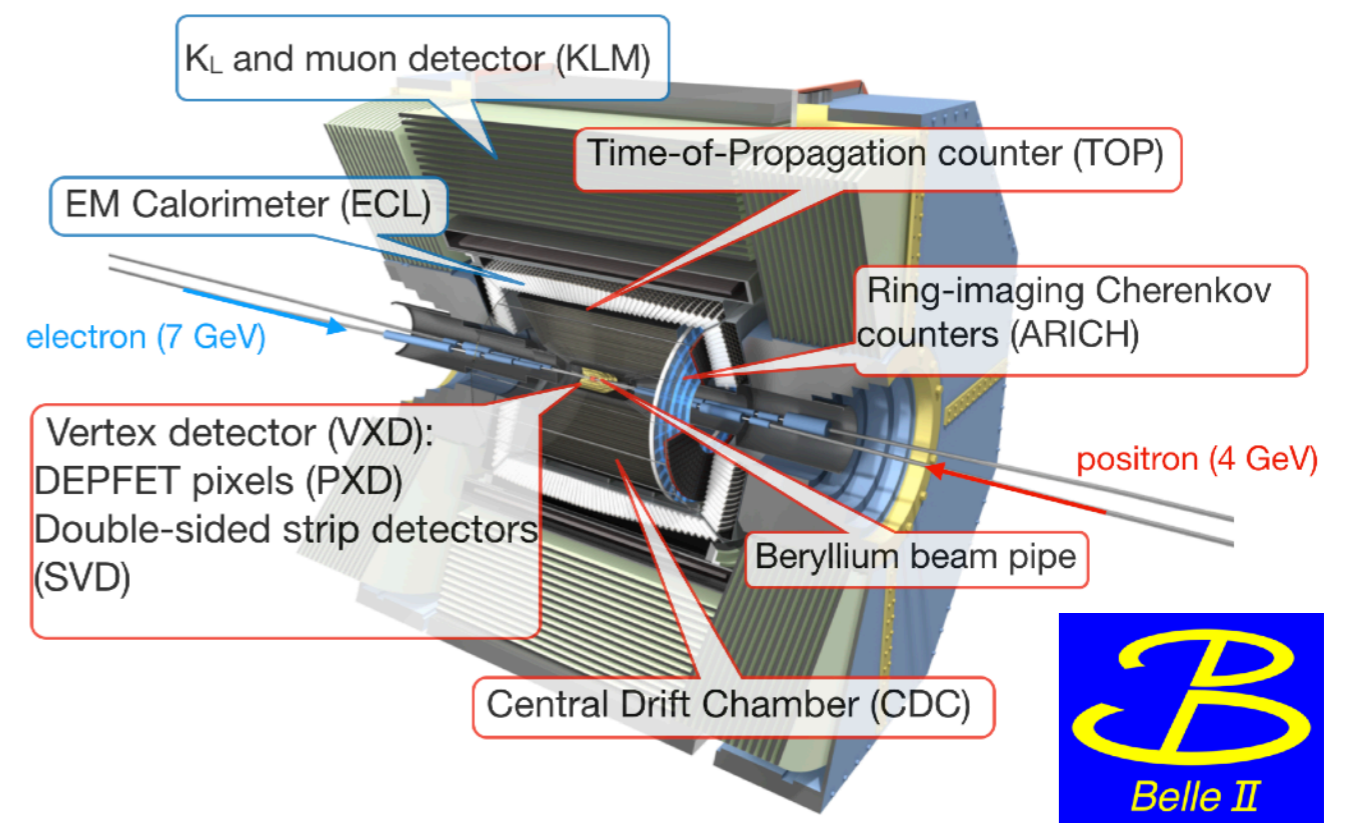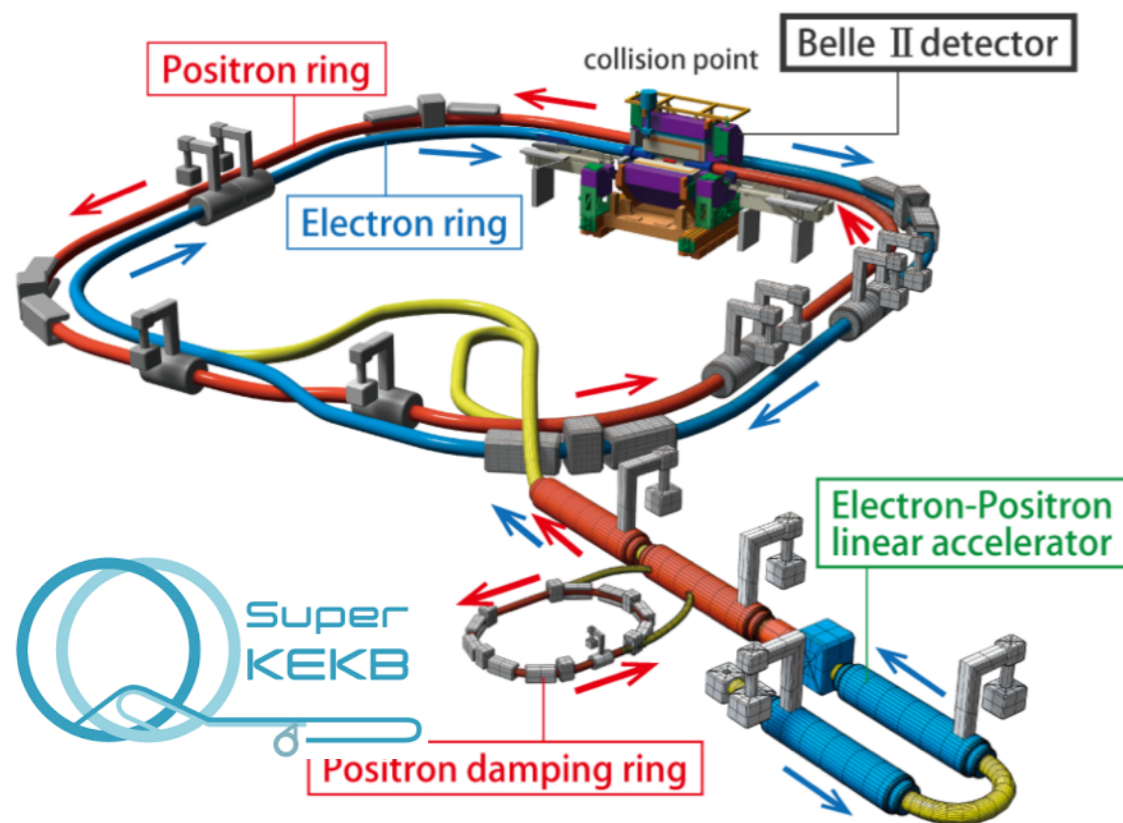# Belle II at SuperKEKB

DESY activities in Belle II experiment

Hua Ye (hua.ye@desy.de)
on behalf of DESY Belle II group

88th PRC Meeting Open Session
DESY, Nov.12, 2019

SuperKEKB and Belle II

❖ SuperKEKB delivers e⁺e⁻ collisions at 10.58 GeV ($M_{\Upsilon(4S)}$), with a target peak luminosity of 8×10^{35} cm^{-2}s^{-1}, 40 times larger than that of KEKB.

    ❖ Increase beam currents twice

    ❖ Reduce beam size by a factor of 20

❖ Belle II detector has accomplished a series of upgrades to

    ❖ Improve the overall performance

    ❖ Cope with the increased background and high trigger rate.

❖ Aim to accumulate a dataset of 50 ab^{-1} by ~2027, to study flavour physics and explore new physics beyond the standard model.

Highlights of SuperKEKB/Belle II Status

❖ Collision started in Spring 2018, "Phase 2".
  ❖ Mainly for beam commissioning,
  ❖ with a dedicated vertex detector to study beam background.
  ❖ **0.5 fb⁻¹ data recorded.**
    • → First Physics results
❖ Physics data taking has started in March 2019, "Phase 3".
  ❖ With Belle II VXD
  ❖ **6 fb⁻¹ accumulated in spring run,**
  ❖ **Aims to collect 200 fb⁻¹ by summer 2020.**
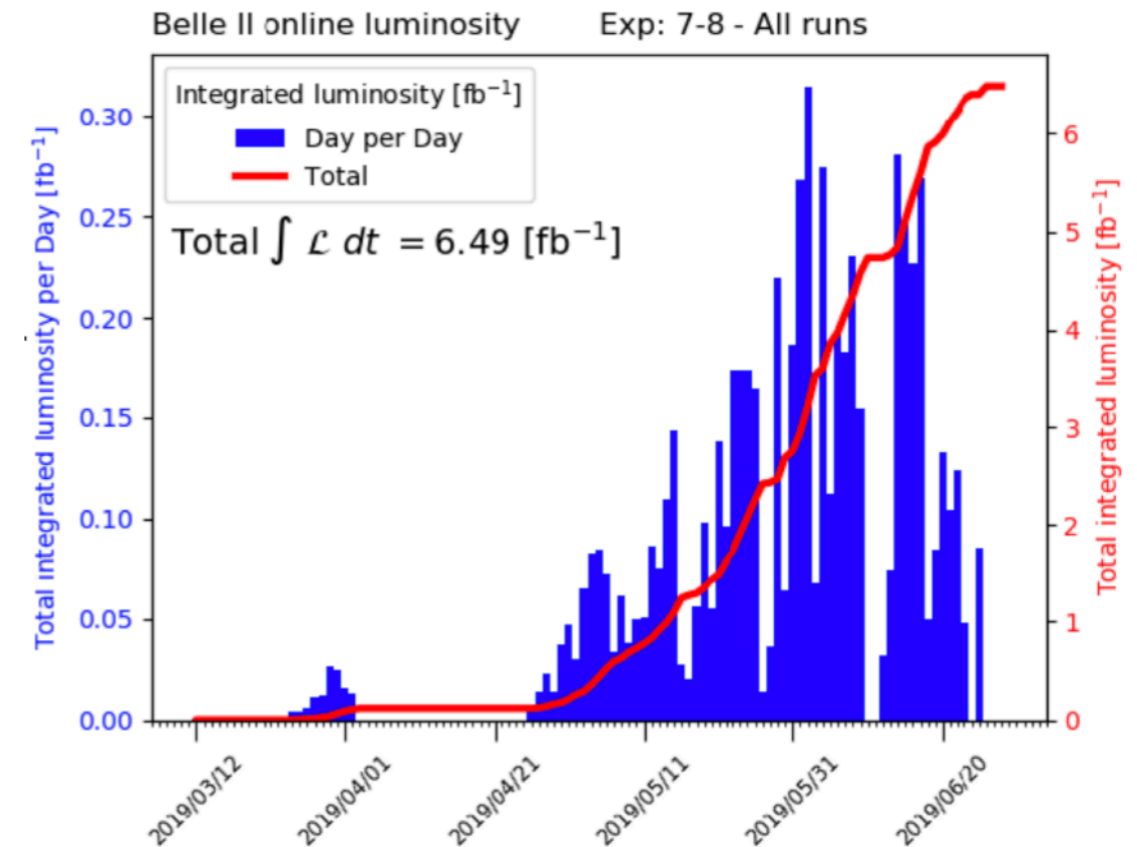
❖ Challenges:
  ❖ Beam-beam effects
    • Vertical emittance blow up
    • Low beam-beam parameter
  ❖ Beam background limits beam current
    • CDC chamber current
  ❖ Beam loss events are a threat to the safety of machine and detector
❖ 2019 autumn run targeted to machine optimisation and background studies

Highlights of SuperKEKB/Belle II Status

❖ Physics data taking, "Phase 3". 2019 spring run

   ❖ Achieved peak luminosity of 1.23×10^{34} cm^{-2}s^{-1} ❖ Achieved with $\beta^*_y = 2$ mm.

