

# First look at CKM parameters from early

- Outline:
- ❖ Belle II and SuperKEKB
  - ❖ Start of the physics run
  - ❖ Main Ingredients for UT angle measurements:
    - ❖ Flavour tagging
    - ❖ Time measurement
    - ❖ Particle reconstruction
  - ❖ Belle II prospects for  $\phi_1$ ,  $\phi_2$  and  $\phi_3$
  - ❖ Conclusion

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on behalf of the Belle II collaboration

# The Belle II experiment



- ❖ Legacy of B factories, BaBar and Belle:
    - ❖ Precise measurement of CPV in B system.
    - ❖ About  $1.15 \text{ ab}^{-1}$  in total at  $\Upsilon(4S)$ .
  
  - ❖ Belle II builds on the excellent B factory experience, shifting focus to search for BSM physics:
    - ❖ Extremely precise measurements: CKM parameters, rare B, D and  $\tau$  decays, light dark matter, ...
    - ❖ Quantum manifestation of New Physics: **high NP mass sensitivity**.
  

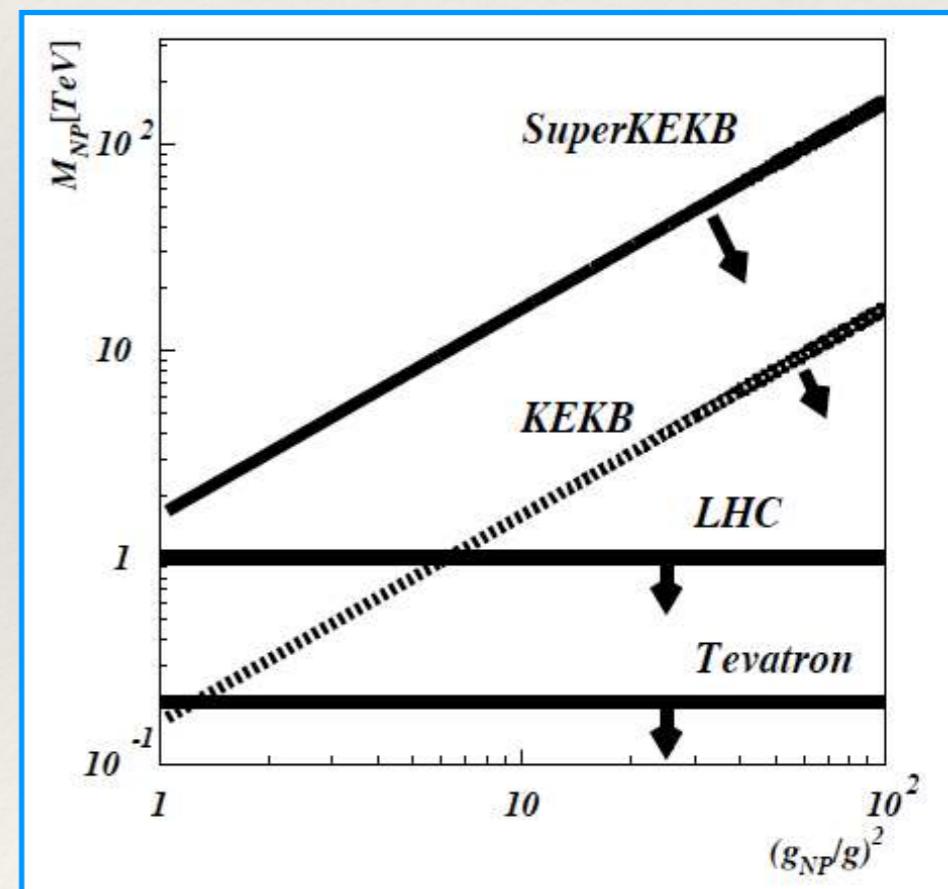
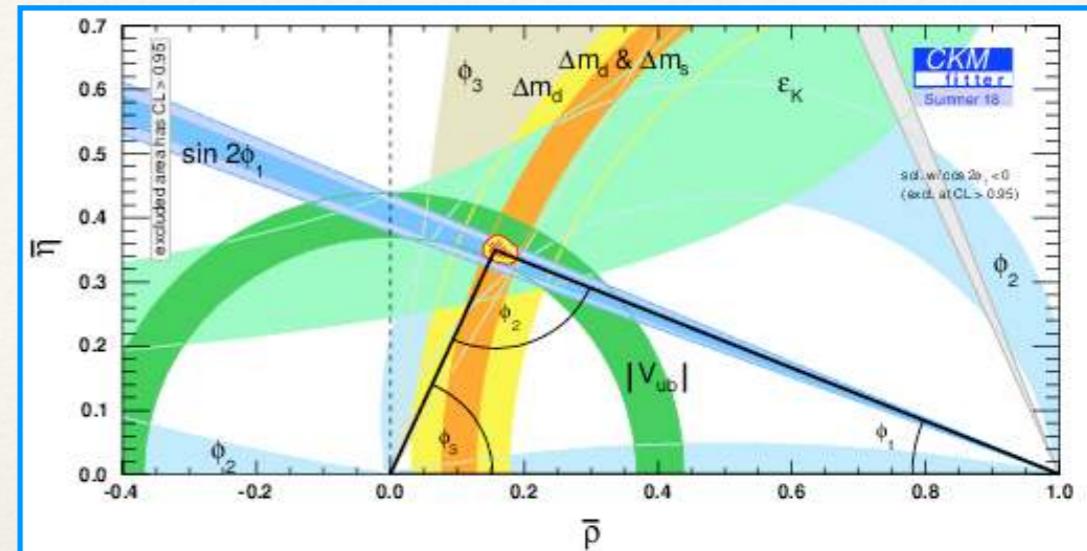
SM

NP

SM

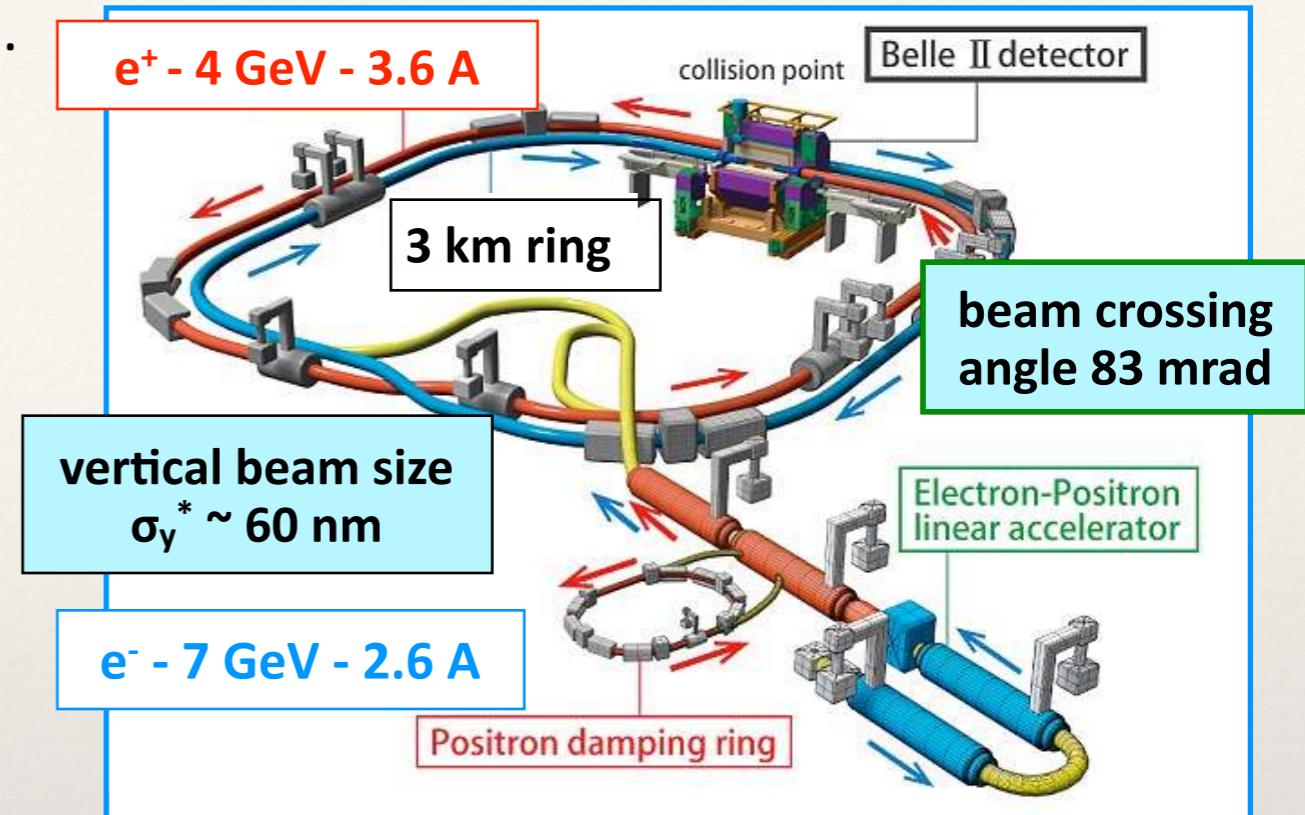
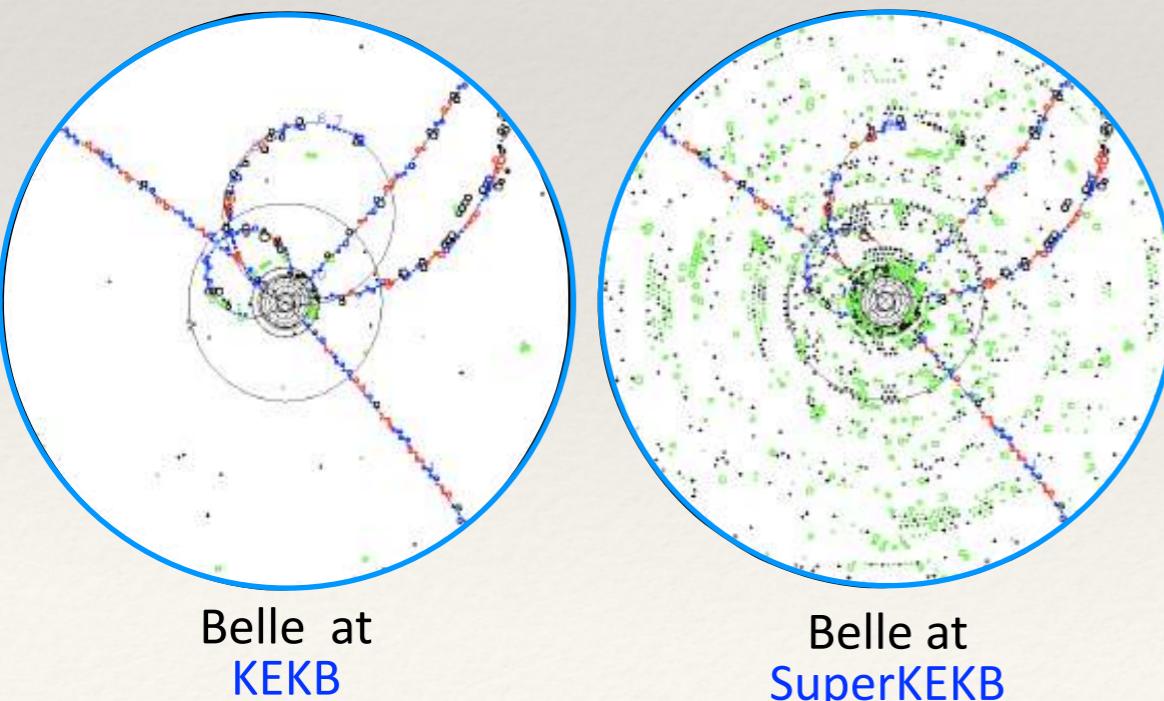
NP

  
  - ❖ Unique skills in Belle II w.r.t.:
    - ❖ **inclusive** measurements.
    - ❖ events with **missing energy**.
    - ❖ events with **neutrals**.
- interesting complementarity with LHCb



# The SuperKEKB collider

- ❖ Asymmetric  $e^+e^-$  circular collider at KEK, Japan.
  - ❖  $E_{\text{collision}} = m_{Y(4S)}$  and from  $Y(1S)$  to  $\sim Y(6S)$ .
  - ❖ New nano-beam collision scheme:
    - ❖ KEKB transverse beam size /20
    - ❖ KEKB beam currents  $\times 2$
    - ❖ KEKB crossing-angle  $\times 3.8$
    - ❖ KEKB boost  $\times 2/3$
- targeted instantaneous luminosity:  
 $8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ , KEKB world record  $\times 40$ .



