Summary of experience with IPM measurements at BNL-RHIC

R. Connolly, R. Michnoff, M. Minty, S. Tepikian

measurement concept and architecture

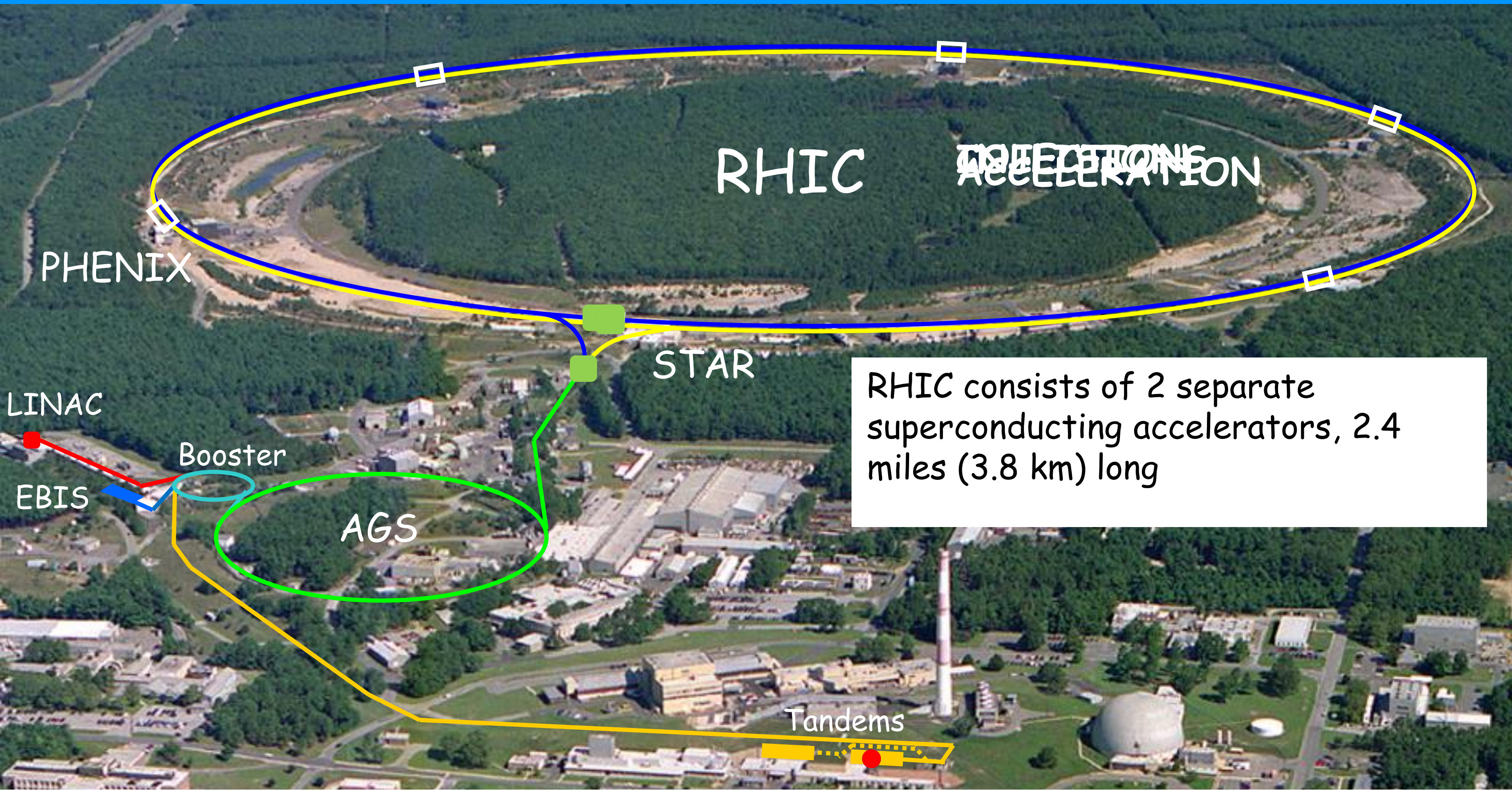
first prototype test and first tests in RHIC

design challenges and solutions

- electron clouds
- sensitivity to beam loss
- dynamic MCP saturation
- rf coupling from beam
- electronic noise

need and plans for absolute beam emittance measurements

Relativistic Heavy Ion Collider (RHIC)



RHIC beams: 110 bunches, each bunch contains ~1E9 ions or ~2E11 protons

RHIC bunches are guided and focused using ~ 1750 superconducting magnets

RHIC bunches are 100 μm at the colliding beam experiements

RHIC bunches circulate at ~ 80 kHz

Measurement Concept

In RHIC the IPMs measure the distribution of free electrons created by ionization of the residual gas.

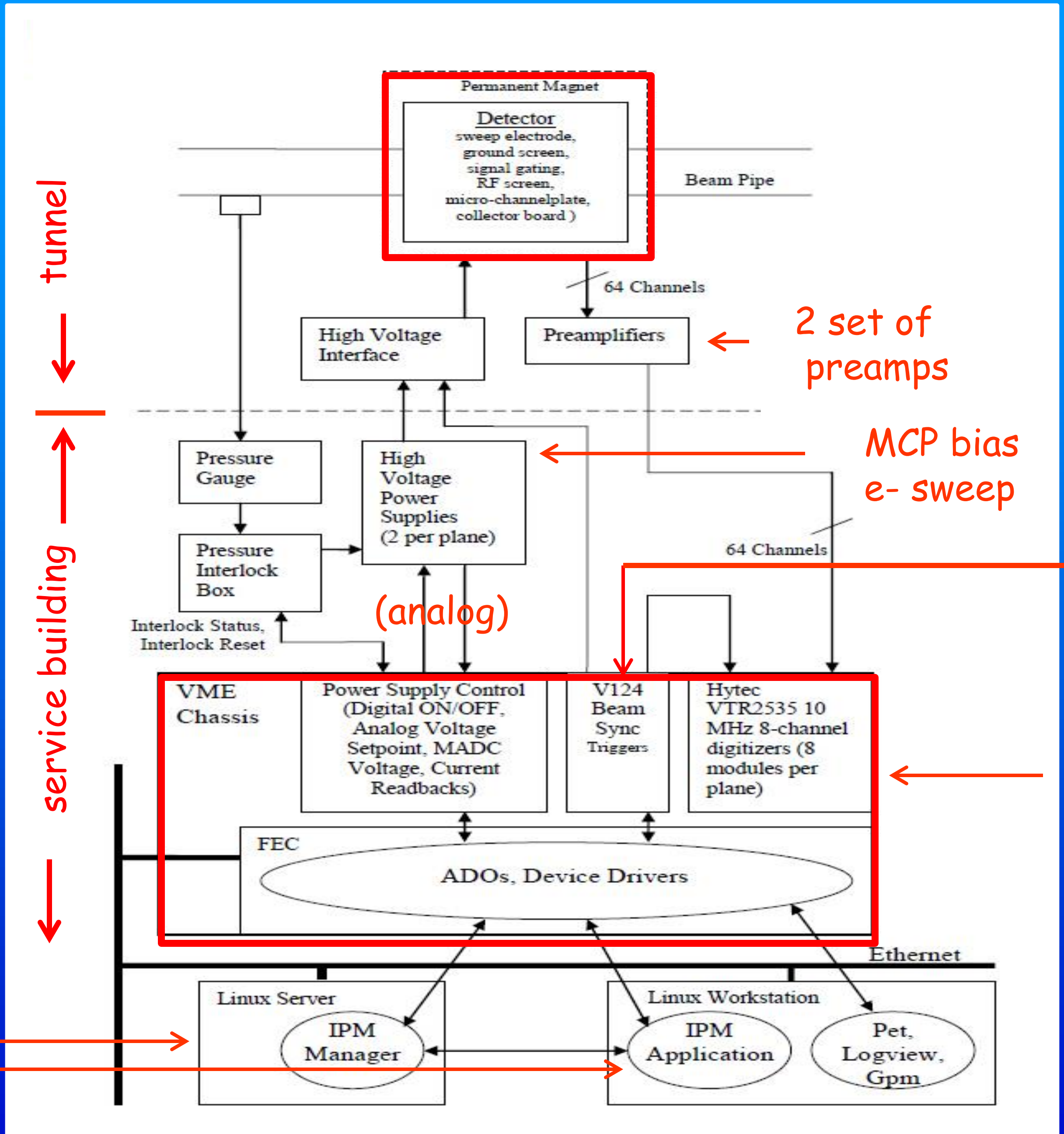
These electrons are swept from the beamline by a transverse electric field, amplified by a microchannel plate (MCP), and collected on an anode consisting of 64 strips oriented parallel to the beam axis.

A beam bunch produces a charge pulse on each strip that is amplified, integrated, and digitized.

The application fits a Gaussian profile to the data. The emittance is calculated using the rms width of the fit and the beta function from the online model.

System Architecture

4 IPMs in RHIC (horizontal and vertical in each of the 2 rings)



provides beam synchronous triggers and bunch pattern request

digitizers

receives from online model dispersion and beta functions; performs fits and displays results

