Transverse Emittance
(with a focus on pp operation)

Kevin Brown

With help from:

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Outline

- Devices / Techniques
- Luminosity Emittance
- RHIC IPM
- AGS IPM
- Comparisons
- BtA Profile Monitors
- CNI Target Scans
- Conclusions

Devices / Techniques

- Commonalities
  - All require knowing optics functions ($\beta_{x,y}$, $\beta\gamma$, $D_{x,y}$)
  - All (most) assume Gaussian distributions
  - All require doing some kind of fitting (to a Gaussian or parabola)
  - All require amplification and have known dynamic ranges (varies depending on system)
- Fittings
  - Generally, fittings weight on central distribution
  - All use Levenberg-Marquardt nonlinear least squares algorithm, but different implementations
  - Sometimes use background subtractions
  - Most use single channel gain/offset corrections (although how determined depends on the system)
  - Dynamic range tests sometimes, but very simple

General Observations/Comments

1. We have the observation that Emittance grows through the accelerator chain, however … what is really going on? (quantitatively)
2. No Consistent measurement context
   1. Dispersion terms routinely not subtracted out
   2. No error bars displayed
   3. Betafunctions not sourced consistently (e.g., AGS polarimeter values are hardcoded in)
   4. Not transformed into "Lumi-equivalent" emittance (defined on next slide)
3. No regular performance record kept
   1. E.G., Weekly/daily emittance during the run
   2. Emittance from ion source to collisions per store?
4. Each technique/instrument contains different physics (should be a good thing)

Emittance from Luminosity

- Emittance from Luminosity is derived from

$$<\varepsilon> \propto 4\pi(\sigma_x \sigma_y) = A f_{rev} N_c I_B I_Y / L$$

  - Where
    - σ_x and σ_y are beam size
    - A is the hour-glass factor = $f(\sigma_z / \beta^*)$
    - N_c is the number of collisions
    - I_B and I_y are the average bunch intensities
    - L is the measured luminosity
    - Note: actual $<\varepsilon>$ value depends on γ and β^* values, adding to total uncertainty
- "Lumi-Equivalent" emittance = what to expect from IPM measured values.

$$<\varepsilon_{\text{IPM}}> = \frac{1}{2}\sqrt{(\varepsilon_B + \varepsilon_Y)_H (\varepsilon_B + \varepsilon_Y)_V}$$

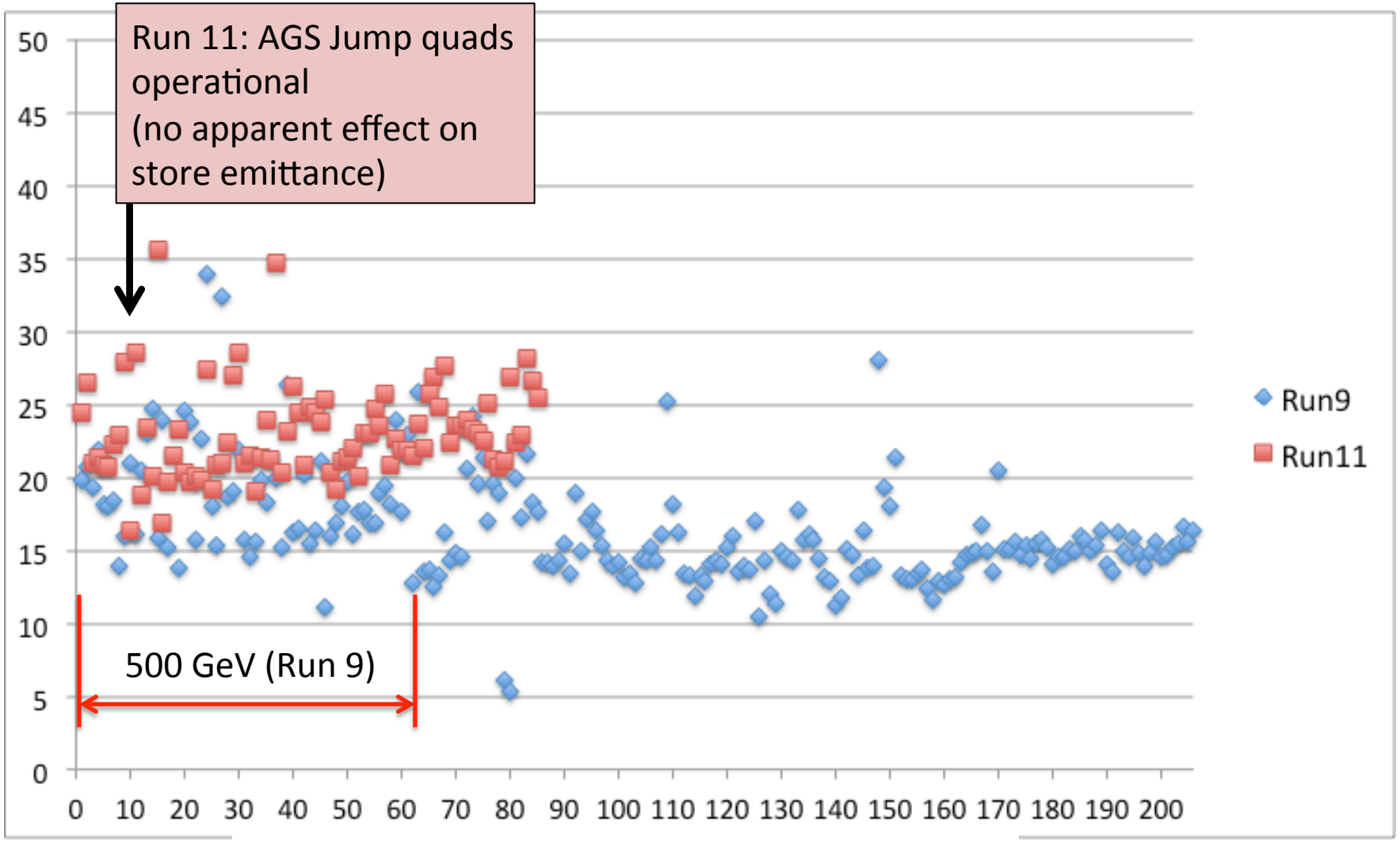
Observations/Comments

- Uncertainty in β^* applies twice (from hour glass factor and from beam size to emittance conversion).
- Uncertainty in Luminosity largely comes from uncertainty in measurement (statistical)
- Uncertainty in average beam intensity can be as much as 2-4% (and counted twice)
- Relative motion of the two beams is not factored into the emittance (although 10Hz feedback should have improved this effect – On since January 25th)
- Single bunch intensities are assumed to be about the same.
- Additional Uncertainty comes from s^*, which is assumed 0 (note: This is like β^* being assumed smaller than it really is)

Comments on the Data

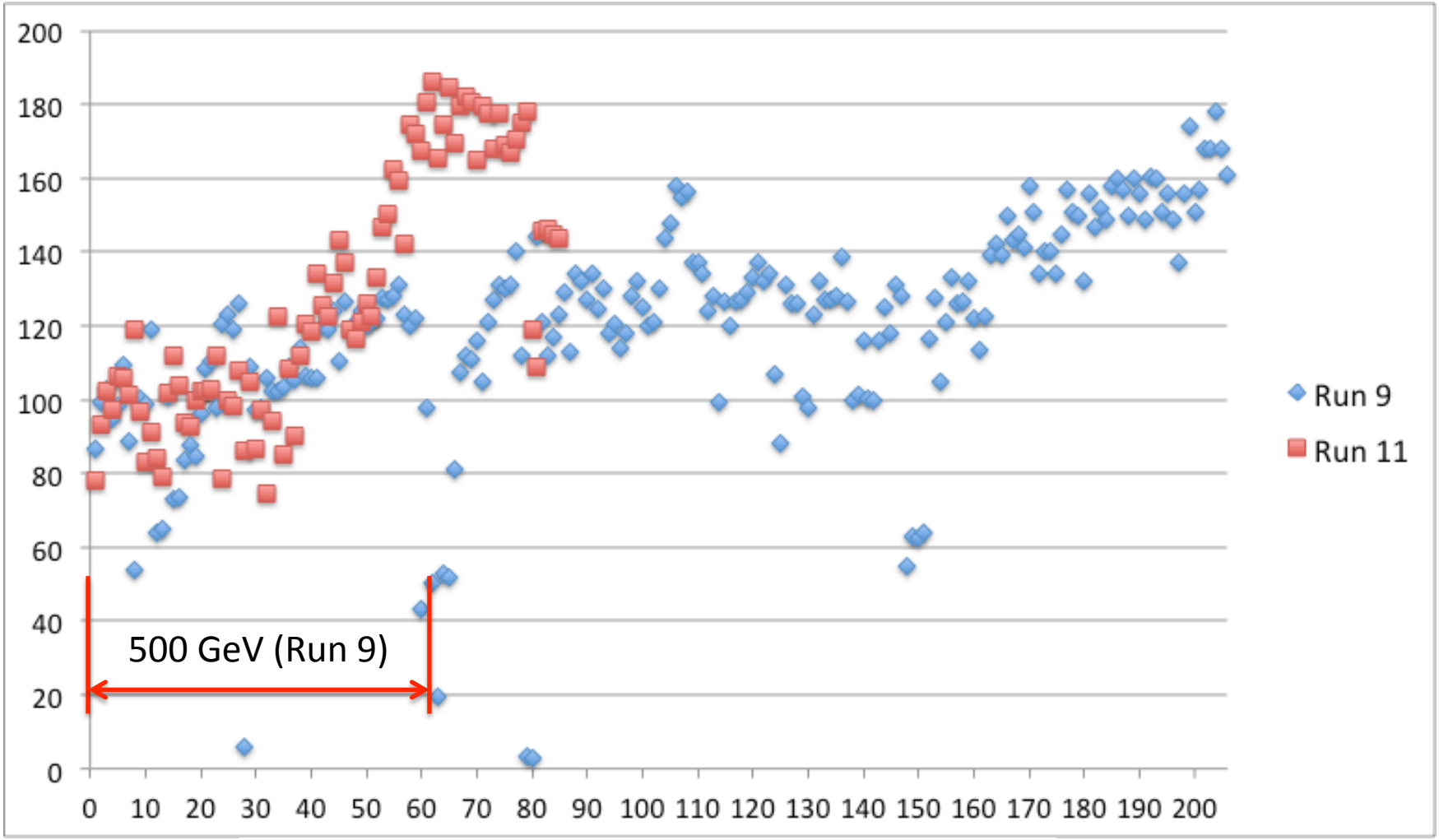
- All Lumi emittances are at beginning of Store.
- All RHIC IPM emittances are at beginning of Store.
- All AGS IPM emittances are 5 sample average just before beam is extracted from AGS (so with RF On).

Emittance from Luminosity



Relative Run number (1 = first store for that run)

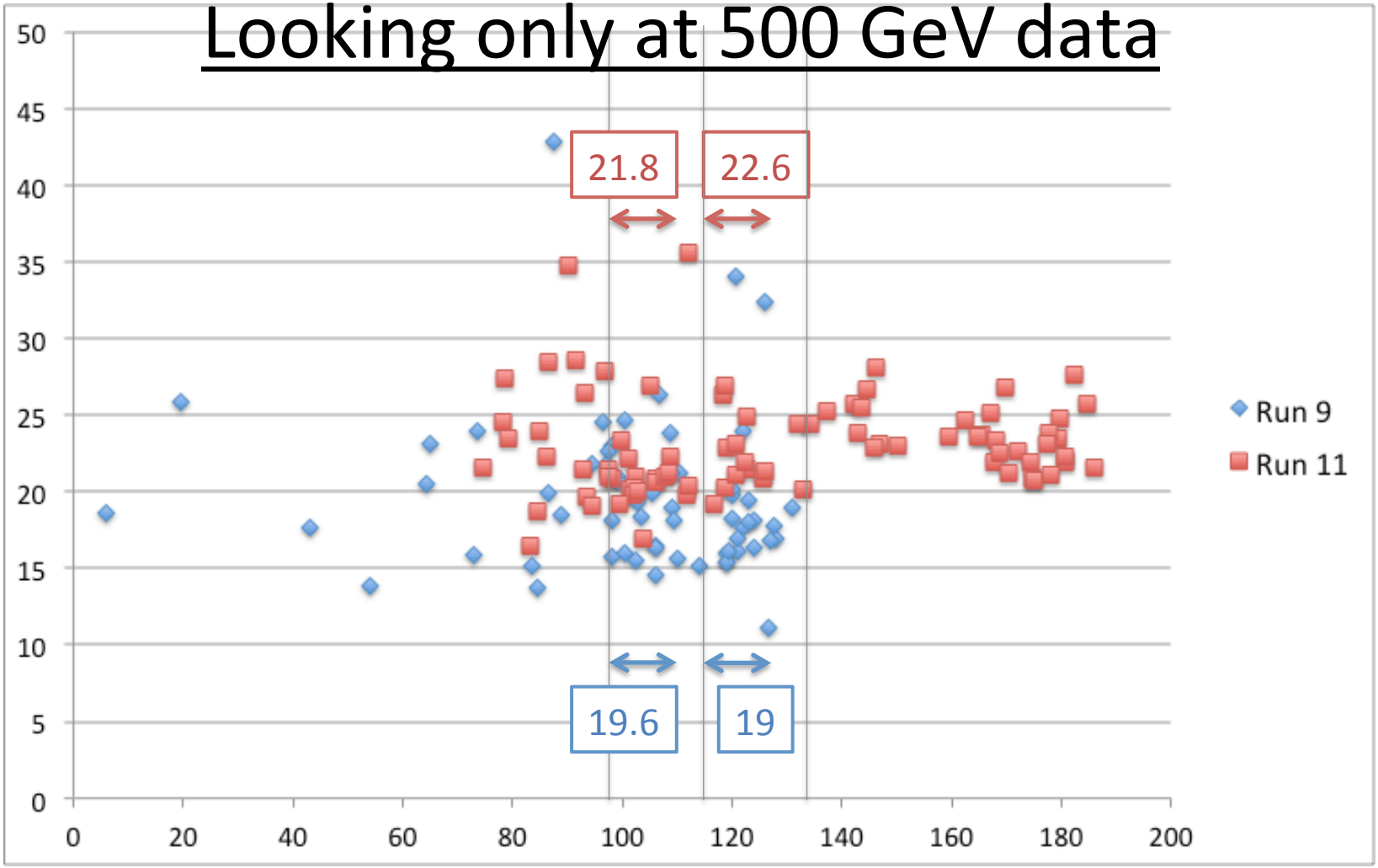
Intensity Evolution: runs 9 & 11



Relative Run number (1 = first store for that run)

