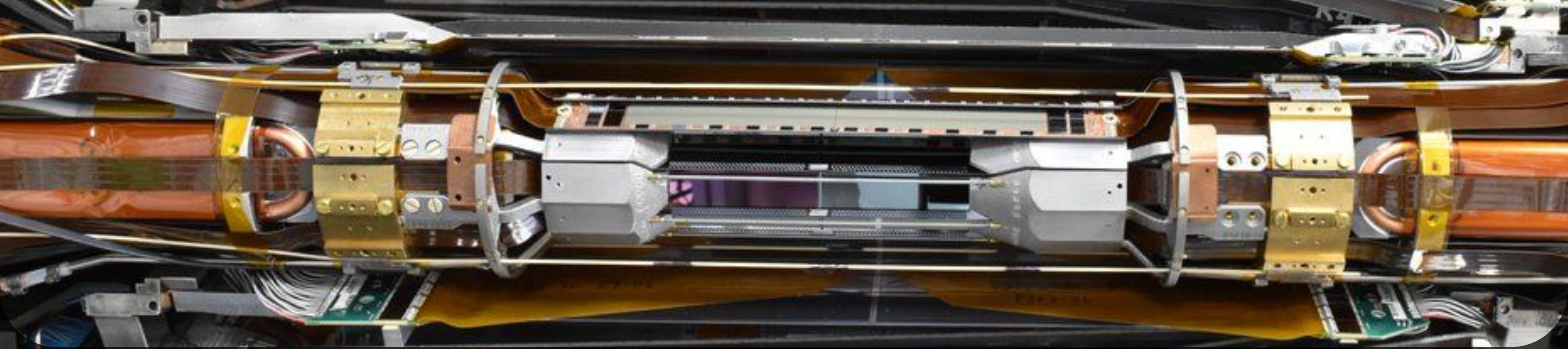


# The Belle II Pixel Vertex Detector

Belle II Germany Meeting 20th-22st September 2021
Arthur Bolz, DESY

# Outline

## Introduction

- SuperKEKB, Belle II,  and the Belle II Vertex Detector

## The Pixel Vertex Detector (PXD)

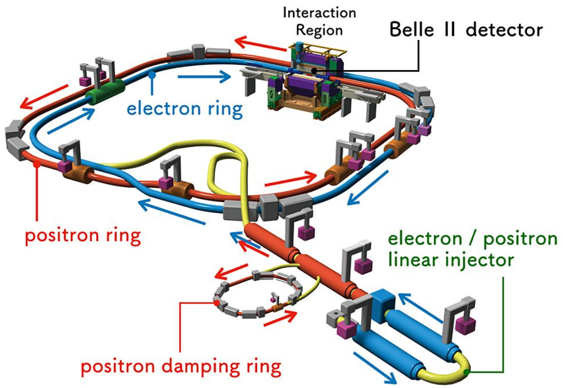
- Working Principles
- PXD Modules and Calibration
- PXD Detector

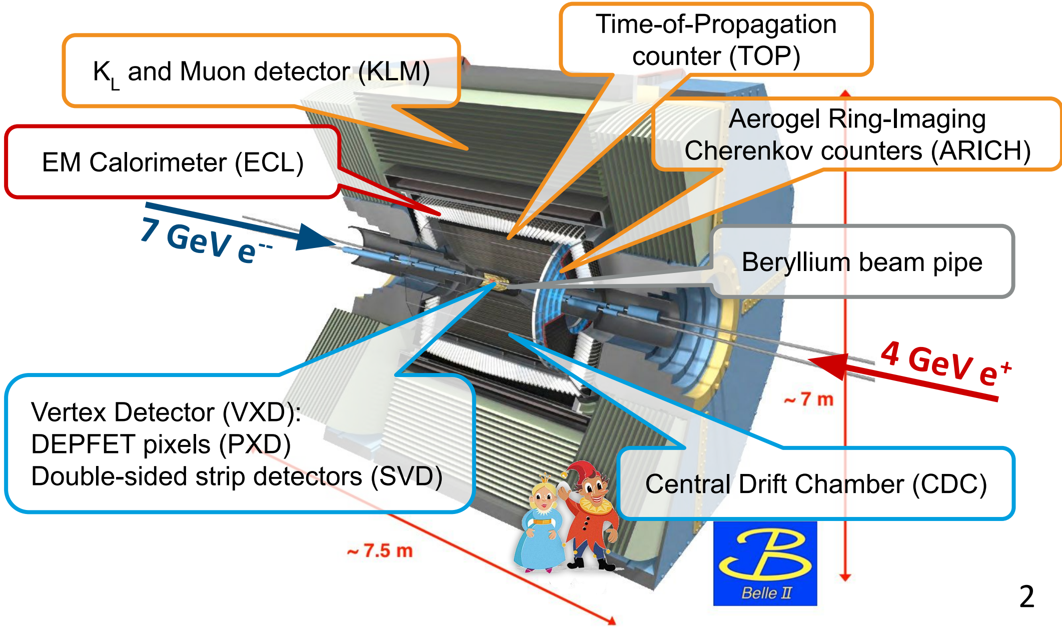
## PXD in Belle II in 2021

- PXD Operation and Performance
- VXD Performance
- Operational Challenges: backgrounds, beam-losses, irradiation and aging

## PXD2 2022 Upgrade

- Future of PXD

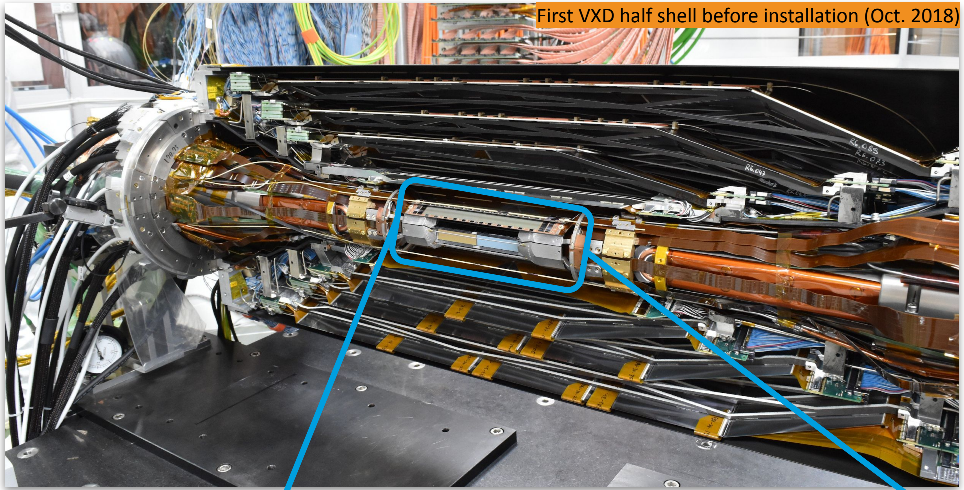


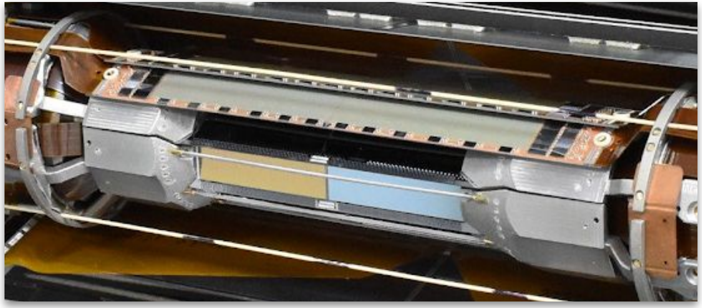



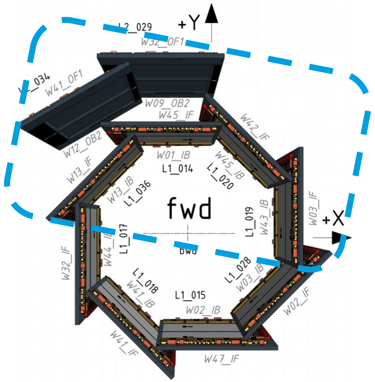
# Setting the Scene

## Belle II Vertex Detector (VXD)

- **Silicon Vertex Detector (SVD)**
  - 4 layers of 2-sided silicon strips
  - $r \lesssim 140$ mm
- **Pixel Vertex Detector (PXD)**
  - 2 layers at radii 14 mm and 22 mm
  - 8 inner + 12 outer module-pairs (“ladders”)
    - ⇒ only 8 (inner) + 2 (outer) ladders installed
  - ~$7.7 \times 10^6$ pixels
  - ~0.21 % $X_0$ / layer material budget
- **acceptance**
  - $17° < \Theta < 150°$
  - $p_T \gtrsim 40$ MeV


First VXD half shell before installation (Oct. 2018)

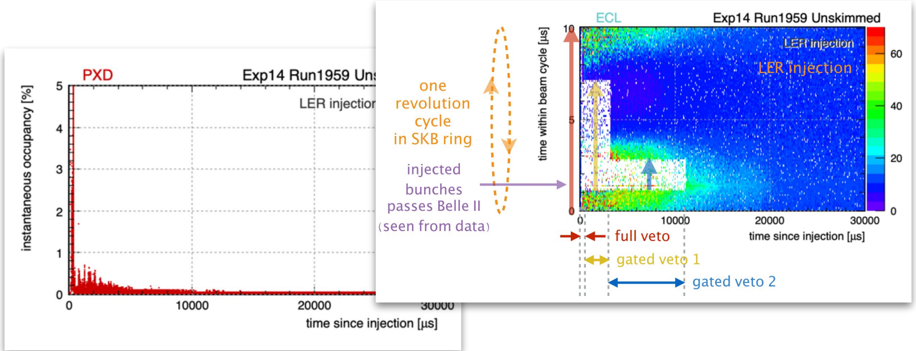


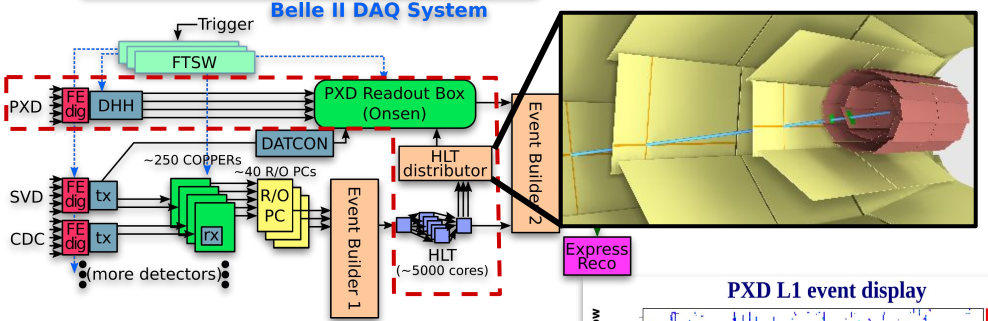


# Tracking at SuperKEKB

## Challenges

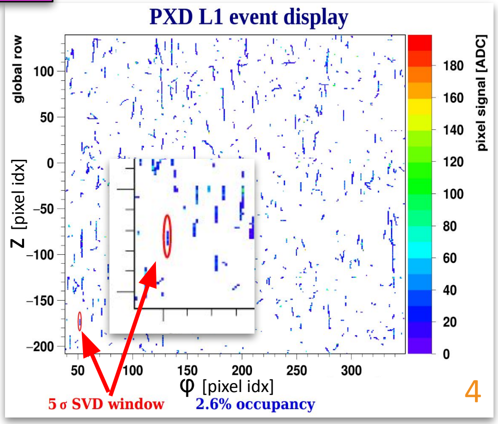
- **increased backgrounds** with instantaneous lumi
  - continuous injection of “noisy” bunches
    ⇒ beam lifetime only few minutes
    (50 Hz, 10 µs revolution, 4 ms cooldown ⇒ present 20 % of time)
  - “Synchrotron”, “Touschek intra-bunch scattering”, “Bhabha”, “2 photon”...
  - challenge for detector/tracking overall
    (challenges for PXD discussed explicitly later)
- **smaller Lorentz boost** (7 on 4 GeV vs KEKB 8 on 3.5 GeV)




## Track reconstruction and PXD role

- PXD *DAQ* separated from rest of Belle II
- (HLT) **track finding seeded in CDC** (pT > 100 MeV) or else **SVD**
- **PXD** hits used in offline track fit → **improved vertex resolution**
- Regions of Interest (**ROI**) filtering:
  - HLT: extrapolates tracks to ROIs on PXD for readout to reduce data rate
- PXD layer one crucial for *impact parameter resolution*
- PXD layer two (will be) crucial for *handling background*



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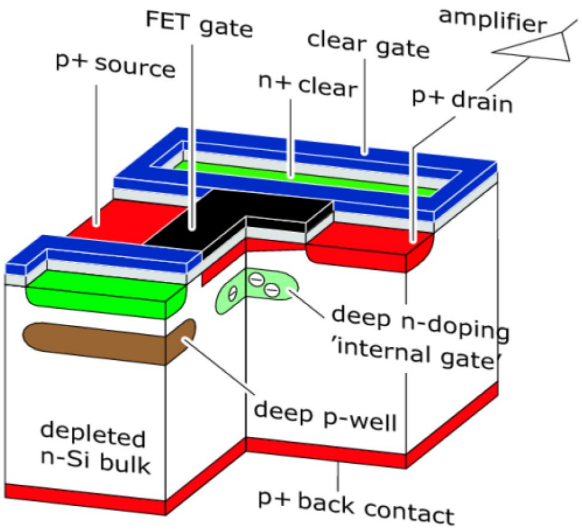
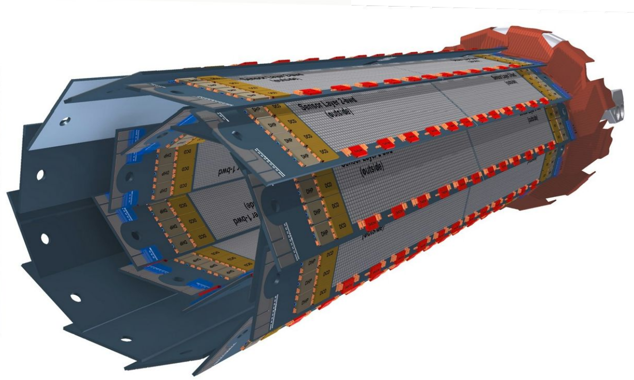
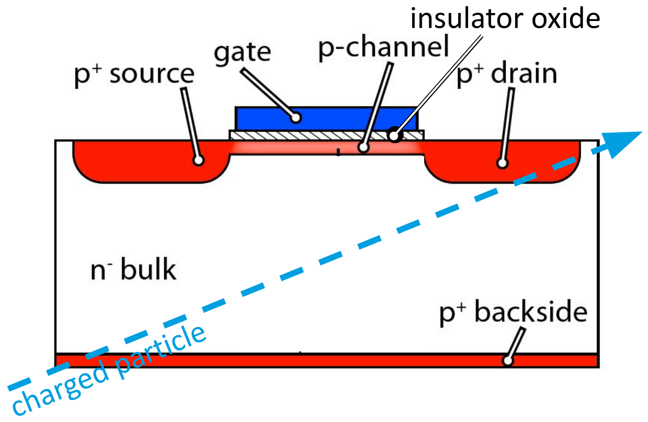


# PXD Working Principle

**DEPFET pixels: depleted p-channel field effect transistors**

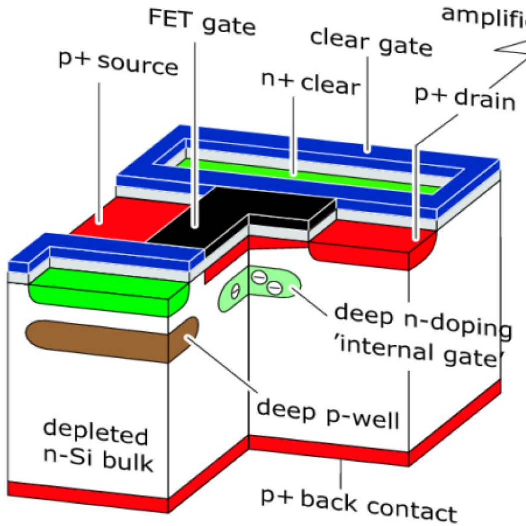



## principle:

- Field Effect Transistor (FET) on top of fully depleted silicon bulk
  - ***gate*** voltage regulates ***source→drain*** current
- ***internal gate***: deep n-implant below FET gate
  - collects free electrons to modulate drain current
- periodic active clearing of internal gate achieved via ***clear implant*** (n+) and "punch through" mechanism

## characteristics:

+ fast charge collection ($O$(ns))
+ internal amplification $g_q = \frac{\partial I}{\partial q} \approx 500 \frac{pA}{e^-}$
+ high signal-to-noise ratio
+ low power consumption
+ thin sensors (75 µm in active region: DEPFET matrix)
- non-destructive signal readout



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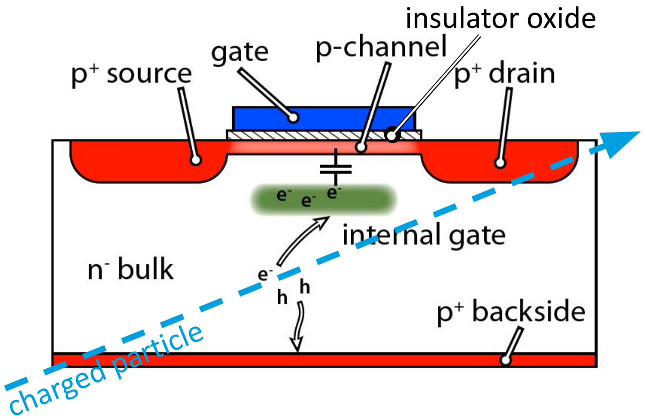


