Test of the OZI rule and spin alignment measurements with the COMPASS experiment

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on behalf of the COMPASS collaboration

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Production mechanisms at beam energies $\mathcal{O}(100 \text{ GeV})$

- **Resonant (diffractive)**
  - $p_{\text{beam}} \rightarrow X \rightarrow p_{\text{target}} \rightarrow p_{\text{recoil}}$
  - $V \rightarrow t$

- **Non-resonant**
  - $p_{\text{beam}} \rightarrow p_{\text{target}} \rightarrow p_{\text{recoil}}$
  - $V \rightarrow t$

- **Central**
  - $p_{\text{beam}} \rightarrow p_{\text{fast}} \rightarrow p_{\text{target}} \rightarrow p_{\text{recoil}}$
  - $V \rightarrow t_{1,2}$

Try to understand interplay by studying **strangeness transfer** in well-understood vector meson production ("strangeness chemistry"):  
- $\phi(1020)$ is close to pure $s\bar{s}$ state
- $\omega(782)$ is close to pure $u\bar{u}/d\bar{d}$ state
Okubo-Zweig-Iizuka rule:
processes with disconnected quark lines suppressed

prediction for $\phi(1020)$ to $\omega(782)$ production ratios:

$$\frac{\sigma(pp \rightarrow \phi X)}{\sigma(pp \rightarrow \omega X)} \simeq \tan^2(\theta - \theta_0) \simeq 4.2 \cdot 10^{-3}$$

- Violation of ratio hints at flavour-neutral exchange processes
The COMPASS spectrometer at CERN

190 GeV/c hadron beam, 75% protons
2 stage high resolution spectrometer with large acceptance

beam PID with CEDAR detectors
particle ID with RICH and Calorimetry

luminosity 0.15 pb$^{-1}$/day

hep-ex/0703049, NIM A 577, 455 (2007)
update in preparation
Event selection of exclusive vector meson production

Study at COMPASS:
Compare $\phi(1020) \rightarrow K^+K^-$ to $\omega(782) \rightarrow \pi^+\pi^-\pi^0$ production

Exclusive events:

<table>
<thead>
<tr>
<th>Calculated beam energy (GeV)</th>
<th>Events / 0.1 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>150</td>
<td>6</td>
</tr>
<tr>
<td>200</td>
<td>8</td>
</tr>
<tr>
<td>250</td>
<td>10</td>
</tr>
<tr>
<td>300</td>
<td>12</td>
</tr>
</tbody>
</table>

COMPASS 2008
$p p \rightarrow p \pi^+\pi^-\pi^0 p$
not acceptance corrected

- All $\pi^+\pi^-\pi^0$
- RPD coplanarity
- $\omega$ mass region

Calculated beam energy (GeV)

preliminary
Analysis

Restriction to similar, well-known phase space for both $\omega$ and $\phi$ by cuts on

- longitudinal momentum share: $0.6 < x_F < 0.9$
- momentum transfer: $0.1 \, (\text{GeV}/c)^2 < t' < 1 \, (\text{GeV}/c)^2$
- mass of $pV$ system
  1. $1.8 \, \text{GeV}/c^2 < M(p\omega) < 4.0 \, \text{GeV}/c^2$
  2. $2.1 \, \text{GeV}/c^2 < M(p\phi) < 4.5 \, \text{GeV}/c^2$

Method:

1. Monte-Carlo simulation of apparatus acceptance, correction in $t'$, $x_F$ and $M_{pV}$
2. fit acceptance corrected invariant mass distributions in $x_F$ bins
3. correct for branching
4. calculate $R = \frac{\text{Number of } \phi}{\text{Number of } \omega}$
Method:
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Preliminary Results $R_{\phi/\omega}$

Systematic uncertainties:

- background subtraction
- apparatus knowledge (ECAL+RICH efficiencies)
Preliminary Results $R_{\phi/\omega}$

Differential cross section ratio $R_{\phi/\omega}(x_F)$ (preliminary):

<table>
<thead>
<tr>
<th>$x_F$</th>
<th>$R_{\phi/\omega}$</th>
<th>OZI violation factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6-0.7</td>
<td>0.019</td>
<td>4.5 ± 0.6</td>
</tr>
<tr>
<td>0.7-0.8</td>
<td>0.017</td>
<td>4.0 ± 0.5</td>
</tr>
<tr>
<td>0.8-0.9</td>
<td>0.012</td>
<td>2.9 ± 0.4</td>
</tr>
</tbody>
</table>
OZI violation

