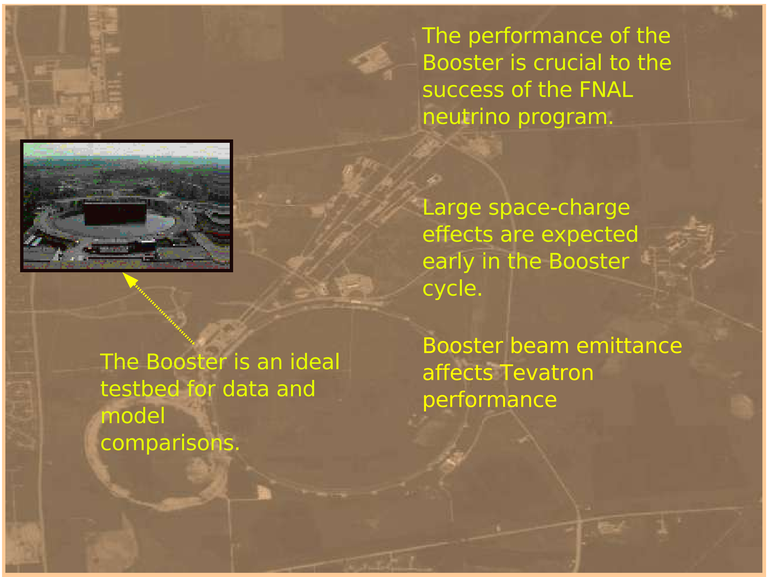
Space Charge Experiments and Simulation in the Fermilab Booster

J. Amundson and P. Spentzouris
Fermi National Accelerator Laboratory

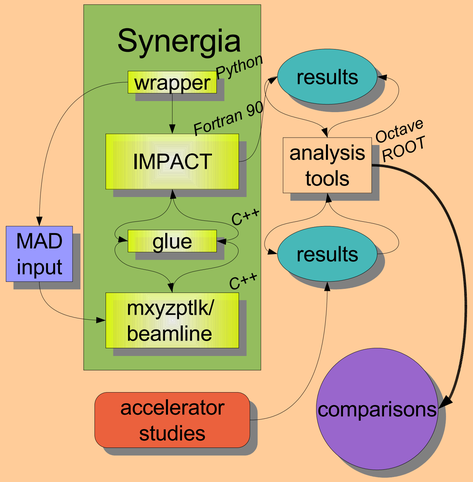
members of the “SciDAC Accelerator Science and Technology” project



The Fermilab Booster

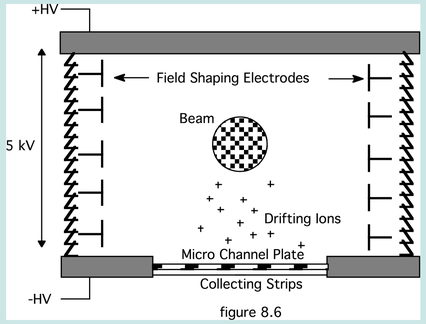
Rapid cycling, 15 Hz, 400 MeV → 8 GeV
24 FOFDOOD 19.76 m long cells
RF: 37.8 ->52.1 MHz
16 RF cavities
Emittance: 12π mm mrad, 0.25 eV sec
H^- injection, injection bump, stripping foil
Injection/capture/bunching ~ 2ms

Synergia



Booster Ion Profile Monitor (IPM)

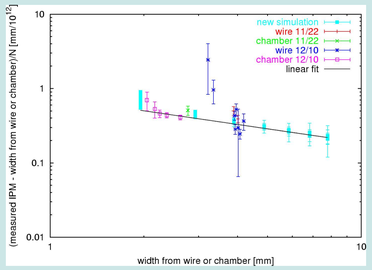
- Horizontal and Vertical transverse profiles
- Turn-by-turn measurements for entire cycle
- Detector response requires non-trivial calibration



IPM layout

IPM Simulation and Calibration

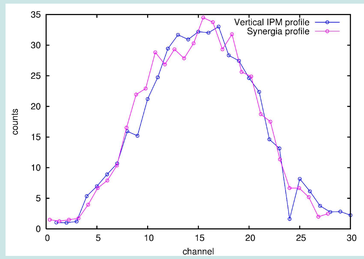
- Model of IPM takes into account detector geometry, beam shape and beam current
- Used for calibration, i.e., extracting true widths from detector
- Used for direct simulation, i.e., comparing beam simulation with detector



