# Moving from BELLE to Belle II

Gagan Mohanty
tifr

DHEP Annual Meeting
May 8-9, 2018

# Group in one slide

CPV and rare B-meson decays

Bottomonium spectroscopy

CPV and rare charm decays

In-house silicon microstrip sensor R&D

TIFR-Belle

Silicon Vertex Detector (L4)

Continuum suppression

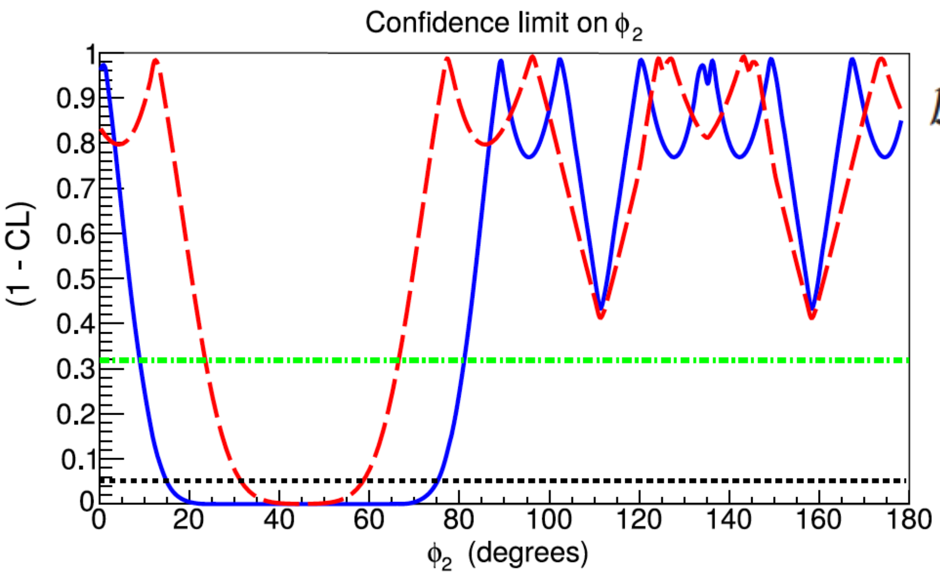
Physics analysis center

Physics sensitivity studies

- High visibility and impact in terms of contribution
- Established leadership within Belle and Belle-II collaborations

# Snapshots of Belle results

**Measurement of the branching fraction and $CP$ asymmetry in $B^0 \to \pi^0\pi^0$ decays, and an improved constraint on $\phi_2$**




PRD 96, 032007 (2017)

$$\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.31 \pm 0.19 \pm 0.19) \times 10^{-6}$$
$$A_{CP} = +0.14 \pm 0.36 \pm 0.10$$

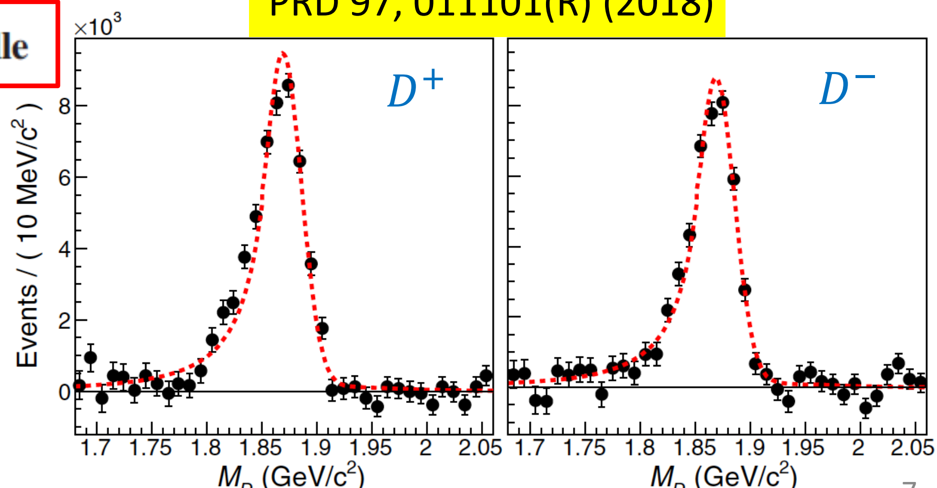
- An isospin analysis including results from $B \to \pi\pi$ decays excludes the UT angle $\phi_2$ from [15.5°,75.0°] at 95% CL
- Belle II will allow stronger constraint on this important angle

**Search for $CP$ violation in the $D^+ \to \pi^+\pi^0$ decay at Belle**

PRD 97, 011101(R) (2018)

$$A_{CP}(D^+ \to \pi^+\pi^0) = (+2.31 \pm 1.24 \pm 0.23)\%$$

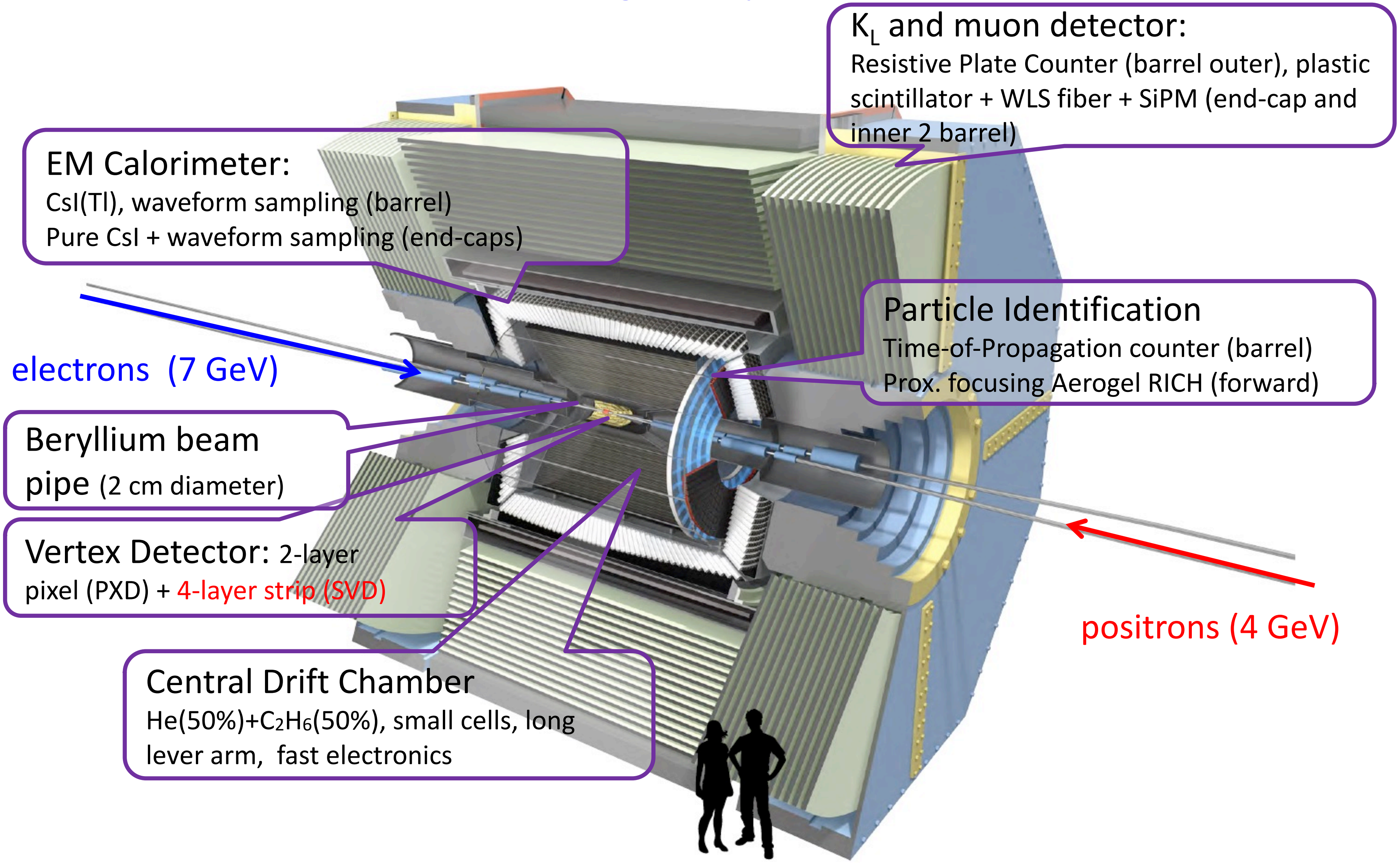
- Improved result by a factor of two over previous best measurement
- An isospin sum rule connecting results from various $D \to \pi\pi$ decays tested to a precision of three per mille



