CP Violation sensitivity at the Belle II Experiment

Luigi Li Gioi – for the Belle II collaboration

Max-Planck-Institut für Physik, München

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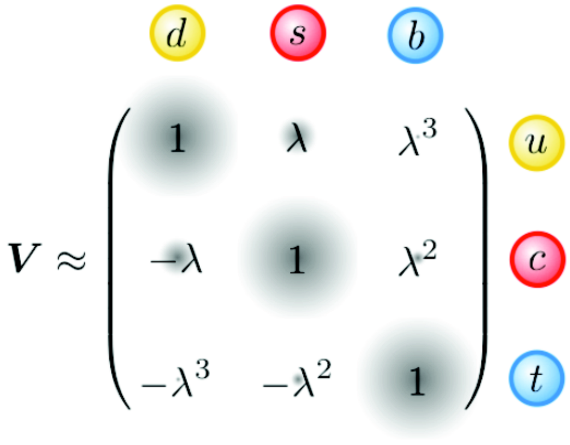
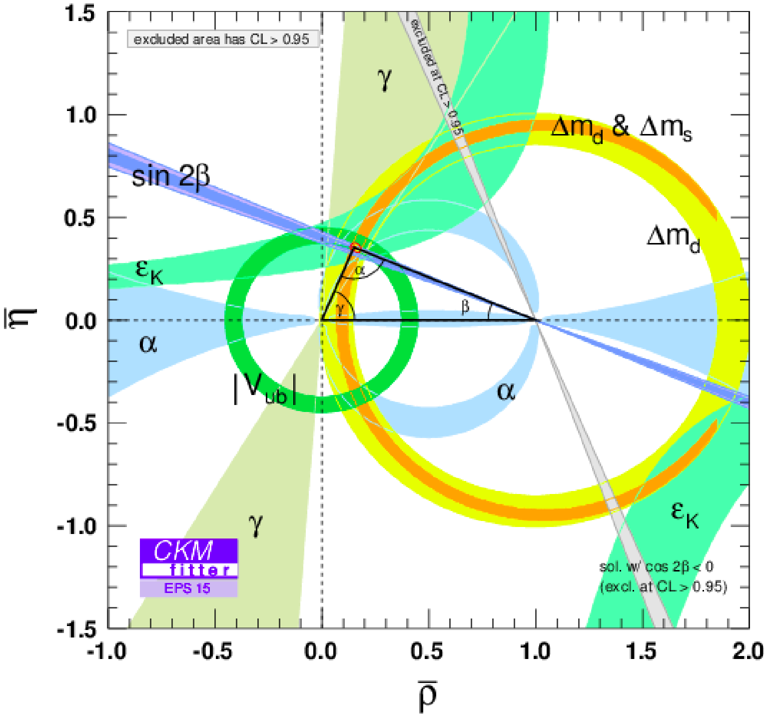
The Unitarity Triangle

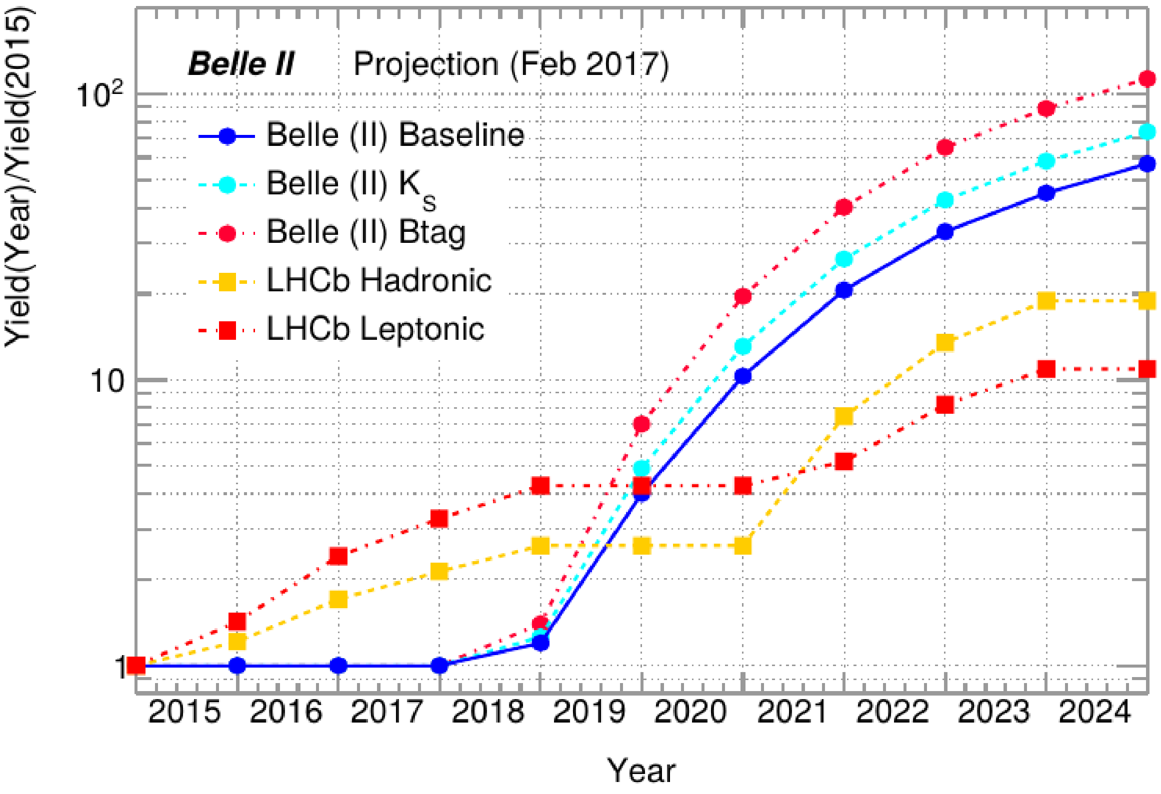


$$V \approx \begin{array}{c|ccc|c} & d & s & b & \\ \hline & 1 & \lambda & \lambda^3 & u \\ & -\lambda & 1 & \lambda^2 & c \\ & -\lambda^3 & -\lambda^2 & 1 & t \end{array}$$

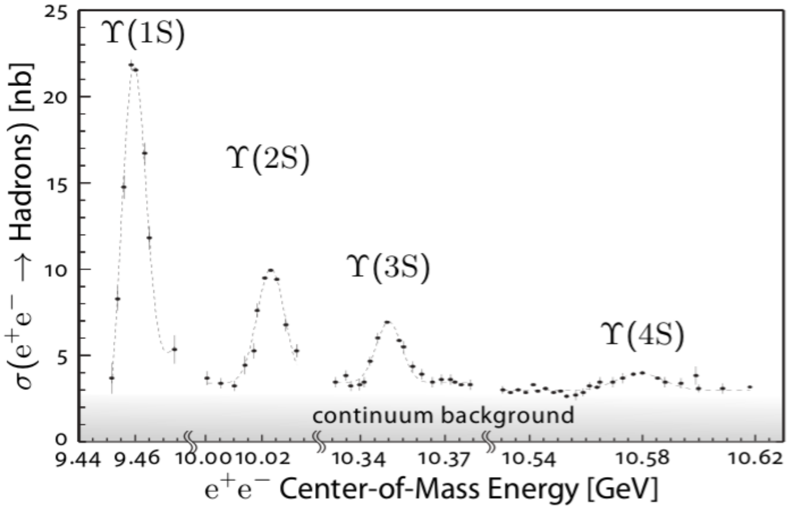
$\lambda \approx 0.22$: Cabibbo angle

- All flavor variables constrained in the SM CKM fit are in good agreement with experimental observations
- Some variables still to be measured precisely
  - → therefore a lot of room for surprises !





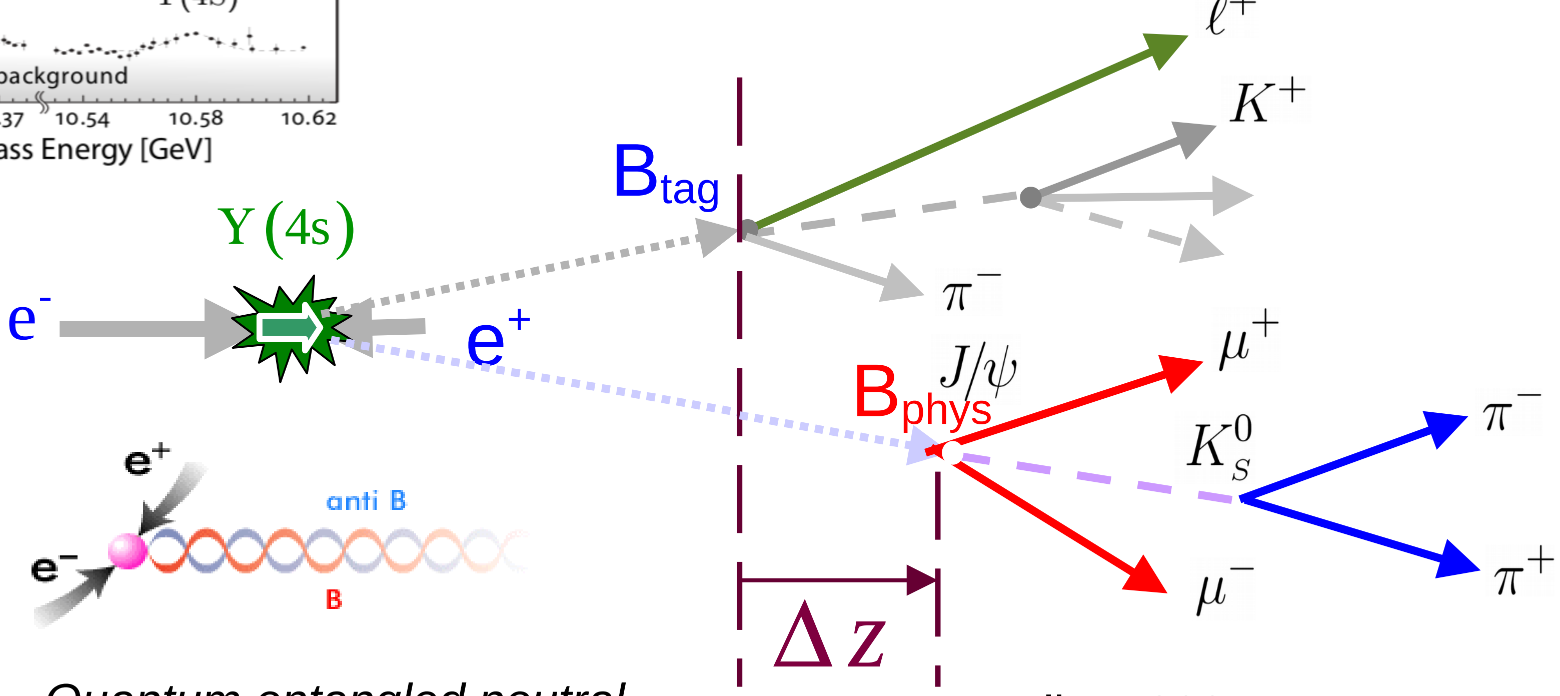
Time dependent measurements



- Y(4S) is the first resonance just above the $B\bar{B}$ production threshold
- Only $B\bar{B}$ pairs are produced, and are at rest in the Y(4S) frame

$$\Delta t = \frac{\Delta z}{\beta \gamma c}$$

Resolution on Δt will be dominated by the resolution of the tagging side vertex



Quantum entangled neutral B meson pair production

Belle ~ 200 μm
Belle II ~ 130 μm

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

Sin(2β) : b → $c\bar{c}s$

Phys. Rev. Lett. 108 171802 (2012)

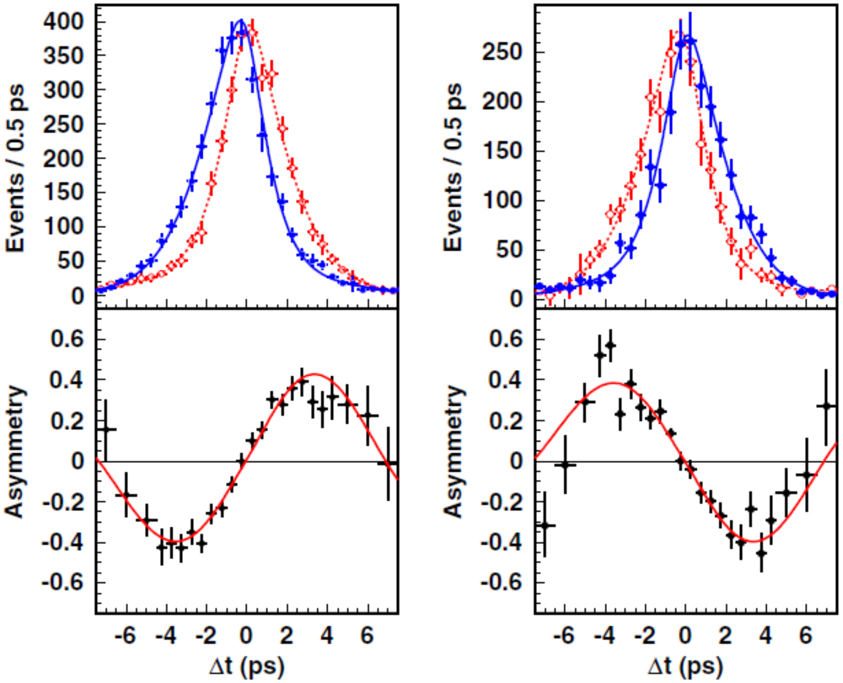


FIG. 2 (color online). The background-subtracted Δt distribution (top) for $q = +1$ (red) and $q = -1$ (blue) events and asymmetry (bottom) for good tag quality ($r > 0.5$) events for all CP-odd modes combined (left) and the CP-even mode (right).

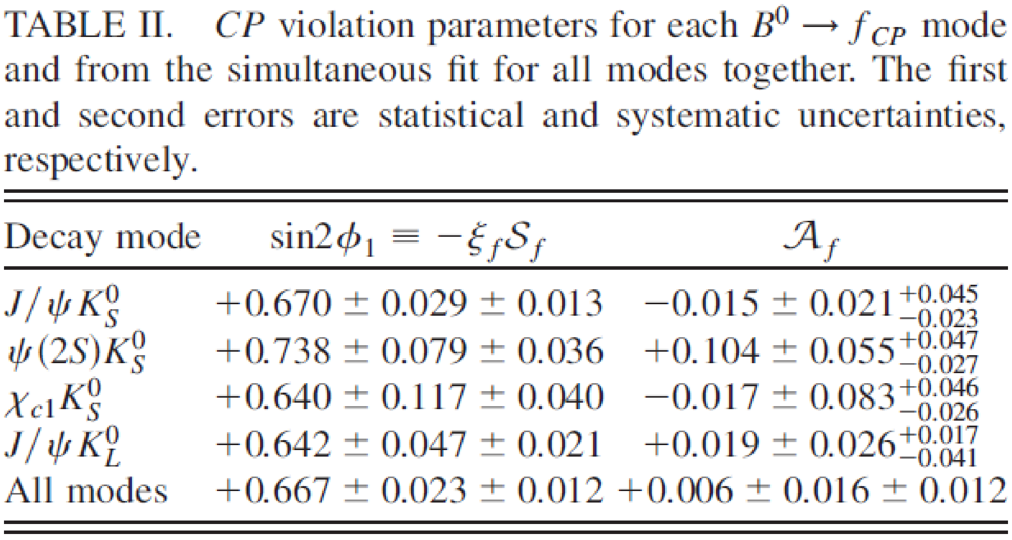
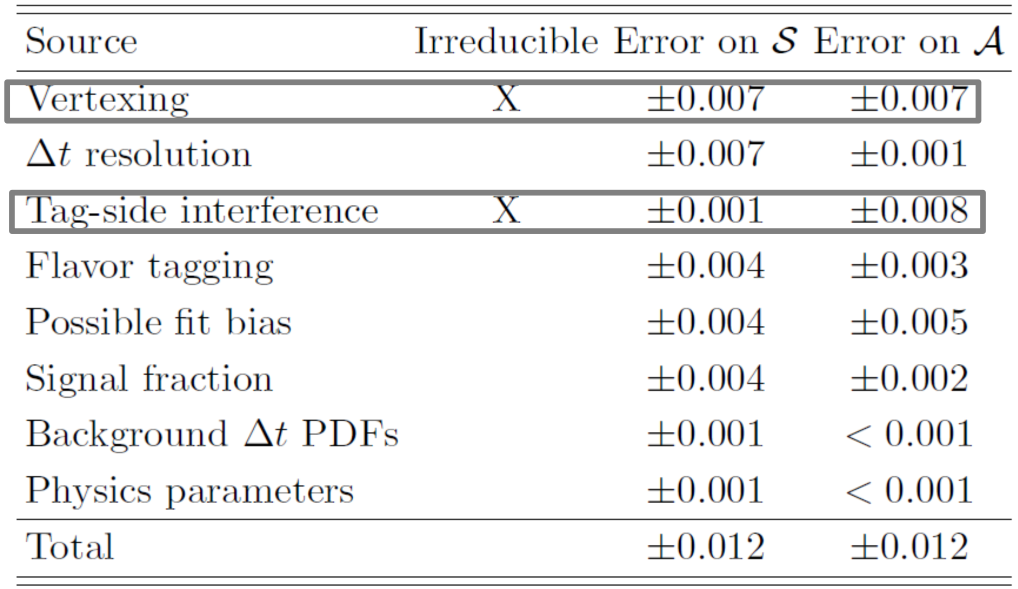


TABLE II. CP violation parameters for each $B^0 \to f_{CP}$ mode and from the simultaneous fit for all modes together. The first and second errors are statistical and systematic uncertainties, respectively.

