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Studies on η meson production in dp collisions at the magnetic spectrometer ANKE

Christopher Fritzsch for the ANKE collaboration

Westfälische Wilhelms-Universität Münster, Institut für Kernphysik

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Hadron Structure and Spectroscopy (Session: R6)

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JÜLICH
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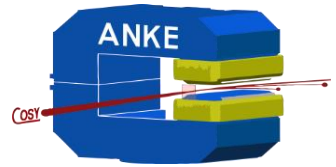
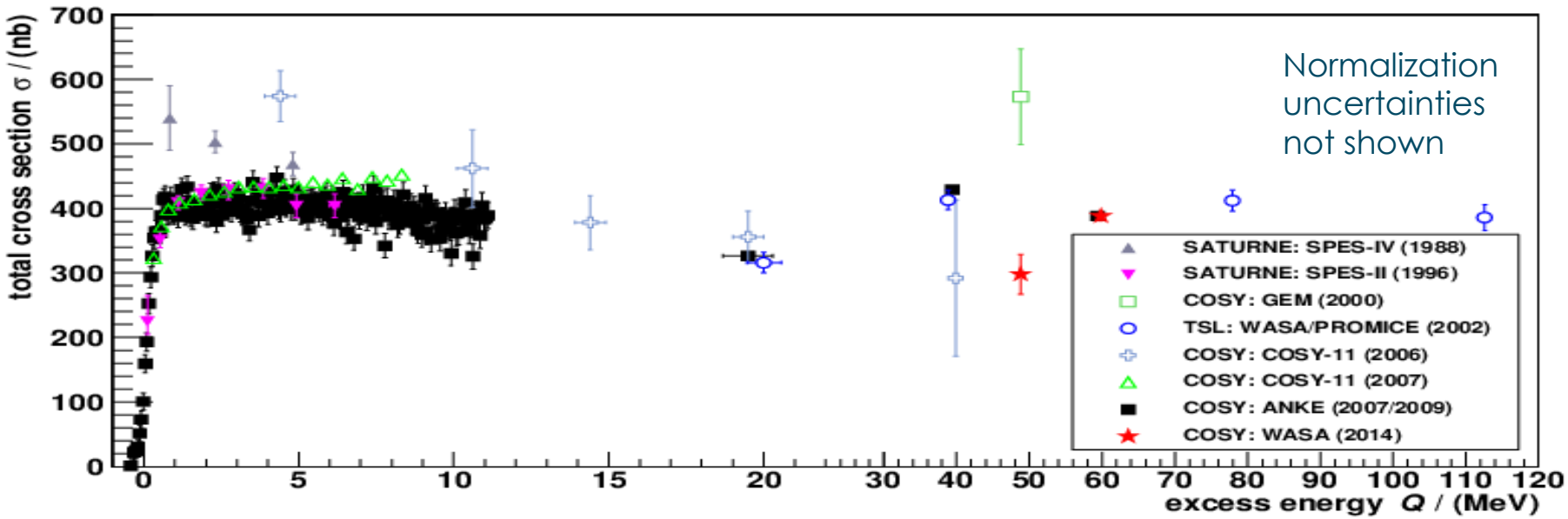
September 15th, 2016

GRK 2149



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

Motivation



- total and differential cross sections of the reaction $dp \rightarrow {}^3\mathrm{He}\eta$ are of special interest
  ⇒ differ strongly from a pure phase space behaviour
- indication of a quasi bound state of the ${}^3\mathrm{He}\eta$-system
- high precision data from the ANKE spectrometer up to $Q = 15\ \mathrm{MeV}$

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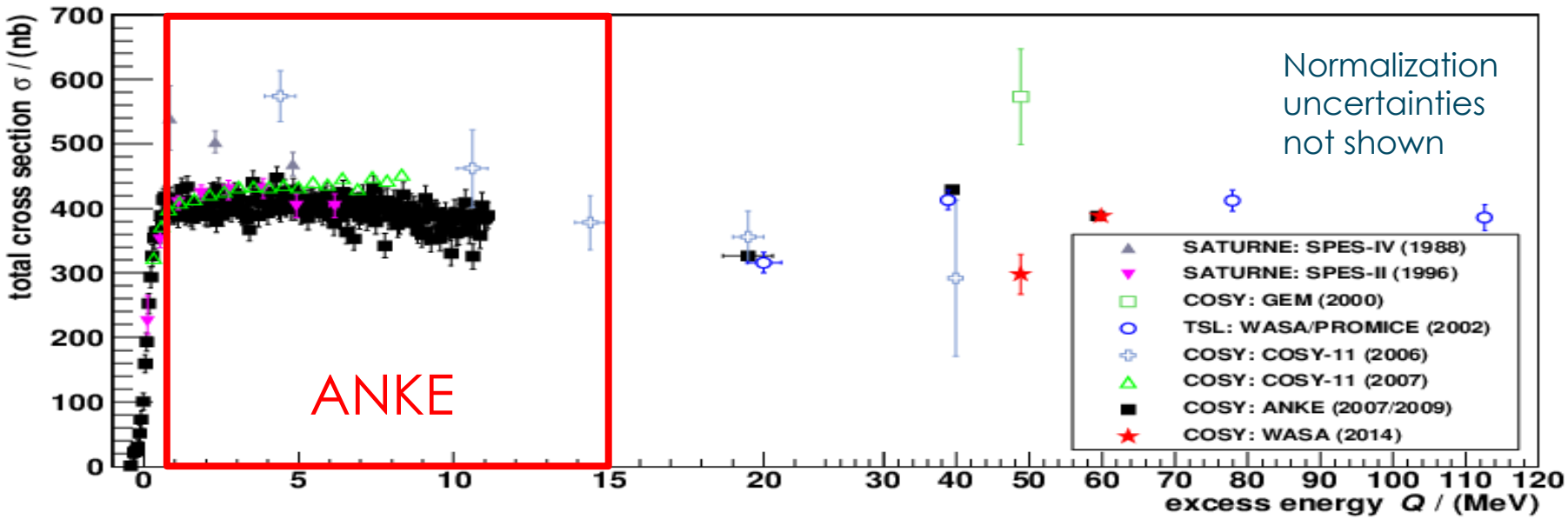

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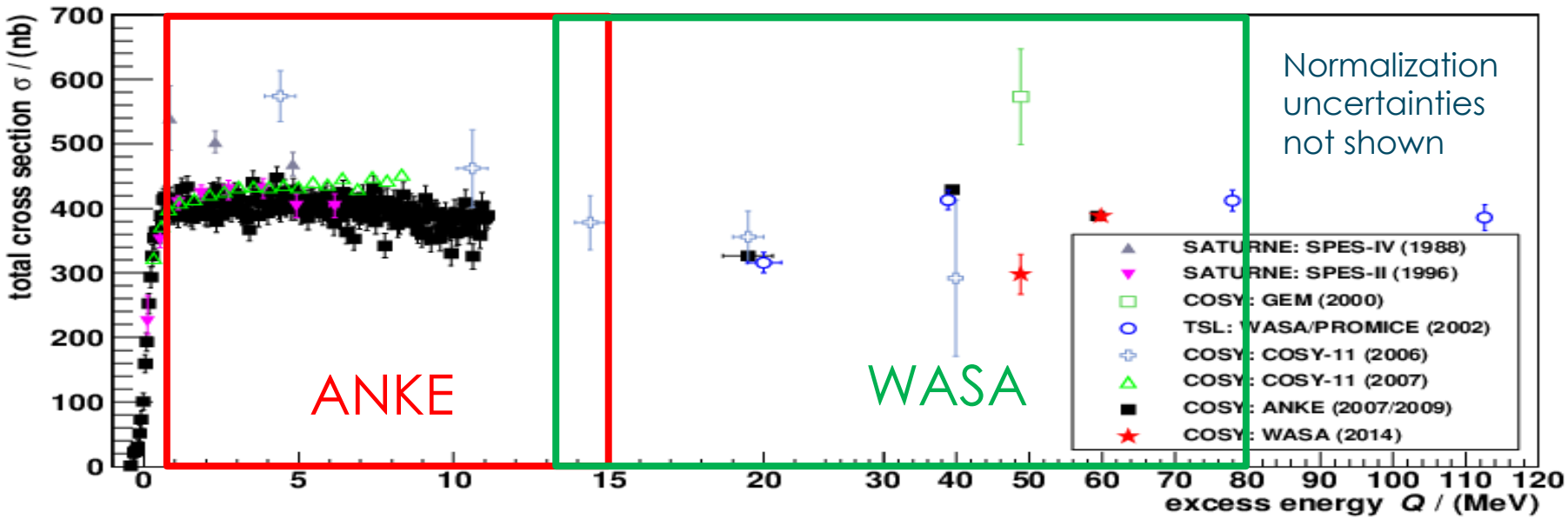

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  ⇒ overlap with data of the WASA experiment (previous talk of Nils Hüsken)

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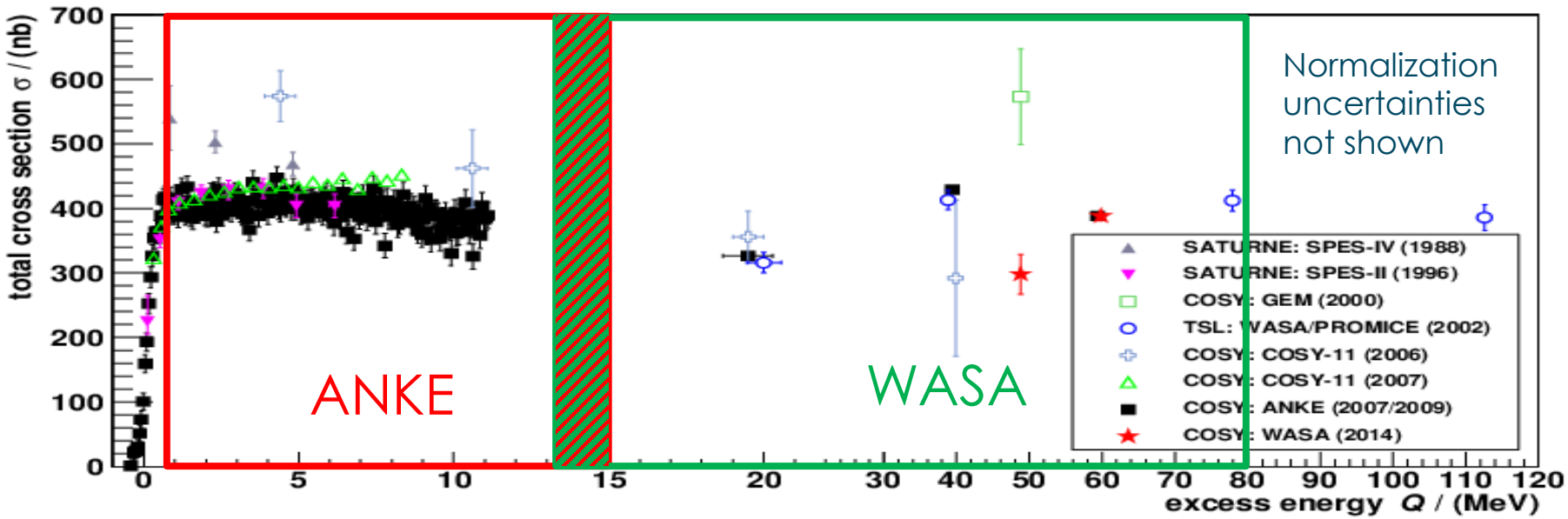

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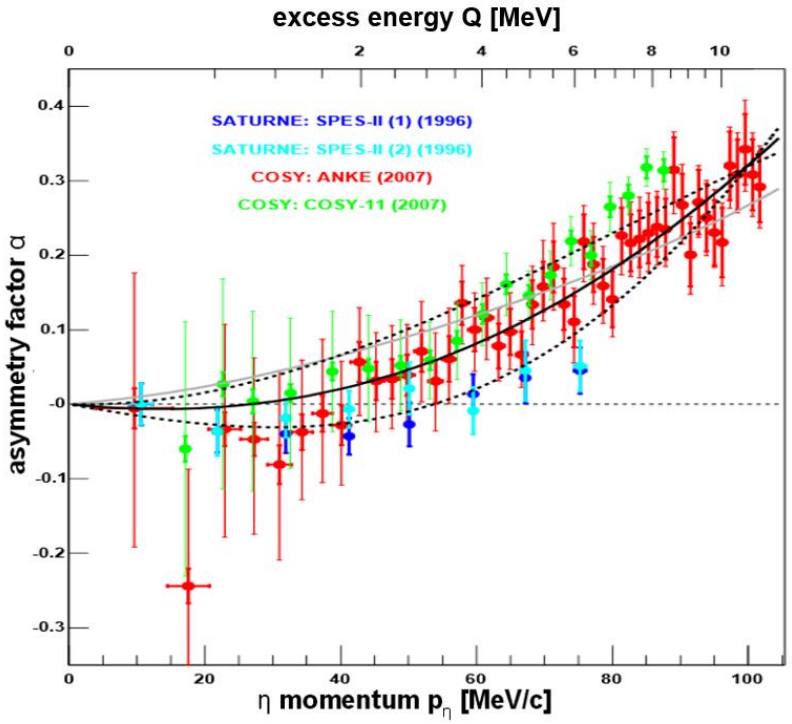


- differential cross section linear in $\cos\theta_\eta^{cms}$
- angular dependence summarized as terms of an asymmetry parameter α

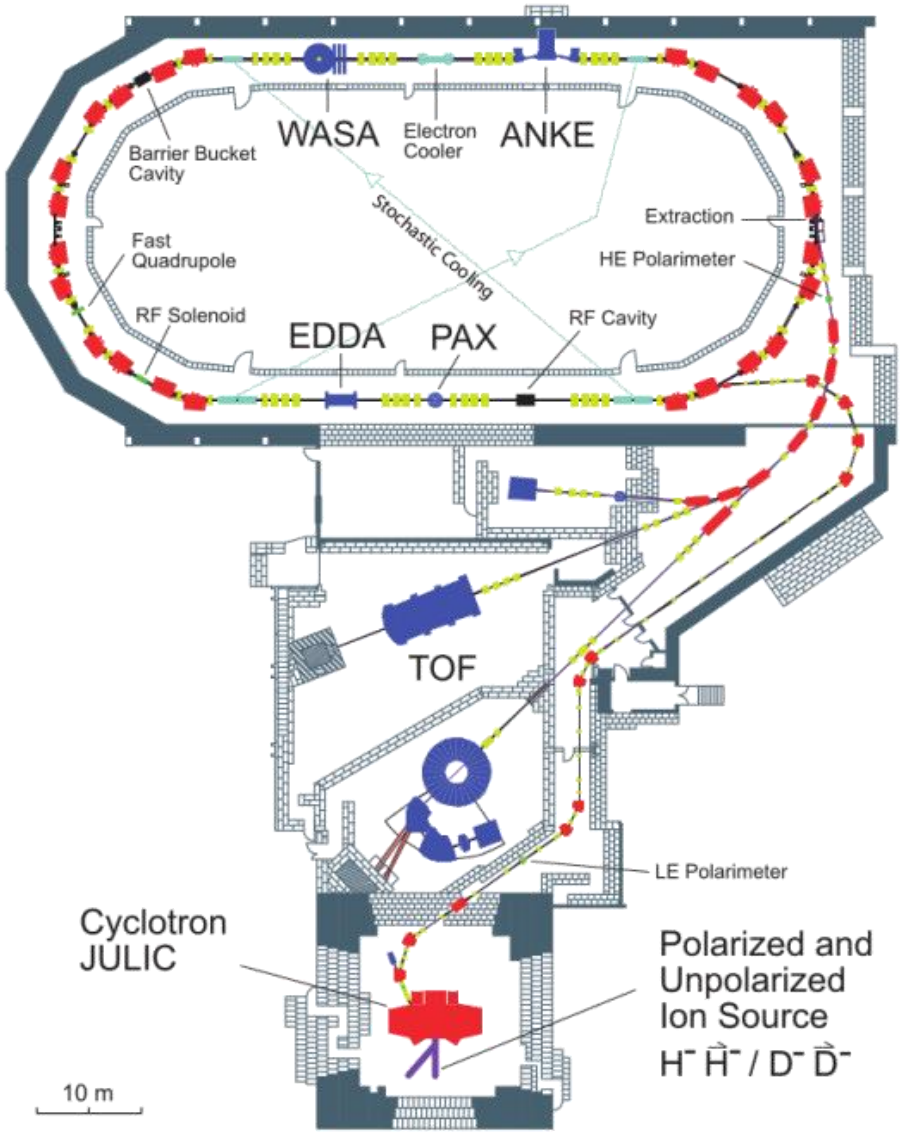
$$\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$$

- data show a distinct effect of an s- and p-wave interference
  - ⇒ rapid variation of the phase
  - ⇒ expected for a pole near threshold

- task: investigate the behaviour of the asymmetry parameter α more precisely
  - ⇒ final state momentum p_η very well-known (P. Goslawski)
  - ⇒ reduce uncertainties of α
- careful luminosity determination necessary

„COoler SYnchrotron“ COSY

- pre-accelerator JULIC
  - ⇒ protons: 45 MeV
  - ⇒ deuterons: 90 MeV
- storage ring COSY
  - ⇒ length: 184 m
  - ⇒ momenta up to 3.7 GeV/c achievable
  - ⇒ 24 dipols (red)
  - ⇒ 56 quadrupol magnets (yellow)
- two cooling systems
  - ⇒ electron cooling
    - ⇒ $p_{beam} < 0.6$ GeV/c
  - ⇒ stochastic cooling
    - ⇒ $p_{beam} = (1.5 - 3.3)$ GeV/c
- possible momentum spread $\Delta p/p = 10^{-4}$



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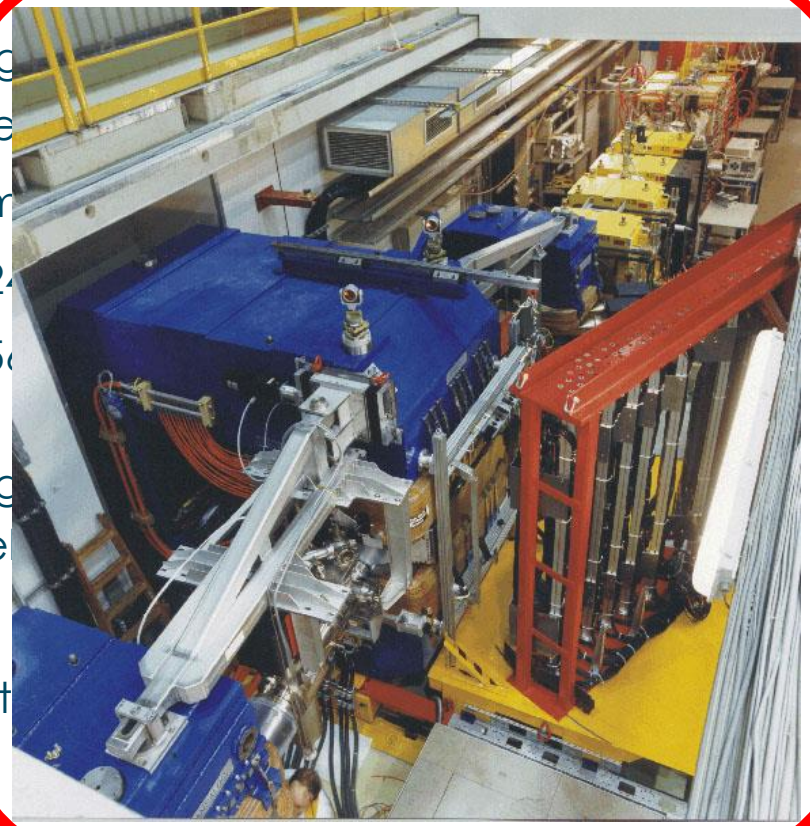
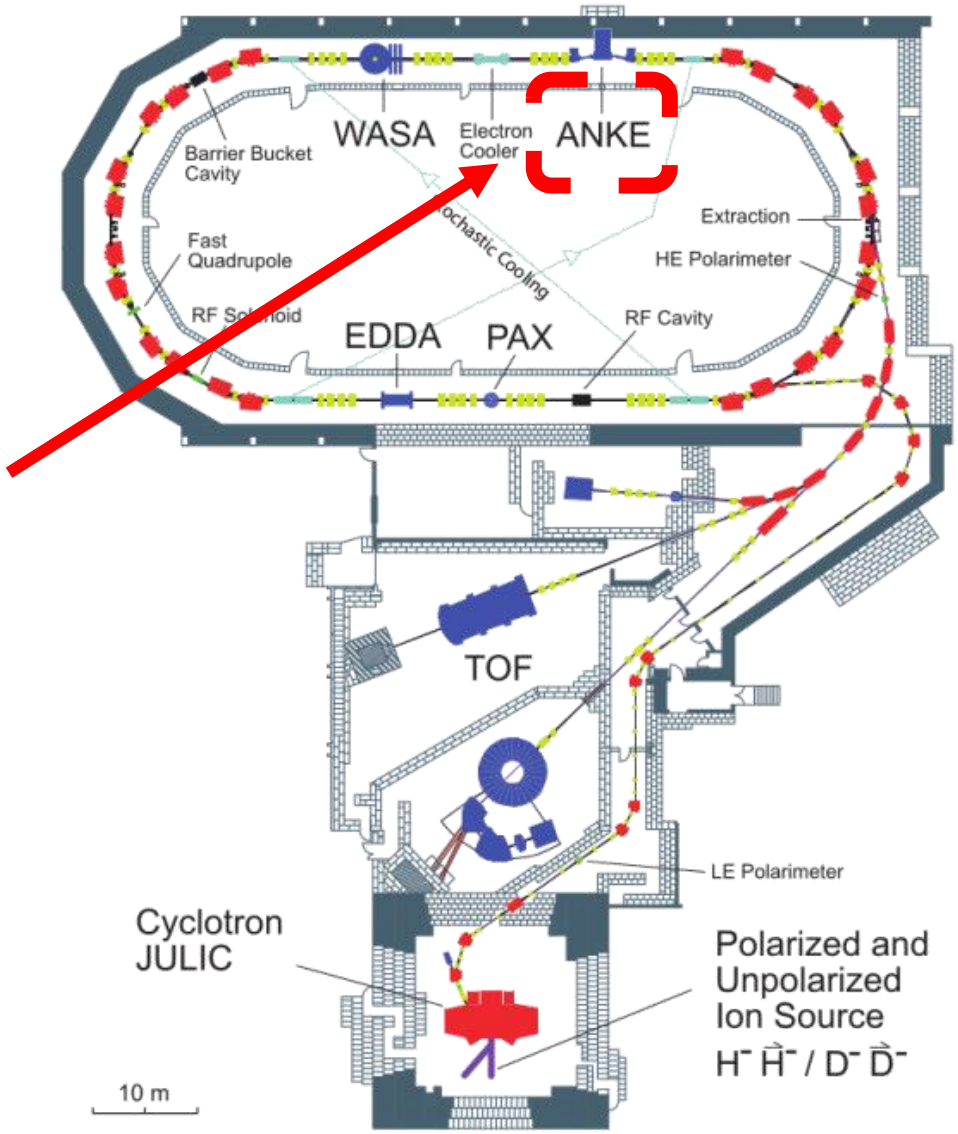
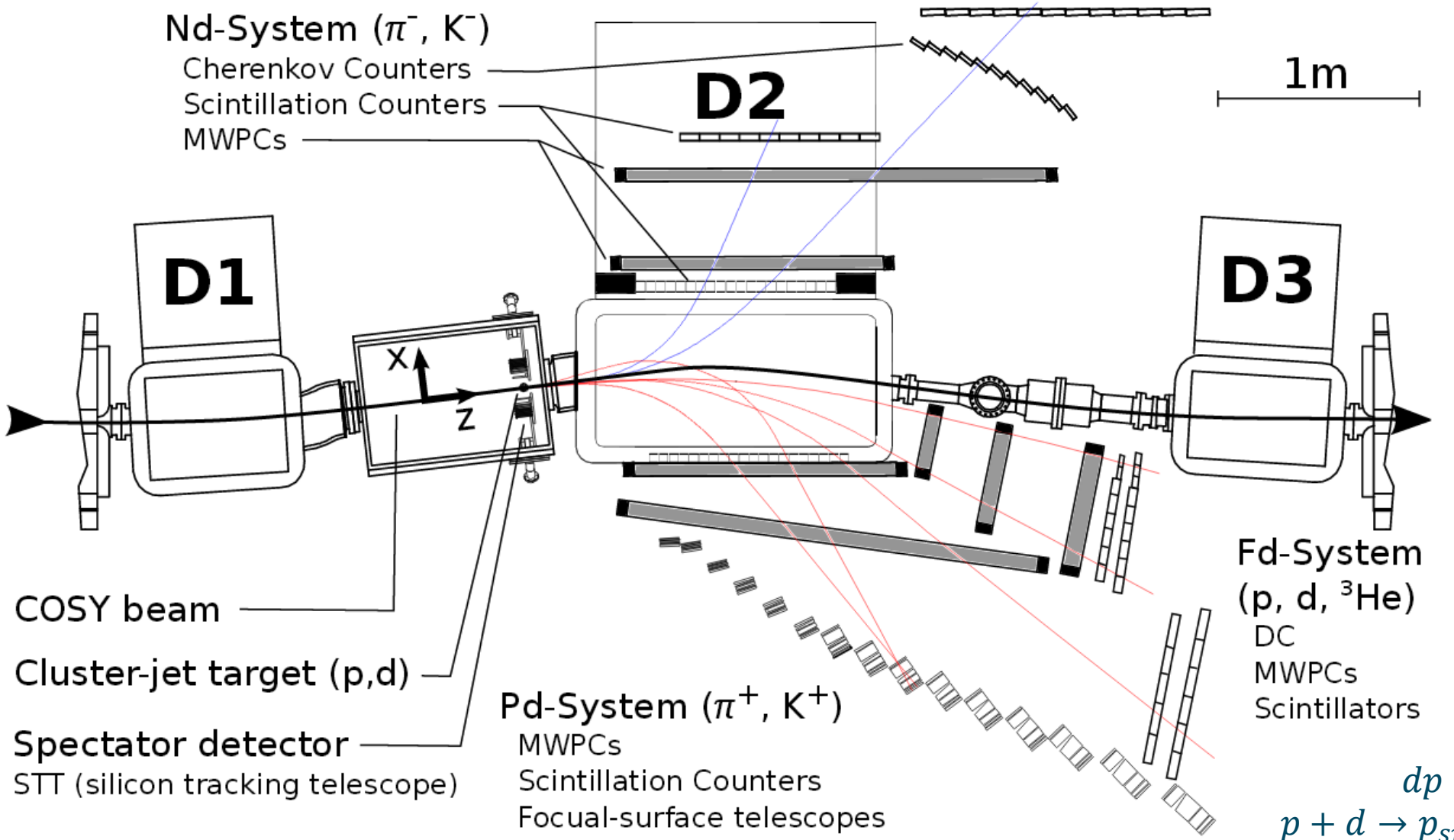




