Non-Destructive Profile Measurement in Rings with Strong Space Charge

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With many contributions from ISIS Diagnostics and Accelerator Physics Groups

Science & Technology Facilities Council
ISIS

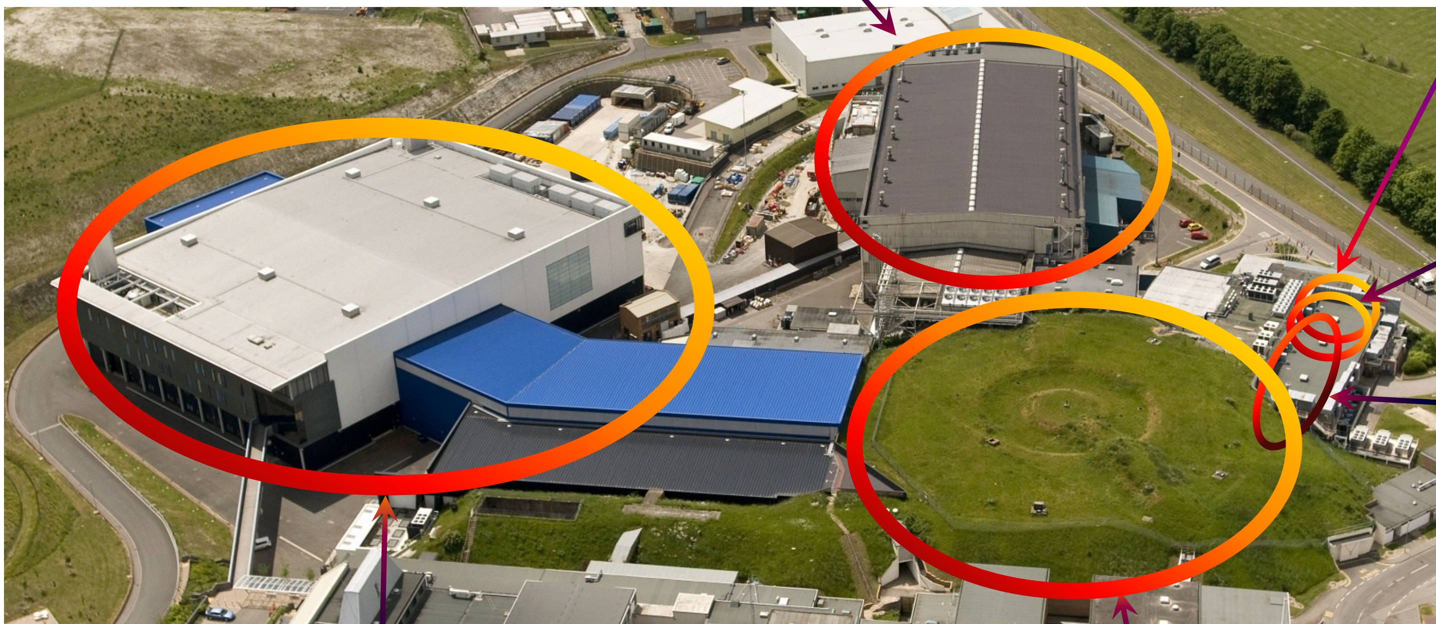
Contents

- Introduction to ISIS
- Residual Gas Ionisation Monitor
- Simulations
- Measurement errors
- Comparison measurements to simulation
- Profile correction
- Application to operation and R&D
- Plans for the future

Introduction

Target Station 1 (40 pps)

H^- ion source, 35 keV



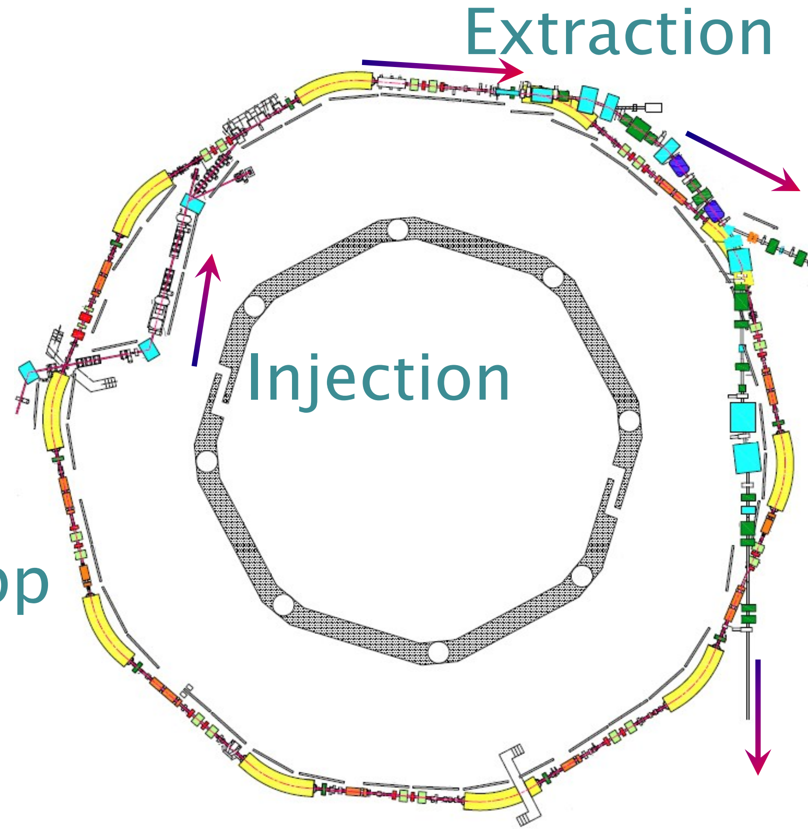
H^- RFQ, 665 keV

H^- Linac, 70 MeV

Target Station 2 (10 pps)

