Science & Technology Facilities Council
ISIS

Simulation and Measurement of Half Integer Resonance in Coasting Beams in the ISIS Ring

C M Warsop,
D J Adams, B Jones, S J Payne, B G Pine, H V Smith, R E Williamson

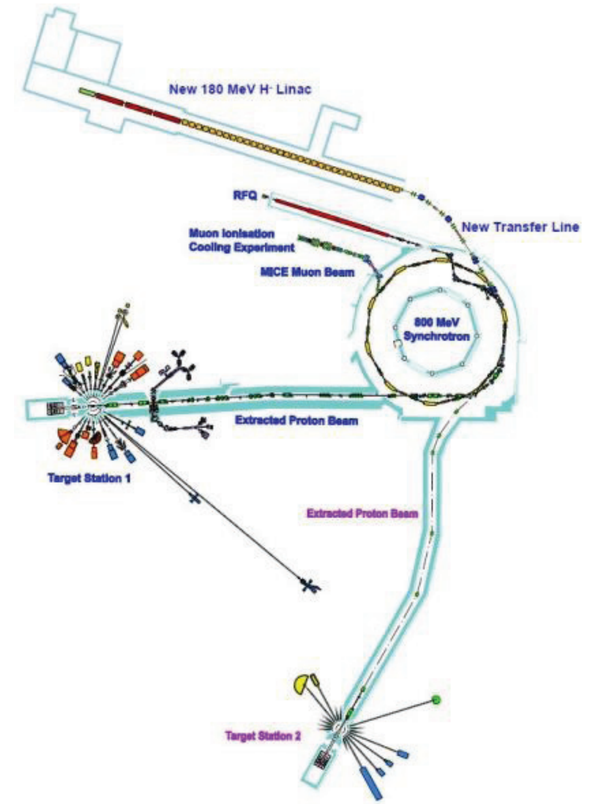
ISIS, Rutherford Appleton Laboratory, UK

HB 2012, Beijing, China, September 2012

Science & Technology Facilities Council
Rutherford Appleton Laboratory

Contents

1. Introduction



- ISIS Facility

  Operation centres on 800 MeV proton RCS
  High intensity limits important

- ISIS Developments and Upgrades

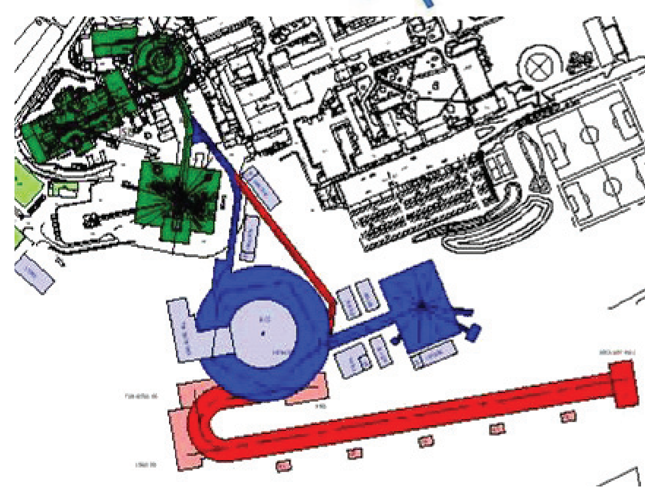
  Ongoing operations, improvements (0.2 MW)
  Upgrade 1: New 180 MeV Linac (~0.5 MW)
  Upgrade 2: New 3.5 GeV RCS (~1+ MW)
  Upgrade 3: New 800 MeV Linac (2-5 MW)

- Limiting Factors

  Space Charge, Instabilities, Injection, ...
  Half integer an important factor for all

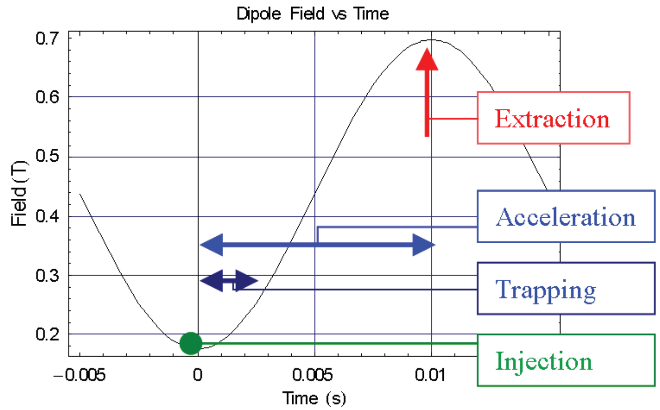
- Related Papers

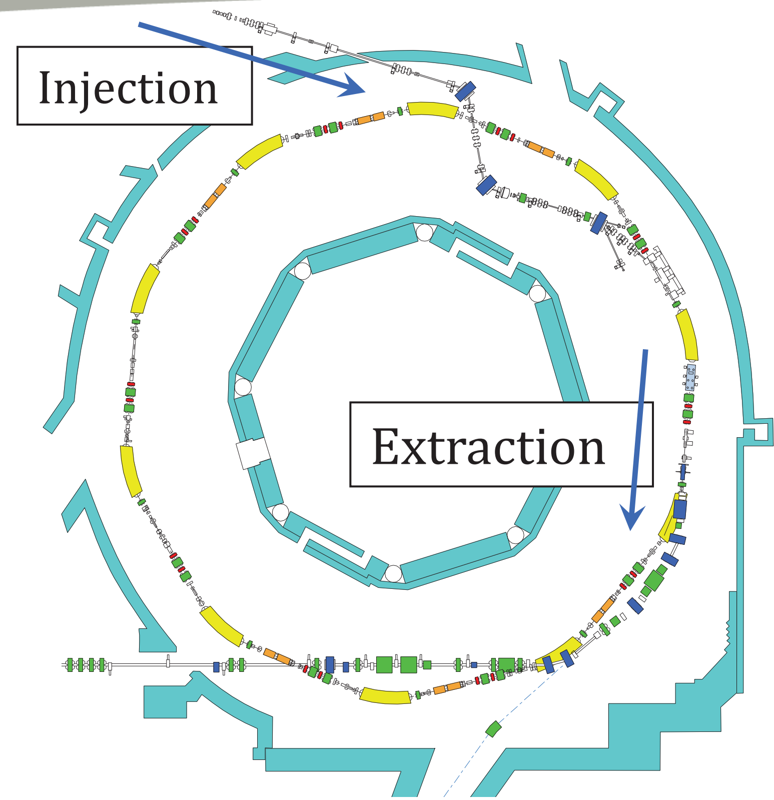
  MOP257 (BGP), WEO3C01 (BJ)
  TH01A04 (REW), THO1C02 (DJA)



