STAR Physics Program

STAR Five-year Beam Use Request for FY09-13

Nu Xu
for the STAR Collaboration

Nuclear Science Division
Lawrence Berkeley National Laboratory
Outline

1) Introduction

2) STAR Physics Results
   - Spin:
   - Heavy Ion:
   - Run 8 performance:

3) STAR Hardware Upgrades
   - DAQ1000:
   - MRPC TOF:

4) BUR for Runs 09 - 13
   - Runs 9 -10:
   - Runs 11 - 13:

5) Summary
STAR Physics Focus at the QCD Lab

1) Heavy-ion program
   - Study medium properties, EoS
   - pQCD in hot and dense medium

2) RHIC beam energy scan
   - Search for critical point
   - Chiral symmetry restoration

1) Longitudinal and transverse spin programs
   - Study proton intrinsic properties

2) Forward programs
   - Study low-x properties and search for CGC

Tagged forward protons
   - Study elastic and inelastic processes
   - Investigate gluonic exchanges and search for gluonic matter
STAR Detectors

TPC  TOF  EMC+EEMC+FMS
(-1 ≤ η ≤ 4)

HFT  DAQ1000

Full azimuthal particle identification!
Selected STAR Spin Results
- Our $A_{LL}$ measurement for inclusive jets has gained significant precision and kinematic reach from Runs 3 & 4 (published) to Run 5 (sub.) and, once more, to Run 6.

- Have placed significant new constraints on the magnitude of $\Delta G$ for $0.02 < x < 0.3$. Our most precise data to date (Run 6) remain statistics limited.
STAR Transverse Spin Results

STAR data from Run 6 and compared with theoretical calculations

⇒ First STAR di-jet analysis using jets from calorimeters, has been published

unexpected smallness observed for the Sivers transverse spin phenomena for $-1 < \eta < 2$

arXiv: 0801.2990

proton spin

Colliding beams
$A_N(x_F)$ for Forward $\pi^0$ Production

STAR: Sub. to PRL, hep-ex/0801.2990

\[ p+p \rightarrow \pi^0 + X \text{ at } \sqrt{s} = 200 \text{ GeV} \]

**Left:** Calculations based on phenomenological fits to SIDIS data account for $x_F$ dependence

**Right:** Sivers mechanism based calculations require $A_N$ to decrease with $p_T$. This trend is not what is observed.


Selected STAR Heavy Ion Results
Search for Mach Cone

with Three Particle Correlations

**STAR**

Nu Xu  
BNL PAC, May 8-9, 2008

$d+Au$

$$\cos \Theta^{\text{Mach}} = \sqrt{p/\varepsilon}$$

"Evidence of conical emission …"
Open Charm and $J/\psi \ R_{AA}(p_T)$

Heavy flavor hadrons freeze-out earlier than light flavor ($u,d,s$) hadrons

STAR Preliminary:

The Cu+Cu data consistent with no suppression at high $p_T$:

$R_{AA}(p_T > 5 \text{ GeV/c}) = 0.9 \pm 0.2$

- Low-$p_T$ $R_{AA} \sim 0.5-0.6$ (PHENIX)

- Most models expect $R_{AA}$ to decrease at high $p_T$. 
Extending to Higher Mass: $\Upsilon$

Sequential dissociation of quarkonia is sensitive to energy density of plasma

$\Upsilon (1S+2S+3S) \rightarrow e^+e^-$

Run 6: 200 GeV p+p

Run 7: 200 GeV Au+Au

STAR high $p_T$ topological electron trigger works!
Bottom Decay Electron Study

- EMC trigger + SSD+SVT vertex cuts: high energy electrons from Bottom

- In the future: HFT will provide a much more powerful tool for studying heavy flavor hadrons
Results from Run 8
Run 8: d-Au and Polarized p+p

