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Eta Meson Production in Proton-Deuteron Collisions

MESON 2014: 13th International Workshop on Meson Production, Properties and Interaction

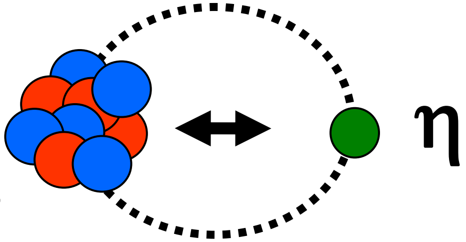
29th May - 3rd June 2014

Institut für Kernphysik

Alfons Khoukaz

wissen.leben WWU Münster

Why η-Meson Production Close to Threshold?



- Attractive *S*-wave ηN interaction

  R.S. Bhalerao and L.C. Liu, Phys. Rev. Lett. 54 (1985) 685

- Possible formation of η-nucleus bound states

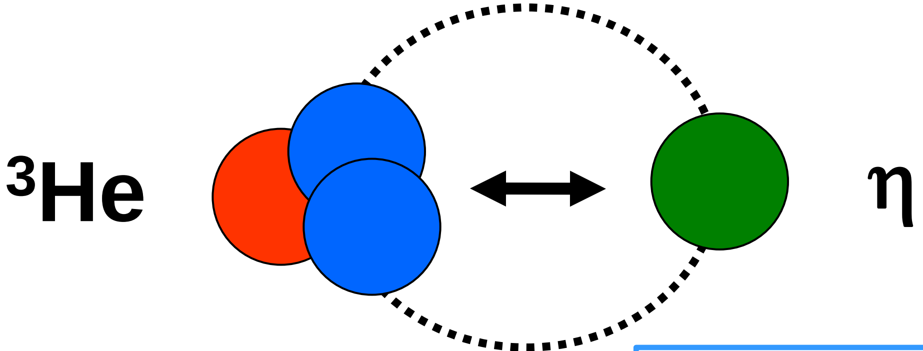
  Q. Haider and L.C. Liu, Phys. Lett. B172 (1986) 257

  C. Wilkin, Phys. Rev. C47 (1993) 938

- Broad η-mesic nuclei program at COSY
  - A>4: GEM (η^7Be)
  - η^4He: ANKE, GEM, WASA-at-COSY
  - η^3He: ANKE, COSY11, GEM, WASA-at-COSY
  - ηd: ANKE
- New data from proton-deuteron collisions

Why η-Meson Production Close to Threshold?

- Do bound meson-nucleus systems exist?



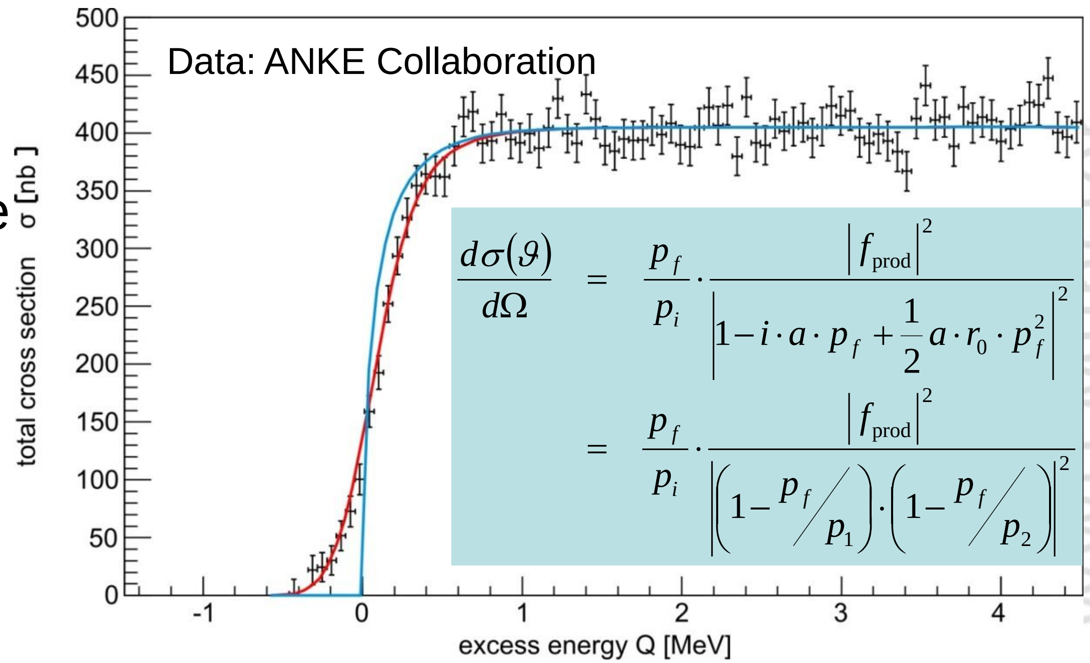
- Experimental access e.g. via

$$d+p \overset{(\rightarrow)}{} \rightarrow {}^3He+\eta$$
$$\gamma+{}^3He \rightarrow {}^3He+\eta$$

- Excitation function close to threshold → FSI
- Polarized beam → Test of FSI hypothesis, role of spins

Results for the Reaction d+p → ^{3}He+η

- A good candidate for a bound state is the η^{3}He-system
  - High precision data from ANKE and COSY-11
  - Observation of strong FSI
  - Strong indication for a pole at $|Q_0| \approx 0.37$ MeV
  - Further evidence for pole hypothesis by angular dependence of dp→η^{3}He

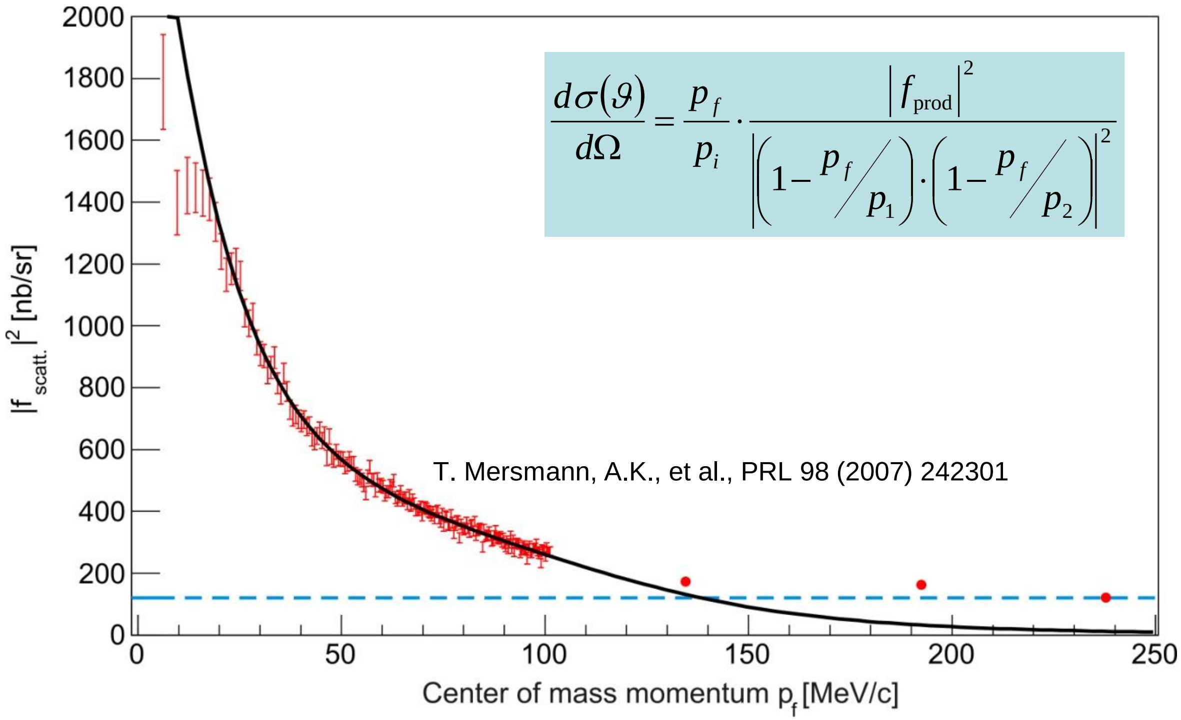


$$\frac{d\sigma(\vartheta)}{d\Omega} = \frac{p_f}{p_i}\cdot\frac{\left|f_{\mathrm{prod}}\right|^2}{\left|1 - i\cdot a\cdot p_f + \frac{1}{2}a\cdot r_0\cdot p_f^2\right|^2} = \frac{p_f}{p_i}\cdot\frac{\left|f_{\mathrm{prod}}\right|^2}{\left|\left(1-\frac{p_f}{p_1}\right)\cdot\left(1-\frac{p_f}{p_2}\right)\right|^2}$$

T. Mersmann et al. , Phys. Rev. Lett. 98 (2007) 242301

The d+p → ^{3}He+η Scattering Amplitude

Extracted scattering amplitude (Q > 0 MeV)

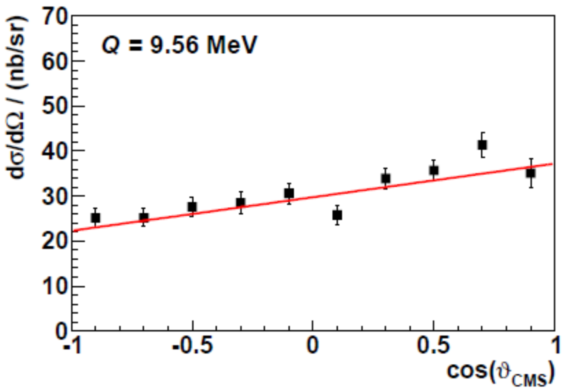


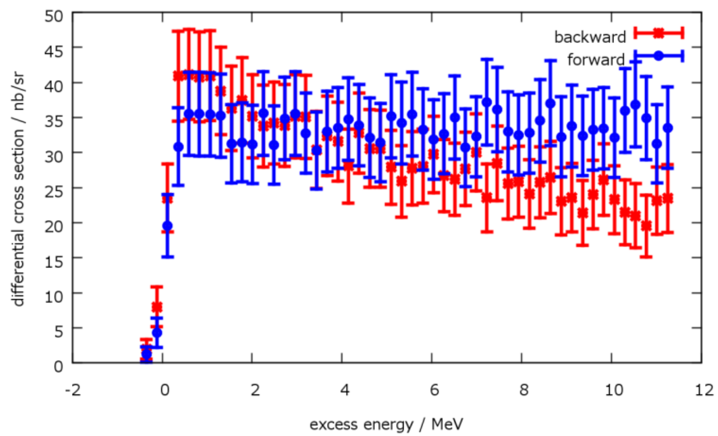
- Scattering amplitude decreases rapidly with increasing final state momentum p_f
- Scattering amplitude almost constant at high energies

→ strong FSI in η^3He system

Consideration of Higher Partial Waves: *P*-Waves

- Close to threshold: $d\sigma/d\Omega(\theta)$ = const. → *s*-wave
- Q > ~ 4 MeV: Contributions ~cos(θ) visible → *p*-wave





- Asymmetry in the angular distribution (η-meson):

  Slope at cos(θ)=0:

