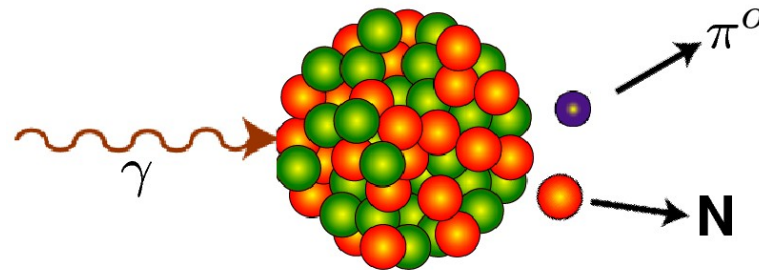


Double pion photoproduction off nuclei

-

Is there evidence for in-medium modifications of the σ -meson?



Yasser Maghrbi

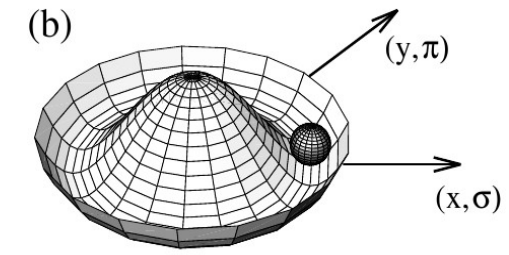
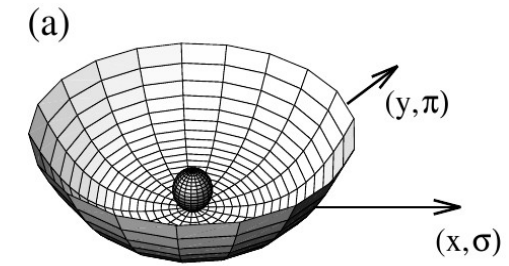
Meson 2012 - Cracow - Poland

Introduction and motivation

Spontaneous breaking of chiral symmetry, fundamental symmetry of QCD

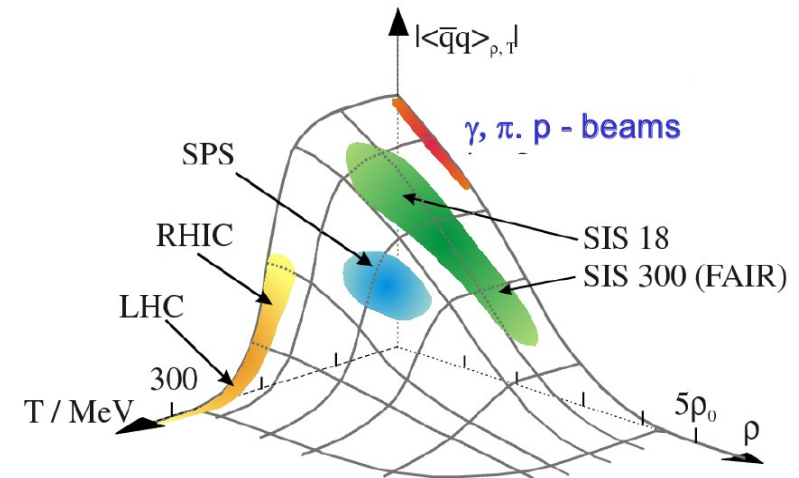
→ Clearly reflected in the hadron spectrum, without it, hadrons would appear as mass degenerate parity doublets

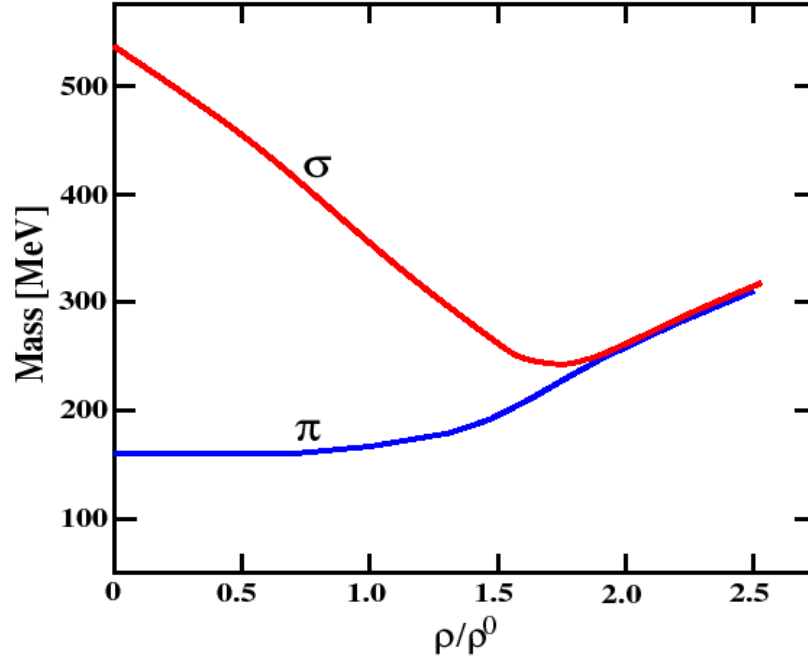
| | baryons | vector mesons | pseudo-scalar mesons |
|---|-----------------------|------------------|-------------------------|
| Particle, J^π, Mass | $P_{11}, 1/2^-, 939$ | $\rho, 1^-, 770$ | $\pi, 0^-, 134.7$ |
| Chiral partner, J^π, Mass | $S_{11}, 1/2^+, 1535$ | $a_1, 1^+, 1260$ | $\sigma, 0^+, 400-1200$ |
| Mass split | ≈ 600 | ≈ 500 | 266-1066 |



