Measurement of helicity dependence of π^0 photoproduction on deuteron

Federico Cividini (University of Mainz)

on behalf of A2 collaboration @ MAMI

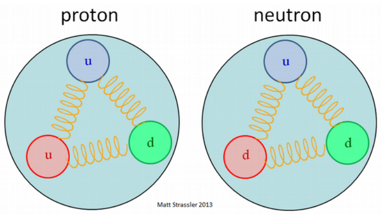
Meson 2018 – 11.06.2018, Kraków

Overview

- Motivation
- A2 experimental setup @ MAMI
- Analysis and results of single π^0 photoproduction from deuteron
- Proton and neutron identification & background subtraction
- Preliminary results of double polarized observable E from quasi-free proton and quasi-free neutron

Motivation

"One very powerful way of experimentally investigating the strongly interacting particles (**hadrons**) is to **look at them**, to probe them with a known particle; in particular the **photon** (no other is known as well). This permits a much finer control of variables, and probably decreases the theoretical complexity of the interactions" (Feynman, 1992).

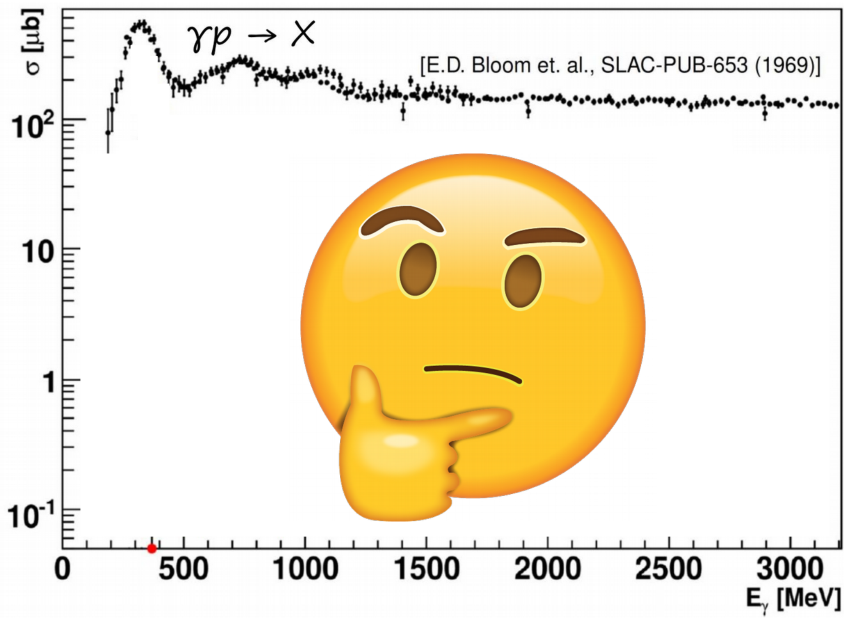


- To access the internal structure of the nucleon (<1 fm), which photon energy is needed?

$$E_\gamma \simeq \frac{200(MeV \cdot fm)}{\lambda_\gamma} \rightarrow E_\gamma \gtrsim 200\,MeV$$

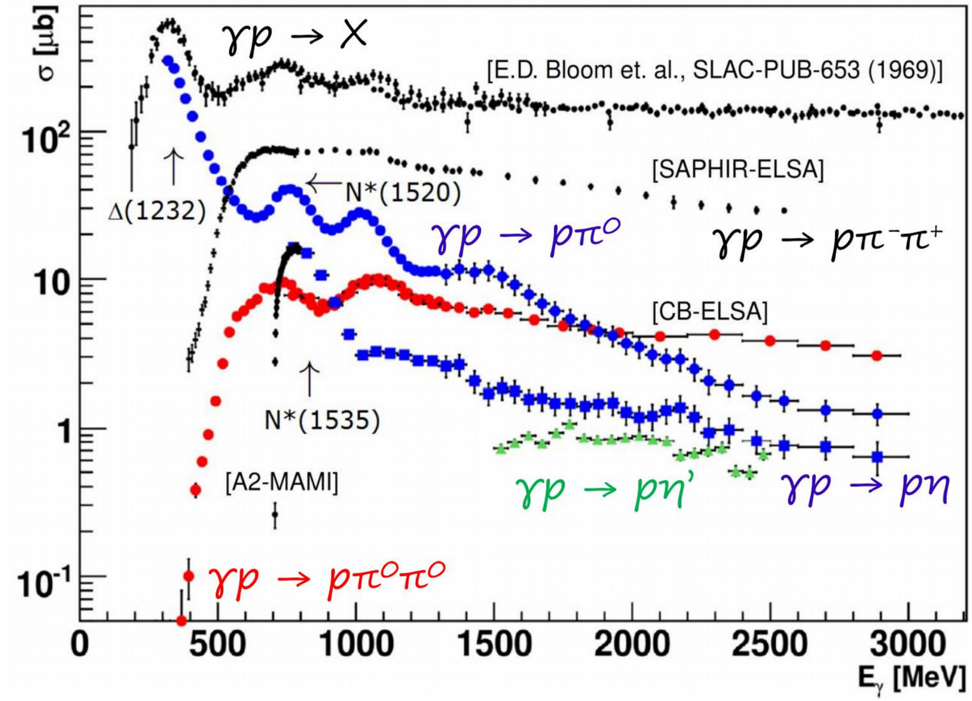
- The photon is absorbed by the nucleon and we can measure the total photo-absorption cross section

- What happens "under" the total unpolarized cross section?
  Is there something else to understand?



Motivation

- The photon changes the internal structure of the nucleon → Excited states (resonances)



- From the excited nucleon one (or more) pseudoscalar meson is emitted
- Nucleon resonances are broad and overlapping, cross section is not sufficient
- It is necessary to investigate the different final states

BARYON SPECTROSCOPY & MEASURE POLARIZATION OBSERVABLES

- To access resonances contributions which are small
- Test the PWA models

Motivation

- 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 $\xrightarrow{\textbf{Parity conservation}}$ **4 matrix elements**

- From these 4 complex amplitudes is possible to construct 16 bilinear products

16 polarization observables

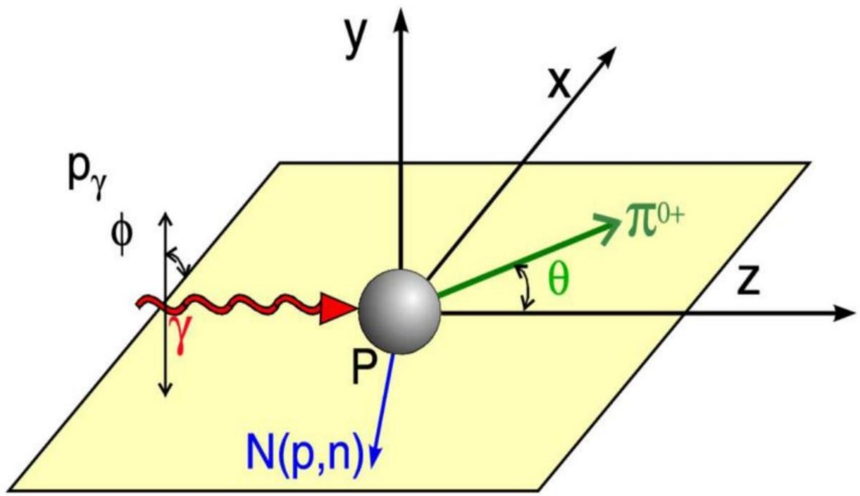
Photon polarization		Target polarization			Recoil nucleon polarization			Target and recoil polarizations			
	- -	- x	- y	- z	- x'	- y'	- x'	x' x	x' z	z' x	z' z
Unpolarized	σ	-	T	-	-	P	-	$T_{x'}$	$L_{x'}$	$T_{z'}$	$L_{z'}$
Linear polariz.	Σ	H	(-P)	G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(L_{z'})$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

1 unpolarized, 3 single polarized, 12 double polarized measurements

Motivation

“Complete (model independent) experiment”

Measurement of 8 observables (4 single polarization and 4 properly chosen double polarization observables) are sufficient to describe the amplitudes without ambiguities



Set		Observables			
Single (none)	S	$d\sigma/d\Sigma$	Σ	T	P
Beam-Target	BT	G	H	E	F
Beam-Recoil	BR	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{x'}$
Target-Recoil	TR	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$

Unpolarized, linearly polarized, circularly polarized beam

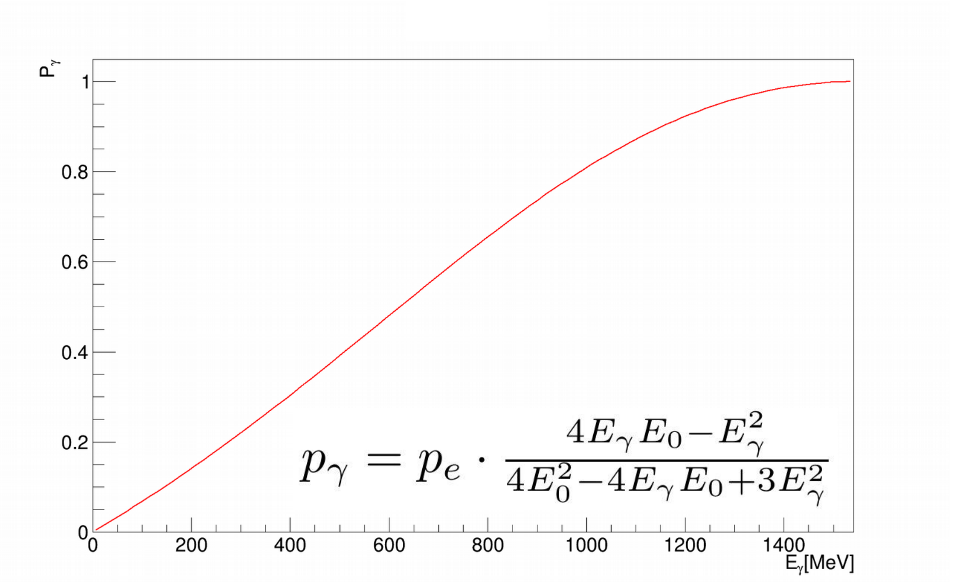
Measurement should include different production products → multiple photoproduction channels