**MinBias usable Events**

- Goal = 30 Mevts
- Recorded 46 Mevts
- 153% of goal

**Integrated FMS FOM (nb^{-1})**

- Goal 3.8 pb^{-1}
- Sampled 1.6 pb^{-1}
- 43% of goal

**FMS Integrated Luminosity**

- Goal = 30 (60) nb^{-1}
- Sampled 48 pb^{-1}
- 160 (80)% of goal

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I. d+Au run: **Success!**

II. Polarized p+p run:

1. FMS CGC reference data: **Good**
2. Forward A_N (x_F, p_T): **Short of what we had intended to achieve**
3. Forward direct photon asymmetries: **Not enough**
4. Electrons from Charm and Bottom, with low material, to resolve STAR/PHENIX discrepancy: **Good**
Forward Meson Spectrometer (FMS)

2.5 \leq \eta \leq 4, \ 0.2 \leq x_F \leq 0.25

476 \times 3.8\text{-}cm\ cells, \ 788 \times 5.8\text{-}cm\ cells

\text{p+p, } \sqrt{s} = 200 \text{ GeV}

\chi^2/\text{ndf} \ 48.16 \ / \ 39

\begin{align*}
A &= 31.15 \pm 3.378 \\
M_\psi &= 3.157 \pm 0.2653 \times 10^{-1} \\
& \quad \pm 0.3133 \times 10^{-1} \\
B_1 &= -157.9 \pm 3.907 \\
B_2 &= 17.62 \pm 1.254 \\
& \quad \pm 0.2262
\end{align*}

Fit data to

\[M = A \exp(-\frac{(M-M_\psi)^2}{2\sigma^2}) + B_1 + B_2 M + B_3 M^2\]

FMS: calibration in progress

Nu Xu

BNL PAC, May 8-9, 2008
Low Energy Test Run (9 GeV)

1) \( \sim 3500 \) collisions collected
2) Gain understanding of triggering issues
3) Determine Luminosity: rate \( \sim 0.6 \) Hz at 9 GeV
4) STAR studying the following:
   Particle identification in TPC; total charged multiplicity
   \( \pi - \pi \) interferometry, particle ratios; \( v_1 \) and \( v_2 \)
5) Physics ready with 2 - 4 Hz collisions
Ready for Physics at Energy Scan

PID will be significantly extended using TOF
STAR Upgrades
STAR Detector

MRPC ToF barrel
Ready for run 10

RPSD

FPD

PMD

DAQ1000
Ready for run 9

MTD

EMC barrel

EMC End Cap

FMS

Complete
Ongoing
R&D

TPC

HFT

FGT

Nu Xu  BNL PAC, May 8-9, 2008  21/38
Run 8 tests:
- One sector of the TPC (1/24) instrumented with DAQ1000 electronics
- Routine operation for physics.
- Speed test: operated at 1 kHz with only 5-7% dead time
- Full TPC will be instrumented before Run 9
Run 8 test:

- Five trays of ToF system installed, commissioned, and used for physics.
- Behind sector with DAQ1000 TPC electronics. Routine operation for physics.
- 90 (of 120) ToF trays to be installed for Run 9 and the full ToF (120) will be completed before Run 10.
## STAR Upgrade Timeline

<table>
<thead>
<tr>
<th>Upgrade</th>
<th>Completion</th>
<th>Key physics measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMS</td>
<td>Completed 2008</td>
<td>(a) Transverse asymmetry at forward rapidity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) CGC</td>
</tr>
<tr>
<td>TPC DAQ (DAQ1000)</td>
<td>Summer 2008 Ready for Run 09</td>
<td>Large data set, minimal dead time</td>
</tr>
<tr>
<td>MRPC TOF</td>
<td>Summer 2009 Full TOF ready for Run 10</td>
<td>Full PID in full azimuthal acceptance (90/120 trays will be used in Run 9) TOF capability is critical for the energy scan</td>
</tr>
<tr>
<td>FGT</td>
<td>Summer 2010 Ready for Run 11</td>
<td>Forward W² for flavor separated quark polarization</td>
</tr>
<tr>
<td>HFT</td>
<td>Summer 2011 Ready for Run 12</td>
<td>(a) Precision hadronic ID for Charm and Bottom hadrons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Charm and Bottom hadron energy loss and flow</td>
</tr>
</tbody>
</table>

1) Physics  
2) Upgrades - technically driven schedule  
3) Request for new measurements
The Frontiers of Nuclear Science

