APEX09

Interplay of space-charge and beam-beam effects

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May 12, 2009

Motivation: Low-energy RHIC operation with heavy ions (critRHIC project)

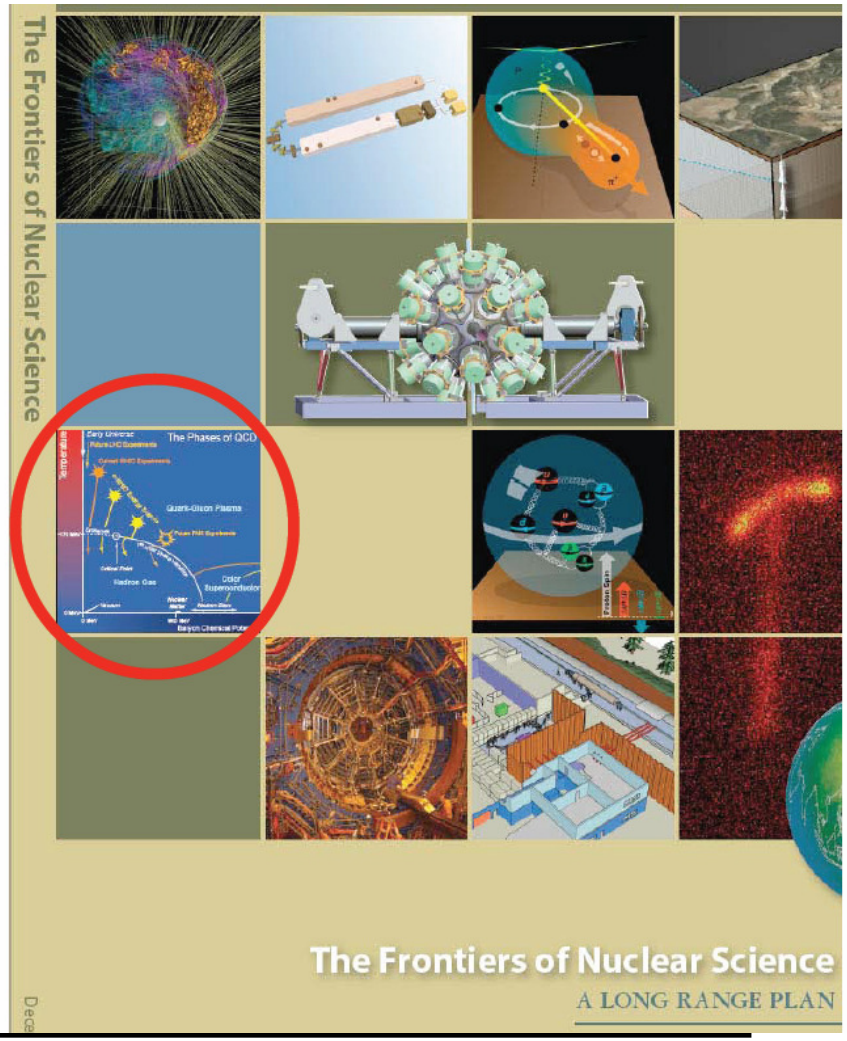
There is substantial and growing interest in RHIC heavy ion collisions with c. m. energy in the range $\sqrt{s_{NN}}$= 5-30 GeV/n

RIKEN workshop (BNL, March 2006):

"Can we discover the QCD critical point at RHIC?"

Suggested energy scan: $\sqrt{s_{NN}}$ = 5, 6.3, 7.6, 8.8, 12.3, 18, 28 GeV/n

Three test runs were done in 2006, 2007, 2008 at low-energies in RHIC (Todd Satogata et al., PAC07; RHIC 2008 retreat).



What is acceptable space-charge tune shift for long life time in RHIC with collisions?

- Presently, for critRHIC we assumed that space-charge tune shift ΔQ=0.05-0.07 as a limit to have reasonable beam life time (>1h).

Can one have ΔQ larger than present ξ limit (0.025 total) for hadron machines?

The answer is yes, if there are no collisions. But what is the limit under collisions?

Can cooling help to operate with larger ΔQ?

Can cooling help to operate with larger ξ?

Need for experiment

- Intensity limit and acceptable space-charge tune shift in RHIC under collisions is an urgent question in order to proceed with Low-Energy Electron Cooling Project (γ=2.7-10).

- Understanding this question is also needed for CritRHIC luminosity projections for coming physics runs (FY10, FY13, …).

We can start looking into this with APEX experiment using protons at injection γ=25:

At injection: high beam intensity and low longitudinal emittances can result in large space-charge tune shifts.

