Time-dependent CP-violation sensitivity at the Belle II

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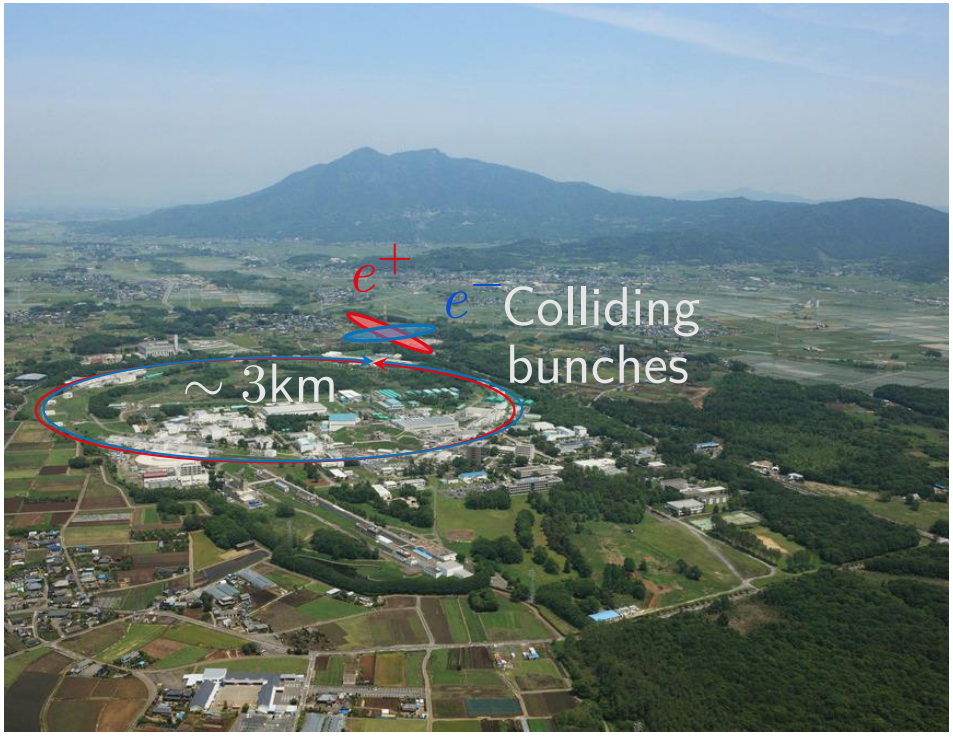
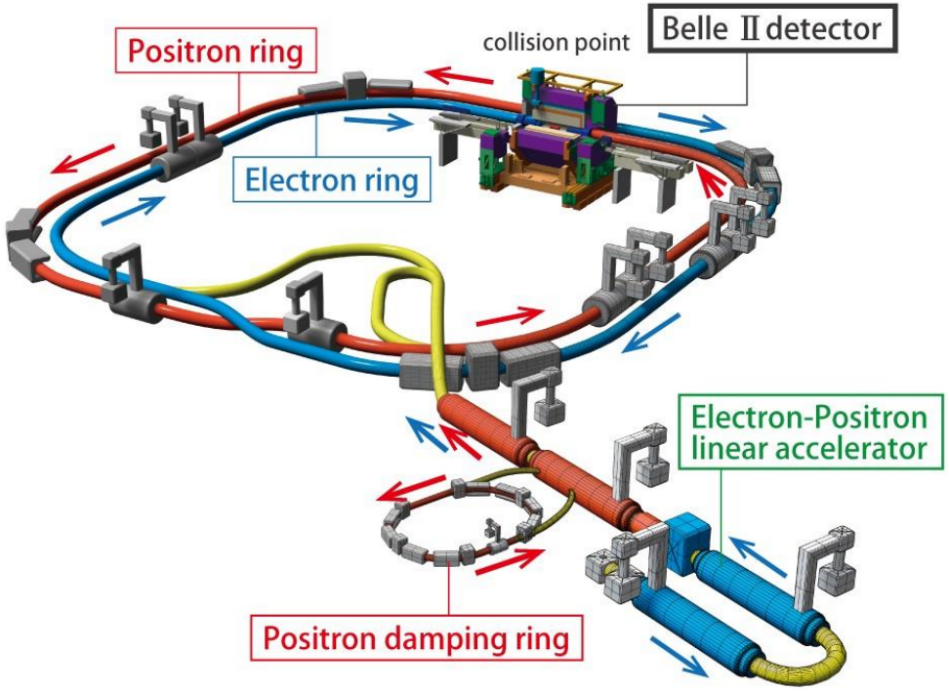
Max-Planck-Institut
für Physik

KEKB/SuperKEKB Collider

Upgrade: KEKB $\Rightarrow$ SuperKEKB

Belle $\Rightarrow$ Belle II



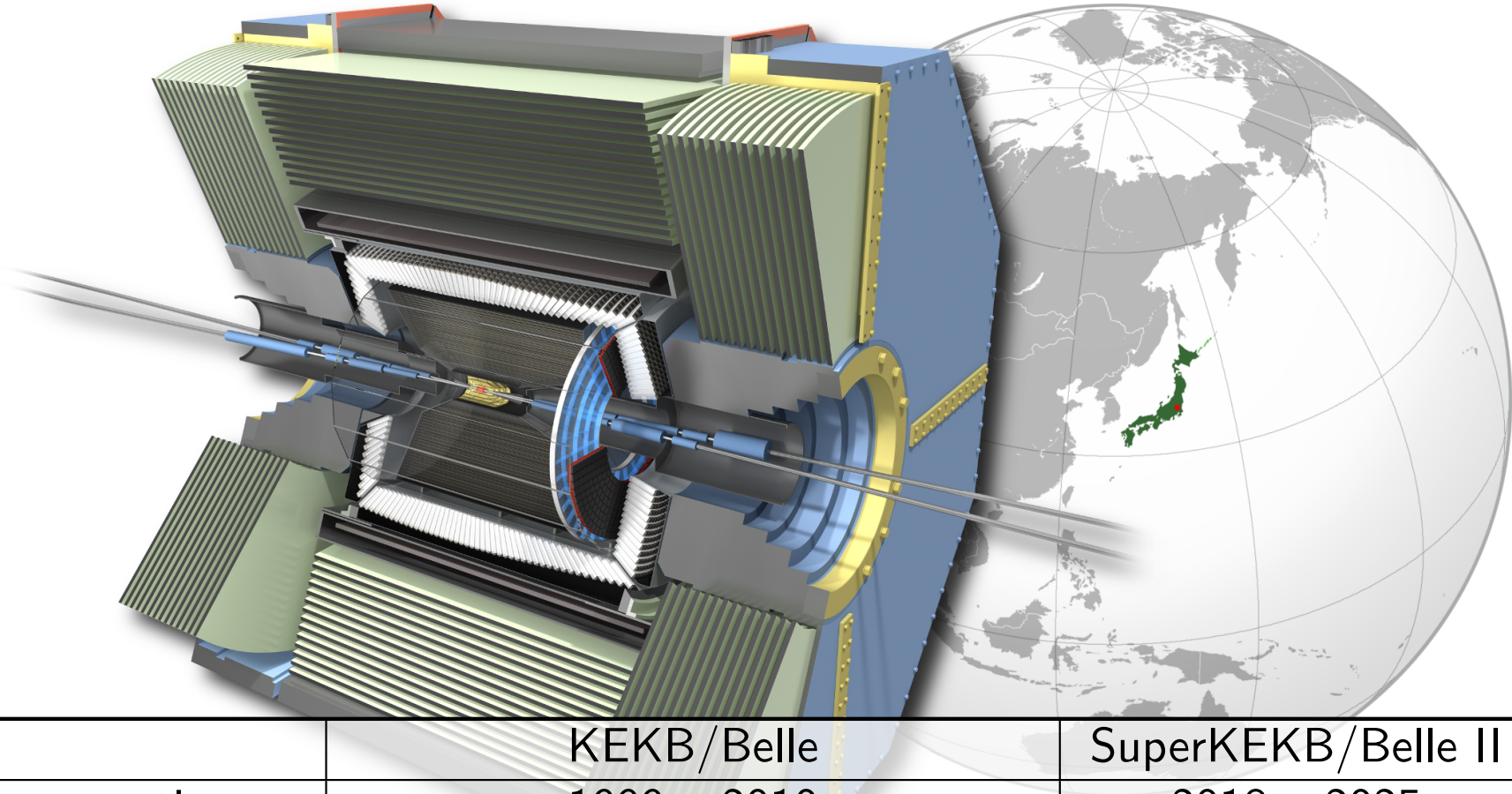


KEK = kō enerugī kasokuki kenkyū kikō

high energy collider research organization

At: Tsukuba, Ibaraki Prefecture, Japan

Belle/Belle II Experiment



	KEKB/Belle	SuperKEKB/Belle II
operation	1999 – 2010	2018 – 2025
e^-/e^+ beam E	$8/3.5$ GeV	$7/4$ GeV
e^-/e^+ beam I	$1.2/1.6$ A	$2.6/3.6$ A
Inst. Lumi. $\mathcal{L}$	$2.11 \cdot 10^{34}\text{cm}^{-2}\text{s}^{-1}$	$8 \cdot 10^{35}\text{cm}^{-2}\text{s}^{-1}$
$\int \mathcal{L} \cdot dt$	$\sim 0.8\,\text{ab}^{-1}$ ($772 \cdot 10^6$ $B\,\overline{B}$ pairs)	$50\,\text{ab}^{-1}$

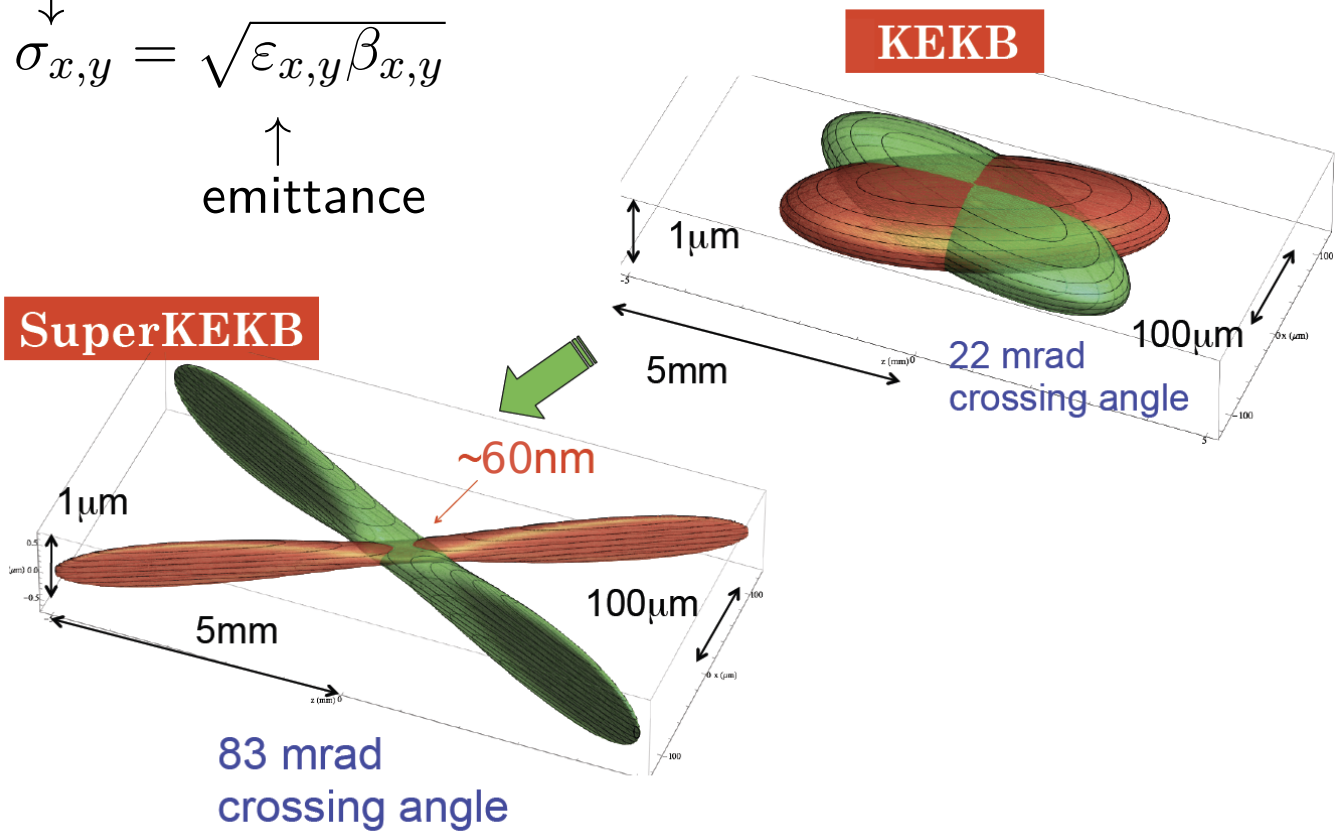
Nano Beam Scheme

Lorentz factor ↓ $\gamma_\pm$ — beam-beam parameters ↓ $I_\pm \xi_\pm$

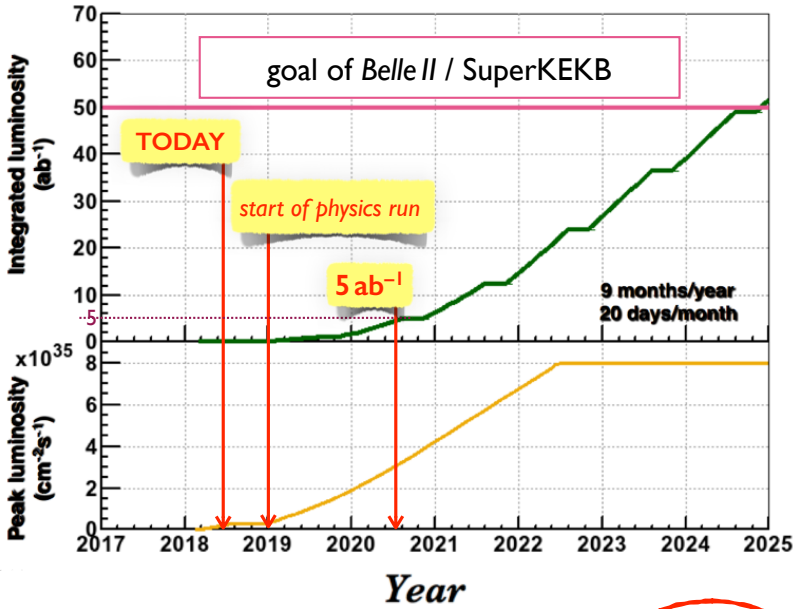
$$\mathcal{L} = \frac{\gamma_\pm}{2 e r_e} \left(1 + \frac{\sigma_y}{\sigma_x}\right) \left(\frac{I_\pm \xi_\pm}{\beta_y}\right) \left(\frac{R_L}{R_{\xi_y}}\right)$$

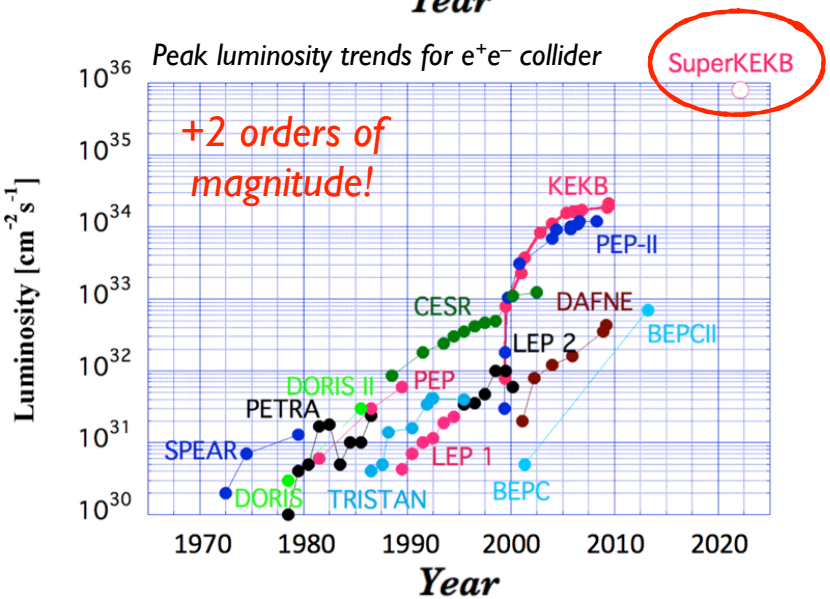
↑ Geometric factors

beam size ↓ $\sigma_{x,y}$ — $\sigma_{x,y} = \sqrt{\varepsilon_{x,y} \beta_{x,y}}$ ↑ emittance

