Measurement of helicity dependence of π^0 photoproduction on deuteron

Federico Cividini for the A2 collaboration @ MAMI

SFB 1044
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

EINN Conference

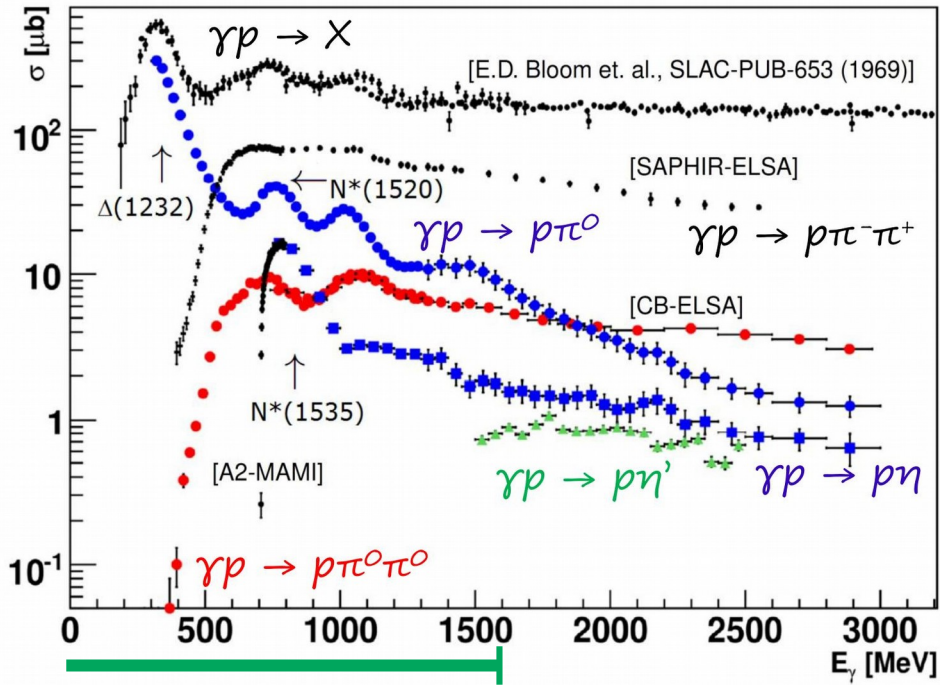
October 29th 2019, Cyprus

JG|U
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Motivation

- The photon interacts with the internal structure of the nucleon → Excited states (resonances)
- From the excited nucleon one (or more) pseudoscalar meson is emitted
- It is necessary to investigate the different final states
- Nucleon resonances are broad and overlapping, unpolarized cross section is not sufficient to disentangle them

BARYON SPECTROSCOPY & POLARIZATION OBSERVABLES



A2 energy range

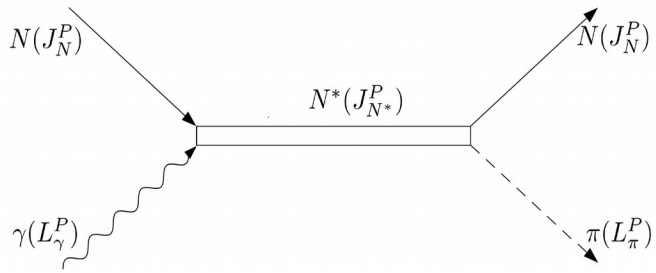
Formalism

- Photo-production of a single pseudo-scalar meson from the nucleon is described theoretically by complex helicity amplitudes:

$$\gamma(\vec{k}) + N(\vec{p_i}) = m(\vec{q}) + N'(\vec{p_f})$$

Spin states: ± 1 ± 1/2 0 ± 1/2

8 matrix elements → **Parity conservation** → **4 matrix elements**



- From these 4 complex amplitudes is possible to construct

16 polarization observables

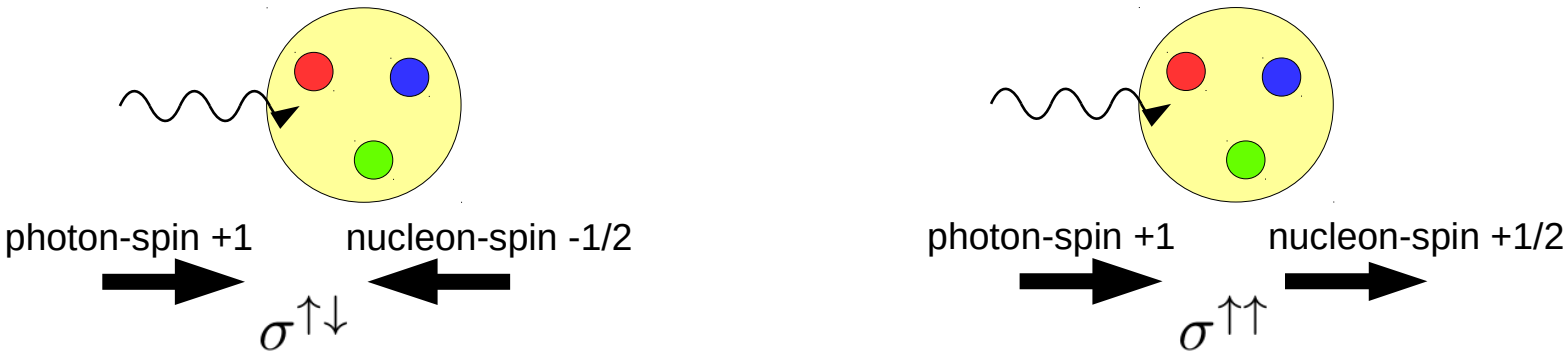
Photon polarization		Target polarization			Recoil nucleon polarization			Target and recoil polarizations			
	-	-	-	-	-	-	-	x'	x'	z'	z'
	-	x	y	z	x'	y'	x'	x	z	x	z
Unpolarized	σ	-	T	-	-	P	-	$T_{x'}$	$L_{x'}$	$T_{z'}$	$L_{z'}$
Linear polariz.	Σ	H	(-P)	G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(L_{z'})$	$(-T_{z'})$
Circular polariz.	-	F	-	**E**	$C_{x'}$	-	$C_{z'}$	-	-	-	-

Formalism

Double polarization observable *E*

- Circularly polarized photon beam
- Longitudinally polarized target

$$\frac{d\sigma}{d\Omega} = \sigma_0 \left\{1 \pm P_z^T P_\odot^\gamma E\right\} \qquad E = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}} = \frac{N^{\uparrow\uparrow} - N^{\uparrow\downarrow}}{N^{\uparrow\uparrow} + N^{\uparrow\downarrow}} \cdot \frac{1}{P_t} \cdot \frac{1}{P_\gamma}$$

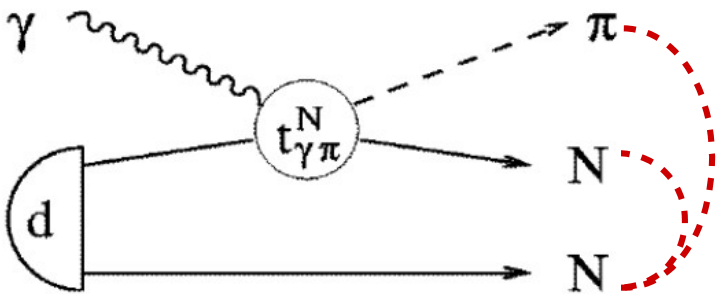


Complete set of pion production measurements on both proton and neutron are necessary!!

