Neutral pion photoproduction on neutron in the A2 experiment

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Bayon Resonances and Pion Photoproduction

- Almost all info on baryon resonances have been obtained from **πN** and **γN** data with **PWA**

- Now, there is no pion beams and this activity is concentrated at e-accelerators: **CEBAF, MAMI, ELSA, ВЭПП-3 et al.** in various directions.

- We involved in accurate evaluation of **EM** couplings **N*→γn & Δ*→γn** which needs pion photoproduction measurements on neutron

Importance of Neutron Data

EM interaction **do not conserve isospin**, so multipole amplitudes contain **isoscalar & isovector** contributions of **EM** current.

Proton

$$A_{\pi^0 p} = A^0 + \tfrac{1}{3} A^{1/2} + \tfrac{2}{3} A^{3/2}$$

$$A_{\pi^+ n} = \sqrt{2}\left(A^0 + \tfrac{1}{3} A^{1/2} - \tfrac{1}{3} A^{3/2}\right)$$

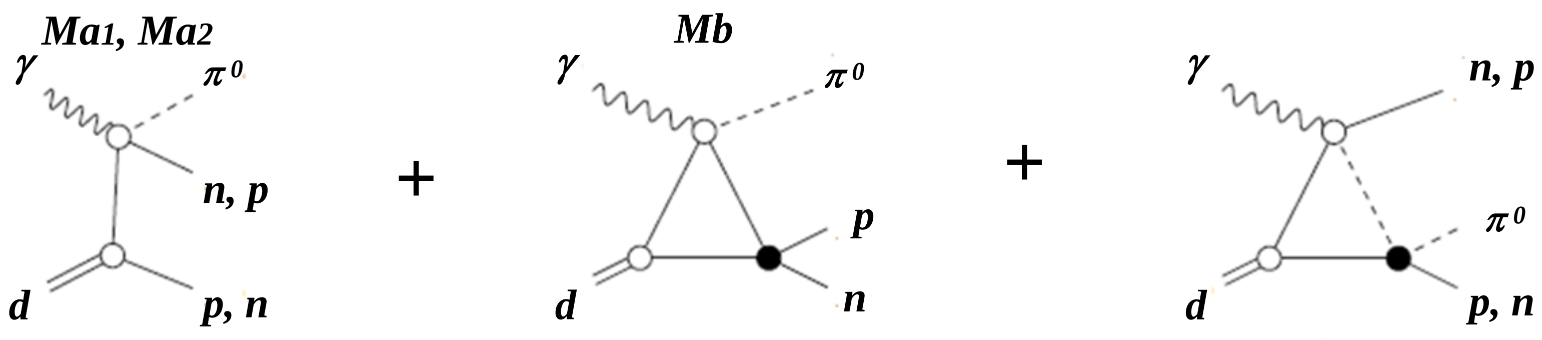
Neutron

$$A_{\pi^0 n} = -A^0 + \tfrac{1}{3} A^{1/2} + \tfrac{2}{3} A^{3/2}$$

$$A_{\pi^- p} = \sqrt{2}\left(A^0 - \tfrac{1}{3} A^{1/2} + \tfrac{1}{3} A^{3/2}\right)$$

4 equations and **3** variables. It seems that $\pi^0 n$ not needed? But **$\pi^- p \to n\gamma$** is limited because of severe **bg of $\pi^0 n$** and **systematics of available data** does not allow separation of **isoscalar & isovector** components with reasonable accuracy. So the data on n are important. They can be obtained on d-target and with theoretical model to get $\gamma n \to \pi^0 n$.

