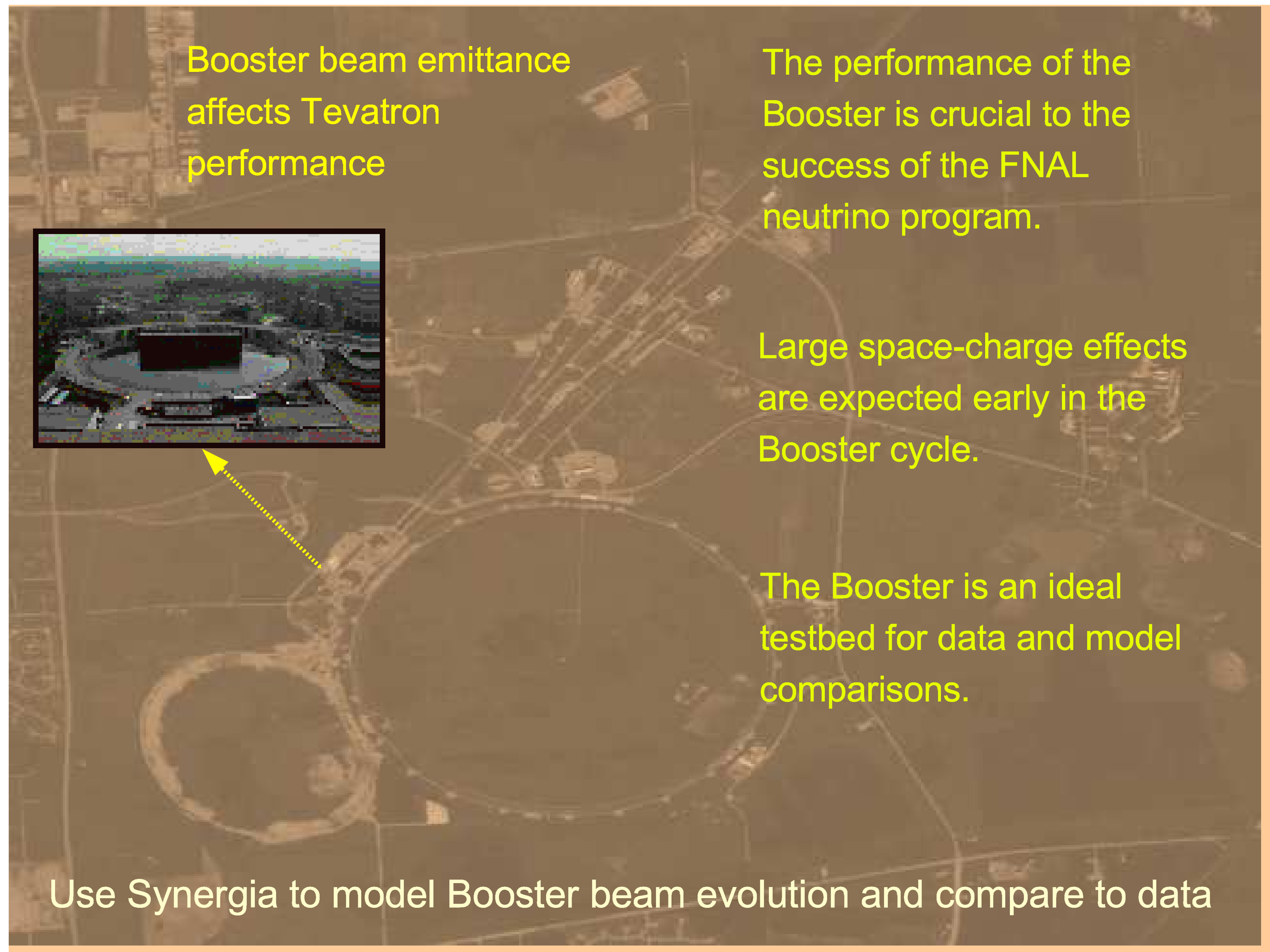
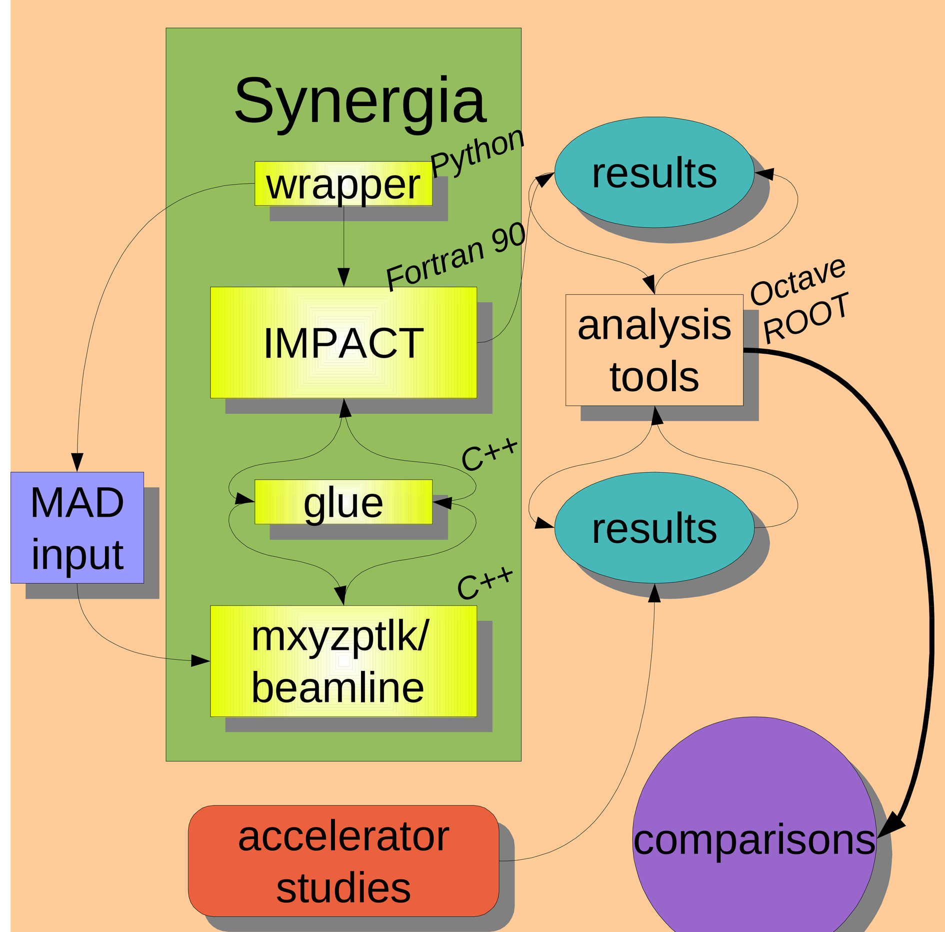
Space Charge in the FNAL Booster: Experiment and Modeling

