BRAHMS

Beam Use Proposal

Runs 4-6

F. Videbæk

For

The BRAHMS collaboration
Overview

- Introduction
- Accomplishments in RUN-2 & 3
  - Au-Au, d-Au, and pp data collected
  - Physics results
- Goals for RUN-4 and RUN-5+
  - Physics
- Detailed request
- Considerations
- Summary
Brahms Physics Goals

Probing and characterizing Hot and Dense Nuclear Matter
By studying:
- Particle Production
- Reaction Mechanisms and Dynamics
- Baryon Stopping
- Hard Processes (high $p_t$ spectra)

Through High Precision Measurements of Identified Hadrons over wide range of
- Rapidity: $0 < y < 4$
  (Central and Fragmentation regions)
- Transverse momentum: $0.2 < p_t < 4$ GeV/c
  (with the current setup)

BRAHMS measurement capabilities (PID and momentum) at large $y$
are unique in the RHIC Program. The PID capabilities at $y\sim0.1$ is at
par or better than other exp.
The Program is well underway with the Au-Au data from RUN-2 and d-Au & pp data from Run-3
Data
- Initial survey of “soft” physics
- Selected high-\(p_t\) runs

Results (highlights)
- Charged particle multiplicity \(dN/d\eta\): PRL 88, 202301
- Rapidity dependent Particle ratios and statistical model analysis: PRL 90, 102301
- Identified hadron spectra and yields at selected rapidities
  - Net-proton (Panic/QM02, in preparation)
  - \(dN/dy\), slope vs. \(y\) for \(\pi,K,p\) (QM02, in preparation)
- High-\(p_t\) hadron yields and suppression in Au-Au An Au PRL 91, 072305
Accomplishments in Run-3

d-Au at 200 GeV
- Brahms recorded ~ 65 nb\(^{-1}\) in the 12 weeks run, albeit most of the statistics came from the last 6 weeks after several background and machine issue were resolved.

p-p at 200 GeV
- Brahms collected ~ 70 nb\(^{-1}\) in the ~4 weeks we took data.

<table>
<thead>
<tr>
<th></th>
<th>d-Au</th>
<th>p-p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRS 90</td>
<td>9M</td>
<td>MRS 5M</td>
</tr>
<tr>
<td>40</td>
<td>10M</td>
<td></td>
</tr>
<tr>
<td>FS 4</td>
<td>4M</td>
<td>FS 6M</td>
</tr>
<tr>
<td>12</td>
<td>1.2M</td>
<td></td>
</tr>
</tbody>
</table>

Spectrometer triggers collected at selected angles.
Data

- Survey of “soft” physics i.e. rapidity distributions for identified hadrons.
- Selected high-$p_t$ runs at $y\sim0,1,2,3$

Results

- High-$p_t$ hadron yields, comparison to p-p; observation of no suppression in d-Au at rapidity $y\sim0$. PRL 91,072305

Some Ongoing analysis

- Charged particle multiplicity distributions
- High-$p_t$ spectra for identified particles at several $y$.
- Spectra at large rapidities to compare with predictions of CGC.
Meson Distributions

The large dynamic range of the Brahms spectrometers yields coverage from $y \sim 0-3$. Data shown for 0-5% centrality.
No wide “plateau” observed in rapidity for identified mesons. Close to a Gaussian shape ($\sigma(\pi^+) = 2.35 \sim \sigma(k^+) = 2.39$)

Total yield in agreement with published $dN/d\eta$ measurements from multiplicity sub-system.

The RMS of $\pi$ distributions from low energy to RHIC is close to prediction of Landau Hydro model (Caruthers)
High-$p_t$ spectra

High-$p_t$ studies have emerged as significant probe of the dense medium. Brahms can contribute significantly to these studies through rapidity dependence of identified hadrons up to $p_t$ of $\sim 4-5$ GeV/c.
High $p_T$ enhancement observed in $d+Au$ collisions at $\sqrt{s_{NN}}=200$ GeV.