Decay mode	$\sin 2\phi_1 \equiv -\xi_f \mathcal{S}_f$	$\mathcal{A}_f$
$J/\psi K_S^0$	$+0.670 \pm 0.029 \pm 0.013$	$-0.015 \pm 0.021^{+0.045}_{-0.023}$
$\psi(2S) K_S^0$	$+0.738 \pm 0.079 \pm 0.036$	$+0.104 \pm 0.055^{+0.047}_{-0.027}$
$\chi_{c1} K_S^0$	$+0.640 \pm 0.117 \pm 0.040$	$-0.017 \pm 0.083^{+0.046}_{-0.026}$
$J/\psi K_L^0$	$+0.642 \pm 0.047 \pm 0.021$	$+0.019 \pm 0.026^{+0.017}_{-0.041}$
All modes	$+0.667 \pm 0.023 \pm 0.012$	$+0.006 \pm 0.016 \pm 0.012$



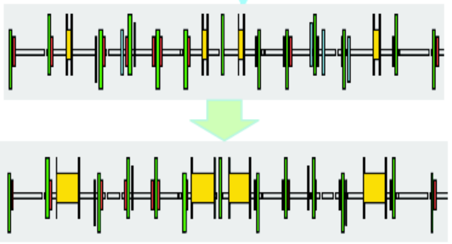
Source	Irreducible	Error on $\mathcal{S}$	Error on $\mathcal{A}$
Vertexing	X	±0.007	±0.007
Δt resolution		±0.007	±0.001
Tag-side interference	X	±0.001	±0.008
Flavor tagging		±0.004	±0.003
Possible fit bias		±0.004	±0.005
Signal fraction		±0.004	±0.002
Background Δt PDFs		±0.001	< 0.001
Physics parameters		±0.001	< 0.001
Total		±0.012	±0.012

Irreducible systematic errors:

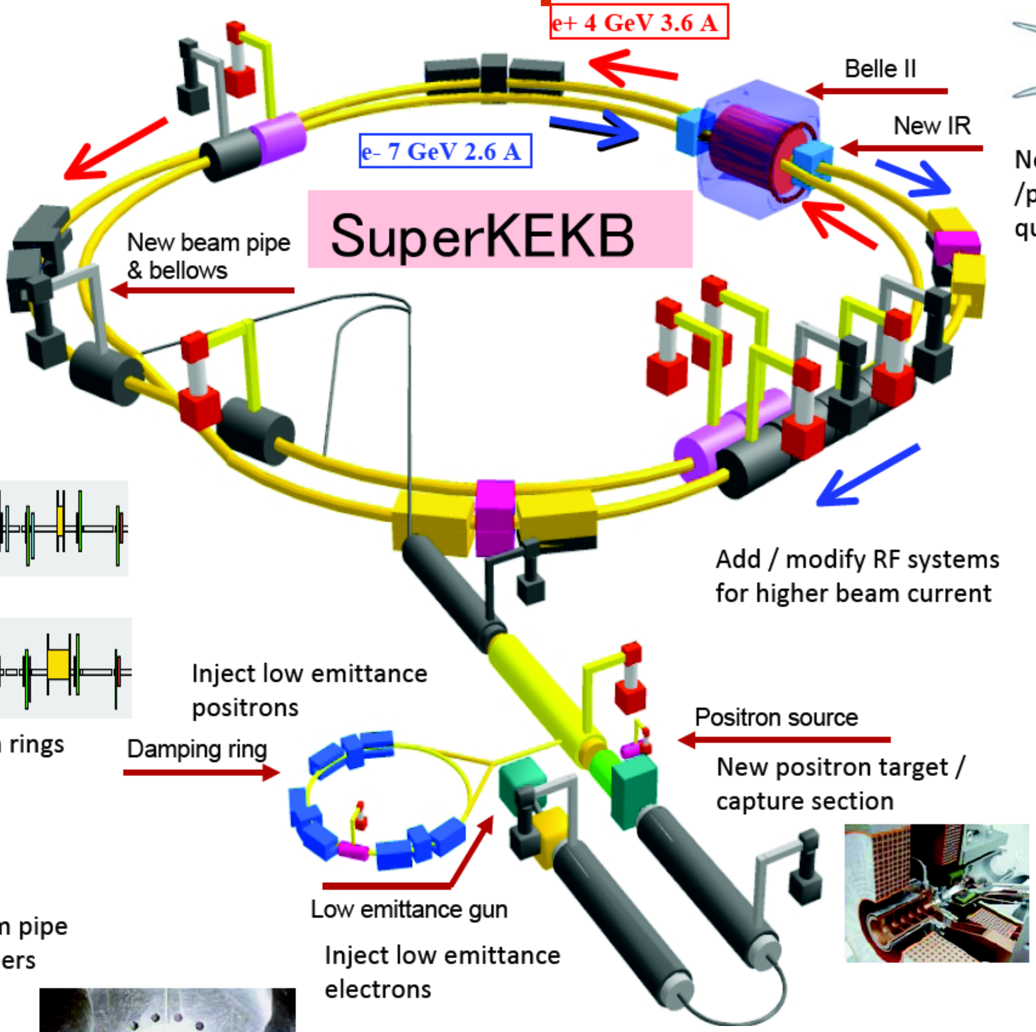
- Vertexing (without detector upgrade)
- Tag-side interference
  - More sophisticated treatment will be considered

SuperKEKB

eplace short dipoles
vith longer ones (LER)



Redesign the lattices of both rings to reduce the emittance



Belle II

New IR

New beam pipe & bellows

Add / modify RF systems for higher beam current

Inject low emittance positrons

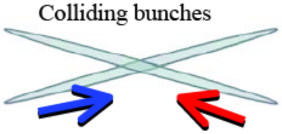
Damping ring

Positron source

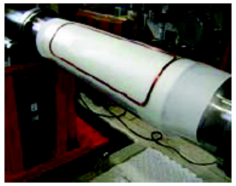
New positron target / capture section

Low emittance gun

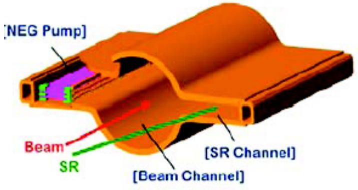
Inject low emittance electrons

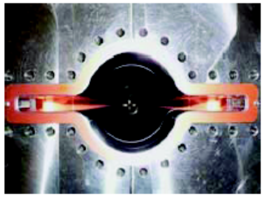


New superconducting /permanent final focusing quads near the IP



TiN-coated beam pipe with antechambers





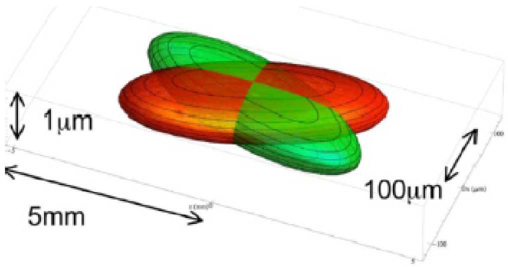
Peak luminosity

- KEKB = 2.11×10^{34} cm^{-2} s^{-1}
- SuperKEKB = $8 \ \times 10^{35}$ cm^{-2} s^{-1}

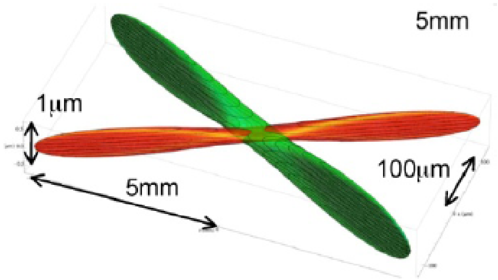
e^+e^- beams energy

- KEKB = 8 GeV / 3.5 GeV
- SuperKEKB = 7 GeV / 4 GeV

SuperKEKB Nanobeam



KEKB



Belle II Pixel Vertex Detector

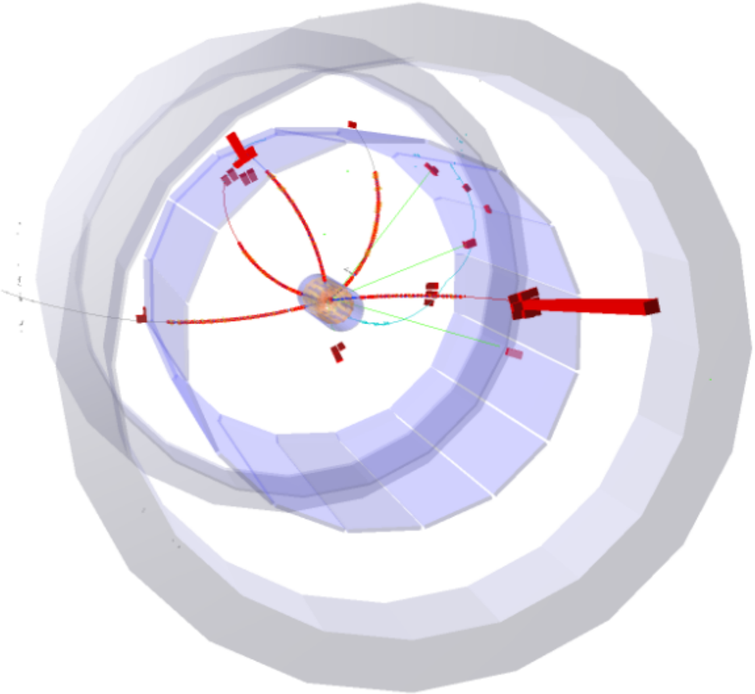
- 40 times increase of luminosity → higher background
- Lower boost → smaller separation between the B mesons

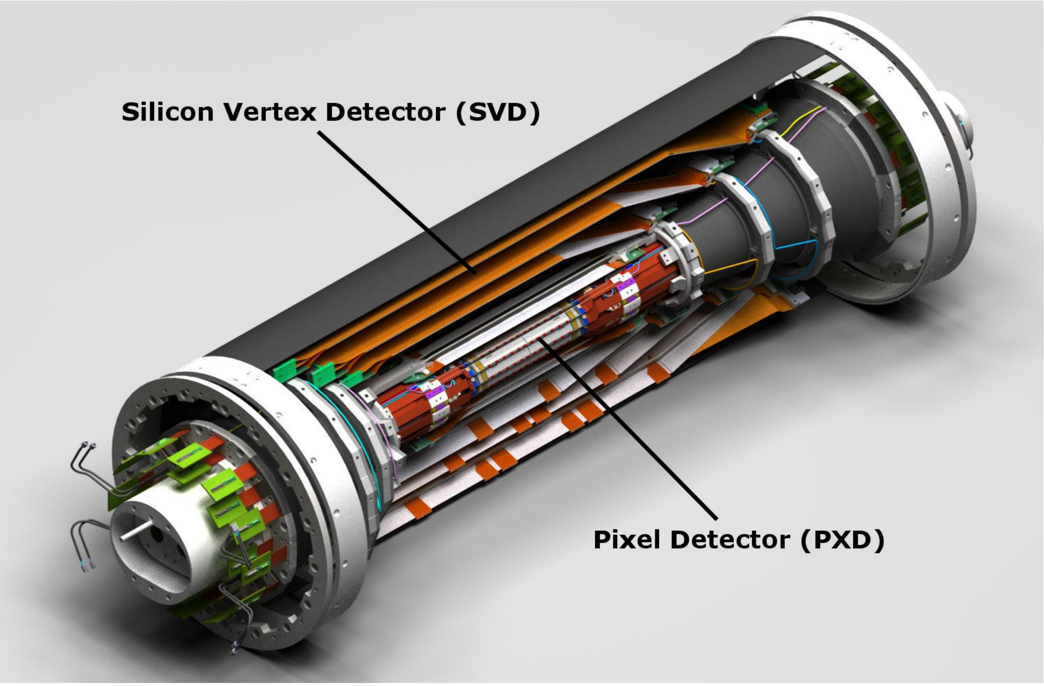
→ Pixel detector needed

Most suited technology : DEPFET

- Innermost detector system as close as possible to IP
- Highly granular pixel sensors provide most accurate 2D position information

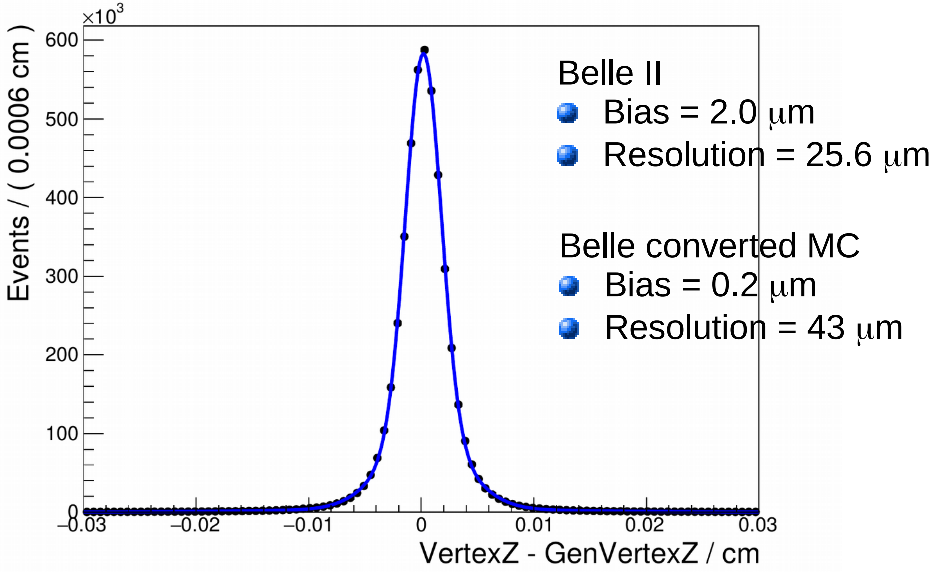
- Reconstruction of primary and secondary vertices of short-lived particles
  - Decay of particles is typical in the order of 100µm from the IP



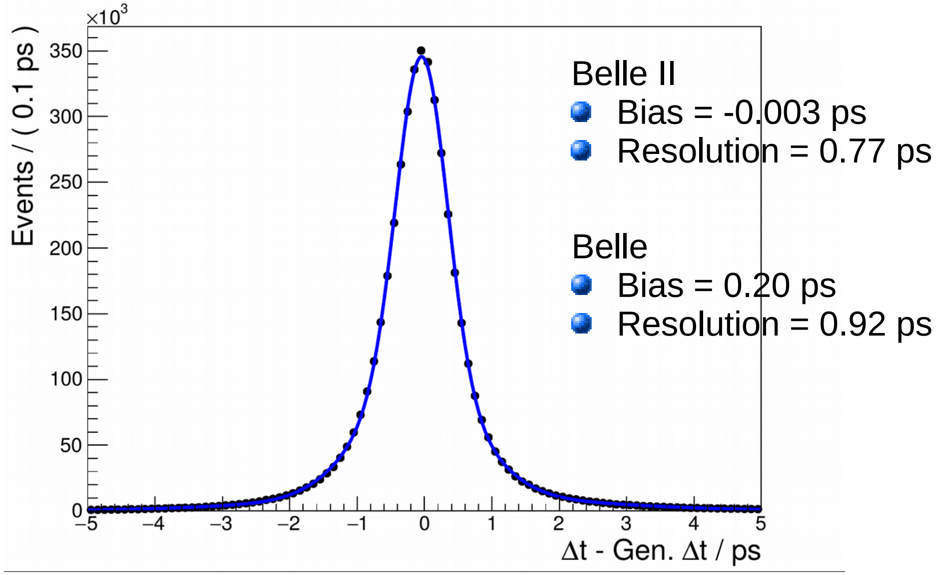


Vertex fit

Kinematic fit: J/ψ → μ μ

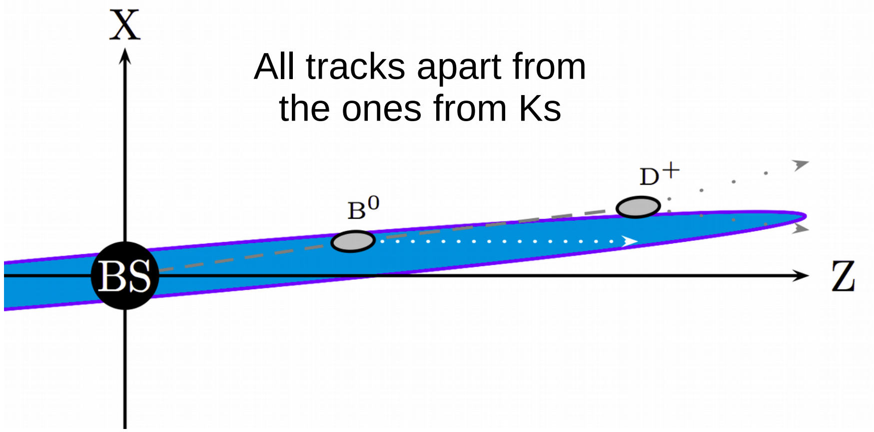


Δt resolution



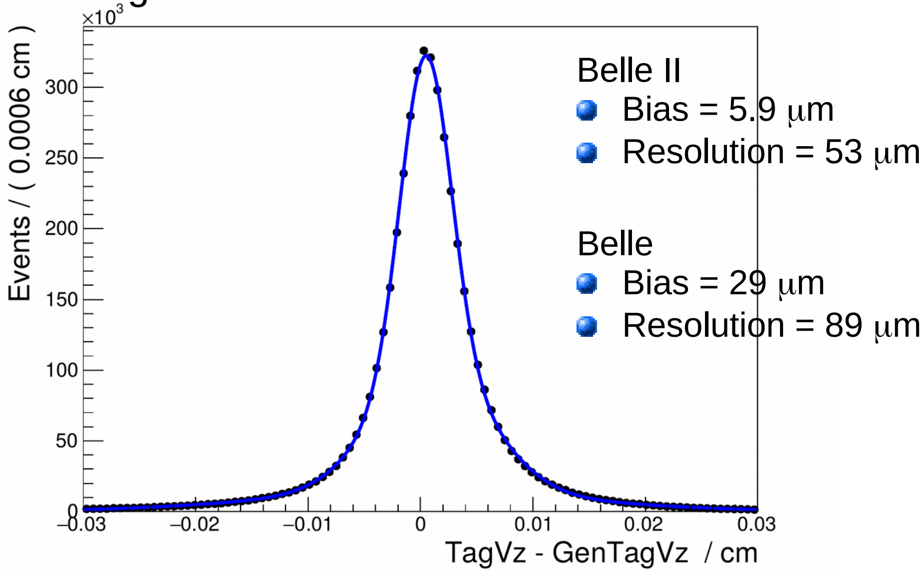
Tag side vertex fit: Using RAVE Adaptive Vertex Fit (AVF) algorithm:

Down-weights outliers dynamically, instead of using hard cutoffs (important for 3+ track vertices). CMS NOTE 2008/033.

