Eta meson production in deuteron proton collisions at COSY-ANKE

η^3He FSI studies and η mass determination using dp $\rightarrow$ ^{3}He η

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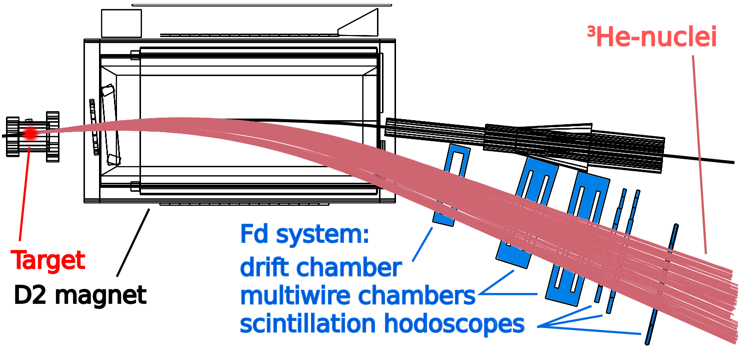
Erice ISNP 33rd Course

The dp $\rightarrow$ ^{3}He$\,\eta$ at ANKE



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

η^3He final state interaction
Is there a quasi bound state?

η^3He final state interaction – quasi bound state?

η-mesic nucleus

Quasi-bound η-mesic nuclei

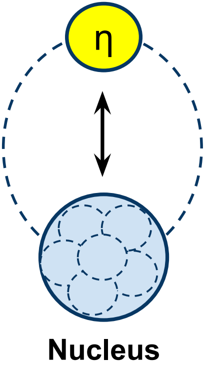
- Attractive S-wave ηN interaction

  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



η-mesic nuclei program at COSY

- $A > 4$: GEM (η^6Li and η^{25}Mg)
- η^4He: ANKE, GEM, WASA
- η^3He: ANKE, COSY-11, GEM, WASA
- ηd & η^3H: Proposed measurements at ANKE

η^3He final state interaction – quasi bound state?

FSI - Final State Interaction

Two ways to investigate η-mesic nuclei

- Signal from such a state **below** the ηA production threshold
  (WASA-at-COSY, Talk of M. Skurzok, Sunday evening)
- Investigation of the excitation function **above** threshold;
  A pole close to threshold should influence the ηA production
  $\rightarrow$ described by a FSI ansatz

S-wave FSI ansatz for dp $\rightarrow$ ^{3}He η:

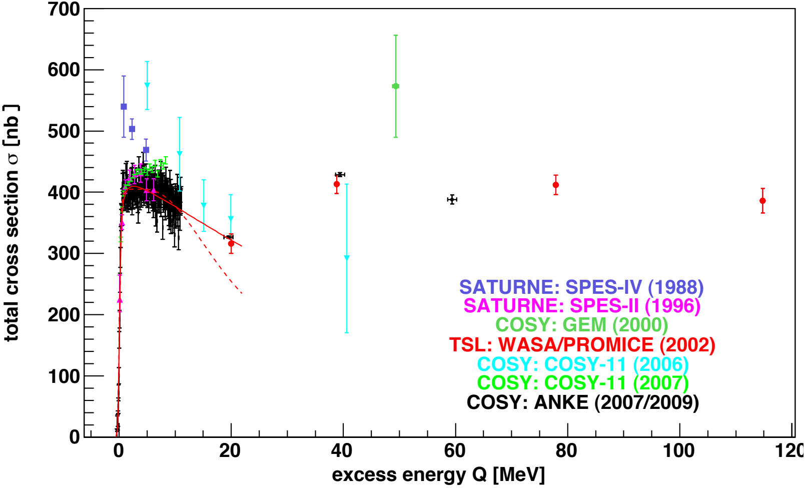
$$\frac{p_i}{p_f} \cdot \frac{d\sigma}{d\Omega} = |f|^2 = |f_{\text{prod.}} \cdot FSI|^2$$