Formalism

Measurements with neutron

- Lack of data on the neutron
- No free-neutron target → **Deuterium** or ^{3}He
  - Deuteron at rest in the lab frame
  - The two nucleons have momentum according to the ***Fermi motion***
  - Re-scattering of the spectator nucleon with the pion or the nucleon involved in the reaction → ***Final state interactions***

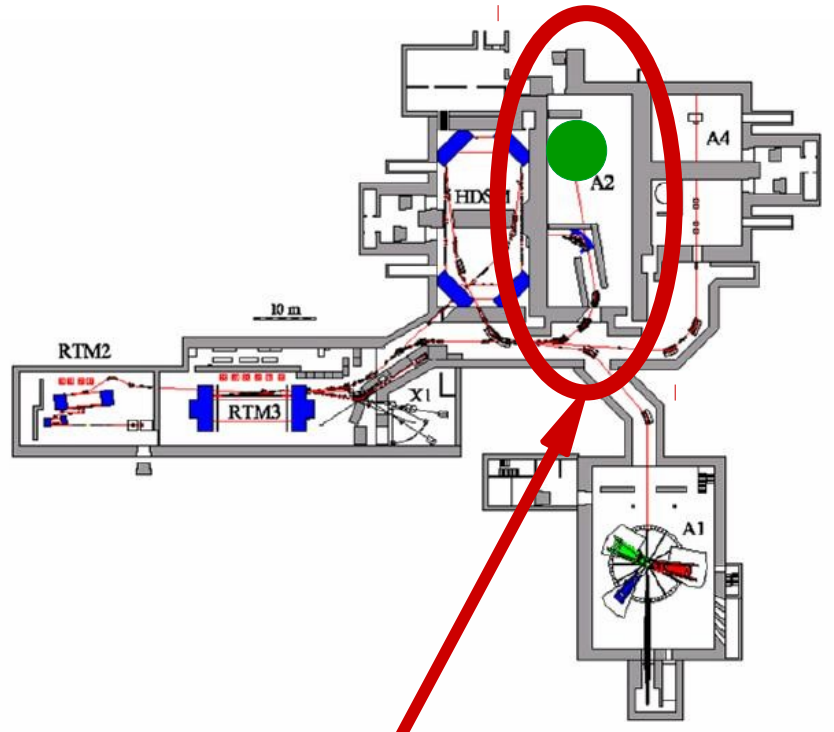


H. Arenhovel et al., Modern Physics Letter A 18, 190-199 (2003).

A2 experimental setup @ MAMI

Electron beam

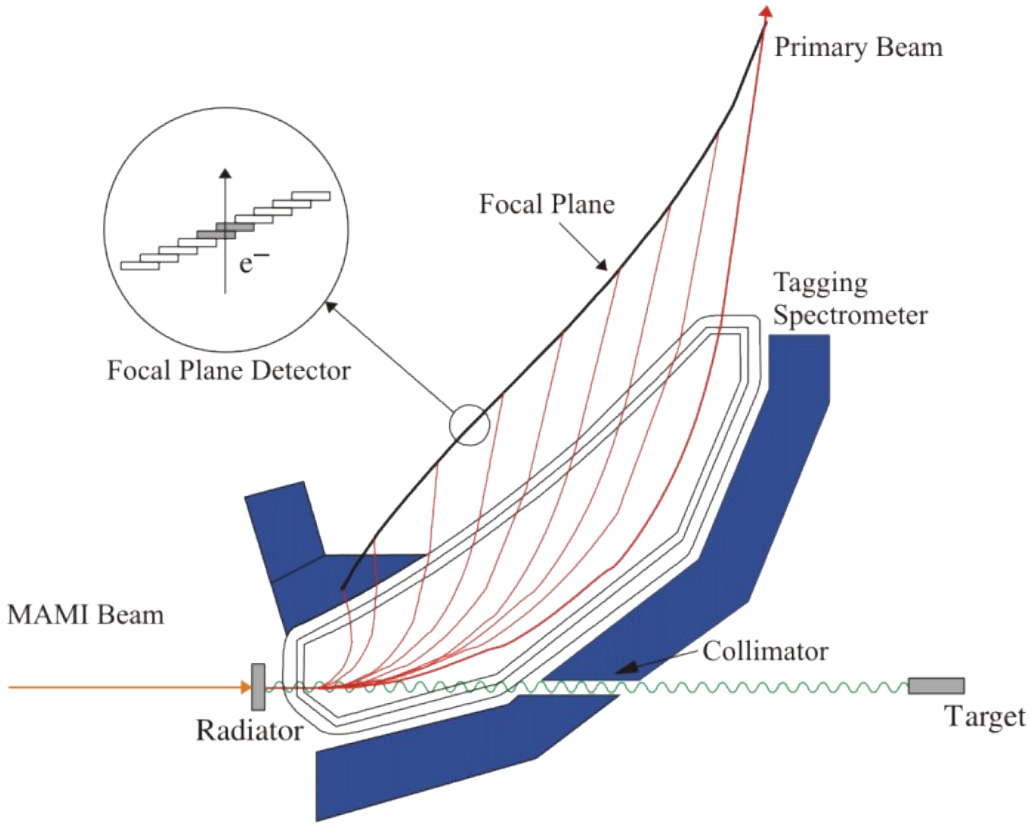
- Polarized electron beam
- Energy: 1557 MeV
- Current: 1~2 nA
- Helicity flipping



