Beam profile measurements based on pixel detectors in the PS

4th ICFA Mini-Workshop on Space Charge 2019
5 November, CERN
https://indico.cern.ch/event/828559/

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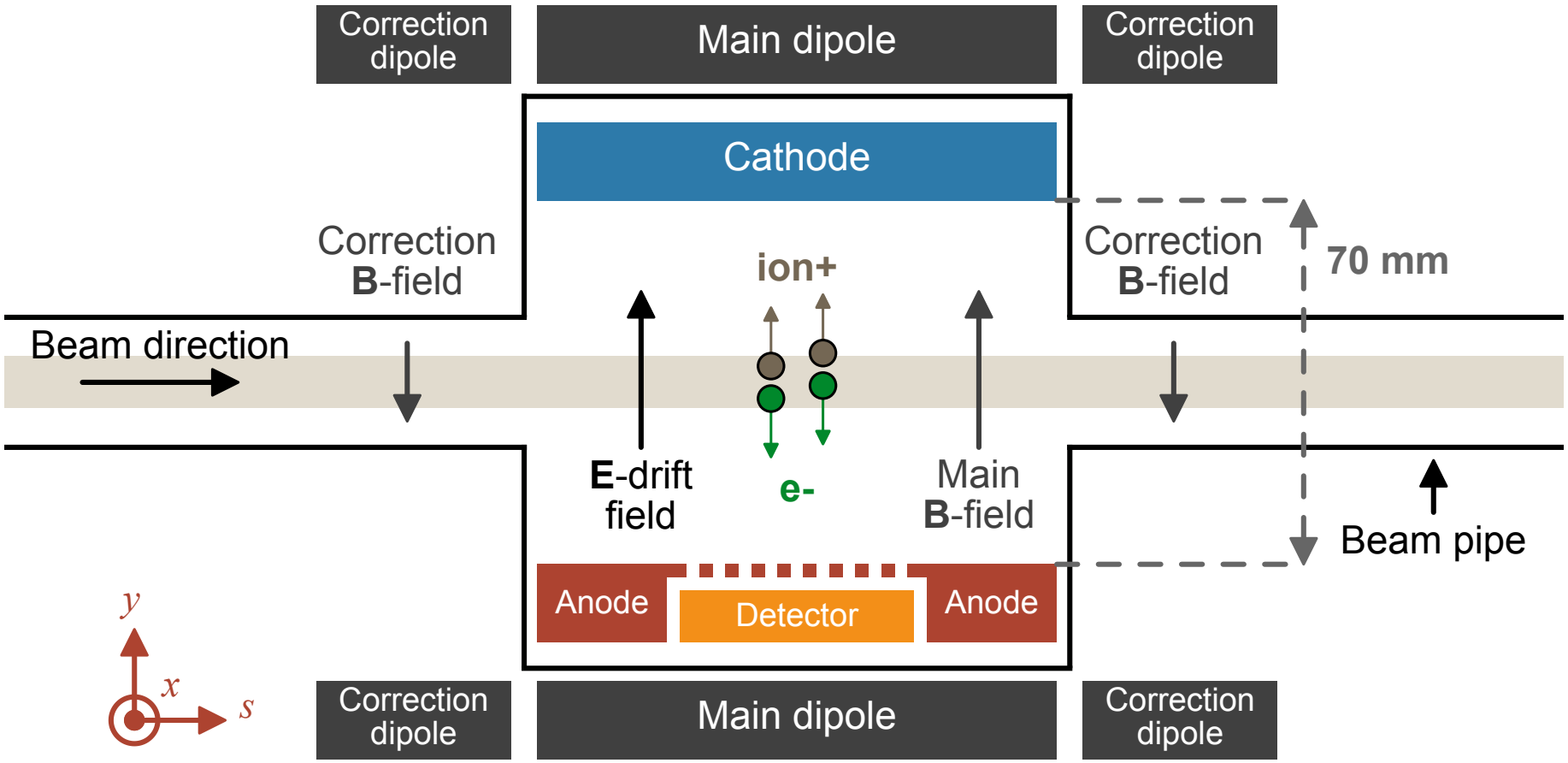
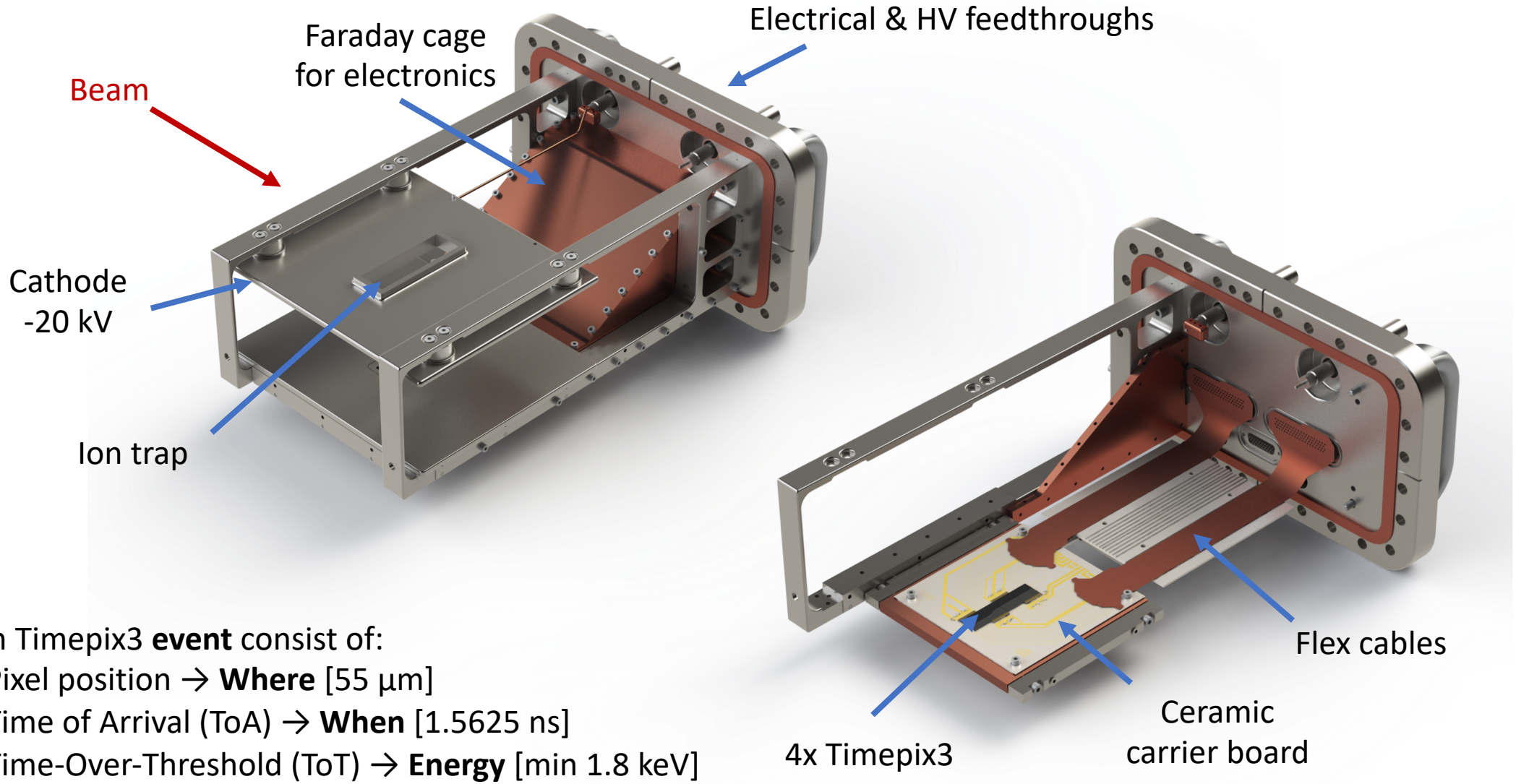
http://bgi-web.web.cern.ch

