WWU MÜNSTER

Meson production in hadronic reactions from COSY

Nils Hüsken

WASA-at-GSI/FAIR Meeting, November 2017, Darmstadt

living.knowledge

Outline

Many interesting topics…

η meson production
- in $pp \to pp\eta$
- in $pn \to d\eta$
- in $pd \to {}^3He\eta$

strangeness production
- in $pp \to pp\phi$
- in $pd \to {}^3He\phi$

multipion production
- in $pp \to pp\pi\pi$
- in $pn \to d\pi\pi$
- in $pd \to {}^3He\pi\pi$
- in $dd \to 4He\pi\pi$

single-pion production
- in $pN \to pN\pi$
- in $pN \to d\pi$
- in $pd \to {}^3H(e)\pi$

η-mesic nuclei
- in $pd \to {}^3He\eta$
- in $dd \to 4He\eta$

charge symmetry breaking
- in $dd \to 4He\pi^0$

and many more…
- $\omega, \eta', a_0, f_0 \ldots$

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η meson production
- in $pp \to pp\eta$
- in $pn \to d\eta$
- in $pd \to {}^3He\eta$

strangeness production
- in $pp \to pp\phi$
- in $pd \to {}^3He\phi$

multipion production
- in $pp \to pp\pi\pi$
- in $pn \to d\pi\pi$
- in $pd \to {}^3He\pi\pi$
- in $dd \to 4He\pi\pi$

covered individually!

single-pion production
- in $pN \to pN\pi$
- in $pN \to d\pi$
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and many more…
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Activities in Münster

$pd \to {}^3He\eta$:

near threshold:

- study FSI at ANKE
- measurement covers excess energies up to $Q < 11\ \mathrm{MeV}$
- detailed study of total cross section and asymmetry
- T_{20} in polarization experiment

away from threshold:

- study production mechanism at WASA
- measurement for $13\ \mathrm{MeV} < Q < 81\ \mathrm{MeV}$

$pd \to {}^3He\pi^0$:

- SPES experiments observed structures in $d\sigma/d\Omega$, $|A|^2$, $|B|^2$ and t_{20} at $cos\vartheta = -1$ around η threshold
- use WASA measurement to study differential cross section in backward hemisphere

$pn \to d\eta$:

- new measurement at ANKE from threshold to $Q \approx 90\ \mathrm{MeV}$
- study A-dependence of FSI

General considerations in $\mathrm{pd} \to {}^3\mathrm{He}X$

- η and π^0 production described by 6 independent helicity amplitudes
- at threshold $(p_X = 0)$ and for collinear production, only A and B contribute
- generally, the full polarization experiment is too complicated

$$\hat{F} = \boldsymbol{\epsilon} \cdot \boldsymbol{T} = A\boldsymbol{\epsilon} \cdot \hat{\boldsymbol{p}}_{\mathrm{p}} + iB\left[\boldsymbol{\epsilon} \times \boldsymbol{\sigma}\right] \cdot \hat{\boldsymbol{p}}_{\mathrm{p}} + C\boldsymbol{\epsilon} \cdot \boldsymbol{p}_{\eta} + iD\left[\boldsymbol{\epsilon} \times \boldsymbol{\sigma}\right] \cdot \boldsymbol{p}_{\eta} + iE(\boldsymbol{\epsilon} \cdot \boldsymbol{n})(\boldsymbol{\sigma} \cdot \hat{\boldsymbol{p}}_{\mathrm{p}}) + iF(\boldsymbol{\epsilon} \cdot \boldsymbol{n})(\boldsymbol{\sigma} \cdot \boldsymbol{p}_{\eta})$$

$$I = \left(|A|^2 + 2|B|^2 + \left(|C|^2 + 2|D|^2\right) p_{\eta}^2 + 2Re\left(AC^* + 2BD^*\right) p_{\eta} \cos\vartheta_{\eta} + \left(|F|^2 p_{\eta}^2 + |E|^2\right) p_{\eta}^2 \sin^2\vartheta_{\eta} + 2Re\left(DE^* - BF^* + EF^* p_{\eta} \cos\vartheta_{\eta}\right) p_{\eta}^2 \sin^2\vartheta_{\eta}\right)$$

$\mathrm{pd} \to {}^3\mathrm{He}\eta/\pi^0$

S_i	L_i	π	J	S_f	L_f
3/2	0	+1	3/2	1/2	1
3/2	1	−1	5/2	1/2	2
1/2	0	+1	1/2	1/2	1
1/2	1	−1	3/2	1/2	2
3/2	1	−1	1/2	1/2	0
1/2	1	−1	1/2	1/2	0
3/2	2	+1	3/2	1/2	1
1/2	2	+1	3/2	1/2	1
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Yu. N. Uzikov, Nucl.Phys. A801 (2008) 114-128

$pd \rightarrow {}^{3}He\pi^{0}$

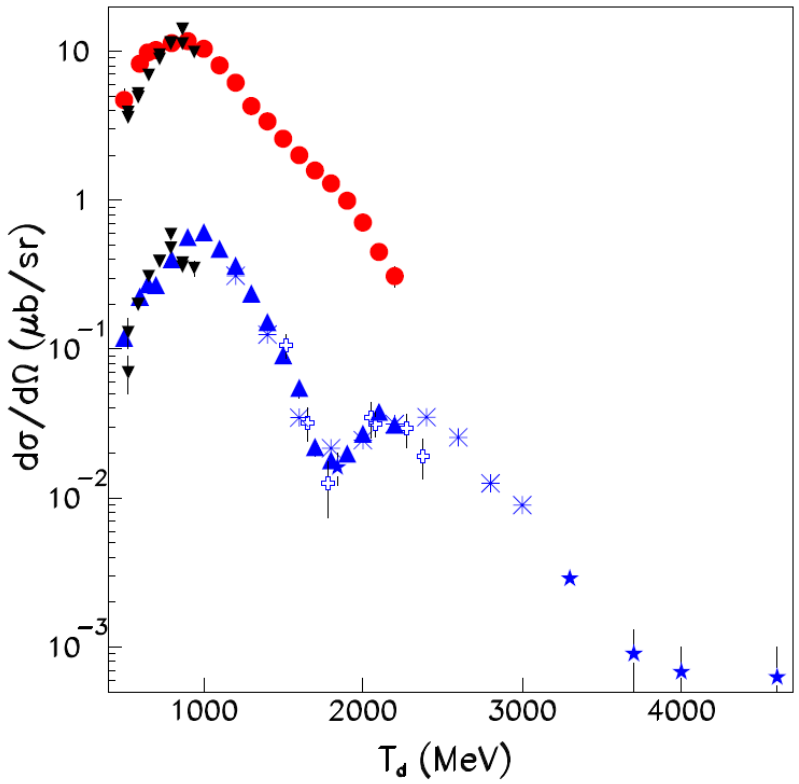
SPES Data from $\vec{d}p \to {}^3He\pi^0$:

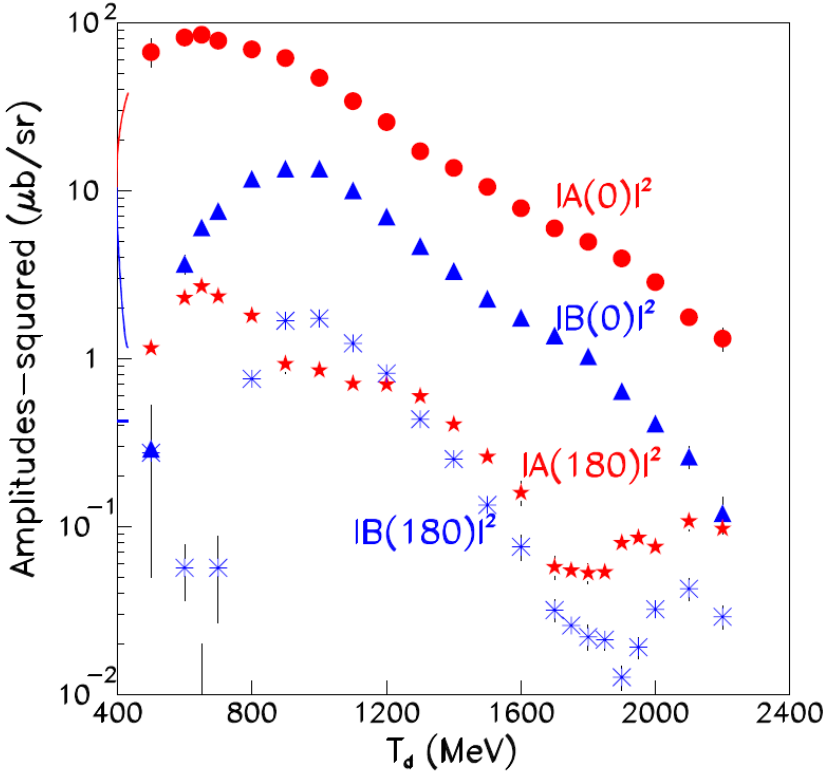
➢ indicates rapid variation close to η production threshold

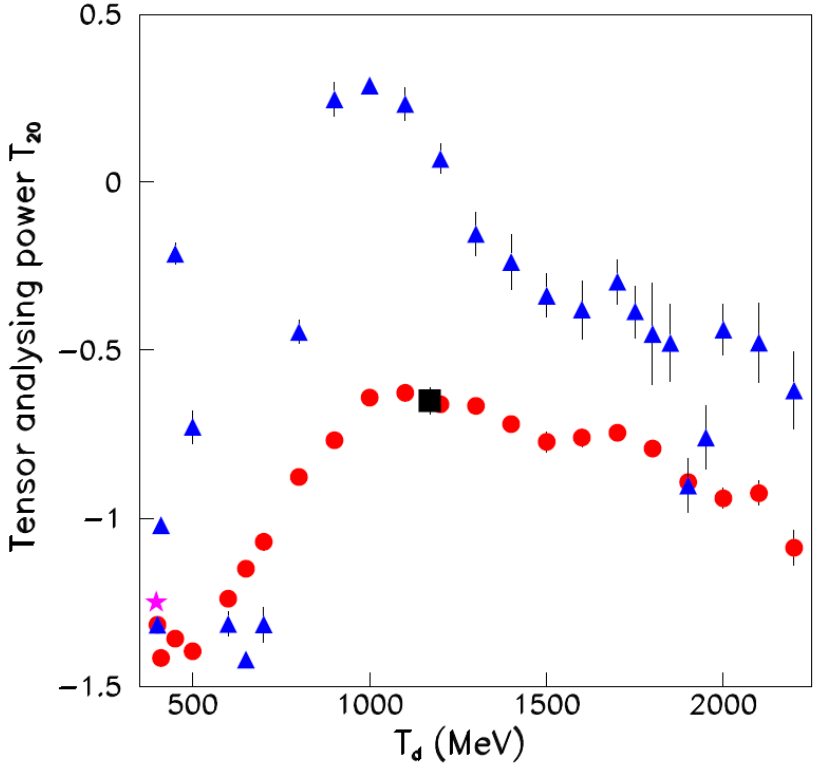
$pd \to {}^3He\pi^0$ / $pd \to {}^3H\pi^+$

$$\frac{d\sigma}{d\Omega} = \frac{kp}{3}\left(|A|^2 + 2|B|^2\right)$$

$$T_{20} = \sqrt{2}\,\frac{|B|^2 - |A|^2}{|A|^2 + 2|B|^2}$$







figures from: C. Wilkin, publication in preparation
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P. Berthet et al., Nucl.Phys. A443 (1985) 589-600
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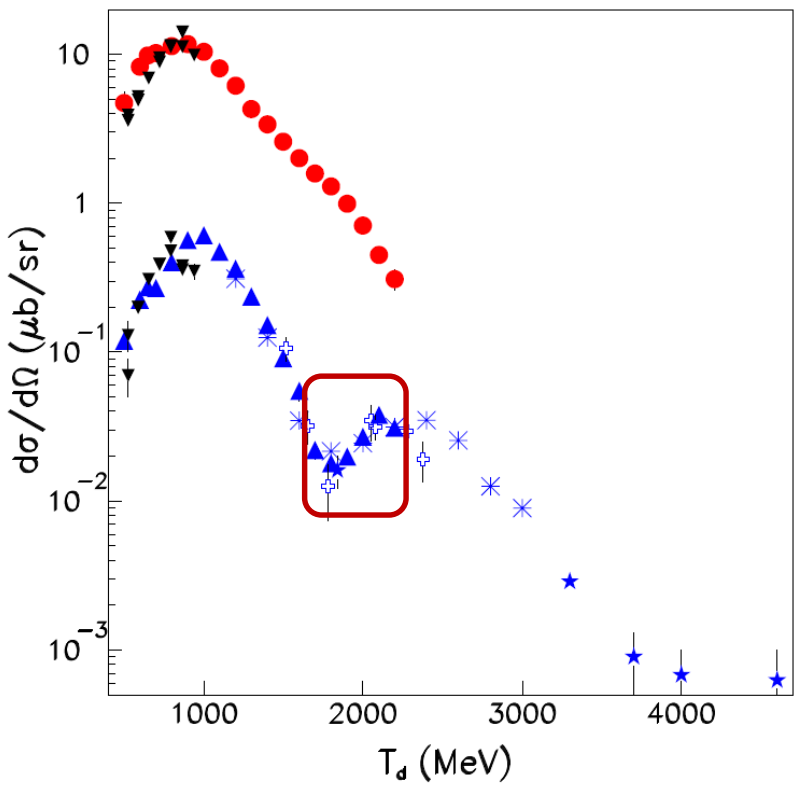