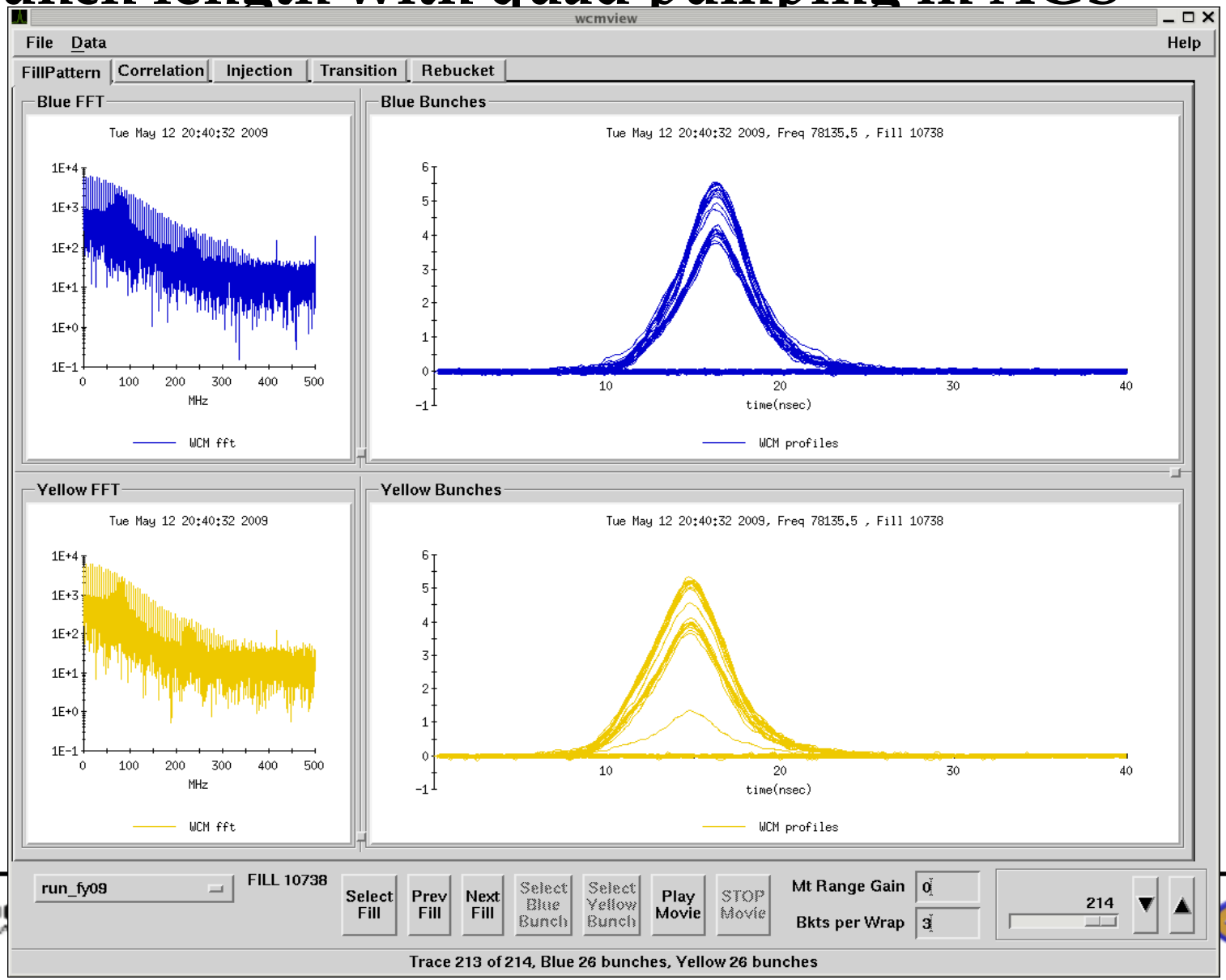
With 28 MHz -> ΔQ could be up to 0.07 (for 2e11, 0.5eV-s, σ_s=0.34m)

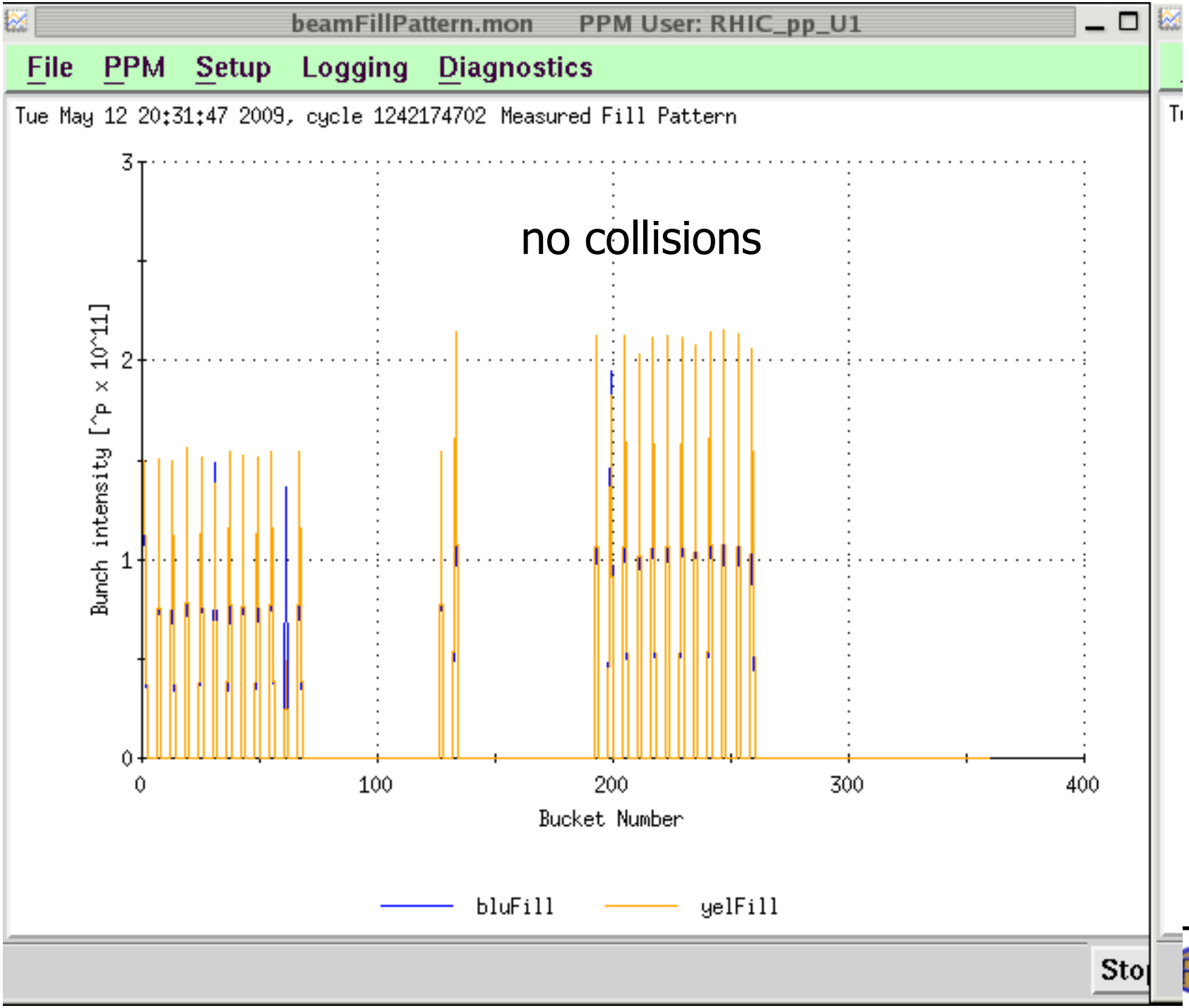
With 197MHz -> ΔQ could be up to 0.2 (for 2e11, 0.5eV-s, σ_s=0.12m – for such short bunch length may have momentum aperture problems: σ_p=2.8e-3).

