30th Rencontres de Blois

June 3-8

PARTICLE PHYSICS AND COSMOLOGY 2018

B D τ

Belle II status and early physics

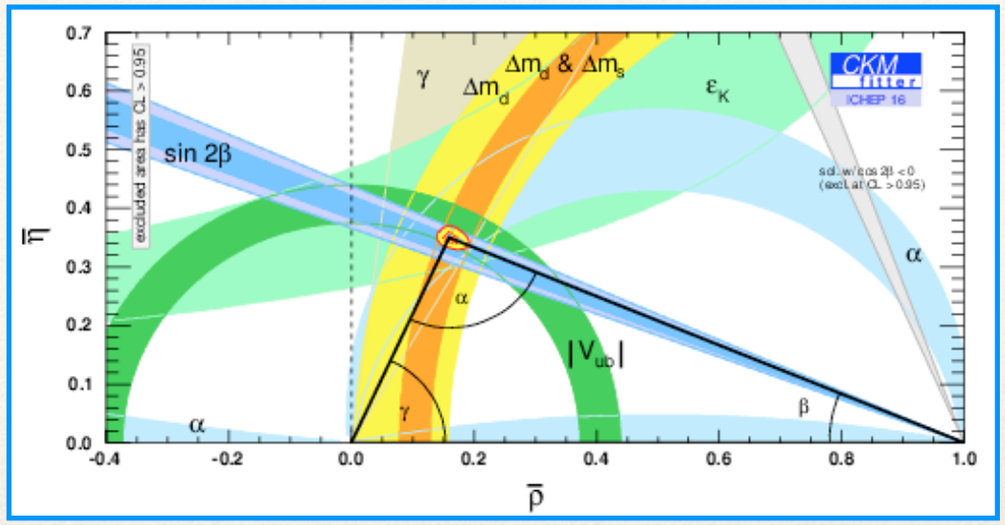
Outline:

- Belle II and SuperKEKB
- Experiment schedule
- On-going Phase 2 run
- Beam induced background
- First collisions in Belle II
- Physics at Belle II
- Opportunities of early scientific impact
- Conclusion

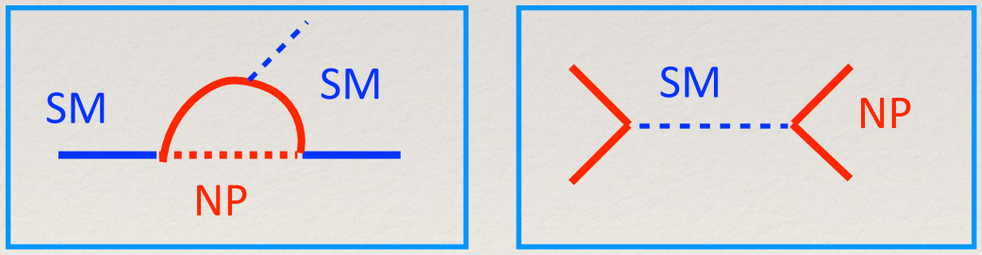
Isabelle Ripp-Baudot
IPHC Strasbourg
on behalf of the Belle II collaboration

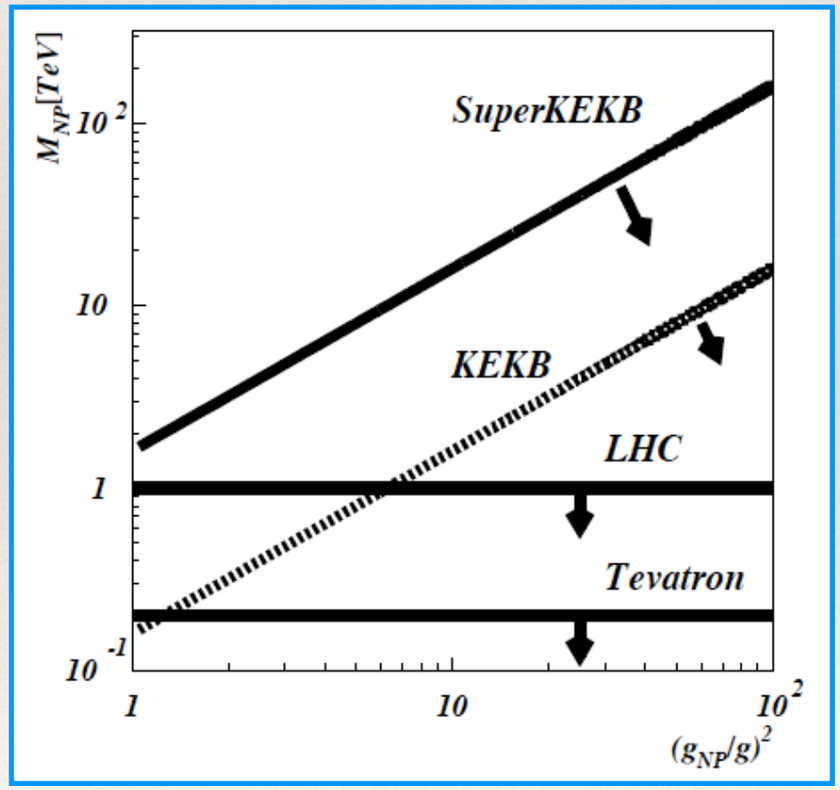
The Belle II experiment

- Legacy of B factories, BaBar and Belle:
  - Precise measurement of CPV in B system.
  - Nobel prize 2008 to Kobayashi, Maskawa (& Nambu).



- Belle II builds on the excellent B factory experience, shifting focus to search for BSM physics:
  - Extremely precise measurements in the quark and charged lepton sectors:
    increased statistics needed, current dataset×50.
  - Quantum manifestation of NP:
    potential higher NP mass sensitivity than Energy Frontier.





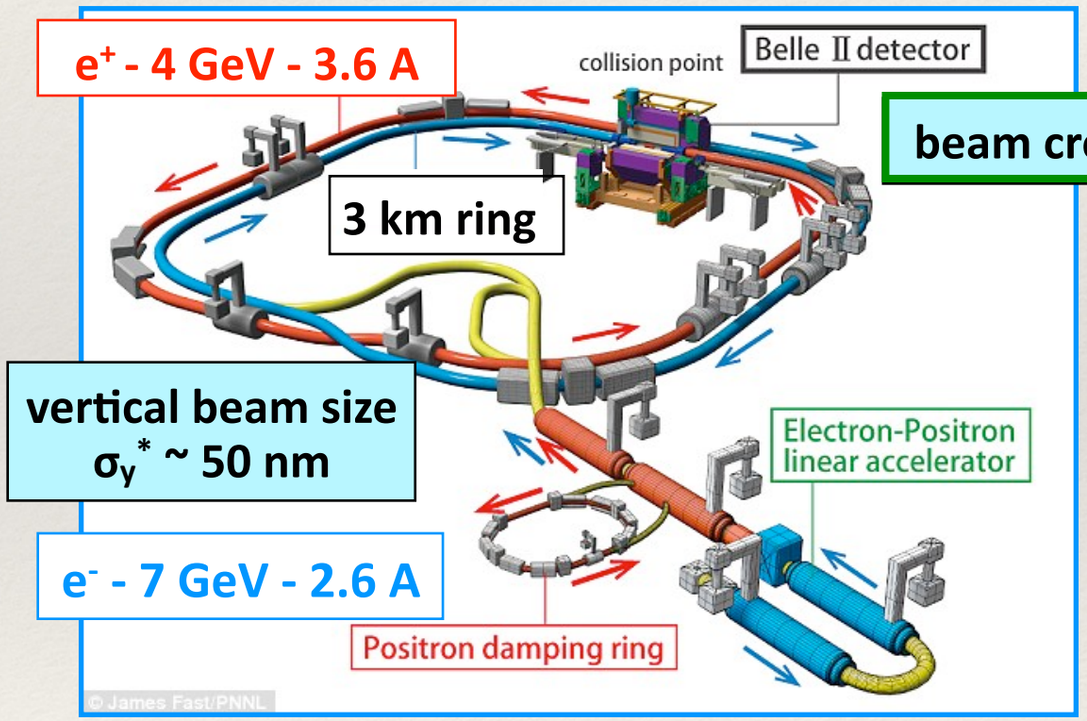
The SuperKEKB collider

- Asymmetric e^+e^- circular collider.
- $E_{collision} = m_{Y(4S)}$ and from Y(1S) to ~ Y(6S).
- New nano-beam collision scheme:
  instantaneous luminosity world record ×40
  ➔ 8×10^{35} cm^{-2} s^{-1}.
- Hosted at KEK, Tsukuba.

beam current — beam-beam parameter

$$\ell = \frac{\gamma_\pm}{2\, e\, r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm\, \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

beam size ratio @IP (flat beams) — vertical beta function @IP



beam crossing angle 83 mrad crossing angle x3.8

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	boost ×2/3
$\epsilon_x(nm)$	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	β_y^*/20
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	I×2
Nb bunches	1584	2500	2500	
$\mathcal{L}(10^{-34}cm^{-2}s^{-1})$	2.11	1	80	ℓ×40

Belle II calendar

- SuperKEKB switched on in Jan. 2016: single beams circulated during 5 months (BEAST Phase 1).
- First collisions delivered in Apr. 2018: BEAST Phase 2 commissioning, March-July 2018.
- Start of physics run scheduled early 2019.

