Highlights of the Highlights from STAR at QM 2008

Helen Caines - Yale University

BNL QM 2008 Overview Symposium
Feb. 27th-29th 2008

Unashamedly derived from talks of B. Mohanty and T. Hallman
What we knew after QM2006

We make the hottest, densest matter yet examined in the laboratory

- Highly opaque to colored probes but not to photons
- Flows as a relativistic quantum liquid with minimal shear viscosity
- Particle formation via valence quark coalescence

Away-side correlation shape modified
Enhance correlation in $\Delta \eta$ on the near-side - The “Ridge”
At high $p_T$ di-jets re-emerge
Heavy quarks are also suppressed
<table>
<thead>
<tr>
<th>Medium properties</th>
<th>Physical phenomenon</th>
<th>Experimental probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density</td>
<td>Parton $E_{\text{loss}}$ in the medium</td>
<td>High $p_T$ particles, $\Delta \phi$ and $\Delta \eta$ correlations</td>
</tr>
<tr>
<td>Velocity of sound</td>
<td>Mach cones</td>
<td>3-particle correlations</td>
</tr>
<tr>
<td>Partonic interactions, Mechanism of $E_{\text{loss}}$</td>
<td>Non-Abelian features of QCD - Color factor effects, path length effects of $E_{\text{loss}}$ Jet-medium coupling</td>
<td>High $p_T$ particle production $\Delta \phi$ and $\Delta \eta$ correlations, correlations with respect to reaction plane</td>
</tr>
<tr>
<td>Collectivity and Thermalization</td>
<td>Partonic collectivity, viscosity and interactions</td>
<td>Azimuthal correlations and fluctuations</td>
</tr>
<tr>
<td>Medium effect on particle production</td>
<td>Parton recombination, modified fragmentation, yield enhancement/suppression</td>
<td>Identified particles – especially heavy flavor</td>
</tr>
<tr>
<td>Initial state and hadronization effects</td>
<td>Fluctuations and correlations</td>
<td>Changes as a function of centrality or $\sqrt{s}$</td>
</tr>
</tbody>
</table>
Outline – What we’ve been looking at since

<table>
<thead>
<tr>
<th>Medium properties</th>
<th>Physical phenomenon</th>
<th>Experimental probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density</td>
<td>Parton $E_{\text{loss}}$ in the medium</td>
<td>High $p_T$ particles, $\Delta \phi$ and $\Delta \eta$ correlations</td>
</tr>
<tr>
<td>Velocity of sound</td>
<td>Mach cones</td>
<td>3-particle correlations</td>
</tr>
<tr>
<td>Partonic interactions, Mechanism of $E_{\text{loss}}$</td>
<td>Non-Abelian features of QCD - Color factor effects, path length effects of $E_{\text{loss}}$</td>
<td>High $p_T$ production $\Delta \phi$ and $\Delta \eta$ correlations, correlations with respect to reaction plane</td>
</tr>
<tr>
<td>Collectivity and Thermalization</td>
<td>Partonic collectivity, viscosity and interactions</td>
<td>Azimuthal correlations and fluctuations</td>
</tr>
<tr>
<td>Medium effect on particle production</td>
<td>Parton recombination, modified fragmentation, yield enhancement/suppression</td>
<td>Identified particles – especially heavy flavour</td>
</tr>
<tr>
<td>Initial state and hadronization effects</td>
<td>Fluctuations and correlations</td>
<td>Changes as a function of centrality or $\sqrt{s}$</td>
</tr>
</tbody>
</table>
Away-side di-hadron fragmentation functions

- Denser medium in central Au+Au than central Cu+Cu
- Similar medium for similar $N_{\text{part}}$
- Vacuum fragmentation after parton $E_{\text{loss}}$ in the medium

---


$6 < p_{T,\text{trig}} < 10$ GeV

---

- Inconsistent with Parton Quenching Model calculation
- Modified fragmentation model better
Towards true jet reconstruction

- Reduce leading trigger particle biases from di-hadron correlations
- First step to jet reconstruction in A+A

