# Time dependent CP-Violation at the Belle II Experiment

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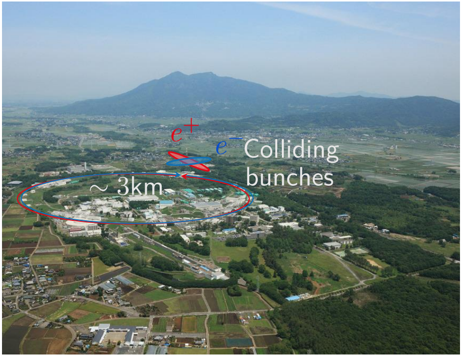
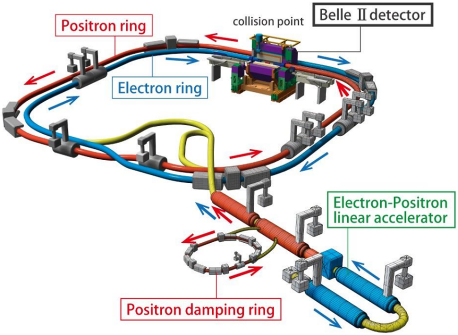
# KEKB/SuperKEKB Collider

Upgrade: KEKB $\Rightarrow$ SuperKEKB

Belle $\Rightarrow$ Belle II



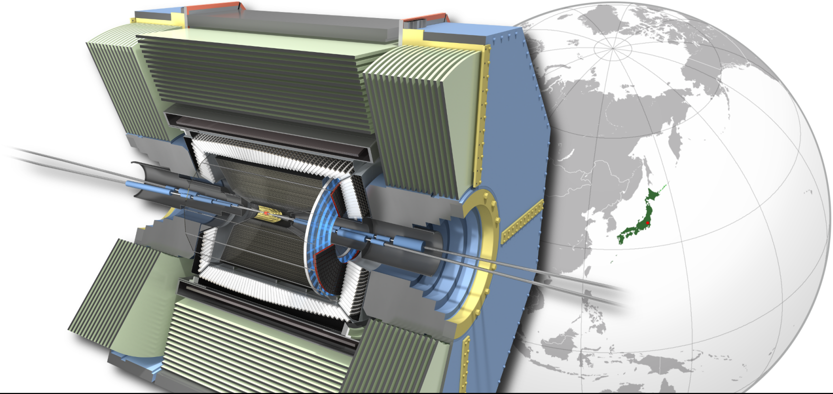




KEK = kō enerugī kasokuki kenkyū kikō

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. $\mathcal{L}$ | $2.11 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ | $8 \cdot 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ |
| $\int \mathcal{L} \cdot dt$ | $1023\,\mathrm{fb}^{-1}$ ($772 \cdot 10^6$ $B\,\overline{B}$ pairs) | $50\,\mathrm{ab}^{-1}$ |

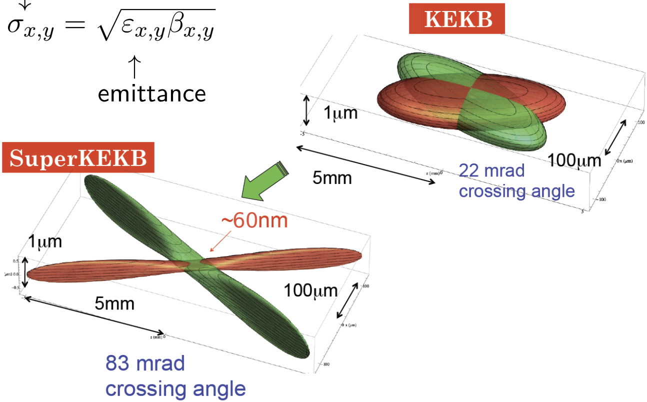
# Nano Beam Scheme

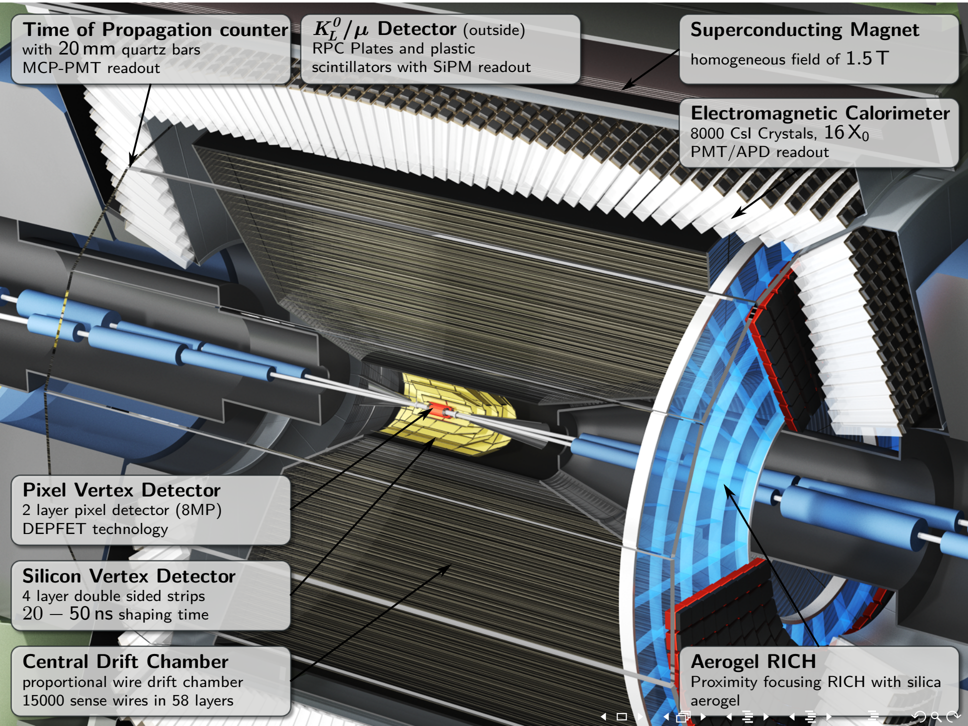
Lorentz factor ($\gamma_\pm$), beam-beam parameters ($\xi_\pm$), Geometric factors ($R_{\xi_y}$):

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

beam size ($\sigma_{x,y}$), emittance ($\varepsilon_{x,y}$):

$$\sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y}}$$





Time of Propagation counter
with 20 mm quartz bars
MCP-PMT readout
$K_L^0/\mu$ 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

# Our Contributions

PXD development:

- Sensor design, prod. and testing

⇒ Analysis of testbeam data

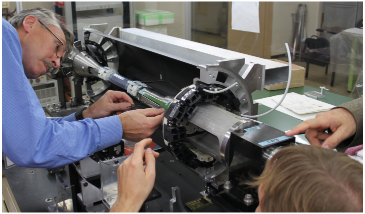
- Mechanical design, final assembly
- Cooling system (IBBelle)

Software development:

- Belle II framework development
- PXD and SVD simulation

⇒ w/o machine background

- Tracking, Vertexing and Flavor Tagging
- Neural $z$-vertex trigger



Machine commissioning:

- Design, prod. and operation of CLAWS detector

Belle CP-Analysis:

- $B^0 \to \pi^+\pi^-$, $\pi^-K^+$, $K^-K^+$ $\rho\rho$, $\omega K_S^0$

Belle II sensitivity studies:

- $B^0 \to J/\psi K_S^0$, $\pi^0\pi^0$

- 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.: $\lambda = \sin\theta_C \approx 0.2, A, \rho, \eta$

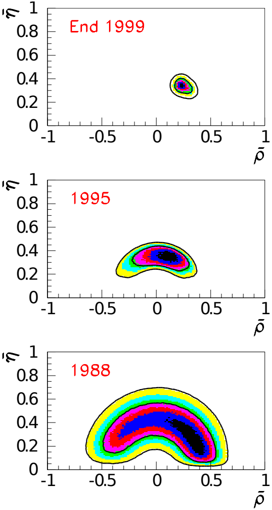
$$\mathbf{V}_{CKM} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta)] & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

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

- Unitarity: $\sum_k V^*_{ki}V_{kj} = 0 \Rightarrow V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$

$$\mathcal{O}(\lambda^3) \quad \mathcal{O}(\lambda^3) \quad \mathcal{O}(\lambda^3)$$

# CKM-Triangle

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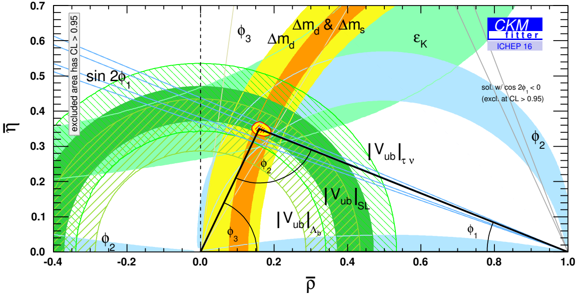
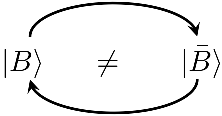
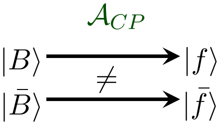
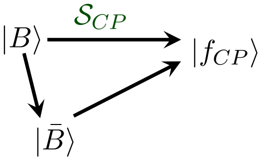
$$\bar{\rho} = \left(1 - \frac{\lambda^2}{2}\right)\rho \qquad \bar{\eta} = \left(1 - \frac{\lambda^2}{2}\right)\eta$$



# Measurement of $\phi_1$

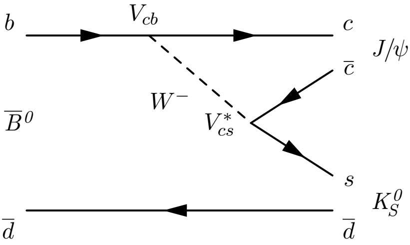


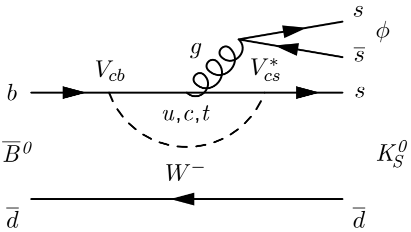




$$\mathcal{A}_{CP}{}^{J/\psi K_S^0} = 0$$
$$\mathcal{S}_{CP}{}^{J/\psi K_S^0} = \sin(2\phi_1)$$