Models : density and temperature dependence of the chiral condensate and QCD and hadron pictures indirectly connected via QCD sum rules

- Partial restoration of chiral symmetry
- In medium modification of hadrons



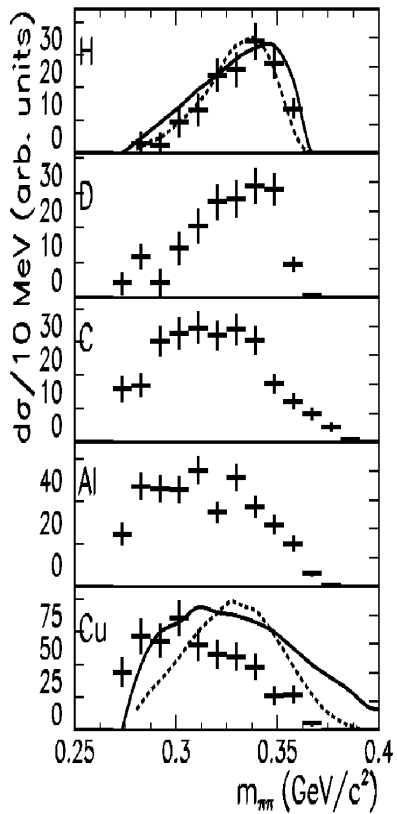


V. Bernard et al.
PRL 59 (1987)

- At high temperature /density, the σ -meson ($J^{\pi} 0^{-}$) becomes degenerate with its chiral partner ($J^{\pi} 0^{+}$) the π -meson
 - σ decays into $\pi^0\pi^0$ but not into $\pi^0\pi^{+/-}$
- **In medium modification of $\pi^0\pi^0$ invariant mass.**
- compare $\pi^0\pi^0$ and $\pi^0\pi^{+/-}$ inv. mass spectra for the same target
 - compare $\pi^0\pi^0$ and $\pi^0\pi^{+/-}$ inv. mass spectra for different targets

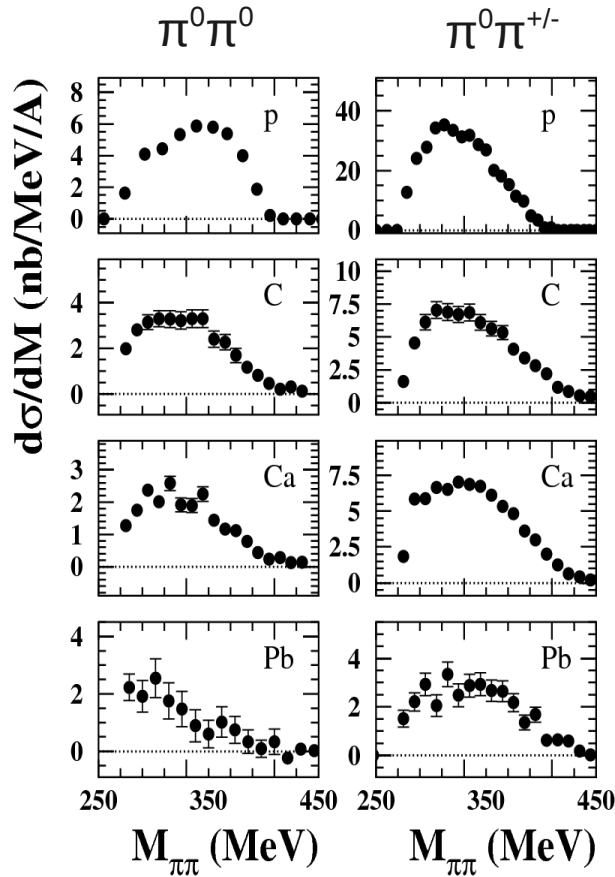
Pion beam

Starostin et al.
Crystalball@BNL (2000)



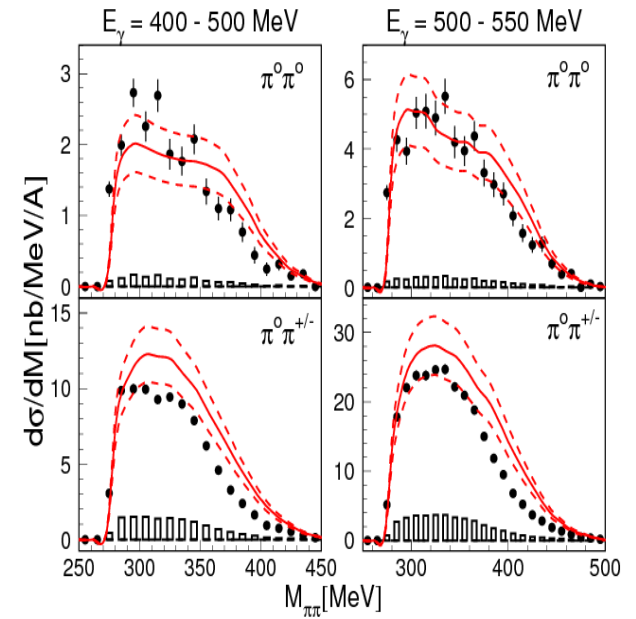
Photon beam

Messchendorp et al.,
TAPS@MAMI (2002)



Photon beam

Bloch et al.,
TAPS@MAMI (2007)

