Belle II SVD operation, performance and upgrade activities

Sagar Hazra

On behalf of TIFR-Belle II group

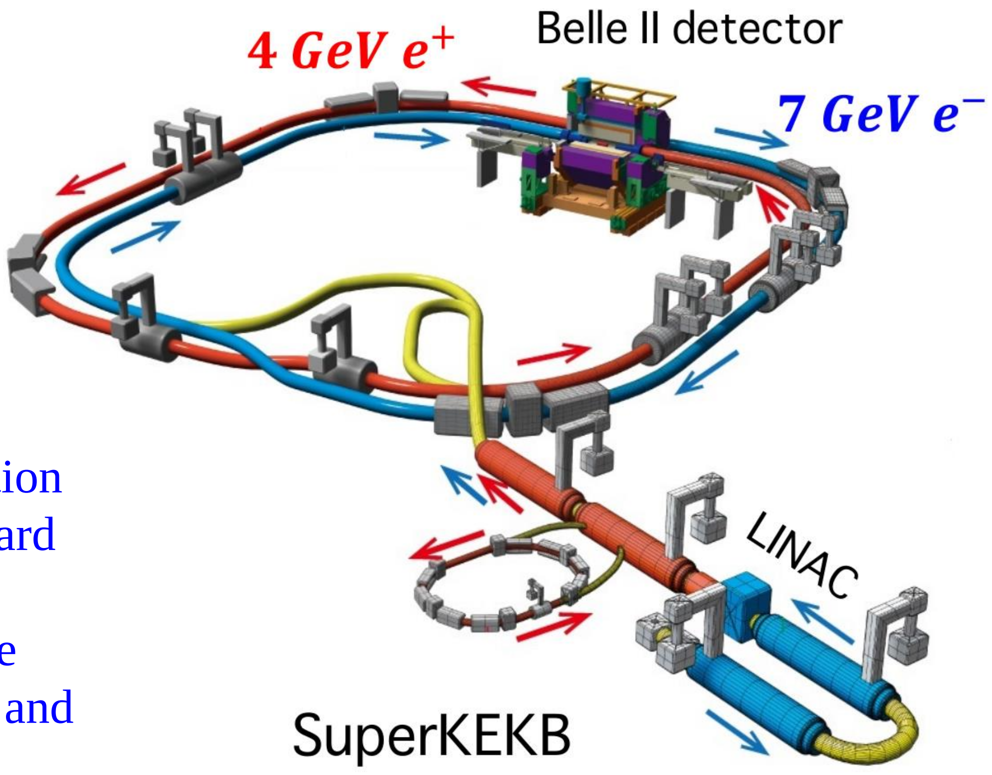
May 5, 2022
@ DHEP annual review 2022

Outline of the talk

- SuperKEKB and Belle II
- Silicon-strip vertex detector (SVD) highlights
- Operational experience
- Performance
- Upgrade activities
- Summary and outlook

SuperKEKB and Belle II

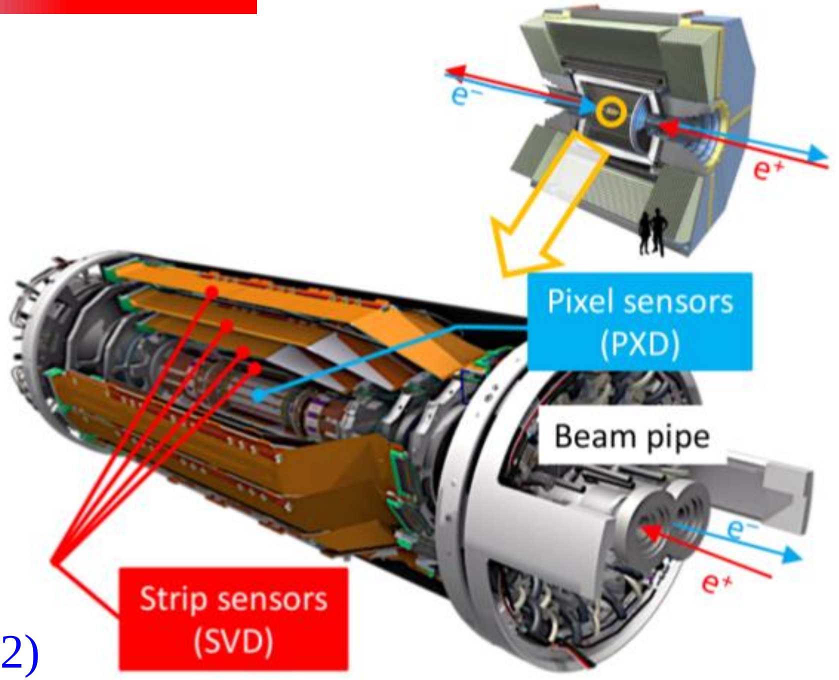
- Second-generation flavor factory
  - Asymmetric e^+e^- collisions at $\Upsilon(4S)$ resonance $\Rightarrow$ 10.58 GeV
  - Target $\mathcal{L}_{\text{int}}$: 50 ab^{-1} and $\mathcal{L}_{\text{peak}}$: $60 \times 10^{35} cm^{-2}s^{-1}$ (30 × KEKB)
  - Current record: $3.8 \times 10^{35} cm^{-2}s^{-1}$
- Belle II Detector
  - Search for new sources of CP violation and probe physics beyond the standard model at the intensity frontier
  - Physics requirements call for precise vertexing, low-momentum tracking and particle identification (PID)



