STAR Physics Program

STAR Beam Use Request for Runs 12, 13

Nu Xu
for the STAR Collaboration
STAR Detectors  *Fast and Full* azimuthal particle identification

EMC+EEMC+FMS  
(-1 \leq \eta \leq 4)
STAR Physics Focus

Polarized $p+p$ program
- Study *proton intrinsic properties*

Forward program
- Study low-$x$ properties, search for **CGC**
- Study elastic (inelastic) processes ($pp2pp$)
- Investigate *gluonic exchanges*

1) At 200 GeV top energy
- Study *medium properties, EoS*
- pQCD in hot and dense medium

2) RHIC beam energy scan
- Search for the *QCD critical point*
- Chiral symmetry restoration
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**Run 12:** 26 cryo-week. 500pp: 50% polarization

**Run 13:** 30 cryo-week. 500pp: 50% polarization // 200pp: 60-65% polarization
Selected Results

1) 200 GeV results

2) Beam Energy Scan results

3) Spin Physics results
Particle Identification at STAR (TPC + TOF + HLT)

- Clean Identification: TPC and ToF

\[ m^2 = p^2 \left( \frac{1}{\beta^2} - 1 \right) \]

- China-US: Time of Flight (ToF) Detector

- High Level Trigger

Nature (2011) DOI: doi:10.1038/nature10079 || STAR Experiment
Received 14 March 2011 | Accepted 04 April 2011 | Published online 24 April 2011
Light Nuclei Production at RHIC

- Production rate reduces by a factor of $1.6 \times 10^{-3} (1.1 \times 10^{-3})$ for each additional antinucleon added to the antinucleus (nucleus).


Received 14 March 2011 | Accepted 04 April 2011 | Published online 24 April 2011
Antimatter Discoveries by STAR at RHIC

"Observation of the Antimatter Helium-4 Nucleus"
by STAR Collaboration

"Observation of an Antimatter Hypernucleus"
by STAR Collaboration
Science, 328, 58(2010).
$v_2$ of $J/\psi$ vs. $p_T$

1) STAR: TPC + TOF + HLT
2) $v_2^{J/\psi}(p_T) \sim 0$ up to $p_T = 8$ GeV/c in 200 GeV Au+Au collisions
3) Either $c$-quarks do not flow or coalescence is not the dominant process for $J/\psi$ production at RHIC.
1) STAR Triggered

2) In central collisions, \( \Upsilon(1S+2S+3S) \) is suppressed, 3\( \sigma \) away from \( R_{AA} = 1! \)

3) \( R_{AA} (0-60\%) = 0.56 \pm 0.11 \) (stat) + 0.02 - 0.14 (sys)
\( R_{AA} (0-10\%) = 0.34 \pm 0.17 \) (stat) + 0.06/-0.07 (sys)

\*QM2011 flash talk

\( \sqrt{s_{NN}} = 200 \text{ GeV} \) Au+Au collisions
1) Direct radiation, penetrating-bulk probe, **new to STAR**!
2) Beam energy, $p_T$, centrality, mass dependence (8-10x more events):
   $R_{AA}$, $v_2$, radial expansion, HBT, polarization, ...
3) HFT/MTD upgrades: key for the correlated charm contributions.
STAR Di-electron Program

\( \sqrt{s_{NN}} = 39 \, \text{GeV} \) Au+Au MinBias

With the large acceptance and low material, STAR beam energy scan program:

\( \sqrt{s_{NN}} = 27, 39, 62.4, 200 \, \text{GeV} \) Au+Au Collisions
RHIC Beam Energy Scan

(Phase-I)
Motivations:
Signals of phase boundary
Signals for critical point

Observations:
(1) $v_2$ - NCQ scaling:
partonic vs. hadronic dof
(2) Dynamical correlations:
partonic vs. hadronic dof
(3) Azimuthally HBT:
1st order phase transition
(4) Fluctuations:
Critical points
(5) Directed flow $v_1$
1st order phase transition

- arXiv:1007.2613
1) Fluctuations in particle ratios are sensitive to particle numbers at chemical FO not kinetic FO; the volume effects may cancel.

*S. Jeon, V. Koch, PRL 83, 5435 (1999)*

2) Apparent differences (results with Kaons) with SPS when $\sqrt{s_{NN}} < 12$ GeV.
Higher Moments of Net-protons

1) STAR results* on net-proton high moments for Au +Au collisions at $\sqrt{s_{NN}} = 200, 62.4$ and $19.6$ GeV.