Emittance vs Intensity: runs 9 & 11

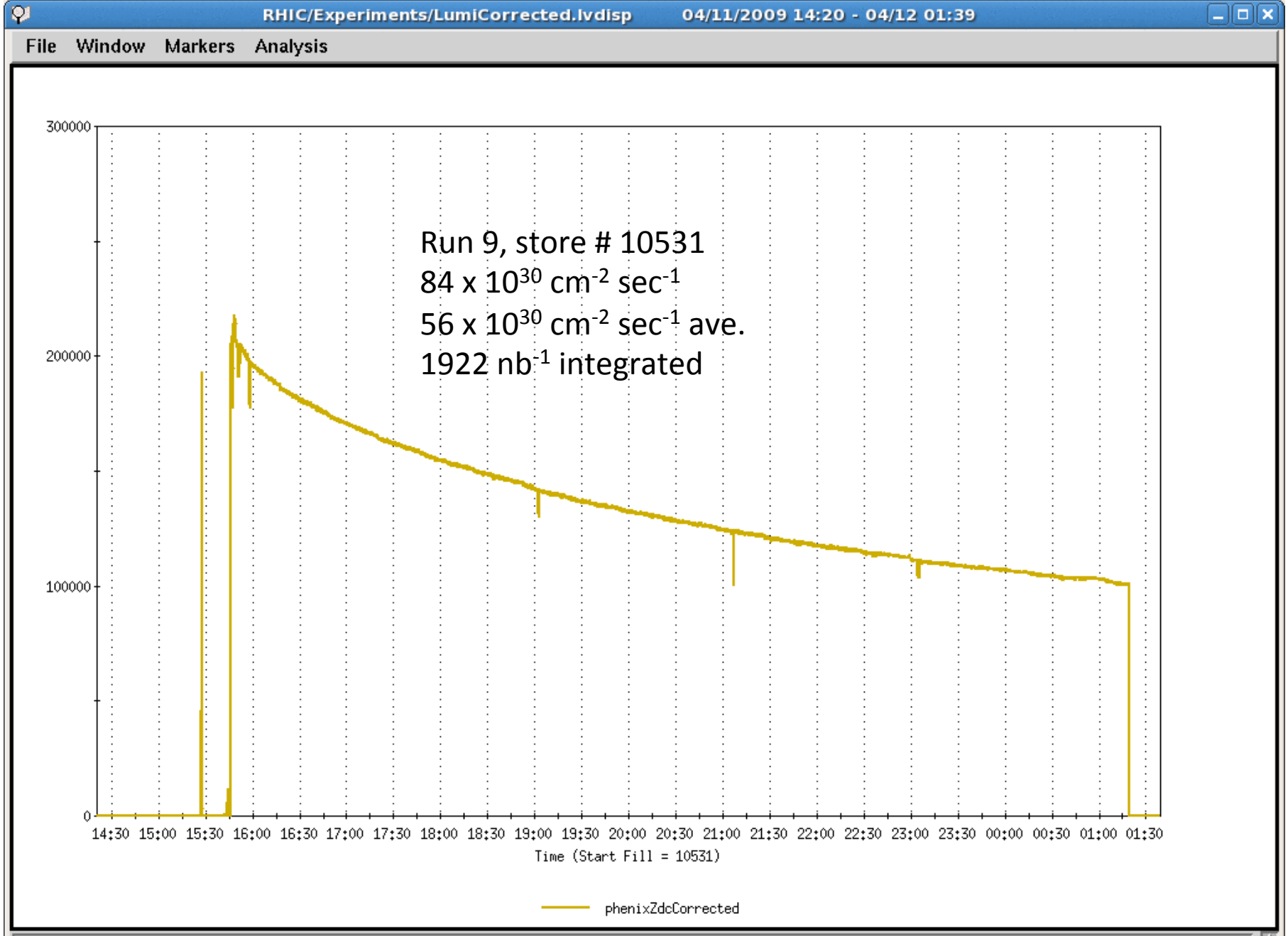
Looking only at 500 GeV data

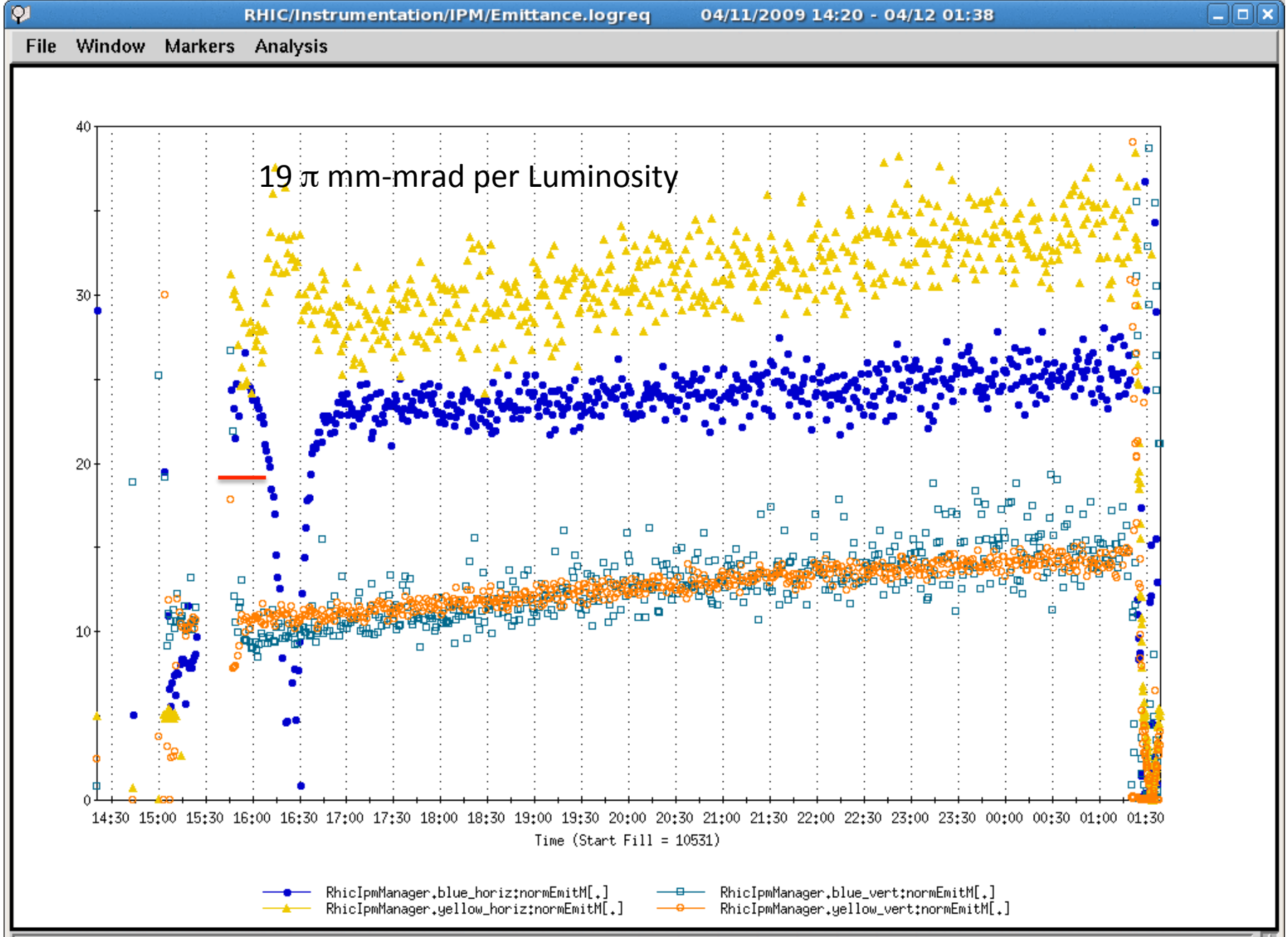


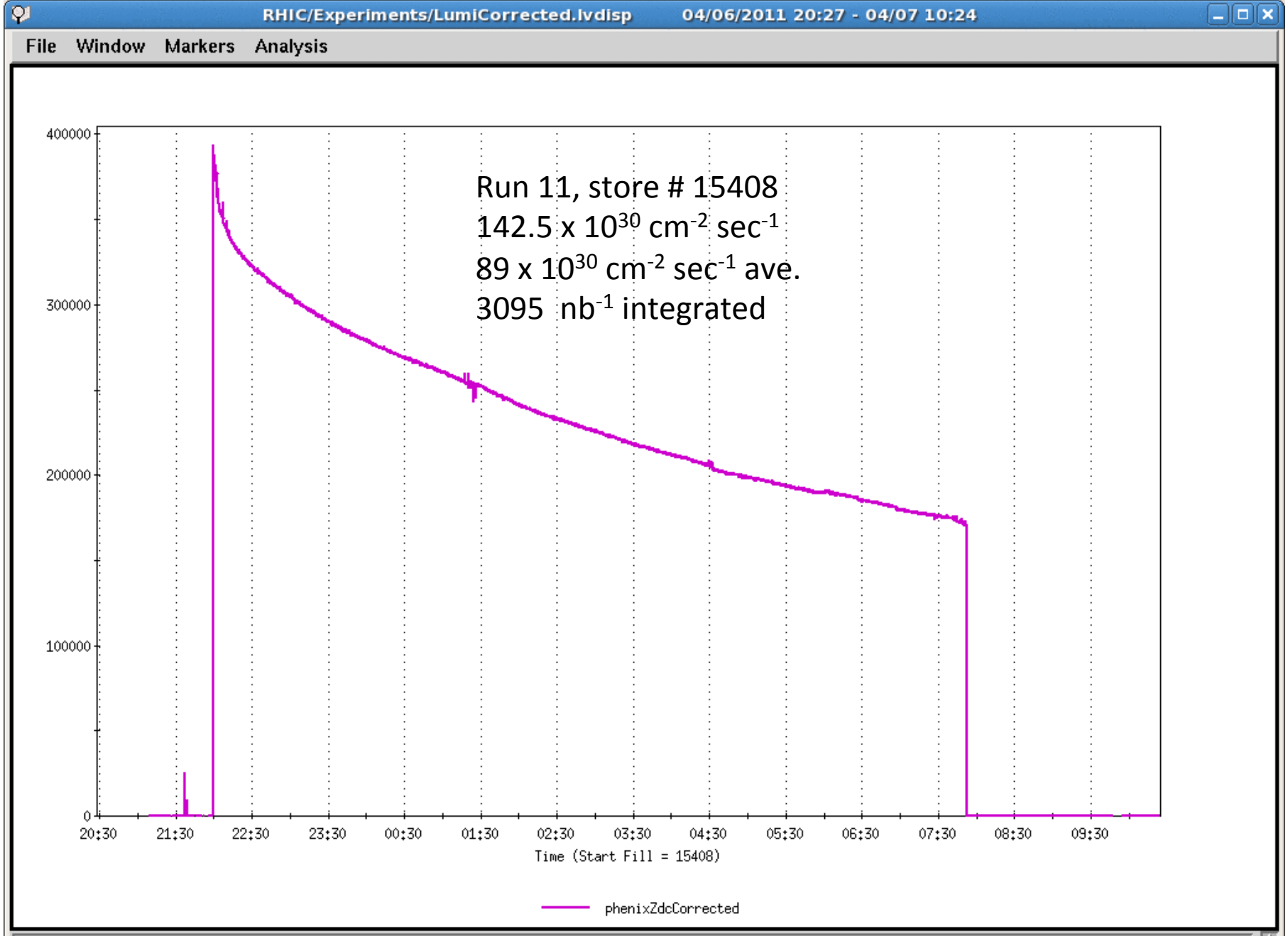
Observations from Luminosity Emittance

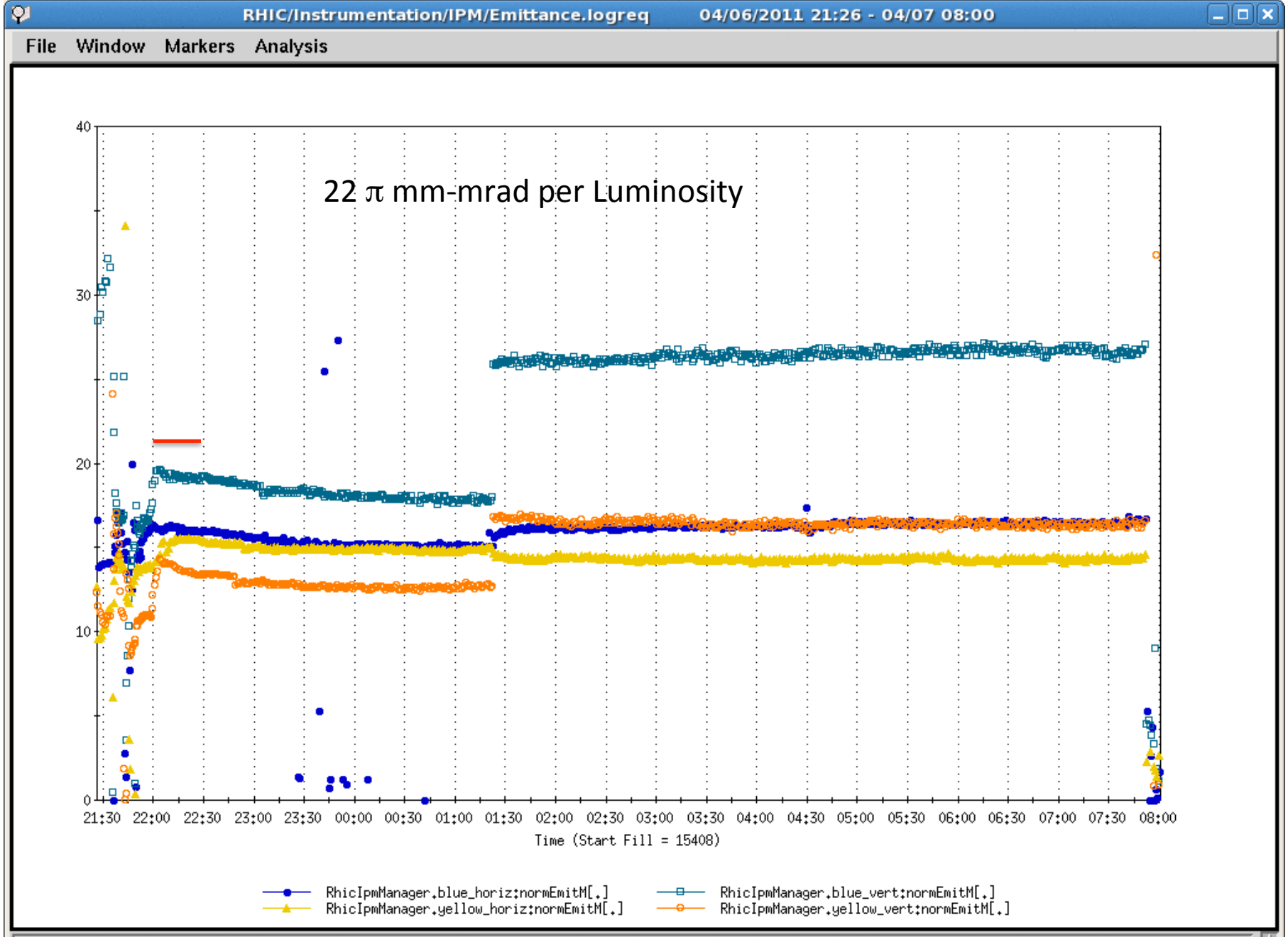
- Suggests emittances are larger than RHIC IPM reported (discussed in next section).
- the best stores in Run-9 have about 18 π mm-mrad,
- the best stores in Run-11 have about 24 π mm-mrad (measured with the same method). "Best" is defined as giving the best integrated luminosity's
- Run-9 emittance was growing during store (next slides)
- Run-11 emittance was not growing during store.

