Hyperons electromagnetic form factors with HADES

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HADES – High Acceptance Dielectron Spectrometer

HADES in 2007

HADES in 2022

Major HADES upgrades:
- RPC (2010)
- Pion Tracker (2014)
- ECAL (2017-2021)
- RICH upgrade (2018)
- Forward Detector (2021)
- iTOF (2021)
- new START (2021)

Previous experiments:
- various HI beams (Ar+KCl, Au+Au, Ag+Ag)
- light system beams:
  - p+p@3.5 GeV ('07)
  - p+Nb@3.5 GeV ('07)
  - π−+p/π−+A ('14)
  - p+p@4.5 GeV ('22)

Particle identification: dEdx, $\beta$ vs momentum
Electromagnetic transitions form-factors (eTFF)

- Sensitive probe of hyperon internal structure
- Measurements of eTFF

→ Space-like region $|Q^2| > 0$ is inaccessible for excited hyperons (as a target or beam)

→ Time-like high $|Q^2|$ is probed by electron-positron annihilation (BaBar, CLEO-C, BESIII)

→ Time-like low $|Q^2|$ available via Dalitz decays

**HADES is an excellent experiment for a Dalitz decay measurements**
Electromagnetic transitions form-factors (eTFF)

- Sensitive probe of hyperon internal structure
- Measurements of eTFF

- Space-like region $|Q^2| > 0$ is inaccessible for excited hyperons (as a target or beam)
- Time-like high $|Q^2|$ is probed by electron-positron anihilation (BaBar, CLEO-C, BESIII)
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HADES is an excellent experiment for a Dalitz decay measurements
Comparison of strange and non-strange baryons

i.e. $\Delta(1232)\rightarrow N^+e^-$ (measured by HADES) with $\Sigma(1385)^0\rightarrow \Lambda^+e^-e^-$ - (flavor sym. partner of $\Delta$ in SU(3))
Tests VDM hypothesis (coupling to $\rho, \omega$) for hyperons.

$\pi\pi$ decays complementary to dileptons.

Independent $\Lambda(1520)$ reconstruction via $\Lambda\pi^-\pi^+$ decay (BR = 6%), and

$\Sigma(1385)$ via $\Lambda\pi$ (BR = 87%)

Radiative decay $Y \rightarrow \Lambda e^+e^-$

Projections for HADES with p+p@4.5 GeV; Expected: ~300 events/Y

Hadronic decay $\Lambda(1520) \rightarrow \Lambda\pi^+\pi^- + X$

Reference HADES results from p+p@3.5 GeV (t.b.pub.)

Projections for HADES p+p@4.5 GeV; Expected: ~500k events
Hyperon electromagnetic decays

- Complementary to Dalitz decay
- Y internal structure sensitive to $\Lambda_\gamma/\Sigma^0_\gamma$ transition rates
- $\Sigma(1385)^0$ and $\Lambda(1520) \rightarrow \Lambda_\gamma$ measured by CLAS

$\Sigma^0$ production

Reconstruction of $\Sigma^0$ as reference for $\Lambda$ production and feed-down in $Y \rightarrow \Lambda e^+ e^-$

Recent HADES results for $\Sigma^0 \rightarrow \Lambda_\gamma$ with p+p@3.5 GeV (t.b.p)

Radiative decays of $Y \rightarrow \Lambda_\gamma$

Projections for HADES with p+p@4.5 GeV;
Expected: 1500 events
### Electromagnetic hyperon decays ($\Lambda\gamma^+$ and $\Lambda\gamma$)

<table>
<thead>
<tr>
<th>Decay</th>
<th>Count Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma(1385)^0 \rightarrow \Lambda e^+ e^-$</td>
<td>302</td>
</tr>
<tr>
<td>$\Lambda(1520) \rightarrow \Lambda e^+ e^-$</td>
<td>352</td>
</tr>
<tr>
<td>$\Sigma(1385) \rightarrow \Lambda\gamma$</td>
<td>1484</td>
</tr>
<tr>
<td>$\Lambda(1520) \rightarrow \Lambda\gamma$</td>
<td>1559</td>
</tr>
</tbody>
</table>