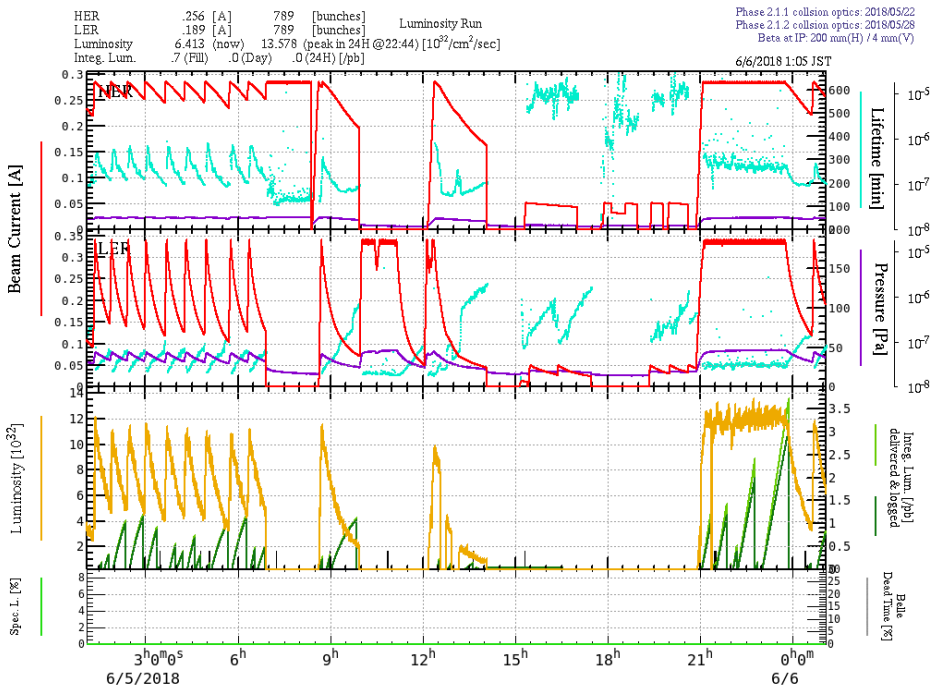


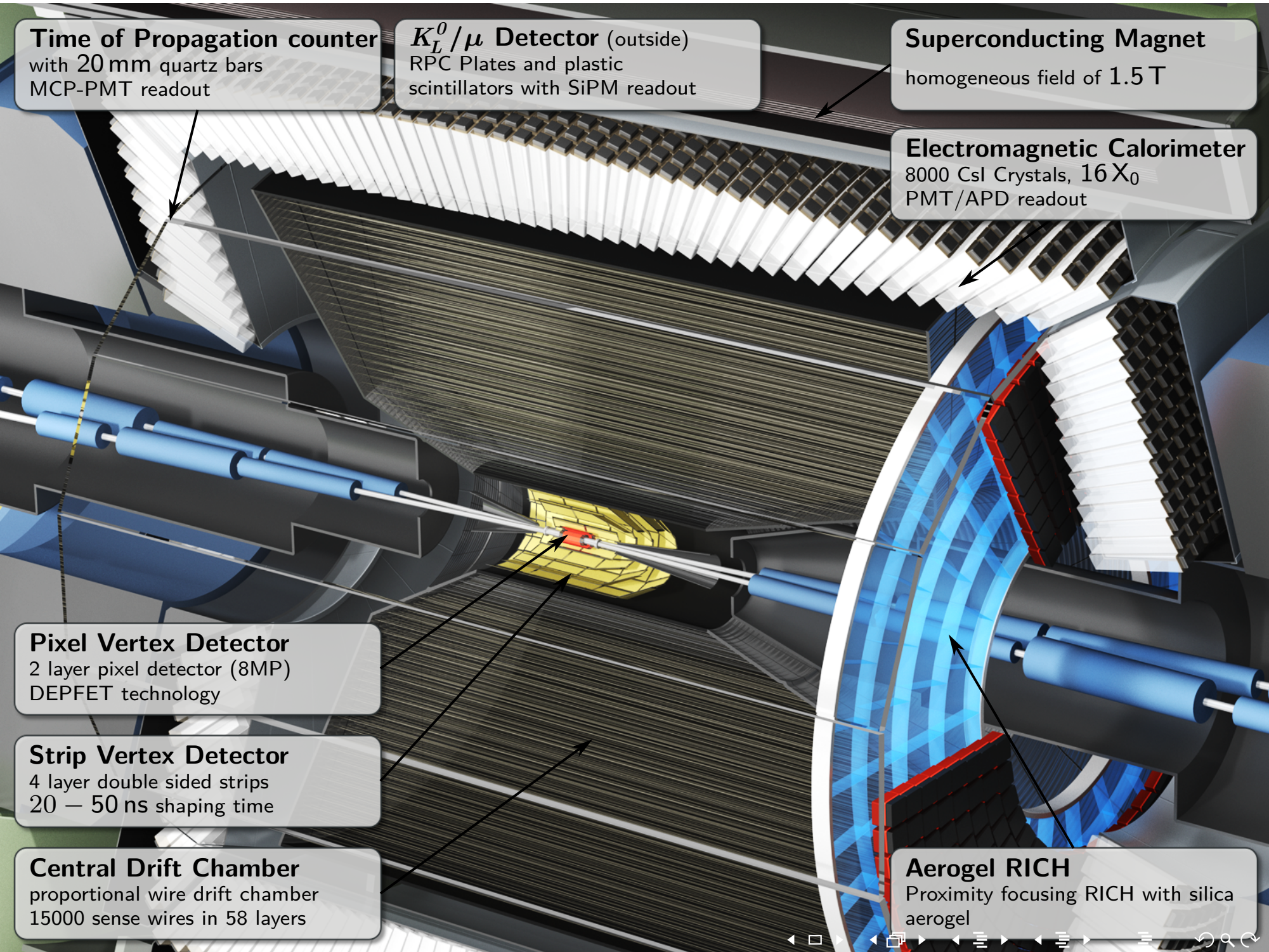
Luminosity at Belle II



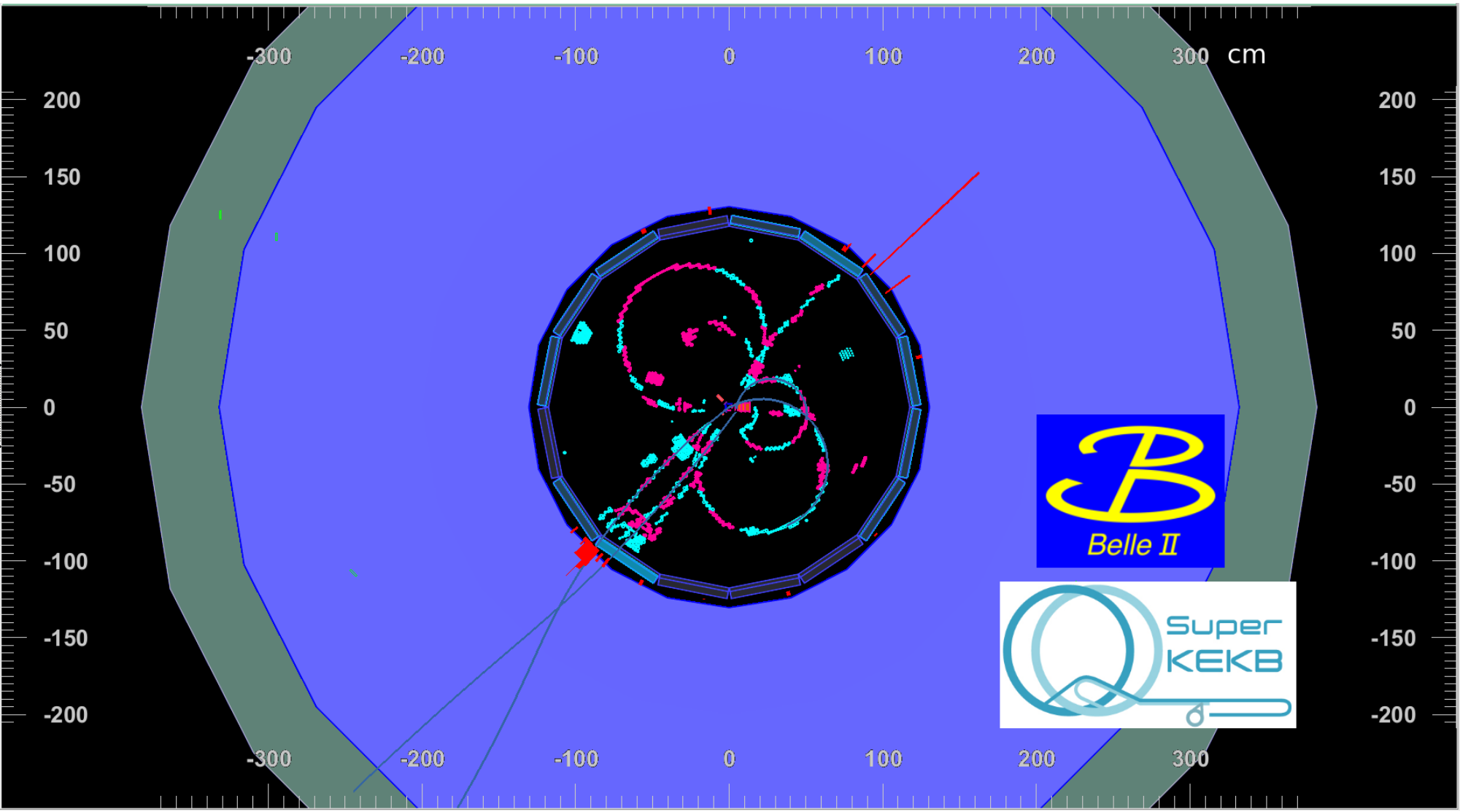


Machine commissioning started on April 25




Time of Propagation counter
with 20 mm quartz bars
MCP-PMT readout
K_L^0/μ Detector (outside)
RPC Plates and plastic
scintillators with SiPM readout
Superconducting Magnet
homogeneous field of 1.5 T
Electromagnetic Calorimeter
8000 CsI Crystals, 16 X_0
PMT/APD readout
Pixel Vertex Detector
2 layer pixel detector (8MP)
DEPFET technology
Strip Vertex Detector
4 layer double sided strips
20 – 50 ns shaping time
Central Drift Chamber
proportional wire drift chamber
15000 sense wires in 58 layers
Aerogel RICH
Proximity focusing RICH with silica
aerogel

Machine commissioning started in April 2018



One of the first hadronic events! April 26 at 0:38 am.

CP-Violation in the SM

- Why CP-Violation? $\Rightarrow$ Matter-Antimatter-Asymm. in the universe larger than in SM. Sakharov's 2nd cond.: C-V, CP-V.
- Why in the B^0-system? $\Rightarrow$ largest CP-V. within the SM.
- CP-V. in the SM $\Rightarrow$ Weak Interaction $\Rightarrow$ $\mathbf{V}_{CKM}$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

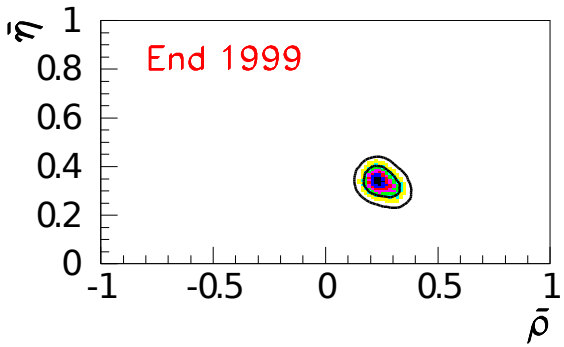
- Params: 3 Real, 1 Im.: $\lambda = \sin\theta_C \approx 0.2, A, \rho, \eta$

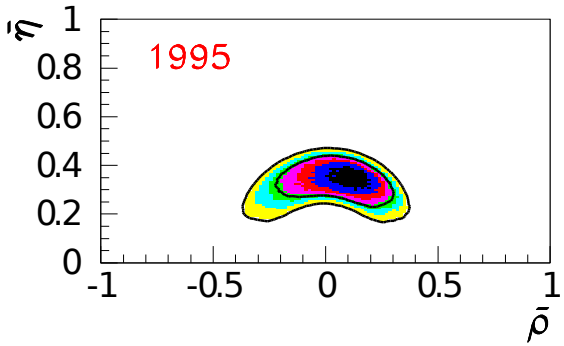
$$\mathbf{V}_{CKM} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta)] & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

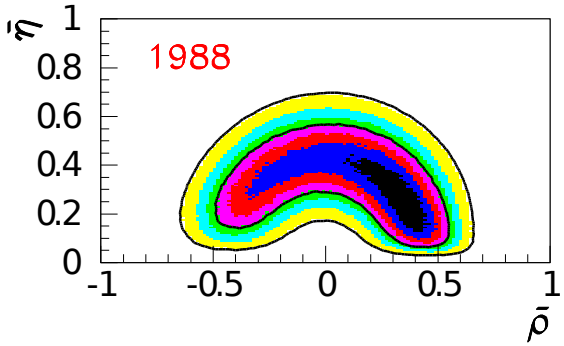
$\Rightarrow$ $\mathcal{L}^{\text{Yuk}} \propto igW^\mu J^{cc}_\mu \Rightarrow J^{cc}_\mu \xrightarrow{CP} J^{cc\,\prime}_\mu \neq J^{cc}_\mu$

- Unitarity: $\sum_k V^*_{ki} V_{kj} = 0 \Rightarrow \underbrace{V_{ud}V^*_{ub}}_{\mathcal{O}(\lambda^3)} + \underbrace{V_{cd}V^*_{cb}}_{\mathcal{O}(\lambda^3)} + \underbrace{V_{td}V^*_{tb}}_{\mathcal{O}(\lambda^3)} = 0$

