$\phi$-meson photoproduction
New results from LEPS/SPring-8

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Outline

- Physics motivation
- Experiment at LEPS/Spring-8
- Data analysis
- Results and discussions
- Summary
Vector Meson Photoproduction

\[ \gamma p \rightarrow \pi, \eta, \sigma, \rho, \omega, \phi, \ldots \]

\[ \gamma p \rightarrow uud \]

\[ \gamma p \rightarrow \rho, \omega, \phi (\sim ss) \]

\[ \gamma p \rightarrow \pi, \eta, \sigma \ldots \]
Glueball hunt by $\phi$ meson photoproduction

Pomeron $\leftrightarrow$ Glueball ($J^{P} = 2^{+}$)
Daughter Pomeron $\leftrightarrow$ Glueball ($J^{P} = 0^{+}$) ??

\[ \frac{d\sigma}{dt}(\gamma p \rightarrow \phi p)(t = 0) = C \left( \frac{p_{\phi}}{p_{\gamma}} \right)^{2} \left( \frac{s - u}{2s_{0}} \right)^{0.16} + a \left( \frac{s - u}{2s_{0}} \right)^{\delta} \]
Ordinary meson exchange

\[ \gamma p \rightarrow \rho p \]
\[ \gamma p \rightarrow \phi p \]

Data from: LAMP2('83), DESY('76), SLAC('73), CERN('82), FNAL('79,'82), ZEUS('95,'96)
Polarization observables with linearly polarized photon

Photon Polarization

Decay angular distribution of $\phi$ meson

Relative contributions from natural, unnatural parity exchanges
Decay angular distribution of $\phi$ meson

$\phi$ meson rest frame (Gottfried-Jackson(GJ) frame)
Available data

SLAC
linear pol., $E_\gamma = 2.8, 4.8$ GeV
(J. Ballam et al. PLD 7 (1972)3150)
53 events in $E_\gamma = 2.8, 4.8$ GeV

Bonn
Unpol, $E_\gamma = 2.0$ GeV (NP B70(1974)257)

CLAS @J-lab
Unpol, linear pol. data at $E_\gamma = 1.6-2.5$ GeV

SAPHIR @ELSA/Bonn
Unpol, $E_\gamma = 1.6-2.6$ GeV (EPJ A17(2003)269)

New measurements near threshold at
LEPS @SPring-8
linear pol., $E_\gamma = 1.6-2.4$ GeV
Super Photon ring-8 GeV SPring-8

- Third-generation synchrotron radiation facility
- Circumference: 1436 m
- 8 GeV
- 100 mA
- 62 beamlines
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P. Shagin
The LEPS facility

Laser Electron Photon at SPring-8

8 GeV → Laser

Laser → 3.5 eV

Compton Scattering

8 GeV Electron

Interaction Region

Laser Hutch

Experimental Hutch

SPring-8:
8 GeV electron storage ring
100 mA

BL33LEP

Detector
Linearly polarized photon

GeV photon
Intensity (typ.) $10^6$/sec
Linear polarization 95% at 2.4 GeV
The tagging counter
Summary of data taking

• Trigger condition: TAG*STA*AC*TOF
• Run period
  2000, Dec. – 2001, June (50mm-long LH2 target)
  2002, May – 2003, Apr (150mm-long LH2 target)
  2002, Oct. – 2003, June (150mm-long LD2 target)

• The first data set with 50mm-long LH2 target
  – Total number of trigger
    1.83*10^8 trigger (48% Horizontal, 52% Vertical pol.)
  – Number of events with charged tracks
    4.37*10^7 events
Charged particle identification

Reconstructed mass

K/π separation (positive charge)

σ(mass) = 30 MeV(typ.) for 1 GeV/c Kaon
Charged particle identification

\[ \gamma \rightarrow \phi \rightarrow \pi^0 \pi^0 \pi^0 \]

\[
\begin{array}{c}
\gamma \\
\phi \\
\pi^0 \\
\pi^0 \\
\pi^0 \\
\end{array}
\]

\[
\begin{array}{c}
p \\
p^+ \\
p^+ \\
p^+ \\
\end{array}
\]
Missing mass distribution

\[
\text{Missing mass (}\gamma, K^+K^-) \text{ (GeV)} \quad \text{events}
\]

\[
\text{Missing mass (}\gamma, K^-p) \text{ (GeV)} \quad \text{events}
\]

