BEAST results on SuperKEKB beam background: focus on the PLUME pixelated system

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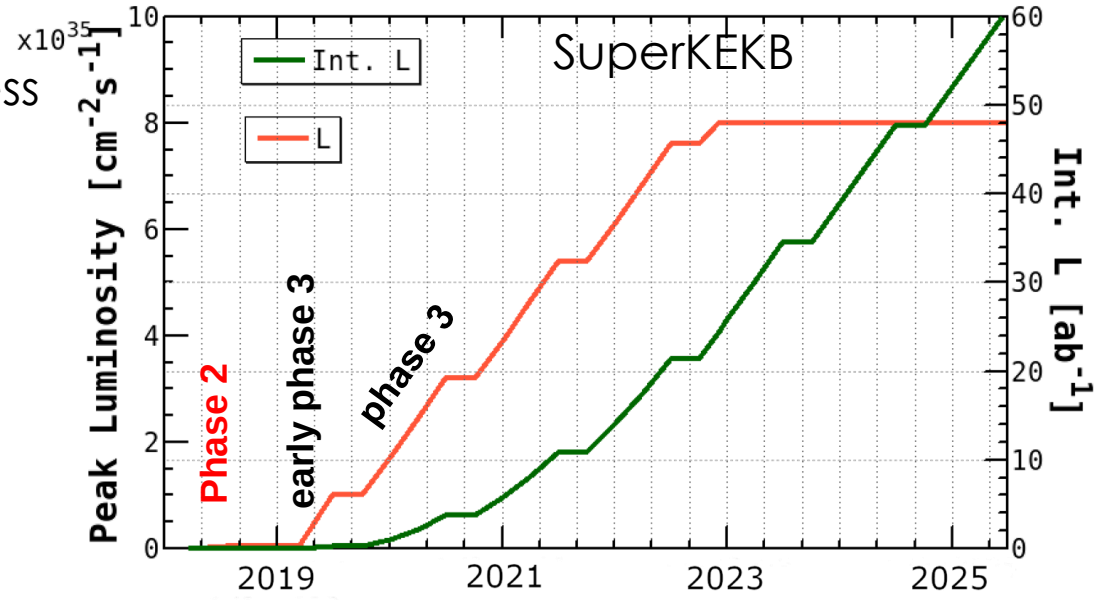
on behalf of the BEAST/Belle II collaboration

- Beam induced background at SuperKEKB & Belle II: BEAST
- The double-sided PLUME device
- Single Beam background estimates
- Outputs with 2-sided measurements

Belle II physics goals

- The intensity frontier
  - Built up on B factories success
    - e+e- coll. at Υ(4s)
    - integrated luminosity x 50
  - Flavour studies
    - New source of CP violations
    - Lepton non-universality
    - Charged lepton flavour violation
    - Left-Right symmetry contribution
    - Dark sector
  - Complementary / LHCb



- Vertex Detector (VXD) Requirements
  - Track impact parameters
    - Goal σ(high p) ~ 15 μm
  - B, D, decay vertices
    - Goal σ ~ 60 μm
  - 30 kHz trigger rate
  - Innermost layer
    - Hit rate >0.4 hits/μm²/s
    - TID: 20 kGy/year

See F. Luetticke's talk from Monday 10th

SuperKEKB collider

Large currents
HER I_{beam} = 3.6 A
LER I_{beam} = 2.6 A

HER: e^- 7GeV

Belle II

e^+ 4GeV :LER

Higher e+ energy
to mitigate Touschek bkg

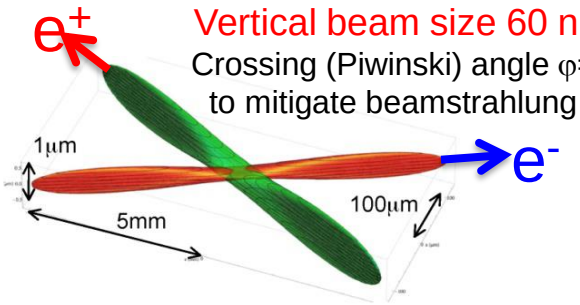
New final
focusing magnets

Nominal L_{peak} = 8x10^{35} cm^{-2}.s^{-1}

Add / modify RF systems
for higher beam current

New LER pipe

Nanobeam scheme
Vertical beam size 60 nm
Crossing (Piwinski) angle φ=83 mrad
to mitigate beamstrahlung