- ❖ High luminosity → many parasitic particles:
  - ❖ dominate occupancy in inner tracker,
  - ❖ damage detectors.

→ success of Belle II physics program relies on the control of the beam induced BG.



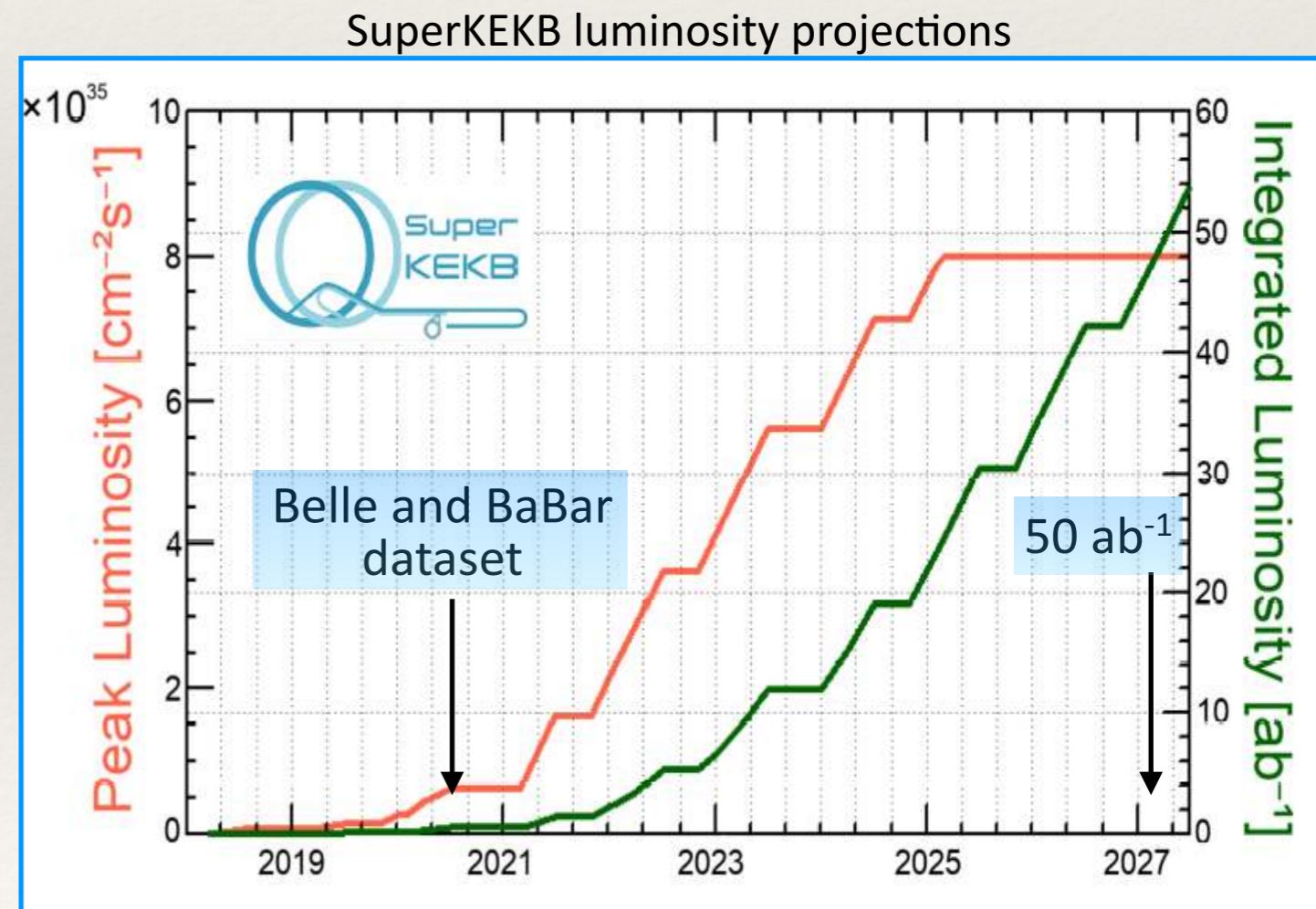
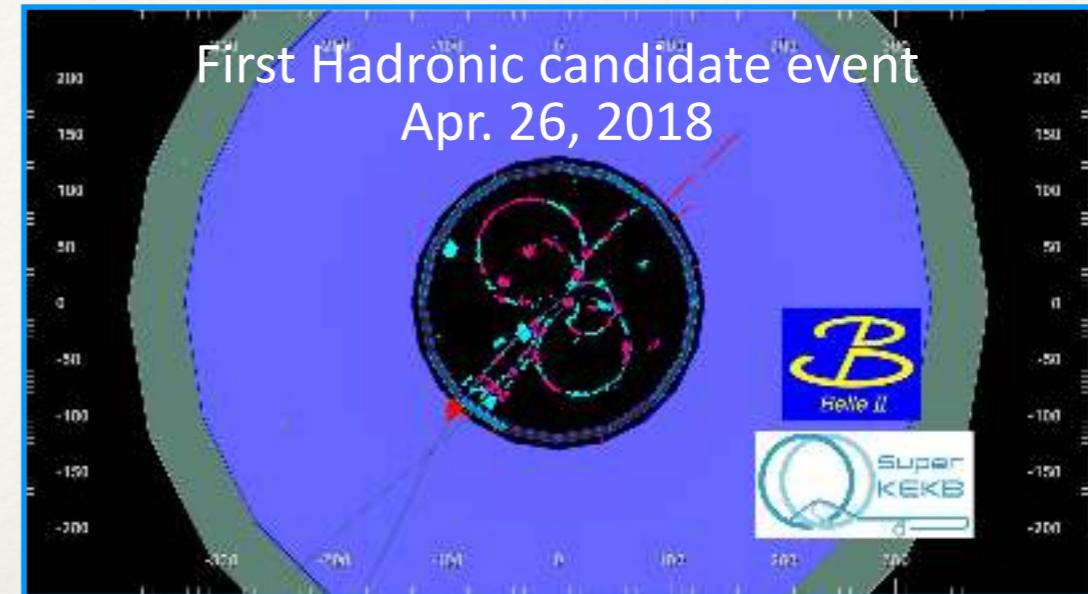
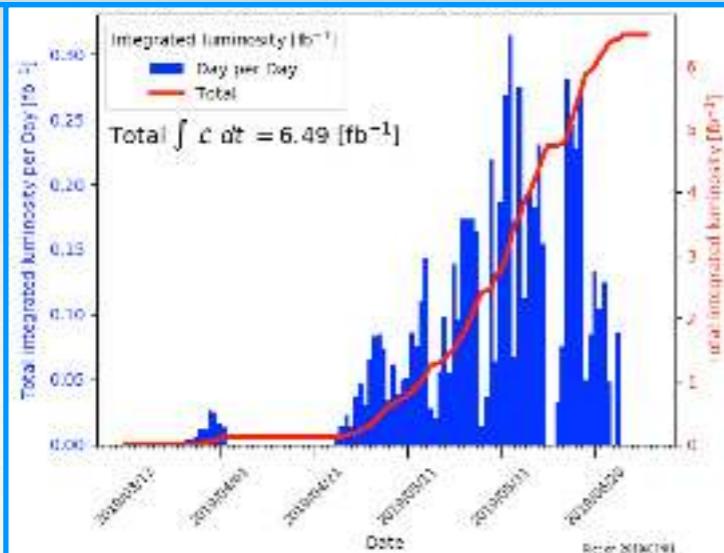
# Belle II calendar



- ❖ **Belle II commissioning:**  
Phase 2, March-July 2018.
  - ❖ Partial  $\phi$  coverage of the inner tracker.
  - ❖ Beam induced background study (BEAST II).
  - ❖  $0.5 \text{ fb}^{-1}$  registered, peak lumi.  $5 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ .
- ❖ **Start of physics run:**  
Phase 3, started 25 March 2019.  
All Belle II sub-detectors in DAQ.

## Status on July 1st:

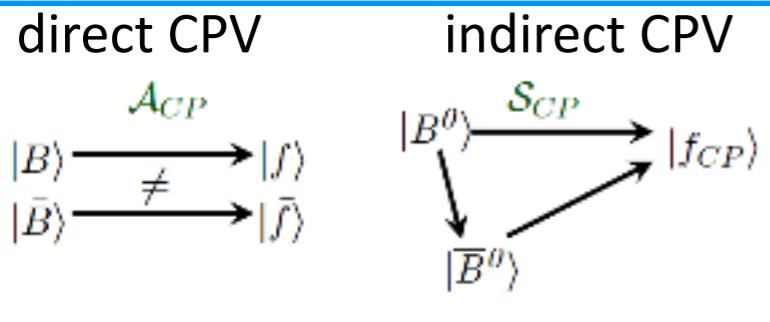
max peak lumi.  $1.2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$   
 $6.5 \text{ fb}^{-1}$  @ $\Upsilon(4S)$ ,  
 $0.8 \text{ fb}^{-1}$  off-resonance.



