Measuring the Beam Profile by Counting Ionization Electrons

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Hampus Sandberg (CERN, University of Manchester UK)

B. Dehning, D. Bodart, G. Schneider, J.W. Storey, R. Veness (CERN, Switzerland), W. Bertsche (University of Manchester, Cockcroft Institute, UK), S. Gibson, S. Levasseur (Royal Holloway, University of London, UK), K. Satou (J-PARC/KEK, Japan)

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

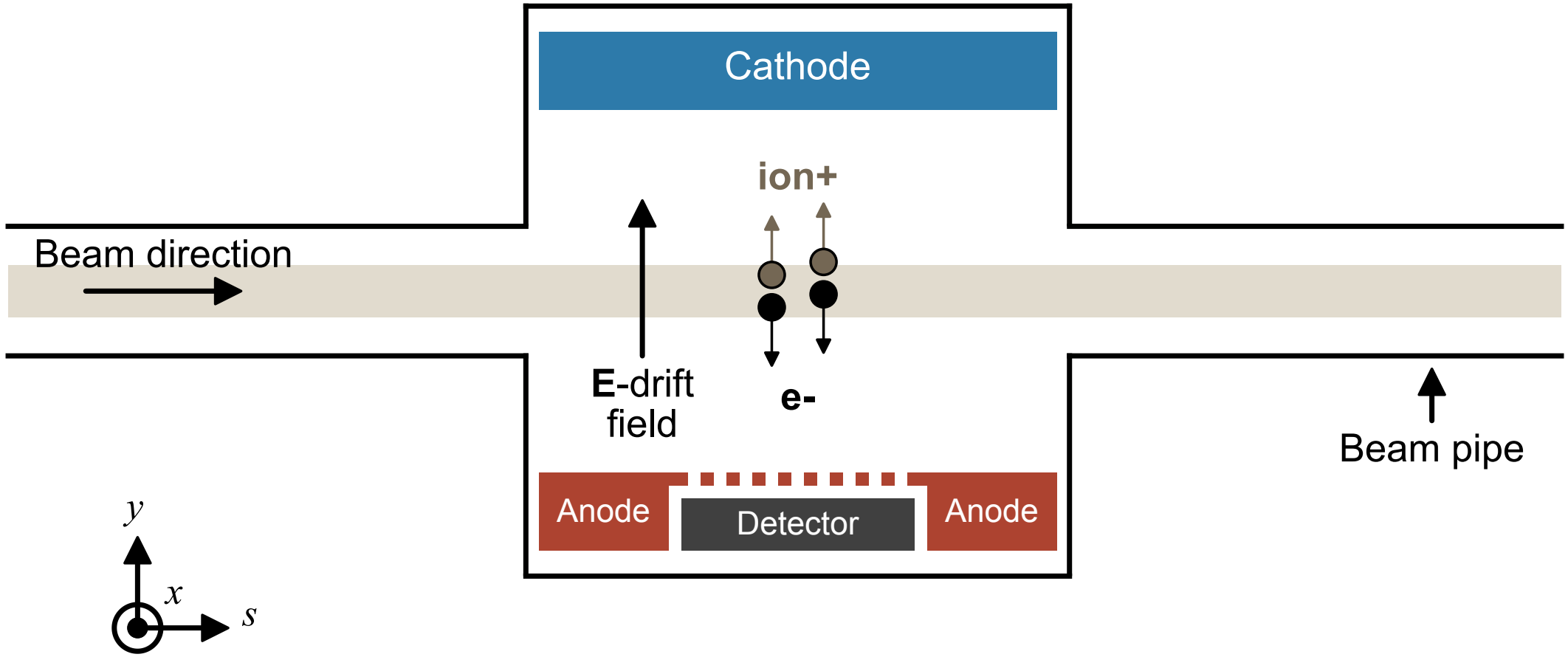
Motivation

Turn-by-turn,

non-invasive

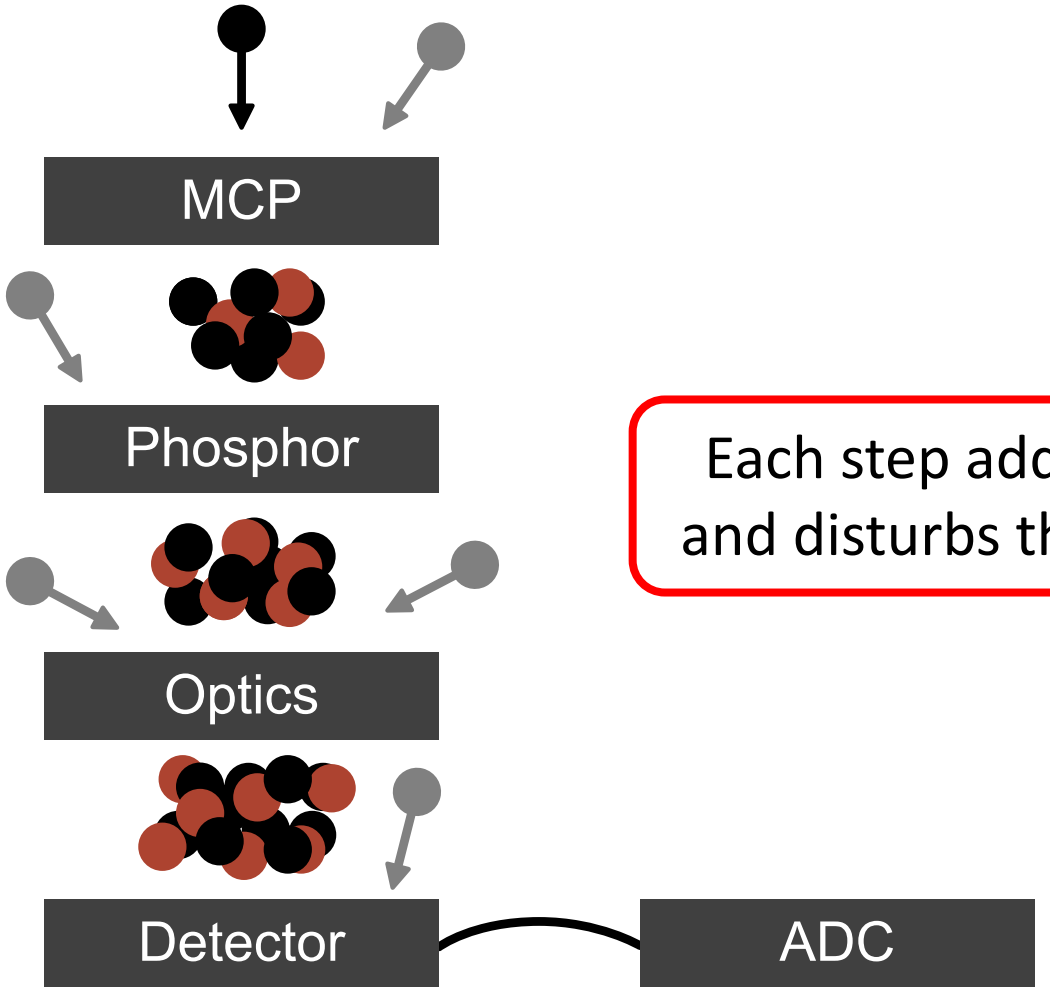
beam profile measurements

