Investigation on the tensor analyzing power t_{20} in the reaction $\vec{\mathrm{d}} + \mathrm{p} \rightarrow {}^3\mathrm{He} + \eta$

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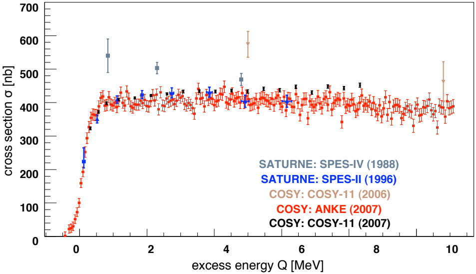
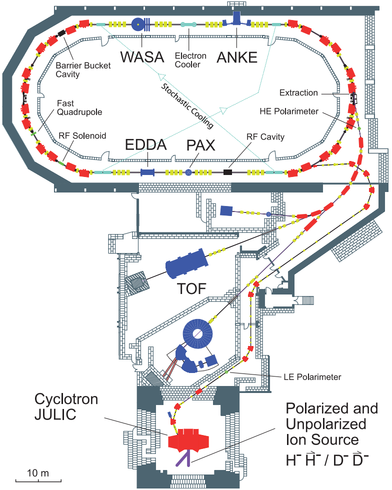
Motivation

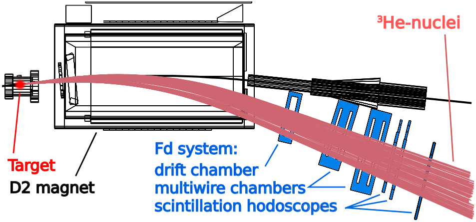
- Previous unpolarized measurements on $\mathbf{dp} \rightarrow {}^{3}\mathbf{He}\eta$ provided detailed cross section data near the production threshold
- Excitation function has shown indications of an unexpected strong final state interaction (FSI)



- Test for contributions to the cross section other than FSI possible by polarized measurements
- ANKE: Investigation of the reaction with a tensor/vector polarized deuteron beam

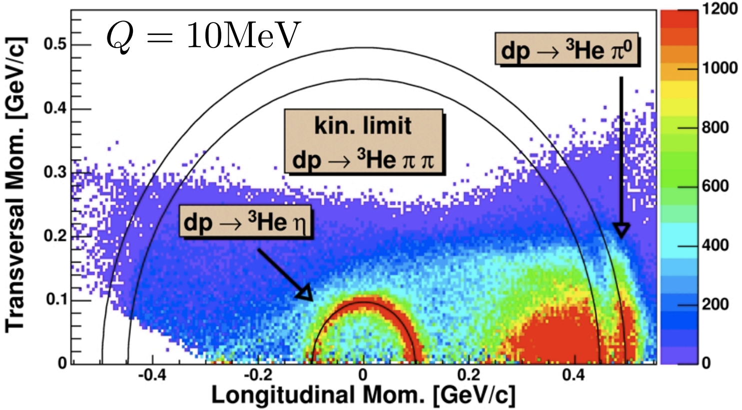
Measuring dp $\rightarrow$ ^{3}He η at ANKE at COSY





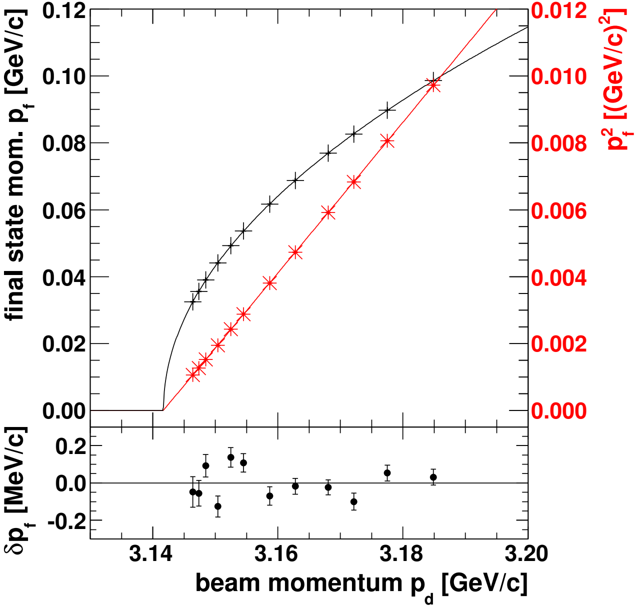
- Internal fixed target experiment with a cluster-jet target
- ^{3}He nuclei detected in the forward-system
- Full geometrical acceptance for dp $\rightarrow$ ^{3}Heη up to 20 MeV excess energy