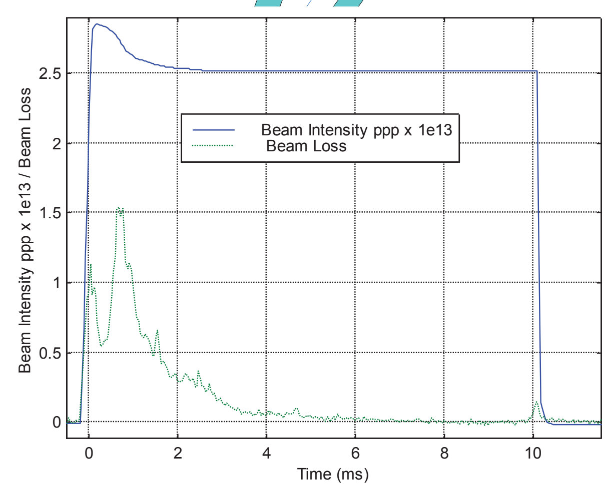
Science & Technology Facilities Council ISIS

2. The ISIS Synchrotron





Circumference:	163 m
Energy Range:	70-800 MeV
Rep Rate:	50 Hz
Intensity:	2.5×10^{13} ppp (3.0×10^{13})
Mean Power:	160 kW (192 kW)
Losses:	Inj: 2%, Trap: <5%, Acc/Ext <0.1%
Injection:	130 turn, charge-exchange
Acceptances:	collimated ~300 π mm mr
RF System:	h=2, f_2=1.3-3.1 MHz, V_2 ~160kV/turn
	h=4, f_4=2.6-6.2 MHz, V_4 ~80 kV/turn
Extraction:	single-turn, vertical
Tunes:	(Q_x, Q_y)=(4.31,3.83) (*variable*)

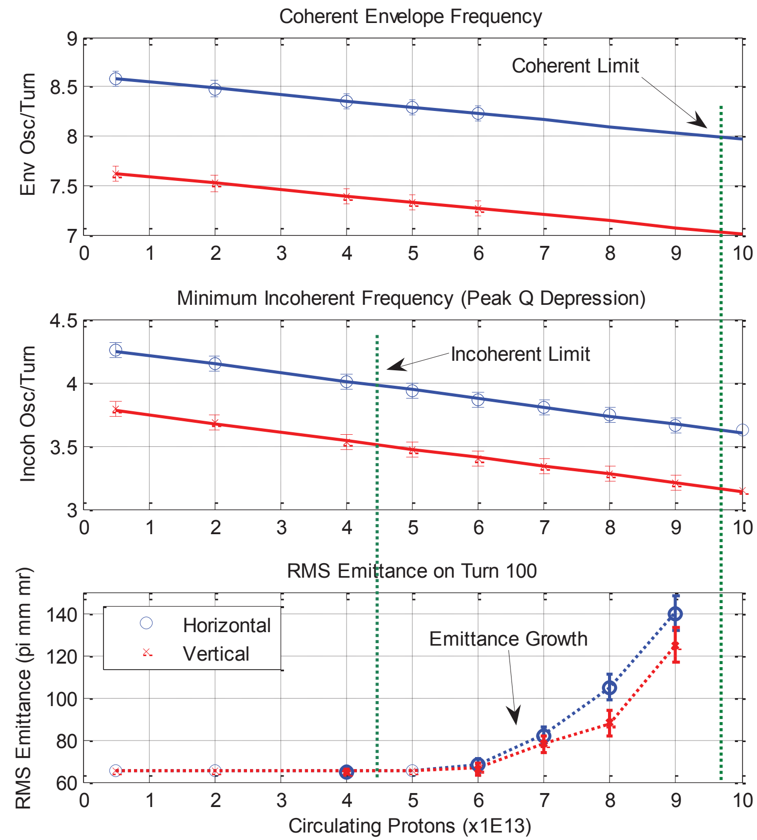


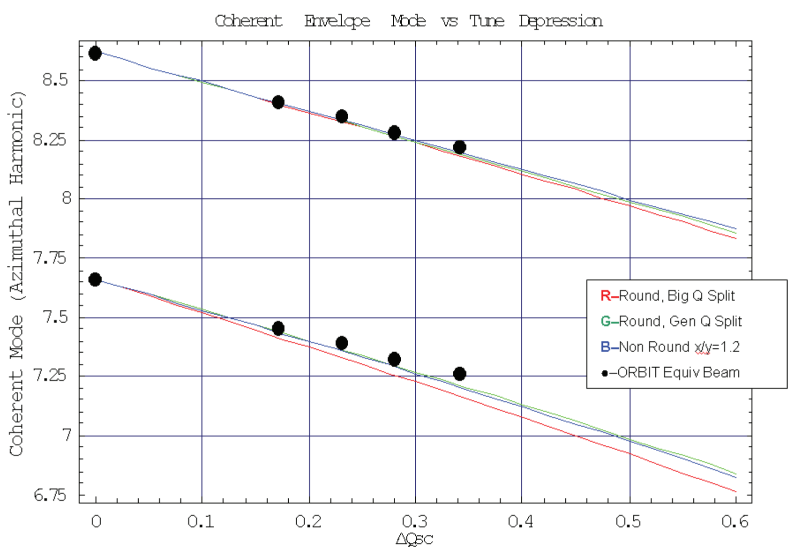
Science & Technology Facilities Council
ISIS

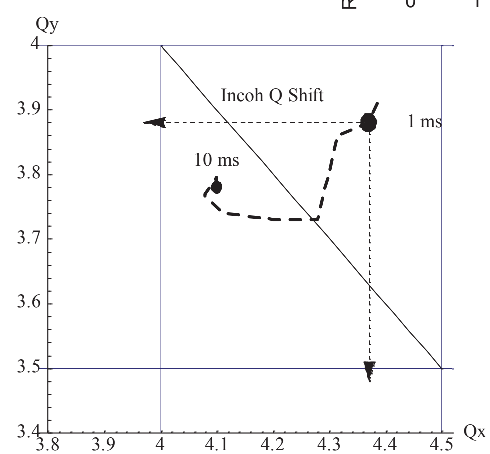
3. ISIS Half Integer Studies

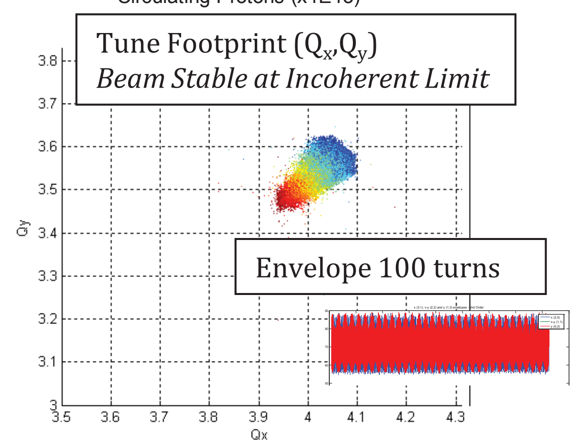
- Want to understand half integer on RCS
  - 3D motion, fast changing parameters
  - Staged study: 2D, static 3D, RCS