CKM-Triangle

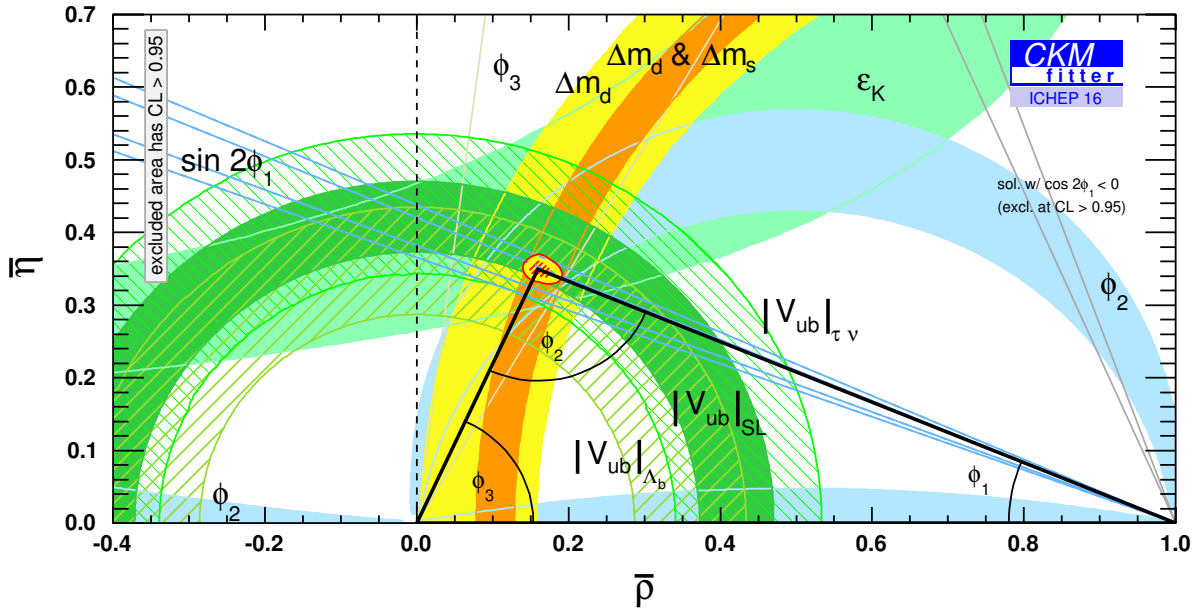






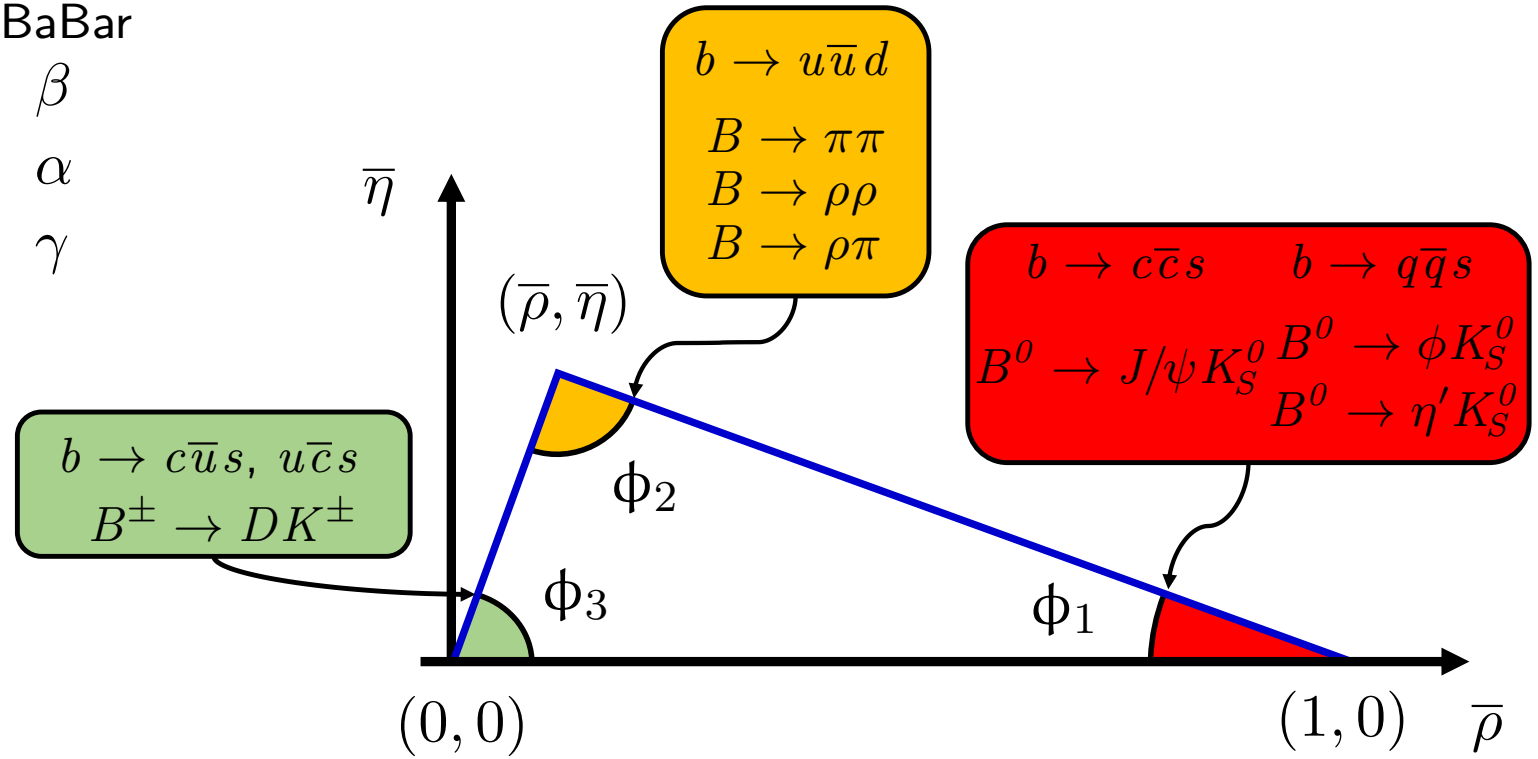
hep-ph/0002171

$$\bar{\rho} = \left(1 - \frac{\lambda^2}{2}\right)\rho \qquad \bar{\eta} = \left(1 - \frac{\lambda^2}{2}\right)\eta$$



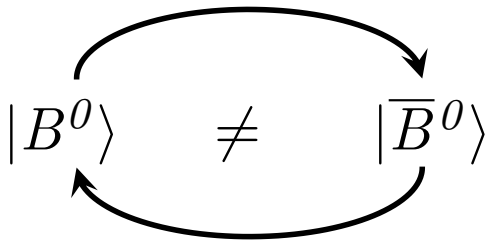
CKM-Triangle

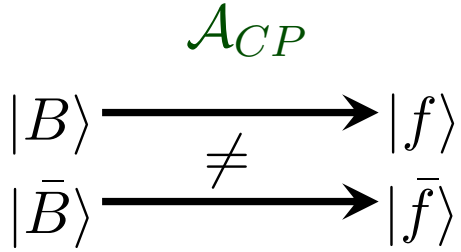
Belle		BaBar
ϕ_1	$=$	β
ϕ_2	$=$	α
ϕ_3	$=$	γ

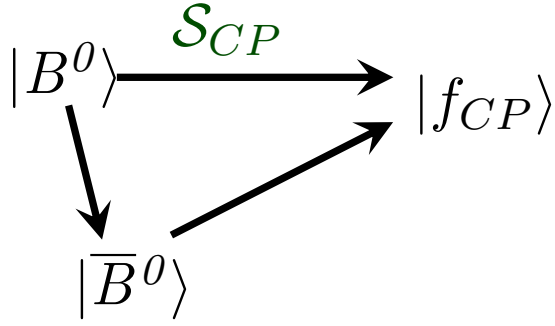


- Sides $\sim$ Decay amplitudes $\sim$ Branching fractions
- Angles $\sim$ Weak Phases $\sim$ CP violation
- ϕ_1 and $\phi_2 \Rightarrow$ Time dependent CP violation

Measurement of ϕ_1







Tree-dominated $b \to c\bar{c}s$ modes

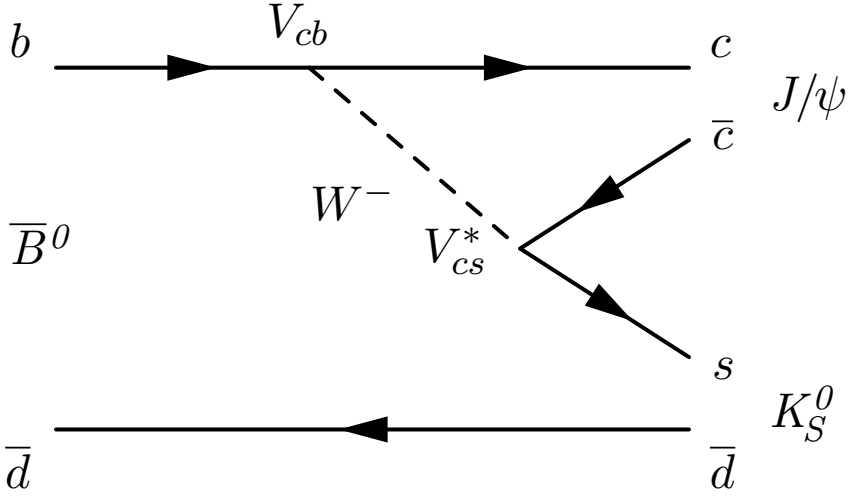
$$\mathcal{A}_{CP}{}^{c\bar{c}s} = 0$$

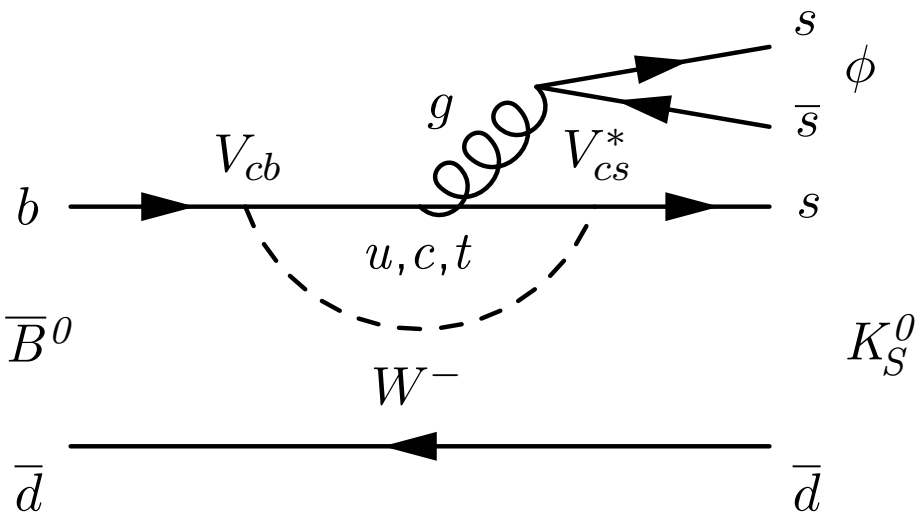
$$\mathcal{S}_{CP}{}^{c\bar{c}s} = -\eta_{CP}\sin(2\phi_1)$$

Penguin-dominated $b \to q\bar{q}s$ modes

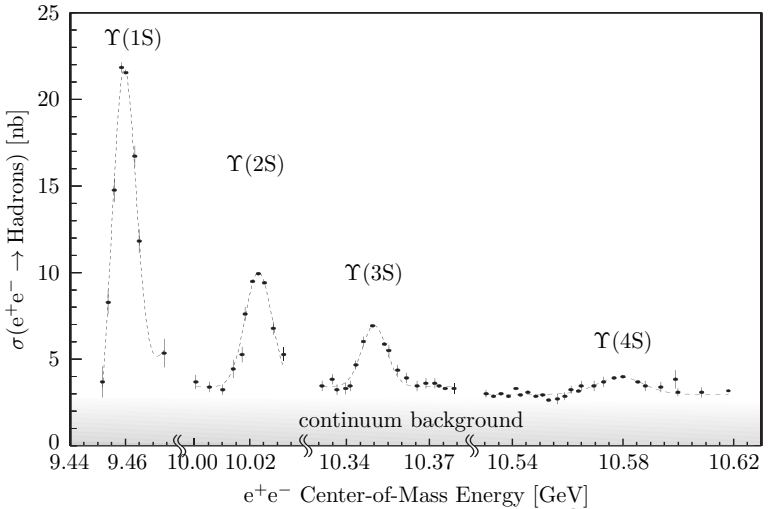
$$\mathcal{A}_{CP}{}^{q\bar{q}s} = 0$$

$$\mathcal{S}_{CP}{}^{q\bar{q}s} = -\eta_{CP}\sin(2\phi_1)$$



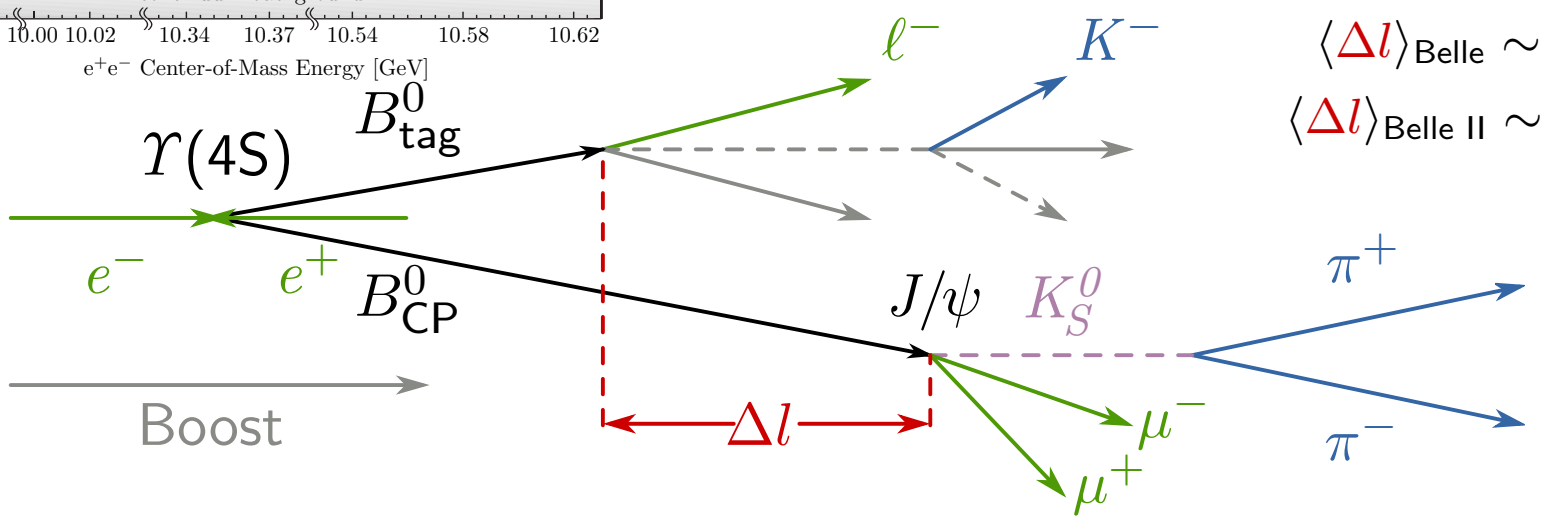


Time-dep. CP-Analysis at B-Factories



- $\Upsilon(4S)$ above $B\overline{B}$ prod. threshold
- $\Upsilon(4S) \rightarrow B\overline{B} > 96\ \%$
- $\frac{\Gamma(B^+B^-)}{\Gamma(B^0\overline{B}^0)} \sim 1.06$

$\Rightarrow$ B-Factory



$\langle \Delta l \rangle_{\text{Belle}} \sim 200\ \mu\text{m}$

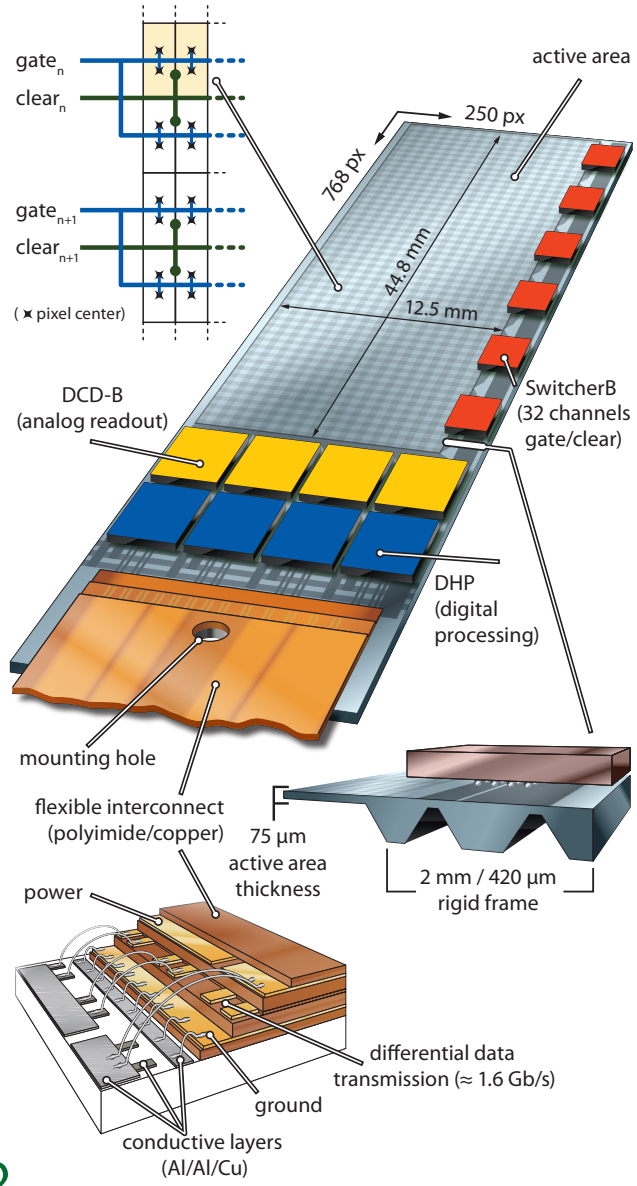
$\langle \Delta l \rangle_{\text{Belle II}} \sim 130\ \mu\text{m}$

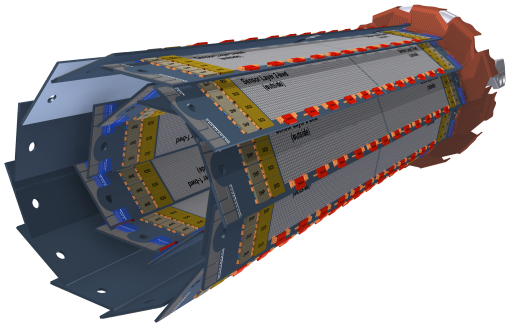
$\Rightarrow$ $\Delta t = \frac{\Delta l}{\langle \beta\gamma \rangle c}$ since $B^0\overline{B}^0$ at rest in $\Upsilon(4S)$ frame

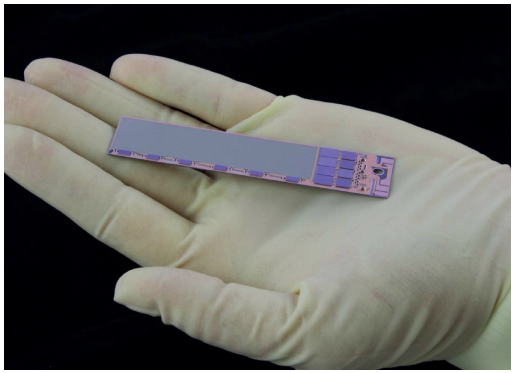
$q_{B^0,\overline{B}^0} = 1, -1$

$$\mathcal{P}^{\text{Sig}}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left[1 + q\left(\mathcal{A}_{CP}\cos(\Delta m \Delta t) + \mathcal{S}_{CP}\sin(\Delta m \Delta t)\right)\right]$$

