Investigation of Space Charge Effects on Polarization

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- Motivation
- Beam experiments
- Simulation

- The polarization of the beam in an accelerator is affected by space charge

- Direct effect:
  Intense self electromagnetic fields in the region of the beam may affect spin precession

- Indirect effects:
  (1) Space charge increases the emittance of the beam
  (2) Space charge generates betatron tune spread and tune shift

- In general, in the machines we are dealing with (AGS, RHIC) we believe that indirect effects are dominant

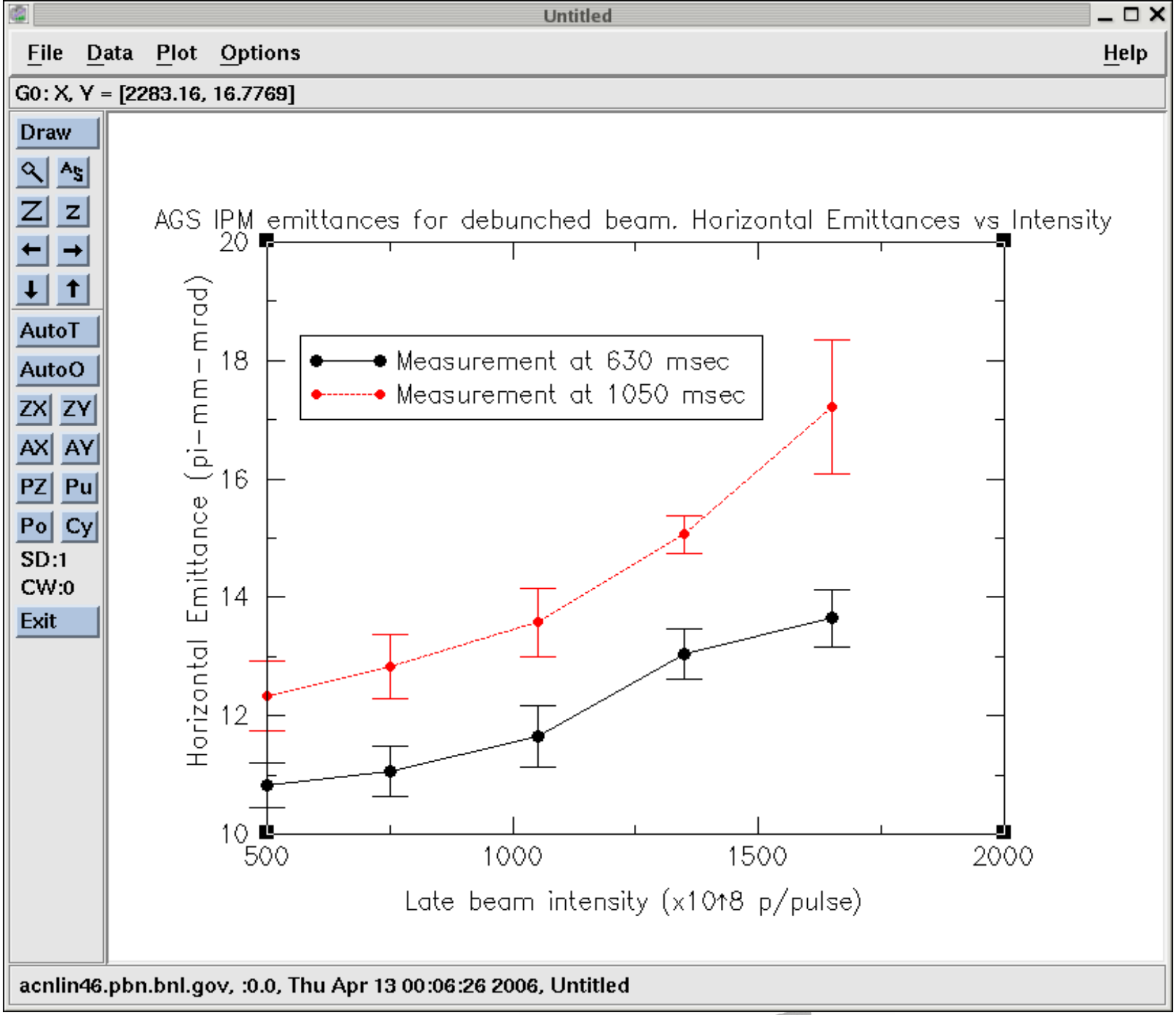
Emittance effects on polarization:

The strength of the spin depolarizing resonances increases with beam emittance

Betatron tune shift and spread effects on polarization:

The position and shape of depolarizing resonance lines depend on betatron tune

Tune spread effectively reduces the “spin tune gap” where the betatron tune should be inserted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AX AY
PZ Pu
Po Cy
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AGS IPM emittances for debunched beam. Horizontal Emittances vs Intensity
Measurement at 630 msec
Measurement at 1050 msec
Horizontal Emittance (pi-mm-mrad)
20
18
16
14
12
10
500
1000
1500
2000
Late beam intensity (x10↑8 p/pulse)
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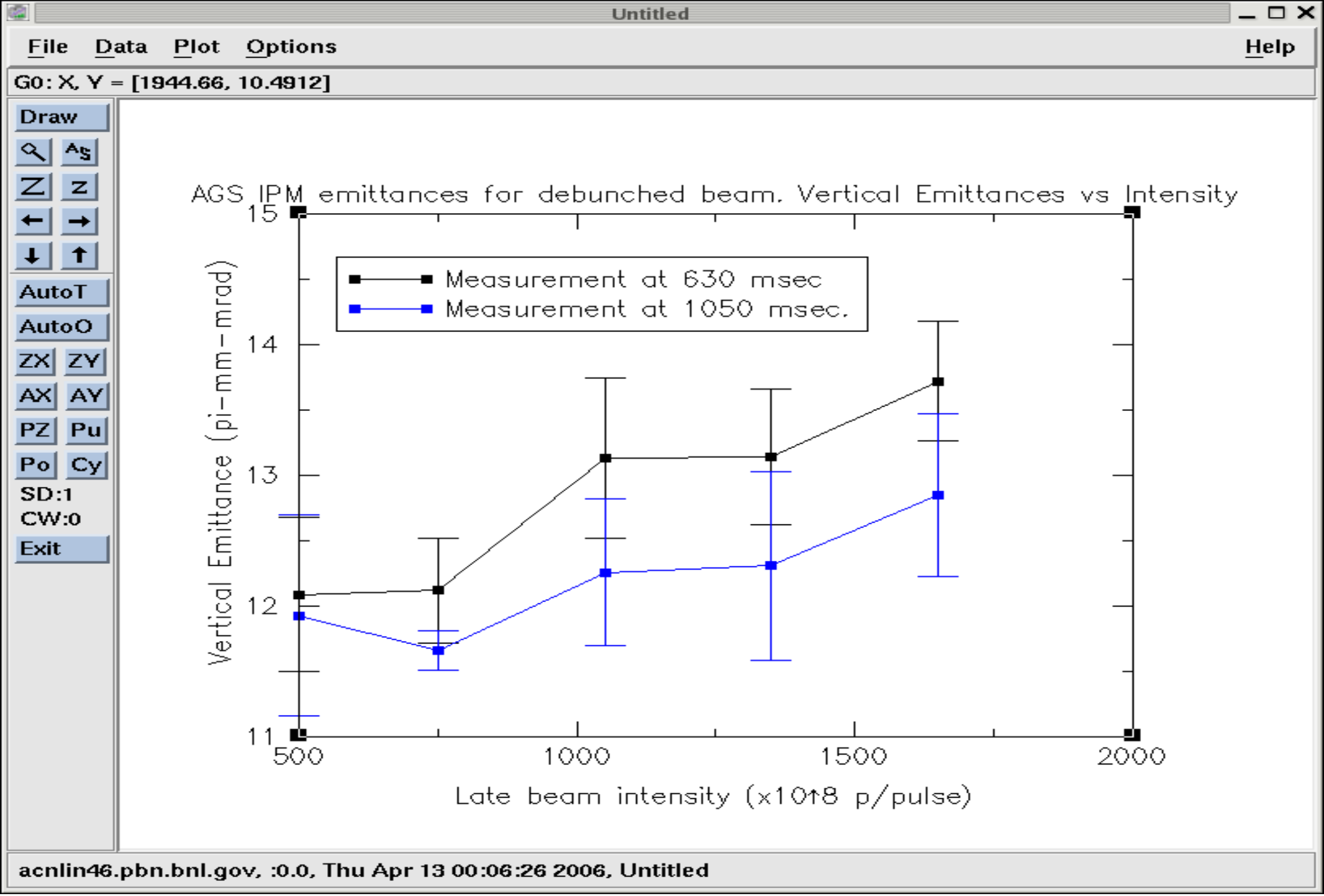
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AutoO
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AX AY
PZ Pu
Po Cy