# Ingredients of TDCPA measurements

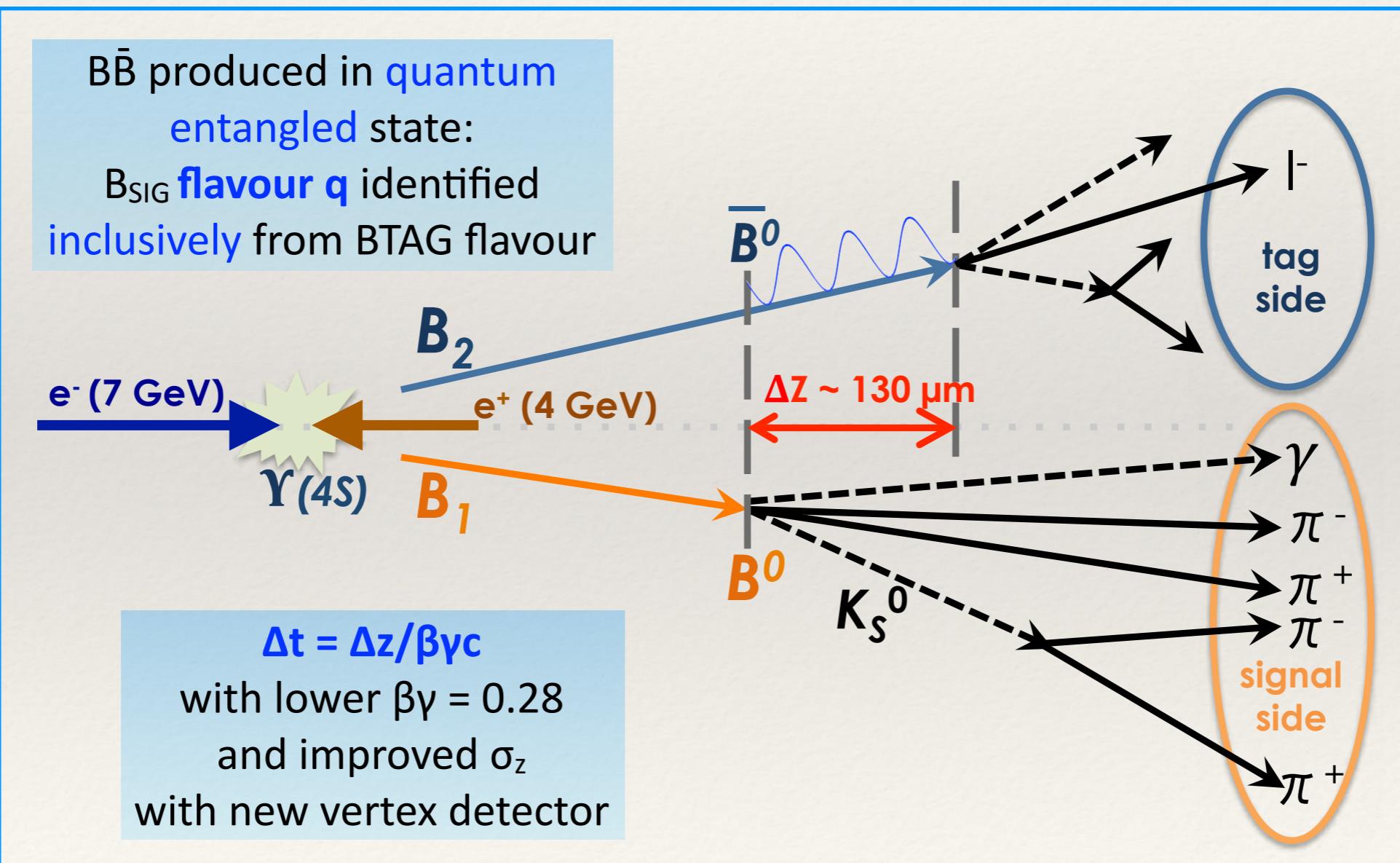


## for $\phi_1$ and $\phi_2$ measurements



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

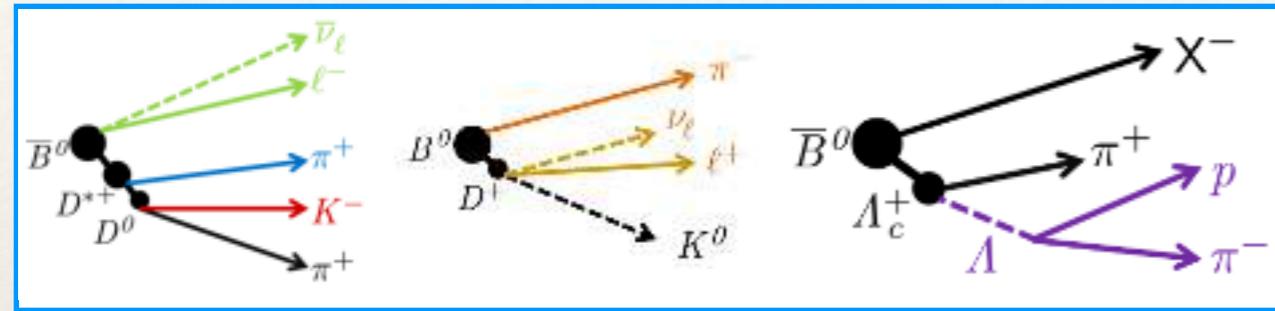
$$A_{CP} = 0 \quad S_{CP} \sim \sin 2\phi_{1,2} \quad (\text{at tree order})$$



# Flavour tagging



- ❖ MVA-based tagger:  
many sub-taggers with many input variables.



- ❖ Total expected effective tagging efficiency:

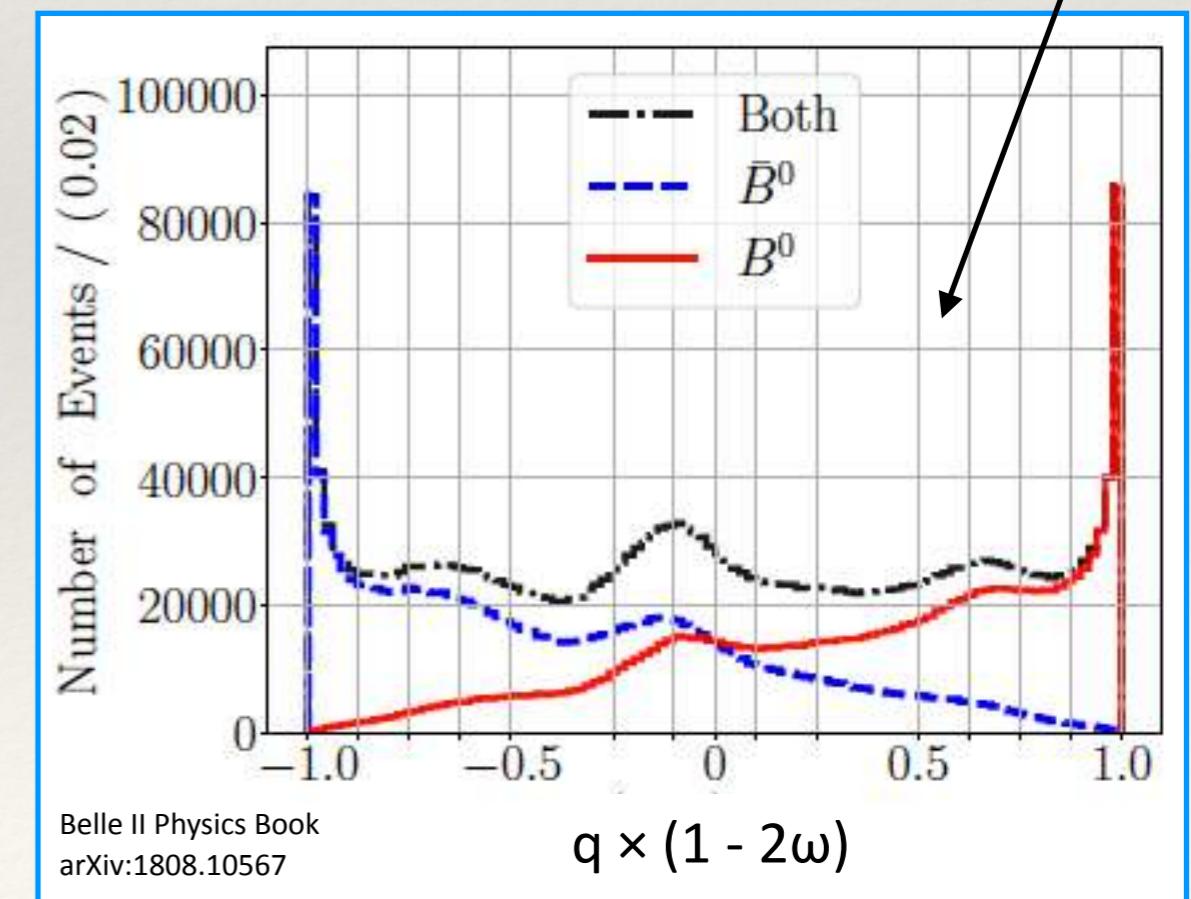
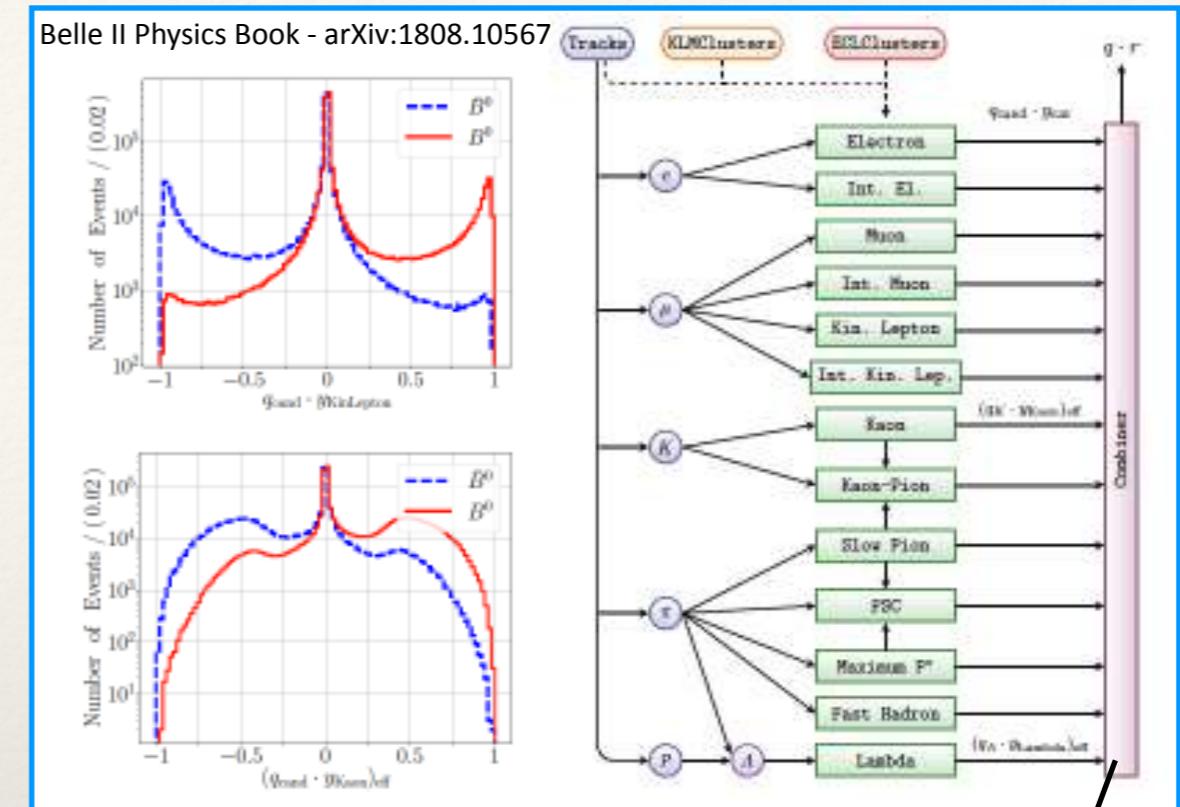
$$\sum \epsilon_i \times (1 - 2\omega_i)^2 = 37.2 \% \quad (\text{Belle II MC})$$

to be compared with 30-33 % in BaBar & Belle.

