The Belle II Experiment

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DFG cluster of excellence
"Origin and Structure of the Universe"

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Outline

- Motivation
- SuperKEKB
- Detector
- Software
- Milestones

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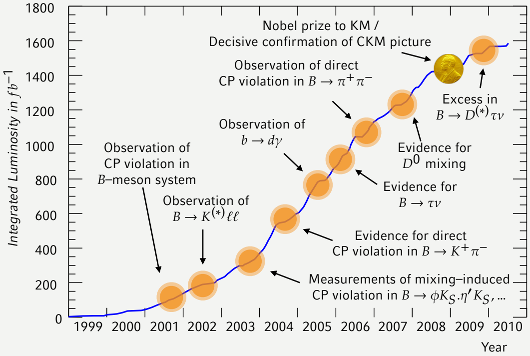

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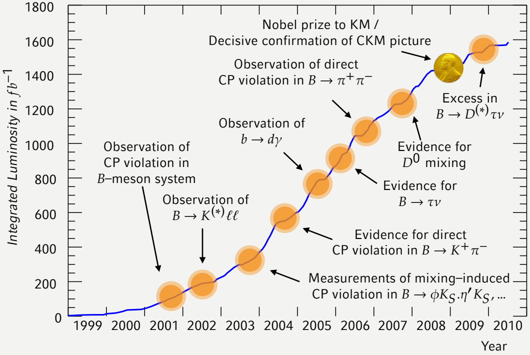

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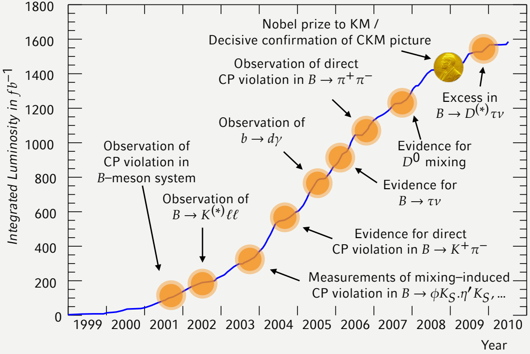

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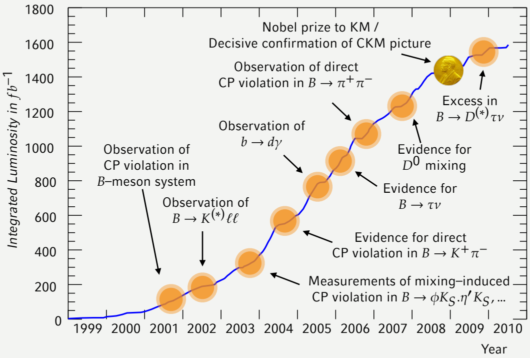

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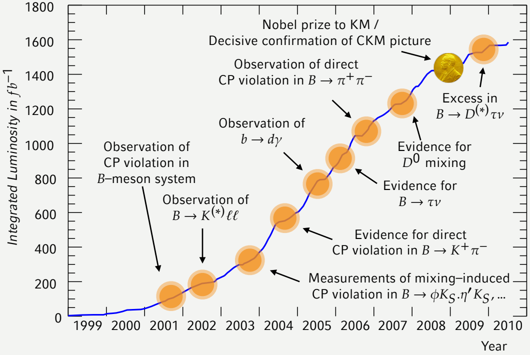

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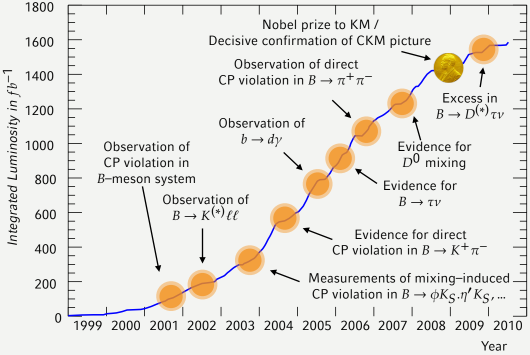

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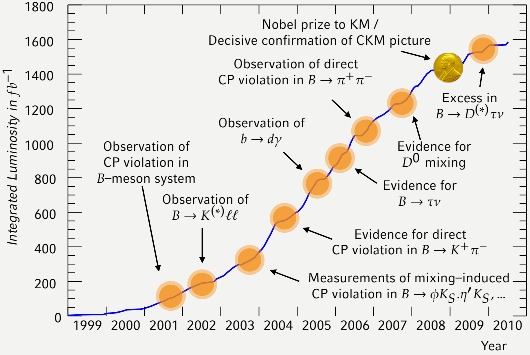

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  - Full event reconstruction/tagging.
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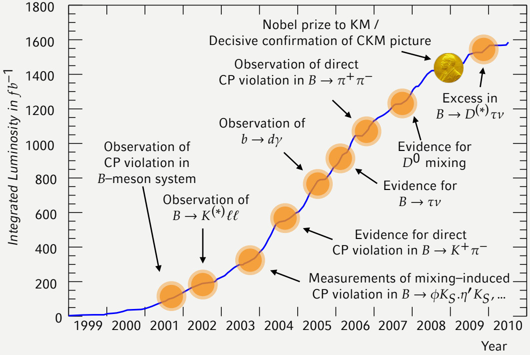
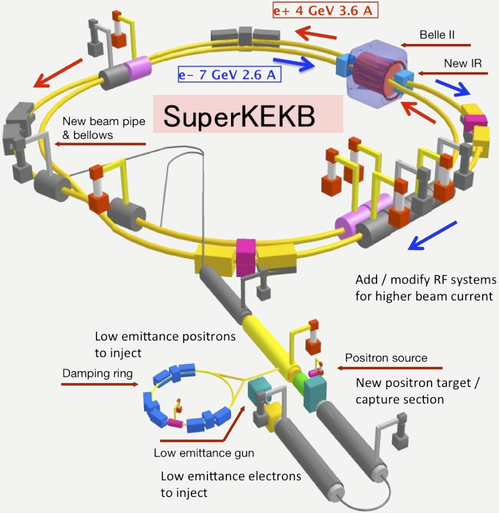
  - Sensitive to mass ranges above direct production.
- Current standing:
  - 649 Members, 99 institutes, 22 countries (Aug 2016)
  - First data: 2018

Makoto Kobayashi Toshihide Maskawa



SuperKEKB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Belle II
New IR
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New beam pipe & bellows
Add / modify RF systems for higher beam current
Low emittance positrons to inject
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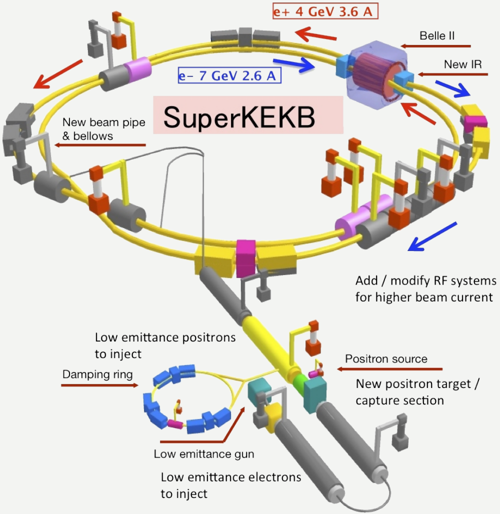
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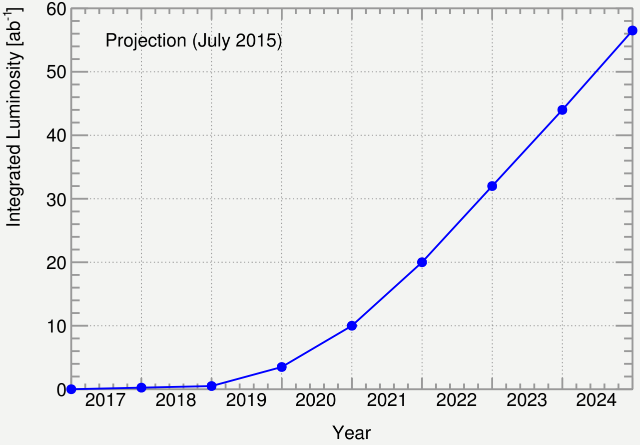
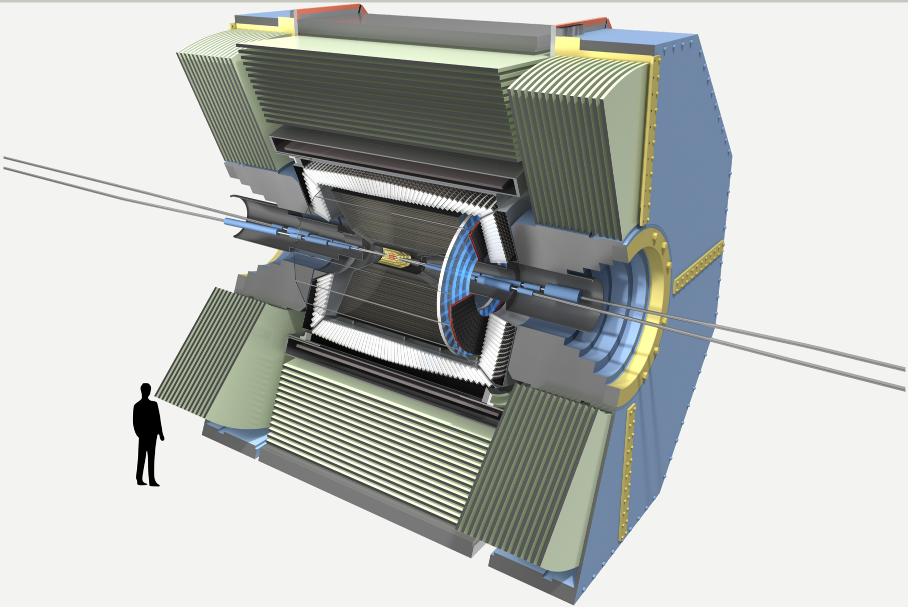


- Peak instantaneous luminosity: $8 \times 10^{35} cm^{-2} s^{-1}$ (Belle: $2.11 \times 10^{34} cm^{-2} s^{-1}$)
- Total integrated luminosity: $50 ab^{-1}$ (Belle: $1 ab^{-1}$)

Process	$\sigma[nb]$	No. events [$\times 10^9$]
$B\bar{B}$	1.1	55
$q\bar{q}$	2.52	185.45
$\tau^+\tau^-$	0.92	45.95

