Belle II Status and SuperKEKB Progress

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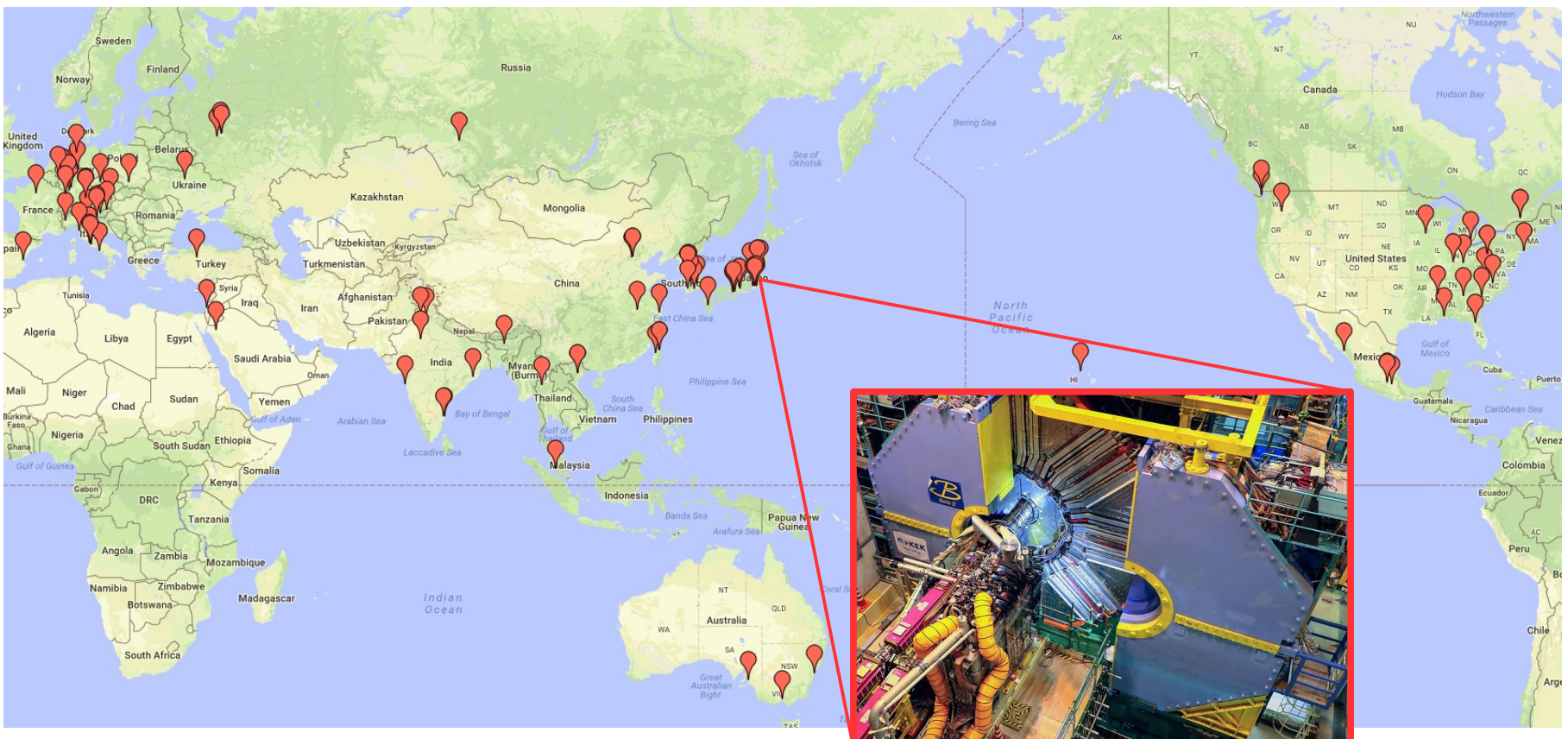
CEA Saclay, 17.09.2018

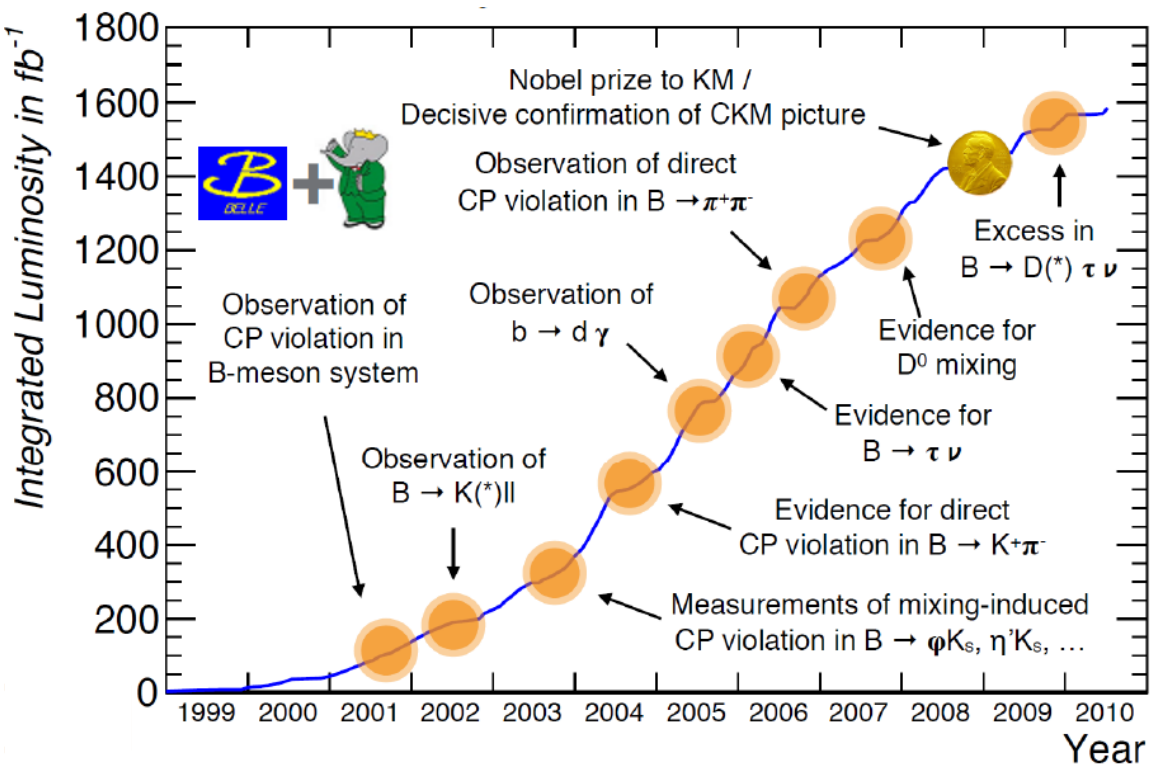
The Belle II Collaboration

- Truly international: now ~800 researchers from 25 countries



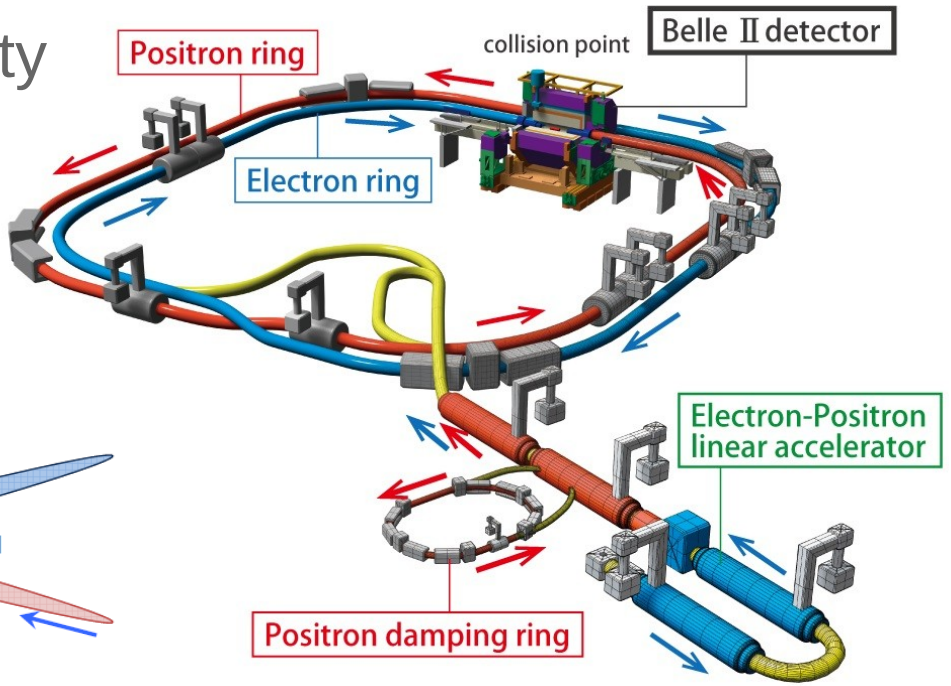
B-Factory Experiments

- Asymmetric beam energies, high luminosity
  → High statistics of boosted B, D and τ
- Flavour physics
  - CKM matrix, unitarity triangle
  - CPV in B system
- BSM limits
  - Rare B/D decays
  - $b \to s\gamma$, $b \to s l^+ l^-$
  - LFV in τ decays
- New particles
  - Tetraquarks

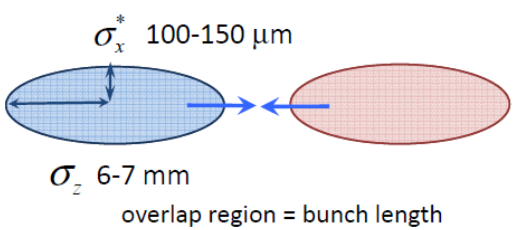


SuperKEKB

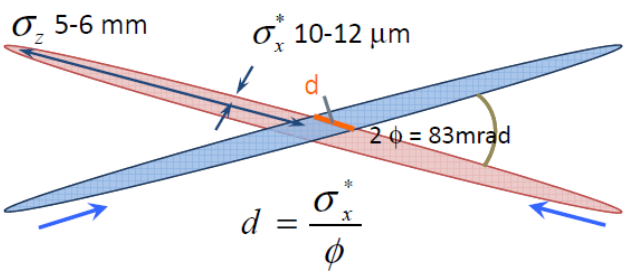
- 40x higher instantaneous luminosity
- Nano-Beam scheme
  - Powerful new superconducting final focus system



KEKB head-on (crab crossing)



Nano-Beam SuperKEKB



		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7.007	GeV
Beam crossing angle	φ	22		83		mrad
β function @ IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam current	I	1.64	1.19	3.6	2.6	A
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

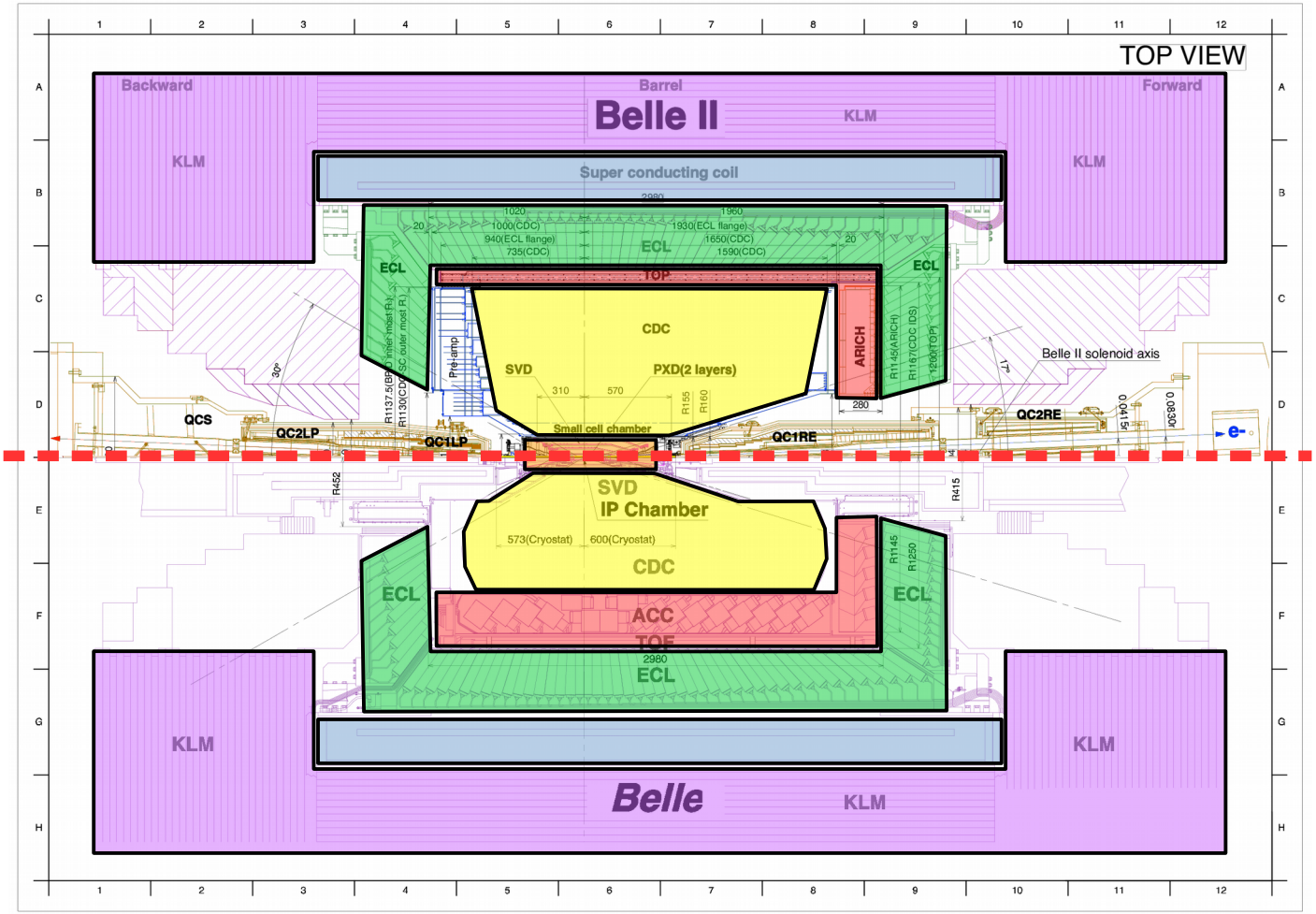
x20
x2
x40

Challenges on the Detector Upgrade

- Significantly increased beam backgrounds (x10-20)
  - Faster frontend electronics to reduce background pileup
- Increased trigger rates, data transfer bandwidth (x10-100)
  - Overhauled DAQ system, pipelined readout
  - Full reconstruction in high level trigger farm (~3000 nodes)
- Reduced initial state boost (-30%)
  - Higher resolution vertexing detectors
  - Addition of two layers of pixel sensors