Positron source

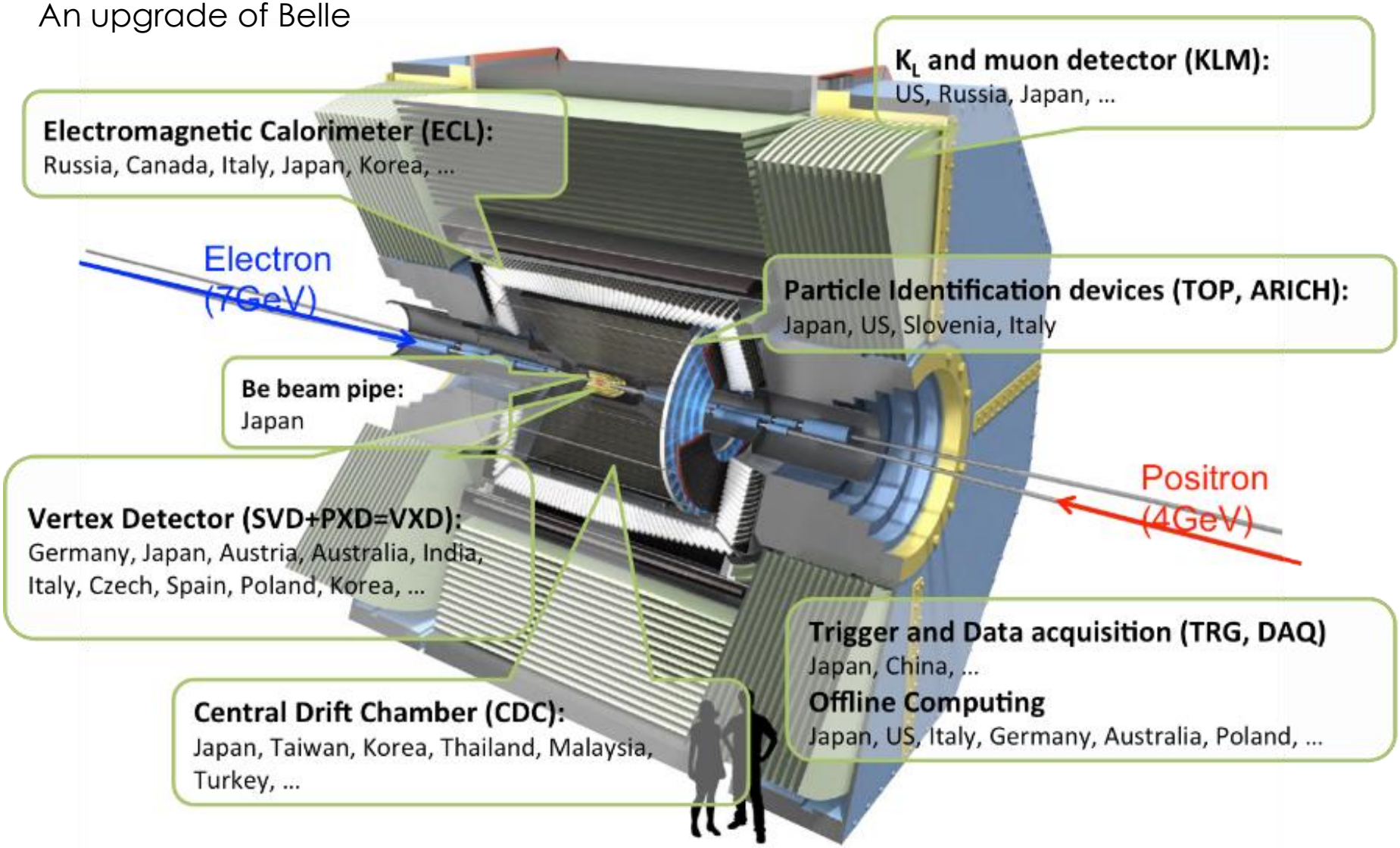
Damping ring
for low emittance e+

low emittance
e- gun

$$L \propto \frac{N_- N_+ f_{revol}}{\sigma_x \sigma_x} = \frac{I_{\pm} \xi_{\pm y}}{\varphi \sigma_z \beta_y^*}$$

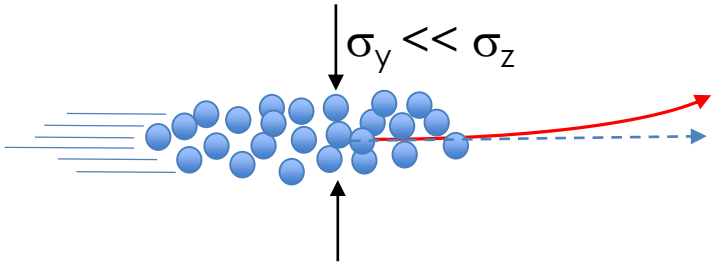
The Belle II detector

An upgrade of Belle

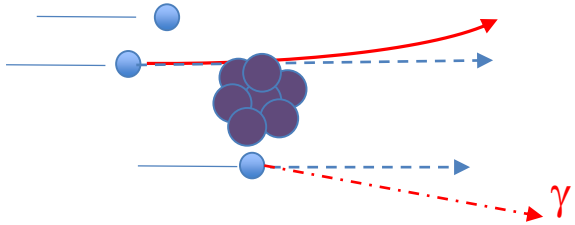


Beam induced backgrounds

- **Single beam effects**
  - Touschek ← intra-beam scattering
    - rate $\propto \frac{I_{bunch}^2 \; N_{bunch}}{(\sigma_x \, \sigma_y) \; E_{beam}^3} = \frac{I_{beam}^2}{(\sigma_x \, \sigma_y) \; E_{beam}^3 \, N_{bunch}}$

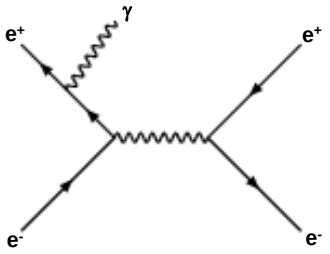


  - Beam gas ← vacuum residues
    - rate $\propto I_{\text{bunch}} \times N_{\text{bunch}} \times P(I)$
    - Dynamic pressure $P(I) = (p_0 + p_1 I_{beam})$