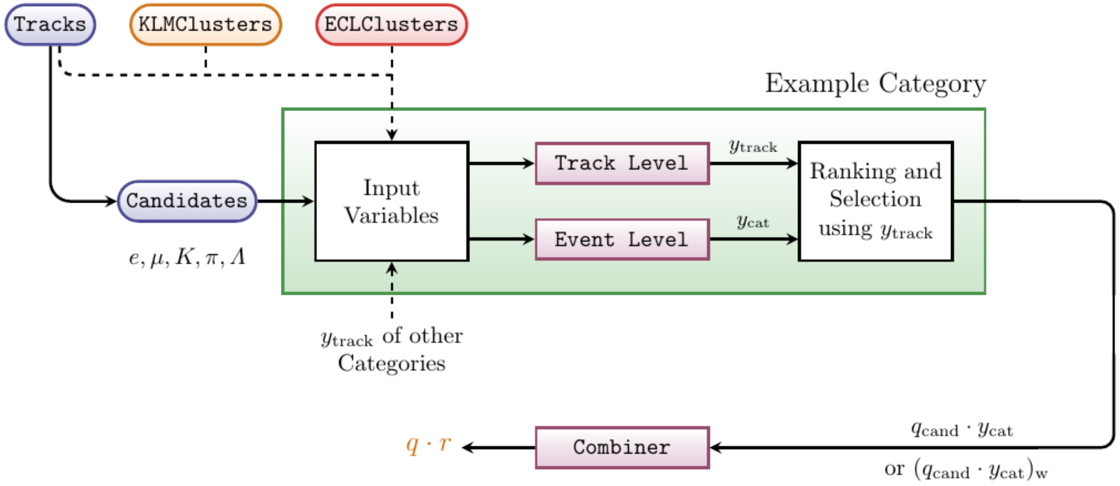


All tracks apart from the ones from Ks

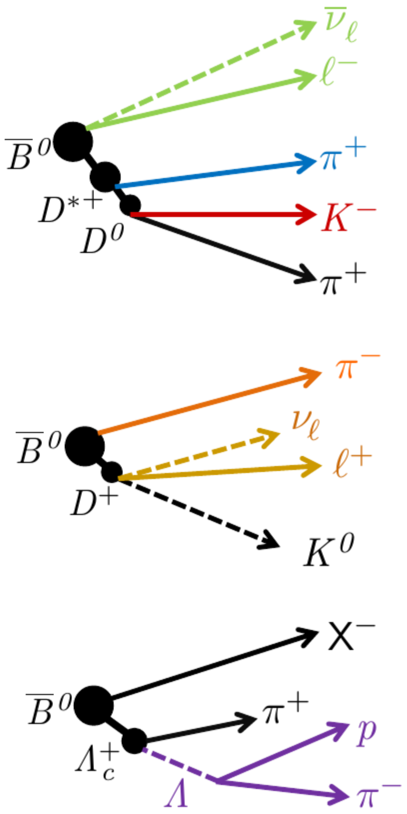
Tag side vertex fit

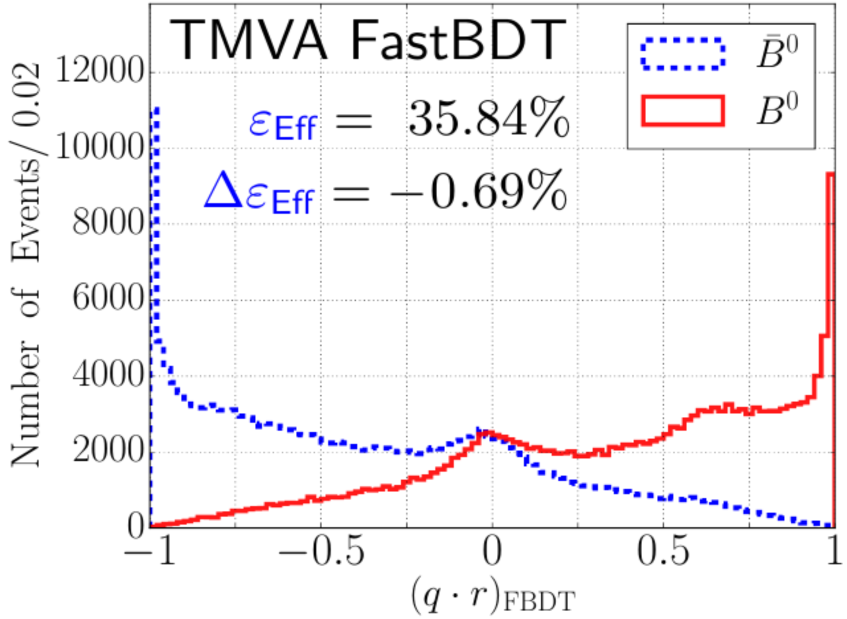


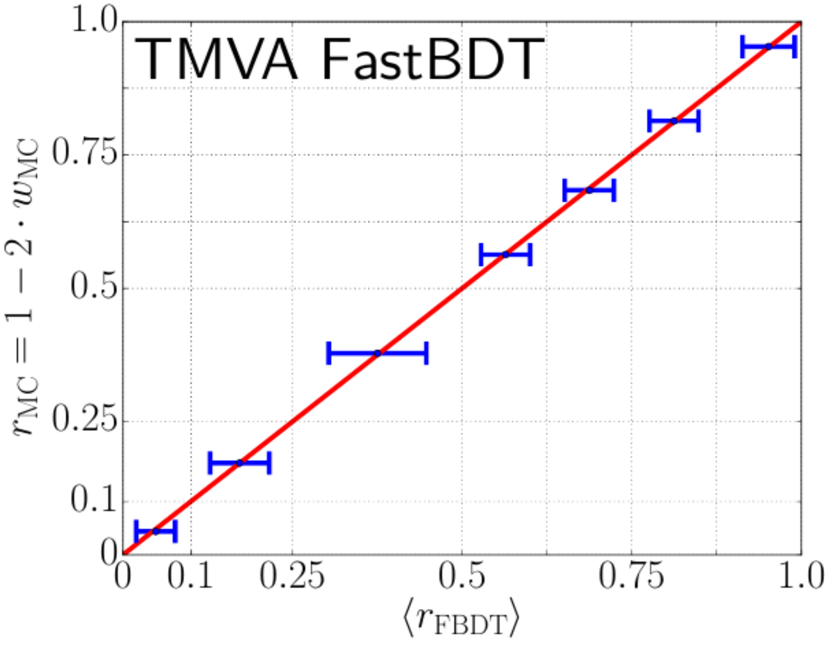
Flavor tagging



Categories	Targets
Electron	e^-
Intermediate Electron	e^+
Muon	μ^-
Intermediate Muon	μ^+
KinLepton	e^-
Intermediate KinLepton	ℓ^+
Kaon	K^-
KaonPion	K^-, π^+
SlowPion	π^+
FastPion	π^-
MaximumP	ℓ^-, π^-
FSC	ℓ^-, π^+
Lambda	Λ
Total= 13	







Sin(2β) : expected errors

$B^0 \to J/\psi\ K_S$

	Belle	Belle II	leptonic categories
S (50 ab^{-1})			
stat.	0.0035	0.0035	0.0060
syst. reducible	0.0012	0.0012	0.0012
syst. irreducible	0.0082	0.0044	0.0040
A (50 ab^{-1})			
stat.	0.0025	0.0025	0.0043
syst. reducible	0.0007	0.0007	0.0007
syst. irreducible	$^{+0.043}_{-0.022}$	$^{+0.042}_{-0.011}$	0.011

$b \to c\,\bar{c}\,s$

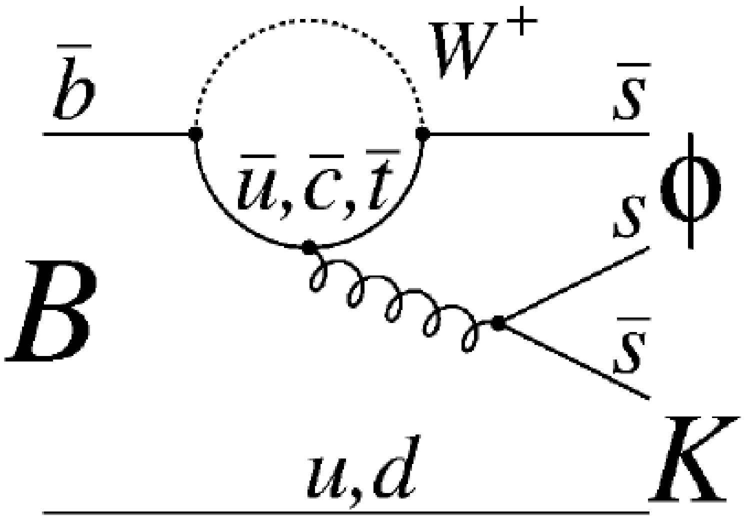
	Belle	Belle II	leptonic categories
S (50 ab^{-1})			
stat.	0.0027	0.0027	0.0048
syst. reducible	0.0026	0.0026	0.0026
syst. irreducible	0.0070	0.0036	0.0035
A (50 ab^{-1})			
stat.	0.0019	0.0019	0.0033
syst. reducible	0.0014	0.0014	0.0014
syst. irreducible	0.0106	0.0087	0.0035

- Sin(2β) will remain the most precise measurement on the Unitarity Triangle parameters
- In Belle II the measurement will be dominated by systematics
  - ➔ Effort concentrated in understand and reducing them

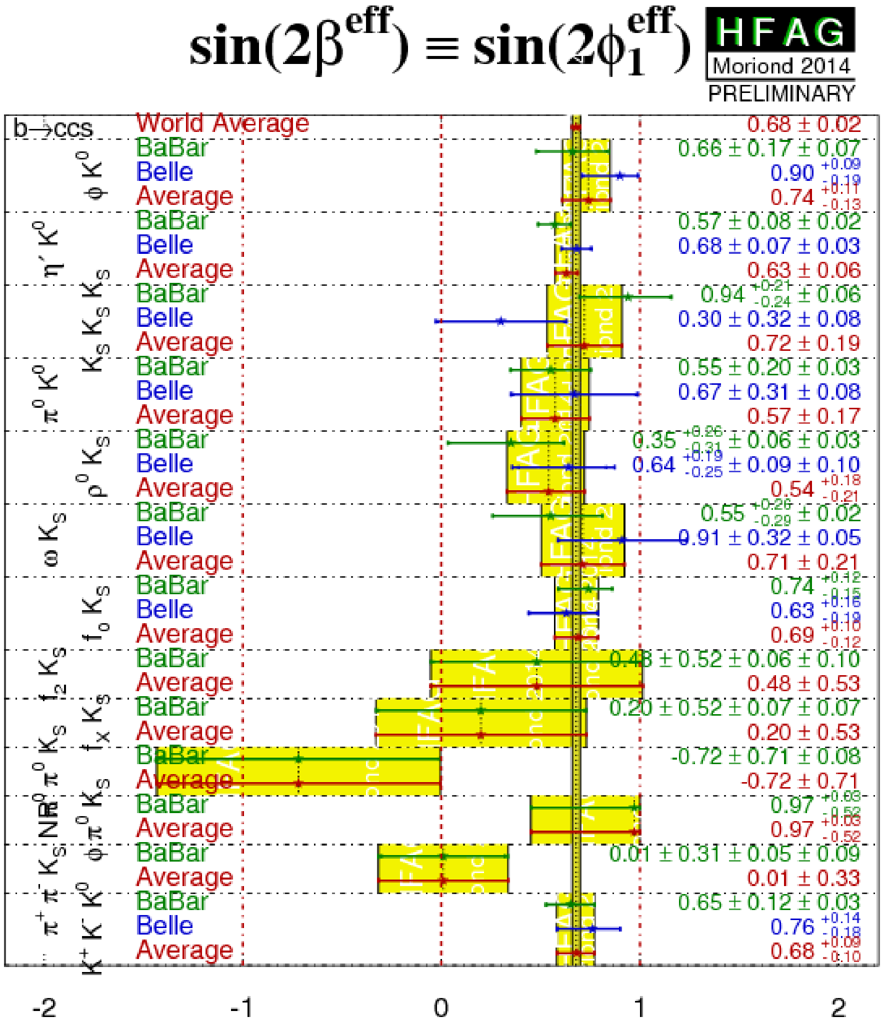
Three hypotheses

- Belle: same Belle non reducible systematics
- Belle II: vertex systematic / 2
- Leptonic category: only leptonic categories for the flavor tagging

Sin(2β): b → q$\bar{q}$s



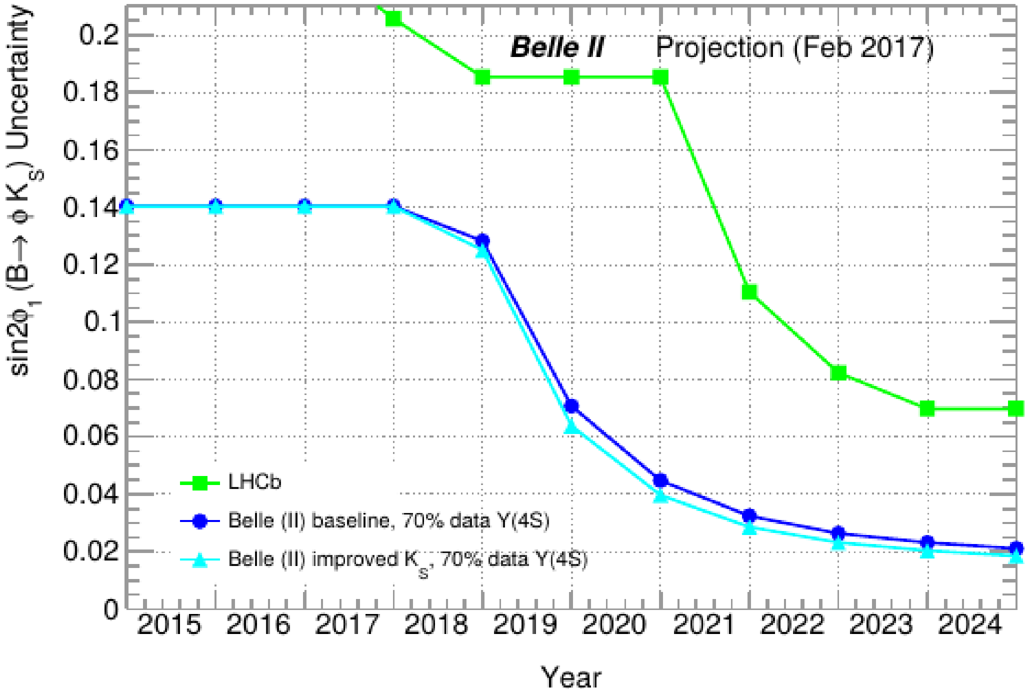
In principle measures sin2β, but sensitive to new physics



$B^0 \rightarrow \phi$ Ks: expected sensitivity

Channel	ε_{reco}	Yield	$\sigma(S)$
1 ab^{-1} scenario:			
$\phi(K^+K^-)K_S(\pi^+\pi^-)$	35%	456	0.174
$\phi(K^+K^-)K_S(\pi^0\pi^0)$	25%	153	0.295
$\phi(\pi^+\pi^-\pi^0)K_S(\pi^+\pi^-)$	28%	109	0.338
K_S modes combination			0.135
$K_S + K_L$ modes combination			0.108
5 ab^{-1} scenario:			
$\phi(K^+K^-)K_S(\pi^+\pi^-)$	35%	2280	0.078
$\phi(K^+K^-)K_S(\pi^0\pi^0)$	25%	765	0.132
$\phi(\pi^+\pi^-\pi^0)K_S(\pi^+\pi^-)$	28%	545	0.151
K_S modes combination			0.060
$K_S + K_L$ modes combination			0.048

we estimate the expected yield of ϕK_L^0 based on previous BaBar and Belle analyses (but use the same Δt resolution we estimate in $\phi \rightarrow K^+K^-$ for Belle II).



