Photoproduction of mesons off ^{7}Li

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In-medium properties of hadrons

11th International Workshop on Meson Production, Properties and Interaction, KRAKÓW, POLAND

Yasser Maghrbi

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Outline

- Introduction : In-medium properties of hadrons

- Motivations

- Experiment

- Results

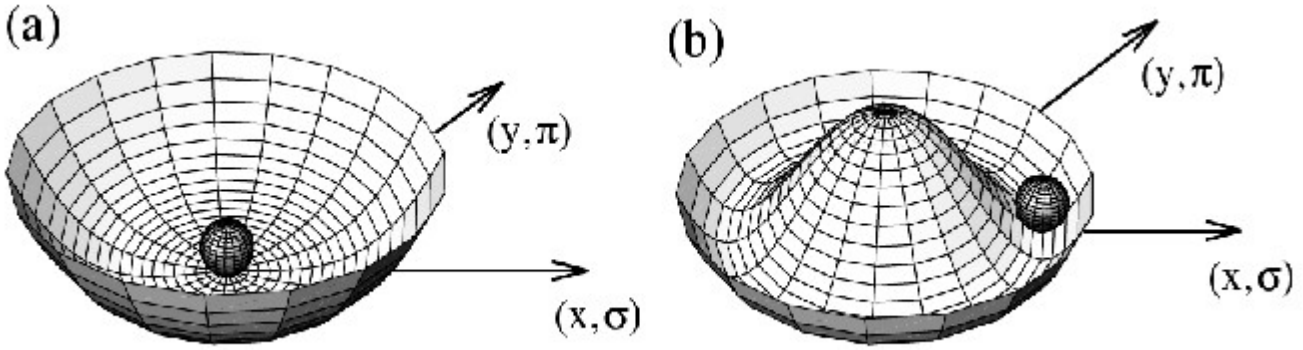
  - *The double pion photoproduction off ^{7}Li*
  - *The coherent π^{0} photoproduction off ^{7}Li*
  - *The coherent η-meson photoproduction off ^{7}Li*

- Summary and outlook

Introduction : In-medium properties of hadrons

- At high energies / short scale, QCD well described by the perturbative approach (point like quarks and gluons)
- At large scales (>0.1fm) : hadrons described as many-body systems

⟶ Chiral symmetry is broken (quark mass << total mass)



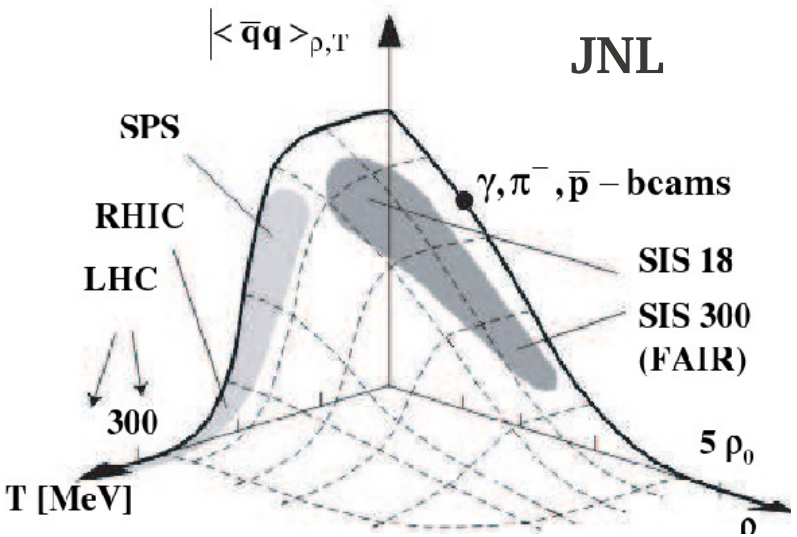
The symmetry breaking is reflected in the hadron spectrum. Without it, hadrons would appear as mass degenerate parity doublets

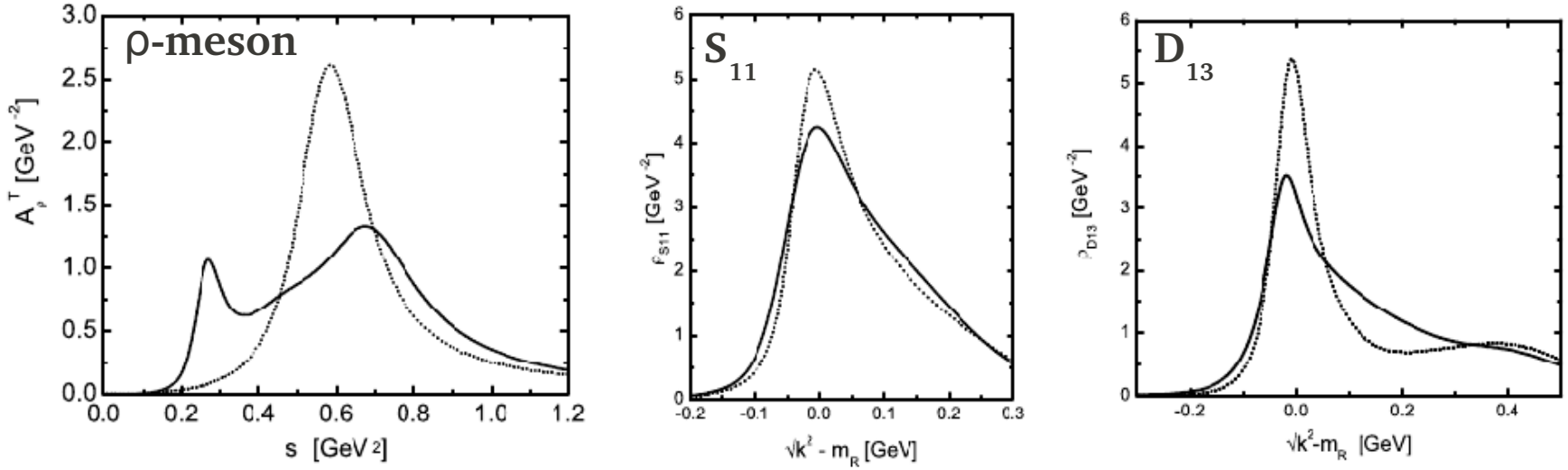
Particle, J^π, Mass	P_{11}, $1/2^-$, 939	ρ, 1^-, 770	π, 0^-, 134.7
Chiral partner, J^π, Mass	S_{11}, $1/2^+$, 1535	a_1, 1^+, 1260	σ, 0^+, 400-1200
Mass split	≈600	≈500	266-1066

Introduction : In-medium properties of hadrons

Models : temperature and density dependence of the chiral condensate $<\bar{q}q>$.

Modifications may arise from :
- Chiral symmetry restoration.
- Trivial effects (Fermi motion, Pauli blocking...)





Spectral functions predicted by Post et. al : Vacuum (dashed) / in medium (solid)

Introduction : In-medium properties of hadrons

In medium modification of σ-meson via ππ invariant mass analysis

- Motivation (models)
- Previous results (pion and photon induced reactions) on H, C, Ca, Pb

In medium modification of the Δ-resonance via the coherent π^0 photoproduction

- previous results on C, Ca, Pb, Nb
- Interest for the nuclear mass distributions.

The possible existence of η-mesic nuclei via the coherent η-photoproduction

- Motivations
- Previous results on ^{3}He

Motivations : ππ properties in-medium

ππ properties in-medium

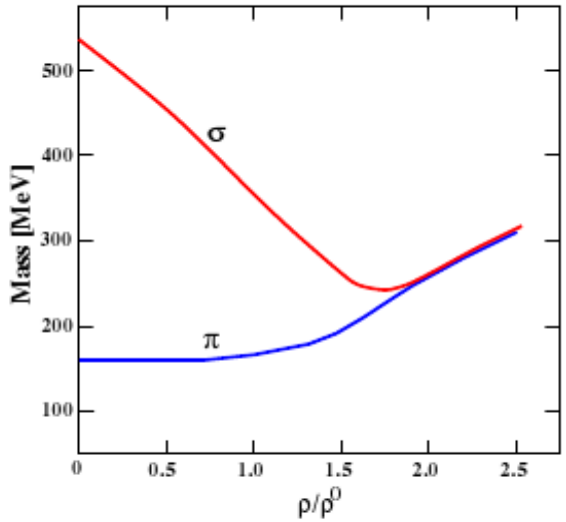
In-medium modification of σ-meson

Models : Mass (σ) ↘ when nuclear density ↗ and σ becomes degenerate with its chiral partner π at large density

σ-meson decays into $\pi^0\pi^0$ but not $\pi^0\pi^{+/-}$

Expect shift in invariant mass distributions towards small values in $\pi^0\pi^0$

- predicted dependence of σ-mass on density (V.Bernard et al.):



- masses of chiral partners degenerate in chiral limit

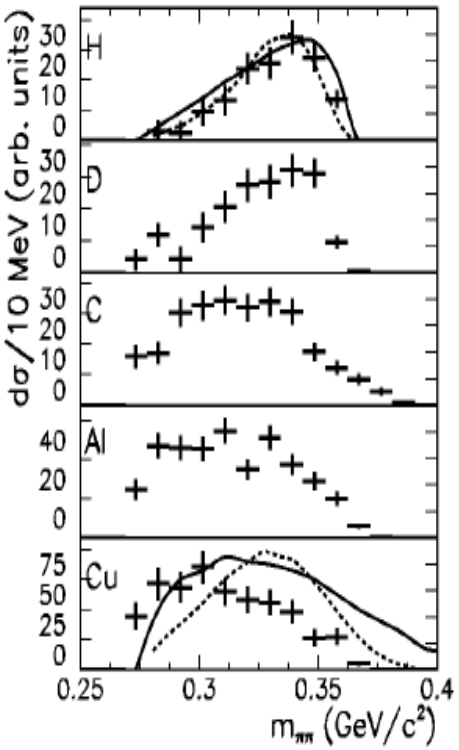
$$m_\sigma = m_{\sigma_o}(1 - \alpha\rho/\rho_o)$$

