RHIC Low-Energy Operations

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RHIC Experiment Meeting

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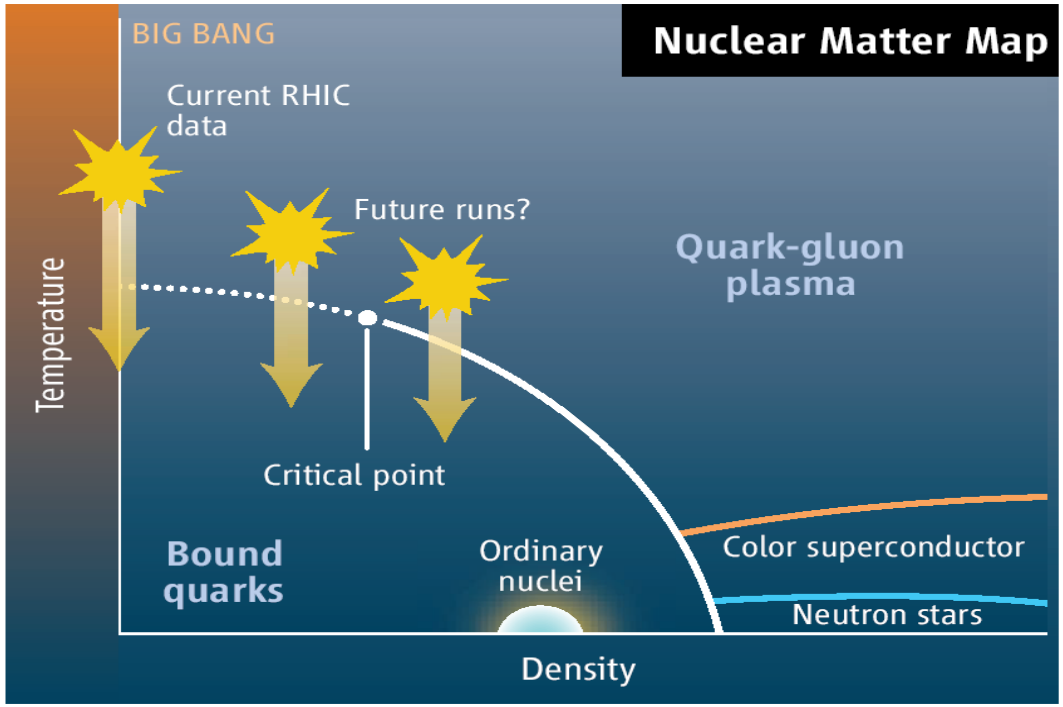
- Some (brief) history of test runs
- Challenges and resolutions
- Motivation, planning, schedule

Searching For The QCD Critical Point: Lots of Interest



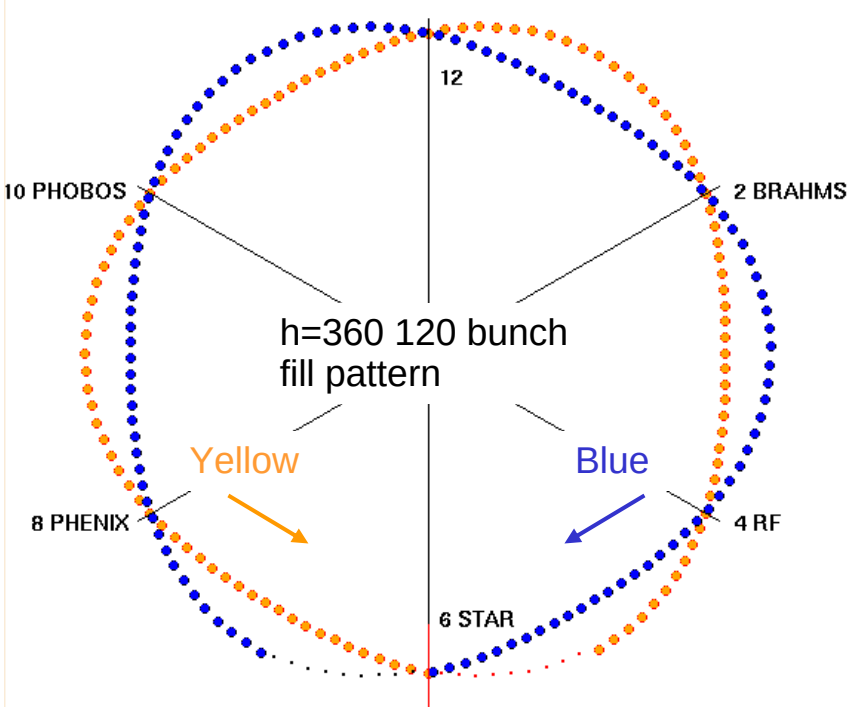
- RIKEN workshop at BNL, Mar 9-10 2006
  - "...a growing body of theoretical and experimental evidence that the critical point on the QCD phase diagram, if it exists, should appear on the QGP transition boundary at baryo-chemical potential ~100 - 500 MeV, corresponding to heavy ion collisions with c.m. energy in the range $\sqrt{s_{NN}}$ = 5 - 50 GeV."
- Critical Point and Onset of Deconfinement Workshop at GSI, Jul 9-13 2007
  - 141 registered participants from 3 continents; 66 presentations
- 120 papers on "QCD critical point" in Google Scholar
  - 77/120 mention RHIC low energy (or, as George Stephens puts it, "critRHIC")

Low Energy Test Run and Lowest Energy Parameters

	Gold 2007-8?	Gold 2008	Gold 2008?
$\sqrt{s_{NN}}$ [GeV]	9.183	5.2	5.0
Beam energy [GeV]	4.59	2.6	2.5
Beam kinetic energy [GeV]	3.660	1.669	1.569
Relativistic γ	4.93	2.79	2.68
Relativistic β	0.979	0.934	0.928
Momentum [GeV/c]	4.496	2.428	2.320
Bρ [T-m]	37.40	20.19	19.30
Injection current scaling	0.384	0.207	0.198
Main dipole current [A]	217.7	117.5	112.3
Main quad current [A]	202.6	109.4	104.6
Revolution frequency [Hz]	76571	73010	72570
RF harmonic number	366	384	387
RF frequency [MHz]	28.03	28.03	28.08
Max beam size $\sigma_{95\%}$ [mm]	15.32	20.85	21.32