Belle II projection

Sensitivity study

$B^0 \rightarrow \eta' K_S$: expected sensitivity

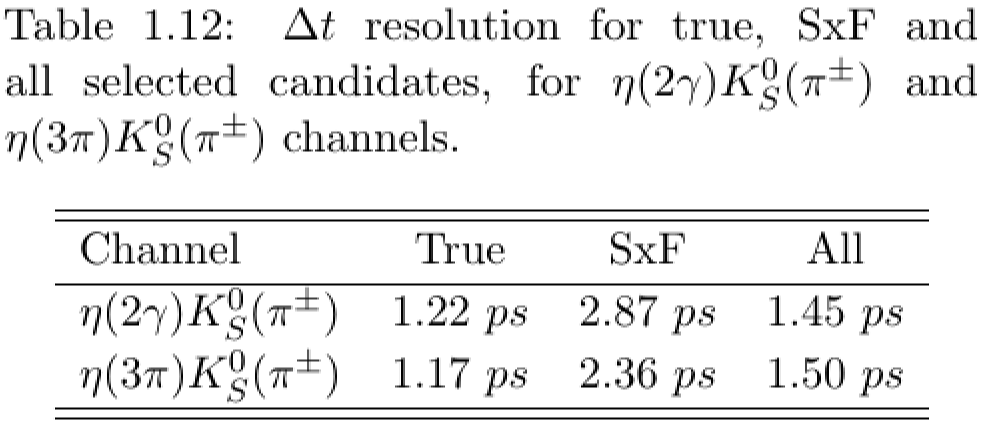
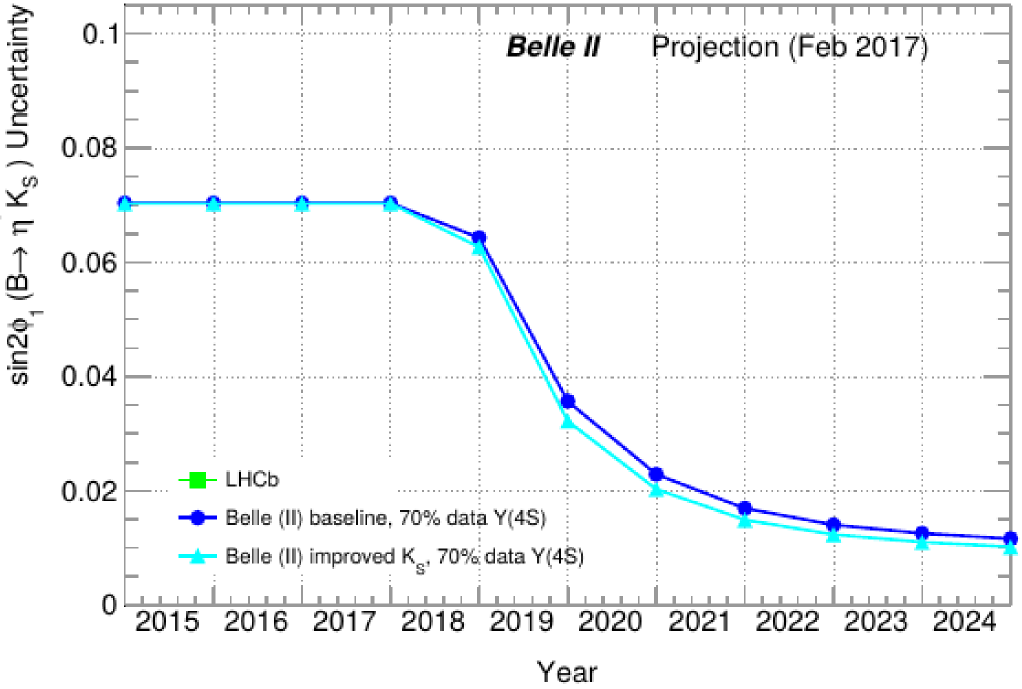


Table 1.12: Δt resolution for true, SxF and all selected candidates, for $\eta(2\gamma)K^0_S(\pi^\pm)$ and $\eta(3\pi)K^0_S(\pi^\pm)$ channels.

Channel	True	SxF	All
$\eta(2\gamma)K^0_S(\pi^\pm)$	1.22 ps	2.87 ps	1.45 ps
$\eta(3\pi)K^0_S(\pi^\pm)$	1.17 ps	2.36 ps	1.50 ps



Similar Belle sensitivity given the same integrated luminosity

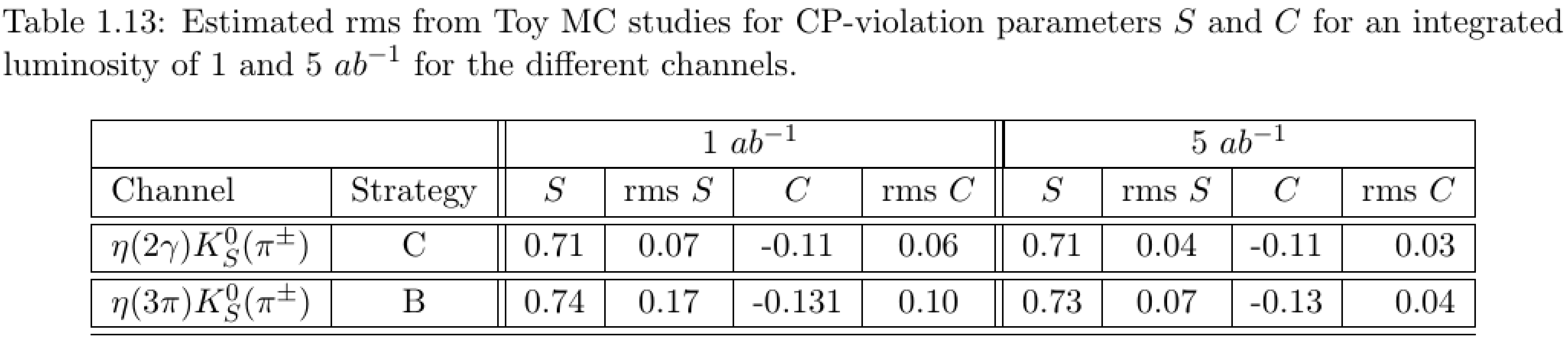


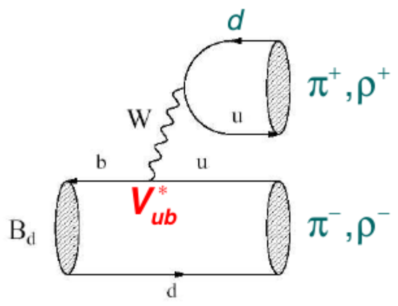
Table 1.13: Estimated rms from Toy MC studies for CP-violation parameters S and C for an integrated luminosity of 1 and 5 ab^{-1} for the different channels.

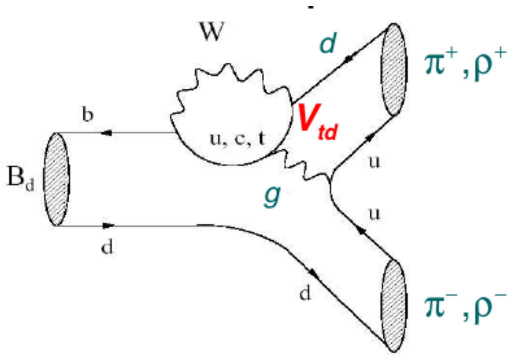
		$1\ ab^{-1}$				$5\ ab^{-1}$			
Channel	Strategy	S	rms S	C	rms C	S	rms S	C	rms C
$\eta(2\gamma)K^0_S(\pi^\pm)$	C	0.71	0.07	-0.11	0.06	0.71	0.04	-0.11	0.03
$\eta(3\pi)K^0_S(\pi^\pm)$	B	0.74	0.17	-0.131	0.10	0.73	0.07	-0.13	0.04

Measurement of α

M. Gronau and D. London, PRL 65 3381 (1990)

Proceeds mainly through $b \to u\bar{u}d$ tree diagram,
but penguin contributions introduce additional phases





Used decay modes:

- $B \to \pi\ \pi$
- $B \to \rho\ \rho$
- $B \to \rho\ \pi$

Extra weak and strong phases + |P/T| modify α by $\Delta\alpha$:

$$\sin(2\alpha) \to \sin(2\alpha_{eff}) \quad \alpha_{eff} = \alpha + \Delta\alpha$$

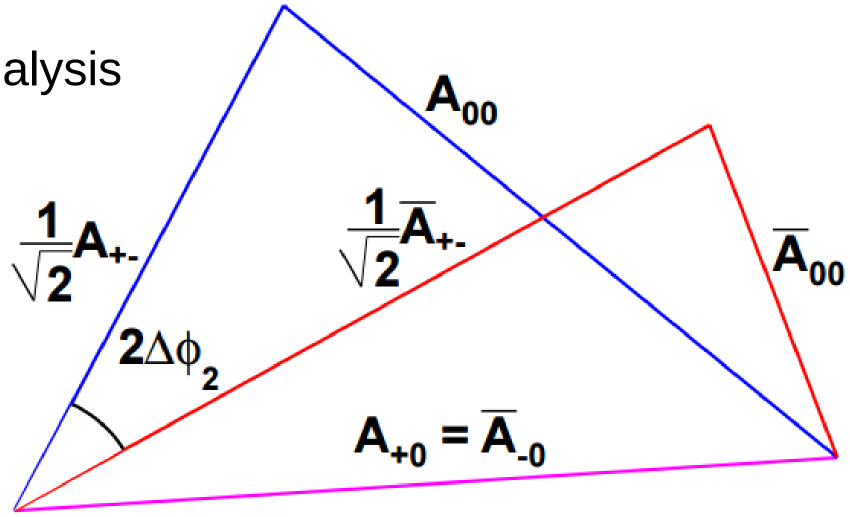
To relate α to α_{eff}:

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

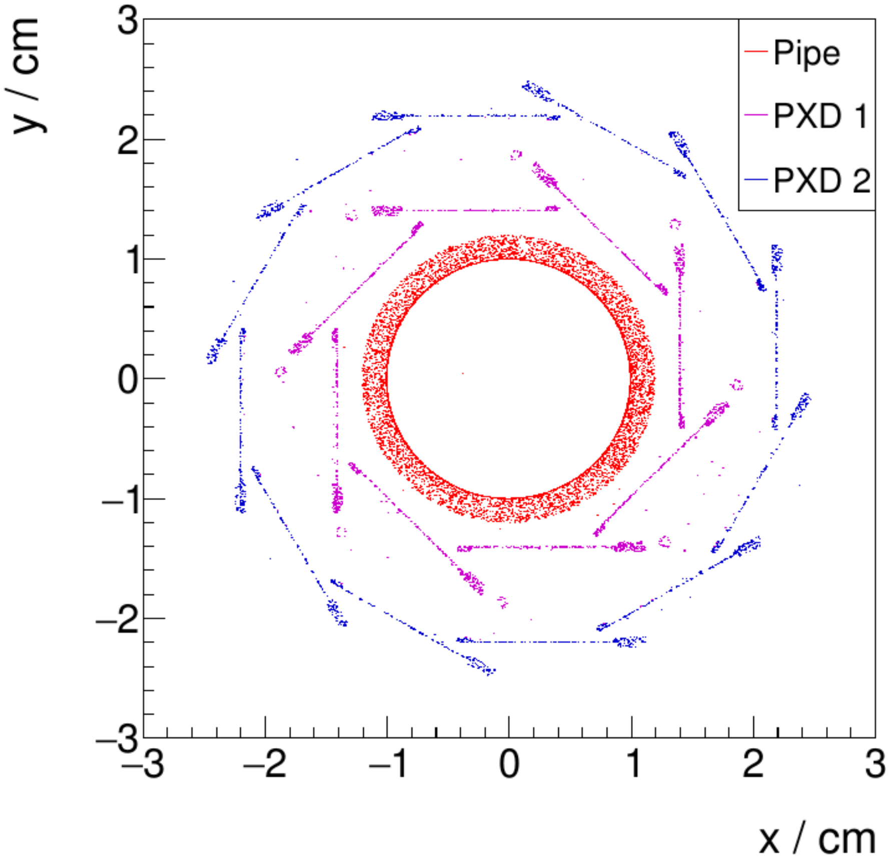
$$\frac{1}{\sqrt{2}}\bar{A}^{+-} + \bar{A}^{00} = \bar{A}^{-0}$$

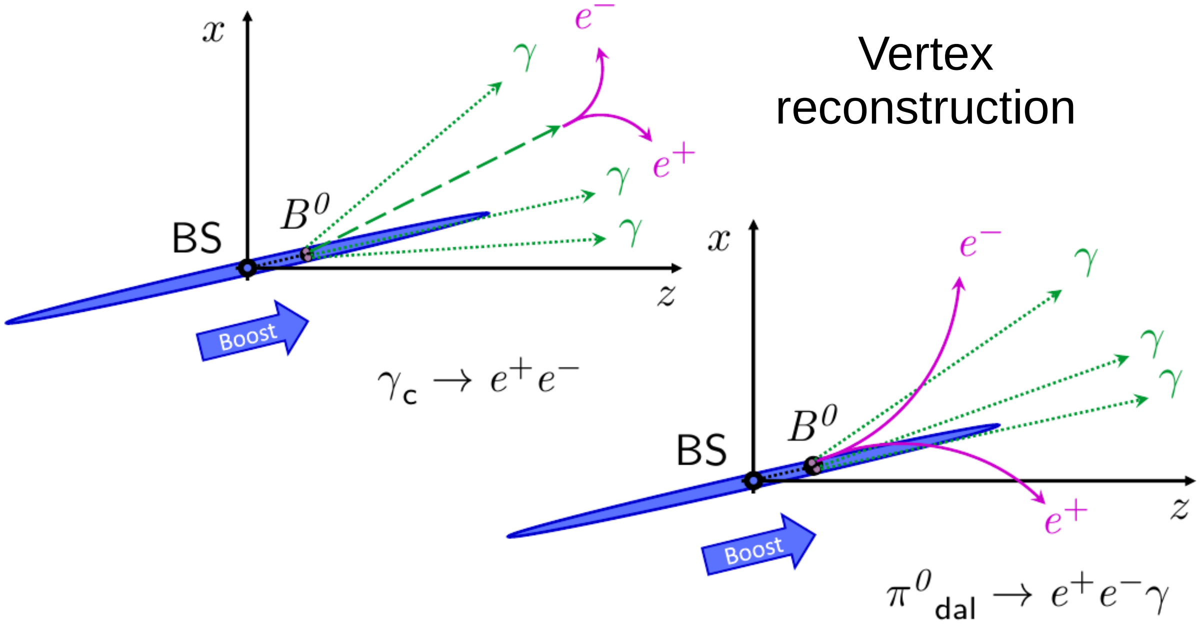
$$A^{+0} = \bar{A}^{-0} \text{ (pure tree)}$$

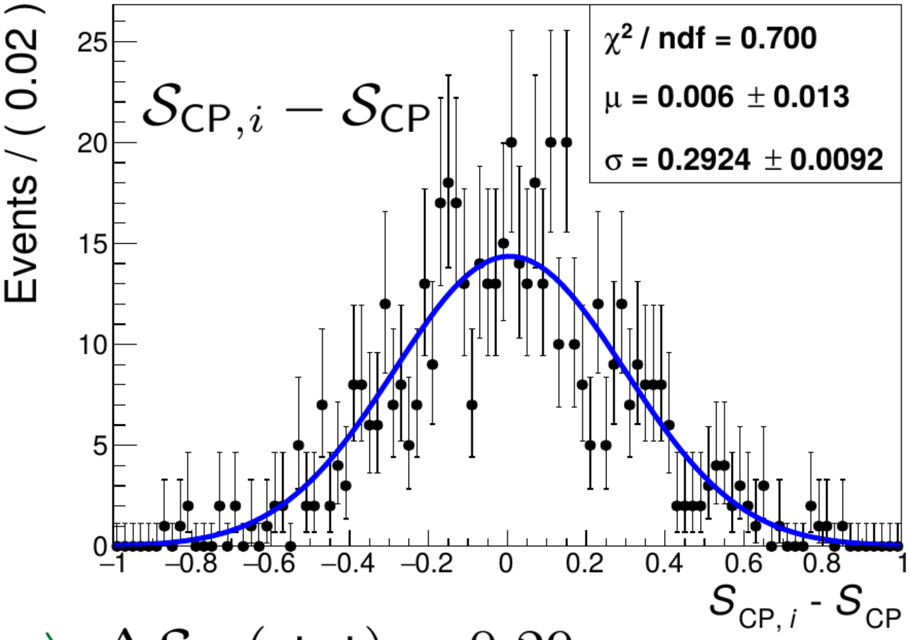
Isospin analysis



$B^0 \rightarrow \pi^0\pi^0$: converted photons



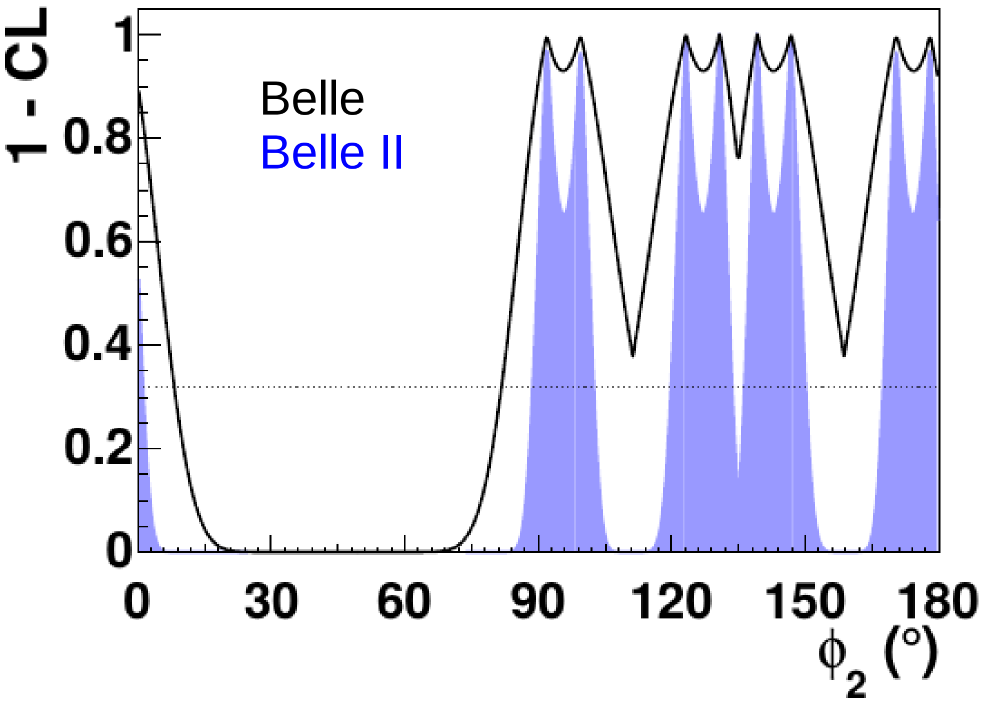

Vertex reconstruction

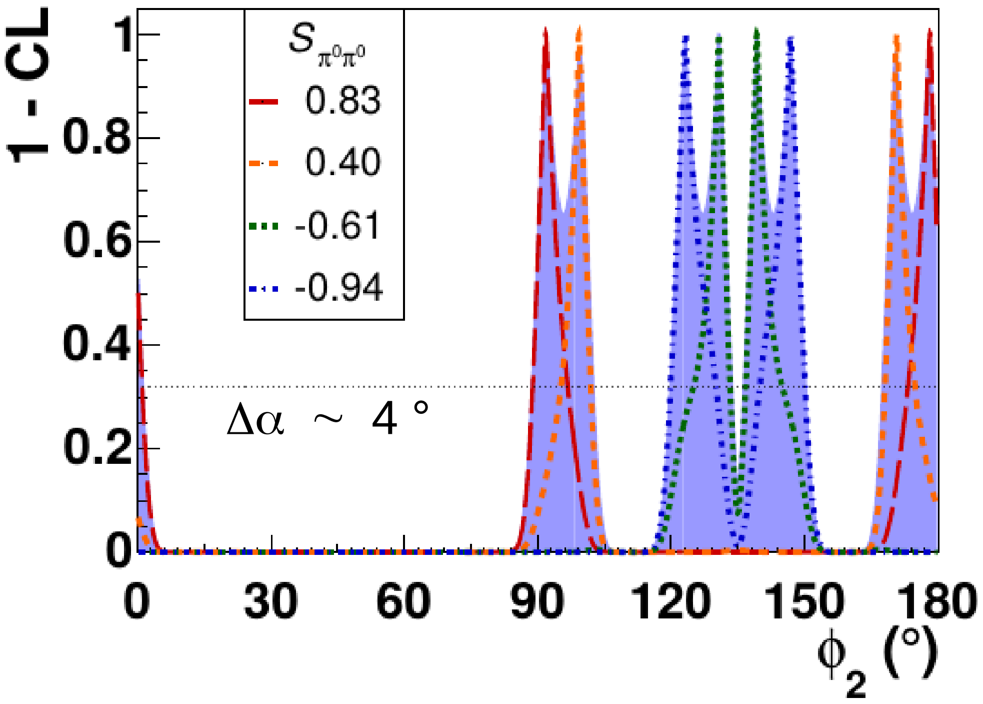


- Photon conversion inside the Belle II detector (Beam pipe + PXD)
- 3 % of $B^0 \rightarrow \pi^0 \pi^0$ events
- ~ 5 % including π^0 Dalitz decay
- Reconstruction efficiency will be crucial