- Summary of 2D work so far
  - Calculated coherent modes (large tune-split)
  - ORBIT models: coherent, incoherent limit
    emittance growth, halo ...









4. Experiments: Machine Configuration

- Aim to make experiment as simple as possible
  - Straight forward observation of essential behaviour

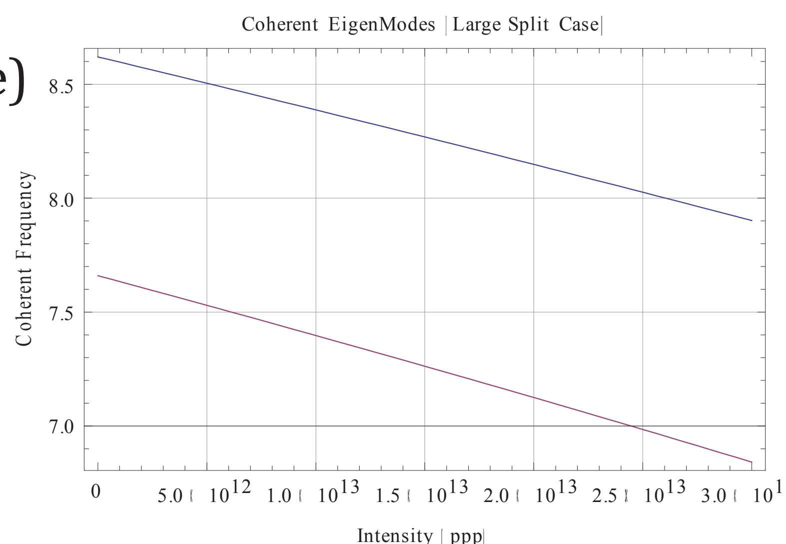
- ISIS ring in Storage Ring Mode (SRM)
  - RF off, main magnets on constant DC
  - Inject and store 70 MeV beam (0→1.3E13 ppp)
  - Constant painting ($\varepsilon_{rmsx} \approx \varepsilon_{rmsy} \approx 20 \pm 4\ \pi$ mm mr)
  - Beam occupies a small fraction of acceptance
  - Set constant lattice (Q_x, Q_y)=(4.30,3.63)
  - Apply $2Q_y$=7 driving term (amplitude/phase)
  - Ramp intensity, push toward $2Q_y$=7

- Look at
  - Beam Loss
  - Transverse Profiles

Coherent frequencies

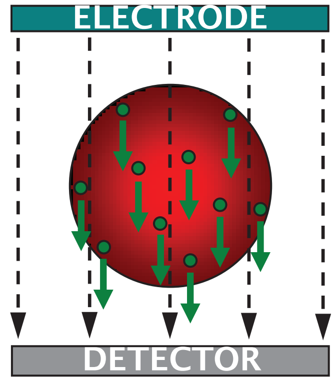
$$\omega_x^2 = 4Q_{0x}^2 - 5Q_{0x}\Delta Q_{inc,x}$$
$$\omega_y^2 = 4Q_{0y}^2 - 5Q_{0x}\Delta Q_{inc,x}$$

$$\Delta Q_{inc} = \frac{r_p N}{2\pi\beta^2\gamma^3\varepsilon}\frac{1}{B}$$

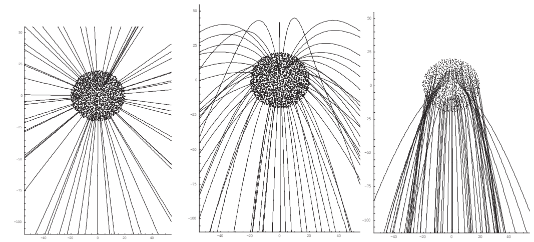


5. Experiments: Diagnostics

- Profile Monitors
  - Residual gas ionisation monitors
  - Non-destructive, sensitive
  - Errors: drift field, space charge
  - Detailed study provided corrections
  - Now refining: more detail

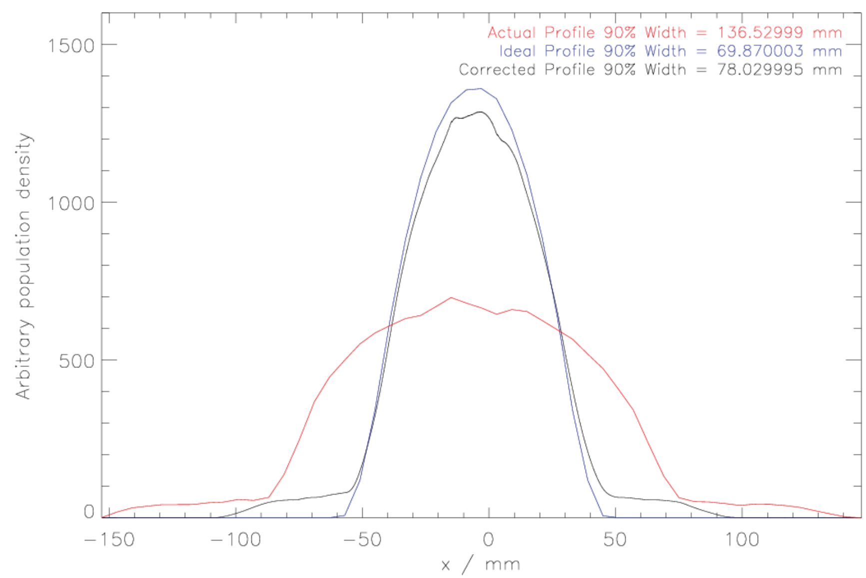


Ion Trajectories (2D)
effect of space charge



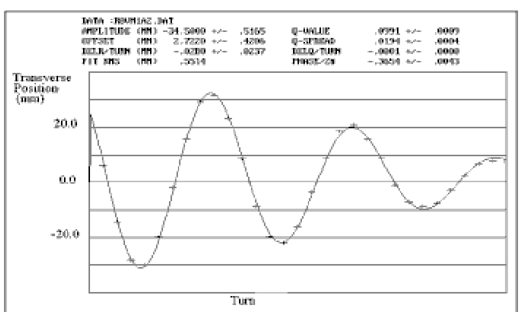
Increasing drift field →

3D Model of Monitor with Correction
(CST Studio fields + in-house particle tracker)



