Beam development and studies for Low-Energy RHIC

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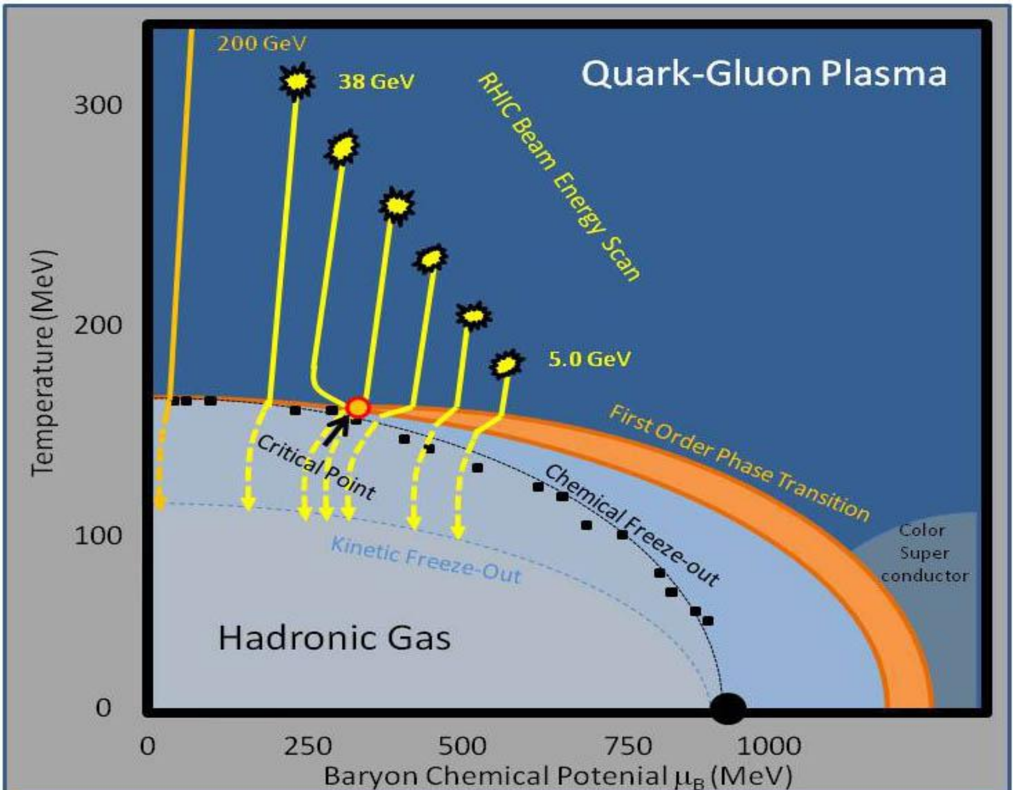
APEX Workshop November 12-13, 2009



- **2010 Physics Program**
- **Background and Collimation**
- **Radiation and Aperture**
- **Beam dynamics studies**