800 MeV Synchrotron

Introduction



Circumference: 163 m

Energy: 70–800 MeV

Repetition Rate: 50 Hz

Intensity: Up to $3\mathrm{x}10^{13}$ ppp

Mean Power: Up to 190 kW

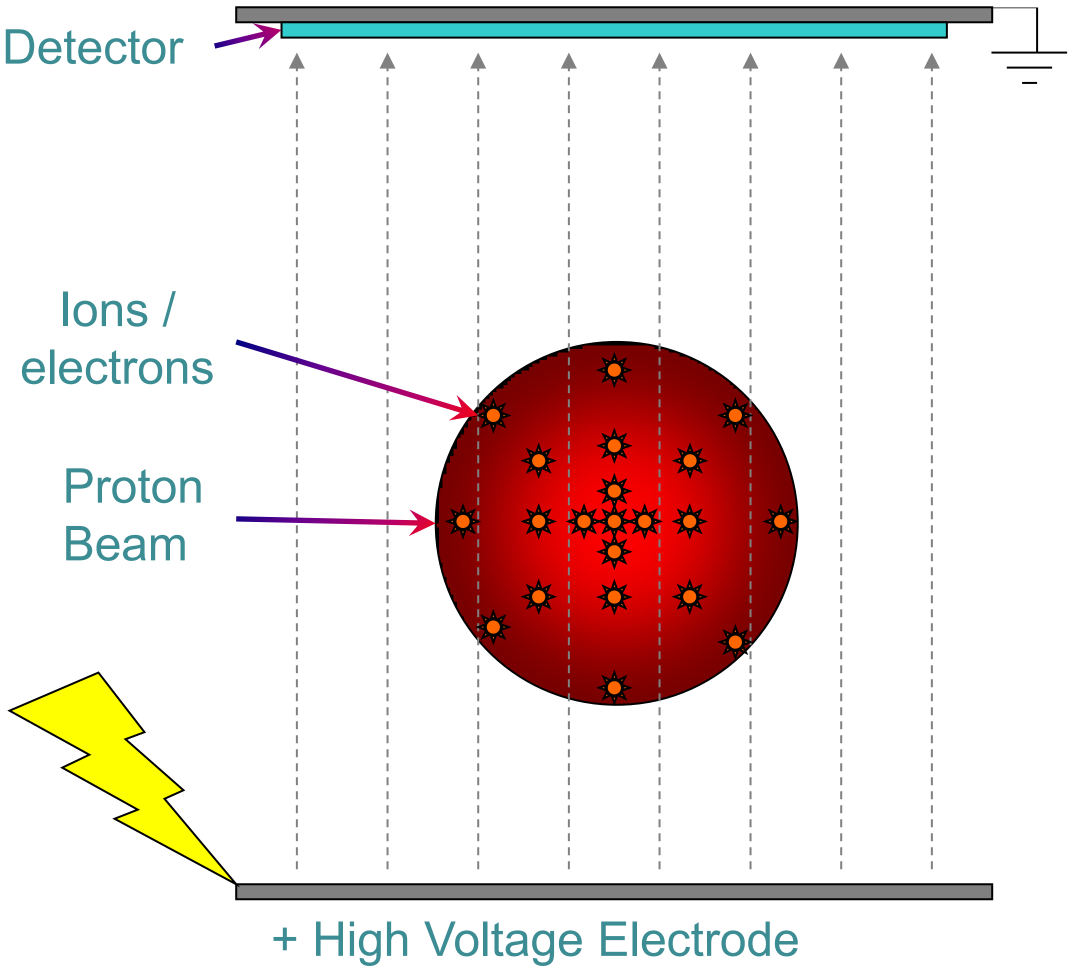
Tune Shift: ~0.5

Injection: 130 turn
charge exchange

RF system: h=2, 1.3-3.1 MHz, 160 kV/turn
h=4, 2.6-6.2 MHz, 80 KV/turn

Extraction: single turn, vertical

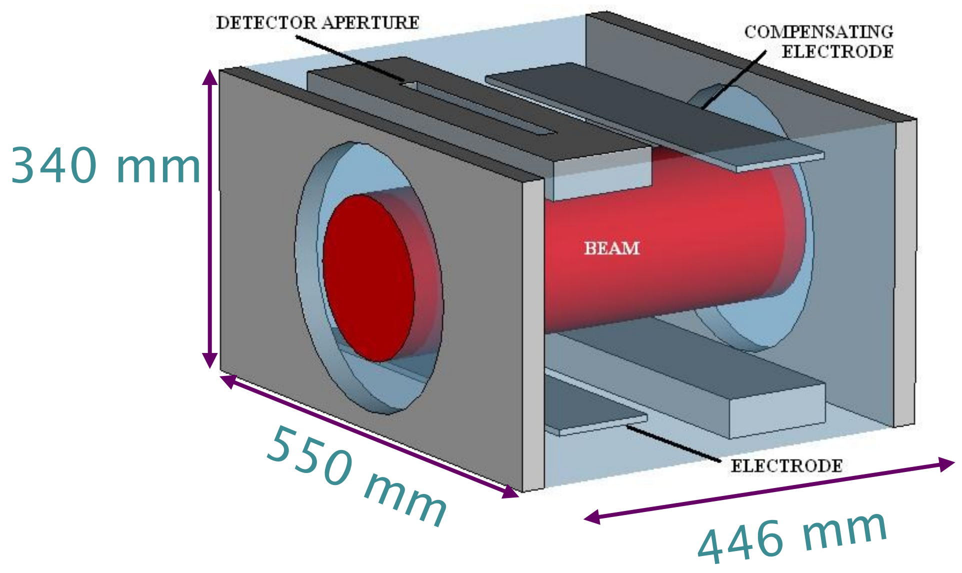
Residual Gas Ionisation Profile Monitor - *Principle of Operation*

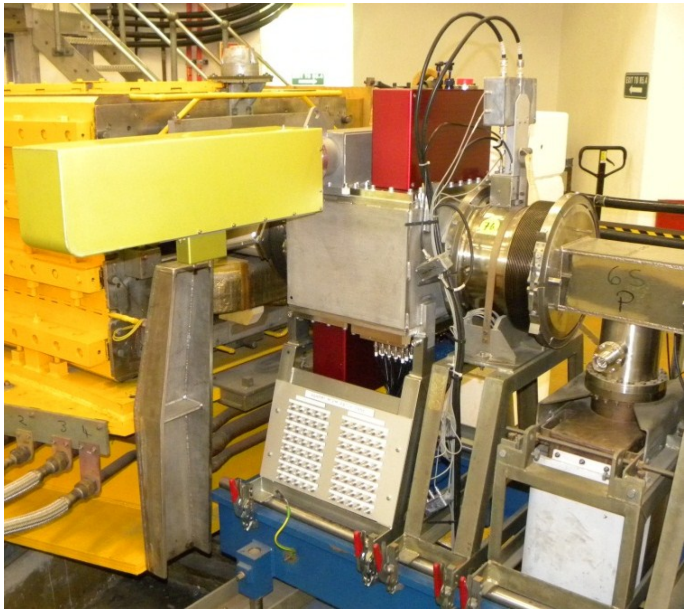


- Non-destructive measurement of beam profile and width
- Ions/electrons produced proportional to beam intensity
- Guided to detector

Residual Gas Ionisation Profile Monitor - *ISIS Design*

- Compensating electrodes double as calibration device – single channel
- Up to 60 kV drift field
- 300 π mm mrad, ~100 mm wide average
- 10^{-7} mbar in synchrotron



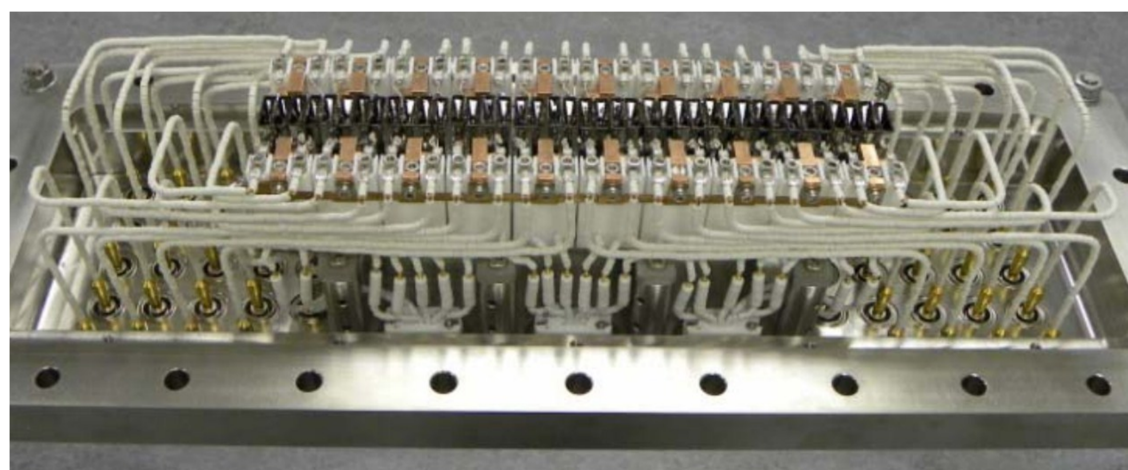


Residual Gas Ionisation Profile Monitor - *Detector Development*

- Single channel electron multipliers - channeltrons®
- Upgrade from one moveable channeltron® (averaged profile) to 40 fixed channeltrons® (single pulse profile)
- 6 mm centre to centre separation
- Single, moveable channeltron® used to calibrate multichannel