Dilution factor  $r$  due to mis-tag  $\omega$ :

$$r = 1 - 2\omega \rightarrow A_{CP}^{\text{obs}} = (1 - 2\omega) A_{CP}$$

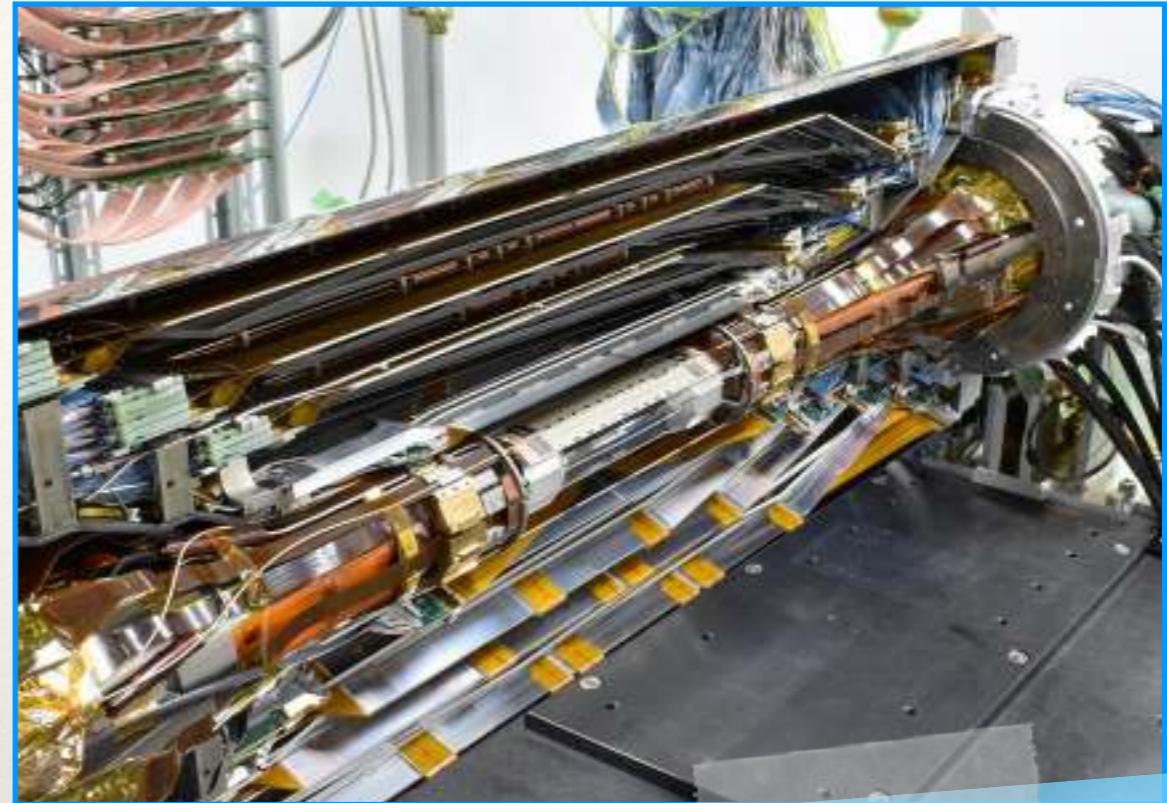
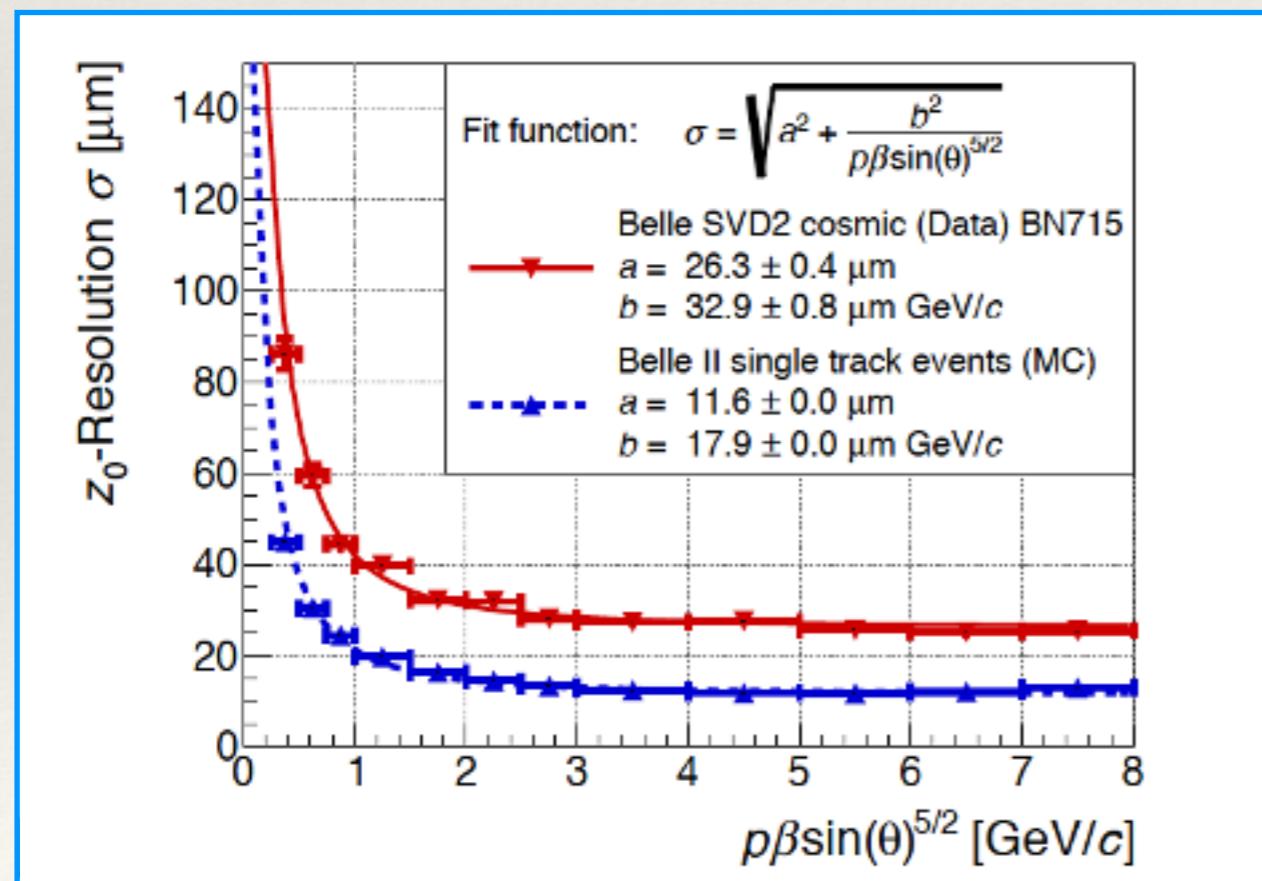
- ❖ Further improvements expected:
  - ❖ More input variables, more categories.
  - ❖ Deep NN.
  - ❖ More than 10% improvement was observed within BaBar and Belle lifetime.



# Time measurement

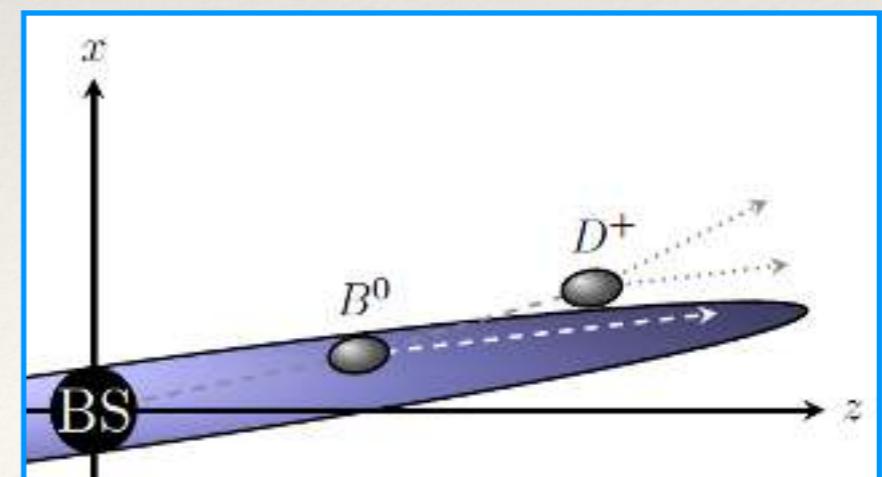


- ❖ Vertex detector inserted in Belle II end of 2018:
  - ❖ 1+ pixelated layer,  $r = 1.4$  cm.  
+ 4 layers of double-sided silicon strips  
with 30% extended acceptance.
  - ❖ Factor of 2 improvement expected on track impact parameters w.r.t. Belle:



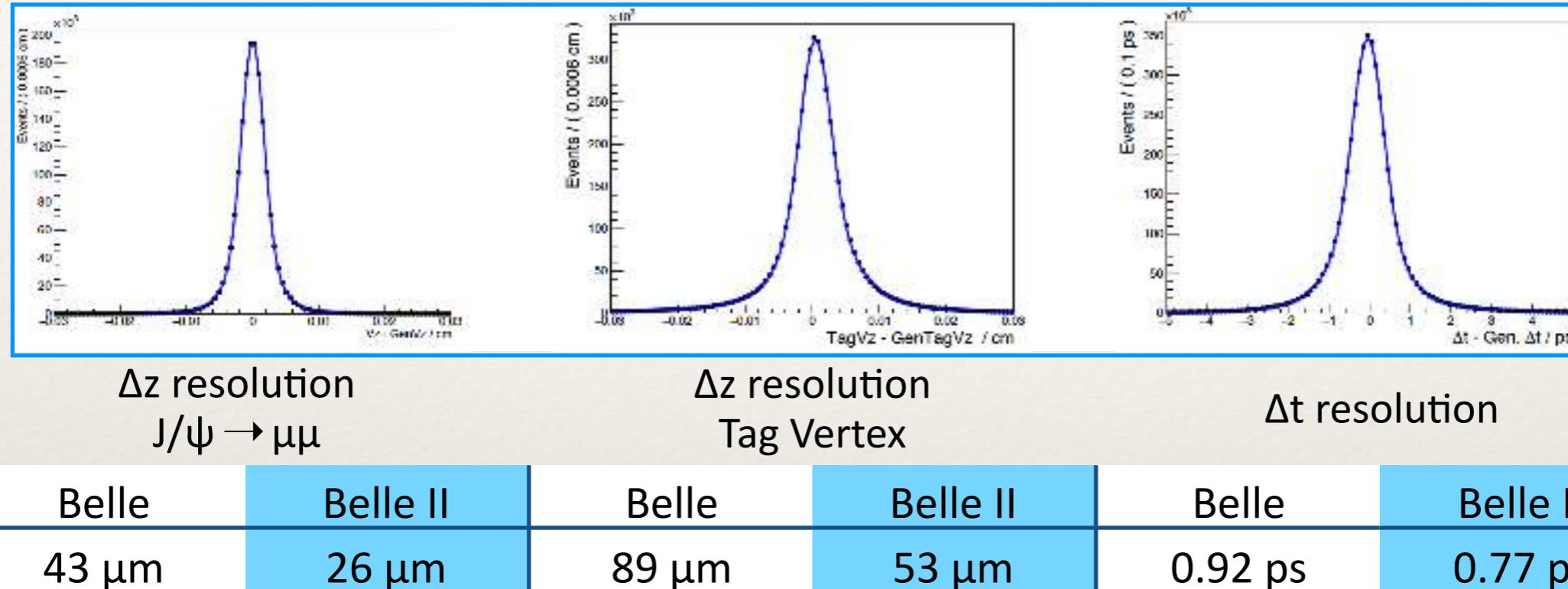
See poster by A. Paladino

- ❖ Very small beam spot size:  
Belle, BaBar beam spot  $(120 \times 5 \times 8000)$  μm<sup>3</sup>  
vs. Belle II beam spot  $(6 \times 0.06 \times 150)$  μm<sup>3</sup>