2010 Low-E (below $\sqrt{s_{NN}}$ = 20 GeV) Run Planning

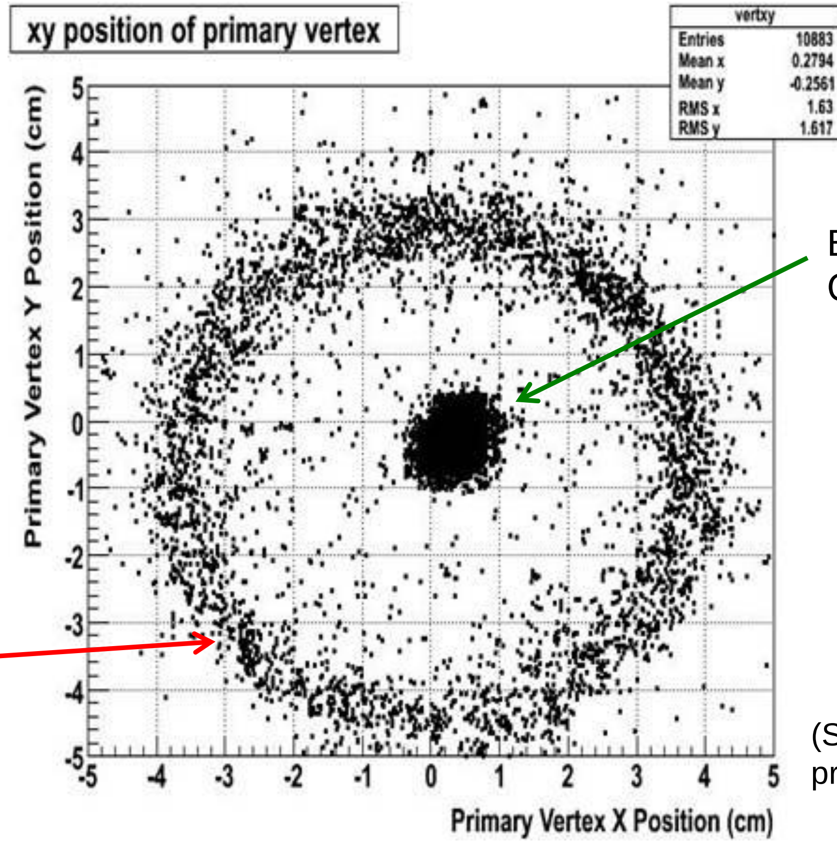
- From $\sqrt{s_{NN}}$ = 9 GeV 2008 experience and expected tuning improvements[2]
  - **Assumes 75% time in physics during running time**
  - **Event rates scale as γ^3 below injection, γ^2 above injection ($\sqrt{s_{NN}}$ = 19.6 GeV)**
- $\sqrt{s_{NN}}$ = 12 GeV precludes optimized luminosity at both experiments
- $\sqrt{s_{NN}}$ = 7.7 GeV – will require 1 day to swap sextupole leads, plus about 2 days of machine development
- Development: collimation/background, radiation, working point
- APEX: space-charge limit, IBS (for luminosity & cooling projections)

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	<Event Rate> [Hz]	Days/ Mevent	# events desired	# beam wks 30 (25) wks	Days of machine development
7.7	**405**	**2.0**	**7.6**	**5M**	**1 (1)**	2-3 (Swap sextupole leads)
8.6	**370**	**3.0**	**5.0**	**5M**	**--**	
12	**295**	**7.5**	**2.0**	**5M**	**2.5 (1.5)**	1
18	**210**	**>30**	**0.5**	**5M**	**1.5 (0)**	1
27	**153**	**>60**	**<<1**	**5M**	**4.5 (2.5)**	

Typical injection at $\sqrt{s_{NN}}$ = 20 GeV

Energies loosely from K. Rajagopalan ("Can We Discover the QCD Critical Point at RHIC?", 2006)

2008 9.2 GeV STAR Transverse Event Distribution



Beam-beam collisions
Consistent with beam σ=3-4mm

Beam-beampipe collisions
Consistent with known beampipe ID=76mm

(STAR collaboration, private communication)

