Status and Physics Opportunities of STAR Heavy Flavor Tracker and Muon Telescope Detector Upgrades

Qiu Hao (LBNL) for the STAR Collaboration
Outline

• STAR detector overview
• New physics direction for STAR heavy ion program
• **Heavy Flavor Tracker** and **Muon Telescope Detector**
  • Physics motivation
  • Design
  • Status and performance
• RHIC run plan
• Summary
STAR Detector Overview

- Tracking & dE/dx: Time Projection Chamber
- Particle ID: Time Of Flight detector
- Electromagnetic Calorimetry: Barrel EMC + Endcap EMC + Forward Meson Spectrometer (-1 \leq \eta \leq 4)
- Muon Telescope Detector (runs 13/14)
- Heavy Flavor Tracker (run 14)
- Forward GEM Tracker (runs 12/13)

- Full azimuthal particle identification at middle rapidity

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New Physics Direction for STAR Heavy Ion Program

- Heavy flavor
  - $m_{b,c} \gg T_C, \Lambda_{QCD}, m_{u,d,s}$
  - Early produce
  - Conserve in total number
  - Less influenced
  - Good probe to QGP

- Thermal di-lepton
  - QGP signal
  - Probing the temperature of the medium
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HFT Physics Motivation

• HFT can be used to study heavy flavor production by the measurement of displaced vertices
  • \( D^0 \rightarrow K^- \pi^+ \)
    • \( BR = 3.83 \% \quad ct \sim 120 \, \mu m \)
  • \( \Lambda_c^+ \rightarrow p K^- \pi^+ \)
    • \( BR = 5.0 \% \quad ct \sim 60 \, \mu m \)
  • B mesons \( \rightarrow J/\psi + X \) or \( e + X \)
    • \( ct \sim 500 \, \mu m \)

• Total charm yield base line for charmonium suppression & coalescence
• \( R_{CP}, R_{AA} \) of charm and bottom energy loss in QGP
• Charm (\( D^0 \)) flow thermalization?
• \( \overline{c}c \ ( D^0 \overline{D^0} ) \) angular correlation interaction with the medium
• \( \Lambda_c^+ / D^0 \) test coalescence model

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Charm Yield, $R_{CP}$ and $R_{AA}$

- Total charm yield: base line for charmonium suppression & coalescence
- $R_{CP}$, $R_{AA}$: energy loss mechanism, QCD in dense medium

Charm Yield, $R_{CP}$ and $R_{AA}$

- Large combinatorial background using primary tracks to reconstruct $D^0$
- Much better S/B ratio with displaced vertex from HFT
Charm Yield, $R_{CP}$ and $R_{AA}$

- Much better precision with HFT than current STAR measurement
- Low radiation length enable reconstruction of $D^0$ with $p_T$ starting from 0, enabling charm total cross section measurement.

STAR projection with HFT


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Charm Yield, $R_{CP}$ and $R_{AA}$

- Probe possible different medium property with different collision energy.
- Low radiation length enable reconstruction of $D^0$ with $p_T$ starting from 0, enabling charm total cross section measurement.
Charm Flow

- Charm collectivity

- $D^0 v_2$ is a more direct measurement of charm flow than non-photonic electron $v_2$.
- With HFT STAR is able to measure $D^0 v_2$ at low $p_T$ region, which is sensitive to charm flow.
Charm Flow

• Charm collectivity

• Measurements at both LHC and RHIC will explore the change of media properties with energy.

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J/ψ from B meson

- Measured before through J/ψ-hadron correlation
  - only in pp collisions
  - large errors
- with HFT can be measured by displace vertex
- with MTD can also be measured through μ⁺μ⁻ channel
HFT Design

<table>
<thead>
<tr>
<th>Sub detector</th>
<th>r (cm)</th>
<th>Sensitive units</th>
<th>$\sigma_{R\phi}$ ($\mu$m)</th>
<th>$\sigma_z$ ($\mu$m)</th>
<th>$X/X_0$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Strip Detector</td>
<td>22</td>
<td>2 side strips with 95 $\mu$m pitch</td>
<td>20</td>
<td>740</td>
<td>1</td>
</tr>
<tr>
<td>Intermediate Silicon Tracker</td>
<td>14</td>
<td>600 $\mu$m x 0.6 cm strips</td>
<td>170</td>
<td>1800</td>
<td>&lt;1.5</td>
</tr>
<tr>
<td>PIXEL</td>
<td>2.5/8</td>
<td>18 $\mu$m pixel pitch</td>
<td>12</td>
<td>12</td>
<td>0.4/layer</td>
</tr>
</tbody>
</table>

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HFT Status

- Engineering run for PXL prototype (3 out of 10 sectors) finished
  - installed on May 8, 2013
    - within 12 hours
  - first PXL data in daq file on May 10
  - 78 M events taken with PXL
- full system to be installed in 2014

PXL prototype insertion

SSD part

IST ladder

PXL prototype half

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PXL Performance

- 2D correlation between measured pxl hit and TPC track projection on a sensor

- Double difference of hit and track projection positions between 2 overlapping sensors

- Single sensor resolution = \( \frac{20}{\sqrt{2}} \approx 14 \) microns

\(~ 12 \) microns resolution of designed goal

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MTD Physics Motivation

- di-muon pairs from
  - QGP thermal radiation
  - quarkonia
  - light vector mesons
  - Drell-Yan production

- single muons from
  - heavy flavor hadrons

- advantages over electrons:
  - no $\gamma$ conversion
  - much less Dalitz decay contribution
  - less affected by radiative losses in the detector materials
  - trigger capability in Au+Au
Different Y states


- Sequential suppression of different Y states can be used as a QGP thermometer
- Di-muon channel is less affected by bremsstrahlung energy losses, enabling separating different Y states.
Sequential suppression of different $\Upsilon$ states can be used as a QGP thermometer.

