A RHIC Low-Energy Test Run With Protons

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Driven by discussions at the
"Can We Discover the QCD Critical Point at RHIC?" Workshop

- Scope
- Parameters
- Schedule

- Significant interest in RHIC heavy ion collisions with c.m. energy in the range $\sqrt{s}$= 5-50 AGeV
  - Corresponds to Au beam γ=2.68 to 26.8
  - Nominal Au injection is γ=10.52, already below design γ=12.6
  - Recommended energies from Krishna Rajagopal's talk:
    $\sqrt{s_{NN}}$ = 5, 6.27, 7.62, 8.77, 12.3, 18, 28 AGeV
  - PHENIX RBUP requested low-energy proton collisions
    $\sqrt{s}$ = 22.5 GeV equivalent to Au $\sqrt{s_{NN}}$ = 9.18 AGeV

- Open machine issues
  - How does machine field quality degrade at lower energies?
  - Can we correct optics with current power supply configuration?
  - Are any power supply regulation/hardware changes required?
  - How do we test changes necessary for RHIC RF?

Proton/Gold parameters at same rigidity

	Protons	Gold (eq)
√s [GeV]	22.5	9.18
Beam energy [GeV]	11.25	4.59
Beam kinetic energy [GeV]	10.312	3.660
Relativistic γ	11.99	4.93
Relativistic β	0.997	0.979
Momentum [GeV/c]	11.211	4.496
$B\rho$ [T-m]	37.40	37.40
Injection current scaling	0.471	0.384
Main dipole current [A]	217.7	217.7
Main quad current [A]	202.6	202.6
Revolution frequency [Hz]	77924	76571
RF frequency [MHz, h=360]	28.053	27.566

RHIC RF frequency range is 27.98-28.17 MHz

- Gold energy for same rigidity is near middle of Krishna's list
- Tests magnets and power supplies at less than half of normal injection current
  - Reasonably balance for initial testing, performance extrapolation
- Does NOT require change to RHIC harmonic number or substantial reconfiguration of RHIC RF
  - h=366 gives RHIC RF frequency of 28.03 MHz

Testing RHIC RF, h=363

	Protons	Gold (eq)
√s [GeV]	15.0	6.25
Beam energy [GeV]	7.50	3.13
Beam kinetic energy [GeV]	6.56	2.19
Relativistic γ	7.99	3.36
Relativistic β	0.992	0.955
Momentum [GeV/c]	7.442	2.984
$B\rho$ [T-m]	24.82	24.82
Injection current scaling	0.255	0.255
Main dipole current [A]	144.5	144.5
Main quad current [A]	134.5	134.5
Revolution frequency [Hz]	77582	74647
RF frequency [MHz, h=363]	28.162	27.097

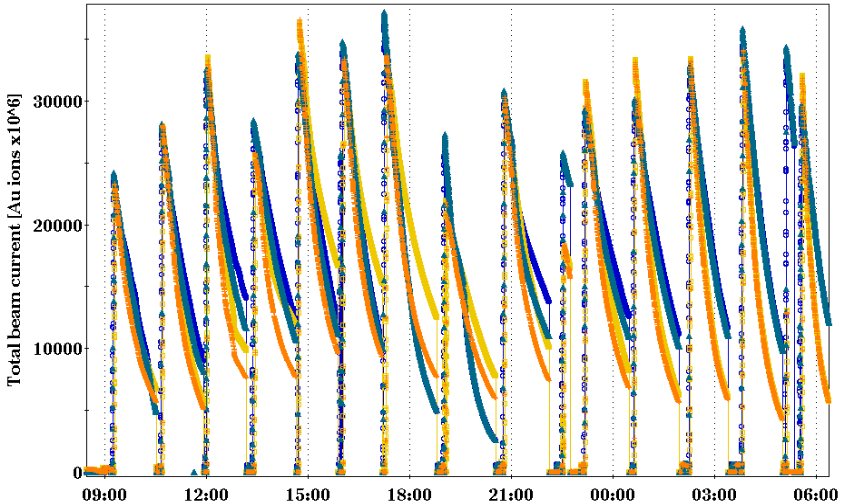
RHIC RF frequency range is 27.98-28.17 MHz

