STAR Multi-Year Beam Use Request For Runs:

VI & VII

VII

VIII (& IX)

Tim Hallman for the STAR Collaboration

Brookhaven National Laboratory
November 3, 2005
Philosophy Behind the STAR BUR

To allocate beam time to measurements that will provide qualitatively new insights into the properties of

- the nucleon
- the nucleus
- dense QCD matter

Specifically:

Run VI  
Place a world-class constraint on gluon polarization in the proton, $\Delta g$
Delineate the roles of parton orbital motion/transversity in creating the transverse single spin asymmetry ($A_N$) observed for inclusive forward $\pi^0$ production
First significant measurement of Sivers effect asymmetry in di-jet production

Run VII  
Decisive test of existence of the Color Glass Condensate in relativistic heavy nuclei
Detailed mapping of the $x$ dependence of gluon polarization in the proton, $\Delta g(x)$

Run VIII  
Precision tests of the properties of quark-gluon matter
# The STAR 3 year Beam Use Request

<table>
<thead>
<tr>
<th>Run</th>
<th>Energy</th>
<th>System</th>
<th>Goal</th>
</tr>
</thead>
</table>
| VI  | $\sqrt{s} = 200$ GeV  
$\sqrt{s} = 200$ GeV  
$\sqrt{s_{NN}} = 19.6, 31$ GeV | $p \uparrow p \uparrow$  
$p \rightarrow p \rightarrow$  
Au + Au | 10 pb\(^{-1}\) sampled  
20 pb\(^{-1}\) sampled  
1 + 1 weeks*  
(10M + 10M evts) |
| VII | $\sqrt{s_{NN}} = 200$ GeV  
$\sqrt{s} = 200$ GeV | $d + Au$  
$p \rightarrow p \rightarrow$ | 11 weeks  
10 weeks |
| VIII| $\sqrt{s_{NN}} = 200$ GeV  
$\sqrt{s} = 200$ GeV | Au + Au  
$p \rightarrow p \rightarrow$ | 15 weeks  
6 weeks |

The philosophy: focus on qualitative, rather than only quantitative steps forward as the machine and detector capability afford these to maximize the scientific impact and discovery potential in the next 3 years.
The Physics Driving Run VI

• What is the gluon contribution to the proton spin?
• What is the role of orbital motion in the structure of the proton?
• What is the role of transversity in the proton?

Measurements at RHIC in Run VI which address these questions can result in a sea change in our understanding of the spin structure of the proton.

All the pieces in STAR and RHIC necessary to accomplish this are in place now; international competition (COMPASS) makes this timely.

No extraordinary assumptions about machine capability beyond what C-AD has projected or already achieved are necessary.
What is the gluon contribution to the proton spin: $A_{LL}$ (preliminary) results in inclusive jet production in p+p collisions at $\sqrt{s}=200\text{GeV}$

Run VI $A_{LL}$ for incl. jets: FOM $\sim 10 \ (2)$ high $E_T$ (low $E_T$) x 3 (2) (detector improvements) $\sim 30$

Run VI $A_{LL}$ for inclusive $\pi^0$ s in BEMC: FOM $\sim 10 \times 4$ (detector improvements) $\sim 40$ overall
The role of orbital motion in the structure of the proton

First measurement of $A_N$ for forward $\pi^0$ production at $\sqrt{s}=200\text{GeV}$

Similar to FNAL E704 result at $\sqrt{s} = 20 \text{ GeV}$

In agreement with several models including different dynamics:

- Sivers: spin and $k_\perp$ correlation in initial state (related to orbital angular momentum?)
- Collins: Transversity distribution function & spin-dependent fragmentation function
- Qiu and Sterman (initial-state) / Koike (final-state) twist-3 pQCD calculations
New Detection Capability in Run VI for Transverse Studies

Larger acceptance of FPD++ brings:

- **Direct Photon capability**
  
  - No fragmentation ⇒ if asym. observed it must come from Sivers

- **Multi particle correlations**
  
  - If Jet asymmetry observed then there must be a Sivers contribution
  
  - Ability to look inside Jet for signatures of Collins fragmentation

- **Increased phase space in \( X_F \) and \( p_t \)**
  
  - Study \( p_t \) dependence to confirm whether or not this is a pQCD process (i.e. \( A_N \) drops as \( 1/p_t \))
A qualitative advance in understanding the role of orbital motion in the structure of the proton

Statistical error projection for $A_N$ for inclusive $\pi^0$ production as function of $p_T$ at fixed $x_F$ during Run 6, together with two theory predictions. These projections assume 10 pb$^{-1}$ with 50% polarization and the acceptance of the FPD++. 

Hallman, BNL PAC, 11/3/2005
The role of transverse spin dynamics in the proton

Back-to-back di-jet production: access to gluon Sivers function

- Search for spin-dependent transverse motion preferences inside proton (related to parton $L_{\text{orbit}}$) via predicted spin-dependent deviation (not power-suppressed) from back-to-back alignment of di-jet axes ⇒ study unique to RHIC spin: Access Sivers function

$p p \to \text{di-jet} + X$

$\sqrt{s} = 200 \text{ GeV}$
**Quality Factors for Run VI Longitudinal Studies**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Increase from FOM</th>
<th>Increase from Detector Improvements</th>
<th>Increase from Trigger Improvements</th>
<th>Bottom Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{LL}$ of jets</td>
<td>x 10 at high $E_T$ (x 2 at low $E_T$) compared to Run 5</td>
<td>x 3 at high $E_T$ (x 2 at low $E_T$) due to completion of the BEMC</td>
<td></td>
<td>First measurement to distinguish between favored models of gluon polarization</td>
</tr>
<tr>
<td>$A_{LL}$ of $\pi^0$ in the EEMC</td>
<td>x 10 compared to Run 5</td>
<td>x 1.3 from shielding in tunnel; x 2 from fast detector data</td>
<td></td>
<td>Significant enrichment at low pT from L2 trigger</td>
</tr>
<tr>
<td>$A_{LL}$ of $\pi^0$ in the BEMC</td>
<td>x 10 compared to Run 5</td>
<td>x 2 from completion of BEMC; x 2 from fast detector data</td>
<td></td>
<td>Meaningful measurements in multiple channels</td>
</tr>
<tr>
<td>$A_{LL}$ of di-jets</td>
<td>x 10 at high $E_T$ (x 2 at low $E_T$) compared to Run 5</td>
<td>x 9 at high $E_T$ (x 3 at low $E_T$) due to completion of the BEMC</td>
<td></td>
<td>First measurement that is sensitive to x dependence of $\Delta G/G$</td>
</tr>
<tr>
<td>$A_{LL}$ of direct photons at mid-rapidity</td>
<td>x 10 compared to Run 5</td>
<td>x 1.5 from completion of BEMC</td>
<td></td>
<td>Increased efficiency near threshold from L2 trigger</td>
</tr>
<tr>
<td>$A_{LL}$ of direct photons at forward rapidity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma$+jet coincidences</td>
<td></td>
<td>FPD++ will allow isolation cuts for the first time</td>
<td></td>
<td></td>
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# Quality Factors for Run VI Transverse Studies

