Westfälische
Wilhelms-Universität
Münster

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

Christopher Fritzsch for the ANKE collaboration

Westfälische Wilhelms-Universität Münster, Institut für Kernphysik

21st International Conference on Few-Body Problems in Physics
(Reactions and Structure)

May 22nd, 2015

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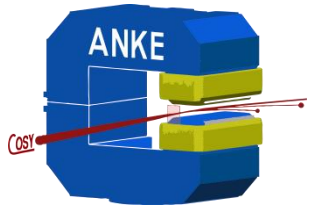

“COoler SYnchrotron“ - COSY

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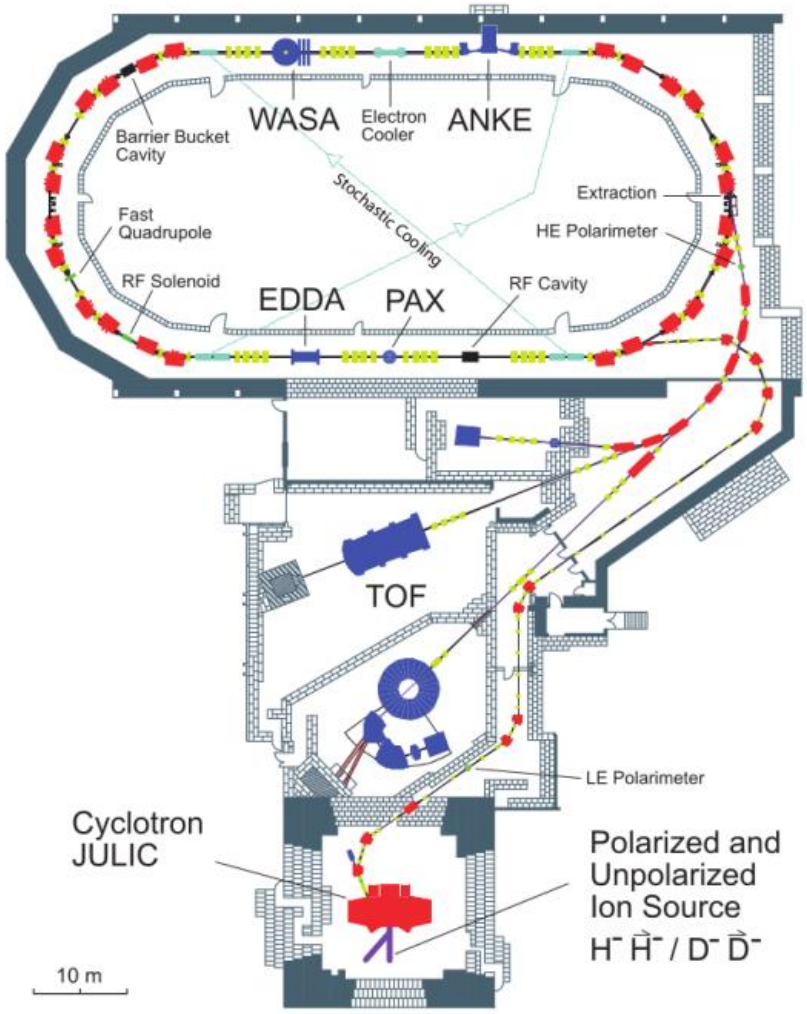
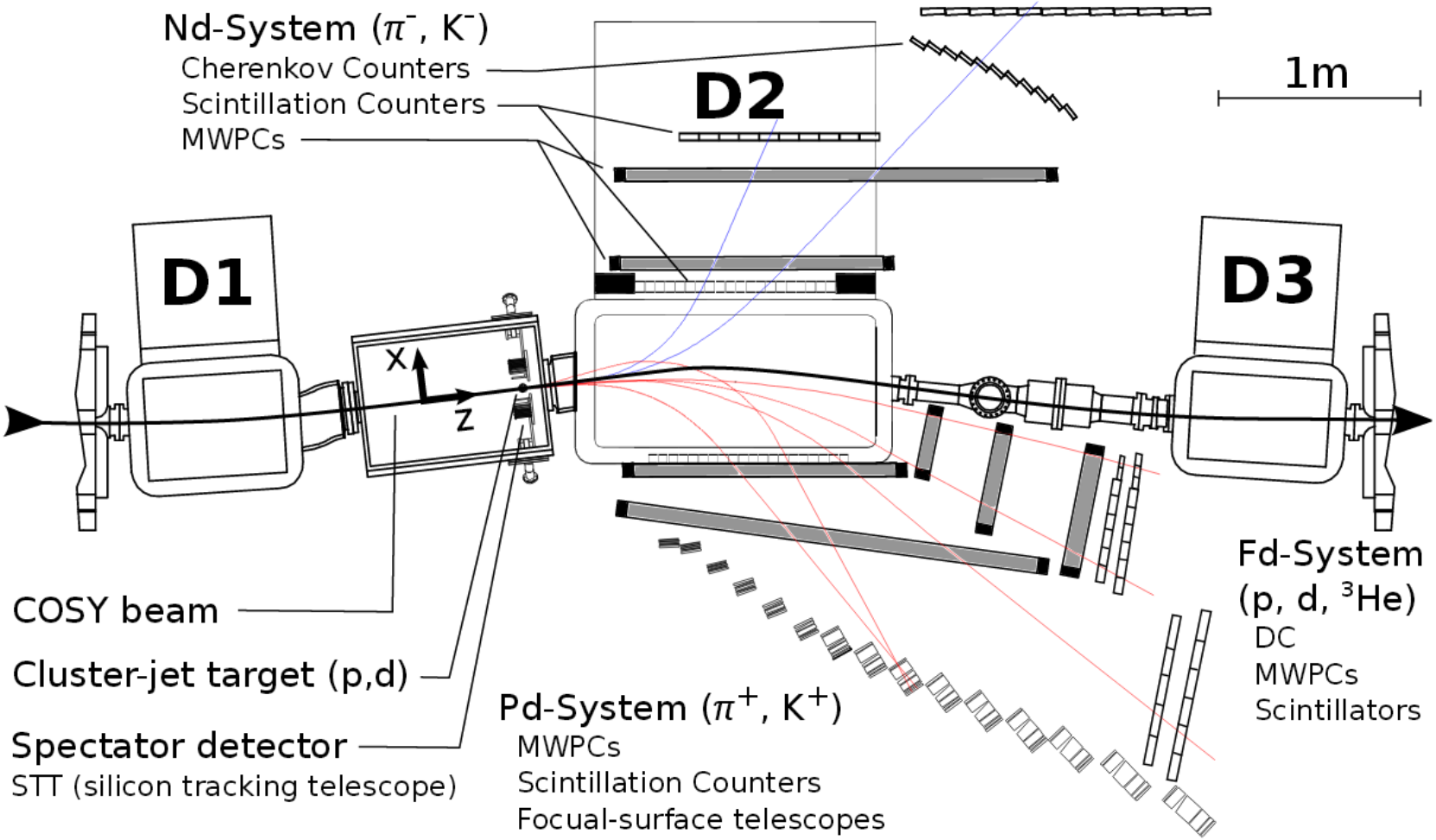
- pre-accelerator JULIC
  - ⇒ protons: $45\ \mathrm{MeV}$
  - ⇒ deuterons: $90\ \mathrm{MeV}$
- storage ring COSY
  - ⇒ circumference: 184 m
  - ⇒ momenta up to $3{,}7$ GeV/c achievable
  - ⇒ energy variation (ramping & supercycle mode)
- two cooling systems
  - ⇒ stochastic cooling
    - ⇒ $\mathrm{p_{beam}} = (1.5\ - 3.3)$ GeV/c
  - ⇒ electron cooling
    - ⇒ whole energy range of COSY
- possible momentum spread $\Delta p/p < 10^{-4}$



ANKE spectrometer

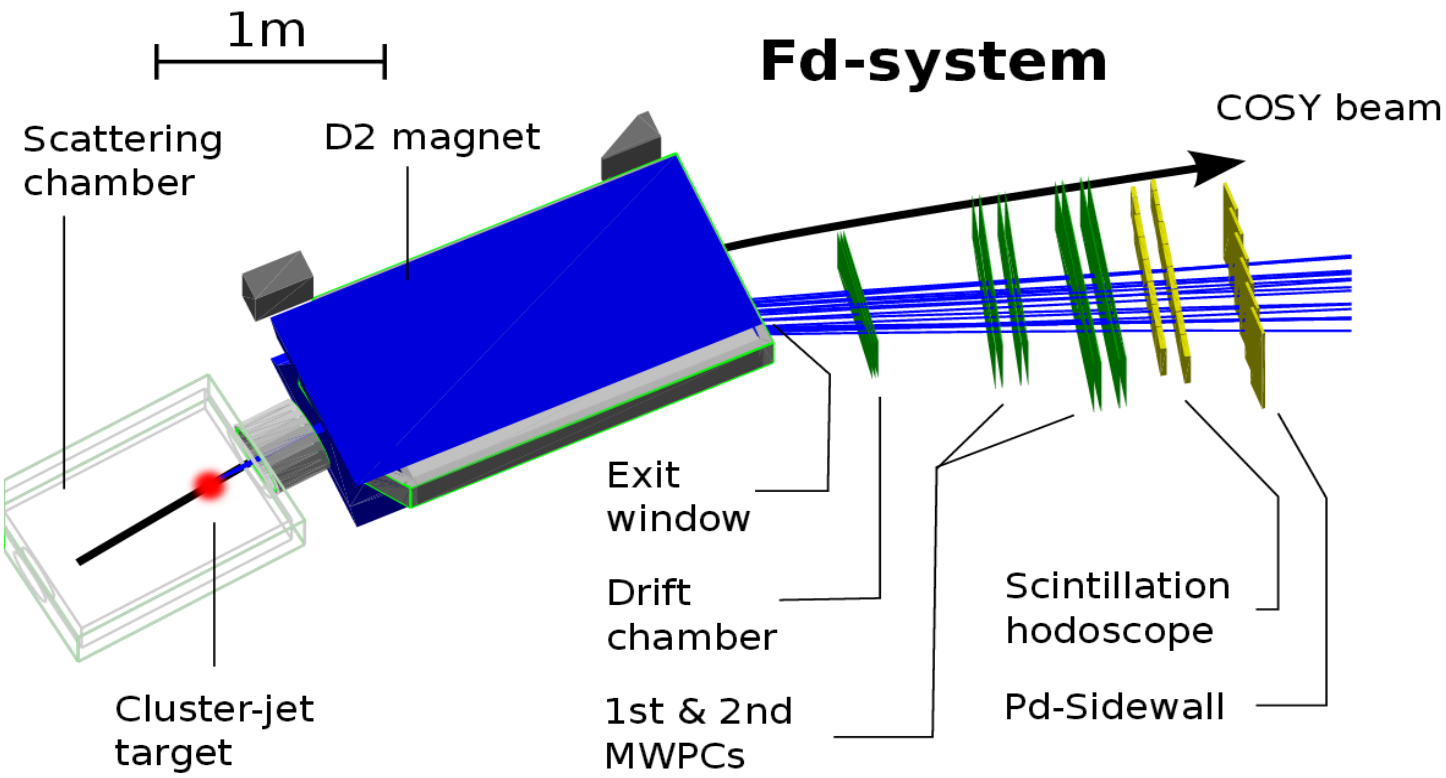


$d + p \rightarrow {}^3\mathrm{He} + \eta$

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

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

Forward detection system (Fd)