Motivations : ππ properties in-medium

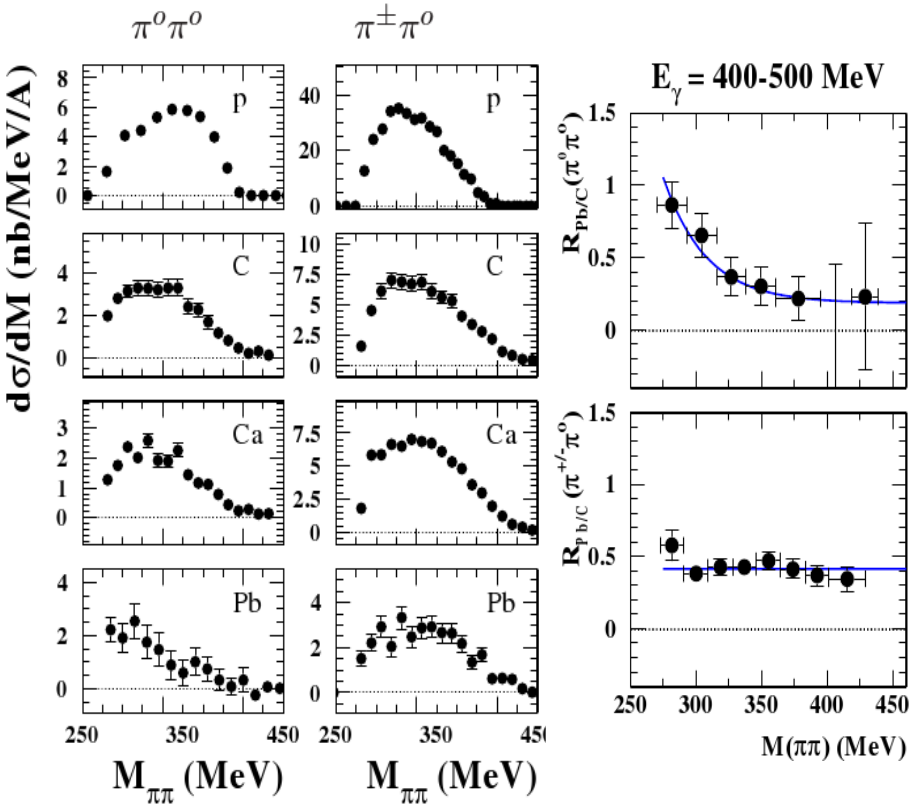
- First results used pion induced reactions (CHAOS, CB@BNL)
- First results using photon beams by TAPS@MAMI
- Results on Ca fit well to BUU calculations which included FSI but no σ effects
- New data under analysis with 4π sr solid angle (CB@MAMI) : Li, C, Ca, Pb

Crystal Ball@BNL: (S. Starostin et al.)

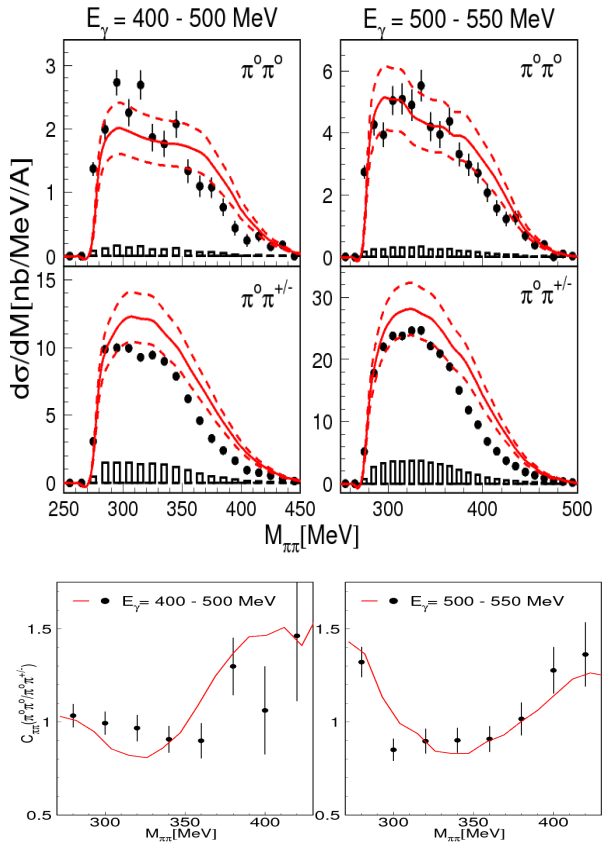
$\pi^- A \rightarrow A' \pi^o \pi^o$ reaction



TAPS@MAMI



F.Bloch et al., EPJ (2007)



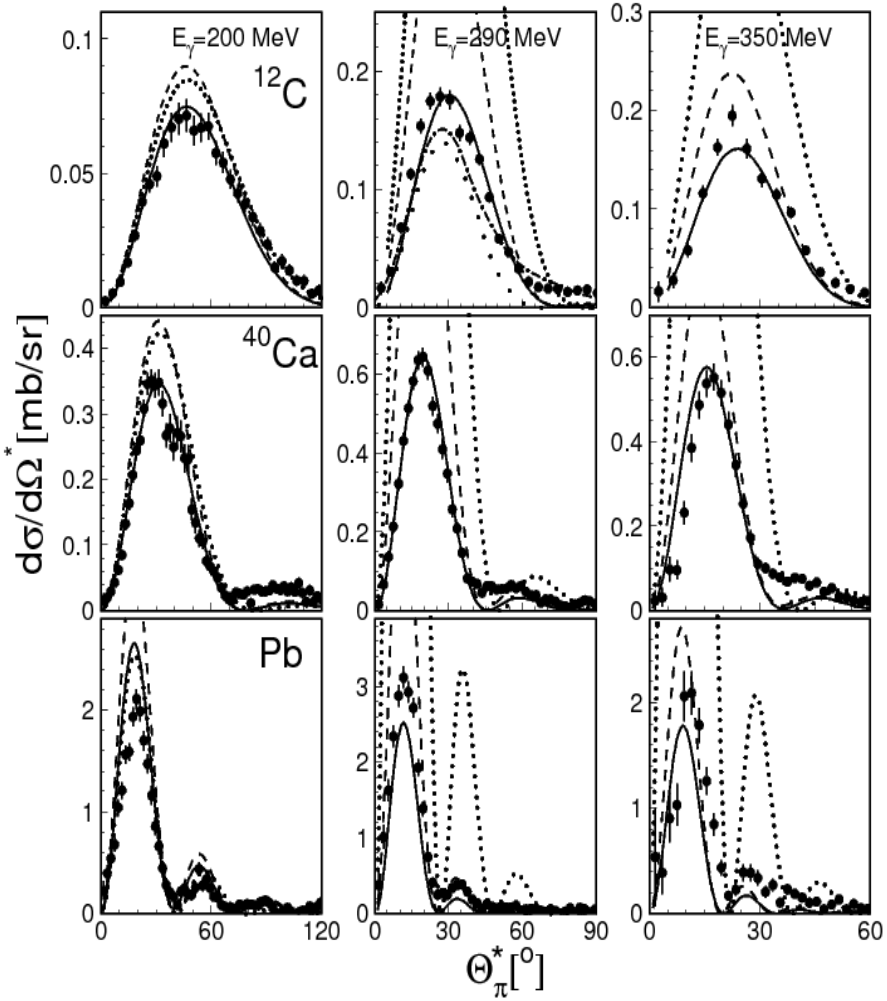
Motivations : coherent π^0 photoproduction off ^{7}Li

- The coherent π^0 photoproduction off nuclei is strongly dominated by the excitation of the Δ-resonance and well understood at low energy regime

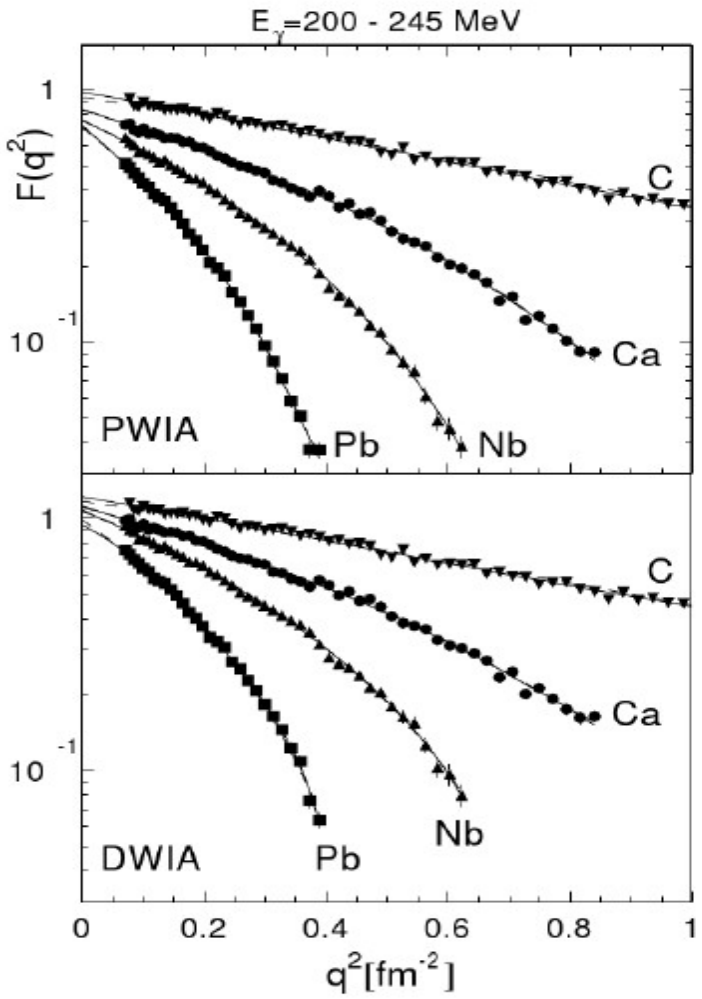
- Data on heavy nuclei fit well to the full model by Drechsel et. al (PWIA, DWIA, Δ-self energy + in-medium modification of Δ)