Blue Ring vertical IPM - view inside tunnel

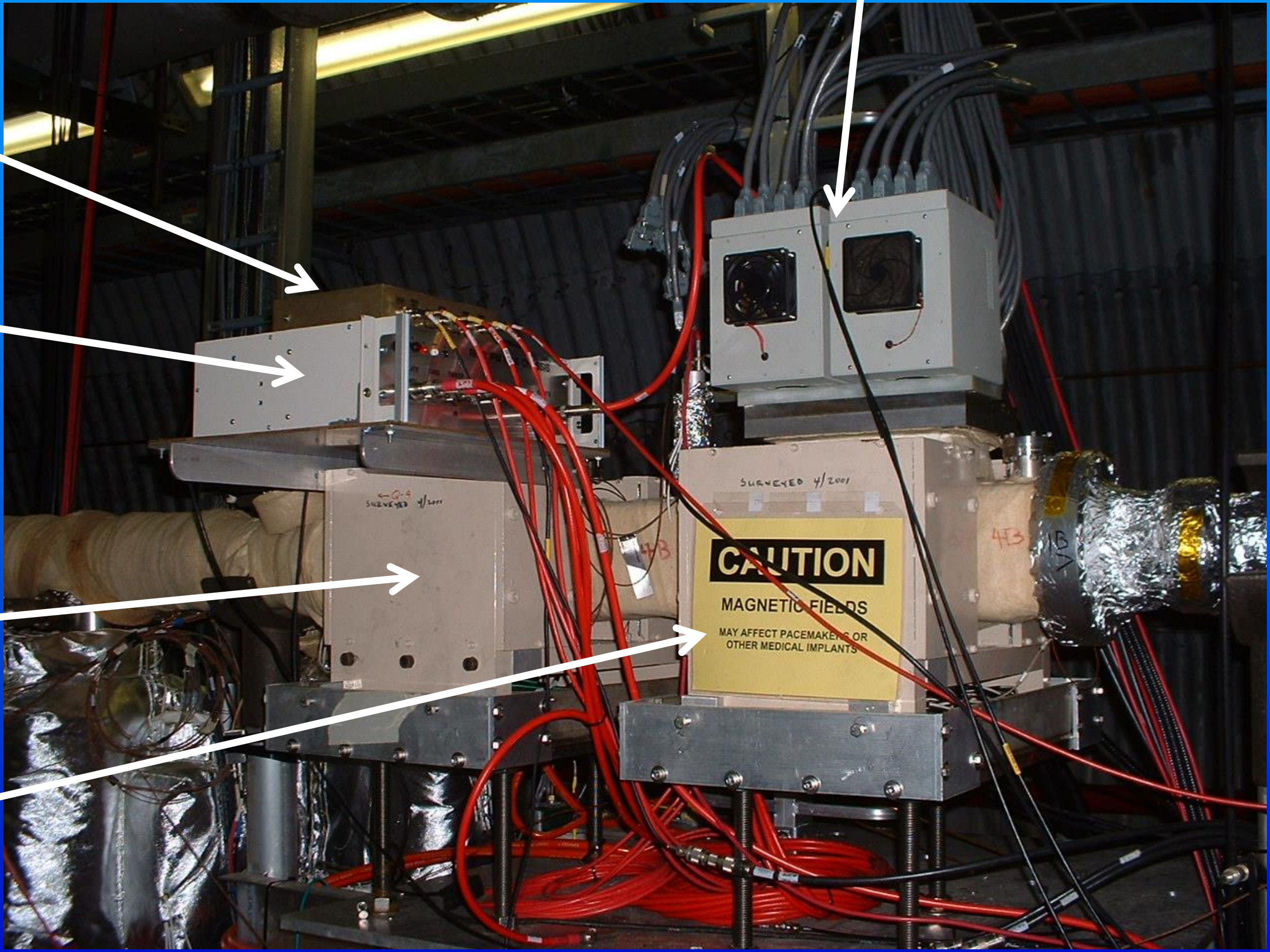
signal amplifiers

MCP bias control

sweep voltage control

corrector magnet

detector magnet



IPM signal processing in service building

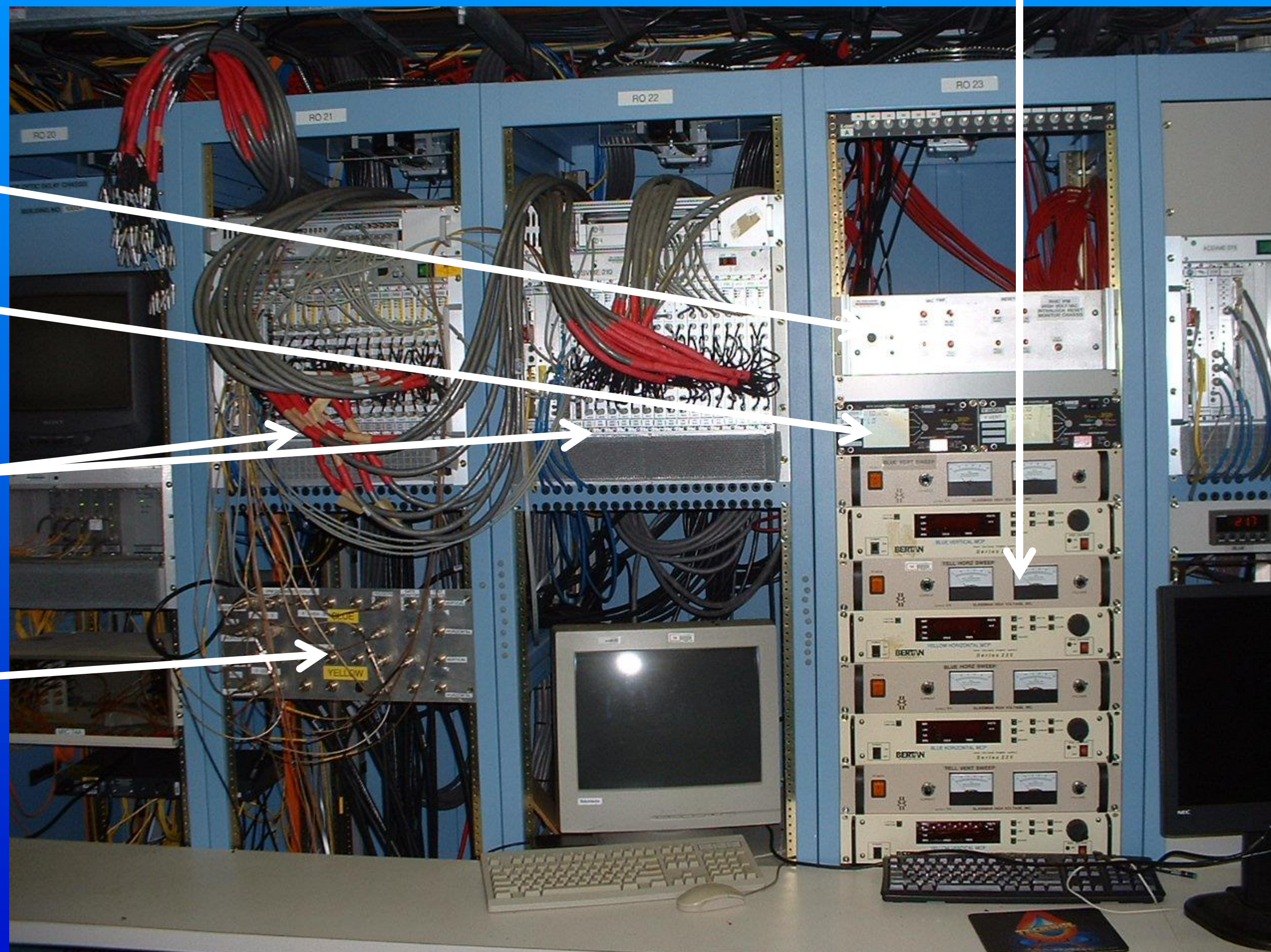
power supplies

vacuum interlock

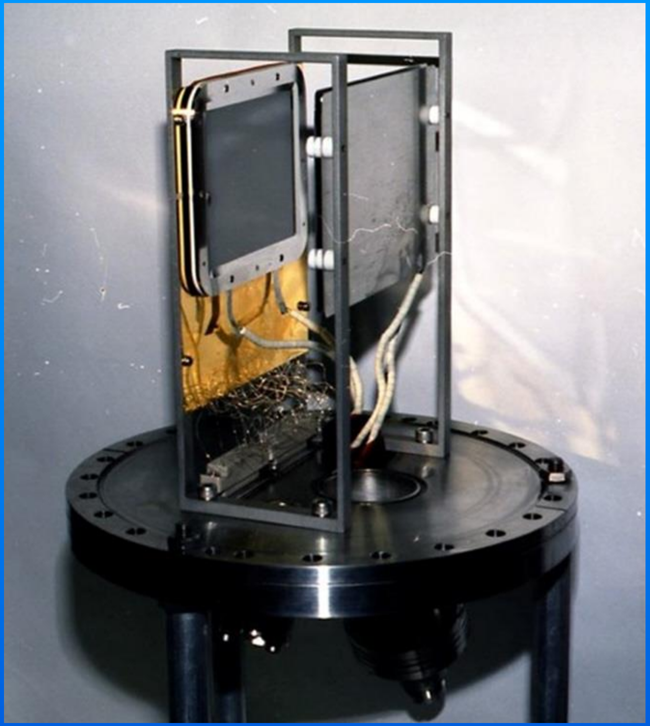
vacuum gauges

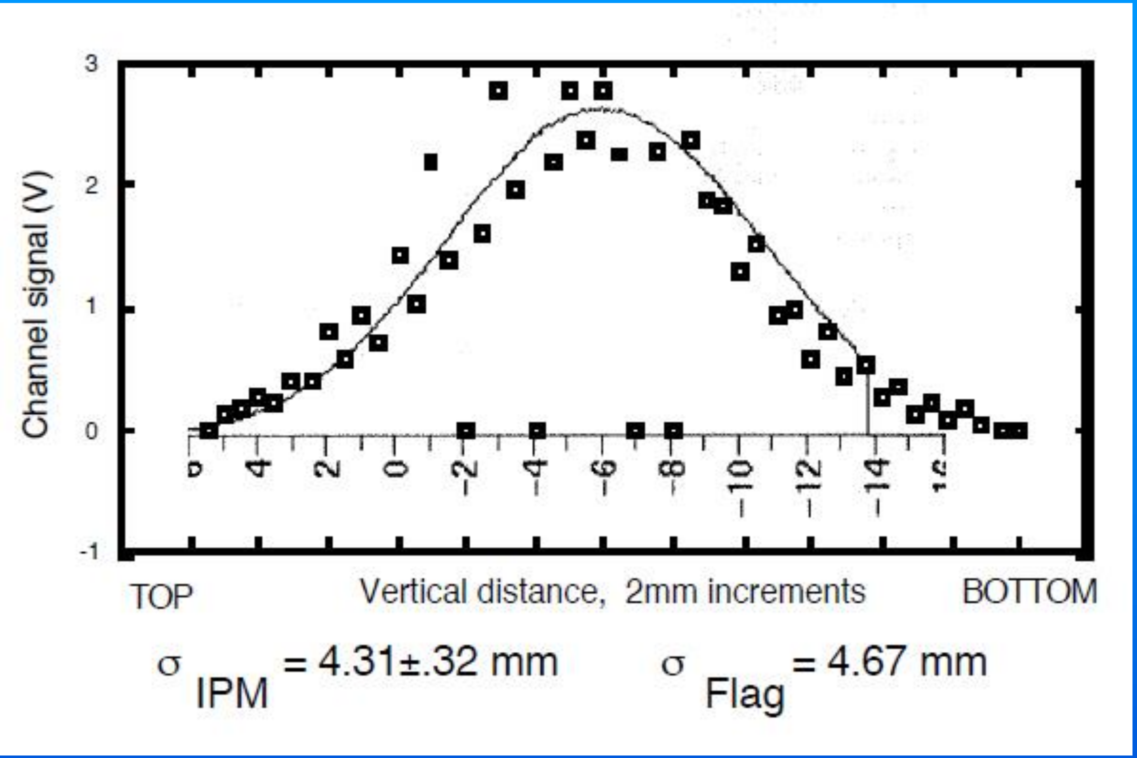
VME crates

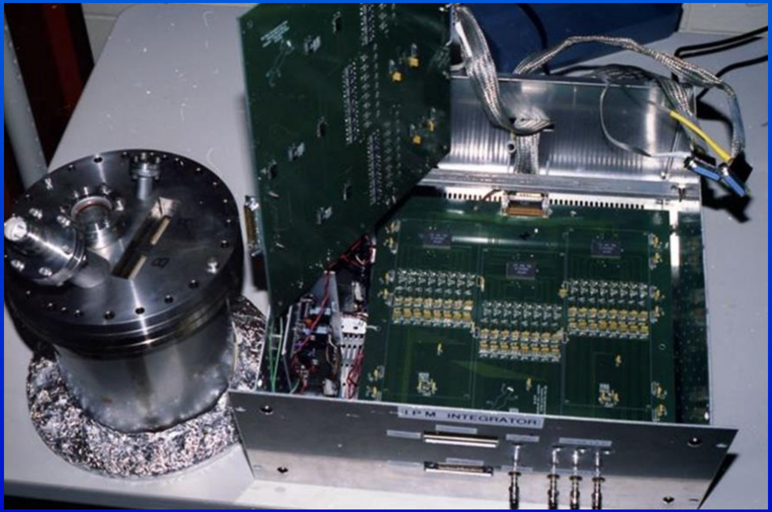
diagnostic patch panel



Dec, 1996 – sextant test

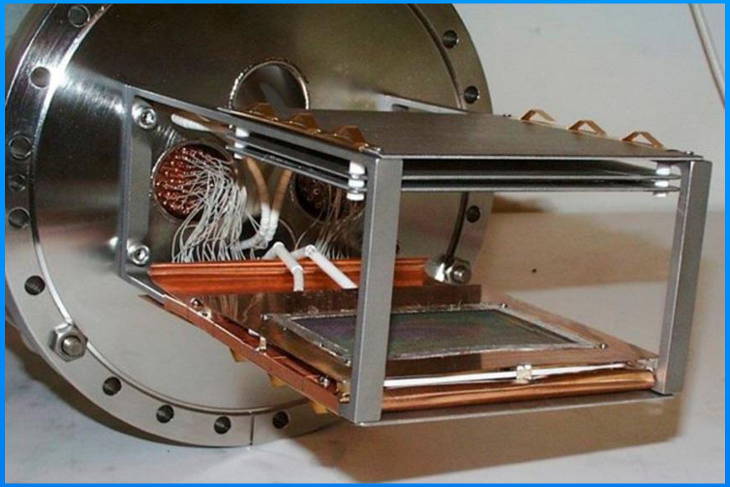


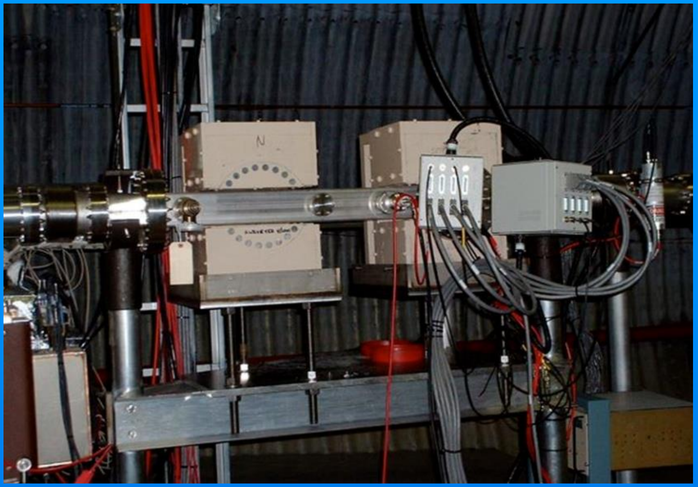


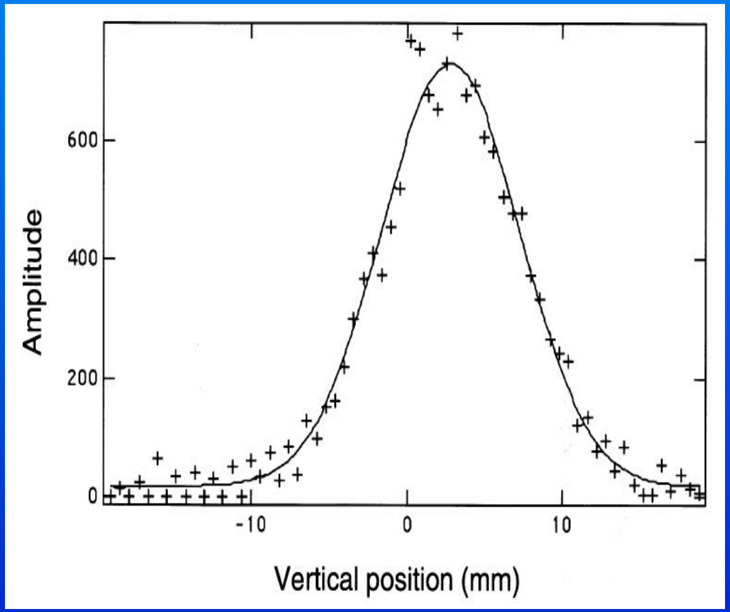


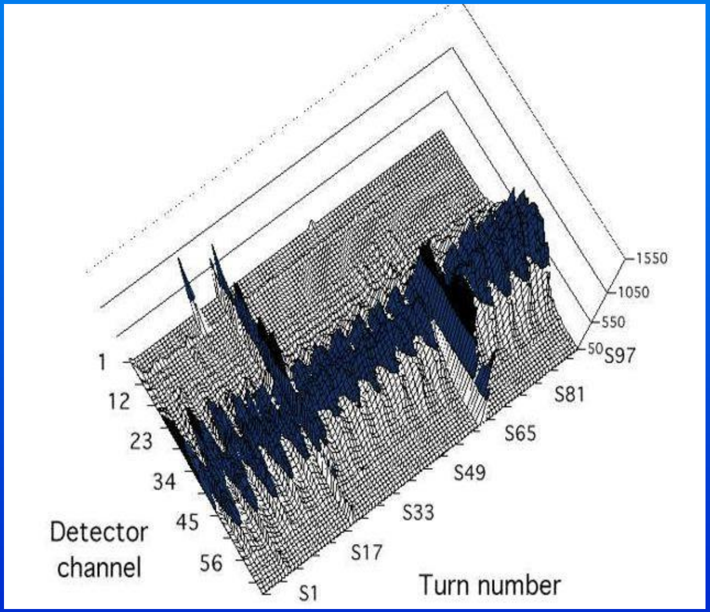
A Prototype Ionization Profile Monitor for RHIC, R. Connolly et al, PAC 1997