$$\Rightarrow \Delta\mathcal{S}_{CP}(\text{stat}) = 0.29$$

Isospin analysis: $B \rightarrow \pi\pi$





	Value	0.8 ab^{-1}	50 ab^{-1}
$\mathcal{B}_{\pi^+\pi^-}$ [10^{-6}]	5.04	$\pm 0.21 \pm 0.18$ [79]	$\pm 0.03 \pm 0.08$
$\mathcal{B}_{\pi^0\pi^0}$ [10^{-6}]	1.31	$\pm 0.19 \pm 0.18$ [78]	$\pm 0.04 \pm 0.04$
$\mathcal{B}_{\pi^+\pi^0}$ [10^{-6}]	5.86	$\pm 0.26 \pm 0.38$ [79]	$\pm 0.03 \pm 0.09$
$C_{\pi^+\pi^-}$	-0.33	$\pm 0.06 \pm 0.03$ [80]	$\pm 0.01 \pm 0.03$
$S_{\pi^+\pi^-}$	-0.64	$\pm 0.08 \pm 0.03$ [80]	$\pm 0.01 \pm 0.01$
$C_{\pi^0\pi^0}$	-0.14	$\pm 0.36 \pm 0.12$ [78]	$\pm 0.03 \pm 0.01$

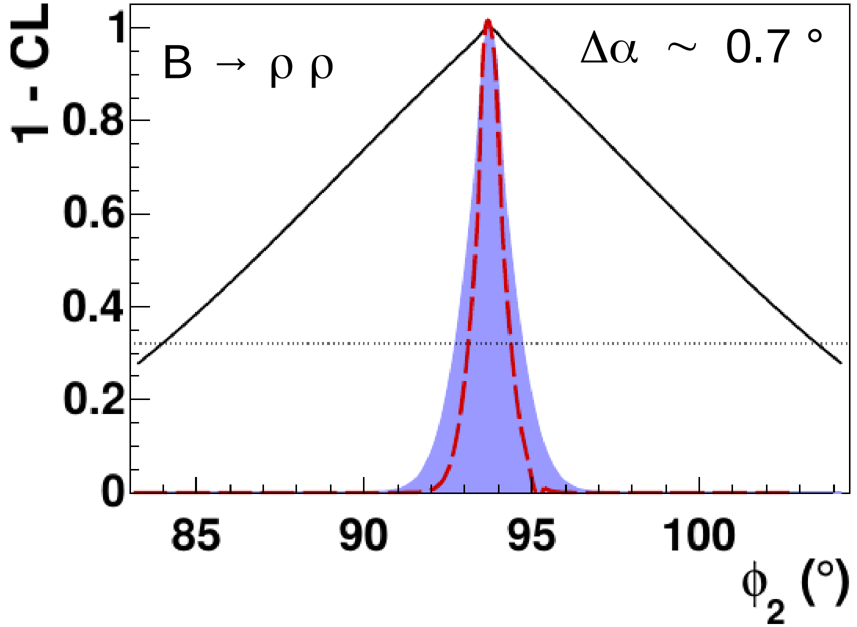
$$\Delta S_{\pi^0\pi^0} = \pm 0.29 \pm 0.03$$

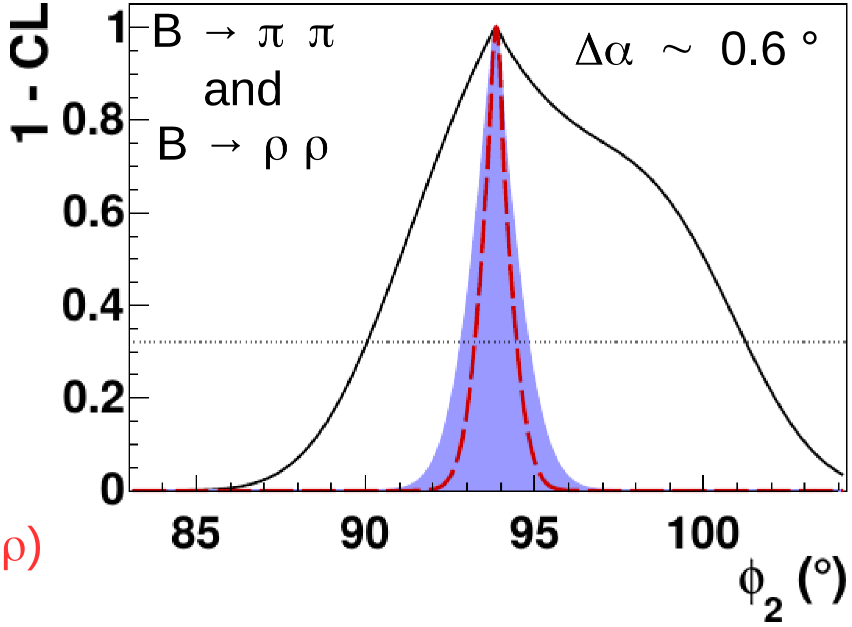
78: arXiv:1705.02083
79: Phys. Rev., D87(3), 031103 (2013)
80: Phys. Rev., D88(9), 092003 (2013)

Isospin analysis: B → ρ ρ

	Value	0.8 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^-}$	0.988	$\pm0.012\pm0.023$ [74]	$\pm0.002\pm0.003$
$f_{L,\rho^0\rho^0}$	0.21	$\pm0.20\pm0.15$ [81]	$\pm0.03\pm0.02$
$\mathcal{B}_{\rho^+\rho^-}$ $[10^{-6}]$	28.3	$\pm1.5\pm1.5$ [74]	$\pm0.19\pm0.4$
$\mathcal{B}_{\rho^0\rho^0}$ $[10^{-6}]$	1.02	$\pm0.30\pm0.15$ [81]	$\pm0.04\pm0.02$
$C_{\rho^+\rho^-}$	0.00	$\pm0.10\pm0.06$ [74]	$\pm0.01\pm0.01$
$S_{\rho^+\rho^-}$	-0.13	$\pm0.15\pm0.05$ [74]	$\pm0.02\pm0.01$
	Value	0.08 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^0}$	0.95	$\pm0.11\pm0.02$ [65]	$\pm0.004\pm0.003$
$\mathcal{B}_{\rho^+\rho^0}$ $[10^{-6}]$	31.7	$\pm7.1\pm5.3$ [65]	$\pm0.3\pm0.5$
	Value	0.5 ab^{-1}	50 ab^{-1}
$C_{\rho^0\rho^0}$	0.2	$\pm0.8\pm0.3$ [64]	$\pm0.08\pm0.01$
$S_{\rho^0\rho^0}$	0.3	$\pm0.7\pm0.2$ [64]	$\pm0.07\pm0.01$

64: Phys. Rev., D78, 071104 (2008)
65: Phys. Rev. Lett., 91, 221801 (2003)
74: Phys. Rev., D93(3), 032010 (2016)
81: [Addendum: Phys. Rev.D89,no.11, 119903(2014)] (2012),

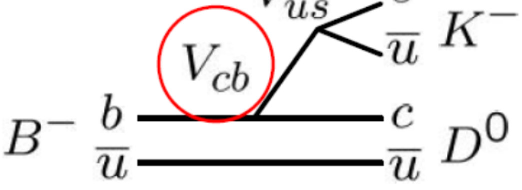




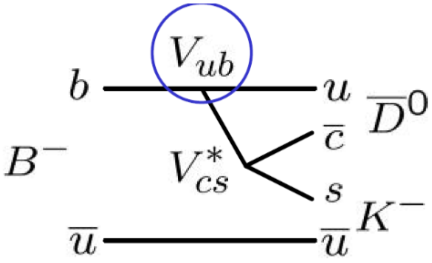
Belle Belle II Belle II + ($S_{00}\pi$ & $S_{00}\rho$)

Measurement of γ with B→D^0 K

γ is the phase between b→u and b→c



$e^{i\delta_B}\ e^{-i\gamma}$

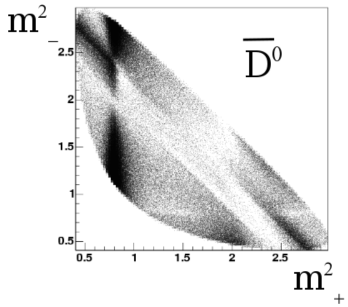


Interference between these amplitudes with $D^0/\overline{D}^0$ decaying in the same final state

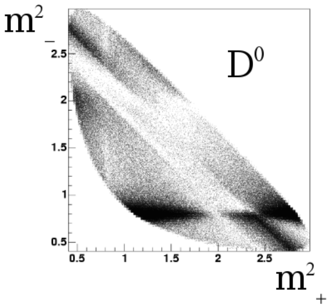
- From tree level processes
- Not affected from NP in loops

$D^0/\overline{D}^0 \rightarrow Ks\ \pi^+\ \pi^-$

$\Gamma_+ \propto \Big|$



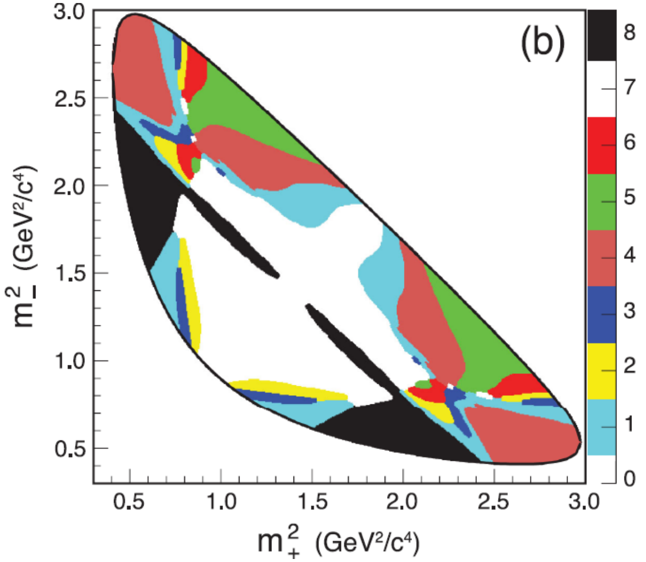
$+\ r_B\ e^{i(\delta+\gamma)}$



$\Big|^2$

The Dalitz model is needed

Strong phase differences can be measured at a charm factory



- CLEO result Phys. Rev. D 82, 112006(2010)
- Improvement expected from BES III

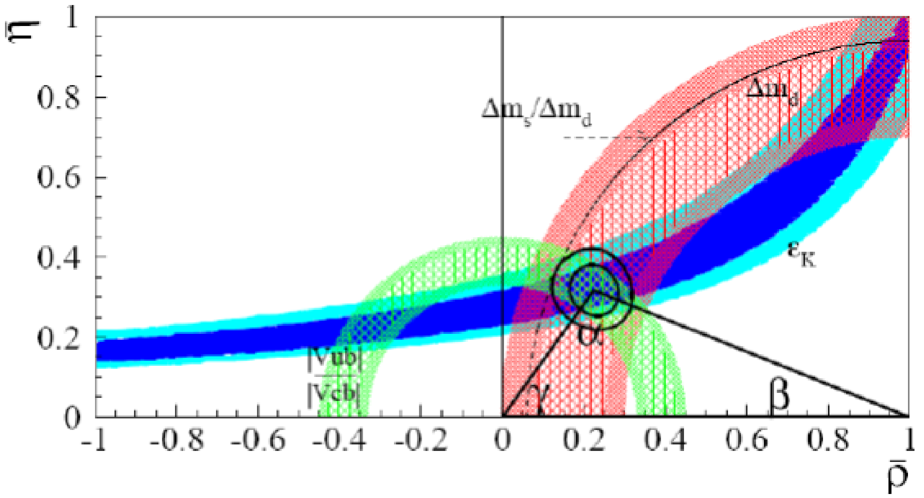
An error of 1.6° is expected

- Including more $D^{(*)}$ decay modes
- Integrated luminosity = 50 ab^{-1}
- Assuming BES III will collect 10 fb^{-1}