\[
\text{Missing mass (}\gamma, K^+p) \text{ (GeV)} \quad \text{events}
\]
KK invariant mass cut
Background subtraction

\[ \alpha = \frac{S_A^{MC}}{A^{MC}} \]

\[ \beta = \frac{S_B^{MC}}{B^{MC}} \]
Acceptance

\[ t + |t|_{\text{min}} \, \text{GeV}^2 \]
Consistency between KK and Kp modes

![Graph showing consistency between KK and Kp modes]
HZ and VT consistency
Results
differential cross sections

\[ \frac{d\sigma}{dt} (\text{\(\mu\)b/GeV}^2) \]

\[ 2.273 < E_\gamma < 2.373 \]
\[ 2.173 < E_\gamma < 2.273 \]
\[ 2.073 < E_\gamma < 2.173 \]
\[ 1.973 < E_\gamma < 2.073 \]
\[ 1.873 < E_\gamma < 1.973 \]
\[ 1.773 < E_\gamma < 1.873 \]
\[ 1.673 < E_\gamma < 1.773 \]
\[ 1.573 < E_\gamma < 1.673 \]
Differential cross sections

\[ \frac{d\sigma}{dt} \text{(µb/GeV²)} \]

\[ t \sim \text{(GeV}² \text{)} \]

\[ 0.03 \quad 0.04 \quad 0.05 \quad 0.06 \quad 0.07 \quad 0.08 \quad 0.09 \quad 0.1 \]

\[ 0.2 \quad 0.3 \quad 0.4 \quad 0.5 \quad 0.6 \quad 0.7 \quad 0.8 \quad 0.9 \quad 1 \]

\[ -1 \quad -0.9 \quad -0.8 \quad -0.7 \quad -0.6 \quad -0.5 \quad -0.4 \quad -0.3 \quad -0.2 \quad -0.1 \quad 0 \]

\[ 4^{1/2} \times 3 \]

\[ + \text{BSUI FUBM&1+} \]

\[ \text{GJCJO1SPDFFEJOHTPGUIF*OUFSOBUJPOBM4ZNQPTJVNl&.*z} \]

\[ 0 \text{TBLB} \]
Differential cross section at $t = -|t|_{\text{min}}$

$$d\sigma/dt(t = -|t|_{\text{min}}) \ (\mu b/GeV^2)$$

E$_\gamma$ (GeV) vs. $E_{\gamma}$ (GeV)

- SLAC(1973)
- BONN(1974)
- DESY(1978)
- DARESBURY(1982)
- SAPHIR(2003)
- LEPS(2004)
Decay angular distribution
Summary of LEPS measurement

- **Differential cross section at t=\(-|t|\)min**
  - Peaking structure around \(E_\gamma=2.0\) GeV
  - Prediction from Regge theory:
    - contribution from Pomeron increases with energy.
  - Meson and/or glueball exchange could be candidates to make the bump.

- **Decay angular distribution**
  - Dominant contribution from helicity conserving amplitude.
  - Natural parity exchange (N) > Unnatural parity exchange (UN).
  - No energy dependence in polarization observables. Ratio \((N/UN)\) is energy independent.

- The bump can not be explained by pseudo scalar exchange only.
- Possible presence of additional natural parity exchange.
Open questions

• **What is origin of the peaking structure?**
  – Natural parity exchange
  – Signature of $0^+$ glueball?
  – A fit by simple model failed.

\[
\frac{d\sigma}{dt}(\gamma p \rightarrow \phi p)(t = 0) = C \left( \frac{p_\phi}{p_\gamma} \right)^2 \left( \frac{s - u}{2s_0} \right)^{0.16} + a \left( \frac{s - u}{2s_0} \right)^\delta
\]

  – Need for further theoretical studies.

• **Isospin symmetry?**
  – Glueball should be “flavor blind”
  – CLAS Deuteron data (g2, g10)

• **Measurements at $E_\gamma=2.4-3$ GeV**
  – near future plan at LEPS
  – Ongoing analysis for large $|t|$ at CLAS (g1)
Summary

• New LEPS results for differential cross section of $\gamma p \rightarrow \phi p$ reaction and decay angular distribution near threshold.

• Non-monotonic rise of differential cross section at $t=-|t|_{\text{min}}$ with energy

• Dominant contribution from natural parity exchange, no energy dependence near the bump.

• A possible presence of additional natural parity exchange.
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