- Proton and neutron contribute with the same amplitude to the coherent π^0 photoproduction

→ The reaction is sensitive to the distribution of nucleons rather than the distribution of charge in the nucleus

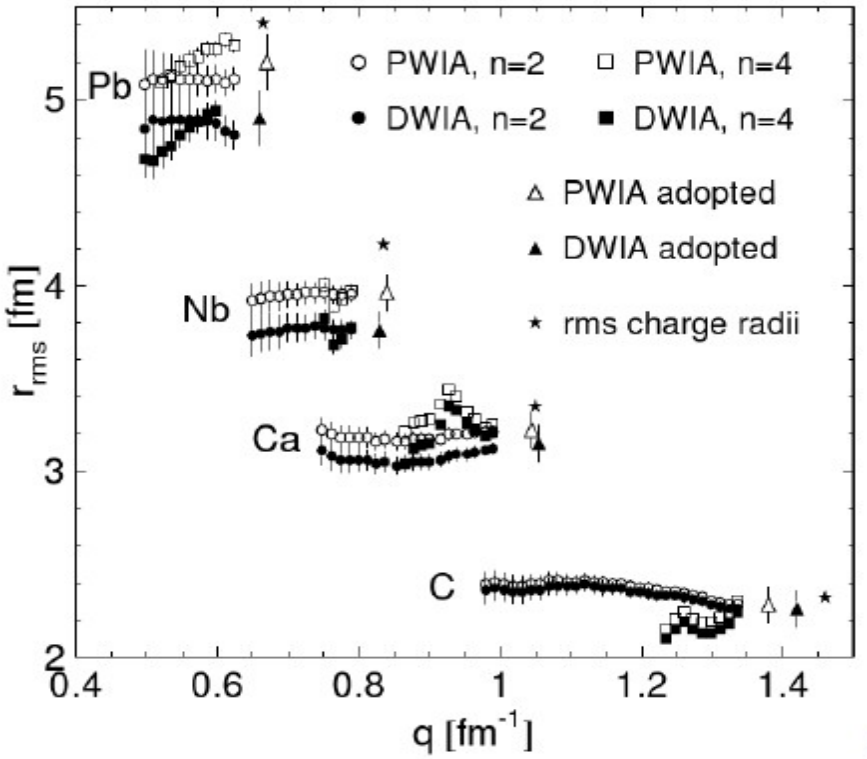


Motivations : coherent π^0 photoproduction off ^{7}Li



$$\frac{d\sigma_{PWIA}}{d\Omega}(E\gamma,\theta_\pi) = \frac{s}{m_N^2} A^2 \frac{d\sigma_{NS}}{d\Omega^*}(E\gamma^*,\theta_\pi^*) F^2(q)\ sin^2(\theta_\pi^*)$$

$$\frac{d\sigma_{NS}}{d\Omega^*}(E\gamma^*,\theta_\pi^*) = \frac{1}{2}\frac{q_\pi}{k^*} \mid F_2(E\gamma^*,\theta_\pi^*) \mid^2$$



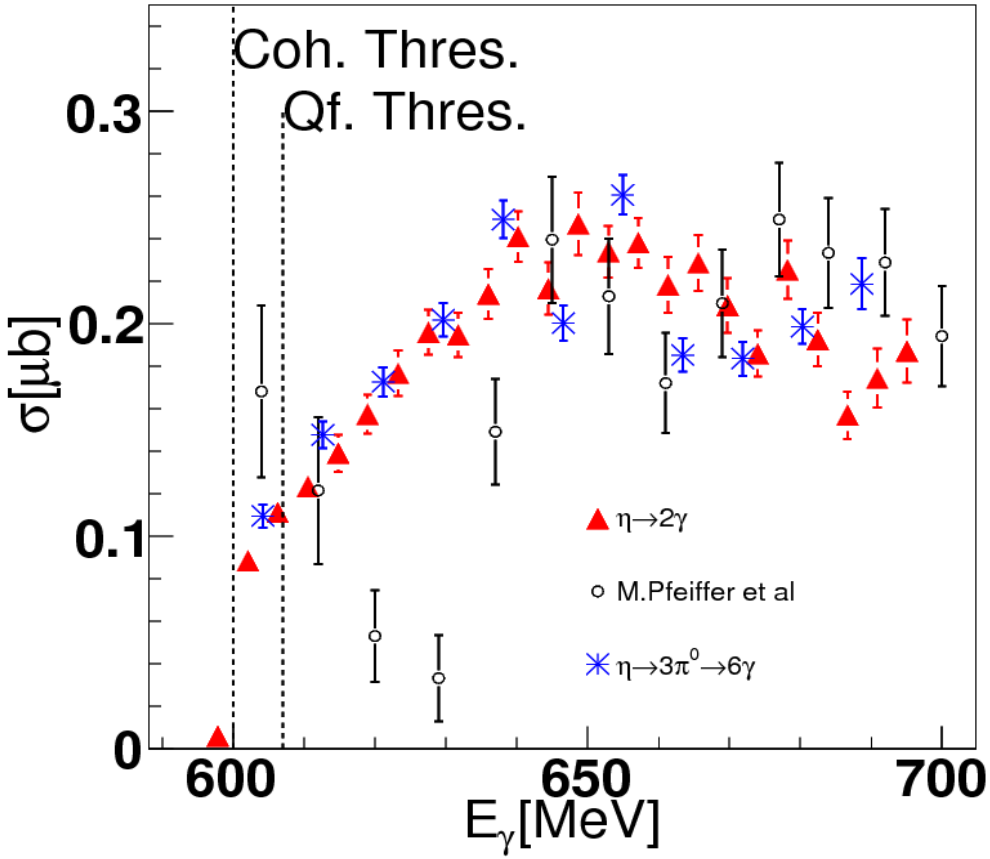
Motivations : coherent η photoproduction off ^{7}Li

search for the η-mesic nuclei

- An enhancement of the total η coherent cross section at threshold is synonym of the formation of a quasi-bound state.

- ^{7}Li is the next best candidate after ^{3}He but form factor approximately one order of magnitude smaller

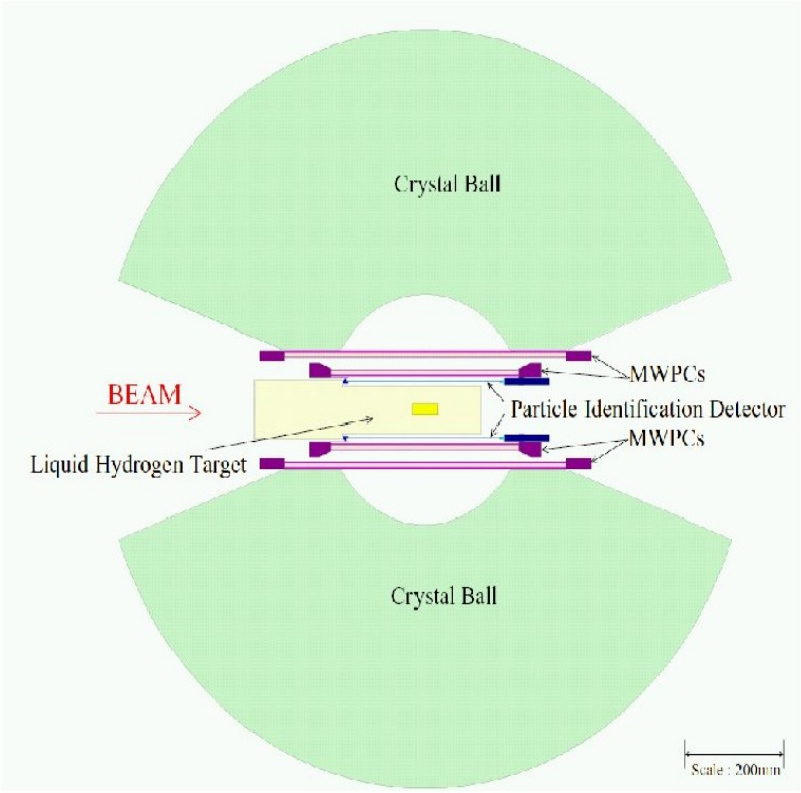
  → ^{7}Li coherent cross section expected to be very small!

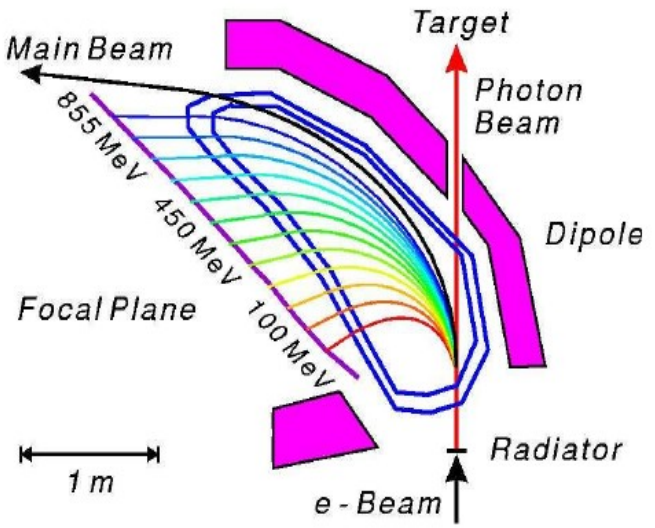


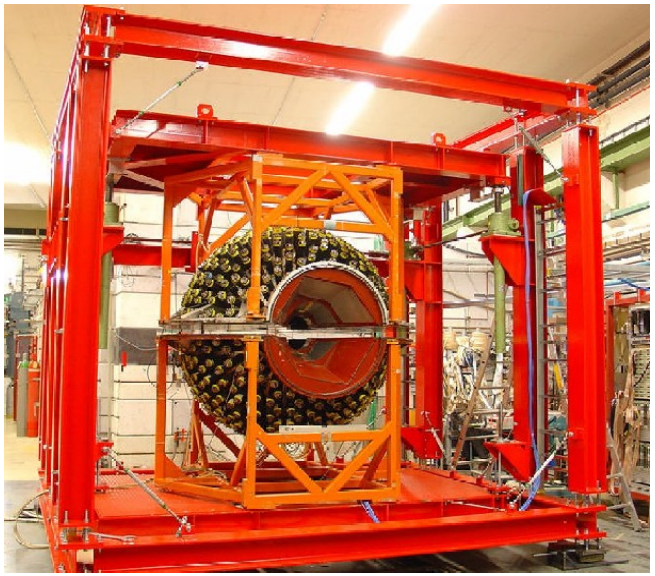
F.Pheron (CB-TAPS@MAMI) / M.Pfeifer (TAPS@MAMI)

Experiment

- Experiment performed in march 2005 (A2 collaboration) (Mainz, Germany) at MAMI B (883 MeV), upgraded in 2007 (up to 1.5 GeV).
- 180 hours of beam at I = 6 nA.