J. Amundson, P. Spentzouris, Fermi National Accelerator Laboratory

part of the “Advanced Computing for 21st Century Accelerator Science and Technology” collaboration



Synergia



3D space-charge code with circular accelerator capabilities

Re-uses existing beam dynamics packages

Advanced parallel computing tools

- particle manger
- load balancing

Modern build system and code distribution tools

Human interface and standard accelerator lattice description

The Fermilab Booster

Rapid cycling, 15 Hz, 400 MeV → 8 GeV

24 FOFDOOD, 19.76 m long, cells

RF: 37.7->52.1 Mhz

16 cavities

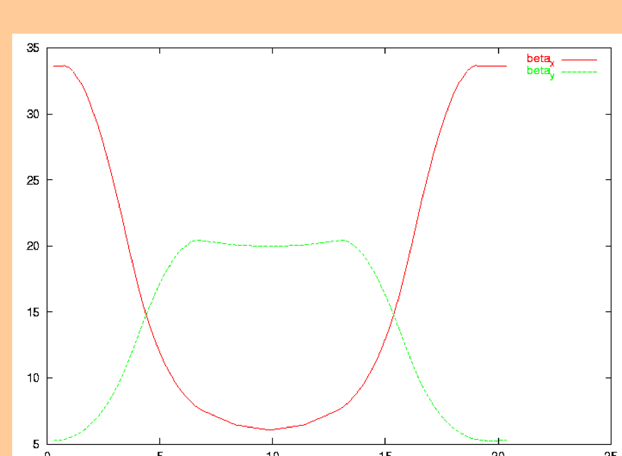
Emittance: 12p mm mrad

0.25 eV sec

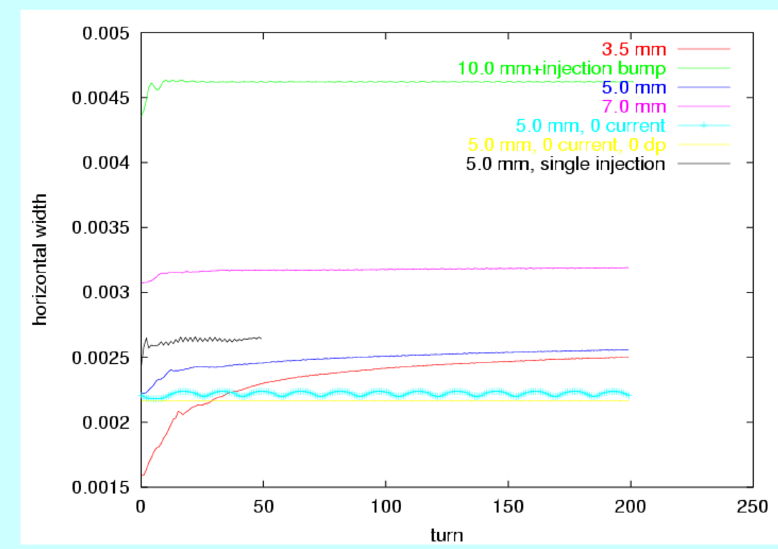
Tune, $v_x \sim v_y \sim 6.7$

H^- injection, injection bump, stripping foil

Injection/capture/bunching ~ 2msec

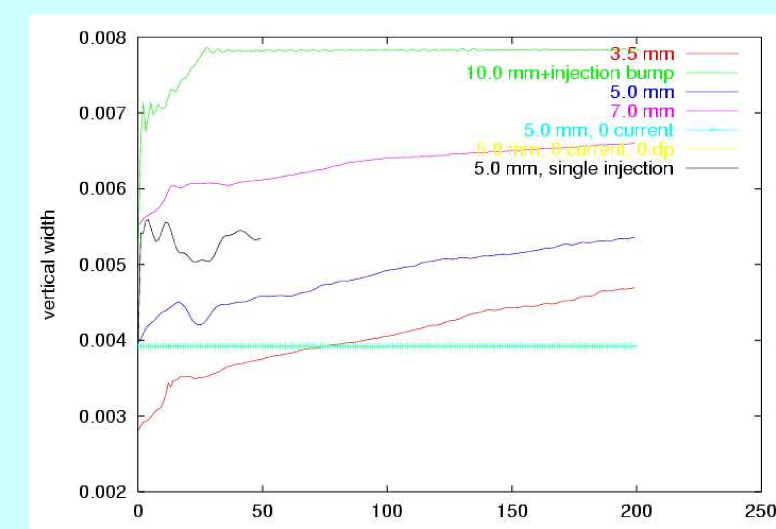


The behavior of the machine under normal operating conditions depends on many parameters, some of which are not precisely measured