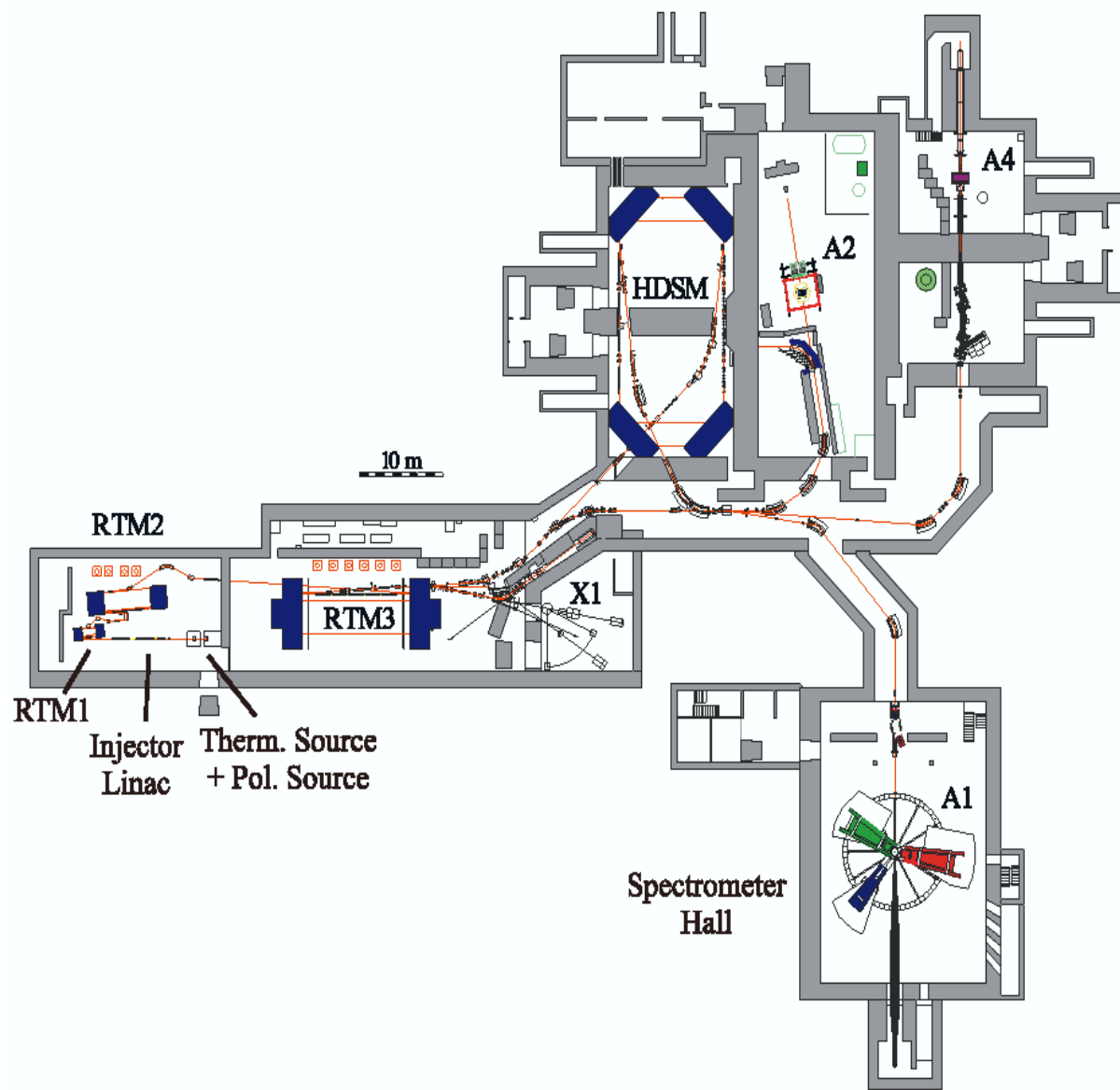


Nuclear mass dependence of the invariant mass distributions is seen in hadron and photon induced reactions, consistent with the σ modification in nuclear matter

The most recent results show that at least in Calcium, FSI are responsible for the effect

**New measurements /
better statistics /
full solid angle coverage /
more targets**

Experimental setup



Accelerator

Racetrack Microtron

Electron beam up to 883 MeV

Upgraded up to 1.5 GeV (2006)