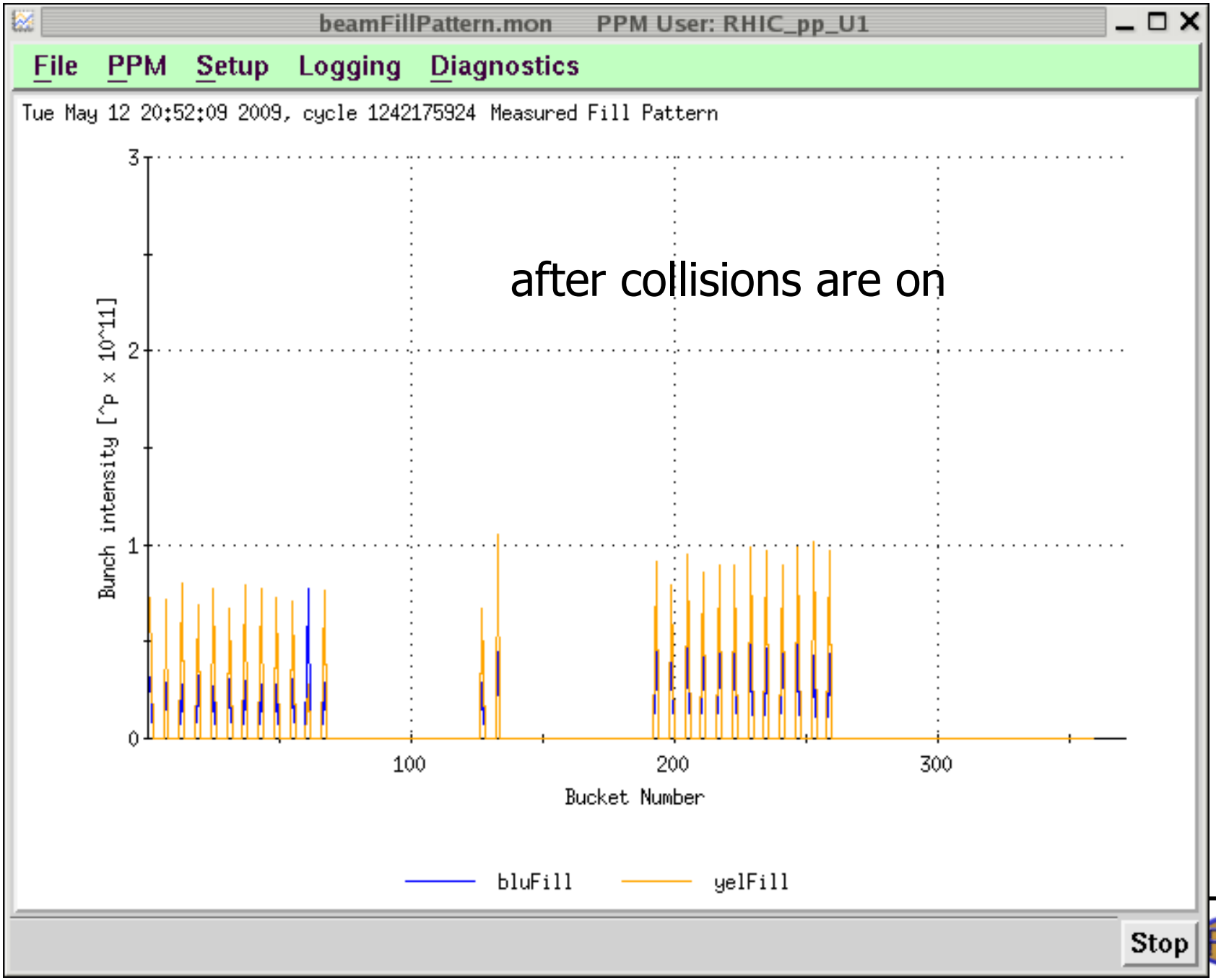
APEX: May 12, 2009 measurements

Protons at injection energy: γ=25

Bunch length with quad pumping in AGS




beamFillPattern.mon PPM User: RHIC_pp_U1
File PPM Setup Logging Diagnostics
Tue May 12 20:31:47 2009, cycle 1242174702 Measured Fill Pattern