   ❖ Goal is 8×10^{35} cm^{-2}s^{-1}
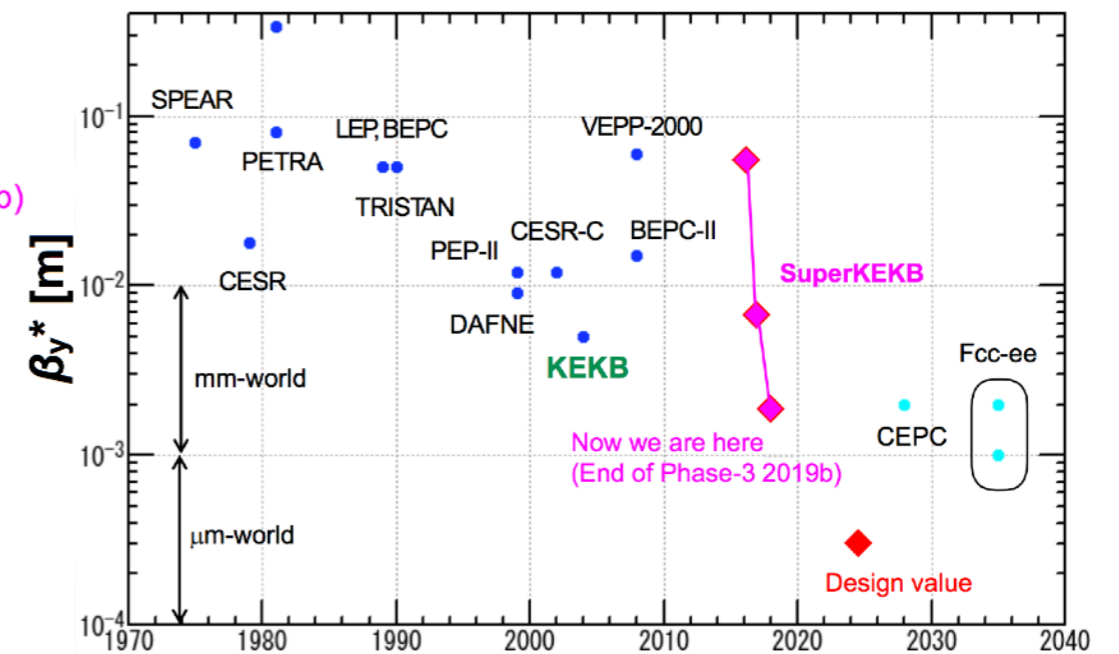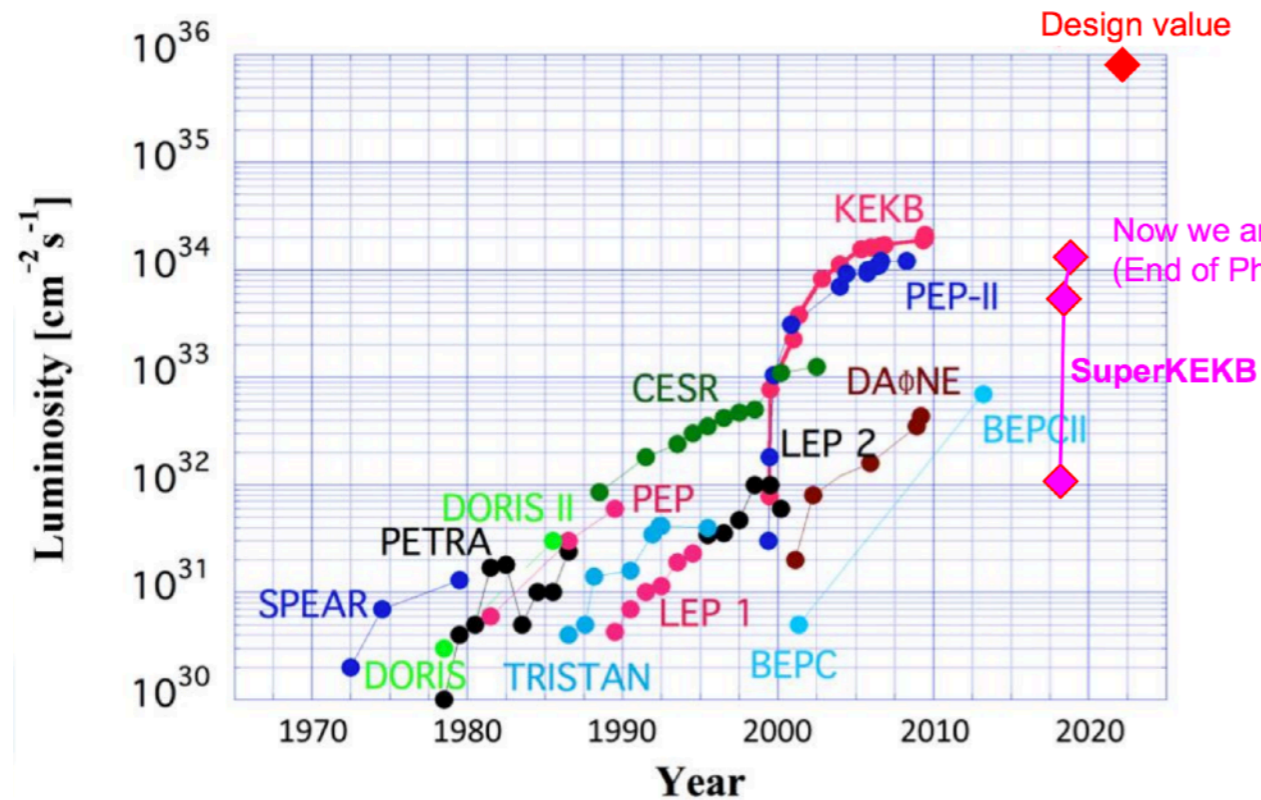
DESY Contributions in Belle II

- ❖ Detector
  - ❖ VXD integration and installation, PXD commissioning and operation
  - ❖ Performance studies
  - ❖ Background studies and mitigation
- ❖ Software
  - ❖ Tracking and vertexing
  - ❖ Alignment
  - ❖ Simulation
  - ❖ ECL clustering, reconstruction, calibration
  - ❖ High-level analysis tools
- ❖ Physics Performance studies
  - ❖ Calorimeter resolution, calibration
  - ❖ Trigger efficiency measurement
  - ❖ Lepton identification
- ❖ Physics analysis
  - ❖ Dark sector
  - ❖ τ physics
  - ❖ B physics
- ❖ Management
  - ❖ DESY plays leading roles in many subgroups,
  - ❖ Physics Performance group is newly established and coordinated by DESY
- ❖ IT infrastructure and Computing

VXD Installation and PXD Commissioning

- ❖ The first real beam experience with a completely new detector type (DEPFET) has been achieved.
- ❖ DESY played a key role in all steps of VXD integration, installation, PXD commissioning and operation at KEK.
- ❖ Challenging operating conditions close to the IP.
- ❖ De-scoped PXD was installed in 2018/2019,
    - ❖ Due to relatively high failure rate in ladder gluing procedure → solved!   [MPP, Munich]
   - ❖ Replacement with full PXD is scheduled in 2021.
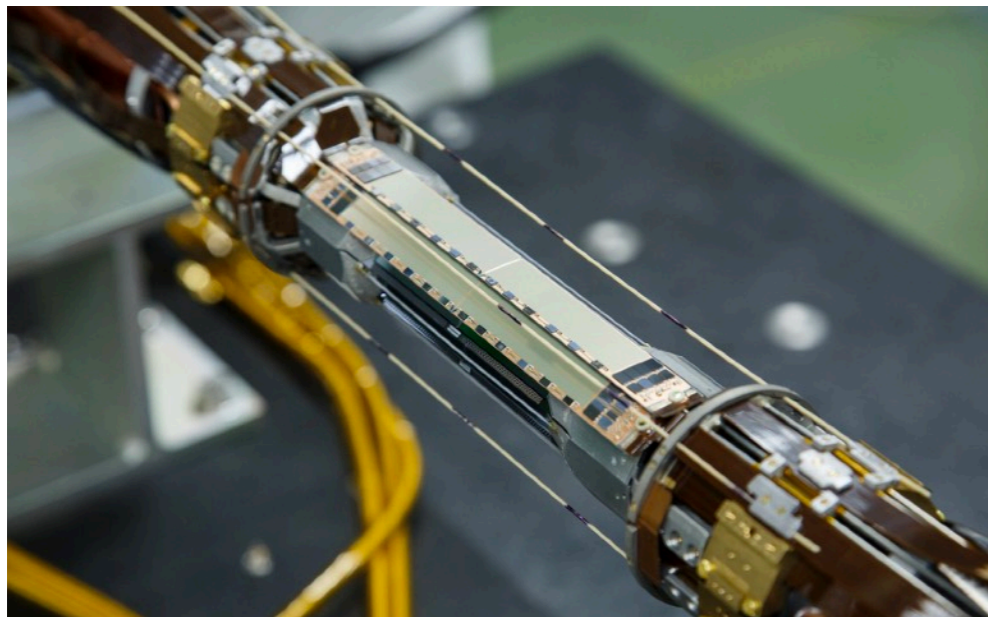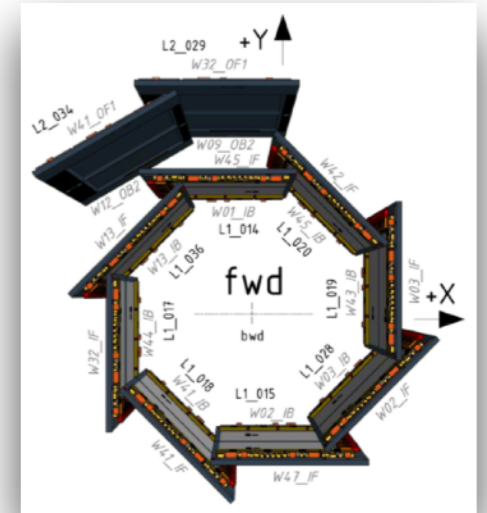
PXD for early Phase 3
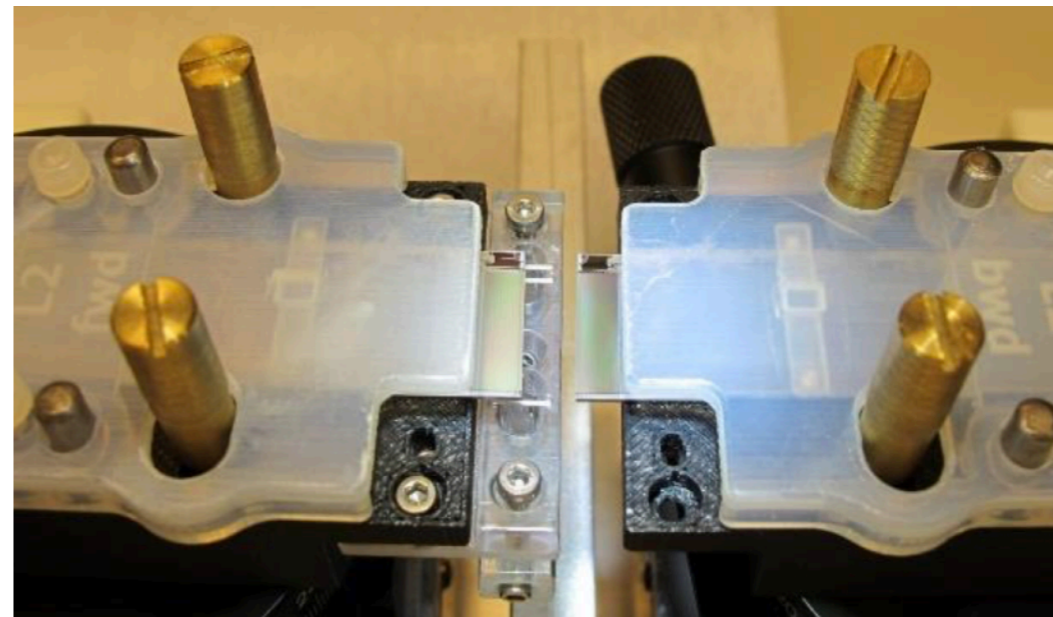
Improved ladder gluing scheme