DEPFET Pixel Vertex Detector







- Inst. Lumi.: $\mathcal{L}_{\text{Belle II}} \sim 40 \cdot \mathcal{L}_{\text{Belle}}$

$\Rightarrow$ Background $\uparrow\uparrow\uparrow$

- Closest to IP

$\Rightarrow$ Occupancy $(\sim r^{-2})$ $\uparrow\uparrow\uparrow$

- $\langle\beta\gamma\rangle_{\text{Belle II}} < \langle\beta\gamma\rangle_{\text{Belle}}$

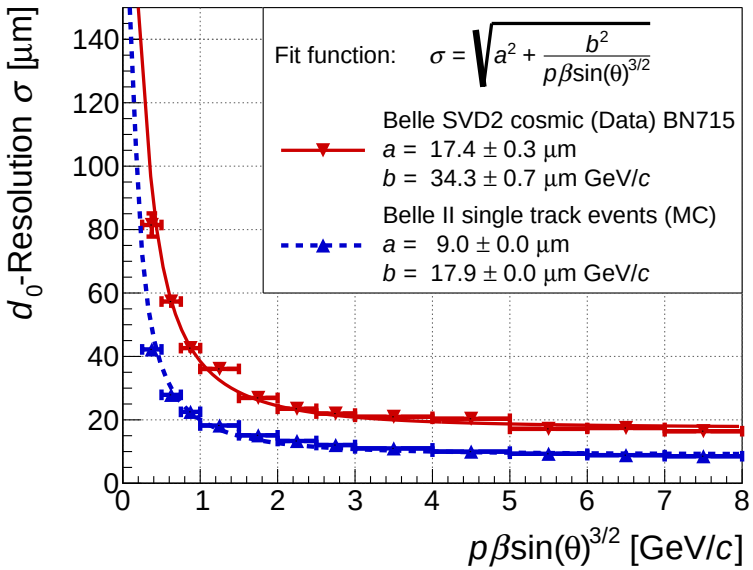
$\Rightarrow$ smaller Δz

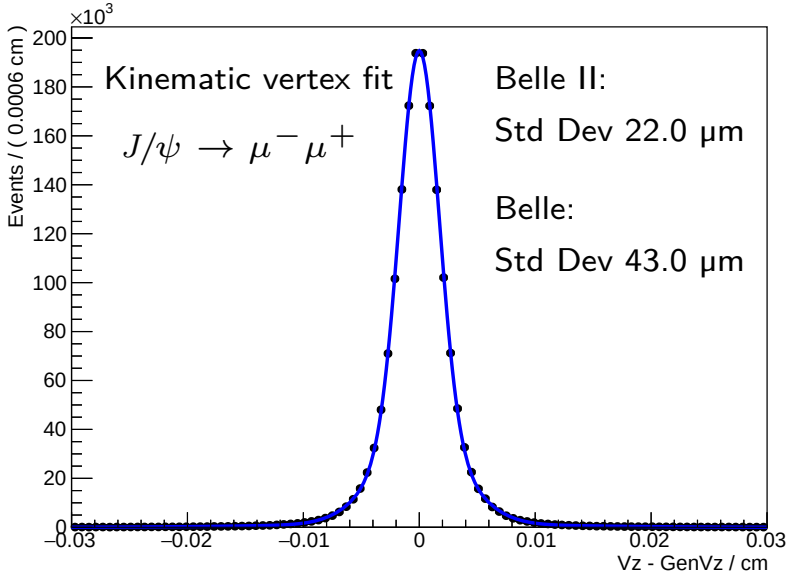
$\Rightarrow$ Pixel Detector needed !

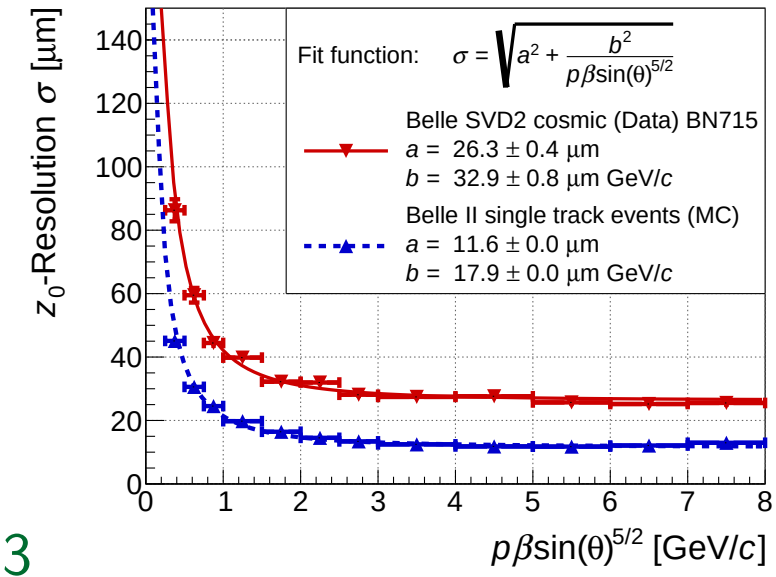
$\Rightarrow$ DEPFET Technology most suited

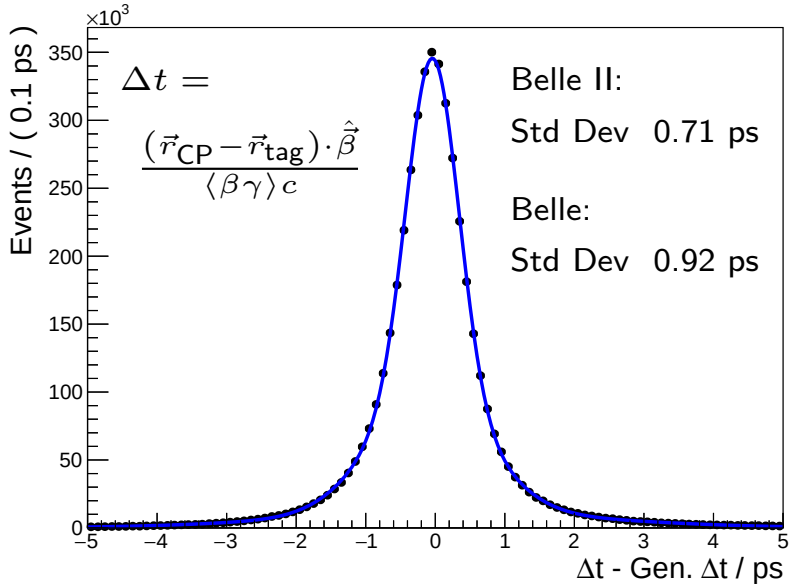
DEPleted Field Effect Transistor

Impact Parameters and Vertex resolutions









ϕ_1 from $b \to c\bar{c}s$ decays

Belle PR Lett 108 171802

$\mathcal{S}_{CP} = 0.667 \pm 0.023 \pm 0.012$

$\mathcal{A}_{CP} = 0.006 \pm 0.016 \pm 0.012$

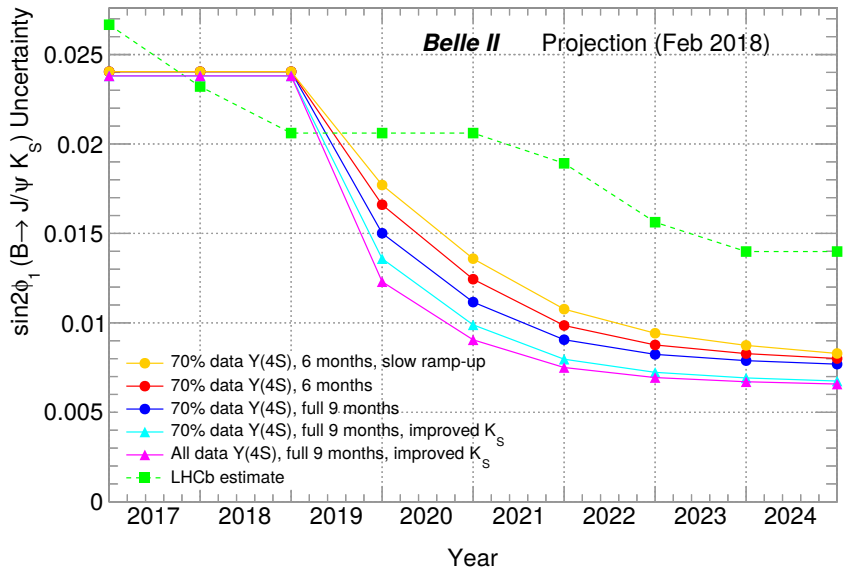
Systematic effect	$\delta\mathcal{S}_{CP}$	$\delta\mathcal{A}_{CP}$
Δt resolution	± 0.007	± 0.001
Vertexing	± 0.007	± 0.007
Tag-side interference	± 0.001	± 0.008
Flavor tagging	± 0.004	± 0.003
Possible fit bias	± 0.004	± 0.005
Signal fraction	± 0.004	± 0.002
Background Δt	± 0.001	< 0.001
Physics parameters	± 0.001	< 0.001
Total Belle	± 0.012	± 0.012

- $\sigma_{\text{stat}} = \sigma_{\text{stat}}^{\text{Belle}} \cdot \sqrt{\frac{\mathcal{L}^{\text{Belle}}}{50\,\text{ab}^{-1}}}$
- $\sigma_{\text{sys}} = \sqrt{(\sigma_{\text{red}}^{\text{Belle}})^2 \cdot \frac{\mathcal{L}^{\text{Belle}}}{50\,\text{ab}^{-1}} + (\sigma_{\text{ired}}^{\text{Belle}})^2}$

Belle II with $50\,\text{ab}^{-1}$

$\delta\mathcal{S}_{CP} = \pm 0.003 \pm 0.004$

$\delta\mathcal{A}_{CP} = \pm 0.002 \pm 0.009$



- Precision at Belle II dominated by systematic effects. $\Rightarrow$ effort concentrated in understanding and reducing them.
- Expected precision: $\phi_1^{c\bar{c}s} \lesssim 0.1^\circ$

ϕ_1 from $b \to q\bar{q}s$ decays

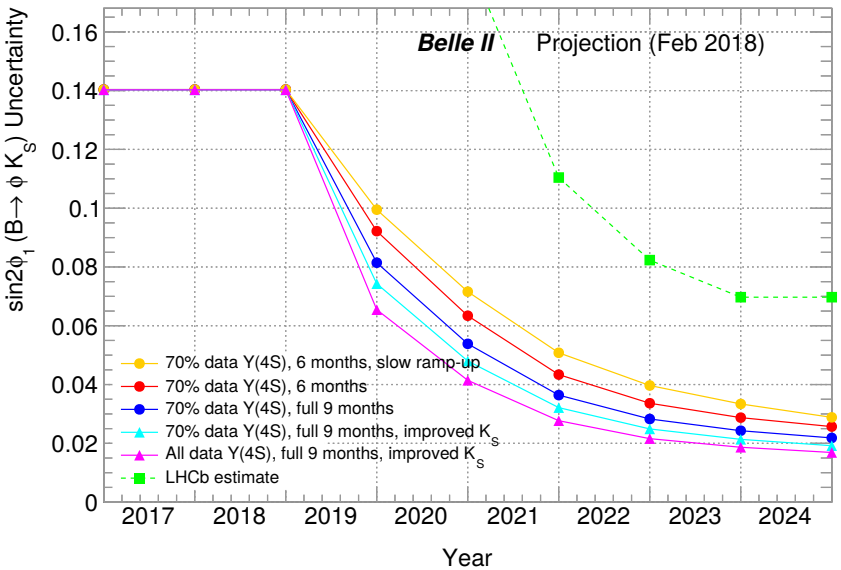
$B^0 \to \phi K^0$

Belle PRD 82 073011

$$\mathcal{S}_{CP} = 0.90^{+0.09}_{-0.19}$$

$$\mathcal{A}_{CP} = 0.04 \pm 0.20 \pm 0.10 \pm 0.02$$

Belle II	$5\,\text{ab}^{-1}$	$50\,\text{ab}^{-1}$
$\delta\mathcal{S}_{CP}$	0.048	0.020
$\delta\mathcal{A}_{CP}$	0.035	0.011



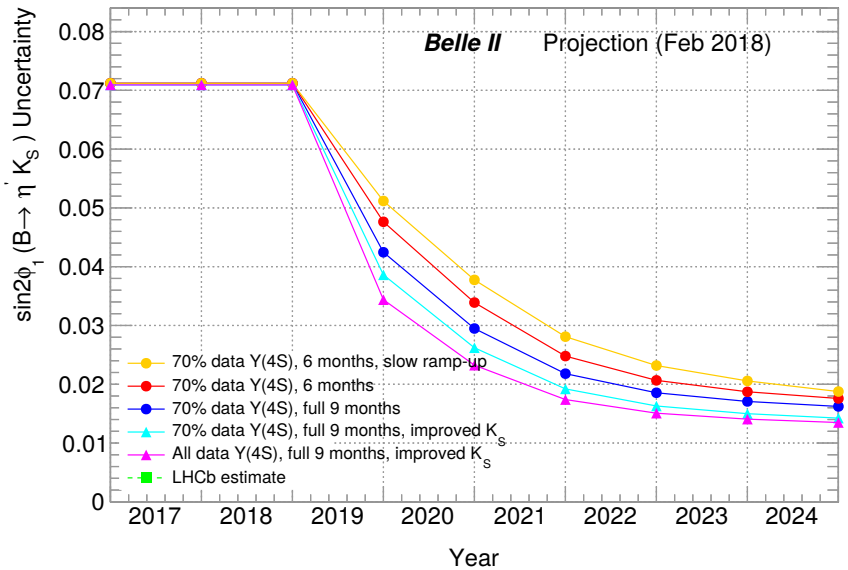
$B^0 \to \eta' K^0$

Belle JHEP 10 (2014) 165

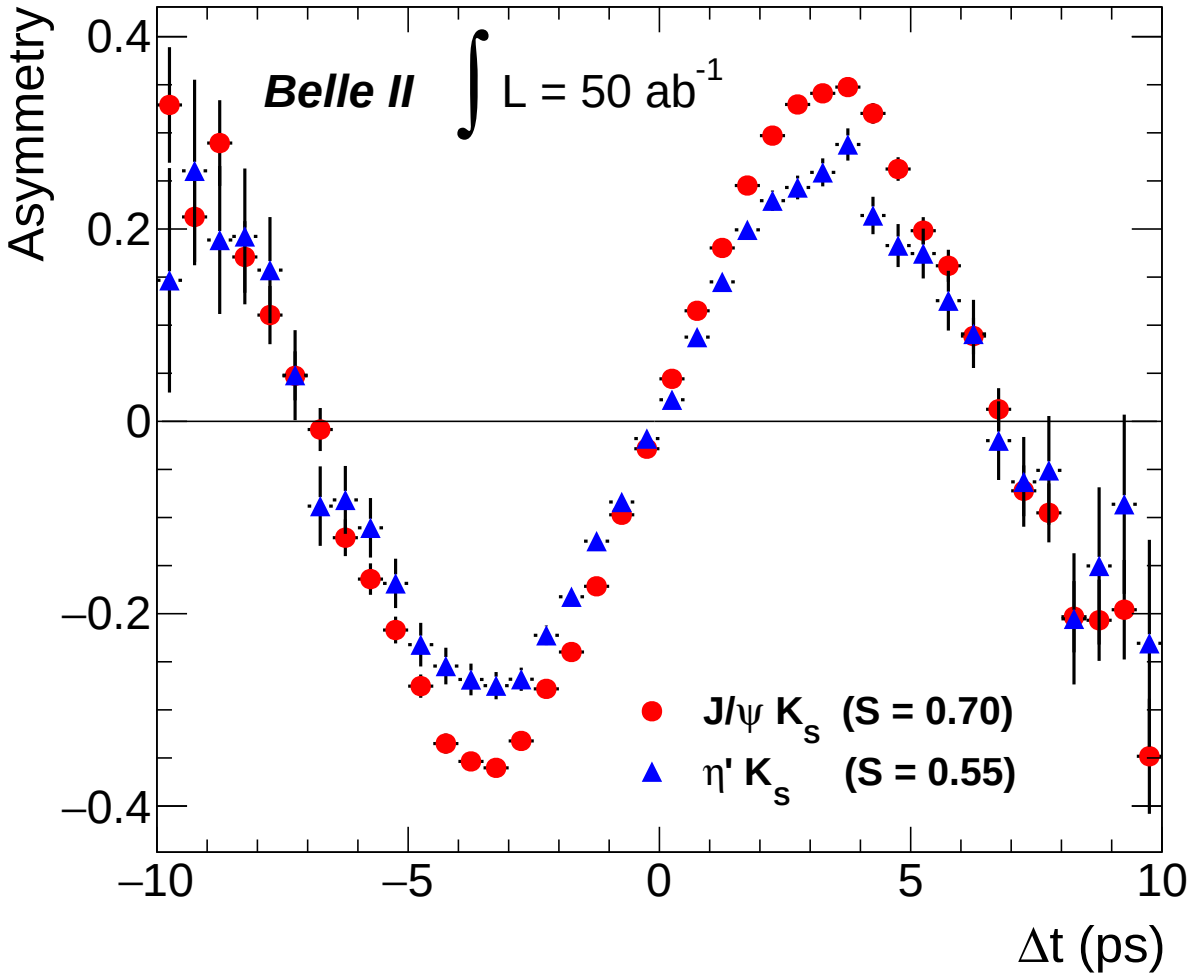
$$\mathcal{S}_{CP} = 0.68 \pm 0.07 \pm 0.03$$