Taggerhall

A2 experimental setup @ MAMI

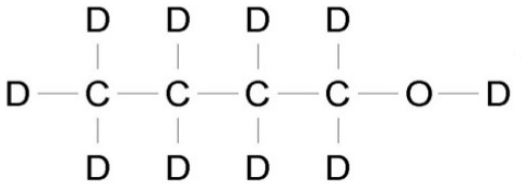
- **Photon beam**
  - Bremsstrahlung
- **Photon tagging with photon tagger**
  - $E_\gamma = E_{beam} - E_{e\ tagger}$
  - $E_\gamma < 1.5$ GeV
  - $\Delta E_\gamma = 2\text{-}4$ MeV
- **Photon flux normalization**
  - Dedicated runs
  - During data taking



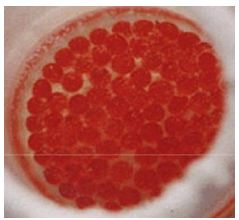
A2 experimental setup @ MAMI

Frozen Spin Target

- **Cryostat**
  - External magnet for polarization procedure
  - Frozen spin at 25 mK
  - Internal coil to maintain the polarization
- **Deuterated Butanol**
  - Quickly polarizable
  - Background nuclei with spin 0
  - Long relaxation time τ > 1000 h
- **Carbon foam**
  - For background subtraction



$$E = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}}$$



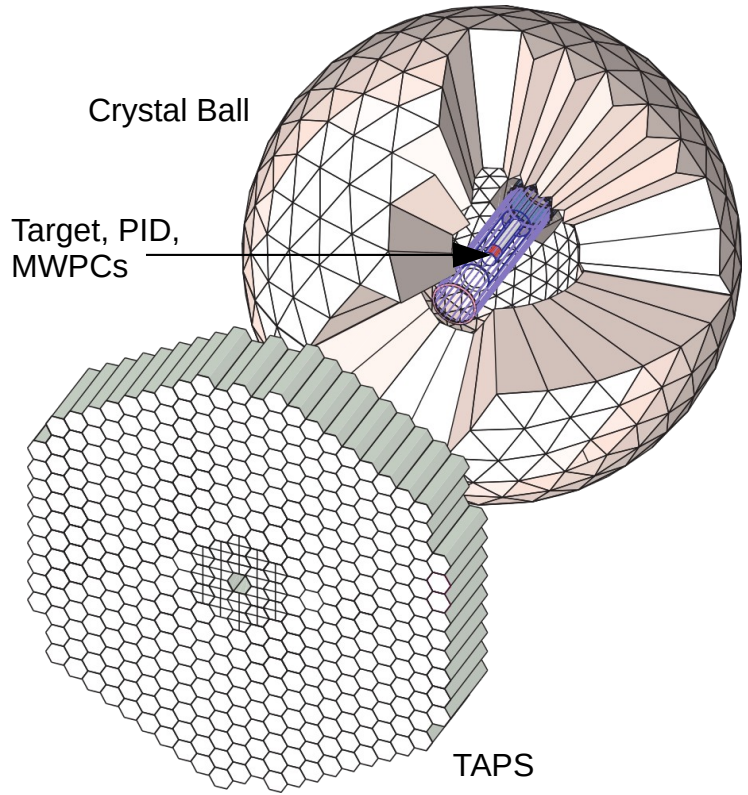
D-Butanol

Carbon

A2 experimental setup @ MAMI

Detectors

- **Crystal Ball**
  - 672 NaI crystals 20°<θ<160° (94%)
  - 24 plastic scintillators for dE-E particle identification
  - 2 MWPCs for charged particles
- **TAPS**
  - 366 BaF_2 crystals
  - 72 $PbWO_4$ crystals
  - 1°<θ<20° (3%)
  - 384 small scintillators for dE-E particle identification
  - Cerenkov for vetoing TAPS trigger



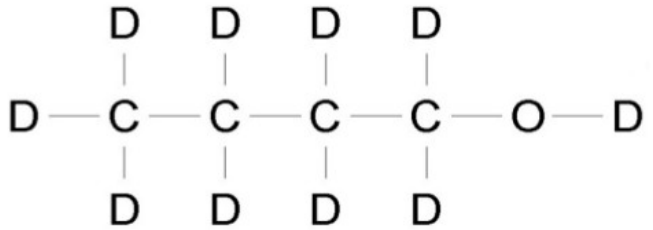
Inclusive π^0 polarized cross section on deuteron

$$\overrightarrow{\sigma} = \sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow} = \frac{N_{\uparrow\downarrow} - N_{\uparrow\uparrow}}{\#\gamma} \cdot \frac{1}{P_t} \cdot \frac{1}{P_\gamma} \cdot \frac{1}{\epsilon_{rec}} \cdot \frac{1}{d}$$