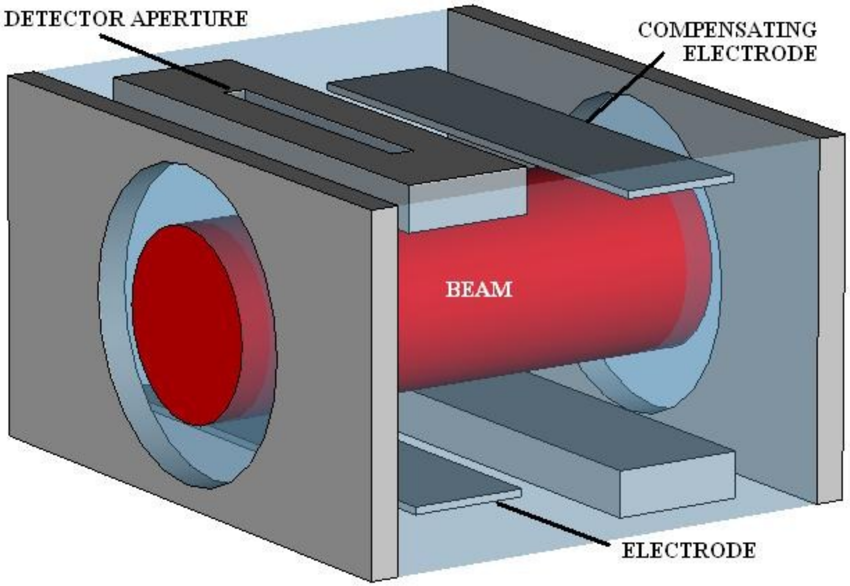
S Whitehead, S Payne, A Pertica et al.

BIW' 10

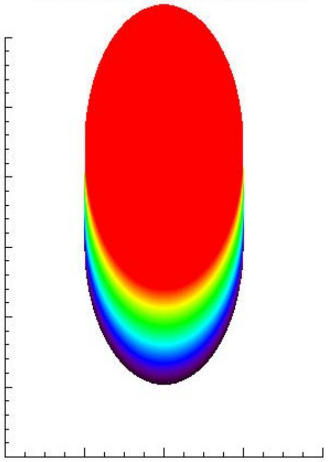


3D Electrostatic Model

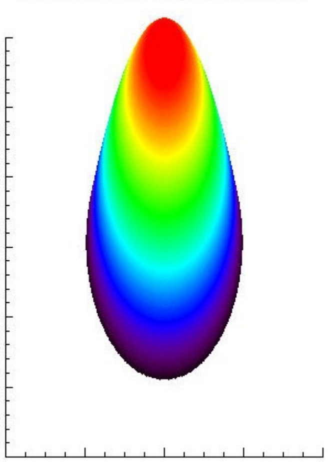
- Beam modelled as concentric cylinders
  - Centred
  - "Normal" beam distributions
- Compensating field



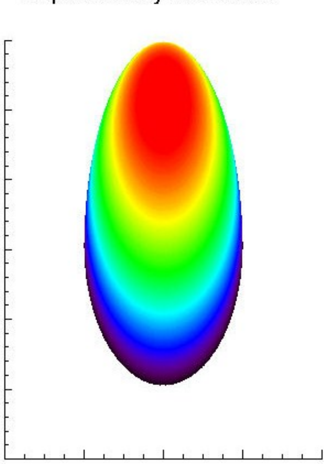
Uniform Density Distribution



Parabolic Density Distribution

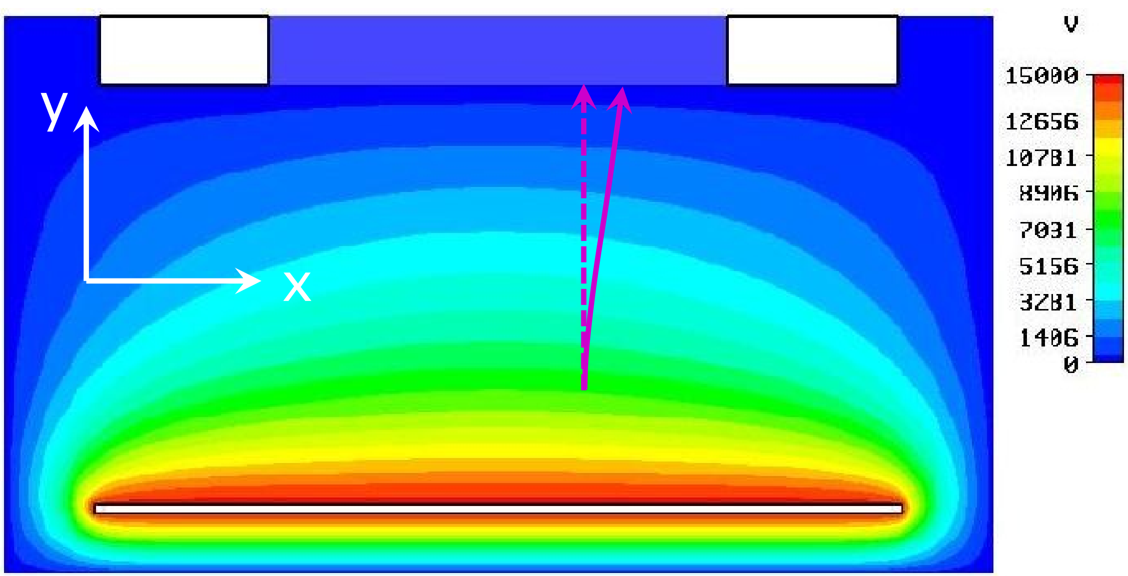


Elliptic Density Distribution



Measurement Error – 2D *Drift Field*

- Non-uniform electric field
- Pushes ions outward from central axis
- Measured profile widened
- Feature of monitor geometry