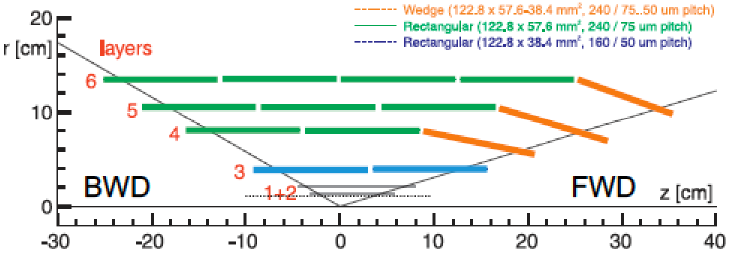
- Vertex Detector is a key component in this pursuit

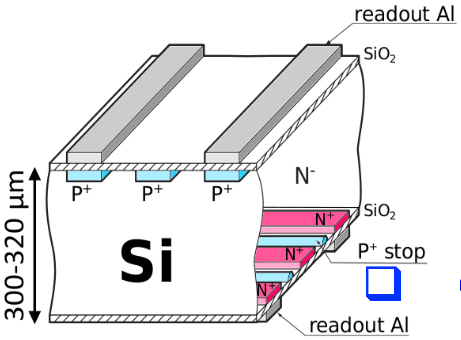
The Vertex Detector

- **Physics requirements:**
  - Better vertexing resolution than Belle to compensate reduced boost ⇒ improved resolution, and lower material budget (0.7% X_0 per layer)
  - Able to operate in high beam background ⇒ hit rate: 3 MHz/cm^2@ SVD layer-3
  - Radiation hard ⇒ 0.2 Mrad/yr @ SVD layer-3
- **Pixel Detector (PXD)**
  - DEPFET pixel sensors: Layer 1-2 (partial L2)
- **Silicon-strip Vertex Detector (SVD)**
  - Double-sided Si strip sensors: Layer 3-6
  - Standalone tracking and PID for low p_T charged particles
  - Extrapolate tracks to PXD (Region of interest)



SVD in one slide

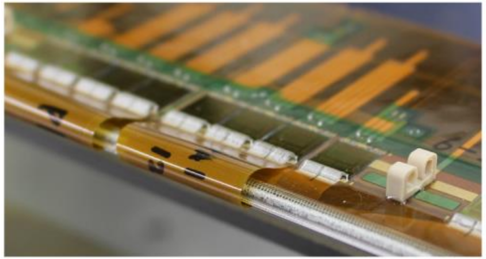




AC coupled strips

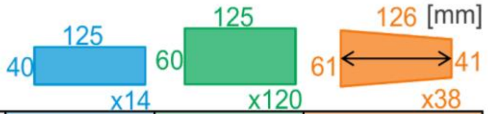
V_{dep}: 2–60 V

V_{op}: 100 V



Origami 'chip-on-sensor' concept⇒ small capacitive noise

172 sensors

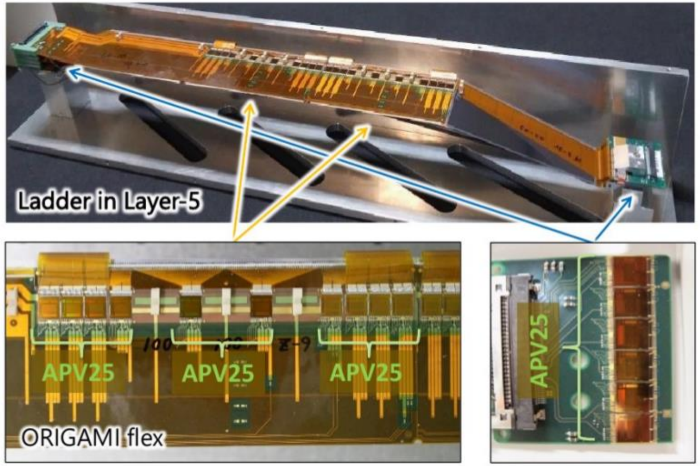


	Small	Large	Trapezoidal
# of p-strips*	768	768	768
p-strip pitch*	50 µm	75 µm	50-75 µm
# of n-strips*	768	512	512
n-strip pitch*	160 µm	240 µm	240 µm
thickness	320 µm	320 µm	300 µm
manufacturer	HPK		Micron

