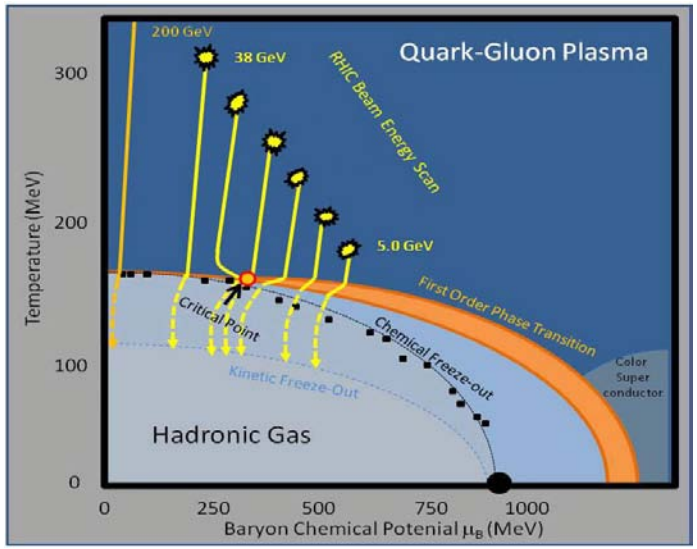
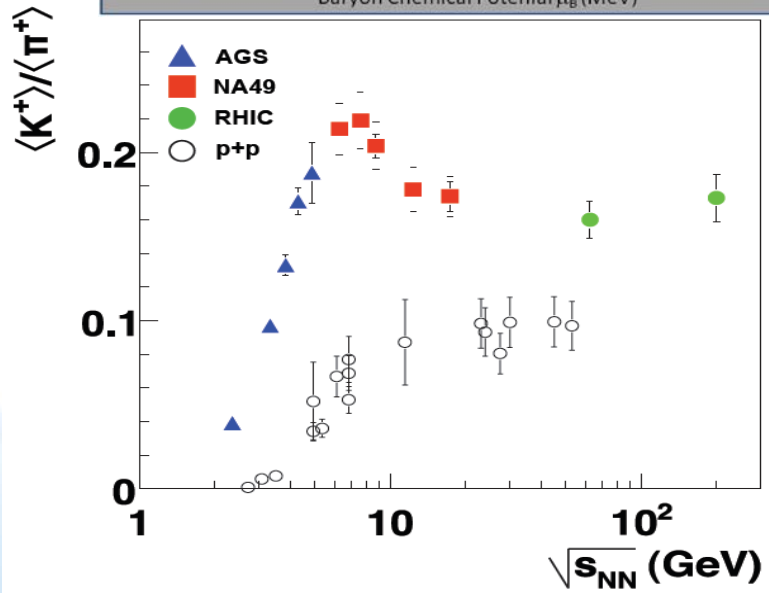
RHIC Low Energy Planning and Issues





- Motivation
  - CPOD 2009
  - 2010 physics program
- Parameters and Experience
  - STAR 2008 physics
  - STAR/PHENIX physics plans
- Top-Off Challenges
- Radiation and Aperture
- 2010 Prognosis
- (Alexei: Electron Cooling)

Motivation / CPOD 2009

- Search for QCD phase diagram critical point signatures
  - Several "competitors": NA41/NA61 (SPS), NICA, CBM (FAIR)
  - Energy range: E=2.5-20 GeV (RHIC dAu injection E=10.38 GeV)
  - AGS/NA49 data show K^+/π^+ "signature" around $\sqrt{s_{NN}}$ = 6-8 GeV
  - How do observed high-energy partonic RHIC behaviors turn off?
  - What is the specific character of the RHIC phase transition?
  - NSAC Long Range Plan:

    "A Landmark Study": The large range of temperatures and chemical potentials… along with… advantages provides by a collider coupled with advanced detectors, give RHIC scientists an excellent opportunity for discovery of the critical point and associated phase boundaries.
- CPOD Workshop at BNL, June 8-12 2009
  - ~100 participants from ~50 institutions worldwide
  - Convergence of interest in collider geometry for energy scan
  - STAR main interest near K^+/π^+ horn at E=7.7 GeV
  - PHENIX main interest at above injection for dileptons, new triggers