Comparing $Au+Au$ to $d+Au$
⇒ strong effect of dense nuclear medium
The rapidity coverage enables us to study the suppression vs. density w/o changing centrality. The Au-AU data from run-2 show similar size effects at \( \eta \approx 0 \) and \( \eta \approx 2 \).
• AGS->RHIC : Stopping -> Transparency
• Net proton peak must be at > y ~ 2
• Estimated rapidity loss at 200 GeV is 2.3
Summary of 200 GeV results I

- $p_T$ spectra of pions and kaons ($0<y<4$)
  - Systematic decrease in inverse slopes with increasing $y$
  - Rapidity distributions are near Gaussian.
  - $K^+/K^-$ at high rapidity a problem for models
  - $\sqrt{s_{NN}}$ dependence of $K/\pi$ (AGS-SPS-RHIC)

- Thermal expansion fits to $\pi$, $K$, $p$
  - Increasing radial expansion with centrality ($y=0$)
  - Decreasing freeze-out temperature with centrality ($y=0$)
  - Radial flow evident to rapidity 3
Summary of 200 GeV results II

- **Net proton Yields**
  - Flat for $0 < y < 1.5$ \( \frac{dN}{dy} = 7.3 \pm 0.5 \) at $y = 0$
  - Rises for $y > 2$ \( \frac{dN}{dy} = 12.9 \pm 0.4 \) at $y = 3$
  - The rapidity loss of protons is estimated to be in the range of 2.0 to 2.4 for central collisions

- **High \( p_T \) suppression**
  - Au+Au high \( p_T \) suppression at $\eta = 0$ and $\eta = 2$
  - d+Au do not see suppression at $\eta = 0$ consistent with Cronin effect.

- **p-p Running**
  - Reference data analysis in progress
  - Commissioned spin physics program
Run-4 Upgrades

- **Heavy Ion running**
  - MRS & FS spectrometer trigger counters
    - Increase efficiency
    - Increase peripheral data sample
  - Rearrange Si-Multiplicity array to attempt Flow Measurement
  - In addition to Baseline configuration a Cherenkov C4 was added to MRS together with additional TOF elements at larger flight path for parts of Run-3. This will enhance PID capabilities for pions in particular.

- Possible additions in Run-5 of subset of ALICE Si-detectors (FMD, ITS) to enhance physics capabilities (forward Mult, vertexing in small dΩ)
Physics program for next RHIC runs.

Completion of Baseline program and follow-up on opportunities in high-pt studies, and spin physics.

- Systematics of high-$p_t$ suppression
- Longitudinal collision dynamics via rapidity distributions.
- Collective effects
  - Transverse flow
  - Source sizes (coalescence)
  - Elliptic flow
- Centrality, System size and energy dependence
- Dedicated spin program (An)
Suppression observed in Au-Au relative to pp and d-Au.

The suppression effect is thought to be \( \sim \rho L \).

Interplay of partonic energy loss, Cronin and possible CGC.

Controlled experiments with systematic change of this via change in system (L), density (rapidity, centrality) and \( \sqrt{s_{NN}} \).

Suppression depends on hadron type.

\( P_t \) dependence of \( \pi, p \) different. \( P/\pi \geq 1 \) at large \( p_t \).
High $p_t$ at forward rapidities

Initial measurement at $y \sim 2.2$ for identified pions. Obtained with $\sim 4 \mu b^{-1}$, but for central events only. Need $\sim 10$ statistics to get high quality peripheral data. Measurements can also be done at somewhat higher $y$ ($\sim 3$) where the $dN(\pi)/dy$ has dropped to $\sim \frac{1}{2}$ the value at $y \sim 0$.

