Westfälische Wilhelms-Universität Münster

Meson production in pd fusion to ^{3}HeX with WASA-at-COSY

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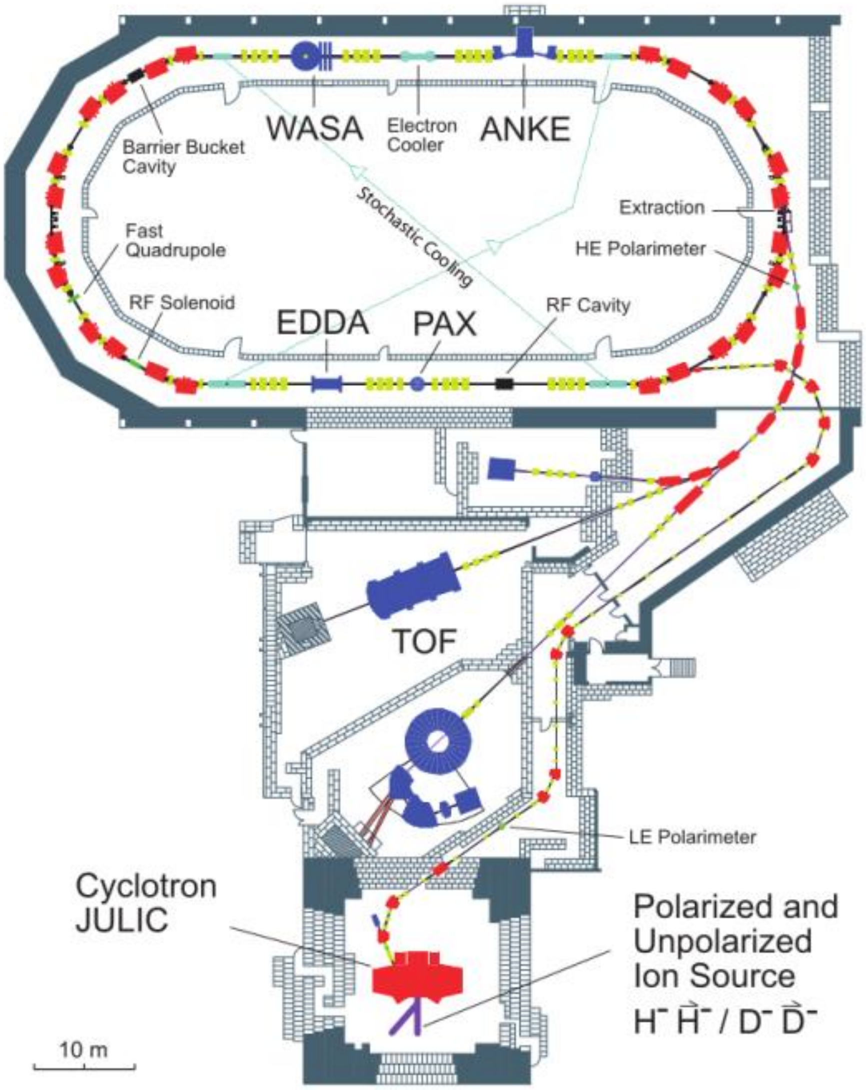
living.knowledge WWU Münster

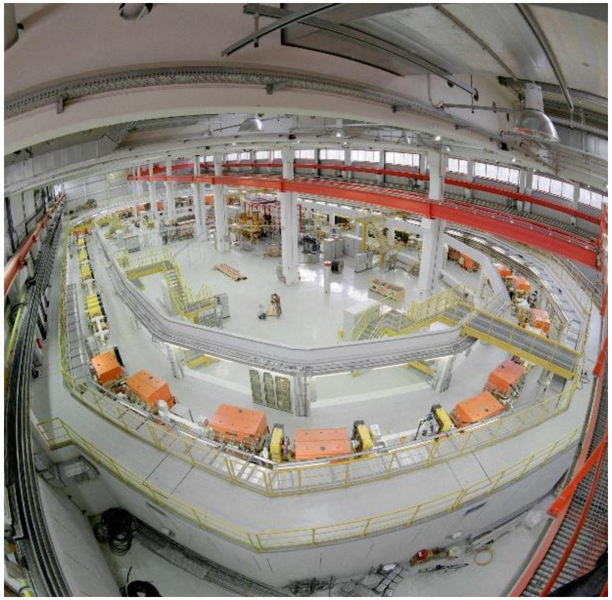
Outline

- the WASA-at-COSY experiment
- η production
- single-pion production
- double-pionic fusion & the ABC effect
- normalization
- summary & outlook

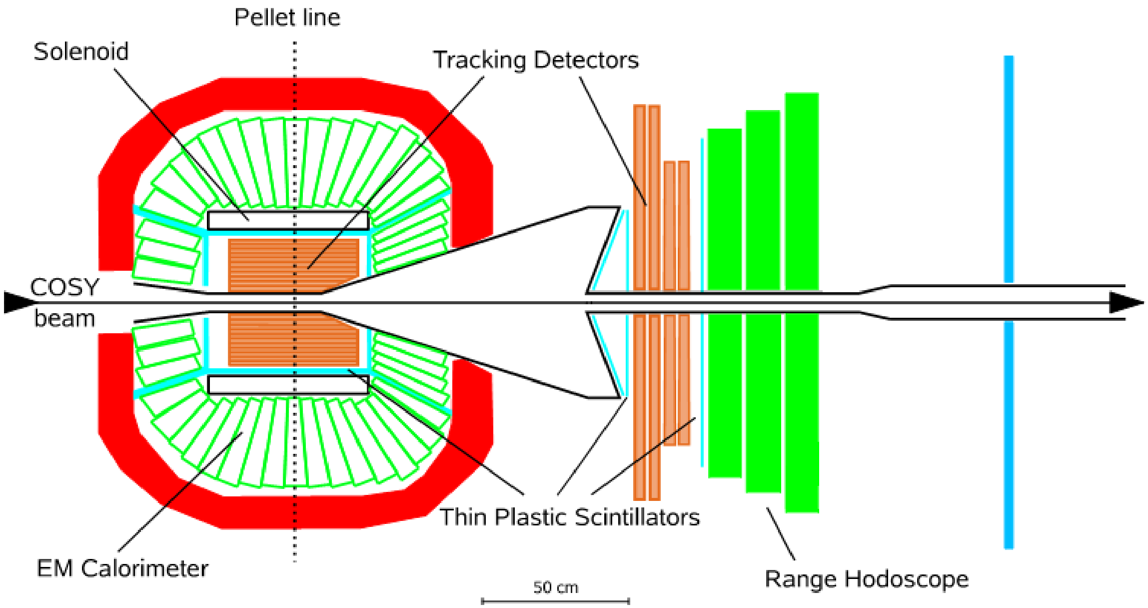
WASA-at-COSY

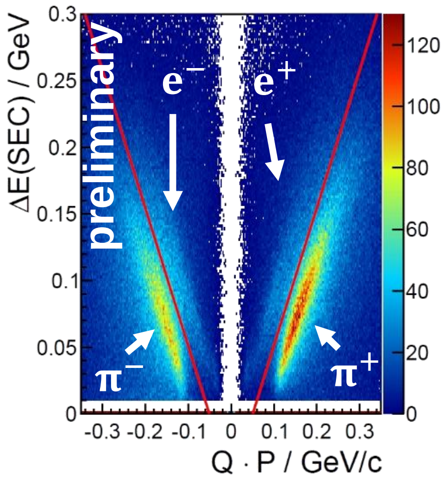


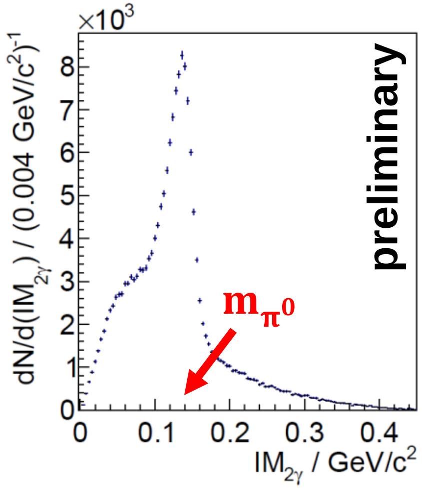
- polarized and unpolarized proton and deuteron beams
- momentum range from 0.3 GeV/c to 3.7 GeV/c
- **WASA**: internal experiment, proton or deuteron pellet target

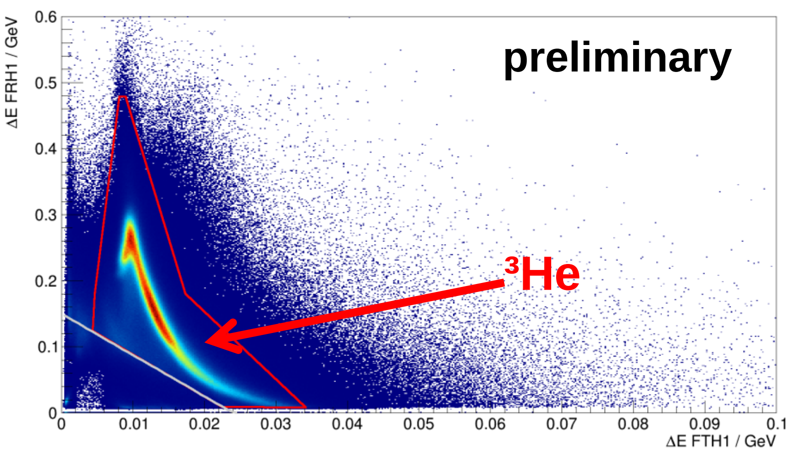


- Central detector:
  - solenoid & drift chamber
  - plastic scintillator
  - calorimeter
- Forward detector:
  - proportional chamber
  - scintillators
- near 4π-coverage
- detection & reconstruction of $\pi^{\pm}, e^{\pm}, \gamma, p, d$ and ³He







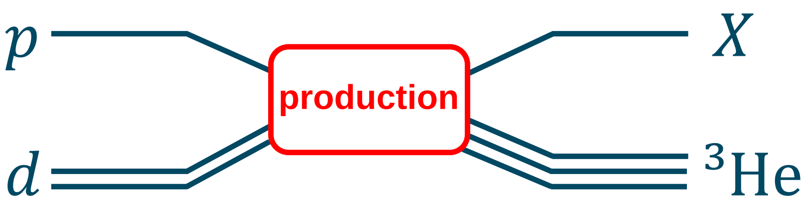


Meson production in pd fusion

Production of (pseudoscalar) mesons in pd collisions:

- many open questions:
  - production mechanism
  - role of nucleon resonances
  - in-medium modifications
  - final state interactions
  - multi-body interactions

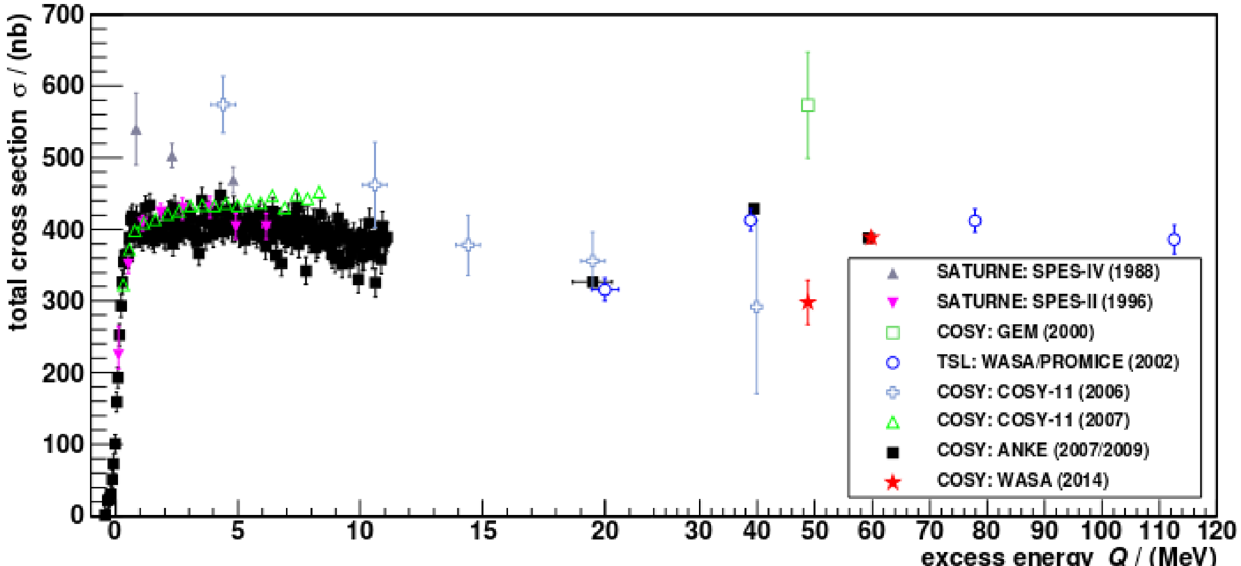
$$pd \rightarrow {}^3\mathrm{He}X$$



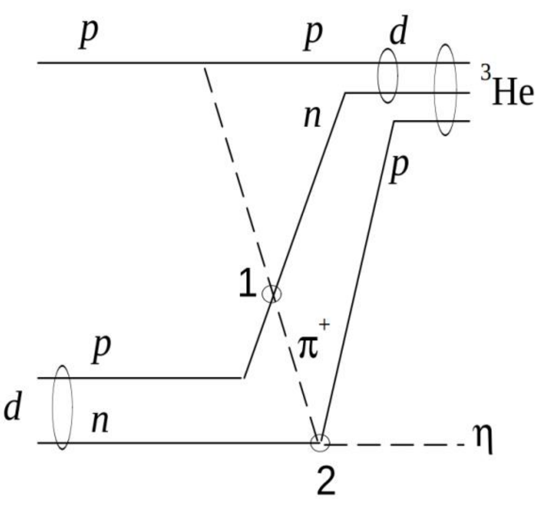
- possible final states X:
  - single meson: ${}^3\mathrm{He}\pi^0$, ${}^3\mathrm{He}\eta$, (${}^3\mathrm{He}\omega$, ${}^3\mathrm{He}\eta'$)
  - two mesons: ${}^3\mathrm{He}\pi^0\pi^0$, ${}^3\mathrm{He}\pi^+\pi^-$
  - three mesons: ${}^3\mathrm{He}\pi^0\pi^0\pi^0$, ${}^3\mathrm{He}\pi^+\pi^-\pi^0$

η production

- Haider & Liu (1986): ηN interaction attractive in s-wave
  - inspired search for η-mesic nuclei
- large database near threshold
  - steep rise for $Q < 1.5$ MeV
  - attributed to quasi-bound ^{3}Heη
- large theory effort
  - two-step (three-body) process nicely describes data
  - FSI plays a strong role



P. Adlarson et al., Eur. Phys. J. A 50, 100 (2014)



K.P. Khemchandani et. al., Phys. Rev. C 76, 069801 (2007)

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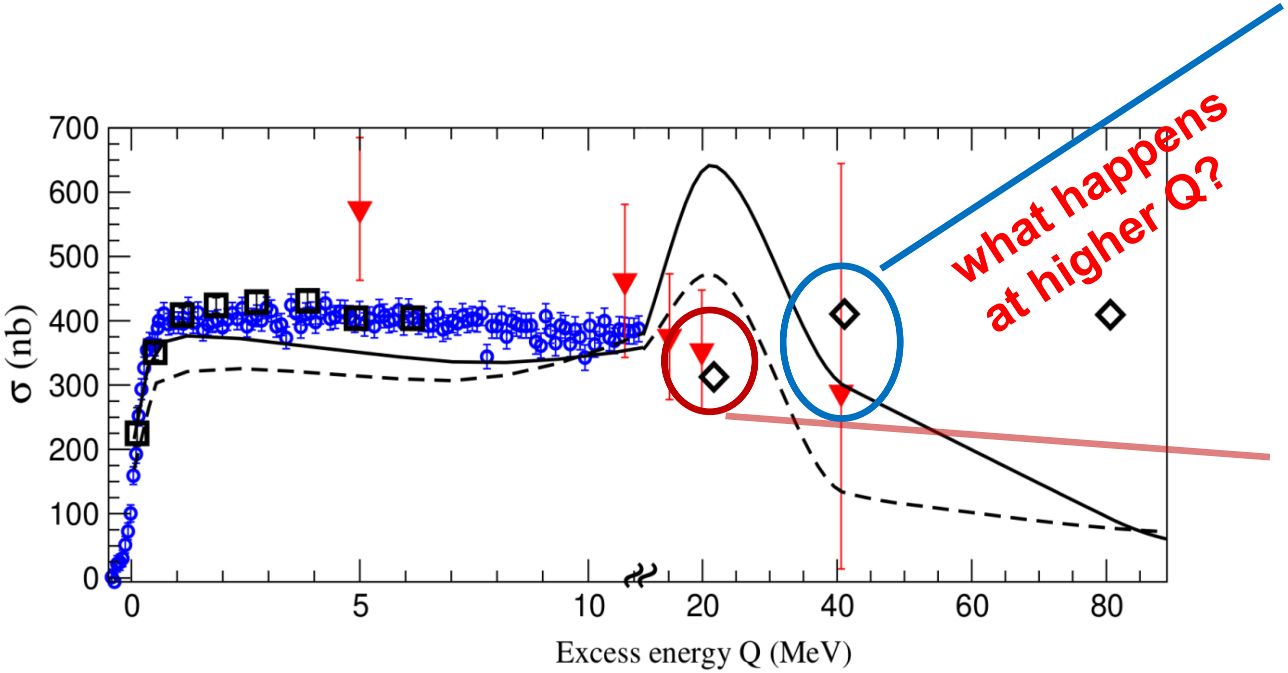