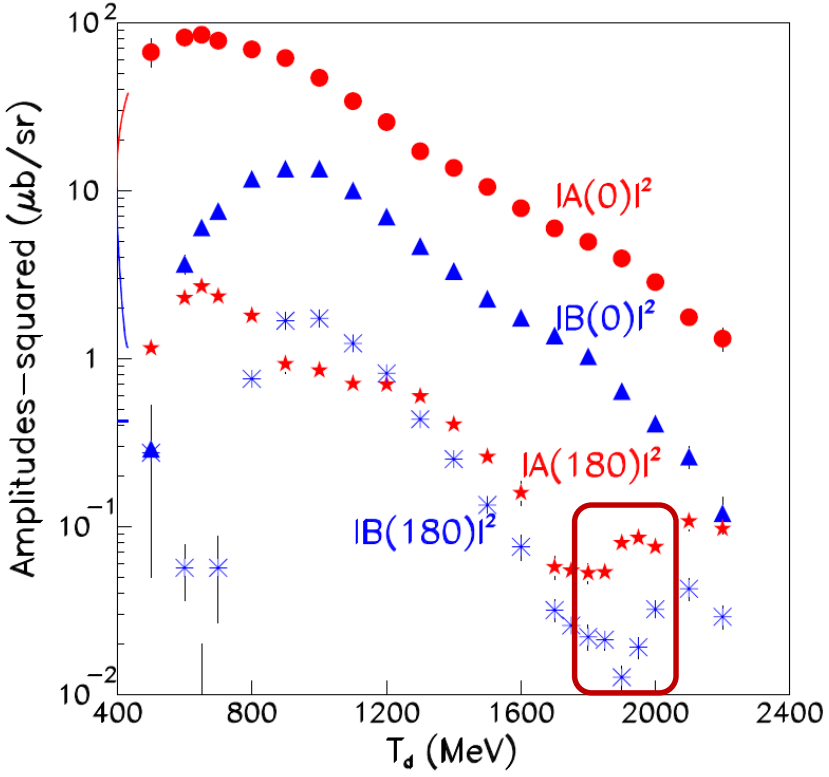

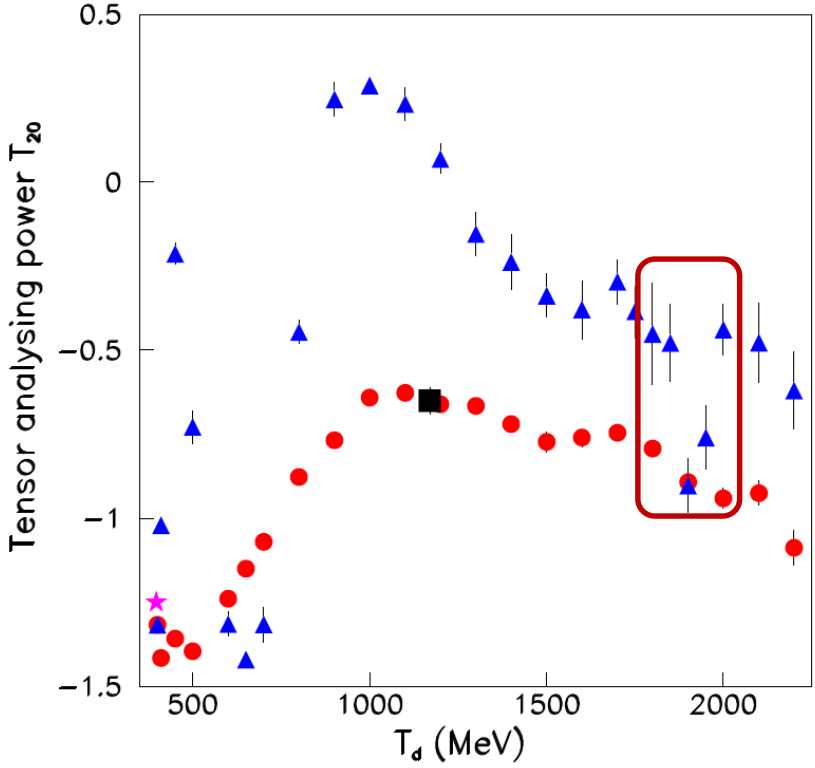

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$pd \to {}^3He\pi^0$ / $pd \to {}^3H\pi^+$

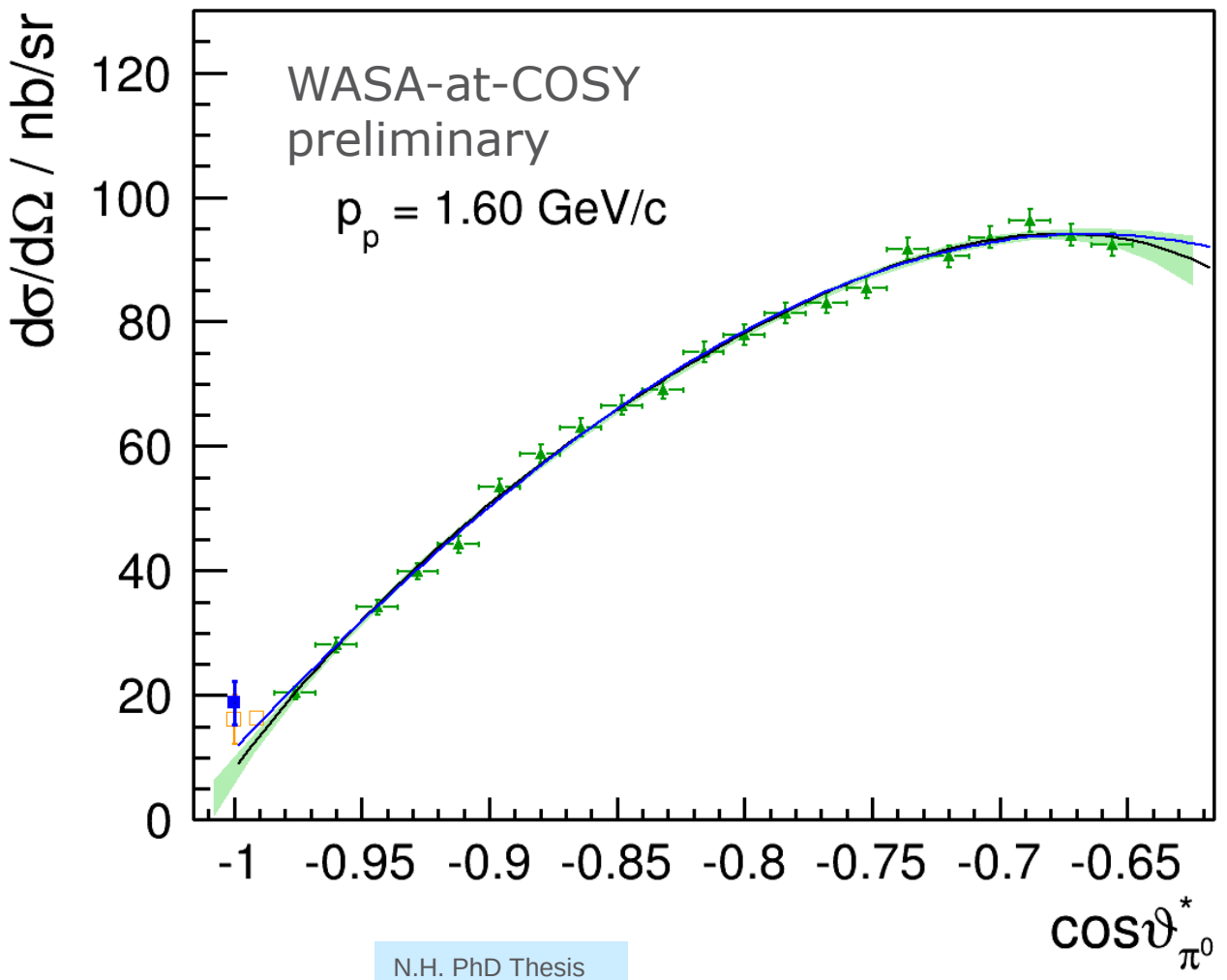
- new WASA measurement at 15 different beam momenta

  $1.60\ \mathrm{GeV/c} \leq p_p \leq 1.74\ \mathrm{GeV/c}$
  with $\Delta p_{\mathrm{step}} = 0.01\ \mathrm{GeV/c}$

- originally meant to study $\mathrm{pd} \to {}^3\mathrm{He}\eta$, parasitically measuring $\mathrm{pd} \to {}^3\mathrm{He}\pi^0$

- identification of the reaction by missing mass technique

- cover large part of backward hemisphere



N.H. PhD Thesis

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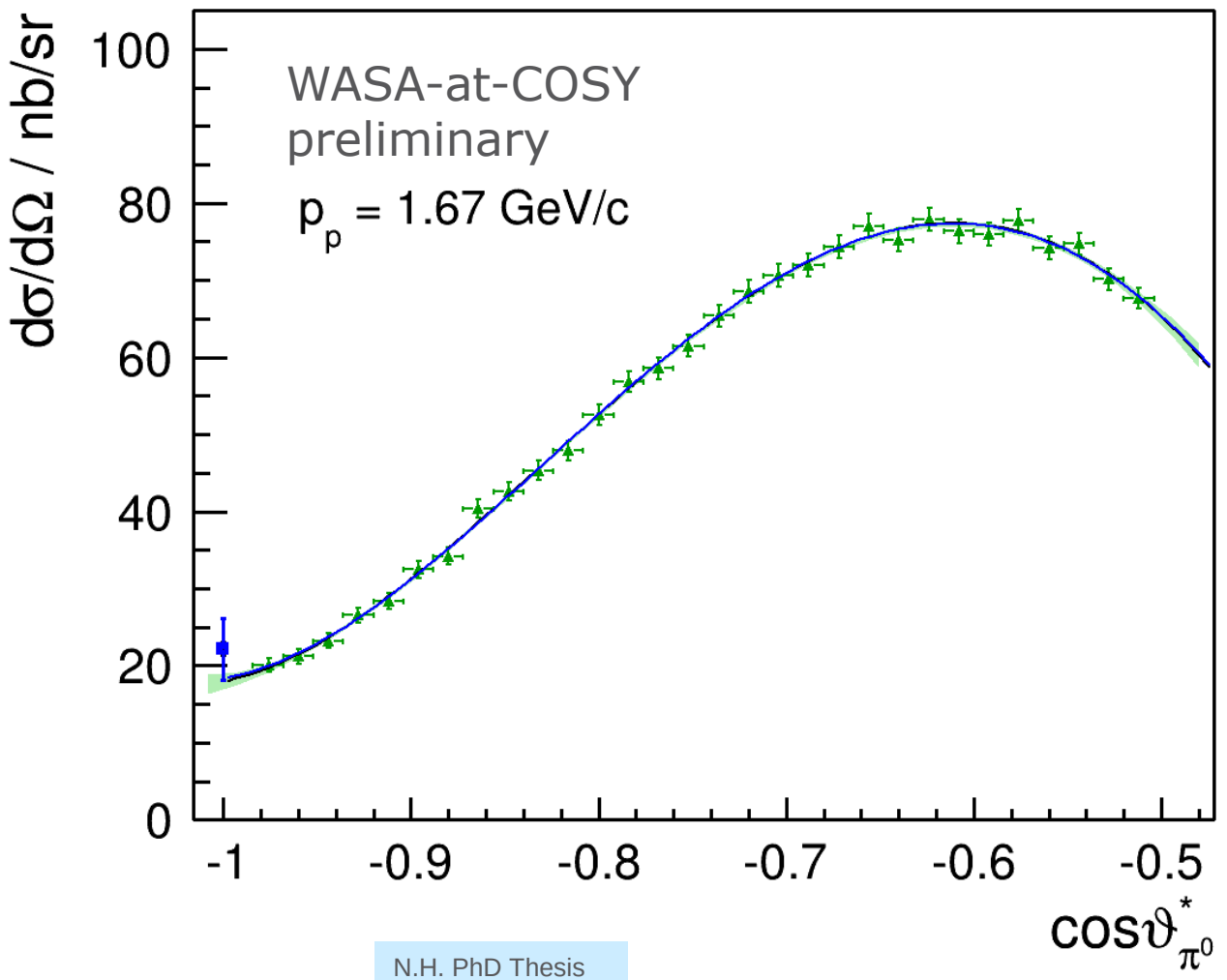

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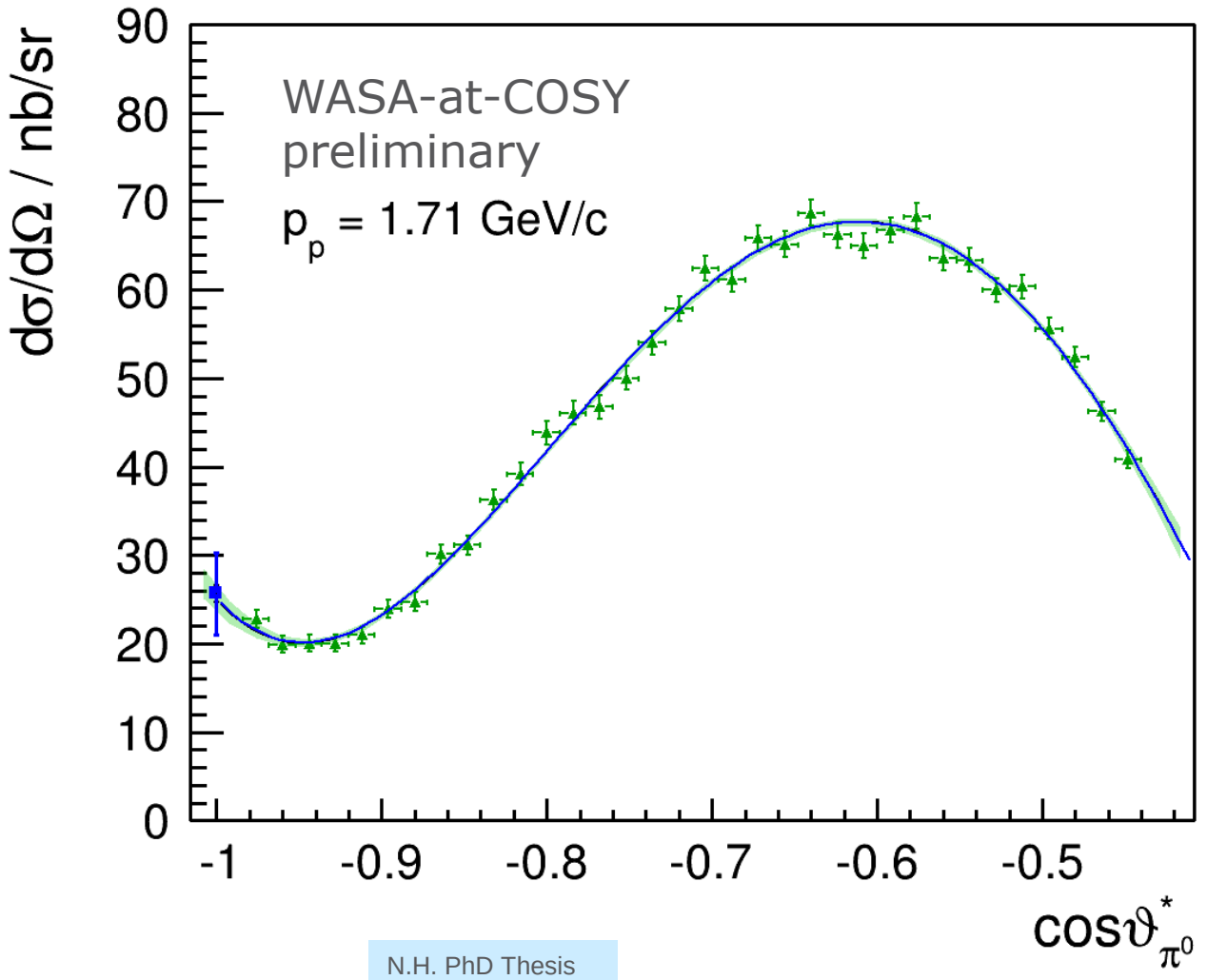