no collisions
Bunch intensity [^p x 10^11]
0
1
2
3
0
100
200
300
400
Bucket Number
bluFill
yelFill
Sto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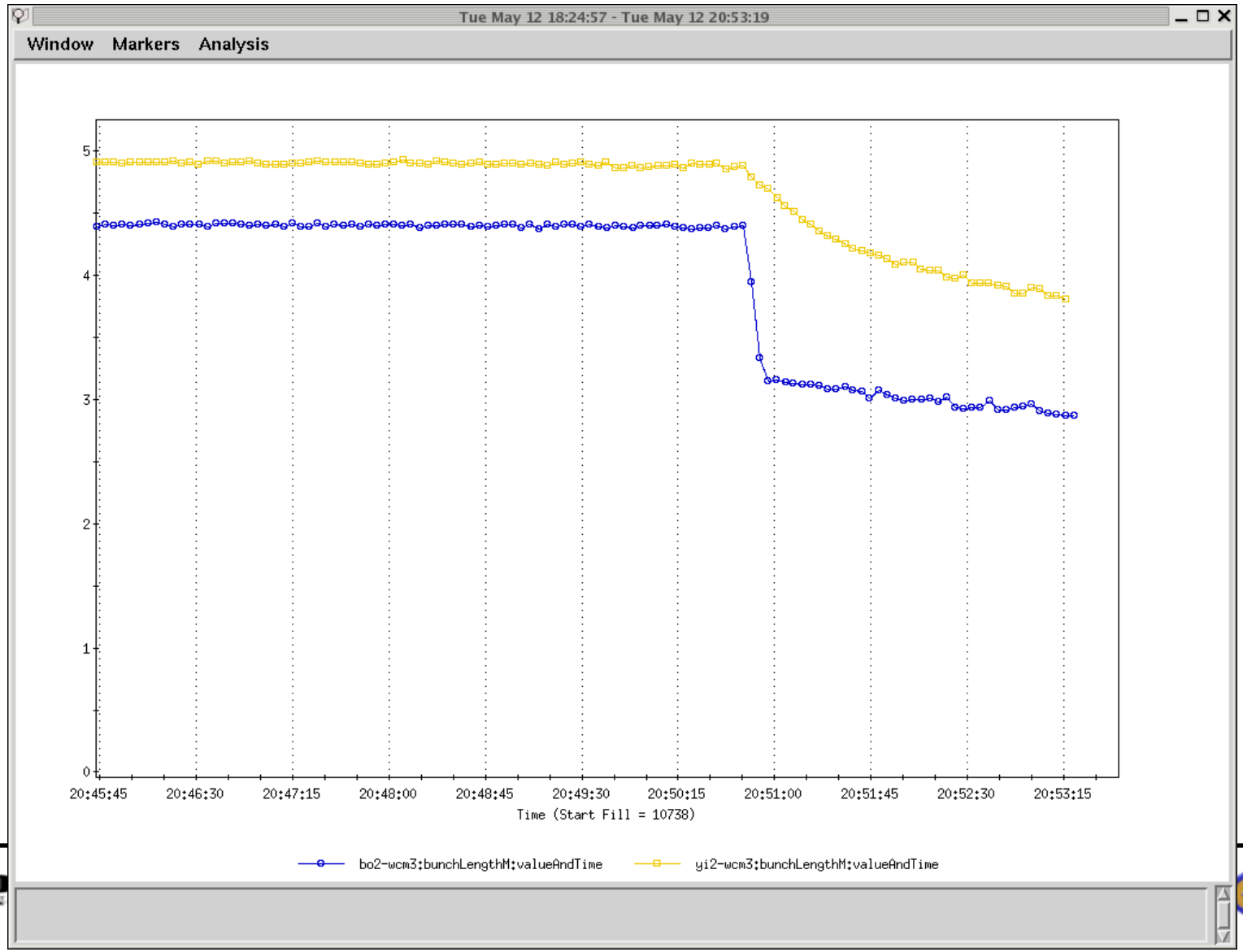
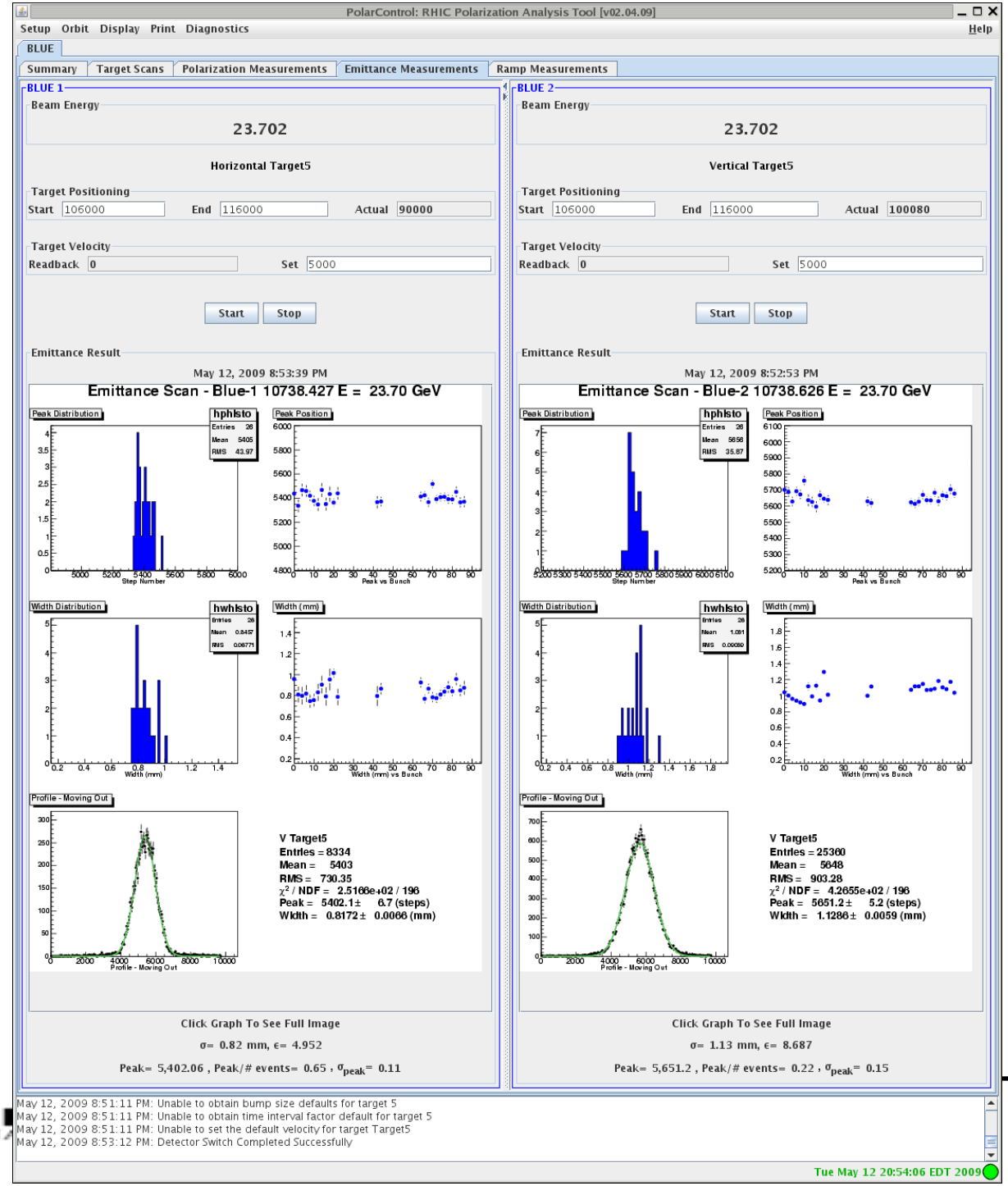
