Start of the Belle II Experiment at SuperKEKB

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for the Belle II Collaboration

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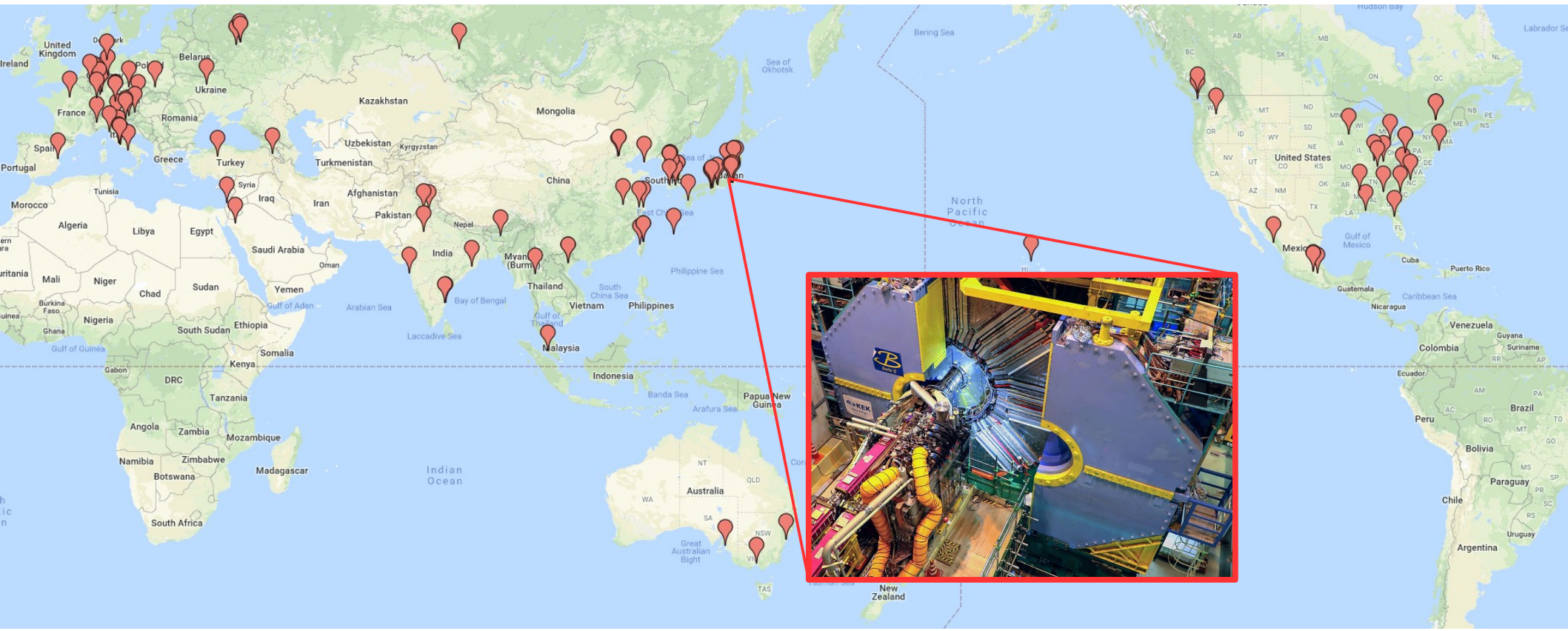
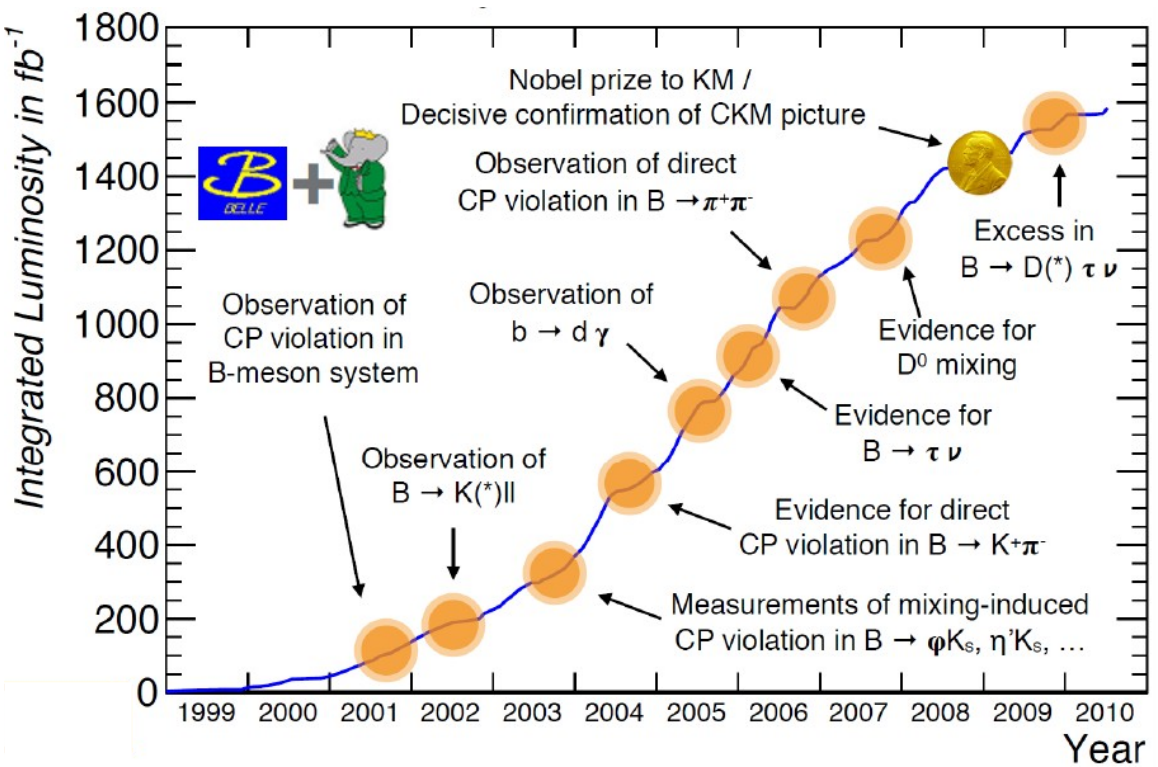
The Belle II Collaboration