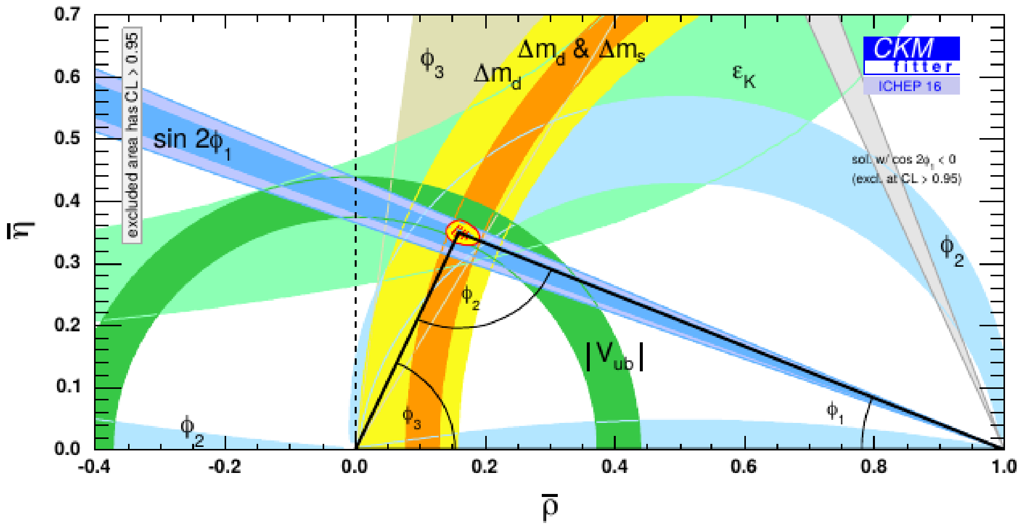
Outlook

The B2TIP report: https://confluence.desy.de/display/BI/B2TiP+WebHome

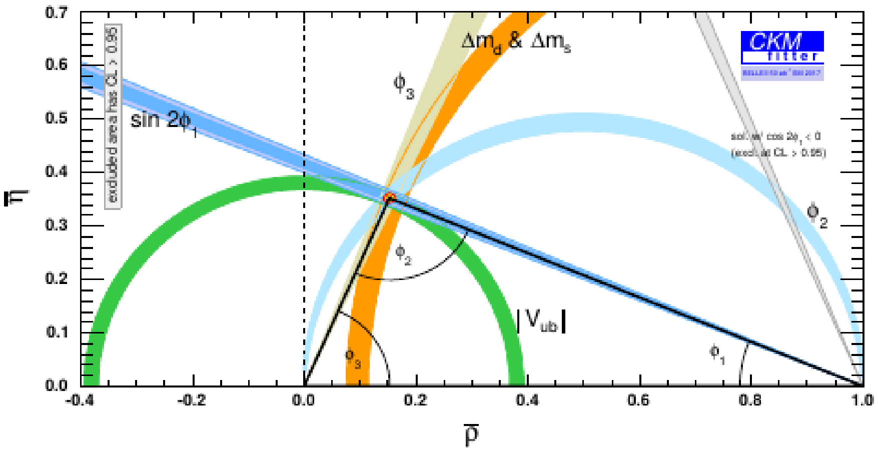
Before the B-factories

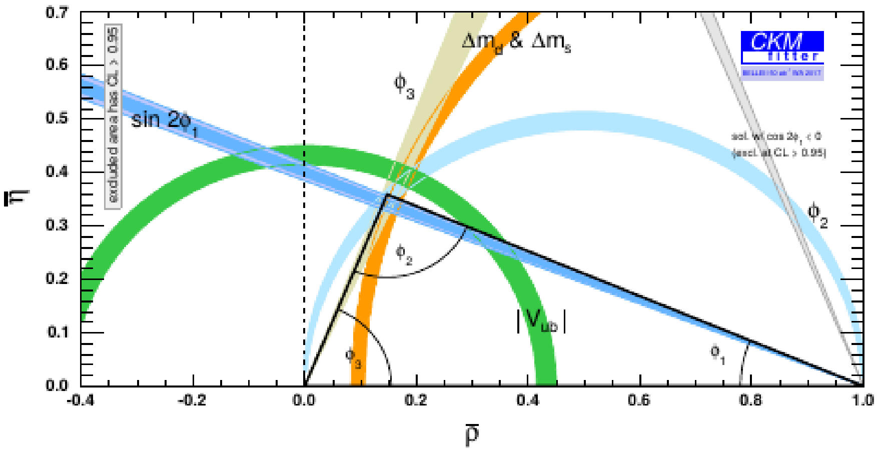


After the B-factories



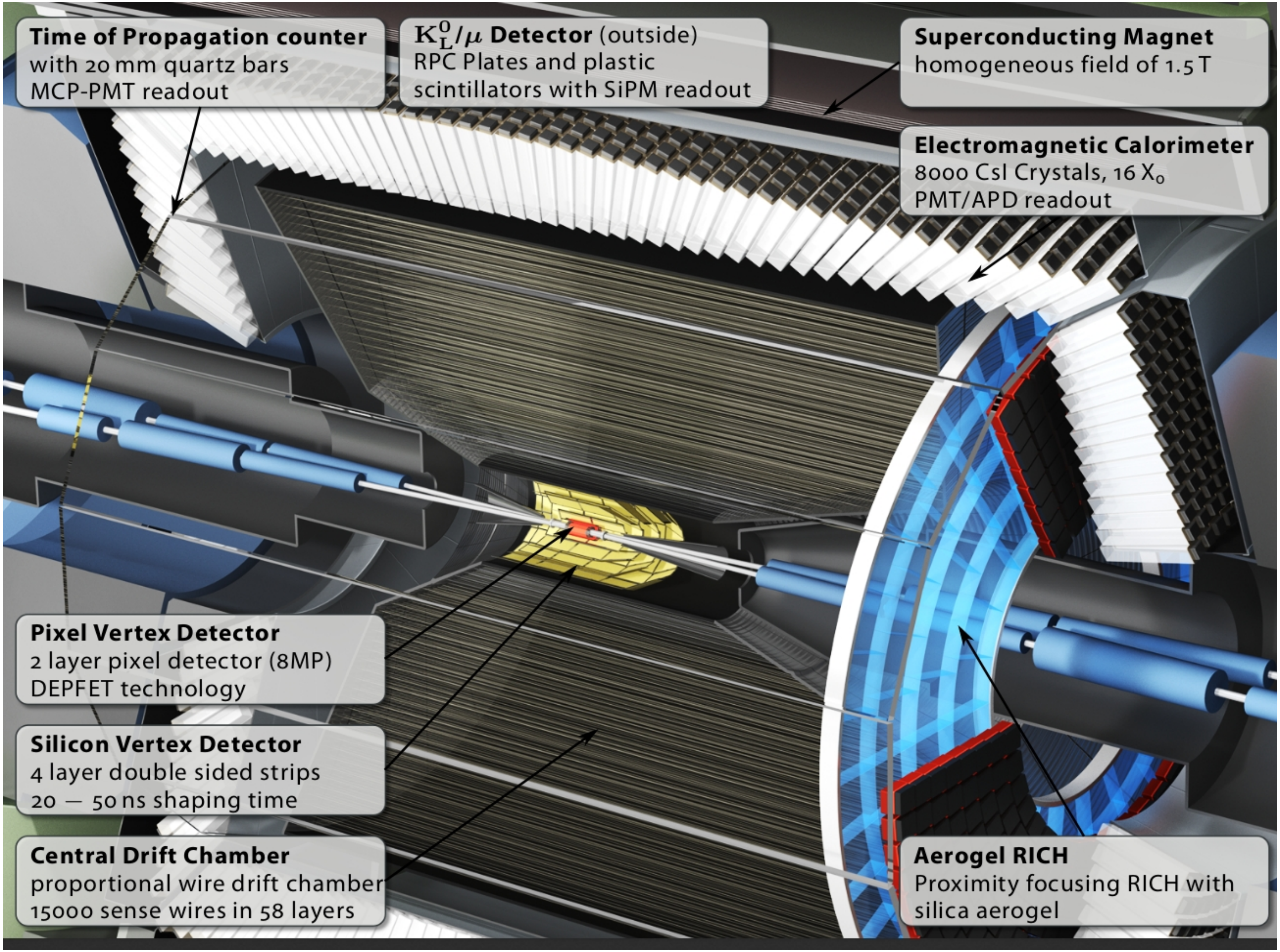
CKM mechanism will be tested at 1% level





Backup slides

Belle II



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

Silicon Vertex Detector
4 layer double sided strips
20 — 50 ns shaping time

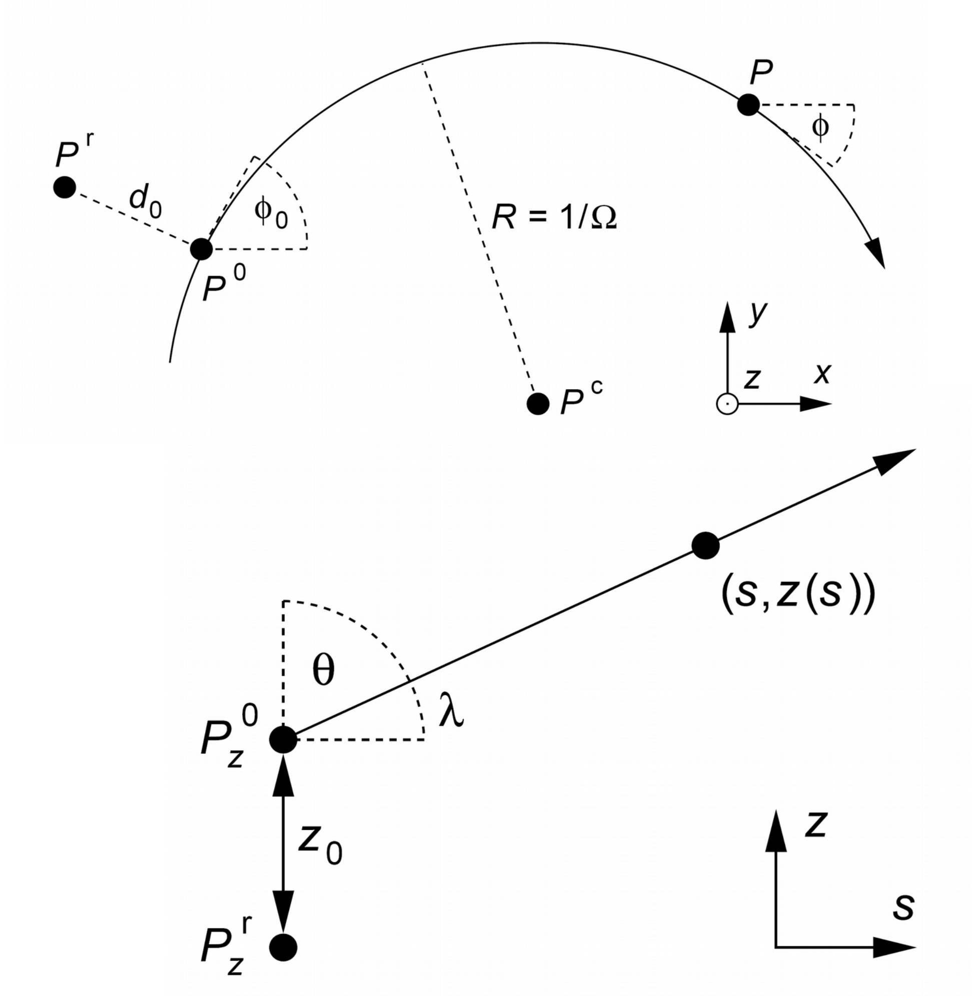
Central Drift Chamber
proportional wire drift chamber
15000 sense wires in 58 layers

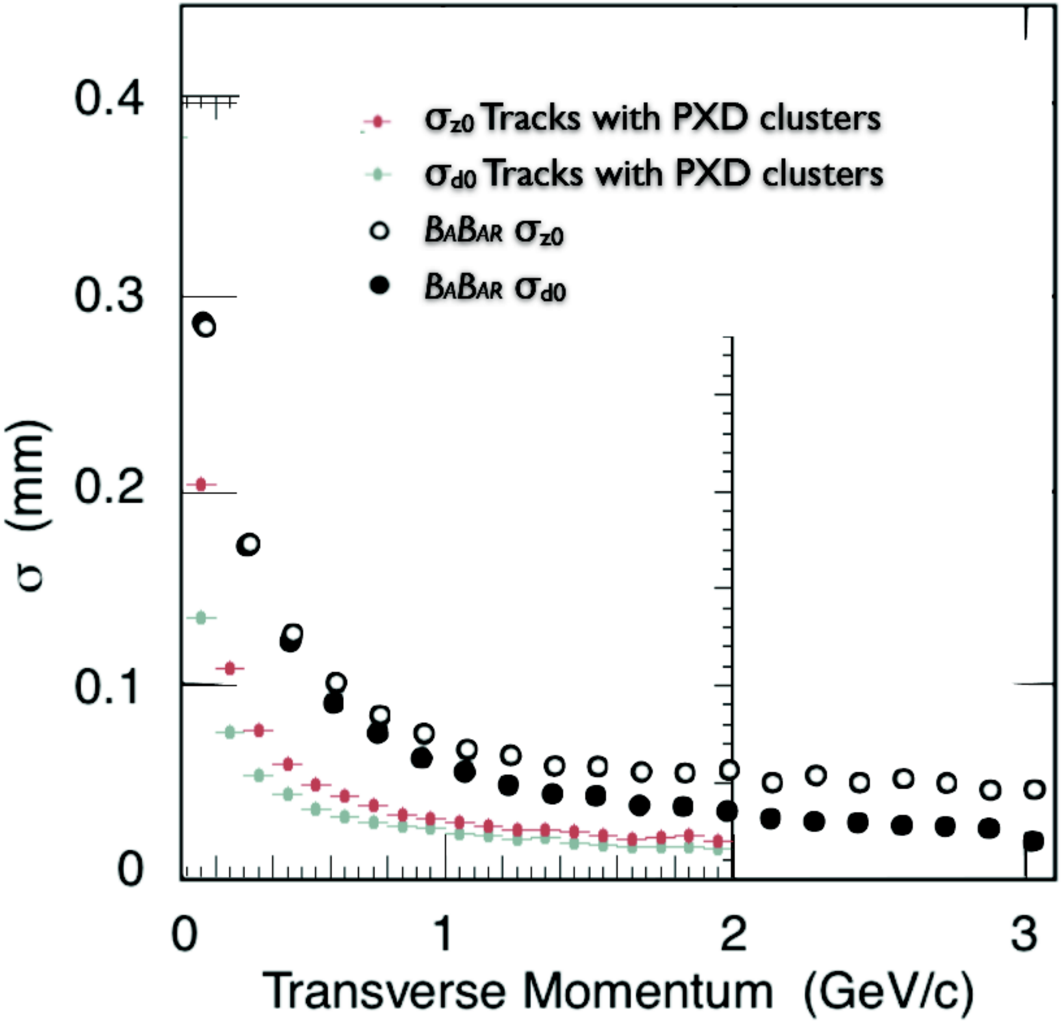
Aerogel RICH
Proximity focusing RICH with
silica aerogel

The impact parameter

The impact parameters: d_0 and z_0

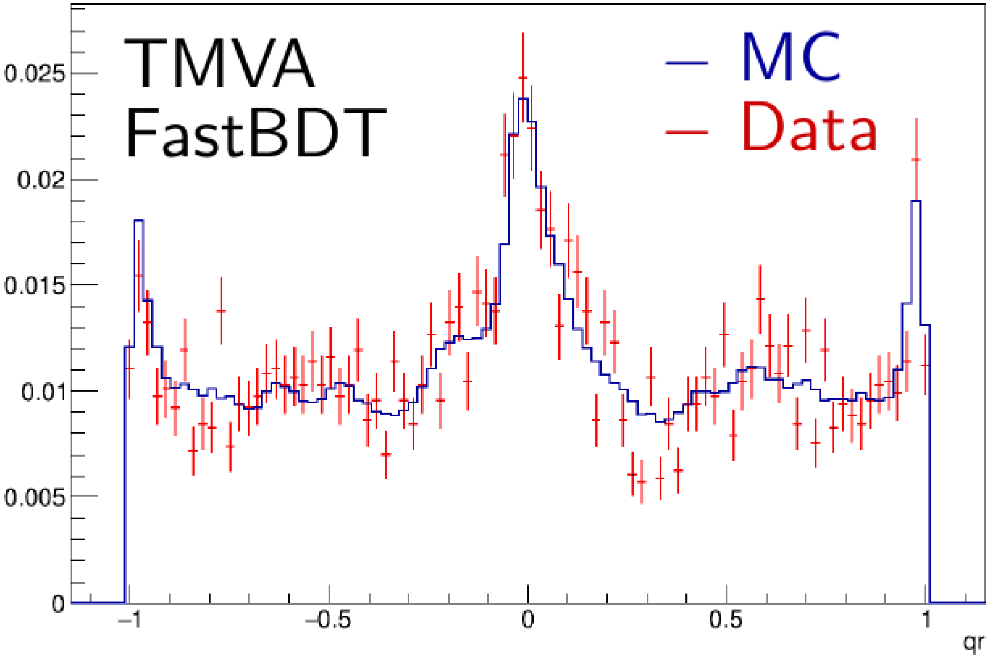
- defined as the projections of distance from the point of closest approach to the origin
- good measure of the overall performance of the tracking system
- used to find the optimal tracker configuration





Almost a factor 2 improvement respect to BaBar

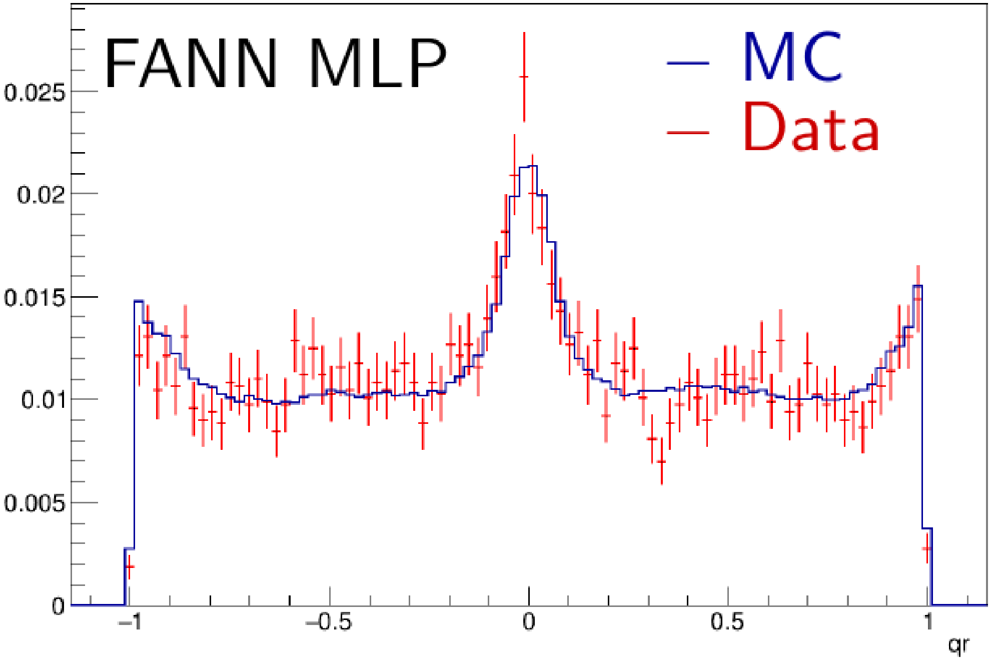
Belle Data – MC comparison



- Belle MC and data
- Belle II flavor tagging algorithm

Efficiency

- Belle Converted MC = 32 %
- Belle = 29 %



$B^0 \rightarrow \phi\ Ks$

1) $\phi \quad K_S^0 \longrightarrow \pi^+\pi^-$

$\quad \hookrightarrow K^+K^-$

Cleanest mode, all charged particles in final state

2) $\phi \quad K_S^0 \longrightarrow \pi^0\pi^0$

$\quad \hookrightarrow K^+K^-$

Lower statistics and harder (because of π^0's)