→ **Focus on eta and pion production for the Beam-Target set in A2, my focus on E**

Motivation

Double polarization observable E

- Helicity transfer from electrons to photons → circularly polarized photon beam
- Longitudinally polarized target

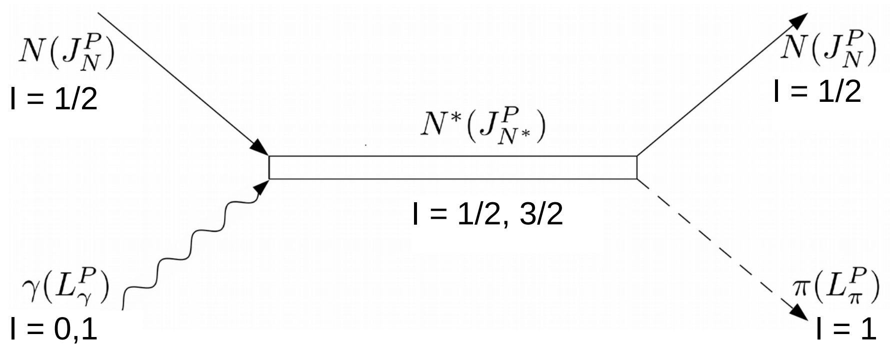


$$\frac{d\sigma}{d\Omega} = \sigma_0\{1 - P_T \sum cos2\varphi$$
$$+P_x\left(-P_T H sin2\varphi + P_\odot F\right)$$
$$+P_y\left(T - P_T P cos2\varphi\right)$$
$$+P_z\left(P_T G sin2\varphi - P_\odot E\right)\} \longrightarrow E = \frac{\sigma^{\frac{3}{2}} - \sigma^{\frac{1}{2}}}{\sigma^{\frac{3}{2}} + \sigma^{\frac{1}{2}}} = \frac{N^{\frac{3}{2}} - N^{\frac{1}{2}}}{N^{\frac{3}{2}} + N^{\frac{1}{2}}} \cdot \frac{1}{P_t} \cdot \frac{1}{P_\gamma}$$

And what about the Isospin?

Motivation

Isospin amplitudes



EM interaction → not conserve isospin

Strong interaction → conserve isospin

$$A(\gamma p \to n\pi^+) = -\sqrt{\frac{1}{3}}A^{V3} + \sqrt{\frac{2}{3}}(A^{VI} - A^{IS})$$

$$A(\gamma n \to p\pi^-) = +\sqrt{\frac{1}{3}}A^{V3} - \sqrt{\frac{2}{3}}(A^{VI} + A^{IS})$$

$$\boxed{\begin{aligned} A(\gamma p \to p\pi^0) &= +\sqrt{\frac{2}{3}}A^{V3} + \sqrt{\frac{1}{3}}(A^{VI} - A^{IS}) \\ A(\gamma n \to n\pi^0) &= +\sqrt{\frac{2}{3}}A^{V3} + \sqrt{\frac{1}{3}}(A^{VI} + A^{IS}) \end{aligned}}$$

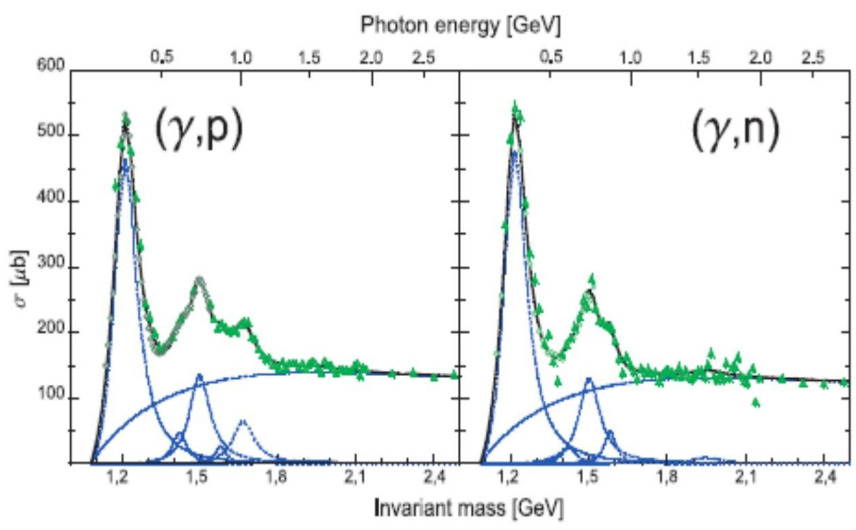
- A^{IS}= isoscalar transition with I=1/2 and I=0
- A^{VI}= isovector transition with I=1/2 and |ΔI|=1
- A^{V3}= isovector transition with I=3/2 and |ΔI|=1

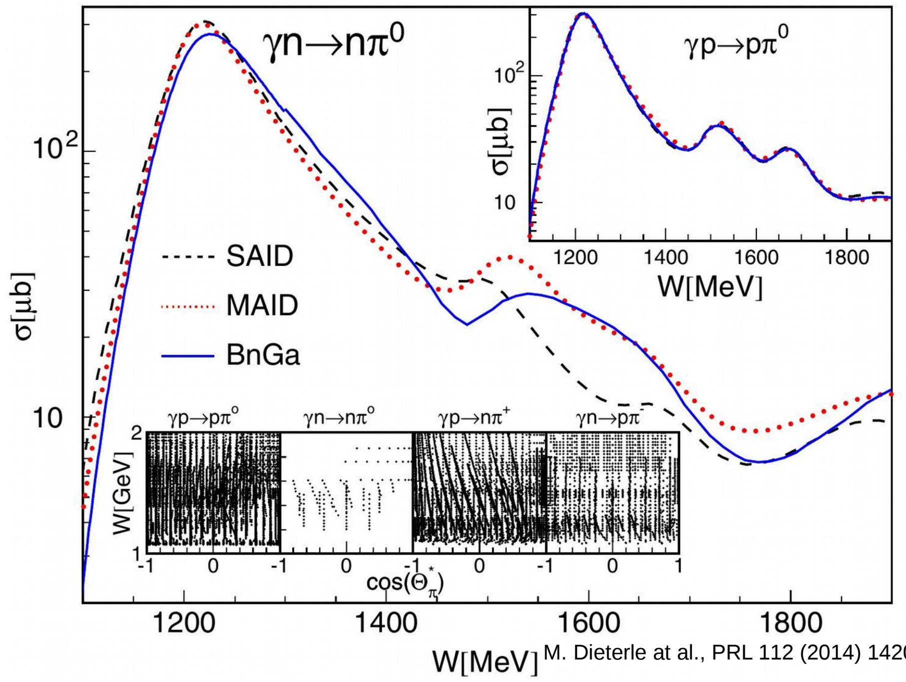
Complete set of pion production measurements on both proton and neutron are necessary!!

Motivation

Measurements with neutron target

- Lack of data for neutron
- No free neutron target → **Deuterium** or ^{3}He
- Nuclear effects → Fermi motion and FSI