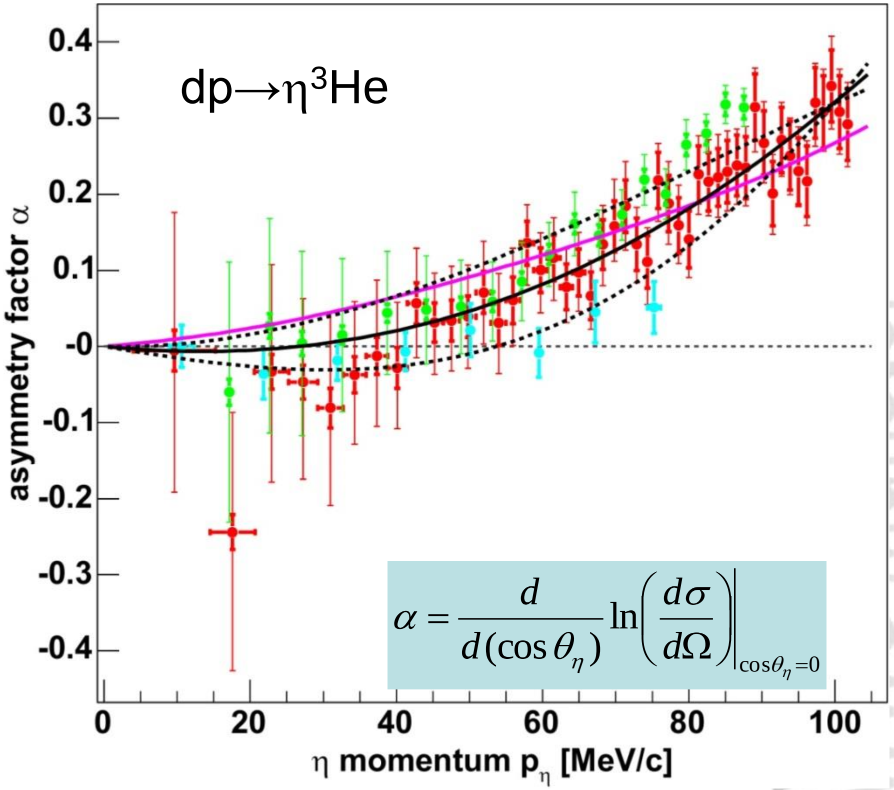
$$\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)\Bigg|_{\cos\theta_\eta = 0}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{CM} = \frac{\sigma_{tot}}{4\pi} \cdot \left(1 + \alpha \cdot \cos\theta_{CM}\right)$$

Consideration of Higher Partial Waves: *P*-Waves

- Slope might arises from the interference between the *s*- and *p*-waves in the η^3He system
- Indication of a strong phase variation of the s-wave at low *Q*
- Data (σ_{total} and dσ/dΩ) can be described well by assumption of a pole close to threshold

$$\left(\frac{d\sigma}{d\Omega}\right)_{CM} = \frac{\sigma_{tot}}{4\pi}\cdot\left(1+\alpha\cdot\cos\theta_{CM}\right)$$



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T. Mersmann et al. , Phys. Rev. Lett. 98 (2007) 242301

C. Wilkin et al., Phys. Rev. B 649 (2007) 92

Consideration of Higher Partial Waves: *P*-Waves

- Assumption: Only *s*- and *p*-waves

  Production operator:

C. Wilkin et al., PLB 654 (2007) 92

$$\hat{f} = A\vec{\varepsilon}\cdot\hat{p}_p + iB(\vec{\varepsilon}\times\vec{\sigma})\cdot\hat{p}_p + C\vec{\varepsilon}\cdot\vec{p}_\eta + iD(\vec{\varepsilon}\times\vec{\sigma})\cdot\vec{p}_\eta$$

A, B: *s*-wave amplitudes

C, D: *p*-wave amplitudes

ε: polarisation vector of the deuteron

$$\frac{d\sigma}{d\Omega} = \frac{p_\eta}{p_p}\overline{|f|^2} = \frac{p_\eta}{3p_p} I$$

$$I = |A|^2 + 2|B|^2 + p_\eta^2|C|^2 + 2p_\eta^2|D|^2 + 2p_\eta \,\mathrm{Re}(A*C + 2B*D)\cos\theta_\eta$$

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Consideration of Higher Partial Waves: *P*-Waves

- Resulting asymmetry factor:

$$\alpha = 2p_\eta \frac{\mathrm{Re}\left(A*C+2B*D\right)}{|A|^2+2|B|^2+p_\eta^2|C|^2+2p_\eta^2|D|^2}$$

Assumption:

- Same *s*-wave amplitudes: $A = B = f_s$

energy dependence due to FSI

- Same *p*-wave amplitudes: $C = D = const.$

$$\sigma = 4\pi \frac{p_\eta}{p_p}\left[|f_s|^2 + p_\eta^2|C|^2\right]$$

$$\alpha = 2p_\eta \frac{\mathrm{Re}\left(f_s^* C\right)}{|f_s|^2+p_\eta^2|C|^2}$$

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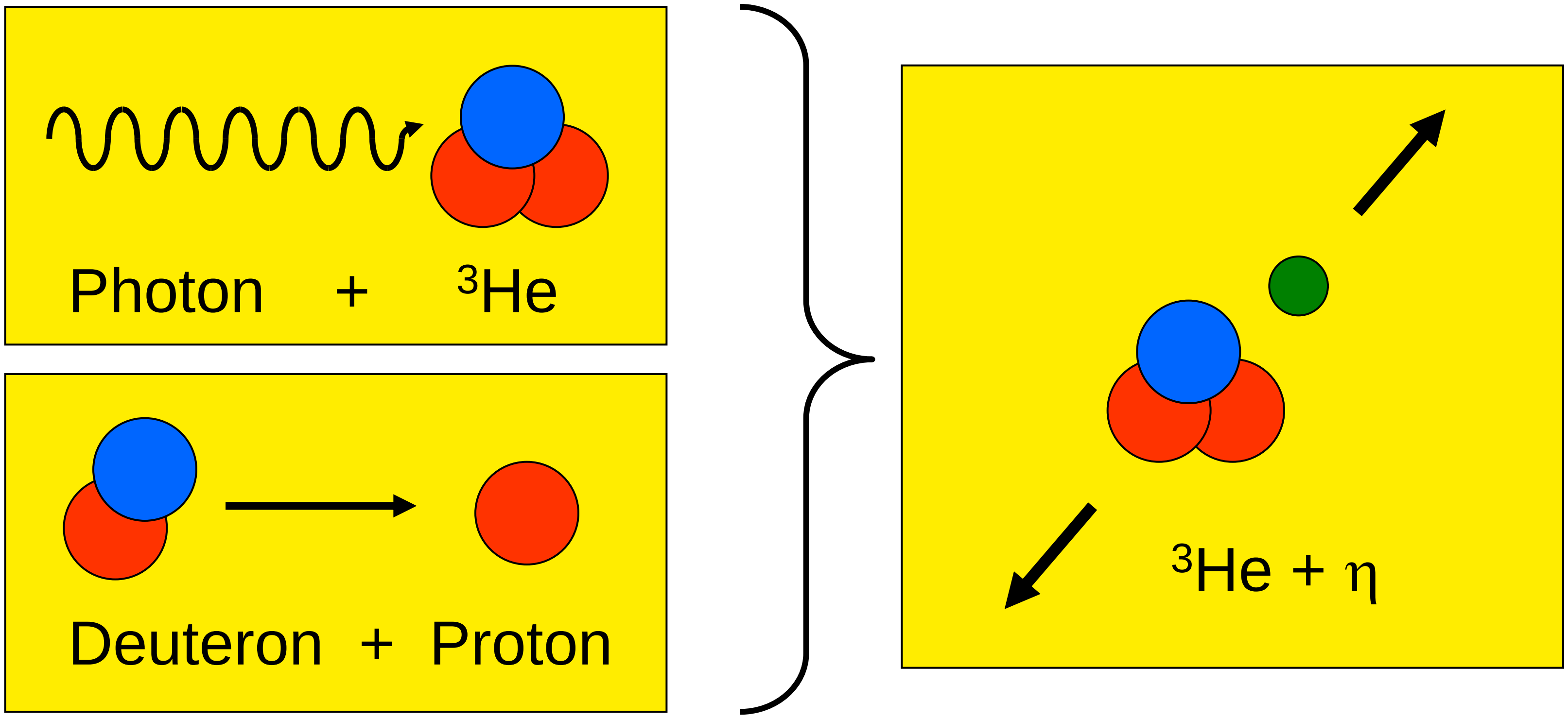
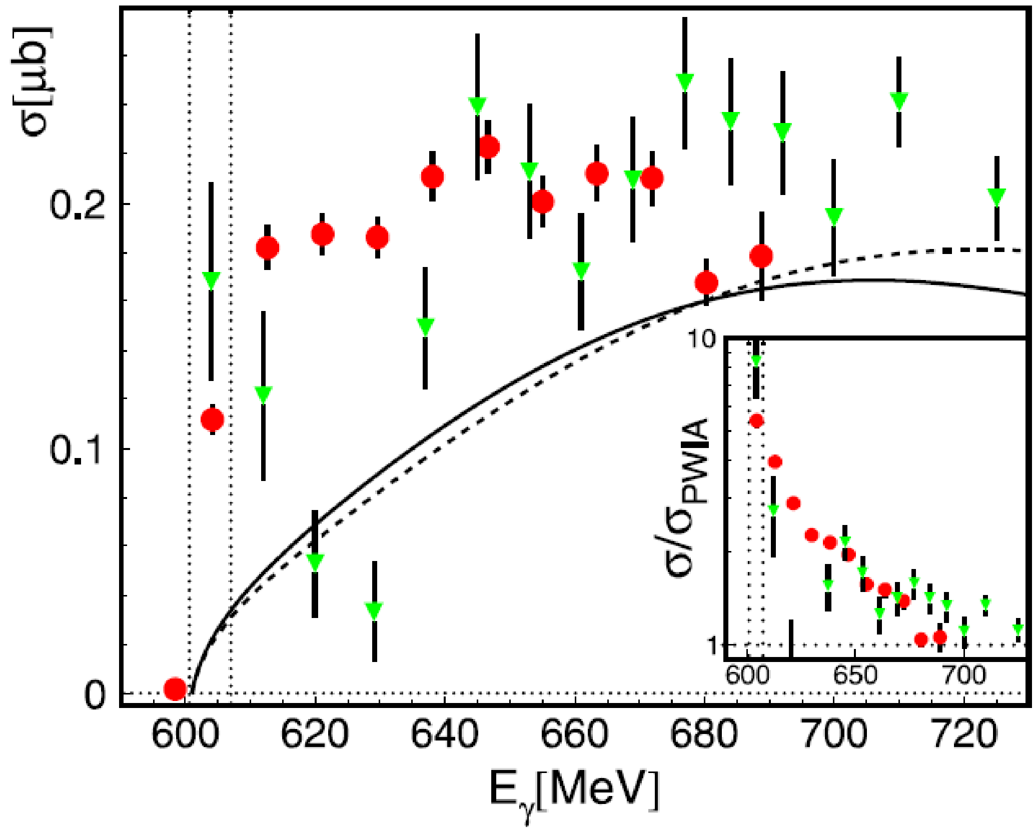
Compare: dp- and γ^3He-Scattering



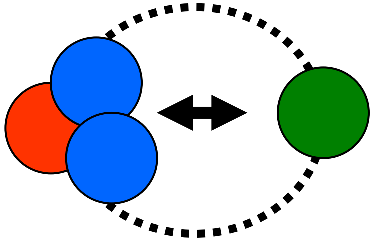
- Different initial states and production mechanism, but same final state

Compare: dp- and γ^3He-Scattering



F. Pheron et al., PLB 709 (2012) 21-27

- Scattering amplitudes show similar energy dependence
- Strong hint for a strong FSI between He-nuclei and η-mesons