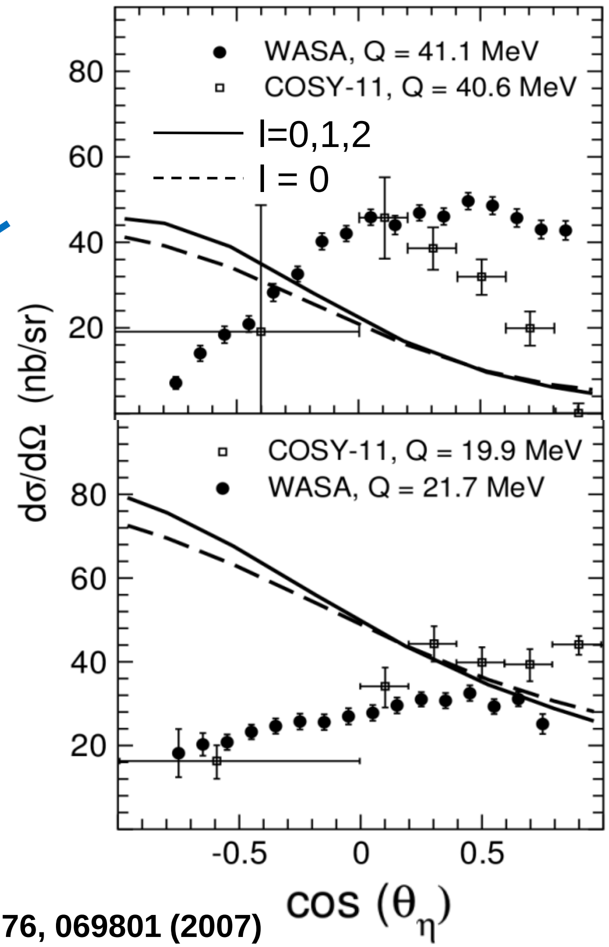

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η production

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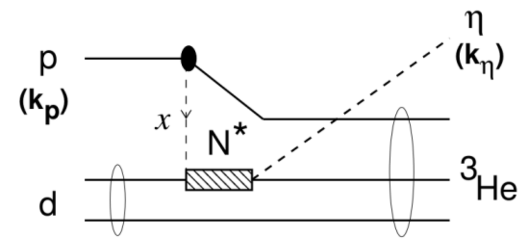
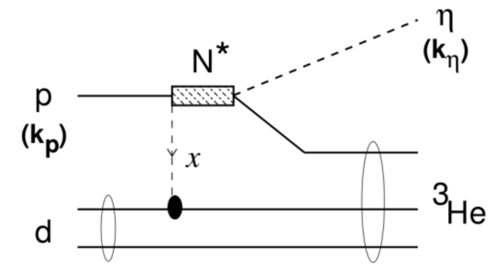
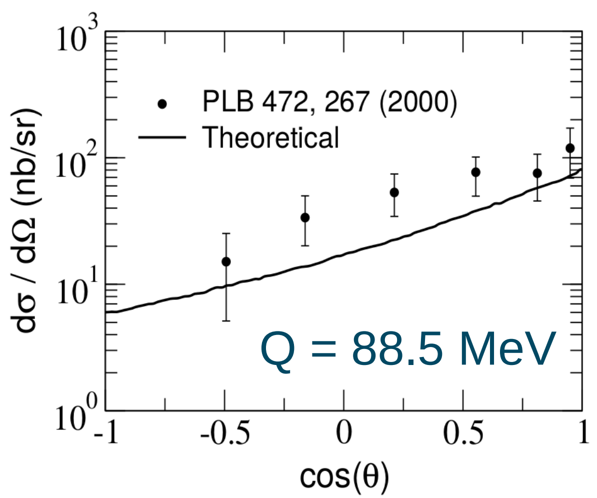
- away from threshold:
  - higher partial waves important
  - no generally accepted model yet
- in pp collisions, $S_{11}(1535)$ dominates the production
- meson exchange model reproduces the anisotropy
- open questions remain:
  - role of other nucleon resonances
  - $S_{11}(1535)$ in nuclear matter
  - change of production mechanism





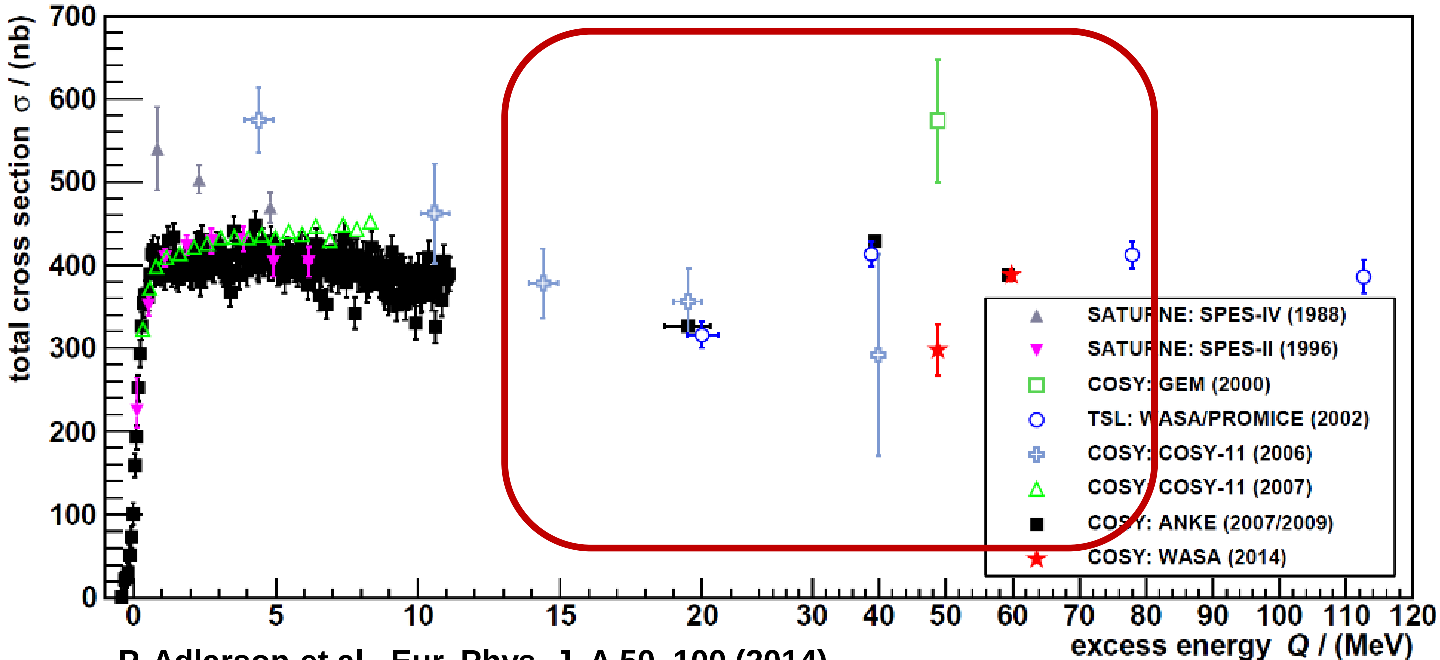


"useful to obtain more data on this reaction at high energies in the future"

N.G. Kelkar, Rep. Prog. Phys. 76 (2013) 066301

A.B. Santra et. al., Phys. Rev. C. 64, 025201 (2001)

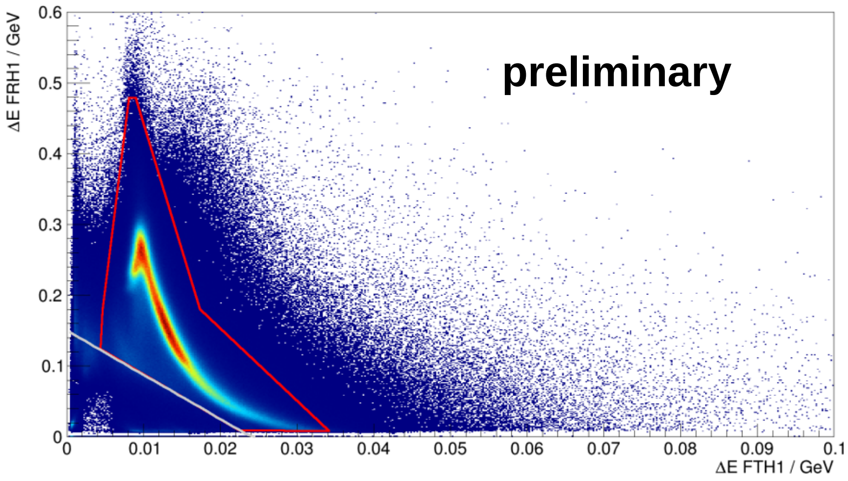
η production



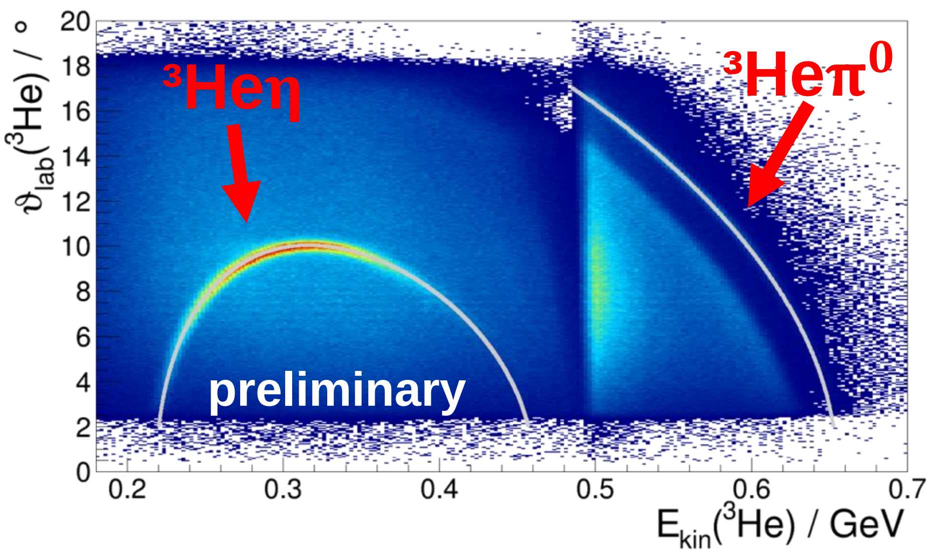
P. Adlarson et al., Eur. Phys. J. A 50, 100 (2014)

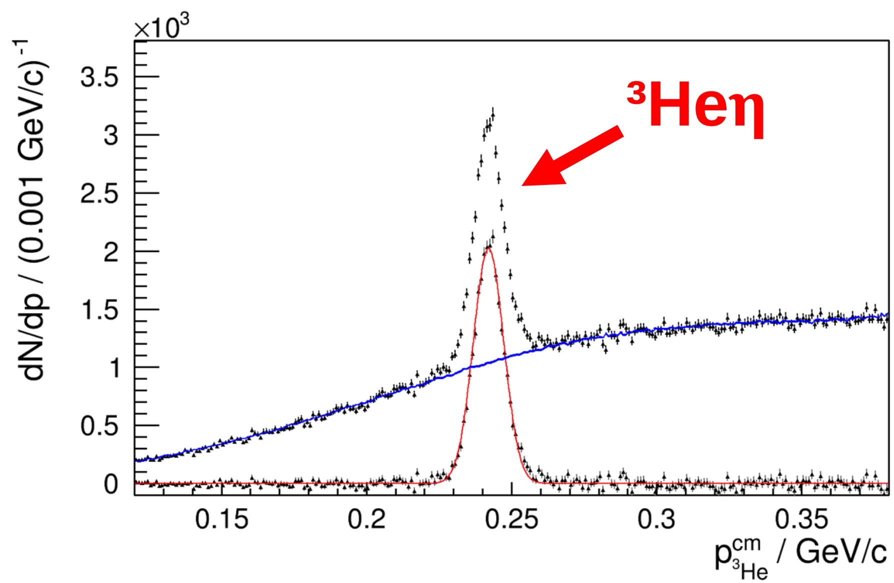
SC 0: p / GeV/c	1.60	1.62	1.64	1.66	1.68	1.70	1.72	1.74
SC 1: p / GeV/c	1.61	1.63	1.65	1.67	1.69	1.70	1.71	1.73

η production



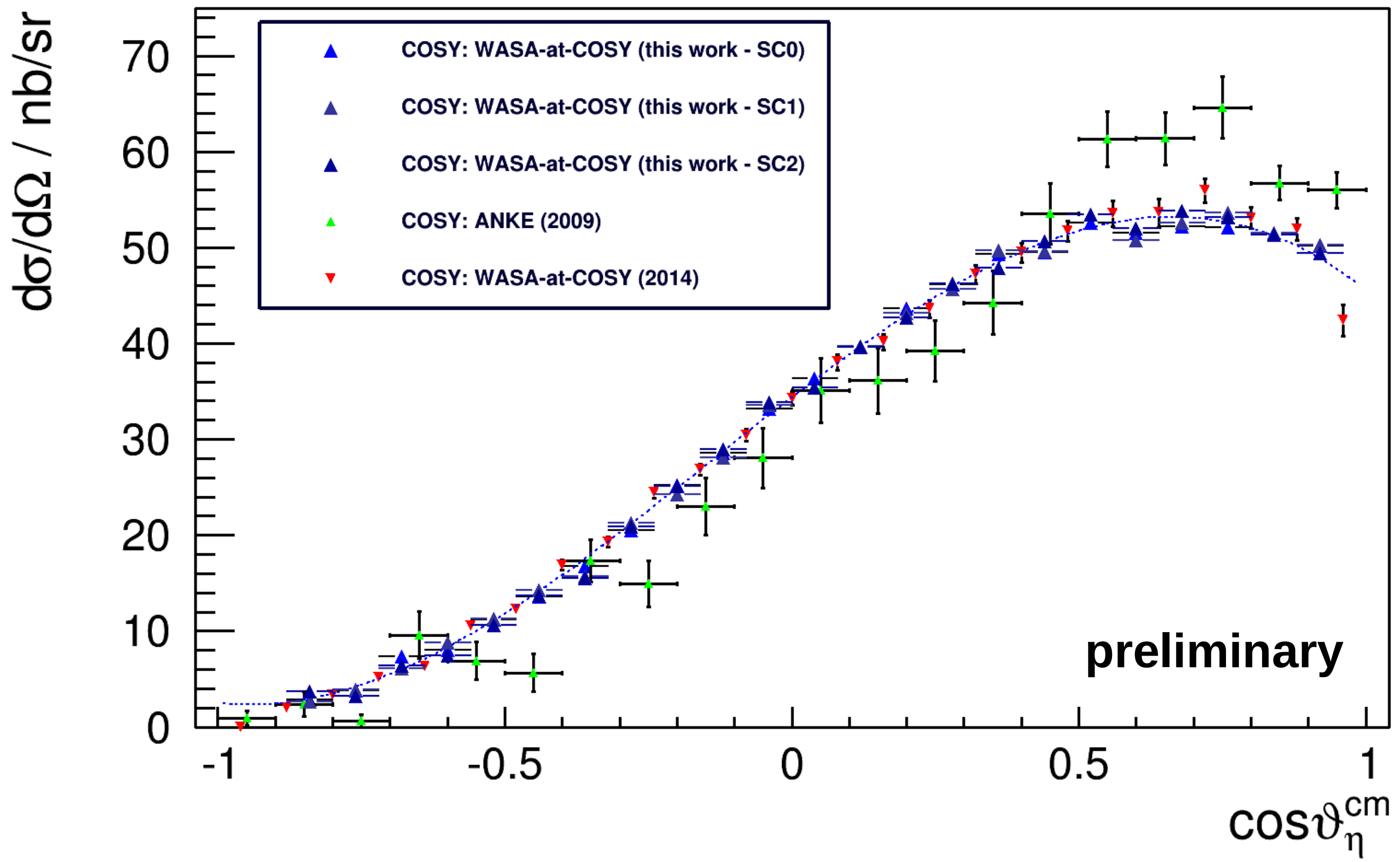
- ^{3}He nuclei identified by energy loss
- calibration can be checked by two-particle kinematical relations
- $^{3}He\eta$ is then identified & quantified with the ^{3}He final state momentum