August, 1999 – first measurements in RHIC









The RHIC Ionization Profile Monitor, R. Connolly et al, PAC 1999

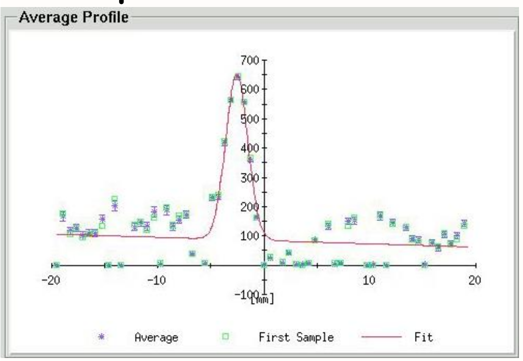
Beam profile measurements and transverse phase-space reconstruction on the relativistic heavy-ion collider, R. Connolly et al, Nucl. Instr. and Meth. A 443 (2000)

Challenges and solutions: electron clouds and sensitivity to beam position

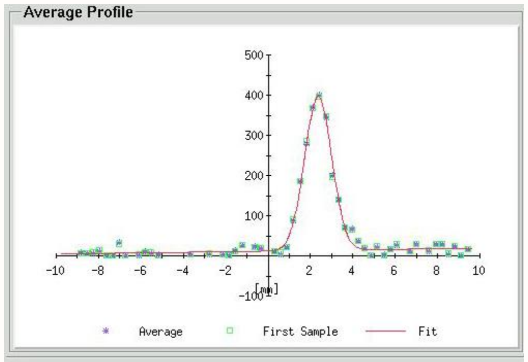
Initially it was thought that dipole would dominate electron transport so no effort was made to shape the electric field. However the beam sizes were observed to vary as the beam was scanned across the aperture.

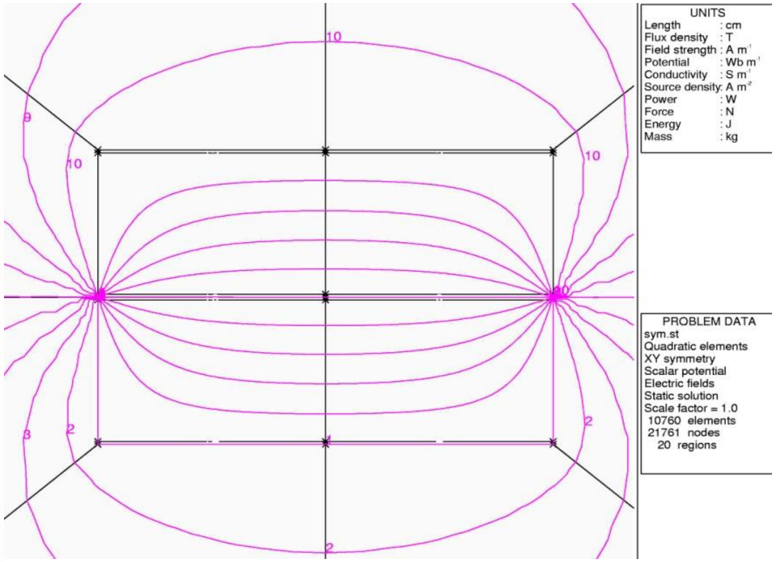
In addition, electron clouds produced large backgrounds

profile before



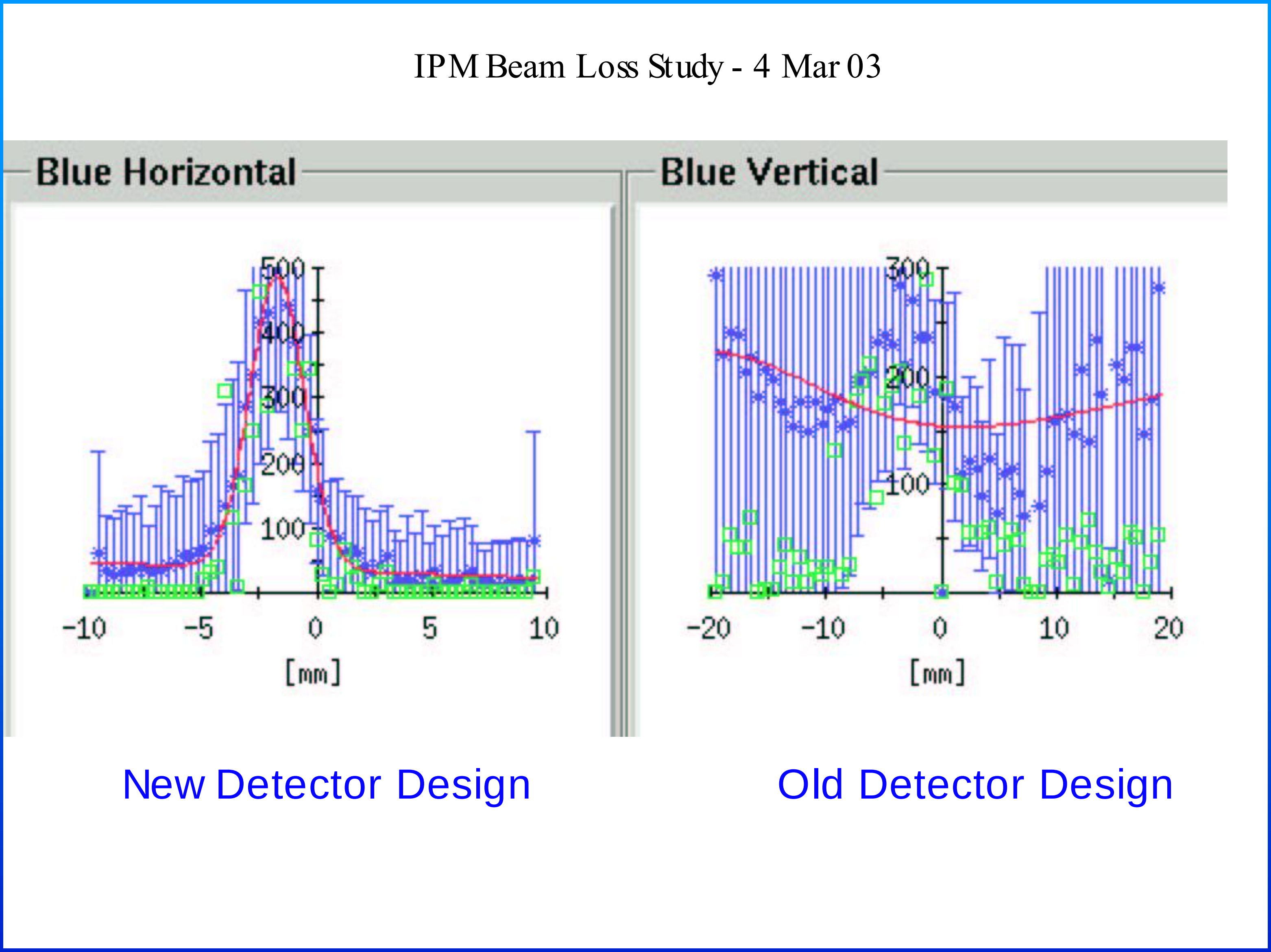
profile after





Both addressed (~2002) by field shaping – extending the high voltage electrodes several cm beyond the volume defined by the MCP aperture

Challenges and solutions: radiation spray from upstream beam losses



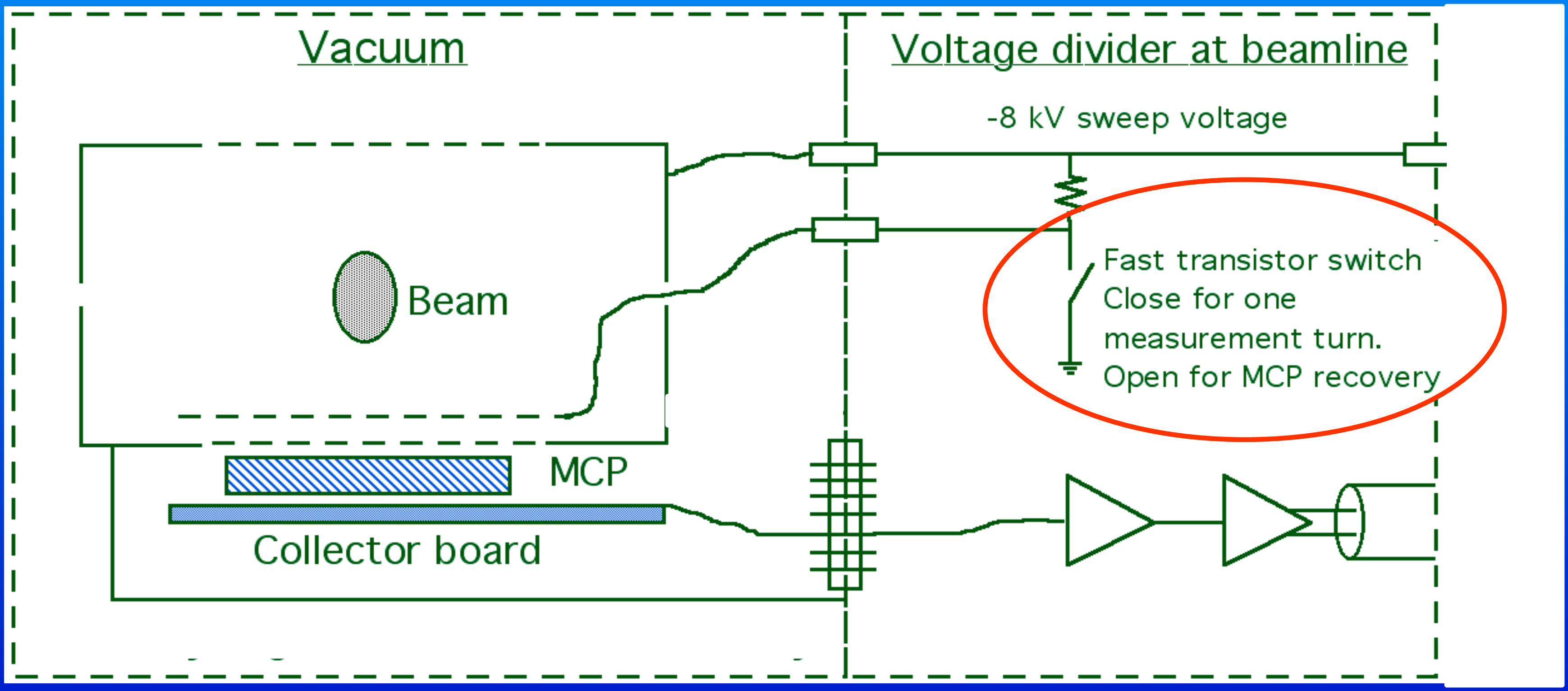
Addressed (~2002) by moving the collector away from the narrow opening angle of the backgrounds and placing the collector in the shadow of several cm of steel

Challenges and solutions: MCP saturation

2003 – signal levels large enough to suppress dynamically the gain of the MCP channels at the center of the beam

2003 – exposure management by switching power supplies on/off inadequate leading to MCP damage

2005 – fast signal gating added to allow MCP to be biased while input signal is absent