- Truly international: now ~980 researchers from 26 countries



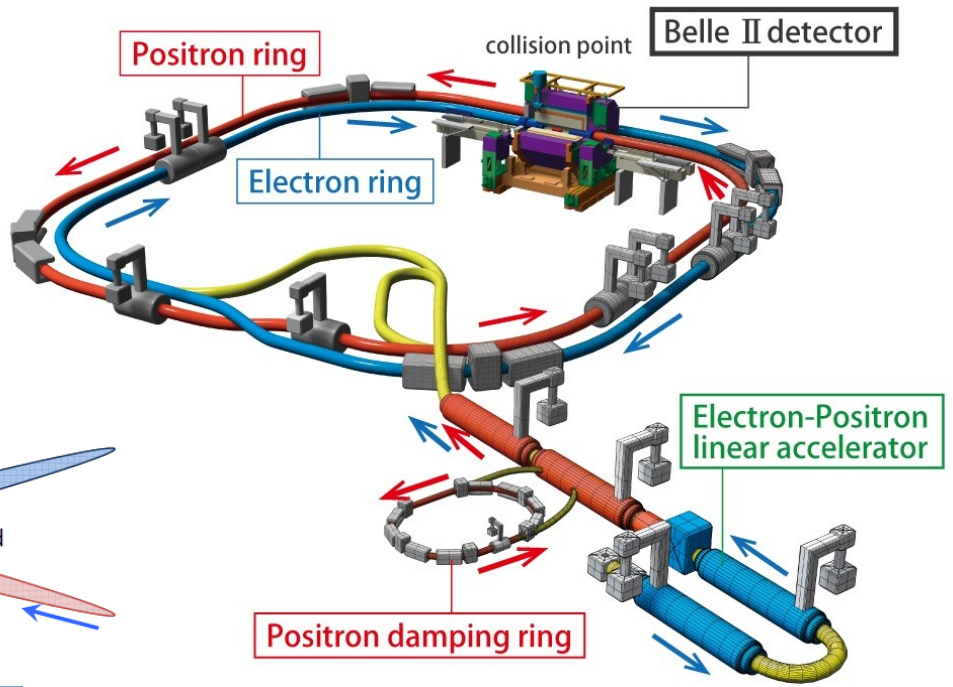
B-Factory Experiments

- 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

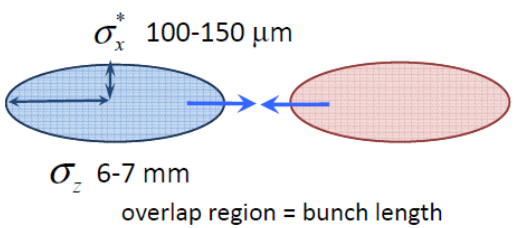


SuperKEKB

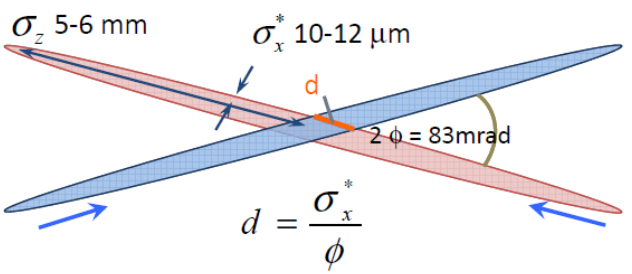
- 40x higher instantaneous luminosity
- Nano-Beam scheme
  - Almost completely new machine
  - New final focus system



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}		$cm^{-2}s^{-1}$

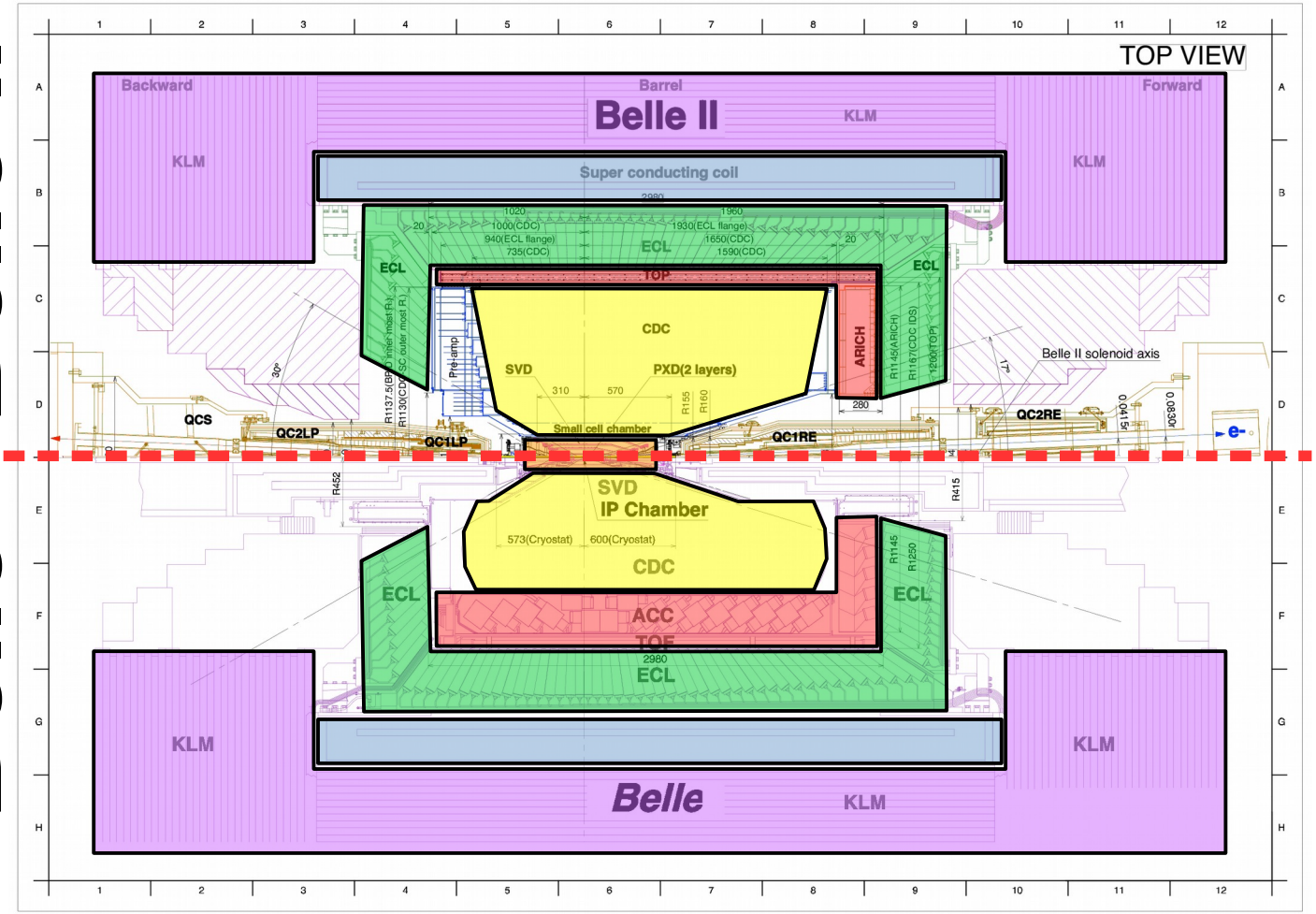
x20
x2
x40

Challenges on the Detector Upgrade

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

Belle II Detector Upgrade

Belle II



Belle

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

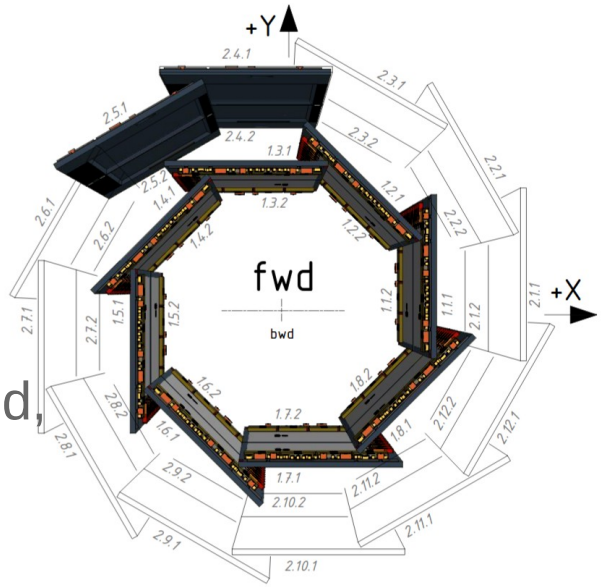
Belle II Detector Upgrade

K_L/Muon System	New readout electronics Many RPC layers replaced with scintillator strips + SiPMs
Magnet Coil	No change
EM Calorimeter	New readout electronics (Crystals, sensors not changed)
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