- Several staged low energy tests
  - Systematically address challenges
  - Leverage available beams
  - Establish luminosity scaling
  - Permit time for upgrade strategy??
- 2006 proton test run a success!
- 2007 Au test run (1 day)
  - Leverage proton test rigidity setup
  - Test RF/timing changes
  - Measure luminosity
  - Test experiment DAQs
- 2008 Au test run (1+2? days)
  - Test RF/timing fixes
  - Reproduce 2007 Au test
  - Explore nearly lowest energy
  - Establish lowest energy baseline

Challenges: RHIC RF Harmonic Number



h	Allowed $\sqrt{s_{NN}}$ [GeV]
360	16.7-107
363	11.4-15.0
366	9.0-10.5
369	7.7-8.6
372	6.9-7.4

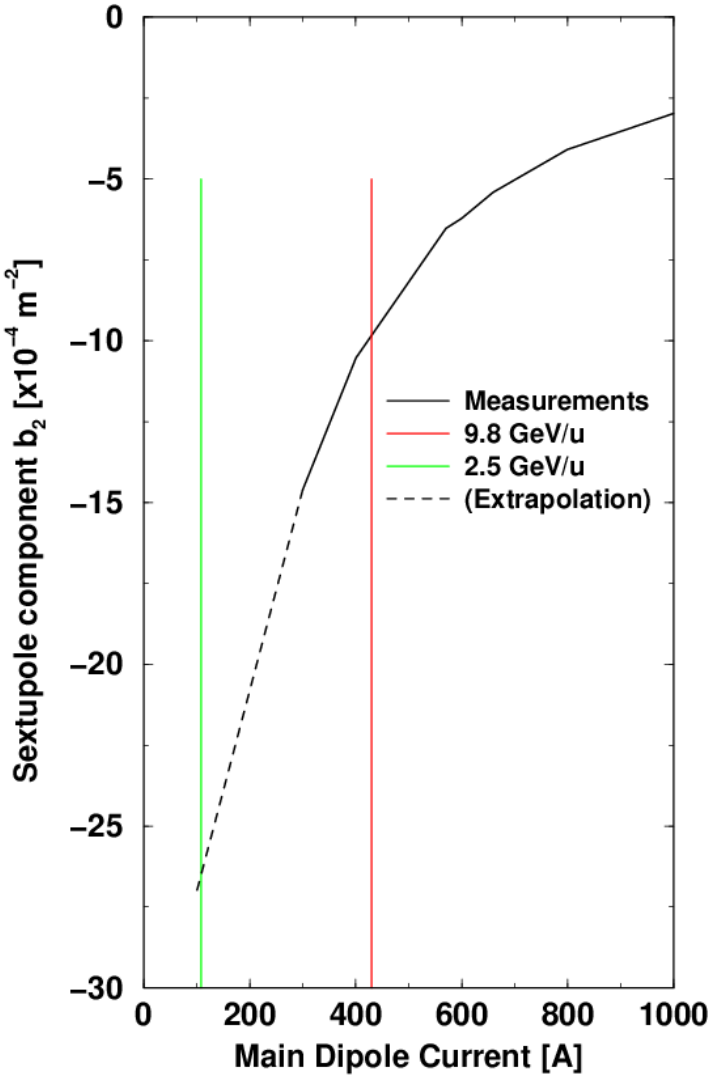
h	Allowed $\sqrt{s_{NN}}$ [GeV]
375	6.3-6.7
378	5.8-6.1
381	5.45-5.7
384	5.15-5.38
387	4.91-5.1

- Nominal RHIC RF: h=360 bunches
- RHIC RF tuning range: 28-28.17 MHz
- With lower energy, RHIC RF frequency cannot fall low enough to maintain h=360
  - Must raise harmonic number
  - Retuning cavities is a prohibitive effort
  - Collisions at both experiments require h(mod3)=0; STAR (and possibly PHENIX) DAQ also requires h(mod3)=0
- All beam-synchronous clocks are driven by this clock
  - All RHIC single-bunch instrumentation
  - Abort system (needs to find gap)
  - Experiment DAQ clocks
    - A problem during Run-7 testing
    - Fixed, Tested in August 2007
    - BPM clock decoding fix underway

Challenges: Chromaticity and Stability

Magnet	Design	Trim
bo6-sxf10	0.24228	-0.01235
bo6-sxd11	-0.01221	0.01922
bo6-sxf12	0.24228	-0.01235
bo6-sxd13	-0.01221	0.01922
bi8-sxd10	-0.01221	0.01922
bi8-sxf11	0.24228	-0.01235
bi8-sxd12	-0.01221	0.01922
bi8-sxf13	0.24228	-0.01235
bo10-sxf10	0.24228	-0.01235
bo10-sxd11	-0.01221	0.01922