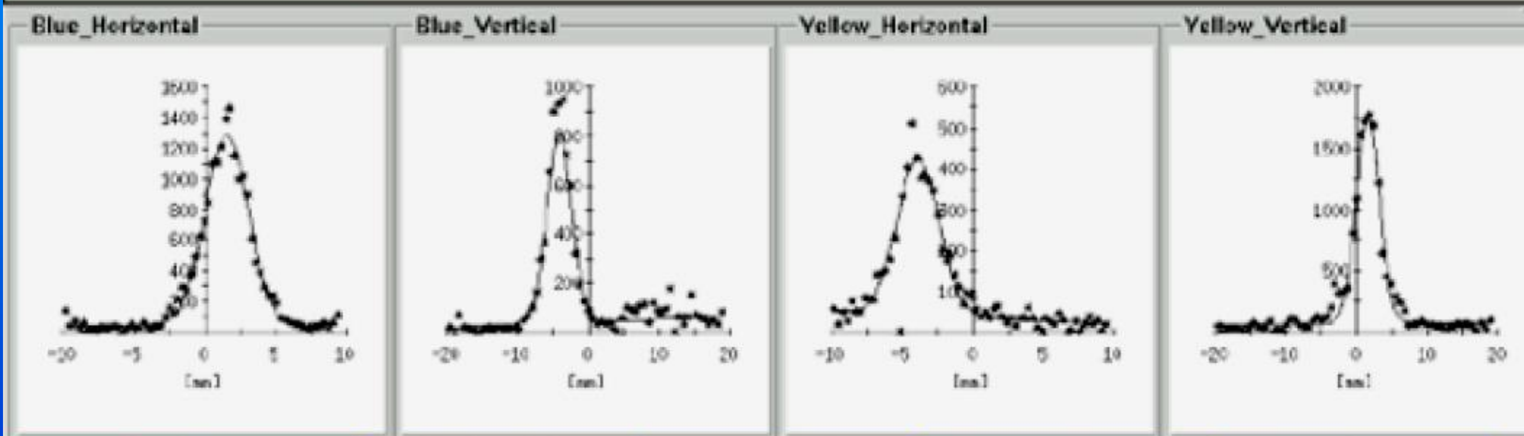


Challenges and solutions: rf coupling from the beam

… due largely to non-negligible detector impedance and antenna-like geometry

2002 – placed rf screen between beam and collector electronics
2005 – replaced screen with hexagonal Al mesh (95% open area, rf attenuation by 80 dB)

Function	Horizontal	Vertical	Horizontal	Vertical
Time-stamp	Apr 07, 19:29:33	Apr 07, 19:29:33	Apr 07, 19:29:33	Apr 07, 19:29:33
Bucket	120	120	120	120
Norm-Emit [pi•mm-mrad]	10.987	7.12025	10.6642	6.52503
Sigma [mm]	1.50847	1.7103	1.48701	1.63341
Intensity	10496.8	8033.9	6791.61	15910
More Info	More...	More...	More...	More...

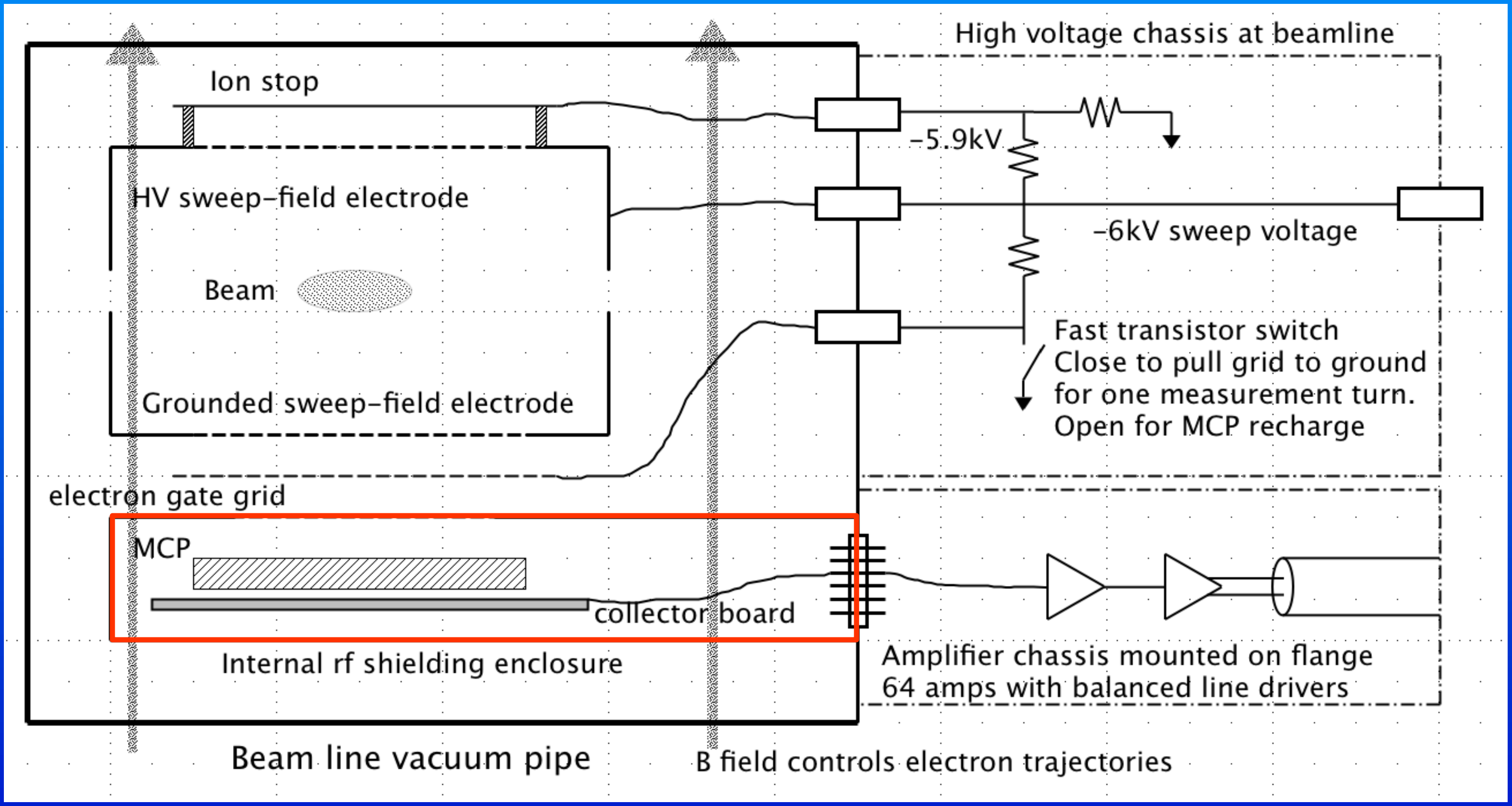


Function	Horizontal	Vertical	Horizontal	Vertical
Time-stamp	Apr 07, 19:34:23	Apr 07, 19:34:23	Apr 07, 19:34:23	Apr 07, 19:34:23
Bucket	120	120	120	120
Norm-Emit [pi•mm-mrad]	10.4295	6.55073	17.7345	8.75073
Sigma [mm]	1.4697	1.64048	1.91761	1.89159
Intensity	20497.4	7436.04	5714.2	13957.2
More Info	More...	More...	More...	More...

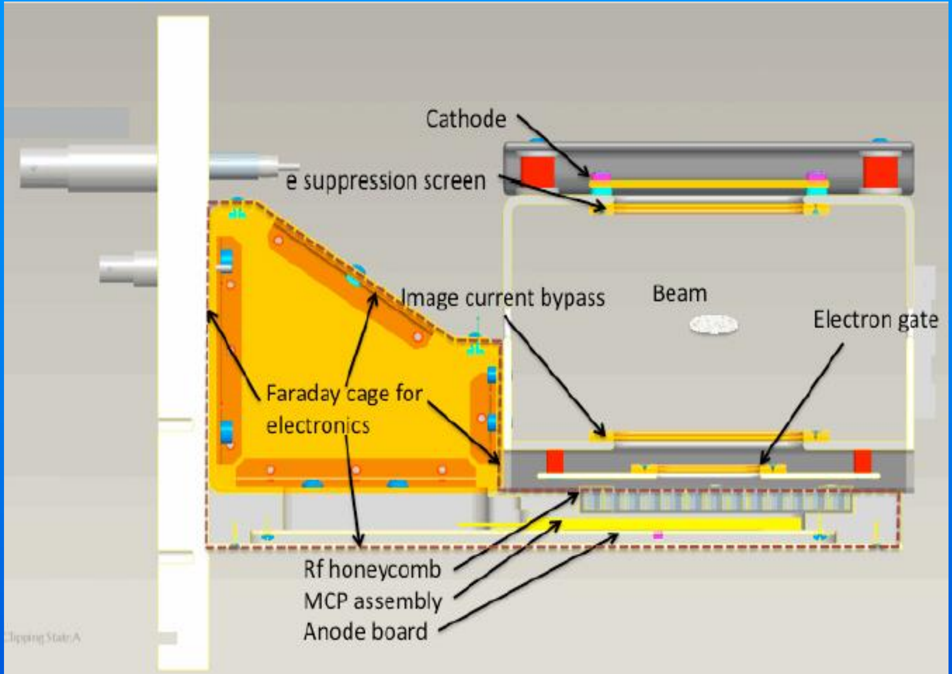
<u>Residual-Gas Ionization Profile Monitors in RHIC</u>, R. Connolly et al, PAC 2005

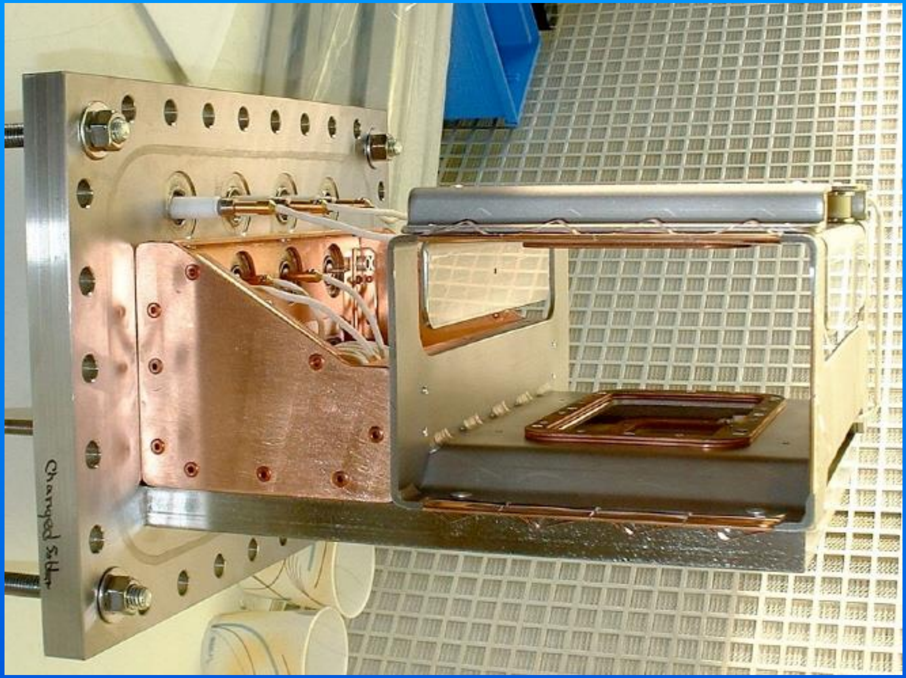
Challenges and solutions: rf coupling from the beam, continued

2007 – all electronics inside Faraday cage electronics → smoother surfaces (low impedance); all electronics out of path of image current