Theoretical model for $\gamma d \to \pi^0 np$

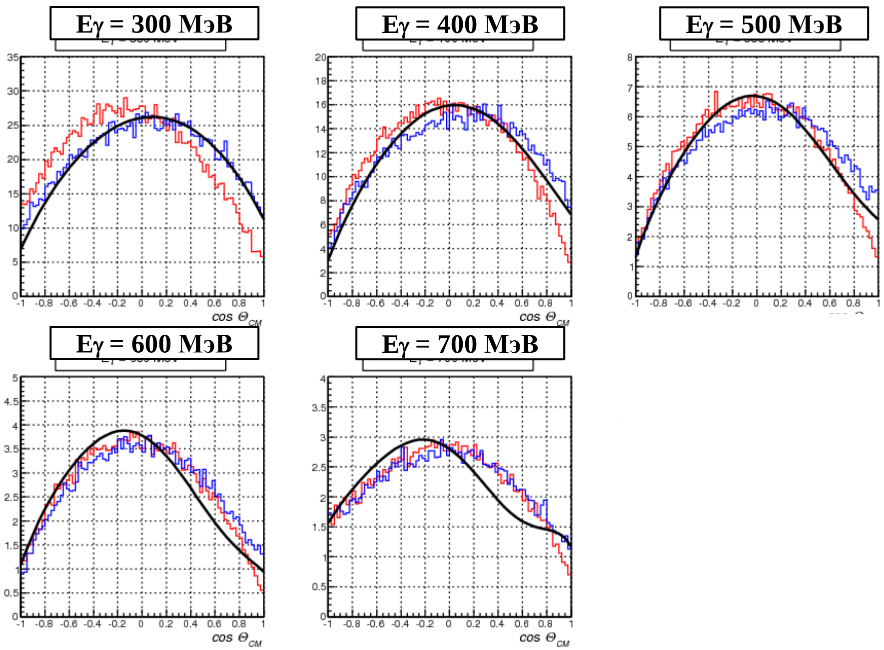


Impulse approximation (IA) — *NN* – final state interaction (FSI) effect — *πN* – final state interaction (FSI) effect

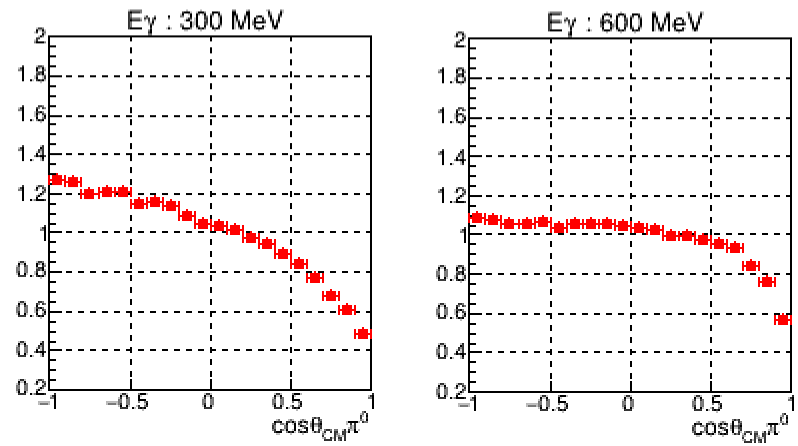
- For the precision measurement of total and differential cross sections for reactions $\gamma n \to \pi^0 n$, $\gamma n \to \pi^- p$, the theoretical group of ITEP (A. Kudryavtsev, V. Tarasov) developed a model based on impulse approximation (IA) and *NN*– and *πN*– final-state interactions (FSI)
- The phenomenological amplitudes $\gamma N \to \pi N$ and *NN* obtained in PWA by SAID group (GWU, USA) were used as inputs for the model.
- Contribution for πN– FSI is small for Eγ > 200 MeV, so model directly includes only *NN* – FSI
- Amplitude *M* of reaction $\gamma d \to \pi^0 np$ can be presented as : $M = M_{a1} + \Delta, \quad \Delta = M_{a2} + M_b,$
  where ***Ma1***, ***Ma2*** – *IA* amplitudes, ***Mb*** – *pn*-FSI