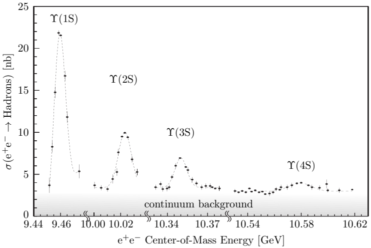
$$\mathcal{A}_{CP}{}^{\phi K_S^0} = 0$$
$$\mathcal{S}_{CP}{}^{\phi K_S^0} = \sin(2\phi_1)$$



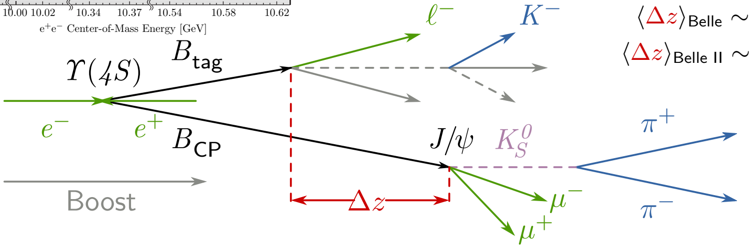
# Time-dep. CP-Analysis at B-Factories






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

$\Rightarrow$ $B$-Factory




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

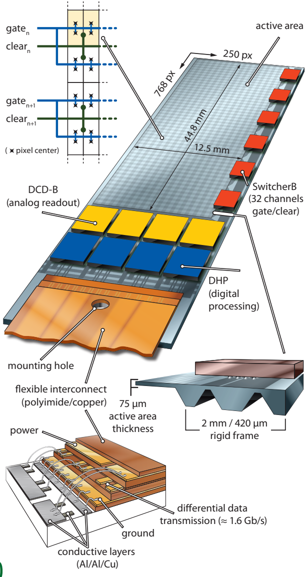
$\langle \Delta z \rangle_{\text{Belle II}} \sim 130\ \mu\text{m}$

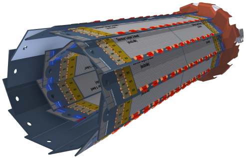
$\Rightarrow \Delta t = \frac{\Delta z}{\langle \beta\gamma \rangle c}$ since $B^0\overline{B}^0$ at rest in $\Upsilon(4S)$ frame

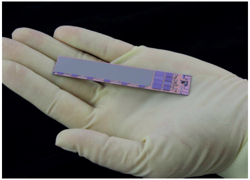
$q_{B^0,\overline{B}^0} = 1, -1$

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

# DEPFET
# Pixel Vertex Detector





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

⇒ Background ↑↑↑

- Closest to IP

⇒ Occupancy $(\sim r^{-2})$ ↑↑↑

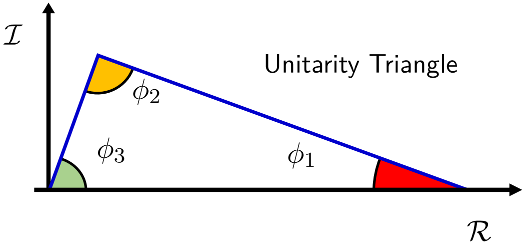
- $\langle\beta\gamma\rangle_{\text{Belle II}} < \langle\beta\gamma\rangle_{\text{Belle}}$

⇒ smaller $\Delta z$

⇒ Pixel Detector needed !

⇒ DEPFET Technology most suited
DEPleted Field Effect Transistor

# Why $B^0 \to \pi^0\pi^0$ ?




Extraction of $\phi_2$ is possible through:

- Isospin analysis of $B \to \pi\pi$ (Isospin triangle).
- Isospin analysis of $B \to \rho\rho$ (Isospin triangle).
- Dalitz plot and Isospin analysis of $B \to \rho\pi$ (Isospin pentagon). Less Isospin breaking but lower experimental precision. Very complicated! (Not considered for Belle II sensitivity)

# Extraction of $\phi_2$ angle from $B \to \pi\pi$

- Penguin and tree diagrams contribute.
- At tree level: $\mathcal{A}_{CP} = 0$
  $\mathcal{S}_{CP} = \sin(2\phi_2)$
- At penguin level: $\mathcal{A}_{CP} \neq 0$
  $\mathcal{S}_{CP} = \sqrt{1-\mathcal{A}_{CP}}\,\sin(2\phi_2^{\text{eff}})$

$\Rightarrow$ $\phi_2^{\text{eff}} = \phi_2 - \Delta\phi_2$

- Extr. $\Delta\phi_2$ through isospin analysis:

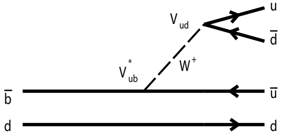
$A^{+-} = A(B \to \pi^+\pi^-)$

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

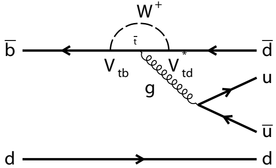
2 $\frac{1}{\sqrt{2}}\bar{A}^{+-} + \bar{A}^{00} = \bar{A}^{-0}$

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

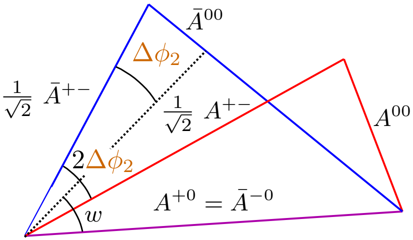
Isospin




$I = 0, 2$




$I = 0$



# Extraction of $\phi_2$ from $B \to \pi\pi$



Isospin analysis: $\mathbf{x}_{\text{theo}}$ contains 6 fit parameters including $\Delta\phi_2$ and $\phi_2$.
The parameters are fitted using $\mathbf{x}_{\text{data}}$

$$\mathbf{x}_{\text{data}} = \begin{pmatrix} \mathcal{B}(B^0 \to \pi^+\pi^-) \\ \mathcal{B}(B^0 \to \pi^0\pi^0) \\ \mathcal{B}(B^+ \to \pi^+\pi^0) \\ \mathcal{A}_{\text{CP}}(B^0 \to \pi^+\pi^-) \\ \mathcal{S}_{\text{CP}}(B^0 \to \pi^+\pi^-) \\ \mathcal{A}_{\text{CP}}(B^0 \to \pi^0\pi^0) \\ \mathcal{S}_{\text{CP}}(B^0 \to \pi^0\pi^0) \end{pmatrix} \begin{matrix} \checkmark \\ \checkmark \\ \checkmark \\ \checkmark \\ \checkmark \\ \checkmark \\ ? \end{matrix}$$

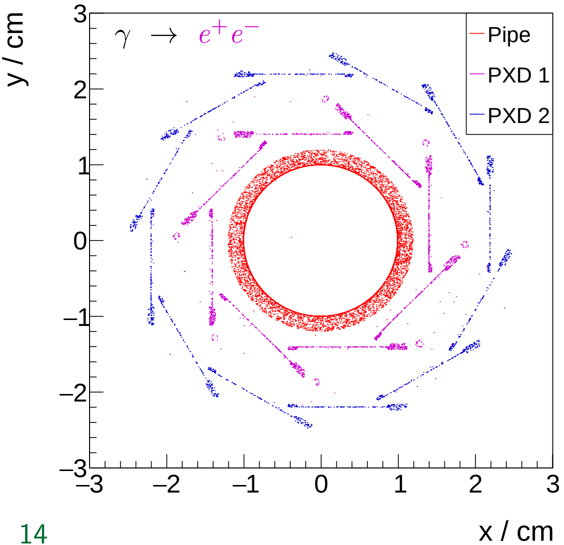
Minimizing

$$\chi^2 = -2\log\left[\frac{\exp\left(\frac{1}{2}\left(\mathbf{x}_{\text{data}} - \mathbf{x}_{\text{theo}}\right)^T \Sigma^{-1} \left(\mathbf{x}_{\text{data}} - \mathbf{x}_{\text{theo}}\right)\right)}{\sqrt{(2\pi)^n \det\Sigma}}\right]$$

$\Rightarrow$ 8 fold ambiguity in $\phi_2$ w/out $\mathcal{S}_{\text{CP}}(B^0 \to \pi^0\pi^0)$ $\Rightarrow$ Sensitivity?

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






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

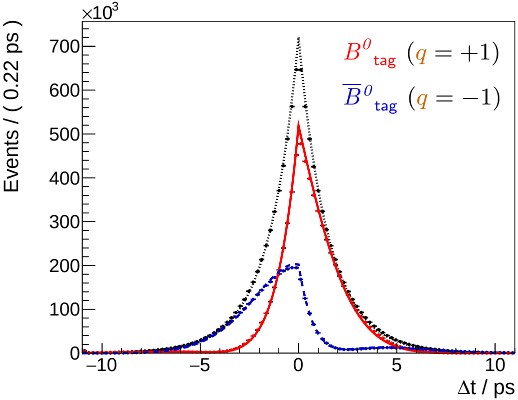
$$
\begin{aligned}
\mathcal{L}_{\text{Belle II}} &\cdot \mathcal{B}(\Upsilon(4S) \to B^0\overline{B}^0) \\
&\cdot 2 \cdot \mathcal{B}(B^0 \to \pi^0\pi^0) \sim \\
50\text{ab}^{-1} &\cdot 1.1\text{nb} \cdot 0.49 \\
&\cdot 2 \cdot 1.91 \cdot 10^{-6}
\end{aligned}
$$

$\sim 100$k events.

