INVESTIGATION OF TIMELIKE TRANSITION FORM FACTORS OF LIGHT MESONS AND EXCITED HYPERONS
OUTLINE

• Why investigate Time-Like Transition Form Factors
• Light meson decays
• Dalitz decay of excited hyperons
• Summary & conclusions
ELECTROMAGNETIC TRANSITION FORM FACTORS

Coupling of Light to Matter

- **Anomalous** Measurement of the muon anomalous magnetic moment $a_\mu$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$a_\mu \sigma_{a_\mu} [10^{-11}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Model</td>
<td>116 591 820.5 (35.6)</td>
</tr>
<tr>
<td>QED</td>
<td>116 584 718.97 (0.1)</td>
</tr>
<tr>
<td>EW</td>
<td>153.6 (1.0)</td>
</tr>
<tr>
<td>Strong</td>
<td></td>
</tr>
<tr>
<td>HVP</td>
<td>6846.9 (24.6)</td>
</tr>
<tr>
<td>HLbL</td>
<td>101 (26.1)</td>
</tr>
</tbody>
</table>

Precision limited by hadronic contributions

HLbL major source of uncertainty

Leading contributions: PS poles, 2-meson int. states

Input from singly and doubly virtual PS-TFF

$$a_\mu = \frac{g_\mu - 2}{2} = a^{\text{QED}}_\mu + a^{\text{weak}}_\mu + a^{\text{hadr}}_\mu$$
ELECTROMAGNETIC TRANSITION FORM FACTORS

Coupling of Light to Matter

- **Anomalous** Measurement of the muon anomalous magnetic moment $a_{\mu}$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$a_{\mu} \pm \sigma_{a_{\mu}} [10^{-11}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Model</td>
<td>116 592 089 (63.0)</td>
</tr>
<tr>
<td>QED</td>
<td>116 584 718.97 (0.1)</td>
</tr>
<tr>
<td>EW Strong</td>
<td>153.6 (1.0)</td>
</tr>
<tr>
<td>HVP</td>
<td>6846.9 (24.6)</td>
</tr>
<tr>
<td>HLbL</td>
<td>101 (26.1)</td>
</tr>
</tbody>
</table>

We are eagerly awaiting Run-2 of g-2 at FNAL

$$a_{\mu} = \frac{g_{\mu} - 2}{2} = a_{\mu}^{\text{QED}} + a_{\mu}^{\text{weak}} + a_{\mu}^{\text{hadr}}$$

Precision limited by hadronic contributions

HLbL major source of uncertainty

Leading contributions: PS poles, 2-meson int. states

Input from singly and doubly virtual PS-TFF
Dispersive analyses of $\pi^0$, $\eta(\prime)$ TFF

- High precision data e.g. $\eta \rightarrow \pi^+\pi^-\gamma$ (KLOE) $\eta^' \rightarrow \pi^+\pi^-\gamma$ (BES-III) are available

- Dispersive analyses allow high precision predictions of $\pi^0, \eta \rightarrow \gamma^*\gamma$
  (see e.g. B. Kubis)

- Further experimental input needed from $\omega/\pi \rightarrow \pi^0\gamma^*$ for precision test of $F_{\pi^0\gamma^*\gamma^*}$
Kinematics of $\pi^0 \rightarrow \gamma^* \gamma^*$ Transition Form Factor

Experimental access to different kinematic regions via different reactions

“Low” $q^2$ region most relevant for $(g-2)_\mu$

\[ \propto F^\pi_V \times T(\gamma\pi \rightarrow \pi\pi) \]

Figure by B. Kubis
Kinematics of $\pi^0 \rightarrow \gamma^* \gamma^*$ Transition Form Factor

\[ e^- \rightarrow \pi^0 \rightarrow e^+e^-e^+e^- \]

VMD Description

\[ |F_{\pi^0}(q_1^2, q_2^2)|^2 \]

Figure by B. Kubis
TL TRANSITION FORM FACTOR for $\omega \rightarrow \pi^0 \ell^+\ell^-$

- Data clearly above VMD
- NA60 data hard to reconcile with $ee \rightarrow \omega\pi^0$
- No tension of calculations with the A2 data that are less precise at higher $q^2$

B. Kubis
STATUS $\omega - \pi$ TRANSITION FORM FACTOR

$\gamma p \rightarrow p \omega \rightarrow p \pi^0 e^+ e^-$

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


further analysis underway

further data from CLAS12

S. Schadmand, DPG2019
TIME-LIKE TFF ABOVE THE OMEGA-MESON

- $\phi$ and $\eta'$ have much more phase space for $\gamma^*$ to cross the $\rho/\omega$ peak
- More statistics needed in the interesting region. ($\phi$ KLOE, $\eta'$ BES-III )
- New measurements needed. e.g. $\rightarrow$ CLAS12-RGA. (up to 28,000 evts/80days)

\[ \text{CLAS12: projected statistics} \]

\[ \text{864} \pm 36 \quad \eta' \rightarrow \gamma ee \]
\( \pi^0 \rightarrow eeee \) Doubly Virtual Decay

- Space-Like data from \( \gamma\gamma \) events (e.g. BES-III)
- New analysis with WASA-at-COSY Time-Like data
- “Background free” \( \rightarrow \)
  - pp below 2\( \pi \) threshold (neg. part. must be e\( ^- \))
- Still including conversion
- Data sets from 2012+2013
\[ \pi^0 \rightarrow e^+e^-e^+e^- \] Doubly Virtual Decay