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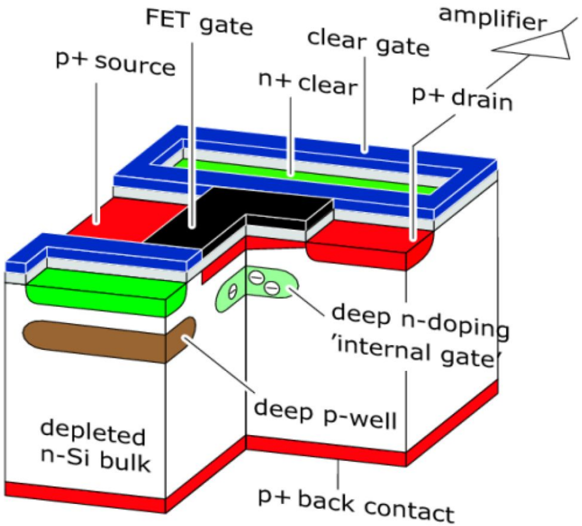


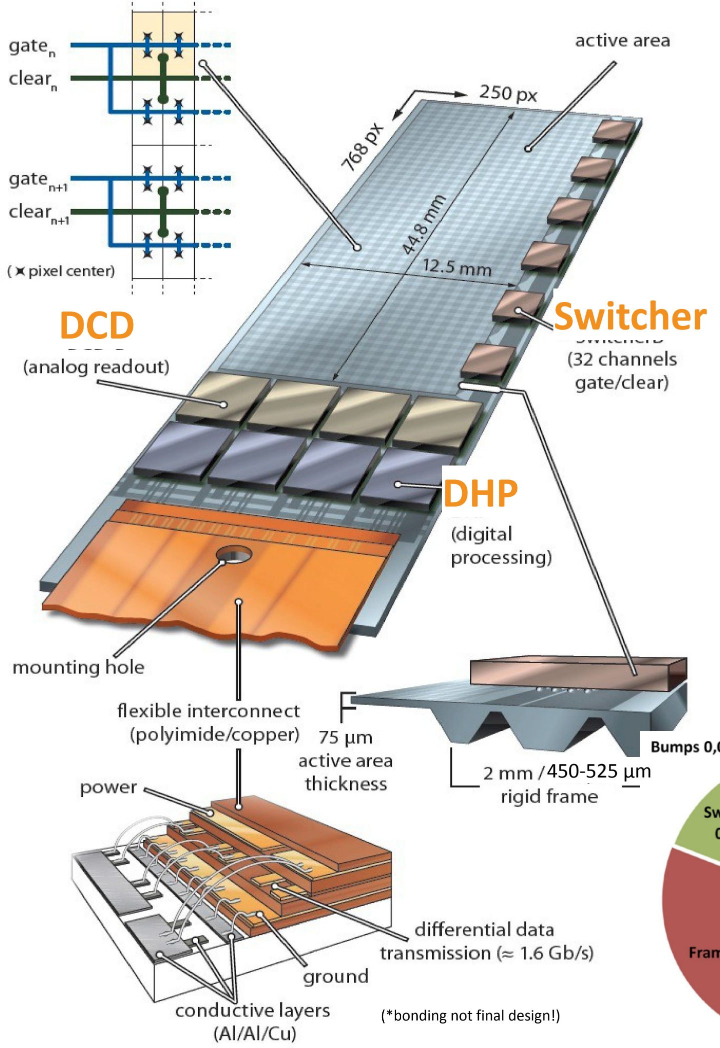
# PXD Sensors

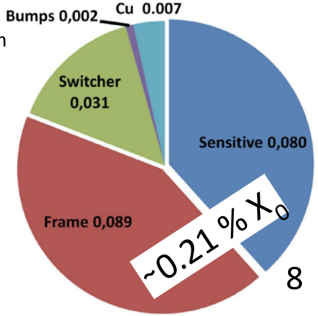
## Layout

- matrix
  - 250x768 pixels, pixel size 50x(55-85) $\mu m^2$
  - mechanically self supporting,
    thinned to 75 µm (active region)
- ASICs
  - *Switchers* → DEPFET control
  - *DCD* → 256 channel ADC
  - *DHP* → data processing
- radiation hard sensors and ASICs

## Operation

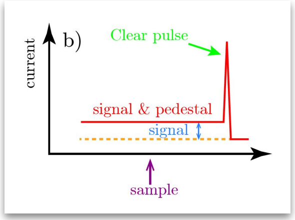
- rolling shutter read-out → low power
  50 kHz → 20 µs integration time (2x SKB revo. cycle)
- design: 1% occupancy (layer 1)
  3 % occupancy limit (DHP, DAQ, tracking)
- power dissipated mainly in ASICS at end of stave
  2 phase $CO_2$ cooling



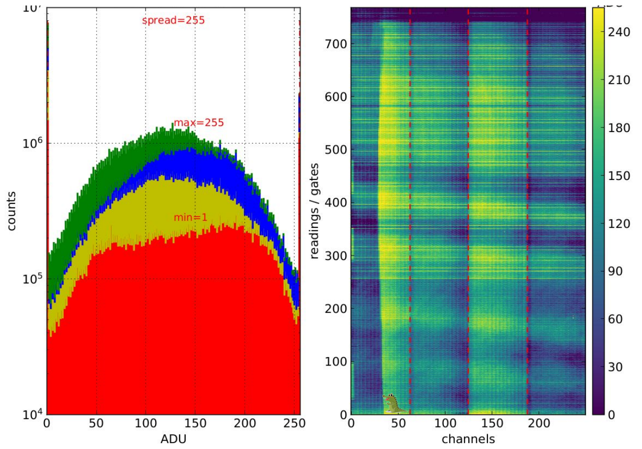
# PXD Modules

## Calibration

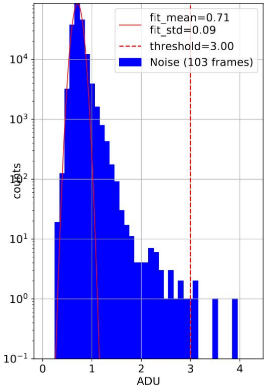



- sensors characterized before installation
  - continuous optimization of working points needed during operation
- median drain current pedestals stored on DHP for zero suppression
- pedestal optimization on DCD
  - pedestal compression via switchable input currents per pixel
  - noise reduction via *Analog Common Mode Correction*

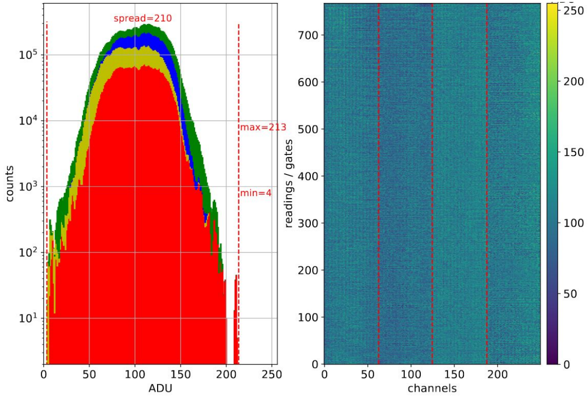
pedestal currents uncalibrated sensor



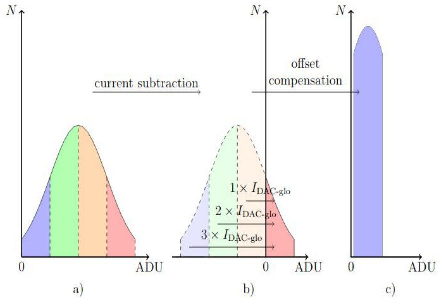

noise distribution
(pedestal fluctuations)



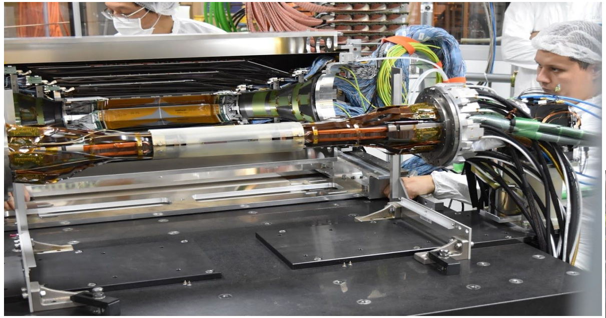

pedestals calibrated sensor




calibration
(pedestal " compression" + offsets)

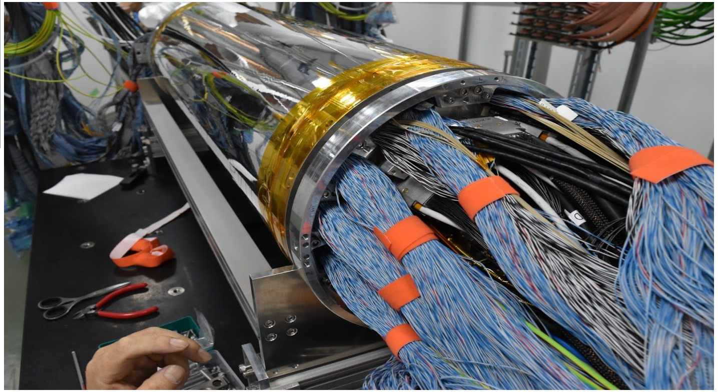


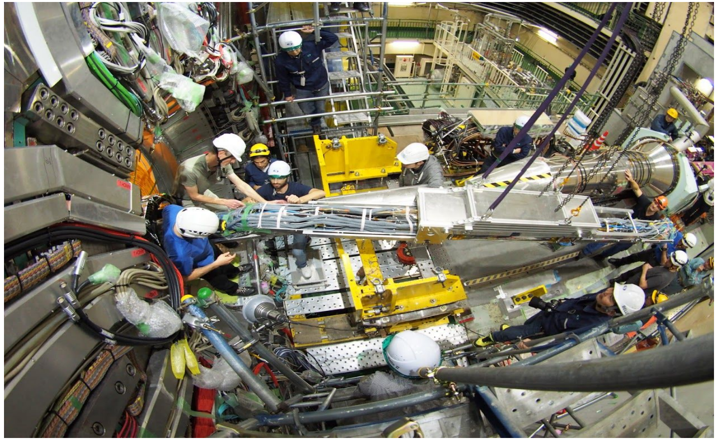
# PXD in Belle II



## Installation 2018 at KEK

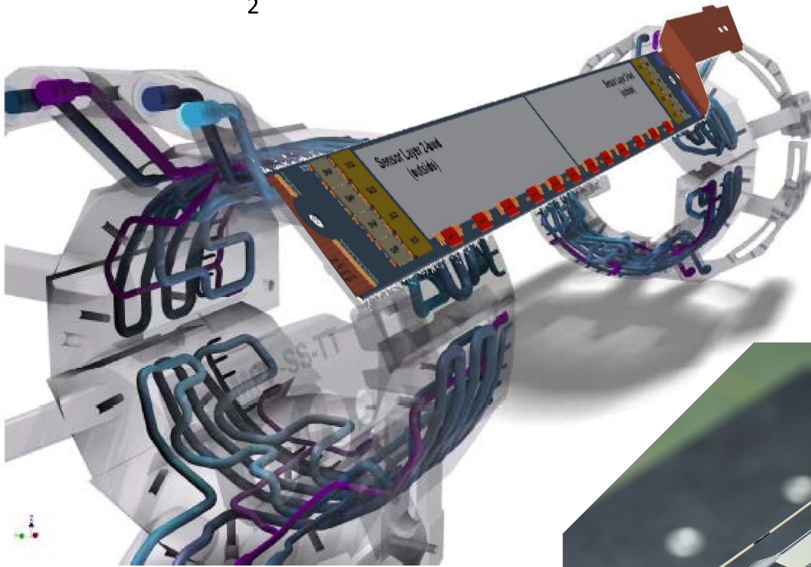
- PXD + BP + SVD marriage
- VXD installation in

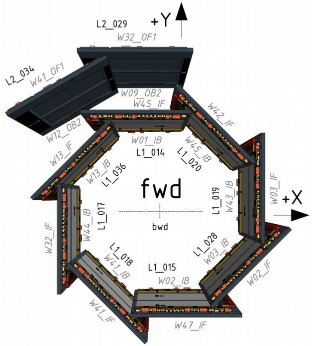


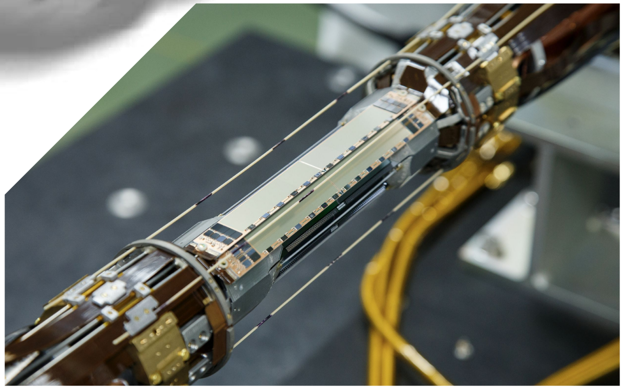


## PXD assembly

- mechanical ladder frame SCB
- provide cooling via 2-phase $CO_2$ and forced $N_2$ flow





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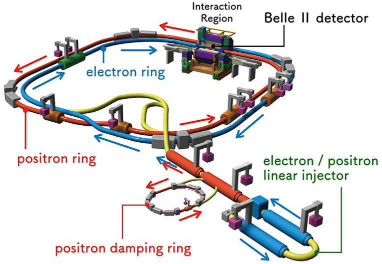
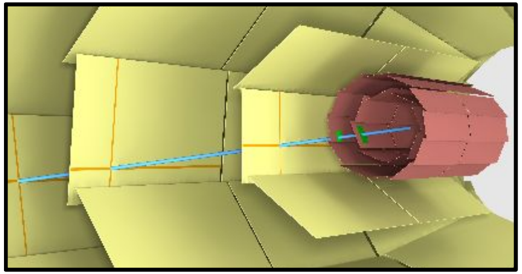
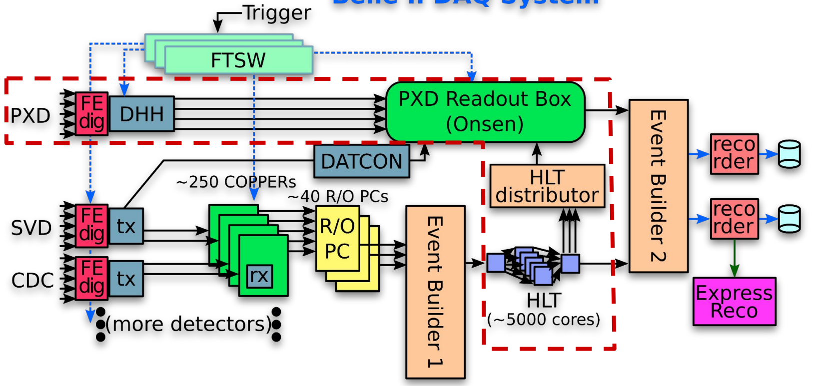


**Belle II DAQ System**

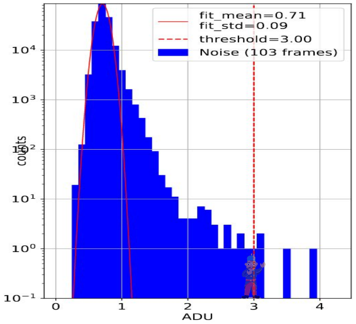


# PXD Performance

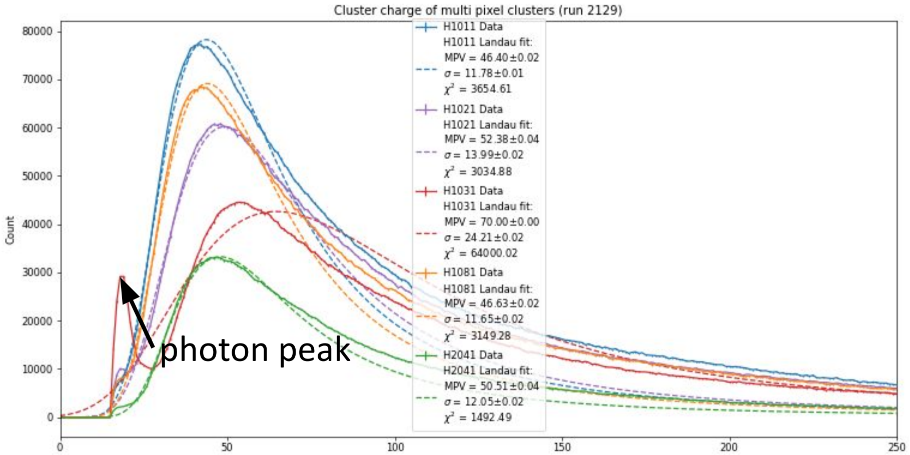
## Signal and noise

- noise performance < 1 ADU (~200 e⁻)
- at a SNR of ~30 - 50
- homogeneous noise and signal response across module matrix

noise distribution
(pedestal fluctuations)



