The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

International Atomic Energy Agency

SMR.1751 - 23

Fifth International Conference on
PERSPECTIVES IN HADRONIC PHYSICS
Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

22 - 26 May 2006

Hadrons in the Nuclear Medium - Recent Experimental Results

Volker METAG
Justus Liebig Universitat
Institut fuer Theoretische Physik II
Heinrich-Buff-Ring 16
35392 Giessen
GERMANY

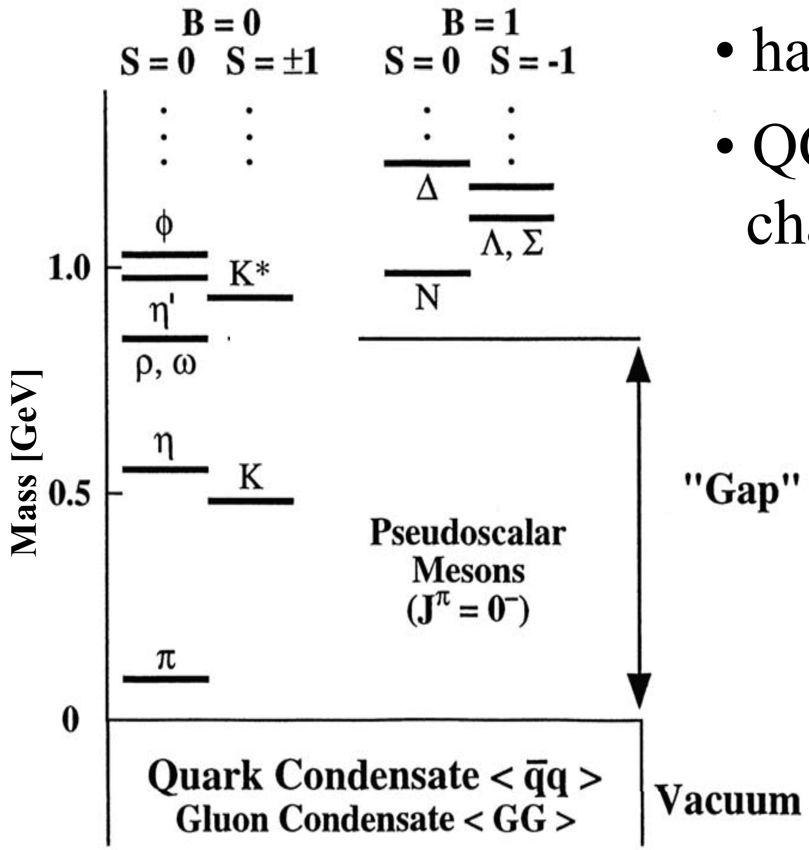
Hadrons in the nuclear medium - recent experimental results

Volker Metag
II. Physikalisches Institut
Universität Giessen
Germany

- motivation
- first observation of medium modifications of the ω meson:
  a.) mass shift
  b.) in-medium width
- first observation of an ω-nucleus bound state: ${}^{11}_{\omega}B$
- summary and outlook

5th. International Conference on Perspectives in Hadron Physics
Trieste, Italy, May 22-26, 2006

Motivation



- hadrons = excitations of the QCD vacuum
- QCD-vacuum: complicated structure characterized by condensates
  - in the nuclear medium: condensates are changed