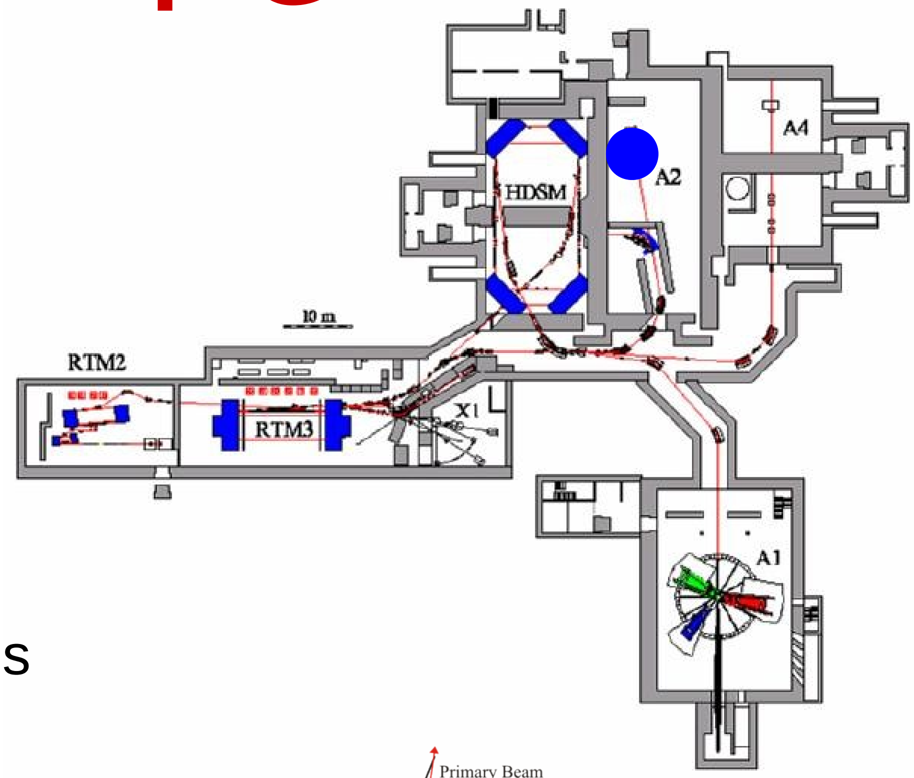


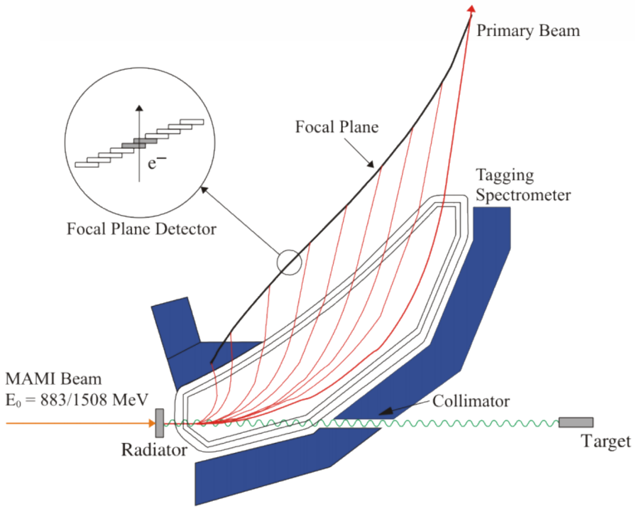
M. Dieterle at al., PRL 112 (2014) 142001

A2 experimental setup @ MAMI

- **Electron beam**
  - Laser source for polarized electrons
  - Energy: 1557 MeV
  - Max pol degree ~ 75-78%
- **Photon beam**
  - Bremsstrahlung $E_\gamma = E_{beam} - E_{e\ tagger}$
  - Helicity transfer from electrons to photons
- **Photon tagging with FPD**
  - E_γ <1.5 GeV
  - ΔE_γ= 2-4 MeV
- **Tagging efficiency**

  for photon flux normalization

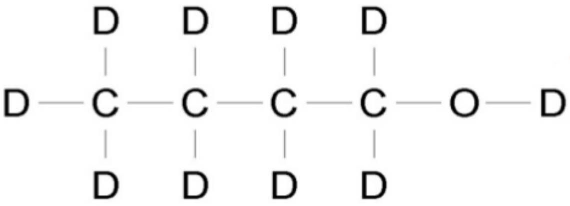


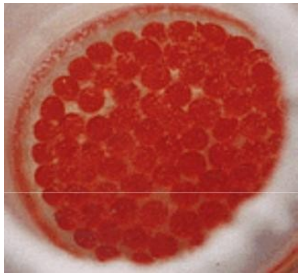


A2 experimental setup @ MAMI

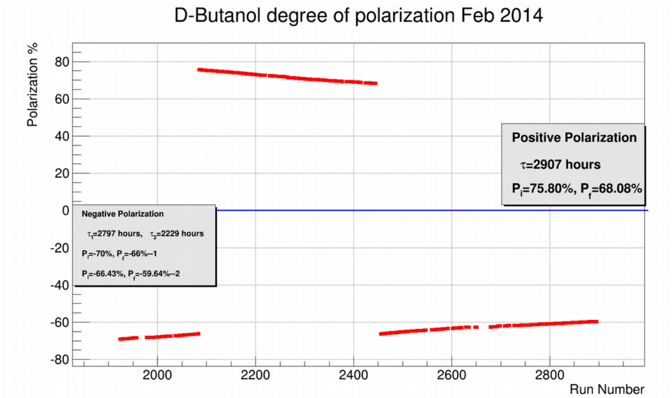
Frozen Spin Target

- **Cryostat**
  - Dynamic nuclear polarization with micro-wave irradiation at 70 GHz and 2.5 T to transfer the polarization from electrons to nucleons
  - Cryostat with mixture of $^3He/^4He$ at 25 mK
  - 0.63 T coil to maintain the polarization





- **Deuterated Butanol**
  - Quickly polarizable
  - Background nuclei with spin 0
  - Long relaxation time t > 2000 h

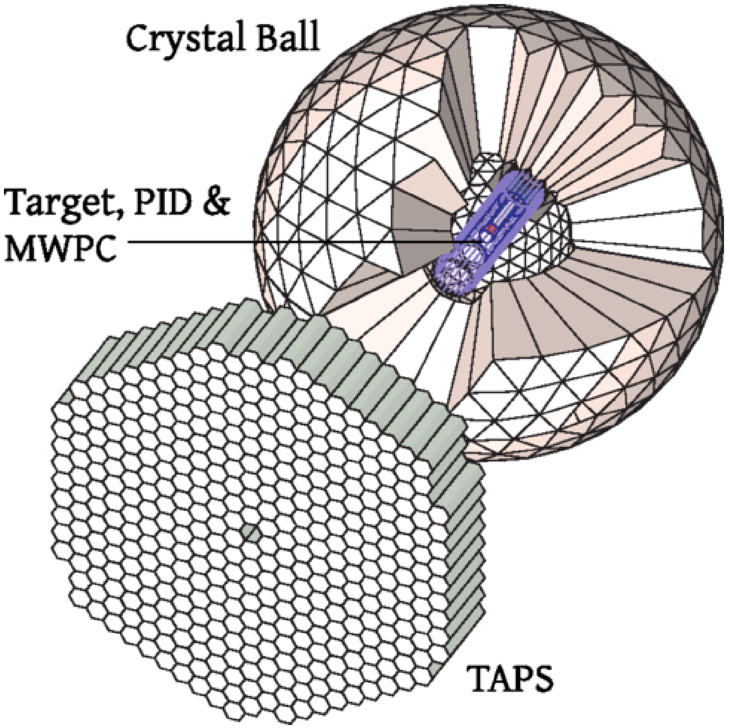


- **Carbon foam**
  - For background subtraction

A2 experimental setup @ MAMI

Detectors

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



Single π^0 on deuteron

Polarized cross section on deuteron

$$\sigma_{pol} = \sigma_A - \sigma_P$$

- Particle selection:
  - Only 1 π^0 reconstruction
- MC simulation
- Tagging efficiency calculation

E observable on proton and neutron

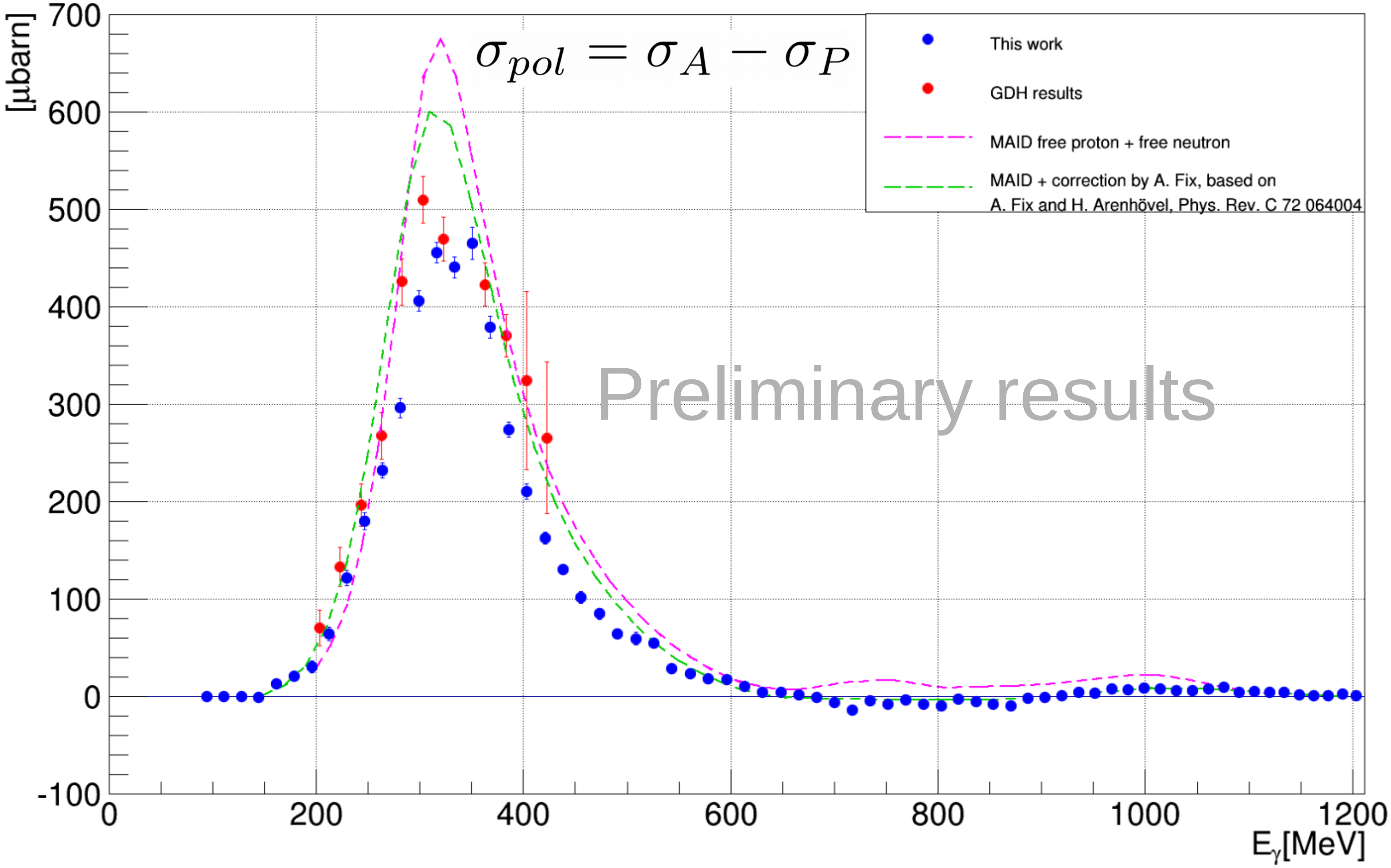
$$E = \frac{\sigma^{\frac{3}{2}} - \sigma^{\frac{1}{2}}}{\sigma^{\frac{3}{2}} + \sigma^{\frac{1}{2}}} = \frac{N^{\frac{3}{2}} - N^{\frac{1}{2}}}{N^{\frac{3}{2}} + N^{\frac{1}{2}}} \cdot \frac{1}{P_t} \cdot \frac{1}{P_\gamma} \cdot \frac{1}{D}$$

