EUROPEAN PHYSICAL SOCIETY HEP2019

European Physical Society
Conference on High Energy Physics
10-17 July 2019 - Ghent, Belgium

First look at CKM parameters from early Belle II data

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 ϕ_1, ϕ_2 and ϕ_3
- Conclusion

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on behalf of the Belle II collaboration

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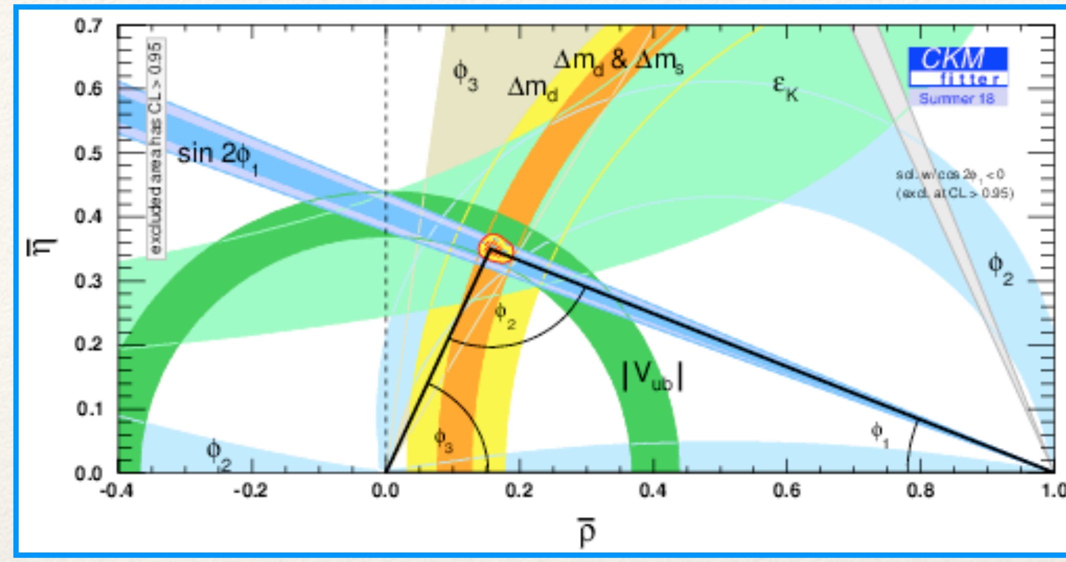
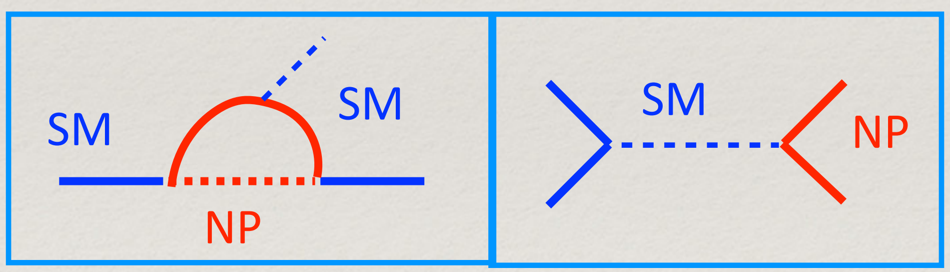
IPHC Institut Pluridisciplinaire Hubert Curien Strasbourg

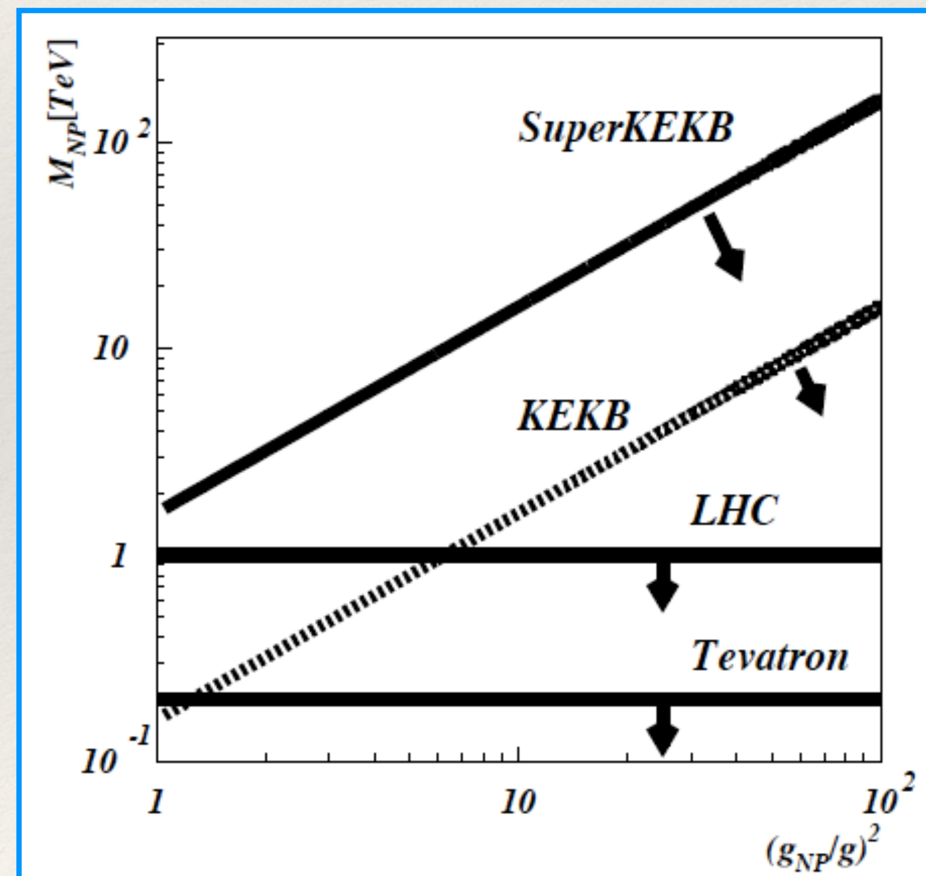
See talk by F. Forti

The Belle II experiment



- Legacy of B factories, BaBar and Belle:
  - Precise measurement of CPV in B system.
  - About 1.15 ab^{-1} in total at Υ(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 τ decays, light dark matter, ...
  - Quantum manifestation of New Physics: high NP mass sensitivity.





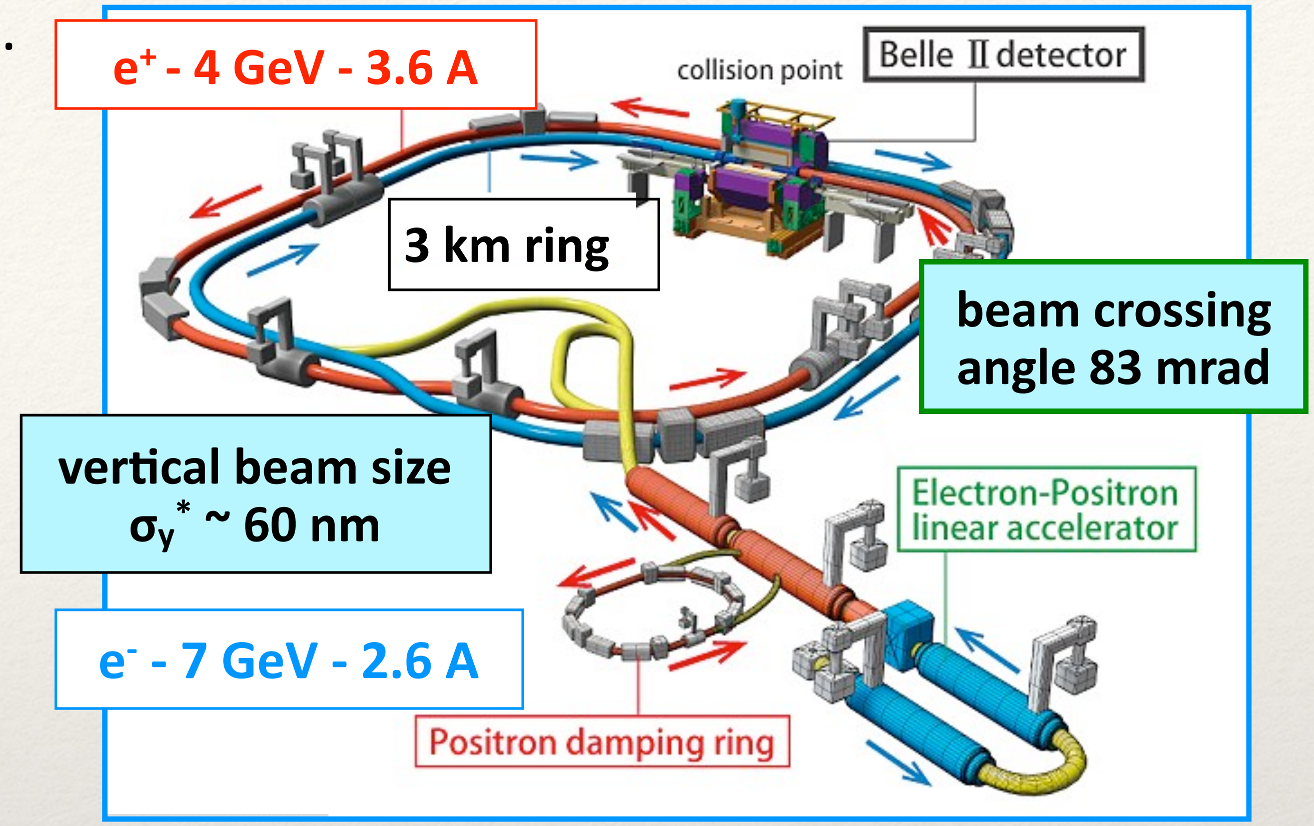
- Unique skills in Belle II w.r.t.:
  - inclusive measurements.
  - events with missing energy.
  - events with neutrals.

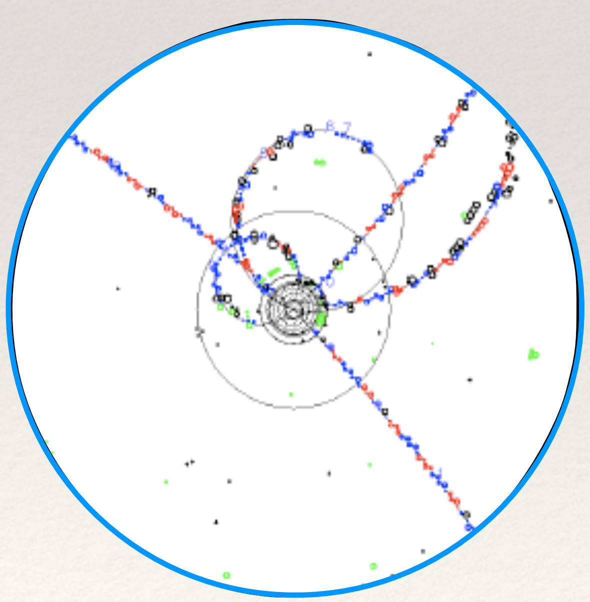
➛ interesting complementarity with LHCb

The SuperKEKB collider

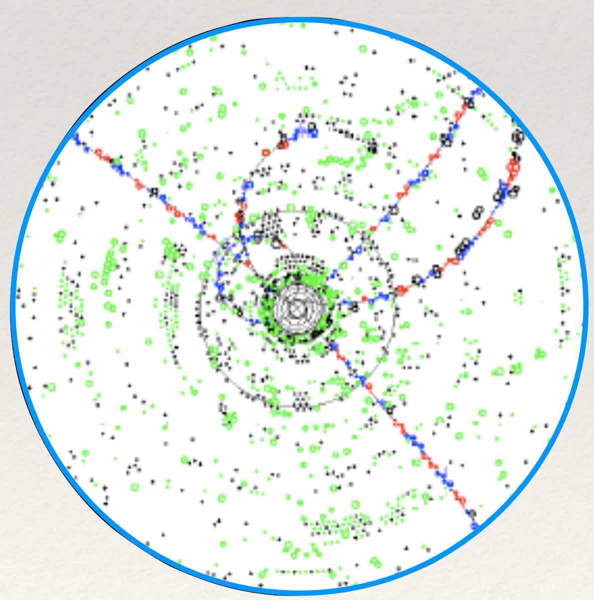
- Asymmetric e^+e^- circular collider at KEK, Japan.
- $E_{collision} = m_{Y(4S)}$ and from Y(1S) to ~ Y(6S).
- New nano-beam collision scheme:
  - KEKB transverse beam size /20
  - KEKB beam currents ×2
  - KEKB crossing-angle ×3.8
  - KEKB boost ×2/3

➛ targeted instantaneous luminosity: 8×10^{35} cm^{-2} s^{-1}, KEKB world record ×40.