$$\mathcal{A}_{CP} = 0.03 \pm 0.05 \pm 0.04$$

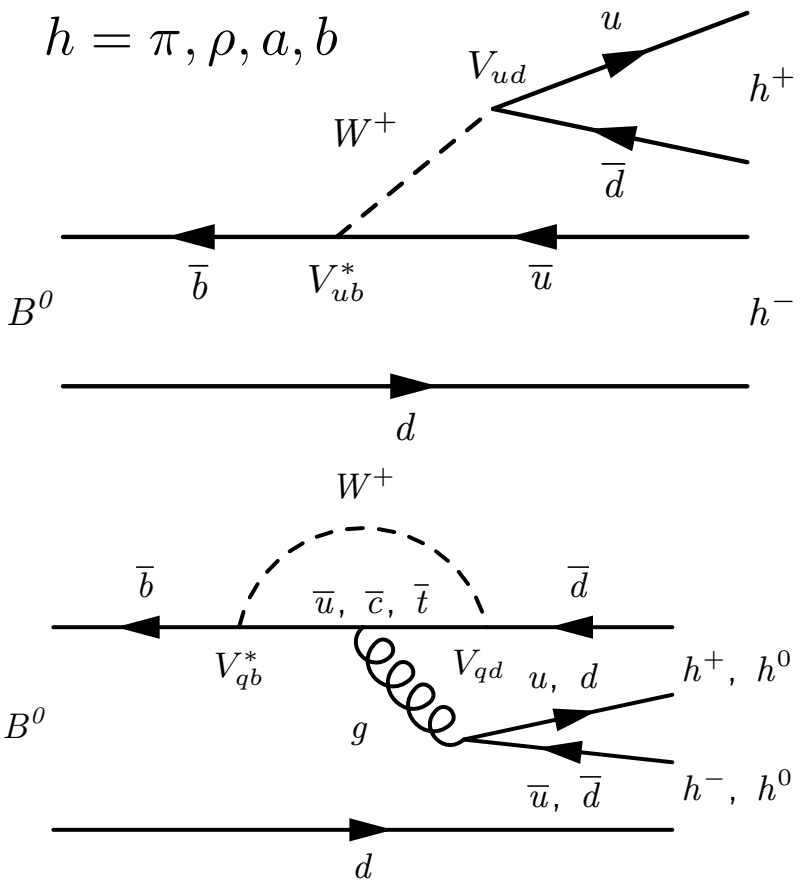
Belle II	$5\,\text{ab}^{-1}$	$50\,\text{ab}^{-1}$
$\delta\mathcal{S}_{CP}$	0.032	0.015
$\delta\mathcal{A}_{CP}$	0.020	0.008

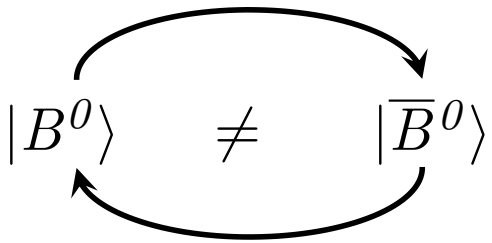


$\mathcal{S}_{CP}(c\bar{c}s)$ and $\mathcal{S}_{CP}(s\bar{s}s)$



B Decays to Isovectors





🌿: $\lambda_{hh} = \left(\frac{q}{p}\right)_{B^0} \cdot \left(\frac{\bar{A}^{hh}}{A^{hh}}\right) = e^{2i\phi_2}$

$\mathcal{A}_{CP} = 0$

$\mathcal{S}_{CP} = \sin(2\phi_2)$

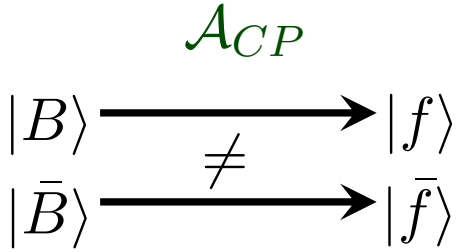
But tree and penguin diags. contribute!

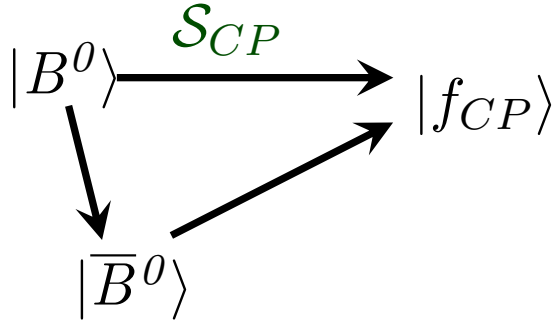
🌿 + 🐦: $\lambda_{hh} = \left|\frac{\tilde{A}^{hh}}{A^{hh}}\right| e^{2i\phi_{2,\text{eff}}}$

$\mathcal{A}_{CP} \neq 0$

$\mathcal{S}_{CP} = \sqrt{1 - \mathcal{A}_{CP}} \sin(2i\phi_{2,\text{eff}})$

$\Rightarrow \phi_{2,\text{eff}} = \phi_2 - \Delta\phi_2$





Extraction of ϕ_2 from $B \to \pi\pi, \rho\rho$

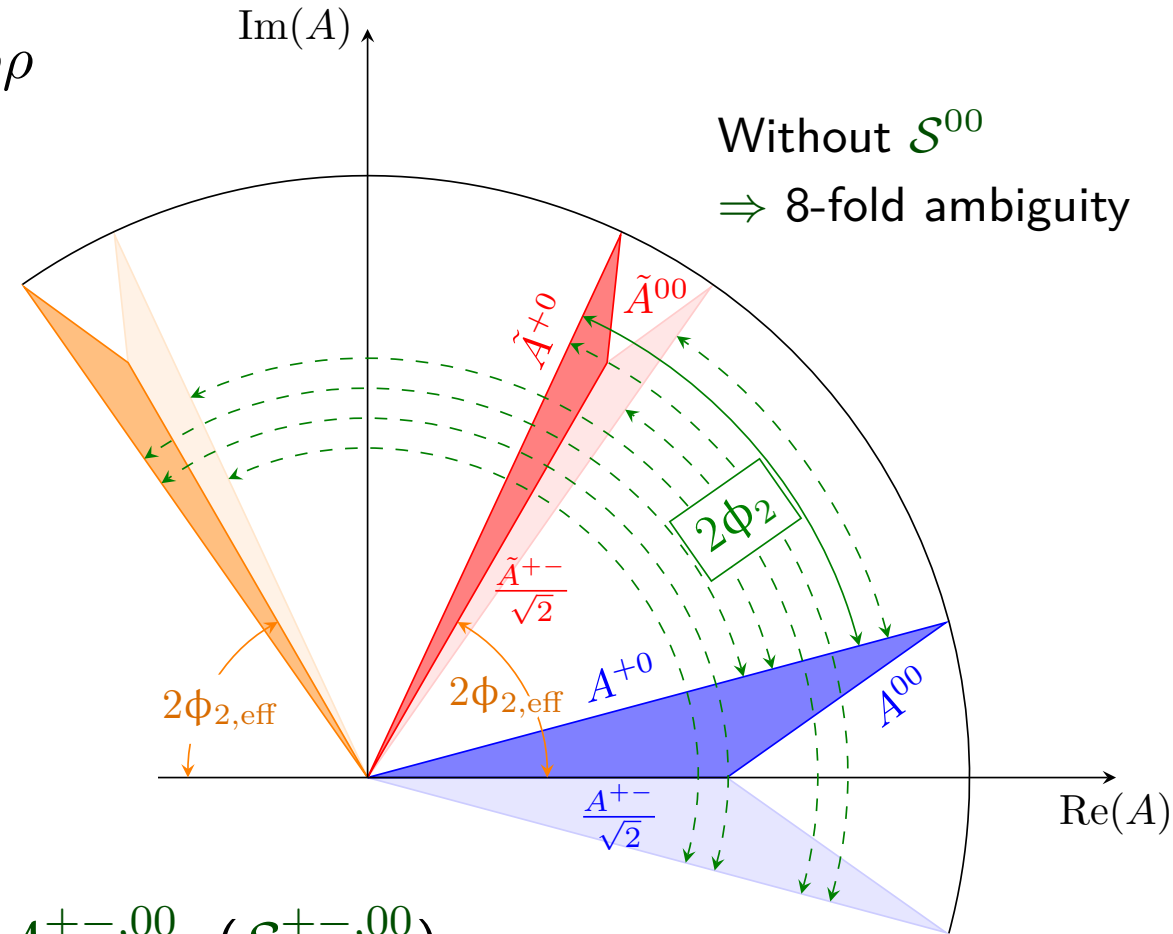
In the case of $hh = \pi\pi,\ \rho\rho$

- Extr. ϕ_2 through Gronau-London isospin analysis:

$$A^{+-} = A(B \to h^+h^-)$$

- $A^{+0} - A^{00} = \frac{1}{\sqrt{2}} A^{+-}$
- $\bar{A}^{+0} - \bar{A}^{00} = \frac{1}{\sqrt{2}} \bar{A}^{+-}$

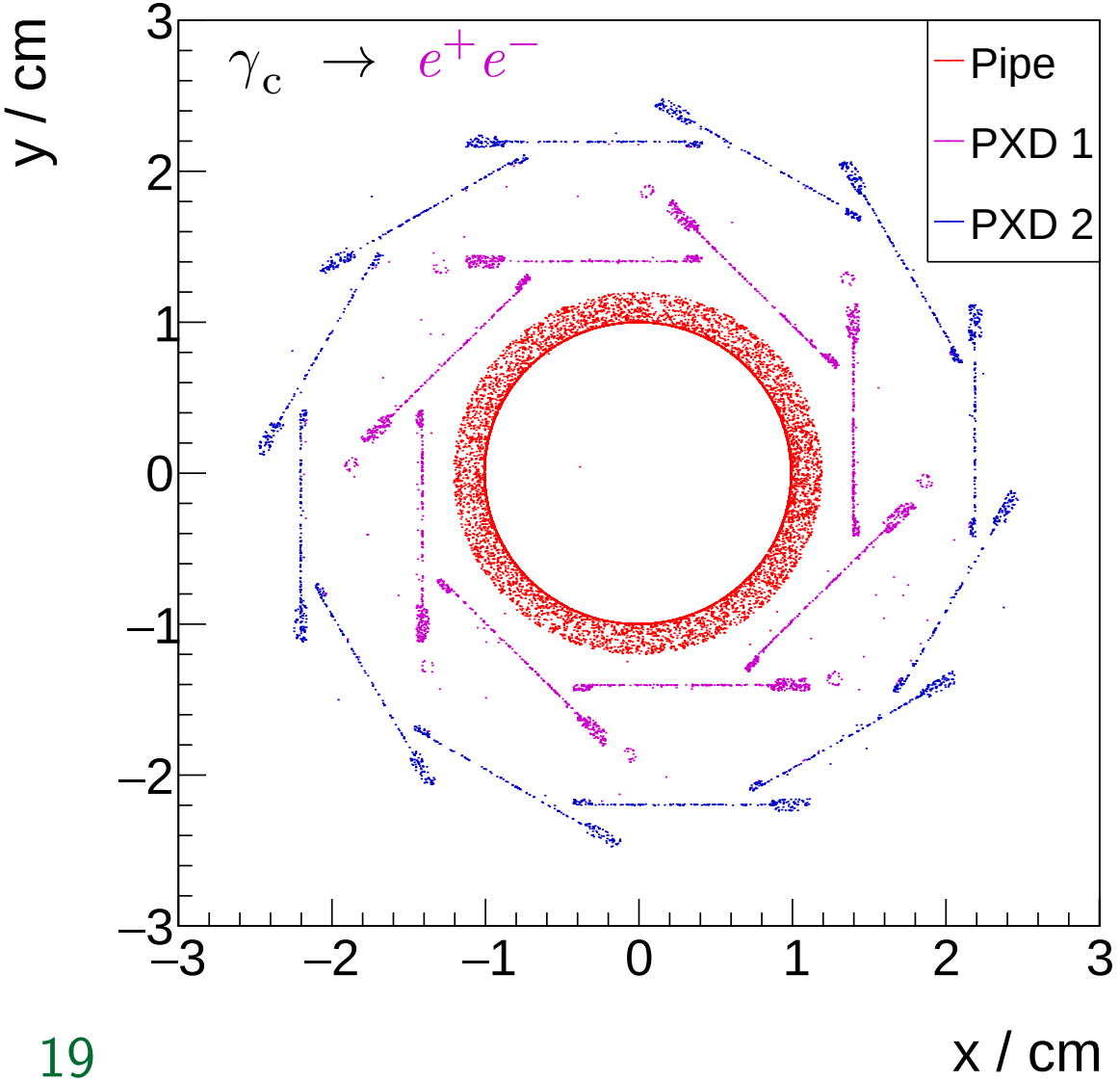
Pure Tree:
$|A^{+0}| = |\bar{A}^{+0}|$



Without $\mathcal{S}^{00}$
$\Rightarrow$ 8-fold ambiguity

- 7 Inputs: $\mathcal{B}^{+0,+-,00}$, $\mathcal{A}_{CP}^{+-,00}$, $(\mathcal{S}_{CP}^{+-,00})$
- $\mathcal{S}_{\pi^0\pi^0}$ needs $\langle \Delta z \rangle \sim 130\mu\mathrm{m}$ of $B \to \pi^0\pi^0$ where $\pi^0 \to \gamma\gamma$
- $\mathcal{S}_{\rho^0\rho^0}$ also challenging (small $\mathcal{B}^{00}$) but not so important.

Vertex of γ-Conversions in $B^0 \to \pi^0\pi^0$



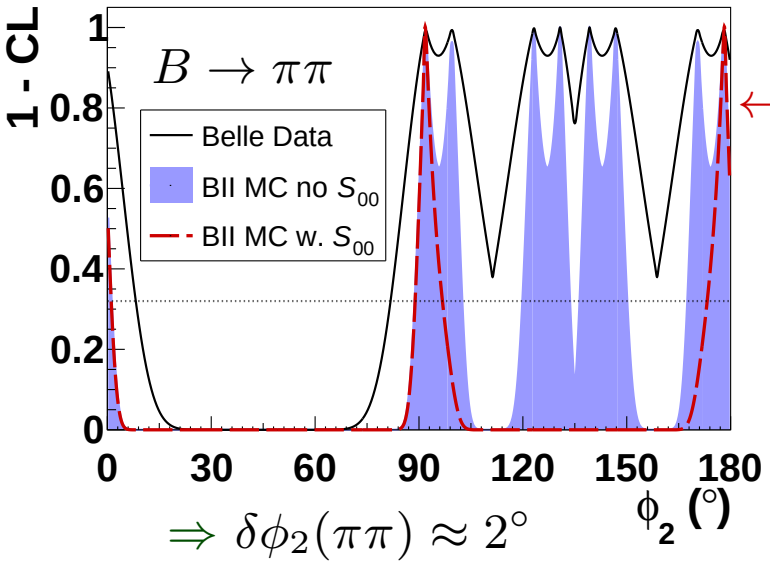
- $\Upsilon(4S) \to {B^0}_1 {B^0}_2 \to$
  $B_1 \to$ generic
  $B_2 \to \pi^0\pi^0$
- ${\pi^0}_{\gamma\gamma} \to \gamma\gamma \qquad (\mathcal{B} = 98.82\%)$
- ${\pi^0}_{\text{dal}} \to e^+e^-\gamma \ (\mathcal{B} = 1.17\%)$
- $N_{\text{Belle II}} =$

$$\begin{aligned} \mathcal{L}_{\text{Belle II}} &\cdot \mathcal{B}(\Upsilon(4S) \to B^0\overline{B}^0) \\ &\cdot 2 \cdot \mathcal{B}(B^0 \to \pi^0\pi^0) \sim \\ 50\text{ab}^{-1} &\cdot 1.1\text{nb} \cdot 0.49 \\ &\cdot 2 \cdot 1.91 \cdot 10^{-6} \end{aligned}$$

$\sim$ 100k events.