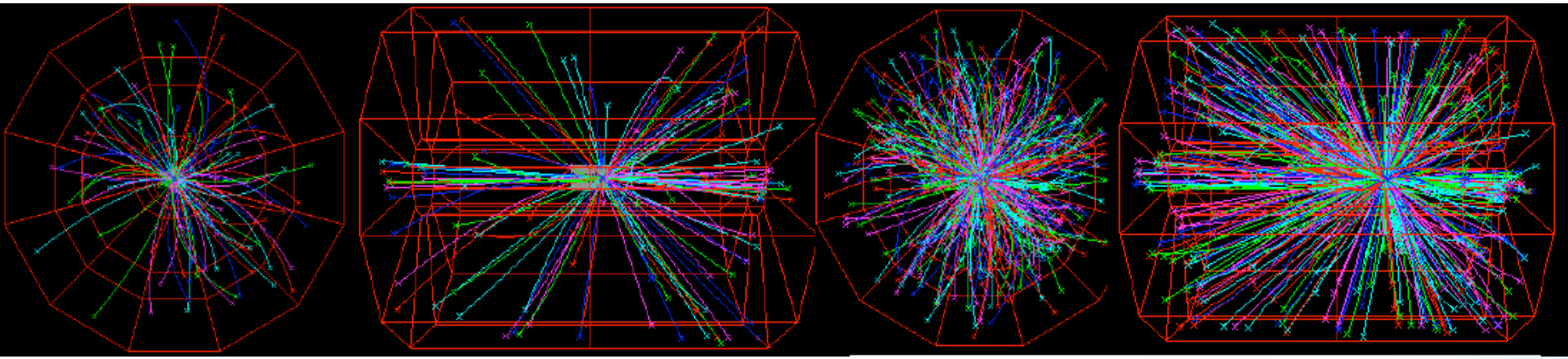
Potential STAR Physics Program

	Collision Energies (GeV)	5	7.7	11.5	17.3	27	39
Section	Observables	Millions of Events Needed					
A1	v_2 (up to ~1.5 GeV/c)	0.3	0.2	0.1	0.1	0.1	0.1
A1	v_1	0.5	0.5	0.5	0.5	0.5	0.5
A2	Azimuthally sensitive HBT	4	4	3.5	3.5	3	3
A3	PID fluctuations (K/π)	1	1	1	1	1	1
A3	net-proton kurtosis	5	5	5	5	5	5
A3	differential corr & fluct vs. centrality	4	5	5	5	5	5
A3	integrated p_T fluct (T fluct)						
B1	n_q scaling π/K/p/Λ $(m_T-m_0)/n<2$GeV		6	5	5	4.5	4.5
B1	φ/Ω up to $p_T/n_q=2$ GeV/c		56	25	18	13	12
B2	R_{CP} up to p_T ~4.5 GeV/c (at 17.3) 5.5 (at 27) & 6 GeV/c (at 39)				15	33	24
B3	untriggered ridge correlations		27	13	8	6	6
B4	parity violation		5	5	5	5	5

Table 3-2: Observables and statistics needed for the first BES run. The observables in the yellow-shaded area relate to the search for a phase transition or critical point (see section A), while observables in the blue-shaded area search for turn-off of new phenomena already established at higher RHIC energies