→ change of the hadronic excitation energy spectrum

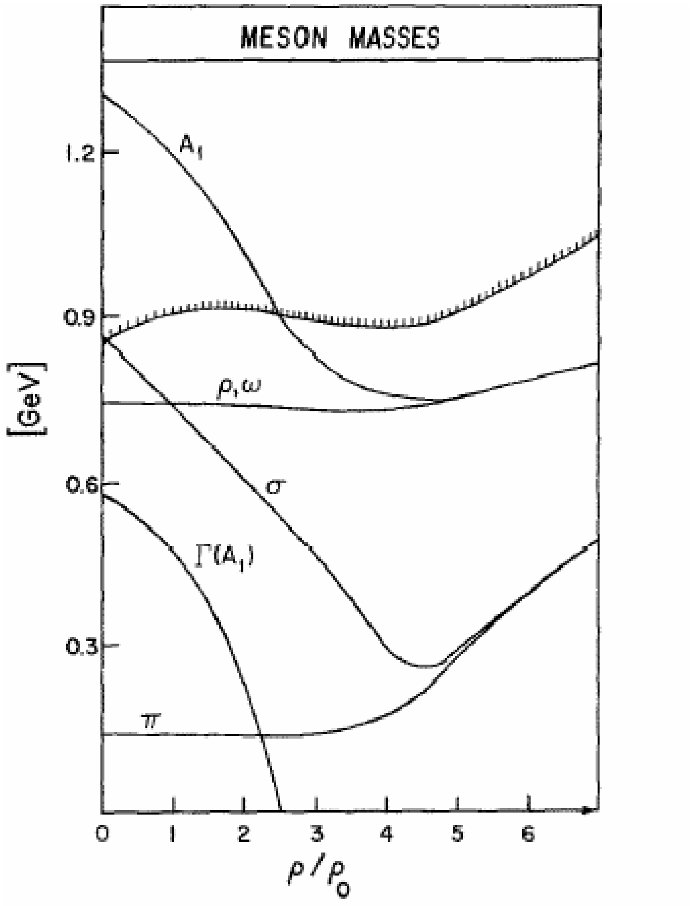
G.E.Brown and M. Rho, PRL 66 (1991) 2720 $\frac{m^*}{m} \approx \frac{\langle \bar{q}q \rangle^*}{\langle \bar{q}q \rangle} \approx 0.8\,(\rho \approx \rho_0)$

T.Hatsuda and S. Lee, PRC 46 (1992) R34 $\frac{m_V^*}{m_V} = \left(1 - \alpha \frac{\rho_B}{\rho_0}\right)$; $\alpha \approx 0.18$

⇒ widespread experimental activities to search for in-medium modifications of hadrons

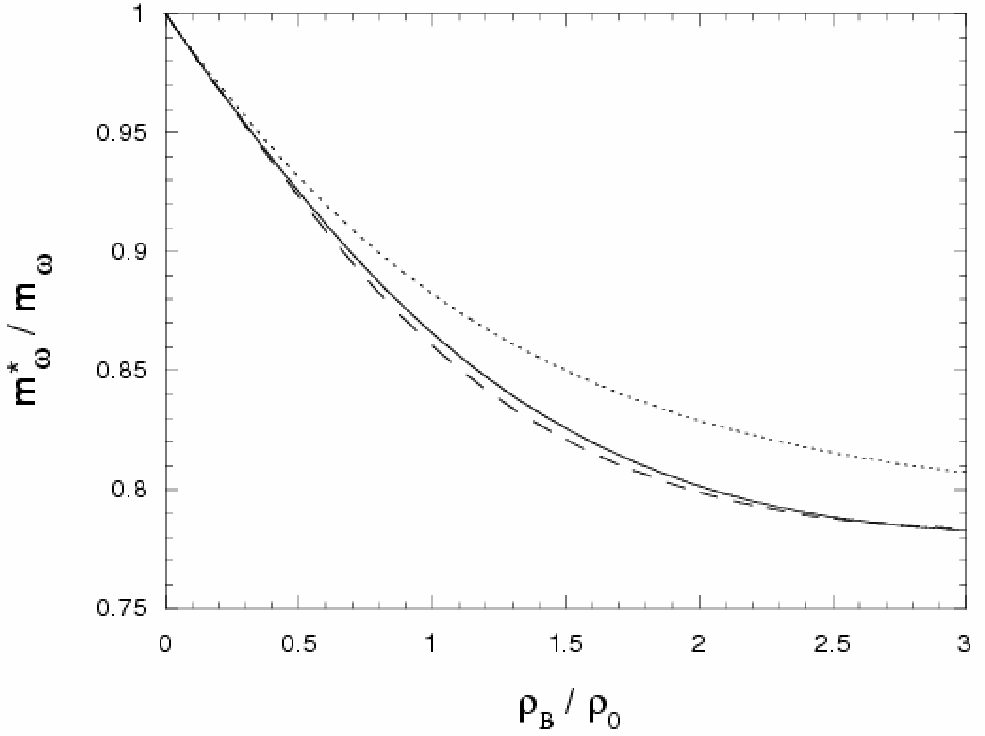
model predictions for in-medium masses of mesons