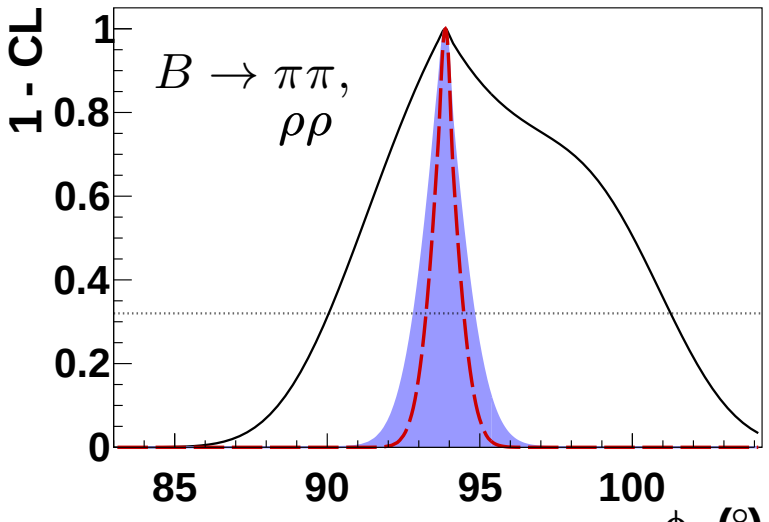
- 2% have ${\pi^0}_{\text{dal}}$
- 3% have γ_c in PXD Vol.

Combined Isospin Analysis

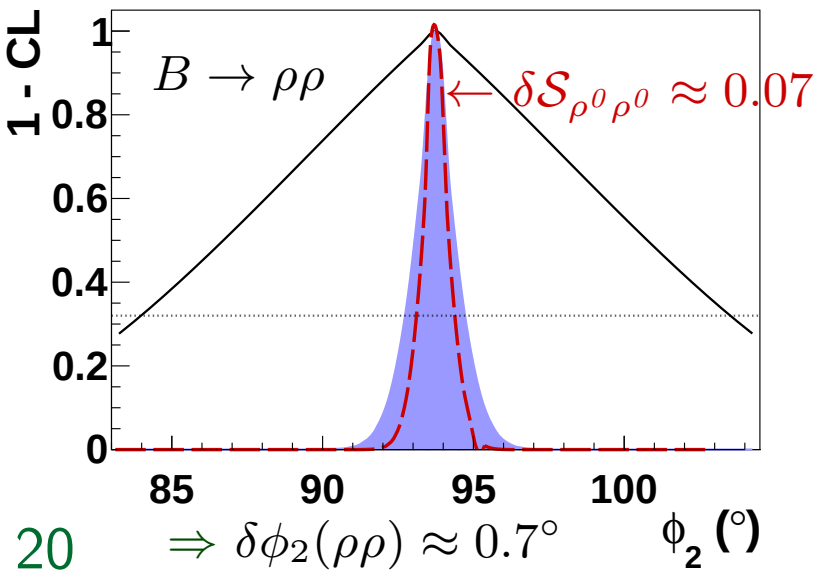


$\leftarrow \delta\mathcal{S}_{\pi^0\pi^0} \approx 0.28$

$\Rightarrow \delta\phi_2(\pi\pi) \approx 2^\circ$



$\Rightarrow \delta\phi_2(\pi\pi, \rho\rho) \approx 0.6^\circ$



$\leftarrow \delta\mathcal{S}_{\rho^0\rho^0} \approx 0.07$

$\Rightarrow \delta\phi_2(\rho\rho) \approx 0.7^\circ$

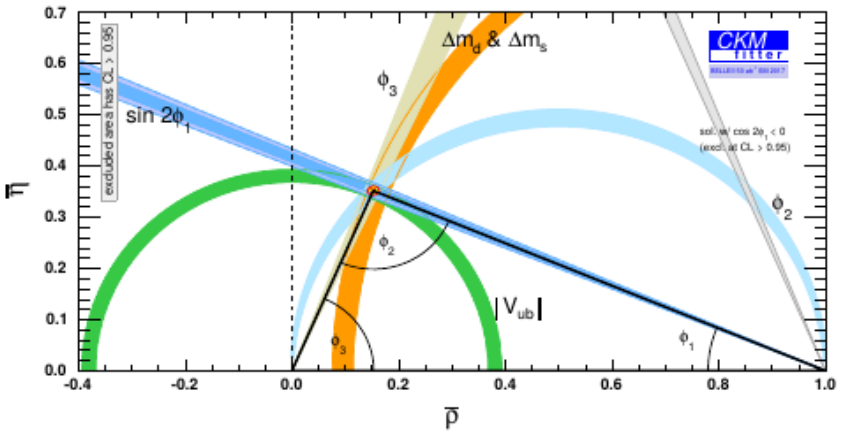
w/out and with $\mathcal{S}_{\pi^0\pi^0}$ and $\mathcal{S}_{\rho^0\rho^0}$

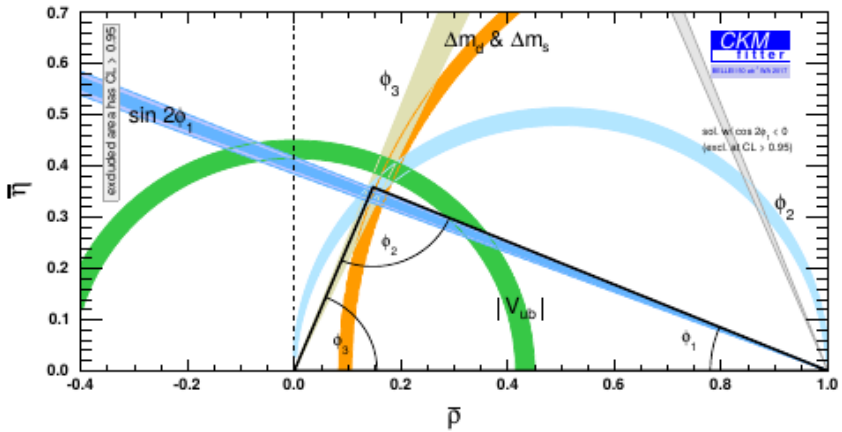
For compatibility $S_{\pi^0\pi^0} = 0.75$

$S_{\rho^0\rho^0} = -0.14$

Summary and Outlook

- Machine commissioning started!
- Search at next generation B-Factory SuperKEKB complementary to LHC. $\int \mathcal{L} \cdot dt = 50$ ab^{-1} $\Rightarrow$??





$\Rightarrow$ Expected sensitivities:

$\delta\phi_1(c\bar{c}s) \lesssim 0.1°$, and $\delta\phi_2(\pi\pi, \rho\rho) \lesssim 1°$.

$\Rightarrow$ CKM mechanism will be tested at 1% level.

Extraction of ϕ_2 from $B \to \rho\rho$

- Larger branching fractions (factor ~ 6 for $\mathcal{B}_{+-}$ and $\mathcal{B}_{+0}$)
- Larger reconstruction efficiencies (factor $\sim 2-4$)

$\Rightarrow$ Most precise measurement of ϕ_2:
Only 2 fold ambiguity even w/out $\mathcal{S}_{00}$ due to large difference between $\mathcal{B}_{00}$ and $\mathcal{B}_{+-}$ ($\mathcal{B}_{+0}$).
Smaller penguin contribution (less isospin breaking)

But: Much more complicated analyses than for $B \to \pi\pi$.
Difficult background modelling.
Non trivial correlations between discriminating variables.

$\Rightarrow$ Extrapolation of uncertainties.

LO Isospin breaking effects

Reference Gronau PR D71 2005 074017.

- Charge difference $\Rightarrow$ EW. Penguin:
  Isospin relations unchanged but $|A^{+0}| \neq |\bar{A}^{+0}|$
  $\frac{\tilde{A}^{+0}}{A^{+0}} = \frac{e^{-2i\phi_1}\bar{A}^{+0}}{A^{+0}} = e^{2i(\phi_2+\Delta\phi_2)}$

$\Rightarrow \Delta\phi_2 = \frac{1}{2}\arg(e^{-2i\phi_2}\tilde{A}^{+0}A^{+0*}) = \frac{3}{2}\left(\frac{\mathcal{C}_9+\mathcal{C}_{10}}{\mathcal{C}_1+\mathcal{C}_2}\right)\frac{\sin(\phi_1+\phi_2)}{\sin\phi_1}\sin\phi_2$

$\Rightarrow \Delta\phi_2 = -1.9^\circ$ for $\pi\pi$ and $\rho\rho$ (CKM Fitter 2017)

- Mass difference $\Rightarrow$ Modifies Isospin relations

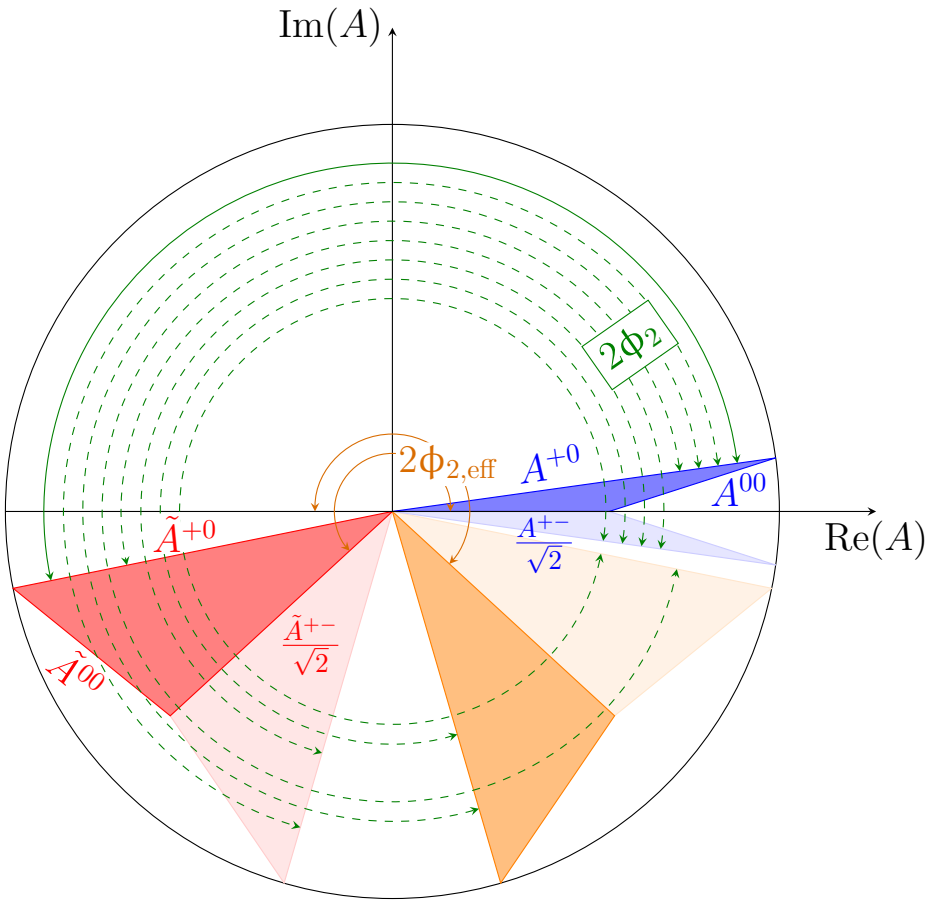
For $\pi\pi$: $\pi^0 - \eta, \eta'$ mixing: $|\Delta\phi_2^{\text{mix}}| \leq \sqrt{2\frac{\tau_{B^+}}{\tau_{B^0}}}\left(\varepsilon_\eta\sqrt{\frac{\mathcal{B}^{\pi^0\eta}}{\mathcal{B}^{\pi^+\pi^0}}} + \varepsilon_{\eta'}\sqrt{\frac{\mathcal{B}^{\pi^0\eta'}}{\mathcal{B}^{\pi^+\pi^0}}}\right)$

$\Rightarrow \Delta\phi_2^{\text{mix}} = -0.5^\circ$ and incr. of uncerty. $\delta\phi_2 = \pm 1.5^\circ$ $(68\%\text{CL})$

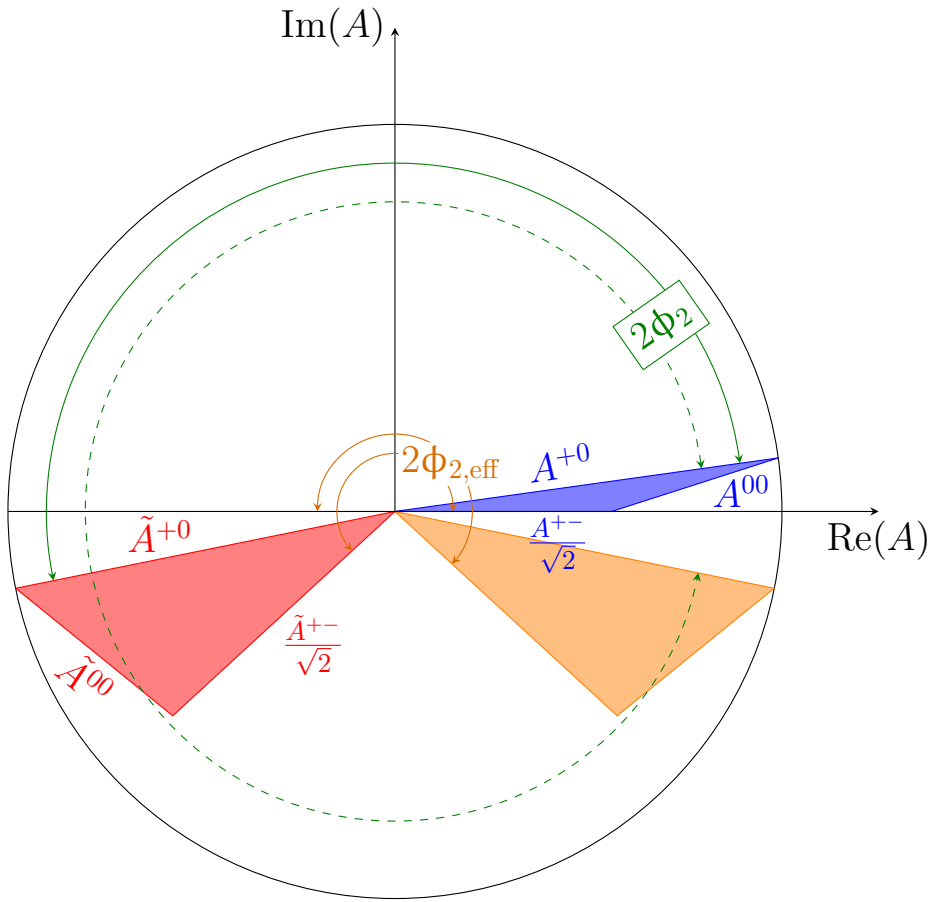
For $\rho\rho$: $\pi^0 - \eta, \eta'$ and $\rho - \omega$ mixing, diff. coupl. $\Gamma_{\rho^+}/\Gamma_{\rho^0}$, ρ width

$\Rightarrow \Delta\phi_2^{\text{mix}} = -0.6^\circ$ and incr. of $\delta\phi_2 = \pm(^{+0.2}_{-1.7})^\circ$ $(68\%\text{CL})$