- Particle identification:
  - 1 π^0 reconstruction
  - Nucleon identification
- Carbon and oxygen background from D-Butanol molecule

Single π^0 on deuteron

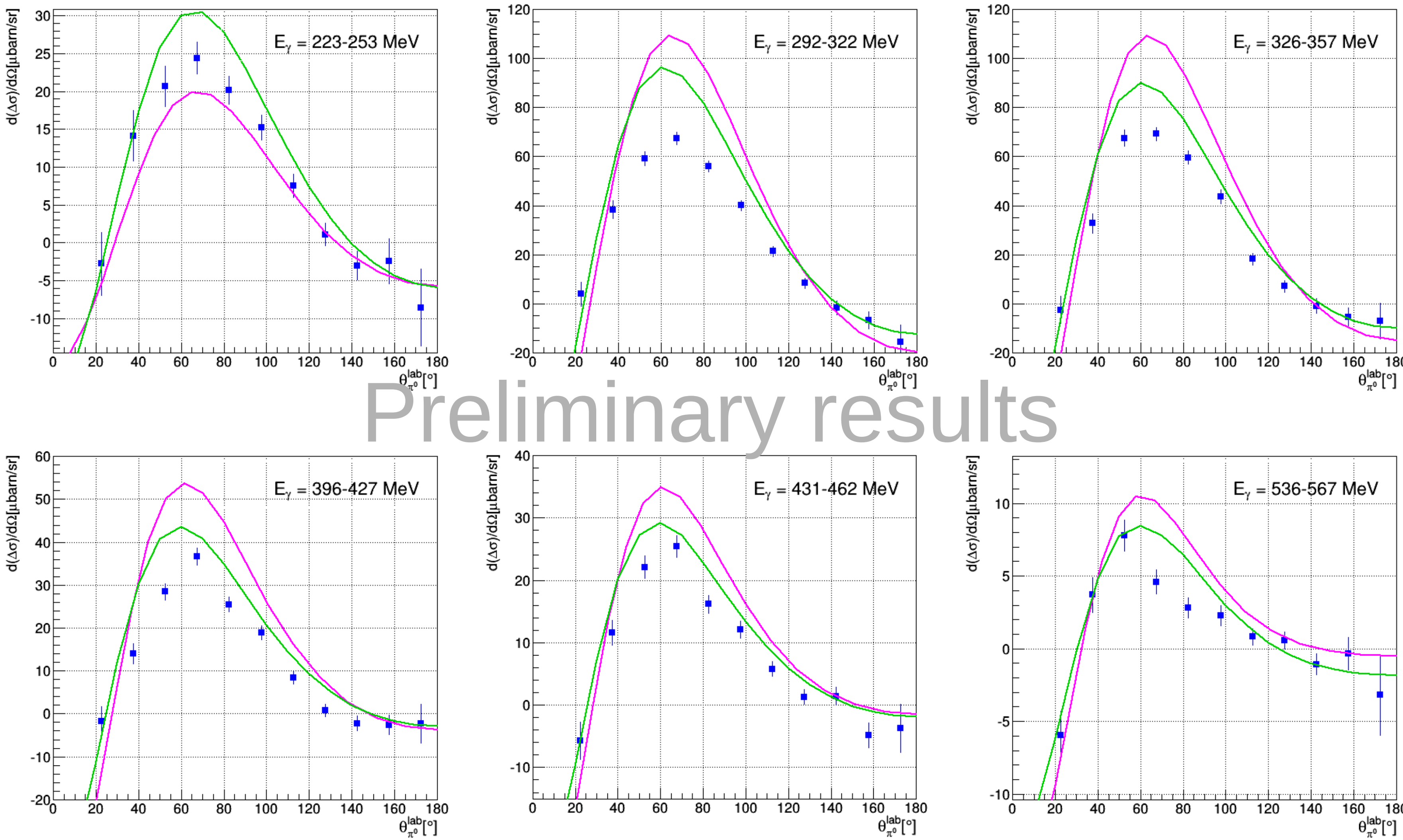
Total single π^0 polarized cross section

Selection of the events: $\gamma + d \rightarrow \pi^0 + X$



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

Single π^0 on deuteron

Polarized cross section on deuteron

$$\sigma_{pol} = \sigma_A - \sigma_P$$

- Particle selection:
  - Only 1 π^0 reconstruction
- Efficiency simulation
- Tagging efficiency calculation

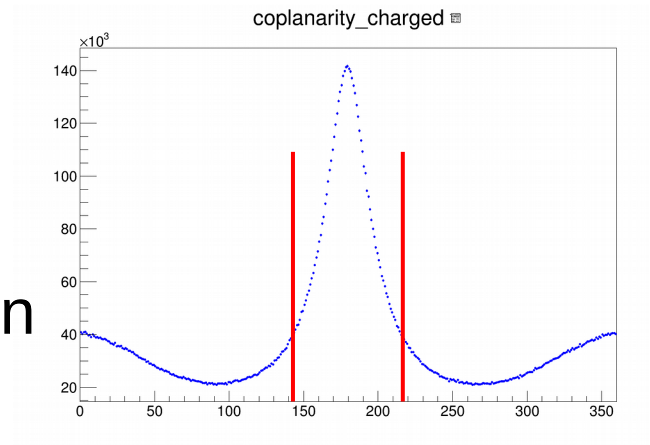
E observable on proton and neutron

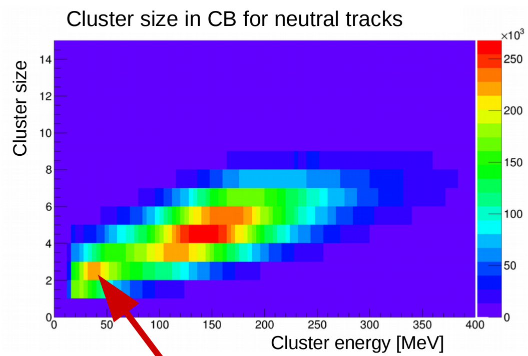
$$E = \frac{\sigma^{\frac{3}{2}} - \sigma^{\frac{1}{2}}}{\sigma^{\frac{3}{2}} + \sigma^{\frac{1}{2}}} = \frac{N^{\frac{3}{2}} - N^{\frac{1}{2}}}{N^{\frac{3}{2}} + N^{\frac{1}{2}}} \cdot \frac{1}{P_t} \cdot \frac{1}{P_\gamma} \cdot \frac{1}{D}$$

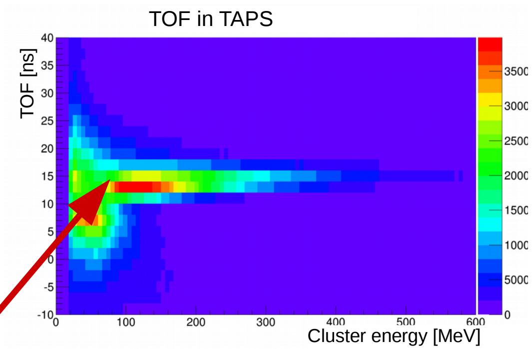
- Particle identification:
  - 1 π^0 reconstruction
  - Nucleon identification
- Carbon and oxygen background from D-Butanol molecule

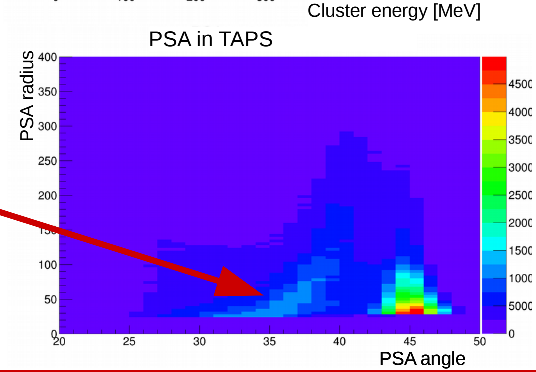
Nucleon identification

- Focus on the tracks not used for π^0 reconstruction
- Coplanarity for nucleon candidates
- TOF and PSA in TAPS
- Cluster size in CB for neutron-photons separation
- dE/E, check for protons selection