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AGS IPM emittances for debunched beam. Vertical Emittances vs Intensity
Measurement at 630 msec
Measurement at 1050 msec.
Vertical Emittance (pi-mm-mrad)
15
14
13
12
11
500
1000
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2000
Late beam intensity (x10↑8 p/pulse)
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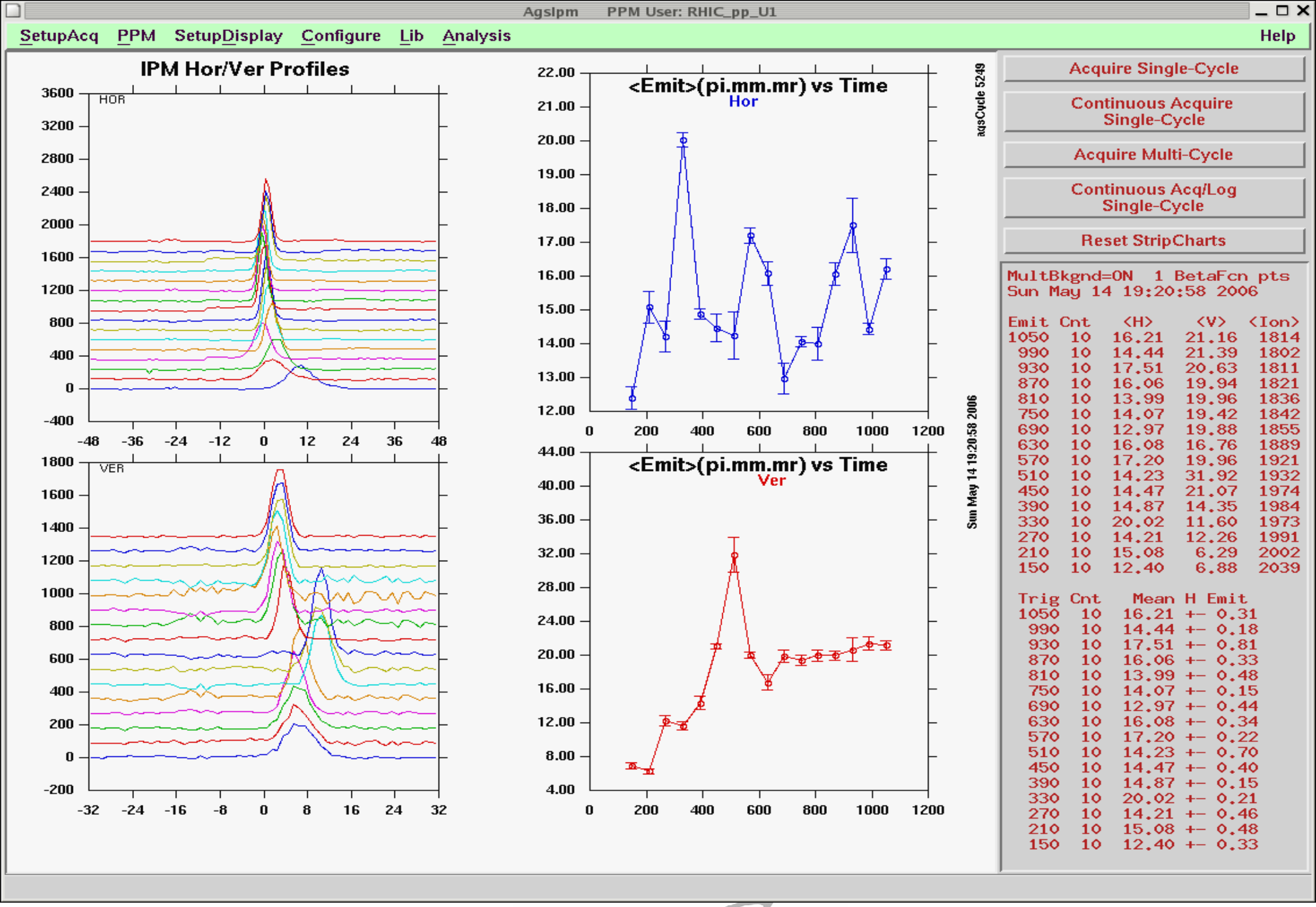
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HOR
VER
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Hor
<Emit>(pi.mm.mr) vs Time
Ver
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Acquire Single-Cycle
Continuous Acquire Single-Cycle
Acquire Multi-Cycle
Continuous Acq/Log Single-Cycle
Reset StripCharts
MultBkgnd=ON 1 BetaFcn pts
Sun May 14 19:20:58 2006
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990 10 14.44 21.39 1802
930 10 17.51 20.63 1811
870 10 16.06 19.94 1821
810 10 13.99 19.96 1836
