SuperKEKB & Belle II

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Dr. Pablo Goldenzweig

Flavor Physics Lectures
X / XII

Winter Semester 2020/2021

10. February, 2021

Reading material and references

Lecture material based on several textbooks and online lectures/notes. Credits for material and figures include:

Literature

Perkins, Donald H. (2000), *Introduction to High Energy Physics*.

Griffiths, David J. (2nd edition), *Introduction to Elementary Particles*.

Stone, Sheldon (2nd edition), *B decays*.

Online Resources

Belle/BaBar Collaborations, *The Phyiscs of the B-Factories*.
http://arxiv.org/abs/1406.6311

Bona, Marcella (University of London), *CP Violation Lecture Notes*,
http://pprc.qmul.ac.uk/ bona/ulpg/cpv/

Richman, Jeremy D. (UCSB), *Heavy Quark Phyiscs and CP Violation*.
http://physics.ucsd.edu/students/courses/winter2010/physics222/references/driver_houches12.pdf

Thomson, Mark (Cambridge University), *Particle Physics Lecture Handouts*,
http://www.hep.phy.cam.ac.uk/ thomson/partIIIparticles/welcome.html

Grossman, Yuval (Cornell University), *Just a Taste. Lectures on Flavor Physics*,
http://www.lepp.cornell.edu/ pt267/files/notes/FlavorNotes.pdf

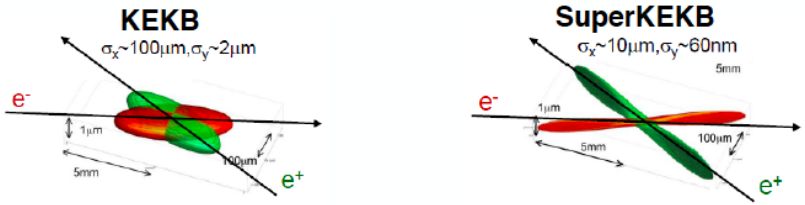
Kooijman, P. & Tuning, N., *CP Violation*,
https://www.nikhef.nl/ h71/Lectures/2015/ppII-cpviolation-29012015.pdf

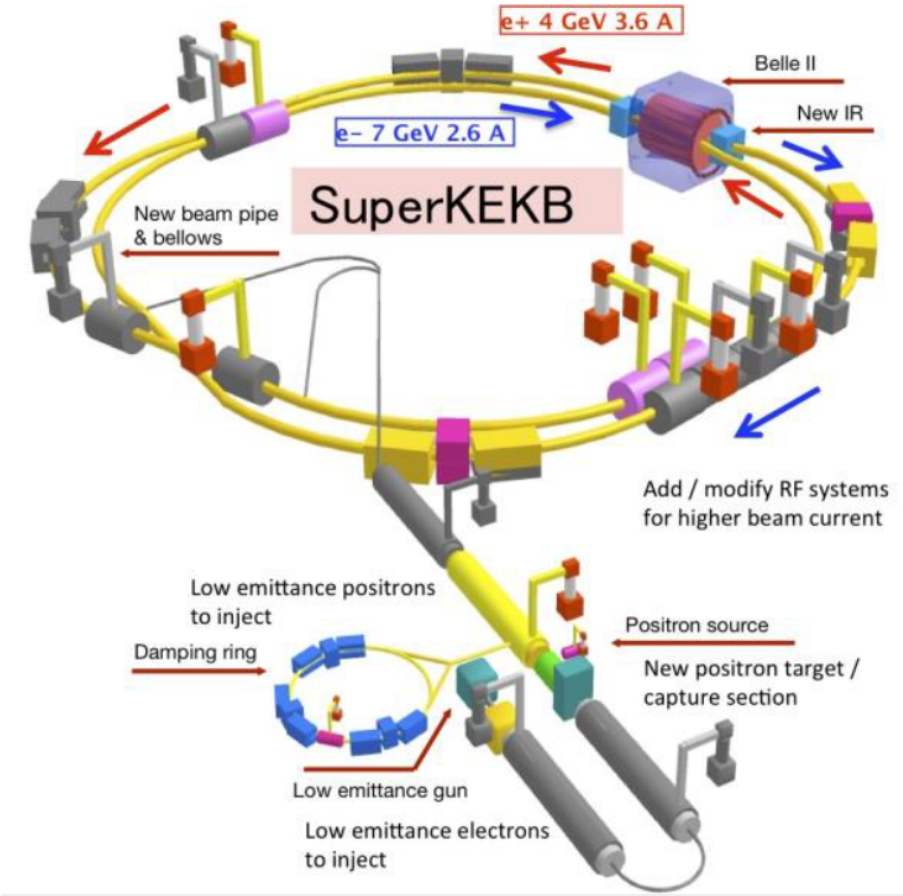
SuperKEKB accelerator

Upgrade for SuperKEKB and Belle II to achieve 40x peak $\mathcal{L}$ under 20x bkgd

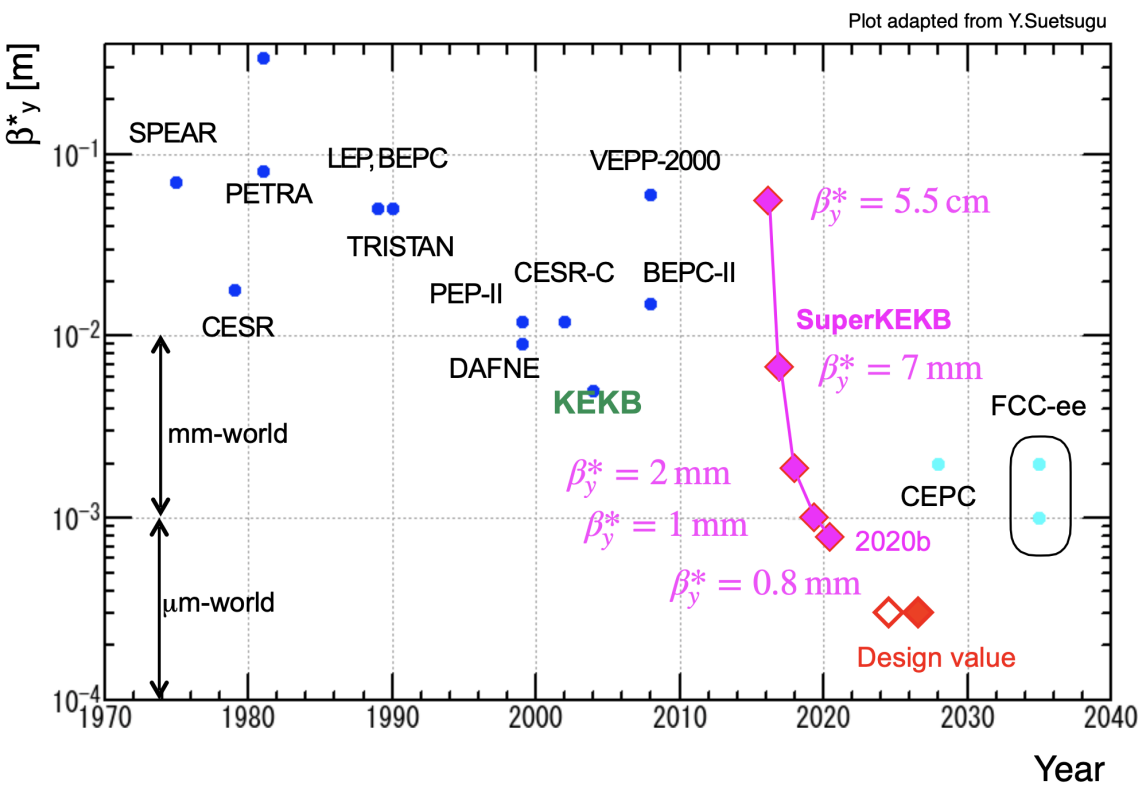
- Reduction in the beam size by 1/20 at the IP.
- Doubling the beam currents.

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





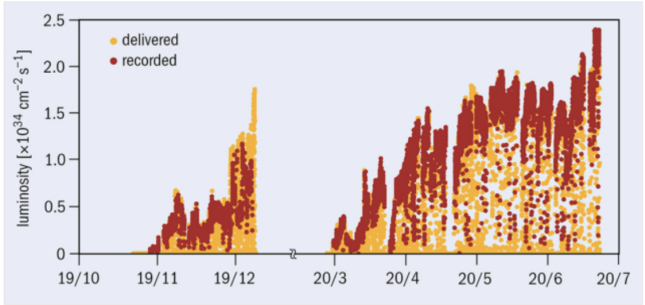
World record $\mathcal{L}_{\text{inst}}$ in 2020



ACCELERATORS | NEWS

KEK reclaims luminosity record

30 June 2020



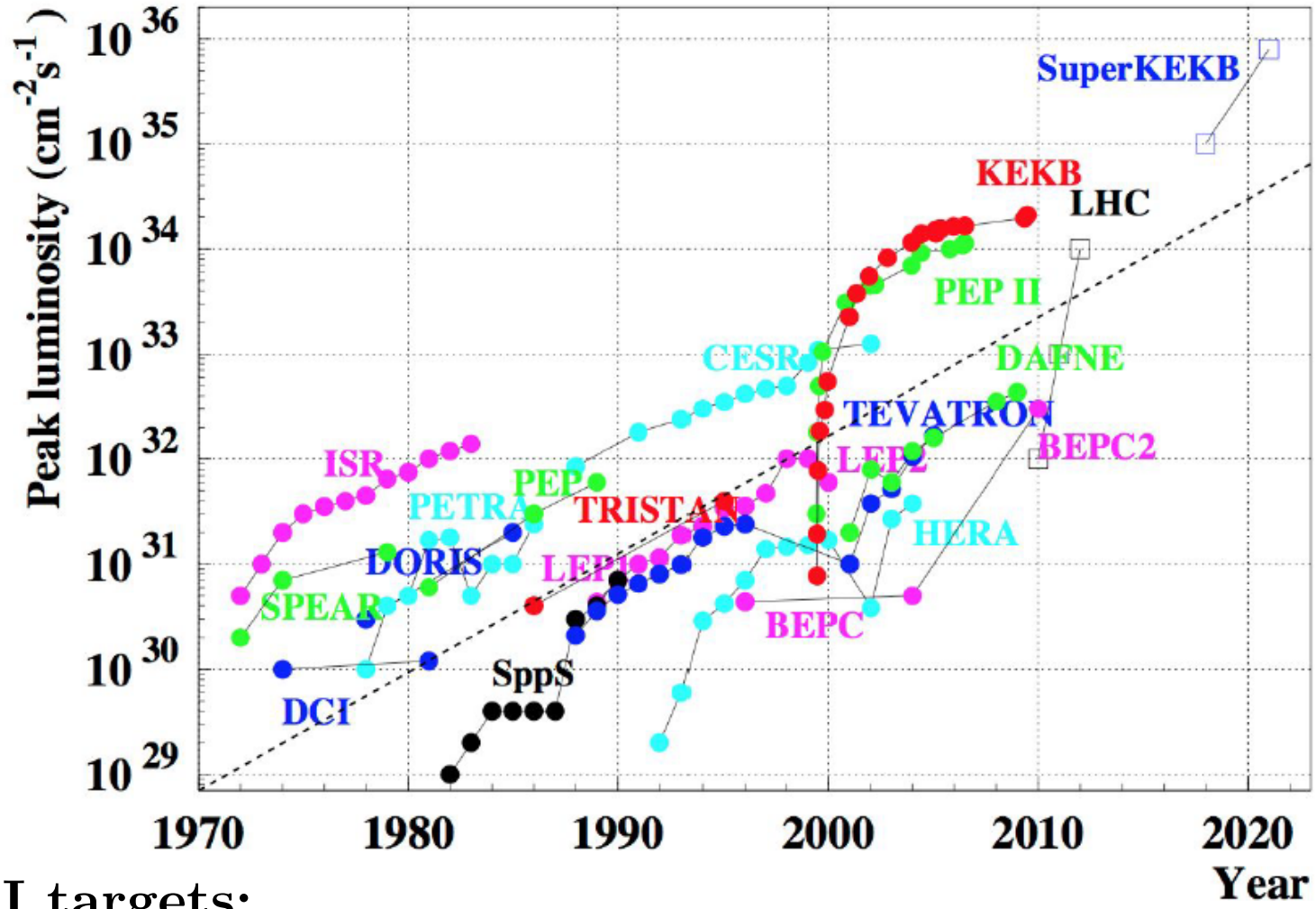
Record breaker The instantaneous luminosity of SuperKEKB measured at 5-minute intervals from late 2019 to 22 June 2020. Values are online measurements and contain an approximate 1% error. Credit: KEK