- track reconstruction

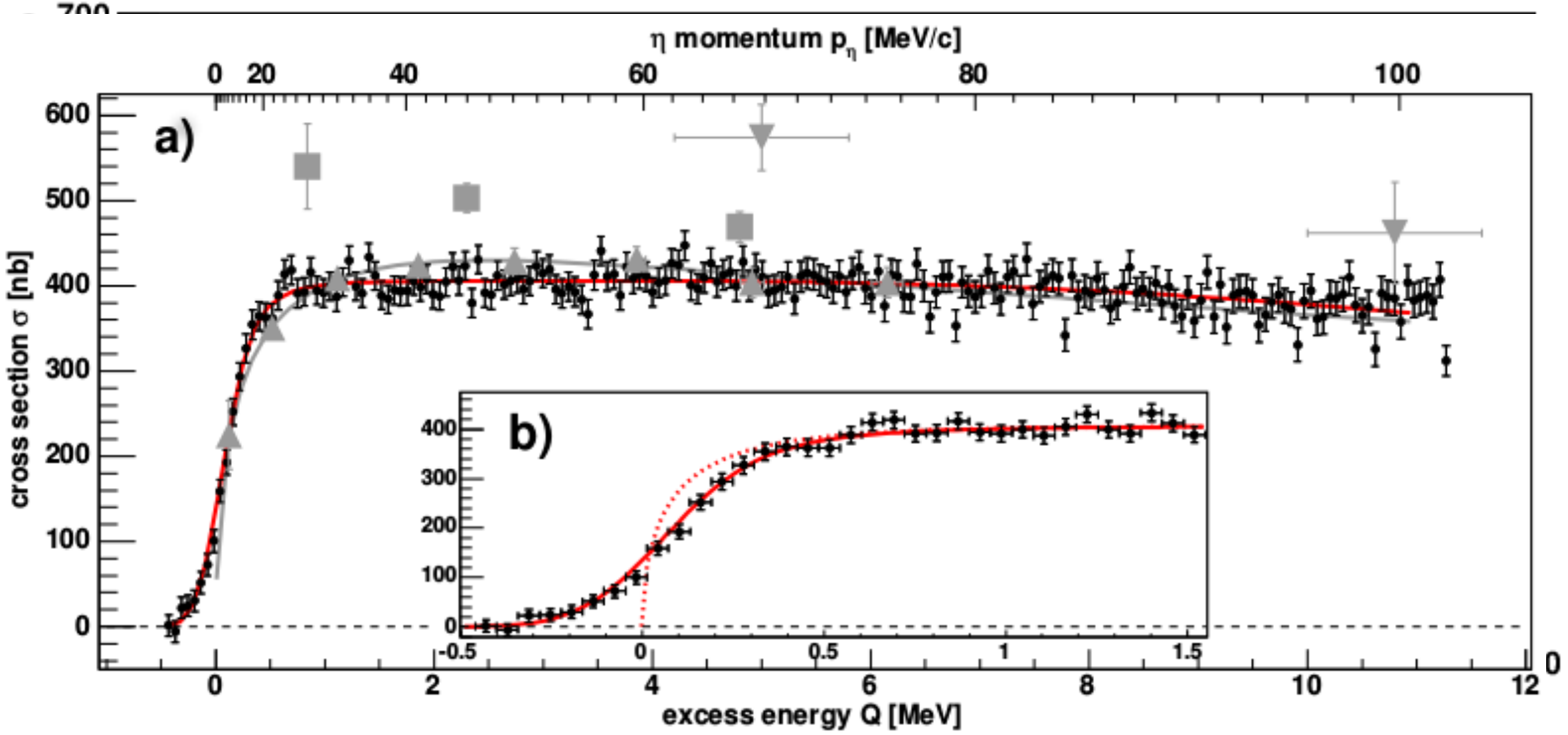
  ⇒ one multiwire drift chamber and two multiwire proportional chambers

- energy loss and time-of-flight measurements

  ⇒ two layers of scintillator hodoscopes

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

Motivation



- total and differential cross sections of the reaction $dp \rightarrow {}^3\mathrm{He}\eta$ are of special interest
- indication of a quasi bound state of the ${}^3\mathrm{He}\eta$-system

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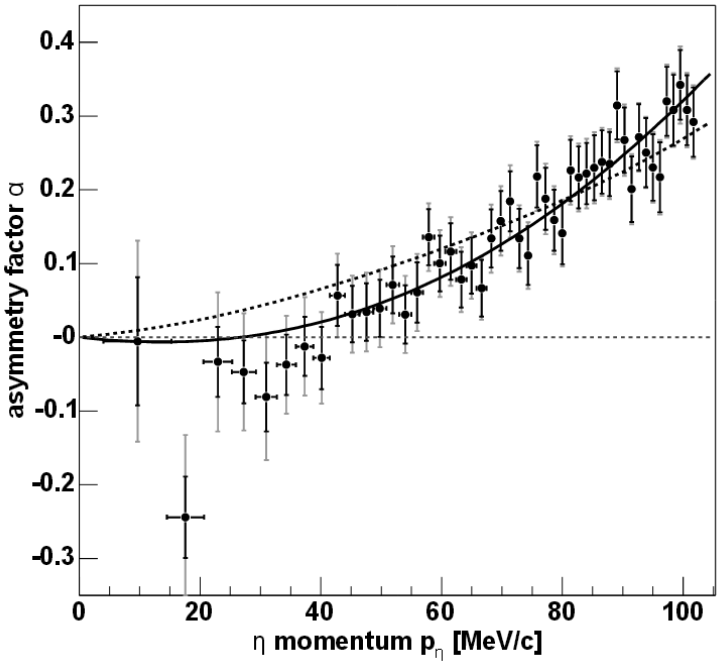

$$\alpha = \frac{\mathrm{d}}{\mathrm{d}(\cos\theta_\eta)} \ln\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)\Bigg|_{\cos\theta_\eta = 0}$$

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

C. Wilkin, Physical Letters B 654:92-96 (2007) DOI 10.1016/j.physletb.2007.08.041

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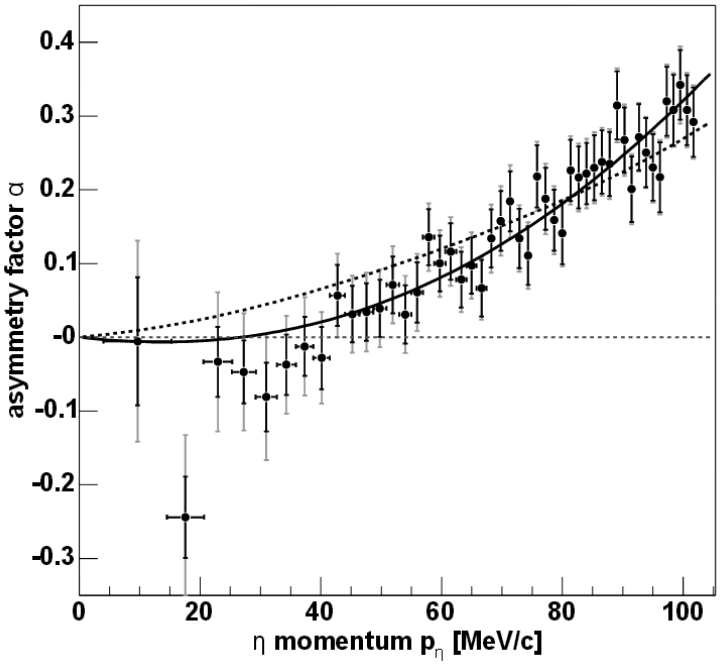

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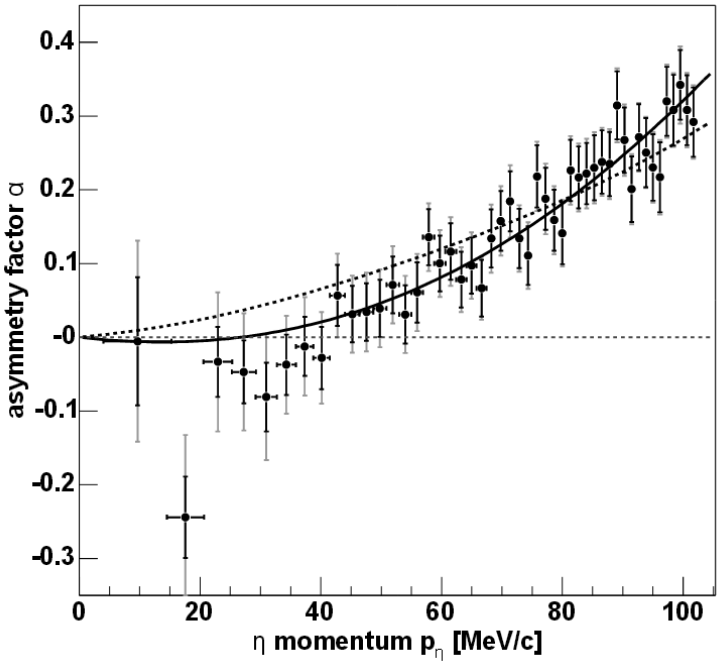
- new high precision data from the ANKE spectrometer at COSY up to $Q = 15$ MeV