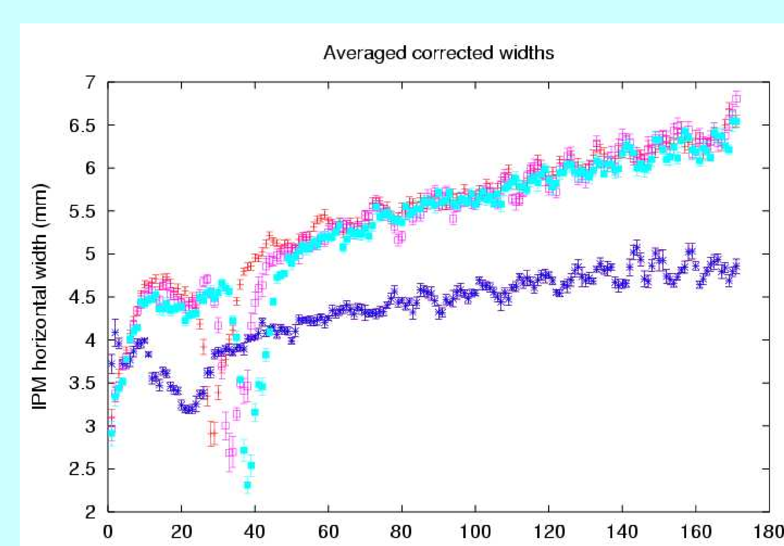


Simulation used to scan parameters and obtain qualitative understanding of sensitivity to various parameters

Synergia horizontal (bending plane) and vertical beam width evolution for different initial parameters

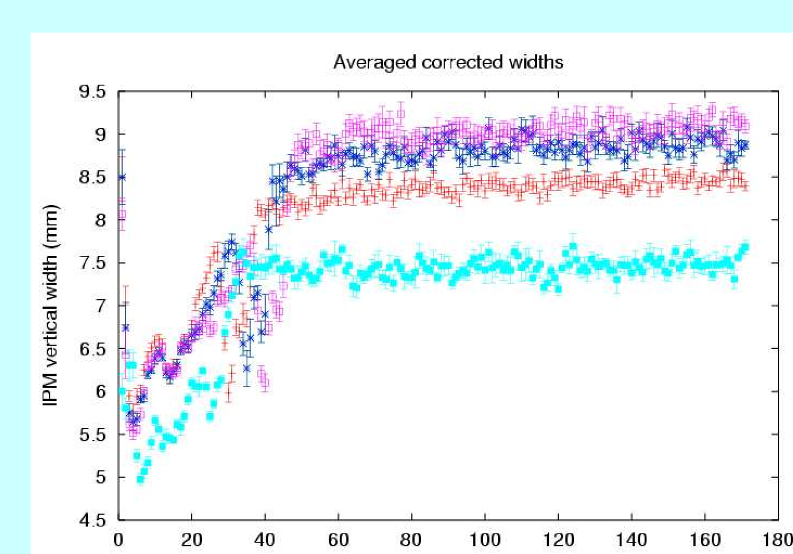


Turn-by-turn measurements of transverse beam profiles are compared to simulation to study effects such as space-charge and lattice perturbations



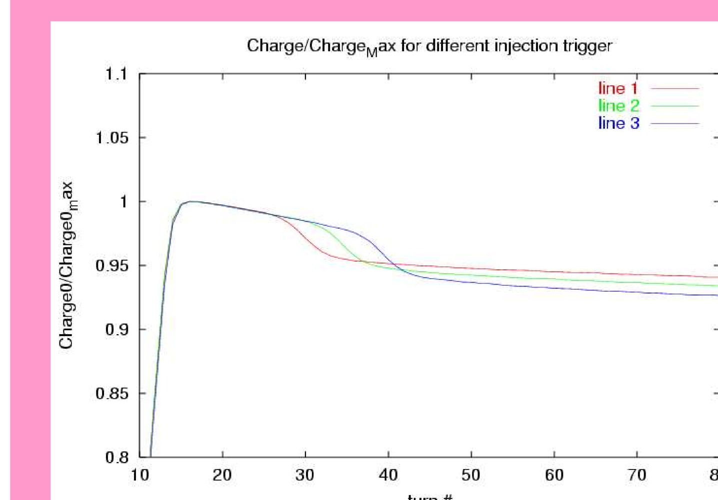
Ionization Profile Monitor (IPM) measurements of the horizontal and vertical beam profiles for different relative beam timing with respect to the injection bump magnet pulse

The fringe-fields of the injection bump (horizontal dipoles) have a larger effect on the vertical beam profile



