Potential for Bose-Einstein Correlation studies at HERA-B

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Due to time constraints, some of the material in this presentation has not been reviewed or approved by the HERA-B collaboration.

This talk is presenting only a feasibility study, made on a small sample of HERA-B data. The results presented here are very preliminary and likely to be adjusted.
Outline

✓ HERA-B detector
✓ Why to study BEC
✓ Why BEC at HERA-B
✓ BEC theory and main ingredients for BEC analysis
✓ Preliminary results $\pi\pi$ in pA with A=C, W
Located at the proton-electron collider HERA at DESY. 920 GeV proton collisions on various targets.
Detailed studies of the two-particles interferometry allow:

- to determine the shape of the region in which the detected particles are produced
- to analyse its spatial and temporal characteristics and to obtain information about the space–time development of the particle emitting source.

BEC analysis results:

- provide crucial information for assessment of theoretical models
- improve our understanding of the reaction mechanisms and help to constrain theoretical models of pA collisions.
- if using various particles may be particularly helpful in understanding the dynamical evolution of pA collisions.
Why BEC at HERA-B

- Can be studied for both $\pi$ and $K$
- Different targets
- Large minimum bias sample
### Table: Target material and events

<table>
<thead>
<tr>
<th>Target position</th>
<th>Target material</th>
<th>Events</th>
<th>Rec. events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer II</td>
<td>C / W</td>
<td>977975</td>
<td>197094</td>
</tr>
<tr>
<td>Inner II</td>
<td>C</td>
<td>28382533</td>
<td>25393707</td>
</tr>
<tr>
<td>Below II</td>
<td>Ti</td>
<td>27278280</td>
<td>26525573</td>
</tr>
<tr>
<td>Above II</td>
<td>Pd</td>
<td>35442</td>
<td>35442</td>
</tr>
<tr>
<td>Outer I</td>
<td>Ti</td>
<td>9603155</td>
<td>1859952</td>
</tr>
<tr>
<td>Inner I</td>
<td>W</td>
<td>75771490</td>
<td>74359075</td>
</tr>
<tr>
<td>Below I</td>
<td>C</td>
<td>83143920</td>
<td>78258259</td>
</tr>
<tr>
<td>Above I</td>
<td>Al</td>
<td>20789</td>
<td>3084</td>
</tr>
<tr>
<td>Inner I + II</td>
<td>W + C</td>
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<td>207874</td>
</tr>
<tr>
<td>Inner I + Bellow I</td>
<td>W + C</td>
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<td>16136361</td>
</tr>
<tr>
<td>Bellow I + II</td>
<td>C′+ Ti</td>
<td>1977804</td>
<td>233118</td>
</tr>
<tr>
<td>Multiwire</td>
<td></td>
<td>5846418</td>
<td>3741135</td>
</tr>
</tbody>
</table>
BEC theory

• Symmetric wave functions of bosons, no exclusion principle;
• Enhanced probability for the identical bosons to be emitted with small relative momenta;
• Quantum statistical correlations between pairs of identical particles.

For two identical bosons the Bose-Einstein correlation is defined as:

$$C(p_1, p_2) = \frac{P(p_1, p_2)}{P(p_1)P(p_2)}$$

$P(p_1, p_2)$ probability density of two particles to be produced with 4-momentum $p_1$ and $p_2$;

$P(p_1), P(p_2)$ probability densities for a single particle to be produced with 4-momentum $p_1$ or $p_2$, difficult to build in practice $\rightarrow$ reference sample.
The correlation function can be parametrized as:

\[ C_2 = N(1 + \lambda e^{-Q^2R^2})(1 + \delta Q) \]

\[ Q = p_1 - p_2 \] invariant four-momentum difference,

\[ \lambda \] related to the fraction of identical bosons which do interfere,

\[ R \] interpreted as the geometrical radius of the presumably spherical boson emitting source,

\[ N \] overall normalization,

\[ \delta \] linear background.
Reference sample

Must contain all the features which are present in the distributions constructed for identical pairs in data (correlations due to energy-momentum conservation etc), except the BEC, and must not contain additional features (dynamical correlations)

✓ Plus-minus sample – resonance peaks, additional correlations.... no longer in fashion.
✓ Mixed sample – tracks from different events, some other kind of correlations are also disappearing (long range correlations, energy-momentum ...)
✓ Monte Carlo without Bose-Einstein correlation (??????)

\[
C_2 = \frac{\left(\frac{dN}{dQ}\right)_{\text{data}}}{\left(\frac{dN}{dQ}\right)_{\text{ref}}}
\]
Event, track and pair selection

✓ minimum bias events from 2002-2003 running period.
✓ pions and kaons (RICH selection).
✓ at least 6 hits SVD and 10 in the main tracker (outer).