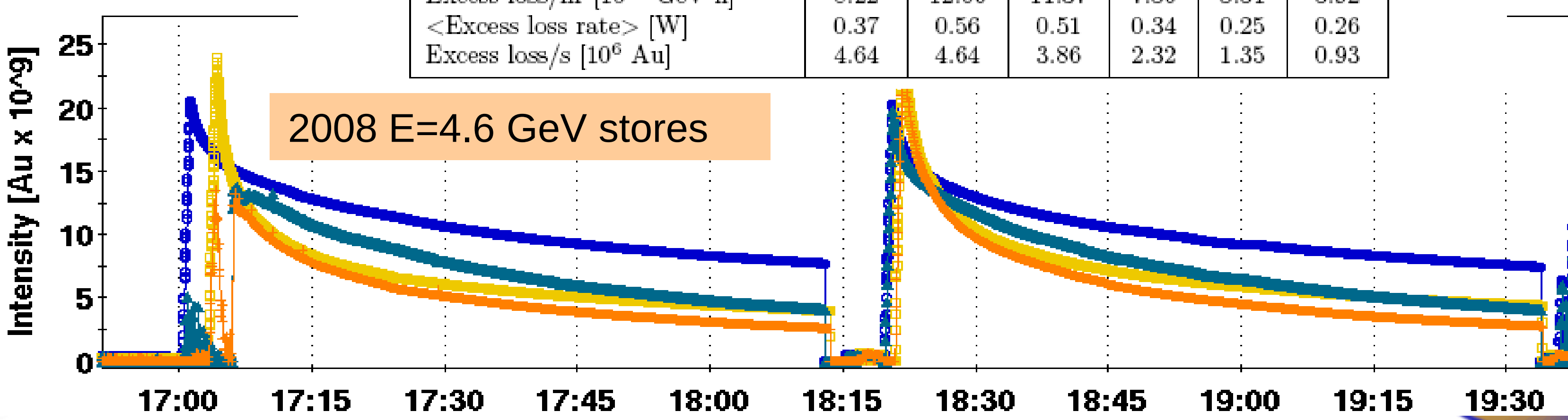
- **Good event vertices separate into beam-beam, beam-beampipe data**
  - All dimensions are consistent with measured beam and beampipe sizes
- **Beam-beampipe events come from small-angle triplet scattering**
  - 2008: No collimation setup; 2010 run must include collimation setup

Low Energy Radiation Issues

Table 1: Nominal RHIC low energy operations chronic beam loss scenarios. Here we inject into each ring, then keep stored beams in collision before dumping both and refilling again. RHIC Au beam lifetime and luminosity lifetime have not been measured below $\sqrt{s_{NN}} = 9.2$ GeV.

CM energy $\sqrt{s_{NN}}$ [GeV]	5	7.7	8.3	9.2	11.5	18
Beam energy E [GeV]	2.5	3.85	4.15	4.6	5.75	9
Fills/hr	4	3	2	1	0.5	0.3
# bunches	110	110	110	110	110	110
AGS bunch intensity [10^9]	1	1	1	1	1	1
Injection efficiency	0.3	0.4	0.5	0.6	0.7	0.8
Total RHIC intensity [10^9]	66	88	110	132	154	176
ATR loss/fill [10^9]	154	132	110	88	66	44
ATR loss/hr [10^9]	616	396	220	88	33	13.2
ATR loss/hr [10^{13} GeV-n]	30.34	30.03	17.99	7.97	3.74	2.34
RHIC loss/fill [10^9]	41.72	55.63	69.53	83.44	97.35	111.25
RHIC loss/hr [10^9]	166.88	166.88	139.07	83.44	48.67	33.38
RHIC loss/hr [10^{13} GeV-n]	8.22	12.66	11.37	7.56	5.51	5.92
Collimator efficiency	0.9	0.9	0.9	0.9	0.9	0.9
Collimator loss/hr [10^{13} GeV-n]	7.40	11.39	10.23	6.81	4.96	5.33
<Collimator loss rate>/ring [W]	1.65	2.53	2.28	1.51	1.10	1.19
Excess loss/hr [10^{12} GeV-n]	8.22	12.66	11.37	7.56	5.51	5.92
<Excess loss rate> [W]	0.37	0.56	0.51	0.34	0.25	0.26
Excess loss/s [10^6 Au]	4.64	4.64	3.86	2.32	1.35	0.93

T. Satogata
Tech Note C-A/AP/#360



Beam dynamics luminosity limits for RHIC operation at low energies

The beam lifetime observed during lower energy test runs was limited by machine nonlinearities – this performance can be improved provided sufficient time is given for machine development.

Other, more fundamental, limitations come from:

Intra-beam Scattering (IBS):

- Strong IBS growth at lowest energies- can be counteracted by Electron Cooling (luminosity improvement needed for $\sqrt{s_{NN}}$ = 5-9 GeV)

Beam-beam:

- Becomes significant limitation for RHIC parameters only at $\gamma > 10$.