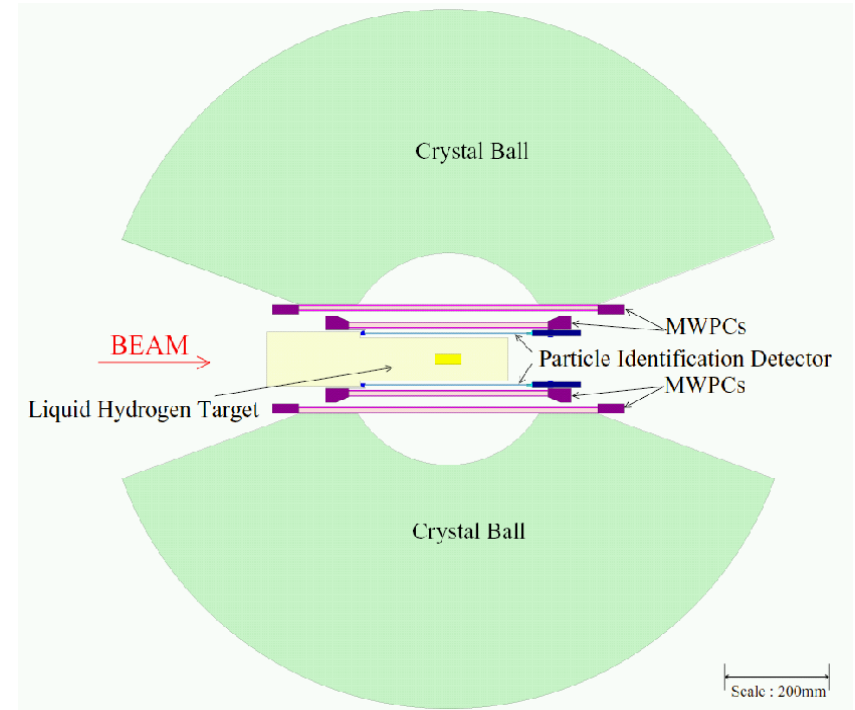
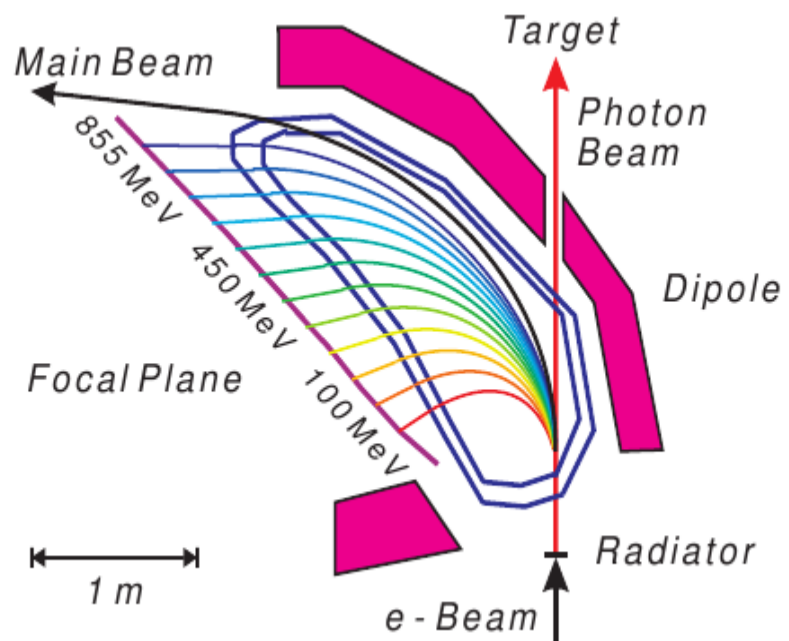
Rich program:

A1 : electron scattering

A2 : real photons

A4 : parity violation

X1 : X-Ray radiation



Detectors

- **Crystal Ball** : 672 NaI Crystals
- **PID** : 24 plastic scintillators
- **2 MWPC**

- **TAPS** : 510 BaF2 Crystals
- **Plastic Veto Wall**

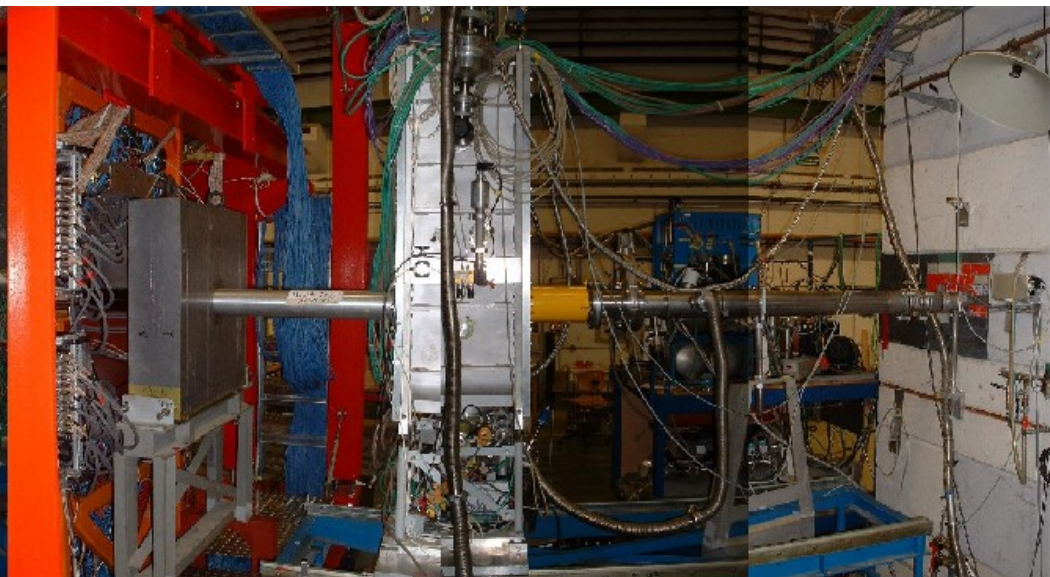
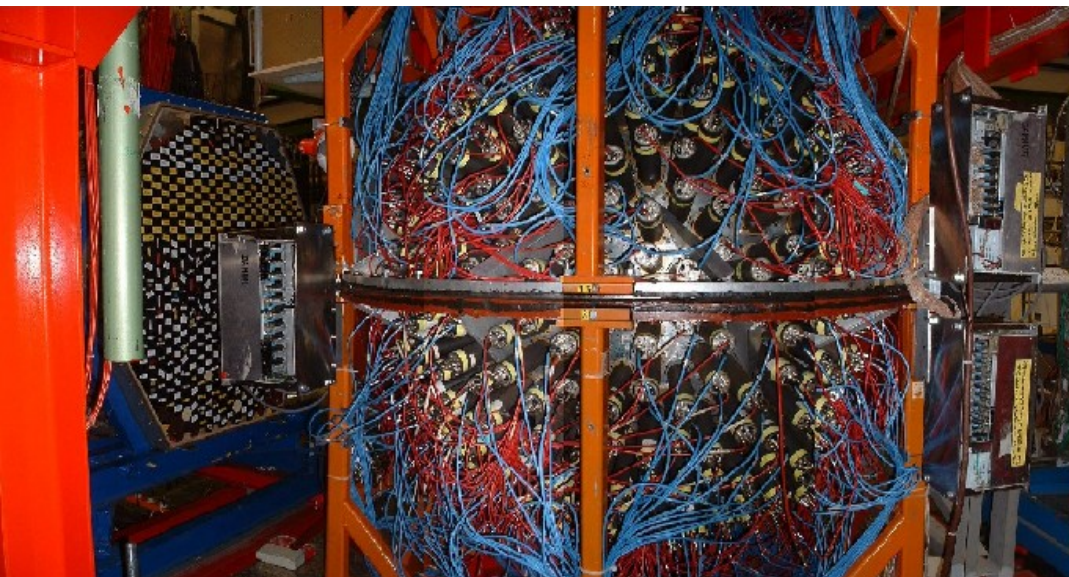
Almost 4π solid angle coverage!

