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Studies of the Time Structure of Ionisation Beam Profile Measurements in the ISIS Extracted Proton Beamline

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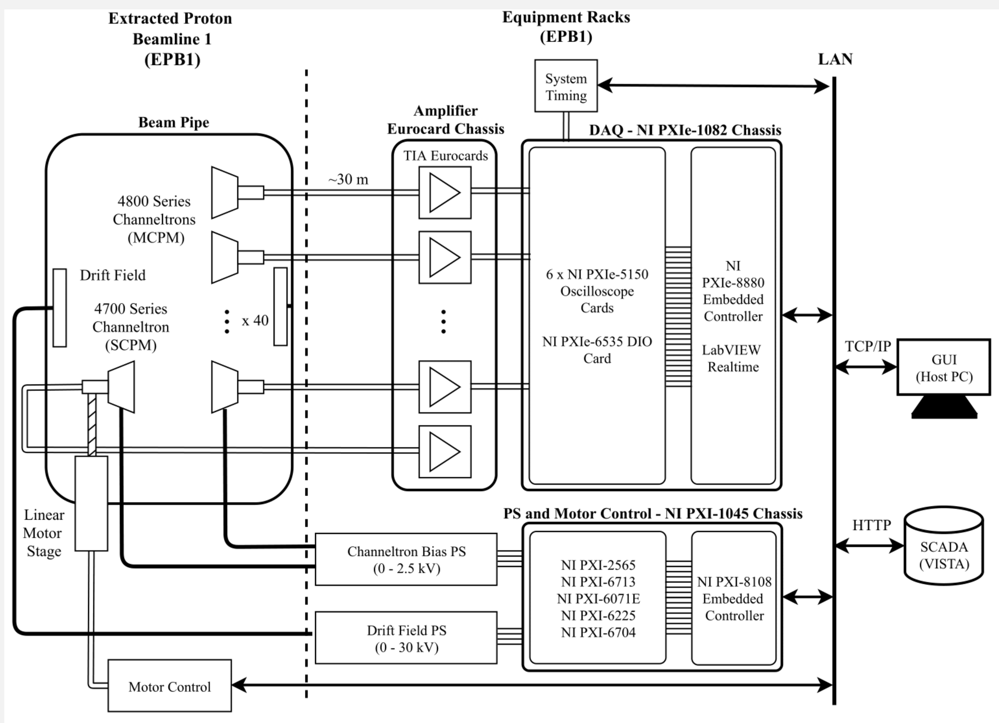
Introduction

- Ionisation Profile Monitors (IPMs) are used at the ISIS neutron and muon source to perform non-destructive transverse beam profile measurements. To allow for detailed benchmarking studies, a test IPM was installed in Extracted Proton Beamline 1 (EPB1), enabling measurements of a single two-bunch beam pulse and comparison with secondary emission (SEM) grid measurements.
- An in-house particle tracking code, combined with electric field maps calculated with CST, is used to study the sources of error in these monitors.
- To provide detailed benchmarking data for the simulation, new high-speed multi-channel data acquisition electronics have been developed for the EPB1 IPM.
- Studies of the measured time structure within each profile measurement have been performed, and compared with the IPM simulation code.