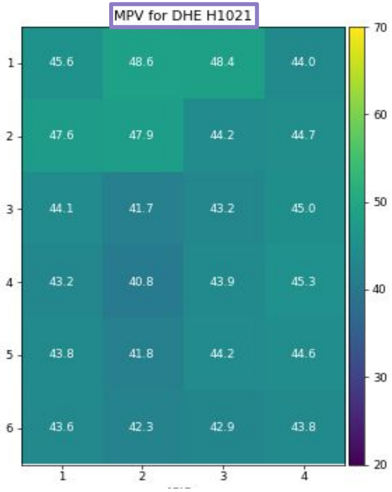

cluster charge distribution




multi pixel cluster ADU

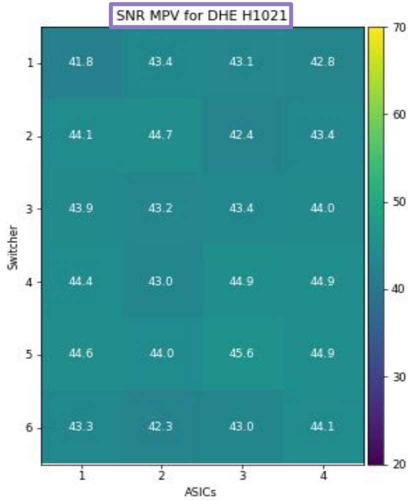
cluster charge MPV

6x switchers




4x DCD/DHPs

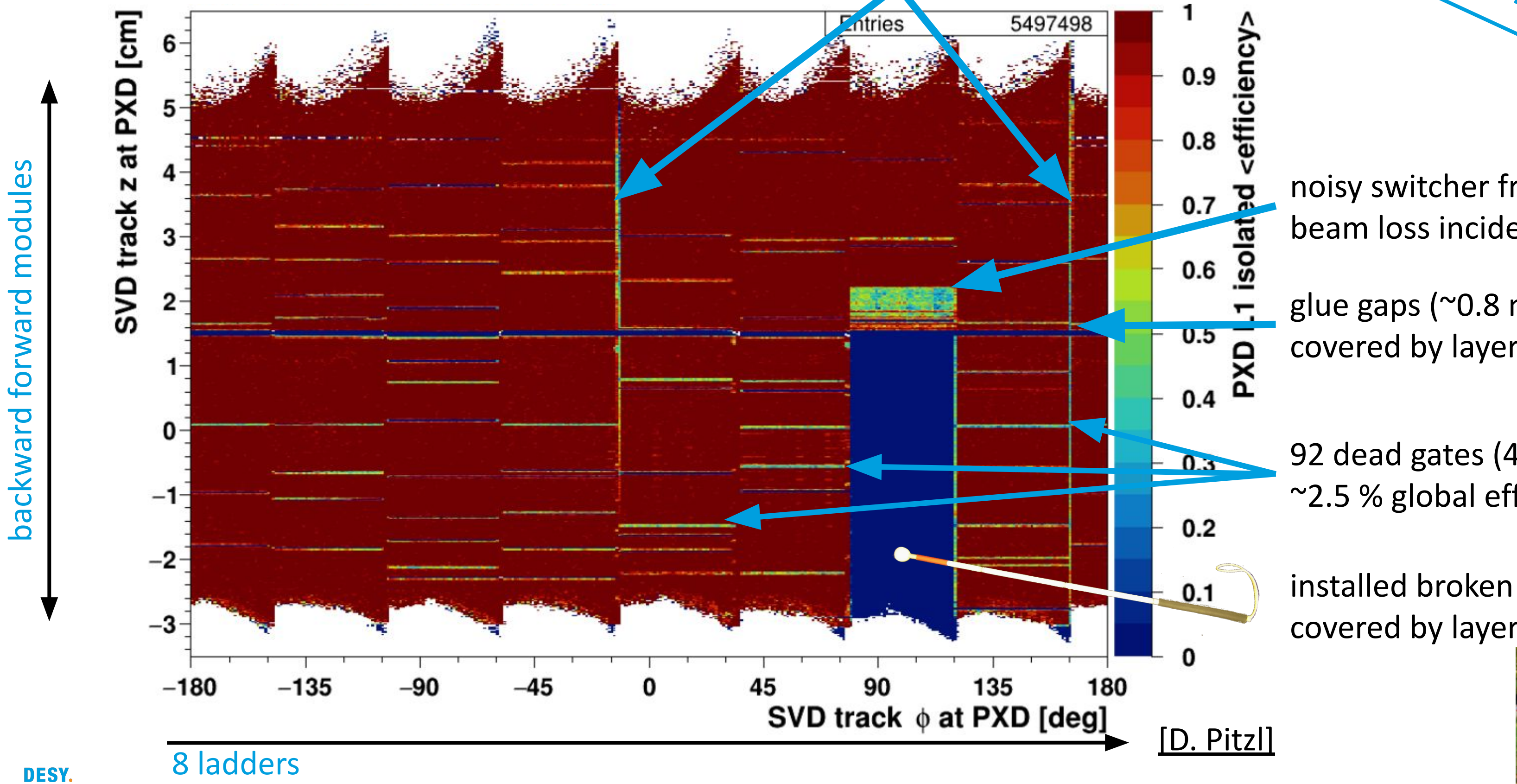
SNR MPV




exp. 14, run 2129

# PXD Performance

## Pixel hit efficiency in layer one (via SVD tracks)

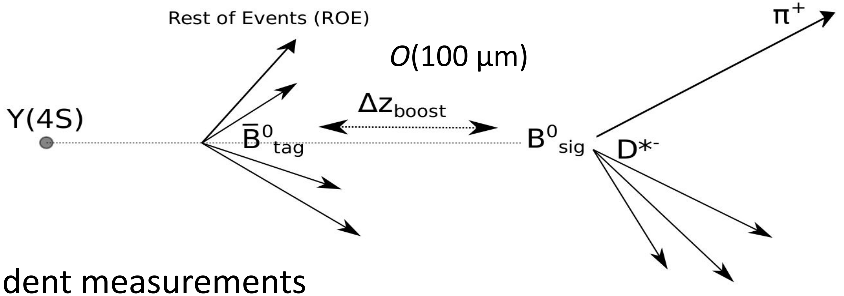



good regions: ~98% hit efficiency

[D. Pitzl]

# VXD Performance

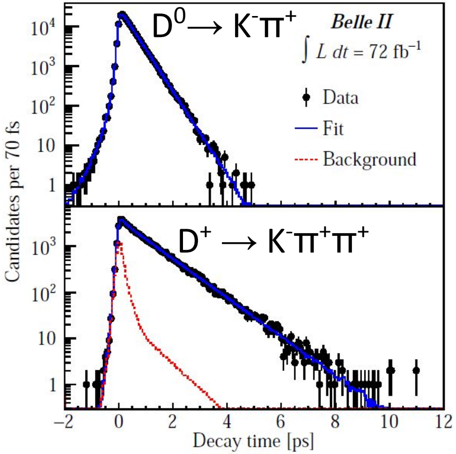
## Impact parameter resolution and lifetimes

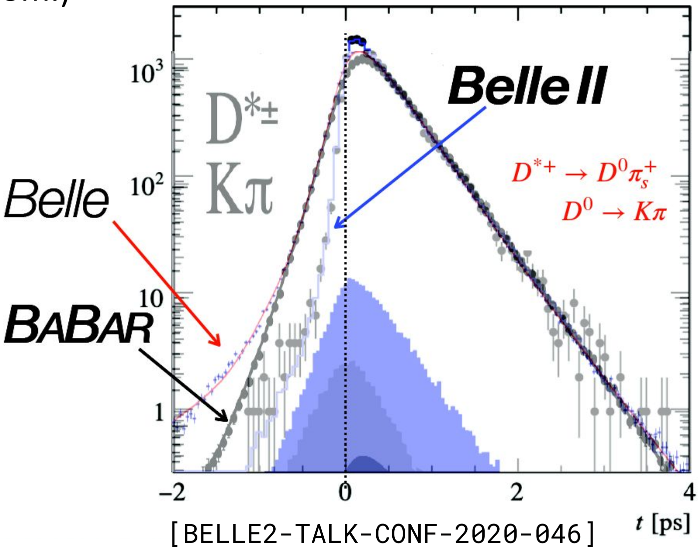



- precise measurements of decay vertices crucial for time dependent measurements
- example D meson lifetime measurement: [arXiv:2108.03216]
  - Belle II proper time resolution ~2x better than Belle
    (despite SuperKEKB operating at smaller Lorentz boost compared to KEKB/Belle)
  - precision better than world average ⟶ yet to be improved (stat. dom.)
  - largely thanks to PXD and smaller beam pipe diameter

$$\tau(D^0) = \quad 410.5 \pm 1.1\,(\mathrm{stat}) \pm 0.8\,(\mathrm{syst})\ \mathrm{fs}$$
$$\tau(D^+) = 1030.4 \pm 4.7\,(\mathrm{stat}) \pm 3.1\,(\mathrm{syst})\ \mathrm{fs}$$

[arXiv:2108.03216]



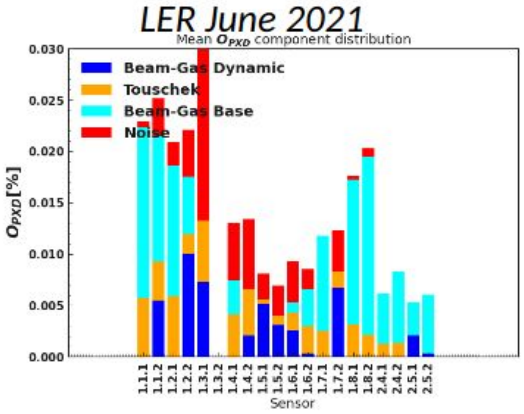




[BELLE2-TALK-CONF-2020-046]

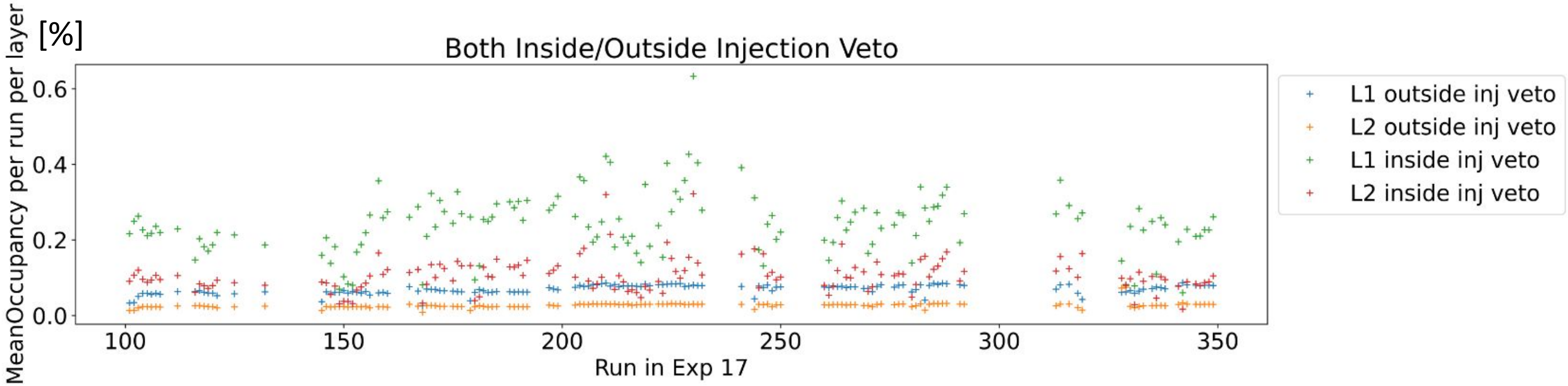
# Operational Challenges

## Backgrounds

- what is background?
  - synchrotron radiation,
  - lost electrons or whole beams inducing secondary particles with pipe or restgas
  - ...
- why important?
  - can deteriorate performance (fake hits)
  - contributes to occupancy (in particular during injections) ⟶ 1%/3% limits not hit yet (on avg)
  - contributes to irradiation ⟶ aging (slow irradiation) or even damages (fast irradiation)




[S. Stefkova]

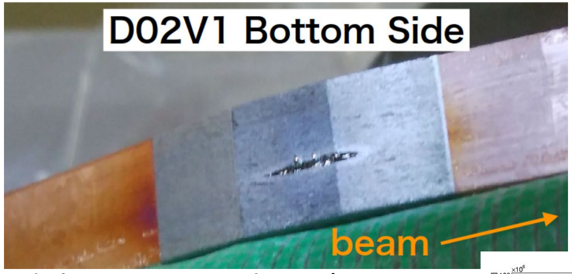


# Operational Challenges

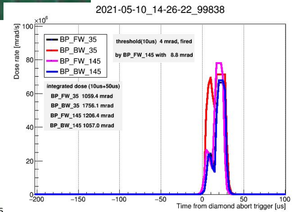
## Beam loss events

- reasons not fully clear
  - unstable beams due to dust particle collisions?
  - glitches of accelerator components?
- not always detected early enough to safely dump beams (min 40 μs delay error ⟶ dump)
  - collimator damage, QCS (superconducting final focussing magnets) quenches, DCU damages, …,

LER collimator damage on Nov 15 '20

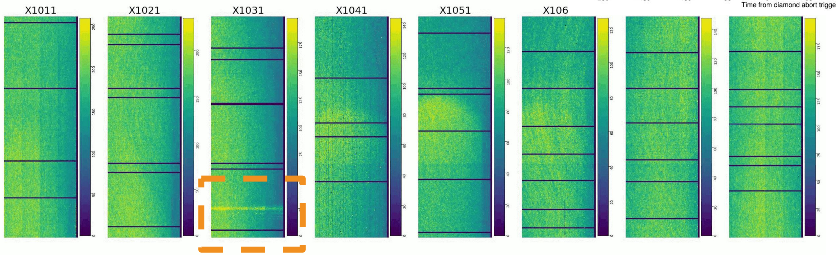



DCU Dose

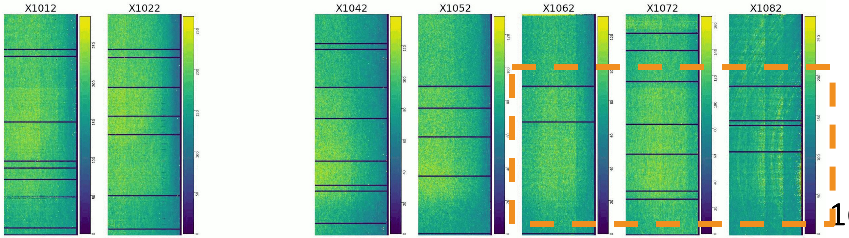



## impact on PXD

- large instant radiation dose before beam could be dumped
  (~40 μs splash, total dose unknown)
- permanent damage: dead switcher gates
- exact failure mechanism still under study
  - radiation studies at MAMI: problem localized in the switcher at clear & gate regulators (cf Jannes' talk)
- mitigation procedures still under study
  - SuperKEKB + Belle II: earlier detection ("CLAWS" cf Hendrik's talk) and faster beam dump
  - PXD: possibility of fast emergency power off
    (could also do harm on its own)
  - (updated switcher design)




layer one occupancy before/after beam loss in May '21



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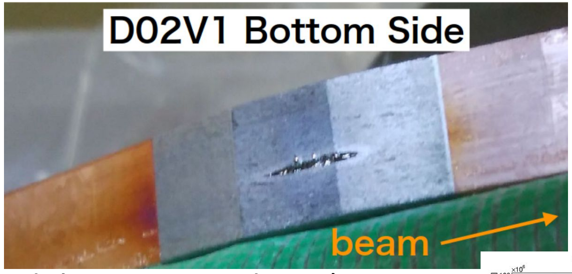
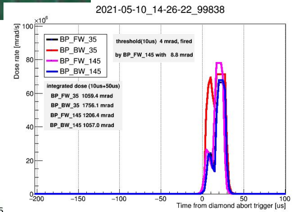



DCU Dose

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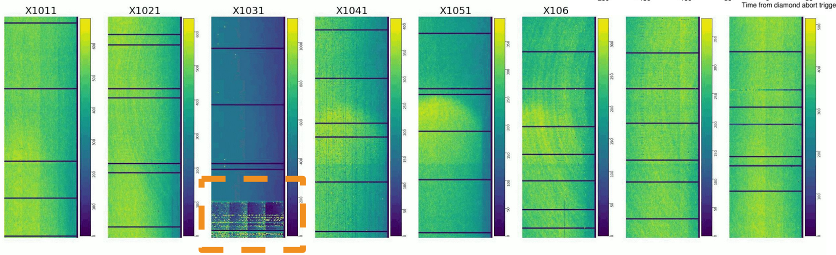


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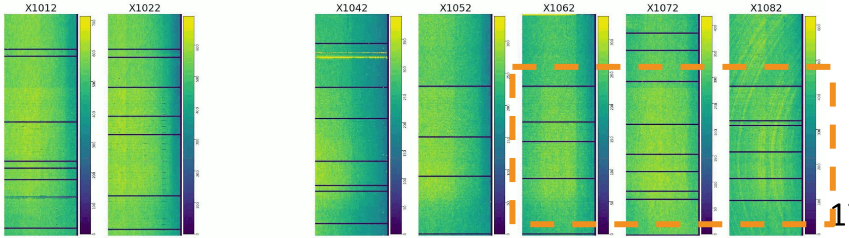
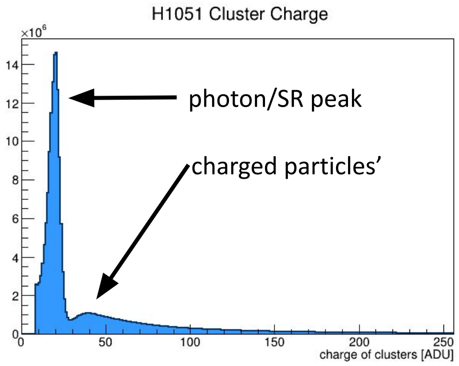