1/E spectrum

- Energy of the produced photons:

$$E_{\gamma} = E_e - E_{e'}$$

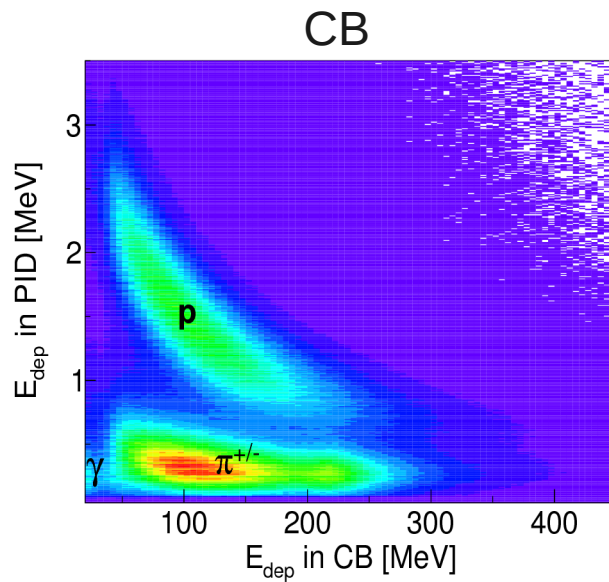
- Total number of scattered electrons
(for the cross sections)



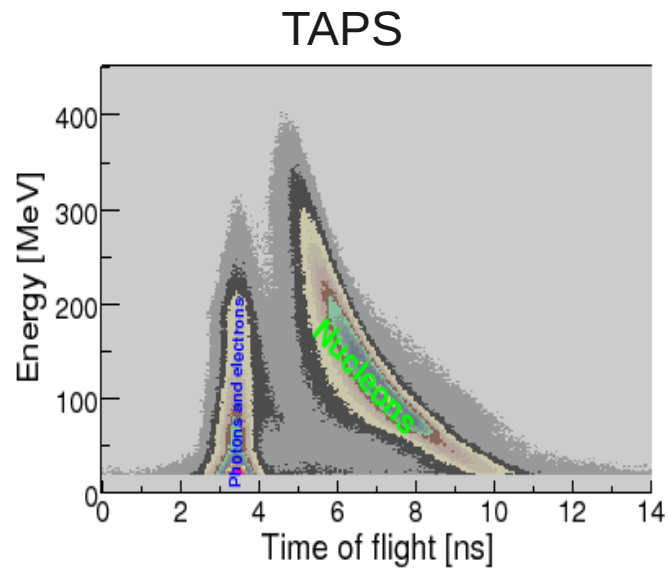
Results

Particle identification:

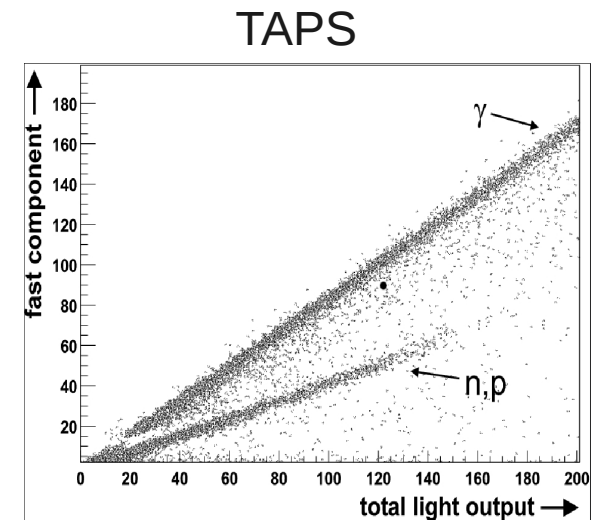
- Charged particles : E- ΔE (CB/PID) + MWPCs
 - Nucleons/photons : E vs Time-of-flight
 - Baryons/electromagnetic shower : Pulse-shape analysis
 - Veto decision : Charged or not.
-
- Reaction identification: Invariant mass / Missing Mass / Missing energy analysis