Space-charge:

- At lowest energies, ultimate limitation on achievable ion beam peak current is expected to be given by space-charge effects.

Need for experiment

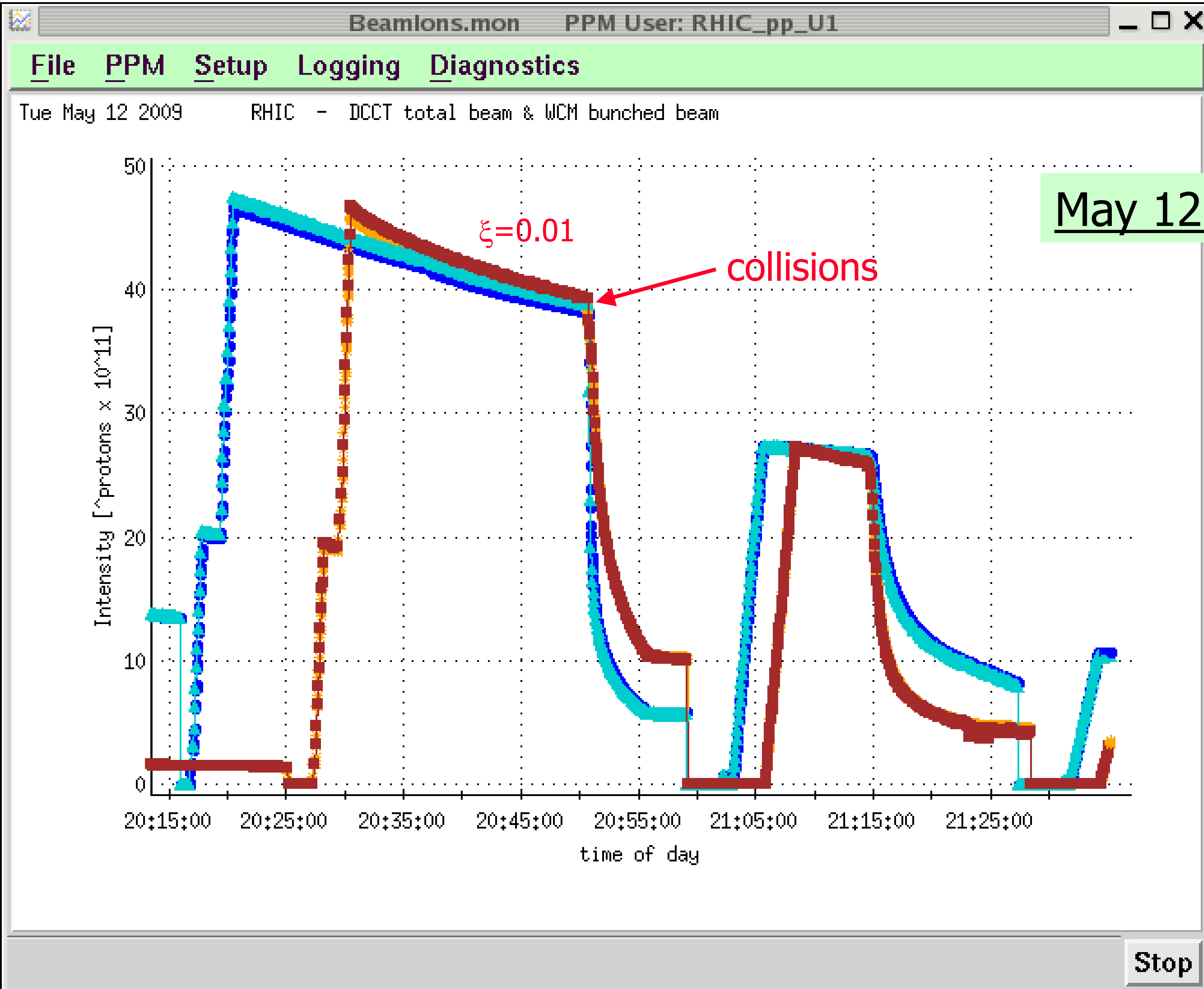
- **Intensity limit and acceptable space-charge tune shift in RHIC under collisions is crucial question in order to understand benefits from Low-Energy Electron Cooling @γ=2.7-10 (**$\sqrt{s_{NN}}$ = 5-20 GeV **)**