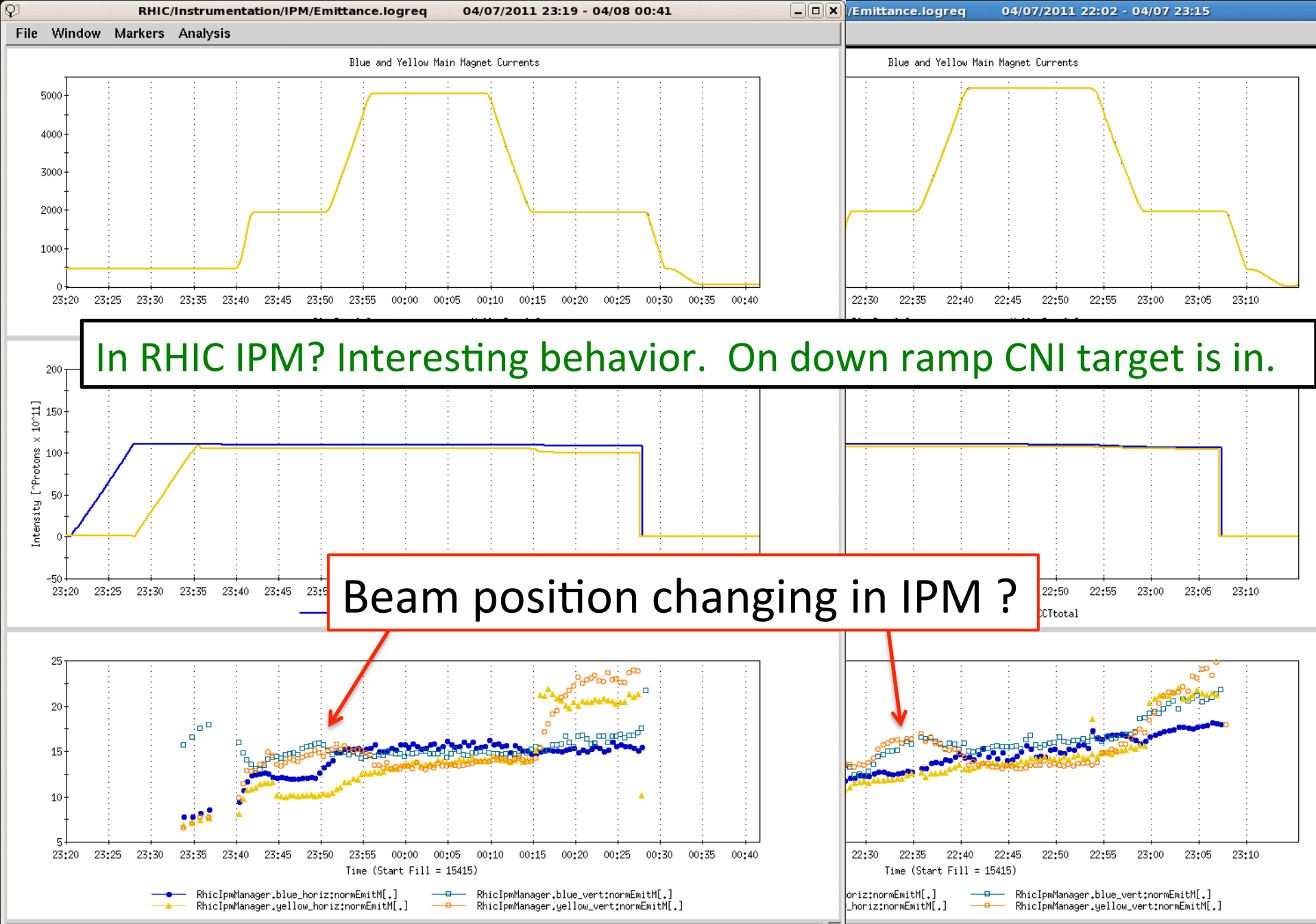
RHIC IPM


RHIC/Experiments/LumiCorrected.lvdisp 04/11/2009 14:20 - 04/12 01:39
File Window Markers Analysis
Run 9, store # 10531
84 x 10^30 cm^-2 sec^-1
56 x 10^30 cm^-2 sec^-1 ave.
1922 nb^-1 integrated
300000
200000
100000
0
14:30 15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30 00:00 00:30 01:00 01:30
Time (Start Fill = 10531)
phenixZdcCorrected


RHIC/Instrumentation/IPM/Emittance.logreq 04/11/2009 14:20 - 04/12 01:38
File Window Markers Analysis
19 π mm-mrad per Luminosity
40
30
20
10
0
14:30 15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30 00:00 00:30 01:00 01:30
Time (Start Fill = 10531)
RhicIpmManager.blue_horiz:normEmitM[.]
RhicIpmManager.yellow_horiz:normEmitM[.]
RhicIpmManager.blue_vert:normEmitM[.]
RhicIpmManager.yellow_vert:normEmitM[.]


RHIC/Experiments/LumiCorrected.lvdisp 04/06/2011 20:27 - 04/07 10:24
File Window Markers Analysis
Run 11, store # 15408
142.5 x 10^30 cm^-2 sec^-1
89 x 10^30 cm^-2 sec^-1 ave.
3095 nb^-1 integrated
400000
300000
200000
100000
0
20:30
21:30
22:30
23:30
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
Time (Start Fill = 15408)
phenixZdcCorrected
ERROR: There is no dataset with this name -> sisScaler.6a-star.2:diffM:valueAndTime
Not all necessary data was available for cell calculations.

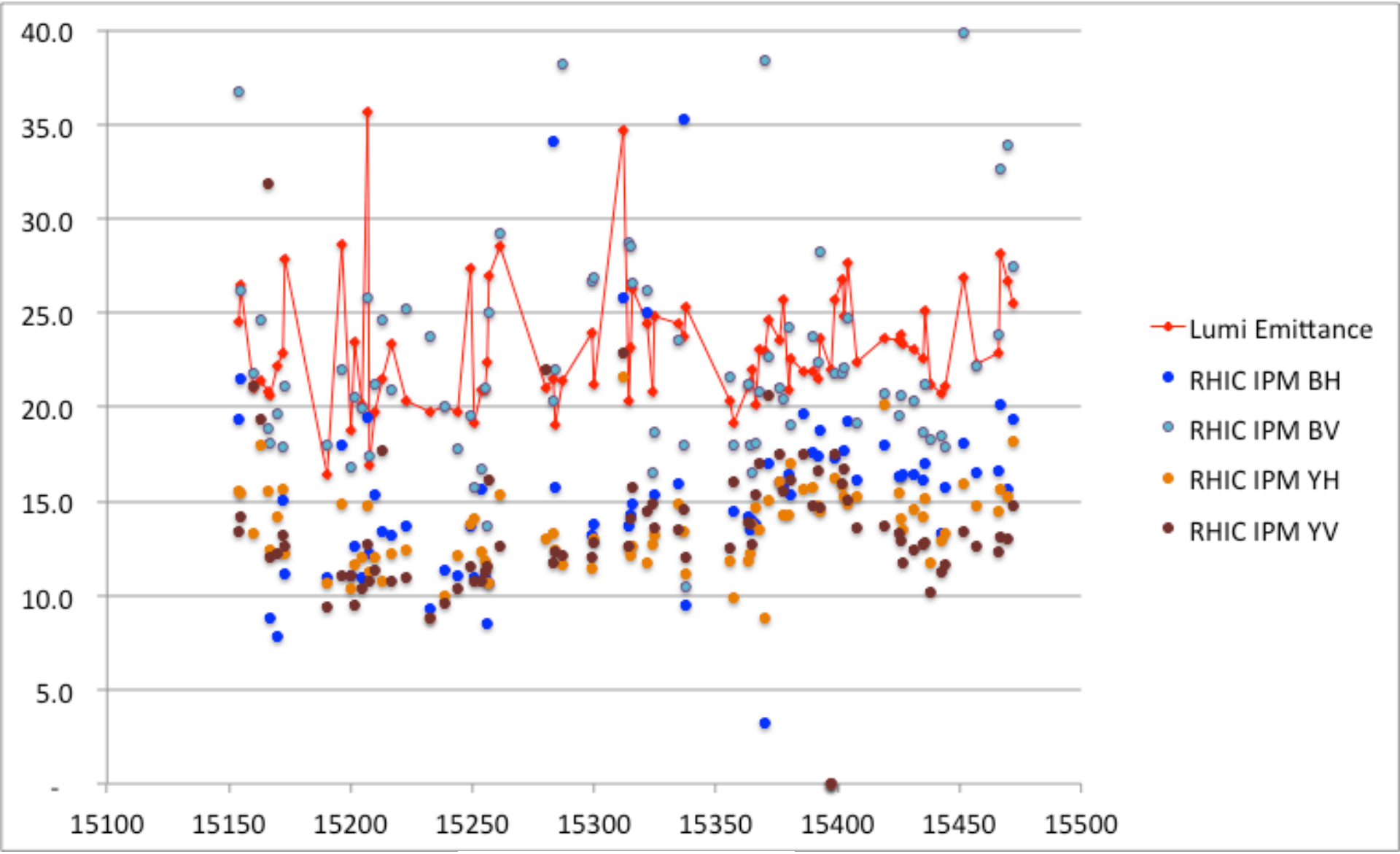

RHIC/Instrumentation/IPM/Emittance.logreq 04/06/2011 21:26 - 04/07 08:00
File Window Markers Analysis
22 π mm-mrad per Luminosity
40
30
20
10
0
21:30 22:00 22:30 23:00 23:30 00:00 00:30 01:00 01:30 02:00 02:30 03:00 03:30 04:00 04:30 05:00 05:30 06:00 06:30 07:00 07:30 08:00
Time (Start Fill = 15408)
RhicIpmManager.blue_horiz:normEmitM[.]
RhicIpmManager.yellow_horiz:normEmitM[.]
RhicIpmManager.blue_vert:normEmitM[.]
RhicIpmManager.yellow_vert:normEmitM[.]



In RHIC IPM? Interesting behavior. On down ramp CNI target is in.

Beam position changing in IPM ?

Comparison between IPM and Lumi Emittances



FY 11 pp Run number

RHIC IPM 2011

We did calibration beam scans on all RHIC IPMs. All IPMs are the same design and they have been in RHIC for three different lengths of time. We thus were able to get a measurement of the aging rate of the MCPs.

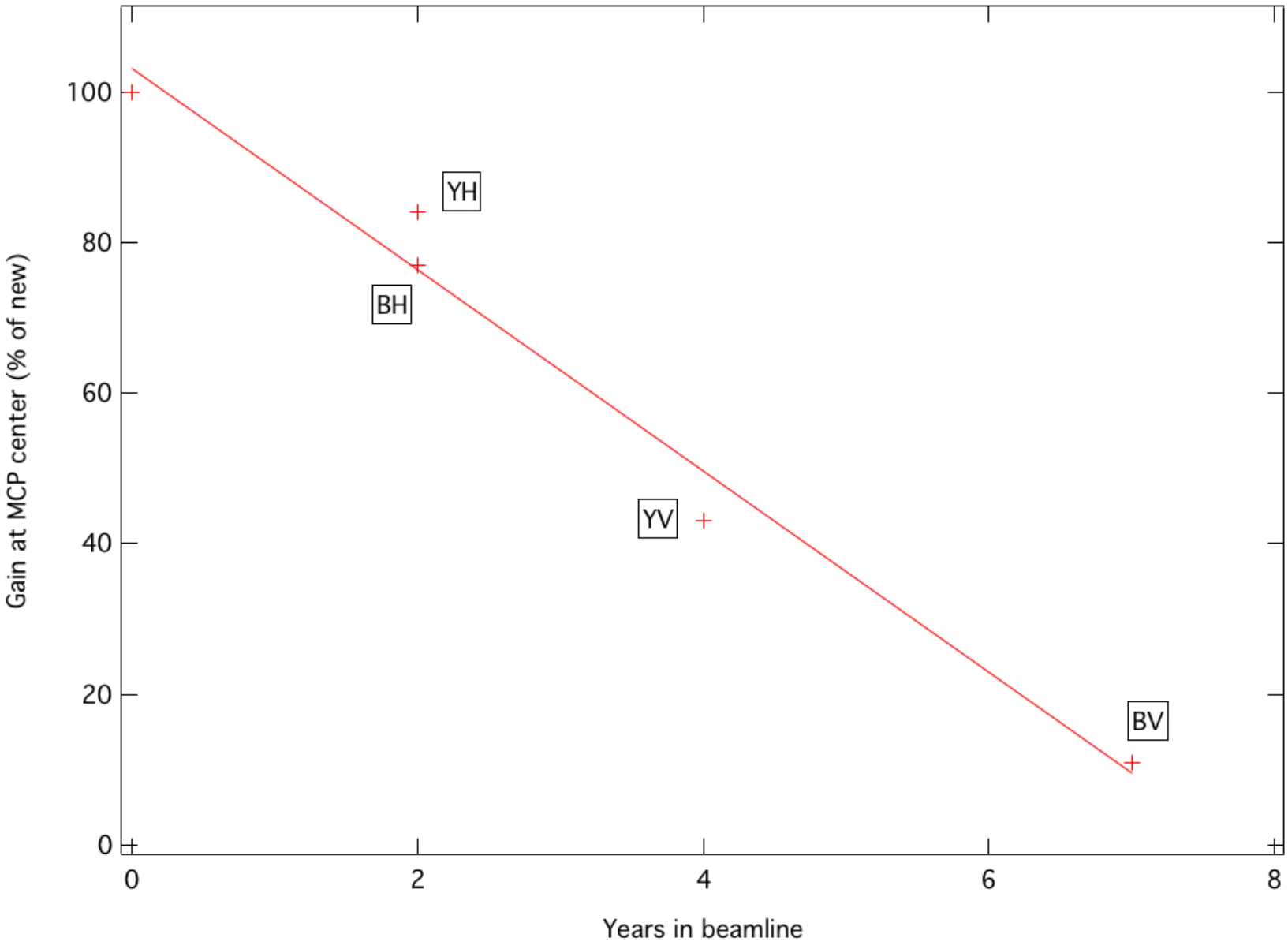
The aging rate is linear with time. The aging pattern is Gaussian with the center losing about 12% of the original gain/year.

A gain correction table was generated for each IPM and implemented in the IPM manager.

MEASUREMENT ACCURACY

The new IPM design greatly reduces rf coupling to the beam. The scatter in repeated measurements of the beam width (σ) **of gold beams** is ±1% for BH, YH, and YV. Blue vertical is an older design and the shot-to-shot scatter is ±3%. The ±1% scatter is near the statistical limit of the measurement. Combined with the resolution limit of the detectors, the estimated uncertainty in σ on each measurement is ±2%.

The error in the calculated emittance value depends on the uncertainty of the model β function. From optics tables supplied by Mei Bai the measured β functions at the IPMs vary from the model β functions by an average of 16%. This indicates the IPM emittance error is ±16%.


Gain at MCP center (% of new)
100
80
60
40
20
0
0
2
4
6
8
Years in beamline
YH
BH
YV
BV

Adding motion control to IPM chambers, a proposal

With frequent scans we can maintain completely flat detector responses over five or more years. We should consider adding motion control to the detector chambers.