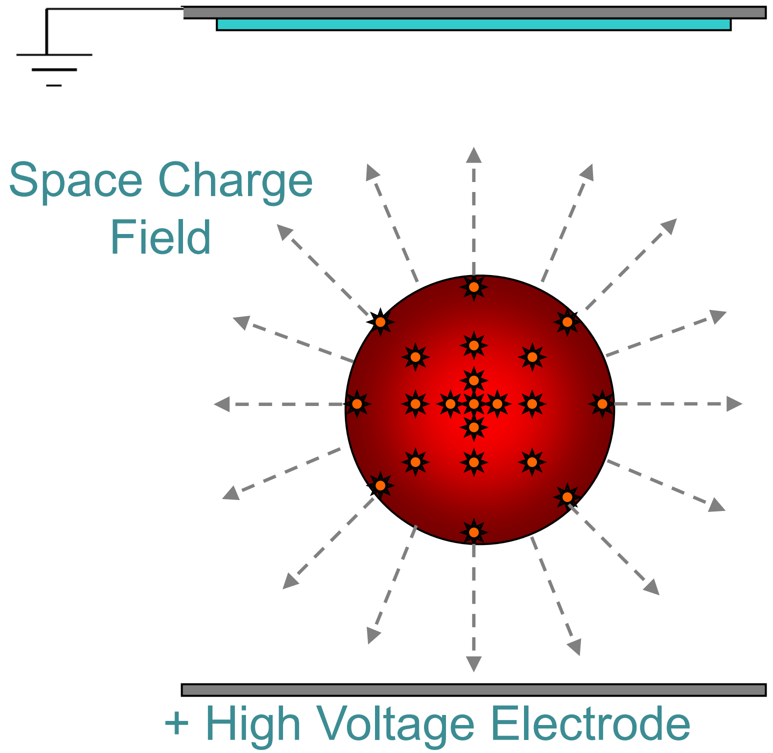
Ideal ion path

Actual ion path

Measurement Error – *Space Charge*

$1x10^{13}$ ppp

- Pushes ions out from centre of beam
- Measured profile widened
- Dependent on beam charge, size, energy, distribution, intensity and drift field voltage



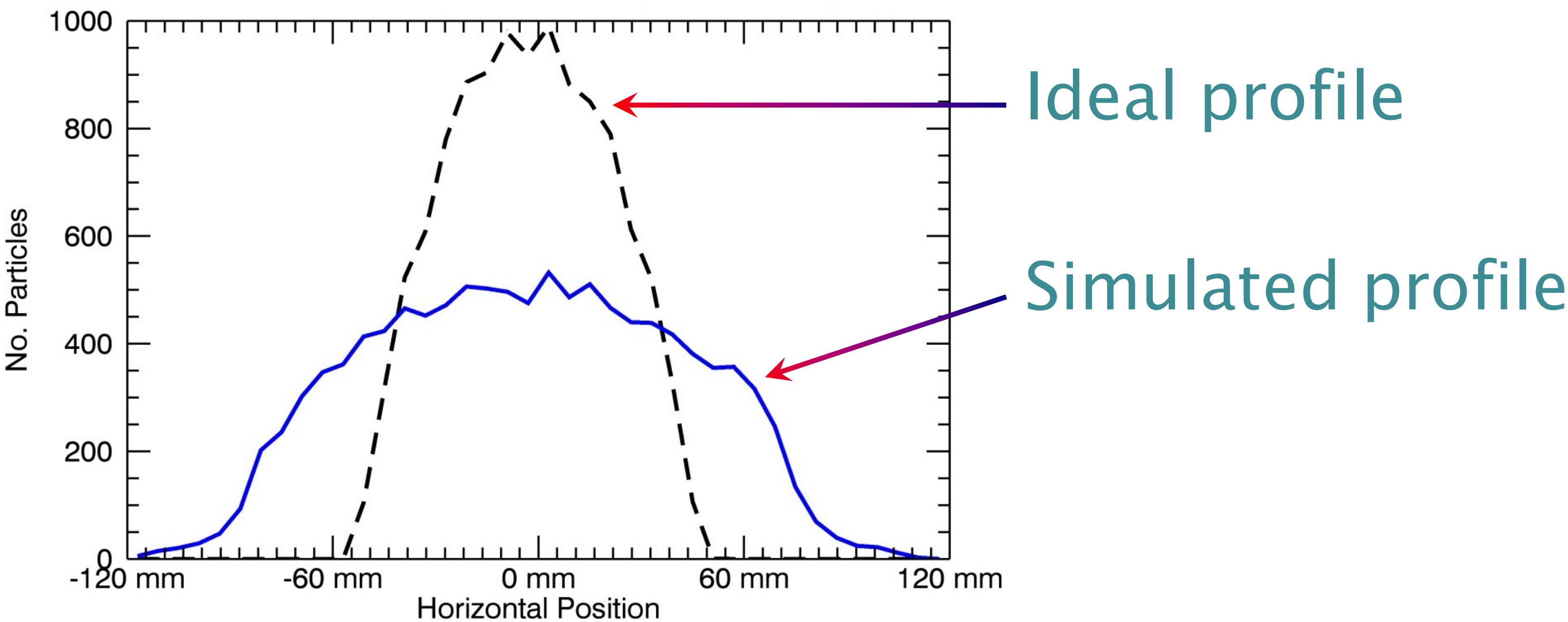
B. Pine
EPAC '06

Ion Tracking – *Full 3D*

- Simple in house code
  - Load electric field
  - Create ions distributed evenly throughout beam volume
  - Track ions with zero initial velocity until enter the detector or exit the monitor
  - Weight tracks with beam distribution

