Electromagnetic Transition Form Factors of Light Mesons

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conversion decays

Reactions of hadrons with virtual photons

• intrinsic structure of hadrons
  • transition form factors
  • validity of vector meson dominance

• background for physics beyond the standard model
  • rare decays
    • eg $\pi \rightarrow ee$
  • $g$-2 anomalous magnetic moment of the muon
    • light-by-light scattering

g-2 measurements: Fermilab and J-PARC
conversion decays

Transition Form Factors

$$\frac{d\Gamma(A \to B \ell^+\ell^-)}{dq^2 \cdot \Gamma(A \to B \gamma)} = |F_{A\to B}(q^2)|^2 \cdot |\text{QED}|$$

$$F_{AB}(q^2) = [1 - q^2/\Lambda^2]^{-1} \quad \text{(single) pole approximation}$$

$$F_{AB}(q^2) \approx 1 + q^2\left[\frac{dF_{AB}}{dq^2}\right]_{q^2 \to 0} = 1 + q^2b_{AB} = 1 + \frac{1}{6}q^2\langle r_{AB}^2 \rangle$$

$$\Lambda \approx m_\rho \ (\Lambda^{-2} = b_{AB})$$

'standard' VMD, $b \sim 1.69/\text{GeV}^2$

\[\text{slope parameter}\]
\[\text{(transition region)}\]
conversion decays

Transition Form Factors

1 - F=1 (QED)
2 - |F(q^2)| > 1 (VMD)
3 - |F(q^2)| < 1

affects branching ratio

form factor: divide experimental q^2 distribution by QED

\[ \Lambda \approx m_\rho \left( \Lambda^{-2} = b_{AB} \right) \]

'standard' VMD, b~1.69/GeV^2
## a tale of two experiments

<table>
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<th>CLAS Jefferson Lab</th>
<th>experimental issue</th>
<th>WASA COSY-Jülich</th>
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| $\gamma + p$ (g12 experiment) | - cross section  
                             | - multipion background            | $p + p$                          |
| LH$_2$ target               | external $\gamma$ conversion                           | pellet target + beam pipe         |
| Cerenkov Counters           | dilepton identification                                 |                                   |
| EM calorimeter              | photon detection                                        | CsI EM Colrimeter                 |
Experimental challenge p+p reactions

**Method:**
reconstruct meson mass peak, use full final state information

2 types of background:

1. **Multi-pion background**
   meson production cross sections
   → smooth background under meson mass peak
   example:
   - signal $\eta \rightarrow \pi^+ \pi^- \pi^0$ decay
   - background direct $\pi^+ \pi^- \pi^0$ production

2. **Competing meson decays**
   relative branching ratios
   → peaked background at the meson mass peak
   subtract via simulations
   example:
   - signal $\eta \rightarrow e^+ e^- \gamma$ decay
   - background (eg) from $\eta \rightarrow \gamma \gamma$ decay
conversion decay $\eta \rightarrow \gamma e^+ e^-$

preliminary

$30\,000\ \eta \rightarrow \gamma e^+ e^-$

'benchmark decay'

analysis: new base class for pp eta analyses
- full particle multiplicities
- improved particle id (neural networks)
- kinematic fit
  → can improve the efficiency and signal/background
  - in parallel, look at $\eta \rightarrow eeee$

further: study in $\gamma p \rightarrow p \eta(\prime)$ and $\omega$ with CLAS/JLab
status analysis $\eta \rightarrow eeee$

$pp \rightarrow pp\eta$

**preliminary**

**further new analysis:**

- improve statistics
- study combinatorics
- look at $pp\,\pi^0$ data?
preliminary look at $\omega - \pi^0$ transition form factor

$\gamma p \rightarrow p \omega$

smooth background subtraction

in-peak background

preliminary analysis:
so far, consistent with A2 result (and 'extended' VMD)

summary
light meson transition form factors

results coming up from the experiments
CLAS g12 and WASA at COSY:

$$\eta \rightarrow \gamma e^+ e^-$$ benchmark channel
$$\eta \rightarrow e^+ e^- e^+ e^-$$ double VMD?

$$\omega - \pi^0$$ transition form factor solve the puzzle?

next generation measurements from CLAS12
xtras
light meson decays

\[
\begin{align*}
\text{Light Mesons} & \quad \text{Hadronic} \quad \text{Radiative} \quad \text{Conversion} \\
\pi & \quad \pi & \quad \pi & \quad \gamma & \quad \gamma & \quad \gamma \\
(\pi^+\pi^-) & \quad \quad & \quad \quad & \quad \quad & \quad \quad & \quad (\pi^+\pi^-)
\end{align*}
\]

\begin{itemize}
\item \text{Quark mass ratio}
\item \text{Isospin violation}
\item \text{QCD anomalies}
\item \text{FSI}
\item \text{Transition Form Factor}
\item \text{CP-violation}
\end{itemize}

\textbf{WASA-at-COSY:} \pi, \eta

\textbf{CLAS:} \pi, \eta, \omega, \eta'

the original proposal for bringing WASA to COSY:

Proposal for the wide angle shower apparatus (WASA) at COSY-Julich: WASA at COSY
WASA-at-COSY Collaboration, e-Print: nucl-ex/0411038

the original proposal:

CAA Photoproduction and Decay of Light Mesons in CLAS
https://wiki.jlab.org/lmd/

Mitglied der Helmholtz-Gemeinschaft
theory confronts experiment

Role of hadronic decays for g-2

[Jegerlehner, arXiv:1705.00263]
status analysis $\eta \rightarrow eeeee$

new analysis:
improve statistics
study combinatorics
look at pp pi0 data?
status of the $\omega$-$\pi$ transition form factor


$\Lambda^{-2} = (1.99 \pm 0.21_{\text{tot}}) \text{ GeV}^{-2}$
1100 overall statistics

**Conclusion:**

- A2 results are in better agreement with theoretical calculations, compared to earlier experiments
- Statistical accuracy of the present data points at large $m$ (ee) masses does not allow a final conclusion
analysis strategy cut-based analysis

- smooth background ← subtract via MMp spectrum
- in-peak background (competing decays) ← simulations
- photon conversion from $\pi \to \gamma \gamma$ (small ee masses) ← simulations
analysis strategy cut-based analysis

missing mass MMp

missing mass MMpee

invariant mass Mee

e^+e^- detection and missing particle

missing pion:
- missing mass is pion
- missing energy finite

missing photon:
- missing mass zero
- missing energy finite

missing nothing:
- missing mass zero
- missing energy zero

\[ \omega \rightarrow \pi ee \]

\[ \eta' \rightarrow \gamma ee \]

\[ \rho/\omega \rightarrow ee \]