Ionization beam Profile Monitors (IPM´s) in a nutshell



- **Detector:** Timepix3 hybrid pixel detector (medipix.web.cern.ch)
- **Electric field:** 280 kV/m
- **Magnet:** 0.2 T
- At CERN: IPM = BGI

Horizontal IPM for the PS

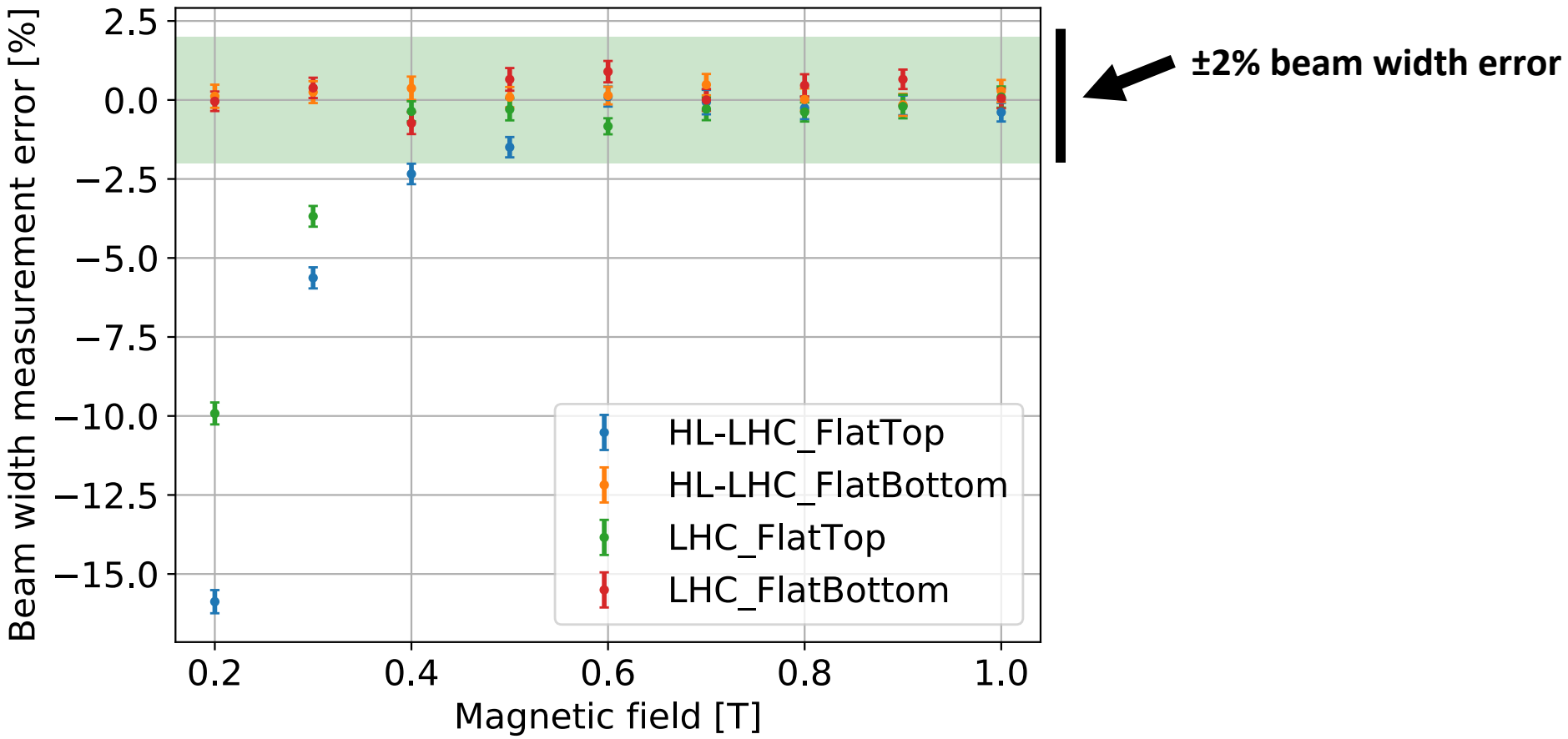


Each Timepix3 **event** consist of:

- Pixel position → **Where** [55 µm]
- Time of Arrival (ToA) → **When** [1.5625 ns]
- Time-Over-Threshold (ToT) → **Energy** [min 1.8 keV]

IPM and space charge simulation (in LHC)

Simulation of IPM: IPMSim collaboration (ipmsim.gitlab.io)
Virtual-IPM repository: gitlab.com/IPMsim/Virtual-IPM
Documentation: ipmsim.gitlab.io/Virtual-IPM/



Measurements of beam size vs. magnetic field strength in the PS

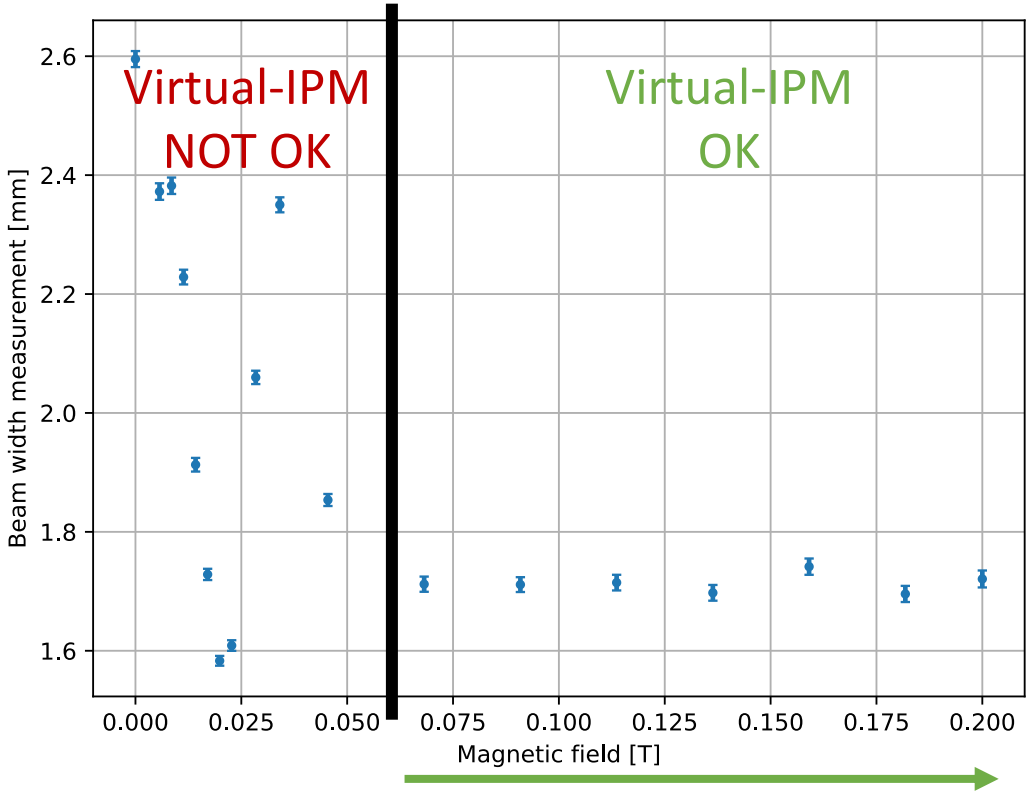
Prediction:

Virtual-IPM predicts B-field of **at least 0.07 T** is needed to prevent distortion to proton beam profile at E = 26 GeV.