We can spare no words in thanking KEK for their pioneering work in achieving results that push forward both the accelerator frontier and the related physics frontier

Pantaleo Raimondi

$$\rightarrow \mathscr{L} = 2.4 \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$$

The intensity frontier and beyond *(with displaced x-axis)*

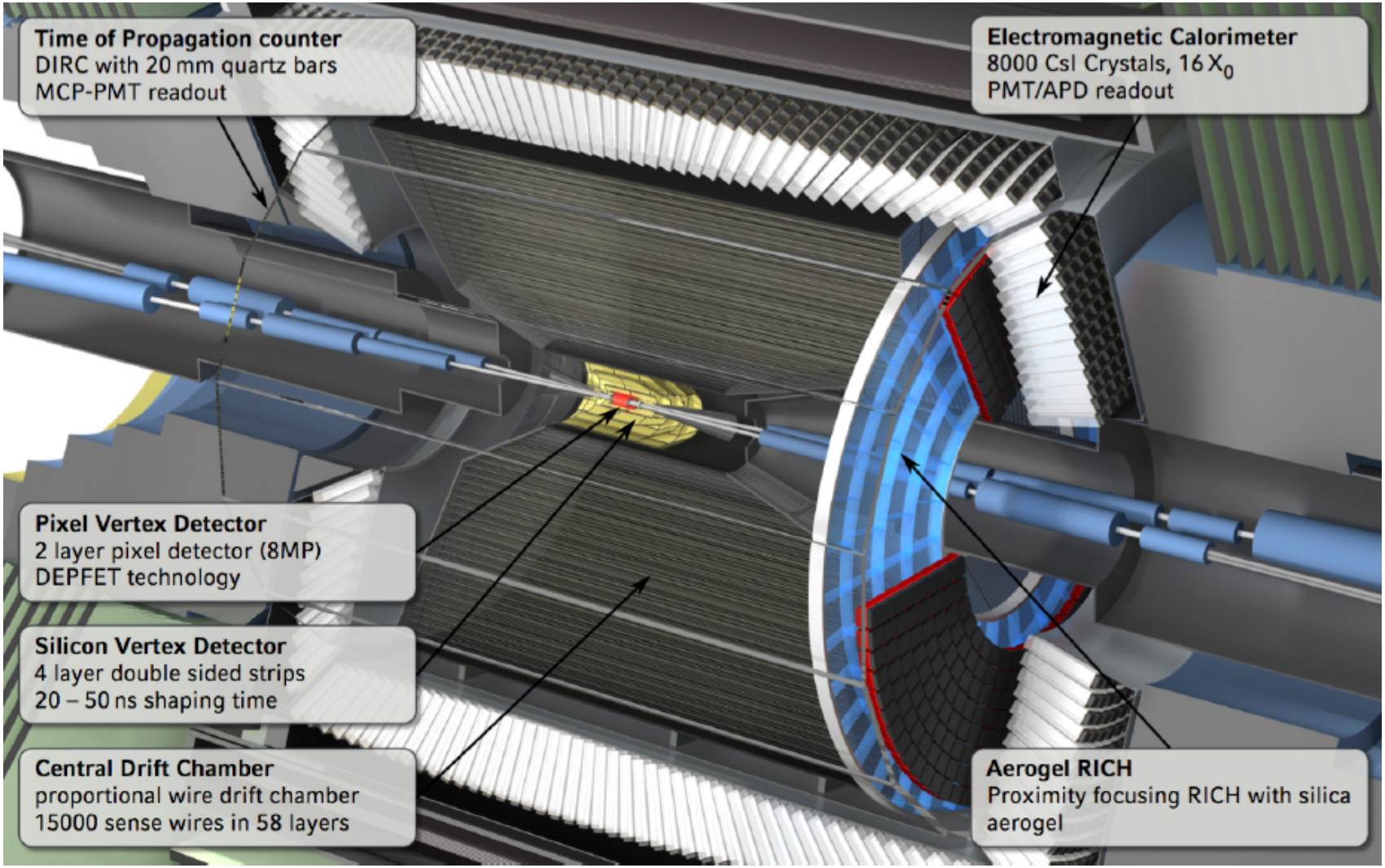


Belle II targets:

Instantaneous luminosity $8 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Integrated luminosity $50\mathrm{ab}^{-1}$ by 2031

Belle II detector



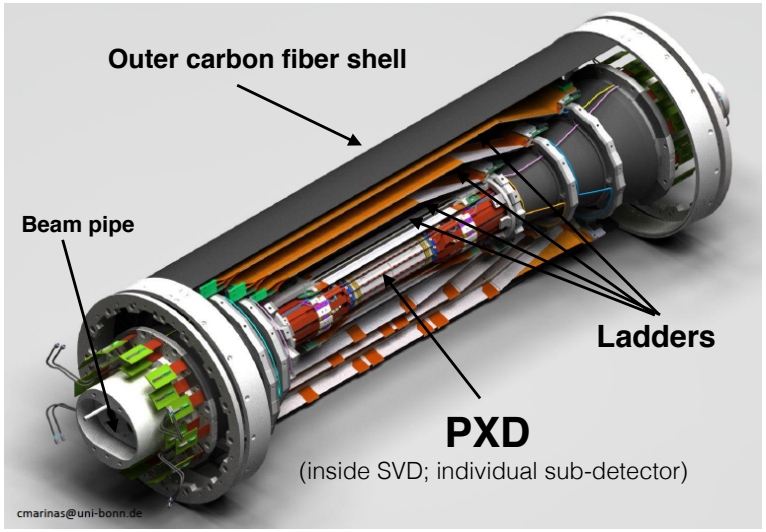
Targeted improvements: *Increase K_S^0 efficiency; Improve IP and secondary vertex resolution, K/π separation, and π^0 efficiency; Particle and μ ID in endcaps.*

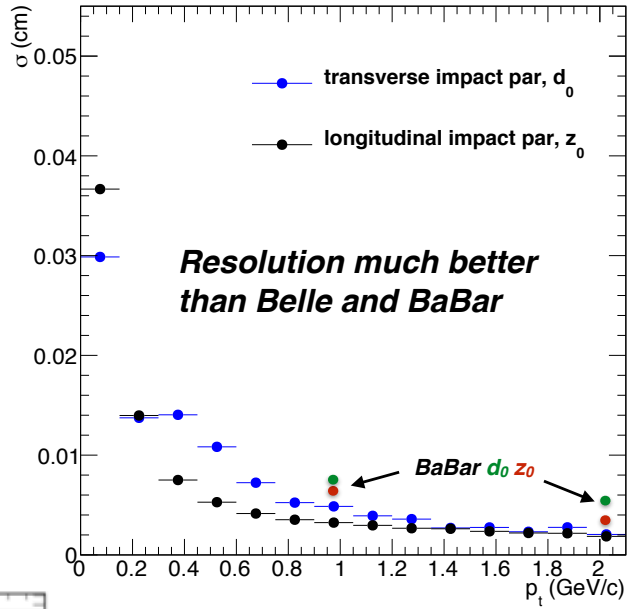
Vertex detector

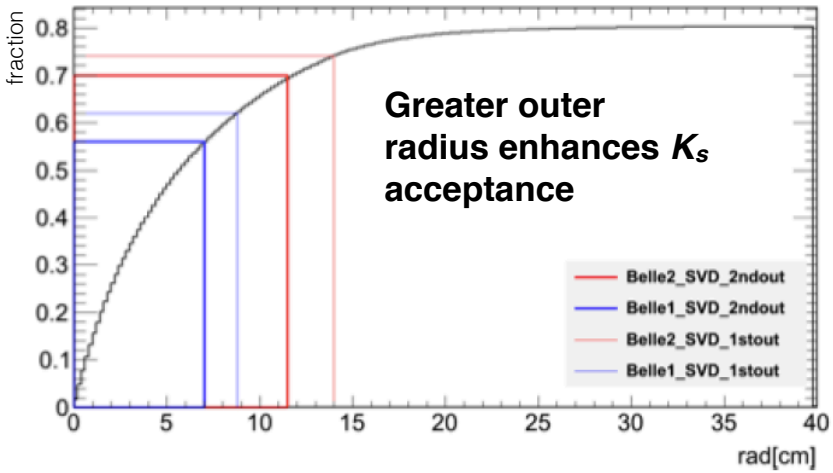
Si pixel (2 layers) and strip (4 layers):

- 1^{st} pixel layer at $r = 14mm$ to IP
  [Belle at $r = 20mm$]
  Improves vertex resolution along z-axis

- Larger SVD w/outer layer at $r = 135mm$.
  [Belle at $r = 88mm$]
  Higher fraction of K_S' with vertex hits improves vertex resolution