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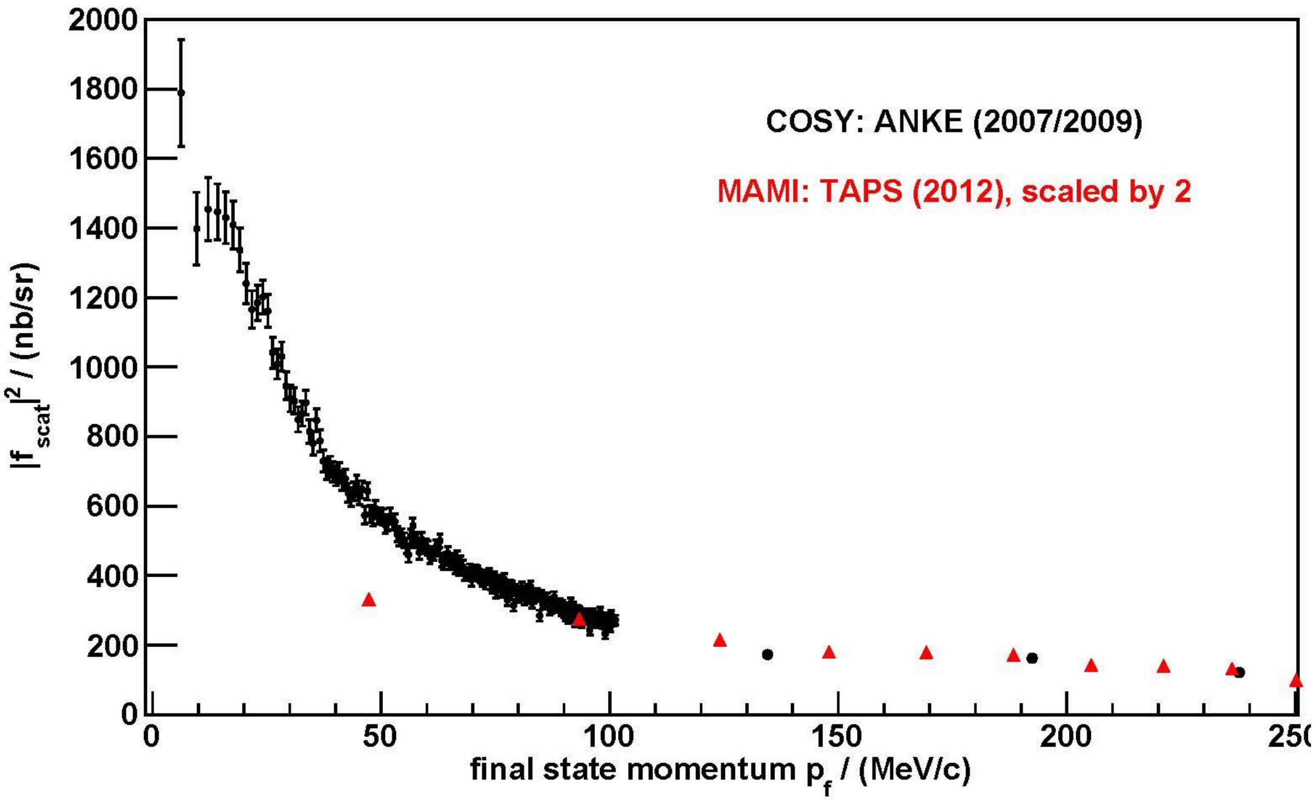
Compare: dp- and γ^3He-Scattering



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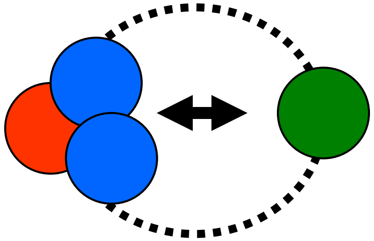
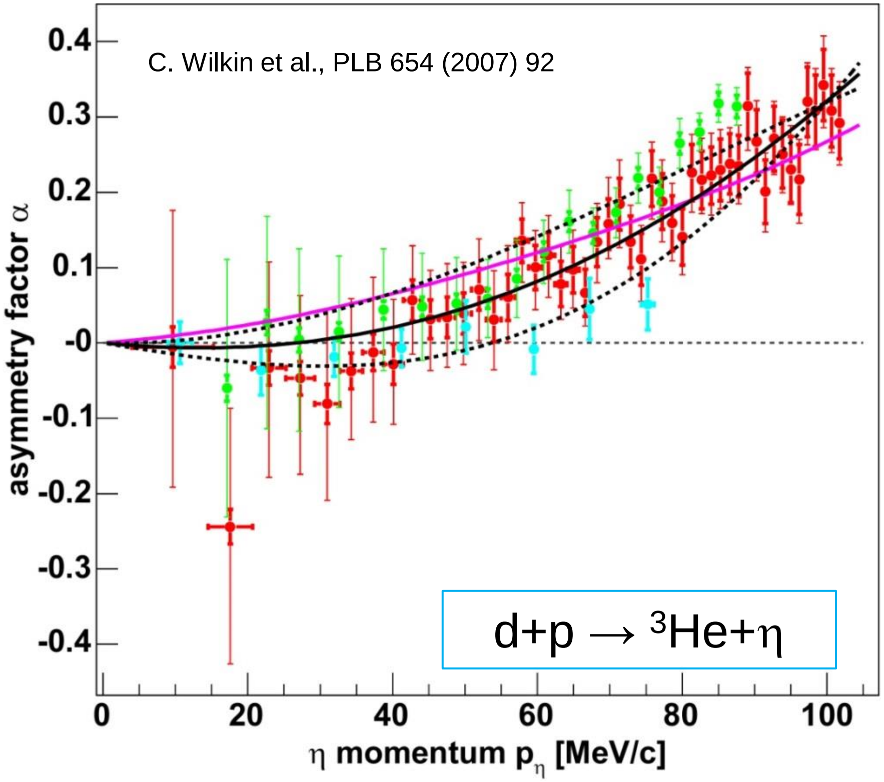
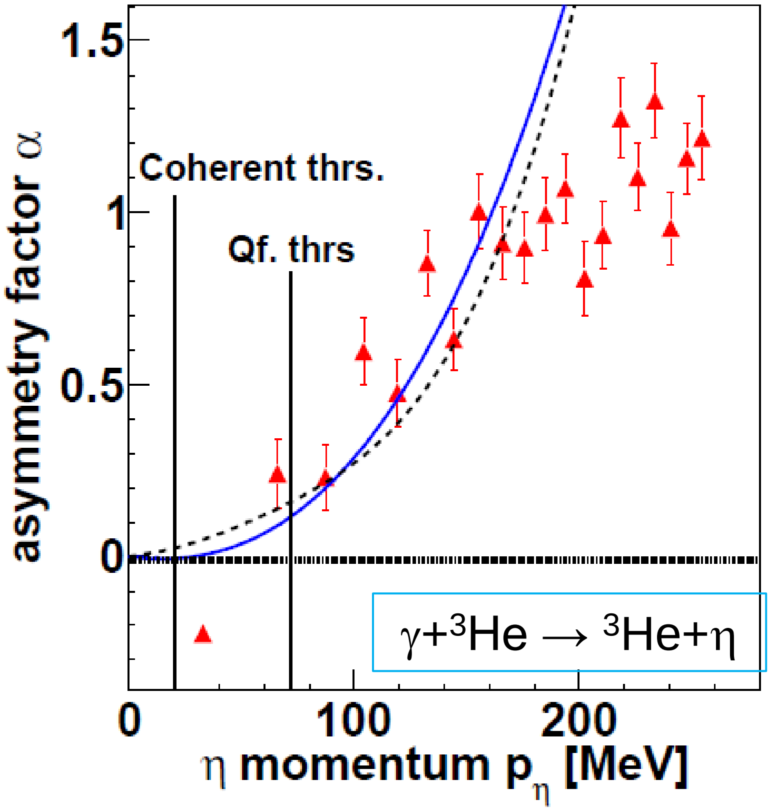


Compare: dp- and γ^3He-Scattering





$$\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)\Bigg|_{\cos\theta_\eta=0}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{CM} = \frac{\sigma_{tot}}{4\pi}\cdot\left(1+\alpha\cdot\cos\theta_{CM}\right)$$

F. Pheron, PhD thesis, University Basel, 2012

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Need of Further Data

- Excitation function(s) and differential cross sections for the η–^{3}He final state are compatible with the presence of a pole close to threshold
- Further input is needed to investigate e.g. the role of the spin of the entrance channel
- Very close to threshold the d+p $\rightarrow$ ^{3}He+η reaction is dominated by an *s*-wave ^{3}He+η system
- ANKE: Studies with tensor polarised deuterons

  $\vec{d}p \rightarrow {}^3He+\eta$

  Possible spins: S_{dp} = 1/2 or 3/2

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Polarized Measurements

Production amplitude for dp→^{3}He+η (π^0):

$$f_B = \bar{u}_\tau \vec{p}_p \cdot (A\vec{\varepsilon}_d + iB\vec{\varepsilon}_d \times \vec{\sigma}) u_p$$

see:
C. Kerboul et al.,
Phys. Lett. B 181, 28 (1986)

Determination of the energy dependence of the amplitudes A and B by measurement of:

$$\frac{d\sigma}{d\Omega} = \frac{1}{3}\frac{p_\eta}{p_p}\left[|A|^2 + 2|B|^2\right] \qquad T_{20} = \sqrt{2}\left[\frac{|B|^2 - |A|^2}{|A|^2 + 2|B|^2}\right]$$

$$|A|^2 = \frac{p_p}{p_\eta}(1-\sqrt{2}T_{20})\frac{d\sigma}{d\Omega} \qquad |B|^2 = \frac{p_p}{p_\eta}(1+\frac{1}{\sqrt{2}}T_{20})\frac{d\sigma}{d\Omega}$$

$$T_{20} = \frac{2\cdot\sqrt{2}}{p_{zz}} \cdot \frac{d\sigma_0/d\Omega(\vartheta) - d\sigma_\uparrow/d\Omega(\vartheta)}{d\sigma_0/d\Omega(\vartheta)} \qquad \vartheta = 0^0 or 180^0$$

Polarized Measurements

Assumption for $\vec{d}p \rightarrow {}^3He + \eta$:

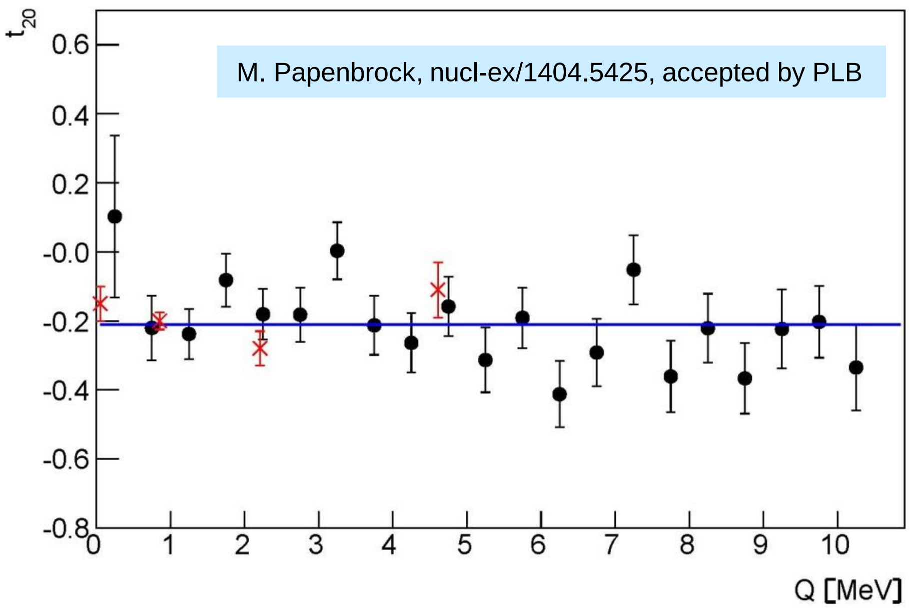
- Negligible effect of ISI
- Energy dependence of $|f|^2$ only given by FSI
  - → Shape of excitation function independent of spins
  - → Same energy dependence of amplitudes $|A|^2$ and $|B|^2$

$$|A|^2 = |A_0|^2 \cdot FSI(p_\eta)$$
$$|B|^2 = |B_0|^2 \cdot FSI(p_\eta)$$

$$\Rightarrow \quad T_{20} = \sqrt{2}\left[\frac{|B_0|^2 - |A_0|^2}{|A_0|^2 + 2|B_0|^2}\right] \cdot \frac{FSI(p_\eta)}{FSI(p_\eta)} = \text{const.}$$

- Measure T_{20} as function of the excess energy

Recent results from ANKE: $\vec{d}+p \rightarrow {}^3He+\eta$



- Data close to threshold consistent with T_{20}=const.