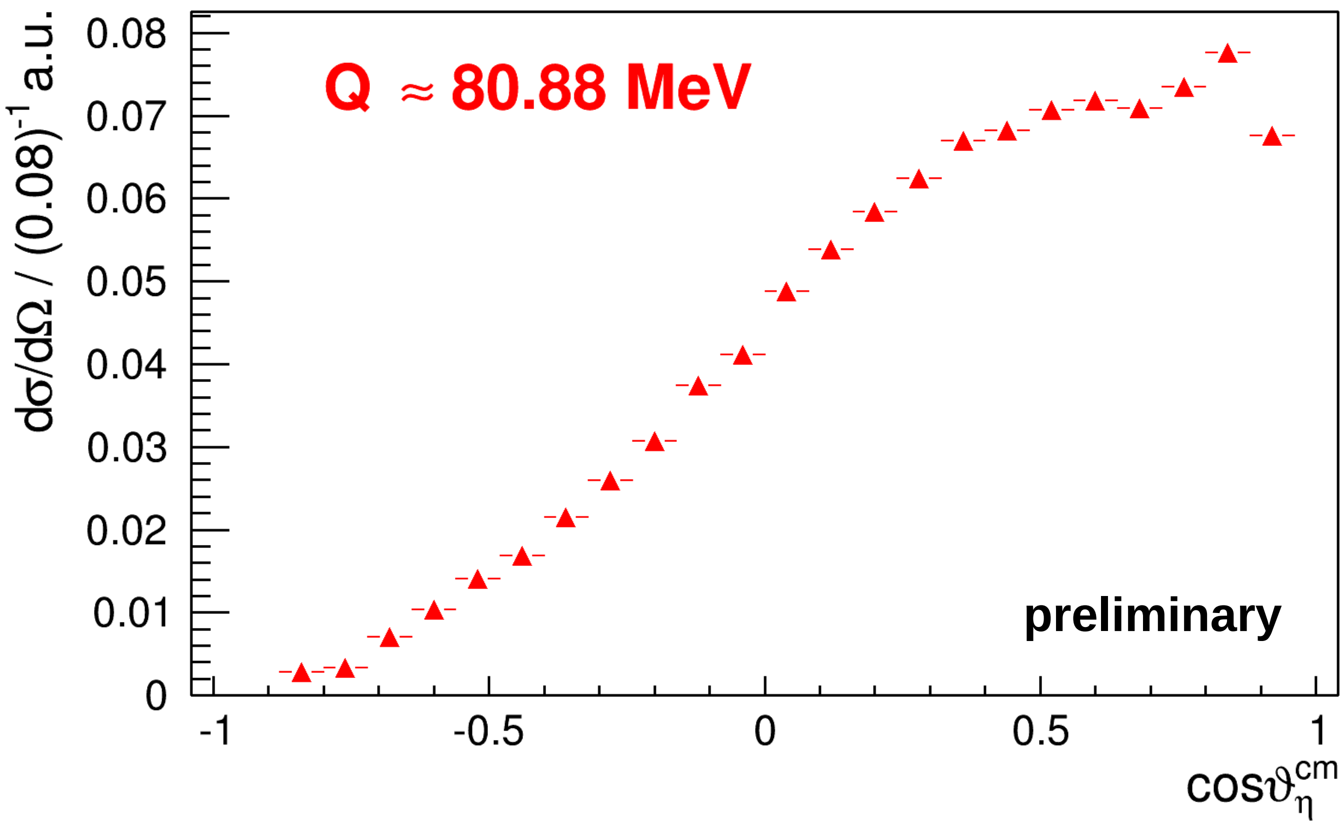
η production

- normalizing to ANKE (2009) and WASA-at-COSY (2014) measurements:
  - nice agreement with previous WASA-at-COSY data
  - systematics in check



η production

- normalizing to unity, compare between energies:
  - distributions remarkably similar down to Q ≈ 40 MeV
  - for lower Q, distributions become more flat



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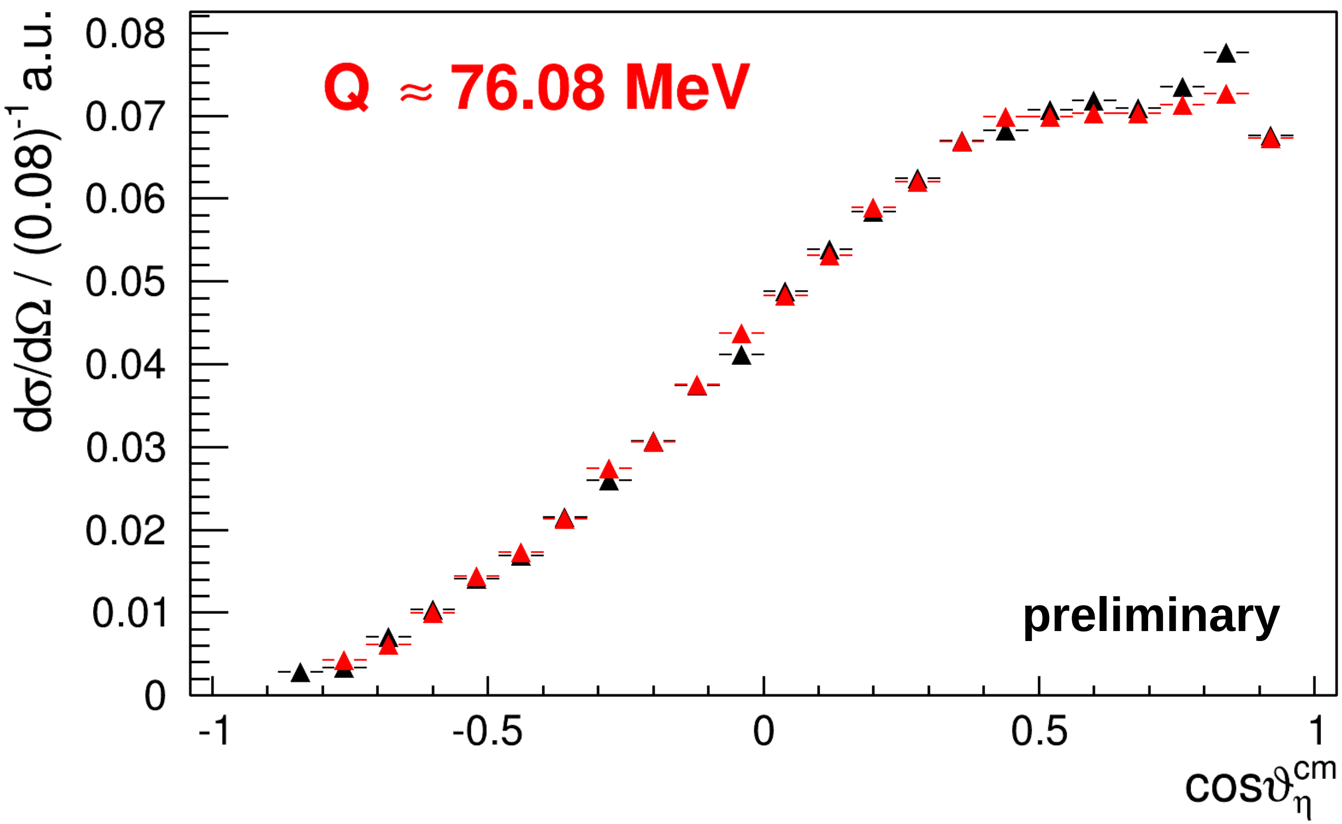

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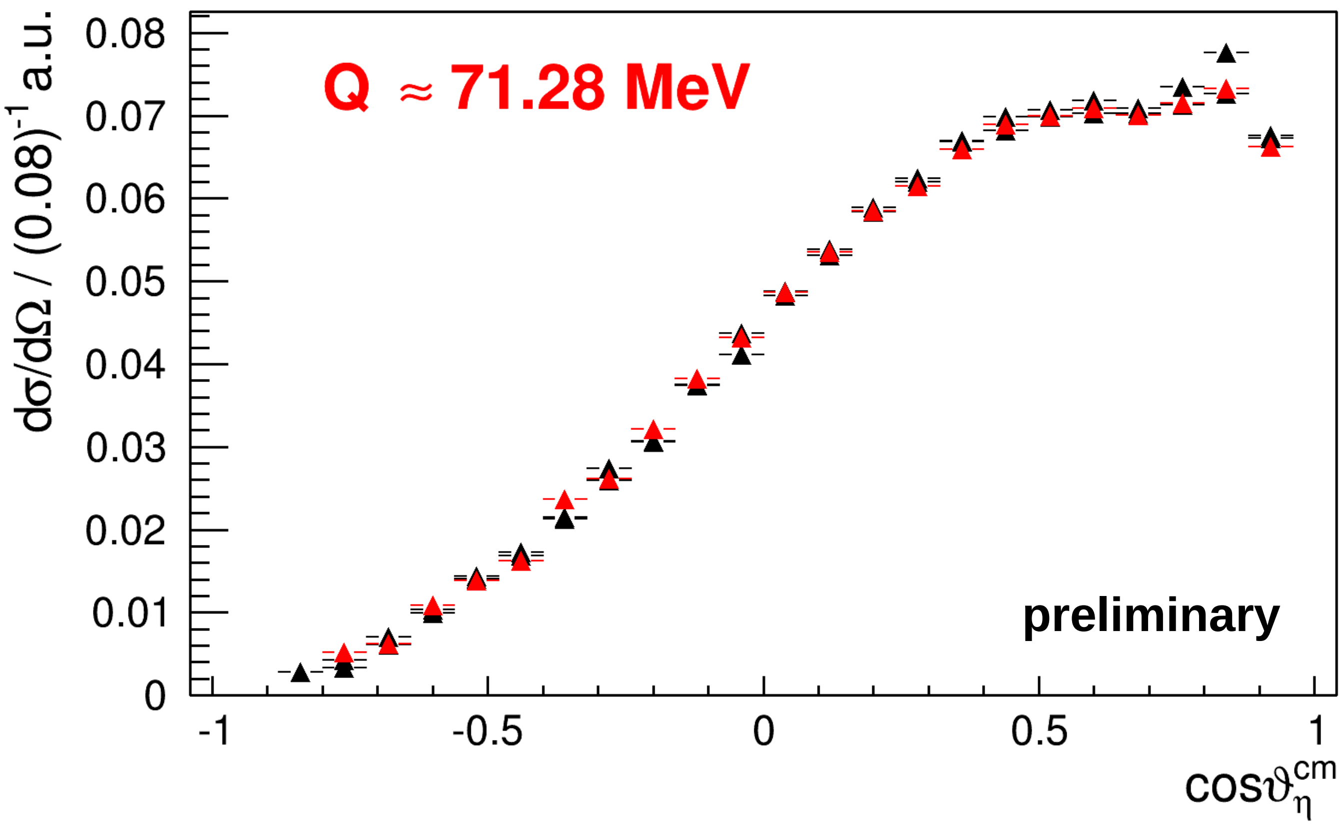

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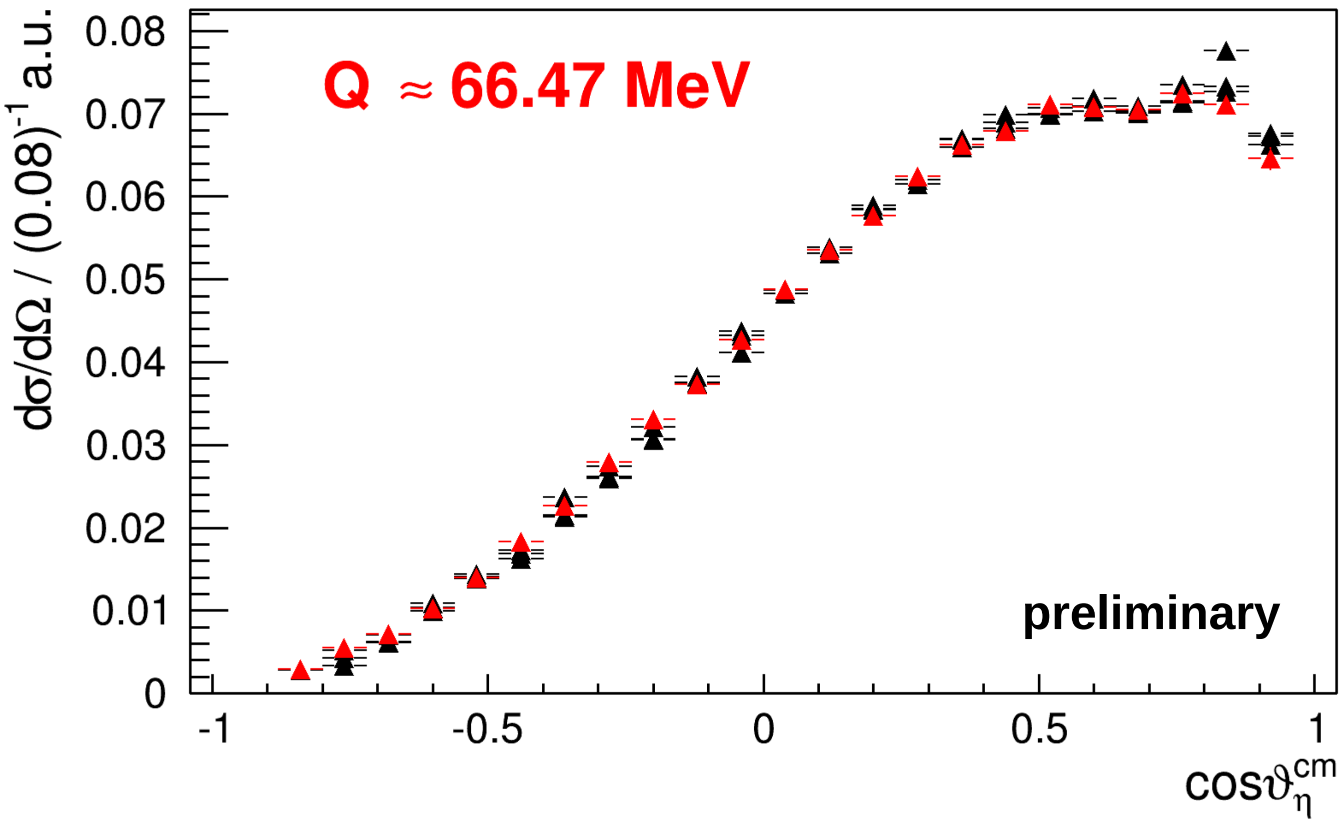