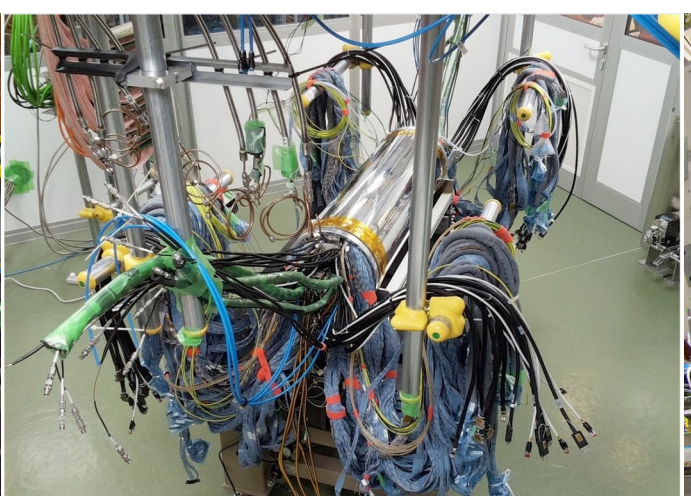
Key Technologies in Detector Upgrade

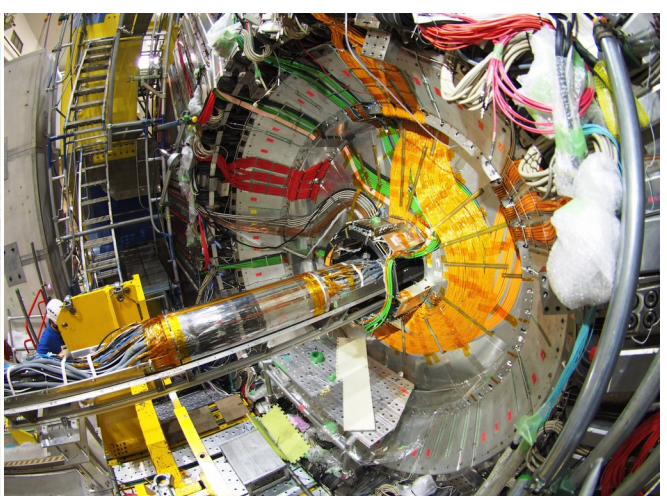
- State-of-the-art silicon detectors
- Pixelated single photon sensors
  - MCP-PMTs in TOP (barrel PID) – time resolution
  - HAPDs in ARICH (end cap PID) – large area
  - SiPMs in KLM – low cost
- Waveform sampling readouts
  - TOP: 8192 channels, 2.7GSa/s: IRSX (Hawaii)
  - Sci-KLM: 16800 channels, 1GSa/s: TARGETX (Hawaii)
  - SVD: 224k channels, 32MSa/s: APV25 (adapted from CMS)
  - CDC: 14336 channels, 30Msa/s
  - ECL: 8736 channels, 2MSa/s

Belle II Vertex Detector

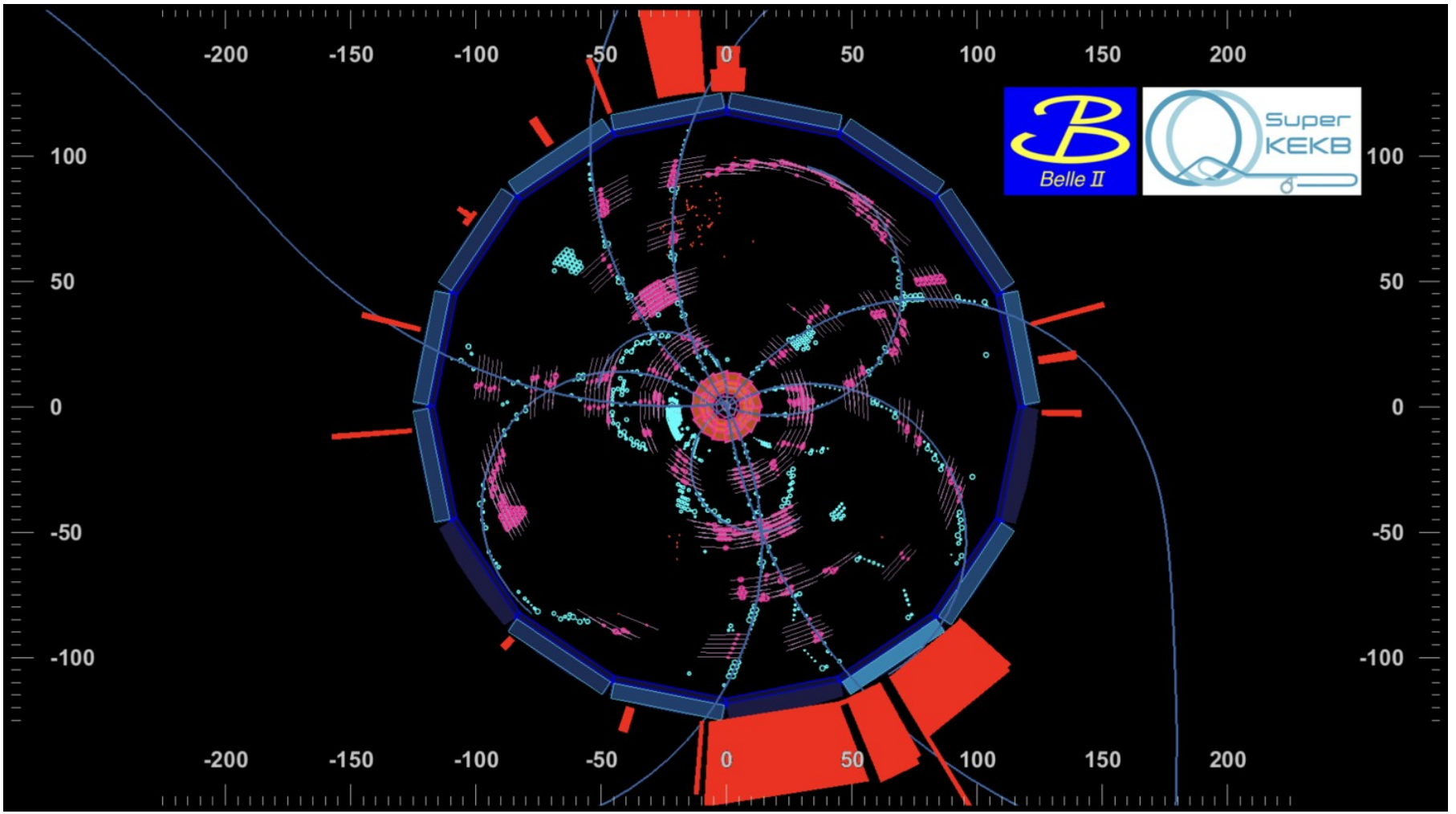


- Two layers of DEPFET pixel sensors
  - r=14mm, r=22mm
  - Only inner layer and small part of outer layer installed, replacement with full system in 2021
- Four layers of double sided strip detectors
  - r=39mm to r=140mm
- Assembled and installed by November 2018 →