# From Belle to Belle II

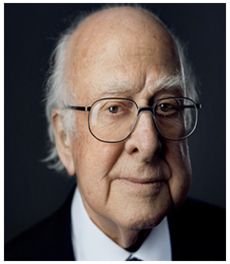


- With 50 times more data than its predecessor, Belle II will be a unique instrument to address several grand questions



# Grand questions for Belle-II

- Are there any new CPV phases? (Search for CPV in B and D decays)
- Any right-handed current from new physics?
- Are there any imprints of physics beyond the SM in flavor changing neutral current transitions in the quark sector? (Search for rare FCNC decays)
- Neutrino oscillation being firmly established, what are the implication of lepton flavor violation in charged lepton sector? (Search for LFV in tau decays)
- Are there any cousins of Mr. Higgs? Charged Higgs?

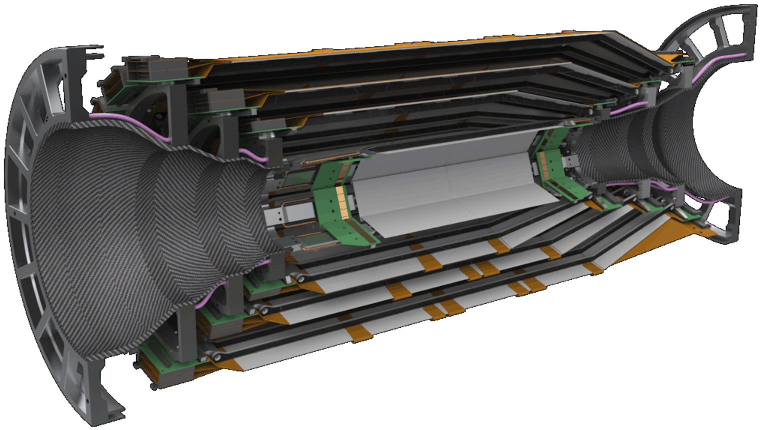


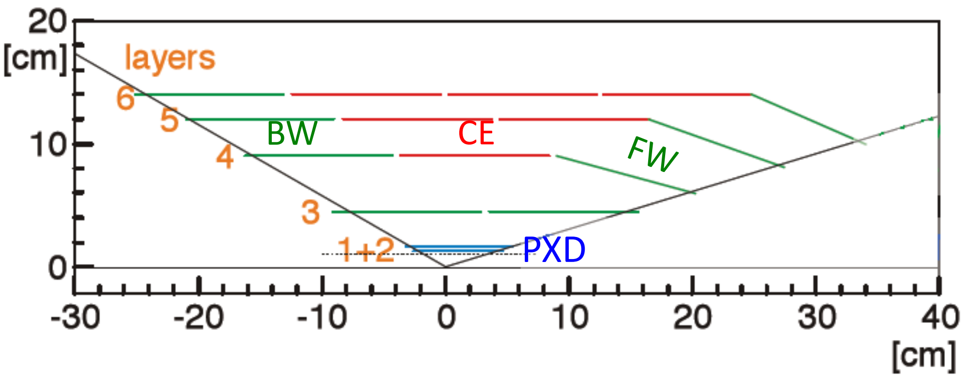
- Understanding exotic QCD states? Tetraquark, pentaquark, hybrid?
- Can we chase down dark matter from bottom? Hidden dark sector?

# Belle-II SVD and TIFR

- SVD will play a key role in physics harvesting
  1) Precise decay vertex determination
  2) Low-momentum tracking & particle ID
  3) $K_S$ reconstruction

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

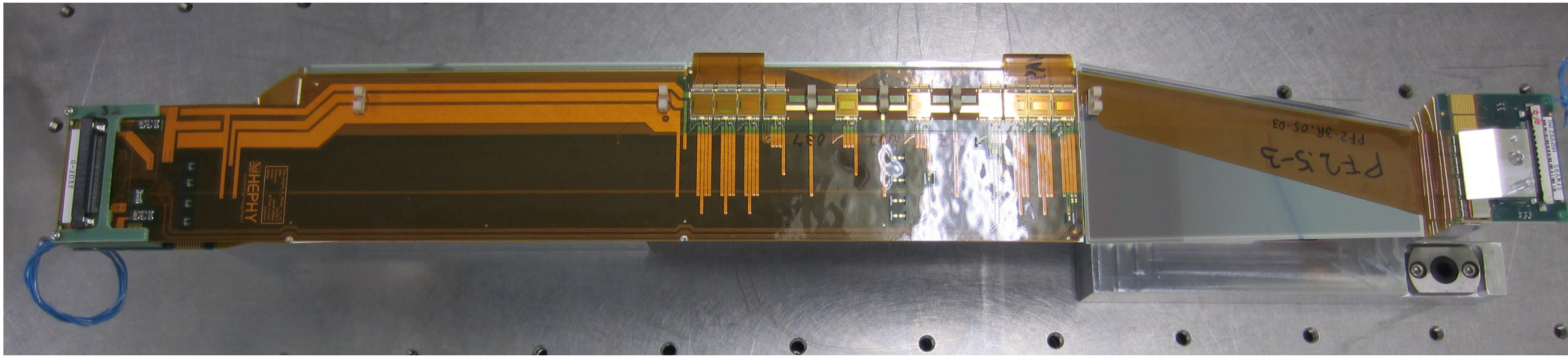




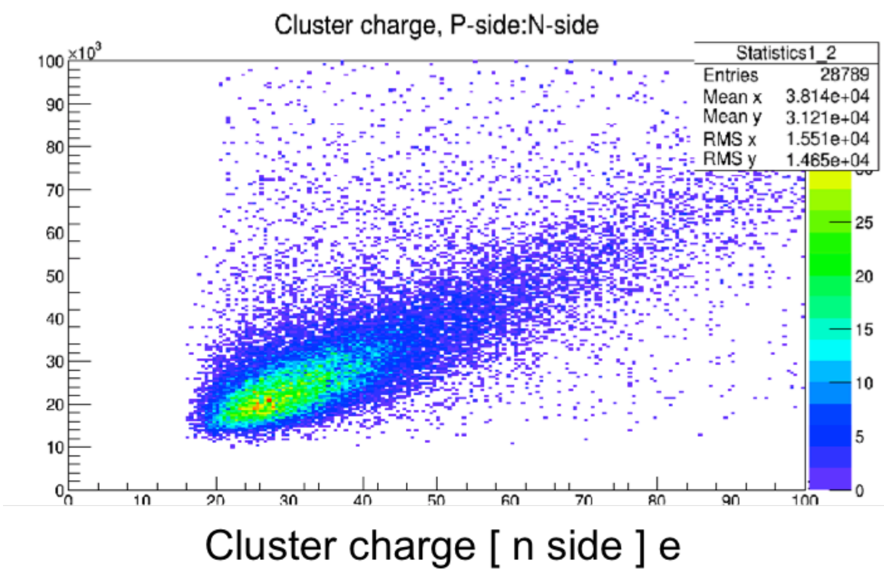

| Layer# | Sensor/ladder | Origami | Length | Radius | Slant angle | Occupancy |
|---|---|---|---|---|---|---|
| 3 | 2 | 0 | 262 mm | 38 mm | $0^o$ | 6.7% |
| 4 | 3 | 1 | 390 mm | 80 mm | $11.9^o$ | 2.7% |
| 5 | 4 | 2 | 515 mm | 104 mm | $17.2^o$ | 1.3% |
| 6 | 5 | 3 | 645 mm | 135 mm | $21.1^o$ | 0.9% |