Belle at KEKB



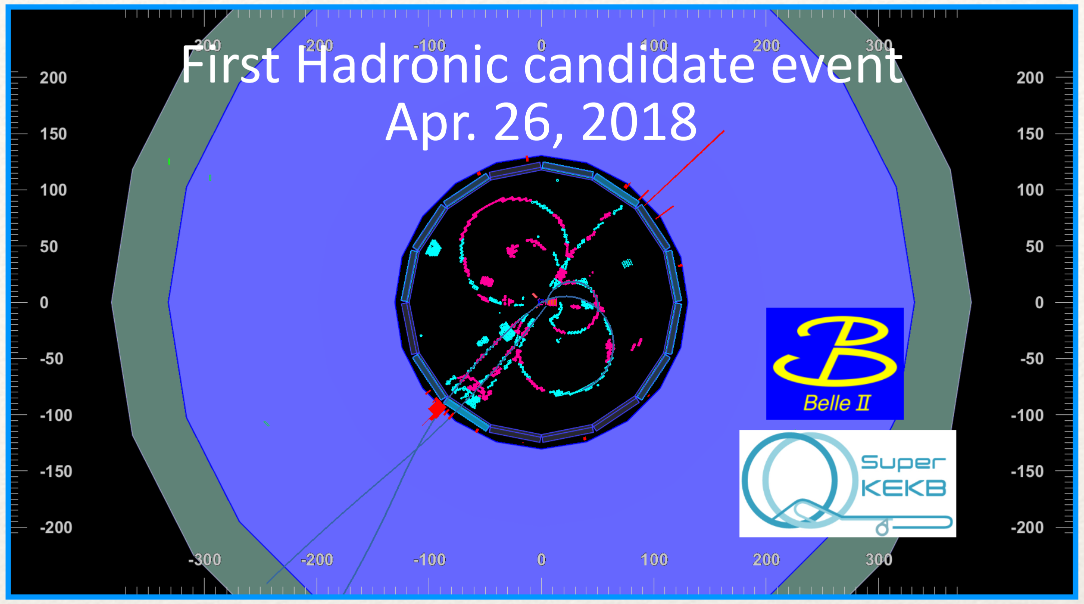
Belle at SuperKEKB

- 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.

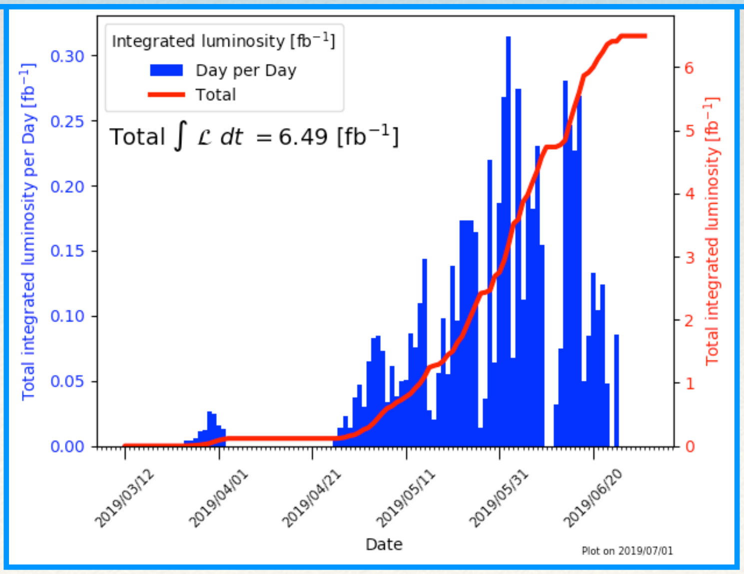
Belle II calendar

- Belle II commissioning:
  Phase 2, March-July 2018.
  - Partial ϕ coverage of the inner tracker.
  - Beam induced background study (BEAST II).
  - 0.5 fb^{-1} registered, peak lumi. 5×10^{33} cm^{-2} s^{-1}.

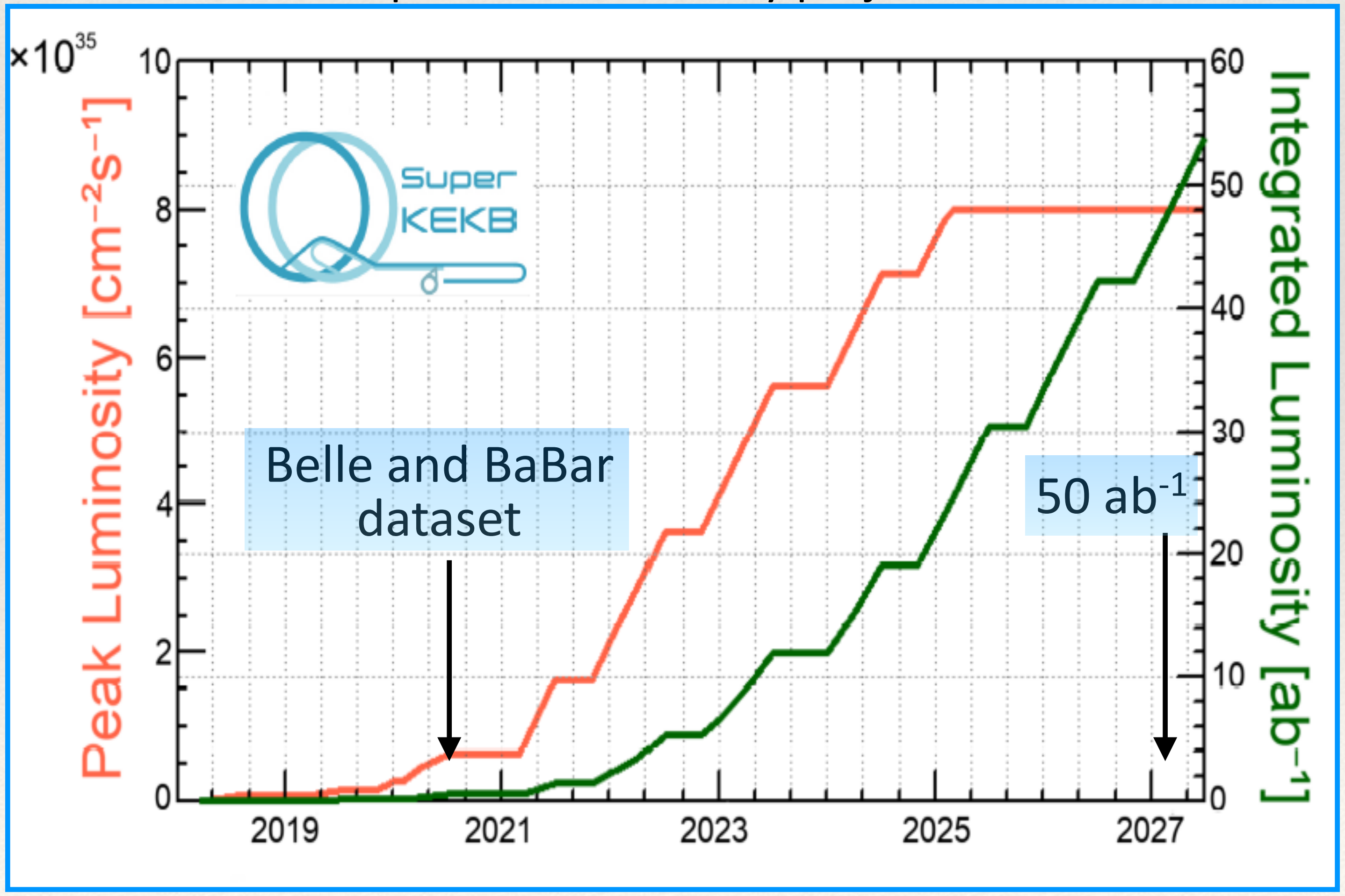


- Start of physics run:
  Phase 3, started 25 March 2019.
  All Belle II sub-detectors in DAQ.

<u>Status on July 1st</u>:
max peak lumi. 1.2×10^{34} cm^{-2} s^{-1}
6.5 fb^{-1} @Υ(4S),
0.8 fb^{-1} off-resonance.