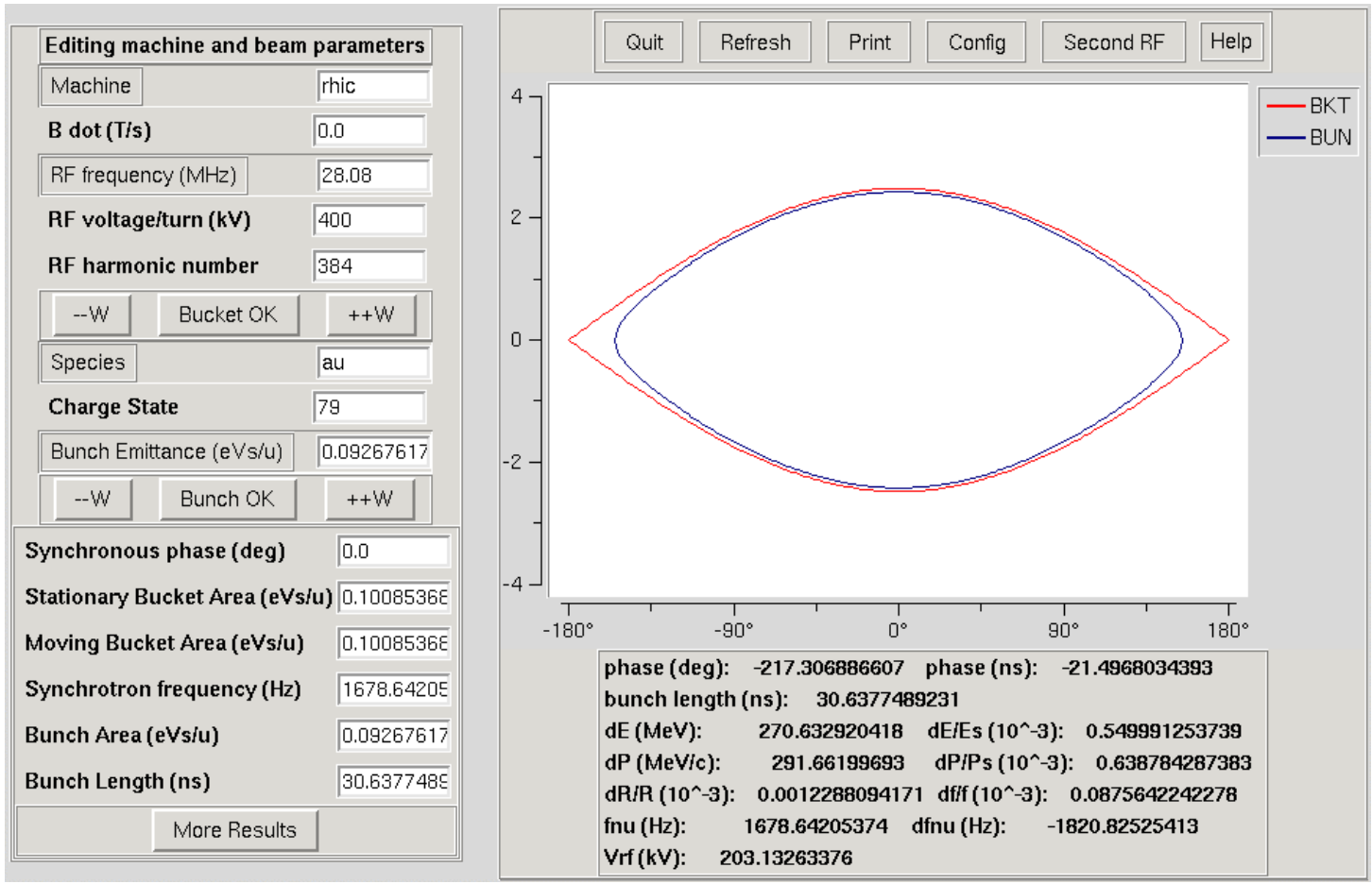
Defocusing sextupole strength should sum to negative



- Low-energy transverse beam stability requires negative chromaticity
- Sextupole component of main dipoles drives vertical chromaticity beyond unipolar power supply tuning range

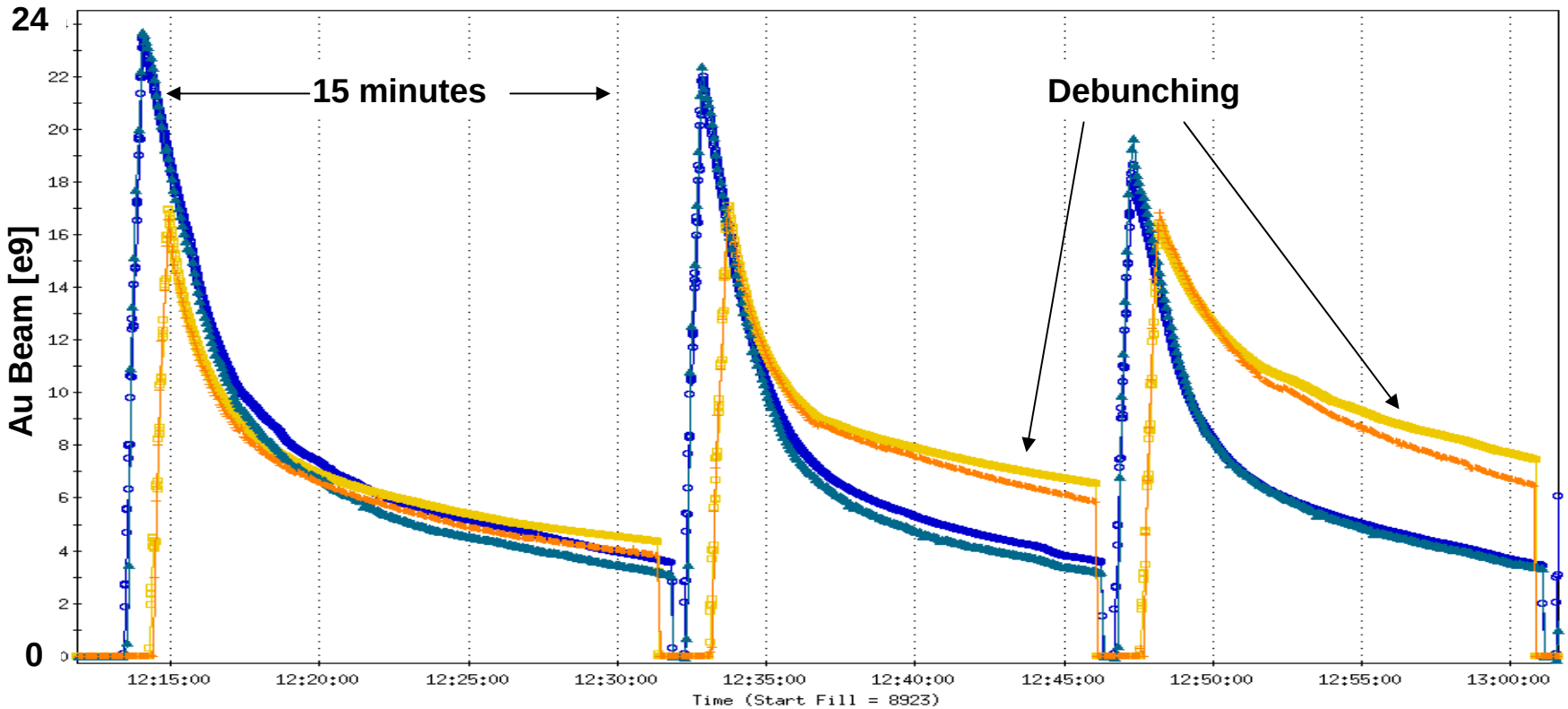
- Below $\sqrt{s_{NN}}$ = 9.3 GeV/u, we require 2 days of maintenance to flip sextupole power supply polarities (1 day each way)
- Strong octupoles were used to stabilize beam during the 2006/7 test runs
  - But this adversely affects beam lifetime...