First Collision in Physics Run- 03/25/2019

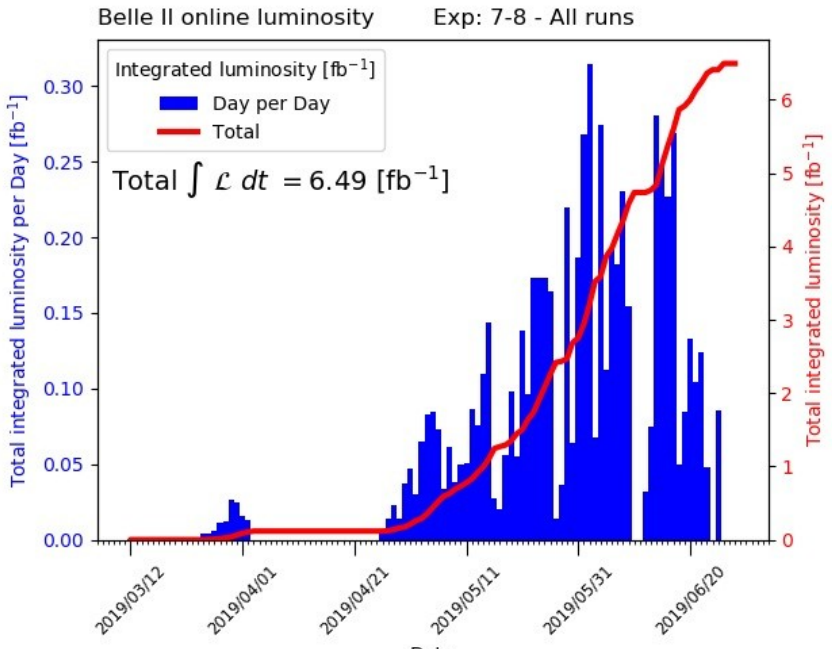


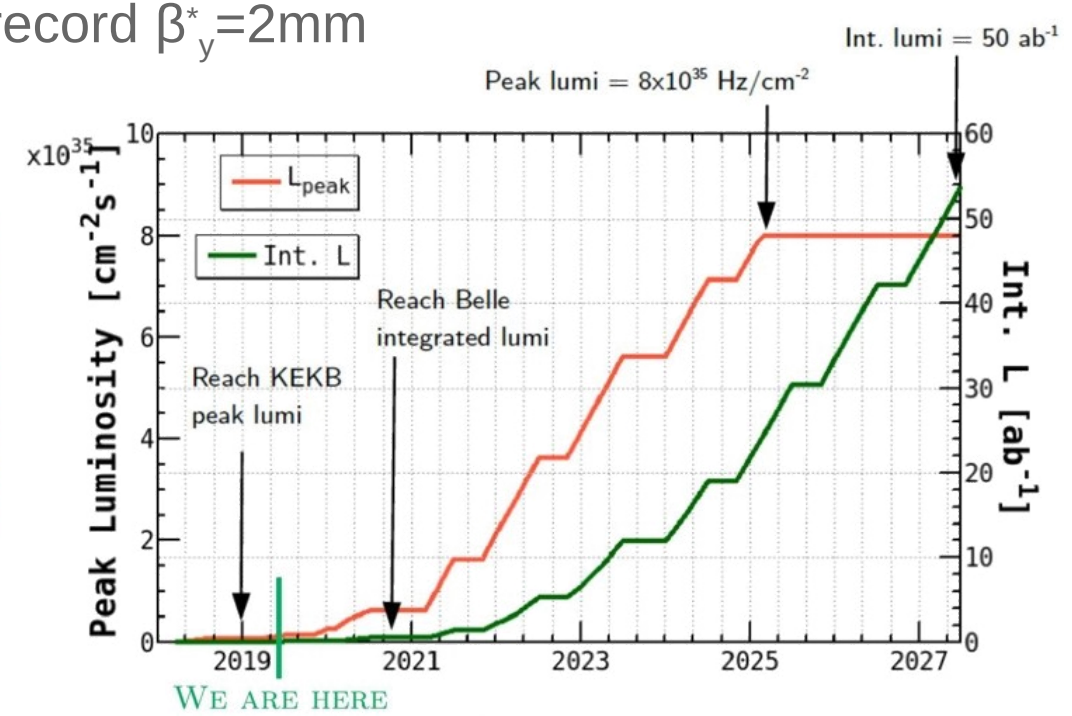
Probably $e^+e \rightarrow \Upsilon(4s) \rightarrow B\overline{B}$

… and the Reaction

Luminosity in 2019

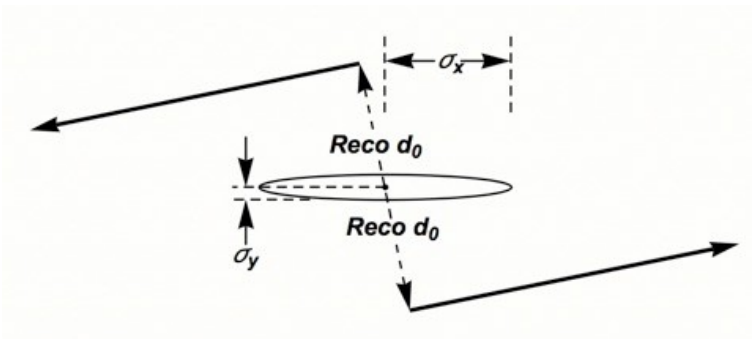
- 6.5fb^{-1} integrated from March 25th to July 1st 2019 (410pb^{-1} for EPS-HEP)
  - L_{peak}: 6.1x10^{33} cm^{-2} s^{-1} (12x10^{33} with Belle II off)
  - Limited by backgrounds, beam-beam blowup
- New machine, entirely new concept, requires tuning
  - Already running at world record β^*_y=2mm



