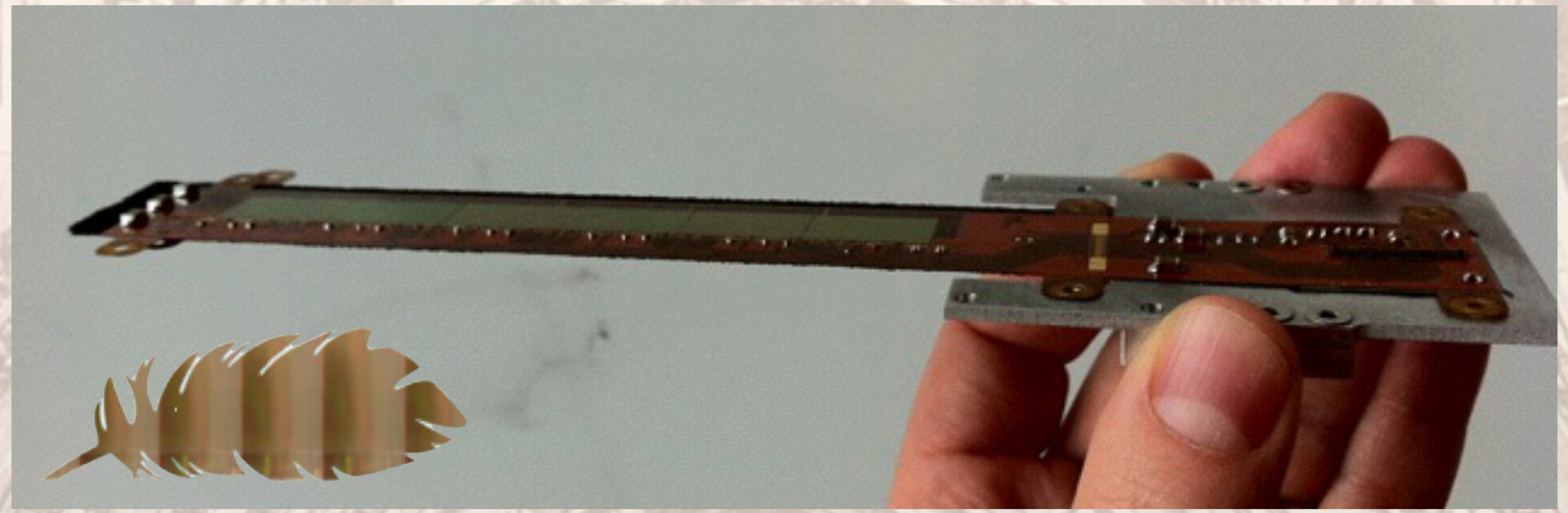
FJPPL meeting on French BEAST/Belle II activity
19-20 January 2015 - IPHC Strasbourg

What can be measured with PLUME?



Outline:

- What questions do we have?
- Detector configuration possibilities
- Occupancy rates
- Damping of the injection noise
- Sensitivity to synchrotron radiation
- Angular measurements
- Very first look at background simulation
- Conclusion

I. Ripp-Baudot
for the IPHC-PICSEL group
support from Université de Strasbourg:
Investissements d'avenir

What questions do we have?

- What beam conditions should we expect during BEAST phase 2?
  Beam parameters (current, luminosity, …): inputs for simulations.

- Limits to operate PLUME:
  - What is the expected radiation load?
    Do we sustain it? Impact of injection noise and beam losses?
  - What is the expected occupancy rate during BEAST phase-2?
    Do we sustain it?
  - Injection noise: is it an issue? Does it saturate the read-out?

- What important measurements can be provided with PLUME:
  - Are we able to provide information about the injection noise damping?
  - Are we sensitive to synchrotron radiation background?
  - Is it possible to disentangle different background sources, e.g. beam-beam vs. single beam, synchrotron radiation:
    - thanks to PLUME angular resolution?
    - thanks to cluster (u,v) size?

Detector configuration possibilities

- PLUME-2 equipped with MIMOSA-26 sensors:
  - integration time ~100 μs
  - sensitive area with 2x 6 sensors: 2x 12x1 cm^2 (2x refers to both sides)
  - $8x10^6$ pixels of dimension 18.4x18.4 μm^2
- PLUME-3 equipped with ALICE-ITS type sensors, e.g. MISTRAL:
  - integration time 20 μs
  - sensitive area with 2x 3 sensors: 2x 9x1.3 cm^2 (if placed at r ~ 1.4 cm)
  - $5.2x10^5$ pixels of dimension 36x62.5 μm^2
- Also to be figured out:
  - What radius should be considered?
  - 2 ladders: either from same PLUME type, or one PLUME-2 and one PLUME-3.
  - PLUME-3: can be operated with full sensitive area & and integration time 20 μs
    or: do not read all lines of pixels ➛ integration time 2 μs
    but sensitive area only 2x 9x0.16 cm^2
- Constrains on the final design:
  - Integration aspects.
  - What inputs are mandatory to safely operate the PXD in Belle II w.r.t. what will be already measured with other devices in the inner tracker volume?
  - Provide also inputs to the design of a future upgraded VXD (+beam pipe)?

Back-of-the-envelope occupancy rate estimation (1)

Luminosity Initial target (example)

	SuperKEKB Design		SuperKEKB Initial Target (example)	
	LER	HER	LER	HER
Luminosity	8×10^{35} cm^{-2} s^{-1}		3×10^{34} cm^{-2} s^{-1}	
I_{beam}	3.6A	2.6A	0.51A	0.37A
ξ_y	0.088	0.081	0.040	0.033
β_y^*	0.27mm	0.30mm	0.54mm	0.60mm
β_x^*	32mm	25mm	62mm	50mm
ε_x	3.2nm	4.6nm	3.2nm	4.6nm
κ (x-y coupling)	0.27%	0.28%	2.1%	2.2%
# of bunches	2500		357	

Discussion : Beta function should be 1 order higher than design value

SuperKEKB Run 3 starting parameters: taken as BEAST-phase 2 parameters.

correction w.r.t. numbers from this table according to Nakayama-san yesterday. Therefore I did:

To estimate BEAST-phase 2 occupancy rates, take Belle II background simulation results and apply:

- single beam bkg /10
  (not taken into account: detuned beams, worse vacuum)
- beam-beam bkg / 80

Very preliminary approach. Conditions during BEAST may be worse than during Belle II physics run, due to beam tuning and beam losses. ??

Back-of-the-envelope occupancy rate estimation (2)

