Measurement of γ (ϕ_3) and first results on CP violation at Belle II

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Outline

- Introduction
- SuperKEKB and Belle II
- Prospects for ϕ_3
- Prospects for ϕ_1 $\rightarrow$ First TDCPV measurement
- Summary

Introduction

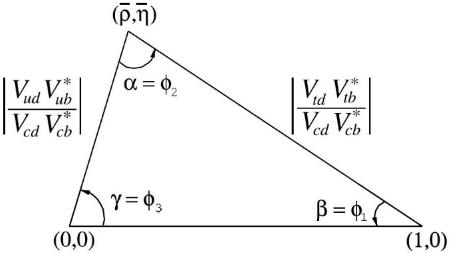
Measuring SM CP violation $\Rightarrow$ Measure complex phase of CKM elements.

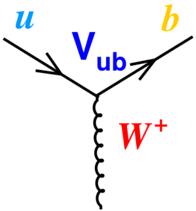
$$V_{ij} \approx \begin{array}{cc} \begin{array}{ccc} d & s & b \end{array} & \\ \begin{pmatrix} \boxed{1} & \boxed{\lambda} & \lambda^3 \\ \boxed{-\lambda} & \boxed{1} & \boxed{\lambda^2} \\ -\lambda^3 & \boxed{-\lambda^2} & \boxed{1} \end{pmatrix} & \begin{array}{c} u \\ c \\ t \end{array} \end{array}$$

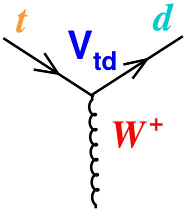
$\lambda \approx 0.22$: Cabbibo angle

Unitarity condition

$(1^{\mathrm{st}} \leftrightarrows 3^{\mathrm{rd}})$





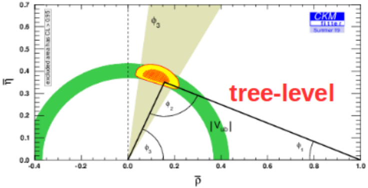


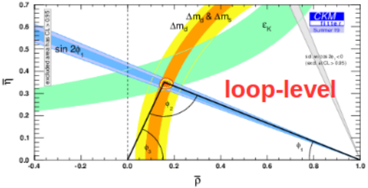
This talk is focused on:

$$\phi_1/\beta \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$
$$\phi_3/\gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

ϕ_2: see Eldar Ganiev's talk.

CKM: Current status





World average (HFLAV)
[hflav.web.cern.ch/]

$$\beta \equiv \phi_1 = (22.2 \pm 0.7)^\circ$$
$$\alpha \equiv \phi_2 = (84.9^{+5.1}_{-4.5})^\circ$$
$$\gamma \equiv \phi_3 = (71.1^{+4.6}_{-5.3})^\circ$$

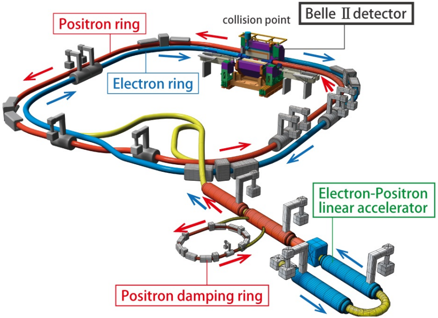
Global fit (CKM fitter)
[ckmfitter.in2p3.fr/]

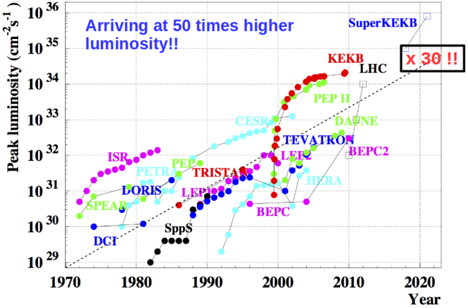
$$\beta \equiv \phi_1 = (22.51^{+0.55}_{-0.40})^\circ$$
$$\alpha \equiv \phi_2 = (91.6^{+1.7}_{-1.1})^\circ$$
$$\gamma \equiv \phi_3 = (65.81^{+0.99}_{-1.66})^\circ$$