Belle II Detector Upgrade

Belle II



Belle

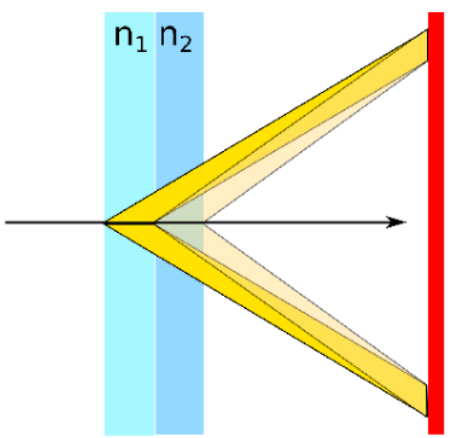
- K_L/Muon System
- Magnet Coil
- EM Calorimeter
- π/K Identification
- Drift Chamber
- Silicon Tracking

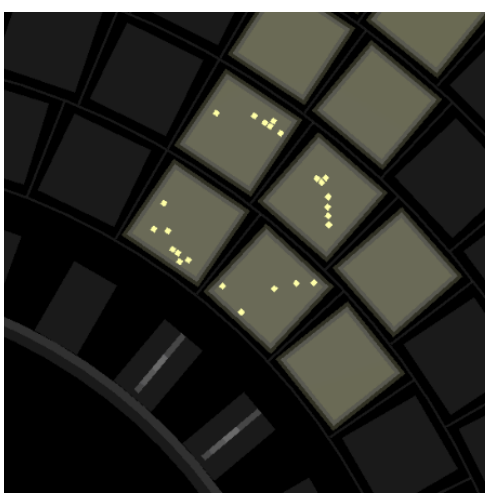
Belle II Detector Upgrade

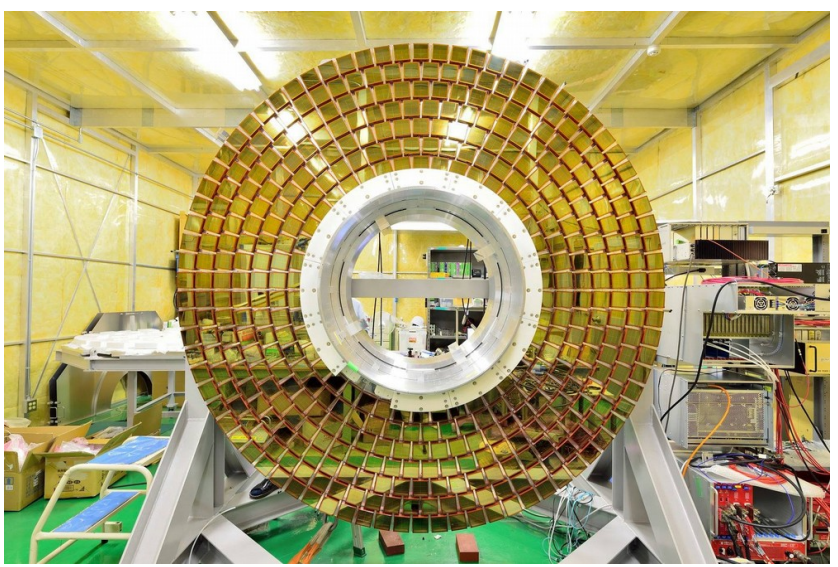
K_L/Muon System	New readout electronics Many RPC layers replaced with scintillator strips + SiPMs
Magnet Coil	No change
EM Calorimeter	New readout electronics (No change to CsI(Tl) crystals)
π/K Identification	Fully replaced
Drift Chamber	Fully replaced Larger outer radius for increased lever arm
Silicon Tracking	Fully replaced 4 layers of double sided silicon strips + 2 layers of DEPFET pixels

Endcap Particle ID: ARICH

- Aerogel ring imaging Cherenkov detector
  - Double aerogel layer for focusing
- Very large sensor area: pixelated, single photon sensitive
  - instrumented with HAPDs (Hamamatsu)

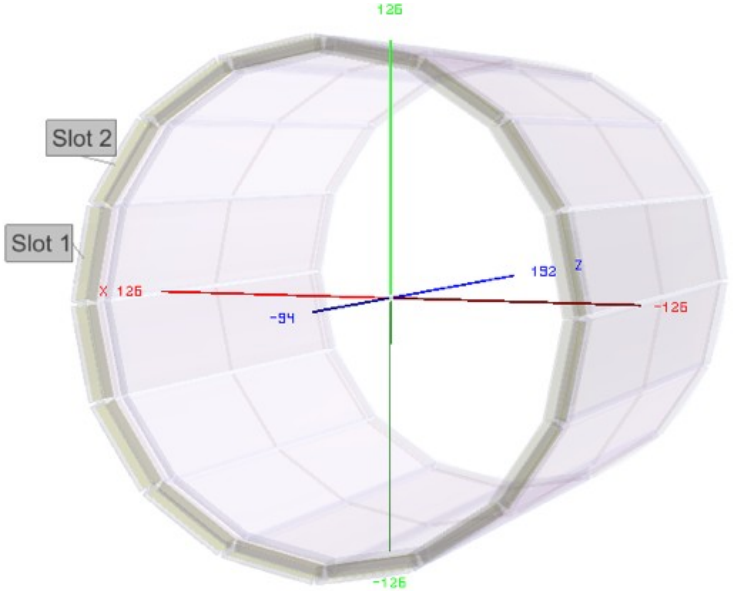


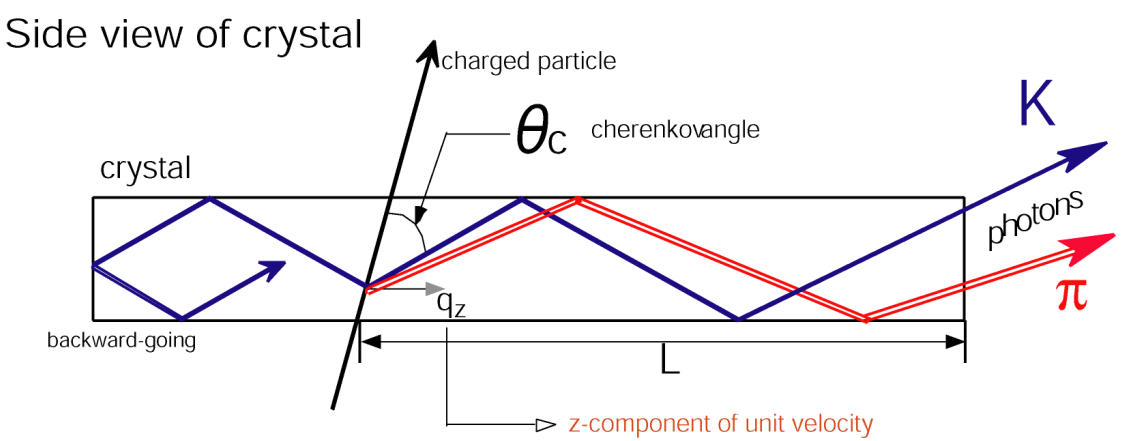


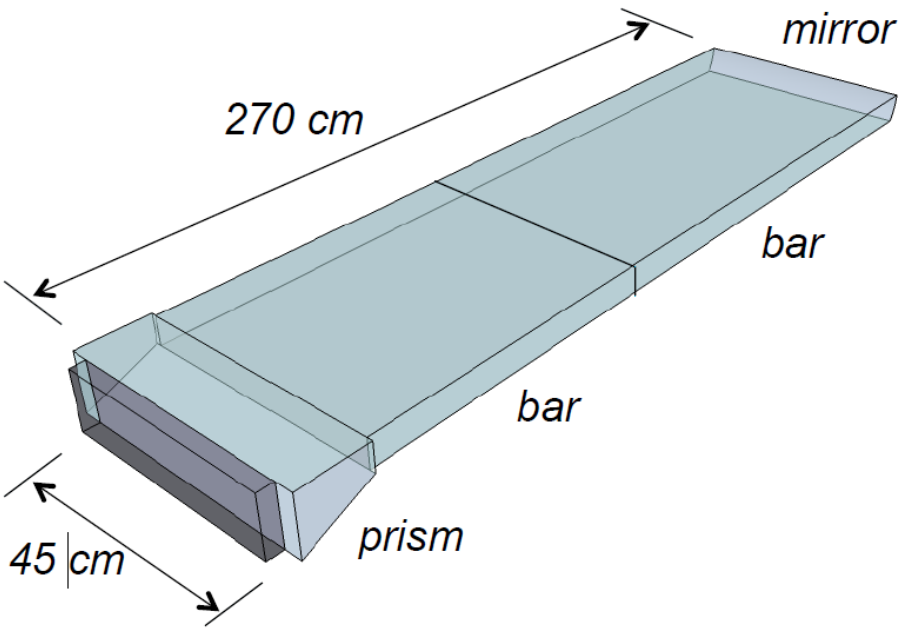


Barrel Particle ID: TOP

- 16 Quartz Cherenkov radiator bars
  - 270cm * 45cm * 2cm each
- Sensor plane at one end of the bar
- Pixelated, single photon sensitive, excellent time resolution <100ps
  - Instrumented with Hamamatsu MCP-PMTs







Key Technologies in Belle II

- Pixelated photo sensors
  - MCP-PMTs in TOP (barrel PID)
  - HAPDs in ARICH (end cap PID)
  - SiPMs in KLM

- Waveform sampling readouts
  - TOP: 8192 channels, 2.7GSa/s: IRSX (Hawaii)
  - Sci-KLM: 16800 channels, 1GSa/s: TARGETX (Hawaii)
  - SVD: 224k channels, 40MSa/s: APV25 (adapted from CMS)
  - CDC: 14336 channels, 30Msa/s
  - ECL: 8736 channels, 2MSa/s

Readout Electronics Example: TOP

- Reads MCP-PMT signals
- Time resolution ~30ps
  - ~Gsa/s sampling
  - ~500MHz bandwidth

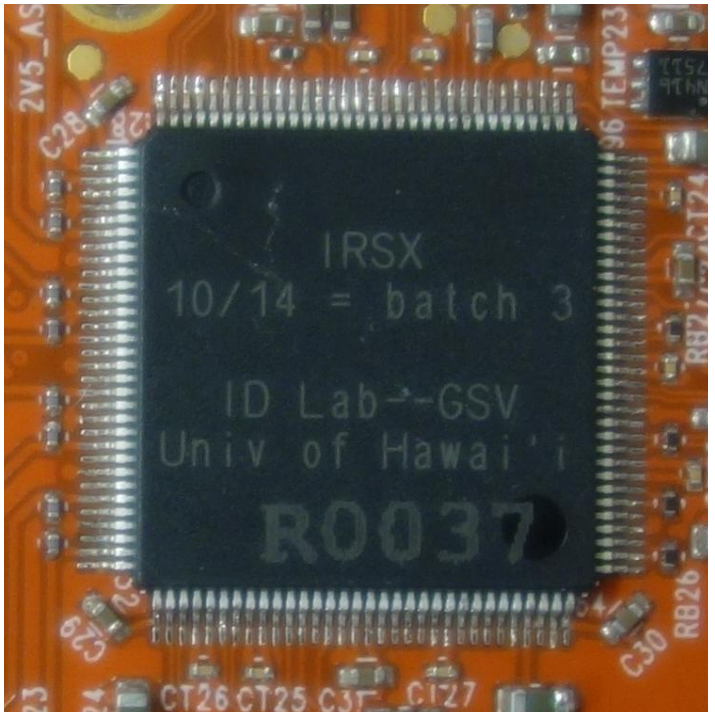
?

Readout Electronics Example: TOP

- Reads MCP-PMT signals
- Time resolution ~30ps
  - ~GSa/s sampling
  - ~500MHz bandwidth
- 8192 channels
- Affordable
- Low power
- Small form factor
- Online data processing
- etc. etc.