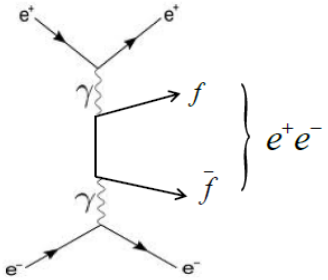


  - Synchrotron radiation ← magnet bending
    - rate $\propto I_{\text{beam}}$

- **Beam-beam effects (QED)**
  - rate $\propto$ Luminosity



Radiative Bhabha scattering



2-photon interaction

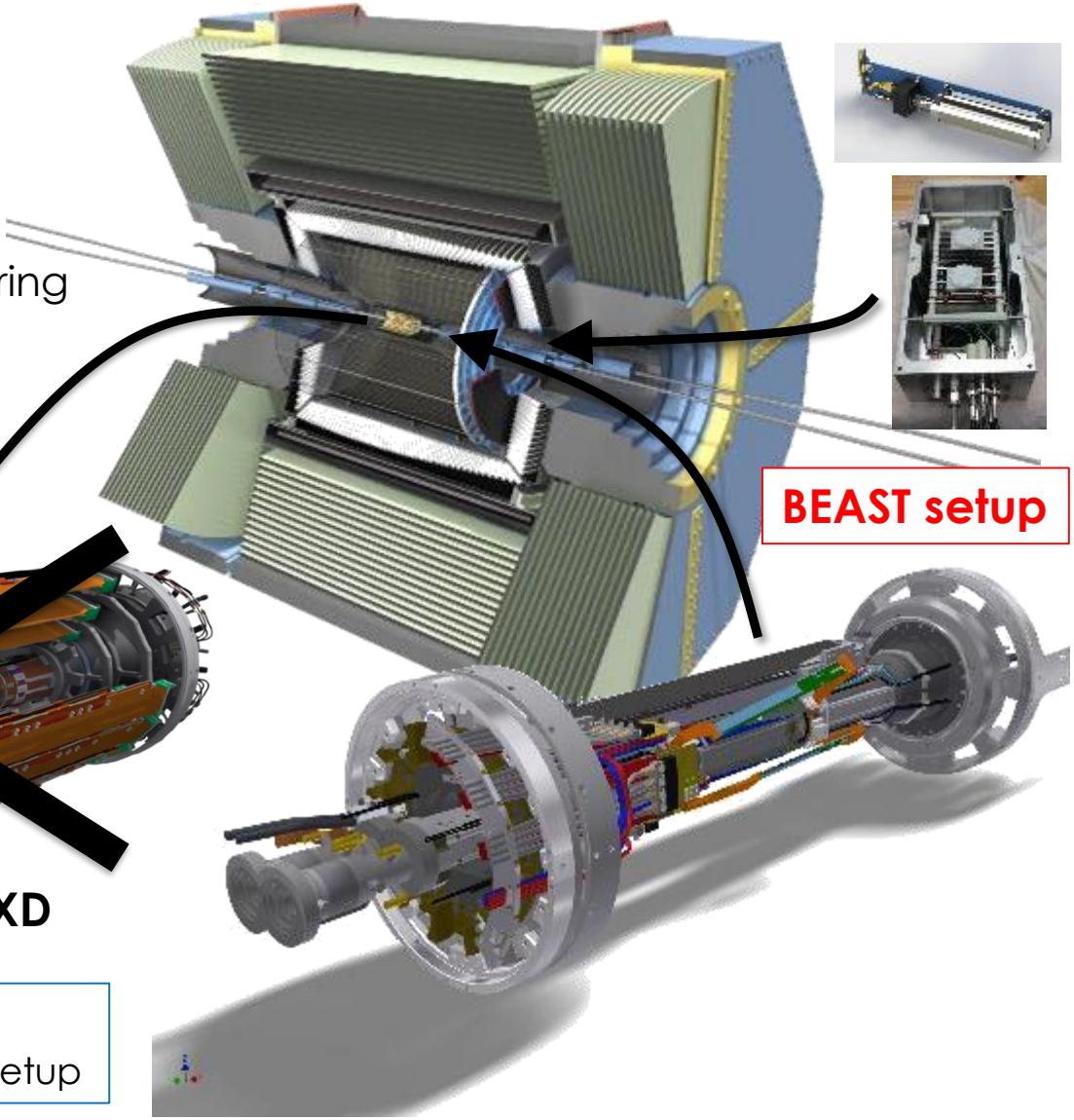
Beam induced backgrounds

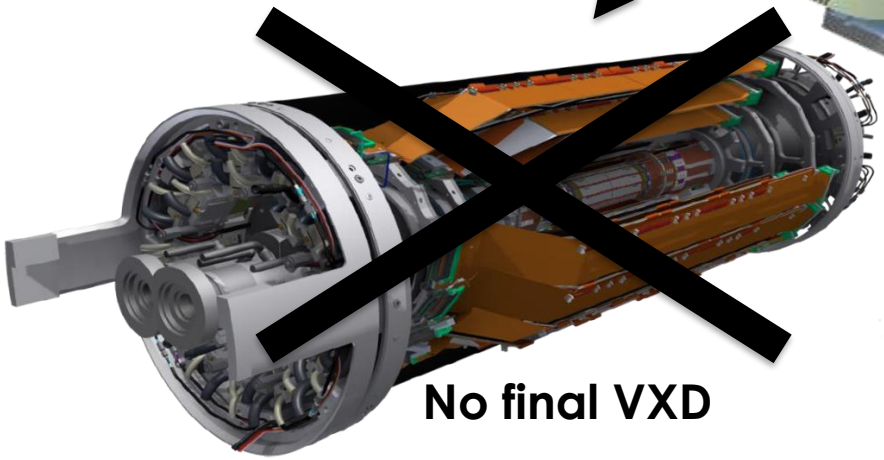
- **Single beam effects**
  - Touschek ← intra-beam scattering
    - rate $\propto \frac{I_{bunch}^2\ N_{bunch}}{(\sigma_x\ \sigma_y)\ E_{beam}^3} = \frac{I_{beam}^2}{(\sigma_x\ \sigma_y)\ E_{beam}^3\ N_{bunch}}$
  - Beam gas ← vacuum residues
    - rate $\propto I_{bunch} \times N_{bunch} \times P(I)$
    - Dynamic pressure $P(I) = (p_0 + p_1 I_{beam})$
  - Synchrotron radiation ← magnet bending
    - rate $\propto I_{\mathrm{beam}}$
- **Beam-beam effects (QED)**
  - rate $\propto$ Luminosity

- **Expectations**
  - Dominates beam lifetime
  - Higher relative impact at large radii (CDC, TOP)
  - Sub-dominant
  - Issue for innermost PXD (mostly horizontal plane)
  - Dominant at $L_{nominal}$
  - Saturate VXD occupancy

Belle II in Phase 2

- BEAST goals
  - Safe background conditions for VXD insertion / phase 3
  - Real-time background monitoring during SuperKEKB tuning
  - Understand individual background components



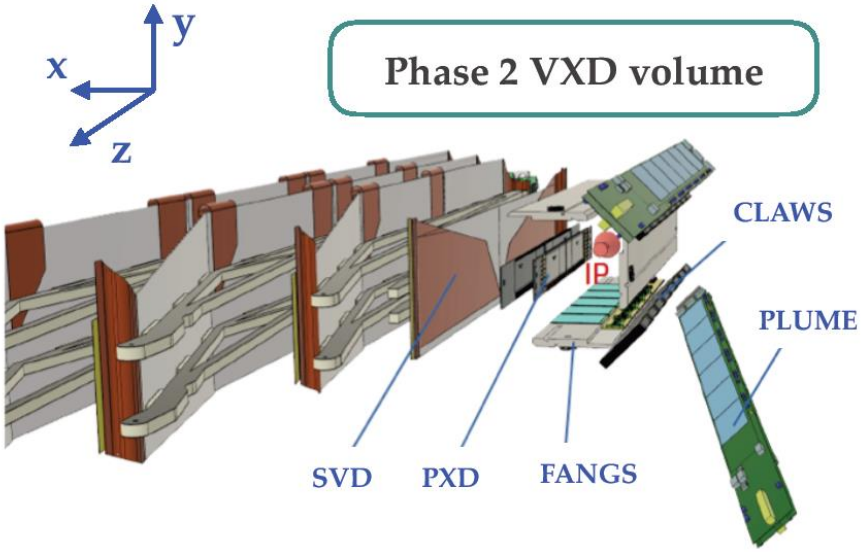


No final VXD

During Phase 1 (no collisions):
Initial measurements with another BEAST setup

The BEAST setup: complementarity

	Sensor	Measurement
B-II PXD	DEPFET 2 ladders	In-situ occupancy tracking & vertexing
B-I SVD	DSSD 4 ladders	
Diamond	8 sensors	Ionizing dose in VXD
FANGS	Hybrid pix (ATLAS) 3 ladders	Charged particle & X-ray synchroton rates
CLAWS	Scint.tile SiPM (ILC) 2 ladders	Rates with ns precision / injection
PLUME	2sided MAPS (ILC) 2 ladders	Rates & two-sided track.
MicroTPC	8 units	Fast neutron rate
He3 tube	4 units	Thermal neutron rate
Rad.Film	Many	Radiation level
PinDiode	80 units	Radiation at focus.magnet