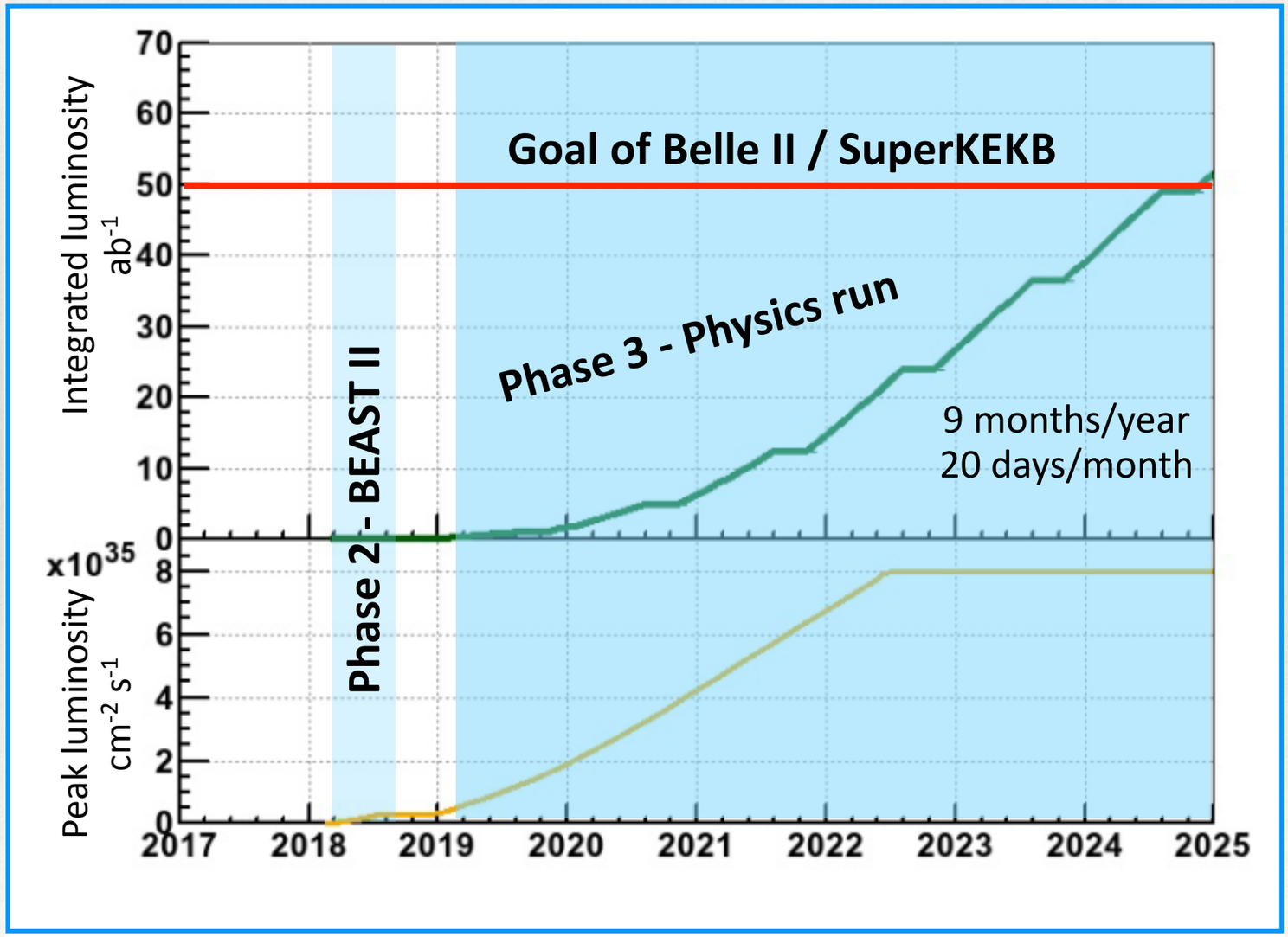
  Target integrated luminosities:
  - 2019-20: 1 ab^{-1} > present dataset.
  - 2021: 10 ab^{-1}.
  - 2024: 50 ab^{-1}

  ➔ SuperKEKB is a B-D-τ Factory:

  55×10^9 $B\bar{B}$,

  45×10^9 $\tau^+\tau^-$,

  65×10^9 $c\bar{c}$.

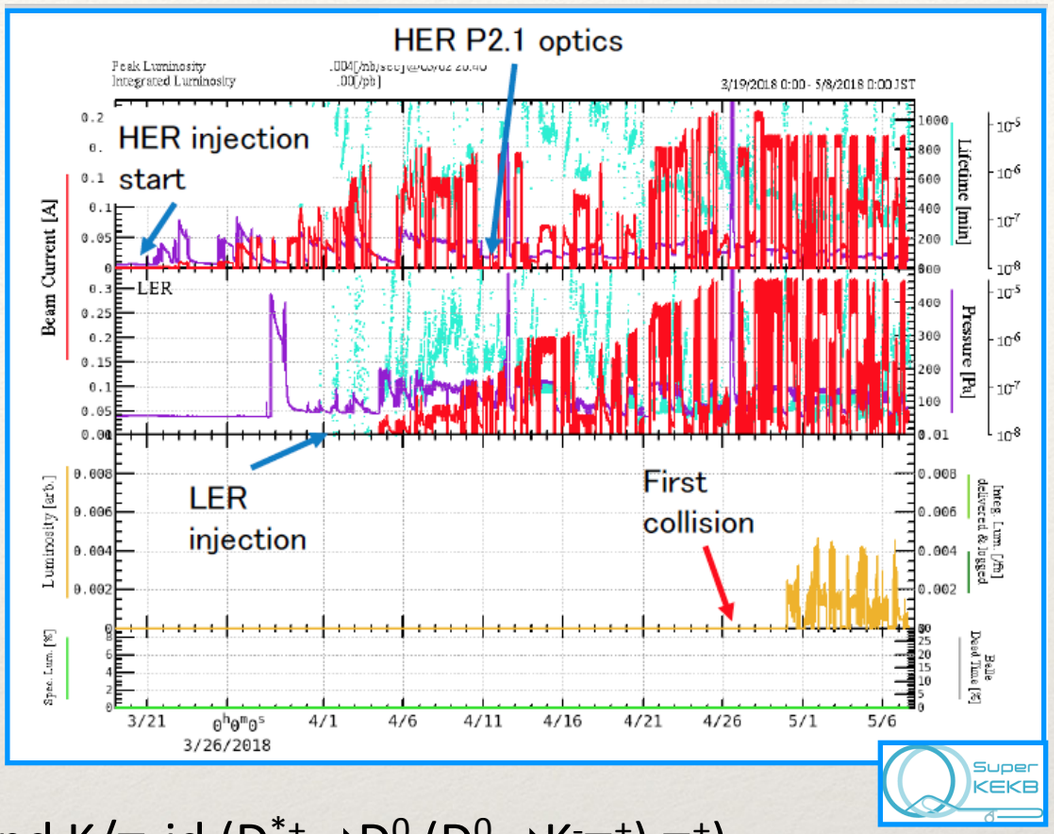


On-going Phase 2 run

- Phase 2 data taking:
  - March-July 2018.
  - First collisions delivered on April 26.

- Increasing the luminosity:
  - Fine tune beam parameters up to 10^{34} cm^{-2} s^{-1}.