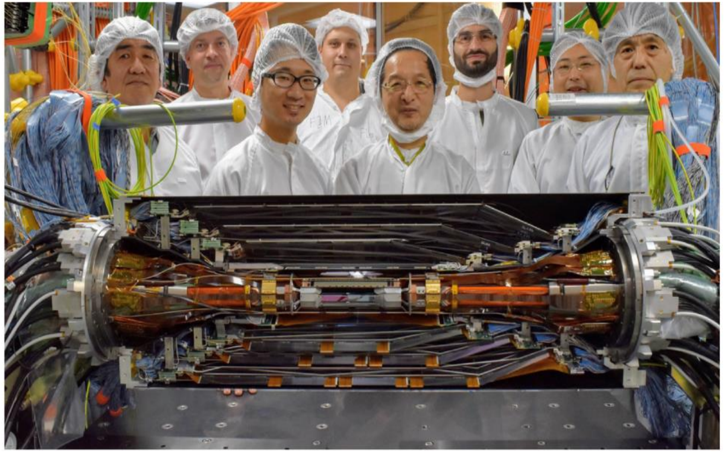
*readout strips – one floating strip on both sides

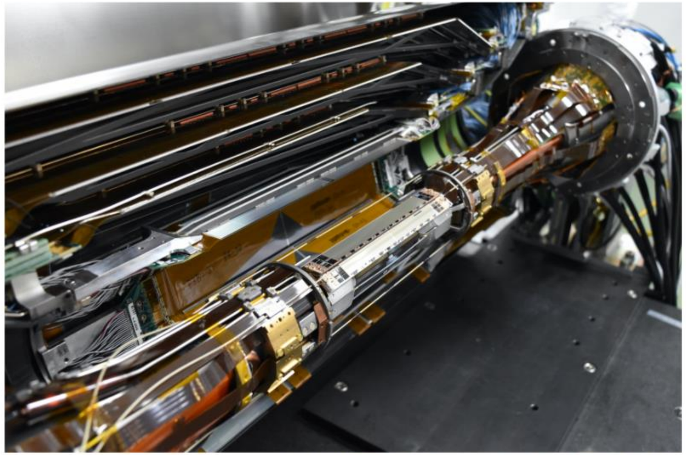
Layer	Ladder	Institute
3	7(+1)	Melbourne
4	10(+2)	TIFR Mumbai
5	12(+3)	HEPHY Vienna
6	16(+4)	Kavli IPMU

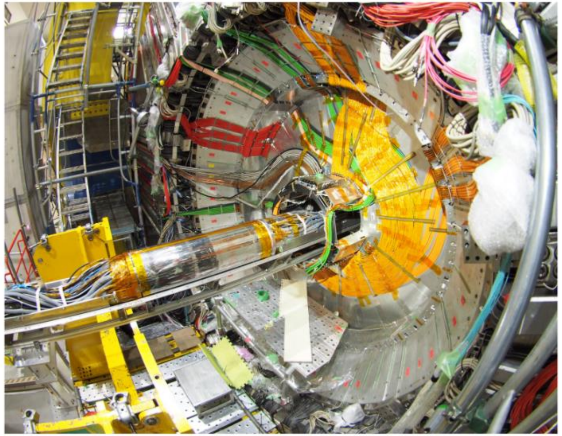
INFN Pisa: Layer 4-6 forward (FWD) and backward (BWD) modules



Various milestones



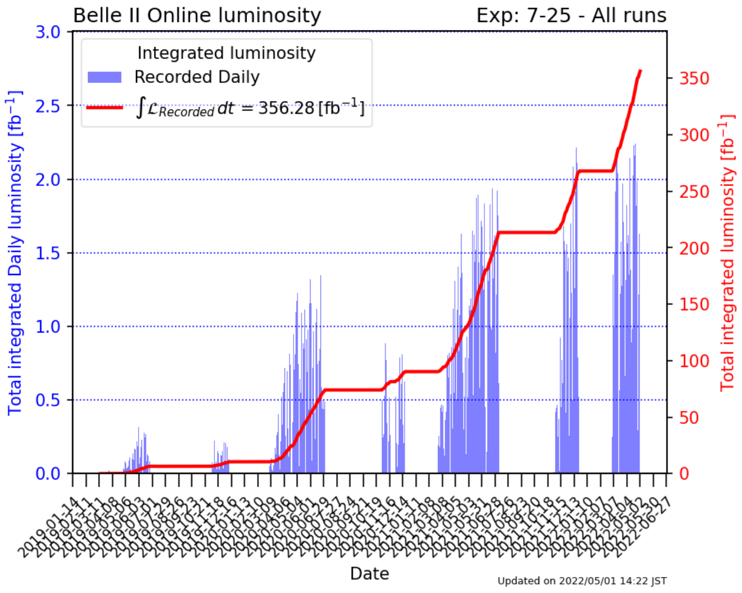




- 09-2008: Origami concept established
- 05-2015: First completed SVD ladder
- 02/07-2018: 1st/2nd “half shell” assembled
- 11-2018: Installed to Belle II
- 03-2019: 1st collision data with full VXD
- 01-2022: SVD paper submitted to JINST