For pairs of pions

✓ tx1 - tx2 > 0.001 rad  two tracks cannot be reconstructed if they are "closer" than maximum resolution in tx MC (where tx is px/pz).
✓ ty1 – ty2 > 0.001 rad two tracks cannot be reconstructed if they are "closer" than maximum resolution in ty MC (where ty is py/pz).
✓ |p1| - |p2| > 1 GeV maximum absolute value of momentum resolution in MC.
✓ Q > 0.01 maximum Q resolution MC.
Correction procedure

\[
C_2 = \frac{\left( \frac{dN}{dQ} \right)_{\text{data,mix}}}{\left( \frac{dN}{dQ} \right)_{\text{MCrec}} \left( \frac{dN}{dQ} \right)_{\text{MCrec,mix}}}
\]

\[
\begin{bmatrix}
\frac{dN}{dQ} & \text{data} \\
\frac{dN}{dQ} & \text{data,mix} \\
\frac{dN}{dQ} & \text{MCrec} \\
\frac{dN}{dQ} & \text{MCrec,mix}
\end{bmatrix}
\]
$\pi - W$ target

$\chi^2$/ndf = 35.75 / 24

- $N = 1.115 \pm 0.3406E-01$
- $\lambda = 0.5117 \pm 0.1290$
- $R = 2.554 \pm 0.4097$
- $\delta = -0.4083 \pm 0.9688E-01$
## Preliminary results - pions

<table>
<thead>
<tr>
<th>Target</th>
<th>Z</th>
<th>( \lambda )</th>
<th>R(fm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>6</td>
<td>0.350 ± 0.102</td>
<td>2.106 ± 0.494</td>
</tr>
<tr>
<td>W</td>
<td>74</td>
<td>0.512 ± 0.129</td>
<td>2.554 ± 0.410</td>
</tr>
</tbody>
</table>

NA44 450 GeV/c published result pPb (Z=82) Pions 2.1 ± 0.1 fm
First results are promising but it is still a lot to be done ......
• Backup slides
π – Ti target

\[ \chi^2 / \text{ndf} = 21.43 / 24 \]

- P1: 1.030 ± 0.1216
- P2: 0.2692 ± 0.2672
- P3: 2.053 ± 0.7181
- P4: -0.1576 ± 0.4049

- Parameters and significance levels for the fit of the data to the model.
Why to study BEC

QGP signature

✓ Positive identification of the QGP state in relativistic heavy-ions collisions is extremely difficult since if created the QGP will have a very transient existence. In the experimental search of QGP formation, a suggested signature is the extended emission time of mesons from a system undergoing a phase-change. This can be measured by the components of two particle correlation function (multidimensional analysis).

✓ Reliable estimates of the source volume and the energy density are indispensable for an experimental proof that high energy collisions can successfully generate large volumes of matter with extreme energy density where a transition in deconfined quark matter can be possible.
K - C target

<table>
<thead>
<tr>
<th>ID</th>
<th>Entries</th>
<th>Mean</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30020</td>
<td>0.5672</td>
<td>0.3473</td>
</tr>
</tbody>
</table>

$\chi^2$/ndf: 43.20 / 42

- $P_1$: 0.1848 ± 0.0149E-01
- $P_2$: 4.301 ± 1.362
- $P_3$: 0.6871 ± 0.5863E-01
- $P_4$: 5.049 ± 2.602
Correction procedure

Correction for detector effects:

\[
C_{\text{det}} = \frac{\left(\frac{dN}{dQ}\right)_{\text{gen}}}{\left(\frac{dN}{dQ}\right)_{\text{rec}}}
\]

\[
C_{\text{det,mix}} = \frac{\left(\frac{dN}{dQ}\right)_{\text{gen,mix}}}{\left(\frac{dN}{dQ}\right)_{\text{rec,mix}}}
\]

Correction for the mixing procedure:

\[
C_{\text{mix}} = \frac{\left(\frac{dN}{dQ}\right)_{\text{noBE}}}{\left(\frac{dN}{dQ}\right)_{\text{noBE,mix}}}
\]

Total correction:

\[
C_{\text{tot}} = C_{\text{det}} / C_{\text{det,mix}} / C_{\text{mix}}
\]

\[
C_2 = C_{\text{tot}} \frac{\left(\frac{dN}{dQ}\right)_{\text{data}}}{\left(\frac{dN}{dQ}\right)_{\text{data,mix}}}
\]

\[
C_2 = \frac{\left(\frac{dN}{dQ}\right)_{\text{data}}}{\left(\frac{dN}{dQ}\right)_{\text{MCrec}} / \left(\frac{dN}{dQ}\right)_{\text{MCrec,mix}}}
\]