Multi-hadron trigger

Associated track
Secondary

Use “cluster energy” as trigger:
- $R_{\text{cone}} = 0.3$
- $p_{T,\text{seed}} > 5$ GeV
- $p_{T,\text{sec seed}} > 3$ GeV

- Single-hadron trig. $\approx$ multi-hadron trig.
- Single high $p_T$ triggered correlations probe jet-like correlations

STAR Preliminary
0-12% Au+Au
Away-side spectrum

Cluster Triggers, $10 < p_T^{\text{trig}} < 12$ GeV/c
Di-hadron Analysis, $10 < p_T^{\text{trig}} < 12$ GeV/c
Cluster Triggers, $12 < p_T^{\text{trig}} < 15$ GeV/c
Di-hadron Analysis, $12 < p_T^{\text{trig}} < 15$ GeV/c
Golden Probe of QCD Energy Loss - $\gamma$-Jet

$\gamma$ emerges “unscathed” from medium

- Full reconstruction of kinematics: real fragmentation function ($D(z)$)

QCD analog of Compton Scattering
\(\gamma\)-hadron and \(\pi^0\)-hadron correlations

Shower shape in Shower Maximum Detector gives \(\gamma\)-, \(\pi^0\)-enriched samples

The \(\gamma\)-rich sample has lower near-side yield than \(\pi^0\).
First measure of away-side $I_{AA}$ for $\gamma$-h

Suppression similar level to inclusives in central collisions

\[ E_{jet} = E_\gamma = E_{trig} \]

\[ I_{AA} = \frac{D_{AA}(z_T, E_T^{trig})}{D_{pp}(z_T, E_T^{trig})} \]

Good agreement between theory and measurement for higher $p_{T,assoc}$

T. Renk and K. Eskola PRC75:054910,2007
## Outline – What we’ve been looking at since

<table>
<thead>
<tr>
<th>Medium properties</th>
<th>Physical phenomenon</th>
<th>Experimental probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density</td>
<td>Parton $E_{\text{loss}}$ in the medium</td>
<td>High $p_T$ particles, $\Delta \phi$ and $\Delta \eta$ correlations</td>
</tr>
<tr>
<td>Velocity of sound</td>
<td>Mach cones</td>
<td>3-particle correlations</td>
</tr>
<tr>
<td>Partonic interactions,</td>
<td>Non-Abelian features of QCD - Color factor effects,</td>
<td>High $p_T$ particle production $\Delta \phi$ and $\Delta \eta$ correlations, correlations with respect to reaction plane</td>
</tr>
<tr>
<td>Mechanism of $E_{\text{loss}}$</td>
<td>path length effects of $E_{\text{loss}}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jet-medium coupling</td>
<td></td>
</tr>
<tr>
<td>Collectivity and</td>
<td>Partonic collectivity, viscosity and interactions</td>
<td>Azimuthal correlations and fluctuations</td>
</tr>
<tr>
<td>Thermalization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium effect on</td>
<td>Parton recombination, yield enhancement/suppression,</td>
<td>Identified particles – especially heavy flavor</td>
</tr>
<tr>
<td>particle production</td>
<td>modified fragmentation</td>
<td></td>
</tr>
<tr>
<td>Initial state and</td>
<td>Fluctuations and correlations</td>
<td>Changes as a function of centrality or $\sqrt{s}$</td>
</tr>
<tr>
<td>hadronization effects</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Deflected jets or conical emission?

Au+Au data consistent with Conical emission

Conical emission in e-h correlations?

\[ \Delta \phi = \left( \Delta \phi_1 - \Delta \phi_2 \right)/2 \]

\[ \Delta \phi = \phi - \phi_{\text{Trig}} \]

\[ 3 < p_{\text{T(trig)}} < 4 \text{ GeV/c}, 1 < p_{\text{T(assoc)}} < 2 \text{ GeV/c} \]

Au+Au 0-12%

Conical emission in e-h correlations?

Au+Au 0-12%
Mach cone or Cerenkov gluons?