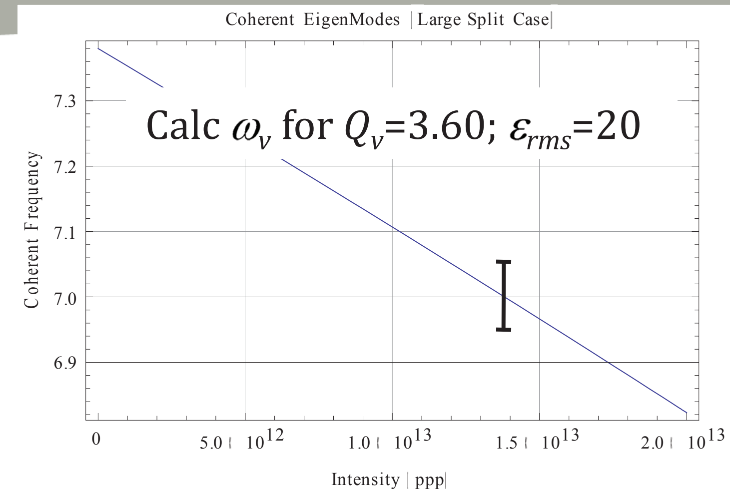
- Low Intensity Chopped Beams
  - Less than 1 turn, small emittance
  - Measurements of (Q_x, Q_y), painting, ...

Fit to turn by turn transverse positions



- Intensity Toroids and Loss Monitors

6. Experiments: Loss Measurements

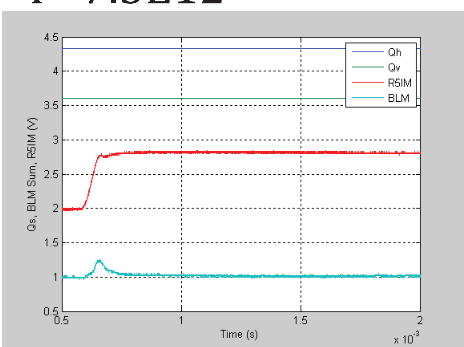


- Beam loss at coherent limit
  - Loss increases as approach limit
  - See "brick wall" where expect

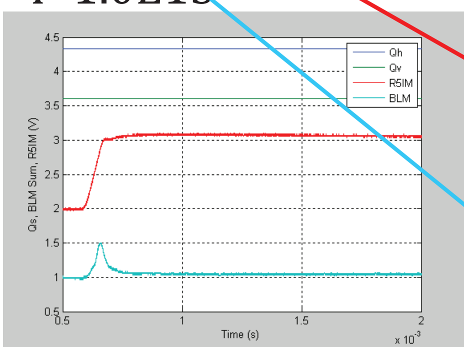
Beam Current (1V=1E13 ppp)

Beam Loss (clipped at > 1V!)