- Involved in such state-of-the-art detector project for the 1st time

# An assembled SVD-L4 module



| Sensor | ΔX (µm) | ΔY (µm) | ΔZ (µm) |
|---|---|---|---|
| BW | -49 | -35 | -34 |
| CE | -6 | -15 | -22 |
| FW | -7 | -47 | 94 |




**Design specs: ±150µm (ΔX, ΔY) ±250µm (ΔZ)**

- Before reaching this point, needed to pass through several stages of a stringent international technical review

# Plan for Belle II

- Focus will continue to be on science → consolidate where expertise lies and venture into new areas e.g., rare FCNC B decays and LFV in tau decays
- Take a good care of SVD → operation maintenance and Q&A shifts
- Work towards how to get best possible performance from that detector or overall experiment → analysis and performance improvement

# Now let's get to details...

11:00 - 11:40 Session on Belle

Convener: Sudeshna Banerjee (Department of High Energy Physics, TIFR)

11:00 **Moving from Belle to Belle II** *10'*

Speaker: Gagan Mohanty (DHEP, TIFR)

11:10 **Building the Layer 4 of Belle II SVD** *15'*

Speaker: K Kameshwar Rao (TIFR)

11:25 **Getting Ready for Belle II** *15'*

Speaker: K. P PRASANTH KRISHNAN (TIFR)

- Also, don't forget about the poster of Debashis Sahoo on display

# Achievements During 2012 – 2017

Detector: Successful Si microstrip sensor R&D; Led the design, prototyping and construction of the Belle-II SVD layer 4

Physics: Thrust area of CP violation and rare decays of charm and beauty mesons as well as bottommonium spectroscopy

HRD Highlights: S. Sandilya, postdoc @ Cincinnati; N.K. Nisar, postdoc @ Pittsburg; V. Gaur, 2nd postdoc @ VT

**TIFR-Belle (Mohanty)**
**PhD (2), Postdoc Mentee (1)**

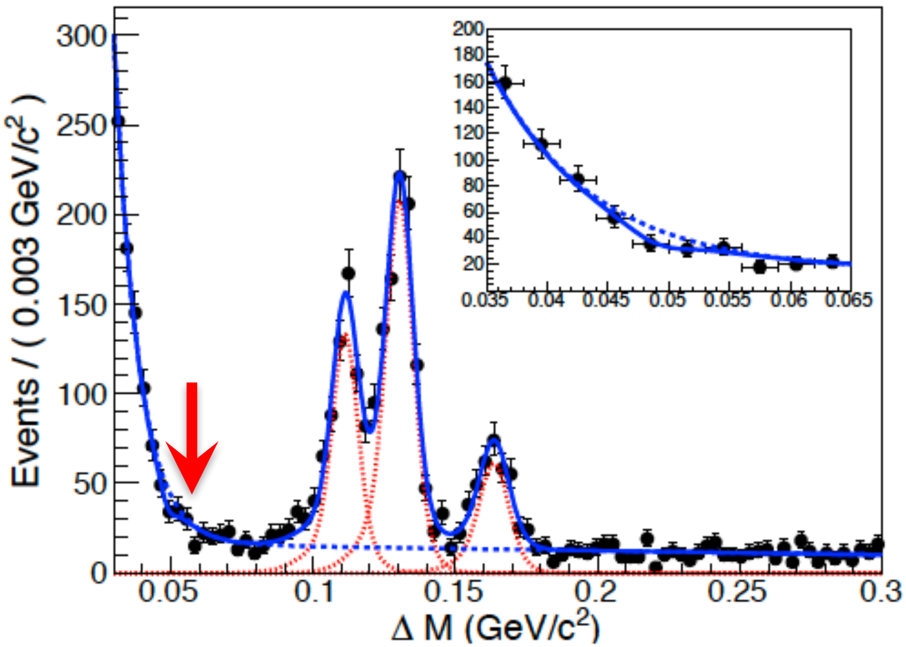
Journal Publications: 25 physics, 12 detector
Internal Notes: 10

Leadership: Leader of Belle Hadronic B-Decay Analysis Group, Belle II SVD PubBoard Chair, Members of Belle and Belle-II Executive Boards

Talks & Outreach: Invited plenary talk (10), parallel session (4) at int'l conference (including one @ ICHEP); similar number of talks, colloquia and lectures within India

# Snapshots of Belle results

**Search for Bottomonium States in Exclusive Radiative $\Upsilon(2S)$ Decays**




PRL 111, 112001 (2013)

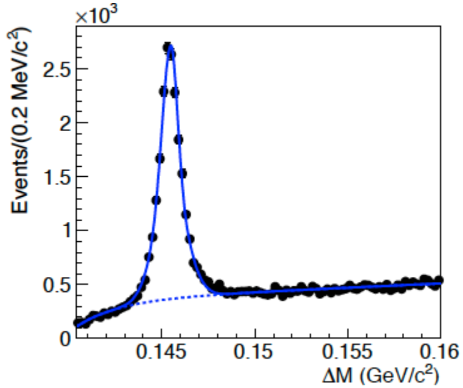
- Unambiguously refuted the claim of dubious $X_{b\bar{b}}(9975)$ state, which was claimed by a study based on CLEO's data
- Paved way for further study on $\chi_{bJ}(1P)$ states

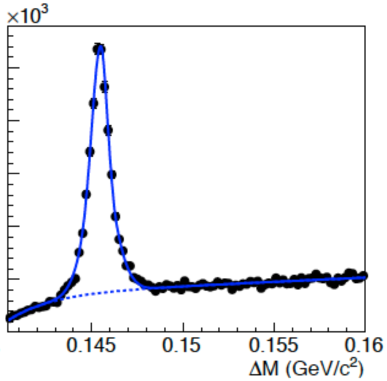
**Search for $CP$ violation in $D^0 \to \pi^0\pi^0$ decays**

PRL 112, 211601 (2014)

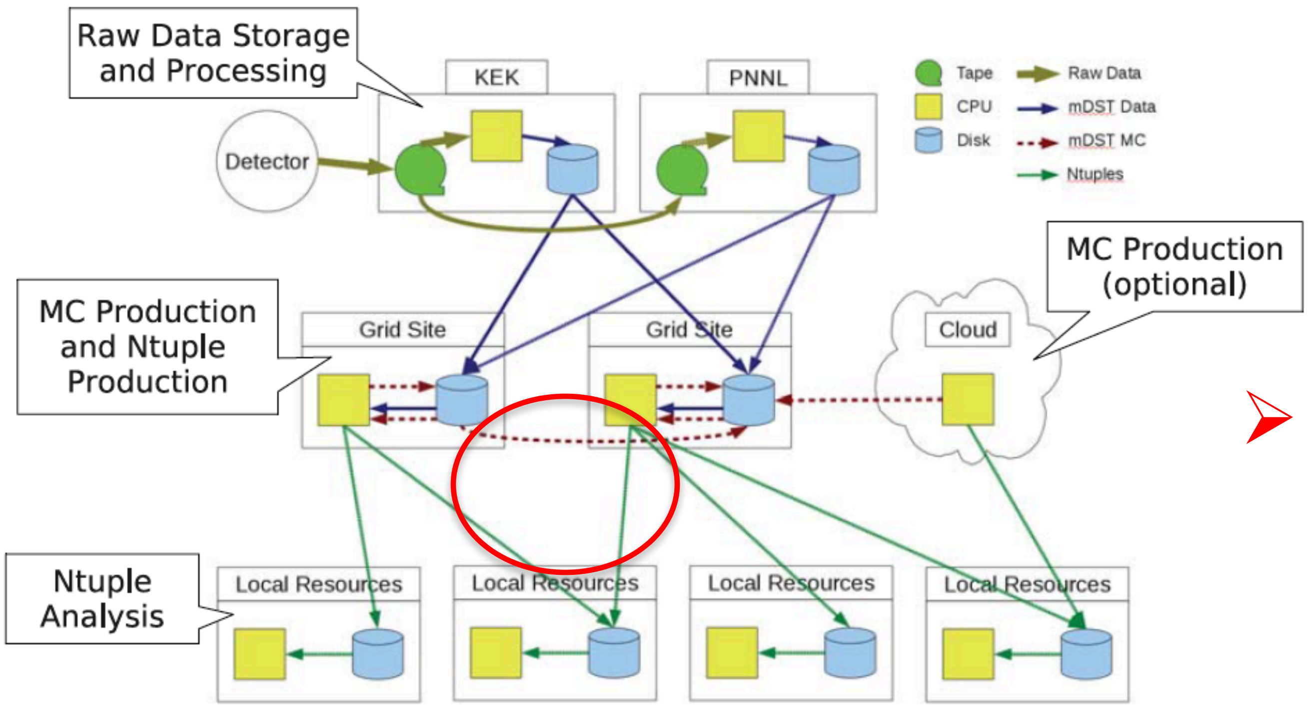
$$A_{CP}(D^0 \to \pi^0\pi^0) = (-0.03 \pm 0.64 \pm 0.10)\%$$