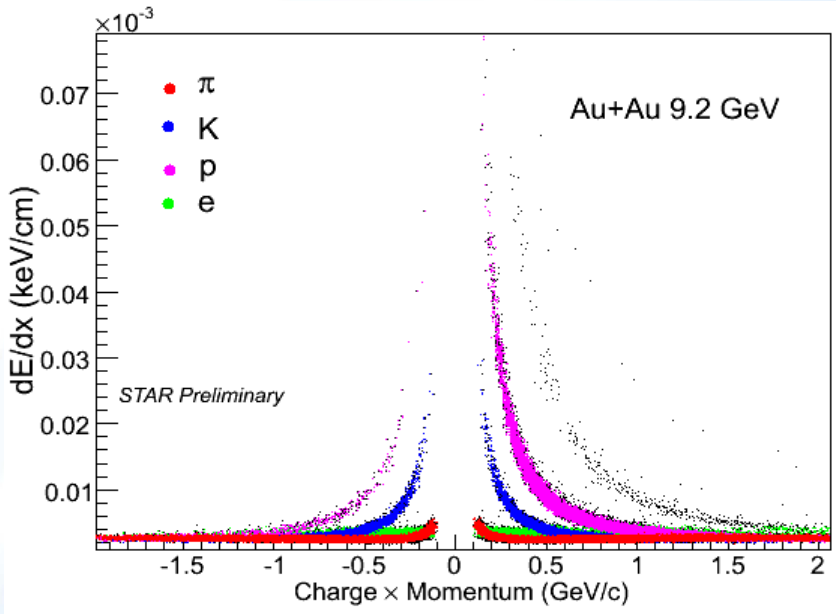
(From 2009 STAR Beam Use Request)

STAR 2008 Physics Results



Peripheral (left) and central (right) TPC collision tracking

- Data taking for <5h
- 3000+ good Au+Au vertices
  - Clear particle separation/ID
  - Data point for K/π ratio
  - Future ToF will improve PID
- Also observed Au+Al collisions



(J. Chen for the STAR collaboration, 2009 CPOD)

Potential PHENIX Physics Program

$\sqrt{s_{NN}}$	Fluctuations in $\langle n \rangle$	Fluctuations in $\langle p_t \rangle$	PID spectra, identified particle ratios	longitudinal density correlations	critical exponent η	1D imaging of pion source	Lévy exponent α	3d Gaussian HBT radii for pions $R_i(m_T)$	HBT intercept parameter $\lambda(m_T)$	dielectron spectra	fluctuations if $\langle K/\pi \rangle$	dihadron correlations	nuclear modification factor R_{AA}	optical opacity κ	heavy flavour electrons	1d image of kaon source	3d image of pion source	Kaon 3d Gaussian HBT radii $R_i(m_T)$
5.5	0.01	0.03	0.03	2		54				50		375	NA		NA	953		
7.7	0.01	0.03	0.02	2		33				50		246	NA		NA	586		
11.5	0.01	0.03	0.02	2		24				50		160	NA		NA	431		
17.3	0.01	0.03	0.01	2		19				50		109	157		NA	340		
27	0.01	0.03	0.01	2		16				50		68	24		NA	276		
39	0.01	0.03	0.01	2		14				50		48	6.3		700	239		

(Millions of events required for good physics)

- Large event gap from 2M to 20-50M in PHENIX physics plan
- Need new low energy trigger, not available until 2011

(From 2009 PHENIX Beam Use Request)