Result:

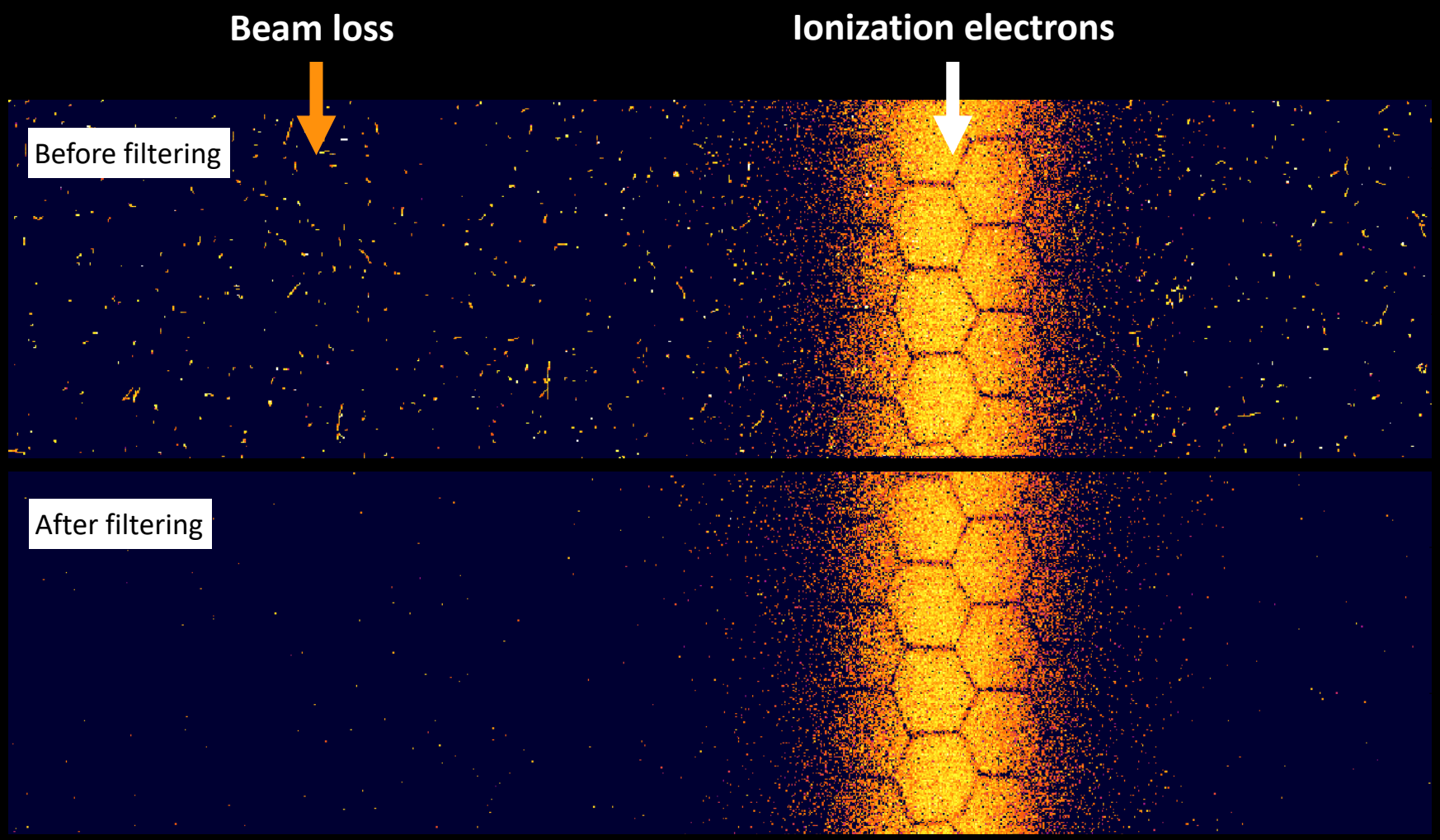
Significant beam profile distortion when B-field is less than ~0.06 T

Reasonable agreement with Virtual-IPM prediction



No distortion for B > ~0.06 T

Example pixel images



- **Signal:** Ionization electrons - single-pixel events with low energy
- **Background**: beam loss particles - multi-pixel events close in time with higher energy

Video of complete LHC Indiv cycle in the PS

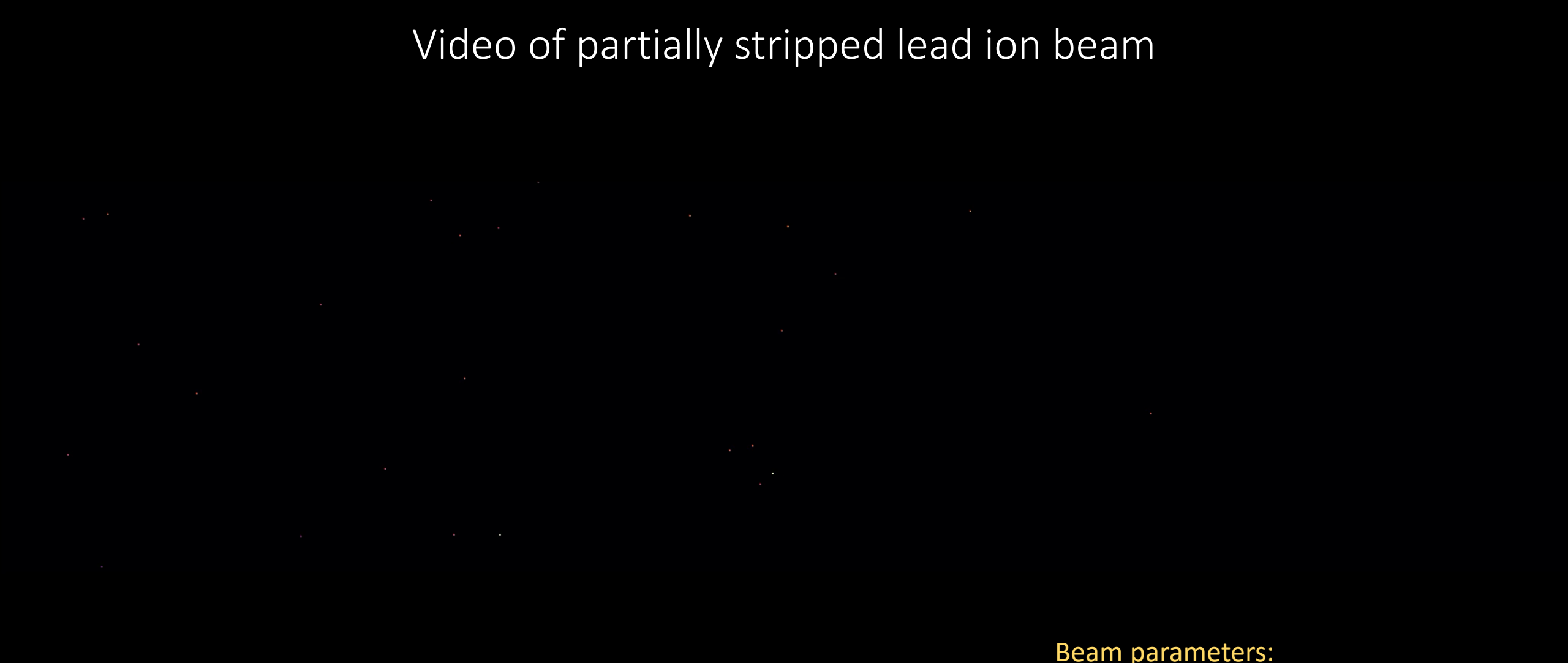
Video of complete LHC Indiv cycle in the PS

- Video shows LHC type beam from injection, through acceleration and finally extraction
- 1.5 seconds in real time: slowed down here for viewing purpose
- Each frame is 10 ms of data
- Not filtered to show background particles
- http://bgi-web.web.cern.ch/bgi-web/images/beam-pixelmap.mp4

Beam parameters:

- LHC Indiv (single bunch cycle for the LHC)
- Intensity = 10.8×10^{10} protons
- Vacuum = 6.3×10^{-10} mbar

