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An Investigation into the Behaviour of Residual Gas Ionisation Profile Monitors in the ISIS Extracted Beamline

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Introduction and Motivation

- Fast, non-destructive beam profile measurements at ISIS are performed using Multi-Channel Profile Monitors (MCPMs), utilising residual gas ionisation to measure beam profile.
- Non-uniform transverse and longitudinal electric fields within these monitors cause errors in the profile measurement, which need to be understood and corrected for.
- Simulations of the profiles obtained by this monitor are performed using CST EM Studio, a simple C++ particle tracking code and an IDL post processing code.
- To allow for simulation benchmarking and studies of the monitor's error mechanisms, an MCPM was placed in Extracted Proton Beamline 1 (EPB1), where the beam is well defined.

Simulation Model

To allow for detailed studies of the monitor's internal behaviour, a simulation model has been developed to calculate residual gas ion trajectories and the associated beam profile measurement by the MCPM.

1) Electric Field Calculation (CST EM Studio 2016)

- CST EM Studio 2016 is used to calculate the electric field within the monitor.

2) Ion Tracking (C++)

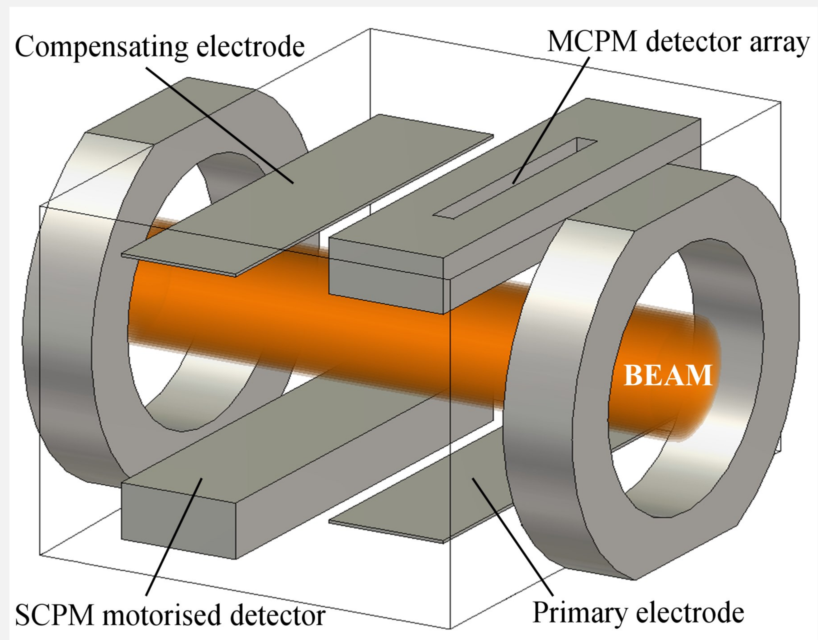
- Ion acceleration is calculated from the Lorentz force applied by the E-field.
- Kinematic equations of motion are solved with a second order Euler method, in time steps of 1 ns, to move the ions through the monitor.
- Final positions of ions that travel into the detector array are recalculated precisely.

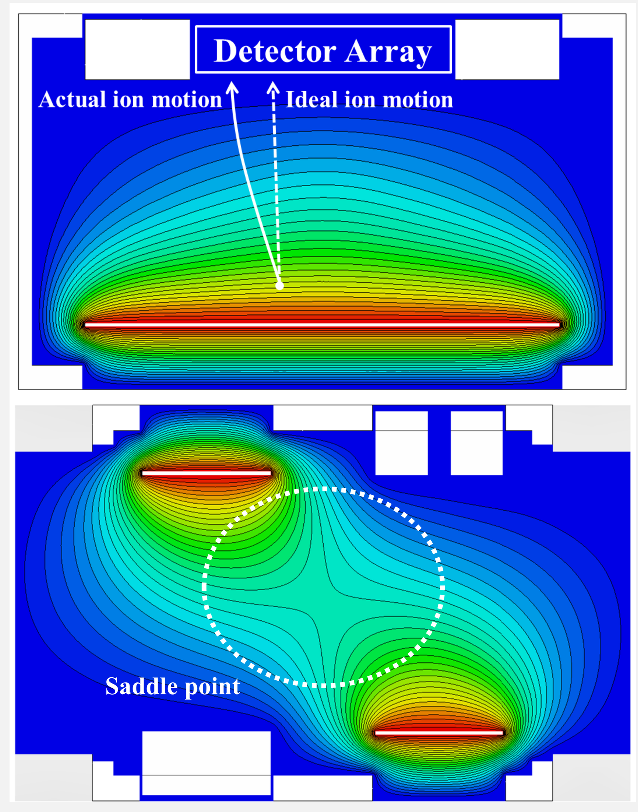
3) Post Processing (IDL)

- Quantities of ions travelling into each Channeltron within the MCPM detector array are used to generate a simulated profile measurement.
- A weighting is applied to each ion, based on its initial position, to model the intensity distribution within the beam.
- A further detector weighting is applied to model the detection efficiency of the Channeltrons, which varies with the incident angle of ions (see below).