- Particle selection:
  - Only 1 π^0 reconstruction

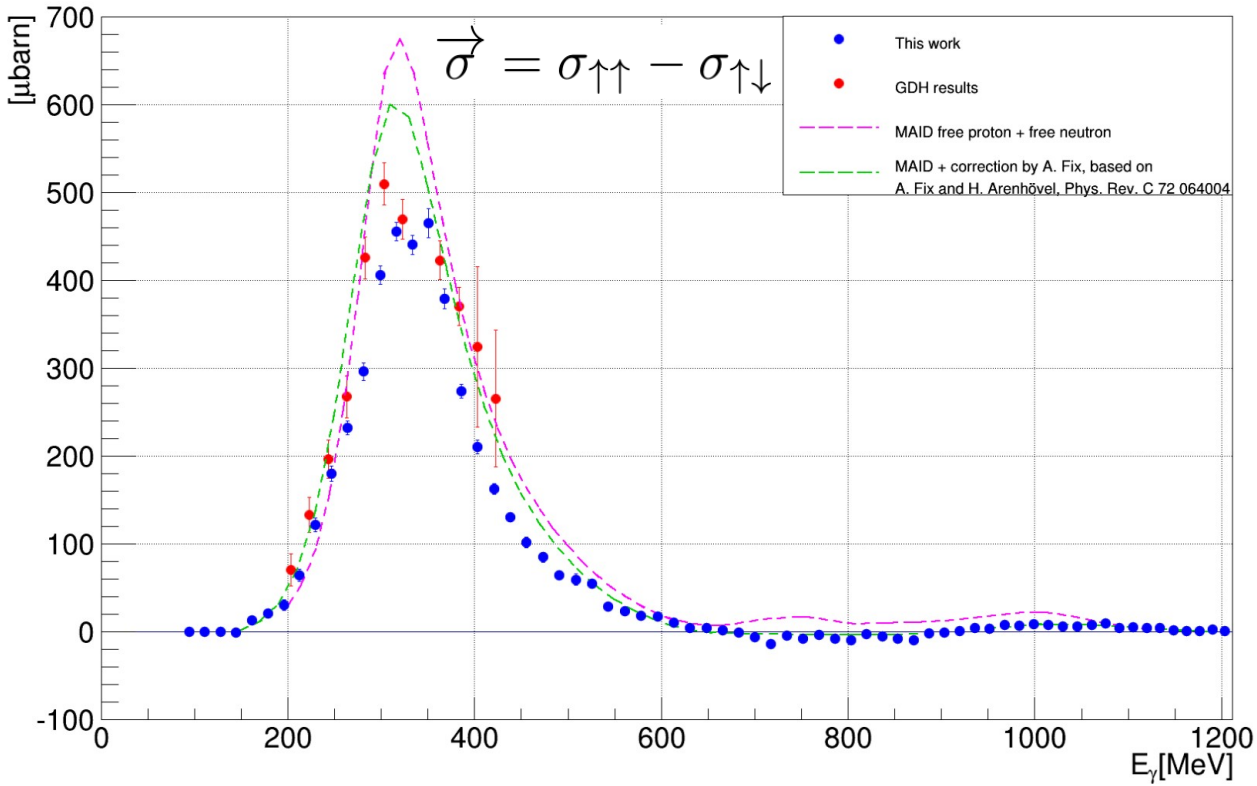
$\gamma + d \rightarrow \pi^0 + X$

- MC simulation for reconstruction efficiency and double pion contamination
- Photon flux normalization
- No contribution from unpolarized nucleons



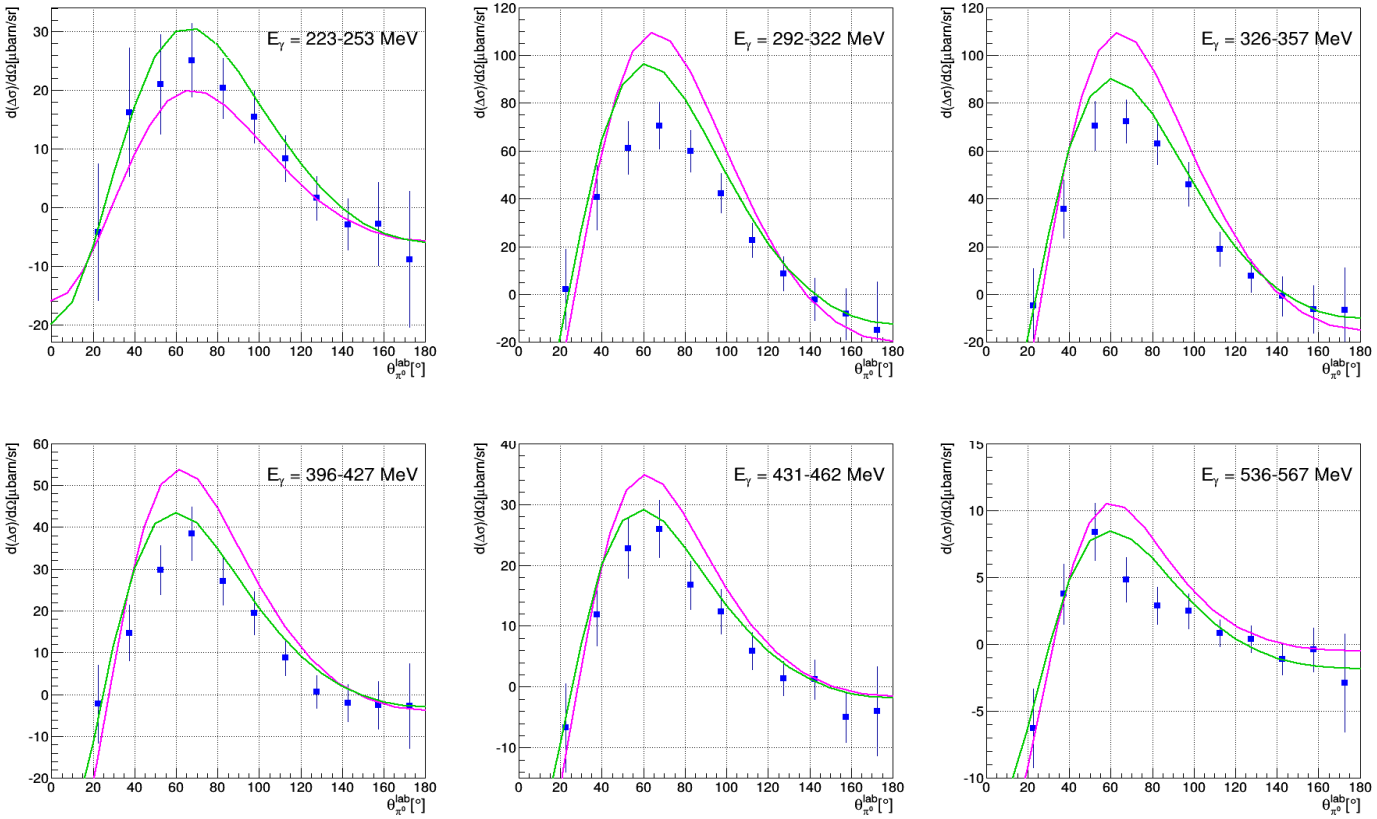
Single π^0 on deuteron

Total single π^0 polarized cross section [γ + d $\rightarrow \pi^0$ + X]



Single π^0 on deuteron

Differential polarized cross section



- 2014-2015 A2 Data
- MAID 2007 free proton + free neutron
- From A. Fix based on A. Fix and H. Arenhövel, Phys. Rev. C 72 064004

E observable for single π^0 on proton and neutron

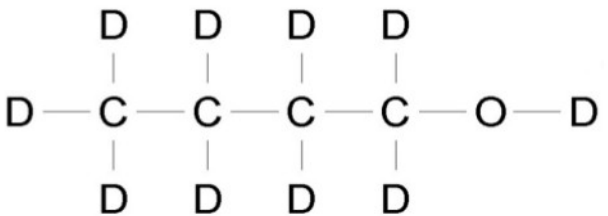
$$E = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}} = \frac{N^{\uparrow\uparrow} - N^{\uparrow\downarrow}}{(N^{\uparrow\uparrow} + N^{\uparrow\downarrow}) - N_C} \cdot \frac{1}{P_t} \cdot \frac{1}{P_\gamma}$$