2) Sensitive to critical point**: 
   \[ \langle (\delta N)^2 \rangle \approx \xi^2, \quad \langle (\delta N)^3 \rangle \approx \xi^{4.5}, \quad \langle (\delta N)^4 \rangle \approx \xi^7 \]

3) Direct comparison with Lattice results**: 

4) Extract susceptibilities and freeze-out temperature. An independent test on thermal equilibrium in HI collisions.

5) 17M good events at 19.6GeV collected in Run 11.

6) Run12 request: 27 GeV Au+Au collisions!

** M. Stephanov: PRL,102, 032301(09).
Search for Local Parity Violation in High Energy Nuclear Collisions

The separation between the same-charge and opposite-charge correlations.

- Strong external EM field
- De-confinement and Chiral symmetry restoration

\[ \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle \]

Parity even observable

Voloshin, PR C62, 044901(00).

STAR; PRL 103, 251601(09); 0909.1717 (PRC).

\[ \cos \phi \]

\[ \alpha \]

\[ \beta \]

\[ \Psi \]

\[ \text{Parity even observable} \]
LPV vs. Beam Energy

1) Difference between same- and opposite-sign correlations decreases as beam energy decreases
2) Same sign charge correlations become positive at 7.7 GeV
3) Several different approaches in the collaboration
Systematic Results on Collectivity

\[ \sqrt{s_{\text{NN}}} = 200 \text{ GeV Collisions at RHIC} \]

**STAR:**
- *PRL* 92, 052302(04)
- *PRL* 95, 122301(05)
- *PRC* 77, 54901(08)
- *PRC* 81, 44902(10)

**Results:**
1. Partonic collectivity at RHIC
2. Number of constituent quark scaling – partonic degrees of freedom at play

\[ \Rightarrow \text{Run 12 request: UU collisions test the hydro limit, LPV, …} \]
1) $v_2 (\text{baryon}) > v_2 (\text{anti-baryon})$; $v_2 (\pi^+) < v_2 (\pi^-)$ at 7.7 GeV

2) Run 12 request: 27 GeV Au+Au collisions
φ meson $v_2$ falls off the scaling trend from other hadrons at 11.5 GeV.
Azimuthally Sensitive HBT vs. $\sqrt{s_{NN}}$

Freeze-out eccentricity w.r.t react plane:
$\left( R_y^2 - R_x^2 \right) / \left( R_y^2 + R_x^2 \right) = 2 R_{s,2}^2 / R_{s,0}^2$

1) Non-monotonic variation in freeze-out eccentricity vs. beam energy
2) UrQMD (and hydro) model does not reproduce the dip by CERES.

<table>
<thead>
<tr>
<th>Expt</th>
<th>$\sqrt{s_{NN}}$ (GeV)</th>
<th>Centrality</th>
<th>$\eta$</th>
<th>Event Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGS/E895</td>
<td>2.35,3.0, 3.6</td>
<td>7.4 - 29.7</td>
<td>+/- 0.6</td>
<td>1st order</td>
</tr>
<tr>
<td>SPS/CERES</td>
<td>17.3</td>
<td>7.5 - 25</td>
<td>-1.0 - 0.5</td>
<td>2nd order</td>
</tr>
<tr>
<td>RHIC/STAR</td>
<td>7.7, 11.5, 39, 62.4 200</td>
<td>5 - 30</td>
<td>+/- 0.5</td>
<td>2nd order</td>
</tr>
</tbody>
</table>
Spin Physics Results
Quark Flavor Measurements: $W^\pm$

1) STAR first results* consistent with models: Universality of the helicity distribution functions!
2) Precision measurements require **large luminosity** and **high polarization** at RHIC!

2009 STAR $A_{LL}$ measurements:
- Results fall between predictions from DSSV and GRSV-STD
- Precision sufficient to merit finer binning in pseudorapidity
• For fixed $M$, different kinematic regions sample different $x$ ranges
  – East-east and west-west sample higher $x_1$, lower $x_2$, and smaller $|\cos(\theta^*)|$ 
  – East-west samples lower $x_1$, higher $x_2$, and larger $|\cos(\theta^*)|$ 
• $A_{LL}$ falls between DSSV and GRSV-STD
Run 12 will provide a very useful complement to Run 9.
During Run 13, we can further reduce the 200 GeV uncertainties compared to Run 9 by:
- A factor of ~2 for jet $p_T >\sim 12$ GeV
- A factor of $\sim\sqrt{2}$ for jet $p_T <\sim 12$ GeV
Projected Sensitivity at 500 GeV