“Oscilloscope on a Chip”

- IRSX designed by IDLAB, Univ. Hawaii
- 8 channels
  - ~100mW/channel
- Operated at 2.7GSa/s in TOP
  - 12bit resolution
  - ~600MHz analog bandwidth
  - 32k analog storage cells (~10us)
  - Sampling/digitisation w/o deadtime

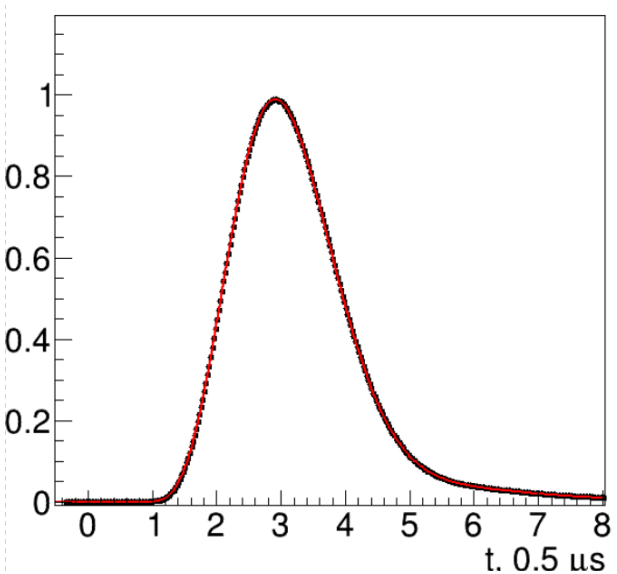


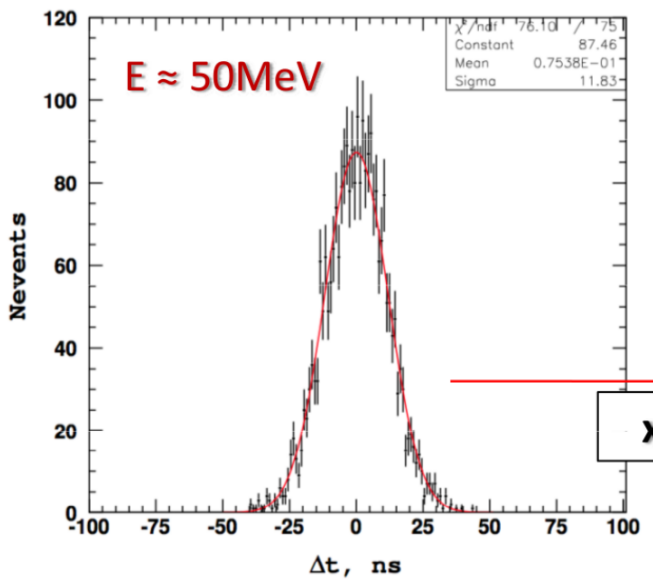
Online Data Reduction

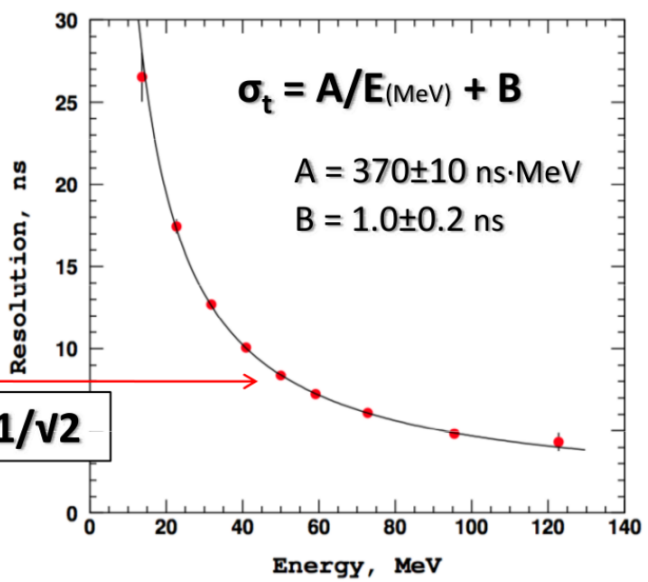
- Raw IRSX output bandwidth of TOP would be 265 TBit/s!
- Only digitise relevant samples
  - Based on global and local trigger information
- Apply all raw data conditioning in frontend
  - Pedestal subtraction
  - Time base calibrations
- Extract waveform features in frontend
  - Pulse timing, amplitude etc.
- Write out only pulse feature parameters
- TOP: ~1GBits/s output bandwidth at full trigger rate

Feature Extraction in ECL

- 128 sample template fit in ECL frontend FPGA
  - Extracting hit amplitude and timing

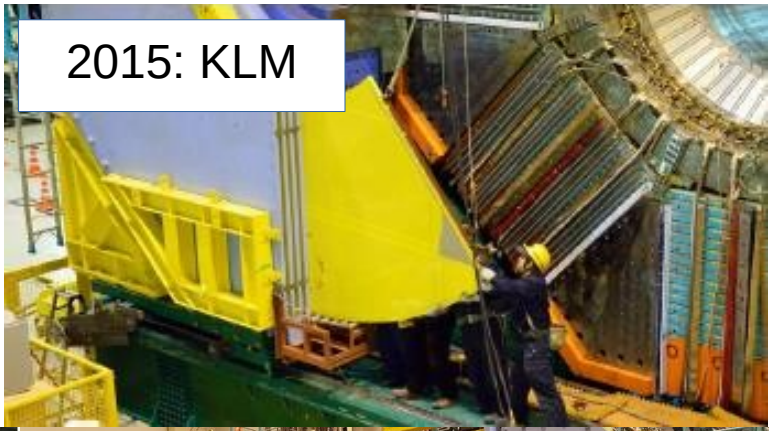


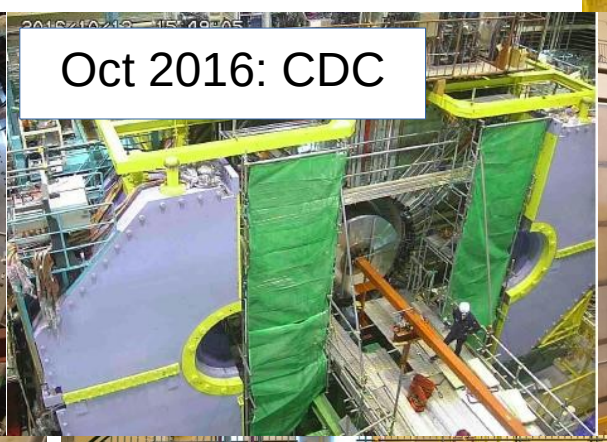


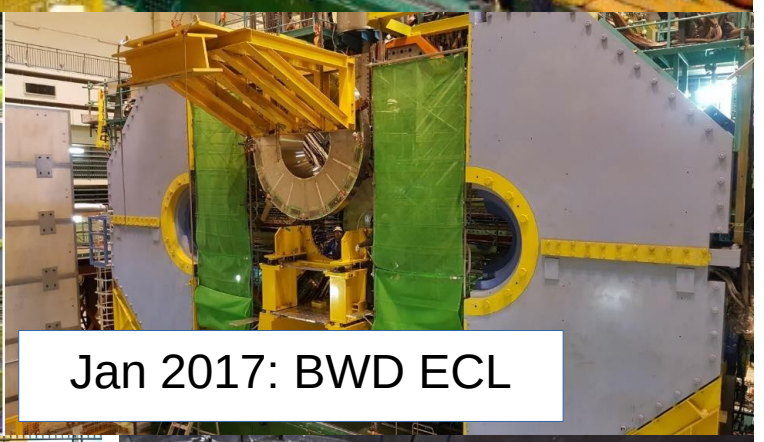


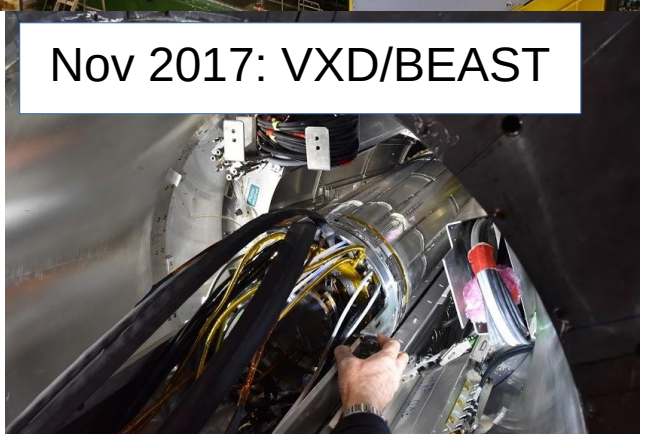
x 1/√2

Belle II Installation



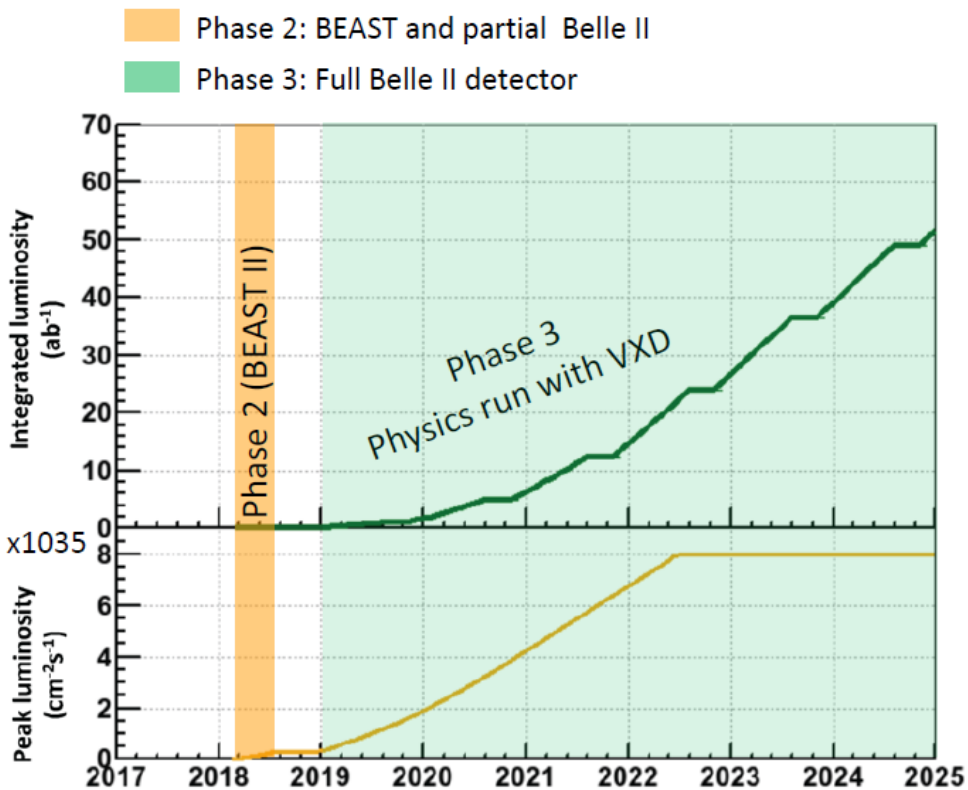




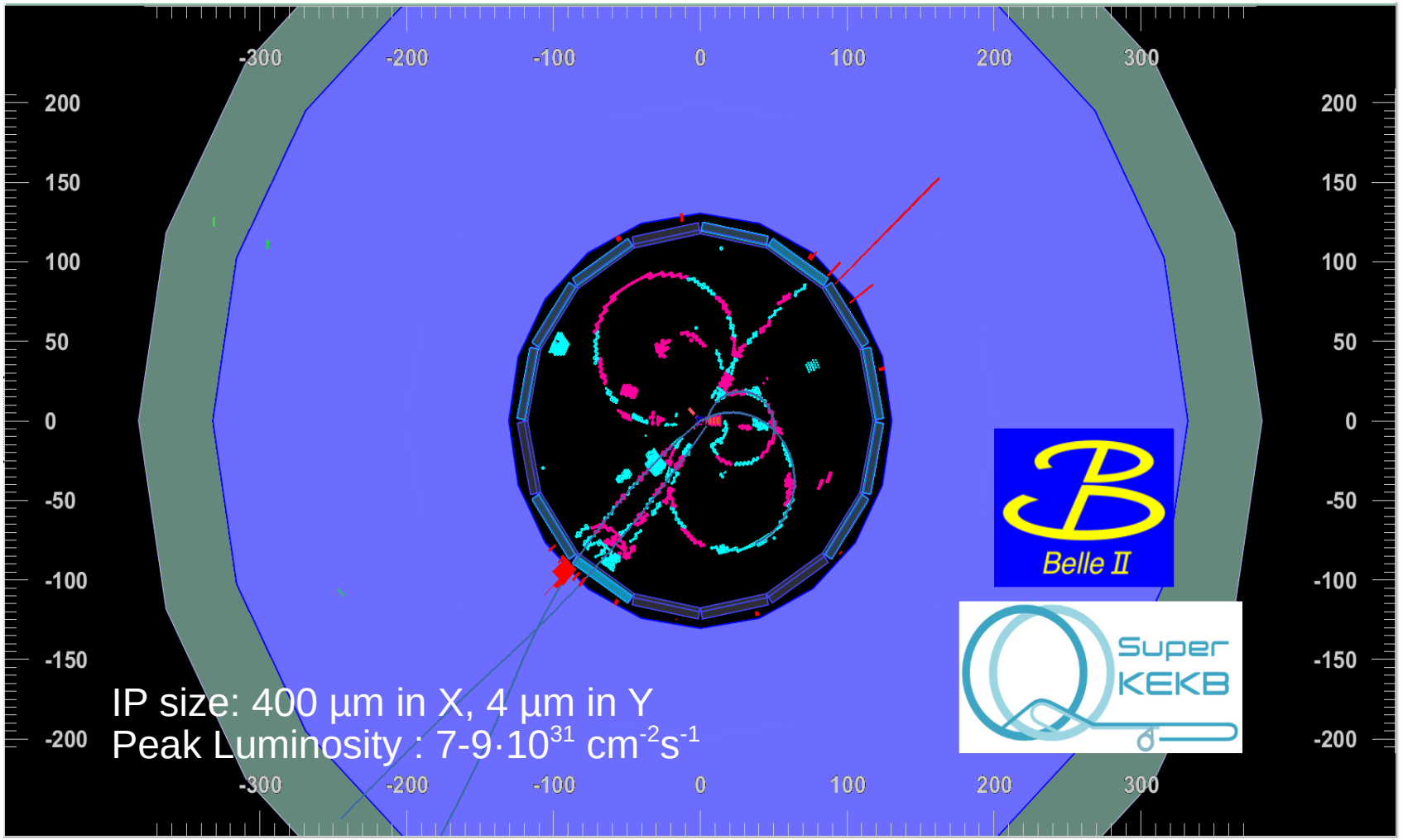


SuperKEKB + Belle II Commissioning

- Phase 1: Operation without Belle II and without final focus system
  - Completed in June 2016
- Phase2: Start data taking with first collisions
  - Full outer Belle II detector
  - BEAST beam background detector instead of inner tracking, contains one ladder each of strip and pixel detectors
  - Luminosity goal ~1x10^{34} cm^{-2} s^{-1}
  - Completed in July 2018
- Phase3: Full Belle II operation
  - Final detector configuration
  - Luminosity goal ~8x10^{35} cm^{-2} s^{-1}
  - Starting Spring 2019