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



Example of Traditional IPM

Detected signal
≠
original signal



Each step adds noise and disturbs the signal

IPM with Hybrid Pixel Detector[1]

Direct detection of single ionization electrons

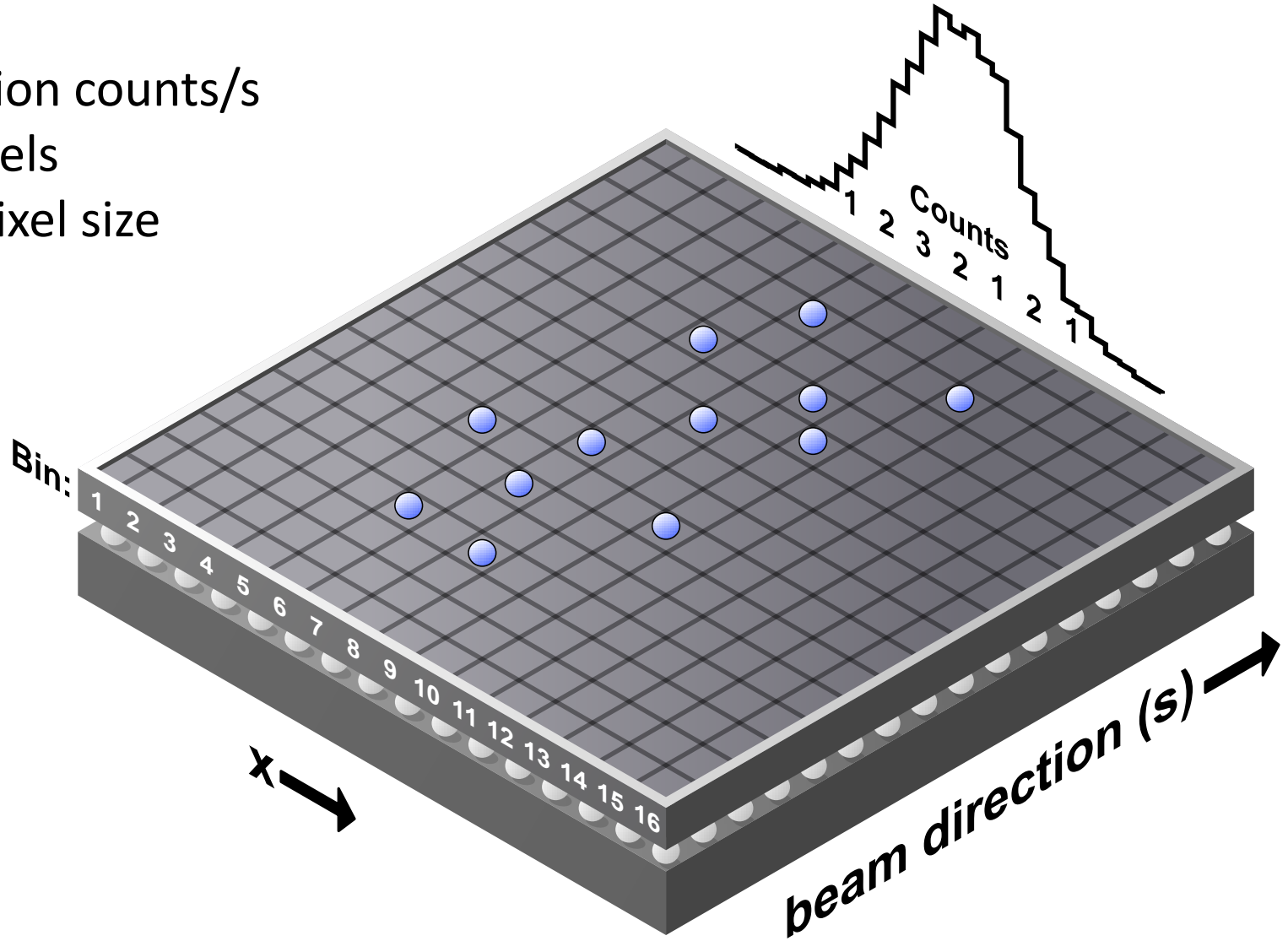
We can apply counting statistics

[1] S. Levasseur *et al.*, "Time-Resolved Transverse Beam Profile Measurements with a Rest Gas Ionisation Profile Monitor Based on Hybrid Pixel Detectors", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 2361–2364. doi:10.18429/ JACoW-IPAC2018-WEPAL075

Hybrid pixel detector to binned profile

Timepix3[2]