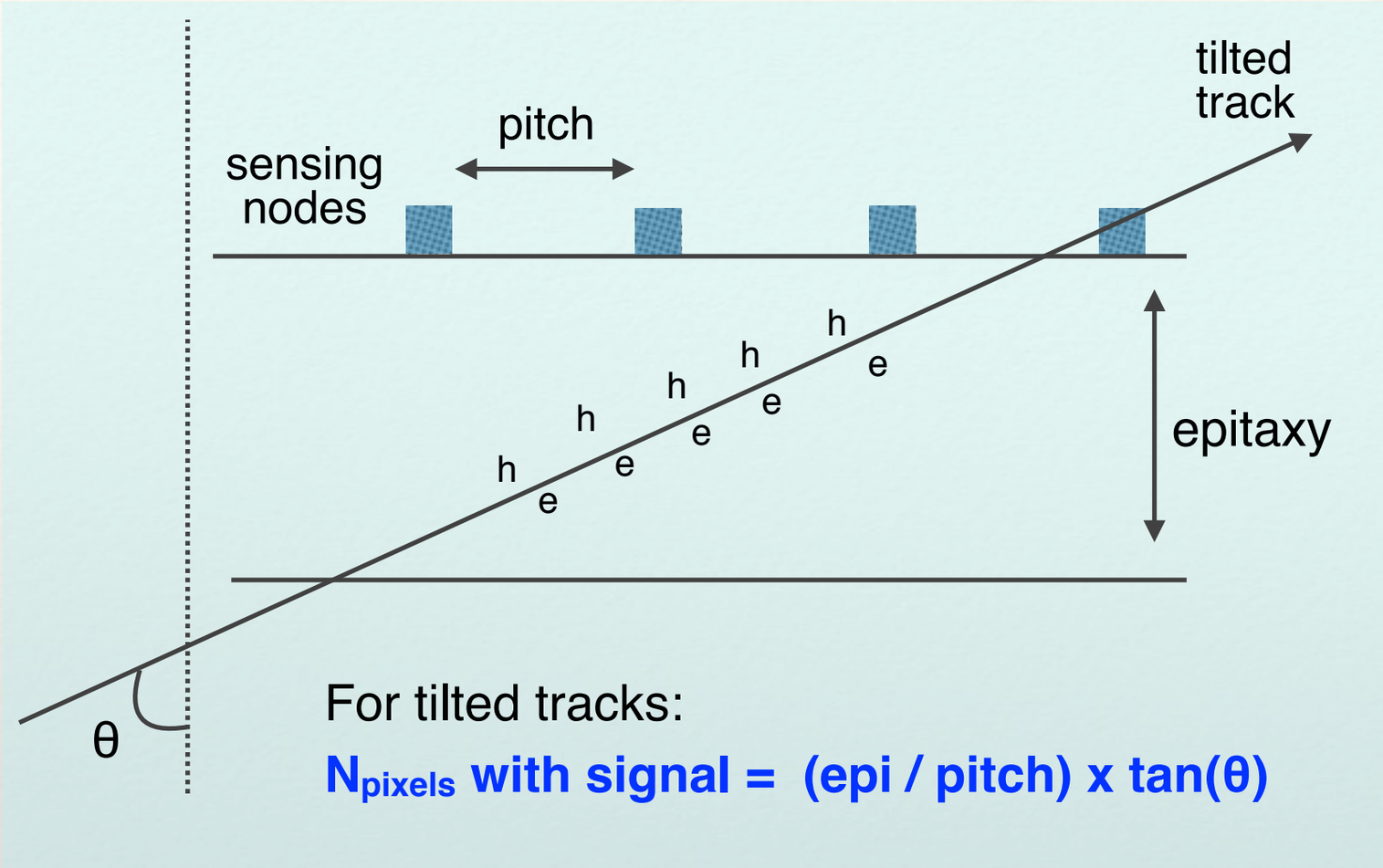
- Furthermore, to translate DEPFET PXD occupancy rates to PLUME-2, also take into account:
  - Pixel surface: DEPFET 50x50 μm² (r=1.4 cm) or 50x75 μm² (r=2.2 cm)
    ➛ MIMOSA-26 18.4x18.4 μm².
  - Sensor integration time: DEPFET 20 μs
    ➛ MIMOSA-26 100 μs.
  - Cluster size: DEPFET ~1.3 pixels/hit ?? for perpendicular tracks
    how does it vary with track incidence?
    ➛ MIMOSA-26 ~3 pixels/hit for perpendicular tracks

This is the main difficulty of this back-of-the-envelope calculation:
Background particles are mainly produced with non-perpendicular incidence and cluster sizes are actually due to:

- Sensitive node network rather than pixel dimension.
- Sensitive depth w.r.t. distance between sensitive nodes.
- Track polar angle and transverse momentum (curvature in the magnetic field).

- Conclusion: such a back-of-the-envelope calculation is only useful to make sure that PLUME can be operated efficiently and have a clue on what measurements may be interesting.
  A full simulation study is needed to go further.

Cluster size and tilted tracks



- CMOS:
  epi / pitch = 15 / 18.4 = 0.8
- DEPFET
  epi / pitch = 75 / 50 = 1.5

➛ increase of cluster size due to track tilt is larger in DEPFET than in PLUME.

- Conclusion: using the ratio MIMOSA-26 / DEPFET ~ 3 / 1.3 for cluster sizes
  which is ~ correct for perpendicular tracks (due to: DEPFET are depleted and pitch is larger)
  (as done in the back-of-the-envelope calculation)
  may predict slightly too high occupancy rate in PLUME.

Back-of-the-envelope occupancy rate estimation (3)

BG sources and Radiation tolerance

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- Radiation environment
  - 4-fermion final state QED process
  - Touschek effect
  - Beam-gas interactions
  - Synchrotron radiation
  - Radiative Bhabha scattering

hit rate decreases >> $1/r^2$ due to low momentum spectrum

Occupancy by each BG source: PXD case

		PXD during Belle II physics run		PLUME-2 during BEAST at r = 1.4 cm	PLUME-2 during BEAST at r = 2.2 cm
		Layer 1	Layer 2		
Touschek	LER	0.1 %	0.07 %	0.016 %	0.0073 %
Touschek	HER	0.0 %	0.0 %	0	0
Beam-Gas Coulomb	LER	$2 \cdot 10^{-4}$ %	$1 \cdot 10^{-4}$ %	3×10^{-5} %	10^{-5} %
Beam-Gas Coulomb	HER	0.0 %	0.0 %	0	0
Radiative Bhabha	LER	$5 \cdot 10^{-3}$ %	$2 \cdot 10^{-3}$ %	1×10^{-4} %	3×10^{-5} %
Radiative Bhabha	HER	0.03 %	0.01 %	6×10^{-4} %	1.3×10^{-4} %
Two-Photon QED		0.8 %	0.2 %	0.016 %	0.0026 %
~Total		0.9 %	0.3 %	~0.033 %	~0.01 %

Synchrotron radiation(very preliminary): 0.14 %
(one ladder in horizontal plane: ~1.8%)

Still under investigation

➤ Beam-pipe Au coating is different in BEAST

Conclusion about hit rates and occupancy rates

- MIMOSA-26 read-out capability ~ few 10^6 cm^{-2} s^{-1} i.e. ~ few 200 hits /sensor / frame

  few means here: function of the track incidence (cluster size)

  ➛ read-out capability ~ few 400 pixels / sensor / frame

  $\gtrsim$ 0.1 %

  because: 1 sensor = 2x1 cm^2 read out in 100 µs (= 1 frame)

  1 hit ~ 2 pixels and $6x10^5$ pixels /sensor

- Digital read-out of MIMOSA-26 ➛ threshold can be changed:
  - Decrease threshold to increase cluster size

    if bkg hit rate is too low w.r.t. fake rate.
  - Increase threshold to decrease cluster size