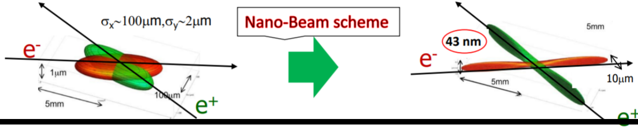
- **New physics (NP) prospects:**
  - **ϕ_1: comparison of TD CP-asymmetry in tree- and loop-dominated processes.**
  - **ϕ_3: test of direct vs indirect disagreement (requires improvement of precision in direct measurement).**

SuperKEKB accelerator

- **SuperKEKB**: 4 GeV e^+ and 7 GeV e^- asymmetric collider at KEK.
- A 30-fold increase in instantaneous luminosity over Belle, $\mathcal{L} \sim \mathbf{6x10^{35}}$ cm^{-2}s^{-1}.

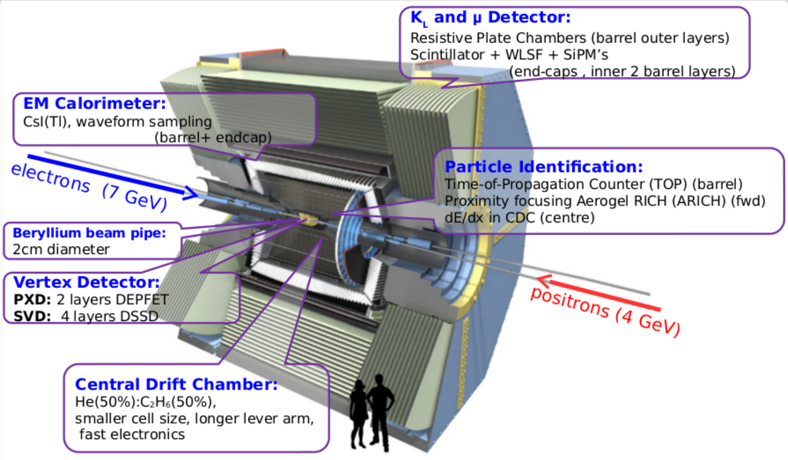






20× smaller beam spot and 1.5× increase in beam current ⇒ 30× Lumi

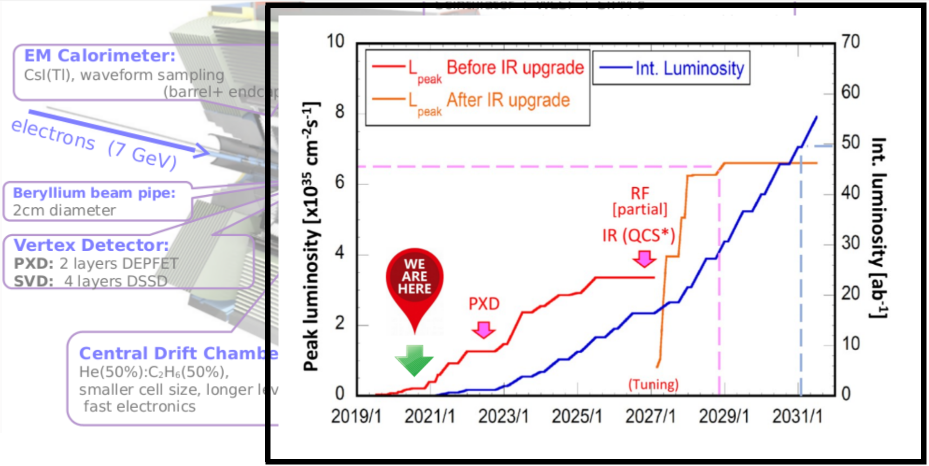
Belle II detector and status



- Improved tracking, vertexing.
- Better particle identification.
- Better calorimeter resolution.