Challenges: RF Acceptance



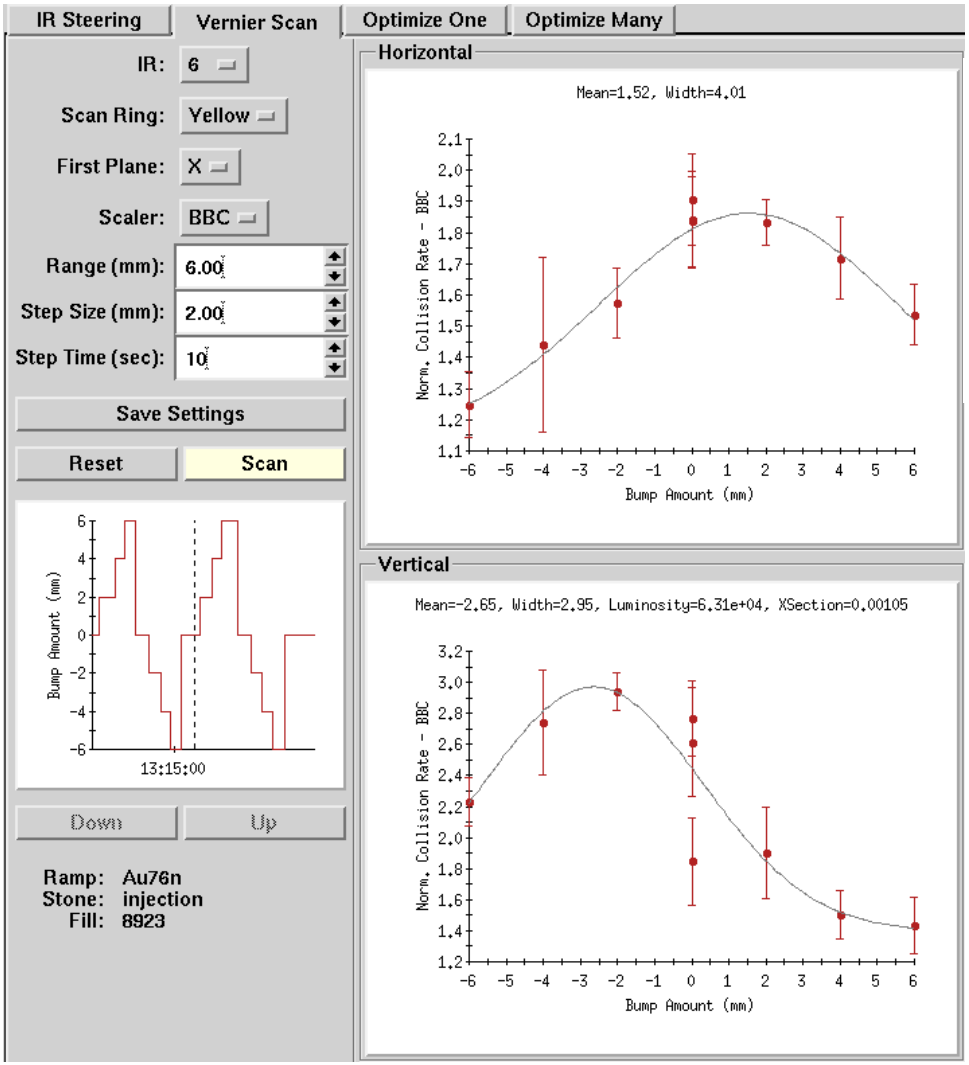
- Present Au beam has about 0.1 eV-s/n Au beam longitudinal emittance
- At $\sqrt{s_{NN}}$ = 5.5 GeV, this beam barely fits into the RHIC RF bucket
  - Low energy injection is very inefficient, but may level off IBS growth time
  - Will evaluate lowest energy capture efficiency during 2008 test run
  - Much better than previous estimates of 0.3-0.4 eV-s/n and debunched beam

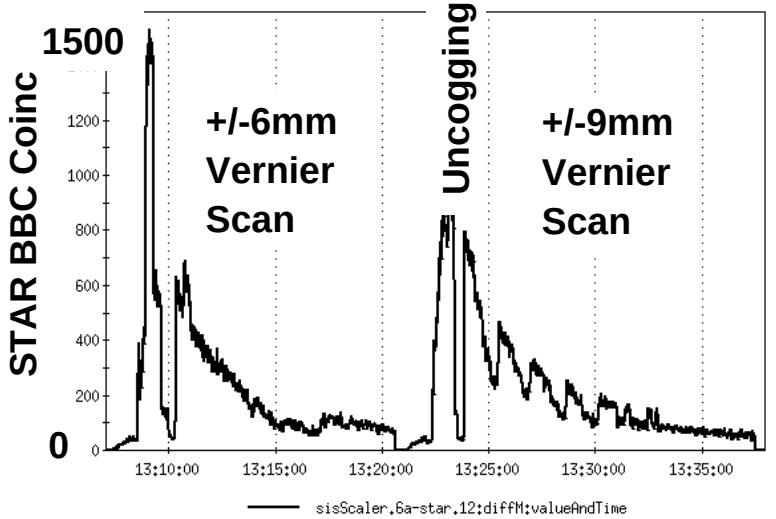
2007 Gold Test Run Stores

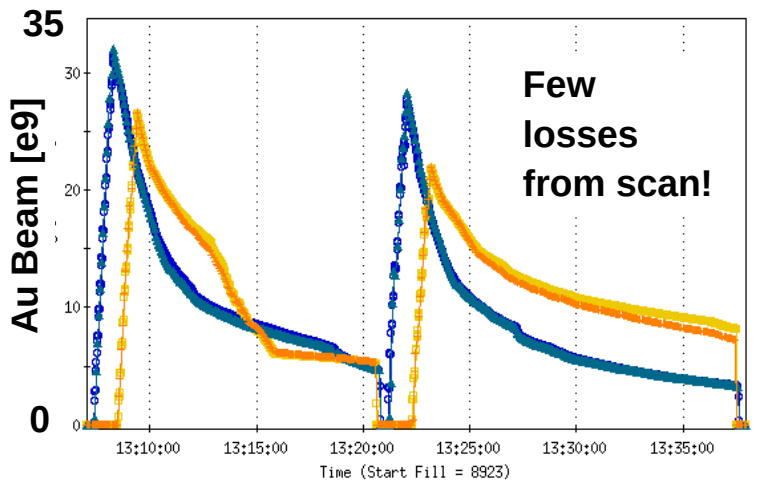


- Double exponential fit to beam lifetimes
  - Fast component lifetime: ~2 minutes (unknown source; octupoles?)
  - Slow component lifetime: ~20 minutes (consistent with IBS prediction)
  - Observed debunching in some stores → not momentum aperture limited
  - Use these lifetimes later for integrated luminosity optimization