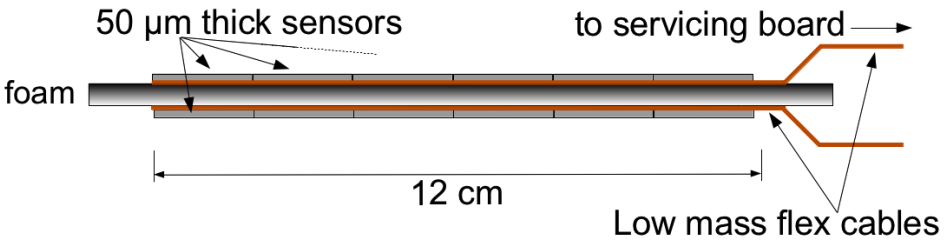
Final VXD ~3.5 % X_0

BEAST ~4.0 % X_0

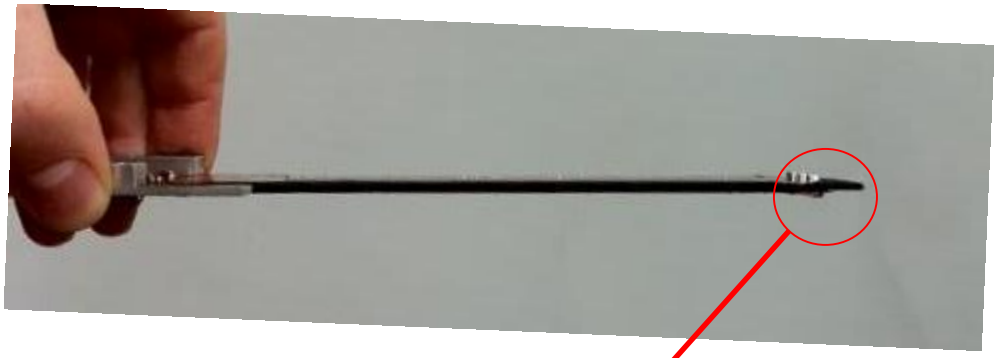
Material budget

PLUME double-sided layer

- Concept
  - Double-sided layer of pixel sensors
  - Designed driven by ILC-VXD
  - Air cooled
  - Collab: Bristol, DESY, IPHC



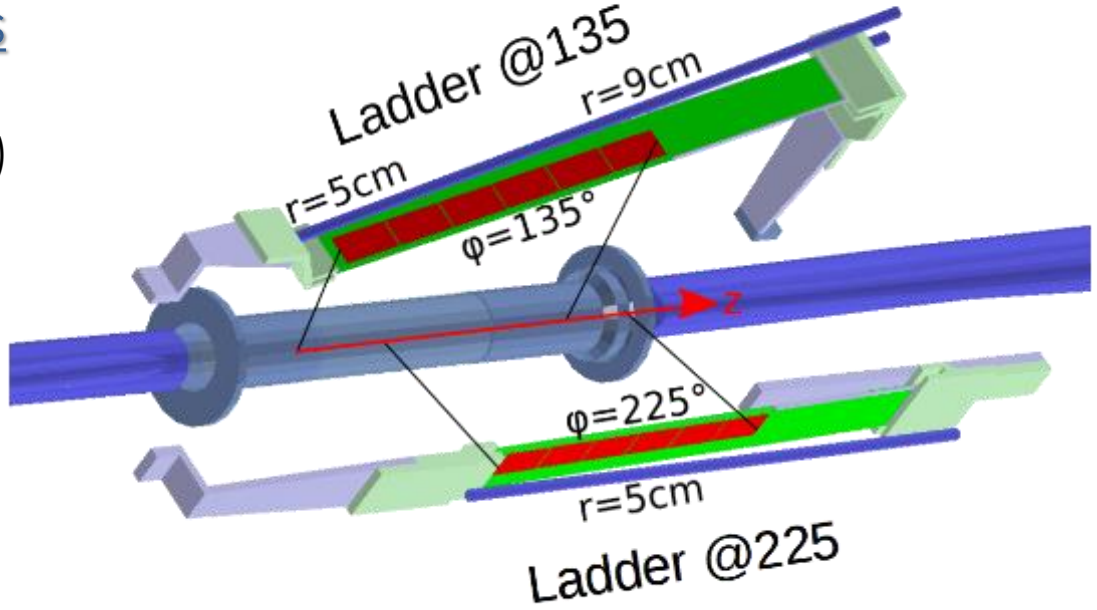
- PLUME-2
  - 2x6 MIMOSA-26 sensors
    - Pitch 18.4 µm
    - Binary output
    - Thinned to 50 µm
  - 8 Mpixels
  - integration time 115 µs
  - 2 mm thick Si-carbide foam
  - Material budget 0.4% X0
  - 4 ladders produced

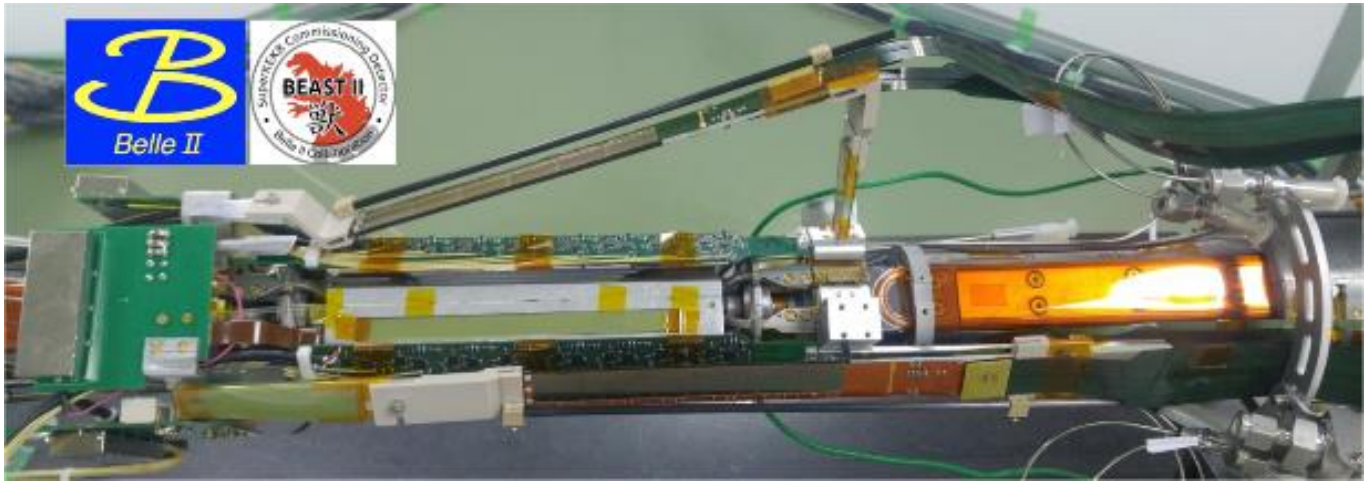


Side view

PLUME geometry in BEAST

- 2 complementary angles
  - 135^0 & 225^o
  - Opposite to VXD sector (0^o)
- Radius covered
  - SVD range



