

# Optimization of the new Pixel Vertex Detector for Physics Running in the Belle II Experiment

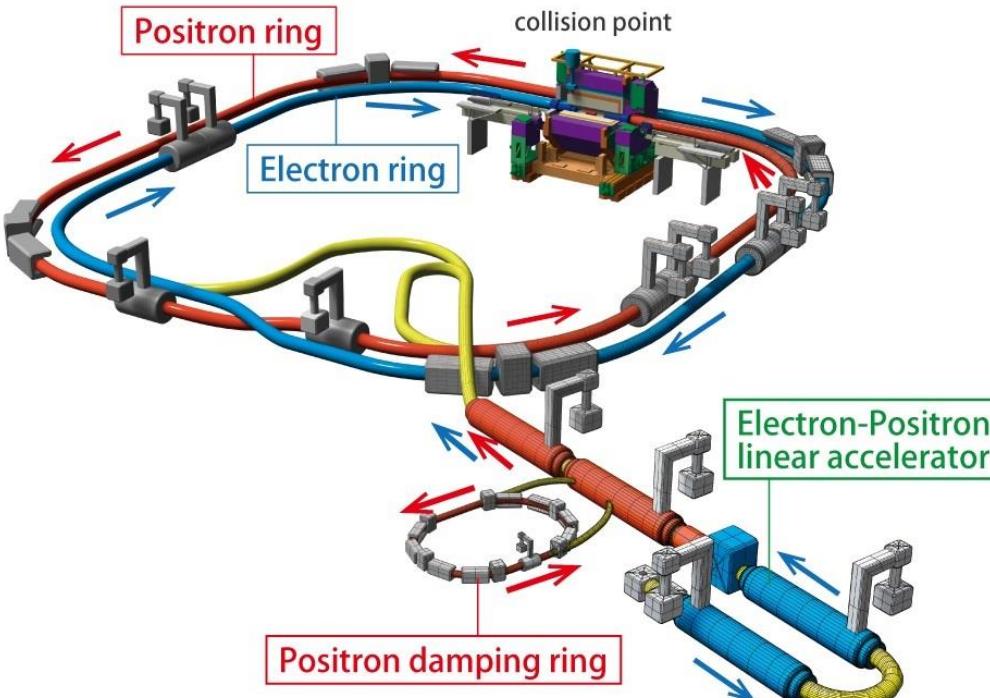
Markus Reif

MPP PhD Recruiting Workshop

3 December, 2019

## SuperKEKB accelerator:

- asymmetric energy  $e^- e^+$  collider
- operating at the  $\Upsilon(4S)$  resonance



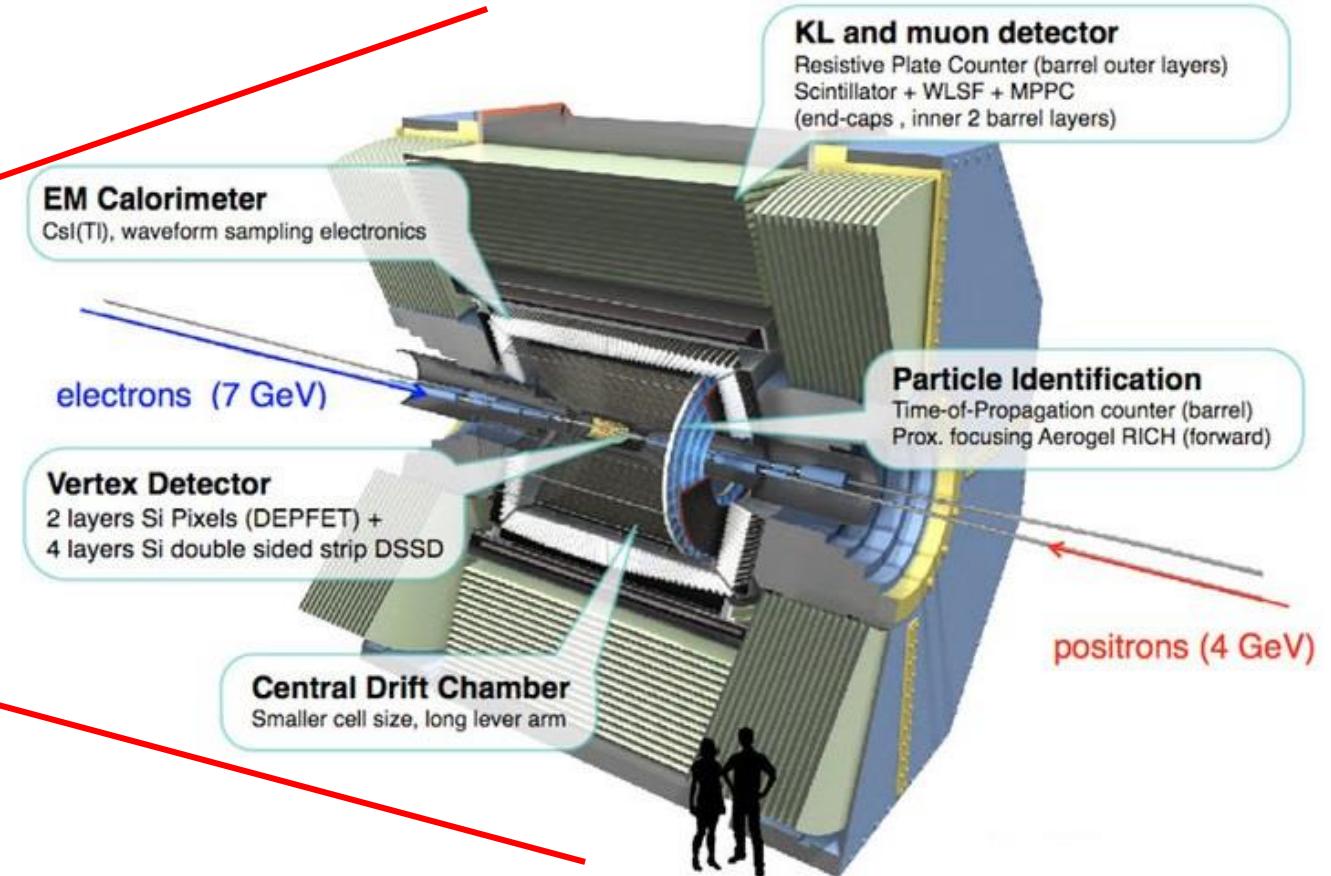
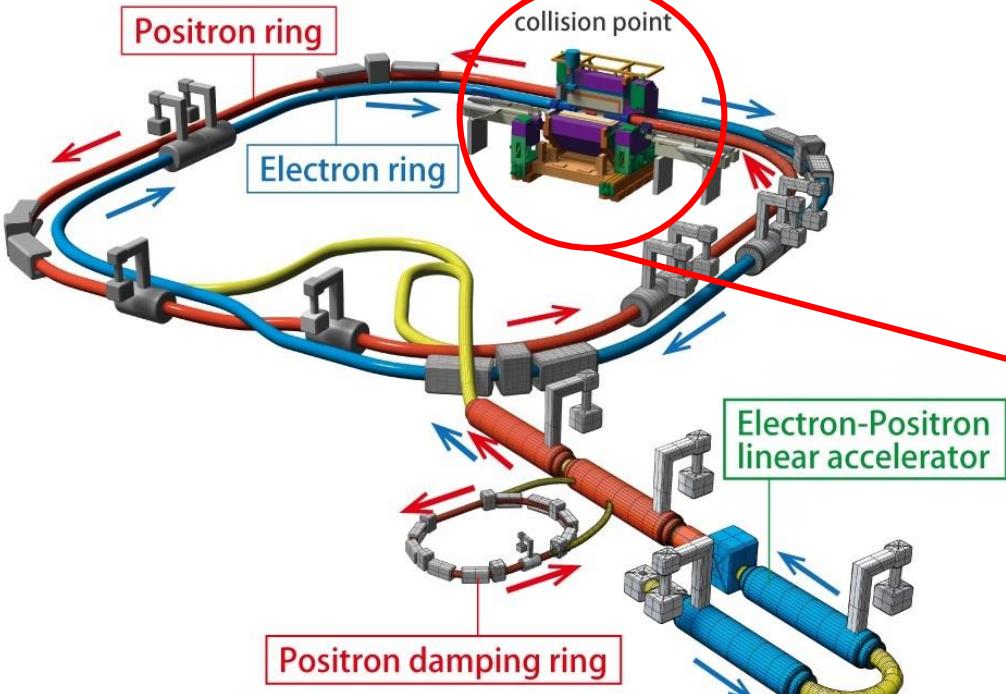
sources:

- SuperKEKB collider: <https://phys.org/news/2016-04-particles-circulate-superkekb.html> (accessed: 14 November, 2019)
- Belle II detector: Dmitry Matvienko, The Belle II experiment: status and physics program

# SuperKEKB and Belle II

## SuperKEKB accelerator:

- asymmetric energy  $e^- e^+$  collider
- operating at the  $\Upsilon(4S)$  resonance



## Belle II detector

- ‘full’ detector started taking data in March 2019
- aims to collect:  $50\text{ab}^{-1}$

sources:

- SuperKEKB collider: <https://phys.org/news/2016-04-particles-circulate-superkekb.html> (accessed: 14 November, 2019)
- Belle II detector: Dmitry Matvienko, The Belle II experiment: status and physics program

# Physics at B-factories

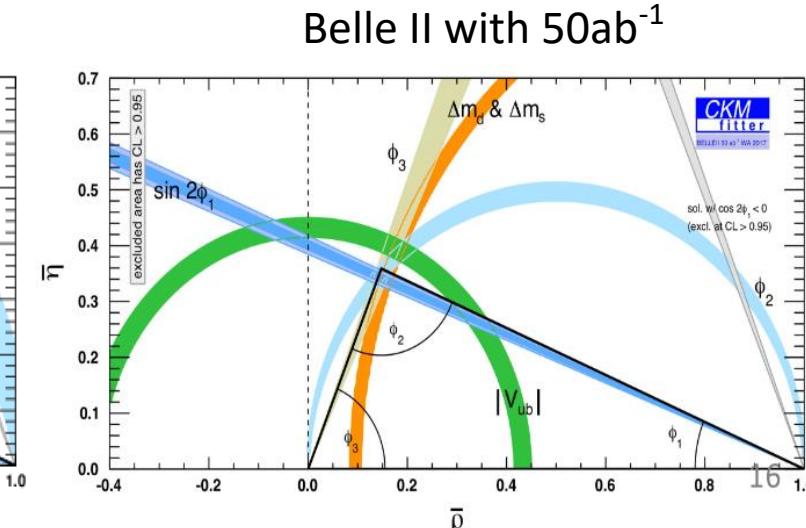
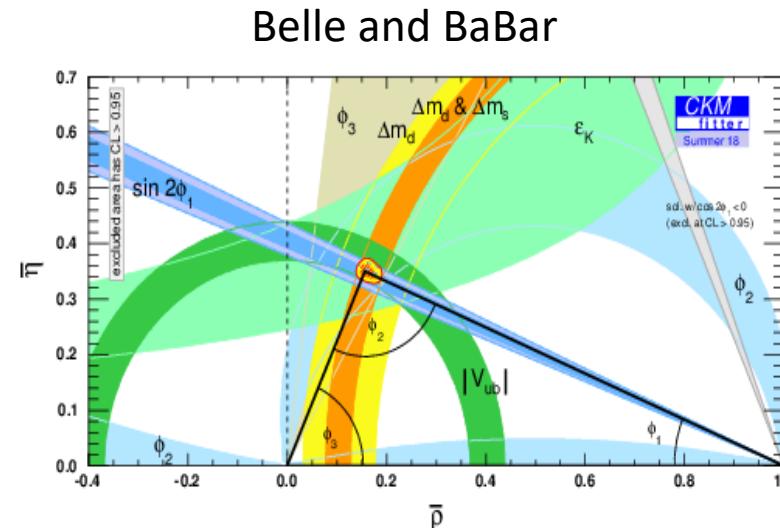
- CP-violation
- measurements of CKM matrix elements
- measurement of rare decays (e.g.  $B \rightarrow \tau v, \mu v, e v$ )
- test of lepton flavor violation (rare  $\tau$  decays) and lepton universality (e.g.  $B \rightarrow D^{(*)}\tau v, D^{(*)}\mu v, D^{(*)}e v$ )