Angle predictions:

- **Mach-cone**: Angle independent of associated $p_T$
- **Cerenkov gluon radiation**: Angle decreases with associated $p_T$

Central Au+Au results consistent with Mach cone emission
Mach cone?

Naive calc. of time averaged velocity of sound in medium:

\[
\frac{c_s}{v_{\text{parton}}} = \cos(\theta_M), \quad v_{\text{parton}} = c
\]

Cone angle \(\sim 1.36\) radians

\[c_s = 0.2c\!\]

- In cumulant approach: no conclusive evidence for conical emission so far

- Strength and shape of away side structures observed depends on assumed magnitude of flow coefficients

\[
\Delta \phi
\]

\[
\Delta \phi
\]

\[
\Delta \phi
\]

\[
\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]

\[\Delta \phi
\]
## Outline – What we’ve been looking at since

<table>
<thead>
<tr>
<th>Medium properties</th>
<th>Physical phenomenon</th>
<th>Experimental probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density</td>
<td>Parton $E_{\text{loss}}$ in the medium</td>
<td>High $p_T$ particles, $\Delta \phi$ and $\Delta \eta$ correlations</td>
</tr>
<tr>
<td>Velocity of sound</td>
<td>Mach cones</td>
<td>3-particle correlations</td>
</tr>
<tr>
<td>Partonic interactions, Mechanism of $E_{\text{loss}}$</td>
<td>Non-Abelian features of QCD - Color factor effects, path length effects of $E_{\text{loss}}$ Jet-medium coupling</td>
<td>High $p_T$ particle production $\Delta \phi$ and $\Delta \eta$ correlations, correlations with respect to reaction plane</td>
</tr>
<tr>
<td>Collectivity and Thermalization</td>
<td>Partonic collectivity, viscosity and interactions</td>
<td>Azimuthal correlations and fluctuations</td>
</tr>
<tr>
<td>Medium effect on particle production</td>
<td>Parton recombination, yield enhancement/suppression, modified fragmentation</td>
<td>Identified particle yields – especially heavy flavor</td>
</tr>
<tr>
<td>Initial state and hadronization effects</td>
<td>Fluctuations and correlations</td>
<td>Changes as a function of centrality or $\sqrt{s}$</td>
</tr>
</tbody>
</table>
Is there a difference in $E_{\text{loss}}$ of $q$ and $g$?

**Mechanism of energy loss:** Medium induced gluon radiation

$$\langle \Delta E \rangle \sim \alpha_s C \langle \hat{q} \rangle L^2$$

**The Color Factor Effect**

\[
\frac{\Delta E_g}{\Delta E_q} \sim \frac{9}{4} 
\]

**Factor 9/4 Color effects not observed up to $p_T \sim 12$ GeV/c**

**Maybe just not sensitive!**

---

X.-N. Wang,
PRC 70 (2004) 031901

P. Fachini – Session V
The Ridge:

Long range $\Delta \eta$ correlations in A+A collisions.

Persists up to high $p_T$-trig.

Is this feature showing us how the energy lost by parton in the medium is distributed?
### Some possible ridge explanations

<table>
<thead>
<tr>
<th>QCD bremsstrahlung radiation boosted by transverse flow</th>
<th>In medium radiation and longitudinal flow push</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.Shuryak, hep-ph:0706.3531</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Broadening of quenched jets in turbulent color fields</th>
<th>Recombination between thermal and shower partons at intermediate $p_T$</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Momentum Kick Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.Y. Wong hep-ph:0712.3282</td>
</tr>
</tbody>
</table>

All qualitatively consistent with the features of ridge

New approaches used in to attempt to disentangle

- System size dependence
- Identified particle correlation
- Di-hadron correlation with respect to reaction plane
- 3-particle correlation
Centrality, system, $\sqrt{s}$ dependences

Ridge yield – increases with $N_{\text{part}}$
independent of colliding system, trigger species (not shown)
increases with $\sqrt{s}$