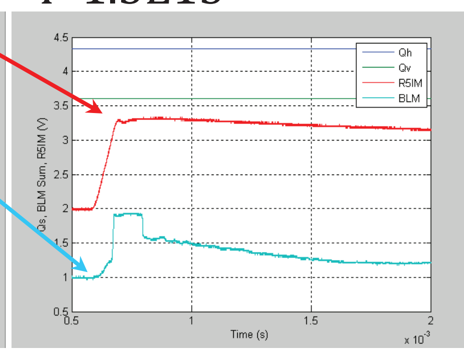
I= 7.5E12



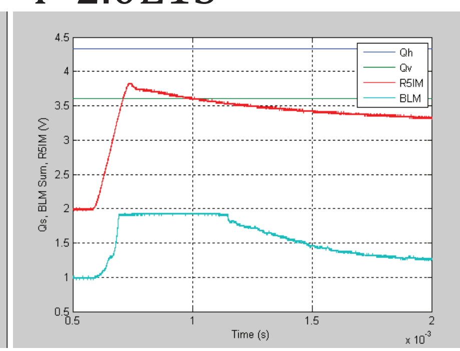
I=1.0E13



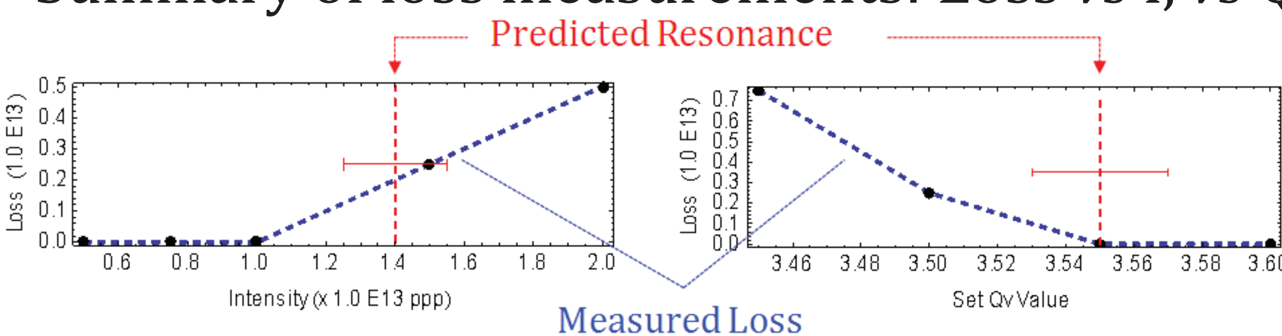
I=1.5E13

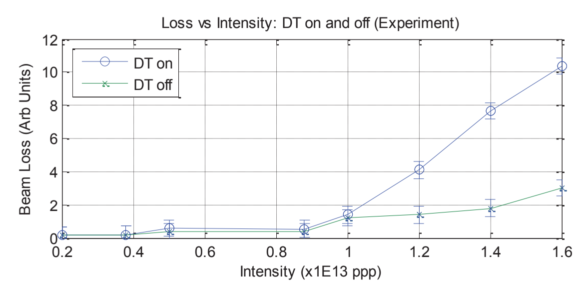


I=2.0E13



- Summary of loss measurements: Loss *vs* I, *vs* Q, *vs* driving term



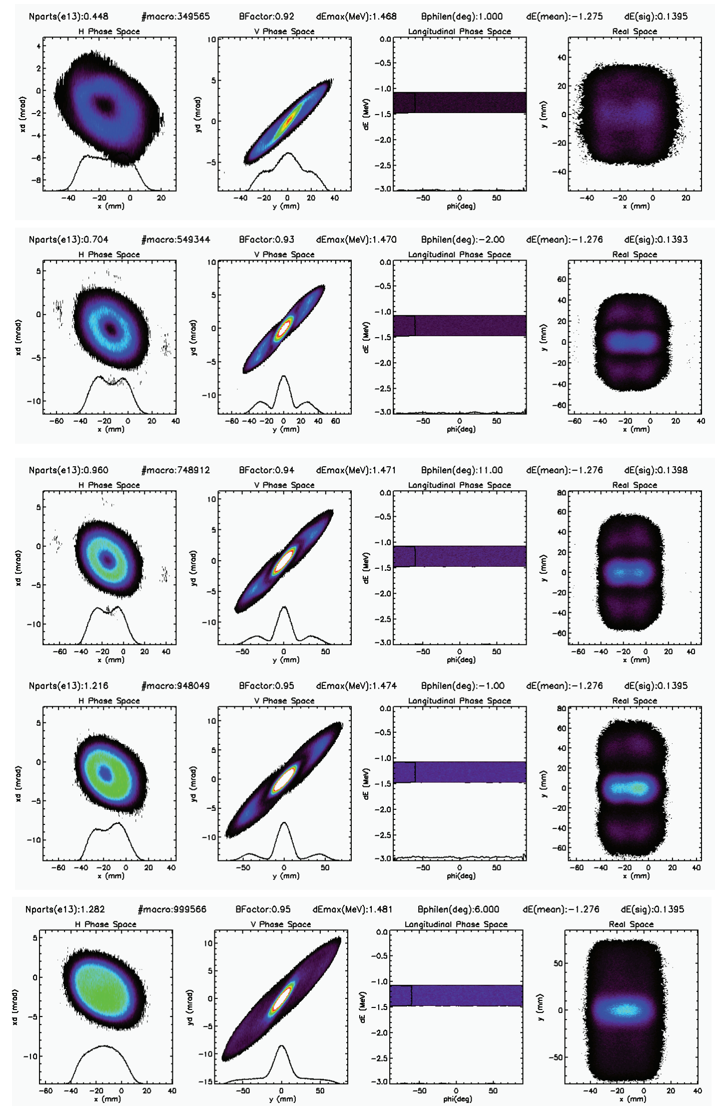


7. ORBIT Model of ISIS

- 3D ORBIT Model of ISIS RCS
  - Detailed AG lattice, injection painting, variable *Q*, apertures, collimation, …
  - Good agreement with observations (D J Adams, IPAC12, THPPP088, p3942)

- Adapted for ISIS SRM
  - Parameters set as in experiment constant *Q*, constant painting, driving terms, …
  - Track ~300 turns, including injection
  - Output distributions, tunes, …

- Plots show SRM example (p_2 case)
  - Left-right: (x, x') (y, y') (phi, dE) (x, y)
  - Top-bottom: turns 14-114 (step 20)
  - See later



8. ORBIT Simulation of Experiments

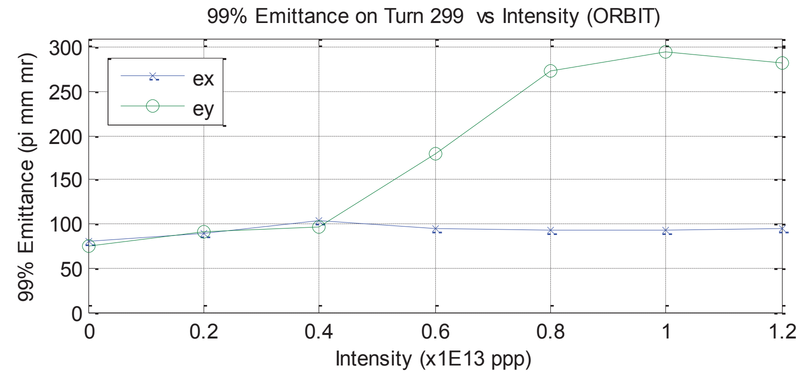
- Multiple runs: vary intensity

  With ε_{rms}= 15±2 π mm mr, Q_v=3.60

  predict resonance at ~0.5 ±0.1 x10^{13} ppp

  For each run: plot $\varepsilon_{99\%}$ on turn 299

  Clear dependence on driving term



- Single run: evolution over 300 turns

  ε_{rms} increases as expect (vertical only)

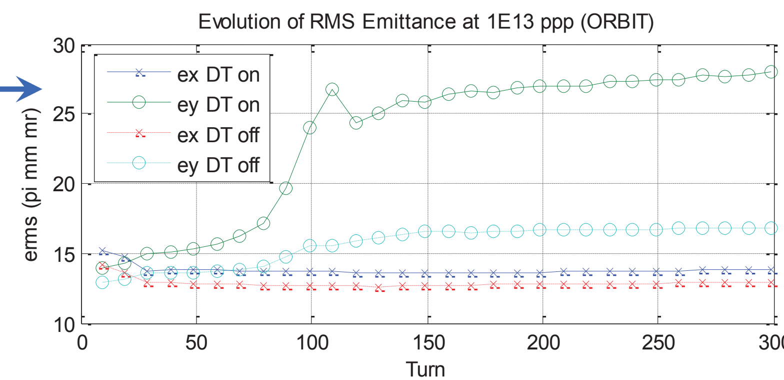
  Intensity reaches ~0.5x10^{13} ppp on turn 68