- Belle II commissioning:
  - Belle II at interaction point, w/o vertex detector.
  - Operation of detector and DAQ.
  - Performances: particle rediscovery (V0, π^0, …),
    counting (luminosity, B, …), lepton-id ($J/\psi \to ee$, $\mu\mu$) and K/π-id ($D^{*+} \to D^0$ ($D^0 \to K^-\pi^+$) π^+), …



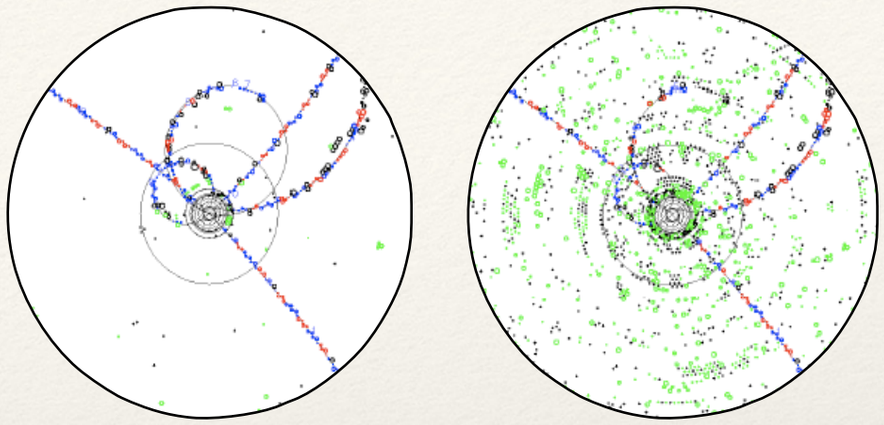
- BEAST SuperKEKB induced background study:
  - Insure safe vertex detector operation.
  - Give feedback to machine: increase luminosity while keeping BG under control.
  - Validate BG simulation and extrapolate of over ~2 orders of magnitude in luminosity.

- Physics with early data:
  - ~20 fb^{-1} and w/o vertex detector.
  - Light NP searches (dark photons, …), quarkonium studies, …

BEAST and beam induced background

- Success of Belle II physics program relies on impact of beam induced background:
  - Possible radiation damage.
  - Possible degraded physics performances due to high detector occupancy.

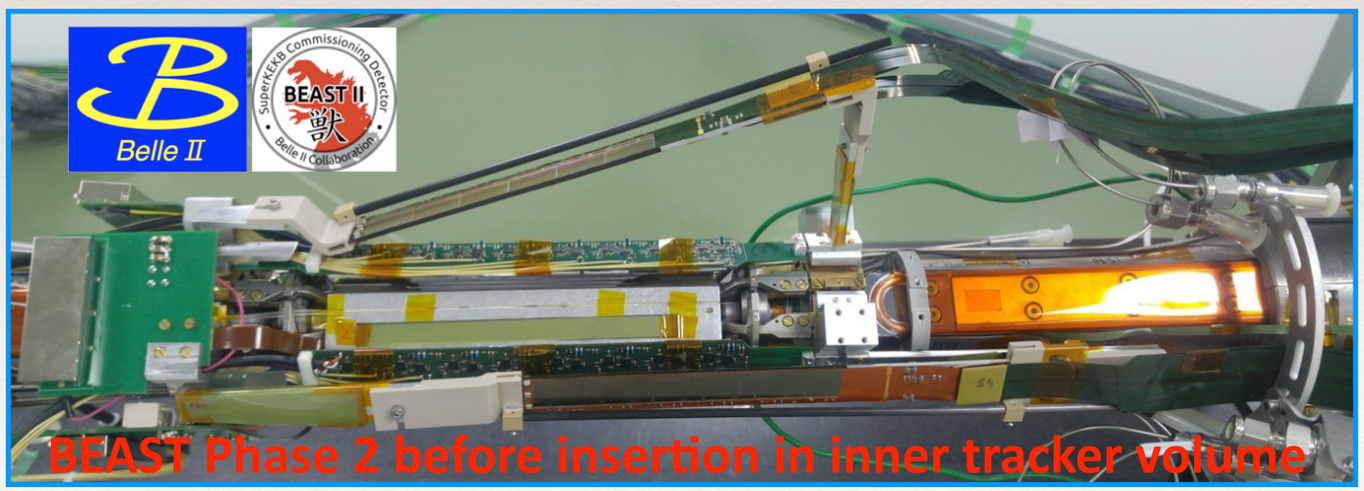
Illustration of impact from beam induced BG



Belle at KEKB Belle at SuperKEKB

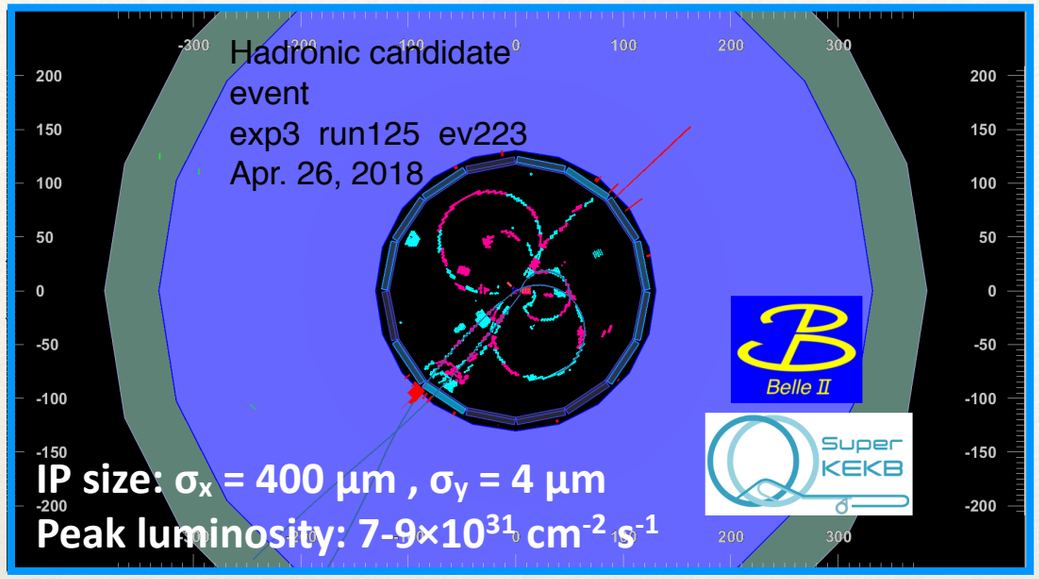
- BEAST BG study, in 2 Phases:
  - Phase 1, Feb.-June 2016:
    - Belle II not at IP, no solenoid, no final focus, dedicated sensors in place of Belle II.
    - Circulation of individual beams: study of single beam BG, published in NIM A 2018: arXiv:1802.01366.
  - Phase 2, March-July 2018:
    - Belle II @IP, dedicated sensors in place of vertex detector (1 phi-module of PXD+SVD installed).
    - Collisions: study of single beam & beam-beam BG.

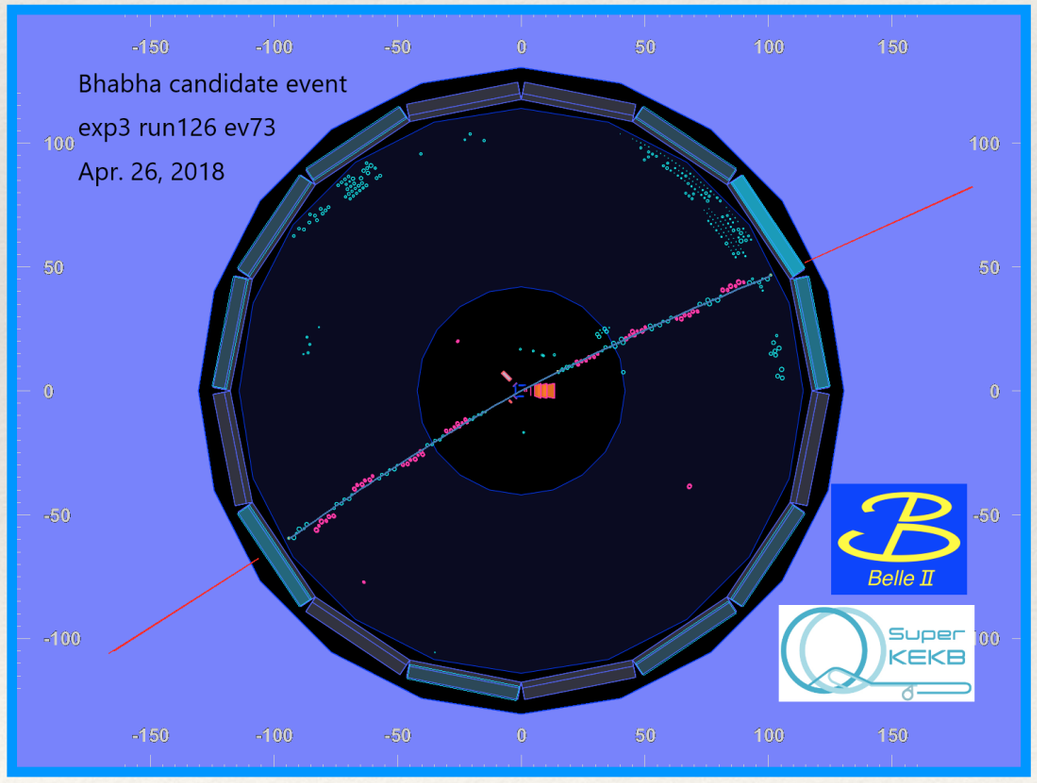
BEAST Phase 1 at IP



BEAST Phase 2 before insertion in inner tracker volume

Breaking news: first collisions in Belle II (1)





April 26, 2018

All Belle II sub-detectors register collisions.