  arXiv:2201.09824

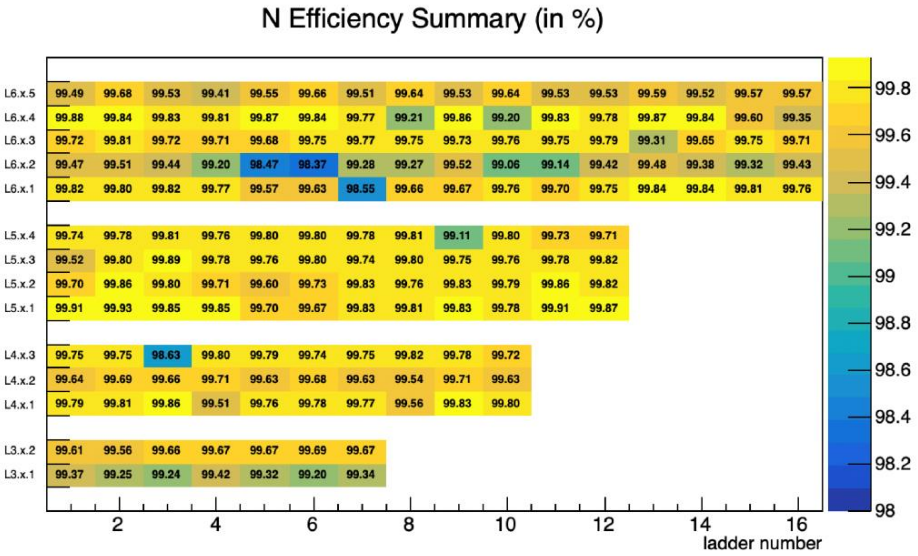
Operational experience in brief

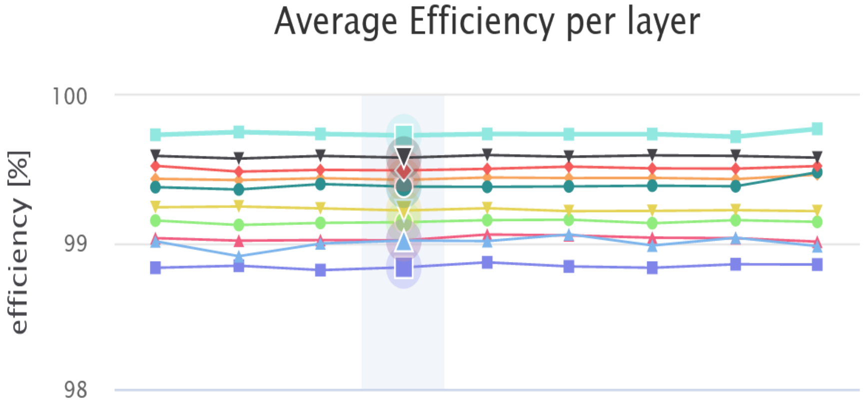


- ❑ Reliable and smooth operation since Mar 2019
- ❑ Excellent detector performance
- ❑ Hit efficiency > 99% in most sensors
- ❑ Reasonable cluster charge distribution
- ❑ Very good SNR in the range 13-30
- ❑ Improved simulation better agrees with the collision data

- ❑ Despite the covid 19 pandemic, Belle II continues to take data.
- ❑ Our group has been very active in taking remote operation and performance monitering shift (22% of the total load)

Hit efficiency





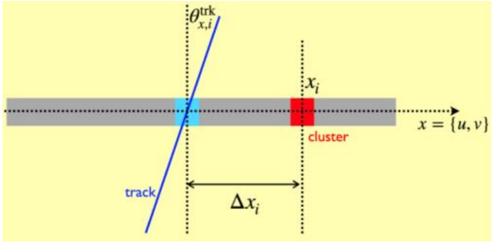
2020 data

layer	$\varepsilon(u/P)(\%)$	$\varepsilon(v/N)(\%)$
3	99.83 ± 0.01	99.48 ± 0.03
4	99.69 ± 0.03	99.68 ± 0.03
5	99.66 ± 0.03	99.77 ± 0.04
6	99.31 ± 0.08	99.58 ± 0.06