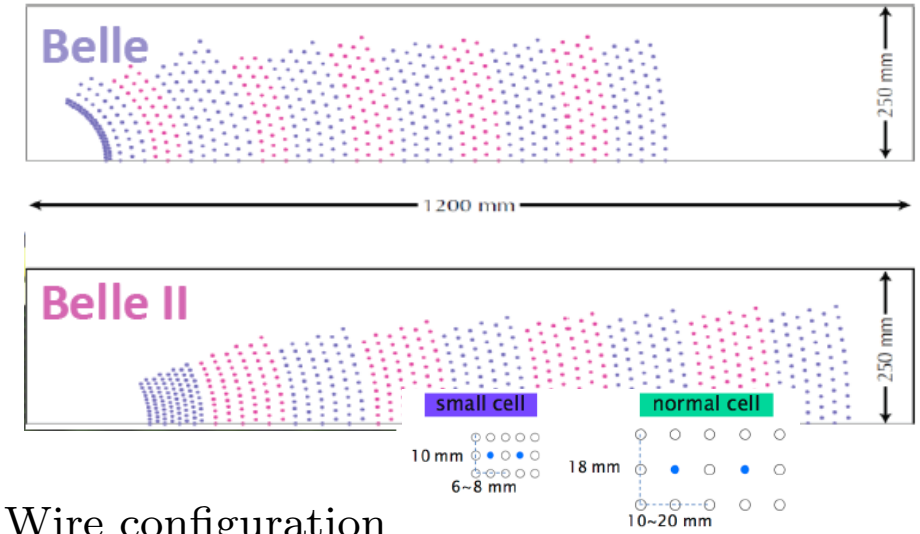




Tracking detector

Central Drift Chamber:

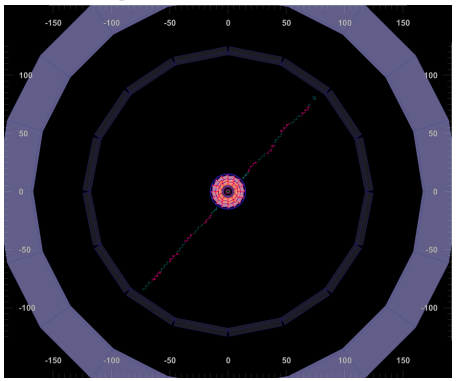
- Larger outer radius of 1111mm (Belle 863mm) allows for improved p resolution.
- Smaller cells with lower occupancy and capacity for higher hit rate.



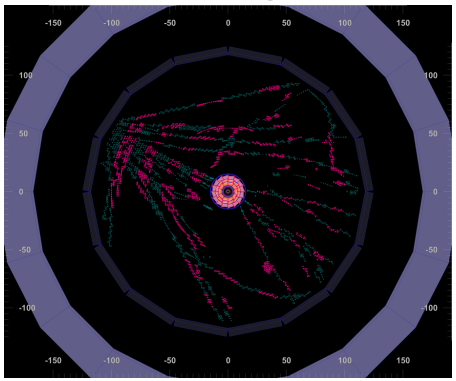
Wire configuration

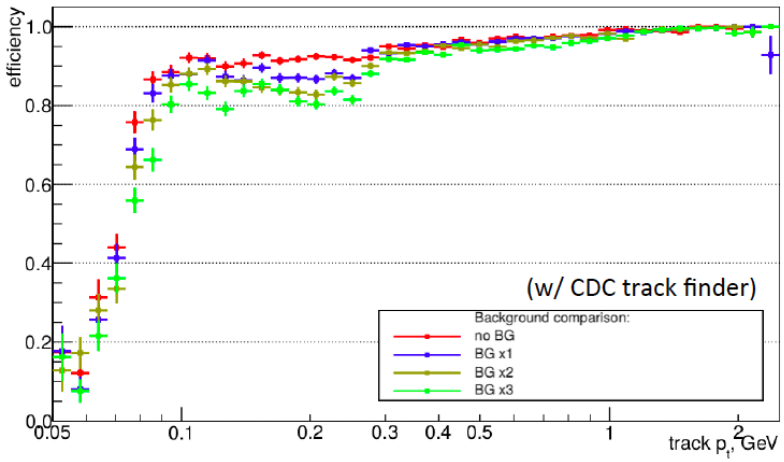
Full readout of the CDC

Single track



Showering event





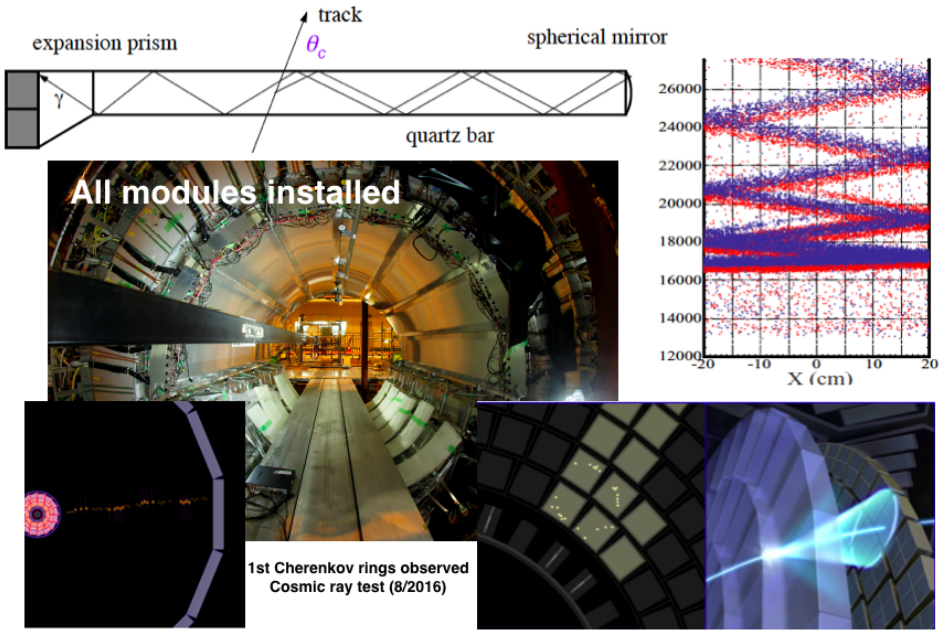
Simulated track reconstruction efficiency

Stable performance for up to 3x predicted beam BG

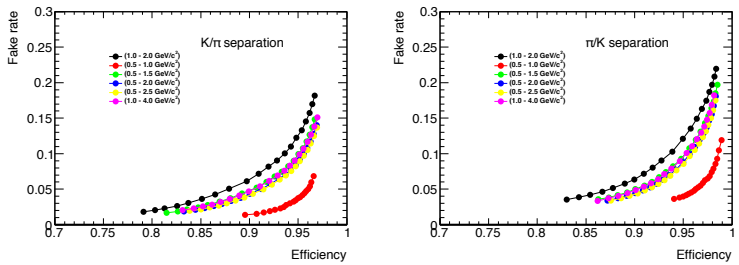
Particle identification

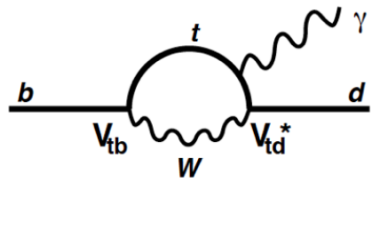
Two RICH systems covering full momentum range

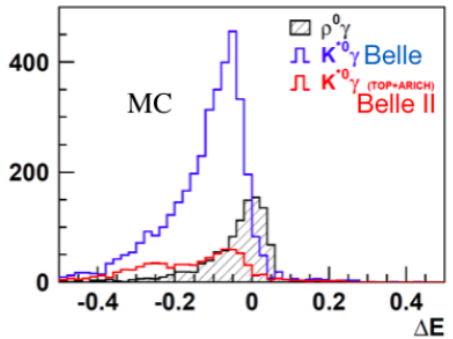
- Barrel: Time of Propagation (TOP) counter (16 modules).
  $\Rightarrow$ *Measure x-y position of Cherenkov γ's and their arrival time.*
- Forward Endcap: Aerogel Ring Imaging Cherenkov detector (ARICH)
  $\Rightarrow$ *Proximity focusing with silica aerogel (4σ separation at $1-3.5$ GeV/c)*



Average ϵ_K vs. π fake rate improved: Fake rate decreases by ≈ 3 for the same ε w.r.t. Belle





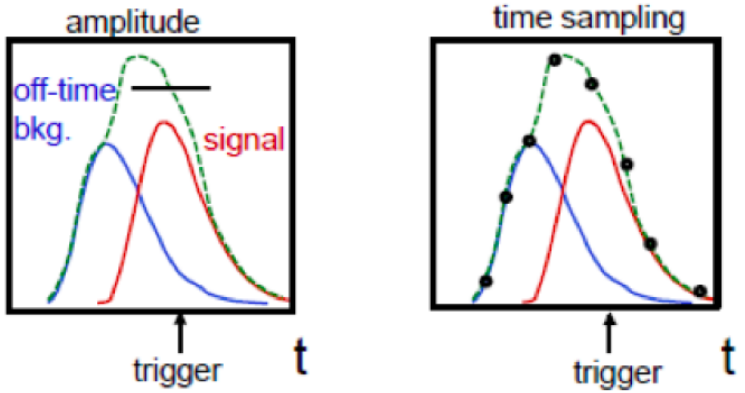


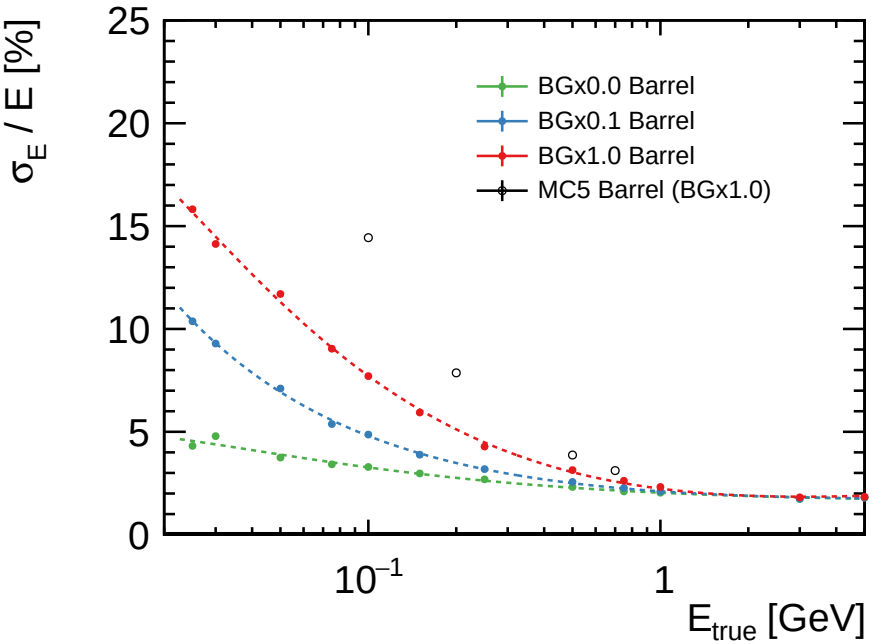
The background $B \to K^*\gamma$ (Belle/Belle II) $\approx 30x$ more abundant than $B \to \rho\gamma$.

Electromagmetic calorimeter

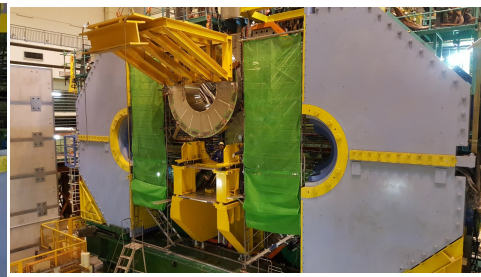
Re-usage of Belle's CsI(TI) crystal calorimeter, but with new electronics with 2MHz wave form sampling to compensate for the larger beam-related backgrounds and the long decay time of CsI(TI) signals.