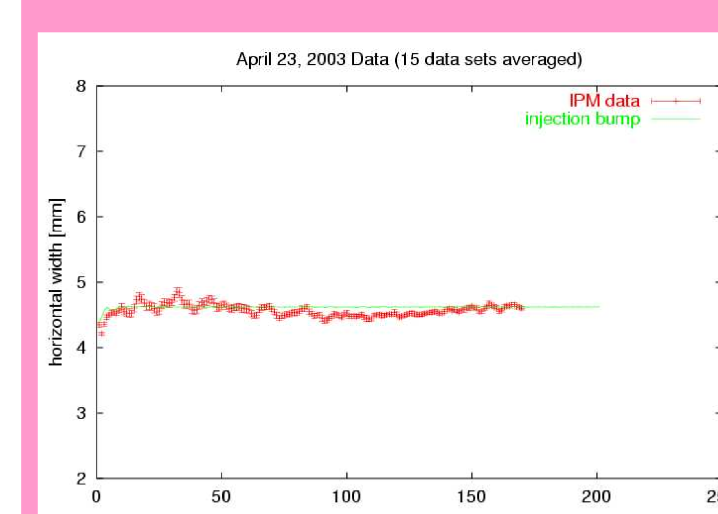
Detail of vertical and horizontal beam width for three different injection bump timing settings

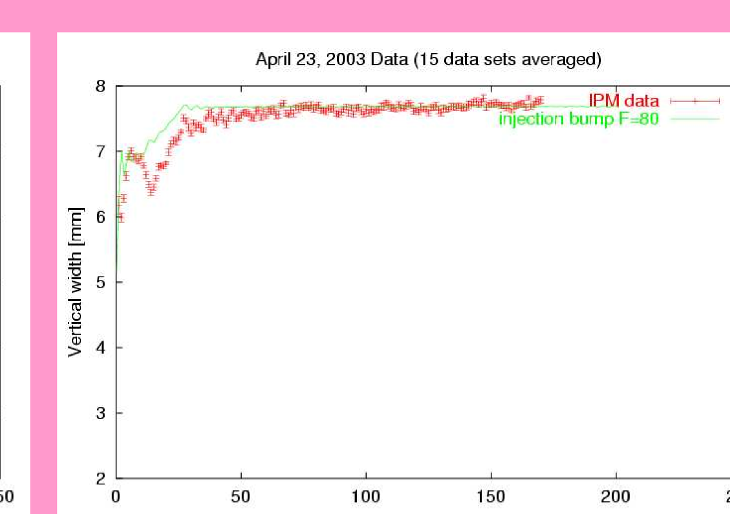
The perturbation of the beam envelope is associated with losses and seems to be correlated to the injection bump magnet operation.

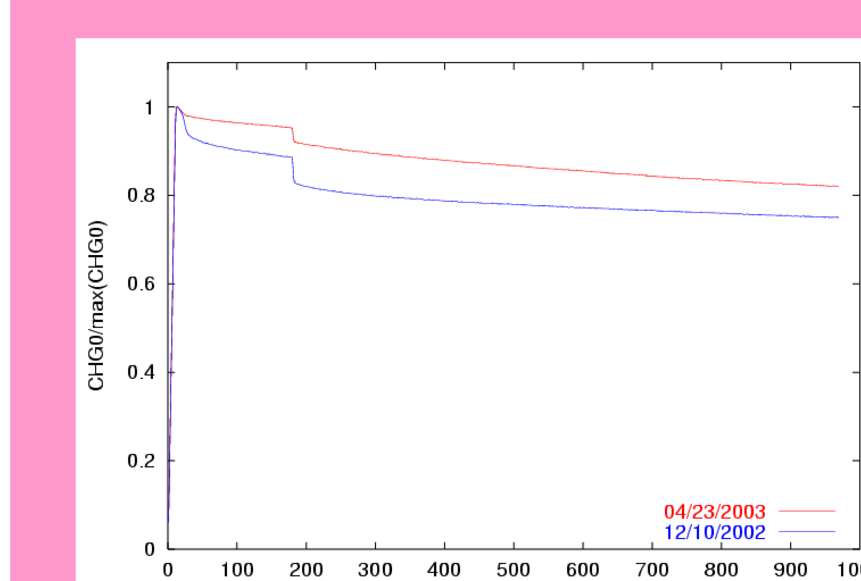


Normalized beam charge early in the cycle. Losses correlate to beam envelope perturbation at injection.

Synergia simulation including a simple model of the injection bump fringe fields, compared to IPM data at injection, for an optimal (minimal losses & beam disturbance) bump configuration