Ridge/Jet yield - increases with $N_{\text{part}}$
independent of $\sqrt{s}$

Different medium at different energies?
Di-hadrons correlated to event plane

Observations:
- 20-60%: away-side: from single-peak ($\phi_S = 0$) to double-peak ($\phi_S = 90^\circ$)
- Top 5%: double peak shows up at a smaller $\phi_S$
- At large $\phi_S$, little difference between two centrality bins

$3 < p_T^{\text{trig}} < 4 \text{ GeV/c}, \quad p_T^{\text{asso}} : 1.0 - 1.5 \text{ GeV/c}, \quad \sqrt{s_{NN}} = 200 \text{ GeV}$

STAR Preliminary
Path length effect on di-hadron correlations

In-plane: 20-60% ~ d+Au
0-5% > d+Au

Out-of-plane: 20-60% ~ 0-5%

Au+Au > d+Au

Away-side features reveal path length effects
Path length effect on ridge correlations

Observations:

Ridge: Decreases with $\varphi_S$
   - Little to no ridge at larger $\varphi_S$

Jet: Slight to no increases with $\varphi_S$
   - $\text{Au+Au }\sim \text{d+Au}$

Strong near-side jet-medium interaction when in reaction plane
   - generates sizable ridge

Minimal near-side jet-medium interaction when perp. to reaction plane
   - generates very little ridge

STAR Preliminary
Au+Au 200 GeV
20-60%

$3 < p_T^{\text{trig}} < 4 \text{ GeV/c, } p_T^{\text{asso}} : 1.0-1.5 \text{ GeV/c}$
Chemistry and $v_2$ associated with Jet and Ridge

Using **Identified associateds**

Jet:
\[ \Lambda/K^0_s \sim 0.5 < \text{inclusive} \]
\[ (\text{anti})p/\pi < \text{inclusive} \]

Ridge:
\[ \Lambda/K^0_s \sim 1 \sim \text{inclusive} \]
\[ (\text{anti})p/\pi \sim \text{inclusive} \]

Jet:
Inferred $v_2$ jet pair events < inclusive

Ridge:
Inferred $v_2$ ridge pair events ~ inclusive
Un-triggered pair correlations

**Au-Au fit function**

Use proton-proton fit function + $\cos(2\phi_{\Delta})$ quadrupole term ("flow"). This gives the *simplest possible* way to describe Au+Au data.

Small residual indicates goodness of fit

Fit residual = data - model

![Graphs showing residual distributions for different centrality classes](image-url)
Evolution of mini-jet with centrality

Same-side peak

83-94%

55-65%

46-55%

0-5%

$\Delta \nu$ width

Binary scaling reference followed until sharp transition at $\rho \sim 2.5$

$\sim$30% of the hadrons in central Au+Au participate in the same-side correlation

$\nu = \frac{\langle N_{\text{bin}} \rangle}{\langle N_{\text{part}} / 2 \rangle}$

Transverse particle density $\tilde{\rho} = \frac{3}{2} \frac{dN_{\text{ch}}}{d\eta}$
Di-jet triggered correlations

Observation of di-jets: punch through

Select di-jets events:

- **T1**: $p_T > 5\text{GeV}/c$
- **T2**: $p_T > 4\text{GeV}/c$
- **A1**: $p_T > 1.5\text{GeV}/c$

What happens to away-side hump and near-side ridge if we trigger on di-jets?
Di-jet triggered correlations