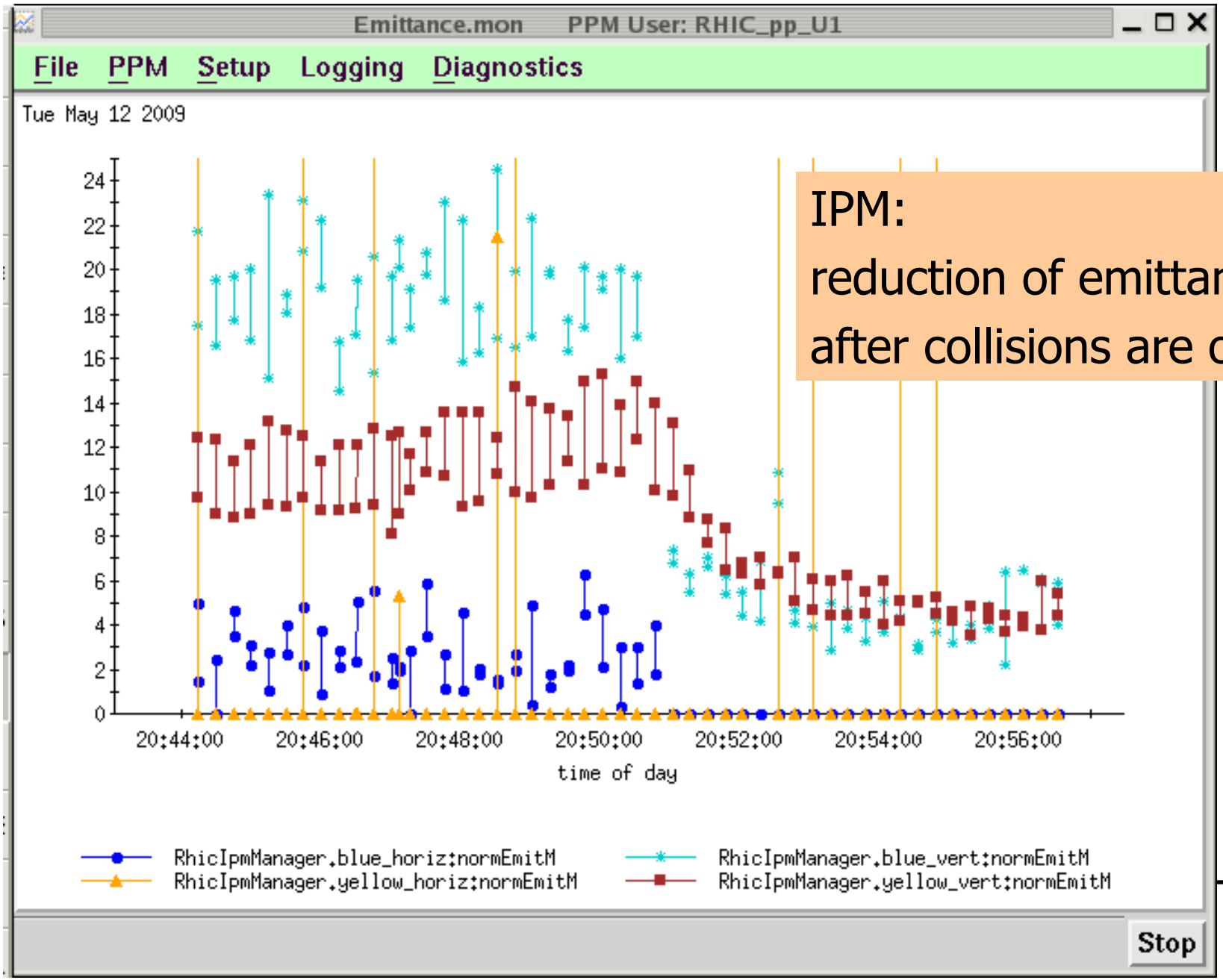
File PPM Setup Logging Diagnostics
Tue May 12 20:52:09 2009, cycle 1242175924 Measured Fill Pattern
after collisions are on
Bunch intensity [^p x 10^11]
3
2
1
0
100
200
300
Bucket Number
bluFill
yelFill
Stop