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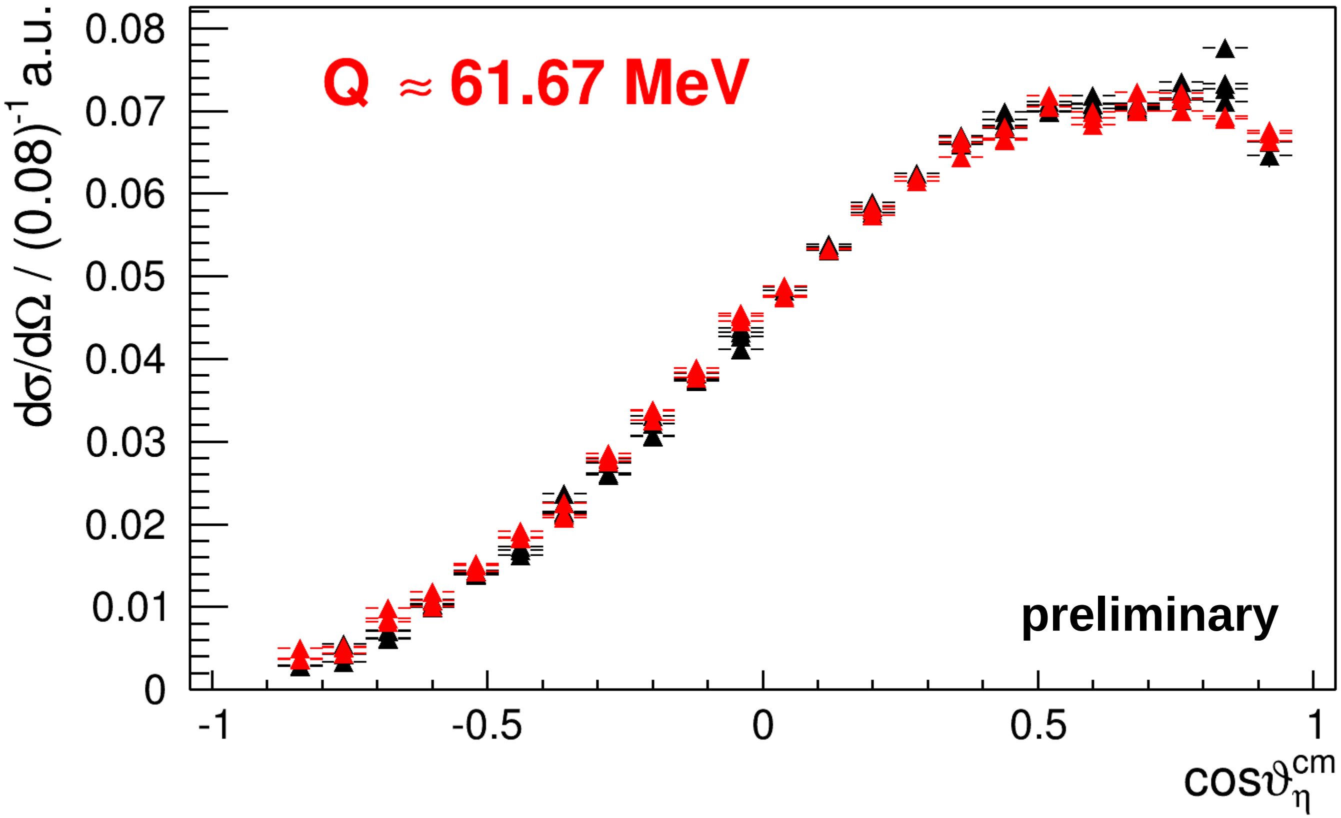

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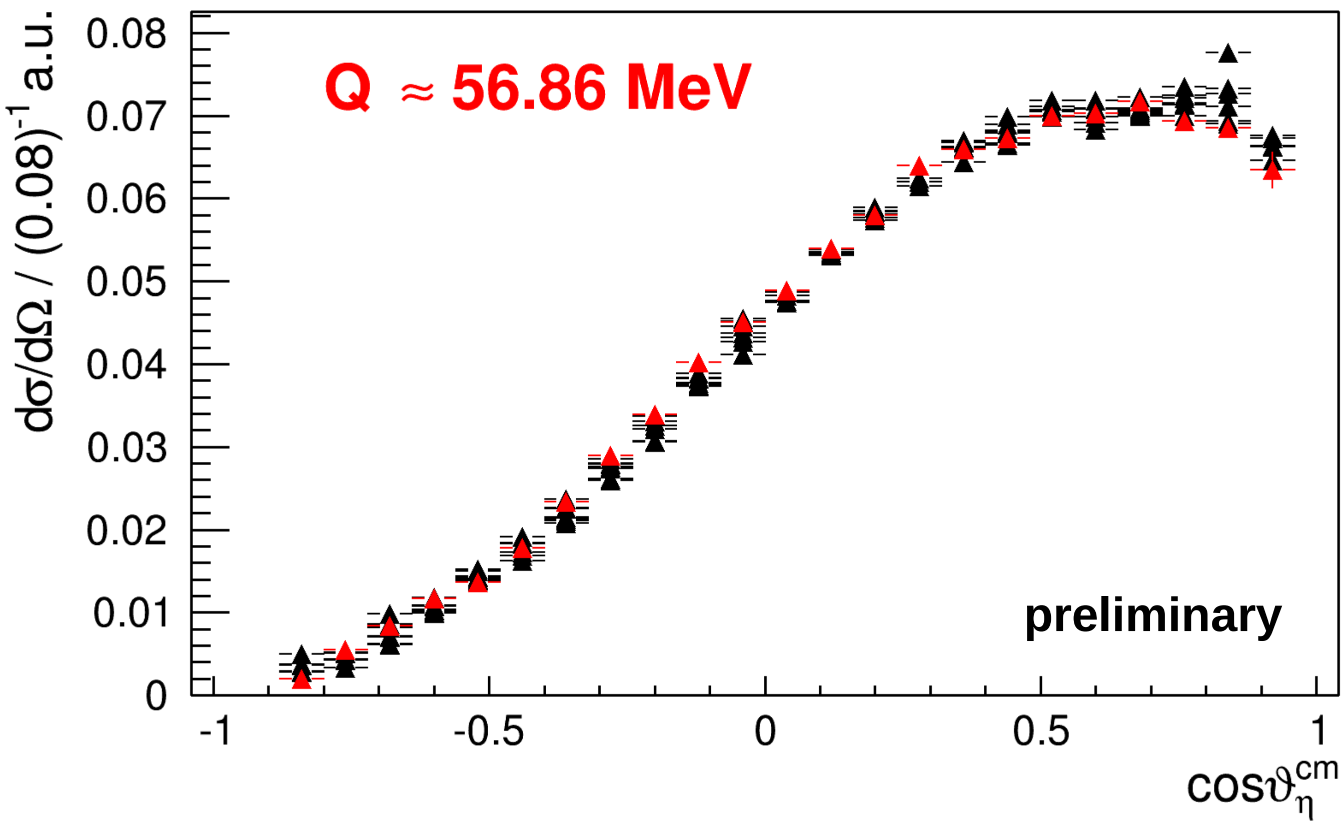

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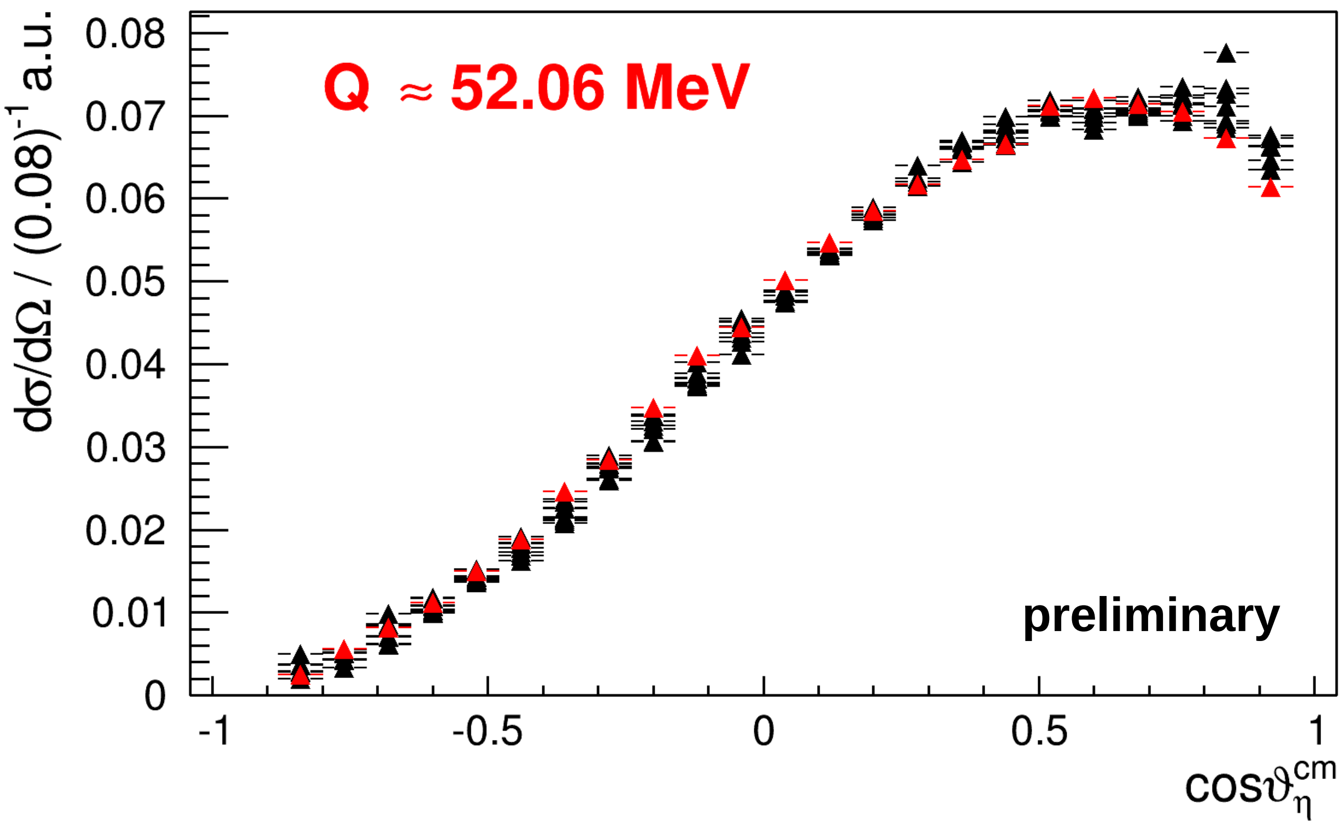

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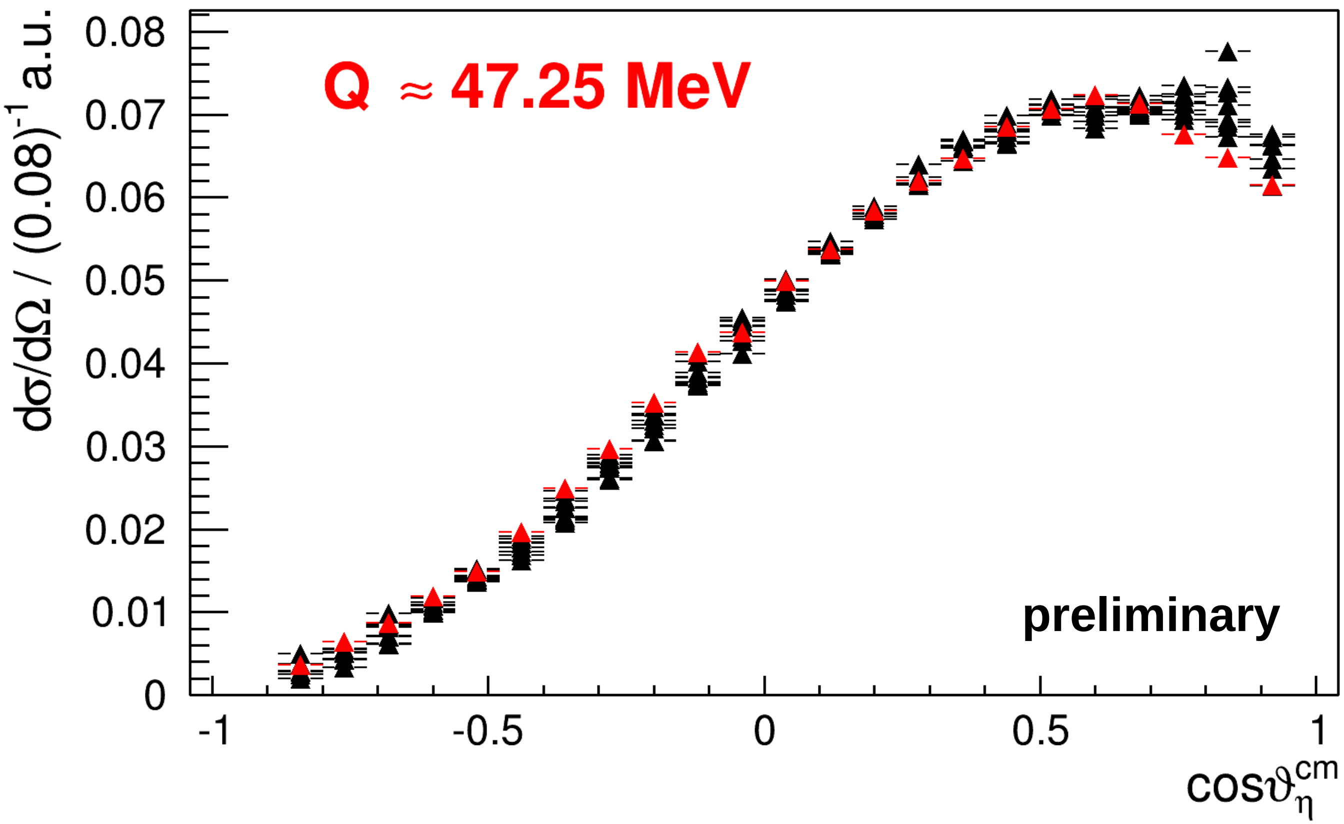

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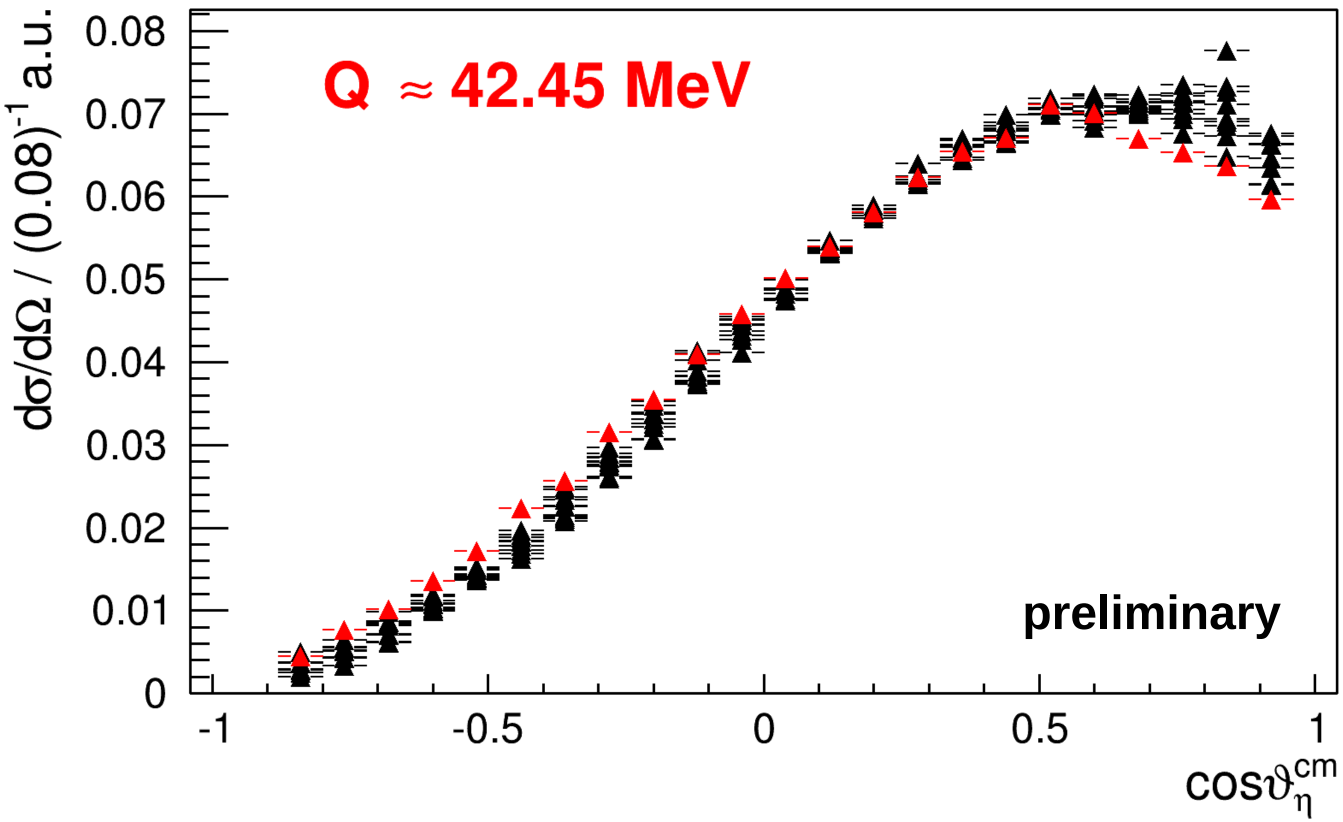