Motivation



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

  ⇒ extraction of total and differential cross sections

  ⇒ careful luminosity determination is necessary

Measurements: experimental conditions

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- data used for: high precision determination of the η meson mass ($dp \rightarrow {}^3\mathrm{He}\eta$) and studies on the two pion production ($dp \rightarrow {}^3\mathrm{He}\pi^+\pi^-$)
- 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)

Measurements: experimental conditions

below η threshold ($dp \rightarrow {}^3\mathrm{He}\eta$) for a smooth model independent background description

flattop	1st supercycle p_d / (MeV/c)	2nd supercycle p_d / (MeV/c)	3rd supercycle p_d / (MeV/c)
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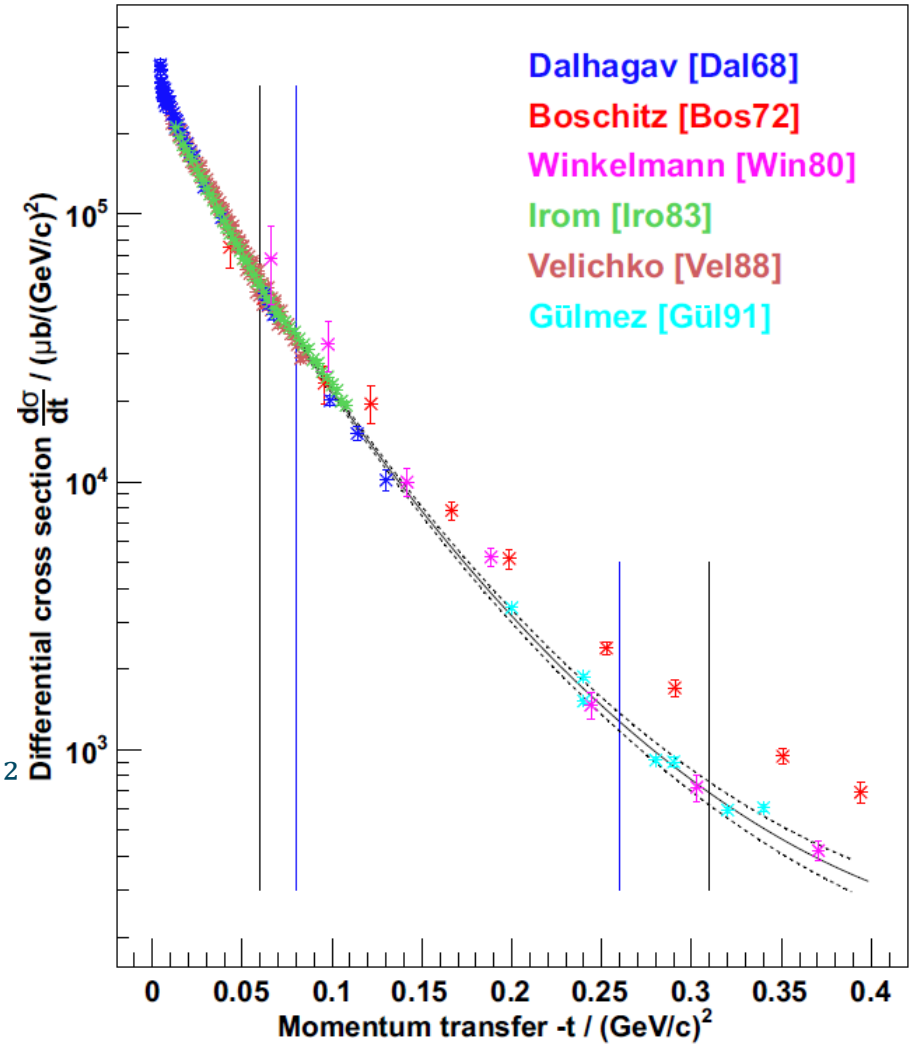
7	3177.51(17)	3184.87(17)	3204.16(23)

Luminosity via $dp \rightarrow dp$

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

  $-t = (0.08 - 0.26)$ (GeV/c)^2



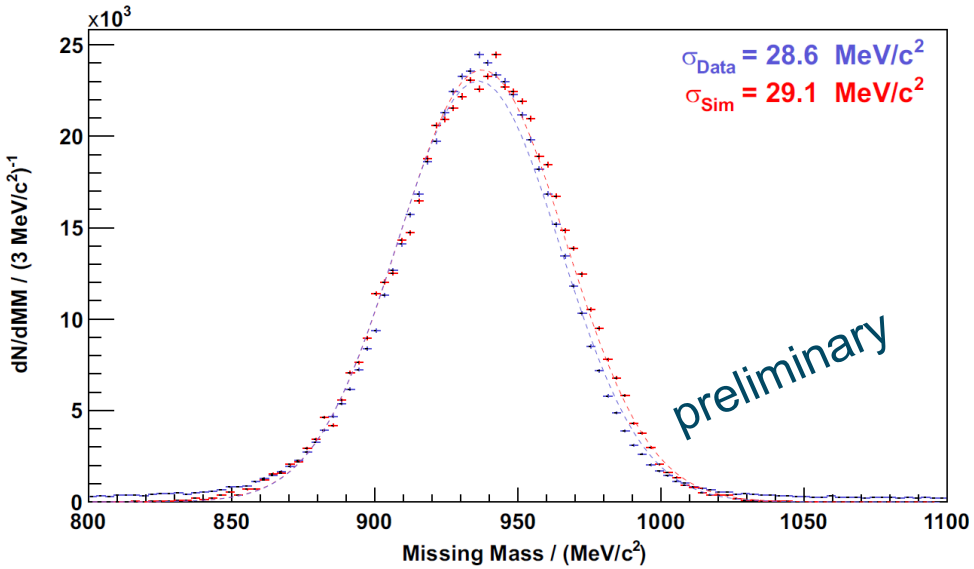
Results for $dp \rightarrow dp$

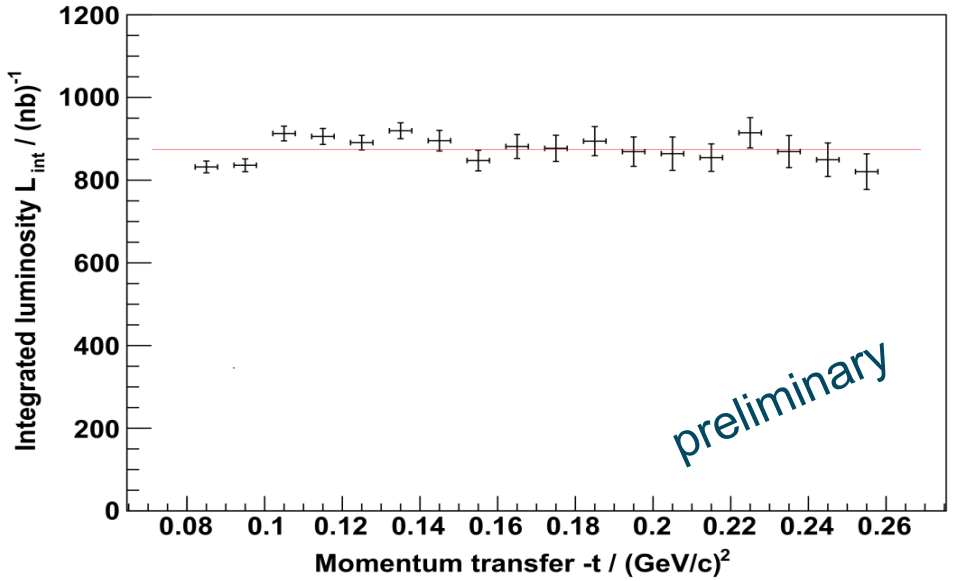
- identification of the reaction via the missing mass technique
- luminosity should be independent of momentum transfer
- determination performed for 18 momentum transfer bins ($\Delta t = 0.01$ (GeV/c)^2)

  $\Rightarrow$ for each of the 19 beam momenta
- luminosity precision achieved:

$$\Delta L_{\text{stat}} = 1\%$$
$$\Delta L_{\text{sys}} = 6\%$$

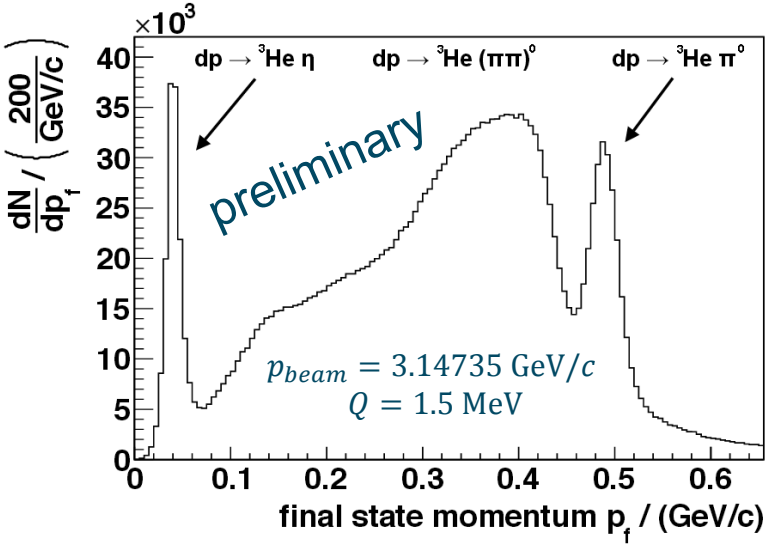
- improvement by at least a factor of two