CB/PID E- ΔE cuts



E vs Time of flight



Pulse shape analysis

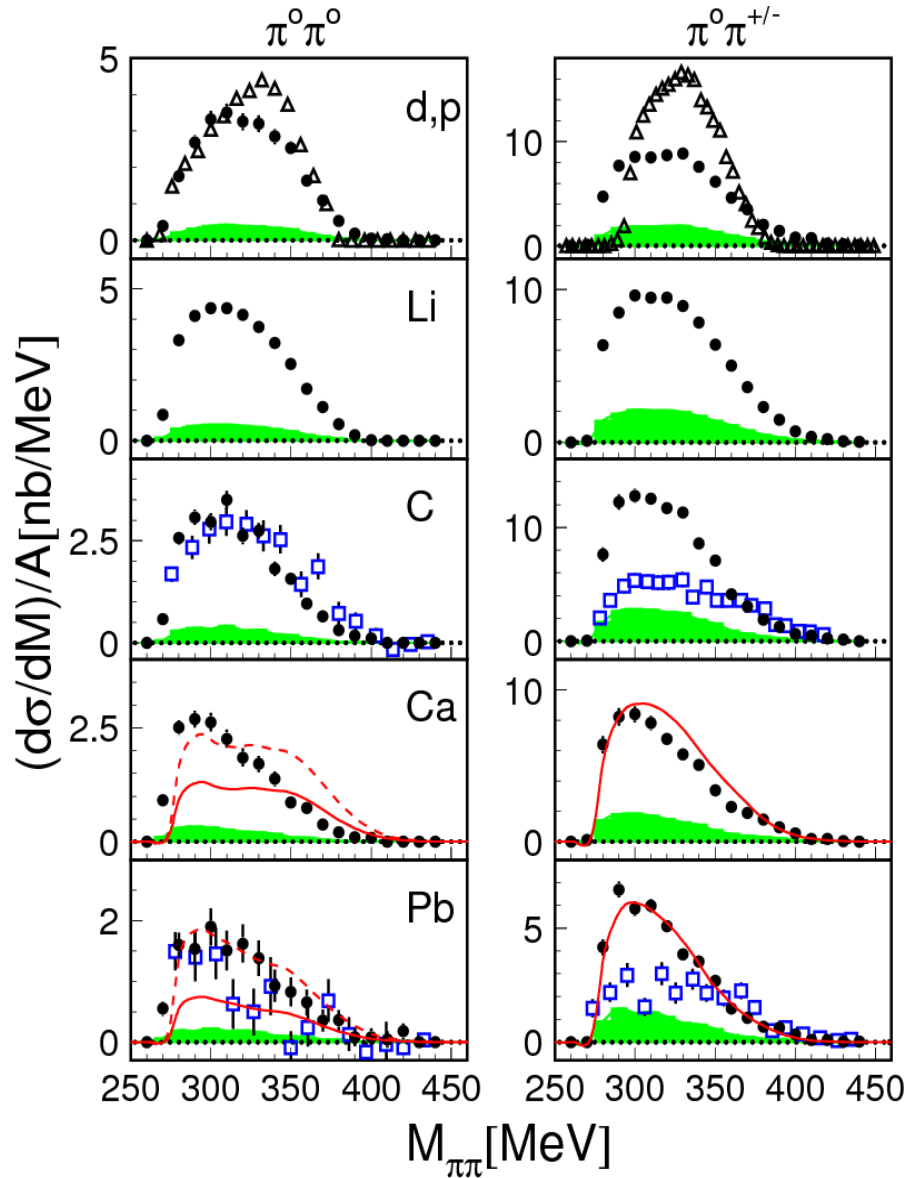
Mass dependence of $\pi^0\pi^0$ and $\pi^0\pi^{+/-}$ invariant mass spectra