- Results consistent with no CP violation
- An order of magnitude improvement over the existing result



# Physics Analysis Center @ TIFR




➢ One of the Grid sites, relying on NKN network

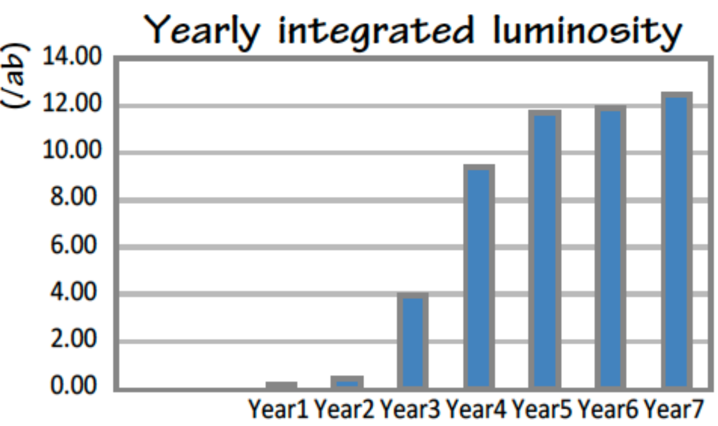
- ❑ Contribution to Belle II computing (CPU: 24 kHepSPEC, storage: 750 TB) over the next five years ➔ 2%
- ❑ Monte Carlo production and storage of trimmed data, catering to needs of (mostly local) Belle II community

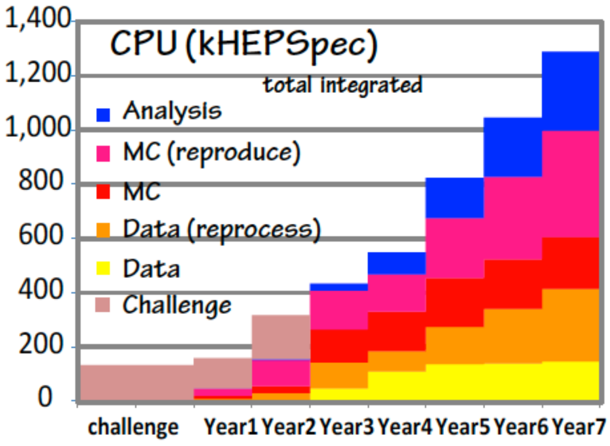
# Belle II Computing Need

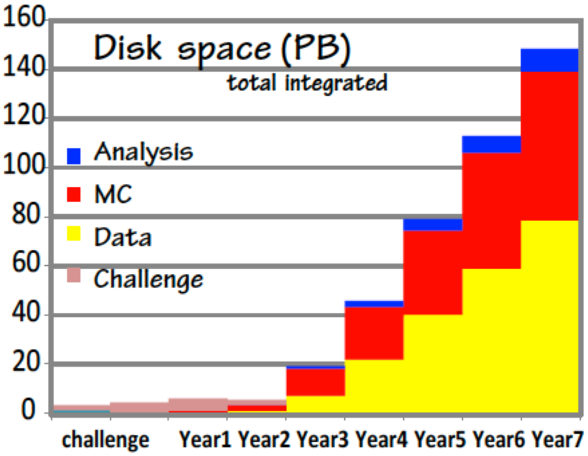
| Experiment | Event size [kB] | Rate @ Storage [event/sec] | Rate @ Storage [MB/sec] |
|---|---|---|---|
| Belle II | 300 | 6,000 | 1,800 |
| | | | |
| ALICE (Pb-Pb) | 50,000 | 100 | 4,000 |
| ALICE (p-p) | 2,000 | 100 | 200 |
| ATLAS | 1,500 | 600 | 700 |
| CMS | 1,500 | 150 | 225 (<~1000) |
| LHCb | 55 | 4,500 | 250 |

(@ max. luminosity)

(LHC experiments : as seen in 2011/2012 runs)