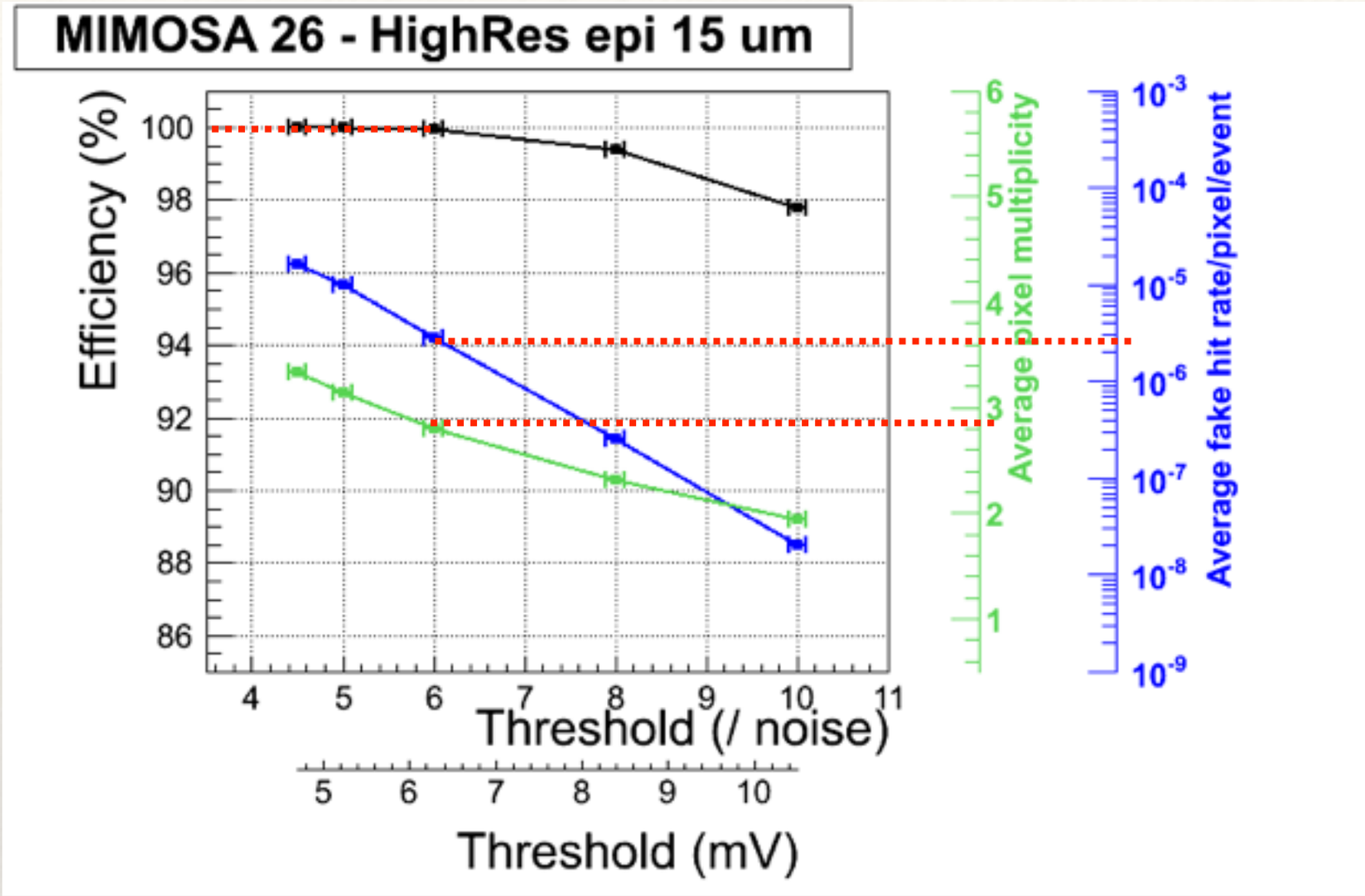
    if bkg hit rate is too high w.r.t. read-out capability.

    ➛ see next slide.

- Fake rate is due to noisy pixels, which are known: these noisy pixels can be killed to lower the fake rate.

  ➛ Conclusion on expected occupancy rate:
  - Hit rate at r = 1.4 cm during BEAST can be easily sustained by PLUME.
  - Attention: if r is too large, occupancy rate may reach the fake level because of the very high granularity of M26.

Cluster size vs. threshold

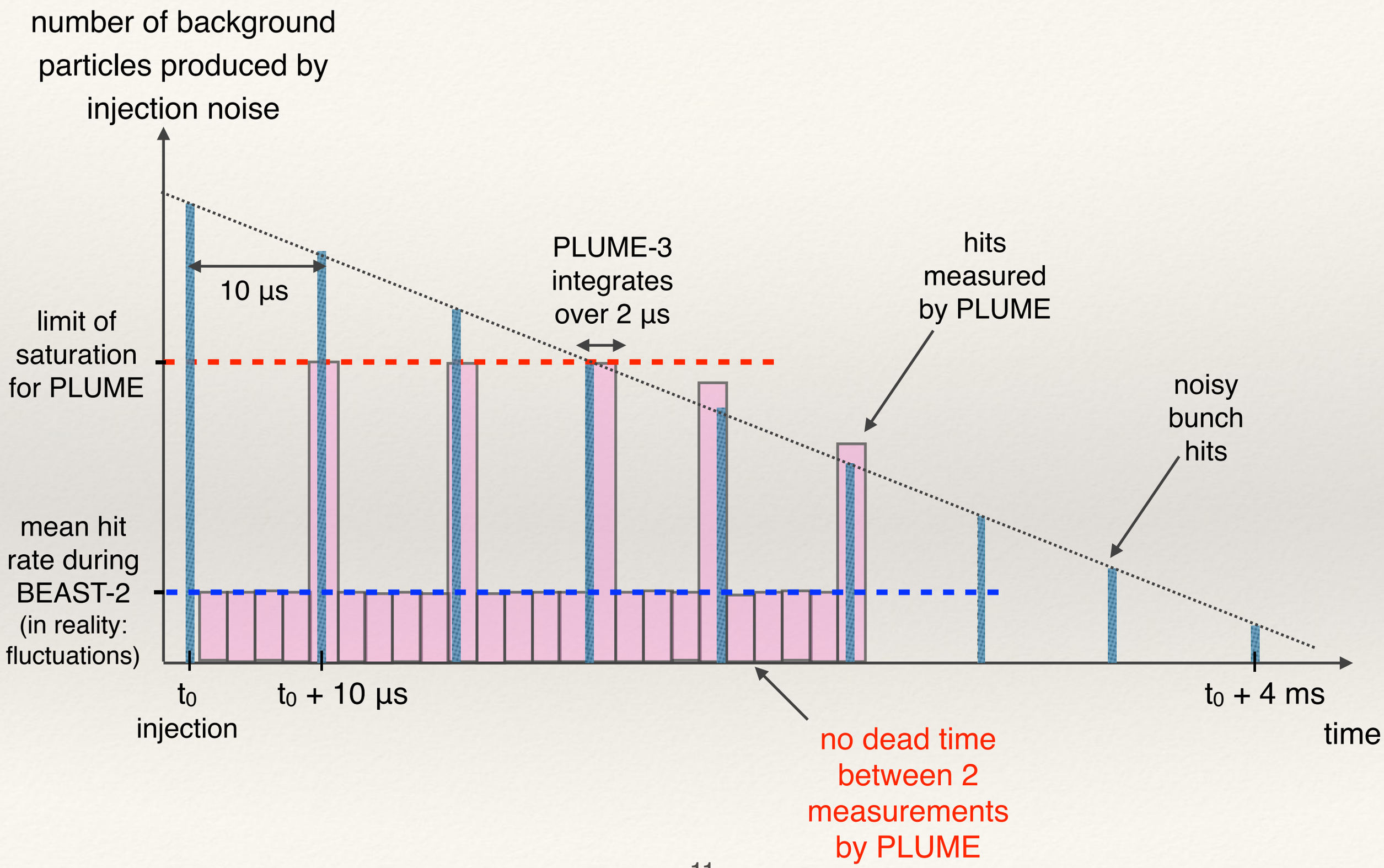


- Possible threshold = 6 x noise:
  - cluster size ~ 3 pixels /hit
  - fake rate 10^{-6}-10^{-5} /pixel with ε = 100 % before ionising irradiation.

Damping of the injection noise (1)

- DEPFET (integration time 20 µs) are impacted (saturation) by injection noise. They are operated in gated mode in order to be blind to this noise. This results in a dead time which must be minimised.
  - ➛ a time-accurate measurement of the injection noise is needed:
    proposition to measure it with FE-I4 ATLAS chips (50x250 µm^2)
    with time resolution of 25 ns
    and also plastic scintillators (2x2 cm) +SiPM (ultra-fast: 800 ps sampling time).
- Integration time of 2 µs from PLUME-3 is not accurate enough to fine tune the DEPFET veto window with the desired time resolution.
- But still, PLUME-3 with integration time of ~2 µs seems able to measure the Damping slope, i.e. hit rate vs. time (see next slide).