200 GeV Au+Au, 12% central

T2A1, T1

Δφ

Di-Jets don’t seem to interact with medium

No Away-side suppression, No shape modification, No ridge
<table>
<thead>
<tr>
<th>Medium properties</th>
<th>Physical phenomenon</th>
<th>Experimental probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density</td>
<td>Parton $E_{\text{loss}}$ in the medium</td>
<td>High $p_T$ particles, $\Delta \phi$ and $\Delta \eta$ correlations</td>
</tr>
<tr>
<td>Velocity of sound</td>
<td>Mach cones</td>
<td>3-particle correlations</td>
</tr>
<tr>
<td>Partonic interactions, Mechanism of $E_{\text{loss}}$</td>
<td>Non-Abelian features of\n QCD - Color factor effects,\n path length effects of $E_{\text{loss}}$\n Jet-medium coupling</td>
<td>High $p_T$ particle production\n $\Delta \phi$ and $\Delta \eta$ correlations,\n correlations with respect to reaction plane</td>
</tr>
<tr>
<td>Collectivity and Thermalization</td>
<td>Partonic collectivity, viscosity and interactions</td>
<td>Azimuthal correlations and fluctuations</td>
</tr>
<tr>
<td>Medium effect on particle production</td>
<td>Parton recombination, yield enhancement/suppression, modified fragmentation</td>
<td>Identified particle yields – especially heavy flavor</td>
</tr>
<tr>
<td>Initial state and hadronization effects</td>
<td>Fluctuations and correlations</td>
<td>Changes as a function of centrality or $\sqrt{s}$</td>
</tr>
</tbody>
</table>
Identified particle $v_2$

- $v_2$ precisely follows NCQ scaling for all centralities and all identified particles
- Suggests coalescence from a hot thermal bath
- Additional data for $\gamma$ at high $\eta$
- For different systems, common scaling with $\varepsilon$, both at forward- and mid-rapidity
- $v_2/\varepsilon$ increases with centrality
- $K^* v_2$ consistent with meson scaling
- Constrains level of regeneration
Initial conditions: Glauber or CGC?

$v_2$ fluctuations may provide some insight/constraints

$\sigma_{v_2}/\langle v_2 \rangle$ MC Glauber
- nucleon $\epsilon$ (standard)
- nucleon $\epsilon$ (part)
- confined quark $\epsilon$ (part)
- color glass (fKLN) $\epsilon$ (part)

\[
\left( \frac{\sigma_{v_2}}{\langle v_2 \rangle} \right)_{\text{meas.}} \approx \left( \frac{\sigma_{\epsilon}}{\langle \epsilon \rangle} \right)_{\text{calc.}}
\]

Confined quark MC:
- constituent quark participants
- decreases $\epsilon$ fluctuations

Color glass MC:
- includes effects of saturation
- increases the mean $\epsilon$

- Upper limit challenges models of initial eccentricity fluctuations
- Nucleon Glauber leaves no room for other fluctuations & correlations
- Data calls for different model of initial eccentricity (e.g. CGC)
Outline – What we’ve been looking at since

<table>
<thead>
<tr>
<th>Medium properties</th>
<th>Physical phenomenon</th>
<th>Experimental probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density</td>
<td>Parton $E_{\text{loss}}$ in the medium</td>
<td>High $p_T$ particles, $\Delta \phi$ and $\Delta \eta$ correlations</td>
</tr>
<tr>
<td>Velocity of sound</td>
<td>Mach cones</td>
<td>3-particle correlations</td>
</tr>
<tr>
<td>Partonic interactions, Mechanism of $E_{\text{loss}}$</td>
<td>Non-Abelian features of QCD - Color factor effects, path length effects of $E_{\text{loss}}$ Jet-medium coupling</td>
<td>High $p_T$ particle production $\Delta \phi$ and $\Delta \eta$ correlations, correlations with respect to reaction plane</td>
</tr>
<tr>
<td>Collectivity and Thermalization</td>
<td>Partonic collectivity, viscosity and interactions</td>
<td>Azimuthal correlations and fluctuations</td>
</tr>
<tr>
<td>Medium effect on particle production</td>
<td>Parton recombination, yield enhancement/suppression, modified fragmentation</td>
<td>Identified particle yields – especially heavy flavor</td>
</tr>
<tr>
<td>Initial state and hadronization effects</td>
<td>Fluctuations and correlations</td>
<td>Changes as a function of centrality or $\sqrt{s}$</td>
</tr>
</tbody>
</table>
At intermediate $p_T$, $\Omega$ (ss) and $\phi$ (s$\bar{s}$) should be dominated by bulk thermal quark coalescence – no jet contribution

(Hwa and Yang PRC 75, 054904 (2007))