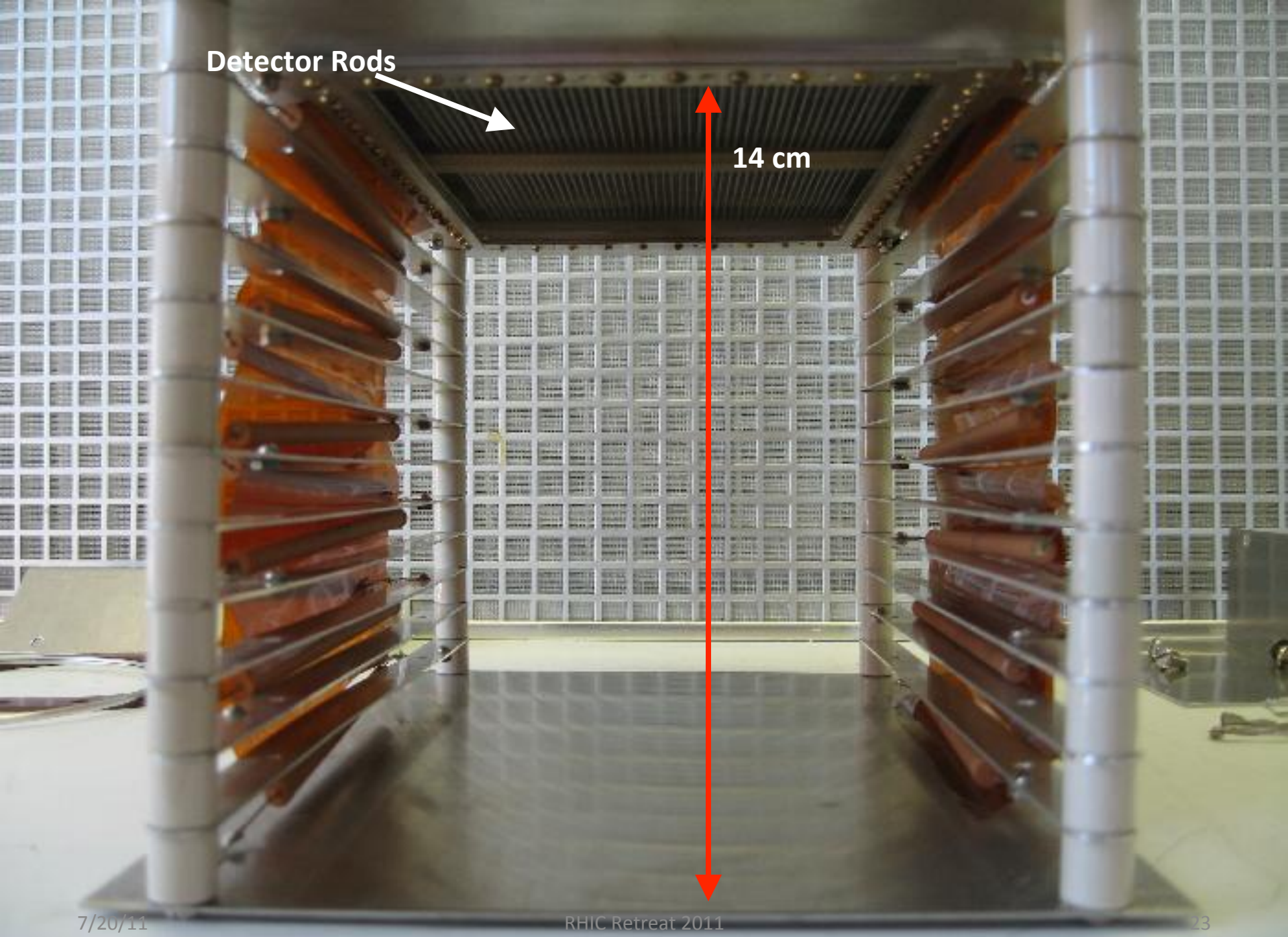
Doing calibration scans by **moving the beam** has several drawbacks:

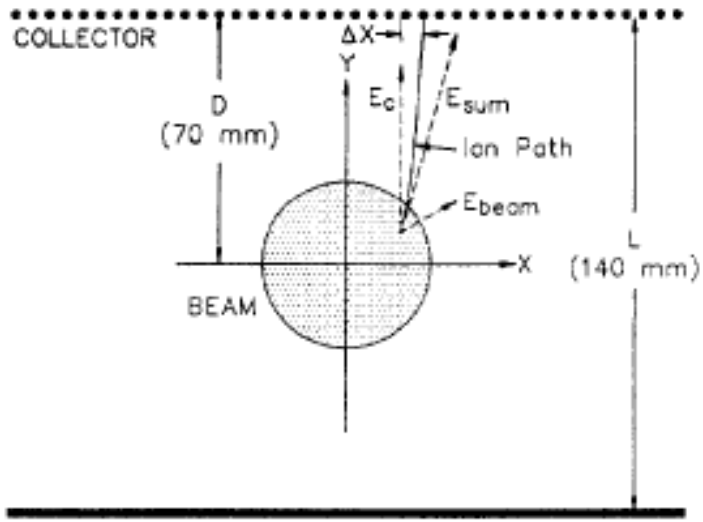
It requires dedicated beam time.
The process is slow. Automating the process would make it faster.
The beam angle through the detector changes during the scan.
We have to monitor for beam loss and we cannot access the full IPM aperture because of beam loss and steering magnet limitations.

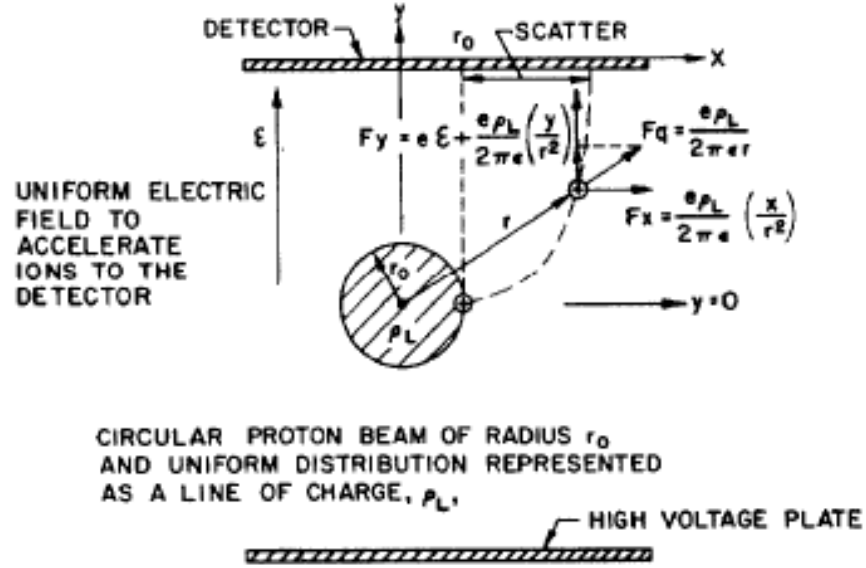
Moving the IPM vacuum chamber would give us several benefits:

Unlimited access to calibration with an ideal source
Access to the full IPM measurement aperture
Scans over the full aperture with step sizes equal to the channel separation
With a completely flat detector response, we can move the chamber in a regular pattern to distribute the beam wear on the MCP over a larger area. We can take out the chamber position when displaying the profiles.

AGS IPM


Detector Rods
14 cm





Model illustrating coulomb force scattering of residual gas ions.

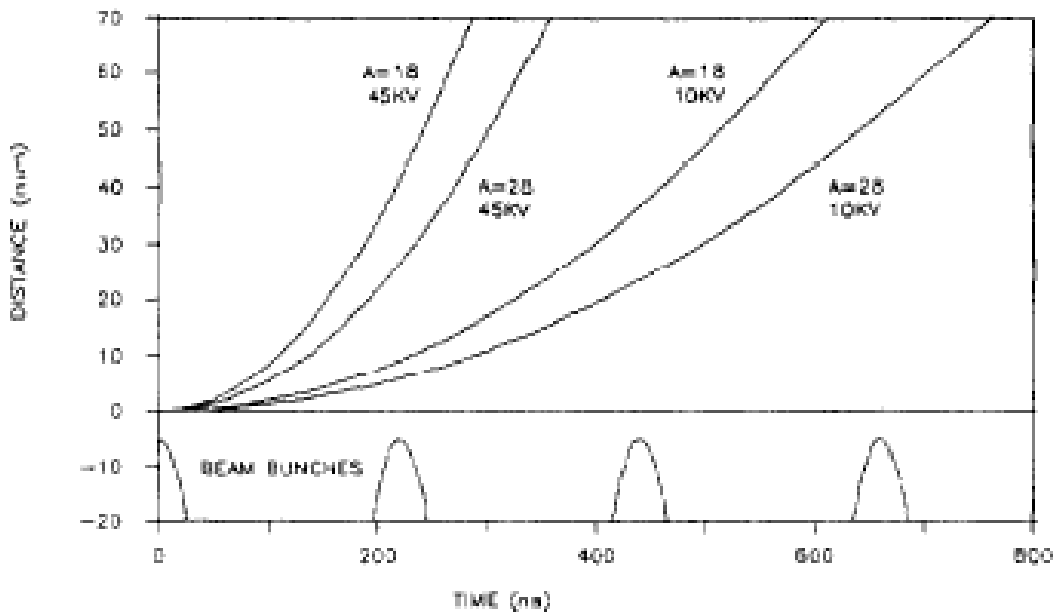
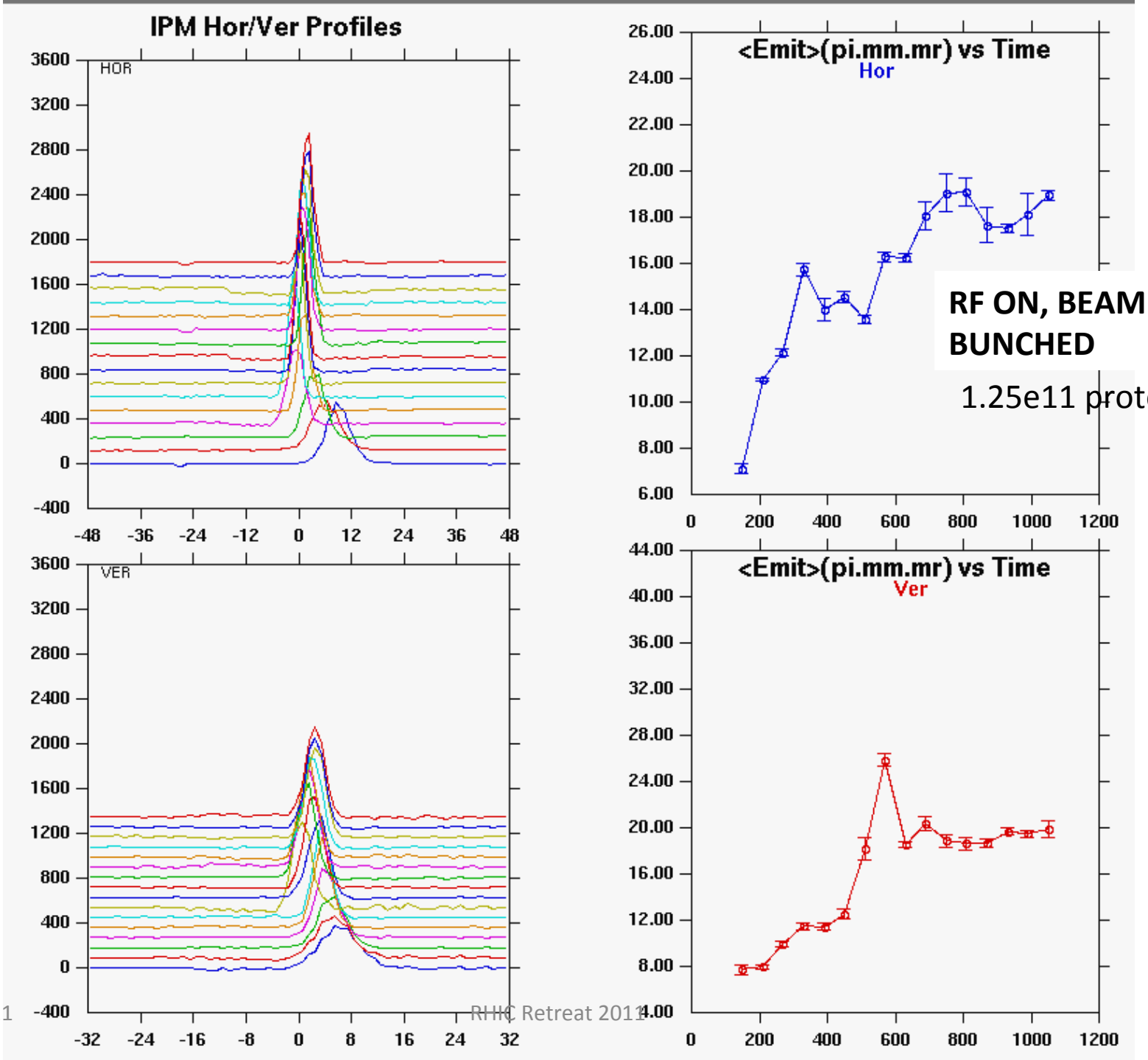
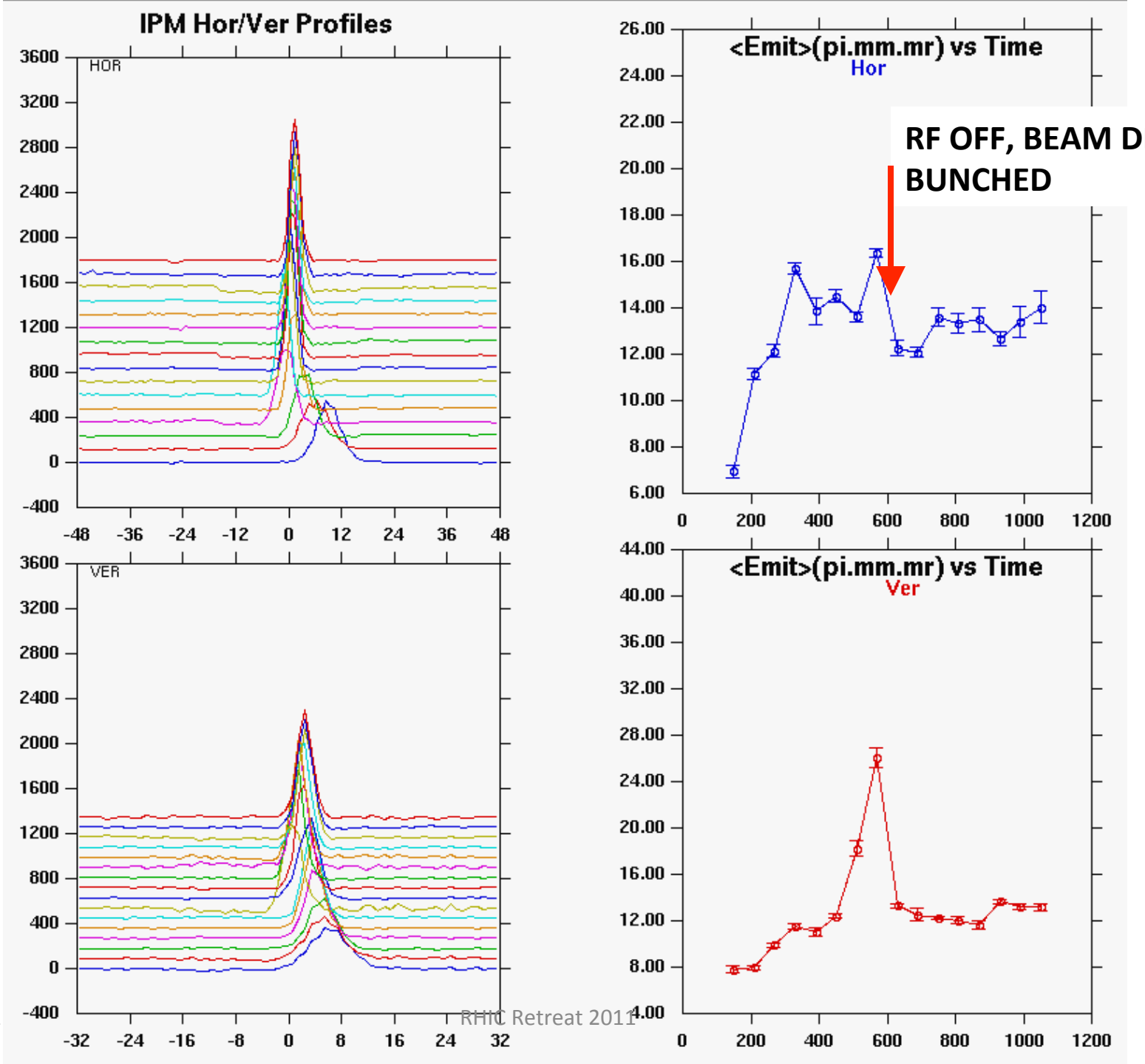
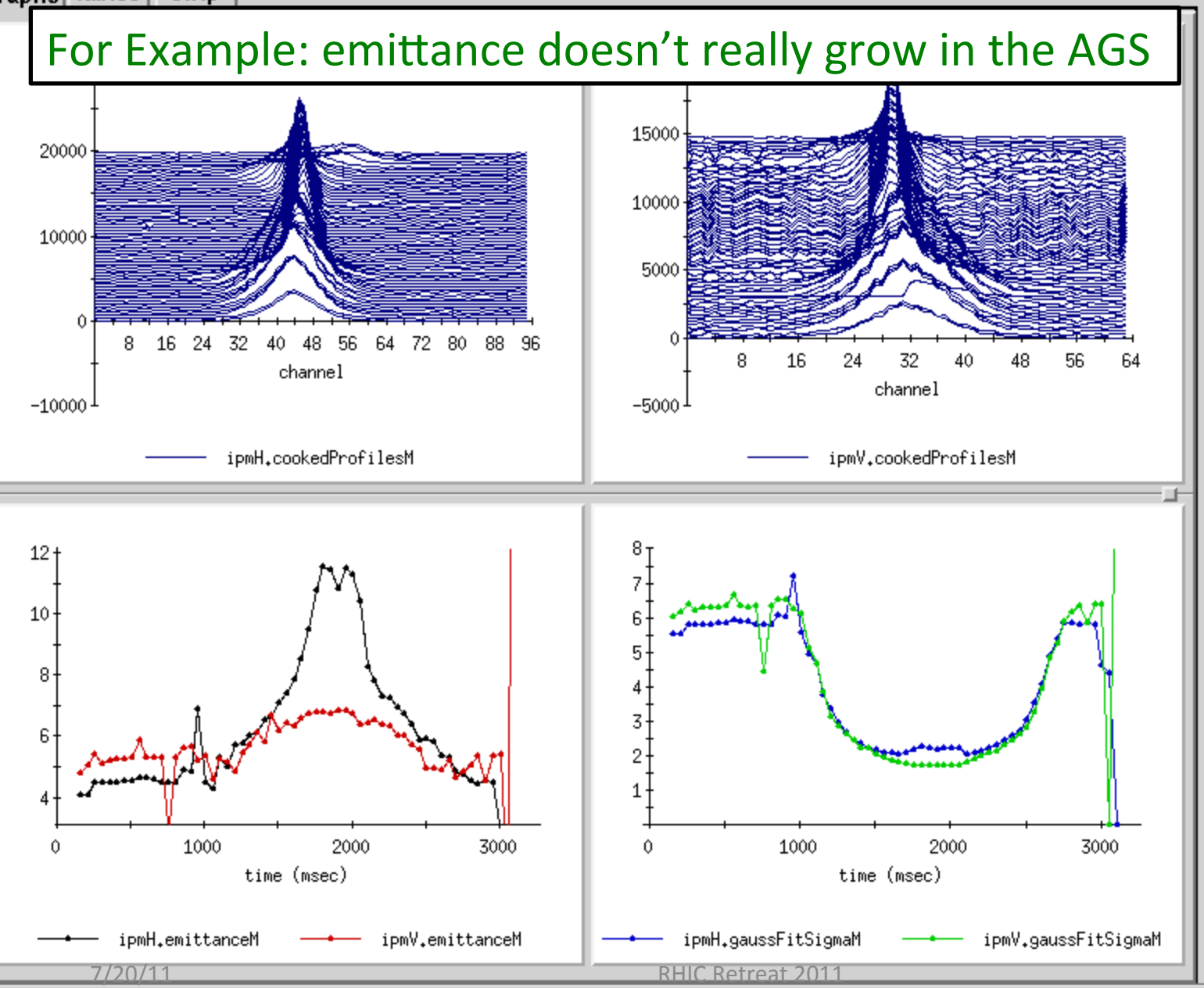