3) $\phi \quad K_S^0 \longrightarrow \pi^+\pi^-$

$\quad \hookrightarrow \pi^+\pi^-\pi^0$

Never tried before at BaBar and Belle

4) $\phi \quad K_L^0$

$\quad \hookrightarrow K^+K^-$

Not yet started looking at K_L^0's

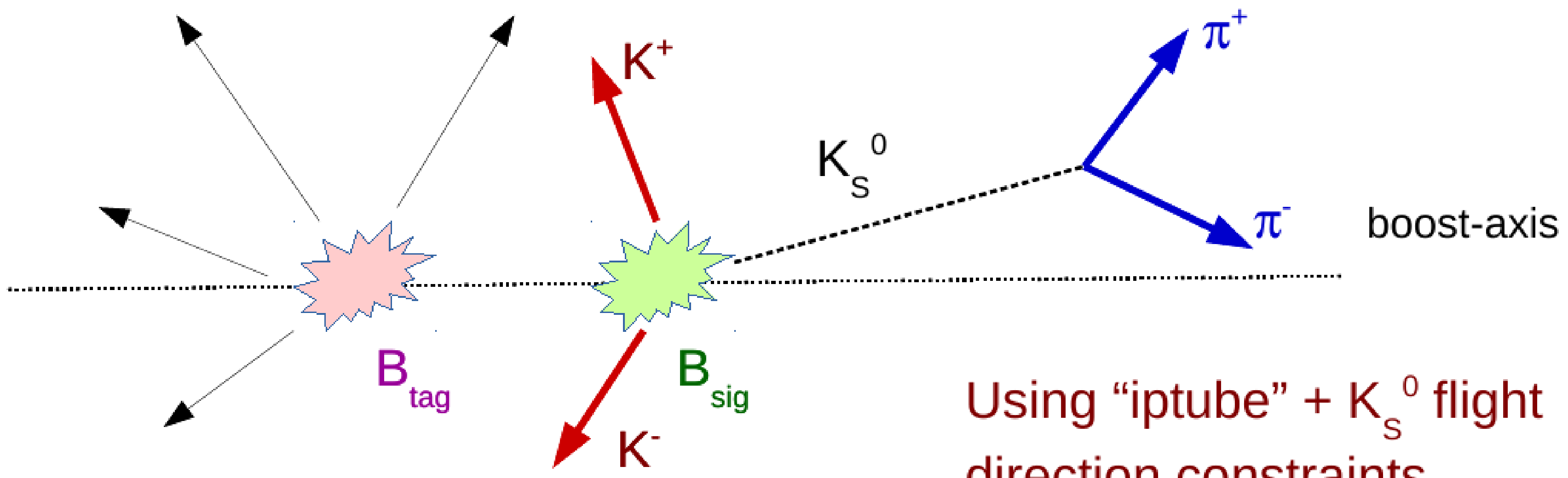
$BF(\phi \rightarrow K^+K^-) \sim 50\%$

$BF(\phi \rightarrow \pi^+\pi^-\pi^0) \sim 15\%$

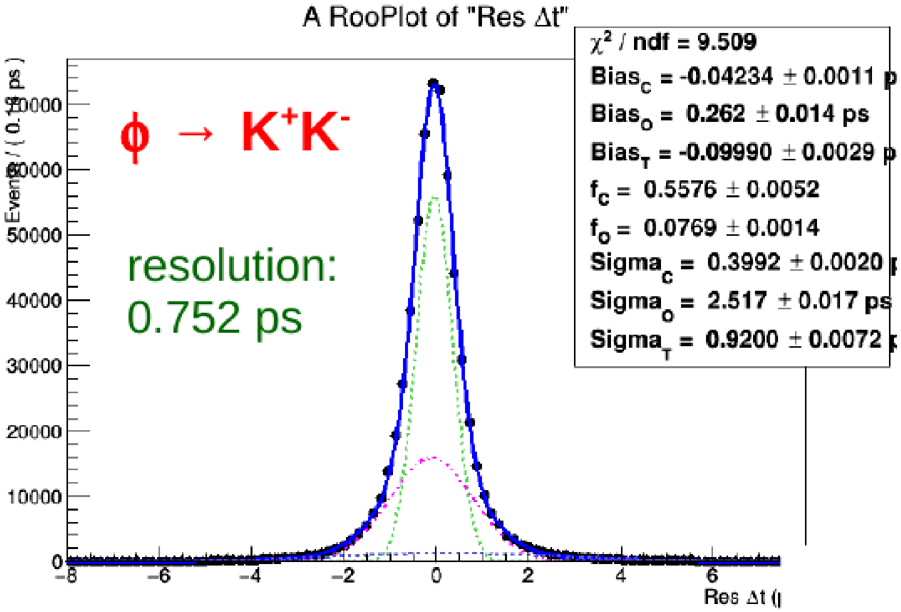
$BF(K_S \rightarrow \pi^+\pi^-) \sim 69\%$

$BF(K_S \rightarrow \pi^0\pi^0) \sim 31\%$

Vertex resolution



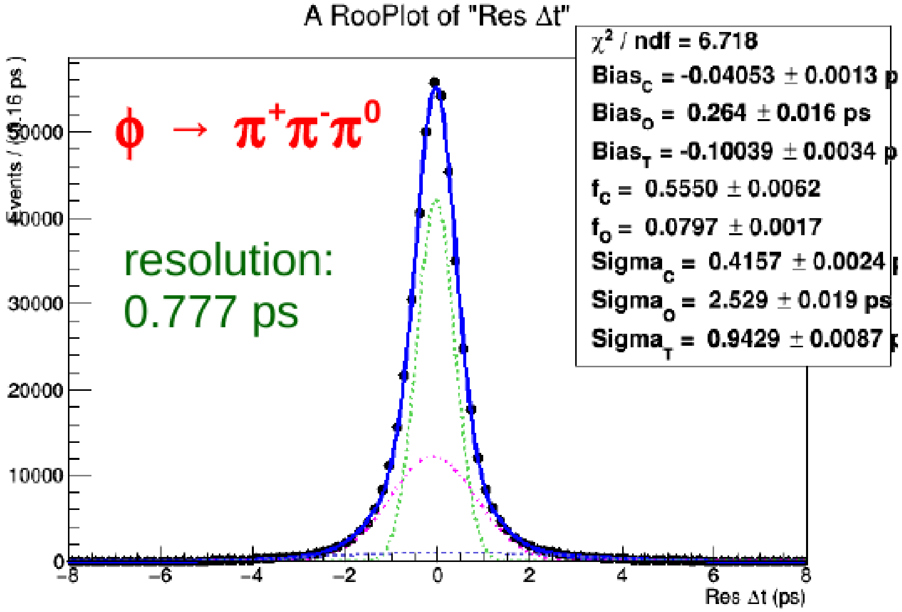
Using “iptube” + K_S^0 flight direction constraints



$\phi \to K^+K^-$

resolution:
0.752 ps

χ^2 / ndf = 9.509
Bias_C = -0.04234 ± 0.0011 p
Bias_O = 0.262 ± 0.014 ps
Bias_T = -0.09990 ± 0.0029 p
f_C = 0.5576 ± 0.0052
f_O = 0.0769 ± 0.0014
Sigma_C = 0.3992 ± 0.0020
Sigma_O = 2.517 ± 0.017 ps
Sigma_T = 0.9200 ± 0.0072



$\phi \to \pi^+\pi^-\pi^0$

resolution:
0.777 ps

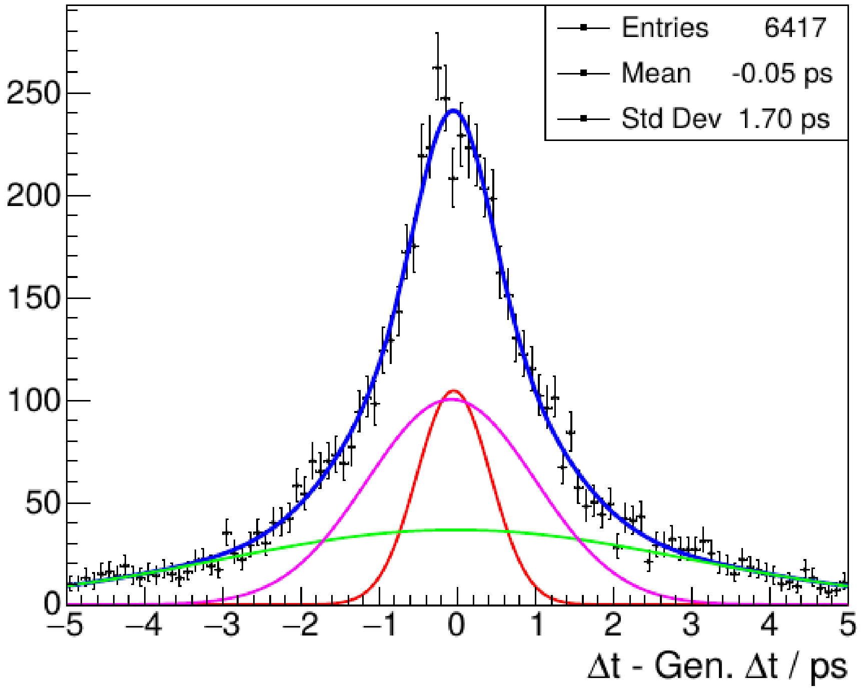
χ^2 / ndf = 6.718
Bias_C = -0.04053 ± 0.0013 p
Bias_O = 0.264 ± 0.016 ps
Bias_T = -0.10039 ± 0.0034 p
f_C = 0.5550 ± 0.0062
f_O = 0.0797 ± 0.0017
Sigma_C = 0.4157 ± 0.0024
Sigma_O = 2.529 ± 0.019 ps
Sigma_T = 0.9429 ± 0.0087

Δt resolution

$B^0{}_{\mathrm{sc}} \rightarrow \pi^0{}_{\mathrm{ss}}\ \pi^0{}_{\mathrm{sc}}$

$\hookrightarrow \gamma_{\mathrm{s}}\ \gamma_{\mathrm{c}}$

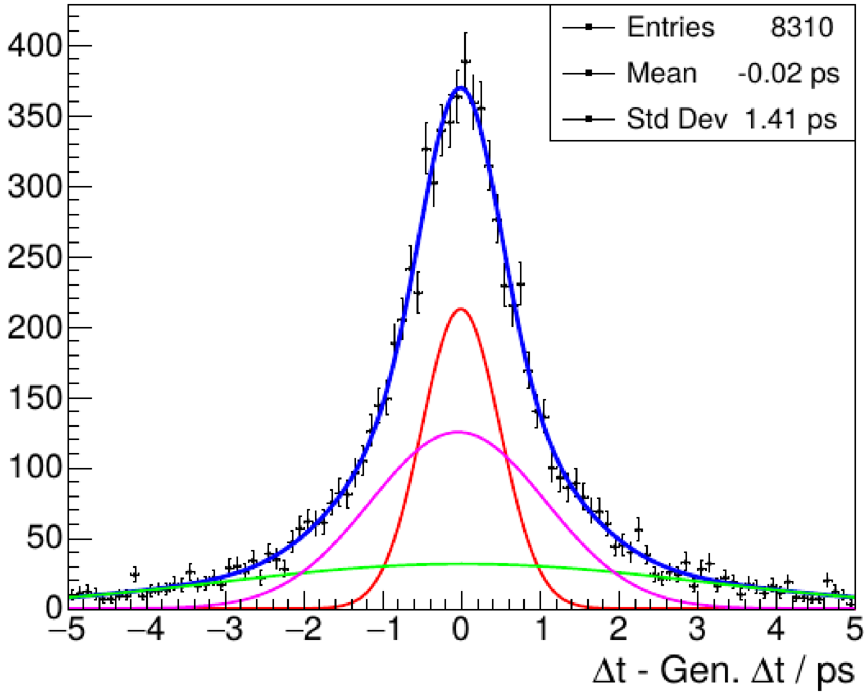
$\hookrightarrow e^+ e^-$



At least one track (e^+ or e^-) has one PXD Hit

$B^0{}_{\mathrm{dal}} \rightarrow \pi^0{}_{\mathrm{ss}}\ \pi^0{}_{\mathrm{dal}}$

$\hookrightarrow e^+\ e^-\ \gamma$

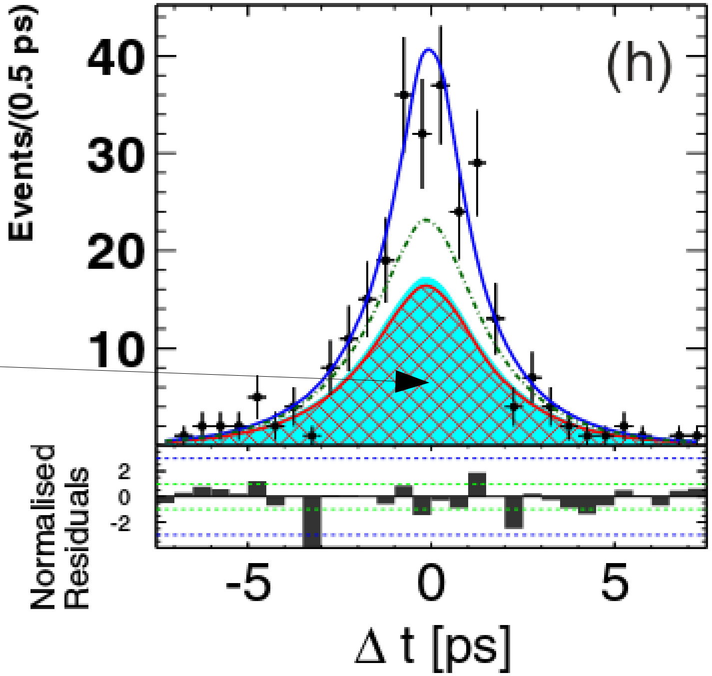


At least one track (e^+ or e^-) has one PXD Hit

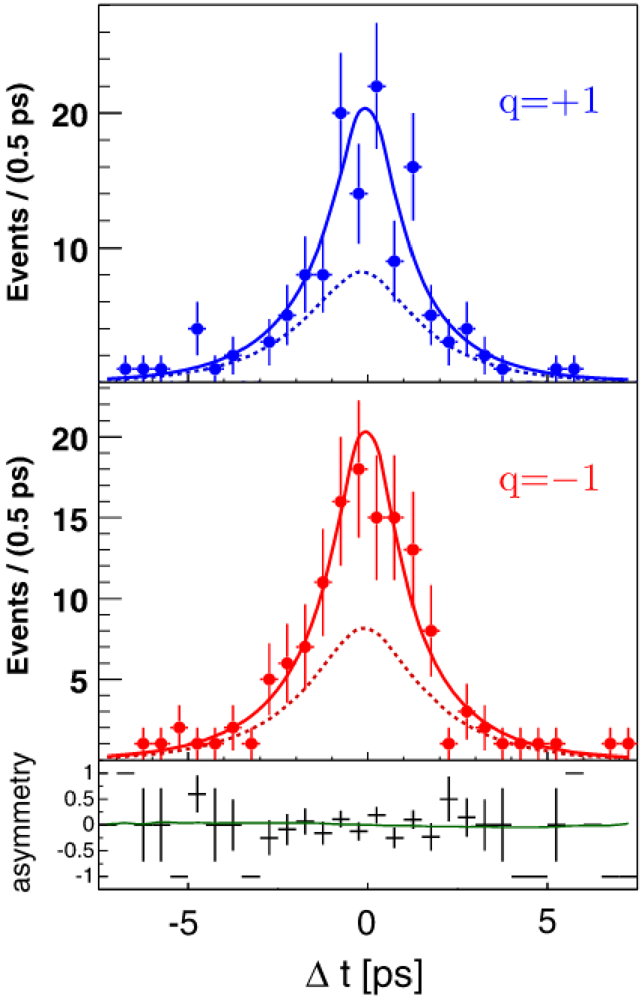
$B^0 \rightarrow \rho^+ \ \rho^-$

Phys. Rev. D **93** 032010 (2016)

Flavor integrated



Four pion final state



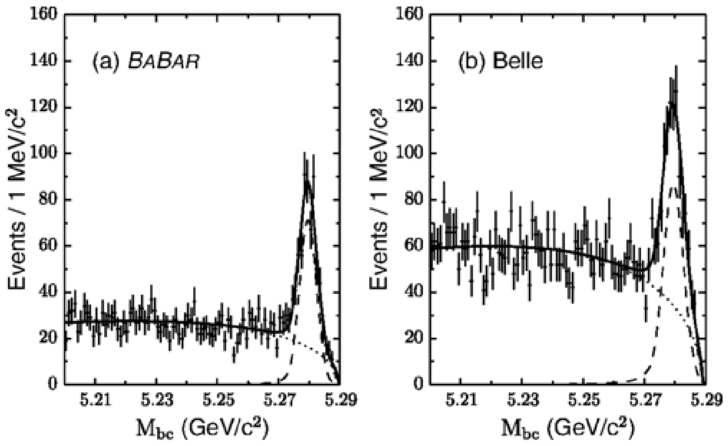
$$\begin{aligned}
\mathcal{B}(B^0 \rightarrow \rho^+\rho^-) &= (28.3 \pm 1.5\ (\mathrm{stat}) \pm 1.5\ (\mathrm{syst})) \times 10^{-6}, \\
f_L &= 0.988 \pm 0.012\ (\mathrm{stat}) \pm 0.023\ (\mathrm{syst}), \\
\mathcal{A}_{CP} &= 0.00 \pm 0.10\ (\mathrm{stat}) \pm 0.06\ (\mathrm{syst}), \\
\mathcal{S}_{CP} &= -0.13 \pm 0.15\ (\mathrm{stat}) \pm 0.05\ (\mathrm{syst}).
\end{aligned}$$

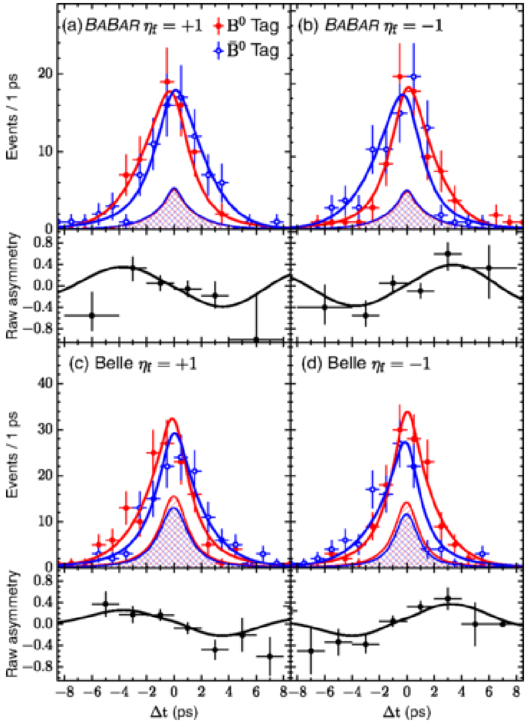
- Precision improvement with respect to the previously published result is factor 2.
- Increase of data, simultaneous extraction of observables and analysis optimization for high signal yield.