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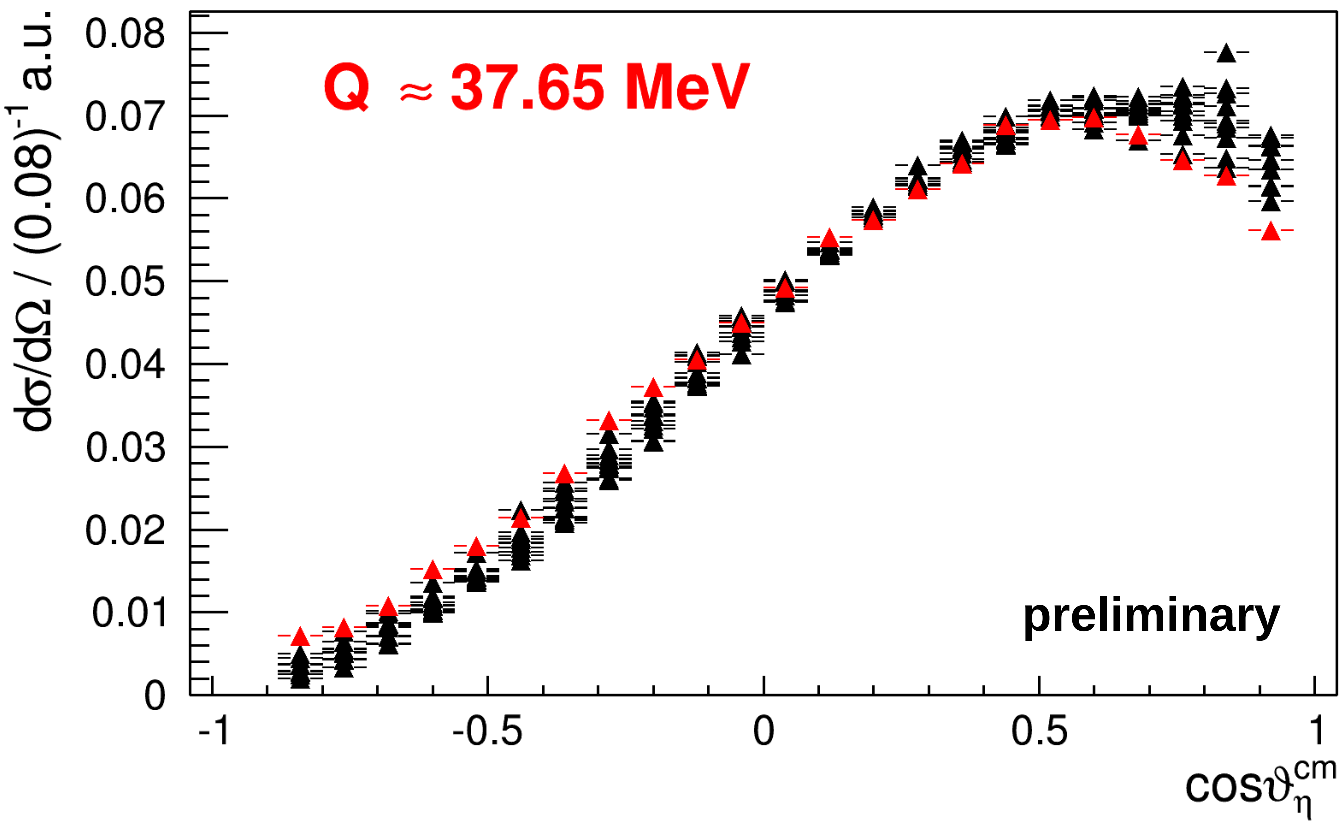

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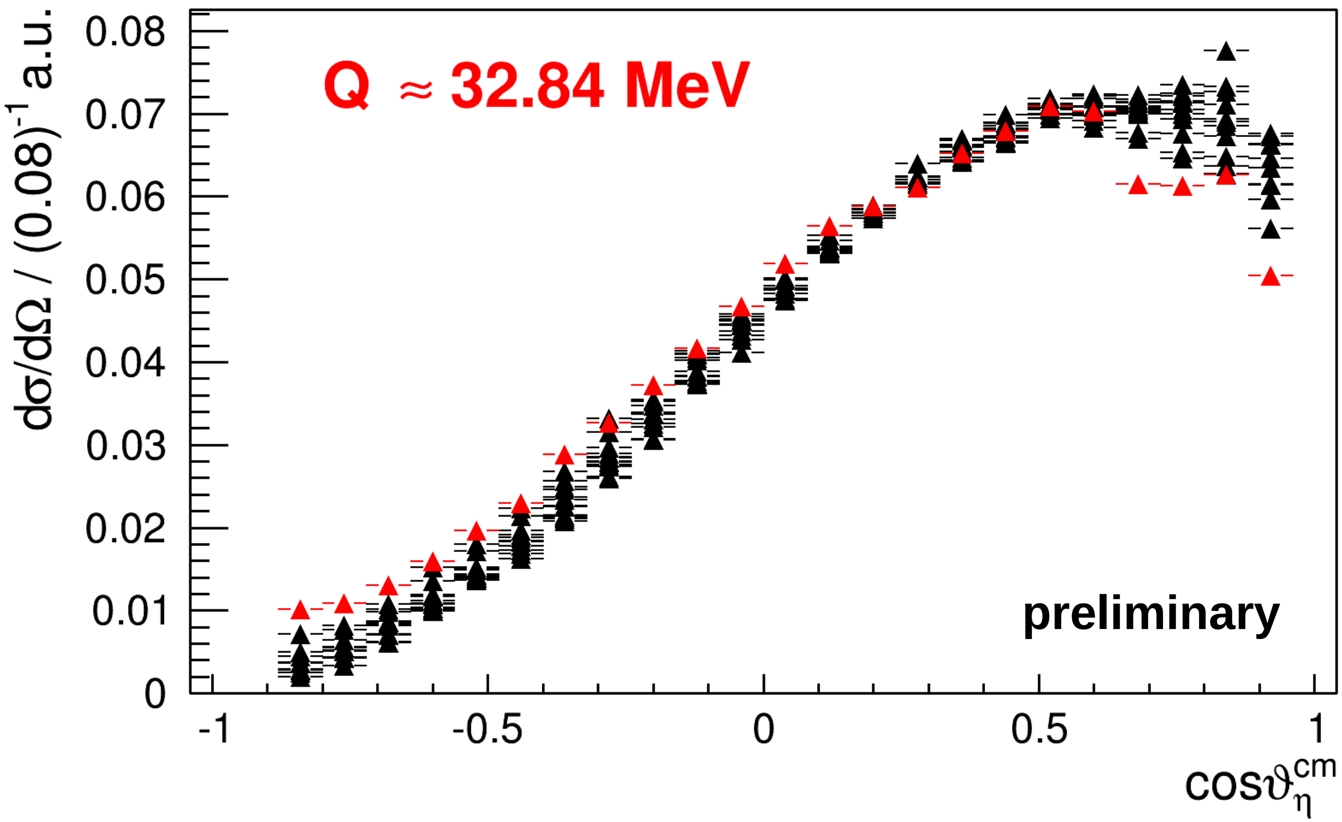

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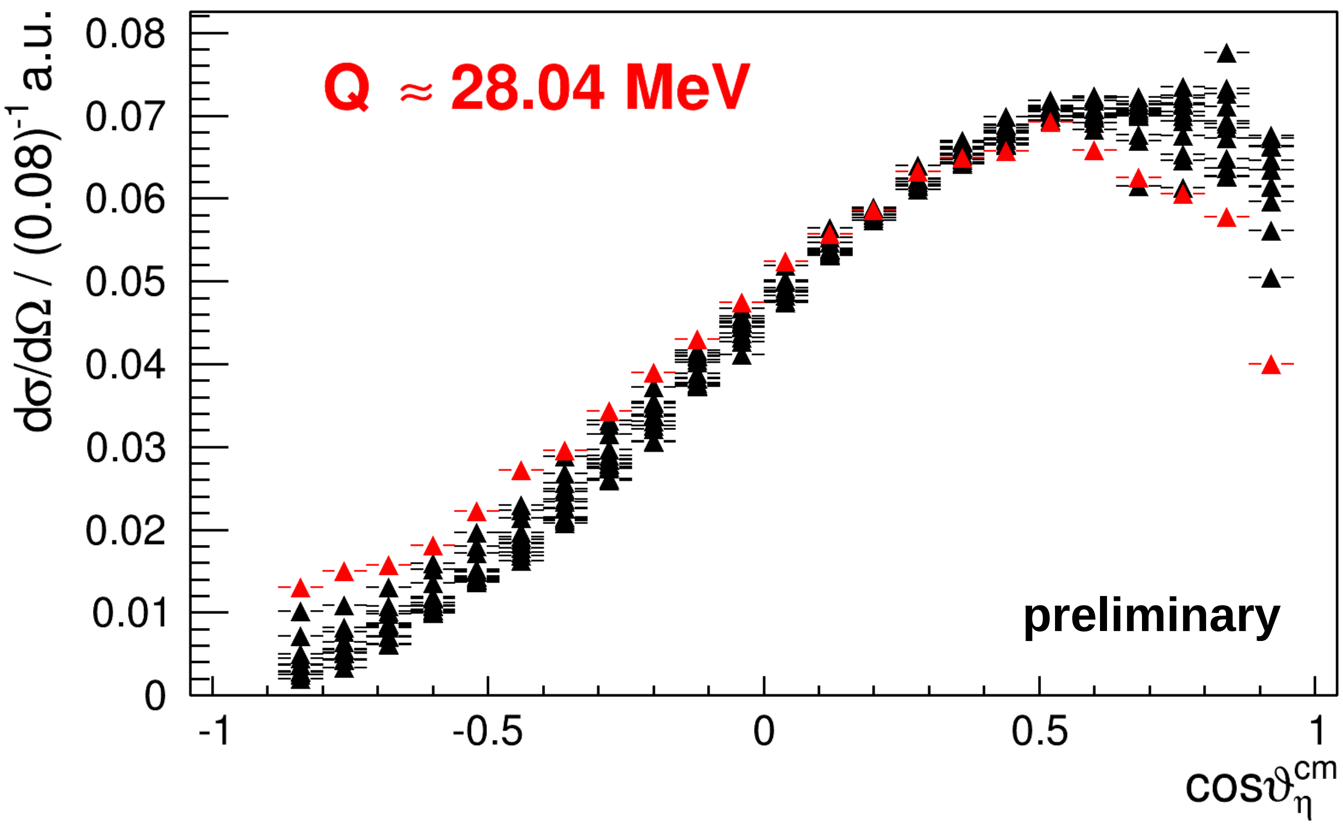

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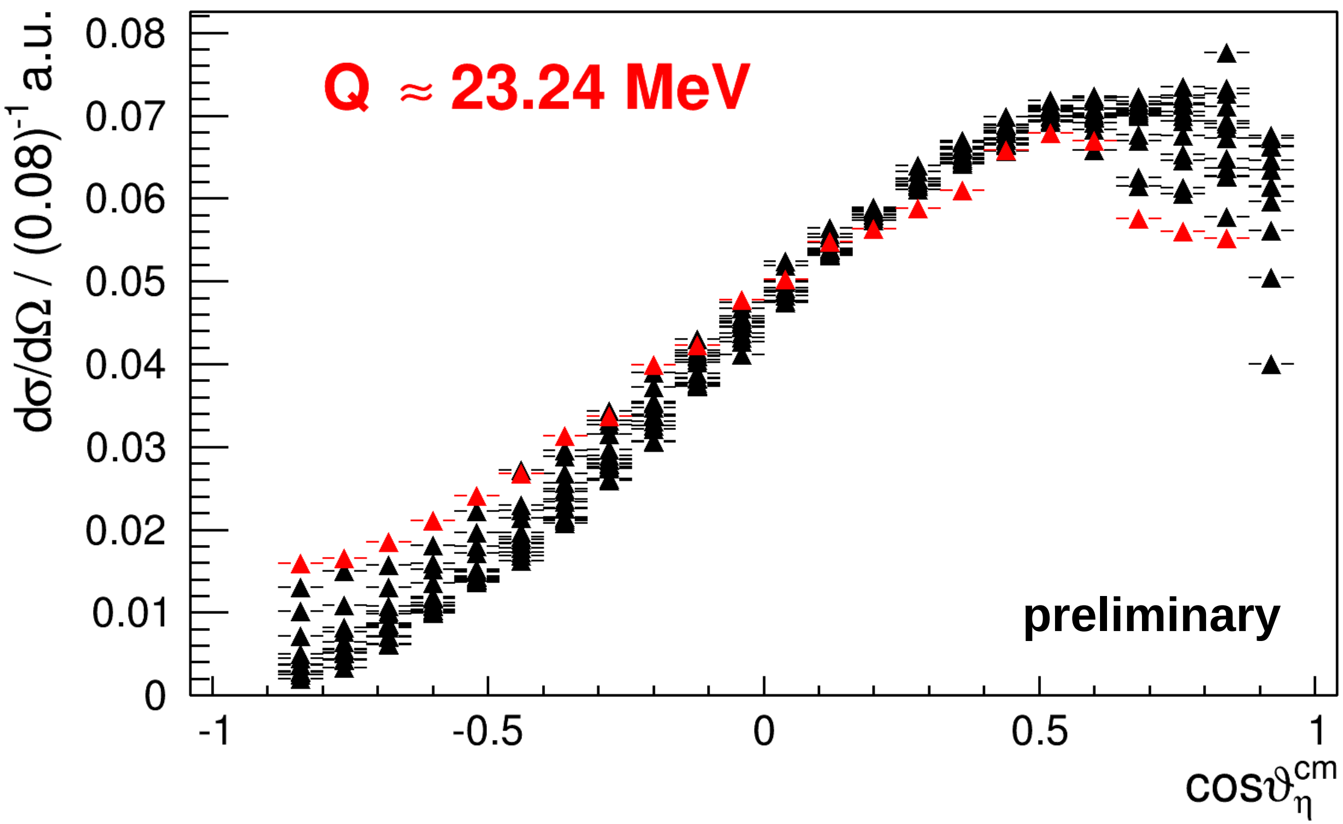

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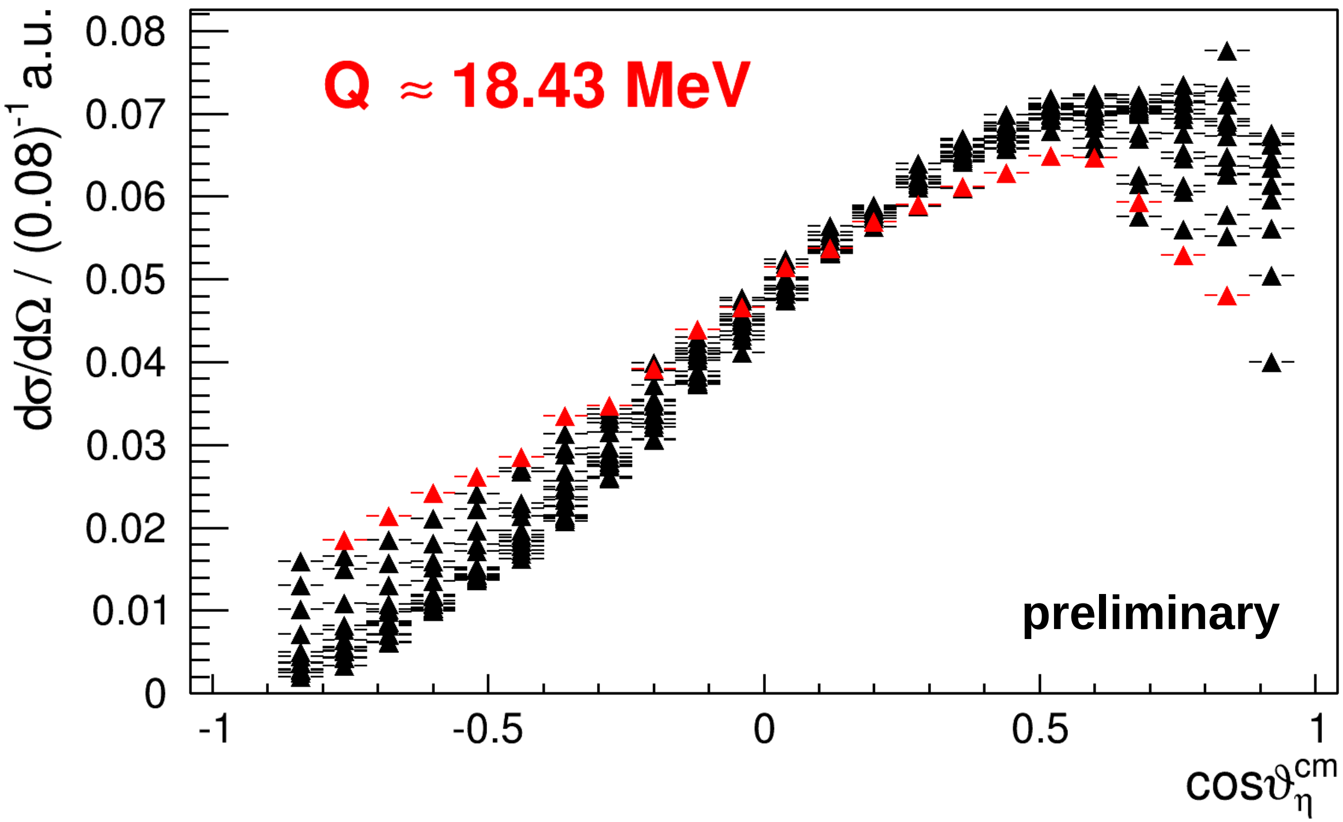