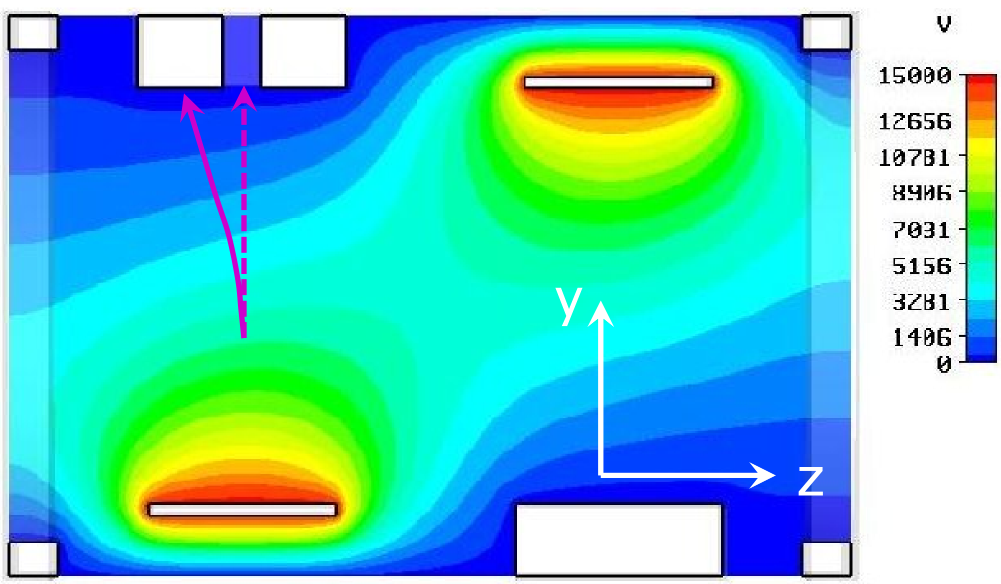
Ion Tracking Results

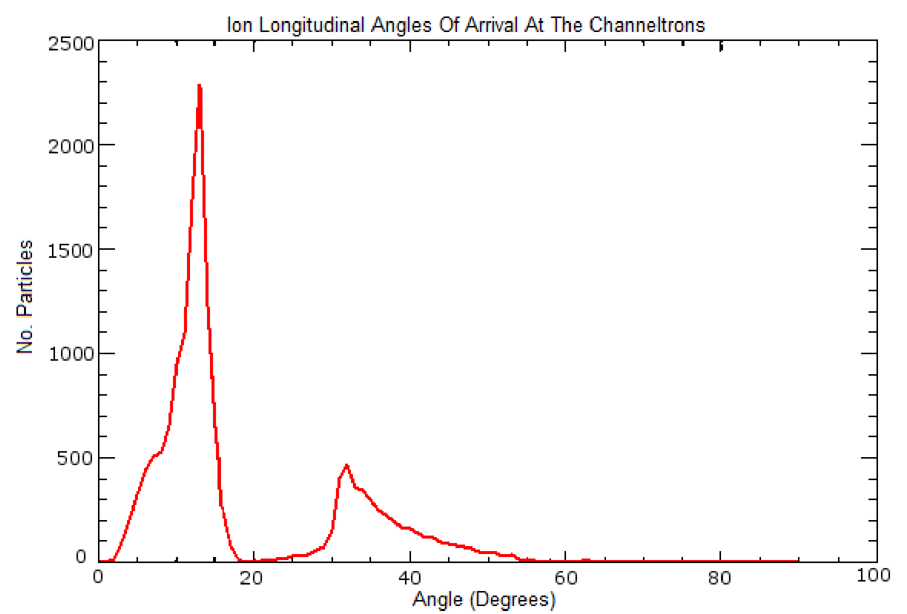
- Combined errors can double the measured profile width in normal running conditions
- Long tails present on profiles



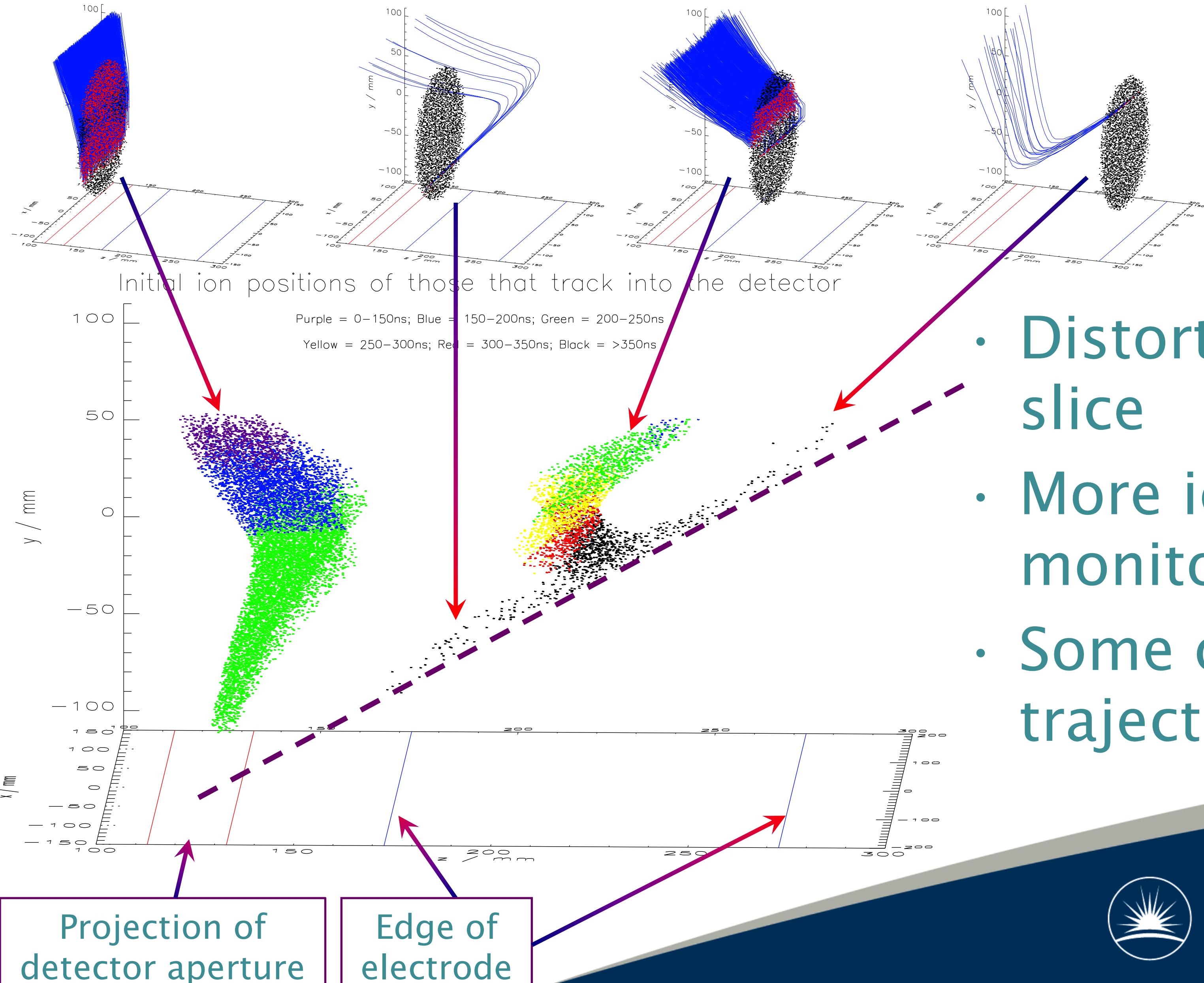
Measurement Error
– *Longitudinal Drift Field*

- Non-uniform electric field
- Longitudinal electric potential saddle point
- More complicated ion trajectories
- Not a pure 1D projection





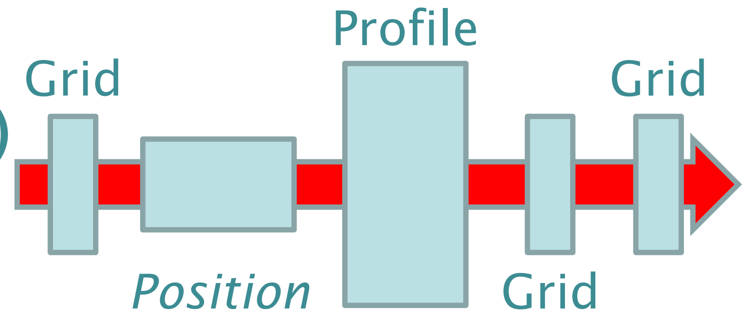
Initial Position of Detected Ions

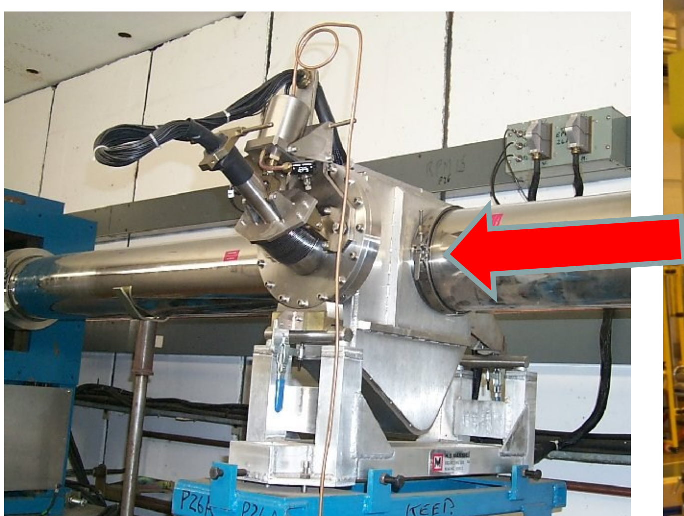


- Distorted 2D slice
- More ions from monitor centre
- Some oscillatory trajectories