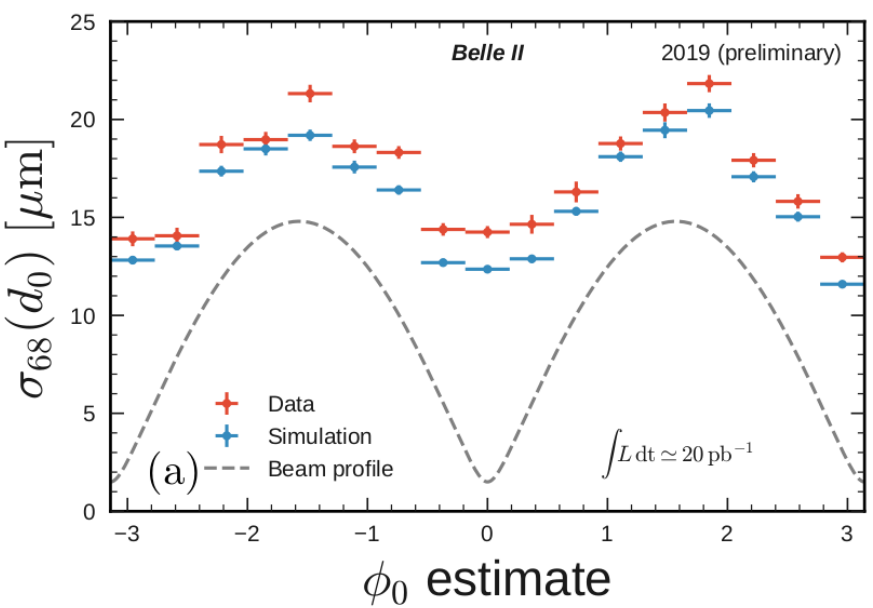


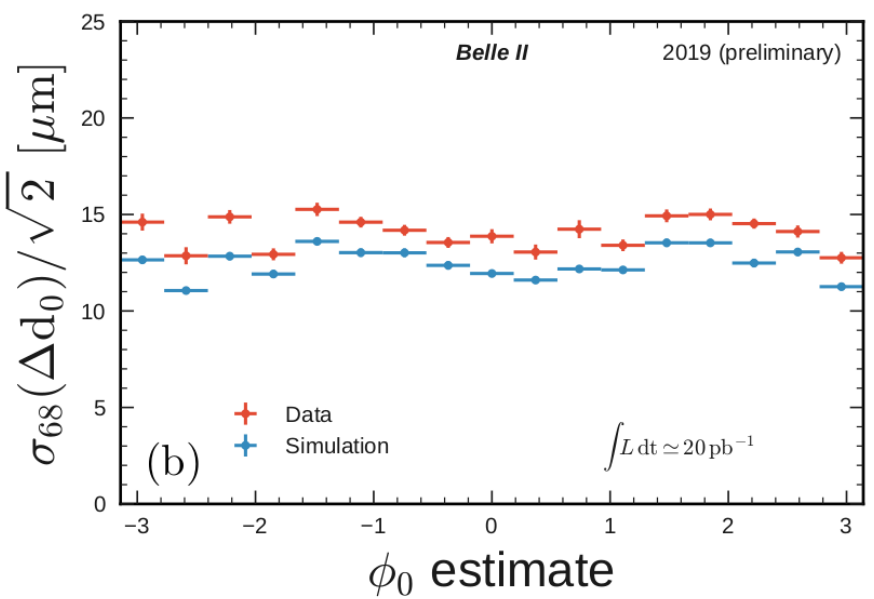
Impact Parameter Resolution

- Small luminous region used as a reference for vertexing resolution studies



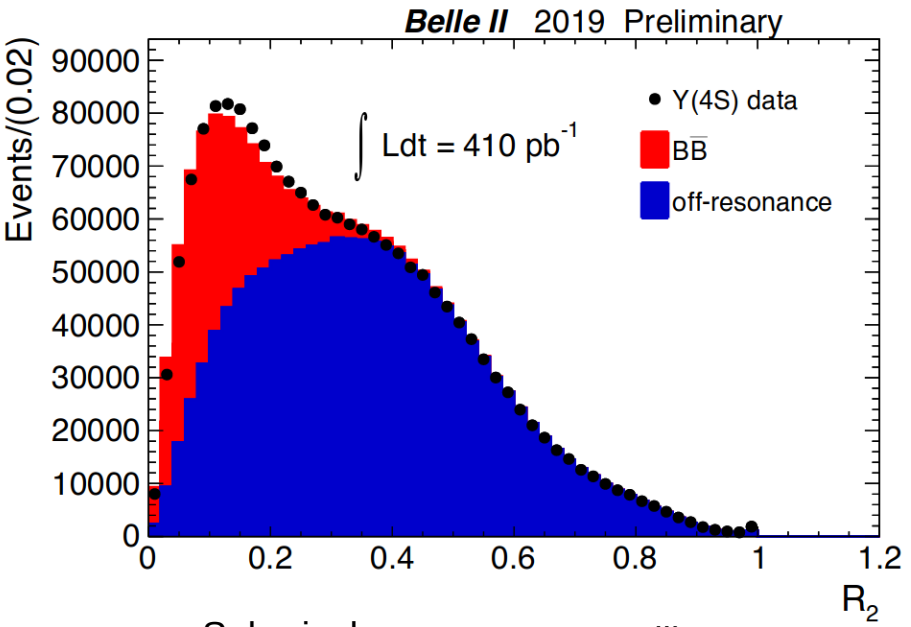
	Data
$\hat{\sigma}(d_0)$ [μm]	$14.2 \pm 0.1\,(\text{stat}) \pm 0.1\,(\text{syst})$
$\hat{\sigma}(z_0)$ [μm]	$16.1 \pm 0.1\,(\text{stat}) \pm 0.1\,(\text{syst})$

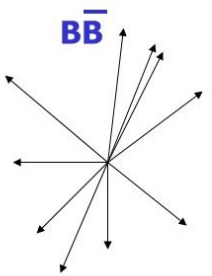


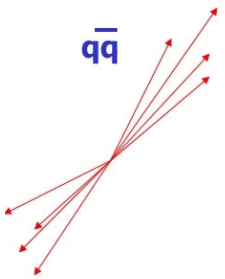


$B\bar{B}$ Pairs in First Data

- Decompose measured R2 distribution into $B\bar{B}$ and continuum components
- Using off-resonance data to model continuum distribution
  - some discrepancies in continuum MC likely due to incomplete machine background modeling
- Many $B\bar{B}$ pairs in first data set
  - We are stably operating on on the Y(4s) resonance



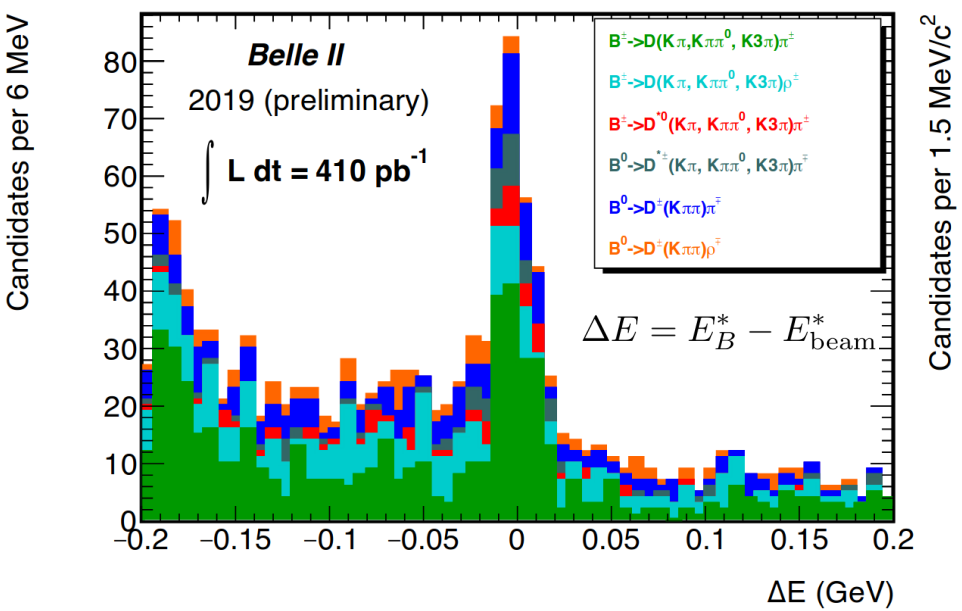


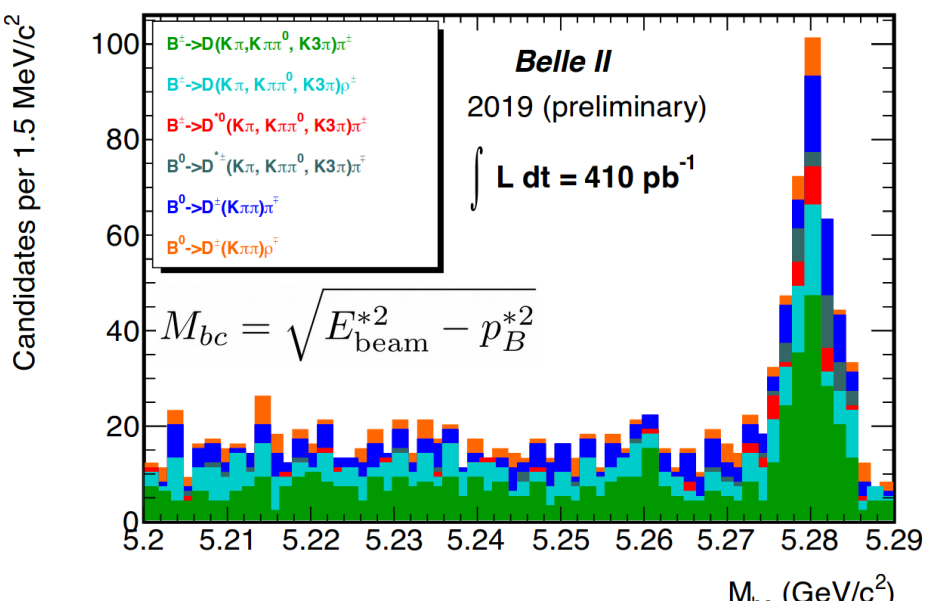


Reconstructed B decays

- B → D(*)h exclusive (h=π,ρ)
  - Various D decays
- ~300 selected event candidates in first 410pb^{-1}

Mode	Exp7
$B \to D\pi$	140 ± 13
$B \to D\rho$	58 ± 11
$B \to D^{*0}\pi$	24 ± 5
$B^0 \to D^{*\pm}\pi$	32 ± 6
$B^0 \to D^-\pi^+$	31 ± 7
$B^0 \to D^-\rho^+$	14 ± 7





Summary

- The Belle II detector is assembled and ready for operation
  - Extensive detector upgrade with cutting edge silicon detectors and readout electronics upgrades
- We started our first physics running period in March 2019
  - The SuperKEKB nano beam scheme works and is already running at world record β^*_y=2mm
  - Delivered and recorded luminosities are ramping up, but still below Belle levels
- Clear signs of first physics out of the detector