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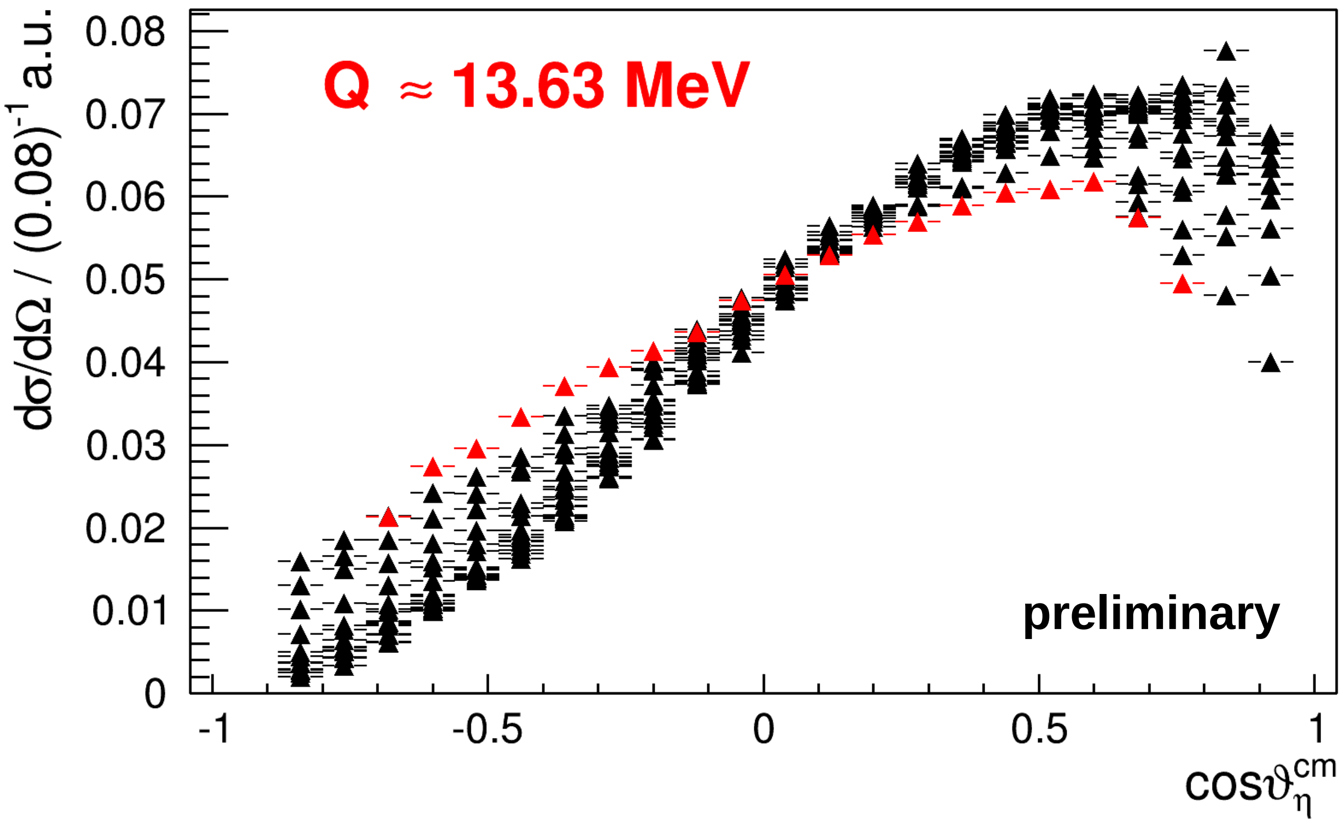

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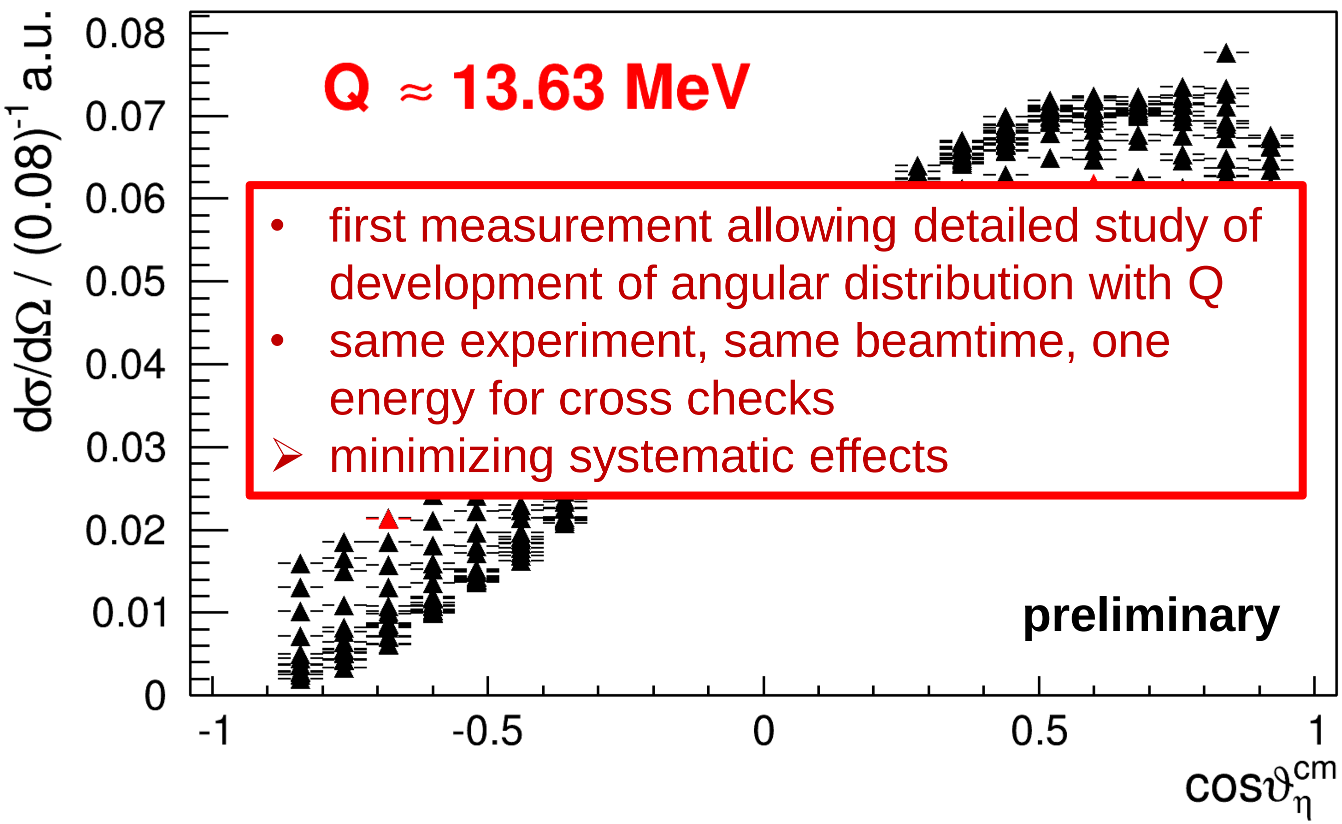
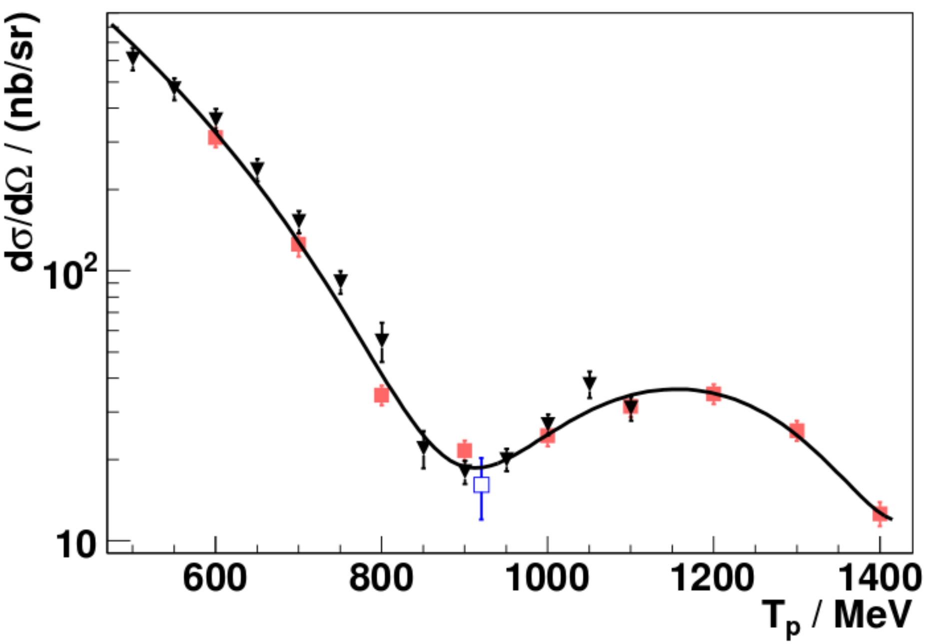


- first measurement allowing detailed study of development of angular distribution with Q
- same experiment, same beamtime, one energy for cross checks
- ➢ minimizing systematic effects

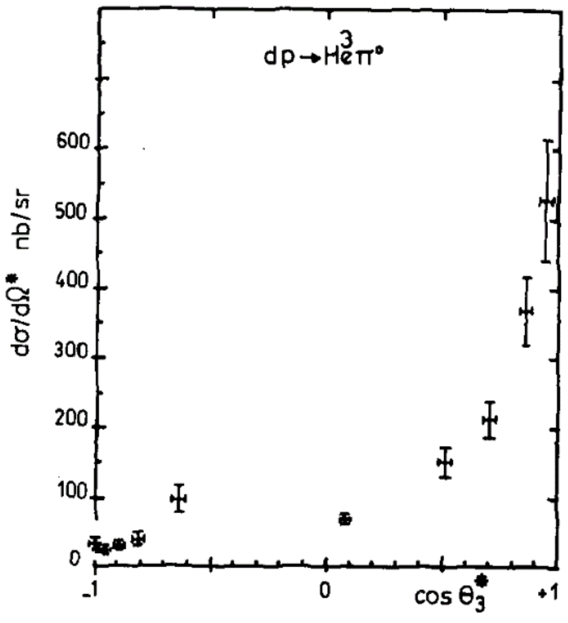
π^0 production

- broad database for $cos\vartheta_{\pi^0} = \pm 1$
- little information on angular distributions
- regularly used for luminosity determination in $\mathrm{pd} \rightarrow {}^3\mathrm{HeX}$ reactions

➢ extracting more information on angular distributions highly useful



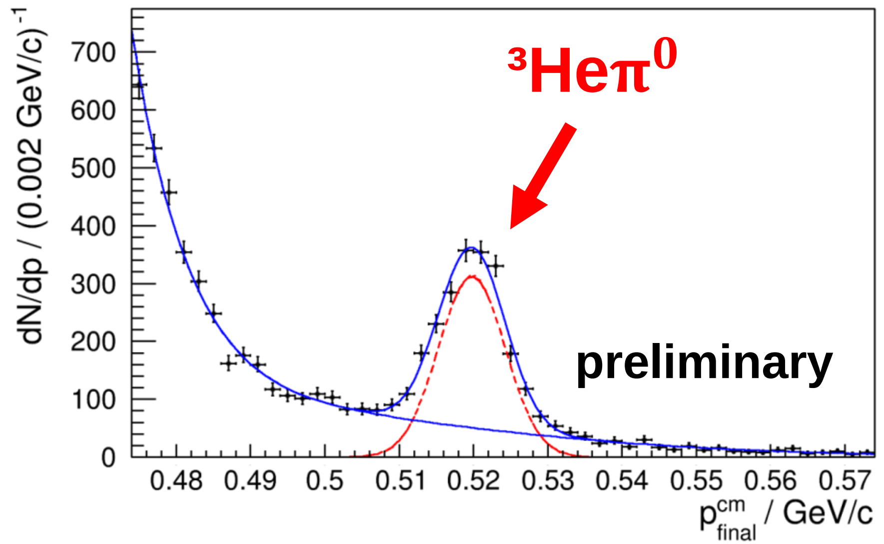
P. Adlarson et al., Eur. Phys. J. A 50, 100 (2014)

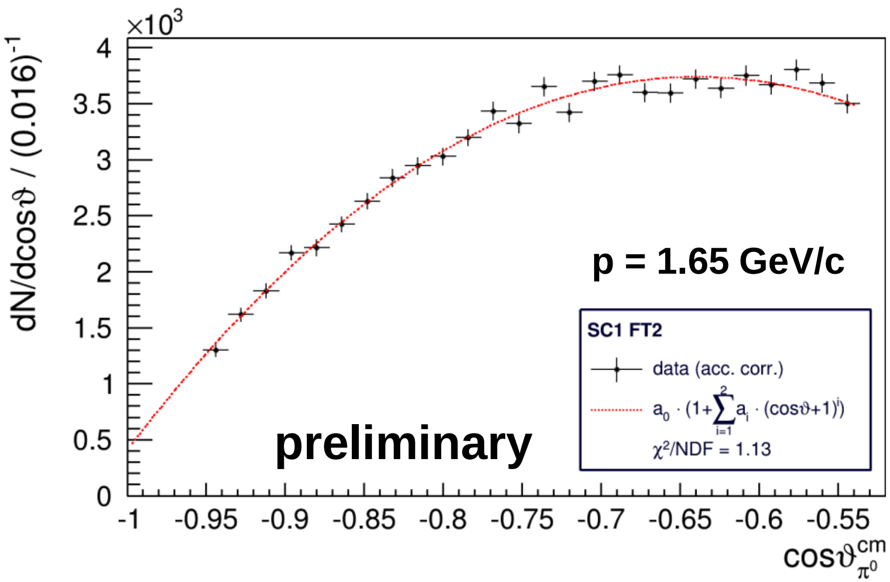


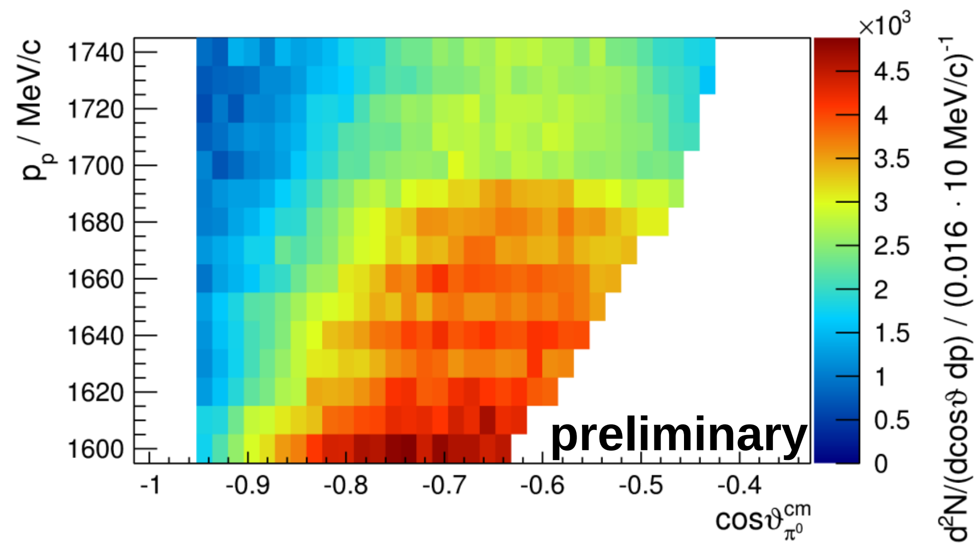
Banaigs, J. et al., Phys. Lett. 45B (1973), Nr. 4, 394

π^0 production

- again, reaction identified by ^3He final state momentum
- angular distributions extracted in high detail
- without a theoretical model, extrapolation to $cos\vartheta_{\pi^0} = -1$ very uncertain
- using *pd* elastic scattering for normalization, $^3He\pi^0$ database can be substantially extended