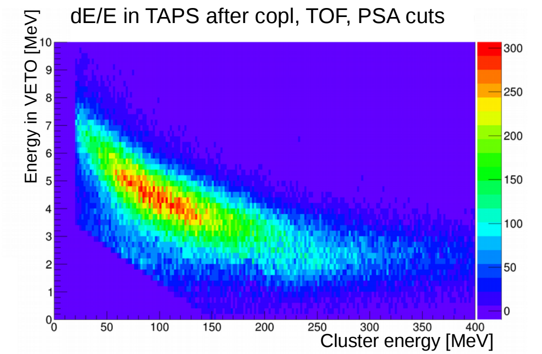


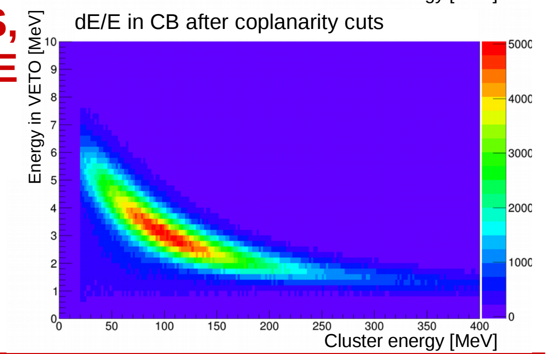




HADRONS

GOOD PROTONS SELECTION AFTER THE CUTS, CHECK WITH dE/E IN CB AND TAPS

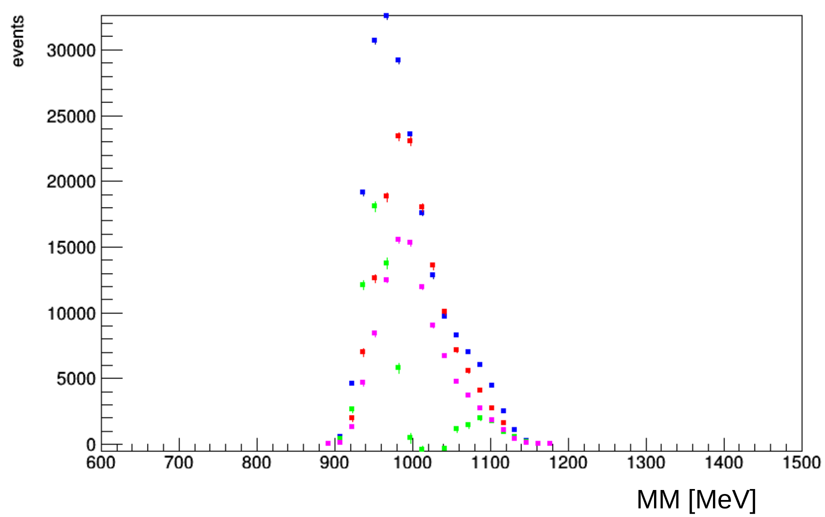




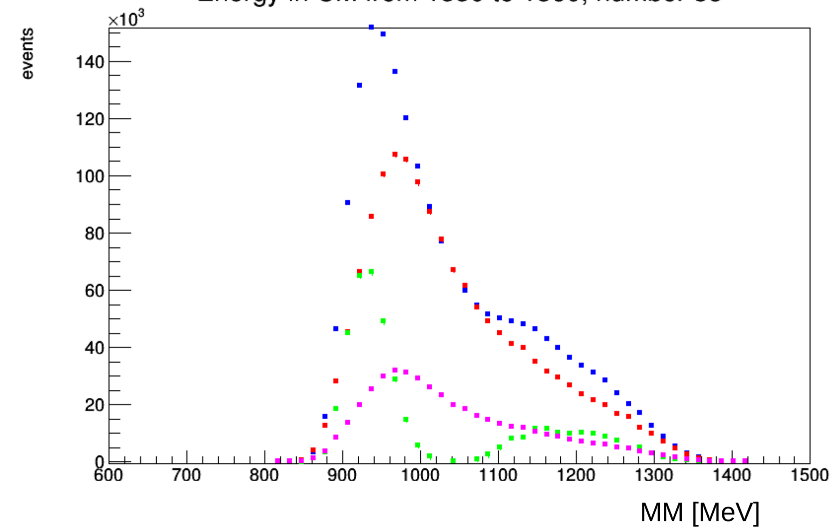
Carbon subtraction

Missing mass plots for proton events

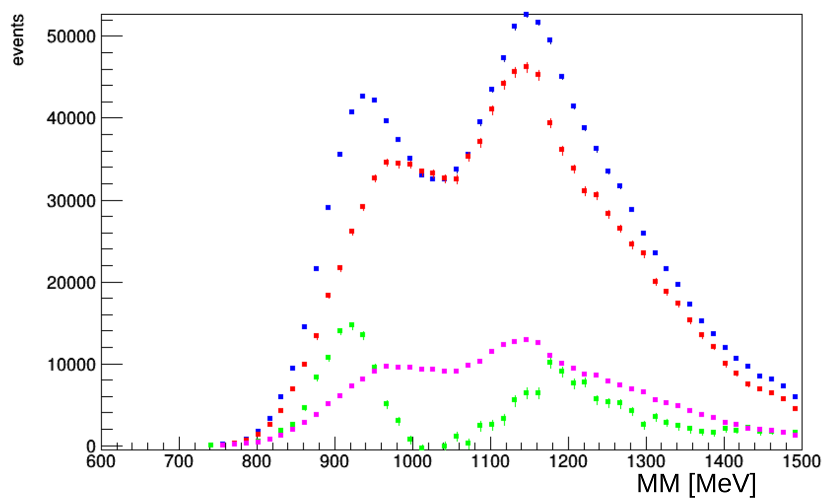
Energy in CM from 1180 to 1210, number 40



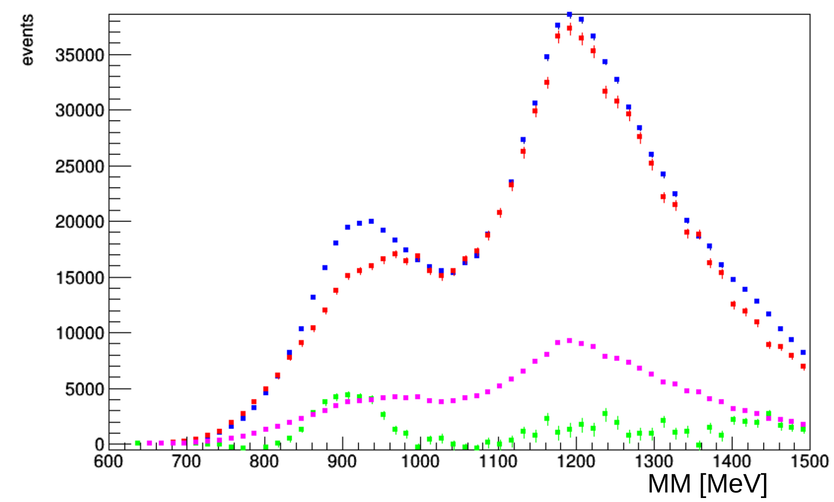
Energy in CM from 1330 to 1360, number 35