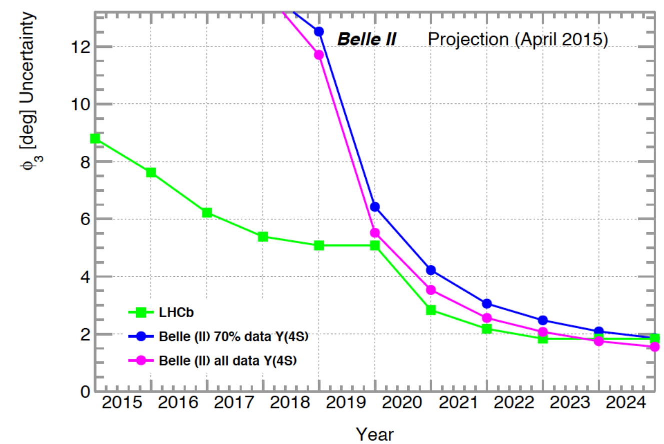



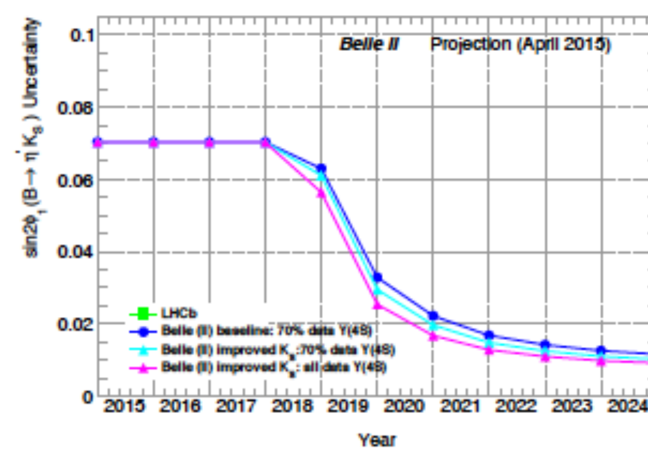



# Belle II vs. LHCb

| Observable | Expected th. accuracy | Expected exp. uncertainty | Facility |
|---|---|---|---|
| CKM matrix | | | |
| $\lvert V_{us}\rvert$ $[K \to \pi\ell\nu]$ | ** | 0.1% | $K$-factory |
| $\lvert V_{cb}\rvert$ $[B \to X_c\ell\nu]$ | ** | 1% | Belle II |
| $\lvert V_{ub}\rvert$ $[B_d \to \pi\ell\nu]$ | * | 4% | Belle II |
| $\sin(2\phi_1)$ $[c\bar{c}K^0_S]$ | *** | $8 \cdot 10^{-3}$ | Belle II/LHCb |
| $\phi_2$ | | 1.5° | Belle II |
| $\phi_3$ | *** | 3° | LHCb |
| CPV | | | |
| $S(B_s \to \psi\phi)$ | ** | 0.01 | LHCb |
| $S(B_s \to \phi\phi)$ | ** | 0.05 | LHCb |
| $S(B_d \to \phi K)$ | *** | 0.05 | Belle II/LHCb |
| $S(B_d \to \eta' K)$ | *** | 0.02 | Belle II |
| $S(B_d \to K^*(\to K^0_S\pi^0)\gamma))$ | *** | 0.03 | Belle II |
| $S(B_s \to \phi\gamma))$ | *** | 0.05 | LHCb |
| $S(B_d \to \rho\gamma))$ | | 0.15 | Belle II |
| $A^d_{SL}$ | *** | 0.001 | LHCb |
| $A^s_{SL}$ | *** | 0.001 | LHCb |
| $A_{CP}(B_d \to s\gamma)$ | * | 0.005 | Belle II |
| rare decays | | | |
| $\mathcal{B}(B \to \tau\nu)$ | ** | 3% | Belle II |
| $\mathcal{B}(B \to D\tau\nu)$ | | 3% | Belle II |
| $\mathcal{B}(B_d \to \mu\nu)$ | ** | 6% | Belle II |
| $\mathcal{B}(B_s \to \mu\mu)$ | *** | 10% | LHCb |
| zero of $A_{FB}(B \to K^*\mu\mu)$ | ** | 0.05 | LHCb |
| $\mathcal{B}(B \to K^{(*)}\nu\nu)$ | *** | 30% | Belle II |
| $\mathcal{B}(B \to s\gamma)$ | | 4% | Belle II |
| $\mathcal{B}(B_s \to \gamma\gamma)$ | | $0.25 \cdot 10^{-6}$ | Belle II (with 5 $ab^{-1}$) |
| $\mathcal{B}(K \to \pi\nu\nu)$ | ** | 10% | $K$-factory |
| $\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$ | *** | 0.1% | $K$-factory |
| charm and $\tau$ | | | |
| $\mathcal{B}(\tau \to \mu\gamma)$ | *** | $3 \cdot 10^{-9}$ | Belle II |
| $\lvert q/p\rvert_D$ | *** | 0.03 | Belle II |
| $arg(q/p)_D$ | *** | 1.5° | Belle II |

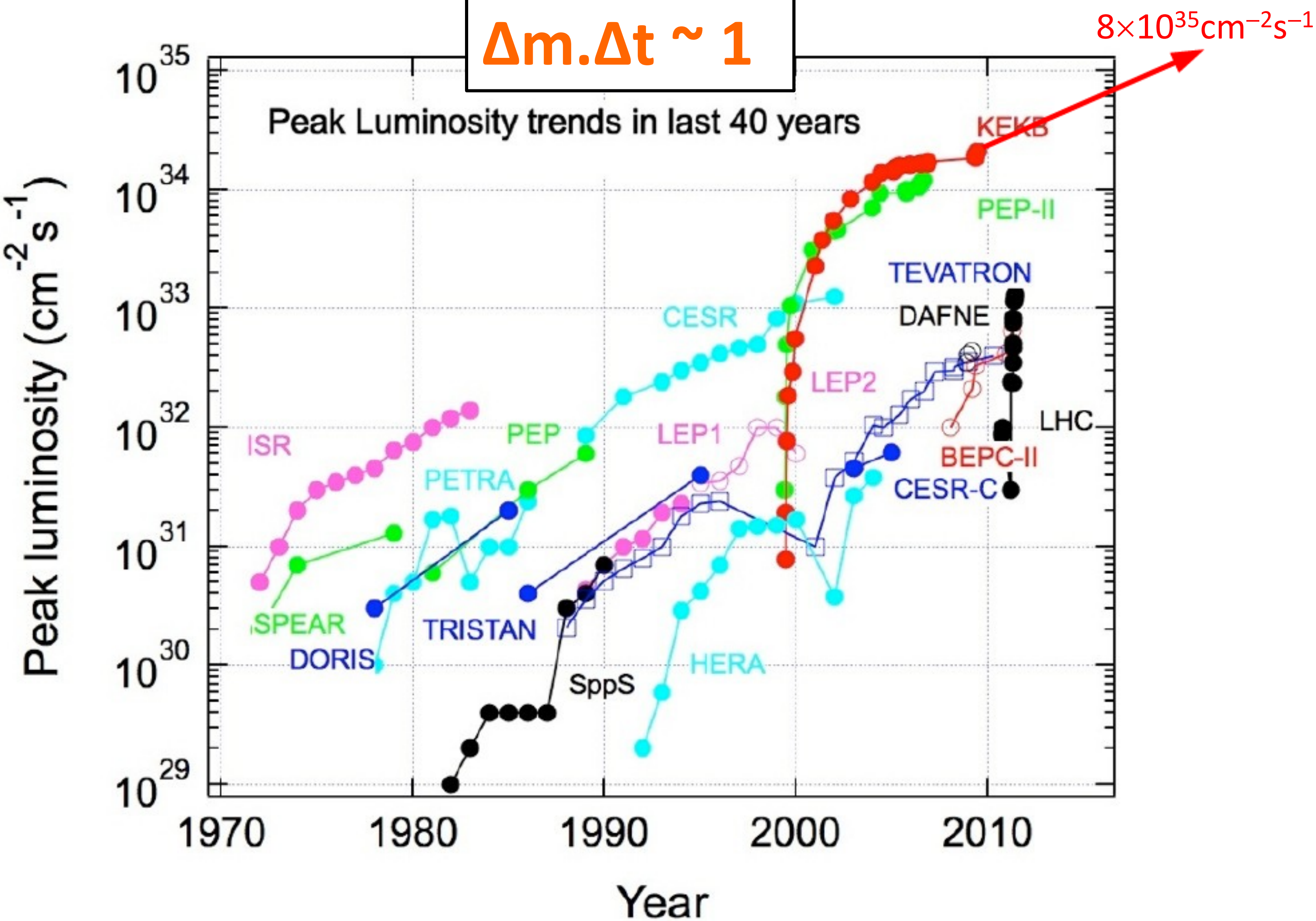
- Great for neutral and missing energy modes
- Inclusive measurement: OK
- Excellent flavor tagging and $K_S$ reconstruction