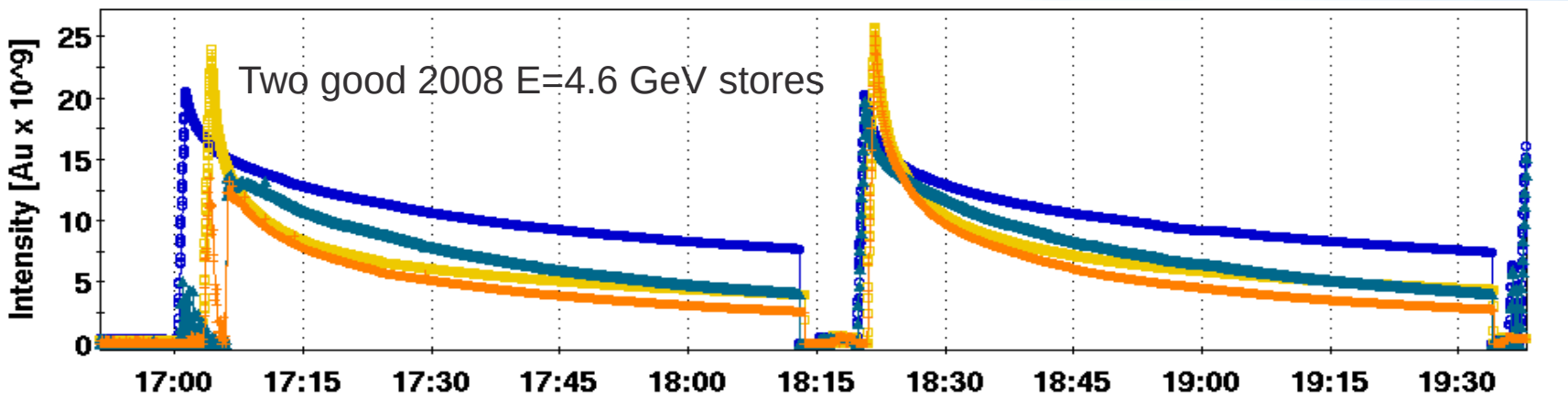
Continuous Injection Issues

- One way to increase low energy luminosity: continuous injection
  - Similar to light source “top-off”, continuously replace oldest bunches

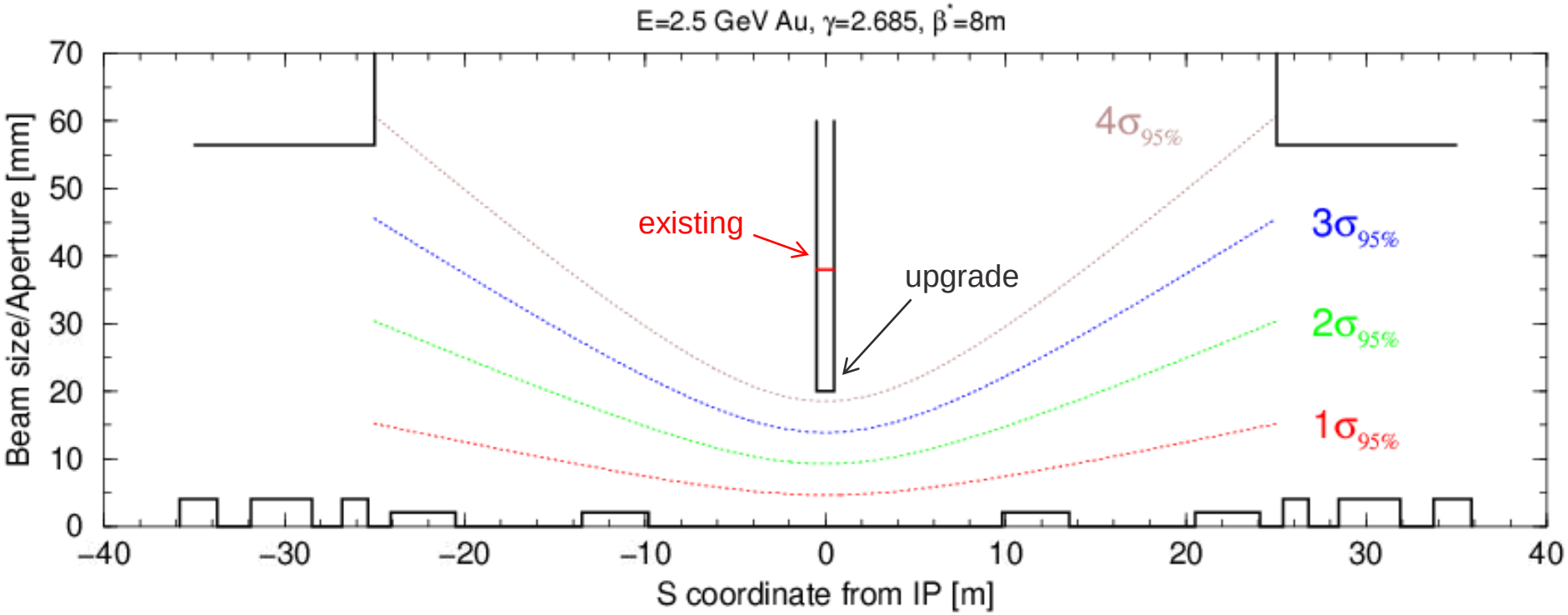
- Continuous injection considerations and challenges
  - Luminosity improvement: x2-3 (Eduard)
  - Injector uptime: Any injector downtime is physics downtime
  - Injection kicker: Match impedance, eliminate reflections
  - Abort kicker: Extensive modifications required (Harald, Eduard)
    - No single-turn full-ring beam abort
  - Engineering support: Required for kicker mods, radiation safety
  - Experiment backgrounds: Can experiments handle them?
  - RF: No technical issues
  - Magnet/equipment radiation hardness
  - Dump/collimator heat loads
  - Radiation safety