- $\pi^0{}_{\text{dal}}$: 2 %
- $\pi^0{}_{\text{c}}$: 3 %

# Generated Asymmetry

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




- $\mathcal{A}_{CP}{}^{\pi^0\pi^0} = 0.44$ (PDG)
- $\mathcal{S}_{CP}{}^{\pi^0\pi^0} = \sqrt{1 - \mathcal{A}_{CP}{}^2}\,\sin 2\cdot(\alpha - \Delta\alpha^*) \;\approx 0.78$

*hep-ex/0703039

# $B^0$ Reconstruction

1 $B^0{}_{4\gamma} \to \pi^0{}_{\gamma\gamma}\pi^0{}_{\gamma\gamma}$

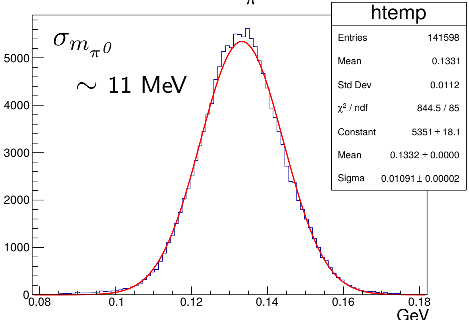
2 $B^0{}_{\mathsf{dal}} \to \pi^0{}_{\mathsf{dal}}(\to e^+e^-\gamma)\pi^0{}_{\gamma\gamma}$

3 $B^0{}_{\mathsf{c}} \to \pi^0{}_{\mathsf{c}}(\to \gamma(\to e^+e^-)\gamma)\pi^0{}_{\gamma\gamma}$

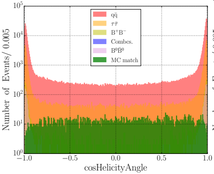
Reconstruction of $\pi^0$s:

- $\gamma$ Selection: $E_\gamma > 50$ MeV (Barrel)
  $E_\gamma > 100$ MeV (Front)
  $E_\gamma > 150$ MeV (Back)
- $e^\pm$ Selection: $d_0 < 0.25$ cm
- At least one PXD hit ($e^+$ or $e^-$)
- $m_{\pi^0} \in [105, 165]$ MeV $\sim \pm 2.5 \cdot \sigma_{m_{\pi^0}}$
- $|\cos(\theta_{\mathsf{helicity}})| < 0.95$

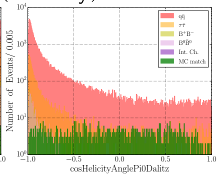
$m_{\pi^0}$




$\cos(\theta_{\mathsf{helicity}})$




$\pi^0{}_{\gamma\gamma}$




$\pi^0{}_{\mathsf{dal}}/\pi^0{}_{\gamma_c\gamma}$

# $B^0$ Vertex Reconstruction

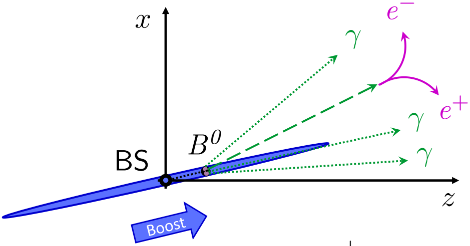
- Vertex Reconstruction with iptube constrain.
- If conversion in beam pipe and $e^\pm$ with PXD hits

$\Rightarrow$ $\pi^0{}_\mathrm{c}$ and $\pi^0{}_\mathrm{dal}$ kinematically indistinguishable.

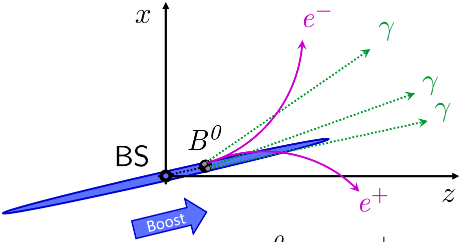
- $\tau_{\pi^0} \sim 0.9$ as $\cong$ $0.1$ nm

$\Rightarrow$ $\pi^0$ Vertex $\hat{=}$ $B^0$ Vertex.

- Check with MC truth.




$\gamma_\mathrm{c} \rightarrow e^+e^-$



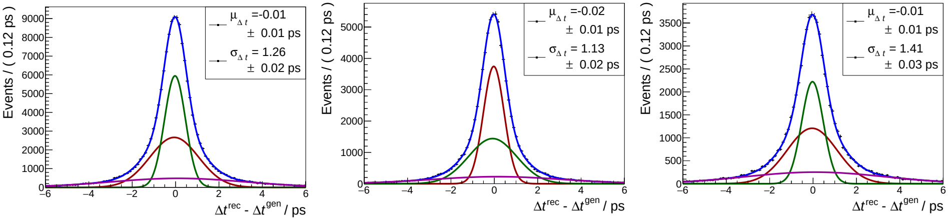

$\pi^0{}_\mathrm{dal} \rightarrow e^+e^-\gamma$

$$\Delta t = \frac{(\vec{r}_\mathrm{CP} - \vec{r}_\mathrm{tag}) \cdot \hat{\vec{\beta}}}{\langle \beta\gamma \rangle c}$$

# $B^0_{CP}$ $\Delta t$ Resolution

Reconstructed as $B^0_{\text{dal}} \rightarrow \pi^0_{\gamma\gamma}\ \pi^0_{\text{dal}}$

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

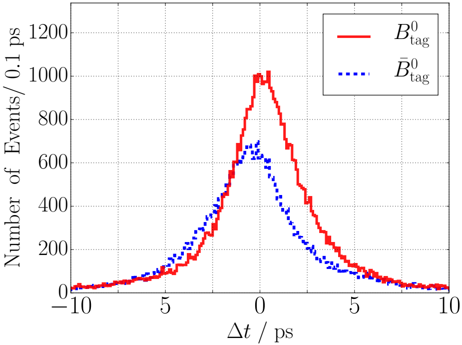


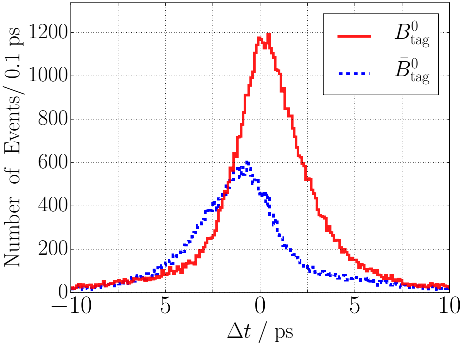

Dalitz and Conversion case

Only Dalitz (54% of Events)

Only Conversion (46% of Events)

# Flavor Tagger with $\Delta t$




$q \cdot r$

$\varepsilon_{\text{Eff}}(\text{Belle II MC5}) = 35.8\%$

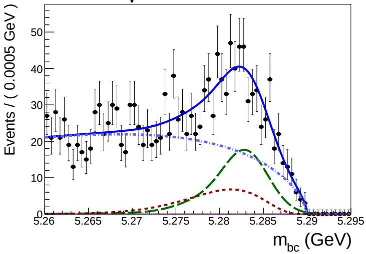
$\varepsilon_{\text{Eff}}(\text{Belle}) = 29\%$

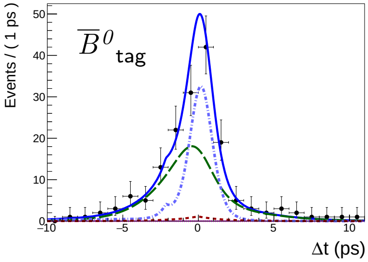
MC Flavor

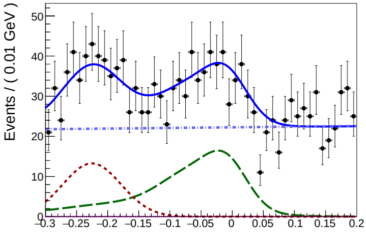
# Toy MC Projections

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

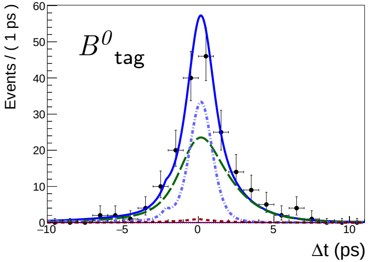
$$m_{\text{bc}} = \sqrt{E^{*\,2}_{\text{beam}} - \mathbf{p}_{B^0}}$$



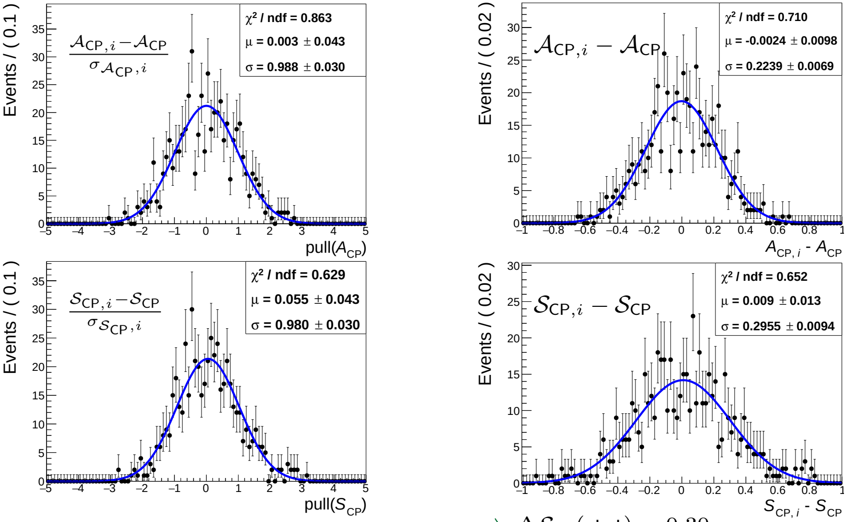




$$\Delta E = E^*_{\text{beam}} - E_{B^0}$$



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

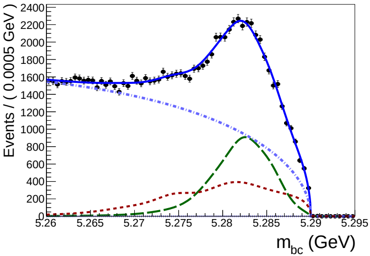
$$B^0 \to \pi^0(\to e^+e^-\gamma)\pi^0(\to \gamma\gamma)$$