Magnetic Spectrometer **ANKE**

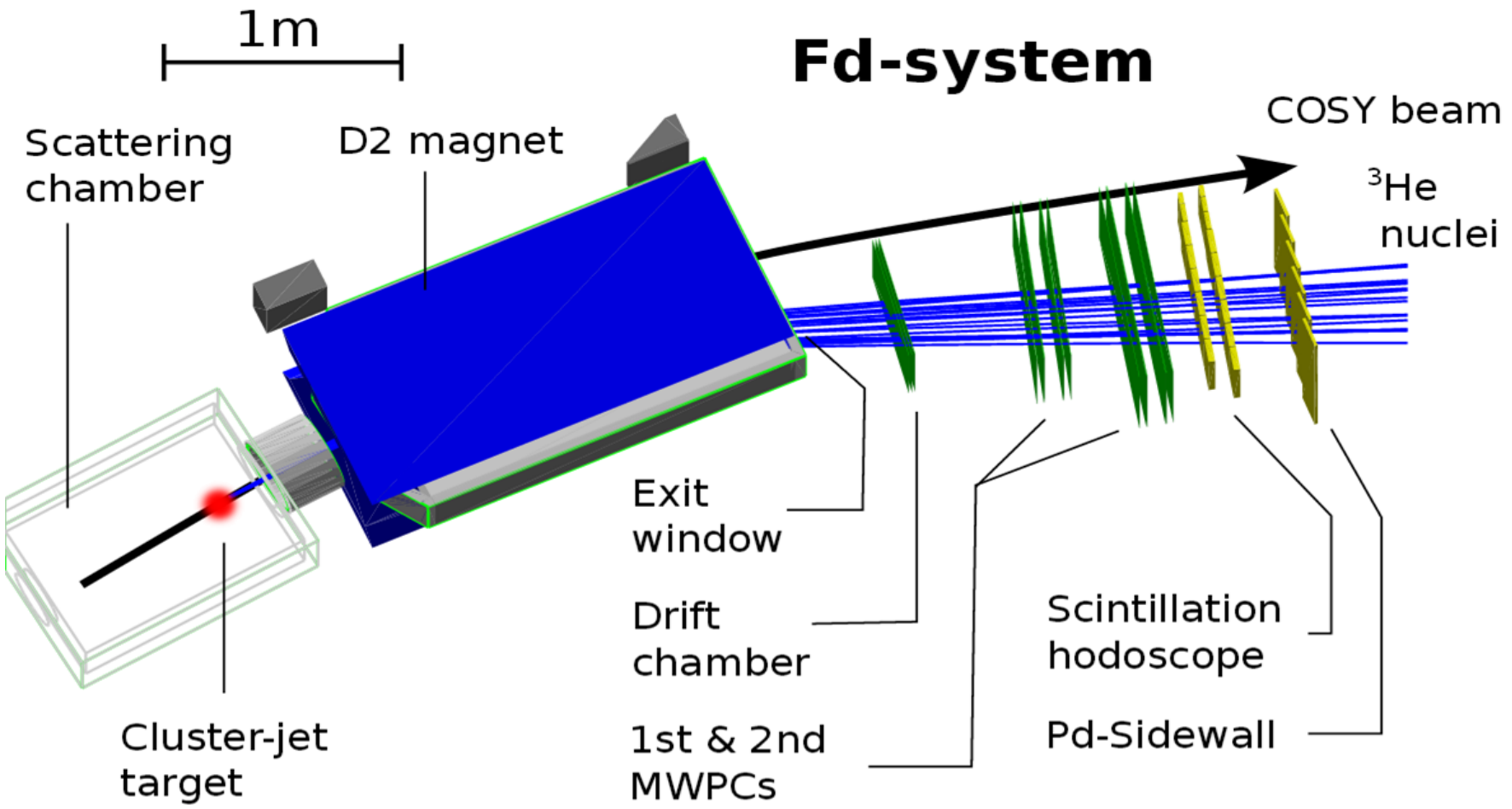


$dp \rightarrow {}^3\mathrm{He}\eta$

$p + d \rightarrow p_{spectator} + d + \eta$

S. Barsov, Nuclear Instruments and Methods in Physics Research A 462 (2001) 364-381

Forward Detection System



- track reconstruction ⇒ three multiwire chambers (green)
- energy loss and time-of-flight measurements ⇒ three layers of scintillator hodoscopes (yellow)

Measurements: Experimental Conditions

- data used for: high precision determination of the η meson mass ($d + p \rightarrow {}^3\mathrm{He} + \eta$) and studies on the two pion production ($d + p \rightarrow {}^3\mathrm{He} + \pi^+ + \pi^-$)
- supercycle mode: one supercycle consists of up to 7 different beam momenta
  ⇒ 19 beam momenta close to η production threshold

flattop	1st supercycle p_d / (MeV/c)	2nd supercycle p_d / (MeV/c)	3rd supercycle p_d / (MeV/c)
0	3120.17(17)	3120.00(22)	3125
2	3146.41(17)	3147.35(17)	3146
3	3148.45(17)	3150.42(17)	-------
4	3152.45(17)	3154.49(17)	3157.48(22)
5	3158.71(17)	3162.78(17)	3160.62(22)
6	3168.05(17)	3172.15(17)	-------
7	3177.51(17)	3184.87(17)	3204.16(23)

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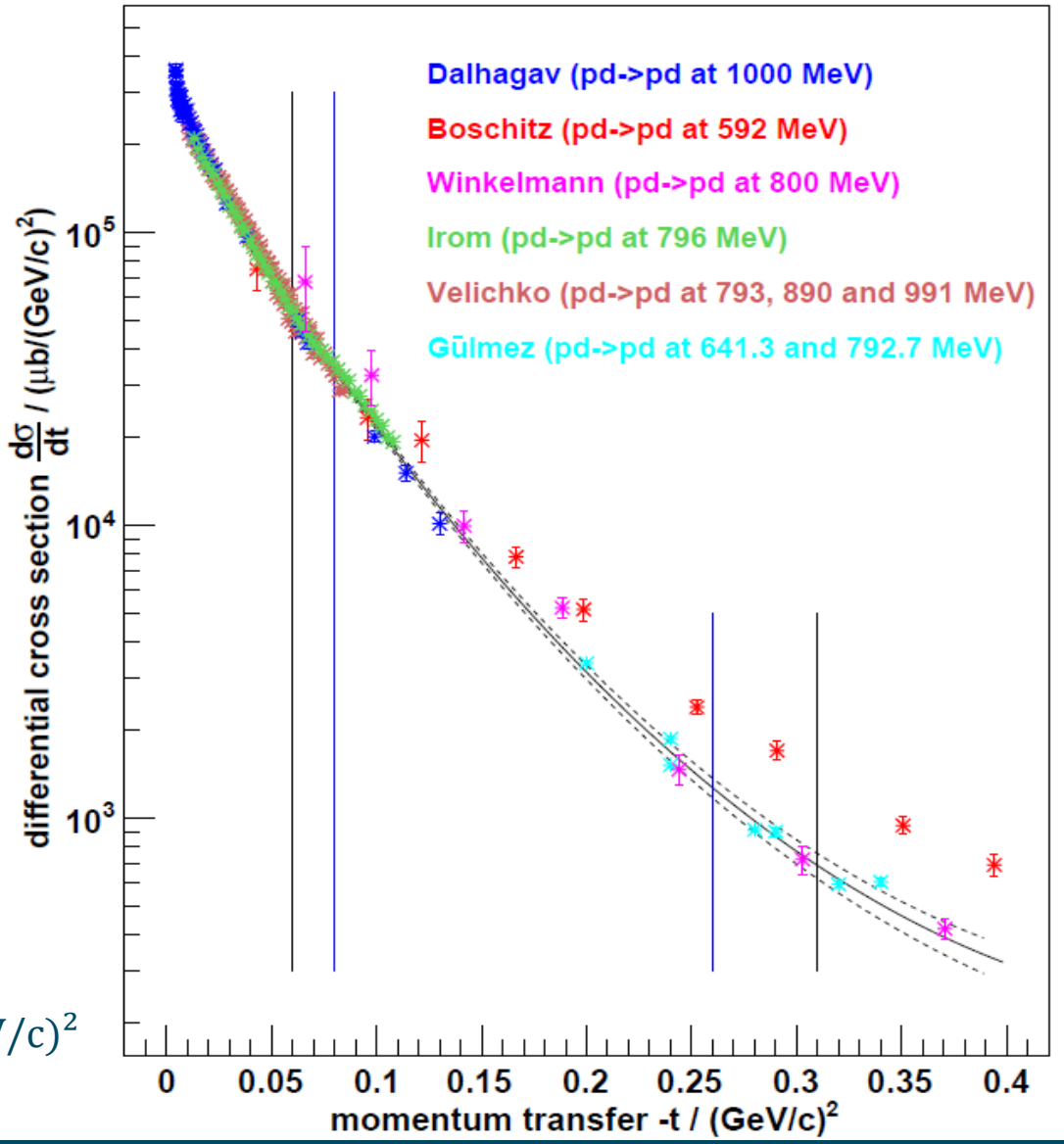
below the η production threshold ($d + p \rightarrow {}^3\mathrm{He} + \eta$) for a smooth model independent background description

Normalization Reaction $d + p \rightarrow d + p$

- advantages of the dp-elastic scattering as normalization reaction:
  - ⇒ broad data base of available differential cross sections
  - ⇒ high diff. cross sections ensure good statistics
  - ⇒ excellent signal-to-noise ratio
- differential cross section as function of momentum transfer
  - ⇒ independent of beam momenta
- ANKE acceptance: $-t = (0.06 - 0.31)\ (\mathrm{GeV}/c)^2$
- range for luminosity determination $-\mathrm{t} = (0.08\ - 0.26)\ (\mathrm{GeV/c})^2$

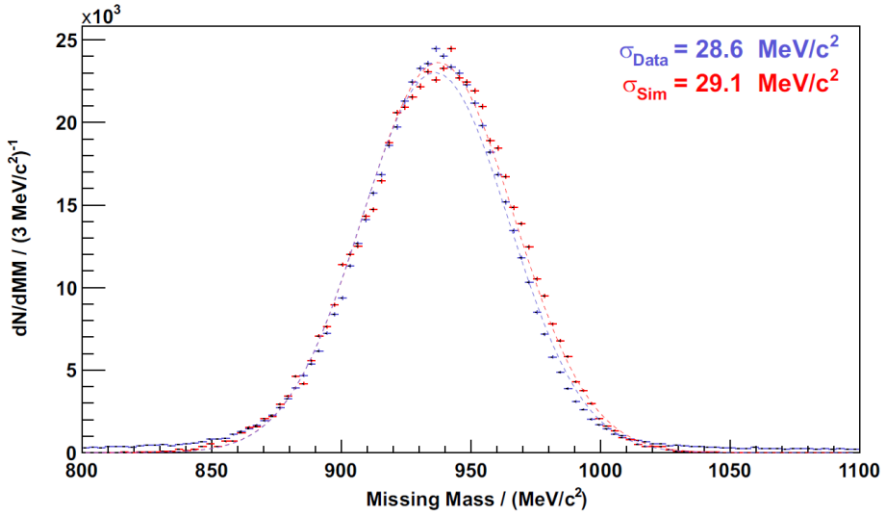


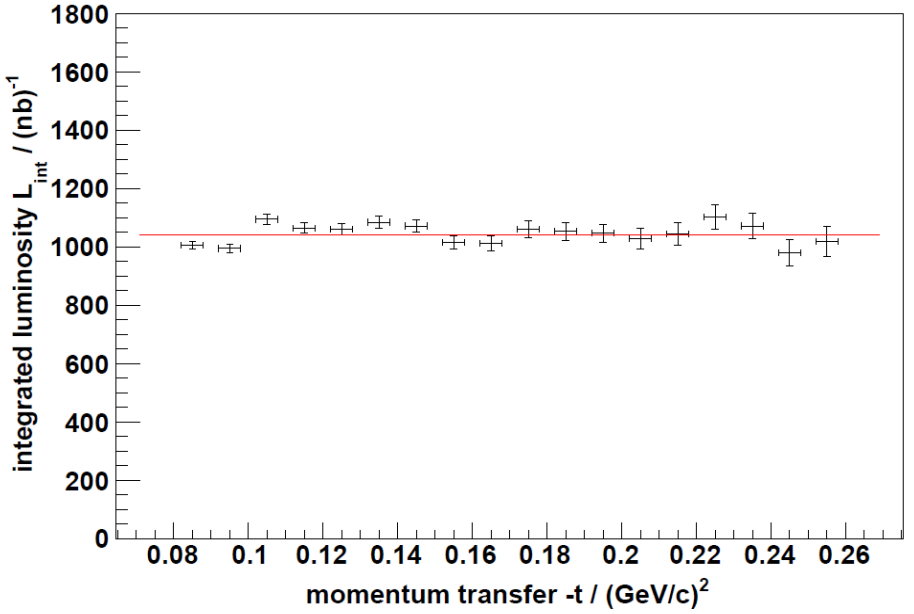
Results for $d + p \rightarrow d + p$

- identification of the reaction via the missing mass technique
- determination performed for 18 momentum transfer bins $\Delta t = 0.01\ (\mathrm{GeV}/c)^2$
  ⇒ for each of the 19 beam momenta
- luminosity precision achieved:

$$\Delta \mathrm{L}_{stat} = 1\%$$
$$\Delta \mathrm{L}_{sys} = 6\%$$

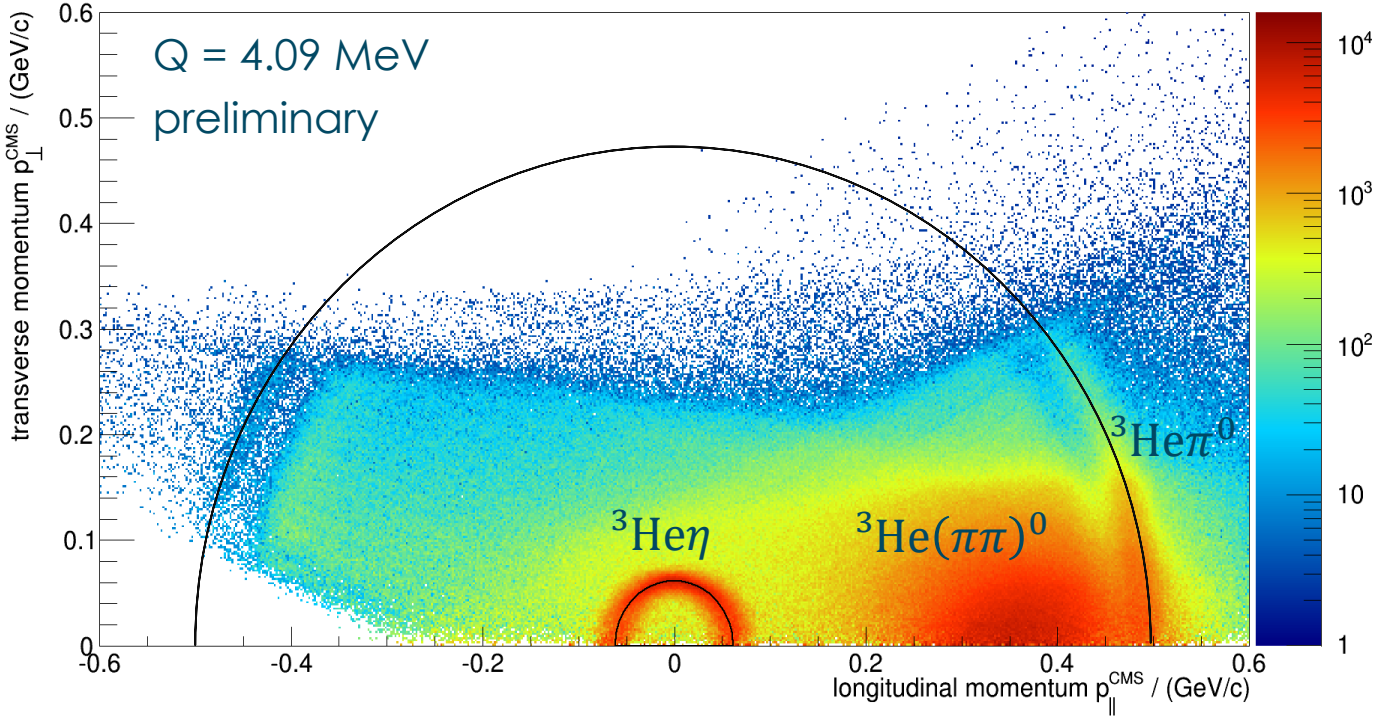
- improvement by at least a factor of two
- cross check via $d + p \rightarrow {}^3\mathrm{He} + \pi^0$ in progress





The η Production Channel $d + p \rightarrow {}^3\mathrm{He} + \eta$

- solid lines indicate the expected kinematical loci for $dp \rightarrow {}^3\mathrm{He}\eta$ and $dp \rightarrow {}^3\mathrm{He}\pi^0$
- ANKE has full geometrical acceptance for the reaction $dp \rightarrow {}^3\mathrm{He}\eta$
- clear separation from other reactions possible



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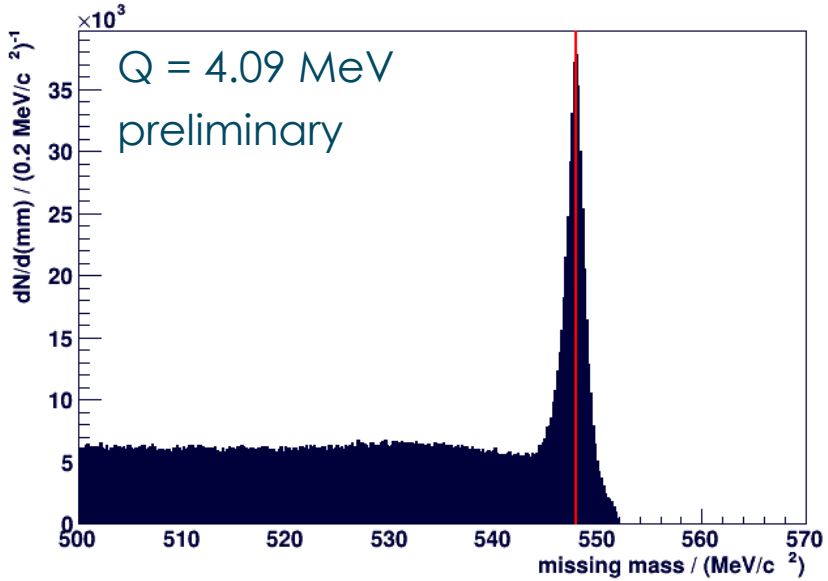
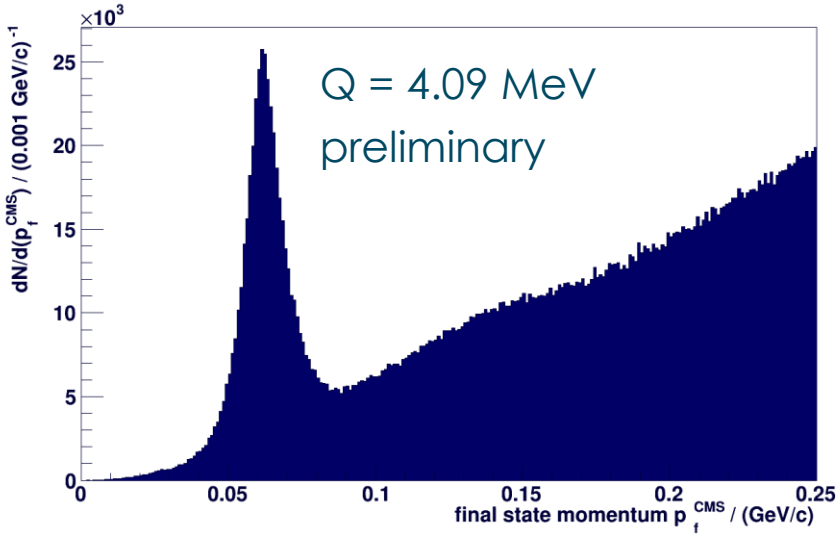
- high statistics of more than 10^5 ${}^3\mathrm{He}\eta$ events per energy