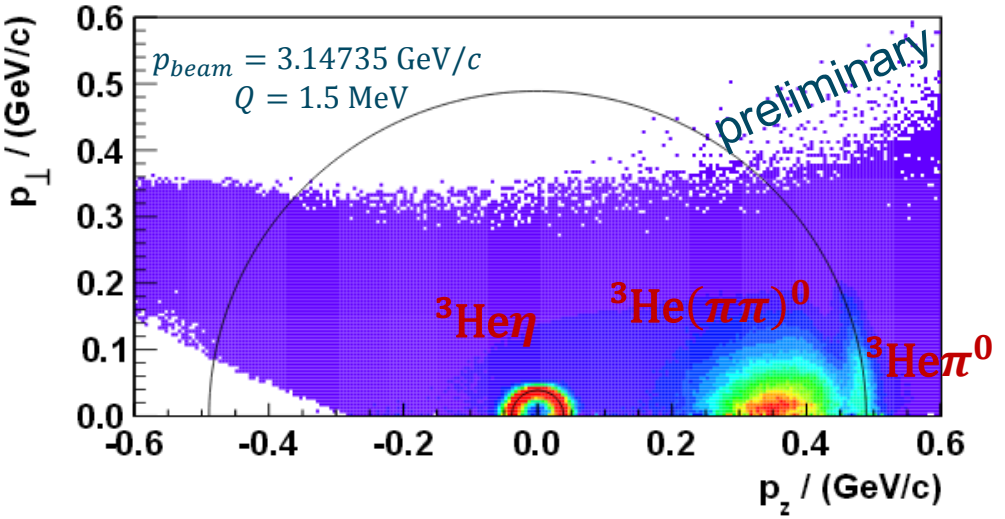


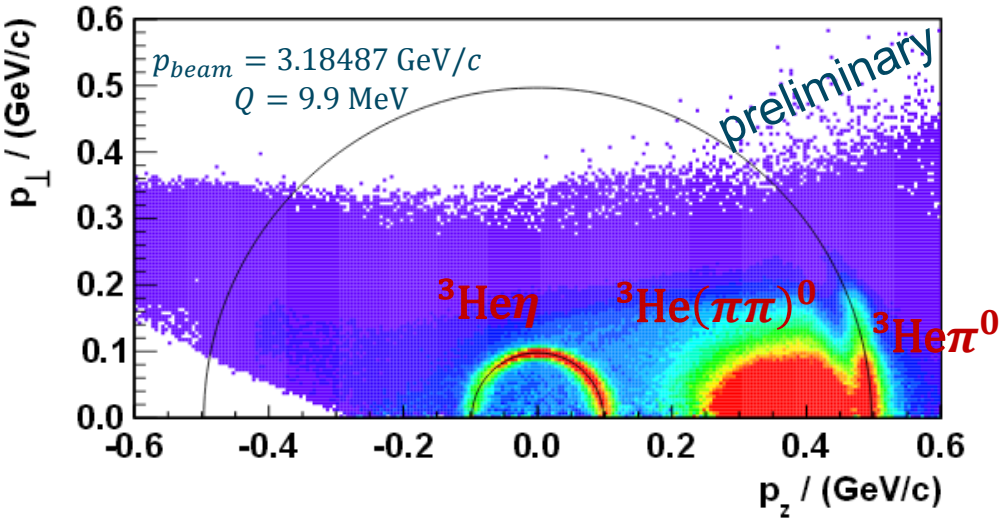


The reaction $dp \rightarrow {}^3\mathrm{He}\eta$

- 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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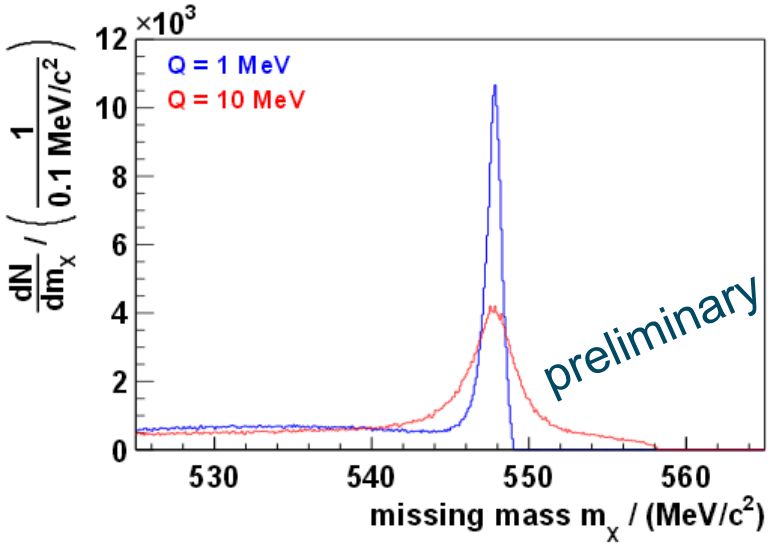
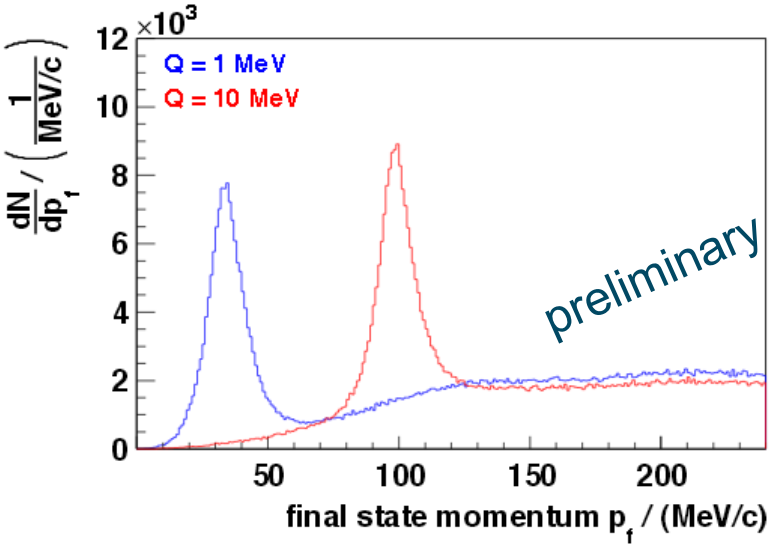
- ANKE has full geometrical acceptance for the reaction $dp \rightarrow {}^3\mathrm{He}\eta$
- clear separation from other reactions possible
- distinct η signal for each beam momentum
- high statistics of more than 10^5 ${}^3\mathrm{He}\eta$ events per energy





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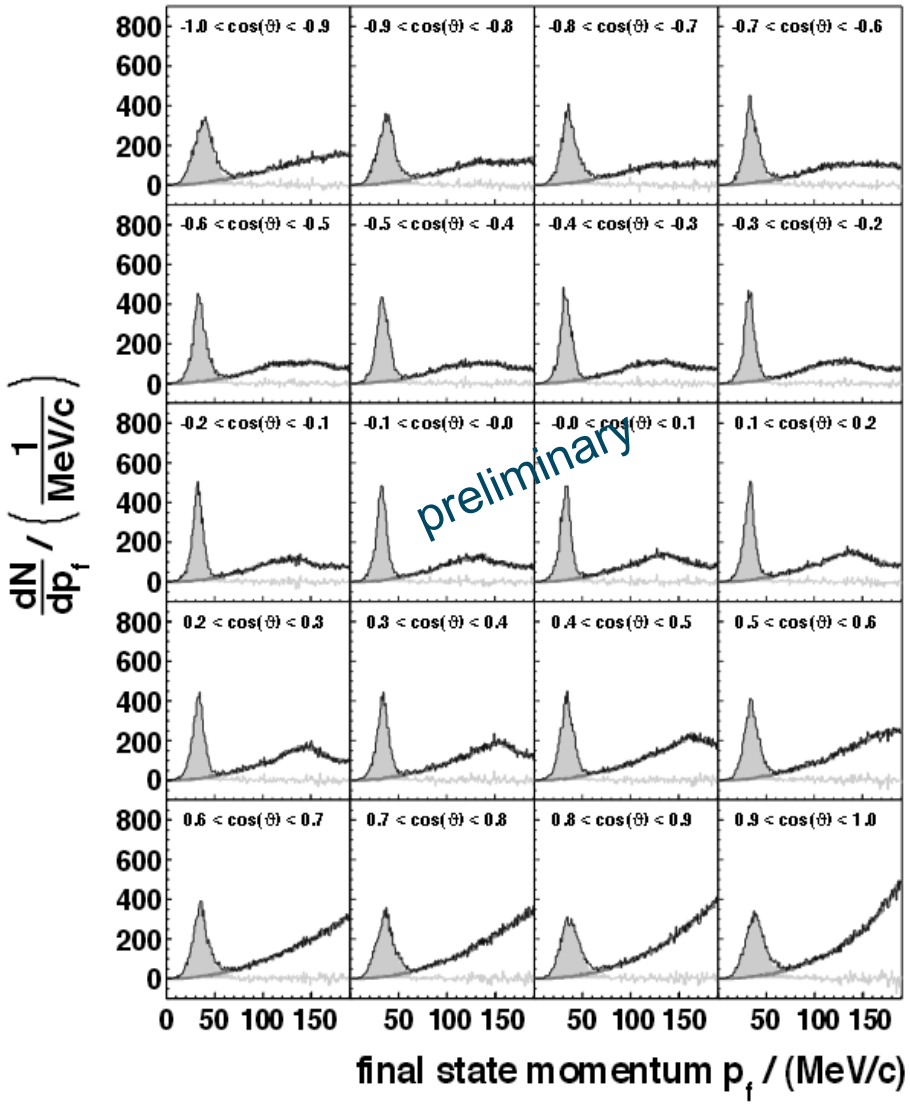
- solid lines indicate the expected kinematical loci for $dp \rightarrow {}^3\mathrm{He}\eta$ and $dp \rightarrow {}^3\mathrm{He}\pi^0$
- ANKE has full geometrical acceptance for the reaction $dp \rightarrow {}^3\mathrm{He}\eta$
- clear separation from other reactions possible
- distinct η signal for each beam momentum
- high statistics of more than 10^5 ${}^3\mathrm{He}\eta$ events per energy
- accurate investigation of the angular dependence possible
- background description using data taken below the η production threshold



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

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)