750 10 14.07 19.42 1842
690 10 12.97 19.88 1855
630 10 16.08 16.76 1889
570 10 17.20 19.96 1921
510 10 14.23 31.92 1932
450 10 14.47 21.07 1974
390 10 14.87 14.35 1984
330 10 20.02 11.60 1973
270 10 14.21 12.26 1991
210 10 15.08 6.29 2002
150 10 12.40 6.88 2039
Trig Cnt Mean H Emit
1050 10 16.21 +- 0.31
990 10 14.44 +- 0.18
930 10 17.51 +- 0.81
870 10 16.06 +- 0.33
810 10 13.99 +- 0.48
750 10 14.07 +- 0.15
690 10 12.97 +- 0.44
630 10 16.08 +- 0.34
570 10 17.20 +- 0.22
510 10 14.23 +- 0.70
450 10 14.47 +- 0.40
390 10 14.87 +- 0.15
330 10 20.02 +- 0.21
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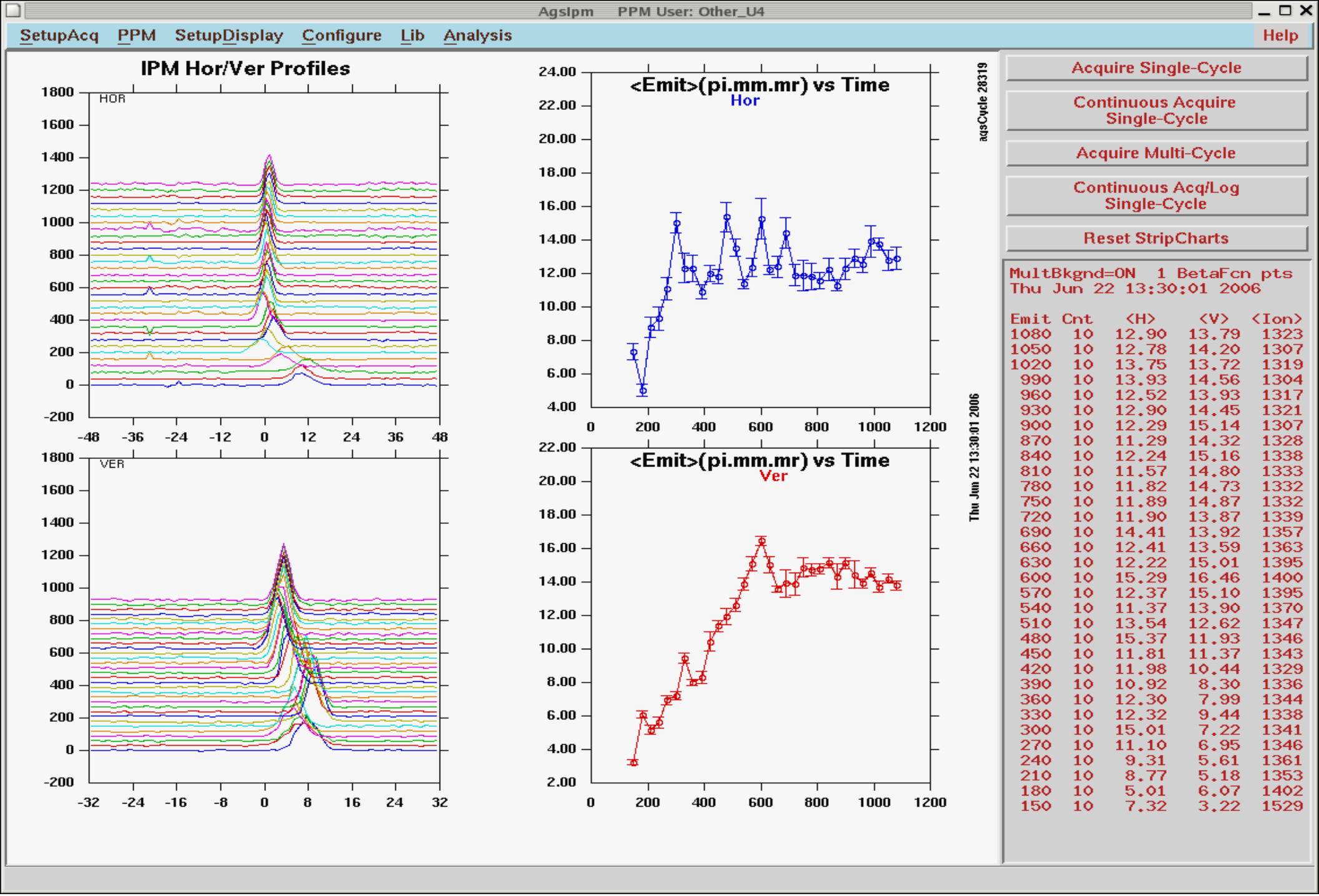
210 10 15.08 +- 0.48
150 10 12.40 +- 0.33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HOR
VER
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Hor
<Emit>(pi.mm.mr) vs Time
Ver
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Acquire Single-Cycle
Continuous Acquire Single-Cycle