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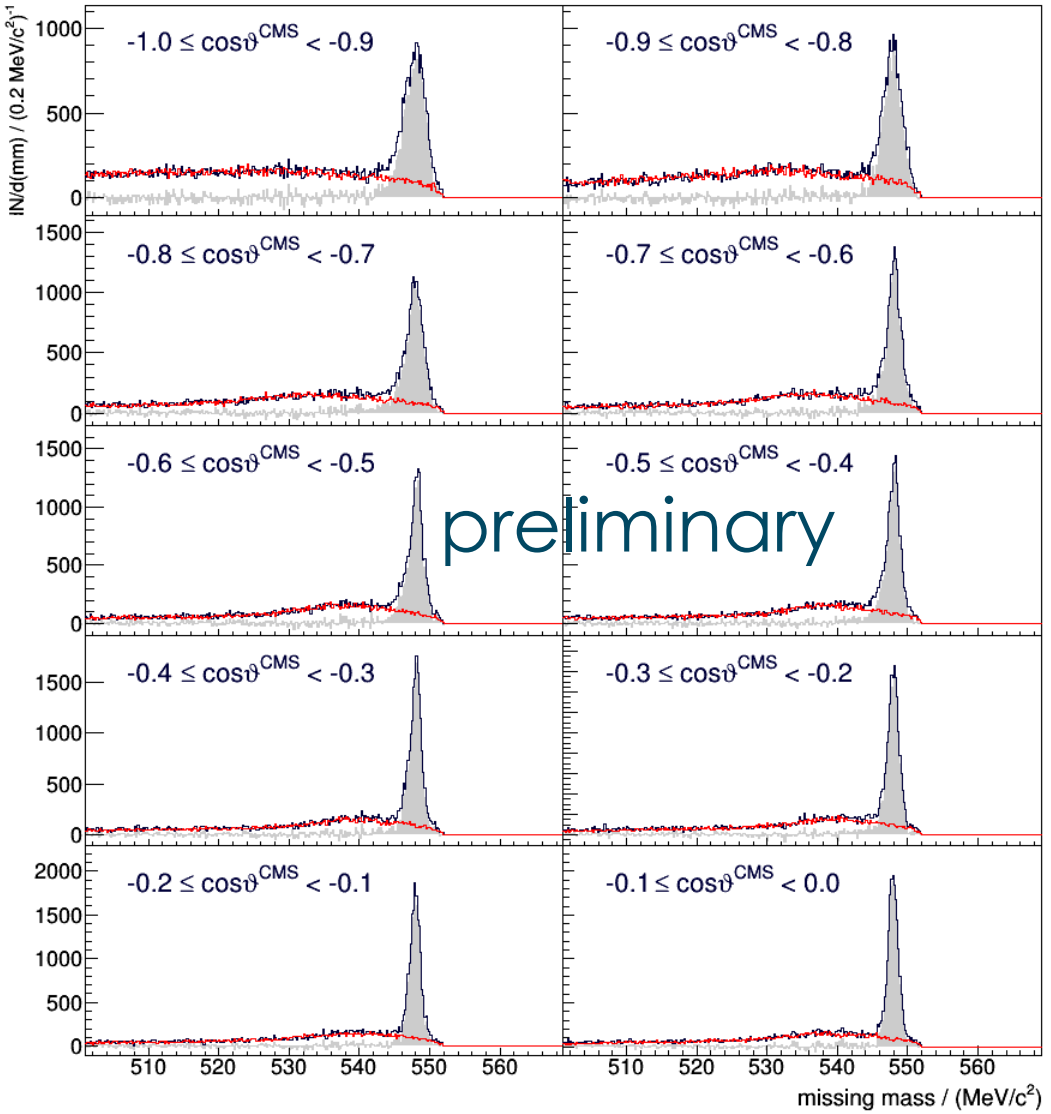
- accurate investigation of the angular dependence possible
- background description using data taken below the η production threshold



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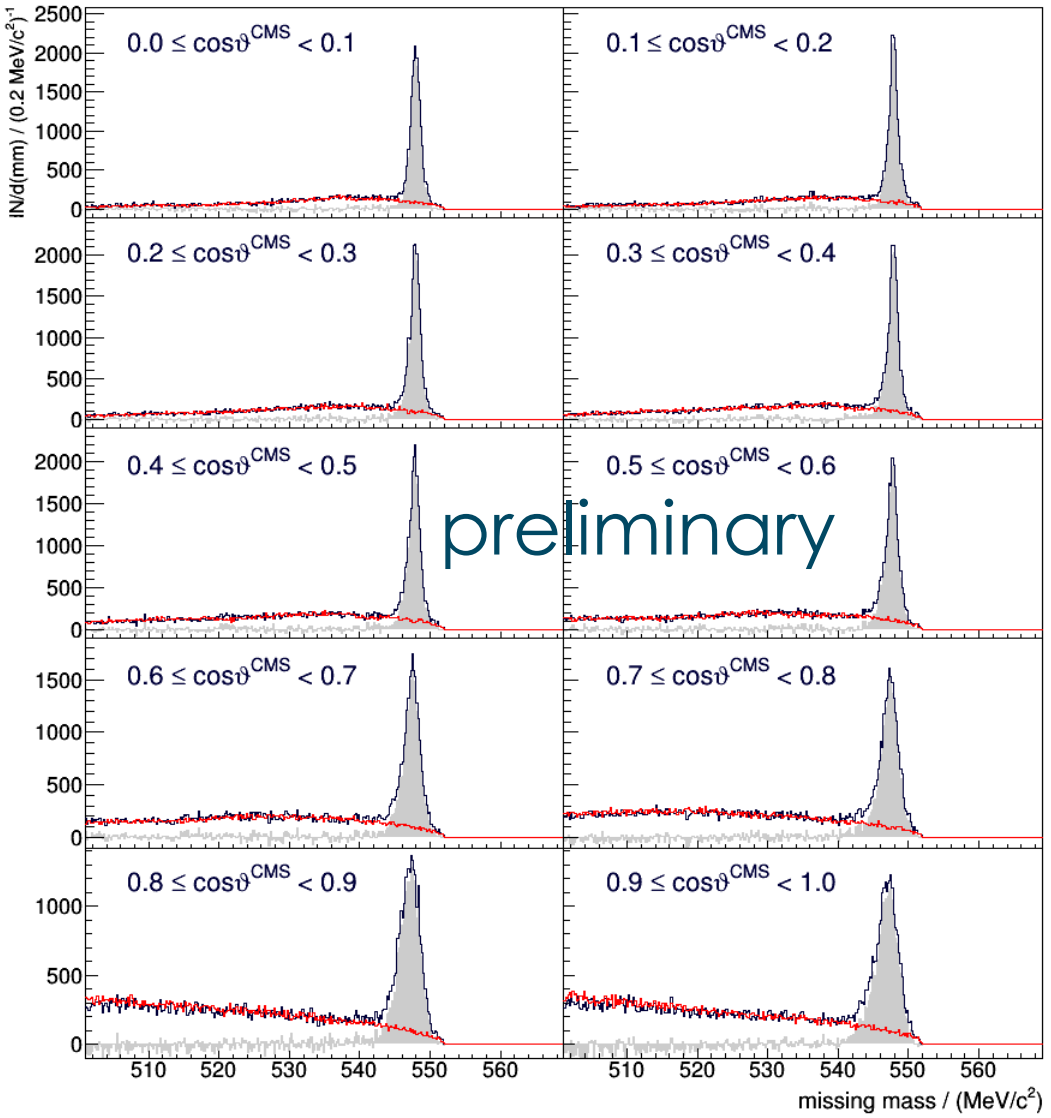
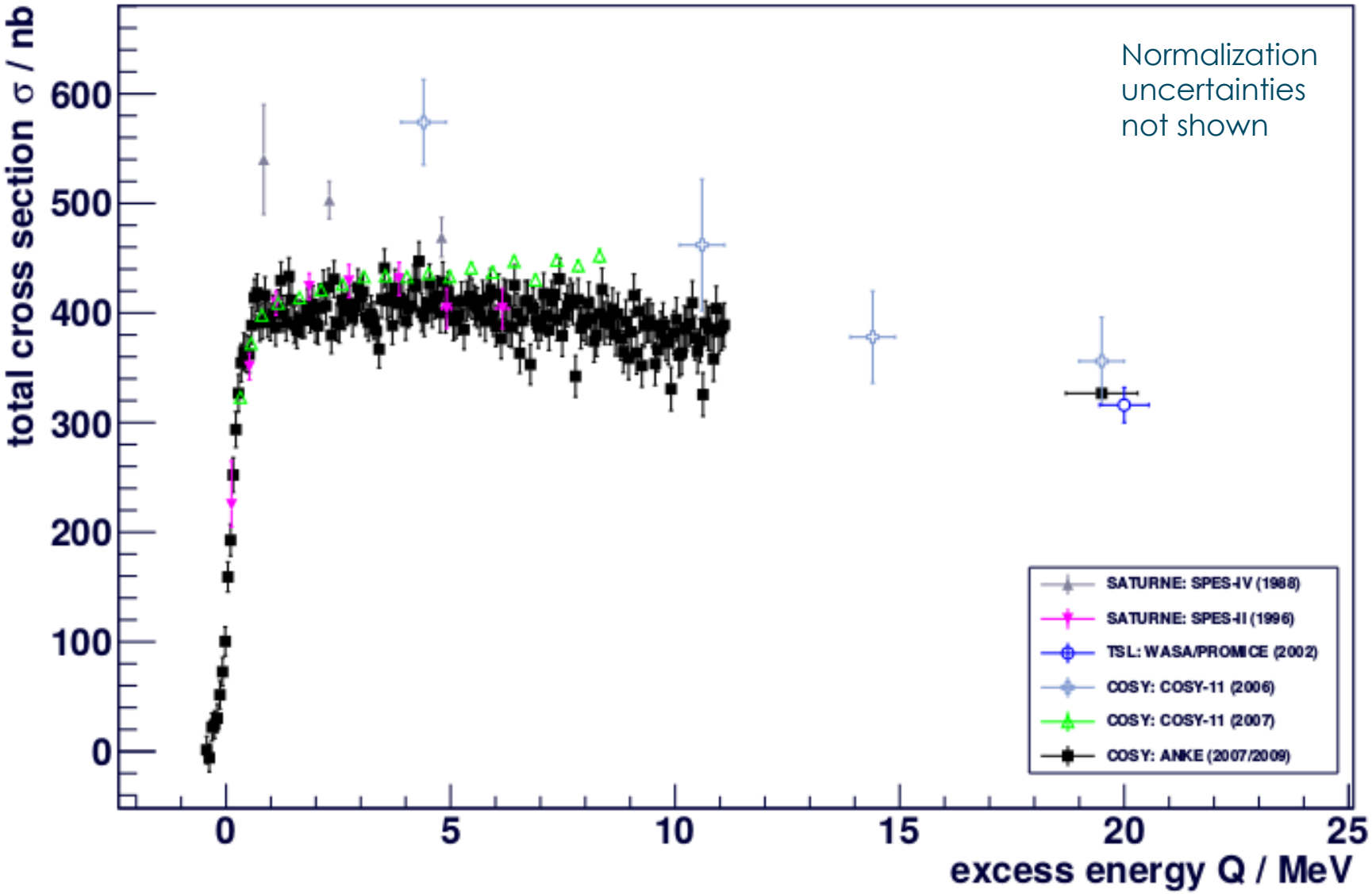


Total cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$



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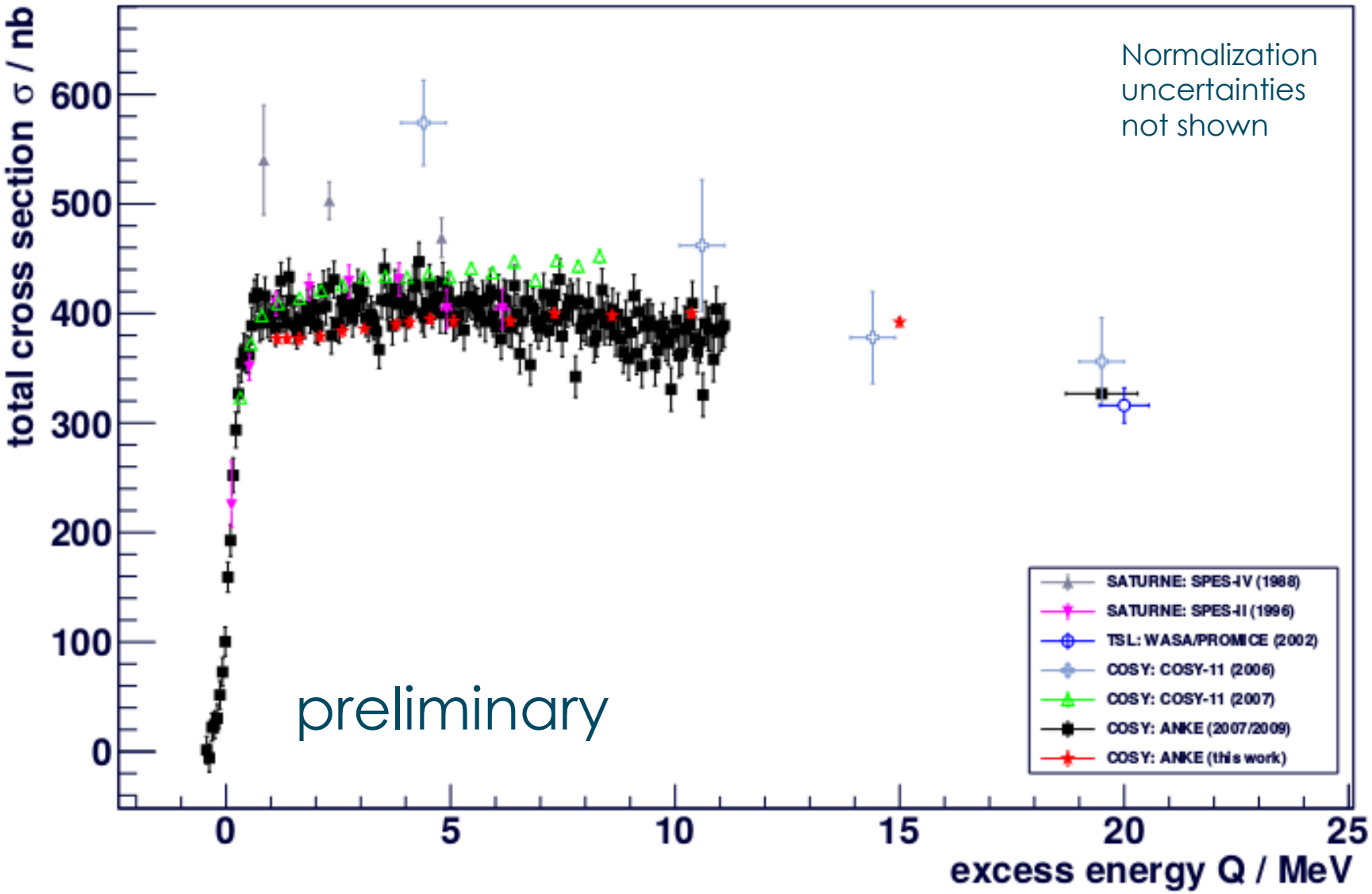
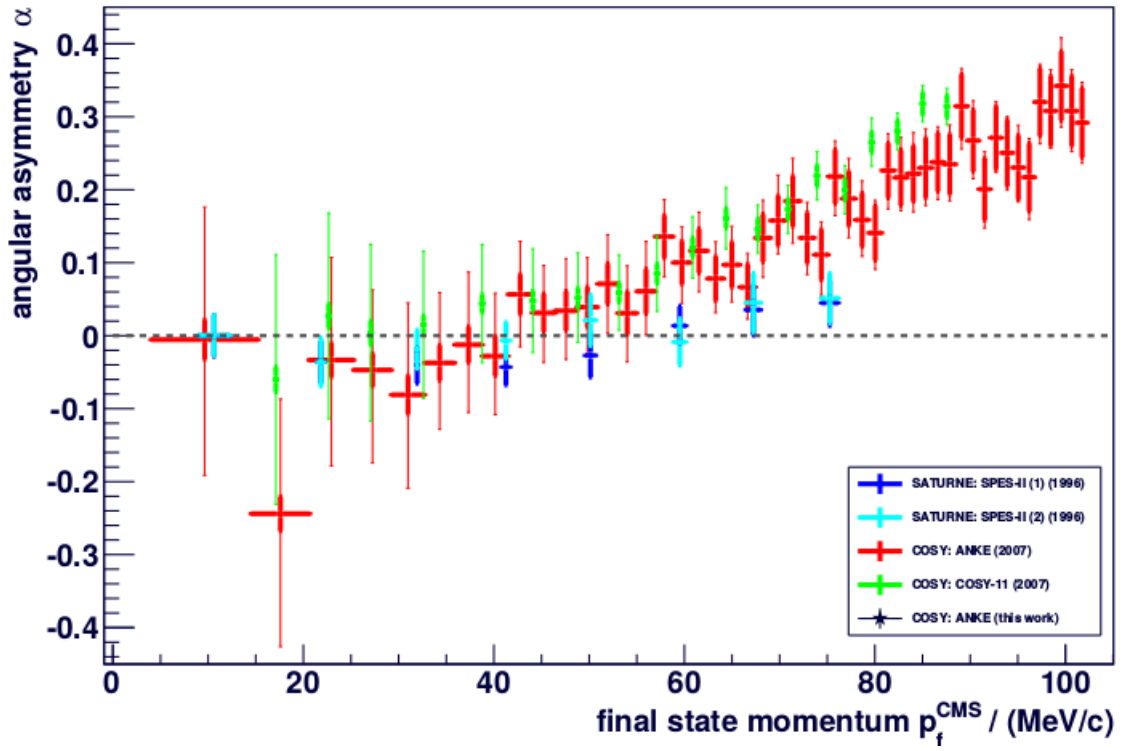


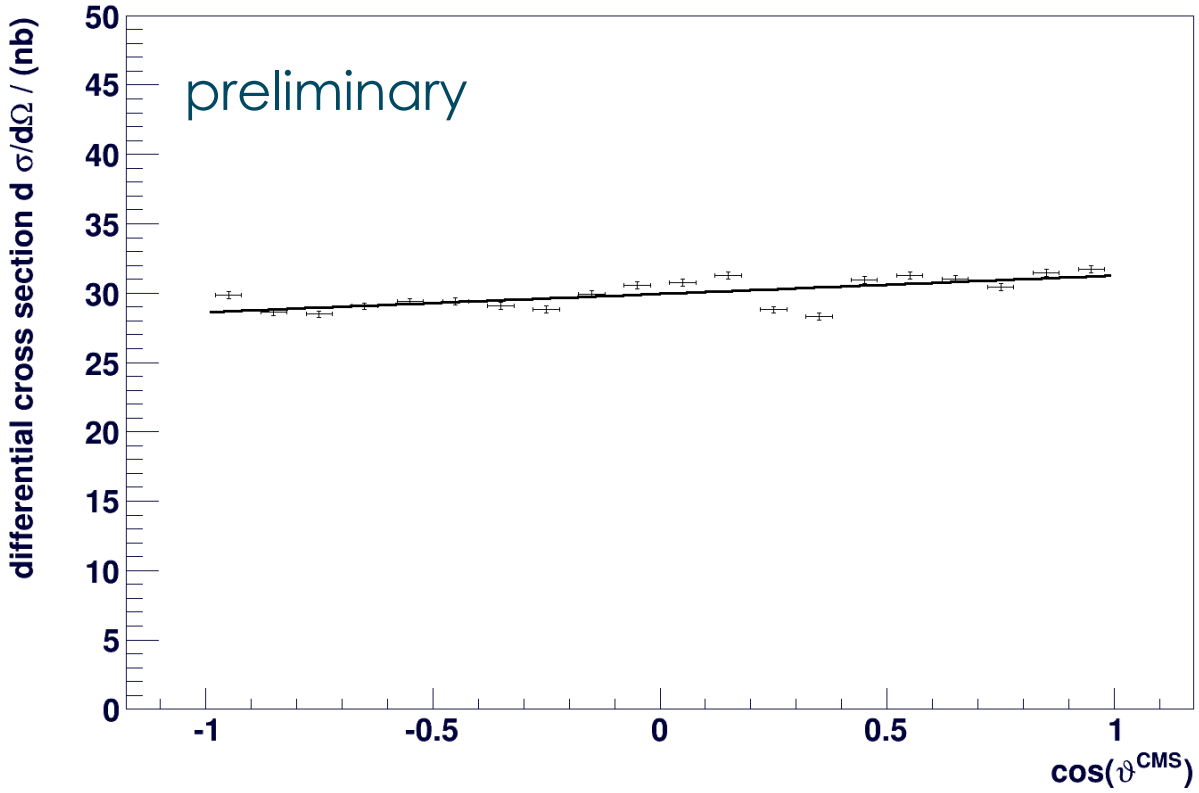
Differential cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$