2007 Gold Test Run: STAR Vernier Scans







- Measured beam size ~ 4mm at β^*=10m
- 700-1000 Hz BBC coincidences

<10% backgrounds

Peak luminosity ~1.5 x 10^{24} cm^{-2} s^{-1}

RHIC Low Energy Program Plans

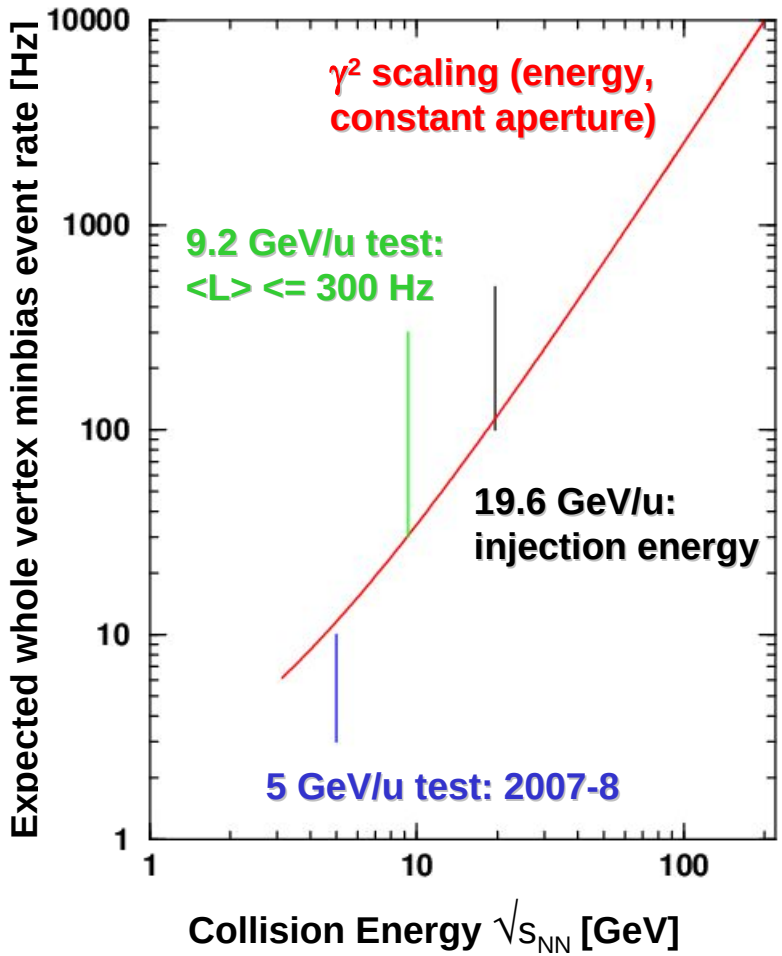
- $\sqrt{s_{NN}}$ = 9 GeV performance was order of magnitude above expectation
- BNL PAC has recommended a 14-week energy scan during RHIC Run-10 in 2010, consistent with the full STAR TOF upgrade
- STAR PAC 2007 strawman proposal reduces to 4.5 weeks
- Dominated by uncertainties in run time at lowest energy
- 1+2 days testing Au-Au at $\sqrt{s_{NN}}$ = 5 GeV requested for FY08
  - Few hours of physics at 9 GeV with new PS setup; explore/evaluate 5 GeV
  - Will drive planning in conjunction with experiments

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	<BBC Rate> [Hz]	Days/ Mevent	# events	# beam days
4.6	570	3 (~5)	9 (3)	5M	45 (15+1)
6.3	470	7 (~50)	4 (0.3)	5M	20 (3+1)
7.6	410	13 (~150)	2 (0.1)	5M	10 (1+1)
8.8	380	20 (300)	1.5 (<1)	5M	7.5 (1+1)
12	300	54 (~1000)	0.5 (<1)	5M (>5M)	2.5 (1+1)
18	220	>100 (>1000)	0.25 (<1)	5M (>5M)	1.5 (1+1)
28	150	>100 (>1000)	0.25 (<1)	5M (>5M)	1.5 (1+2)

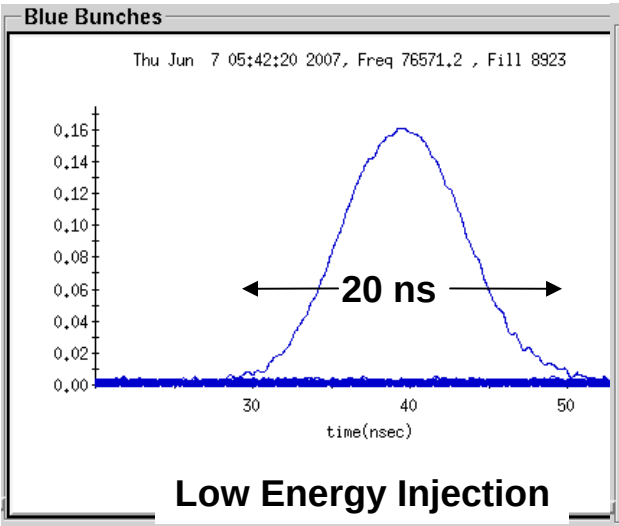
STAR PAC 2007 Strawman proposal (with 2007 Low energy test extrapolation)