Damping of the injection noise (2)

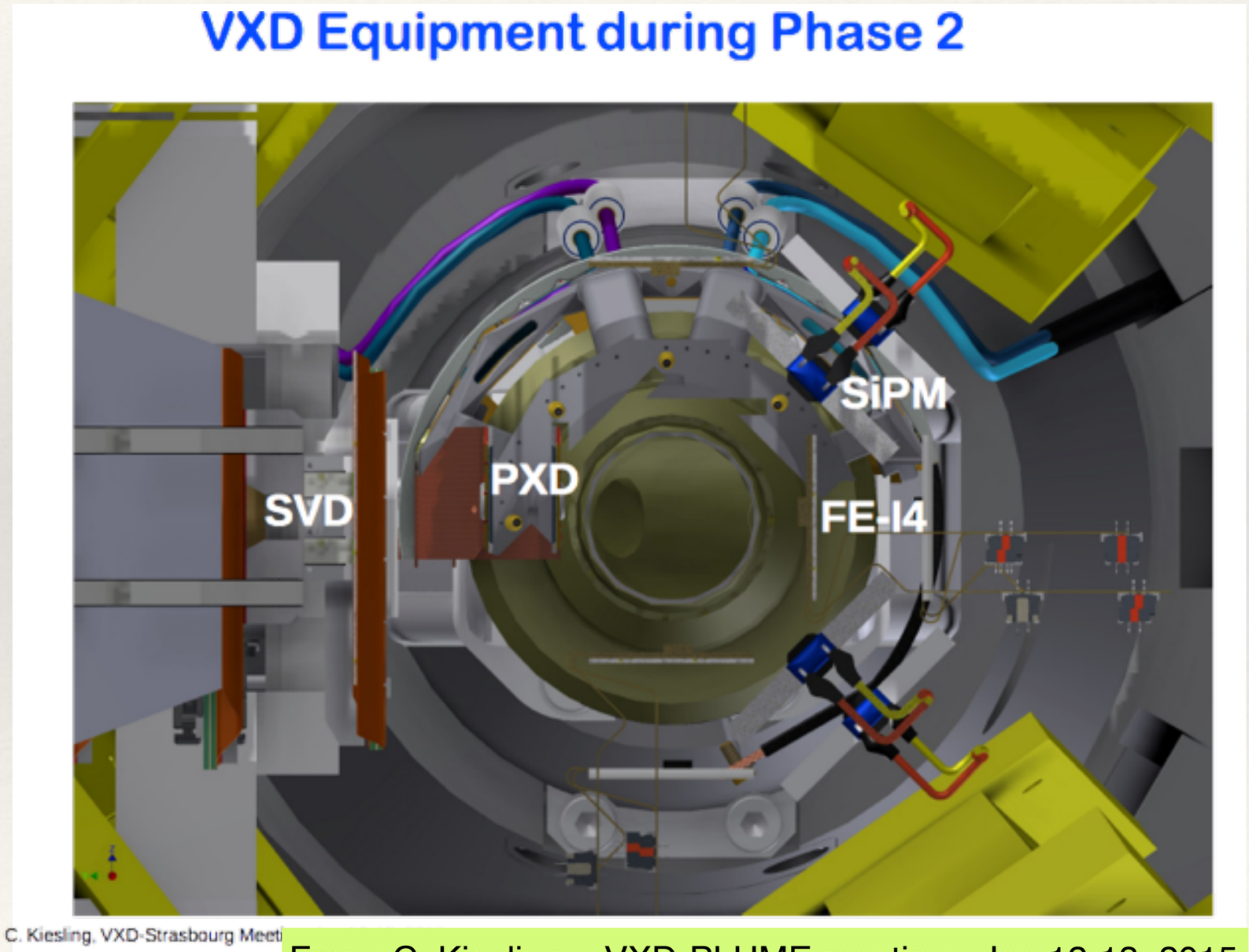


Correlate PLUME with Si-PM

- Correlate PLUME and SiPM measurements to take advantage of SiPM good time resolution & of PLUME good spatial resolution?
  - Proposed by Munich.
  - Where can we put PLUME?

- PLUME in front of SiPM:
  Does PLUME degrade SiPM measurement of X-rays?

- PLUME behind SiPM:
  High radius: very low counting rate in 18.7x18.7 μm^2 pixels.



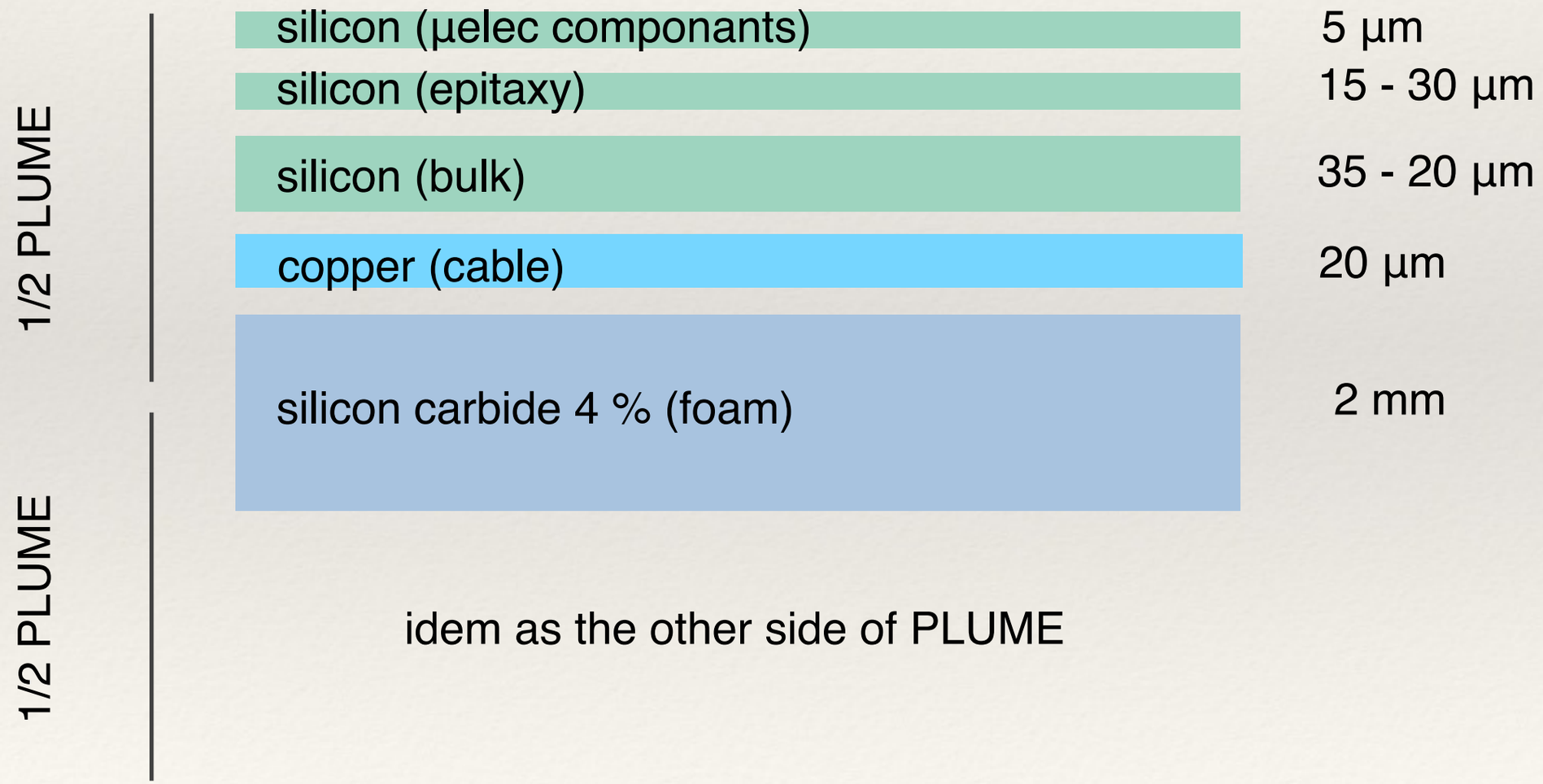
From: C. Kiesling - VXD-PLUME meeting - Jan.12-13, 2015

Sensitivity of PLUME to X-Rays (1)