Results

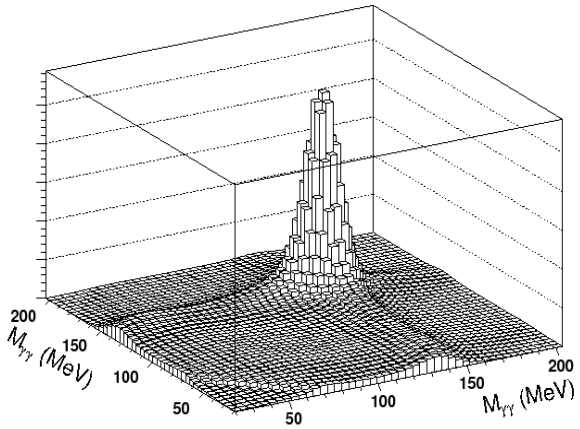
- The double pion photoproduction off ^{7}Li
- Reaction identification
- Charged and neutral invariant Mass distributions
- Ratios

- The coherent π^0 photoproduction off ^{7}Li
- Missing energy spectra
- Cross sections
- Form factor and mass rms radius

- The coherent η-meson photoproduction off ^{7}Li
- Missing energy for 2γ and 6γ channels
- Preliminary coherent cross sections

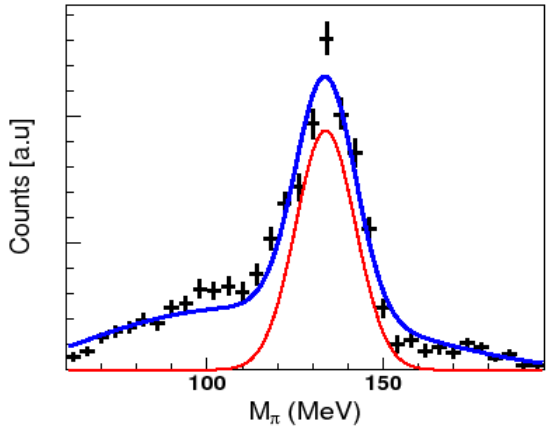
Results : *The double pion photoproduction off ^{7}Li*

- ***Neutral channel*** :
  - 3 cases : $\pi^0\pi^0$, $\pi^0\pi^0$ + 1p, $\pi^0\pi^0$ + 1n
  - Best combination of 2 photon pairs by χ^2-test
  - Cut on each π^0 Invariant mass
  - Background removed by gaus+pol. fit

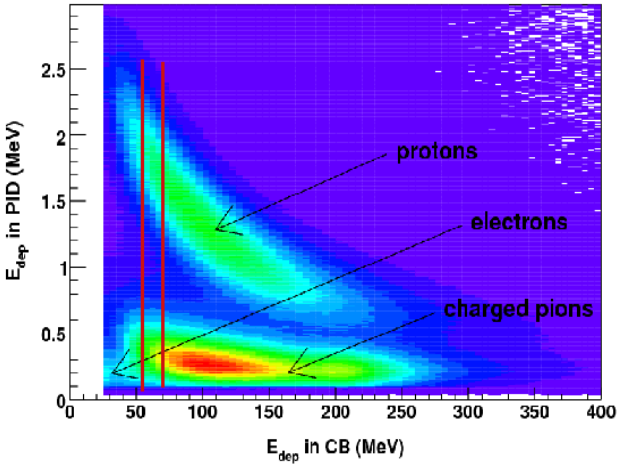


Invariant mass system of $\pi^0\pi^0$

Removing background:
- signal +BG : gaus+pol fit
- Signal : gauss (red)

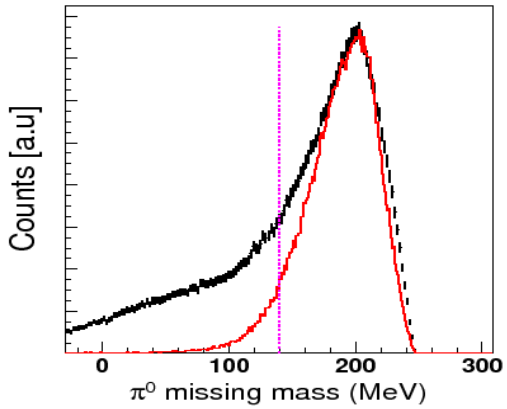


- ***Charged channel***
  - *3 cases :* $\pi^0\pi^{+/-}$, $\pi^0\pi^+$n, $\pi^0\pi^-$p
  - Charged pion identified via CB/PID banana cuts
  - Missing mass cut : proton identified as $\pi^{+/-}$
  - Background removed by gaus+pol. fit



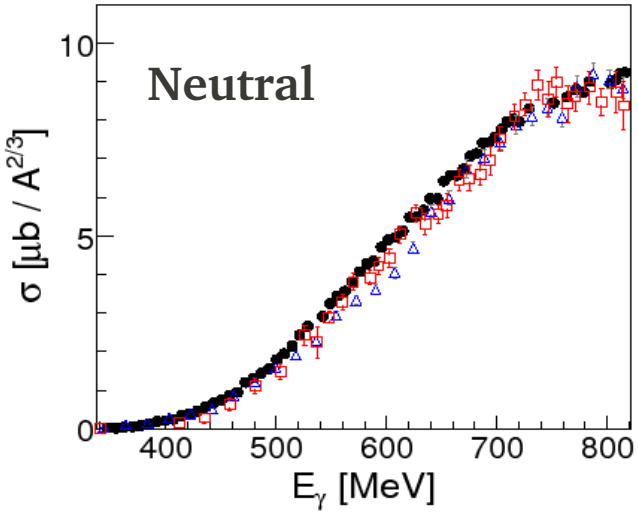
CB / PID banana cuts

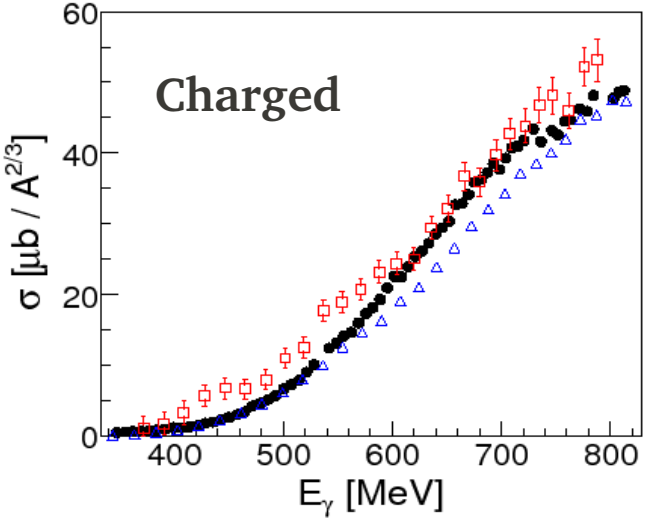
Missing massa cut:
proton identified as $\pi^{+/-}$



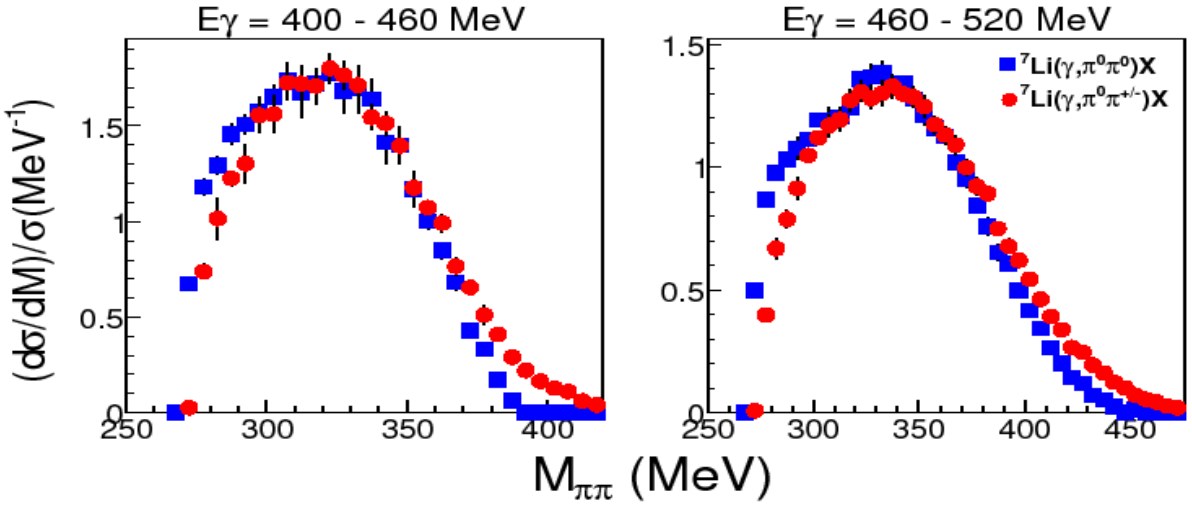
Results : *The double pion photoproduction off ^{7}Li*

Total cross sections compared to Ca (blue) and D (red)