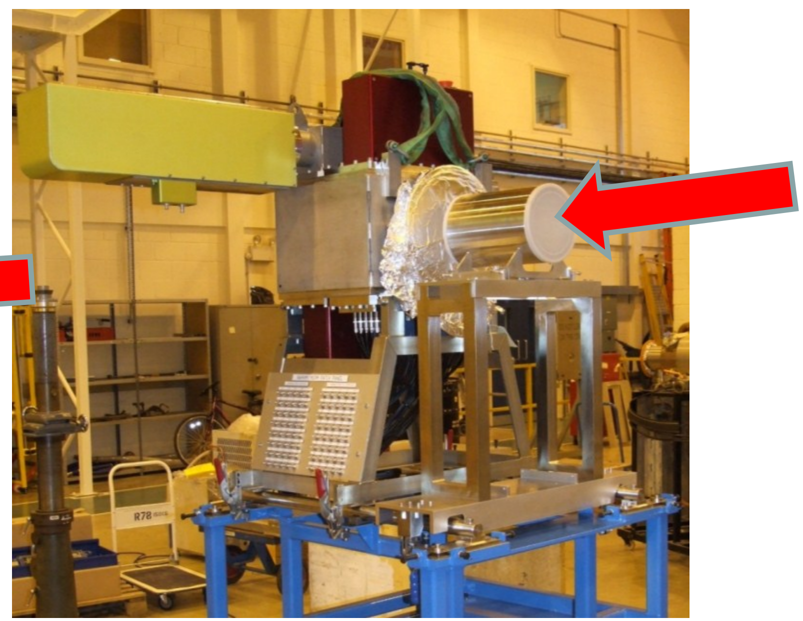
EPB Profile Study

- Check understanding of profile monitor with other diagnostics
  - Position monitor (*planned*)
  - Ionisation profile monitor
  - 3 x SEM grid profile monitors





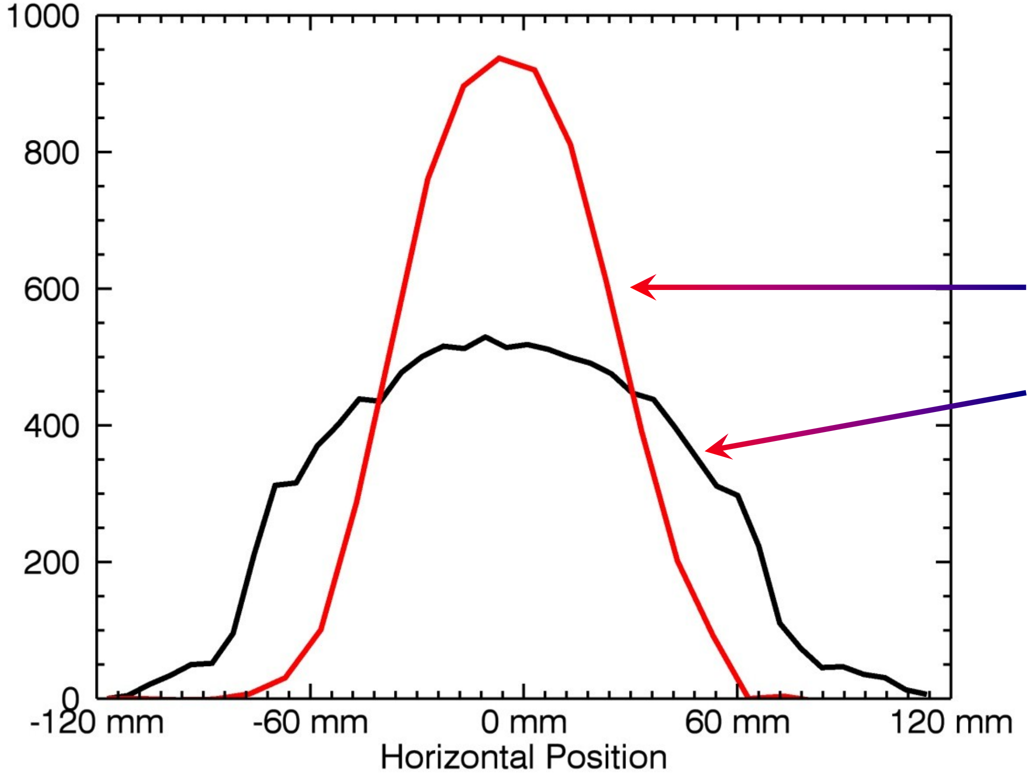
SEM Grid



Ionisation Profile Monitor

SEM Grid Vs Ionisation Profile

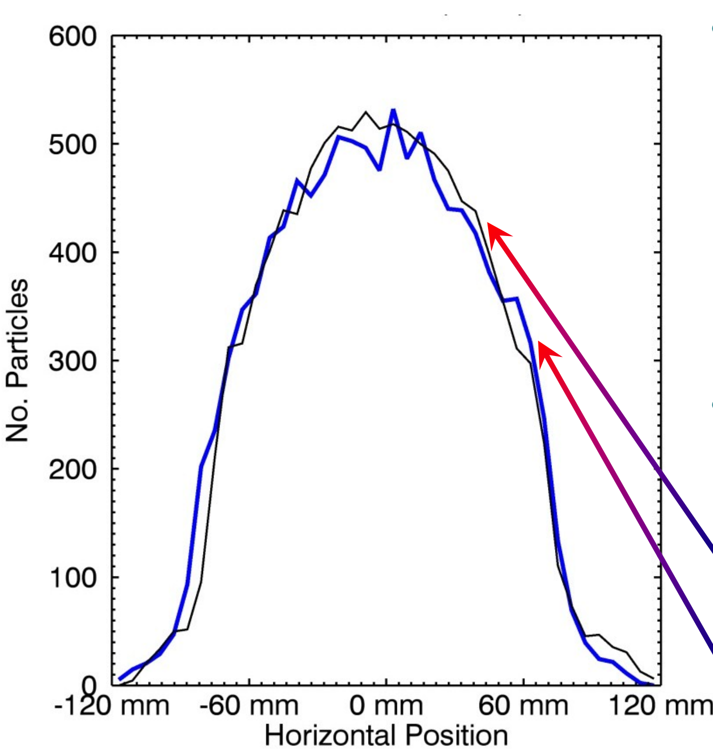
- Measurement at 2.5×10^{13} ppp
- Nominal 15 kV drift field
- 95% width:



SEM Grid – 100 mm
IPM – 158 mm
Accuracy +/- 3 mm

Simulation Vs Measurement

- Model beam in ionisation monitor as measured using SEM grid profile monitor
- Simulate resulting profile
- Compare with measured ionisation profile



- Many profile comparisons in the synchrotron confirm model with space charge and drift field
- EPB comparisons promising

Simulated profile (black)

Measured profile (blue)