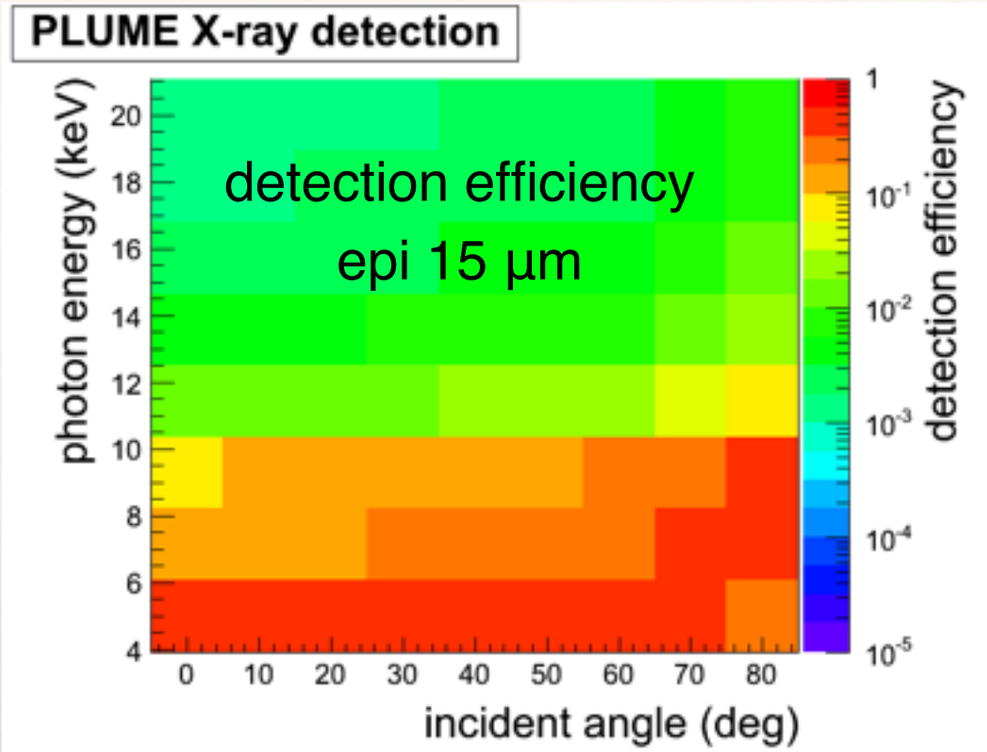
- PLUME epitaxy is very thin: MIMOSA-26 (PLUME-2) epi =15 µm
  MISTRAL (PLUME-3) epi = 30 µm

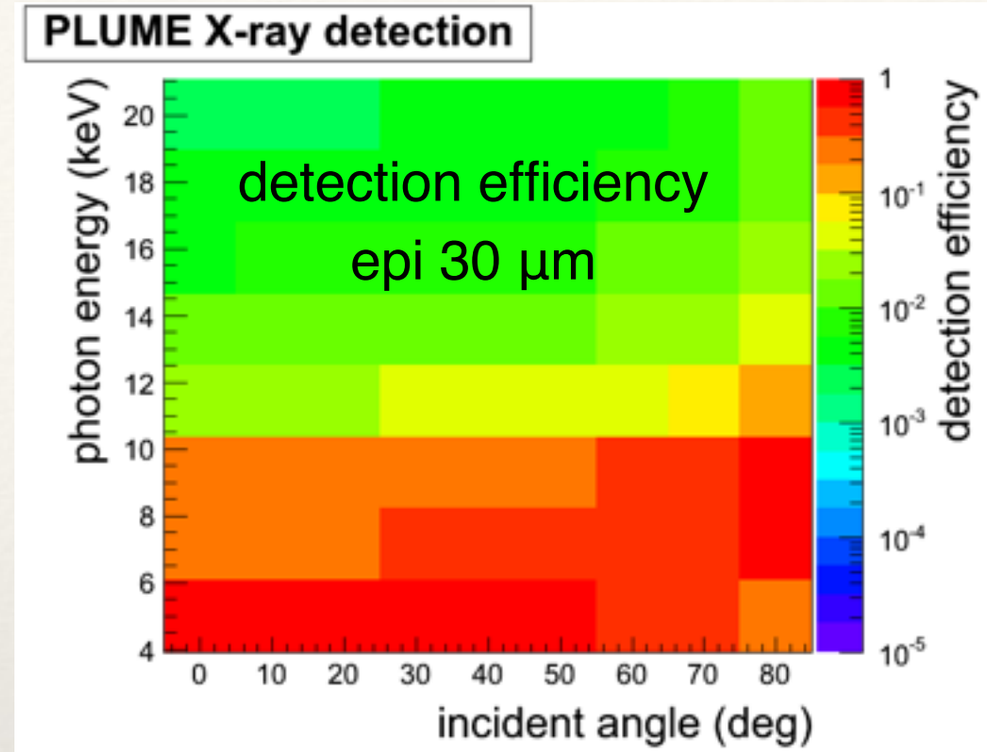
  ➛ how much is PLUME transparent / sensitive to X-Rays?

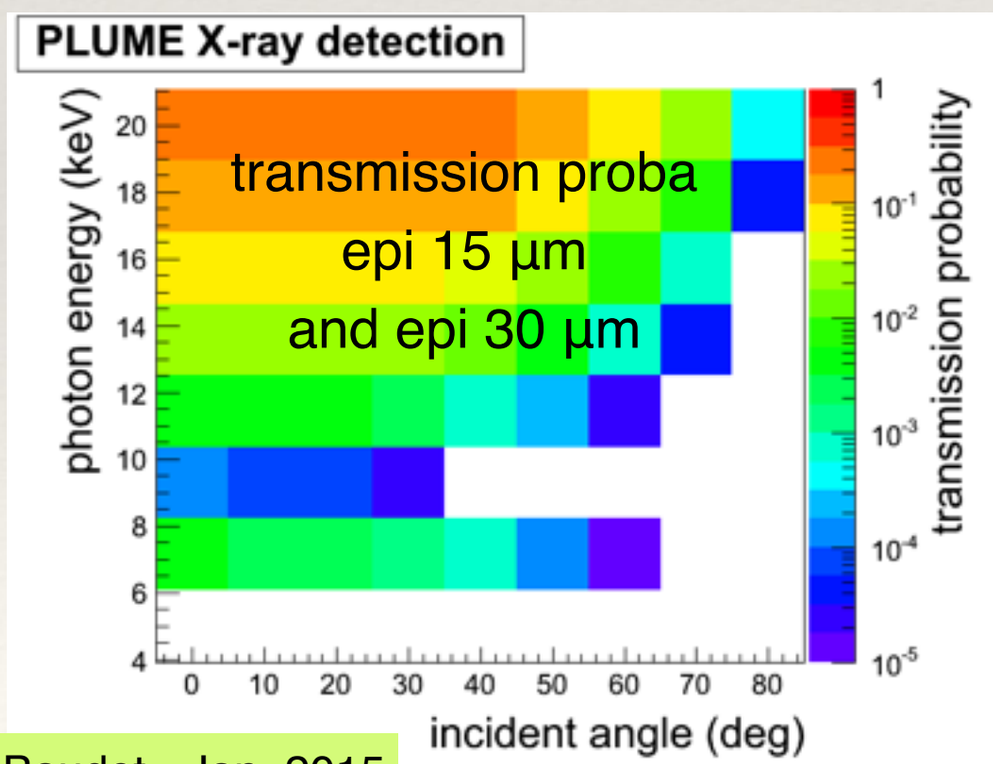
- Calculate attenuation of X-Rays in PLUME with Beer-Lambert exp(-µ·d).
  (study from J. Baudot - Jan. 2015).