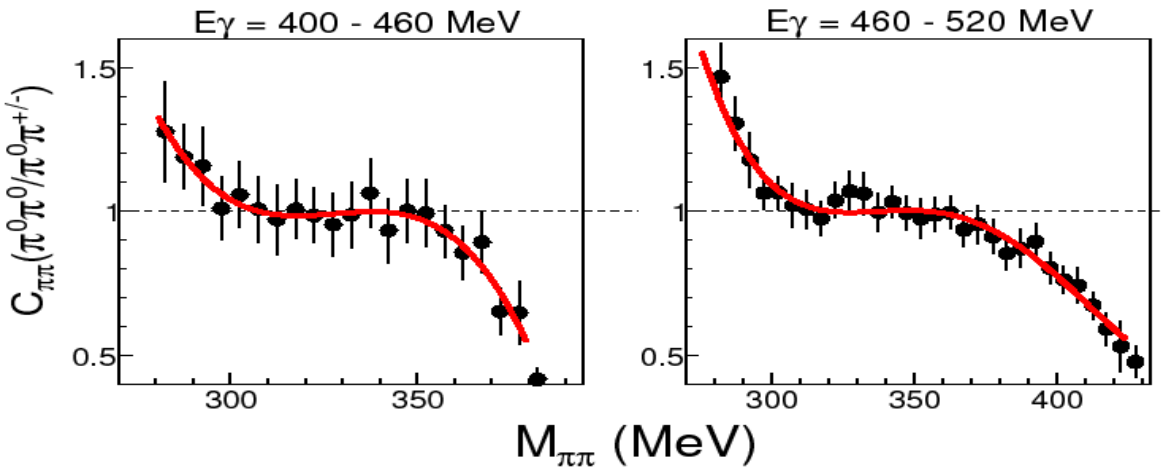




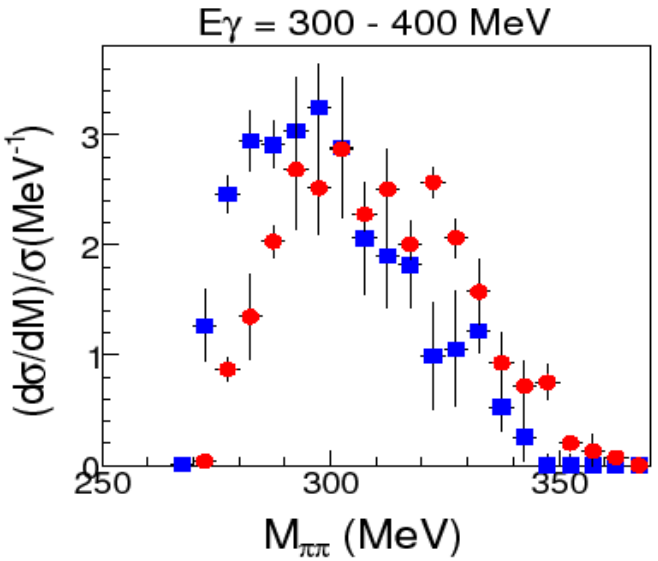
Invariant mass dist. normalized to total cross sections

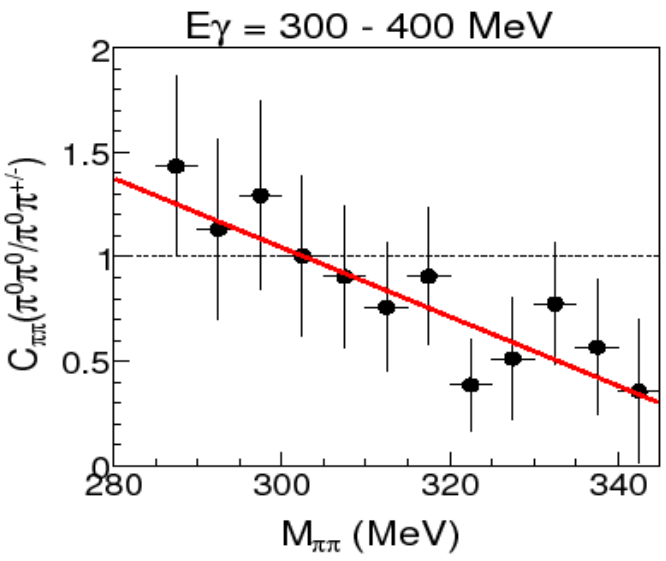


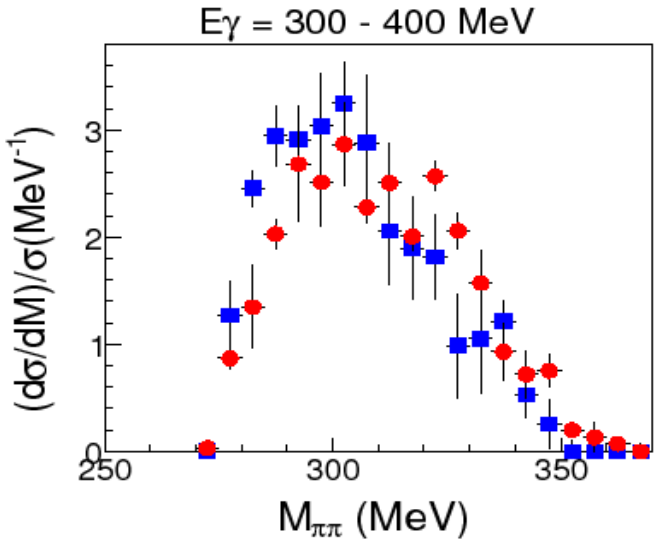
Ratio Neutral/Charged mass distributions fitted

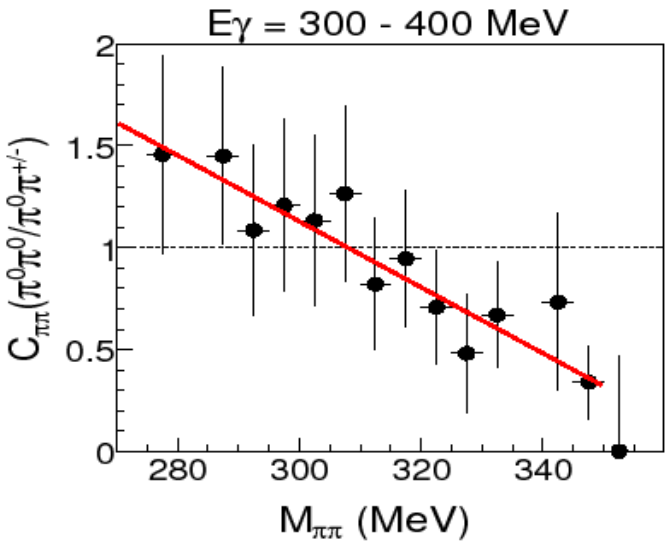


Results : *The double pion photoproduction off ^{7}Li*









Lower beam energy : 300 – 400 MeV in order to minimize FSI.

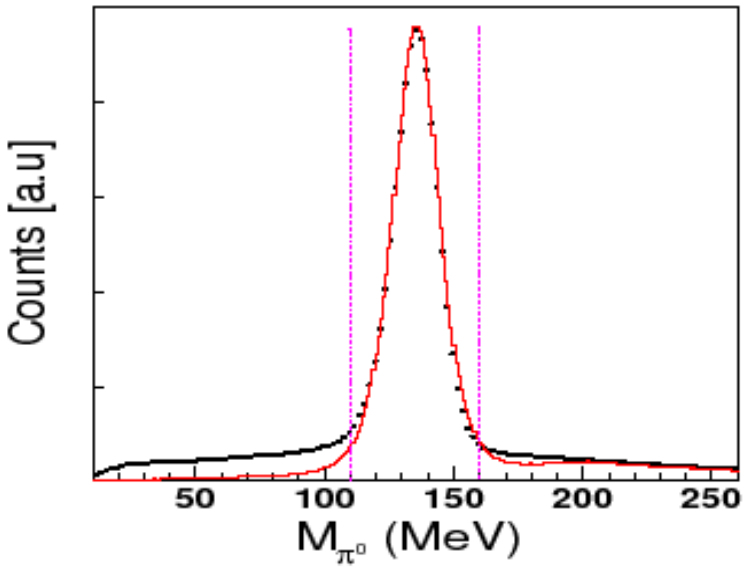
The neutral mass dist has been shifted by 4.6 MeV in order to account for the mass difference between the neutral and the charged pion.

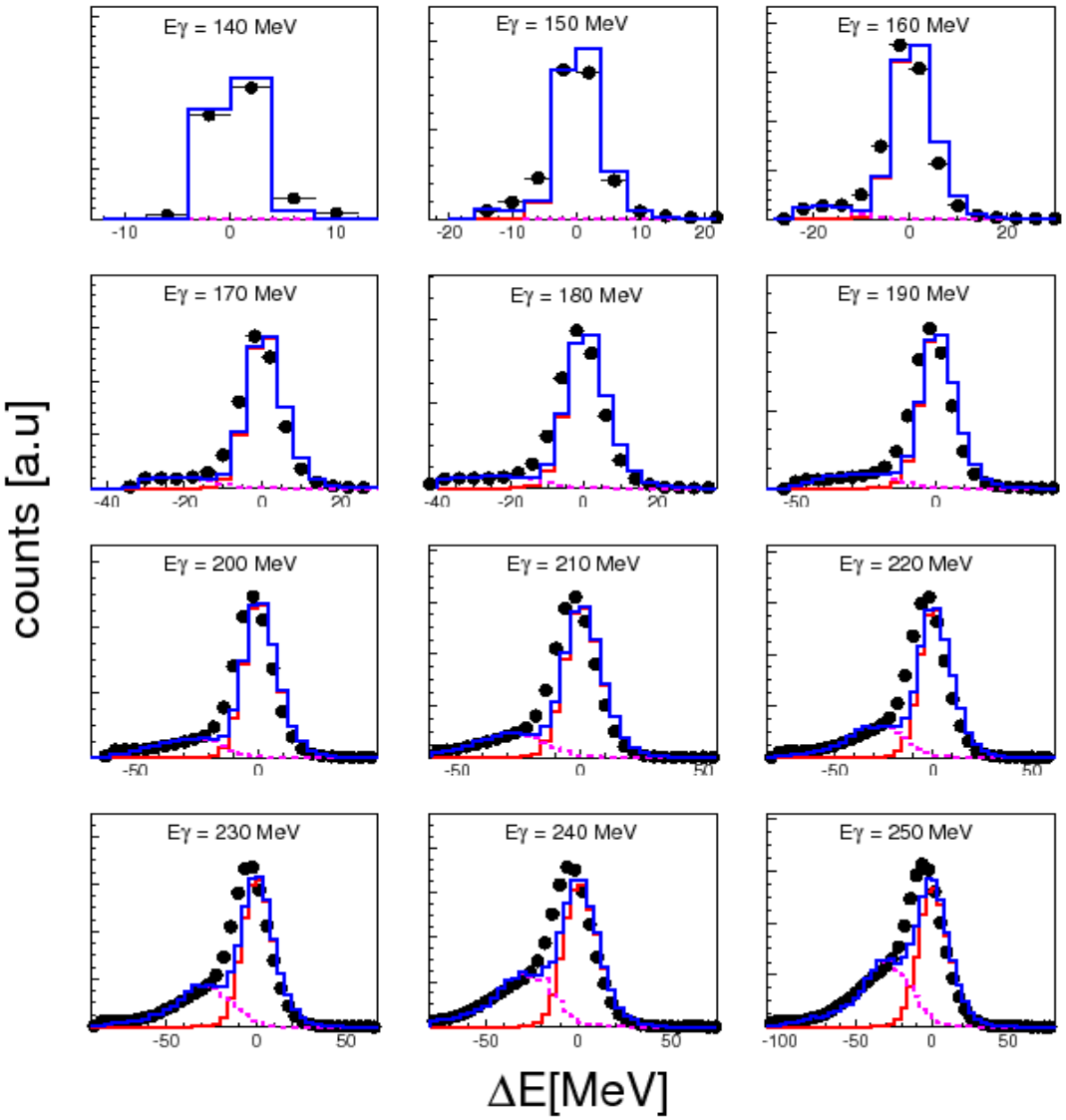
Clear shift observed in both cases.