# Moving from KEKB to SuperKEKB

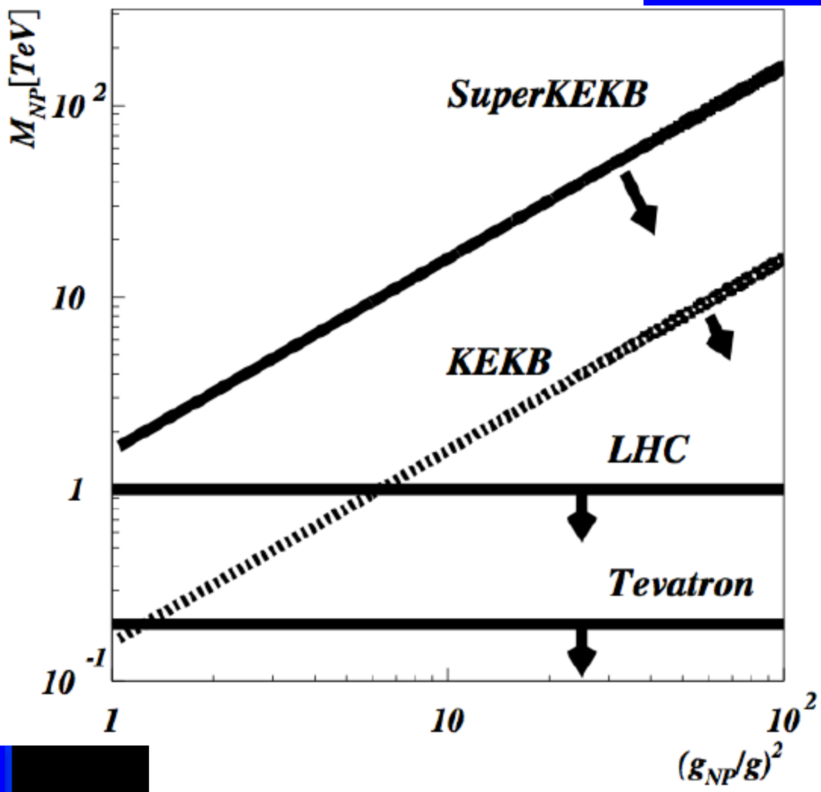
**Δm.Δt ~ 1**

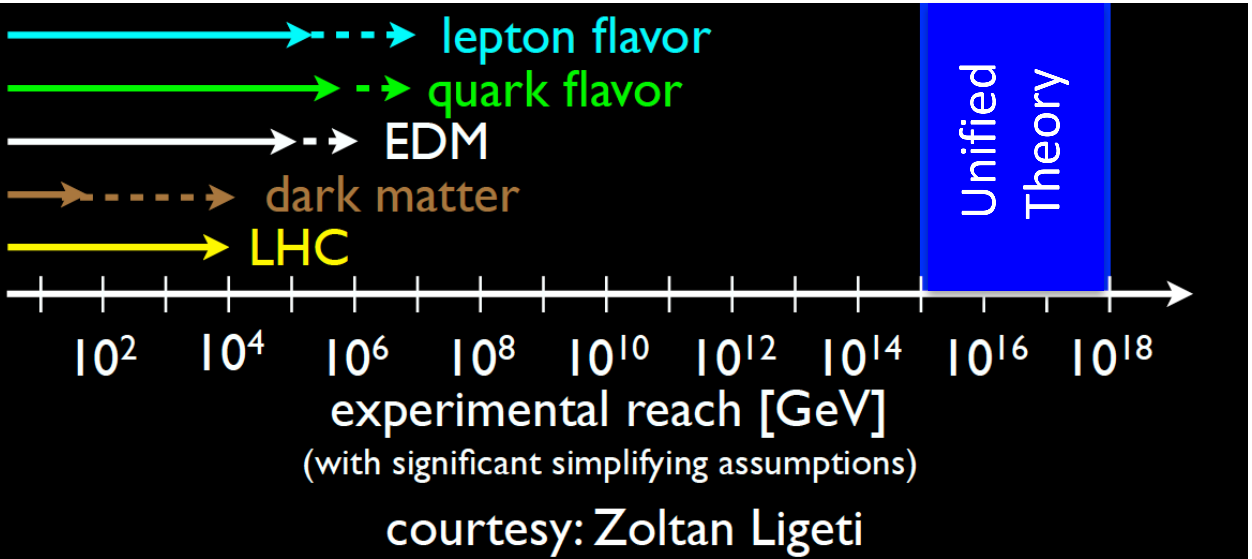



- Leap frog the luminosity by almost two orders of magnitude

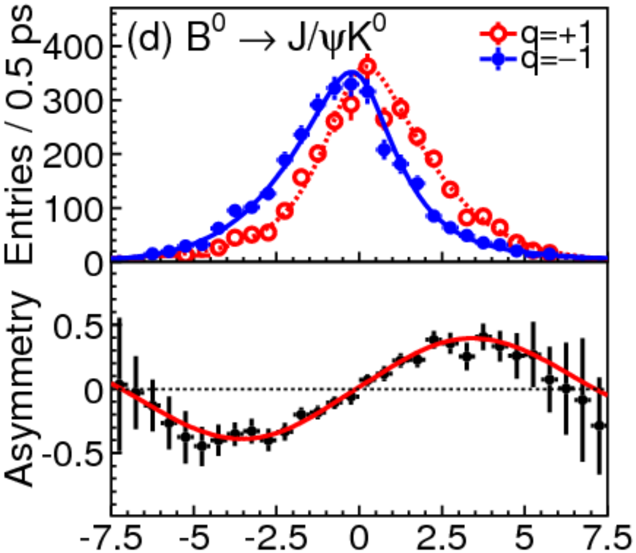
# Power of Luminosity Frontier

- Complementary to the energy frontier
- Can probe a mass scale, beyond the reach of LHC
- Even for the minimal flavor violating (SM-like) case
- Win-win situation if LHC finds new physics to decipher its flavor structure
- Even otherwise, can give an approximate scale of new physics

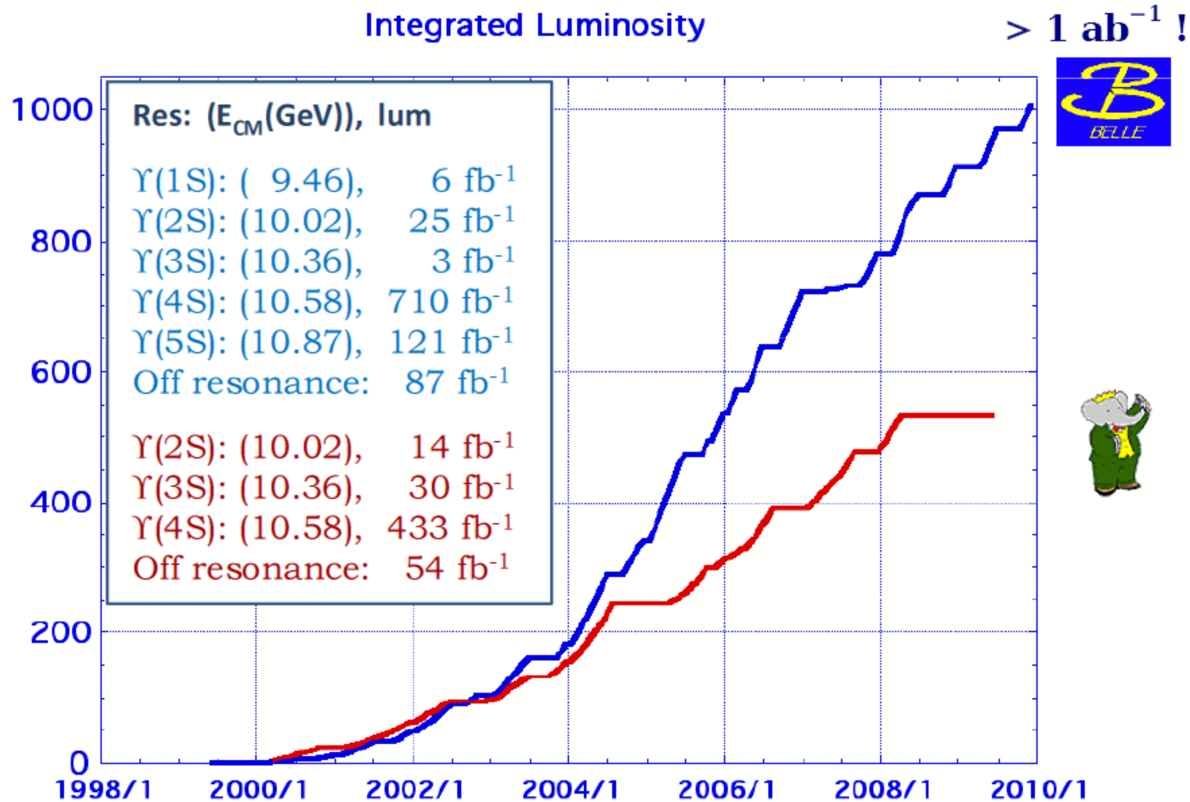


# Most Visible Legacy of Belle




**Proper time difference between two B mesons**




- Established beyond any doubt that the Kobayashi-Maskawa phase is responsible for CP violation (CPV) within the standard model
- Led to the 2009 Physics Nobel prize to Kobayashi and Maskawa