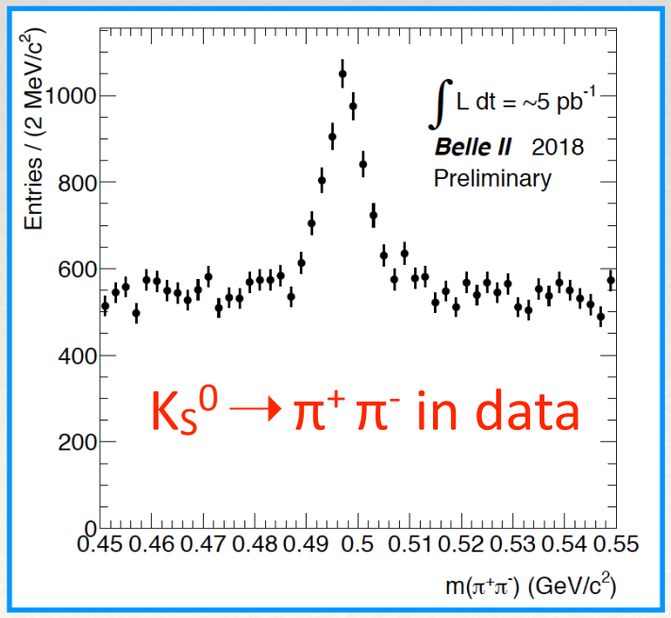
- Collision tuning to reach 10^{34} cm^{-2} s^{-1} adiabatically

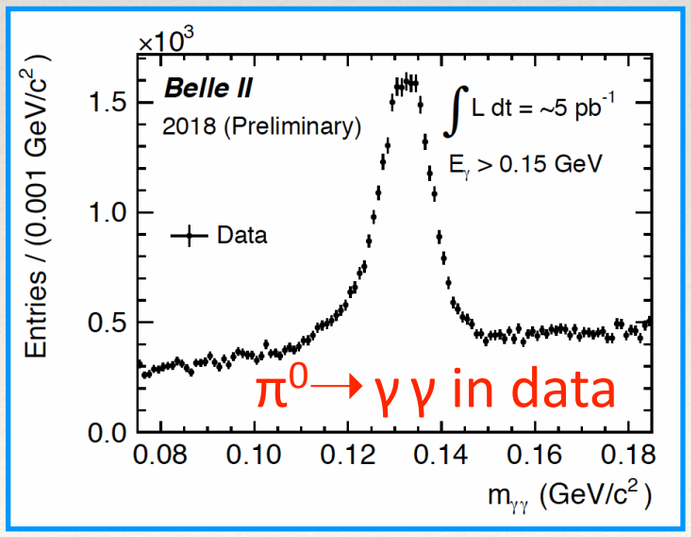
  (starting e.g. from 4.7×10^{32} cm^{-2} s^{-1} , as of May 5):

  - Squeeze β_y^* = 8mm ➛ 3 mm (final goal ➛ 2 mm).
  - Increase $I_{\pm}$ = 250 mA / 220 mA ➛ 1 A / 0.88 A.
  - Increase beam parameter $\xi_{\pm y}$ ~0.014 ➛ 0.03.
  - Increase number of bunches = 600 ➛ 1576.

Improving every day!

- Particle "rediscovery" in Belle II, with first data:





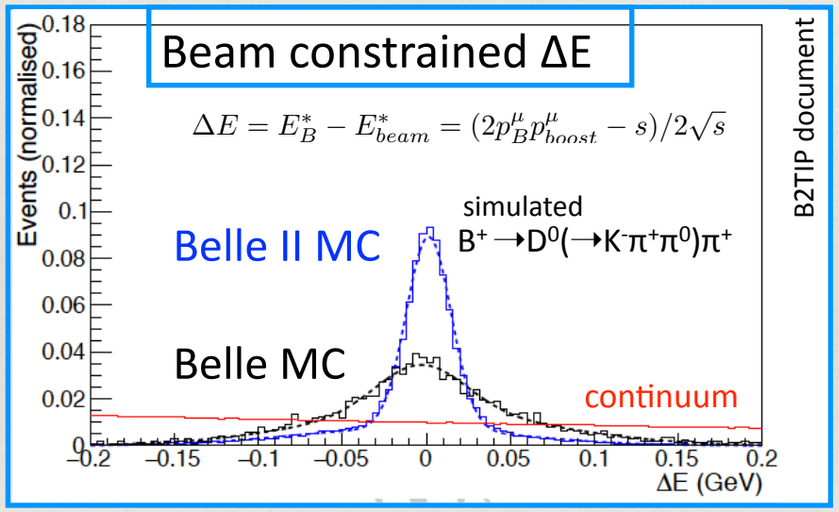
Physics at Belle II

- Update of Belle II sensitivities:
  Belle II Theory Interface Platform (B2TIP)
  (to be published soon in Prog.Theor.Exp.Phys.).

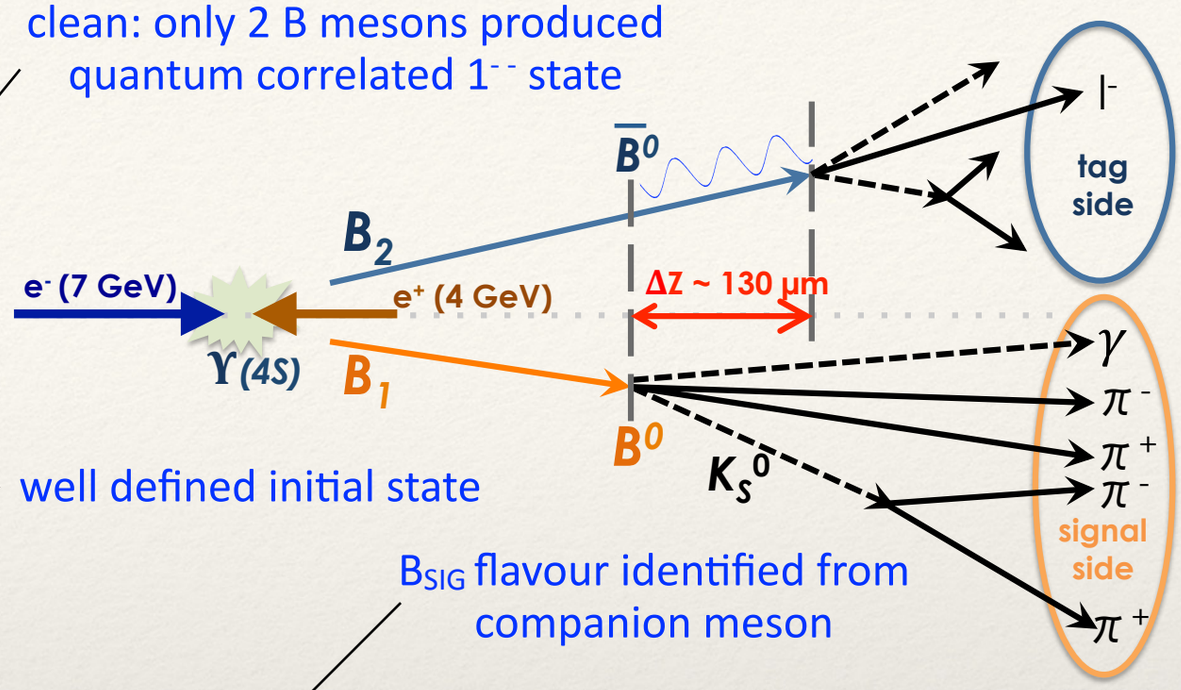
Full Event Interpretation:

Tag	FR[10] @ Belle	FEI @ Belle MC	FEI @ Belle II MC
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %

B2TIP document

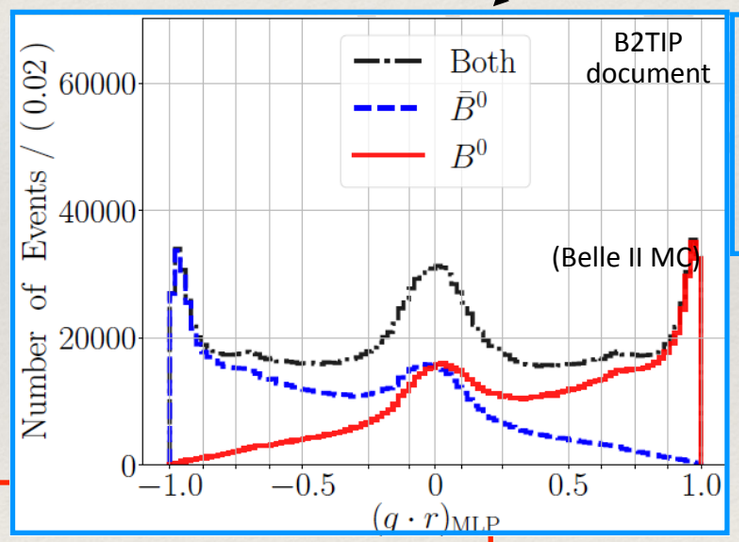


clean: only 2 B mesons produced
quantum correlated 1^{--} state



well defined initial state

B_{SIG} flavour identified from companion meson



Flavour tagging:
$\sum \varepsilon_i \times (1 - 2\omega_i)^2$ = 37.4 %
(was 30.1 % in Belle)

➔ significant hardware & software improvement w.r.t. Belle.