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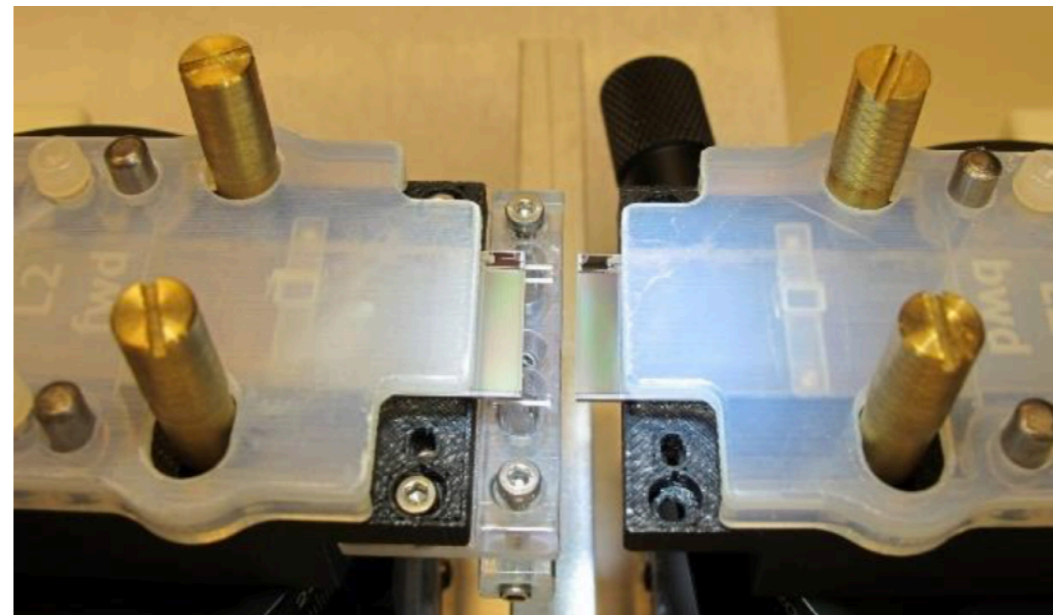
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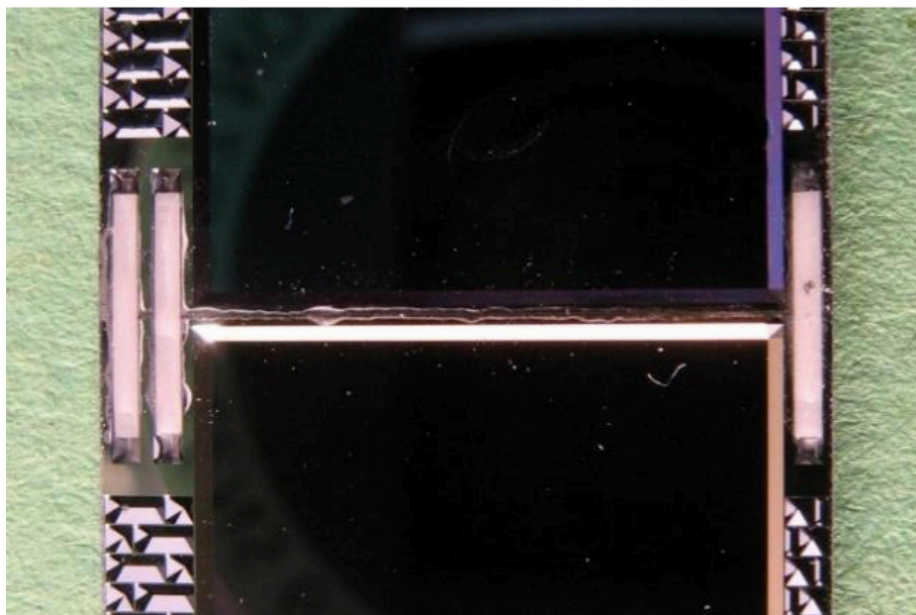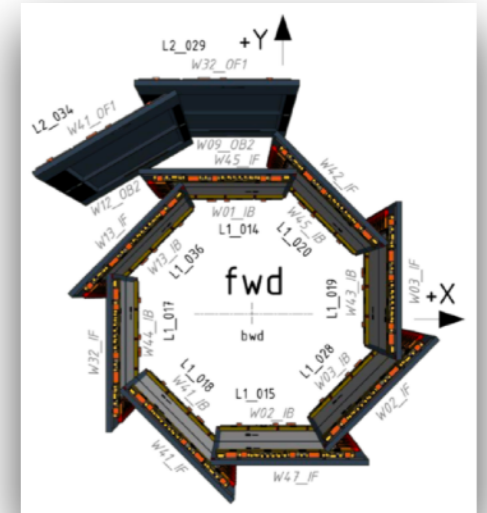
Small ceramic inserts on the back side
→ reinforcement of the joint

Improved ladder gluing scheme

PXD Commissioning

❖ DESY hosts a test setup of multiple PXD modules within the final DAQ chain, which allows close conditions to that at KEK.

    ❖ Tests
    ❖ Developments
    ❖ PXD shift training
    ❖ Mass testing for PXD 2021

❖ DESY hosts the two-phase CO_2 cooling system for multi-module scale commissioning.
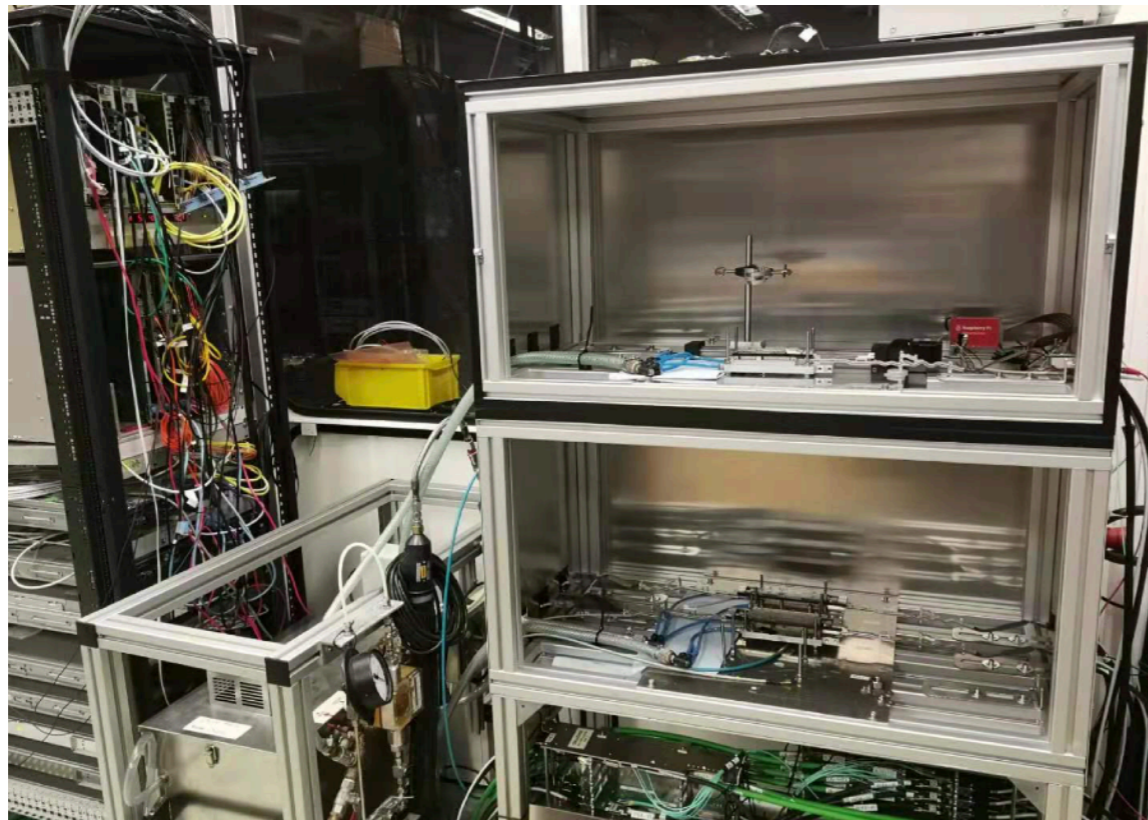
2-phase CO_2 cooling plant: Marco

PXD Operation & Performance

Hit Efficiency

PXD L1
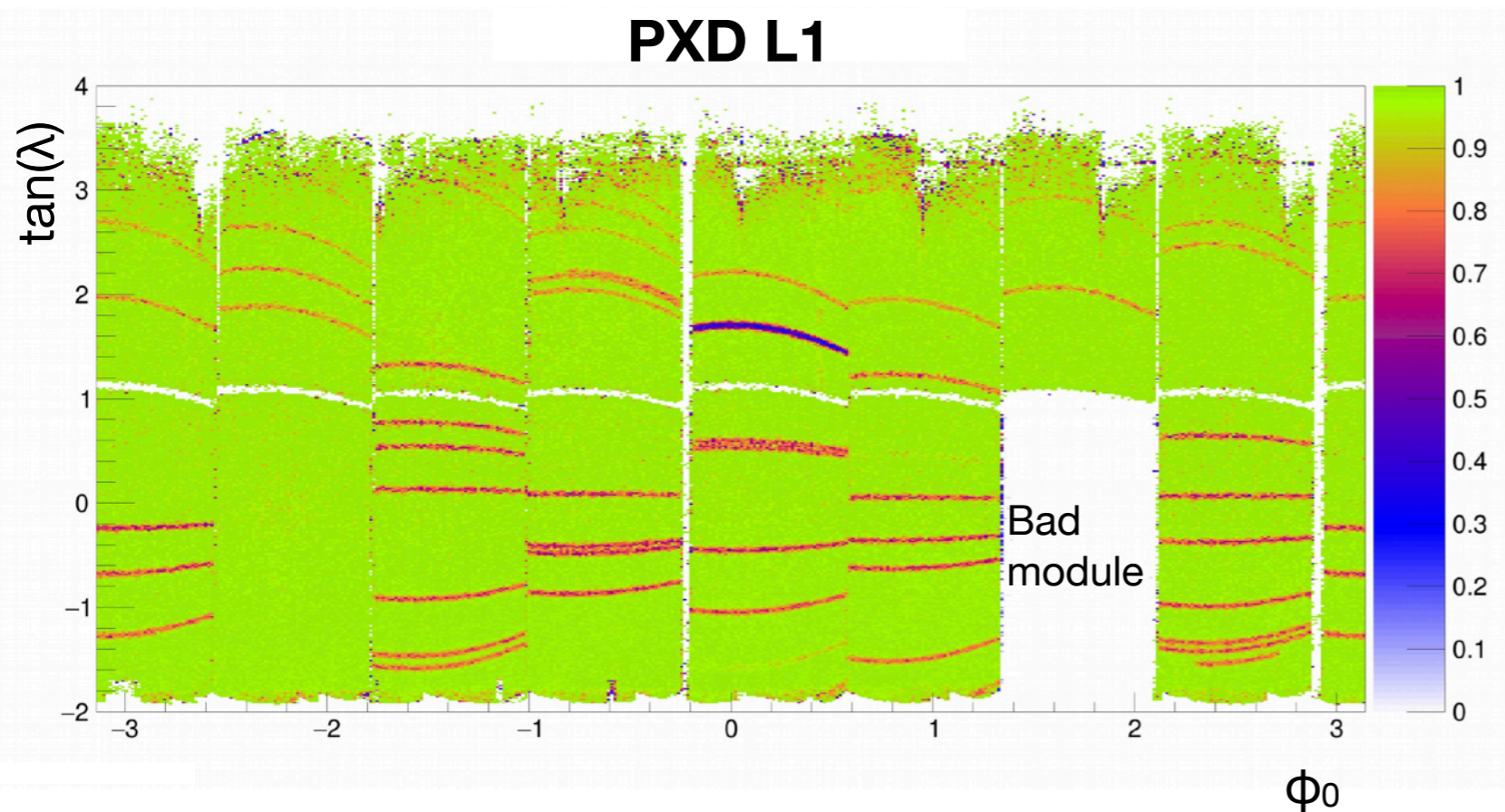
- ❖ Projection on the ϕ_0-tan(λ) plane.
- ❖ $\lambda \equiv \pi/2 - \theta$, : angle between a track and the plane $\perp$ to the beam.
- ❖ A bad L1 module was installed due to time constrains integration
  - ❖ covered by module in L2
- ❖ PXD is continuously optimized.