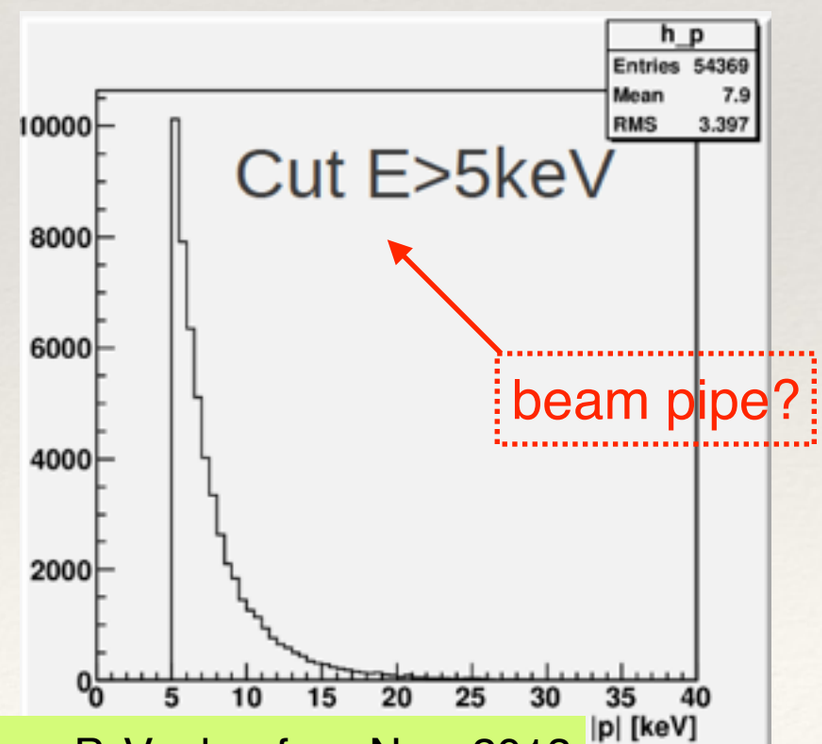


Sensitivity of PLUME to X-rays (2)









From: J. Baudot - Jan. 2015

From: P. Vanhoefer - Nov. 2013

Sensitivity of PLUME to X-Rays (3)

- Detection efficiency:
  - X-rays with E < 10 keV are detected in PLUME with efficiency decreasing from ~100 % to ~ (few) 10 % with increasing E.
  - PLUME becomes transparent to X-Rays with E > 10 keV, i.e. they don't increase the occupancy rate.
  - Cluster size =1 pixel/hit for clusters produced by X-Rays (≠ from charged particles).
- Transmission probability:
  - Transmission ≠ 1 - detection efficiency: mainly absorption in 20 µm Cu (not a sensitive volume).
  - That's why: no significative difference if 15 or 30 µm of epitaxy.
  - PLUME is not transparent to X-Rays, in particular if E < 15 keV.
  - Use an Al cable to build PLUME instead of a Cu cable would help being more transparent.

Track incidence angular measurement

- Angular resolution was measured with high E $\pi^{\pm}$ beam at CERN-SPS:

  $\sigma = 0.11 + 0.01°$ with perpendicular tracks

  $\sigma = 0.2 \pm 0.01°$ if track incidence of 40 °.

  ➛ - Could we use this accuracy to provide information on background particle origin?

  - Is it useful while the detector is reached mainly by secondaries?

- Due to low momentum spectrum of background particles

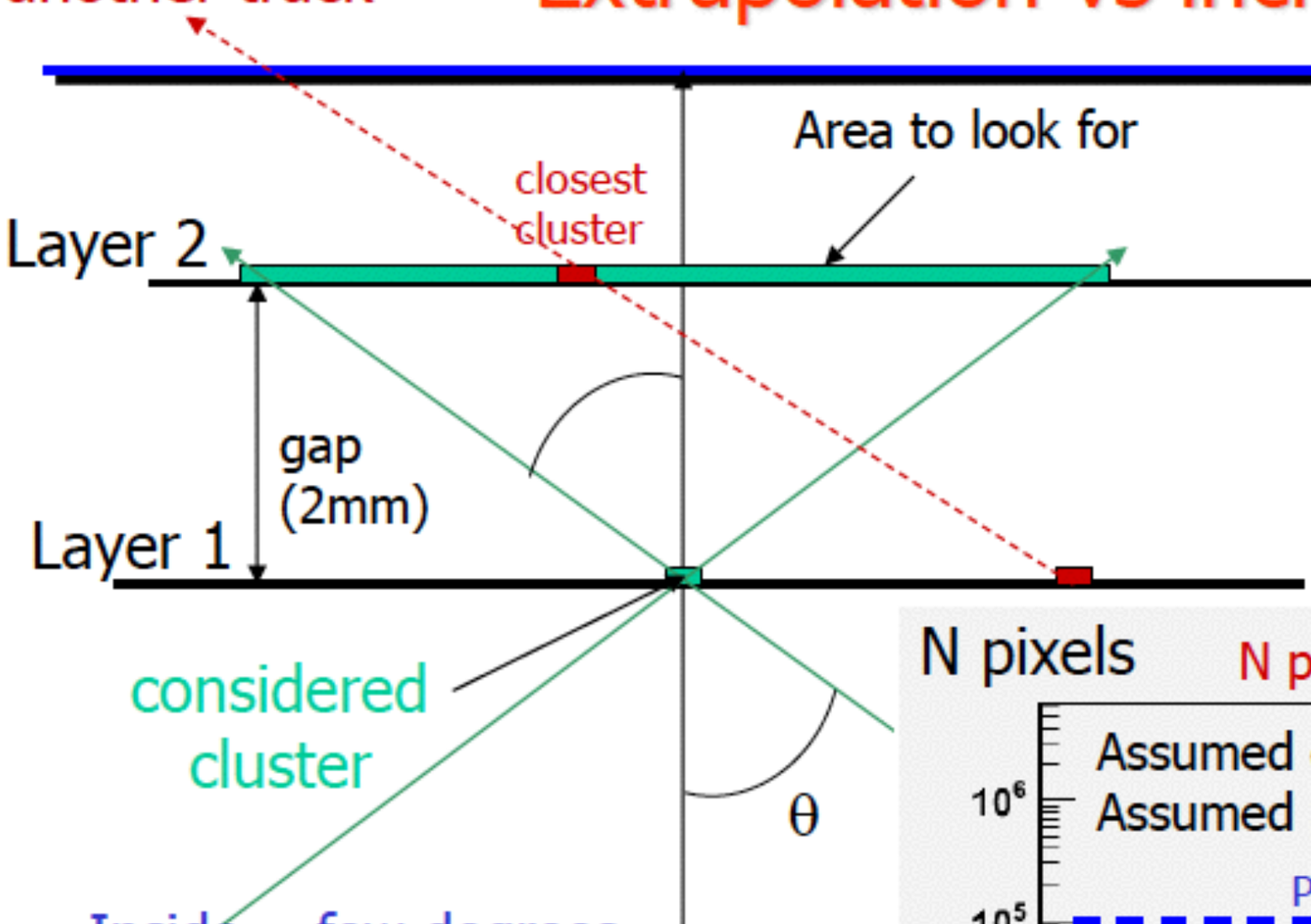
  + angular large incidence of track arriving on the sensor:

  ➛ cluster association between both sides of PLUME may be tough.