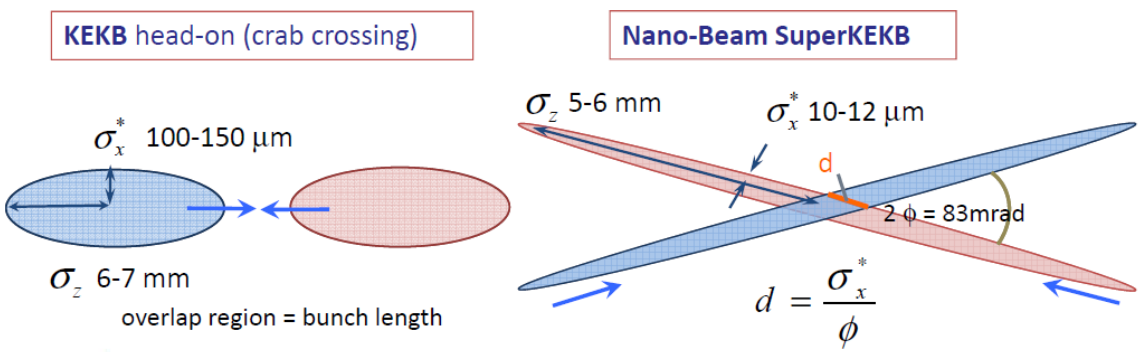
Other Belle II Talks at EPS-HEP

- First Physics:
  - I. Ripp-Baudot: "*First look at CKM parameters from early Belle II data*"
    Flavour Physics and CP Violation: Thursday 09:00
  - K. Lautenbach: *"Exotic and Conventional Quarkonium Physics Prospects at Belle II"*
    QCD and Hadronic Physics: Thursday 14:45
  - S. Cunliffe: *"Dark Sector Physics with Belle II"*
    Dark Matter: Thursday 15:10
  - W. Sutcliffe: *"Missing energy and electroweak penguin modes in early Belle II data"*
    Flavour Physics and CP Violation: Friday 09:45
  - F. Forti: *"BELLE II and flavor physics in e+e-"*
    Plenary: Tuesday 10:00
- Detectors:
  - H. Ye: *"Commissioning of the Belle II Pixel Vertex Detector"*
    Detector R&D and Data Handling: Thursday 10:15
  - OH: *"First Experiences with the Novel Time of Propagation (TOP) Barrel PID Detector in the Belle II Experiment"*
    Detector R&D and Data Handling: Thursday 11:30
  - S. Longo: *"A Novel Approach to Calorimeter-based Particle Identification at the Belle II Experiment using Scintillator Pulse Shape Discrimination"*
    Detector R&D and Data Handling: Friday 09:30
  - A. Paladino: *"Performance of the Belle II Silicon Vertex Detector"*
    Poster: Monday 18:30
  - L. Santelj: *"The Aerogel RICH detector of the Belle II experiment "*
    Poster: Monday 18:30

SuperKEKB Beam Spot

- Measurement for all three dimensions
- Nanobeam scheme works as intended

	Data
$\hat{\sigma}_x$ [μm]	$14.6 \pm 0.4\,(\text{stat}) \pm 0.2\,(\text{syst})$
$\hat{\sigma}_z$ [μm]	$346.9 \pm 1.8\,(\text{stat}) \pm 0.1\,(\text{syst})$



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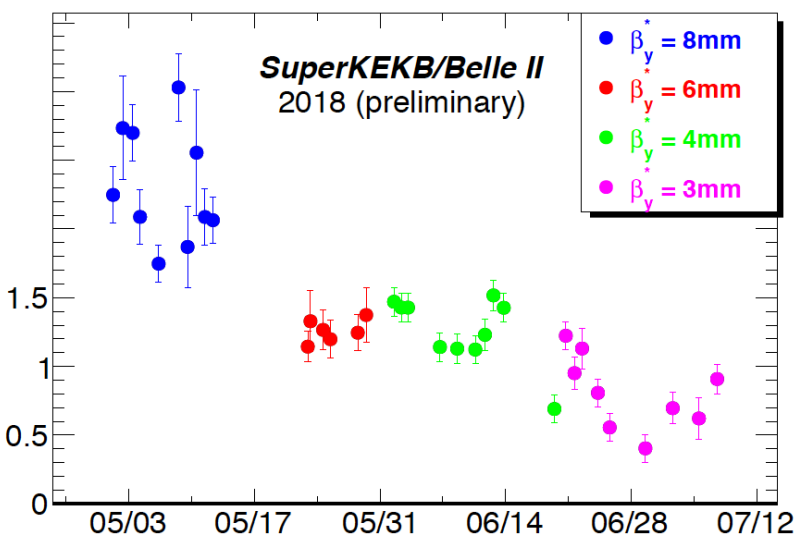
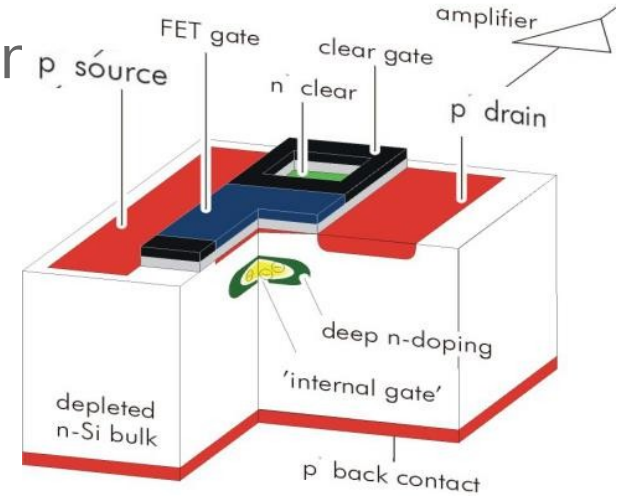
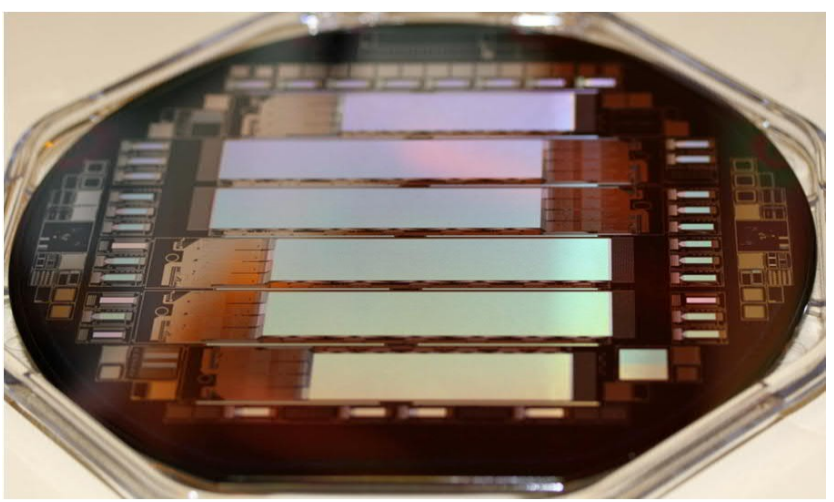


PXD: Inner Vertexing with DEPFET Pixels

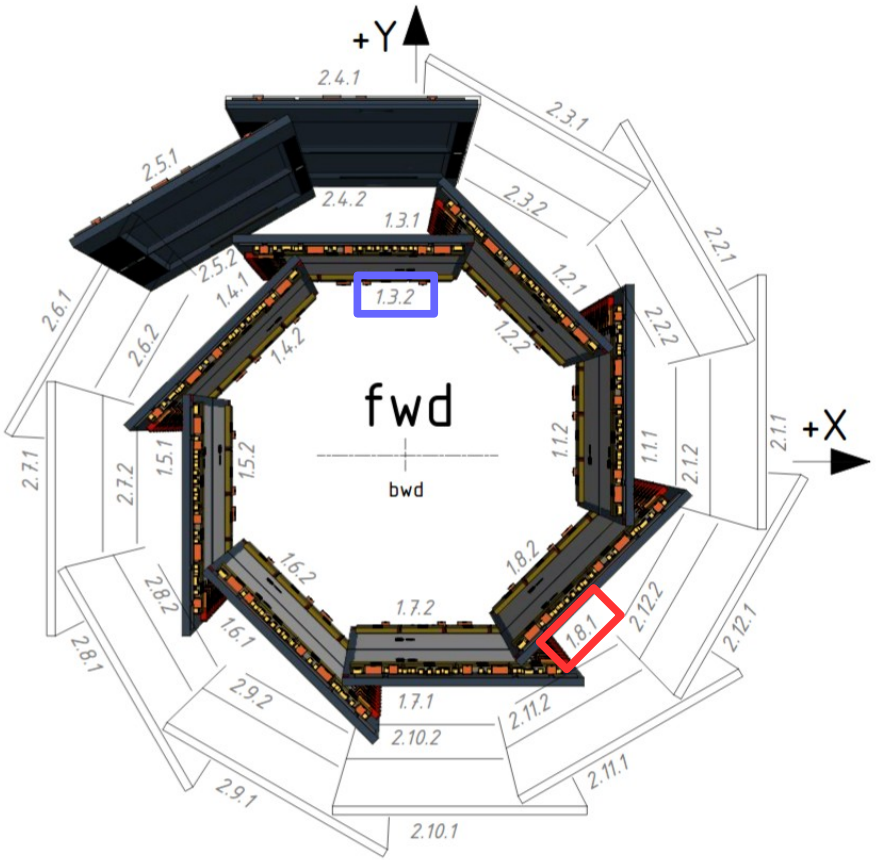
- DEPFET: internal charge to current amplificatior
  - Very good S/N for thin sensors
  - Relatively low power
    (no cooling in active area)
  - Rolling shutter readout
    (20us frame time)
- Sensors thinned to 75um
  - <0.25% X_0 per layer
- Two layers (r=14mm, 22mm)
  - Down to 50*55um pixels
  - 40 sensors total, 7.7Mpixel