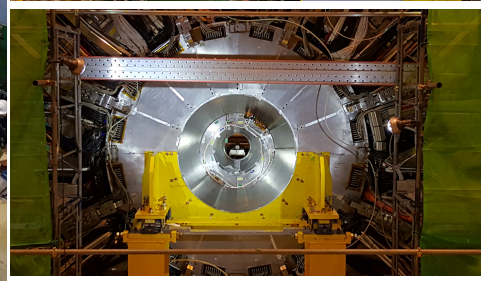
⇒ *Resolution much better at Belle II*





Peak energy resolution in the ECL barrel as a function of true photon energy





Endcap Installation

Run plan

Phase 1: 2011

- Beam background monitor.

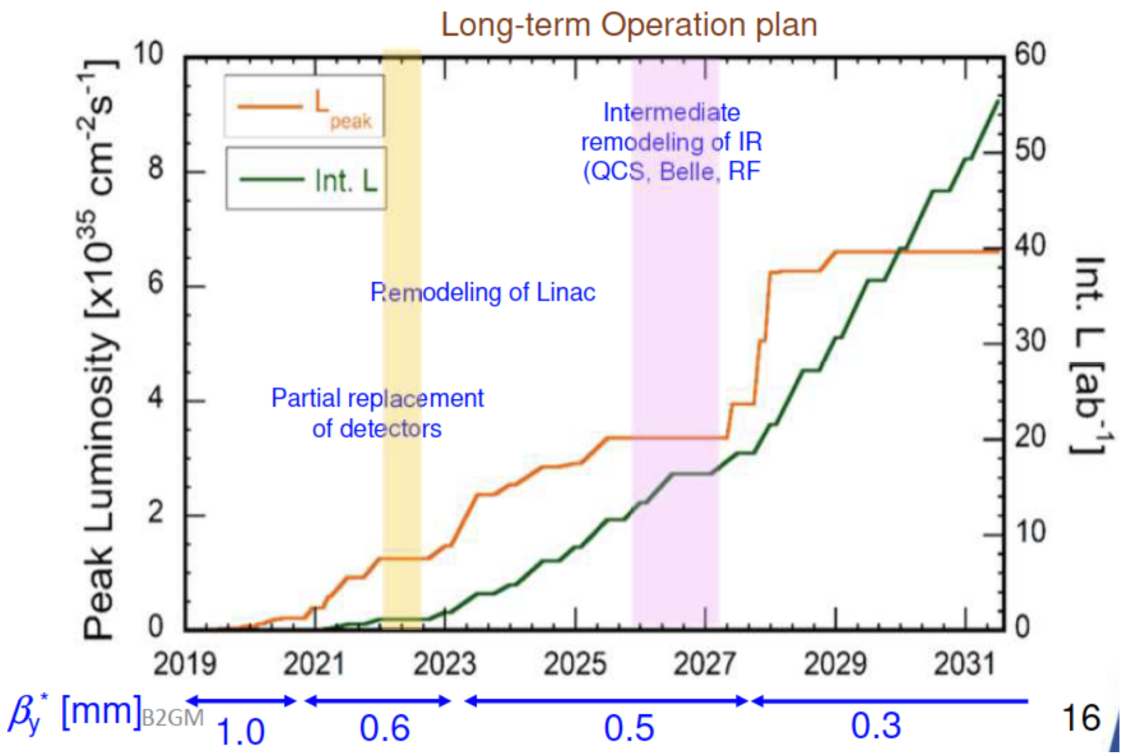
  (No Belle II detector.)

Phase 2: Feb.-July 2018

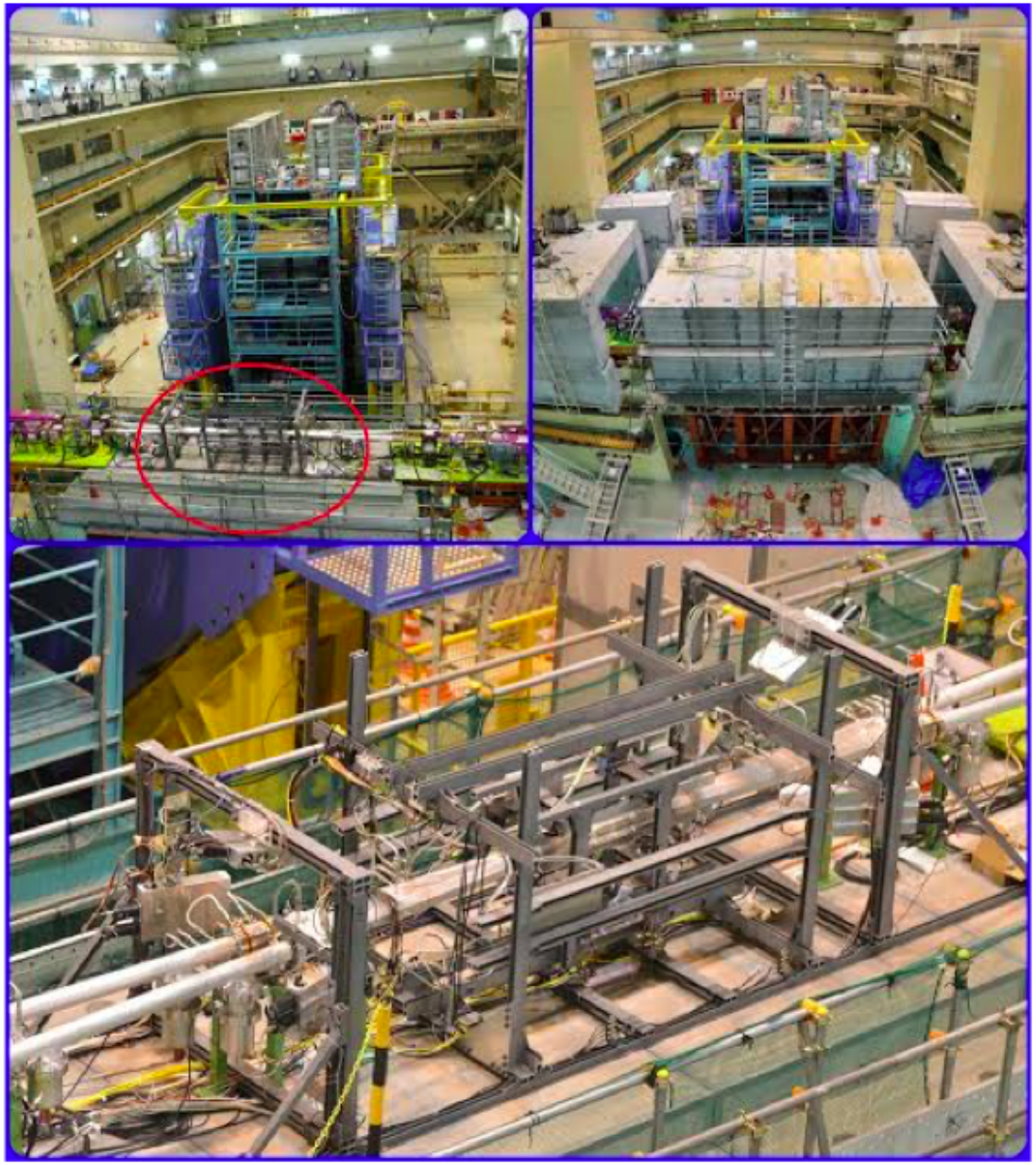
- First collisions.
- Beam commissioning.
- Physics run without VXD.
- New triggers for exotic dark signatures in low multiplicity events.

Phase 3:

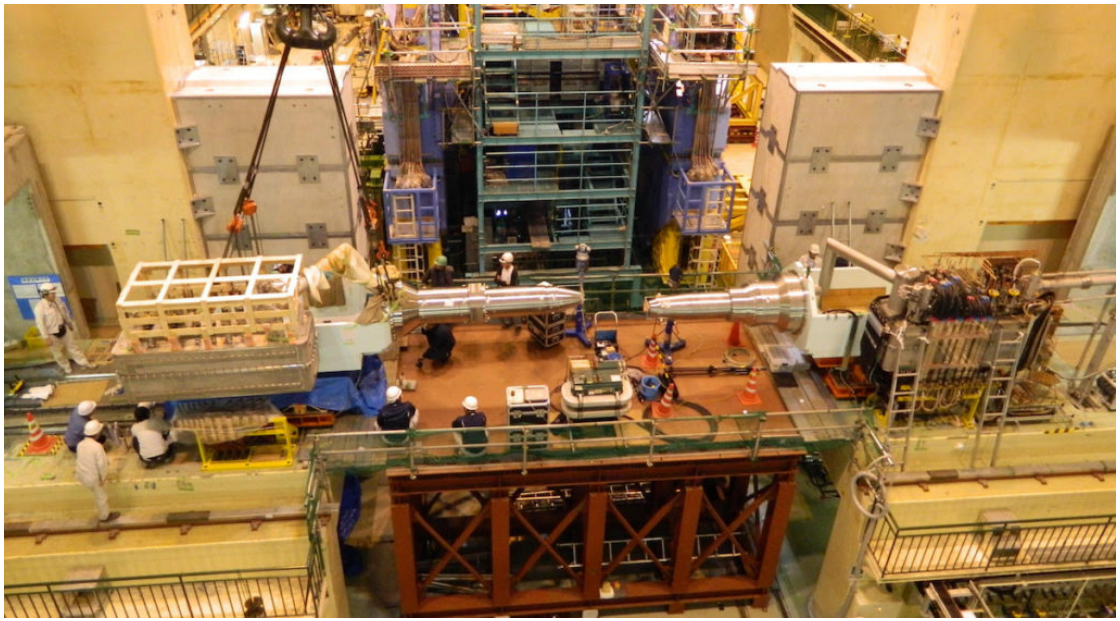
- Luminosity tuning.
- Physics run with partial and then full Belle II VXD.