Belle II Detector



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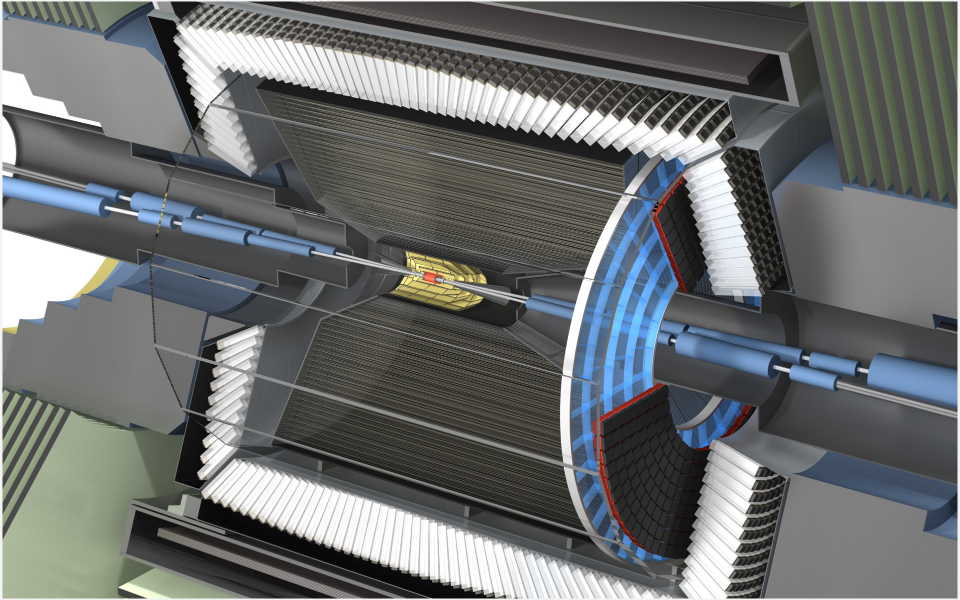

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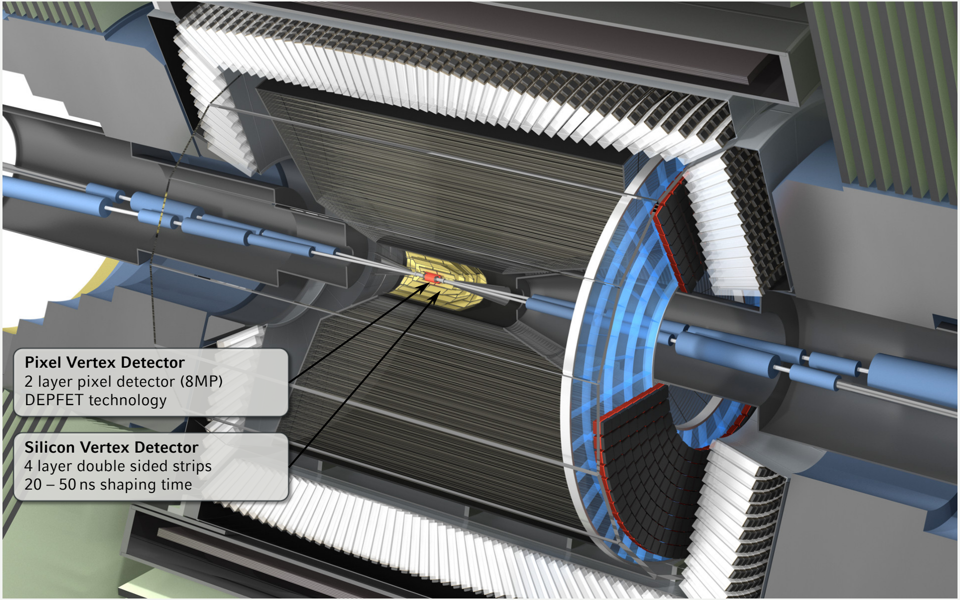
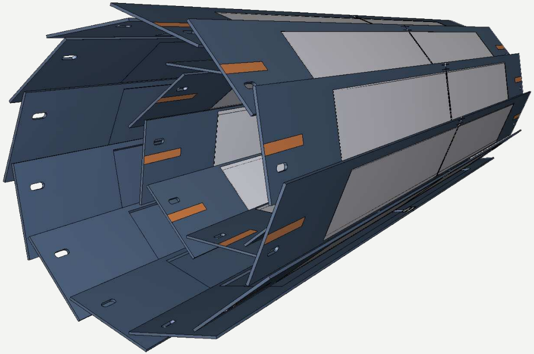


Pixel Detector

- High luminosity
  $\rightarrow$ high hit–rate.
- 14mm and 22mm from beampipe
  $\rightarrow$ high occupancy.



Pixel Detector

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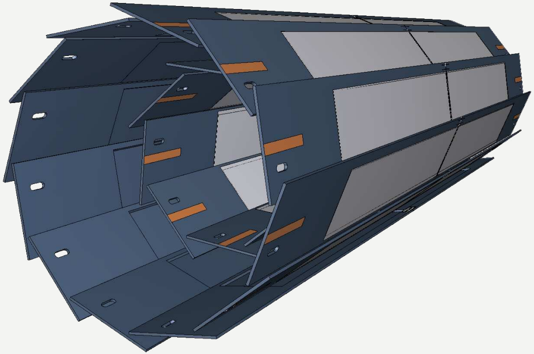
- Ladder structure:
  - Inner layer: 8 modules, 3.072M pixels.
  - Outer layer: 12 modules, 4.608M pixels.



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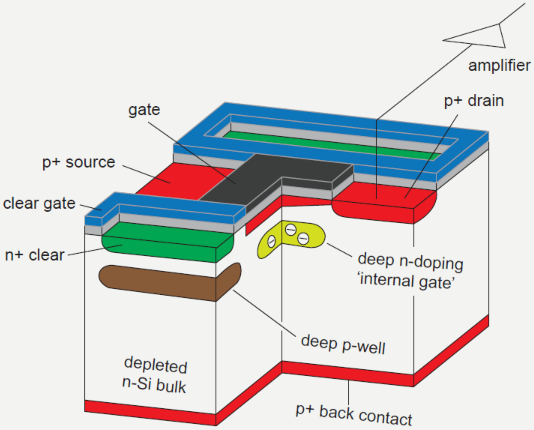
- DEPleted Field Effect Transistor (DEPFET):



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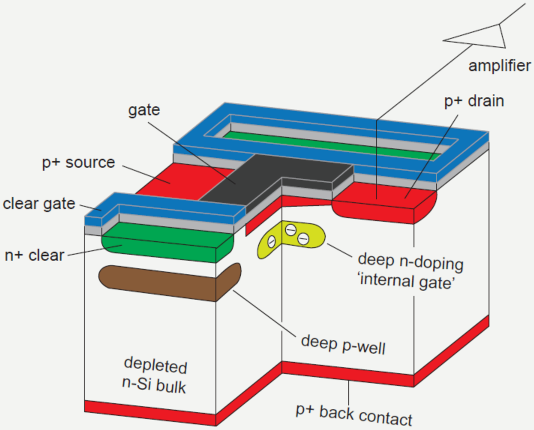
- DEPleted Field Effect Transistor (DEPFET):
  - 50μm thin.
  - Air–cooled.
  - Radiation hard.
- Still in production (lithography in progress).



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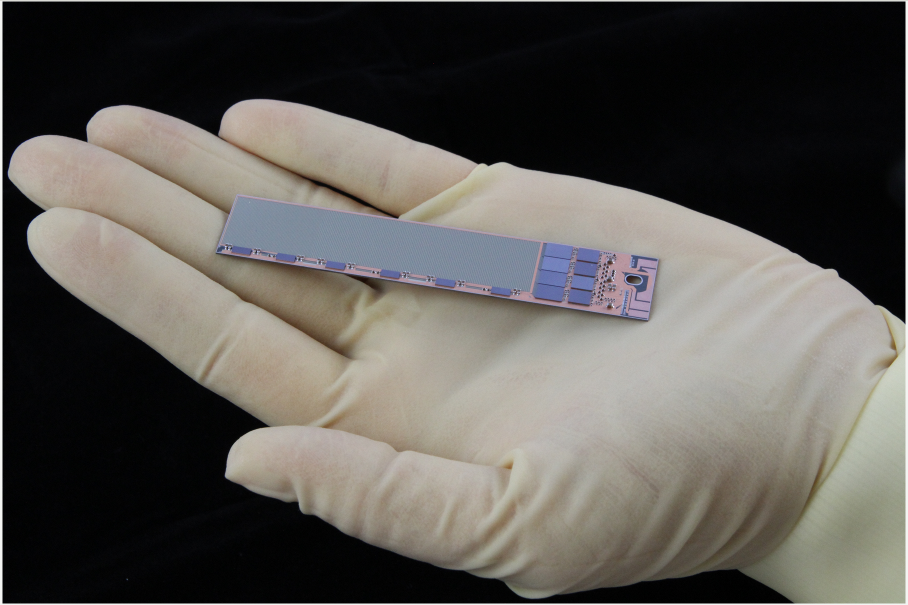
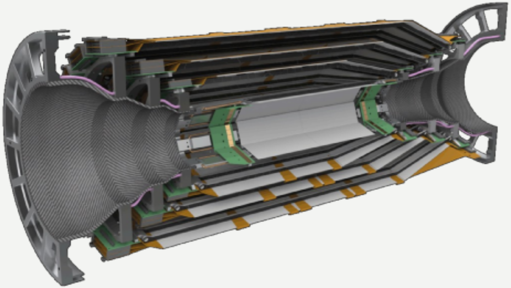
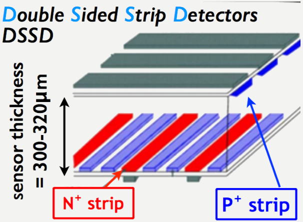


Silicon Vertex Detector

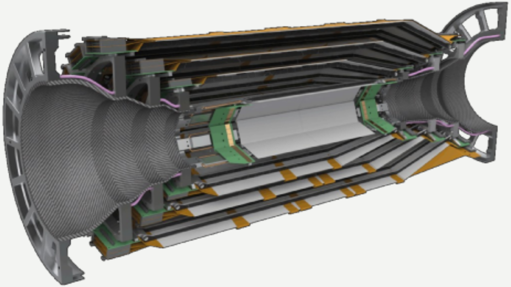
- Four ladder layers: 38, 80, 115, 140mm.

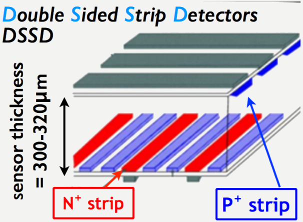




Silicon Vertex Detector

- Four ladder layers: 38, 80, 115, 140mm.
- Three sizes of DSSDs used for outer, inner, forward layers.