First Collision in Belle II - 04/26/2018

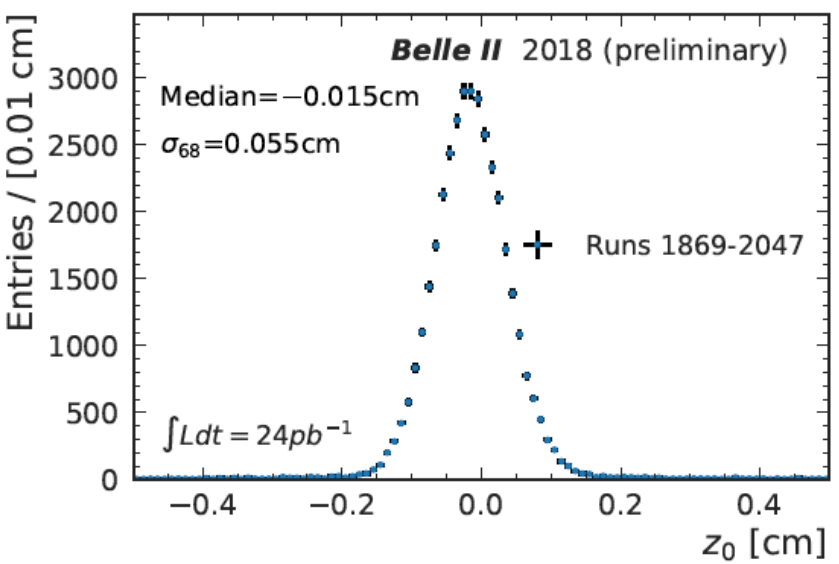


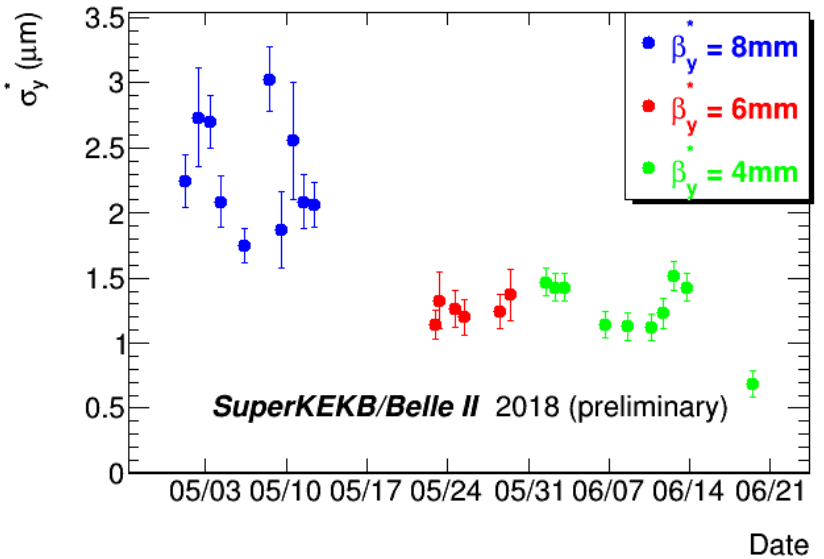
Probably $e^+e^- \rightarrow \gamma^* \rightarrow q\bar{q}$

… and the Reaction

SuperKEKB Phase 2 Beam Size

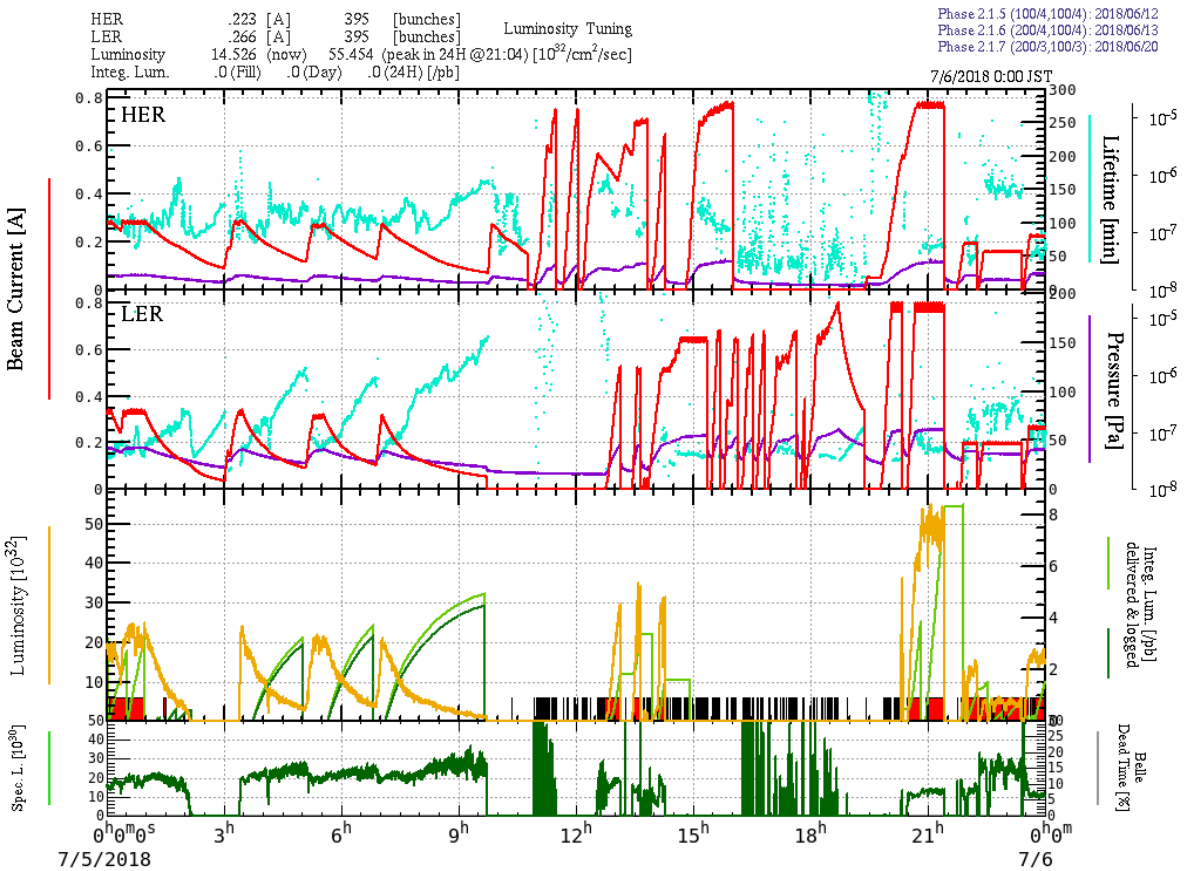
- Effective bunch length is **0.5mm**! (x20 smaller than KEKB)
  - Measured by Belle II using two track events
- Vertical beam spot size down to 330nm
  - Some beam-beam blowup observed at higher currents, increases up to ~700nm
  - Will decrease by another order of magnitude with focus tuning





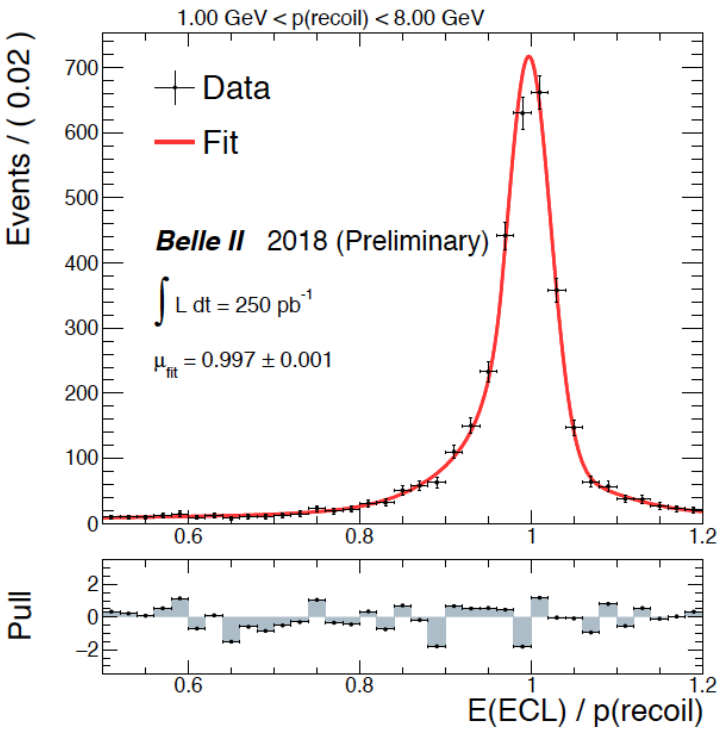
SuperKEKB Phase 2 Luminosity

- Up to ~5.5x10^{33} cm^{-2} s^{-1}, 500 pb^{-1} recorded in Phase 2
  - Focus on machine and detector commissioning



Photons in Belle II

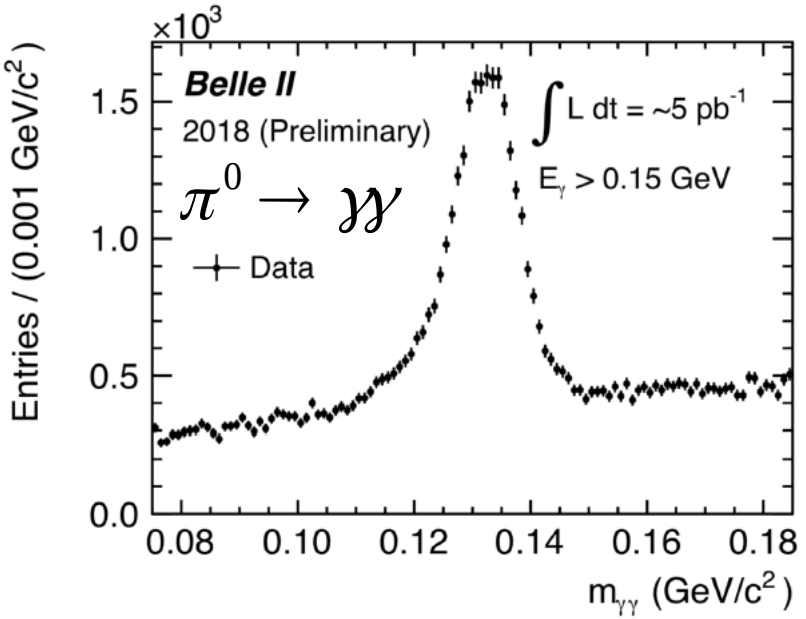
$e^+e^- \to \mu^+\mu^-\gamma$

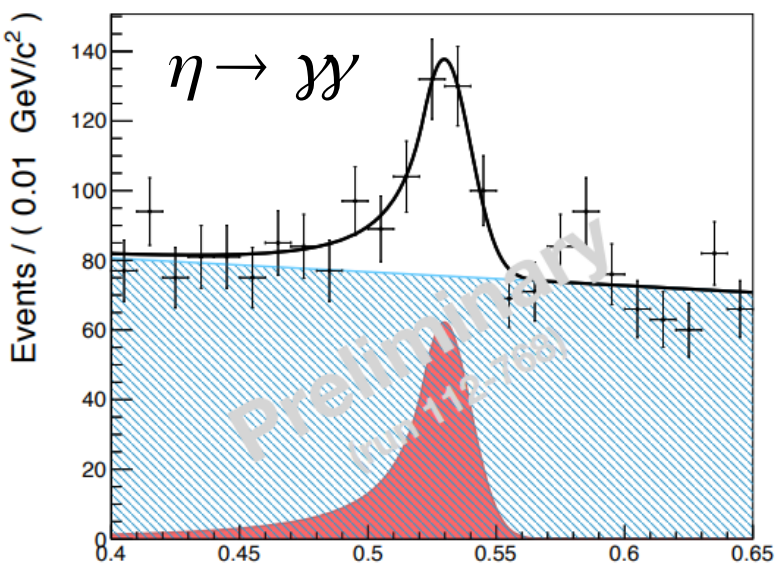


Ready for the dark sector !