PXD Operation & Performance

Hit Efficiency

PXD L1

LER beam loss event

- ❖ 150mA beam current lost in 40 µs
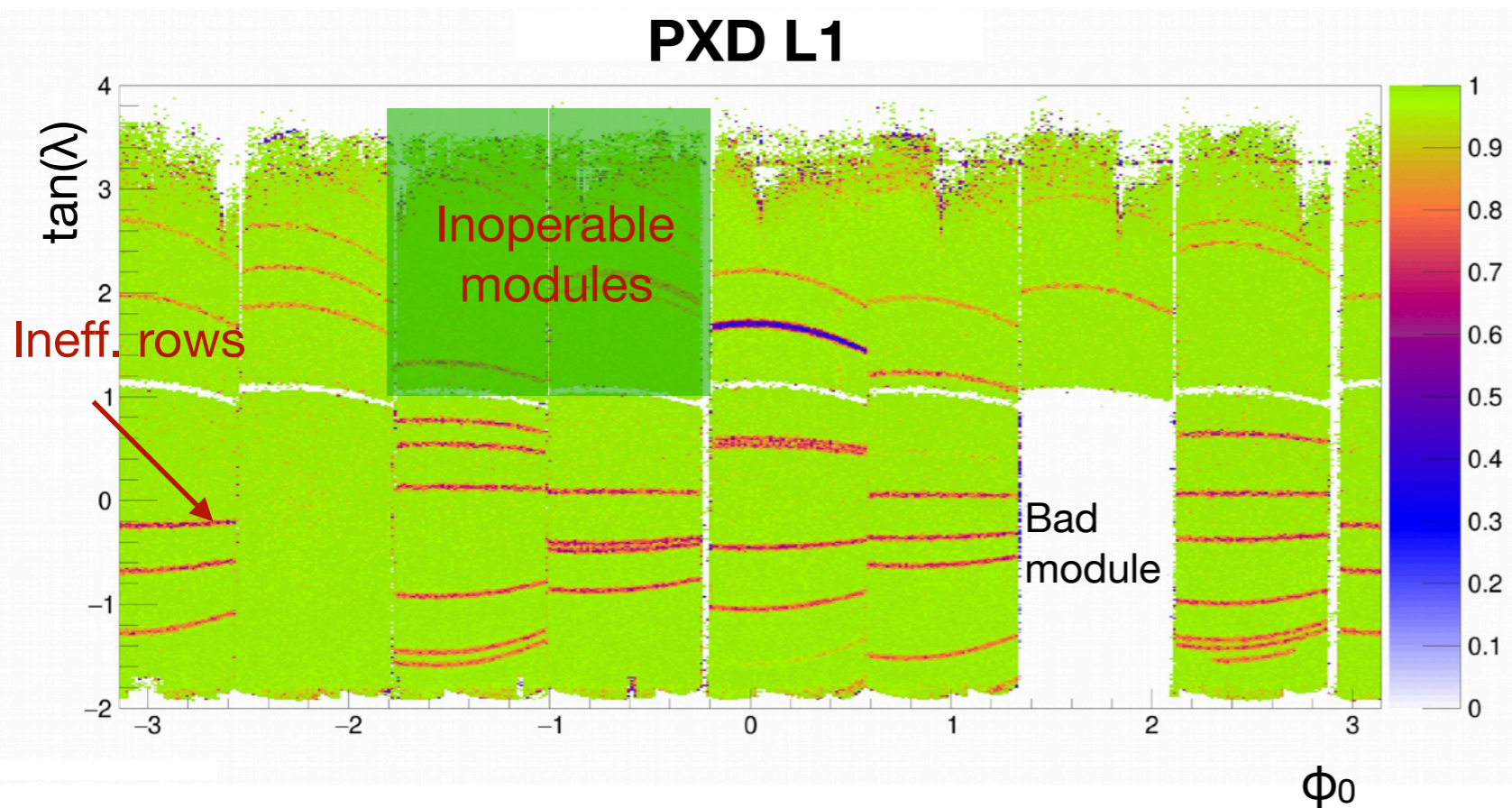- ❖ Severely damaged vertical collimator
- ❖ Major quench of final focus magnet system
- ❖ Damage in PXD
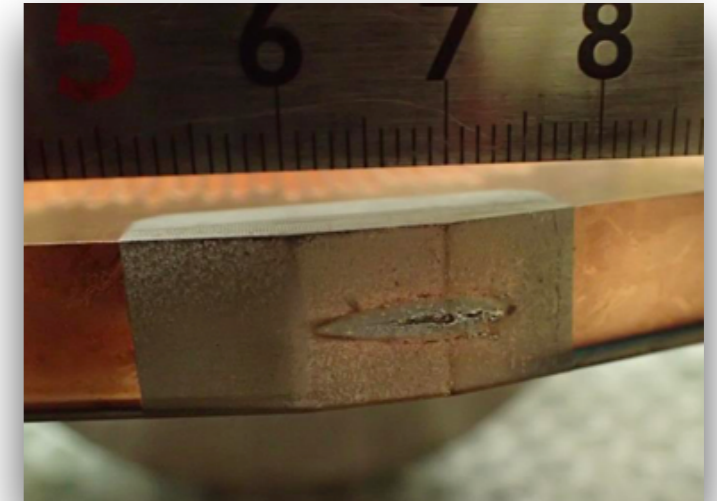
The high radiation dose in the beam loss is a threat to the machine (collimator, magnet) and pixel detector.

- ❖ Inoperable PXD module, recovered afterwards.
- ❖ Working point shifted.
- ❖ Increased number of inefficient rows (~2%). → points to possible damages in ASIC
- ❖ PXD: the scheme of fast emergency shutdown is in preparation,
- ❖ Machine side: faster abort, increase number of abort gaps (1->2), modify the collimator system.

VXD Performance

Transverse Impact Parameter Resolution

❖ Align the tracking system using Millepede-II

❖ Exploit small and flat transverse beam spot size in SuperKEKB

    ❖ Use φ-dependence of track impact parameter (d_0) resolution to study beam profile

    ❖ Use dimuon events to measure intrinsic d_0 resolution

❖ Unfold the beam profile: size consistent with expectations.
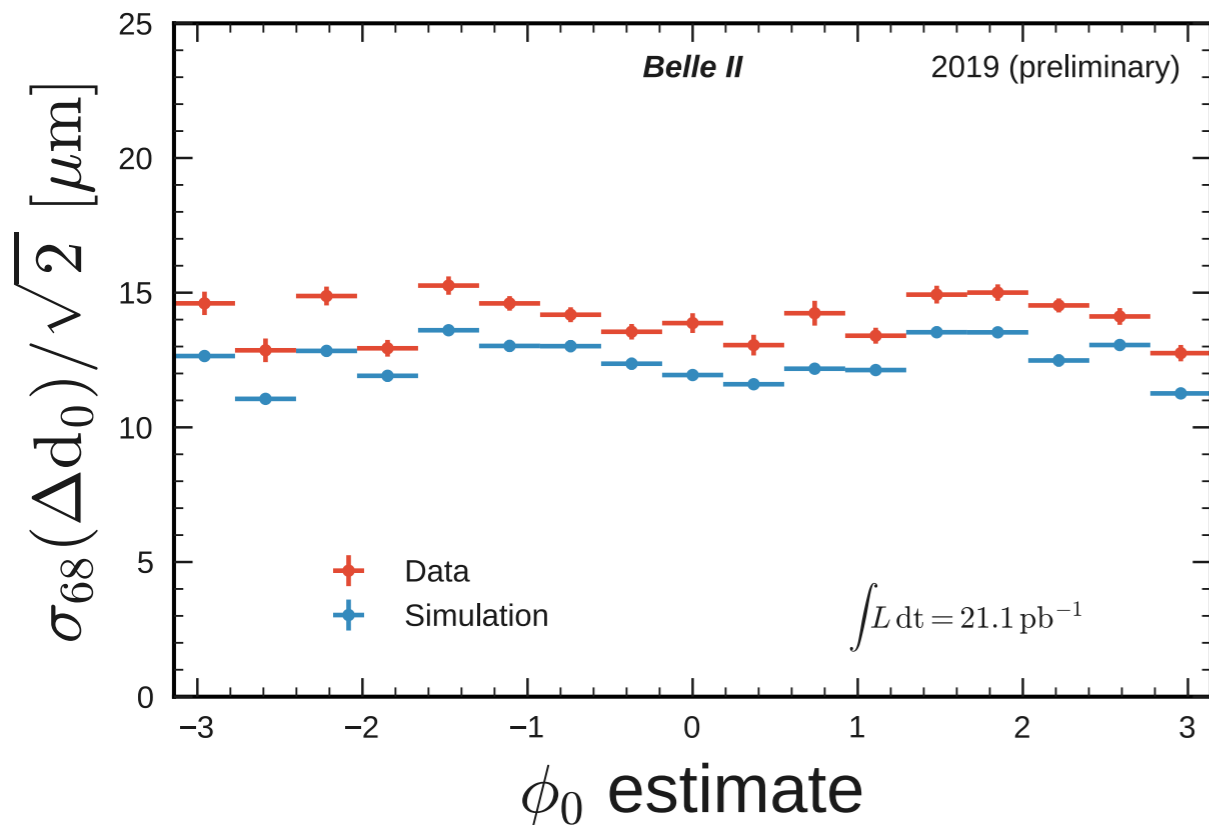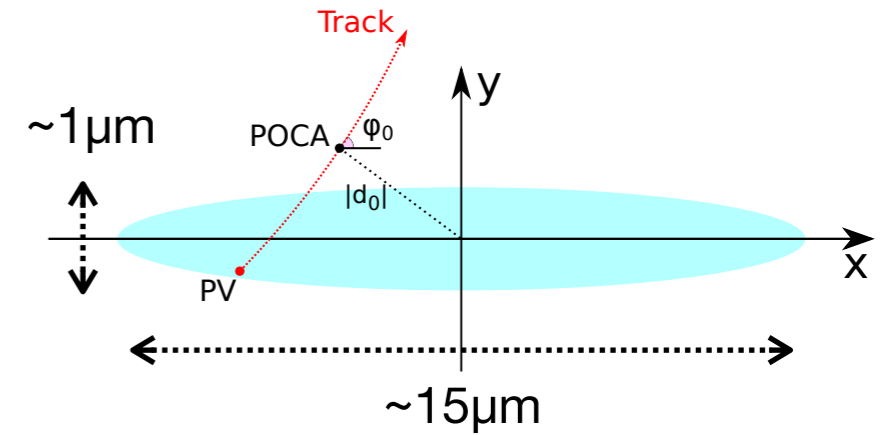
Beam profile described by $\sqrt{(\tilde{\sigma}_x sin\phi_0)^2 + (\tilde{\sigma}_y cos\phi_0)^2}$

Data: $\sigma_i = 14.1 \pm 0.1 \mu m$

MC: $\sigma_i = 12.5 \pm 0.1 \mu m$

VXD Performance

Transverse Impact Parameter Resolution

❖ Align the tracking system using Millepede-II

❖ Exploit small and flat transverse beam spot size in SuperKEKB ≈1μm

  ❖ U...
     st...