Results : *The coherent π^0 photoproduction off ^{7}Li*

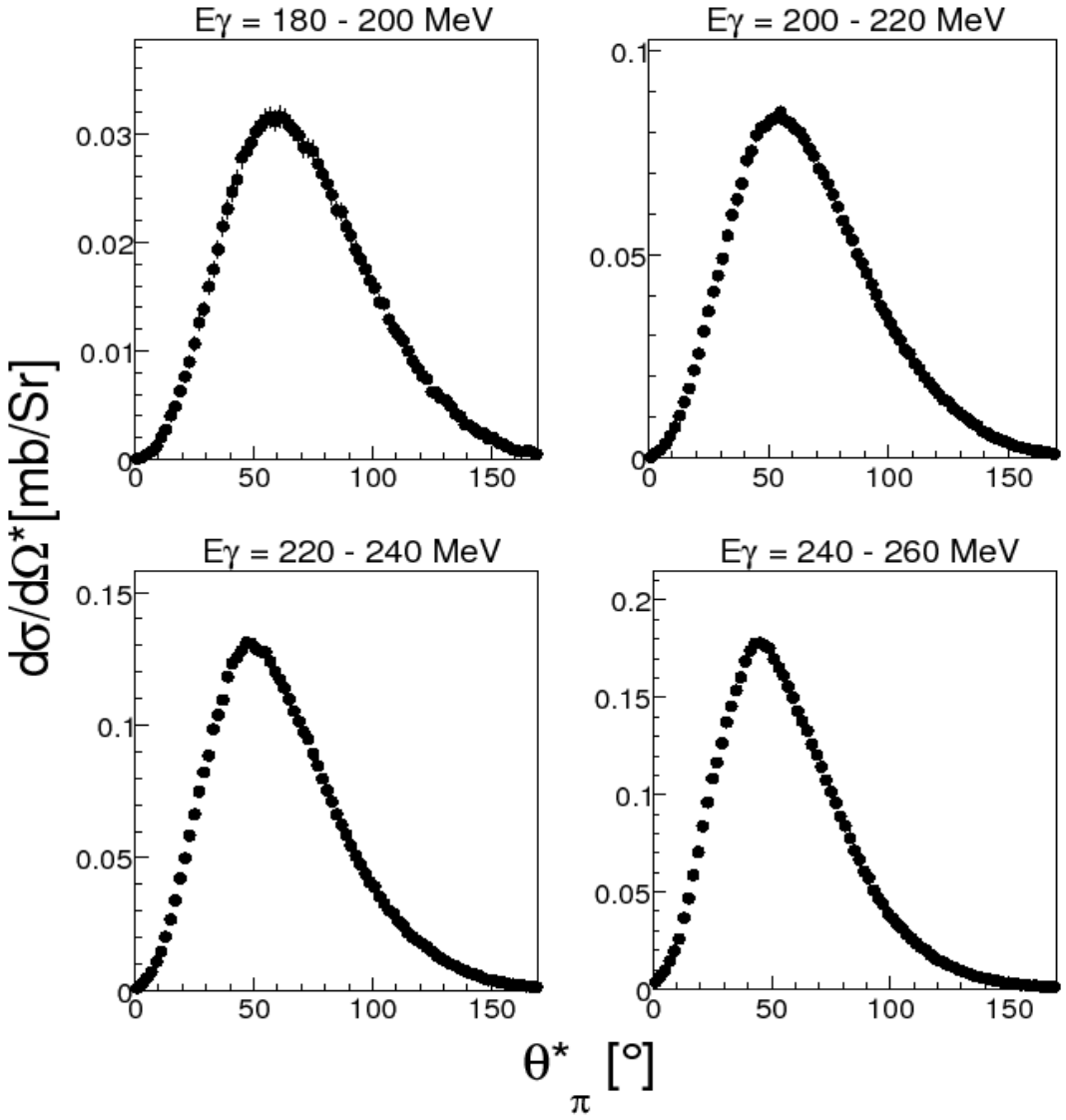
Reaction identification

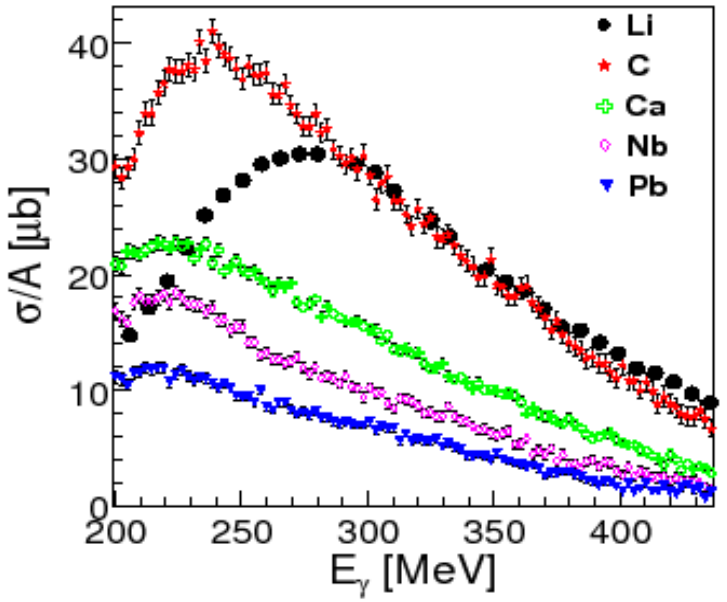
- 2 photons, no charged hits, no hit in PID/MWPC/Veto wall.
- Coherent peak at threshold (~137 MeV)
- Contribution from incoherent and breakup reactions when E↗ at ΔE>0
- Cuts : ΔE>0 and on π^0 invariant mass (110-160 MeV) in data and simu.





Results : *The coherent π^0 photoproduction off ^{7}Li*





- Angular distributions to be compared to calculations for ^{7}Li
- Angular distributions integrated over E_γ and scaled by A to be compared to heavy targets
  → A and $F^2(q)$ dependence

Results : *The coherent π⁰ photoproduction off ^{7}Li*

Form Factor in PWIA :

$$F^2(q)|_{PWIA} = \frac{d\sigma_{exp}}{d\Omega} / [\frac{s}{m_N^2} A^2 (\frac{d\sigma_{NS}}{d\Omega^*})]$$

Mass rms radius extracted from the slope of the form factor when $q^2 \rightarrow 0$ via :

$$F(q^2) = 1 - \frac{q^2}{6} r_{rms}^2 + O(q^4)$$

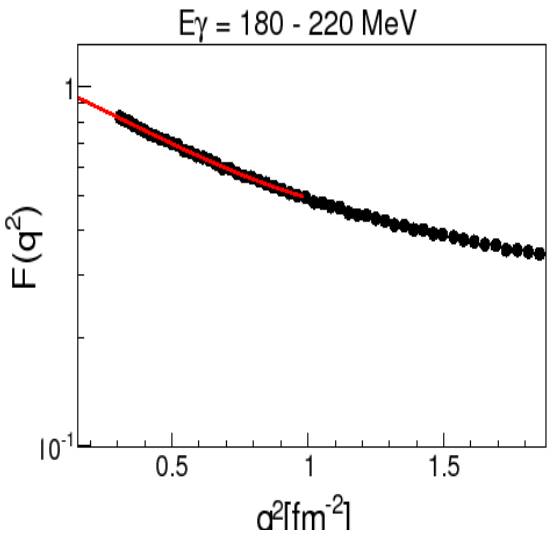
which is done by fitting a polynomial :

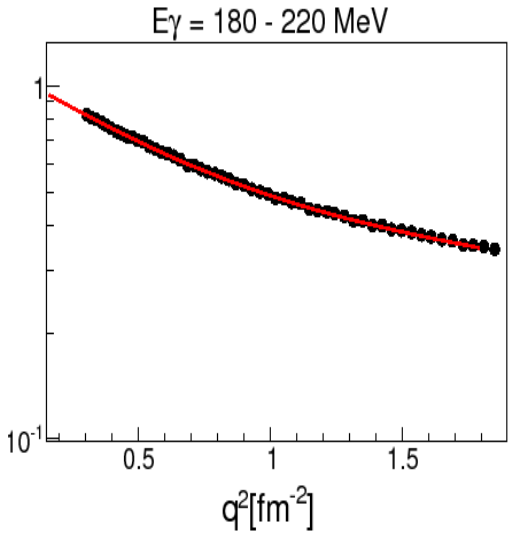
$$F(q^2) = \sum (-1)^n a_n q^{2n}$$

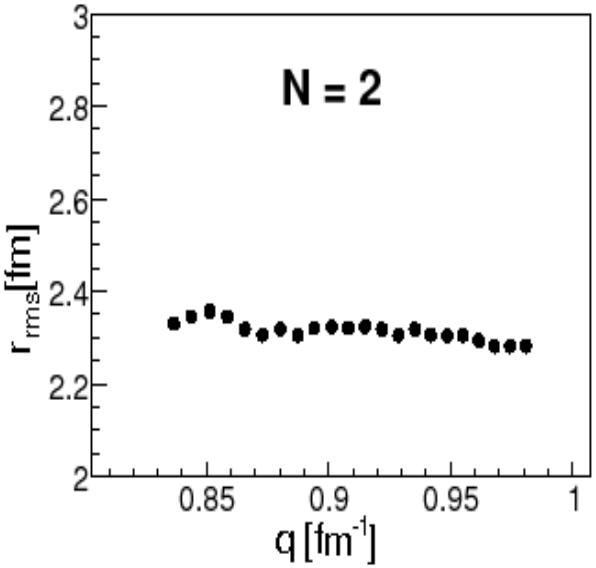
to the data.