Reduction in average bunch length

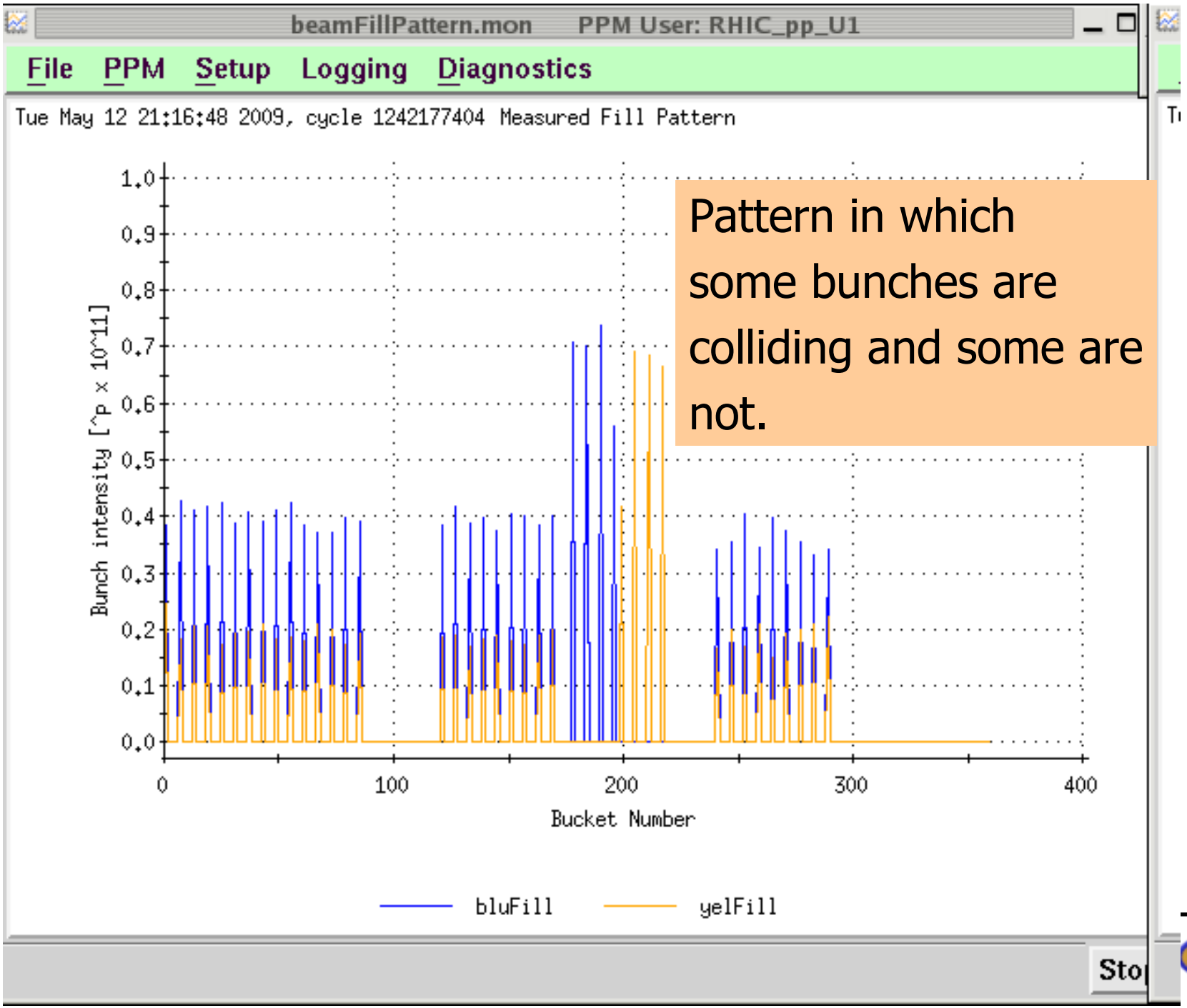


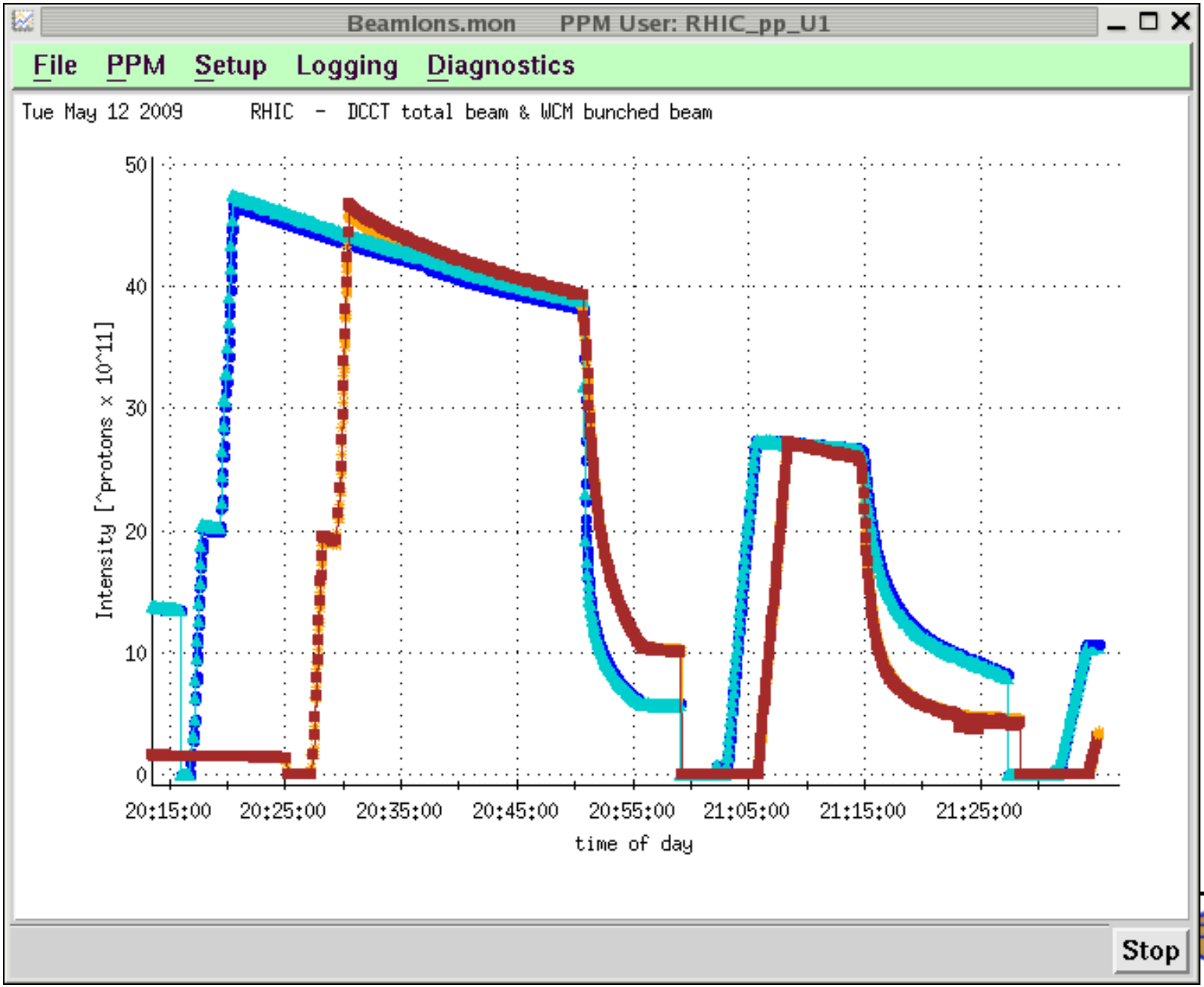


Reduction in emittance after collision are on: 16 π->5 π

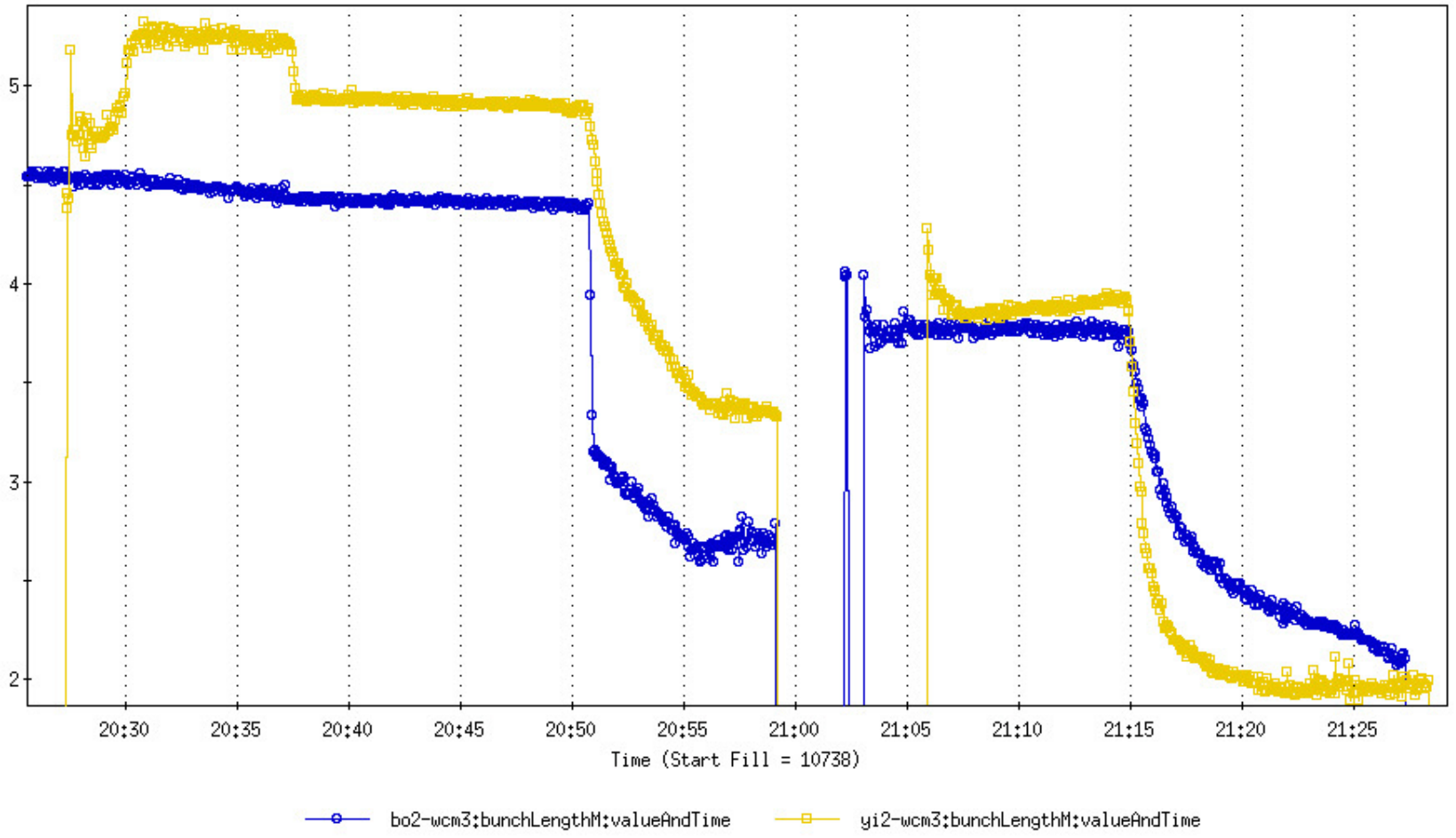


IPM:
reduction of emittance after collisions are on


beamFillPattern.mon PPM User: RHIC_pp_U1
File PPM Setup Logging Diagnostics
Tue May 12 21:16:48 2009, cycle 1242177404 Measured Fill Pattern
Bunch intensity [^p x 10^11]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
100
200
300
400
Bucket Number
bluFill
yelFill
Pattern in which some bunches are colliding and some are not.


Beamlons.mon PPM User: RHIC_pp_U1
File PPM Setup Logging Diagnostics
Tue May 12 2009 RHIC - DCCT total beam & WCM bunched beam
Intensity [^protons x 10^11]
50
40
30
20
10
0
20:15:00
20:25:00
20:35:00
20:45:00
20:55:00
21:05:00
21:15:00