FSI – contribution

dσ/dΩ (μb/sr) by *cos* $(\Theta)_{CM}$ π^0 for $\gamma n \rightarrow \pi^0 n$



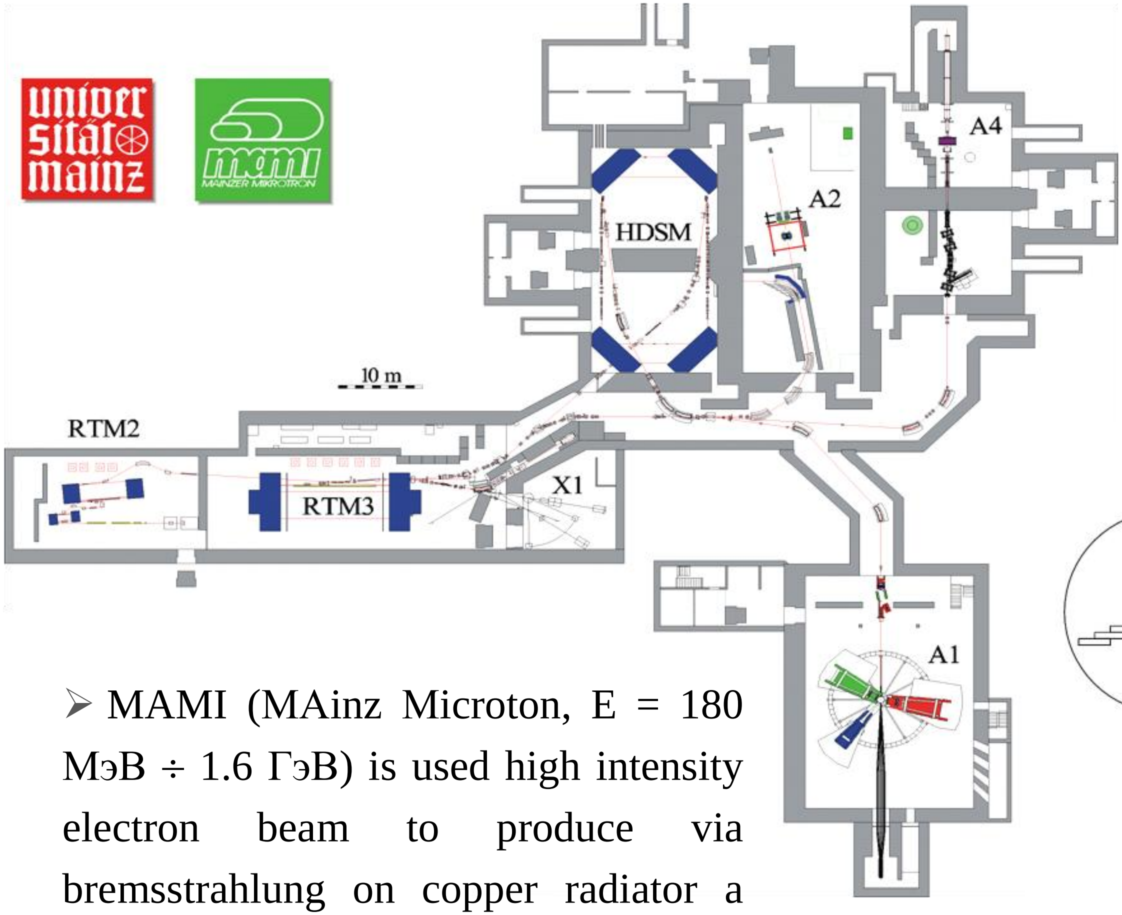
(IA+FSI)/IA



SAID
IA
IA+FSI

- $\gamma n \rightarrow \pi^0 n$: theoretical prediction is based only on PWA analysis. The difference for SAID (PWA) and model prediction becomes significant for high energy. FSI effect is essential for low energies (Eγ < 400 MeV) , but neutron detection efficiency is low at this region

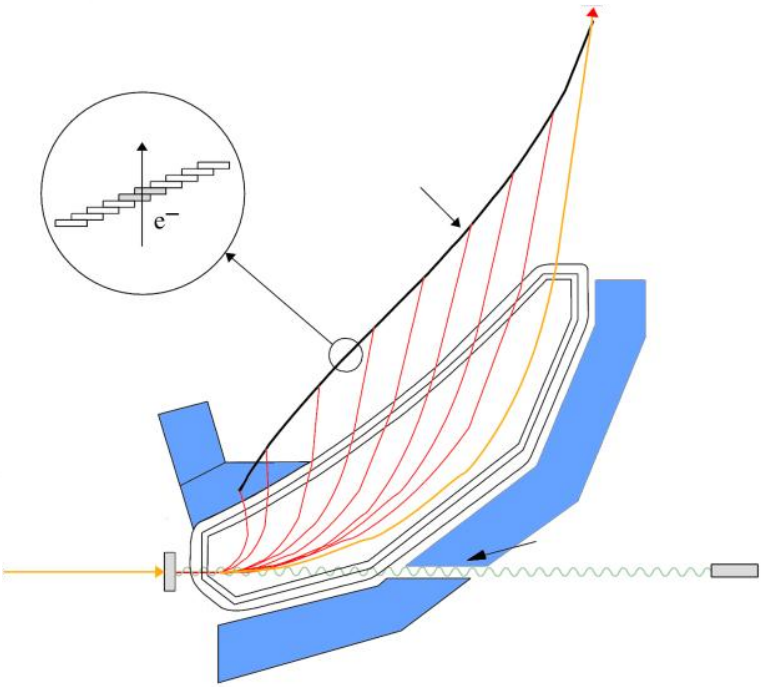
Mainz Microtron (MAMI)



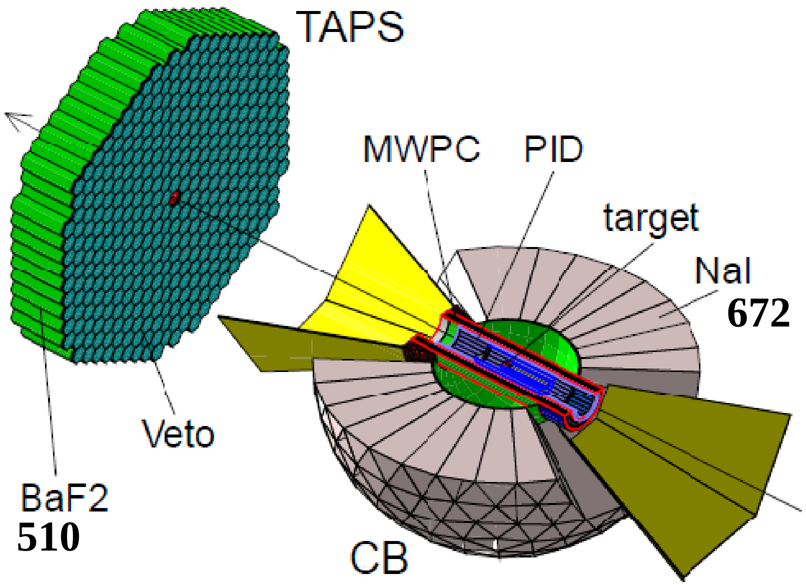
➢Tagging system has 352 channels (Eγ < 1.5 GeV)