Central Au+Au data agrees with model up to $p_T \sim 4$ GeV/c

Peripheral data pulls away earlier

Cu+Cu data agrees with Au+Au of same centrality NOT same $N_{part}$
Hidden charm: $R_{AA}$ J/$\Psi$

Provides means to investigate heavy quarkonium production mechanisms


$R_{AA}$ ($p_T < 4$ GeV/c): 0.5-0.6

$R_{AA}$ ($p_T > 5$ GeV/c): 0.9±0.2

consistent with no suppression

Many models expect a decrease in $R_{AA}$ as function of $p_T$

Next step the $\Upsilon$ - almost there

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

STAR Preliminary
J/Ψ – hadron correlations in p+p

1) \( g + g \rightarrow \chi + g \rightarrow J/\psi + \gamma \)
   no near side correlation

2) \( g + g \rightarrow b + \bar{b} \rightarrow B_{hadron} + X \rightarrow J/\psi + X \)
   strong near side correlation

Away side: consistent with leading charged hadron correlations

Near side: consistent with no associated hadron production

\( B \rightarrow J/\psi \) not a dominant contributor to inclusive J/ψ

No near side correlation seen!
The total charm cross-section

- Charm cross section scale with $N_{\text{bin}}$ collisions
- Multiple measurements in different channels all give the same result
Electron tagged correlations

- Experimental approach: non-photonic electrons from semi-leptonic charm decay are used to trigger on $c\bar{c}$, $b\bar{b}$ pairs - back-to-back $D_0$ mesons are reconstructed via their hadronic decay channel (probe)

- Underlying production mechanism can be identified using second charm particle

Heavy quark production

- Flavor creation: gluon splitting/fragmentation

- Essentially from $B$ decays only
  - $\approx 75\%$ from charm
  - $\approx 25\%$ from beauty

- $\Delta \phi \approx \pi$
Unraveling heavy quark production in p+p at $\sqrt{s} = 200$ GeV

In p+p collisions:

- The B contribution to non-photonic electrons is sizeable based on e-h and e-D correlations
- Gluon splitting contribution to charm is as expected (~6%)

Taken together with suppression of non-photonic electrons in Au+Au suggests significant suppression of non-photonic electrons from bottom in medium
## Outline – What we’ve been looking at since

<table>
<thead>
<tr>
<th>Medium properties</th>
<th>Physical phenomenon</th>
<th>Experimental probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density</td>
<td>Parton $E_{\text{loss}}$ in the medium</td>
<td>High $p_T$ particles, $\Delta\phi$ and $\Delta\eta$ correlations</td>
</tr>
<tr>
<td>Velocity of sound</td>
<td>Mach cones</td>
<td>3-particle correlations</td>
</tr>
<tr>
<td>Partonic interactions, Mechanism of $E_{\text{loss}}$</td>
<td>Non-Abelian features of QCD - Color factor effects, path length effects of $E_{\text{loss}}$ - Jet-medium coupling</td>
<td>High $p_T$ particle production $\Delta\phi$ and $\Delta\eta$ correlations, correlations with respect to reaction plane</td>
</tr>
<tr>
<td>Collectivity and Thermalization</td>
<td>Partonic collectivity, viscosity and interactions</td>
<td>Azimuthal correlations and fluctuations</td>
</tr>
<tr>
<td>Medium effect on particle production</td>
<td>Parton recombination, modified fragmentation, yield enhancement/suppression</td>
<td>Identified particles – especially heavy flavor</td>
</tr>
<tr>
<td>Initial state and hadronization effects</td>
<td>Fluctuations and correlations</td>
<td>Changes as a function of centrality or $\sqrt{s}$</td>
</tr>
</tbody>
</table>
Fluctuations and the Critical Point search

- 20 GeV data consistent with systematics observed at SPS

- Rise in fluctuations ($K\pi$ and $\gamma$-$h$) scale roughly with $dN/d\eta$ across energy and centrality – consistent with NA49

Ready for the Energy scan Critical point (and DCC) search
Large acceptance means can do a lot with small amount of data
Conclusions