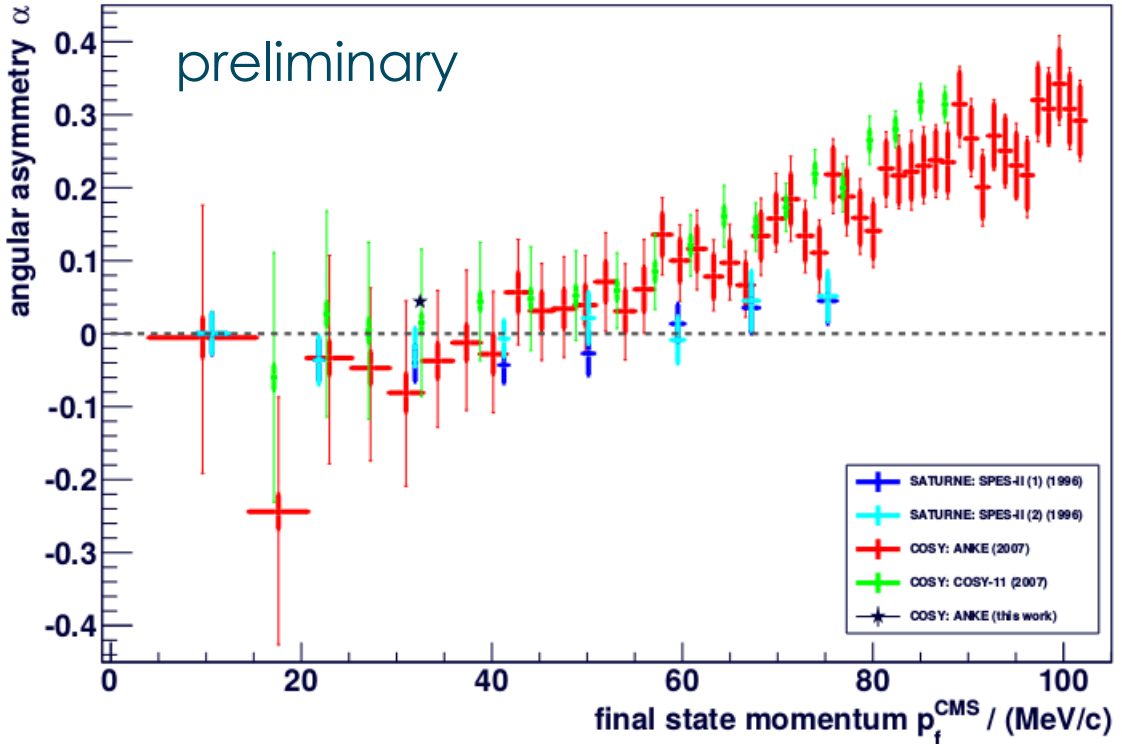


Differential cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$

- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 1.14 MeV





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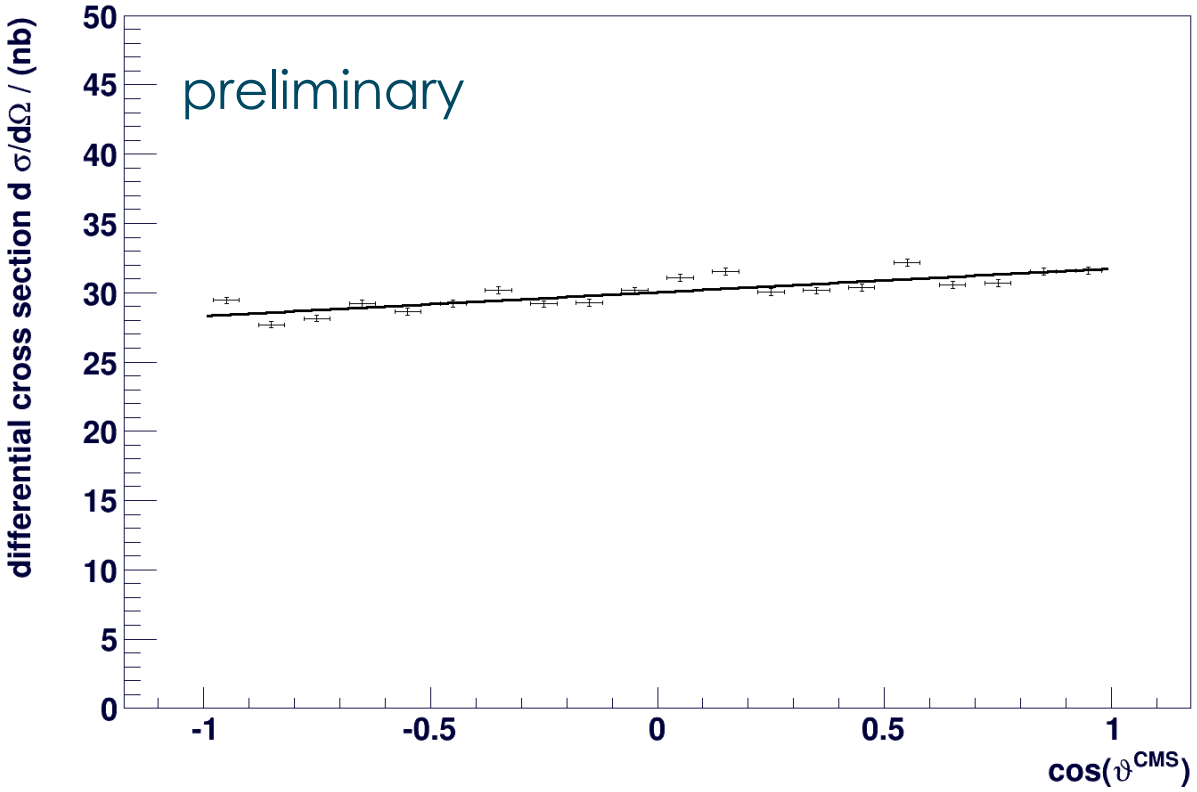
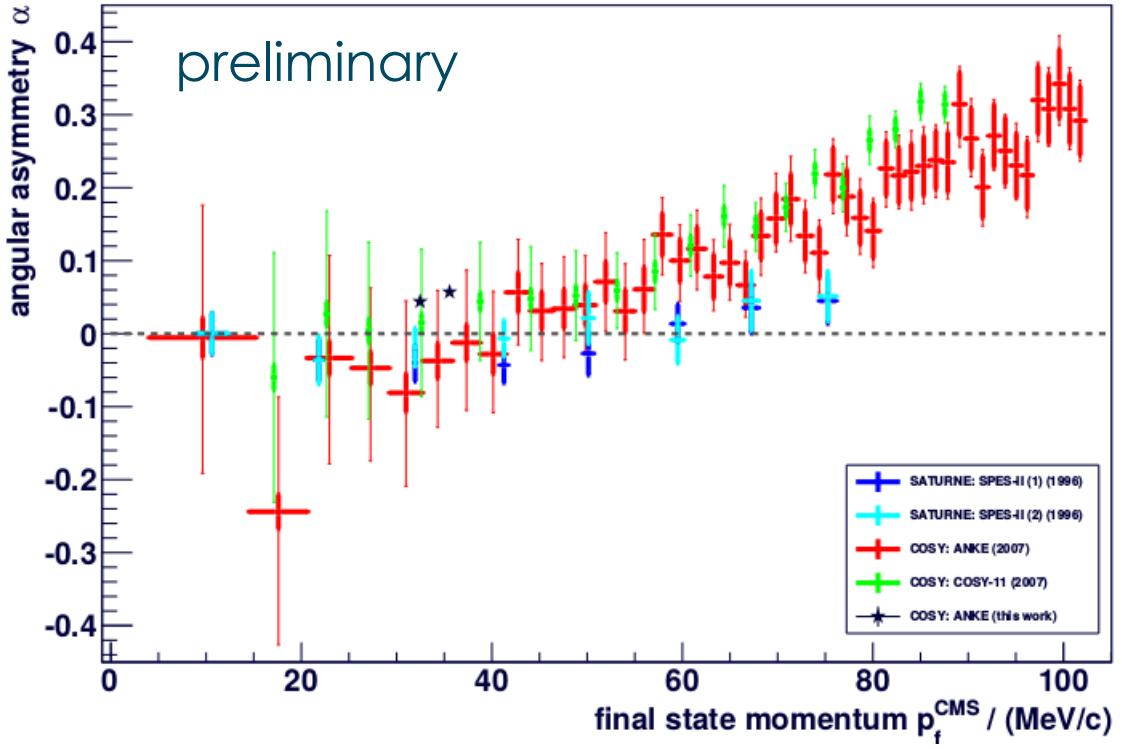
Q = 1.36 MeV





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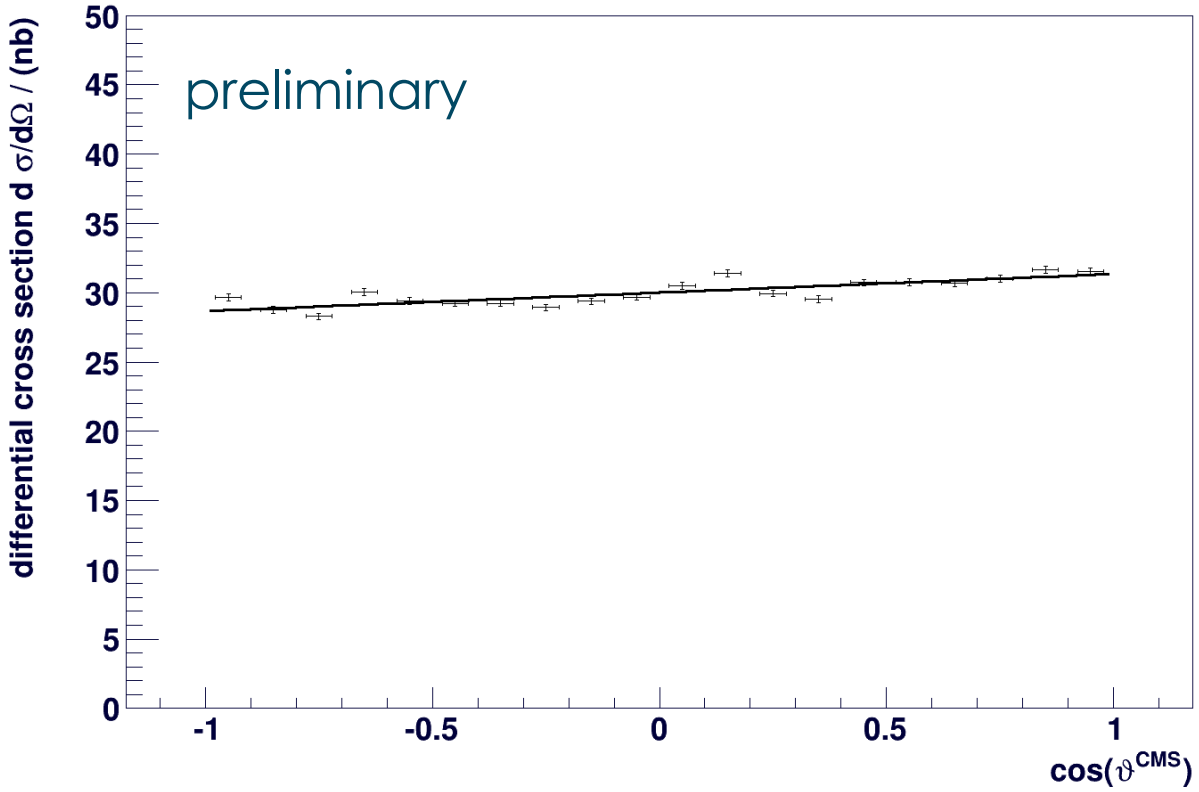
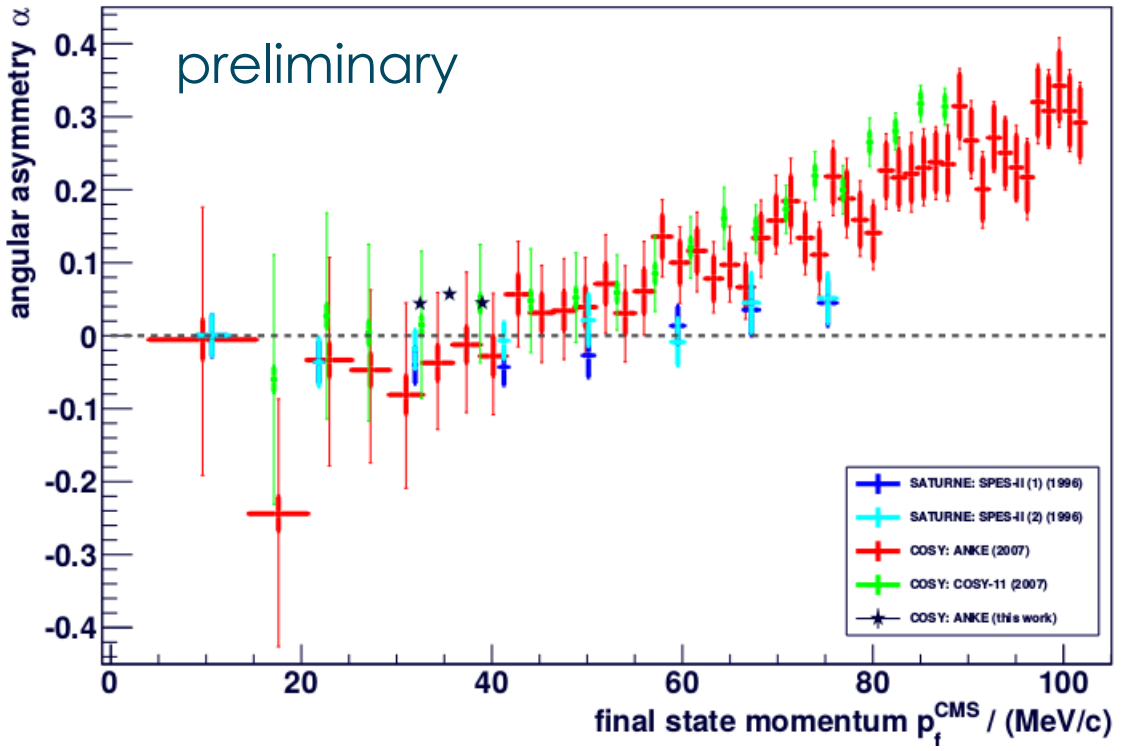
- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 1.63 MeV

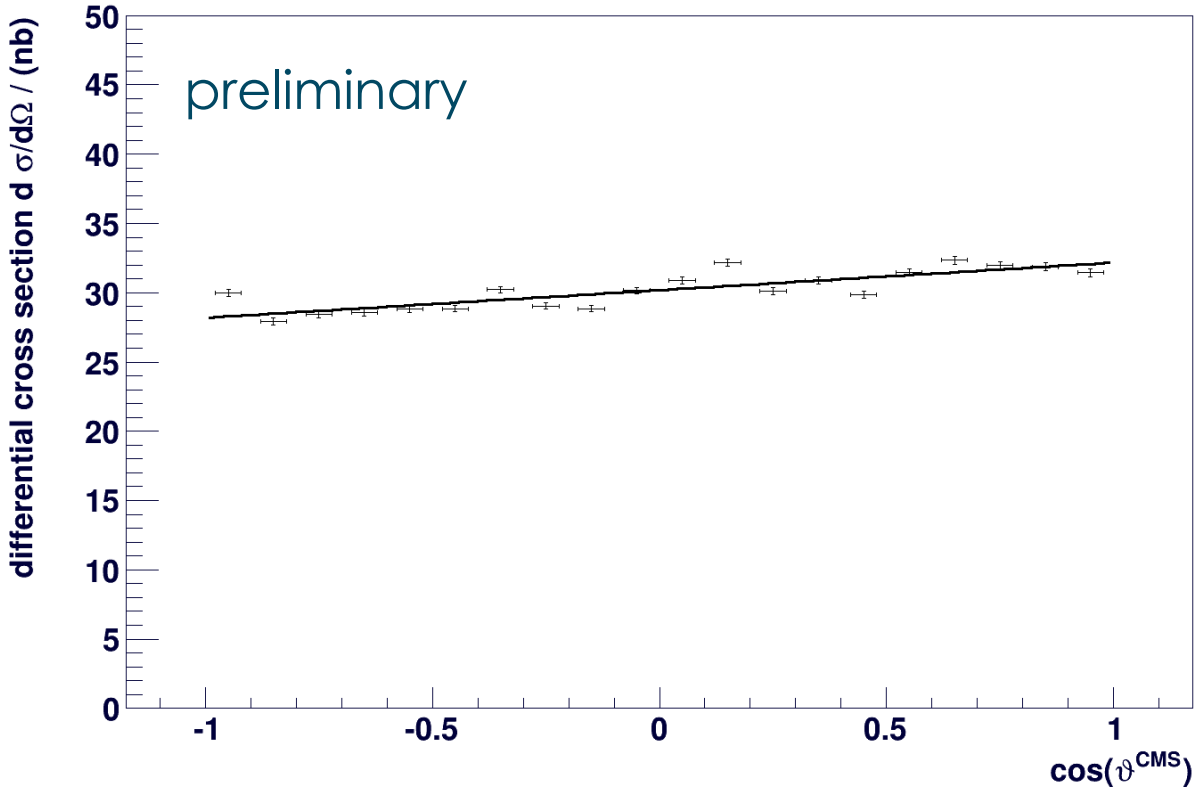


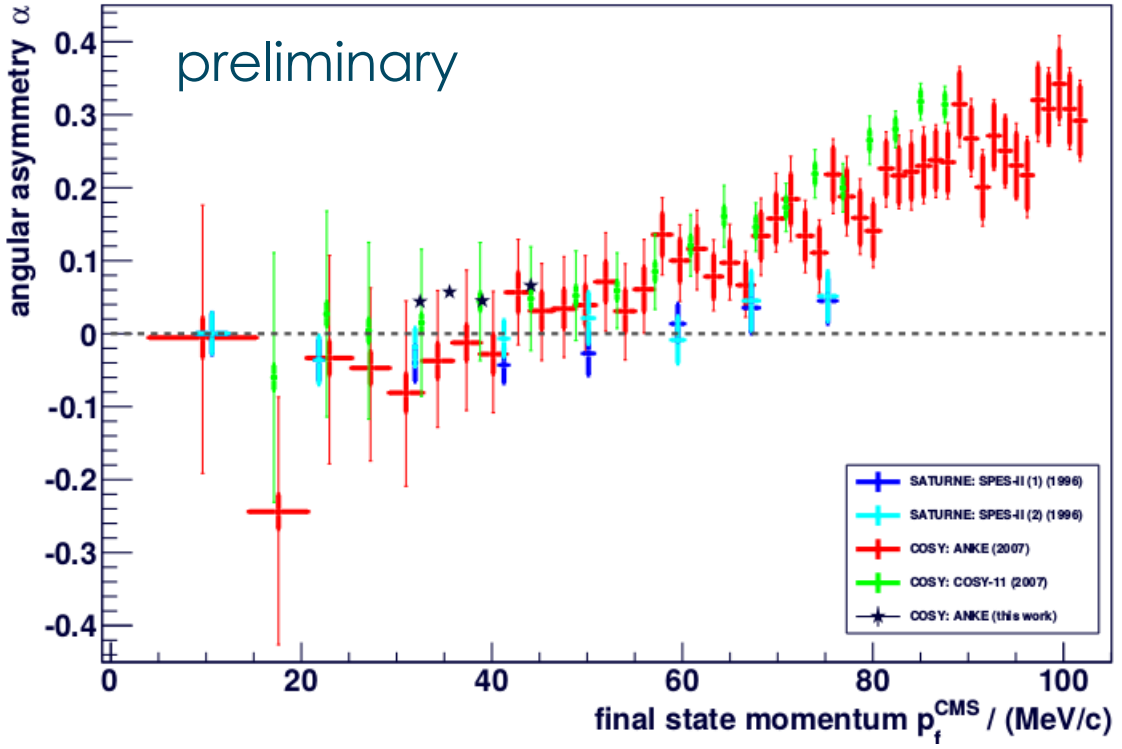


Differential cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$

- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 2.10 MeV





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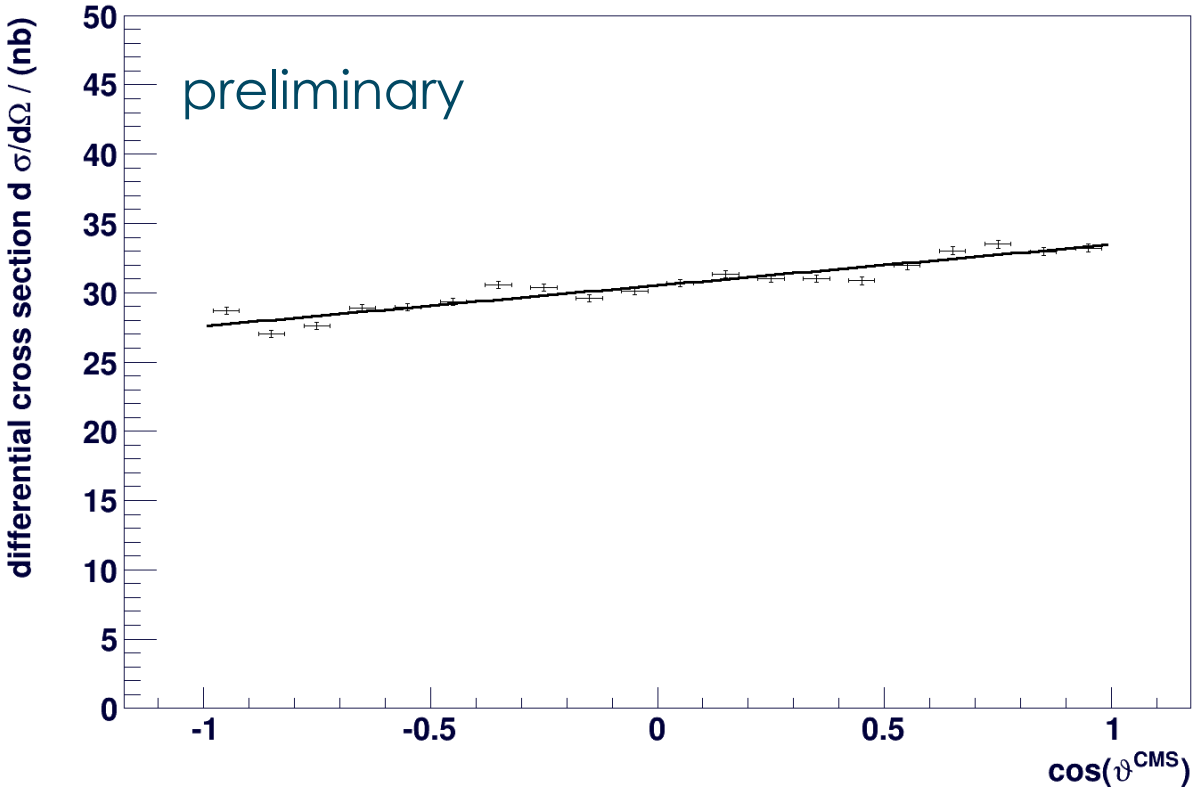
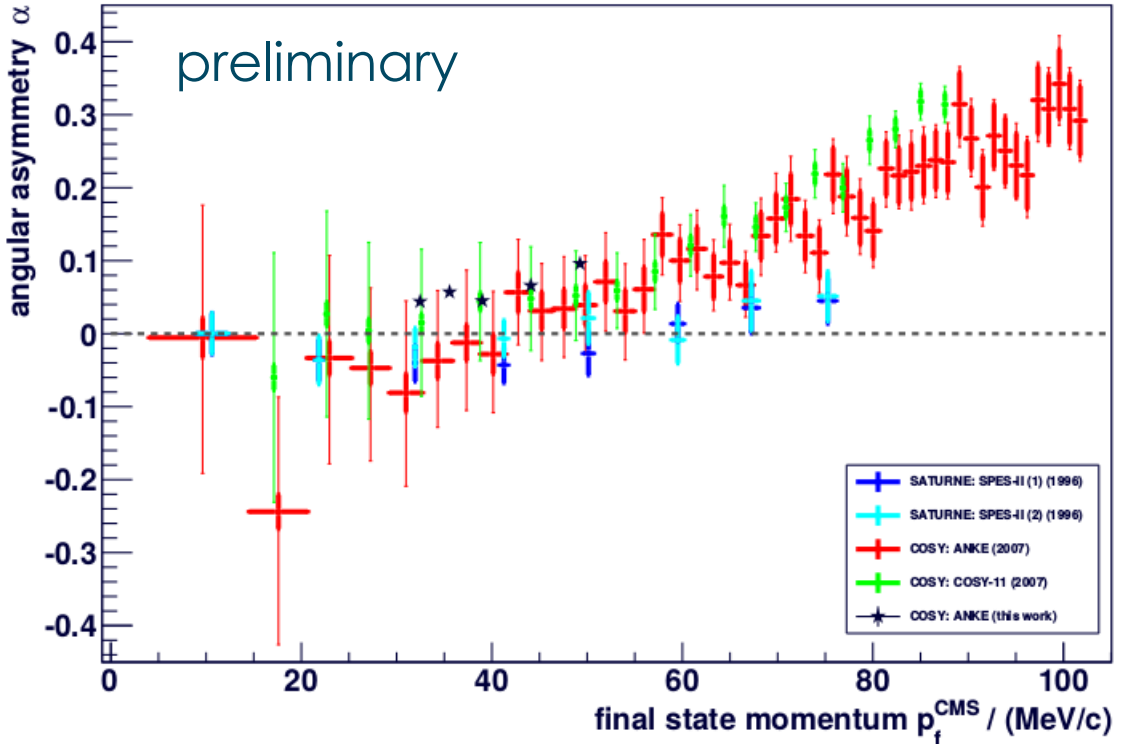
- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 2.59 MeV