Video of partially stripped lead ion beam

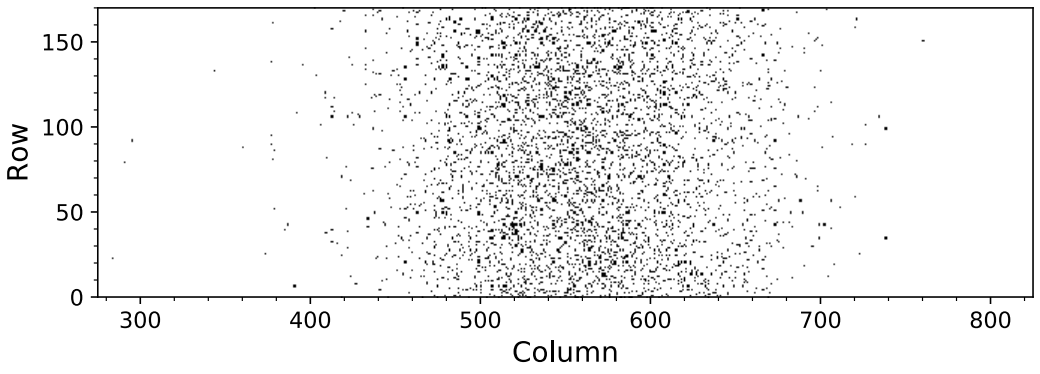


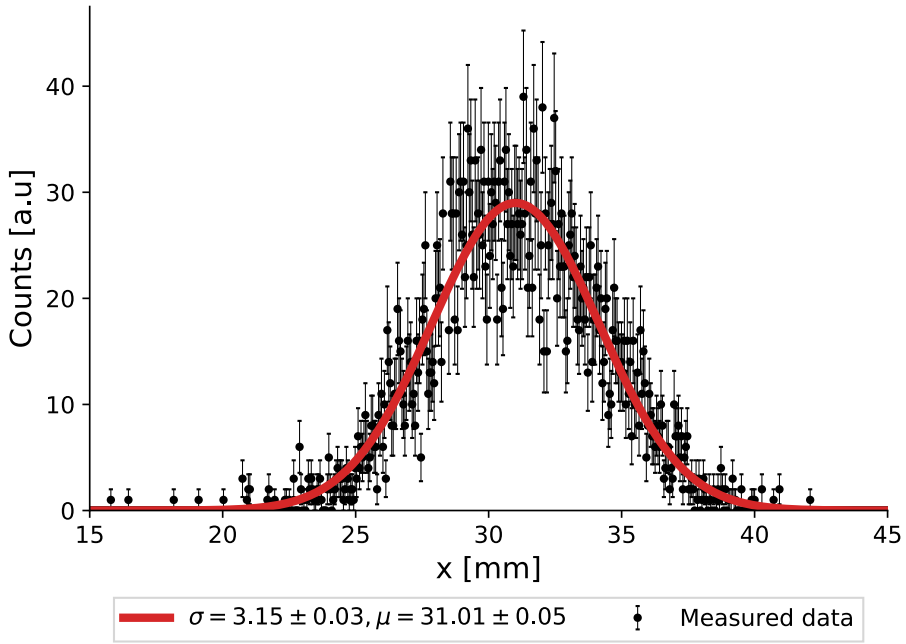
Beam parameters:

- ILHC200#2b_2018_partial_strip
- Intensity = 8.9×10^{10}
- Vacuum = 9.8×10^{-11} mbar

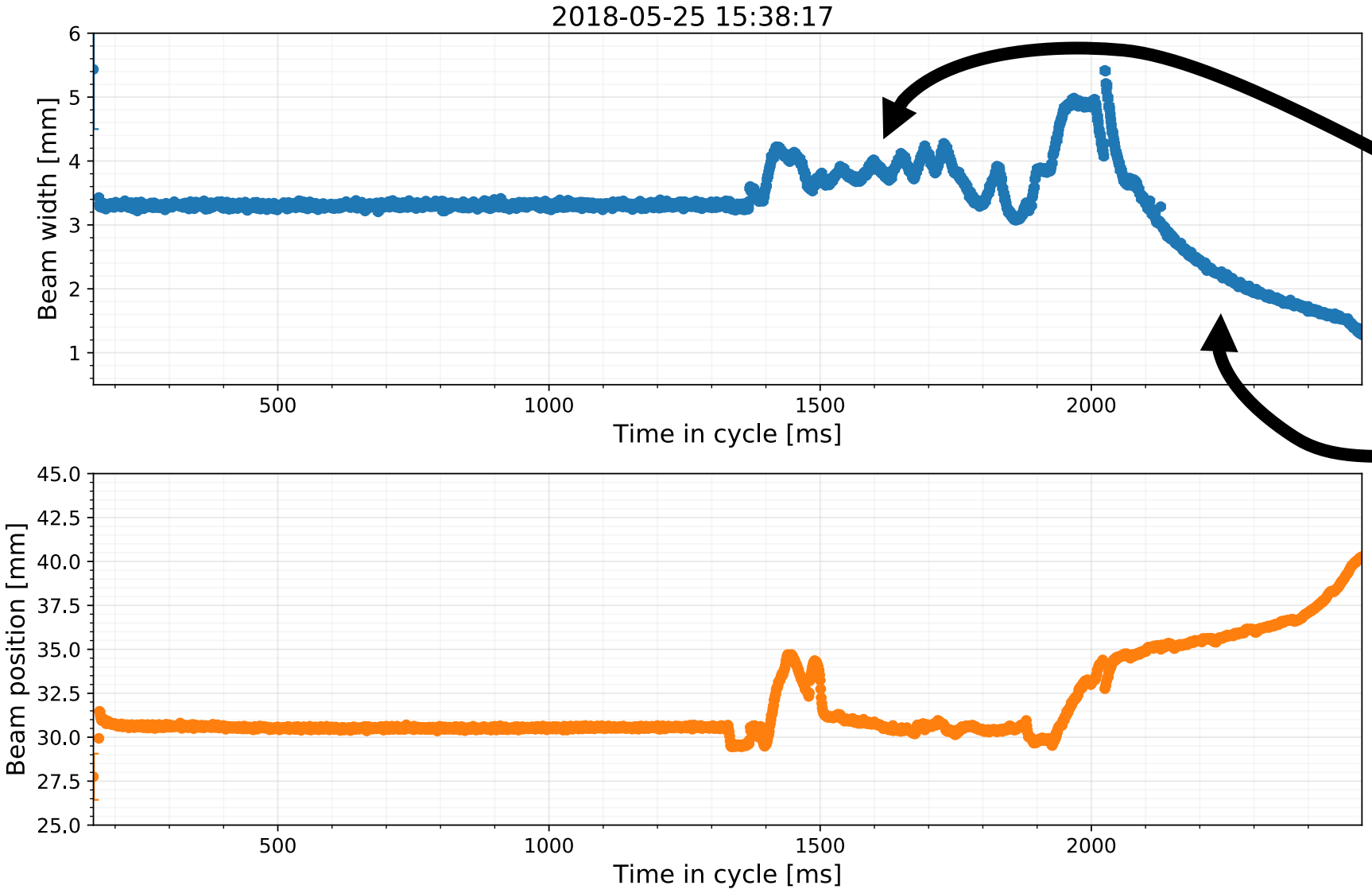
Beam profile measurement

- Effect of “Honeycomb” shaped RF-shield removed
- Sum of events in each column = beam profile
- Horizontal pixel IPM instrument
- Intensity: 60e10 protons
- Vacuum: 1e-10 mbar
- 5 ms gives 5500 ionization electrons
  - 1-2 per bunch per turn