- **Understanding this question is also needed for Low-E RHIC luminosity projections for future Low-E physics runs (FY11, FY14, …)**

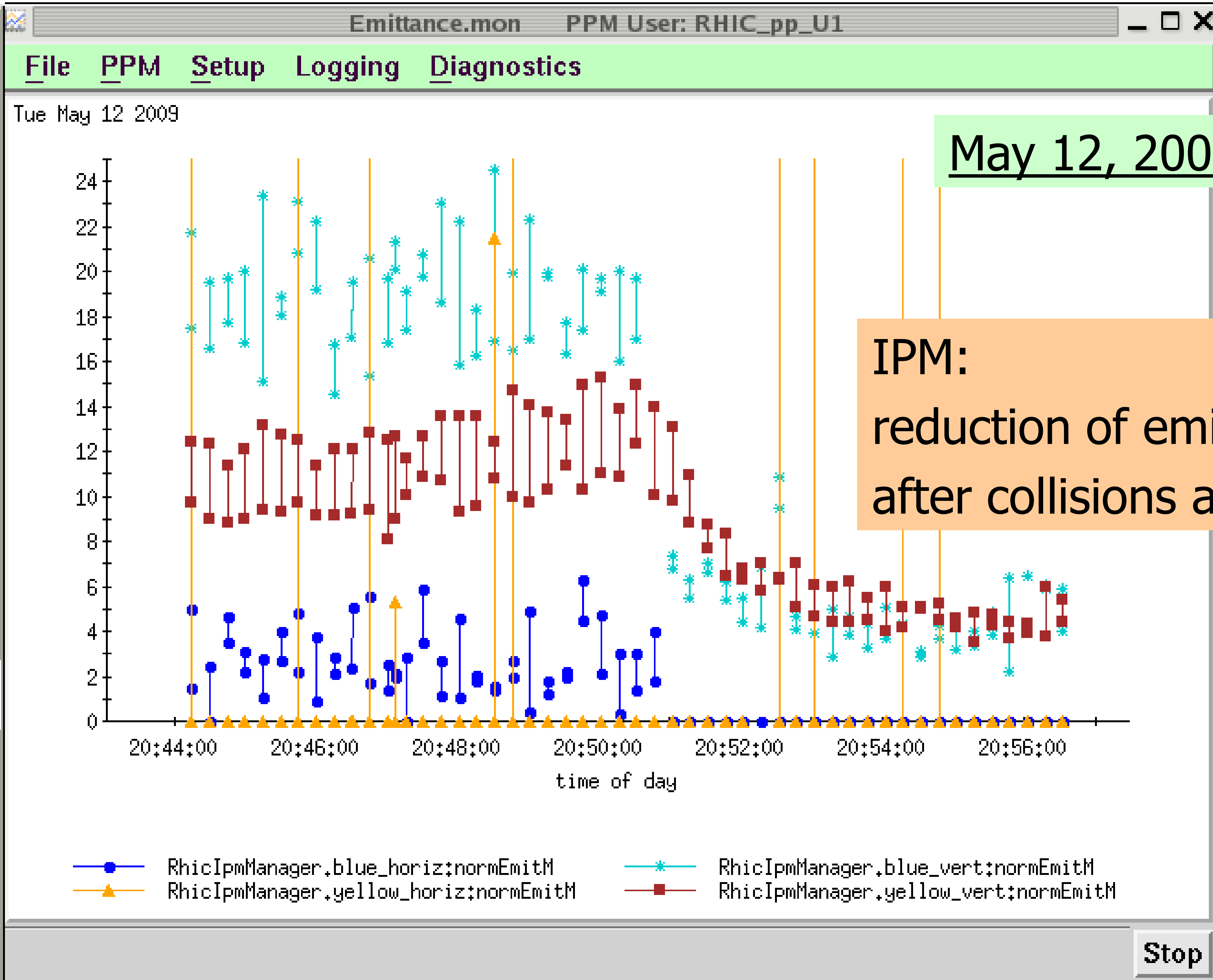
We started looking into this with APEX experiments in 2009, using protons at injection energy γ=25 (high beam intensity and low longitudinal emittances can result in large space-charge tune shift):