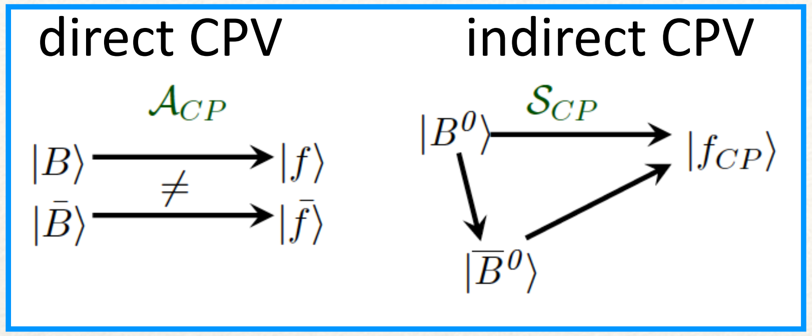


SuperKEKB luminosity projections



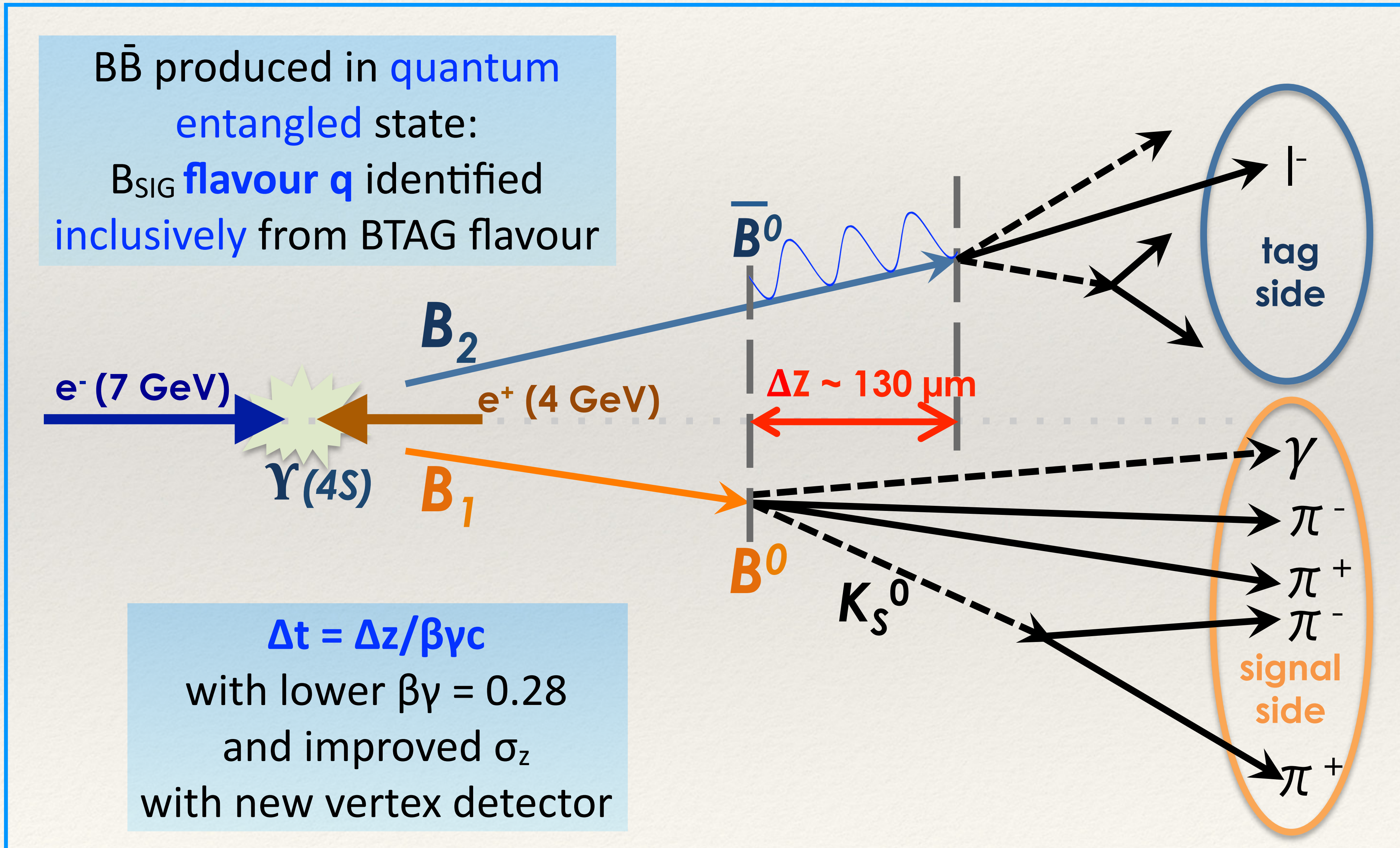
Ingredients of TDCPA measurements

for ϕ_1 and ϕ_2 measurements



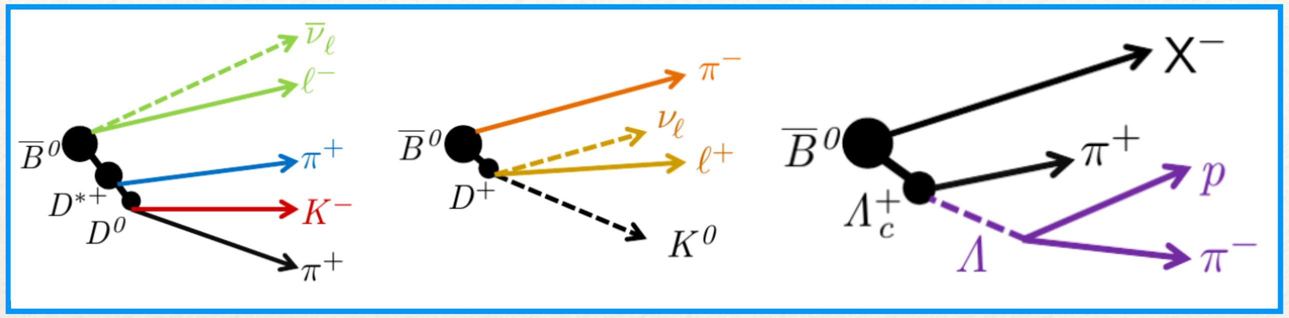
$$\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left[1 + q\left(\mathcal{A}_{CP}\cos\Delta m_d \Delta t + S_{CP}\sin\Delta m_d\Delta t\right)\right]$$

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



Flavour tagging

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



- Total expected effective tagging efficiency:

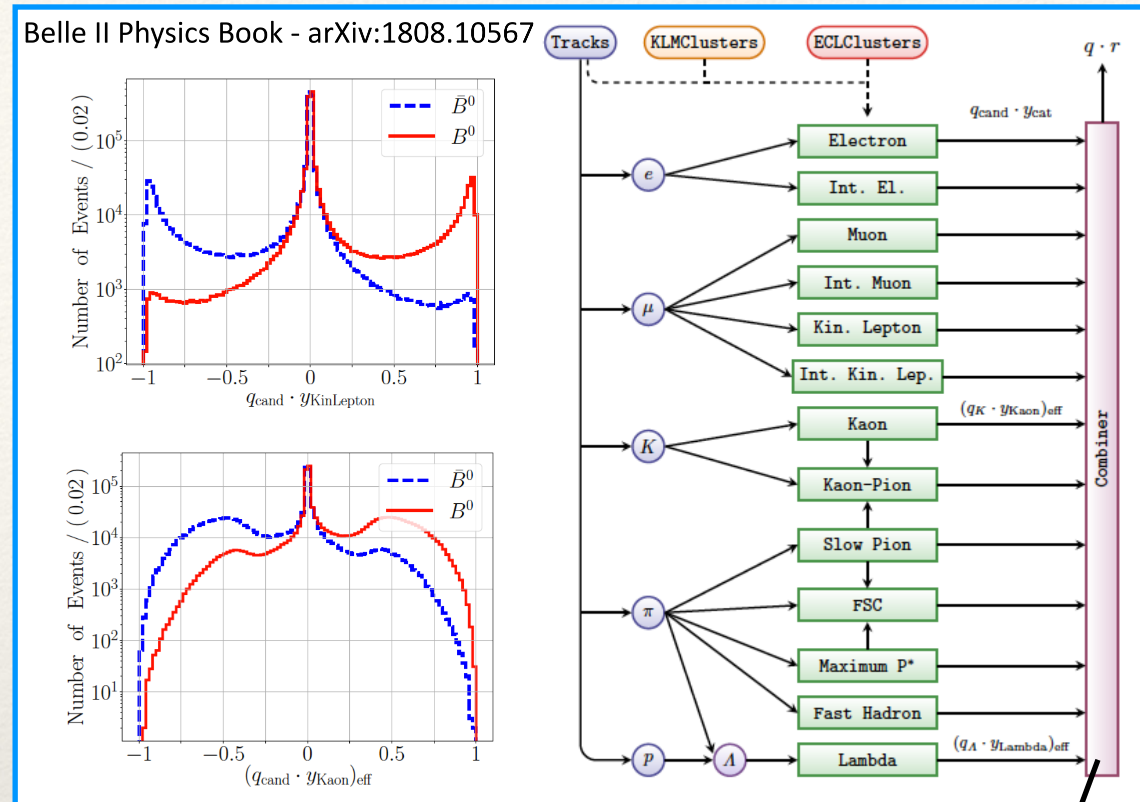
  $\sum \varepsilon_i \times (1 - 2\omega_i)^2 = 37.2\ \%$ (Belle II MC)

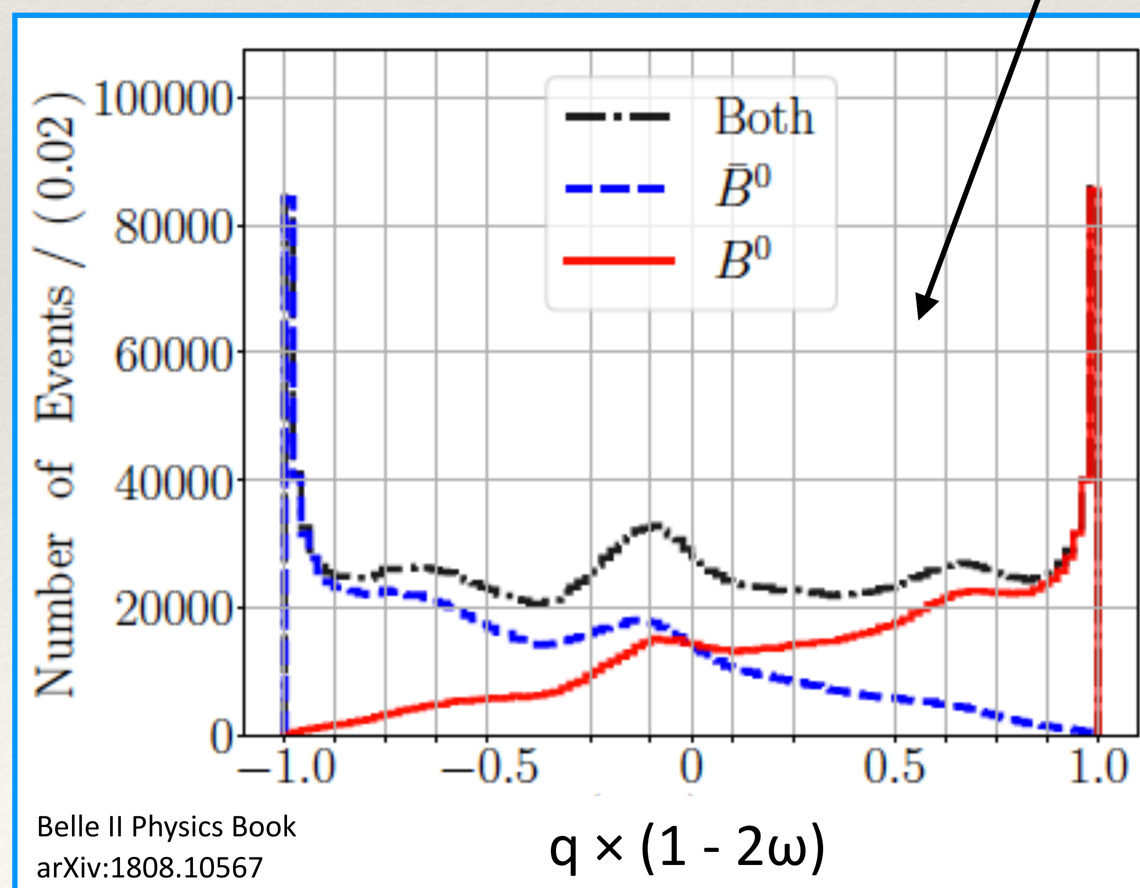
  to be compared with 30-33 % in BaBar & Belle.

