Belle II readiness for Phase II

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on behalf of the Belle II collaboration

Lake Louise Winter Institute
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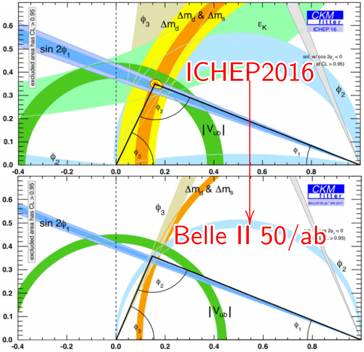
Belle II physics program

- B physics at the intensity frontier
  - precision measurements of CKM elements:
    is $\phi_1 + \phi_2 + \phi_3 = 180^\circ$?
    currently PDG gives $(175 \pm 9)^\circ$.
    expecting at Belle II with 50/ab
    $\delta\phi_1 \sim 0.3^\circ$, $\delta\phi_2 \sim 1^\circ$, $\delta\phi_3 \sim 1.5^\circ$.
  - rare B decays
  - other B decay physics
  - ...
- Charm physics (Mixing, CPV in charm, rare charm decays, ...)
- τ physics (LFV, CPV, ...)
- others
  - bottomonium spectrum
  - exotics state (tetraquark, ...)
  - dark photon searches
  - other new physics searching (Higgs BSM, ALP, leptoquark, ...)

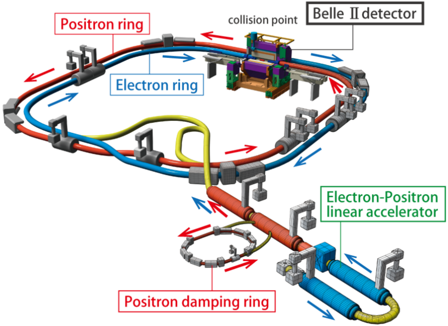
Hermetic detector ⇒ advantage for missing energy studies.
B meson can be identified by the full decay chain reconstruction.

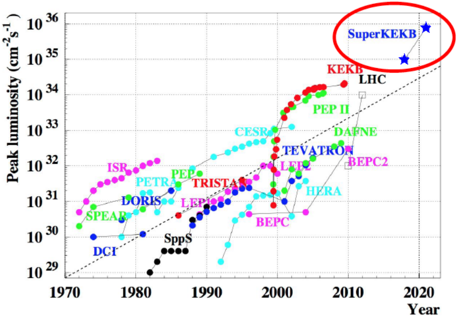


Phase II physics plans

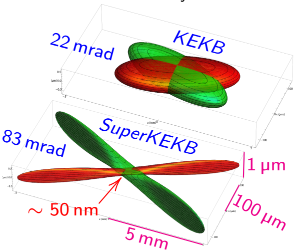
- Bottomonium spectroscopy
- Dark photon searches

Liminosity of KEKB and SuperKEKB



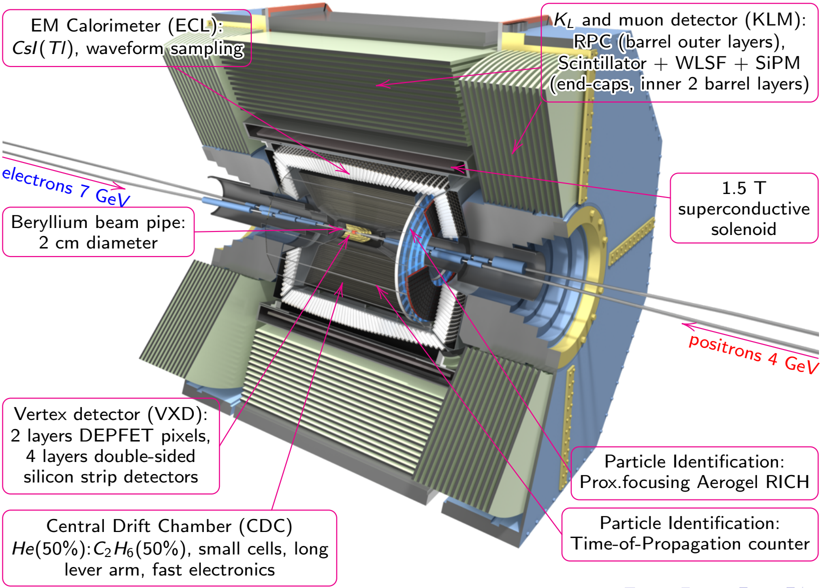


Nano-beam scheme by P.Raimondi:

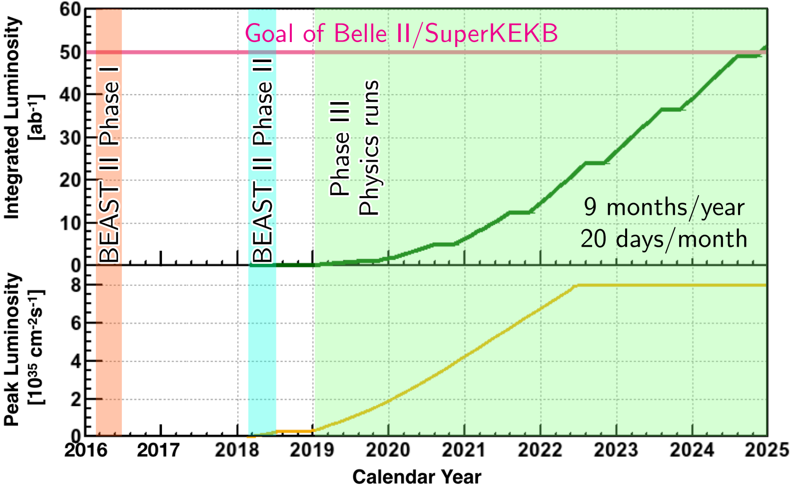


	KEKB achieved	SuperKEKB nano-beam	
	LER/HER	LER/HER	
E_{beam} (GeV)	3.5/7.5	4.0/7.0	$\beta\gamma \sim 2/3$
I_{beam} (A)	1.6/1.2	3.6/2.6	$\times 2$
β_γ (mm)	5.9/5.9	0.27/0.30	$\times 20$
$\mathcal{L}$ (Hz/cm^2)	2.1×10^{34}	8×10^{35}	**$\times 40$**

Belle II detector (TDR arXiv:1011.0352)



SuperKEKB luminosity projection

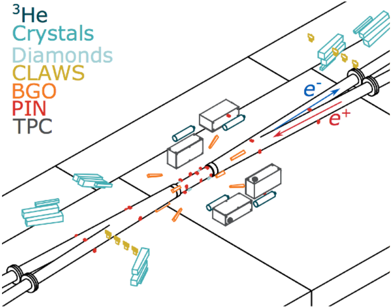


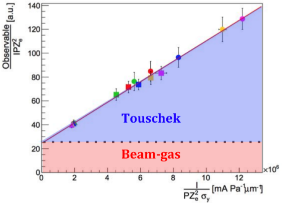
Phase II expected physics data – 0 . . . 20 fb^{-1}

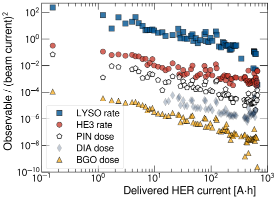
Phase 1 February-June 2016

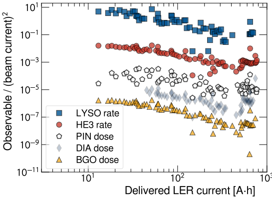
- SuperKEKB accelerator commissioning.
- Circulate both beams, no collisions, no Belle II.
- Vacuum scrubbing:

  LER current of 1 A, dose of 780 A·h, 10^{-6} Pa;
  HER current of 0.87 A, dose of 660 A·h, 10^{-7} Pa;
  - Stable high current beams were achieved!
- Special set of detectors (BEAST II) to measure beam backgrounds important in Physics Phase (Touschek intra-beam scattering, beam-gas Coulomb, beam-gas bremsstrahlung, injection background, beam dust)
- Results submitted to NIMA: "First Measurements of Beam Backgrounds at SuperKEKB", arXiv:1802.01366.