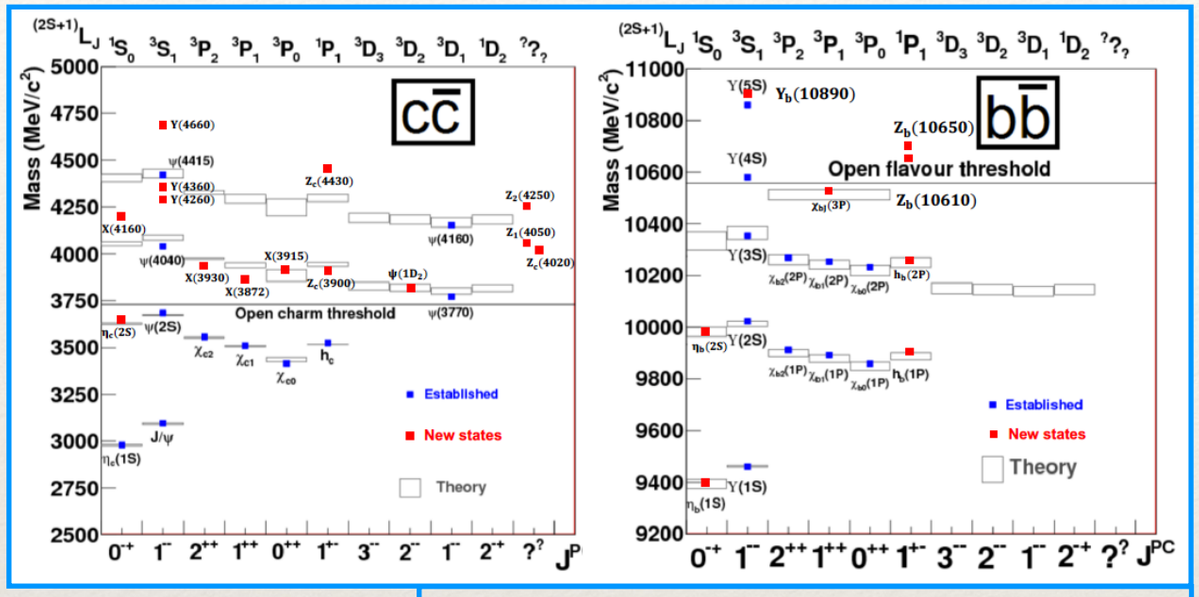
- Unique skills of Belle II for:
  - inclusive measurements: $B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$, …
  - events with missing energy: $B^+ \to \tau^+\nu$, $B \to D^{(*)}\tau\nu$, τ decays, …
  - events with neutrals: $B^0 \to K_S^0\pi^0\gamma$, $B^0 \to K_S^0K_S^0K_S^0$, $B^0 \to \gamma\gamma$, …

see next talk by Ami Rostomyan

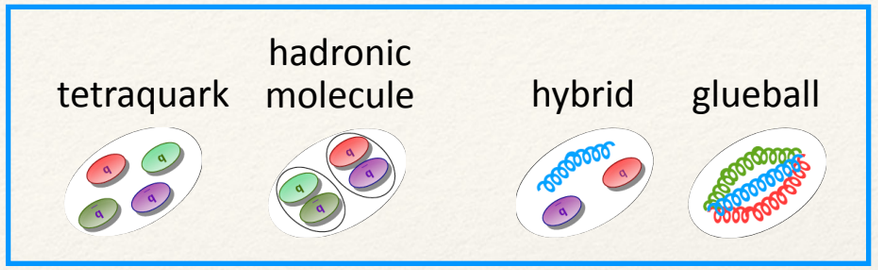
➔ good complementary with LHCb.

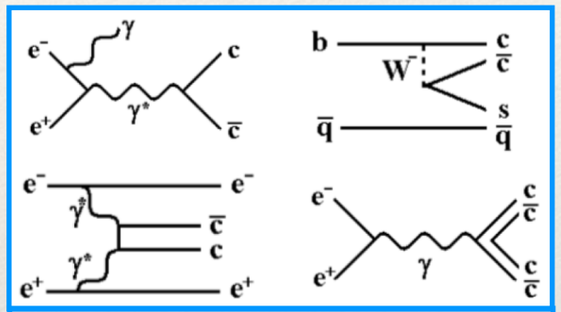
Early physics: quarkonia and exotics

- Plethora of quarkonium-like states observed in the last decade:



Post B-factories era quarkonium spectra





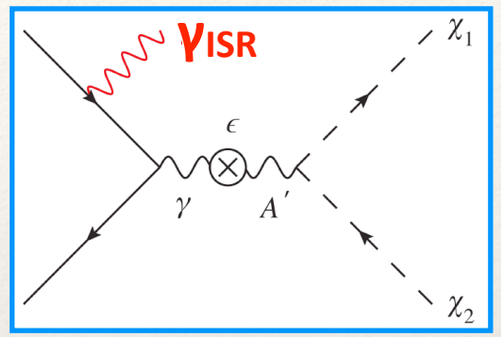
Charmonium-like production modes

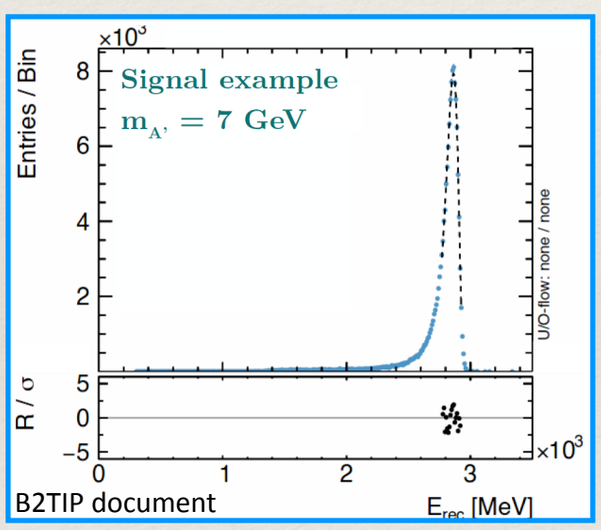
- Belle II features unique skills for further bottonium- and charmonium-like characterisation:
  - Various production modes, e.g. of charmonia: ISR, B-decays, two-photon, double-charmonium.
  - Energy scans at / above / below thresholds, from Y(1S) to Y(6S), possibly 11.35 GeV ($\Lambda_b\Lambda_b$ threshold), 11.5-11.6 GeV (partners of X(3872) and $Z_b(10610)$, $Z_b(10650)$).
  - Many properties can be measured: absolute and inclusive branching ratios, angular distributions, spin-parity, line shapes, final states involving neutrals, …
  - Very small existing datasets: increased stat.×10, 10 fb^{-1} per 10 MeV-scan point, 500 fb^{-1} at each new vector state.

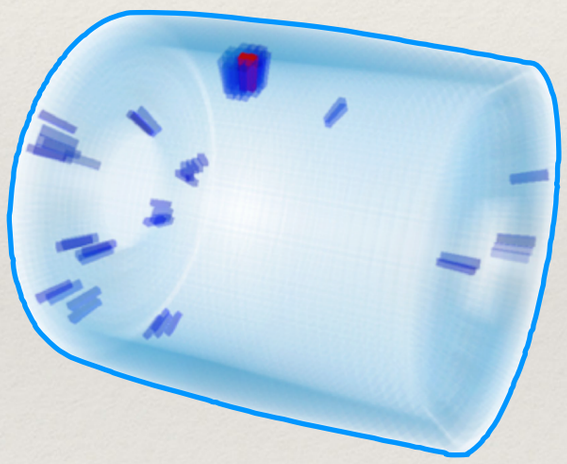
➛ opportunity for Belle II of a possible unique early scientific impact.