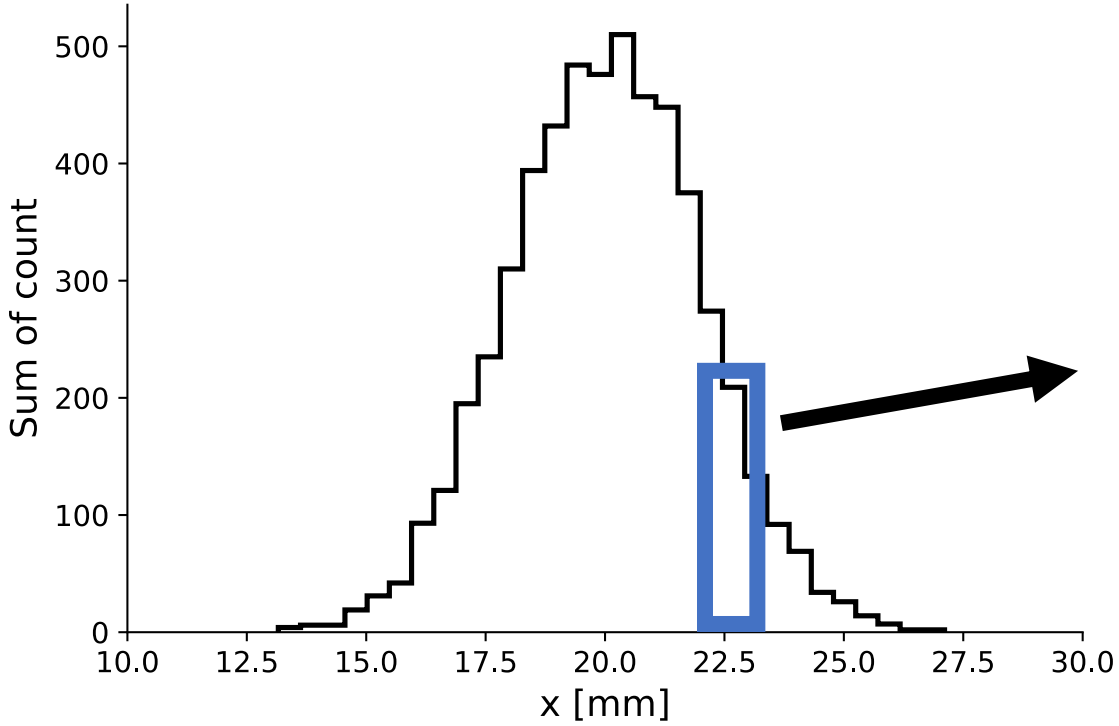
- Up to 80 million counts/s
- 256 x 256 pixels
- 55 x 55 µm pixel size
- 14 x 14 mm



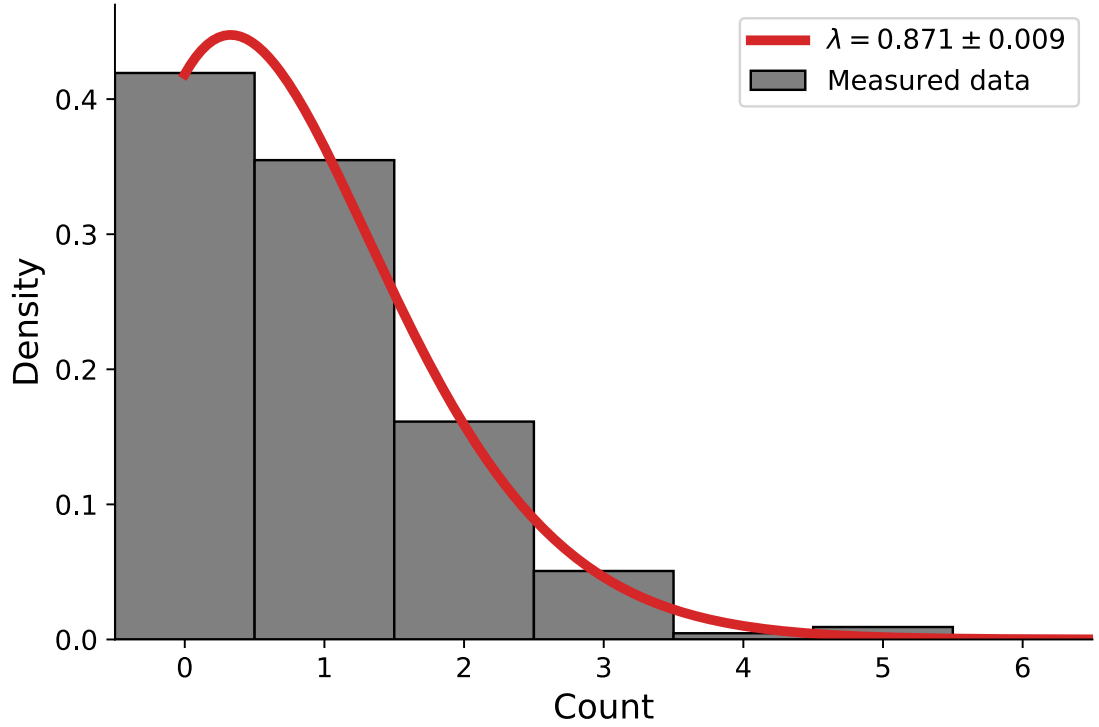
[2] https://medipix.web.cern.ch/technology-chip/timepix3-chip

Counting Statistics - Poisson process

Sum of counts for all columns (bins)