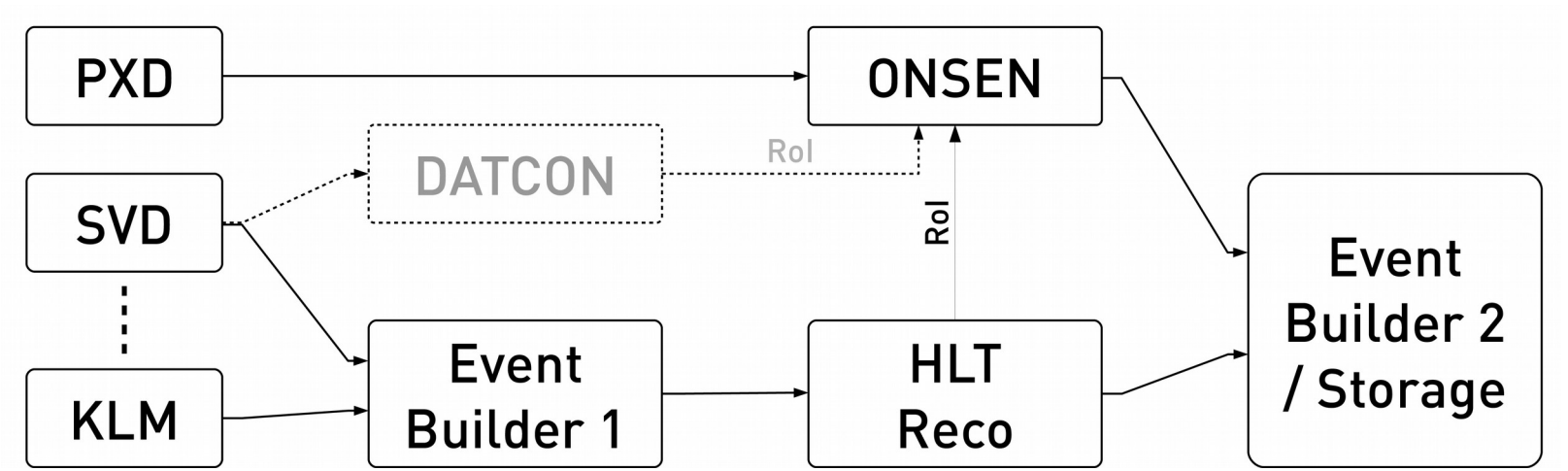
PXD: Current Installation

- After technical troubles in module production and assembly: only inner layer installed
  - +2 ladders on outer layer
  - 10/20 sensors (3.8Mpixel)
- Restarted production of all sensor types to provide modules for a complete replacement of the currently installed PXD by 2021



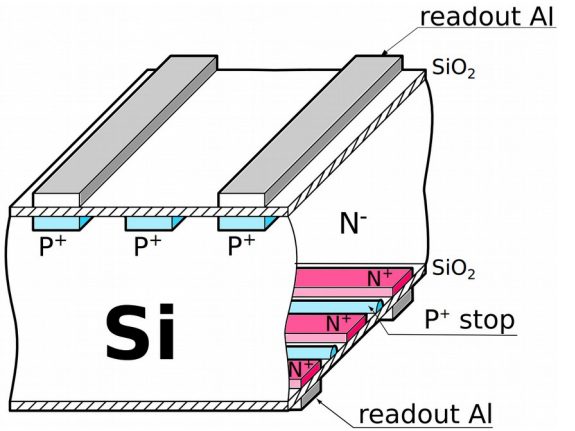
PXD: Readout

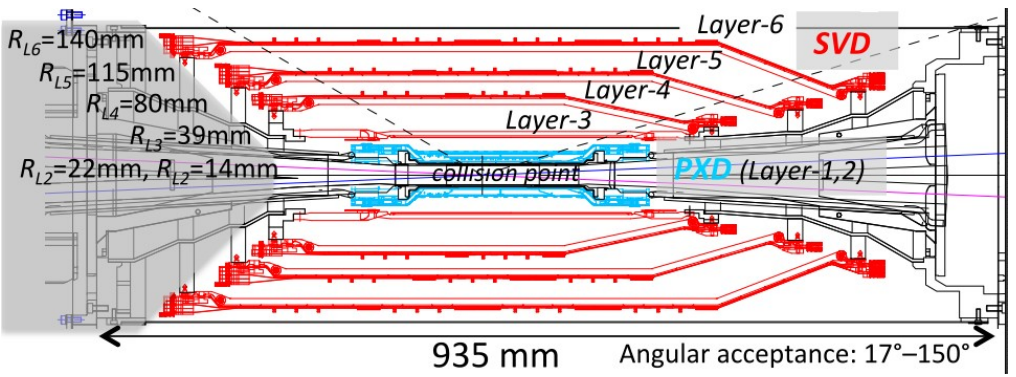
- PXD is virtually noise free, but rather long integration time (20us, two full accelerator revolutions)
- ONSEN system reads out full PXD on each trigger and keeps data in local buffer
  - HLT reconstruction identifies regions of interest on PXD surface, ONSEN only transfers relevant parts of PXD hitmaps to EB2/storage
  - DATCON: FPGA based tracking to generate RoIs directly from SVD raw data
- Still PXD accounts for ~75% of total Belle II raw data size



SVD: Silicon Vertex Detector

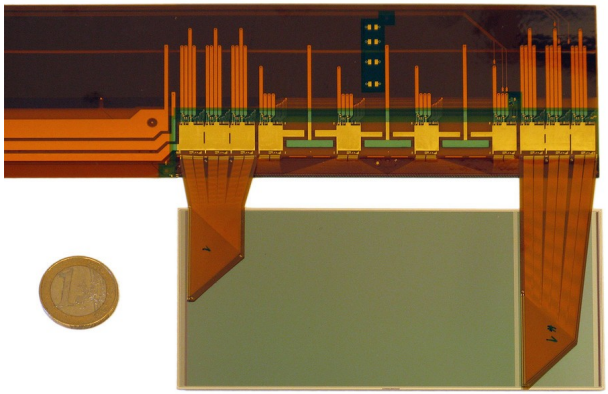
- Four layers of double-sided strip detectors
  - r=39mm to r=140mm
  - Lampshade geometry
- 224k strips
  - 50-75um pitch tangential
  - 160-240um pitch axial
- Read out by APV25 ASICs
  - Adapted from CMS
  - 50ns shaping,40MHz sampling
  - Partially thinned to 100um