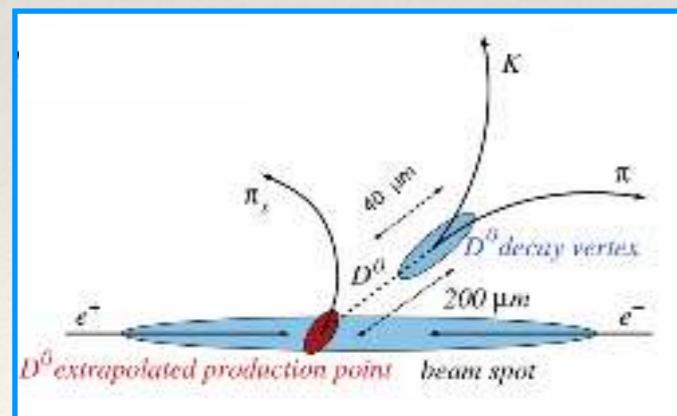


# Time measurement

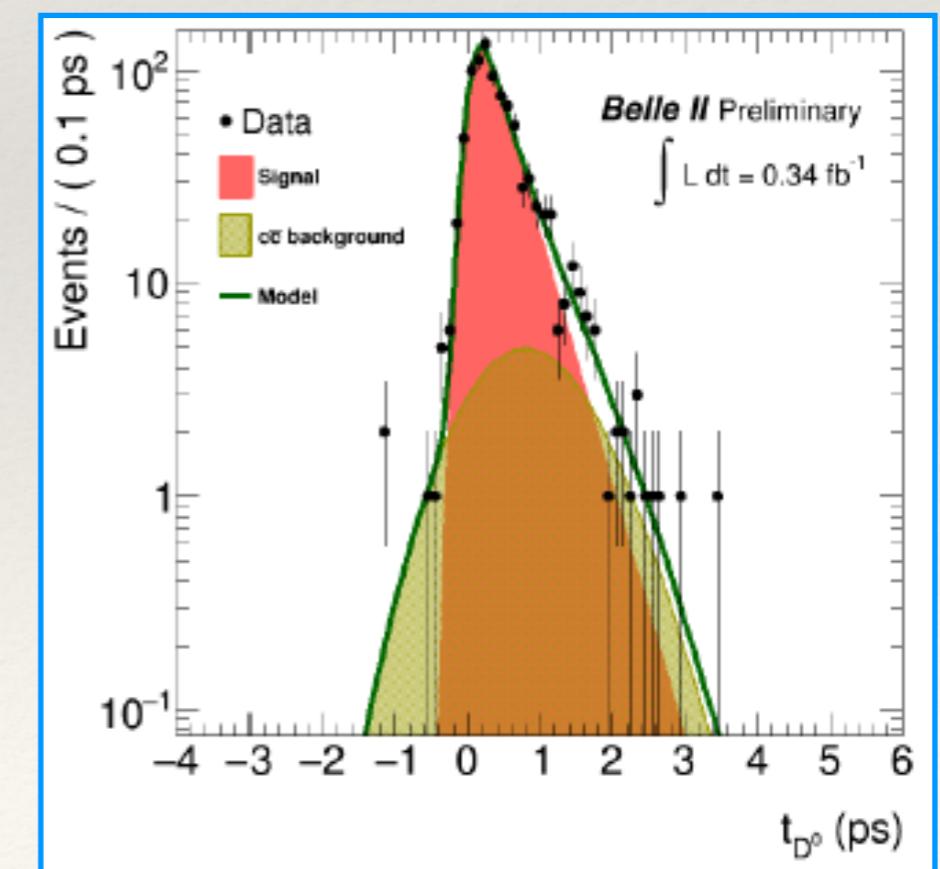
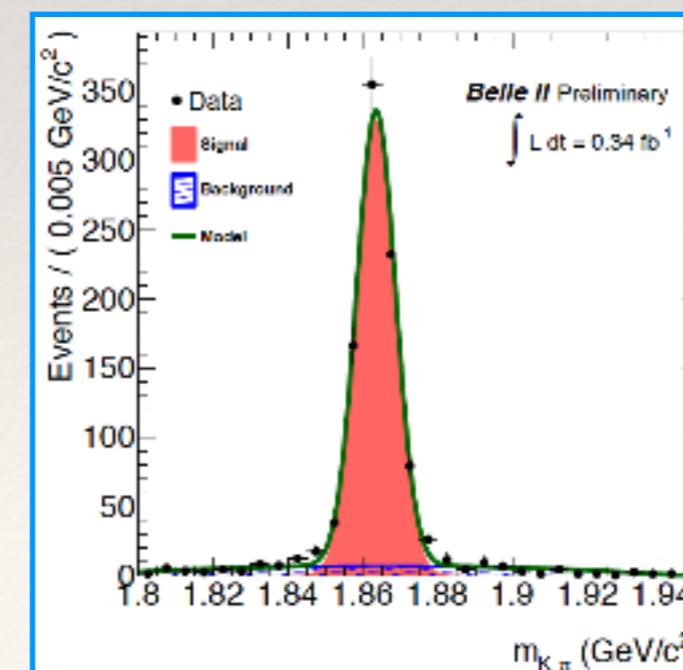
- ❖  $\Delta t$  resolution is dominated by Tag-side vertex resolution:



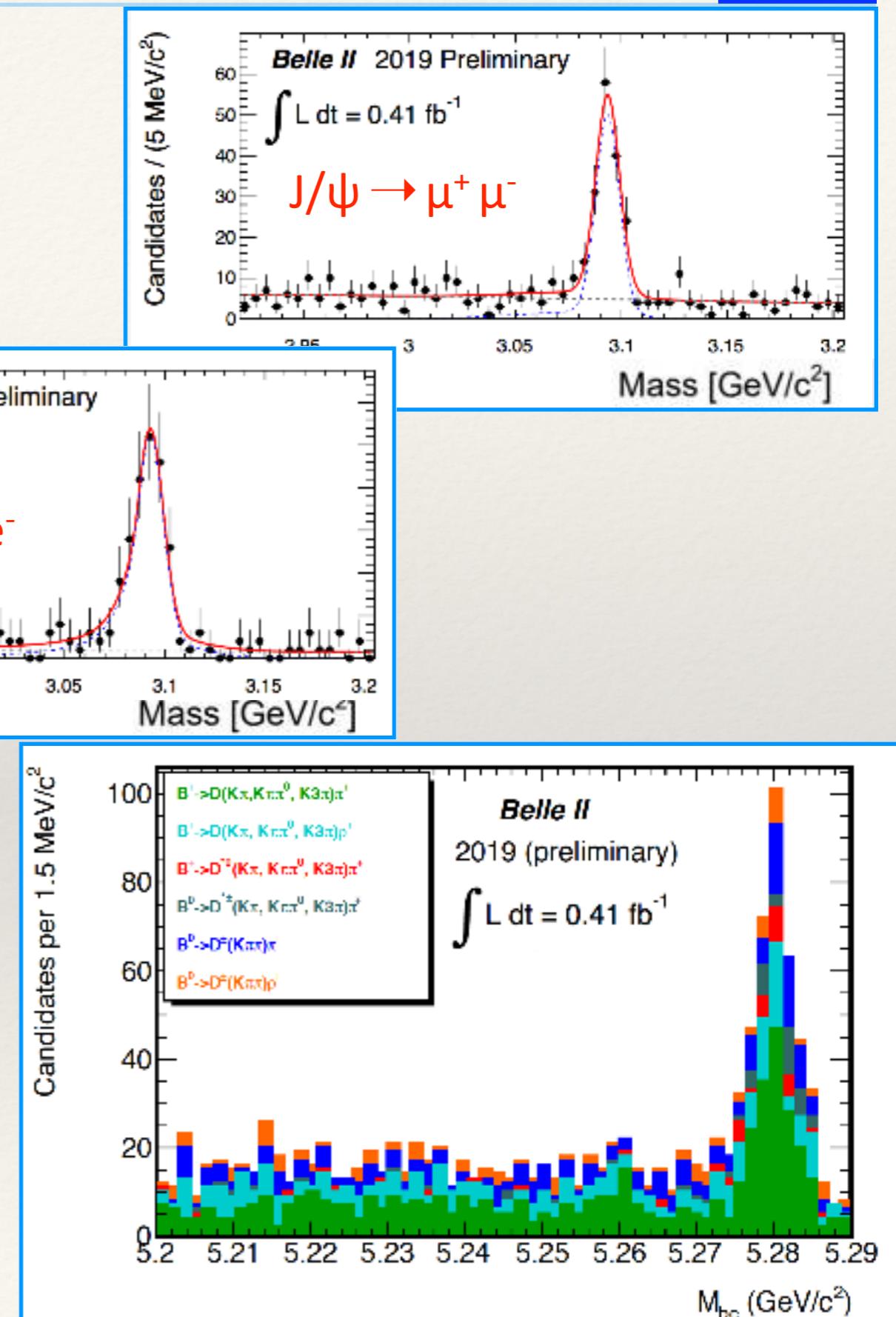
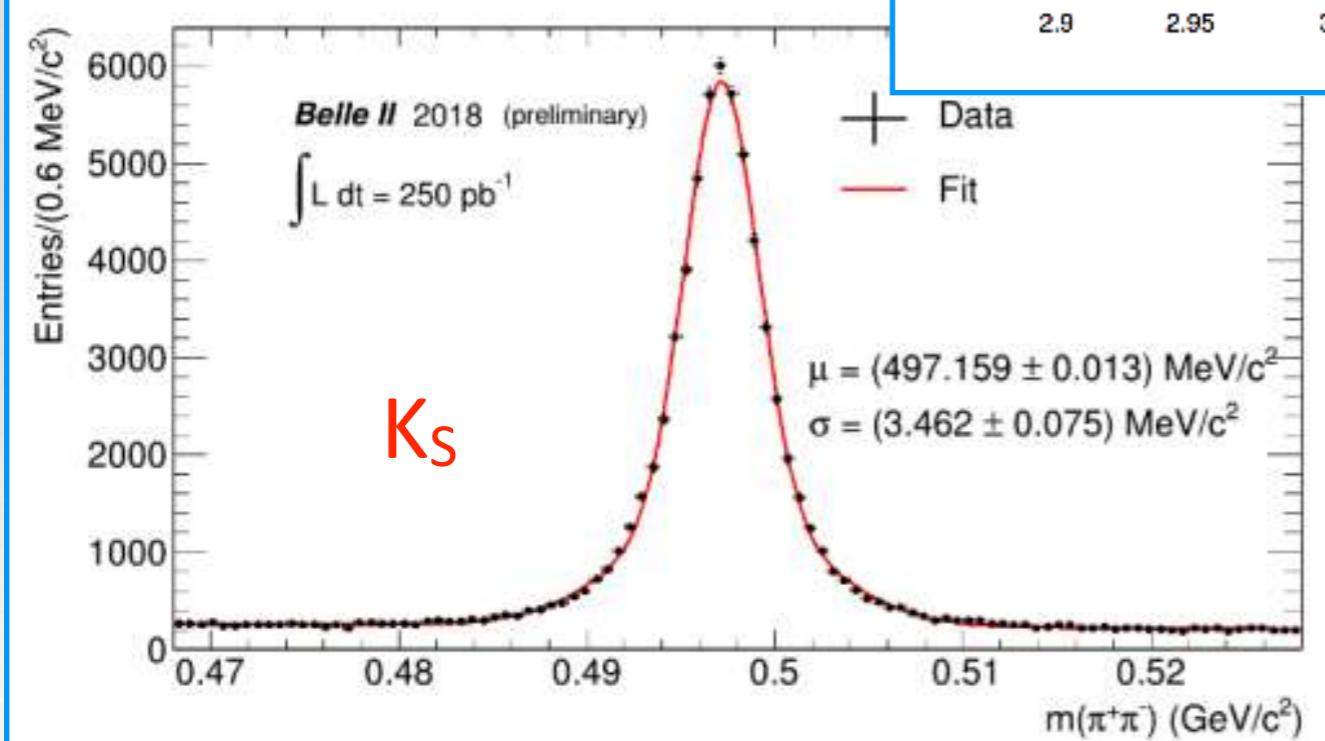
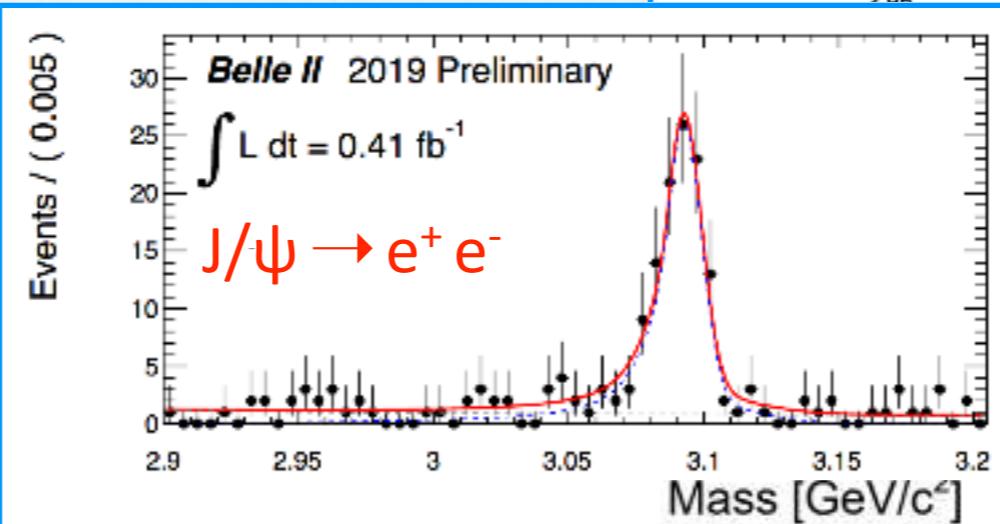
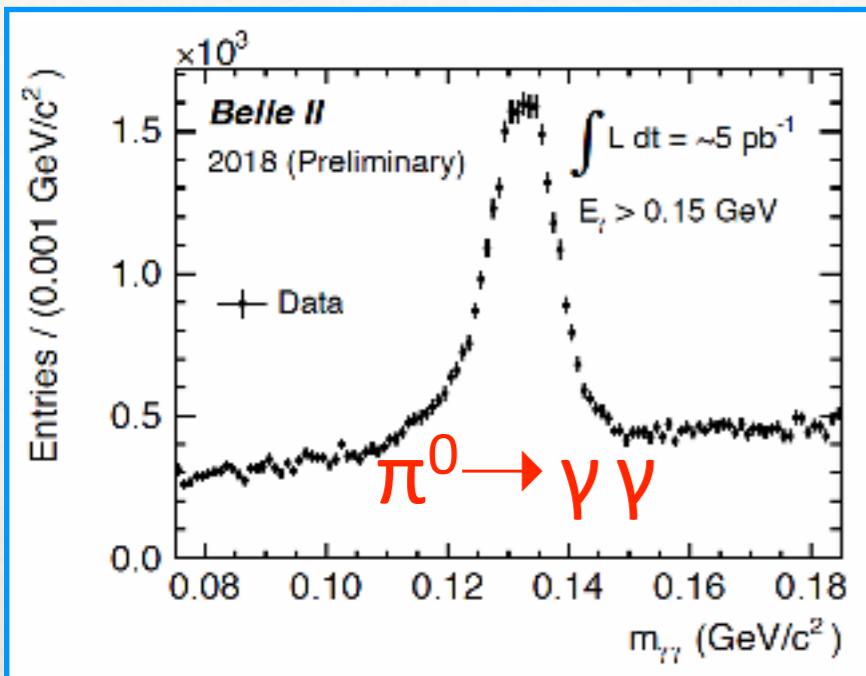
- ❖ Measurement of  $D^0$  lifetime with Belle II first data