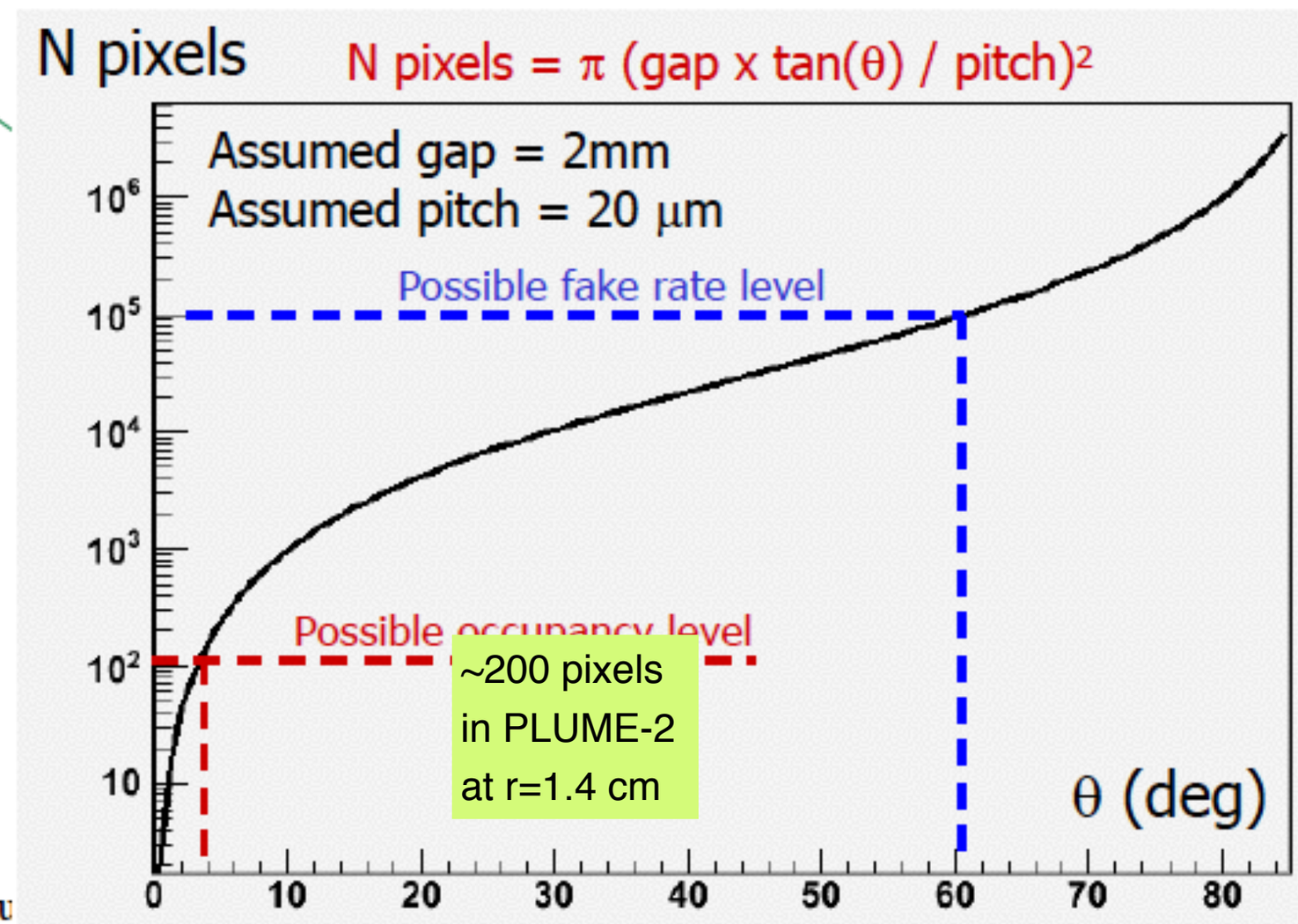
  see next slide.

Extrapolation vs incident angle

(ILC study)



- Where to look for clusters in 2nd layer ?
- What θ angle to chose to define the search area ?
- Depending on the acceptance
  - the Number of pixels can be huge



- Inside ~ few degrees
  - There will be some hits coming from beam background
- Probability that the closest cluster on the 2nd layer comes from another track seems high.

From: A. Besson for ILC - June 2014

Track incidence angular measurement

- Angular resolution was measured with high E $\pi^{\pm}$ beam at CERN-SPS:
  $\sigma = 0.11 + 0.01°$ with perpendicular tracks
  $\sigma = 0.2 \pm 0.01°$ if track incidence of 40 °.
  ➛ - Could we use this accuracy to provide information on background particle origin?
  - Is it useful? (only secondaries reach the detector)

- Due to low momentum spectrum of background particles
  + angular large incidence of track arriving on the sensor:
  ➛ cluster association between both sides of PLUME may be tough.
  see next slide.

- Conclusion:
  - Try to build PLUME with reduced thickness (gap).
    ➛ OK, possible to use foam with thickness 1 mm or even 500 µm instead of 2 mm.
    Purity of association increases ~ 1 / gap^2.
  - Acceptance issue if the sensitive area is reduced to accelerate integration time.

- To help defining the area where to look for the associated cluster: possible use of cluster size increase along u-direction or v-direction. (cf. study by A. Besson for ILC)
  Only possible with small pitch, e.g. 18.4x18.4 µm^2, to insure >> 1 cluster size.

Background simulation studies (1)

- Simulation studies of SuperKEKB induced background during Belle II physics run:
  - Inputs from Onishi-san (SuperKEKB) → Nakayama-san (Belle II).
    Rootuples from the 10th campaign (nov. 2014):
    /home/belle/nakayama/fs2/BGdata/10th_fullsim/EvtbyEvt
  - Final merged rootuples corresponding to: integration time = 1 ms
  - Belle II detector geometry
  - Touschek, Beam Gas (Coulomb) and Radiative Bhabha

- In addition to that, other background sources impacting only & particularly VXD, produced and studied in the frame of the physics run:
  - 2-photons QED pairs by M. Ritter (MPI Munich).
  - Synchrotron radiation bkg by Y. Soloviev (DESY).

Background simulation studies (2)

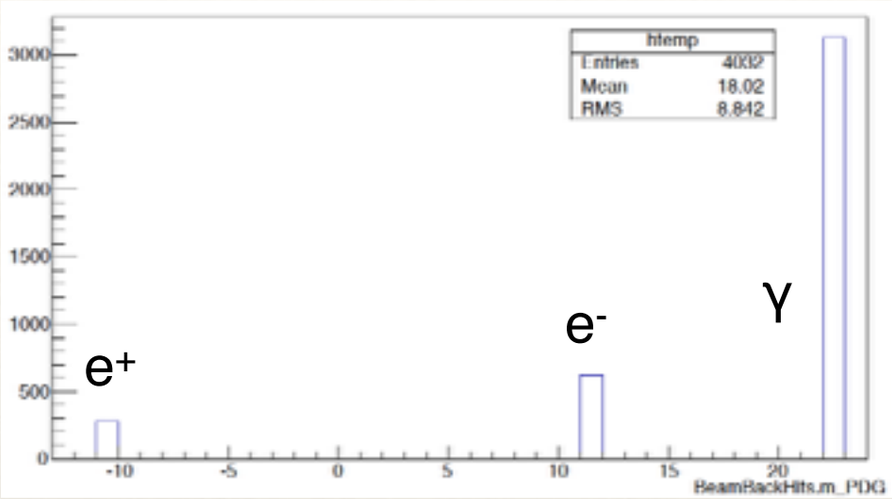
- To do BEAST-phase 2 simulation studies:
  - need input files provided by Onishi-san and Nakayama-san for Touschek, Coulomb and RBB (produced with correct beam conditions).
  - what about 2-photons QED & Synchr. rad.?
  - set the PLUME integration time = 100 μs (easy in RunSadByMC.py)
  - create PLUME geometry: /beast/plume/data/*.xml ➛ OK.

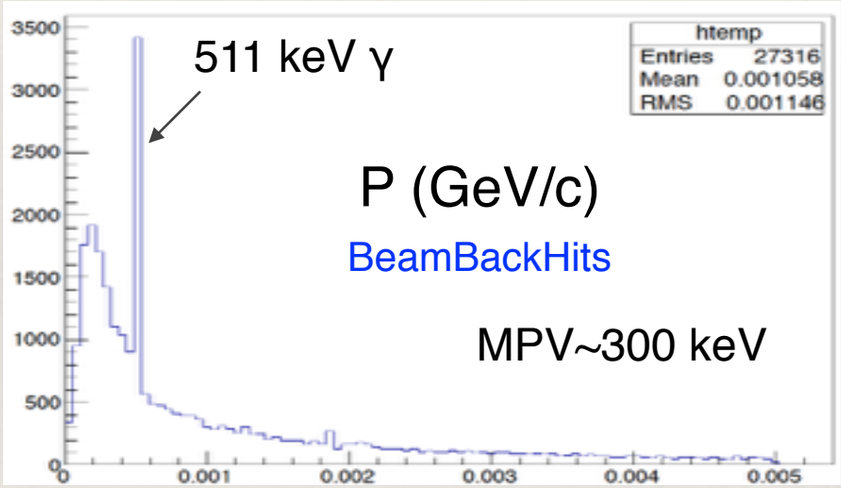
- Preliminary possible study: look at Belle II-physics run simulations to figure out what will happen in BEAST
  - SuperKEKB lattice is the same.
  - Beam-pipe Au coating is only 6.6 μm in BEAST (w.r.t. possibly 10 μm during run 3): impact mainly synchrotron rad.?
  - Bkg angular distribution + energy spectrum should be OK?