V. Bernard and U.-G. Meißner
NPA 489 (1988) 647
NJL-model



ω-mass roughly constant

K. Saito, K. Tushima, and A.W. Thomas
PRC 55 (1997) 2637
Quark-meson coupling model (QMC)

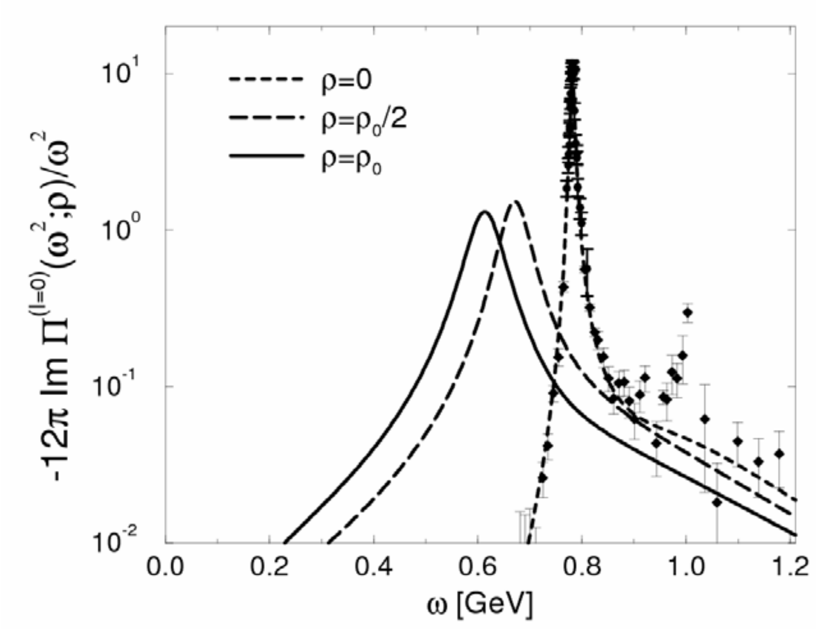


decrease of ω -mass by ≈ 15%
at normal nuclear matter density

Model predictions for spectral functions of ρ and ω mesons

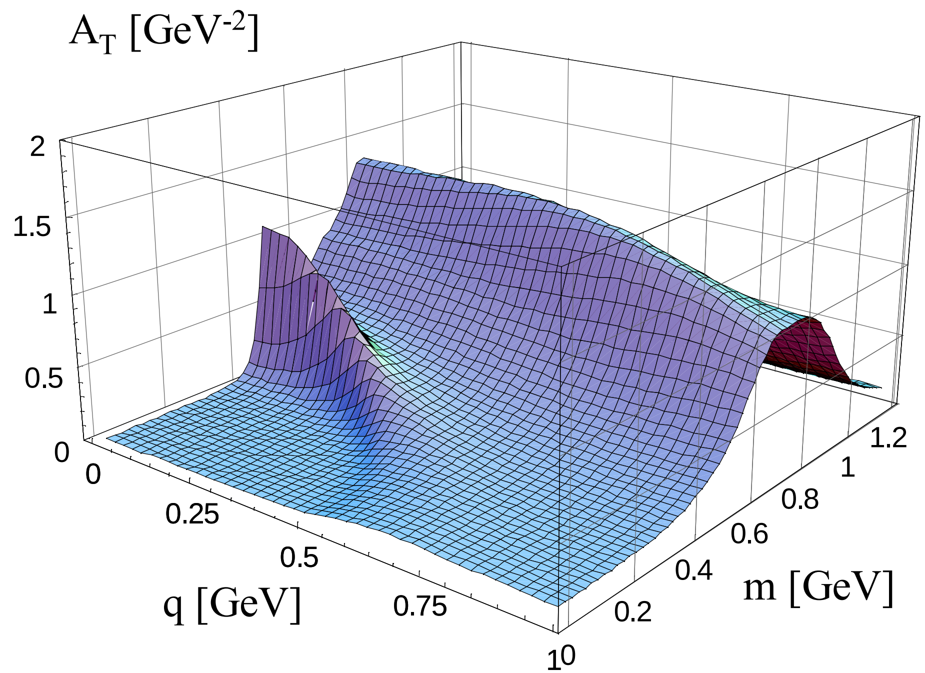
ω- meson

F. Klingl et al. NPA 610 (1997) 297
NPA 650 (1999) 299



ρ-meson

M. Post et al., nucl-th/0309085

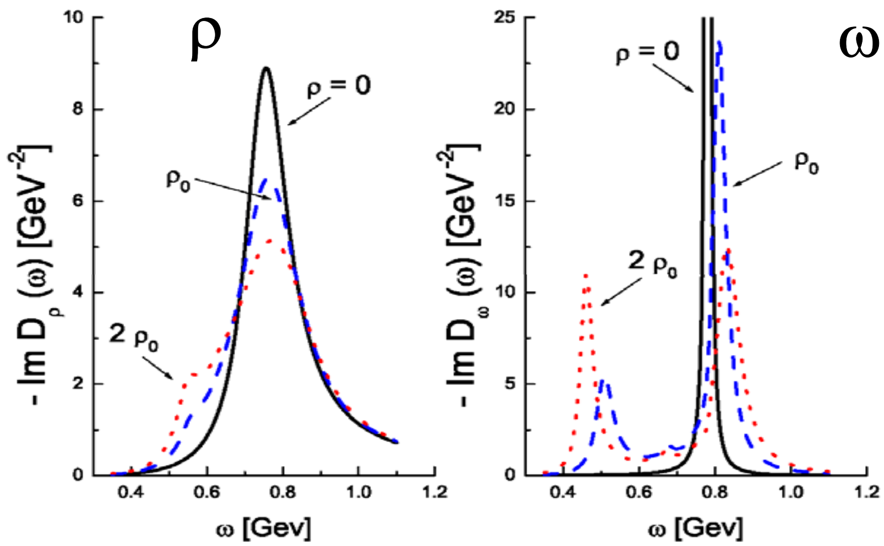


1.) **lowering of in-medium mass**
2.) **broadening of resonance**