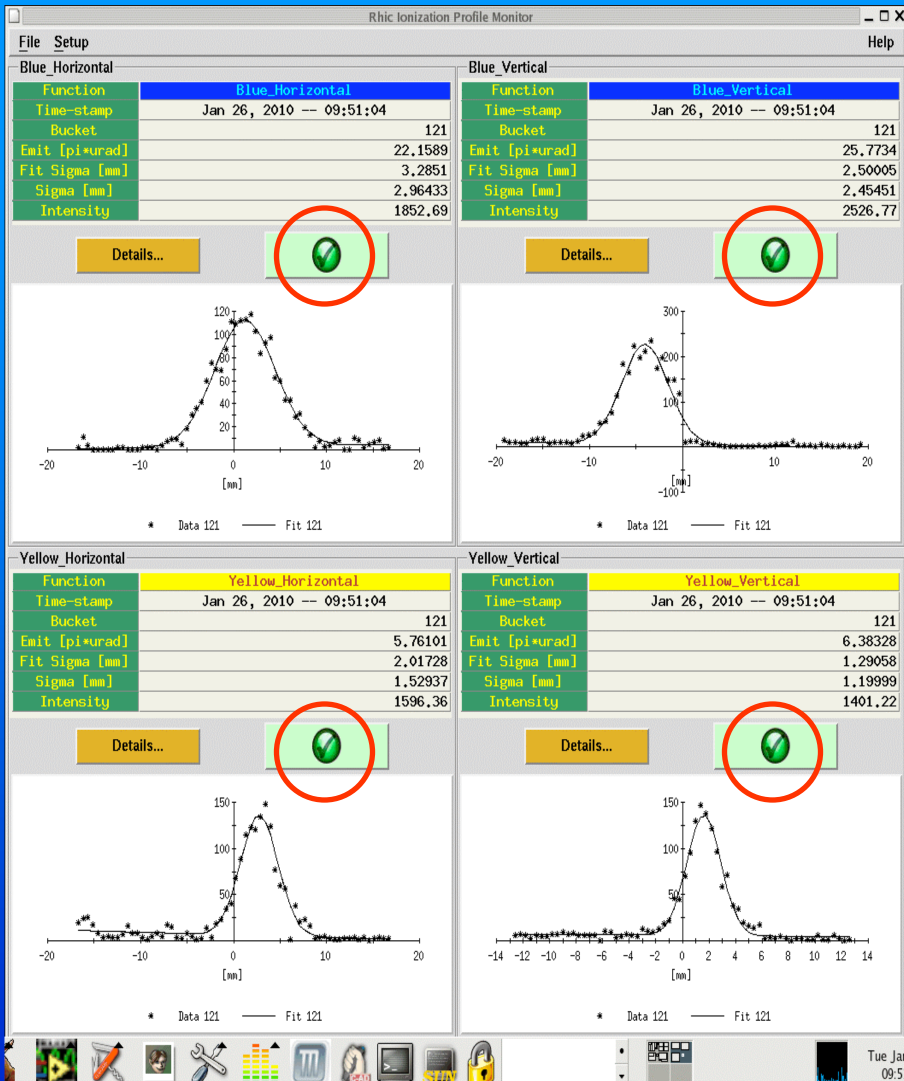


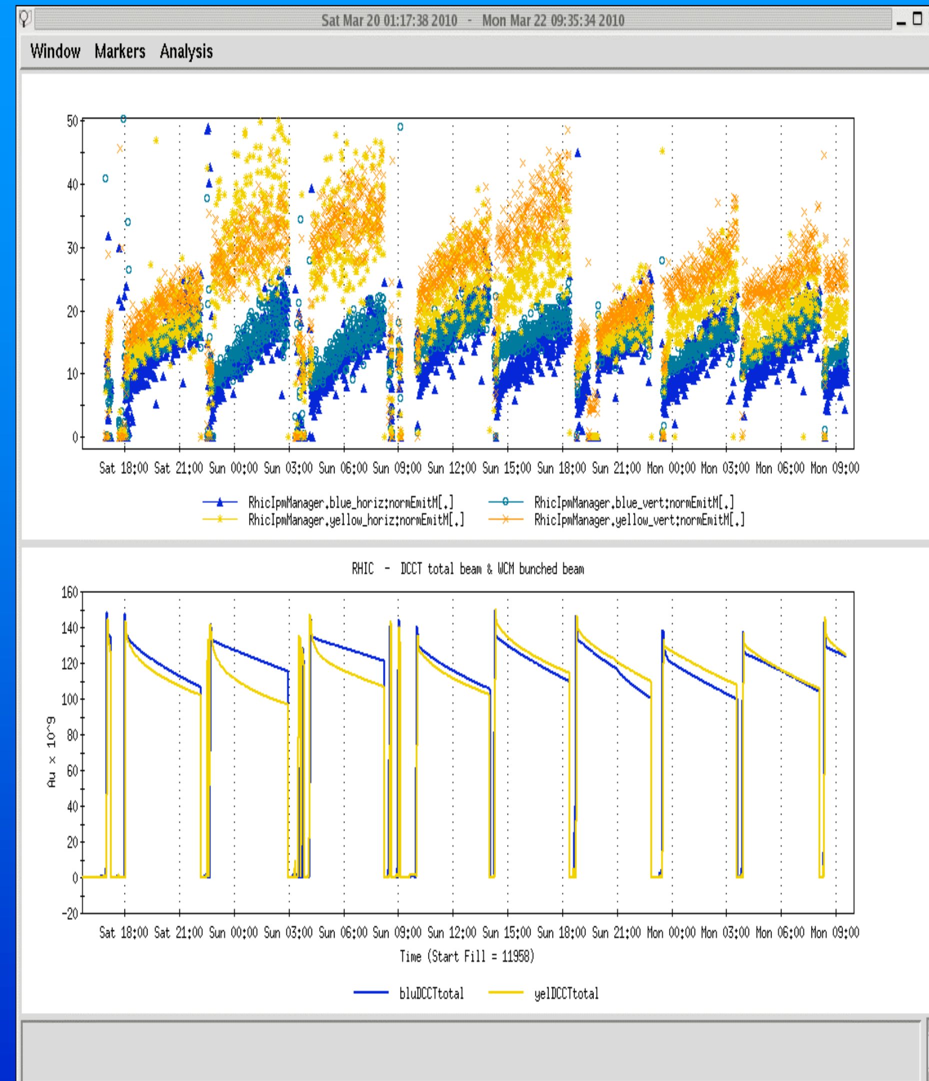
Present RHIC IPM design (mechanical engineering by J. Fite)





Residual-Gas Ionization Beam Profile Monitors in RHIC, R. Connolly et al, PAC 2010

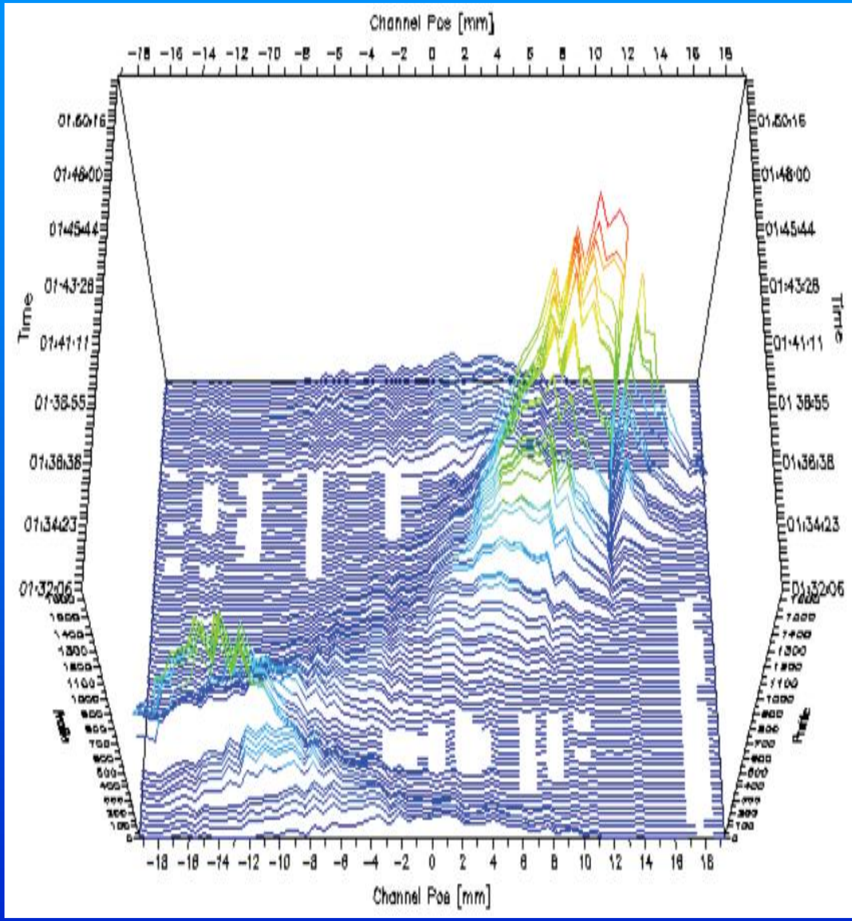


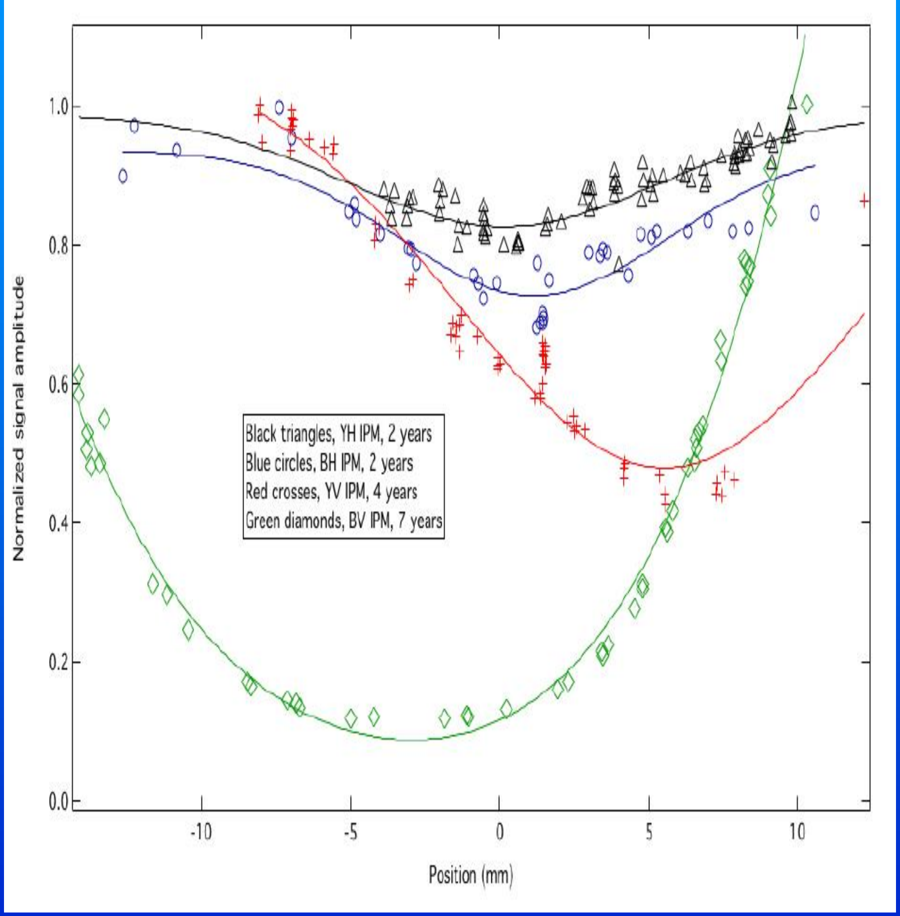


Residual-Gas Ionization Beam Profile Monitors in RHIC, R. Connolly et al, 2010 Beam Instrumentation Workshop

Challenges and solutions: electronic noise

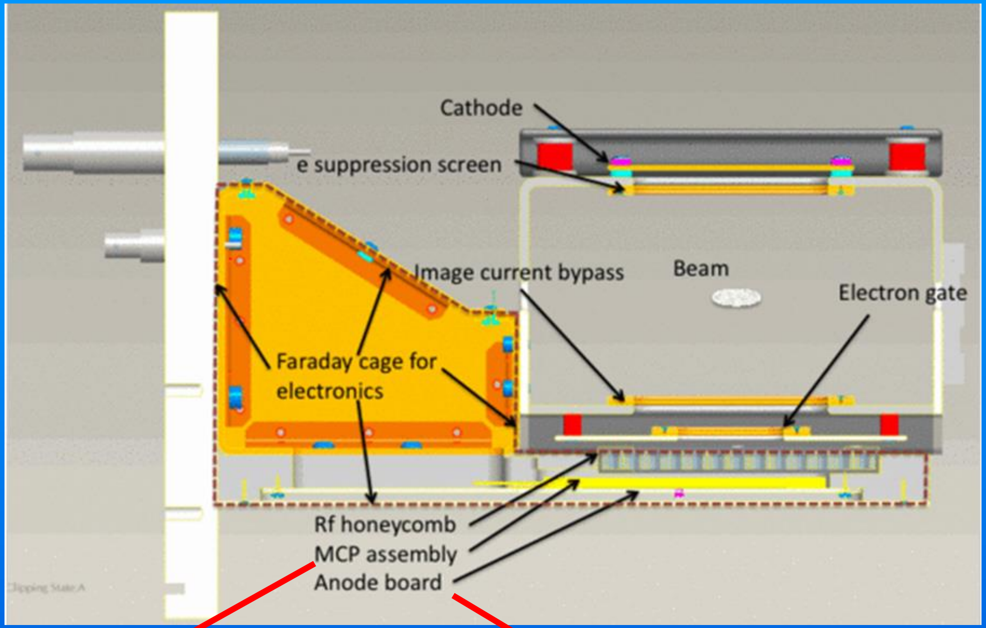
2011: reported emittance changes with separation bump collapse at 3rd colliding beam experiment motivated calibration scans which were performed by moving the beam in discrete steps across each IPM and recording images

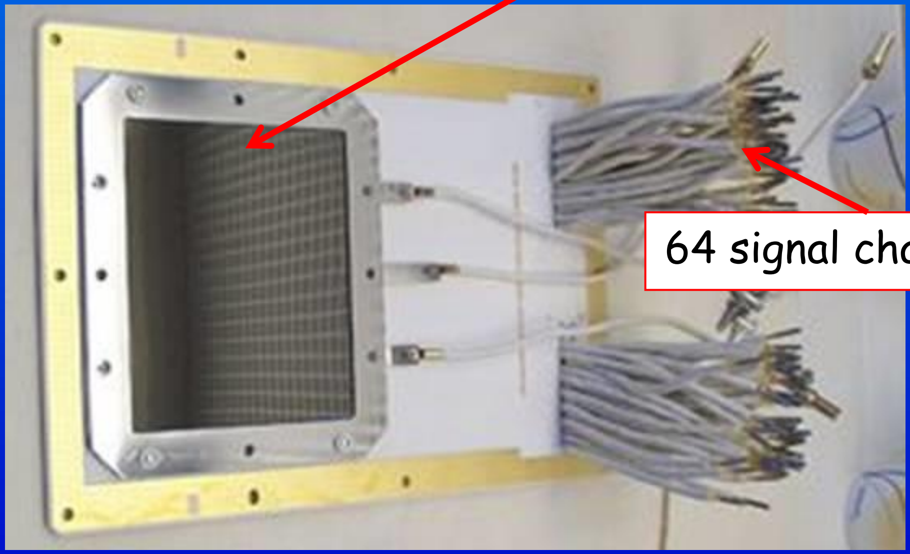


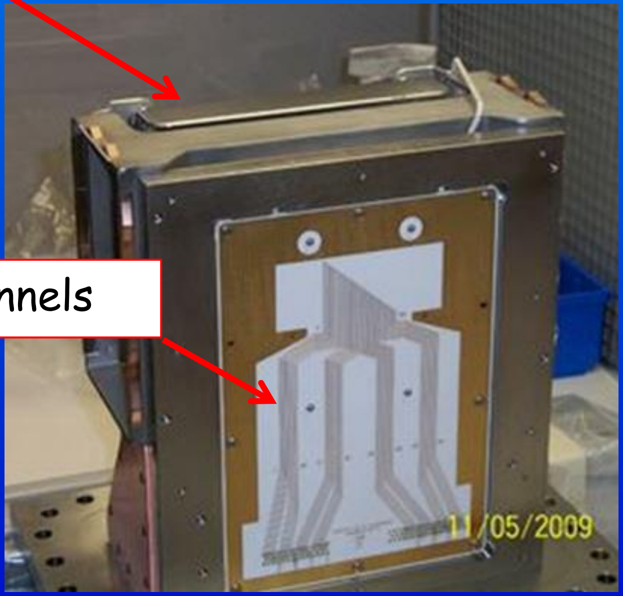


(figures from R. Connolly, 05/13/11 APEX meeting presentation)