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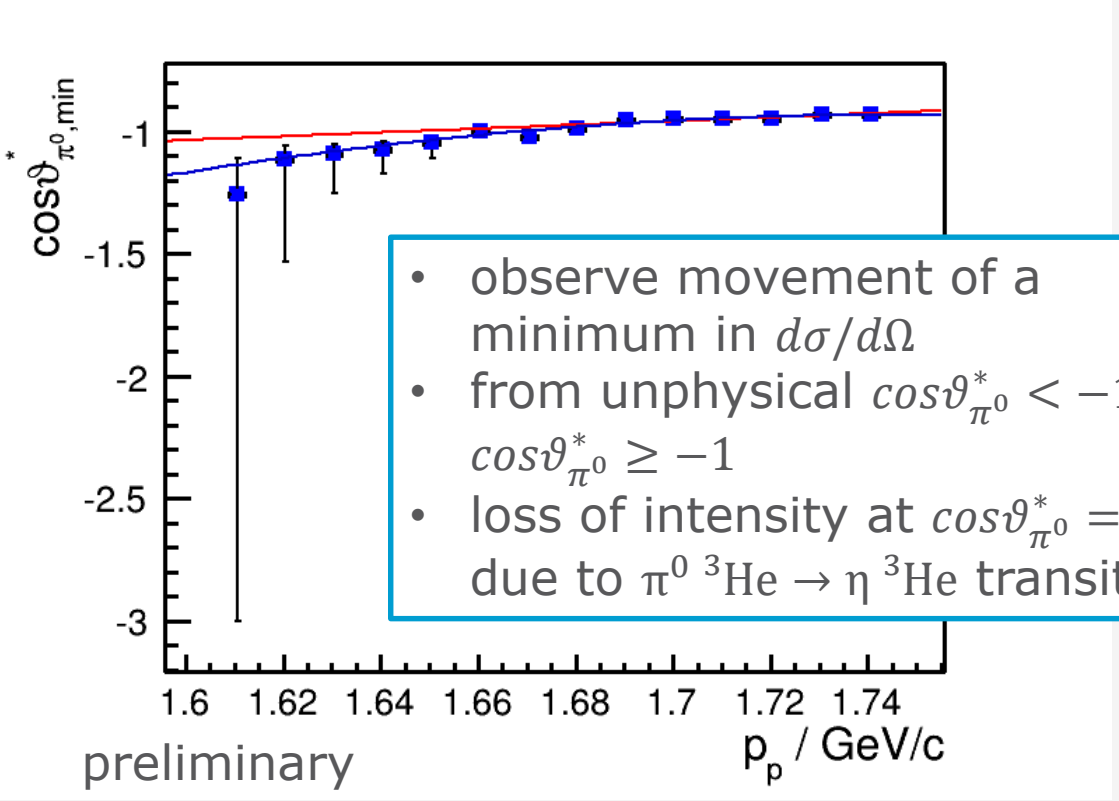
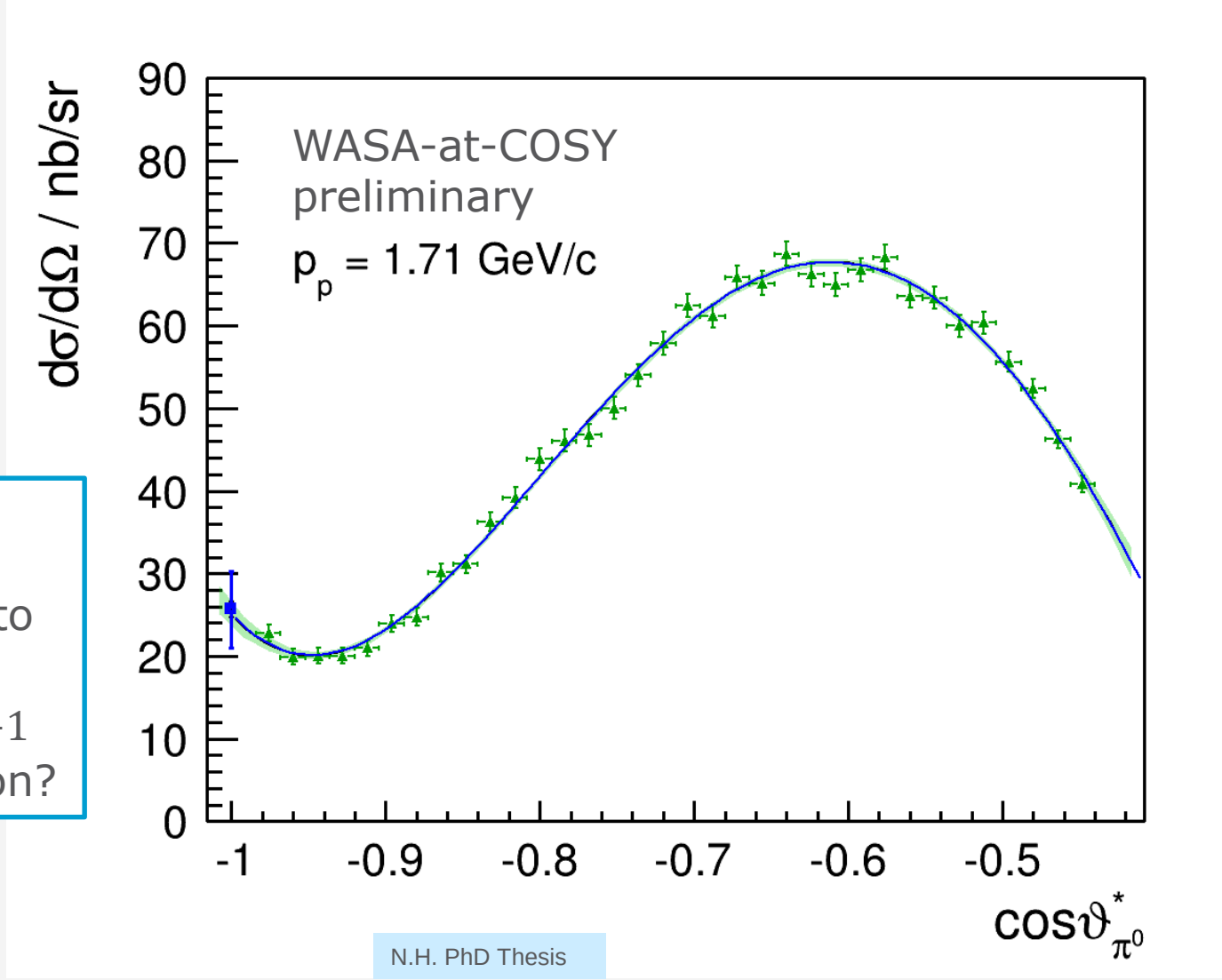


- observe movement of a minimum in $d\sigma/d\Omega$
- from unphysical $cos\vartheta^*_{\pi^0} < -1$ to $cos\vartheta^*_{\pi^0} \geq -1$
- loss of intensity at $cos\vartheta^*_{\pi^0} = -1$ due to $\pi^0\ {}^3He \rightarrow \eta\ {}^3He$ transition?

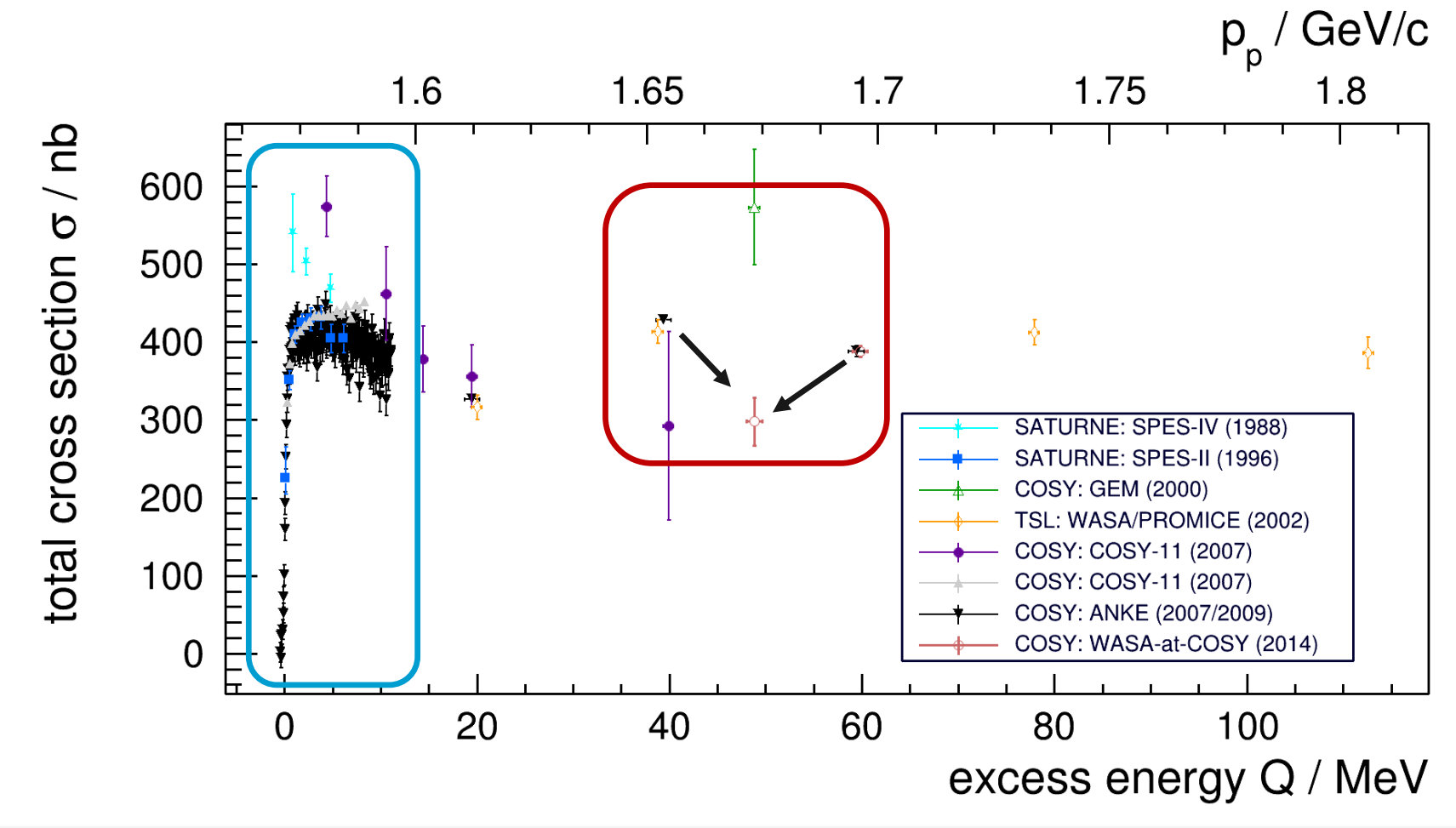


$pd \rightarrow {}^{3}He\eta$

$pd \rightarrow {}^3He\eta$

- near threshold:
  - fast rise of σ
  - effect of strong FSI
  - existence of η^3He – (quasi-)bound state?

- above threshold:
  - production mechanism?
  - sharp variation at $Q = 50\ \mathrm{MeV}$?



$pd \to {}^3He\eta$ - Close to Threshold

Assumption 1: $E = F = 0$

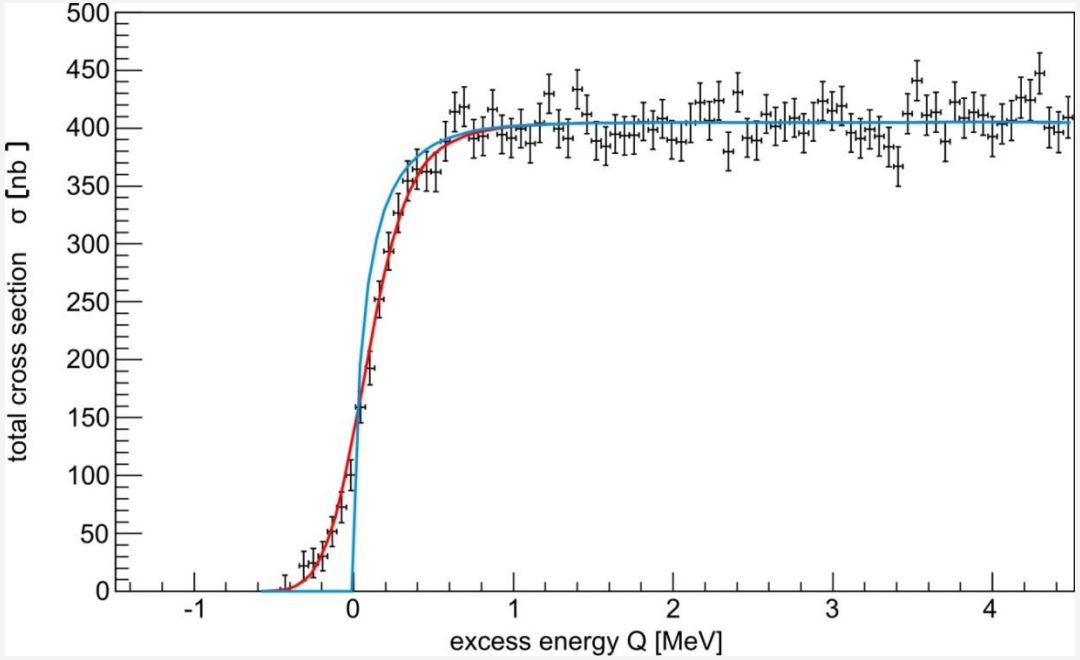
$$I = |A|^2 + 2|B|^2 + \left(|C|^2 + 2|D|^2\right) p_\eta^2 + 2Re\left(AC^* + 2BD^*\right) p_\eta \cos\vartheta_\eta$$