(I) Systematically study the partonic medium properties at RHIC

(II) Search for QCD critical point

(III) Study proton intrinsic structure

Run 9: 25 Cryo-week (scenario I)

STAR priorities for Runs 9 and 10:

(1) 200 GeV longitudinally polarized p+p - $\Delta g(x)$

(2) Beam energy scan down to $\sqrt{s_{\text{NN}}} \sim 5-6$ GeV

- Search for the QCD critical point

** C-AD transverse stochastic cooling test important!

<table>
<thead>
<tr>
<th>Run</th>
<th>Energy (GeV)</th>
<th>System</th>
<th>Time</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>$\sqrt{s} = 200$</td>
<td>p→ p→</td>
<td>12 week</td>
<td>50 pb$^{-1}$ P$^4$L 6.5 pb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s} = 500$</td>
<td>p↑p↑</td>
<td>2 week</td>
<td>Commissioning</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s} = 200$</td>
<td>p↑p↑</td>
<td>$\frac{1}{2}$ week</td>
<td>pp2pp</td>
</tr>
<tr>
<td>**</td>
<td>$\sqrt{s_{\text{NN}}} = 200$</td>
<td>Au + Au</td>
<td>3 week</td>
<td>0.3B minbias, 0.5 nb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s_{\text{NN}}} = 5$</td>
<td>Au + Au</td>
<td>$\frac{1}{2}$ week*</td>
<td>Commissioning</td>
</tr>
<tr>
<td>10</td>
<td>$\sqrt{s_{\text{NN}}} = 39 – 6.1$</td>
<td>Au + Au</td>
<td>14 week</td>
<td>1$^{\text{st}}$ energy scan</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s_{\text{NN}}} = 5$</td>
<td>Au + Au</td>
<td>1 week</td>
<td>Commissioning</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s_{\text{NN}}} = 200$</td>
<td>Au + Au</td>
<td>2 week</td>
<td>200M central</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s_{\text{NN}}} = 200$</td>
<td>Au + Au</td>
<td>1 week</td>
<td>50M central</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s} = 200$</td>
<td>p→ p→</td>
<td>$\frac{1}{2}$ week</td>
<td>pp2pp</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s} = 500$ or 200</td>
<td>p↑p↑ or p↓ p↓</td>
<td>4 $\frac{1}{2}$ week</td>
<td>Spin studies</td>
</tr>
</tbody>
</table>
# Run 9: 16 Cryo-week (scenario II)

<table>
<thead>
<tr>
<th>Run</th>
<th>Energy (GeV)</th>
<th>System</th>
<th>Time</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>√s = 200</td>
<td>p→p→</td>
<td>11 weeks</td>
<td>50 pb⁻¹, P⁴L 6.5 pb⁻¹</td>
</tr>
<tr>
<td></td>
<td>√s = 200</td>
<td>p↑p↑</td>
<td>½ week*</td>
<td>pp2pp</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Run</th>
<th>√s = 200</th>
<th>√s = 200</th>
<th>√s = 200</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>√sNN = 39 – 6.1</td>
<td>√sNN = 5</td>
<td>**√sNN = 200</td>
<td>√s = 500</td>
</tr>
<tr>
<td></td>
<td>Au + Au</td>
<td>Au + Au</td>
<td>Au + Au</td>
<td>p↑p↑ or p↓ p↓</td>
</tr>
<tr>
<td></td>
<td>12 weeks</td>
<td>1 week</td>
<td>3½ weeks</td>
<td>5 weeks</td>
</tr>
<tr>
<td></td>
<td>1st energy scan</td>
<td>Commissioning</td>
<td>0.5B events, 0.5 nb⁻¹</td>
<td>Commissioning</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50M central</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pp2pp</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

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**STAR priorities for Runs 9 and 10:**

1. 200 GeV longitudinally polarized p+p - \( \Delta g(x) \)
2. Beam energy scan down to \( √s_{NN} \sim 5-6 \text{ GeV} \) - *Search for the QCD critical point*