Profile Correction

Drift field correction

Space charge correction

Beam intensity

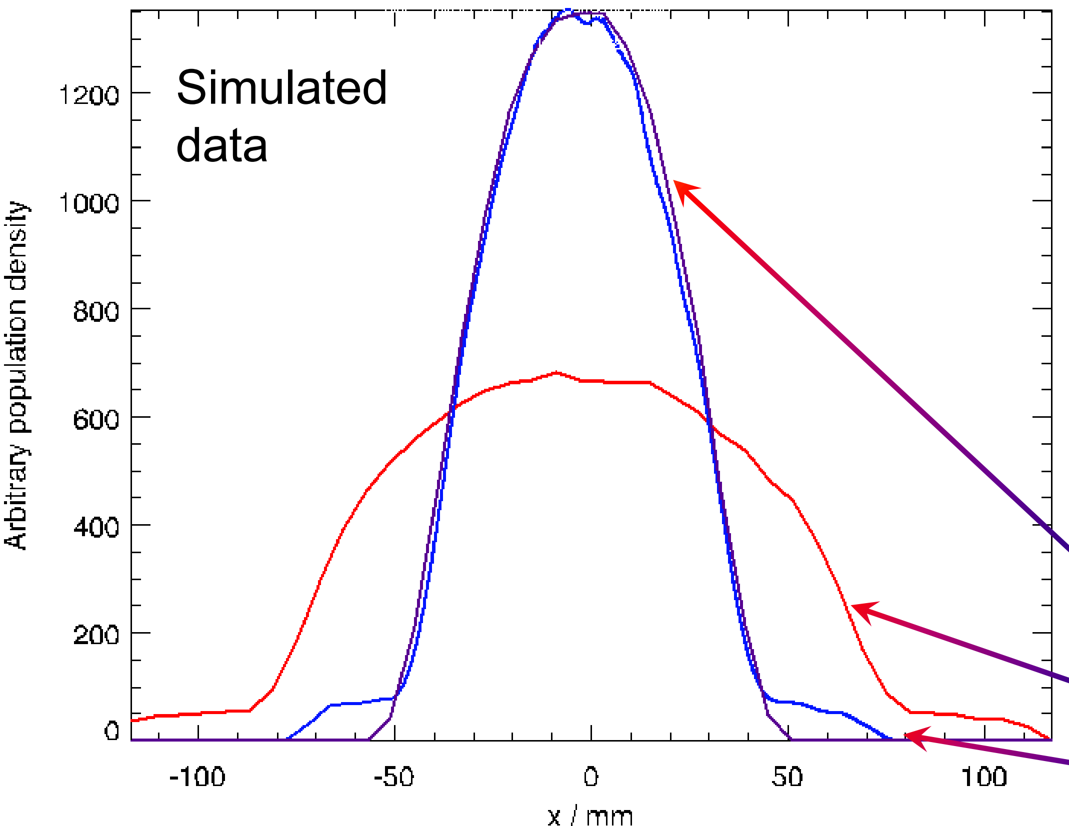
Relativistic gamma

Drift field voltage

$$w_{m,p} = k_d w_{t,p} + \frac{k_{sc} p \gamma I}{V}$$

Ionisation monitor measured width and true beam width at percentage p

R. Williamson
EPAC '08



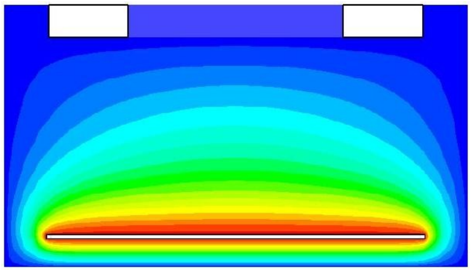
- Derived from combination of simulation and measurements
- Correct synchrotron profiles to within 6 mm
- Profile tails

Ideal profile (purple)
Simulated profile (red)
Corrected profile (blue)

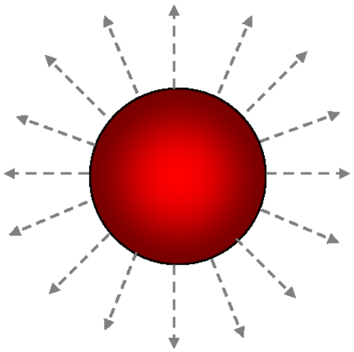
Error Summary

In decreasing order of importance

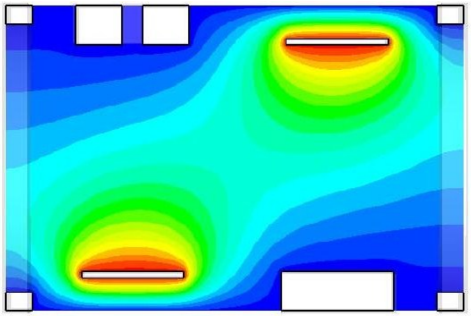
- **2D non-uniform drift field**
  - Verification at low intensities
  - ~30% error on width
  - Simple correction
  - Shaping fields



- **Space charge**
  - Verification with altering drift field
  - Error dependent on beam parameters, drift field, ~30% error on width
  - Simple correction for centrally peaked, centred distributions
  - Increase drift field voltage

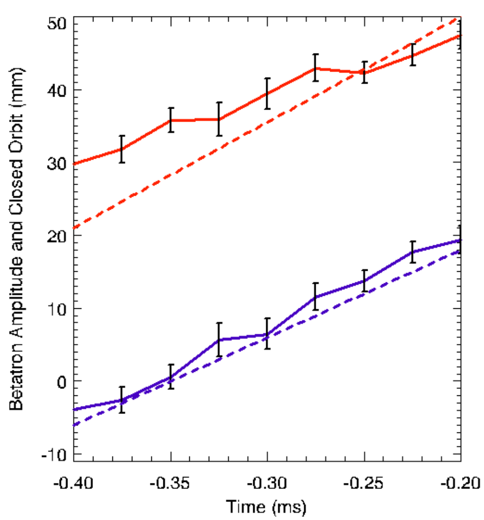


- **3D non-uniform drift field**
  - Needs to be experimentally verified
  - Small effect
  - Remove compensating field?

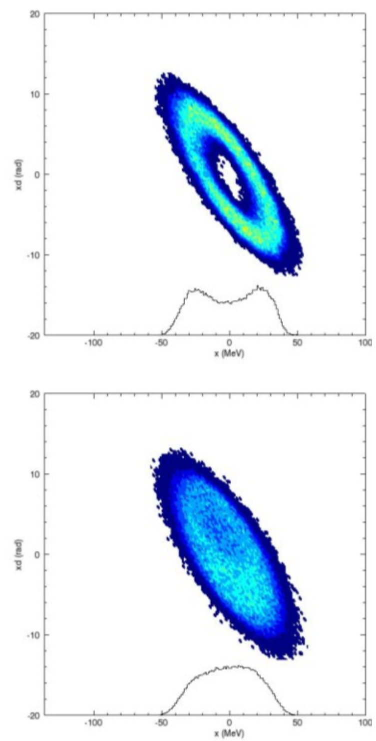


Injection Painting Measurements

- Closed orbit and Relative Betatron amplitude measured over injection
- Results used in ORBIT simulation of painting
- Beam distributions generated by ORBIT compared to MCPM measurements at high and low intensity
- Space charge correction applied to HI data