Assumption 2: $A = B = f_s$ and $C = D = f_p$ with

$$f_s = \frac{f_{\text{prod}}}{\left(1 - \frac{p_\eta}{p_1}\right) \cdot \left(1 - \frac{p_\eta}{p_2}\right)}$$

So that

$$\sigma = \frac{p_\eta}{3 \cdot p_p} \int\int I \; d\varphi d\cos\vartheta_\eta = \frac{4\pi p_\eta}{p_p} \cdot \left(|f_s|^2 + p_\eta^2 \cdot |f_p|^2\right)$$



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

$pd \to {}^3He\eta$ - Close to Threshold

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

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

And for the asymmetry parameter:

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

$$= 2p_\eta \frac{Re\,(AC^* + 2BD^*)}{|A|^2 + 2|B|^2 + (|C|^2 + 2|D|^2)\,p_\eta^2} = 2p_\eta \frac{Re\left(f_s^* f_p\right)}{|f_s|^2 + 2p_\eta |f_p|^2}$$

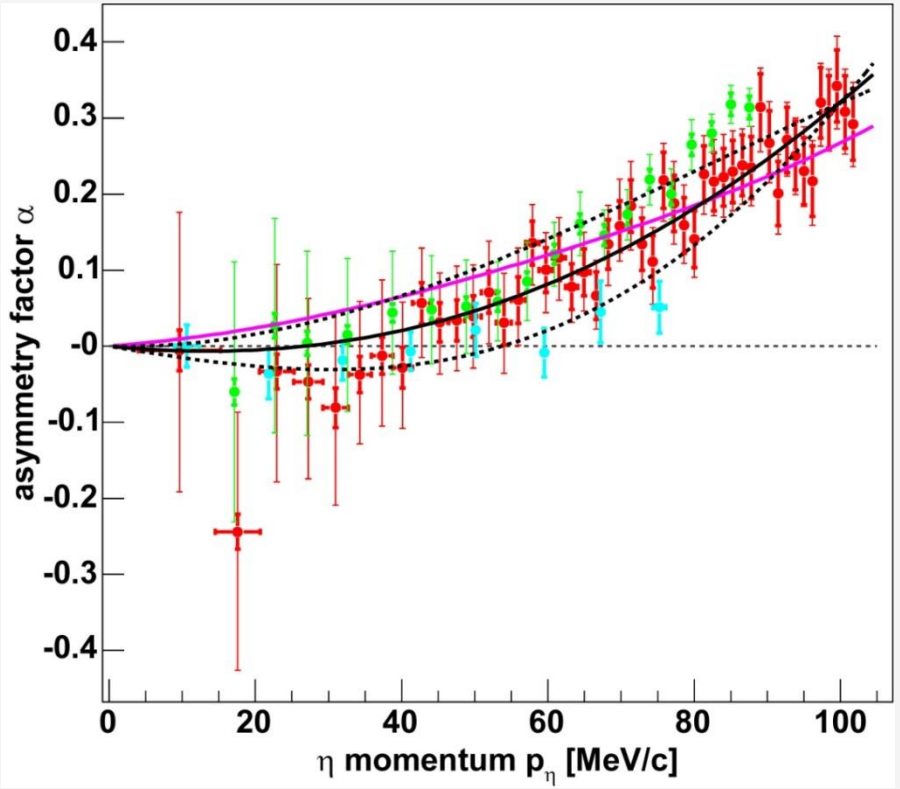
Resulting in a pole below threshold:

$$f_{\text{prod}} = (50 \pm 8)\,(\text{nb/sr})^{1/2} \quad ,$$

$$f_p/f_{\text{prod}} = ((-0.47 \pm 0.08 \pm 0.20) + i \cdot (0.33 \pm 0.02 \pm 0.12))\,(\text{GeV/c})^{-1} \quad ,$$

$$p_1 = ((-4 \pm 7^{+2}_{-1}) - i \cdot (19 \pm 2 \pm 1))\,\text{MeV/c} \quad ,$$

$$p_2 = ((103 \pm 4) - i \cdot (74 \pm 12^{+1}_{-2}))\,\text{MeV/c} \quad .$$



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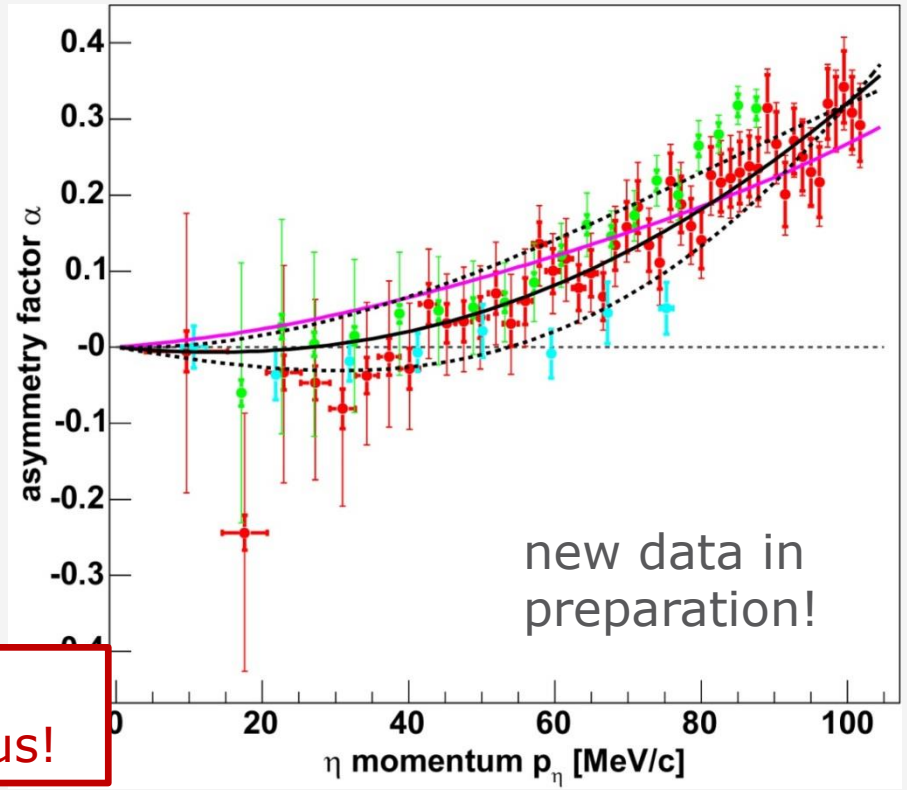
signs of imaginary parts are ambiguous!



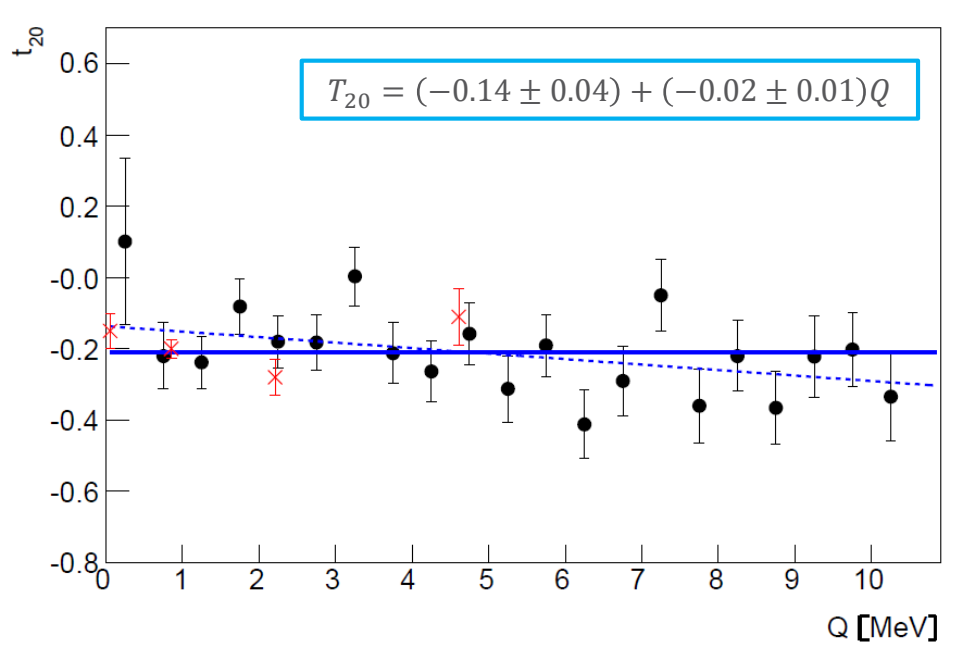
$pd \to {}^3He\eta$ - Close to Threshold

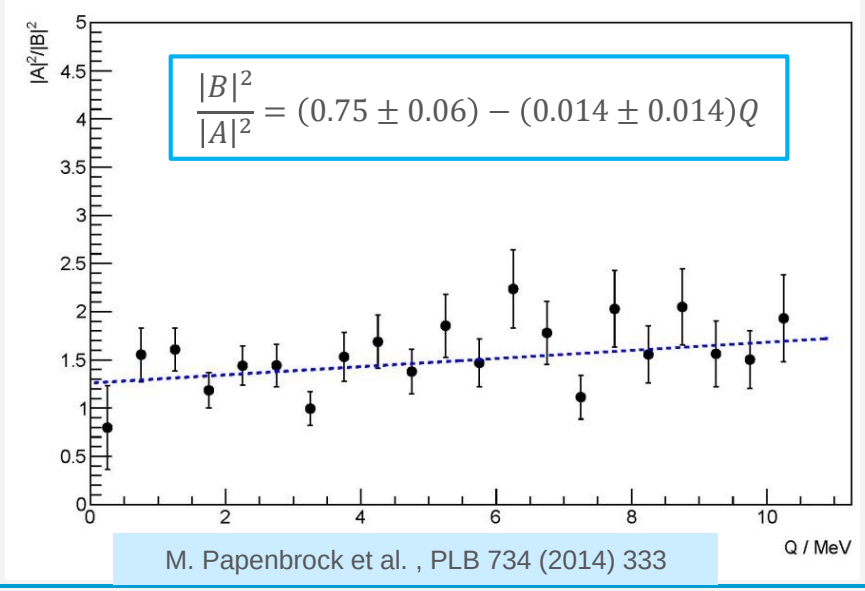
Polarization measurement $\vec{d}p \to {}^3He\eta$

Assumption:
Very close to threshold, only A and B contribute

$$\frac{d\sigma}{d\Omega} = \frac{p_\eta}{3p_p}\left(|A|^2 + 2|B|^2\right) \quad \text{and} \quad t_{20} = \sqrt{2}\,\frac{|B|^2 - |A|^2}{2|B|^2 + |A|^2}$$

Observation:
- (near) constant t_{20}
- and thus, near constant $|A|^2/|B|^2$ (variation on the scale of $50\ \mathrm{MeV}$)
- strong s-wave FSI influences $|A|^2$ and $|B|^2$ similarly

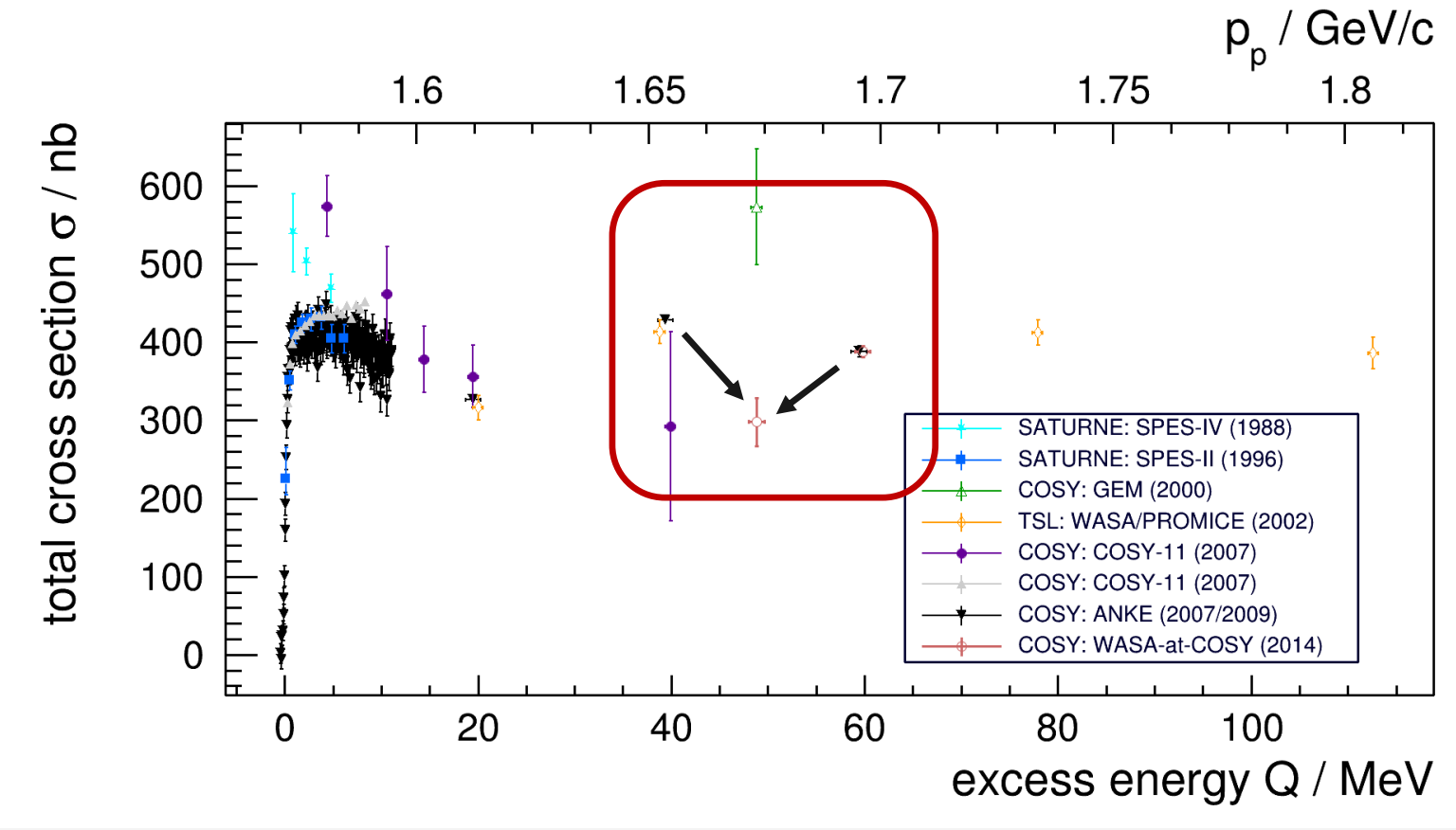




M. Papenbrock et al. , PLB 734 (2014) 333

$pd \to {}^3He\eta$ - Above Threshold

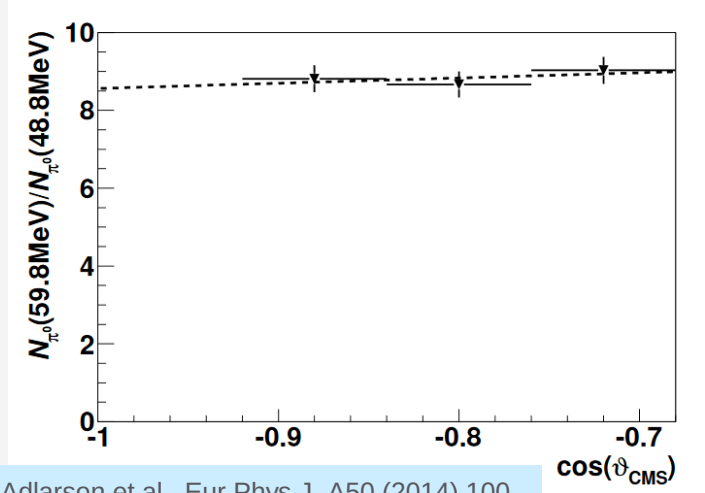
- Variation around $Q \approx 50\,\mathrm{MeV}$