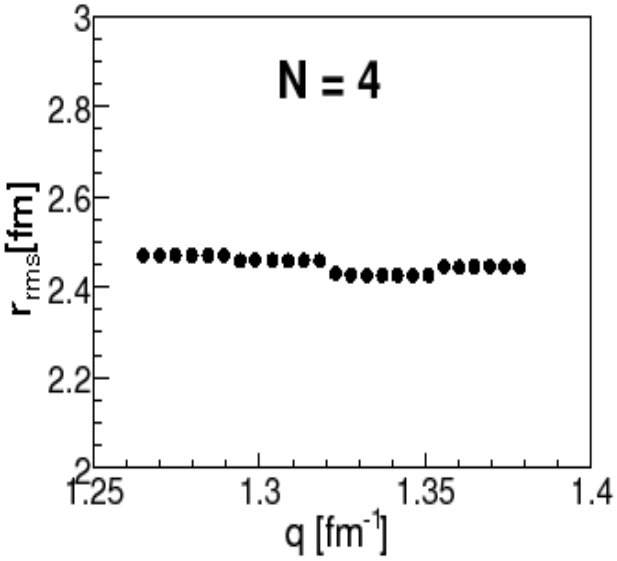
$$r_{rms} = \sqrt{6 a_1 / a_0}$$

To be compared to charge rms in litt. : 2.39 – 2.41 fm







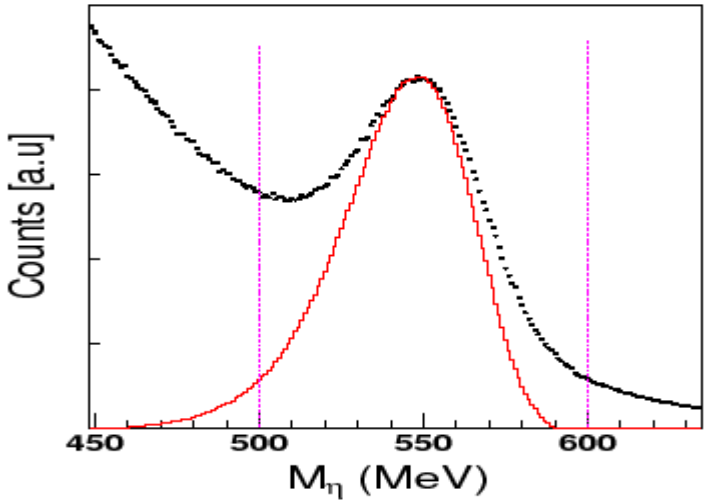


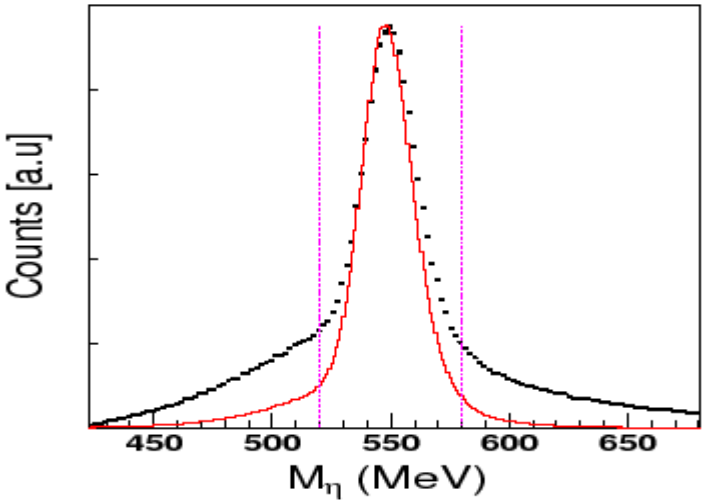
Results : *The coherent η photoproduction off ^{7}Li*

2 studied reactions :

$\eta \rightarrow \gamma\gamma$ (39%) : Select events with 2 or 3 neutral hits
Best combination : χ^2-test
Cut on the inv. Mass 500 – 600 MeV
Gaus + pol fit to remove background

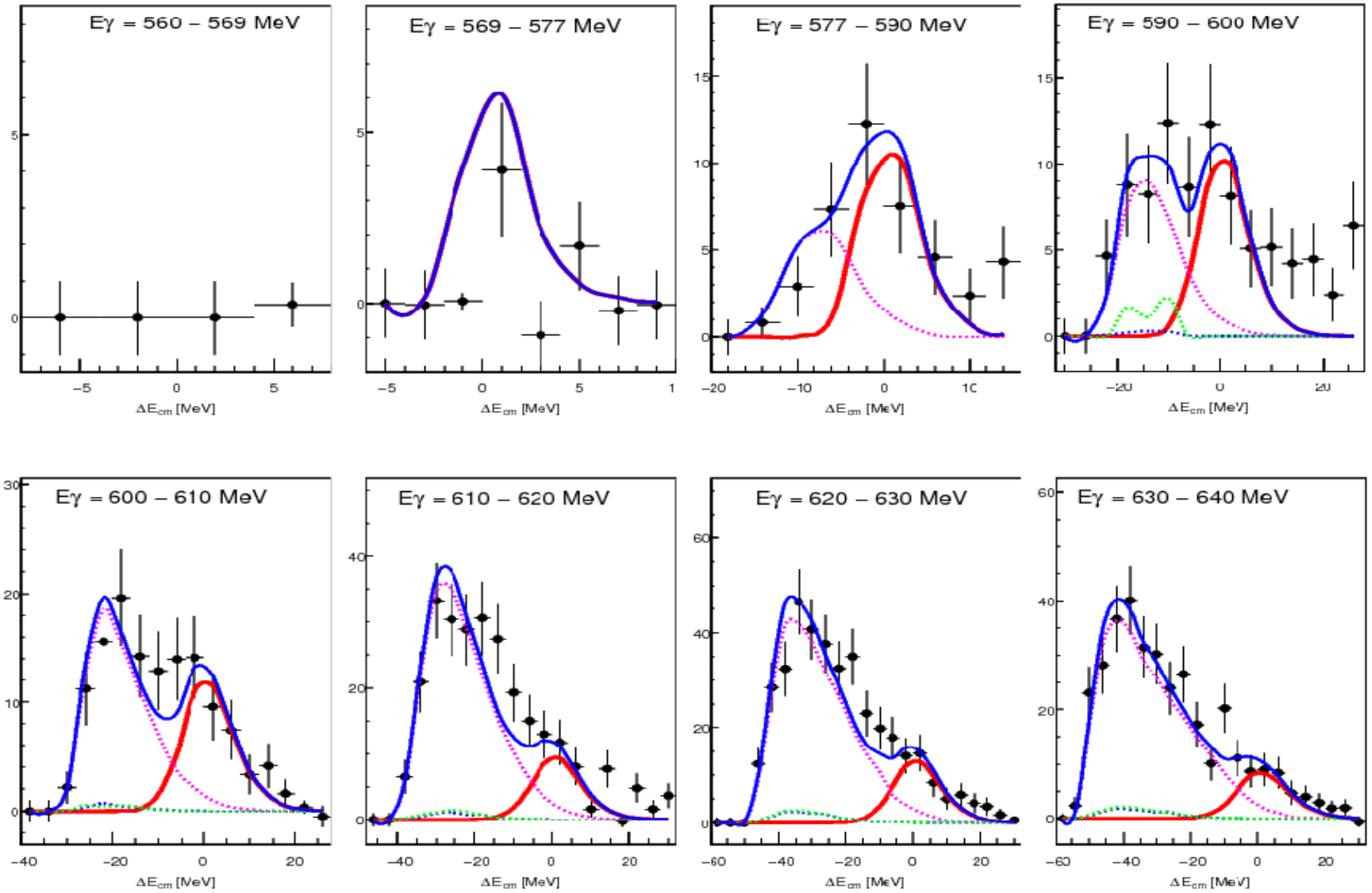
$\eta \rightarrow 3\pi^0 \rightarrow 6\gamma$ (32%) : Select events with 6 or 7 neutral hits
Best combination : χ^2-test
Cut on the inv mass 520 – 600 MeV
Gaus + pol fit to remove background