Isospin Triangles for $B \to \pi\pi$

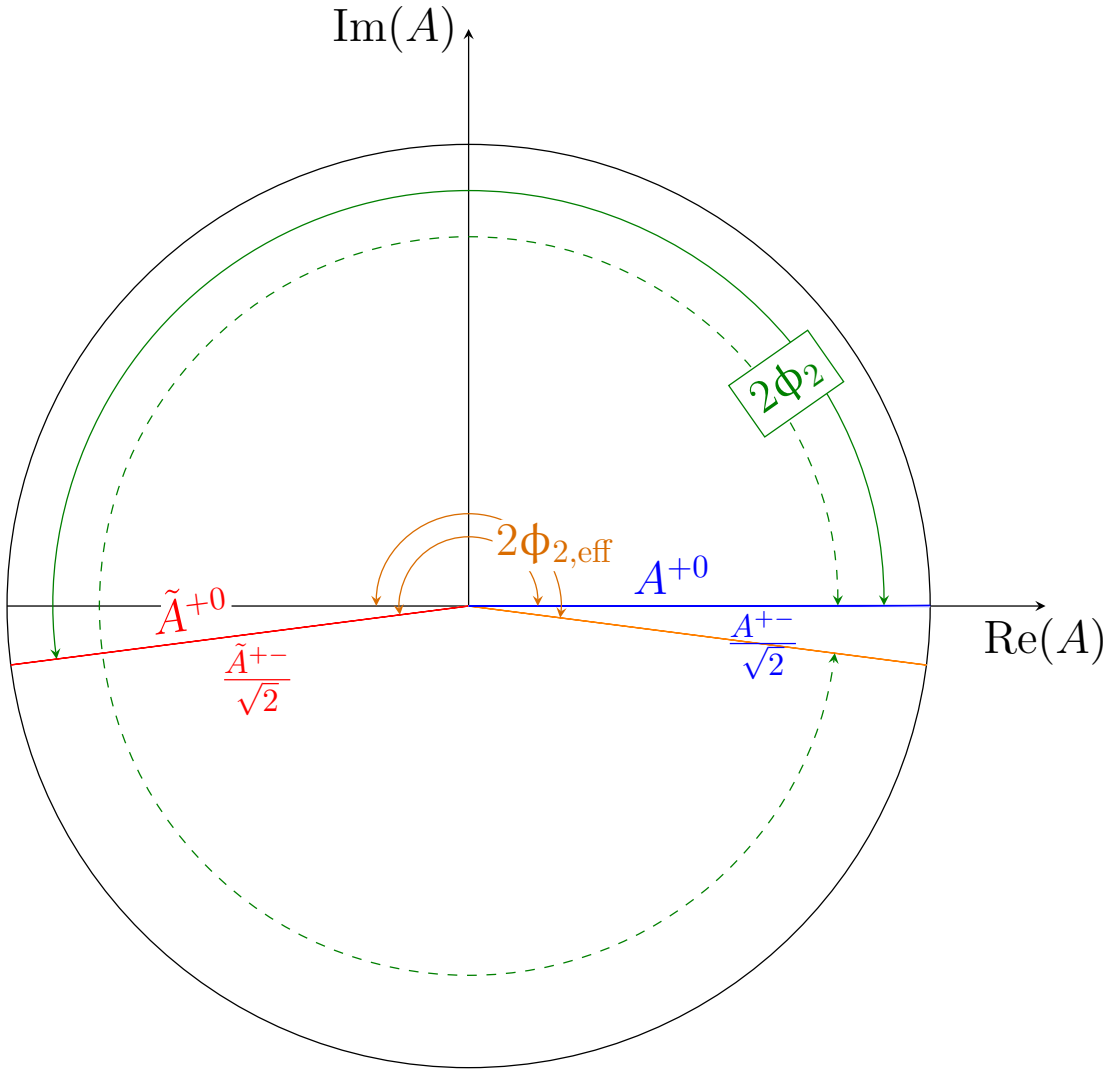


Without $\mathcal{S}^{\pi^0\pi^0}$

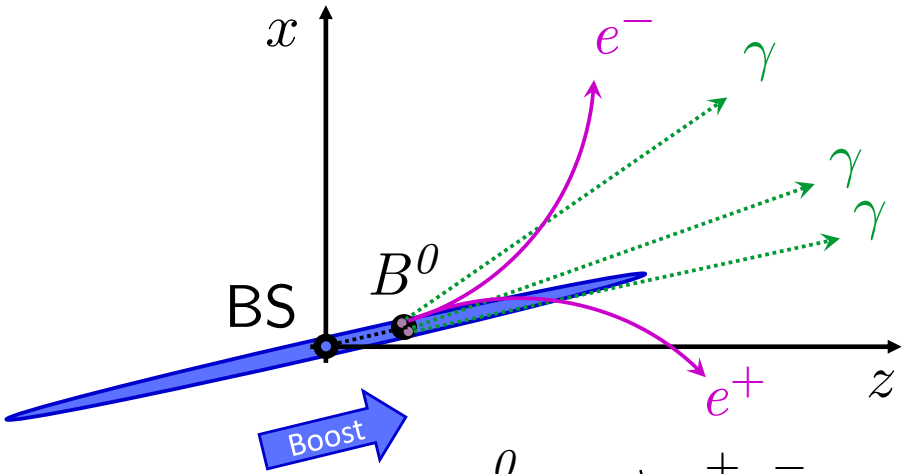


With $\mathcal{S}^{\pi^0\pi^0} = 0.83$

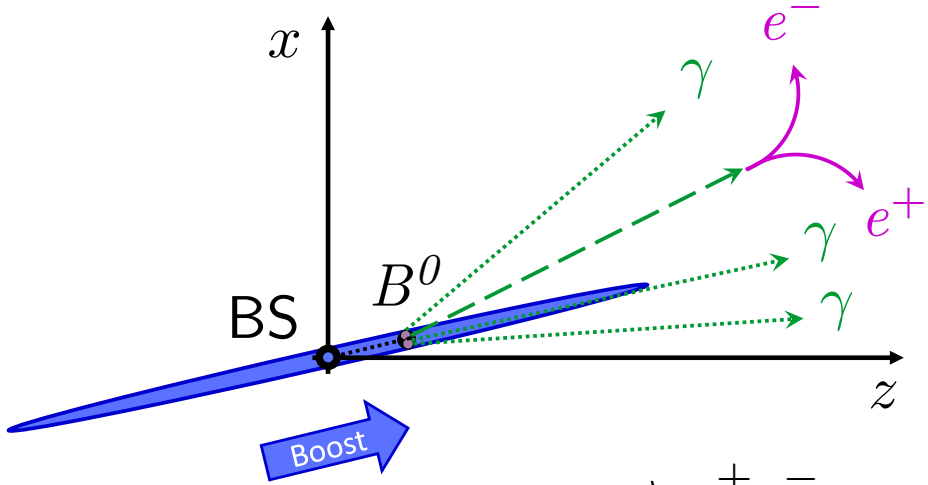
Isospin Triangles for $B \to \rho\rho$



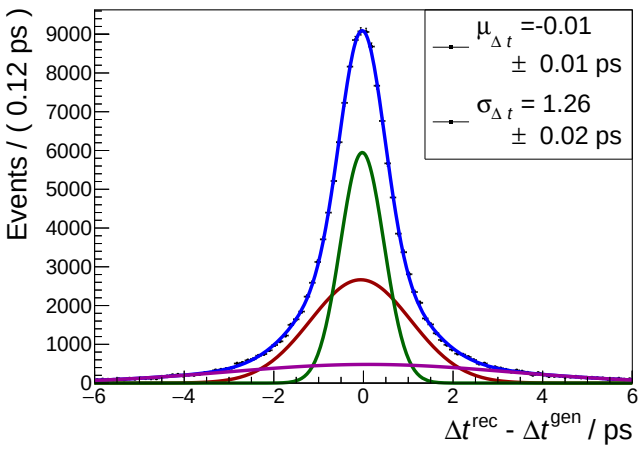
B^0 CP Δt Resolution



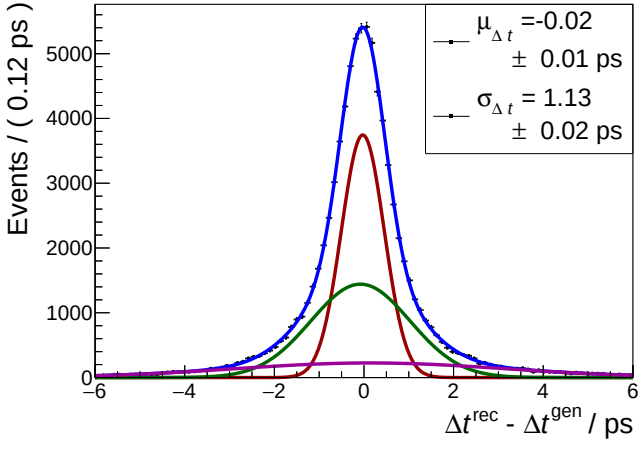
$\pi^0_{\text{dal}} \rightarrow e^+e^-\gamma$



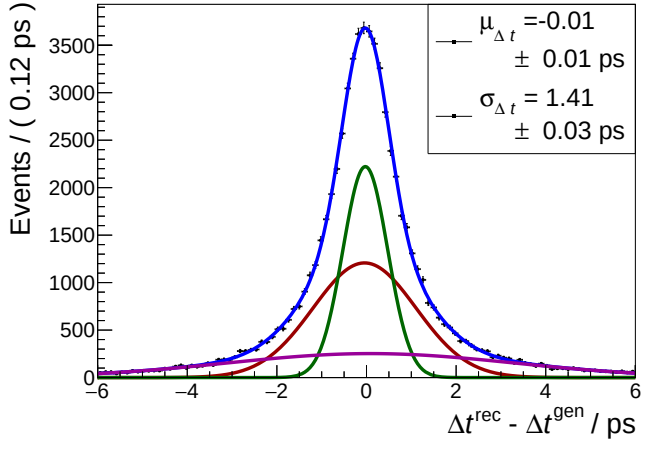
$\gamma_c \rightarrow e^+e^-$



Dalitz and Conversion case

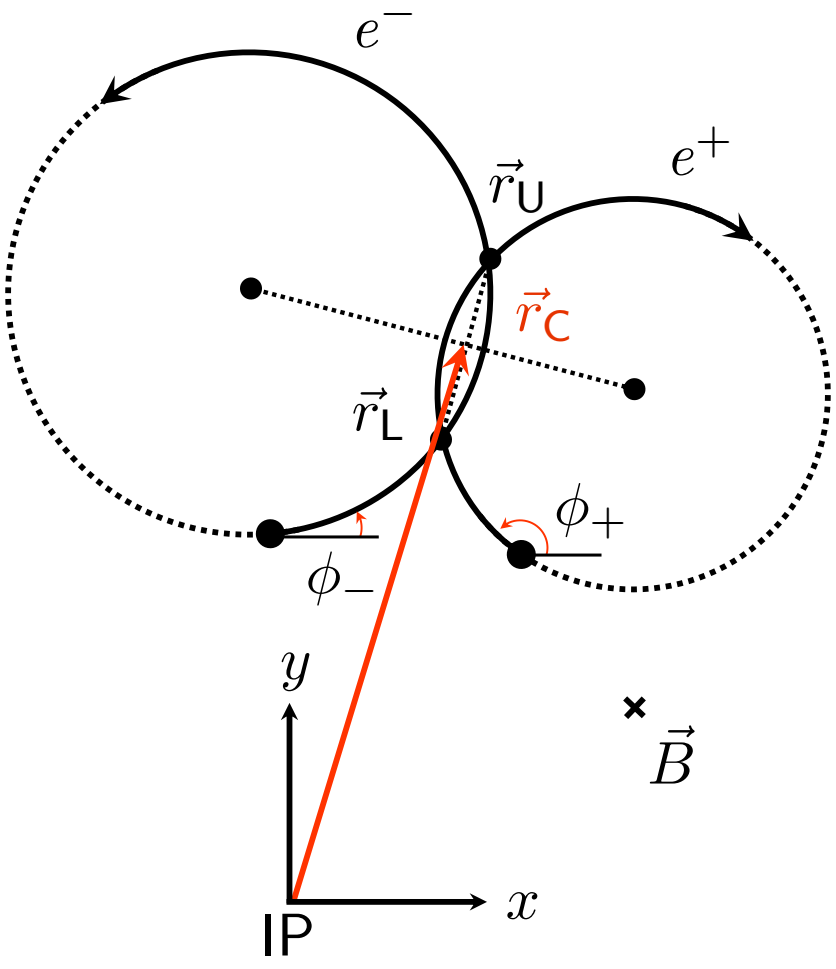


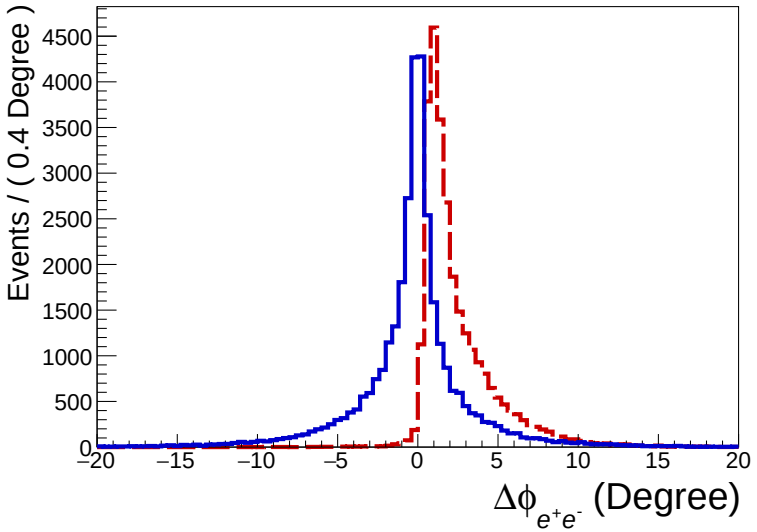
Only Dalitz (54% of Events)

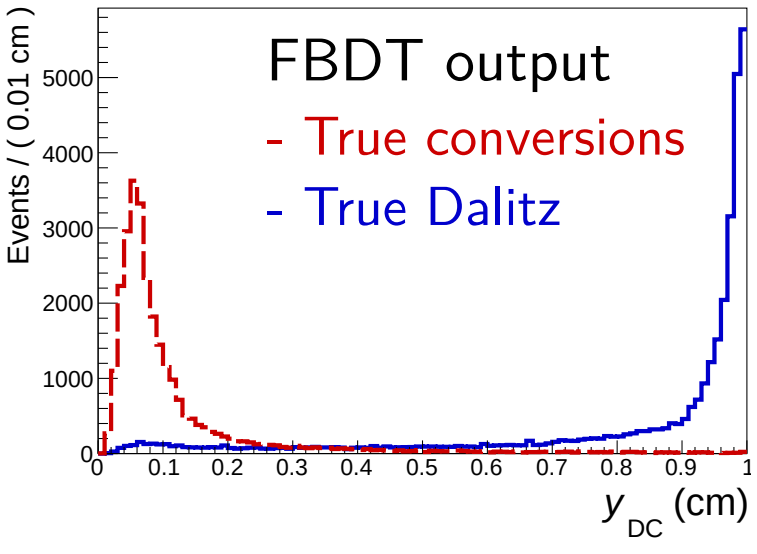


Only Conversion (46% of Events)

Separation between Signal Candidates



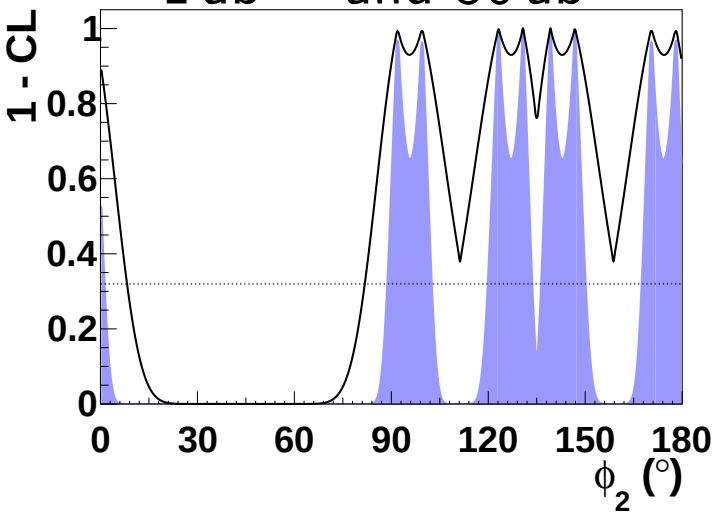




Inputs: $\vec{r}_U$, $\vec{r}_L$, $\vec{r}_C$, $\Delta\phi_{e^+e^-}$, $\Delta\theta_{e^+e^-}$