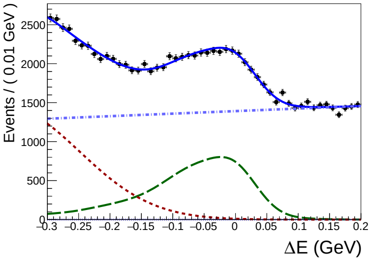


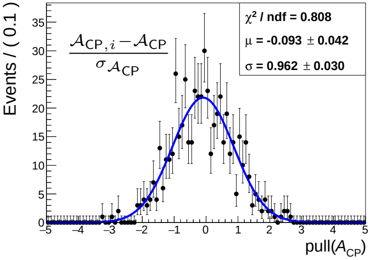

$\Rightarrow \Delta\mathcal{S}_{\mathrm{CP}}(\mathrm{stat}) = 0.30$

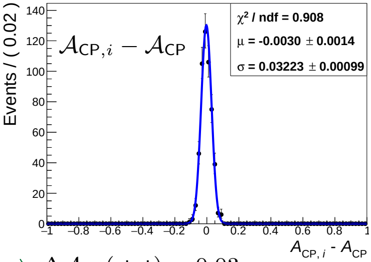
# Toy MC and $\mathcal{A}_{\mathrm{CP}}$ Pull and Uncertainty

$$B^0 \to \pi^0(\to \gamma\gamma)\pi^0(\to \gamma\gamma)$$



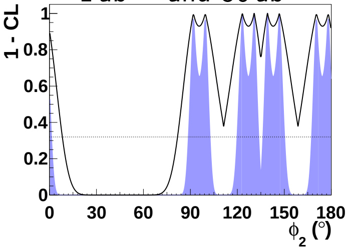




$\Rightarrow \Delta\mathcal{A}_{\mathrm{CP}}(\mathrm{stat}) = 0.03$

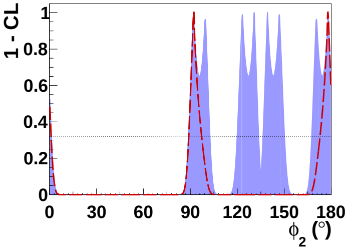
# Result of Isospin analysis

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

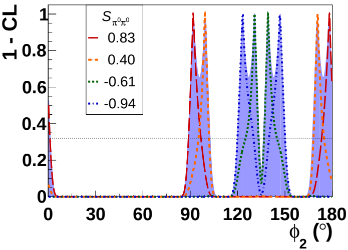



| | Value | $0.8\,\mathrm{ab}^{-1}$ | $50\,\mathrm{ab}^{-1}$ |
|---|---|---|---|
| $^{a}\mathcal{B}_{\pi^+\pi^-}$ $[10^{-6}]$ | 5.04 | $\pm 0.21 \pm 0.18$ | $\pm 0.03 \pm 0.08$ |
| $^{b}\mathcal{B}_{\pi^0\pi^0}$ $[10^{-6}]$ | 1.31 | $\pm 0.19 \pm 0.18$ | $\pm 0.04 \pm 0.04$ |
| $^{a}\mathcal{B}_{\pi^+\pi^0}$ $[10^{-6}]$ | 5.86 | $\pm 0.26 \pm 0.38$ | $\pm 0.03 \pm 0.09$ |
| $^{c}\mathcal{A}_{\pi^+\pi^-}$ | 0.33 | $\pm 0.06 \pm 0.03$ | $\pm 0.01 \pm 0.03$ |
| $^{c}\mathcal{S}_{\pi^+\pi^-}$ | -0.64 | $\pm 0.08 \pm 0.03$ | $\pm 0.01 \pm 0.01$ |
| $^{b}\mathcal{A}_{\pi^0\pi^0}$ | 0.14 | $\pm 0.36 \pm 0.12$ | $\pm 0.05 \pm 0.01$ |
| $\mathcal{S}_{\pi^0\pi^0}$ | 0.83 | | $\pm 0.30 \pm 0.03$ |

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




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




[a] PRD 87 031103
[b] Belle Draft
[c] PRD 88 092003

# Extraction of $\phi_2$ from $B \to \rho\rho$

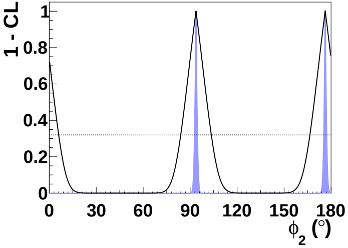


Isospin analysis for dominant $\rho$ polarization $\rho_\mathsf{L}$ (CP even). $\Rightarrow$

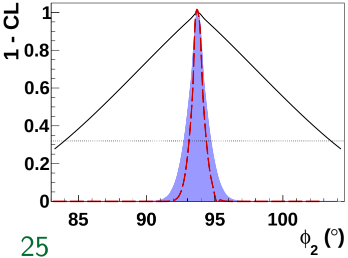
$$\mathbf{x}_\mathsf{data} = \begin{pmatrix} f_{\mathsf{L},\ \rho^+\rho^-} \cdot \mathcal{B}(B^0 \to \rho^+\rho^-) \\ f_{\mathsf{L},\ \rho^0\rho^0} \cdot \mathcal{B}(B^0 \to \rho^0\rho^0) \\ f_{\mathsf{L},\ \rho^+\rho^0} \cdot \mathcal{B}(B^+ \to \rho^+\rho^0) \\ \mathcal{A}_\mathsf{CP}(B^0 \to \rho^+\rho^-) \\ \mathcal{S}_\mathsf{CP}(B^0 \to \rho^+\rho^-) \\ \mathcal{A}_\mathsf{CP}(B^0 \to \rho^0\rho^0) \\ \mathcal{S}_\mathsf{CP}(B^0 \to \rho^0\rho^0) \end{pmatrix} \begin{matrix} \checkmark \\ \checkmark \\ \checkmark \\ \checkmark \\ \checkmark \\ \checkmark \\ \checkmark \end{matrix}$$

# Result of Isospin analysis

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




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

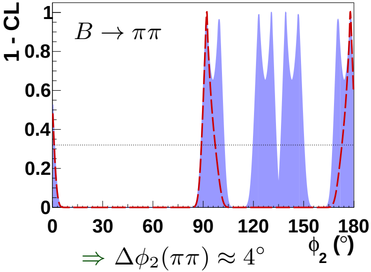



| Belle | Value | $0.8$ ab$^{-1}$ | $50$ ab$^{-1}$ |
|---|---|---|---|
| $^a f_{\mathrm{L},\ \rho^+\rho^-}$ | $0.988$ | $\pm0.012\pm0.023$ | $\pm0.002\pm0.003$ |
| $^b f_{\mathrm{L},\ \rho^0\rho^0}$ | $0.21$ | $\pm0.20\pm0.15$ | $\pm0.03\pm0.02$ |
| $^a\mathcal{B}_{\rho^+\rho^-}$ [$10^{-6}$] | $28.3$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

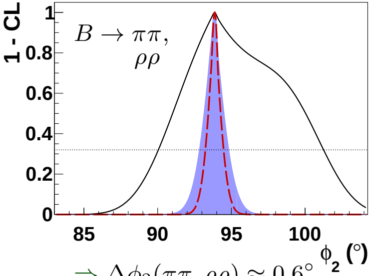
For compatibility $S_{\rho^0\rho^0} = -0.14$

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

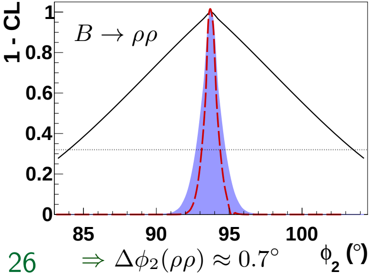
# Combined Isospin Analysis




$\Rightarrow \Delta\phi_2(\pi\pi) \approx 4^\circ$




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




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

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

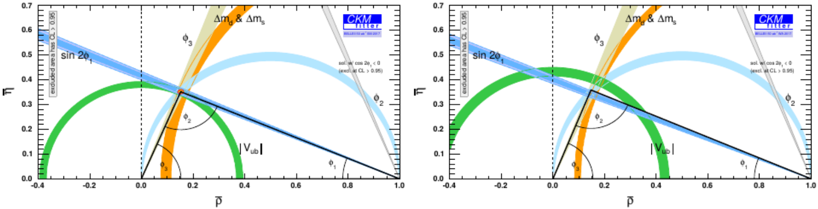
For compatibility $S_{\pi^0\pi^0} = 0.75$

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

# Summary and Outlook

- Machine commissioning started! Begin of data taking planned for 2018! Strong contribution from our institute!

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




$\Rightarrow$ Expected sensitivities:

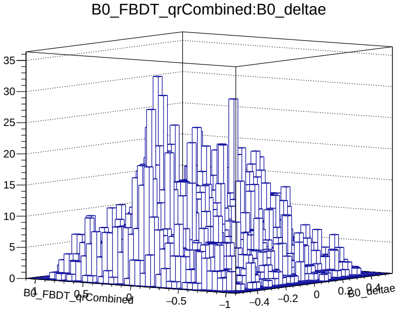
$\Delta\phi_2(\pi\pi) \approx 4°$, $\Delta\phi_2(\rho\rho) \approx 0.7°$ and $\Delta\phi_2(\pi\pi, \rho\rho) \approx 0.6°$.

