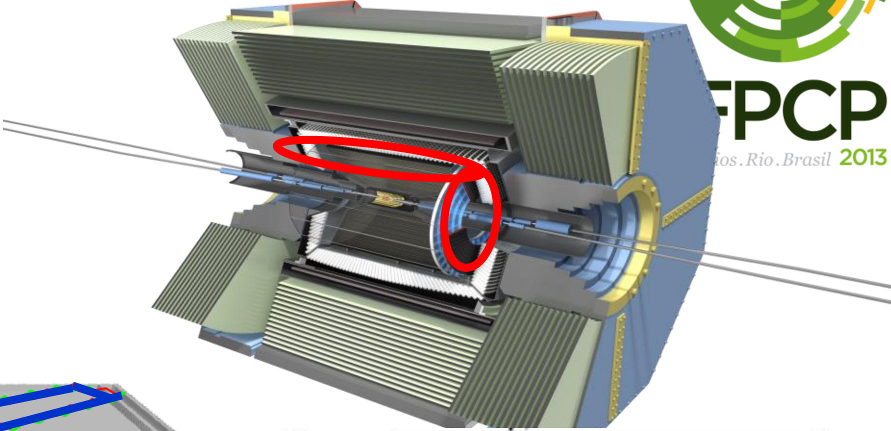

prototype quartz bar

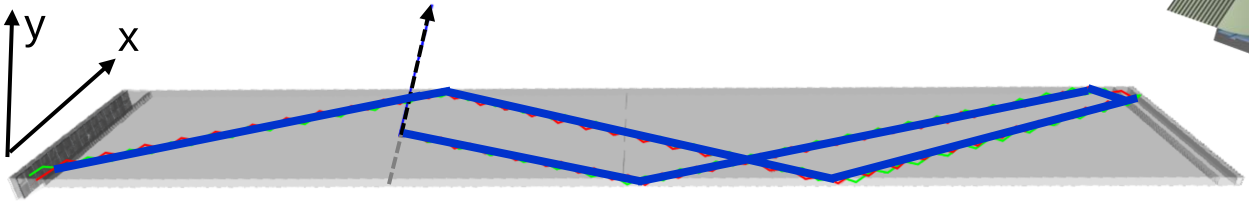
endcap: Proximity
focusing Aerogel
RICH

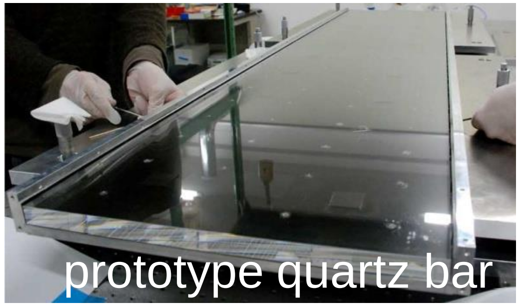


Belle II / Inclusive $b \rightarrow s(+d)\gamma$

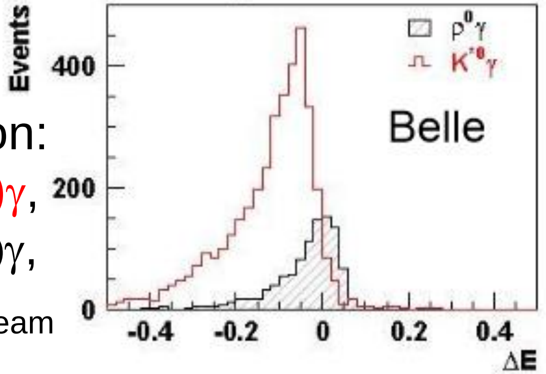
barrel: TOP detector
partial Cerenkov ring reconstruction
from x, y and t of propagation



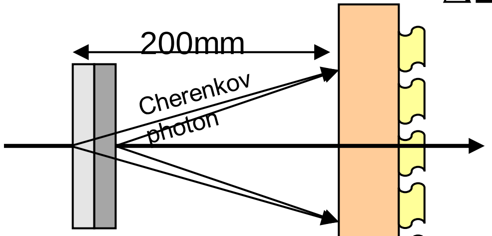


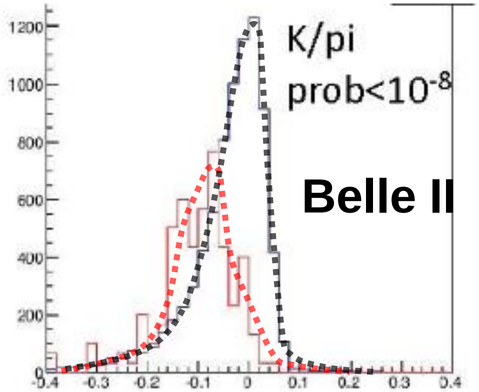


Belle/Belle II full simulation:
$B^0 \rightarrow K^*(K\pi)\gamma$,
$B^0 \rightarrow \rho(\pi\pi)\gamma$,
$\Delta E = E_B^* - E_{beam}$



endcap: Proximity focusing Aerogel RICH





Improved PID performance

Neutrals

$B \to K^* (\to K_S \pi^0)\gamma$
t-dependent CPV

t-dependent decays rate of $B \to f_{CP}$;
S and A: CP violating parameters

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

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SM:
$S_{CP}^{K^*\gamma} \sim -(2m_s/m_b)\sin 2\phi_1 \sim -0.04$

Left-Right Symmetric Models:
$S_{CP}^{K^*\gamma} \sim 0.67 \cos 2\phi_1 \sim 0.5$

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$S_{CP}^{K_S\pi^0\gamma} = -0.15 \pm 0.20$
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HFAG, Summer'12

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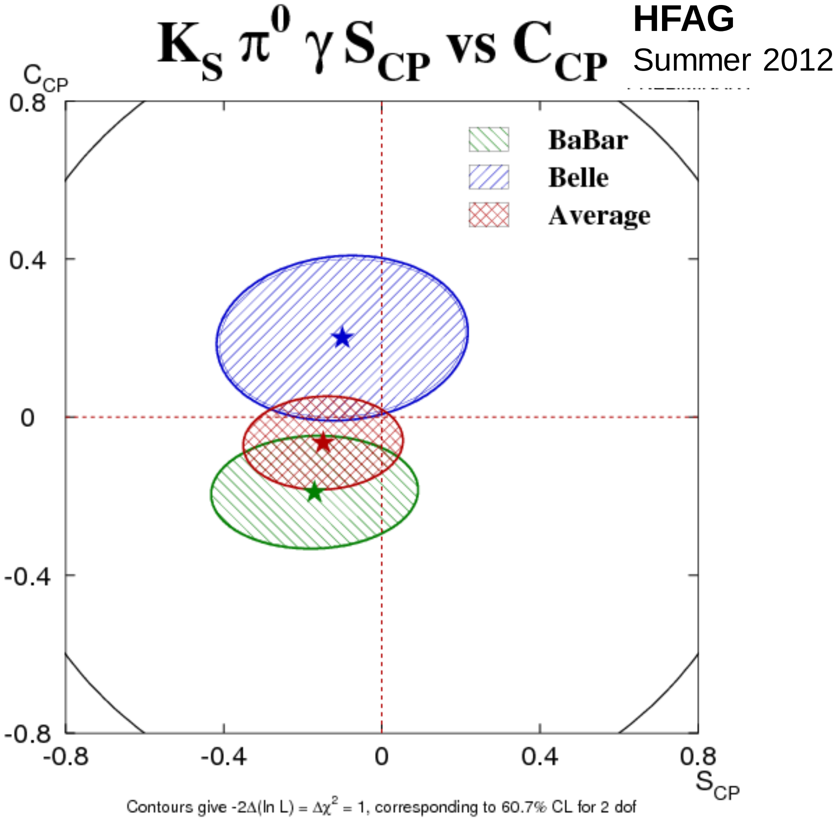

Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 60.7% CL for 2 dof

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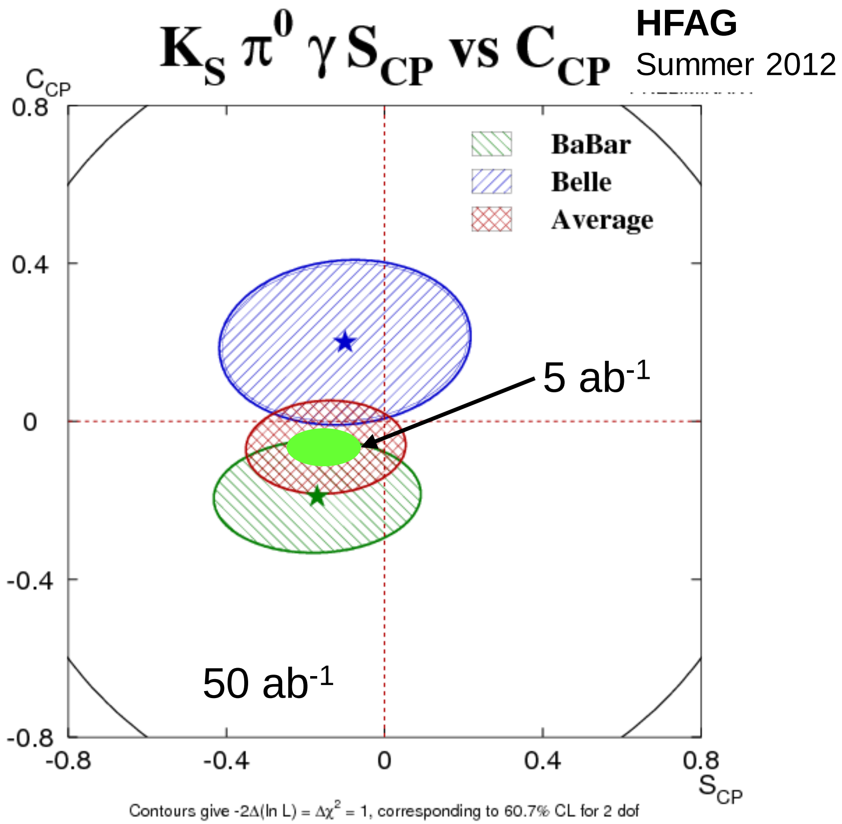
0.03 @ 50 ab^{-1}
(~SM prediction)



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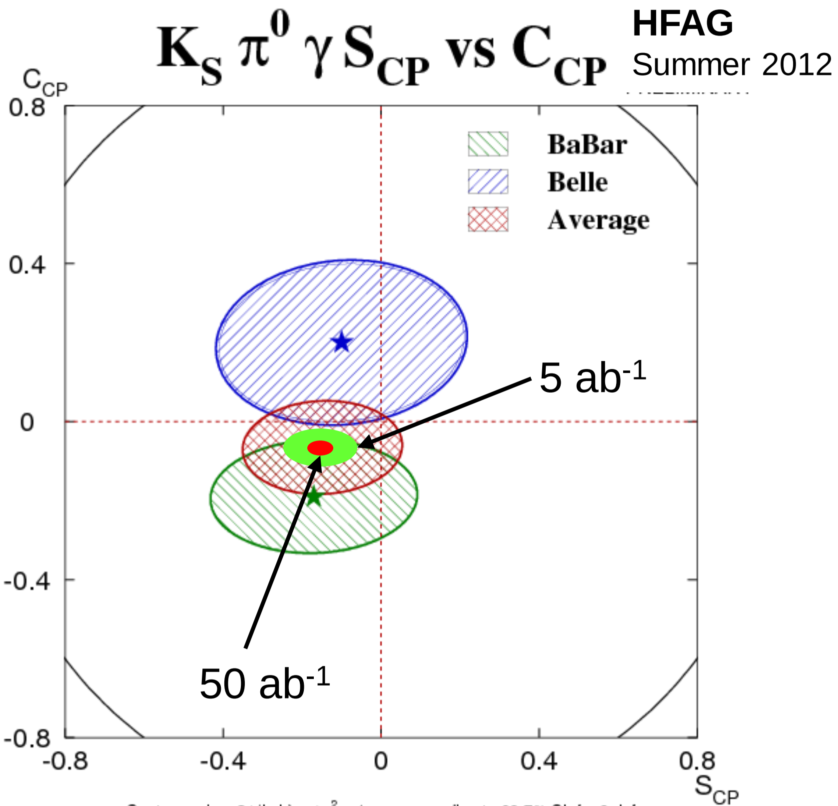

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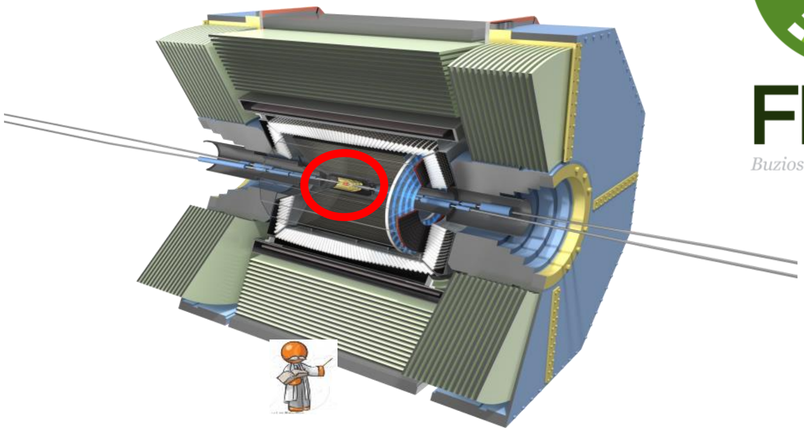
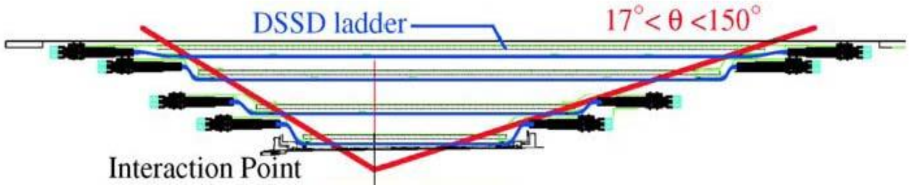
Vertex detector

SVD+PXD



SVD Belle



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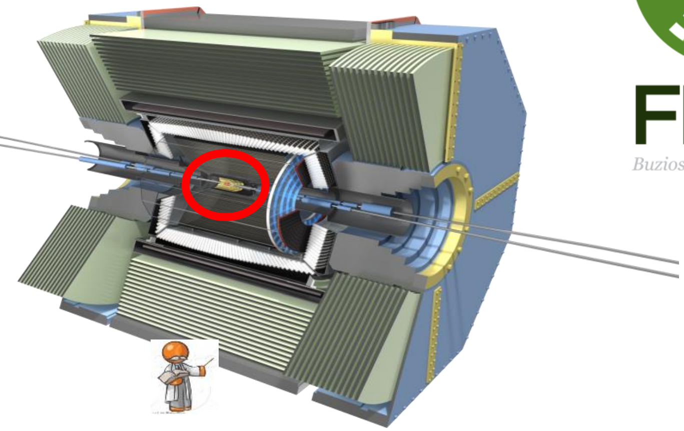
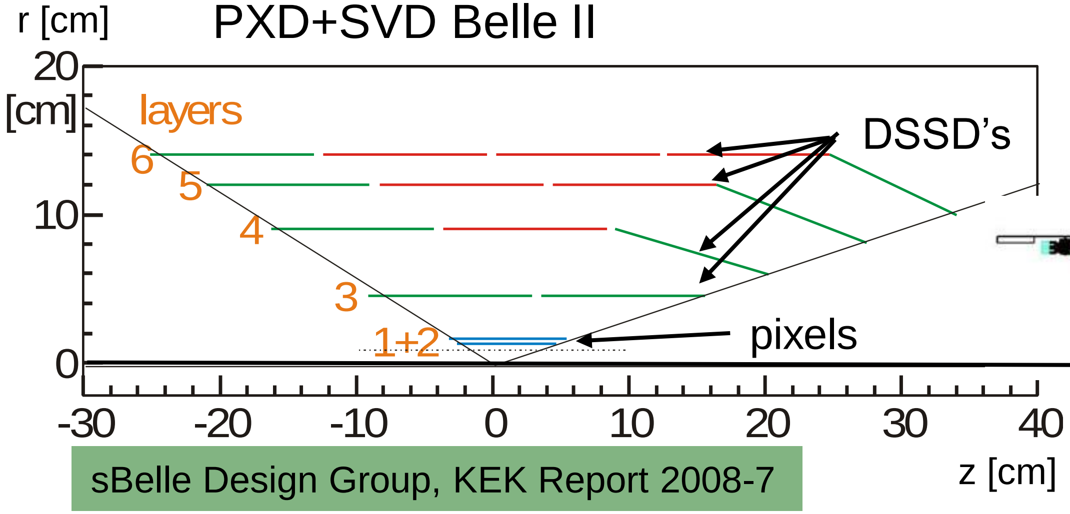
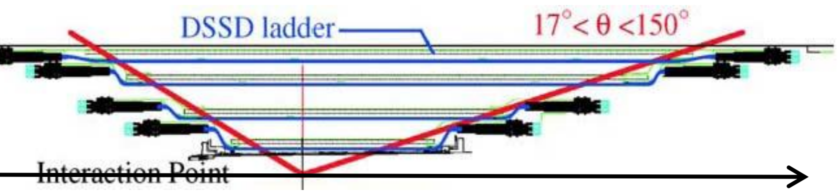


PXD+SVD Belle II



sBelle Design Group, KEK Report 2008-7

SVD Belle



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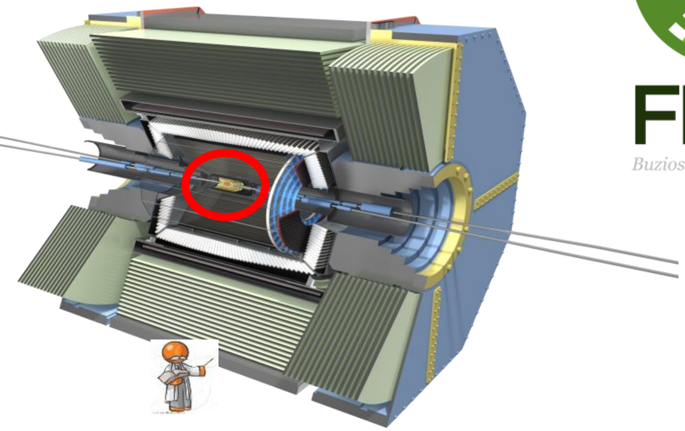

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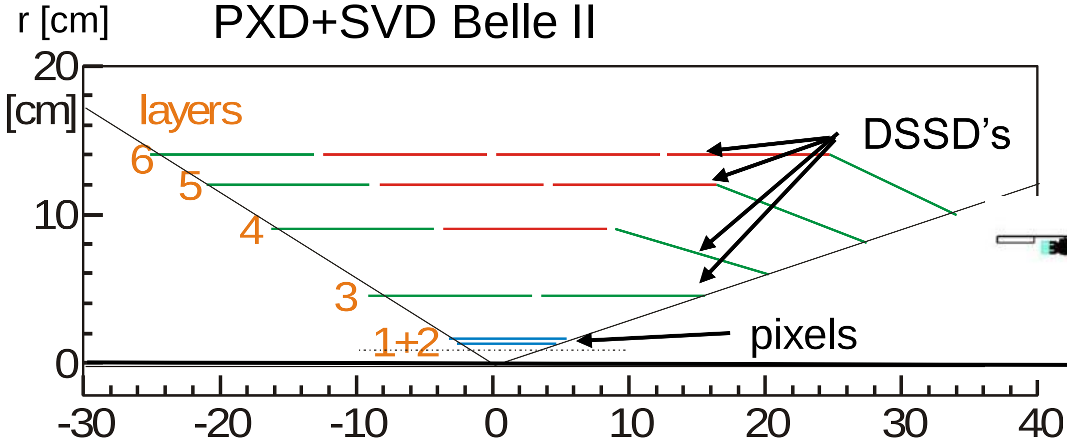

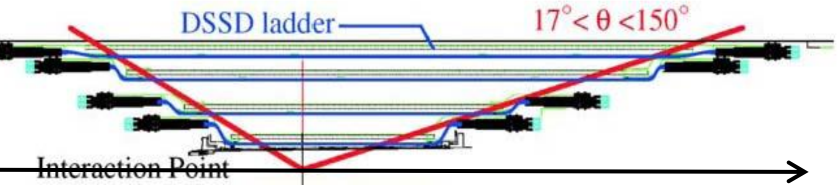

sBelle Design Group, KEK Report 2008-7

Improved vertex determination accuracy;
Improved $K_s \rightarrow \pi^+\pi^-$ (with π hits in PXD+SVD) reconstruction efficiency

Requirements for SBF

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- $\mathcal{O}(10^2)$ higher luminosity

- complementarity to other intensity frontiers experiments (LHCb, BES III, ...);

- accurate theoretical predictions to compare to

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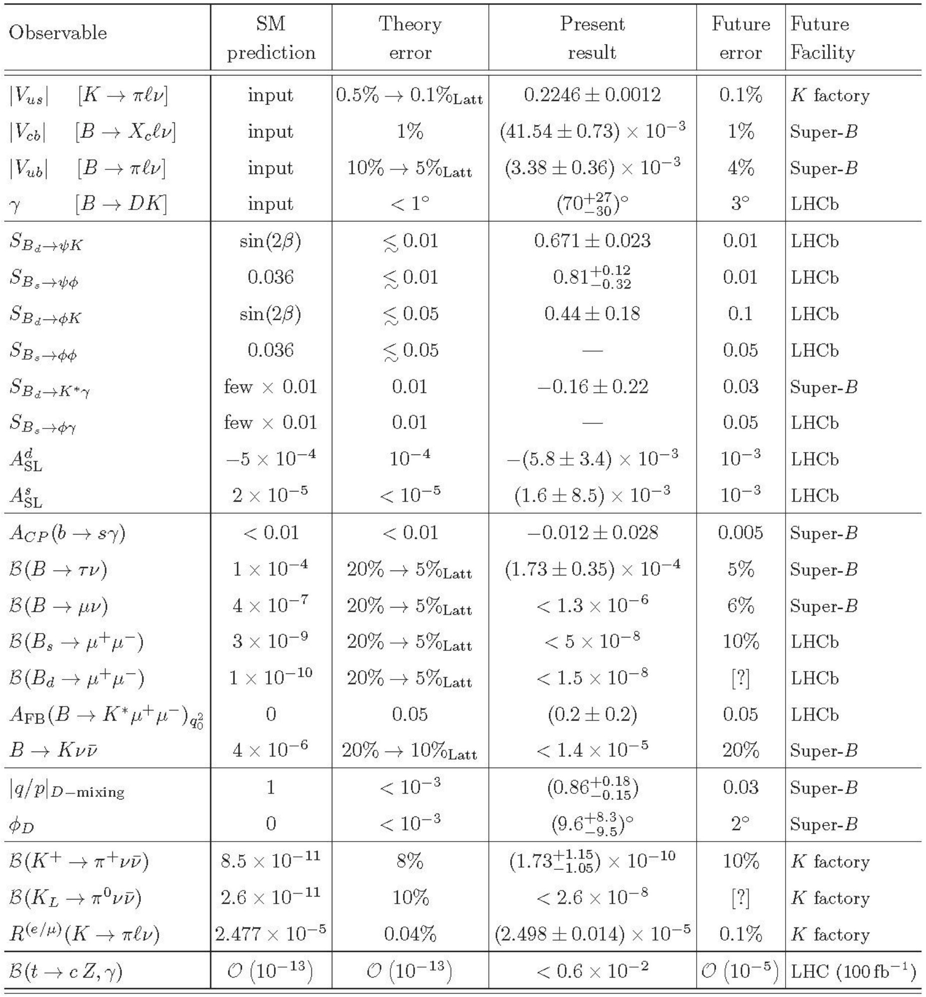

Observable	SM prediction	Theory error	Present result	Future error	Future Facility
$\lvert V_{us}\rvert$ $[K \to \pi\ell\nu]$	input	$0.5\% \to 0.1\%_{\text{Latt}}$	0.2246 ± 0.0012	0.1%	K factory
$\lvert V_{cb}\rvert$ $[B \to X_c\ell\nu]$	input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super-B
$\lvert V_{ub}\rvert$ $[B \to \pi\ell\nu]$	input	$10\% \to 5\%_{\text{Latt}}$	$(3.38 \pm 0.36) \times 10^{-3}$	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_{SL}	-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
A^s_{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}	$20\% \to 5\%_{\text{Latt}}$	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super-B
$\mathcal{B}(B \to \mu\nu)$	4×10^{-7}	$20\% \to 5\%_{\text{Latt}}$	$< 1.3 \times 10^{-6}$	6%	Super-B
$\mathcal{B}(B_s \to \mu^+\mu^-)$	3×10^{-9}	$20\% \to 5\%_{\text{Latt}}$	$< 5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \to \mu^+\mu^-)$	1×10^{-10}	$20\% \to 5\%_{\text{Latt}}$	$< 1.5 \times 10^{-8}$	[?]	LHCb
$A_{\text{FB}}(B \to K^*\mu^+\mu^-)_{q_0^2}$	0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \to K\nu\bar{\nu}$	4×10^{-6}	$20\% \to 10\%_{\text{Latt}}$	$< 1.4 \times 10^{-5}$	20%	Super-B
$\lvert q/p\rvert_{D-\text{mixing}}$	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})
$\mathcal{B}(B \to X_s\gamma)$				6%	Super-B
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$S(B \to \rho\gamma)$				0.15	Super-B
$\mathcal{B}(\tau \to \mu\gamma)$				$3 \cdot 10^{-9}$	Super-B (90% U.L.)
$\mathcal{B}(B^+ \to D\tau\nu)$				3%	Super-B
$\mathcal{B}(B_s \to \gamma\gamma)$				$0.25 \cdot 10^{-6}$	Super-B (5 ab^{-1})
$\sin^2\theta_W$ @ $\Upsilon(4S)$				$3 \cdot 10^{-4}$	Super-B