  ❖ U...

❖ Unfol...

$\sigma_{68}(\Delta d_0)/\sqrt{2}$ [μm]

ϕ_0 estimate

Data: $\sigma_i = 14.1 \pm 0.1 \mu m$
MC: $\sigma_i = 12.5 \pm 0.1 \mu m$

D^0 flight time

Events / (0.005 GeV/c^2)

- Data
  Signal
  Background
  Model

Belle II Preliminary

$\int L\, dt = 0.34\, fb^{-1}$

$m_{K\pi}$ (GeV/c^2)

Events / (0.1 ps)

- Data
  Signal
  $c\bar{c}$ background
  Model

Belle II Preliminary

$\int L\, dt = 0.34\, fb^{-1}$

t_{D^0} (ps)

$\tau_{measure} = (370 \pm 40)$ fs

$\tau_{PDG} = (410.1 \pm 1.5)$ fs

ϕ_0 estimate

DESY. Belle II at SuperKEKB, H. Ye, 88th PRC Meeting
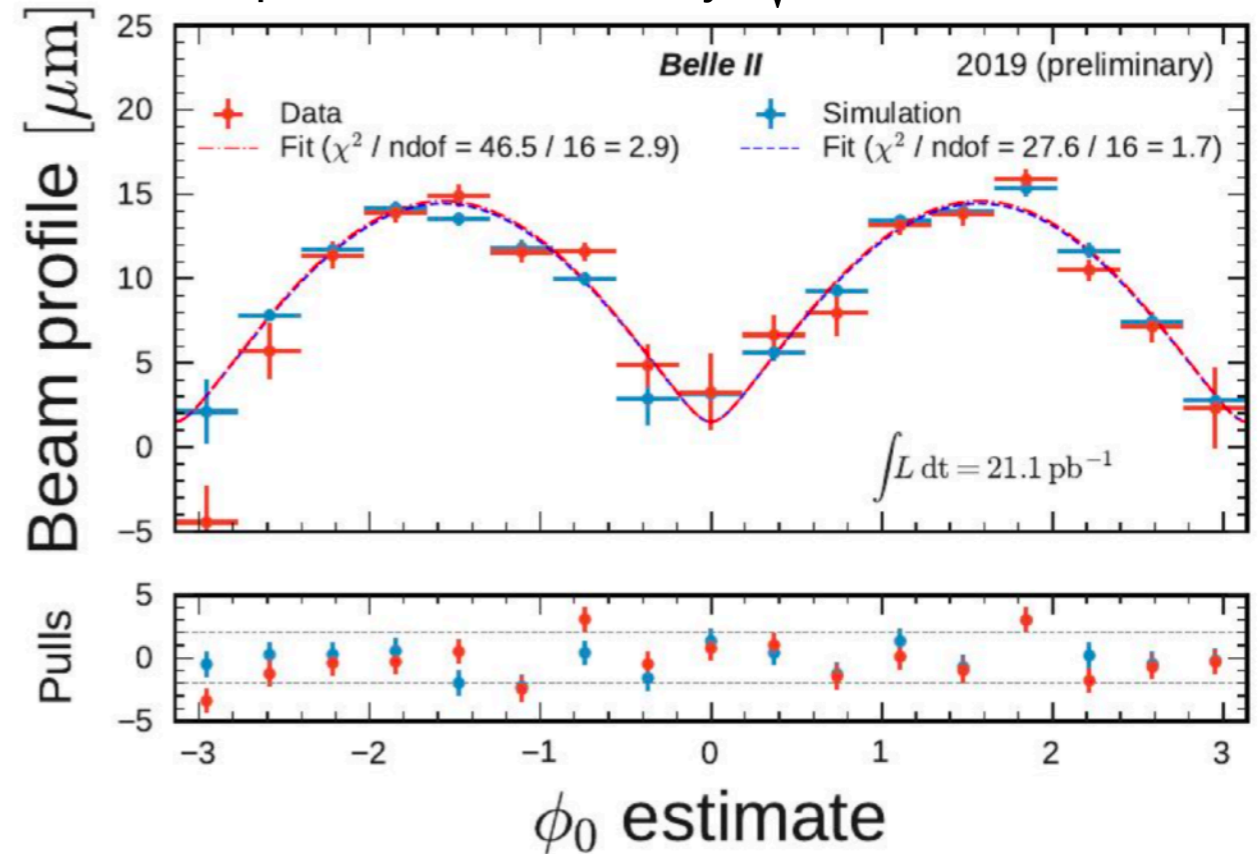
VXD Performance
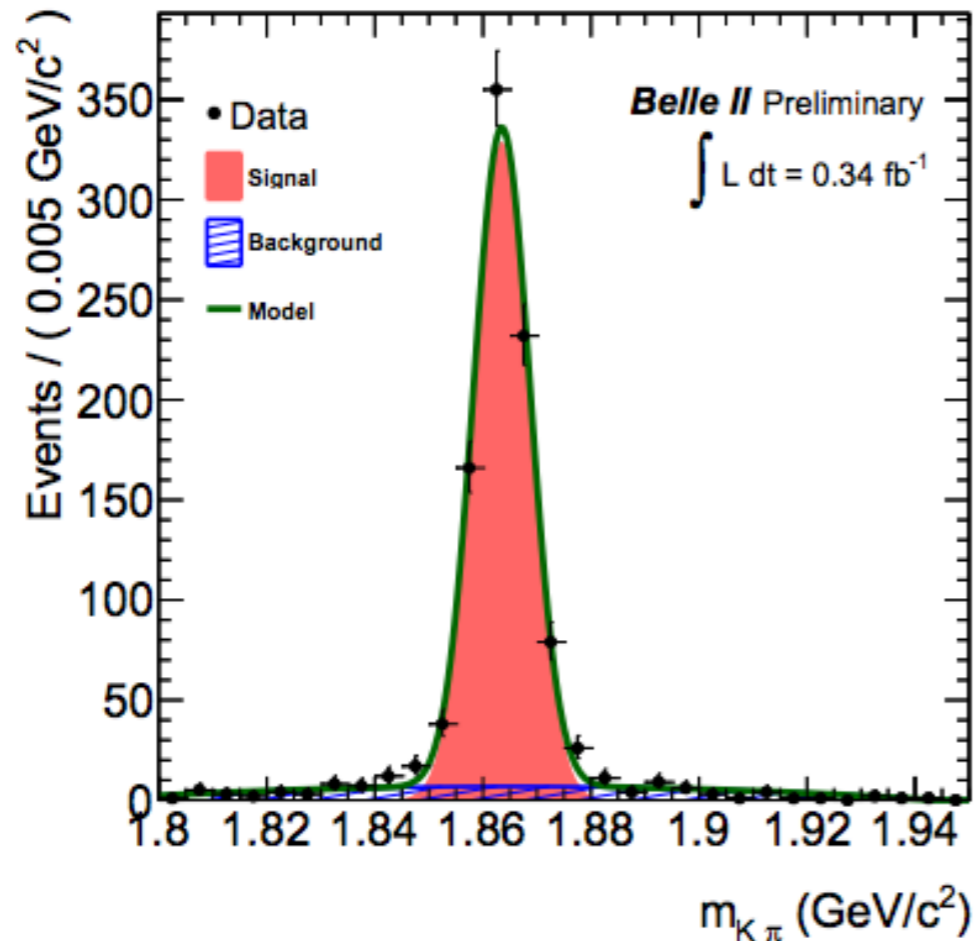
Transverse Impact Parameter Resolution

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  ❖ U...
     st...

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❖ Unfol...

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ϕ_0 estimate

Track

CDC Operation & Performance

❖ High CDC chamber current is limiting factor for beam current

❖ Persistent current problem first observed in phase II is believed to be due to Malter effect

    ❖ Switch off L54 & increase H_2O content -> no further problems seen so far
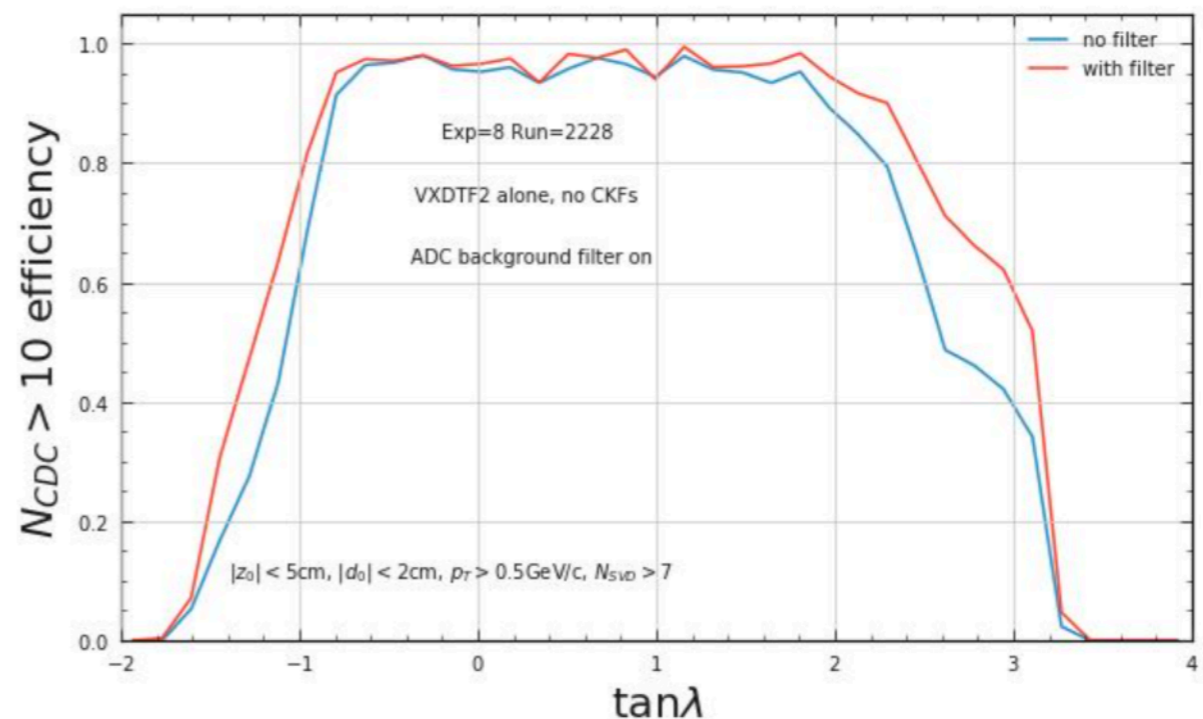
    ❖ Modified HV trip scheme

❖ CDC wire efficiency monitor at DESY

    ❖ tool under development to automatically detect changes in performance

    ❖ presently no indication for significant sense wire ageing

❖ CDC cross talk

    ❖ DESY group introduces a cross-talk filter

        • Improve tracking efficiency.