$$\boxed{T_{20} = -0.21 \pm 0.02 \pm 0.05}$$

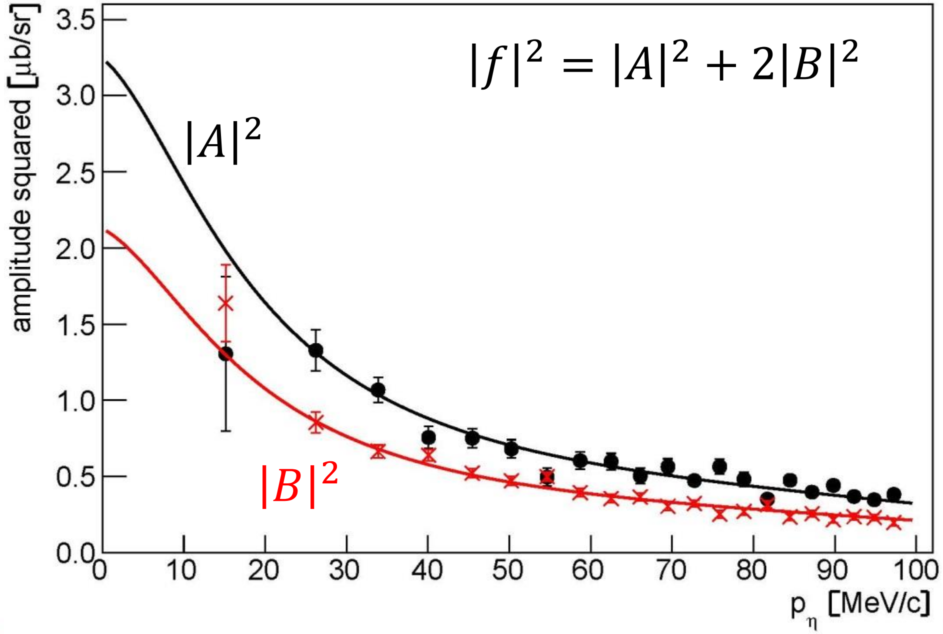
- $|T_{20}| << 1 \rightarrow |A|^2/|B|^2 = O(1)$

- *S*-Wave amplitudes $|A|^2$ and $|B|^2$ are of similar size

Recent Results: $\vec{d}$+p → ^{3}He+η

- Energy dependence of $|f|^2$ known from „old“ unpolarized measurements

  → $|A|^2(p_f)$ and $|B|^2(p_f)$ can be calculated



$$\frac{d\sigma}{d\Omega} = \frac{1}{3}\frac{p_\eta}{p_p}\left[|A|^2 + 2|B|^2\right]$$

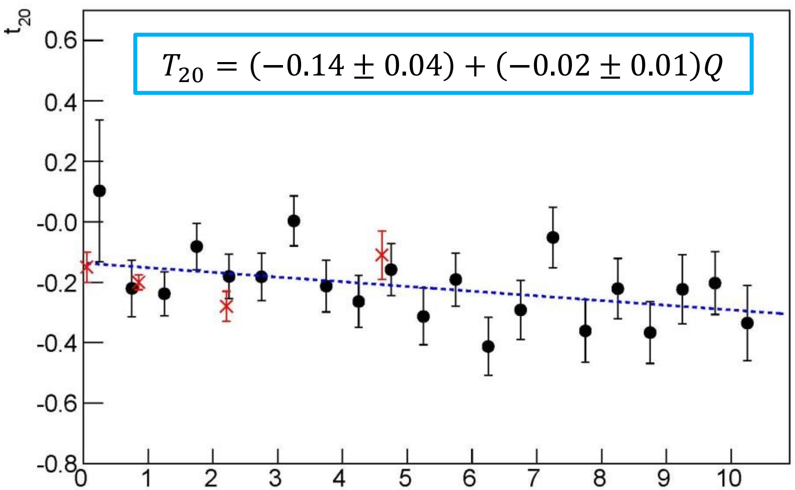
$$|A|^2 = \frac{p_p}{p_\eta}(1-\sqrt{2}T_{20})\frac{d\sigma}{d\Omega}$$

$$|B|^2 = \frac{p_p}{p_\eta}(1+\frac{1}{\sqrt{2}}T_{20})\frac{d\sigma}{d\Omega}$$

M. Papenbrock, nucl-ex/1404.5425, accepted by PLB

Recent Results: $\vec{d}$+p → ^{3}He+η

- Allow for a linear energy dependence of T_{20} and $|A|^2/|B|^2$:



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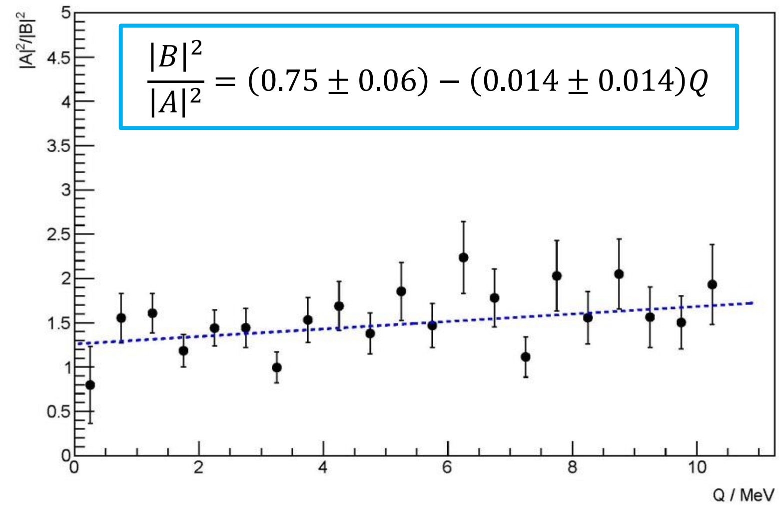
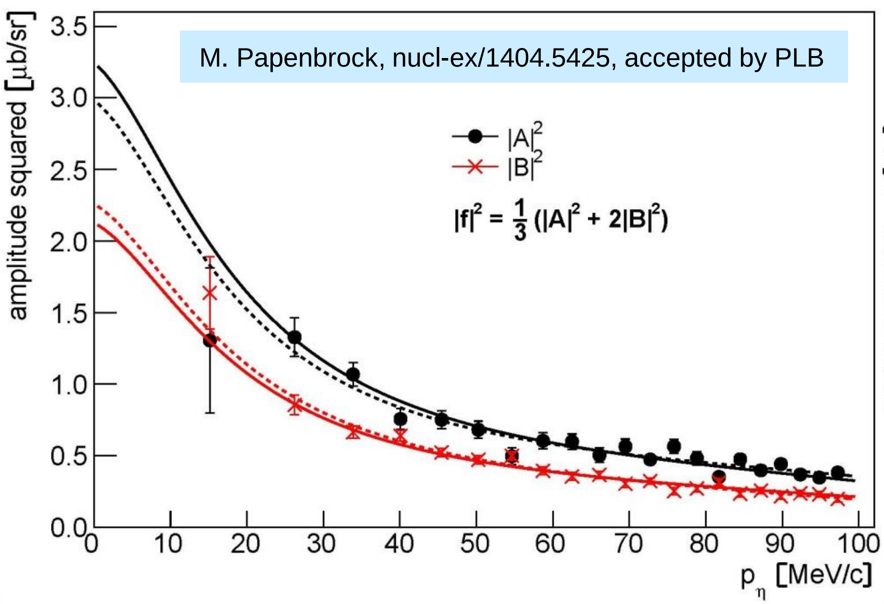
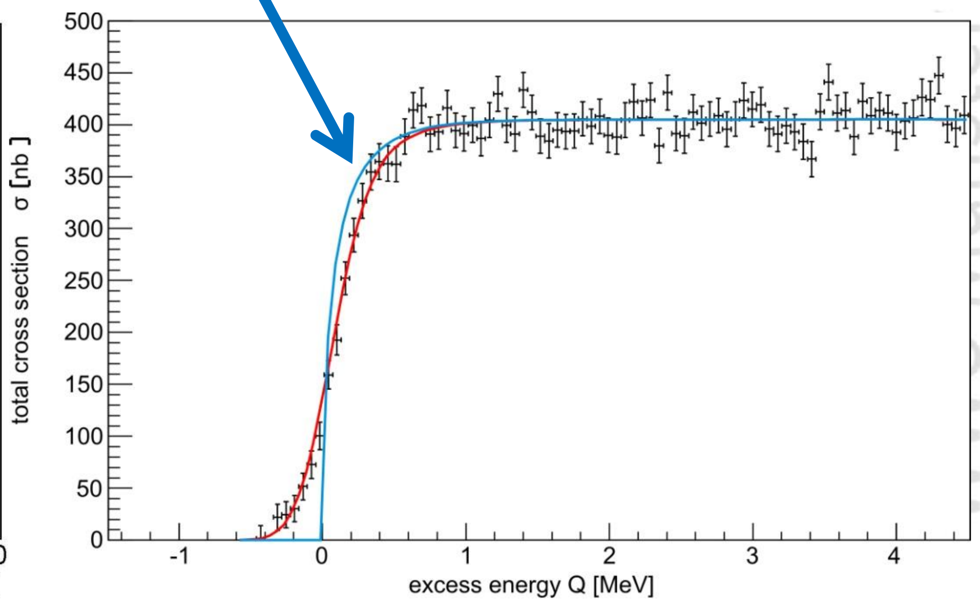


→ Possible energy variation of $|A|^2(p_f)$ and $|B|^2(p_f)$ on the scale of 0.75/0.014 MeV ≈ 50 MeV

Recent Results: $\vec{d}+p \rightarrow {}^3He+\eta$

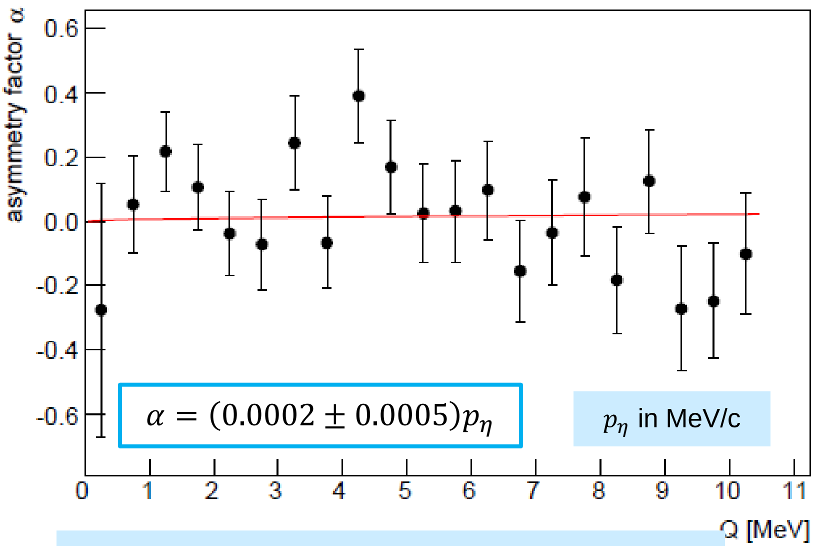
- No significant different energy dependence of $|A|^2$ and $|B|^2$
- Remarkable excitation function of $d+p \rightarrow {}^3He+\eta$ still an indication for very strong FSI effect





Angular Dependence of T_{20}

- Asymmetry parameter: $$\alpha = \left.\frac{dT_{20}}{d\cos\vartheta}\right|_{\cos\vartheta=0}$$
  - sensitive to interferences between even and odd η partial waves
  - odd function of p_η with $\alpha(Q=0)=0$



M. Papenbrock, nucl-ex/1404.5425, accepted by PLB

- No sign for any *s*-*p* interference here

But:

- Unpolarized data show already at *Q* = 4 MeV a non-isotropy dσ/dΩ

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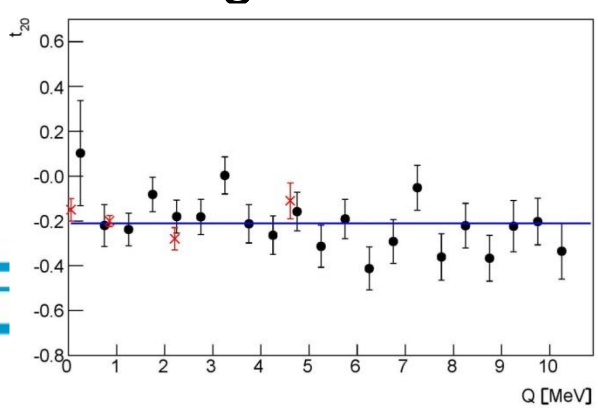
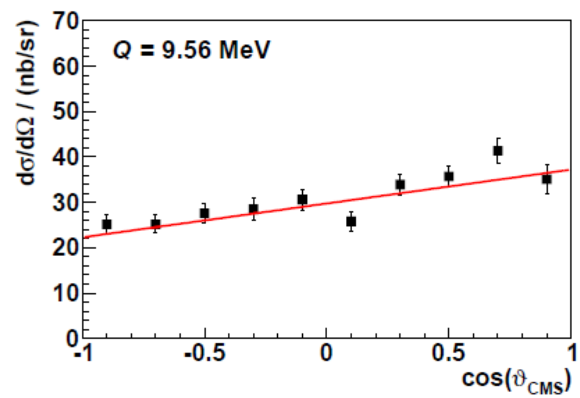
Ansatz for Structure of Amplitudes *A* and *B*

$$A = A_0\left[FSI(p_\eta) + \alpha p_\eta \cos\vartheta + \beta {p_\eta}^2(3\cos^2\vartheta - 1)/2\right]$$
$$B = B_0\left[FSI(p_\eta) + \alpha p_\eta \cos\vartheta + \beta {p_\eta}^2(3\cos^2\vartheta - 1)/2\right]$$