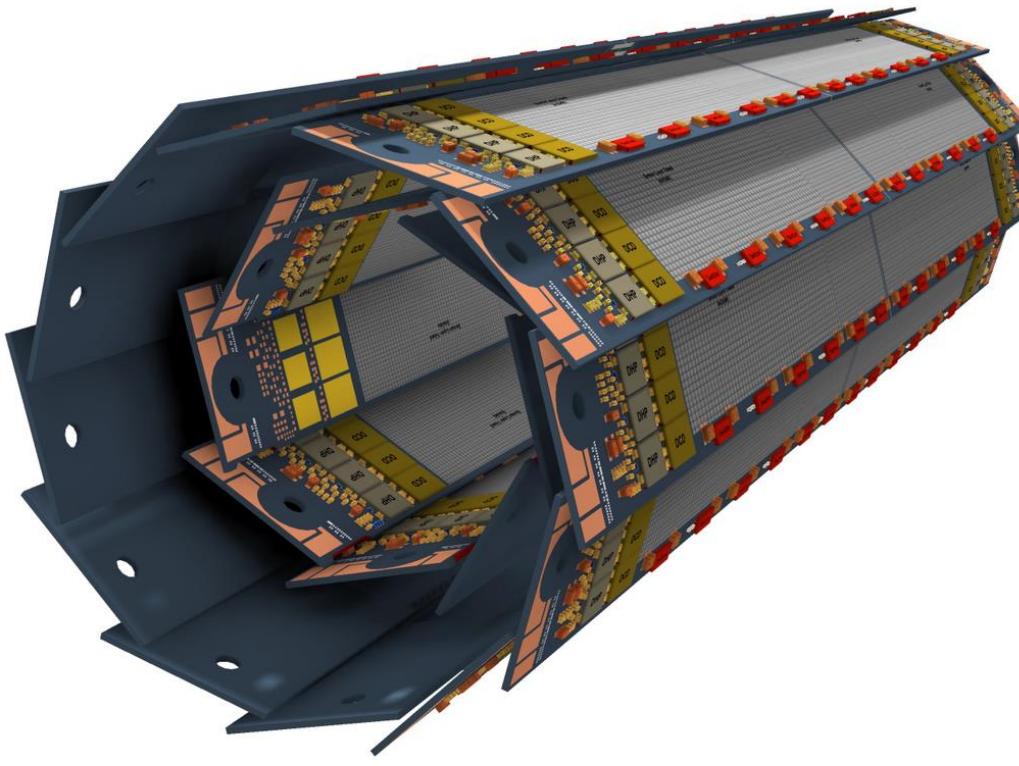
Nobel Prize 2008:  
Maskawa and Kobayashi  
for CKM theory

## Motivation for SuperKEKB and Belle II:

- precise measurements of the unitarity triangle
- look for deviations from SM
- hope for indirect discovery of New Physics via loop processes



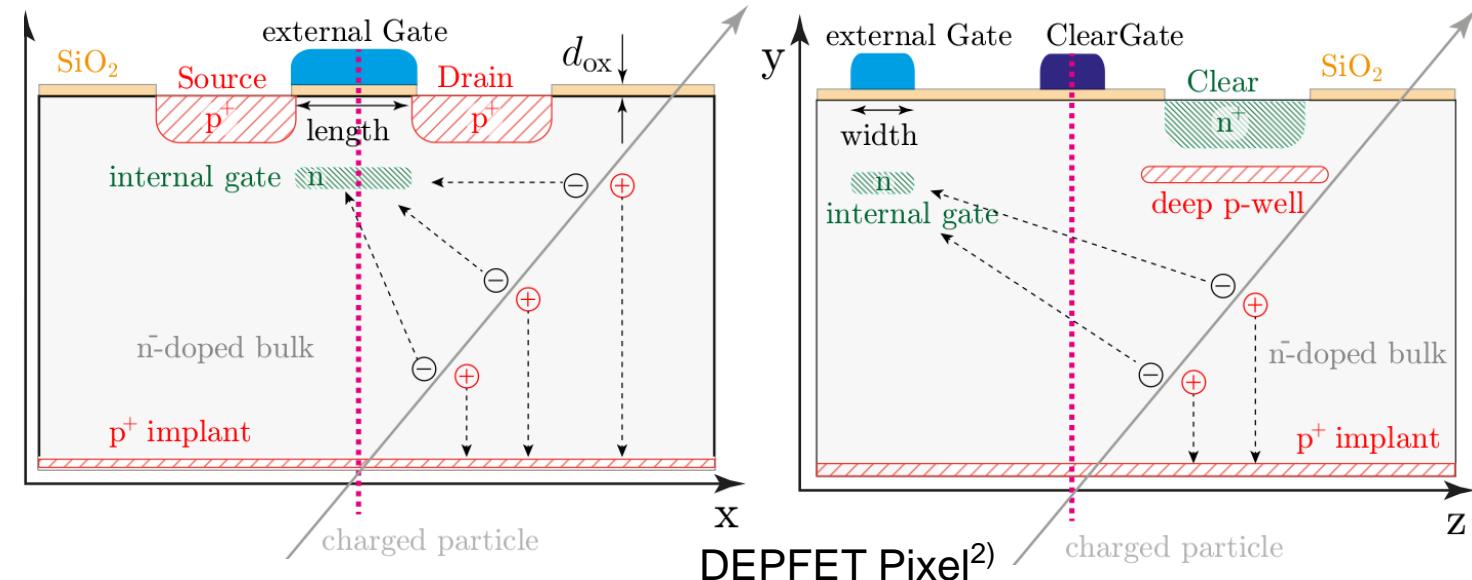
# The Pixel Vertex Detector

PXD Layout<sup>1)</sup>

## Current situation:

- inner layer: complete
- outer layer: only two ladders

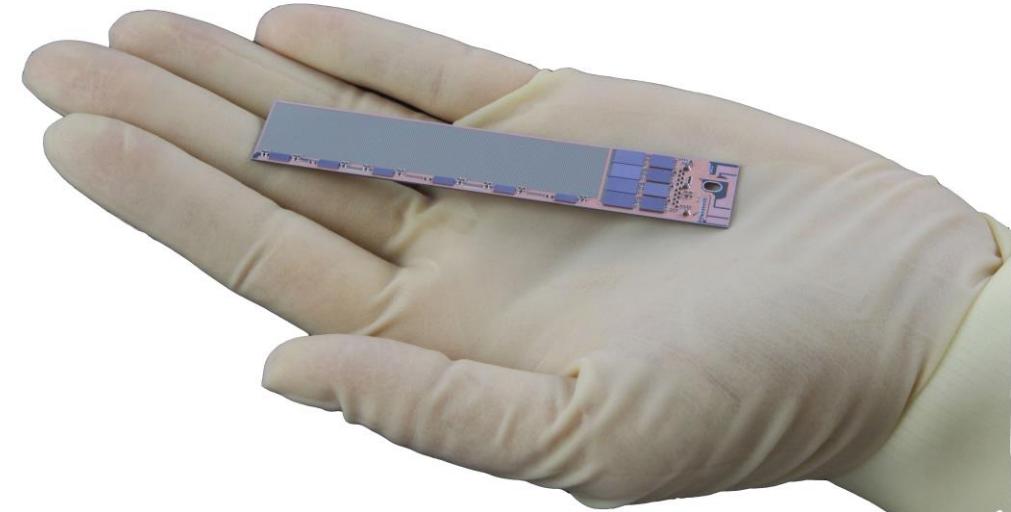
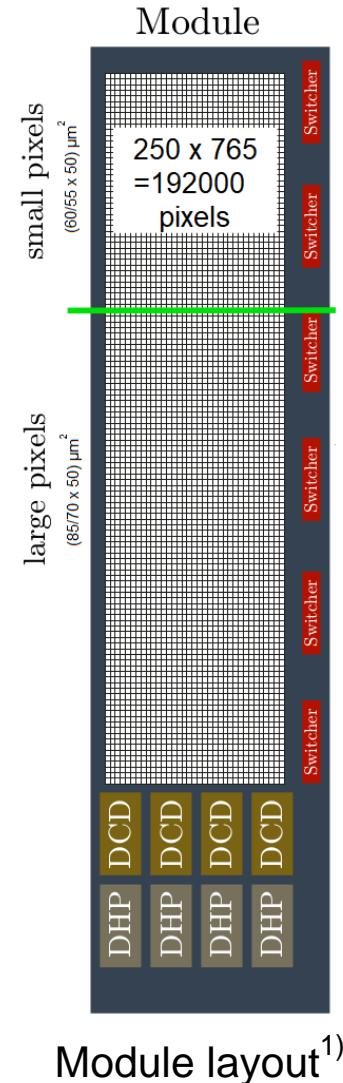
- German contribution to Belle II
- 2 layers at radii 14mm and 20mm around beam pipe
- 20 ladders  $\Leftrightarrow$  40 modules
  - produced at HLL of MPG
  - assembled and tested at MPP



sources: 1) Karlheinz Ackermann

2) Felix B. Müller, Characterization and Optimization of the Prototype DEPFET Modules for the Belle II Pixel Vertex Detector