$e^+e^- \to \gamma X$

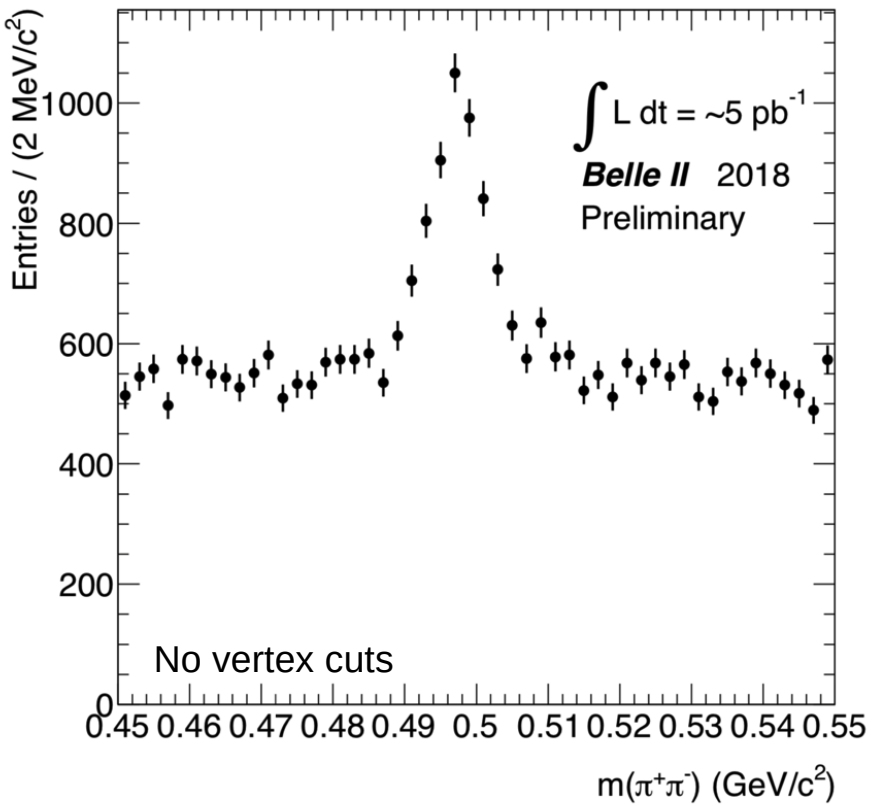
$e^+e^- \to \gamma ALP \to \gamma(\gamma\gamma)$



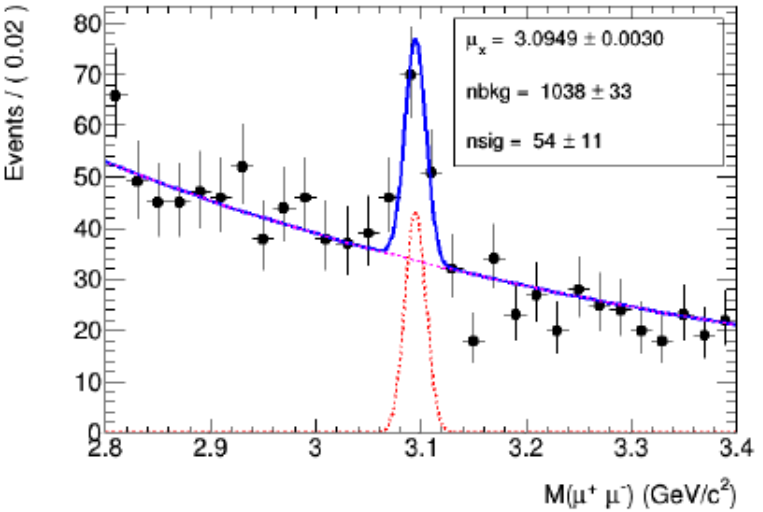


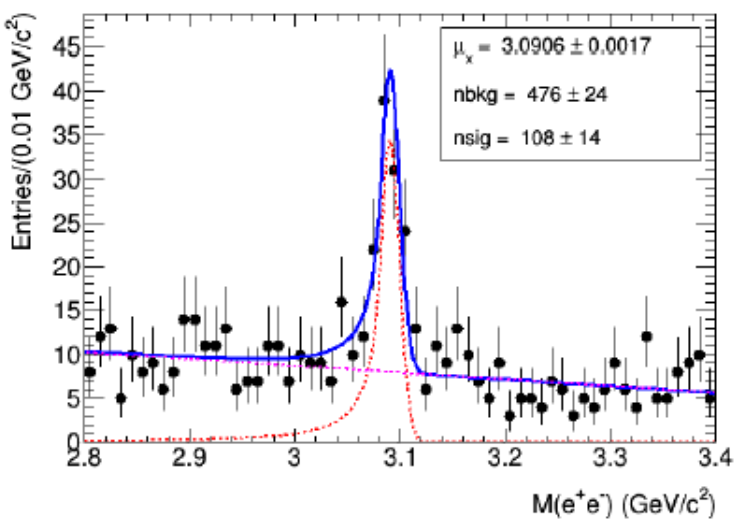
Tracks in Belle II

$K_S \to \pi^+\pi^-$



$J/\psi \to \mu^+\mu^-$, $J/\psi \to e^+e^-$



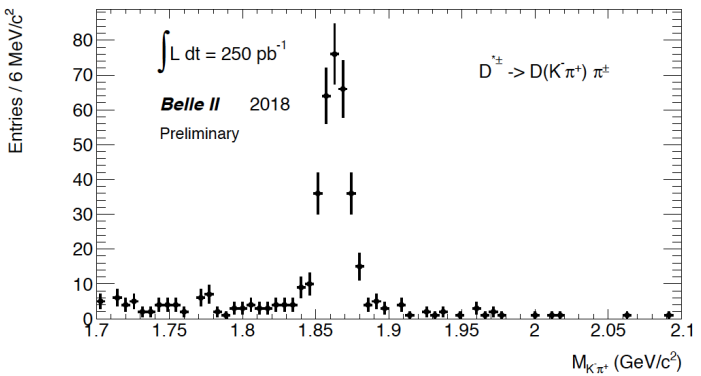


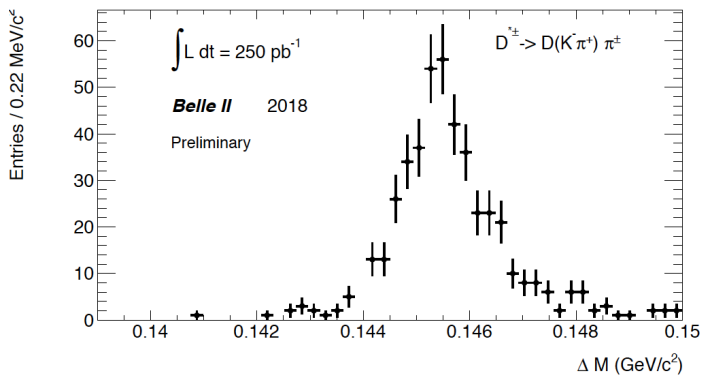
$e^+e^- \to c\bar{c}$ in Belle II

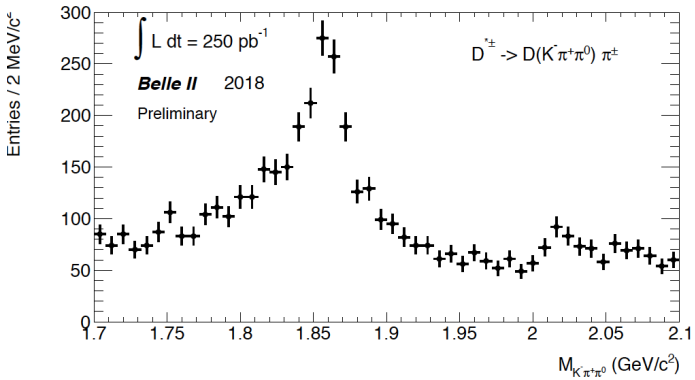
$$D^{*+} \to D^0\pi^+,$$

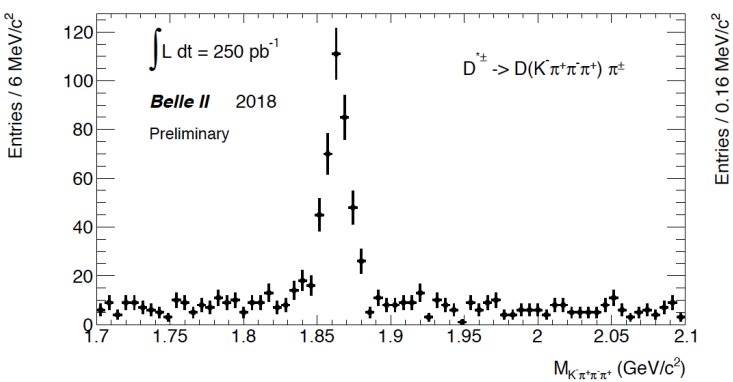
$$D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+$$

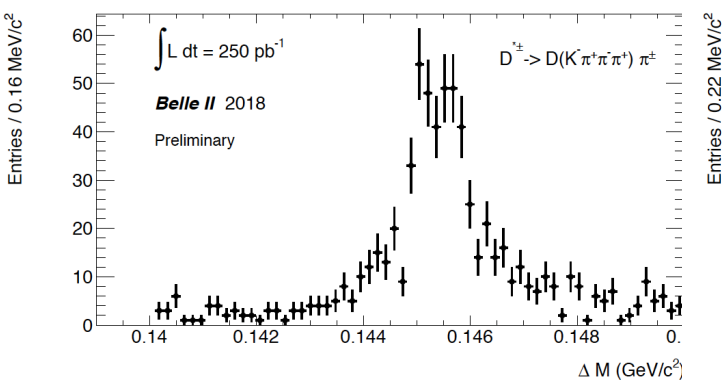
- Building blocks of B mesons
- Signals peaks are charm in continuum, not from B decays

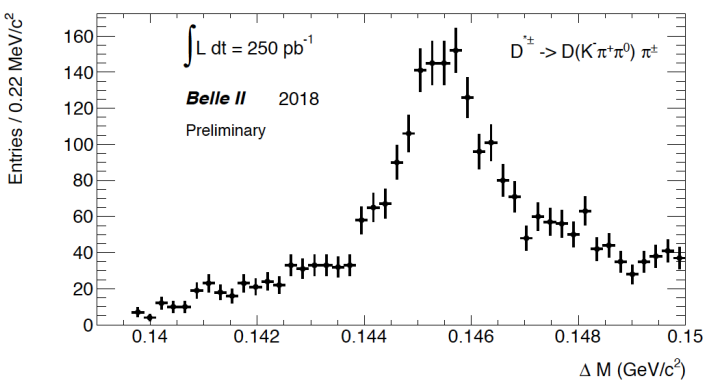












Neutral Final States $D^0 \to K_S \pi^0$

- Pair of pions with a displaced vertex and two photons measured with good resolution and low background
  - Quite impossible at LHCb