Assumes 600 pb\(^{-1}\) delivered @ P = 50%

\[ x_1, x_2 = \frac{M}{\sqrt{s}} \exp \left( \pm \frac{\eta_3 + \eta_4}{2} \right) \]

- Higher energy accesses lower \(x_g\)
- Expect smaller \(A_{LL}\)
- Projections include information on trigger rates, etc., from 2009
- Uncertainties shown are purely statistical
- Maybe add EEMC-EEMC di-jets to reach lowest \(x\) values once FGT is installed (?)
Run 11 Status

U+U Collisions
Run11: Integrated Luminosities

1) 500 GeV transverse p+p collisions
   - FMS, small-x

2) 19.6 GeV Au+Au collisions
   - critical point search

3) 200 GeV Au+Au collisions
   - di-electron and Upsilon
Run 12 Request U+U Collisions

1) Significant increase in energy density for hydrodynamic studies
2) Prolate shape: path-length dependence of $E_{\text{loss}}$ at much higher density

Run 12 request: 200M MB and 200M central U+U collisions.
Left plot: **Black**: \(<\epsilon_{\text{part}}\) as a function of measured mid-rapidity multiplicity in the most 1% central U+U collisions, as selected by the number of participants. **Red**: estimated uncertainties on \(v_2\{AA-pp\}\) for \(p_T = 4\) GeV/c for such events, as selected with the ZDCs.

Right plot*: \(v_2\) and external B-field vs. mid-y multiplicity. Greater sensitivity seen in U+U central collisions for \(dN_{\text{ch}}/d\eta > 1000\).

* S. Voloshin, PRL105, 172301(2010).
FGT Status

STAR Future Upgrades

eSTAR Task Force
Forward GEM Tracker

1) FGT: RHIC CP project
2) Six light-weight triple-GEM disks
3) New mechanical support structure
4) Planned installation: Summer 2011

1) Full charge-sign discrimination at high-\( p_T \)
2) Design polarization performance of \( 70\% \) or better to collect at least 300pb\(^{-1}\)
3) Ready\(^*\) for Run 12!

\(^*\) minimal configuration
FGT Quadrant

- FGT Quarter section Layout

- GEM layers (1-3) 2mm apart! No spacer!

- Pressure volume

- HV board

- 2D readout board

- Interconnect board

- HV layer

- Readout module

- Terminator board
FGT Quadrant Problems and Solutions

- Quarter section fully assembled and operational (Cosmic-ray signal / 55Fe signal) without spacer grid:

P1: GEM foils cannot be stretched sufficiently to guarantee that GEM foils separated by 2mm. Original design to avoid efficiency loss.

- Solution: Need for a spacer grid. Order has been placed and expect full quarter section assembly including spacer grid by mid of June.

P2: GEM foil frames are part of HV distribution. The distance between HV lines and metallic pins are ~1mm / Difficulty in holding full HV (~4kV).

- Solution: Need for non-metallic pins providing sufficient strength / Likely G10 in addition to stretching bars
I. Minimal configuration

1) Full FGT: 24 quarter sections / 6 disks (4 quarter sections per disk)
2) Minimal configuration: 4 disks with 3 quarter sections each, i.e. 50% of full FGT system (24 quarter sections)
3) 4 disks, i.e. 4 space points are required for proper charge-sign discrimination

II. Schedule (draft)

1) July-September 2011: Quarter section assembly and testing
2) September 2011: Disk assembly and WSC integration
3) October 2011: Integration of ESC / WSC / Beam pipe
4) November 2011: Installation in STAR

Request RHIC cool down: January 1, 2012
in order to install as many FGT disks as possible
# STAR Upgrade Timeline