- Space-Like data from \( \gamma\gamma \) events (e.g. BES-III)
- New analysis with WASA-at-COSY Time-Like data
- "Background free" \( \rightarrow \) pp below \( 2\pi \) threshold (neg. part. must be \( e^- \))
- Still including conversion
- Data sets from 2012+2013

- KLOE 329 evts PLB702(2011)324
- KTeV: published 30,000 evts. PRL 100 182001

preliminary

MM(2p) (GeV)
DALITZ DECAY OF EXCITED HYPERONS
HYPERON TL-TRANSITION FORM FACTORS

- Hyperon electromagnetic form factors probe SU(3)F flavor symmetry breaking and the effects of explicit and hidden strangeness on electromagnetic observables
- Applying SU(3)F flavor symmetry enables predictions of the hyperon form factors in terms of model parameters fixed by the nucleon data
- Currently best way to study hyperon structure (no hyperon target)
- Very little data available:
  - Annihilation reactions: time-like with high $q^2 > (m_1+m_2)^2$ e.g. $e^+e^- \rightarrow Y_1 Y_2$
  - Dalitz Decays: time-like with low $q^2 > (m_1-m_2)^2$ e.g. $Y_1 \rightarrow Y_2 e^+e^-$
RADIATIVE DECAYS OF EXCITED BARYONS

- Timelike \((G_M(q^2), G_E(q^2))\) complementary to Spacelike kinematic region

  - Time-like electromagnetic form factors
  - Space-like electromagnetic form factors

- Low energy TL complementary to high energy TL (e.g. BES-III, CLEO)

- Access to kinematically forbidden region for annihilation

- Higher mass resonances…
## COMPARISON OF $\Xi^*$ STATISTICS

(#RECONSTRUCTED HADRONIC DECAYS)

- $\Xi(1530) \to KK\pi$  CLAS12  270,000 evts/80 days (el.pr., E12-11-005a)
- $\gamma p \to K^+K^+\Xi'(1530)$  GlueX  100,000 evts/run (ph.pr., DIRC-Upgrade...)
- $K^-p \to K^+\Xi^-$  JPARC(P50)  300,000 evts/30 days (ground state)
- $pp \to pK^+\Xi^-$  HADES  300,000 evts/30 days (semi inclusive, gs $\Xi$)
- $K_L^0 p \to K^+ \Xi$  KLF  400,000 evts/100 days (exclusive, gs $\Xi$)
- $K_L^0 p \to K^+ \Xi^0$  KLF  40,000 evts/100 days (exclusive, L=10$^{31}$)
- $\bar{p}p \to \Xi^+\Xi^*$  PANDA  $10^6$ evts/100 days (exclusive, L=10$^{31}$)
- $pp \to \Xi^*X$  LHCb
- $e^+e^- \to \Xi^*X$  Belle II
- $e^+e^- \to \Xi^*X$  BES III
USING HADES TO MEASURE $Y^* \rightarrow \Lambda ee$

- Proposed reaction:
  $$p \ p(A) \rightarrow Y \ (\text{any hyperon}) \ X \rightarrow \Lambda e^+e^- X \quad (BR \sim 10^{-5})$$

- High intensity AND energy proton beams ($T = 4.5 \text{ GeV}$)
- Measured BR ($\Lambda \gamma$) are large! (comparable to $\Delta \rightarrow N \gamma$)
- Hyperon states are narrow
- HADES has excellent $\Lambda$ and $e^+e^-$ capabilities

- Upgrade challenges:
  - Increase DAQ rate up to 200 kHz
  - Improve $\gamma$, $e^+e^-$ efficiency (ECAL, RICH) In operation in March 2019
  - Improve $\Lambda$ efficiency (STS, FTOF) Installation Q3/19
HADES UPGRADE

New:

- RICH photon-detector & Readout
- $e^+e^-$ eff. gain x 5

ECAL (Pb-glass)
- $g, e^+, e^-$
- $\sigma(E) / \sqrt{E} \sim 5.5\%$

Forward Detector:
- PANDA Straws
- $\sigma(x) \sim 140$ micron

RPC TOF
- $\sigma(t) \sim 70$ ps

- tracking with straws
- tof with RPC
- no PID with magnetic field
EXCITED HYPERON PROGRAM WITH PROTON BEAM AT HADES

Plan: 30 days of proton beam at close to max. SIS18 energy

1. Improve BR for $\Sigma^*^0 \rightarrow \Lambda \gamma$  
   $(10\% \rightarrow 3\%)$

2. Improve BR for $\Sigma^*^+ \rightarrow \Sigma^+ \gamma$  
   $(25\% \rightarrow 5\%)$

3. Establish BR for $\Sigma^0 \rightarrow \Lambda e^+ e^-$  
   $(\text{QED} 0.5\%)$

4. Establish BR for $\Sigma^*^0 \rightarrow \Lambda e^+ e^-$  
   $(\sim 10^{-4})$

5. Establish BR for $\Lambda^* (1520) \rightarrow \Lambda e^+ e^-$  
   $(\sim 8 \times 10^{-5})$

6. Form Factors (mostly magnetic) $q^2 < (260) \text{MeV}^2$  
   (never measured, expect 600-4000 events)

7. Explore double strange $\Xi^- (1321)$ production
SUMMARY & CONCLUSIONS

- Knowledge of Transition Form Factors important for fundamental physics
- Different experiments explore complementary kinematic regions
- Data on $\omega - \pi$ transition to $\gamma^*$ difficult to understand
- Hyperon TFF probe SU(3)F symmetry
- Many running/upcoming experiments addressing (multi-s) hyperons, with roughly similar statistics for the excited cascades
- New results on the TL-TFF from Dalitz decays will be coming soon
THANK YOU