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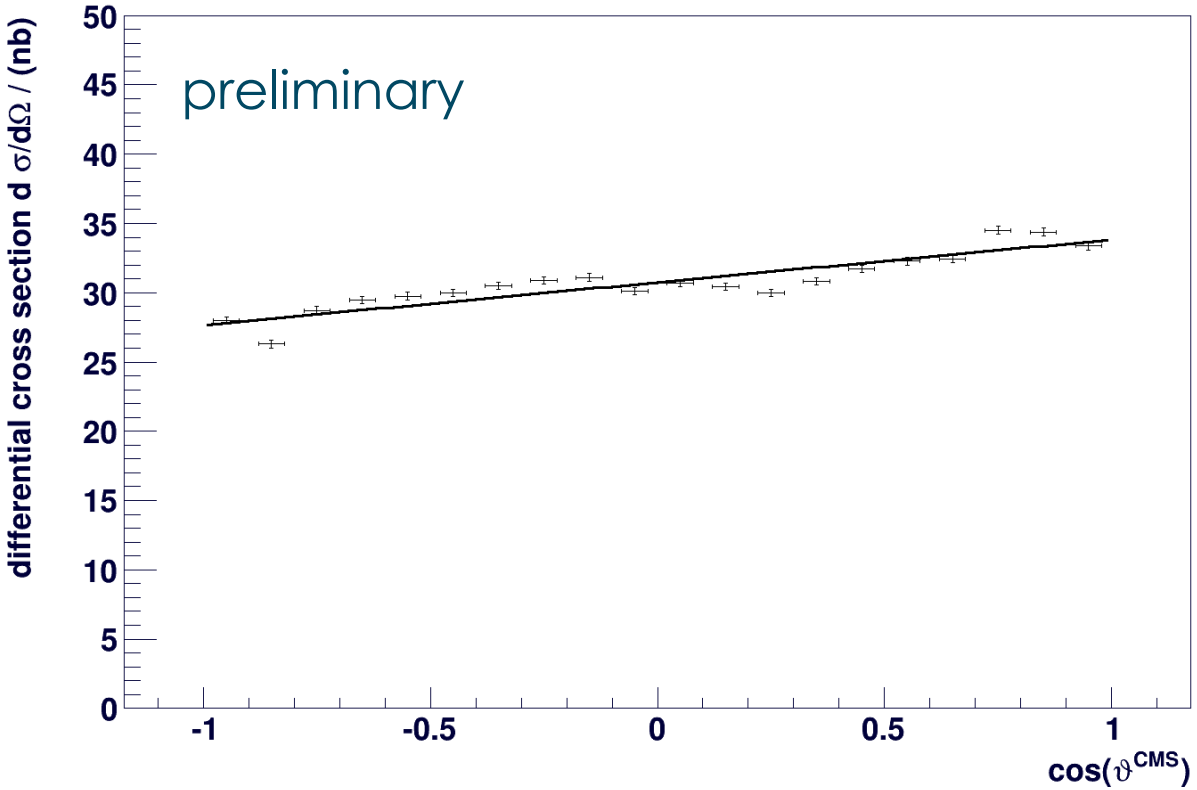
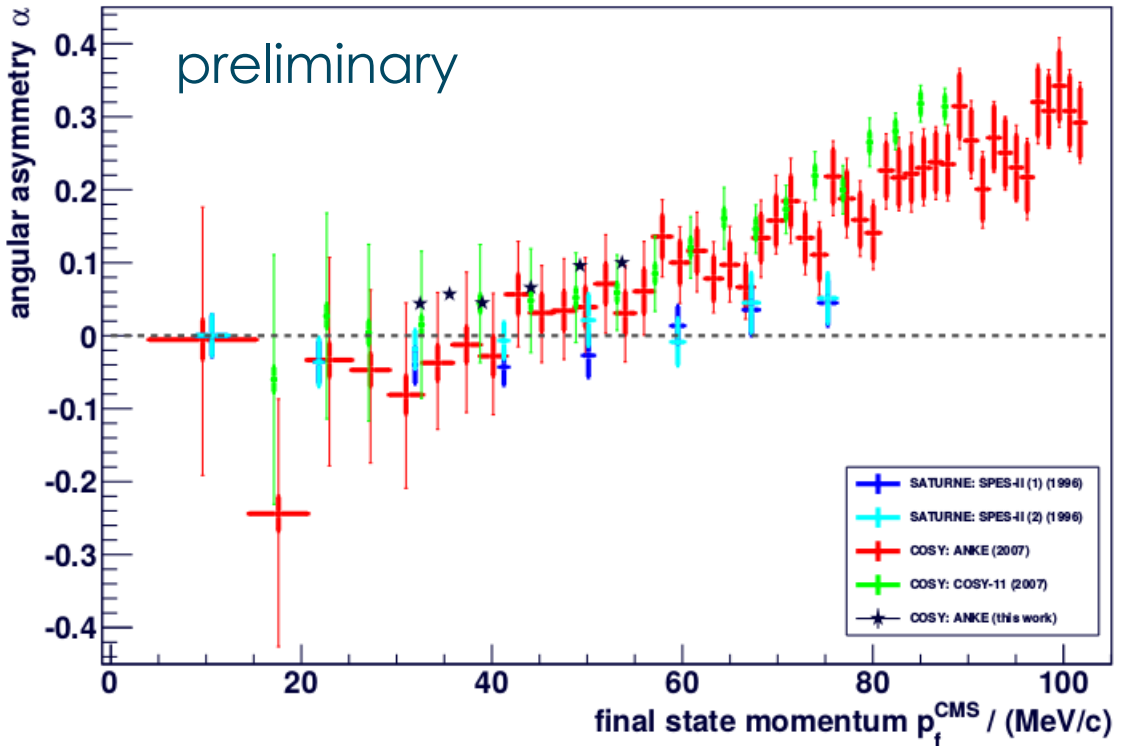
- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 3.08 MeV





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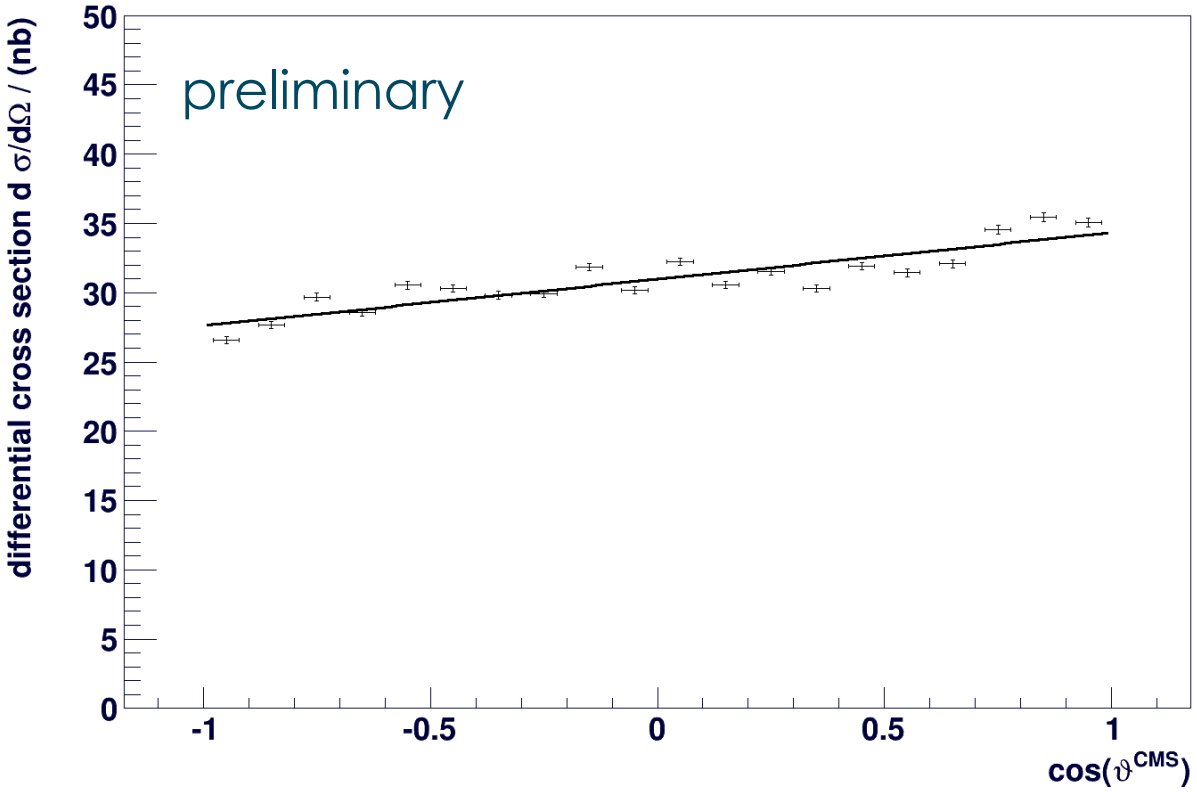
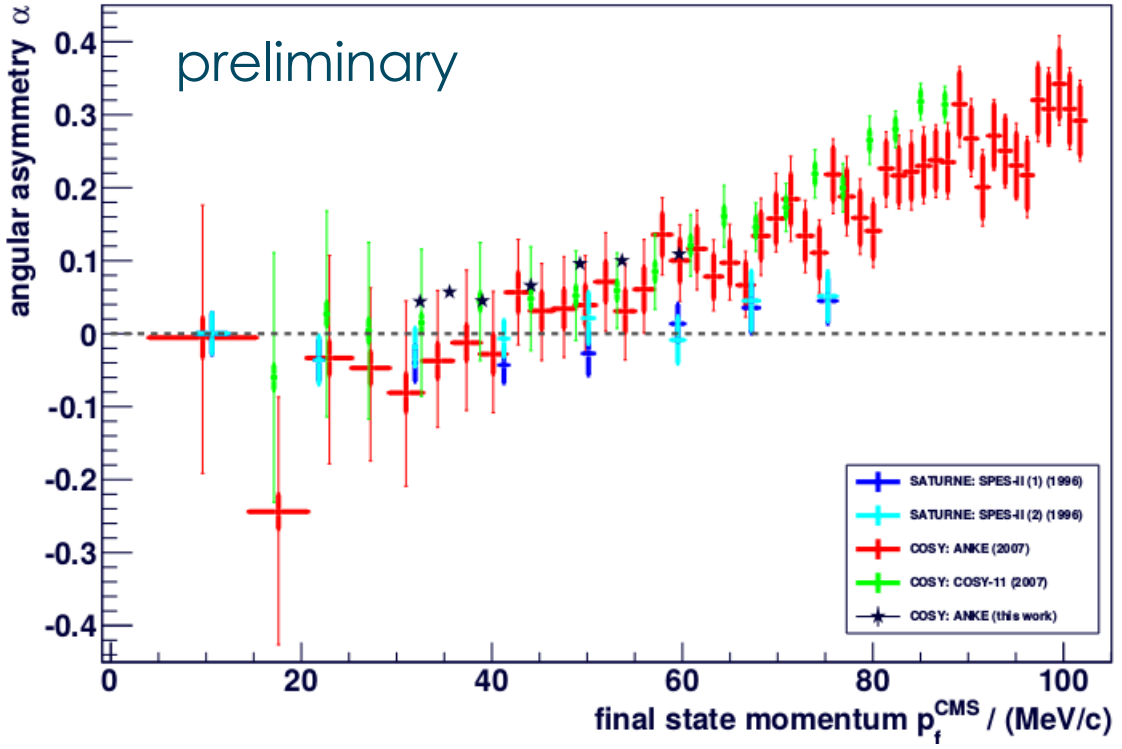
Q = 3.79 MeV





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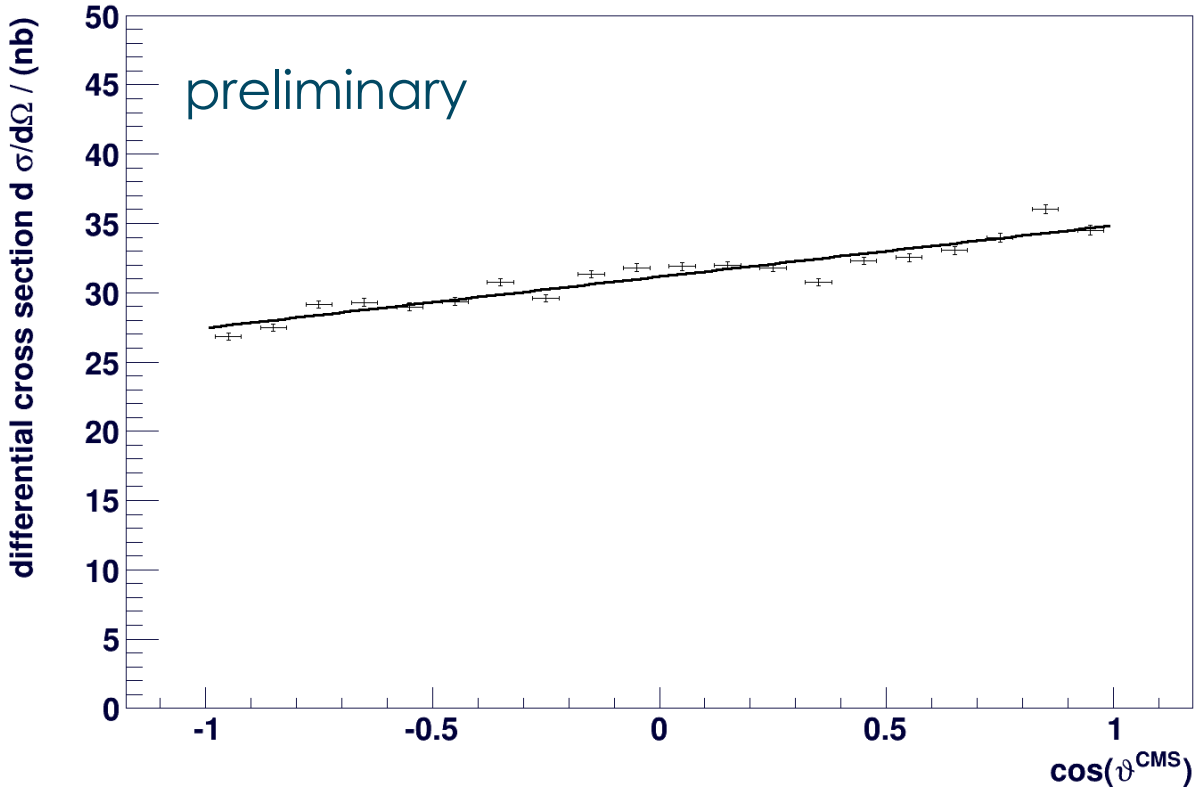
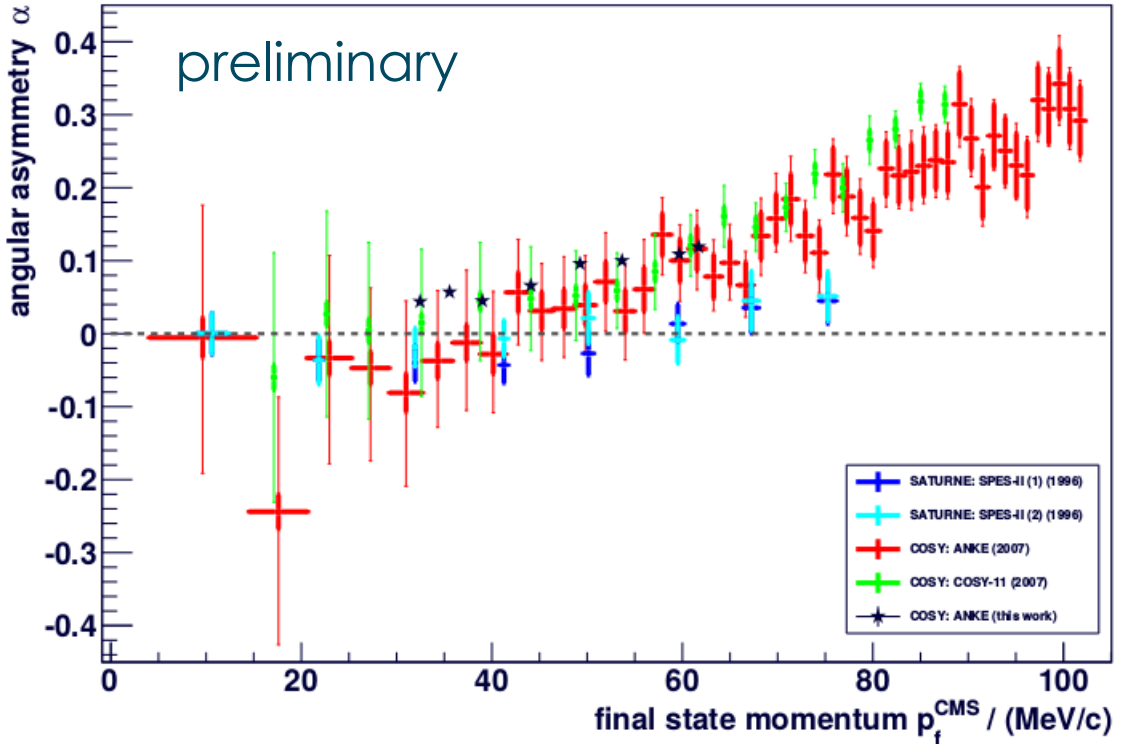
- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 4.09 MeV