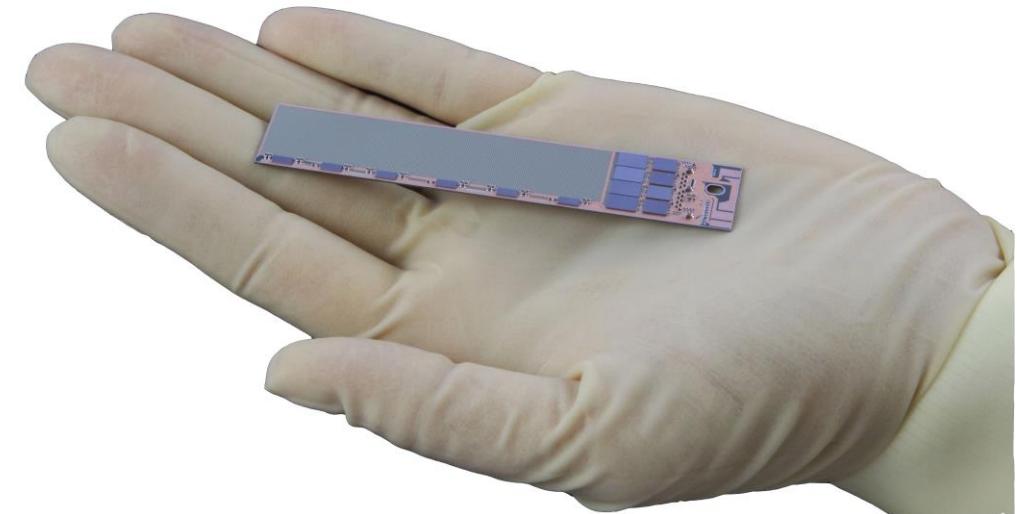
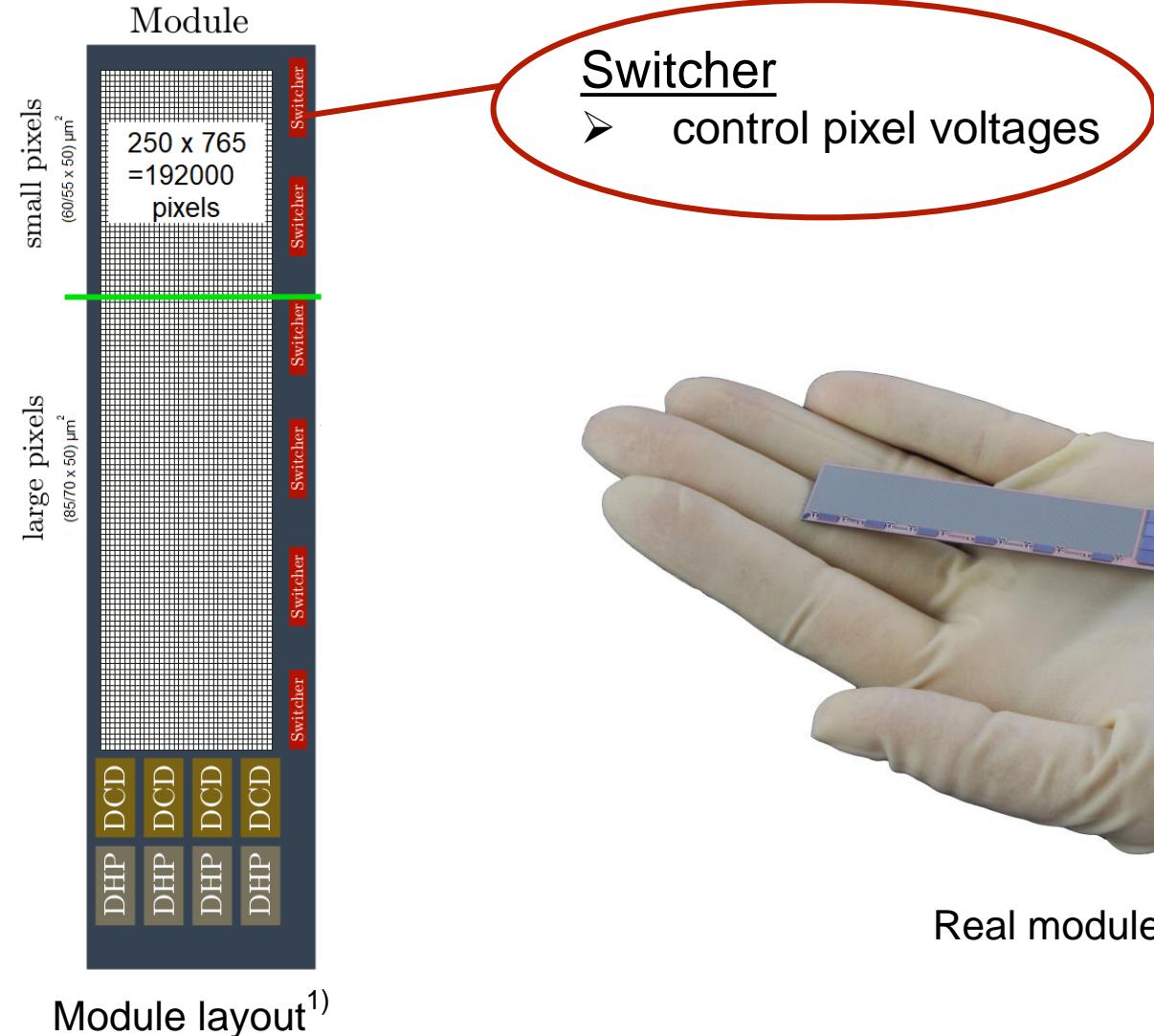
# Modules of the PXD



Real module<sup>2)</sup>

- sources:
- 1) Felix B. Müller, Characterization and Optimization of the Prototype DEPFET Modules for the Belle II Pixel Vertex Detector
  - 2) Ladislav Andricek, Halbleiterlabor der MPG

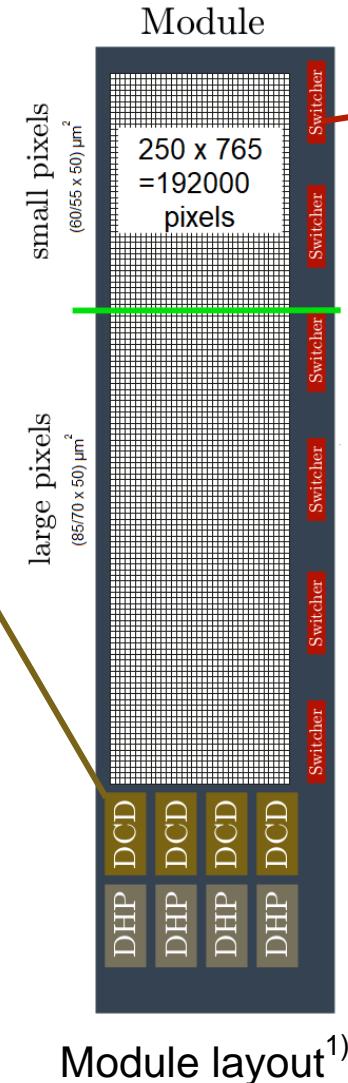
# Modules of the PXD



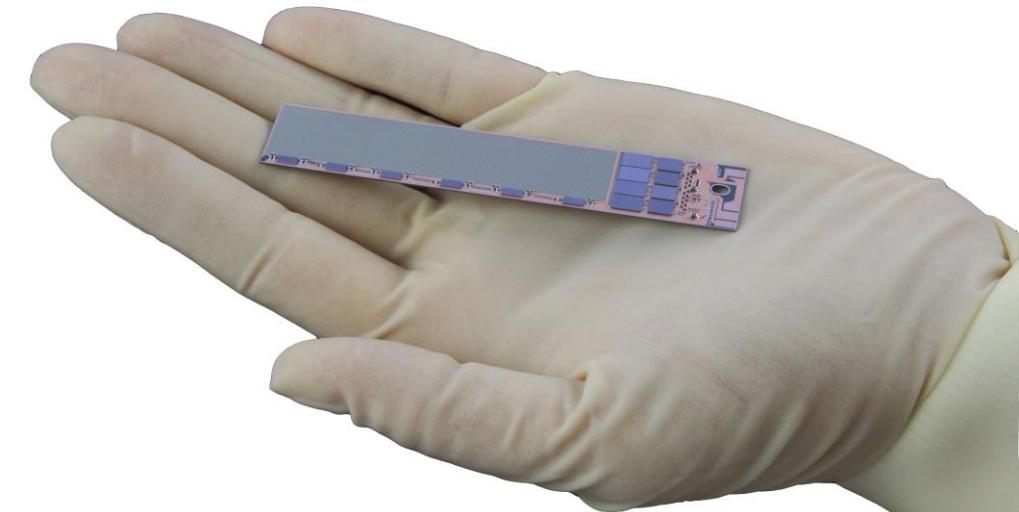
- sources:
- 1) Felix B. Müller, Characterization and Optimization of the Prototype DEPFET Modules for the Belle II Pixel Vertex Detector
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# Modules of the PXD

**Drain Current Digitizer**  
➤ measure and digitize drain current (8bit)



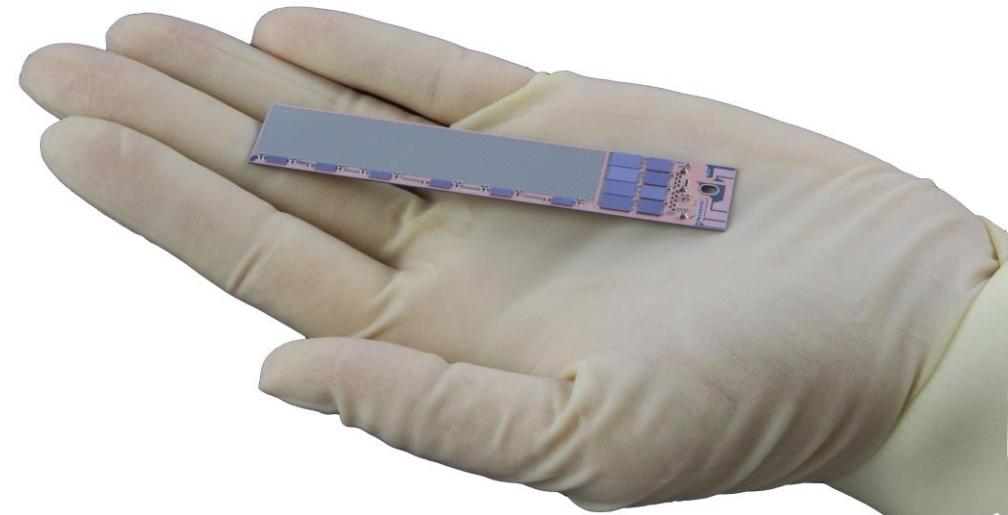
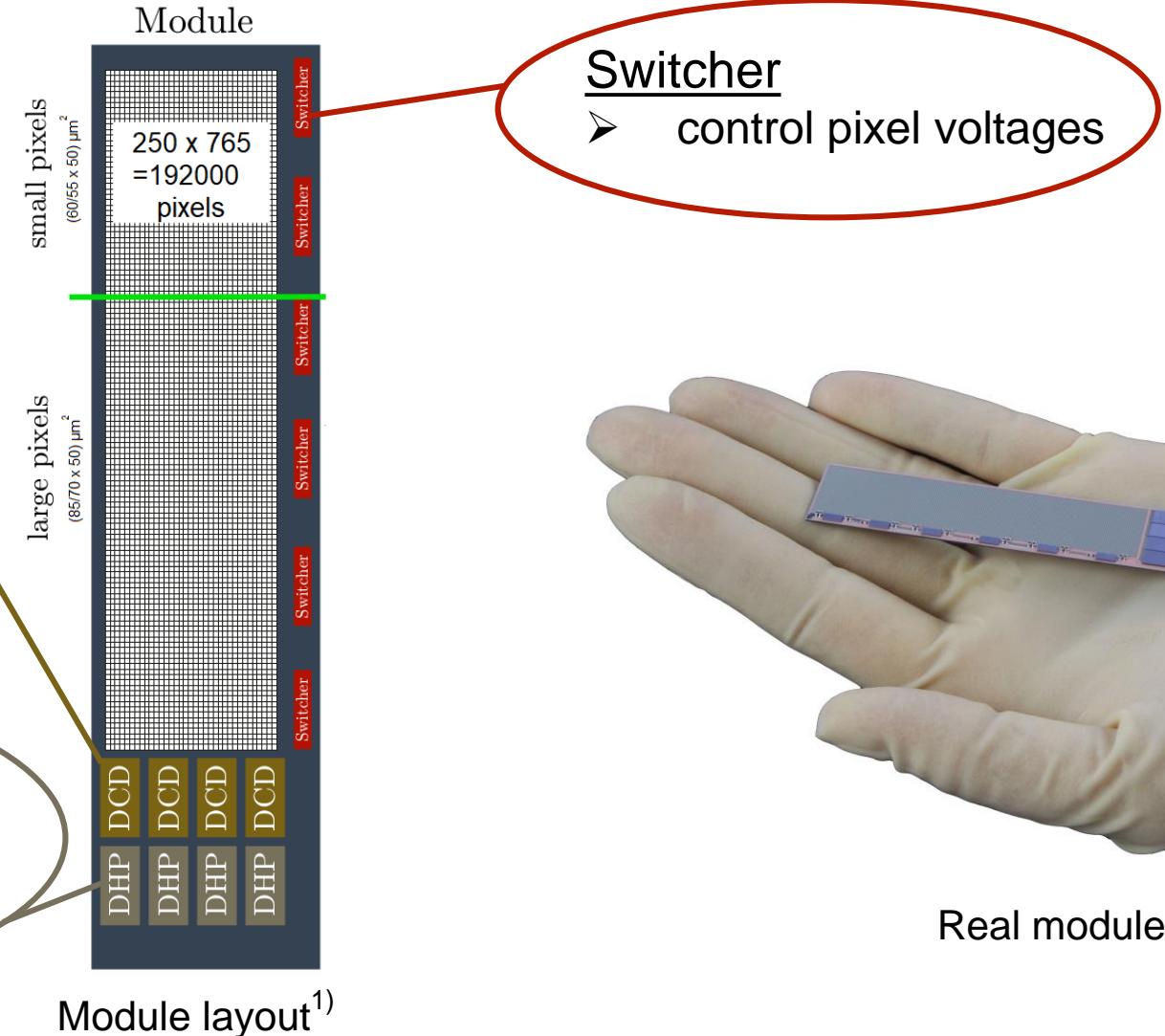
**Switcher**  
➤ control pixel voltages