- Classical description with a and r_0: $FSI = \frac{1}{1 - i \cdot a \cdot p_f + \frac{1}{2} \cdot a \cdot r_0 \cdot p_f^2}$
- Alternative description with poles: $FSI = \frac{1}{(1 - p_f/p_1)(1 - p_f/p_2)}$

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

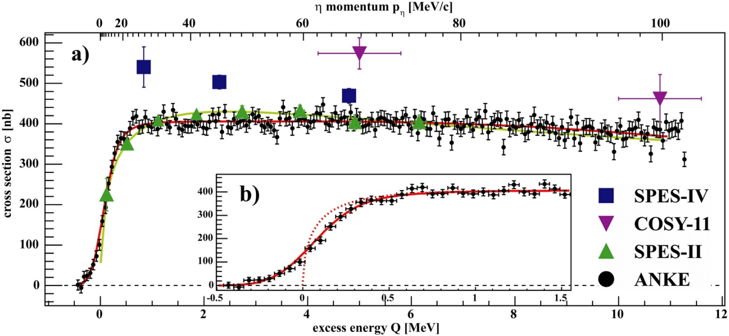
η^3He final state interaction – quasi bound state?

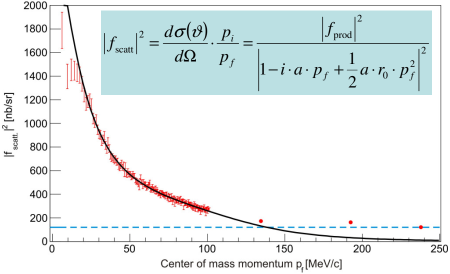
Total cross section of dp $\rightarrow$ ^{3}He η



T. Mersmann et al., Phys. Rev. Lett. 98 (2007) 242301; T. Rausmann et al., Phys. Rev. C80 (2009) 017001.

η^3He final state interaction – quasi bound state?





- Very good description of the whole energy range with FSI ansatz
- Momentum smearing of the COSY beam has to be taken into account

Status and results of the ANKE η^3He program

- Strong attractive FSI: large $|a|$ and small $|p_1|$
- Fit to the data for $Q < 11$ MeV:
  Pole of the scattering amplitude:

$$Q_0 = p_1^2/2m_{\text{red}} = [(-0.30 \pm 0.15\ ) \pm i\,(0.21 \pm 0.29)]\,\text{MeV}$$

  Scattering length:

$$a(\eta^3\text{He}) = [\pm\,(10.7 \pm 0.8) + i\,(1.5 \pm 2.6)]\,\text{fm}$$

  C. Wilkin, Phys. Rev. C47 (1993) 938: $a(\eta^3\text{He}) = (-2.31 + i2.57)$ fm

- **Indication for a quasi-bound or virtual state!**
  C. Wilkin et al., Phys. Lett. B654 (2007) 92-96;

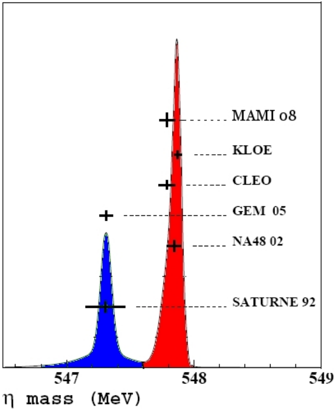
Further investigations

- Polarized measurement: Verification of FSI
- Other ηN systems: ηd & η^3H

High precision η mass determination

High precision η mass determination

Current situation on the η meson mass



Results of the η mass experiments with uncertainties below 60 keV/c^2

Experimental Facility	Mass [MeV/c^2]	Measuring Method
SPES-SATURNE	547.300	dp → ^{3}He η
NA48-SPS	547.843	decay products
GEM-COSY	547.311	pd → ^{3}He η
CLEO-CESR	547.785	decay products
KLOE-DAΦNE	547.873	decay products
CB-MAMI	547.760	photoproduction

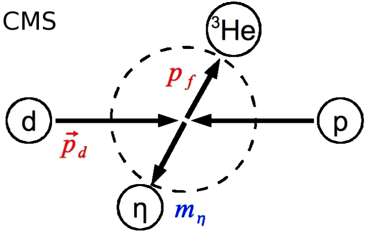
Current PDG η mass value: 547.853 ± 0.024 MeV/c^2