➢ Energy resolution : 2 – 5 МэВ

➢ MAMI (MAinz Microton, E = 180 МэВ ÷ 1.6 ГэВ) is used high intensity electron beam to produce via bremsstrahlung on copper radiator a high-energy photons. Tagging system (magnetic spectrometer) allows to determine the photon energy



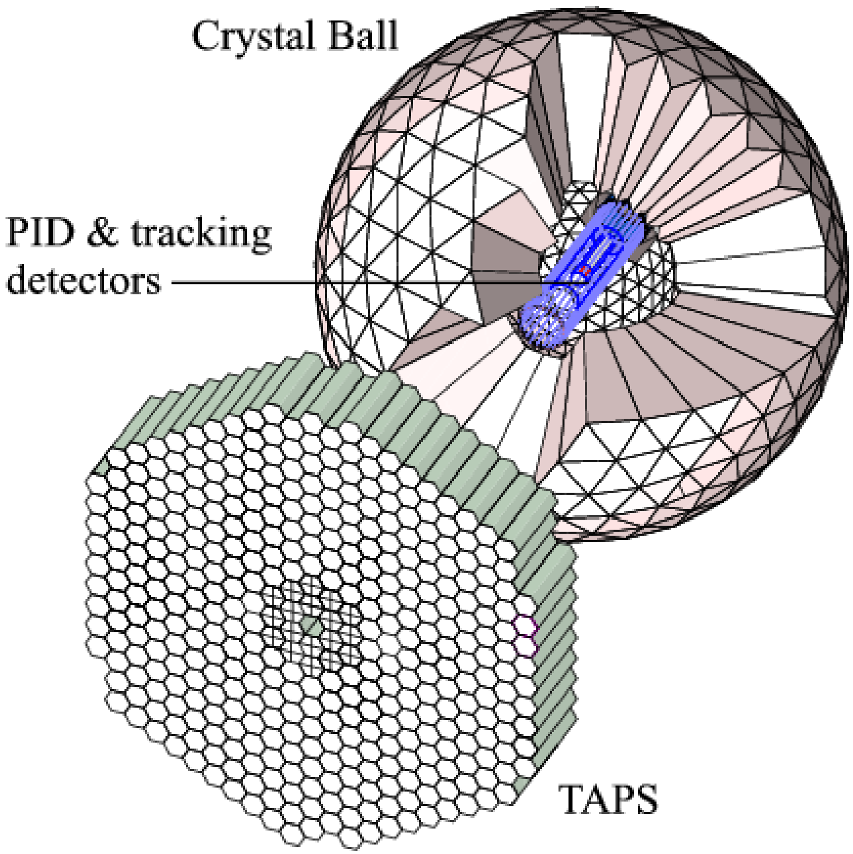
Experimental setup



- MAMI is used to produce bremsstrahlung photons on a copper radiator (length ~ 10 μm). The photons are tagged by magnetic spectrometer
- Calorimeter system consists of spherical (Crystal Ball) and forward (TAPS) detectors that covered almost 4π

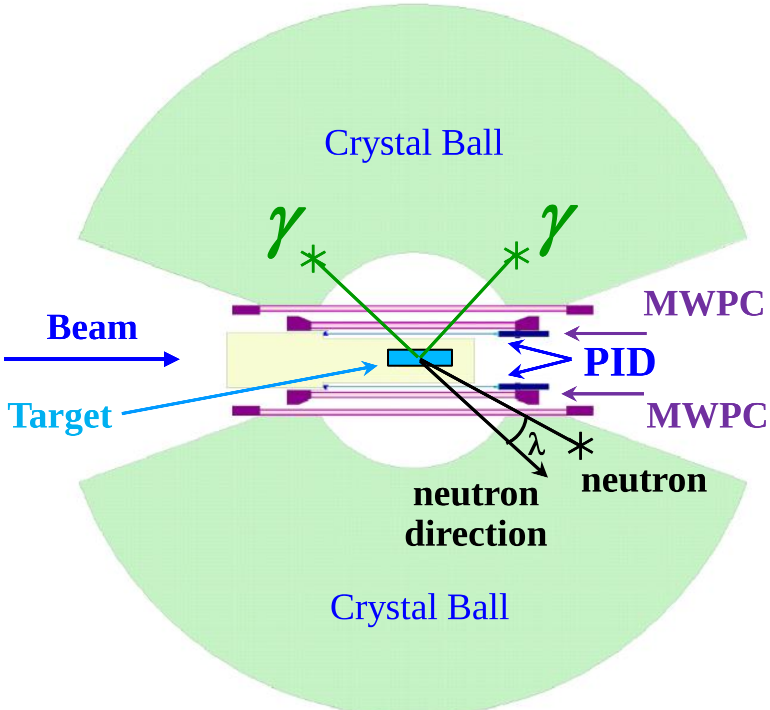
- Particle Identification Detector (PID) detector gives an separation of the charged particles based on dE/dx measurements in a scintillator
- Multiwire proportional chambers measure three dimensional space points
- Target – kapton cylinder (∅: 4 cm, L: 10 cm)filled with liquid hydrogen / deuterium