21:25:00
time of day
Stop

Bunch length



We saw dramatic effects after beams were put in collisions.

Fortunately, it seems that we created very interesting regime which is interesting by itself but has little relevance to Low-Energy regime which we wanted to study.

May 12 APEX conditions

$$\Delta Q_{sc,G} = -\frac{N_b Z^2 r_p}{4\pi A \beta\gamma^2 \varepsilon_{rms}} \frac{C}{(2\pi)^{1/2}\sigma_z}$$

$$\Delta Q_{bb,G} = -\frac{N_b Z^2 r_p}{4\pi A \varepsilon_{rms}} \frac{\left(1+\beta^2\right)}{2\beta^2}$$

Example:
N=2e11
ΔQ_{sc}=0.03
ΔQ_{bb}=0.01

1. Very large beam-beam by itself.
2. Significant contribution to space-charge tune spread – loss due to resonances.
3. When both effects are strong – significant Coupling of large and small amplitudes.
4. Interplay with chromatic spread.

Such regime is of fundamental interest but of little relevance to critRHIC.

critRHIC regime

$$\frac{\Delta Q_{sc,G}}{\Delta Q_{bb,G}} = -\frac{1}{\gamma^2}\frac{C}{(2\pi)^{1/2}\sigma_z}$$

Example:

critRHIC lowest energy point Au ions γ=2.7

when limitted by ΔQ_{sc}=0.05

beam-beam tune shift is very small

ΔQ_{bb}=0.00057

$\Delta Q_{sc}/\Delta Q_{bb}$=88

Example:

March 2008 test run with Au ions γ=4.9

ΔQ_{sc}=0.036

ΔQ_{bb}=0.0016

$\Delta Q_{sc}/\Delta Q_{bb}$=23

So, we are interested In the regime:

$\Delta Q_{sc} >> \Delta Q_{bb}$

Expected effect is mostly lifetime due to large tune spread crossing of resonance.

Summary

1. **We got good data – could be used for fundamental study of strong beam-beam and space-charge. But of little relevance to what we need for critRHIC program.**
2. **We need to repeat similar or somewhat modified experiment with Au ions at injection.**