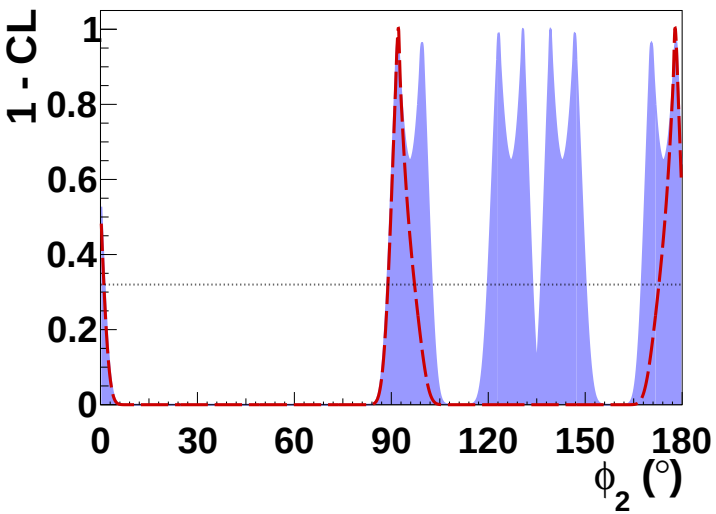
Result of Isospin analysis

$1\,\mathrm{ab}^{-1}$ and $50\,\mathrm{ab}^{-1}$

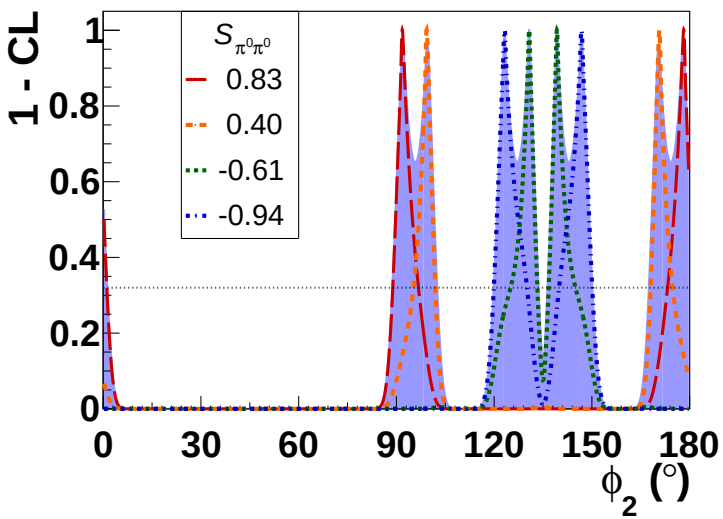


	Value	$0.8\,\mathrm{ab}^{-1}$	$50\,\mathrm{ab}^{-1}$
${}^{a}\mathcal{B}_{\pi^+\pi^-}$ $[10^{-6}]$	5.04	$\pm0.21\pm0.18$	$\pm0.03\pm0.08$
${}^{b}\mathcal{B}_{\pi^0\pi^0}$ $[10^{-6}]$	1.31	$\pm0.19\pm0.18$	$\pm0.04\pm0.04$
${}^{a}\mathcal{B}_{\pi^+\pi^0}$ $[10^{-6}]$	5.86	$\pm0.26\pm0.38$	$\pm0.03\pm0.09$
${}^{c}\mathcal{A}_{\pi^+\pi^-}$	0.33	$\pm0.06\pm0.03$	$\pm0.01\pm0.03$
${}^{c}\mathcal{S}_{\pi^+\pi^-}$	-0.64	$\pm0.08\pm0.03$	$\pm0.01\pm0.01$
${}^{b}\mathcal{A}_{\pi^0\pi^0}$	0.14	$\pm0.36\pm0.12$	$\pm0.05\pm0.01$
$\mathcal{S}_{\pi^0\pi^0}$	0.83		$\pm0.28\pm0.03$

w/out and with $\mathcal{S}_{\pi^0\pi^0}$



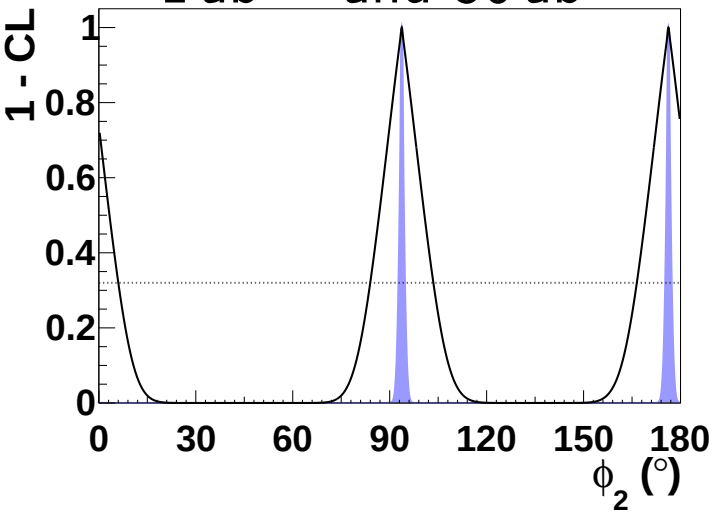
Comparison diff. $\mathcal{S}_{\pi^0\pi^0}$



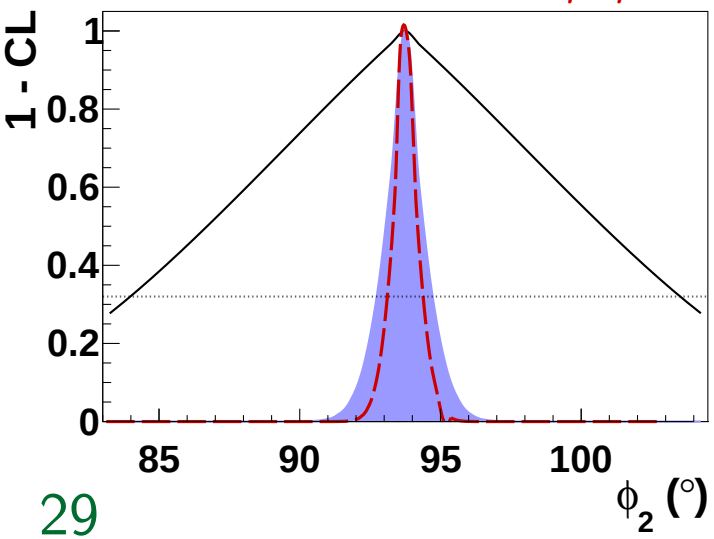
[a] PRD 87 031103
[b] PRD 96 032007
[c] PRD 88 092003

Result of Isospin analysis

1 ab^{-1} and 50 ab^{-1}



w/out and with $\mathcal{S}_{\rho^0\rho^0}$



Belle	Value	0.8 ab^{-1}	50 ab^{-1}
[a] $f_{L,\ \rho^+\rho^-}$	0.988	$\pm0.012 \pm 0.023$	$\pm0.002 \pm 0.003$
[b] $f_{L,\ \rho^0\rho^0}$	0.21	$\pm0.20 \pm 0.15$	$\pm0.03 \pm 0.02$
[a] $\mathcal{B}_{\rho^+\rho^-}$ [10^{-6}]	28.3	$\pm1.5 \pm 1.5$	$\pm0.19 \pm 0.4$
[b] $\mathcal{B}_{\rho^0\rho^0}$ [10^{-6}]	1.02	$\pm0.30 \pm 0.15$	$\pm0.04 \pm 0.02$
[a] $\mathcal{A}_{\rho^+\rho^-}$	0.00	$\pm0.10 \pm 0.06$	$\pm0.01 \pm 0.01$
[a] $\mathcal{S}_{\rho^+\rho^-}$	-0.13	$\pm0.15 \pm 0.05$	$\pm0.02 \pm 0.01$
Belle	**Value**	**0.08 ab^{-1}**	**50 ab^{-1}**
[c] $f_{L,\ \rho^+\rho^0}$	0.95	$\pm0.11 \pm 0.02$	$\pm0.004 \pm 0.003$
[c] $\mathcal{B}_{\rho^+\rho^0}$ [10^{-6}]	31.7	$\pm7.1 \pm 5.3$	$\pm0.3 \pm 0.5$
BaBar	**Value**	**0.5 ab^{-1}**	**50 ab^{-1}**
[d] $\mathcal{A}_{\rho^0\rho^0}$	-0.2	$\pm0.8 \pm 0.3$	$\pm0.08 \pm 0.01$
[d] $\mathcal{S}_{\rho^0\rho^0}$	0.3	$\pm0.7 \pm 0.2$	$\pm0.07 \pm 0.01$

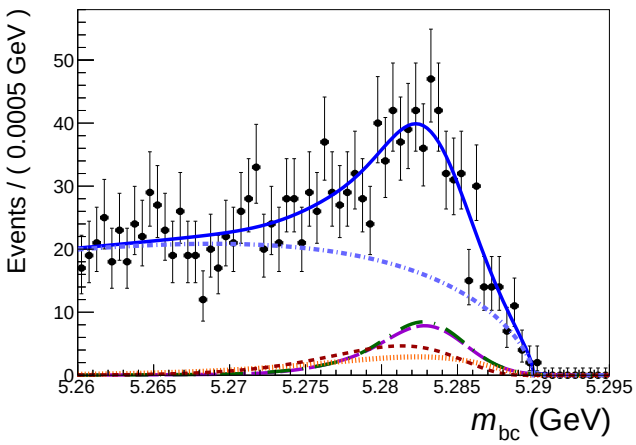
For compatibility $S_{\rho^0\rho^0}$ = -0.14

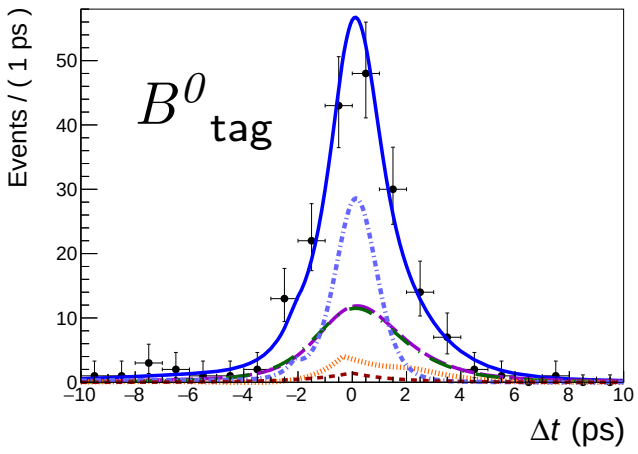
[a] PRD 93 032010
[b] PRD 89 072008
[c] PR Lett 91 221801
[d] PRD 78 071104

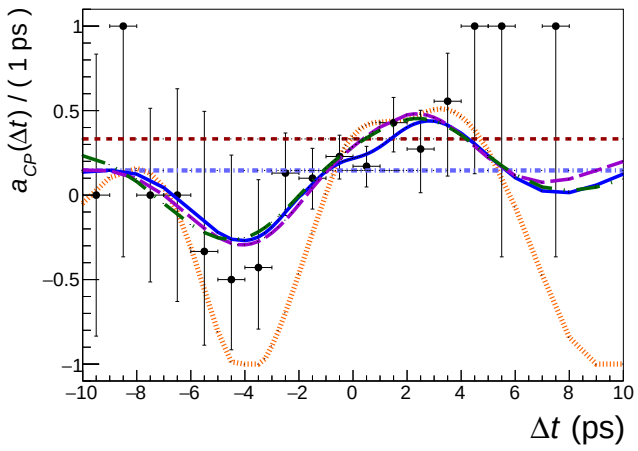
Toy MC Projections

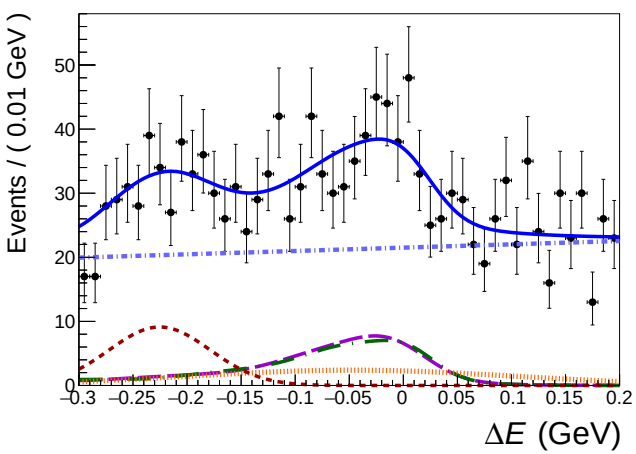
$$m_{\text{bc}} = \sqrt{E^{*}_{\text{beam}}{}^{2} - \mathbf{p}_{B^0}}$$

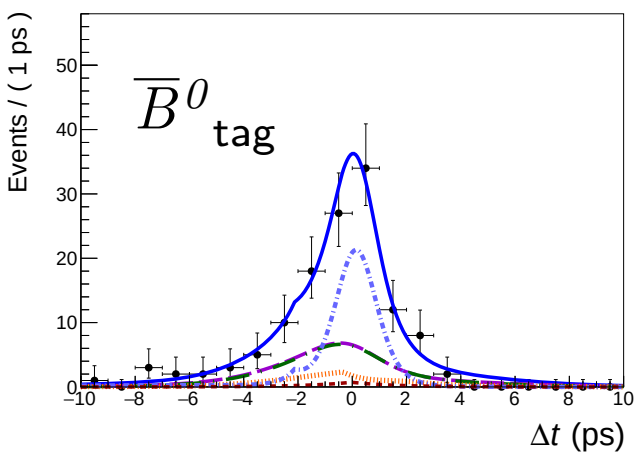
$$B^0 \to \pi^0(\to e^+e^-\gamma)\pi^0(\to \gamma\gamma)$$

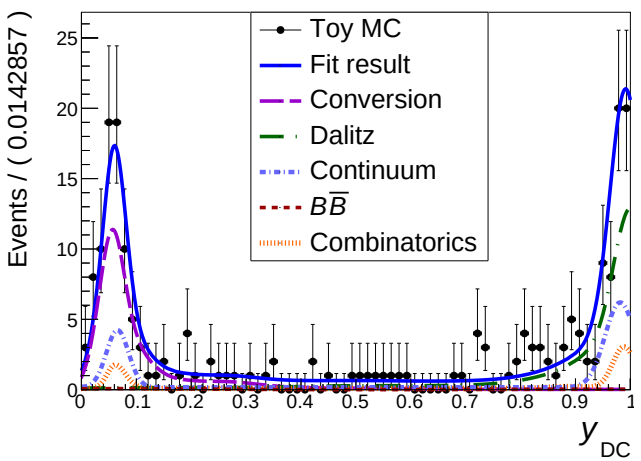












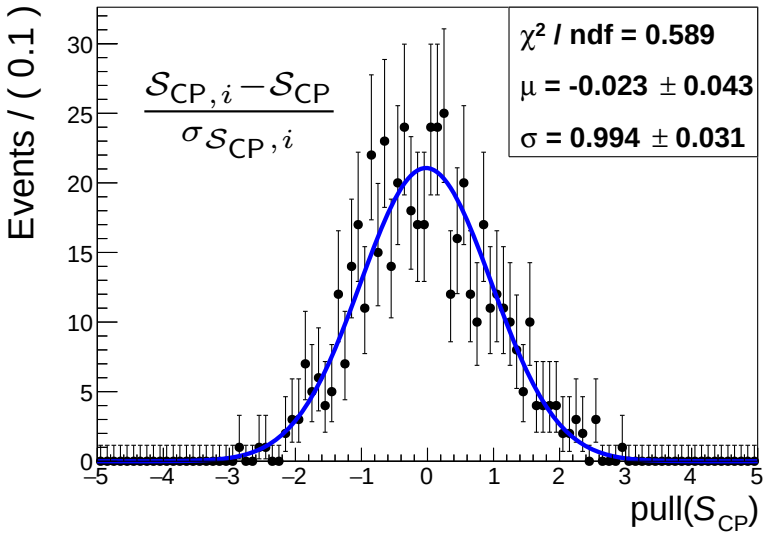
$$\Delta E = E^{*}_{\text{beam}} - E_{B^0}$$

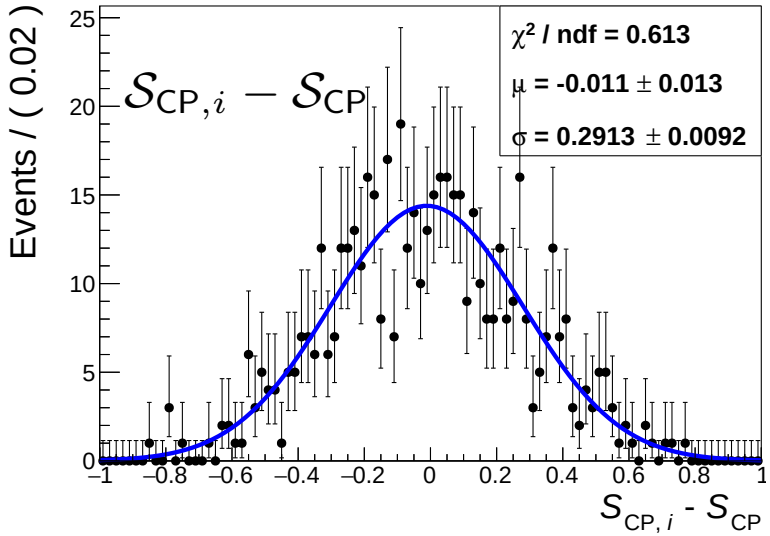
$\varepsilon_{\text{REC}} = 5.0\% \mathrel{\hat{=}} 270$ Events

Tagging $\varepsilon_{\text{eff}} \approx 37\%$

$\mathcal{S}_{CP}$ Pulls and Statistical Uncertainties

$$B^0 \to \pi^0(\to e^+e^-\gamma)\pi^0(\to \gamma\gamma)$$





Input values		Time-dependent		Time-integrated
$A_{\pi^0\pi^0}$	$S_{\pi^0\pi^0}$	$\delta A_{\pi^0\pi^0}$	$\delta S_{\pi^0\pi^0}$	$\delta A_{\pi^0\pi^0}$
[a]0.34	[a]0.65	0.22	0.28	0.03
[b]0.43	0.79	0.23	0.29	0.03
[c]0.14	0.83	0.21	0.26	0.03
[c]0.14	0.40	0.20	0.29	0.03
[c]0.14	−0.61	0.22	0.27	0.03
[c]0.14	−0.94	0.22	0.28	0.03

[a] CKMFitter 2017
[b] PDG 2016
[c] PRD 96 032007