CST Model: Monitor Geometry and E-Fields

- CST EM Studio is used to calculate the monitor's internal electric field.
- The effect of space charge is included by modelling the beam as concentric charge distributions within the monitor.





Above: The CST model showing the layout of the monitor.
Right: Internal electrostatic potential distributions in the transverse (top) and longitudinal (bottom) planes.

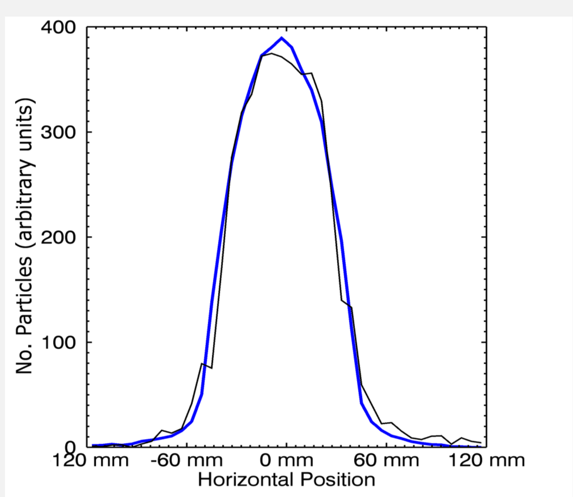
Main Sources of Measurement Error

- Non-uniform transverse E-field caused by the monitor's drift field and the beam's space charge causes artificial broadening of the measured profile.
- Longitudinal E-field distribution includes a saddle point in the monitor's centre, directing additional, unwanted, ions towards the detector array.

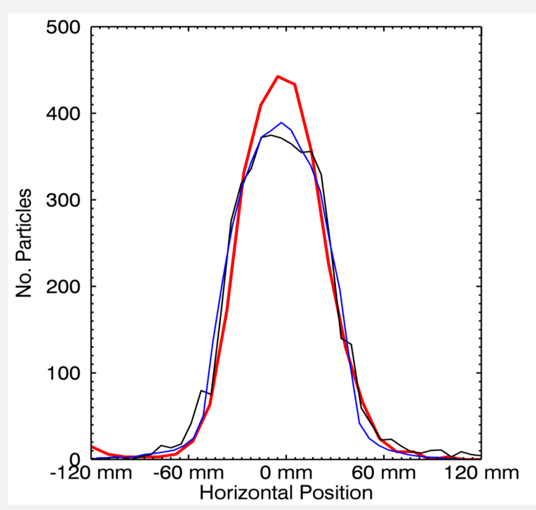
Simulation Results

Simulated vs. Measured Profiles

- Simulations give a close match to low intensity benchmarking measurements in EPB1, with 95% widths varying by <2 mm between simulation and measurement.
- This verifies the simulation, meaning it can be used to study the sources of error in detail, providing information that will be used to improve future monitor designs.
- In the EPB, nearby SEM grid monitors can be used to give a reliable profile for simulation input, showing the levels of artificial broadening measured by the MCPM.
- This allows tests to be carried out to verify the profile correction scheme currently used to account for this broadening.