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<tbody>
<tr>
<td>$A_N$ of $\pi^0$ at forward rapidity</td>
<td>x 20 compared to previous measurements</td>
<td>FPD++ acceptance ~9 times that of the FPD</td>
<td></td>
<td>Are we seeing quark orbital motion and/or transversity?</td>
</tr>
<tr>
<td>$A_N$ of direct photons at forward rapidity</td>
<td></td>
<td>FPD++ will allow isolation cuts for the first time</td>
<td></td>
<td>100K direct photons for 10 pb$^{-1}$ Direct measure of the quark Sivers function</td>
</tr>
<tr>
<td>$A_N$ for jets at forward rapidity and asymmetry of forward jets about thrust axis</td>
<td></td>
<td>FPD++ will encompass the jet cone for the first time</td>
<td></td>
<td>Direct sensitivities to the Sivers ($jet A_N$) vs. Collins (jet anisotropy) effects</td>
</tr>
<tr>
<td>$A_N$ for back-to-back di-jet opening angle</td>
<td></td>
<td>x 4 when compared to previous sensitivity estimates due to di-jet selection by L2 trigger</td>
<td></td>
<td>Measure gluon Sivers function</td>
</tr>
</tbody>
</table>
The Physics Driving Run VII

• Is the Color Glass Condensate present in nuclei at small $x_{\text{BJ}}$? (if so, where does it set in?)

• What is the $x$ dependence of the gluon polarization in the proton?

Measurements at RHIC in Run VII which address these questions can result in a sea change in our understanding of the initial state of RHIC collisions.

The STAR Forward Meson Spectrometer (FMS) will be in place by Run VII; international competition and interest (LHC startup) makes this timely.

(Forward hadron production at RHIC samples similar $x$ values as mid-rapidity production at the LHC).

No extraordinary assumptions about machine capability beyond what C-AD has projected or already achieved are necessary.
Mid-rapidity vs. forward rapidity

Gluon density can’t grow forever. Saturation may set in at forward rapidity when gluons start to overlap.

Hallman, BNL PAC, 11/3/2005
Expectations for a Color Glass Condensate

\[ \tau \text{ related to rapidity of produced hadrons.} \]

\[ \tau_s(k_\perp) \]

Iancu and Venugopalan, hep-ph/0303204

Is there evidence for gluon saturation at RHIC energies?

D. Kharzeev, hep-ph/0307037
Observe significant rapidity dependence, similar to BRAHMS measurements and expectations from saturation framework.
Correlations, a more sensitive test; any difference between p+p and d+Au?

p+p: **Di-jet**

d+Au: **Mono-jet?**

Kharzeev, Levin, McLerran gives physics picture (NP A748, 627)

Color glass condensate predicts that the back-to-back correlation from p+p should be suppressed
An initial glimpse: correlations in d+Au

• suppressed at small $<x_F>$ and $<p_{T,\pi}>$

$S_{pp} - S_{dAu} = (9.0 \pm 1.5) \%$

consistent with CGC picture

• are consistent in d+Au and p+p at larger $<x_F>$ and $<p_{T,\pi}>$

as expected by HIJING
STAR Forward Meson Spectrometer upgrade

- FMS increases areal coverage of forward EMC from 0.2 m² to 4 m²
- Addition of FMS to STAR provides nearly continuous EMC from -1<η<+4
p+p and d+Au → π^0+π^0+X correlations with forward π^0

Conventional shadowing will change yield, but not coincidence structure. Coherent effects such as CGC evolution will change the structure. Sensitive to $x_g \sim 10^{-3}$ in pQCD scenario; few $x 10^{-4}$ in CGC scenario.
STAR Sensitivity to $\Delta G$

STAR's wide acceptance = Coincident detection of $\gamma$ and away-side jet direction

Determination of initial-state partonic kinematics.

$\Delta G (Q^2) = \int_0^1 \Delta G(x, Q^2) \, dx$

Hallman, BNL PAC, 11/3/2005
The Physics Driving Return to AuAu (Run VIII & IX)

• What are the relative yields of charm and bottom?
• What is “really going on” at intermediate $p_T$?
• What will PID’d correlations reveal?
• What will higher precision for short wavelength probes tell us?