Energy in CM from 1480 to 1510, number 30

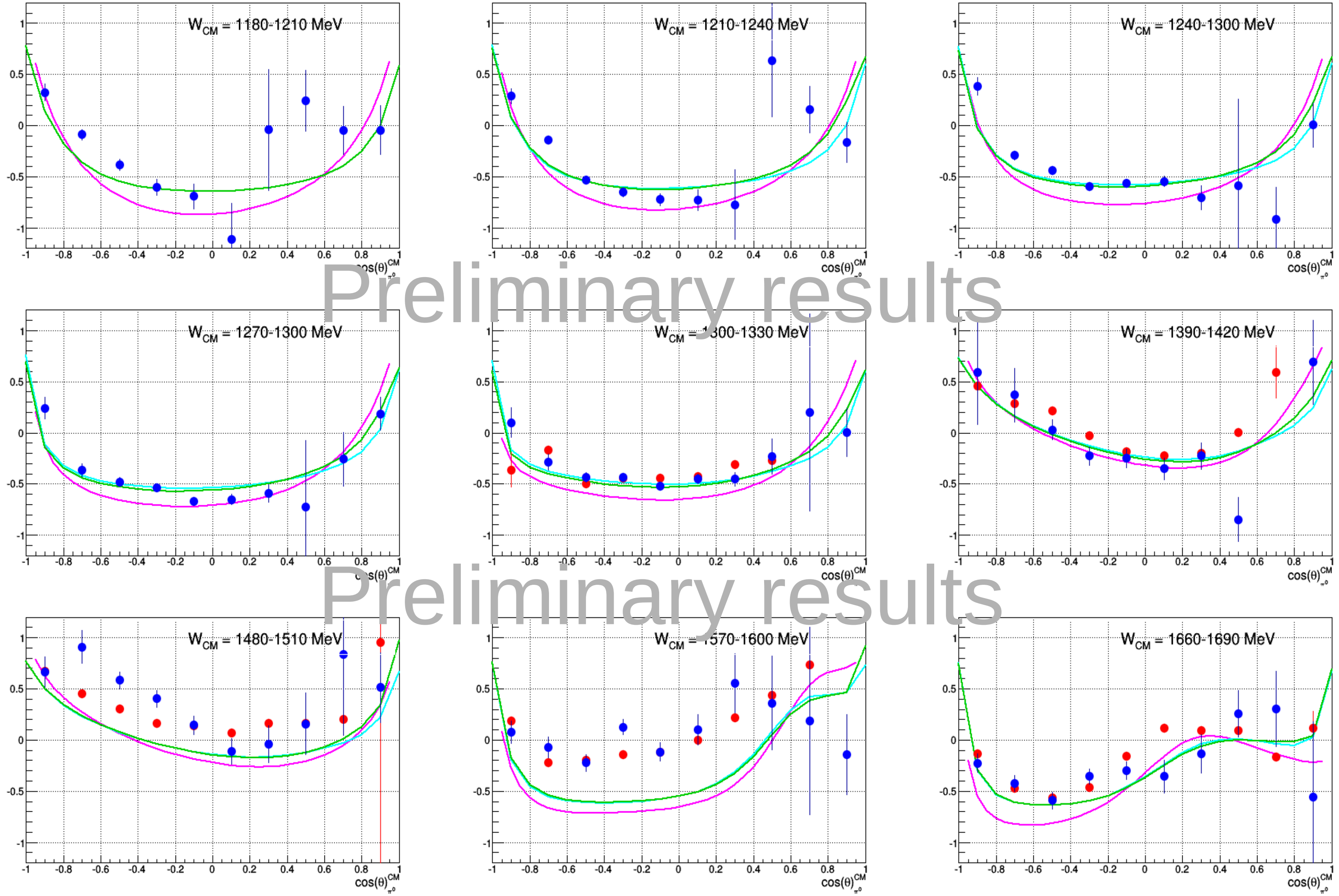


Energy in CM from 1630 to 1660, number 25



Events from: Butanol, Carbon_original, Carbon_with_scaling_factor, Protons

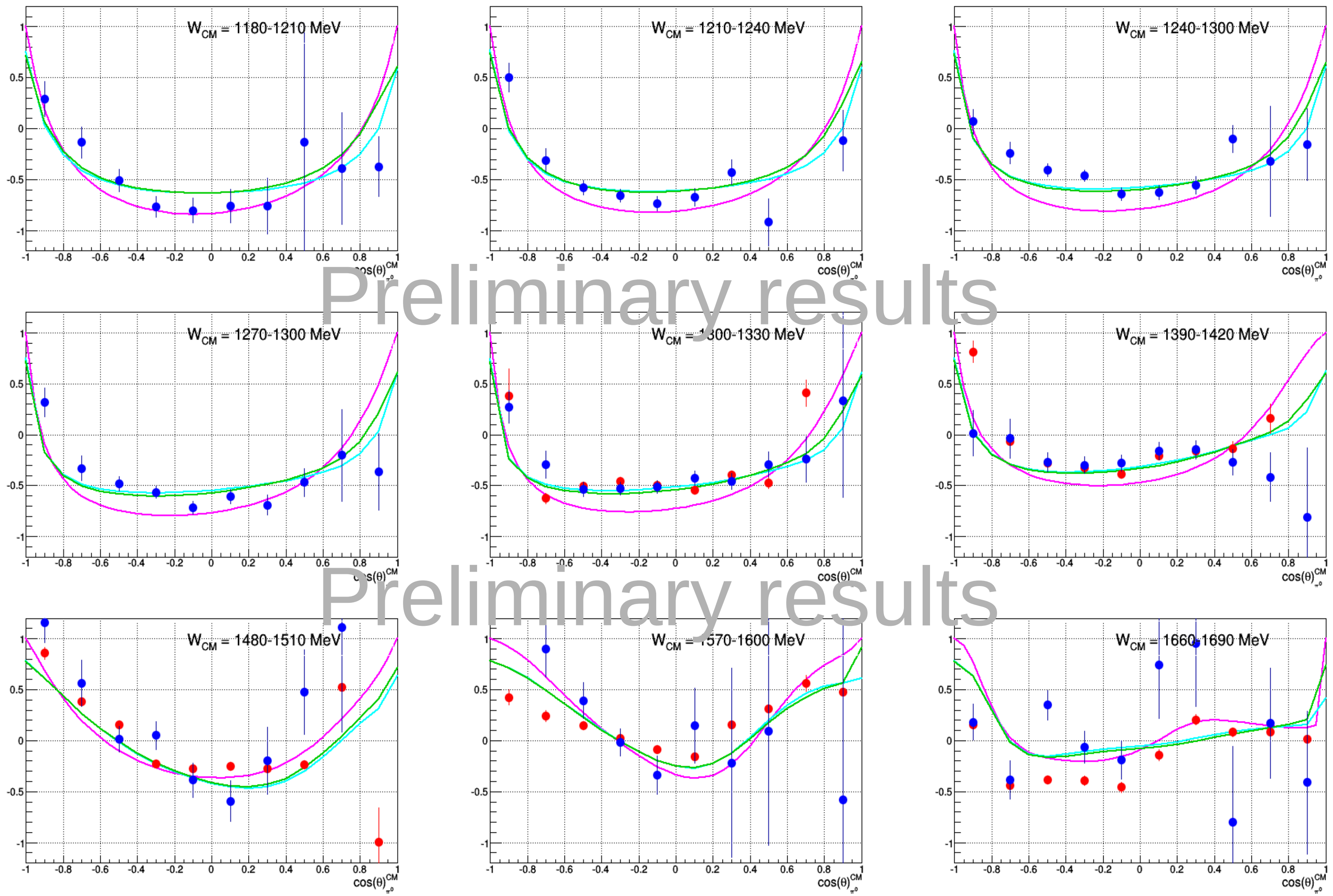
Results for observable E - proton



● This work ● Dieterle et al., Phys Lett B 770, 523, 2017 — MAID 2007 free proton

— MAID 2007 + IA, from A. Fix — MAID 2007 + IA + FSI, from A. Fix (based on A. Fix and H. Arenhövel, Phys. Rev. C 72 064005)

Results for observable E - neutron



● This work ● Dieterle et al., Phys Lett B 770, 523, 2017 — MAID 2007 free neutron
— MAID 2007 + IA, from A. Fix — MAID 2007 + IA + FSI, from A. Fix (based on A. Fix and H. Arenhövel, Phys. Rev. C 72 064005)

Conclusions

- First data with large energy range for $\gamma + d \rightarrow \pi^0 + X$
- Preliminary results in agreement with previous measurements
- Larger energy range for E observable from quasi-free proton and quasi-free neutron

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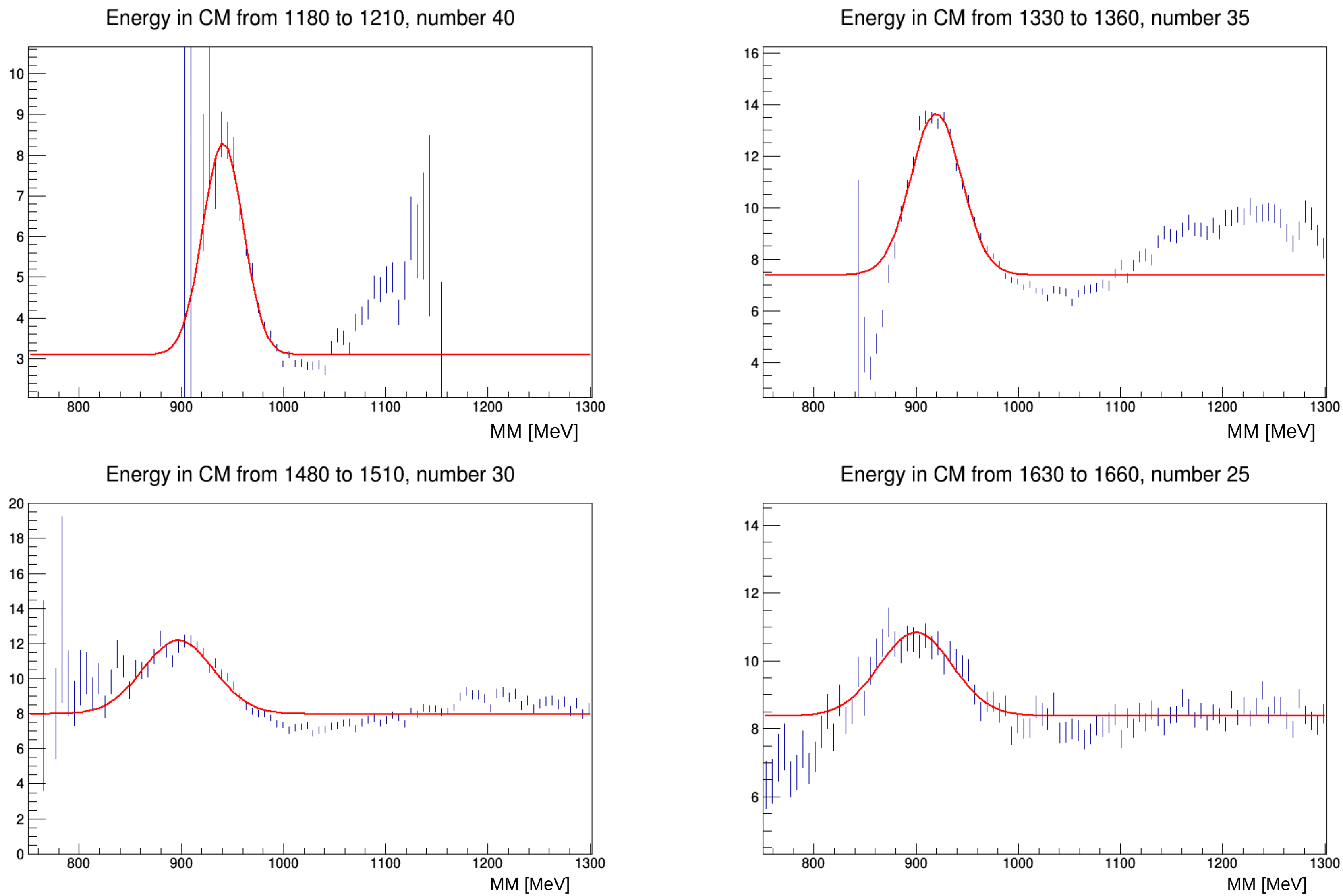
Thank you for your attention!