Figure 3. Relationship between AGS bunched beam structure, and the time scale for ion collection, for several ion species and collector voltages.

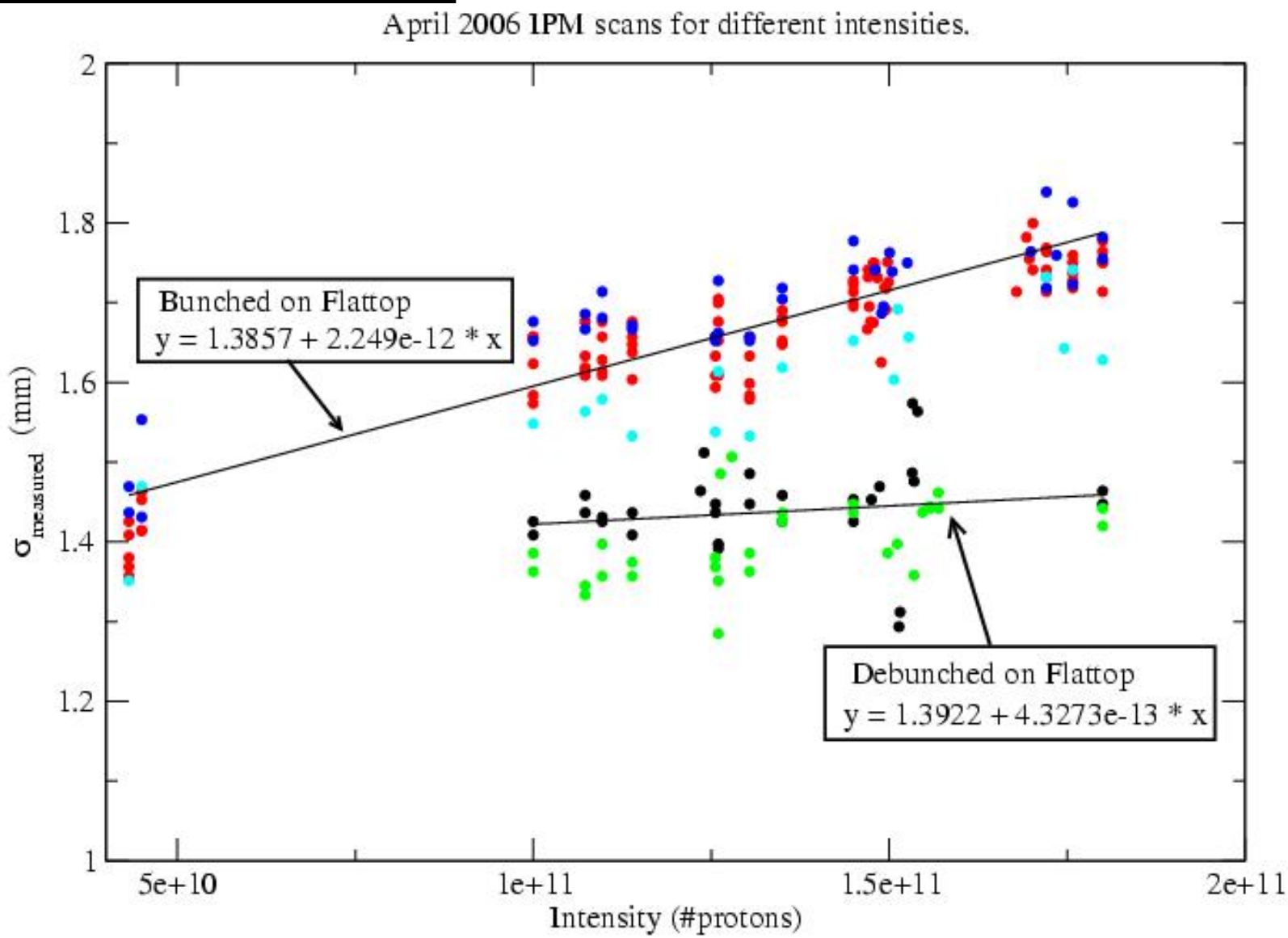

IPM Hor/Ver Profiles
HOR
VER
<Emit>(pi.mm.mr) vs Time
Hor
<Emit>(pi.mm.mr) vs Time
Ver
RF ON, BEAM BUNCHED
1.25e11 protons


IPM Hor/Ver Profiles
HOR
VER
<Emit>(pi.mm.mr) vs Time
Hor
<Emit>(pi.mm.mr) vs Time
Ver
RF OFF, BEAM DE-BUNCHED

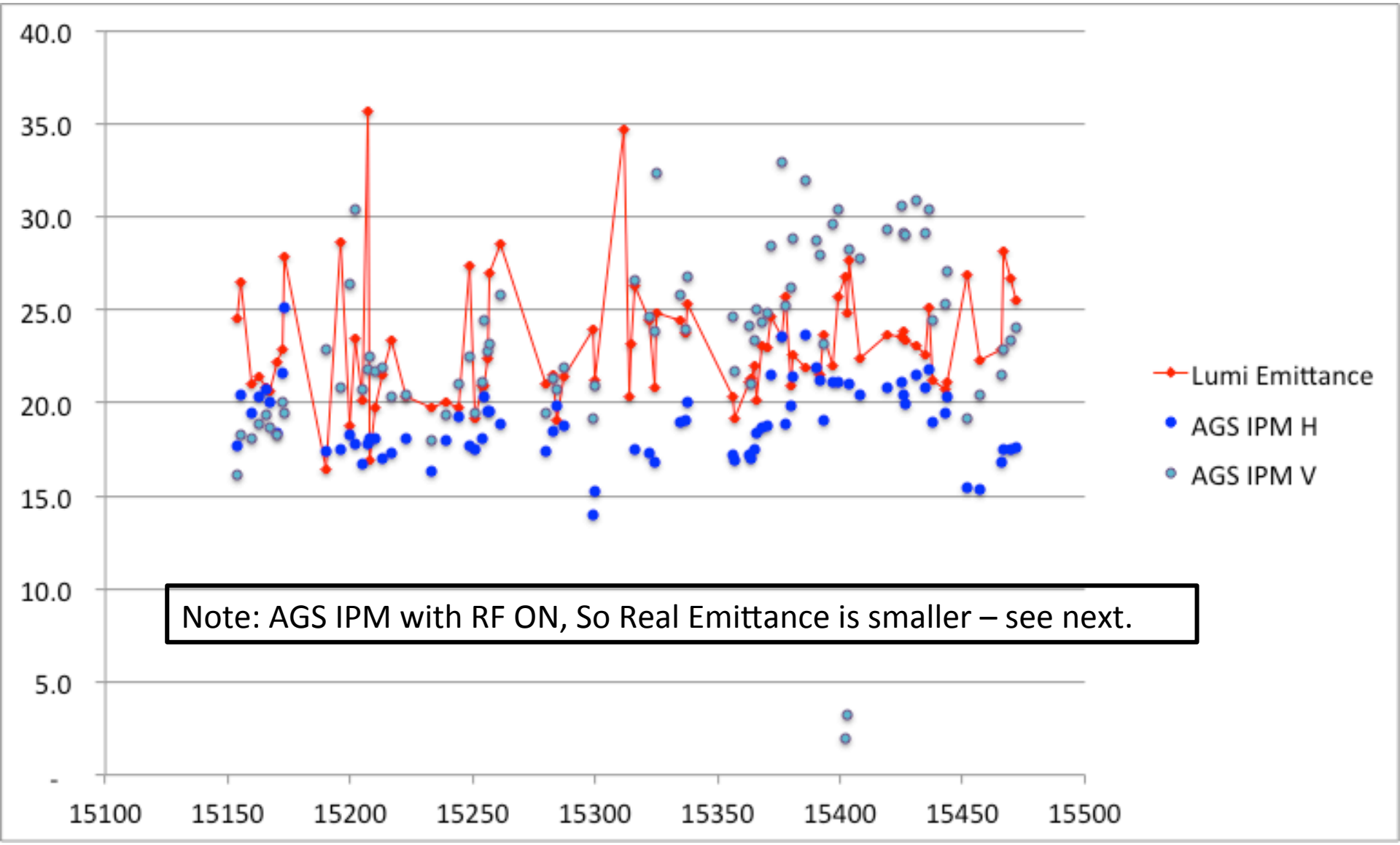
For Example: emittance doesn't really grow in the AGS