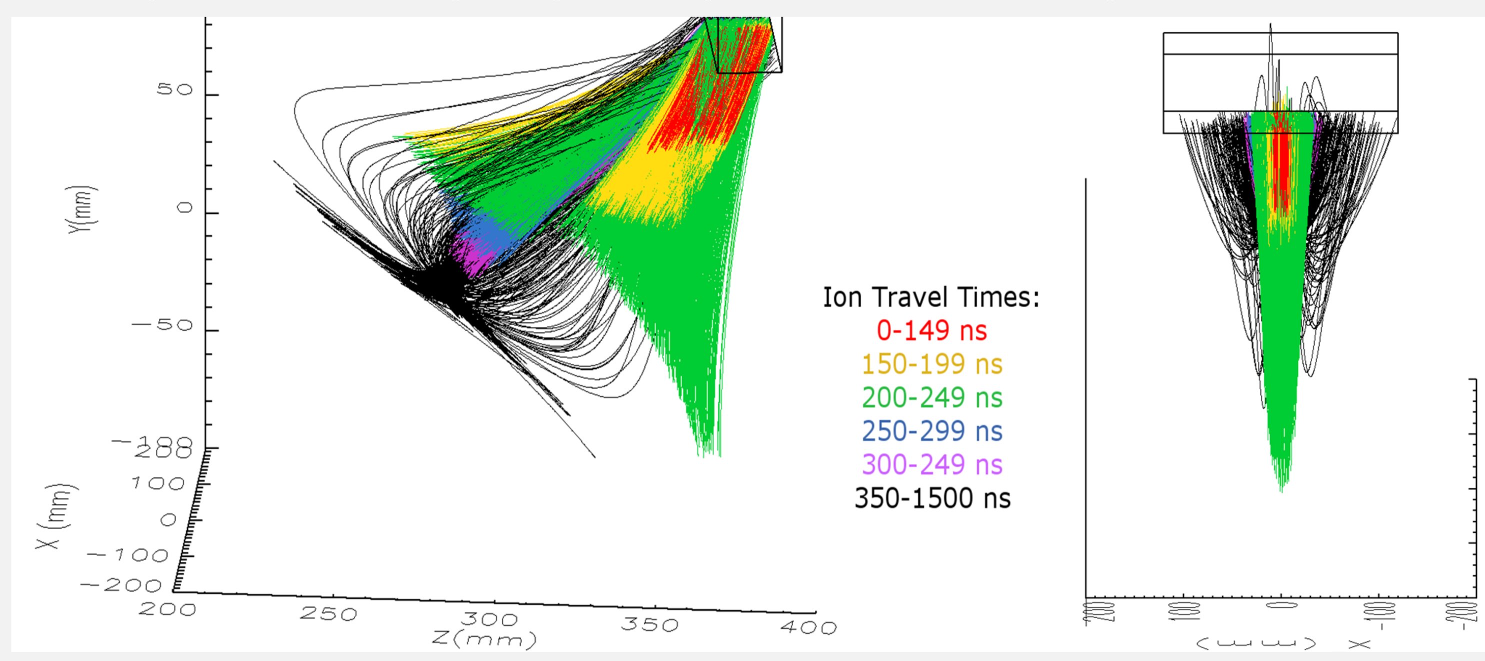
A comparison between a low intensity MCPM profile measurement (black) and the profile calculated by the simulation (blue).



EPB measurements allow the use of destructive SEM grid monitors to measure the true profile (red). A correction scheme is applied to MCPM measurements to account for the differences caused by the error mechanisms discussed here.

Ion Trajectories

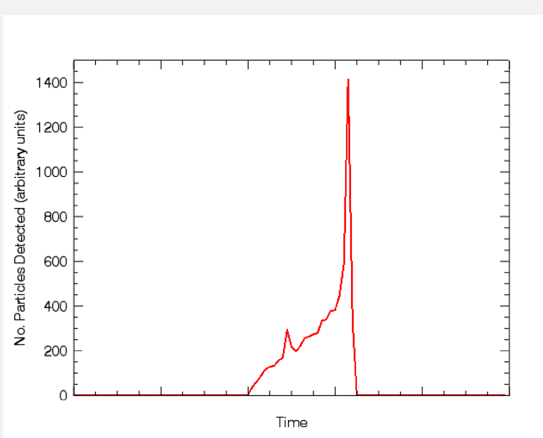
- The simulation shows the complex ion motion in the monitor.
- The broadening effects of the drift field and space charge are seen in the results.
- Extra ions from the saddle point in the monitor centre are directed into the detectors, with many of these taking irregular trajectories and causing extra profile broadening:



Trajectories of ions that travel into the MCPM detectors, shown in the longitudinal (left) and transverse (right) planes. In an ideal monitor ions would travel directly upwards into the detectors. The detector array is shown by the black box.