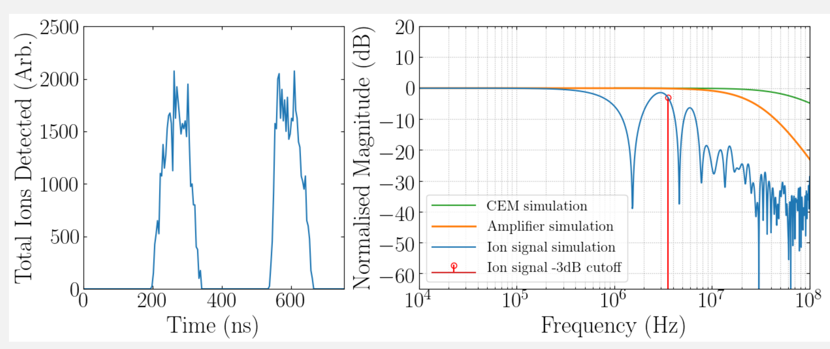
Data Acquisition System

Electronics

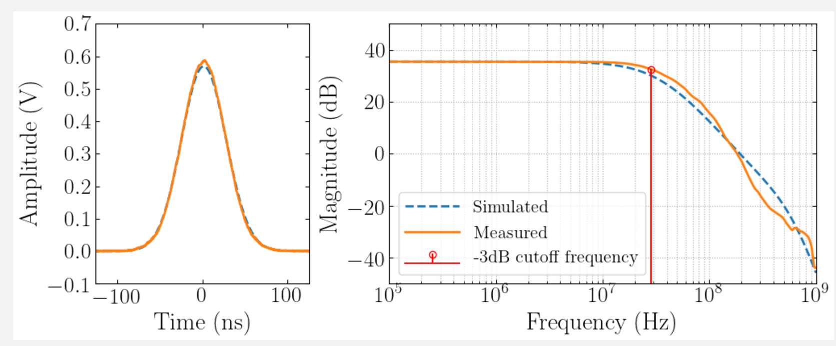
- The data acquisition (DAQ) system consists of 41 channels, each including a Channeltron (CEM), custom transimpedance amplifiers (TIAs) and National Instruments (NI) PXIe-5105 digitisers.
- Each custom amplifier channel contains existing 7 kHz ISIS IPM amplifiers and new 30 MHz amplifiers, including the required relay switching circuits controlled from a single PXIe-6535 digital I/O card.
- A custom timing unit is used to synchronise the DAQ to the EPB1 extraction rate, with each channel sampled at 60 MS/s over a configurable time interval, typically 20 µs.
- If required, the data is then averaged over multiple machine cycles and sent over the ISIS network to a host PC via TCP/IP.



A block diagram of the IPM DAQ system in the ISIS EPB1.



(Left) Simulation of H+ ion arrival at the CEMs in EPB1. (Right) Simulated CEM and amplifier frequency responses compared with the ion signal spectrum.



(Left) Response of the new amplifiers to a 100 ns, 10 mV Gaussian pulse. (Right) the corresponding frequency response.

Detectors

- An array of 40 Channeltron electron multipliers (CEMs) are used to detect and amplify the residual ion signal.
- Each CEM has an adjustable gain, controlled by its applied bias voltage.
- An additional motorised CEM is used to measure gain variations between individual CEMs. A calibration routine is applied to normalise these.

A single 4800 series Channeltron detector.

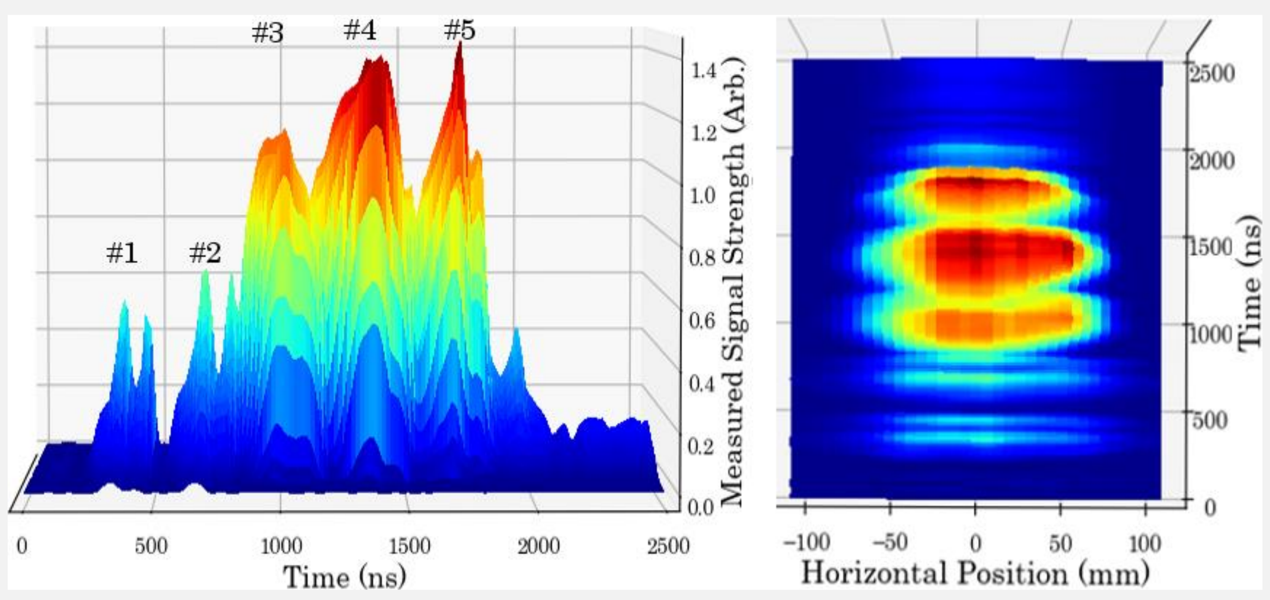
DAQ Software

- LabVIEW software is used for signal processing, analysis, logging and visualisation.
- Baseline restoration, background removal and remote amplifier selection is implemented.
- Networked control of the drift field, CEM bias power supplies and motorised CEM is enabled via the ISIS Control System, VISTA Vsystem.