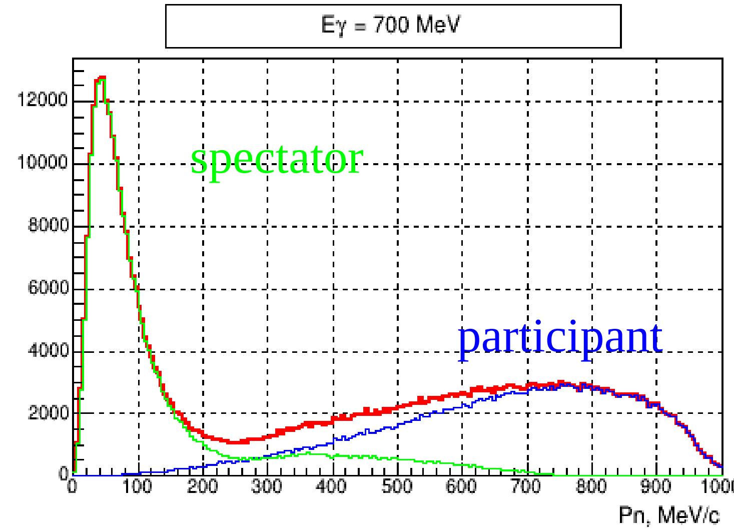
Crystal Ball



- Crystal Ball detector was constructed in 1976
- 1978 – 1981 at SPEAR experiment at SLAC (e^+e^- collider and Ecm = 3 – 7 GeV)
- 1982 – 1986 at DORIS experiment at DESY (e^+e^- collider and Ecm = 9 – 10 GeV)
- 1996 – 2002 at BNL – AGS on $\pi^\pm$, $K^\pm$ beams
- In 2002 detector was transported to Mainz and installed on the MAMI photon facility
- CB is a sphere consisting of 672 isolated NaI crystals, shaped as truncated triangular pyramids
- Detector covers 93 % of 4π or polar angle of 20–160^0
- NaI crystals have a length of 40.7 cm
- Energy resolution : $\sigma E / E \approx \frac{2\,\%}{\sqrt{E(\mathrm{GeV})}}$