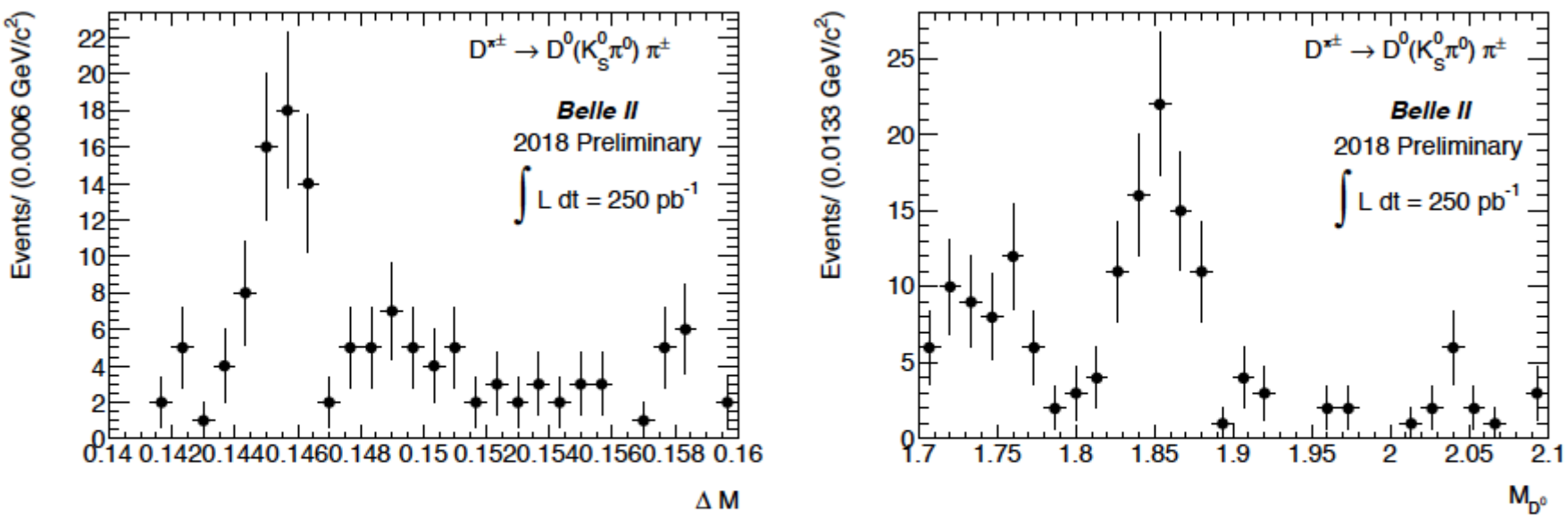
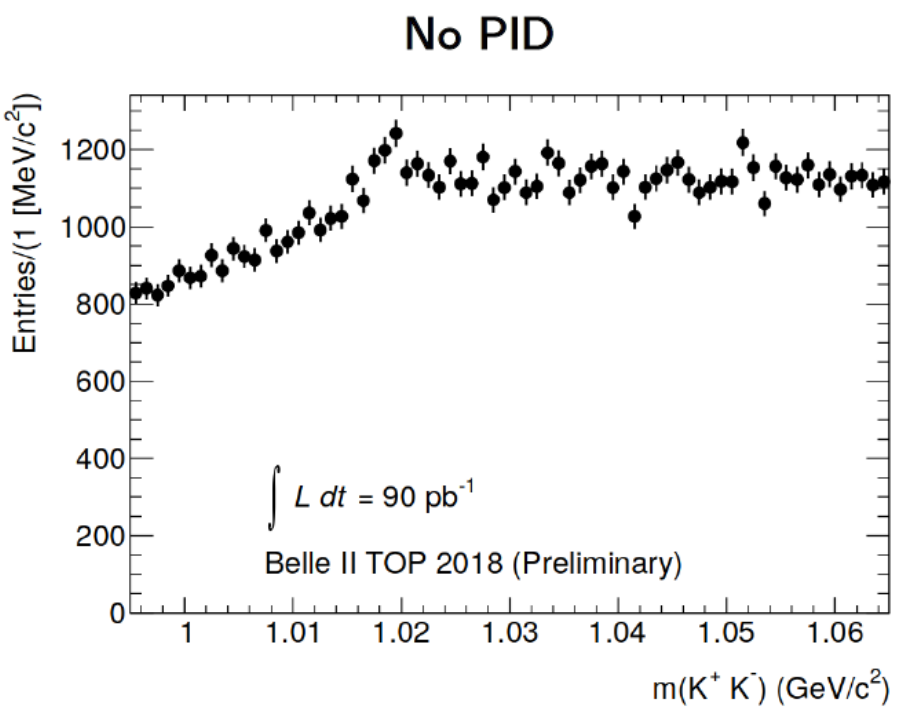
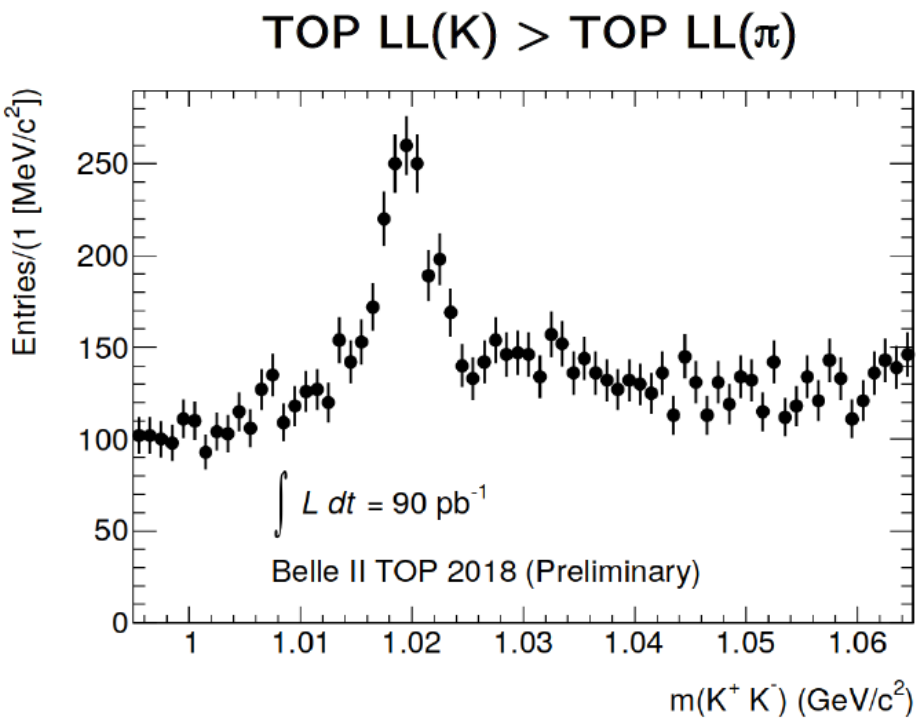


FIG. 36: ΔM (left) and M_D (right) signal-enhanced projections in 250 pb^{-1} prod4 data sample for $D \to K^0_S\pi^0$ final state.

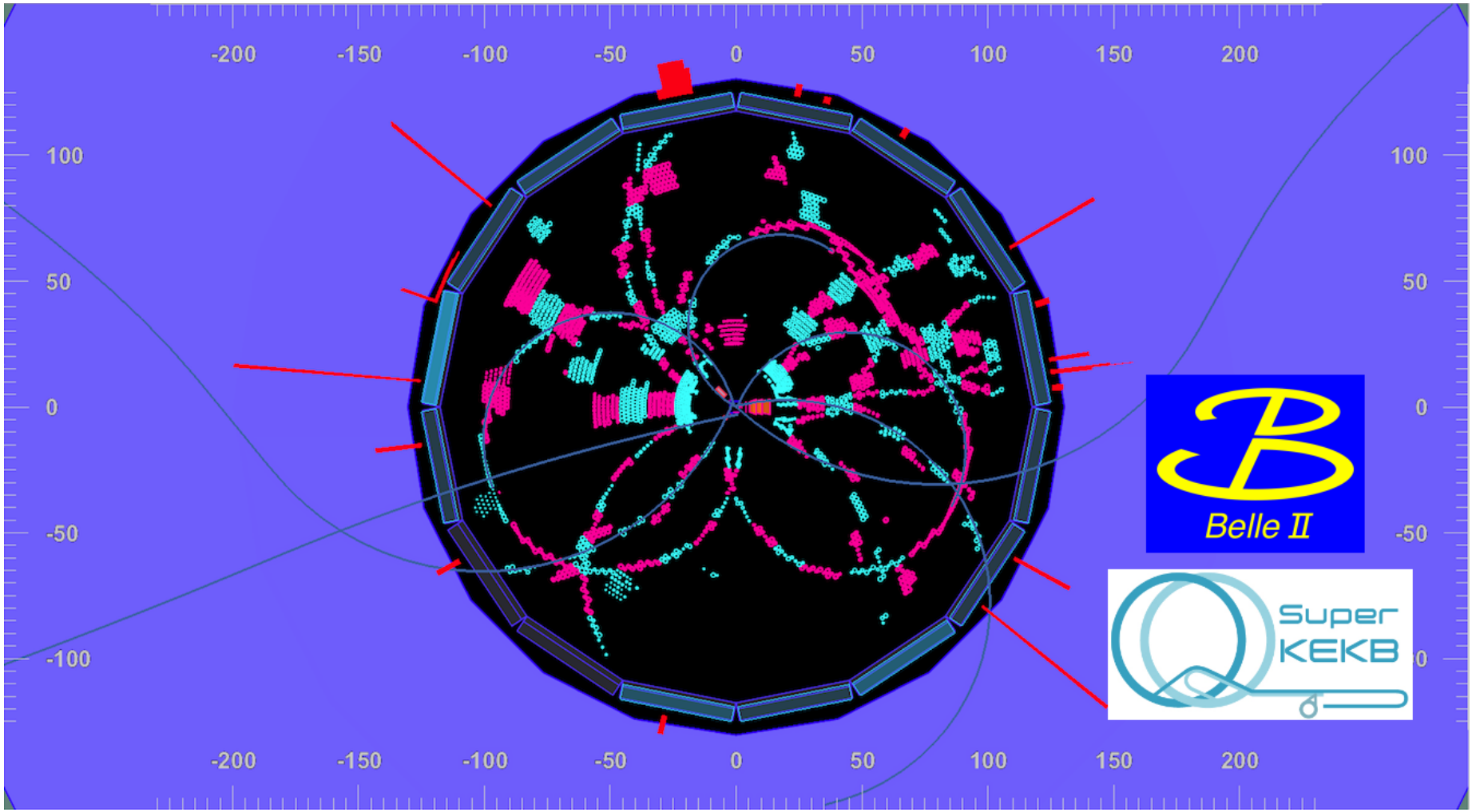
TOP Particle ID Performance

$\phi \rightarrow K^+K^-$ with both the tracks in the TOP acceptance





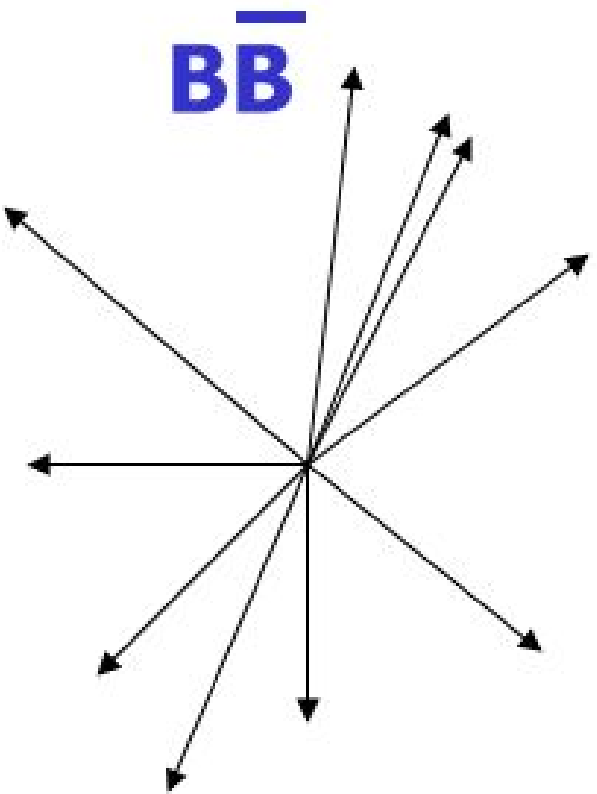
… Later During the First Night of Collisions

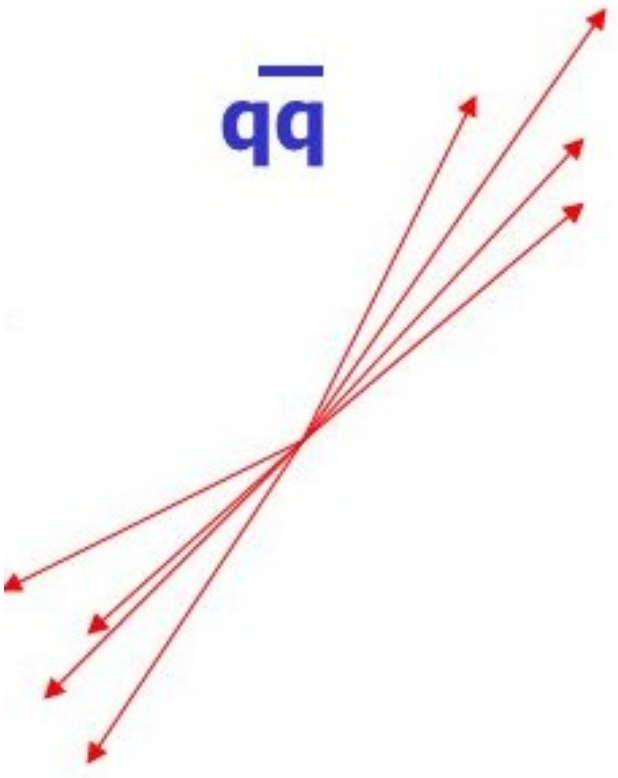


Possibly $e^+e^- \to \gamma^* \to B\bar{B}$

Event Topology of B's

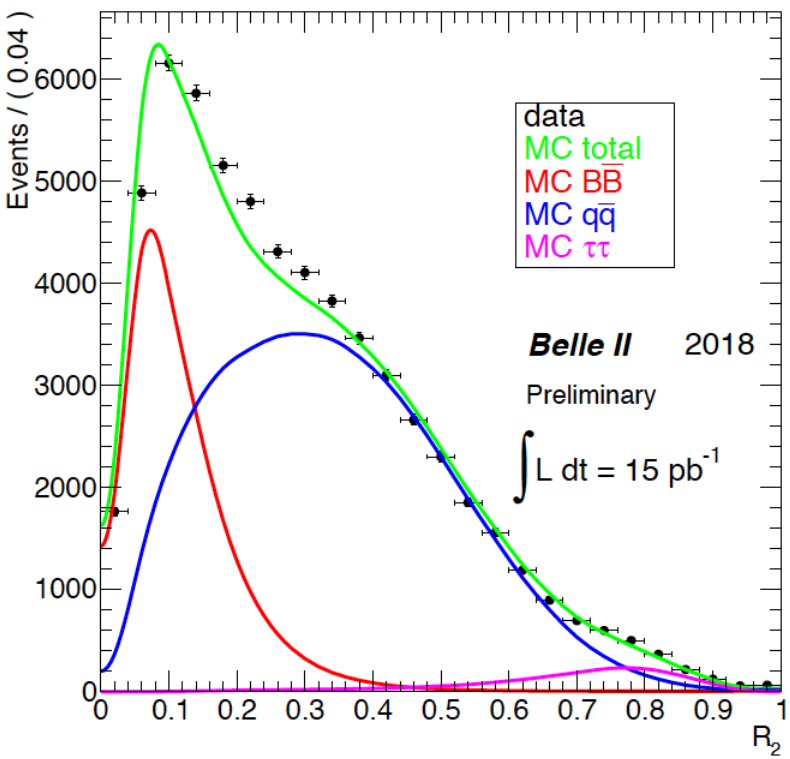
- In CM frame: $B\bar{B}$ look "spherical", $q\bar{q}$ looks "jetty"
  - Quantified by "R_2" variable