Acceptance of the ANKE detector system



- Full acceptance for dp $\to$ ^{3}Heη
- Continuously ramped beam from $Q = -5$ MeV to $Q = 11$ MeV

High precision η mass determination

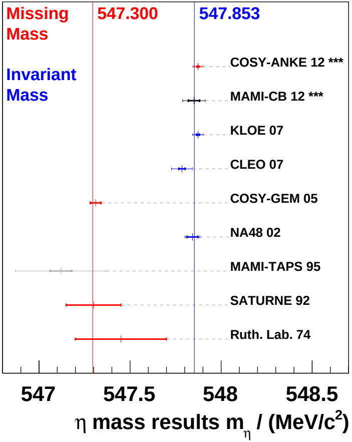


ANKE-COSY result of the η mass

$$m_\eta = (547.873 \pm 0.005_{\text{stat.}} \pm 0.023_{\text{sys.}})\ \text{MeV}/c^2$$

ANKE η meson mass

- Highest precision measurement yet
- In agreement with higher η meson mass measurements
- Published in Physical Review D85, 112011 (2012)



^{3}Heη final state interaction

Description of the differential cross section

- Differential cross section of a two-body reaction:

$$\frac{p_i}{p_f} \cdot \frac{d\sigma}{d\Omega} = |f|^2 = |f_B \cdot FSI|^2 = |f_B|^2 \cdot |FSI|^2$$

- Effective range approximation:

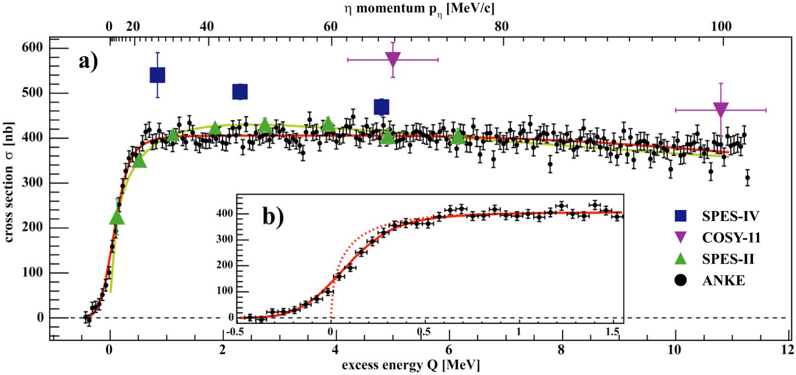
$$FSI = \frac{1}{1 + i \cdot a \cdot p_f + \frac{1}{2} a \cdot r_0 \cdot p_f^2}$$

- Alternative description with poles:

$$FSI = \frac{1}{\left(1 - \frac{p_f}{p_1}\right) \cdot \left(1 - \frac{p_f}{p_2}\right)}$$

with $a = -i \cdot \frac{p_1 + p_2}{p_1 \cdot p_2}$ and $r_0 = +\frac{2 \cdot i}{p_1 + p_2}$

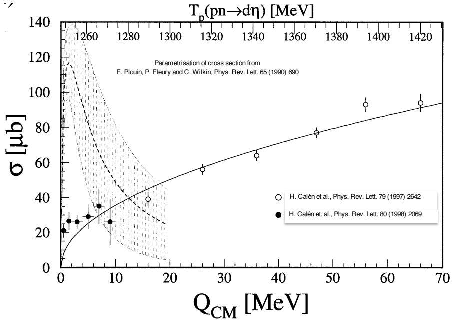
^{3}Heη final state interaction: unpolarized data



- Very good description for the whole energy range
- Pole close to threshold ($|Q_0| \approx 0.4\,\text{MeV}$) might be an indication for a quasi-bound state

Investigation of the reaction pn$\rightarrow$ dη

- Investigation of A dependence of the η-nucleus FSI
  $\rightarrow$ further important information about η-mesic nuclei
- Determination of dη scattering length
  $\rightarrow$ information about still unprecisely known ηN scattering length



- Measurement has been performed earlier this year

Why polarised measurements?