MCP depletion correction implemented, but puzzles remained hypothesis: channel-by-channel (anode board + processing electronics) systematics relevant

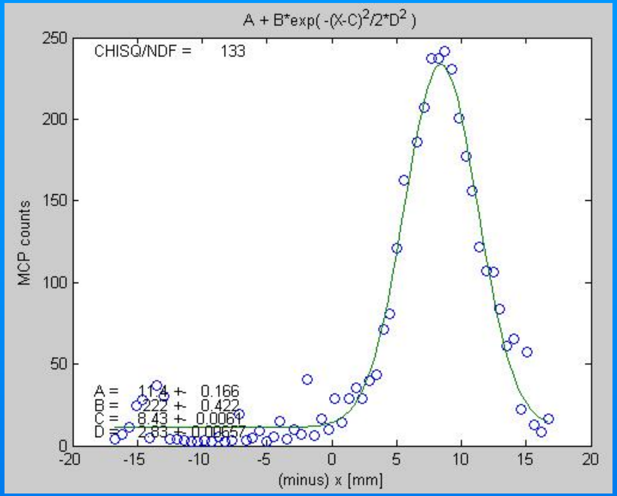




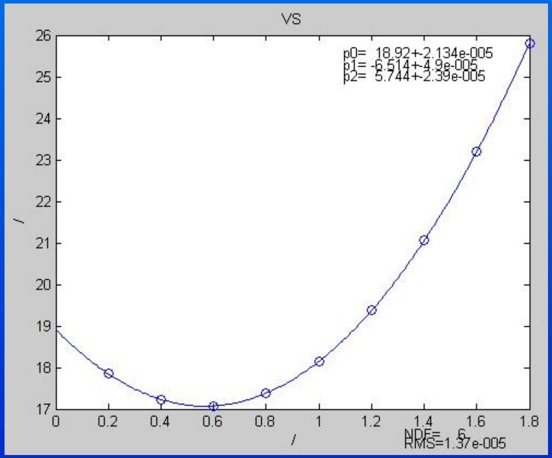


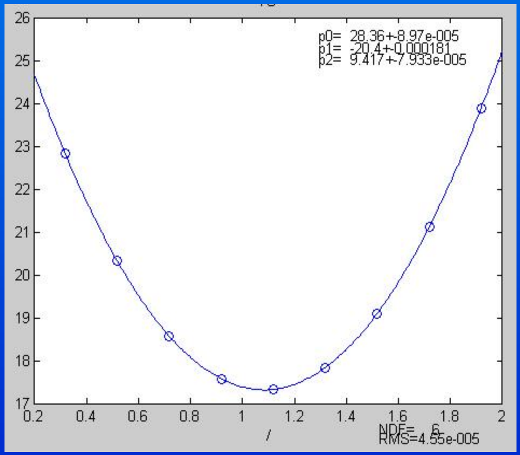
channel-by-channel gain calibration algorithm (M. Minty)

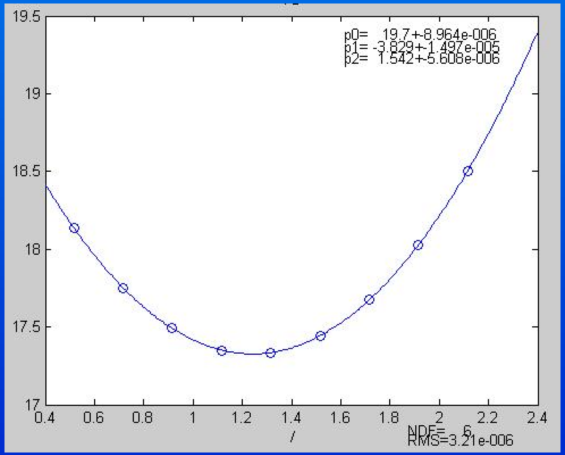
1. Gauss-fit each profile in the data set
2. calculate chi-squared of Gaussian fit
3. calculate figure of merit:
   mean chi-squared averaged of all profiles
4. iterate over a range of gain settings



5. polynomial fit to figure of merit versus gain to extract gain corresponding to minimum average chi-squared

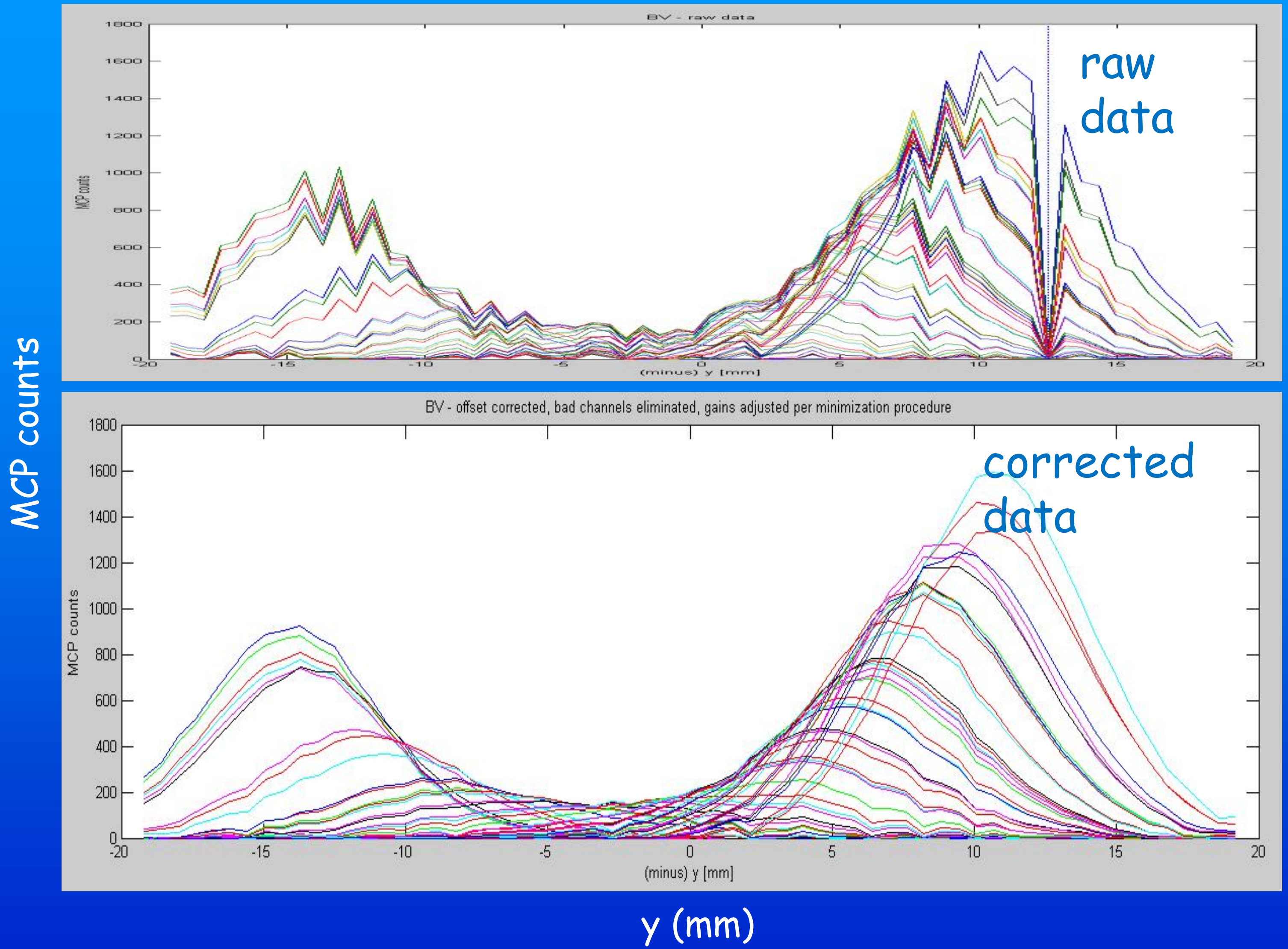






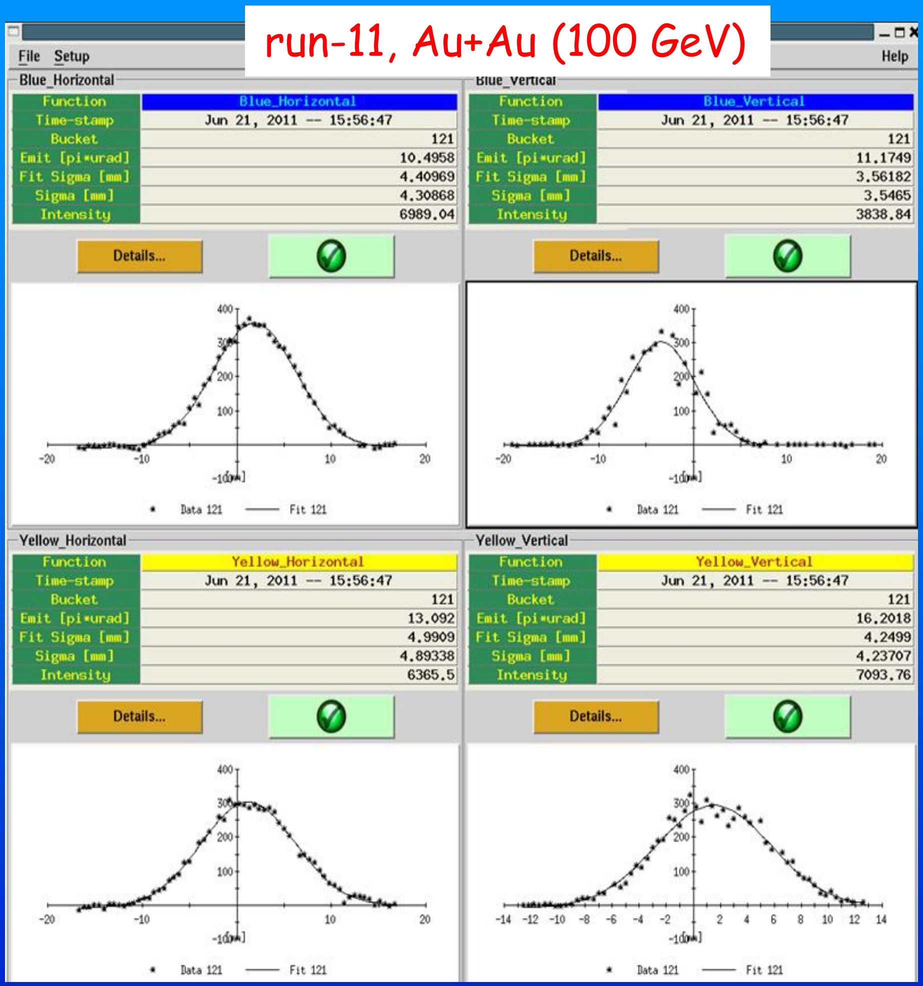
6. implement this gain
7. iterate over channels