- Particle identification:
  - 1 π^0 reconstruction
  - Nucleon identification

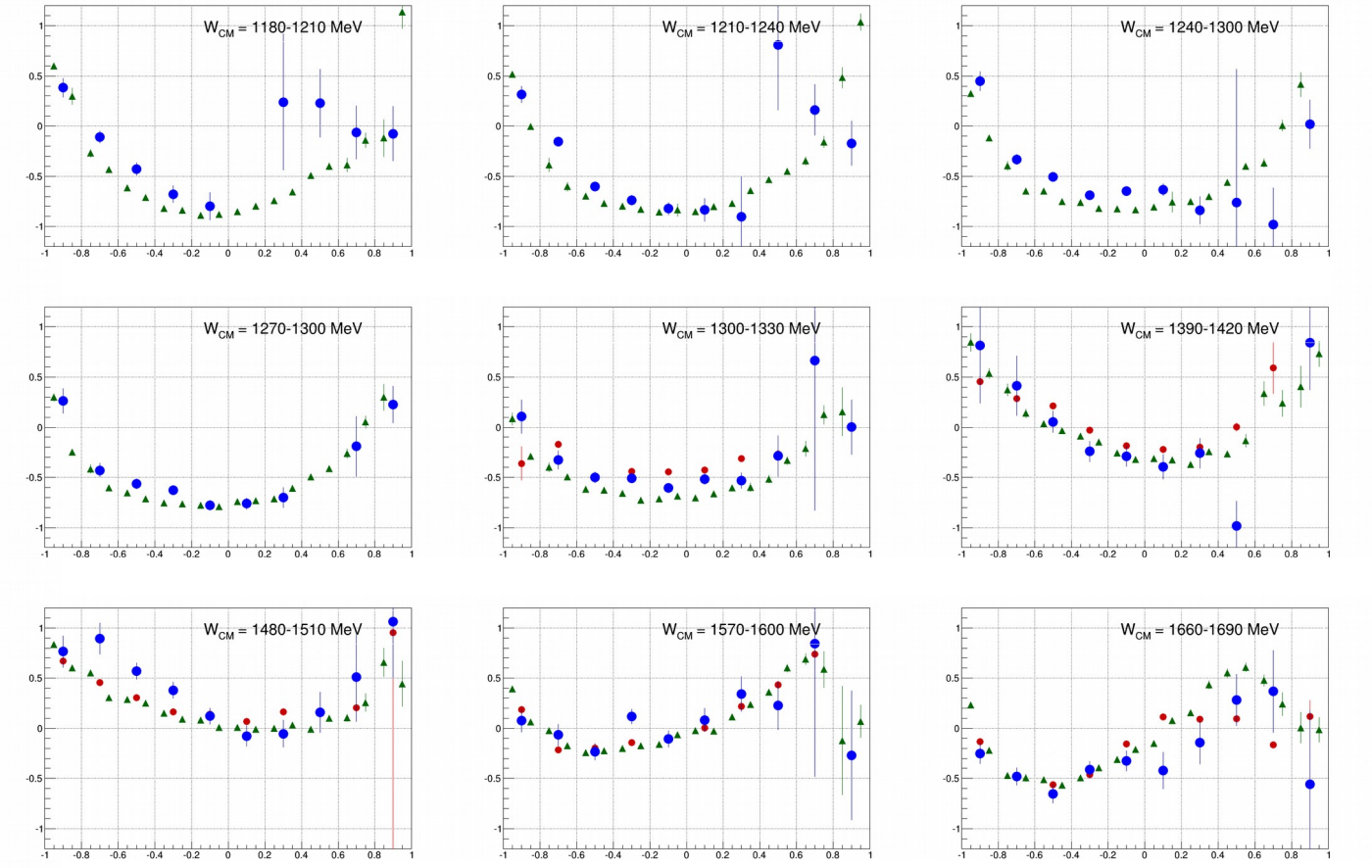
γ + d → **π^0 + p** + (n)

γ + d → **π^0 + n** + (p)