Strategy to select $\gamma n \to \pi^0 n$ from $\gamma d \to \pi^0 np$



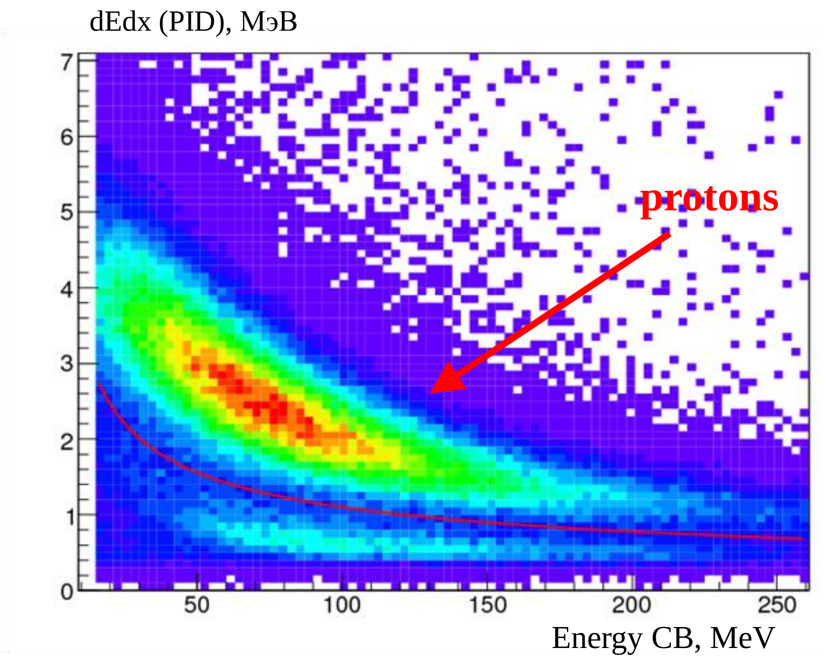


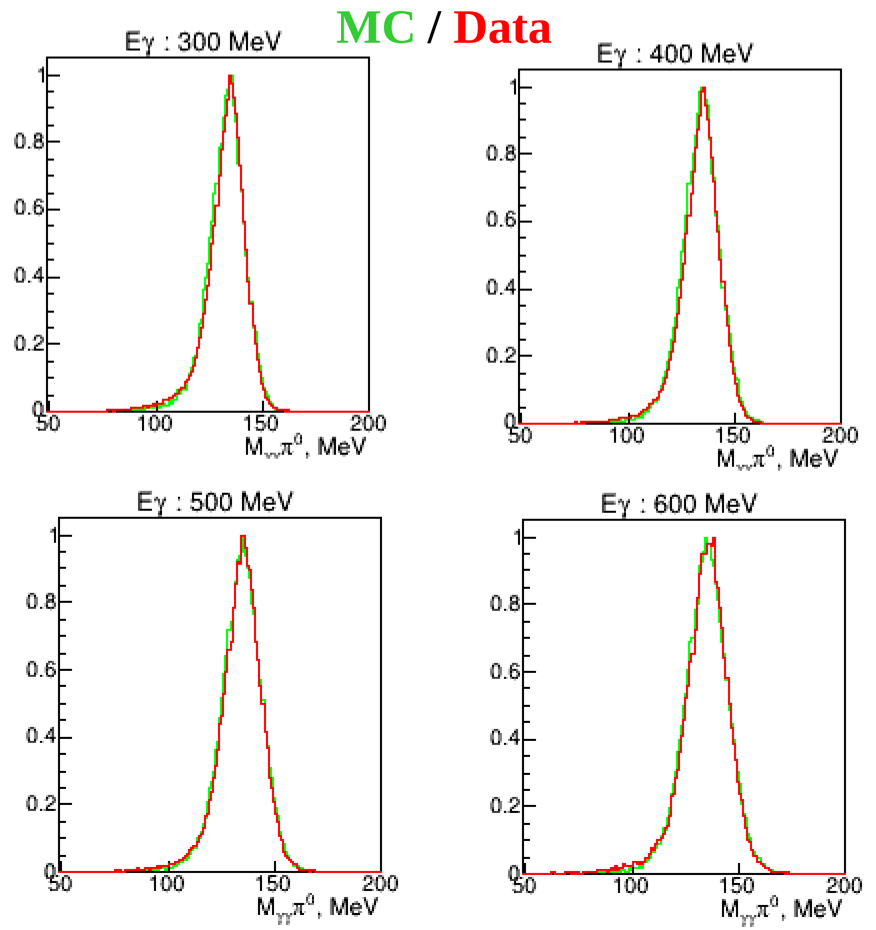
Neutron momentum (MC) from $\gamma d \to \pi^0 np$

- ✓ Reconstructed π^0 and neutron cluster in CB gives a full kinematic picture

- ✓ Number of clusters in CB – 3 (2 cluster combine effective mass close to π^0 nominal value)
- ✓ PID has no signal, so detector suppresses the charged component corresponding to $\gamma p \to \pi^0 p$, when proton has a high momentum («participant»)
- ✓ In reaction $\gamma n \to \pi^0 n$ neutron is registered by CB, while proton – spectator is not detected and stopped in the target
- ✓ It's important to know neutron detection efficiency value with high precision
- ✓ This efficiency can be calculated by proton – spectator and corresponding low momentum neutron (4 clusters in CB)

Event selection





✓Two dimensional plot CB (energy) vs PID (energy losses) is used to select protons and charged pions .

✓ For π^0 selection we apply cut , 120 < M $\gamma_1\gamma_2$ < 150 MэB on effective mass of two neutral clusters in CB (no PID signal).

Neutron detection by CB

- To obtain the neutron detection efficiency we registered neutral pion and proton and searched for neutron interaction in predicted direction.

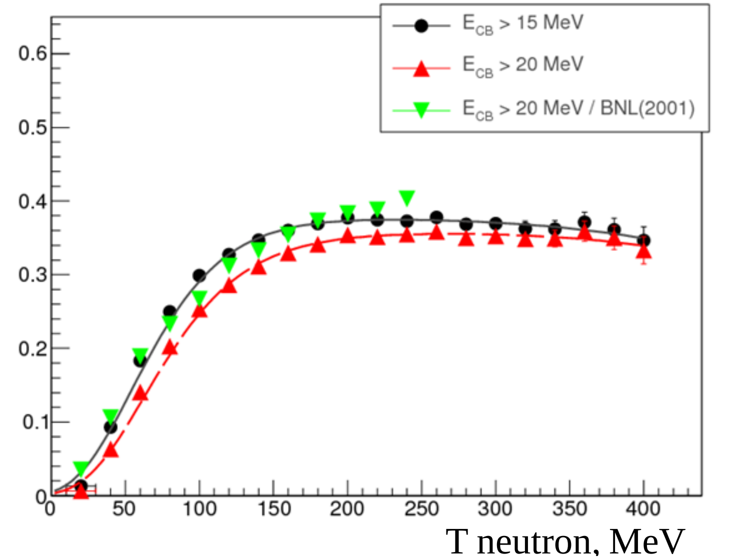
- Neutron efficiency is flat (~ 40 %) at Tn > 150 MeV and decreases at lower energies