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

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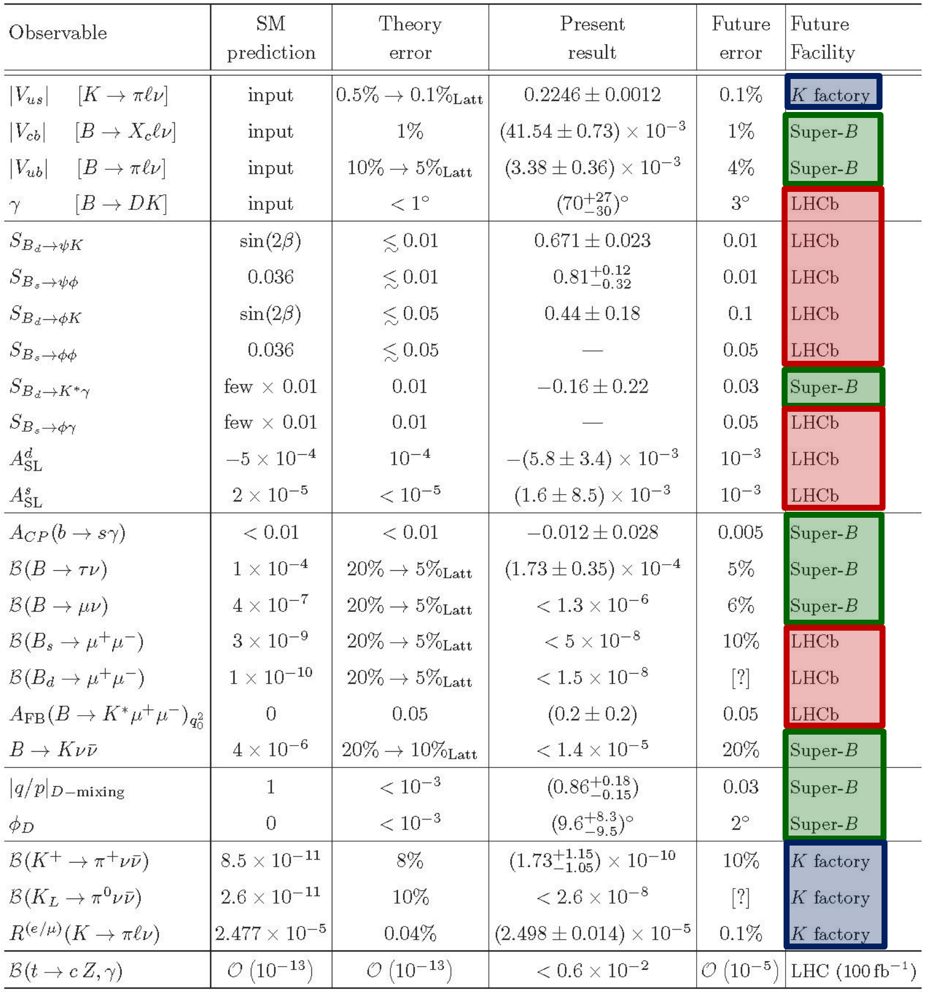

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$\gamma \quad [B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	3°	LHCb
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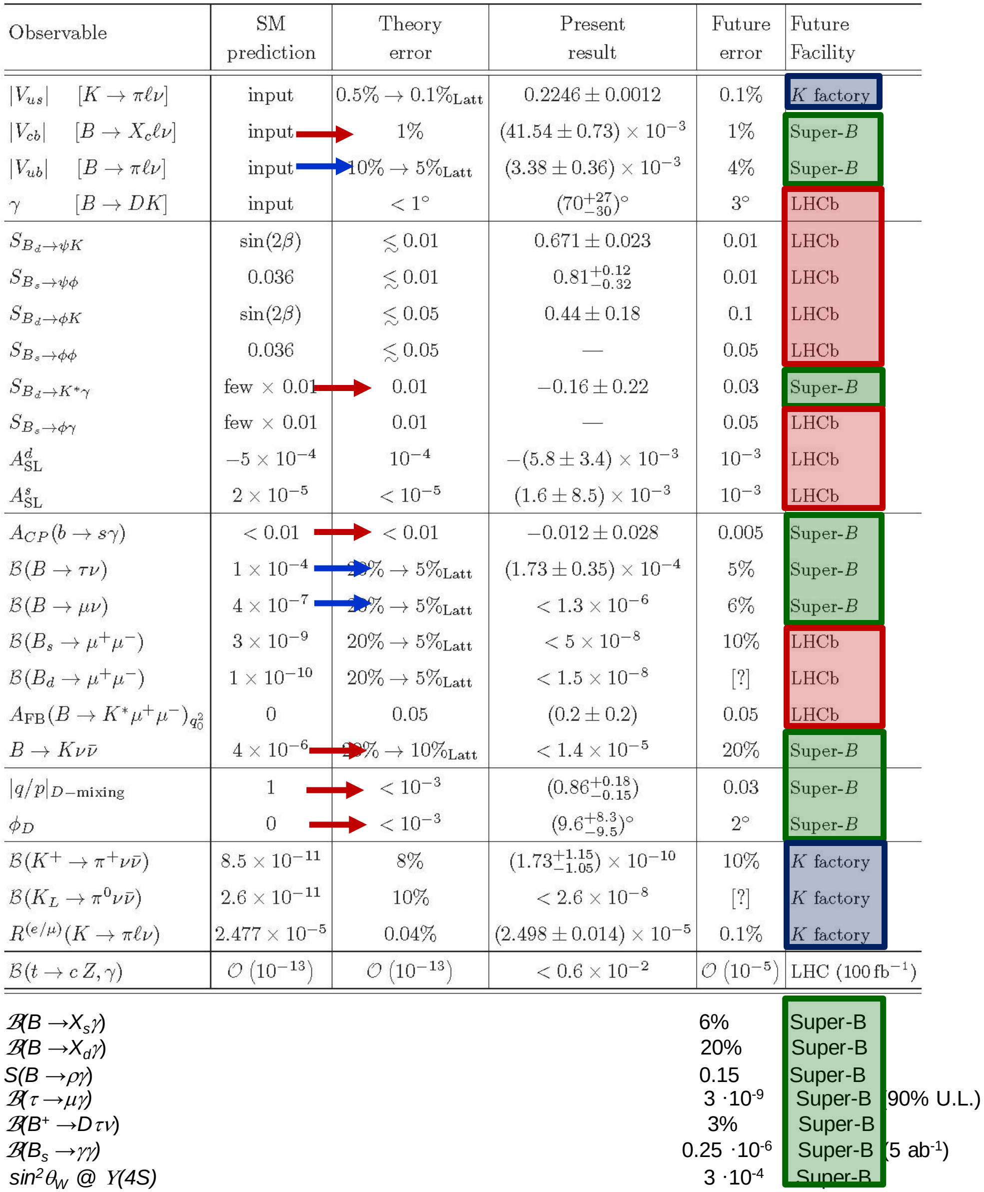
→ theory uncertainty matches the expected exp. precision

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



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

Summary

- Belle II: successor to B factories with $\mathcal{O}(10^2)$ larger data sample

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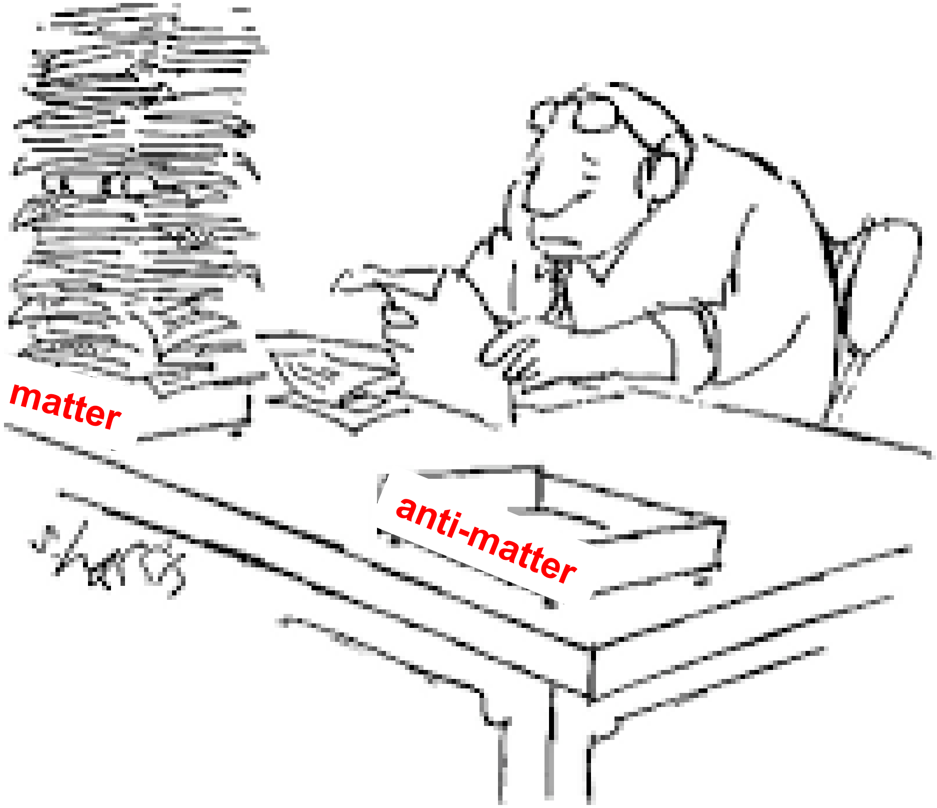

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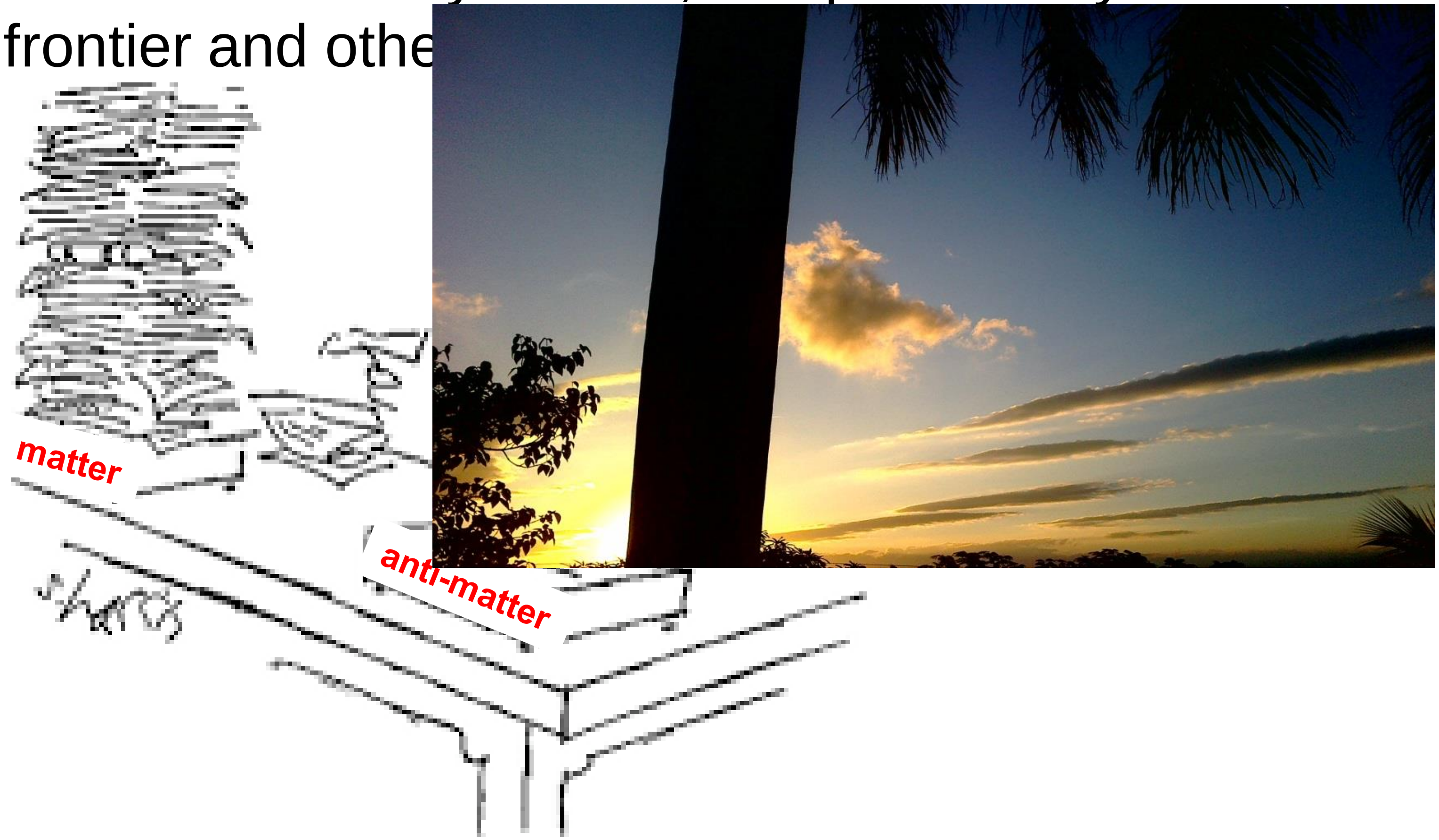

Summary

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- search for NP at intensity frontier, complementary to energy frontier and other precision experiments
- physics benchmarks, methods, ... known from B factories, need to think about modification of those (and new ones) more appropriate for huge statistics

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- Belle II: successor to B factories with $\mathcal{O}(10^2)$ larger data sample

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- Belle II and SuperKEKB well on track, scheduled to start in 2015

Additional material

accelerator
beam backgrounds
beam asymmetry

detector upgrade
high level trigger
detector upgrade schedule

$B^0 \to K_S \pi^0 \gamma$

SVD+PXD

$B \to K\pi$ DCPV

TOP

inclusive $b \to s\gamma$

$\sin 2\phi_1$

$B \to \tau\nu$
$B \to h\nu\nu$

$\tau \to \mu\gamma$

S in $b \to s\gamma$

CPT violation
T violation

$\sin^2\theta_W$

$B^0 \to K\pi\pi^0$

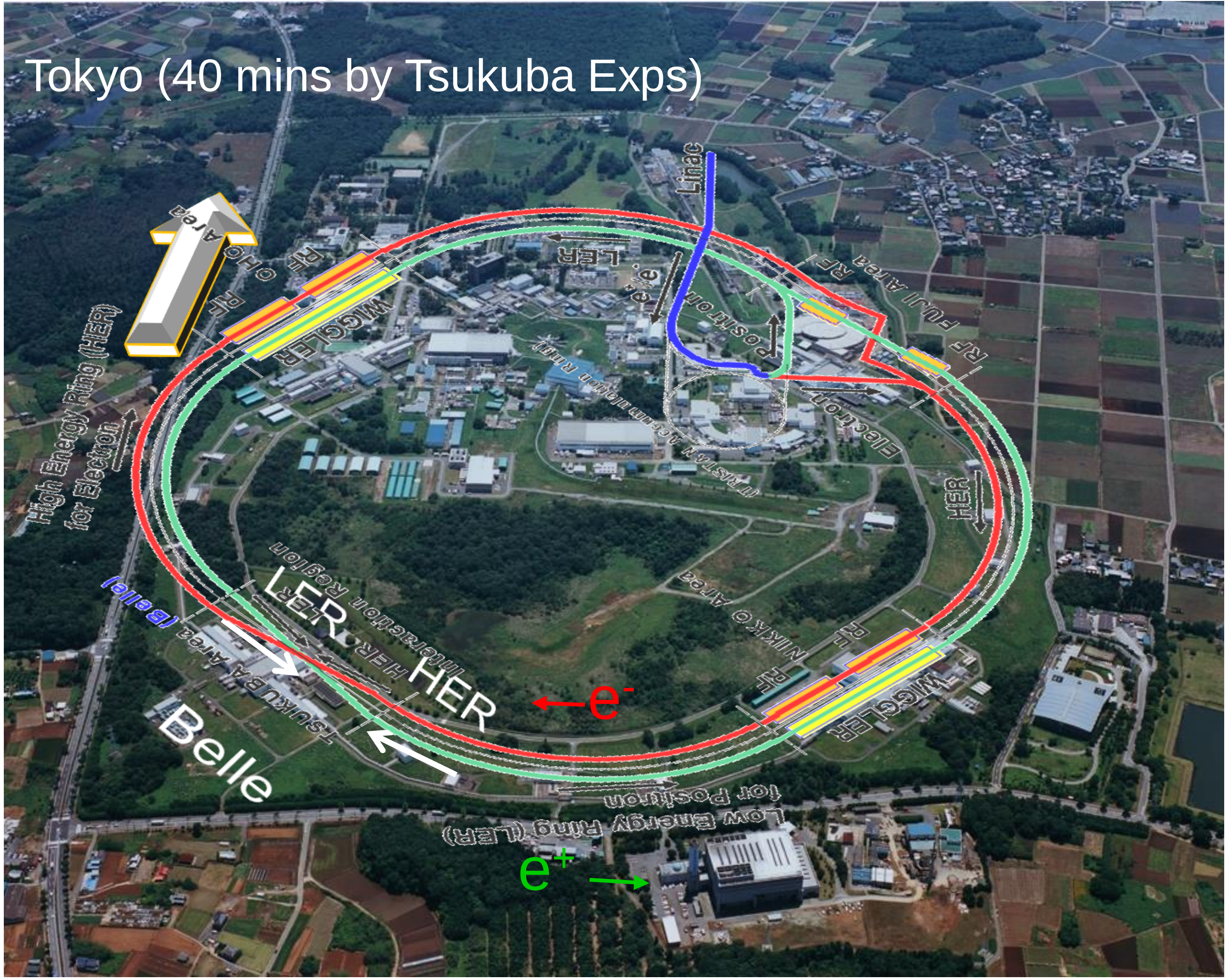
Charm mixing and CPV

Accelerator

“B-Factory”, KEKB @ KEK

KEKB → accelerator

KEK → institute



KEKB:

e^- (HER): 8.0 GeV
e^+ (LER): 3.5 GeV

crossing angle:
22 mrad

$E_{CMS}=M(\Upsilon(4S))c^2$

$dN_f/dt = \sigma(e^+e^- \to f)\,\mathcal{L}$

$$\int_{1999}^{2010} \mathcal{L}dt = 1020 \text{ fb}^{-1}$$

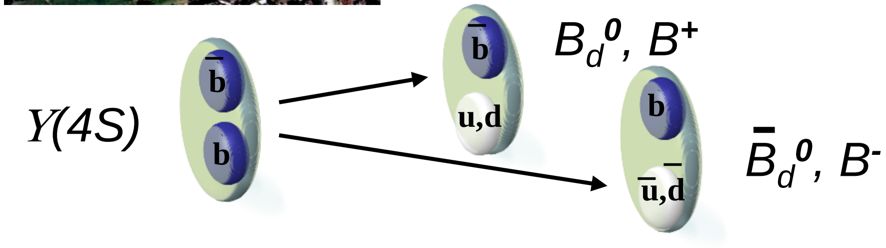
(1.02 ab^{-1})

back

Accelerator

BF, KEKB @ KEK / PEPII @ SLAC

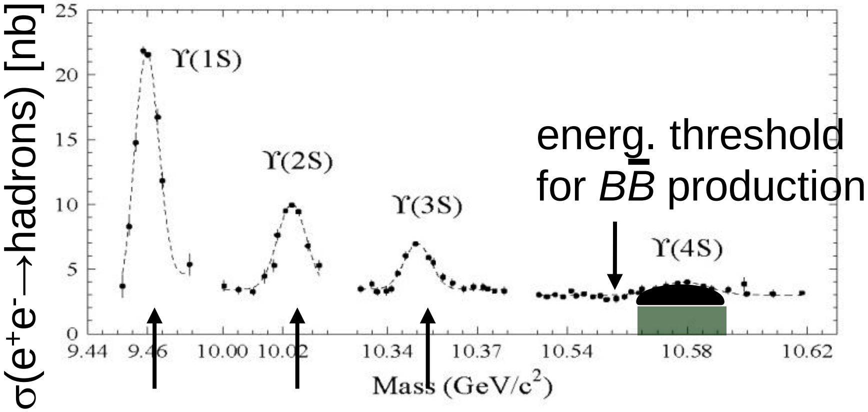
Belle $\int\mathcal{L}dt \approx 1020$ fb^{-1}
BaBar $\int\mathcal{L}dt \approx 550$ fb-1



$\Upsilon(4S)$

B_d^0, B^+

$\bar{B}_d^0$, B^-



energ. threshold for $B\bar{B}$ production

"on resonance" production

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

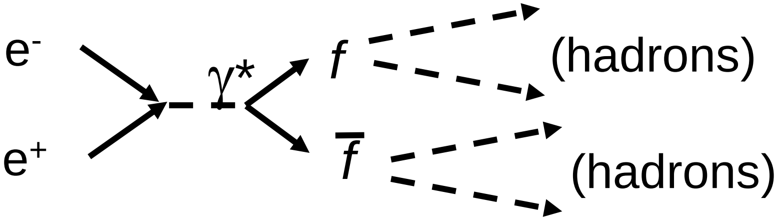
$\sigma(e^+e^- \to B\bar{B}) \approx 1.1$ nb (~10^9 $B\bar{B}$ pairs Belle)

"continuum" production, $q\bar{q}$, $\ell\ell$, $\tau\tau$

$\sigma(e^+e^- \to c\,\bar{c}) \approx 1.3$ nb (~1.3×10^9 $X_c\bar{Y}_c$ pairs Belle)

running at $Y(nS)$, e.g. $Y(5S)$ ($B_s\bar{B}_s$)

back



e^-

e^+

γ^*

f

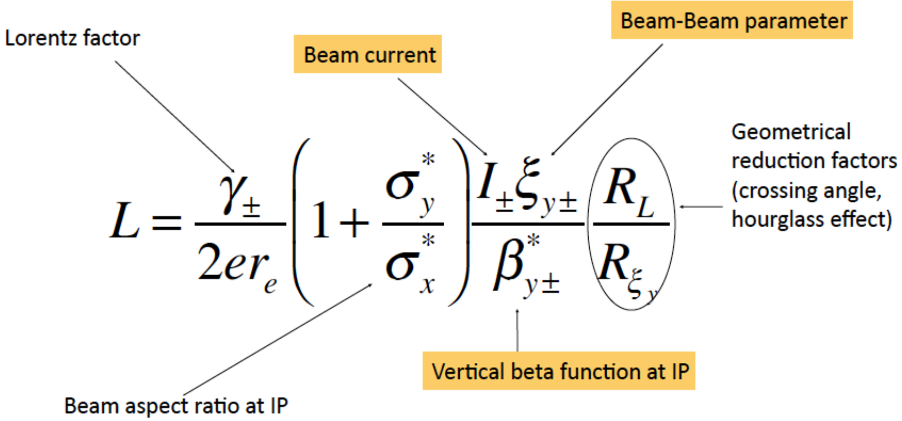
$\bar{f}$

(hadrons)

(hadrons)

Accelerator

Luminosity:



$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lorentz factor

Beam current

Beam-Beam parameter

Geometrical reduction factors (crossing angle, hourglass effect)

Vertical beta function at IP

Beam aspect ratio at IP

high-current: large *I*

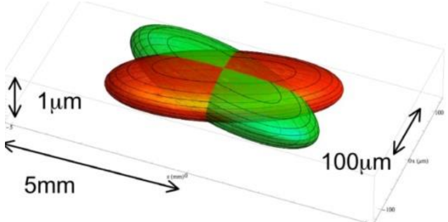
nano-beam:

small β_y^*

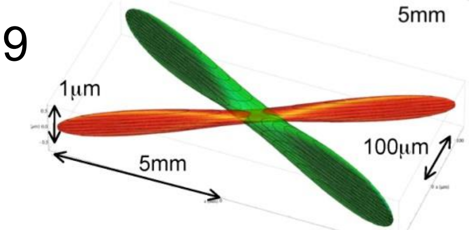
large $\xi_y \propto \sqrt{(\beta_y^*/\varepsilon_y)} \Rightarrow$ small ε_y

hourglass effect $\Rightarrow$ small β_x^*

β^*: beta-function (trajectories envelope) at IP



σ_x~100µm,σ_y~2µm



σ_x~10µm,σ_y~60nm

small β_y^*[mm]: 5.9(LER)/5.9(HER)→ 0.27/0.30
small β_x^*[mm]: 1200(LER)/1200(HER)→ 32/25
small ε_y: keep current ξ_y 0.101(LER)/0.096(HER) → 0.09/0.09
increase *I* [A]: 1.8(LER)/1.45(HER) → 3.6/2.1

small ε LER: longer bends; HER: more arc cells
small β^*: separate quadrupoles closer to IP
small ε, β^*: small dynamic aperture, larger Touschek background and smaller τ_{beam}

dynamic aperture: phase space volume of acceptable trajectories;
Touschek effect: Coulomb scattering causing transfer of transverse to longitud. momentum between particles in a bunch; if transfer is too large particles are lost

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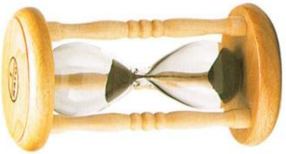
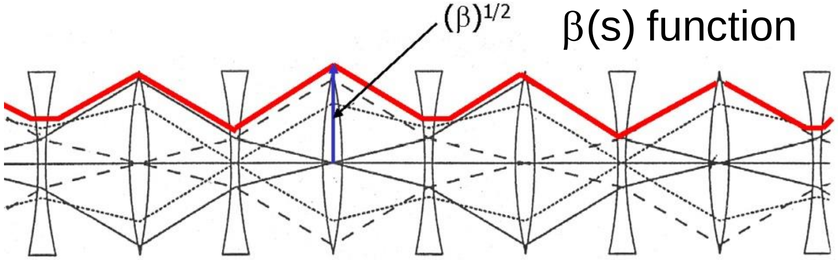
Hourglass effect

naive luminosity formula: $\mathcal{L} = \frac{N_1 N_2}{2\pi \Sigma_x^* \Sigma_y^*}$

$\Sigma_{x,y}^*$: $\sqrt{(\sigma_{x,y1}^{*2} + \sigma_{x,y2}^{*2})}$
horiz., vertical bunch size @ IP

valid if $\sigma_z << \beta^*_{x,y}$;
if not $\Rightarrow \sigma_{x,y}$ depending on $\beta^*_{x,y} \Rightarrow$ reduction of luminosity;