● This data

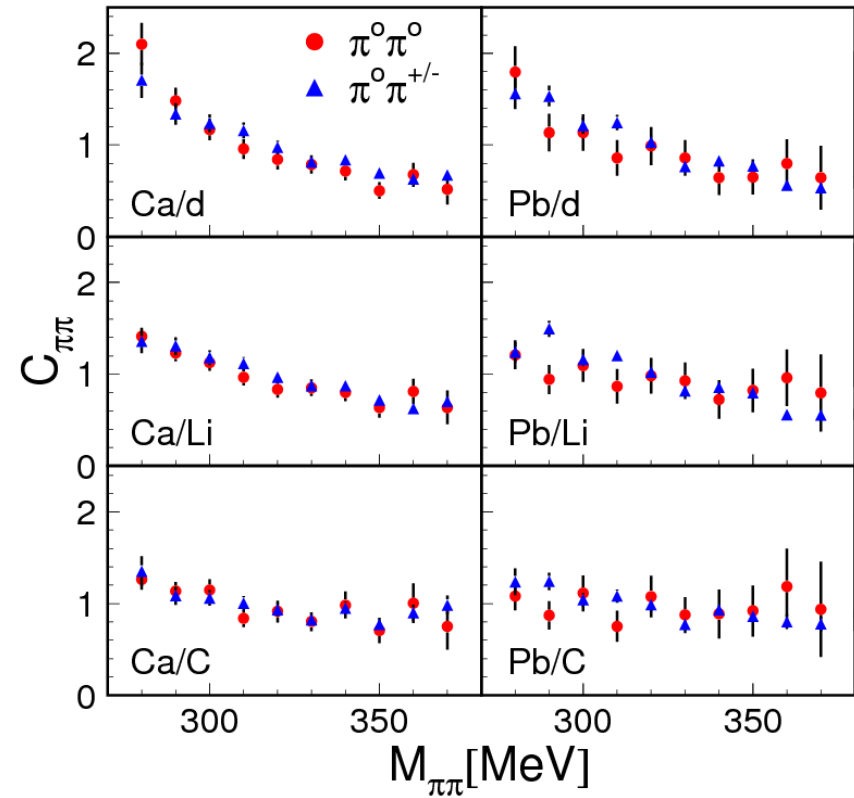
△ Proton

□ Bloch et al

— GiBUU model



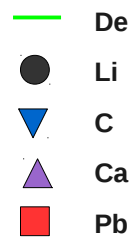
$$C_{\pi\pi}(A_1, A_2) = \frac{(d\sigma(A_1)/dM)/\sigma(A_1)}{(d\sigma(A_2)/dM)/\sigma(A_2)}$$



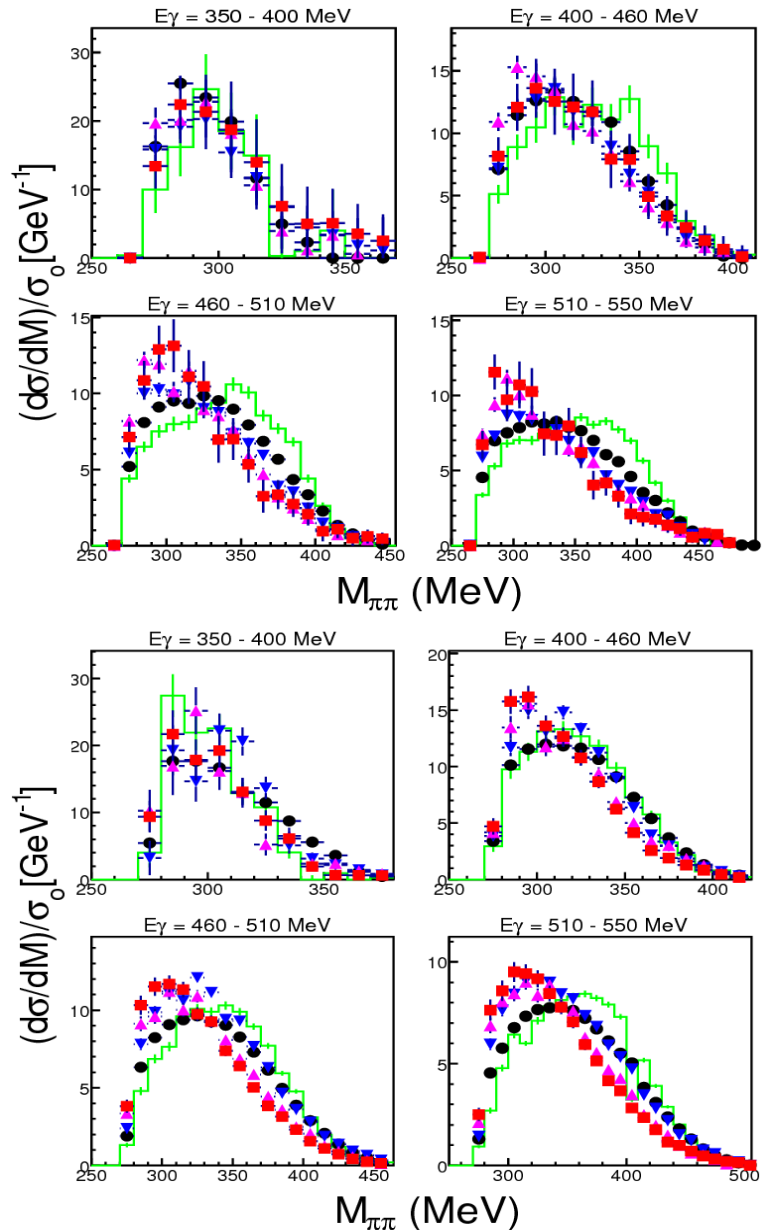
Very similar behavior for both $\pi^0\pi^{+/-}$ to $\pi^0\pi^0$ reactions