changing the injection bump pulse shape seems to improve losses

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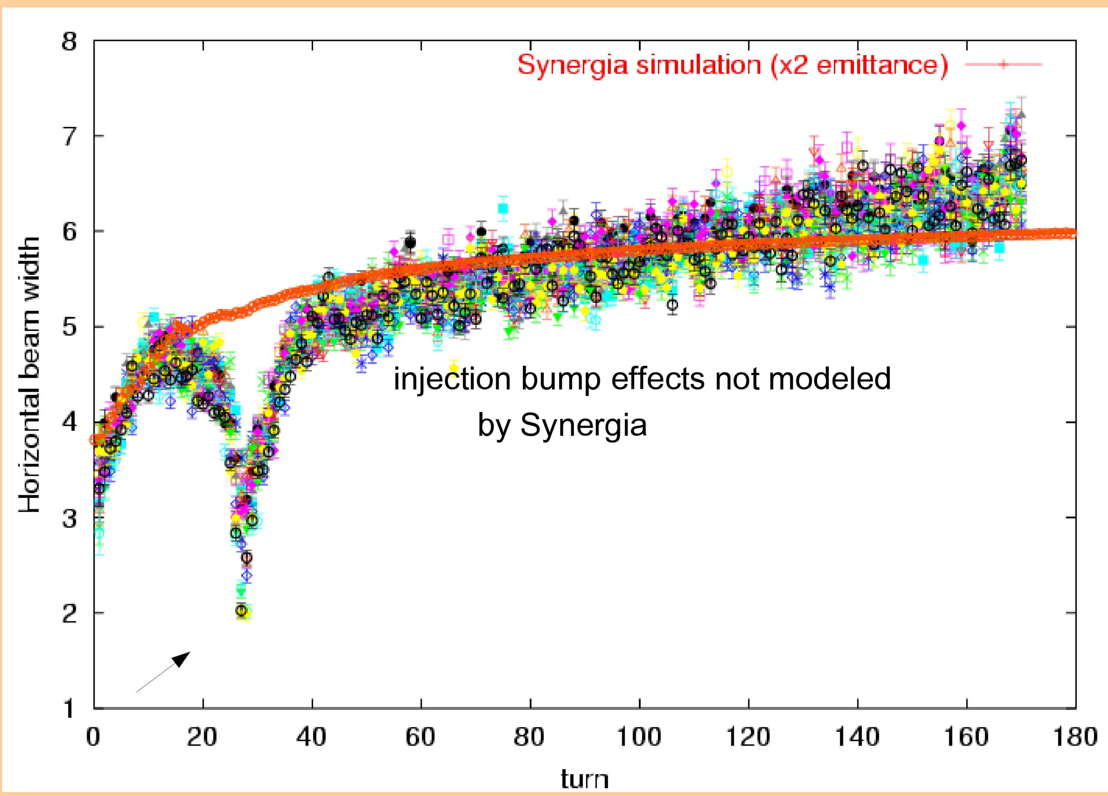
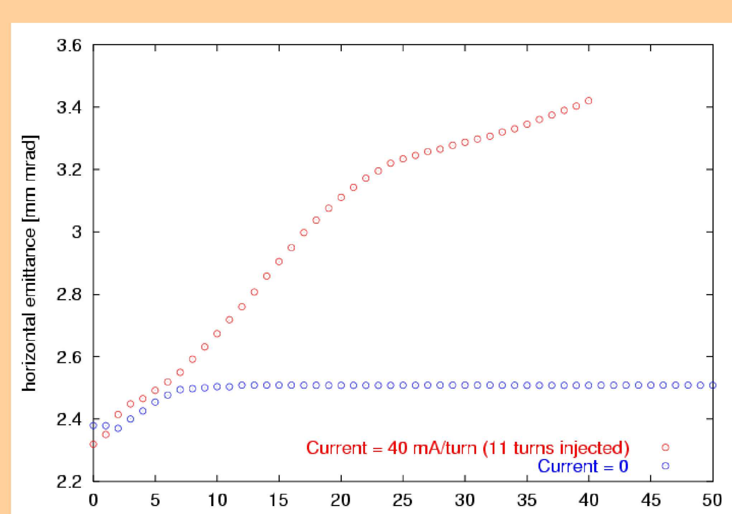
Transverse beam width measurements and simulation

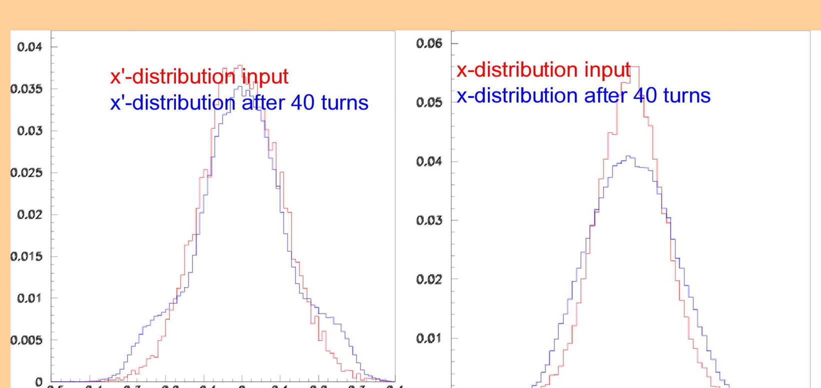
Turn-by-turn Ionization Profile Monitor horizontal beam width measurements for 11 turns of injected beam (400 mA total). 15 data sets are displayed.



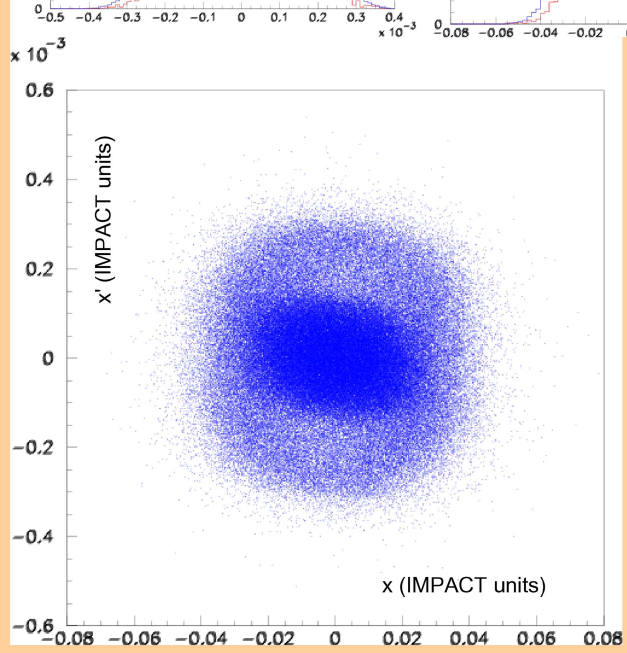
simulated beam with 2 times smaller emittance than nominal Booster emittance