- Di-muon channel is less affected by bremsstrahlung energy losses, enabling separating different $\Upsilon$ states.

e-µ Correlation


- e-µ correlation
- $c\bar{c}$ correlation
- charm interaction with the medium
- subtract $c\bar{c}$ contribution from di-lepton
- Thermal production
- medium thermometer

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J/$\psi$ $R_{AA}$ and Flow

- $R_{AA}$ & $v_2$ → J/$\psi$ production mechanism & charm flow
- $\mu^+\mu^-$ channel
  - Trigger capability for low $p_T$ J/$\psi$
  - lower background

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MTD Design

- Multi-gap Resistive Plate Chamber (MRPC):
  - gas detector, avalanche mode
  - use the magnet iron bars as absorber and leave the gaps in-between uncovered
  - Acceptance: 45% at $|\eta|<0.5$
  - 118 modules, 1416 readout strips, 2832 readout channels
- Long-MRPC detector technology
- electronics same as used in STAR-TOF

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MTD Status

We are installed

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<table>
<thead>
<tr>
<th>Proposed</th>
<th>Actual</th>
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<tbody>
<tr>
<td>10% installation for 2012</td>
<td>10% installation for 2012</td>
</tr>
<tr>
<td>43% for 2013</td>
<td>63% for 2013</td>
</tr>
<tr>
<td>80% for Run 14</td>
<td>100% for 2014</td>
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<tr>
<td>Finish 2014</td>
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</table>
MTD Performance

- MTD hit – TPC track projection correlation
- Time resolution measured with cosmic data: 96 ps

Run 12

Intrinsic space resolution 2.6 cm
J/ψ from Di-muon Trigger

- J/ψ from Di-muon Trigger with only 7 M events, out of 120 M in total from Run 13.
- without time calibration, which will further suppress background
<table>
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<tr>
<th>Run</th>
<th>Energy</th>
<th>Time</th>
<th>System</th>
<th>Goal</th>
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<tr>
<td>14(^{(1)})</td>
<td>$\sqrt{S_{NN}}=200\text{GeV}$</td>
<td>14-week</td>
<td>Au+Au</td>
<td>HFT &amp; MTD heavy flavor measurements, $\mathcal{L}=10\text{ nb}^{-1}$, 1000M M.B.</td>
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</table>
|      | $\sqrt{S_{NN}}=15\text{GeV}$ | 3-week  | Au+Au  | 1) Collect 150M M.B. events for CP search  
2) Fixed-target data taking\(^{(3)}\) |
| 15\(^{(2)}\) | $\sqrt{S_{NN}}=200\text{GeV}$ | 5-week  | p+Au   | Study saturation physics, pA-ridge and heavy ion reference, $\mathcal{L}=300\text{ nb}^{-1}$ |
|      | $\sqrt{s}=200\text{GeV}$ | 12-week | 1) p+p  | 1) Heavy ion reference data $\mathcal{L}=90\text{ pb}^{-1}$, 500M M.B.  
2) transverse 6 weeks  
3) longitudinal 6 weeks |
|      |         |         | 2) Study transversity, Sivers effects $\mathcal{L}=40\text{ pb}^{-1}$, 60% pol. |
|      |         |         | 3) Study $\Delta g(x)$ $\mathcal{L}=50\text{ pb}^{-1}$, 60% pol. |

- STAR Beam User Request, endorsed by RHIC PAC.
- Focus on 200 GeV AA, pA, and pp collisions for heavy ion programs with new upgrades.
RHIC Run Plan

- HF-I: Charm
  - Di-lepton
  - sQGP properties

- QCD phase structure
  - Critical Point

- HF-II: B, Λc
  - Jet, gamma
  - CNM, spin

- CNM, CGC
  - Phase structure with glue

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<tr>
<td>HF, (e.u)</td>
<td>BESII</td>
<td>HF’, p.A</td>
<td>eSTAR</td>
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- HFT/MTD
  - e-Cooling, iTPC

- HFT’, Tracking, EM/HCAL (West side)

- EMCAL (East side)

physics

upgrade
Summary

- STAR is conducting two major upgrades for heavy ion program:
  - HFT for heavy flavor measurements
  - MTD for muon detection
- These upgrades will enable or enhance a rich set of physics programs:
  - open and closed heavy flavor measurements, a clear probe to the QGP phase
  - thermal radiation, QGP thermometer
- The combination of HFT and MTD, together with the existing mid-rapidity subsystems, will make STAR the best suited detector to carry out the mission of studying the hot QCD matter properties.
- Construction of both detectors are going well
  - technical run for PXL prototype just finished successfully
  - 63 % of MTD installed, with desirable performance
- Both detectors will be finished for Run 14.
- New physics results with them will greatly enhance our understanding of QGP created at RHIC.

Qiu Hao (LBNL)
Thank you 😊