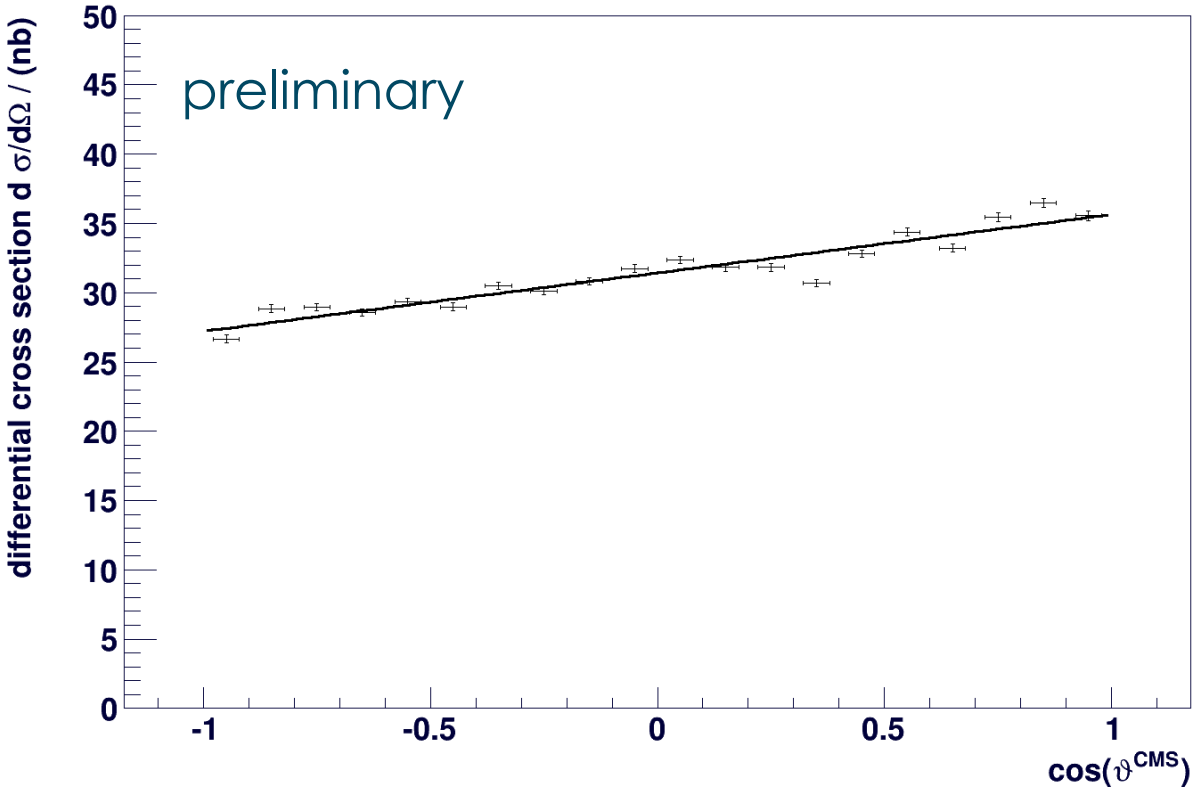


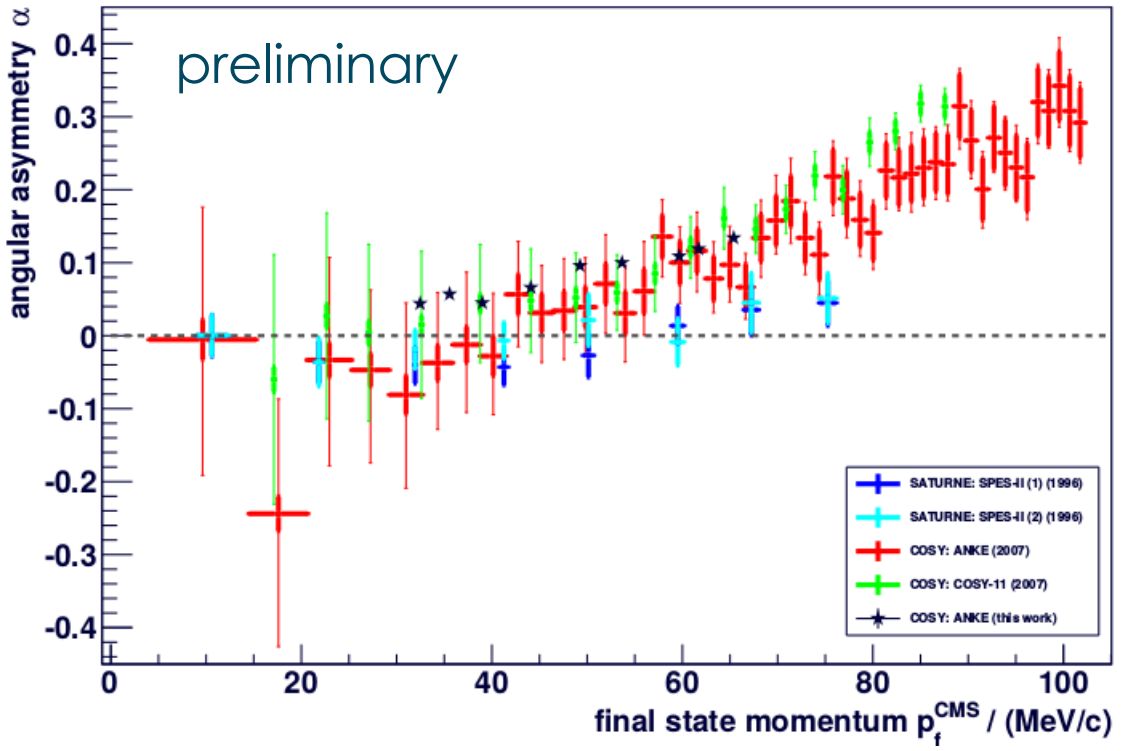


Differential cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$

- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 4.55 MeV

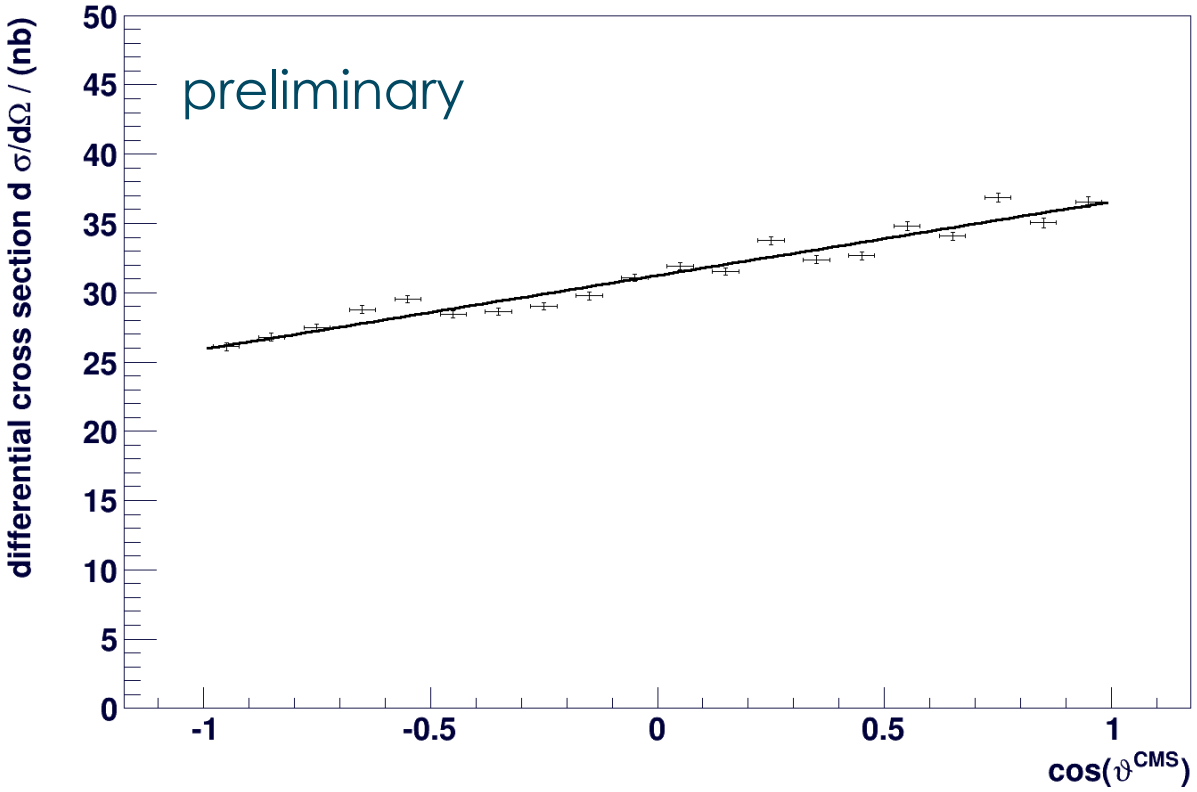


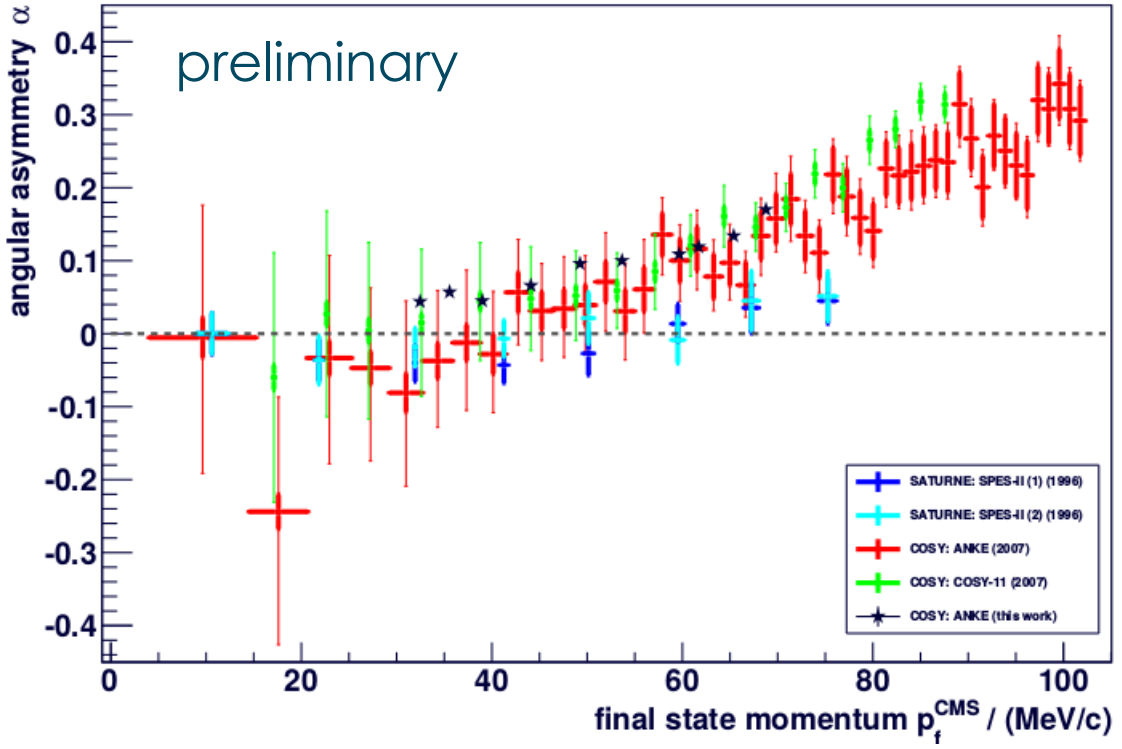


Differential cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$

- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 5.07 MeV



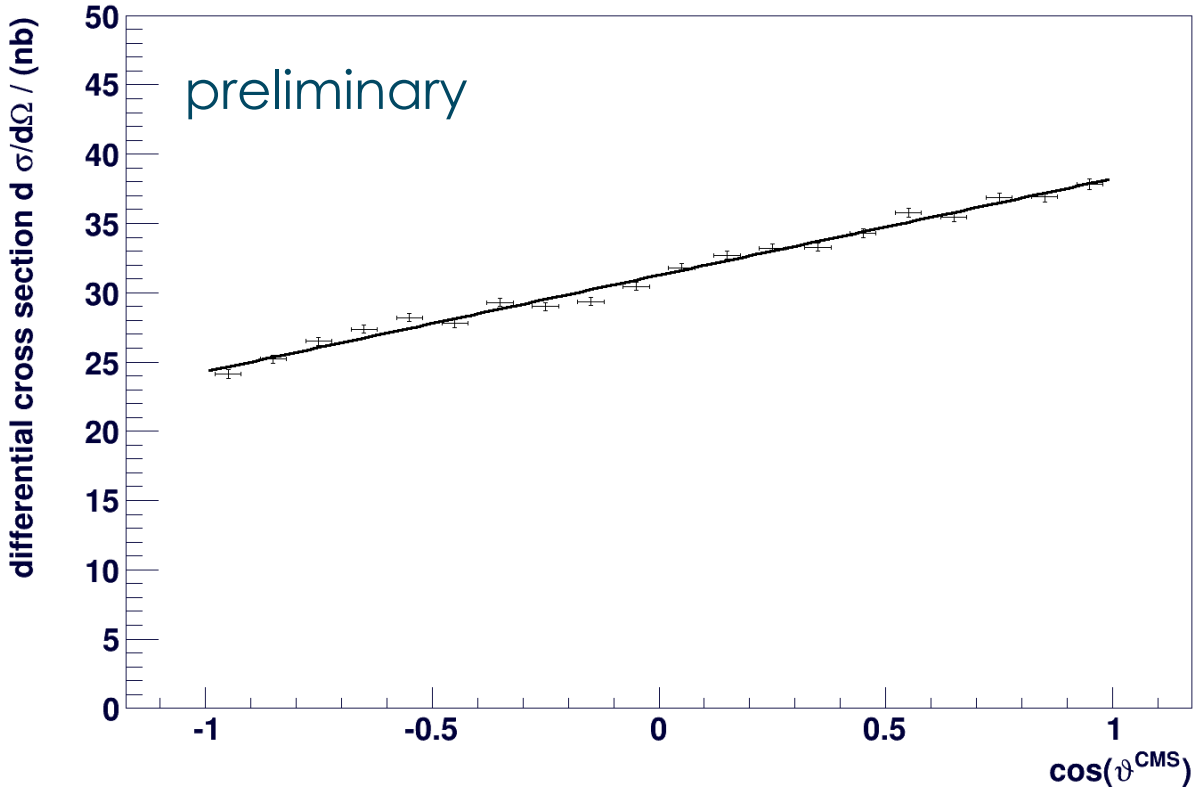


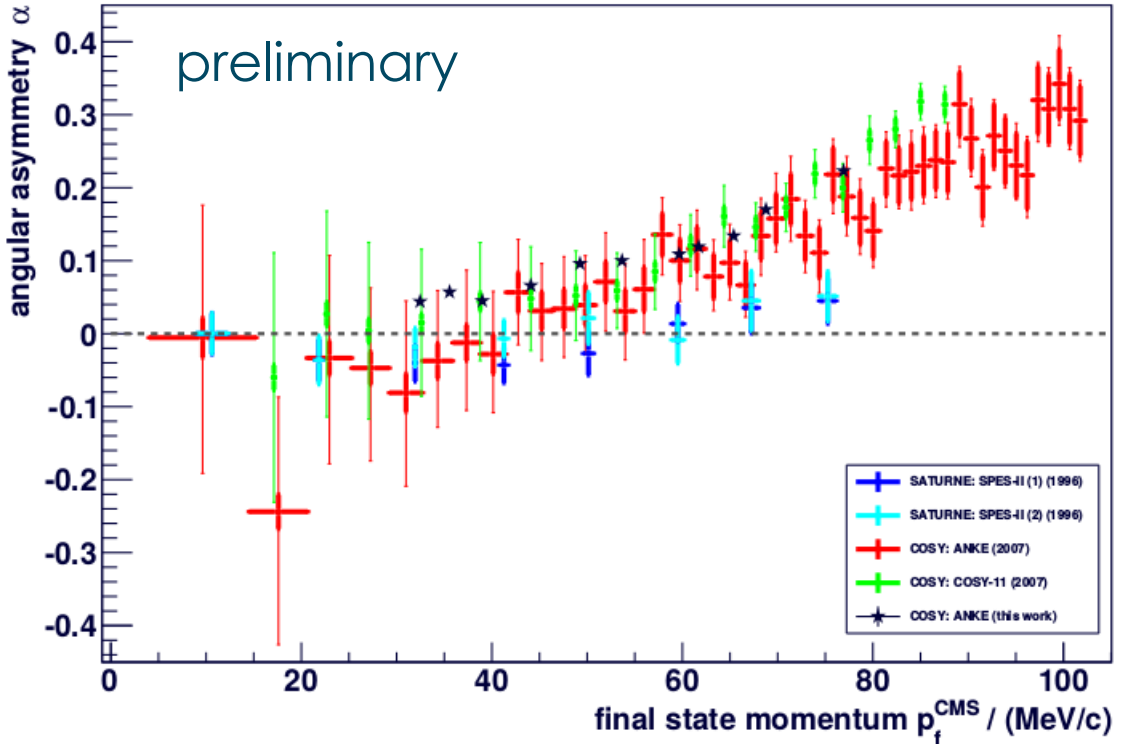
Differential cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$

Westfälische Wilhelms-Universität Münster

- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 6.33 MeV

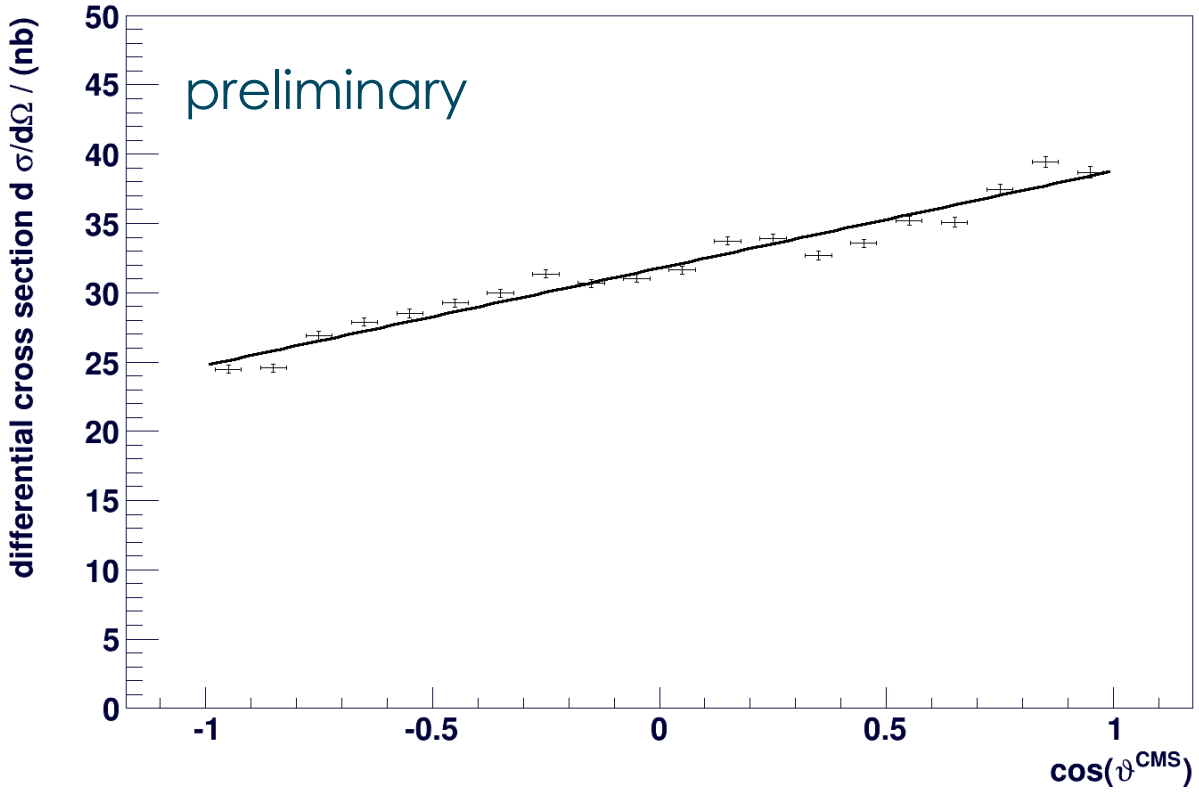


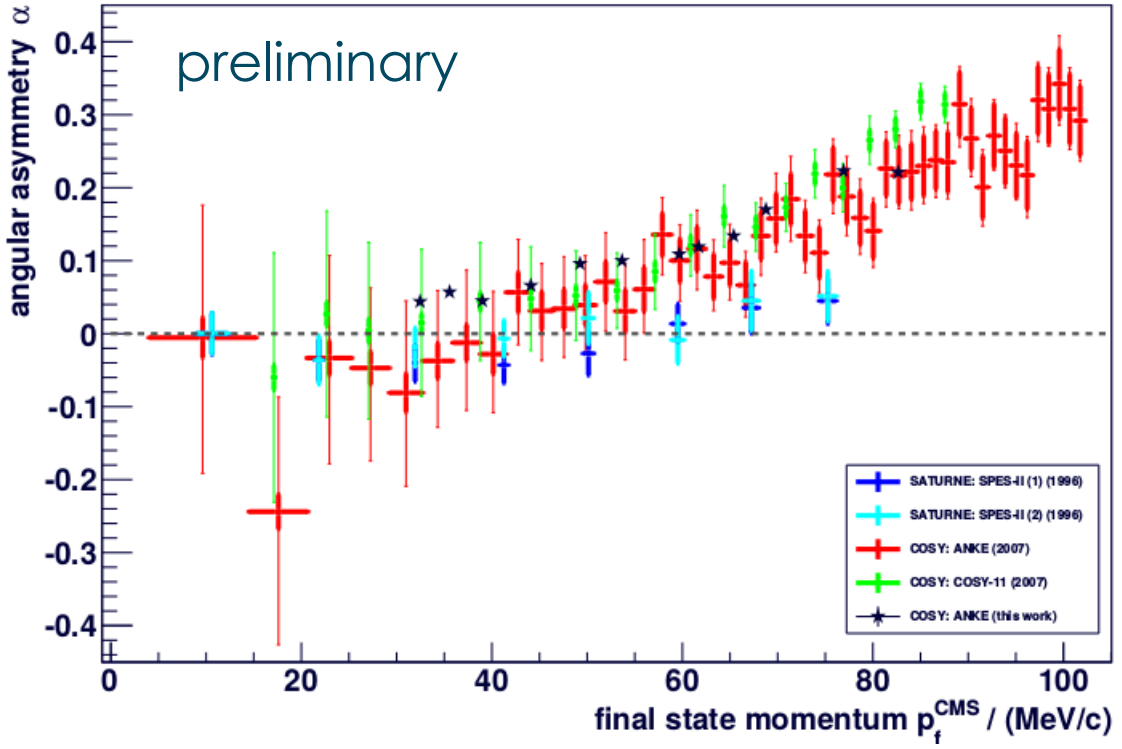


Differential cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$

- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 7.32 MeV



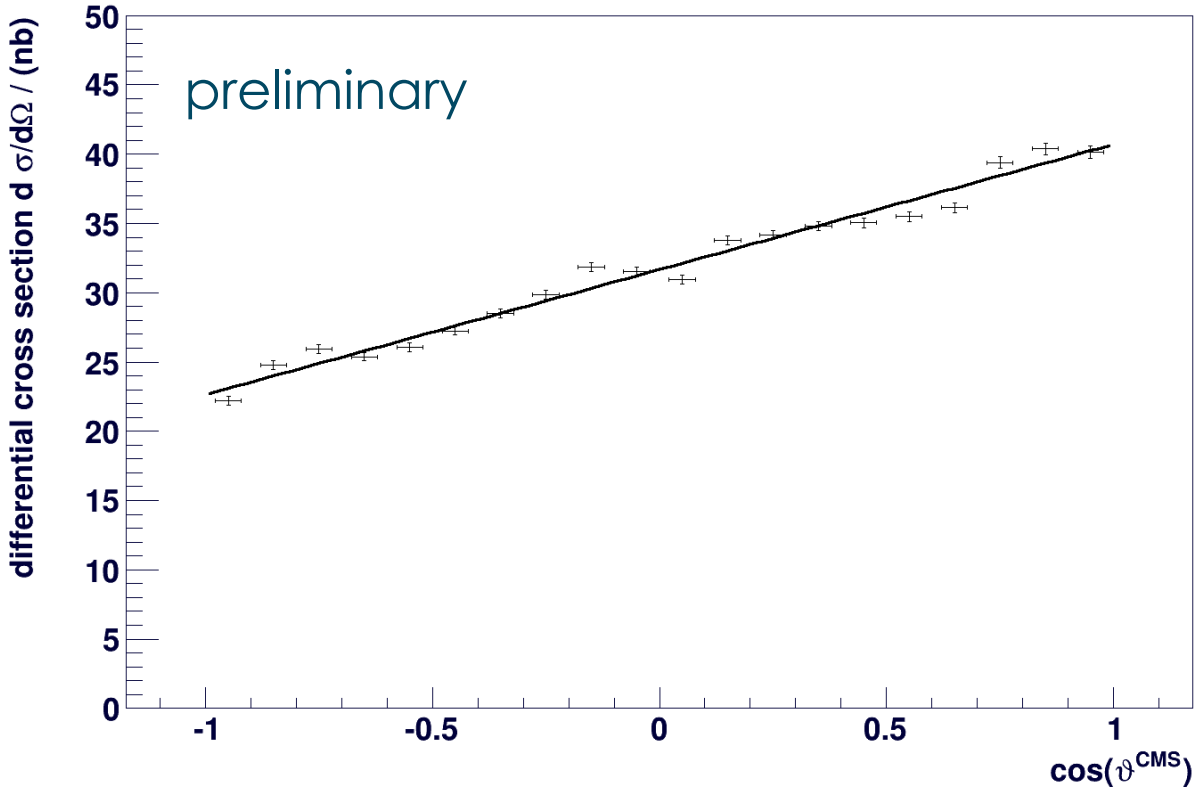


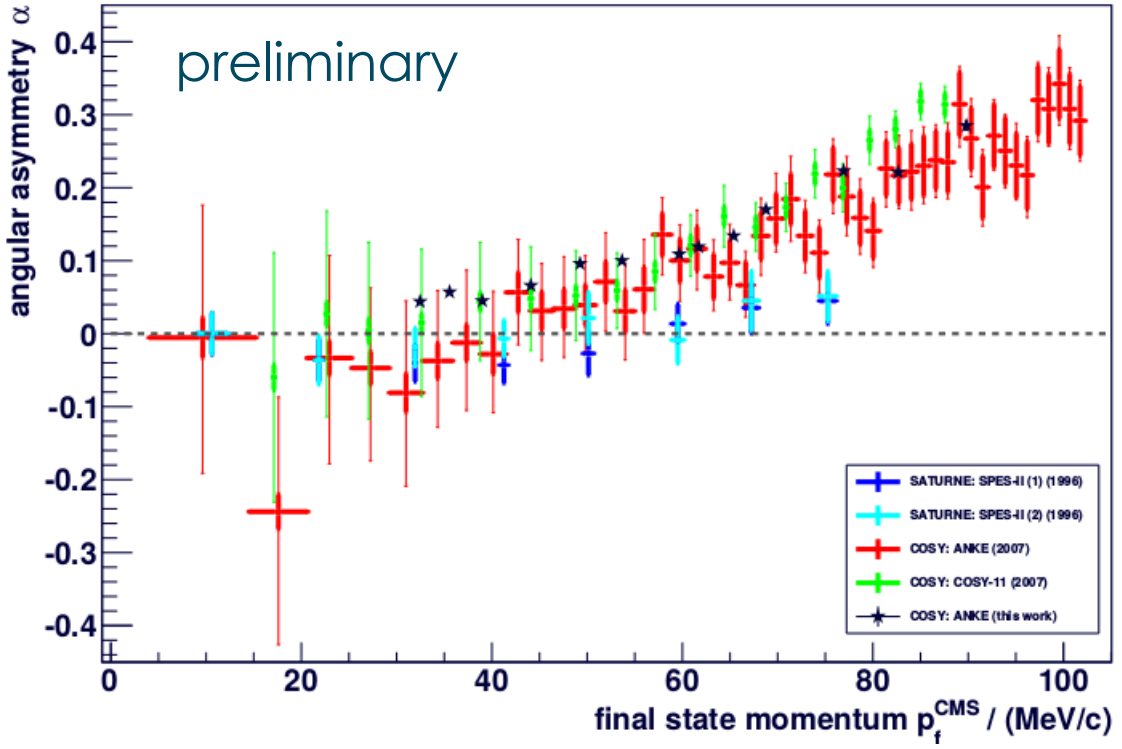
Differential cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$