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

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

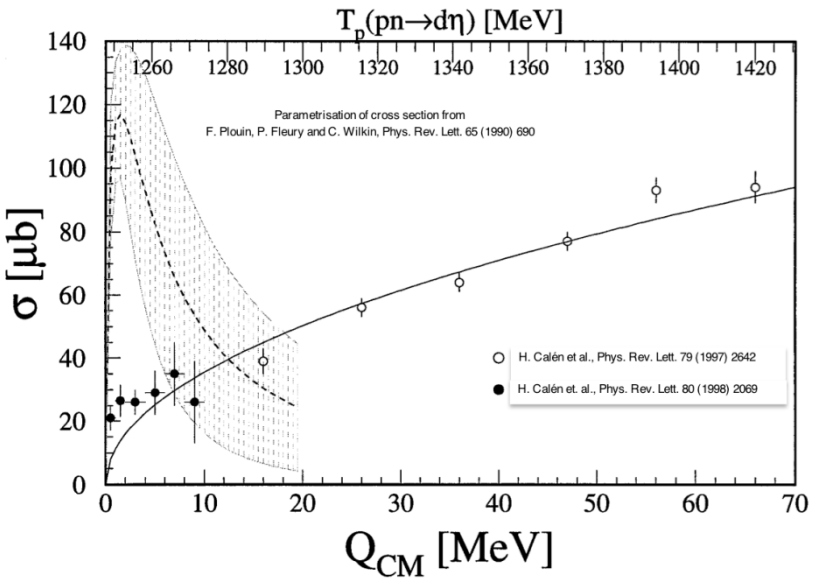
Motivation

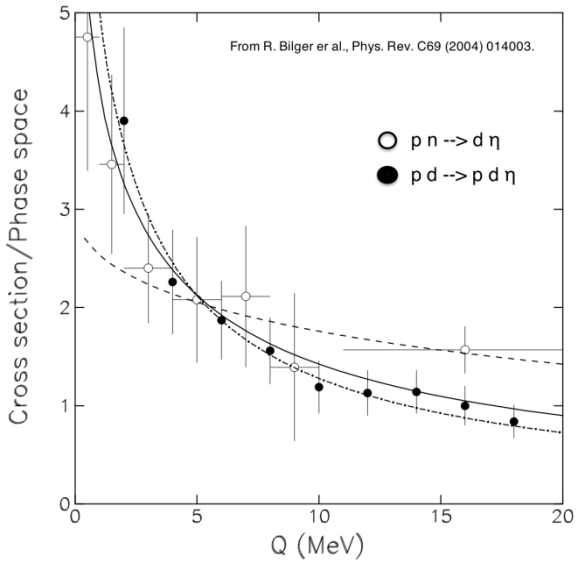
- current database on $pn \rightarrow d\eta$:
  - ✓PINOT: η production much stronger in pn than in pp collisions
  - ✓two measurements by PROMICE-WASA at CELSIUS

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

    H.Calén et al., Phys.Rev.Lett. 79 (1997) 2642

    H.Calén et al., Phys.Rev.Lett. 80 (1998) 2069





- 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

Measurements: experimental conditions

- main goals: extraction of scattering length a with data close to threshold and investigation of the influence of N*(1535) on the η production process at higher energies

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

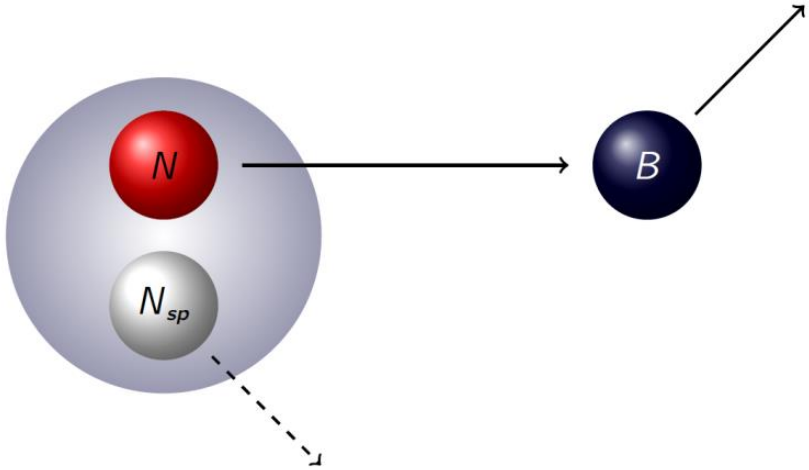
  $\Rightarrow$ quasi free reaction $p + n \rightarrow d + \eta$

- p_{spec} = fermi motion within nucleus

- supercycle mode: alternate between two different beam momenta

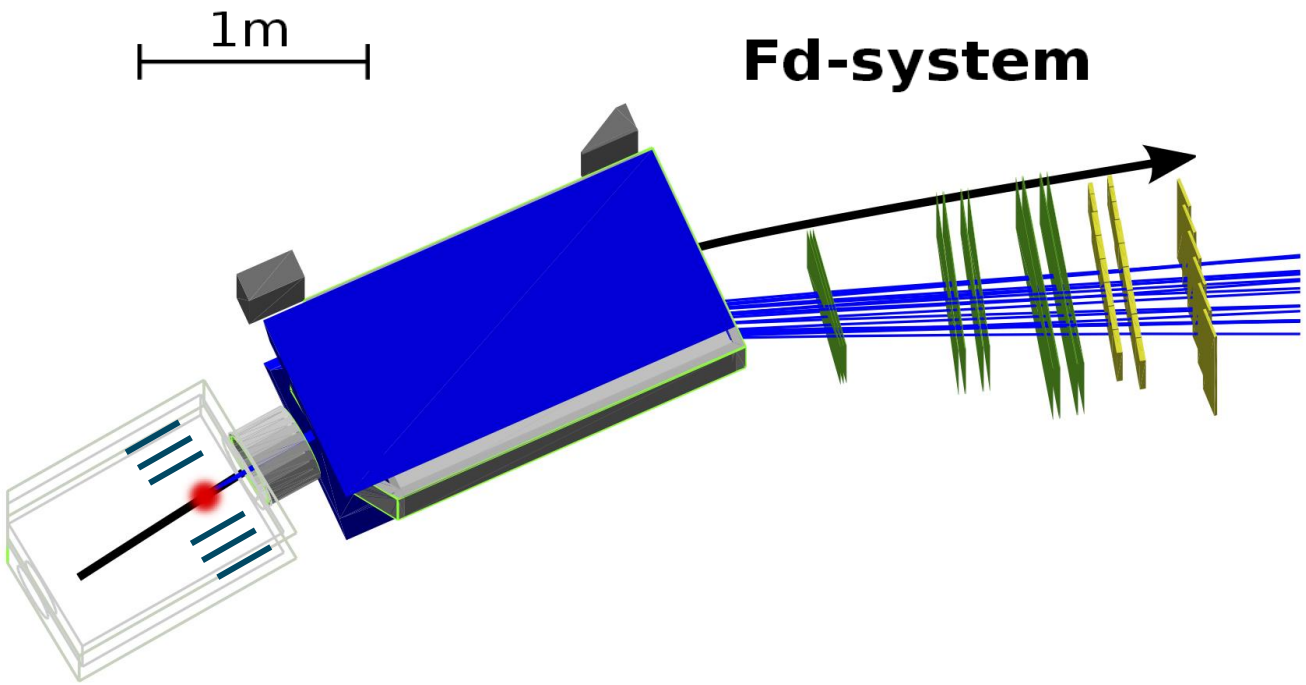
  $p_{\mathrm{beam}} = 2.09\ \mathrm{GeV}/c$

  $p_{\mathrm{beam}} = 2.25\ \mathrm{GeV}/c$



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

Fd-system with STT



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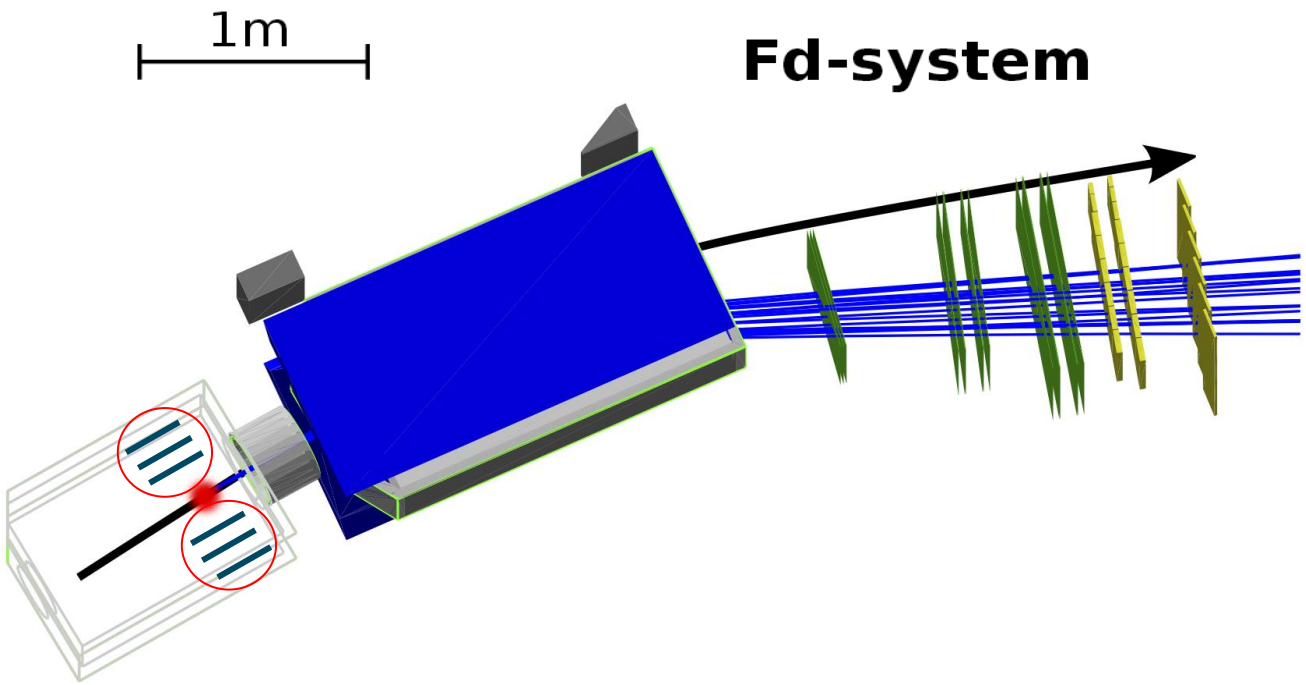