  Strong dependence on driving term

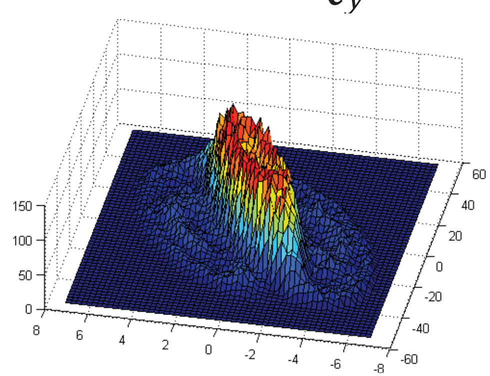
  Clear growth in second moment

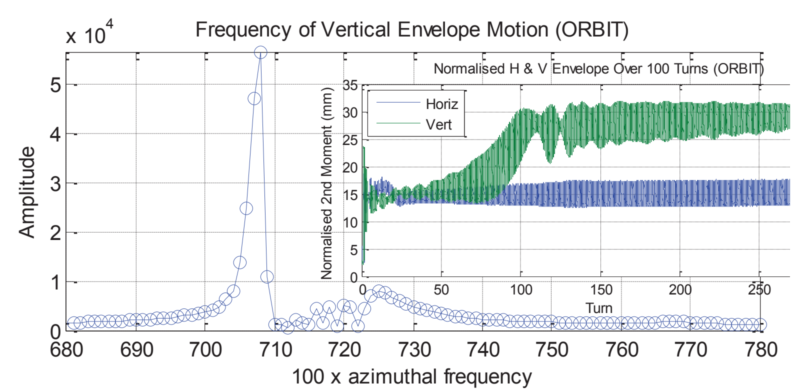
  Frequency of 2^{nd} moment near $2Q_y$=7

  Expected "halo"



Particle distribution in (y,y') on turn 109





9. Experiments: Profile Measurements

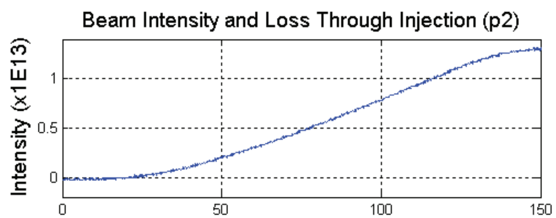
- Measure profiles as approach resonance

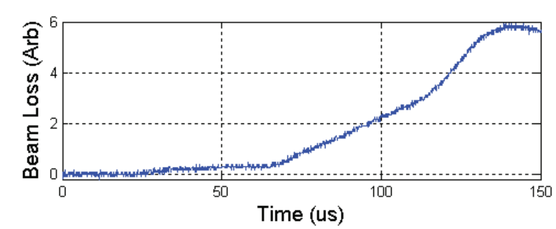
- Identify as half integer halo?
  - Control with driving term
  - $\Delta k(\theta)=k_0 \cos(2Q_y \theta+\phi)$
  - p_0: $k_0=0$
  - p_1: $k_0=0.02\ m^{-2}$, $\phi=0$
  - p_2: $k_0=0.02\ m^{-2}$, $\phi=\pi$

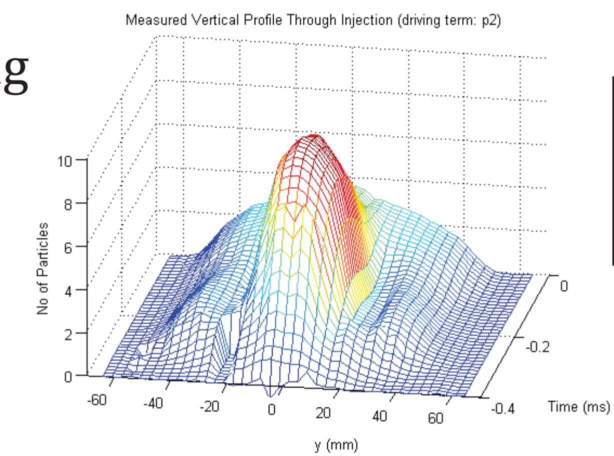
- For driven resonance
  - (y, y') structure locked to θ
  - rotates $2Q_y$ times around ring

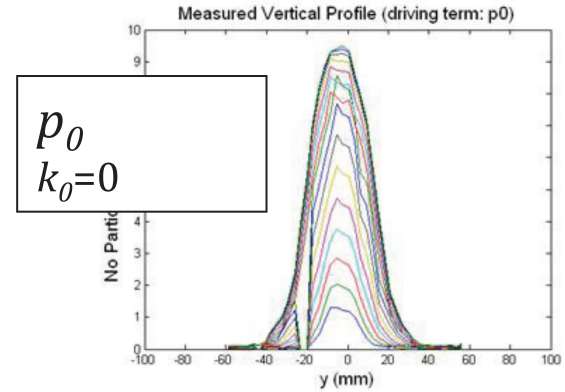
- Effects of these?
  - Strength: loss
  - Phase: (y, y') orientation
    - ~ profile is y projection