Two APEX experiments were done:

1. **May 12, 2009**
2. **June 17, 2009**


BeamIons.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
ξ=0.01
collisions
Stop

May 12, 2009



May 12, 2009

IPM:

reduction of emittance after collisions are on

May 12, 2009 APEX conditions

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

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

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

1. Strong 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 NOT of direct relevance to Low-E RHIC.

Low-E RHIC (critRHIC) regime

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

Example:

Low-E RHIC lowest energy point Au ions γ=2.7

when limited 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

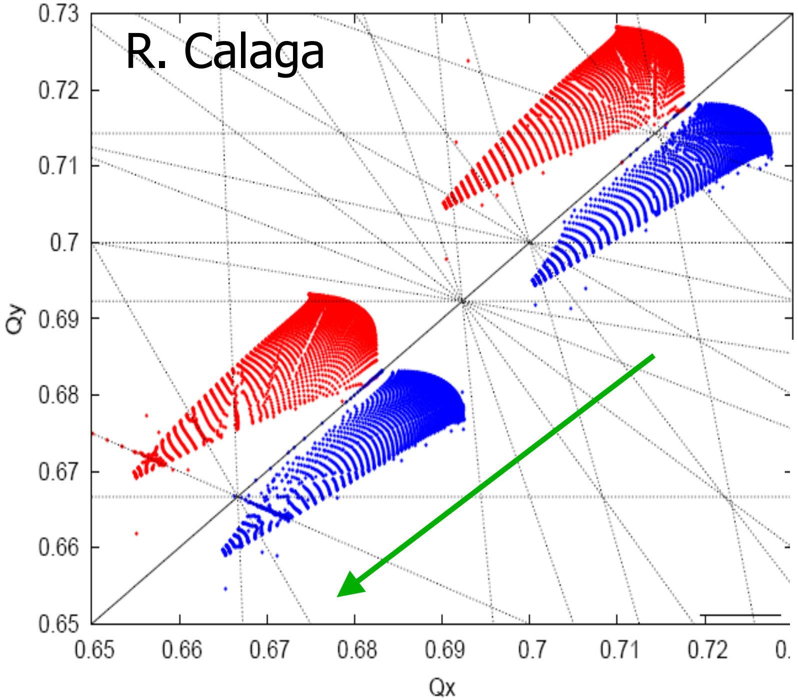
$\Delta Q_{sc}/\Delta Q_{bb}$=23

So, we are interested in the regime:

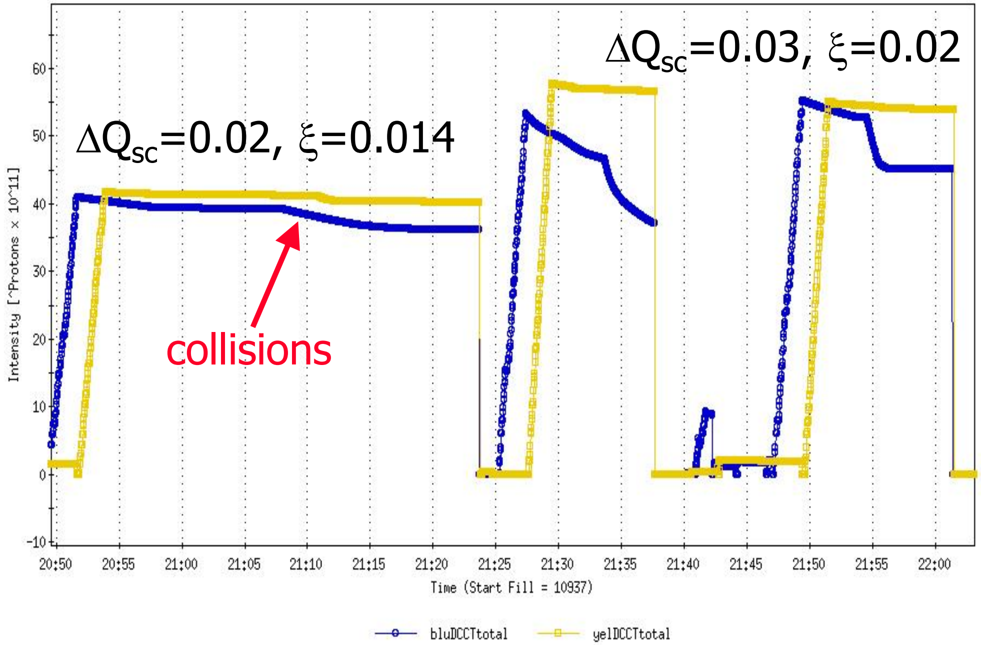
$\Delta Q_{sc} >> \Delta Q_{bb}$

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

June 17, 2009 experiment with new working point



June 17, 2009



Choosing different working point for regime with large beam-beam.

The question still remains:

What is the limit on space-charge tune shift in RHIC under collisions for Low-E RHIC regime ($\Delta Q_{sc} >> \xi$)?

Possible 2010 APEX experiments:

1. **Sqrt[s]=11.5 GeV (γ=6.13):**

-Typical (expected) parameters: N=1e9, ΔQ_{sc}=0.05, ξ=1.6e-3; $\Delta Q/\xi$=30

- For higher bunch intensity and quad pumping can reach ΔQ_{sc}=0.1

2. **Au@injection energy (γ=10.6):**

- **Typical parameters: N=1e9, ΔQ_{sc}=0.024, ξ=1.6e-3; $\Delta Q/\xi$=16**
- **To get to higher space charge we need both high intensity and quad pumping: should be able to reach ΔQ_{sc}=0.07, $\Delta Q/\xi$=27**

It would be useful to have Run-10 APEX time to study beam limits:

1. **Start with Au ions at typical injection energy**

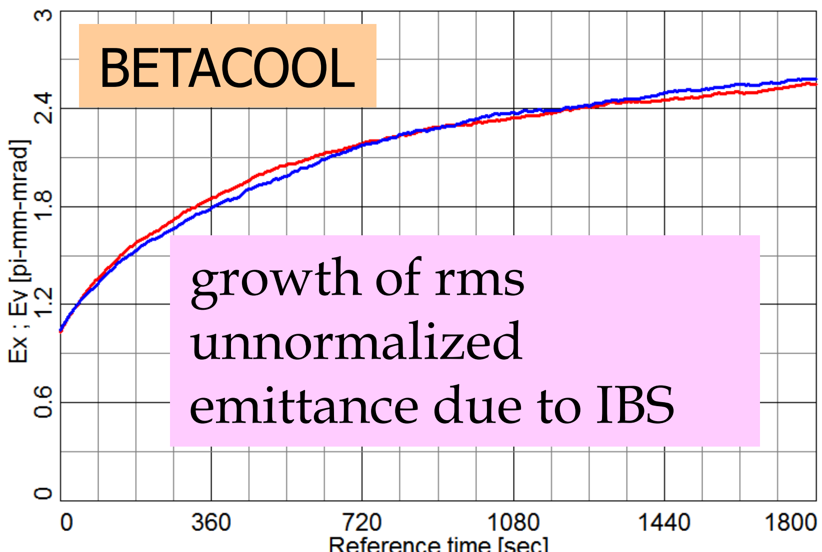
With <u>high intensity and quad pumping</u> explore high space-charge regime.