Radiation Issues

- All low energy runs thus far have chronic beam lifetime issues
  - Beam lifetimes 4 (fast) to 50 (slow) min in E=4.6 GeV 2008 run
  - 50-80% of stored beam lost before dump without collimation
  - Draft AP note with loss estimates for normal/continuous injection
    - 2008: 10^{10} E=4.6 GeV/u Au/hr
    - 2010: 4-10x10^{9} E=3.9 GeV/u Au/hr (1.1-2.7x10^{6} Au/s)
    - Assumes 90% collimation efficiency; heat load of a few W on collimators
    - Continuous injection non-collimated/dumped losses are about 5x larger
    - Continuous injection collimator heat load is likely above 100W



Aperture and Beampipe Upgrades



- IR beampipe upgrade marginally constrains 2.5 GeV operation
  - β* = 10m to 8m changes beam sizes by 12%
  - No separation bumps in experiment IRs needed for low energy operation

BNL C-A/AP/250: “Aperture… of detector upgrade beampipe”,C. Montag et al, Aug 2006

2010 Run Planning

- Do we run low energy Au-Au in 2010? Plan for success…
  - …but requires guidance/decision from management

- PHENIX prefers a run above injection energy
  - Planning is straightforward for operations in this regime

- STAR prefers a run near $\sqrt{s_{NN}}$=7.7 GeV, E=3.85 GeV
  - h=369 will satisfy this and provide collisions at both experiments
  - Must resolve radiation safety concerns: run later rather than earlier
  - Take advantage of improvements in AGS Au longitudinal emittance
  - No top-off, modest setup times per energy (days)
  - Swap defocusing sextupole leads (1+ shift) below $\sqrt{s_{NN}}$=9.3 GeV
  - β^*=10m lattice, optimize apertures (IR, abort kickers)
  - Collimation setup

2010 Run Planning

- From $\sqrt{s_{NN}}$ = 9 GeV 2008 experience and expected tuning improvements
  - Assumes 75% time in physics during running time
  - Event rates scale as γ^3 below injection, γ^2 above injection ($\sqrt{s_{NN}}$ = 21.2 GeV)
- Assumes STAR run plan to initially explore near $\sqrt{s_{NN}}$ = 7.7 GeV
- $\sqrt{s_{NN}}$ = 12 GeV precludes optimized luminosity at both experiments
- Also desire 3-5 days development time for electron cooling projections

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	<Event Rate> [Hz]	Days/ Mevent	# events	# beam days (phys+setup)
5.0	535	0.55	28	5M	140+5
6.1	470	1.0	15	5M	75+4
7.7	405	2.0	7.6	5M	38+3
8.6	370	3.0	5.0	5M	26+2
12	295	--	--	--	--
18	210	>30	0.5	5M	3+1
28	145	>60	<<1	5M	1+2 (ramp)