** C-AD transverse stochastic cooling test important!
Global Fits with Inclusive RHIC Data

Goals for taking: Run 9 ~ 16* Run 6

**Run 9:** STAR bottom line is to collect FoM: 6.5 pb$^{-1}$

*inclusive jet, di-jets, γ-jet… analysis*

de Florian et al, arXiv: 0804.0422
Di-jet Sensitivity in Run 9

- Di-jets provide **direct access** to $\Delta g(x)$ in leading order
- Full NLO asymmetry calculations for di-jets are similar to LO estimates
- Sensitivity is shown for $\text{FoM} = P^4L = 6.5 \text{ pb}^{-1}$
- Significant discrimination amongst allowed models

Significant contributions at 200 GeV from quark-gluon scattering with highly polarized quarks.
Search for QCD Critical Point

STAR Beam Use Request FY10

<table>
<thead>
<tr>
<th>$\sqrt{s_{NN}}$ [GeV]</th>
<th>$\mu_B$ [MeV]</th>
<th>Rate [Hz]</th>
<th>Goal [Events]</th>
<th>Duration [Days]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>550</td>
<td>0.5</td>
<td>0.5</td>
<td>7</td>
</tr>
<tr>
<td>6.1</td>
<td>491</td>
<td>1.4</td>
<td>1 M</td>
<td>20</td>
</tr>
<tr>
<td>7.7</td>
<td>410</td>
<td>2.7</td>
<td>2 M</td>
<td>20</td>
</tr>
<tr>
<td>8.6</td>
<td>385</td>
<td>4</td>
<td>2 M</td>
<td>15</td>
</tr>
<tr>
<td>12.3</td>
<td>300</td>
<td>10</td>
<td>5 M</td>
<td>15</td>
</tr>
<tr>
<td>17.3</td>
<td>229</td>
<td>25</td>
<td>10 M</td>
<td>12</td>
</tr>
<tr>
<td>27</td>
<td>151</td>
<td>30</td>
<td>10 M</td>
<td>7</td>
</tr>
<tr>
<td>39</td>
<td>112</td>
<td>50</td>
<td>10 M</td>
<td>6</td>
</tr>
</tbody>
</table>

Key measurements:

1. All PID hadron spectra and $v_2$
2. $K/\pi$, $<p_T>$ ... fluctuations

Strategy:

1. From high to low energy, disappearance of high energy density phenomena (controlled experiment)
2. Cover SPS range $\sqrt{s_{NN}} = 5 - 20$ GeV, look for the onset of de-confinement
Observables and Advantages

Advantages at STAR:
- Large acceptance: full azimuthal coverage and $|y| < 1.0$
- Clean particle identification: (TPC, ToF, EMC)
- Acceptance does not change with beam energy, systematic errors under control
- High potential for discovery
Tagged Forward Protons

Elastic and Inelastic Processes

In terms of QCD, Pomeron exchange consists of the exchange of a color singlet combination of gluons. Hence, triggering on forward protons at high (RHIC) energies predominantly selects exchanges mediated by *gluonic matter*.

Elastic Scattering: Roman Pots only

Single Diffraction: RP + FMS or RP + BBC

For each proton vertex one has

\[ t = \text{four-momentum transfer} \]

\[ \xi = \frac{\Delta p}{p} - \text{proton momentum loss} \]

\[ M_X = \text{invariant mass} \]

Central Production: RP + ToF; Tracks in the TPC *full azimuthal acceptance*
Roman Pots (RP) were installed East and West of STAR (Phase I);
pp2pp integrated into trigger and DAQ;
Inserted pots into the beam pipe during last 2 hours of Run 8 (pp):
- Triggered on elastic and inelastic coincidences in pp2pp RP
- No impact on background levels in STAR mid-rapidity detectors

Phase II: Install RP between DX-D0 magnets, allowing to trigger on forward protons with standard tune, hence taking data with STAR without need for dedicated time.
pp2pp Plan for Runs 9 and/or 10

A dedicated 1/2 -1 week run, including setup of \( \beta^* = 20 \text{m} \) optics, and about 30 hrs of data taking will produce:

1. Elastic scattering:
   - 100% acceptance for elastic scattering for 0.003 < \(|t|\) < 0.024;
   - \(40 \times 10^6\) elastic events: \(\Delta b = 0.31 \text{ (GeV/c)}^2\), \(\Delta \rho = 0.01\), \(\Delta \sigma_{\text{tot}} = 2-3 \text{ mb}\);
   - In eight \(t\) subintervals we shall have \(\sim 5 \times 10^6\) events in each resulting in corresponding errors \(\delta A_n = 0.0017\), \(\delta A_{nn} = \delta A_{ss} = 0.003\).