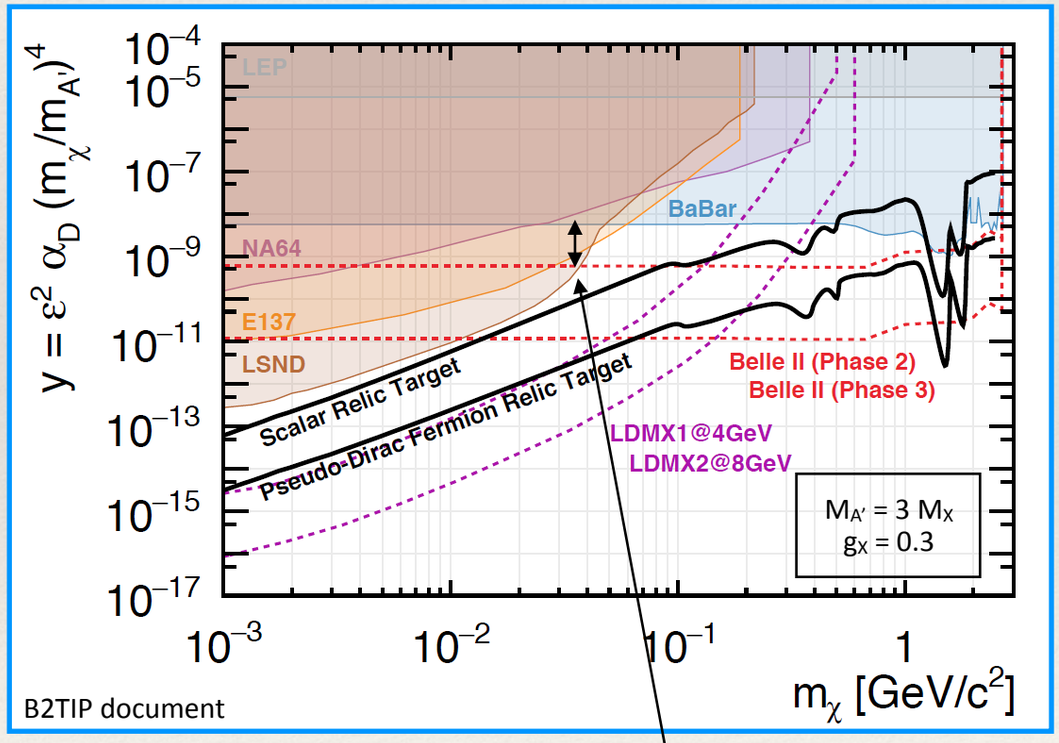
Early physics: the dark sector

- Light dark matter and light mediator searches in Belle II:
  - Dark photons, dark higgs, axion-like particles (ALPs), mass scale ~GeV or sub-GeV.
  - Production, e.g.: $e^+e^- \rightarrow M+X$, $e^+e^- \rightarrow Y(ns) \rightarrow M+X$, $e^+e^- \rightarrow B+X \rightarrow K+M+X$.
- Example: on-shell dark photon decaying to invisible DM:
  - Signal: single, mono-energetic, high-E photon & peak in recoil mass.
  - Single Photon trigger with 1 GeV threshold.









- Particularly relevant with Phase 2 data:
  - Low luminosity and lower beam background allow to open up triggers.
  - Small dataset can still give world best sensitivity.

Belle II calo more hermetic than BaBar

Conclusion and outlooks

- Belle II has started successfully taking data.

- Belle II will play a key role in particle physics:
  - Accumulated experience from Belle & BaBar.
  - Unique skills for various measurements.
  - Good opportunities of early scientific impact.
  - Huge dataset of 50 ab^{-1}: many 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.

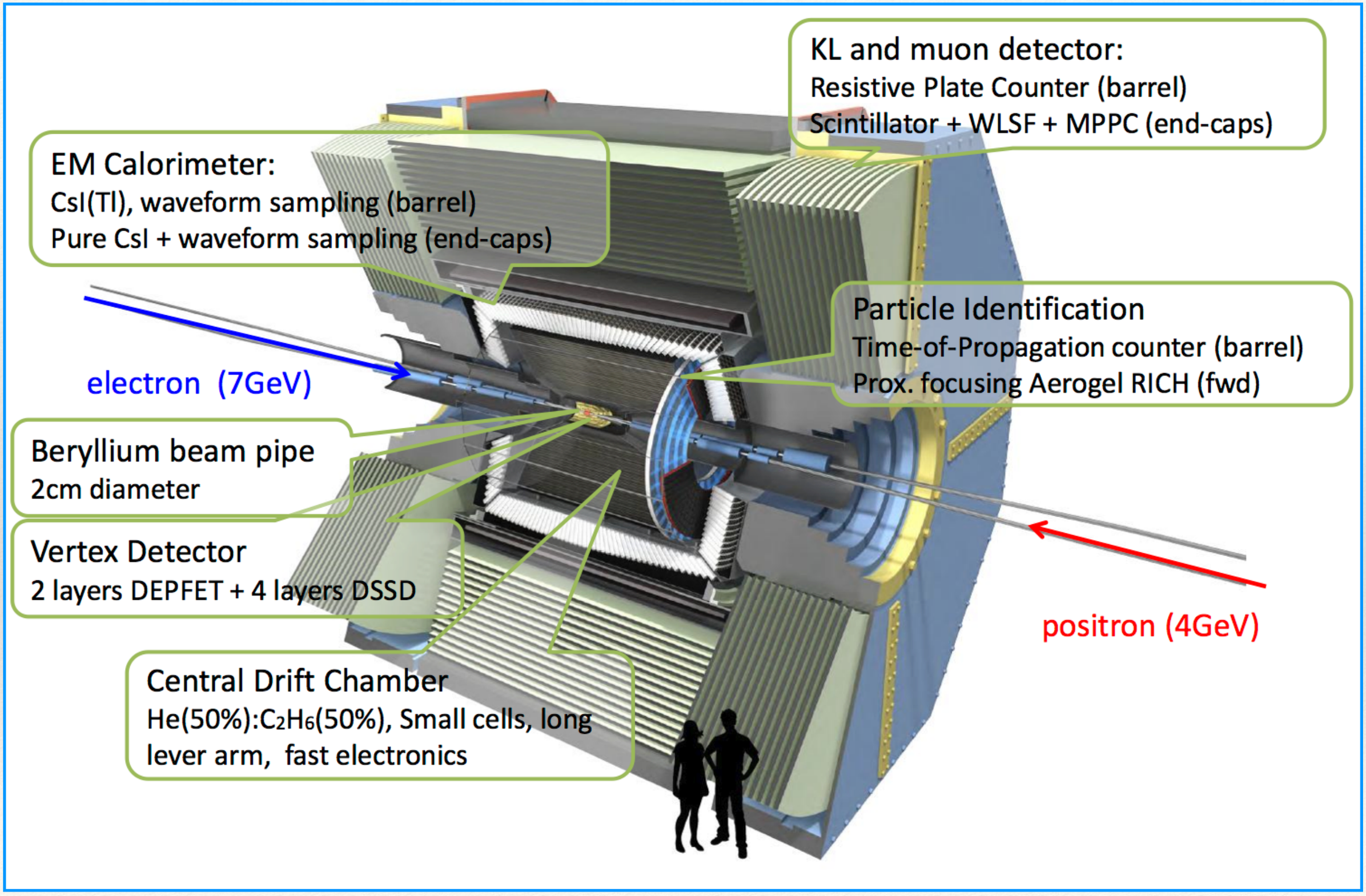
- Looking forward to the next decade of exciting Belle II results!