Real module<sup>2)</sup>

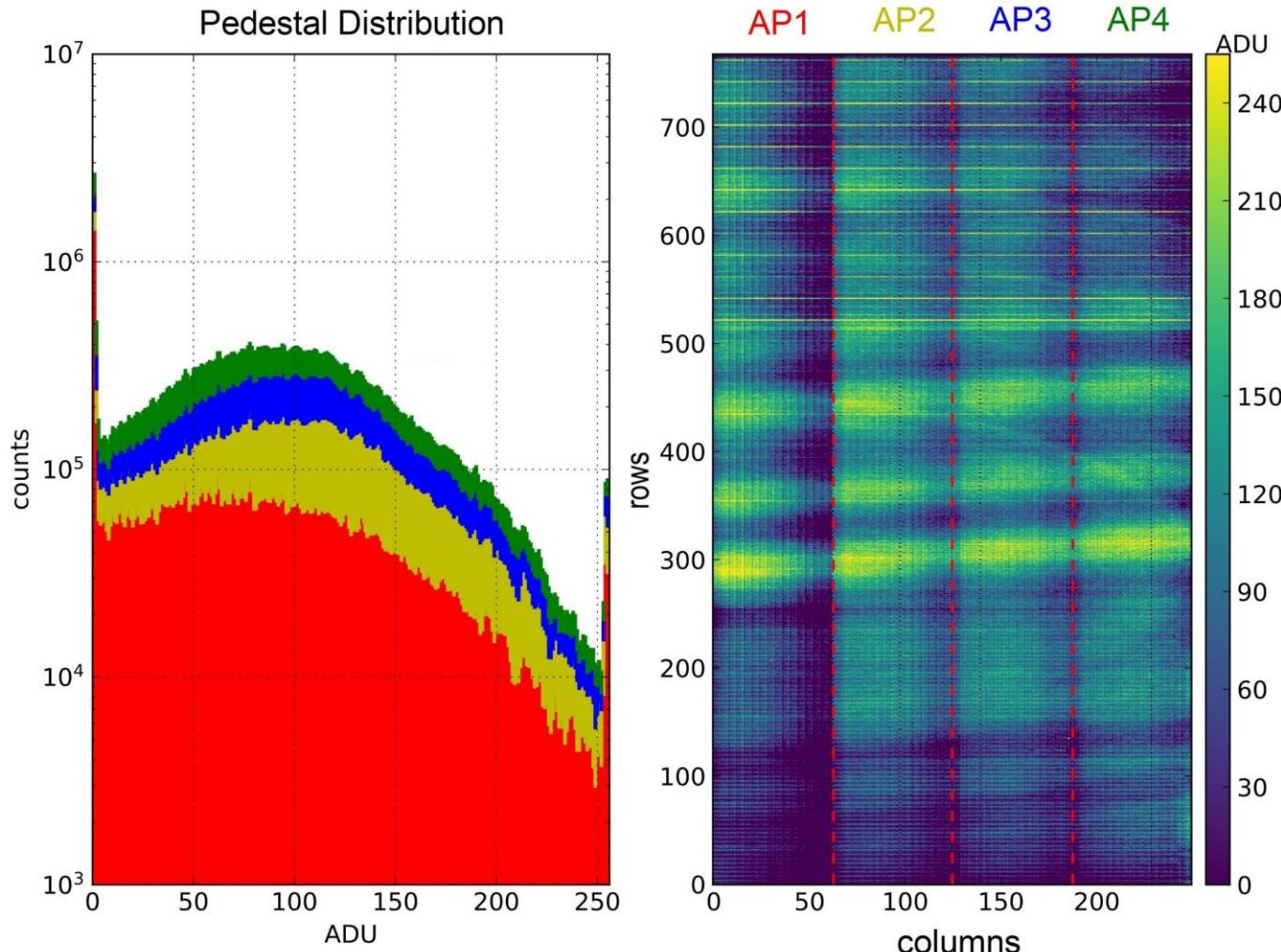
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2) Ladislav Andricek, Halbleiterlabor der MPG

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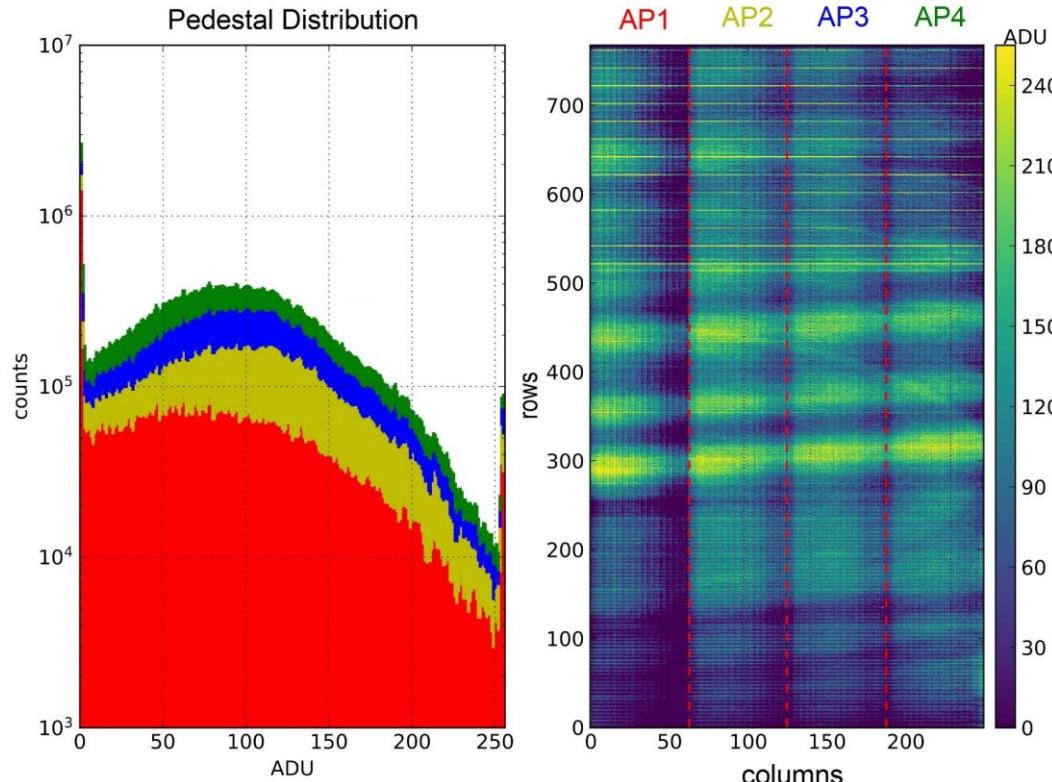
# Pedestals



- drain current without signal charge (=pedestal)
- average over 100 frames

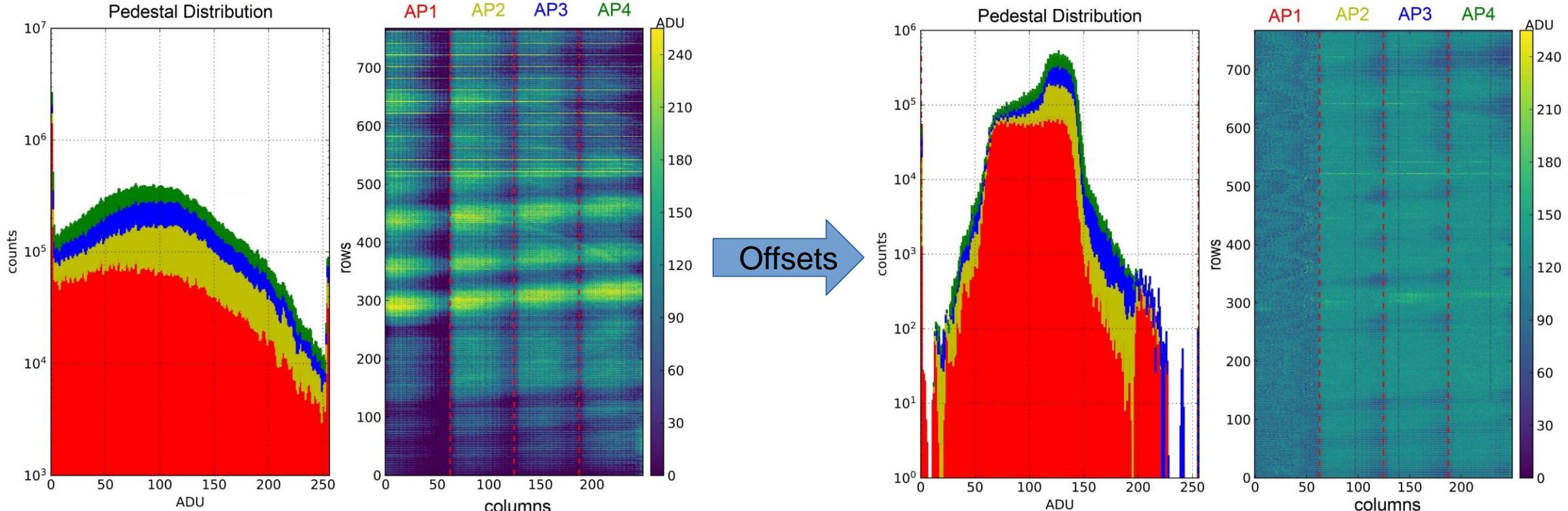
# Offset Calibration

- DCD can add:  $0, 1, 2, 3 * I_{glo}$  to each pixel
- scan through  $0, 1, 2, 3$  and  $I_{glo}$  and determine best combination