Too much data to give a one slide summary

Taken as a whole STAR’s results make important steps towards in constraining models that try to explain:

• How partons interact with and lose energy in the medium
• How the medium changes with \( \sqrt{s} \), centrality and ion collided
• Where that energy goes
• How particles are created out of the medium
• What the initial conditions look like and how much they fluctuate
• How charm quarks are created and distributed among particles
• How much bottom is produced

RHIC on the threshold of new era of quantitative comparison between theory and experiment that will characterize the properties of the remarkable new matter discovered at here
# STAR presentations at QM2008

<table>
<thead>
<tr>
<th>Name</th>
<th>Session</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timothy Hallman</td>
<td>Plenary I</td>
<td>Recent Highlights from STAR</td>
</tr>
<tr>
<td>Bedanga Mohanty</td>
<td>Plenary III</td>
<td>Medium properties and response to highly energetic particles</td>
</tr>
<tr>
<td>Pawan Kumar Netrakanti</td>
<td>Plenary IV</td>
<td>The ridge via 3-particle $\Delta \eta$-$\Delta \eta$ correlations in STAR</td>
</tr>
<tr>
<td>Guoji Lin</td>
<td>Session I</td>
<td>First results on $\pi^0$ production over extended $p_T$ range</td>
</tr>
<tr>
<td>Yan Lu</td>
<td>Session III</td>
<td>System Size Dependence Of Strange Hadron Elliptic Flow</td>
</tr>
<tr>
<td>J. H. Chen</td>
<td>Session III</td>
<td>Energy and System Size Dependence of $\phi$-meson</td>
</tr>
<tr>
<td>Sadhana Dash</td>
<td>Session III</td>
<td>$K^+$ production in Cu+Cu and Au+Au collisions</td>
</tr>
<tr>
<td>Patricia Fachini</td>
<td>Session V</td>
<td>$\rho^0$ production at High-$p_T$ in Au+Au and p+p Collisions</td>
</tr>
<tr>
<td>Xiaobin Wang</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aooqi Feng</td>
<td>Session VIII</td>
<td>Away-side Modification and Near-side Ridge</td>
</tr>
<tr>
<td>Michael Daugherity</td>
<td>Session IX</td>
<td>Anomalous centrality variation of minijet correlations</td>
</tr>
<tr>
<td>Oana Catu</td>
<td>Session IX</td>
<td>System size dependence of jet-like di-hadron correlations</td>
</tr>
<tr>
<td>Olga Barannikova</td>
<td>Session IX</td>
<td>Back-to-back di-jet triggered multi-hadron correlations</td>
</tr>
<tr>
<td>Zubayer Ahammed</td>
<td>Session X</td>
<td>Energy and System Size dependence of $K/\pi$ Fluctuations at RHIC</td>
</tr>
<tr>
<td>Sunil Dogra</td>
<td>Session X</td>
<td>Correlation &amp; fluctuations between photons &amp; Charged particles</td>
</tr>
<tr>
<td>Rashmi Raniwala</td>
<td>Session XI</td>
<td>Elliptic Flow of Inclusive Photons in AuAu &amp; CuCu collisions at 200 GeV</td>
</tr>
<tr>
<td>Paul Sorensen</td>
<td>Session XII</td>
<td>Elliptic flow fluctuations and non-flow correlations measured by STAR</td>
</tr>
<tr>
<td>Christine Nattrass</td>
<td>Session XIII</td>
<td>System size dependence of di-hadron correlations</td>
</tr>
<tr>
<td>Gang Wang</td>
<td>Session XIII</td>
<td>Study of Conical Emission of Particles from Heavy Quark Energy Loss</td>
</tr>
<tr>
<td>Andre Mischke</td>
<td>Session XIV</td>
<td>Heavy-flavor correlations via electron correlations with open charm</td>
</tr>
<tr>
<td>Alexandre Shabetai</td>
<td>Session XIV</td>
<td>The Open Charm Cross-Section in $\sqrt{s_{NN}} = 200$ GeV Cu+Cu</td>
</tr>
<tr>
<td>Ahmed Hamed</td>
<td>Session XV</td>
<td>Probing the medium with $\gamma$-jet correlation measurements</td>
</tr>
<tr>
<td>Daniel Cebra</td>
<td>Session XVII</td>
<td>Charged Hadron Spectra in 19.6 GeV Au+Au collisions</td>
</tr>
<tr>
<td>Zebo Tang</td>
<td>Session XVII</td>
<td>High-$p_T$ J/Psi production in p+p and A+A collisions</td>
</tr>
<tr>
<td>Brijesh K. Srivastava</td>
<td>Session XIX</td>
<td>Long-range forward-backward multiplicity correlations</td>
</tr>
<tr>
<td>Debashish Das</td>
<td>Session XXII</td>
<td>Upsilon production in p+p and Au+Au collisions in STAR</td>
</tr>
<tr>
<td>Grazyna Odyniec</td>
<td>Session XXIV</td>
<td>The RHIC Energy Scan</td>
</tr>
</tbody>
</table>
Thanks to the whole STAR Collaboration