  Stay tuned: https://twitter.com/belle2collab https://www.facebook.com/belle2collab and like us!

thank you for your attention

ありがとうございます

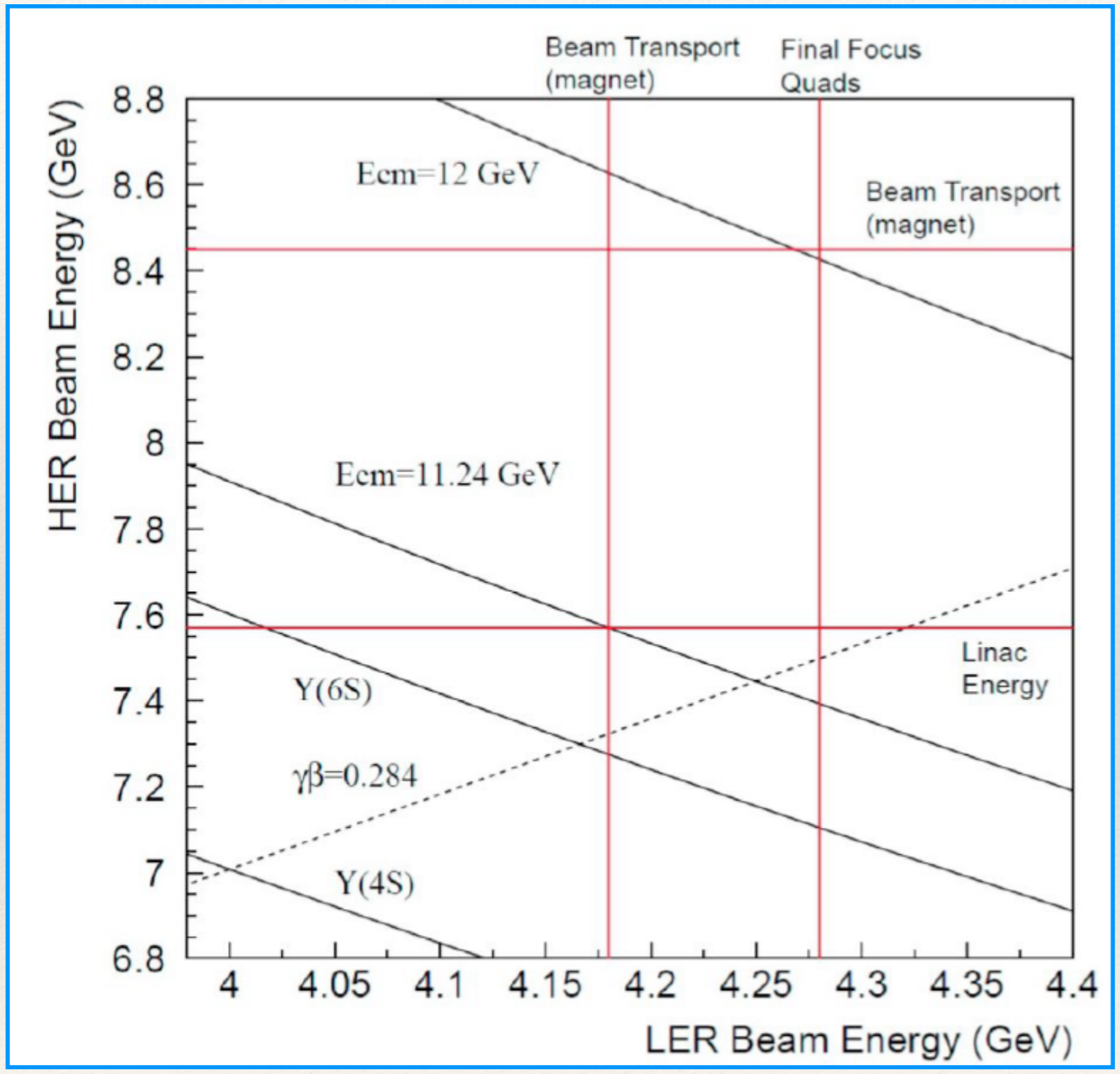
Belle II detector



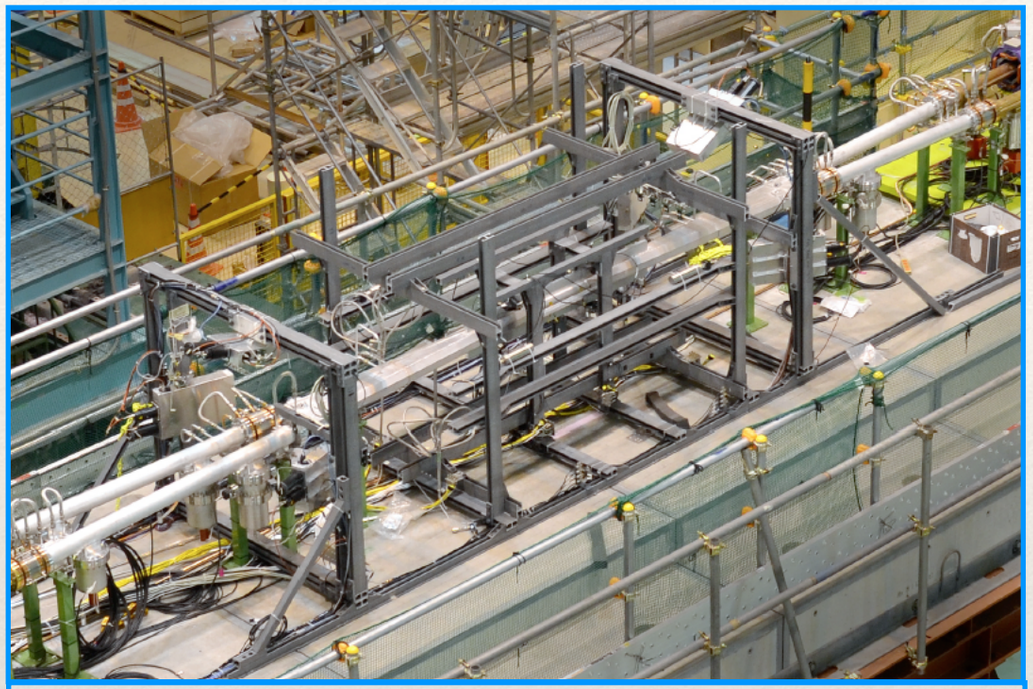
SuperKEKB parameters

	KEKB LER /HER	**Phase 1**	**Phase 2 4x8**	**Phase 3**
β_x^* (mm)	1200 / 1200	/	128 / 100	32 / 25
β_y^* (mm)	5.9 / 5.9	/	2.16 / 2.4	0.27 / 0.30
ε_x (nm)	18 / 24	2.0 / 4.6	2.1 / 4.6	3.2 / 4.6
ε_y (pm) , coupling	1498 / 1598	~ 10 / -	29.4 / 64.4, 1.4% (105 / 230, 5.0%)	8.64 / 12.9 (0.27% / 0.28%)
ξ_y	0.129 / 0.090	-	0.0484 / 0.0500 (0.0257 / 0.0265)	0.088/0.081
σ_y^* (μm)	0.94 / 0.94	-	0.25 / 0.39 (0.48 / 0.74)	0.048/0.062
I_{beam} (A)	1.64/1.19	1.01/0.87	1.0/0.8	3.6/2.6
$N_{bunches}$	1584	1576	1576	2500
Luminosity (10^{34} cm^{-2} s^{-1})	2.1	-	2 (1)	80