Plenary talk by Philippe Martel, tomorrow at 10:30
"Meson Investigations by the MAMI A2 Collaboration"

ADDITIONAL MATERIAL

Carbon subtraction

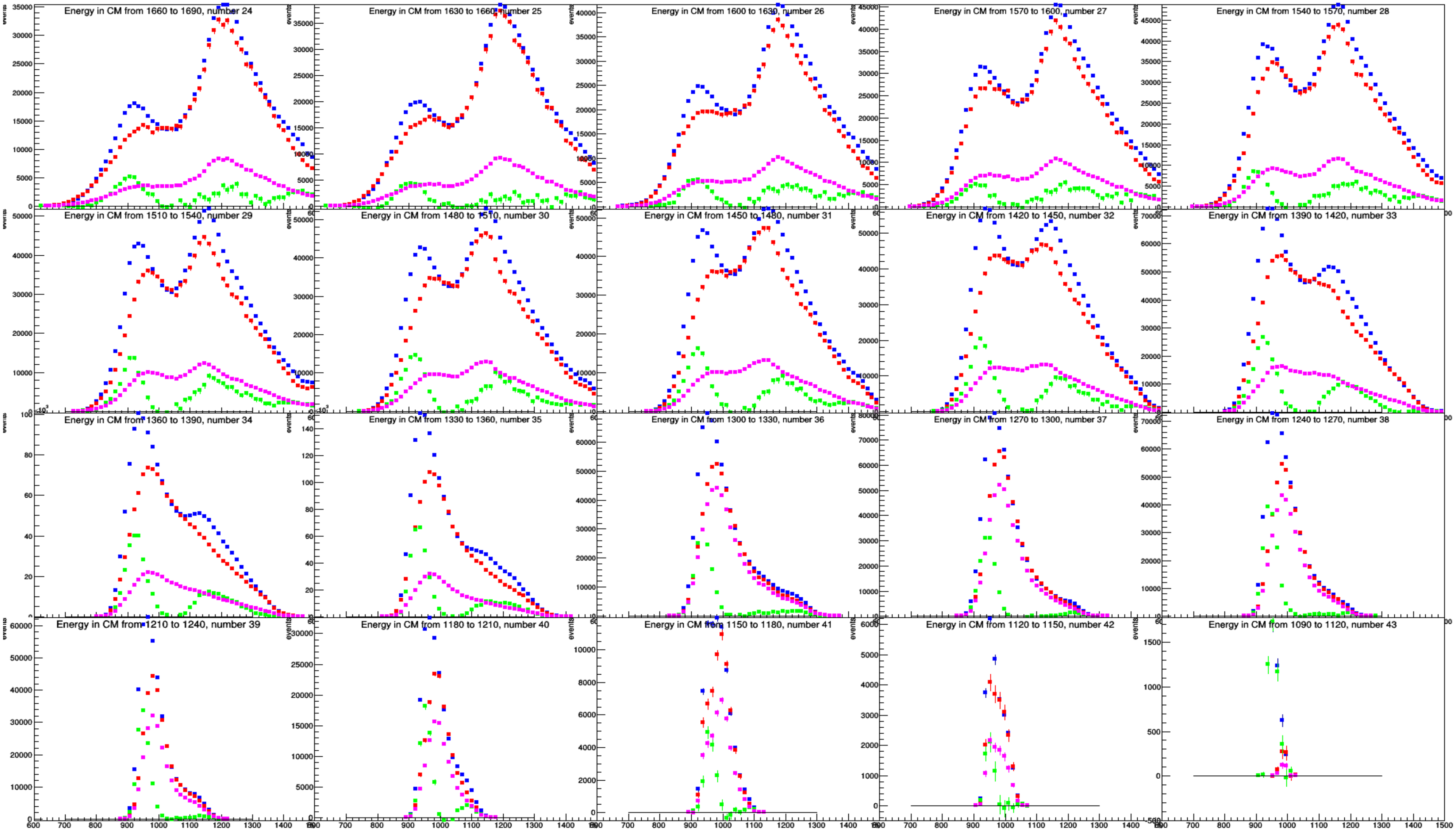
Ratio between butanol and carbon missing mass



Fit with a gaussian+pol(0), the pol(0) is the scaling factor

Single π^0 on quasi-free proton

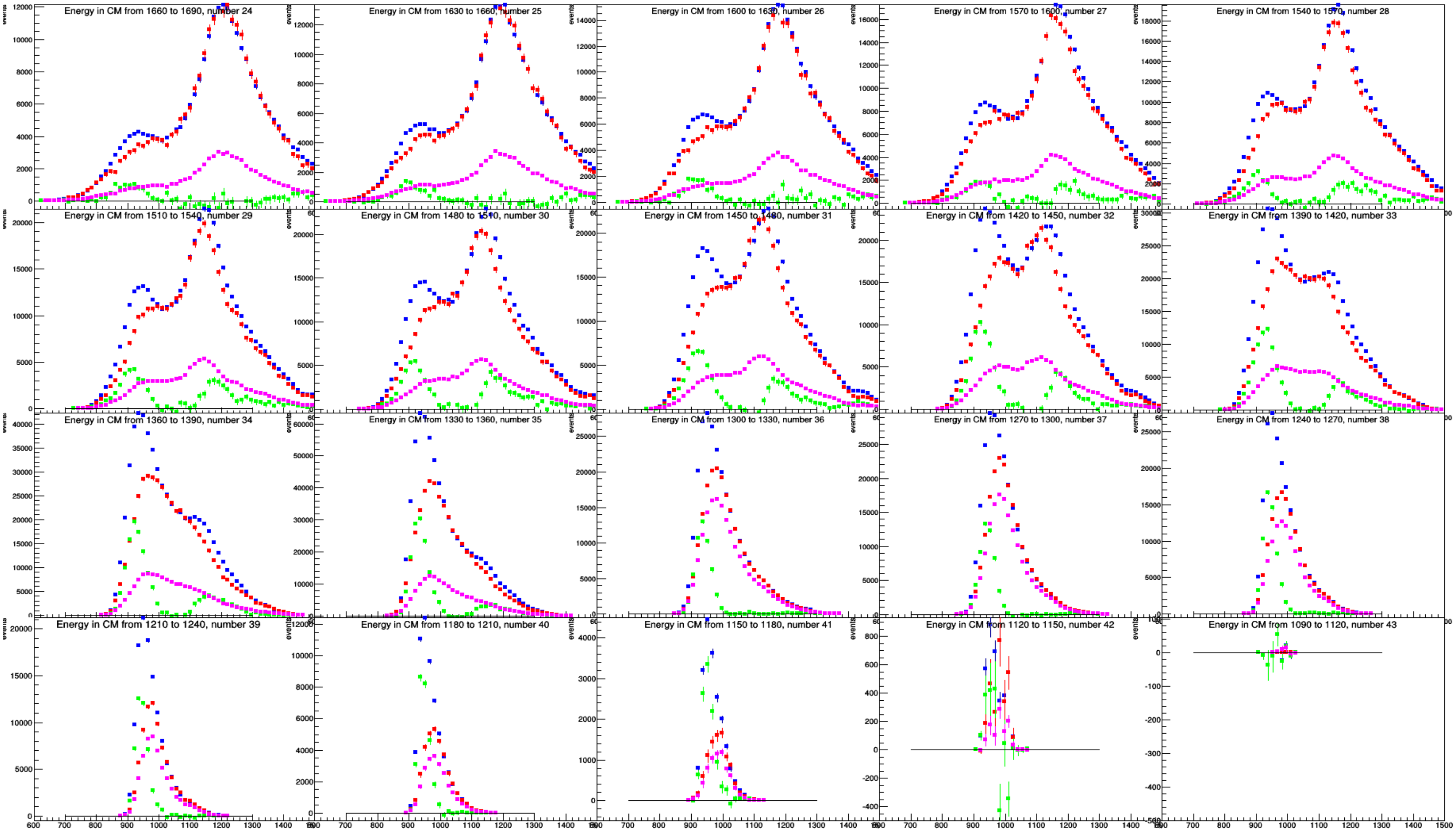
Missing mass plots for Carbon background subtraction