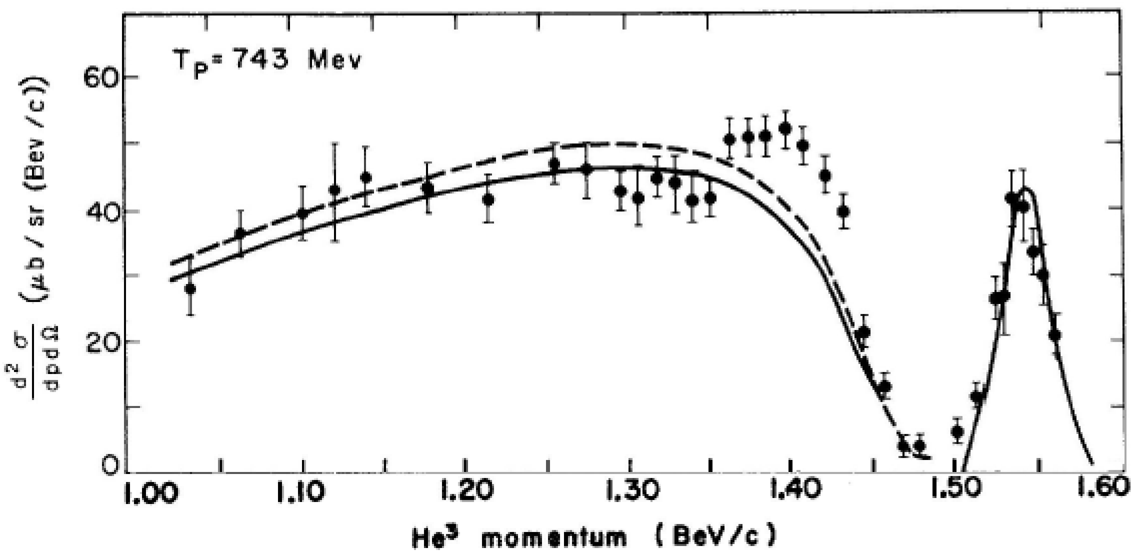






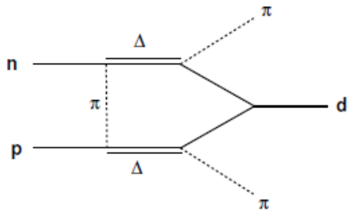
$\pi^0\pi^0$ production

- ABC effect discovered in 1960 by Abashian, Booth & Crowe



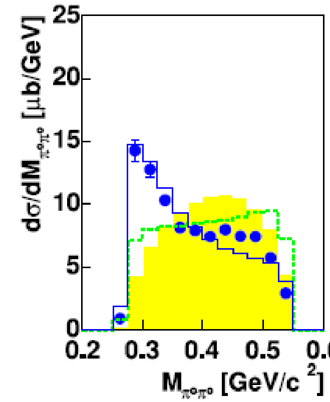
- enhancement over phase-space for high ^{3}He momenta
- so for low $\pi\pi$-invariant masses
- many possible explanations were explored

- $\pi\pi$-final state interaction?
- free (double-) $\Delta(1232)$ excitation?



- inclusive measurements could not give a definitive answer
- ➢ exclusive measurement needed!

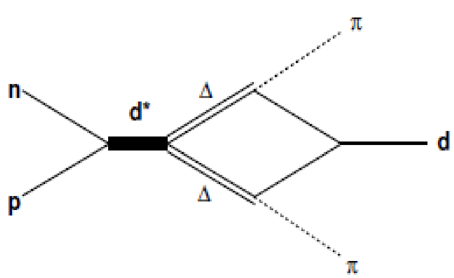
- only in 2005, the first exclusive measurement in the region of the ABC effect was conducted with CELSIUS/WASA
- showed clear low-mass enhancement
- ruled out the free double-Δ explanation (shown in green)

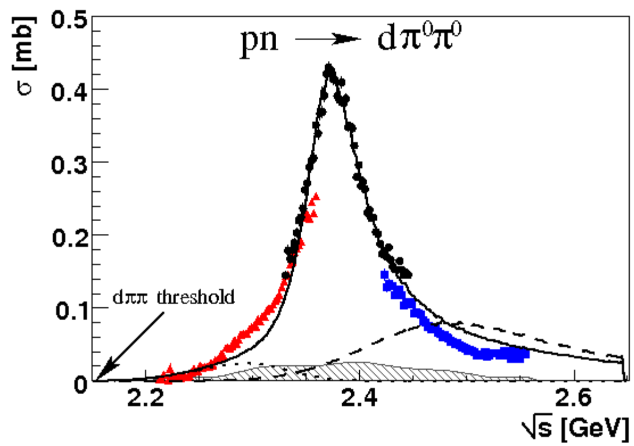


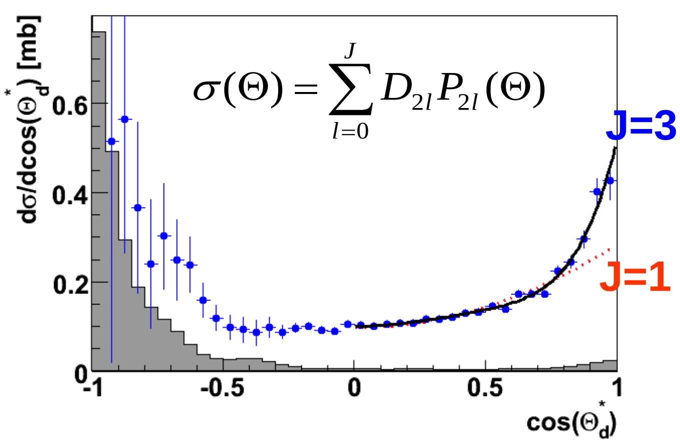
M. Bashkanov et al., Phys. Lett. B 637:223-228, 2006.

- 2008: high statistics measurement $pd \to d(\pi\pi)^0\, p_{spect}$ with WASA-at-COSY
- resonance structure in the total cross section with quantum numbers **I(J^p) = 0(3$^+$)**
- $M_{d^*} = 2.38\ GeV \approx 2M_\Delta - 80\ MeV$ **and** $\Gamma_{d^*} = 70\ \mathrm{MeV} \ll \Gamma_{\Delta\Delta} = 240\ MeV$

P. Adlarson et. al Phys. Rev. Lett. 106:242302, 2011





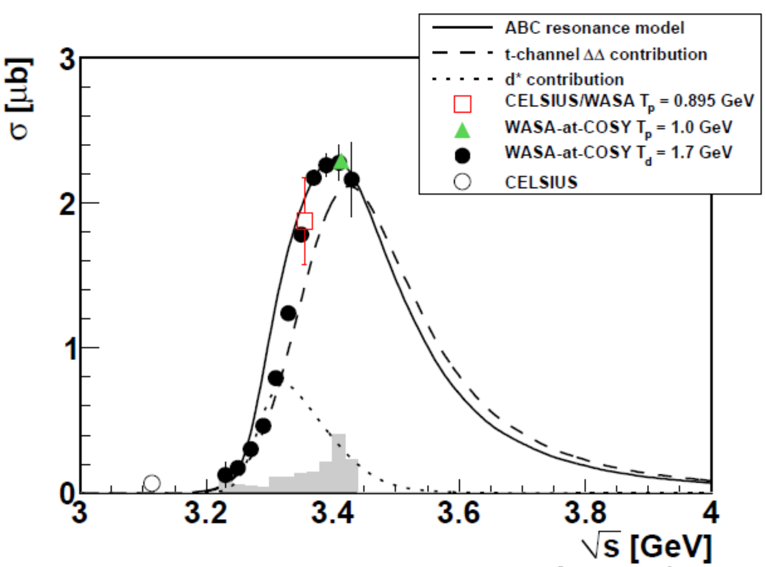


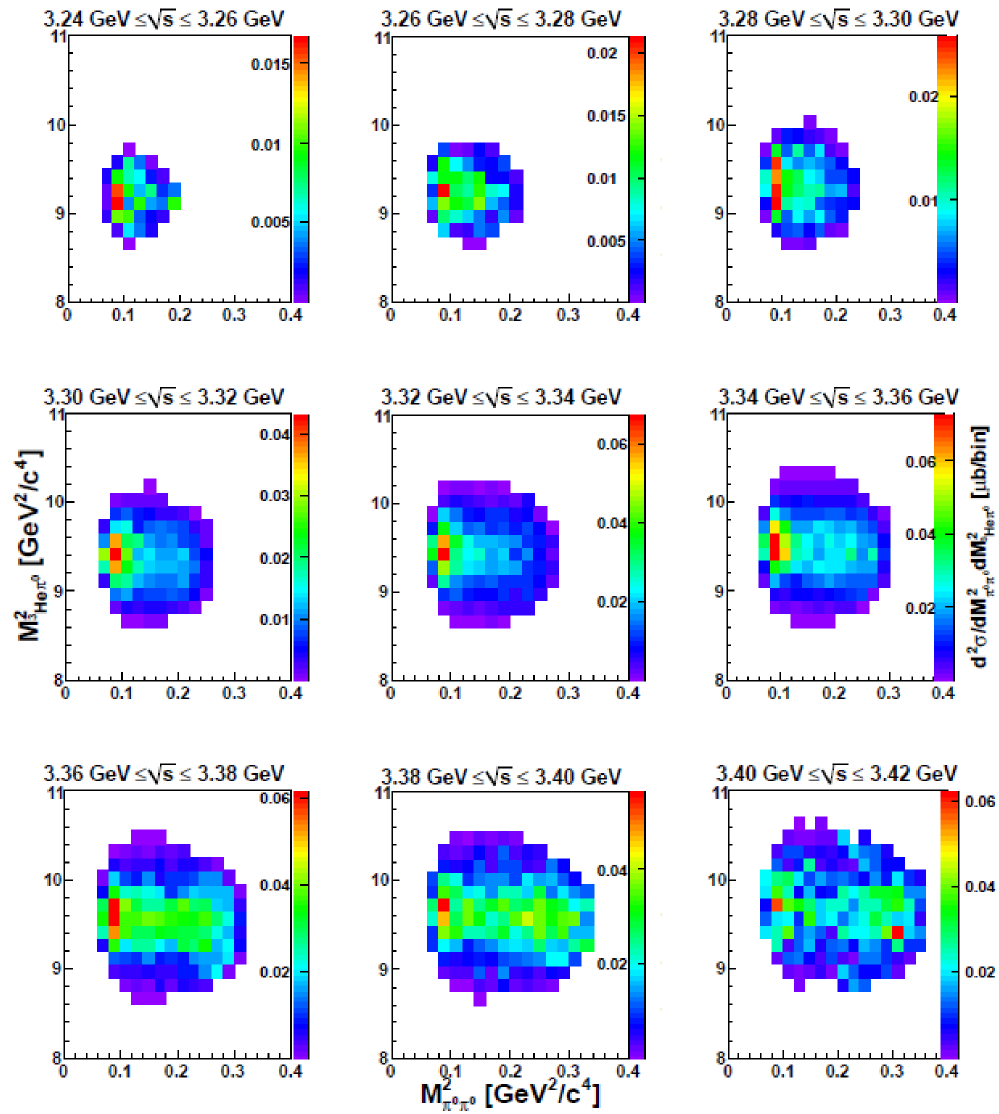
➢ **identified as a dibaryon**

$\pi^0\pi^0$ production

How is $\mathrm{pd} \rightarrow\ ^3\mathrm{He}(\pi\pi)^0$ influenced by this?

- WASA-at-COSY measurements in 2007, 2009 and 2010
- from quasi-free $\mathrm{dd} \rightarrow\ ^3\mathrm{He}\pi^0\pi^0\ \mathrm{n}_{\mathrm{spect}}$
- compatible with d*(2380) model





Figures from: E. Pérez del Río: ABC Effect and d* Resonance in Double-Pionic Fusion to ³He

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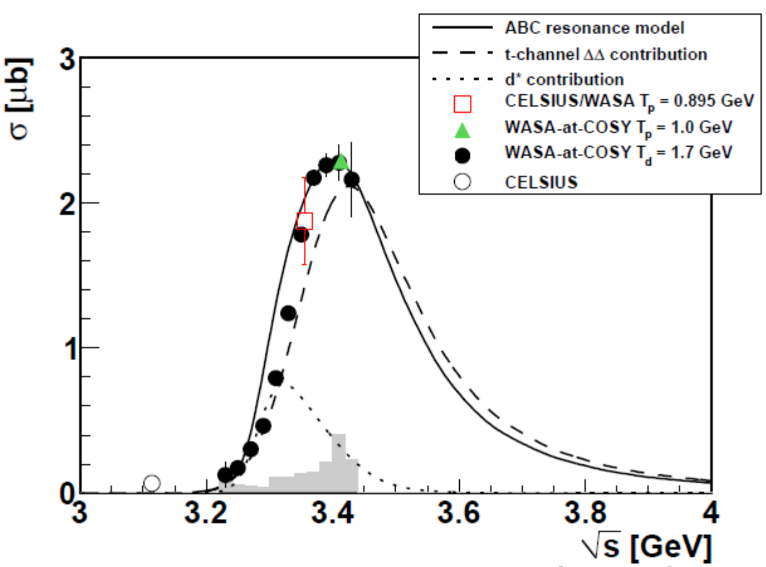