The STAR DAQ upgrade, and half of the TOF Barrel planned to be available for in Run VIII. Full TOF barrel and prototype heavy flavor tracker planned to be available in Run IX. These upgrades will provide a qualitative advance in STAR detector capability for heavy ion studies.
New Electron Identification Capability in STAR: MRPC ToF

Electron identification:
TOFr $|1/\beta - 1| < 0.03$
TPC dE/dx electrons!!!

Extending STAR Particle ID

Methods paper submitted to NIM A, nucl-ex/0505026.
Results to 12 GeV in Au+Au

- **TPC:**
  - Pion: 0.0\sim0.6\text{GeV/c}
  - Kaon: 0.2\sim0.6\text{GeV/c}
  - Proton: 0.2\sim1\text{GeV/c}

- **TOF:**
  - Pion: 0.2\sim1.6\text{GeV/c}
  - Kaon: 0.2\sim1.6\text{GeV/c}
  - Proton: 0.2\sim3\text{GeV/c}

- **TPC+TOF:**
  - Pion: 0.\sim10\text{GeV/c}
  - Kaon: 0.2\sim3\text{GeV/c}
  - Proton: 0.2\sim?\text{GeV/c}
DAQ – TPC Readout Upgrade

- Acquisition of very large data samples for precision and rare process studies: e.g., symmetry restoration/breaking, $\gamma \gamma$ HBT, …
- Space for end cap tracker for W physics

Make use of CERN developments for ALICE/LHC:
- PASA (preamp/shaper amp)
- ALTRO (digitizer, digital filter, zero suppression, buffer)
- SIU (RDO, optical data sender)
- D-RORC (PCI receiver board)

Goal: Increase data rate for most detectors to $\geq 1$kHz
Dead time reduced to zero for triggered data sets
Triggered and untriggered data acquired without DAQ bandwidth constraint
Measurements with upgraded capability in RUN VIII

Upgrades in place: DAQ1000, Half-barrel TOF

- DAQ1000: untriggered AND triggered at same time
  - 15 weeks: ~900 ub⁻¹ sampled AND few x 100M minbias events
- Significant capabilities brought by large-acceptance TOF
  - Identified particle correlations in the intermediate $p_T$ regime
  - Dileptons: Significant (~10 $\sigma$) signal in $\phi \to e^+e^-$
  - Initial survey (statistical) measurement of $D^0 \to K + \pi$ to 4-5 GeV/c
Upgraded Detector Capability in Run VIII

Two (3) particle correlations at intermediate $p_T$

Constituent-quark-scaled $v_2$ at intermediate $p_T$

Two particle correlations at low $p_T$

Further examples of the types of measurements which will make a major advance with the combination of upgraded PID capability and increased DAQ throughput in Run VIII
A central question: the relative yield of c and b

The observed suppression of NPEs is not presently understood!
Attempts to reproduce it have completely changed the paradigm for the energy loss of light and heavy quarks

Armesto et al, private comm.

Resolving this is a crucial next step
Further measurements of NPEs alone won’t solve the problem

The low end

The high end

The relative yield of charm and bottom is highly uncertain

The collisional and radiative energy loss for the two is predicted to be different

The charm spectra must be measured directly to untangle the two contributions

(Bears on the interpretation of the suppression for light quarks as well)
An enabling technology for event-by-event charm measurement

in STAR: the Heavy Flavor Tracker

- Heavy flavor collectivity
- Charm quark kinetic equilibration
- Heavy flavor (c,b) energy loss
- Vector mesons $\rightarrow e^+e^-$

Two layers of CMOS pixel detector around a new thin (0.5mm) small radius (14 mm) beam pipe

- $10^8$ pixels, $(30 \ \mu m)^2$
- 50 $\mu$m thick
- 10 $\mu$m point resolution

Significant progress on:

- Simulations
- Mechanical design
  - integration and installation
  - support
  - alignment
  - calibration
- Sensor prototype
- Readout design
**D Measurements with HFT: Run IX**

Simulated statistical uncertainties from 50M central Au+Au events w/ HFT

\[ D^0 \to K + \pi \]