- Unpolarized carbon and oxygen background from D-Butanol molecule

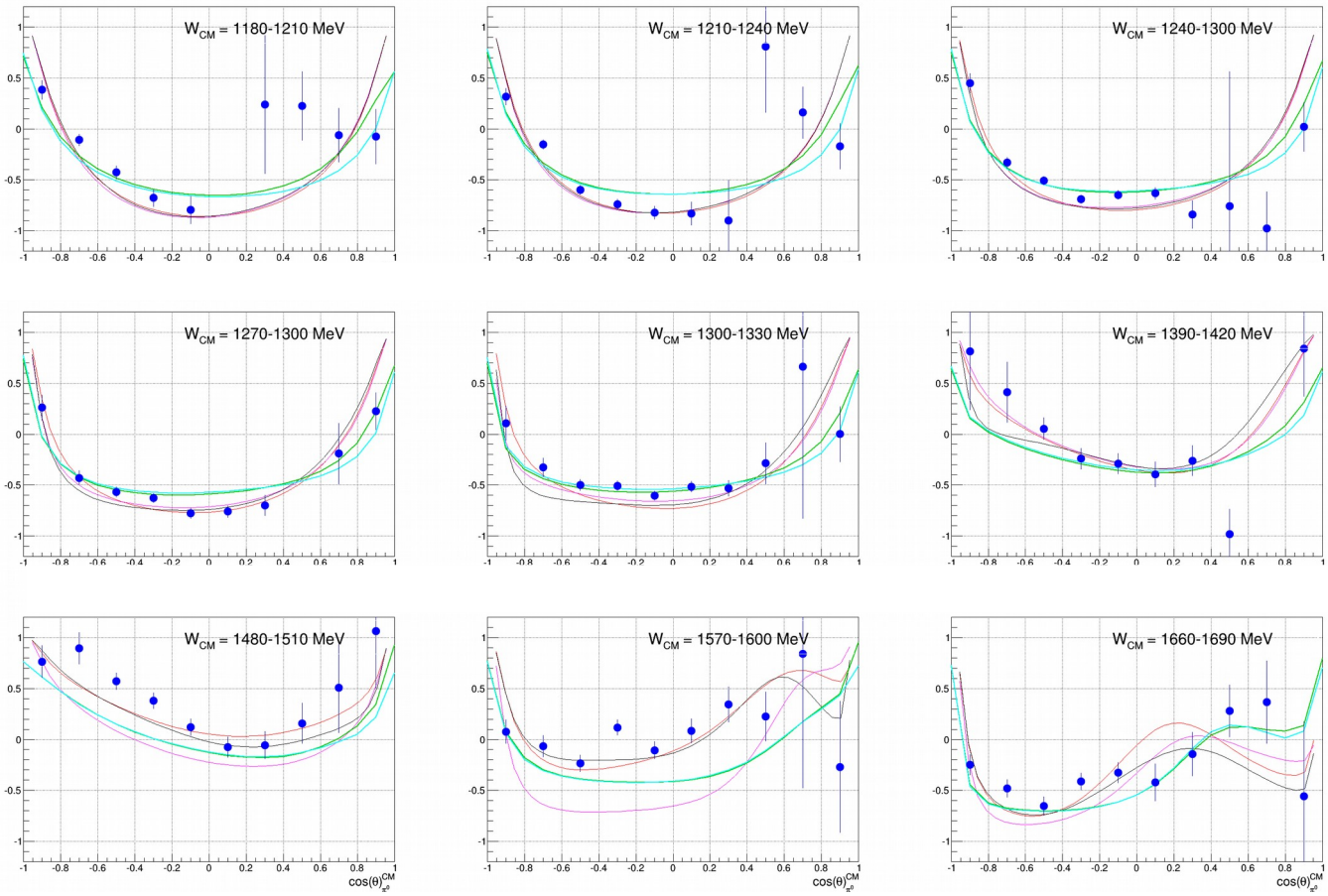


Results for observable E - proton



- This work
- Dieterle et al., Phys Lett B 770, 523, 2017
- E data for free proton from F. Afzal

Results for observable E - proton



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- Bonn-Gatchina 2014 02
- SAID 2007 cm 12
- MAID 2007 free proton
- MAID 2007 + IA, from A. Fix
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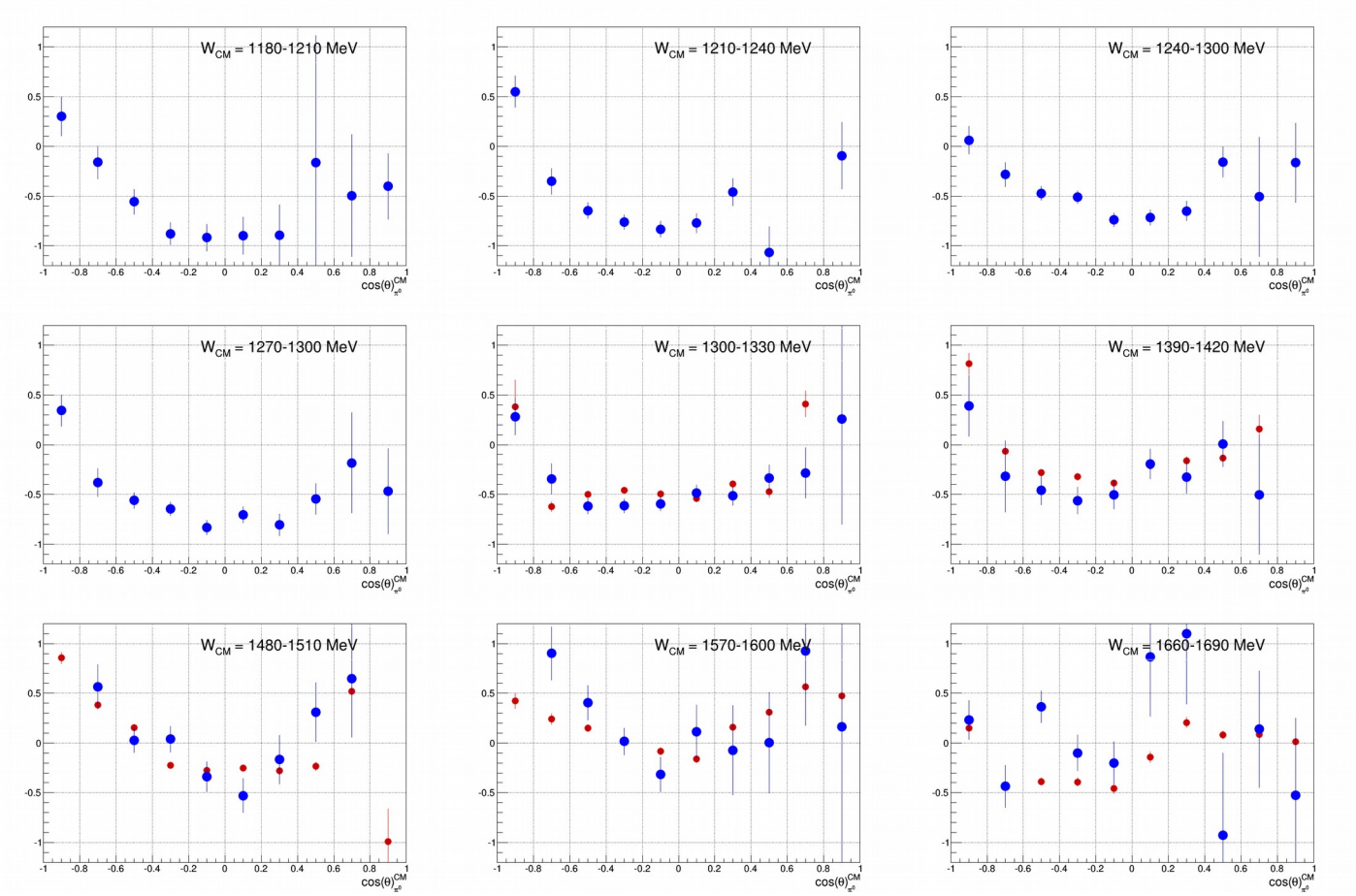
Results for observable E - neutron



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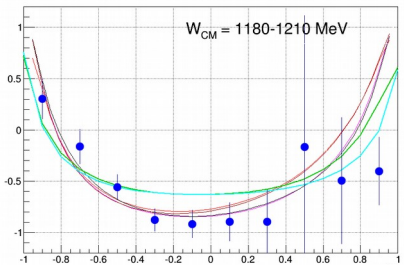