IPM Measurements - Time Structure Analysis

Profile Measurement Time Structure

- During a measurement, two 100 ns bunches, separated by 225 ns, pass through the IPM.
- However, the measured time structure is more complicated, containing multiple peaks spread out over 1-4 µs (depending on drift field strength).
- Channeltron gain, drift field strength and beam intensity affect the relative peak amplitudes and separation.
- These peaks are grouped into 5 main peaks (see figure), though there are additional smaller peaks visible in some measurements.



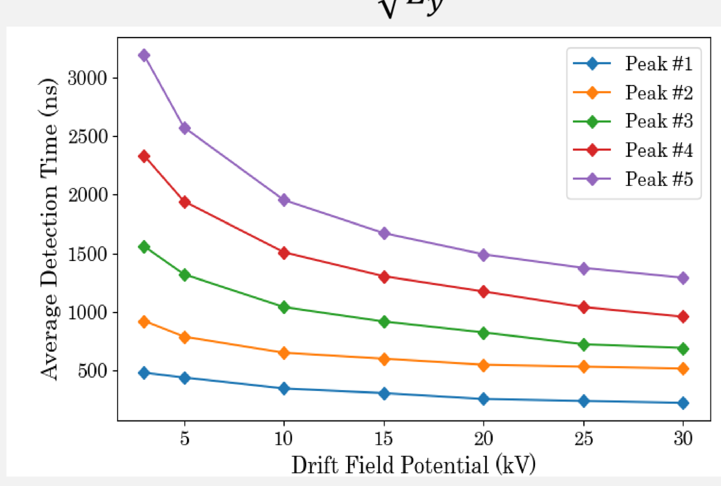
The time structure of an IPM measurement, taken with a 15 kV drift field and Channeltron bias of -1.5 kV, showing the multiple peak structure.

Varying Drift Field Strengths

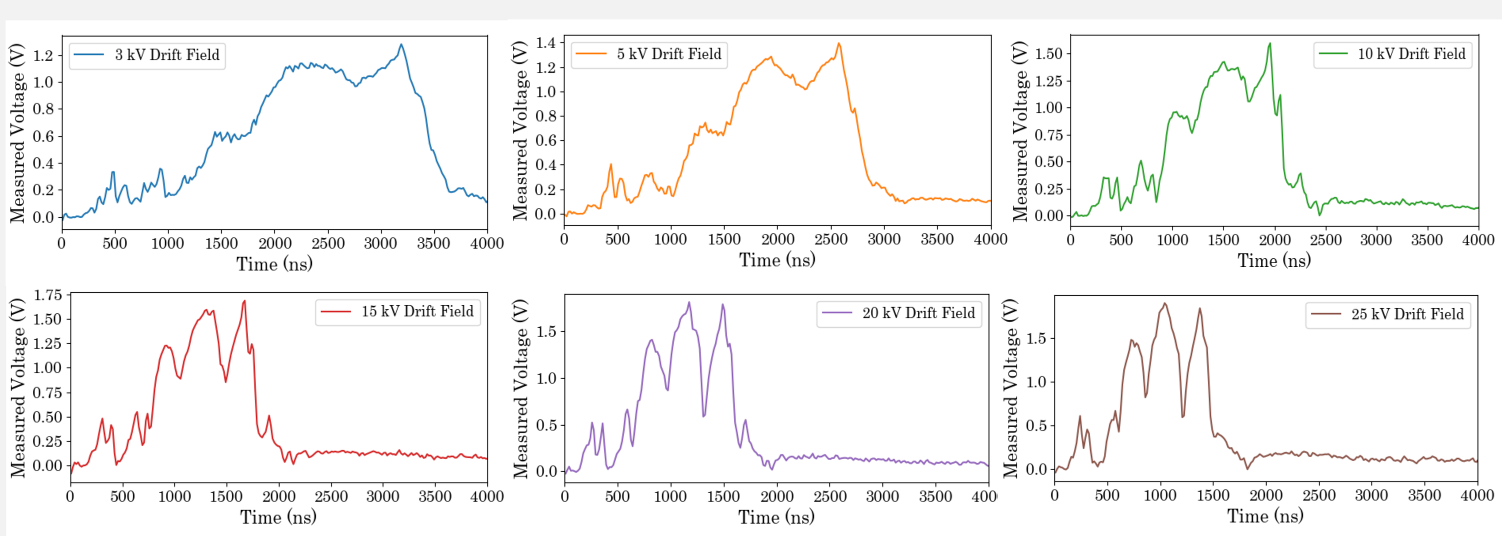
- Particle tracking simulations showed the multiple peaks could be made by different species of ions, generated by each bunch ionising various elements present in the EPB1 beampipe vacuum's residual gas.
- This was verified by studying the effect of varying the IPM drift field.
- Residual ion detection times should decrease proportionally to the inverse square root of the drift field as it is increased (neglecting the space charge effects), while noise detection times would be unaffected.
- This relationship held true for all five peaks in the signal.