M. Papenbrock, nucl-ex/1404.5425, accepted by PLB

- FSI term influences only the *s*-wave term
- *A* proportional to *B* → T_{20} independent of p_η and ϑ
- Ansatz allows for observed non-isotropy of dσ/dΩ at higher excess energies





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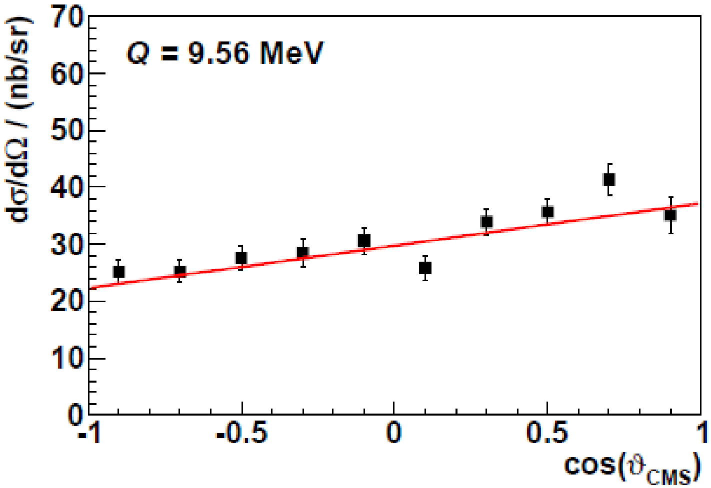
Ansatz for Structure of Amplitudes A and B

$$A = A_0\left[FSI(p_\eta) + \alpha p_\eta \cos\vartheta + \beta {p_\eta}^2 (3\cos^2\vartheta - 1)/2\right]$$
$$B = B_0\left[FSI(p_\eta) + \alpha p_\eta \cos\vartheta + \beta {p_\eta}^2 (3\cos^2\vartheta - 1)/2\right]$$

- Unpolarized data show linearity in dσ/dΩ for Q>4 MeV
- Can be explained by cancellation of interference between *s* and *d* waves and the square of *p* waves

→ Important new information on $|f|^2$



T. Mersmann et al., PRL 98 (2007) 242301

The Reaction $d+p \rightarrow {}^3He+\eta$ at Higher Q-Values

- Good understanding of the production mechanism is important for an even better investigation of the FSI effects at threshold and/or of possible bound states
- Threshold data are not sufficient for solid investigations
  - FSI effects dominate very close to threshold

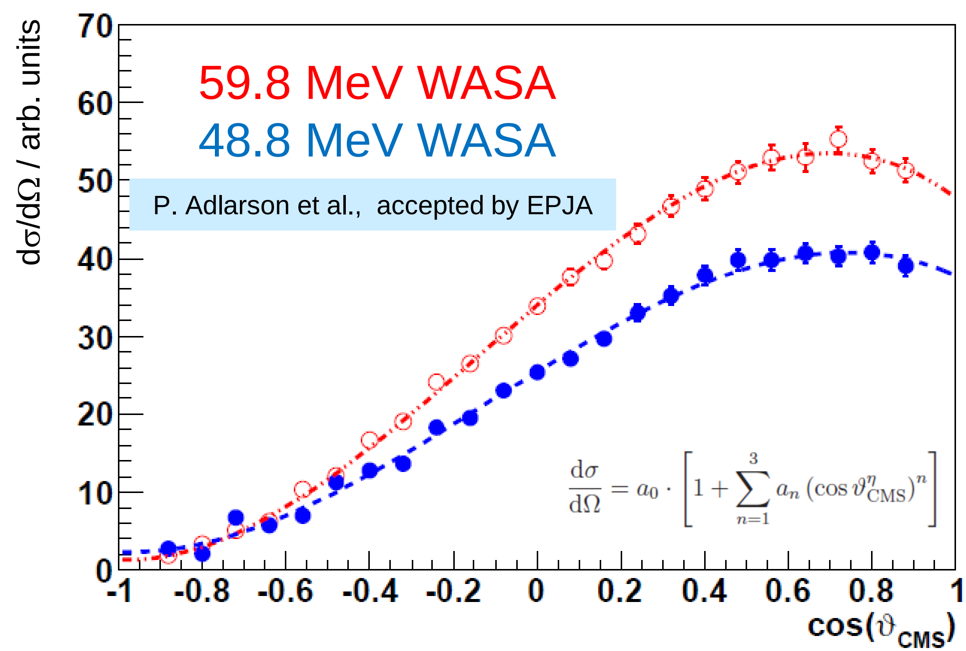
  → data at higher excess energies (>10 MeV) important
- New differential cross section data from WASA-at-COSY recently published (Q = 48.8 MeV & 59.8 MeV)

Recent Results from WASA-at-COSY

- Angular distributions show strong anisotropy
- Precise determination of total cross section ratio

But

- Theoretical models (*e.g.* two-step process) completely fail to explain total & differential cross sections

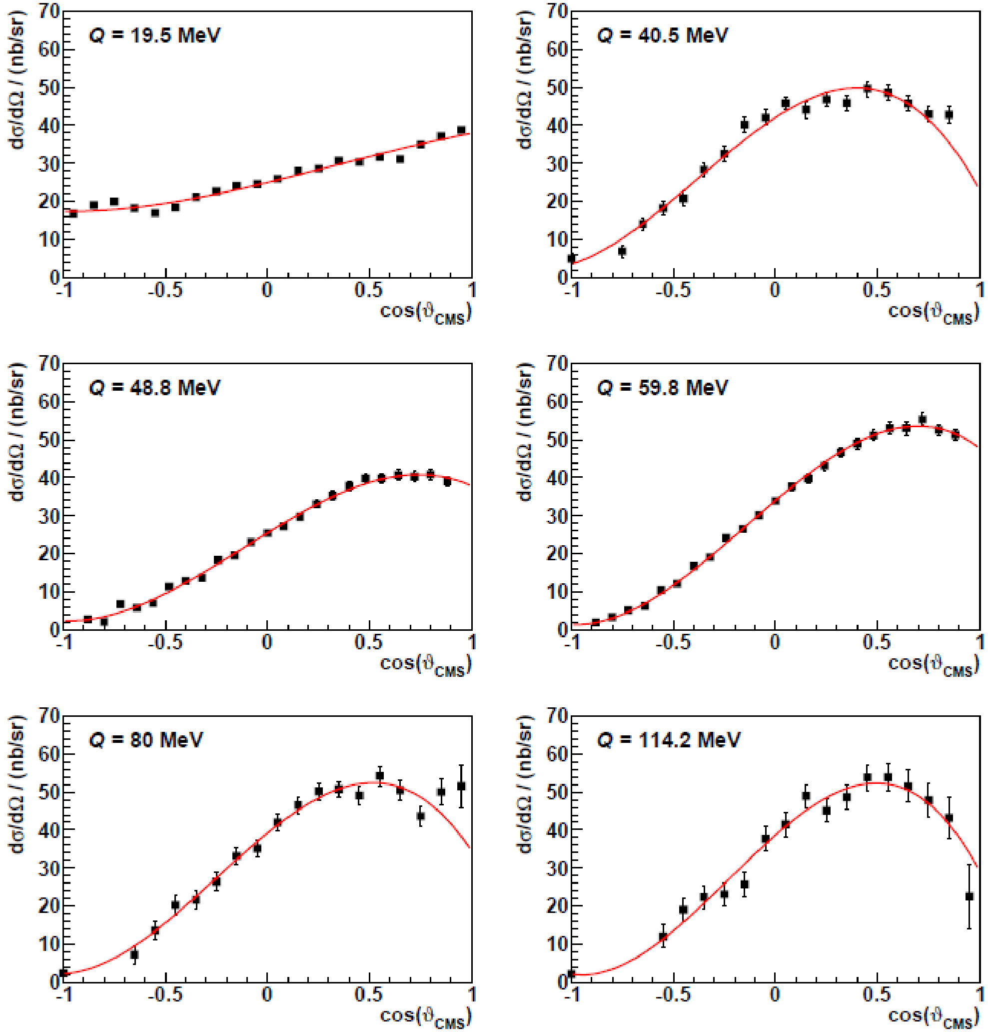


$$\boxed{\frac{\sigma(48.8\mathrm{MeV})}{\sigma(59.8\mathrm{MeV})} = 0.77 \pm 0.06}$$

Development of Angular Distributions

ANKE

WASA-Promice



WASA-at-COSY

WASA-at-COSY

WASA-Promice

WASA-Promice

Predictions from a Two-Step Model

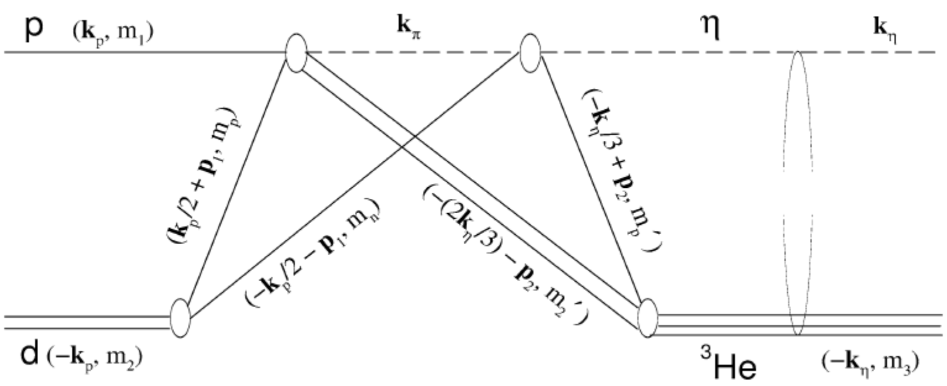
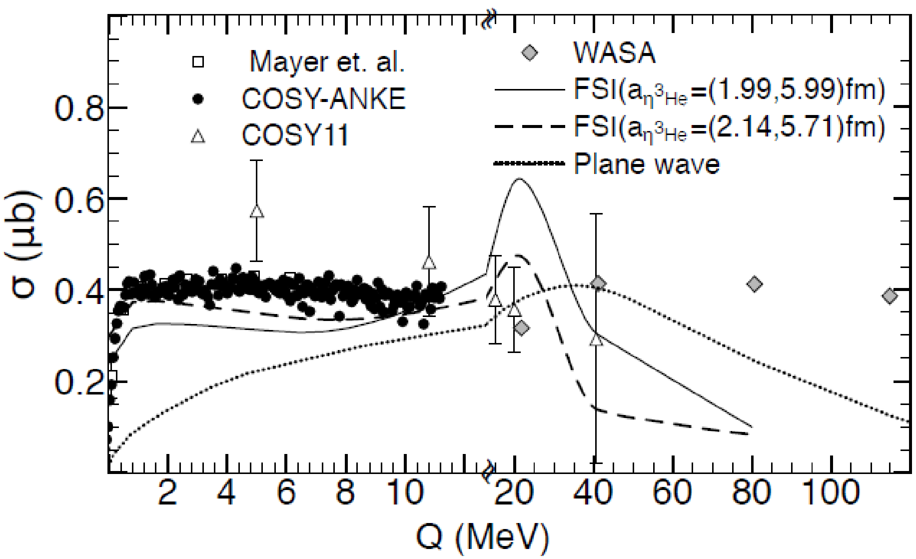
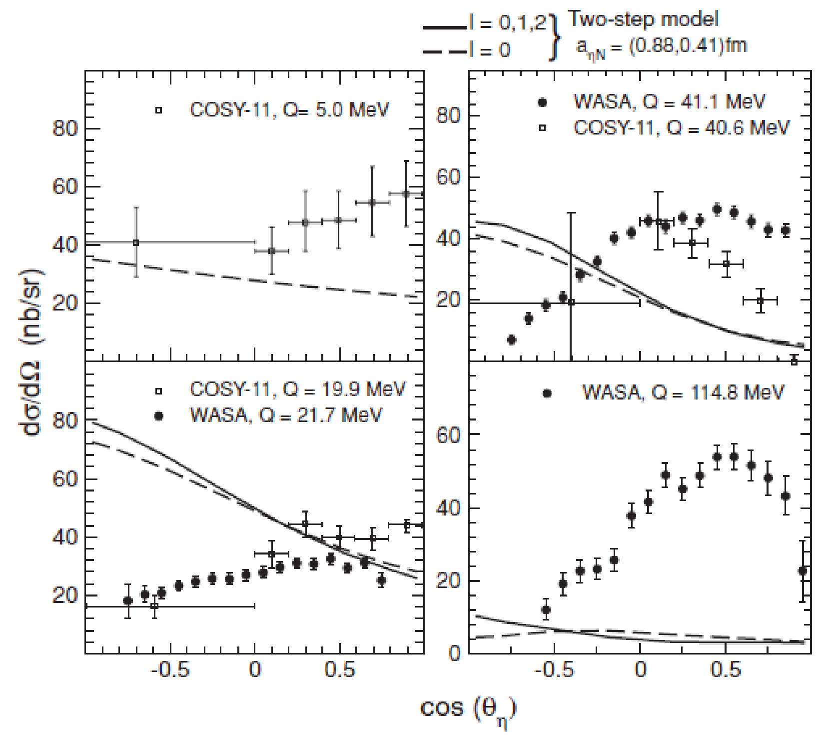