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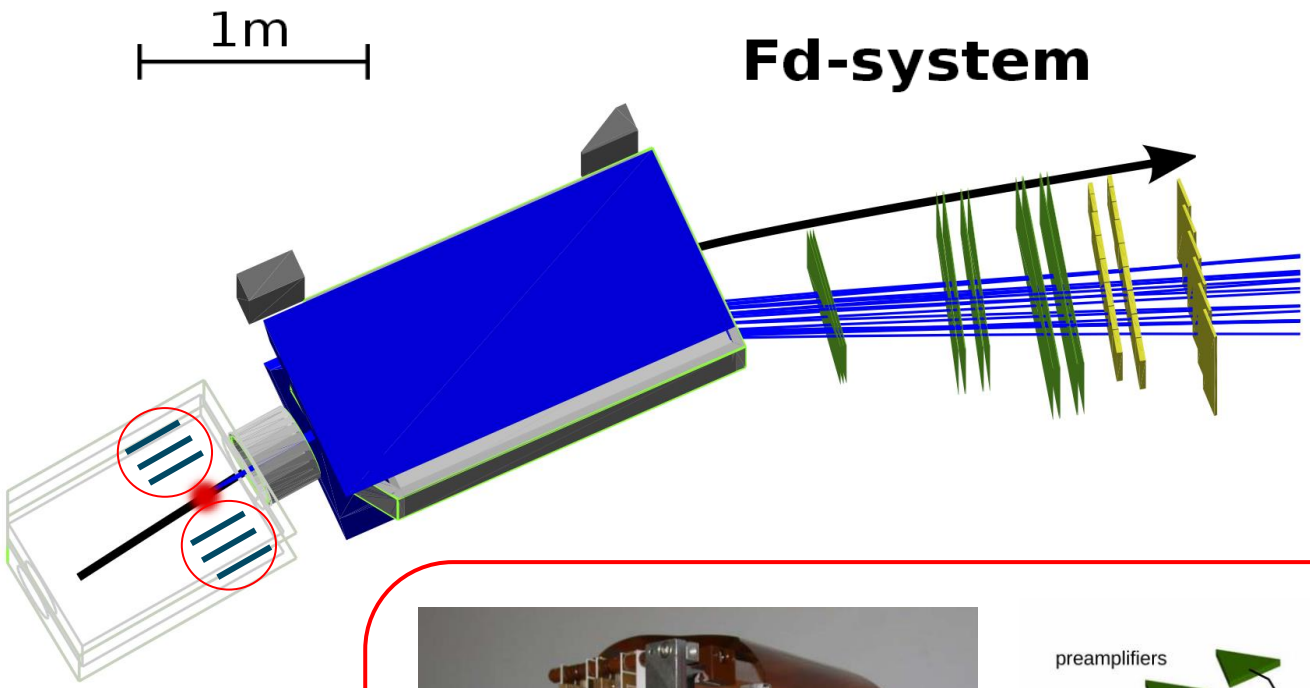
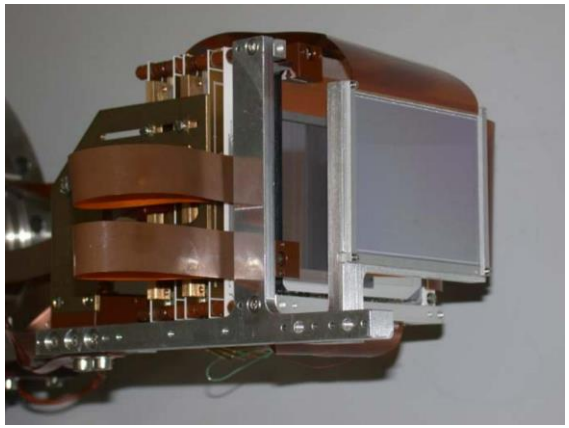
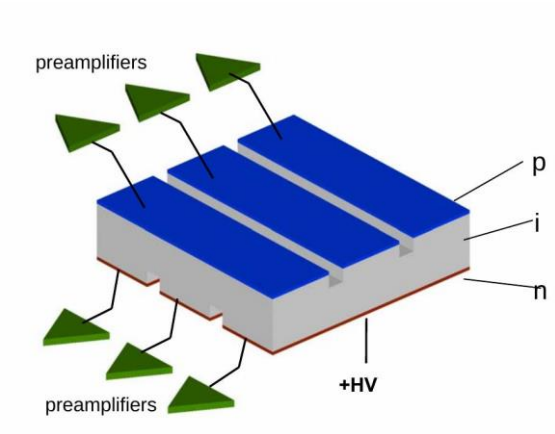


Silicon **T**racking **T**elescopes **(STT)**





Particle identification ($p_{spectator}$)

- determination of excess energy on an event-by-event basis

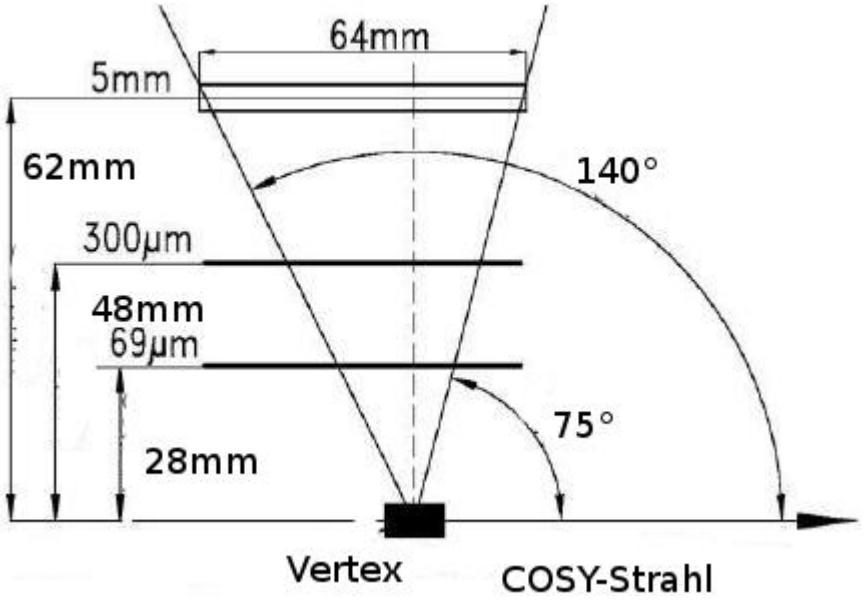
  ⇒ one beam momentum = wide excess energy range

- 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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  wide excess energy range

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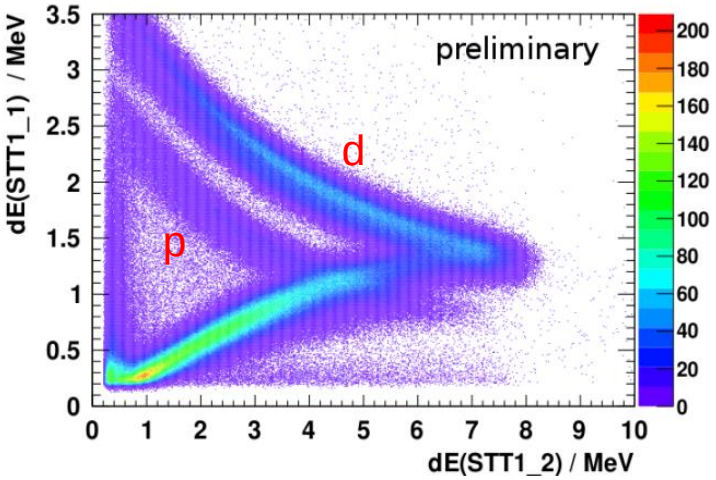
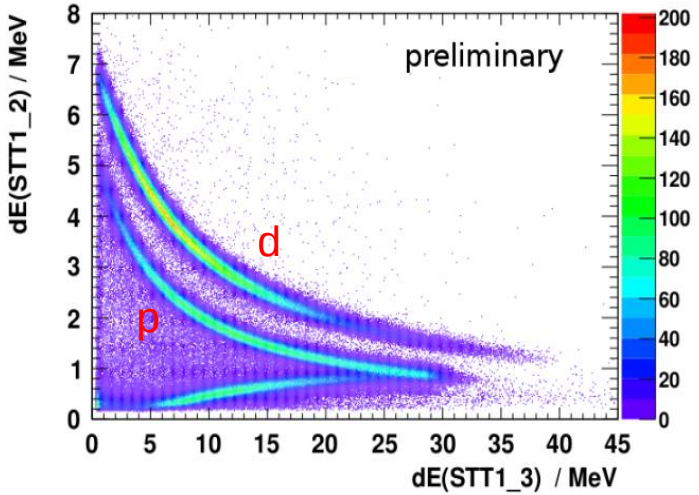
- use of two Silicon Tracking Telescopes (STT)
- consist of three layers of semiconductor