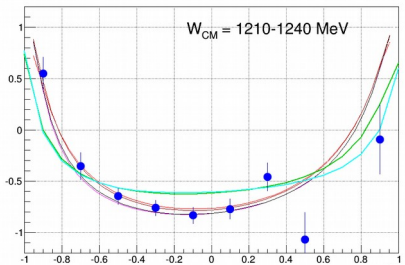

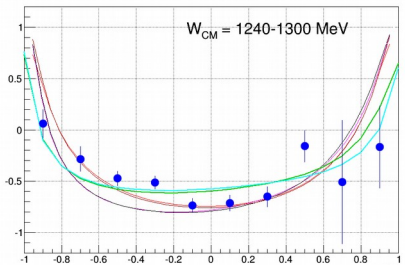

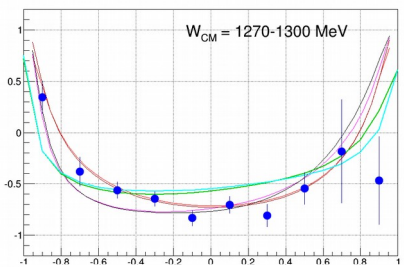

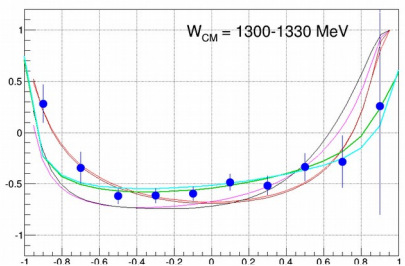

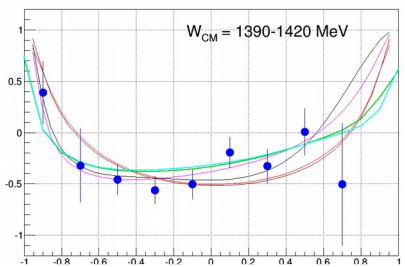

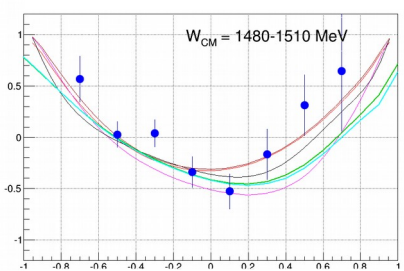

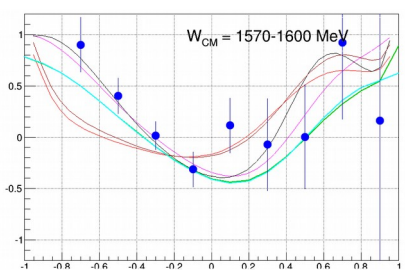

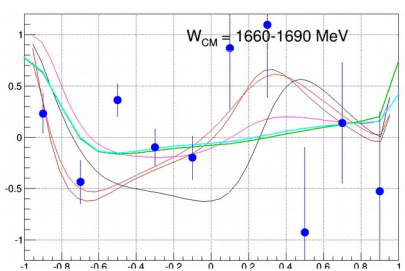

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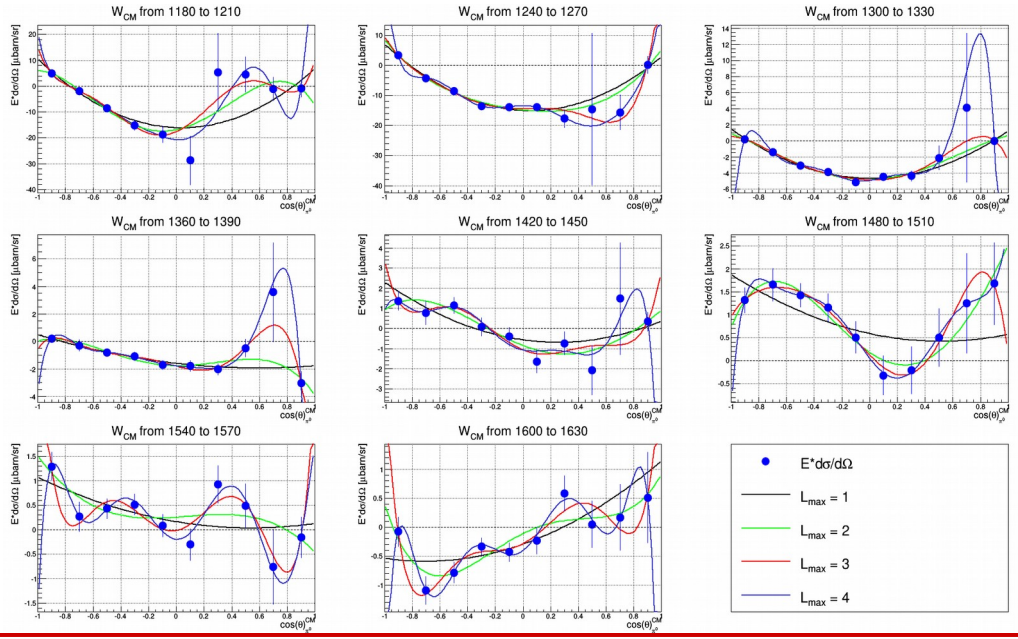
Legendre polynomials

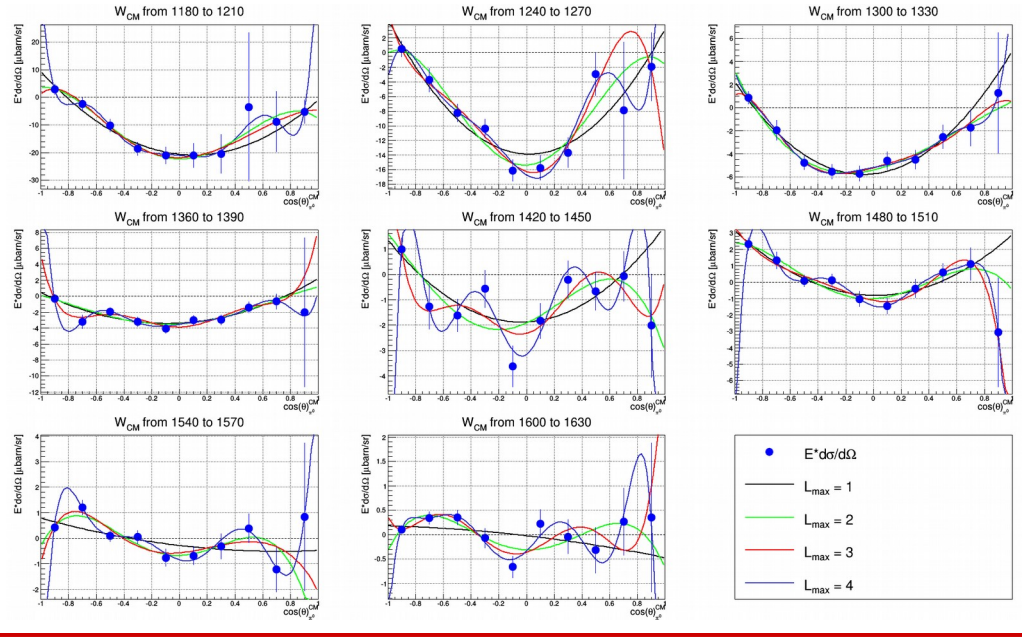
- *E* asymmetry multiplied with the unpolarized cross section from SAID model
- Fit performed with the Legendre associated function of 2nd order with L_{max} = 1, 2, 3, 4.