# Tagging Variables

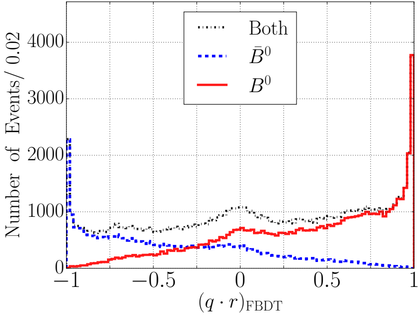
| Categories | Discriminating input variables |
|---|---|
| Electron | $p^*,\ p^*_{\mathrm{t}},\ p,\ p_{\mathrm{t}},\ \mathcal{L}_e,\ M_{\mathrm{recoil}},\ p^*_{\mathrm{miss}},\ \cos\theta^*_{\mathrm{miss}},\ E^W_{90},\ \chi^2$ |
| Int. Electron | $p^*,\ p^*_{\mathrm{t}},\ p,\ p_{\mathrm{t}},\ \mathcal{L}_e,\ M_{\mathrm{recoil}},\ p^*_{\mathrm{miss}},\ \cos\theta^*_{\mathrm{miss}},\ E^W_{90},\ \chi^2$ |
| Muon | $p^*,\ p^*_{\mathrm{t}},\ p,\ p_{\mathrm{t}},\ \mathcal{L}_\mu,\ M_{\mathrm{recoil}},\ p^*_{\mathrm{miss}},\ \cos\theta^*_{\mathrm{miss}},\ E^W_{90},\ \chi^2$ |
| Int. Muon | $p^*,\ p^*_{\mathrm{t}},\ p,\ p_{\mathrm{t}},\ \mathcal{L}_\mu,\ M_{\mathrm{recoil}},\ p^*_{\mathrm{miss}},\ \cos\theta^*_{\mathrm{miss}},\ E^W_{90},\ \chi^2$ |
| KinLepton | $p^*,\ p^*_{\mathrm{t}},\ p,\ p_{\mathrm{t}},\ \mathcal{L}_\mu,\ \mathcal{L}_e,\ M_{\mathrm{recoil}},\ p^*_{\mathrm{miss}},\ \cos\theta^*_{\mathrm{miss}},\ E^W_{90},\ \chi^2$ |
| Int. KinLepton | $p^*,\ p^*_{\mathrm{t}},\ p,\ p_{\mathrm{t}},\ \mathcal{L}_\mu,\ \mathcal{L}_e,\ M_{\mathrm{recoil}},\ p^*_{\mathrm{miss}},\ \cos\theta^*_{\mathrm{miss}},\ E^W_{90},\ \chi^2$ |
| Kaon | $p^*,\ p^*_{\mathrm{t}},\ p_{\mathrm{t}},\ \mathcal{L}_K,\ \cos\theta,\ n_{K^0_S},\ \sum p_{\mathrm{t}},\ \lvert\mathbf{x}\rvert,\ \chi^2$ |
| KaonPion | $y_{\mathrm{Kaon}},\ y_{\mathrm{SlowPion}},\ \cos\theta_{K,\pi},\ q_K\cdot q_\pi,\ \mathcal{L}_K$ |
| SlowPion | $p^*,\ p^*_{\mathrm{t}},\ p,\ p_{\mathrm{t}},\ \mathcal{L}_\pi,\ \mathcal{L}_K,\ \mathcal{L}_e,\ \cos\theta,\ \cos\theta_{\mathrm{Thrust}},\ \chi^2$ |
| MaximumP* | $p^*,\ p^*_{\mathrm{t}},\ p,\ p_{\mathrm{t}},\ \cos\theta_{\mathrm{Thrust}},\ d_0$ |
| FSC | $p^*_{\mathrm{Slow}},\ p^*_{\mathrm{Fast}},\ \mathcal{L}_K,\ \cos\theta_{\mathrm{ThrustSlow}},\ \cos\theta_{\mathrm{ThrustFast}},\ \cos\theta_{\mathrm{SlowFast}},\ q_{\mathrm{Slow}}\cdot q_{\mathrm{Fast}}$ |
| FastPion | $p^*,\ p^*_{\mathrm{t}},\ p,\ p_{\mathrm{t}},\ \mathcal{L}_\pi,\ \mathcal{L}_K,\ \mathcal{L}_e,\ \cos\theta,\ \cos\theta_{\mathrm{Thrust}},\ \chi^2$ |
| Lambda | $p^*_\Lambda,\ p_\Lambda,\ p^*_{\mathrm{proton}},\ p_{\mathrm{proton}},\ q_\Lambda,\ M_\Lambda,\ n_{K^0_S},\ \cos\theta_{\mathbf{x}_\Lambda,\mathbf{p}_\Lambda},\ \lvert\mathbf{x}_\Lambda\rvert,\ \sigma^{zz}_\Lambda,\ \chi^2_\Lambda$ |

Optimized for CPU: 76 Calculations instead of 242

# Flavor Tagger Output

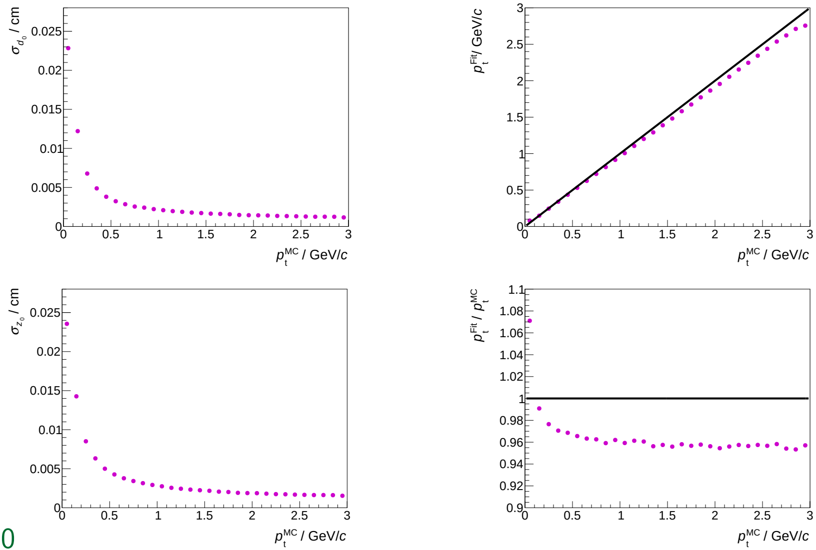



Distribution of Continuum




Distribution on signal $B^0 \to \pi^0\pi^0{}_{\mathsf{dal}}$

- $e^+$, $e^-$

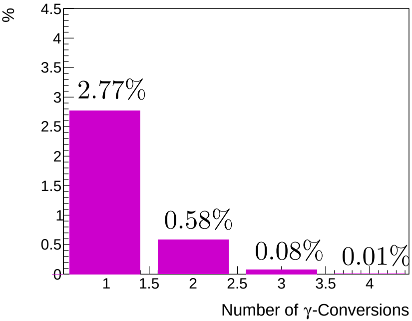


σ_d0 / cm
p_t^MC / GeV/c
p_t^Fit / GeV/c
p_t^MC / GeV/c
σ_z0 / cm
p_t^MC / GeV/c
p_t^Fit / p_t^MC
p_t^MC / GeV/c

# Events with $\gamma$-Conversions

a) If there is an event with $\gamma$-conversions

$\Rightarrow$ How Many?




b) How many Events have at least one $\gamma$-conversion?

| Vertex in | Events % |
|---|---|
| Beam Pipe | 2.00 % |
| 1st. PXD Layer | 0.60 % |
| 2nd. PXD Layer | 0.50 % |
| **Total** inside PXD | 3.10 % |

c) ... and at least one $\gamma$-conversion or one $\pi^0 \to e^+e^-\gamma$ decay?

| | |
|---|---|
| $\pi^0 \to e^+e^-\gamma$ | 2.00 % |
| **Total** $\pi^0 \cup \gamma$ | 5.05 % |

Requirement: All converted $\gamma$ in accept. and not converted in ECL

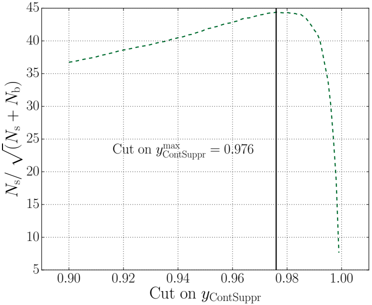
# Final Selection

- $m_{\text{bc}} = \sqrt{{E^*_{\text{beam}}}^2 - \mathbf{p}_{B^0}} > 5.26\ \text{GeV}/c^2$
- $\Delta E = E^*_{\text{beam}} - E_{B^0} \in [-0.3, 0.2]\ \text{GeV}$
- Continuum Suppr. $y_{\text{FBDT}} > 0.976$

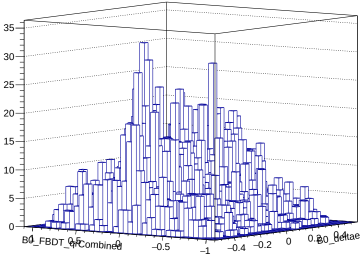
$\Rightarrow$ Maximizes $\frac{n_{\text{sig}}}{\sqrt{n_{\text{sig}} + n_{\text{bkg}}}}$

- Flavor Dilution $r > 0.1$
- Multiplicity $\lesssim 1.01$

$\Rightarrow$ Ranking according to Dilution




B0_FBDT_qrCombined:B0_deltae



# Two Options

Option 1: ${B^0}_{\mathrm{dal}}$ candidates have priority.

| Candidate | $n_{\mathrm{sig}}$ | $\frac{n_{\mathrm{dal}}}{n_{\mathrm{sig}}}$ [%] | $\frac{n_{\mathrm{c}}}{n_{\mathrm{sig}}}$ [%] | $\frac{n_{\mathrm{combin}}}{n_{\mathrm{sig}}+n_{\mathrm{comb}}}$ [%] | FoM [%] |
|---|---|---|---|---|---|
| ${B^0}_{\mathrm{dal}}$ | 274 | 54 | 46 | 1.1 | 7.0 |
| ${B^0}_{\mathrm{c}}$ | 46 | 28 | 72 | 3.3 | 3.6 |

Option 2: ${B^0}_{\mathrm{c}}$ candidates have priority.

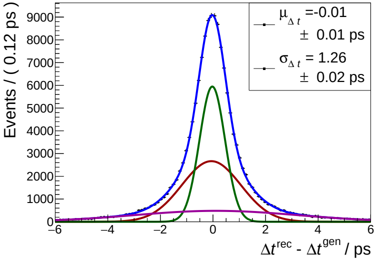
| Candidate | $n_{\mathrm{sig}}$ | $\frac{n_{\mathrm{dal}}}{n_{\mathrm{sig}}}$ [%] | $\frac{n_{\mathrm{c}}}{n_{\mathrm{sig}}}$ [%] | $\frac{n_{\mathrm{combin}}}{n_{\mathrm{sig}}+n_{\mathrm{comb}}}$ [%] | FoM [%] |
|---|---|---|---|---|---|
| ${B^0}_{\mathrm{dal}}$ | 90 | 47 | 53 | 1.3 | 3.6 |
| ${B^0}_{\mathrm{c}}$ | 160 | 50 | 50 | 1.5 | 6.6 |

$$\mathrm{FoM} = \frac{n_{\mathrm{sig}}}{\sqrt{n_{\mathrm{sig}} + n_{\mathrm{combin}} + n_{\mathrm{cont}} + n_{B\overline{B}}}}$$