# Operational Challenges

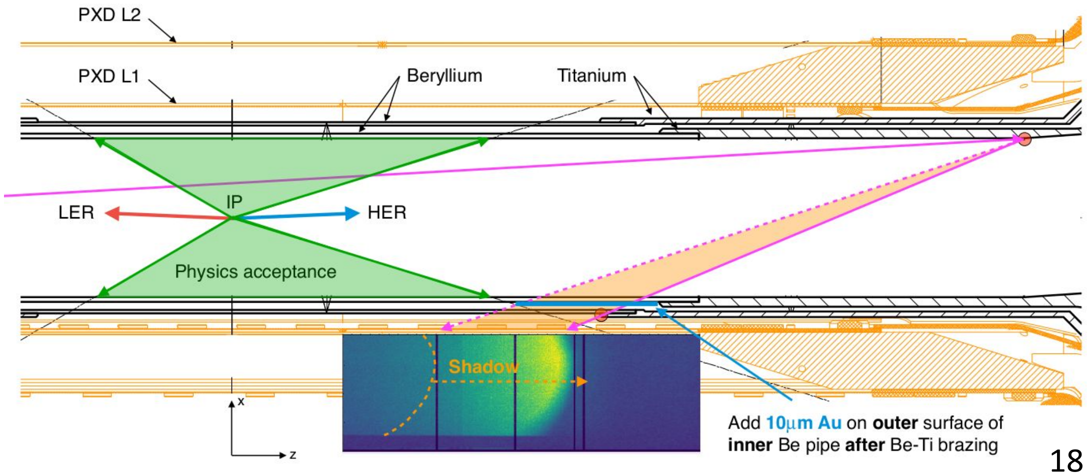
## Synchrotron radiation

- interaction region designed to avoid direct SR photons hitting central Be beam pipe
- still: large SR background observed in several -x modules after change of optics
  - dominated by low energy, single pixel clusters (<10 keV)
  - appear during HER injections (→ large betatron oscillations during cooldown)
  - origin: back-scattering photons from SR fan hitting +x edge of Ti beam pipe
- results in high localized hit density
  - inhomogeneous module irradiation
  - deterioration of clustering and tracking




## mitigation

- small modification of HER beam orbit
- new modified beam pipe w/ additional gold plating to be installed with PXD 2022 update



# Operational Challenges

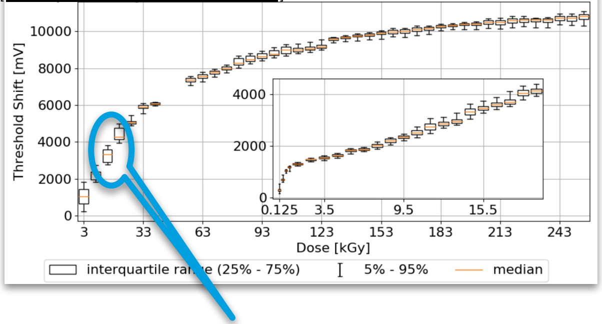
## Radiation effects: threshold shift

- radiation damages oxide layer
  - causes shift of MOSFET threshold voltage
  - compensated by continuous adjustment of gate voltag

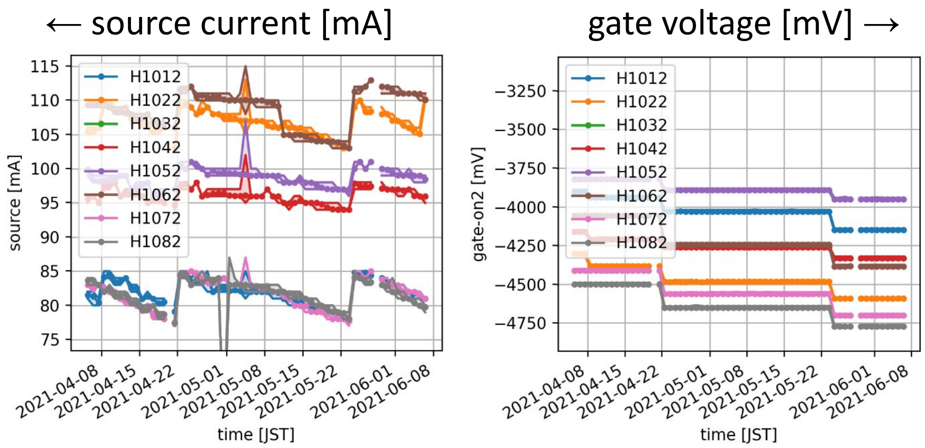
$$\mathrm{MPV} \sim g_q \sim \sqrt{I_\mathrm{D}} \sim (U_\mathrm{Gate} - U_\mathrm{Threshold})$$

- X-ray radiation campaign @ 200 krad/h:

[doi.org/10.1016/j.nima.2020.163522]

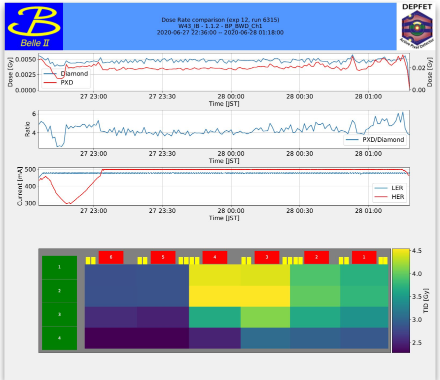



- integrated dose in PXD
  - rough estimate < 20 kGy until end of 2020
  - more precise/2021 measurements in progress

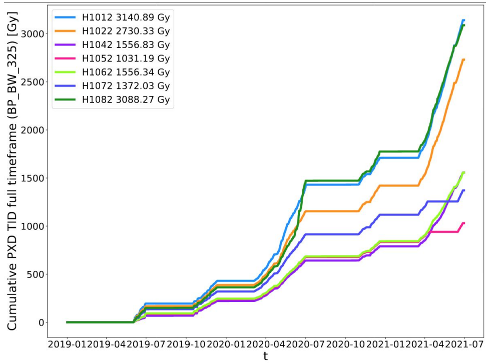



## TID per module

- estimate via DCU and (mean) PXD occupancy




[H. Schreeck]

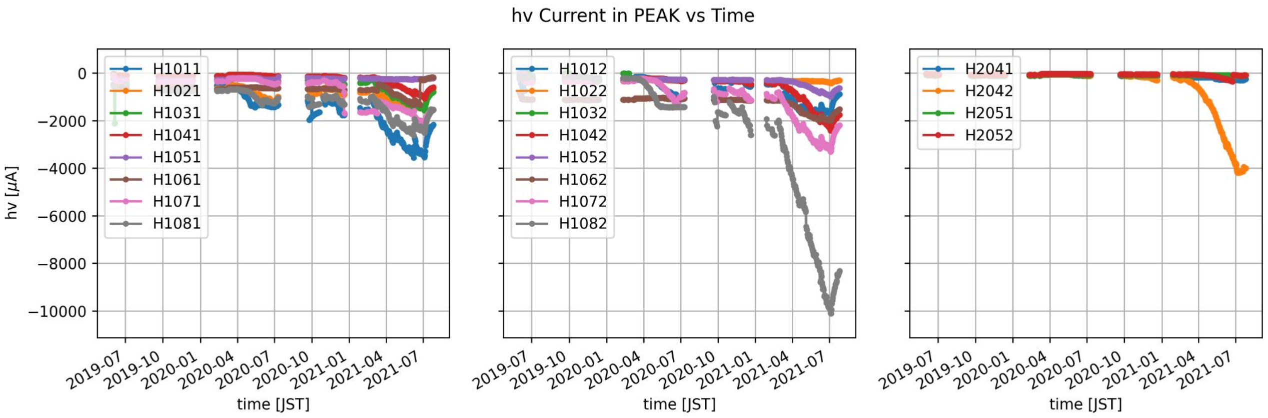



[Y. Buch]

# Operational Challenges

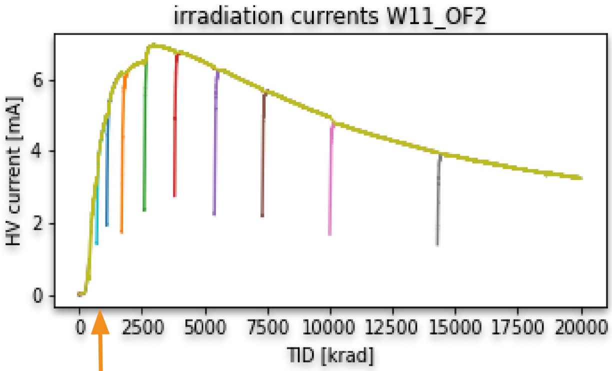
## Radiation effects: increasing hv currents

- observe increase in HV currents of some modules
  - some modules reached power supply limits
  - can not reach set voltage ⟶ worse SNR and efficiency
- some annealing during *(beam off / HV on)* and *(beam on / HV off)* times
- expect currents saturate at certain dose
- mitigation by modifying power supplies ⟶ higher current limits




beams off

lab x-ray irradiation studies



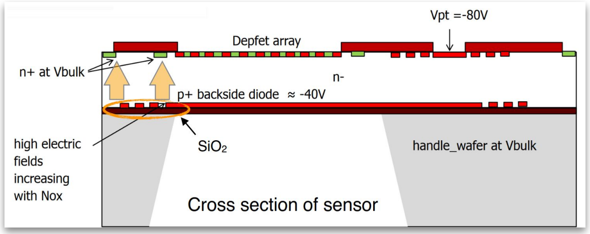

[M. Schwickardi]

PXD modules around here

(cf Georgios' talk)

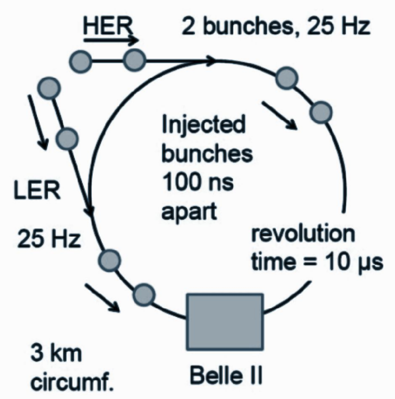
## interpretation

charge-up effect at handle wafer bond oxide and avalanches at bulk

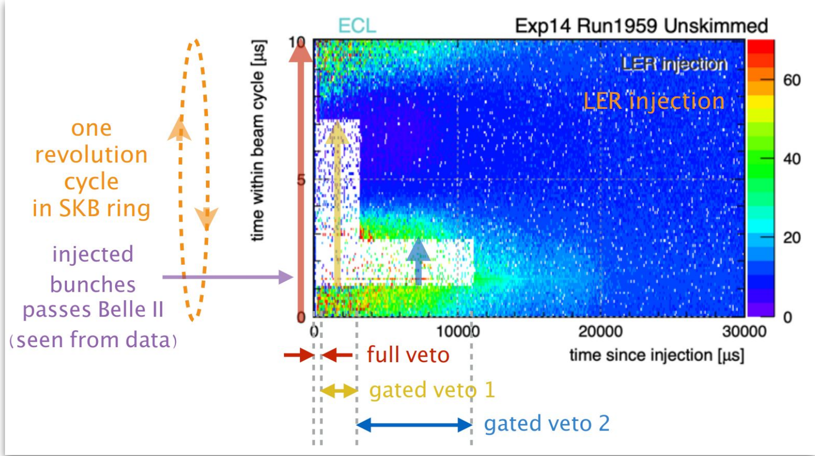


# Operational Challenges

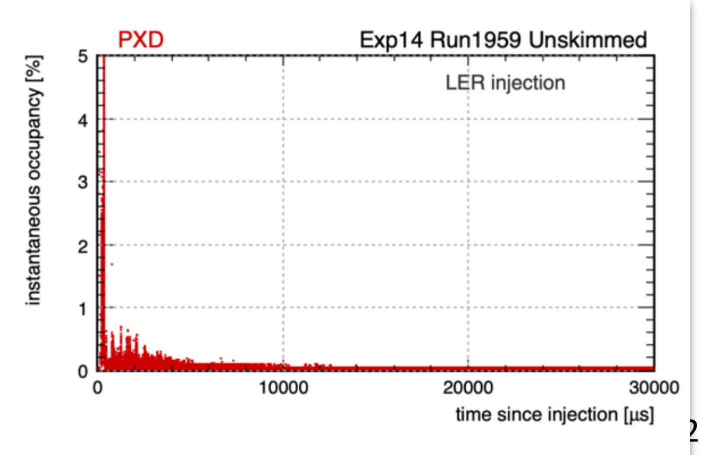
## Backgrounds: injection




- SuperKEKB is operated in top-up mode: continuous injection up to 50 Hz
  - at design luminosity, Touschek effects limit beam lifetime to few mins
  - injected bunches produce high background rates, damping takes few ms
  - mitigation: full veto (all BII detectors) + gated veto (all but PXD)
- PXD cannot halt data collection (default operation):
  - 20 µs integration time vs 10 µs beam revolution time
  - injection spikes can saturate DAQ → not yet critical (partial data loss at sub-permille level)
  - goal is to avoid by operating in PXD gated mode → avoid noise of passing injected bunch




PXD integrates over

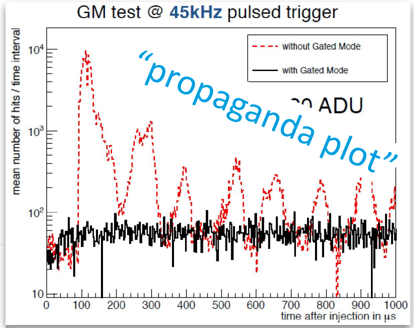


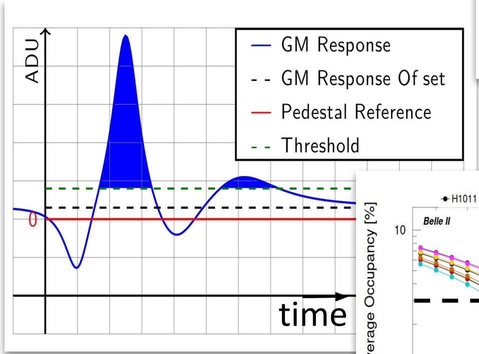
# Operational Challenges

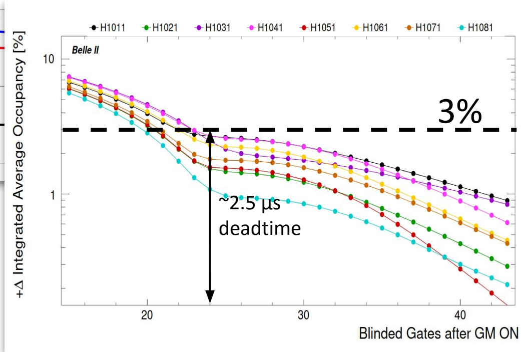
## Gated mode

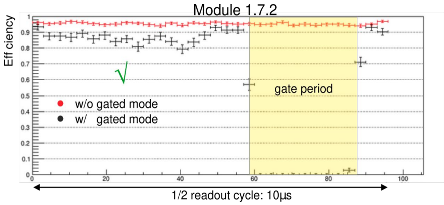
- "gated mode" can blind PXD modules when noisy bunches pass
  - newly created charges are not collected
  - charges at internal gate are preserved

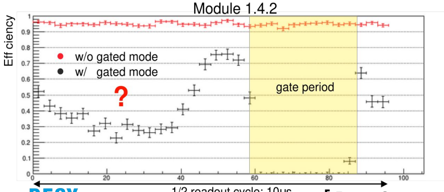
- challenges:
  - switching into gated mode results in pedestal fluctuations
    - produce noise on their own
      $\longrightarrow$ still larger than injection noise
  - synchronization with injections
  - optimizing module parameters for GM




DESY.

[B. Spruck]

[real GM "efficiencies"]

- 2021 dedicated runs for PXD GM studies
  - inconsistent module behaviour
  - GM not ready yet
    nor useful for current injection conditions

[R. Karl]

"gaited mode"

# Outline

Introduction

- SuperKEKB, Belle II,  and the Belle II Vertex Detector

The Pixel Vertex Detector (PXD)

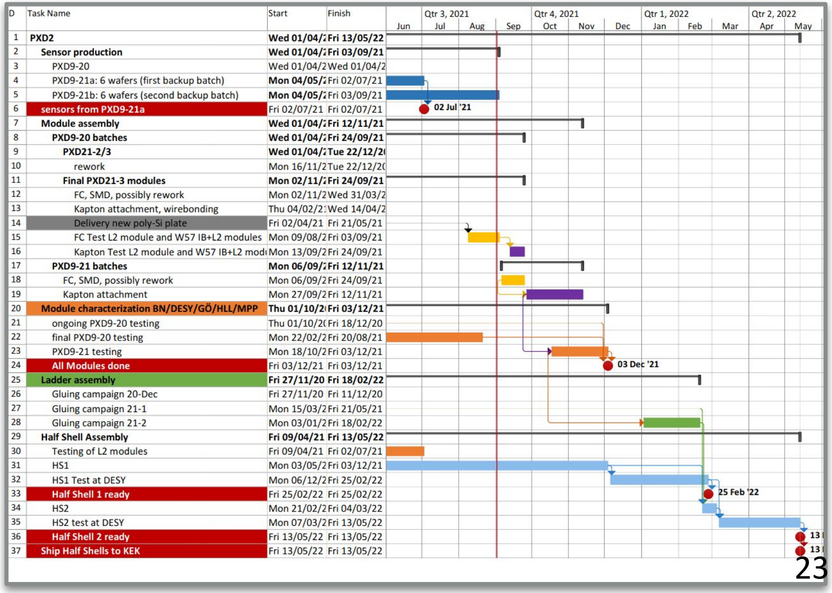
- Working Principles
- PXD Modules and Calibration
- PXD Detector

PXD in Belle II in 2021

- PXD Operation and Performance
- VXD Performance
- Operational Challenges: backgrounds, beam-losses, irradiation and aging