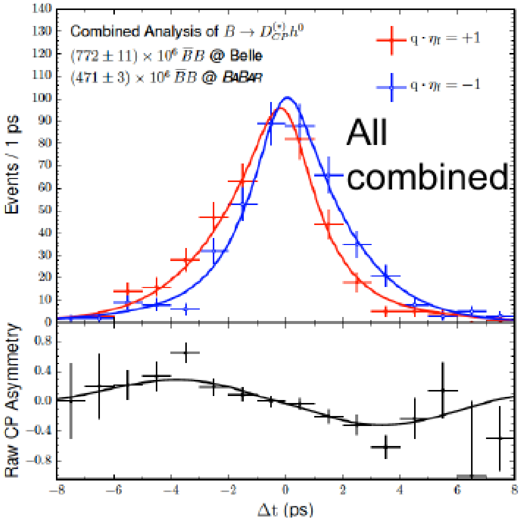
BaBar + Belle $B^0 \rightarrow D_{CP}\, h^0$

Phys. Rev. Lett. 115, 121604

- Leading order: tree
- Sub-leading order: tree, phase within the SM
- Independent form NP in loops
- Suitable to measure β
- Branching fraction is the limiting factor







$B0 \rightarrow D(*)^0\, h^0$, $h^0 = \pi^0, \eta, \omega$

$D^0 \rightarrow K^+K^-$, Ks π^0 and Ks ω

Yields =

- 508±31events(BaBar)
- 757±44events(Belle)

$$-\eta_f \mathcal{S} = +0.66 \pm 0.10\,(\text{stat.}) \pm 0.06\,(\text{syst.}),$$
$$\mathcal{C} = -0.02 \pm 0.07\,(\text{stat.}) \pm 0.03\,(\text{syst.}).$$

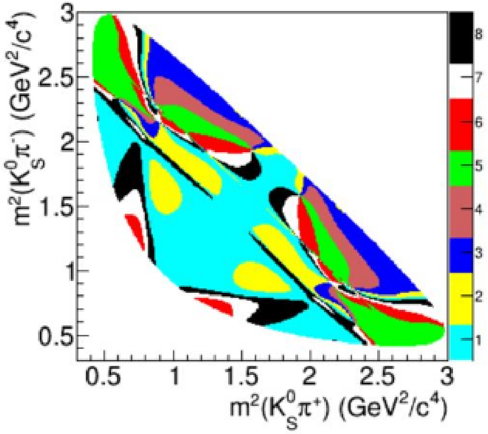
- First observation of CPV(5.4σ)
- Belle II : δ(β) ~ 0.015
- Important test for $b \rightarrow c\,\bar{c}\,s$

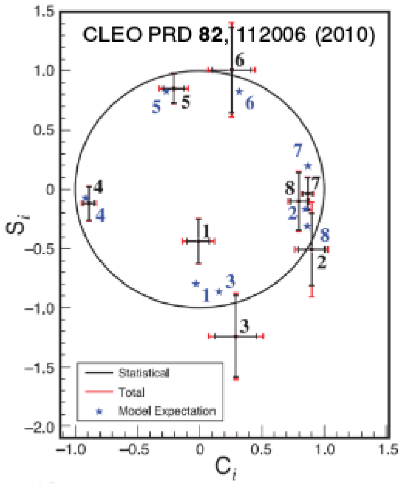
cos 2β with $B^0 \to D_{CP}\, h^0$

Phys. Rev. D **94** 052004 (2016)

D^0 multi-body decay: $D^0 \to K_S\, \pi\, \pi$ model independent

cos 2β And sin 2β can be extracted independently PLB 6241 (2005)





$$C_i = \frac{\int_{\mathcal{D}_i} |\mathcal{A}_D|\,|\overline{\mathcal{A}}_D| \cos \Delta\delta_D \, dm_+^2 dm_-^2}{\sqrt{K_i K_{-i}}}$$

$$S_i = \frac{\int_{\mathcal{D}_i} |\mathcal{A}_D|\,|\overline{\mathcal{A}}_D| \sin \Delta\delta_D \, dm_+^2 dm_-^2}{\sqrt{K_i K_{-i}}}$$

$$\mathcal{P}_i\left(\Delta t, \varphi_1\right) = h_2 e^{-\frac{|\Delta t|}{\tau_B}} \left[1 + q_B \frac{K_i - K_{-i}}{K_i + K_{-i}} \cos\left(\Delta m_B \Delta t\right) \; + 2 q_B \xi_{h^0} (-1)^L \frac{\sqrt{K_i K_{-i}}}{K_i + K_{-i}} \sin\left(\Delta m_B \Delta t\right) \left(S_i \cos 2\varphi_1 + C_i \sin 2\varphi_1\right)\right]$$

$$\begin{aligned} \sin 2\varphi_1 &= 0.43 \pm 0.27(\text{stat}) \pm 0.08(\text{syst}), \\ \cos 2\varphi_1 &= 1.06 \pm 0.33(\text{stat})^{+0.21}_{-0.15}(\text{syst}), \\ \varphi_1 &= 11.7^\circ \pm 7.8^\circ(\text{stat}) \pm 2.1^\circ(\text{syst}). \end{aligned}$$

Photon polarization

Radiative B decays, with b→s γ transitions, dominated by loop (penguin) diagrams
New physics could enter at same order (1-loop) as Standard Model

Standard Model makes definite prediction of photon helicity
(D. Atwood et al., Phys. Rev. Lea. 79, 185 (1997)):

- $B^0 \rightarrow X_s \gamma_R$
- $\overline{B}^0 \rightarrow X_s \gamma_L$

If a helicity flip occurs, the photon will also flip its helicity, producing $B^0 \rightarrow X_s \gamma_L$

- Rate ~ m_s/m_b at the leading contribution (P. Ball and R. Zwicky, Phys. Lea. B 642, 478 (2006))
- Corrections can increase this value

No common final state for B^0 and $\overline{B}^0$

- Suppression of asymmetry S due to interference between B^0 mixing and decay diagrams (TD CP asymmetry)

$$\mathcal{S}^{\mathrm{SM}} = -\sin 2\phi_1 \frac{m_s}{m_b}\left[2 + \mathcal{O}(\alpha_s)\right] + \mathcal{S}^{\mathrm{SM},s\gamma g}$$

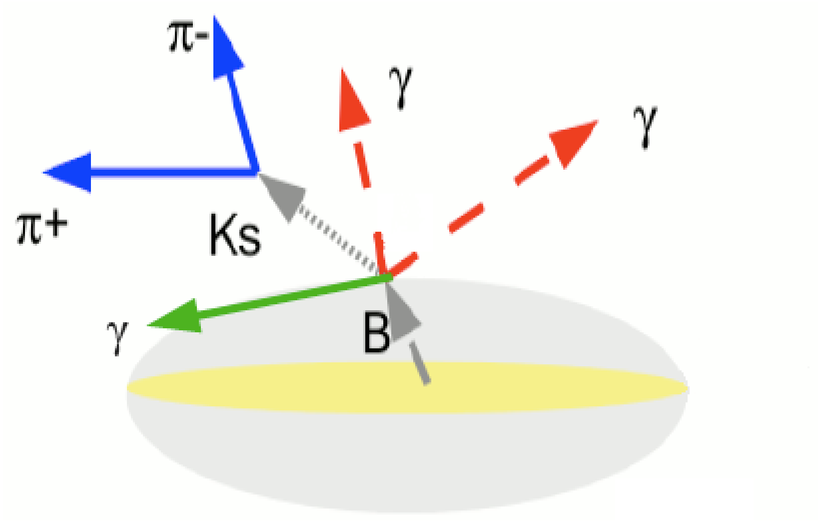
C < 0.01 (direct CP violation) (Greub at al., Nucl. Phys B 434, 39 (1995))

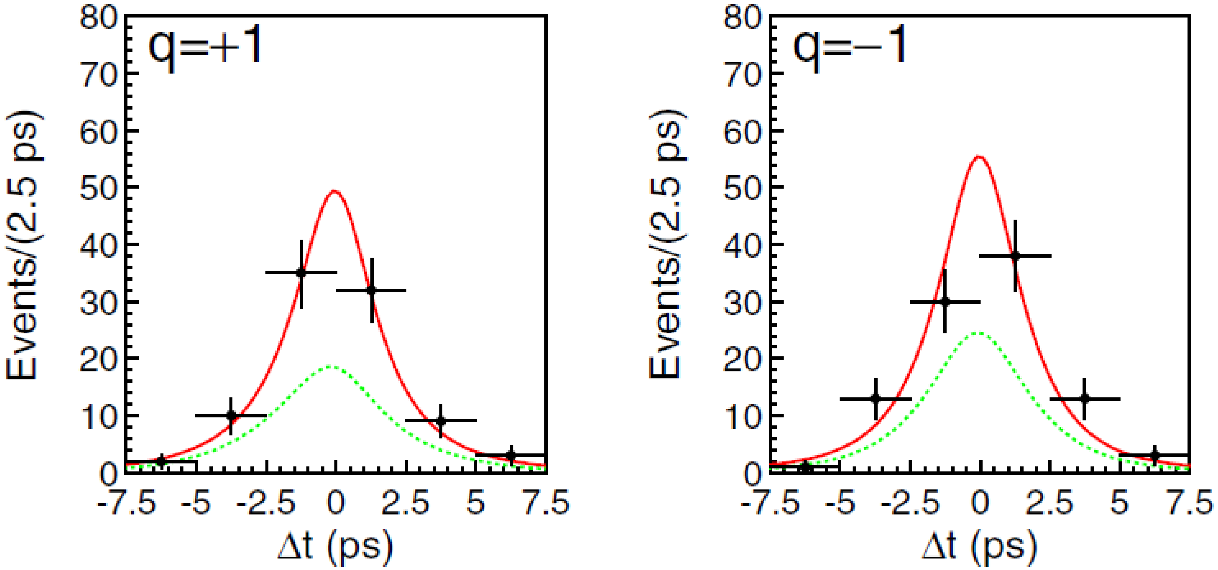
- TD CP asymmetry measurements give an indirect measurement of photon polarization

$B^0 \to K_S \pi^0 \gamma$: TD analysis

Phys. Rev. D 74, 111104(R) (2006)

B vertex reconstruction

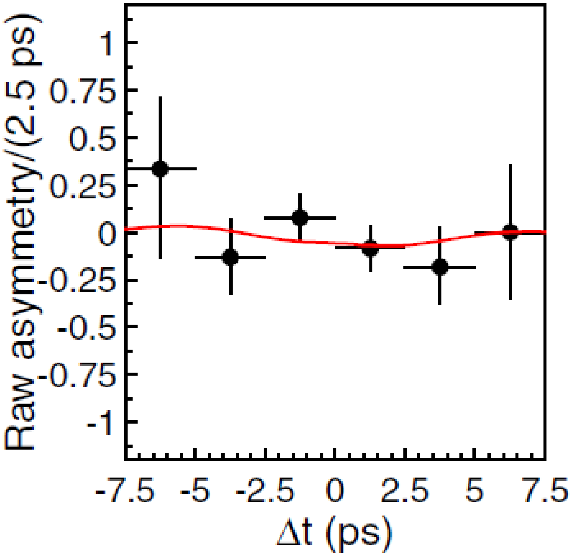




$$\mathcal{S}_{K_S^0\pi^0\gamma} = -0.10 \pm 0.31(\mathrm{stat}) \pm 0.07(\mathrm{syst}),$$

$$\mathcal{A}_{K_S^0\pi^0\gamma} = -0.20 \pm 0.20(\mathrm{stat}) \pm 0.06(\mathrm{syst}),$$

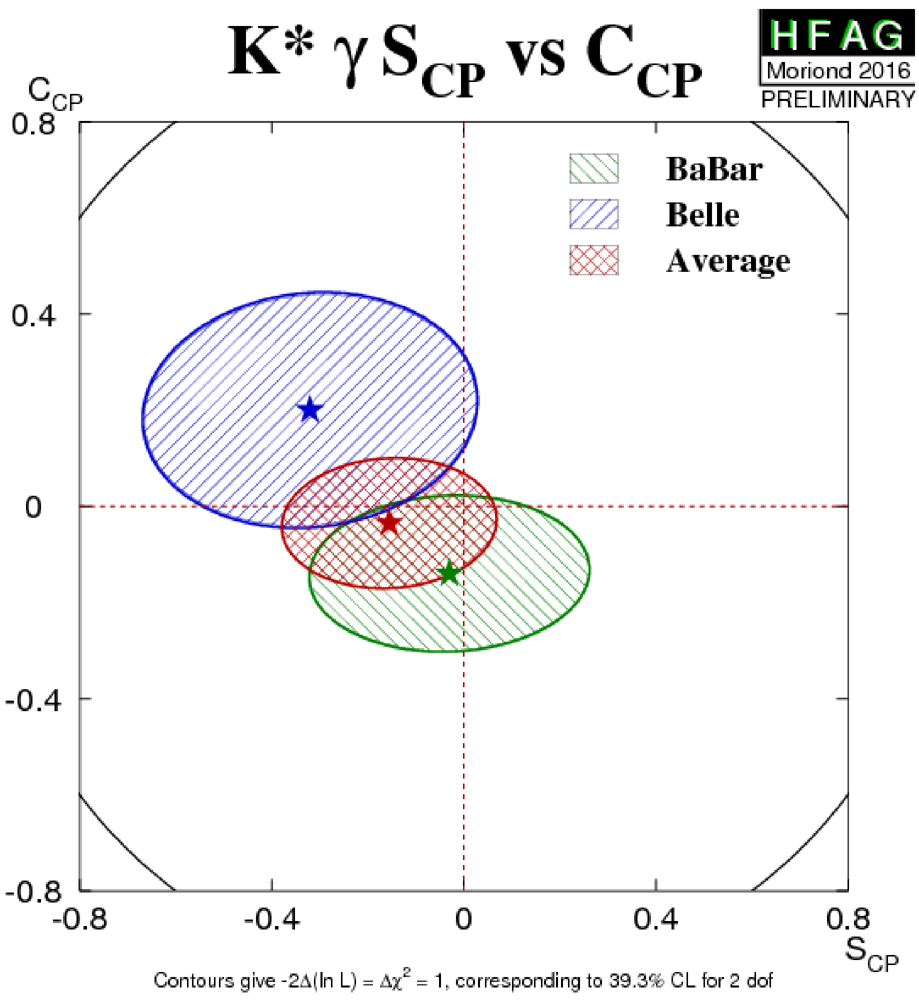
No significant CP asymmetry



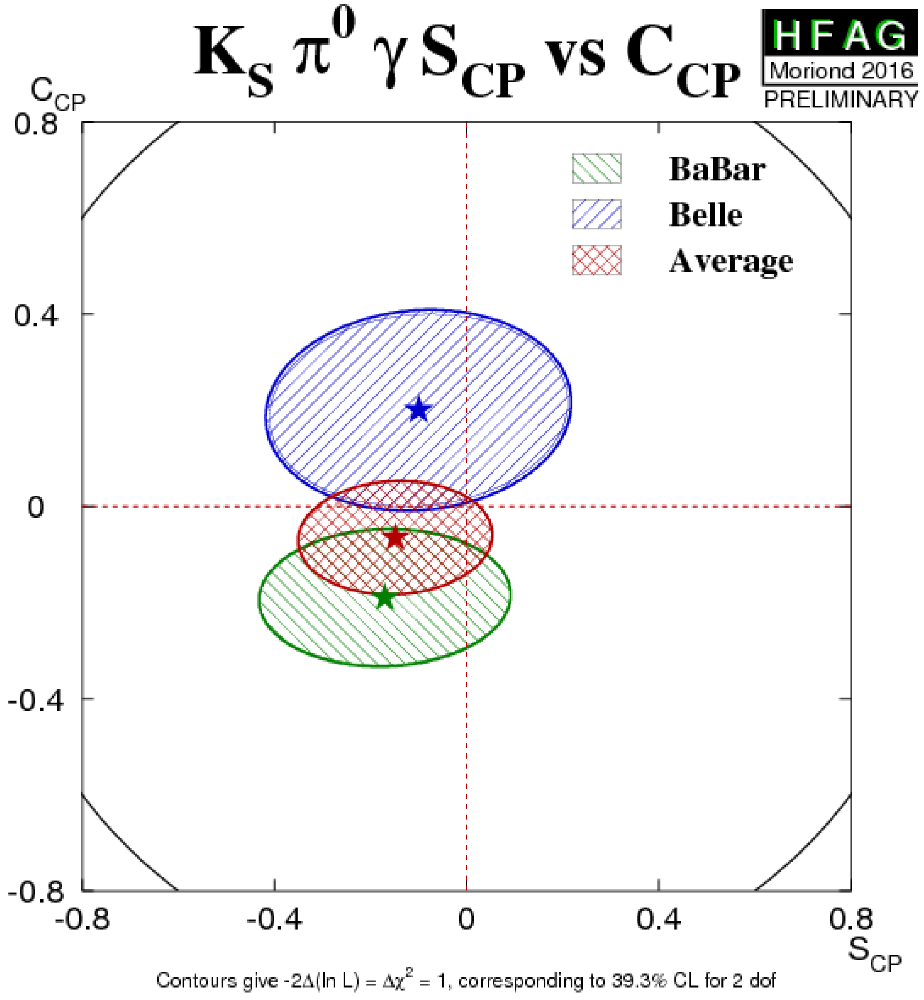
$$\mathcal{S}_{K^{*0}\gamma} = -0.32^{+0.36}_{-0.33} \pm 0.05$$

$$\mathcal{A}_{K^{*0}\gamma} = -0.20 \pm 0.24 \pm 0.05$$

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



Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 39.3% CL for 2 dof



Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 39.3% CL for 2 dof

Very important decay mode for Belle II