Fig. 1. Diagram of η production in the $pd \to {}^3\mathrm{He}\,\eta$ reaction with a two step process. The ellipse indicates the final state interaction of ^{3}He and η.



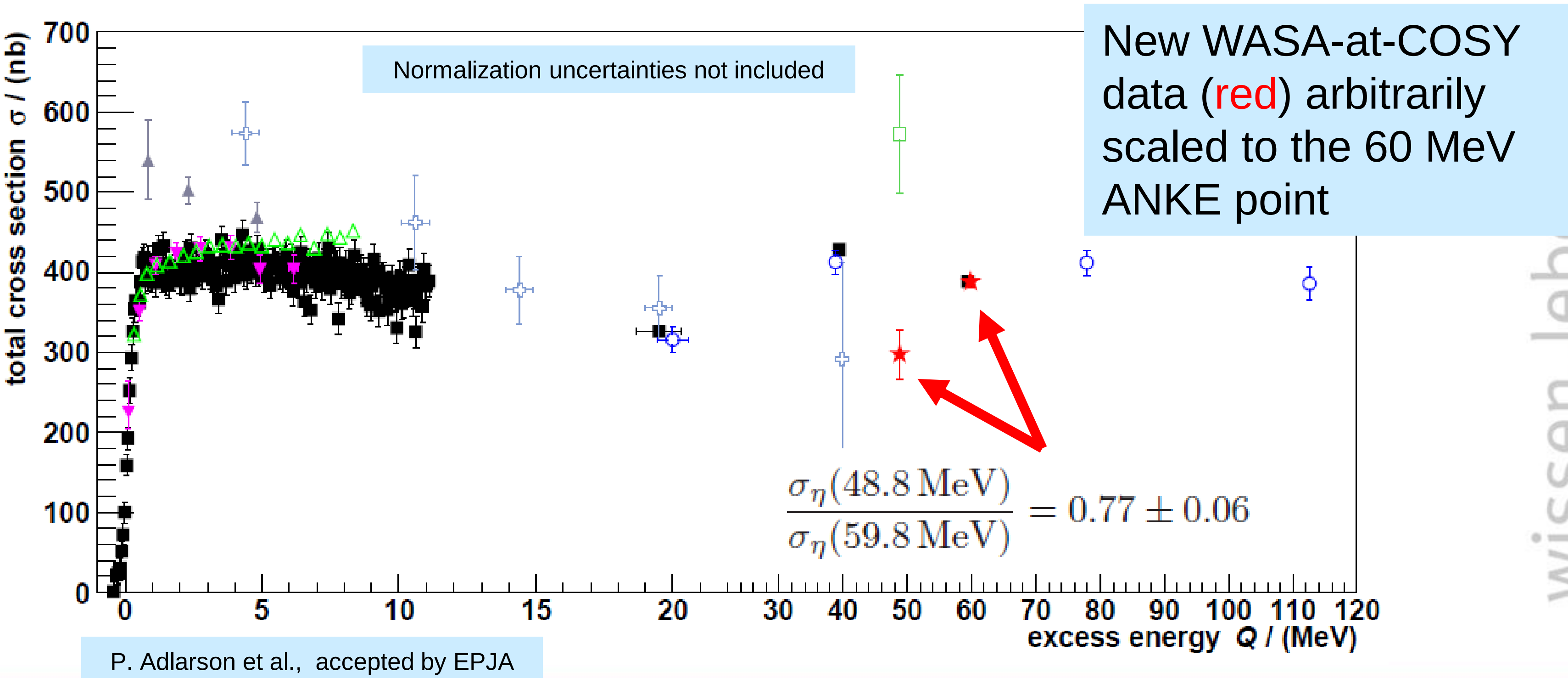


KP Khemchandani , Phys. Rev. C 76 (2007) 069801

K.P. Khemchandani, N.G. Kelkar, B.K Jain,
NPA 708 (2002) 312-324

The Reaction d+p → ^{3}He+η at Higher Q-Values

- Recent data might indicate a cross section variation at higher excess energies, i.e. at 20 MeV...60 MeV



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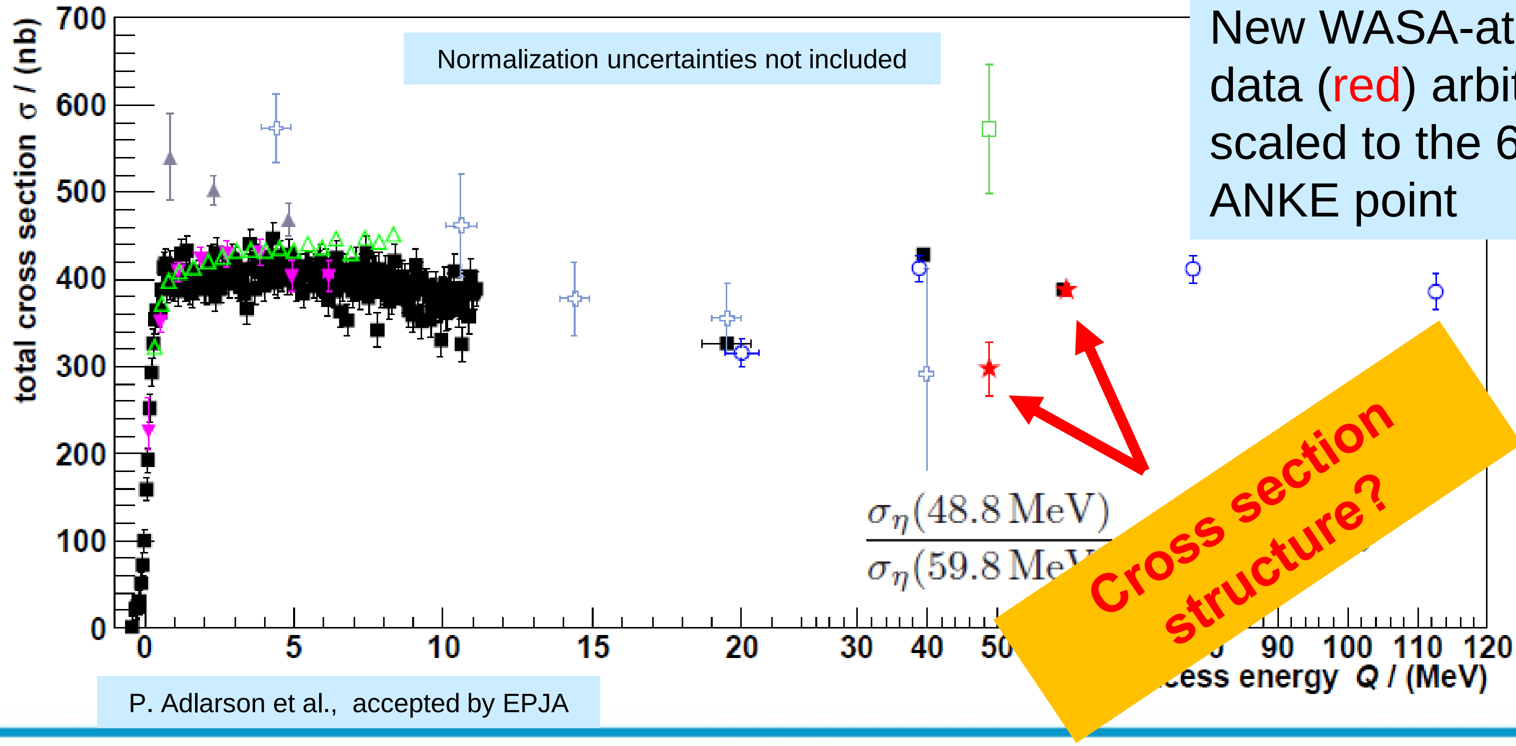


New WASA-at-COSY data (red) arbitrarily scaled to the 60 MeV ANKE point

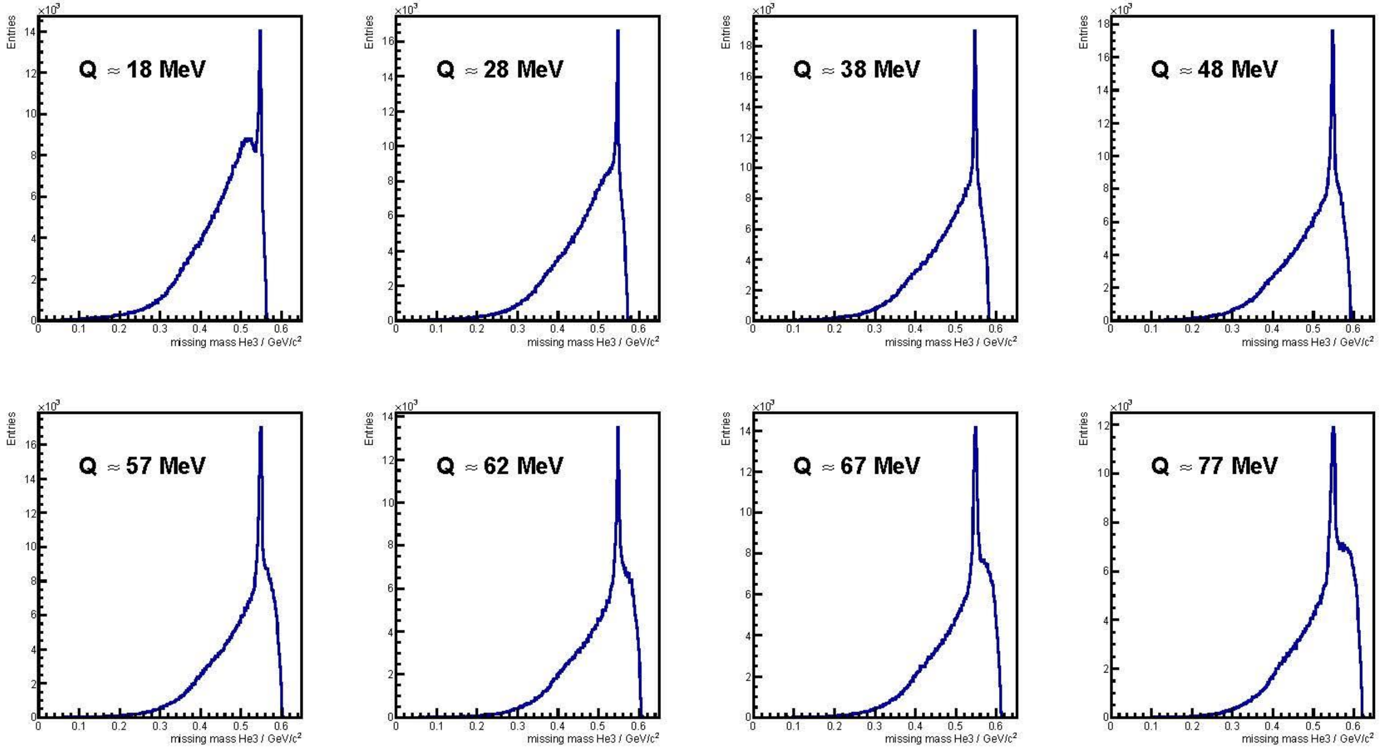
P. Adlarson et al., accepted by EPJA

The Reaction d+p → ^{3}He+η at Higher Q-Values

- Current data base for *Q* > 20 MeV not sufficient for solid investigations → new data needed
- Very recently new high statistics data have been recorded at WASA-at-COSY at 15 Q-values, i.e. in the interval Q = 14 MeV – 88 MeV
- Precise total and differential cross sections can be expected for the future (>100 kevents per energy!)
- Solid data base for further investigations on
  - Production processes
  - Possible cross section structures