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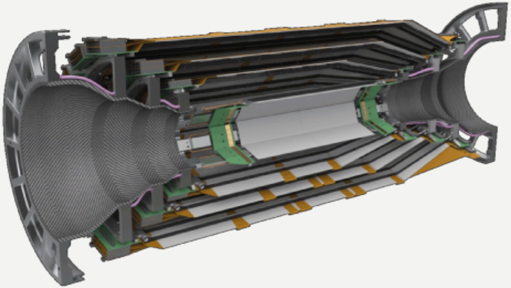
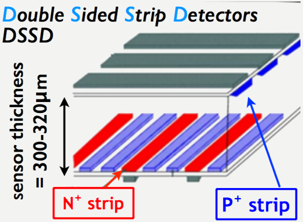
- Excellent timing resolution ($\sim 2-3ns$) $\rightarrow$ complements PXD.





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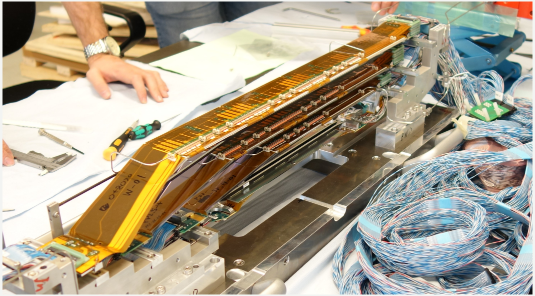
- Undergone beam tests at DESY.



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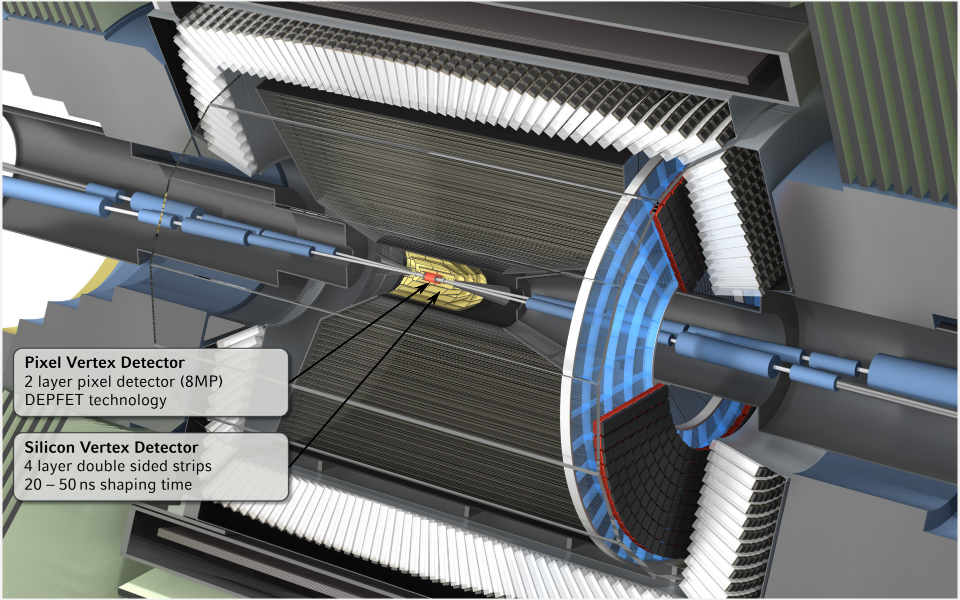

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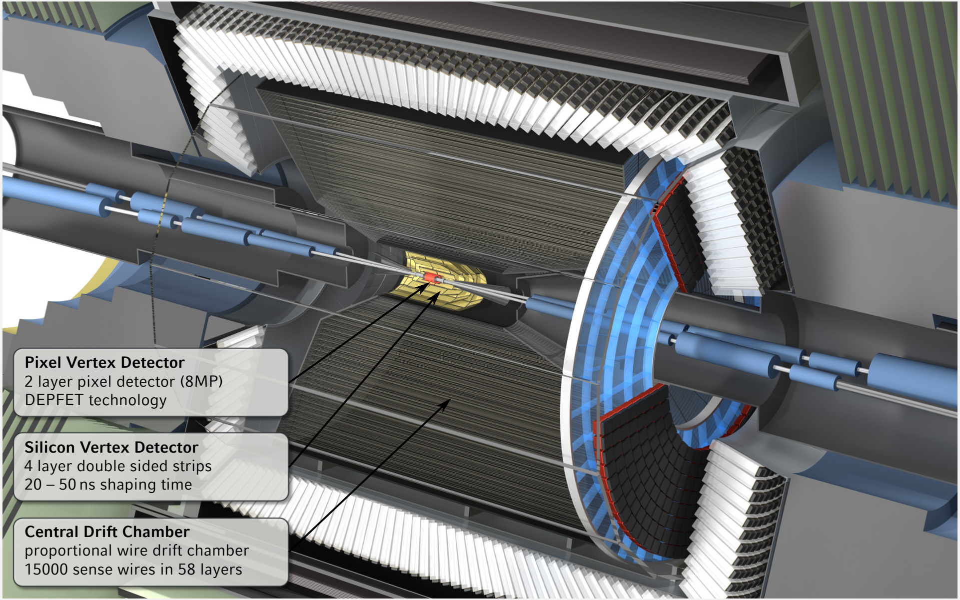
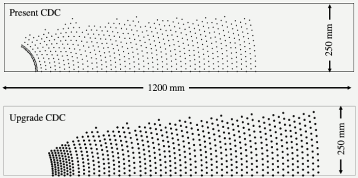
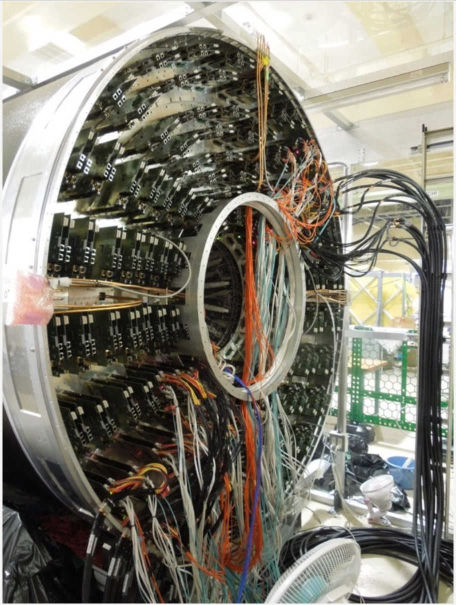


Central Drift Chamber

- $\sim 51,500$ sense wires inside $1.5T$ magnetic field.





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  1. Reconstruct charged tracks with precision momentum measurements.
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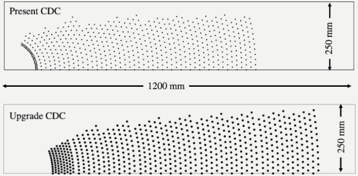
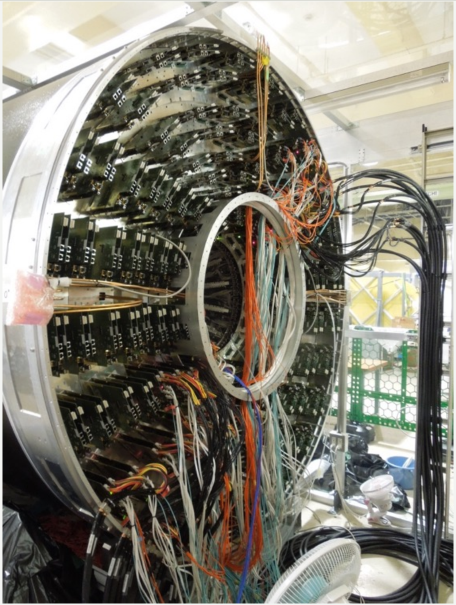
  3. Trigger for charged particles.





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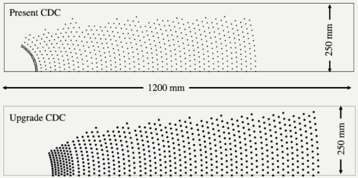
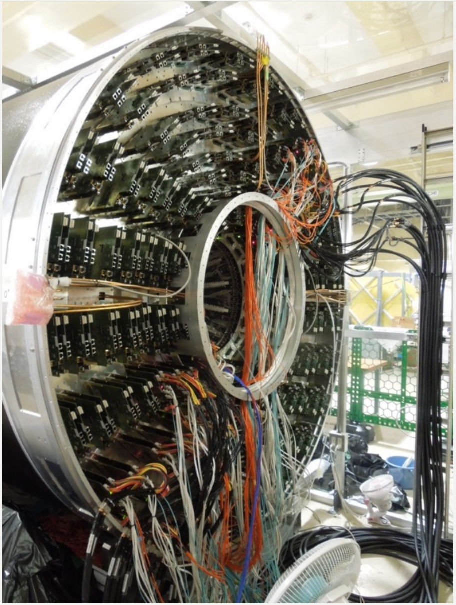
- Moving into final position + cosmic ray testing ongoing.





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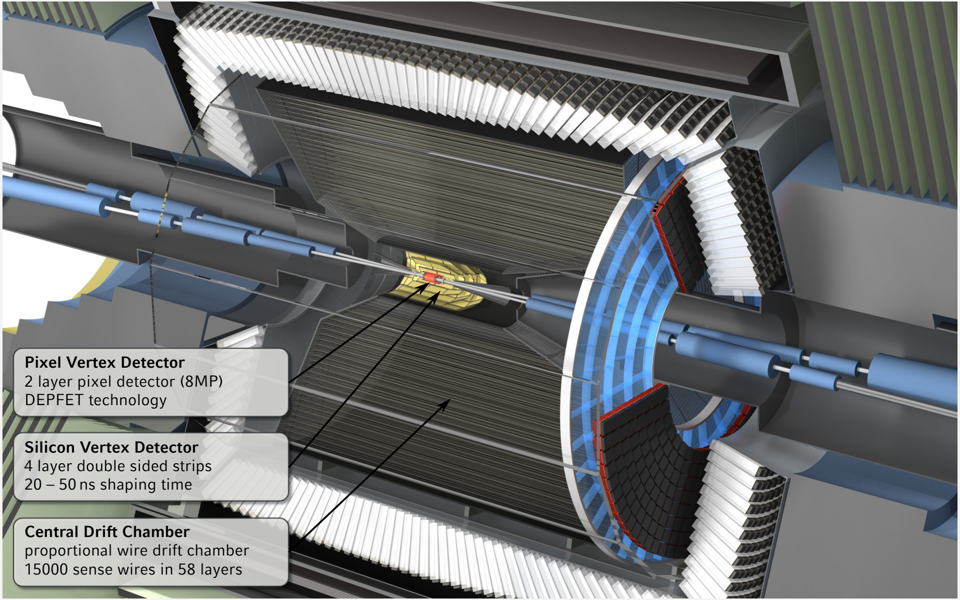