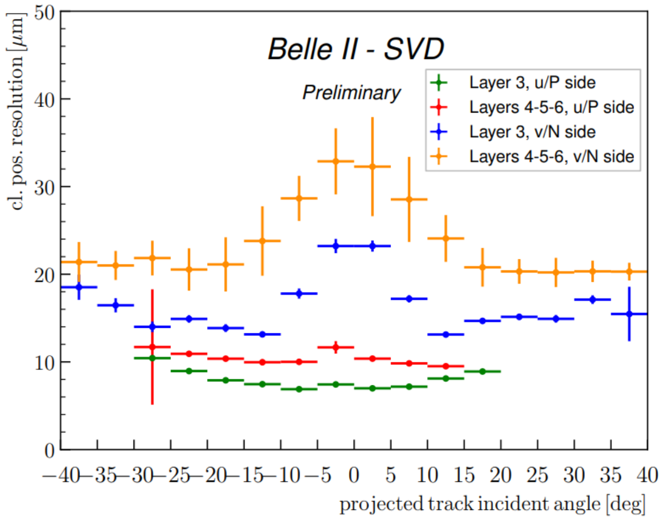
- Efficiency very high and stable in time
- > 99% for majority of sensors

Cluster position resolution

- Measured in $e^+e^- \to \mu^+\mu^-$ data
- Estimated from the residual of cluster position with respect to the track



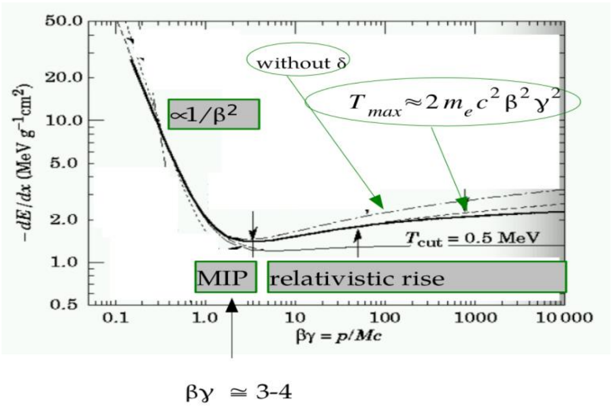
- Position resolution in agreement with expectations from strip pitch
- Work continues to further improvement, especially in the u/P side