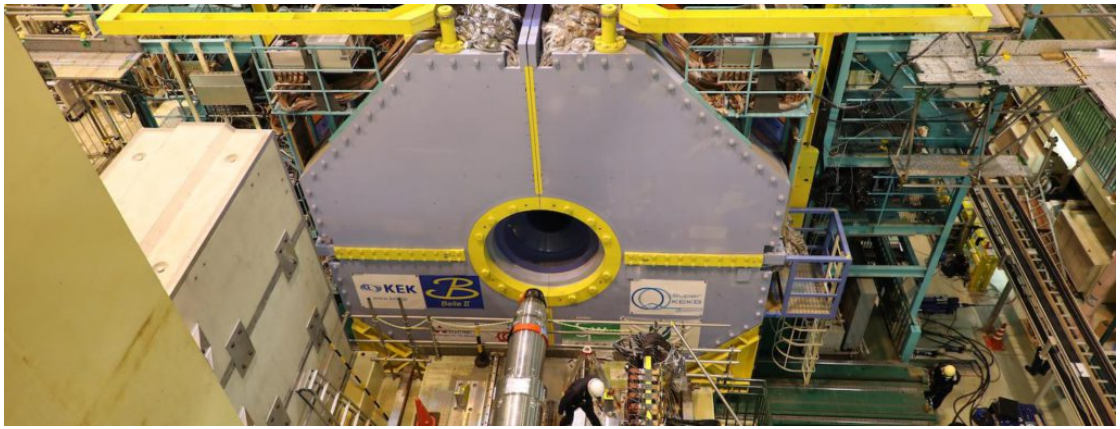


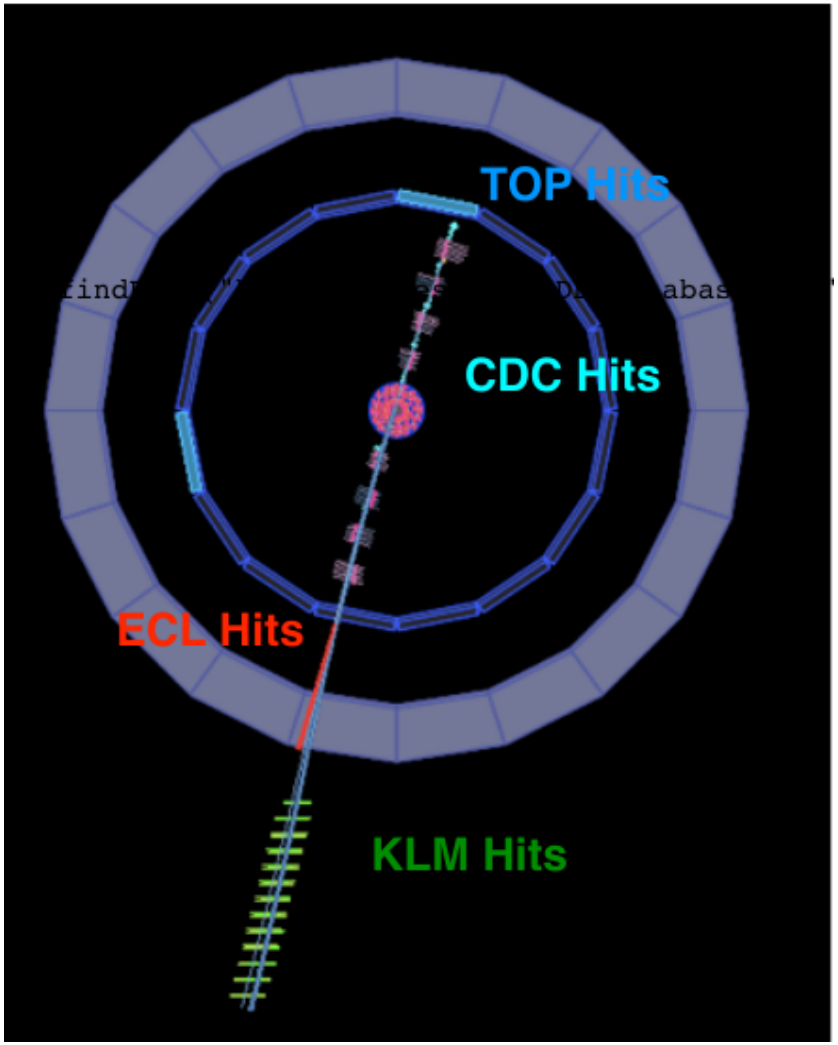
Phase I - beam background detector



Belle II roll-in (April 2011)

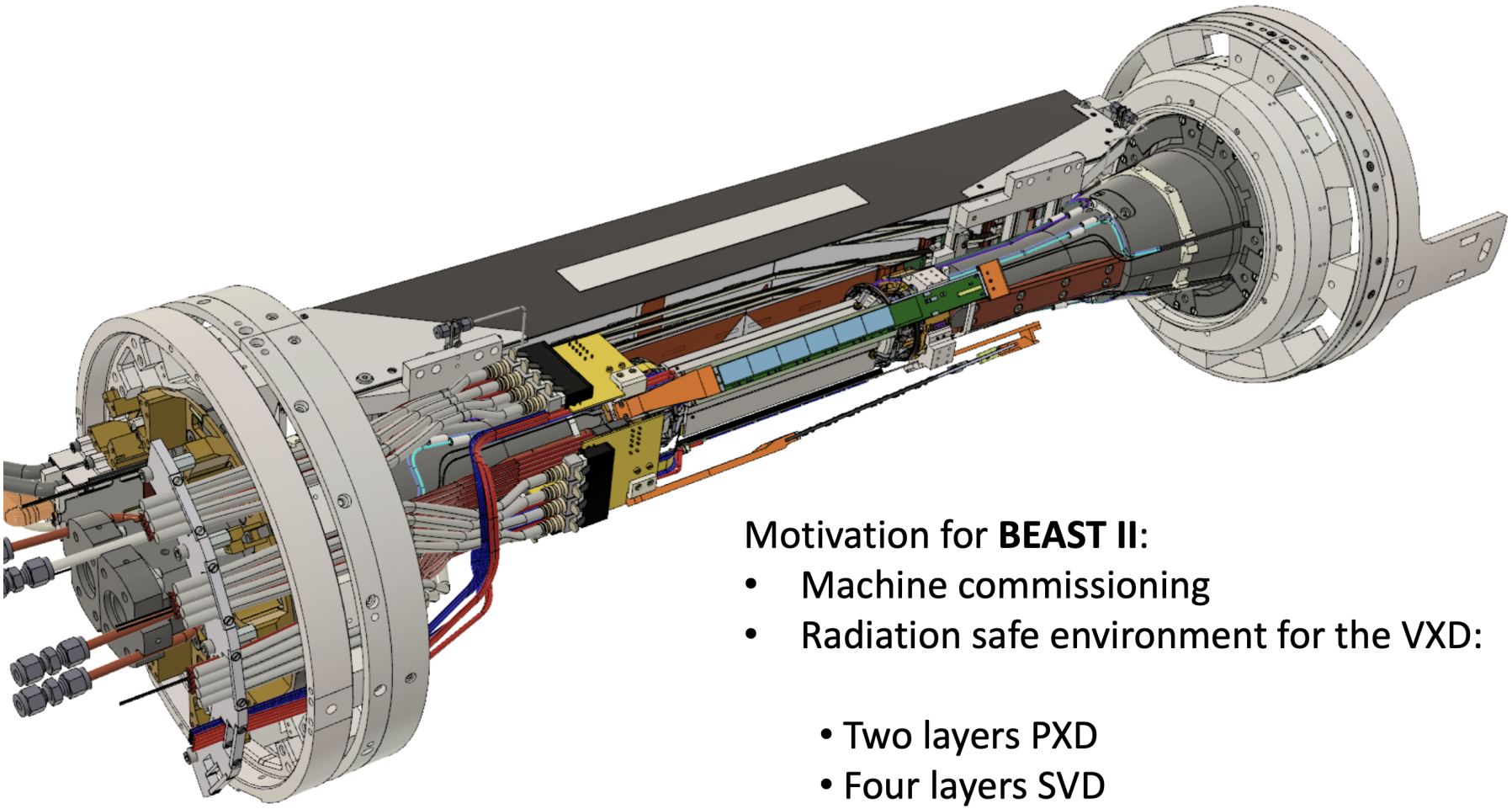






Global cosmic run

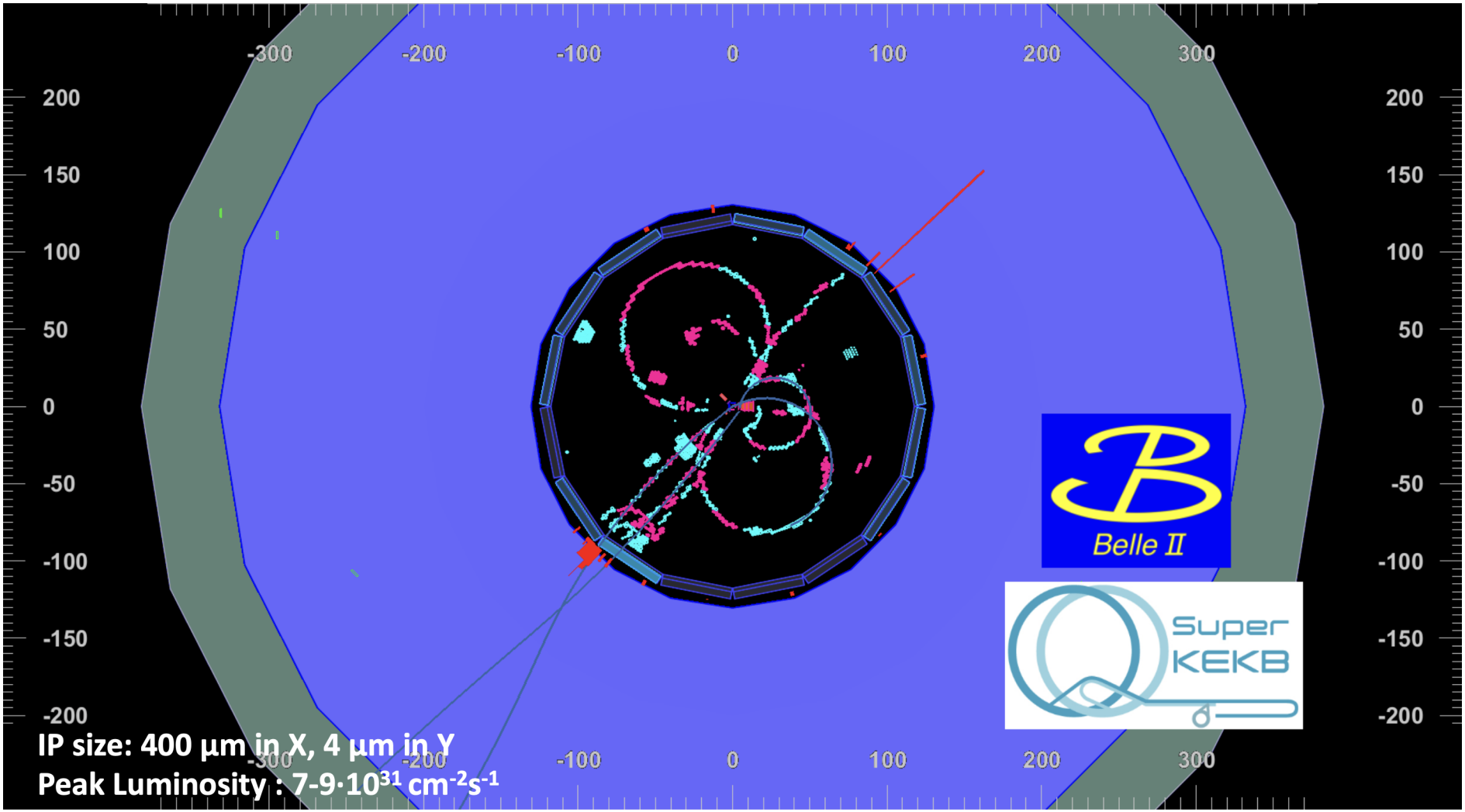
Phase 2 - Commissioning phase



Motivation for **BEAST II**:

- Machine commissioning
- Radiation safe environment for the VXD:
  - Two layers PXD
  - Four layers SVD
  - Dedicated radiation monitors

Phase 2 - First collision



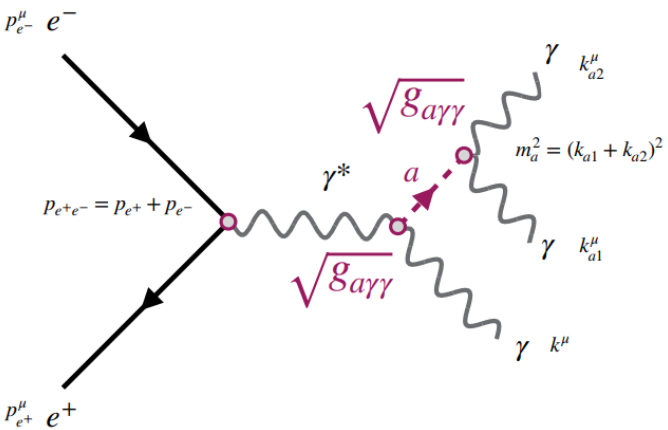
Phase 2 - First Belle II publication

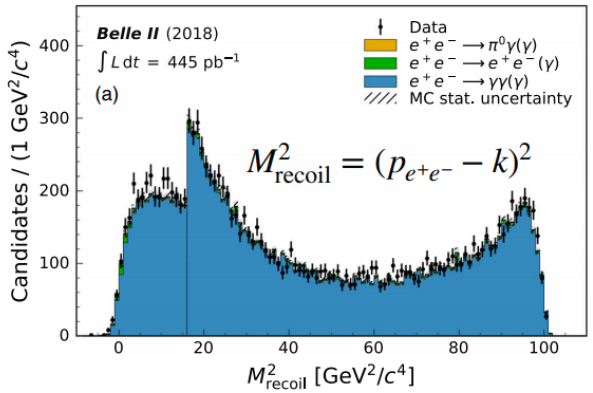
Axionartige Teilchen

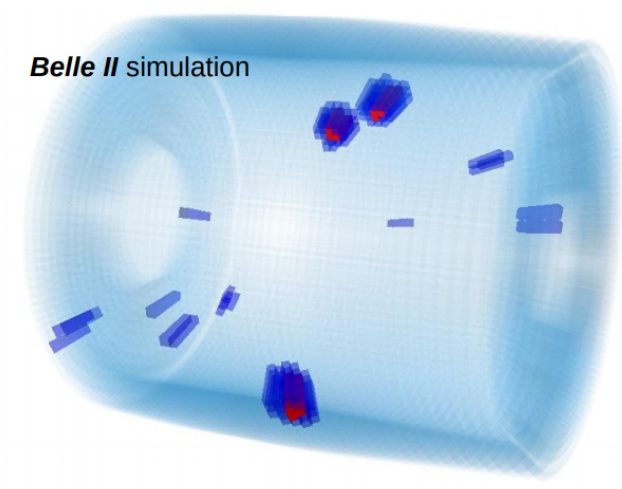
PHYSICAL REVIEW LETTERS **125,** 161806 (2020)

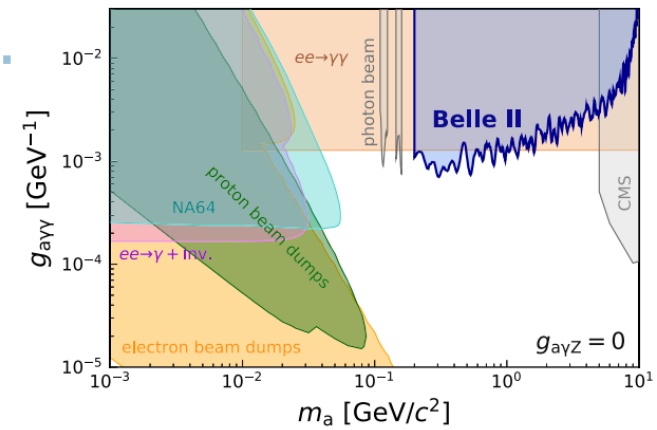
Search for Axionlike Particles Produced in e^+e^- Collisions at Belle II

F. Abudinén,[42] I. Adachi,[21,18] H. Aihara,[115] N. Akopov,[121] A. Aloisio,[87,35] F. Ameli,[39] N. Anh Ky,[32,11] D. M. Asner,[2] T. Aushev,[23] V. Aushev,[77] V. Babu,[9] S. Baehr,[46] S. Bahinipati,[25] P. Bambade,[96] Sw. Banerjee,[105] S. Bansal,[68] J. Baudot,[97] J. Becker,[46] P. K. Behera,[27] J. V. Bennett,[109] E. Bernieri,[40] F. U. Bernlochner,[99] M. Bertemes,[29] M. Bessner,[102]