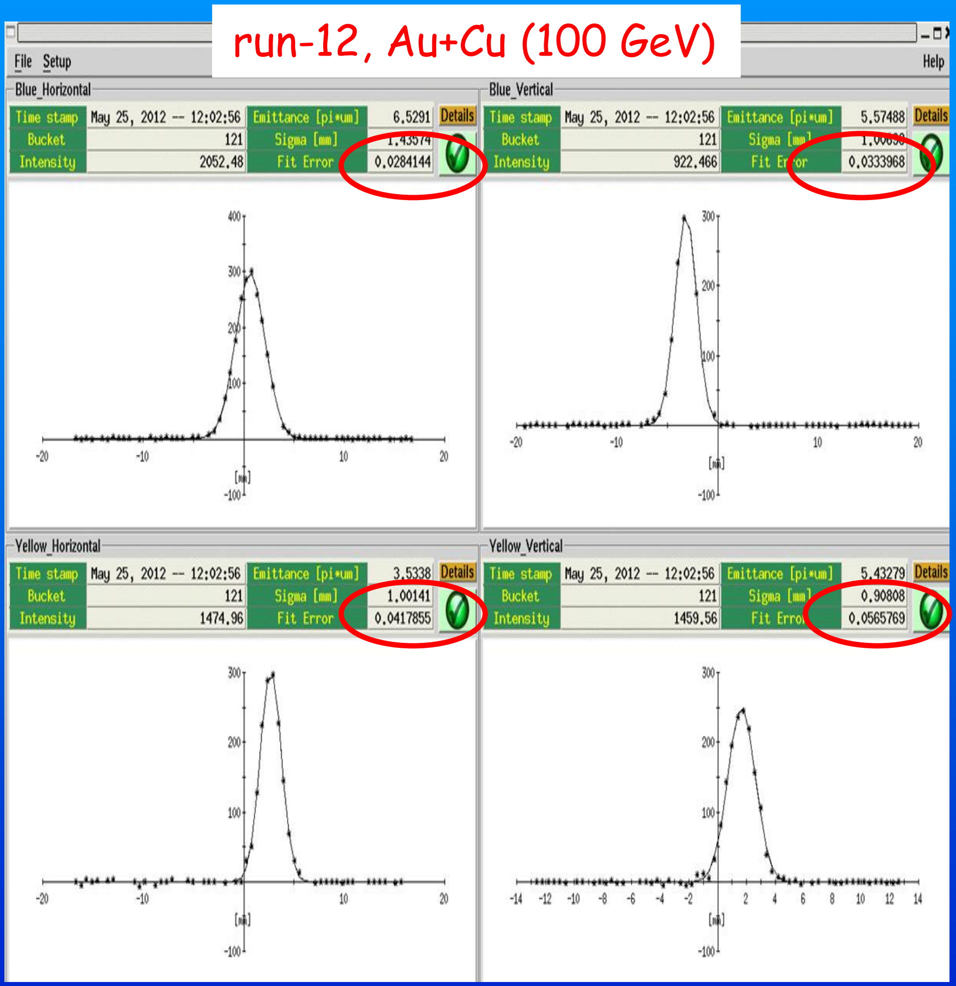
Offline comparison before and after calibration



offline analyses confirmed that channel-to-channel variations dominated measurement error

Online comparison before and after calibration





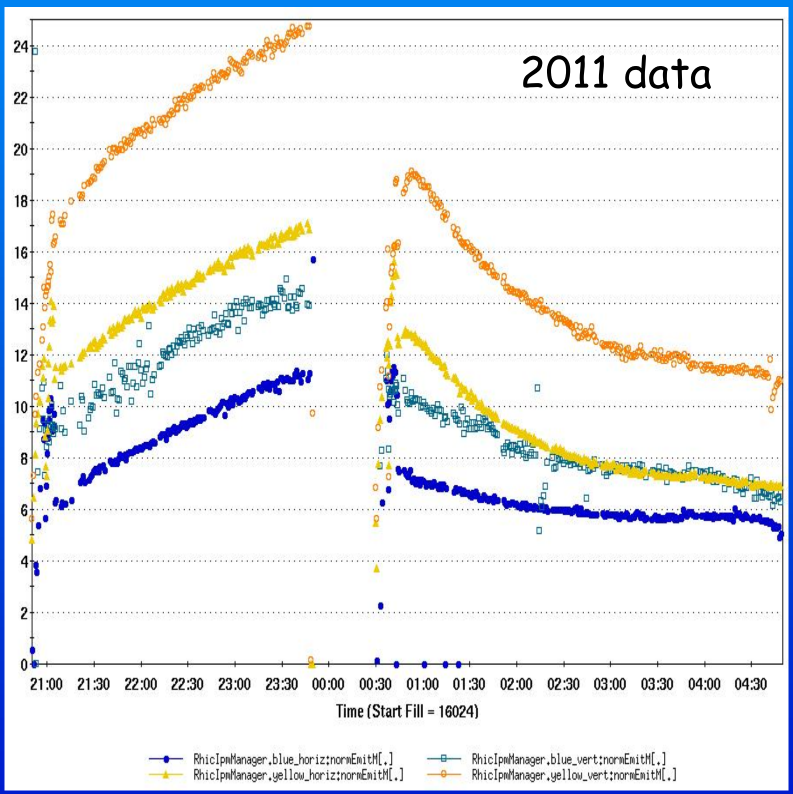
from Developments in beam instrumentation and control, M. Minty et al, 2012 RHIC Retreat

Challenges and solutions: absolute emittance measurements

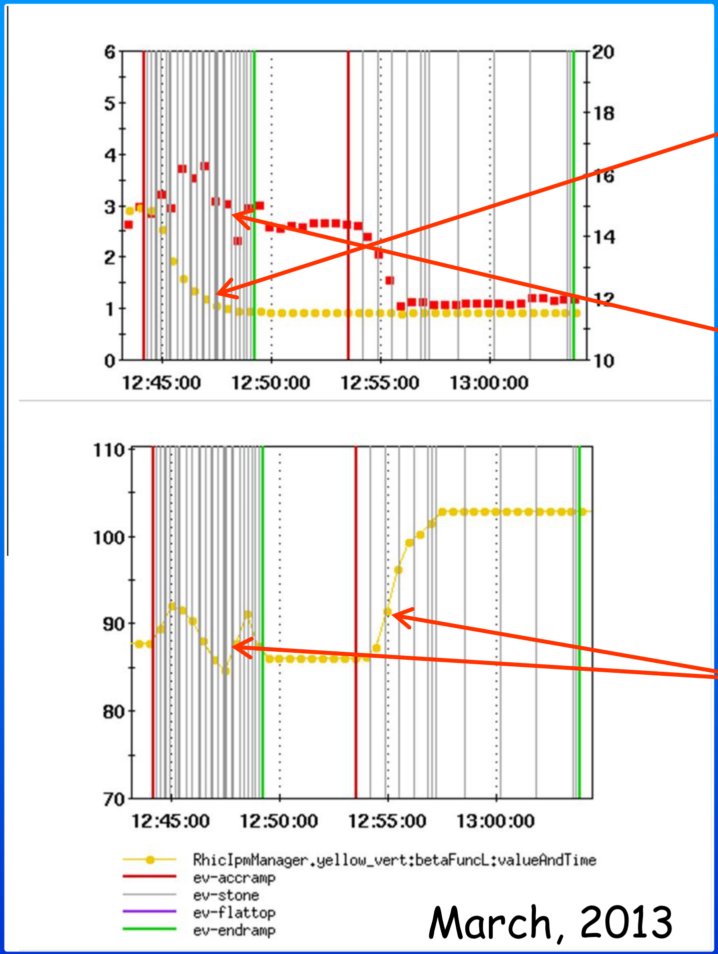
Motivation – fixed energy:

(protons) discrepancies between IPM and luminosity-based emittances

(ions) non-equal horizontal and vertical emittances with coupled beams and stochastic cooling



Motivation – energy ramp:



smoothly varying beam sigma

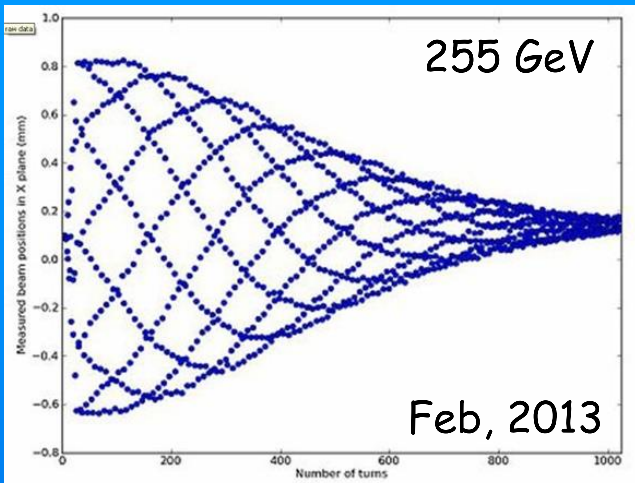
unphysical emittance

bad model beta functions!

(This is an extreme case, however we do often observe reported emittance growth and shrinkage during ramping)

Next a preview of work in progress…

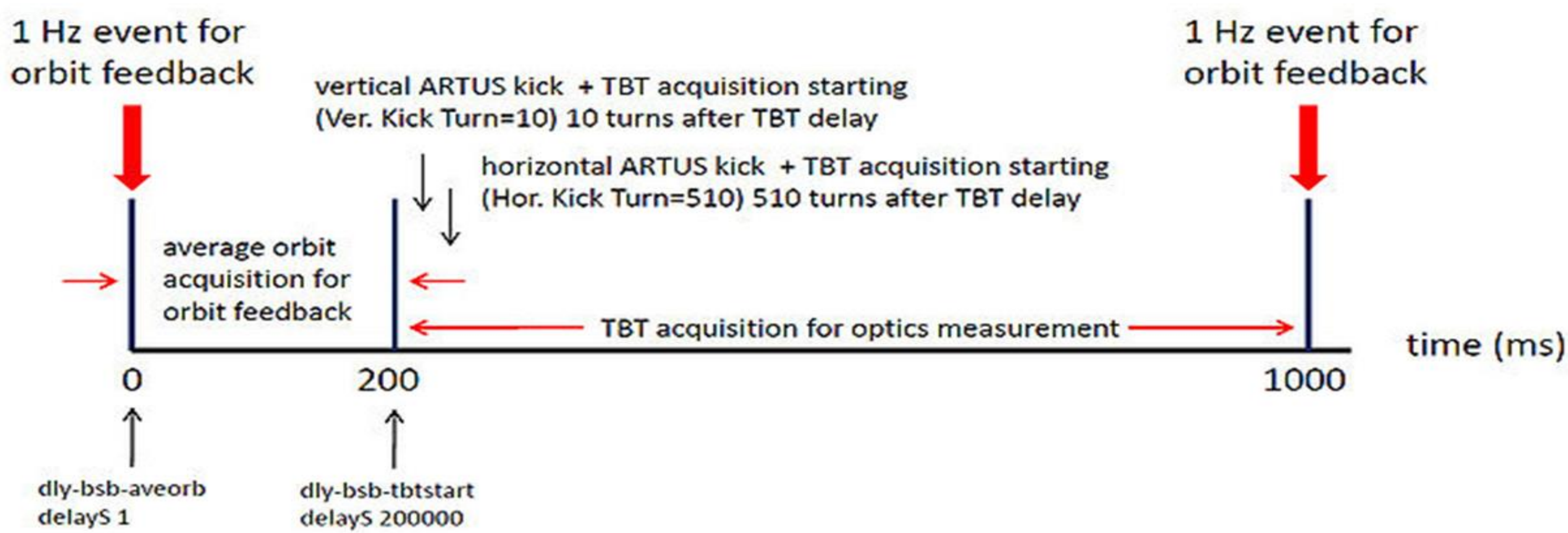
2013: optics measurements



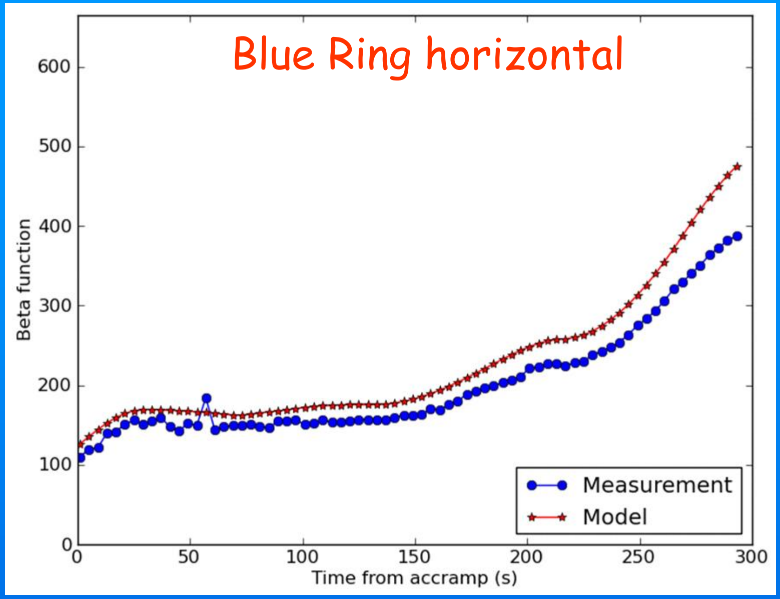
In 2012 we demonstrated high precision turn-by-turn BPM measurements (~15 microns, rms) with pinged-beams allowing for phase determination with 0.1 deg rms phase precision (P. Thieberger, C. Liu)

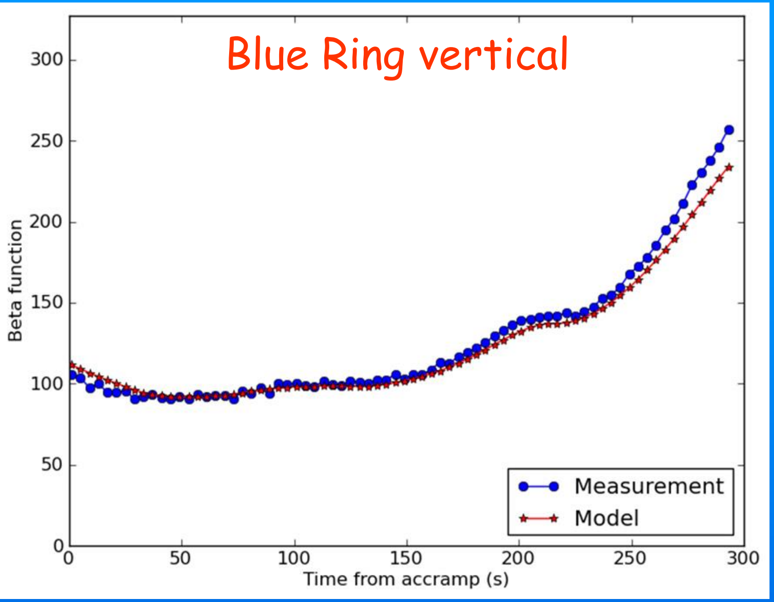
In 2013 we've combined this analysis to measure the beam optics along the energy ramp (A. Marusic, R. Michnoff, R. Hulsart et al)