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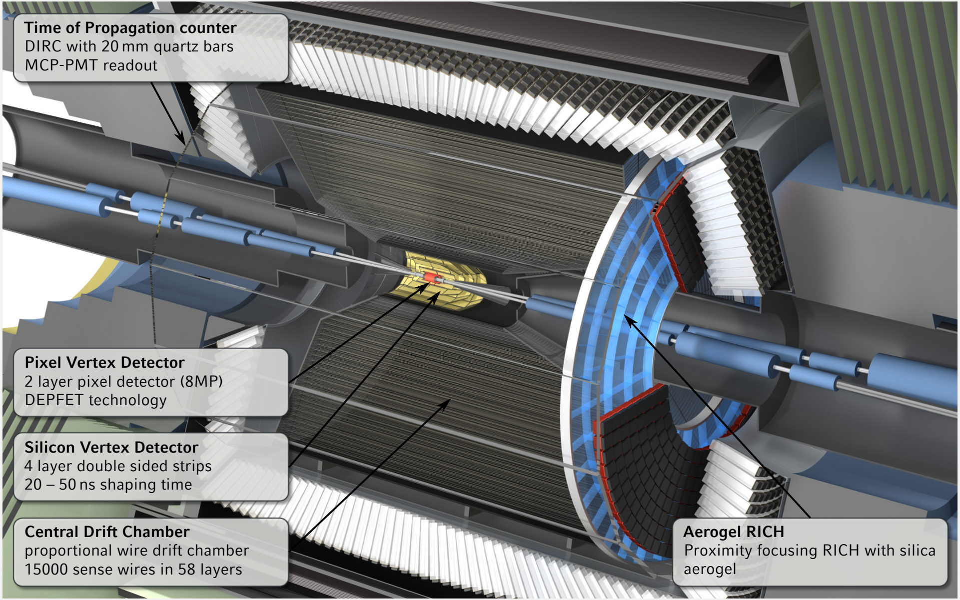
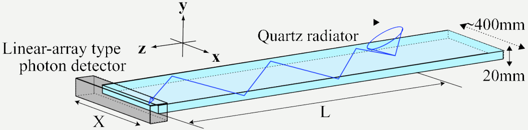
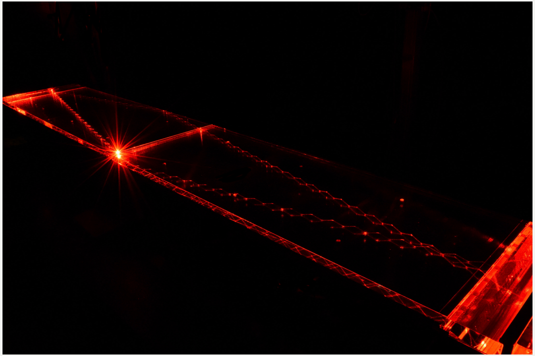


Time of Propagation Detector

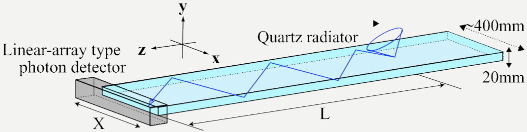
- Particle identification in barrel region.

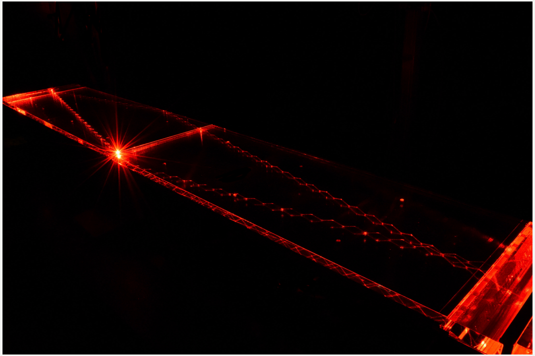




Time of Propagation Detector

- Particle identification in barrel region.
- Sixteen modules, each containing:
  - Two 2.7m long quartz bars.
  - A spherical mirror.
  - An expansion prism.
  - An array of photo–detectors.





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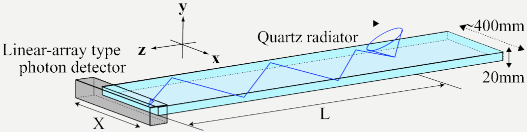
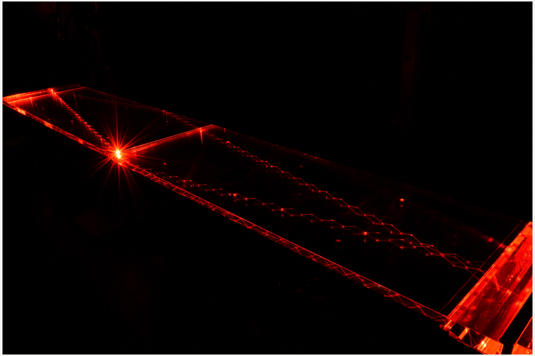
- Cherenkov ring reconstructed in 3D from time and the $x - y$ position.





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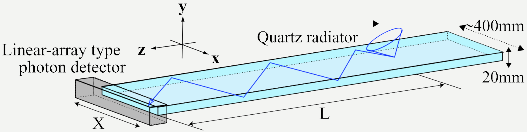
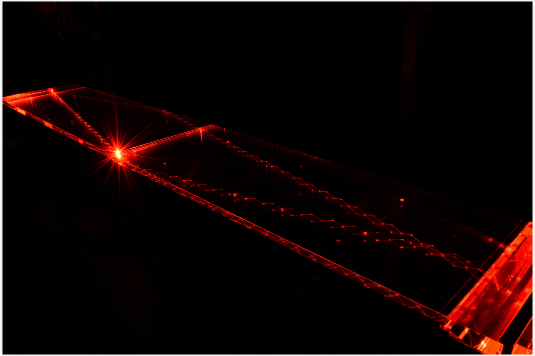
- Cherenkov ring reconstructed in 3D from time and the $x - y$ position.
- TOP installed – undergoing background tests.





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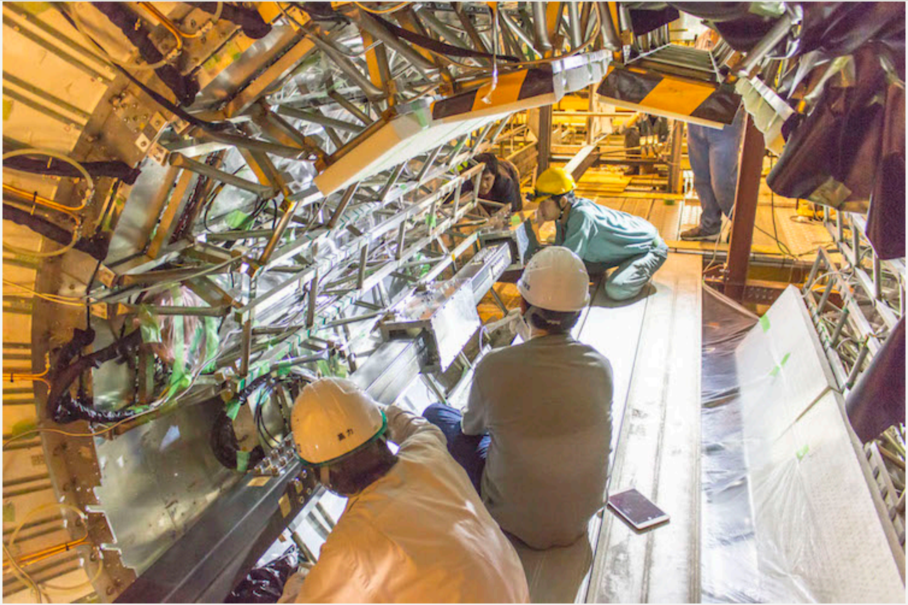
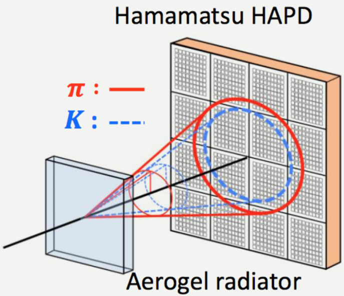
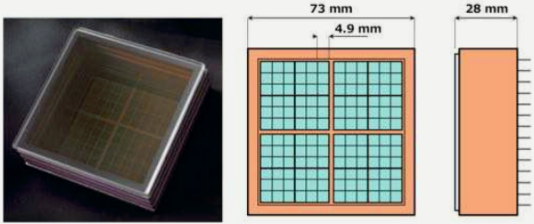


Aerogel Ring Imaging Cherenkov Detector

- Particle identification in forward end–cap.





Aerogel Ring Imaging Cherenkov Detector

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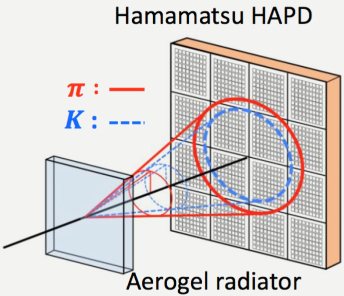
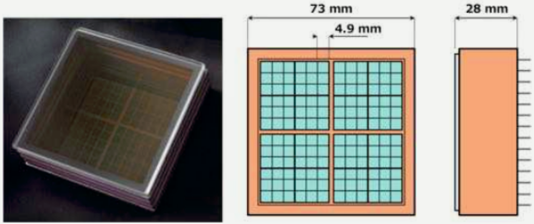
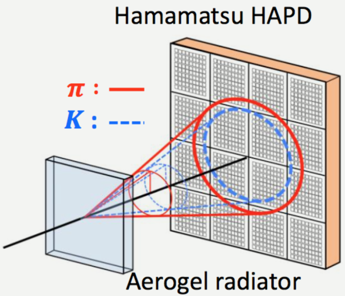
- Components:

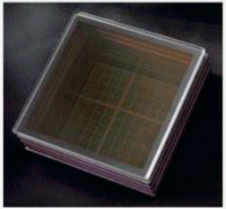


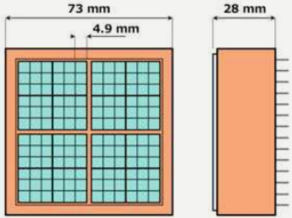


Aerogel Ring Imaging Cherenkov Detector

- Particle identification in forward end–cap.
- Components:
  - Aerogel radiator → produces Cherenkov photons.
  - Expansion volume.
  - $2D$ array of photon detectors (420 Hybrid Avalanche Photo Detectors).
  - Read–out system for photon detectors.