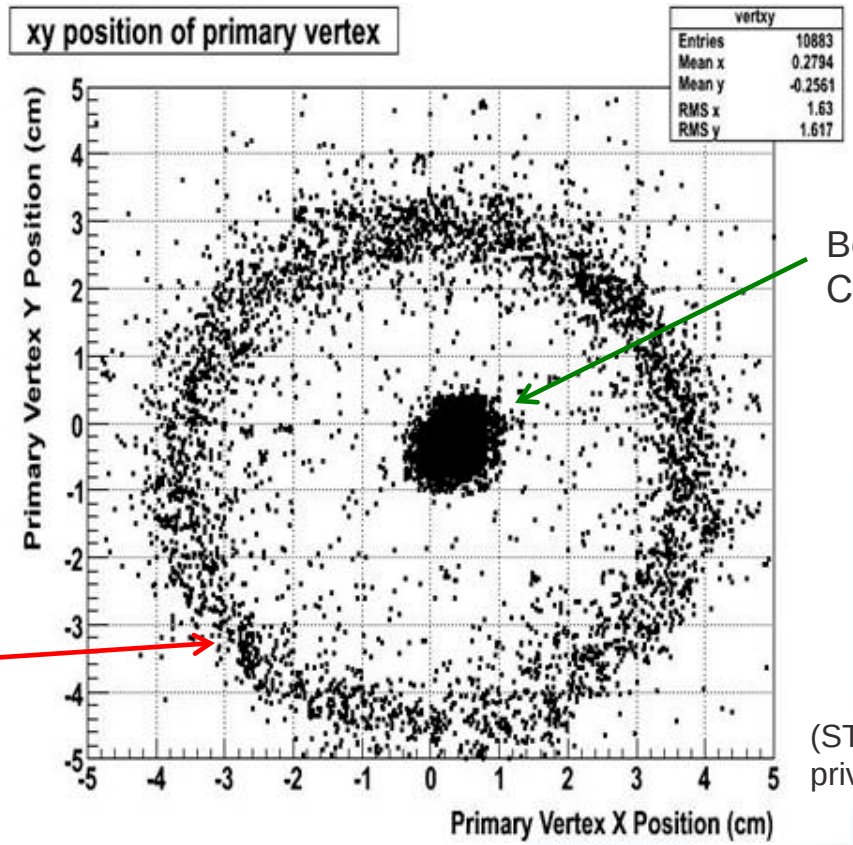
2010 Operations?

(Swap sextupole leads)

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

Thanks!

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
  - No collimation setup in 2008 test run; future runs will include collimation setup

RHIC Low Energy Parameters

	Gold 2007-8	Gold 2008
$\sqrt{s_{NN}}$ [GeV]	9.18	5.0
Baryochemical potential μ_B [MeV]	360	530
Beam energy [GeV/u]	4.59	2.5
Beam kinetic energy [GeV/u]	3.660	1.569
Relativistic γ	4.93	2.68
Relativistic β	0.979	0.928
Momentum [GeV/c]	4.496	2.320
Rigidity $B\rho$ [T-m]	37.40	19.30
RF harmonic number	366	387
RF frequency [MHz]	28.03	28.08
Max beam size $\hat{\sigma}$ [mm]	15.32	21.32
Beam/ring time available	27/30.5h	3.5/7h
Luminosity [$\times 10^{23}$ cm^{-2} s^{-1}]	~3.5	--