### Hyperon hadronic decays

<table>
<thead>
<tr>
<th>Decay</th>
<th>Count Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda(1405) \rightarrow \Sigma^0 \pi^0 \rightarrow \Lambda 3\gamma$</td>
<td>$3.6 \times 10^4$</td>
</tr>
<tr>
<td>$\Lambda(1405) \rightarrow \Sigma^0 \pi^0 \rightarrow \Lambda \gamma$</td>
<td>$7.2 \times 10^4$</td>
</tr>
<tr>
<td>$\Lambda(1405) \rightarrow \Sigma^\pm \pi^\mp \rightarrow \Lambda \gamma$</td>
<td>$5.2 \times 10^5$</td>
</tr>
</tbody>
</table>

### Production of double and hidden strangeness

<table>
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<tr>
<th>Decay</th>
<th>Count Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Xi^- \rightarrow \Lambda\pi^-$</td>
<td>$(4.7 - 47.6) \times 10^4$</td>
</tr>
<tr>
<td>$\Lambda\Lambda$</td>
<td>$(0.62 - 6.17) \times 10^4$</td>
</tr>
<tr>
<td>$\varphi \rightarrow \Lambda\pi^-$</td>
<td>$3.1 \times 10^6$</td>
</tr>
</tbody>
</table>

### Inclusive measurement of hadrons and dielectrons

<table>
<thead>
<tr>
<th>$M_{ee}$</th>
<th>Count Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{ee} &lt; 0.15 \text{ GeV}/c^2$</td>
<td>$5.72 \times 10^6$</td>
</tr>
<tr>
<td>$M_{ee} &gt; 0.15 \text{ GeV}/c^2$</td>
<td>$7.41 \times 10^5$</td>
</tr>
<tr>
<td>$\omega \rightarrow e^+ e^-$</td>
<td>$5.8 \times 10^4$</td>
</tr>
<tr>
<td>$\varphi \rightarrow e^+ e^-$</td>
<td>$1.86 \times 10^3$</td>
</tr>
<tr>
<td>$M_{ee} &gt; 1.1 \text{ GeV}/c^2$</td>
<td>$69$</td>
</tr>
</tbody>
</table>
$\Lambda(1520)$ production at 3.5 GeV – reference for dilepton decay channel

$p+p@3.5$ GeV and $p+Nb@3.5$ GeV beams (2007)

- production via $p+p \rightarrow pK^+ \Lambda(1520)[\Lambda^+\pi^-]$
- $\Lambda^+\pi^-\pi^-$ threshold is 220 MeV below total energy for $p+p$
- inclusive analysis of $p\pi^-\pi^+\pi^-$ final state
- dominating backgroud from $\Delta^{++}\pi^-\Delta^{++}\pi^-\pi^-$ channel
- also from $p+p \rightarrow \Lambda[p\pi^-]K^0[\pi^+\pi^-]p\pi^+$
Λ(1520) production at 3.5 GeV – reference for dilepton decay channel

p+p@3.5 GeV and p+Nb@3.5 GeV beams (2007)

- production via p+p→pK⁺Λ(1520)[Λπ⁺π⁻]
- Λπ⁺π⁻ threshold is 220 MeV below total energy for p+p
- inclusive analysis of pπ⁻π⁺π⁻ final state
- dominating background from Δ++π⁻Δ++π⁻ channel
- also from p+p→Λ[π⁻]K⁰[π⁺π⁻]pπ⁺

Λ selection

- TMVA based selection
- A set - \( M \in (1015, 1025) \)
- B set - outside above
- no simulations required
\( \Lambda(1520) \) production at 3.5 GeV – reference for dilepton decay channel

**\( \Lambda \) selection**
- topological cuts selected by TMVA

\( \Lambda(1520) \) selection
- sideband analysis for \( \Lambda(1520) \) signal

\( \Lambda \) in \( p+p \)

\( \Lambda \) in \( p+Nb \)

\( \Lambda \pi^- \pi^+ \) in \( p+p \)