Evolution of the beam profile in the cycle



RF manipulations

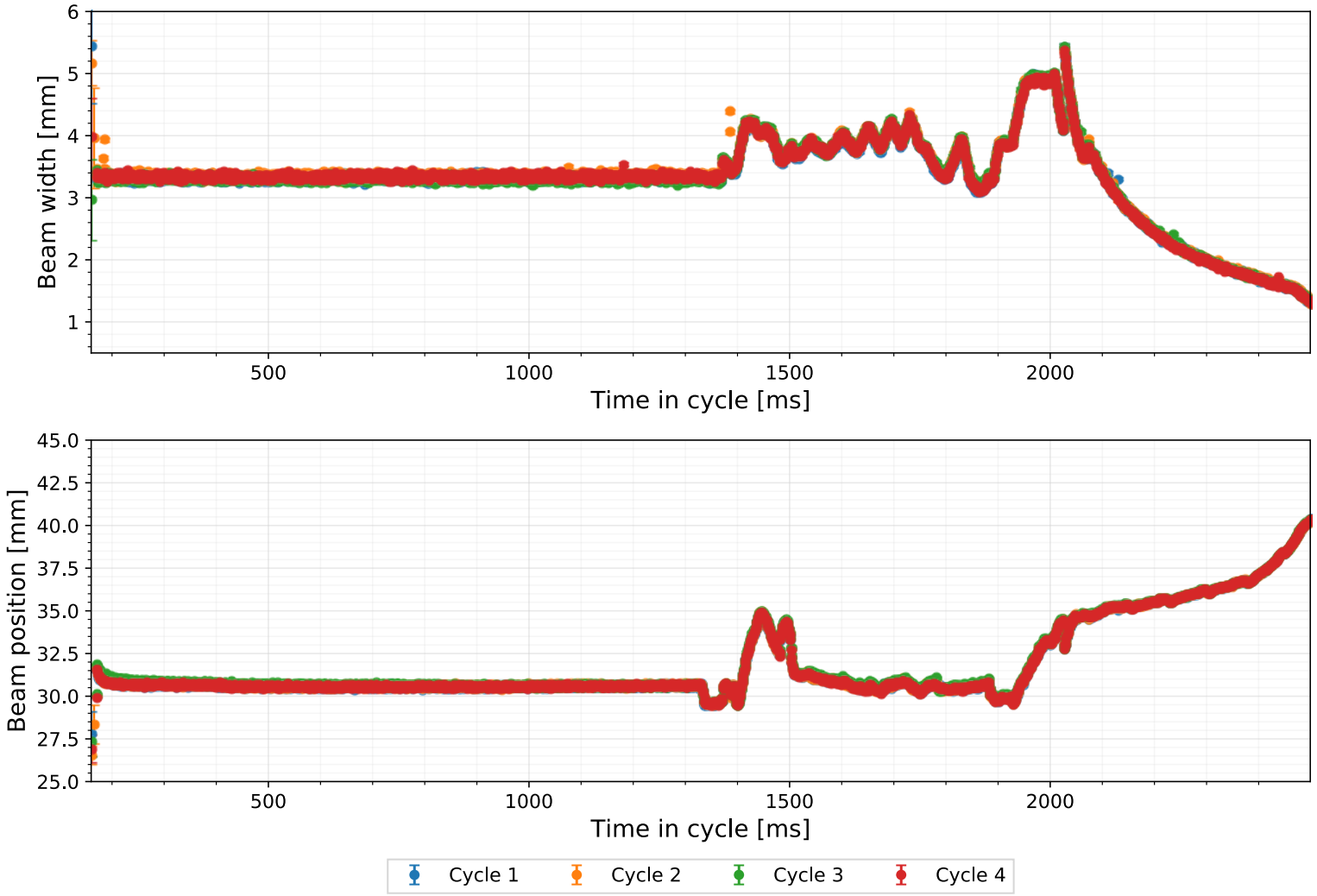
- **B**atch **C**ompression
- **M**erging
- **S**plitting
- => **BCMS**

Adiabatic shrinkage of the beam size during acceleration

Beam parameters:

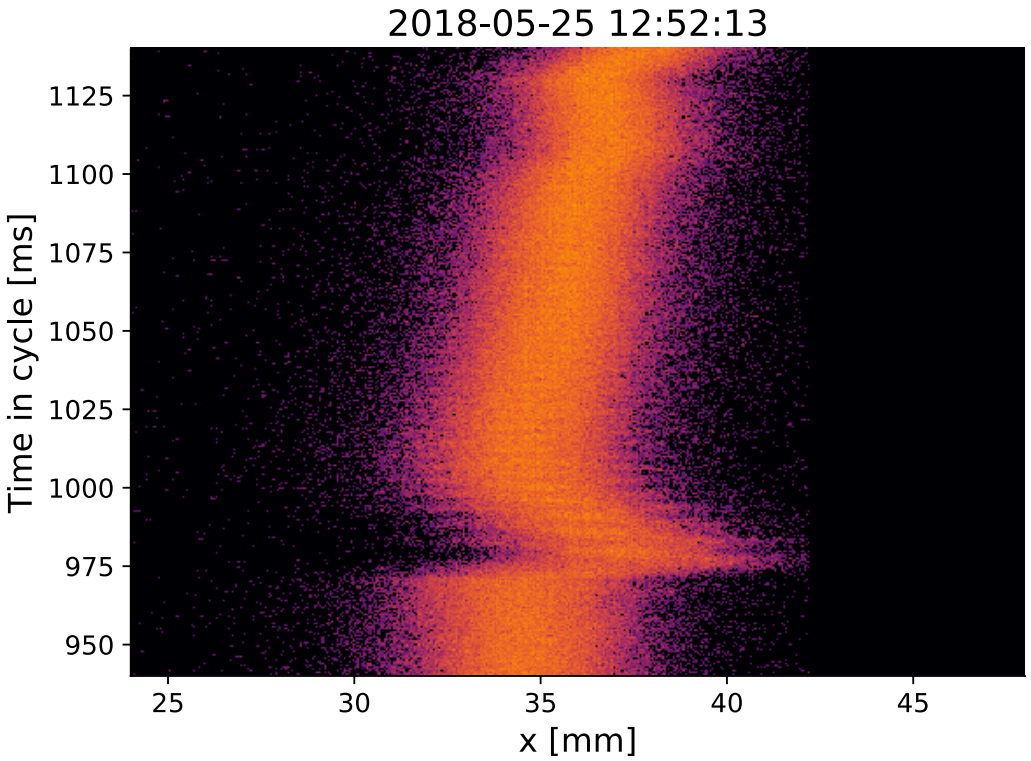
- LHC25_48b_BCMS_PS
- Intensity = 282 x 10^{10}
- Vacuum = 4.7 x 10^{-11} mbar