# Offset Calibration

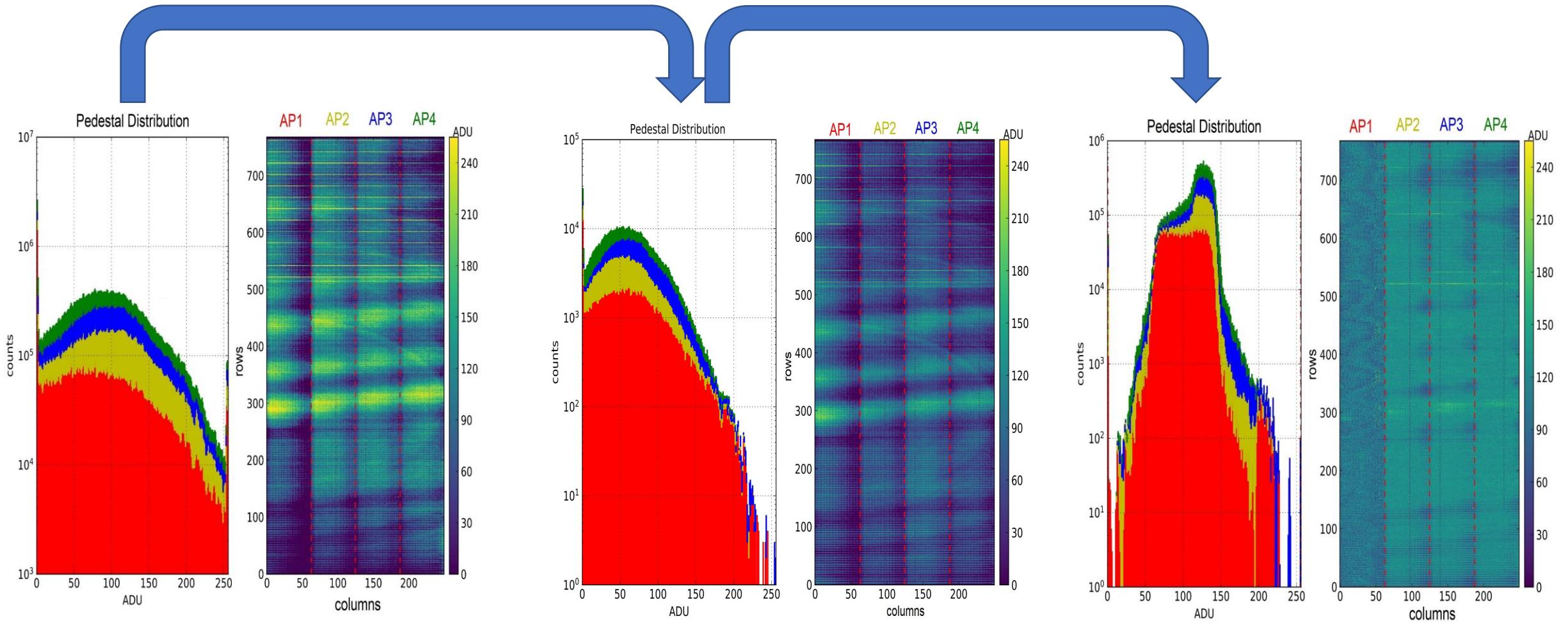
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# Preparation for the Offset Calibration

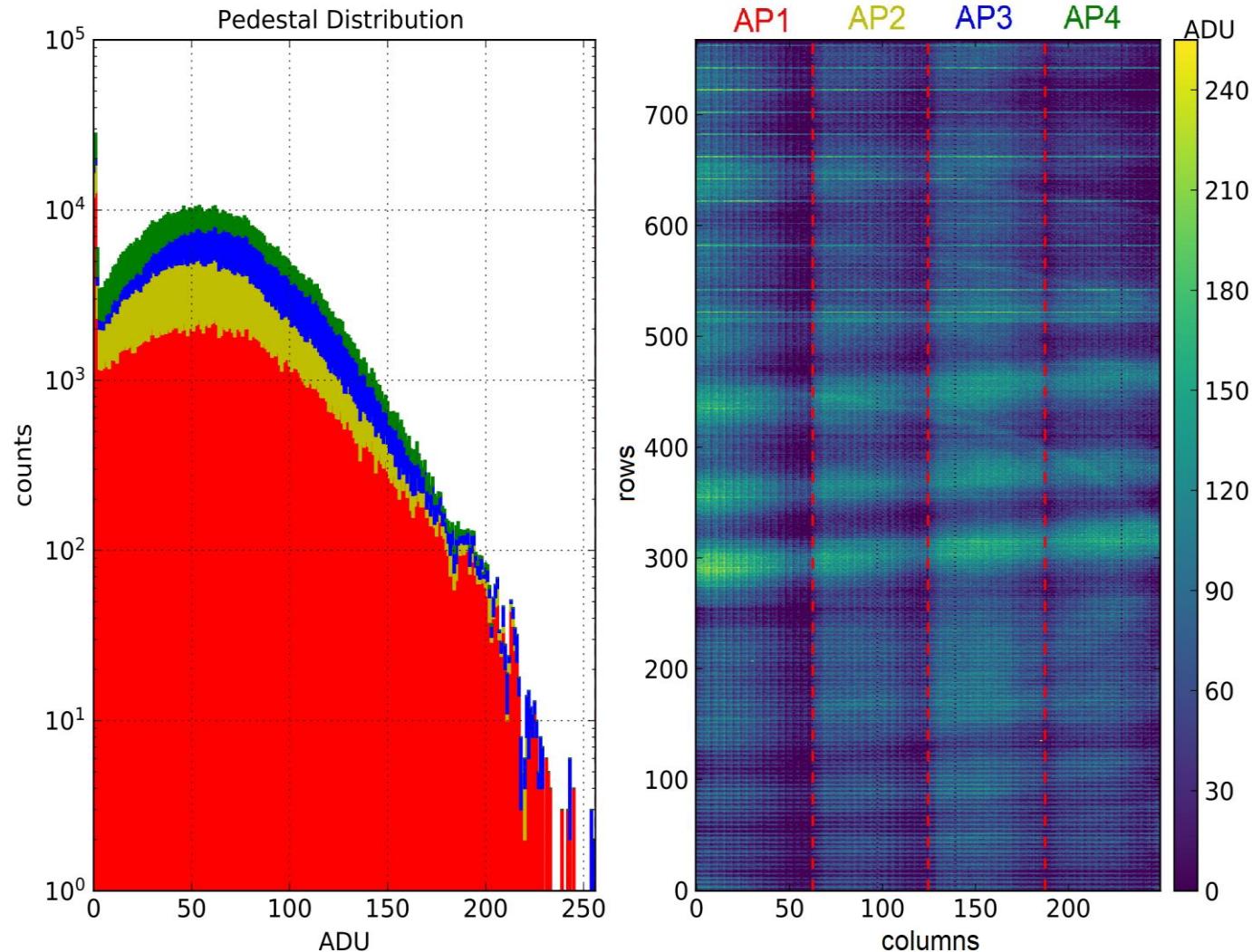
shift pedestals to lower region of dynamic range

Offset Calibration



# The Problem

- offset optimization needs pedestals in the lower region of dynamic range
- $I_{\text{sub}}$  (i.e. VNSubIn)
  - current subtracted from each drain line
  - higher  $I_{\text{sub}}$  → shift to left
- currently done by hand  
 → takes a lot of time ( $\sim 2 \frac{\text{min}}{\text{module}}$ )



# The Idea

Mimic the human operator:

1. take pedestals
  2. look at median of distribution
  3. determine new  $I_{\text{sub}}$  based on:
    - median
    - present  $I_{\text{sub}}$
    - wanted median
- repeat until new and present  $I_{\text{sub}}$  differ no more than 1 DAC

# Calculation of new I\_sub

$$I_{\text{sub,new}} = I_{\text{sub,pre}} + w * (\text{Median}_{\text{pre}} - \text{Median}_{\text{wanted}})$$

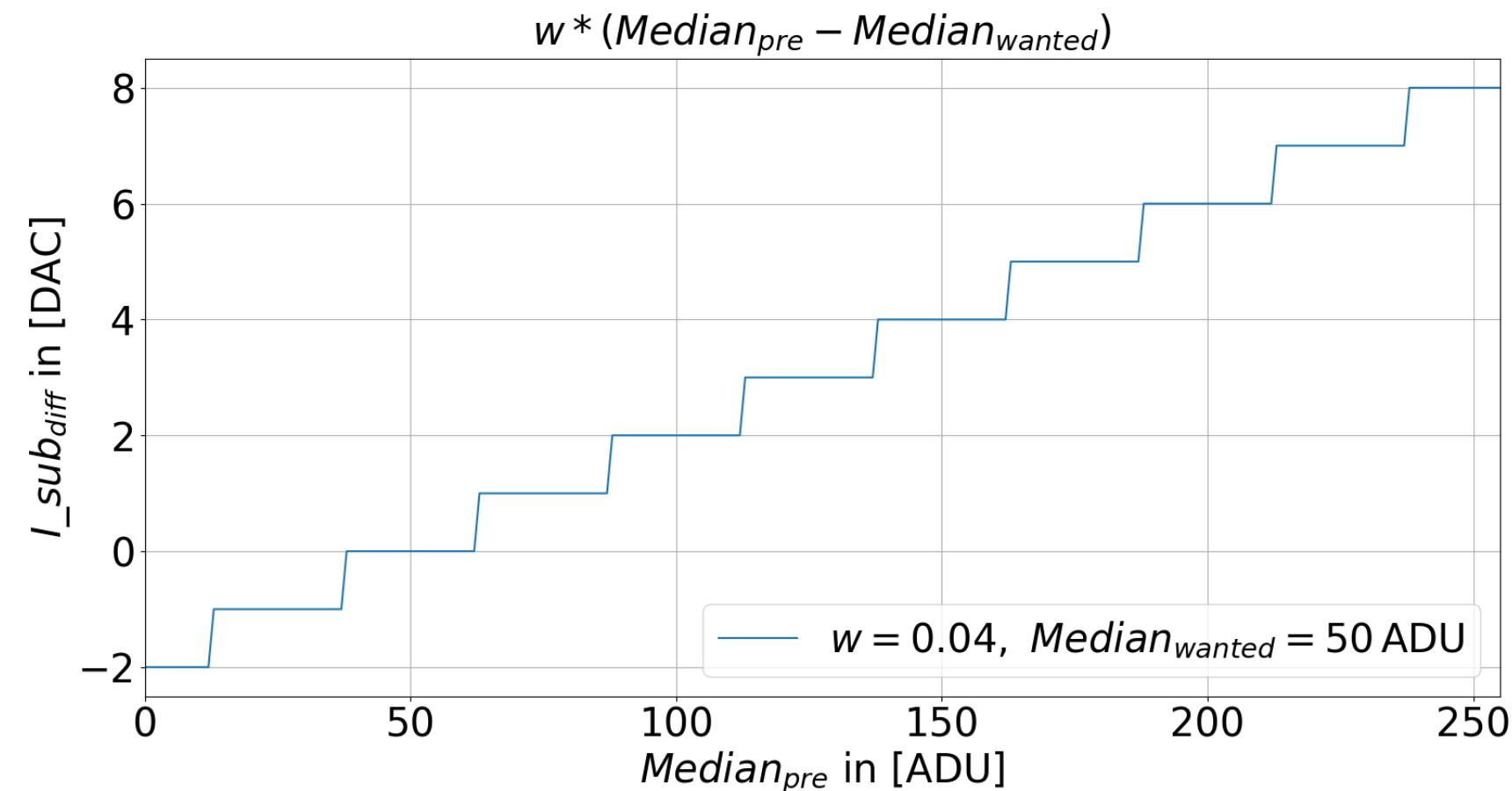
$$I_{\text{sub,new}} = I_{\text{sub,pre}} + w * (\text{Median}_{\text{pre}} - \text{Median}_{\text{wanted}})$$