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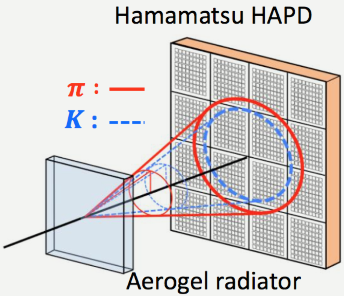
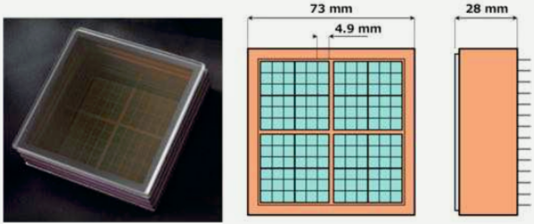
  - Read–out system for photon detectors.

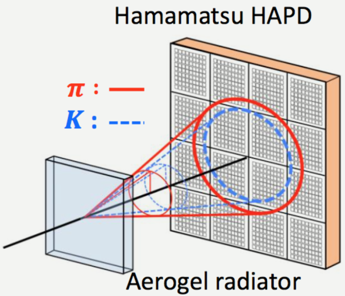
- Focusing constructed to seperate K and π photons across most of their momentum range.

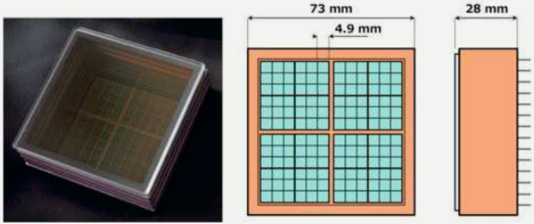




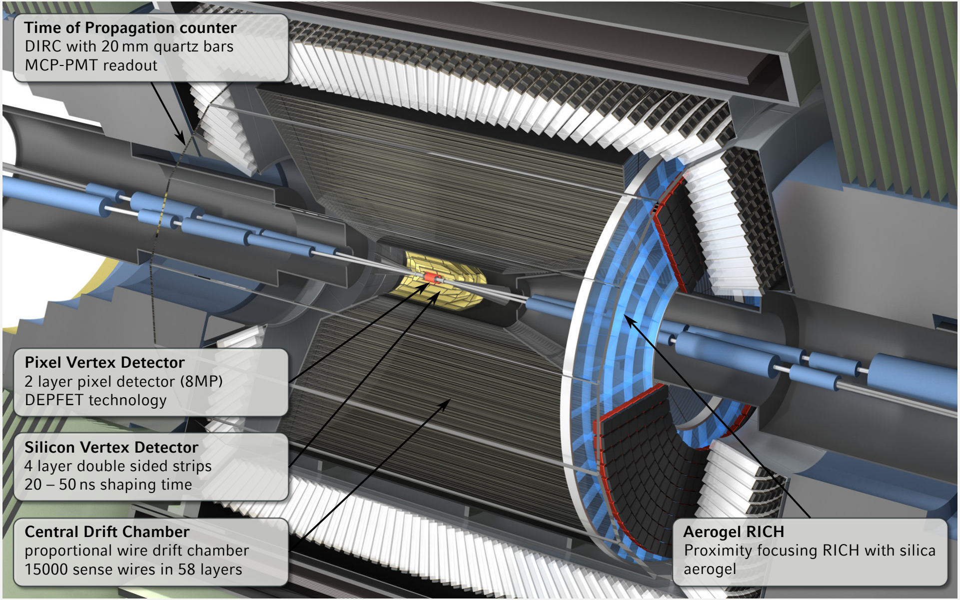
Aerogel Ring Imaging Cherenkov Detector

- Particle identification in forward end–cap.
- Components:
  - Aerogel radiator → produces Cherenkov photons.
  - Expansion volume.
  - $2D$ array of photon detectors (420 Hybrid Avalanche Photo Detectors).
  - Read–out system for photon detectors.
- Focusing constructed to seperate K and π photons across most of their momentum range.
- Partially installed, cosmic ray tests ongoing.





Belle II Detector



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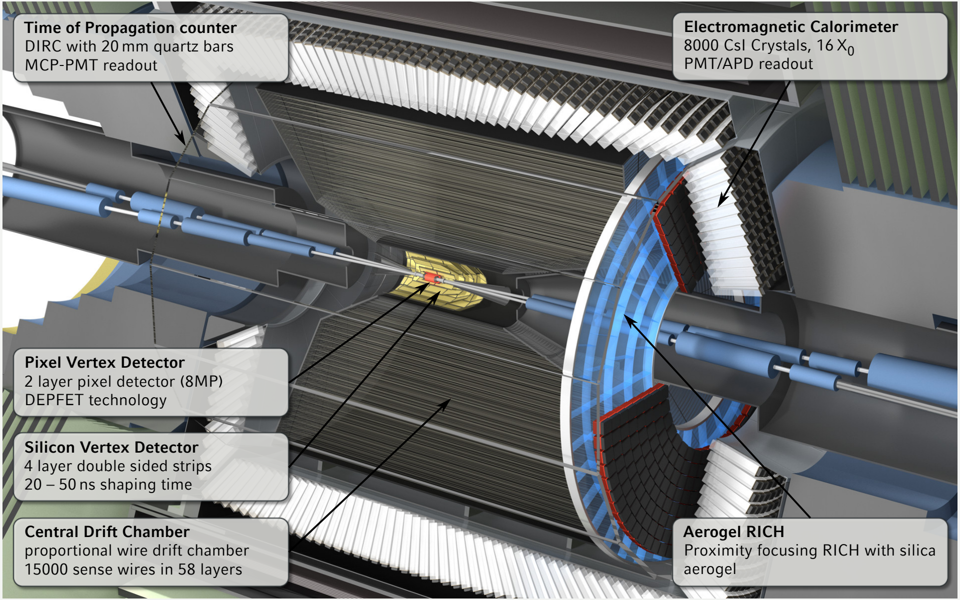
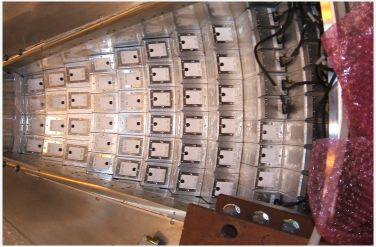


Electromagnetic Calorimeter

- Reuse barrel crystals from Belle (new waveform sampling electronics).



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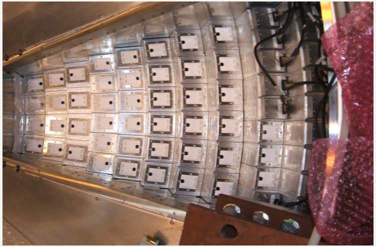

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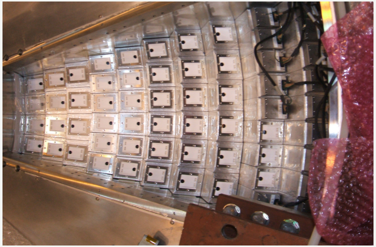

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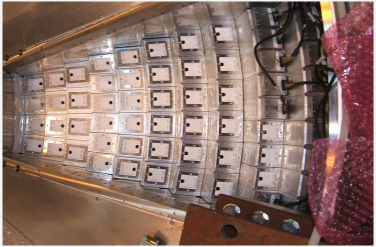
- Hardware tests carried out on crystals – Electronics still in contruction/testing.



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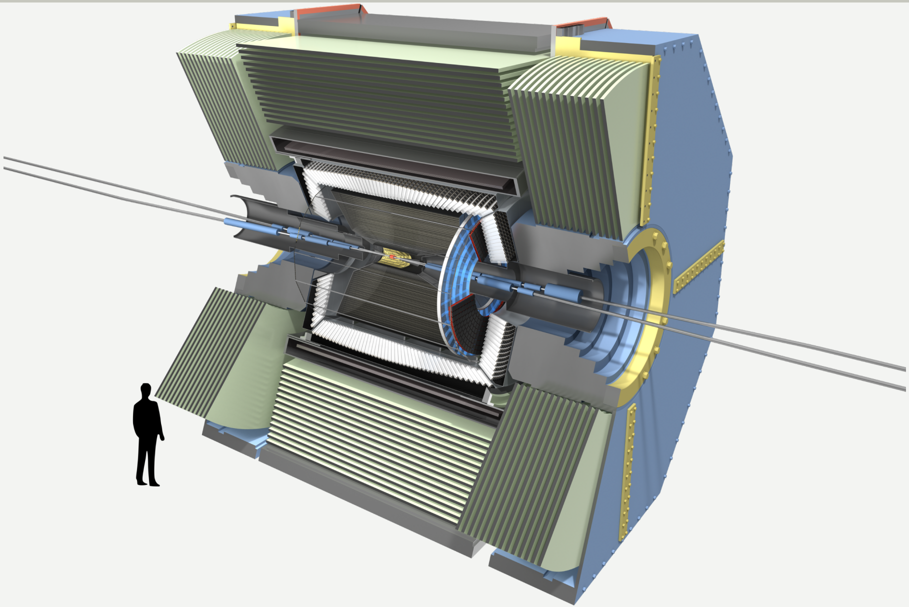
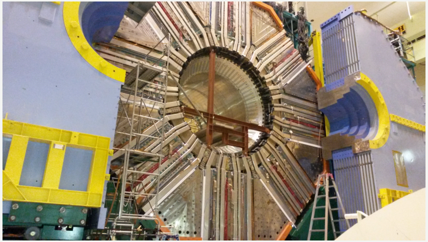
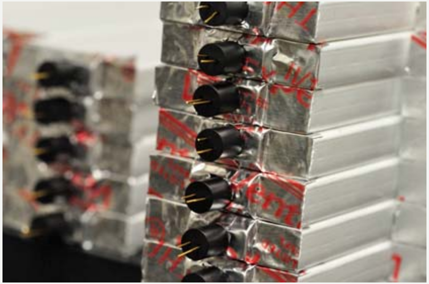


K_L and μ Detector

- Alternating layers of iron plates and detector components.