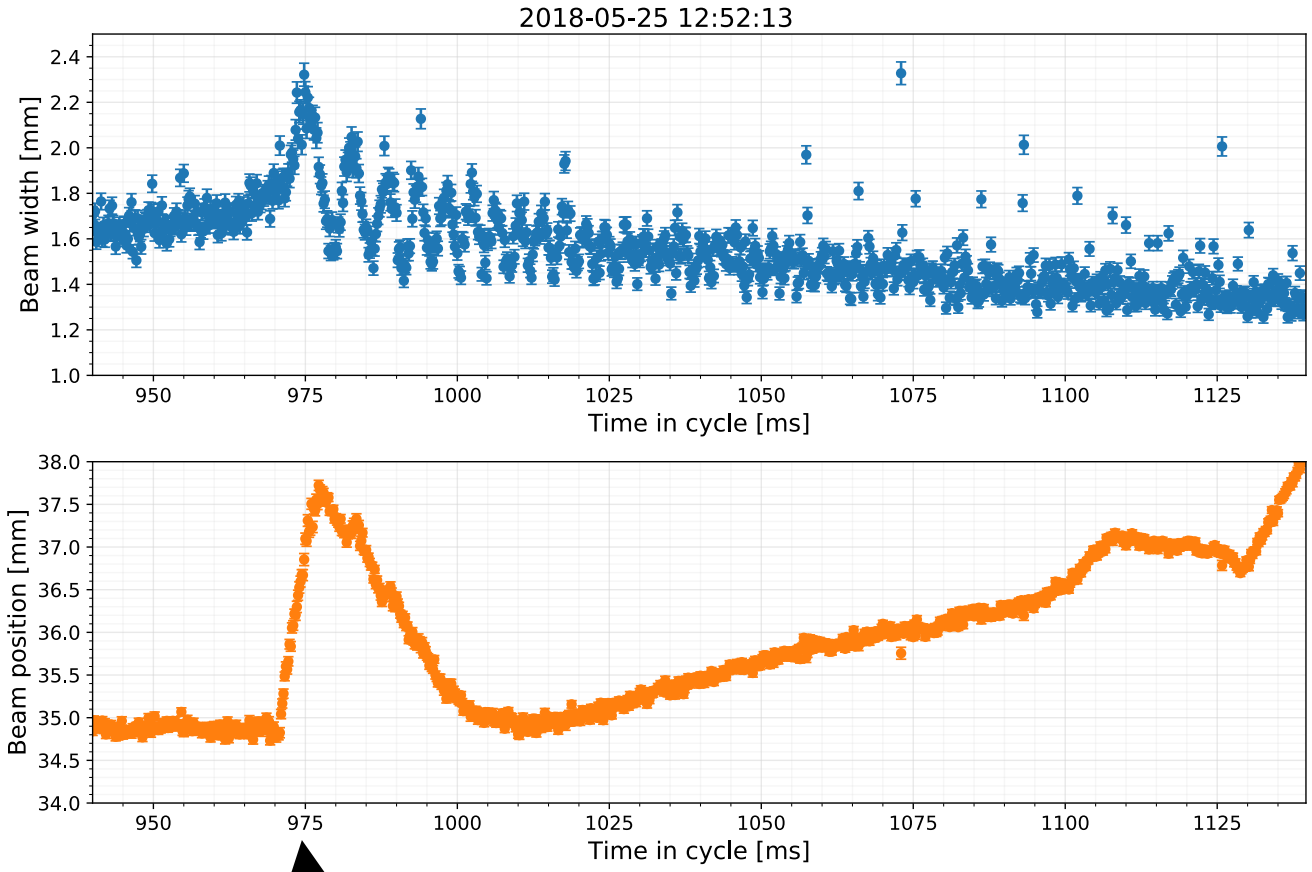
Evolution of the beam profile - multiple cycles



Consistent measurements for a stable beam

Oscillations during transition crossing



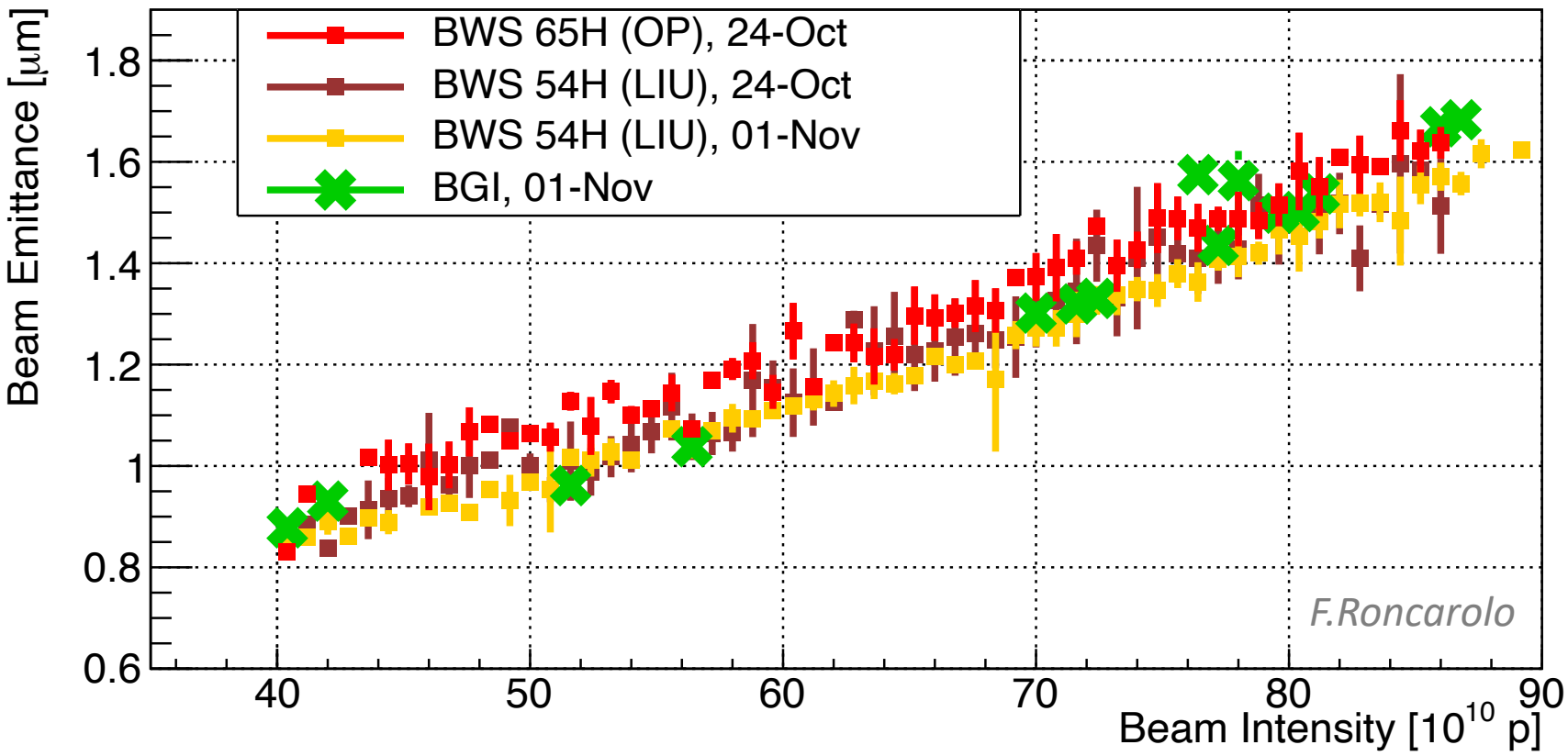


Transition crossing at around 975 ms

Beam parameters:

- ILHC100_4b (Pb54 ion beam)
- Intensity = 5.26 x 10^{10}
- Vacuum = 5.4 x 10^{-11} mbar

Brightness curve



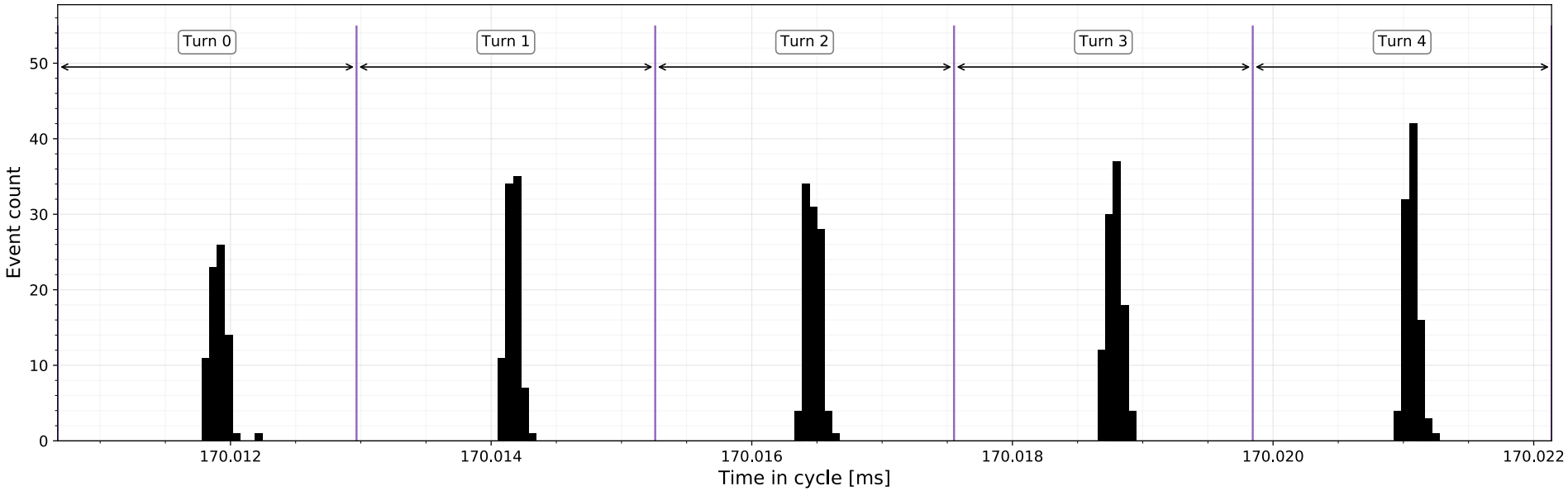
Good agreement between the Beam Wire Scanner (BWS) & IPM (BGI):