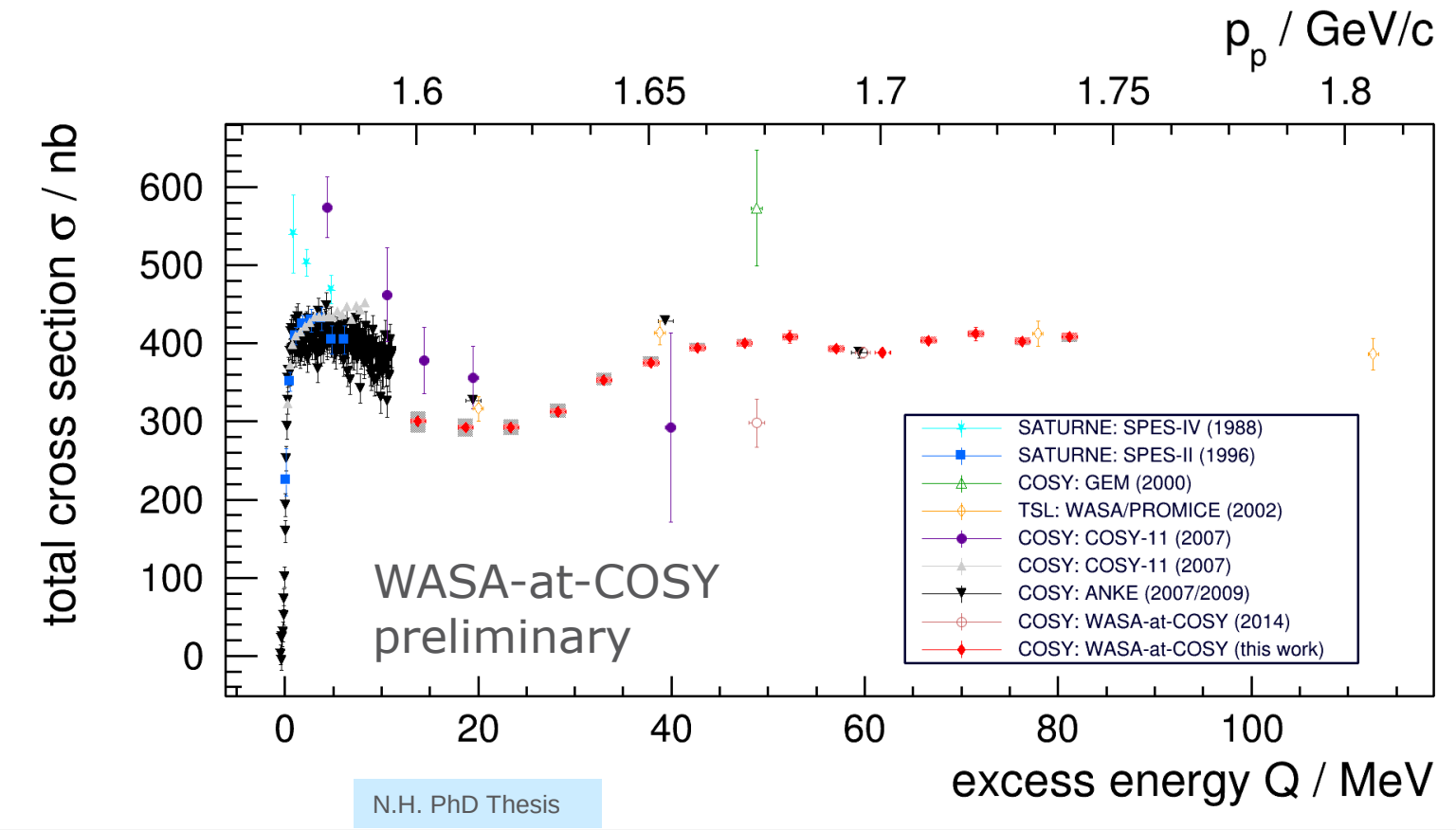
$pd \rightarrow {}^3He\eta$ - Above Threshold

- Variation around $Q \approx 50\,\mathrm{MeV}$
  - ➢ new data does not confirm it!

Difference?
  - ➢ normalization method



P. Adlarson et al., Eur.Phys.J. A50 (2014) 100



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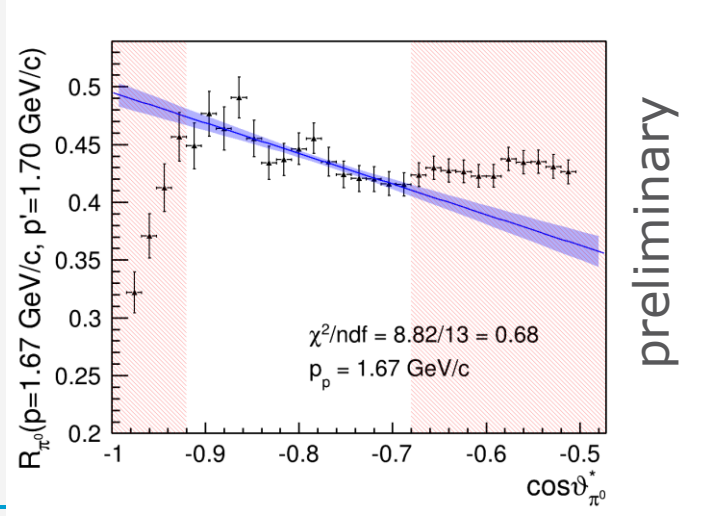