Calibration of detector using independent beam width measurements

J. Amundson, J. Lackey, P. Spentzouris, G. Jungman and L. Spentzouris, ***Phys. Rev. ST Accel. Beams 6:102801, 2003***

Simulated beam from Synergia processed through IPM simulation and compared with raw IPM data



Transverse Profiles

Fit the function

$$f(x) = g(x) + \ell(x),$$

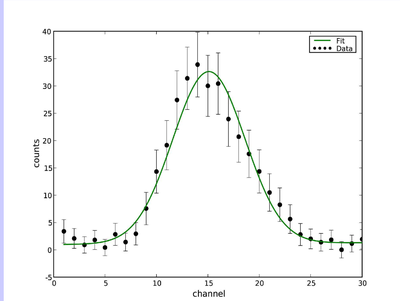
where

$$g(x) \equiv N exp\left[-\frac{(x-x_o)^2}{2\sigma^2}\right]$$ *Gaussian*

and

$$\ell(x) \equiv c_o + c_1 x$$ *Linear*

Function f(x) fit to typical IPM profile



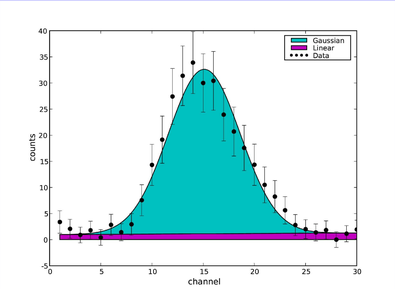
Characterizing Beam Shape by L/G

Define

$$L \equiv \int_{detector} \ell(x)dx$$ *Linear (non-Gaussian) contribution to integral*

$$G \equiv \int_{detector} g(x)dx$$ *Gaussian contribution to integral*

L/G characterizes the beam shape.
Non-zero L/G indicates the presence of halo.



Same profile as above showing Gaussian (G) and Linear (L) contributions

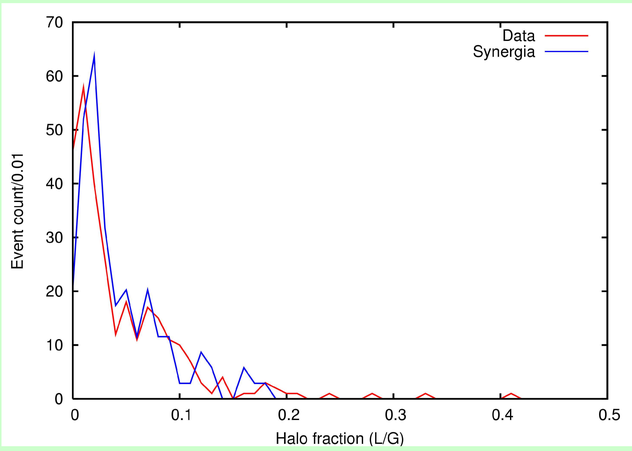
Space Charge Experiments and Simulation in the Fermilab Booster

J. Amundson and P. Spentzouris
Fermi National Accelerator Laboratory

members of the “SciDAC Accelerator Science and Technology” project

Simulated and Measured L/G

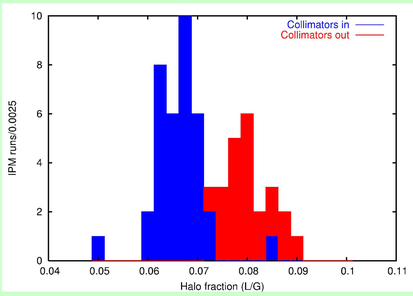
- Calculate L/G from IPM data
- Apply detector simulation to beam from Synergia run
- Calculate distribution of L/G values



Distribution of L/G values from experiment, as compared with results from Synergia

Using L/G to see the effects of FNAL Booster collimators

- Collimators recently added to Booster
- L/G measurement demonstrates that the collimators are effective in reducing halo