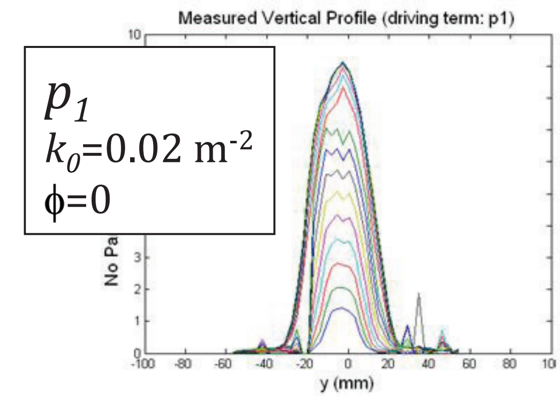
I and Loss vs time

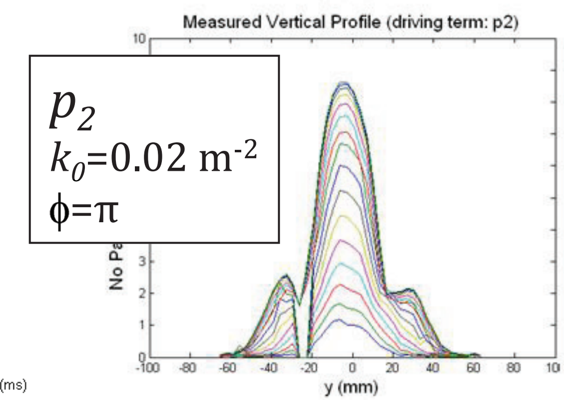








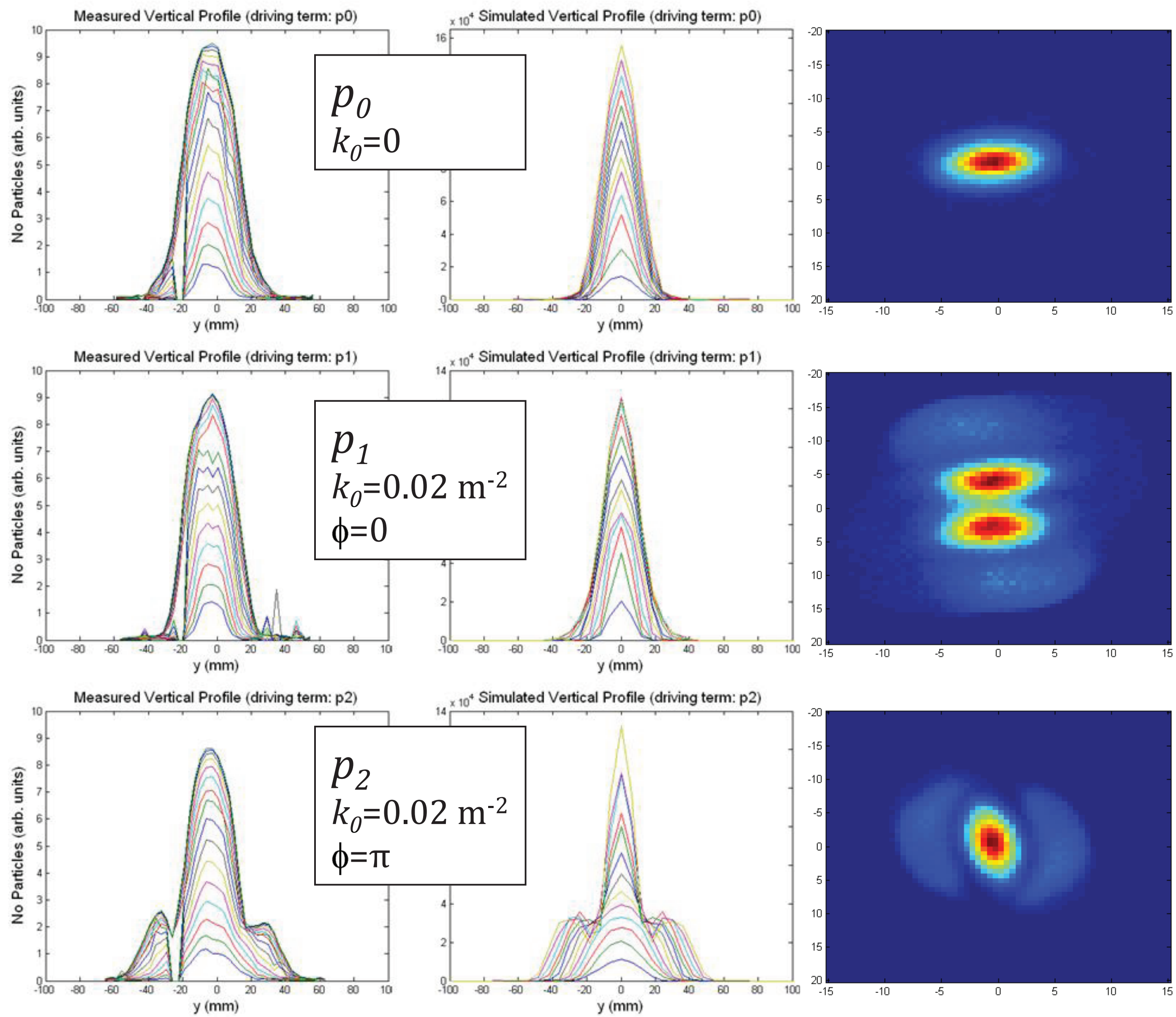




10. Compare with ORBIT simulation

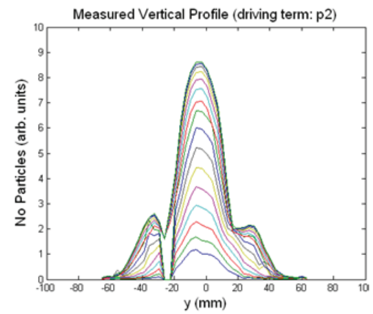
- Compare ORBIT
- Same Features
- See “Hips”
  due to phase
- Details?

Measured profile | ORBIT profile | ORBIT (Y,Y')