} **for ρ_B ↗**

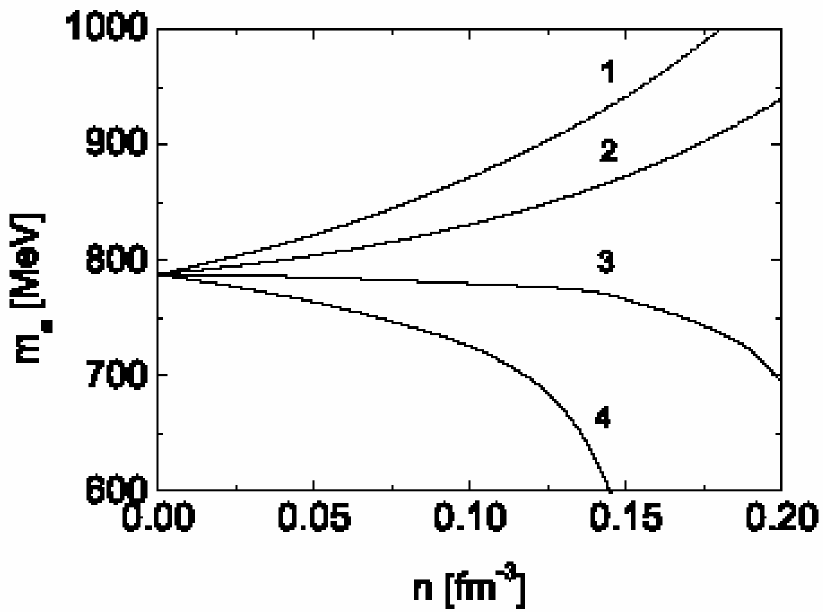
Model predictions for spectral functions of ρ and ω mesons

M. Lutz et al. , Nucl. Phys. A 706 (2002) 431



structure in spectral function due to coupling to baryon resonances

S. Zchocke et al. , Phys. Lett. B 562 (2003) 562



variation in ω-mass due to density dependence of 4-quark condensate

experimental approach: dilepton spectroscopy: $\rho, \omega, \phi \to e^+e^-$

reconstruction of invariant mass from 4-momenta of decay products:

$$m_\omega = \sqrt{(p_1 + p_2)^2}$$

essential advantage: no final state interactions !!