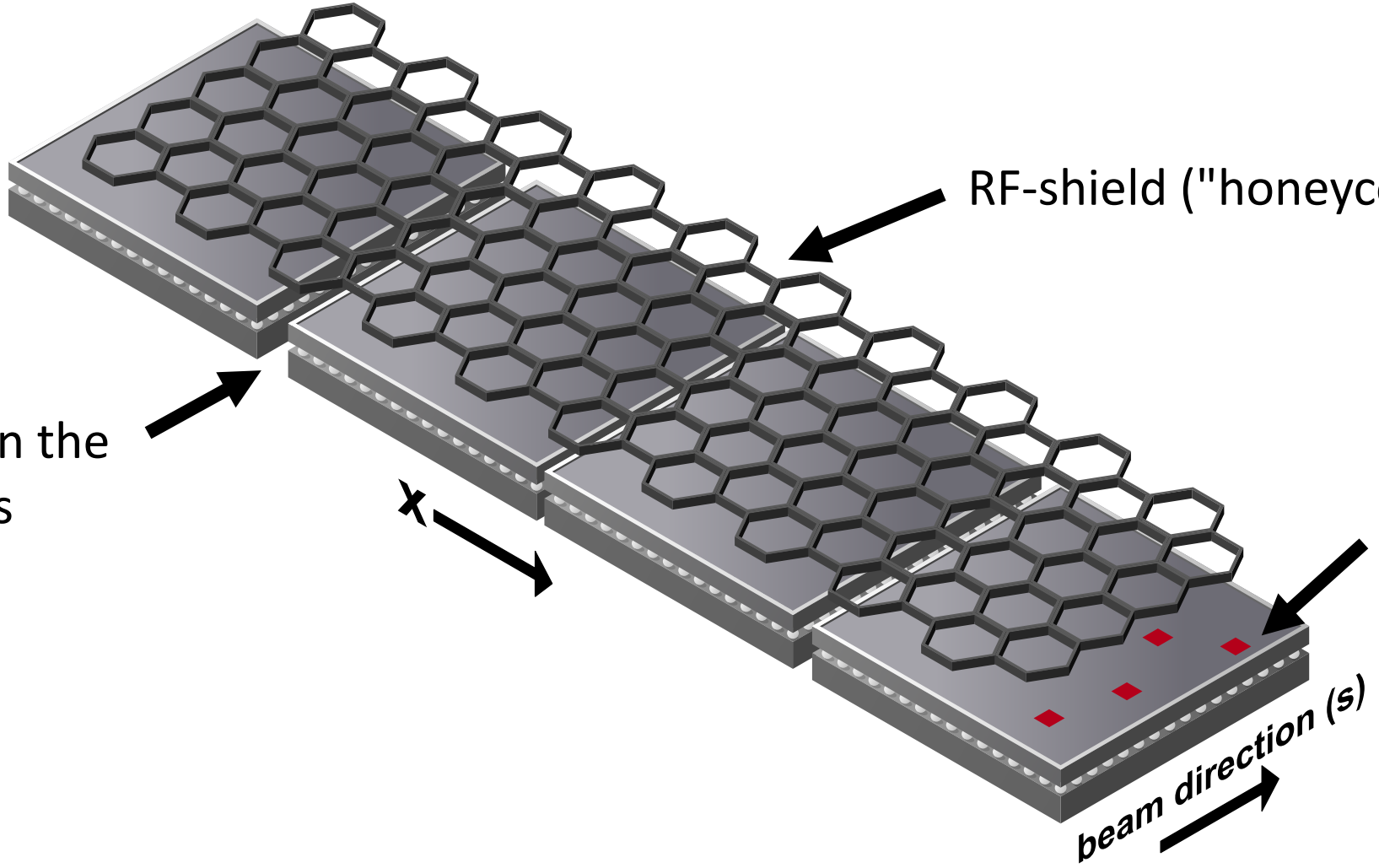


Distribution of counts in a single column (bin)



Counts in each bin can be modeled as a Poisson process

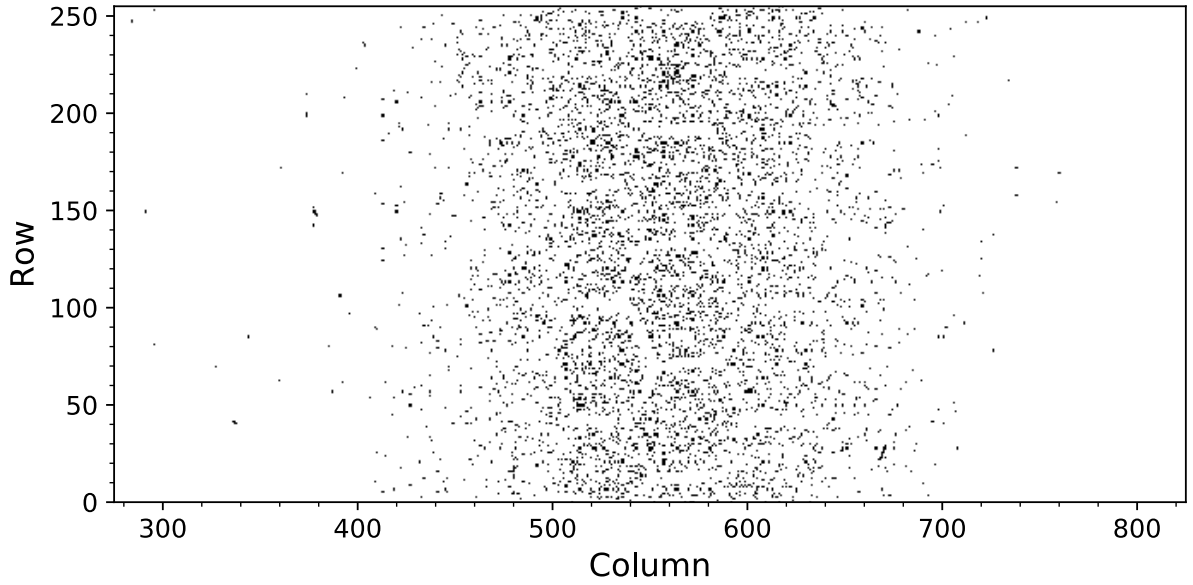
IPM with pixel detectors - things to correct for



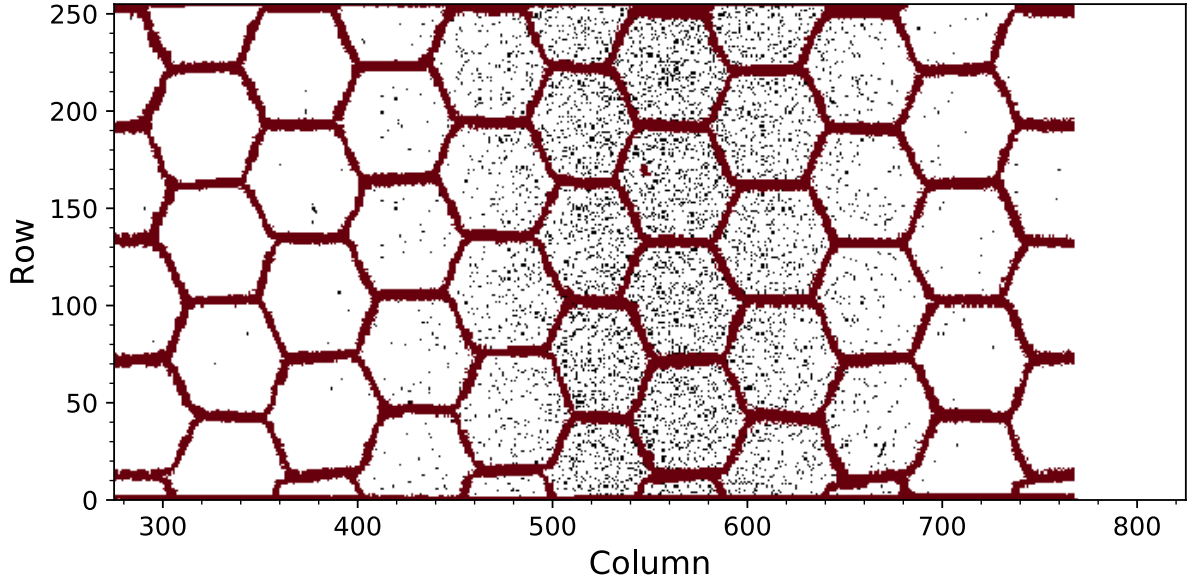
Pixels under RF-shield + noisy pixels = unresponsive pixels