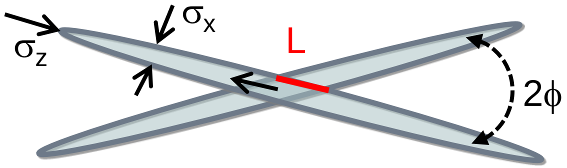
effect: more involved formula

$$\sigma_{xi}^2 = \sigma_{xi}^{*2}\left(1 + \frac{z^2}{\beta_{xi}^{*2}}\right) \qquad \frac{1}{u_x^2} = \frac{\Sigma_z^2}{2\Sigma_x^{*2}}\left(\frac{\sigma_{x1}^{*2}}{\beta_{x1}^{*2}} + \frac{\sigma_{x2}^{*2}}{\beta_{x2}^{*2}}\right)$$

$$\sigma_{yi}^2 = \sigma_{yi}^{*2}\left(1 + \frac{z^2}{\beta_{yi}^{*2}}\right) \qquad \frac{1}{u_y^2} = \frac{\Sigma_z^2}{2\Sigma_y^{*2}}\left(\frac{\sigma_{y1}^{*2}}{\beta_{y1}^{*2}} + \frac{\sigma_{y2}^{*2}}{\beta_{y2}^{*2}}\right)$$

$$\mathcal{L}_0 = \frac{N_1 N_2}{2\pi \Sigma_x^* \Sigma_y^*} \int_{-\infty}^{\infty} \frac{du}{\sqrt{\pi}} \frac{e^{-u^2}}{\sqrt{1 + u^2/u_x^2}\sqrt{1 + u^2/u_y^2}}$$

to avoid large hourglass effect (reducing $\mathcal{L}$):



head-on: $\beta_y^* \geq \sigma_z$ crossing-angle: $\beta_y^* \geq L = \sigma_x/\phi \propto \beta_x^*/\phi$

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Accelerator

Touschek effect

In Coulomb scattering between particles in a bunch transverse momentum is transfered to longitudinal one (multiplied by γ);
if the longitudinal momentum transfer exceeds accelerator momentum acceptance particles are lost;
beam current decreases exponentially:

$$\frac{1}{\tau} = -\frac{1}{N_{bunch}}\frac{dN_{bunch}}{dt}$$

H. Wiedemann, Particle Accelerator Physics, Springer

$$\tau = \frac{8\pi\sigma_x\sigma_y\sigma_z}{r_c^2 c N_{bunch}}\gamma^2\left(\frac{\Delta p}{p_0}\right)^3_{acc}\frac{1}{D(\varepsilon)} \qquad \varepsilon = \left(\frac{\Delta p\beta_x}{mc\gamma^2\sigma_x}\right)$$

effect more important for LER

$N_{bunch}/\sigma_x\sigma_y\sigma_z$: particle density in bunch
$(\Delta p/p_0)_{acc}$: momentum acceptance
r_C: orbit radius

for large τ: increase $(\Delta p/p_0)_{acc}$; this also reduces $\sigma_x\sigma_y\sigma_z$ but the overall effect on τ is positive

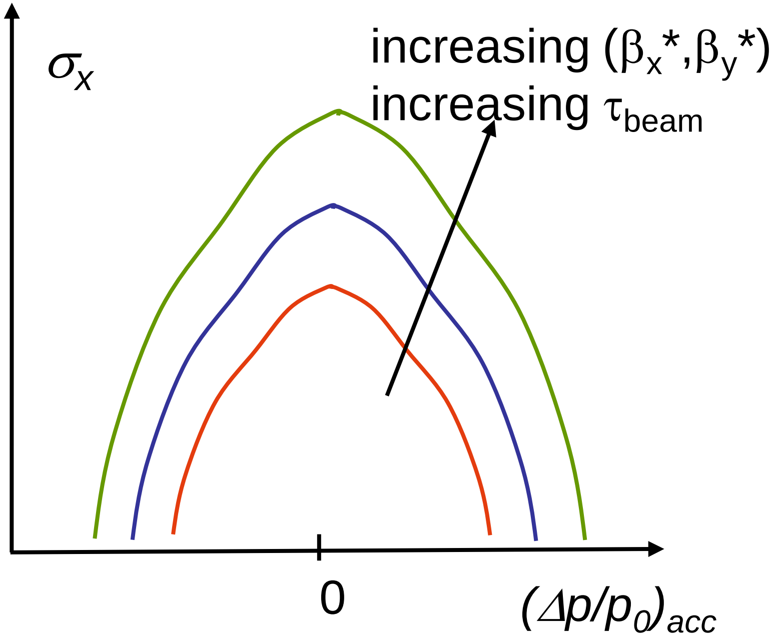
back

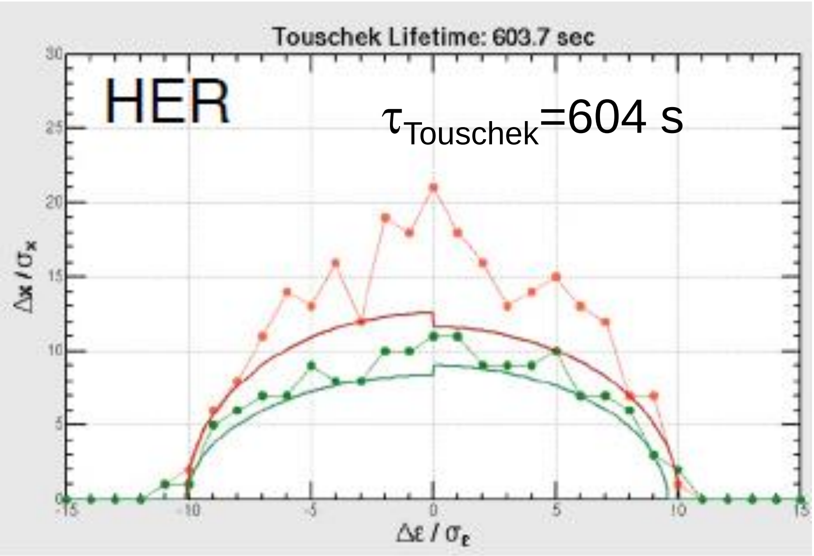
Accelerator

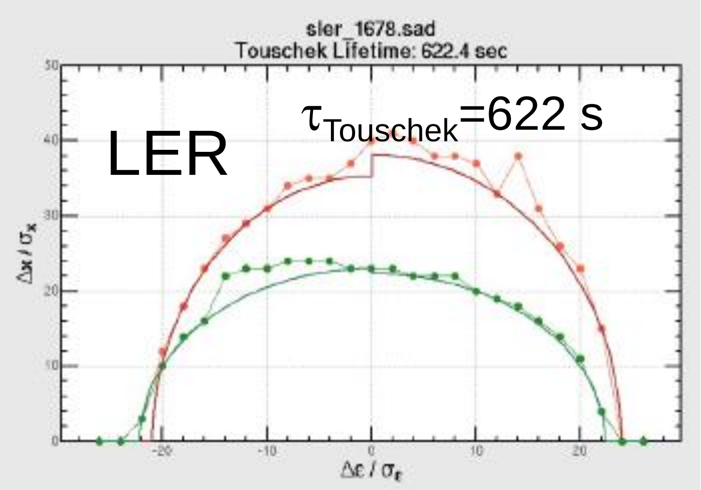
high current option:

- high operation costs
- too low beam-beam parameter
- CSR prevents squeezing the beam
- difficult to find solution for IR with low enough β^*

dynamic aperture:







design value for $\tau_{Touschek}$: 600 s

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SuperKEKB parameters

	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	ε_x (nm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	18/24	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	3.2/4.6	41.5	3.6/2.6	$80\text{x}10^{34}$

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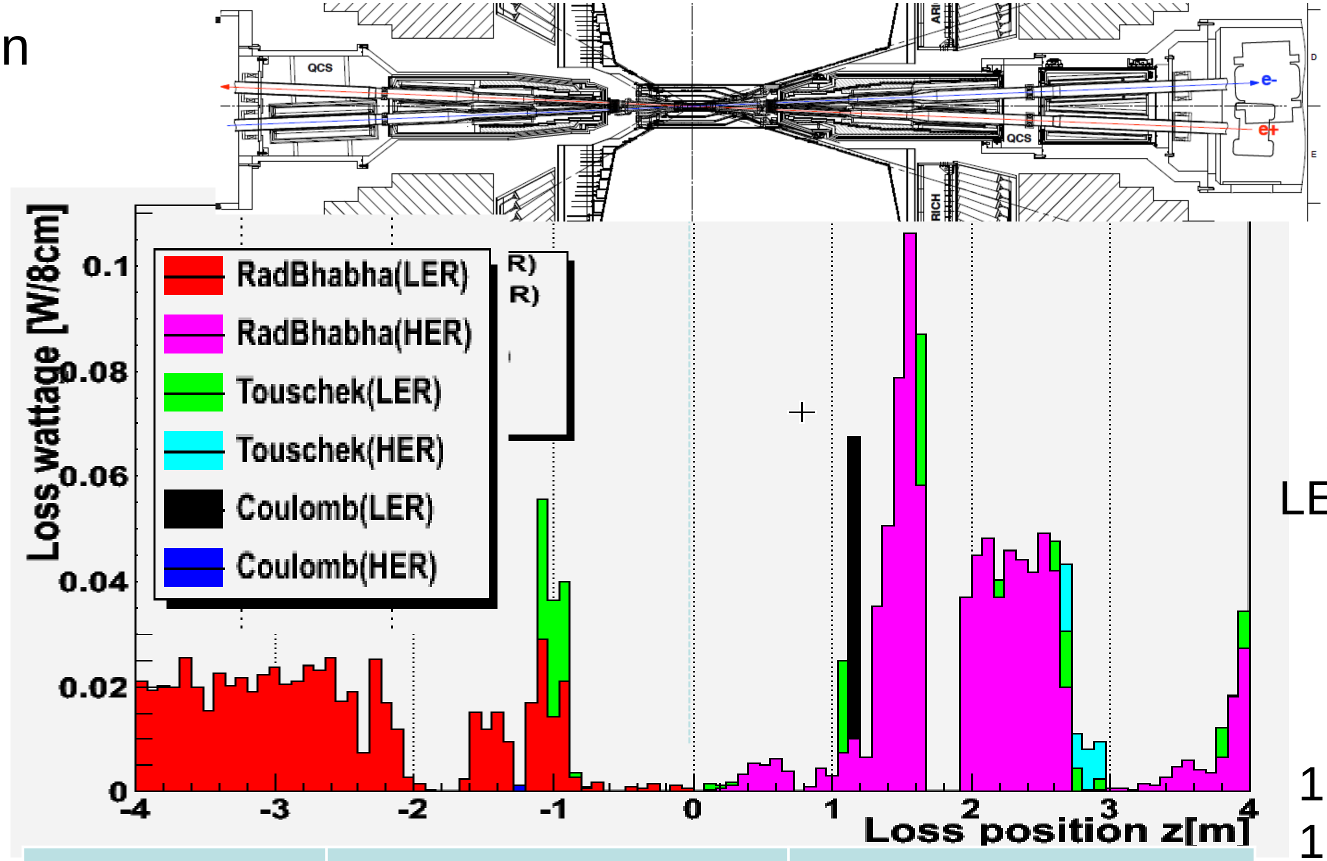
Beam backgrounds

BG loss position
by type

HER
(e-)



LER(e+)

1GeV ,
1GHz
= 0.16W

	LER (4GeV e+)	HER (7GeV e-)
Rad. Bhabha	0.63 W (eff. 0.98GHz)	0.88W (eff. 0.78GHz)
Touschek	0.16 W (0.25GHz)	0.03 W (0.03 GHz)
Coulomb	0.06 W (0.09GHz)	0.001W (0.001GHz)

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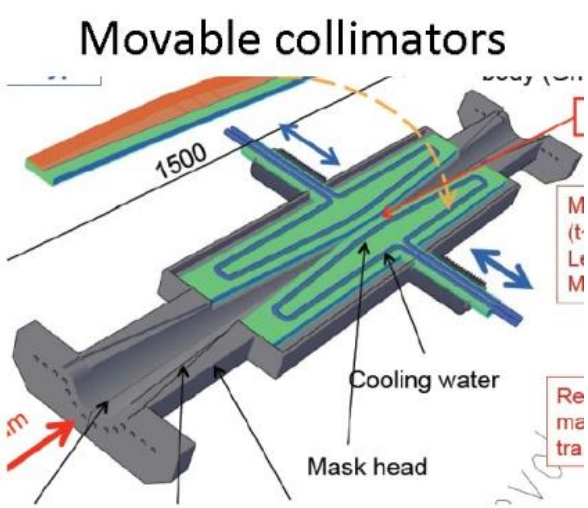
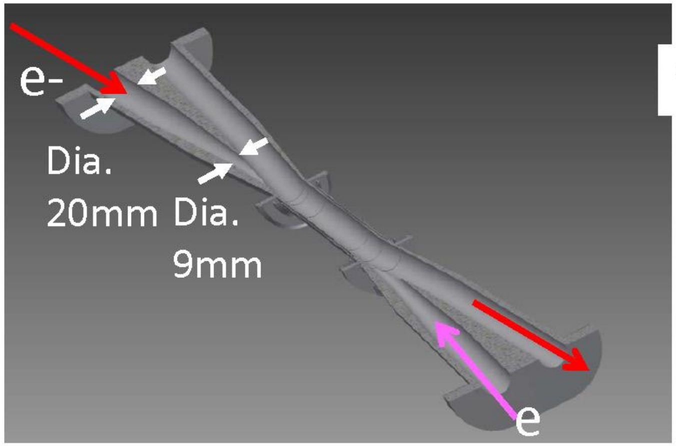
Accelerator background

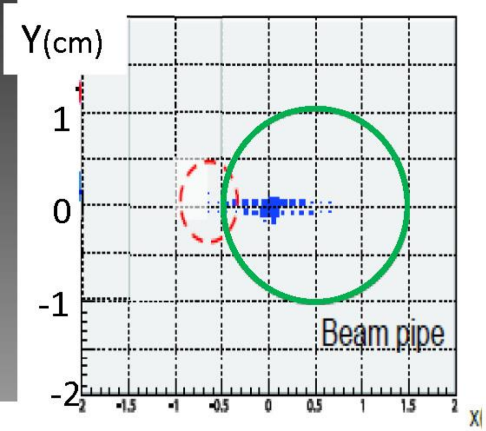


Touschek background: reduced by horizontal collimators

Beam-gas background: reduced by vertical collimators

Synchrotron radiation: reduced by collimation on incoming beam pipe





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Beam backgrounds

PXD occupancy due to SR:

Occupancy at good alignment
LER SR: 0.6%+-0.15% (1st half at phi=0)
HER SR: 0.5%+-0.3 % (all ladders)

In case of misalignment,
LER SR: 1.0%+-0.15% (1st half at phi=0)

PXD, SVD: not dominated by rad. Bhabha, SR at limit

CDC: wire hit rate, dose ok; neutron (<2.6 $\cdot 10^{11}$ n/cm^2/year) not satisfactory

TOP: dose , neutrons ok, photoelec. flux too high (2 MHz/PMT, mainly from rad. Bhabha)

ARICH: dose ok, neutron flux on inner rings high (limit 10^{11} n/cm^2/year)

ECL: crystal neutron flux, diode dose ok, crystal dose (10% over 10 year tolerance) and diode neutron flux (2x 10 year tolerance) high; main source rad. Bhabha HER

$\Rightarrow$

further mitigation of specific types of backgrounds for some detectors

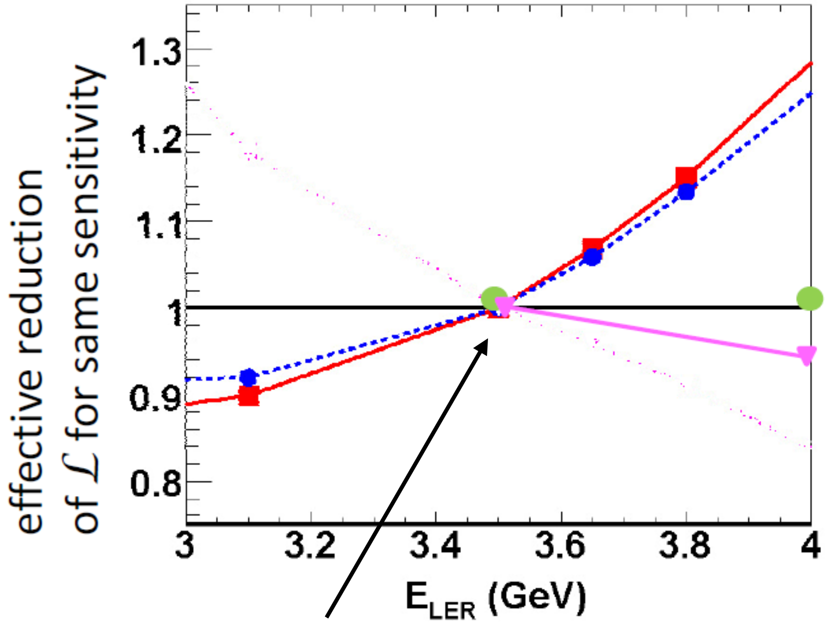
back

Accelerator Asymmetry

larger asymm.: larger boost, better relative decay time resolution, better continuum bkg. rejection

smaller asymm.: more isotropic events, better hermeticity

sBelle Design Group, KEK Report 2008-7



$\sigma_{\Delta z}$ = 180 μm, $\beta\gamma$=0.425 → $\sigma_{\Delta t}$=1.4 ps

t-dependent:

— $B \to J/\psi\ K_S$

— $B \to \phi\ K_S$

● $D^* \to D^0\pi,\ D^0 \to K^+K^-$

t-independent:

— $B \to \tau\nu$

not including improved resol. of upgraded PXD+SVD!

if $\sigma(\Delta z)$ improved by 10%-15% → σ(t-dependent) improved by 5%-10%

→ effective $\int\mathcal{L}dt$: ↓10%-20%

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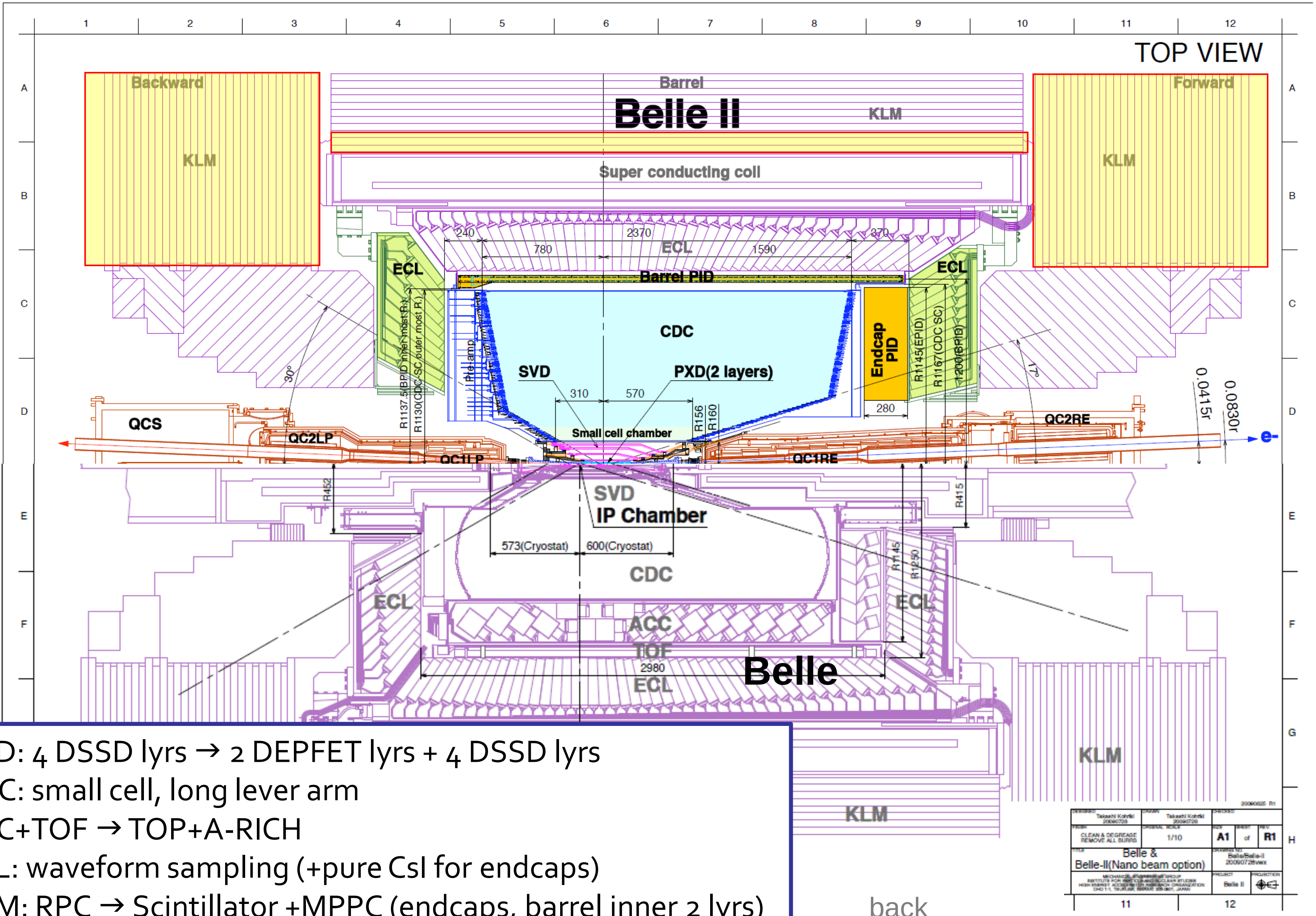
Detector upgrade



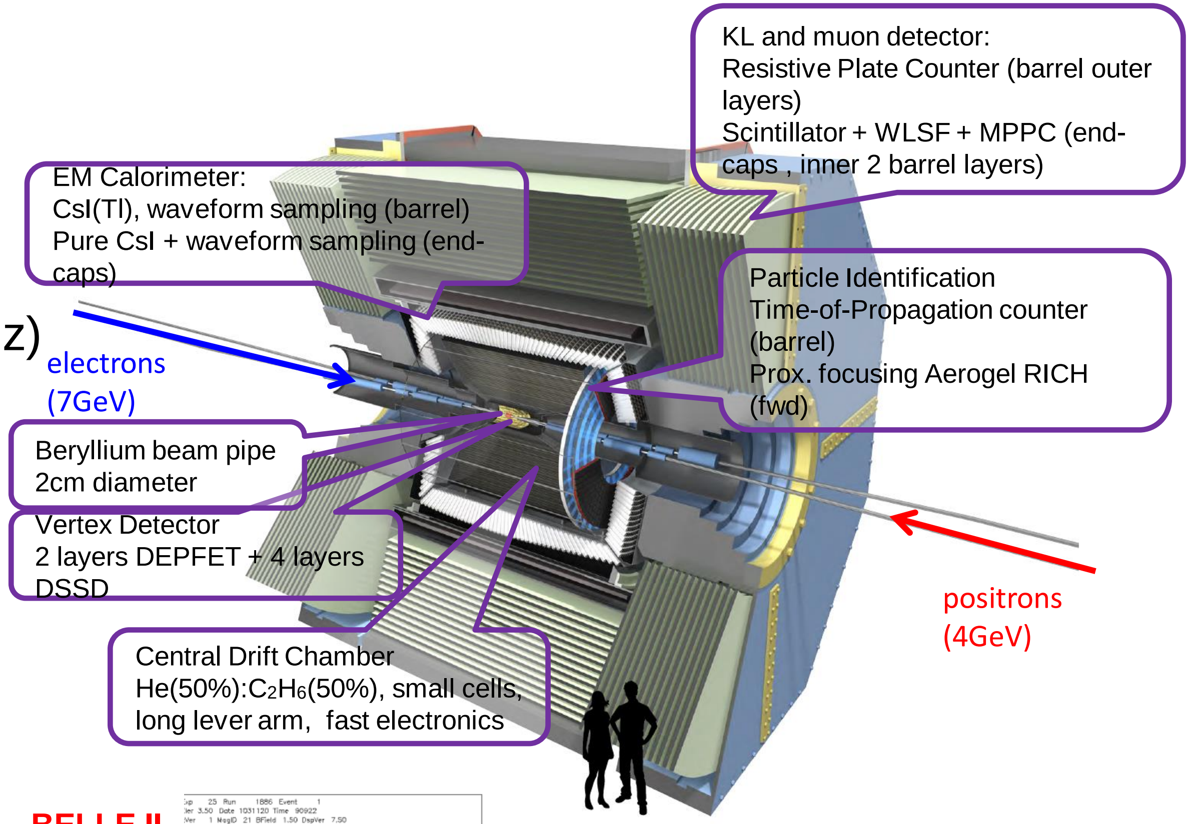
SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

back

Detector upgrade

have to deal with:

- higher background (10-20x)
  radiation damage,
  higher occupancy
- higher event rates
  DAQ (L1 trigg. 0.5 →30 kHz)
  HLT (→5 kHz)
- improved performance
  hermeticity



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

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

electrons (7GeV)

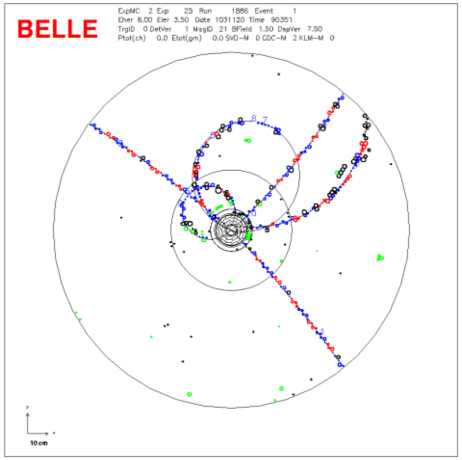
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

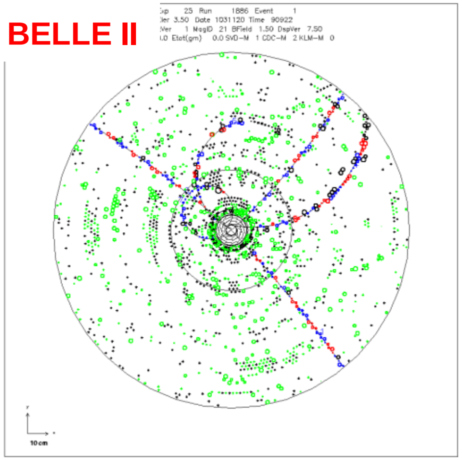
Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

positrons (4GeV)

Central Drift Chamber
He(50%):C_2H_6(50%), small cells, long lever arm, fast electronics