Conclusions

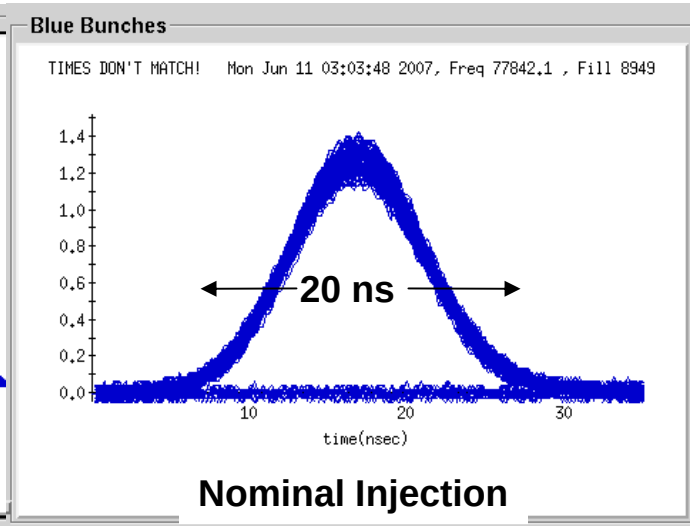
- RHIC low-energy operations is challenging
  - RF acceptance, IBS, field quality are acceptable at mid-range energies; vertex also an issue
  - Low energy lumi uncertainty dominates planning
- Tests of low-energy operations successful
  - $\sqrt{s_{NN}}$=9.2 GeV produced 100-700 Hz BBC rates in STAR, uncovered harmonic number challenges
  - Peak luminosity approximately 1.5 x 10^{24} cm^{-2} s^{-1}
  - 3 day $\sqrt{s_{NN}}$=5 GeV test run requested within this run
  - Should provide enough data for program planning
  - Should easily produce some physics at 9.2 GeV
- RHIC PAC has recommended 14 weeks operation in 2010
  - Driven by completion of STAR TOF upgrade
  - Modest energy scan of 5-50M events/point is feasible, dominated by uncertainty in $\sqrt{s_{NN}}$<8 GeV luminosity projections



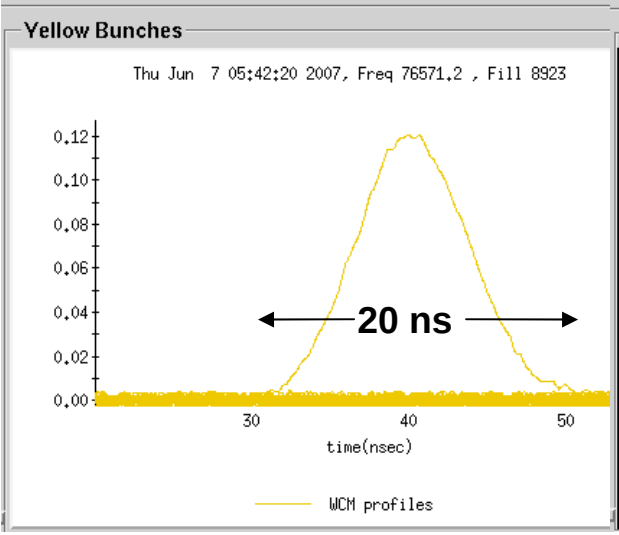
2007 Gold Test Run: Bunch Lengths

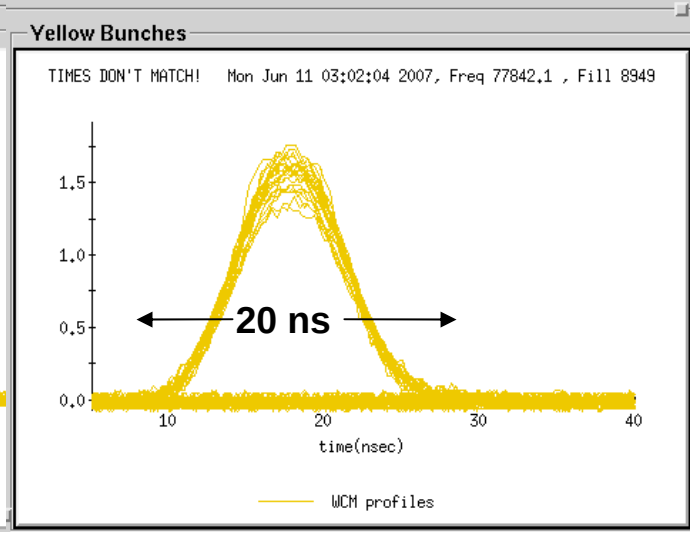


Low Energy Injection



Nominal Injection



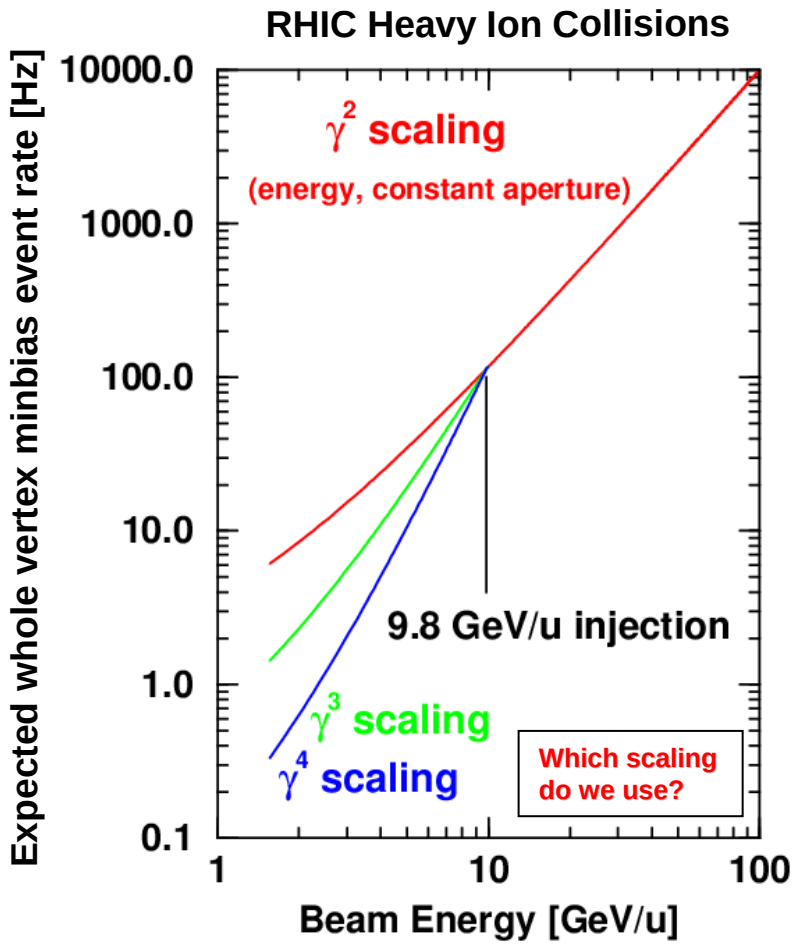


- $\sqrt{s_{NN}}$ = 9.3 GeV bunch lengths were short!
  - Expected 25-30 ns
  - Nearly indistinguishable from normal injection
  - Consistent even for high intensity injection
- Longitudinal emittance
  - Consistent with 0.14 eV-s
  - Possibly improved by avoiding transition in AGS
- Bunch length still 6m
  - Long interaction diamond
  - What is reduction for PHENIX luminosity?