PXD2 2022 Upgrade

- Future of PXD



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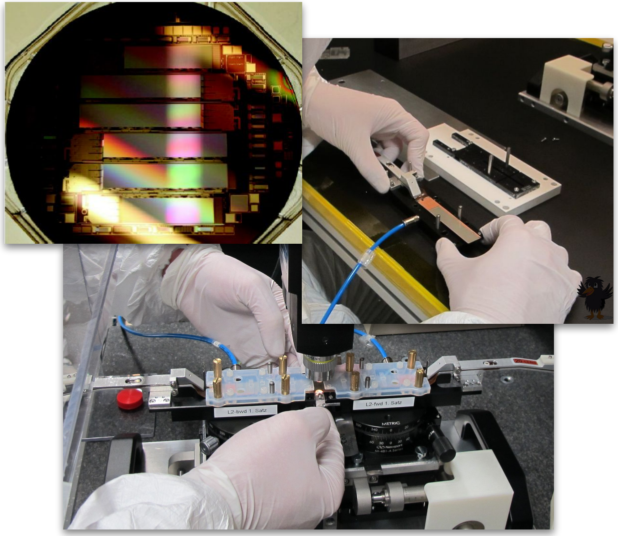
| 34 | HS2 | Mon 21/02/2 | Fri 04/03/22 |
| 35 | HS2 test at DESY | Mon 07/03/2 | Fri 13/05/22 |
| 36 | **Half Shell 2 ready** | Fri 13/05/22 | Fri 13/05/22 |
| 37 | **Ship Half Shells to KEK** | Fri 13/05/22 | Fri 13/05/22 |

# PXD 2022

## Building a 2nd PXD



### PXD remains incomplete

- only 10/20 ladders (8/8 inner, ½ broken, 2/12 outer) installed
  - not enough good modules available pre-2018
- good vertexing performance so far
  - but not guaranteed for higher future lumi ⇒ higher backgrounds

### ongoing efforts to build 2nd, complete PXD2

- same technology but improved manufacturing processes + time
- module production & HS assembly & testing ongoing (with some delays)
- PXD2 to be installed during next long shutdown 2022+X ($L_{int}$ , SKB safety, uncertainty, delays w/ BP production)

**modules:** (x 40+)
assembly
testing +
characterization

→ **ladders:** (x 20+)
gluing
testing

→ **half shells:** (x 2)
assembly
testing

→ **VXD:**
PXD to beam pipe
PXD+SVD marriage
testing
installation

# PXD 2022

## Status

x 40+

**modules:**
- assembly
- testing + characterization

x 20+

**ladders:**
- gluing
- testing

x 2

**half shells:**
- assembly
- testing

**VXD:**
- PXD to beam pipe
- PXD+SVD marriage
- testing
- installation

- several production and characterization campaigns in 2021
- still more modules needed & are being produced at HLL/MPP
- characterization campaign foreseen in fall

- enough (good) ladders for HS1
- glueing campaign of new modules for HS2 foreseen for January

- first dummy HS (w/ dead modules) was produced at MPP and tested at DESY
- several issues observed and investigated
- 2nd dummy HS in preparation → final dress test

- assembly of hot HS1 stalled to await results of dummy HS studies → planned to be finished by December
- HS source setup teststand under commissioning at DESY
- HS2 assembly to be finished in early spring 2022

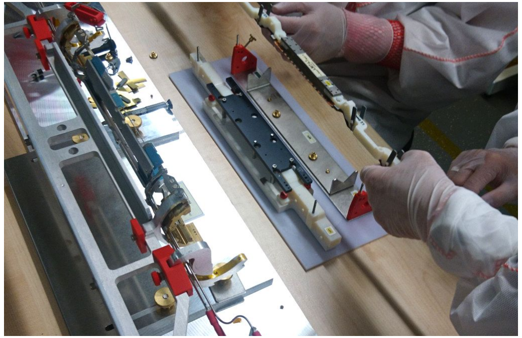
- delays but on track for installation at KEK in July 2022
- long shutdown under discussion: balance of interest w/ lumi collection and machine studies

**L1 ladders**

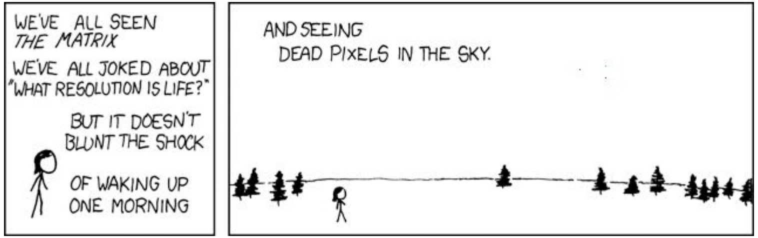
| | | | | |
|---|---|---|---|---|
| (L35 | W04_IF | W04_IB | C/D | DESY) – water damage |
| L37 | W05_IF | W42_IB | B/A | KEK |
| L56 | W37_IF | W06_IB | Ph II/C | |
| L57 | W11_IF | W46_IB | B/B | |
| L58 | W10_IF | W05_IB | A/A | |
| L61 | W52_IF | W55_IB | A/A | |
| L62 | W53_IF | W53_IB | B/B | |
| L63 | W54_IF | W54_IB | A/A | |
| L64 | W56_IF | W52_IB | A/A | |
| L65 | W59_IF | W56_IB | A/A | |

**L2 ladders**

| | | | |
|---|---|---|---|
| L42 | W02_OF1 | W03_OB1 | ?/B |
| L44 | W32_OF1 | W32_OB2 | A/A |
| L45 | W33_OF1 | W42_OB1 | A/A |
| L46 | W33_OF2 | W46_OB2 | A/A |
| L47 | W46_OF1 | W45_OB2 | A/A |
| L48 | W03_OF2 | W46_OB1 | A/A |
| L49 | W08_OF2 | W08_OB1 | A/A |
| L50 | W46_OF2 | W08_OB2 | A/A |
| L51 | W45_OF1 | W42_OB2 | A/A |
| L52 | W43_OF1 | W33_OB1 | A/A |
| L53 | W05_OF1 | W04_OB1 | A/A |
| L54 | W45_OF2 | W10_OB1 | A/A |
| L55 | W37_OF1 | W37_OB1 | Ph II/I |



# Conclusion

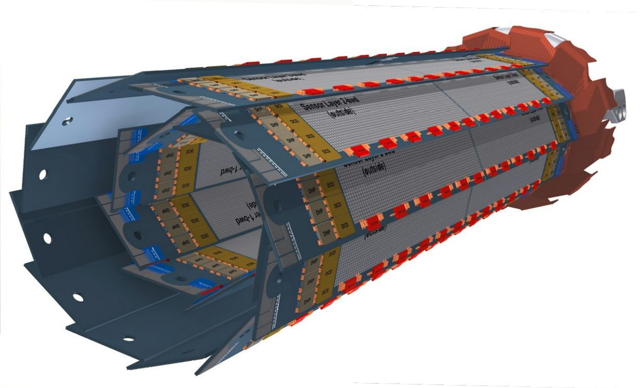



## PXD status

- very good performance of PXD and stable operation in 2020/2021
- setbacks from beam loss events with high instantaneous dose rate
  - damages to detector
  - so far have remained out of full control and biggest risk for detector
- improved / automated operation and calibration procedures for reduced load on shifters
- still lot of effort needed to operate detector, in particular
  - in face of further damages from SKB beam-losses
  - in face of many experienced scientists having left PXD in 2021
- big thanks to those who make it possible!

## PXD future

- great efforts from various institutions to prepare new PXD
  - remains difficult even with experience from PXD1
  - also here, knowledge transfer and COVID pose big challenges
- nonetheless still on track for installation in summer 2022

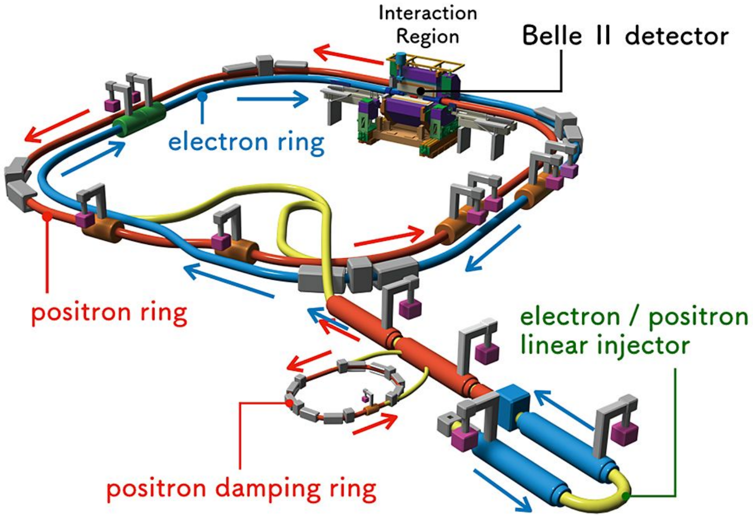


# Backup

# Setting the Scene

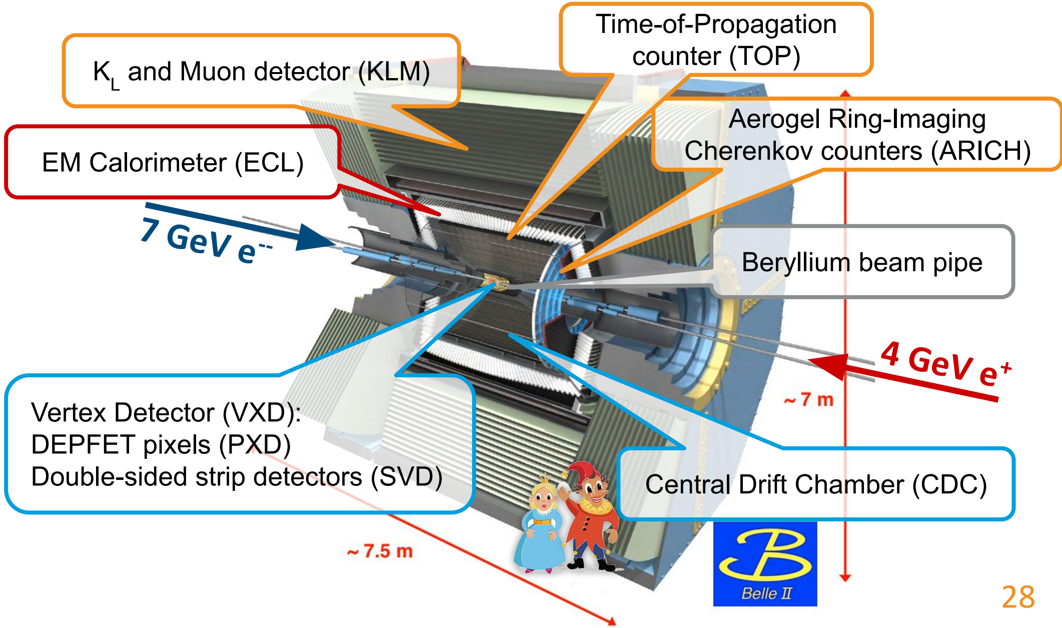
## Super KEKB

- asymmetric $e^+e^-$ collider
- $E_{cm} = M_{Y(4S)} \approx 10.58$ GeV ⇒ “B factory”
- goal: $L_{peak} = 6 \times 10^{35}$ cm$^{-2}$s$^{-1}$
  - “nano-beam” scheme and increased currents
  - record $3.12 \times 10^{34}$ cm$^{-2}$s$^{-1}$ on June 22, 2021




## Belle II

- target $L_{int}$: 50 ab$^{-1}$ by ~2030/2031
  - physics data-taking w/ full setup since March 2019
  - 213 fb$^{-1}$ recorded by end of 2021 ab
- upgraded trigger rate: 30 kHz
- upgraded detectors



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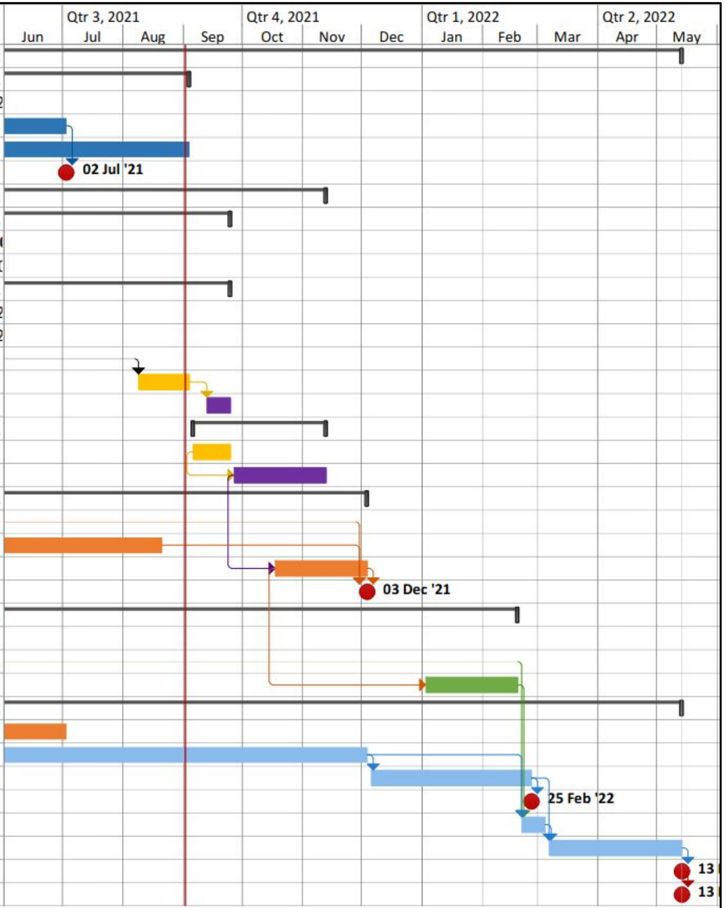
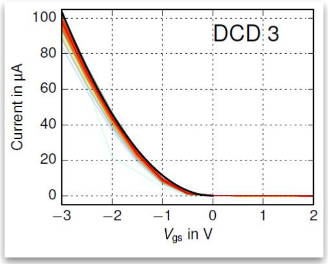
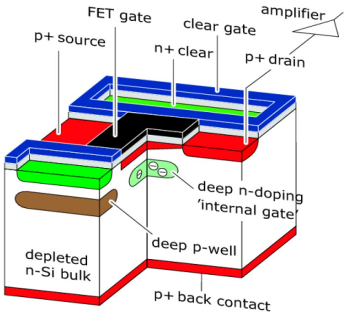


# PXD Working Principle

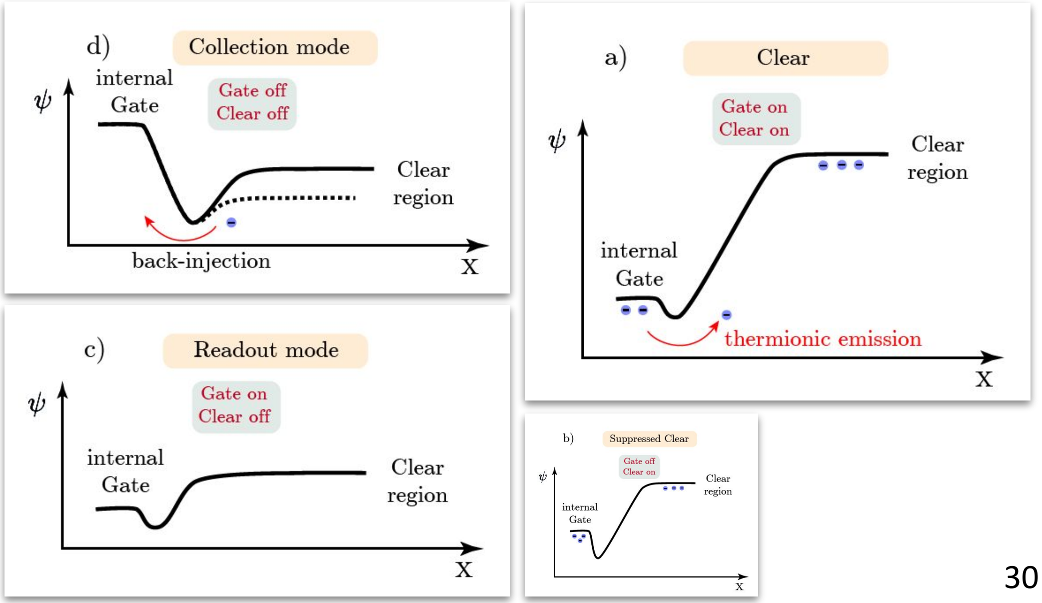
## DEPFET: operational States

- pixel state changed by regular change of *gate* and *clear* voltages
  - gate on/off (-2.5 V / 3 V vs Source)
  - clear on/off (19 V / 5 V)




- **charge collection** *gate off, clear off*:
  - charges drift to internal gate
  - no drain current
- **readout** *gate on, clear off*:
  - new charges drift to clear
  - stable drain current can be read out
- **clear** *gate on, clear on*:
  - charges drift from internal gate to clear