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<tr>
<th>Upgrade</th>
<th>Completion</th>
<th>Key Physics Measurements</th>
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<td>FMS</td>
<td>Completed 2008</td>
<td>(a) Trans. Asymmetry at forward-y ( W^{\pm} ) for flavor separated quark polarization</td>
</tr>
<tr>
<td>TPC DAQ1000</td>
<td>Completed 2009</td>
<td>Minimal dead time, large data set</td>
</tr>
<tr>
<td>MRPC TOF</td>
<td>Completed 2010</td>
<td>Fast PID in full azimuthal acceptance</td>
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<tr>
<td>FGT</td>
<td>Summer 2011</td>
<td>Forward-y ( W^{\pm} ) for flavor separated quark polarization</td>
</tr>
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<td></td>
<td>Ready* for Run 12</td>
<td></td>
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<tr>
<td>HFT</td>
<td>Summer 2013</td>
<td>(a) Precision hadronic ID for charm and Bottom hadrons</td>
</tr>
<tr>
<td></td>
<td>Ready for Run 14</td>
<td>(b) Charm and Bottom hadron energy loss and flow</td>
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<td>MTD</td>
<td>Summer 2013</td>
<td>(a) High ( p_T ) muon trigger</td>
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<td>(b) Quarkonia states</td>
</tr>
<tr>
<td>pp2pp’</td>
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<td></td>
</tr>
<tr>
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* Minimal configuration
1) Identify heavy flavor hadron directly
2) Precision measurement HF hadron energy loss and collectivity
3) Run 13: PXL sectors will be ready
STAR: Muon Telescope Detector

Muon Telescope Detector (MTD) at STAR:

1) MRPC technology; $\mu_\varepsilon \sim 36\%$; cover $\sim 45\%$ azimuthally and $|y| < 0.5$
2) TPC+TOF+MTD: muon/hadron enhancement factor $\sim 10^{2-3}$
3) For high $p_T$ muon trigger, heavy quarkonia, light vector mesons, $B \rightarrow J/\Psi + X$
4) China-India-STAR collaboration: approved by DOE and China + India
5) Run 13: 50% MTD will be ready
eSTAR Task Force

Membership: Subhasis Chattopadhyay, Hank Crawford, Renee Fatemi, Carl Gargliardi*, Jeong-Hun Lee, Bill Llope, Ernst Sichtermann, Huan Huang, Thomas Ullrich, Flemming Videbaek, Anselm Vossen, Wei Xie, Qinghua Xu, Zhangbu Xu

Ex-officio: B. Christie, J. Dunlop, O. Evdokimov, B. Mohanty, B. Surrow, N. Xu

Charges: In order to prepare the experiment to complement the ongoing physics programs related to AA, pA and pp collisions with a strong ep and eA program by an additional electron beam and prepare the collaboration to participate in the US Nuclear Physics Long Range Planning exercises during 2012-2013, we establish the eSTAR Task Force. This task force will be in function during the next three years. The main charges for the task force are:

(1) Identify important physics measurements and assess their science impact during the eSTAR era (2017-2020). Prepare a white paper or an updated decadal plan including physics sensitivities and detailed R&D projects.
(2) With (1) in mind as well as the eRHIC interaction region design(s) and other constraints, identify and advise STAR Management on priorities for detector R&D projects within the collaboration.
(3) Engage the collaboration by organizing special ep/eA workshops, document the progress and report annually to the collaboration.
(4) Work with the STAR management and the EIC task force (setup by the BNL management) to strengthen the physics case(s) for eSTAR and a future EIC
Summary

STAR has been very effective and productive:

1) TOF, HLT, DAQ1k upgrades successfully completed

2) 200 GeV Au+Au collisions
   - Large acceptance di-electron program started
   - Upsilon suppression vs. centrality and high statistics J/ψ ν₂
   - Full jets reconstruction program presses on
   - … anti-⁴He, …

3) Beam Energy Scan
   - Systematic analysis of Au+Au collisions at 7.7/11.5/19.6/39/62.4GeV:
     $\sqrt{s_{NN}} \geq 39$ GeV: partonic // $\sqrt{s_{NN}} \leq 11.5$ GeV: hadronic

4) Spin Physics
   - First W± Aₐ analysis published
   - di-jet AₐLL analysis

5) High statistics, high quality data have been collected
   - pp 500 GeV FMS and low material Au+Au 200 GeV
1) Spin Physics (polarized p+p collisions)
   - $W^\pm A_L$ at both mid-y and forward-y (2012/2013)
   - DPE and hadronic spin-flip amplitude (2012)
   - $\Delta g$ measurements at 500 GeV (2012) and 200 GeV* (2013)
   * Reference data for heavy ion programs

2) Heavy Ion Physics (A+A collisions)
   - Complete the Phase-I RHIC BES at 27 GeV (2012)
   - U+U collisions: hydro limit, LPV, path length dep. (2012)
   - Engineering run for HFT & MTD in Au+Au(Pb+Pb) (2013)

3) Start of Run12: January 1, 2012
## STAR BUR for Runs 12 and 13

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