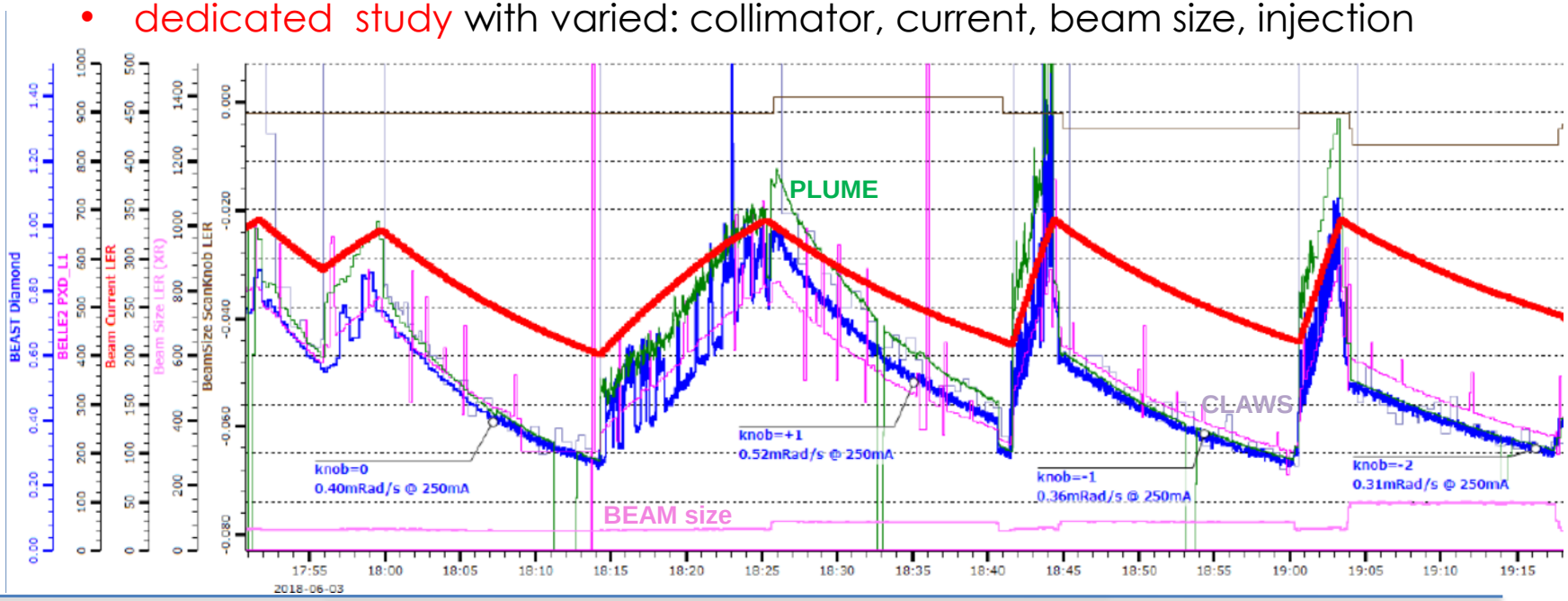


Phase 2 data taking

- SuperKEKB
  - Started March → Ended July 2018
  - Collimator adjustment and tuning
  - β_y^* decreased from 8 to 3 mm (σ^*_y ~ 400 nm)
  - Beam current up to ~800 mA

Best peak lumi: 5.4×10^{33} cm^{-2}.s^{-1}

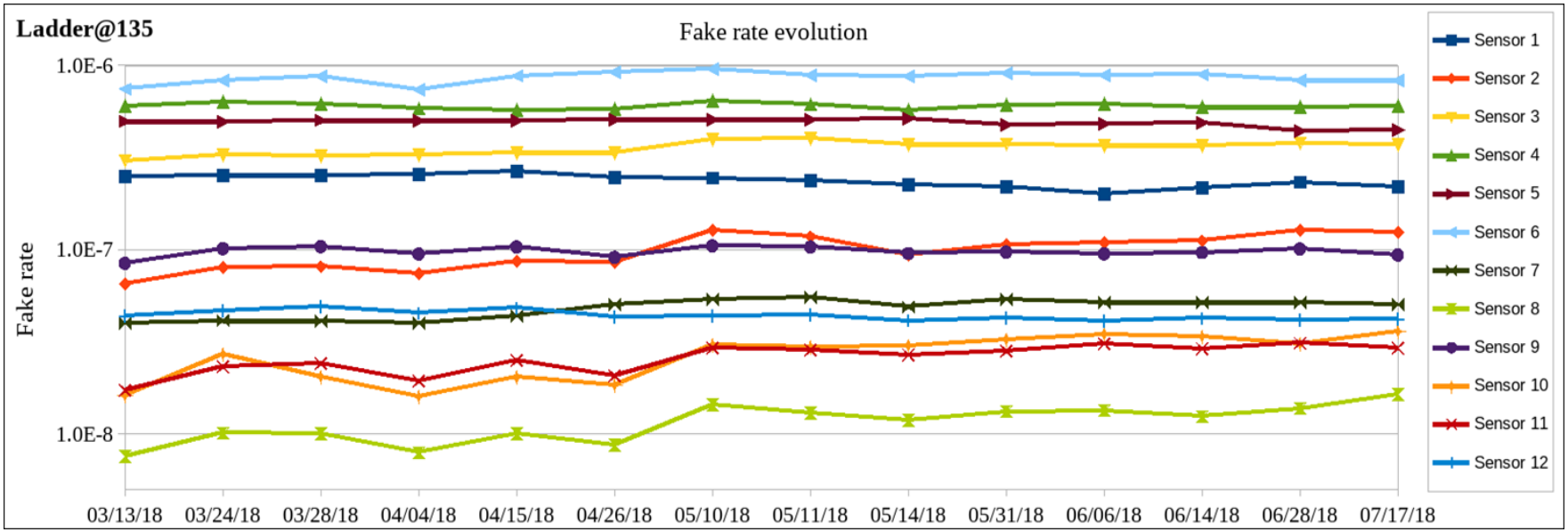
- BEAST
  - Permanent online monitoring during tuning
  - dedicated study with varied: collimator, current, beam size, injection



Radiation levels

- From radiochromic films
  - Decrease with radius in inner volume: ~1 kGy → few 100's Gy
  - Clear contribution from low penetrating radiations

- PLUME specific
  - 99% up time during all Phase 2 period
  - No significant sign of TID ⇔ crosschecked by radio.films (~200 Gy)