$$\text{Ion Detection Time} = \sqrt{\left(\frac{2lm}{qE_y}\right)}$$

$$\therefore\ t \ \alpha\ \frac{1}{\sqrt{E_y}}$$



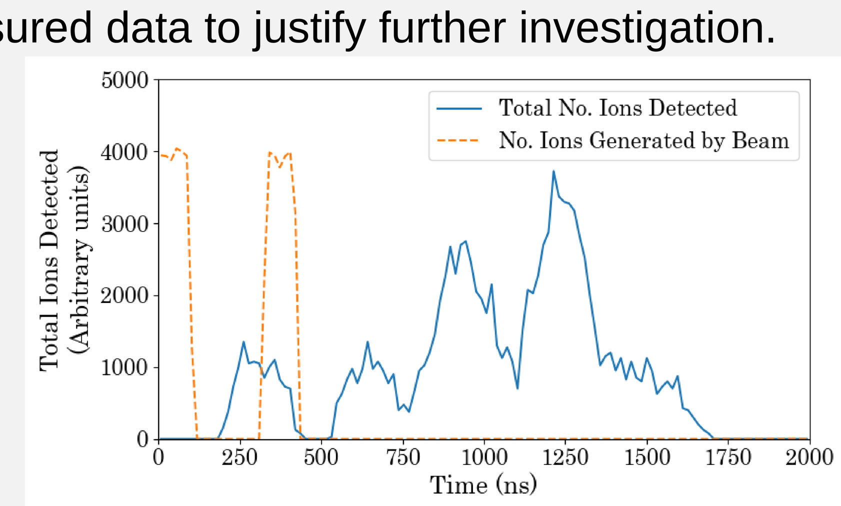
(Top) Variation of each peak's average detection time as the drift field is varied.



(Left) Variation in the time structures measured by a CEM in the centre of the beam aperture at various drift field values.

Residual Gas Composition

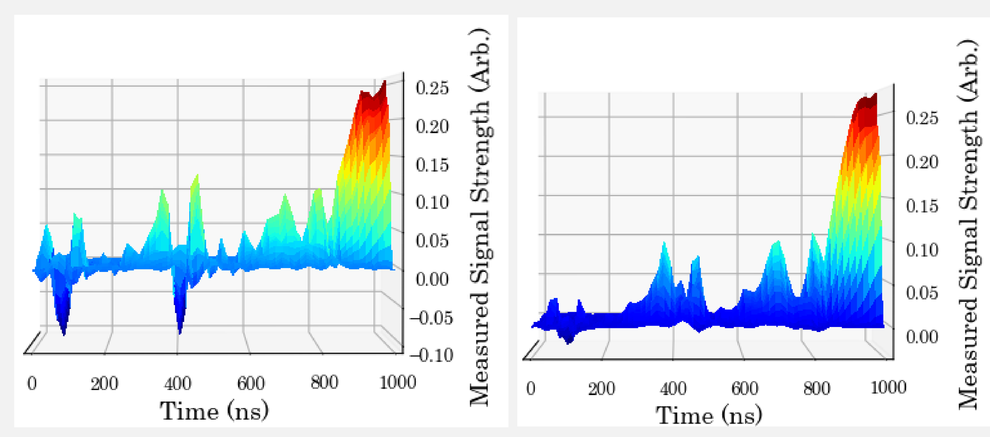
- IPM simulations were run using a varied, estimated residual gas mixture. Particles commonly found in vacuum systems were included, such as water vapour & nitrogen.
- Results from this estimate were similar enough to the measured data to justify further investigation.



IPM particle tracking simulation data showing ion detection times summed over all CEMs, generated from a residual ion composition including: H^+, H_2^+, H_2O^+, OH^+, N^+ and N_2^+ ions.

Capacitive Beam Pickup

- Differential signals are seen while each bunch is passing through the IPM, even if the drift field is switched off.
- Their amplitudes are fairly even across the beam aperture.
- These signals were determined to be capacitive pickup of the beam's electric field in the CEMS.
- The DAQ software was modified to remove this from all measurements shown.



The first 1 µs of the time structure before (left) and after (right) the capacitive pickup signal was removed.

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