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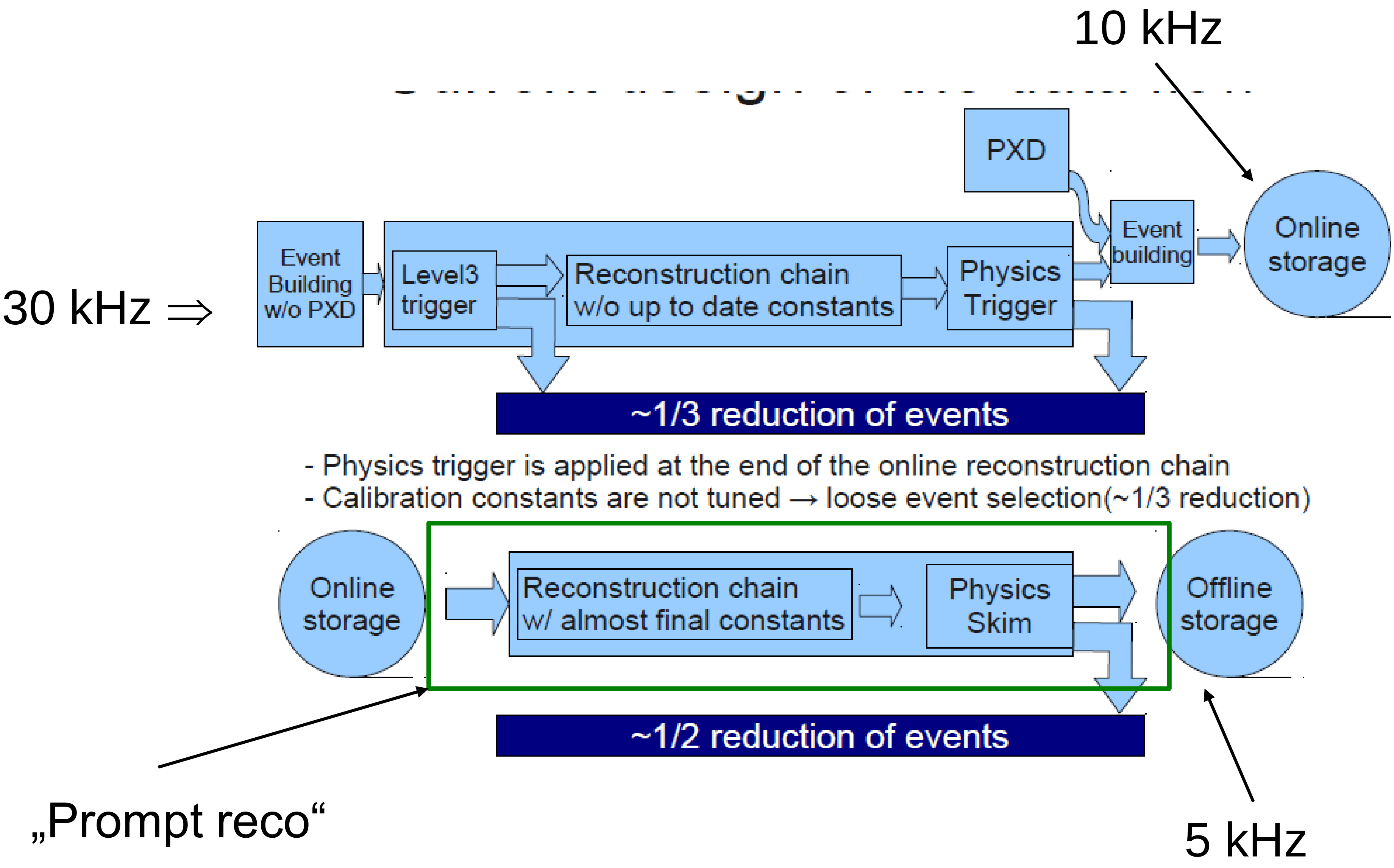
High Level Trigger



10 kHz

30 kHz ⇒

~1/3 reduction of events

- Physics trigger is applied at the end of the online reconstruction chain
- Calibration constants are not tuned → loose event selection(~1/3 reduction)

~1/2 reduction of events

„Prompt reco“

5 kHz

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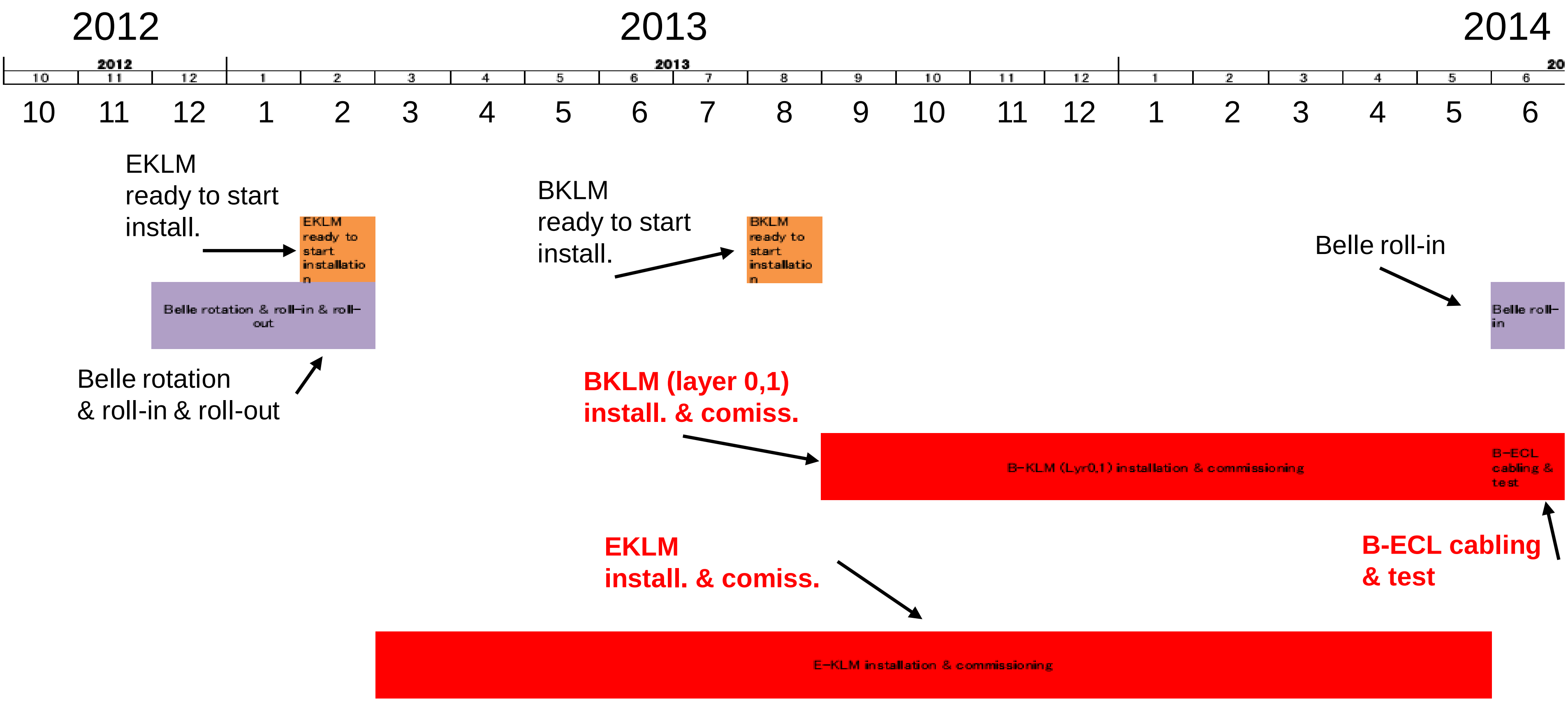
Schedule



EKLM
ready to start
install.

BKLM
ready to start
install.

Belle roll-in

Belle rotation
& roll-in & roll-out

BKLM (layer 0,1)
install. & comiss.

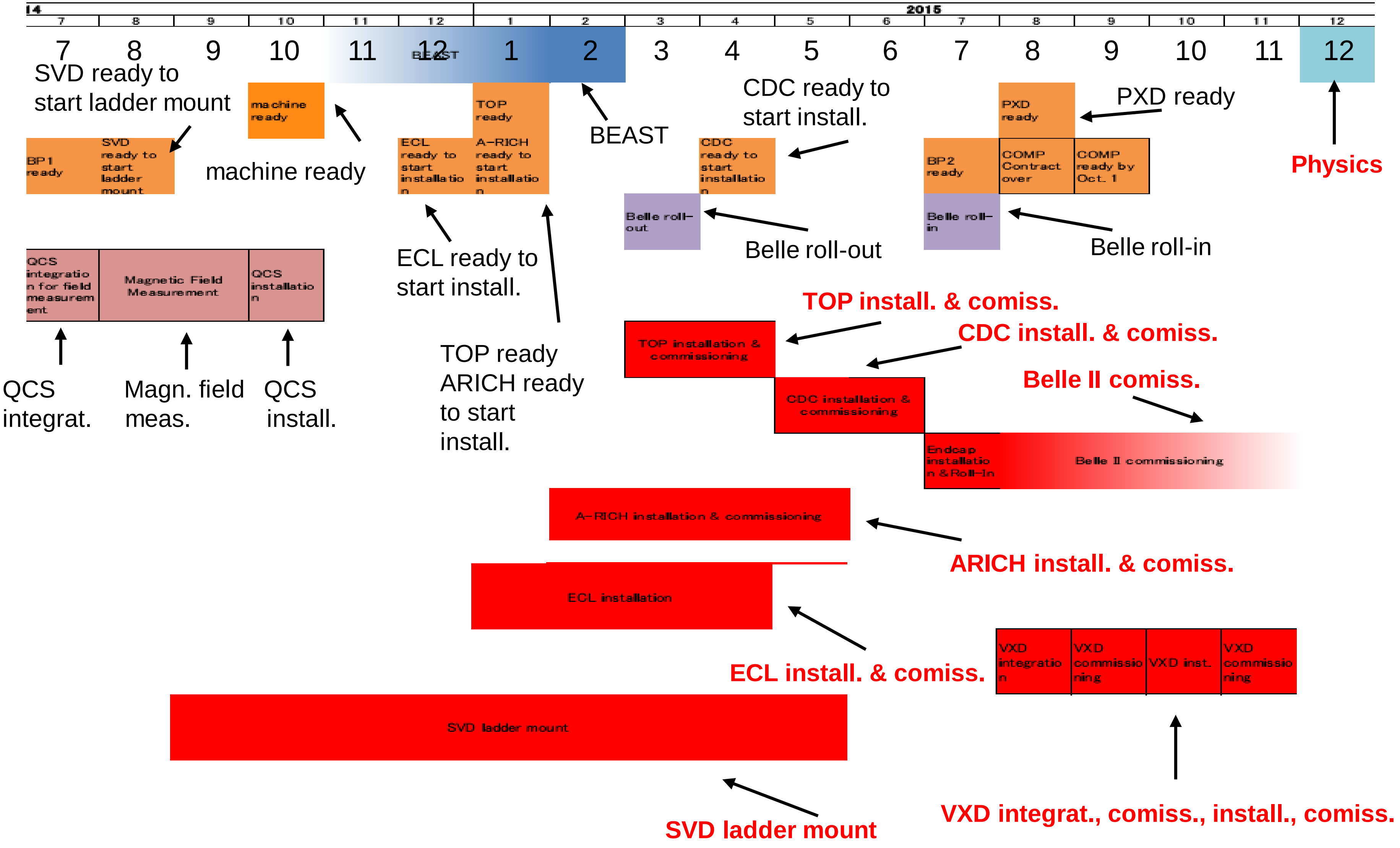
EKLM
install. & comiss.

B-ECL cabling
& test

back

Schedule

2014 2015



SVD ready to start ladder mount

machine ready

BEAST

CDC ready to start install.

PXD ready

Physics

Belle roll-out

Belle roll-in

ECL ready to start install.

TOP ready ARICH ready to start install.

QCS integrat.

Magn. field meas.

QCS install.

TOP install. & comiss.

CDC install. & comiss.

Belle II comiss.

ARICH install. & comiss.

ECL install. & comiss.

VXD integrat., comiss., install., comiss.

SVD ladder mount

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Neutrals $K_S\pi^0\gamma$

D. Atwood et al., PRL79, 185 (1997)

t-dependent CPV

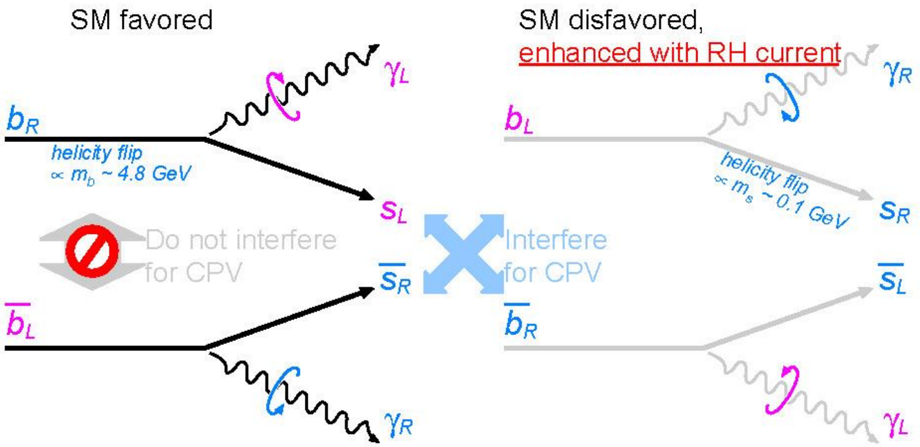
in SM: helicity structure of effective Hamiltonian

$b_R \rightarrow s_L\gamma_L \quad \propto m_b$ (since W in loop couples to b_L spin flip required)
or
$b_L \rightarrow s_R\gamma_R \quad \propto m_s$

interference
mixing/no-mixing for
$b_R \rightarrow s_L\gamma_L \quad \propto m_b$

$b_R \rightarrow \overline{b}_R \rightarrow \overline{s}_L\gamma_L \quad \propto m_s$

CPV in SM $\propto m_s/m_b$



appropriate modes: $K^{*0}(K_s\pi^0)\gamma$, $K_s\eta\gamma$, $K_s\phi\gamma$ (ang. analysis necessary), ...
NP with heavy right-handed fermions in loop can enhance CPV;

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Neutrals $K_S\pi^0\gamma$

D. Atwood et al., PRL79, 185 (1997)
B. Grinstein et al., PRD71, 011504 (2005)

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

in SM: $S_{CP}(K^*\gamma) \sim -(2m_s/m_b)\sin 2\phi_1 \sim -0.04$

Left-Right Symmetric Model: $S_{CP}(K^*\gamma) \sim 0.67 \sin 2\phi_1 \sim 0.5$

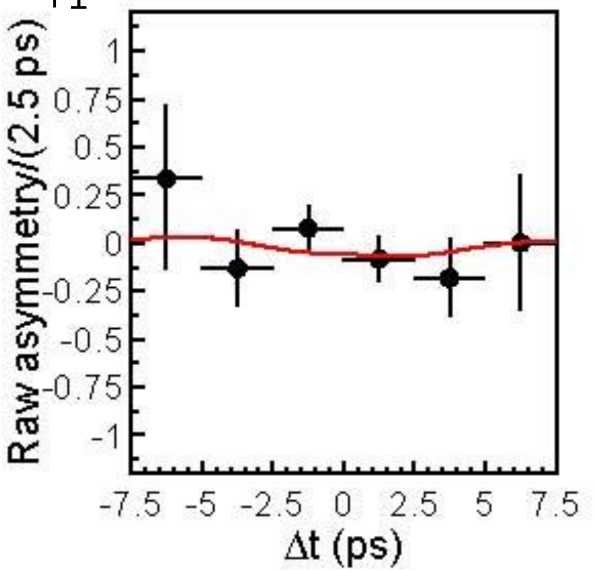
$S_{CP}(K_s\pi^0\gamma) = -0.10 \pm 0.31 \pm 0.07$

$A_{CP}(K_s\pi^0\gamma) = -0.20 \pm 0.20 \pm 0.06$

for $m(K_s\pi^0) < 1.8$ GeV (mainly $K^*\gamma$)

largest syst. from signal fract. and resol. f.

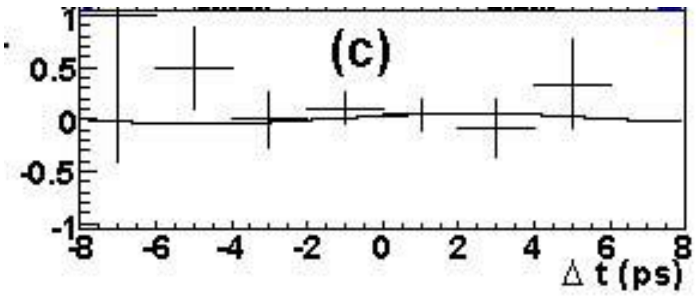
Belle, PRD74, 111104 (2006), 535M BB



important additional improvements with upgraded SVD (K_s - IP vtx)

similar sensitivity for $K_s\rho^0\gamma$
(dilution from $K^*\pi\gamma$)

Belle, PRL101, 251601(2008), 657M BB



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Neutrals $K_S\pi^0\gamma$

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

t-dependent CPV

expectation:

main syst. scales with luminosity

$\sigma(S(K_s\pi^0\gamma))=0.09$ @5 ab^{-1}

0.03 @50 ab^{-1} (~SM value)

+20% increase in K_s acceptance with SVD

DCPV

suppressed by $|V_{ub}V_{us}^*/V_{tb}V_{ts}^*|$, $\alpha_s(m_b)$ (strong phase), $(m_c/m_b)^2$ (GIM);

OPE:

$A_{CP}(B\to X_s\gamma) = (0.44\pm^{0.24}_{0.14})\%$

T. Hurth et al., Nucl.Phys. B704, 56 (2005)

semi-inclusive analysis:

$K+(1\text{-}4)\pi$; $KKK(\pi)$, $K_SKK(\pi)$;

$A_{CP}(B\to X_s\gamma;M_{Xs}<2.1\text{ GeV}) = (0.2\pm5.0\pm3.0)\%$

Belle, PRL93, 031803 (2004), 140 fb^{-1}

syst.: bias (detector charge asymmetry), possible bkg. asymmetry, uncertainty of M(Xs) shape

$D\pi$ control sample	measured asymmetries in other decay modes	non-scaling

back

Neutrals $K_S\pi^0\gamma$

Example of complementarity:
MSSM searches

$$m_{\tilde{q}} = m_{\tilde{g}} = 1 TeV$$

$S(K_S\pi^0\gamma) \sim -0.4\pm0.1$
$S(K_S\pi^0\gamma) \sim 0.1\pm0.1$

→ Belle II constraints shown @ 5 ab^{-1}

$\mathcal{B}(B_s \to \mu^+\mu^-) \sim (0.8\pm^{1.8}_{1.3})\cdot10^{-9}$
($\mathcal{B}(B_s \to \mu^+\mu^-) \sim <4.5\cdot10^{-9}$@95% C.L.)

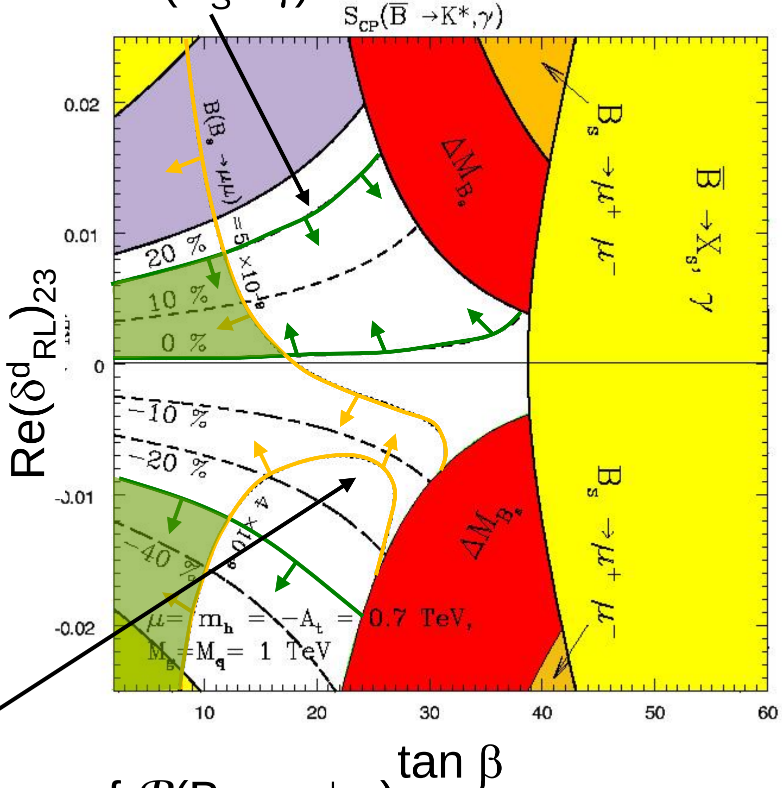
LHCb, 1 fb^{-1}, Moriond EW 2012

→ LHCb constraint: $Br(B_s \to \mu^+\mu^-) \sim (4\text{-}5)\times10^{-9}$ (@ 3 fb^{-1})
(not yet updated for the recent LHCb measurement)

🟩 Belle II/LHCb combination: stringent limits on $Re(\delta^d_{RL})_{23}$, tanβ

back

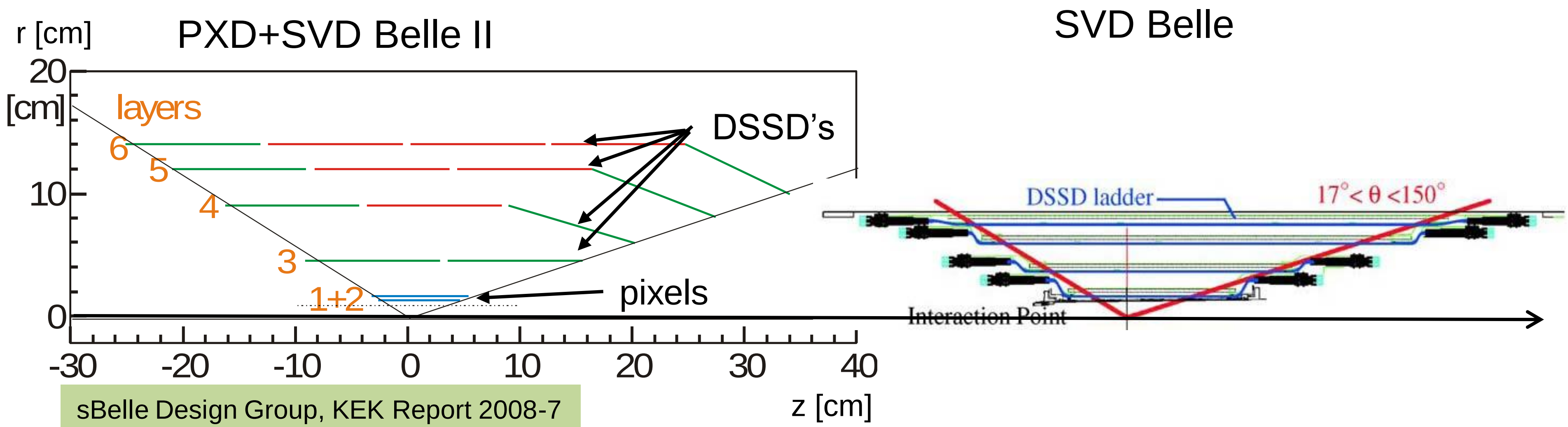
contours of $S(K_S\pi^0\gamma)$



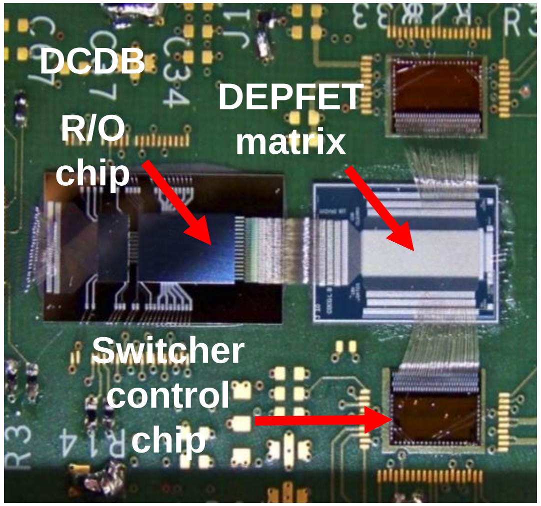
contours of $\mathcal{B}(B_s \to \mu^+\mu^-)$