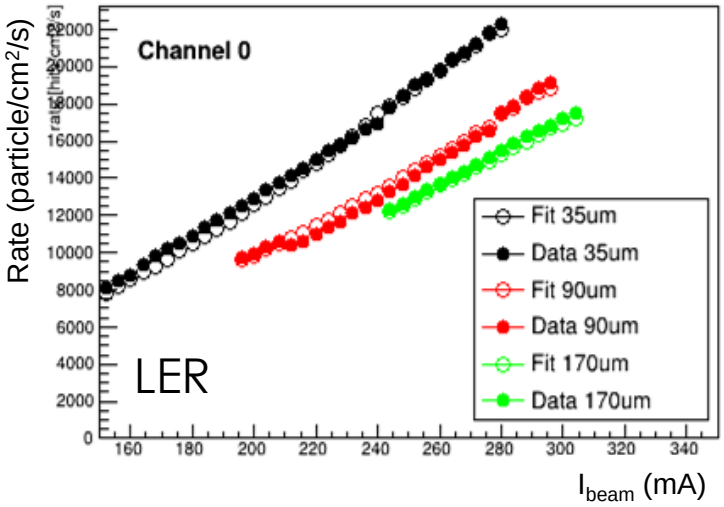
Single-Beam background estimates

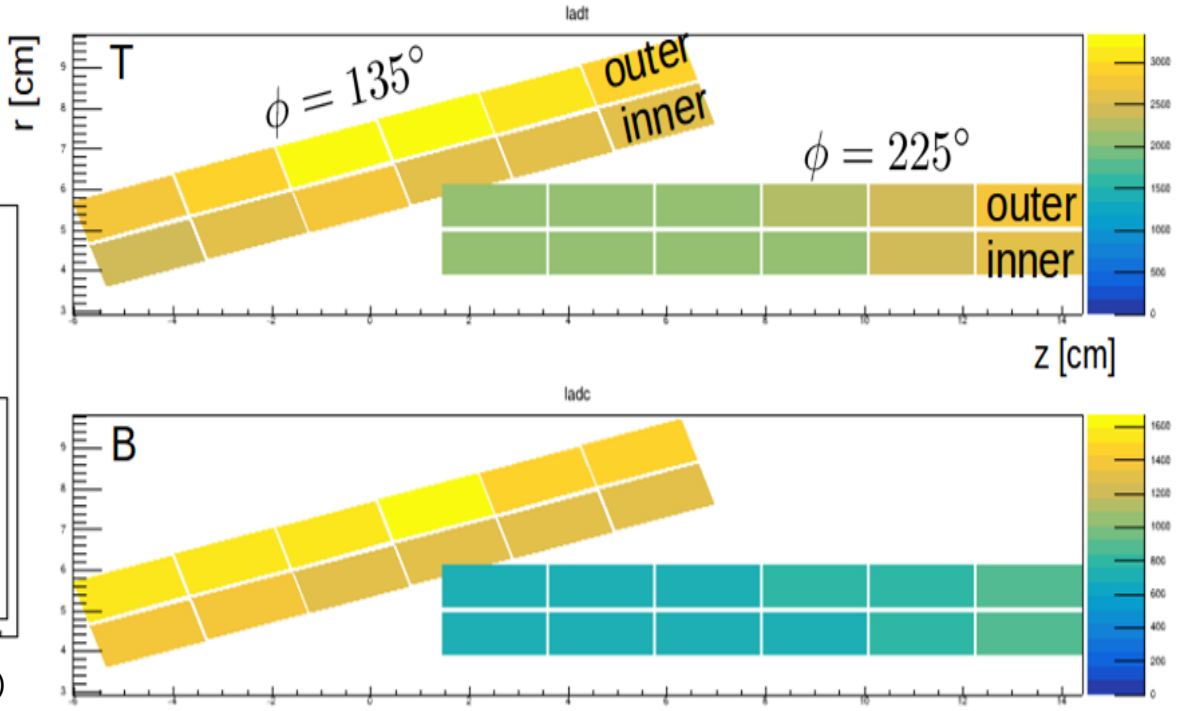
- Separate contributions through their dependence to current and beam-size

$$Rate(I, \sigma_y) = T\left(\frac{I_{beam}^2}{\sigma_y N_{bunch}}\right) + \mathrm{B}\left(p_1 I_{beam}^2 + p_0 I_{beam}\right)$$

  - 2 absolute contributions to rate: T (Touschek), B (Beam-gas)
    - T, B specific to each detector

- PLUME fit examples



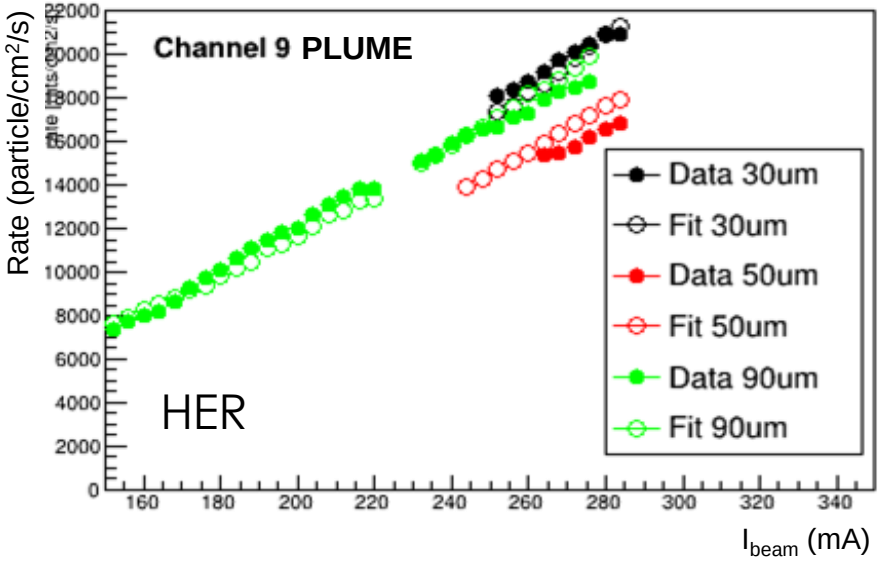


Single-Beam background estimates

- Unknown additional contribution for HER
  - For large beam size, rate rise again!
  - Data favour a "Touschek-like" contribution

$$Rate(I,\sigma_y) = T\left(\frac{I_{beam}^2}{\sigma_y N_{bunch}}\right) + \mathrm{B}\left(p_1 I_{beam}^2 + p_0 I_{beam}\right) + \mathrm{X}\left(\frac{I_{beam}^2}{N_{bunch}}\sigma_y^3\right)$$

  - Unclear origin
    - Large beam tails to account for it



Single-Beam background findings

- *PLUME data shown so far, but of course similar plots for all BEAST/Belle II*

- Rates in inner volume during Phase 2
  - Of course $O(10^2)$ smaller than expectation for phase 3
  - Dominated by LER wrt HER
    → Additional collimators for phase-3
  - Beam Gas ≥ Touschek for PXD radii
  - Beam Gas < Touschek for SVD radii