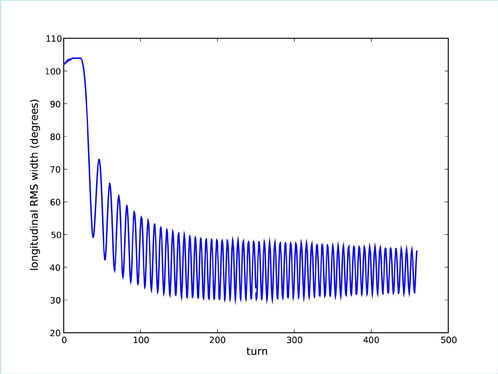
Comparison of L/G measurements with and without Booster collimators

Booster Bunching Phase Simulation with Space Charge

Parameters

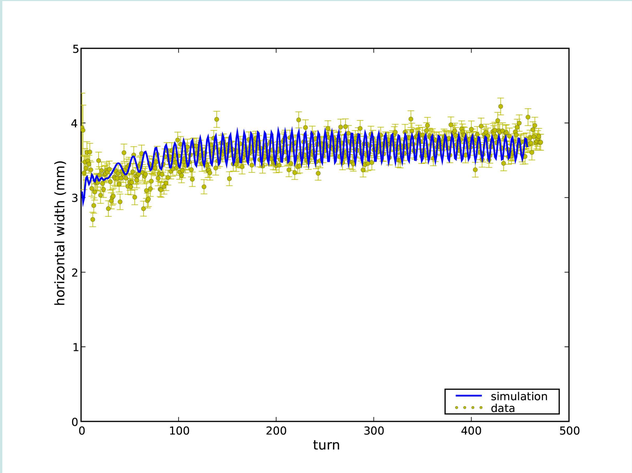
- 42 mA Linac beam with 200 MHz structure injected over 10 turns for a total of 420 mA
- Beam debunches for 20 turns
- Adiabatic capture in 37.8 MHz buckets achieved by ramping from paraphased RF cavities to fully-bunching RF cavities over the course of 200 turns

Longitudinal evolution



Evolution of longitudinal beam size during injection and adiabatic capture in a Synergia simulation

Horizontal evolution



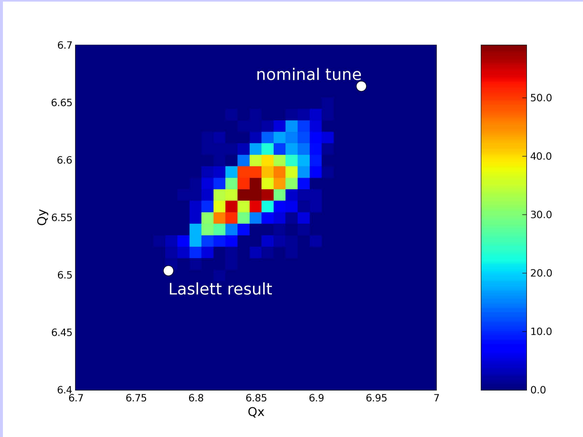
Evolution of horizontal beam size during injection and adiabatic capture in a Synergia simulation compared with IPM data

Space Charge Tune Studies

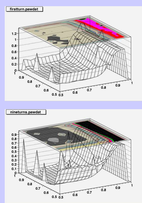
Tune footprint

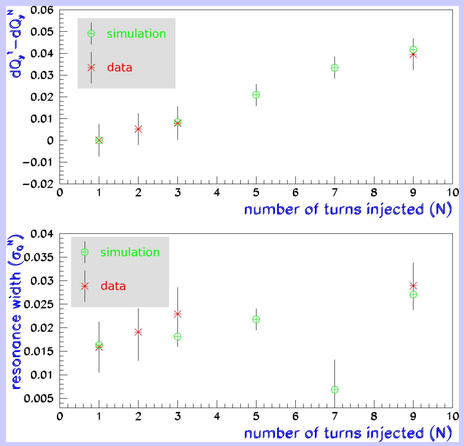
- Calculated using Synergia simulation without bunching
- Results compared to Laslett formula for a Gaussian beam

$$\Delta\nu = \frac{-N r_0}{4\pi\beta^2\gamma^3\epsilon_{\rm rms}}$$



Coherent tune measurement



- Horizontal and vertical tunes varied by tuning quads
- Resonances located by measuring beam transmission
- Multiple currents
- Tune shifts extracted from shifted resonance locations

Extracted tune shifts as a function of current. Simulation results are from Synergia.