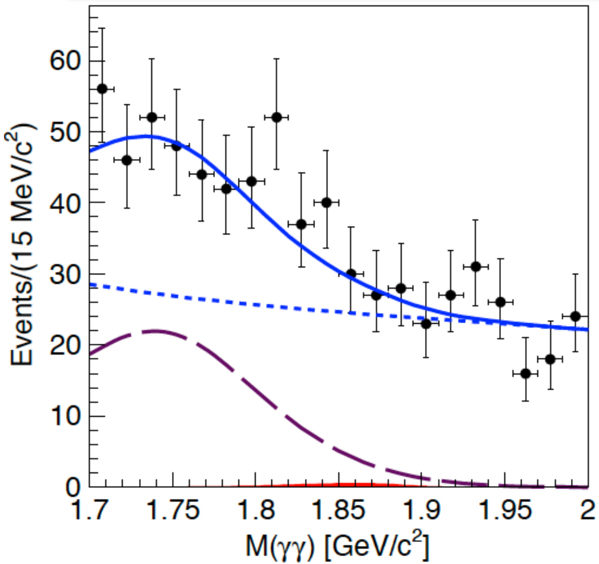
# Other Highlighted Physics Papers

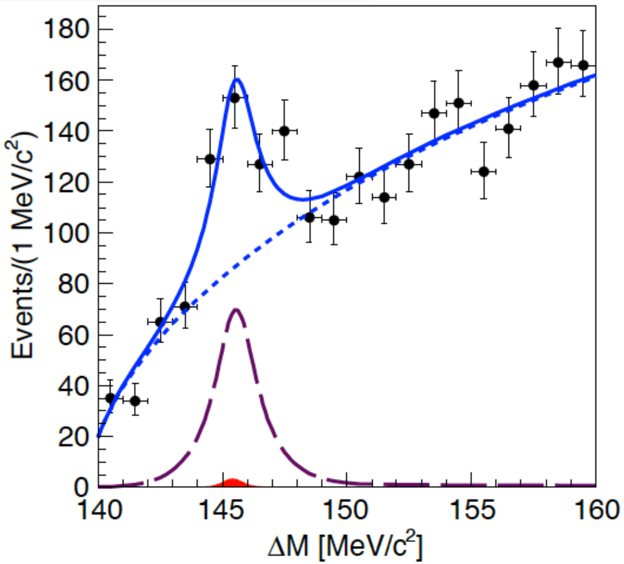


## Measurements of Branching Fractions and Direct $CP$ Asymmetries for $B \to K\pi, B \to \pi\pi$ and $B \to KK$ Decays

PRD 87, 031103(R) (2013)

We report measurements of the branching fractions and direct $CP$ asymmetries ($\mathcal{A}_{CP}$) for $B \to K\pi, \pi\pi$ and $KK$ decays (but not $\pi^0\pi^0$) based on the final data sample of $772 \times 10^6$ $B\overline{B}$ pairs collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy $e^+e^-$ collider. We set a 90% confidence-level upper limit for $K^+K^-$ at $2.0 \times 10^{-7}$; all other decays are observed with branching fractions ranging from $10^{-6}$ to $10^{-5}$. In the $B^0/\overline{B}^0 \to K^\pm\pi^\mp$ mode, we confirm Belle's previously reported large $\mathcal{A}_{CP}$ with a value of $-0.069 \pm 0.014 \pm 0.007$ and a significance of $4.4\sigma$. For all other flavor-specific modes, we find $\mathcal{A}_{CP}$ values consistent with zero, including $\mathcal{A}_{CP}(K^+\pi^0) = +0.043 \pm 0.024 \pm 0.007$ with $1.8\sigma$ significance. The difference of $CP$ asymmetry between $B^\pm \to K^\pm\pi^0$ and $B^0/\overline{B}^0 \to K^\pm\pi^\mp$ is found to be $\Delta\mathcal{A}_{K\pi} \equiv \mathcal{A}_{CP}(K^+\pi^0) - \mathcal{A}_{CP}(K^+\pi^-) = +0.112 \pm 0.027 \pm 0.007$ with $4.0\sigma$ significance. We also calculate the ratios of partial widths for the $B \to K\pi$ decays. Using our results, we test the validity of the sum rule $\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\Gamma(K^0\pi^+)}{\Gamma(K^+\pi^-)} - \mathcal{A}_{CP}(K^+\pi^0)\frac{2\Gamma(K^+\pi^0)}{\Gamma(K^+\pi^-)} - \mathcal{A}_{CP}(K^0\pi^0)\frac{2\Gamma(K^0\pi^0)}{\Gamma(K^+\pi^-)} = 0$ and obtain a sum of $-0.270 \pm 0.132 \pm 0.060$ with $1.9\sigma$ significance.



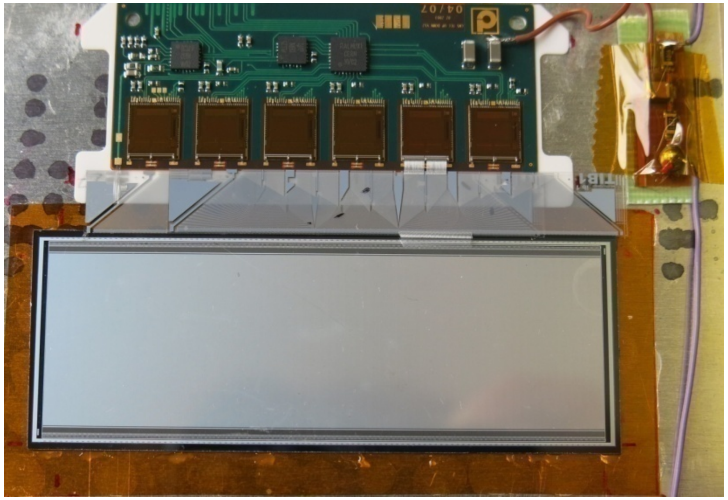

PRD 93, 051102(R) (2016)

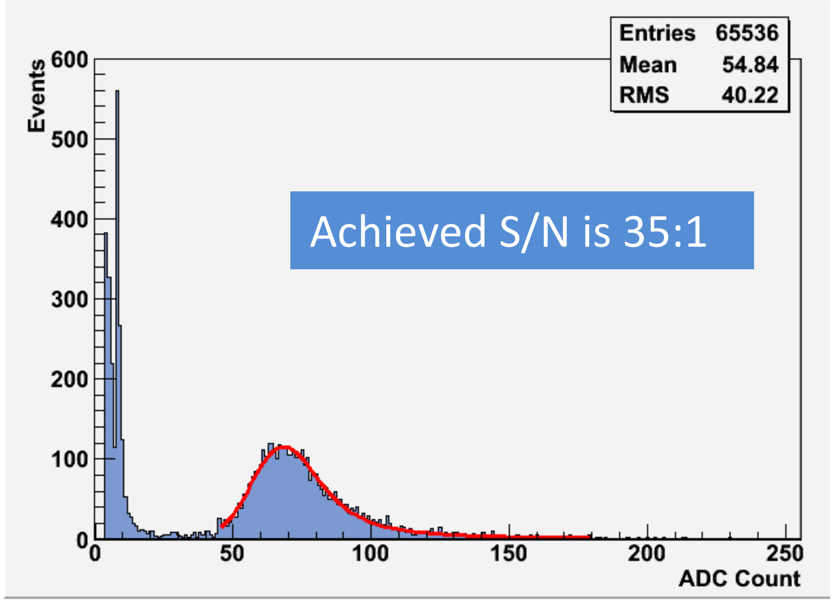
- A nice channel for NP, which can only be studied at $e^+e^-$ flavor factories
- Set world's best limit ($8.5\times10^{-7}$) in absence of a signal

# Ongoing Belle (II) Physics Analyses

- Search for new sources of CP violation in B-meson decays → S. Mohanty
- Charmless hadronic B decays → A. Basith (+V. Gaur)
- Search for LFV in tau decays → D. Sahoo
- Continue to lead several front-ranking HBD analyses → G.B. Mohanty
- Now another feather on the cap: physics coordinator