$$\text{measured } \tau_{D^0} = (370 \pm 40) \text{ fs}$$



# Sample of particles reconstructed in first data



# Belle II prospects for $\phi_1 / \beta$



Phase of  $V_{td}$ :  $\phi_1 \equiv \beta \equiv \arg[-V_{cb}^* V_{cd} / (V_{tb}^* V_{td})]$

- ❖  $\sin 2\phi_1$  is the most precisely measured UT parameter:

w.a:  $\phi_1^{\text{HFLAV}} = (22.2 \pm 0.7)^\circ$  / global fit:  $\phi_1^{\text{CKMFitter}} = (22.51^{+0.55}_{-0.40})^\circ$

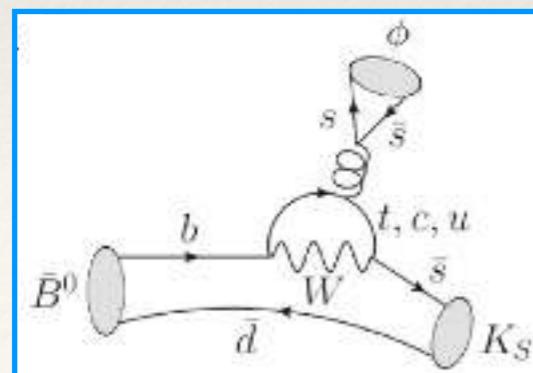
- ❖ Tree-dominated  $b \rightarrow c \bar{c} s$ : golden mode  $B^0 \rightarrow J/\psi K_s$ .

- ❖ Theoretically and experimentally precise.
- ❖ Syst. due to vertex and  $\Delta t$  resolution will be the limiting uncertainty with  $50 \text{ ab}^{-1}$  of data.
- ❖ Penguin pollution controlled with  $B^0 \rightarrow J/\psi \pi^0$  data.
- ❖ Expected total uncertainty  $\delta\phi_1 \lesssim 0.1^\circ$  with  $50 \text{ ab}^{-1}$ .

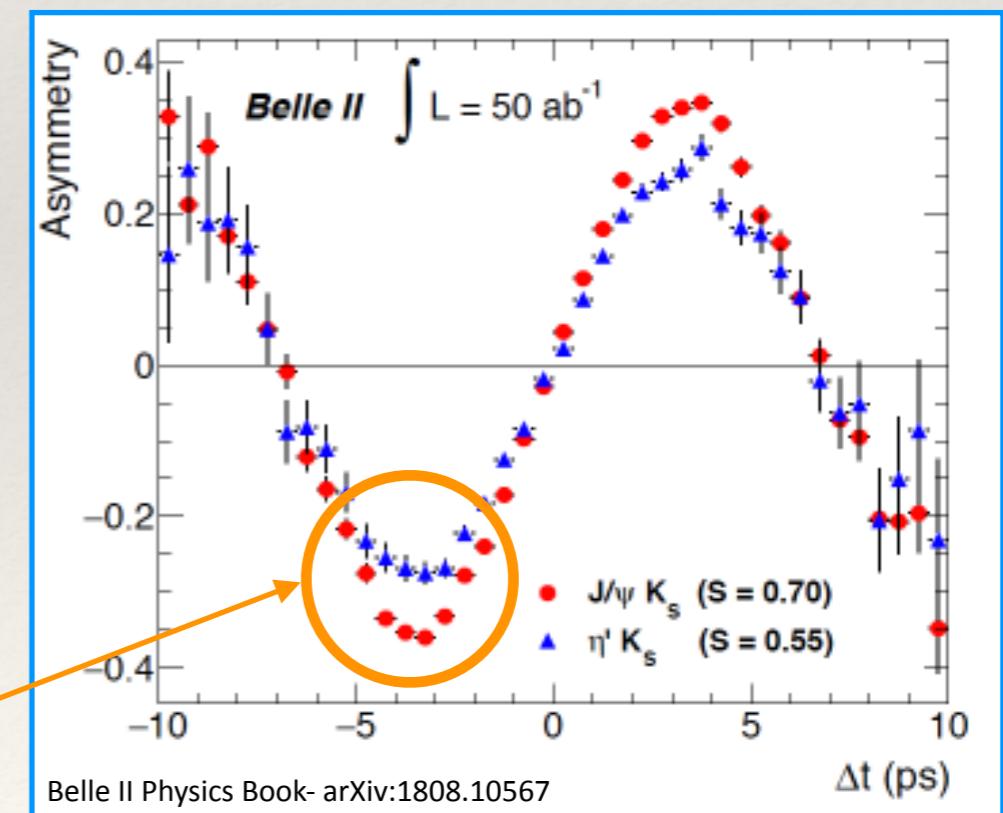
- ❖ Gluonic-penguin-dominated  $b \rightarrow q \bar{q} s$ :

$B^0 \rightarrow \phi K_s, \eta' K_s, \omega K_s, K_s \pi^0, K_s \pi^0 \gamma$ .

- ❖ Particularly sensitive to NP.
- ❖ With increased stat.: additional decays, e.g.,  $\phi \rightarrow \pi^+ \pi^- \pi^0$ .



NP would be discovered  
(mode w/o competition from LHCb)



# Belle II prospects for $\phi_2 / \alpha$



- Measurement based on  $b \rightarrow u \bar{u} d$  processes.

$$\phi_2 \equiv \alpha \equiv \arg[-V_{tb}^* V_{td} / (V_{ub}^* V_{ud})]$$

Significant contribution from Penguins:

$$\mathcal{A}_{CP} \neq 0 \text{ and } \phi_2^{\text{eff}} = \phi_2 + \Delta \phi_2.$$

Most precise determination of  $\phi_2$  from isospin analysis of  $B^0 \rightarrow \pi\pi, \rho\rho$  decays.

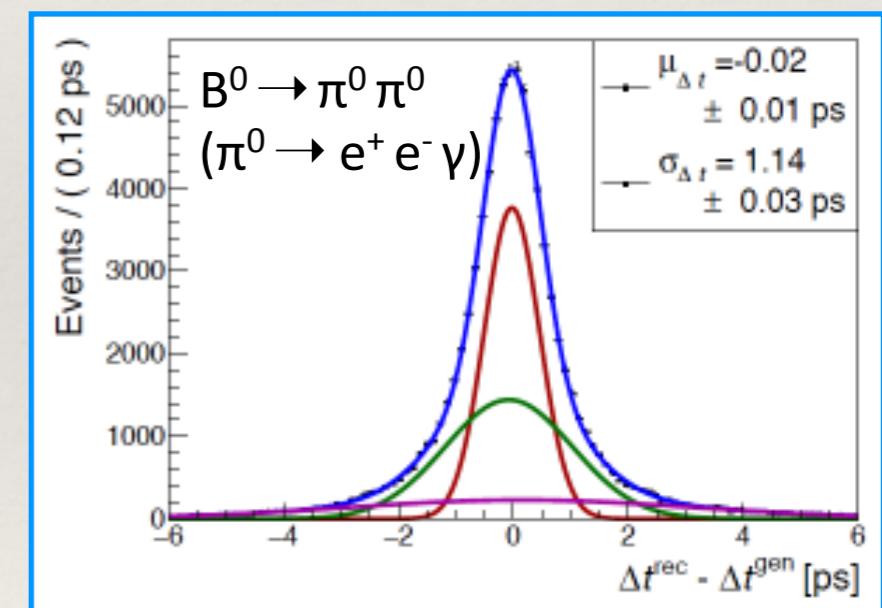
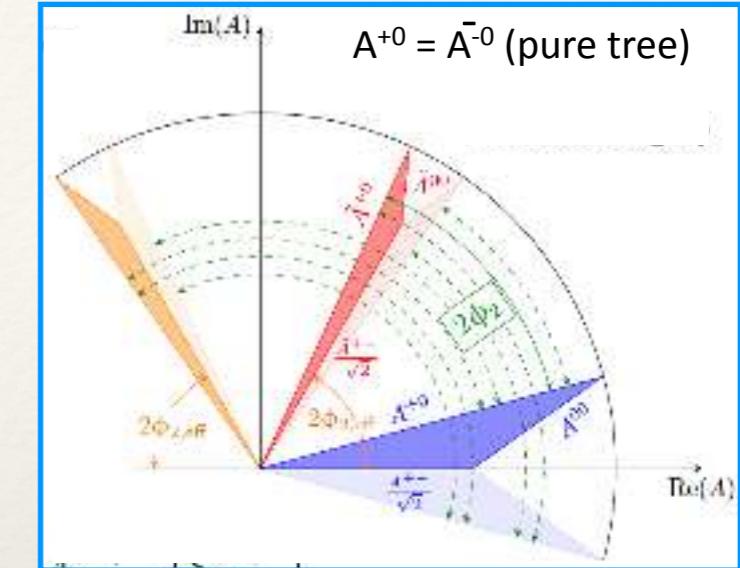
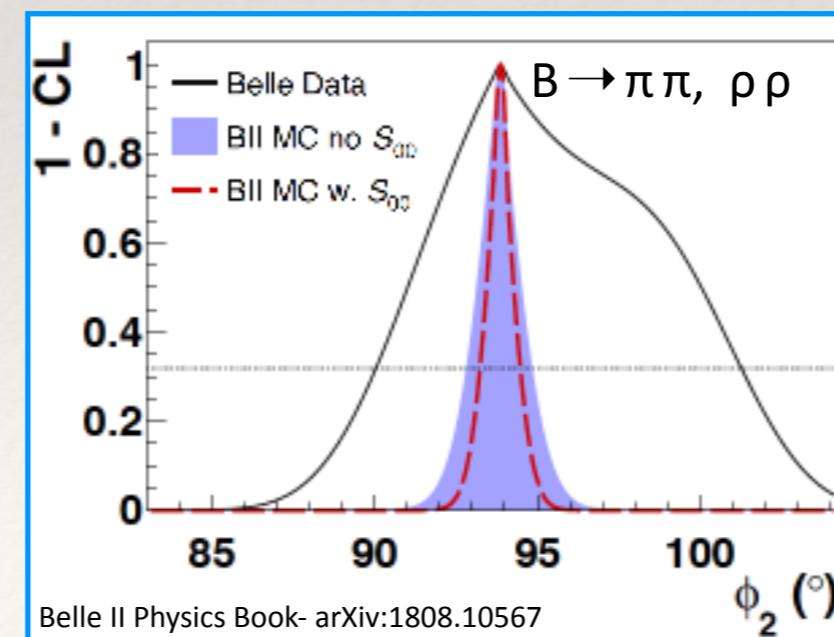
- $B^0 \rightarrow \pi^0 \pi^0$  (never measured so far): solve 8-fold ambiguity on  $\phi_2$ .