- **KEK-E325: M. Naruki et al., PRL 96 (2006) 092301: p (12 GeV) A$\to$ ρ, ω +X**

  ρ-meson: $m_\rho = m_0\left(1 - 0.092\frac{\rho}{\rho_0}\right)$; no broadening in the medium!!

- **NA60: R. Arnaldi et al., PRL 96 (2006) 162302: In + In (158 AGeV)**

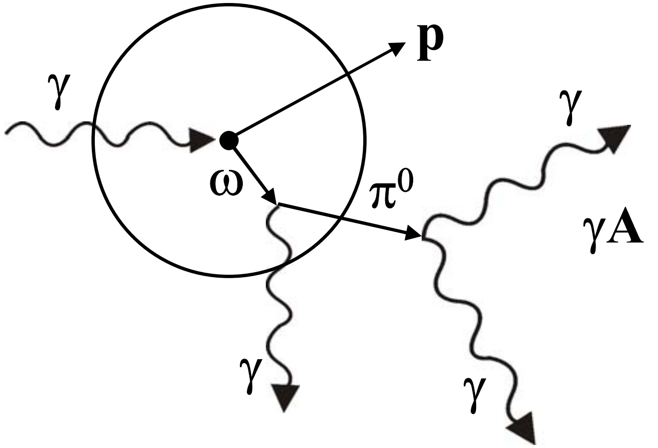
  ρ-spectral function shows strong broadening but no shift in mass

- **CLAS (Jlab): C. Tur et al., γA $\to \rho$, ω, Φ +X**

- **HADES (GSI): planned experiment $\pi^- p \to \omega n$ on bound proton**

ω-mass in nuclei from photonuclear reactions

J.G.Messchendorp et al., Eur. Phys. J. A 11 (2001) 95



$\gamma A \rightarrow \omega + X$

$\quad \hookrightarrow \pi^0\gamma$

$\quad\quad \hookrightarrow \gamma\gamma$

$$m_\omega = \sqrt{(p_\pi + p_\gamma)^2}$$

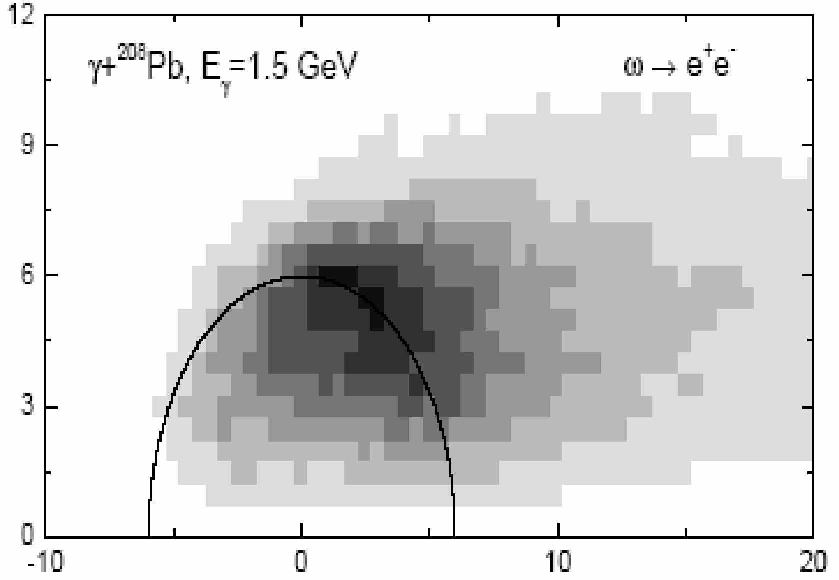
advantage:

- $\pi^0\gamma$ large branching ratio (8 %)
- no ρ-contribution ($\rho \rightarrow \pi^0\gamma$: $7 \cdot 10^{-4}$)

disadvantage:

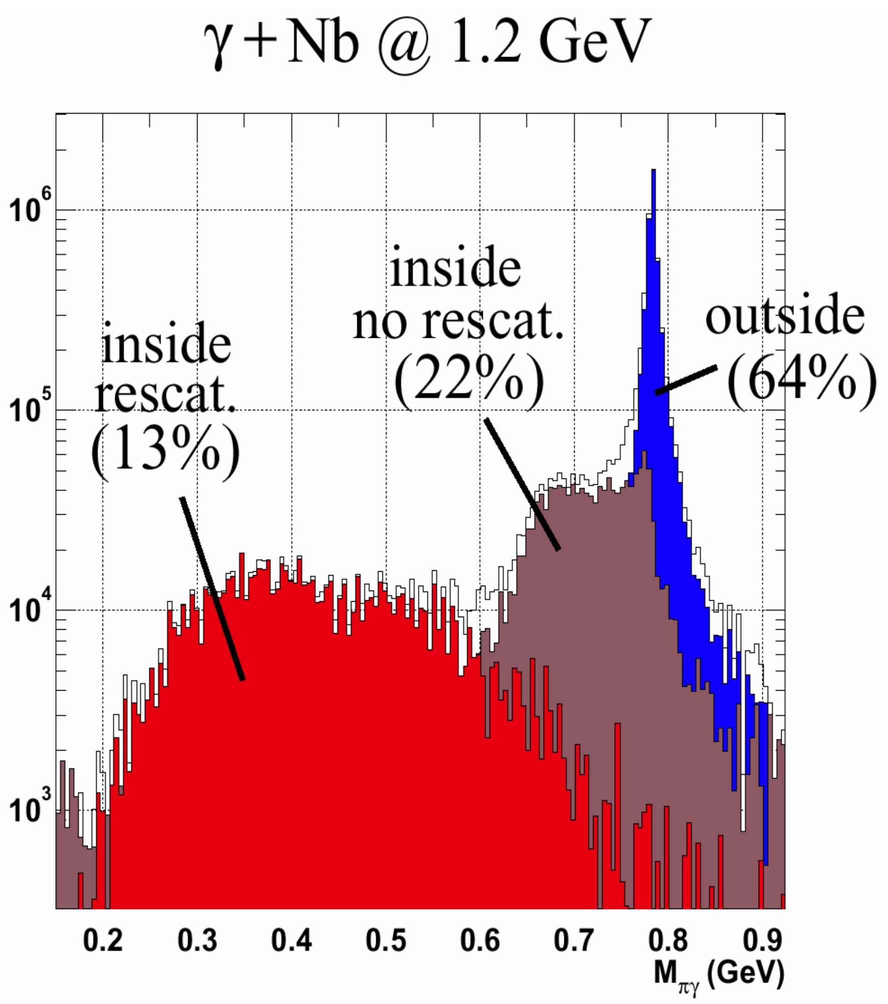
- π^0-rescattering

M. Effenberger et al.

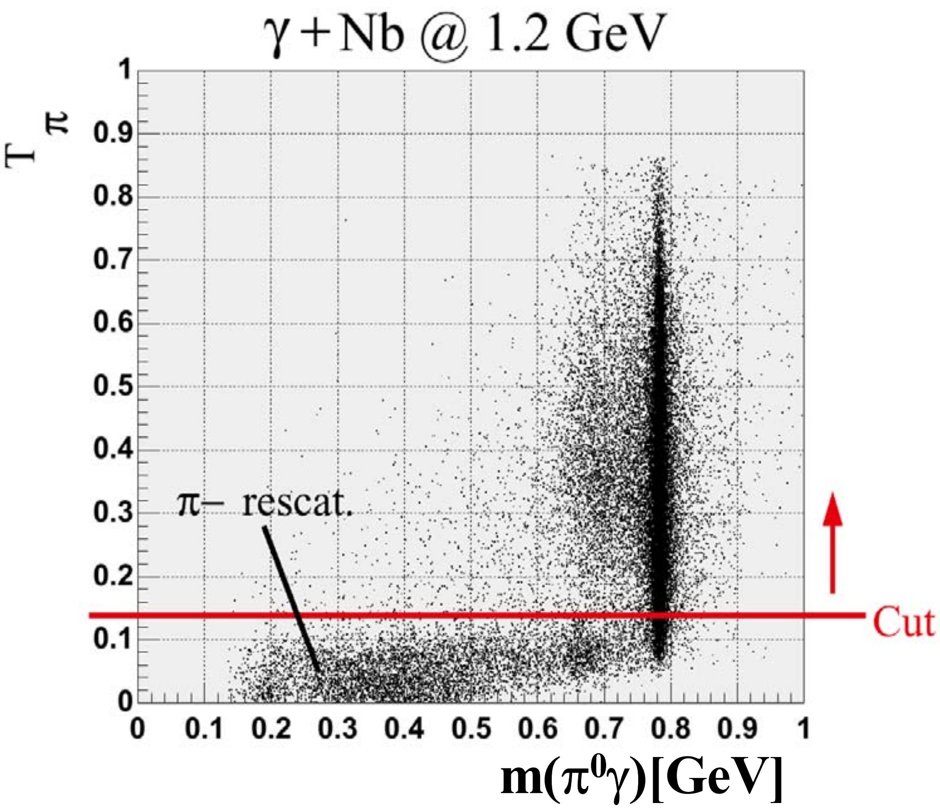


fraction of ω-decays in the medium ($\rho \geq 0.1\ \rho_0$) : ≈ 35%

Expected ω in-medium signal



rescattering of pions in nuclei predominantly proceeds through Δ(1232) excitation:
scattered pions have $E_{kin} \leq 150$ MeV