$$\sigma_{measured} = \sigma_{real} + \sigma_{sc}$$

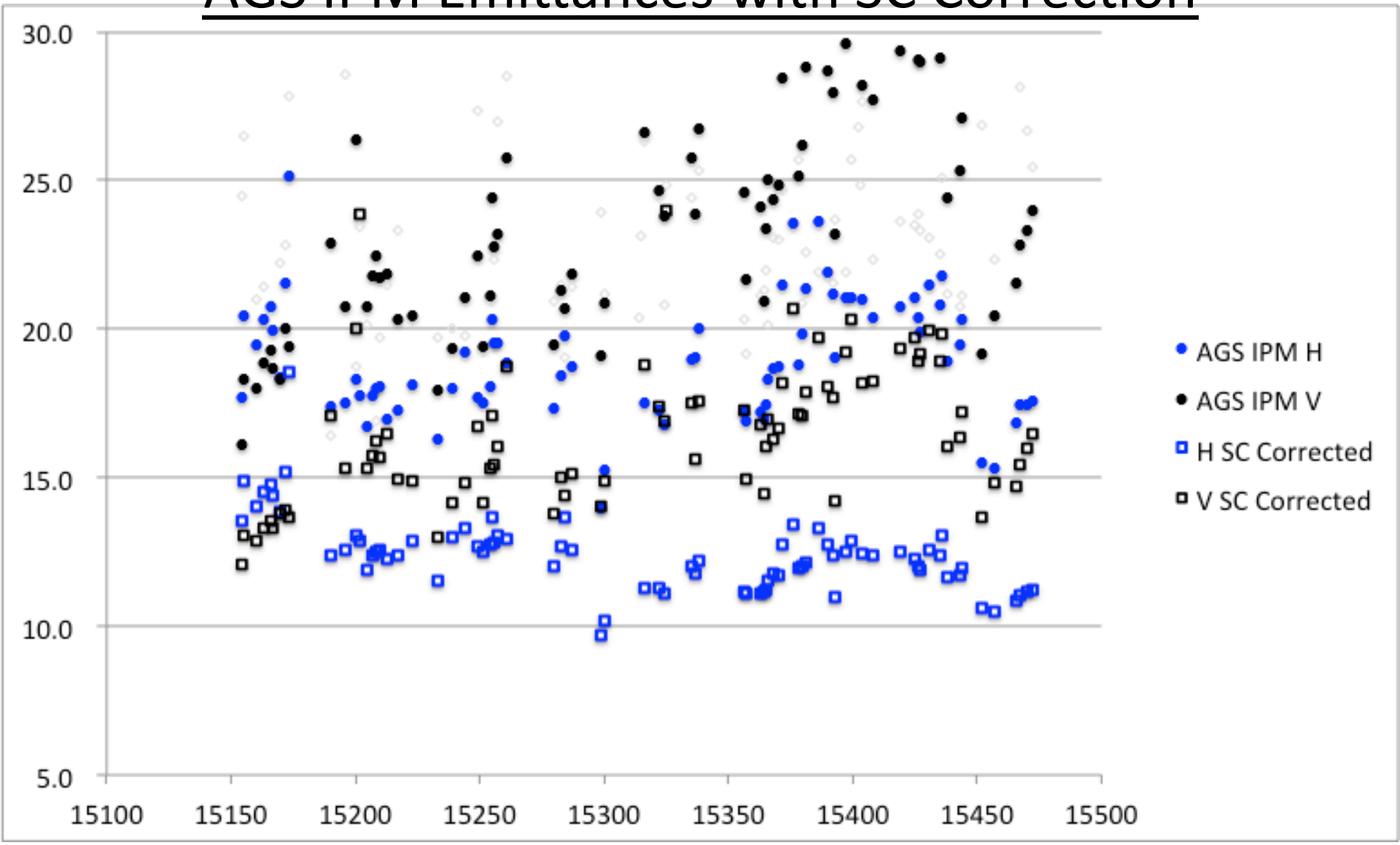


Comparison between AGS IPM and Lumi Emittances



FY 11 pp Run number

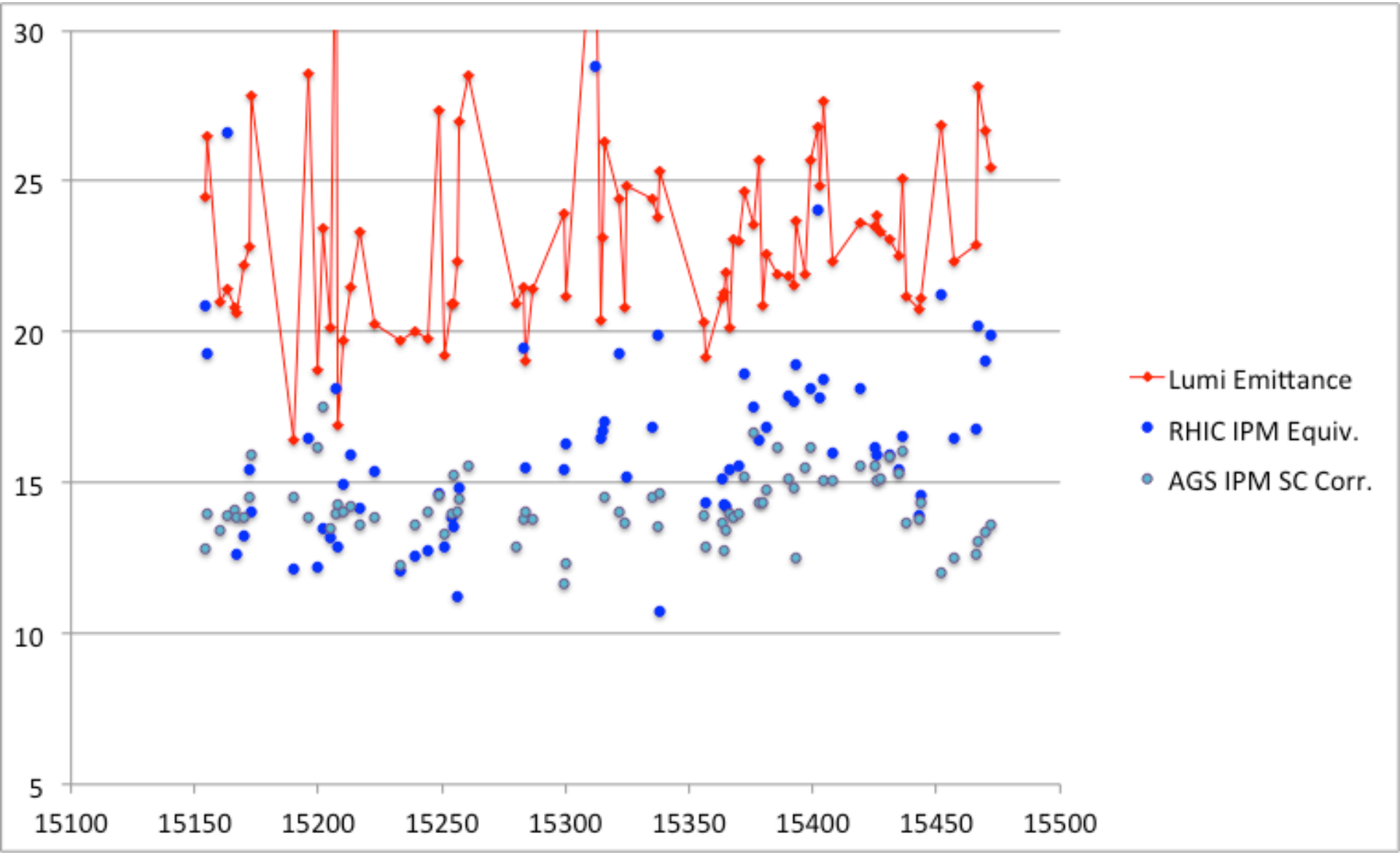
AGS IPM Emittances with SC Correction



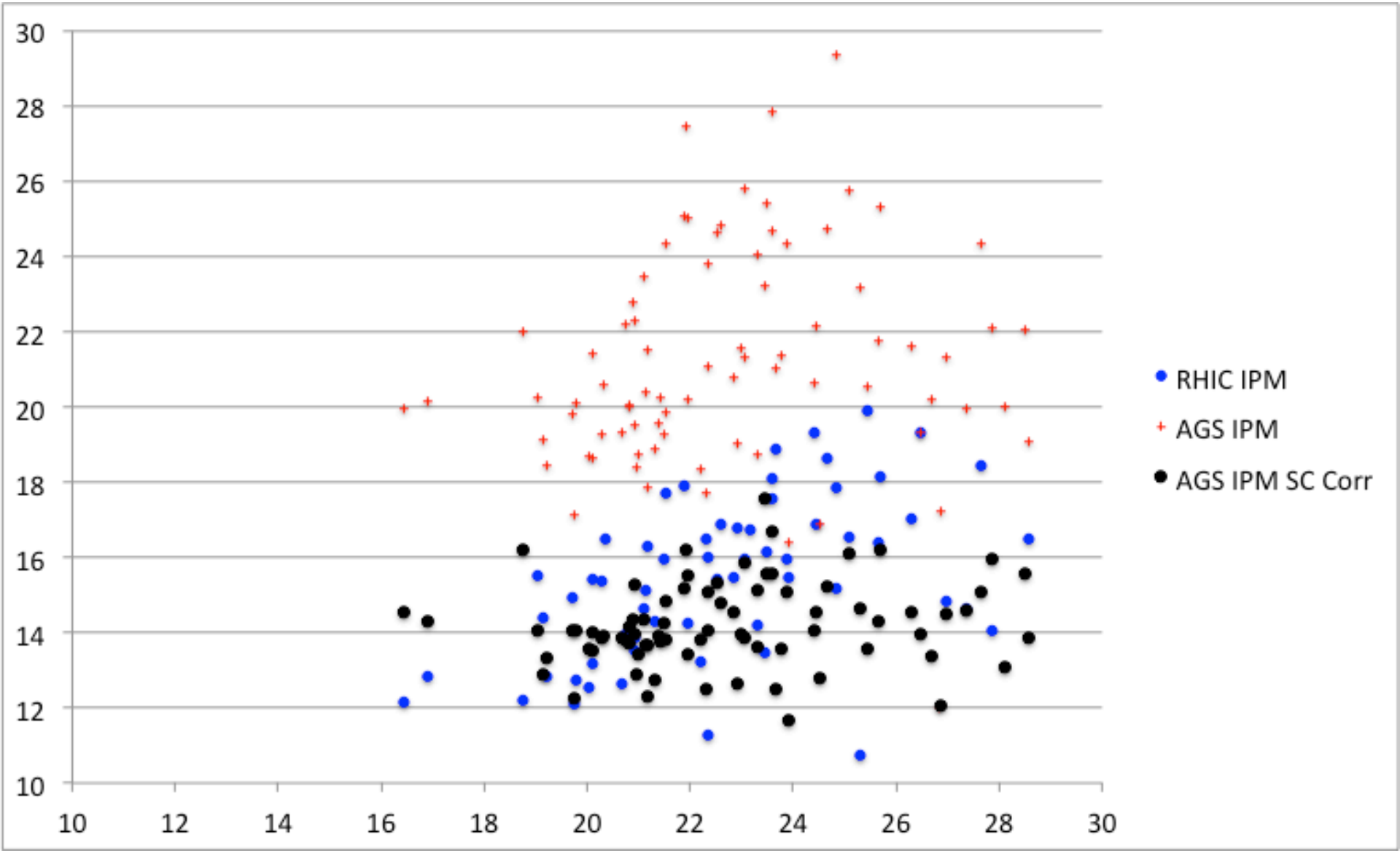
Comparisons

(now work in Lumi-equivalent)

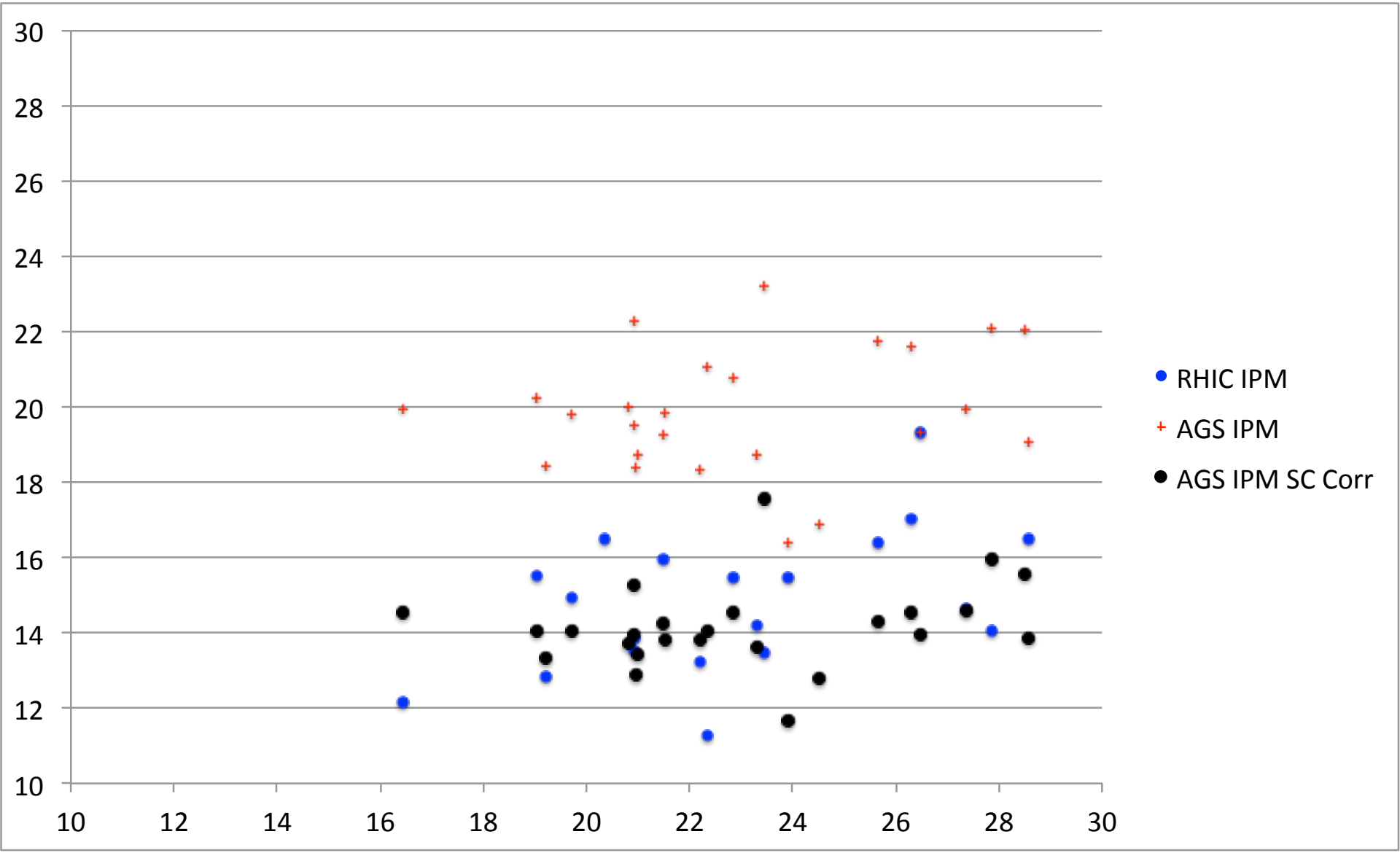
IPM Lumi-Equiv. Emittances & Lumi Emittance



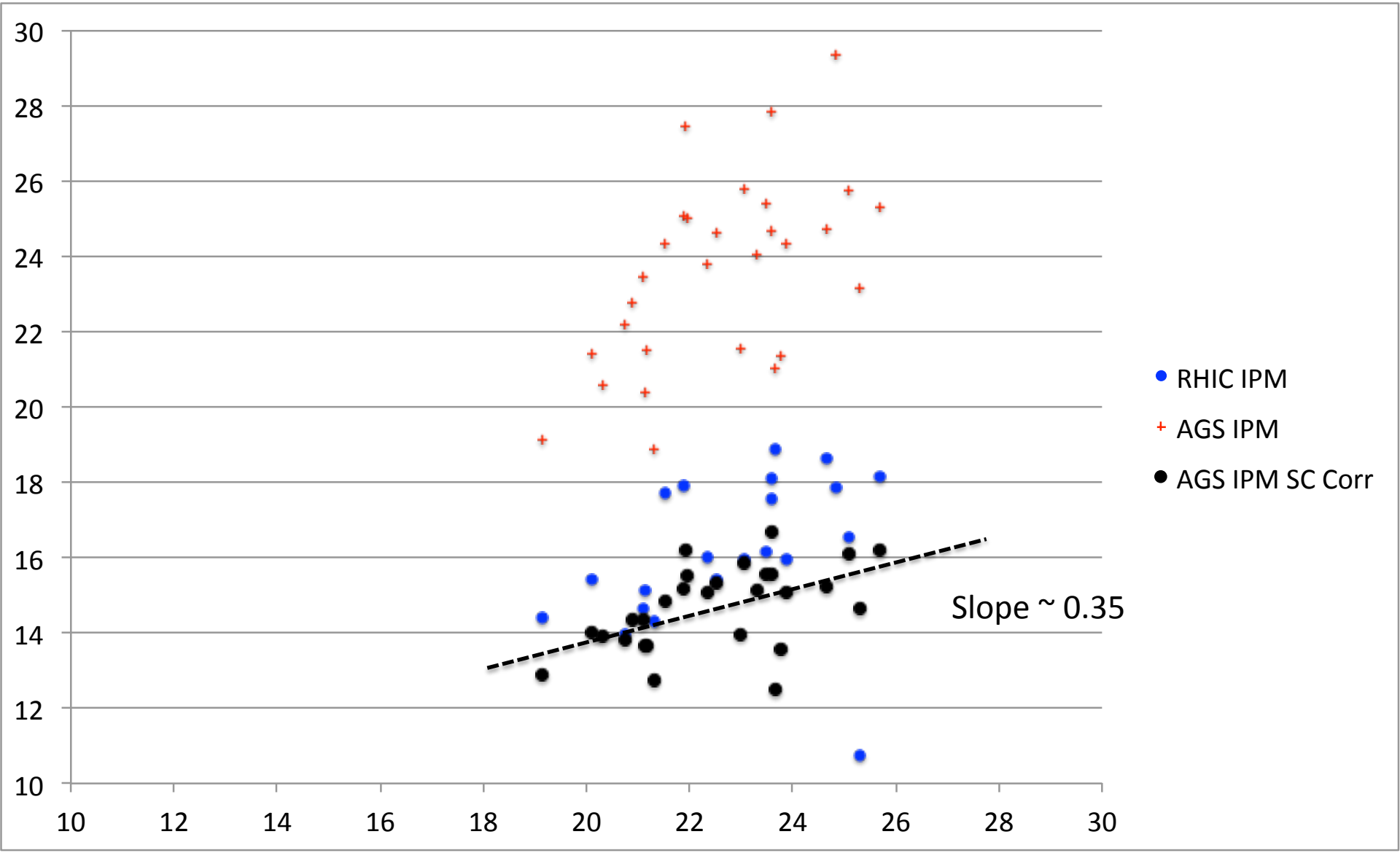
IPM Emittances vs Lumi Emittance: All Data