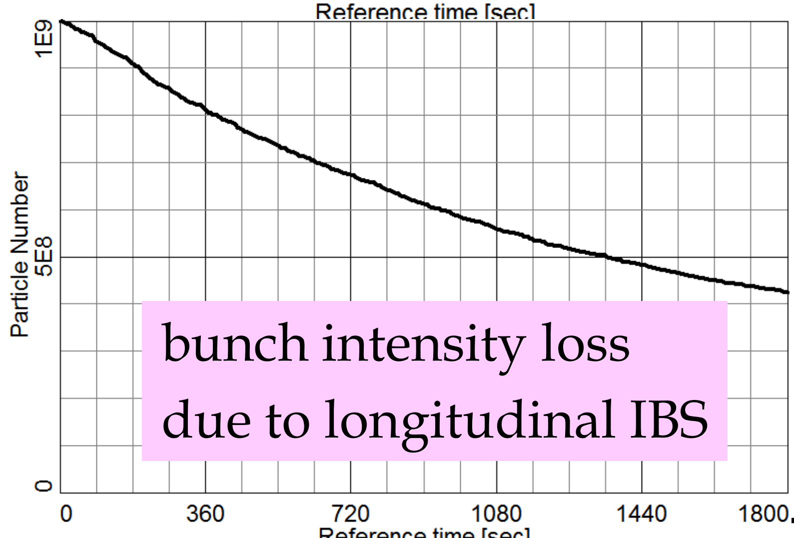
<u>Backup:</u>

2. **Although getting APEX time for γ=6.13 (1.5 weeks run) will be probably difficult, we may have sufficient data from physics stores with high intensity bunches.**

It is important that we have good measurement of beam parameters. IPM should work reliably in all planes.

IBS for Au ions in RHIC for lowest energy point ($\sqrt{s_{NN}}$ = 5 GeV) from proposed Low-E RHIC energy scan





Simulation parameters

Parameters	Value
Kinetic energy of Au ions, GeV/nucleon	1.57
Relativistic γ	2.68
Bunch intensity, 10^9	1.0
Rms momentum spread	4×10^{-4}
Rms bunch length, cm	155
Rms emittance (unnormalized), μm	1.04
RF harmonic	387
RF voltage, kV	300

IBS redistribution

Below transition energy (in RHIC γ_t is about 23):

If we could shrink bunch length -> increase ion beam momentum spread, we could make longitudinal beam temperature larger than transverse.

This would minimize longitudinal emittance increase due to IBS and prevent beam loss from RF bucket.

For luminosity improvement, the bunch length growth, intensity loss due to debunching, and transverse emittance growth are all important.

Can we expect luminosity improvement for RHIC at lowest energies ?

A. Fedotov, Tech Note C-A/AP/#339 (Dec. 2008) from C-A/AP/#339 Tech Note:

Table 5. Initial longitudinal τ_z^{-1} and transverse τ_x^{-1} IBS rates ($\tau_x^{-1} \equiv d\varepsilon_x/(\varepsilon_x dt)$, $\tau_z^{-1} \equiv d\sigma_p^2/(\sigma_p^2 dt)$) for different longitudinal emittance ($S_{95\%}$) for 28 MHz RF with 500 kV total gap voltage. Bunch intensity $N=1\times10^9$, transverse beam emittance $\varepsilon=15\mu m$ (95%, normalized).

γ	h	$S_{95\%}$, eV-s/n	τ_x^{-1}, sec^{-1}	τ_z^{-1}, sec^{-1}
2.7	387	0.1	0.007	0.004
3.2	378	0.1	0.004	0.006
		0.14	0.0044	0.002
4.3	369	0.1	0.0015	0.013
		0.14	0.0018	0.005
		0.2	0.002	0.0016
6.4	363	0.1	0.0002	0.016
		0.2	0.0006	0.003
		0.4	0.0007	0.0006

Machine development and IBS optimization

Since for sqrt[s]=11.5 GeV (γ=6.1) beam parameters close to equilibrium can be probably achieved (will be limited by RF bucket acceptance), we can try to optimize physics stores during machine development time.

If APEX time will be given for γ=6.1 run (1.5 weeks of physics), such optimization/study can be done during APEX.

If transverse emittance growth is minimized we can try lattice with smaller β^*. β^*=5m or even 3m?

Thank you