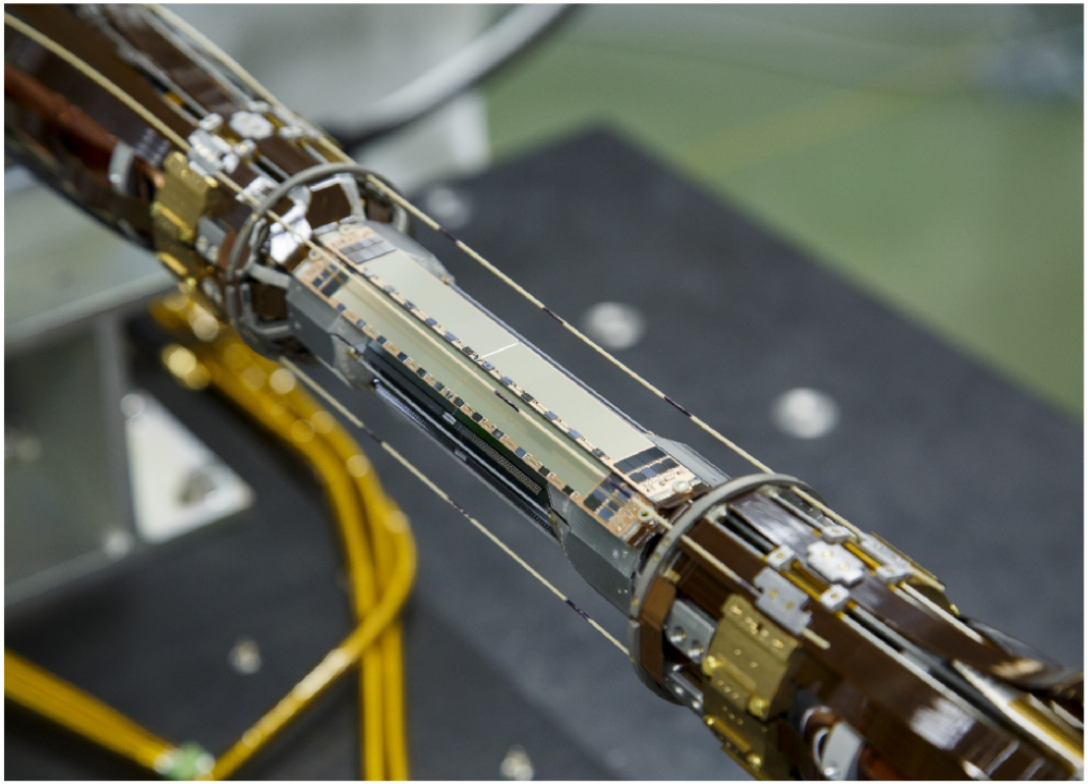


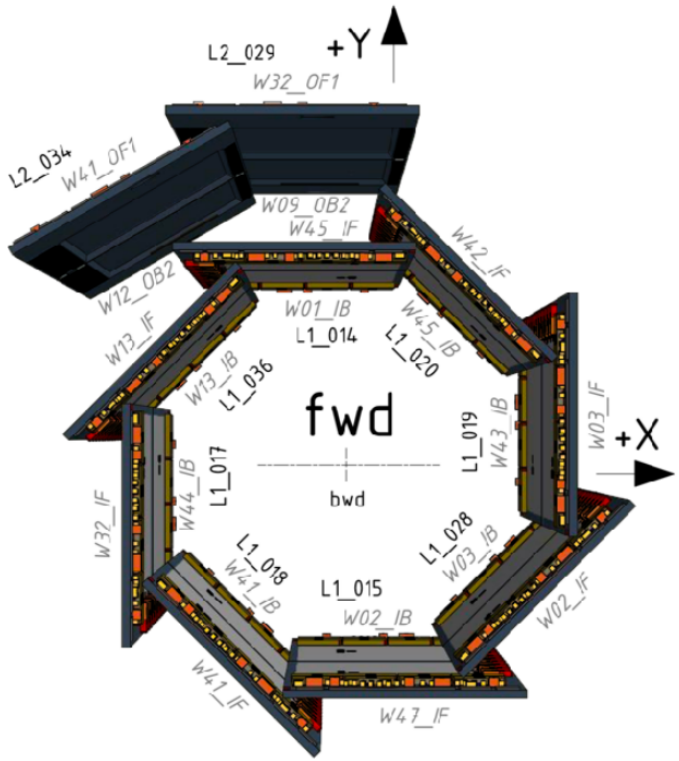






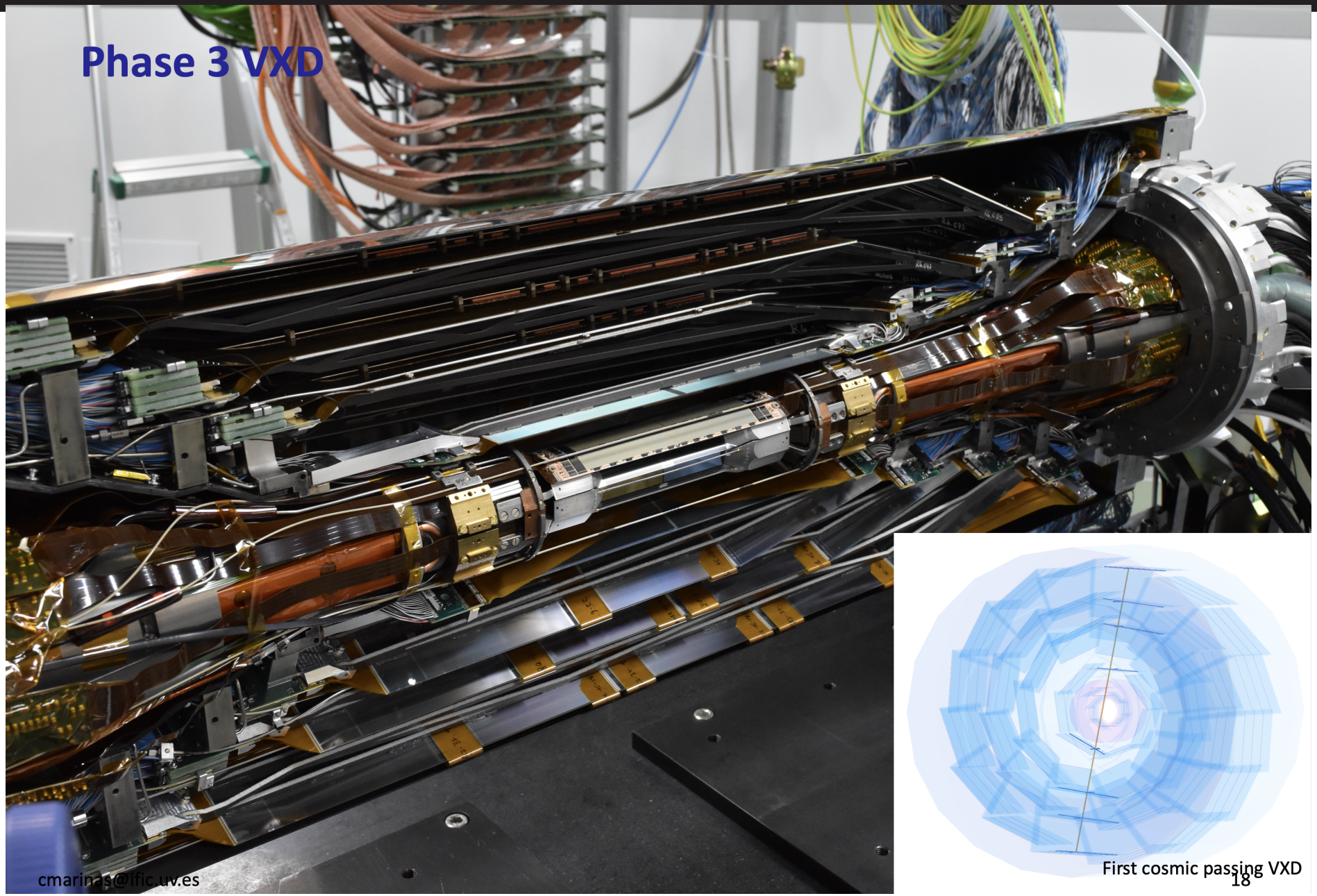
Phase 3 - Partial PXD



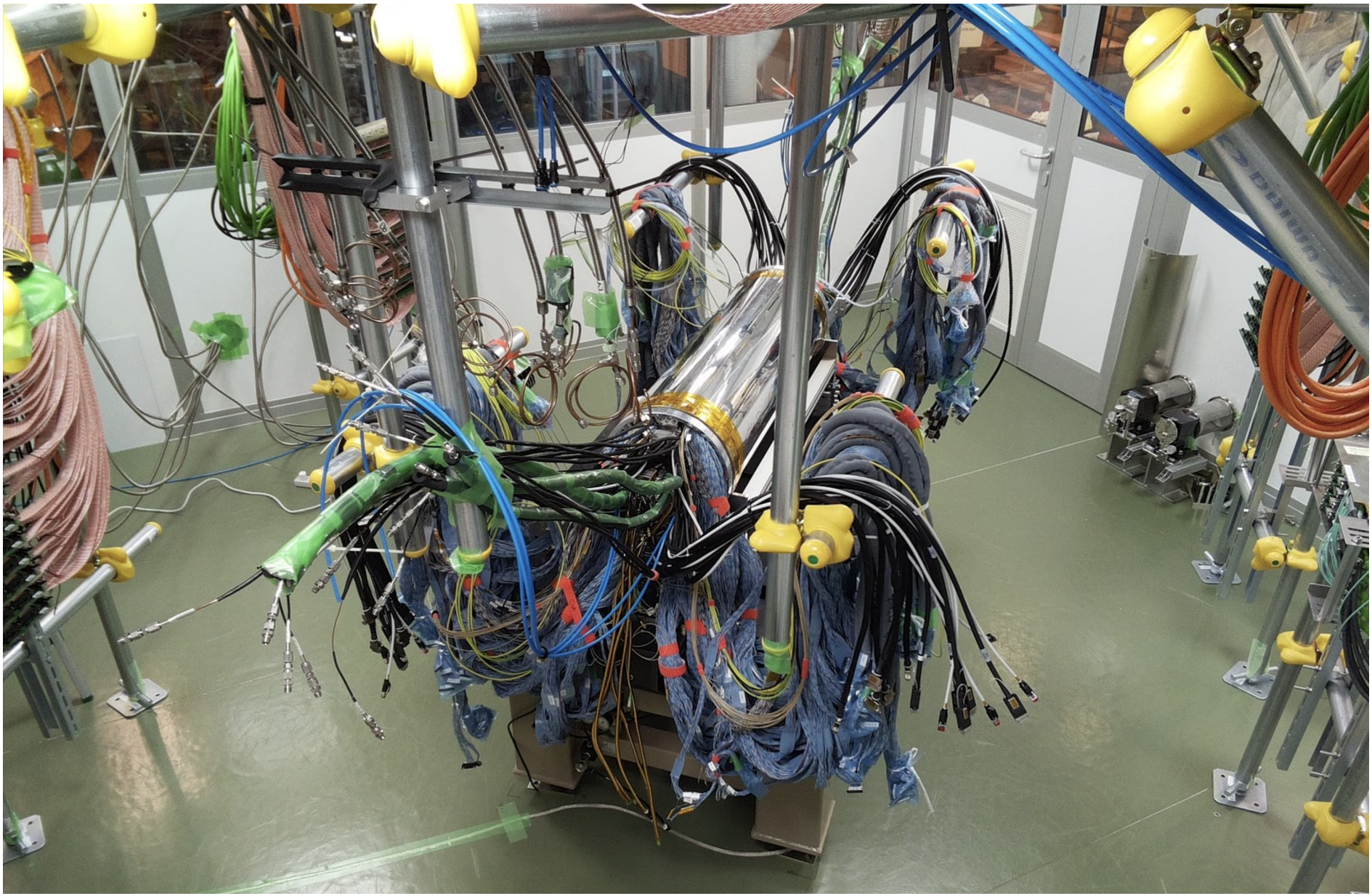


(A complete PXD will be installed during a long shutdown in 2022)

Phase 3 - PXD + SVD (half-shell for illustration)



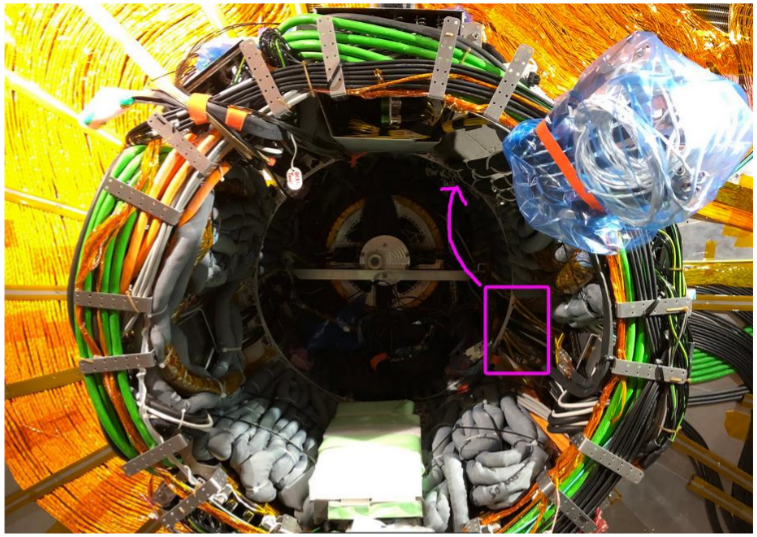
Phase 3 - VXD cabling nightmare



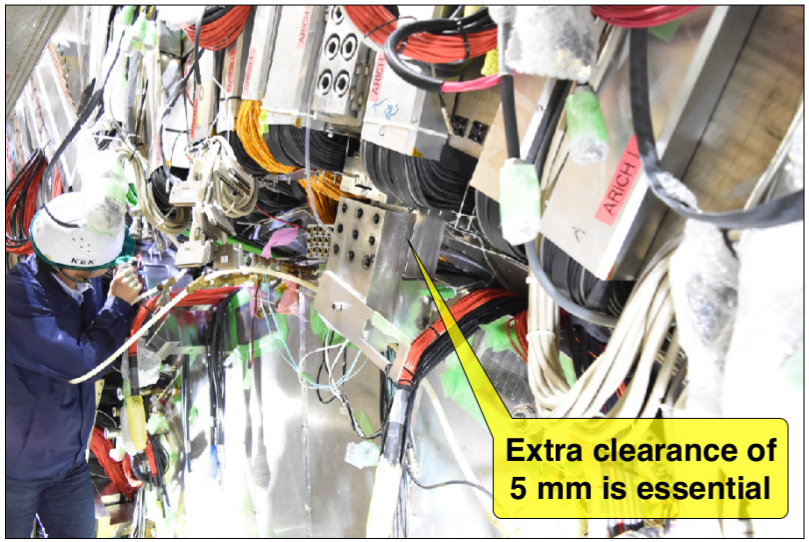
Phase 3 - VXD & endcap & QCS installation