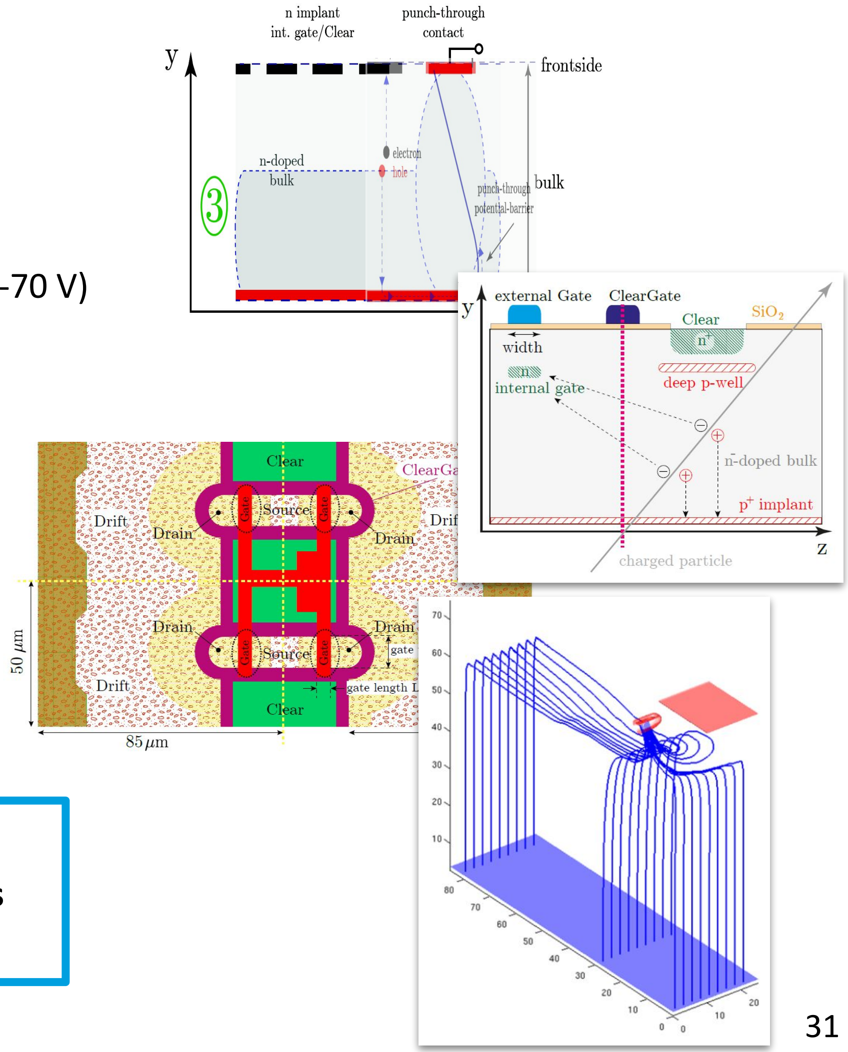



-  fact:
  - 4th configuration state also has application

# PXD Working Principle

## DEPFET: depletion and field shaping

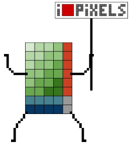
- bulk depletion
  - negative backside HV via frontside punch-through contact (~-70 V)
- field shaping
  - *deep p-well* prevents free e⁻ drift to clear
  - *clear gate* potential barrier between internal gate and clear
  - *drift voltage* to guide free e⁻ to internal gate
  - ...
- *bulk* ($n^+$, V+) and *guard* ($p^+$, V-)
  - structures around whole matrix to keep external charge carriers out




“it’s complicated”:

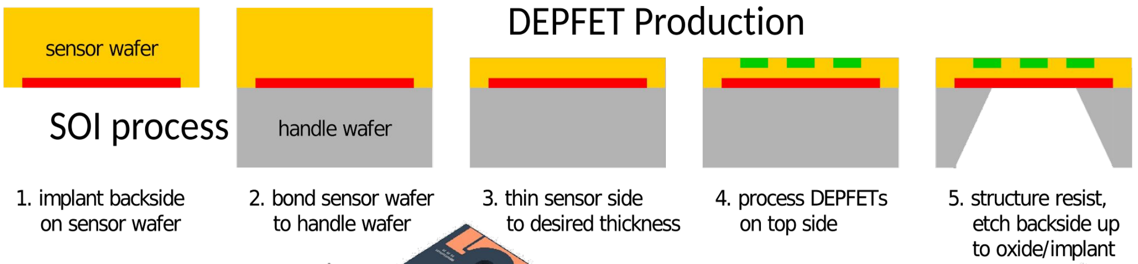
➢ **PXD modules operated with 24 different voltages**
(for pixel matrix and ASICS)

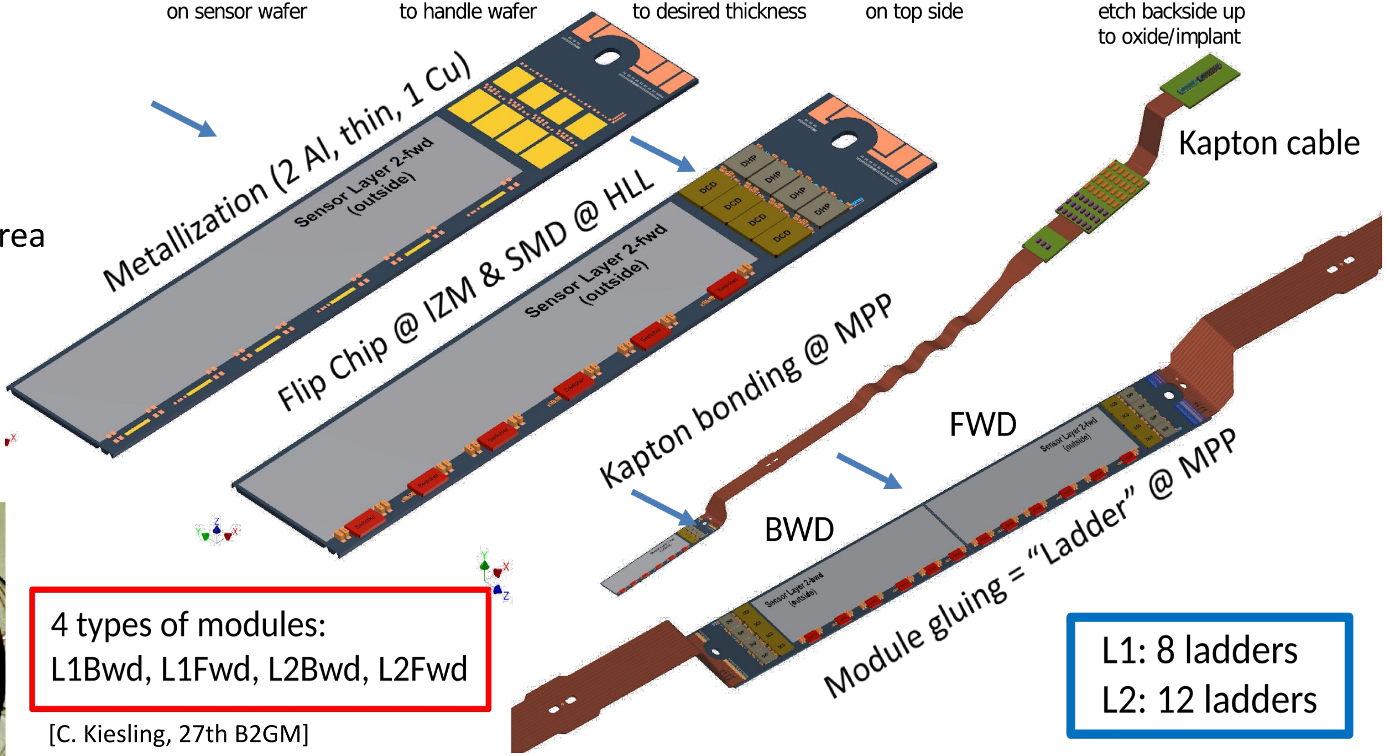
# PXD Modules




## Production

- 250 x 768 pixels per module
- pixel pitch varies in z-direction
  50 x 55 - 85 µm$^2$
  - best resolution in Belle II forward direction (at 45° incident angle)
- thinned to 75 µm in sensitive area
- mechanically self-supporting
  - thicker end of stave and (perforated) frame
  - host readout and control ASICS

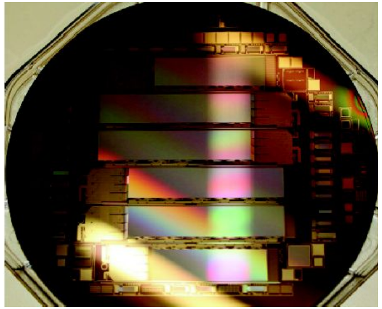



4 types of modules:
L1Bwd, L1Fwd, L2Bwd, L2Fwd

[C. Kiesling, 27th B2GM]

L1: 8 ladders
L2: 12 ladders

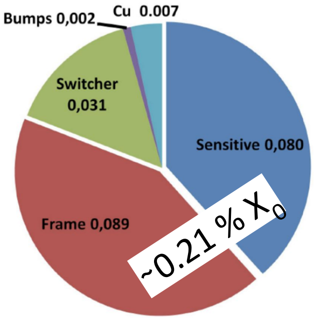


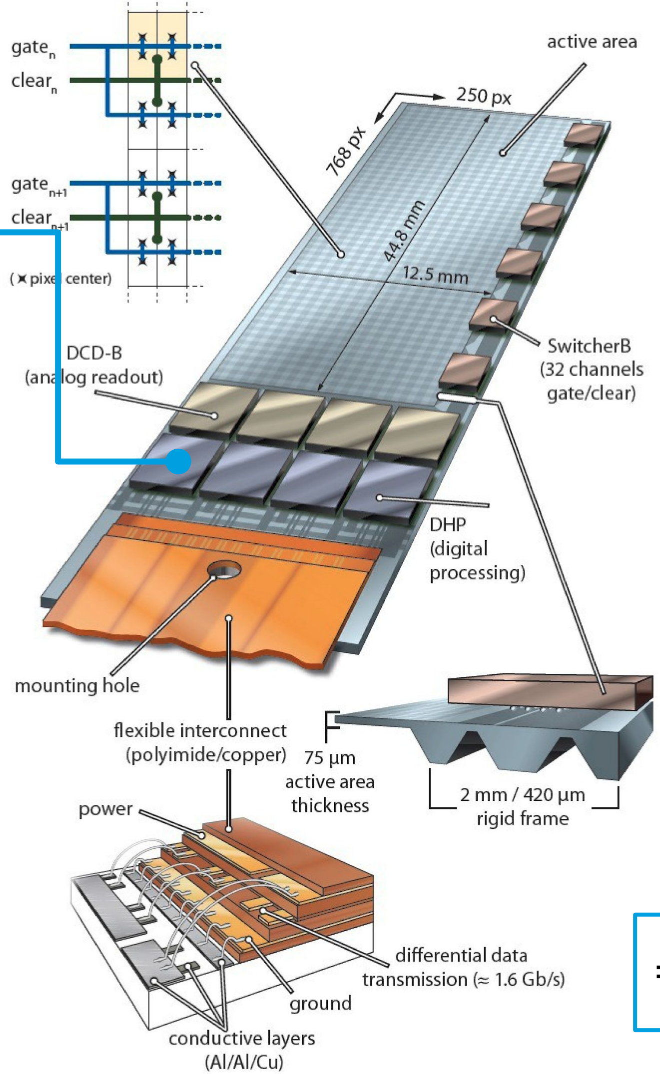
# PXD Modules

## ASICS

**4 x DHP: Data Handling Processor**

- sensor, timing, trigger control
- **data processing and transmission**
  - pedestal correction
  - data reduction (zero suppression)
  - transmission at 1.6 Gbit/s
- TSMC 65 nm
- size 4.0 x 3.2 $mm^2$
- rad. hard. provd (100 Mrad)




**6 x Switcher: Row Control**

- **gate and clear signals**
  - 32 channels control 4 rows each ("gates")
- fast HV ramping for clear
- AMS/IBM HV CMOS 180 nm
- size 3.6 x 1.5 $mm^2$
- rad. hard proved (36 Mrad)

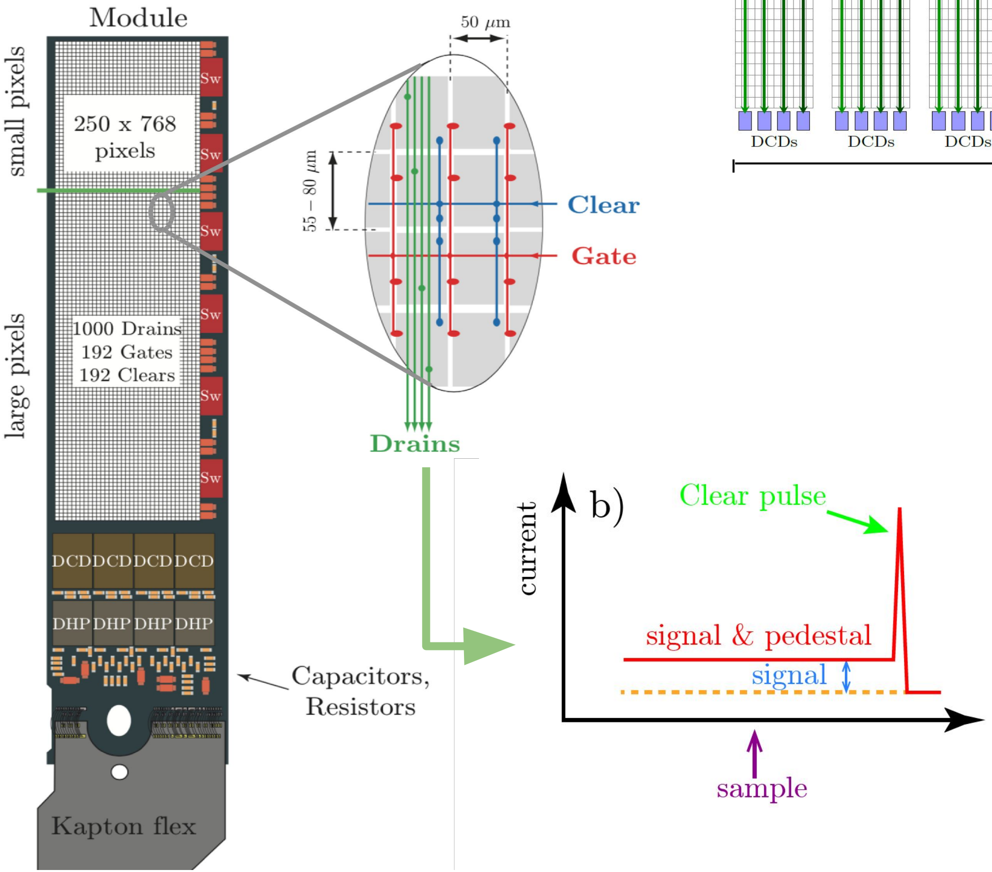
**4 x DCD: Drain Current Digitizer**

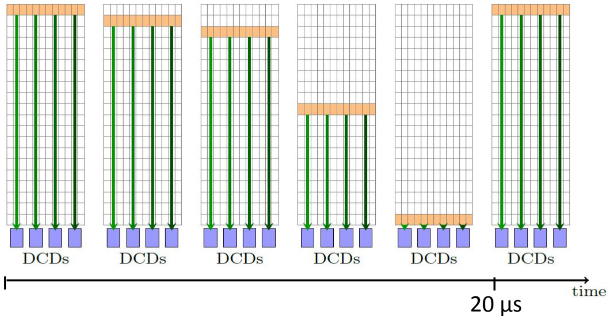
- **pipeline 8-bit ADC per channel**
- 256 input channels
- 92 ns sampling time
- UMC 180 nm
- rad. hard proved (10 Mrad)

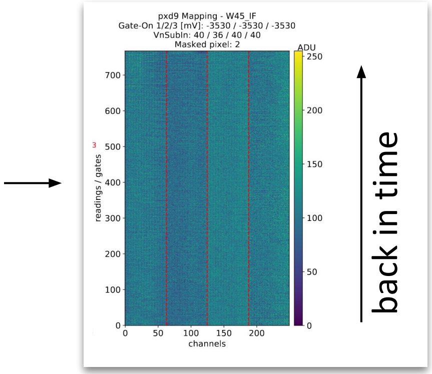
⇒ all 3 custom PXD designs

# PXD Modules

## Readout scheme




rolling shutter mode

- signals read gate by gate
- read-clear cycle in ~100 ns
  - full integration time 20 μs (1 “frame”)
  - twice SuperKEKB revolution time

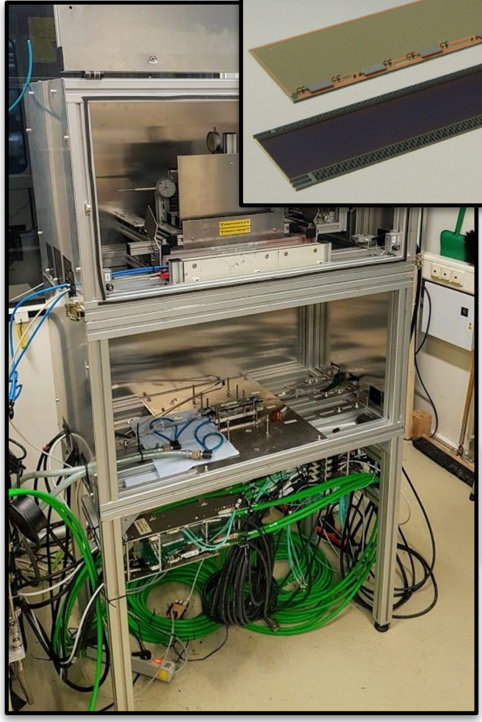
sampling:

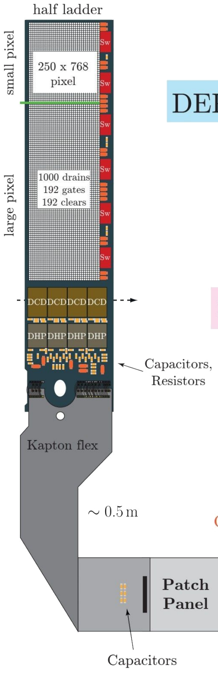
- drain currents measured once
- pedestal correction on DHP
- zero suppression:
  - only signals above threshold send out

# PXD Module Operation

## Readout and control

(pictures: testsetup at DESY)