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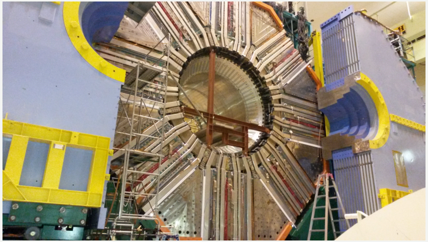

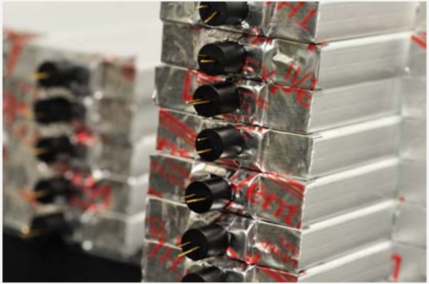

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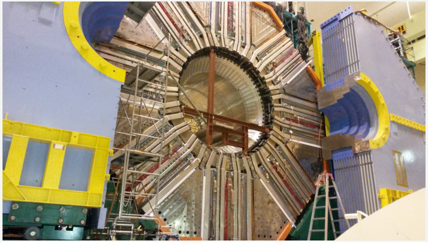

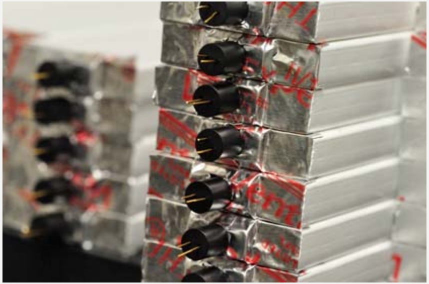

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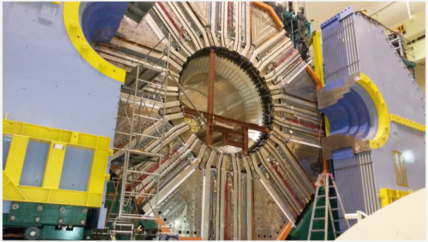

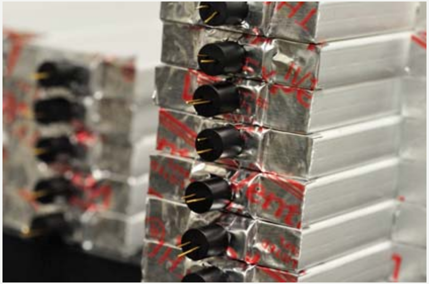

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- Iron plates:
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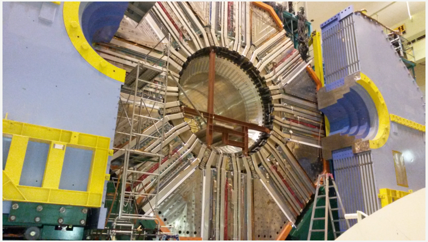
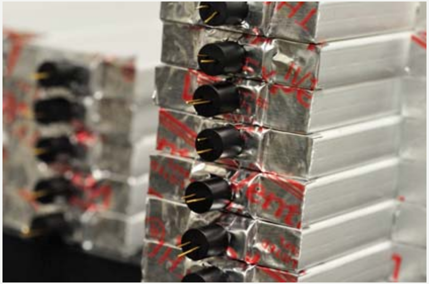
  - Flux return for magnet.
- Replaced end–cap and inner–most barrel RPCs with scintillators.
- Barrel (End–cap) installed in 2013 (2014).
- Currently undergoing commissioning/cosmic ray testing.





Software

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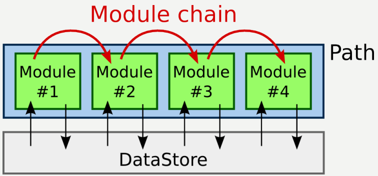

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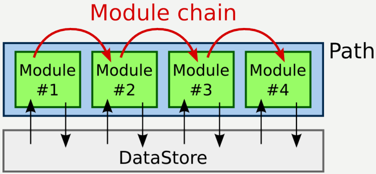

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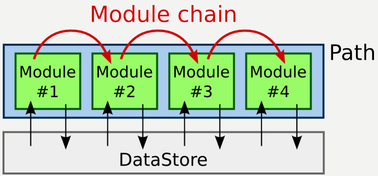

Example: reconstruct $B^0 \to D^0{}_{(\to\pi^0\pi^0)}\pi^0$

```
# Load up a data set to analyse
inputMdstList('B2D0pi0_mdst.root')

# Create "pi0:all" and "pi0:good" ParticleLists
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goodPi0()

# Reconstruct D0 -> pi0 pi0 decay.
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# Perform MC matching (MC truth asociation)
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# Write out the flat ntuple
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ntupleTree('b0', 'B0:all', toolsB0)

# Process the events
process(analysis_main)
```

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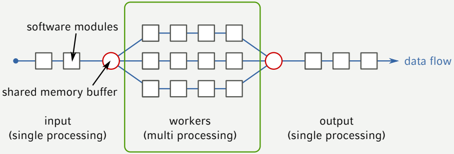
- Events independent → trivial parallelisation.



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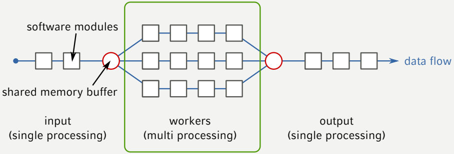

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Software

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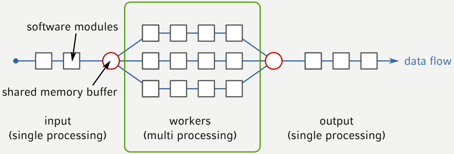
- CVMFS mountable central builds OR ~ 1 min binaries setup.
- First full release: 08.2017



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- Phase 2 (Dec 2017):
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- Phase 3 (Nov 2018):
  Physics run

Summary

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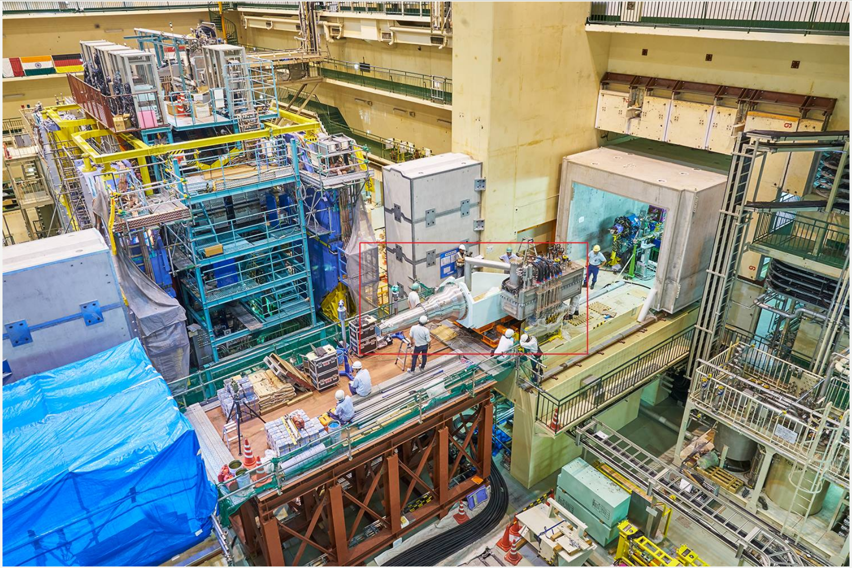
- End–2018: Data taking to begin.

Thank you



Belle II Collaboration

Belle2 Collaboration

BACKUP

Belle II + LHCb

Belle II

- Missing particles
- Inclusive measurements
- LFV

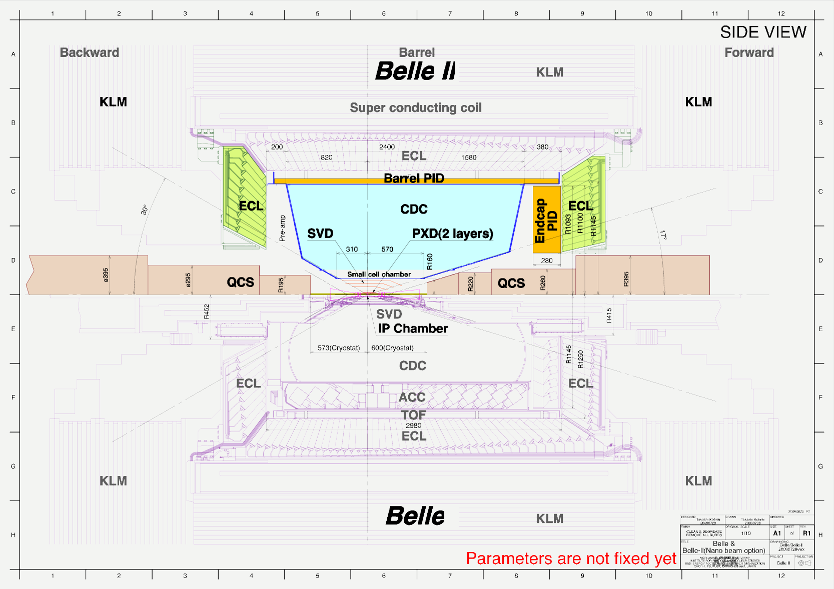
Overlap

- CPV
- Semi–leptonic
- EWP
- Charm physics
- Low–multiplicity signatures.

LHCb

- Large baryonic samples
- Deccays to visible particles.

Belle II changes

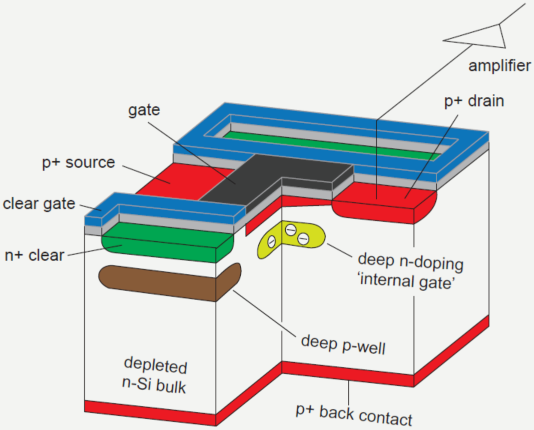


Belle II changes

Belle II is the upgraded Belle detector. Most components have been upgraded. The key changes are:

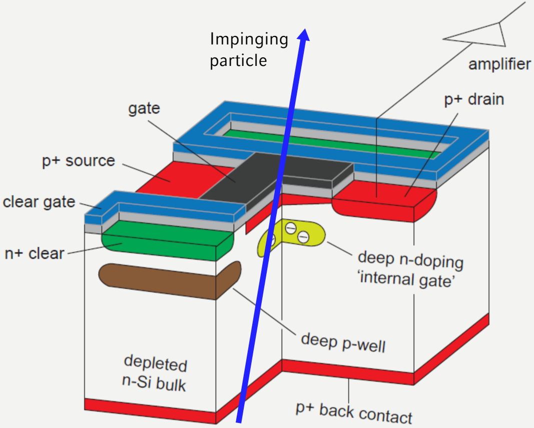
- The old silicon strip detector immediately outside the beam pipe will be replaced with a two–layer pixel detector.
- The remaining silicon strip detector is to be extended to have a larger radius than in Belle.
- The readout of the silicon strip detector will be changed from one based on the VA1TA chip to one based on the APV25 chip featuring a decreased shaping time.
- The central drift chamber, the primary tracking device, will have a larger volume and smaller cell sizes than in Belle.
- Particle identification is to be performed by entirely new devices using erenkov imaging with faster read–outs than in Belle.
- The end–cap scintillator crystals (CsI(T1)) in the electromagnetic calorimeter will be replaced with faster, more radiation tolerant pure CsI crystals, and new electronics will be used.
- The end–cap and inner layers of the K_L and μ detector are to be replaced with scintillators.