<table>
<thead>
<tr>
<th>Argonne National Laboratory</th>
<th>Moscow Engineering Physics Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institute of High Energy Physics - Beijing</td>
<td>City College of New York</td>
</tr>
<tr>
<td>University of Birmingham</td>
<td>NIKHEF and Utrecht University</td>
</tr>
<tr>
<td>Brookhaven National Laboratory</td>
<td>Ohio State University</td>
</tr>
<tr>
<td>University of California, Berkeley</td>
<td>Panjab University</td>
</tr>
<tr>
<td>University of California - Davis</td>
<td>Pennsylvania State University</td>
</tr>
<tr>
<td>University of California - Los Angeles</td>
<td>Institute of High Energy Physics - Protvino</td>
</tr>
<tr>
<td>Universidade Estadual de Campinas</td>
<td>Purdue University</td>
</tr>
<tr>
<td>Carnegie Mellon University</td>
<td>Pusan National University</td>
</tr>
<tr>
<td>University of Illinois at Chicago</td>
<td>University of Rajasthan</td>
</tr>
<tr>
<td>Creighton University</td>
<td>Rice University</td>
</tr>
<tr>
<td>Nuclear Physics Inst., Academy of Sciences</td>
<td>Instituto de Fisica da Universidade de Sao Paulo</td>
</tr>
<tr>
<td>Laboratory of High Energy Physics - Dubna</td>
<td>University of Science and Technology of China</td>
</tr>
<tr>
<td>Particle Physics Laboratory - Dubna</td>
<td>Shanghai Institute of Applied Physics</td>
</tr>
<tr>
<td>Institute of Physics, Bhubaneswar</td>
<td>SUBATECH</td>
</tr>
<tr>
<td>Indian Institute of Technology, Mumbai</td>
<td>Texas A&amp;M University</td>
</tr>
<tr>
<td>Indiana University Cyclotron Facility</td>
<td>University of Texas - Austin</td>
</tr>
<tr>
<td>Institut Pluridisciplinaire Hubert Curien</td>
<td>Tsinghua University</td>
</tr>
<tr>
<td>University of Jammu</td>
<td>Valparaiso University</td>
</tr>
<tr>
<td>Kent State University</td>
<td>Variable Energy Cyclotron Centre, Kolkata</td>
</tr>
<tr>
<td>University of Kentucky</td>
<td>Wayne State University</td>
</tr>
<tr>
<td>Valley State University</td>
<td>Warsaw University of Technology</td>
</tr>
<tr>
<td>Institute of Modern Physics, Lanzhou</td>
<td>University of Washington</td>
</tr>
<tr>
<td>Lawrence Berkeley National Laboratory</td>
<td>Institute of Particle Physics</td>
</tr>
<tr>
<td>Massachusetts Institute of Technology</td>
<td>Yale University</td>
</tr>
<tr>
<td>Max-Planck-Institut fuer Physics</td>
<td>University of Zagreb</td>
</tr>
<tr>
<td>Michigan State University</td>
<td></td>
</tr>
</tbody>
</table>