- $w = 0.04$
- $\text{Median}_{\text{wanted}} = 50 \text{ ADU}$

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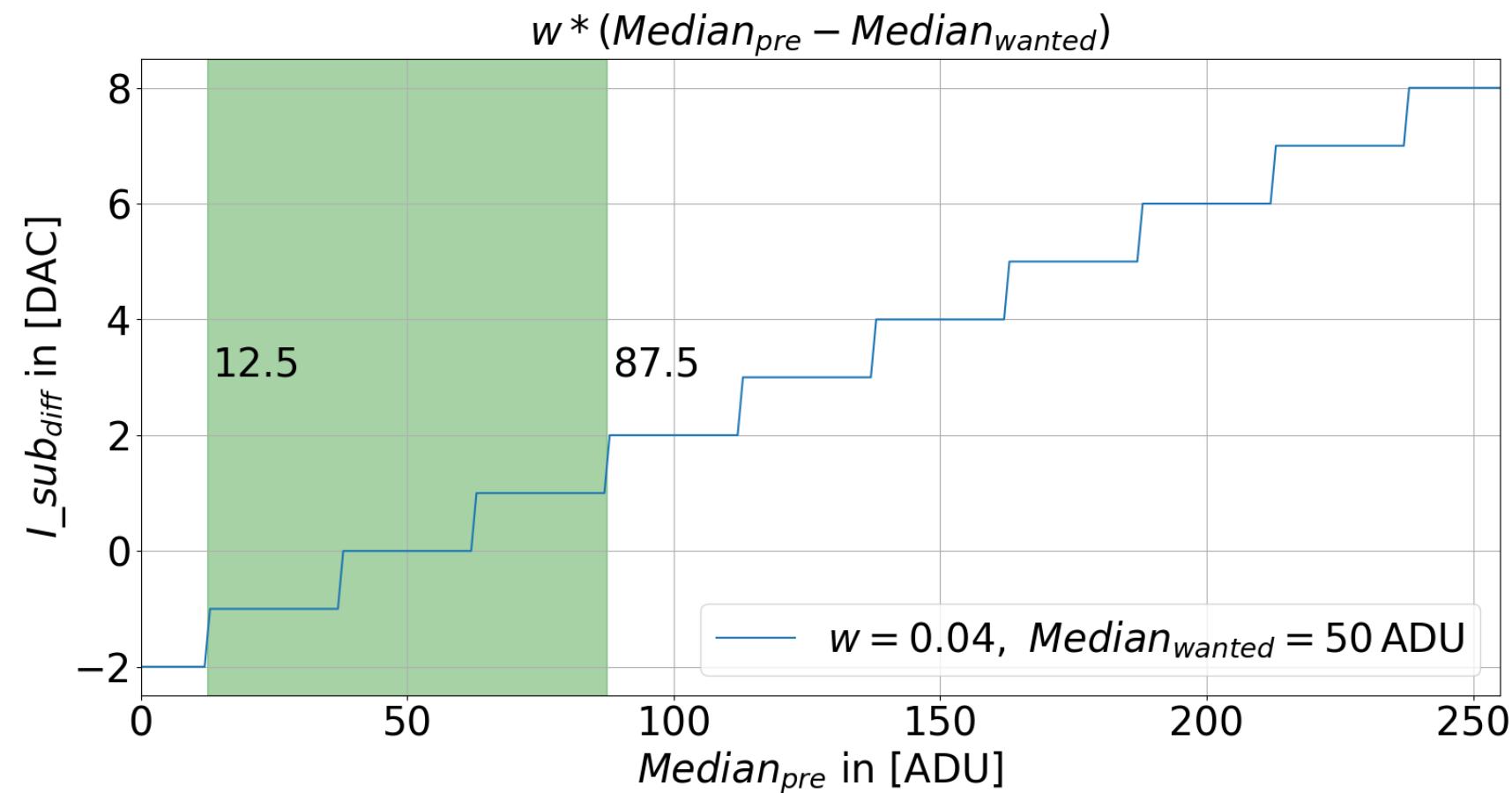


# Calculation of new I\_sub

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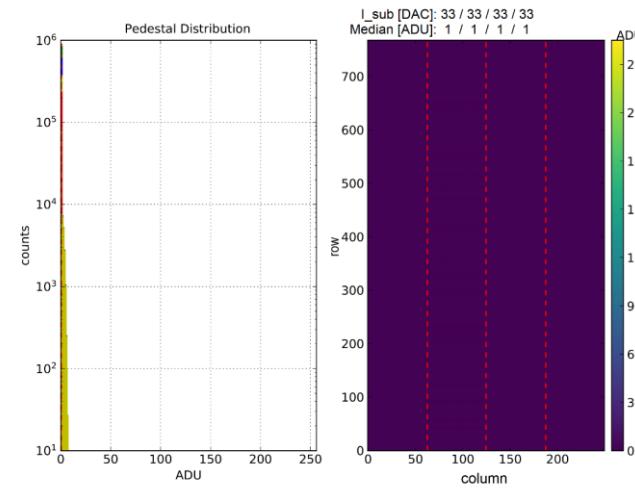
- $w = 0.04$
- $\text{Median}_{\text{wanted}} = 50 \text{ ADU}$

→ accepted range:  $12.5 - 87.5$   
 $(|I_{\text{sub}}_{\text{diff}}| < 1 \text{ DAC})$

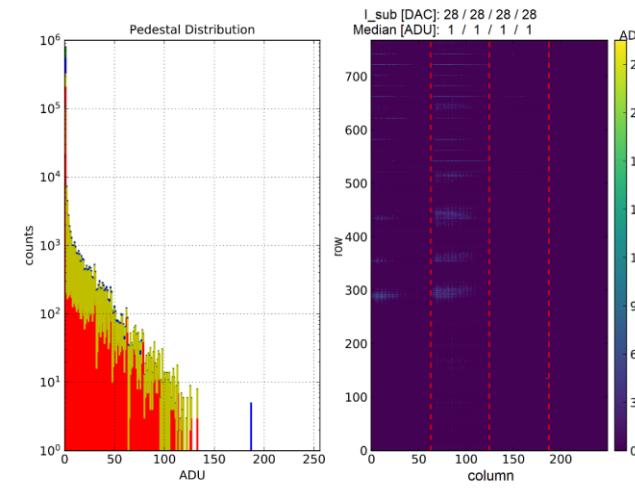


# Example at MPP

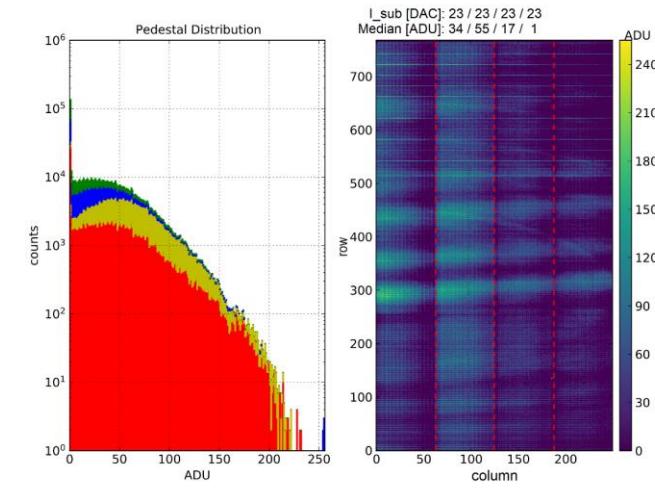
Start



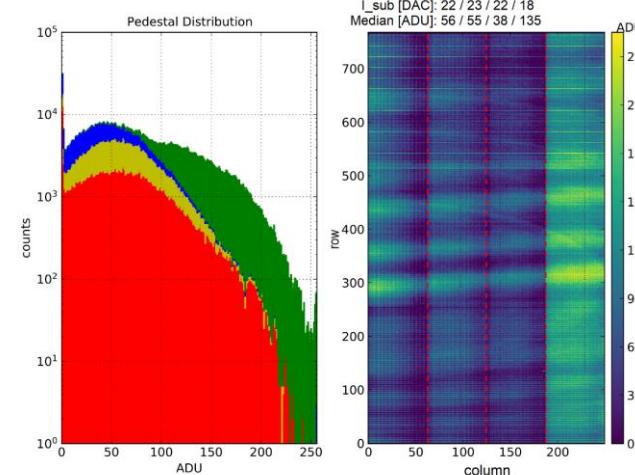
Iteration 1



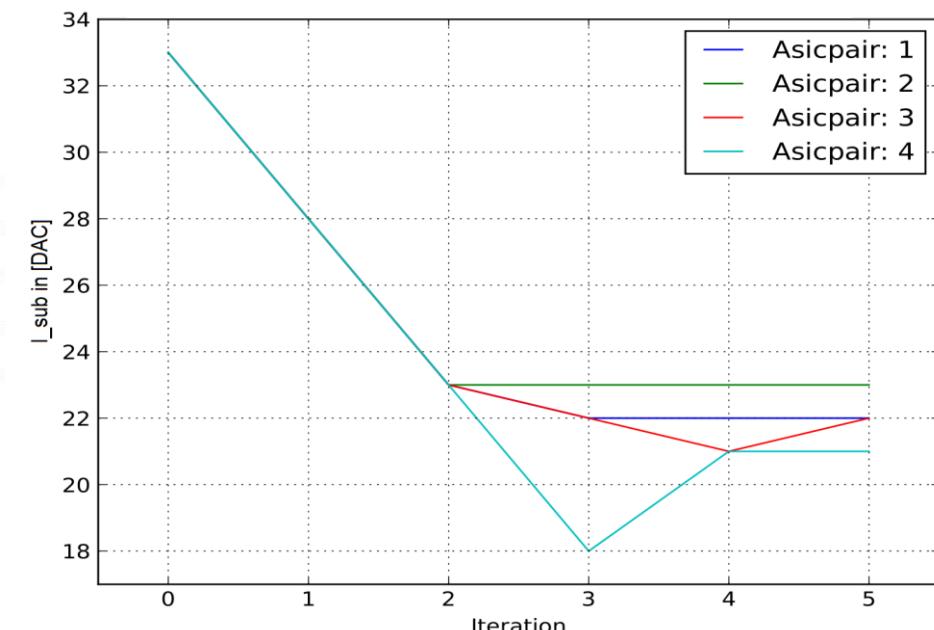
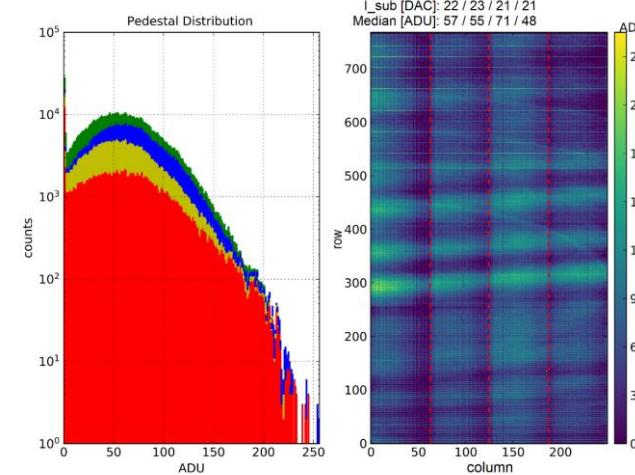
Iteration 2