Westfälische Wilhelms-Universität Münster

- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 8.60 MeV

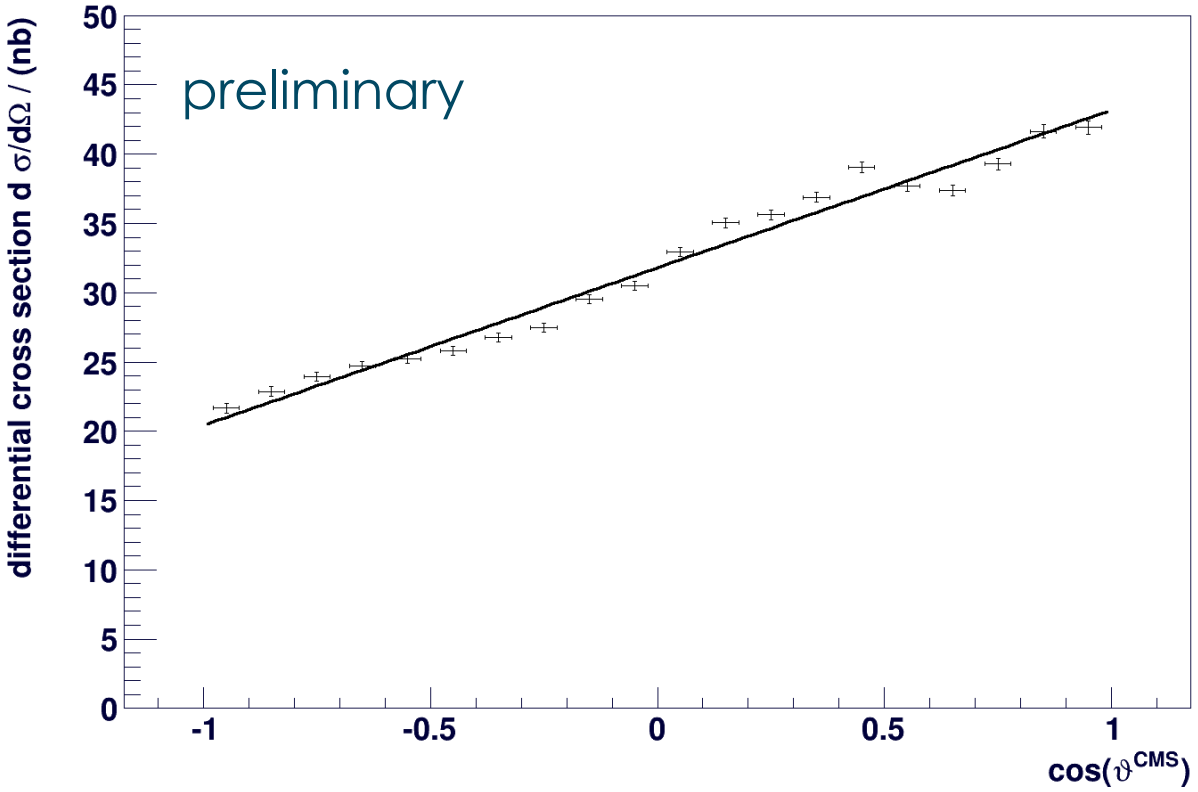


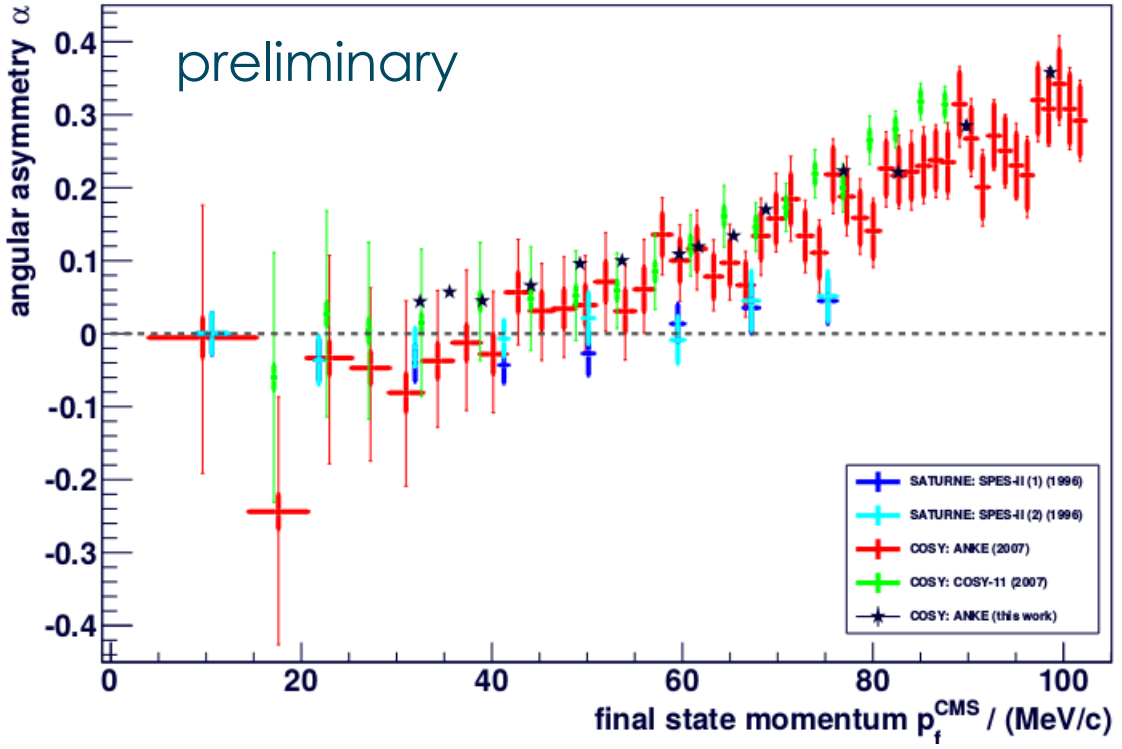


Differential cross section of $d + p \rightarrow {}^3\mathrm{He} + \eta$

- asymmetry parameter $\alpha = \frac{d}{d(\cos\theta_\eta)} \ln\left(\frac{d\sigma}{d\Omega}\right)_{|cos\theta_\eta^{cms}=0}$

Q = 10.37 MeV





$$p + n \rightarrow d + \eta$$

via the reaction

$$p + d \rightarrow p_{spectator} + d + \eta$$

Motivation

- indication of a quasi bound state of the ^{3}Heη-system

- study of A-dependency of the Final State Interaction (FSI) important

  ⇒ investigation of the $d\eta$-system

- pole near threshold would influence the ηN production above threshold

  ⇒ described by a FSI-ansatz (s-wave)

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

$$\mathrm{FSI} = \frac{1}{1 - i \cdot a \cdot p_f + \frac{1}{2} r_0 a p_f^2} = \frac{1}{(1 - p_f / p_1)(1 - p_f / p2)}$$

Motivation

- current database on $pn \rightarrow d\eta$:

  ✓PINOT: η production much stronger in pn than in pp collisions

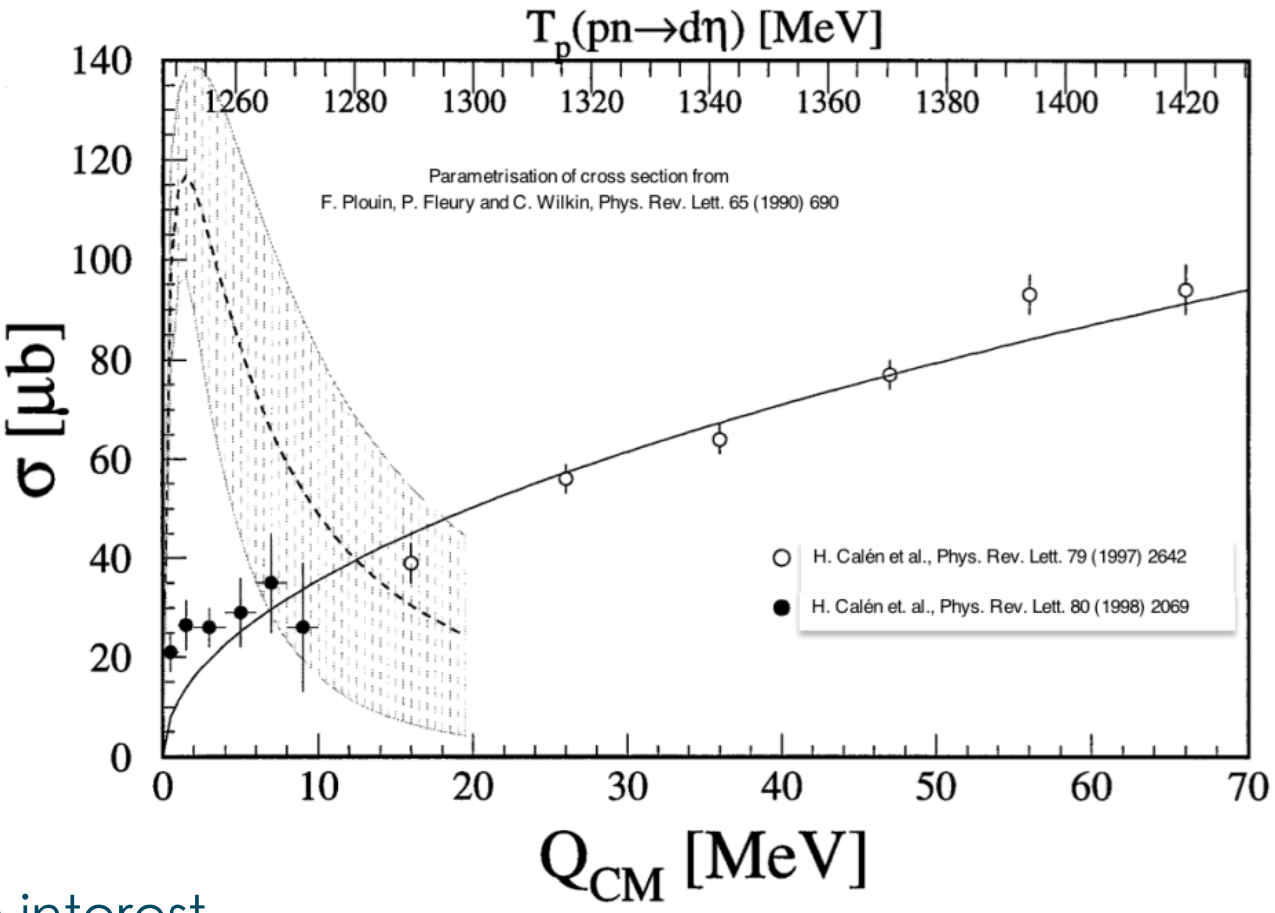
  ✓two measurements by PROMICE-WASA at CELSIUS

  $pn \rightarrow d\eta$ via $pn \rightarrow d\eta p_{spectator}$

- near threshold data show clear FSI enhancement

- steep rise of cross section up to $30\ \mu b$

- more detailed and independent data of high interest



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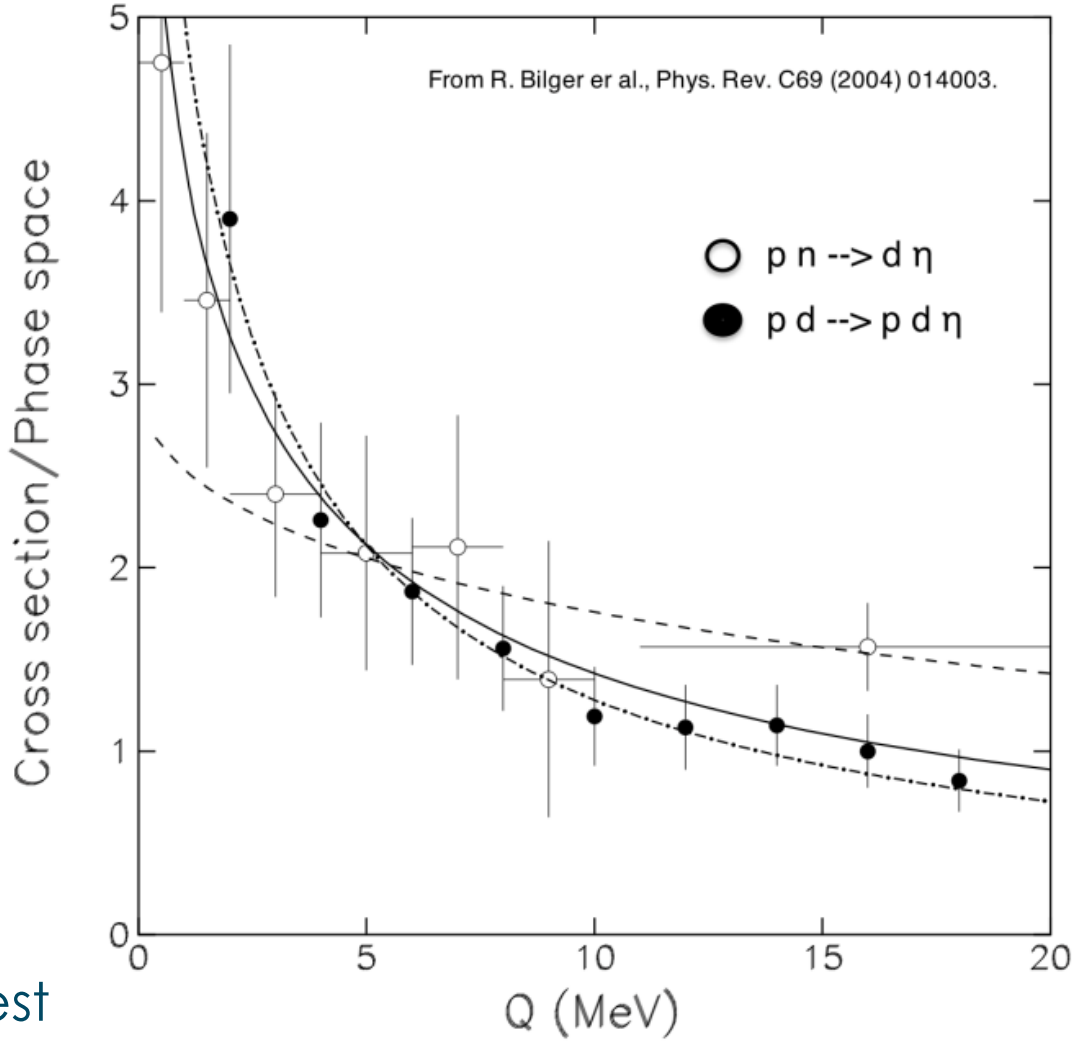


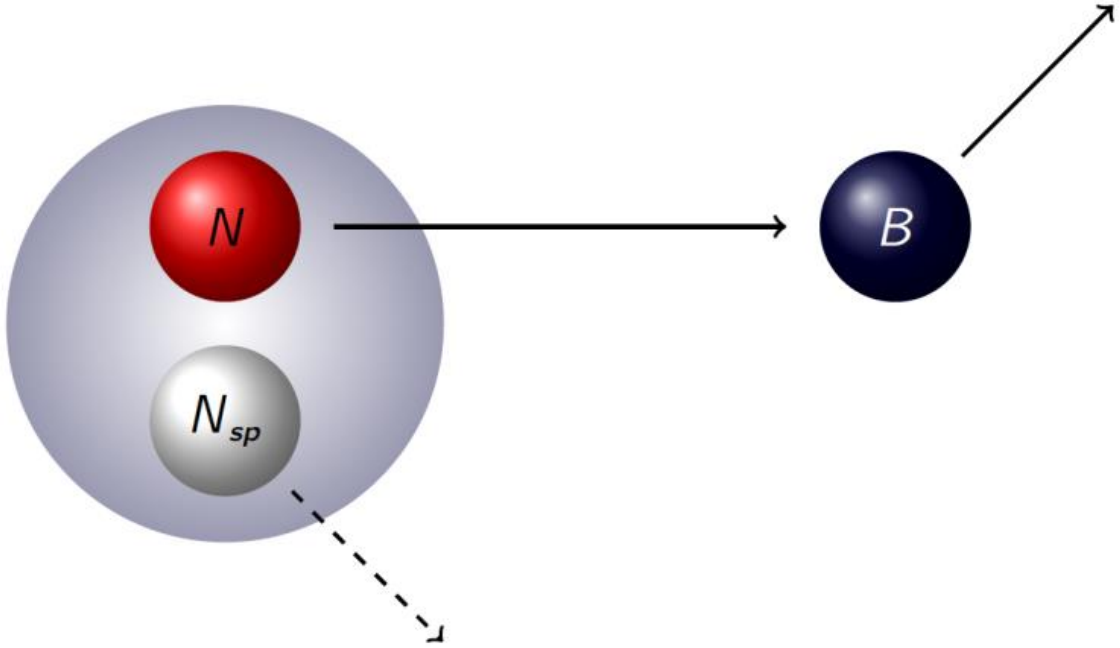
Measurements: Experimental Conditions

- main goals: extraction of scattering length $a_{d\eta}$ with data close to threshold and differential cross section to determine the limit of the s-wave FSI-ansatz

- reaction used: $\mathrm{p} + d \rightarrow p_{spectator} + d + \eta$

  $\Rightarrow$ quasi free reaction $p + n \rightarrow d + \eta$

- $p_{spectator}$ carries Fermi motion within the nucleus



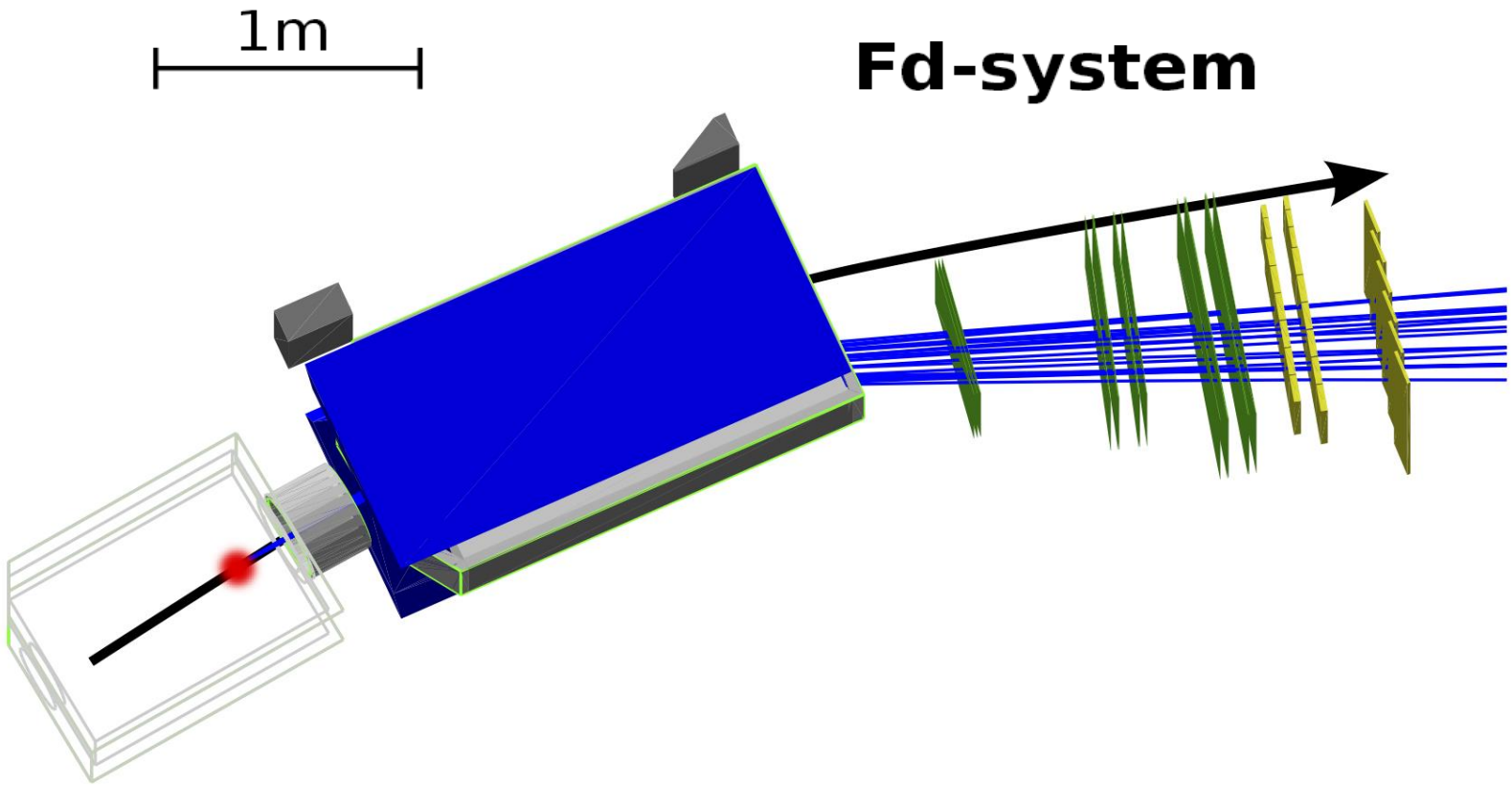
- supercycle mode: alternate between two different beam momenta

  $p_1 = 2.09\ \mathrm{GeV}/c$

  $p_2 = 2.25\ \mathrm{GeV}/c$

- setup allows to determine cross sections in an excess energy range up to $Q = 100$ MeV

Fd-System with STT Detectors



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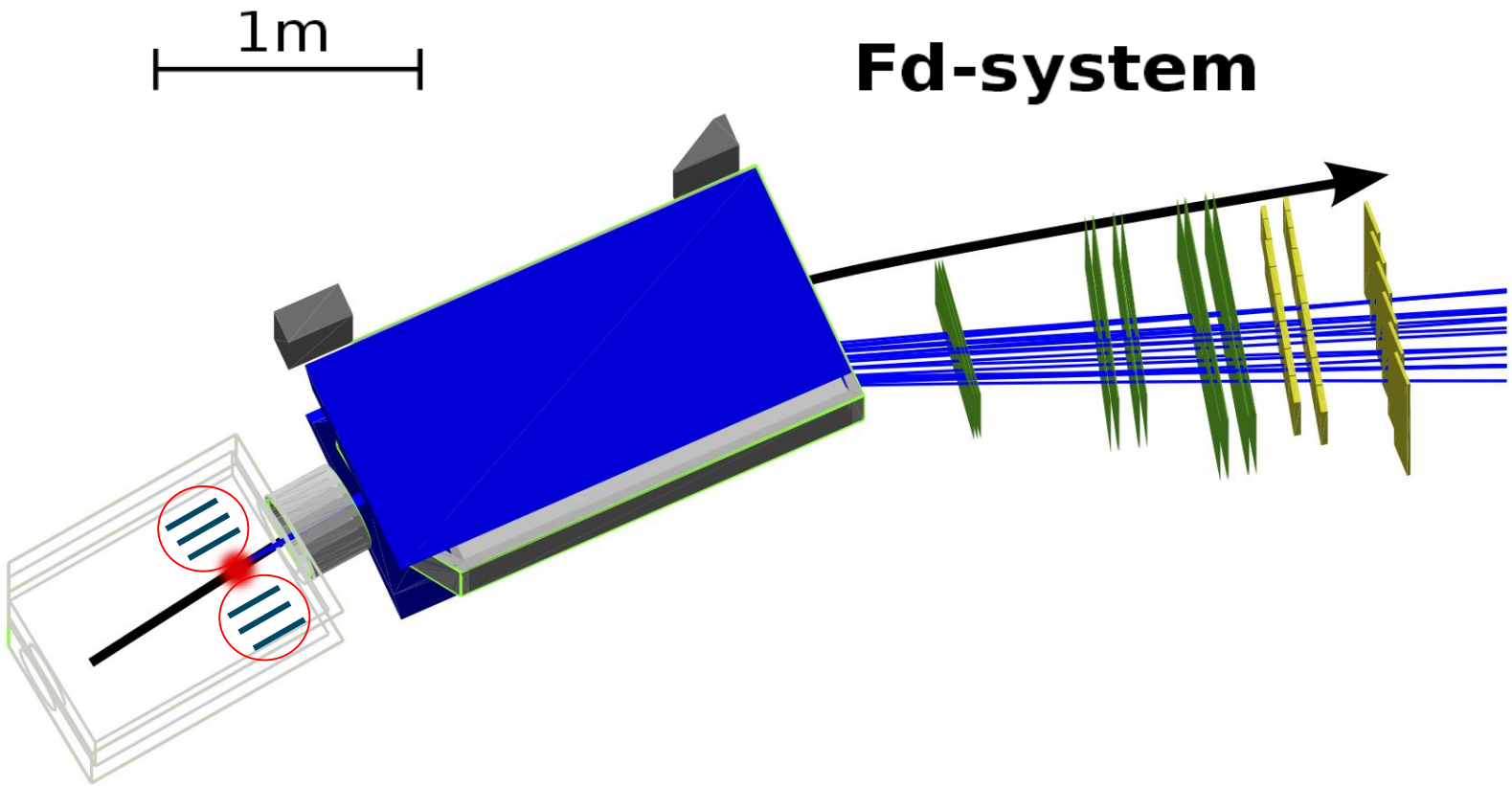