DEPFET


amplifier
p+ drain
gate
p+ source
clear gate
n+ clear
deep n-doping
'internal gate'
deep p-well
depleted
n-Si bulk
p+ back contact

DEPFET

1. Particle hits → electron–hole pairs produced.



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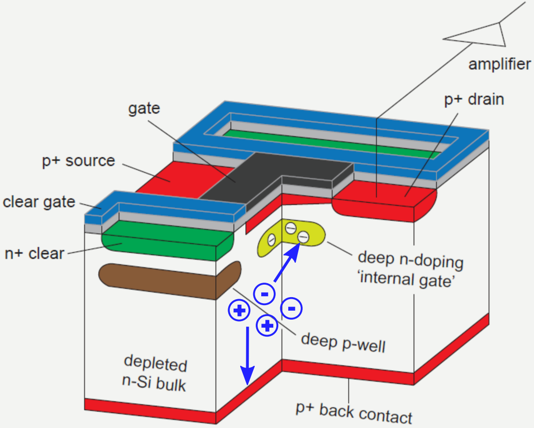
2. Holes drift to the p+ back contact.
   Electrons accumulate in 'internal gate'.



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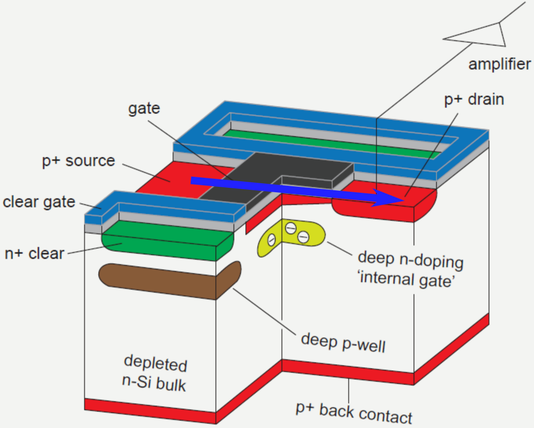

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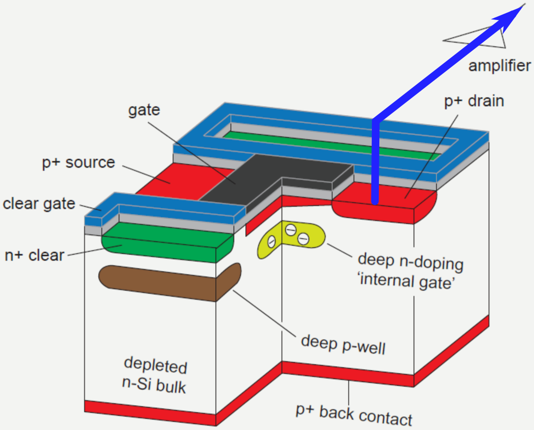

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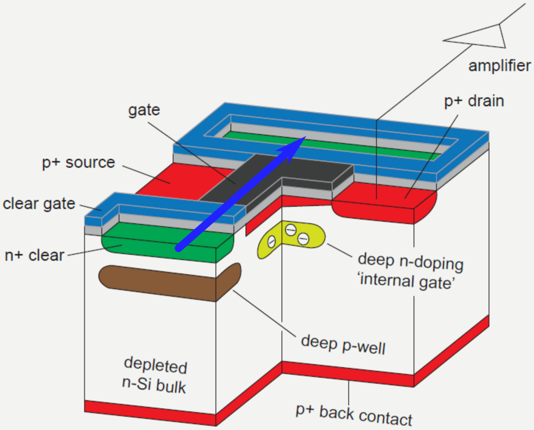

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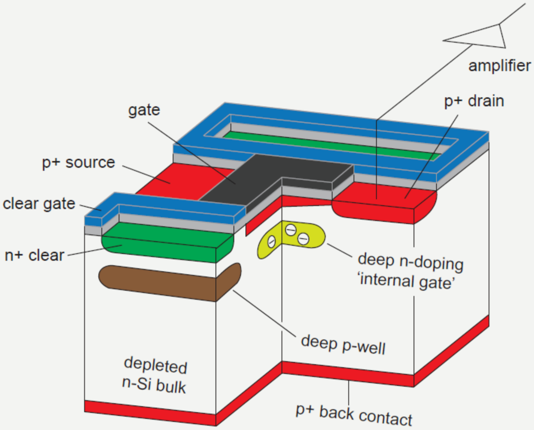
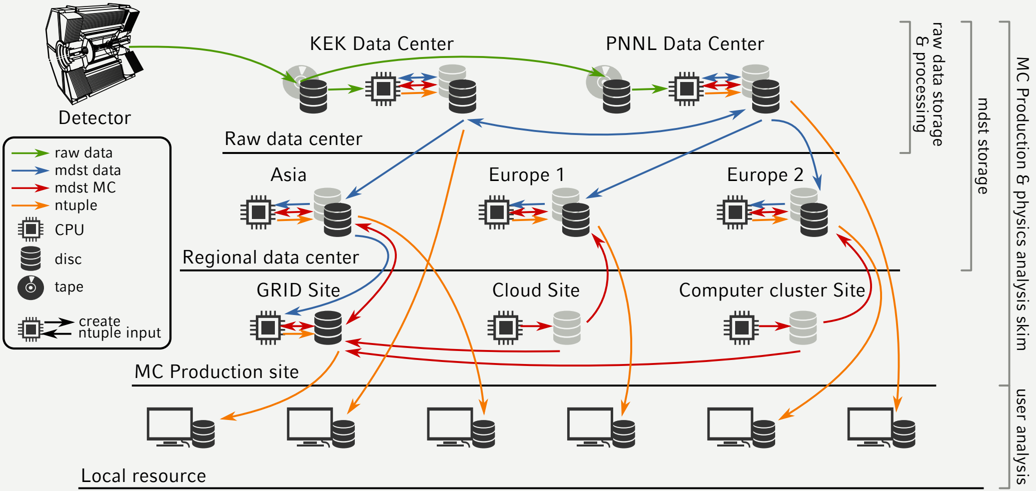
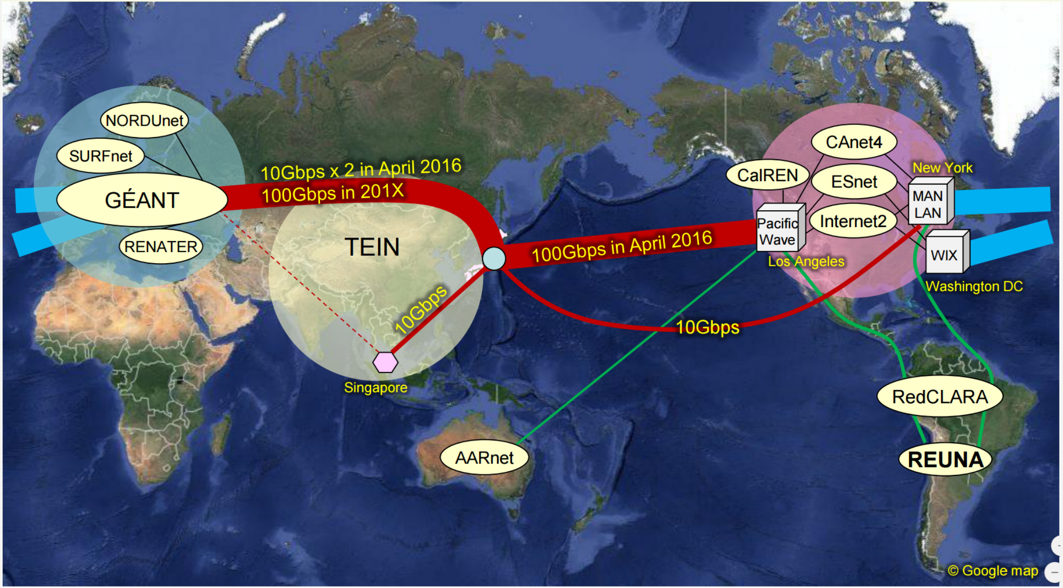
6. Device is now reset and ready again.



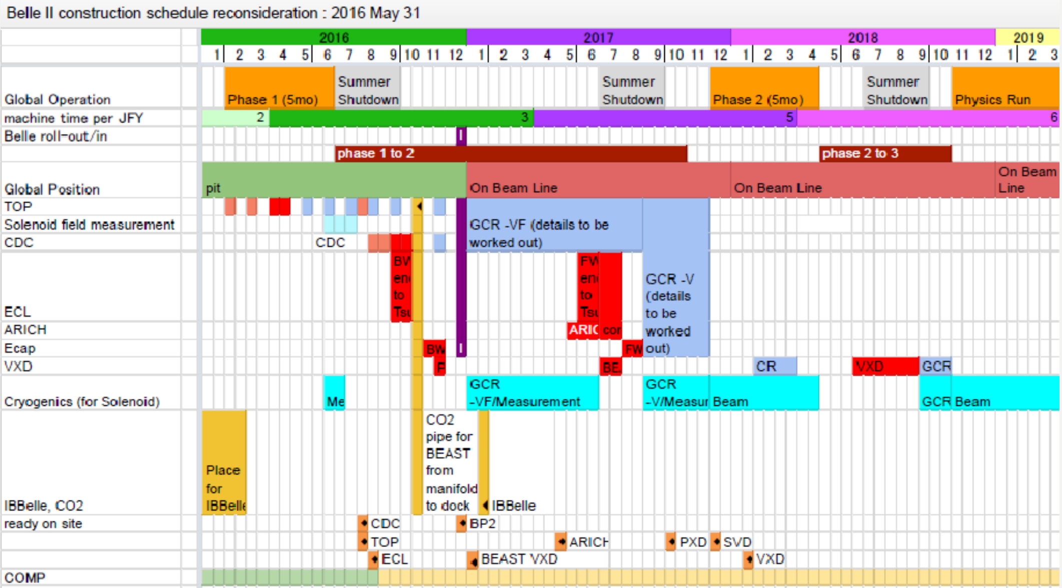
Computing


KEK Data Center
PNNL Data Center
Detector
raw data
mdst data
mdst MC
ntuple
CPU
disc
tape
create
ntuple input
Raw data center
Asia
Europe 1
Europe 2
Regional data center
GRID Site
Cloud Site
Computer cluster Site
MC Production site
Local resource
raw data storage & processing
mdst storage
MC Production & physics analysis skim
user analysis