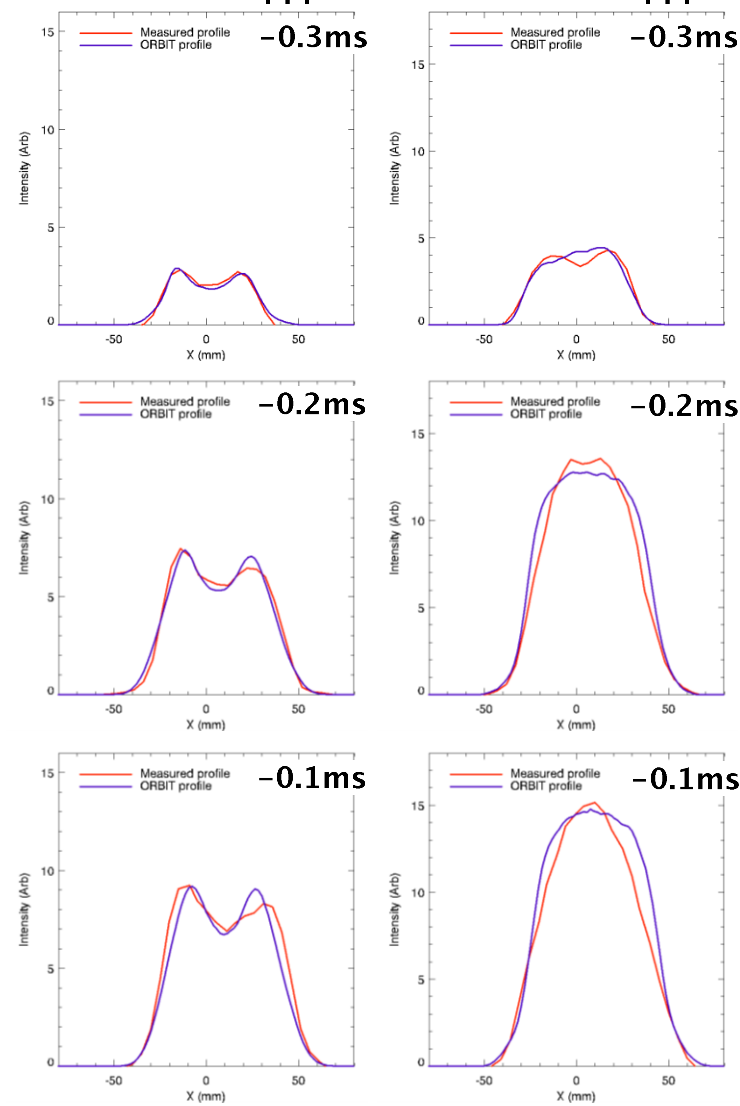
B. Jones
EPAC '08



Low intensity
Drift corr.

High intensity
Drift and SC corr.

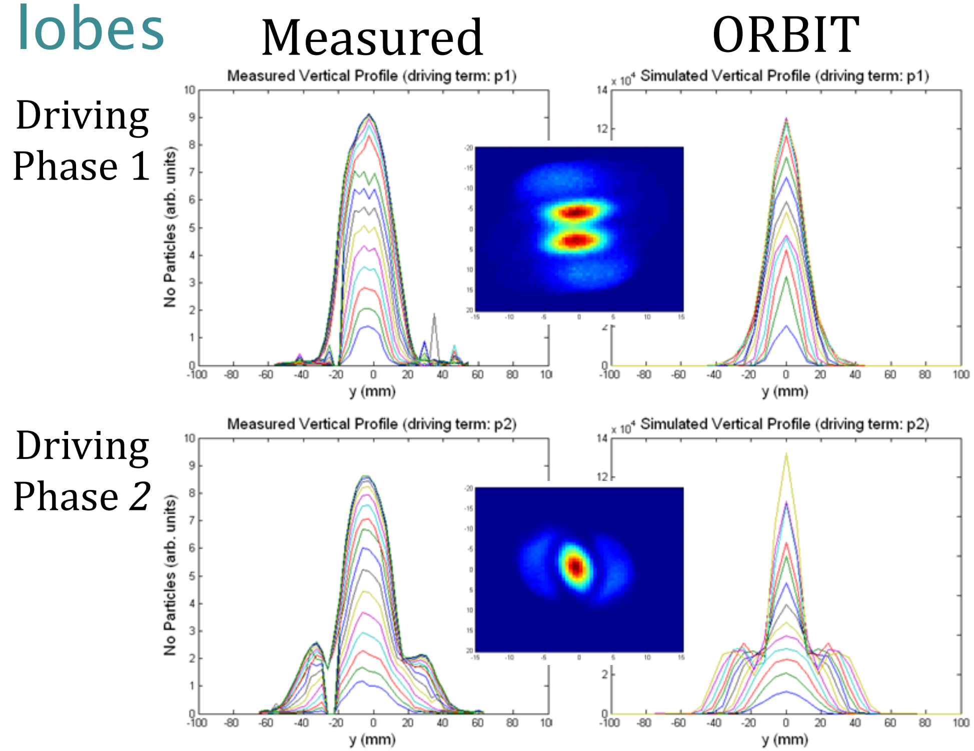
2.5×10^{12} ppp | **2.5×10^{13} ppp**



Half Integer Studies

Half integer resonance with space charge

- **Key loss mechanism**
- **Experimental studies 2D coasting beam**
  $\varepsilon_x = \varepsilon_y$, $\varepsilon_{rms} \approx 20\ \pi$ mm mr, $2Q_y$=7 driving term, Q_y=3.6
  Ramp intensity (1E13 ppp), push onto resonance
- **Study evolution of corrected profiles, not just loss**
  Observations agree with ORBIT models
  Clear formation of core and lobes
- **Using to understand loss mechanism**
  1D and 2D models of core-to-halo dynamics
- **Good model of profile monitor key**



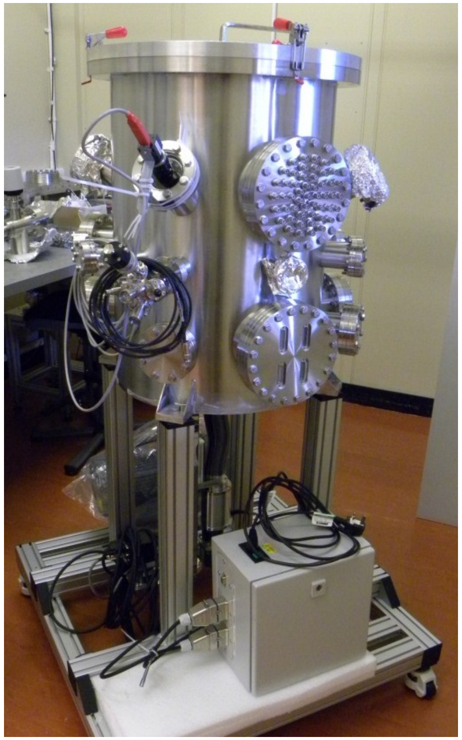
C. Warsop
Space Charge '15

Summary

- Good model of the ISIS residual gas ionisation profile monitor
- Measurement errors
  - 2D non-uniform drift field
  - Space charge
  - 3D non-uniform drift field
- Simulations Vs Measurement
- Correction works well for “normal” centred beams
  - Applied in different scenarios
- Key measurements for understanding machines with high space charge

Plans for the Future

- Effectiveness of profile correction for different beam types
  - Intensity
  - Off-centre
  - Unusual beam distributions
- Experimental check of beam width by different methods in the synchrotron
- Characterisation of the channeltrons® in new diagnostic vacuum vessel
- Development of the correction model and the monitor itself



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Additional slides

HEDS Monitor

- Newer IPM installed in HEDS space between the Linac and ring in 2010.
- Beam profile here is narrow (~19mm width) so channeltrons not suitable.
- 32 channel micro channel plate (MCP) used to detect ions instead.
- MCP can be rotated 90º to allow for calibration of each channel.
- Shaping field electrodes added to the design to remove widening effect of the drift field.