Beam profile measurements based on pixel detectors in the PS

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On behalf of the CERN BE-BI BGI team:
Hampus Sandberg (CERN, University of Manchester UK)
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
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/

±2% beam width error
Measurements of beam size vs. magnetic field strength in the PS

Prediction:
Virtual-IPM predicts B-field of \textbf{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 \sim 0.06 \text{T}
Reasonable agreement with Virtual-IPM prediction

No distortion for B > \sim 0.06 \text{T}
• **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

Beam parameters:
- LHC Indiv (single bunch cycle for the LHC)
- Intensity = $10.8 \times 10^{10}$ protons
- Vacuum = $6.3 \times 10^{-10}$ mbar
Video of partially stripped lead ion beam

Beam parameters:
- ILHC200#2b_2018_partial_strip
- Intensity = $8.9 \times 10^{10}$
- Vacuum = $9.8 \times 10^{-11}$ 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

Evolution of the beam profile in the cycle

Beam parameters:
- LHC25_48b_BCMS_PS
- Intensity = $2.82 \times 10^{10}$
- Vacuum = $4.7 \times 10^{-11}$ mbar

RF manipulations
- Batch Compression
- Merging
- Splitting
- $\Rightarrow$ BCMS

Adiabatic shrinkage of the beam size during acceleration
Evolution of the beam profile - multiple cycles

Consistent measurements for a stable beam
Oscillations during transition crossing

Beam parameters:
- ILHC100_4b (Pb54 ion beam)
- Intensity = $5.26 \times 10^{10}$
- Vacuum = $5.4 \times 10^{-11}$ mbar

Transition crossing at around 975 ms
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**

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!