- → Timepix3-IPM point spread function is negligible.
- **IPM beam size measurement independent of other profile monitors & beta function.**

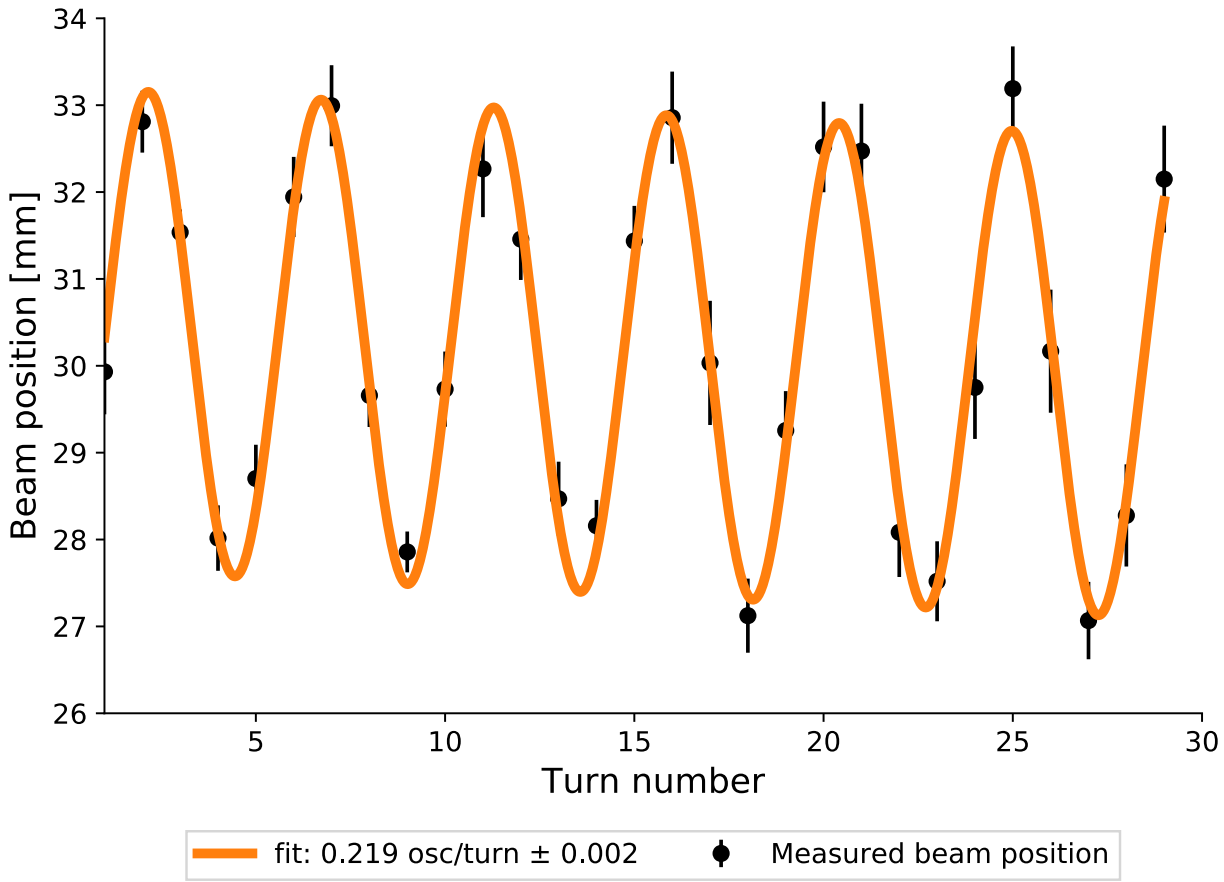
Turn-by-turn measurements at injection

- **Single bunch** operational beam with intensity: 70e10 protons
- 2 ionization electrons per turn not enough for turn-by-turn
- Pressure bump from sublimation of ion pump
  - From nominal 2e-10 mbar to approx. 1e-8 mbar

- On average: 80 ionization electrons per turn



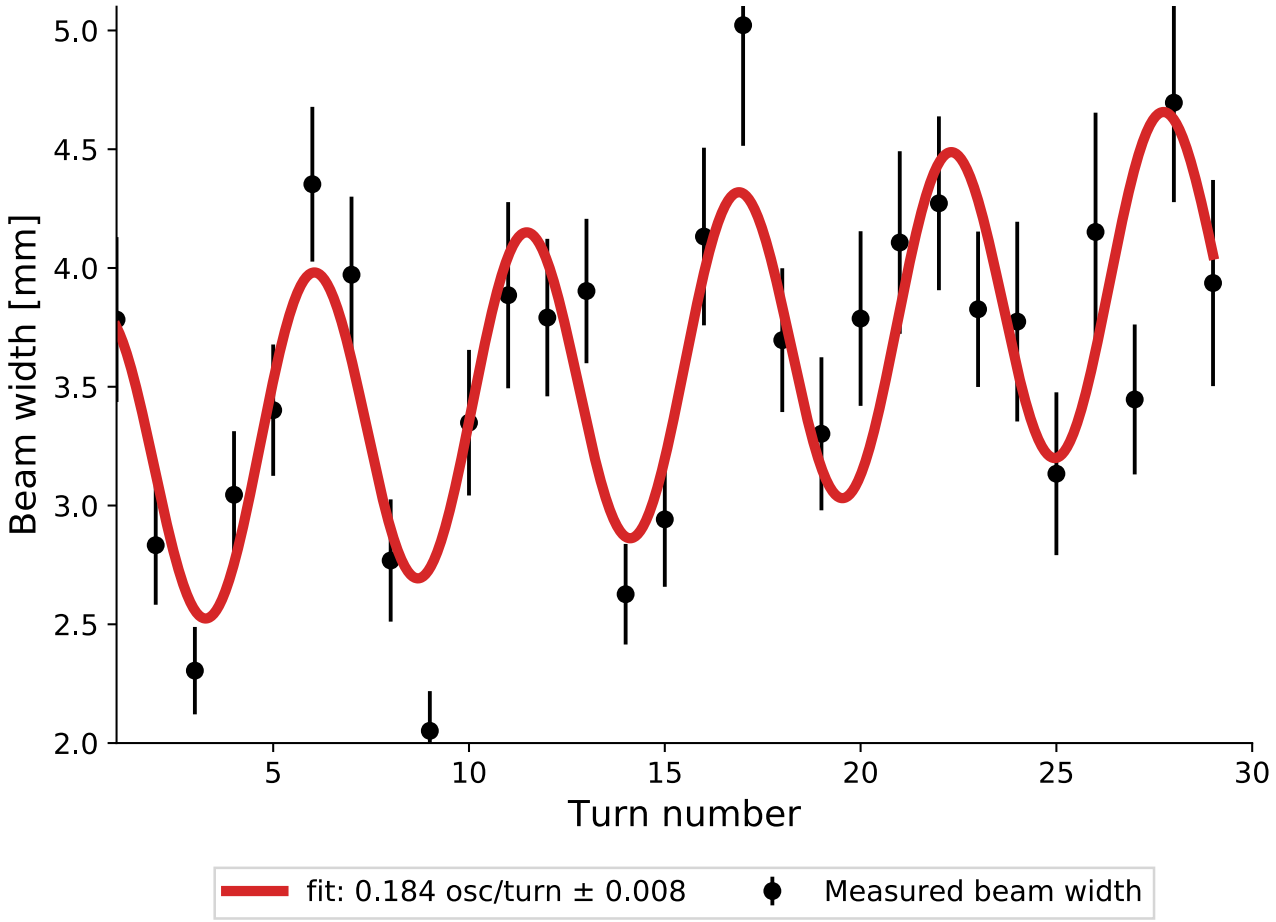
Turn-by-turn **beam position** at injection