$$E(W,\theta)\cdot\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(W,\theta)=\sum_{k=0}^{2l_{max}}A_k^E(W)P_k^0(\cos\theta)$$

Proton



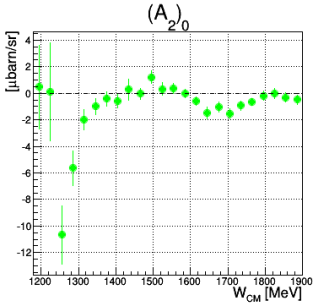
Neutron

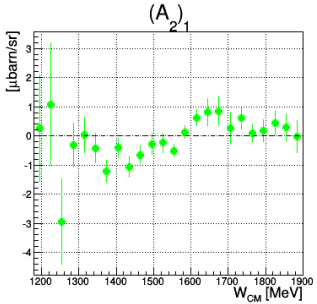


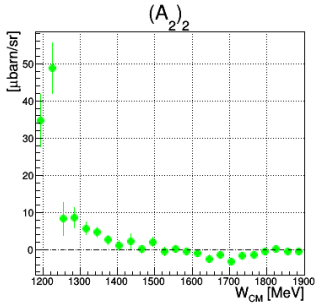
Legendre polynomials - proton

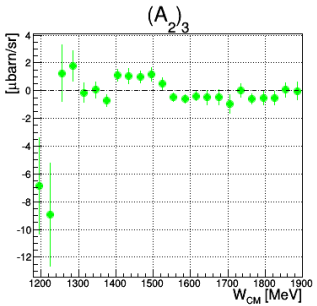
Parameters from the fits with $L_{max} = 2$

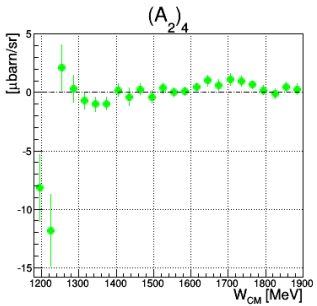
Proton











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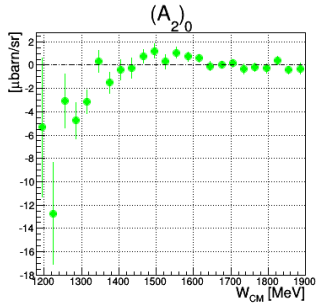
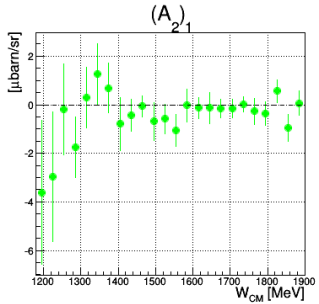
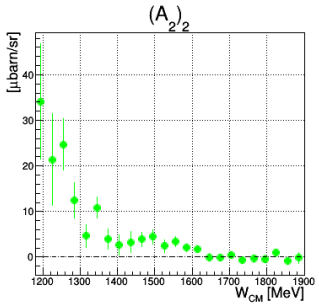
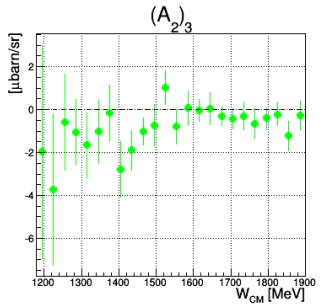
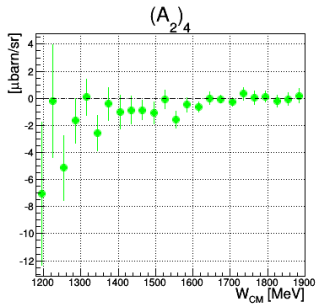




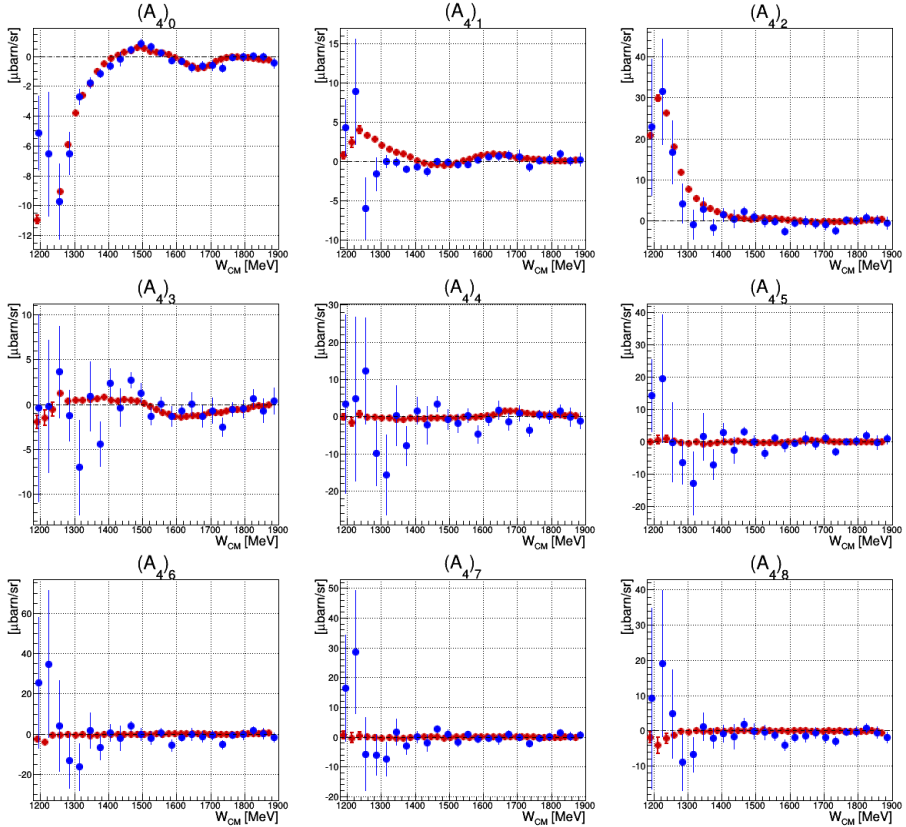






Legendre polynomials - proton

Parameters from the fits with $L_{max} = 4$



- This work
- From F. Afzal on free proton

Summary and conclusions

- Measurement of:
  - inclusive polarized single π^0 photoproduction on the deuteron
  - exclusive *E* asymmetry for π^0 from quasi-free proton and quasi-free neutron
- Extended energy range for *E*
- Agreement between independent analysis and measurements in A2
- Extraction of Legendre parameters
- New input for PWA for π^0 neutron

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Thank you for your attention!