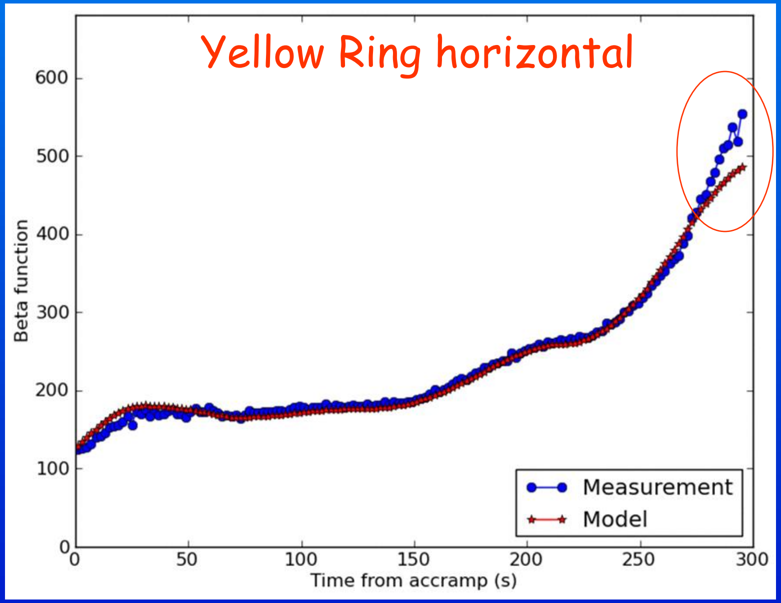
2013: ramp optics measurements

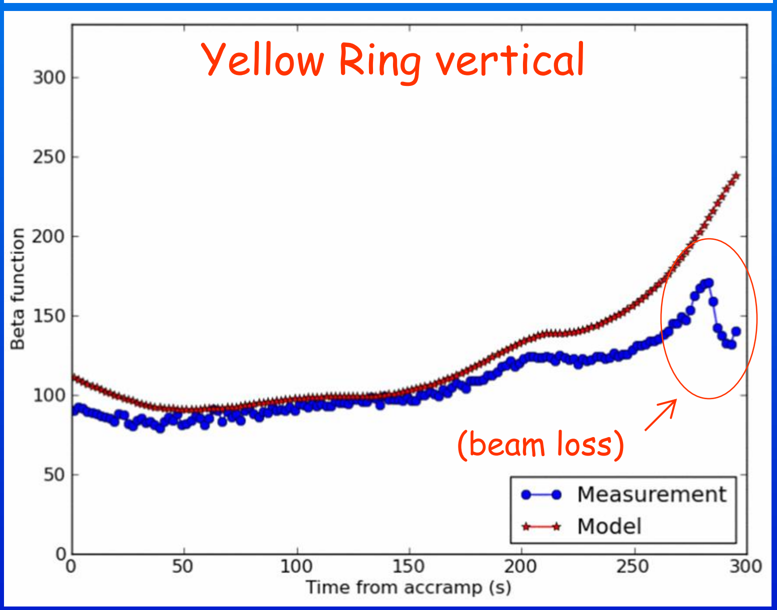


April, 2013: beta functions at the IPMs during the energy ramp









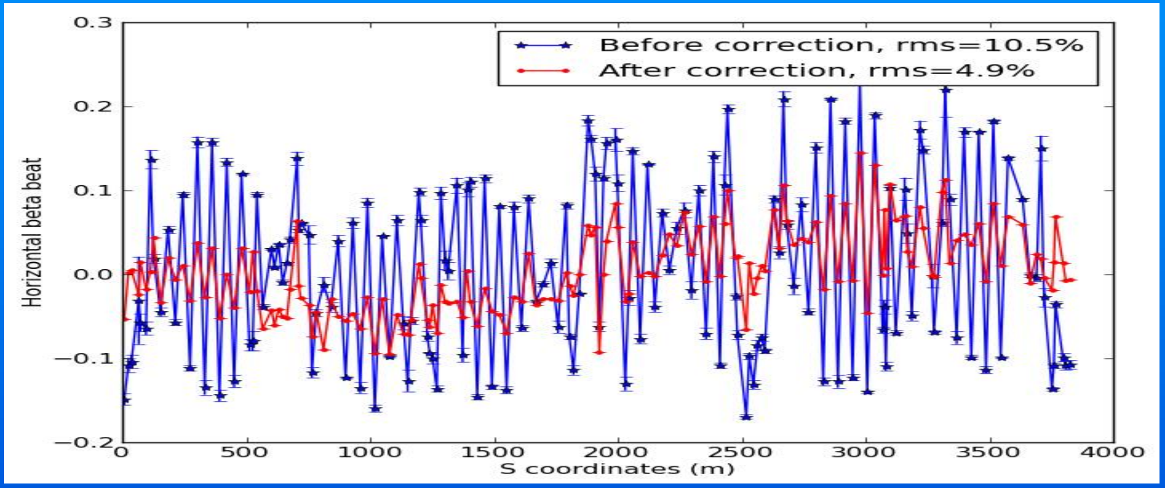
(by C. Liu)

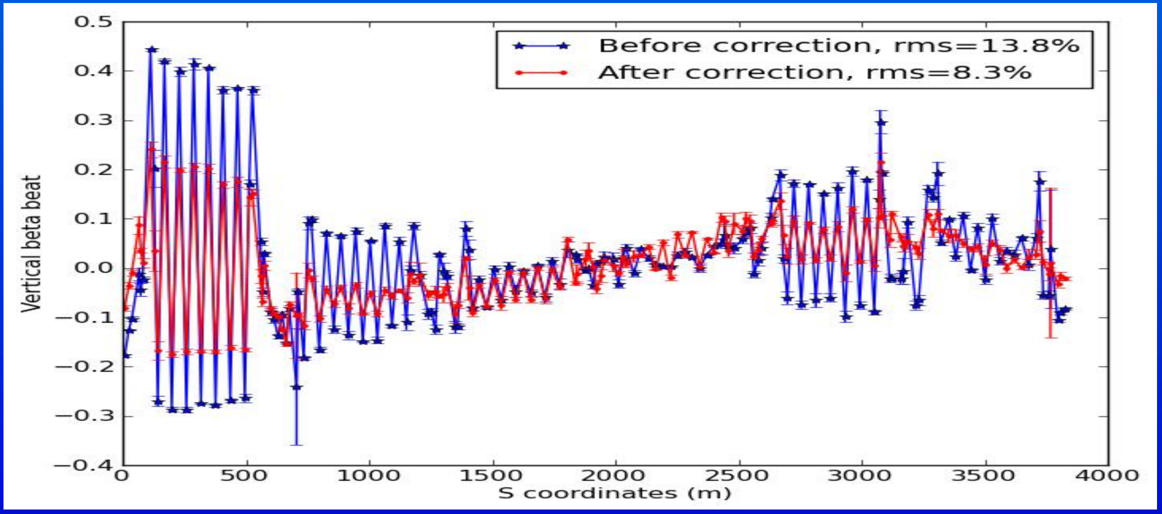
Present status:

largest systematic in IPM emittance measurement is knowledge of beta function

propagation of beta functions to IPM locations based on measurements at adjacent BPMs necessarily requires model

we will analyze the error in that approach and continue work on fixing the lattice (both at store energy and along the energy ramp)





April, 2013:

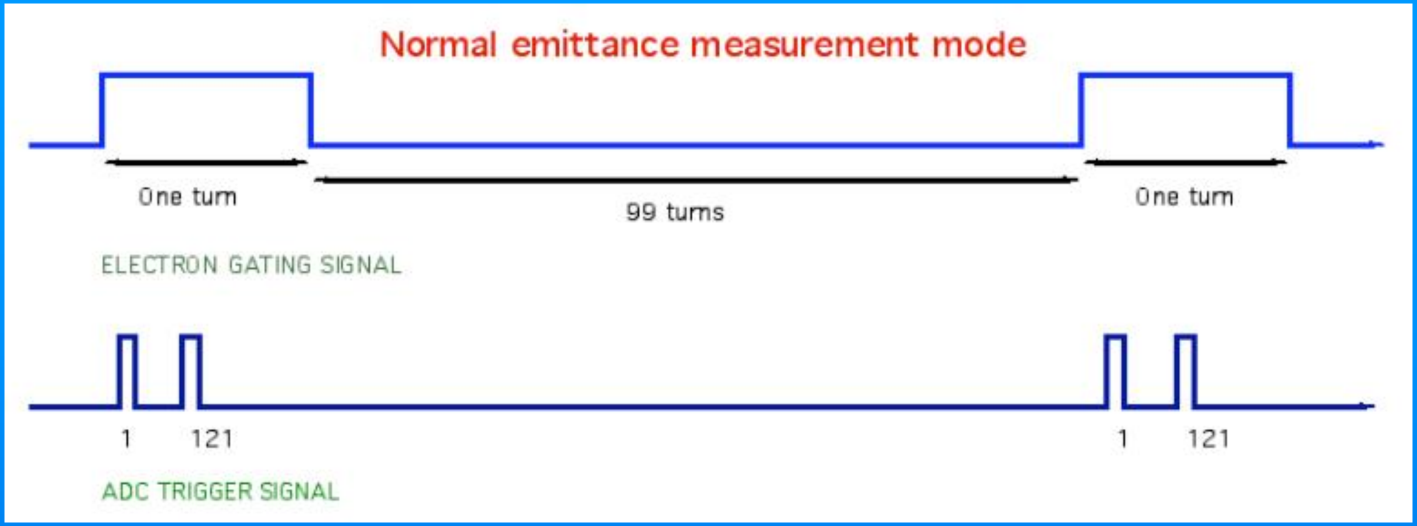
global optics correction (1 iteration) at store energy by C. Liu

Summary of experience with IPM measurements at BNL-RHIC

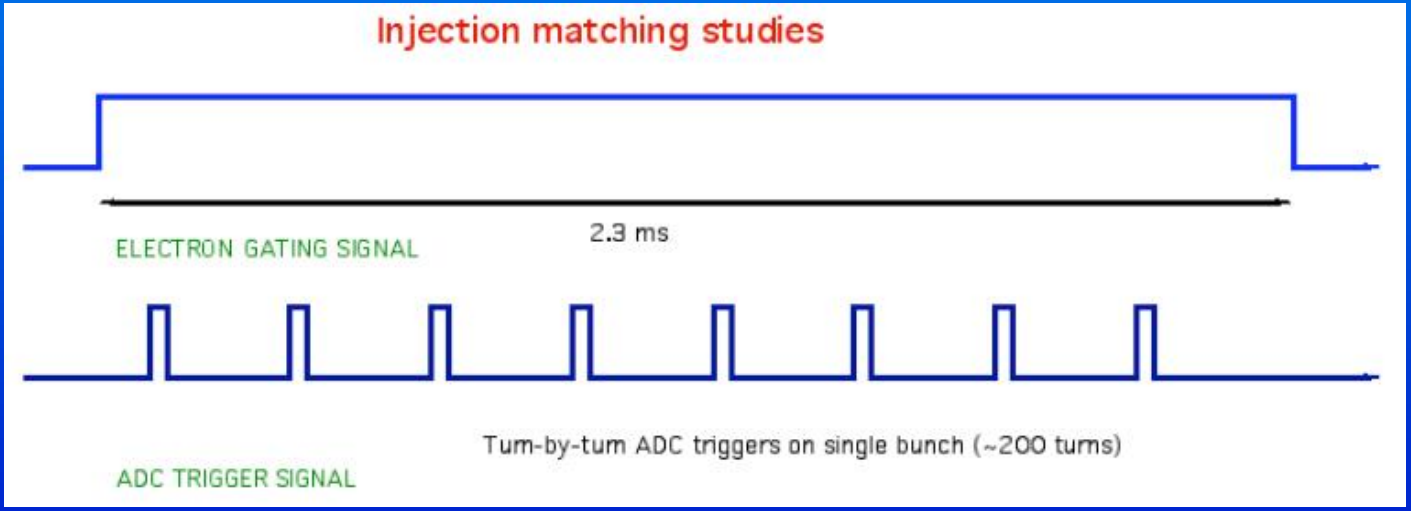
reviewed measurement concept and architecture
showed first prototype test and first tests in RHIC
reviewed design challenges and solutions

- electron clouds
- sensitivity to beam loss
- dynamic MCP saturation
- rf coupling from beam
- electronic noise

demonstrated need and described plans for determining absolute beam emittances using the IPMs



Gate is opened for 1 turn every 100 turns. During this turn the digitizers are triggered on all buckets of interest.



Gate is held open for 2.3 ms (~200 turns). During this time the digitizers are triggered on every turn.