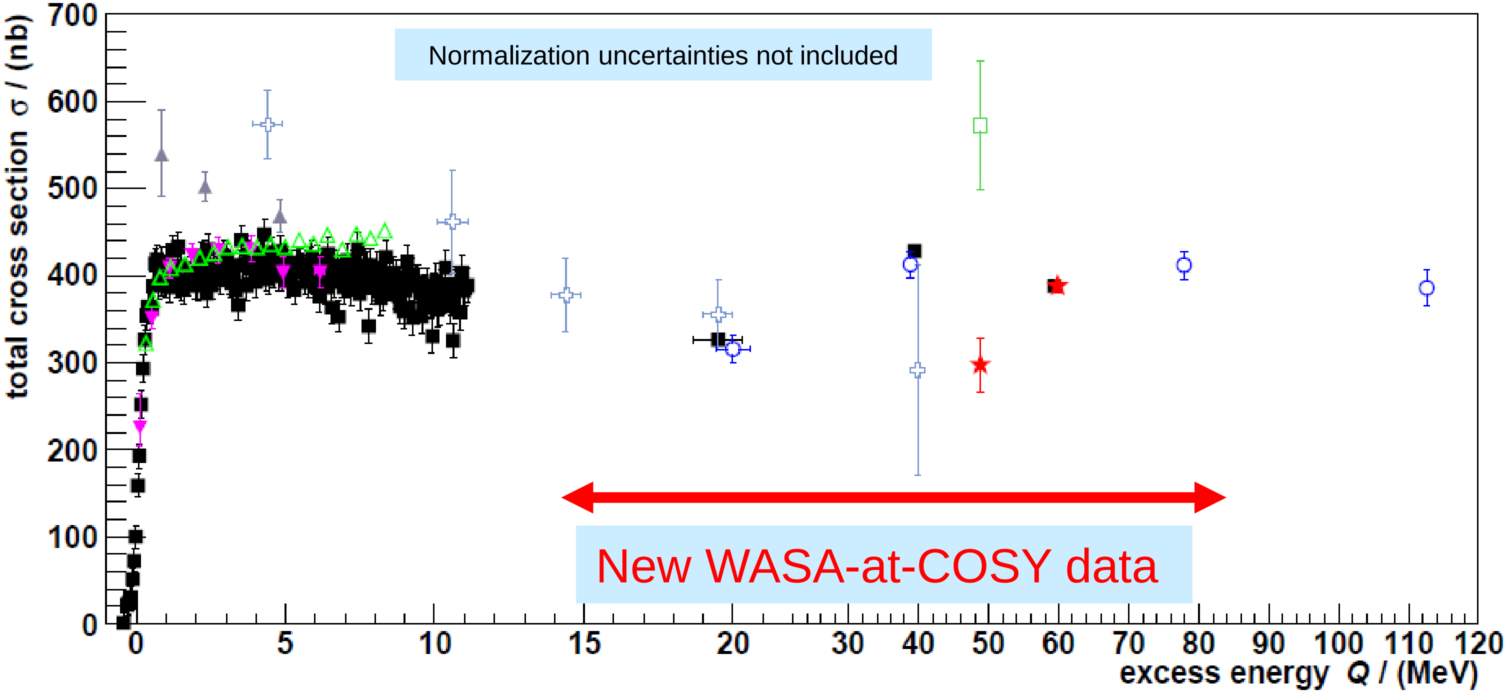
WASA-at-COSY Beam Time: May 2014

„Online spectra“ from supercycle 2: 8 energies



Nils Hüsken, private communication

The Reaction d+p → ^{3}He+η at Higher Q-Values



P. Adlarson et al., accepted by EPJA

Outlook: pd→p_{sp}dη

- Threshold enhancement
  σ/PS ↔ FSI calculations
- Filled symbols: pd→pdη taken below NN→NNη threshold

→ far from quasi-free (controversial)

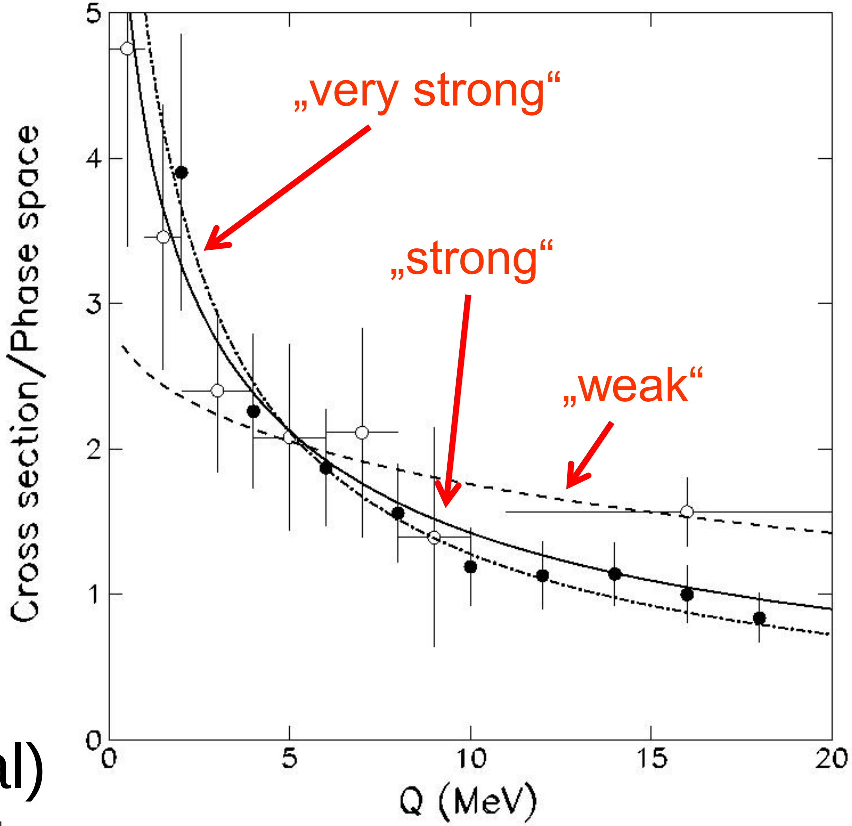


TABLE II. Results of the AGS and three different approximate calculations of $A_{\eta d}$ with $\alpha = 3.316\ \mathrm{fm}^{-1}$.

Ref.	ηN input $a_{\eta N}$ (fm)	Exact $A_{\eta d}$ (fm) AGS	Approximate $A_{\eta d}$ (fm) MST I [8]	MST II [8]	FRA
[20]	0.25+i0.16	0.73+i0.56	0.66+i0.71	0.66+i0.58	0.65+i0.70
[2]	0.27+i0.22	0.71+i0.84	0.57+i0.97	0.64+i0.81	0.59+i0.96
[21]	0.291+i0.360	0.38+i1.36	0.17+i1.35	0.42+i1.25	0.21+i1.35
[3]	0.30+i0.30	0.61+i1.22	0.39+i1.28	0.58+i1.11	0.42+i1.27
[21]	0.430+i0.394	0.50+i2.07	0.14+i1.91	0.65+i1.73	0.24+i1.88
[2]	0.44+i0.30	1.15+i1.89	0.63+i1.93	1.01+i1.50	0.68+i1.86
[20]	0.46+i0.29	1.31+i1.99	0.72+i2.04	1.11+i1.54	0.76+i1.96
[22]	0.476+i0.279	1.49+i2.06	0.81+i2.15	1.22+i1.56	0.84+i2.05
[23]	0.51+i0.21	2.37+i1.77	1.48+i2.31	1.65+i1.39	1.38+i2.22
[3]	0.55+i0.30	1.64+i2.99	0.61+i2.73	1.40+i1.98	0.69+i2.51
[21]	0.579+i0.399	0.34+i3.31	−0.13+i2.64	0.93+i2.41	0.13+i2.52
[24]	0.62+i0.30	1.80+i4.30	0.36+i3.36	1.65+i2.41	0.55+i2.95
[22]	0.876+i0.274	−8.81+i4.30	−2.76+i4.24	2.42+i5.55	−0.67+i3.98
[22]	0.888+i0.274	−8.63+i3.49	−2.90+i4.12	2.37+i5.79	−0.73+i3.99
[25]	0.98+i0.37	−4.69+i1.59	−2.75+i2.77	−0.06+i6.20	−1.18+i3.59

$$\left|f\left(p_f\right)\right|^2 = \frac{S}{\left|1 - i\cdot a_{d\eta}\cdot p_f\right|^2}$$

N.V. Shevchenko et al. , Phys. Rev. C 58 (1998) 3055

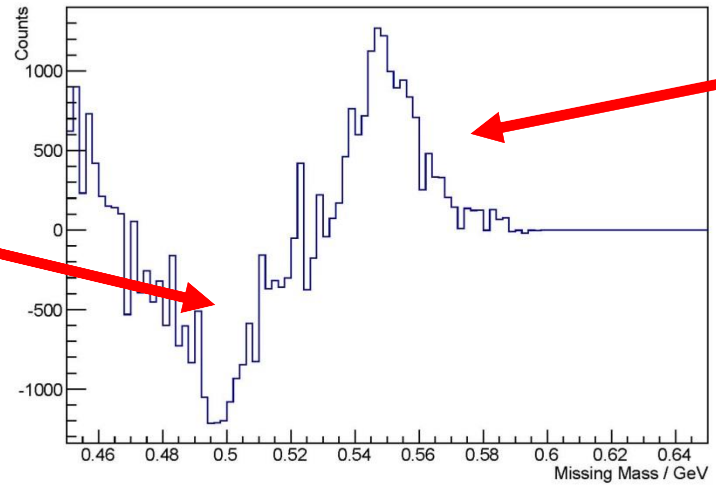
Outlook: $pd \to p_{sp} d \eta$

- New data from ANKE/COSY are expected to allow for
  - a scattering length $|a_{d\eta}|$ determination with a precision of ~5%
  - the determination of angular distributions

in the excess energy range Q = 0...100 MeV

  - First signals: Subtraction from two data sets obtained at different beam momenta, but analyzed assuming the same beam momentum

η-peak 2



η-peak 1

Daniel Schröer, private communication

Summary

- New data on η meson production in pd-collisions give important information on η-nucleus systems
- Results from measurements with polarized beams
  - support the strong $^3He+\eta$ FSI interpretation
  - show no spin-dependent contributions on a scale of ~MeV above threshold
  - give new insight into the structure of the relevant production amplitudes
- Data at higher excess energies might indicate an unexpected cross section structure
- New data have been recorded recently and will allow for more detailed experimental and theoretical investigations

Thank you very much....

Citation: J. Beringer et al. (Particle Data Group), PR D86, 010001 (2012) and 2013 partial update for the 2014 edition (URL: http://pdg.lbl.gov)

η

$$I^G(J^{PC}) = 0^+(0^{-+})$$

We have omitted some results that have been superseded by later experiments. The omitted results may be found in our 1988 edition Physics Letters **B204** (1988).