High precision η mass determination

Determination of the η mass with a two-body reaction: Kinematics

Two-body reaction:

$$dp \rightarrow {}^{3}He\,\eta$$



- Final state momentum of ^{3}He and η

$$p_f = \frac{\sqrt{(s - \{m_{^3He} + m_\eta\}^2) \cdot (s - \{m_{^3He} - m_\eta\}^2)}}{2\sqrt{s}}$$

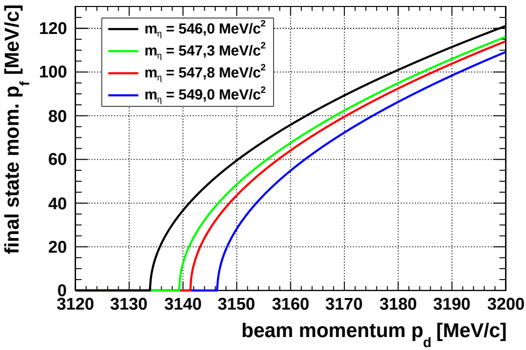
- CM-energy depends only on the beam momentum $\vec{p_d}$

$$\sqrt{s} = |P_d + P_p| = \sqrt{2m_p\sqrt{{m_d}^2 + \vec{p_d}^2} + {m_d}^2 + {m_p}^2}$$

High precision η mass determination

Determination of the η mass with a two-body reaction: Kinematics

Dependency: $p_f = p_f(p_d, m_\eta)$



Needed accuracy: $\frac{\Delta p_d}{p_d} < 10^{-4}$

Near threshold:

Final state momentum is very sensitive to the η mass!

The goal:

- Accuracy of the η-mass: $\Delta m_\eta < 50\ \text{keV}/\text{c}^2$
- Final state momentum of the ^{3}He-nuclei: p_f $\Delta p_f = 400\ \text{keV}/\text{c}$
- Beam momentum: p_d $\Delta p_d = 300\ \text{keV}/\text{c}$

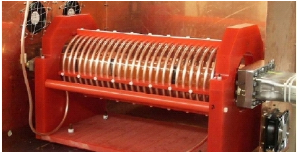
High precision η mass determination

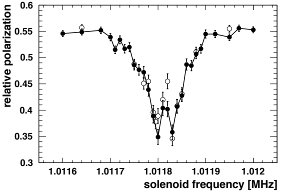
Beam momentum determination

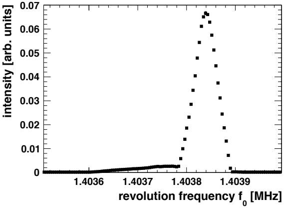
Artificial spin resonance

Published in Phys. Rev. ST Accel. Beams 13 (2010) 022803

- Induced by a horizontal magnetic rf-field
- Depolarization of a vertically polarized deuteron beam







Resonance condition:

$$f_r = (1 + \gamma G_d)\, f_0$$

$$\gamma = \frac{1}{G_d}\left(\frac{f_r}{f_0} - 1\right)$$

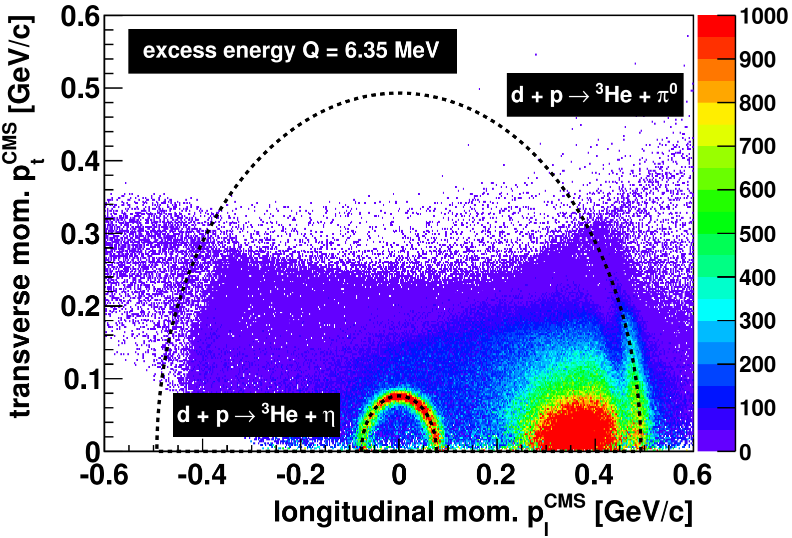
$$p_d = m_d\sqrt{\gamma^2 - 1}$$

$$\frac{\Delta p_d}{p_d} < 6 \cdot 10^{-5}$$

$$3146.41 \pm 0.05 \pm 0.17 \text{ MeV/c}$$

High precision η mass determination

Final state momentum determination



High precision η mass determination

Final state momentum determination

Using a two body reaction to verify the calibration

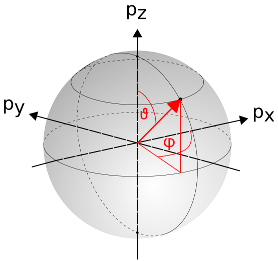
- Perfect symmetric momentum sphere in p_x, p_y, p_z with radius

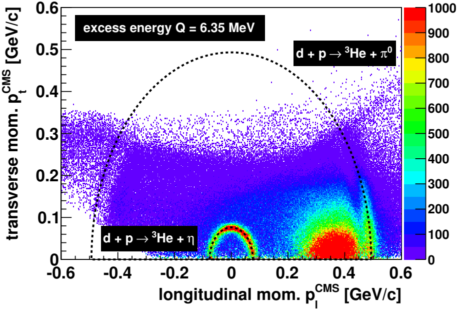
$$p_f = \sqrt{p_x^2 + p_y^2 + p_z^2}$$

- Deviations of symmetric shape $\rightarrow$ improve calibration
- Study $\cos\vartheta$ and ϕ dependency of the final state momentum

$$p_f = p_f(\cos\vartheta) \text{ and } p_f = p_f(\phi)$$

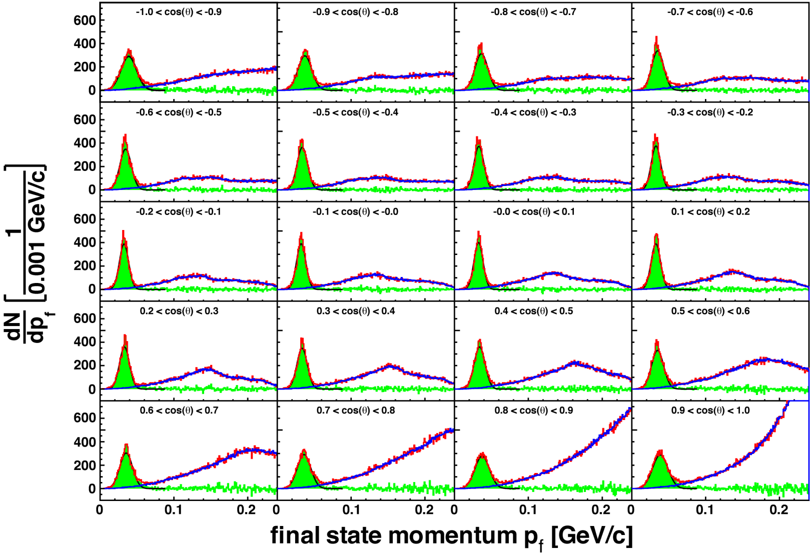
- Therefore full geometrical acceptance is needed





High precision η mass determination

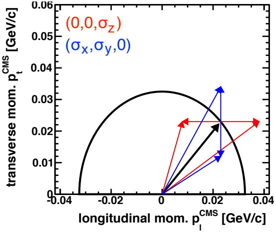
Angular dependence of the $^3\text{He}\,\eta$ final state momentum $p_f = p_f(\cos\vartheta)$ at an excess energy of $Q = 1.2$ MeV

