Azimuthal Anisotropy: The Higher Harmonics

Art Poskanzer
Event plane determination in TPC

- $v_2$ signal drops by about a factor of 1.8 from mid-rapidity to $\eta = 3$
- PHOBOS fall off confirmed
Search for higher harmonics

- Long History
  - Voloshin at CERES
  - Me and Voloshin with NA49 data
- Large, and decreasing slowly with harmonic number
- Probably all non-flow effects
- Except Voloshin and Zhang at AGS
  - E877: PRL 73, 2532 (1994)
  - Q distribution method
**Peter Kolb**

- $v_4$ - a small, but sensitive observable for heavy ion collisions: PRC 68, 031902(R)
  - Strong potential to constrain model calculations and carries valuable information on the dynamical evolution of the system
  - Magnitude, and even the sign, sensitive to initial conditions of hydro
$v_2$ determines the reaction plane

- $v_1$ (Aihong Tang), $v_4$, $v_6$ and $v_8$ using second harmonic particles
- Possible because $v_2$ is so large at RHIC and event plane resolution is so good in STAR

4\textsuperscript{th} harmonic of one subevent relative to 2\textsuperscript{nd} harmonic of other subevent: $v_4$ positive

Poskanzer
Terminology

- $n = \text{harmonic number}$
- **Old**
  - $v_n = \text{harmonic order } n \text{ with respect to event plane of same order}$
  - $v_n\{N\} = \text{N-particle cumulant for } v_n$
- **Addition**
  - $v_n\{EP_2\} = \text{harmonic order } n \text{ with respect to event plane of order 2}$
Method

Described in methods paper:

Square-root of subevent correlation

\[ v = \frac{v_{\text{observed}}}{\text{resolution}} \]

- \( V_4 \) vs. 2\text{nd}
- \( V_6 \) vs. 2\text{nd}
- \( V_8 \) vs. 2\text{nd}

Signal to fluctuation noise
Resolution

For v_2
For v_4
For v_6

Resolution vs Centrality

k=1
k=2
k=3
$v_4(p_t)$

![Graph showing $v_4(p_t)$]
$v_4(p_t)$

![Graph showing $v_n$ vs. $p_t$](image)
The figure illustrates the behavior of various v_n coefficients as a function of p_t, with a focus on v_4(p_t). The graph shows:

- v_n \approx v_2^{n/2}
- v_4 \{3\}
- v_4 \{EP_2\}
- v_6 \{EP_2\}

The plot compares the calculated v_n values against the theoretical predictions for different orders of n, demonstrating the scaling behavior of these coefficients with p_t.
$v_4(p_t)$ Scaling

\[ \frac{v_4}{v_2^2} \]

\[ p_t \text{ (GeV/c)} \]

Snellings and Poskanzer
The Waist

High $p_t$
- 16.5% $v_2$
- 3.8% $v_4$

Kolb no waist:

$v_4 = (10 \times v_2 - 1) / 34$

mean values

Poskanzer
$v_4\{EP_2\}$ in the FTPC

- $v_4$ with respect to the 2nd harmonic event plane in the TPC
- Signal in the FTPCs consistent with 0 ($0.03 \pm 0.06$)% with two sigma upper limit of 0.15%
- Drop of $v_4$ from TPC to FTPC faster than for $v_2$
$v_4(\text{centrality})$
$v_4(\text{centrality})$
**v triply integrated in MTPC**

<table>
<thead>
<tr>
<th>v</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5.18 +/- 0.005</td>
</tr>
<tr>
<td>4</td>
<td>0.44 +/- 0.009</td>
</tr>
<tr>
<td>6</td>
<td>0.043 +/- 0.037</td>
</tr>
<tr>
<td>8</td>
<td>-0.06 +/- 0.14</td>
</tr>
</tbody>
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Two sigma upper limit is 0.1%
Non-flow and/or Fluctuations

For $v_2$, about 20% reduction from $v_2\{2\}$ to $v_2\{4\}$

For $v_4$, up to a factor 3 difference!
Conclusions

- $v_4$ compared to $v_2$
  - Integrated, a factor of 12 smaller
  - $v_2^2$ scaling

- $v_6$
  - Probably another factor of 10 smaller
  - Consistent with $v_2^3$ scaling

- Hydro, sensitive to initial conditions
  - $v_4$ fits very well
  - $v_6$ is zero instead of negative from hydro

- Waist
  - $v_4$ larger than needed to remove the waist

- $v_4\{EP_4\}$
  - 3x high because of either fluctuations or nonflow