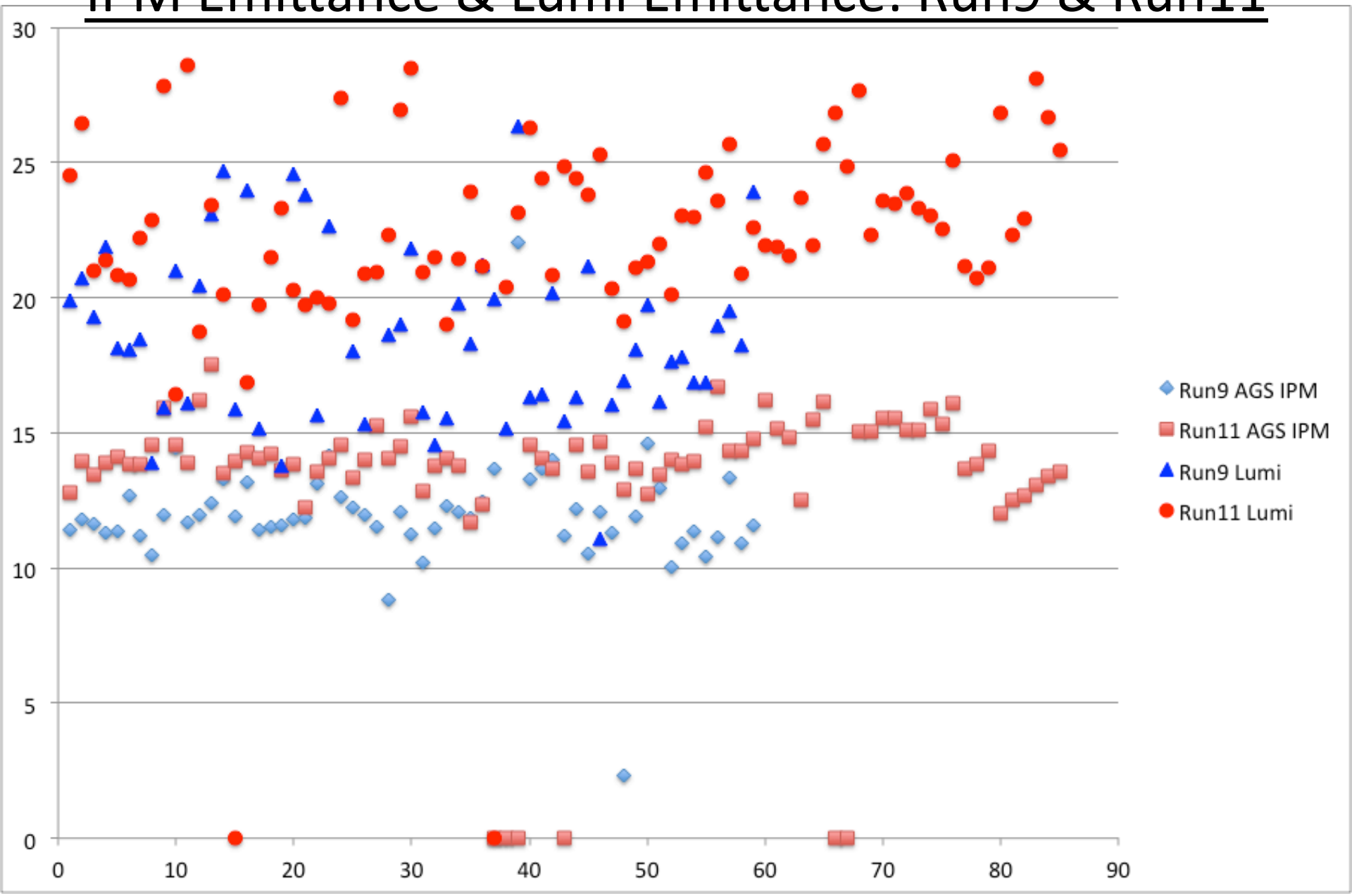
IPM Emittances vs Lumi Emittance: Below Average



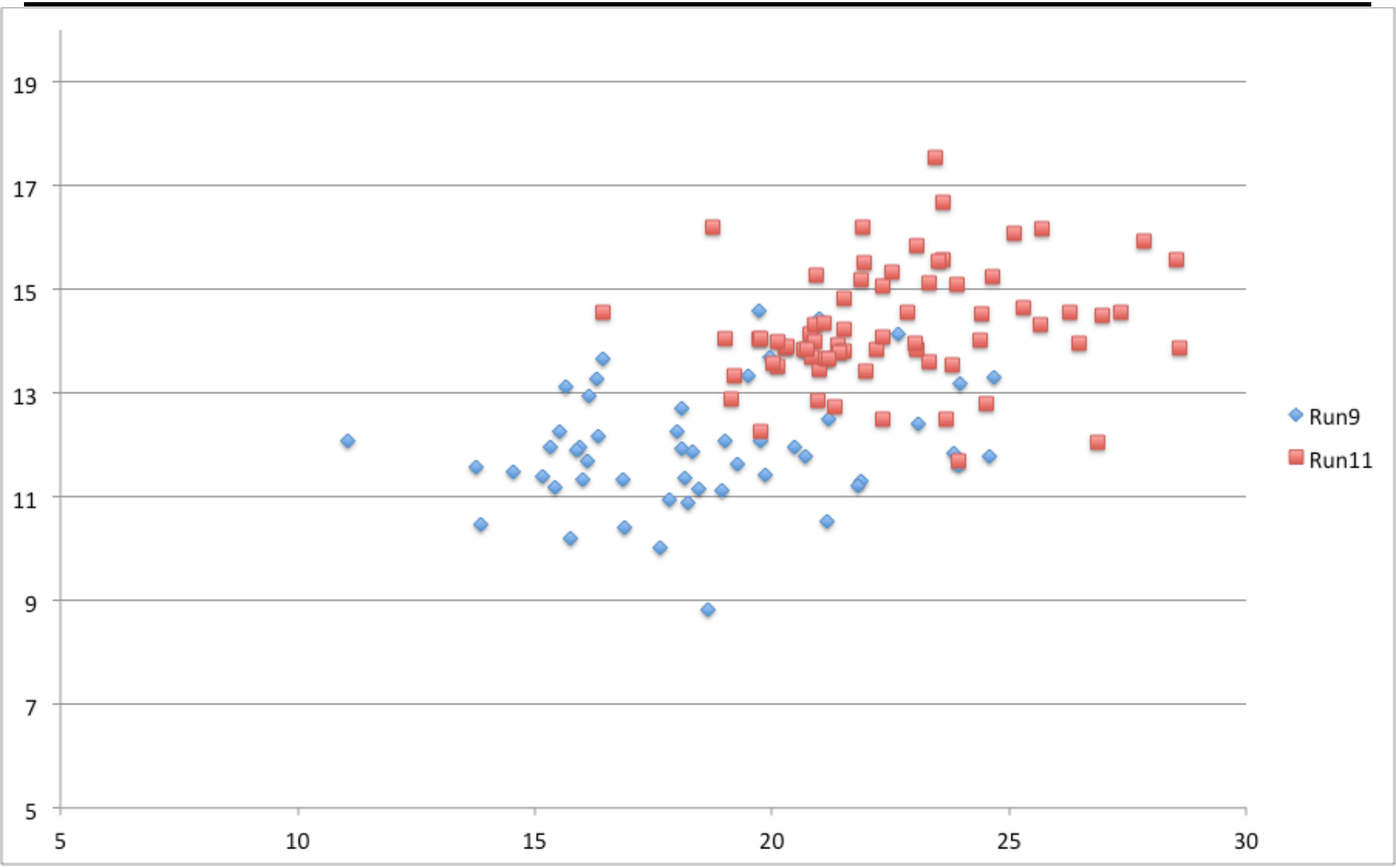
IPM Emittances vs Lumi Emittance: Above Average



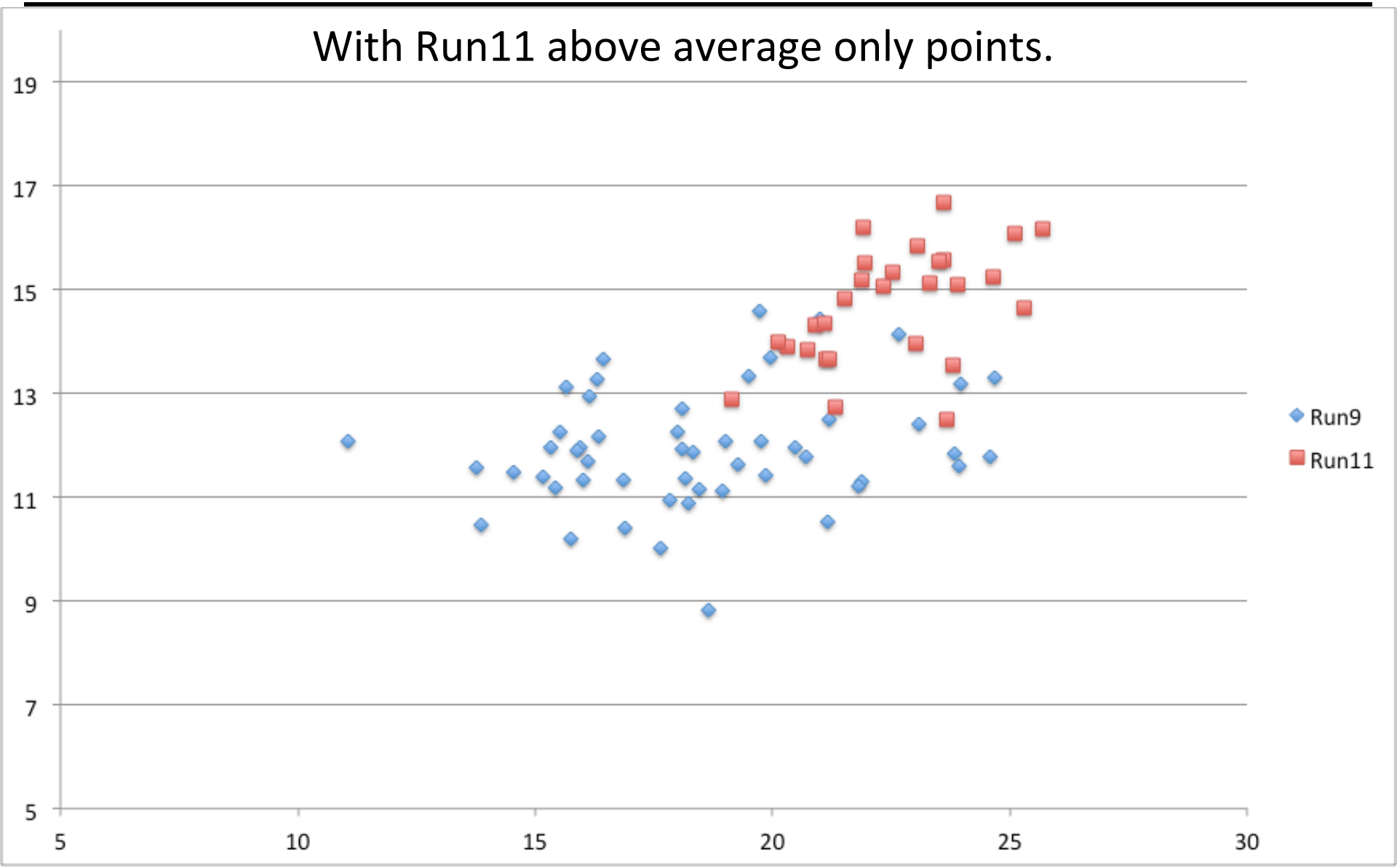
IPM Emittance & Lumi Emittance: Run9 & Run11



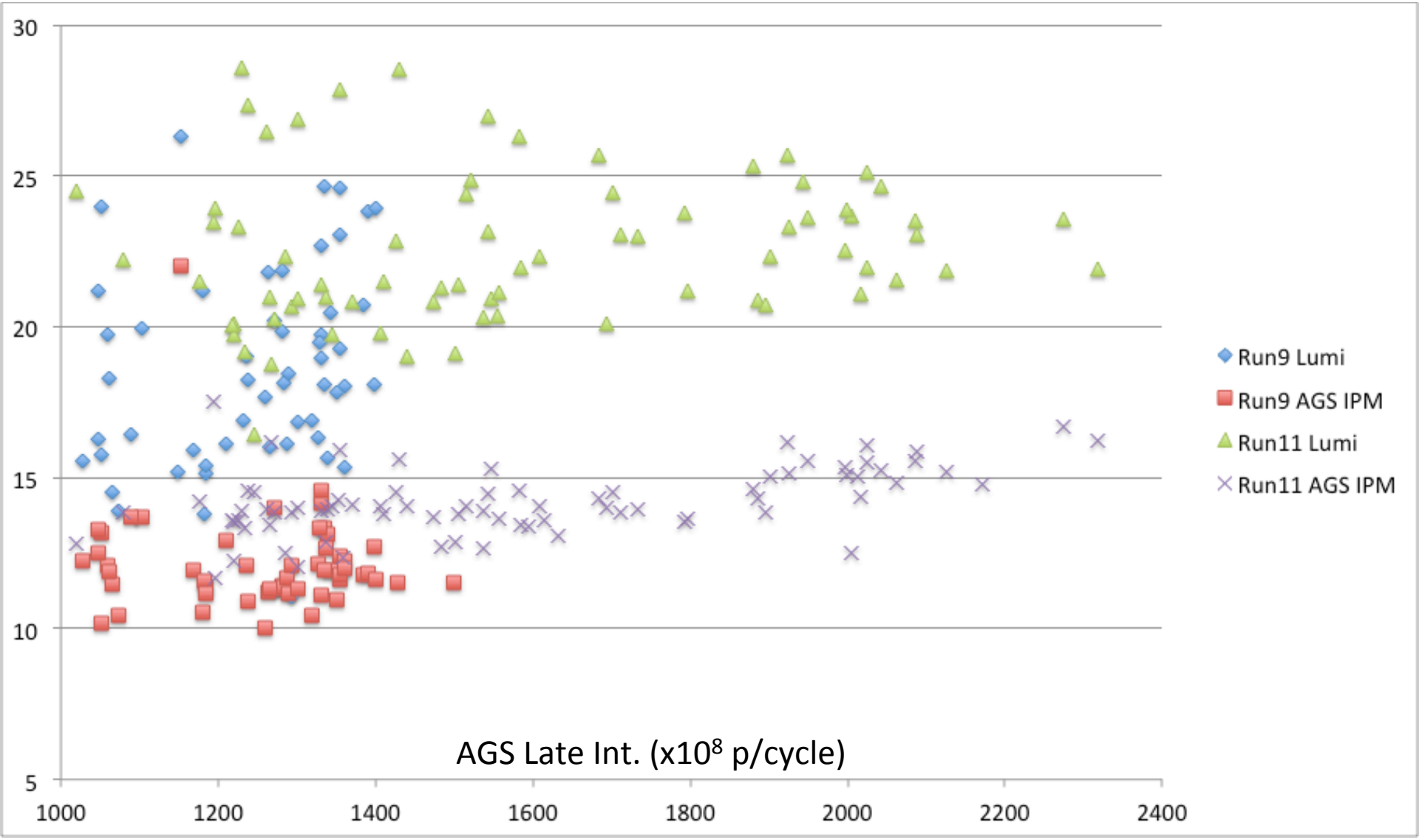
AGS IPM Emittance vs Lumi Emittance: Run9 & Run11



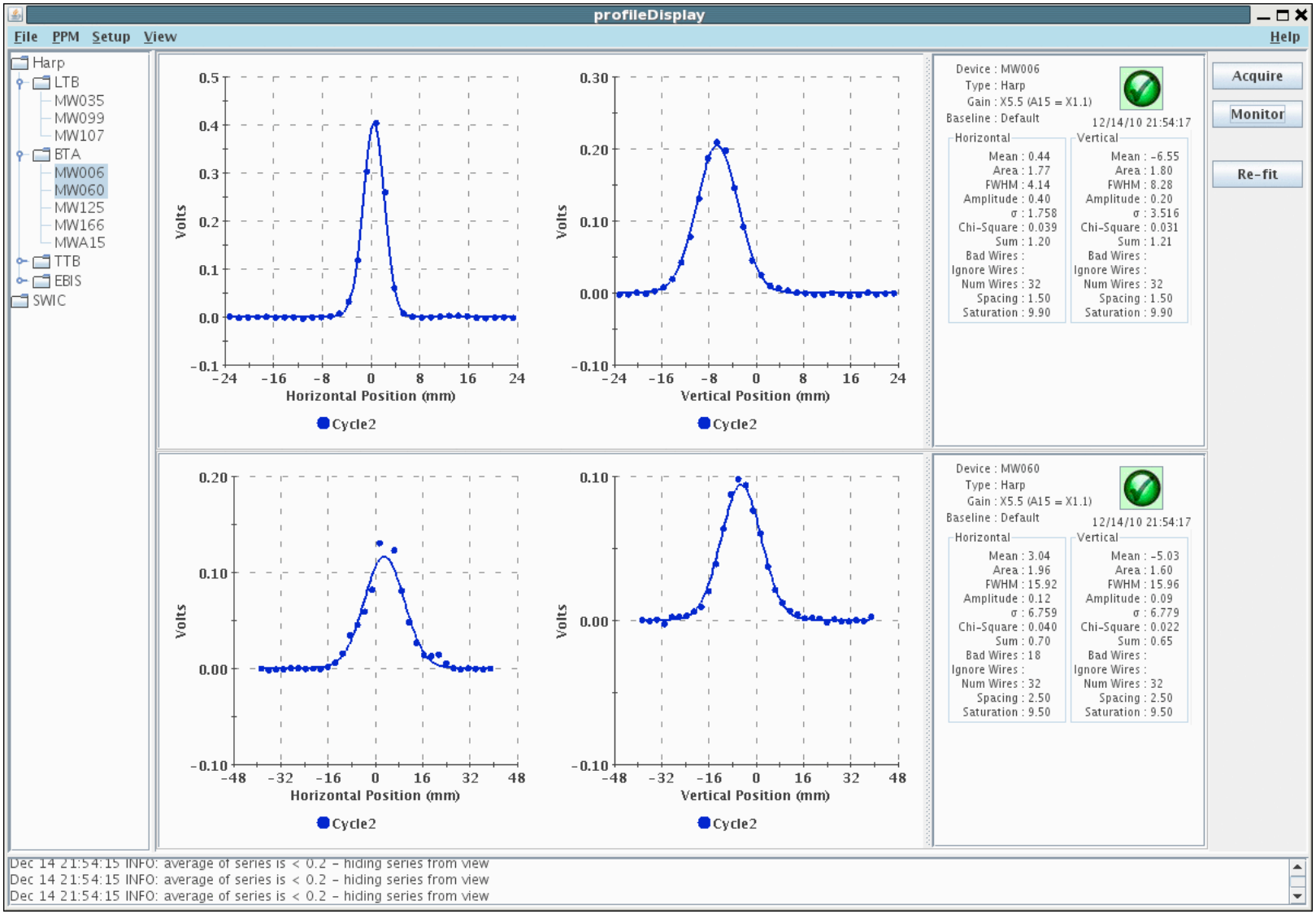
AGS IPM Emittance vs Lumi Emittance: Run9 & Run11