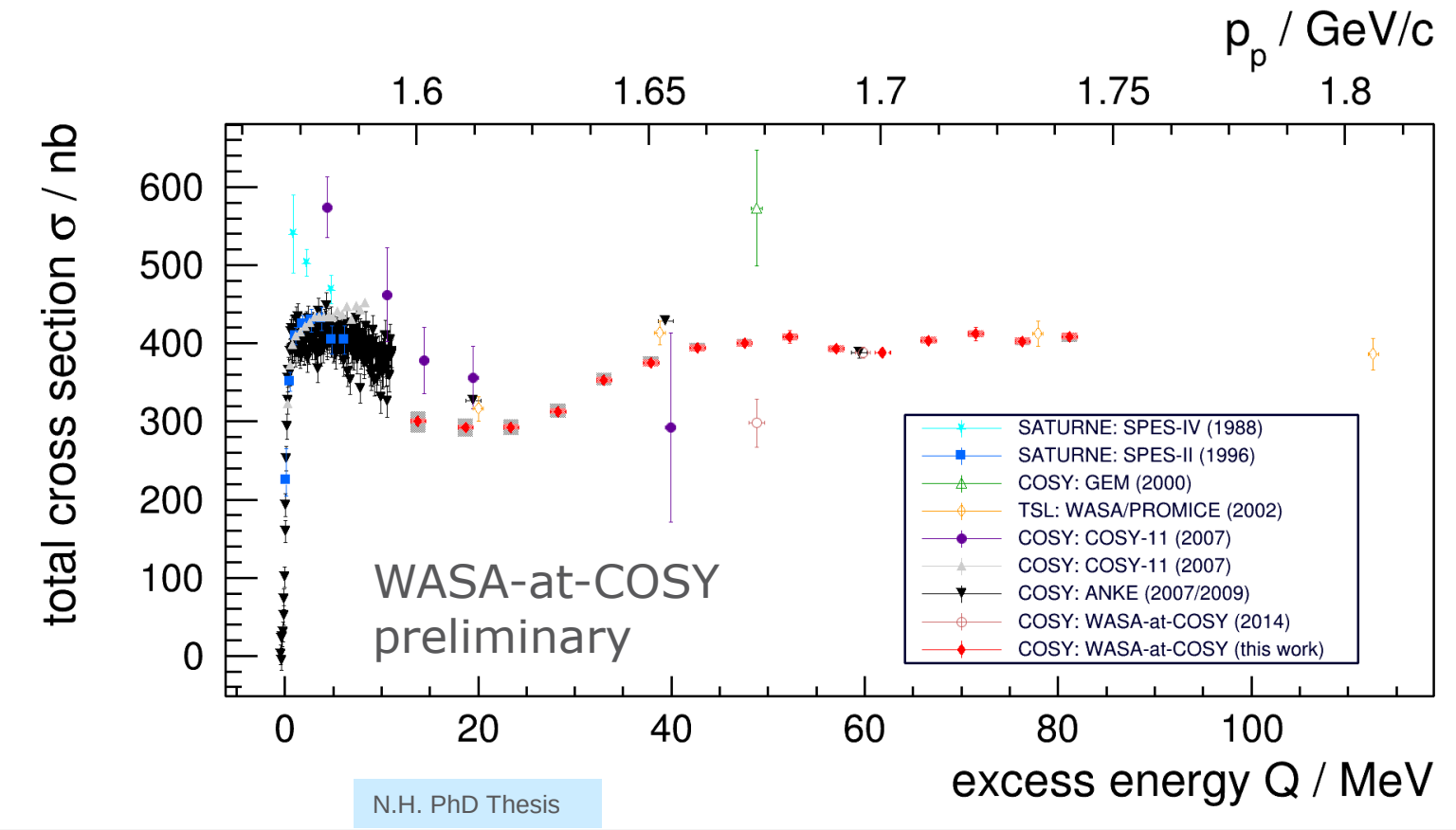

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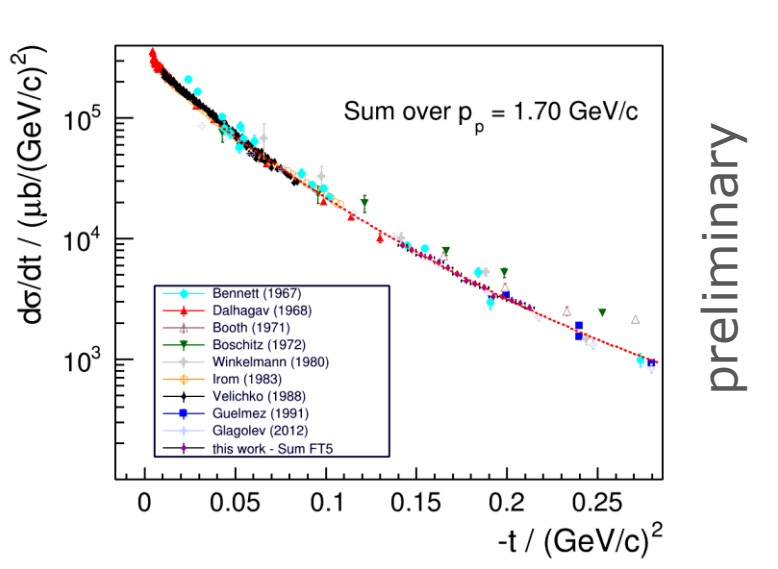
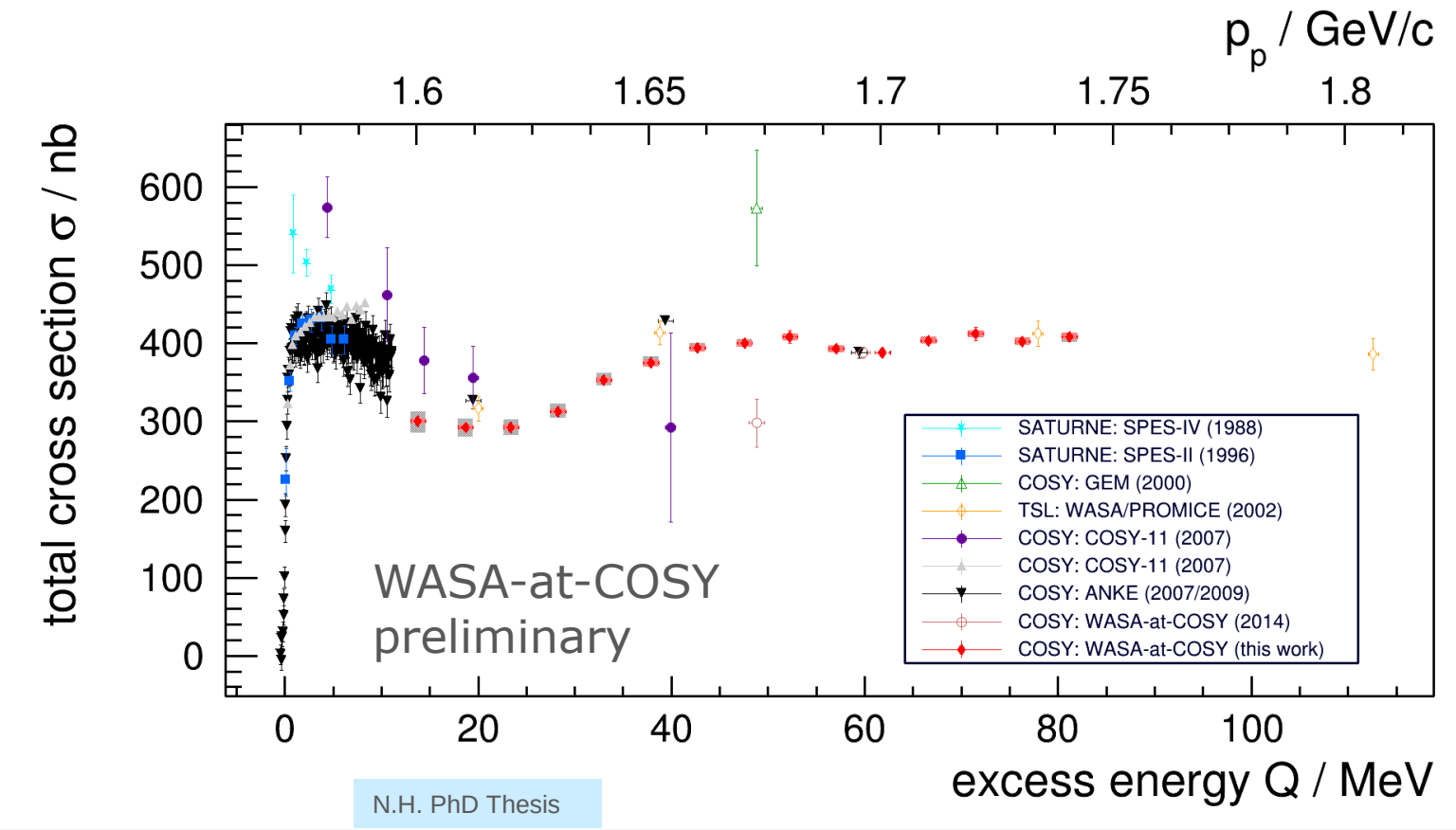
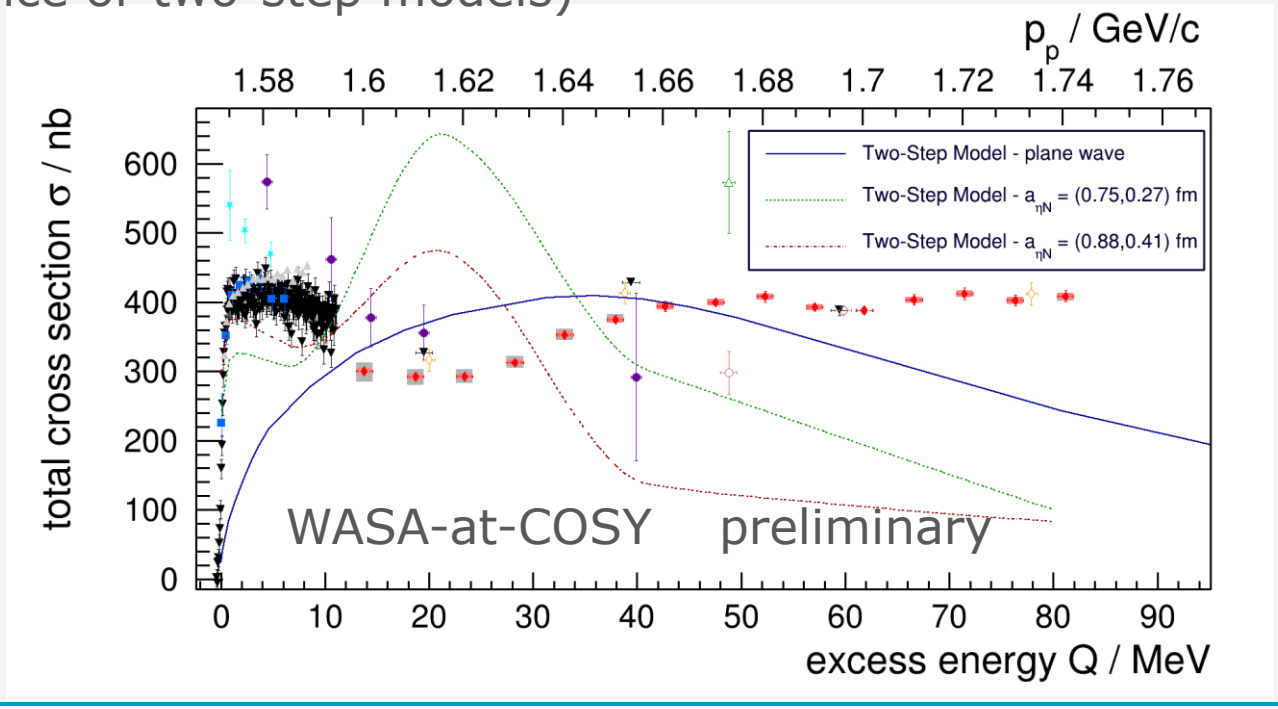


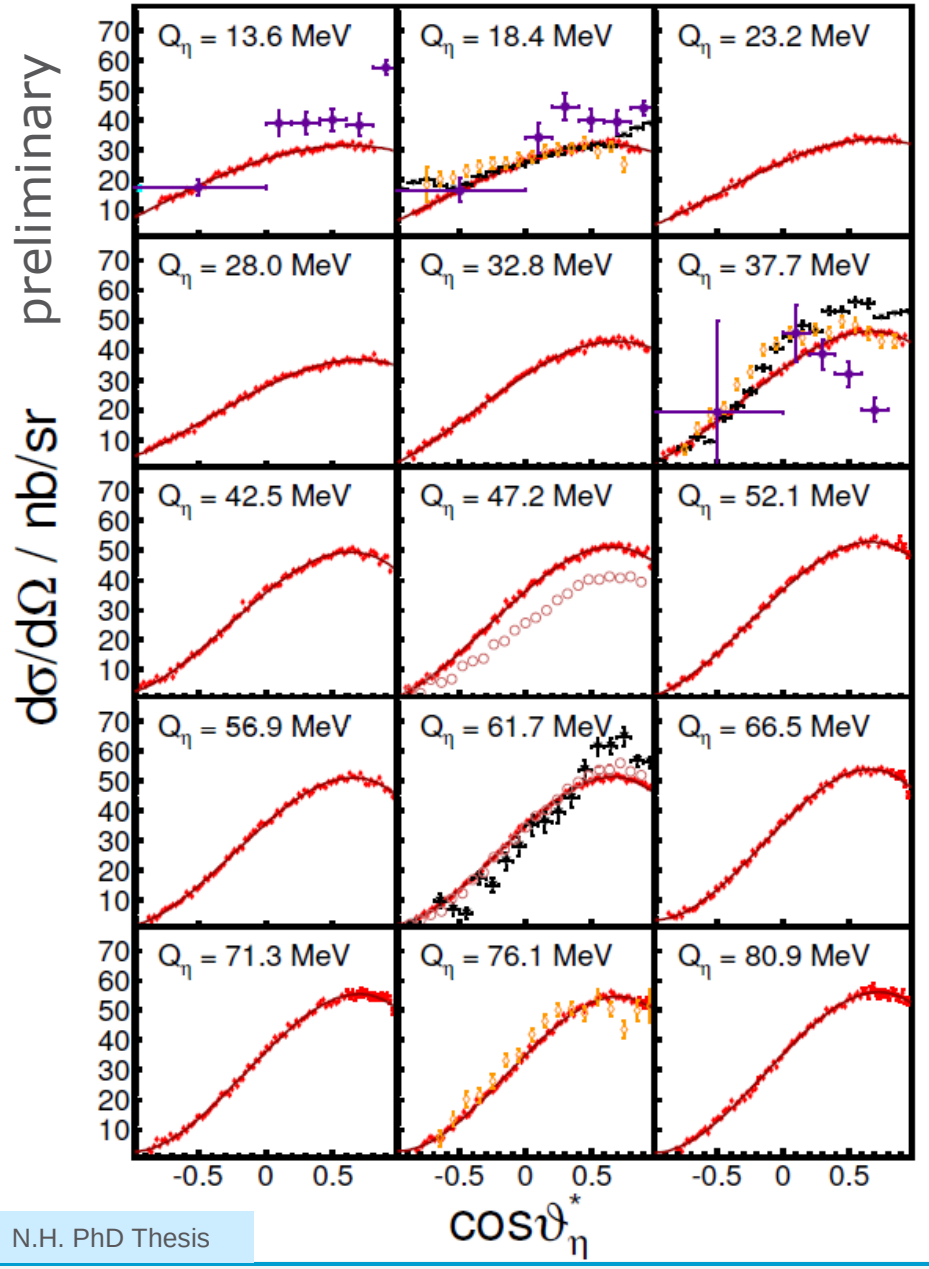


N.H. PhD Thesis

$pd \rightarrow {}^3He\eta$ - Above Threshold

- differential cross sections are strongly anisotropic
- not in accordance with any conventional production model (resonance or two-step models)





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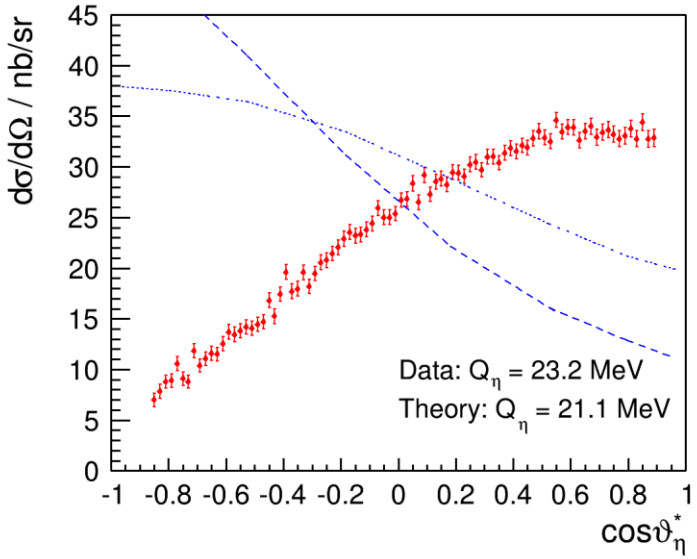
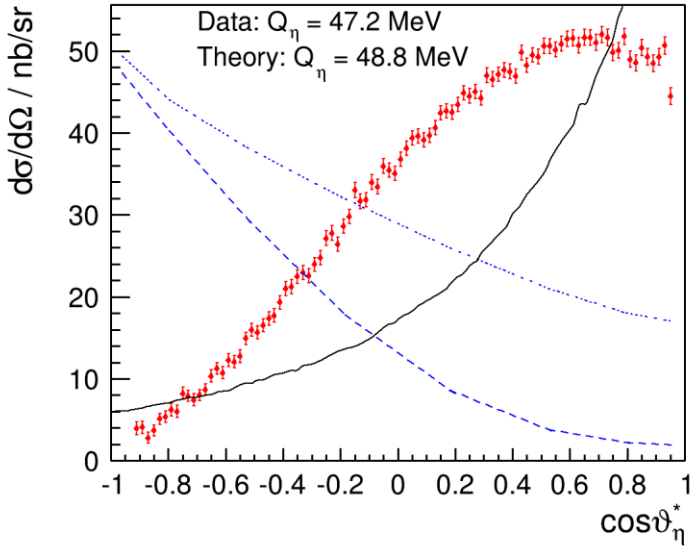


preliminary



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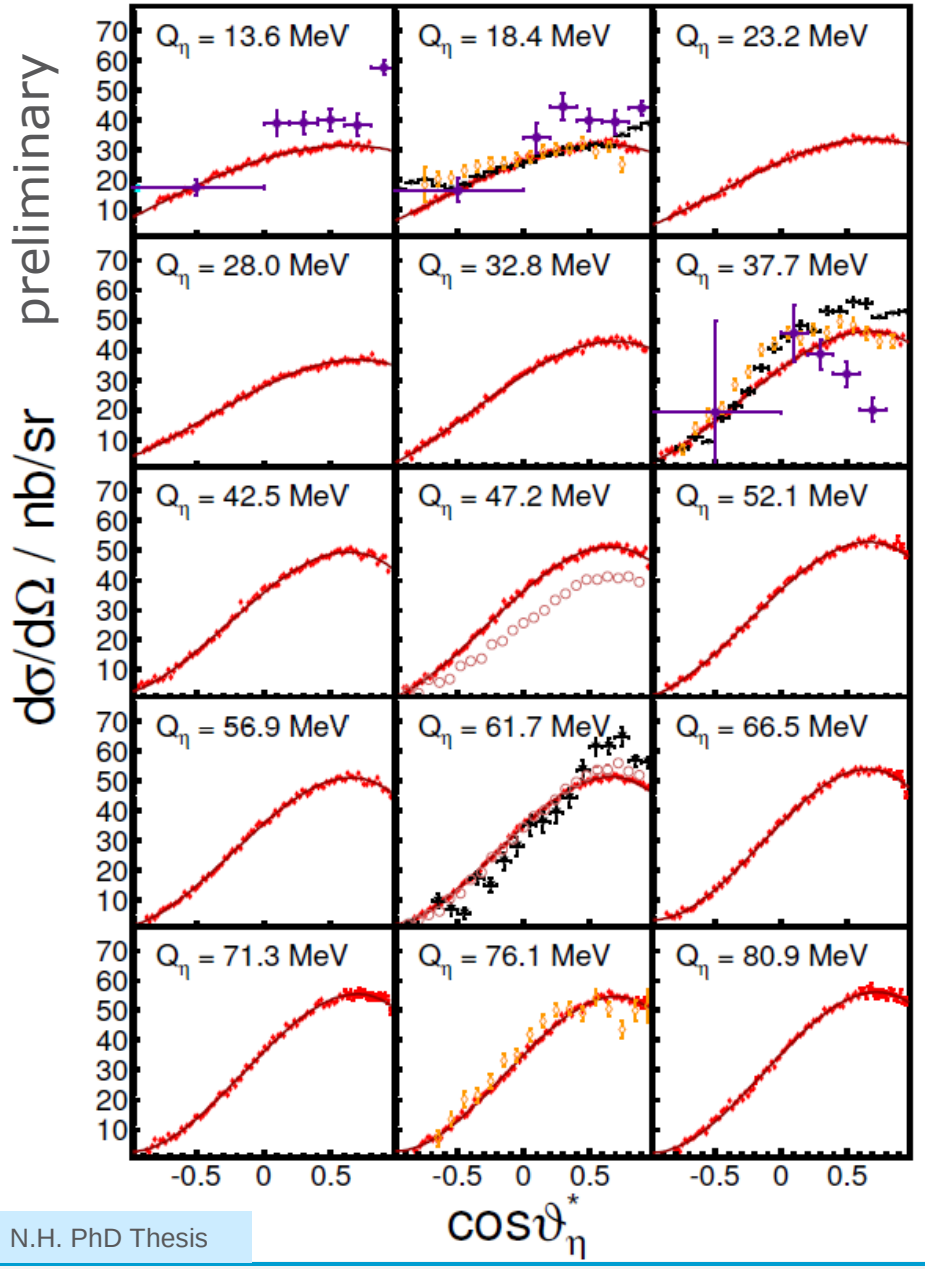