A.G. Akeroyd et al., arXiv:1002.5012

SVD+PXD



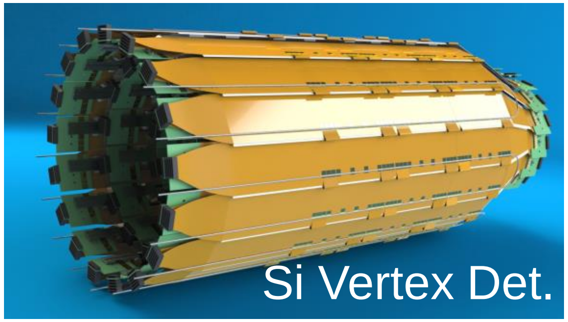
sBelle Design Group, KEK Report 2008-7

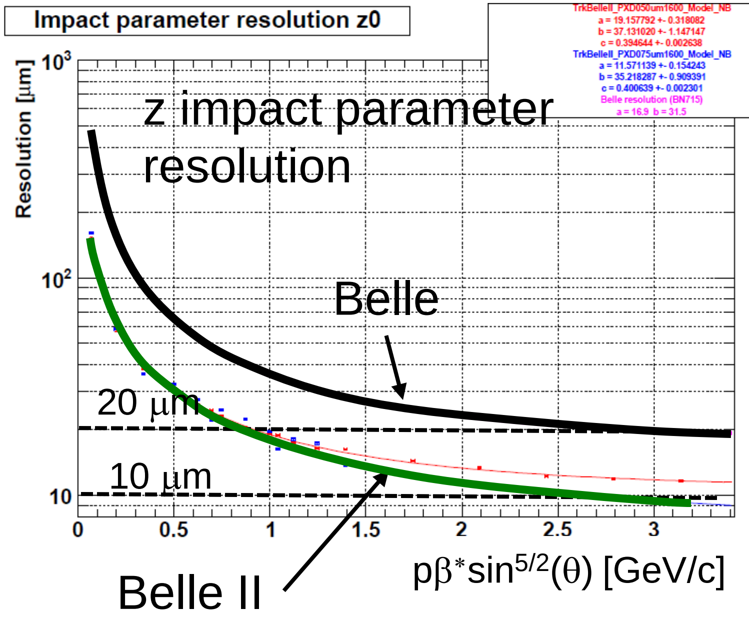


prototype DEPFET sensor

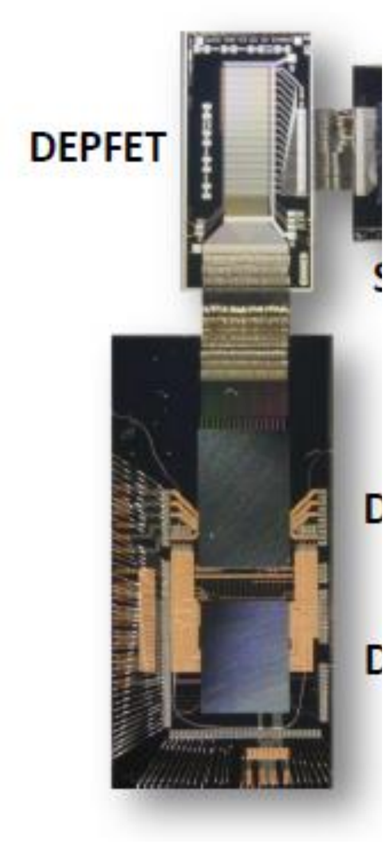
back

DEPFET mockup

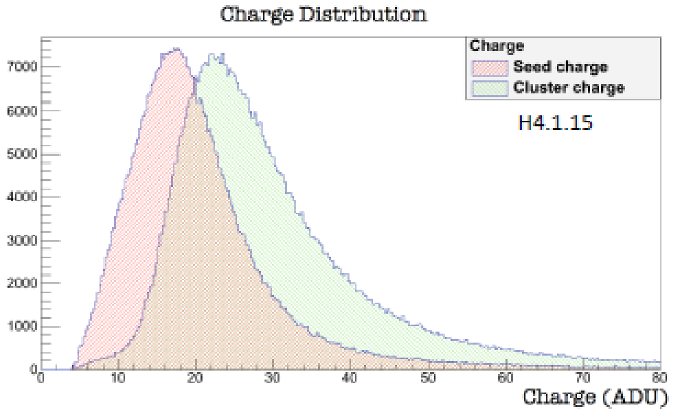


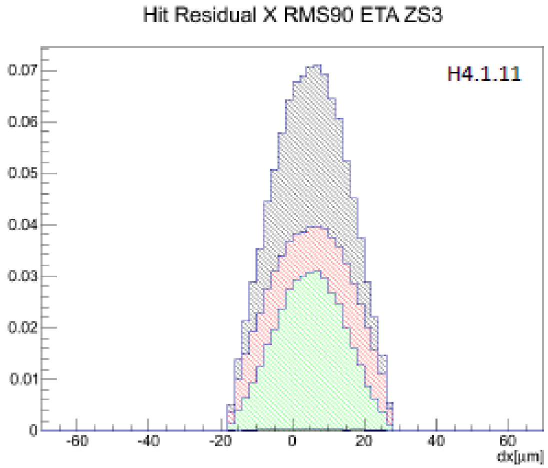


SVD+PXD



- In 2012, Belle II SD DEPFET sensors with different characteristics where tested under 6 GeV electrons and 120 GeV pions


Charge Distribution


Hit Residual X RMS90 ETA ZS3

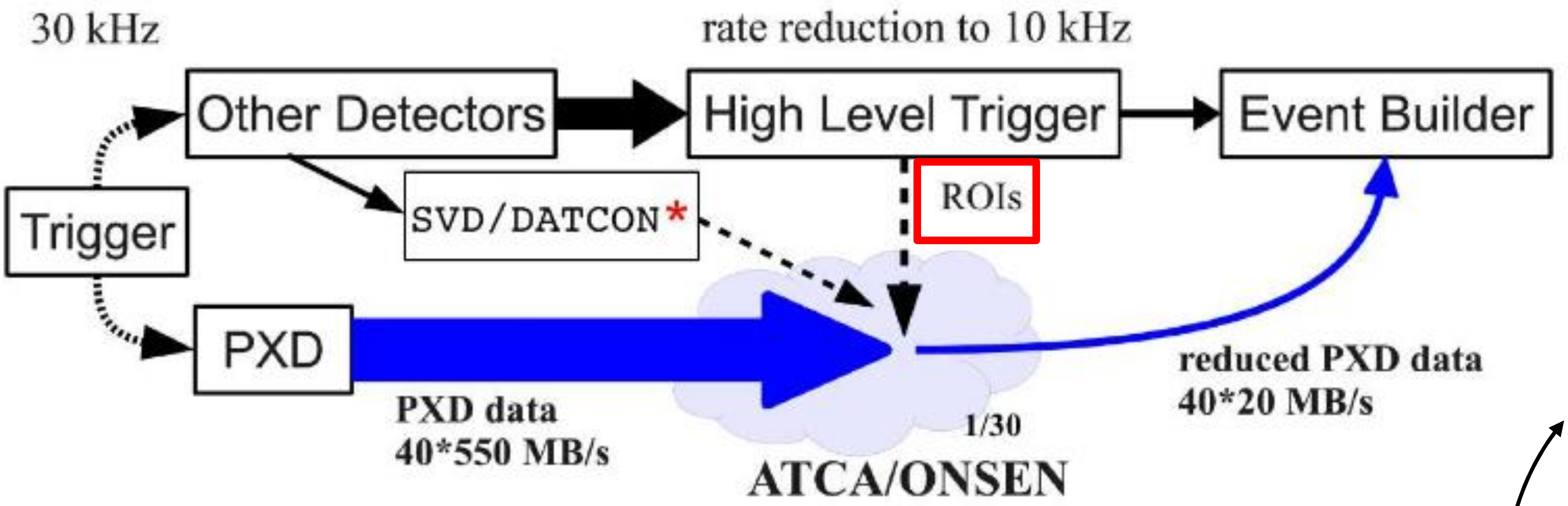
	Pitch [μm²]	Sig 3x3 [ADU]	Noise [ADU]	SNR	Residuals [μm]
H.4.1.04 (6 μm)	50x50	10.7	0.5	21.4	~ 8
H.4.1.11 (5 μm)	50x75	20.9	0.6	34.8	~ 13
H.4.1.15 (5 μm)	50x75	23.9	0.6	39.8	~ 13

Sensor production runnig, 3 months ahead of schedule

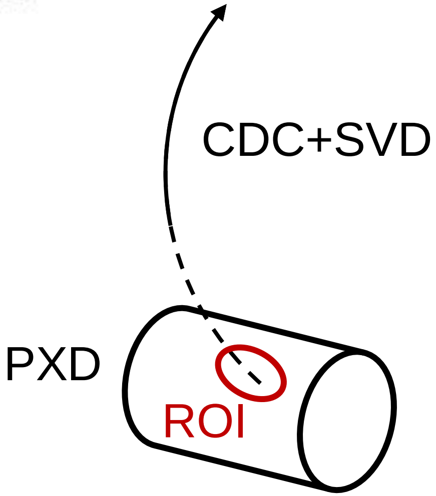
back

PXD DAQ

PXD: separated readout



Region Of Interest provided by HLT helps reducing PXD data by factor ~25



back

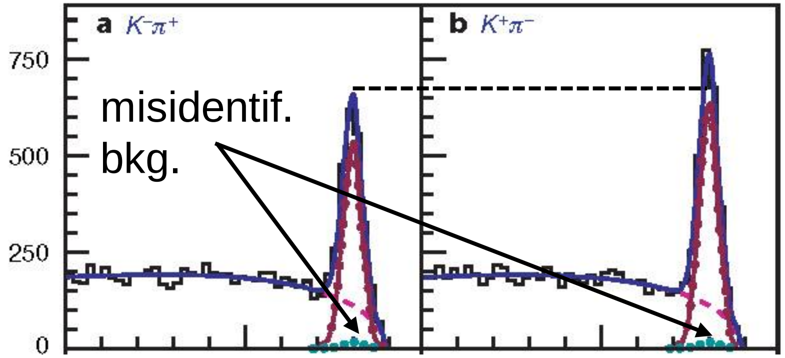
DCPV $K\pi$

DCPV puzzle:

tree+penguin processes, $B^{+(0)} \rightarrow K^+\pi^{0(-)}$

$\Delta A_{K\pi} = A(K^+\pi^-) - A(K^+\pi^0) = -0.147 \pm 0.028$

$B^0 \rightarrow K^+\pi^-$



Belle, Nature 452, 332 (2008), 480 fb^{-1}

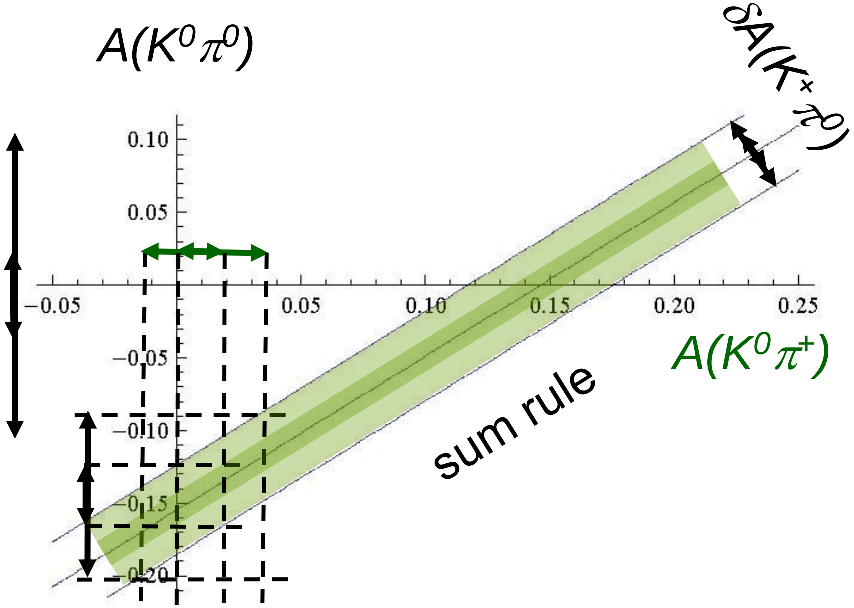
model independent sum rule:

$$\mathcal{A}_f(K^+\pi^-) + \mathcal{A}_f(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)\tau_{B^0}}{\mathcal{B}(K^+\pi^-)\tau_{B^+}} = \mathcal{A}_f(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)\tau_{B^0}}{\mathcal{B}(K^+\pi^-)\tau_{B^+}} + \mathcal{A}_f(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}.$$

M. Gronau, PLB627, 82 (2005);
D. Atwood, A. Soni, PRD58, 036005 (1998)

$A(K^0\pi^+) = 0.009 \pm 0.025$
$A(K^+\pi^0) = 0.050 \pm 0.025$
$A(K^+\pi^-) = -0.098 \pm 0.012$
$A(K^0\pi^0) = -0.01 \pm 0.10$
Belle II 50 ab^{-1}

HFAG, Summer'11



measured
(HFAG)

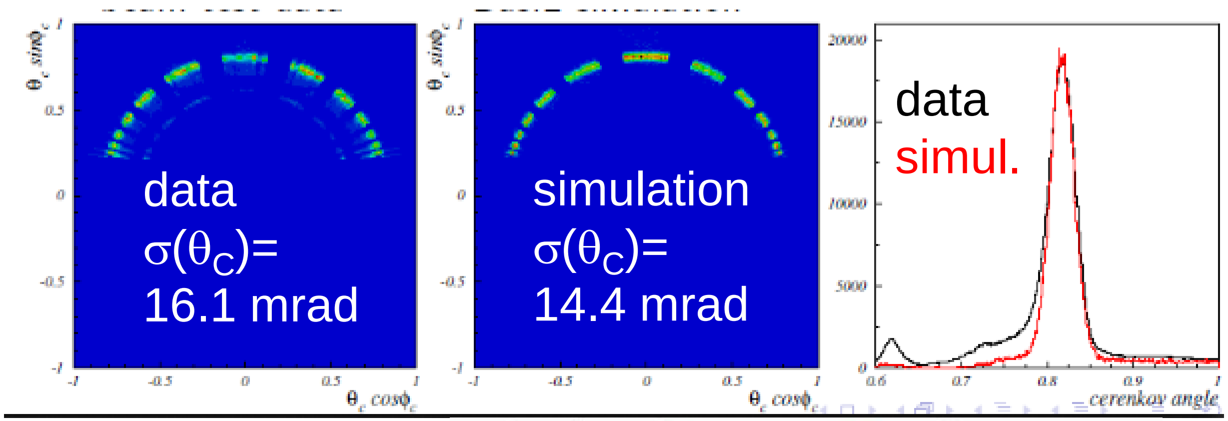
expected
(sum rule)

back

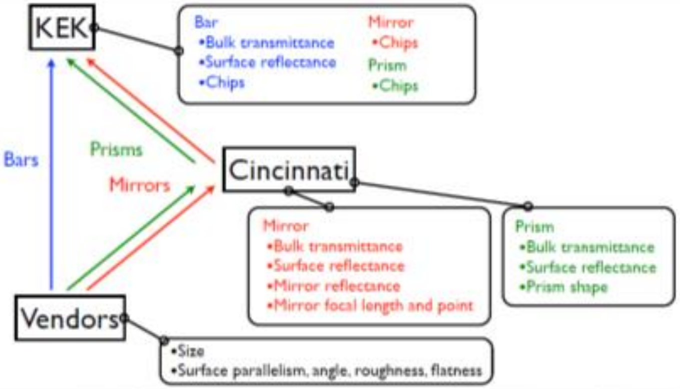
TOP

Test beam 2010, Cern:

next test beam in June



System of quartz testing:



KEK

Bar
- Bulk transmittance
- Surface reflectance
- Chips

Mirror
- Chips

Prism
- Chips

Bars

Prisms

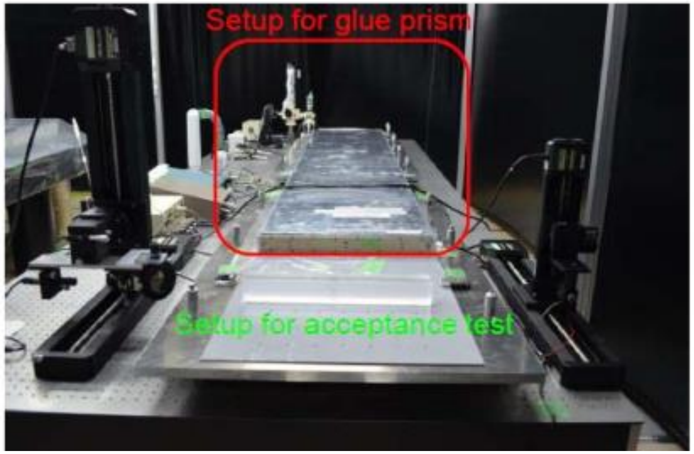
Mirrors

Cincinnati

Mirror
- Bulk transmittance
- Surface reflectance
- Mirror reflectance
- Mirror focal length and point

Prism
- Bulk transmittance
- Surface reflectance
- Prism shape

Vendors
- Size
- Surface parallelism, angle, roughness, flatness



Electronics:
baseline electronics after problems achieving requested <100 ps resol.; tested with cosmic rays just recently

backup electroncs prepared (robust and proven system) to be used for June test beam if necessary

back

Inclusive b →$s\gamma$

Inclusive $b \rightarrow s(+d)\gamma$

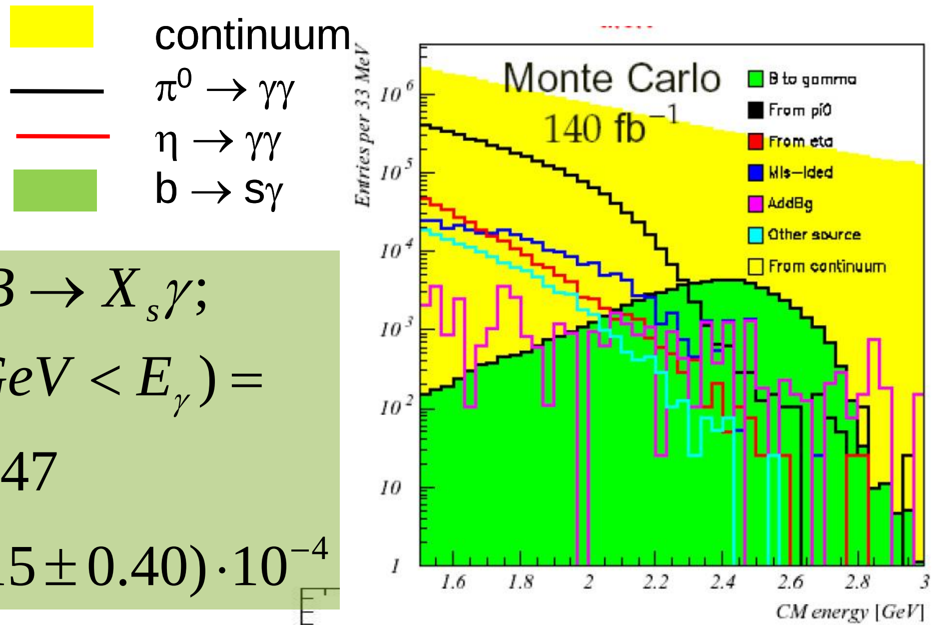
FCNC process;
sensitive to NP in loop;

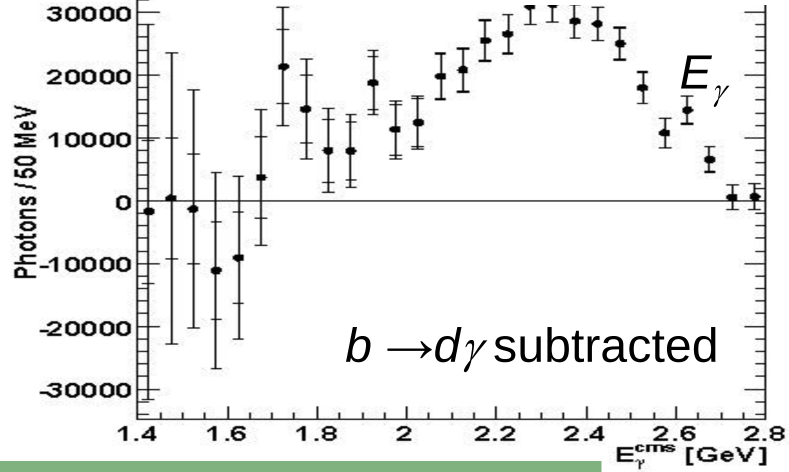
experimental challenge:
huge background

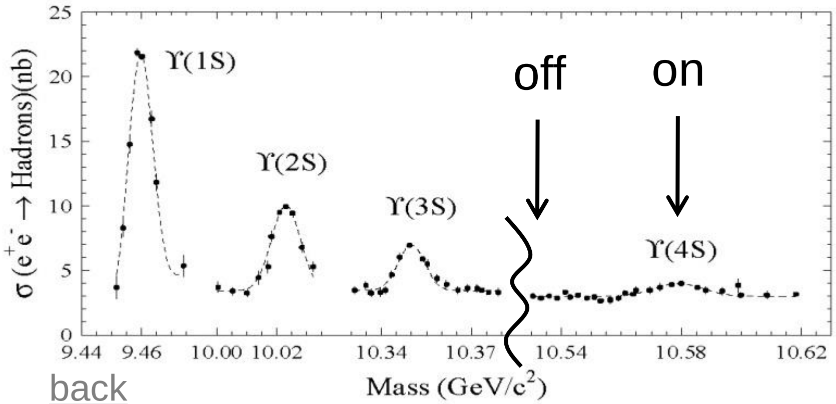
only γ reconstructed on signal side

1.26 GeV < E < 2.20 GeV

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







back

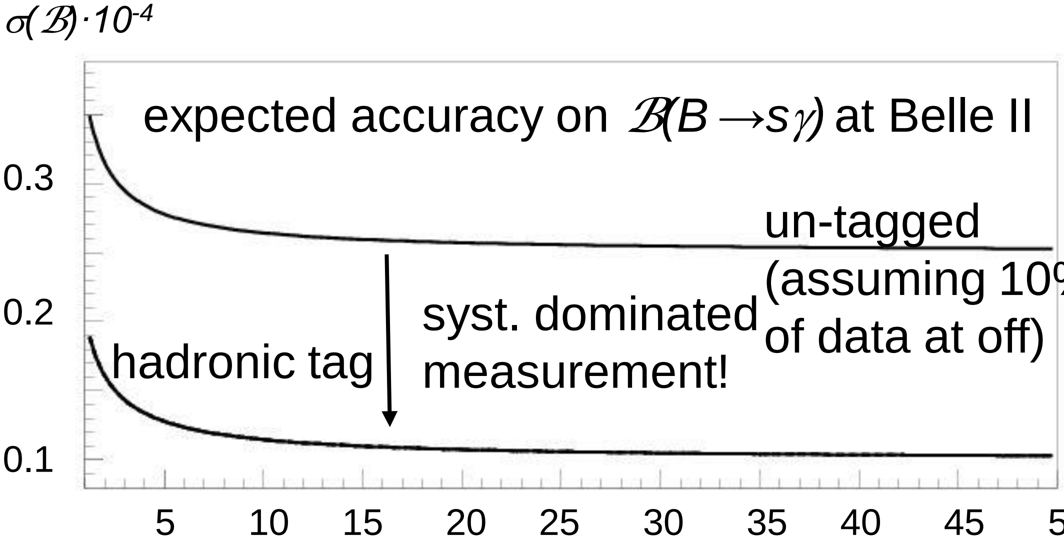
Belle, PRL103, 241801, (2008), 605 fb^{-1}

E_γ

Inclusive b →$s\gamma$

Inclusive $b \to s(+d)\gamma$

main syst. uncertainties: continuum subtraction, γ's from sources other than π^0, η



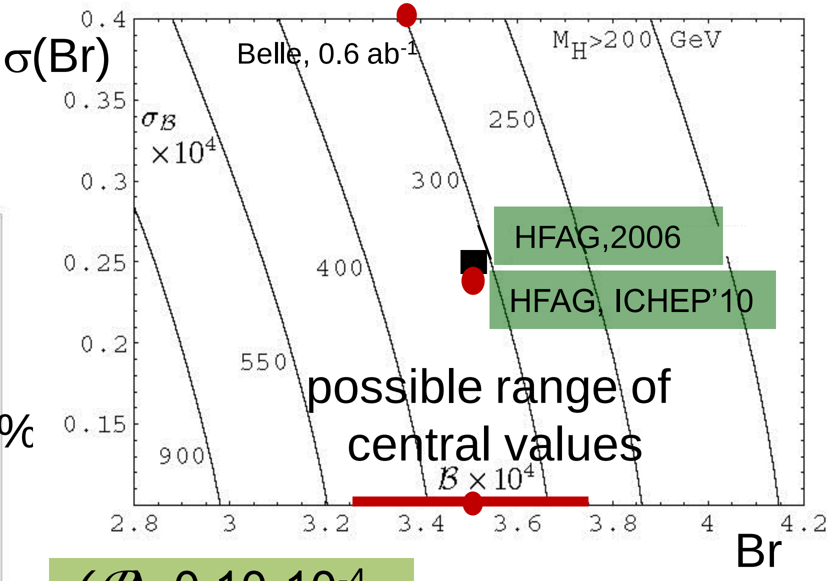
expected accuracy on $\mathcal{B}(B \to s\gamma)$ at Belle II

un-tagged (assuming 10% of data at off)

hadronic tag

syst. dominated measurement!