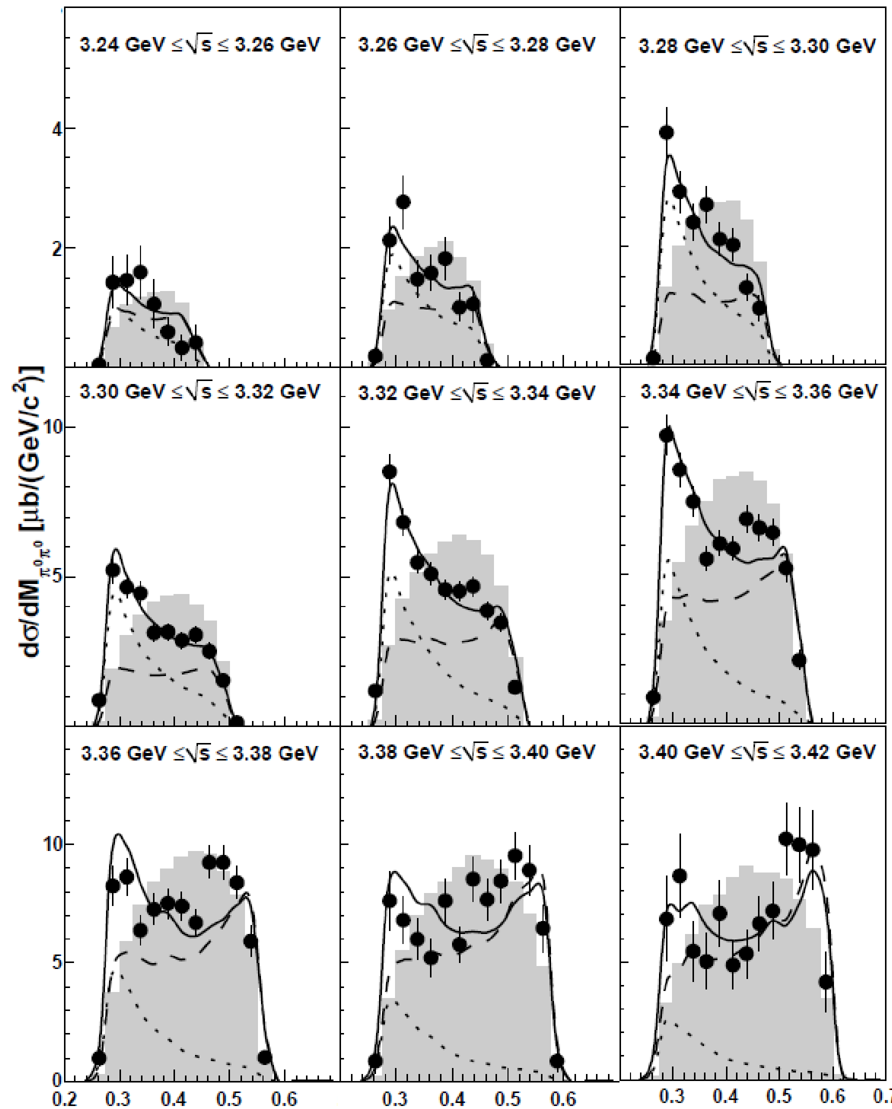

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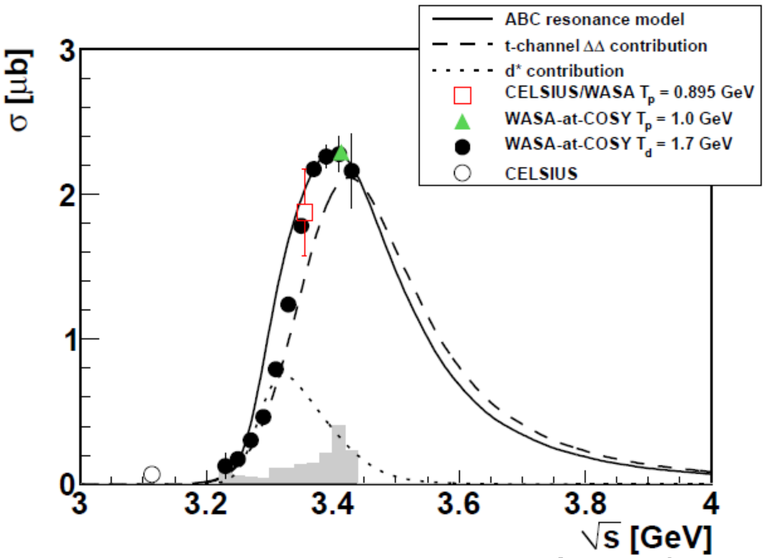
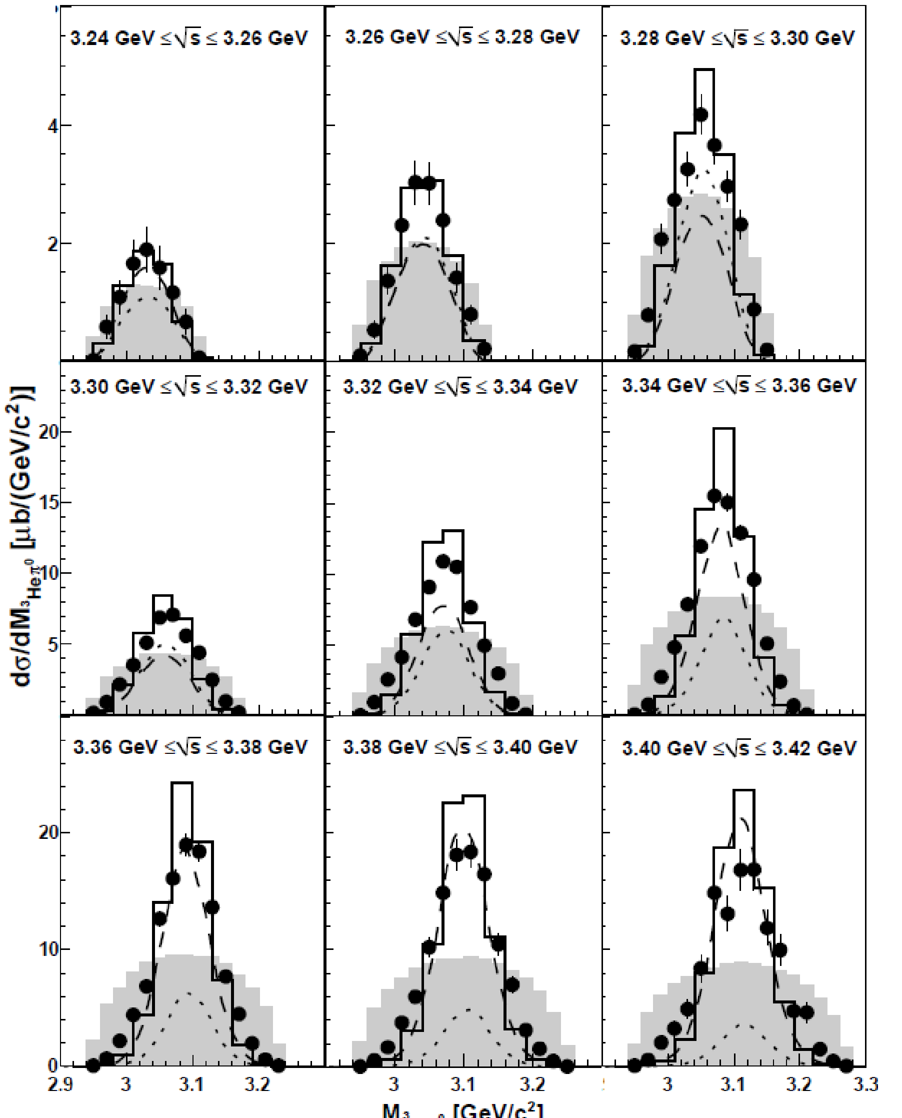
- compatible with d*(2380) model



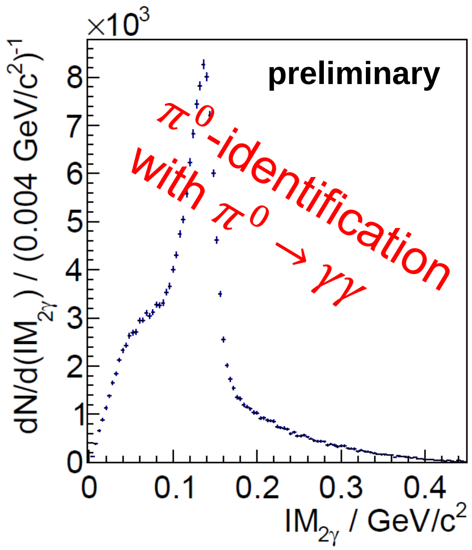


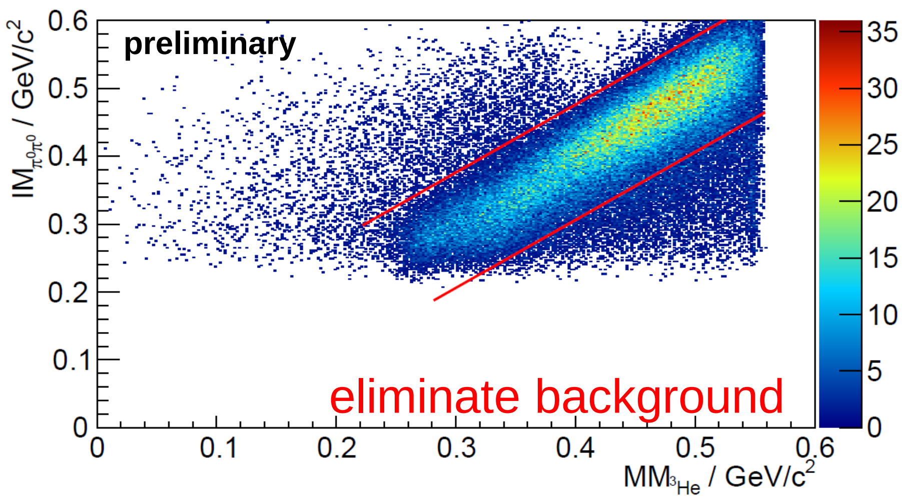
Figures from: E. Pérez del Río: ABC Effect and d* Resonance in Double-Pionic Fusion to ³He

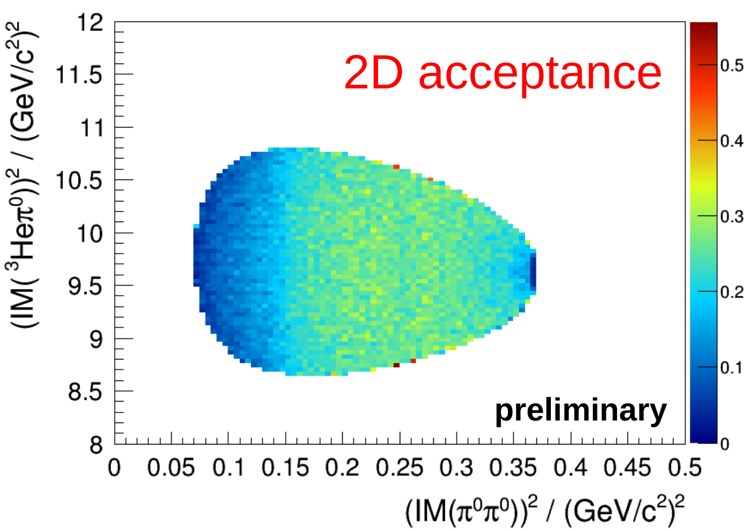
$\pi^0\pi^0$ production

Westfälische Wilhelms-Universität Münster

- one of our main *background* reactions
- π^0 reconstructed from $\gamma\gamma$ decays
- excellent background suppression
- kinematically complete measurement allows use of kinematic fit
- 2D acceptance correction performed



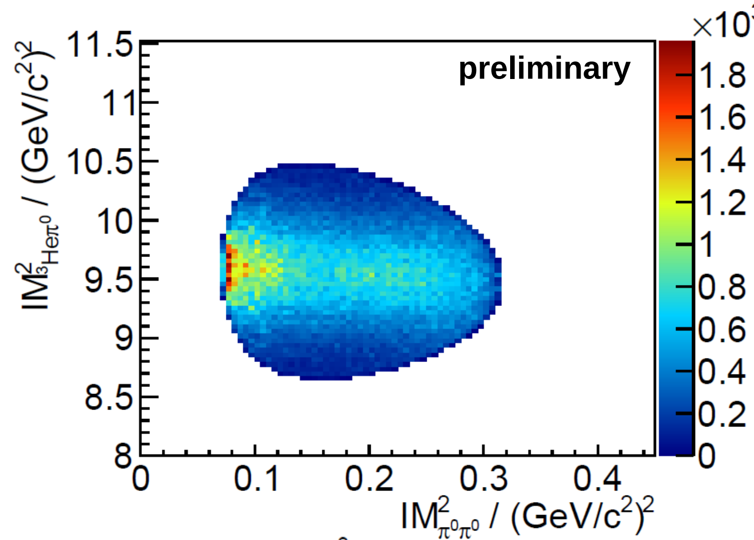


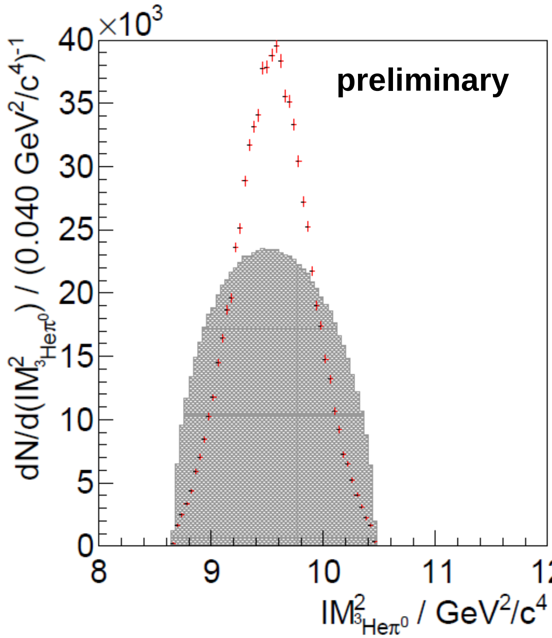


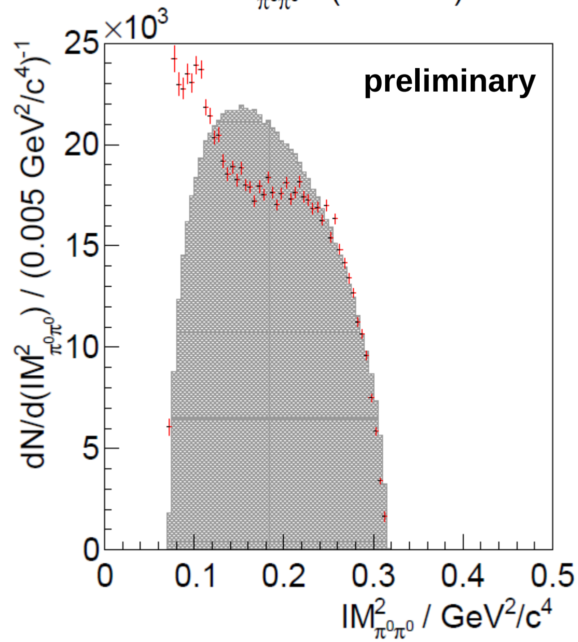
Figures from: L. Wölfer, BSc Thesis

$\pi^0\pi^0$ production

- very clean & large sample of double-pion production
- allows detailed investigation of this reaction with regard to IM($\pi^0\pi^0$), IM(³Heπ^0), $cos\vartheta_{\pi\pi}$ and $\sqrt{s}$
- comparison with d*(2380) model might clarify its role in the ³He$\pi^0\pi^0$ reaction



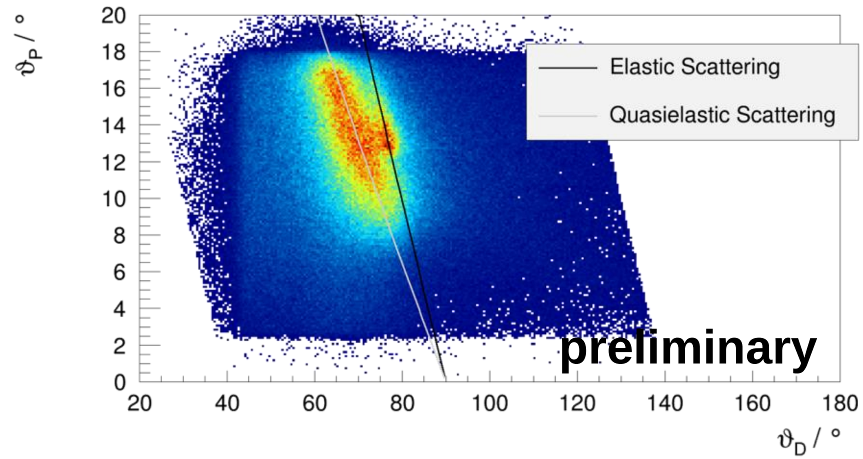


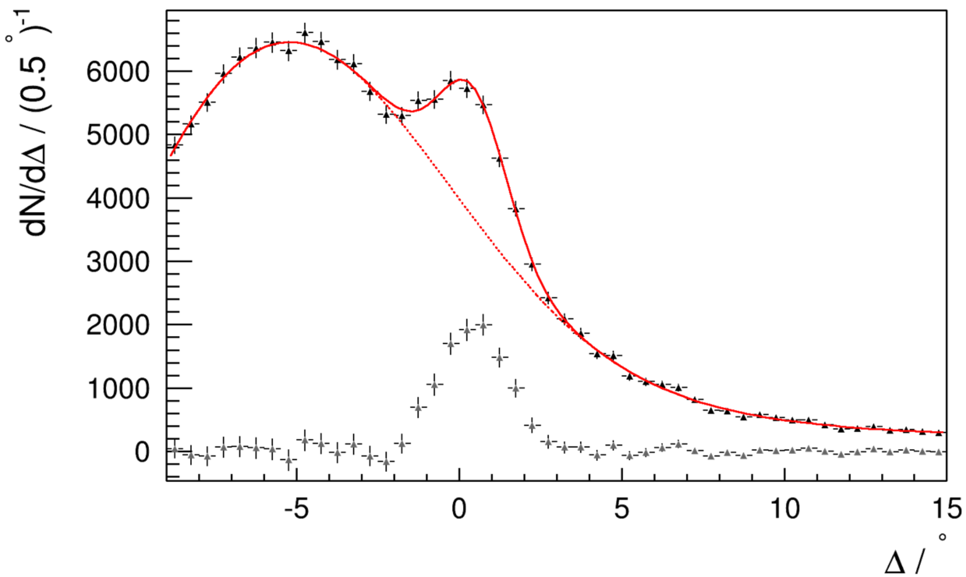


Figures from: L. Wölfer, BSc Thesis

pd elastic scattering

- with all the nice possibilities our dataset presents, a careful normalization is critical (and the missing piece to the puzzle)
- at small momentum transfers -t *pd* elastic scattering does (in 1st order) not depend on beam momentum, just on -t
- in a relative normalization, literature cross sections will cancel
- momentum resolution for p and d not sufficient
- Idea: use angle relation
- Outlook: will result in point-to-point uncertainties in the order of 8-10%





L. Fisch, BSc thesis

Summary & Outlook

- new $\mathrm{pd} \to {}^{3}\mathrm{HeX}$ dataset at 15 different p_p between 1.60 GeV/c and 1.74 GeV/c
- no consensus on the η-production mechanism away from threshold
- detailed investigation of ϑ and Q dependency will provide new insight
- considerable extension of the current ${}^{3}\mathrm{He}\pi^{0}$ database
- ${}^{3}\mathrm{He}\pi^{0}\pi^{0}$ can be studied in unprecedented detail
- ${}^{3}\mathrm{He}\pi^{+}\pi^{-}$ currently under investigation
- (relative) normalization using pd elastic scattering

Thank you for your attention!