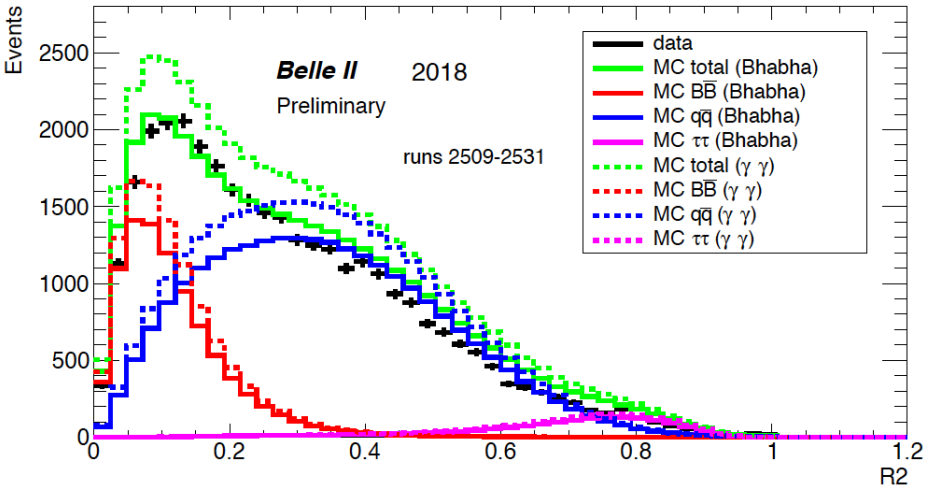


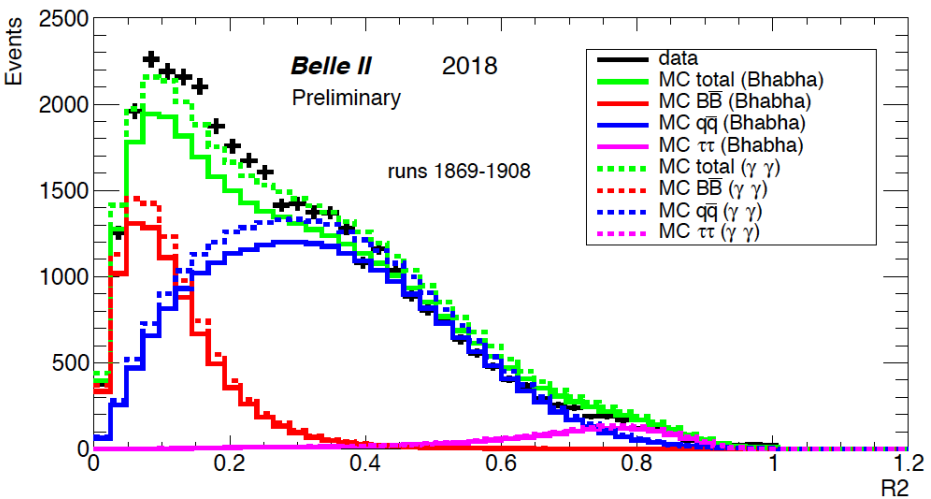
Many B's in Belle II

- We are and stay on Y(4s) resonance



Spherical R_2 Jet-like

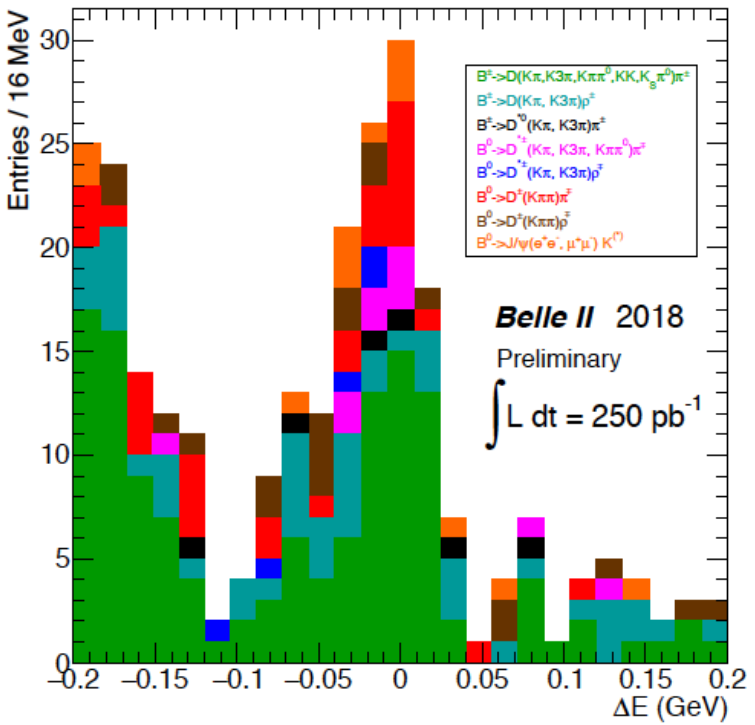


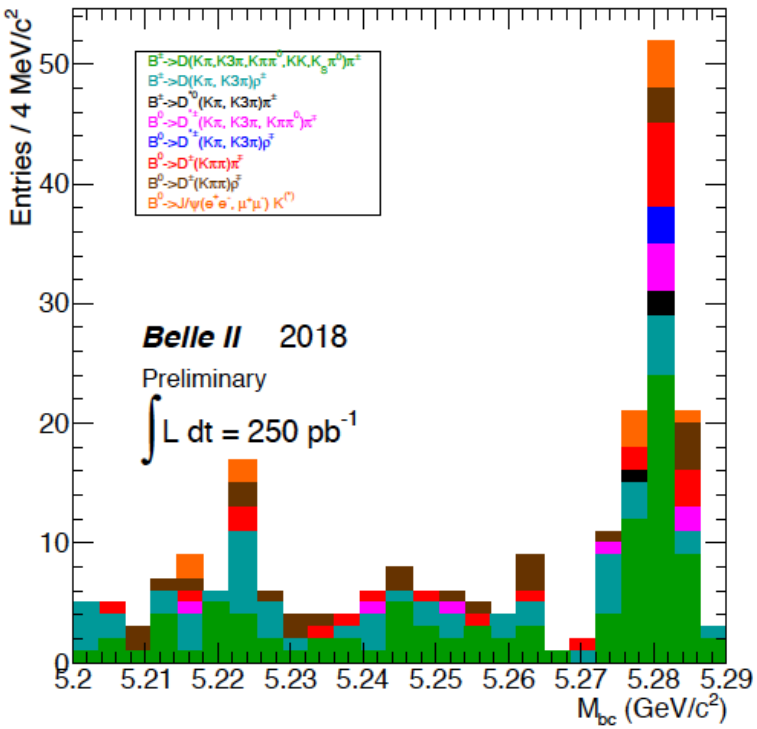


Single B's in Belle II

$$\Delta E = E_{cm}/2 - E_{recon}$$

$$M_{bc} = \sqrt{(E_{cm}/2)^2 - p^2_{recon}}$$



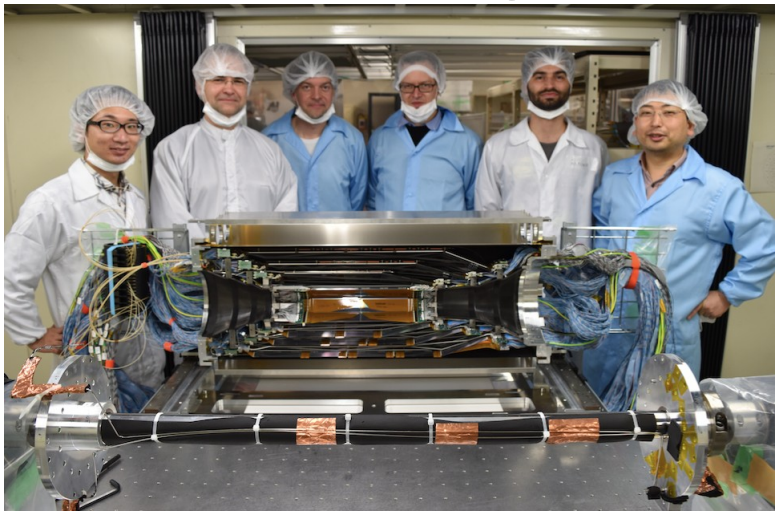


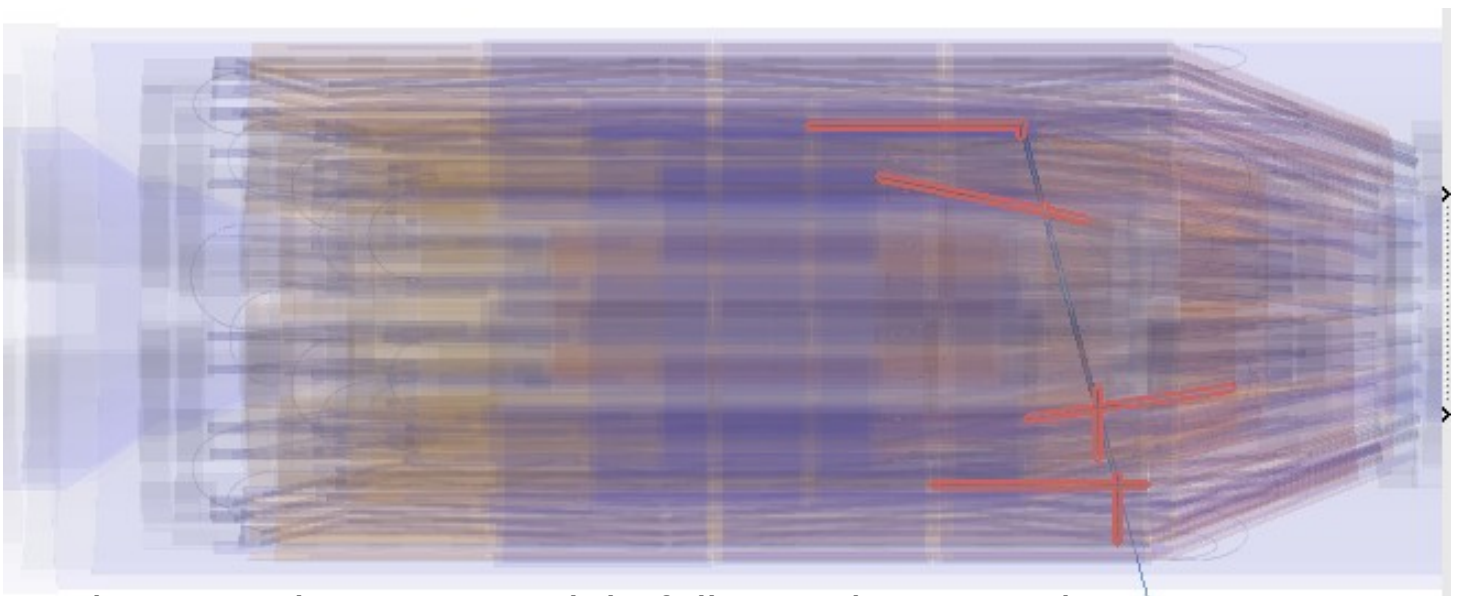
VOLUME 50, NUMBER 12 PHYSICAL REVIEW LETTERS 21 MARCH 1983

Observation of Exclusive Decay Modes of *b*-Flavored Mesons **40.7 pb^{-1}**

B-meson decays to final states consisting of a D^0 or $D^{*\pm}$ and one or two charged pions have been observed. The charged-*B* mass is $5270.8 \pm 2.3 \pm 2.0$ MeV and the neutral-*B* mass is $5274.2 \pm 1.9 \pm 2.0$ MeV.