Estimated $\pi$ spectrum at $y \sim 2.7$, with $40 \mu b^{-1}$. Lower $p_t$ range requires $\sim 10 \mu b^{-1}$.
Bulk and Collective Properties
- longitudinal dynamics

- Development of stopping
  - Projectile and energy dependence
- \(\sim 4\pi\) identified hadron yields
- Collective flow (transverse & elliptic)
  - \(\langle p_t \rangle\) vs. centrality and rapidity
- Correlation measurements
  - Coalescence (anti) deuterons.
  - HBT
- Explore particle production at low \(N_{\text{collision}}\) and \(N_{\text{part}}\)
  - (10-100) by utilizing light projectile

29 September 2003

Brahms Beam use proposal
Coalescence Measurements

Data from mid-rapidity $y \sim 0.1$,
$B_2 \sim 10^{-3}$. Au-Au.

Expected $d$–$\bar{d}$ statistics at
$y \sim 2.5$ for $10 \mu b^{-1}$.

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p-p measurements

- Transverse Spin asymmetry measurements at moderately large $X_F$.
- Completion of reference data; In particular high $p_t$ spectra for identified hadrons at $y \sim 2$ and 3.
Low energy data (AGS) show clear differences between $\pi^+$ and $\pi^-$. At higher energies the models used to describe the data differ. Large spin effects reported by STAR for $\sqrt{s} = 200$ GeV $pp$ collisions. This makes it an appealing measurement within the RHIC spin program, and has been discussed within the RHIC spin group.
Transverse Spin in BRAHMS

Charged pions at $x_f \sim 0.2-0.4$

Expect asymmetry of 1-5% for $\pi^+$

Requires good control of systematic error (< 0.3% with 40% beam polarization.)

  - Run-3 measurement $\sim 0.15\%$

Under Run-3 Conditions, 2 weeks to make a significant first measurement.

Prefer to do program in two phases

  • $\pi^+$, $\pi^-$ at $x_f \sim 0.25$ (requires $\sim 0.6$ pb$^{-1}$)
  • Extend to higher $X_f \sim 0.3-0.4$ (longer measurement)
Considerations for request

- Assumed $\beta^* = 3$ for RUN-4; $\beta^* = 2$ in subsequent years
- Assumed the Au-Au at full energy likely to achieve better than minimum projection. (was reached at end of run-2)
- There was no Fe projection at time of writing of BUP. The estimate given later is slightly smaller than our projection from Si/Au estimates. To reach 1.2 like 12 weeks is needed at $\beta^*$ of 2. Tables following updated to reflect this change for 27/37 week request for Run-5
The Au-Au program for 200 GeV, which we would like to see done in Run IV, is tabulated below. The measurements at y~1 can be performed in parallel with those of the forward spectrometer(high rapidity) which sets the length of the request.

1. Collect high statistics for high-\(p_t\) spectra at y~2.5 and y~3.5 for both charge states. (100 + 40 \(\mu b^{-1}\))

2. Flow (\(v2\)-measurements up to about \(p_t\sim2\) vs. centrality) \(p_t\sim3\) overall. (40 \(\mu b^{-1}\))

3. Supplement existing lower \(p_t\) data where needed. (40 \(\mu b^{-1}\))

4. Perform simultaneous coalescence measurements at y~2.5. Part of this will be done under 1, but requires additional settings. (20 \(\mu b^{-1}\))

5. Centrality dependence of \(p,K,p\) in 0.2-6 GeV/c at y~1, and 0.
Fe-Fe at 200 GeV

- The focus will be on measuring the higher $p_t$ region of identified particle at $y \sim 1$ and $y \sim 2.5$. This will help in disentangling the importance of medium size vs. energy density experimentally, leading to a greater understanding of the phenomena observed with Au-Au at 200 and 130 GeV. ($R_{Fe} \sim 2/3R_{Au}$)

- Identified charged hadrons at $y \sim 1$ and 2.5. (0.9 nb$^{-1}$)

- Complete rapidity distribution for net-protons (baryons), particle composition, and strangeness production vs. rapidity. (0.3 nb$^{-1}$)
**Au-Au at 63 GeV**