M. Misiak et al., PRL98, 022002 (2007)



Belle, 0.6 ab^{-1}

HFAG,2006

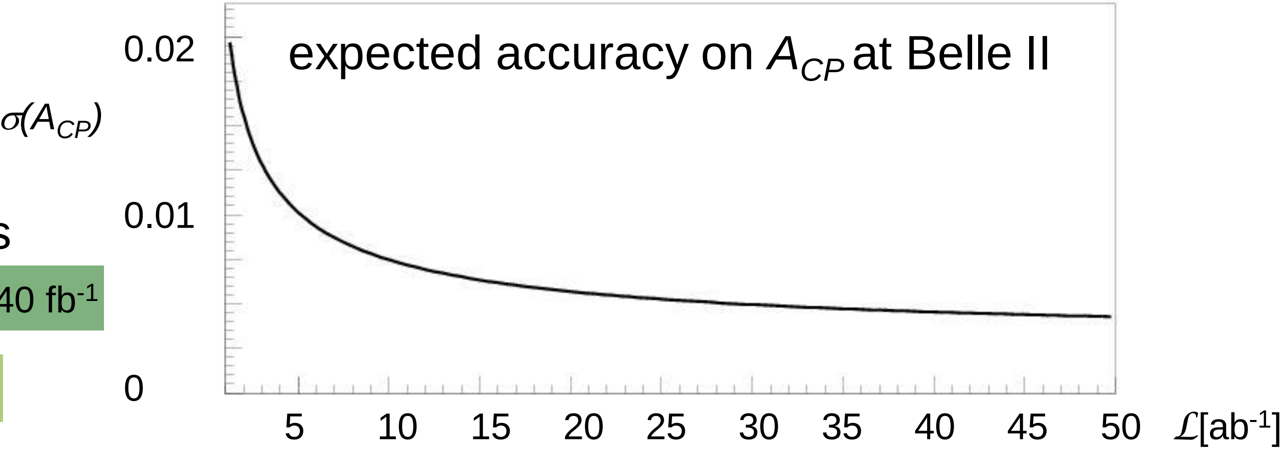
HFAG, ICHEP'10

possible range of central values

$\sigma(\mathcal{B})$~0.10·10^{-4}

sum of exclusive states

Belle, PRL93, 031803 (2004), 140 fb^{-1}



expected accuracy on A_{CP} at Belle II

$\sigma(A_{CP})$~4·10^{-3}

back

$\sin 2\phi_1$

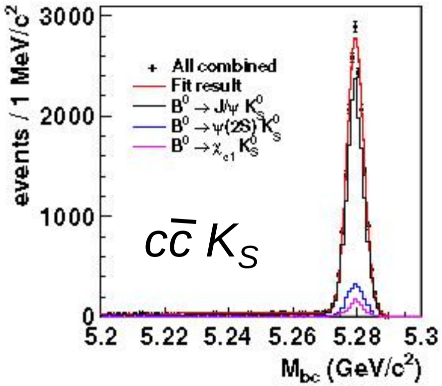
Belle, 710 fb^{-1}, arXiv:1201.4643

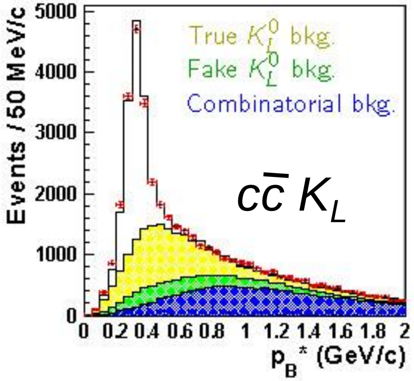
ϕ_1 from $B^0 \to c\bar{c}\, K^0$

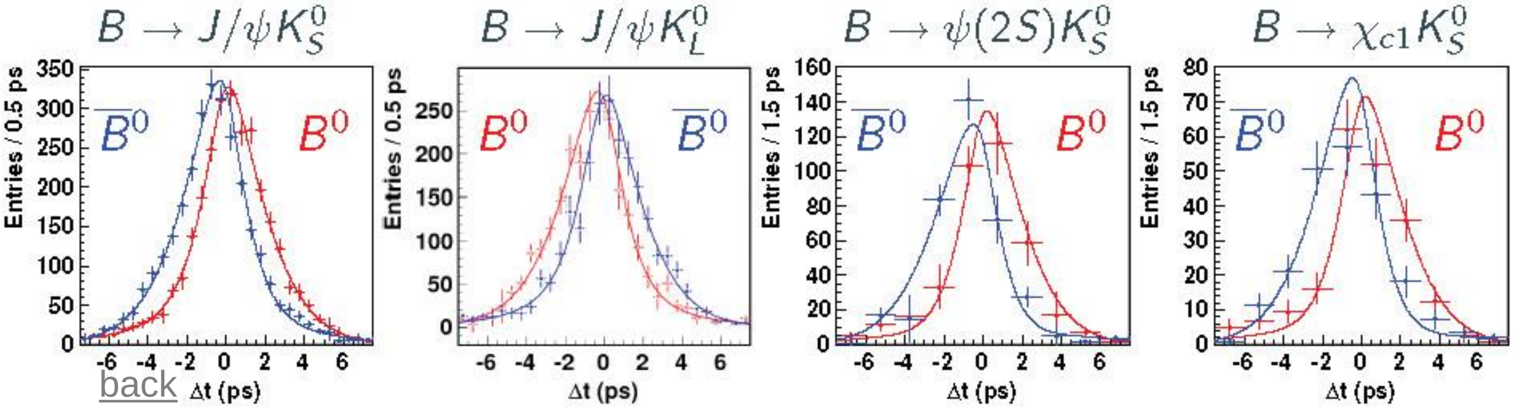
Improved tracking, more data
(50% more statistics than last result with 480 fb^{-1});
$c\bar{c} = J/\psi,\ \psi(2S),\ \chi_{c1}$
for K_L only cluster (direction) in ECL, KLM;
missing info from kinematic constraints;

$$p(\Delta t) = \frac{e^{|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\{1 \pm [S_{f_{CP}} \sin(\Delta m_d \Delta t) + A_{f_{CP}} \cos(\Delta m_d \Delta t)]$$

detector effects: wrong tagging, finite Δt resolution,
determined using control data samples







back

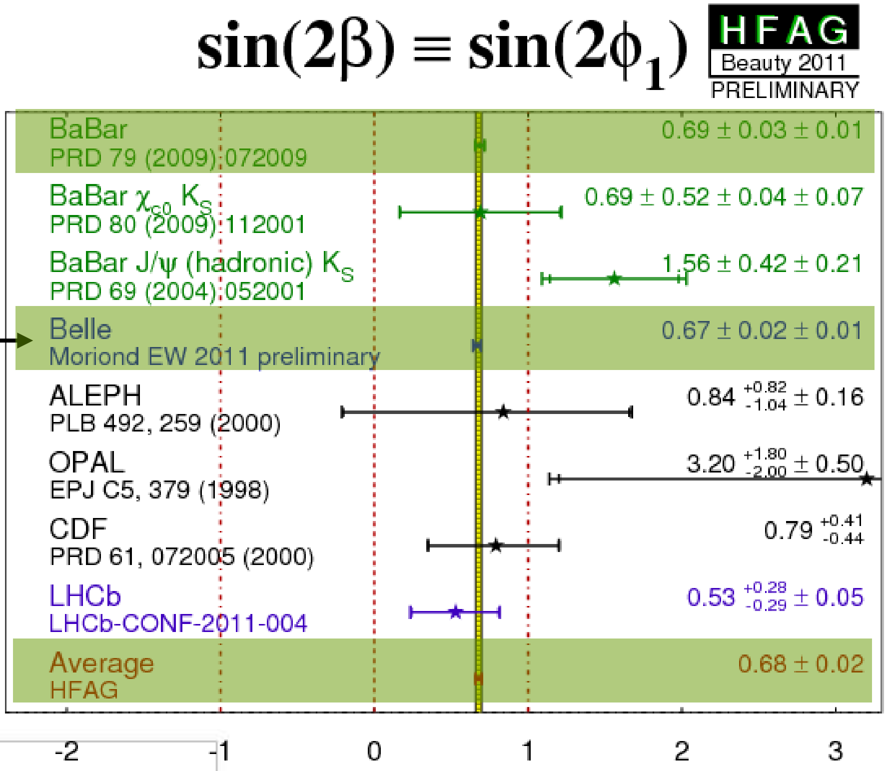
$$S_{c\bar{c}K_s} =$$
$$= -\eta_{CP} \sin 2\varphi_1$$
$$A_{c\bar{c}K_s} = 0$$

$\sin 2\phi_1$

Belle, 710 fb^{-1}, arXiv:1201.4643

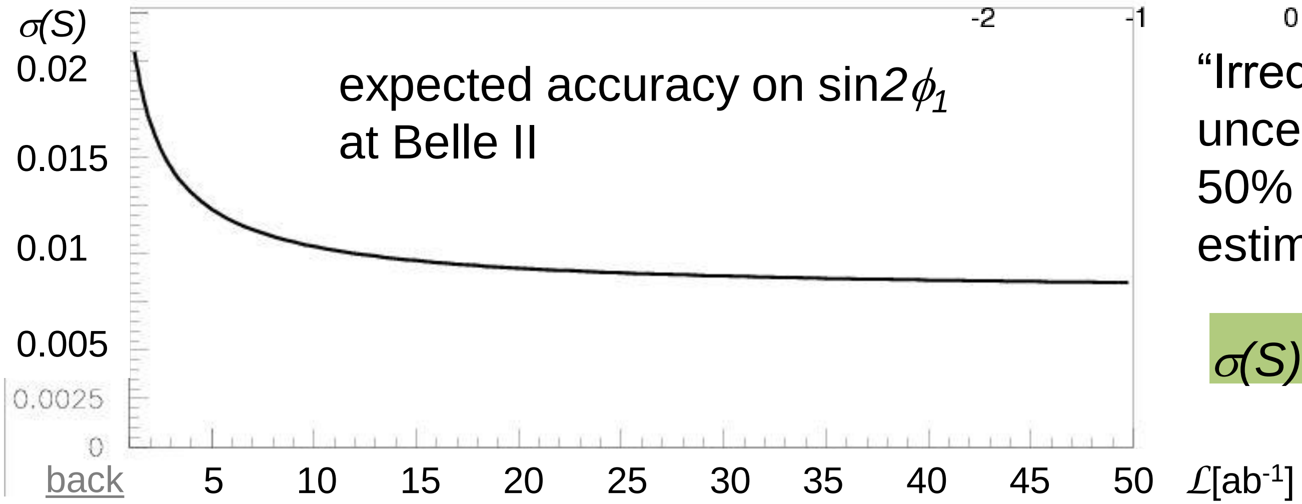
$S = 0.667 \pm 0.023 \pm 0.012$

$A = 0.006 \pm 0.016 \pm 0.012$



main systematic uncertainties:
vertexing, Δt resolution, tag side interf.

"bread&butter" of BF;
not the main motivation of SBF,
but still extremely important



expected accuracy on $\sin 2\phi_1$ at Belle II

back

"Irreducible" systematic uncertainty decreased by 50% compared to previous estimate

$\sigma(S) \sim 0.008$

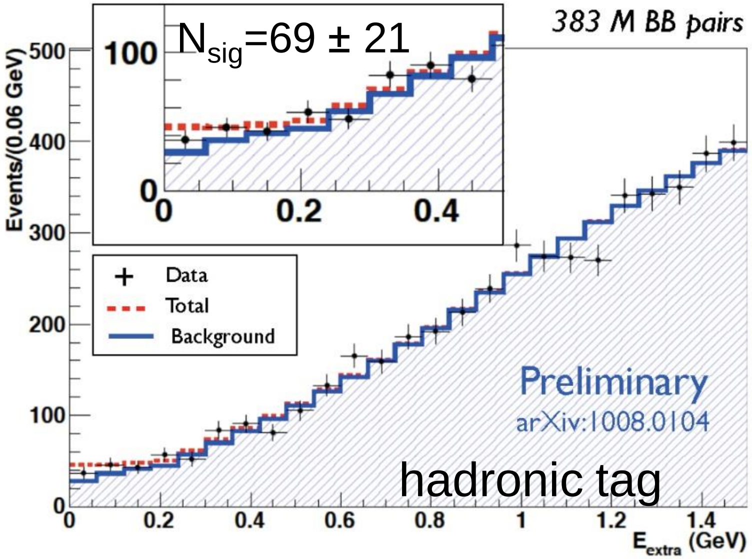
$B \to \tau\nu$

$\mathcal{B}(B^+ \to \tau^+\nu)=(1.80 \pm 0.56 \pm 0.26)\cdot 10^{-4}$

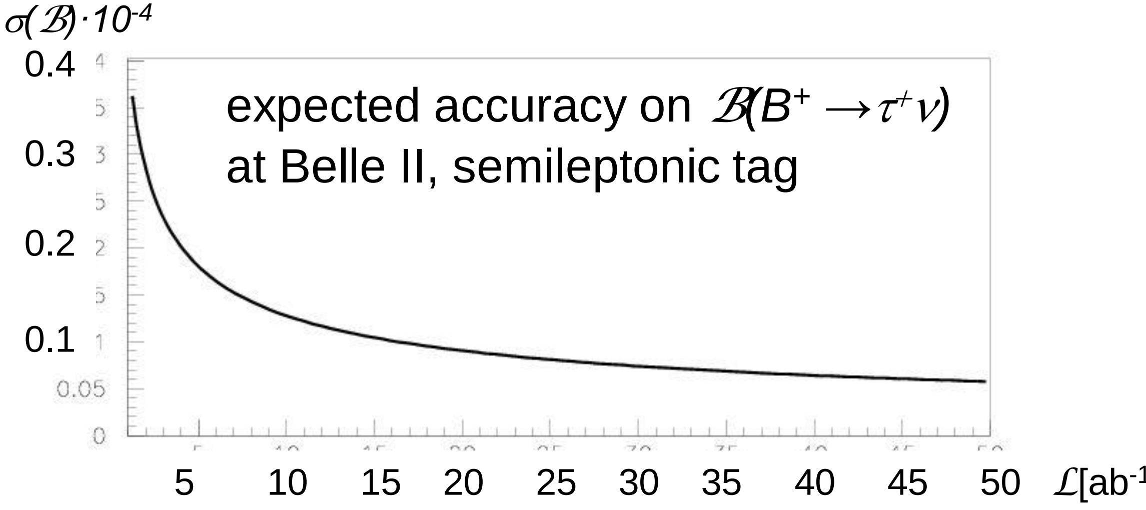
BaBar, arXiv: 1008.0104, 350 fb^{-1}

$\mathcal{B}(B^+ \to \tau^+\nu)=(1.65 \pm 0.38 \pm 0.36)\cdot 10^{-4}$

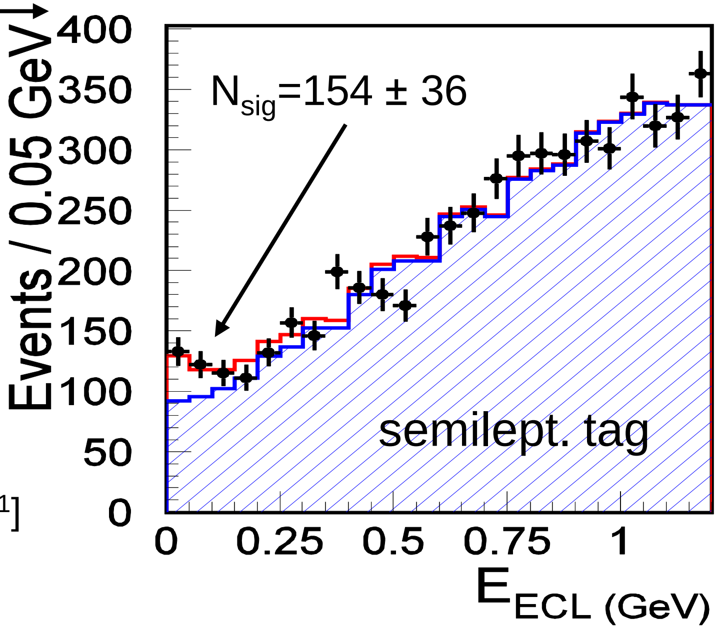
Belle,PRD82, 071101 (2010), 605 fb^{-1}



main syst. is reducible: bkg. ECL shape, ε B_{tag});



expected accuracy on $\mathcal{B}(B^+ \to \tau^+\nu)$ at Belle II, semileptonic tag



including hadronic tag, $\sigma(\mathcal{B})$~$0.06\cdot10^{-4}$

back

$B \to \tau\nu$

Belle, PRD 82, 071101(R) (2010) 605 fb^{-1}

$B^+ \to \tau\nu$

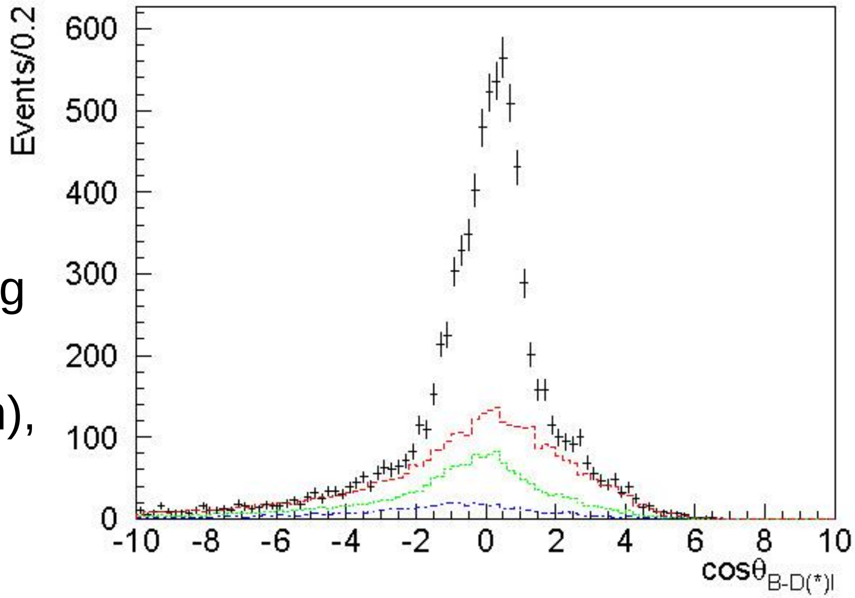
semil. tagging $B_{tag}{}^+ \to D^{(*)0}\,\ell\,\nu$

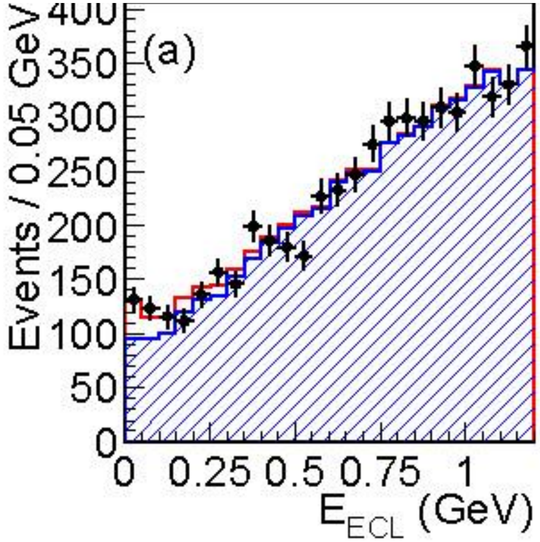
control samples:

$B_{tag}{}^0 \to D^{(*)+}\,\ell\,\nu$ (B bkg., including peaking bkg.),
off-resonance data (bkg. from continuum),
E_{ECL} sideband (data/MC comparison),
select. variables sidebands (shape of mainly non-B bkg.),
double tagged $B_{tag}{}^+ \to D^{(*)0}\,\ell\,\nu$
and $B_{sig}{}^- \to D^{(*)0}\,\ell\,\nu$ (signal shape)

main syst.: tagging ε (estimated
by $\mathcal{B}(B^+ \to D^{*0}\,\ell\,\nu)$ from double tagged events),
signal yield (peaking bkg. with K_L's, variation of $\mathcal{B}$'s for K_S)

$$\sigma(Br(B^+ \to \tau\nu)) \approx 0.05\cdot 10^{-4}$$ @ 50 ab^{-1}





back

$B \to h\nu\nu$

$B \to h\nu\nu$

$B_{sig}B_{tag} \to (h\nu\nu)(X\ell\nu)$ semil. tag
$\to (h\nu\nu)(X)$ hadr. tag

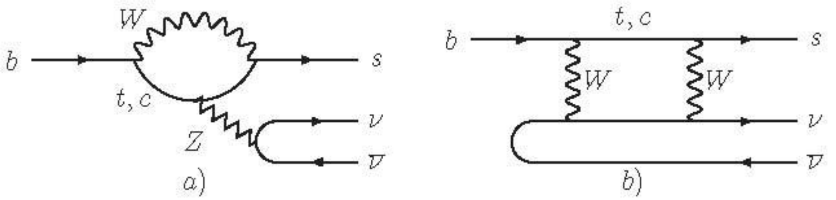
fully (partially) reconstruct B_{tag};
reconstruct h from $B_{sig} \to h\nu\nu$;
no additional energy in EM calorim.; signal at $E_{ECL} \sim 0$;

new B_{tag} full reconstruction:
NeuroBayes, ε_{had}^{full} x1.8;
TOP detector $\varepsilon_{PID}^{K,\pi}$ x1.1-1.15/track;
ECL, increased background:
ε_{had}^{full} x0.8, purity x0.9;

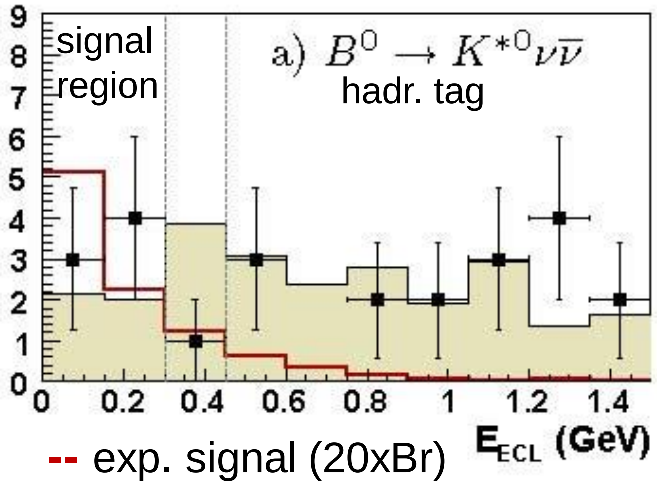
together: N_{sig}: x1.8; N_{bkg}: x0.9

semilep. tag:
$\varepsilon_{semil} \sim 5\ \varepsilon_{had}^{full}$
$N_{bkg}^{semil} \sim 10\ N_{bkg}^{had}$

back



Belle, PRL99, 221802 (2007), 490 fb^{-1}



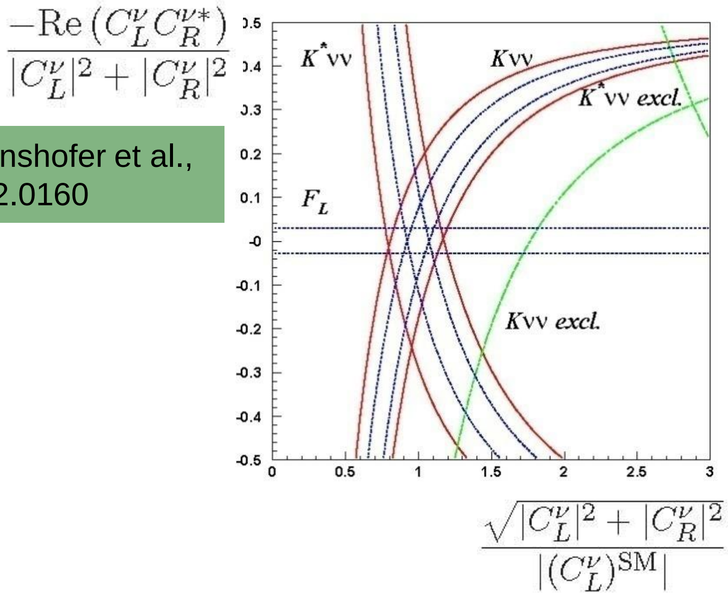
-- exp. signal (20xBr)
🟩 exp. bkg. (scaled to sideband)

$B^0 \to K^{*0}\nu\nu$
N_{bkg}^{exp}=4.2 ±1.4
(stat. of MC and sidebands,
ECL distr. checked with wrong-sign)
N_{sig}^{exp}=0.34
($\mathcal{B}(B^0 \to K^{*0}\nu\nu) = 1.3\times10^{-5}$
G. Buchalla et al., PRD63, 014015 (2001))

$B \to h\nu\nu$

$\int\mathcal{L}dt$=50 ab^{-1}
semil.+hadr. tag:
N_{sig} ~240; N_{bkg} ~4600
$\mathcal{B}(B^0 \to K^{*0}\nu\nu)$ can be measured to ±30%;
similar precision for $\mathcal{B}(B^0 \to K_S\nu\nu)$;

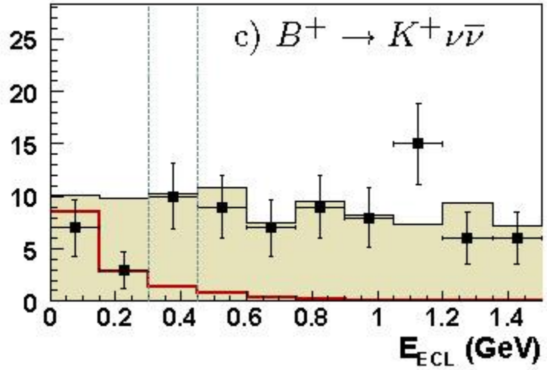
W. Altmannshofer et al., arXiv:0902.0160



$B^+ \to K^+\nu\nu$
includes irreducible background from
$B^+ \to \tau\nu \quad \tau \to K^+\nu$;
$\mathcal{B}(B^+ \to K\nu\nu)/\mathcal{B}(B^+ \to \tau\nu)\ \mathcal{B}(\tau \to K^+\nu) \sim 20\%$;
if $\mathcal{B}(B^+ \to \tau\nu)$ known to ±8% ⇒ negligible contribution to uncertainty;

$B^+ \to K^+\nu\nu$ suffers from larger bkg. than $B^0 \to K^{*0}\nu\nu$
need to use NeuroBayes with larger purity
and smaller eff. (P x2, ε_{had}^{full} x1.6)

N_{sig} ~500; N_{bkg} ~17.5x10^3
$\mathcal{B}(B^+ \to K^+\nu\nu)$ can be measured to ±30%;



N_{bkg}^{exp}=20.0 ±4.0
N_{sig}^{exp}=0.52
($\mathcal{B}(B^+ \to K^+\nu\nu)$ = 3.6x10^{-6}

G. Buchalla et al., PRD63, 014015 (2001)

back

$\tau \to \mu\,\gamma$

Search for $\tau \to \mu\,\gamma$

w/o polarization:
$UL_{90\%}(\mathcal{B}(\tau \to \mu\,\gamma)) \sim 3\times10^{-9}$ @ 50 ab^{-1}

w/ polarization:
factor ~(2-3)x better sensitivity

decays $\tau \to 3\ell, \ell h^0$ background free
$UL_{90\%}(\mathcal{B}(\tau \to \mu\,\gamma)) \sim \propto 1/\mathcal{L}$ to ~10ab^{-1}

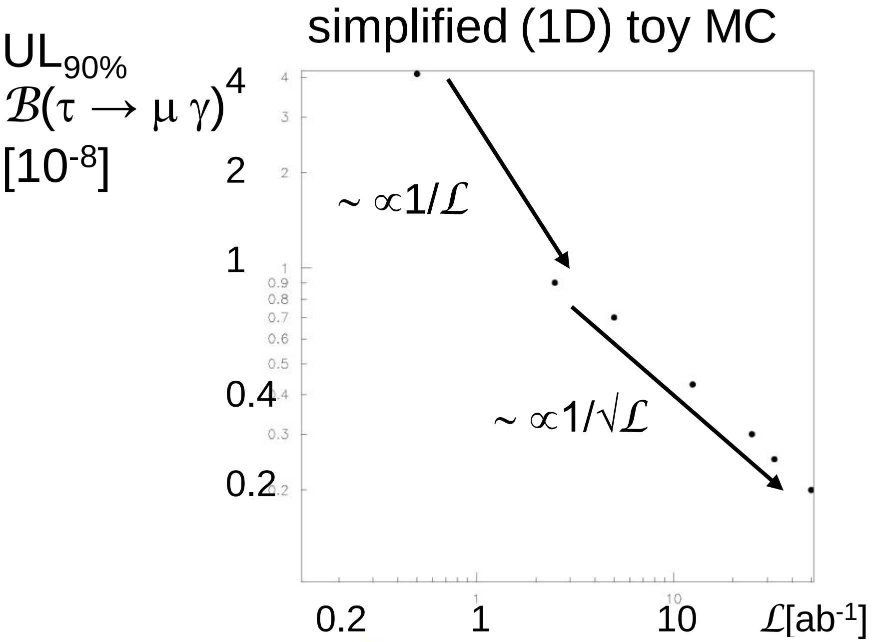
$\mathcal{B}(\tau \to \mu\,\gamma) < 4.4 \cdot 10^{-8}$