        • Reduce the execution time for CDC tracking, save time for high level trigger (HLT) processing.

combined runs

wire efficiency, Layer 14

dead wire

RO Board // 2
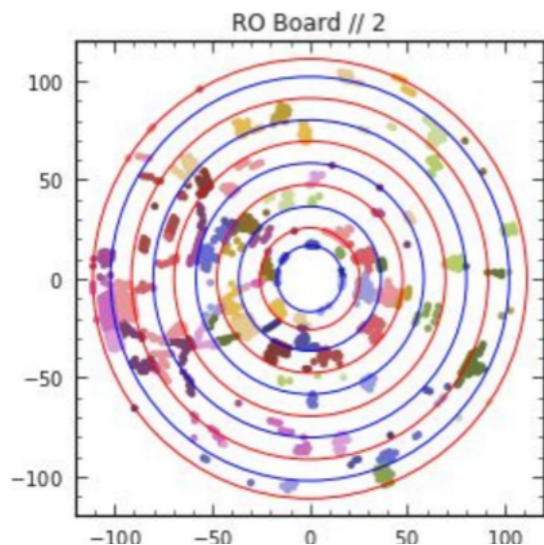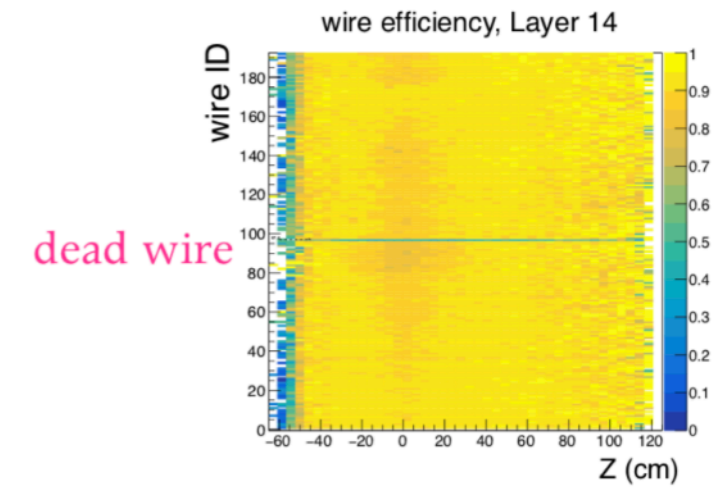
X-Y view of all CDC wires fired in an event, colour coding according to pairs of front-end readout boards

Exp=8 Run=2228

VXDTF2 alone, no CKFs

ADC background filter on

$|z_0| < 5cm$, $|d_0| < 2cm$, $p_T > 0.5 GeV/c$, $N_{SVD} > 7$

no filter
with filter

$N_{CDC} > 10$ efficiency

$\tan\lambda$

Physics Scope

DESY group affords for wide and ambitious physics programme in Belle/Belle II.

- Angular measurements of B → K*ll, R(K*) with Belle data
- Search for B → Kπ with Belle data
- R(K*) with Belle II data
- Search for B → hv$\bar{v}$ with Belle II data

B Physics

Helmholtz W2/W3
- Inclusive |V$_{xb}$| measurements
  - Inclusive B→X$_s$γ
  - Inclusive B→X$_u$l nu

Belle II
- Defined Initial and final kinematics
- Clean environment
- B factory (σ~1.1 nb)
- τ factory (σ~0.9 nb)
- Detector hermeticity

Low Multiplicity:
- Dark Photon
- ALPs search
- long-lived particles } **YIG**
- LFV Z' search

Tau Physics
- Precision measurements
- LFV searches

Analysis Facility (NAF) is used for many of the Belle II analyses

Belle II Papers based on Phase II Data

1) "Measurement of the integrated luminosity of the Phase II data of the Belle II experiment",

- arXiv:1910.05365[hep-ex]

- submitted to "Chinese Physics C"

2) "Search for an invisibly decaying Z' boson at Belle II in $e^+e^- \mu^+\mu^- (e^\pm\mu^\mp)$ + missing energy final states"

- Physics result under wide Collaboration review.

3) "Search for Axion-Like Particles produced in e^+e^- collisions at BelleII"

- Unblinding of Phase 2 dataset is in progress.

4) …

DESY participation

DESY analysis

Search for Z'


❖ A variety of theories which aim at describing physics beyond the SM assume the existence of an additional neutral vector boson, Z'.

❖ Using the phase2 data search for invisibly decaying Z' boson

  ❖ ee→$\mu\mu$Z', Z'→Inv. flavour conserving mode.

  ❖ ee→eμZ', Z'→Inv. flavour violating mode.

❖ Upper limits to the cross section σ[e+e- → μ+μ-Z' (→ invisible)] are set and interpreted in terms of a new coupling constant g'

❖ Analysis under Collaboration Wide Review!
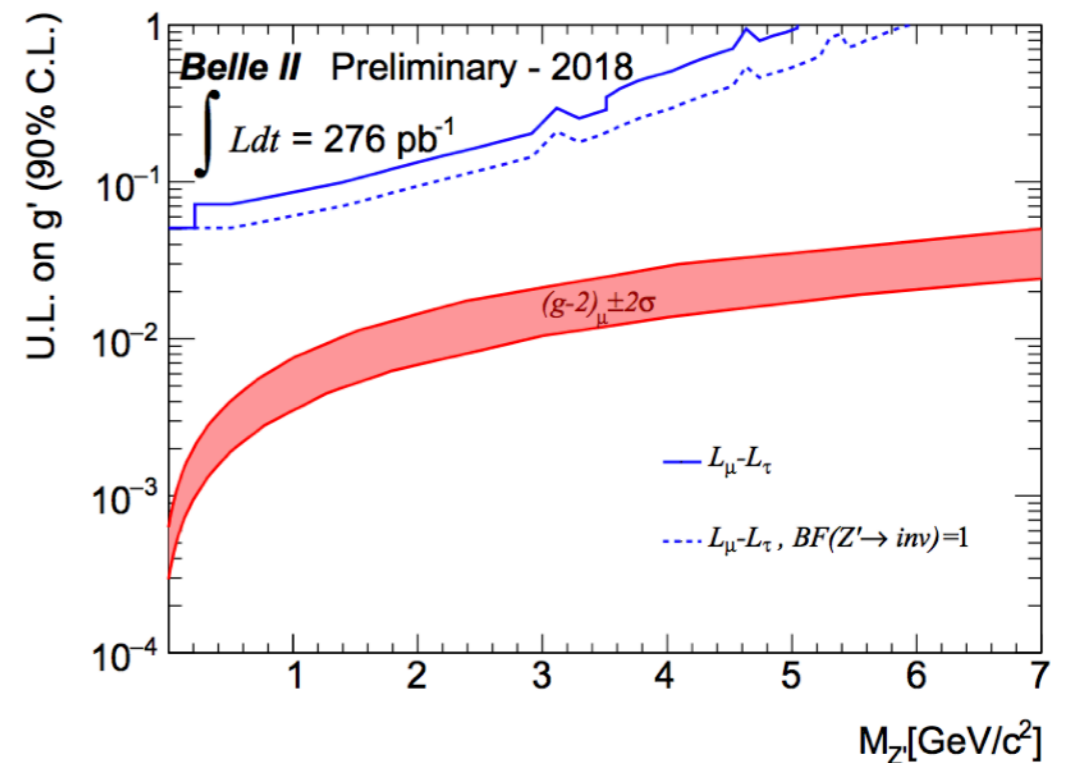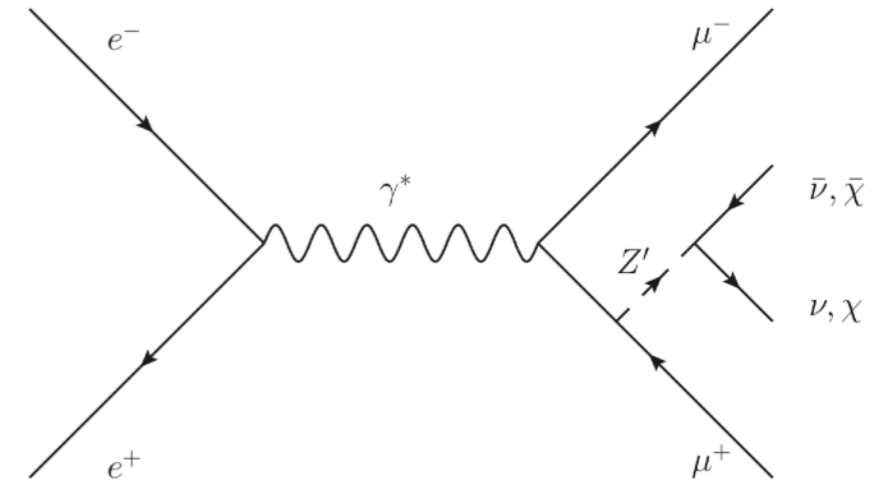
Axion Like Particles

❖ ALPs are pseudo-scalars particles (a) that couple to bosons.

❖ No results from B-factory yet.

❖ ALPs can also decay to DM

❖ Searching for visible ALPs decays with Phase 2 data.

   ❖ Final state: 3γ that add up to the beam energy

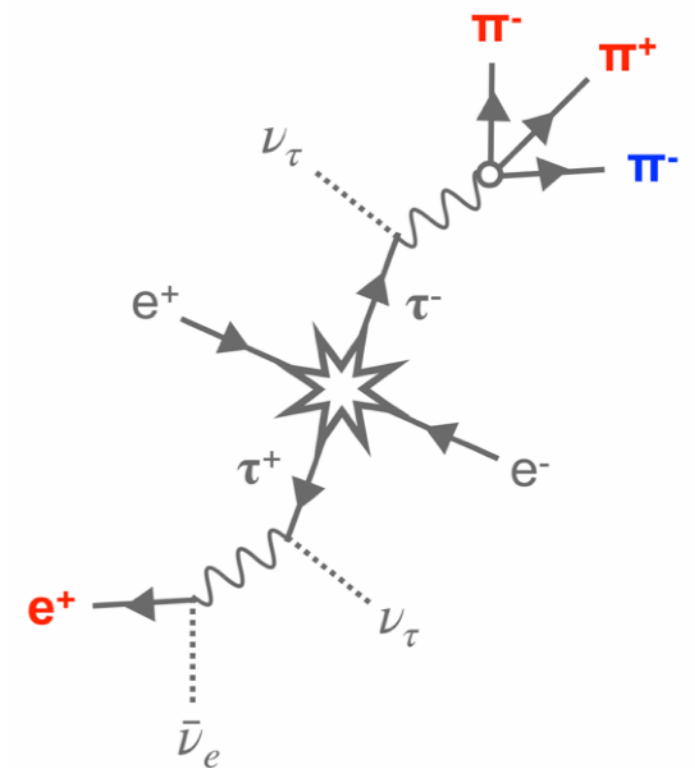❖ Will be published in this year.