Acquire Multi-Cycle
Continuous Acq/Log Single-Cycle
Reset StripCharts
MultBkgnd=ON 1 BetaFcn pts
Thu Jun 22 13:30:01 2006
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1050 10 12.78 14.20 1307
1020 10 13.75 13.72 1319
990 10 13.93 14.56 1304
960 10 12.52 13.93 1317
930 10 12.90 14.45 1321
900 10 12.29 15.14 1307
870 10 11.29 14.32 1328
840 10 12.24 15.16 1338
810 10 11.57 14.80 1333
780 10 11.82 14.73 1332
750 10 11.89 14.87 1332
720 10 11.90 13.87 1339
690 10 14.41 13.92 1357
660 10 12.41 13.59 1363
630 10 12.22 15.01 1395
600 10 15.29 16.46 1400
570 10 12.37 15.10 1395
540 10 11.37 13.90 1370
510 10 13.54 12.62 1347
480 10 15.37 11.93 1346
450 10 11.81 11.37 1343
420 10 11.98 10.44 1329
390 10 10.92 8.30 1336
360 10 12.30 7.99 1344
330 10 12.32 9.44 1338
300 10 15.01 7.22 1341
270 10 11.10 6.95 1346
240 10 9.31 5.61 1361
210 10 8.77 5.18 1353
180 10 5.01 6.07 1402
150 10 7.32 3.22 1529