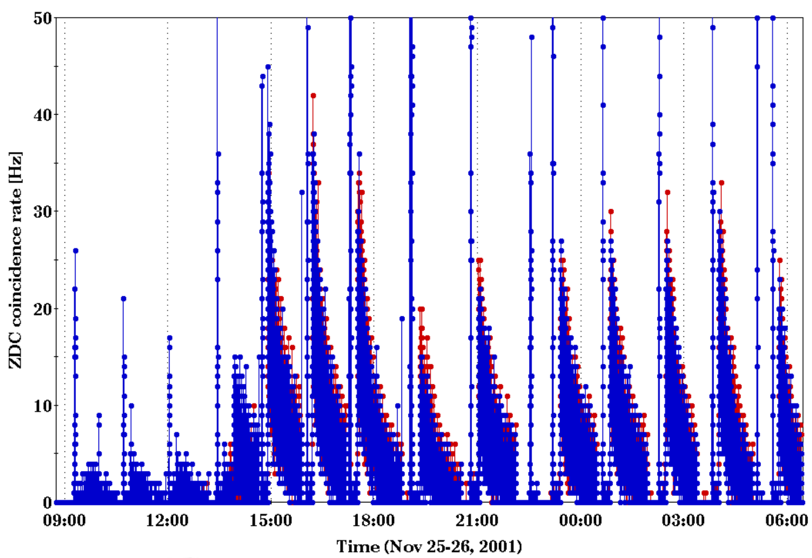
- Alternate RHIC RF harmonic numbers are required for low-energy ion collisions
  - Must be divisible by 3 to have collisions at both experiments
  - Only code changes, no hardware changes
- h=363 is testable with proton beam at energy/rigidity that are still within low-energy range of interest
  - But aggressive rigidity
- RF personnel state that cogging and harmonic number changes can be completely tested during shutdown without beam time

Suggested low energy collision setup schedule

- Scale existing injection optics (β^*=10m) to $B\rho$ =37.40
  - Zero out transition jump quadrupoles to improve optics
- Assume AGS setup has been completed on separate user
- Hysteresis cycles (1h)
- Tune ATR, establish injection, circulating beam (3h)
- Establish RF capture, instrumentation setup, tune for lifetime (4h)
- Tune scans (1-2h)
- Power supply stability evaluation (parasitic)
- Optics measurements (1h) and correction/verification (3h)
- Steer to optimize collisions (3-4h) using experiment BBCs
  - Lifetime objective is > 30min (longer than fill time)
- Contingency (~6h)

- There is substantial interest in RHIC operations at low energies ($\sqrt{s_{NN}}$= 5-50 AGeV)
- A low-energy proton test run of ~24h (with contingency) provides important information on program feasibility
  - $\sqrt{s}$ = 22.5 GeV provides best balance of objectives with reasonable likelihood of success
  - Low-current field quality measurements and optics correction are the most important objectives.
  - Other objectives include power supply stability evaluation, working point evaluation, and collision steering
  - Ready for testing within three weeks after go-ahead
- RHIC RF harmonic number changes will be tested without beam during summer shutdown
  - Testing RF changes with protons requires significantly lower energy ($\sqrt{s}$ = 15 GeV, corresponding to $\sqrt{s_{NN}}$ = 6.25 AGeV)





- 2 days of 9.8 GeV/u collisions
  - 0.4 μb^{-1} integrated luminosity
  - β^*=3m by necessity
  - 60-90 minute stores
  - 56 Au bunches, 0.6×10^9/bunch
  - 10-30 Hz ZDC rates
  - IBS and aperture dominated beam and luminosity lifetime

- Another run at this energy may improve this by factor of 2-5
  - $1.0^+ \times 10^9$/bunch
  - Raise β^* to improve lifetime

- RHIC is best used as a storage ring collider below beam energies of ~12 GeV/u

Beam Studies for Low-Energy Injection

- ~1 day of studies required in run before low-energy operations

- Initial studies
  - Trivially scale nominal injection to lower energies
  - Provides reality check of power supplies, optics
  - Test injection, establish circulating beam, optimize lifetime
  - Initial global optics measurements, field quality, tune scan, energy resolution/momentum aperture
  - IBS growth time study require 3-6 hours extra time
    - All but IBS growth evaluation can be done with Run6 p