History: March 2006 RIKEN Workshop Accelerator Summary

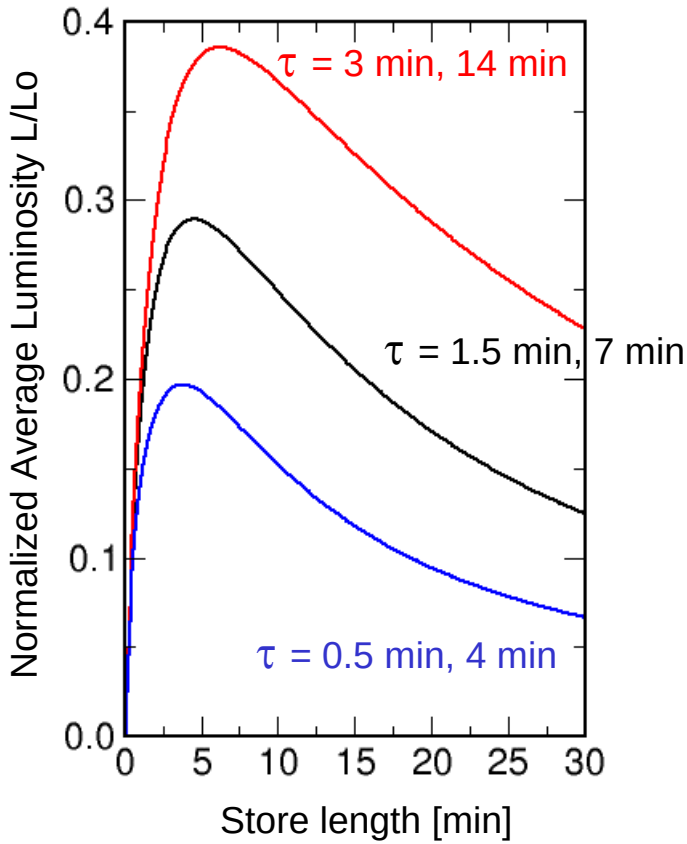
- No apparent show-stoppers for RHIC collisions at $\sqrt{s_{NN}}$ = 5-50 GeV
  - Only equal energies
  - Unequal species possible only if minimum rigidity > 200 T-m
  - Without cooling → long vertex distribution
- Small set of specific energies should be (was) a workshop deliverable for planning:
  - 2.5,3.2,3.8,4.4… GeV/n total beam energy
- Studies that should be done soon:
  - A ~1 day study period at low total beam energy to identify power supply, lifetime, tuning issues, other intrinsic limitations
  - Low-current superconducting magnet measurements
- Pre-cooling in AGS → 10x luminosity ?
- Electron cooling would (might) make this a fantastic facility: ~100x luminosity, small vertex distribution, long stores

- Main questions:
  - Which scaling to use for luminosity projections?
  - Do power supplies fail to regulate at some energy?
  - How low can we go and still get usable luminosity?