  ⇒ track reconstruction

  ⇒ energy loss measurements

- cover polar angles between 75° and 140°



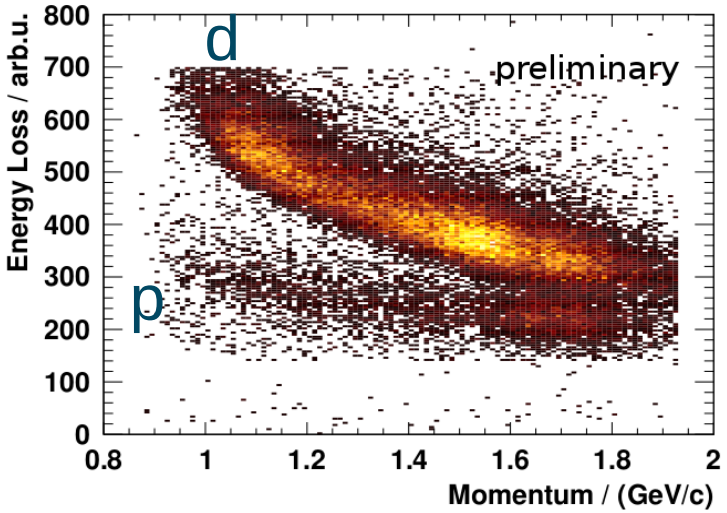


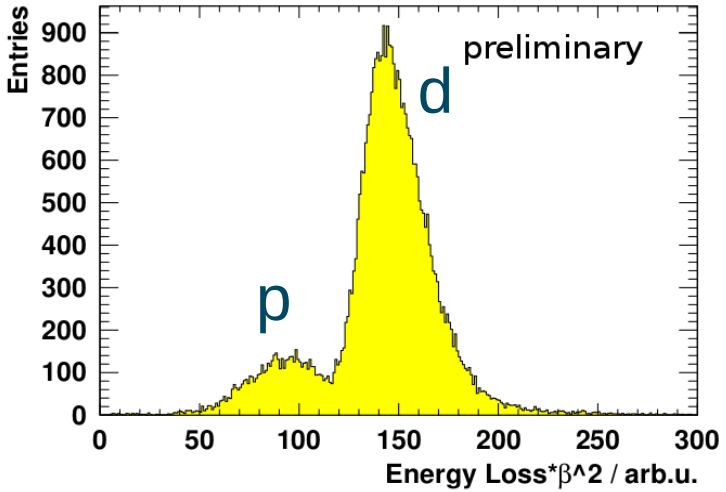
Particle identification (d)

- 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





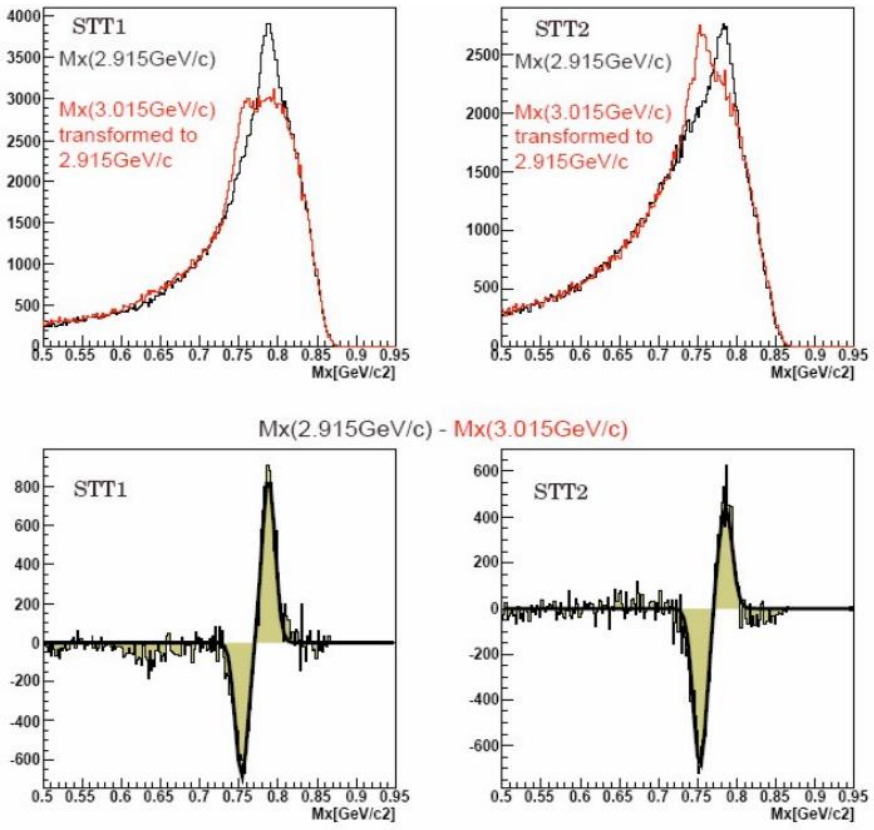
Background description

- 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

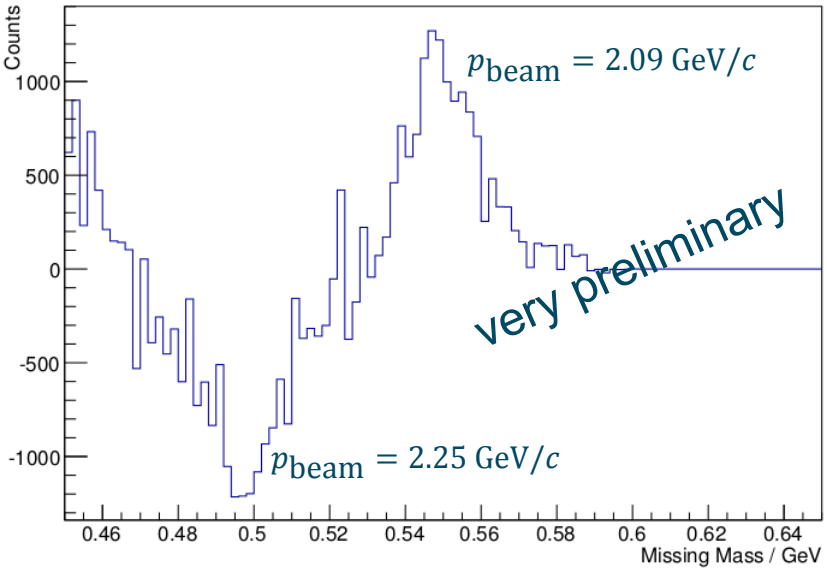
example for $p + d \rightarrow p_{spectator} + d + \omega$



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
- very preliminary results for a small data sample
- approximately 100k η –events

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



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

    $\Rightarrow$ improvement by at least a factor of two compared to previous calculations
  - 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 ³Heη events per energy
- in progress:
  - extraction of total and differential cross sections
  - determination of asymmetry parameter α

    $\Rightarrow$ shed new light on the near threshold region of η production

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

    $\Rightarrow$ STT calibration almost finalized
  - identification of deuterons with Fd-system in progress

    $\Rightarrow$ 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!

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work presented was done or supported by:

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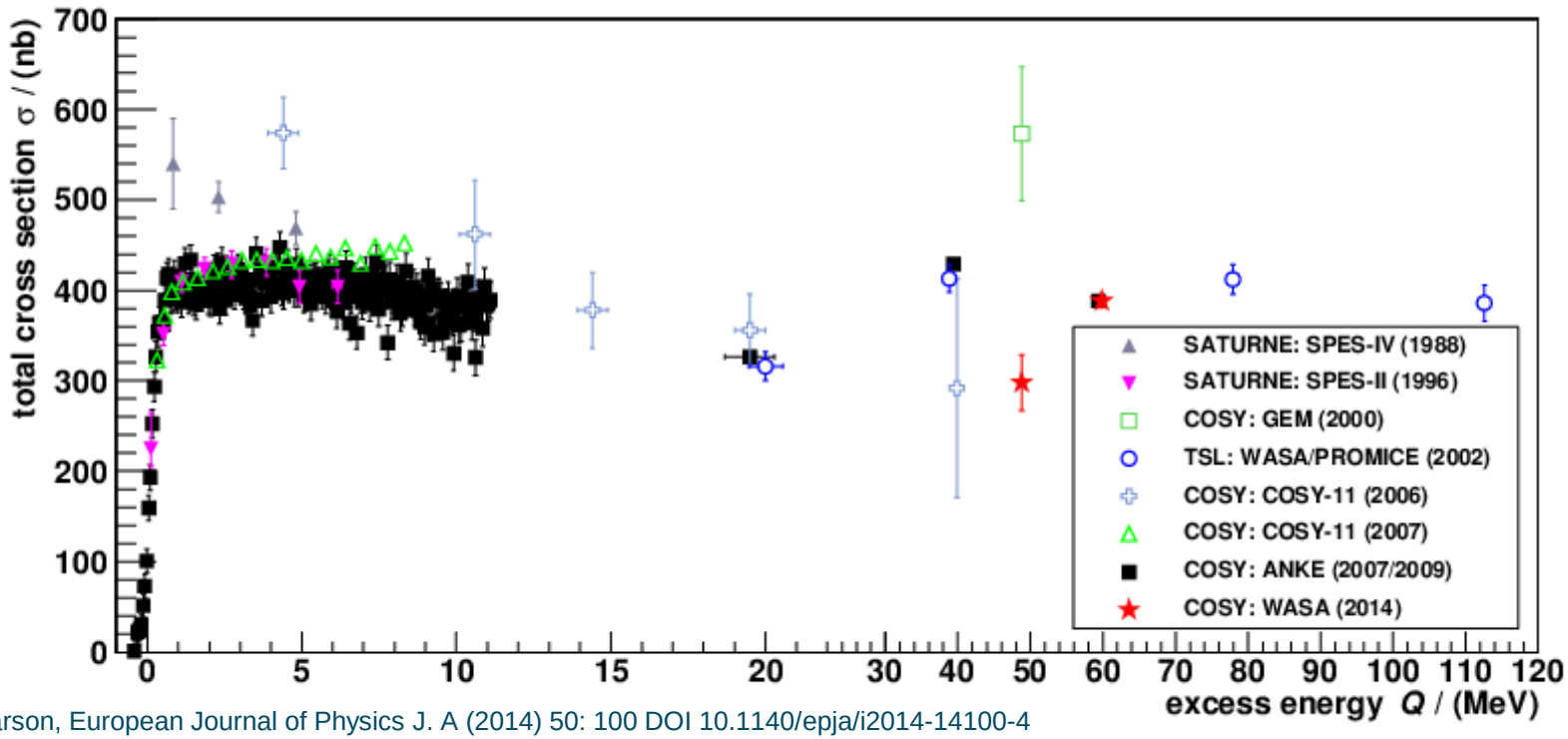
Alfons Khoukaz,
Marcel Rump,
Daniel Schröer,
and the ANKE collaboration

This work has been supported by the COSY-FFE program of the Forschungszentrum Jülich