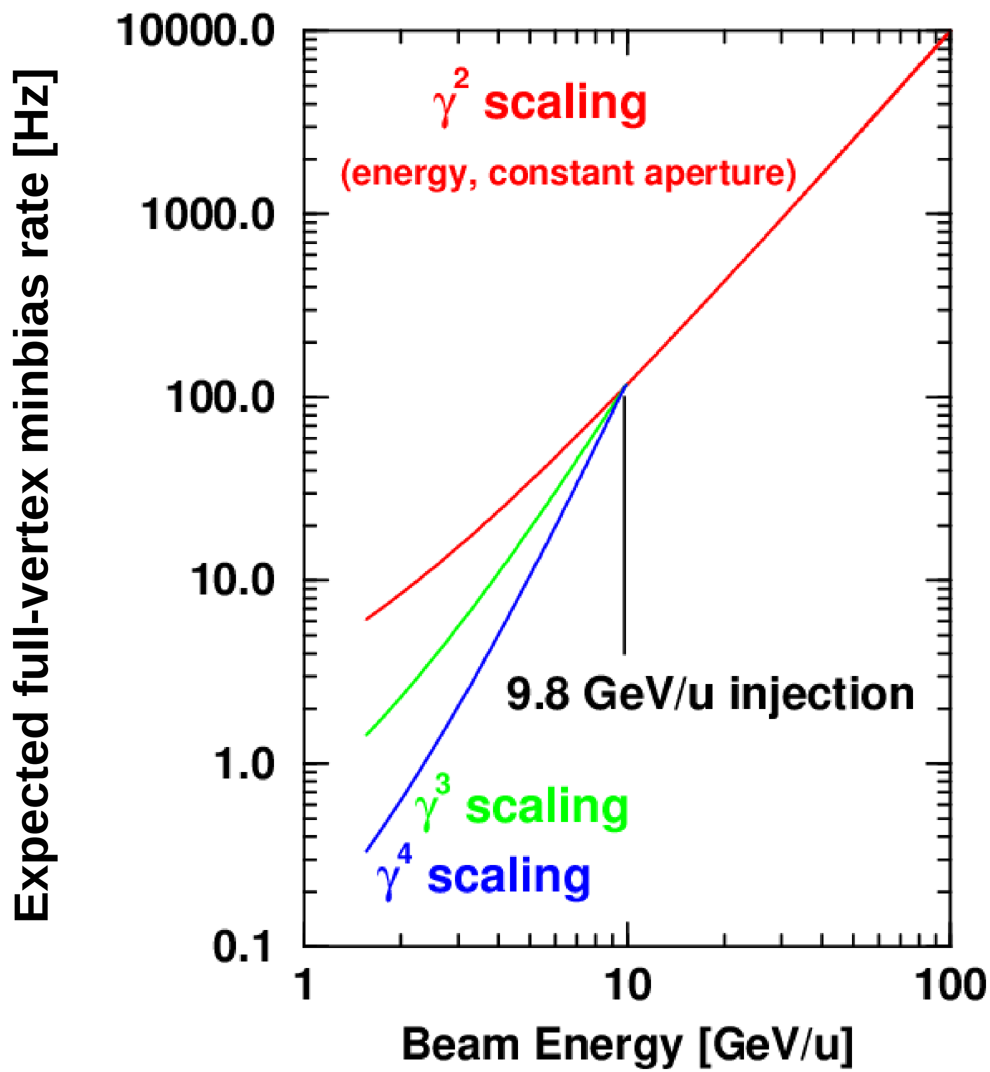
- Later studies
  - IBS modification lattice development
  - Field quality and detailed optics measurement/correction

Initial Machine Projections

- Scaling laws apply above injection energies
- When aperture dominated:
  - Peak luminosity $\alpha\ \gamma^2$

- No clear scaling laws apply below injection energies
  - Injected beam already fills aperture
  - Magnetic field quality degrades very quickly
  - Power supply regulation

- Strawman model
  - Peak luminosity $\alpha\ \gamma^{3\text{-}4}$



Initial Machine Projections

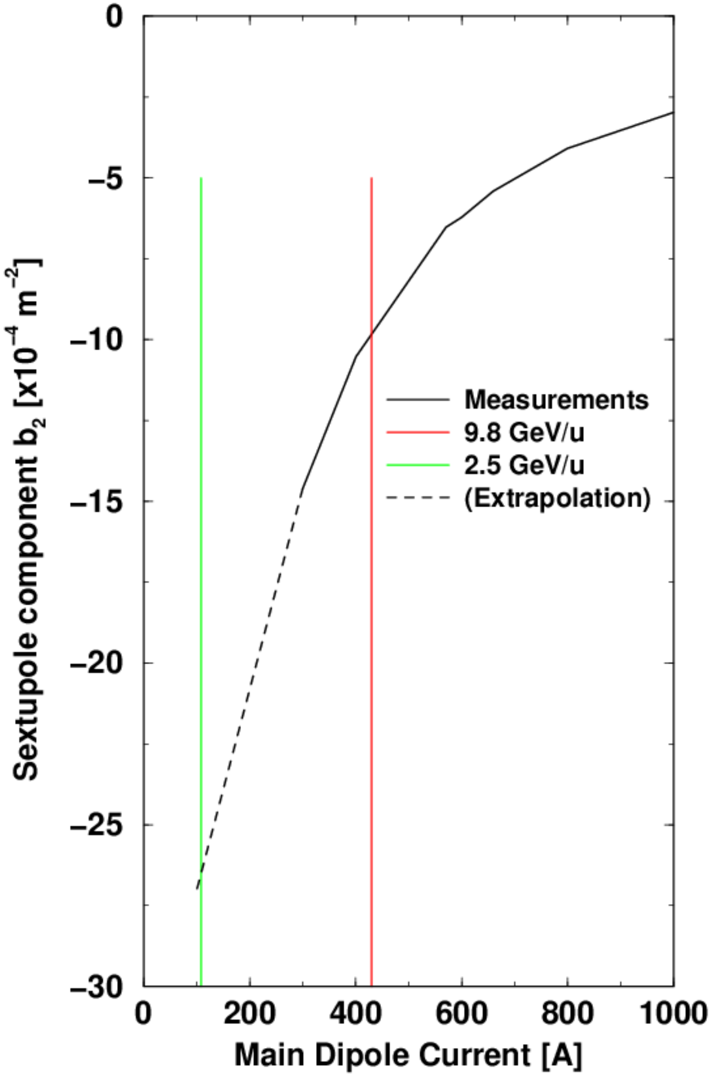
Mode	Beam Energy [GeV/u]	$N_{bunches}$	Ions/bunch [10^9]	β* [m]	Emittance [μm]	L_{peak} [$cm^{-2}s^{-1}$]
Au-Au 2001-2	9.8	55	0.6	3	15	8.0×10^{24}
Au-Au 2003-4	31.2	45	1.0	3	15-30	1.2×10^{26}
Au-Au	9.8	55	1.2	10	15-40	1.0×10^{25}
Au-Au	2.5	55	1.0	10	15-30	1.1×10^{23}
Au-Au	25	55	1.2	3	15-40	2.0×10^{26}