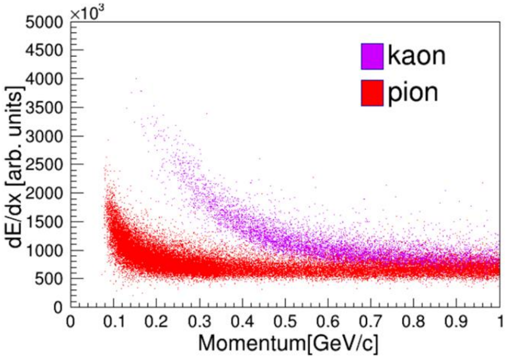


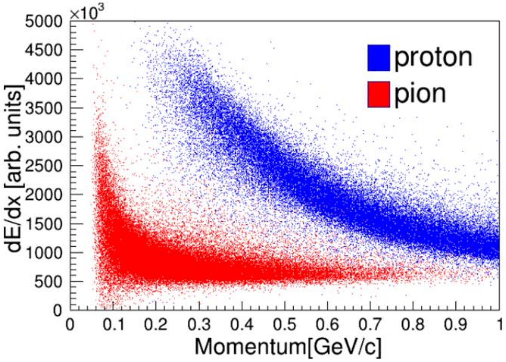
PID using SVD

- Low p_T charged particles are mostly unable to reach CDC

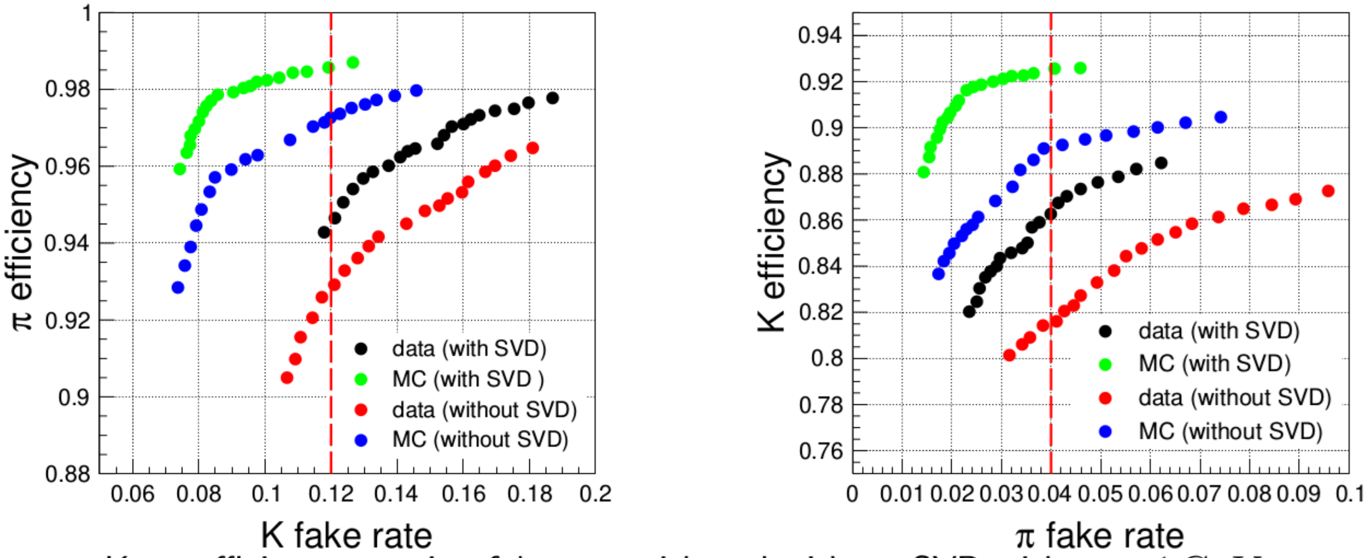
- Exploit the specific ionization (dE/dx) information of SVD to identify various charged particles, especially pions vs. kaons
- Use control samples of kinematically identified $D^{*+} \to D^0(K^-\pi^+)\pi_s^+$ and $\Lambda \to p\pi^-$ decays







PID performance



Kaon efficiency vs. pion fake rate with and without SVD with $p < 1\,\mathrm{GeV}$

- Addition of SVD dE/dx information leads to significant improvement in the PID performance
- Data-MC difference arises mostly due to a suboptimal simulation of the cluster energy ⇒ work in progress

Physics performance

Excellent vertex resolution!

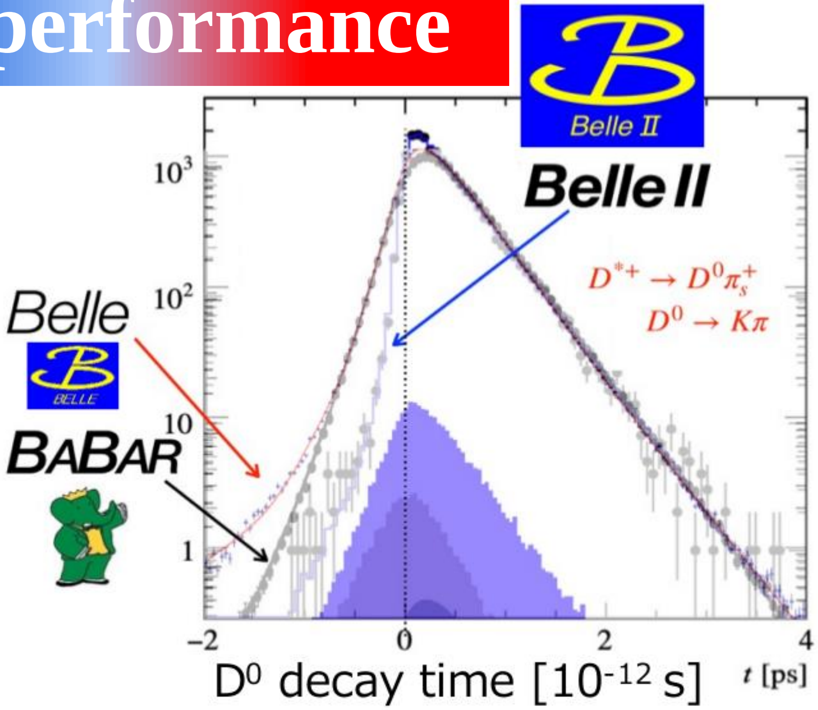
- ❑ Measured impact parameter resolut of 14.1 ± 0.1 μm

- D lifetime measurement

- ❑ Vertex determination plays a key role in this measurement

- ❑ Belle II time resolution is better than Belle by factor about two

- ❑ World's most precise D lifetime measurements!