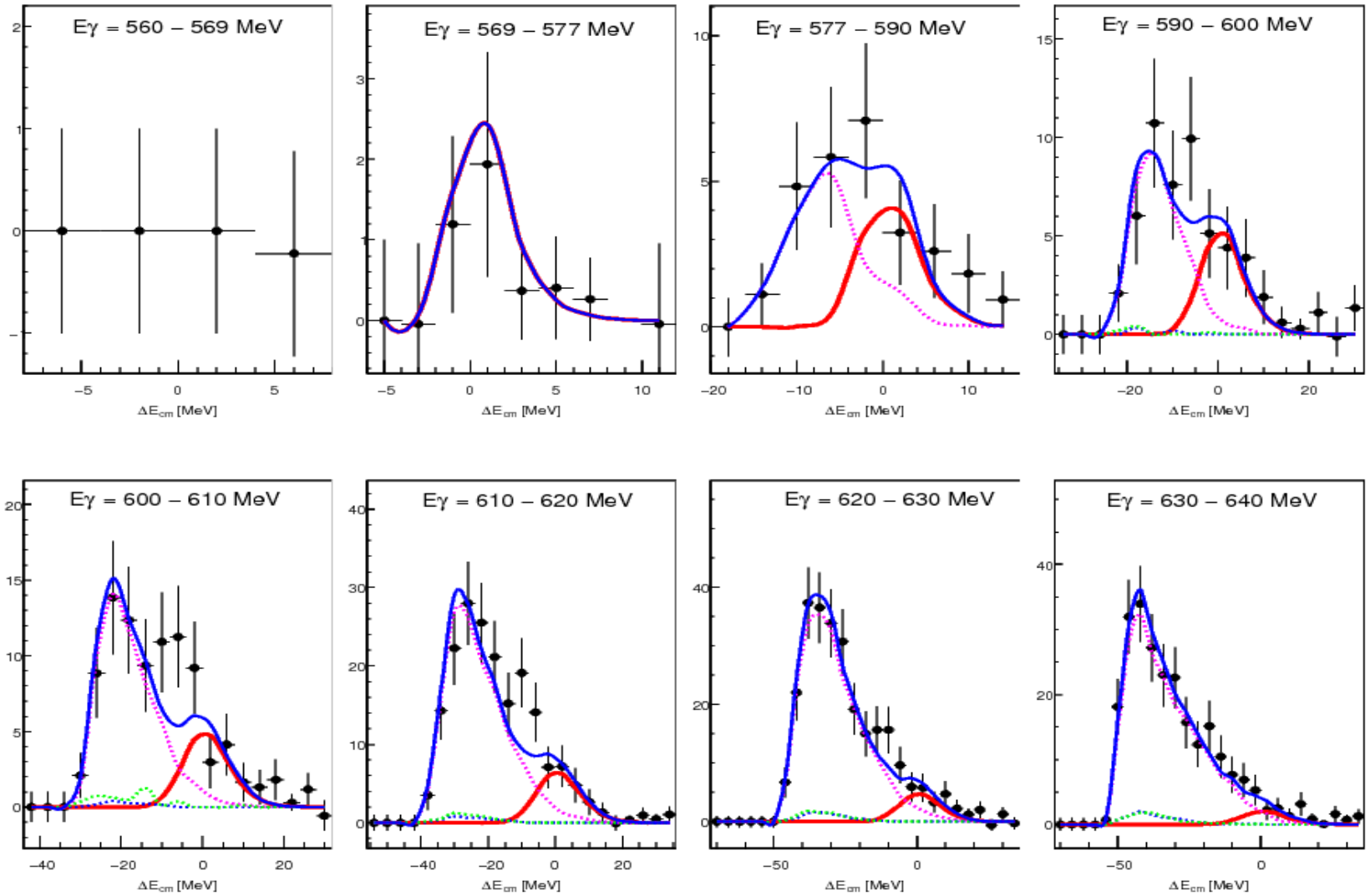
Results : *The coherent η photoproduction off ^{7}Li*

Missing energy spectra for η →γγ for different incident photon beam energies

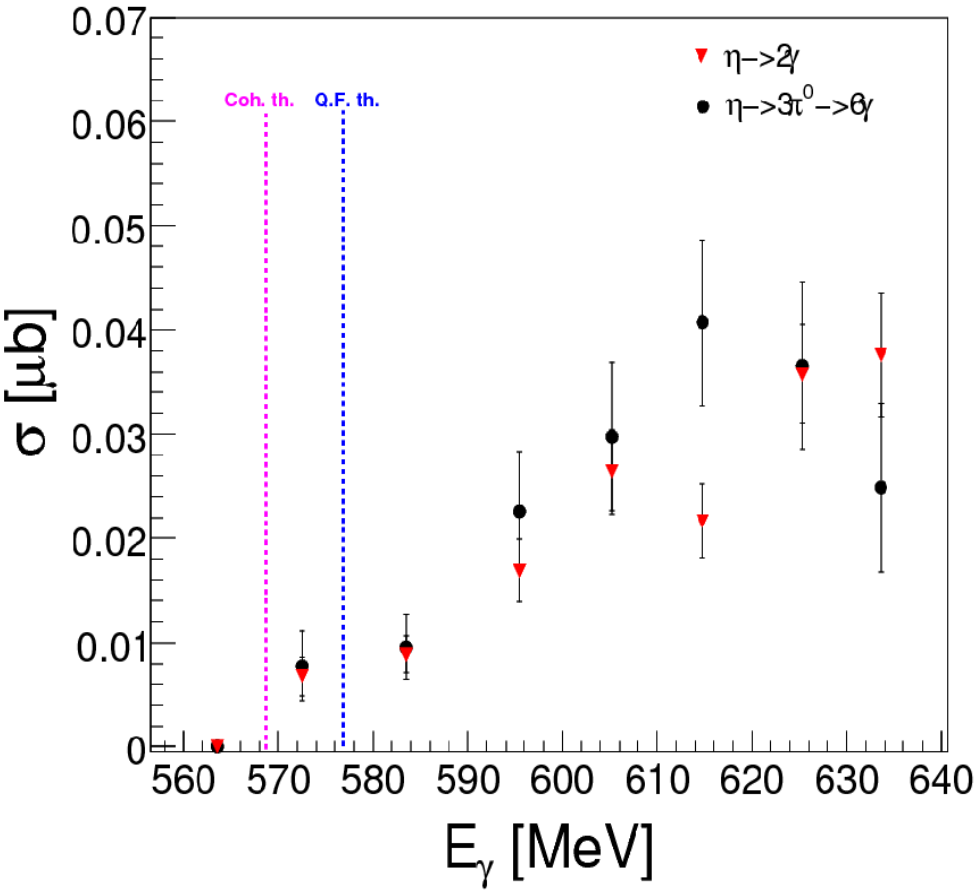


Results : *The coherent η photoproduction off ^{7}Li*

Missing energy spectra for $\eta \rightarrow 3\pi^0 \rightarrow 6\gamma$ for different incident photon beam energies

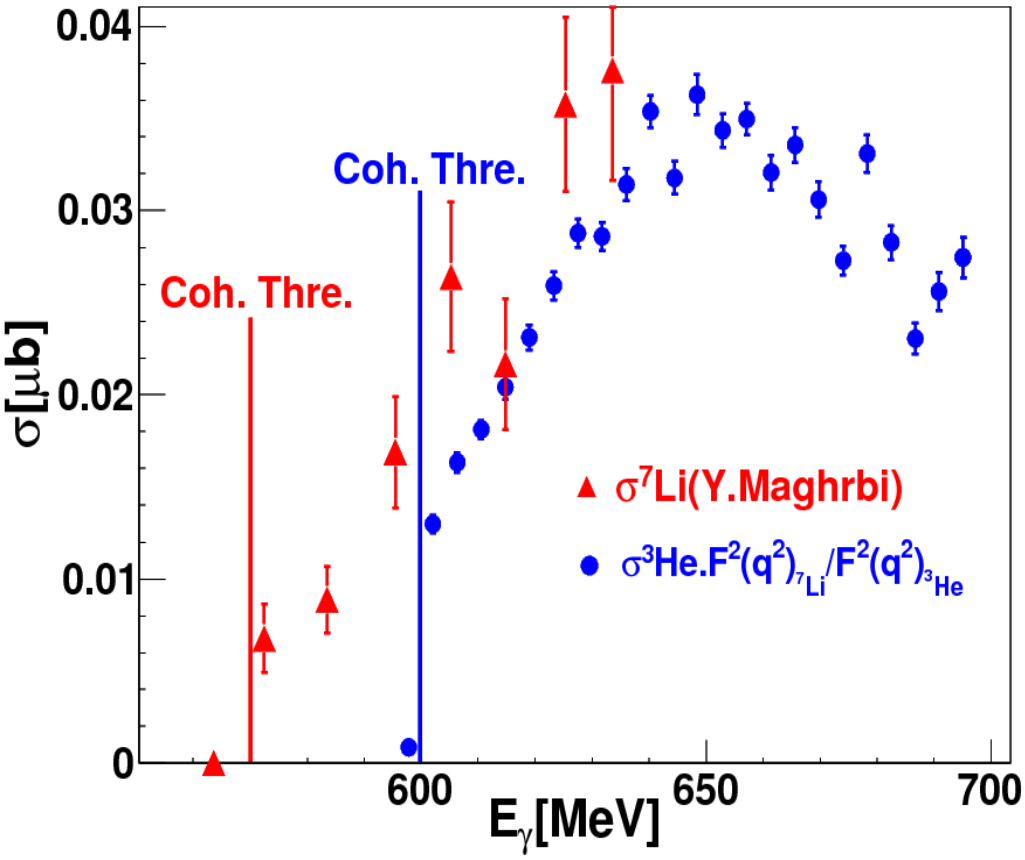


Results : *The coherent η photoproduction off ^{7}Li*



Preliminary Total coherent cross section

➡ A relative enhancement can be seen



Total coherent cross section normalized and compared to ^{3}He (F.Pheron)

Summary and outlook

- High statistical quality experiment and improved detection efficiency

→ Rich program : In-medium σ properties , coherent π^0 and η photoproduction.

- Shift towards small invariant masses observed in $\pi^0\pi^0$ compared to $\pi^0\pi^{+/-}$
- Coherent π^0 photoproduction with large statistics, form factor and mass rms radius in good agreement with other results.

- Small η coherent signal observed in Li. Preliminary cross section in good agreement with He.

Coming up :

- Finishing analysis on heavy targets (C, Ca, Pb)
- Comparison to DWIA calculation for Li
- Investigate π^0p channel.

Thank you for your attention

The work was supported by *the Swiss National Fund*