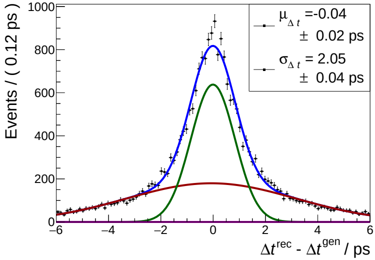
# $\Delta t$ Resolution

## Option1:

$B^0{}_{dal}$ Candidates

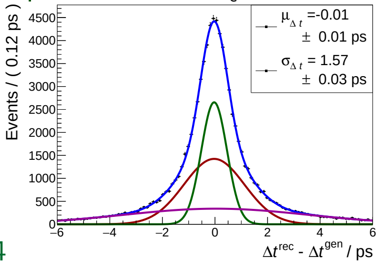



Discarded $B^0{}_{c}$ Candidates

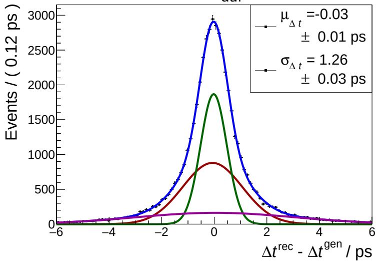



## Option2:

$B^0{}_{c}$ Candidates

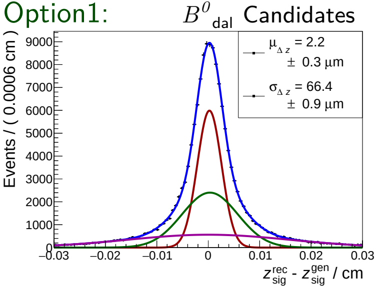


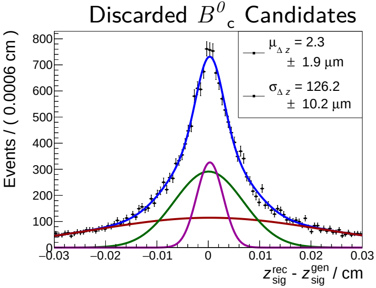

Discarded $B^0{}_{dal}$ Candidates



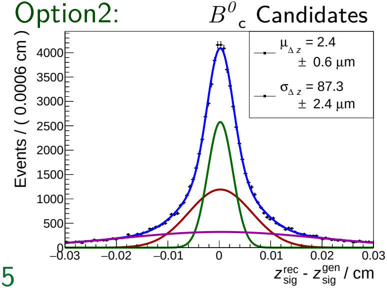
# $z_{sig}$ Resolution

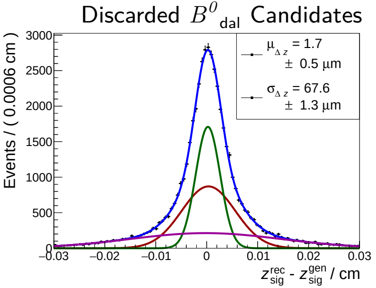
Option1:




Option2:

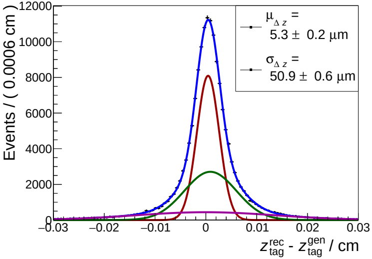


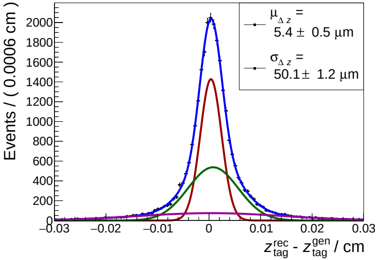
# $z_{tag}$ Resolution

## Option1:

$B^0{}_{dal}$ Candidates

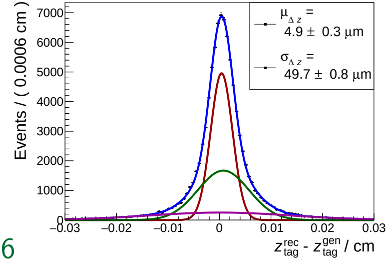



Discarded $B^0{}_c$ Candidates

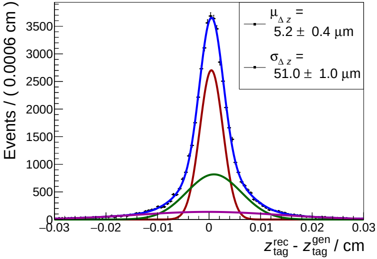



## Option2:

$B^0{}_c$ Candidates



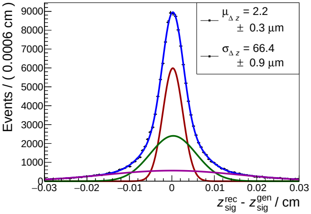

Discarded $B^0{}_{dal}$ Candidates



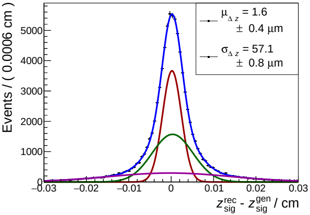
# $B^0{}_{\text{CP}}$ Vertex Resolution

Reconstructed as $B^0{}_{\text{dal}} \rightarrow \pi^0{}_{\gamma\gamma}\ \pi^0{}_{\text{dal}}$

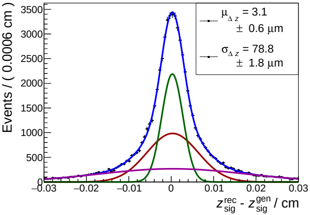
$\hookrightarrow e^+\ e^-\ \gamma$




Dalitz and Conversion case




Only Dalitz (54% of Events)

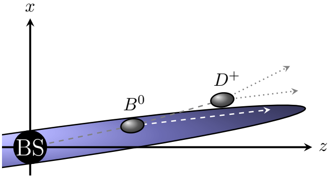



Only Conversion (46% of Events)

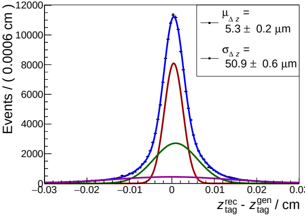
**Tag Side:** Tracks which remain from reco. side. $B_{\text{CP}}$

**Algorithm:** RAVE's Adaptive Vertex Fit

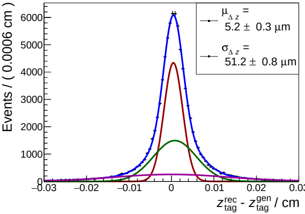
- Track weighting according to proximity to other tracks and spatial constraint.
- Various instances.



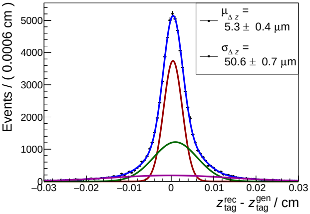

- Class. acc. mother: $B$✓, $D$✓, $K_S^0$✗




Dalitz and Conversion case



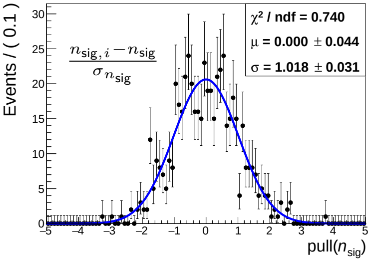

Only Dalitz (54% of Events)

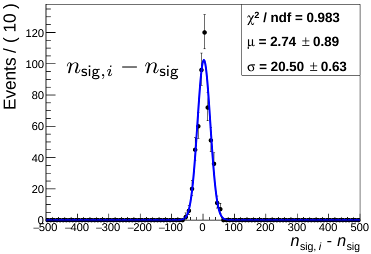



Only Conversion (46% of Events)

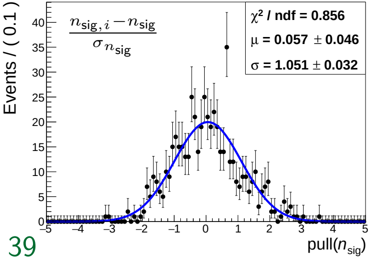
# Pull and Uncertainties on Signal Yields

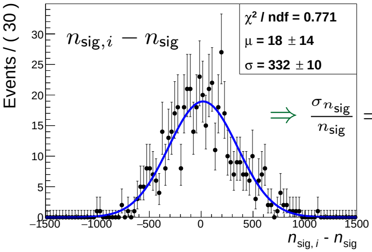
$$B^0 \to \pi^0(\to e^+e^-\gamma)\pi^0(\to \gamma\gamma)$$




$$B^0 \to \pi^0(\to \gamma\gamma)\pi^0(\to \gamma\gamma)$$




$$\Rightarrow \frac{\sigma_{n_{\text{sig}}}}{n_{\text{sig}}} = 2.2\%$$

# Systematic Uncertainties

$\mathcal{A}_{\text{CP}}(B^0 \to \pi^0\pi^0)$

| Source | Belle[a] | $50\,\frac{1}{\text{ab}}$ [%] |
|---|---|---|
| Flavor Tagging[b] | 0.034 | 0.0034 |
| $B\overline{B}$ Bkg. Param. | 0.06 | 0.008 |
| Cont. Bkg. Param | 0.08 | 0.010 |
| Fit Bias | 0.02 | 0.003 |
| **Total** | 0.12 | 0.01 |

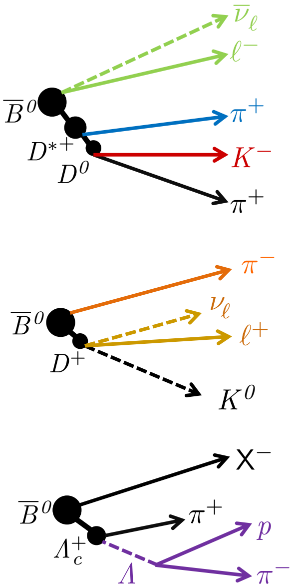
$\mathcal{B}(B^0 \to \pi^0\pi^0)$

| Source | Belle[a] [%] | $50\,\frac{1}{\text{ab}}$ [%] |
|---|---|---|
| Signal Sel. | 1.5 | 0.19 |
| Cont. Bkg. Param | 11.0 | 1.39 |
| Off-res Cont. Bkg. | 3.0 | 0.38 |
| $\Delta E$ and $m_{bc}$ | 4.0 | 0.51 |
| $\pi^0$ det. eff. | 4.4 | 0.56 |
| $B\overline{B}$ Bkg. Param. | 5 | 0.60 |
| Luminosity | 1.4 | 1.40 |
| Rec. Conv. Ph. | 1.0 | 0 |
| Timing Cut | 0.5 | 0.06 |
| Fit Bias | 1.0 | 0.13 |
| **Total** | 14.0 | 2.25 |

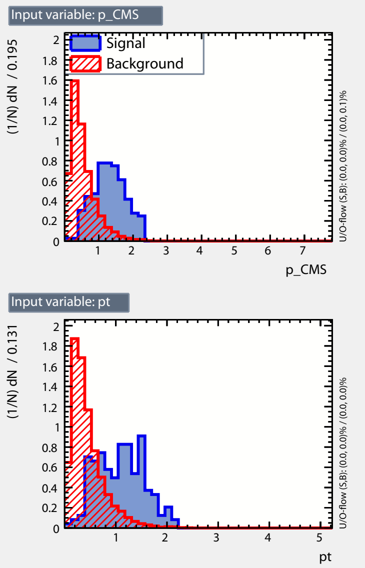
[a] Belle Draft M. Sevior
[b] BaBar PRD 87 052009