Inner Tracking Status - SVD

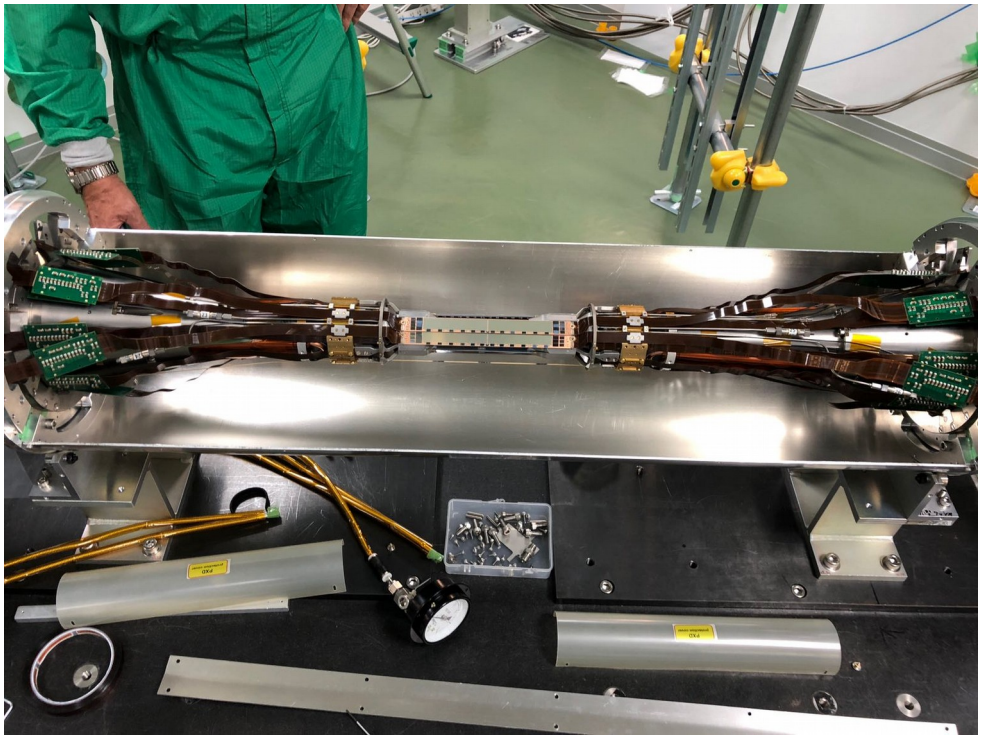




First Cosmic Muon Track in full SVD (Aug 2018)

Inner Tracking Status - PXD

- As of last week: both PXD half shells arrived at KEK
- Installation and commissioning ongoing in Tsukuba Hall B4



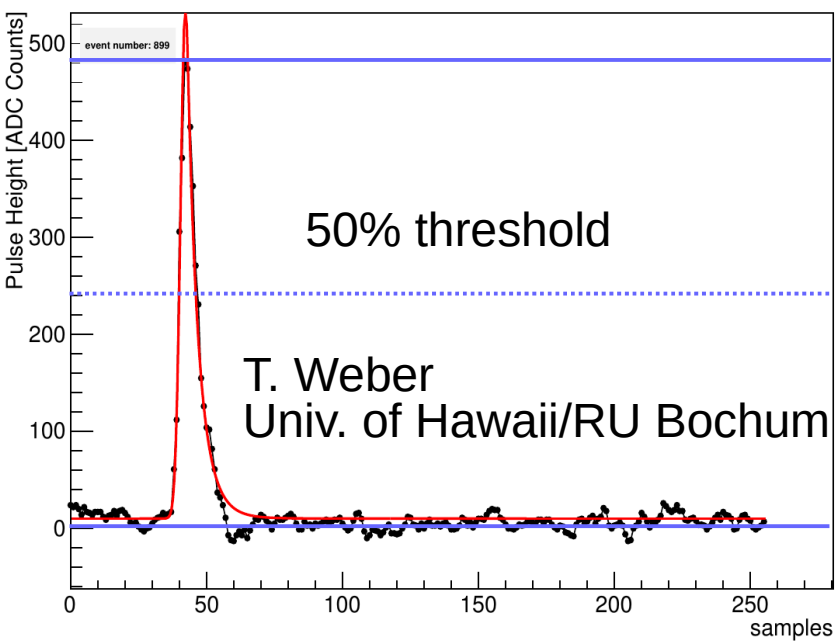
Summary

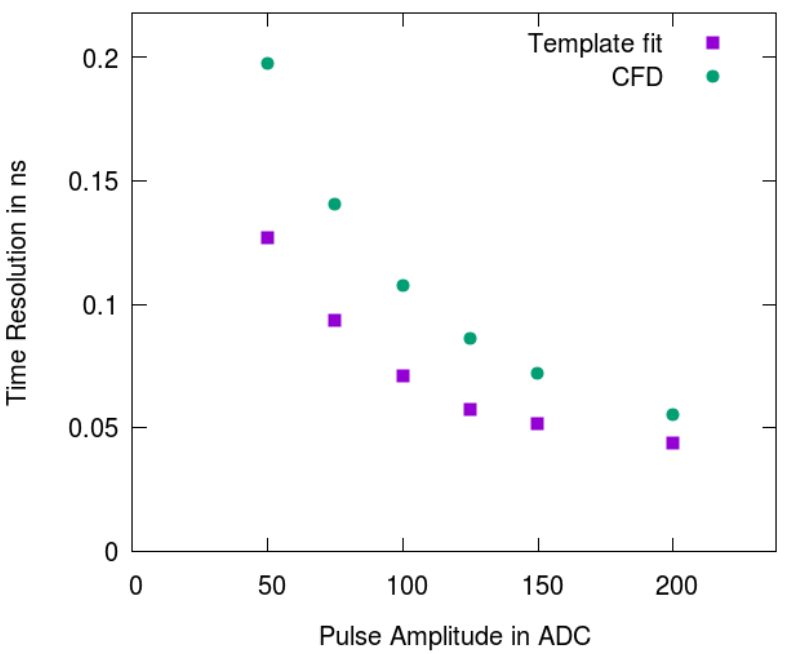
- First collisions and commissioning runs of phase 2 earlier this year were very successful
  - Saw first physics
  - First understanding of beam backgrounds
  - Initial calibrations for outer detectors
- Silicon tracking is being assembled at KEK, insertion this Fall

- SuperKEKB will deliver highest luminosity e^+e^- collisions to the full Belle II detector starting from Spring 2019
- Soon, the intensity frontier will come to save particle physics once again

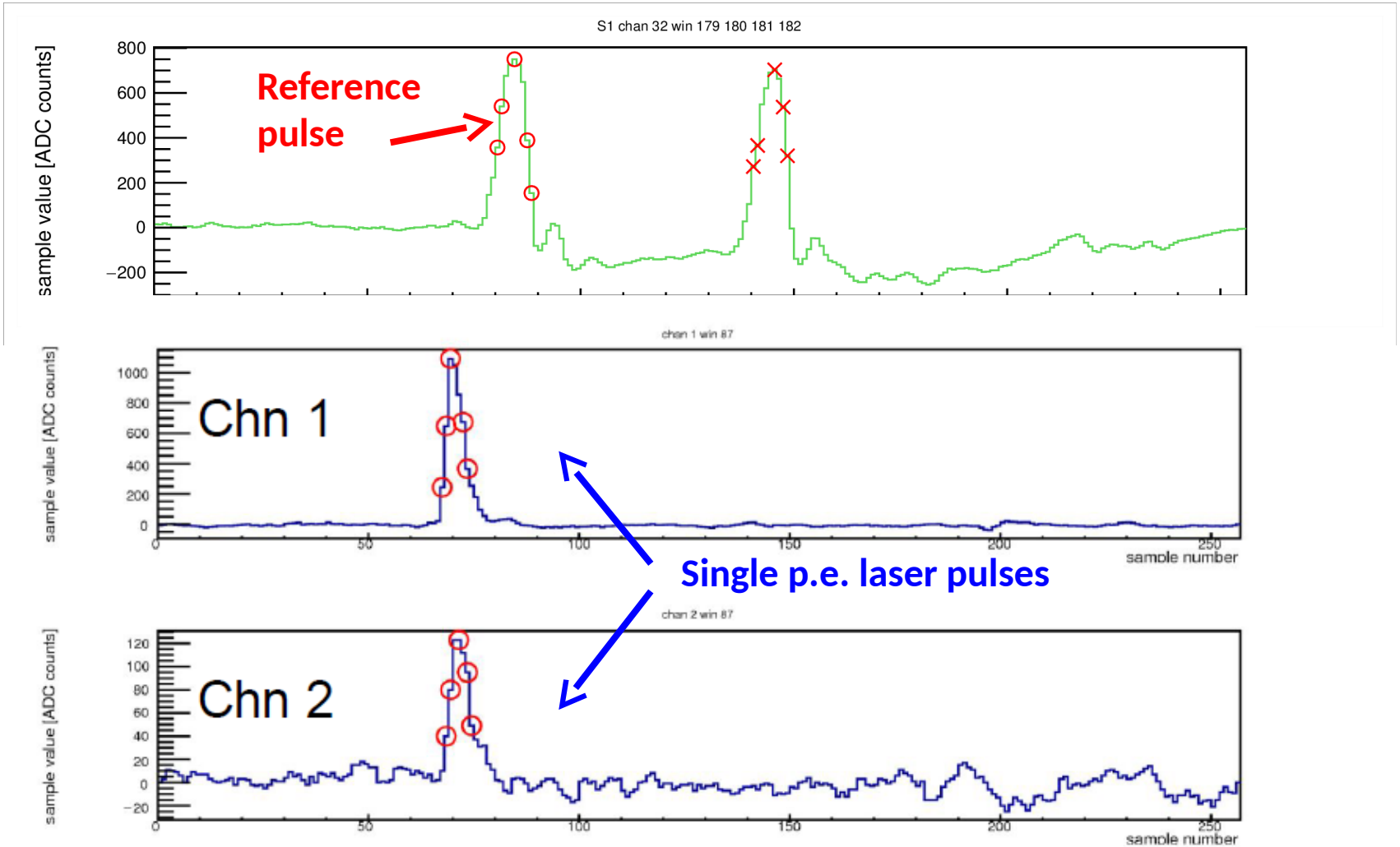
Feature Extraction

- Constant fraction discrimination
- Template fit to photon pulses
  - Computationally complex, possible on Zynq DSPs?
  - but only needed for low amplitude hits





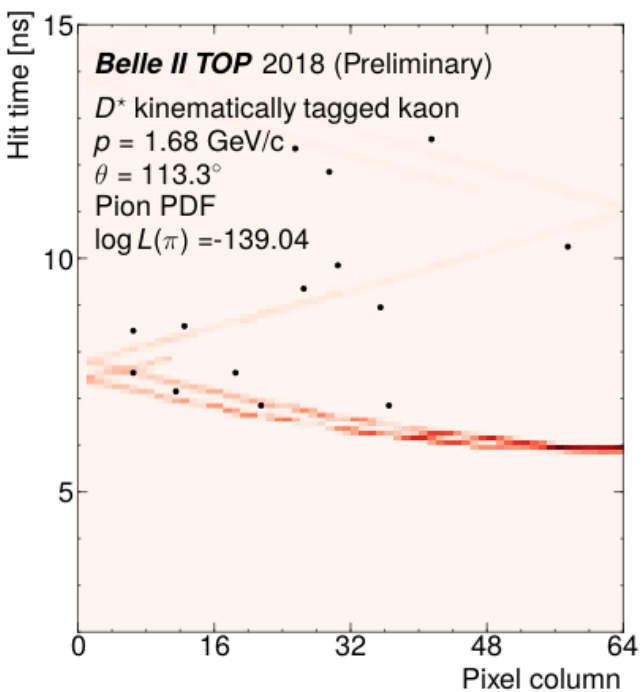
Feature Extraction Implementation Status

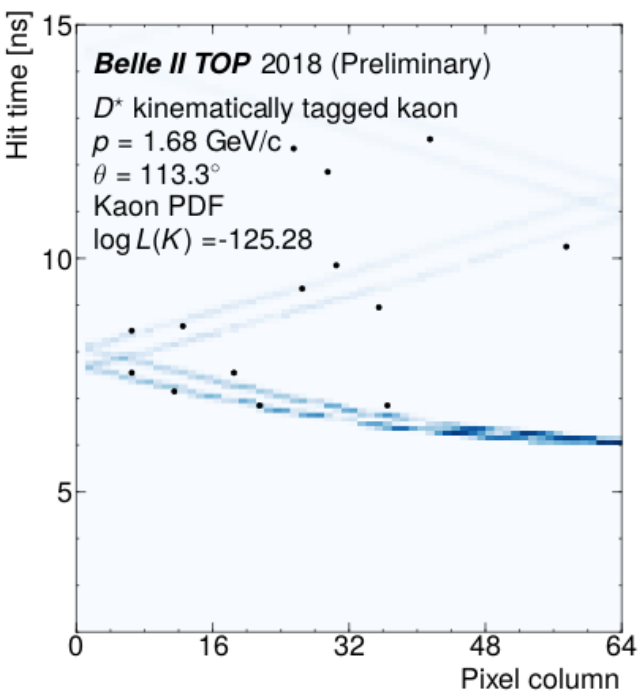


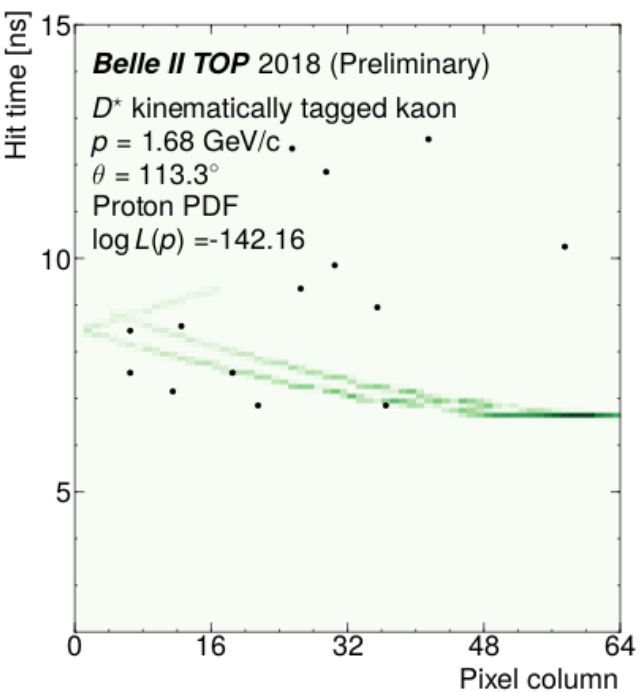
TOP Particle ID

- $D^{*+} \rightarrow D^0 \pi_s^+; D^0 \rightarrow K^- \pi^+$

  "Nature's MC truth" -Sam Cunliffe







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