Top: $\pi^0\pi^0$

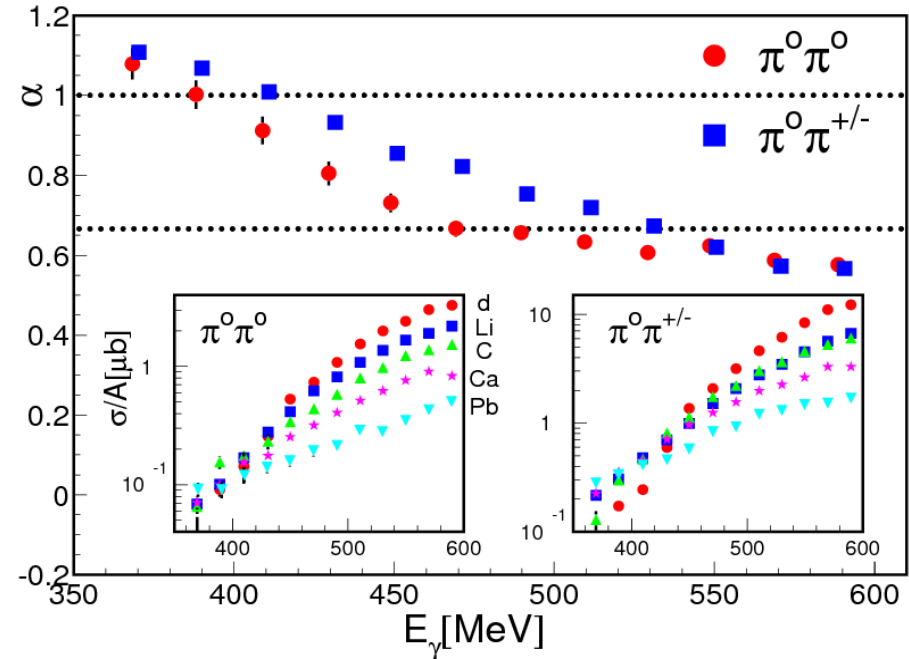
Bottom: $\pi^0\pi^{+/-}$



Size and influence of Final State Interactions



$$\sigma(A, E_\gamma) \propto A^\alpha(E_\gamma)$$



Scaling factor

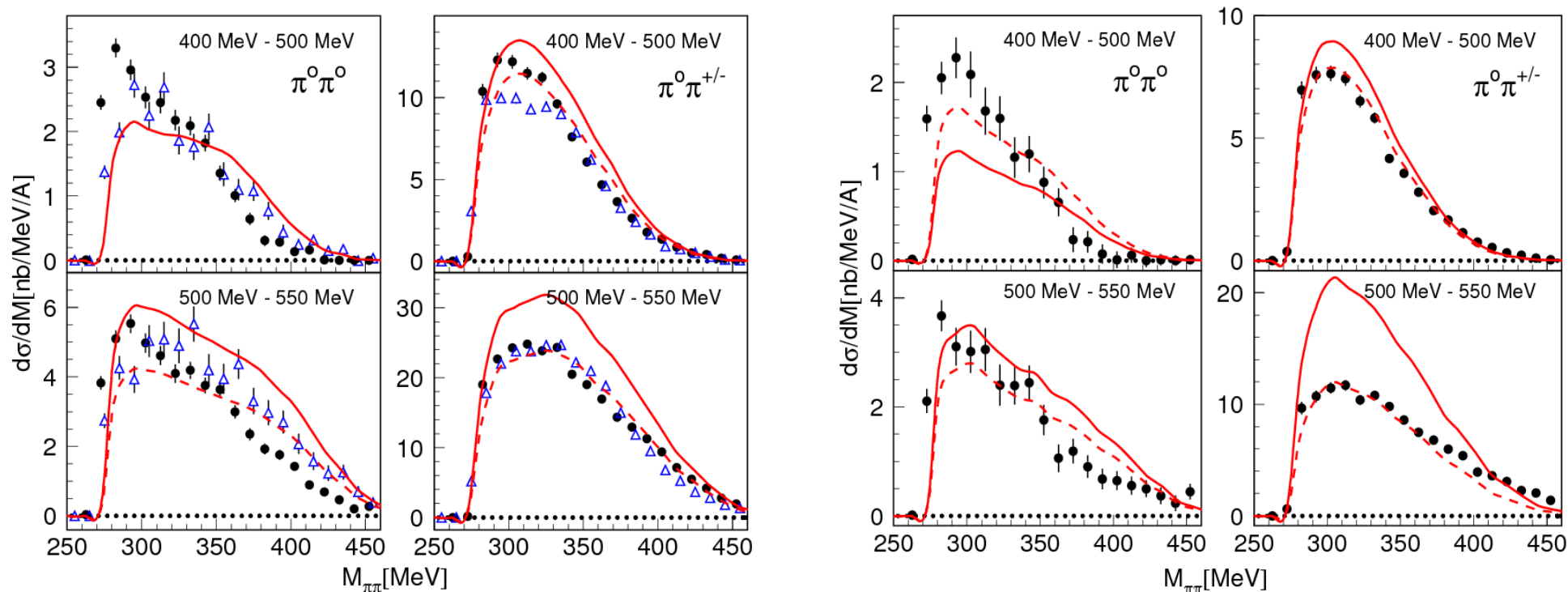
- close to 1 : cross sections scale like number of nucleons (negligible loss due to pion absorption)
 - close to 2/3 : cross sections scale like surface (strong absorption)
- FSI almost negligible at low E_γ , substantial at high E_γ
 - Shape change of Invariant mass distributions correlates with energy dependence of FSI effects.

Comparison of invariant mass spectra to transport model calculations

△ Bloch et al

Calcium

Lead



- Excellent agreement of mixed charge channel and the model
- Strong softening of invariant mass of the neutral channel compared to the model

Conclusions and outlook

- Precise results obtained for the invariant mass distributions of $\pi^0\pi^0$ and $\pi^0\pi^{+/-}$ from LD_2 , Li, C, Ca and Pb from threshold up to 600 MeV.
- Total and differential cross section in agreement with previous measurements
- A pronounced shift of strength towards small invariant masses is observed
- In contrast to previous results, the shift is observed in both final states
- Effect negligible at threshold and increases with increasing beam energy
→ FSI plays an important role in the effect
- Investigation of possible modification of the σ meson in medium needs model calculations

Further interesting results on:

- photoproduction of $\pi^0\pi^0$ by Markus Oberle
- photoproduction of π^0 by Manuel Dieterle

are shown in the poster session on **Saturday**
from **15:00 to 17:00**



Thank you for your attention