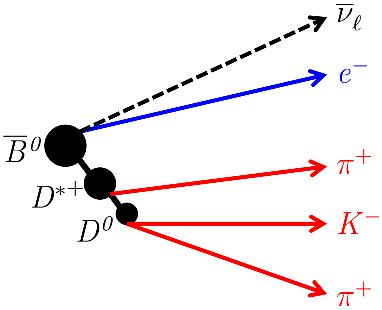
# Flavor Tagger Categories

| Categories | Targets |
|---|---|
| Electron | $e^-$ |
| Intermediate Electron | $e^+$ |
| Muon | $\mu^-$ |
| Intermediate Muon | $\mu^+$ |
| KinLepton | $e^-$ |
| Intermediate KinLepton | $\ell^+$ |
| Kaon | $K^-$ |
| KaonPion | $K^-$, $\pi^+$ |
| SlowPion | $\pi^+$ |
| FastPion | $\pi^-$ |
| MaximumP | $\ell^-$, $\pi^-$ |
| FSC | $\ell^-$, $\pi^+$ |
| Lambda | $\Lambda$ |
| Total= 13 | |

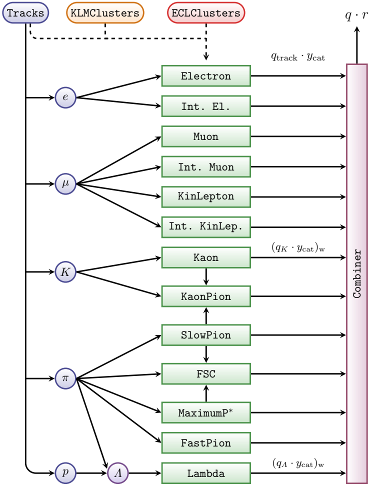


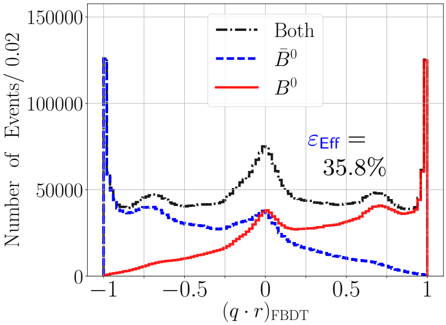
# Tagging Variables



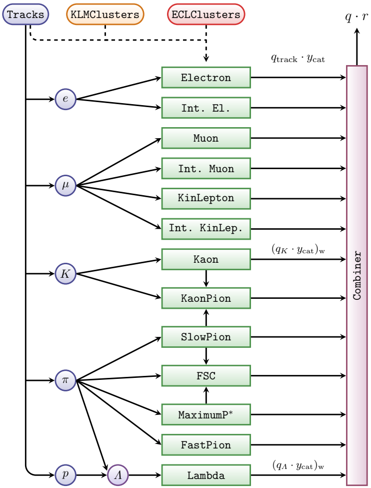



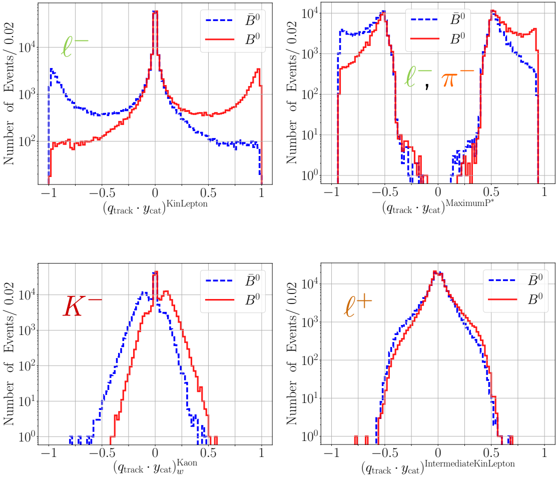
# Output


Tracks
KLMClusters
ECLClusters
$q \cdot r$
$q_{\text{track}} \cdot y_{\text{cat}}$
Electron
Int. El.
Muon
Int. Muon
KinLepton
Int. KinLep.
$(q_K \cdot y_{\text{cat}})_{\text{w}}$
Kaon
KaonPion
SlowPion
FSC
MaximumP*
FastPion
$(q_\Lambda \cdot y_{\text{cat}})_{\text{w}}$
Lambda
Combiner
$e$
$\mu$
$K$
$\pi$
$p$
$\Lambda$


Both
$\bar{B}^0$
$B^0$
$\varepsilon_{\text{Eff}} =$
35.8%
Number of Events/ 0.02
150000
100000
50000
0
−1
−0.5
0
0.5
1
$(q \cdot r)_{\text{FBDT}}$

# Procedure

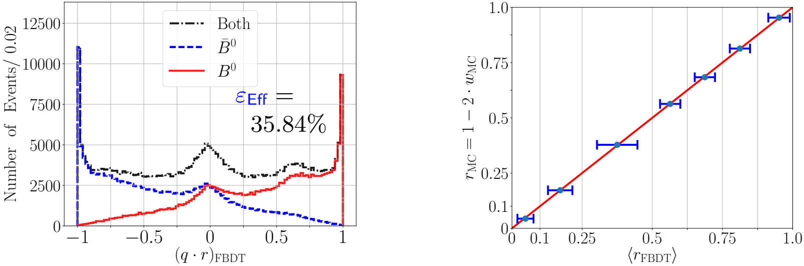

Tracks
KLMClusters
ECLClusters
$q \cdot r$
$q_{\mathrm{track}} \cdot y_{\mathrm{cat}}$
$e$
$\mu$
$K$
$\pi$
$p$
$\Lambda$
Electron
Int. El.
Muon
Int. Muon
KinLepton
Int. KinLep.
$(q_K \cdot y_{\mathrm{cat}})_{\mathrm{w}}$
Kaon
KaonPion
SlowPion
FSC
MaximumP*
FastPion
$(q_\Lambda \cdot y_{\mathrm{cat}})_{\mathrm{w}}$
Lambda
Combiner


Number of Events/ 0.02
$\bar{B}^0$
$B^0$
$\ell^-$
$(q_{\mathrm{track}} \cdot y_{\mathrm{cat}})^{\mathrm{KinLepton}}$
$\ell^-, \pi^-$
$(q_{\mathrm{track}} \cdot y_{\mathrm{cat}})^{\mathrm{MaximumP^*}}$
$K^-$
$(q_{\mathrm{track}} \cdot y_{\mathrm{cat}})_w^{\mathrm{Kaon}}$
$\ell^+$
$(q_{\mathrm{track}} \cdot y_{\mathrm{cat}})^{\mathrm{IntermediateKinLepton}}$

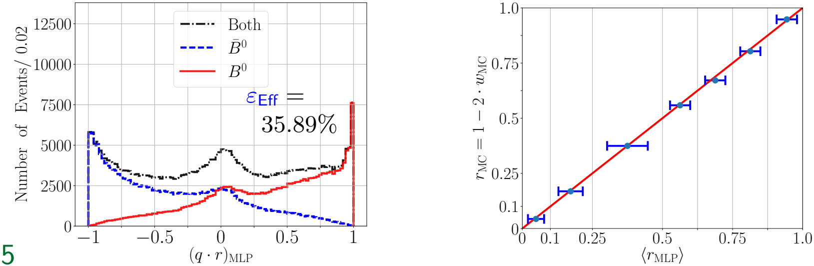
# Flavor Tagger Output

## TMVA FBDT

## Calibration

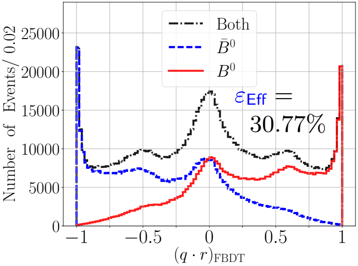


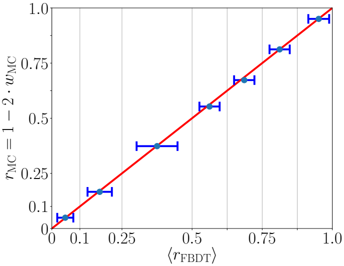

## FANN MLP

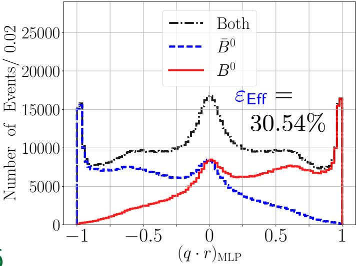


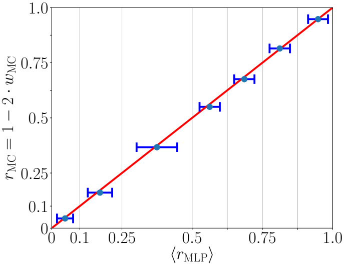
# Flavor Tagger Validation (B2BII)

## rel9 with converted Belle MC



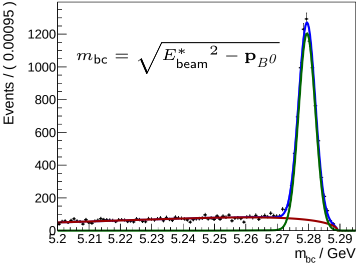



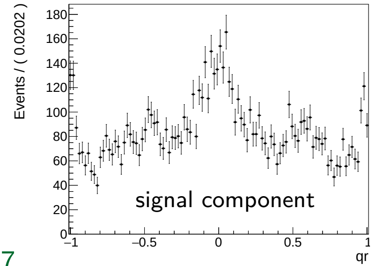
# Flavor Tagger Validation (B2BII)

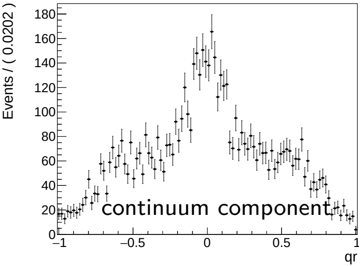


## rel9 with converted Belle Data

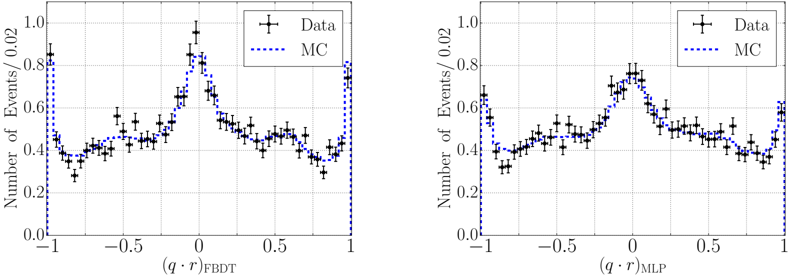



- Splot performed with converted Belle data using $m_{bc}$ as discriminating variable.
- Full Belle $0.8\,\text{ab}^{-1}$ $B^0 \to J/\psi K^0_S$



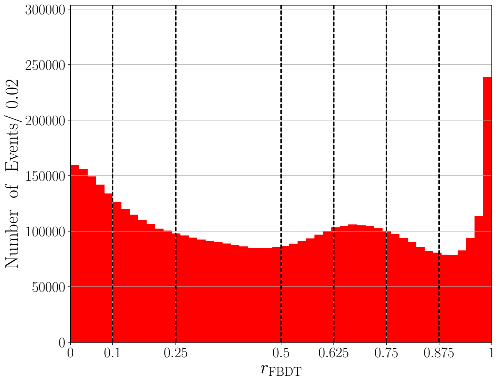
- Belle Data distribution weighted with splot output variable (signal component).