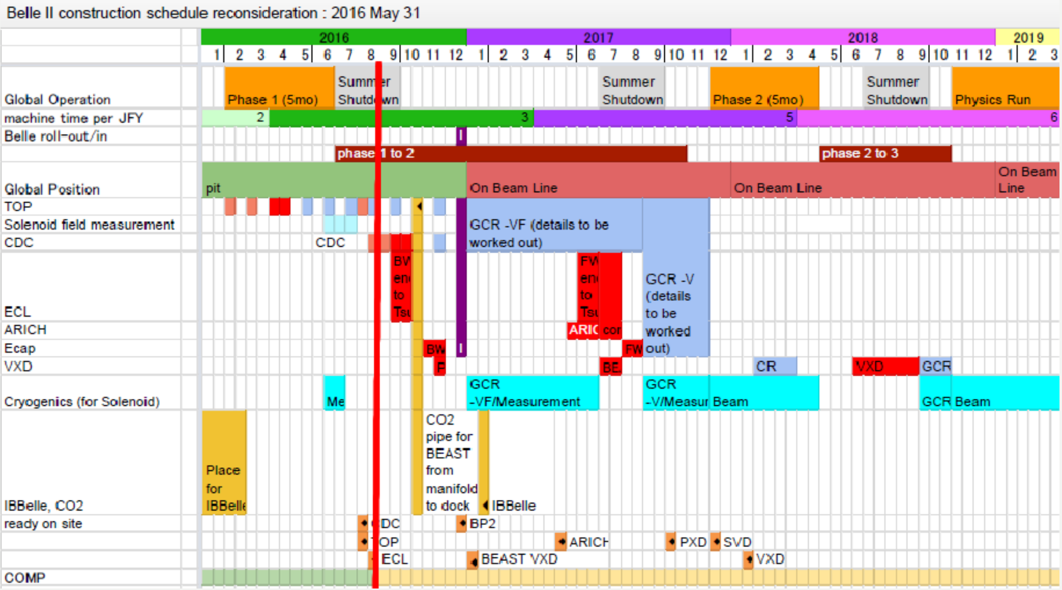
Computing


NORDUnet
SURFnet
GÉANT
RENATER
10Gbps x 2 in April 2016
100Gbps in 201X
TEIN
10Gbps
Singapore
100Gbps in April 2016
CAnet4
CalREN
ESnet
New York
MAN LAN
Pacific Wave
Internet2
WIX
Los Angeles
Washington DC
10Gbps
RedCLARA
REUNA
AARnet
© Google map

Milestones


Belle II construction schedule reconsideration : 2016 May 31
2016
2017
2018
2019
1 2 3 4 5 6 7 8 9 10 11 12
Global Operation
Phase 1 (5mo)
Summer Shutdown
Phase 2 (5mo)
Physics Run
machine time per JFY
2
3
5
6
Belle roll-out/in
phase 1 to 2
phase 2 to 3
Global Position
pit
On Beam Line
On Beam Line
TOP
Solenoid field measurement
CDC
GCR -VF (details to be worked out)
ECL
GCR -V (details to be worked out)
ARICH
Ecap
VXD
CR
VXD
GCR
Cryogenics (for Solenoid)
GCR -VF/Measurement
GCR -V/Measur
Beam
GCR Beam
IBBelle, CO2
Place for IBBelle
CO2 pipe for BEAST from manifold to dock
IBBelle
ready on site
CDC
BP2
TOP
ARICH
PXD
SVD
ECL
BEAST VXD
VXD
COMP

Milestones


Belle II construction schedule reconsideration : 2016 May 31
2016
2017
2018
2019
Global Operation
Phase 1 (5mo)
Summer Shutdown
Summer Shutdown
Phase 2 (5mo)
Summer Shutdown
Physics Run
machine time per JFY
2
3
5
6
Belle roll-out/in
phase 1 to 2
phase 2 to 3
Global Position
pit
On Beam Line
On Beam Line
On Beam Line
TOP
Solenoid field measurement
GCR -VF (details to be worked out)
CDC
CDC
ECL
GCR -V (details to be worked out)
ARICH
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VXD
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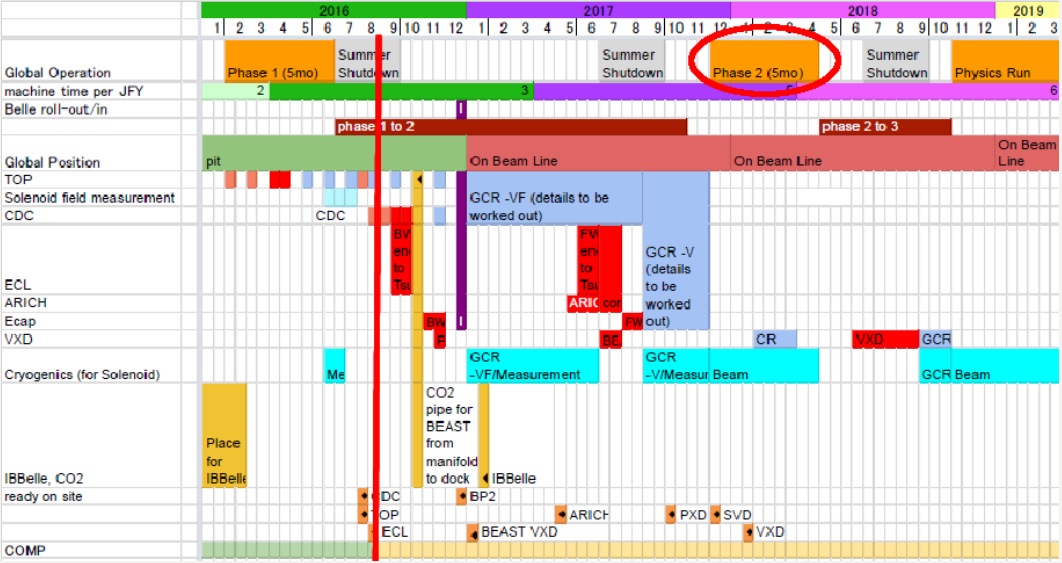
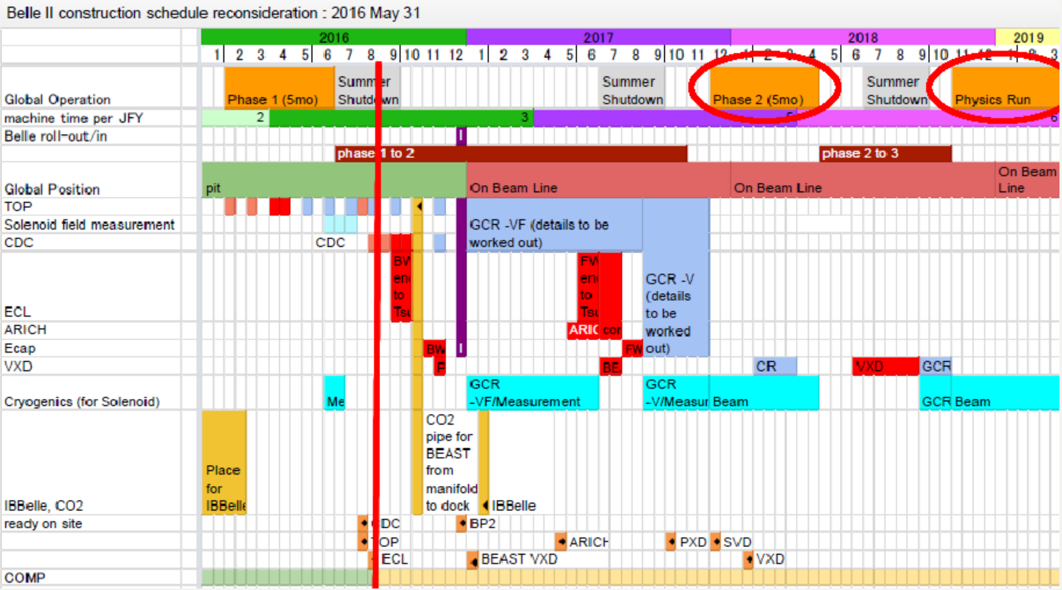
Milestones

Belle II construction schedule reconsideration : 2016 May 31



Milestones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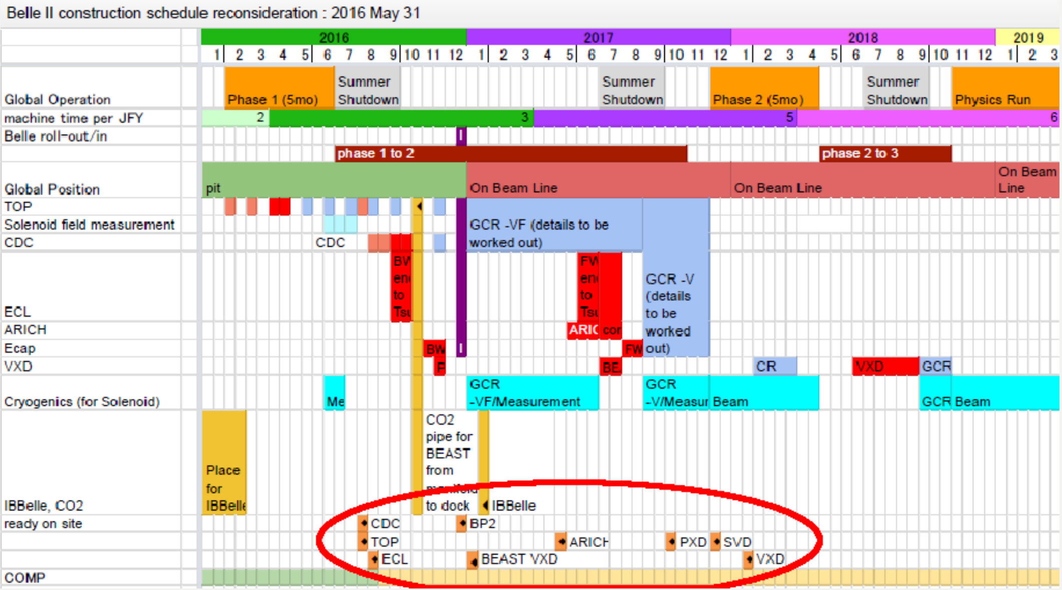
Milestones


Belle II construction schedule reconsideration : 2016 May 31
2016
2017
2018
2019
1 2 3 4 5 6 7 8 9 10 11 12
Global Operation
Phase 1 (5mo)
Summer Shutdown
Phase 2 (5mo)
Physics Run
machine time per JFY
2
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