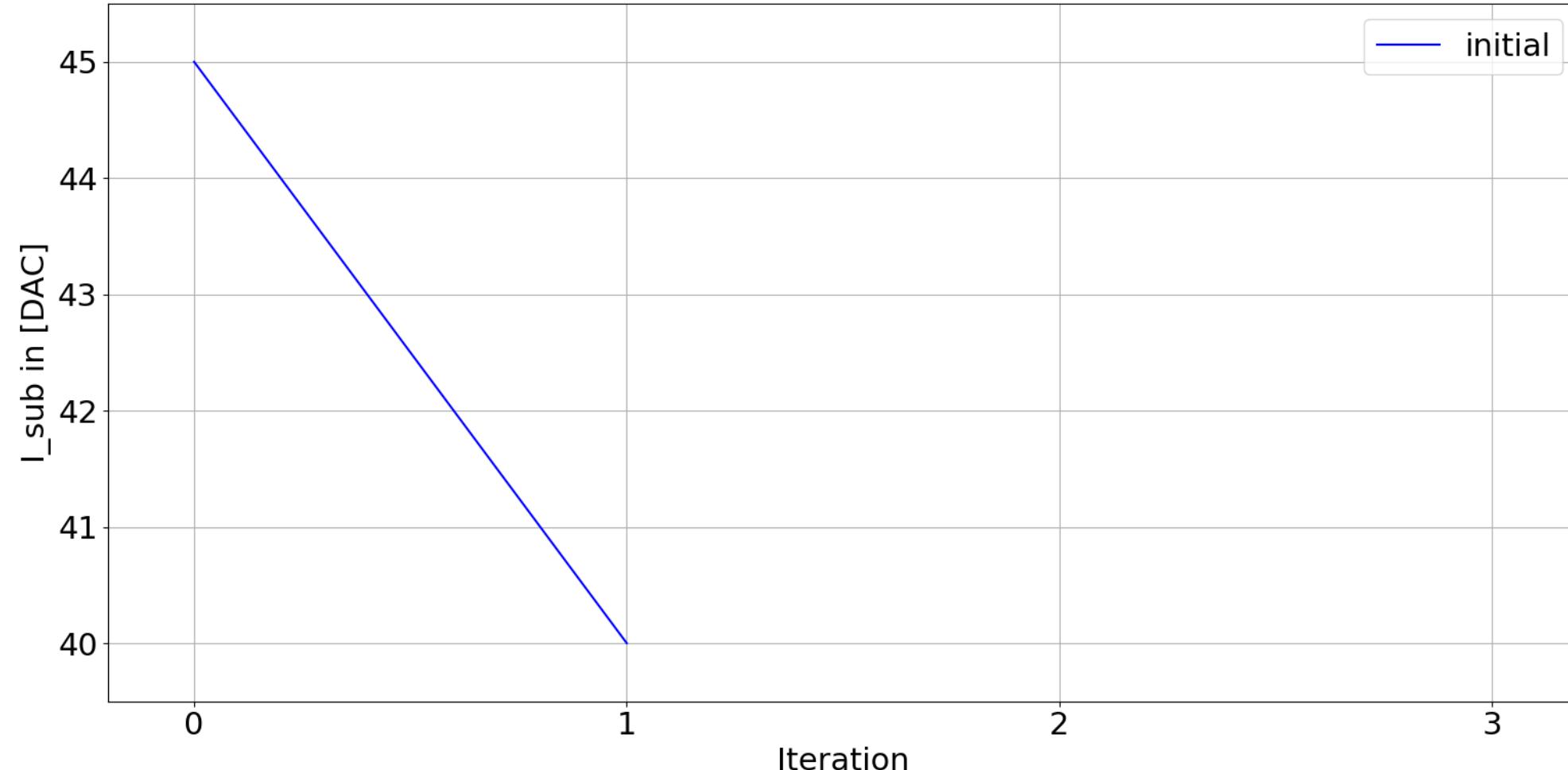
Iteration 3



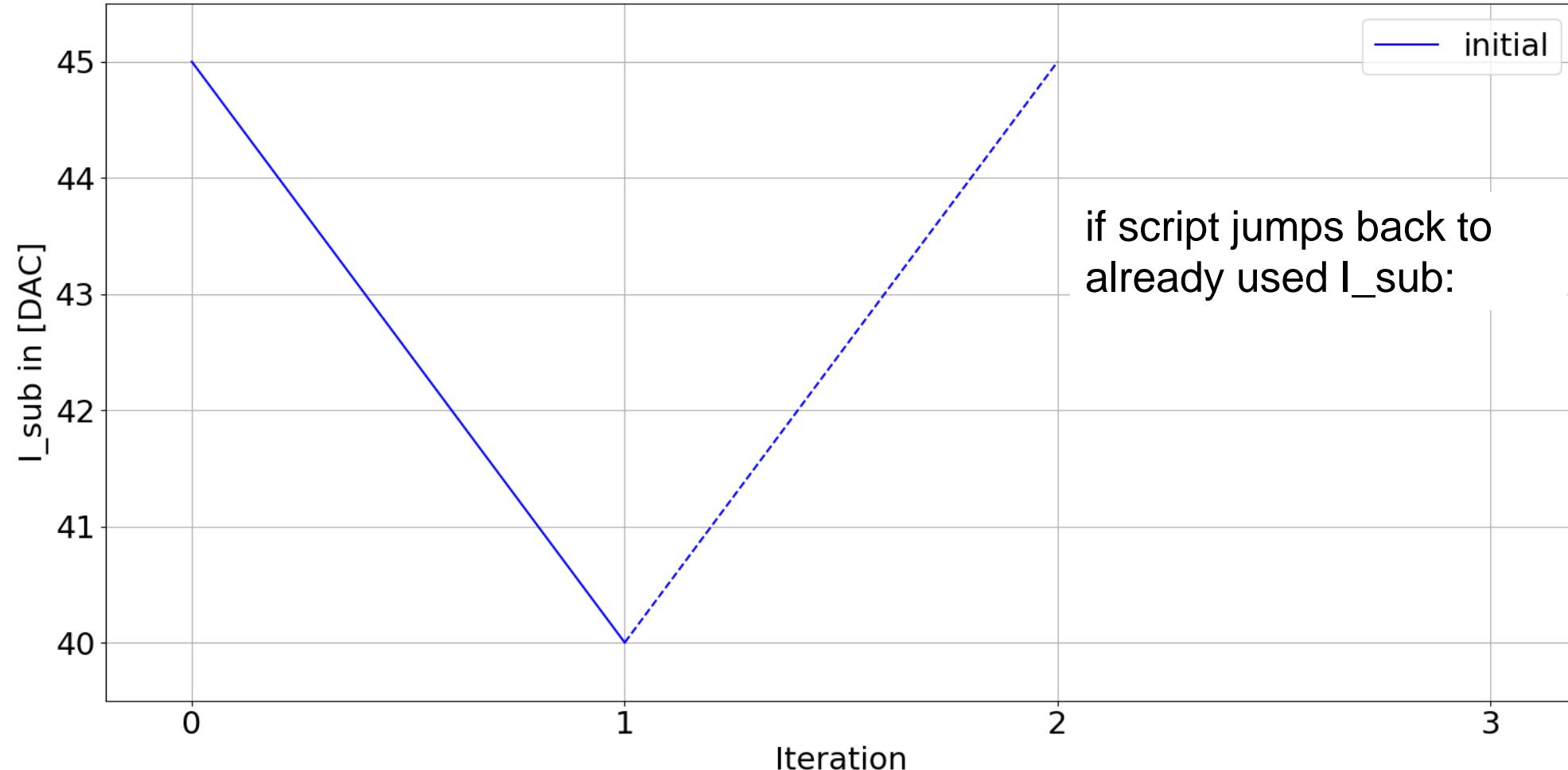
Iteration 4



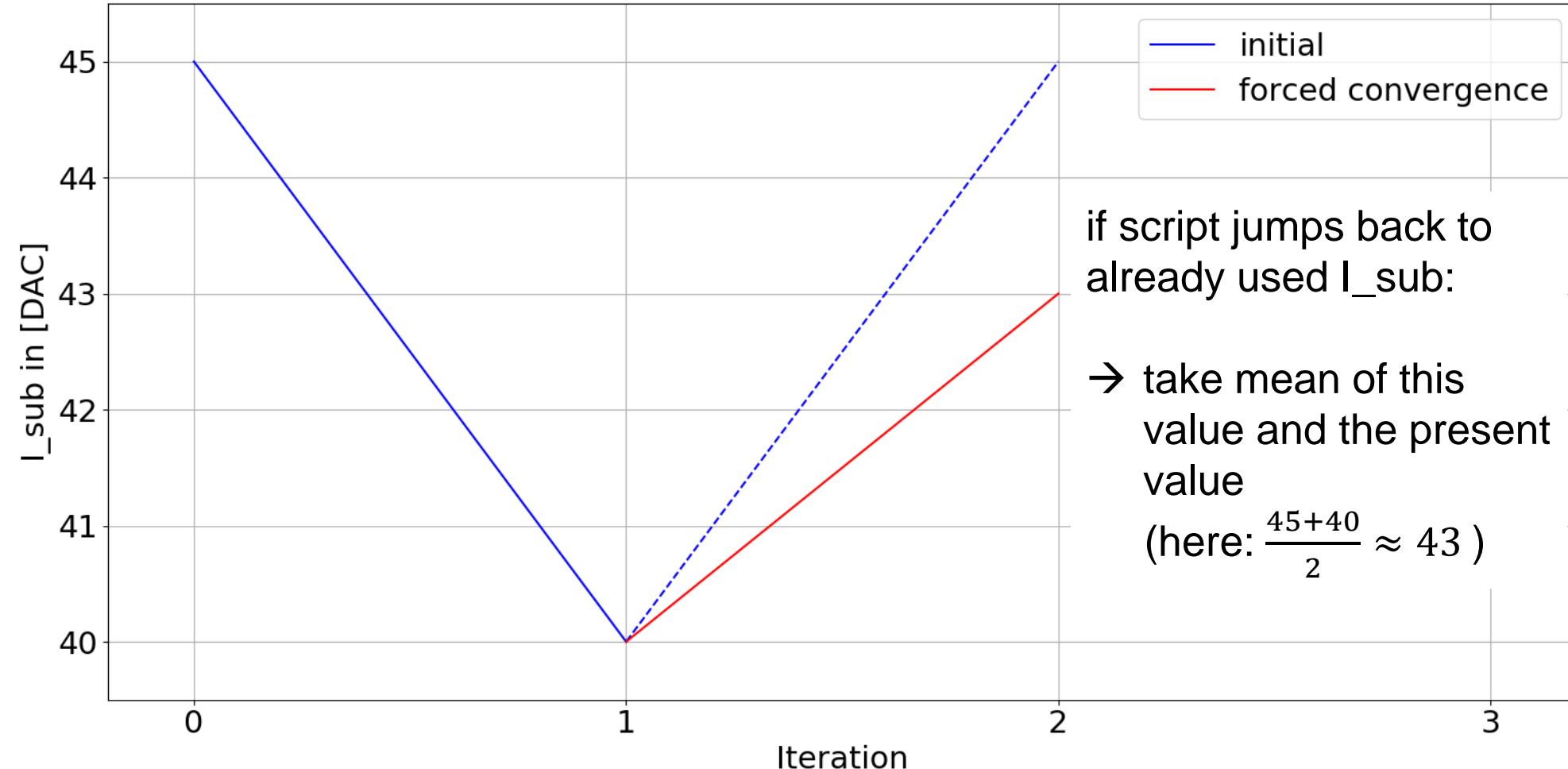
# Forcing Convergence



# Forcing Convergence



# Forcing Convergence



# Summary and Outlook

- Belle II started taking data in March 2019 →  $\sim 9 \text{ fb}^{-1}$
- 8 M pixels of PXD need to be calibrated frequently (once a week)
- fast procedure established to automatically adjust the pedestals to a starting position for the offset calibration
  - $\sim 20 \frac{\text{sec}}{\text{module}}$  and parallel for up to 24 modules →  $\sim 40\text{s}$  for whole detector
  - manually:  $\sim 2 \frac{\text{min}}{\text{module}}$  →  $\sim 80\text{min}$  for whole detector
- automatic procedure thoroughly tested and routinely used in lab setups for characterization of modules
- will soon be tested and used at KEK

## PXD Hardware:

- PXD needs to be completed
- new batch of modules is currently produced

## Belle II Analysis:

- $\Delta\Gamma_d$  between mass eigenstates of neutral  $B_d$  system
- SM asserts:  $\mathcal{O}(10^{-3}) \rightarrow$  null test of SM