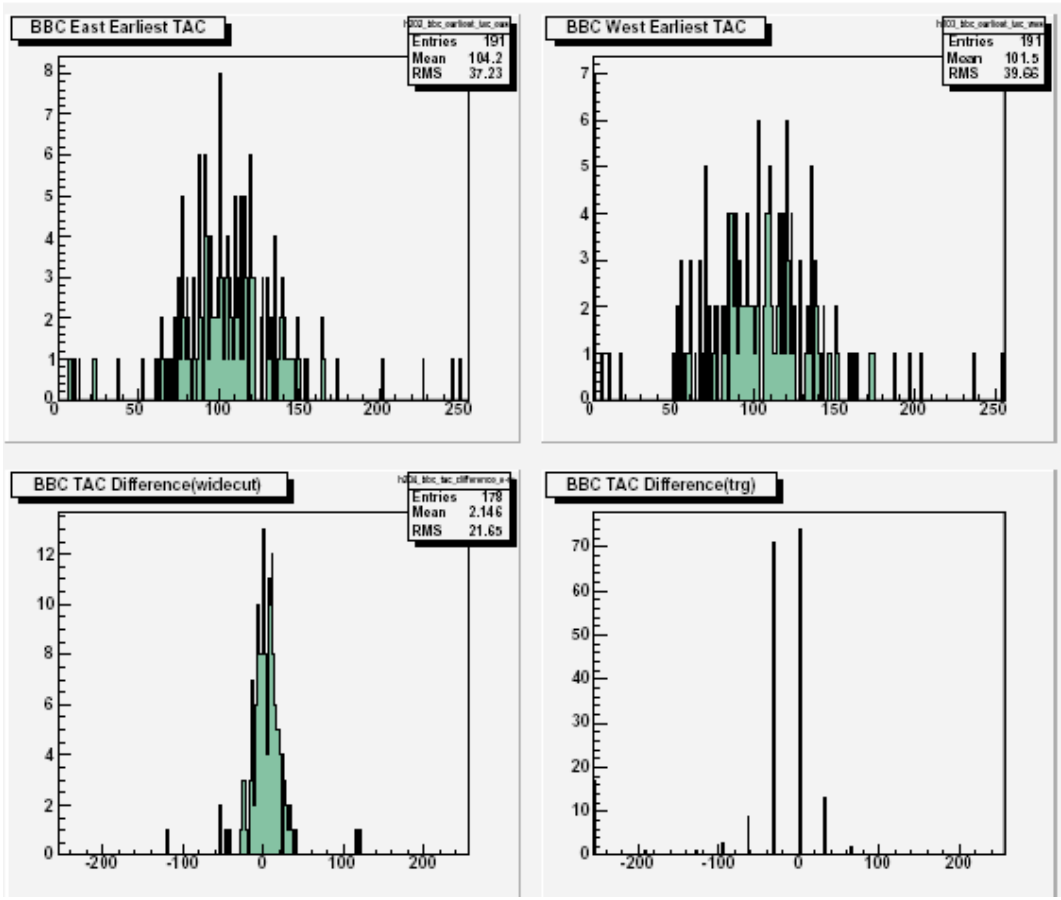
T. Roser, T. Satogata

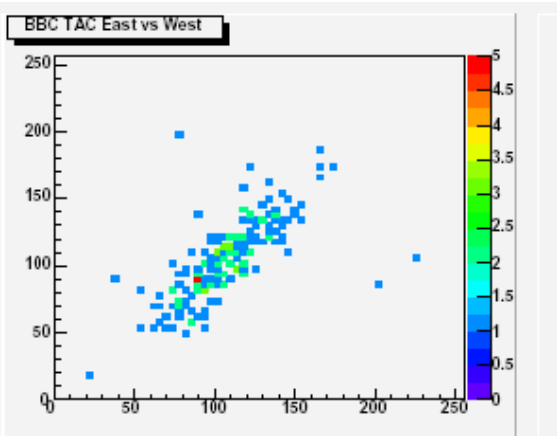
- Question: What statistics and energy granularity are desired?
  - These range from 5M events over 7 energies (T. Nayak/STAR, 2006) for a broad scan to 50-500M events (A. Toia/PHENIX, CPOD 2007) for dilepton statistics
- With fast luminosity decay components, optimal store lengths are 5-10 minutes
  - Luckily experiments can stay on during injection
- Optimized luminosity varies strongly with luminosity decay rates τ when $\tau \sim o(T_{fill})$
- For $\sqrt{s_{NN}}$ = 9.3 GeV/u, 80% uptime
  - $<L_{bbc}>$ = 300 Hz, 20M events/day
  - Vertex cut reduces this significantly
- For $\sqrt{s_{NN}}$ = 5 GeV/u, 80% uptime
  - Luminosity down by at least factor x20
  - $<L_{bbc}> \sim$ 5 Hz, 0.3M events/day
  - Consistent with 15d to acquire ~5M BBC triggers



Run 8158115: (TPC gain low)

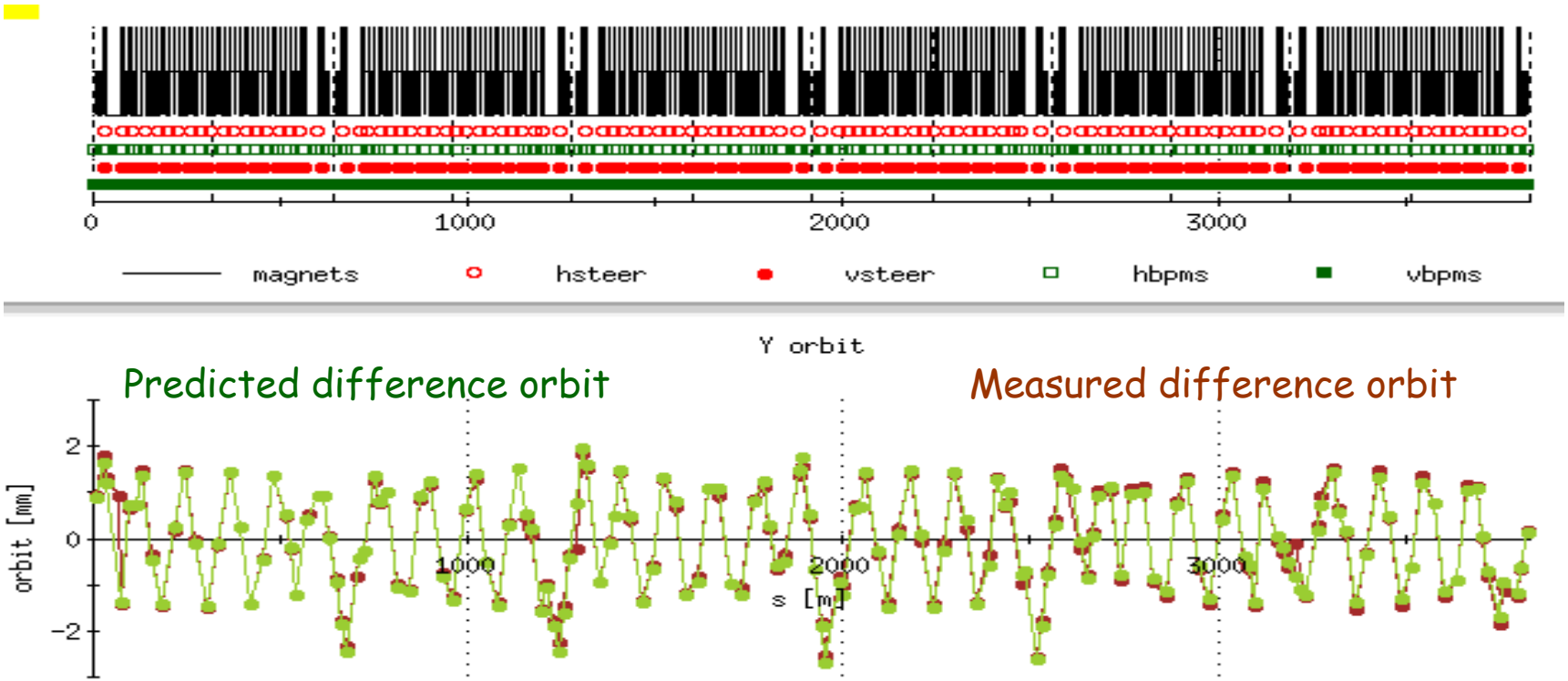
- 2015 BBC-small triggers
- 536 BBC-Large triggers
- 310 both bbc s&l
- 1 vpd triggers (+ bbc s&l)





W. Christie

2006 Proton Test Run Optics



S-coordinate [m]

- Measured optics in both rings are surprisingly good
  - No indications of linear optics problems, quadrupole magnet or power supplies with aberrant low-current behavior