**Challenge of Belle II:**  $B^0$  decay vertex reconstructed based on  $\gamma$  conversion and Dalitz  $\pi^0$  decays with IP-tube constraint.

- Current precision:

w.a.:  $\phi_2^{\text{HFLAV}} = (84.9^{+5.1}_{-4.5})^\circ$  / global fit:  $\phi_2^{\text{CKMFitter}} = (91.6^{+1.7}_{-1.1})^\circ$

Expected total uncertainty:  
 $\delta\phi_2 \lesssim 1^\circ$  with  $50 \text{ ab}^{-1}$ .



# Belle II prospects for $\phi_3 / \gamma$

Phase of  $V_{ub}$  and of CPV:  $\phi_3 \equiv \gamma \equiv -\arg[V_{ub}^* V_{ud} / (V_{cb}^* V_{cd})]$

- ❖  $\phi_3$  is a standard candle: accessible at tree level.

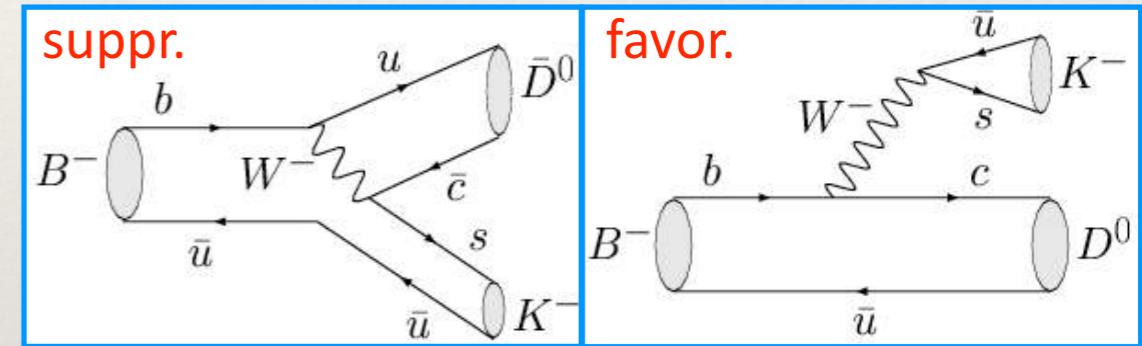
Very precise theoretical prediction  $\delta\phi_3/\phi_3 \sim 10^{-7}$ .

Current precision: w.a.  $\phi_3^{\text{HFLAV}} = (71.1^{+4.6}_{-5.3})^\circ$  / global fit  $\phi_3^{\text{CKMFitter}} = (65.81^{+0.99}_{-1.66})^\circ$

→ target  $\sim 1^\circ$  precision with Belle II and LHCb.

- ❖  $\phi_3$  is the phase between  $b \rightarrow u$  and  $b \rightarrow c$  transition:

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



- ❖ Measured via the interference between  $B^- \rightarrow D^0 K^-$  and  $B^- \rightarrow \bar{D}^0 K^-$  with various  $D^0$  channels:

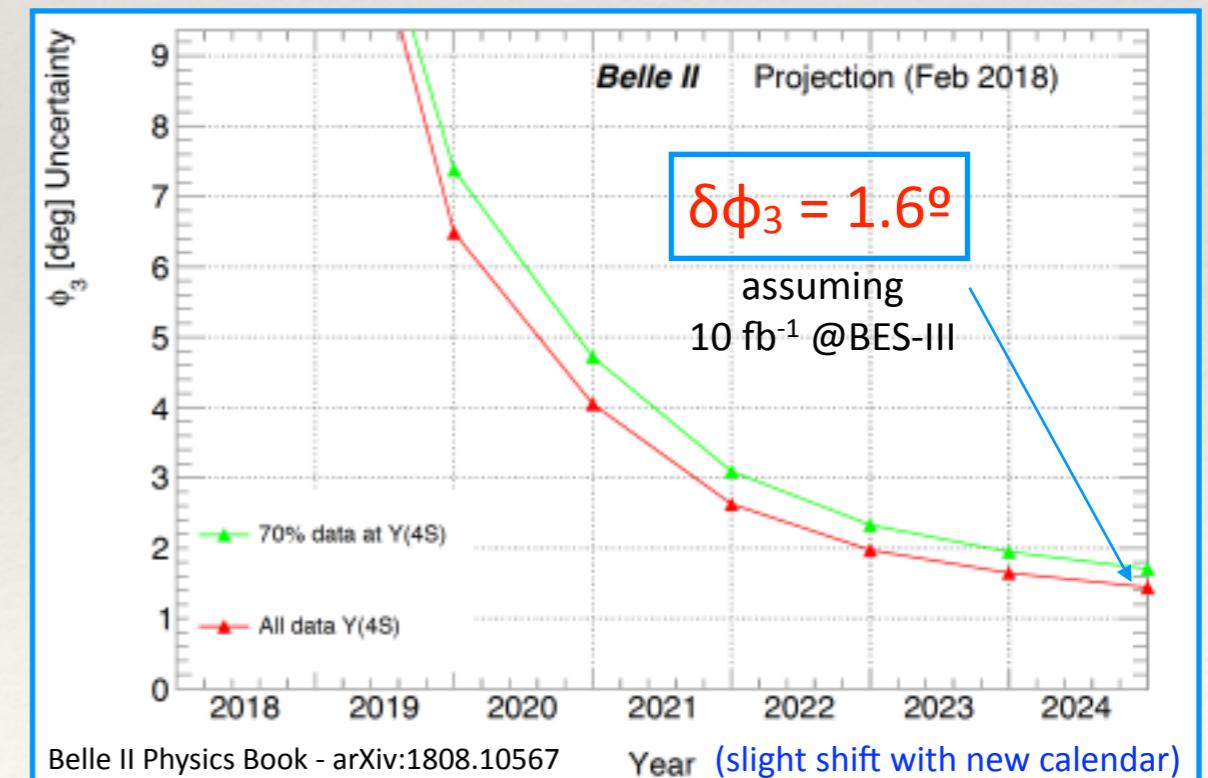
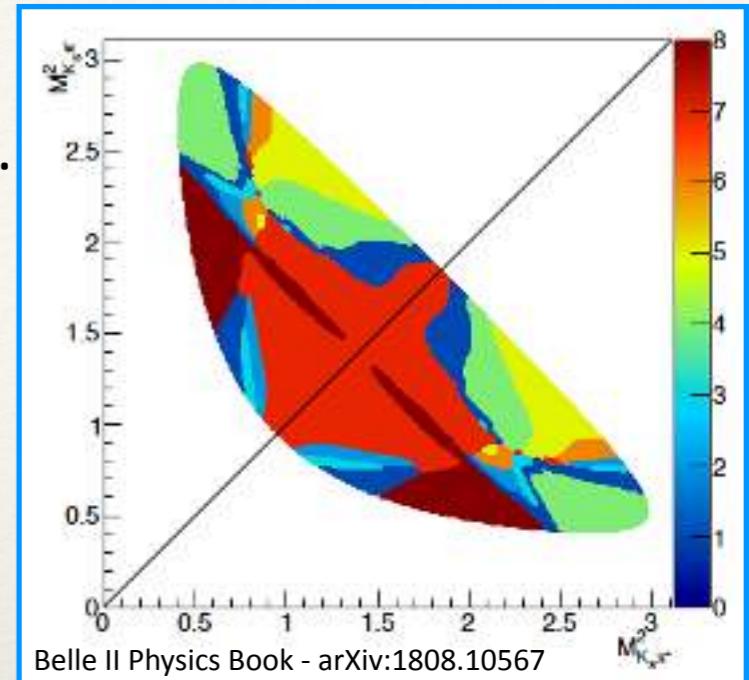
- ❖ GLW method: CP eigenstates  $K^+K^-$ ,  $\pi^+\pi^-$ ,  $K_S\pi^0$ , ...
- ❖ ADS method:  $K^+$  ( $n\pi$ ) $^-$
- ❖ GGSZ method: self-conjugate multi-body states  $K_S\pi^+\pi^-$ ,  $K_S\pi^+\pi^-\pi^0$ , ...

→ complementarity as far as ambiguities and sensitivity are concerned, combination needed to reach good accuracy.

# Belle II prospects for $\phi_3 / \gamma$



- ❖ Golden method in Belle II: GGSZ  $B^- \rightarrow (K_S \pi^+ \pi^-) K^-$ 
  - ❖ Model-independent binned Dalitz plot. Many inputs from data.
  - ❖ Precise strong phase measurement needed to match Belle II stat precision : expected from BES-III D decays.
  
- ❖ Belle II assets:
  - ❖ Unbiased trigger.
  - ❖ Good neutrals reconstruction.
  - ❖ Part of syst. will improve with integrated luminosity (see  $B \rightarrow D \pi$  control sample).
  
- ❖ Other modes become also sensitive:
  - $D^* \rightarrow D^0 \pi^0, D^0 \gamma$
  - $D^* \rightarrow \pi^0 \pi^0, K_L \pi^0, K_S \pi^0 \pi^0, K_S K_S K_L, \dots$
 with:
  - ❖ increasing stat.,
  - ❖ better K/ $\pi$  identification,
  - ❖ better continuum suppression.