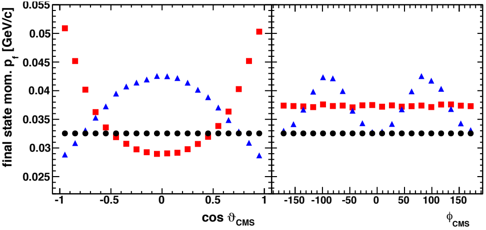


High precision η mass determination

Influence of different momentum resolutions for p_x, p_y, p_z on p_f

Mom. are gaussian distributed with $(\sigma_{p_x}, \sigma_{p_y}, \sigma_{p_z}) = (10, 20, 30)\,\mathrm{MeV/c}$

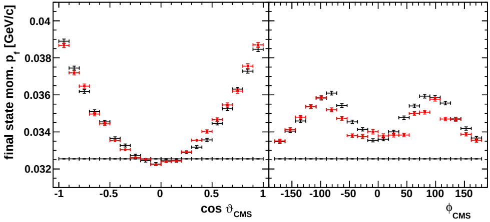




Extracted momentum resolution $(\sigma_{p_x}, \sigma_{p_y}, \sigma_{p_z}) = (3.2, 7.8, 16.4)$ MeV/c

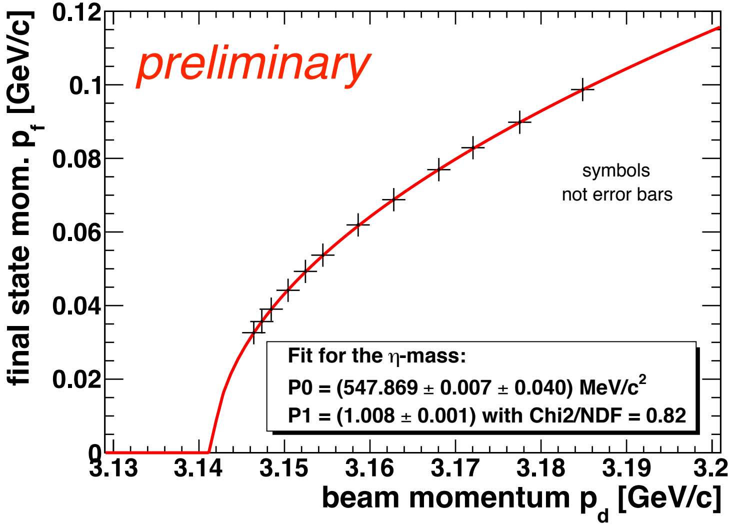
Final state momenta in the range of $p_f = 30 - 100$ MeV/c

Accuracy: $\Delta p_f < 320$ keV/c



High precision η mass determination

Preliminary "final" ANKE-COSY result of the η mass



High precision η mass determination

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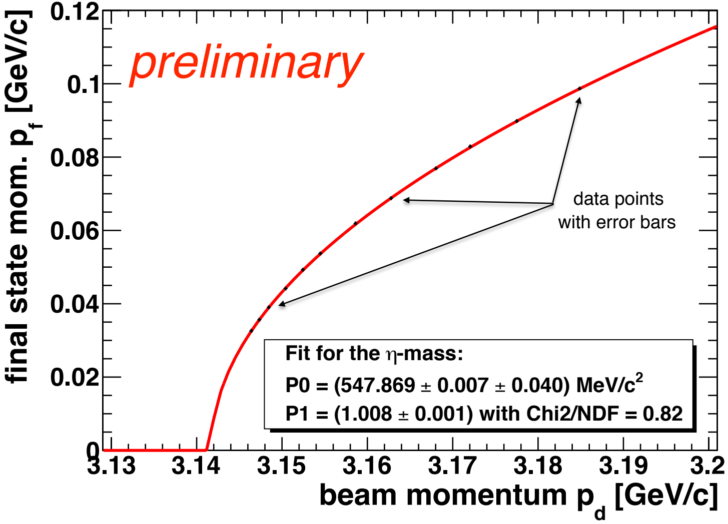

Thank you for your attention