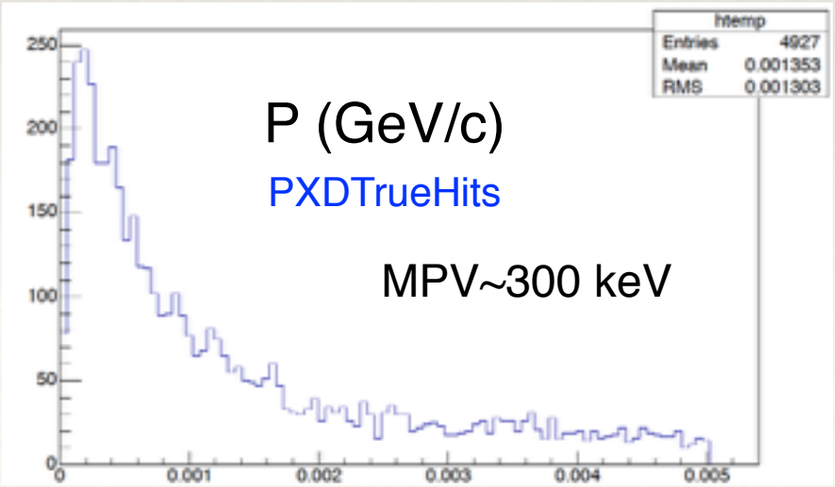
- Information provided in rootuples:
  - MCParticles: production and decay point, daughters, mother, PDG id, momentum, + relation to PXDTrueHits and PXDTrueHits.
  - PXDTrueHits: sensor id, momentum, position, energy deposit.
  - BeamBackHits: ?? detector id, PDG id, momentum, position, energy deposit, …

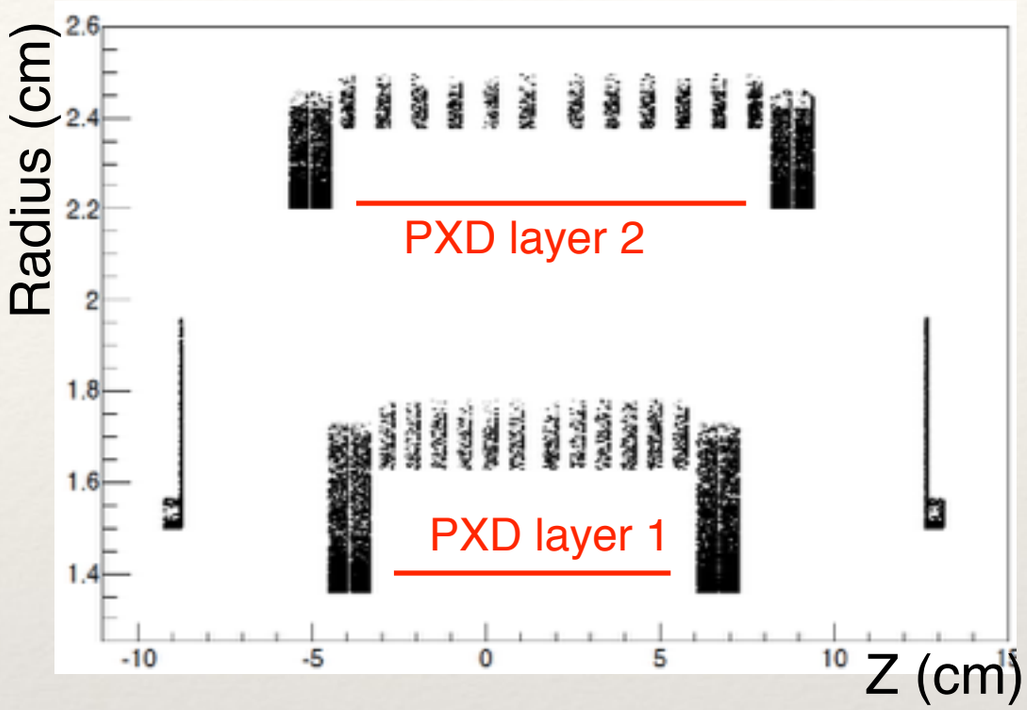
Very first look at Touschek LER

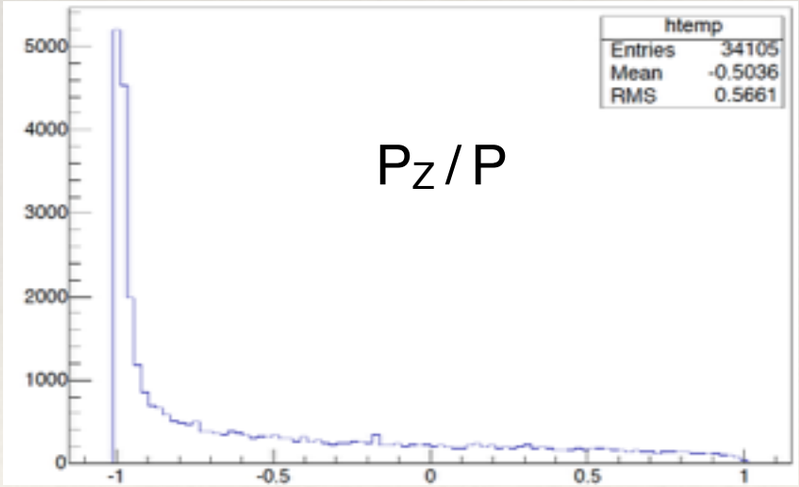
- BeamBackHits in PXD during 1 ms

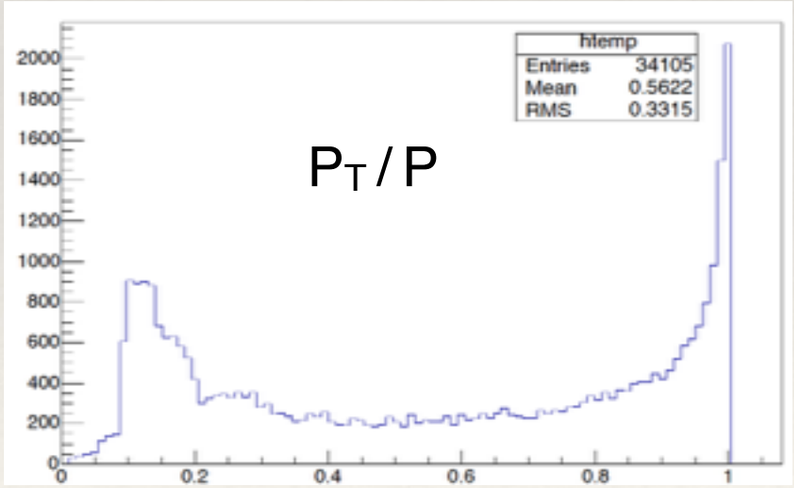












Conclusion

- At first sight PLUME can be operated safely in BEAST phase 2.
  - PLUME-2 integration time is ~100 μs.
  - PLUME-3 can be operated with integration time of 2 μs or 20 μs (with possible switch between both). Reduced integration time of 2 μs is obtained thanks to a reduced sensitive area (therefore cluster association is not possible anymore).
- What measurements are considered:
  - Hit rate.
  - Track incidence: association of clusters measured on both sides of PLUME-2 may be possible to take advantage of its good angular resolution.
    Cluster increase along u or v direction may help.
    Obviously, to build the new PLUME-2: the thinner the better.
  - Synchrotron radiation: PLUME is actually not transparent to X-Rays. We have to check how much it would help to use an Al cable instead of Cu.
- As for other detectors, better knowledge of what beam conditions can be expected and full simulation inputs are needed to make final conclusion.

back-up material