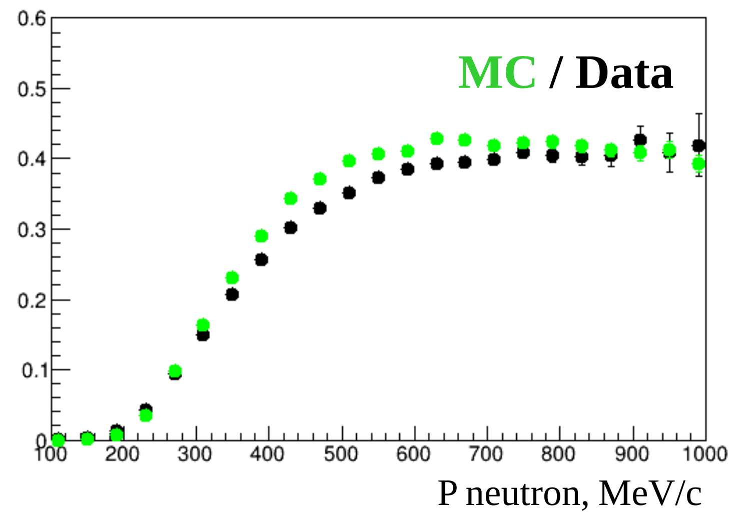
- Efficiency is a function of the Crystal Ball threshold (15 MэB was used)

- BNL – AGS data, obtained with the reaction $\pi^{-}p \rightarrow \pi^{0}n$ twenty years ago are in a good agreement with our measurements.

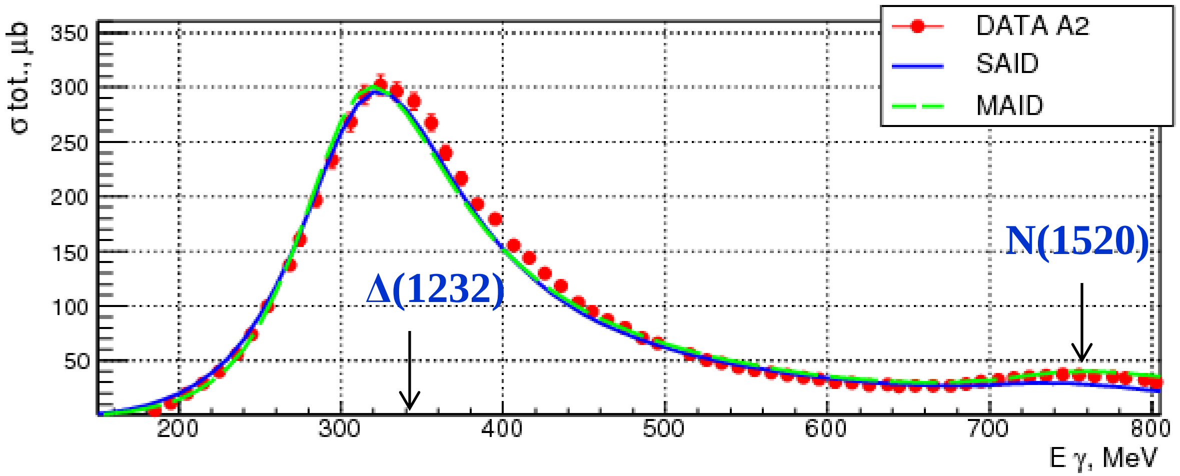
- Detection efficiency equality for MC and Data is important because detection efficiency for $\gamma d \rightarrow \pi^{0} np$ is calculated from MC.

Neutron detection efficiency





Total cross section



✓Total cross section was measured in a wide energy range from 180 to 800 MeV with step on γ – energy of 10 MeV