  Dilution factor r due to **mis-tag ω:**

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

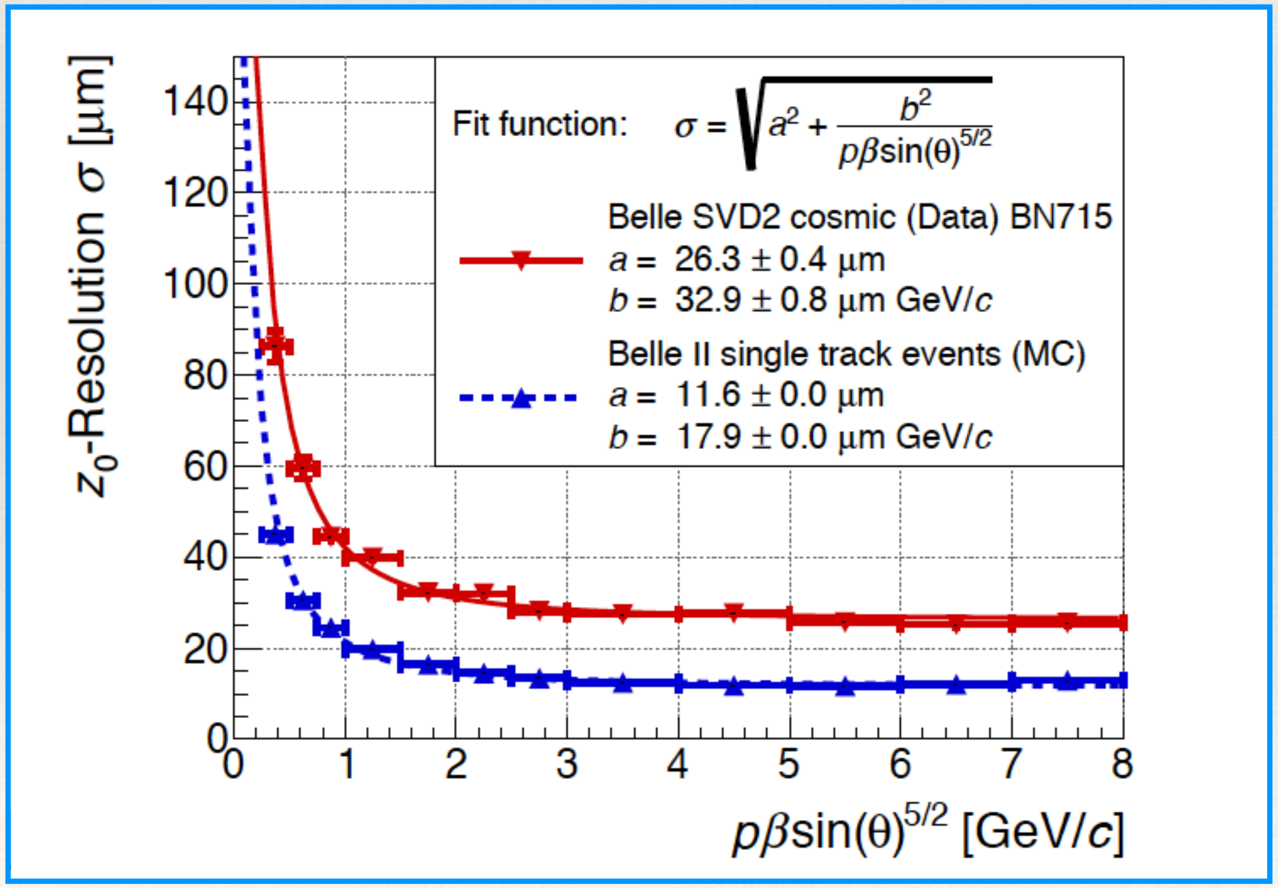
- Further improvements expected:
  - More input variables, more categories.
  - Deep NN.
  - More than 10% improvement was observed within BaBar and Belle lifetime.

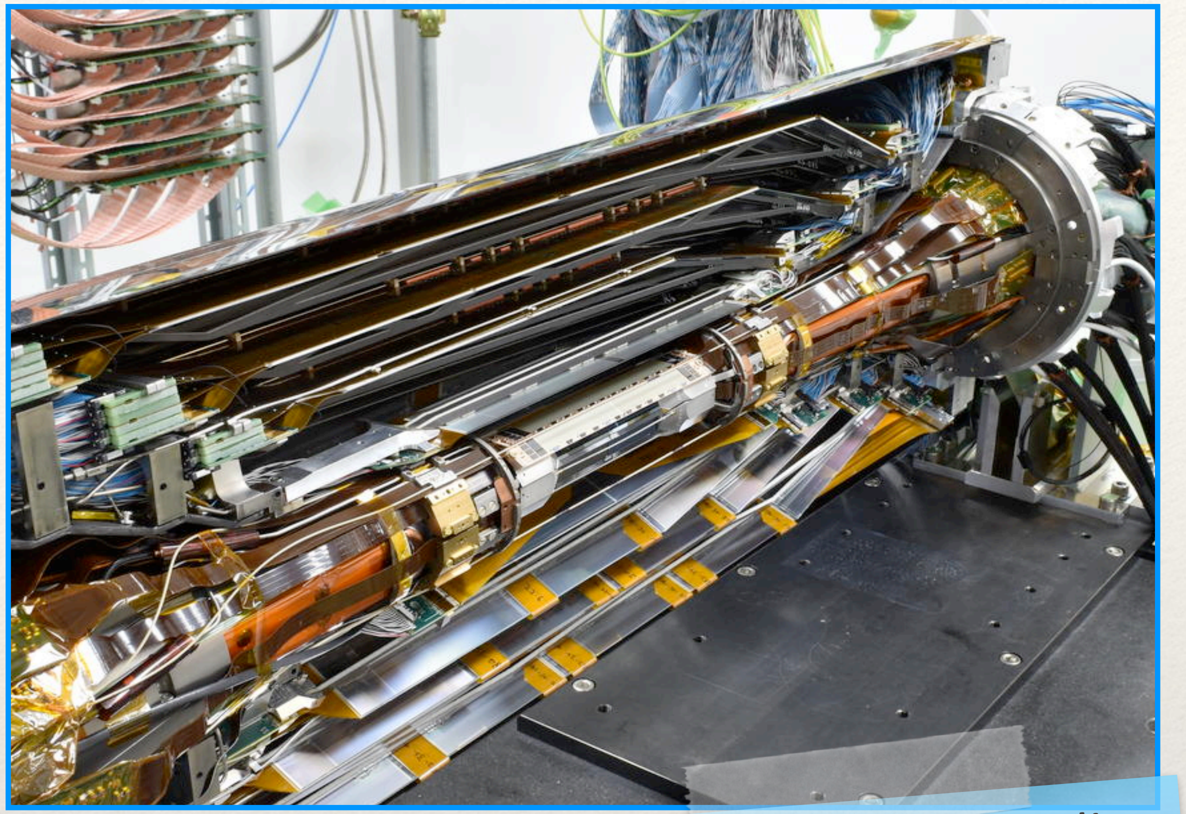




Time measurement

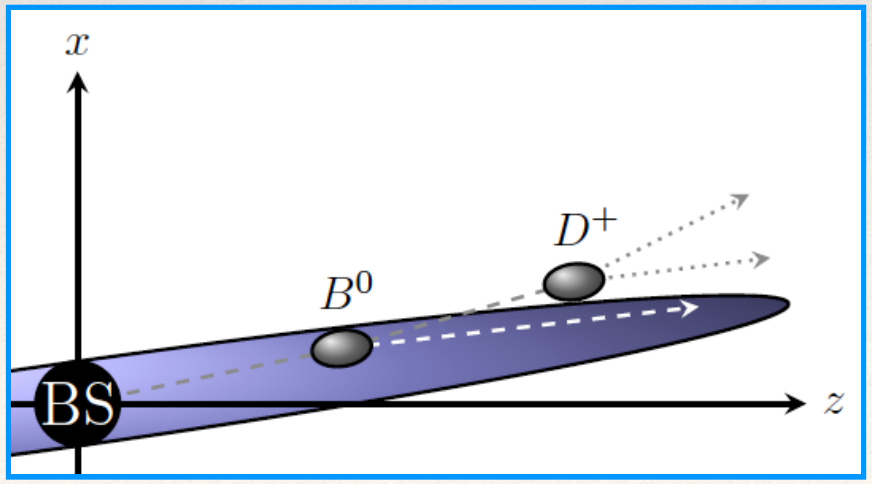
- Vertex detector inserted in Belle II end of 2018:
  - 1+ pixelated layer, r = 1.4 cm.
    + 4 layers of double-sided silicon strips with 30% extended acceptance.
  - Factor of 2 improvement expected on track impact parameters w.r.t. Belle:





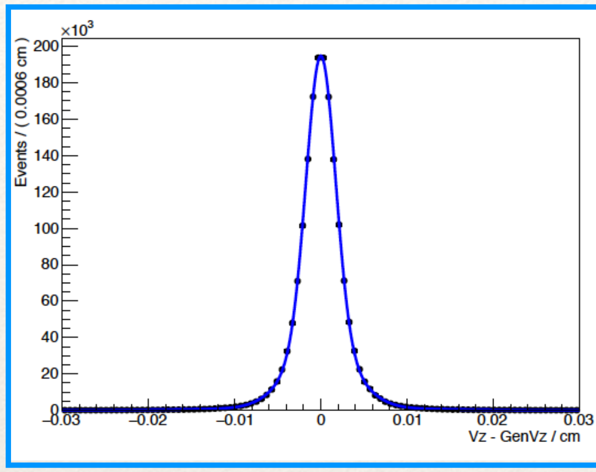
See poster by A. Paladino

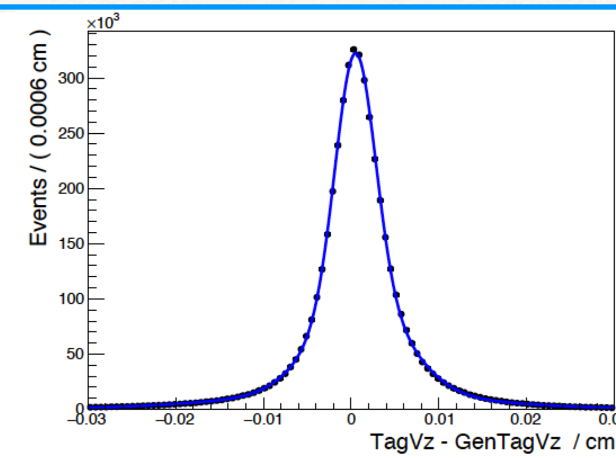
- Very small beam spot size:
  Belle, BaBar beam spot (120 × 5 × 8000) μm^3
  vs. Belle II beam spot (6 × 0.06 × 150) μm^3

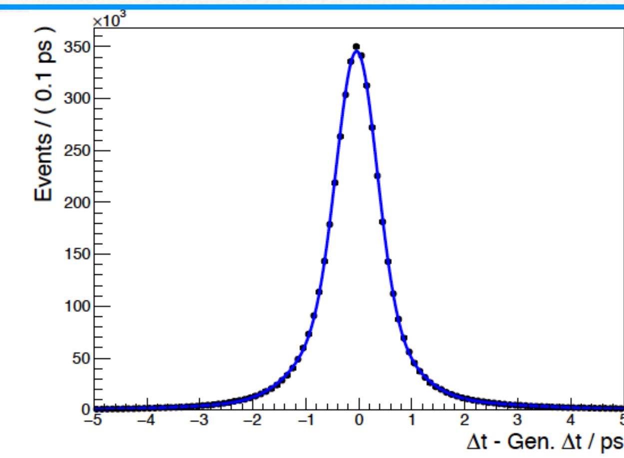


Time measurement

- Δt resolution is dominated by Tag-side vertex resolution:

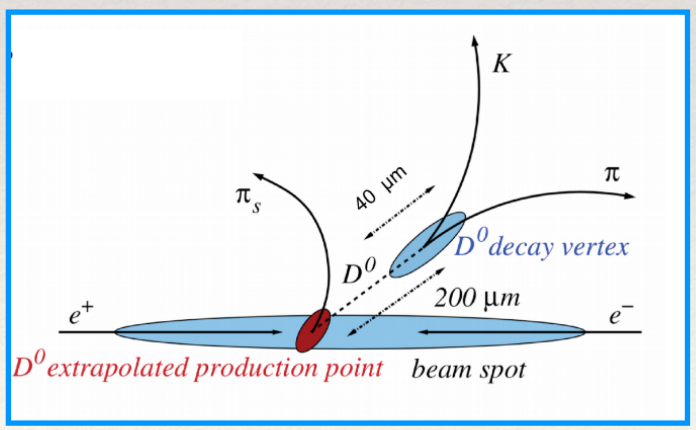




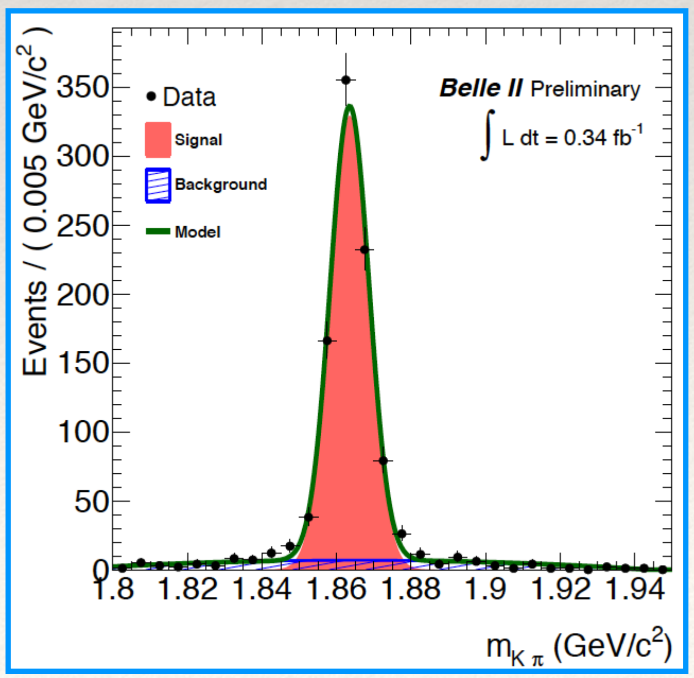


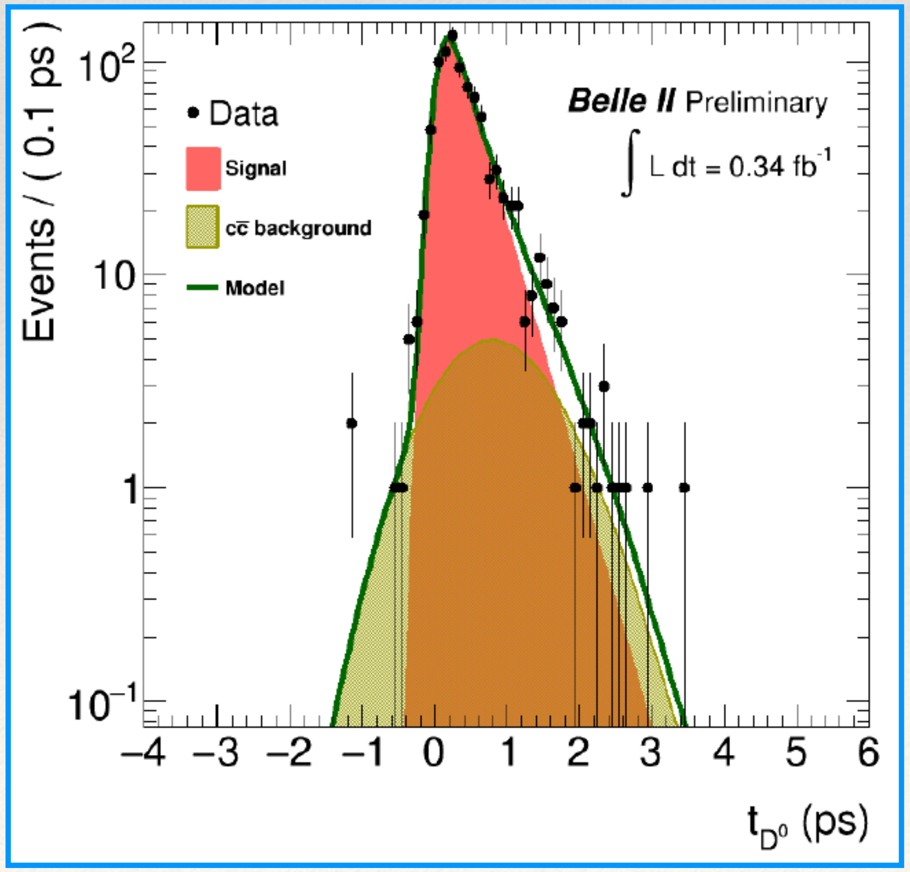
Δz resolution J/ψ → μμ		Δz resolution Tag Vertex		Δt resolution	
Belle	Belle II	Belle	Belle II	Belle	Belle II
43 μm	26 μm	89 μm	53 μm	0.92 ps	0.77 ps