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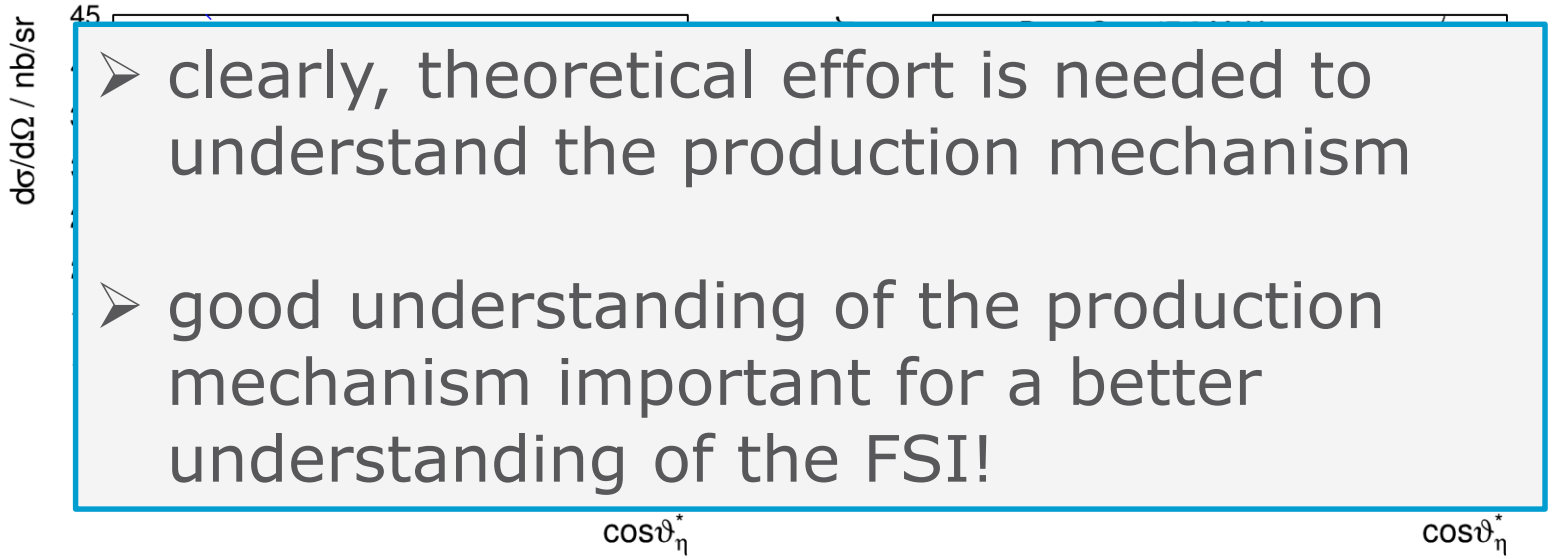
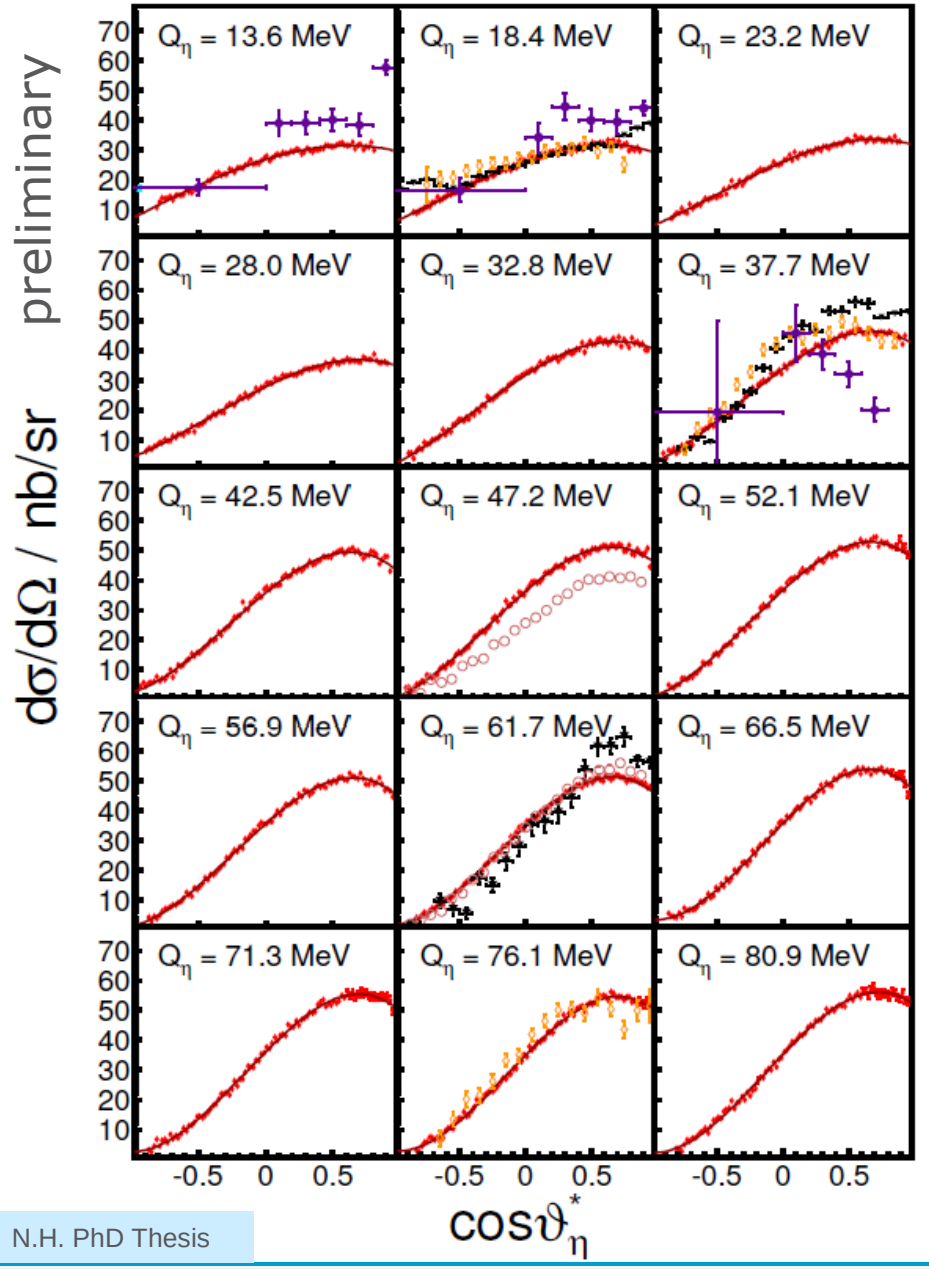


- ➢ clearly, theoretical effort is needed to understand the production mechanism
- ➢ good understanding of the production mechanism important for a better understanding of the FSI!

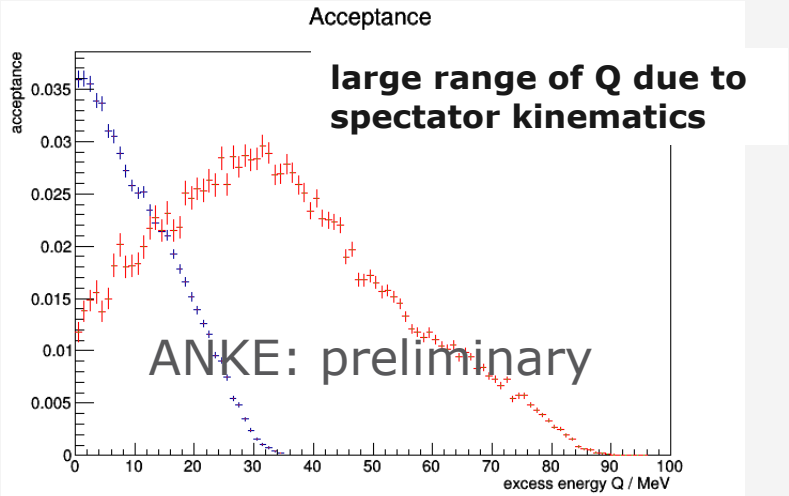


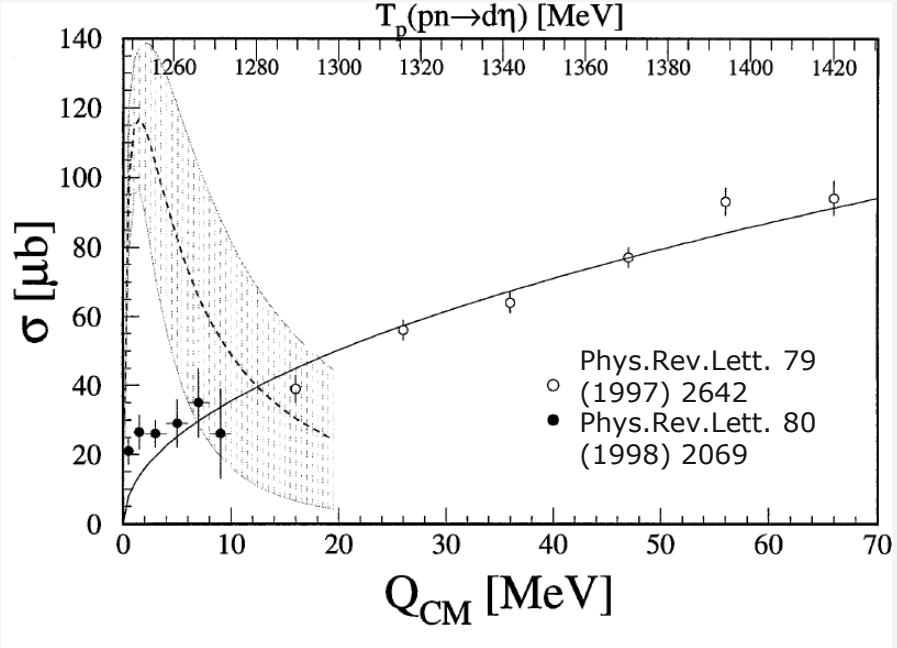
N.H. PhD Thesis

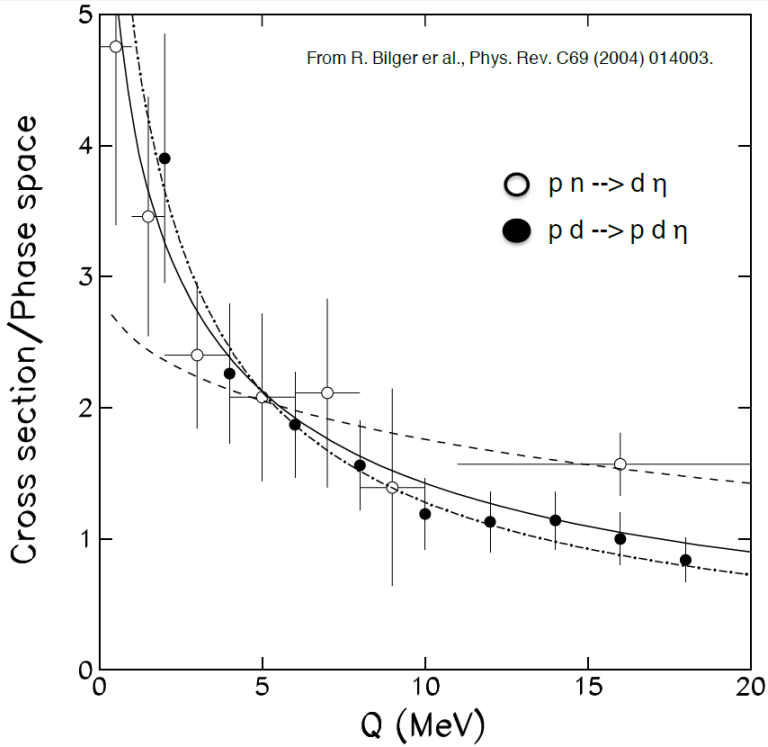
$\mathbf{pn \rightarrow d\eta}$

$pn \to d\eta$

- study the A dependence of the FSI
- CELSIUS/WASA data show clear indication of FSI
- ➢ new ANKE measurements of $pd \to d\eta p_{spec}$