Additional slide



P. Adlarson, European Journal of Physics J. A (2014) 50: 100 DOI 10.1140/epja/i2014-14100-4

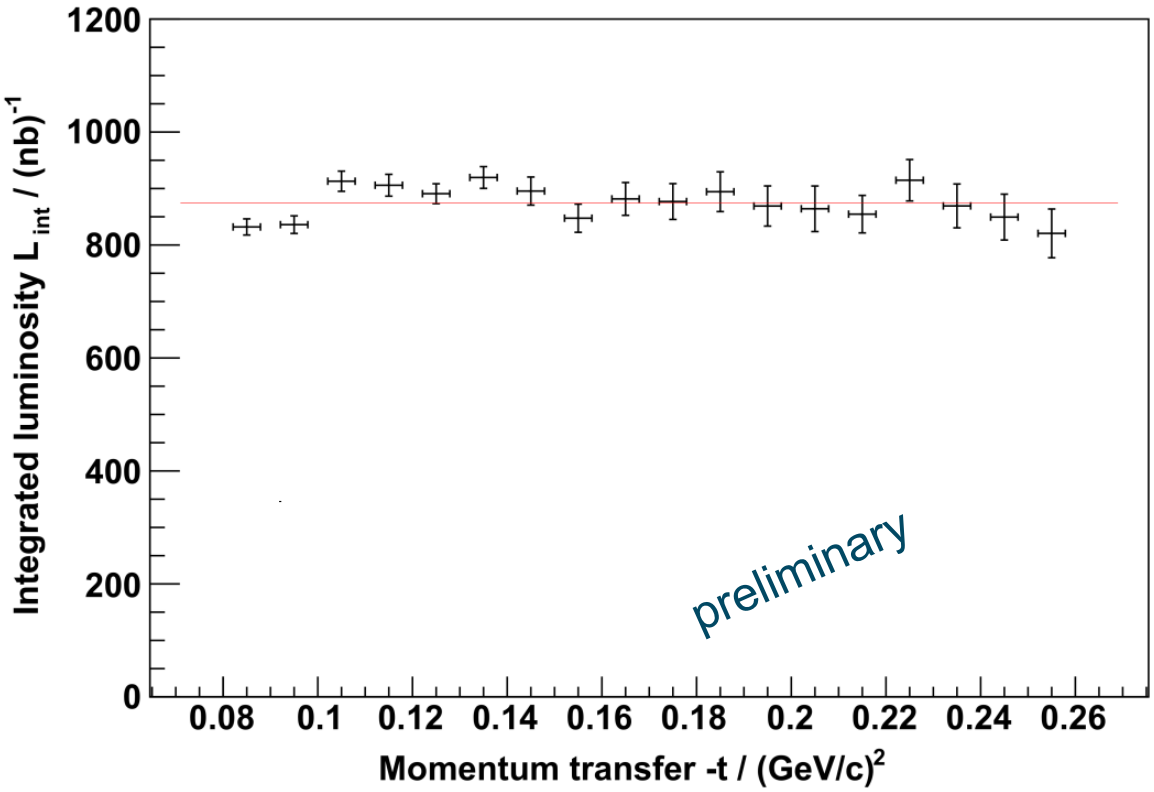
- total and differential cross sections of the reaction $dp \rightarrow {}^3\mathrm{He}\eta$ are of special interest
- indication of a quasi bound state of the ${}^3\mathrm{He}\eta$-system

Additional slide

- luminosity should be independent of momentum transfer
- 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:

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

- improvement by at least a factor of two
- relative normalization via the reactions $dp \rightarrow p_{\mathrm{spec}}X$ by determination of the number of spectator protons in the Fd-system



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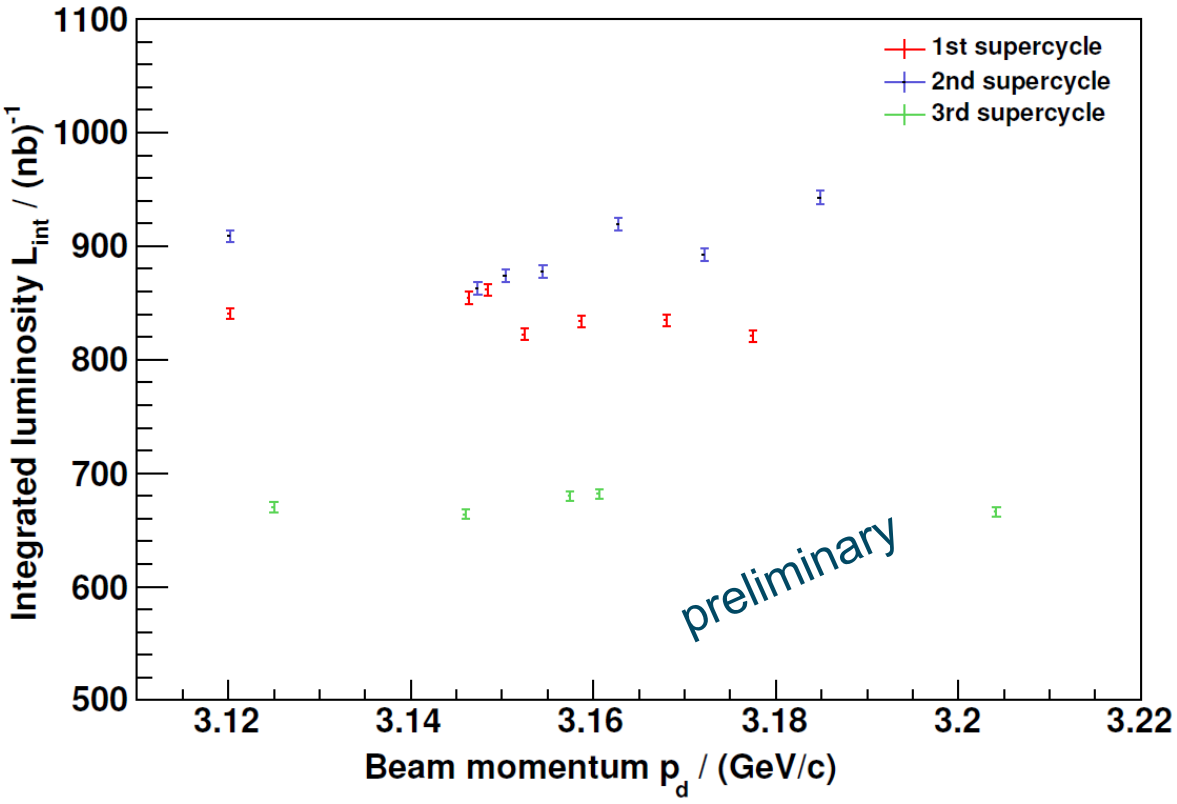

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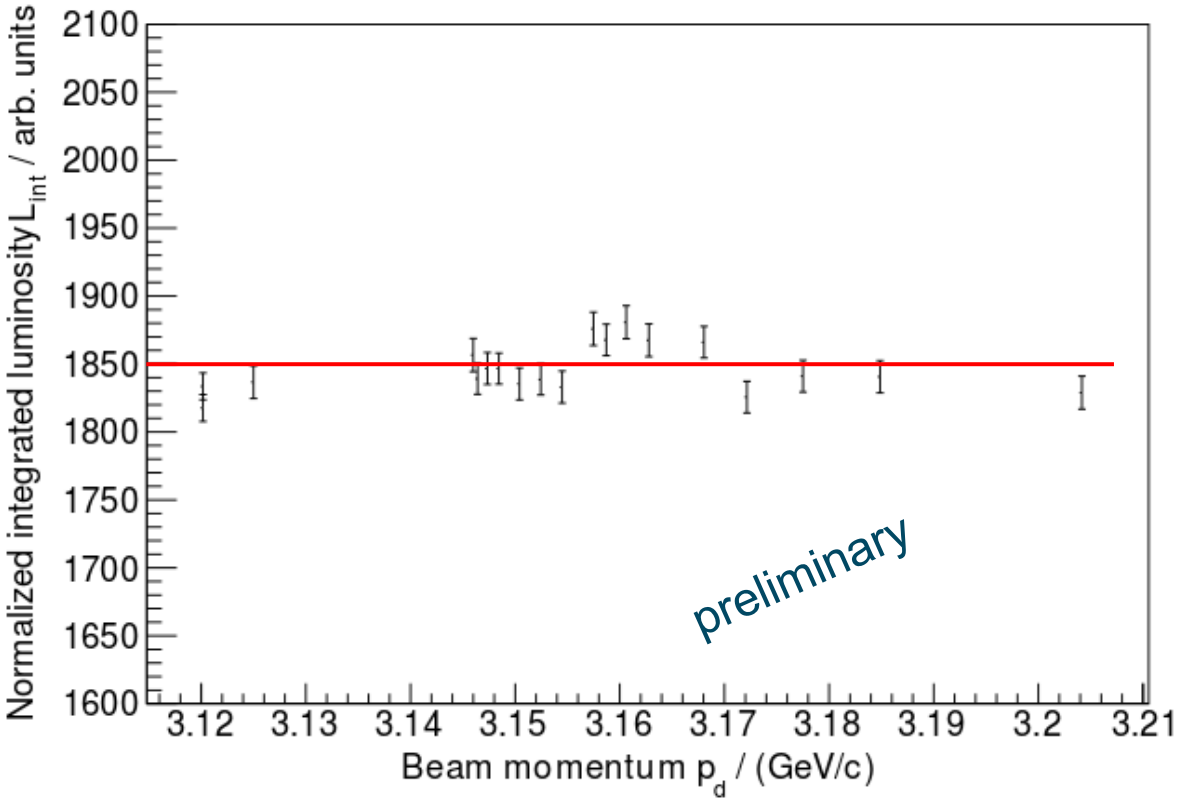

Additional slide

trigger reduction

efficiency correction

$$L_{int} = \frac{1024 \cdot N_{det}(\Delta t)}{\int_{t_1}^{t_2} \left(\frac{d\sigma}{dt}(t)\right)_{Ref} dt} \cdot \kappa^{-1} \cdot \epsilon^{-1} \cdot \tau^{-1}$$

acceptance correction

dead time correction