Has to be removed to ensure a known average rate in each bin

Data processing steps

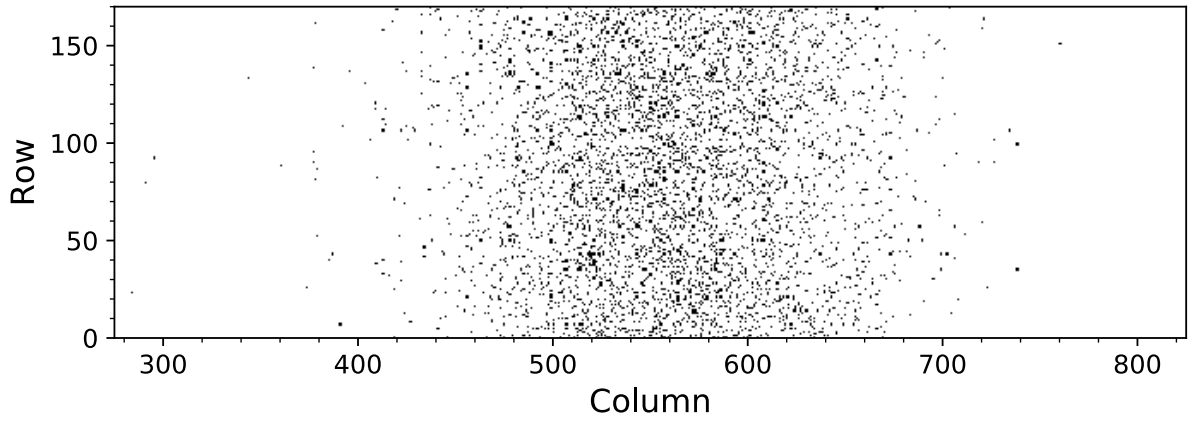


1.
Raw data from the pixel detectors

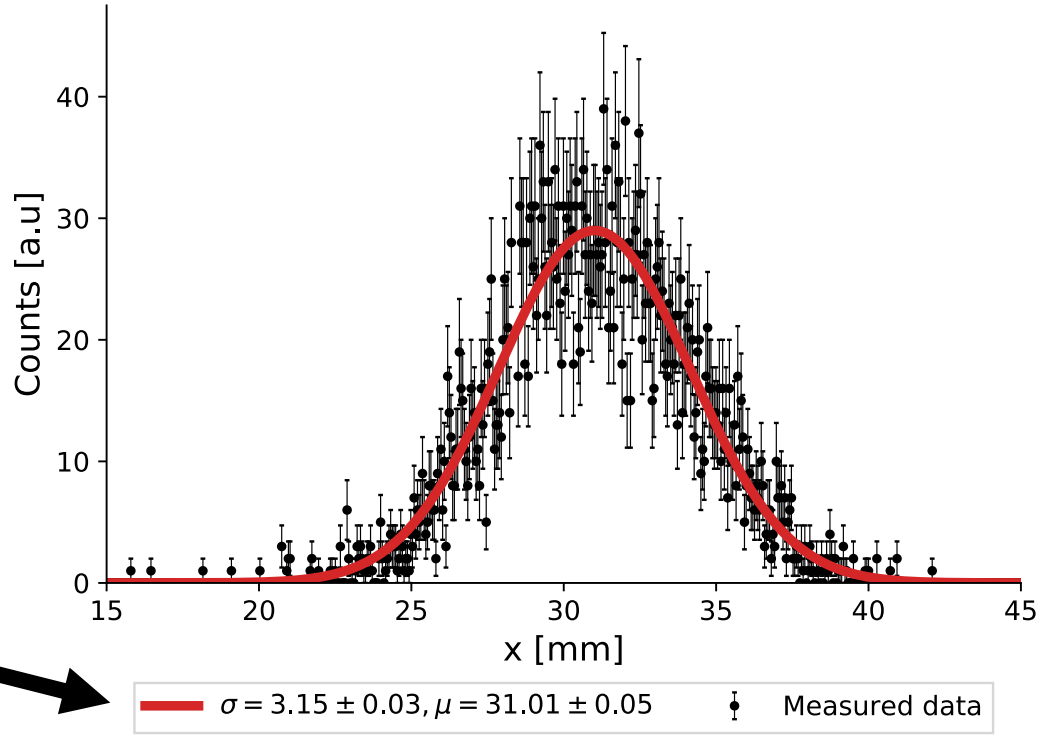


2.
Mark unresponsive pixels

Data processing steps



3.
Remove unresponsive pixels

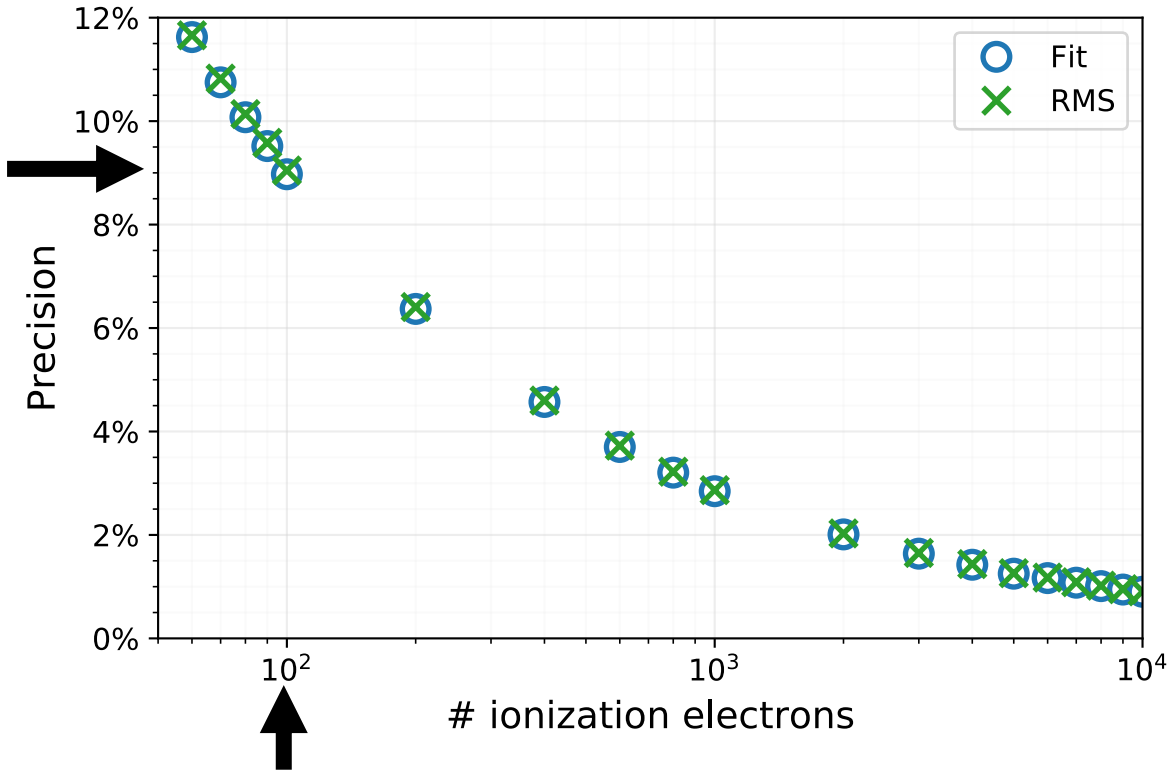


4.