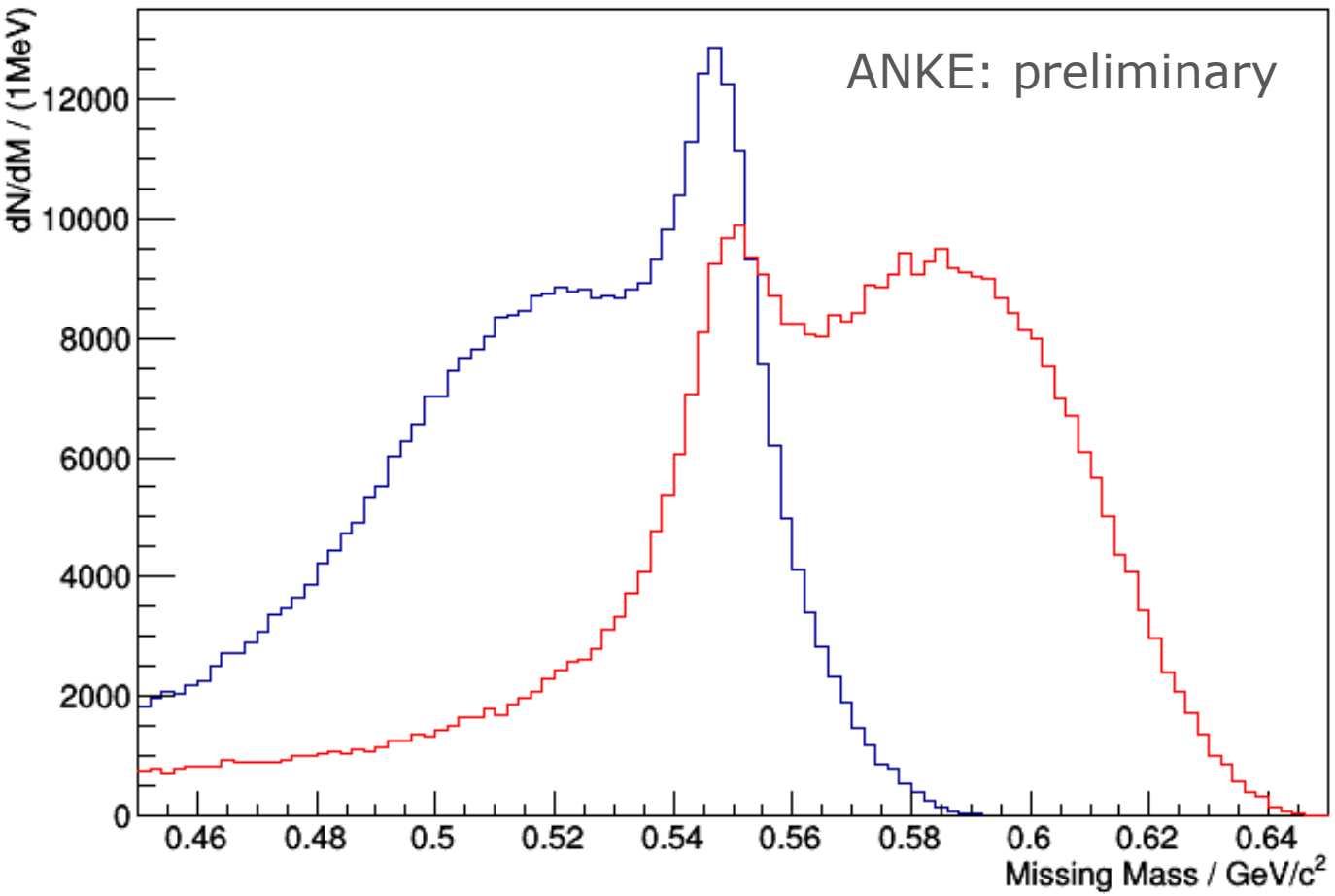






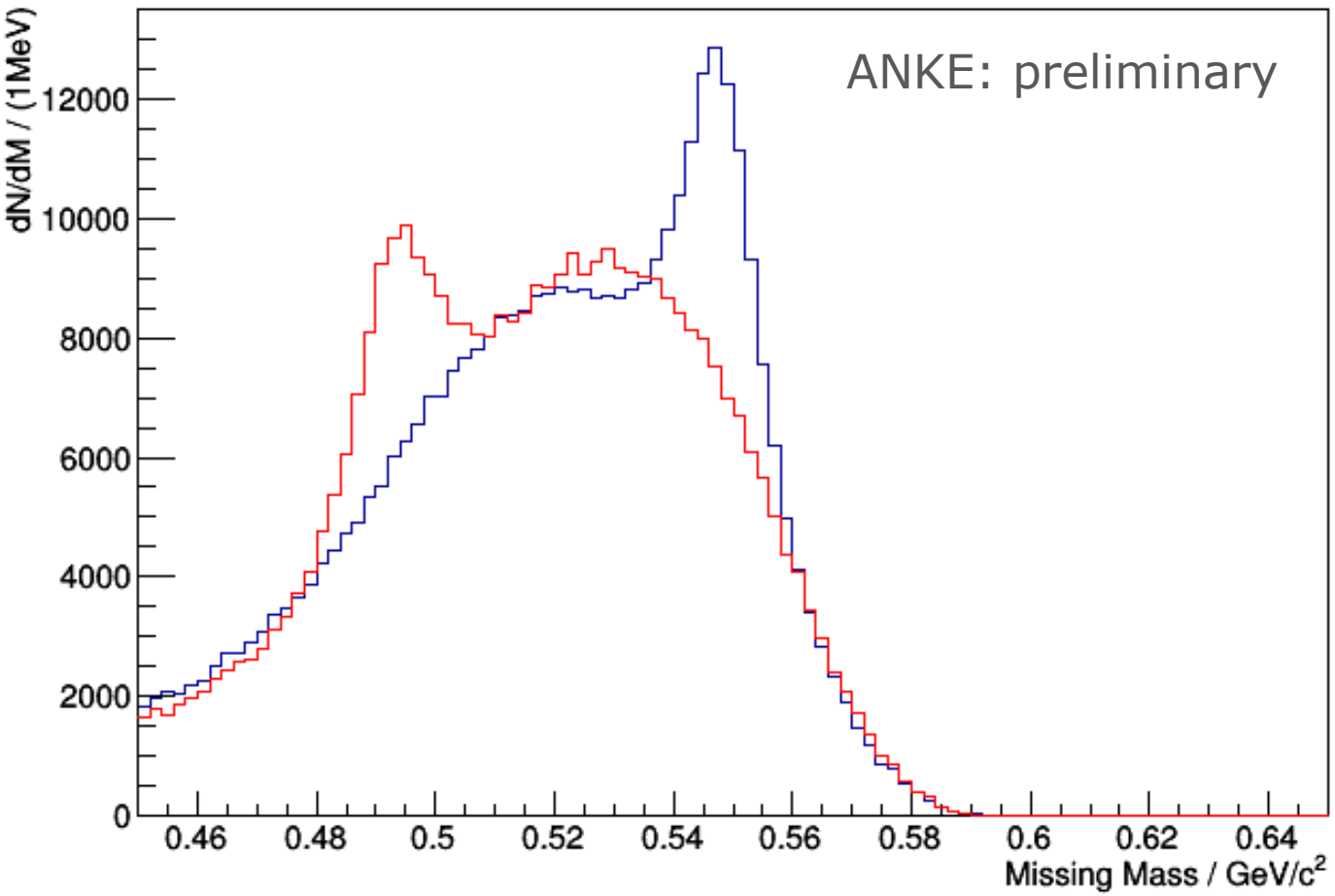
$pn \to d\eta$

- two measurements at $p_p = 2.09\ \mathrm{GeV/c}$ and $p_p = 2.25\ \mathrm{GeV/c}$
- model background by analysing higher p_p data at lower beam momentum



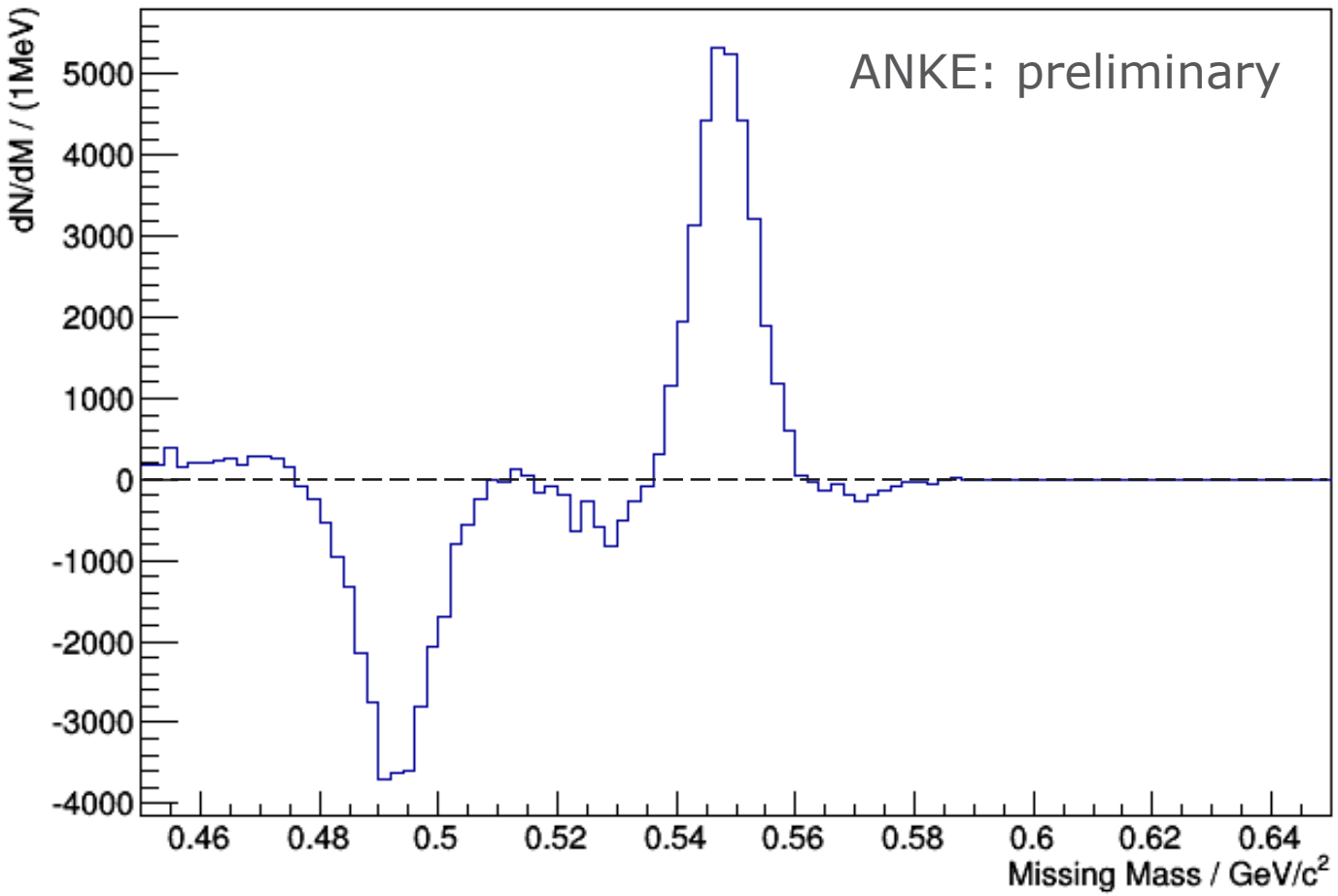
$pn \to d\eta$

- two measurements at $p_p = 2.09\ \mathrm{GeV/c}$ and $p_p = 2.25\ \mathrm{GeV/c}$
- model background by analysing higher p_p data at lower beam momentum
- slight discrepancies remain



$pn \to d\eta$

- two measurements at $p_p = 2.09\ \mathrm{GeV/c}$ and $p_p = 2.25\ \mathrm{GeV/c}$
- model background by analysing higher p_p data at lower beam momentum
- slight discrepancies remain
- background description by MC simulations in the making



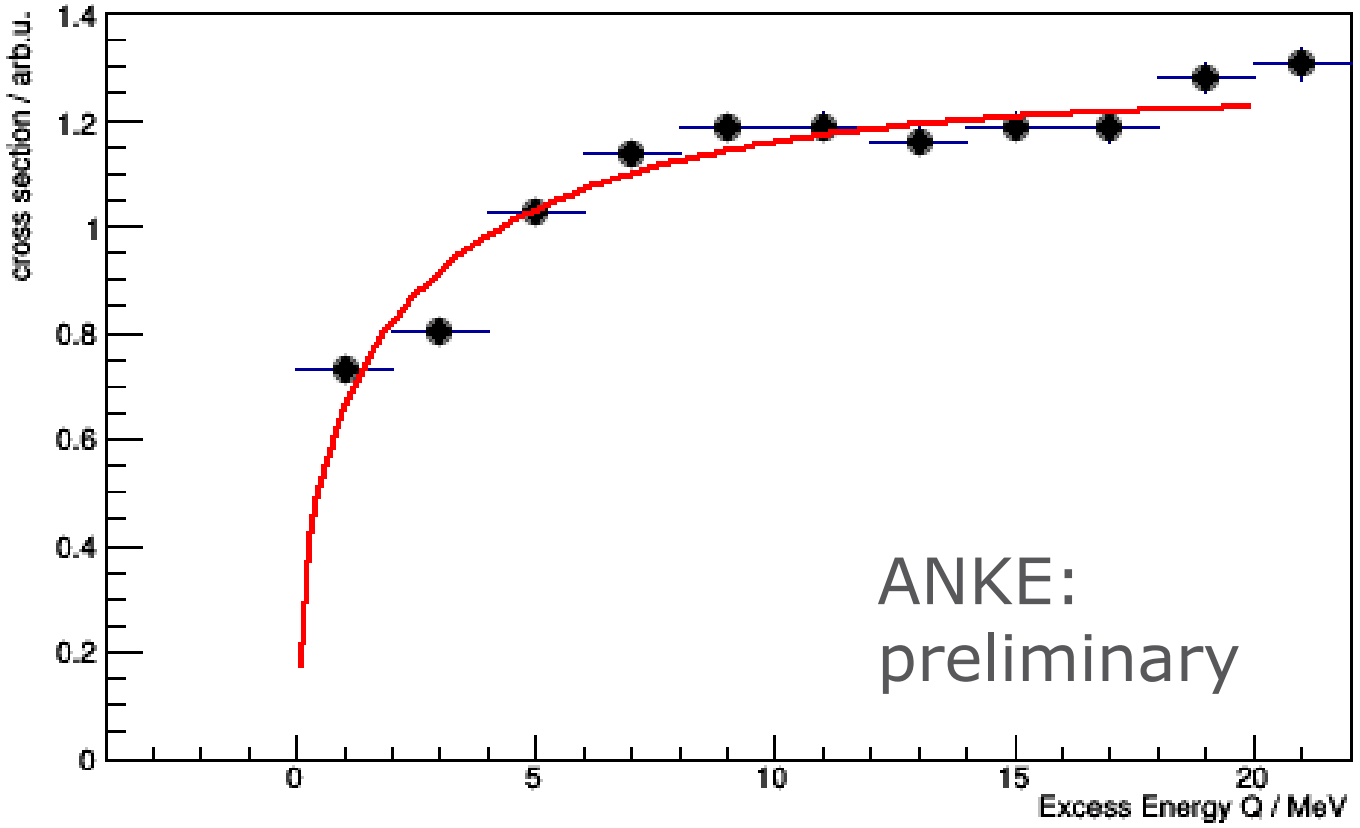
$pn \to d\eta$

preliminary excitation function

- parameterize as:

$$\frac{p_i}{p_f} \cdot \frac{d\sigma}{d\Omega} = |f|^2 = |f_s \cdot FSI|^2 \quad \text{with}$$
$$\text{FSI} = \frac{1}{1 - i \cdot a \cdot p_f + \frac{1}{2} r_0 a p_f^2}$$

- here, r_0 is set to zero
- final results will be available soon



Summary

- Meson production off light nuclei remains an interesting topic
- Close to production thresholds, FSI effects are crucial
- More theoretical effort is needed to understand production mechanisms

a (much) more comprehensive review is given in arXiv:1611.07250

Thank you for your attention!

included work by:

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Dr. Timo Mersmann
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