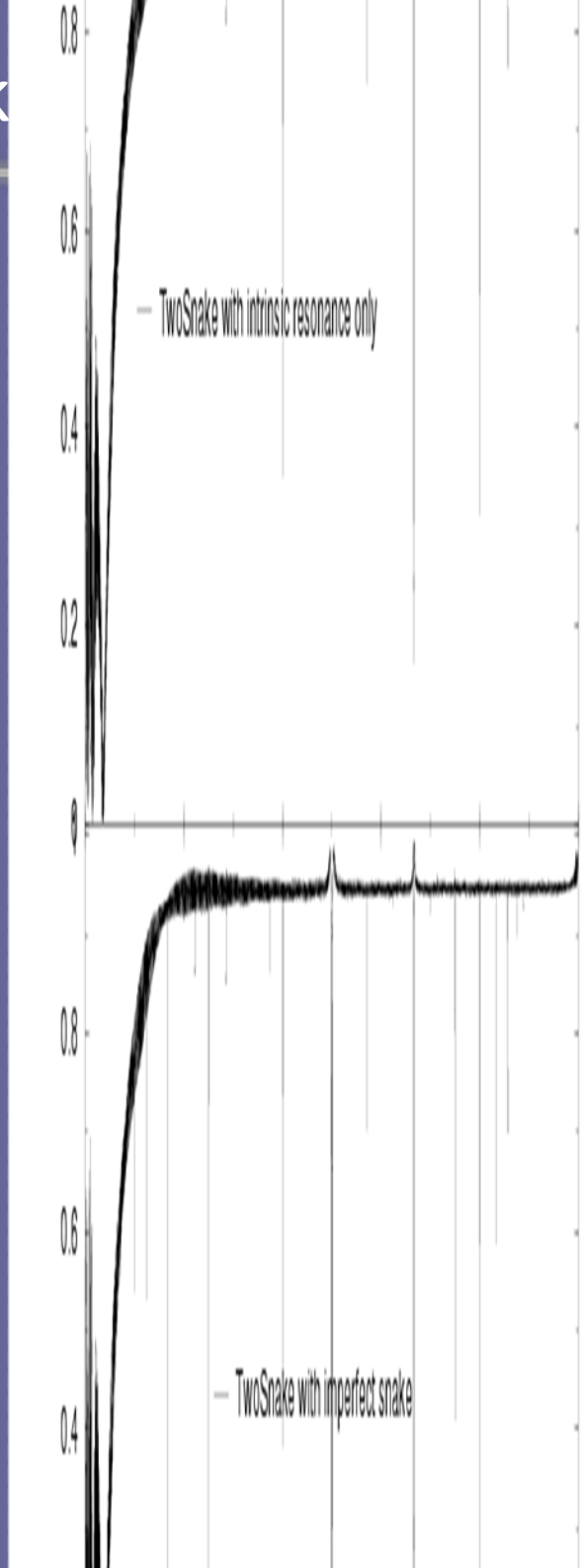
Possible causes of emittance growth

- Space Charge
- Coupling resonances
- Magnet rotation
- Power supply noise
- Orbit harmonics
- Injection misalignments
- ?

Team

- M. Bai, H. Huang, A. Luccio, V. Ptitsyn, T. Roser, A. Zelenski, W. Fischer
- Instrument
  - BBQ and BTF measurement
  - CNI polarimeter
  - AGS polarimeter

Snak m


0.8
0.6
0.4
0.2
0
TwoSnake with intrinsic resonance only
0.8
0.6
0.4
TwoSnake with imperfect snake

Experimental setup

- Measure space charge tune shift, both incoherent and coherent
  - Coherent tune shift: BBQ
  - Tune spread: BTF for different bunch intensity. Expect the change of the tune width from BTF is proportional to the space change tune spread
- Measure beam polarization for different bunch intensity both at AGS extraction as well as at RHIC injection to exclude the polarization dependence from AGS

Experimental procedure

- Energy: RHIC injection
- Push the working point close to 0.7, a location of snake resonance
- Inject one bunch with different intensity and measure its betatron tune as well as tune spread
- Inject multipole bunches with the same intensity, measure the polarization in RHIC as well as in the AGS
- Repeat the above procedure for 4-5 different beam intensities: 0.5x10^11 to 2x10^11

Some previous theoretical and simulation (Spink) analysis

"Effects of Beam-Beam Interaction on Spin Motion"
by A.Luccio and M.Syphers
AGS/RHIC/SN no.068 – November 25, 1997
also: Desy Workshop on Snakes, 1998

Small, but noticeable effects found in RHIC at low energy

code SIMBAD for space charge
code SPINK for spin tracking

- SIMBAD uses a LU solver for the Poisson problem: differential Laplacian with boundary conditions at walls, producing space potential and wall images

- SIMBAD uses algorithms based on eigenvalues of the one turn matrix to calculate tune distribution in 3 dimensions

Differential Poisson-Ampere

These are methods for the solution of the Poisson Equation, that we here rewrite, including boundary condition on the walls (Dirichlet condition for the function or Neumann condition for its derivative at the walls)

$$\nabla^2\Phi(P) = -\frac{\rho(P)}{\epsilon_0},$$
$$\Phi(P_{wall}) = 0$$

As we already observed, the potential at the wall is an *input* to the problem, while the image charges are obtained as *output*. For perfectly conductive walls, the field outside is zero and then, by Gauss's Theorem, the total image charge must equal the beam charge.