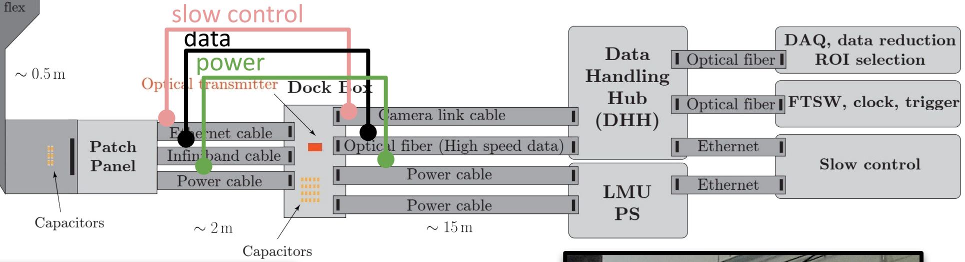

Data Readout Chain

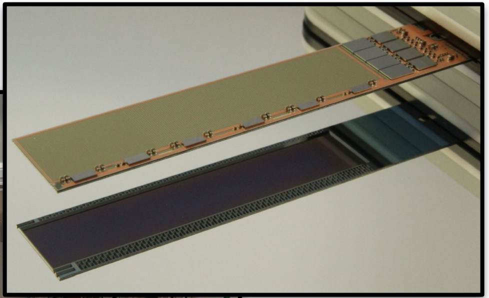
DEPFET → DCD → DHP → DHH → ONSEN → Belle II DAQ

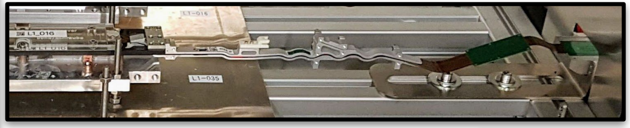
Module control

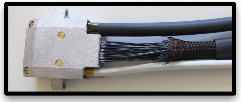
Slow Control GUI → DHH → DHP → DCD, Switcher

Slow Control GUI → PS



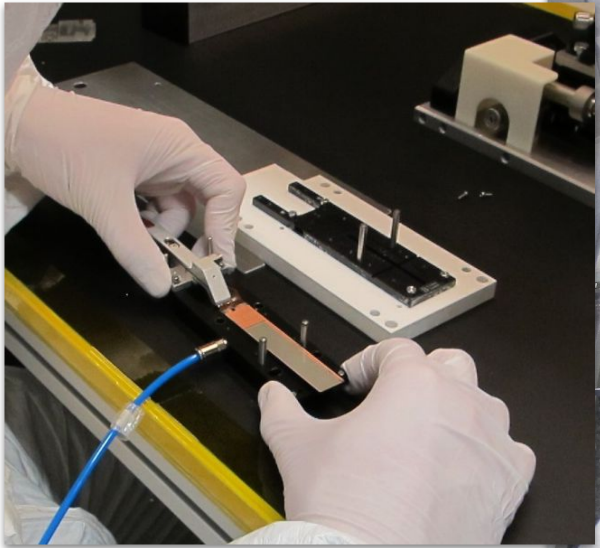


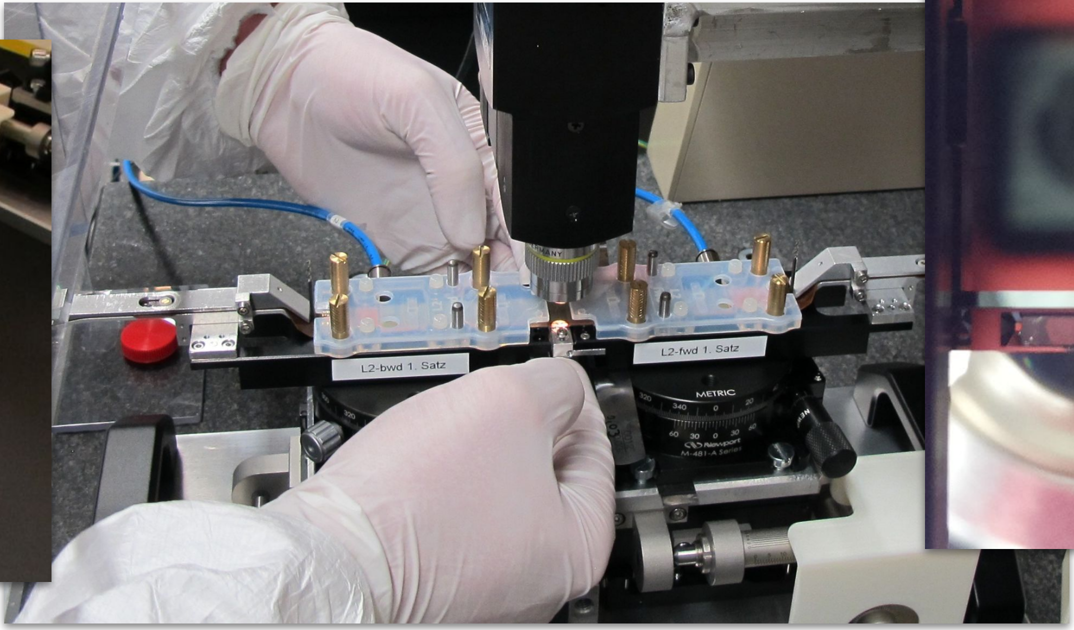


# Module Production

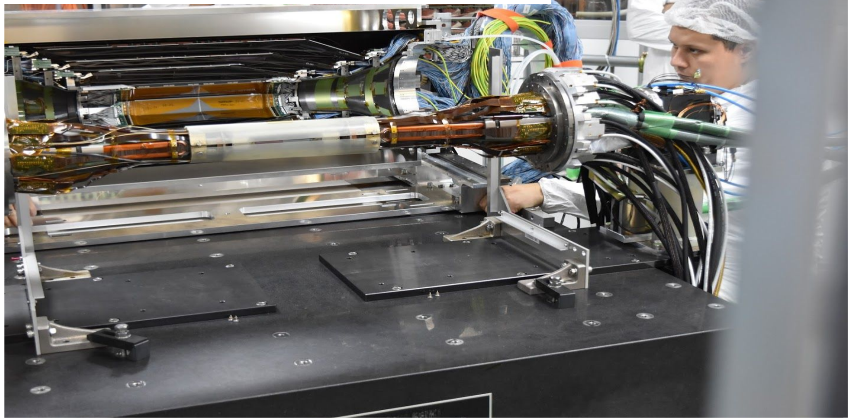
## Ladder gluing

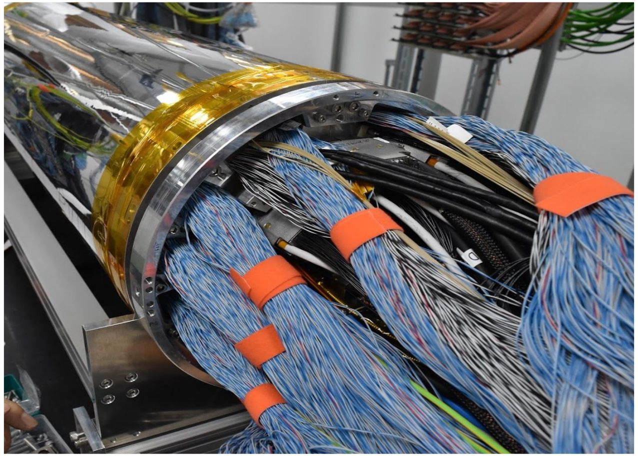
- special jig for module handling, glue dispersion, alignment under microscope
- ceramic stiffening rods on backside
- critical step in PXD1 production
    - revised procedure for PXD 2022 avoids touching matrix side of sensors

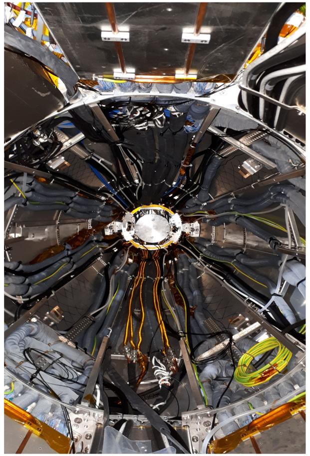


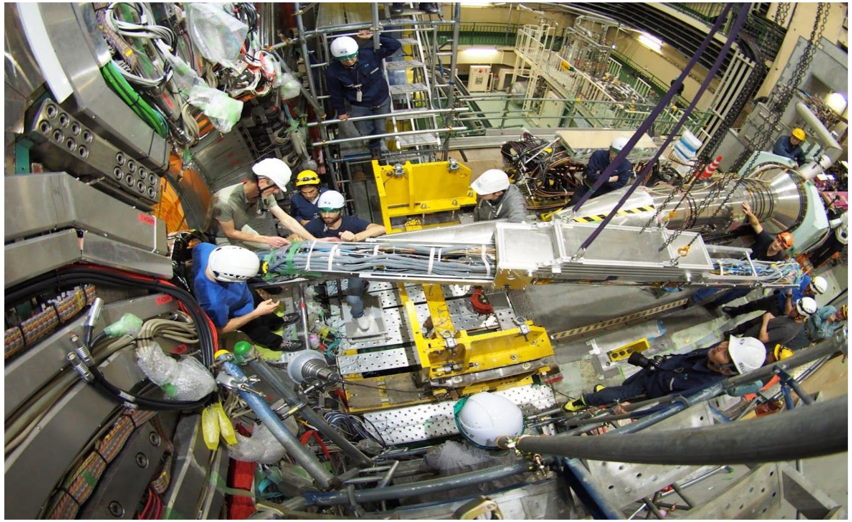


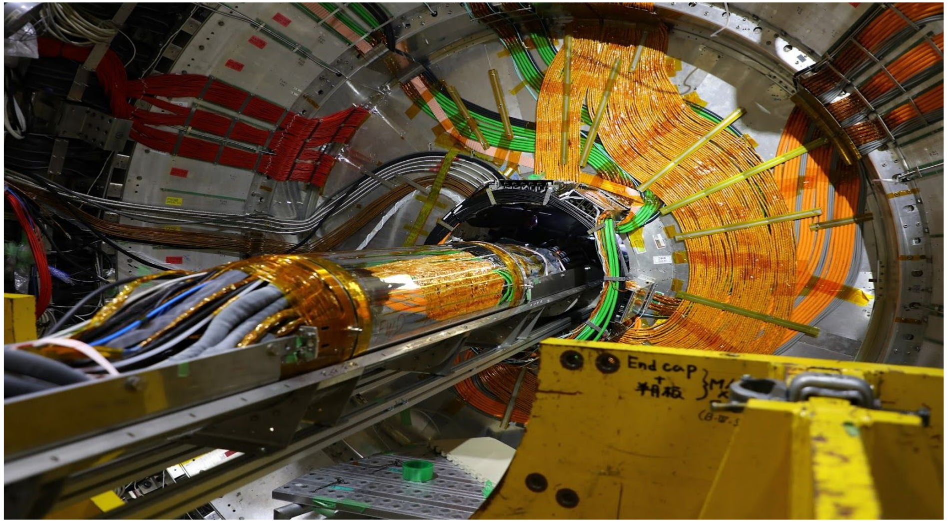

# VXD Installation 2018





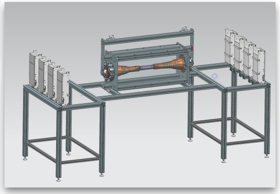


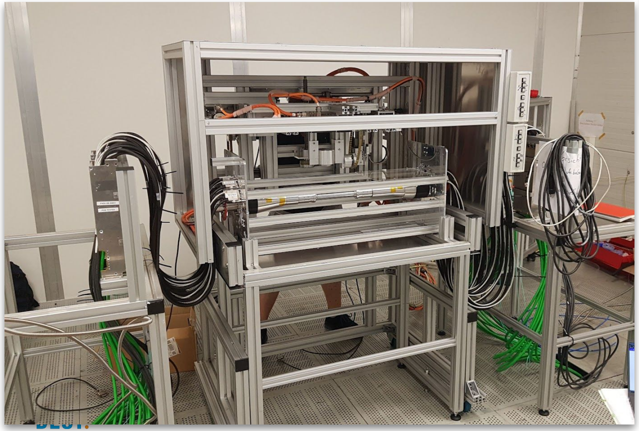


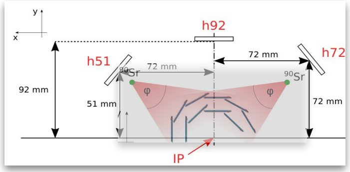


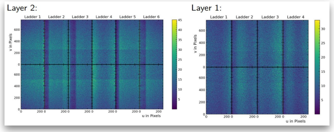
# PXD 2022

## Activities at DESY: half shell test preparations

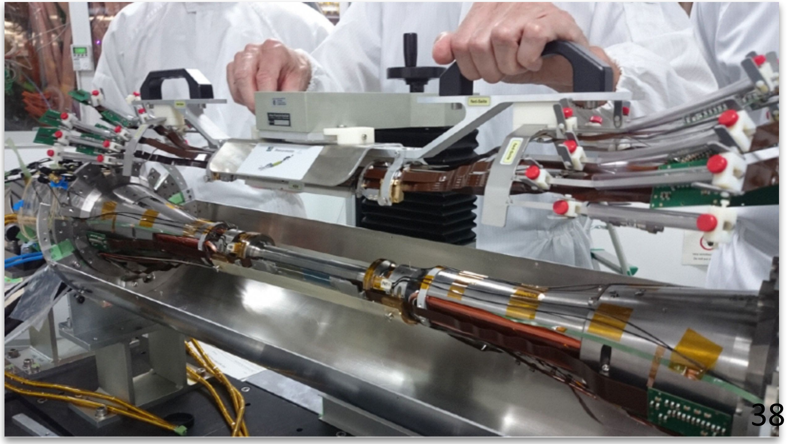







- from summer / fall 2021 in Hall-West clean room
- preparation ongoing
  - infrastructure, services, mechanics, simulations, ...
- tests to include
  - mechanical studies (mounting half shells on beam pipe mockup)
  - module / half shell operation and calibration
  - irradiation studies with new radiative source setup
  - temperature / “dry environment” studies
  - ...



# VXD Performance

## Impact parameter and beam profile

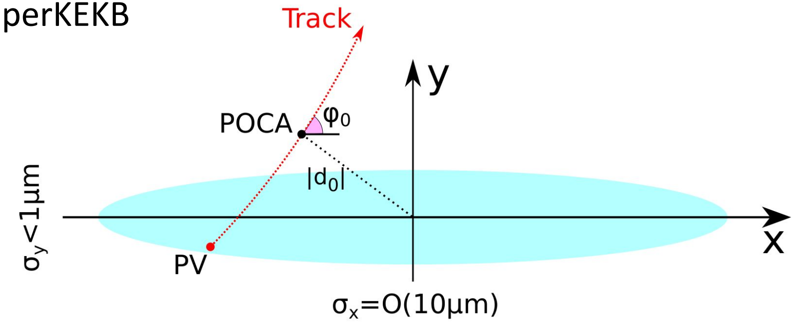
- resolution: 1.5 - 2 x better than Belle

| | Data | Simulation |
|---|---|---|
| $\hat{\sigma}(d_0)$ [$\mu$m] | $14.2 \pm 0.1\,(\text{stat}) \pm 0.1\,(\text{syst})$ | $12.5 \pm 0.1\,(\text{stat})$ |
| $\hat{\sigma}(z_0)$ [$\mu$m] | $16.1 \pm 0.1\,(\text{stat}) \pm 0.1\,(\text{syst})$ | $13.9 \pm 0.1\,(\text{stat})$ |

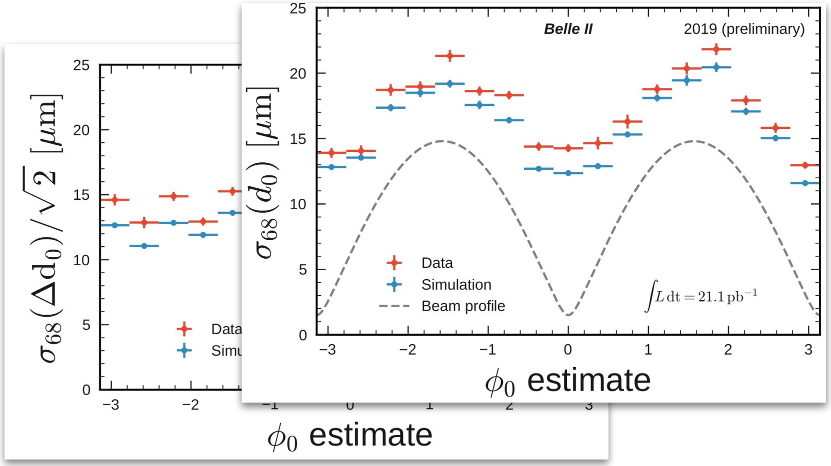
- beam profile:
  - study impact parameter $d_0$ and resolution in di-muon events
  - φ-dependence gives info about beam profile:

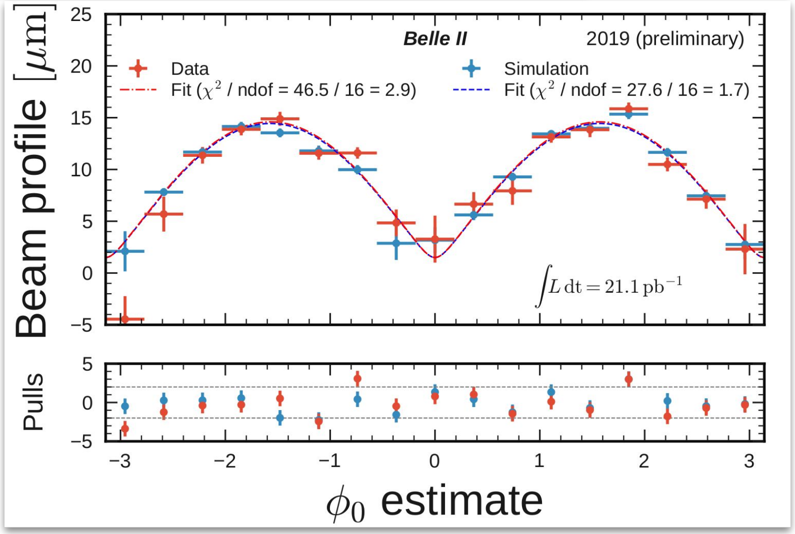
$$\sigma^2_{d0} = \sigma^2_{intr} + (\sigma_x \sin\varphi)^2 + (\sigma_y \cos\varphi)^2$$