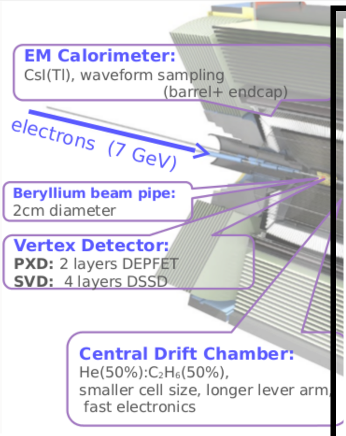
- Challenge:
  - Higher beam background
  - Higher trigger rate

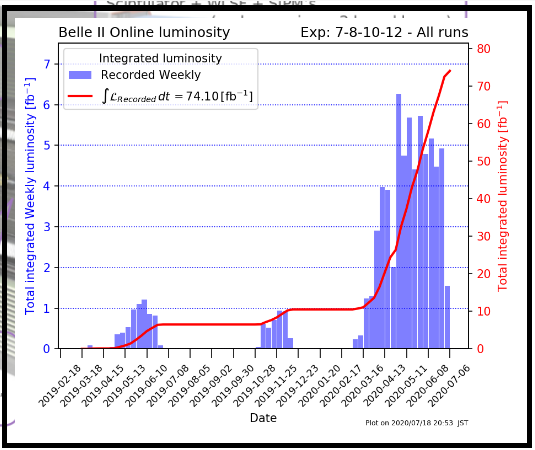
Belle II detector and status



- Improved tracking, vertexing.
- Better particle identification. More details in K.Matsuoka's talk.
- Better calorimeter resolution.

Belle II detector and status





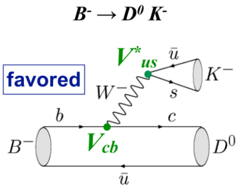
- Improved tracking, vertexing.
- Better particle identification.
- Better calorimeter resolution.

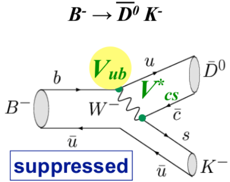
World Record by SuperKEKB on June 15th 2020:
$\mathcal{L} = 2.4\text{x}10^{34}\ \text{cm}^{-2}\text{s}^{-1}$

Extraction of ϕ_3

- Only CKM angle accessible at tree level.
- Very precise theoretical prediction $\delta\phi_3/\phi_3 \sim 10^{-7}$ [J. Brod, J. Zupan, arxiv:1308.5663].
- **ϕ_3 is the phase between $b \to u$ and $b \to c$ transition:**

$$\boxed{\frac{\mathcal{A}^{\text{suppr.}}(B^- \to \overline{D^0}K^-)}{\mathcal{A}^{\text{favor.}}(B^- \to D^0K^-)} = r_B e^{i(\delta_B - \phi_3)}}$$





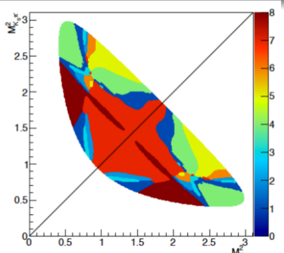
- Measured via the interference between $B^- \to D^0K^-$ and $B^- \to \overline{D}^0K^-$ with various D^0 channels.
  - **GLW method**: CP eigenstates: $K^-K^+, \pi^-\pi^+, K^0_S\pi^0$ *[Phys. Lett. B* ***253****, 483]*
  - **ADS method**: DCS modes: $K^+\pi^-, K\pi\pi^0$ *[Phys. Rev. Lett.* ***78****, 3257]*
  - **BPGGSZ method**: self-conjugate multibody final states: $K^0_S\pi^-\pi^+$, $K^0_S\pi^-\pi^+\pi^0, K^0_SK^-K^+$ *[Phys. Rev. D* ***68****, 054018]*

Belle II prospects for ϕ_3

- Golden mode in Belle II: $\mathbf{B^{\pm} \to D^0(K^0_S\pi^-\pi^+)K^{\pm}}$
  - Model-independent binned Dalitz plot approach.
  - Number of events in i^{th} bin is a function of $x_{\pm}/y_{\pm}$:

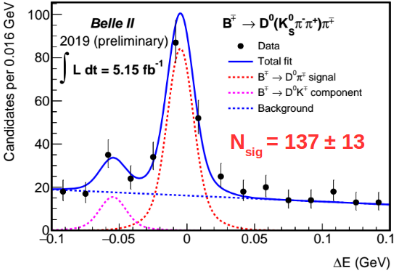
$$\boxed{N_i^{\pm} = h_B[K_{\pm i} + r_B^2 K_{\mp i} + \sqrt{K_i K_{-i}}(x_{\pm}c_i \pm y_{\pm}s_i)]}$$

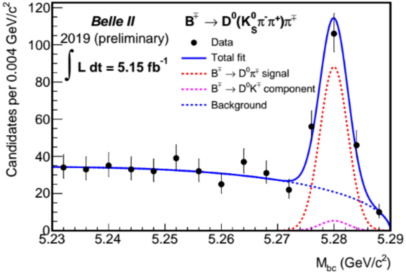
$$\boxed{(x_{\pm}, y_{\pm}) = r_B(\cos(\pm\phi_3 + \delta_B), \sin(\pm\phi_3 + \delta_B))}$$



Belle II Physics Book - arXiv:1808.10567

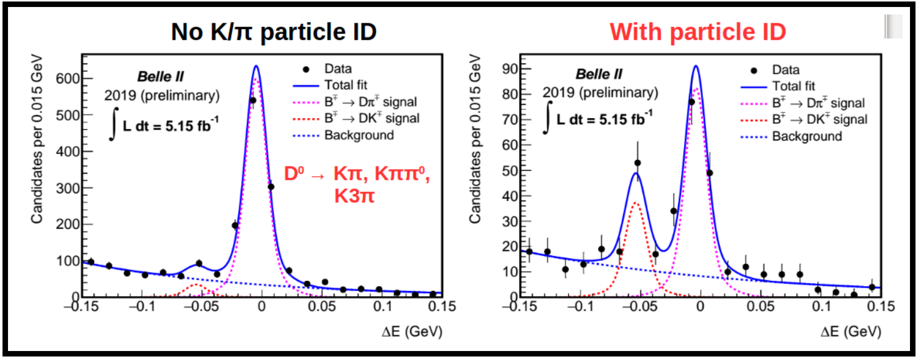
- Precise strong phase measurement needed to match Belle II stat. precision: expected from **20 fb^{-1}** BESIII data set.





$B \to DK$ @Belle II

- More sensitive to ϕ_3 than $B \to D\pi$ because of its higher r_B value.
- **Rediscovery of B $\to$ DK with more than 5σ evidence using the continuum suppression tool and particle identification technique of Belle II.**



- Total 53 ± 9 signal candidates are obtained with a 1D maximum likelihood fit to the ΔE.

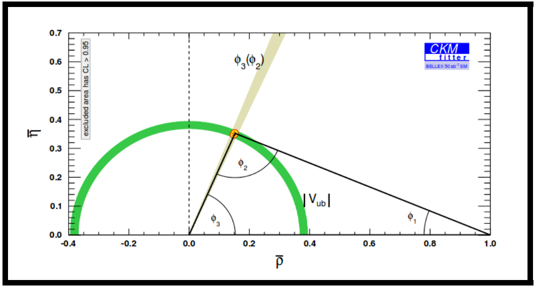
Future prospects

- Expect Belle II and LHCb upgrade to match each other's performance!
- $\delta(\phi_3) < 1.6^\circ$ with 50 ab^{-1} data set.

- Modes that are good for Belle II:
  - $D^* \to D^0\pi^0, D^0\gamma$
  - $D^0 \to K_S^0\pi^0$, $K_S^0\pi\pi\pi^0$...