Differential Poisson-Ampere

The differential Poisson's can be solved by LU decomposition. First, discretize the equation on a $M \times N$ mesh, that for the sake of illustration we assume Cartesian with equal spacing in the transverse coordinates x, y

$$-4\pi\rho_{ij} = \mathcal{L}_{ij}^{kl}\Phi_{kl},$$

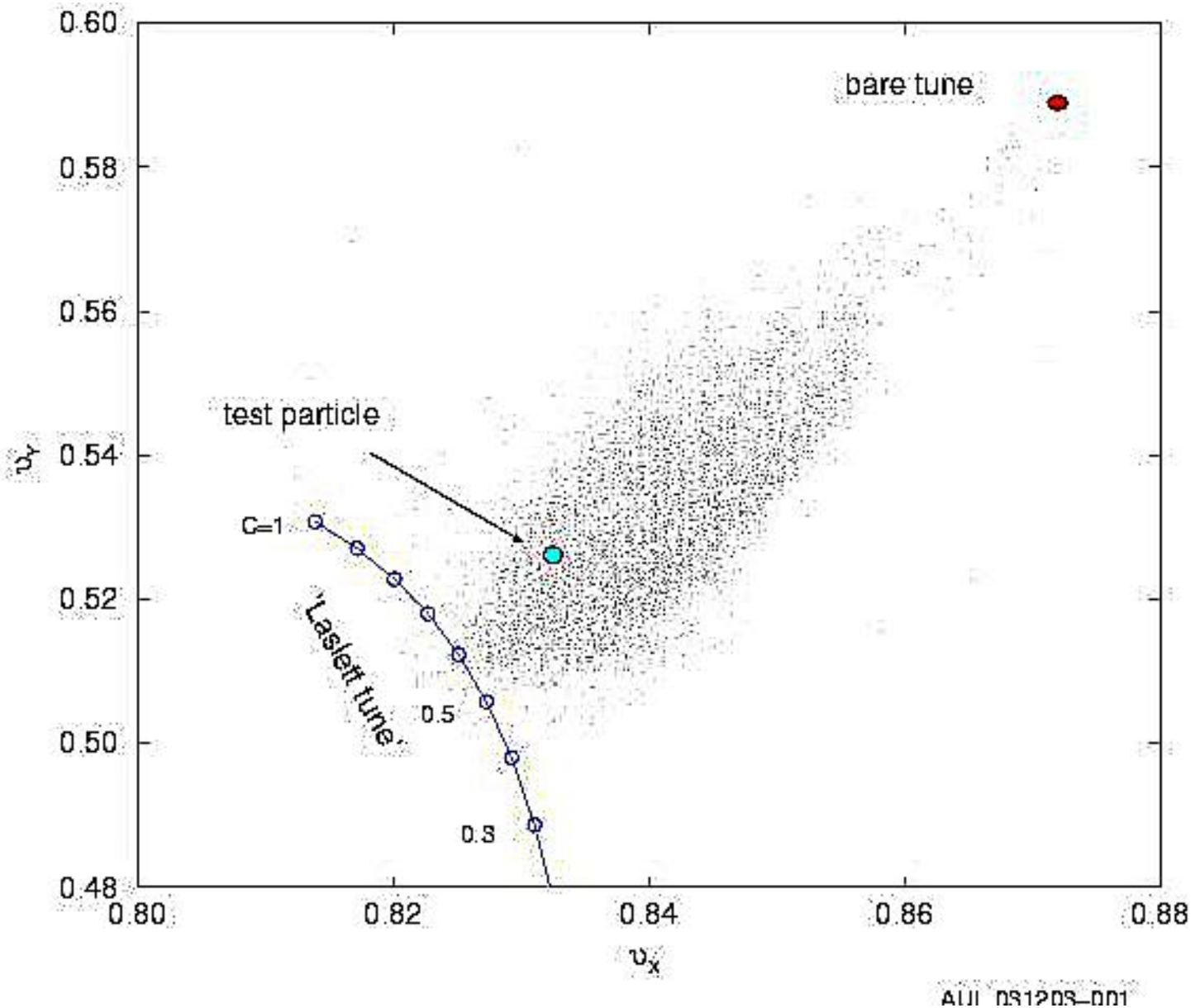
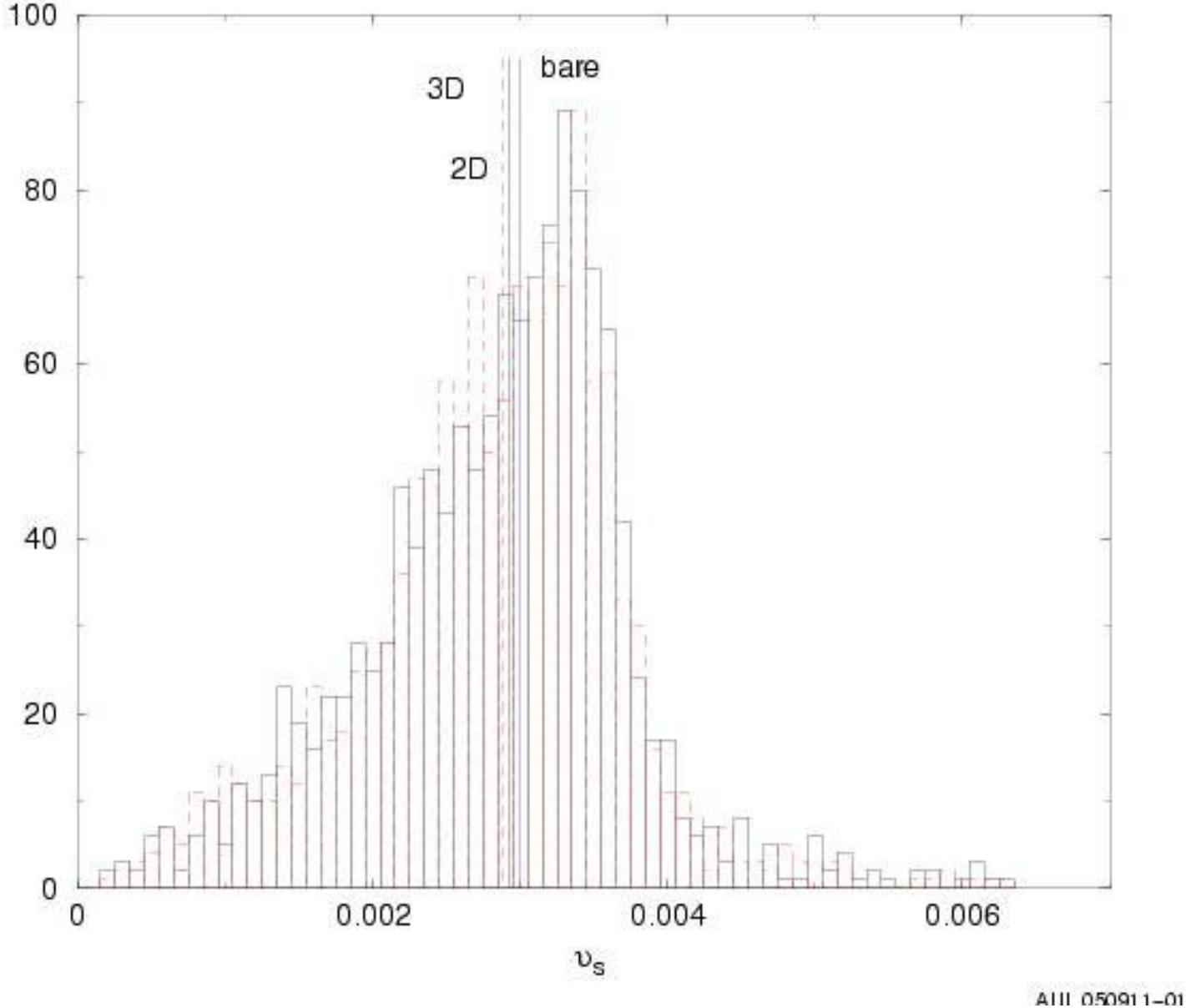
(implicit sum on subscript and superscript indeces). Its solution is

$$\Phi(P) = -\frac{1}{4\pi}\mathcal{L}^{-1}\rho(Q).$$

Use the local expression for the second partial derivative (in x, and similarly in y)

$$\frac{\partial^2\Phi}{\partial x^2} = \frac{1}{h^2}\left(\Phi_{i-1,j} - 2\Phi_{i,j} + \Phi_{i+1,j}\right),$$

Betatron Tune footprint with space charge



Synchro Tune dispersion with space charge