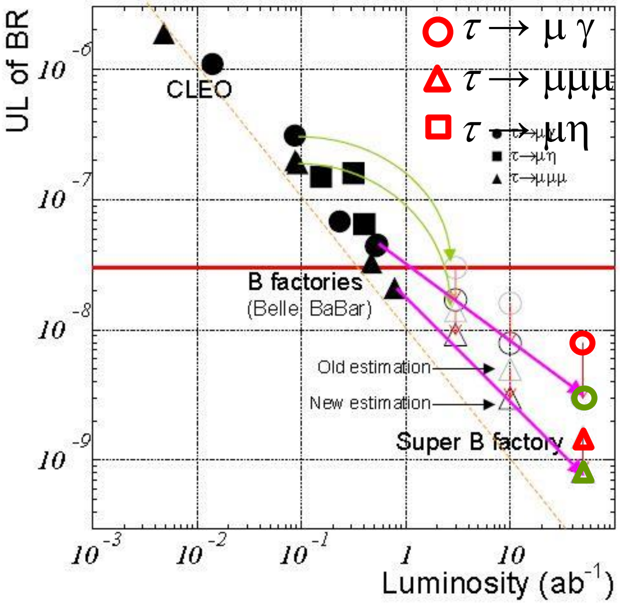
Belle, PLB66, 16 (2008), 535 fb^{-1}

Updated expected sensitivities

K. Inami, PANIC 2011

back





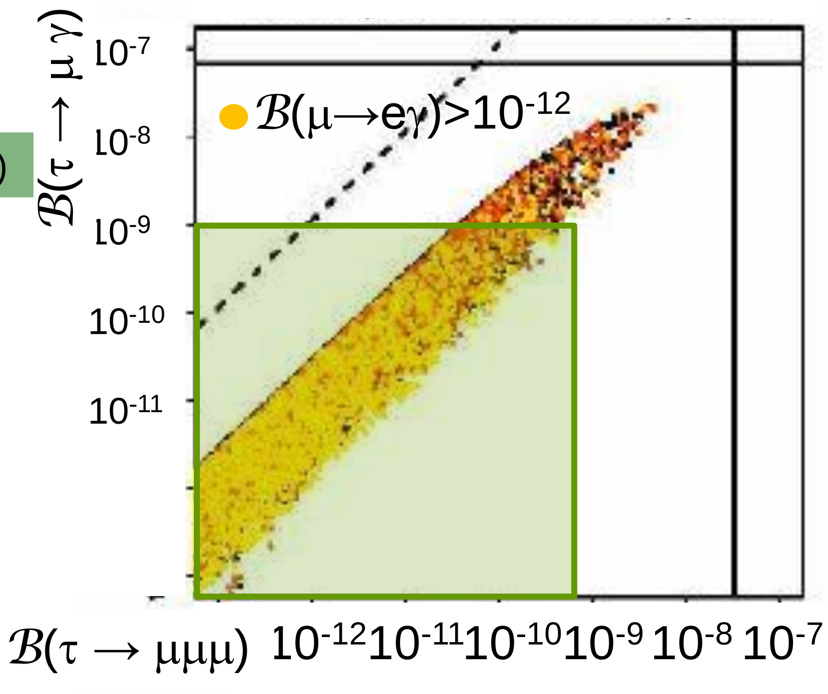
Search for $\tau \to \mu\,\gamma$

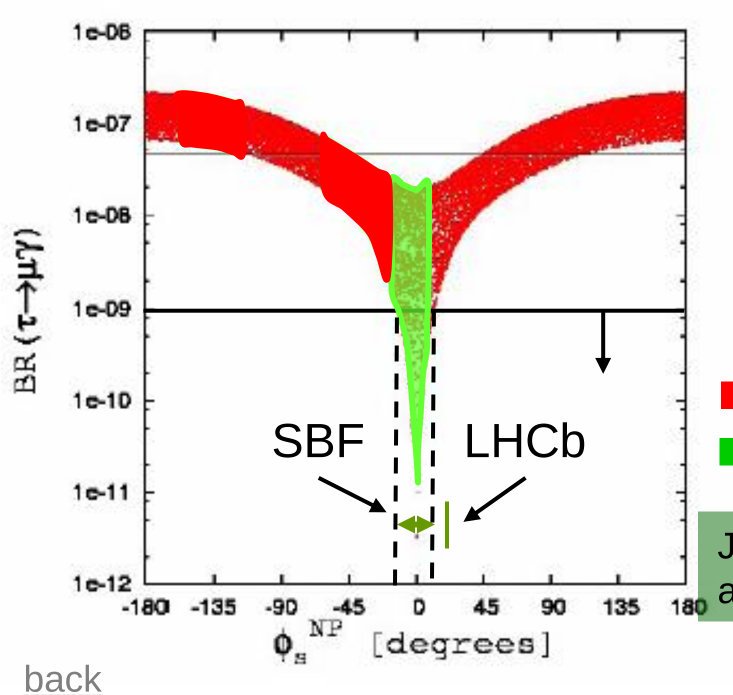
Littlest Higgs model with T parity

T. Goto et al., PRD83, 053011 (2011)

m(T-odd ℓ)=100GeV – 1 TeV,m(T-odd q)=500GeV

expected sensitivity on $\mathcal{B}(\tau \to \mu\mu\mu)$ and $\mathcal{B}(\tau \to \mu\gamma)$ will severly constrain allowed parameter space





SUSY GUT
95% C.L.

🟥 allowed from Δm_s
🟩 allowed from ϕ_s

J.K. Parry, H.-H. Zhang, arXiv:0710.5443

with expected precision from LHCb and from Belle II it can easily happen that allowed regions do not match

back

S in b → s penguins

b →s penguin dominated processes:

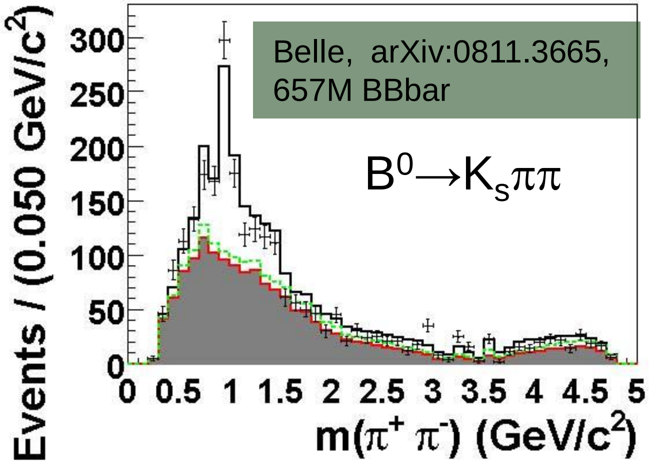
t-dependent Dalitz analyses

$5\,ab^{-1}$:

$$\sigma(\Delta S)\approx\begin{cases}0.05\ f_0K_s\\ 0.10\ \varphi K_s\\ 0.05\ \eta' K_s\end{cases}$$

$50\,ab^{-1}$:

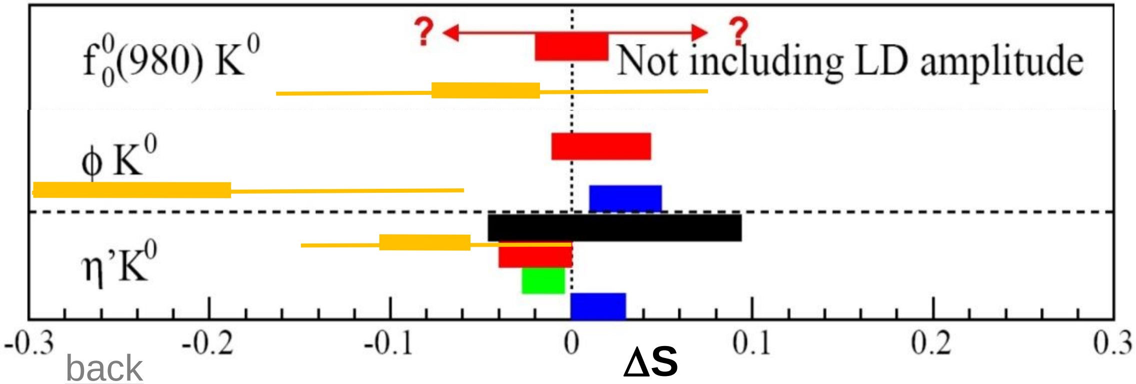
$$\sigma(\Delta S)\approx\begin{cases}0.03\ f_0K_s\\ 0.05\ \varphi K_s\\ 0.02\ \eta' K_s\end{cases}$$



measure ϕ_1^{eff} associated with individual amplitudes (ϕK_s, f_0K_s,...)

vtx reconstr. (non-scaling) improved with better tracking
sig. model (non-scaling) misreconstructed events;

some syst. errors cancel in $\Delta S = S(sqq)-S(J/\psi K_s)$



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▬ SuperBelle, 50 ab^{-1}
▬ range allowed with current HFAG central values

determine possible new phase with $\sigma \leq \sigma_{th}$(current)

Search for CPT violation

allowing for CPT violation the decay time evolution of $B^0\overline{B}{}^0$ pair is a bit more complex:

$$\begin{aligned}\mathcal{P}(\Delta t; f_{\rm rec} f_{\rm tag}) \;=\; \frac{\Gamma_d}{2} e^{-\Gamma_d|\Delta t|}\Big[& \frac{|\eta_+|^2+|\eta_-|^2}{2}\cosh\left(\frac{\Delta\Gamma_d}{2}\Delta t\right) - \mathcal{R}e(\eta_+^*\eta_-)\sinh\left(\frac{\Delta\Gamma_d}{2}\Delta t\right) \\ & + \frac{|\eta_+|^2-|\eta_-|^2}{2}\cos(\Delta m_d\Delta t) + \mathcal{I}m(\eta_+^*\eta_-)\sin(\Delta m_d\Delta t)\Big]\end{aligned}$$

$$\begin{aligned}\eta_+ &\equiv \mathcal{A}_{B^0\to f_{\rm rec}}\mathcal{A}_{\overline{B}{}^0\to f_{\rm tag}} - \mathcal{A}_{\overline{B}{}^0\to f_{\rm rec}}\mathcal{A}_{B^0\to f_{\rm tag}}, \\ \eta_- &\equiv \boxed{\sqrt{1-z^2}}\left(\frac{p}{q}\mathcal{A}_{B^0\to f_{\rm rec}}\mathcal{A}_{B^0\to f_{\rm tag}} - \frac{q}{p}\mathcal{A}_{\overline{B}{}^0\to f_{\rm rec}}\mathcal{A}_{\overline{B}{}^0\to f_{\rm tag}}\right) + \boxed{z}\left(\mathcal{A}_{B^0\to f_{\rm rec}}\mathcal{A}_{\overline{B}{}^0\to f_{\rm tag}} + \mathcal{A}_{\overline{B}{}^0\to f_{\rm rec}}\mathcal{A}_{B^0\to f_{\rm tag}}\right)\end{aligned}$$

$z \neq 0$: CPTV ($\Re(z)$, $\Im(z)$);
for $z=0$, $\Delta\Gamma_d=0$ and $f_{rec}=f_{CP}$ this expression reduces to the one used for $\sin 2\phi_1$ measurement;

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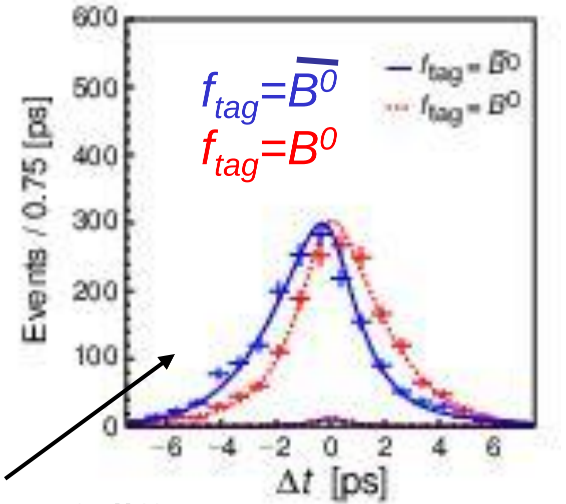
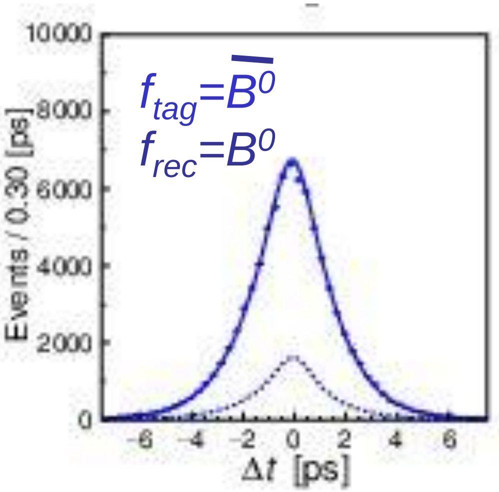
Search for CPT violation

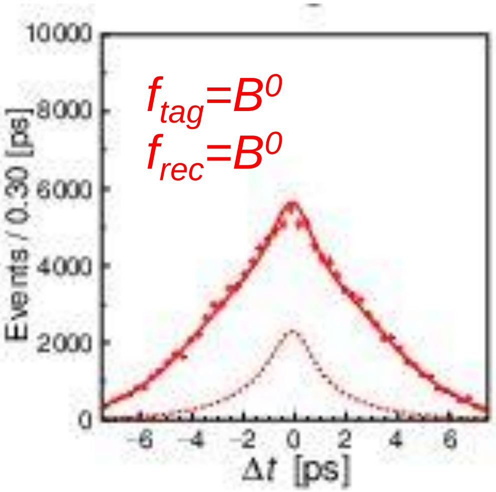
Belle, PRD85, 071105 (2012), 535 M BB

Reconstructed decays: $B^0 \to$ $J/\psi\, K^0$, $D^{(*)-}\pi^+(\rho^+)$, $D^{*-}\ell^+\nu$

f_{CP} $\sim f_{flav}$ f_{flav}



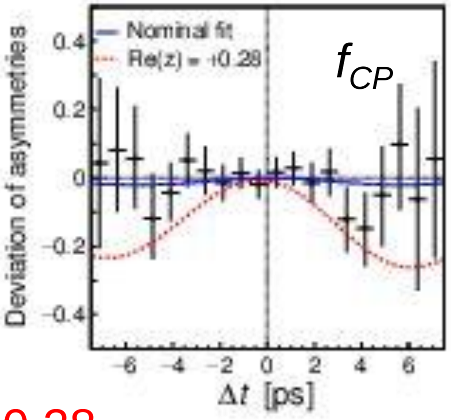




most of difference due to CPV, not CPTV

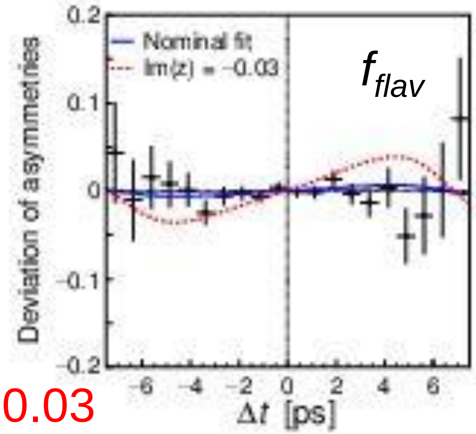
Fit to $B^0/\overline{B^0}$ asymm.

Expect. for $\Re(z)=0.28$



Fit to OS asymm.

Expect. for $\Im(z)=-0.03$



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Neutrals CPT

Search for CPT violation

$\Re(z)=(1.9 \pm 3.7 \pm 3.3) \cdot 10^{-2}$
$\Im(z)=(-5.7 \pm 3.3 \pm 3.3) \cdot 10^{-3}$
$\Delta\Gamma_d/\Gamma_d=(-1.7 \pm 1.8 \pm 1.1) \cdot 10^{-2}$

sensitivity ~2x better than previous
most sensitive search

BaBar, PRD70, 012007 (2004)
PRL92, 181801 (2004)
PRL96, 251802 (2006)

main syst. uncertainites:
$\Re(z)$: tag side interference (reducible)
$\Im(z)$, $\Delta\Gamma_d/\Gamma_d$: vertex reconstruction (partially reducible)

relatively easy with high statistics to reduce the errors by (2-4)x:

$\sigma(\Re(z))\sim 2 \cdot 10^{-2}$
$\sigma((\Im(z))\sim 3 \cdot 10^{-3}$
$\sigma(\Delta\Gamma_d/\Gamma_d)\sim 1 \cdot 10^{-2}$

to reduce further significant work on systematic uncertainties needed

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Measurement of T violation

A. Bevan, MITP workshop on T violation, April 2013

method acc. to

BaBar, Phys. Rev. Lett. 109, 211801 (2012)

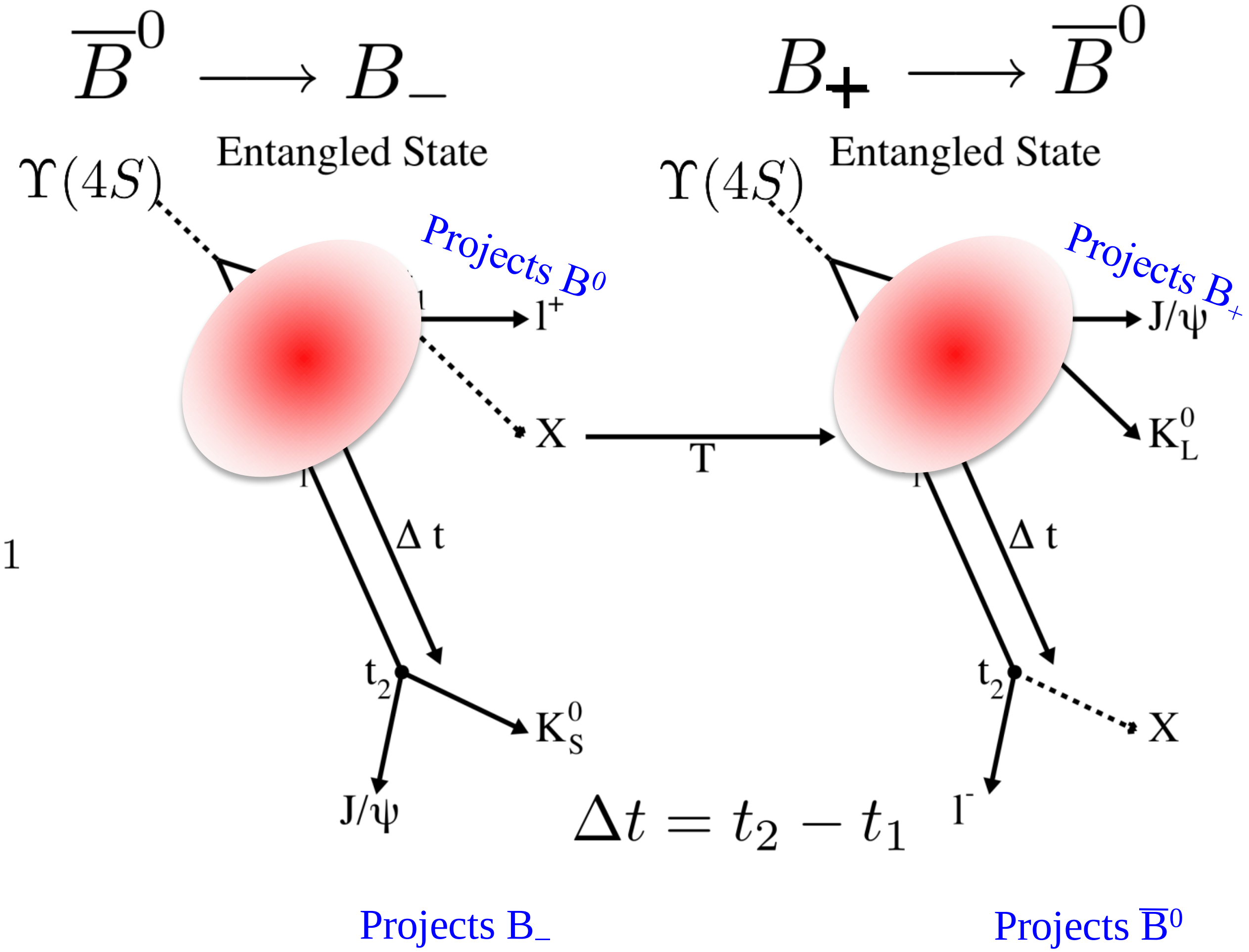
$$C^{\pm}_{\alpha,\beta} = \frac{1-|\lambda|^2}{1+|\lambda|^2}$$

$$S^{\pm}_{\alpha,\beta} = \frac{2Im\lambda}{1+|\lambda|^2}$$

$\beta \in \{K_S, K_L\}$ i.e. $CP = \pm 1$

$\alpha \in \{\ell^+, \ell^-\}$

Superscripts:
$+$ = normal ordering
$-$ = T reversed ordering



$$g^{\pm}_{\alpha,\beta}(\Delta t) \propto e^{-\Gamma \Delta t}\left[1 + C^{\pm}_{\alpha,\beta}\cos(\Delta m \Delta t) + S^{\pm}_{\alpha,\beta}\sin(\Delta m \Delta t)\right]$$

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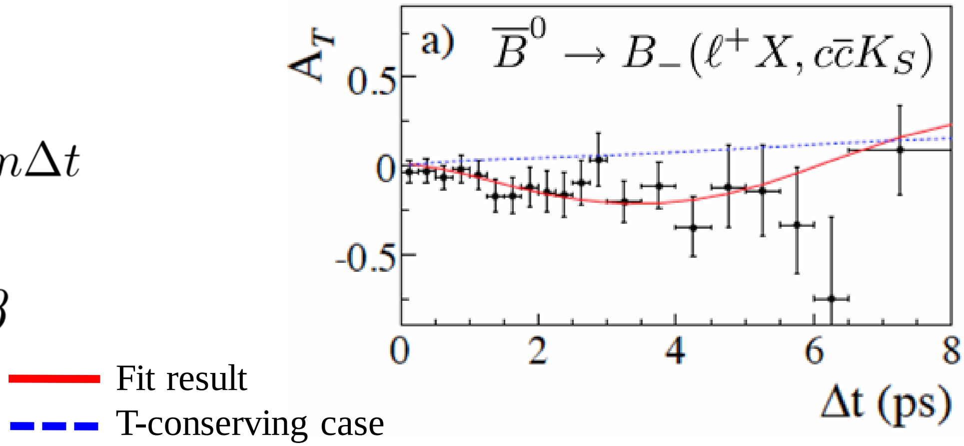
Neutrals T violation

Measurement of T violation

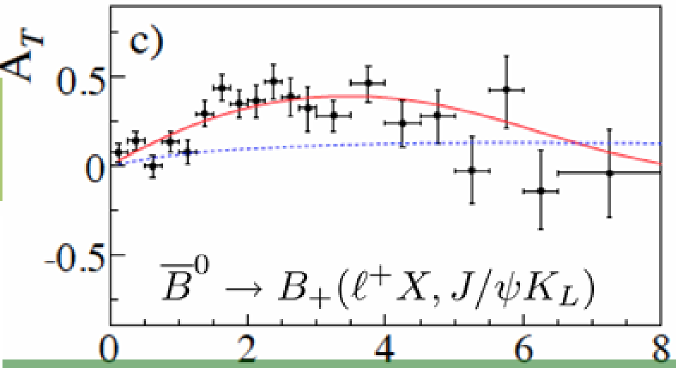
$$A_T \simeq \frac{\Delta C_T^{\pm}}{2} \cos \Delta m \Delta t + \frac{\Delta S_T^{\pm}}{2} \sin \Delta m \Delta t$$

in SM for ccK^0: $\Delta S_T^{\pm} = \mp 2 \sin 2\beta$

$\Delta C_T^{\pm} = 0$



$\Delta S_T^+ = S^-_{\ell^-,K_L^0} - S^+_{\ell^+,K_S^0}$	$-1.37 \pm 0.14 \pm 0.06$
$\Delta S_T^- = S^+_{\ell^-,K_L^0} - S^-_{\ell^+,K_S^0}$	$1.17 \pm 0.18 \pm 0.11$



BaBar, Phys. Rev. Lett. 109, 211801 (2012)

exepectation for Belle II (naive extrapol.):
$\sigma(\Delta S^{\pm})$~0.022
comparison to the CPV ($\sin 2\phi_1$) represents search for CPTV
(probably stat. uncertainties for $\sin 2\phi_1$ and $\Delta S^{\pm}$ correlated
→ CPTV tested to ~$2 \cdot 10^{-2}$)
to be compared to $\sigma(|z|) \sim 2 \cdot 10^{-2}$

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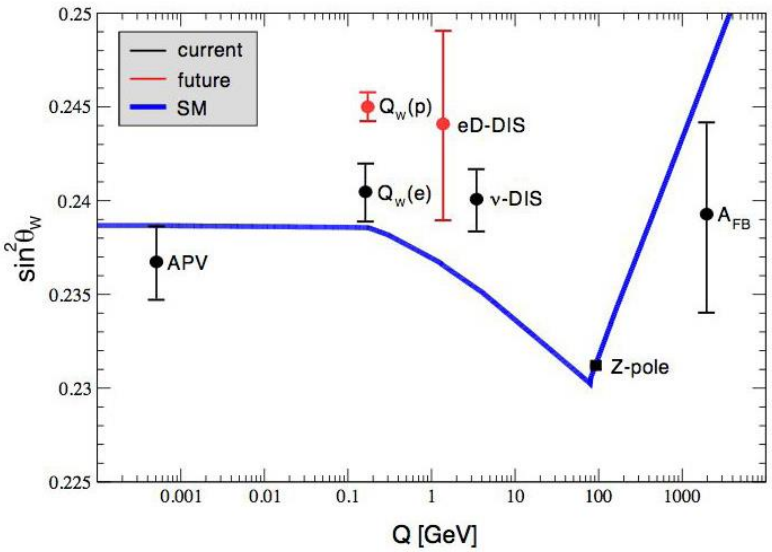
W. T. H. Van Oers et al. (Qweak),
http://qweak.jlab.org/DocDB/0007/000703/005/Qweak_Update_final2.pdf