IPM:
0.219 oscillations per turn

Consistent with fractional tune measurements

Turn-by-turn **beam size** at injection



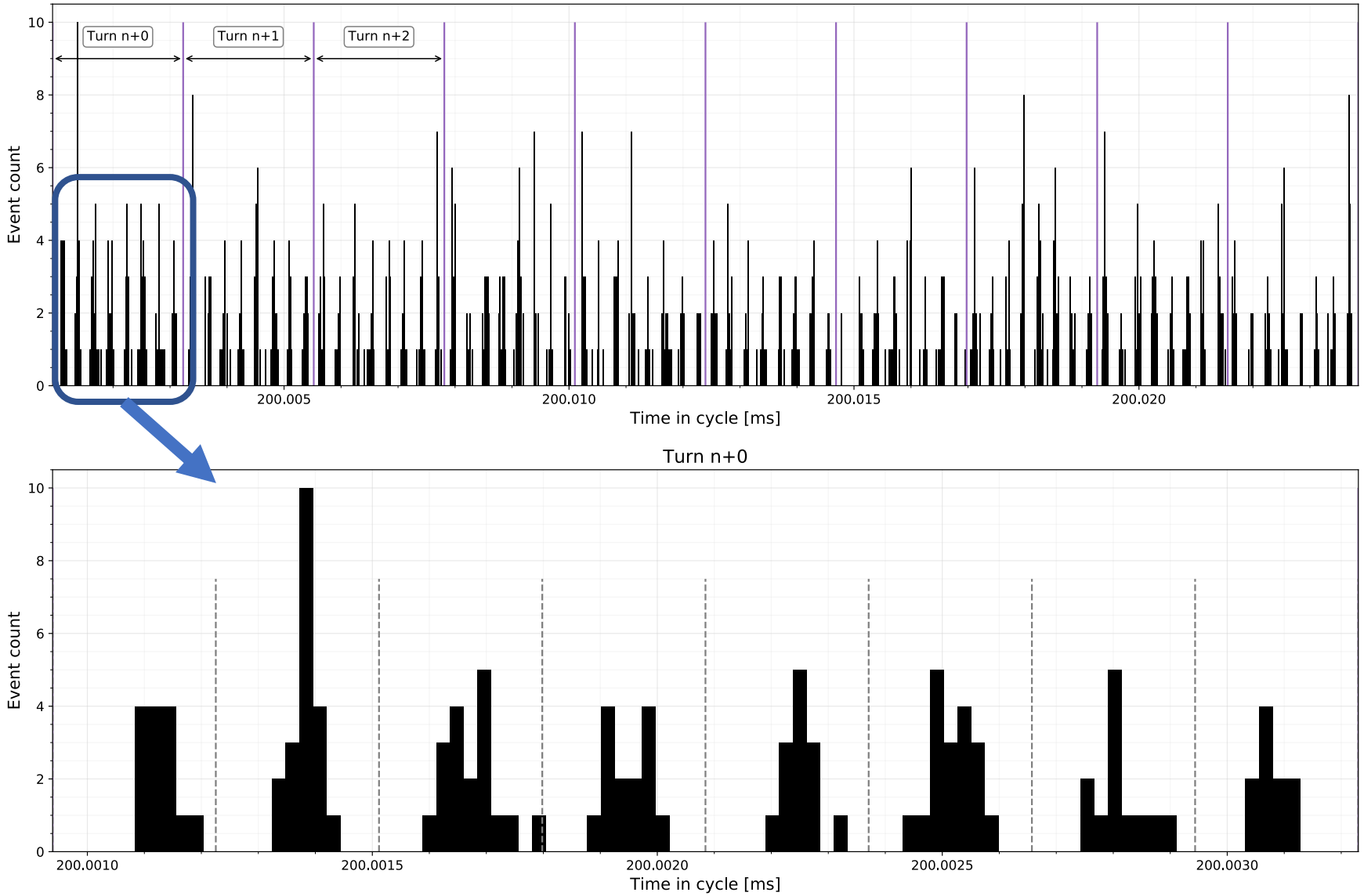
IPM:
0.184 oscillations per turn

SEM-grid measurement[1]:
0.182 oscillations per turn

Good agreement

[1] M. A. Fraser *et al.*, "Matching Studies Between CERN PSB and PS Through Multi-Turn Beam Profile Acquisitions", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 2367–2370. doi:10. 18429/JACoW-IPAC2019-WEPMP025

Multi bunch turn-by-turn measurements



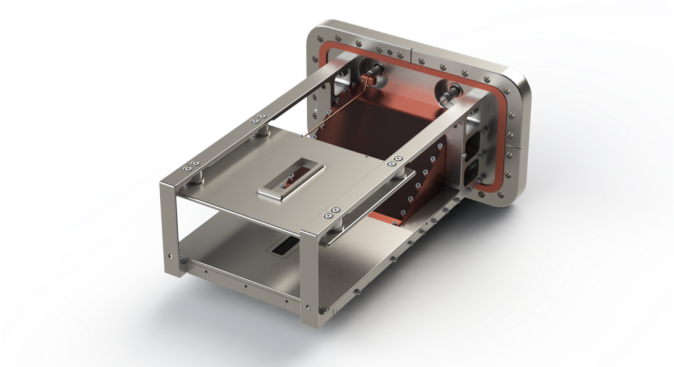
~ 15 electrons per bunch per turn

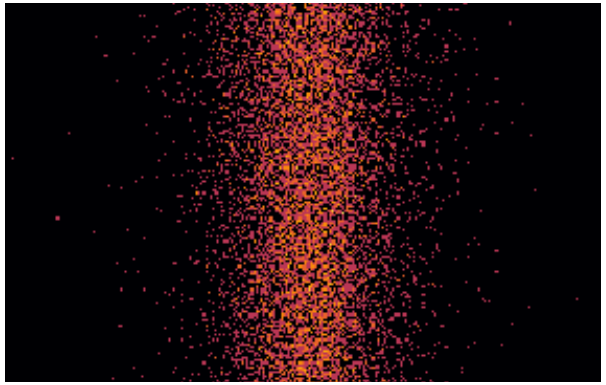
Not enough...

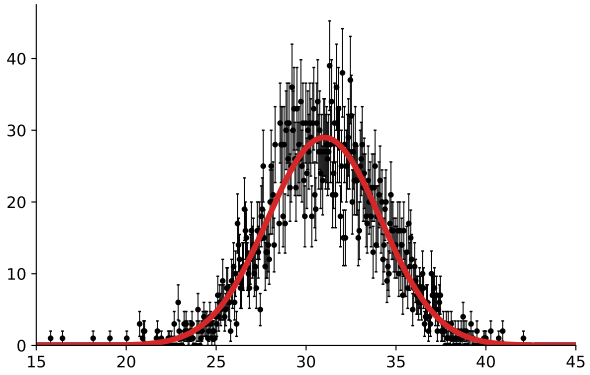
Gas injection needed

Summary

- Beam gas Ionisation Profile Monitor (IPM) using pixel detectors is a powerful and useful beam instrumentation
- Simulation framework developed for IPM instruments allows rigorous understanding of limitations
- Enables non-destructive beam profile monitoring throughout the full cycle
- Turn-by-turn at injection useful for commissioning as matching monitor
  - Gas injection recommended to get more signal and more precise measurement







Thank you for your attention!