# Silicon Microstrip Sensor R&D

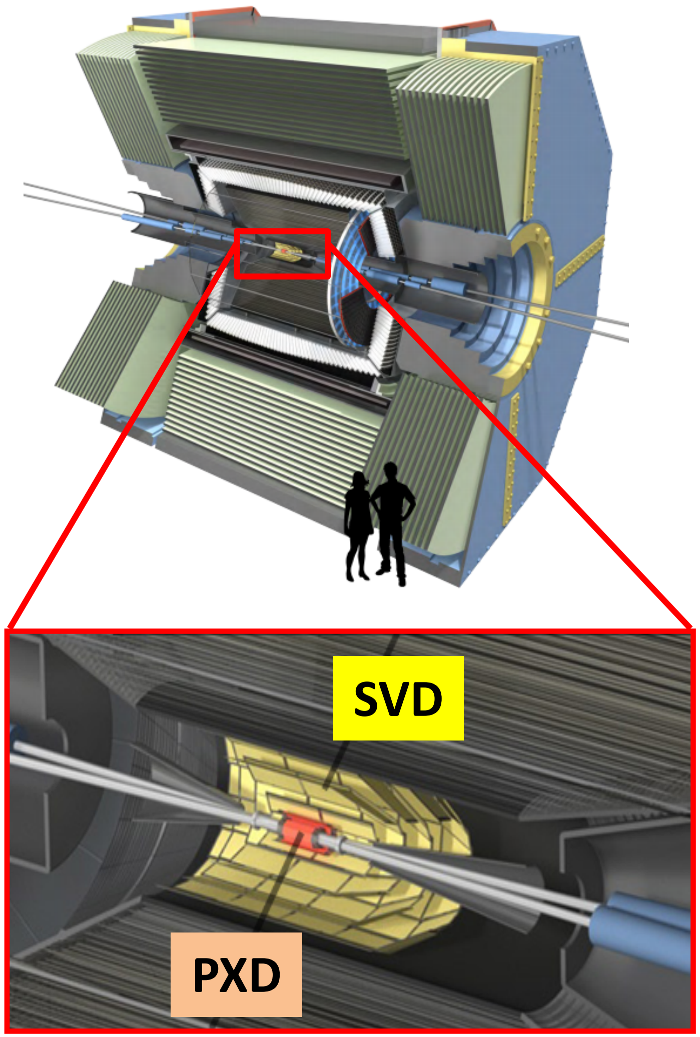





Design, fabrication and characterization of the first AC-coupled silicon microstrip sensors in India, T. Aziz *et al*., [JINST **9** (2014) P06008]

# Belle-II VXD: What, Why and How…

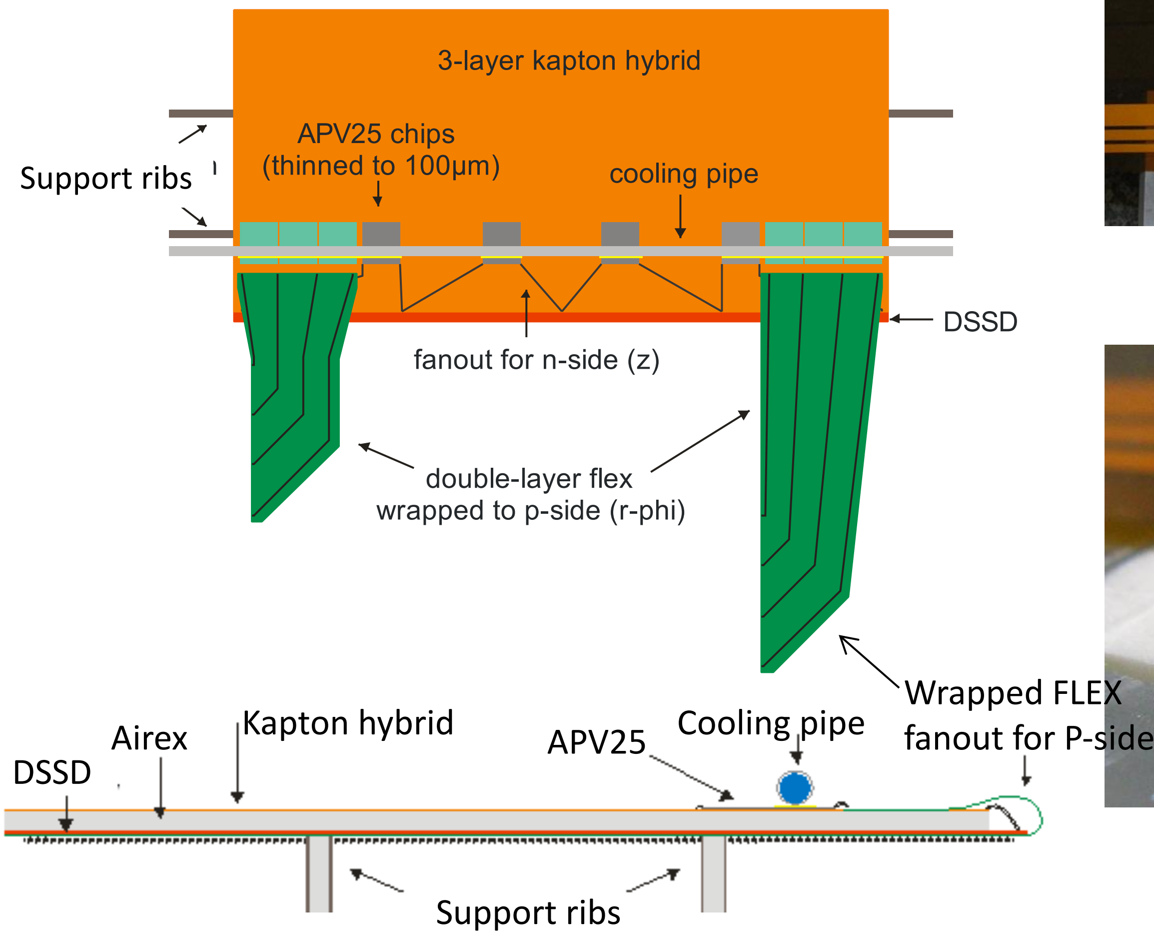
- A sophisticated vertexing and inner tracking system:
  - Determine the vertex position of the weakly decaying particles
  - Precisely measure the track position and momentum for low-$p_T$ tracks

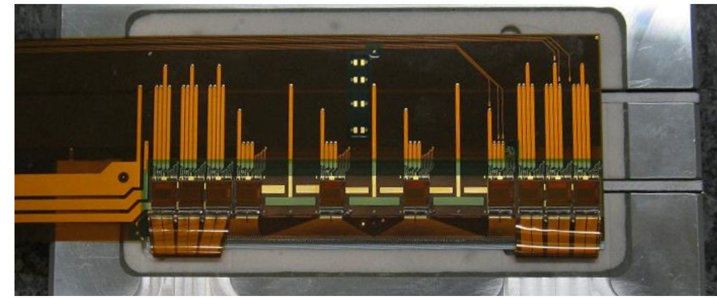


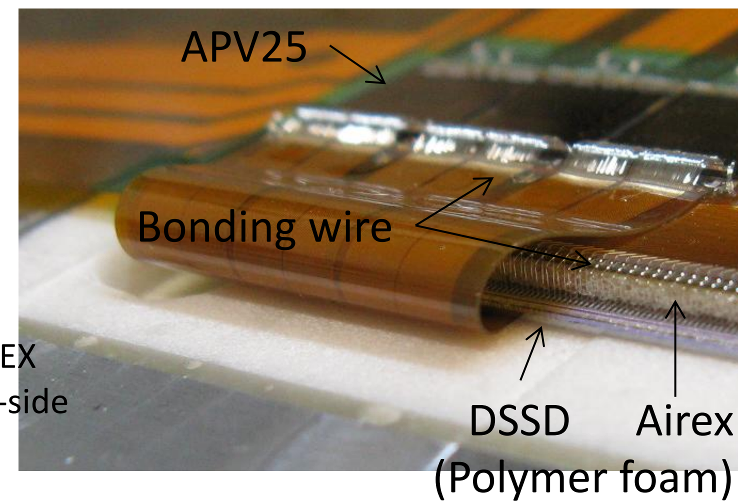

- Composed of:
  a) Pixel detector (PXD)
  b) Silicon micro-vertex detector (SVD)
     – Double-sided Si microstrip sensors

- Requirements:
  - Fast – to operate in high rate environment
  - Excellent spatial resolution (~15 µm)
  - Radiation hard (up to 100 kGray)
  - Good tracking capability – to track charged particles down to 50 MeV in $p_T$

# Origami Chip-on-Sensor Concept






- Chip-on-sensor  for double-sided readout, named “Origami”
- All chips aligned on one side → single cooling pipe (Ave. 0.59% $X_0$)