VXD installation on Nov 21/22

Service space conflicts for 2020 w/ full PXD

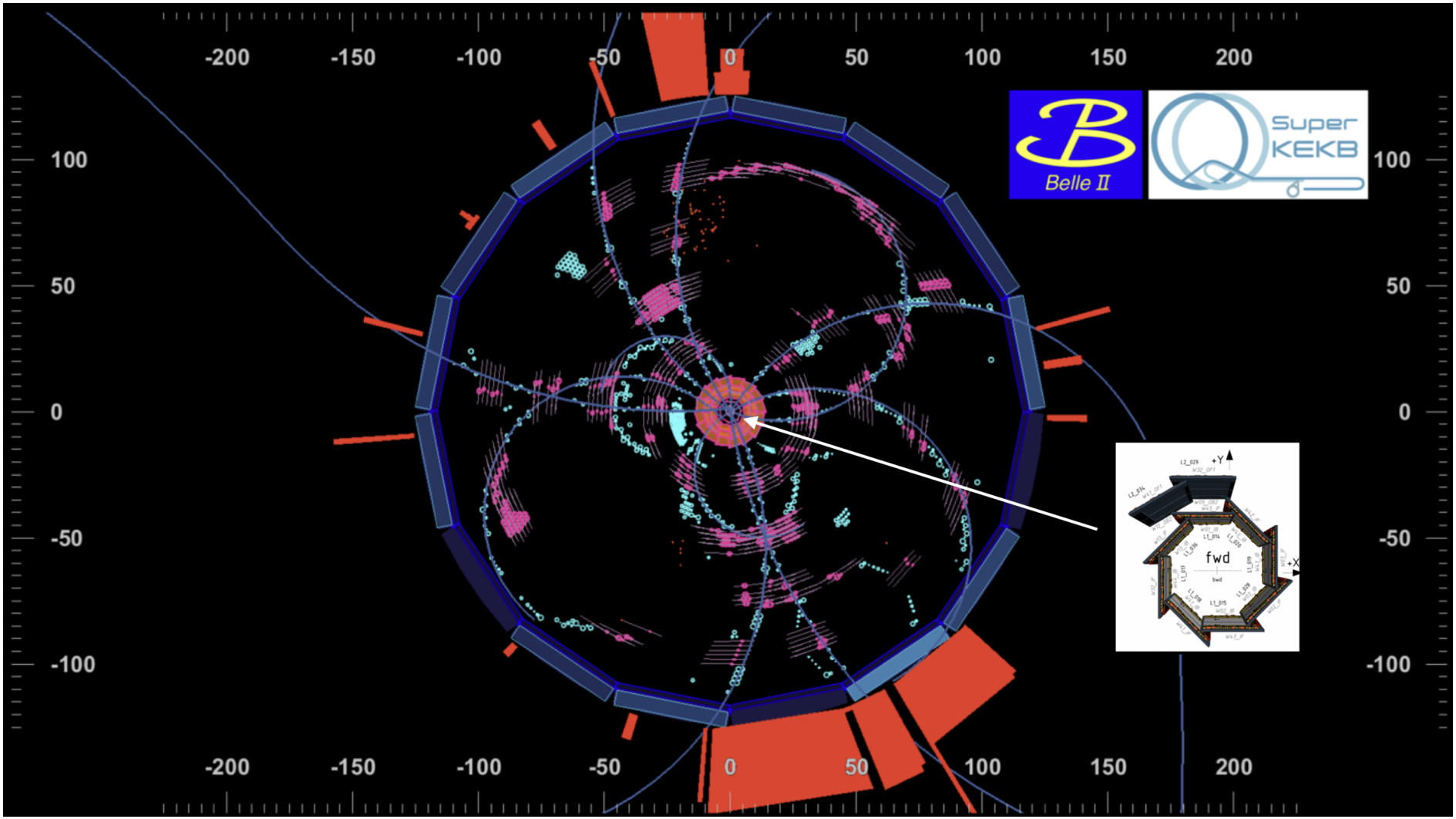


FWD Endcap push-in on Jan 25



QCS insertion & RVC closing on Jan17/18

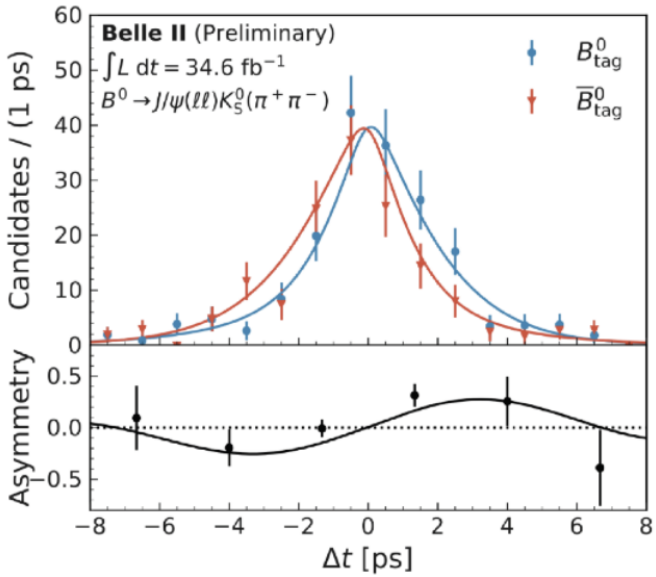
Phase 3 - First collision



Phase 3 - First physics summer 2020

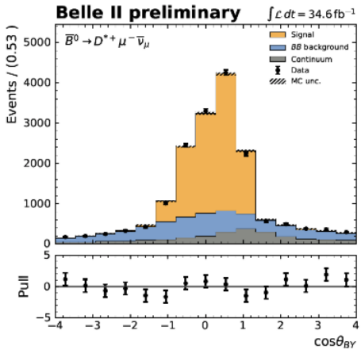
- 13 public documents of rediscoveries and performance on data;
- 9 conference papers uploaded to the arXiv;
- 3 sensitivity studies based on the simulation.
- Summary of all results is publicly accessible here.

TDCPV ($B \to J/\psi K_S^0$)

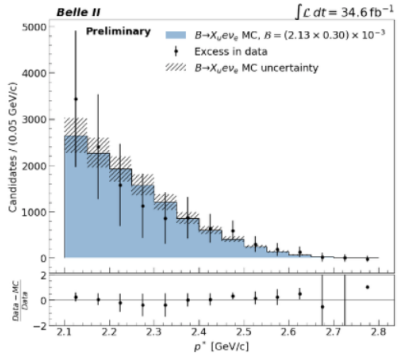


$$S_{CP} = 0.55 \pm 0.21(\text{stat.}) \pm 0.04(\text{syst.})$$

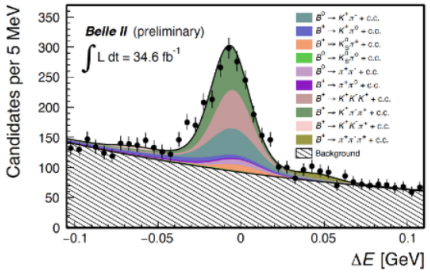
Exclusive B→D*lν



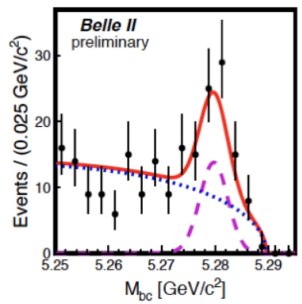
Inclusive b→u



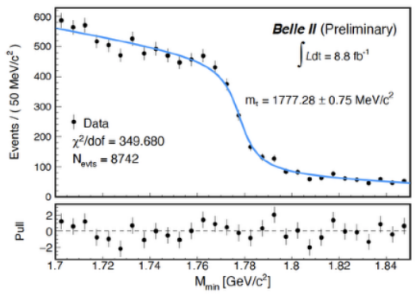
Charmless B decays



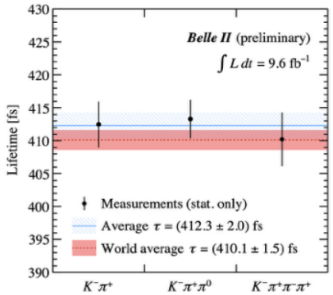
B → ΦK(*)



τ mass measurement

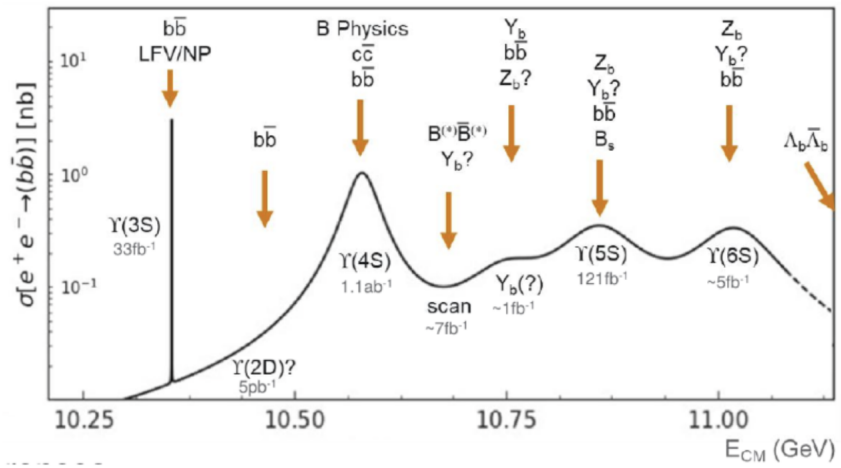


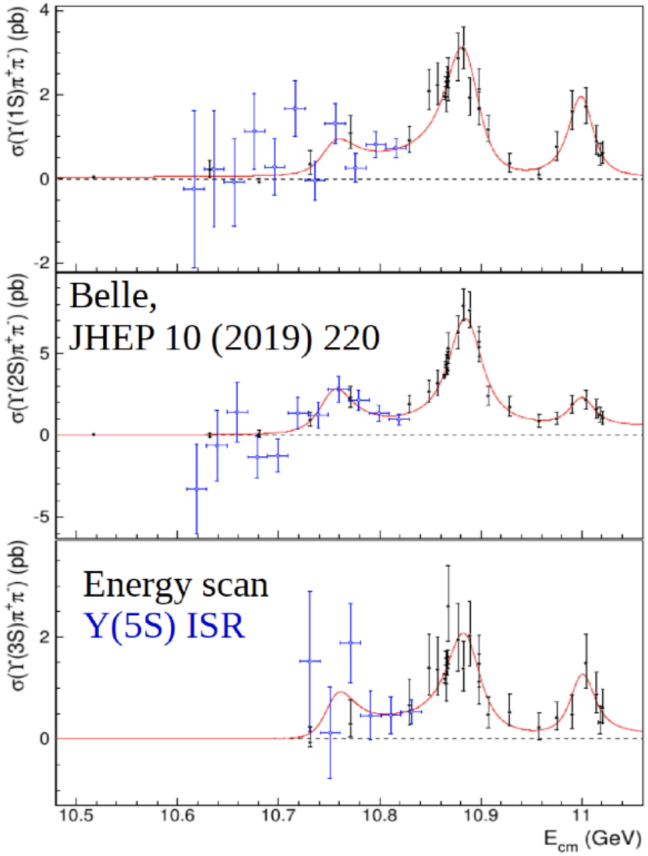
D⁰ lifetime



Beyond the $\Upsilon(4S)$ - Sometime in 2021(?)

A run above the the $\Upsilon(4S)$ would greatly expand the physics program.
Physics measurements: $\Upsilon(6S)$ *conventional bottonium and exotic states (e.g.,* Z_b*, QCD hybrids in* BB^**).*





- Long list of potential analyses
  - $\Upsilon(6S/b) \to \pi\pi X$ inclusive
  - $\Upsilon(6S/b) \to \pi\pi\Upsilon(pS)$ exclusive
  - Also $\pi^o\pi^o$ modes
  - $\Upsilon(6S) \to \gamma W_b \to \omega\Upsilon(1S)$
  - $\Upsilon(6S/b) \to \gamma\, \chi_b$ exclusive
  - $\Upsilon(6S/b) \to \gamma$ X inclusive
  - $\Upsilon(6S/b) \to \eta X$ inclusive
  - $\Upsilon(6S/b) \to \eta\Upsilon(pS)$ exclusive
  - $\Upsilon(6S/b) \to \eta'\Upsilon(pS)$ exclusive
  - $\Upsilon(6S/b) \to \omega X$ exclusive
  - $\Upsilon(6S) \to \phi\chi_b(1P)$ exclusive
  - $\Upsilon(6S/b) \to BB$
  - Each represents a publication unique to Belle II