Emittances vs AGS Intensity: Run9 & Run11



BtA Profile Monitors



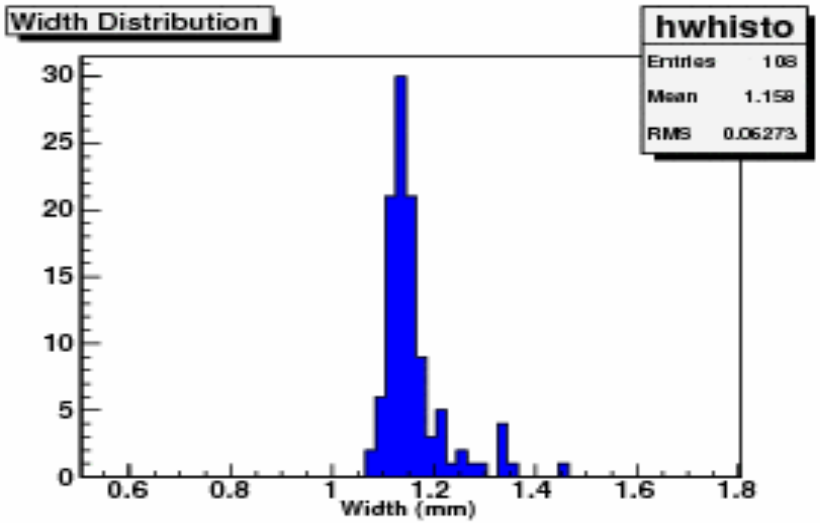
BtA Emittance: Run9 & Run11

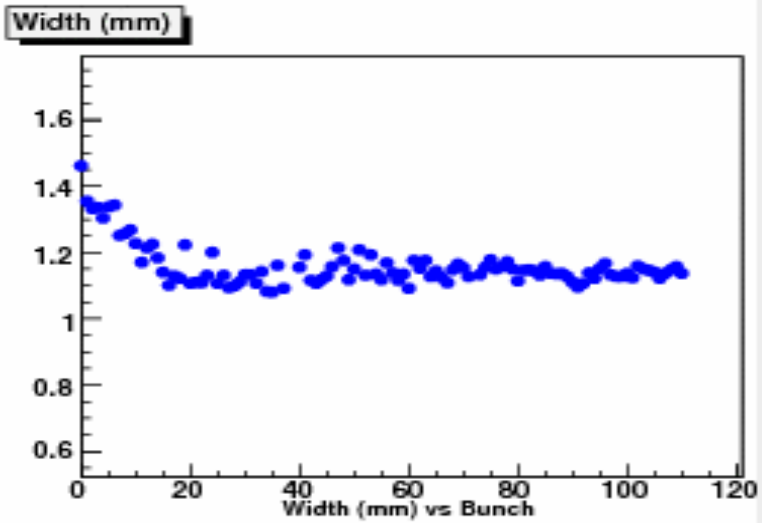
	'09 (from cad note 404)	'11 (from elog profiles)
H fwhm	3.59 mm +/- 0.20 mm	3.88 mm+/-0.24 mm
V fwhm	6.84 mm +/- 0.45 mm	6.99 mm+/-0.55 mm
H emit	10.7 +/- 1.19 pi mm mr	12.4+/-1.54 pi mm mr
V emit	7.3 +/- 1.00 pi mm mr	7.6+/-1.28 pi mm mr

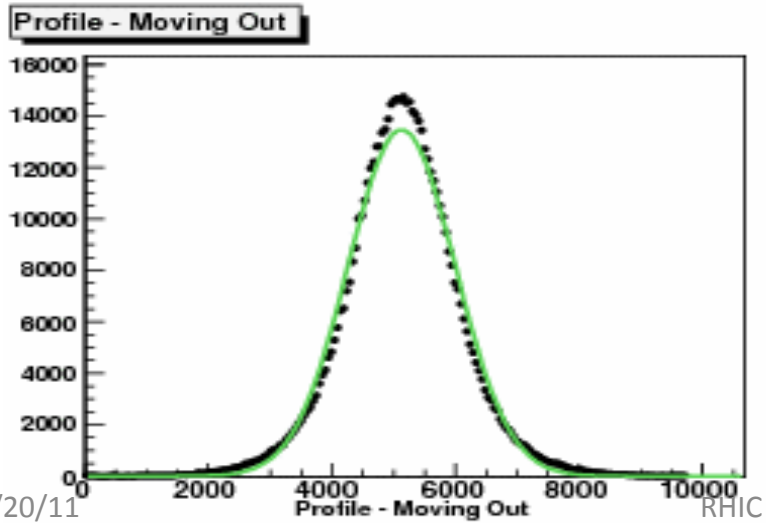
Table of BtA MW006 profile data for unscraped beam using gaussian fit.

CNI Target Scans

April 18, 2011, Vertical emittance at 24GeV



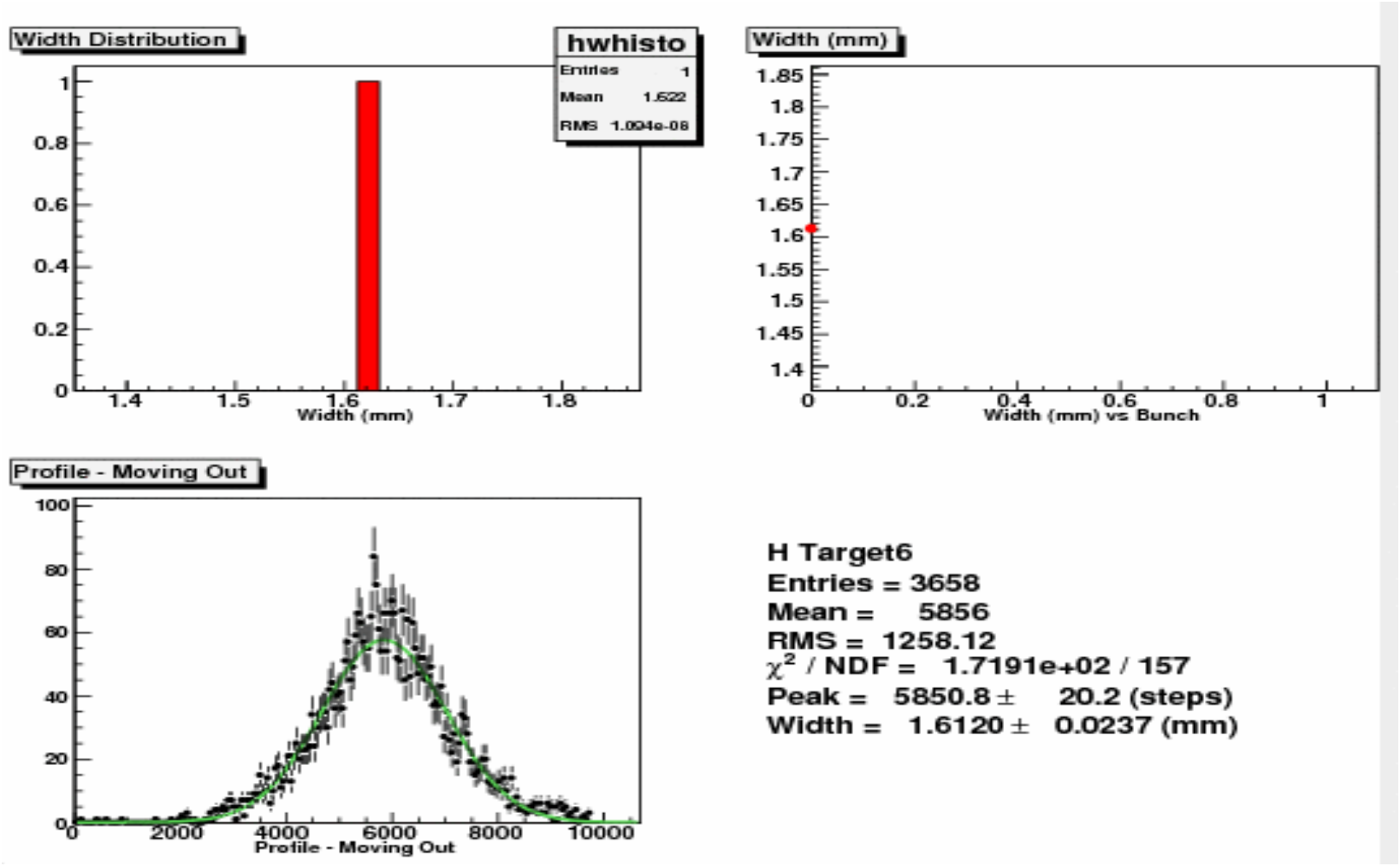




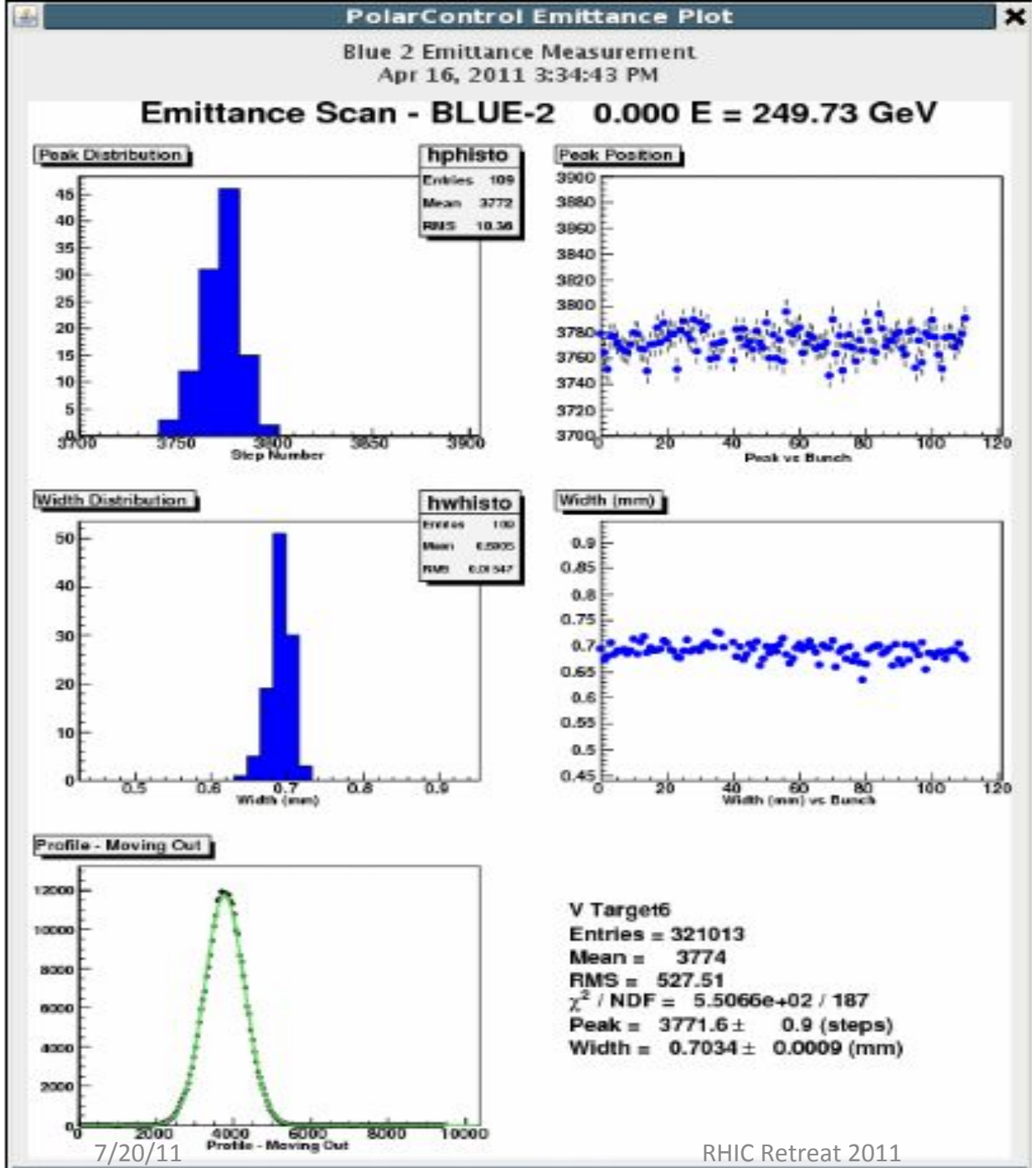
H Target6
Entries = 608094
Mean = 5134
RMS = 915.94
χ^2 / NDF = 1.0936e+04 / 190
Peak = 5134.3 ± 1.1 (steps)
Width = 1.1845 ± 0.0014 (mm)

Vertical emittance-12pi

April 18, 2011, Yellow vert. single bunch emittance



Vert.-11pi


PolarControl Emittance Plot
Blue 2 Emittance Measurement
Apr 16, 2011 3:34:43 PM
Emittance Scan - BLUE-2 0.000 E = 249.73 GeV
Peak Distribution
hphisto
Entries 109
Mean 3772
RMS 10.36
Step Number
Peak Position
Peak vs Bunch
Width Distribution
hwhisto
Width (mm)
Width (mm) vs Bunch
Profile - Moving Out
V Target6
Entries = 321013
Mean = 3774
RMS = 527.51
χ² / NDF = 5.5066e+02 / 187
Peak = 3771.6 ± 0.9 (steps)
Width = 0.7034 ± 0.0009 (mm)
Close

SUMMARY, Run 9

- Small emittances out of linac. V-5pi, H-5 pi.
- Small emittances with 300 us linac pulse and about 50% scraping in Booster in BTA. V-6 pi. H- 8pi.
- Smaller beam emittances out of AGS and at injection to RHIC.
- ATR flags: V - 8pi, H - 12 pi
- CNI V -11pi, H - 12.6 pi
- No emittance growth during energy ramp in RHIC.
- Small emittance growth during the store.
  After 9 hrs at store: V – 15 pi, H – 13pi.

- Vernier scan ~ 16 pi, very small growth during the store time.

Conclusions

- For all emittance devices, truth is elusive.
- Run11 emittances were larger than in Run9, in all measurements.
- All emittance devices need to take a consistent approach
  - Subtract dispersion terms
  - Include error bars
  - Generate Lumi equivalent values
  - Use data quality checks! (e.g., check on dynamic range)
- Emittances need to be kept in a summary record (e.g., along with luminosity in spreadsheets would be excellent)
- We need a device in the AGS that is not space charge sensitive. {okay, we should get SC into the existing one}
- CNI targets show great promise as emittance monitors