Events from: Butanol, Carbon_original, Carbon_with_scaling_factor, Protons

Single π on quasi-free neutron

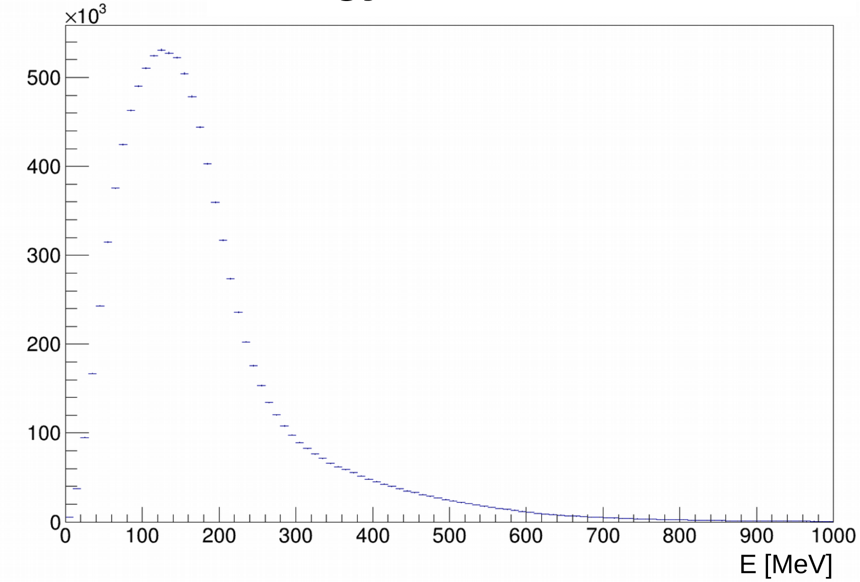
Missing mass plots for Carbon background subtraction



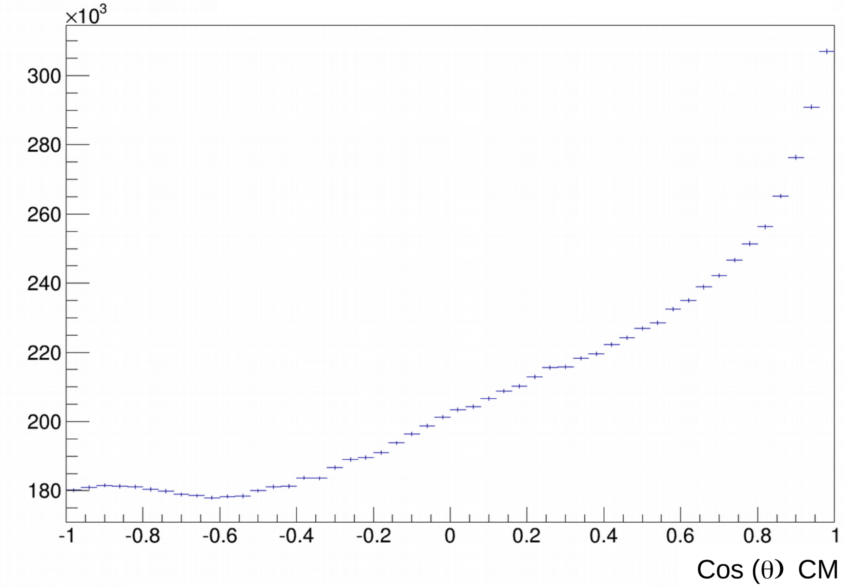
Events from: Butanol, Carbon_original, Carbon_with_scaling_factor, Neutrons

Recoil neutron (proton identified)

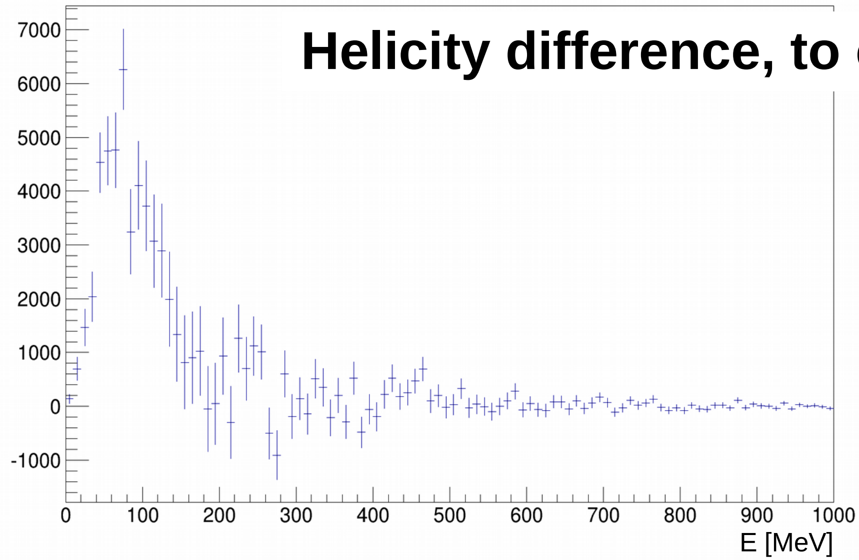
Energy

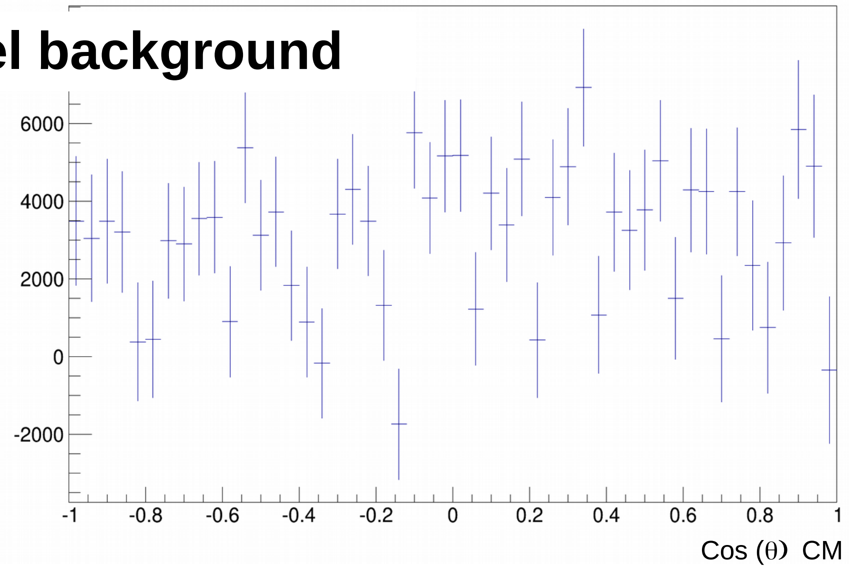


Angle



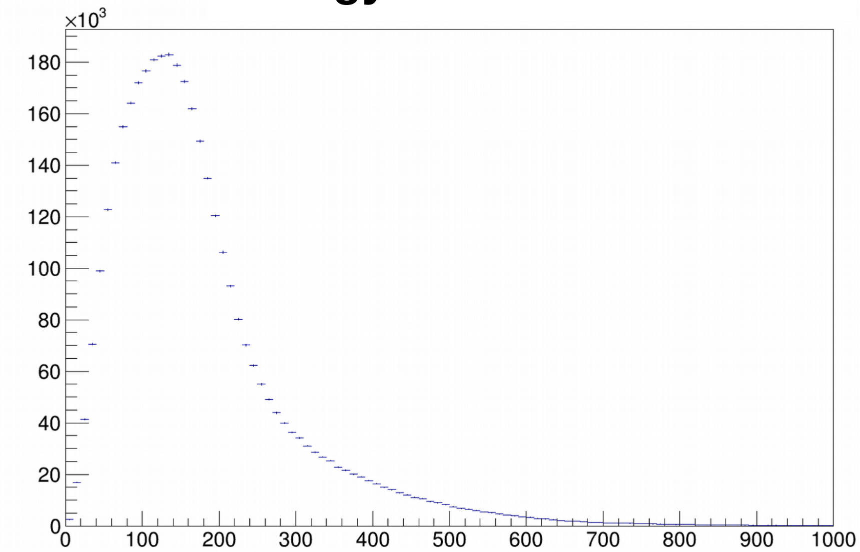
Helicity difference, to cancel background



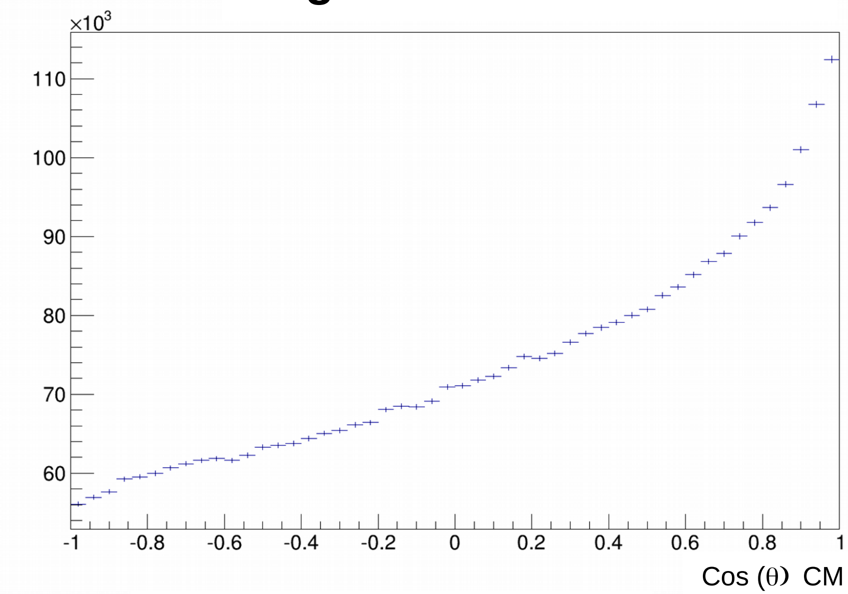


Recoil proton (neutron identified)

Energy



Angle



Helicity difference, to cancel background