Additional information for FSI ansatz needed

- Test for further contributions besides FSI
- Investigate production amplitude close to threshold

Alternative description of the η^3He s-wave production amplitude:

$$f = \bar{u}_{^3\mathrm{He}} \hat{p}_\mathrm{p} \cdot \left(A\vec{\varepsilon}_\mathrm{d} + iB\vec{\varepsilon}_\mathrm{d} \times \vec{\sigma}\right) u_\mathrm{p}$$

(Shown in J.-F. Germond & C. Wilkin, J. Phys. G 14, 181 (1988))

$$\frac{d\sigma}{d\Omega} = \frac{1}{3}\frac{p_f}{p_i}\left[|A|^2 + 2 \cdot |B|^2\right]$$

with A, B as the two s-wave amplitudes of the $^3\mathrm{He}\eta$ system

Why polarised measurements?

Assumption 1 Cross sections only differ from phase space because of FSI
$\Rightarrow A, B$ show same energy dependence

Assumption 2 Cross sections depend on spin dependent production amplitudes (no FSI effect)
$\Rightarrow A, B$ might show different energy dependence

How to separate $|A|^2$ and $|B|^2$?

$\Rightarrow$ Tensor analysing power t_{20}:

$$t_{20}(p_f) = \sqrt{2}\frac{|B|^2 - |A|^2}{|A|^2 + 2|B|^2}$$

Why polarised measurements?

Assumption: $|A|^2$ and $|B|^2$ only depend on FSI

$$|A|^2 = |A_0|^2 \cdot \text{FSI}(p_f)$$
$$|B|^2 = |B_0|^2 \cdot \text{FSI}(p_f)$$

$$\Rightarrow t_{20}(p_f) = \sqrt{2} \cdot \frac{|B_0|^2 - |A_0|^2}{|A_0|^2 + 2|B_0|^2} \cdot \frac{\text{FSI}(p_f)}{\text{FSI}(p_f)} = const.$$

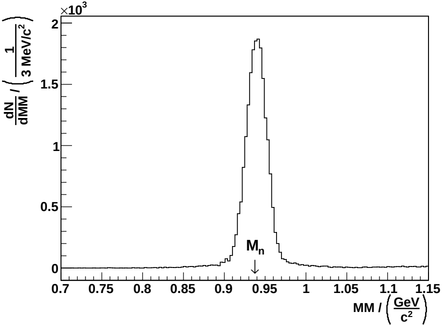
Measure t_{20} in collinear kinematics

$$t_{20}(p_f) = \frac{2\sqrt{2}}{p_{zz}} \cdot \left(\frac{\frac{d\sigma^0}{d\Omega}(\vartheta) - \frac{d\sigma^\uparrow}{d\Omega}(\vartheta)}{\frac{d\sigma^0}{d\Omega}(\vartheta)} \right)$$

Determining p_{zz}

Investigate reaction $d + p \to (pp) + n$ with known analyzing powers at lower energy ($T_d = 1.2\,\text{GeV}$)

$$\frac{d\sigma^{\uparrow}}{dt}(q,\varphi) / \frac{d\sigma^{0}}{dt}(q) = 1 + \sqrt{3} p_z i t_{11}(\vartheta)\cos\varphi$$
$$- \frac{1}{2\sqrt{2}} p_{zz} t_{20}(\vartheta) - \frac{\sqrt{3}}{2} p_{zz} t_{22}(\vartheta)\cos 2\varphi$$



Determining t_{20}

- Reminder:

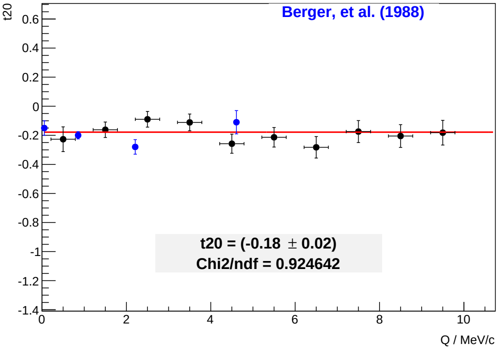
$$t_{20}(p_f) = \frac{2\sqrt{2}}{p_{zz}} \cdot \left(\frac{\frac{d\sigma^0}{d\Omega}(\vartheta) - \frac{d\sigma^\uparrow}{d\Omega}(\vartheta)}{\frac{d\sigma^0}{d\Omega}(\vartheta)} \right) \qquad \vartheta = 0^\circ, 180^\circ$$

- Hence:

$$t_{20}(p_f) = \frac{2\sqrt{2}}{p_{zz}} \left(1 - \frac{N^\uparrow}{N^0} \right)$$