Electroweak measurements, $\sin^2\theta_W$



Possibilities:
forward-backward asymmetry A_{FB} ($e^+e^- \rightarrow \mu^+\mu^-$);
left-right asymmetry A_{LR} (polarized beam);

at tree level, $s << M_Z^2$:

$$A_{FB}^{\mu} \equiv \frac{\sigma(e^-e^+ \rightarrow \mu^+\mu^-;\theta_{\mu^-} < 90^\circ) - \sigma(e^-e^+ \rightarrow \mu^+\mu^-;\theta_{\mu^-} > 90^\circ)}{\sigma(e^-e^+ \rightarrow \mu^+\mu^-;\theta_{\mu^-} < 90^\circ) + \sigma(e^-e^+ \rightarrow \mu^+\mu^-;\theta_{\mu^-} > 90^\circ)} \approx$$

$$\approx -\frac{3}{32}\frac{1}{\sin^2\vartheta_W \cos^2\vartheta_W}\frac{s}{s - M_Z^2}$$

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$\sin^2\theta_W$

ZFITTER:
A.B. Arbuzov et al., Comput. Phys. Commun. 174,728 (2006)

Electroweak measurements, $\sin^2\theta_W$

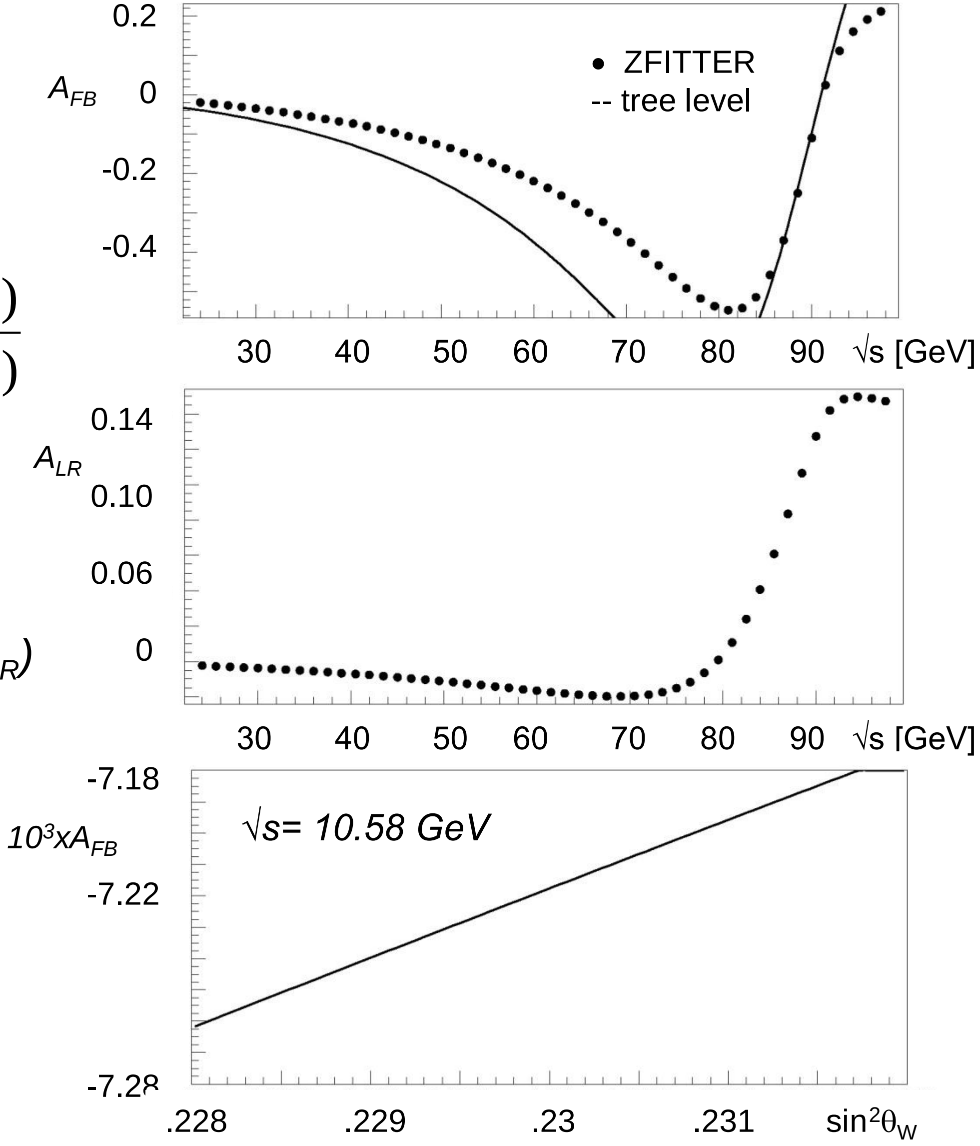
$$A_{LR}^{\mu} \equiv \frac{\sigma(e_L^- e^+ \to \mu^+\mu^-) - \sigma(e_R^- e^+ \to \mu^+\mu^-)}{\sigma(e_L^- e^+ \to \mu^+\mu^-) + \sigma(e_R^- e^+ \to \mu^+\mu^-)}$$

at $s = M_Z^2$:

$\sigma(\sin^2\theta_W) \approx 0.55\,\sigma(A_{FB})$ $\sigma(\sin^2\theta_W) \approx 0.13\,\sigma(A_{LR})$
A_{LR} 4x more sensitive to $\sin^2\theta_W$ than A_{FB}

at $s = (10.58\ \text{GeV})^2$:

$\sigma(\sin^2\theta_W) \approx 46\,\sigma(A_{FB})$ $\sigma(\sin^2\theta_W) \approx 24\,\sigma(A_{LR})$
A_{LR} 2x more sensitive to $\sin^2\theta_W$ than A_{FB}



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Electroweak measurements, $\sin^2\theta_W$

$\int\mathcal{L}dt = 10\ \text{ab}^{-1}$

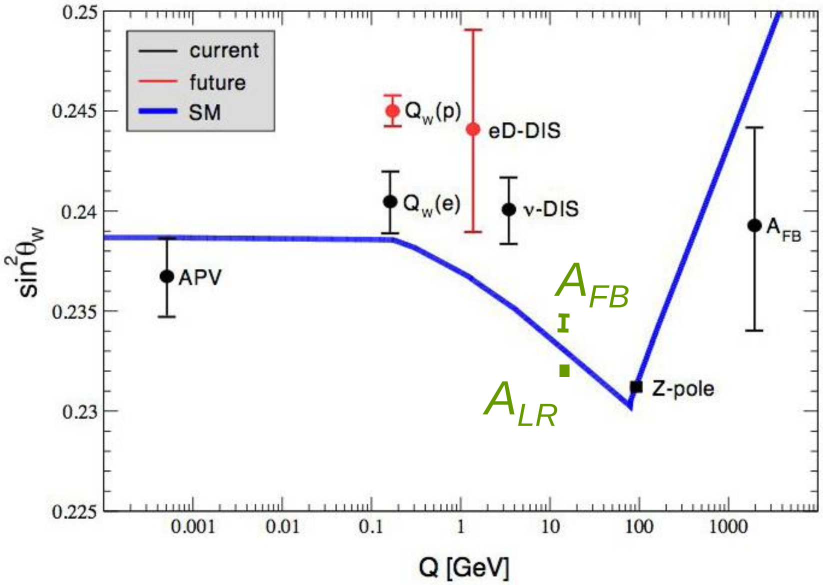
$\varepsilon_{\mu\mu} \sim 0.6$, $N_{\mu\mu} \sim 7\times10^9$

stat. uncertainties:
$\sigma(A_{FB})/A_{FB} \sim 0.2\%$
$\sigma(\sin^2\theta_W) \sim 6\times10^{-4}$ from A_{FB} (±0.25%)

$\sigma(A_{LR})/A_{LR} \sim 2.4\%$
$\sigma(\sin^2\theta_W) \sim 3\times10^{-4}$ from A_{LR} (±0.13%)
(80% polarization)

comparison SLD A_{LR} :
$\sigma(\sin^2\theta_W)/\sin^2\theta_W \sim \pm0.10\%$ total uncertainty

polarization uncertainty affects directly A_{LR}:
SLD: $\sigma(A_{LR})/A_{LR} \sim 0.5\%$ from polarization
$\Rightarrow \sigma(\sin^2\theta_W)/\sin^2\theta_W \sim 0.05\%$



SuperB polarimetry
(Compton polarimeters):
$\sigma(A_{LR})/A_{LR} \sim 1\%$

M. Sullivan et al., IPAC-2010-TUPEB025 (2010)

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$B^0 \to K\pi\pi^0$

tree+penguin processes, $B^0 \to K\pi\pi^0$

$K^*\pi$, $K\rho$: $T+P_{EW}/P_{QCD}$ larger than in $K\pi$

M. Gronau, D. Pirjol, J. Zupan, arXiv:1001.0702

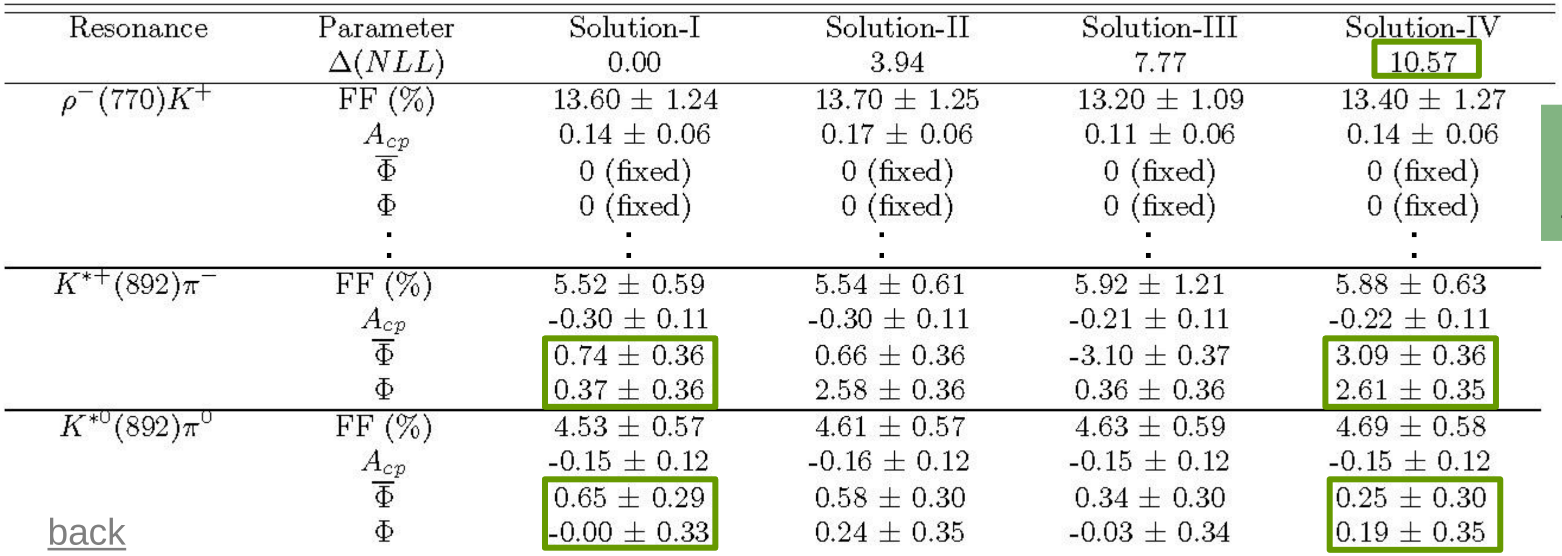
similar as in $K\pi$: isospin sum rule

$$-A(K^{*+}\pi^-) = \lambda_t^{(s)}\left(P_{tc,P} + \frac{2}{3}P^C_{EW,P}\right) + \lambda_u^{(s)}(P_{uc,P} + T_P)$$

$$\sqrt{2}A(K^{*0}\pi^0) = \lambda_t^{(s)}\left(P_{tc,P} - P_{EW,V} - \frac{1}{3}P^C_{EW,P}\right) + \lambda_u^{(s)}(P_{uc,P} - C_V)$$

$$A(K^{*+}\pi^-) + \sqrt{2}A(K^{*0}\pi^0) = P_{EW} + T << P_{tc}$$

$B^0 \to K\pi\pi^0$: $A(K^{*+}\pi^-)$ & $A(K^{*0}\pi^0)$ should destructively interfere



Resonance	Parameter	Solution-I	Solution-II	Solution-III	Solution-IV
	$\Delta(NLL)$	0.00	3.94	7.77	10.57
$\rho^-(770)K^+$	FF (%)	13.60 ± 1.24	13.70 ± 1.25	13.20 ± 1.09	13.40 ± 1.27
	A_{cp}	0.14 ± 0.06	0.17 ± 0.06	0.11 ± 0.06	0.14 ± 0.06
	$\overline{\Phi}$	0 (fixed)	0 (fixed)	0 (fixed)	0 (fixed)
	Φ	0 (fixed)	0 (fixed)	0 (fixed)	0 (fixed)
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$K^{*+}(892)\pi^-$	FF (%)	5.52 ± 0.59	5.54 ± 0.61	5.92 ± 1.21	5.88 ± 0.63
	A_{cp}	-0.30 ± 0.11	-0.30 ± 0.11	-0.21 ± 0.11	-0.22 ± 0.11
	$\overline{\Phi}$	0.74 ± 0.36	0.66 ± 0.36	-3.10 ± 0.37	3.09 ± 0.36
	Φ	0.37 ± 0.36	2.58 ± 0.36	0.36 ± 0.36	2.61 ± 0.35
$K^{*0}(892)\pi^0$	FF (%)	4.53 ± 0.57	4.61 ± 0.57	4.63 ± 0.59	4.69 ± 0.58
	A_{cp}	-0.15 ± 0.12	-0.16 ± 0.12	-0.15 ± 0.12	-0.15 ± 0.12
	$\overline{\Phi}$	0.65 ± 0.29	0.58 ± 0.30	0.34 ± 0.30	0.25 ± 0.30
	Φ	-0.00 ± 0.33	0.24 ± 0.35	-0.03 ± 0.34	0.19 ± 0.35

BaBar,
arXiv:0807.4567,
400 fb^{-1}

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$B^0 \rightarrow K\pi\pi^0$

$K\pi\pi^0$: example of final state depending on PID performance

check of $A(K^{*+}\pi^-)$ & $A(K^{*0}\pi^0)$ interference: Belle @ 1 ab^{-1}?

if $A_{CP}(K^*\pi)$~20% (~2x$A_{CP}(K\pi)$)

5 σ observation @ 10 ab^{-1} (stat. only)

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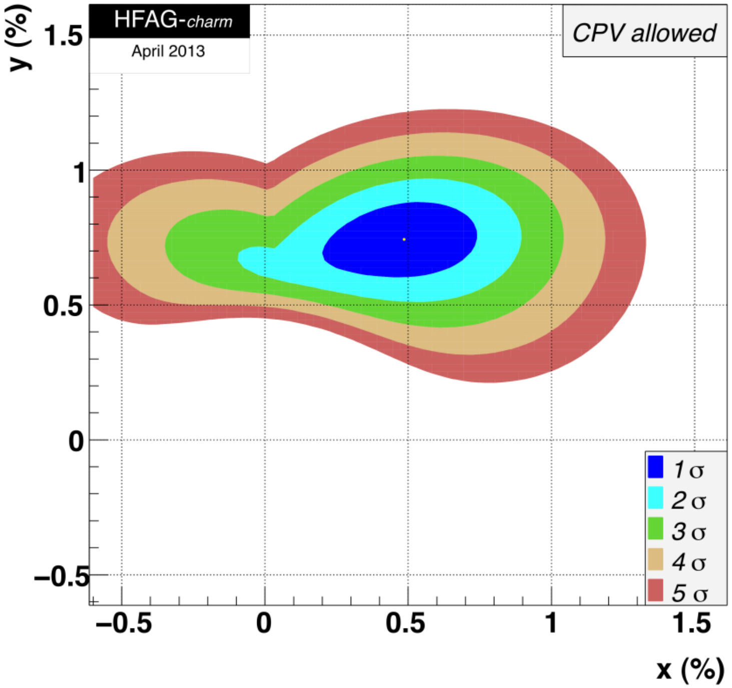
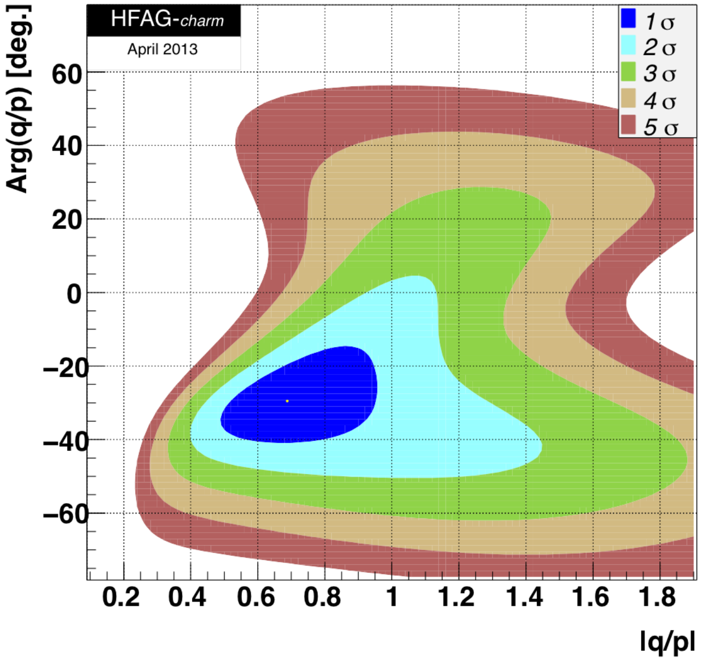
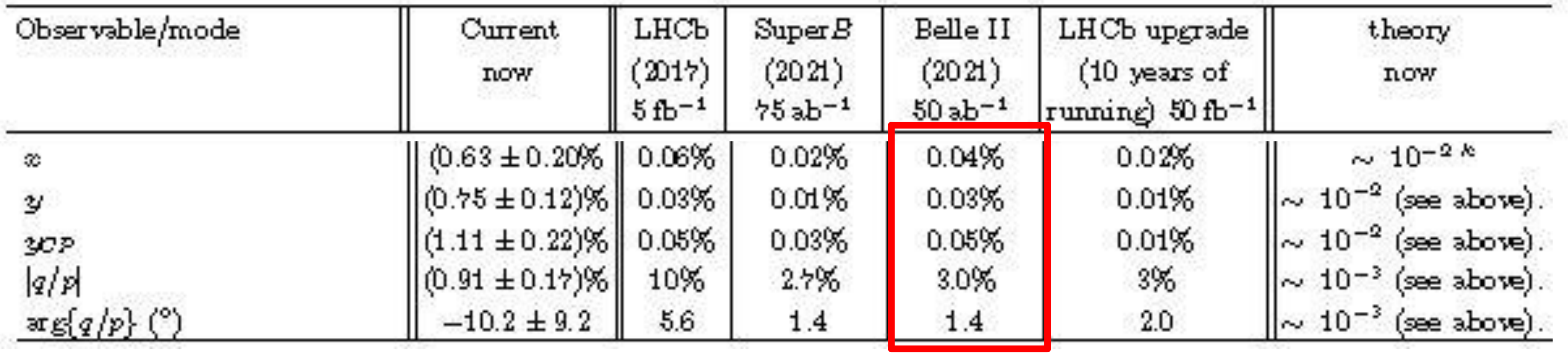
Charm mixing and CPV

Current (WA) situation:





Expected precision:



Observable/mode	Current now	LHCb (2017) 5 fb^{-1}	Super*B* (2021) 75 ab^{-1}	Belle II (2021) 50 ab^{-1}	LHCb upgrade (10 years of running) 50 fb^{-1}	theory now
x	(0.63 ± 0.20%	0.06%	0.02%	0.04%	0.02%	$\sim 10^{-2}$ k
y	(0.75 ± 0.12)%	0.03%	0.01%	0.03%	0.01%	$\sim 10^{-2}$ (see above).
y_{CP}	(1.11 ± 0.22)%	0.05%	0.03%	0.05%	0.01%	$\sim 10^{-2}$ (see above).
$\lvert q/p\rvert$	(0.91 ± 0.17)%	10%	2.7%	3.0%	3%	$\sim 10^{-3}$ (see above).
$\arg\{q/p\}$ (°)	−10.2 ± 9.2	5.6	1.4	1.4	2.0	$\sim 10^{-3}$ (see above).

B. Meadows et al., arXiv:1109.5028

compilation of

A.G. Akeroyd et al., arXiv: 1002.5012

B. O'Leary et al., arXiv: 1008.1541

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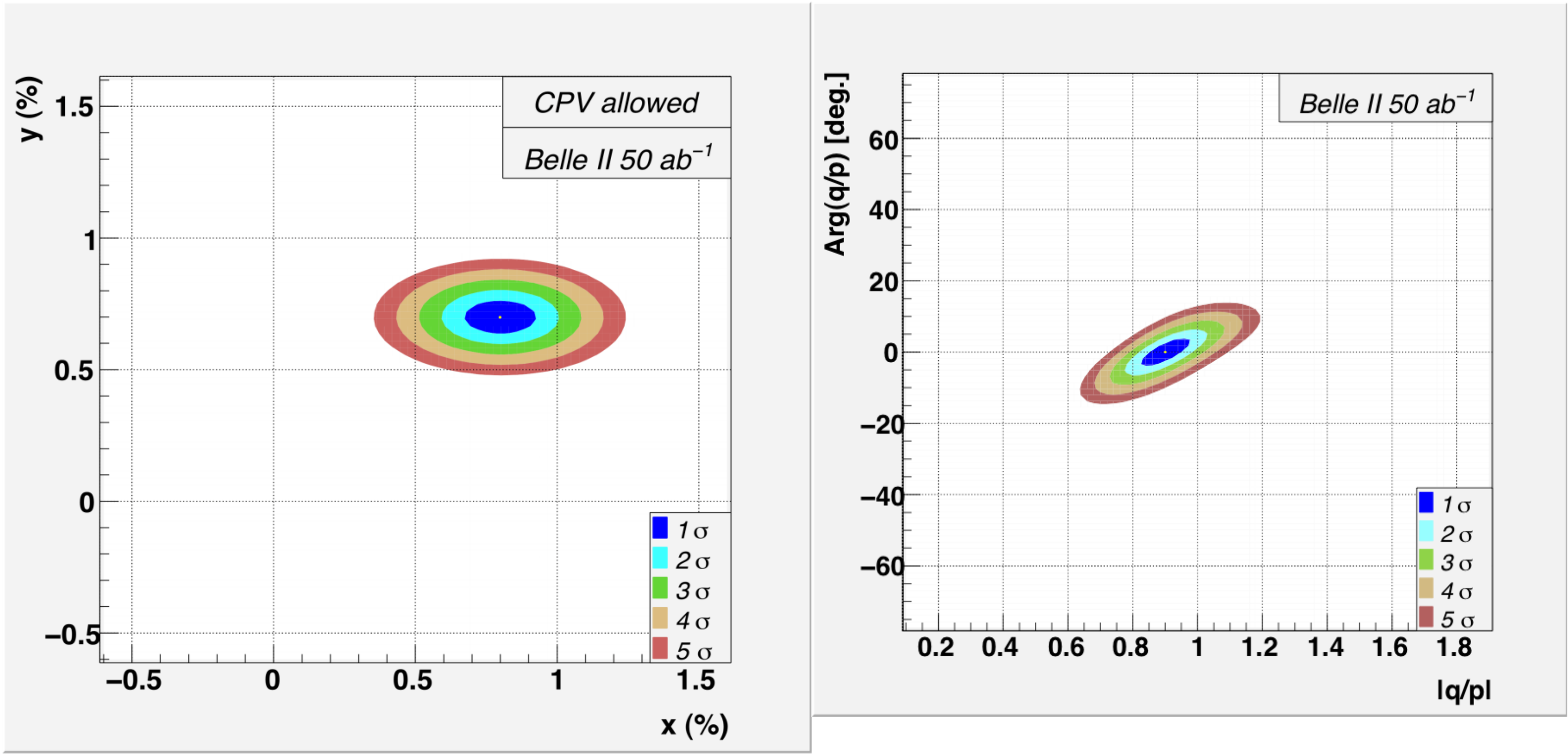
Charm mixing and CPV



Expected sensitivity with 50 ab^{-1} arising from $D^0 \rightarrow KK/\pi\pi$, $K_S\pi\pi$, $K\pi$

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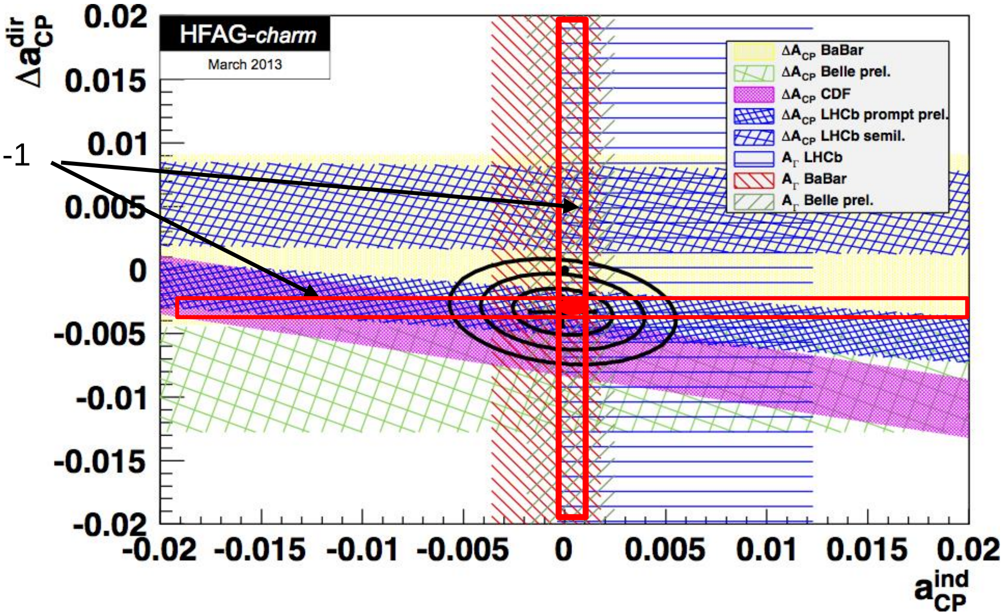
Charm mixing and CPV



50 ab^{-1}

(S)BF determine $A_{CP}(\pi\pi)$ and $A_{CP}(KK)$ separately; in future important for interpretation;

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