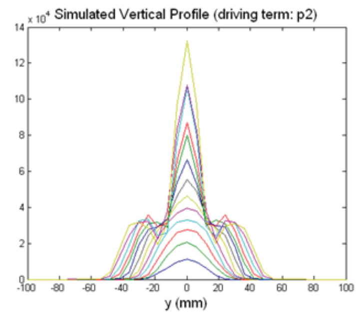


11. ORBIT Simulation Details

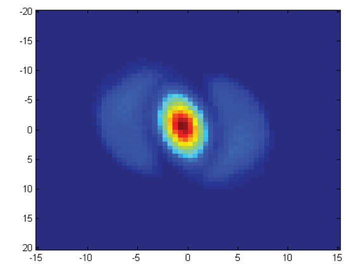
Measured



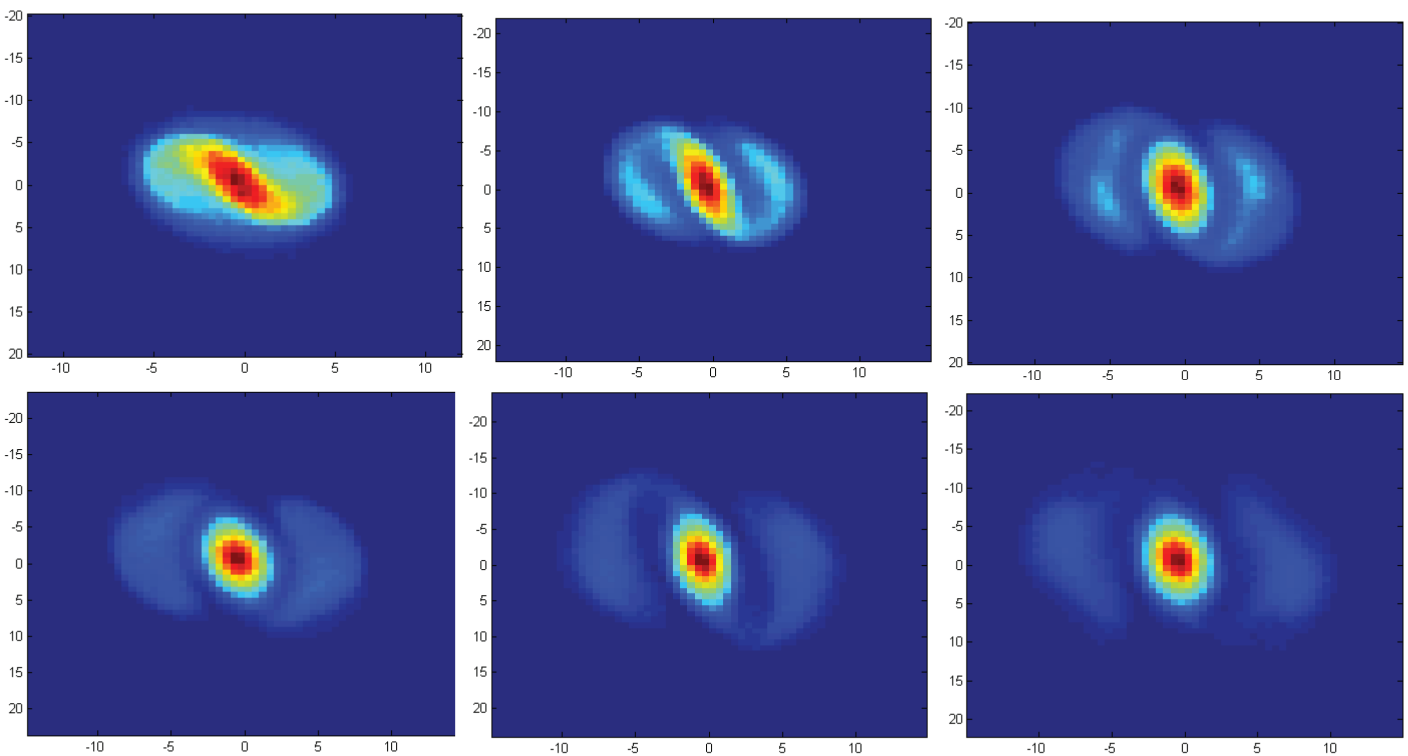
ORBIT



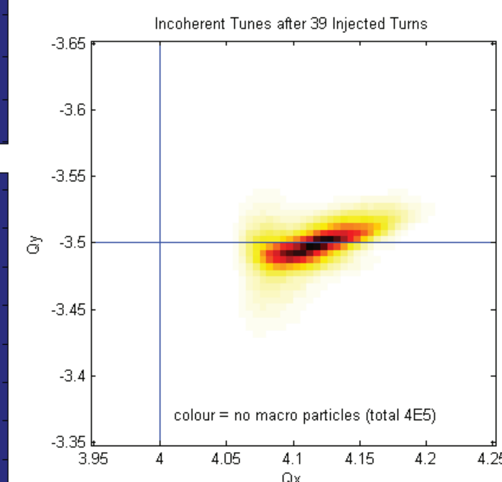
ORBIT (Y,Y')



- More detail of p_2 case
  - Evolution (Y,Y') in ORBIT
  - Turns 29-79 (step 10)
  - Intensity ramps 0.2-1.2 E13 ppp
  - Pushes onto resonance ~ single particles at Q_y=3.5



Typical tune footprint at resonance



12. Interpretation and Models

- Beam Models
  Experiments presently ahead of beam model!

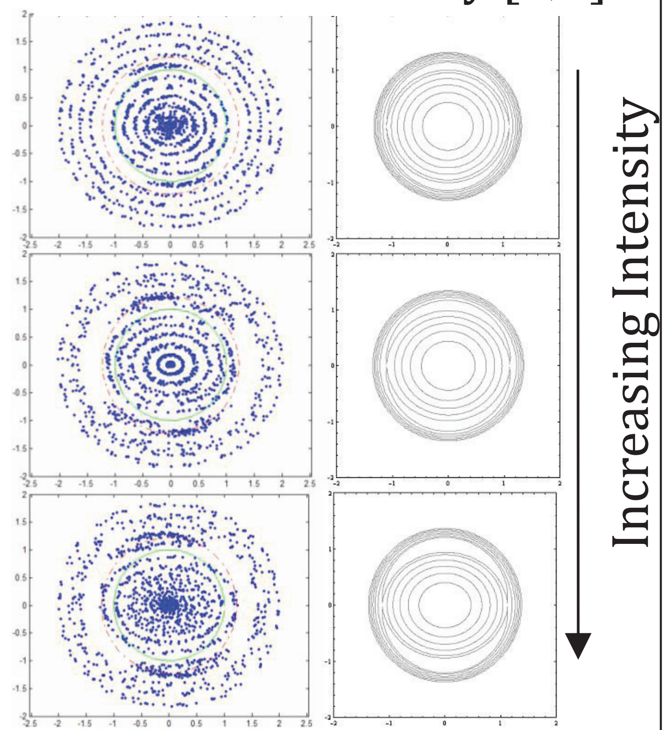
- Coherent model useful
  Until beam blows up ...

- Very useful model in literature
  Venturini & Gluckstern [1]
  KV, self-consistent, driven, equal tunes ...
  1D halo ~ looked at in [2] – *similar behaviour*

- Experiments show observable halo
  Next – try a simple non self-consistent model
  e.g. waterbag, particle-core, driven ...
  Will hopefully describe short term structure

Vertical (Y, Y')

Simulation Theory [2,1]



7.00 x10^13 ppp	7.25 x10^13 ppp
8.00 x10^13 ppp	7.50 x10^13 ppp
8.50 x10^13 ppp	7.75 x10^13 ppp

[1] M. Venturini et al., Resonance Analysis for a Space Charge Dominated Beam in a Circular Lattice, PRST-AB, V3, 034203, 2000.
[2] C M Warsop et al., Space Charge Loss Mechanisms Associated with Half Integer Resonance on the ISIS Synchrotron, Proc. EPAC08, p373.

13. Next Steps

- Results are promising, but there is much further to go!

- Reduce errors and optimise use of profile monitors
  - Better models of beam and machine (beam parameter measurements)
  - More detailed information from profile monitors (more modelling)

- Develop simple models
  - Simplified simulation/analytical models (particle-core, WB, driving term)

- Develop experiments and link with closely related work
  - Studies of ISIS working point and image effects (MOP257)
  - Planning experiments with bunched, non-accelerated beams (TH01A04)
  - Study of RCS mode (3D ORBIT simulations and use of ISIS Set 3Di code)

Science & Technology Facilities Council
ISIS

14. Summary

- Detailed observation of half integer resonance

  Measurement and manipulation of halo as predicted by simulation

- Promising results

  Now hope to improve detail and accuracy …

15. Acknowledgements

- Many thanks to …

  ISIS Diagnostics Section
  ISIS Operations

  ORNL/SNS for use of ORBIT

- As always … useful discussions with ASTeC/IB