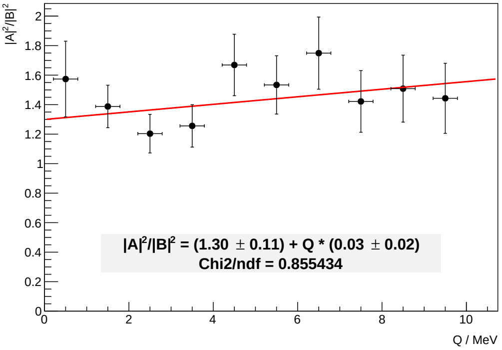
$N^\uparrow, N^0$ are normalized counts

Current status



- Data on t_{20} consistent with Berger, et al.
- No energy dependence visible within uncertainties

Current status



- Allow slope to put upper limit on spin dependent contributions

Summary

- Studied reaction $\vec{\mathrm{d}} + \mathrm{p} \to {}^3\mathrm{He} + \eta$ in energy range $Q = -5\,\mathrm{MeV}$ to $15\,\mathrm{MeV}$ relative to η-threshold
- No energy dependence of t_{20} observed, t_{20} consistent with Berger, et al.
- Amplitudes A, B show same energy dependence within uncertainties
- Ratio of $|A|^2/|B|^2$ will allow to quantify spin dependent contributions

→ Threshold behavior of $\mathrm{d} + \mathrm{p} \to {}^3\mathrm{He} + \eta$ consistent with pure FSI ansatz

Final data available soon

Thank you for your attention

Additional Slides

Production amplitude

- Two independent η s-wave amplitudes (close to threshold)
- Possible dp spin combinations: $S = \frac{3}{2}, \frac{1}{2}$
- Couples with orbital angular momentum of dp: $L_{dp} = 1$
  $\Rightarrow \quad J = \frac{1}{2}^{-}$
- Alternative production amplitude used for analogous π^0 production
  $f = \bar{u}_{^3\mathrm{He}} \hat{p}_{\mathrm{p}} \cdot \left(A\vec{\varepsilon}_{\mathrm{d}} + iB\vec{\varepsilon}_{\mathrm{d}} \times \vec{\sigma}\right) u_{\mathrm{p}}$

$\bar{u}_{^3\mathrm{He}}$:Spinors of the particles

$\vec{\varepsilon}_{\mathrm{d}}$:Polarisation vector of the deuteron

$\hat{p}_{\mathrm{p}}$:Direction of momentum

$\vec{\sigma}$:Pauli matrix

^{3}Heη final state interaction

- Fit to the data for $Q < 11$MeV

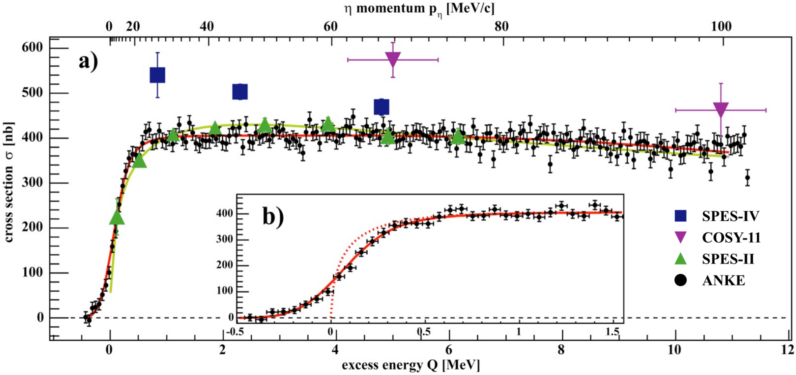
$$p_1 = \left[\left(-5 \pm 7^{+2}_{-1}\right) \pm i \cdot (19 \pm 2 \pm 1)\right] \frac{\text{MeV}}{\text{c}}$$
$$p_2 = \left[(106 \pm 5) \pm i \cdot \left(76 \pm 13^{+1}_{-2}\right)\right] \frac{\text{MeV}}{\text{c}}$$

- Pole of the production amplitude:

$$Q_0 = \frac{p_1^2}{2 \cdot m_{\text{red}}}$$
$$= [(-0.30 \pm 0.15 \pm 0.04) \pm i \cdot (0.21 \pm 0.29 \pm 0.06)]\,\text{MeV}$$
$$|Q_0| \approx 0.4$$

- Pole close to threshold expected from a quasi-bound state

^{3}Heη final state interaction



- Very good description for the whole energy range
- Unexpected large scattering length:
  $a_{^3\mathrm{He}\eta} = \left[\pm\left(10.7 \pm 0.8^{+0.1}_{-0.5}\right) + i\cdot\left(1.5 \pm 2.6^{-0.3}_{+1.0}\right)\right]$ fm