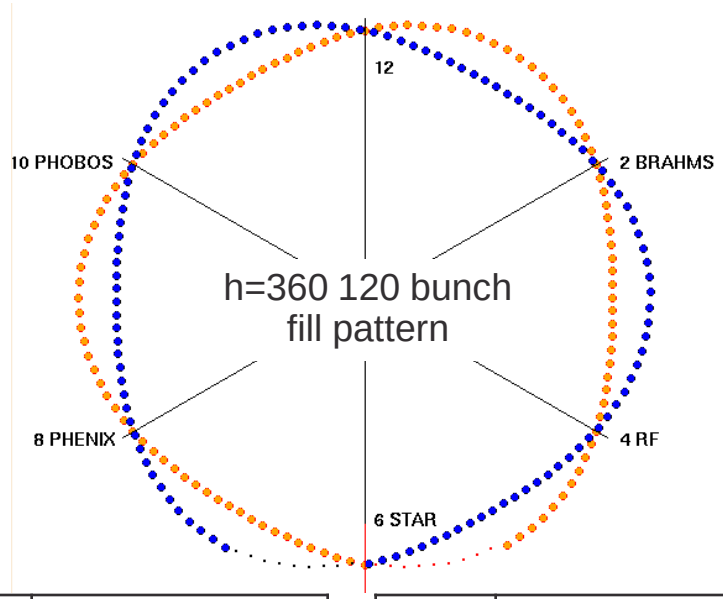
- Test runs: 2006 (p), 2007-8 (Au)
- Mar 10-12 2008 Au run
- 2008 $\sqrt{s_{NN}}$ = 9.18 GeV
  - 2007 9 GeV setup "in the can"
  - Test RF/timing/expt trigger fixes
  - Au h=366 setup went "well"
  - Reproduce 2007 Au test; physics!
- 2008 $\sqrt{s_{NN}}$ = 5.0 GeV
  - To establish lowest energy baseline
  - Au h=387 setup went well
  - b4-dh0 PS failure; no blue ring
  - Established circulating beam
  - Very nonlinear lattice

Radiation Issues II

- Previous low energy tests had modest limits from Dana
  - Beam loss, total injected beam intensity

- Developing plan with Ed Lessard and Dana Beavis
  - Planning for normal low energy run readiness by Feb 2010
    - Requires document preparation and analysis by Sep 2009
  - Covers dose rates in labyrinths, berm, penetrations, soil activation
  - NEPA approval, radiation controls
  - Review RHIC safety envelope, permission to operate from DOE
    - Internal department RSC/ALARA/ASSRC safety reviews
    - Preparation of USI (Unresolved Safety Issue) document
    - Possibly requires Accelerator Readiness Review in January 2010
  - Should include ATR beam loss considerations

RHIC Low Energy Harmonic Number Limitations



h	Allowed $\sqrt{s_{NN}}$ [GeV]
360	18.0-107
363	11.34-15.15
366	9.0-10.55
369	7.71-8.60
372	6.87-7.47

h	Allowed $\sqrt{s_{NN}}$ [GeV]
375	6.27-6.71
378	5.8-6.15
381	5.45-5.72
384	5.15-5.38
387	4.91-5.10

- Nominal RHIC RF: h=360 bunches
- RHIC RF tuning range: 28-28.17 MHz
- With lower energy, RHIC RF frequency cannot fall low enough for h=360
  - Must raise harmonic number
  - Retuning cavities is a prohibitive effort
  - Collisions at both experiments require h(mod3)=0; Experiment DAQ clocks also requires another h(mod3)=0
  - Cannot both have optimized collisions in energy range $\sqrt{s_{NN}}$=8.6-16.7 GeV!
- 2008: All C-AD beam sync timing fixes worked well

C-AD AP/309, "RHIC RF Harmonic Numbers for Low Energy Operations"

Aperture and Beampipe Upgrades

Norm emit [pi um]	40							
beta* [m]	8							
beta_T [m]	86.125							
gamma (relativistic	2.685							
beta (relativistic)	0.928							
Device	Ax[mm]	Ay[mm]	sqrt[beta_x]	sqrt[beta_y]	sigma_x [mm]	sigma_y [mm]	Ax/sigma_x	Ay/sigma_y
Old IR	38.00	38.00	2.83	2.83	4.63	4.63	8.21	8.21
New IR	20.00	20.00	2.83	2.83	4.63	4.63	4.32	4.32
Triplet	56.40	56.40	9.28	9.28	15.18	15.18	3.72	3.72
Abort	25.40	38.10	6.06	11.02	9.91	18.03	2.56	2.11

- Available aperture area scales with A/σ, or A/sqrt(β)
- Biggest concern is abort kicker apertures
  - In large β location with small beampipe (so small A)
  - Optimize IR10 optics to level out physical aperture
- Aperture management also important for low energy electron cooling