Observation: Lower violation than found by previous experiments

Investigate mass distribution of $p\nu$ system:

$p\phi$: phase-space-like, no structures  
$p\omega$: resonances
cut on vector meson momentum $p_V$

- independent of $\omega/\phi$ mass differences

<table>
<thead>
<tr>
<th>$x_F$</th>
<th>$R_{\phi/\omega}$</th>
<th>$OZI$ viol.</th>
<th>$R_{\phi/\omega}$</th>
<th>$OZI$ viol.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6-0.7</td>
<td>0.032</td>
<td>$7.6 \pm 1.0$</td>
<td>0.032</td>
<td>$7.6 \pm 1.0$</td>
</tr>
<tr>
<td>0.7-0.8</td>
<td>0.038</td>
<td>$9.0 \pm 1.1$</td>
<td>0.033</td>
<td>$7.9 \pm 1.1$</td>
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Preliminary Results $R_{\phi/\omega}$ - II

preliminary!
another handle to distinguish production mechanisms:
cross section linearly parameterised$^2$ in terms of
spin density matrix element $\rho_{00}$

$$\frac{d\sigma}{d\cos \theta} = \frac{4}{3} \left( 1 - \rho_{00} + (3\rho_{00} - 1) \cos^2 \theta \right)$$

$\rho_{00} = 0$ long. alignment, $\rho_{00} = 0.33$ arbitrary alignment, $\rho_{00} = 1$ transverse alignment

Spin Alignment

Spin density matrix has representation depending on reference frame
resonant (diffractive)  non-resonant  central

- helicity frame: $\hat{z} = |\vec{X}|$ in CM(V) system
  sensitive to diffractive / resonant production
- exchange frame: $\hat{z} = |\vec{p}_{beam} - \vec{p}_{fast}|$
  sensitive to central mechanisms / two particle exchanges
Spin Alignment

another handle to distinguish production mechanisms: cross section linearly parameterised\(^2\) in terms of spin density matrix element \(\rho_{00}\)

\[
\frac{d\sigma}{d\cos \theta} = \frac{4}{3} \left( 1 - \rho_{00} + (3\rho_{00} - 1) \cos^2 \theta \right)
\]

\(\omega\), helicity frame:

\(\rho_{00} = 0.289 \pm 0.004\) \(\rho_{00} = 0.33 \pm 0.003\) \(\rho_{00} = 0.449 \pm 0.003\)

Spin Alignment

another handle to distinguish production mechanisms: cross section linearly parameterised\(^2\) in terms of spin density matrix element \(\rho_{00}\)

\[
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\]

\(\phi\), helicity frame:

\(\rho_{00} = 0.38 \pm 0.03\) \(\rho_{00} = 0.35 \pm 0.02\) \(\rho_{00} = 0.39 \pm 0.04\)

Resonances in the $p\omega$ system

$0.2 < x_F < 0.6$

$0.6 < x_F < 0.7$

$0.7 < x_F < 0.8$

$0.8 < x_F < 0.9$
Helicity frame: scan over $p\omega$ mass

mass range 1.8-3.8 GeV/c$^2$
Exchange frame: Spin alignment $\phi$

COMPASS 2008/9

$p p \rightarrow p \phi p$

$0.6 < x_F < 0.7$

$\rho_{00} = 0.51 \pm 0.03$

$0.7 < x_F < 0.8$

$\rho_{00} = 0.58 \pm 0.02$

$0.8 < x_F < 0.9$

$\rho_{00} = 0.67 \pm 0.04$
Exchange frame: Spin alignment $\omega$

- **0.2 < $x_F$ < 0.6**
  - $p\ p \rightarrow p\ \omega\ p$
  - $W(\cos^2 \theta_{EX})$
  - $\rho_{00} = 0.402 \pm 0.002$

- **0.6 < $x_F$ < 0.7**
  - $p\ p \rightarrow p\ \omega\ p$
  - $W(\cos^2 \theta_{EX})$
  - $\rho_{00} = 0.492 \pm 0.003$

- **0.7 < $x_F$ < 0.8**
  - $p\ p \rightarrow p\ \omega\ p$
  - $W(\cos^2 \theta_{EX})$
  - $\rho_{00} = 0.582 \pm 0.002$

- **0.8 < $x_F$ < 0.9**
  - $p\ p \rightarrow p\ \omega\ p$
  - $W(\cos^2 \theta_{EX})$
  - $\rho_{00} = 0.572 \pm 0.002$