  [P. K Resmi, J. High Energy Phys. **10**, *178 (2019)]*
- Belle II strength:
  - Increasing statistics
  - **Good neutral reconstruction**
  - Better K/π separation
  - Better continuum suppression

Figure: Fit extrapolated to 50 ab^{-1} for a SM-like scenario



Belle II Physics book: arXiv:1808.10567

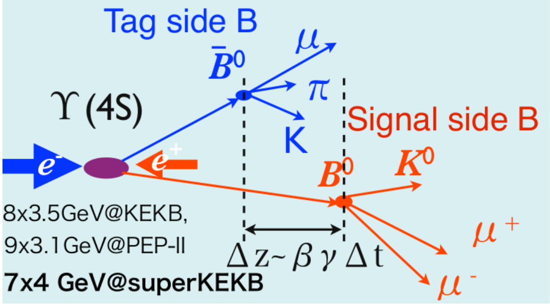
- LHCb will clearly have more precise results in fully-charged final states.

TDCPV at Belle II

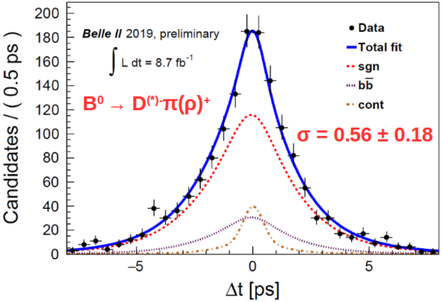
- Decay rate of B^0 meson to CP eigen-states:

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

- **Key element:** Vertex position measurement, B meson flavor tagging.

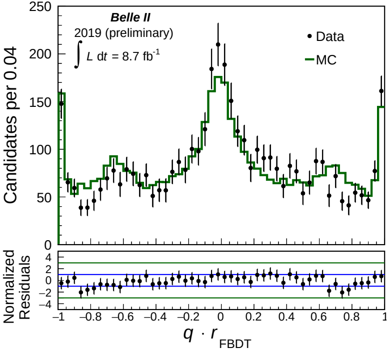


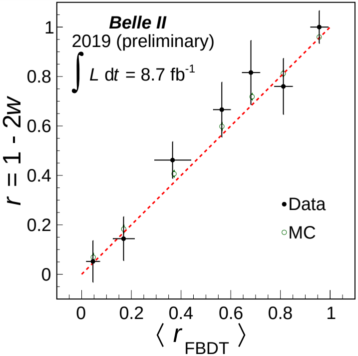
BELLE2-CONF-PH-2020-003

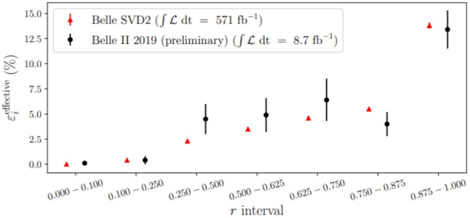


see Cyrille Praz's talk.

First calibration of flavor tagging at Belle II







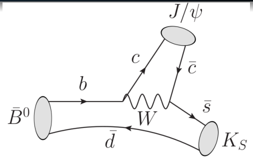
BELLE2-CONF-PH-2020-004

- Good data-simulation agreement
- Effective tagging efficiency: $33.8 \pm 3.9\%$

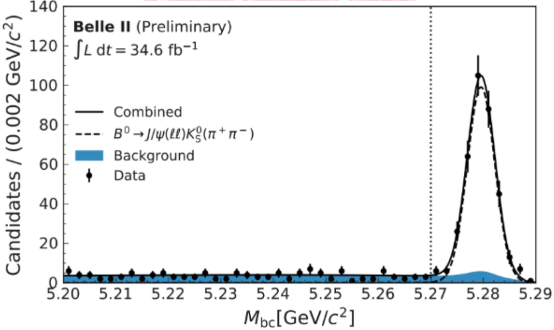
$\Rightarrow$ Comparable with best of Belle and BaBar.

First $\sin 2\phi_1$ measurement: $B^0 \to J/\psi K^0_S$

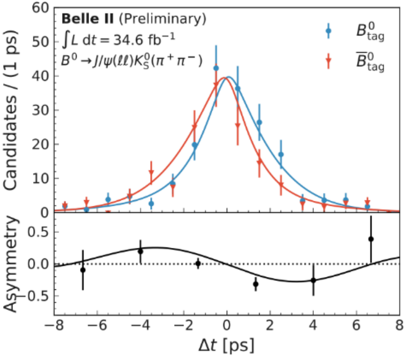
- Most precisely measured UT parameter so far.
- Tree-dominated $b \to c\bar{c}s$ golden mode.
- Theoretically and experimentally precise.