- Nice overlap of converted Belle MC and data ☺.
- $\varepsilon_{\mathrm{Eff}} \approx 31\%$ on converted Belle MC (Belle $\sim 29\%$) ☺.
- Optimized also for CPU time ☺.
- $\varepsilon_{\mathrm{Eff}}$ on Belle II MC is software release (tracking) dependent ☹.

# Efficiency Calculation






- Binning $\Rightarrow$ correction with real data!
- Efficiency:

$$\varepsilon_{\text{Eff}} = \sum_i \varepsilon_i \cdot \langle r_i \rangle^2$$

- $r_{\text{MC}} = 1 - 2 \cdot w_{\text{MC}}$
- Calibration: $r_{\text{MC}}$ linear to $r_{\text{Output}}$

# Systematic Uncertainties

$\mathcal{B}(B^0 \to \pi^+\pi^-)$

| Source | Belle[a] [%] | $50\,\frac{1}{\text{ab}}$ [%] |
|---|---|---|
| Signal PDF | 0.50 | 0.06 |
| $B\overline{B}$ Bkg. Param. | 1.77 | 0.22 |
| Tracking | 0.70 | 0.09 |
| Luminosity | 1.37 | 1.37 |
| Kpi PID | 1.72 | 0.22 |
| Ratio Cut | 0.24 | 0.03 |
| MC Statistics | 0.15 | 0.02 |
| Feed-accross | 1.50 | 0.19 |
| PHOTOS | 0.80 | 0.80 |
| **Total** | 3.42 | 1.63 |

$\mathcal{B}(B^+ \to \pi^+\pi^0)$

| Source | Belle[a] [%] | $50\,\frac{1}{\text{ab}}$ [%] |
|---|---|---|
| Signal PDF | 0.73 | 0.09 |
| $B\overline{B}$ Bkg. Param. | 4.53 | 0.57 |
| Tracking | 0.70 | 0.09 |
| Luminosity | 1.37 | 1.37 |
| Kpi PID | 0.86 | 0.11 |
| Ratio Cut | 0.92 | 0.12 |
| MC Statistics | 0.17 | 0.02 |
| Feed-accross | 1.19 | 0.15 |
| $\pi^0$ det. eff. | 4.00 | 0.51 |
| **Total** | 6.52 | 1.59 |

[a] Belle PRD 87 031103

Max-Planck-Institut für Physik

# Systematic Uncertainties

LMU Ludwig-Maximilians-Universität München · DEPFET Active Pixel Detector · Belle II

$\mathcal{A}_{CP}(B^0 \to \pi^+\pi^-)$

| Source | Belle[a] $[10^{-2}]$ | $50\,\frac{1}{\text{ab}}$ [%] |
|---|---|---|
| Track Helix | 0 | 0 |
| $\Delta t$ Sel. | 0.01 | 0.001 |
| Missalign. | 0.40 | 0.051 |
| $\Delta z$ Bias | 0.50 | 0.063 |
| IP Profile | 0.13 | 0.016 |
| Flavor Tagging | 0.40 | 0.051 |
| $m_d$ and $\tau$ | 0.12 | 0.015 |
| Fit Bias | 0.54 | 0.068 |
| Tag-Side Int. | 3.18 | 3.18 |
| $B_{\text{tag}}$ Track Sel. | 0.30 | 0.038 |
| Vertex Sel. | 0.37 | 0.047 |
| MC Shape | 0.15 | 0.019 |
| $\Delta t$ Res. | 0.83 | 0.415 |
| Bkg. Shape | 0.15 | 0.019 |
| Bkg. NP. S. | 0.37 | 0.047 |
| **Total** | 3.48 | 3.21 |

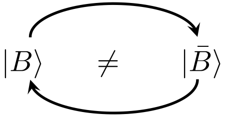
$\mathcal{S}_{CP}(B^0 \to \pi^+\pi^-)$

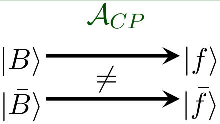
| Source | Belle[a] $[10^{-2}]$ | $50\,\frac{1}{\text{ab}}$ [%] |
|---|---|---|
| Track Helix | 0.01 | 0.001 |
| $\Delta t$ Sel. | 0.03 | 0.004 |
| Missalign. | 0.20 | 0.025 |
| $\Delta z$ Bias | 0.40 | 0.051 |
| IP Profile | 1.19 | 0.151 |
| Flavor Tagging | 0.31 | 0.039 |
| $m_d$ and $\tau$ | 0.09 | 0.011 |
| Fit Bias | 0.86 | 0.109 |
| Tag-Side Int. | 0.17 | 0.170 |
| $B_{\text{tag}}$ Track Sel. | 0.33 | 0.042 |
| Vertex Sel. | 0.23 | 0.029 |
| MC Shape | 0.19 | 0.024 |
| $\Delta t$ Res. | 2.02 | 1.010 |
| Bkg. Shape | 0.28 | 0.035 |
| Bkg. NP. S. | 0.57 | 0.072 |
| **Total** | 2.68 | 1.05 |

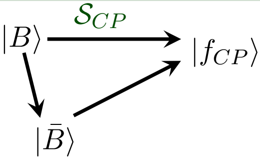
[a] Belle PRD 88 092003

# Time-dependent CP-Analysis





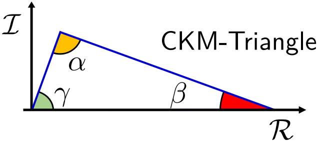



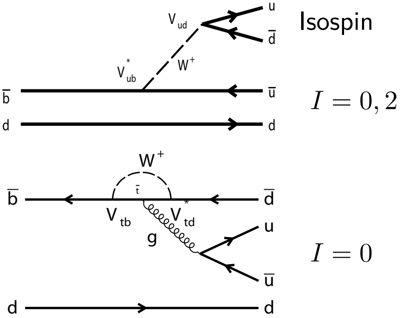

For $B \to \pi\pi$: tree and penguin diags. contribute!

: $\mathcal{A}_{CP} = 0$
$\mathcal{S}_{CP} = \sin(2\alpha)$

$+$ : $\mathcal{A}_{CP} \neq 0$
$\mathcal{S}_{CP} = \sqrt{1 - \mathcal{A}_{CP}} \sin(2\alpha^{\text{eff}})$

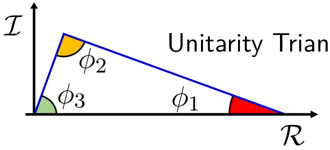
$\Rightarrow \alpha^{\text{eff}} = \alpha - \Delta\alpha$



# Extraction of $\phi_2$ from $B \to \pi\pi$

PhysRevLett.65.3381

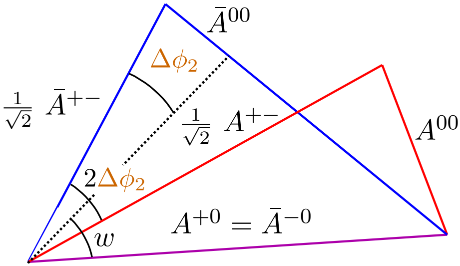



- $\phi_2 = \phi_2^{\text{eff}} - \Delta\phi_2$

⇒ Extr. $\phi_2$ through isospin analysis:

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

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




Parametrization in hep-ph/0406263

$$|A^{00}|^2 = \frac{1}{2}|A^{+-}|^2 + |A^{+0}|^2 - \sqrt{2}|A^{+-}||A^{+0}| \cos\left(\phi_2 - \delta\right)$$

$$|\bar{A}^{00}|^2 = \frac{1}{2}|\bar{A}^{+-}|^2 + |A^{+0}|^2 - \sqrt{2}|\bar{A}^{+-}||A^{+0}| \cos\left(\phi_2 + \delta - 2\phi_2^{\text{eff}}\right)$$

Theoretical predictions $\mathbf{x}_{\text{theo}}$:

$$\begin{aligned}
\mathcal{B}_{+-} &= \frac{1}{2}\left(A_{+-}^2 + \bar{A}_{+-}^2\right) \\
\mathcal{B}_{00} &= \frac{1}{2}\left(A_{00}^2 + \bar{A}_{00}^2\right) \\
\mathcal{B}_{+0} &= \frac{\tau_{B+}}{\tau_{B^0}} A_{+0}^2 \\
\mathcal{A}_{+-} &= \mathcal{A}_{+-} \\
\mathcal{S}_{+-} &= \sqrt{1 - \mathcal{A}_{+-}^2}\,\sin\left(2 \cdot \phi_2^{\text{eff}}\right) \\
\mathcal{A}_{00} &= \frac{\bar{A}_{00}^2 - A_{00}^2}{\bar{A}_{00}^2 + A_{00}^2} \\
\mathcal{S}_{00} &= \frac{1}{\bar{A}_{00}^2 + A_{00}^2}\Bigg(2A_{+0}^2 \sin\left(2\phi_2\right) + A_{+-}\bar{A}_{+-} \sin\left(2\phi_2^{\text{eff}}\right) \\
&\qquad + \sqrt{2}A_{+0}\left(A_{+-} \sin\left(\phi_2 + \delta\right) - \bar{A}_{+-} \sin\left(\phi_2 - \delta + 2\phi_2^{\text{eff}}\right)\right)\Bigg)
\end{aligned}$$

# Extraction of $\phi_2$ from $B \to \rho\rho$



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

$\Rightarrow$ Most precise measurement of $\phi_2$:
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.