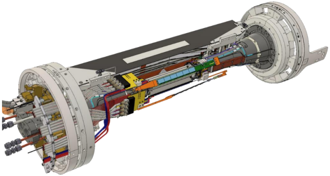


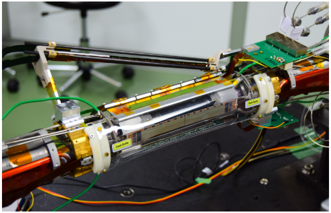






Phase 2 February-July 2018





Phase II goals

- Almost final setup: Belle II is at IP with 1.5 T magnetic field + final focusing solendoids
- **Accelerator commissioning**
- **Radiation safe enviroment for the full VXD**
- First collisions at mid-April
- Aim 10^{34} Hz/cm^2 and 20 fb^{-1}
- Further study of collision dependent beam backgrounds with radiation monitors in the VXD volume:
  - One sector of 2 PXD and 4 SVD layers where the highest backgrounds are expected.
  - FANGS, FE-I4 based hybrid pixel to investigate the Synchrotron Radiation (SR) background.
  - CLAWS, scintillators with SiPM to measure the time evolution of the injection background.
  - PLUME, double-sided high granularity MIMOSA pixels
- Outer detectors commissioning and performance study
- Possible first physics results in the bottomonium spectroscopy and the dark sector

Challenges for vertex reconstruction

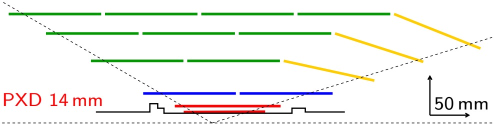
Higher backgrounds (luminosity increase, nano-beam) ⇒ higher occupancy
Boost reduced from $\beta\gamma = 0.42$ to 0.28 ⇒ B-meson flight length of 125 μm

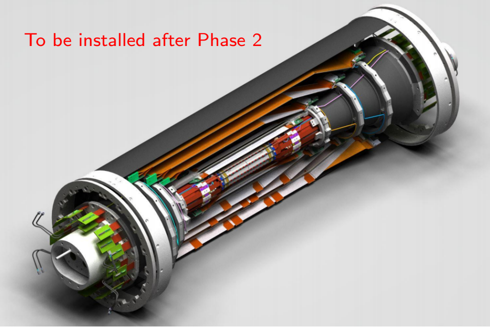
Pixel Detector (PXD)

- 40 DEPFET modules into 2 layers;
- Pixel size: $50 \times [55, 60, 70, 85]$ μm^2;
- Occupancy: 0.4 hits/μm^2/s (3% max);
- Integration time: 20 μs (rolling shutter);
- Thickness: 75 μm, 0.21% X_0/layer;

Silicon Vertex Detector (SVD)

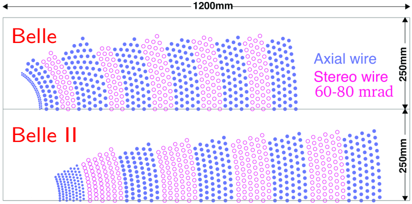
- 172 double-sided silicon strip detectors (DSSDs) in 4 layers;
- Slant shapes in FWD region for the material budget reduction;
- Thickness: 0.7% X_0/layer;





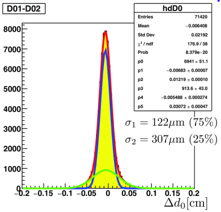
Central Drift Chamber (CDC)

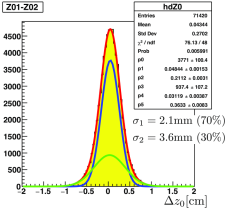
- 14336 sense wires in 56 stereo-layers in $He(50\%)$:$C_2H_6(50\%)$ gas mixture.
- Larger compared to Belle.
- Smaller drift with sense wires and more layers allow better charged track reconstruction and dE/dx measurement compared to Belle.
- Faster readout electronics.
- CDC was installed on Oct 2016.
- Cosmic runs to test readout electronics and to validate performance.



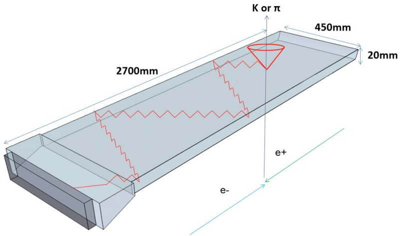
Belle2 CDC   Belle CDC

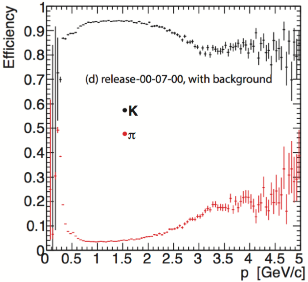
Muon close to IP produces two tracks

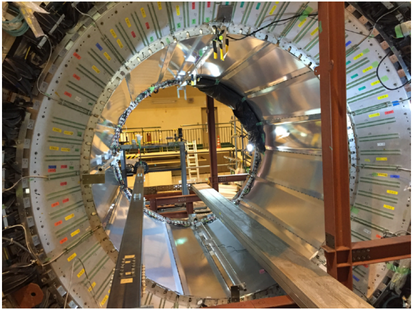




PID: TOP (Time of Propagation)