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

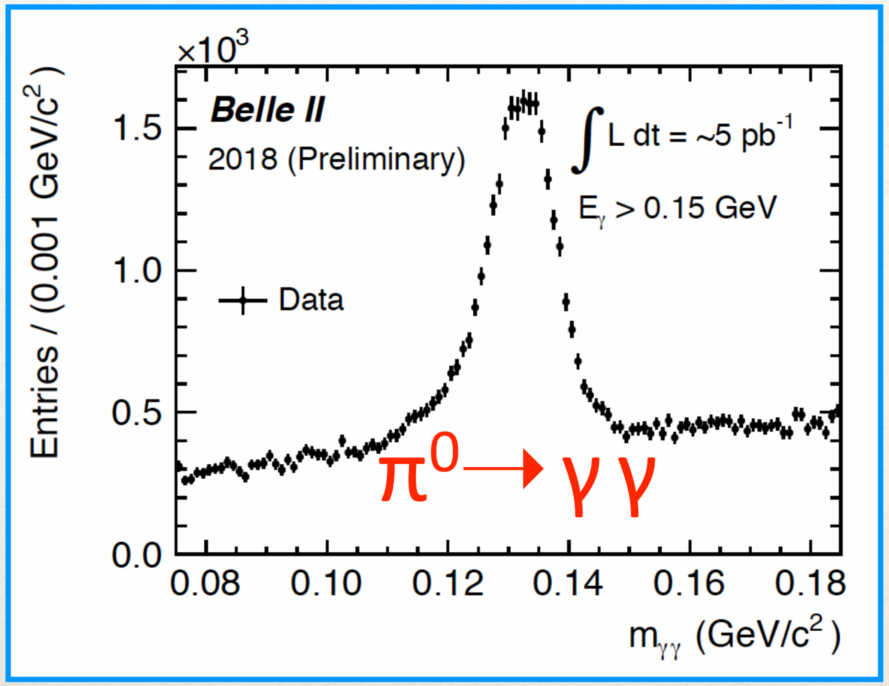


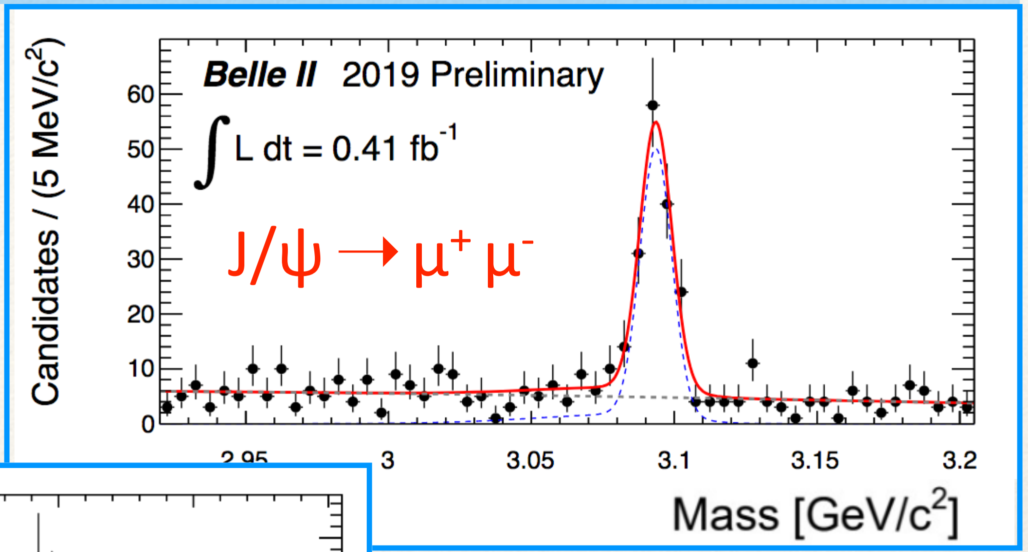
measured τ_{D^0} = (370 ± 40) fs

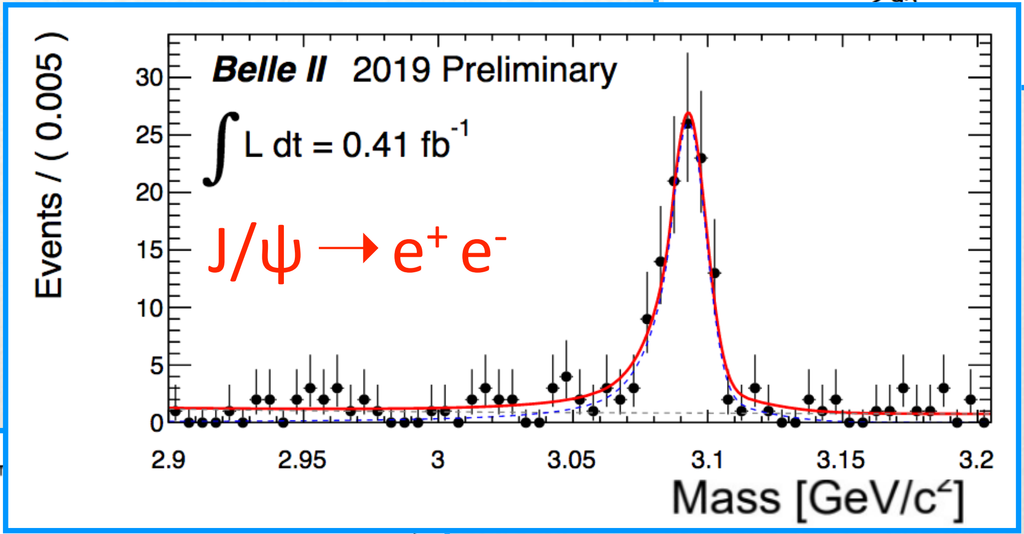


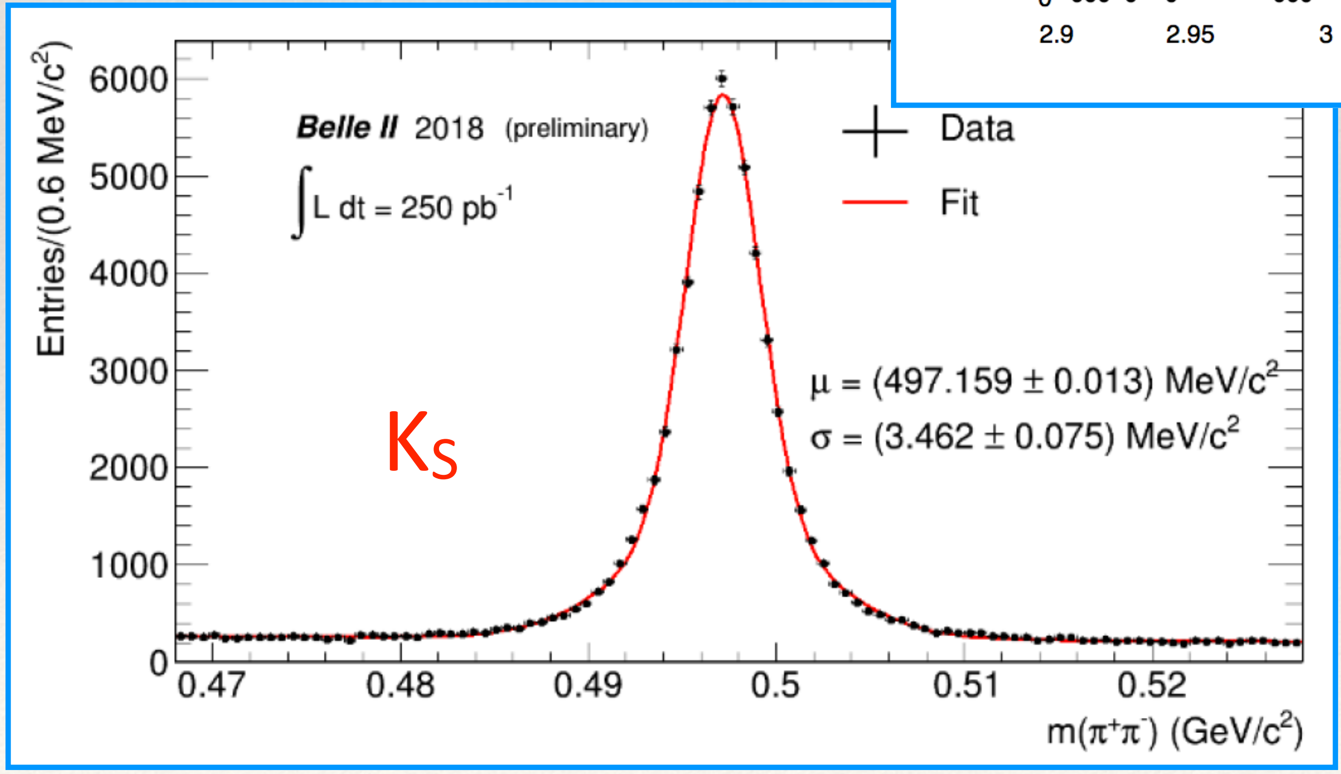


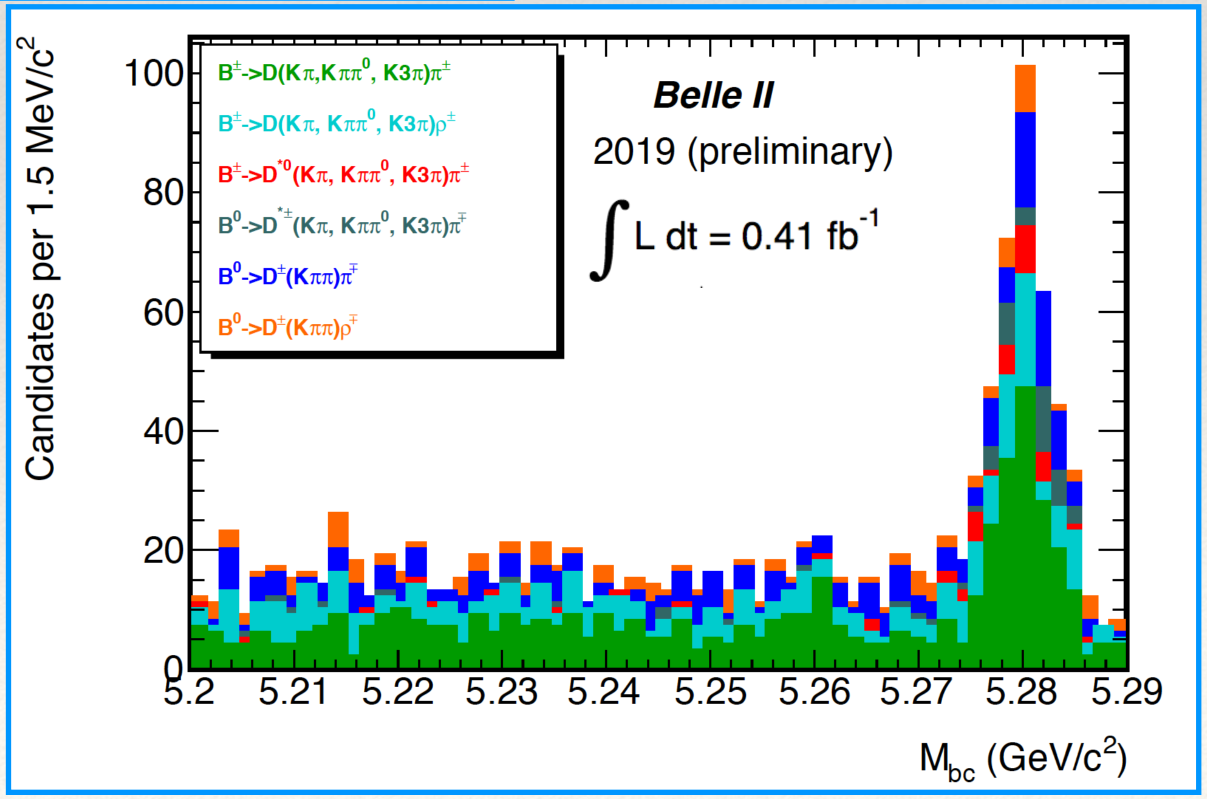
Sample of particles reconstructed in first data











Belle II prospects for ϕ_1 / β

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

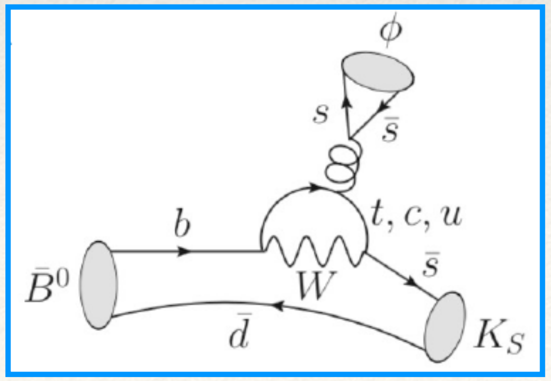
- Sin $2\phi_1$ is the most precisely measured UT parameter:

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

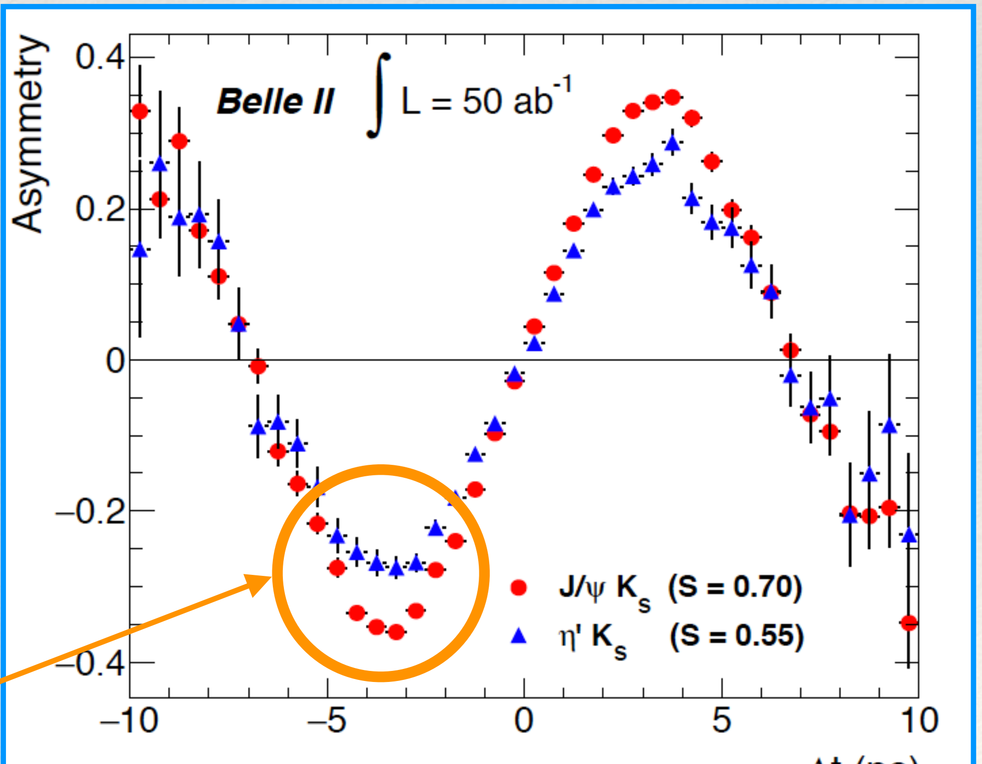
- Tree-dominated $b \to c\bar{c}s$: golden mode $B^0 \to J/\psi K_S$.
  - Theoretically and experimentally precise.
  - Syst. due to vertex and Δt resolution will be the limiting uncertainty with 50 ab^{-1} of data.
  - Penguin pollution controlled with $B^0 \to J/\psi \pi^0$ data.
  - Expected total uncertainty $\delta\phi_1 \lesssim 0.1^\circ$ with 50 ab^{-1}.

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

  $B^0 \to \phi K_S$, $\eta' K_S$, ωK_S, $K_S \pi^0$, $K_S \pi^0 \gamma$.
  - Particularly sensitive to NP.
  - With increased stat.: additional decays, e.g., $\phi \to \pi^+ \pi^- \pi^0$.