η MASS

Recent measurements resolve the obvious inconsistency in previous η mass measurements in favor of the higher value first reported by NA48 (LAI 02). We use only precise measurements consistent with this higher mass value for our η mass average.

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
547.862±0.018 OUR AVERAGE					
547.873±0.005±0.027	1M	GOSLAWSKI	12	SPEC	$d p \to {}^3\mathrm{He}\,\eta$
547.874±0.007±0.029		AMBROSINO	07B	KLOE	$e^+ e^- \to \phi \to \eta\gamma$
547.785±0.017±0.057	16k	MILLER	07	CLEO	$\psi(2S) \to J/\psi\,\eta$
547.843±0.030±0.041	1134	LAI	02	NA48	$\eta \to 3\pi^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
547.311±0.028±0.032		[1] ABDEL-BARY	05	SPEC	$d p \to {}^3\mathrm{He}\,\eta$
547.12 ±0.06 ±0.25		KRUSCHE	95D	SPEC	$\gamma p \to \eta p$, threshold
547.30 ±0.15		PLOUIN	92	SPEC	$d p \to {}^3\mathrm{He}\,\eta$
547.45 ±0.25		DUANE	74	SPEC	$\pi^- p \to n$ neutrals
548.2 ±0.65		FOSTER	65C	HBC	
549.0 ±0.7	148	FOELSCHE	64	HBC	
548.0 ±1.0	91	ALFF-...	62	HBC	
549.0 ±1.2	53	BASTIEN	62	HBC	

[1] ABDEL-BARY 05 disagrees significantly with recent measurements of similar or better precision. See comment in the header.

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The COSY-Accelerator at Jülich

Energy range
- 0.045 – 2.8 GeV (p)
- 0.023 – 2.3 GeV (d) (momentum 3.7 GeV/c)

Beam cooling
- Electron cooling
- Stochastic cooling

Polarisation
- p, d beams & targets

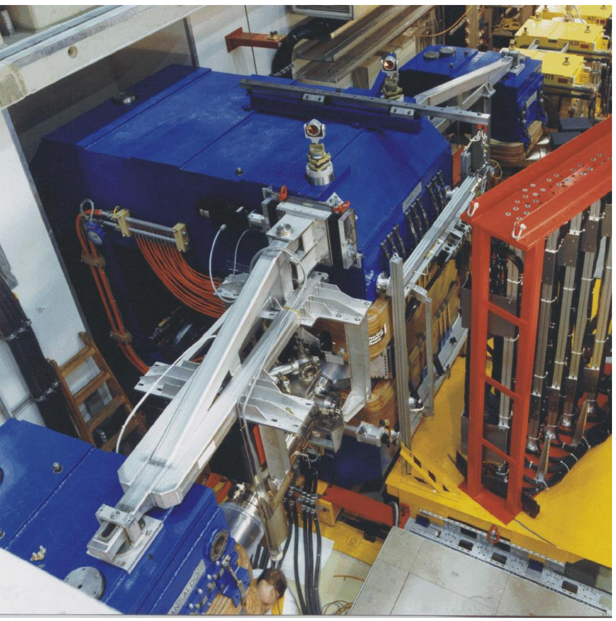
Beams
- internal, external

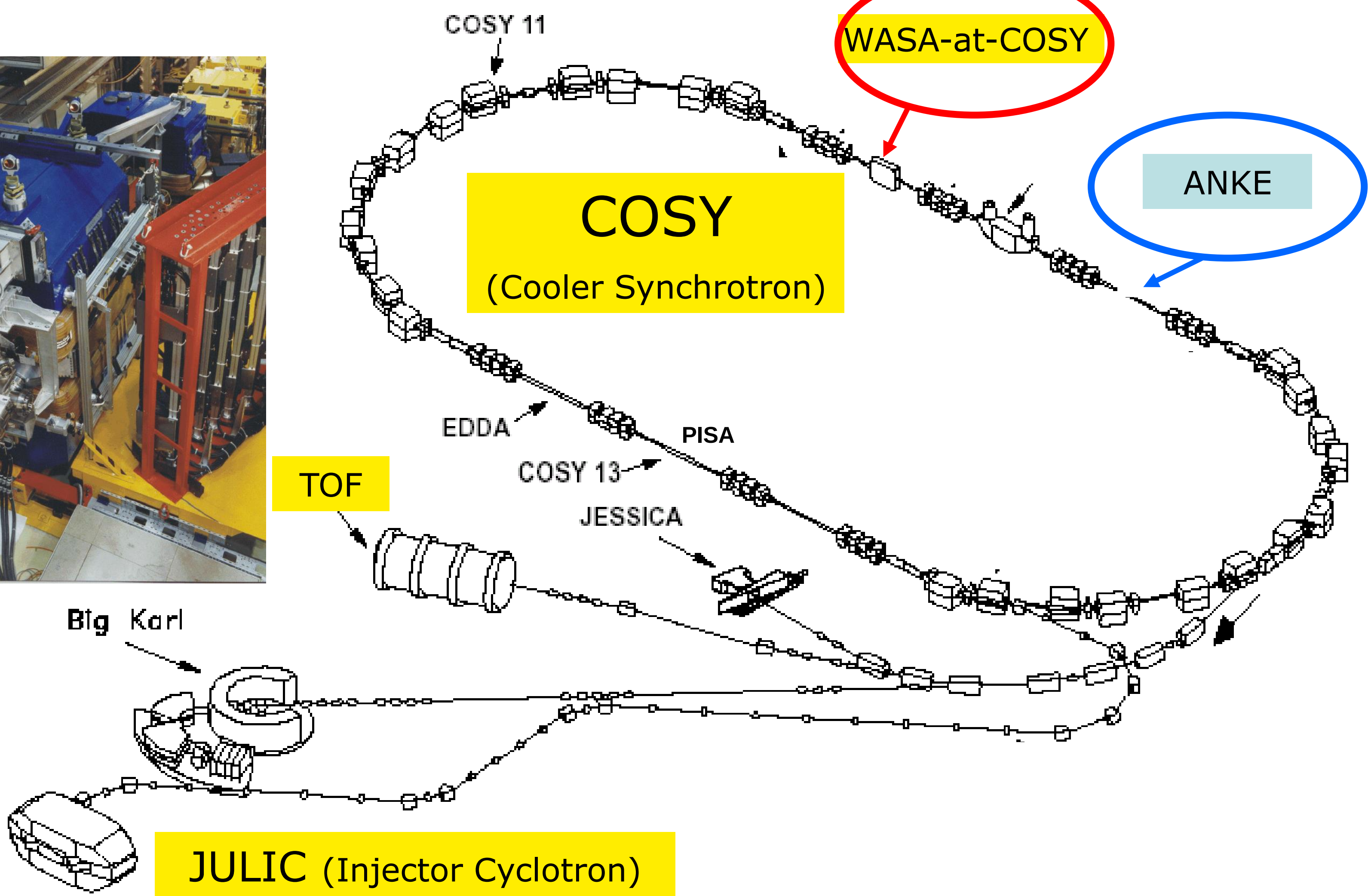
Experiments, Detectors
- ANKE, TOF, WASA, …

COSY (Cooler Synchrotron)

Westfälische
Wilhelms-Universität
Münster

The Experiments ANKE and WASA-at-COSY





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Scattering Theory and Final State Interaction

- The scattering length can deliver informationen about possible bound states
- Conditions for bound η^3He state:
  - Existence of a pole in the complex p_f plane

$$f_s = \frac{f_{\mathrm{prod}}}{1 - i \cdot a \cdot p_f + \frac{1}{2} a \cdot r \cdot p_f^2}$$

$$a \equiv a_r + i a_i$$

$$r \equiv r_r + i r_i$$

  - As well as

$$a_r < 0, \qquad a_i > 0, \qquad R = \frac{|a_i|}{|a_r|} < 1$$

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η–^{3}He Scattering Length

Fit to data delivers information about the complex η–^{3}He scattering length:

$$\left(\frac{d\sigma(\vartheta)}{d\Omega}\right)\cdot\frac{p_i}{p_f}=\left|f_{\mathrm{scat}}\right|^2=\left|f_{\mathrm{prod}}\cdot FSI\right|^2=\left|f_{\mathrm{prod}}\right|^2\cdot\left|FSI\right|^2$$

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

Result:

$$a=\left[\pm\left(10.7\pm0.8^{+0.1}_{-0.5}\right)+i\left(1.5\pm2.6^{+1.0}_{-0.9}\right)\right]\mathrm{fm}$$

T. Mersmann, A.K., et al., PRL 98 (2007) 242301

Notice: Determination of $|a_r|$!

η–³He-Interaction: Determination of Pols

$$\left(\frac{d\sigma(\vartheta)}{d\Omega}\right)\cdot\frac{p_i}{p_f} = \left|f_{\mathrm{scatt}}\right|^2 = \left|f_{\mathrm{prod}}\cdot FSI\right|^2 = \left|f_{\mathrm{prod}}\right|^2\cdot\left|FSI\right|^2$$

$$FSI = \frac{1}{1 - i\cdot a\cdot p_f + \frac{1}{2}a\cdot r_0\cdot p_f^2} \quad \longleftrightarrow \quad FSI = \frac{1}{\left(1-{p_f}/{p_1}\right)\cdot\left(1-{p_f}/{p_2}\right)}$$

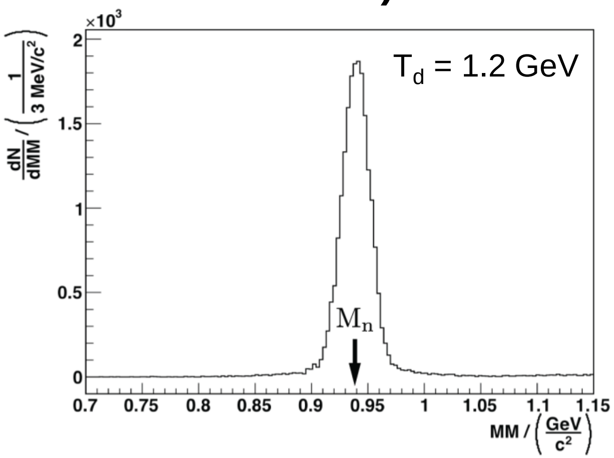
$$a = -i\cdot\frac{p_1+p_2}{p_1\cdot p_2} \qquad r_0 = +\frac{2\cdot i}{p_1+p_2}$$

$$p_1 = \left[\left(-5\pm 7^{+2}_{-1}\right)\pm i\cdot\left(19\pm 2\pm 1\right)\right]\mathrm{MeV/c}$$

$$p_2 = \left[\left(106\pm 5\right)\pm i\cdot\left(76\pm 13^{+1}_{-2}\right)\right]\mathrm{MeV/c}$$

The Reaction $\vec{d}$+p → ^{3}He+η at ANKE

- Alternating injection of unpolarized and tensor polarized deuterons in COSY
- Ramped COSY beam: Q = -5 MeV ... +10 MeV (300 s)
- Full geometrical acceptance of ANKE for d+p → ^{3}He+η
- Determination of p_{zz} by, e.g., d+p → (pp)+n (analyzing powers known)



$$\frac{d\sigma_{\uparrow}}{dt}(q,\varphi)\Big/\frac{d\sigma_0}{dt}(q,\varphi)=$$
$$1+\cancel{\sqrt{3}p_z it_{11}(\vartheta)\cos(\varphi)}-\frac{1}{2\sqrt{2}}p_{zz}t_{20}(\vartheta)$$
$$-\frac{\sqrt{3}}{2}p_{zz}t_{22}(\vartheta)\cos(2\varphi)$$

Tensor Polarizations

- Three different polarizations used for the experiment

1.) Nominal: $p_{zz} = -1$, $p_z = +1/3$

Measured: $p_{zz} = -0.635 \pm 0.087$

2.) Nominal: $p_{zz} = +1$, $p_z = -1$

Measured: $p_{zz} = 0.529 \pm 0.077$

3.) Nominal: $p_{zz} = +1$, $p_z = +1$

Measured: $p_{zz} = 0.217 \pm 0.082$