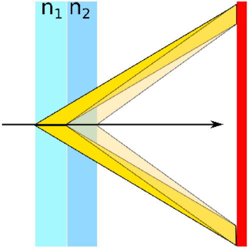


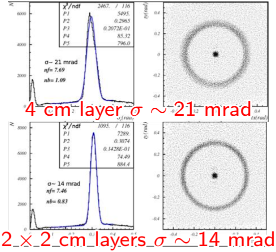


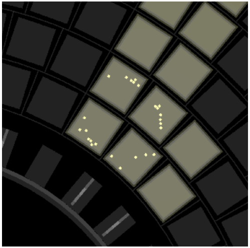


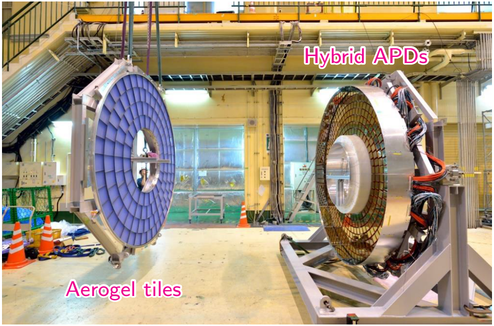
- K/π velocity difference $\Rightarrow$ different Cherenkov angle θ_c. θ_c is reconstructed from hit position (x, y) in the photo detector plane and time of propagation.
- 16 quartz bars: $2 \times 125\,\mathrm{cm} \times 45\,\mathrm{cm} \times 2\,\mathrm{cm}$
- 32 (segmented anode 4×4) Micro-channel plate PMTs Hamamatsu SL-10 MCP PMT
- May 2016 – TOP is integrated into the Belle II detector.

PID: ARICH (Aerogel Ring Imaging Cherenkov detector)



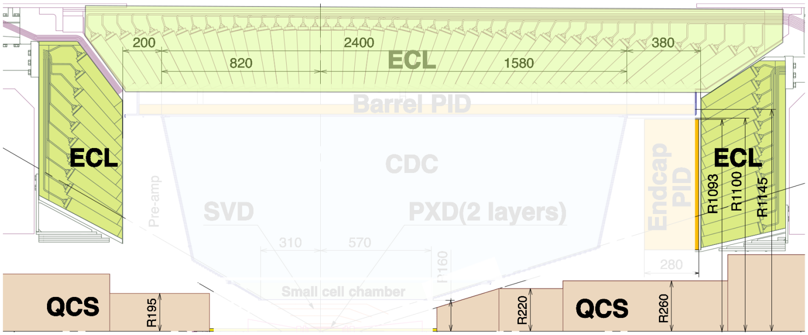






- Non-homogeneous radiator of two 2 cm aerogel tiles ($n_1 = 1.046$ and $n_2 = 1.056$) to reduce the emission point uncertainty.
- 4 cm aerogel is enough to register ~ 10 photons.
- 420 Hybrid Avalanche Photo Detectors, 144 channels each, 5 mm pixelated.
- Oct. 2017 – ARICH is fully integrated into the Belle II detector.

Electromagnetic calorimeter (ECL)



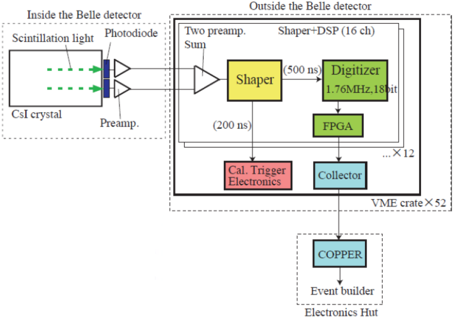
ECL re-uses Belle's *CsI(Tl)* crystals and mechanical structure

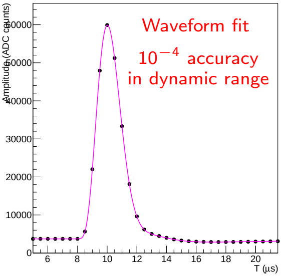
- $6 \times 6 \times 30$ cm^3 (16.1 X_0) in length
- 1152 in forward endcap
- 6624 in barrel
- 960 in backward endcap

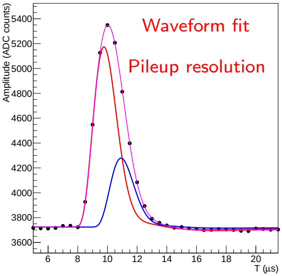
R&D to replace in future endcap crystals with pure *CsI* with faster light emission but smaller yield.