Compute beam profile by taking sum of counts in each column

Binned maximum likelihood fit

Precision - Monte Carlo simulation

- How much spread do we expect in the measured value?
- 10 000 simulated profiles for each case

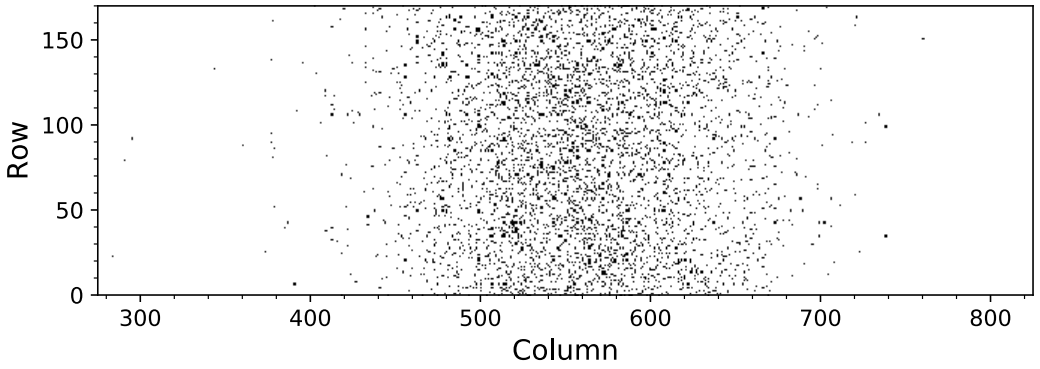


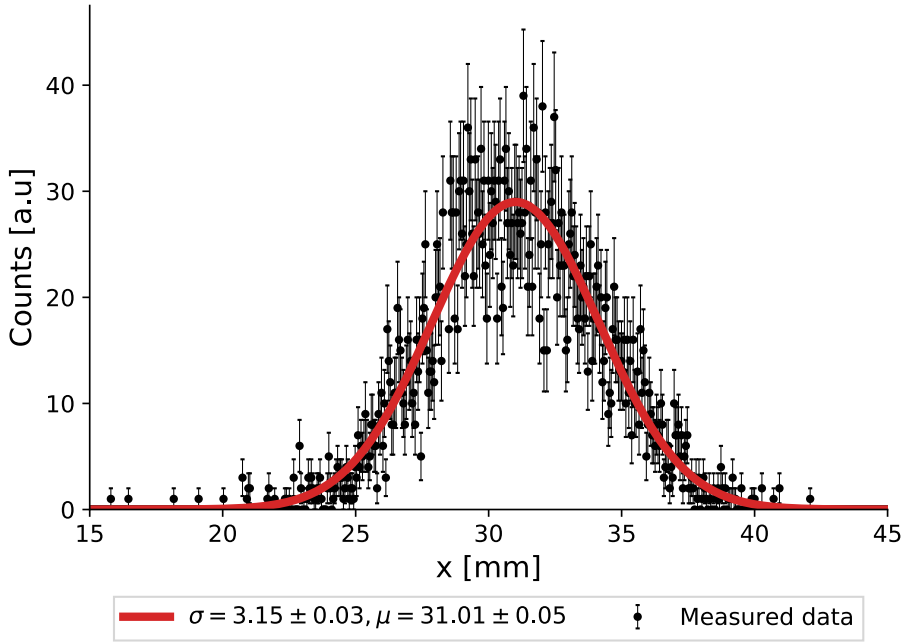
9% expected precision for 100 ionization electrons