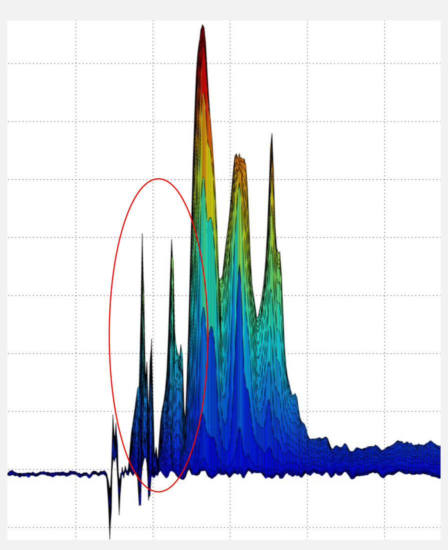
Ion Time Structure

- Measurements with a fast amplifier have been taken, providing alternative data for simulation benchmarking and the study of further broadening levels, which are seen only in the EPB.
- The compensating field was switched off to remove the effect of the saddle point, and reduce the overall time spread of the ion travel times.
- A large signal was detected *after* the bunches had left the monitor.
- This is currently assumed to be a splashback effect from the spallation target, and could explain why the MCPM measurements in the EPB are broader than those in the ring.



Left: The times at which ions created by a single bunch are detected, calculated in the simulation.

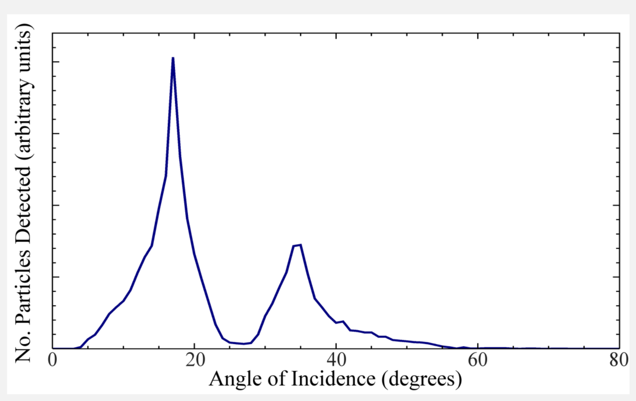
Right: Fast amplifier measurements recently taken in EPB 1. The time structure of the initial two peaks (circled) matches that seen in simulation, suggesting these are the ions created by the two proton bunches.

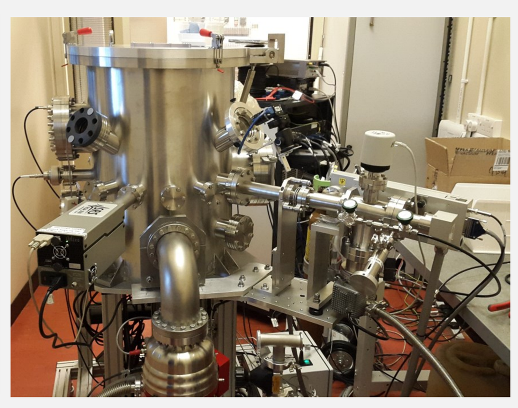


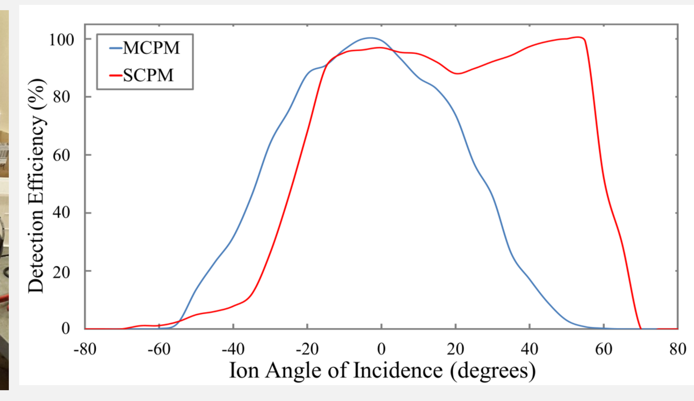
Ongoing Studies

Detector Characterisation

- Trajectory simulations show a large variation in incident angle of ions as they reach the Channeltron detector array.
- Tests carried out in a laboratory vacuum tank on the Channeltrons showed significant variation of ion detection efficiency with angle of incidence.
- The irregular characterisation results have led to the inclusion of a *detector weighting* in the simulation to take this behaviour into account.
- The vacuum tank and channeltron test assembly will be used to test alterations to future monitors, with the aim of preventing high angle saddle point ions reaching the detectors.







Left: Quantities of ions arriving at the Channeltrons at different angles of incidence, as calculated in the simulation.
Centre: The vacuum tank test setup, with the ion gun shown on the right of the vessel.
Right: The experimentally measured variation in Channeltron detection efficiencies with ion angle of incidence.

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