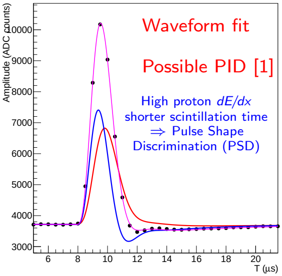
Electromagnetic calorimeter (ECL)

- New readout electronics with waveform sampling (18 bit @ 1.76 MHz) to cope higher rate (physics + background).
- Store ADC samples in a FPGA internal buffer. Perform waveform fit depend on trigger signal.
- Extract amplitude and timing information.
- ECL readout electronics was installed and DAQ integration tests are going on. Record waveforms above 50 MeV threshold in Phase II for the offline waveform fit.



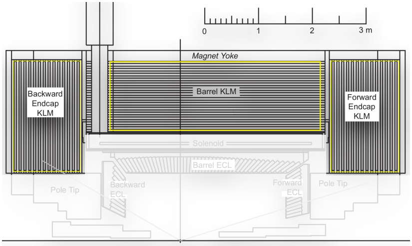


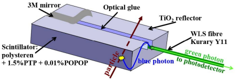


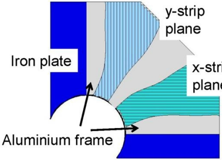


[1] arXiv:1801.07774

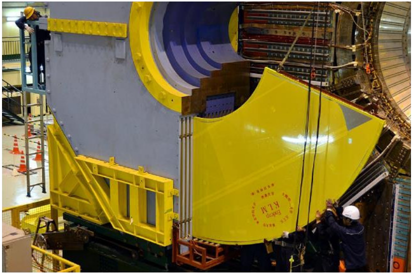
K_L and muon system (KLM)







- Sensitive layers are interleaved with the iron plates (47 mm thick) of the flux return yoke.
- 14 endcap sensitive layers (scintillator strips + WLS + SiPM)
- 2 innermost barrel sensitive layers (scintillator strips + WLS + SiPM) to resist higher rates. 13 barrel sensitive layers (double glass RPC + 5 cm orthogonal ϕ, z strips)
- Installed on 2014 – ongoing cosmic tests of readout electronics.



L1 trigger, DAQ and near term schedule

L1 trigger information

- Belle II Level 1 trigger (CDC + ECL + TOP + KLM)
- Beam bunch crossing rate 254 MHz (max.)
- Nominal beam background rate ~ 10 MHz
- Maximal L1 trigger rate ~ 30 kHz
- L1 maximal latency 5 μs
- L1 Z-vertex trigger
- L1 Global Reconstruction Logic
- Logic for single γ trigger for the dark photon searches

DAQ

- Event size: ~35 kB with SVD + CDC + ECL (PXD ~5-20 kB in addition)
- Tested readout from detector to storage : ~200 MB/sec/unit × 5 units = 1 GB/sec in total (3 GB/sec max.)
- SVD + CDC + ECL + ARICH(partial) + TRG is confirmed to work at the rate of 30 kHz.
- PXD, TOP and KLM: work in progress (bottlenecks are identified, new firmware in preparation).
- The high-rate operation for Phase II is confirmed!

Short term plan

February	March	April
Global Cosmic with Belle Solenoid ON	Beam circulation HER ⇒ LER	Tuning ⇒ beam collision

Conclusion

- Belle II is going to cover a wide range of physics goals.
- SuperKEKB and Belle II are preparing for the first collisions in April 2018.
- First 20 fb^{-1} will allow to study detector performance, calibrate detector subsystems and reliably estimate future background conditions.
- First physics results are expected in the bottomonium spectorscopy and the dark photon search.
- The most critical backgrounds for Belle II are luminosity dependent, to be measured in Phase 2.
- Physics data taking with the fully equiped detector is planed in the begining of 2019 as well as further maching tuning to reach designed limunosity.

Backup slides

First cosmic events in Phase II SVD