ALP-strahlung

Tau Physics
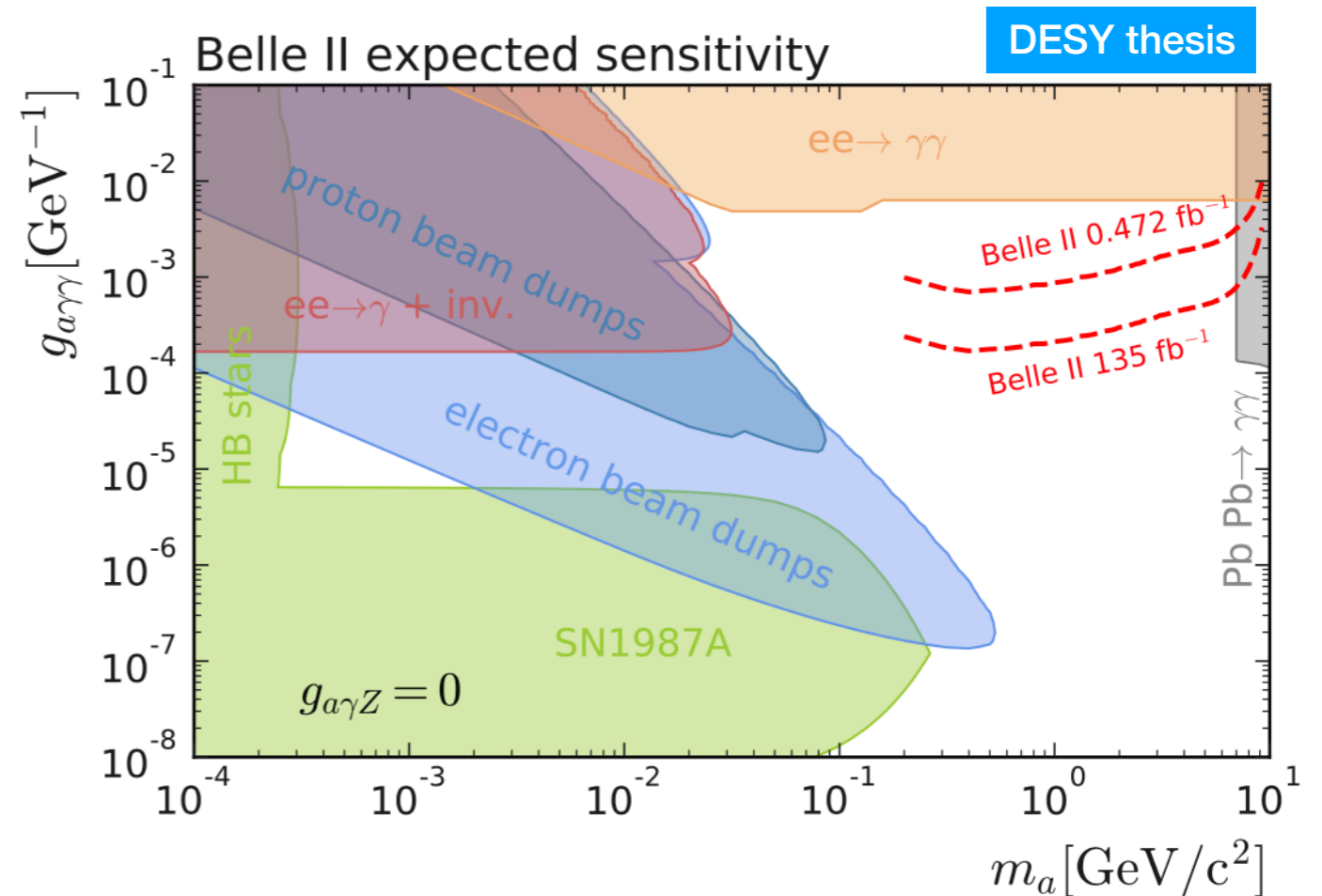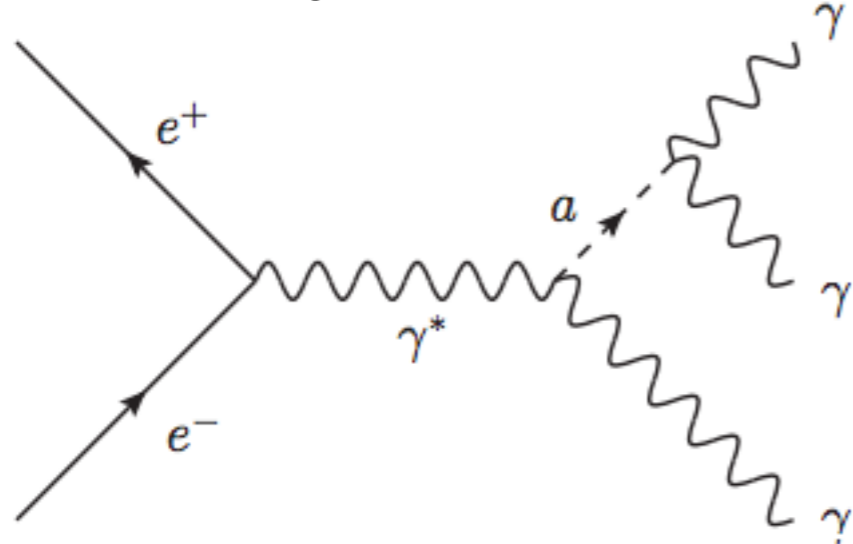
Trigger and tracking efficiencies using the taus

❖ **τ**-pair events provide a good testbed of CDC+ECL trigger performance

   ❖ Variety of low multi signatures involving both tracks and clusters

   ❖ ee→ττ→1x3 prong: e-3π, π-3π, μ-3π

   ❖ ee→ττ→1x1 prong: ee, eπ, eμ, ππ, μπ, μμ

❖ The monitoring of the trigger performance in close collaboration with Belle II trigger group

$$\epsilon_{L1} = \frac{\text{ref and L1}}{\text{ref}}$$

▸ ref = orthogonal trigger

❖ Tag-and-probe study with 1x3 prong events to provide a kinematic dependent tracking efficiency

   ❖ tag: 3 good quality tracks with $\sum q = \pm 1$,

   ❖ prob: look for loose 4th track that conserves charge

   ❖ Advantages:

      ❖ Large cross section: $\sigma(\tau\tau) \simeq \sigma(BB)$, at $\sqrt{s}=m_{\Upsilon(4s)}$

      ❖ Low multiplicity, but high track density. Good coverage at low track momentum

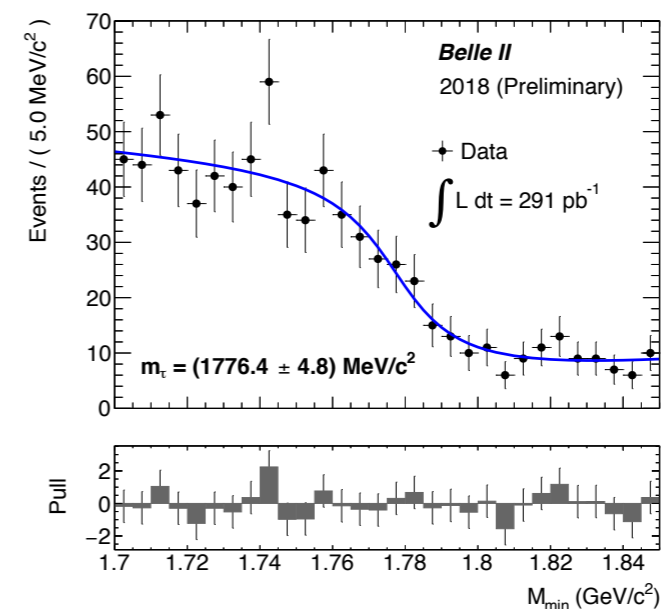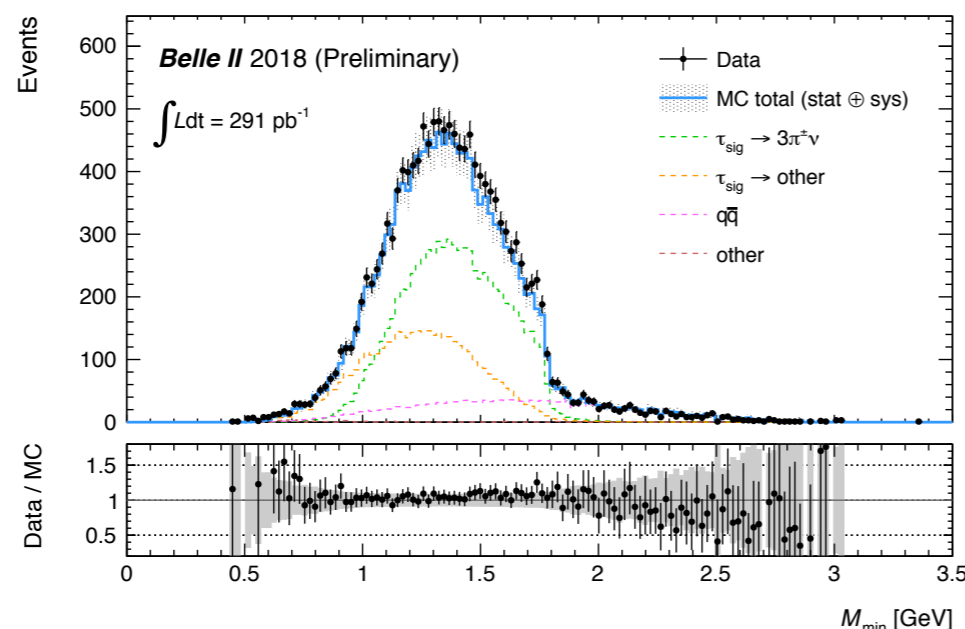   ❖ Data and MC discrepancy is calibrated with 2019 spring run data

Tau Physics

Tau Branching Ratios, Performance studies and tau Mass Measurements
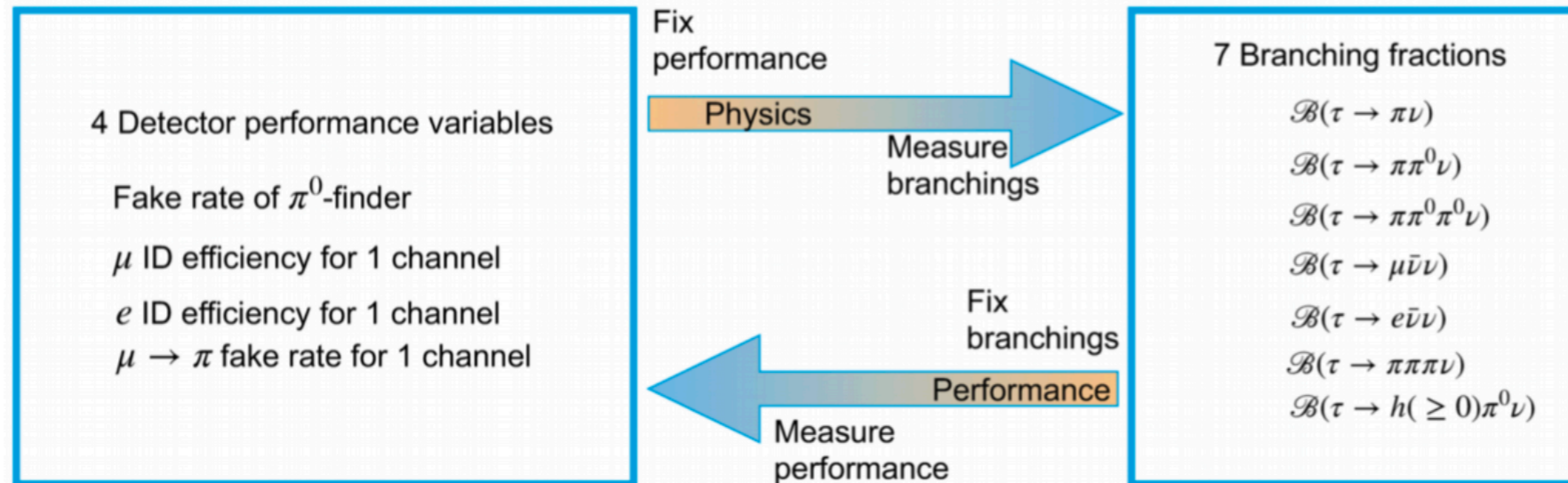
- ❖ M(τ) measured in τ -> 3πν
 - ❖ Pseudomass $M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})}$
- ❖ Analysis for Phase3 is currently blinded. Procedure validated in data challenge sample. Results expected for winter conferences.

B Physics

Ongoing/Planned B-physics Activities:

❖ Search for B → hνν̄ decays in Belle II

  ❖ Search for contribution of new physics processes (such as leptoquarks) which significantly increases the branching fraction.

  ❖ Using the full event interpretation (FEI) with the tag-B reconstructed from semileptonic decays (SL).

  ❖ DESY is active in development of SL FEI preselection criteria, FEI performance studies, and testing of conversion framework 'B2BII'.

❖ Inclusive B→$X_s\gamma$

  ❖ B→$X_s\gamma$ branching ratio gives tight constraints on physics beyond the SM.