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

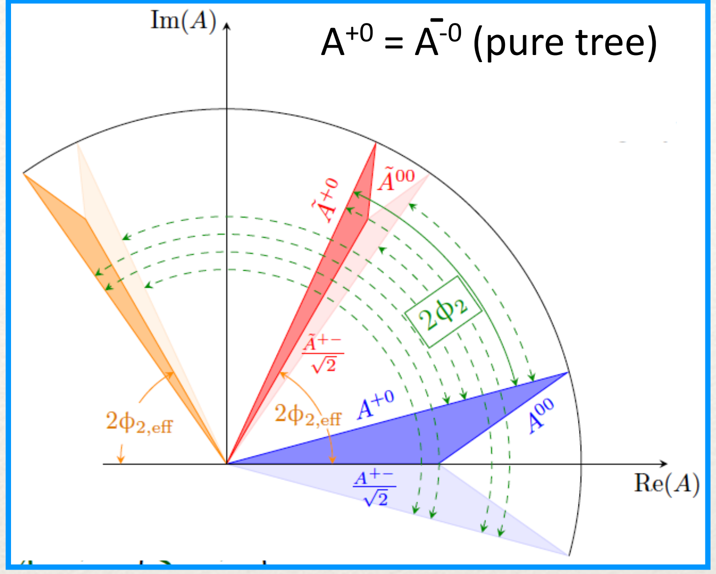


Belle II Physics Book- arXiv:1808.10567

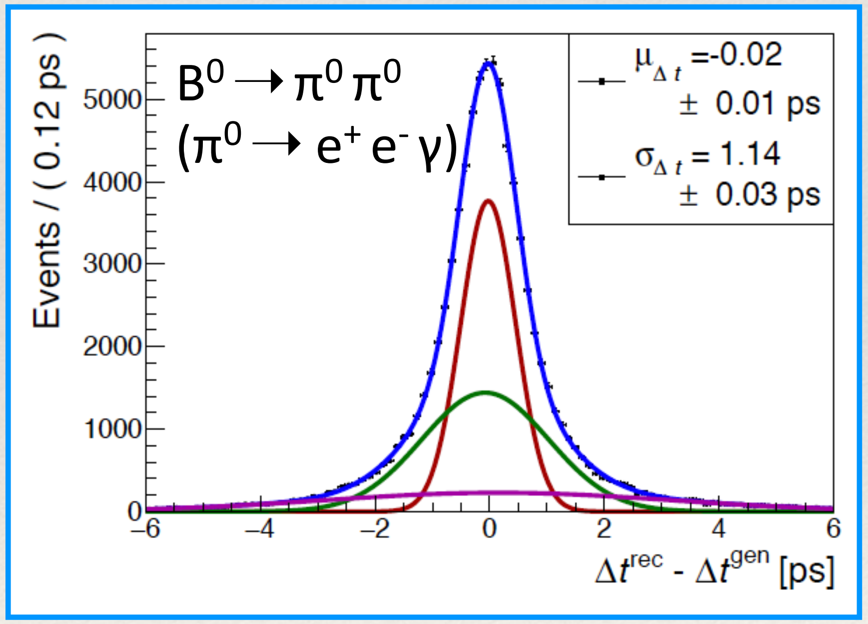
Belle II prospects for ϕ_2 / α

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

- Measurement based on $b \to u\bar{u}d$ processes.
  Significant contribution from Penguins:
  $\mathcal{A}_{CP} \neq 0$ and $\phi_2^{eff} = \phi_2 + \Delta\phi_2$.
  Most precise determination of ϕ_2 from isospin analysis of $B^0 \to \pi\pi$, $\rho\rho$ decays.

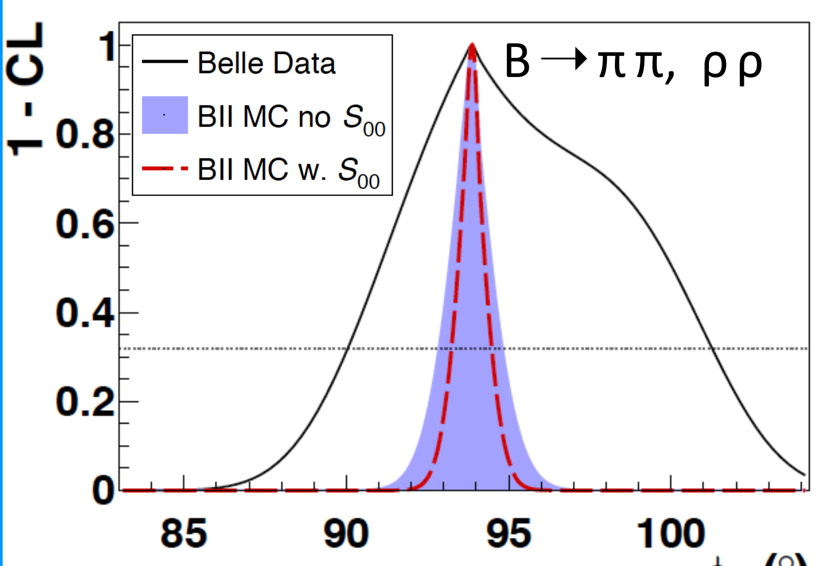


- $B^0 \to \pi^0\pi^0$ (never measured so far): solve 8-fold ambiguity on ϕ_2.
  Challenge of Belle II: B^0 decay vertex reconstructed based on γ conversion and Dalitz π^0 decays with IP-tube constraint.



- 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 ab^{-1}.



Belle II Physics Book- arXiv:1808.10567

Belle II prospects for φ3 / γ

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

- φ3 is a standard candle: accessible at tree level.

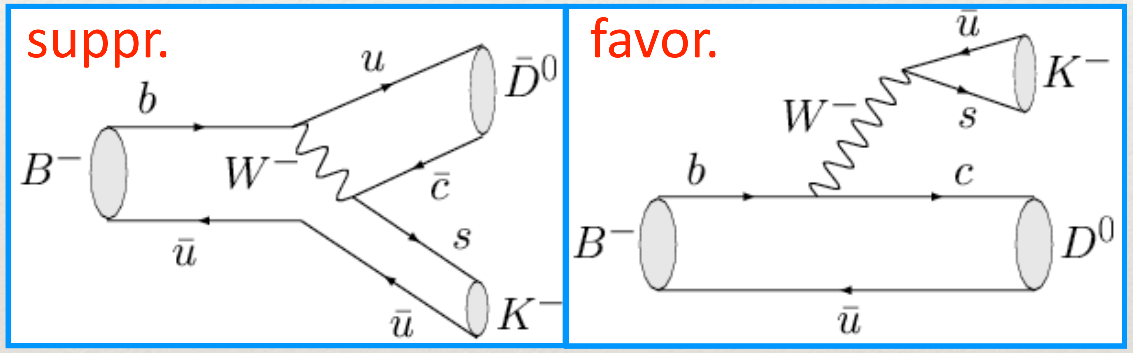
  Very precise theoretical prediction $\delta\phi_3/\phi_3 \sim 10^{-7}$.

  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 ~1º precision with Belle II and LHCb.

- φ3 is the phase between b➝u and b➝c transition:

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

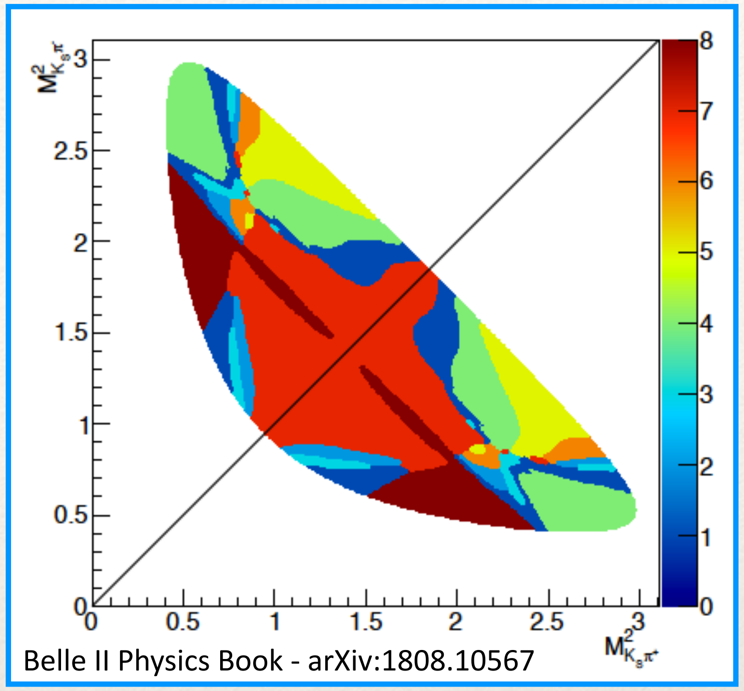


- Measured via the interference between $B^- \to D^0 K^-$ and $B^- \to \bar{D}^0 K^-$ with various D^0 channels:
  - GLW method: CP eigenstates K^+K^-, $\pi^+\pi^-$, $K_S\pi^0$, …
  - ADS method: $K^+(n\pi)^-$
  - GGSZ method: self-conjugate multi-body states $K_S\pi^+\pi^-$, $K_S\pi^+\pi^-\pi^0$, …

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

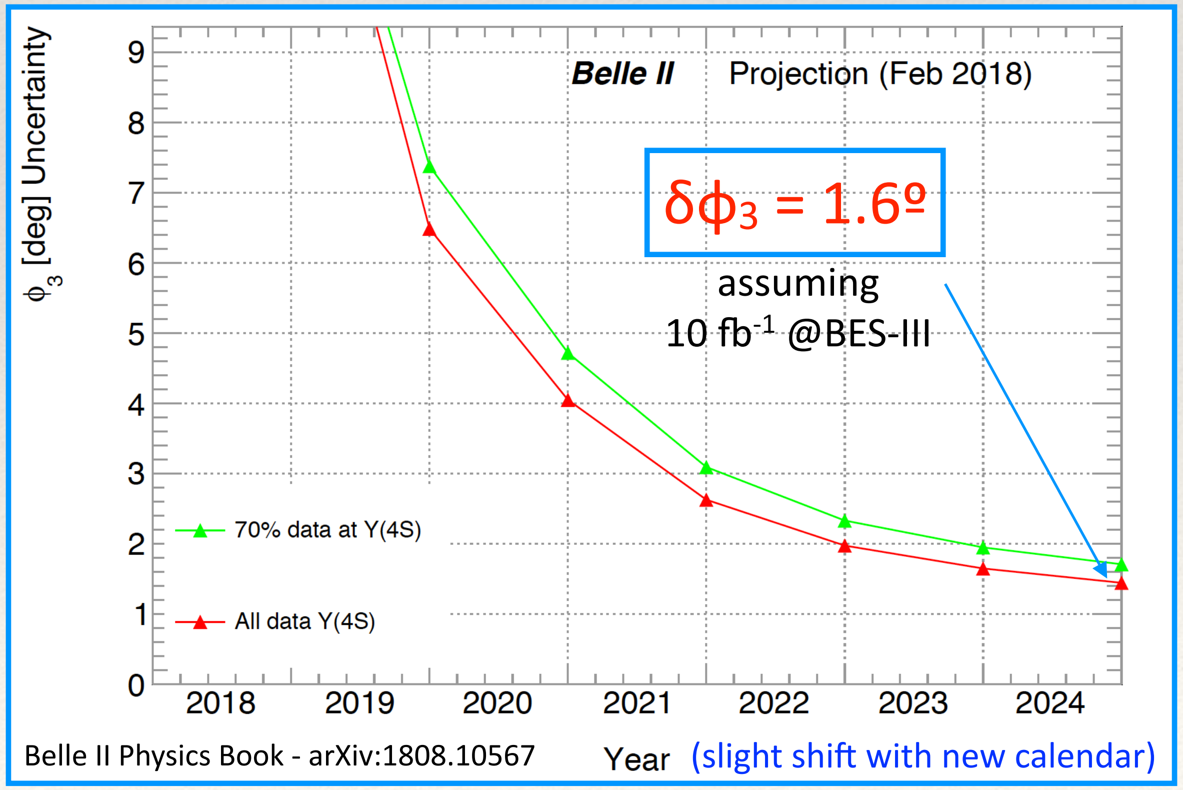
Belle II prospects for ϕ_3 / γ

- Golden method in Belle II: GGSZ $B^- \to (K_S \pi^+ \pi^-) K^-$
  - 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 $B \to D\pi$ control sample).