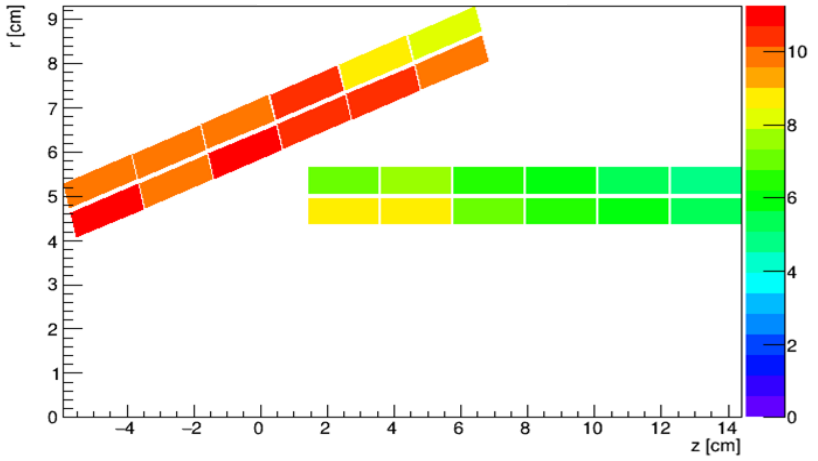
- Synchrotron radiation
  - 1st observation (PXD, SVD, FANGS)
    - X-rays in 8-15 keV range
  - Not well reproduced in simulation
  - Not seen in PLUME

Sinlge-Beam background findings

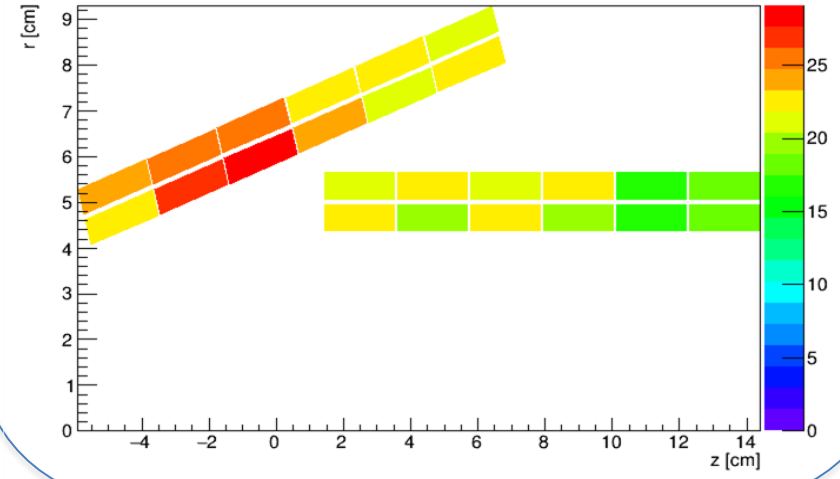
- Comparison to simulation
  - Dedicated beam simulation (SAD) + GEANT 4
  - Relative rates (r, ϕ) OK
  - LER rates reproduced within a factor 5-20
  - HER rates not reproduced reasonably
    ⇒Under investigation

PLUME preliminary

Touschek DATA/MC



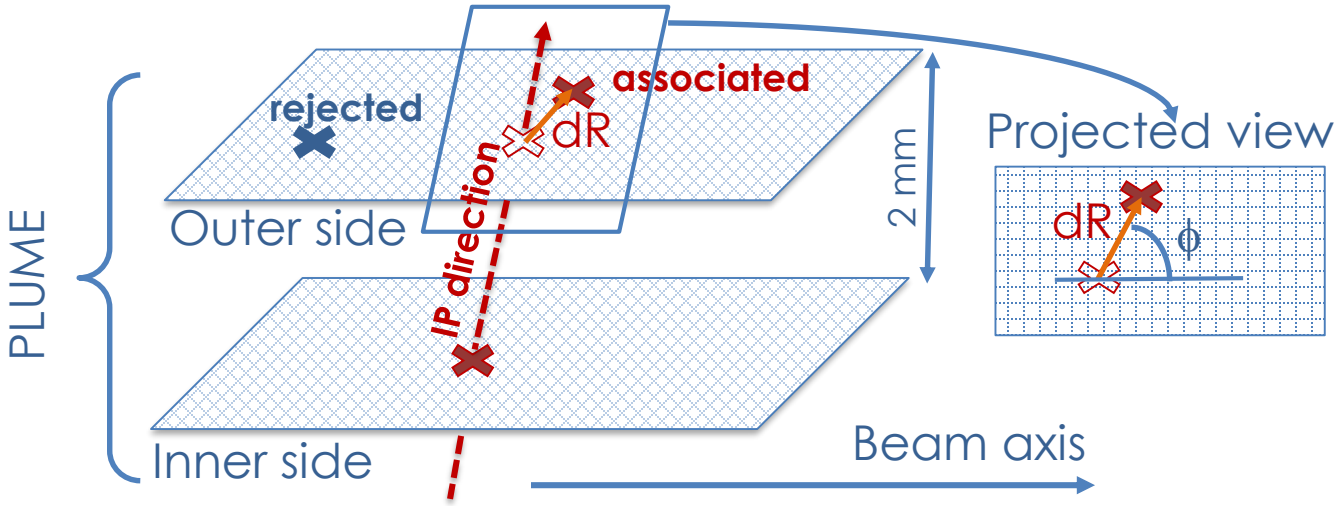
Beam Gas DATA/MC



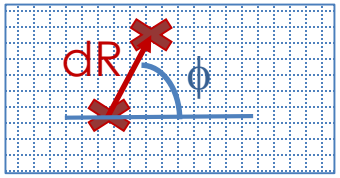
Luminosity background ?

- Luminosity background
  - Mostly $e^{\pm}$ from interaction point (IP) at low momentum (< 50 MeV)
  - p_T > 15 MeV to reach PLUME (5 cm radius)

- "Tracking" with PLUME double-sided feature
  - Associate nearest hits on both sides pointing to IP
  - Bending & low p => dR< few mm & $\phi \sim \pi/2$