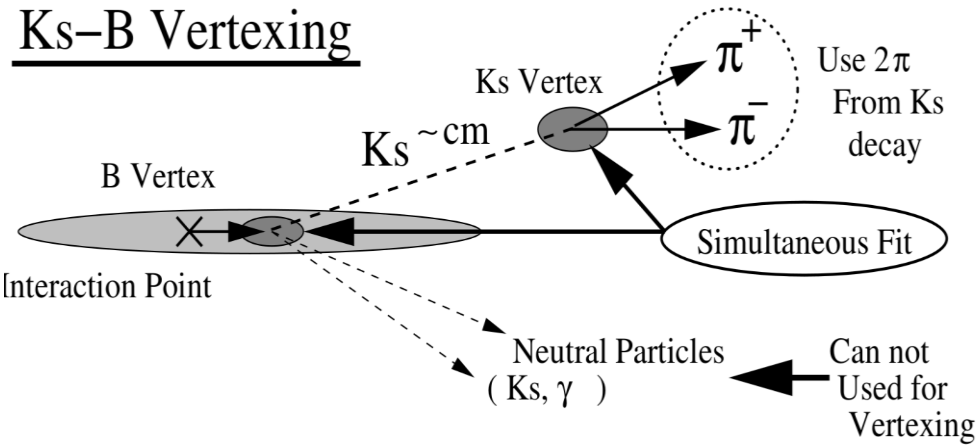
$$\tau(D^0) = 410.5 \pm 1.1\,(\text{stat}) \pm 0.8\,(\text{syst})\text{ fs}$$

$$\tau(D^+) = 1030.4 \pm 4.7\,(\text{stat}) \pm 3.1\,(\text{syst})\text{ fs}$$

Phys Rev Lett 127, 211801 (2021)

Something closer to my heart

- Perform a time-dependent study to measure the branching fraction and direct CP asymmetry for $B^0 \rightarrow K_S^0 \Pi^0$ decays.



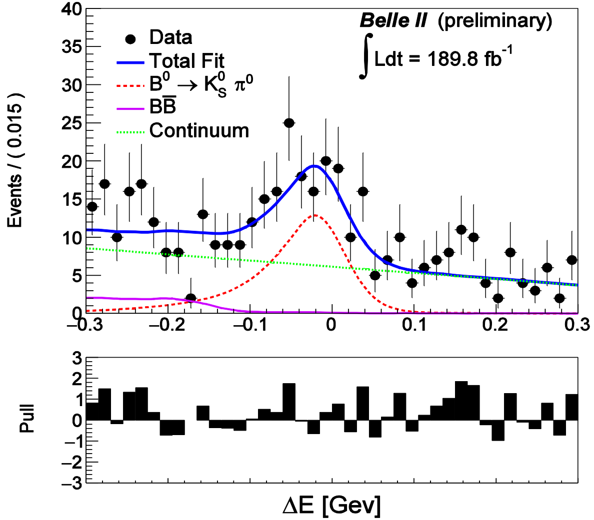
Challenge: No primary charge tracks to acilitate B^0

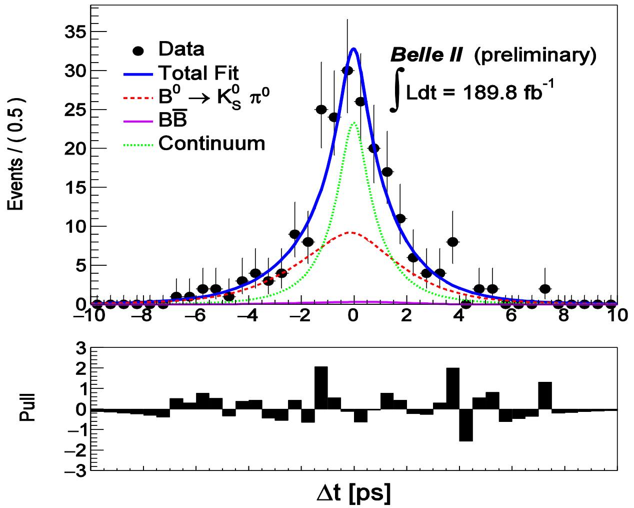
- B^0 vertex position is determined by projecting the K_S^0 trajectory to the interaction region.

- Excellent/ precise K_S^0 vertexing in SVD.

Results on $\mathcal{B}$ and A_{CP} for $B^0 \rightarrow K_S^0\ \Pi^0$

- 4D fit comprising M_{bc}, ΔE, continuum suppression output and Δt
- Use $B^0 \Rightarrow J/\psi\ (\mu^+\ \mu^-)\ K_S^0$ to calibrate the signal Δt shape