BRAND NEW



$0.2 < |r| \leq 1$

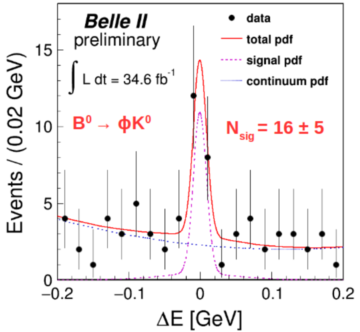


- $\mathcal{S}_{\mathrm{CP}} = 0.55 \pm 0.21(\mathrm{stat.}) \pm 0.04(\mathrm{syst.})$; **good agreement with the PDG value.**

Future prospects

- Challenge both for experiment and theory: penguin pollution.
- Can be controlled experimentally: $\mathbf{B^0 \to J/\psi\pi^0}$
- Other modes which can also contribute $(b \to q\bar{q}s)$: $\mathbf{B^0 \to \phi K_S, \eta' K_S, \omega K_S}$: specifically NP sensitive if any significant deviation from $B^0 \to J/\psi K^0_S$ is observed.
- Rediscovery of $\mathbf{B^0 \to \phi K^0_S}$ at Belle II.
- Measured B.F. $\mathcal{B}(x10^{-6}) = 3.0 \pm 0.9 \pm 0.4$
- In agreement with the world average.

$\sin 2\phi_1$ Belle II Physics book: arXiv:1808.10567			
Belle II		LHCb	
5 ab^{-1}	50 ab^{-1}	8 fb^{-1}	50 fb^{-1}
0.4°	0.3°	0.6°	0.3°

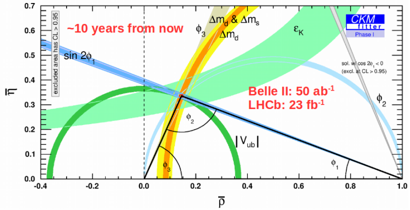


Summary

- **Flavor physics at high luminosity B-factories offers good probe for testing SM and looking for NP.**

- Belle II will play a key role in particle physics.
  - Experience from Belle and Babar.
  - Good complementarity with LHCb.
  - CKM angle measurements can be improved with just 5 -10 ab^{-1} data set.
  - Huge data set of 50 ab^{-1}: several measurements will be syst. limited $\rightarrow$ lots of work ahead!

Belle II Physics book: arXiv:1808.10567



$$\delta\phi_1 \lesssim 0.1^\circ$$
$$\delta\phi_2 \lesssim 1^\circ$$
$$\delta\phi_3 \lesssim 1.6^\circ$$

- First $\sin 2\phi_1$ results at Belle II: $\mathbf{B^0 \rightarrow J/\psi K^0_S}$; good agreement with W.A.
- Expected experimental performance often better w.r.t Belle despite 20x higher beam background and lower boost.
- Looking forward to the next decade of Belle II results!!

Thank you!