*COMPASS 2008/9*

*preliminary*
Exchange frame: Spin alignment $\omega$ with mass cuts

\begin{align*}
\text{COMPASS 2008/9} & \quad p\ p \rightarrow p\ \omega\ p \\
p_{\omega} > 1 \text{ GeV/c} & \\
0.6 < x_F < 0.7 & \quad \rho_{00} = 0.39 \pm 0.01 \\
\text{Signal} & \\
\text{Sidebands} & \\
\text{COMPASS 2008/9} & \quad p\ p \rightarrow p\ \omega\ p \\
p_{\omega} > 1 \text{ GeV/c} & \\
0.7 < x_F < 0.8 & \quad \rho_{00} = 0.527 \pm 0.005 \\
\text{Signal} & \\
\text{Sidebands} & \\
\text{COMPASS 2008/9} & \quad p\ p \rightarrow p\ \omega\ p \\
p_{\omega} > 1 \text{ GeV/c} & \\
0.8 < x_F < 0.9 & \quad \rho_{00} = 0.577 \pm 0.002 \\
\text{Signal} & \\
\text{Sidebands} & \\
\text{COMPASS 2008/9} & \quad p\ p \rightarrow p\ \omega\ p \\
p_{\omega} > 1.4 \text{ GeV/c} & \\
0.8 < x_F < 0.9 & \quad \rho_{00} = 0.601 \pm 0.005 \\
\text{Signal} & \\
\text{Sidebands} & \\
\end{align*}
Summary

Study of production mechanisms via

1. OZI rule violation / production ratio $R(\phi/\omega)$
2. spin alignment

Results:

- found OZI violation of factor 3-4, low violation due to $p\omega$ resonances
- OZI violation universally 8 when visible $p\omega$ resonances excluded (interestingly, also for low energy measurements near threshold!)
- weak alignment of $\phi$ mesons, no obvious structures in $p\phi$ mass spectrum due to OZI suppression
- resonances in $p\omega$, sensitivity in helicity frame → diffractive production
- strong sensitivities in exchange frame for $\omega$ and $\phi$ → central production / knock-out
Backup
<table>
<thead>
<tr>
<th>Reaction</th>
<th>$x_F$</th>
<th>$\rho_{00}$</th>
<th>Unc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \rightarrow pp\phi$</td>
<td>0.6-0.7</td>
<td>0.38</td>
<td>0.03</td>
</tr>
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<td>0.02</td>
</tr>
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<td>0.8-0.9</td>
<td>0.39</td>
<td>0.04</td>
</tr>
<tr>
<td>$pp \rightarrow pp\omega$</td>
<td>0.2-0.6</td>
<td>0.232</td>
<td>0.003</td>
</tr>
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<td>$pp \rightarrow pp\omega$</td>
<td>0.6-0.7</td>
<td>0.289</td>
<td>0.004</td>
</tr>
<tr>
<td>$pp \rightarrow pp\omega$</td>
<td>0.7-0.8</td>
<td>0.330</td>
<td>0.003</td>
</tr>
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<td>0.8-0.9</td>
<td>0.449</td>
<td>0.003</td>
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<tr>
<td>$pp \rightarrow pp\omega$, $p_V &gt; 1.0$ GeV/c</td>
<td>0.2-0.6</td>
<td>0.30</td>
<td>0.01</td>
</tr>
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<td>$pp \rightarrow pp\omega$, $p_V &gt; 1.0$ GeV/c</td>
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<td>0.34</td>
<td>0.01</td>
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<tr>
<td>$pp \rightarrow pp\omega$, $p_V &gt; 1.0$ GeV/c</td>
<td>0.7-0.8</td>
<td>0.306</td>
<td>0.006</td>
</tr>
<tr>
<td>$pp \rightarrow pp\omega$, $p_V &gt; 1.0$ GeV/c</td>
<td>0.8-0.9</td>
<td>0.463</td>
<td>0.003</td>
</tr>
<tr>
<td>$pp \rightarrow pp\omega$, $p_V &gt; 1.4$ GeV/c</td>
<td>0.8-0.9</td>
<td>0.37</td>
<td>0.03</td>
</tr>
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</table>

helicity frame, preliminary!
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<td>0.408</td>
<td>0.002</td>
</tr>
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<td>0.492</td>
<td>0.003</td>
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exchange frame, *preliminary!*