- \( D^0 \to K + \pi \) direct reconstruction becomes extremely clean
- Event-by-event identification of charm
- Identified suppression, flow, correlations with no ambiguity from semi-leptonic decay and bottom contributions

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Hallman, BNL PAC, 11/3/2005
Taking upgrade strategy into account is central to optimizing the plan

STAR will make much, much more effective utilization of AuAu beams in the 2008-2009 timeframe once several key upgrades have come on-line
Future STAR physics prospects
STAR tracking upgrade: conceptual layout

- APS pixel detector
- Heavy Flavor Tracker (HFT)
- Inner Silicon Tracker (IST)
- Forward Silicon Tracker (FST)
- Forward triple-GEM Tracker (FGT)

Hallman, BNL PAC, 11/3/2005
Conclusions

• The STAR Collaboration strongly believes the proposed plan will provide for qualitative advances in our understanding of the nucleon, the nucleus, and dense QCD matter in a way that make maximal use of RHIC beams and STAR/RHIC capability as it evolves.

• STAR maintains this is an optimal plan for maximizing the scientific impact and discovery potential in the next 3 years.
The STAR Collaboration: 51 Institutions, 14 countries, ~ 550 People

U.S. Labs:
- Argonne, Berkeley, and Brookhaven National Labs

U.S. Universities:
- UC Berkeley, UC Davis, UCLA, Caltech, Carnegie Mellon, Creighton, Indiana, Kent State, MSU, CCNY, Ohio State, Penn State, Purdue, Rice, Texas A&M, UT Austin, Washington, Wayne State, Valparaiso, Yale, MIT

Brazil:
- Universidade de Sao Paolo

China:
- IHEP - Beijing, IPP - Wuhan, USTC, Tsinghua, SINR, IMP Lanzhou

Croatia:
- Zagreb University

Czech Republic:
- Institute of Nuclear Physics

England:
- University of Birmingham

France:
- Institut de Recherches Subatomiques Strasbourg, SUBATECH – Nantes

Germany:
- Max Planck Institute – Munich University of Frankfurt

India:
- Bhubaneswar, Jammu, IIT-Mumbai, Panjab, Rajasthan, VECC

Poland:
- Warsaw University of Technology

Russia:
- MEPHI – Moscow, LPP/LHE JINR – Dubna, IHEP – Protvino

South Korea:
- Pusan National University

Switzerland:
- University of Bern

STAR is a vital, growing, international collaboration
## Science productivity of the STAR Collaboration

<table>
<thead>
<tr>
<th>Published:</th>
<th>Papers</th>
<th>Spires</th>
<th>Citebase</th>
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<td>PRL</td>
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<tbody>
<tr>
<td></td>
<td>5</td>
<td>37</td>
<td>38</td>
</tr>
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</table>

Thus far, 74 advanced degrees awarded on STAR work:

- **56** Ph.D.’s
- **11** Master’s
- **7** Diploma
What could STAR get from run 6 Au+Au?

Achieved run 4 with 25 $\text{ub}^{-1}$ sampled (additional 25 $\text{ub}^{-1}$ still being analyzed)

- Total sampled luminosity from run 4 on tape: $\sim$50 $\text{ub}^{-1}$
- Run 6: $\sim$400 $\text{ub}^{-1}$ if devote 10 weeks completely to triggered data
  - Lose completely untriggered dataset (including D)
  - Increased reach in $\gamma$-h, non-photonic electrons
    - Some progress towards separating direct $\gamma$-h signal from $\pi^0$ $\gamma$-h
    - No separation of bottom from charm contribution in non-photonic electrons
  - Effective signal in Upsilon: few hundred particles

No Upsilon signal, Upper limit

$\gamma$-h, $E_T > 10 \text{ GeV/c}$, $p_T^{\text{assoc}} > 4 \text{ GeV/c}$

Non-photonic electron $R_{AA}$