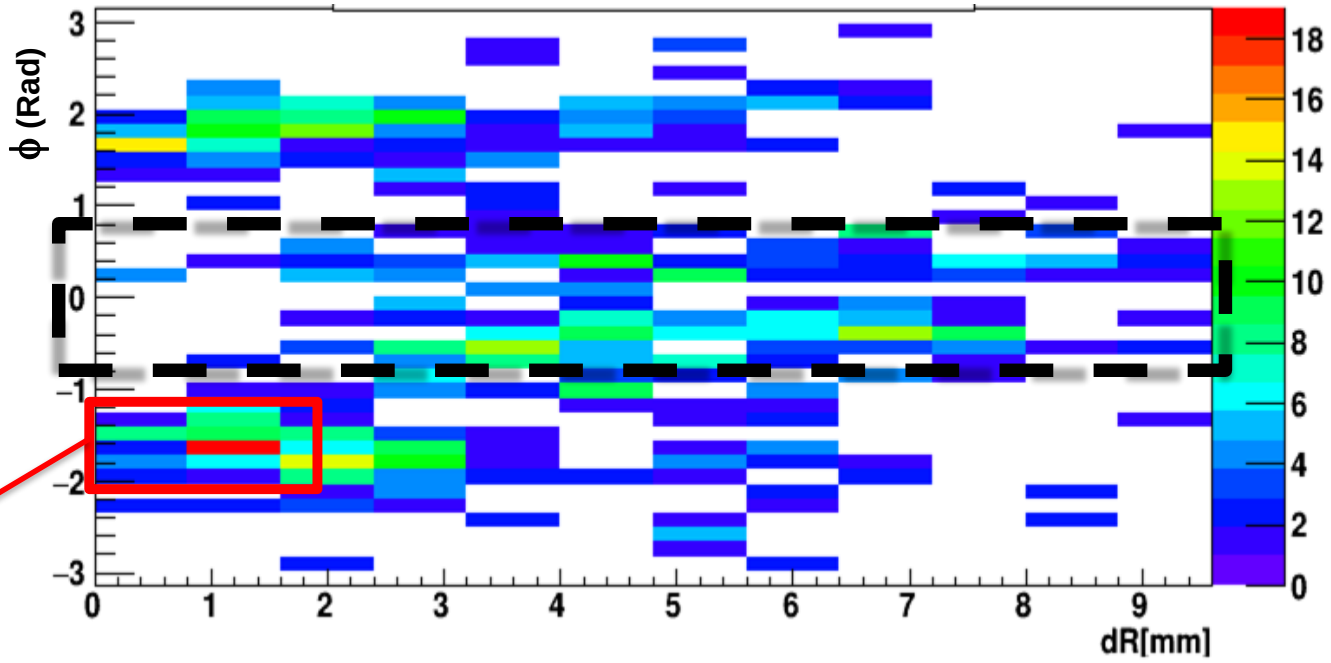


Luminosity background in MC



Projected view

200 ms of Two Photon simulation



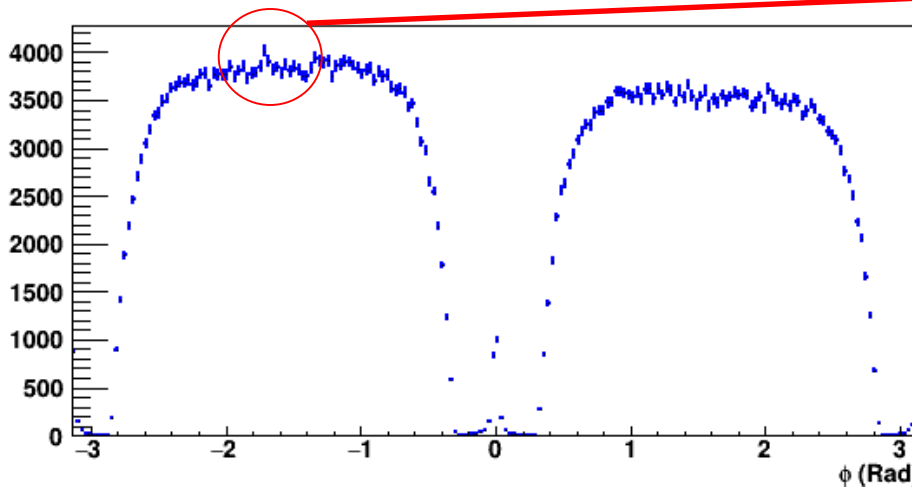
- Combinatorial
  - Ultra-dominant in real data
- Selections
  - Sensors nearest IP along beam axis
  - $-2.0 < \phi < 1.4$ Rad
  - dR < 2 mm

⇒ Efficiency on total # particles from luminosity background = $(5 \pm 1)\ 10^{-3}$

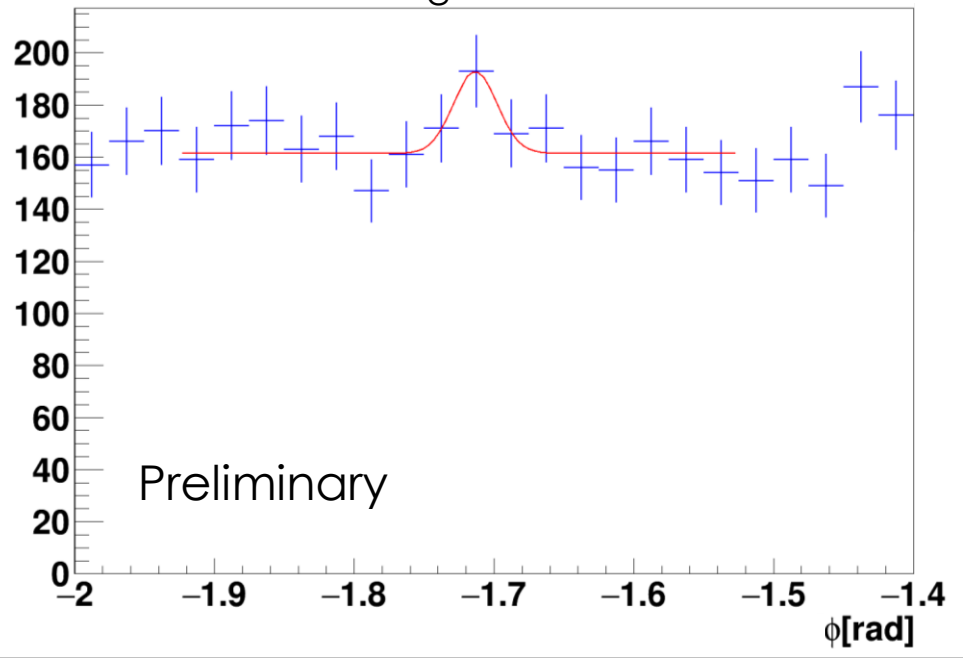
Luminosity background in data

- Run with average luminosity 1.3 10^{33} $cm^{-2}.s^{-1}$
  - After selection (dR< 2mm)

200 s of data taking



10 s of data taking



- After correcting for efficiency
- Background from luminosity ~1 hitscm^2/s for L~10^{33} $cm^{-2}.s^{-1}$
- Hit rate / Lumi ratio agrees within 10% between MC and data

⇒ Lumi. Background barely visible
160 to 650 x lower
than Single Beam background

Summary

- Beam induced background from phase-2 (current status)
  - Low enough to start operation of full VXD & Belle II in general
  - Low Energy Ring contribution dominates High Energy ring
  - Discrepancy with respect to current simulation
    ⇒ under investigation
  - Further background mitigation during early phase-3
    - Dedicated devices: CLAWS, more Diamonds, pin-diodes, He3

- PLUME in BEAST
  - Went through complete data taking during phase-2
    - Still perfectly usable
  - Double-sided feature provide 1st glimpse on luminosity-related background
    - Negligible for lumi < 10^{34} $cm^{-2}.s^{-1}$ as expected

- Future of PLUME as a versatile double-sided pixelated system
  - Current version exploits 10 years design
    - Still proves very useful
    - Needs upgrade with newest (fastest) thin sensors
  - Demonstration of longer ~50 cm range close to 0.3 % X_0