1% precision requires > 5000

Beam profile measurement - example data shown earlier

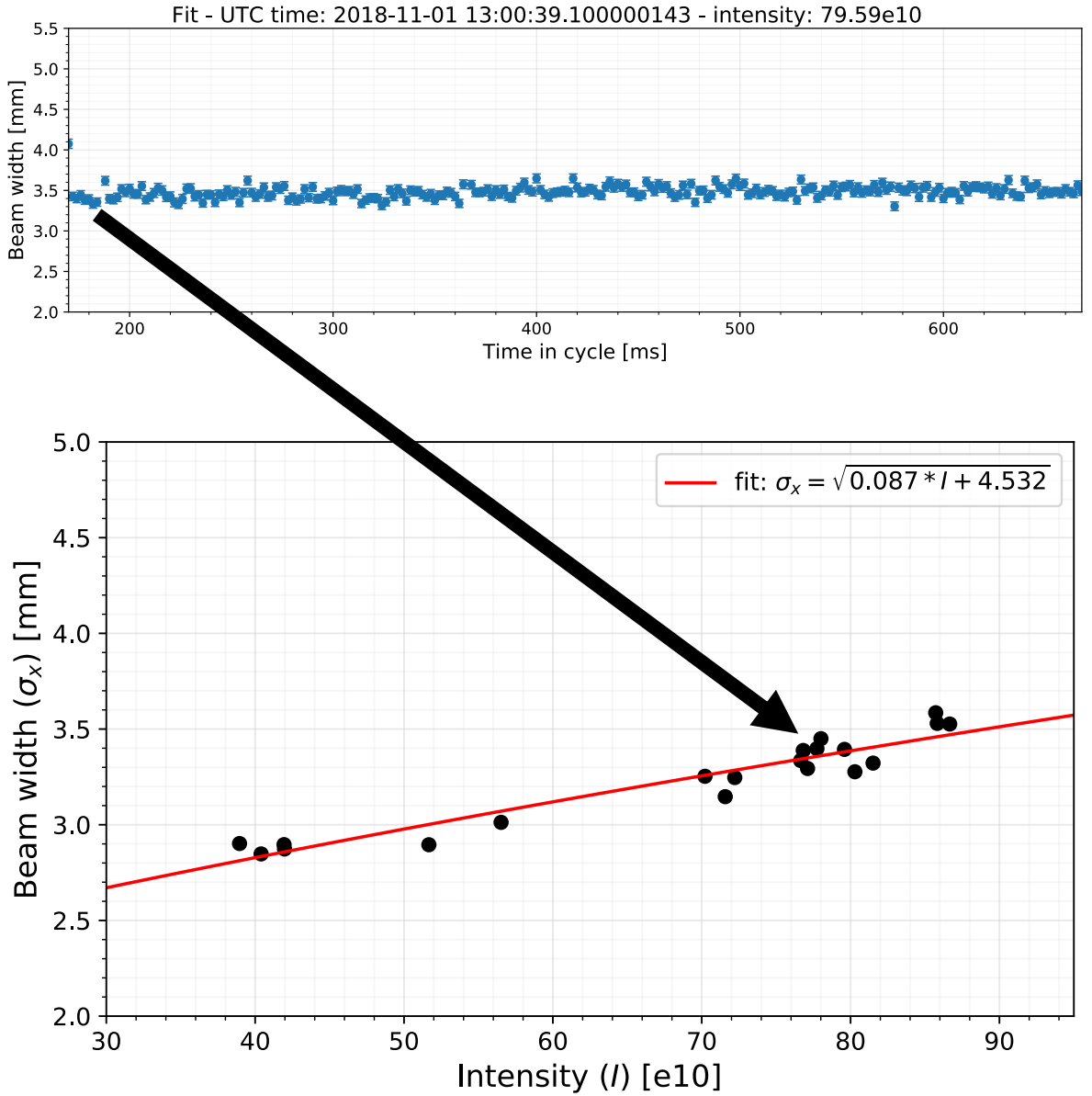
- @ CERN Proton Synchrotron
- Horizontal pixel IPM instrument
- Intensity: 60e10 protons
- Vacuum: 1e-10 mbar
- 5 ms gives 5500 ionization electrons





Brightness curve

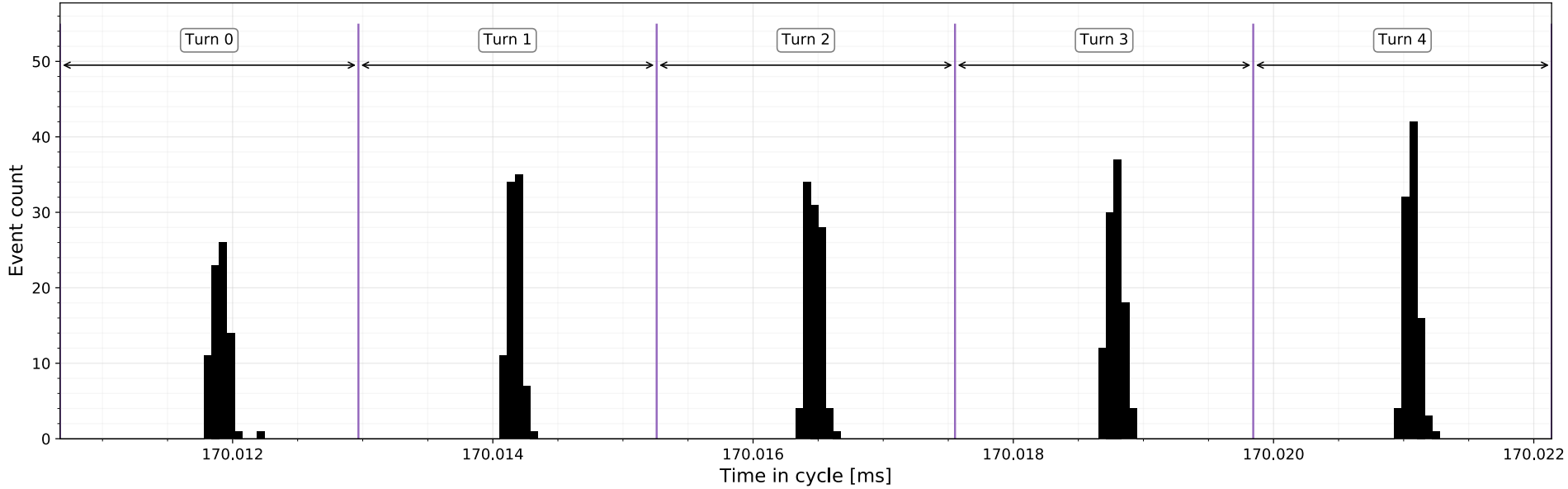
- 20 cycles with varying intensities
  - 40e10 to 85e10 protons
  - 1000 to 2500 ionization electrons
- Vacuum: 1e-10 mbar
- 2 ms time window
- Beam width for each intensity shown on the right at 180 ms in the cycle