\( \Lambda \pi^- \pi^+ \) in \( p+Nb \)
Cross-sections normalizations

**p+p**

- data driven model

  J. Aamczewski-Musch et al. (HADES), Phys. Rev. C 95, 015207 (2017)

<table>
<thead>
<tr>
<th>no.</th>
<th>Channel</th>
<th>$\sigma$ [µb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\Lambda(1520)pK^+$</td>
<td>$5.6 \pm 1.1 \pm 0.4^{+1.1}_{-1.6}$</td>
</tr>
<tr>
<td>2</td>
<td>$\Lambda\Delta^{++}K^0$</td>
<td>$29.45 \pm 0.08^{+1.67}_{-1.46} \pm 2.06$</td>
</tr>
<tr>
<td>3</td>
<td>$\Sigma^0\Delta^{++}K^0$</td>
<td>$9.26 \pm 0.05^{+1.41}_{0.31} \pm 0.65$</td>
</tr>
<tr>
<td>4</td>
<td>$\Sigma(1385)^+pK^0$</td>
<td>$14.05 \pm 0.05^{+1.79}_{-2.14} \pm 1.00$</td>
</tr>
<tr>
<td>5</td>
<td>$\Delta^{++} \Lambda(1405)K^0$</td>
<td>$5.0 \pm 20%$</td>
</tr>
<tr>
<td>6</td>
<td>$\Delta^{++}\Sigma(1385)^0K^0$</td>
<td>$3.5 \pm 20%$</td>
</tr>
<tr>
<td>7</td>
<td>$\Delta^+\Sigma(1385)^0K^0$</td>
<td>$2.3 \pm 20%$</td>
</tr>
</tbody>
</table>

**4-body reactions**

<table>
<thead>
<tr>
<th>no.</th>
<th>Channel</th>
<th>$\sigma$ [µb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>$\Lambda p\pi^+K^0$</td>
<td>$2.57 \pm 0.02^{+0.21}_{-1.98} \pm 0.18$</td>
</tr>
<tr>
<td>9</td>
<td>$\Sigma^0 p\pi^+K^0$</td>
<td>$1.35 \pm 0.02^{+0.10}_{-1.35} \pm 0.09$</td>
</tr>
</tbody>
</table>

**p+Nb**

- with use of UrQMD model


- no $\Lambda(1520)$ production included
- but non-resonant $\Lambda\pi^-\pi^+$ can be simulated
- $\Lambda(1520)$ simulated with thermal source from Pluto:
  - $\rightarrow$ a static (not expanding) thermal source characterized by temperature $T_S = 75$ MeV and rapidity $y_S = 1.04$
$\Lambda(1520)$ candidates

**p+p**
- red – non-resonant $\Lambda\pi^+\pi^-$ background
- green – $\Lambda(1520)$ signal

**p+Nb**
- red – URQMD non-resonant $\Lambda\pi^+\pi^-$ background
- green – $\Lambda(1520)$ signal
- orange – $\Sigma(1385)$ signal

### $\Lambda(1520)$ candidates

<table>
<thead>
<tr>
<th>$M_{\Lambda(1520)}$ [$\text{MeV}/c^2$]</th>
<th>$\sigma_{\Lambda(1520)}$ [$\text{MeV}/c^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDG</td>
<td>1519.5 ± 1.0</td>
</tr>
<tr>
<td>$p+p$</td>
<td>1504.5 ± 4.7</td>
</tr>
<tr>
<td>sim</td>
<td>1515.6 ± 2.1</td>
</tr>
</tbody>
</table>

$\sigma_{p+p\rightarrow\Lambda(1520)X} = 7.1 ± 1.1 ± 0.0^{+0.0}_{-2.14} \text{ mb}$

### $p+Nb$ candidates

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<tr>
<th>$M_{\Lambda(1520)}$ [$\text{MeV}/c^2$]</th>
<th>$\sigma_{\Lambda(1520)}$ [$\text{MeV}/c^2$]</th>
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<tr>
<td>$p+p$</td>
<td>1504.5 ± 4.7</td>
</tr>
<tr>
<td>$p+Nb$</td>
<td>1507.7 ± 3.3</td>
</tr>
</tbody>
</table>

$\sigma_{p+Nb\rightarrow\Lambda(1520)X} = 4.97 ± 0.45 ± 3.58^{+3.58}_{-2.53} \text{ mb}$
Hades can provide first data of hyperon Dalitz decay
The 3.5 GeV (2007) data provide reference measurements of $\Lambda(1520) \rightarrow \Lambda \pi^+\pi^-$
The 4.5 GeV (2022) data will allow for the first hyperon Dalitz decays of $\Lambda(1520)$ and $\Sigma(1385)$

$\Lambda(1520)$ from 3.5 GeV paper is being written, expect it for 2023
First hyperon Dalitz data from p+p@4.5 GeV to be also expected in 2023, stay tuned