2. DPE process: (luminosity \(2 \times 10^{29} \text{ cm}^{-2}\text{sec}^{-1}\))
   - About \(1 \cdot 10^6\) events with the proton tag on each side, proton in either pot;
   - \(3 \cdot 10^5\) DPE events with fully reconstructed proton momentum.
## Runs 11 - 13 (30 cryo-week/yr)

<table>
<thead>
<tr>
<th>Run</th>
<th>Energy (GeV)</th>
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<th>Time</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>$\sqrt{s} = 200$</td>
<td>$p_\uparrow p_\uparrow$ or $p_\uparrow p_-$</td>
<td>6 week</td>
<td>20-30 pb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s} = 500$</td>
<td>$p_\uparrow p_\uparrow$ or $p_\uparrow p_-$</td>
<td>15 week</td>
<td>150 pb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s_{NN}} = 200$</td>
<td>$U + U$</td>
<td>2 week</td>
<td>Commissioning</td>
</tr>
<tr>
<td>12</td>
<td>$\sqrt{s_{NN}} = 200$</td>
<td>$Au + Au$</td>
<td>12 week</td>
<td>0.5B minbias, 5 nb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s_{NN}} = 39 - 5$</td>
<td>$Au + Au$</td>
<td>13 week</td>
<td>2nd energy scan</td>
</tr>
<tr>
<td>13</td>
<td>$\sqrt{s} = 200$</td>
<td>$p_\uparrow p_\uparrow$ or $p_\uparrow p_-$</td>
<td>13 week</td>
<td>2B minbias, 100 pb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s} = 500$</td>
<td>$p_\uparrow p_\uparrow$ or $p_\uparrow p_-$</td>
<td>12 week</td>
<td>300 pb$^{-1}$</td>
</tr>
</tbody>
</table>

Run 11: (i) 1st measurement of flavor dependence of sea q/anti-q polarization in the proton at $\sqrt{s} = 500$ GeV $p+p$ collisions
(ii) HFT engineering prototyping in $\sqrt{s_{NN}} = 200$ GeV $U+U$ collisions

Run 12: **Anticipating RHIC-II high luminosity**
(i) 1st HFT physics measurements of charm hadron $v_2(p_T)$ and $R_{CP}(p_T)$ in $\sqrt{s_{NN}} = 200$ GeV $Au+Au$ collisions
(ii) Focused energy-scan in the search for the QCD critical point. Prior accelerator development is crucial at $\sqrt{s_{NN}} = 5-6$ GeV
(iii) gamma-jet and quarkonia states measurements

Run 13: (i) HFT physics reference measurement of charm hadron spectra in $\sqrt{s} = 200$ GeV $pp$ collisions; complete remaining $\sqrt{s} = 200$ GeV spin milestones.
(ii) Measurement of the x dependence of W production at $\sqrt{s} = 500$ GeV

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Nu Xu  
BNL PAC, May 8-9, 2008
Future Physics Goals

Heavy Flavor

W± Physics
L=300 pb⁻¹, pol.~ 70%

Plan to be accomplished
In Runs 11-13
(1) 200 GeV longitudinally polarized p+p
   - $\Delta g(x)$

(2) Beam energy scan down to $\sqrt{s_{NN}} \sim 5$-6 GeV
   - Search for the QCD critical point

(3) Top energy high statistics Au+Au data set and transverse stochastic cooling test

(4) 500 GeV p+p collision

(5) pp2pp program
Summary

- Without high stat. 200 GeV $p \Rightarrow +p$, we won’t know $\Delta g(x)$
- Without energy scan to 5 GeV, we won’t find the QCD critical point

**STAR at the QCD Lab:**

- Unique physics program
- National priorities
- Must be done in a timely fashion