  - unfold beam profile → consistent with expectations from SuperKEKB




  - more involved methods study $d_{01}$ and $d_{02}$ correlations in 2-track events



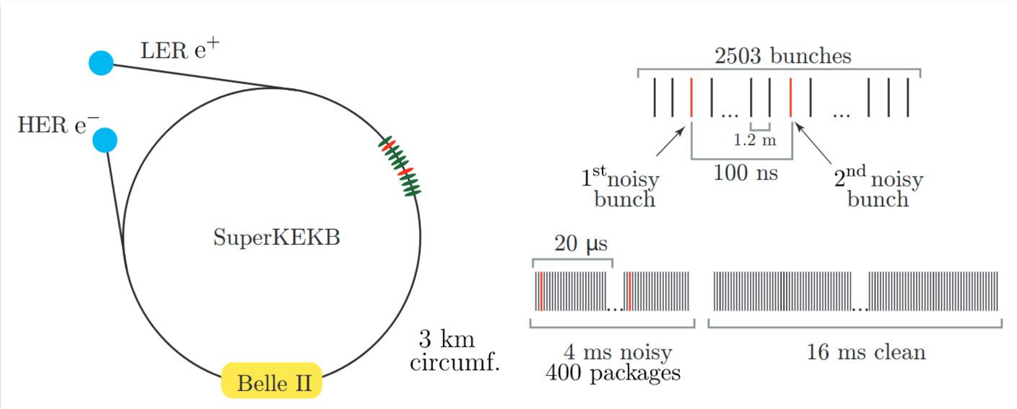



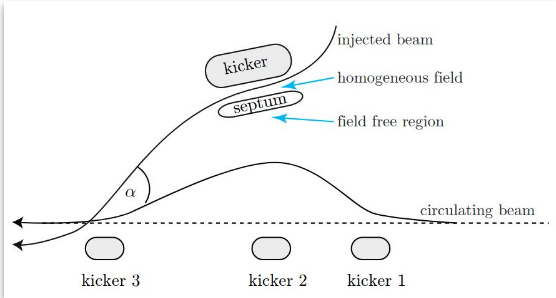

[BELLE2-NOTE-PL-2019-011], [BELLE2-PUB-TE-2020-001]

# SuperKEKB

## Design parameters and injection scheme

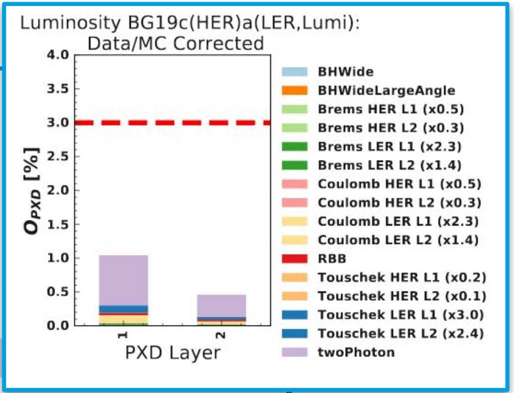
| | LER | HER | |
|---|---|---|---|
| Energy | 4.0 | 7.0 | GeV |
| Current | 3.6 | 2.6 | A |
| Number of bunches | 2500 | | |
| Bunch Current | 1.44 | 1.04 | mA |
| Circumference | 3016 | | m |
| Emittance $\varepsilon_x$ | 3.2(1.9) | 4.6(4.4) | nm |
| Emittance $\varepsilon_y$ | 8.64(2.8) | 12.9(1.5) | pm |
| Coupling | 0.27 | 0.28 | |
| Beta function $\beta_x$ | 32 | 25 | mm |
| Beta function $\beta_y$ | 0.27 | 0.30 | mm |
| Crossing angle $(2\Theta_c)$ | 83 | | mrad |
| Beam-beam parameter $\xi_x$ | 0.0028 | 0.0012 | |
| Beam-beam parameter $\xi_y$ | 0.0881 | 0.0807 | |
| Luminosity $\mathcal{L}$ | $8 \times 10^{35}$ | | $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ |



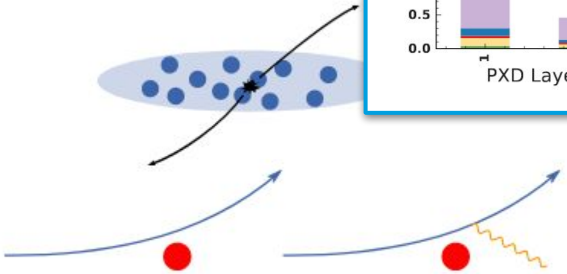




→ beam lifetime limited by (unavoidable) Touchek effect to few minutes
→ 50 Hz injection
→ 10 µs revolution time
→ 4 ms cooldown
⇒ 20% noisy *dead-time* w/o detector readout
⇒ PXD: cannot (simply) *stop* charge collection

# PXD Backgrounds @ Belle II




Single-beam backgrounds:



- **Touschek scattering** $\rightarrow$ scattering of particles within a bunch $\rightarrow$ **Touschek rate** $\propto N_{particles} \times \rho \rightarrow \mathbf{I} \times \frac{\mathbf{I}}{\sigma_y \mathbf{n_b}}$
- **beam-gas scattering** $\rightarrow$ Coulomb scattering and Bremsstrahlung (scattering off gas molecules) $\rightarrow$ **Beam-gas rate** $\propto N_{gas\ molecules} \times N_{particles} \rightarrow \mathbf{P} \times \mathbf{I} \times \mathbf{Z_{eff}^2}$
- **synchrotron radiation background** $\rightarrow$ consequence of a radial acceleration of the beam's particles achieved in bending magnets and quadrupoles
- **injection background** $\rightarrow$ continuous injection of charge into beam bunch modifying the beam bunch

Single-beam backgrounds can be mitigated with beam-steering, collimators, and vacuum-scrubbing

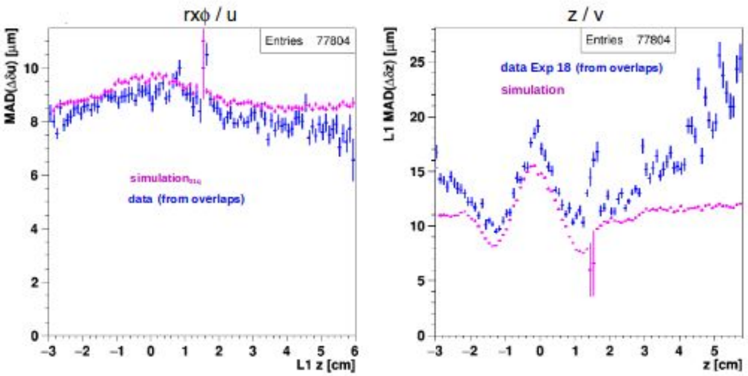
Luminosity backgrounds:

- **two-photon background** $\rightarrow$ leading luminosity background ($e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-e^+e^-$), unlike any of the backgrounds above cannot be reduced!

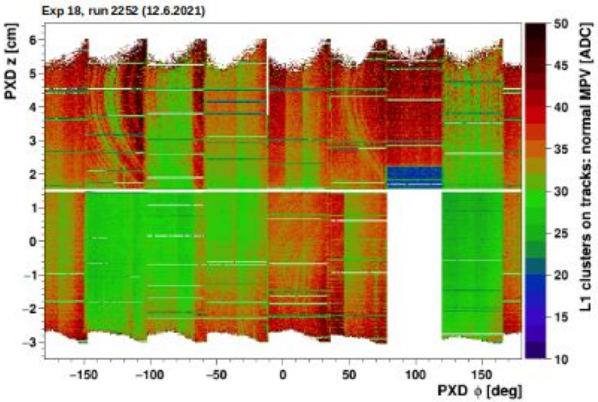
# PXD Offline Monitoring

- Development of fast offline performance monitoring with HoT (Hits-on-Track) continued
  - provides fast feedback to operation and input for MC tuning
  - can help to define run ranges for official alignment & calibration
- First dose estimate based on analysis of data from new 2 Hz Poisson trigger line in reasonable agreement with expectations from MC considering the additional injection background in data

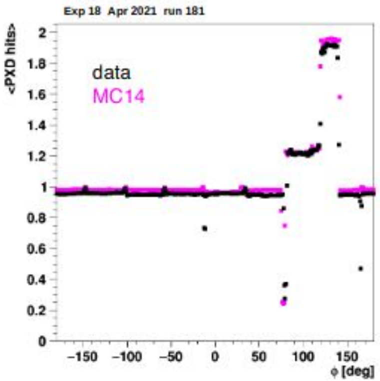
Resolution data vs MC



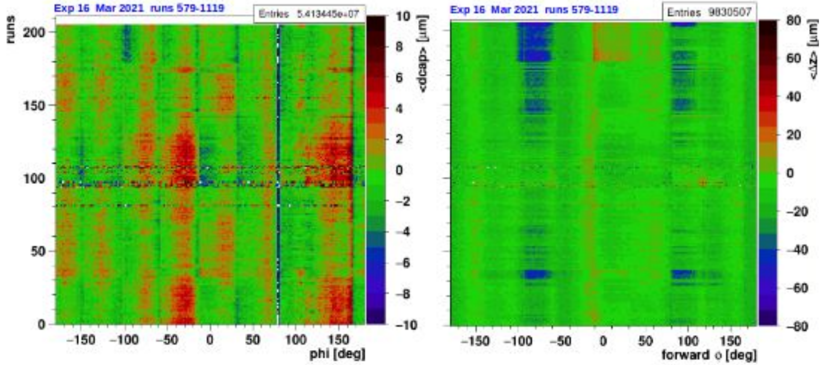

L1 cluster MPV



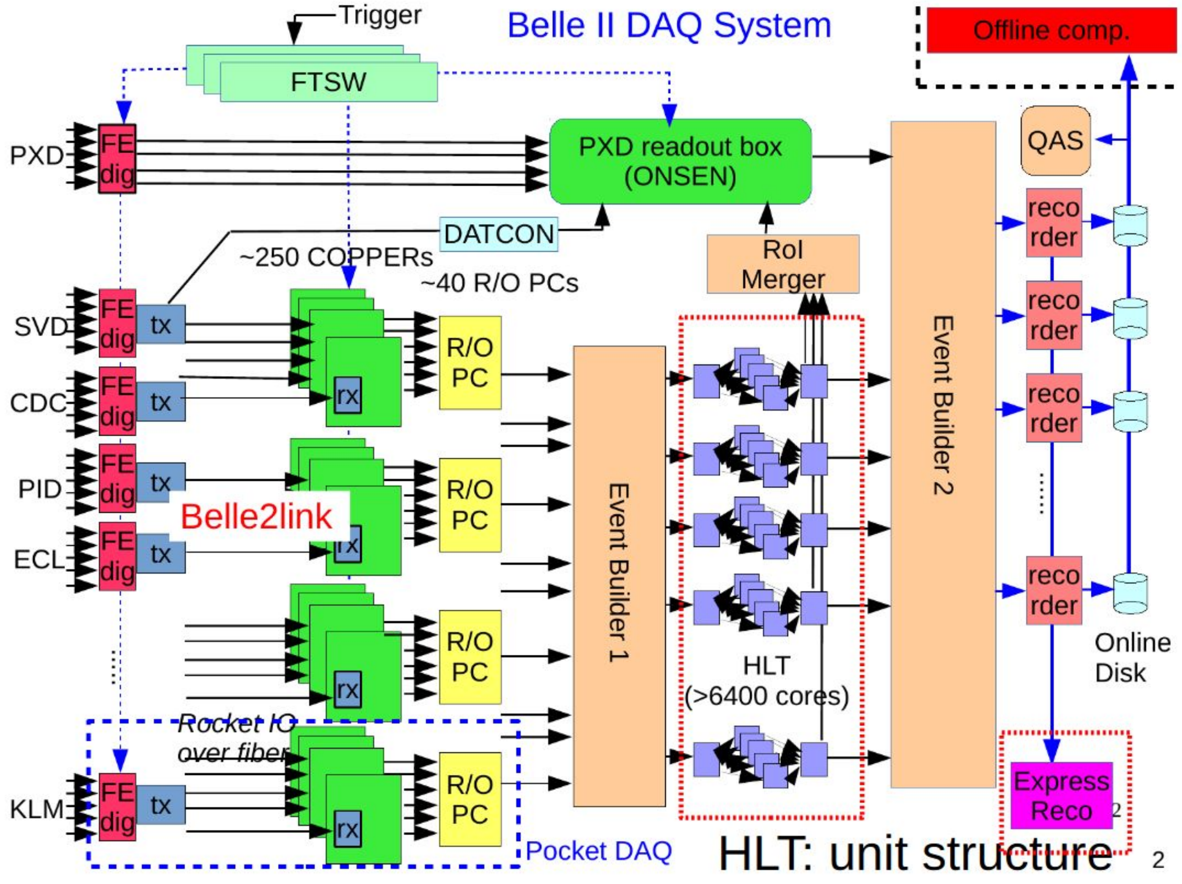

PXD hits on tracks

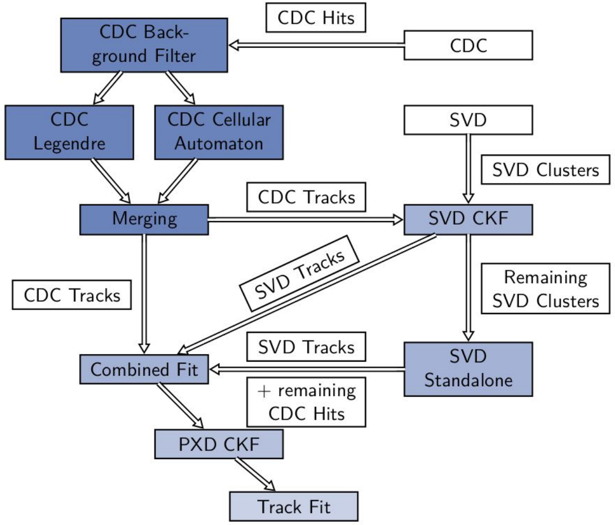



Run-wise monitoring of PXD movement



# HLT and Track Finding




DESY.

# PXD Collaboration

## Institutes

- ~20 institutes
  - dominant German contribution
- ~120 PXD associated Belle II members
  - hardware, operation, analysis, …

- University of Barcelona, Departament d'Electrònica, C/Marti Franques, 1, 08028-Barcelona, Spain
  - *Oscar Alonso, Angel Dieguez*
- IHEP Bejing, China
  - *Zhen'An Liu, Chunjie Wang, Jingzhou Zhao*
- University of Bonn, Physikalisches Institut, Nussallee 12, 53115 Bonn, Germany
  - *Patrick Ahlburg, Bruno Deschamps, Jochen Dingfelder, Georgios Giakoustidis, Hans Krüger, Florian Lütticke, Botho Paschen, Christian Wessel*
- University of Giessen, II. Physikalisches Institut, Heinrich-Buff-Ring 16, 35392 Giessen, Germany
  - *Thomas Geßler, Jens Sören Lange, Klemens Lautenbach, Simon P. Reiter*
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- DESY, Notkestrasse 85, 22607 Hamburg, Gemany
  - *Varghese Babu, Qingyuan Liu, Felix J. Mueller, Carsten Niebuhr, Slavomira Staykova, Maiko Takahashi, Hua Ye*
- University of Hamburg, Germany
  - ..
- University of Mainz, Germany
  - *Matthias Hoek, Bianca Scavino, Björn Spruck, Concettina Sfienti*
- University of Heidelberg, Lehrstuhl für Schaltungstechnik und Simulation, Institut für Technische Informatik (ziti), 68131 Mannheim, Germany
  - *Michael Ritzert*
- KIT, Karlsruhe, Institut für Experimentelle Kernphysik, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
  - *Martin Heck, Ivan Peric*
- Institute of Nuclear Physics, Institute of Nuclear Physics PAN , ul. Radzikowskiego 152, 31-342 Kraków, Poland
  - *Andrzej Bozek, Pjotr Kapusta, Bartlomiej Kisielewski*
- LMU, Excellence Cluster Universe, Boltzmannstrasse 2, 85748 Garching, Germany
  - *Thomas Kuhr, Martin Ritter, Thomas Lück*
- TU, Muenchen, Germany
  - *Dmytro Levit, Stephan Paul, Andrei Rabusov, Daniel Greenwald*
- MPI fuer Physik, Föhringer Ring 6, 80805 München, Germany
  - *Vladimir Chekelian, Philipp Leitl, Hans-Günther Moser, Felix Müller, Ketevan Parlagashvili, Markus Reif, Boqun Wang*
- MPG Halbleiterlabor, Otto-Hahn-Ring 6, 81739 München, Germany
  - *Laci Andricek, Martin Hensel, Christian Koffmane, Jelena Ninkovic*
- Charles University, Faculty of Mathematics and Physics, V Holesovickach 2, CZ180 00 Praha 8 - Troja, Czech Republic
  - *Tadeas Bilka, Zdenek Dolezal, Jakub Kandra, Peter Kodys, Peter Kvasnicka*
- Instituto de Física de cantabria ,(CSIC-UC), Avd. de los Castros s/n, 39005 Santander, Spain
  - *Javier Gonzalez Sanchez, David Moya, Amparo Lopez Virto, Ivan Vila,*
- University of Tabuk, Saudi Arabia
  - *Rachid Ayad*
- Institute for Structural Biology, Tsukuba, Japan
  - ...
- IFIC, Instituto de Física Corpuscular, Edificio Institutos de Investigación, Apartado de Correos 22085, E-46071 Valencia, Spain
  - *Marca Boronat, Daniel Esperante, Juan Fuster, Pablo Gomis, Carlos Lacasta, Carlos Mariñas, Marcel Vos*