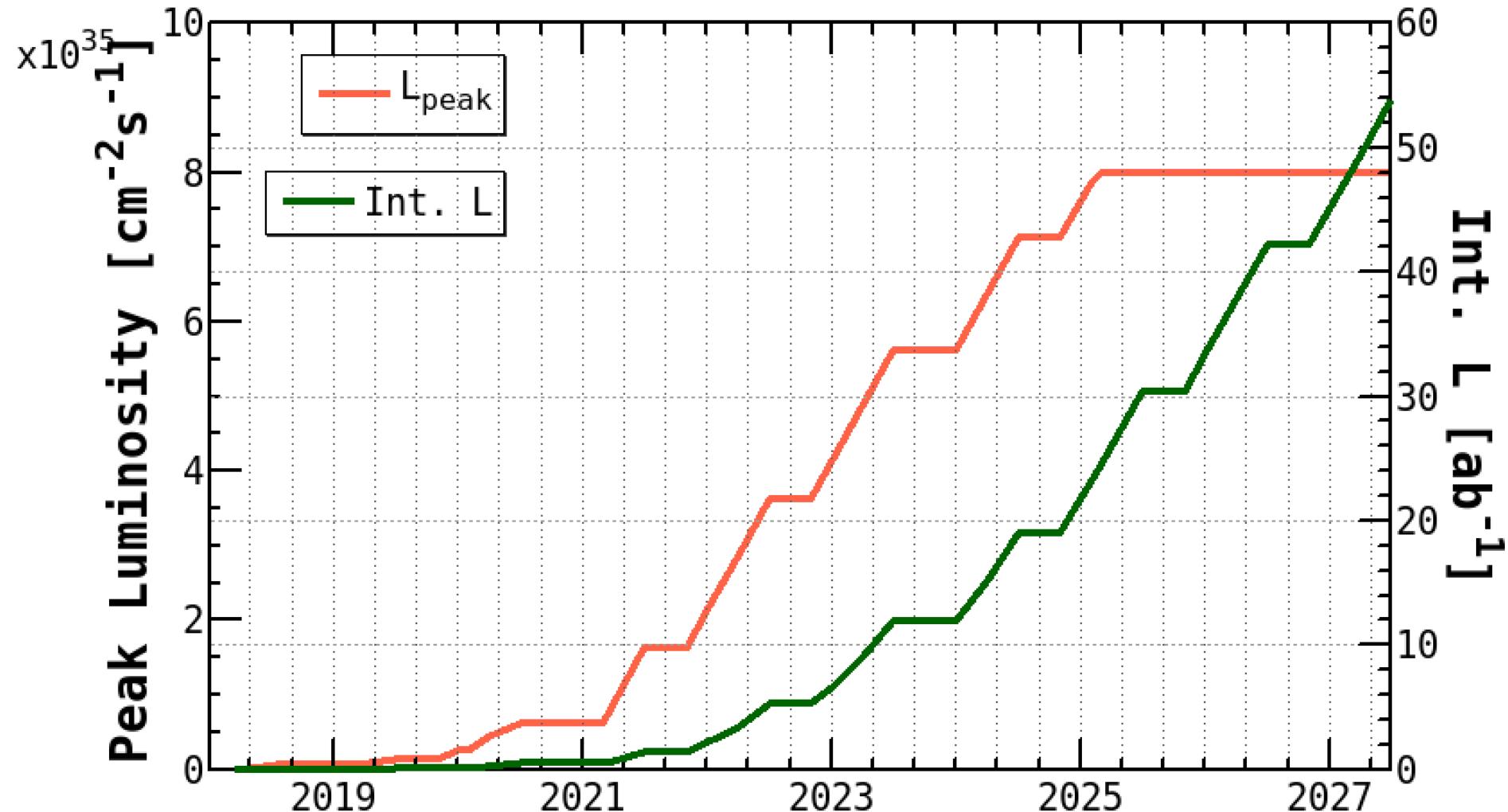
Strategies:

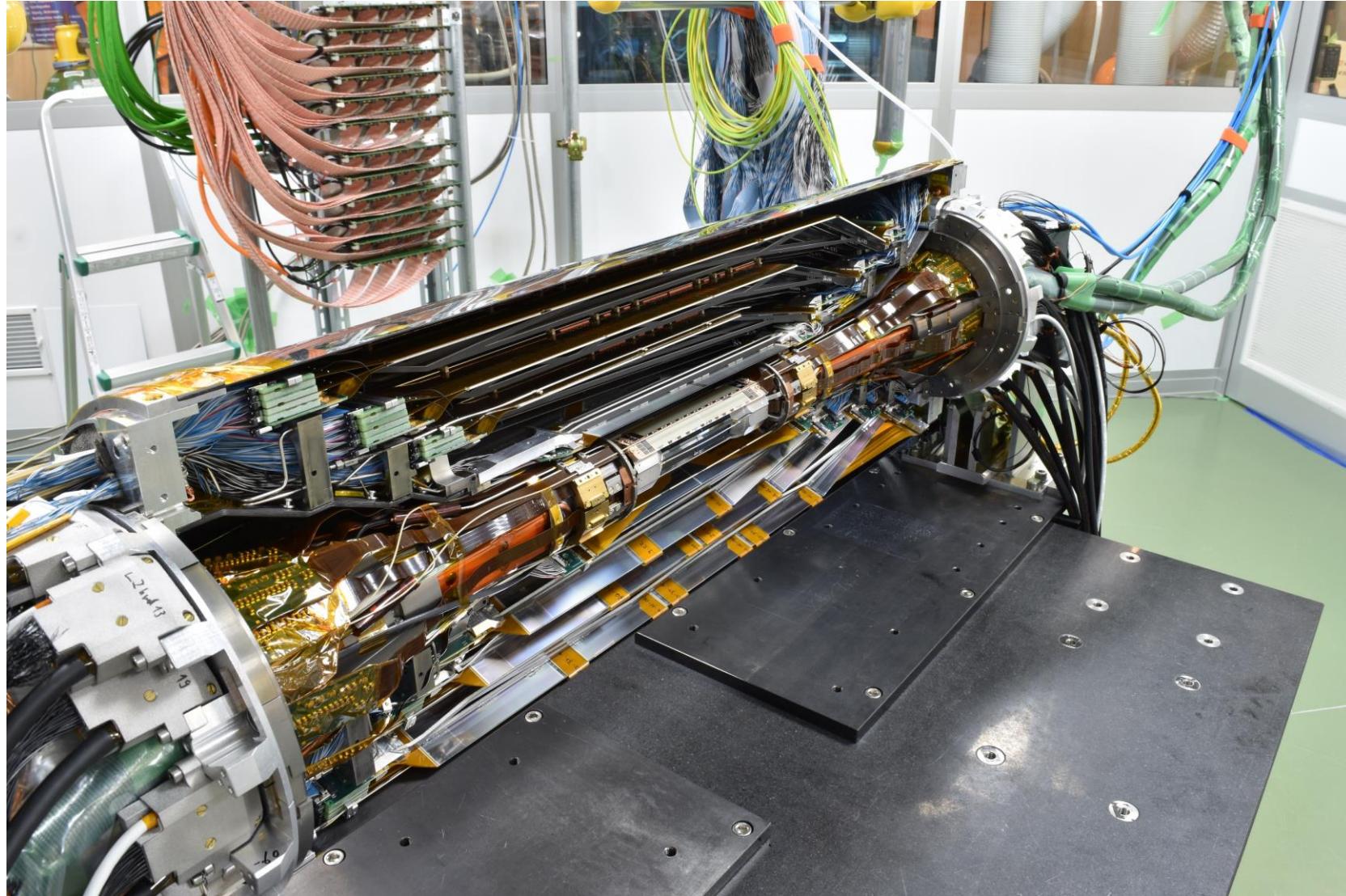
1. difference in lifetime between decays into CP-eigenstates and flavor-specific final states
2. separate CP-even and CP-odd in same final state with angular analysis

# Thank you!

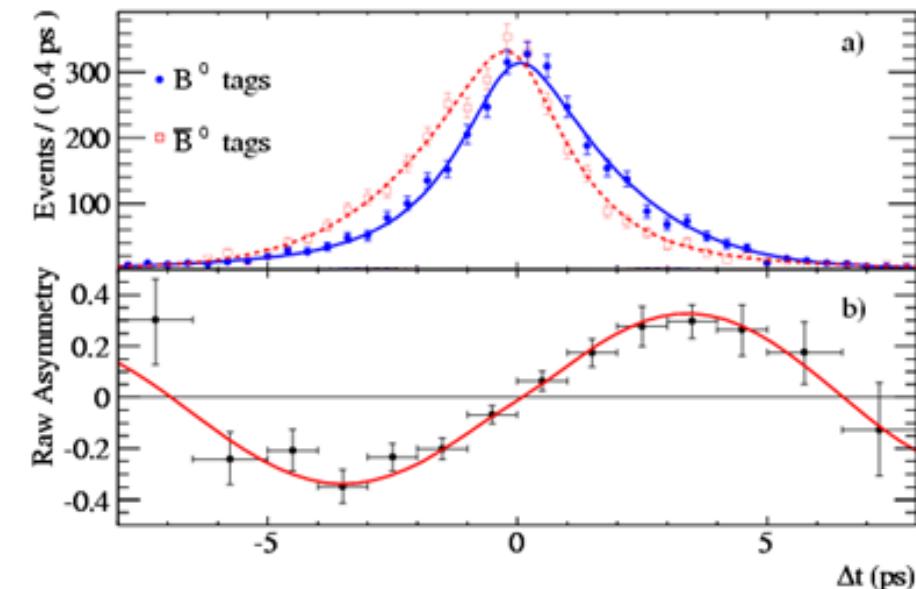
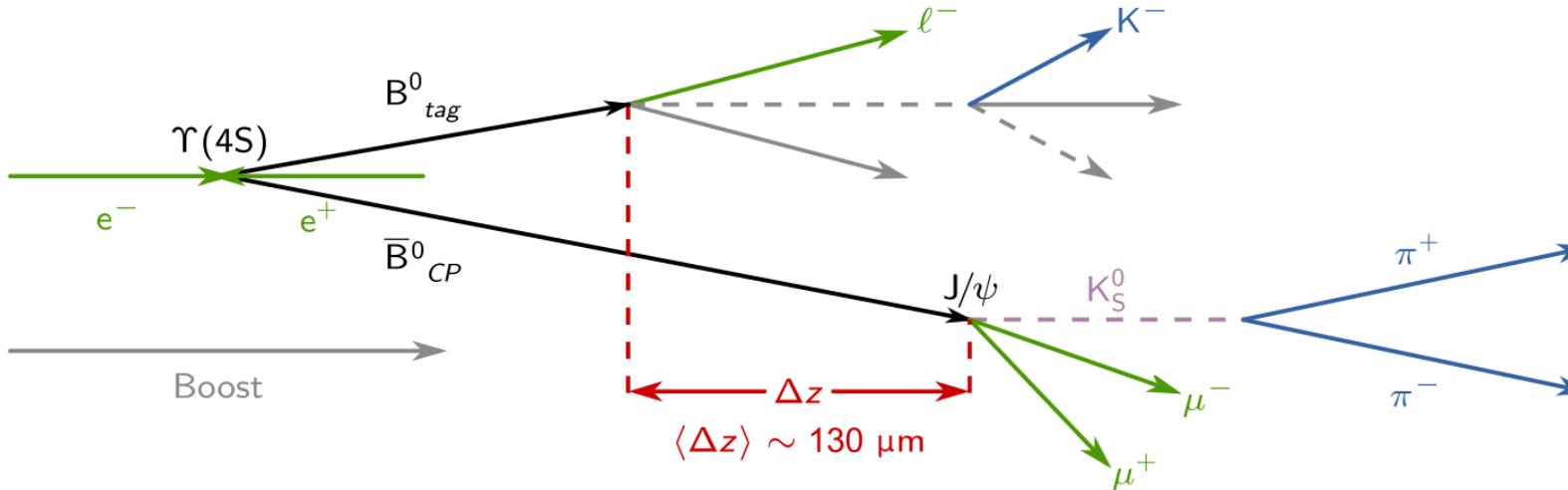
# Backup

# Luminosity





# Belle II Physics



- sources:
- B meson asymmetry: <https://www-public.slac.stanford.edu/babar/Nobel2008.aspx> (accessed: 28 November, 2019)
  - Principle of t-dep CPV studies: Felix B. Müller, Characterization and Optimization of the Prototype DEPFET Modules for the Belle II Pixel Vertex Detector