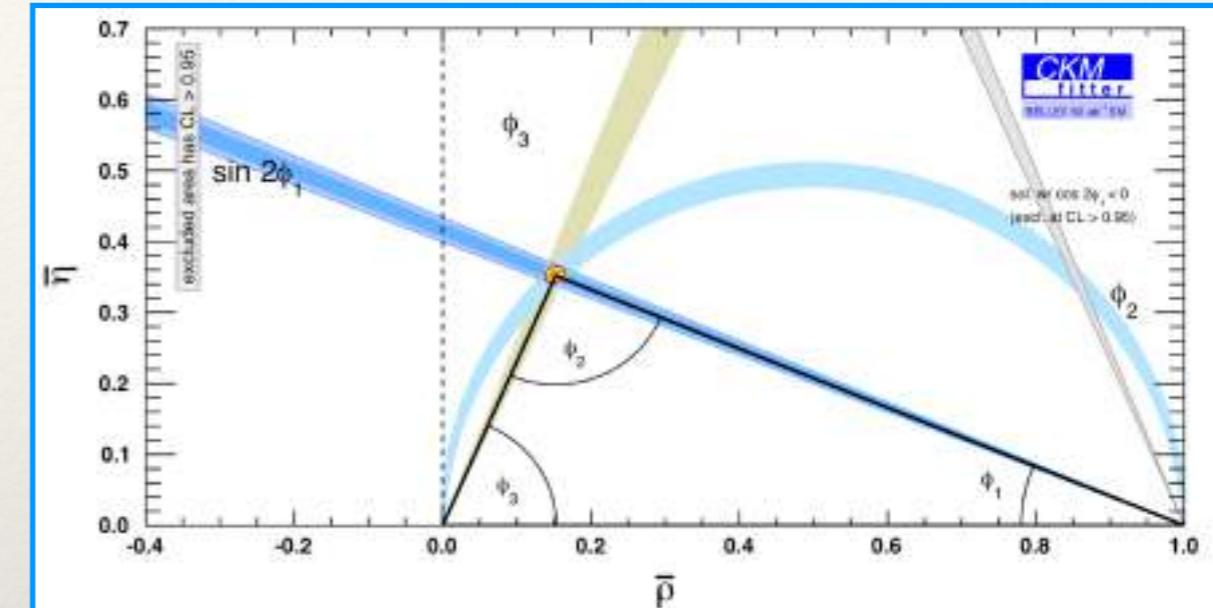
# Conclusion and outlooks



- ❖ Belle II physics run has started.

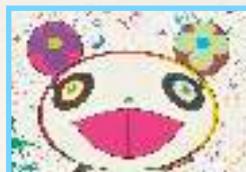
See talk by  
O. Hartbrich

- ❖ Belle II will play a key role in particle physics:
  - ❖ Accumulated experience from Belle & BaBar.
  - ❖ Unique skills for various measurements, good complementarity with LHCb.
  - ❖ CKM angle measurements will improve very quickly already with  $5\text{-}10 \text{ ab}^{-1}$ .
  - ❖ Huge dataset of  $50 \text{ ab}^{-1}$ : several measurements will start to be syst. limited → lots of work ahead!



- ❖ Expected experimental performances often improve w.r.t. Belle despite 20× higher beam induced background and lower boost.

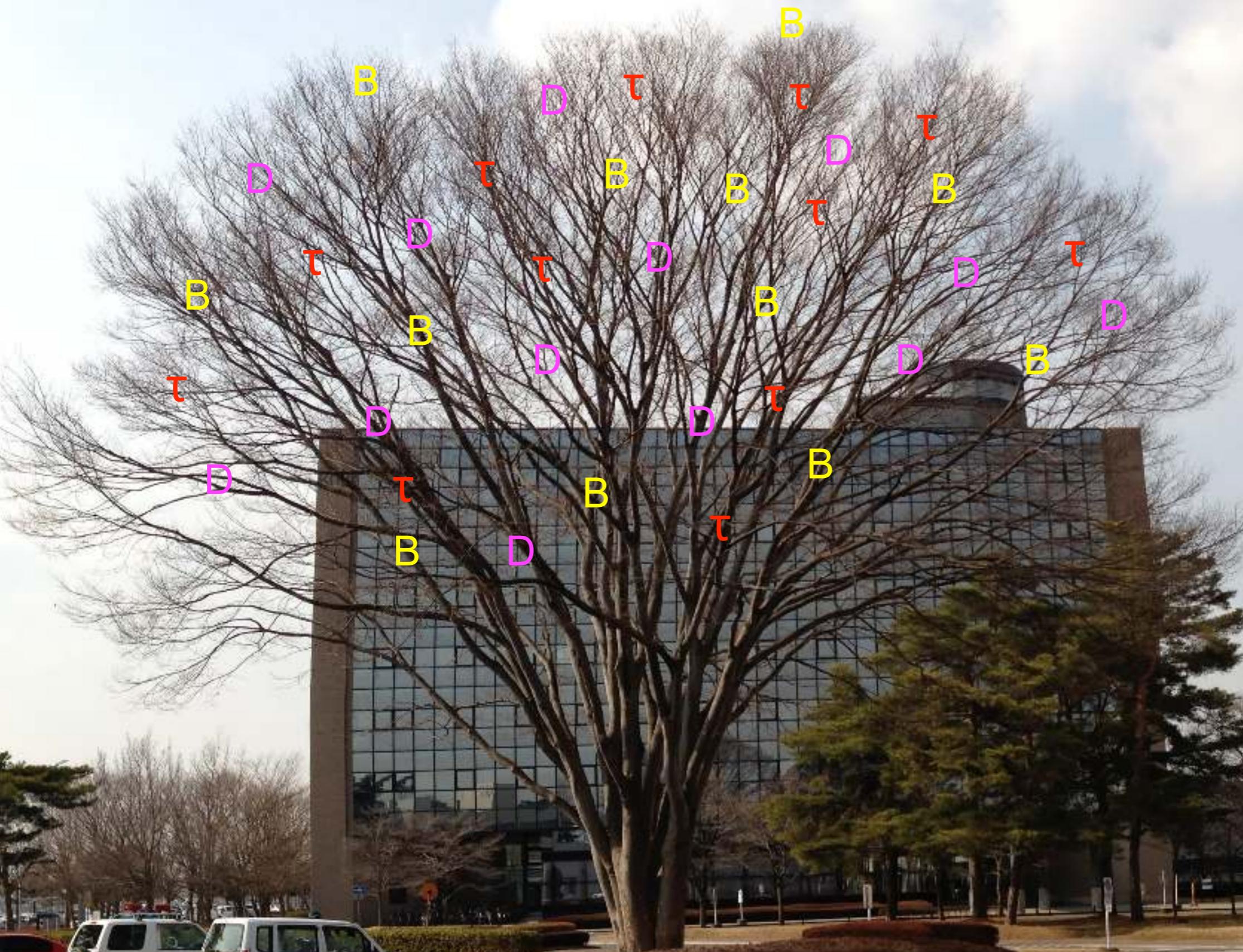
- ❖ Looking forward to the next decade of exciting Belle II results!  
Stay tuned: <https://twitter.com/belle2collab> <https://www.facebook.com/belle2collab>



and like us!

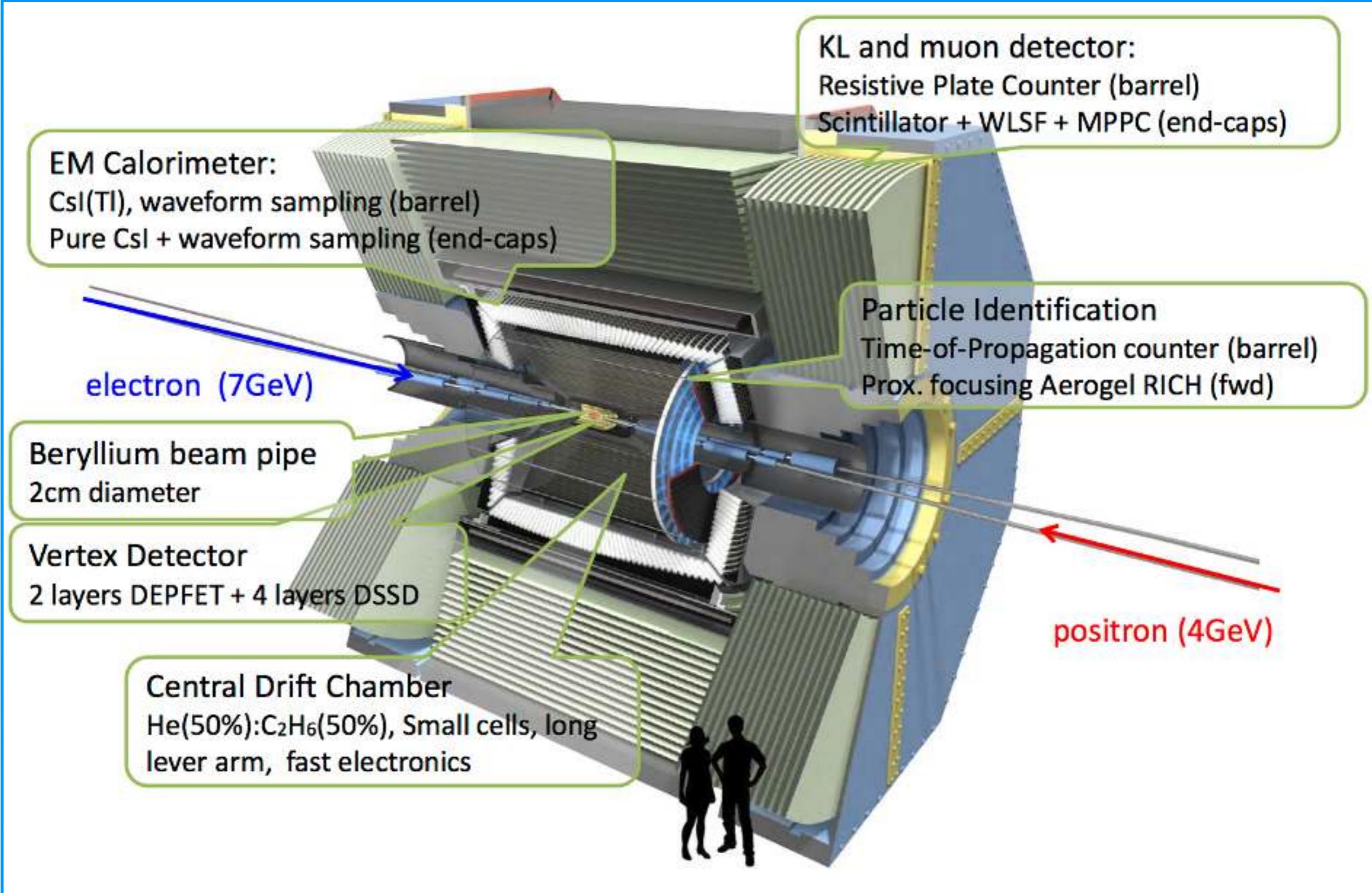
$$\begin{aligned}\delta\phi_1 &\lesssim 0.1^\circ \\ \delta\phi_2 &\lesssim 1^\circ \\ \delta\phi_3 &\lesssim 1.6^\circ\end{aligned}$$

thank you for your attention



ありがとうございます

# Belle II detector





# The SuperKEKB collider



Parameters (LER / HER)	KEKB crab cavities	SuperKEKB phase 2	SuperKEKB phase 3
En. (GeV)	3.5 / 8.0	4.0 / 7.007	4.0 / 7.007
$\epsilon_x(nm)$	18 / 24	2.2 / 5.2	3.2 / 4.6
$\sigma_x^*(\mu m)$	147 / 170	16.8 / 22.8	10 / 11
$\sigma_y^*(\mu m)$	0.94 / 0.94	0.308 / 0.5	0.048 / 0.062
$\beta_x^*(mm)$	1200 / 1200	128 / 100	32 / 25
$\beta_y^*(mm)$	5.9 / 5.9	2.16 / 2.4	0.27 / 0.30
$\xi_y$	0.129 / 0.09	0.0240 / 0.0257	0.088 / 0.081
$2\phi(mrad)$	22	83	83
$I_{beam} (A)$	1.64 / 1.19	1.0 / 0.8	3.6 / 2.6
Nb bunches	1584	2500	2500
$\mathcal{L}(10^{-34}cm^{-2}s^{-1})$	2.11	1	80