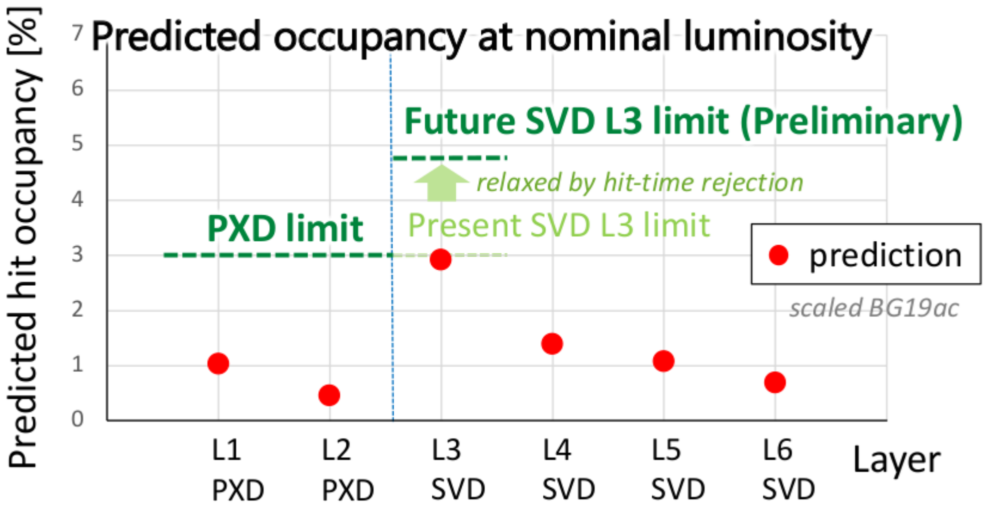
$$\mathcal{A}_{CP} = -0.41^{+0.30}_{-0.32}(\text{stat}) \pm 0.09(\text{syst})$$

$$\mathcal{B} = [11.0 \pm 1.2(\text{stat}) \pm 1.0(\text{syst})] \times 10^{-6}$$

Presented at Moriond 2022 conference

Limits on current VXD and upgrade

Tolerance for beam-induced background (BG)



Room to improve vertex resolution with better hit position resolution

- **Belle II VXD upgrade project formed**

Several technology options under investigation by R &D subgroups

- Thin fine pitch sensor
- Upgraded DEPFET sensor
- SOI pixel sensor
- CMOS pixel sensor

- Predicted BG within limits, BUT without enough safety margin

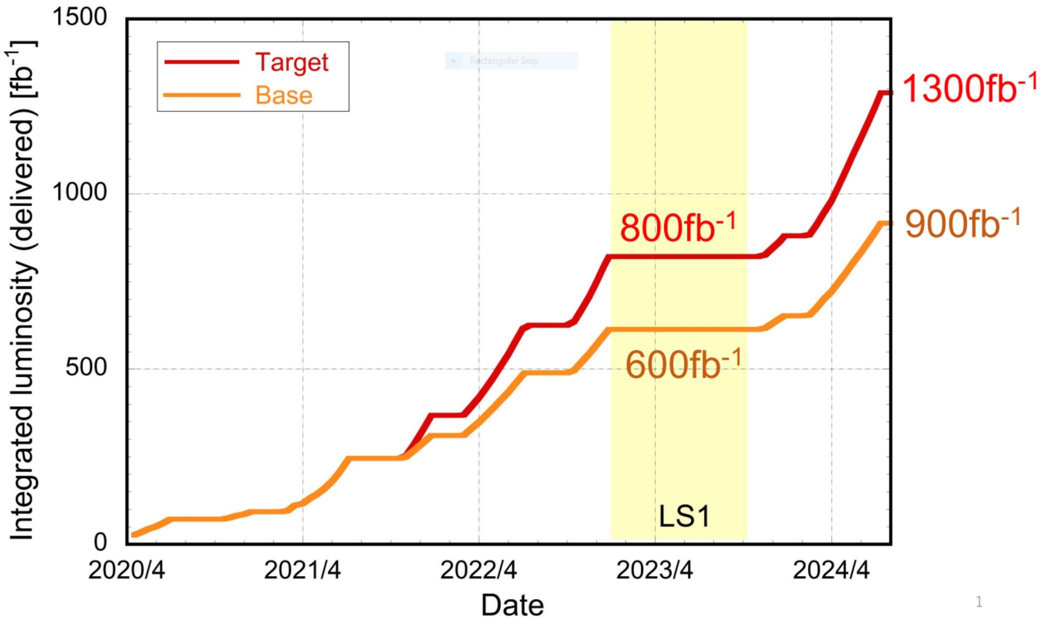
TIFR is a part of SVD-TFP upgrade project.

Time scale of the VXD upgrade project

- **Occasion of new VXD installation**:

  Timeframe expected to 2026-27
  but still with uncertainty

- **R& D activities will access the options**
  - Which concept bring best performance?
  - Which technologies fit the requirements?
  - Which technology fit timeframe of installation?



❑ Development of a test-bench for silicon strip detector present in Rahul's poster.

Summary and outlook

- SVD has been successfully recording data since Mar 2019 ⇒ smooth and reliable operation
- Our group is a key player in the remote operation and monitoring of SVD.
- Very good and stable performance ⇒ there is still room for improvement, especially in tuning of simulation
- Addition of SVD dE/dx information improves the particle identification in the low momentum region.
- Upgrade of Belle II VXD is desirable.

Thank you