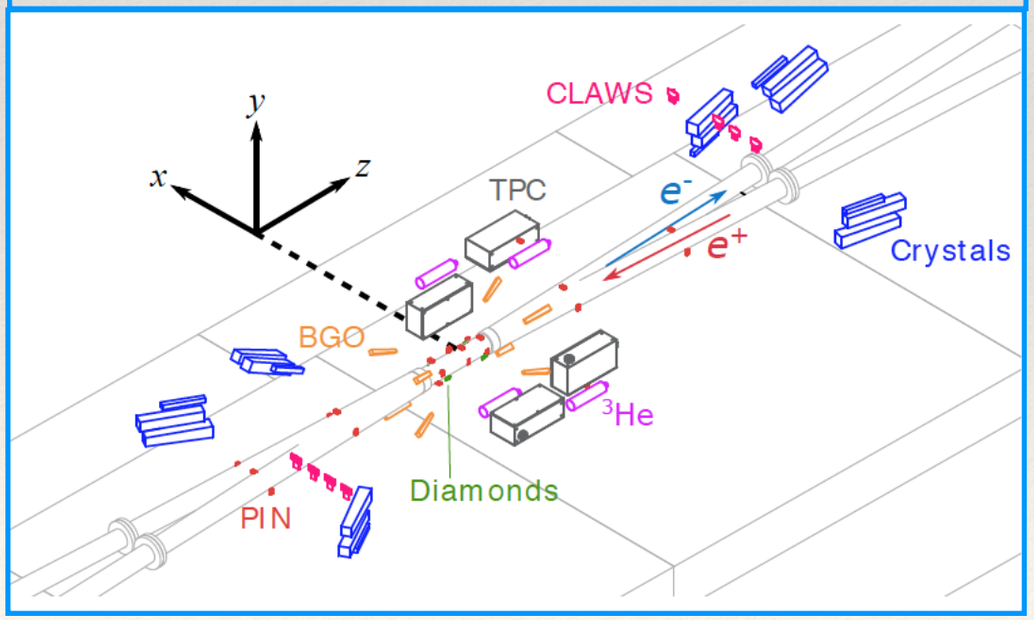
SuperKEKB beam energy



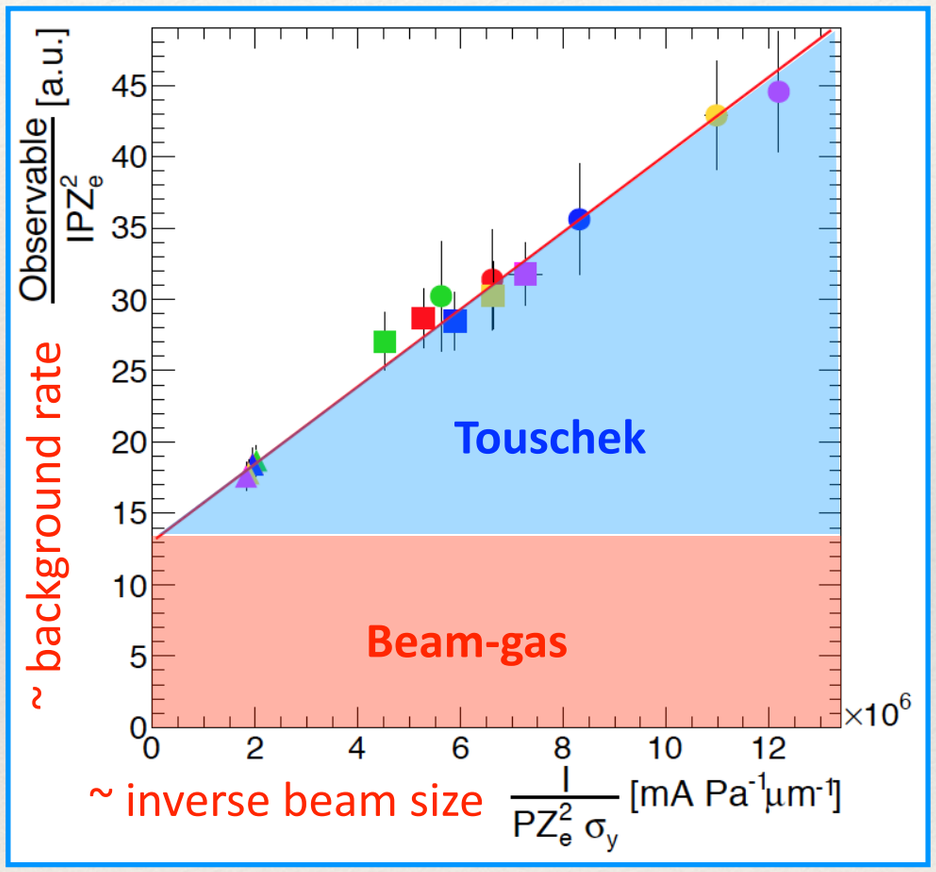
BEAST Phase 1 beam background study



BEAST Phase 1 dedicated sensors at IP (picture and CAD).



Publication in NIM A, 2018:
First Measurements of Beam Backgrounds at SuperKEKB
arXiv:1802.01366



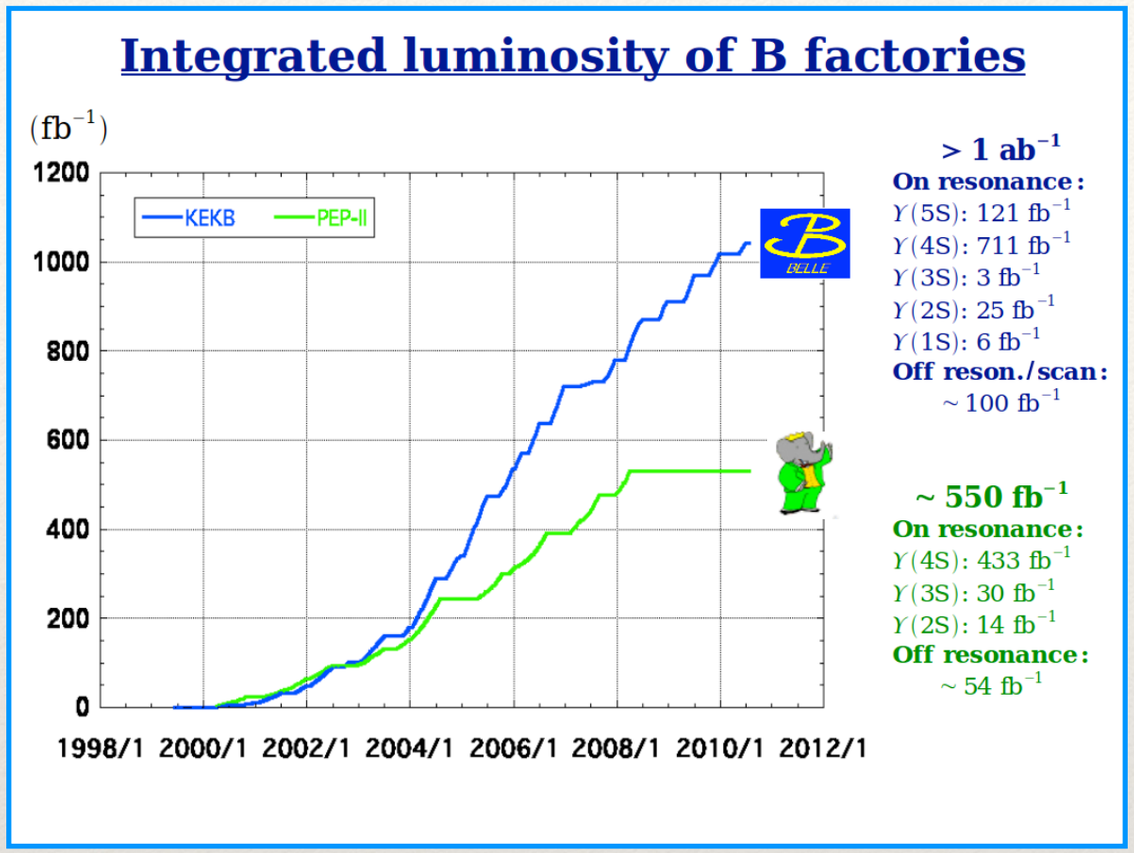
B2TIP document

Belle II Physics Book to be published soon in PTEP: update of Belle II sensitivity studies.

See Belle II Theory Interface Platform: https://confluence.desy.de/display/BI/B2TiP+WebHome

- Inclusive and exclusive Leptonic and Semi-leptonic B decays, $|V_{ub}|$ and $|V_{cb}|$:
  $B\to\tau\nu$, $B\to\mu\nu$, $B\to D^{(*)}\tau\nu$, $B\to\pi\tau\nu$, $B\to X_c\tau\nu$, $B\to D^{**}\ell\nu$, $B\to\pi\ell\nu$, $B_s\to K\ell\nu$, $B\to X_u\ell\nu$, $B_{(s)}\to X_c\ell\nu$, …
- Radiative and electroweak Penguin B decays:
  $B\to X_{s,d}\gamma$, $B_{(s)}\to V\gamma$, $B_{(s)}\to\gamma\gamma$, $B\to X_s\gamma\gamma$, $B\to X_{s,d}\ell\ell$, $B\to K^{(*)}\ell\ell$ (inclunding $\tau\tau$), $B_{(s)}\to\tau\tau$, $B\to K^{(*)}\nu\nu$, $B_{d,s}\to\nu\nu$, $b\to q\tau\tau$, …
- Time Dependent CPV, β and α:
  $B\to J/\psi K_S$, $B\to J/\psi\pi^0$, $B\to\phi K^0$, $B\to\eta' K^0$, $B\to\omega K_s$, $B\to K_S\pi^0$, $B\to K_S\pi^0\gamma$, $B\to\pi\pi$, $B\to\pi^0\pi^0$, $B\to\rho\rho$, $B\to\rho\pi$,…
- Determination of γ.
- Charmless hadronic B decays and direct CPV:
  $B\to\rho K^*$, $B\to K^*\pi$, …
- Charm physics:
- Quarkonium-like physics.
- τ physics: cLFV decays, CPV, …
- Dark sectors and Light Higgs.

Available datasets



Existing datasets in fb^{-1} (M events)

Experiment	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(4S)$	$\Upsilon(5S)$	$\Upsilon(6S)$
CLEO	1.2 (21)	1.2 (10)	1.2 (5)	16 (17.1)	0.1 (0.4)	-
BaBar	-	14 (99)	30 (122)	433 (471)	R_b scan	R_b scan
Belle	6 (102)	25 (158)	3 (12)	711 (772)	121 (36)	5.5