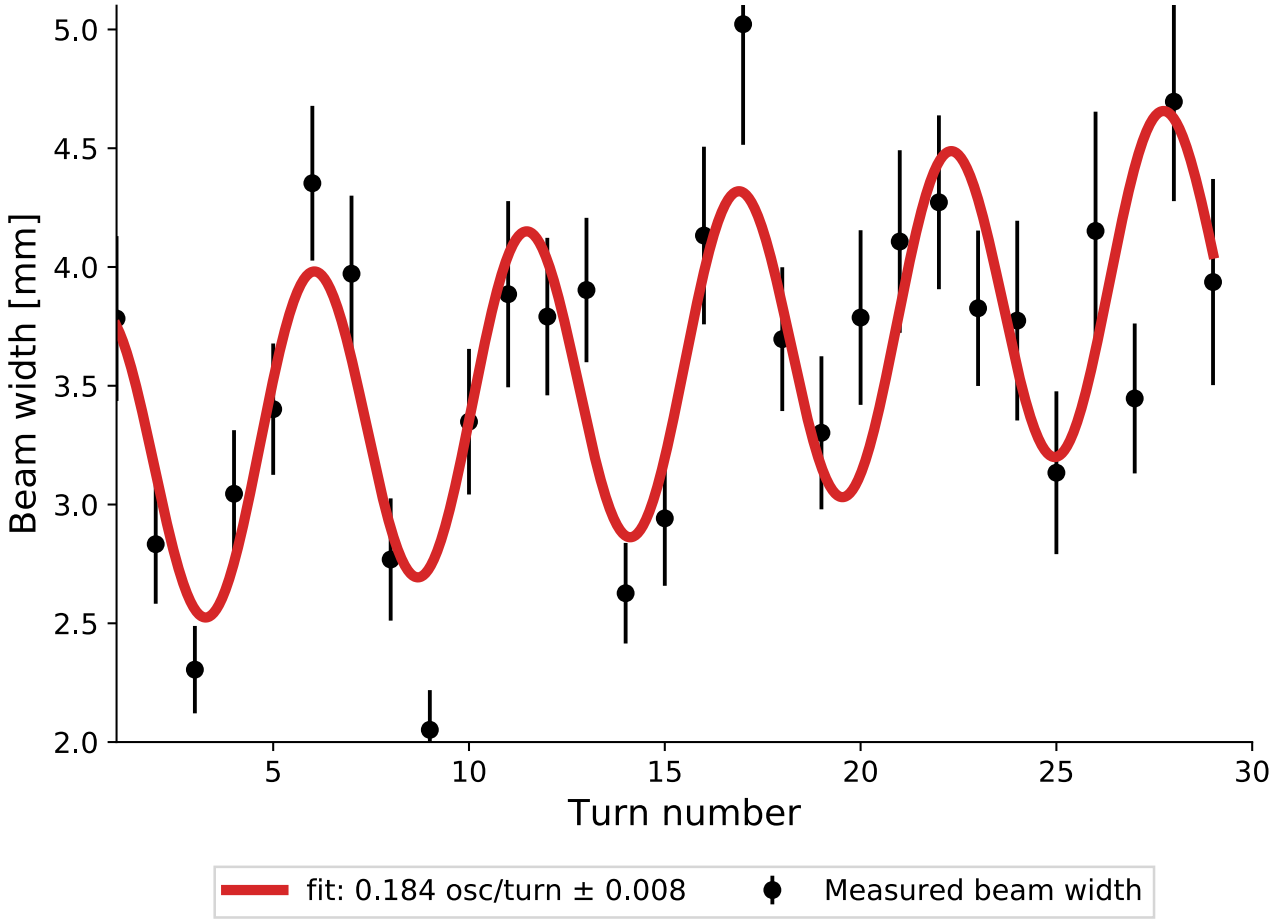
Turn-by-turn measurements at injection

- 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 measurements at injection



IPM:
0.184 oscillations per turn

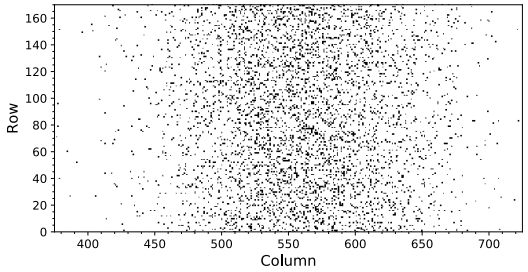
SEM-grid measurement[3]:
0.182 oscillations per turn

Good agreement

[3] 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

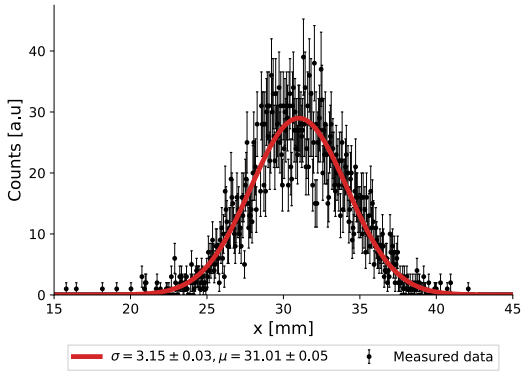
Conclusion

- Hybrid pixel detectors enables **detecting and counting** individual ionization electrons
  - Allows application of counting statistics
  - Each bin modeled as a Poisson process
  - Binned maximum likelihood fit



- Removal of unwanted:
  - noisy pixels
  - pixels under the RF-shield

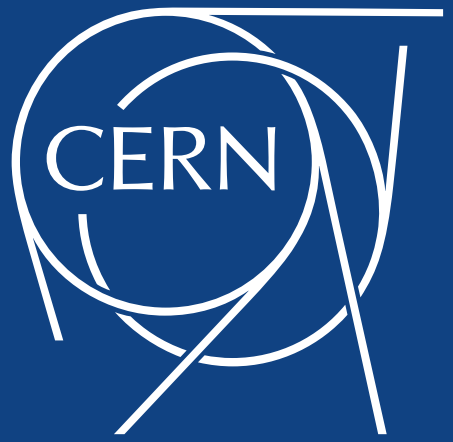
- Monte Carlo simulation used for validation and expected precision



- Beam profile measurements
  - Single 5 ms beam profile
  - Brightness curve
  - Turn-by-turn at injection in good agreement with independent SEM-grid measurements

A meaningful beam profile can be extracted from only 100 ionization electrons

Thank you for your attention!



Acknowledgements: M. A. Fraser, A. Huschauer

Extra information

How do we know if it's a good fit?

- No simple analytical expression

- Run Toy Monte Carlo Simulations
  - Known beam width
  - Known sample size (i.e. number of ionization electrons)
  - Store calculated likelihood value for a range of width and sample size combinations
  - One simulation run seen on the right

- Fit to measured data
  - Is this likelihood value within the simulated range?
  - If not, calculate an RMS beam width instead