  ❖ The photon energy spectrum allows measurements of the b-quark mass and non-perturbative parameters, which are important inputs to $|V_{ub}|$ measurements.

❖ Inclusive $|V_{ub}|$ measurements

  ❖ The CKM element with the highest relative uncertainty, and determines the side of the unitarity triangle opposite to $\sin(2\phi_1)$

  ❖ Discrepancy between exclusive and inclusive V_{ub} measurements.
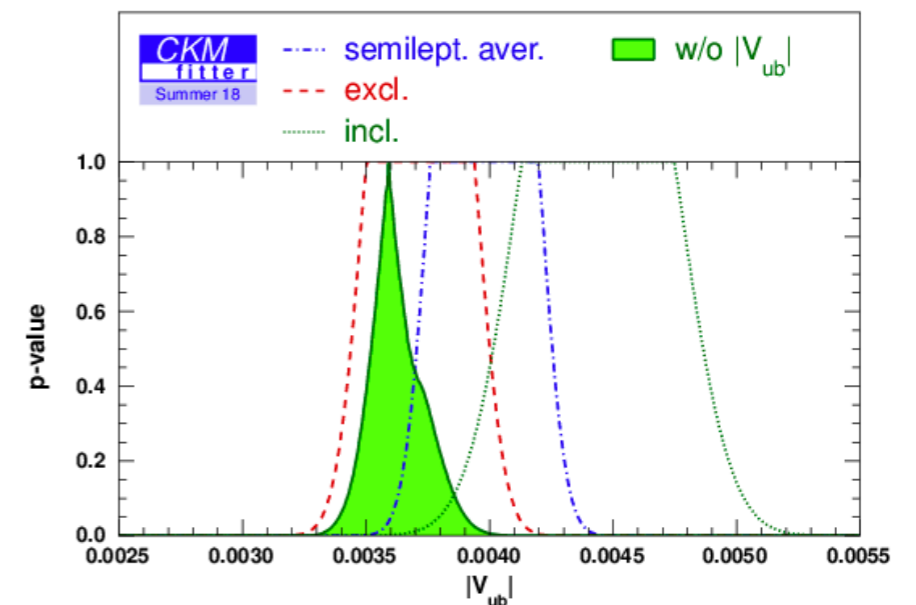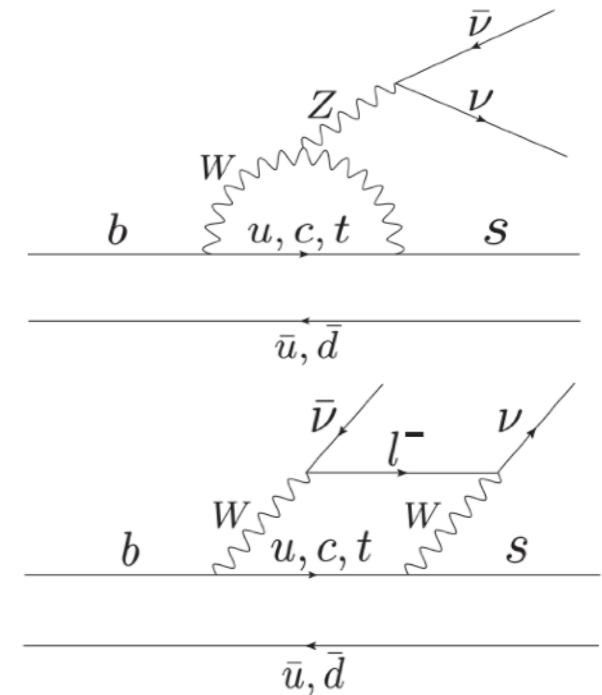
Computing
DESY host the Belle II collaborative services and tools

❖ Belle II collaborative services and tools are integrated into the production-grade IT infrastructure at DESY.

- User registry

- Web (*ZMS2*)

- Wiki (*Confluence*), GIT (*Stash*), Issue tracker (*JIRA*) ATLASSIAN tool suit

- Mailing list servcie (*Sympa*)

- Agenda (*Indico*)

❖ Belle II Membership Management System (B2MMS)

❖ Various services run by Belle II on virtual host at DESY (Authorship, eLog, Run DB, Document, Chat, Monitoring)

❖ In 2021 DESY will become a Belle Raw Data Centre to store 10% of the copy of the Belle II raw data
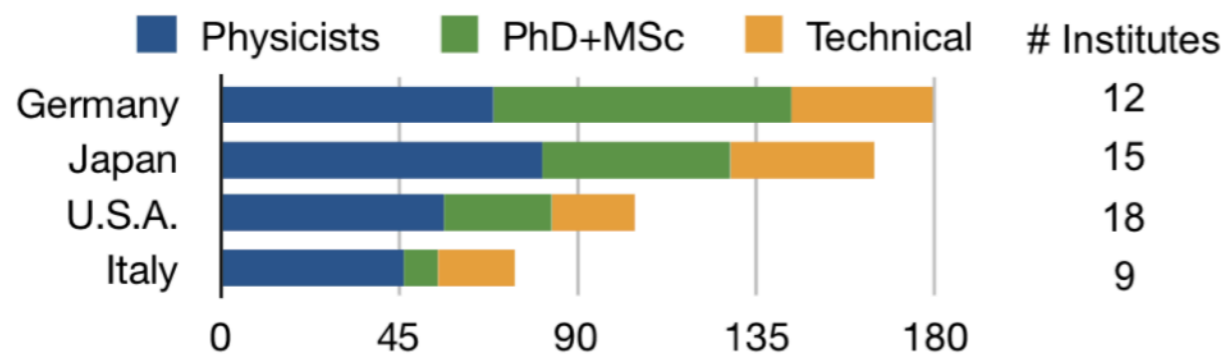
Summary

❖ SuperKEKB/Belle II successfully started operation, 6 fb^{-1} data sample accumulated in spring physics run.

    ❖ Challenges ahead of us: beam background, machine safety, beam-beam effects.

    ❖ DESY group is dedicated in the relevant studies of beam background and mitigation.

❖ Performance of detector is being characterized and optimized.

    ❖ DESY group plays a key role in the PXD operation and performance studies, as well as the software and physics performance studies including tracking, vertexing, alignment, simulation, calibration, trigger efficiency, lepton-identification performance…

❖ Wide physics programmes with Phase 2 and early Phase 3 data.

    ❖ First Belle II results are being released, where DESY group has made significant contribution.

Backup

Belle II Collaboration

Belle II Collaboration contains over 950 members from 26 countries in 19 time zones

Four largest countries by members / institutes

|	Physicists	PhD+MSc	Technical	# Institutes
Germany				12
Japan				15
U.S.A.				18
Italy				9

DESY Belle II group is actively growing

❖ 24 physicists

❖ 9 students

❖ 5 technicians

Extrapolation of PXD background to full luminosity

❖ Limitation in data throughput of the DAQ system and combinatorics in tracking limit maximum acceptable occupancy to <3%

❖ In early Phase3, PXD occupancy < 0.1%, dominated by beam-related backgrounds

    ❖ Beam gas (LER Coulomb)

❖ Correct the simulation by the observed Data/MC scaling factors from the background studies in May 2019

    ❖ Large Touschek HER data/MC discrepancy

    ❖ Coulomb LER → can be mitigated with collimators and/or extensive scrubbing

    ❖ Two photon QED process → irreducible

❖ Predicted occupancy at design luminosity x2 larger than PXD limit

PXD occupancy in early Phase3
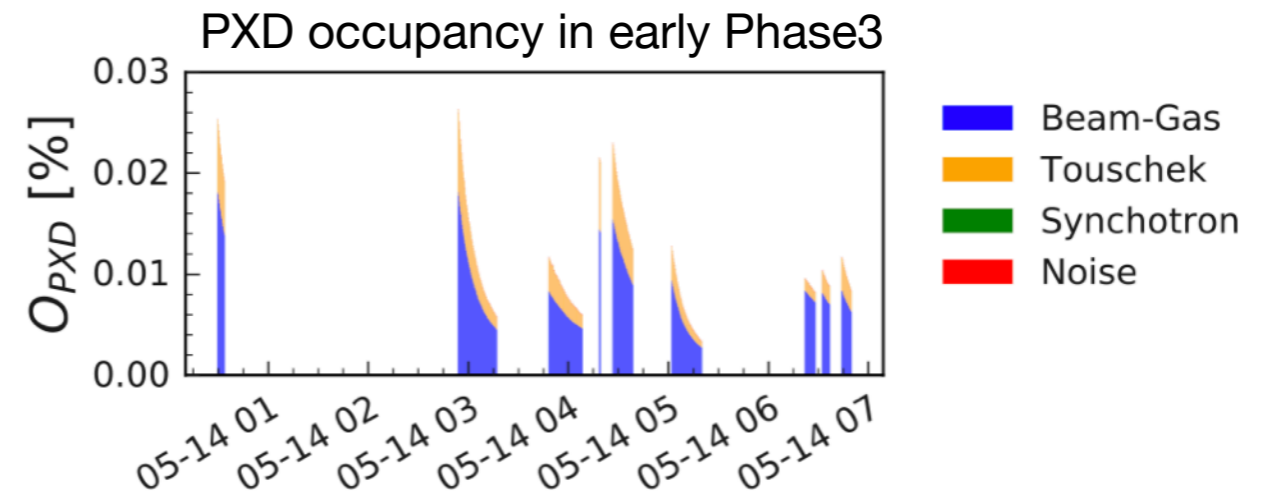
Scaled by data/MC in 2019 spring run
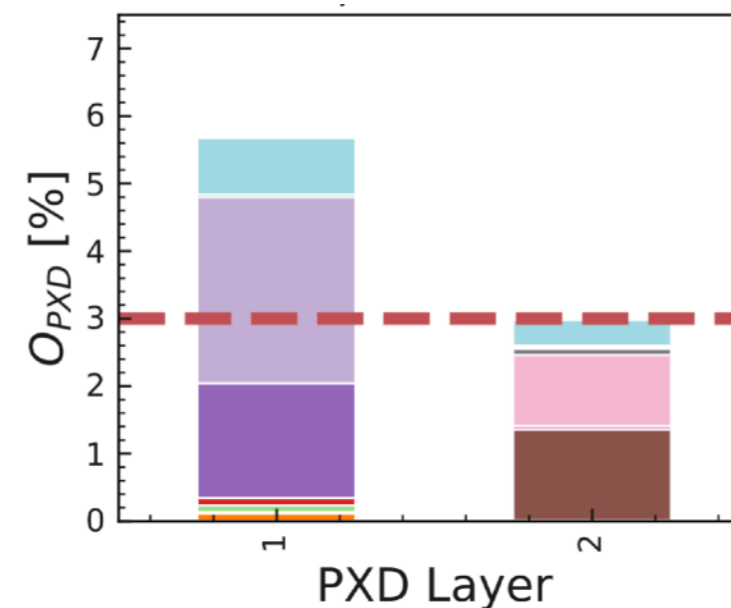
Gated Mode Studies

❖ At design luminosity Touschek effects limit beam life time to 10 mins
  ❖ → SuperKEKB has to be operated in top-up mode: continuous injection
  ❖ Every 20 ms single e^+/e^- bunches are injected.
❖ Freshly injected bunches produce high background
  ❖ Revolution time 10 μs
  ❖ PXD integration time 20 μs
  ❖ Damping time few ms
❖ Gated Mode can make PXD blind when noisy bunches pass.
  ❖ DESY is leading the gated mode tests and offline studies.

HER   2 bunches, 25 Hz
Injected bunches 100 ns apart
LER
25 Hz
revolution time = 10 μs
3 km circumf.
Belle II

SuperKEKB bunch pattern

20 μs frame

~ cooling: 4ms noisy /~ 400 packets   ~ 16 ms "clean"