For this emittance, *Synergia* model indicates that growth in width is due to space charge



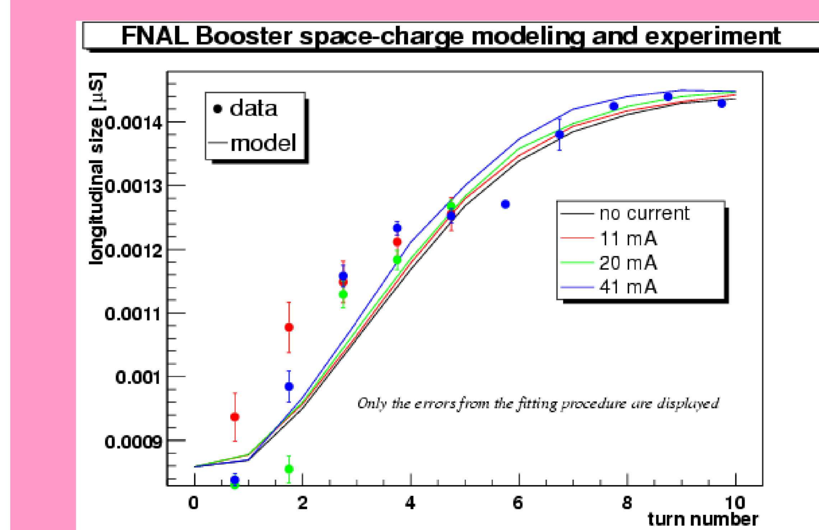


Simulation displays halo growth typical of space charge effects



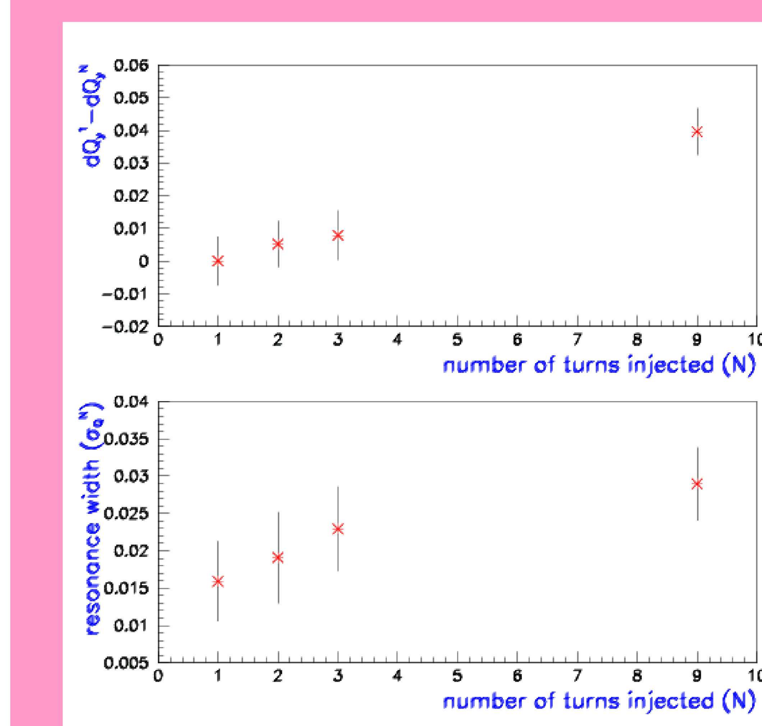
Simulated transverse phase space projected onto horizontal plane after 40 turns (88 ms)

Longitudinal beam width evolution at injection measured with a Resistive Wall Monitor and compared to the Synergia prediction



Measurement shows little if any space charge dependence as predicted by Synergia for beam currents in the range 10-40 mA.

Studies of tune shift versus injected charge using resonance scans



Calculating the relationship between measured tune difference (dQ) and the space-charge tune shift (ΔQ_{sc}):