- Other modes become also sensitive:
  $D^* \to D^0 \pi^0$, $D^0 \gamma$
  $D^* \to \pi^0 \pi^0$, $K_L \pi^0$, $K_S \pi^0 \pi^0$, $K_S K_S K_L$, ...
  with:
  - increasing stat.,
  - better K/π identification,
  - better continuum suppression.

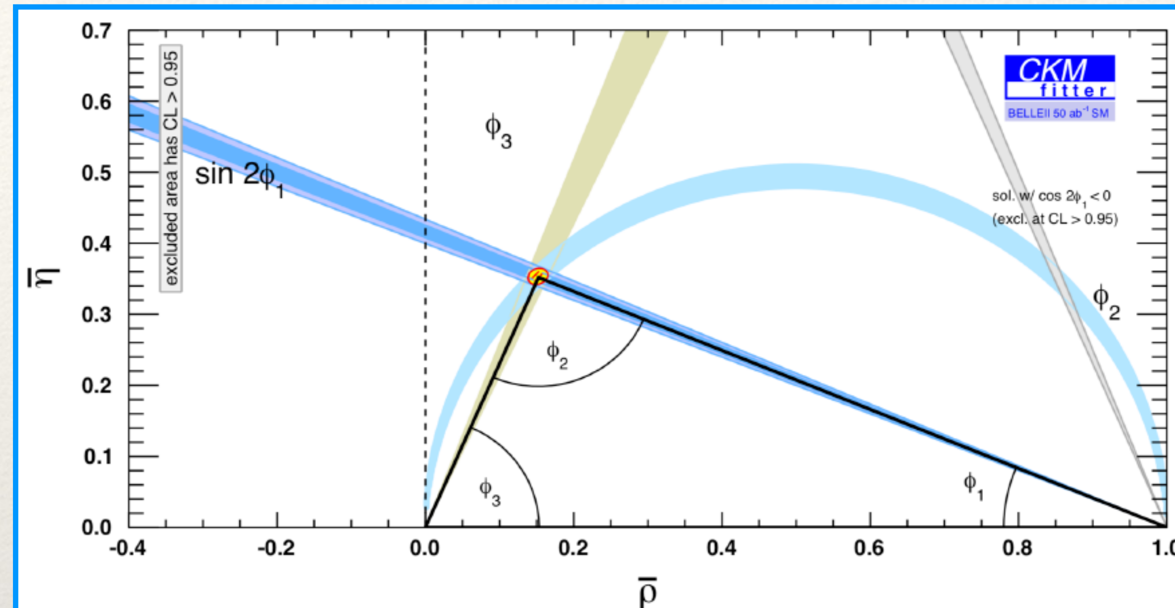


Conclusion and outlooks

- 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 5-10 ab^{-1}.
  - Huge dataset of 50 ab^{-1}: several measurements will start to be syst. limited ➛ lots of work ahead!

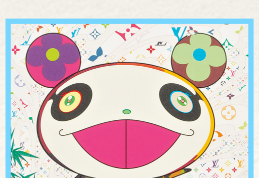


$\delta\phi_1 \lesssim 0.1^\circ$
$\delta\phi_2 \lesssim 1^\circ$
$\delta\phi_3 \lesssim 1.6^\circ$

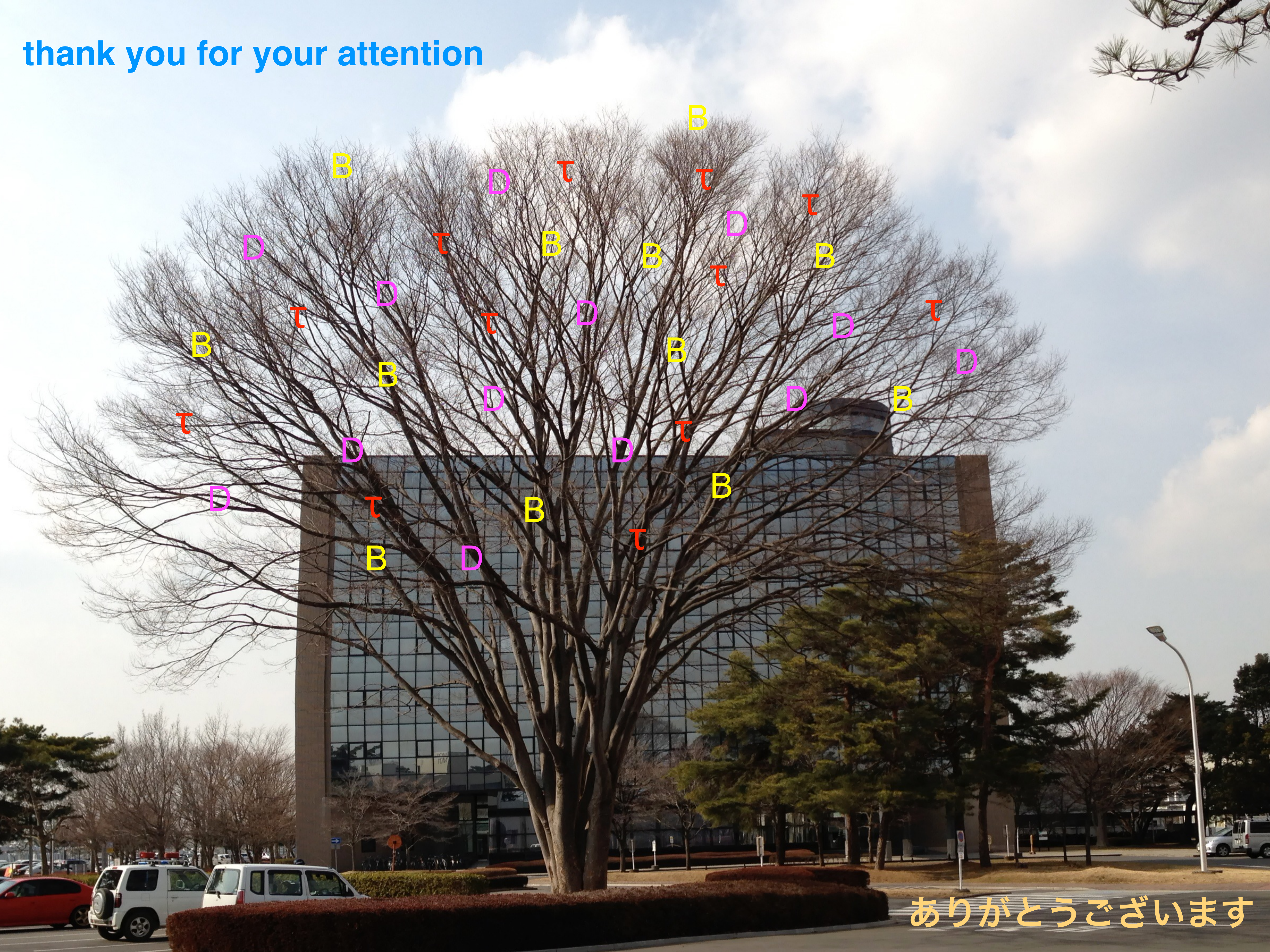
- Expected experimental performances often improve w.r.t. Belle despite 20× higher beam induced background and lower boost.

- Looking forward to the next decade of exciting Belle II results!

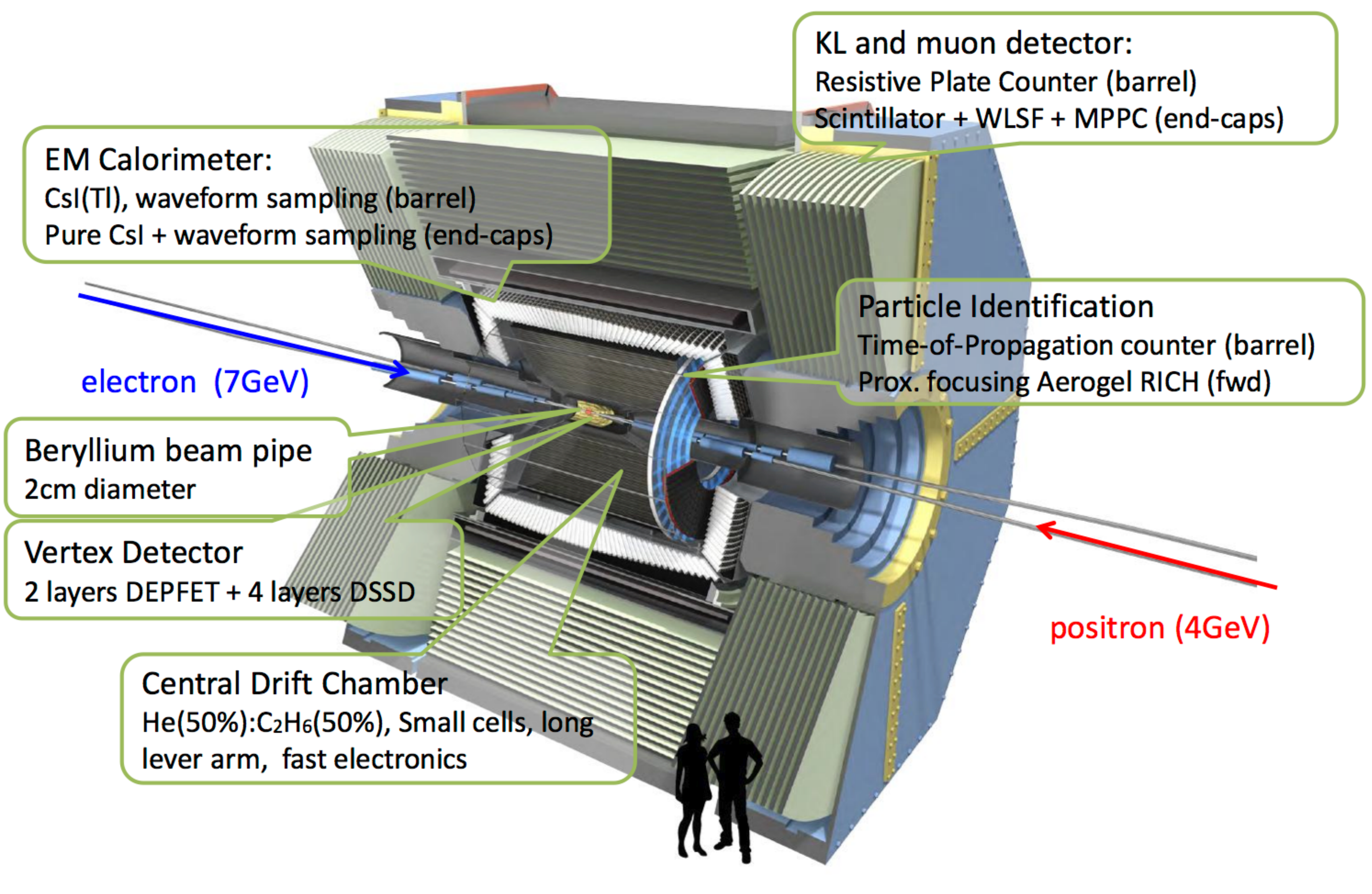
Stay tuned: https://twitter.com/belle2collab https://www.facebook.com/belle2collab



and like us!


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
σ_x^* (μm)	147 / 170	16.8 / 22.8	10 / 11
σ_y^* (μm)	0.94 / 0.94	0.308 / 0.5	0.048 / 0.062
β_x^* (mm)	1200 / 1200	128 / 100	32 / 25
β_y^* (mm)	5.9 / 5.9	2.16 / 2.4	0.27 / 0.30
ξ_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