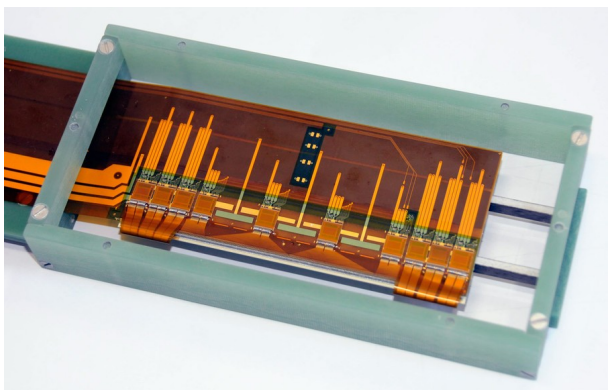


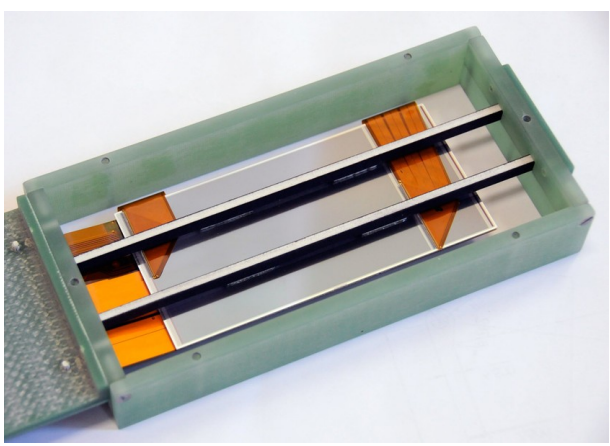


SVD: Production

- Readout chips of central sensors bonded to “Origami” Kapton flex
  - Folded around sensors
- Ladders assembled all around the world:
  - Layer 3: Uni Melbourne, Australia
  - Layer 4: TIFR, India
  - Layer 5: HEPHY, Austria
  - Layer 6: Kavli-IPMU, Japan
- Final assembly into half shells and full vertexing system at KEK







Hawaii Waveform Sampling ASICs

- Hawaii Instrumentation Development Lab spinoff: Nalu Scientific
  - Founded by Isar Mostafanezhad (ex-postdoc of IDLab)
- Commercialisation of switched capacitor waveform sampling ASICs based on IDLab designs
- Three ASICs available:
  - SiRead: 32 channels, ~1 GSa/s
  - ASoC: 8 Channels, ~3 GSa/s
  - Aardvarc: 4 Channels, ~14 Gsa/s

Nalu Scientific

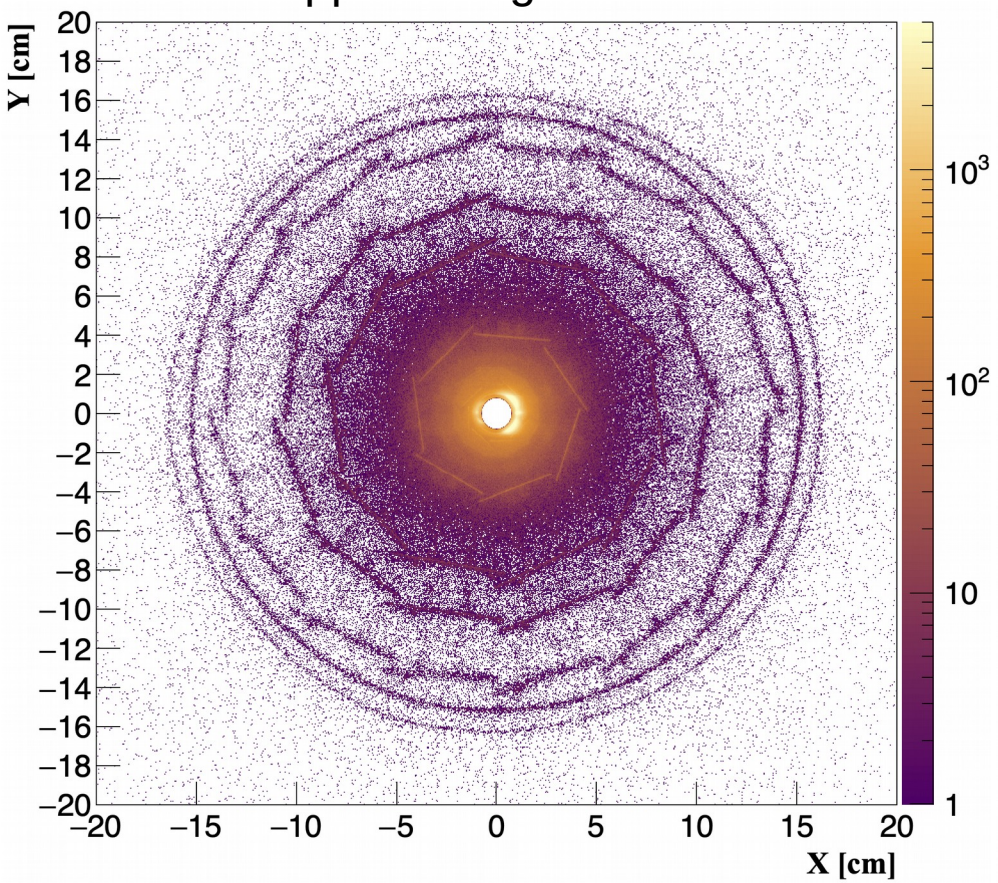
Data Acquisition Systems

isar@naluscientific.com

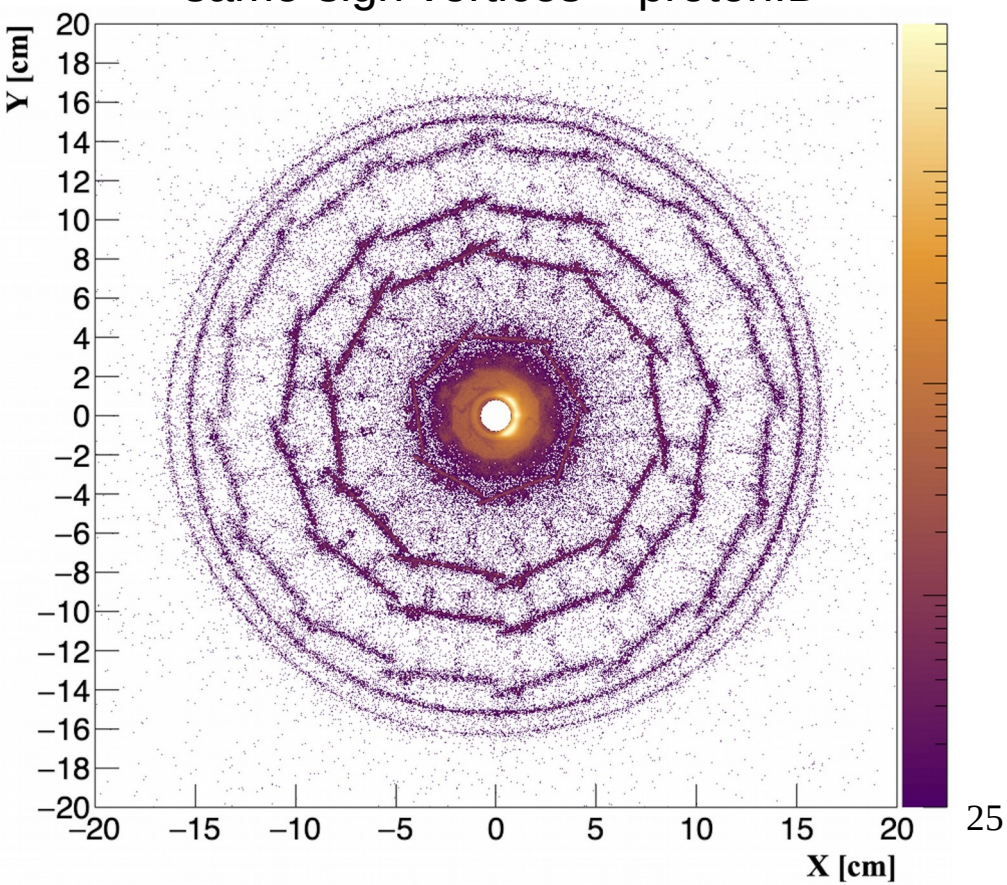
Understanding Belle II

X-Y view

opposite-sign vertices



same-sign vertices + protonID



Understanding Belle II

X-Z view