$$Q = Q_0 + \Delta Q_{sc} + \Delta Q_{quad}$$

$$\Delta Q_{quad} = \frac{dQ}{dI}(\Delta I_{quad})$$

$$A: \frac{1}{2} = Q_0 + \Delta Q_{sc}^1 + \frac{dQ}{dI}(\Delta I_Q^1)$$

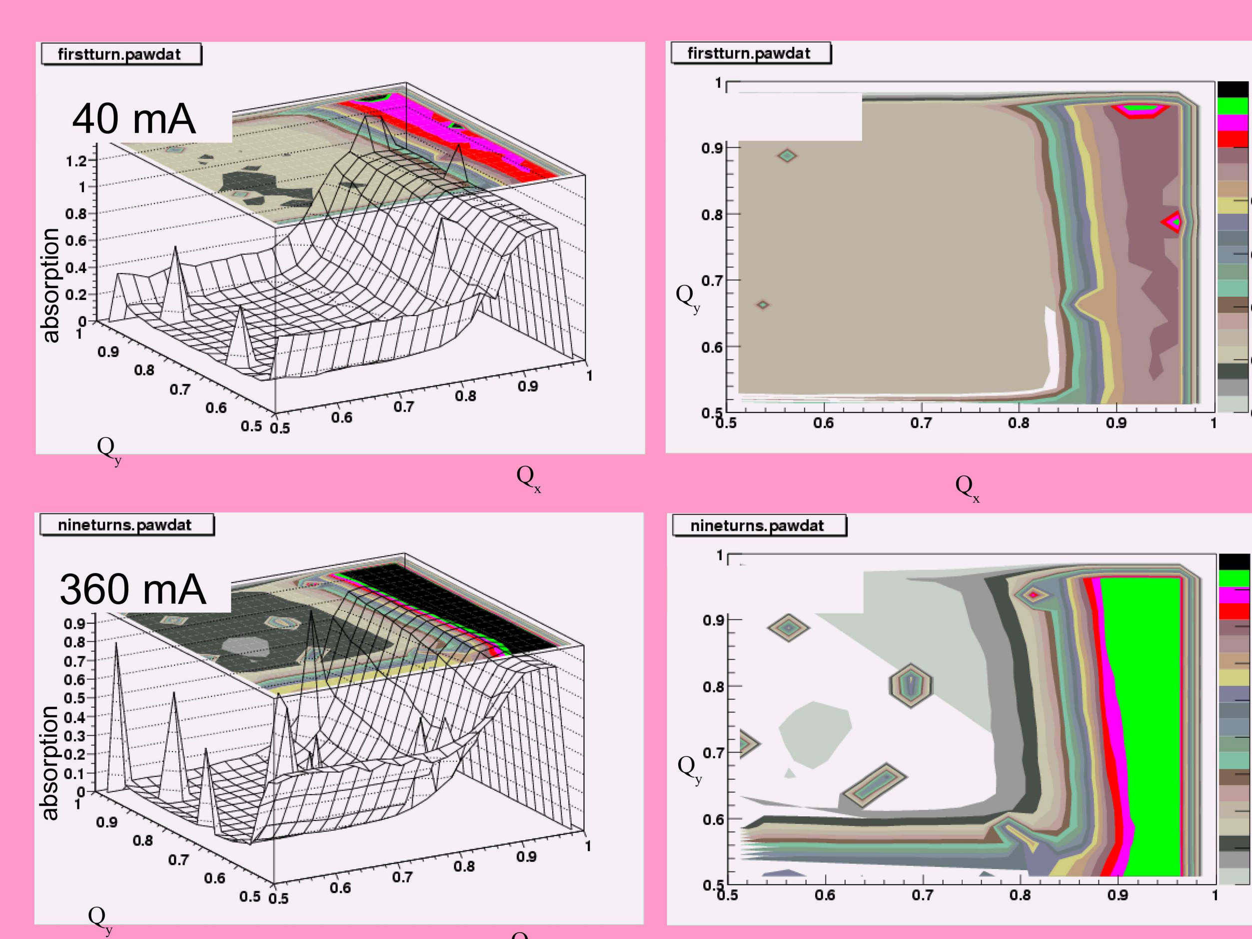
$$B: \frac{1}{2} = Q_0 + \Delta Q_{sc}^N + \frac{dQ}{dI}(\Delta I_Q^N)$$

$$B - A: 0 = \Delta Q_{sc}^N - \Delta Q_{sc}^1 + \frac{dQ}{dI}(\Delta I_Q^N - \Delta I_Q^1)$$

$$\Delta Q_{sc}^N - \Delta Q_{sc}^1 = \frac{dQ}{dI}(\Delta I_Q^1 - \Delta I_Q^N)$$

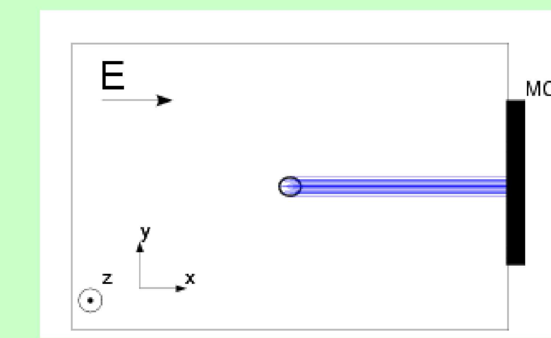
$$\Delta Q_{sc}^N - \Delta Q_{sc}^1 = dQ_{(x/y)}^1 - dQ_{(x/y)}^N$$

Individual resonance scans

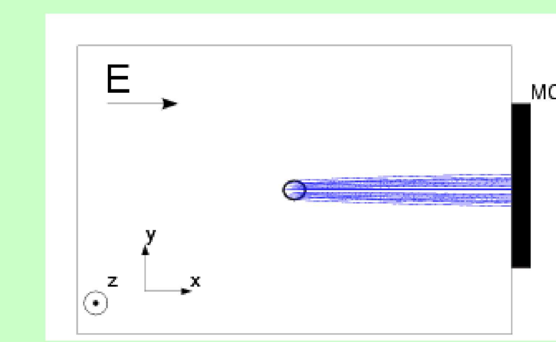


Calibrating the Booster Ionization Profile Monitor

The IPM is the only device in the Booster which can provide turn-by-turn information on the transverse beam profile throughout the machine cycle