- The reduced expected luminosities (~9 times less than at full energy) implies that only a few focused measurements will be performed for the high-$p_t$ measurements due to the solid angles of the BRAHMS spectrometers. Complete rapidity distributions for soft physics particle production will be obtained. The main request is for two simultaneous measurements of
  1. High-$p_t$ measurement at $y \approx 1$. (10 $\mu b^{-1}$) (MRS)
  2. Survey of net-proton, kaon and $\pi$ distributions utilizing the FS. (10 $\mu b^{-1}$)
### Summary of Total request for Run 4-6

<table>
<thead>
<tr>
<th>Species</th>
<th>Energy</th>
<th>Luminosity</th>
<th>Weeks (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au-Au</td>
<td>200</td>
<td>240 µb⁻¹</td>
<td>19</td>
</tr>
<tr>
<td>Fe-Fe</td>
<td>200</td>
<td>1.2 nb⁻¹</td>
<td>8-&gt;10</td>
</tr>
<tr>
<td>Au-Au</td>
<td>63</td>
<td>10 µb⁻¹</td>
<td>10</td>
</tr>
<tr>
<td>p-p</td>
<td>200</td>
<td>1.2 pb⁻¹</td>
<td>6-&gt; 10</td>
</tr>
</tbody>
</table>

Table 1. Summary of requested species and luminosities.
The $\beta^*$ is 3 for 200 GeV Au; 2 otherwise

The pp estimate did not have the *2 loss for additional IR’s running (working point issue)
Requests per year

- Priorities, considerations
  - The experiments were requested to propose a run plan under assumptions of 27 and 37 weeks.
  - The greatest advantage of the longer running time is the reduction of risk i.e. being able to achieve the physics goals laid out in the next 3 years.

- Comments
  The numbers are different than in submitted proposal adjusted to reflect better our understanding of luminosity (particular pp and Fe).
<table>
<thead>
<tr>
<th>RUN 4</th>
<th>Au-Au 200 GeV</th>
<th>19 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUN 5</td>
<td>Fe-Fe 200 GeV pp</td>
<td>10 weeks 4 weeks</td>
</tr>
<tr>
<td>RUN 6</td>
<td>Au-Au 63 GeV pp 200 GeV (Au-Au 200 GeV)</td>
<td>10 weeks 4 weeks (as needed)</td>
</tr>
<tr>
<td>RUN 7</td>
<td>Depends on progress in IV-VI</td>
<td></td>
</tr>
</tbody>
</table>

* In case of a pp commissioning period we wish to perform a first An transverse asymmetry measurement in the order of 1 week.
### 37 Week Run Plan

<table>
<thead>
<tr>
<th>RUN 4</th>
<th>Au-Au 200 GeV</th>
<th>19 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Au-Au 63 GeV</td>
<td>8 weeks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RUN 5</th>
<th>Fe-Fe 200 GeV</th>
<th>12 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pp</td>
<td>10 weeks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RUN 6</th>
<th>Au-Au 200 GeV</th>
<th>as needed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pp 200 GeV</td>
<td>4 weeks</td>
</tr>
</tbody>
</table>

The major advantage of longer runs than 27 weeks is that the risks in not achieving the luminosity goals is much reduced, and high statistics sample can be reached, and that the two-modes requests yields much more physics.
Summary

- The highest priority is a high statistics Au-Au run at full energy to study in detail high-$p_t$ suppression at larger rapidities for identified hadrons.
  - This is in good agreement with requests from other experiments.
- Subsequent heavy-ions runs should be for 200 GeV Fe, and a lower energy Au run, preferentially at 63 GeV.
- The collaboration also puts importance to a measurement of the transverse spin asymmetries at large $x_F$ for identified pions within the next 3 year period, preferentially split over two periods.
- Additional Au at full energy may be warranted, pending outcome of Run-4 and lessons learned.
Systematic error estimated from variation in bunch Luminosity measurement using ZDC, INEL and BB Detector systems.