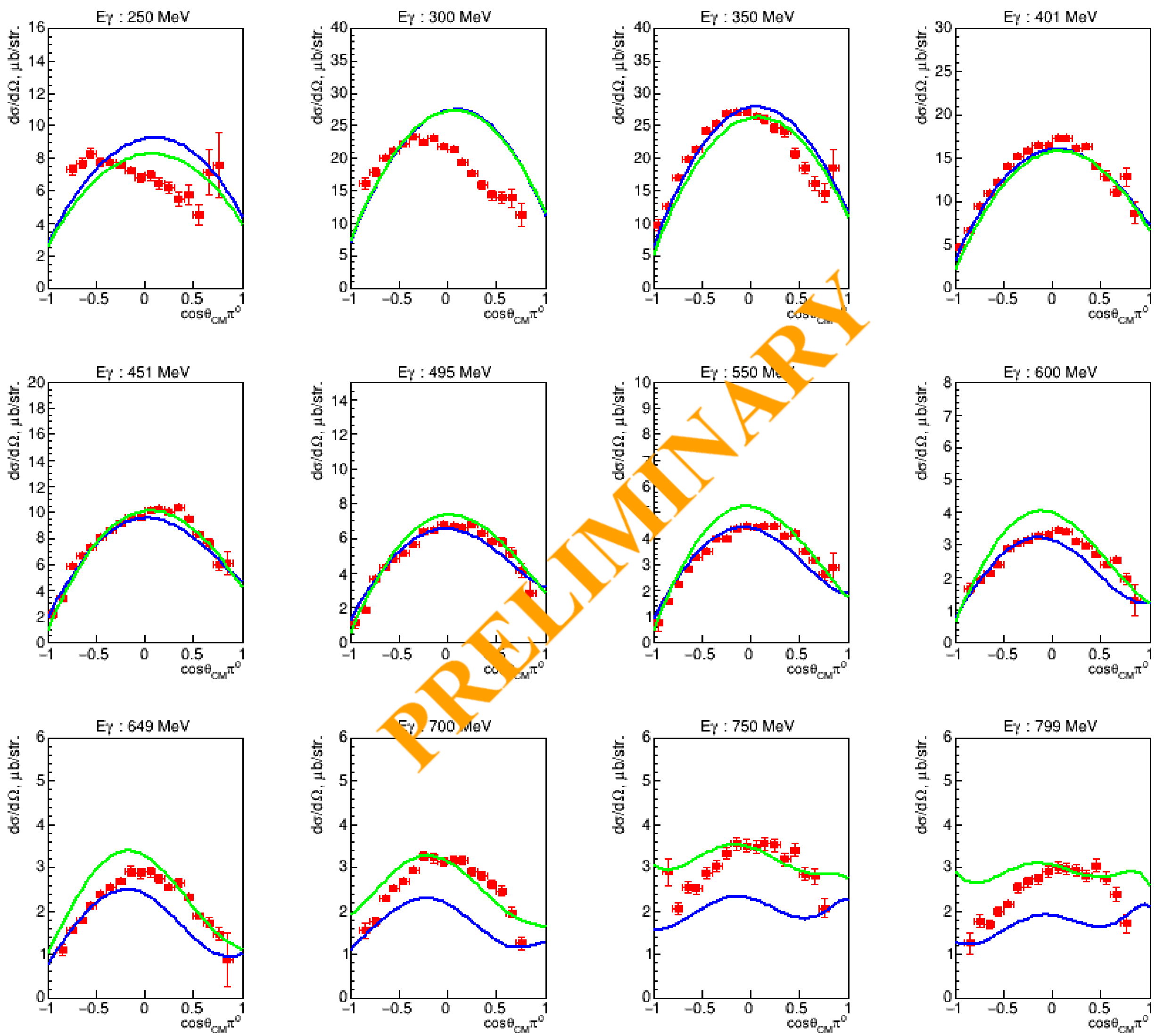
✓ Our experimental result is in a good agreement with data obtained by the theoretical groups SAID and MAID

✓Theoretical prediction presented by MAID better reflects the data, since it takes into account the contribution of various high-impulse resonances

✓The relative measurement error is 1.5 – 3 %

✓ Corrections within a few percent are possible as a result of the accuracy of MC generator predictions, systematics studies and etc.

Differential cross sections



- ✓ Points – *Cos(Θ)$_{CM}$* distributions for neutral pions in the CM frame
- ✓ Lines – theoretical predictions of SAID and MAID
- ✓ At photon energies 200 and 300 MeV energy of the neutron detection efficiency is too low energy neutrons with low to rely on.
- ✓ *At 350-700 MeV – good agreement with MAID*
- ✓ At higher energies - bad agreement. Predictions of PWAs are are limited by low available data/

Conclusions

1. Experimental data, obtained by A2 collaboration, allowed us to select a reaction of photoproduction on neutron $\gamma n \to \pi^0 n$. This measurement was performed on the deuterium target with tagged photons at energies from 180 to 800 MeV.

2. Model of $\gamma d \to NN\pi$ was developed to extract $\gamma n \to n\pi^0$ channel. The model includes IA, off-shell effects, FSI (NN and πN– to be added).

3. Measurement of neutron detection efficiency of Crystal Ball calorimeter is a crucial for $\gamma n \to n\pi^0$ cross sections calculation.

4. Preliminary results on the total and differential cross sections for $\gamma n \to \pi^0 n$ are presented and compared with predictions of SAID and MAID groups.

5. We plan to study systematic uncertainty of 800 MeV data and start to analyze 1.6 GeV data which have been taken in March of this year by A2 collaboration at MAMI.

Thank You

A2 Collaboration

~70 participants, 20 institutes from 10 countries

25th International A2 Collaboration Meeting, Dubna, Russia, September 2014