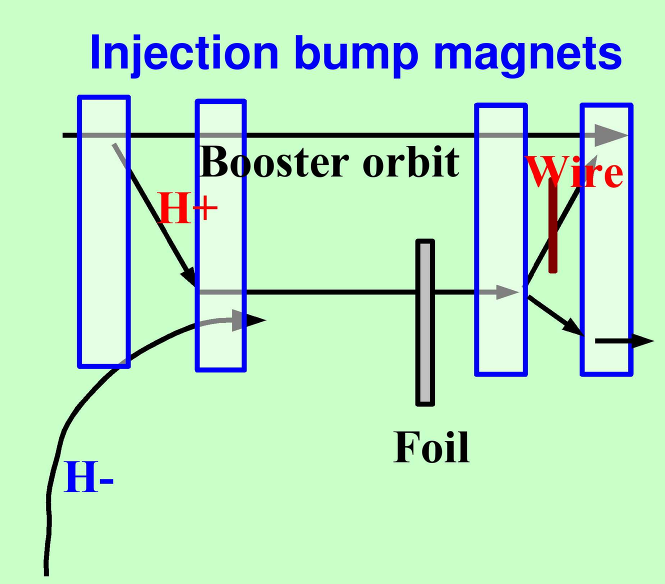
modeled IPM response: limit of zero charge

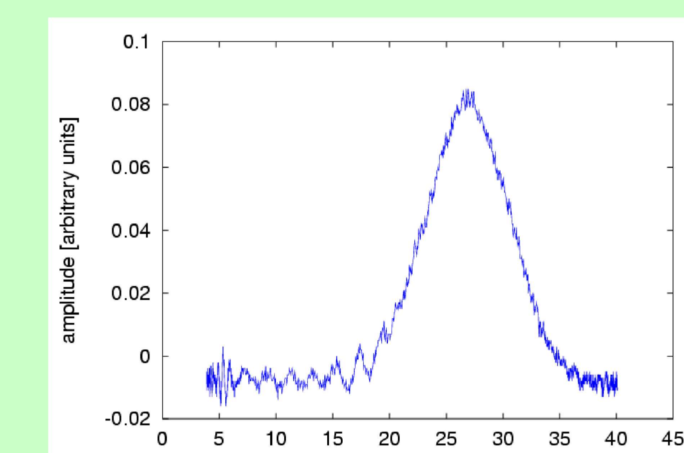


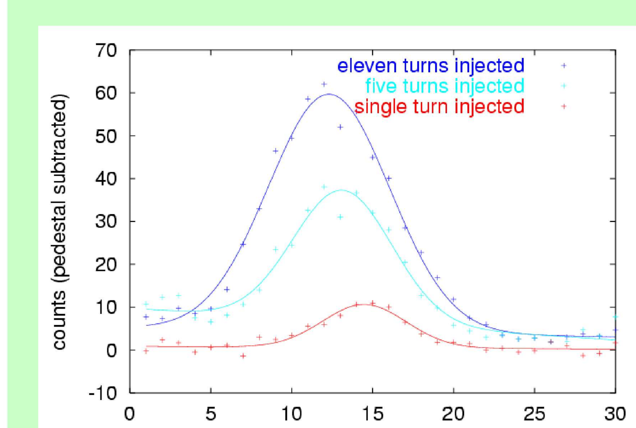
modeled IPM response: beam charge effects on ion trajectories

The response of the IPM depends on the size and charge of the beam, so it is imperative to calibrate the detector for different beam conditions.

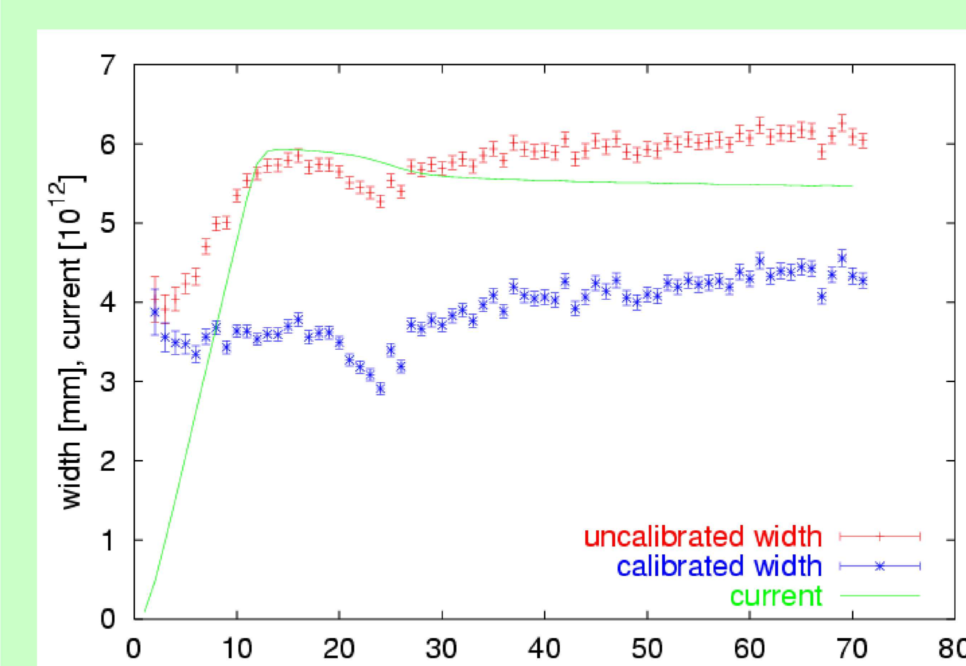
use MWPC at extraction line and "flying beam wire" at injection together with 2-D electromagnetics model of IPM to calibrate







IPM measured widths are compared to "flying wire beam" and MWPC widths for different beam currents. Calibration function extracted as a function of charge and tranverse beam size.



IPM calibration results:
uncalibrated width shows apparent growth at injection correlated with the increase of machine current during injection. Calibration eliminates this problem.