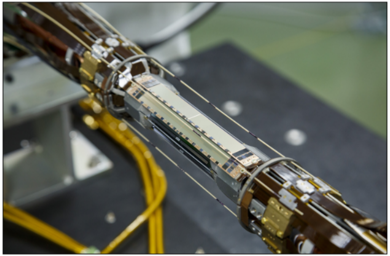
Belle II highlights at ICHEP 2020

- CPV and CKM: Experimental overview: **Doris Kim**
- First results and prospects for τ LFV decays: **Francesco Tenchini**
- First results on V_{ub} and V_{cb} with Belle II: **Racha Cheaib**
- Leptonic and semileptonic decays with τs at the Belle II experiment: **Marco Milesi**
- Early charmless B decay physics at Belle II: **Eldar Ganiev**
- Tau physics prospects at Belle II: **Kenji Inami**
- Charm potential at Belle II: **Giulia Casarosa**
- Results and Prospects of Radiative and EWP Decays at Belle II: **Yo Sato**
- First results from Belle II on exotic and conventional quarkonium: **Roberto Mussa**
- Dark Sector first results at Belle II: **Enrico Graziani**
- The Belle II Experiment: Status and Prospects: **Kodai Matsuoka**
- Status and Future development of the FEI Algorithm at Belle II: **William Sutcliffe**
- B lifetimes at Belle II: **Cyrille Praz**
- Track rec. eff. measurement using $e^+e^- \to \tau^+\tau^-$ events at Belle II: **Laura Zani**
- Trg eff measurement using $e^+e^- \to \tau^+\tau^-$ events at Belle II: **Petar Rados**

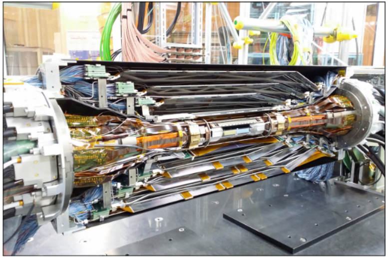
Stay tuned!!

Backup

Vertex detectors

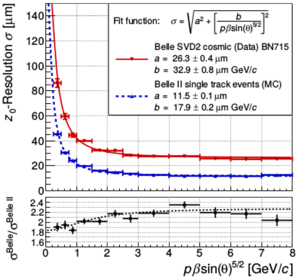


PXD mounted on beam pipe

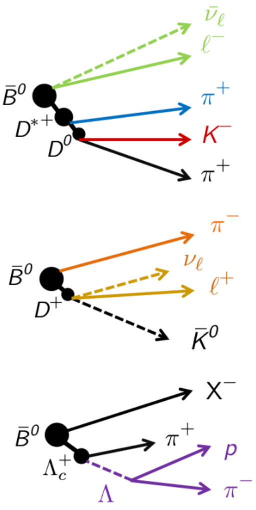


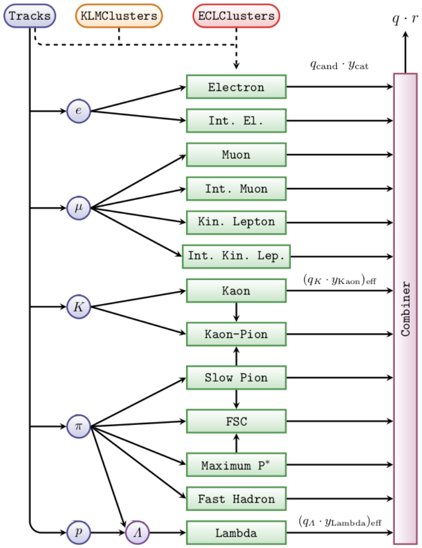
PXD combined with one half of SVD

- 1st pixel layer at r = 14 mm to IP. [Belle r = 20 mm]
- Improves vertex resolution along z-axis.
- Larger SVD outer layer at r = 135 mm. [Belle r = 88 mm]
- Higher fraction of K_S with vertex hits improves vertex resolution.



Flavor tagger





source	$\Delta\ \Delta m_d$ [%]	$\Delta\ S_f$ [%]
1. BKG scale & shift	-0.2	-0.3
2. Peaking BKG $J/\psi K_S$ $\pm100\%$	–	-2.7
3. $b\bar{b}$ frac. $D\pi$ $\pm50\%$	$+0.03$	-2.1
4. Δm_{eff} for $b\bar{b}$ free	$+0.8$	$+0.4$
5. w_{eff} for $b\bar{b}$ free	-0.15	$+4.9$

source	$\Delta\ \Delta m_d$ [%]	$\Delta\ S_f$ [%]
6. w difference $J/\psi K_S$ vs $D\pi$	–	$+2.9$
7. Res. function tail scale	$+1.2$	$+0.6$
8. Res. function tail fraction $\pm50\%$	$+1.4$	$+0.4$
9. Kin approx w, Δm_d	$+1.2$	0.0
10. Kin approx S_f	–	-0.9
11. VXD alignment	$+0.4$	$+2.0$
total	2.4	7.1