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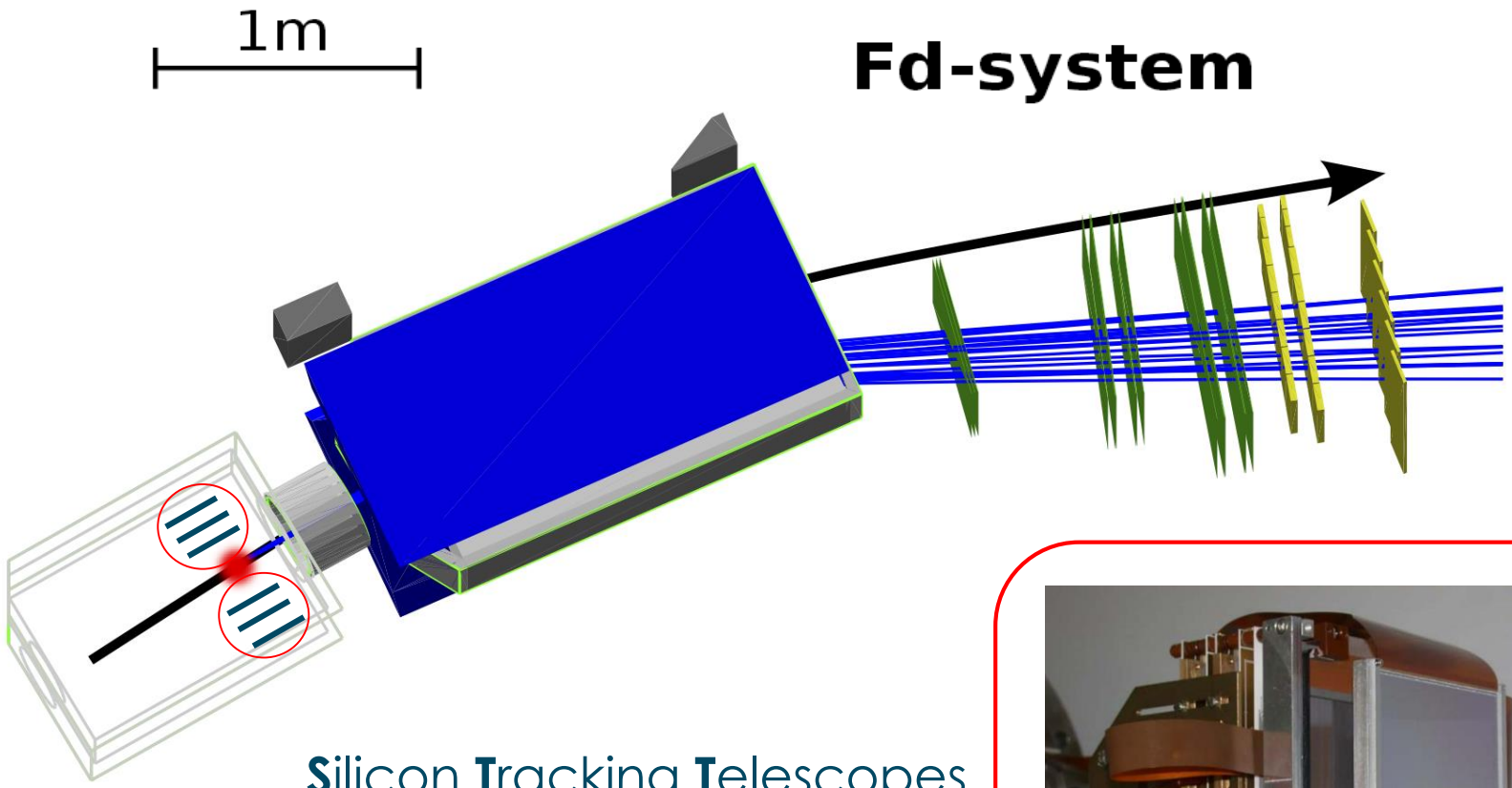
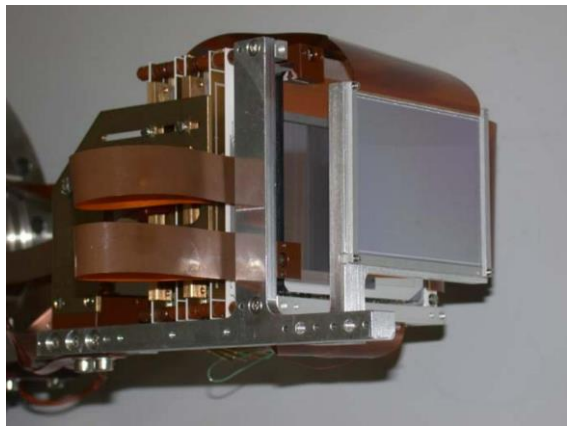
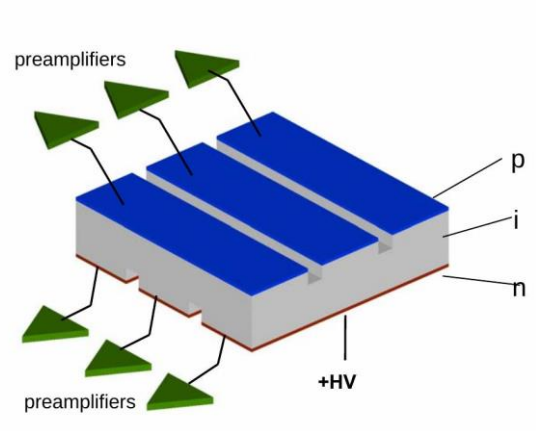


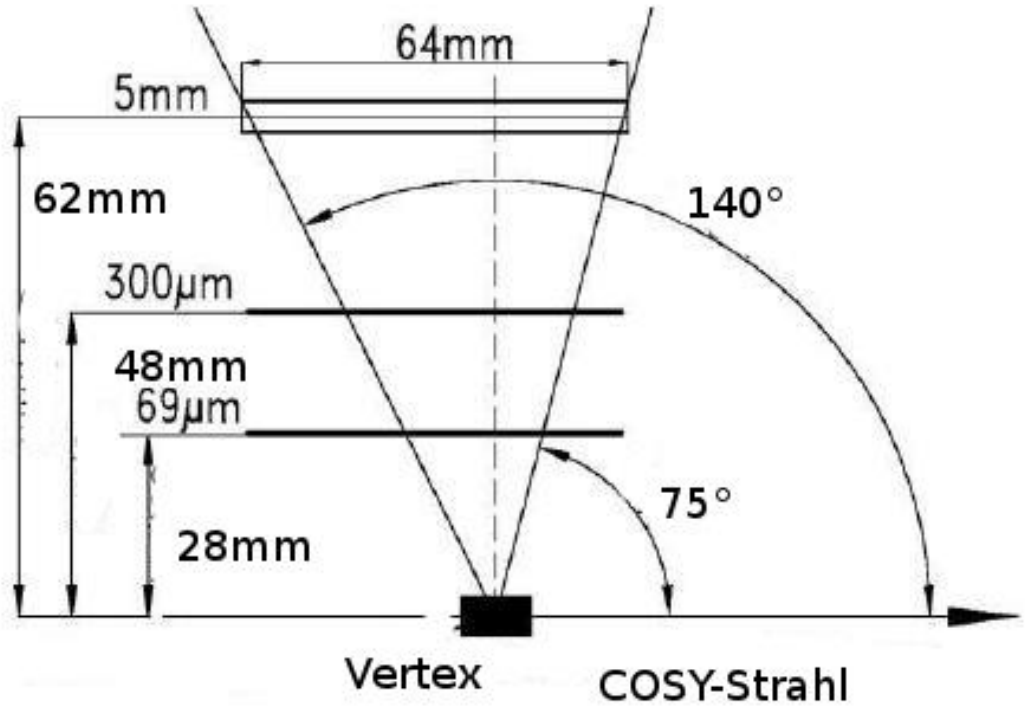
Silicon **T**racking **T**elescopes
(STT)





Particle Identification ($p_{spectator}$)

- determination of excess energy on an event-by-event basis
  - ⇒ one beam momentum = wide excess energy range
- identification of spectator protons mandatory
- use of two Silicon Tracking Telescopes (STT)
- consist of three layers of semiconductor
  - ⇒ track reconstruction
  - ⇒ energy loss measurements
- cover polar angles between 75° and 140°



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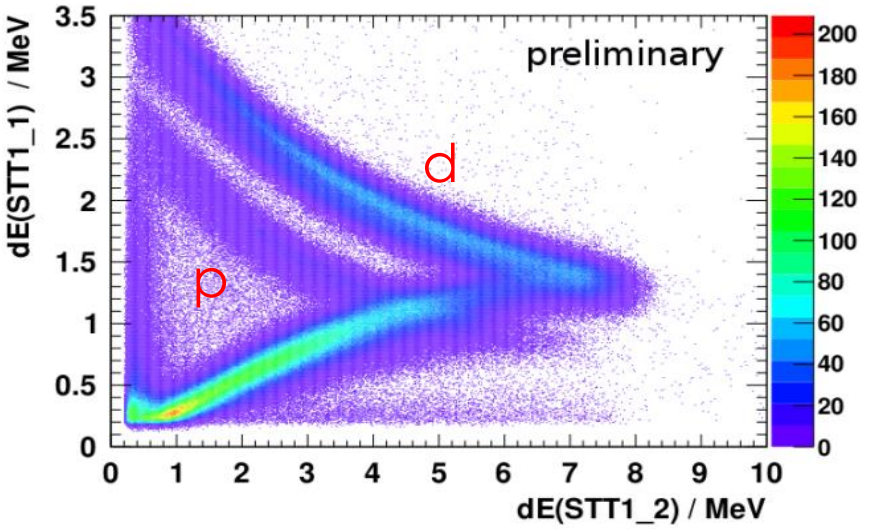
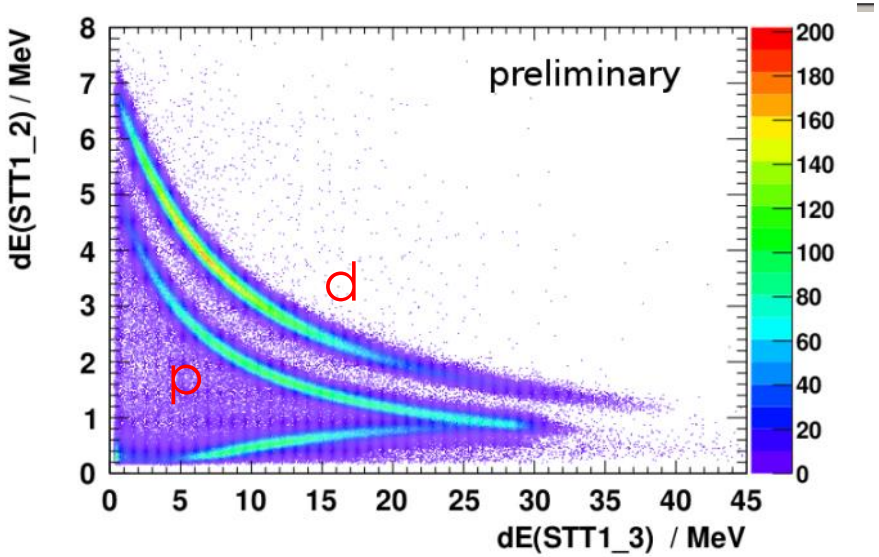


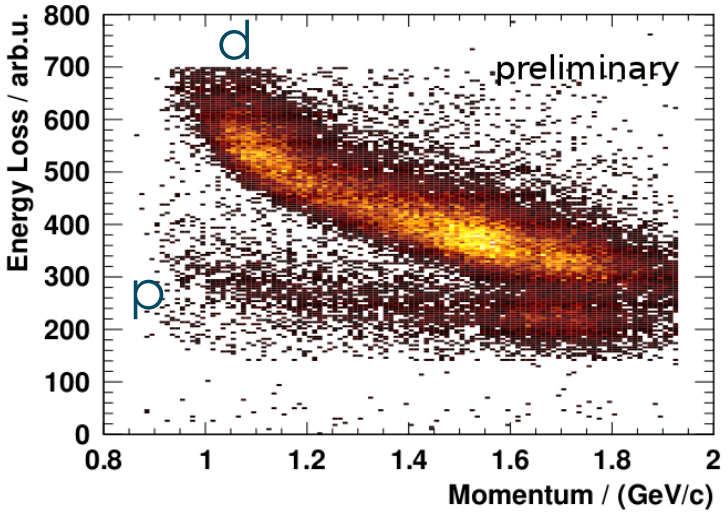


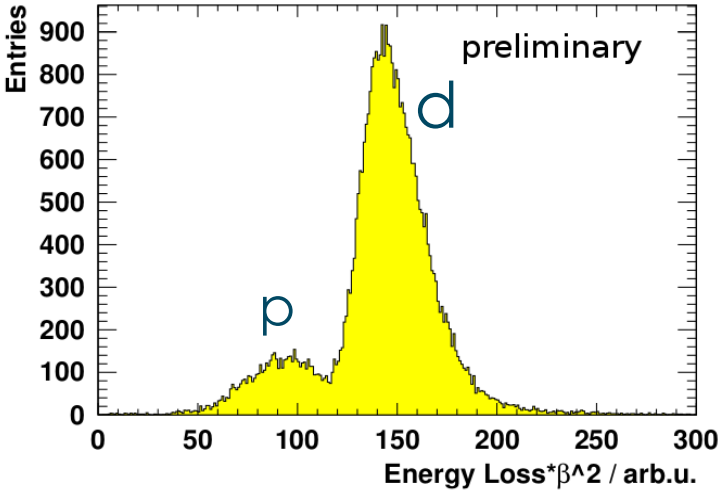
Particle Identification (d)

- detection of fast deuteron in the Fd-system
- separation from protons using energy loss and time of flight measurements
- cut parameters determined via the reaction $p + d \rightarrow d + \pi^+ + X$

Fd-system Pd-system

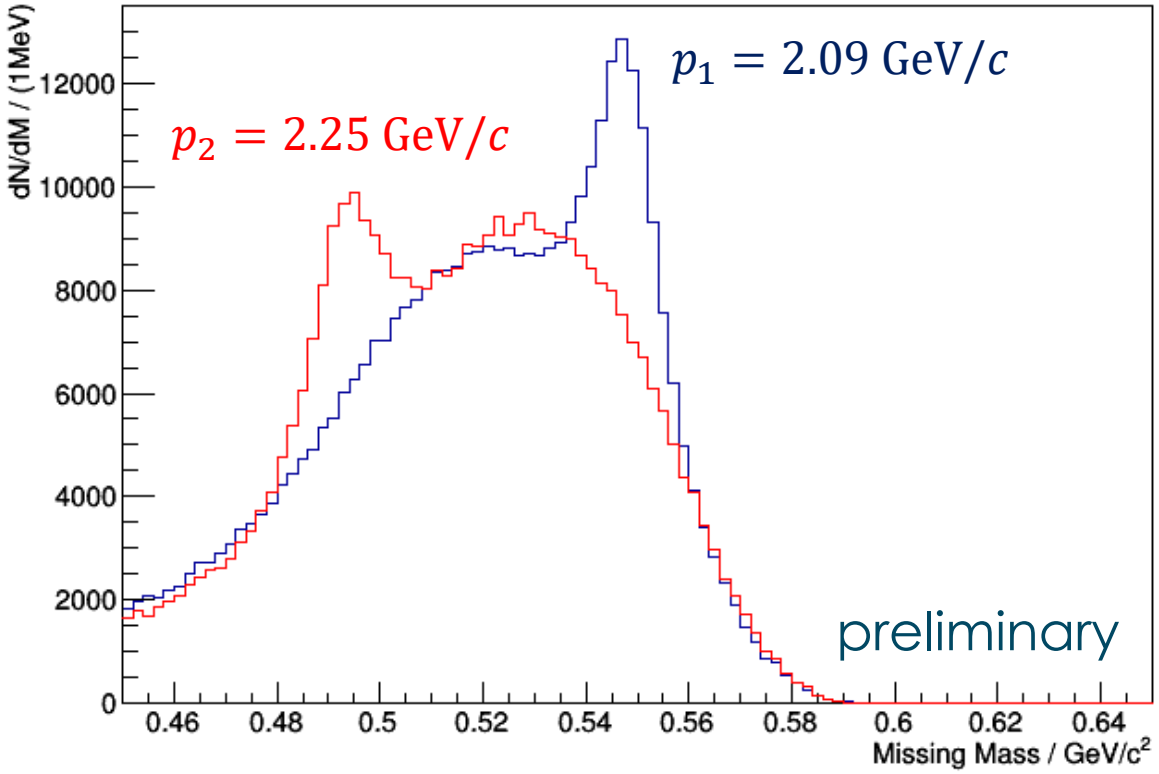
- event selection via missing mass technique





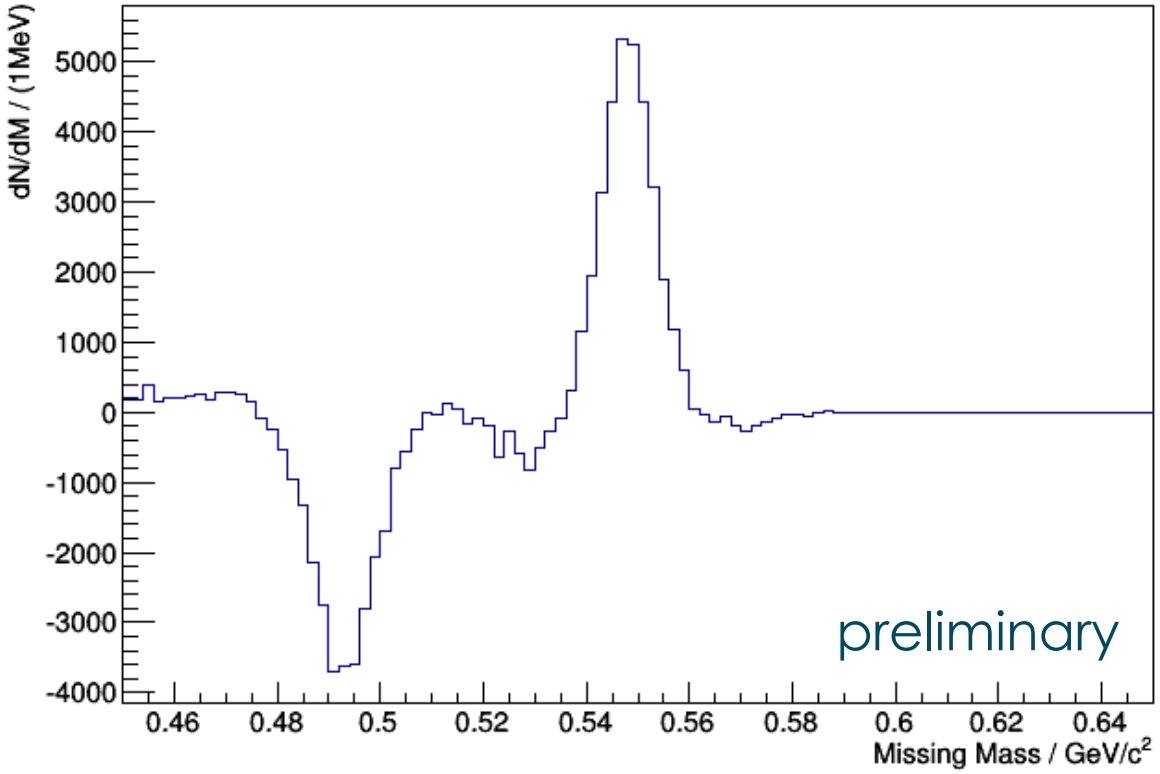
Background Description

- background mainly multi pion production
- model-independent approach for background subtraction
- analyze data with "false" beam momentum
  - ⇒ event-by-event Lorentz transformation of measured particle to "false" laboratory system
  - ⇒ same kinematical limit



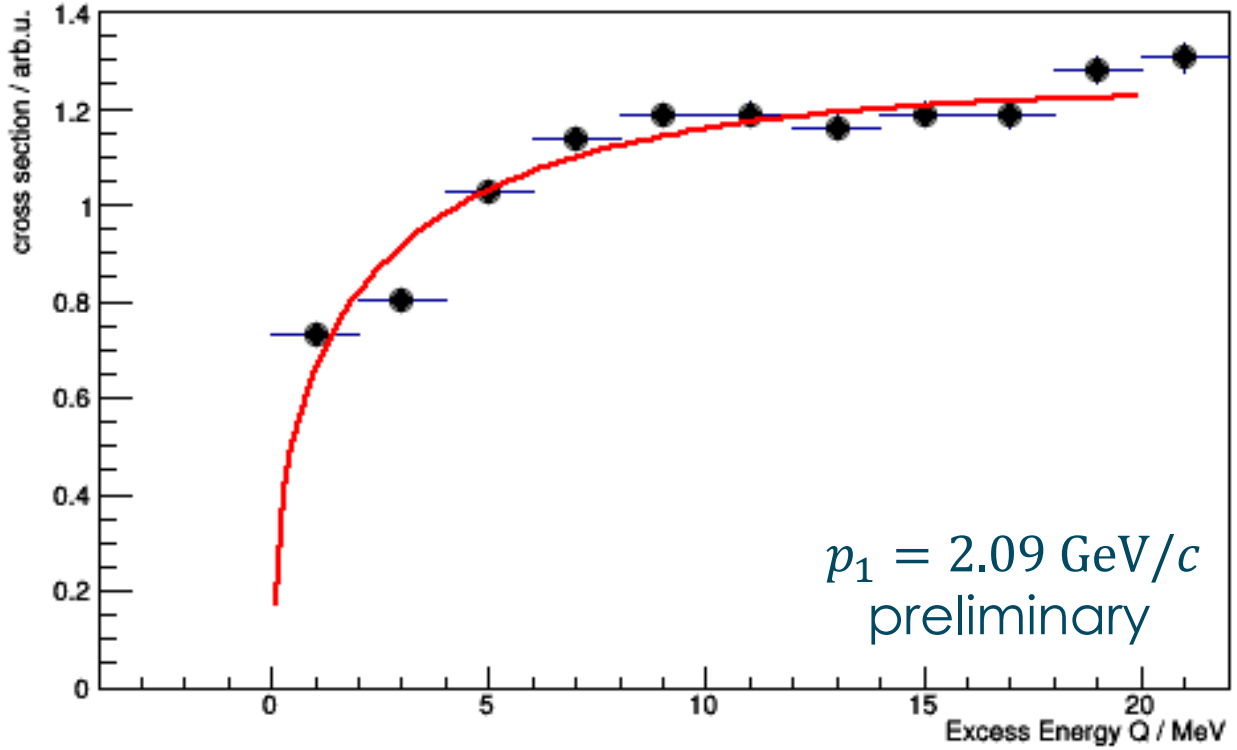
Preliminary Results for $p + d \rightarrow p_{spectator} + d + \eta$

- background mainly multi pion production
- model-independent approach for background subtraction
- analyze data with "false" beam momentum
  - ⇒ event-by-event Lorentz transformation of measured particle to "false" laboratory system
  - ⇒ same kinematical limit
- subtraction results in peak at η-mass and shifted negativ peak



Preliminary Results for $p + d \rightarrow p_{spectator} + d + \eta$

- background mainly multi pion production
- model-independent approach for background subtraction
- analyze data with "false" beam momentum
  - ⇒ event-by-event Lorentz transformation of measured particle to "false" laboratory system
  - ⇒ same kinematical limit
- subtraction results in peak at η-mass and shifted negativ peak
- steep rise near threshold observed



- very preliminary fit data with s-wave FSI ansatz ⇒ $|a| \approx 1.2$ fm

Summary & Outlook

- $d + p \rightarrow {}^3\mathrm{He} + \eta$:
  - luminosities were determined via dp-elastic scattering for each of the 19 beam momenta
  - high precision of $\Delta L_{\mathrm{stat}} = 1\%$ and $\Delta L_{\mathrm{sys}} = 6\%$ achieved
    ⇒ improvement by at least a factor of two compared to previous analyses
  - ANKE has full geometrical acceptance for the reaction $dp \rightarrow {}^3\mathrm{He}\eta$
  - clear separation from other reactions possible
  - high statistics of more than 10^5 ${}^3\mathrm{He}\eta$ events per energy
  - determination of total and differential cross section and angular asymmetry parameter α
- in progress:
  - iterative acceptance correction
  - luminosity cross check via $d + p \rightarrow {}^3\mathrm{He} + \pi^0$
  - checks of systematics

Summary & Outlook

- $p + d \rightarrow p_{spectator} + d + \eta$:
  - approximately 100k events between $Q = 0$ MeV and $Q = 100$ MeV
  - reconstruction of spectator protons with STTs

    ⇒ STT calibration almost finalized
  - identification of deuterons with Fd-system in progress

    ⇒ preliminary calibration of Fd-system

- in progress:
  - fine calibration of the Fd-system
  - luminosity determination via elastic scattering
  - extraction of total and differential cross sections
  - determination of limit for s-wave FSI-ansatz
  - constrain allowed region for the scattering length of the $d\eta$-system

Thank you for your attention!

Acknowledgements:

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Alfons Khoukaz,
Marcel Rump,
Daniel Schröer,
and the ANKE collaboration

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