- Assumes expected luminosity scaling as γ^3 below 9.8 GeV/u
- β*/aperture and integrated luminosity tradeoffs must be studied
- Projections do not include potential improvements
  - Electron and stochastic cooling (peak and integrated luminosity)
  - Lattice modifications to mitigate IBS (integrated luminosity)
  - Total bunch intensity from vacuum improvements (peak luminosity)
- Small set of specific energies (and species?) should be a workshop deliverable for planning

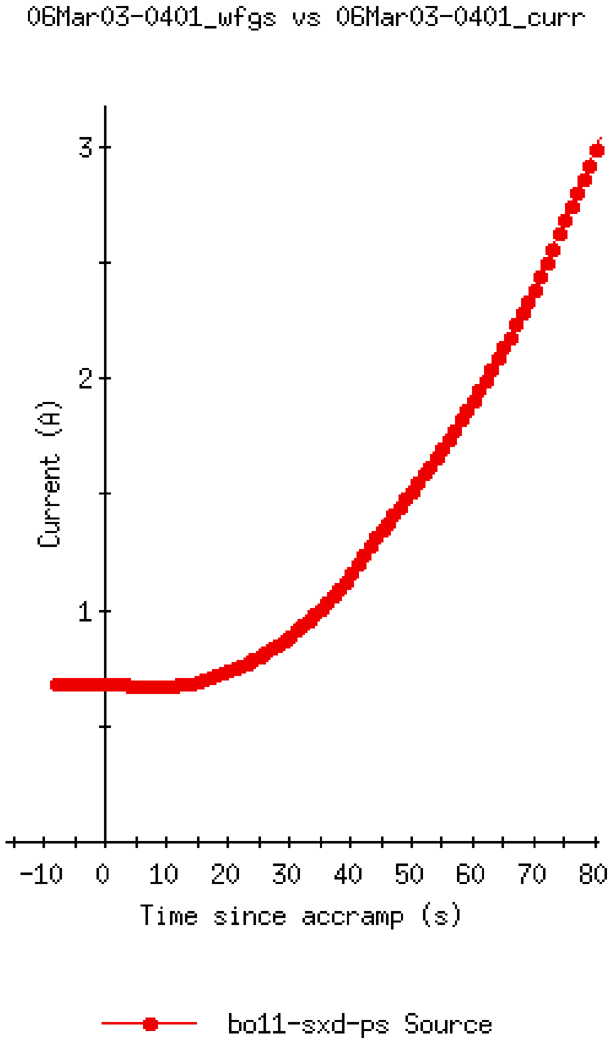
Low-Energy Magnetic Field Quality

Total Energy	γ	$B\rho$	Dipole Current
9.8 GeV/u	10.52	81.11	430 A
2.5 GeV/u	2.68	20.69	110 A

- Magnet currents scale with rigidity $B\rho$ which scale with γ
- Field quality deteriorates rapidly at very low currents
- Currently have no magnet measurements at very low currents, few at low energy
  - Must extrapolate field behavior for simulations
  - Low-current magnet measurements are a priority



Power Supply Regulation Issues



- Several power supply issues
  - Chromaticity sextupoles
  - Main power supplies
- Sextupoles: 0.6-0.7 A -> 0.15-0.2 A
  - CMOS regulation, works to 0.01 A
  - Study option of using only some sextupoles with higher current
  - Aperture and lifetime concerns
  - Correction of large main dipole b_2
- Main dipoles: 430 A -> 110 A
  - Requires testing to check regulation
  - Will test during Run6 maintenance
- Pulsed injection/extraction kickers
  - May have low-voltage limitations