no distortion by pion rescattering expected in mass range of interest

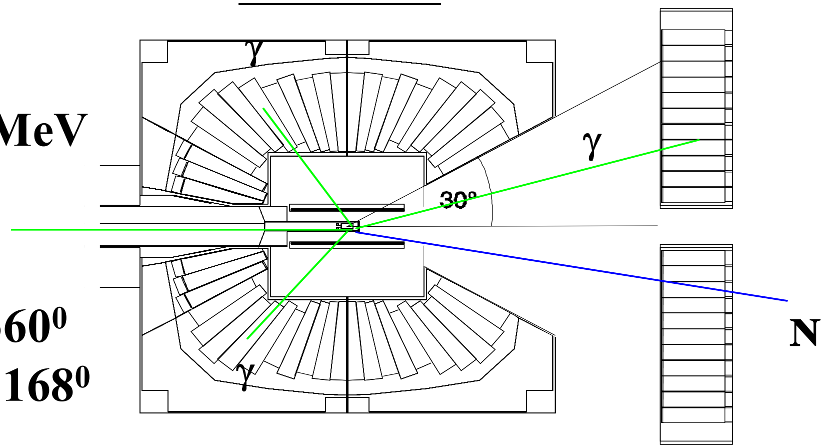
4 π detector system CB/TAPS @ ELSA

Crystal Barrel

1290 CsI

side view

E_γ =
900-2200 MeV

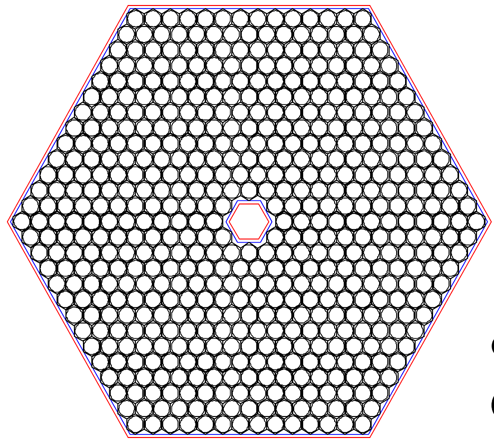


$\Phi = 0^0$ to 360^0
$\Theta = 30^0$ to 168^0

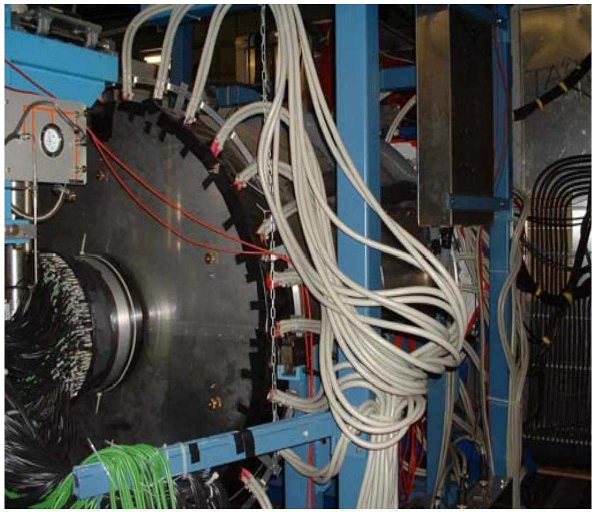
TAPS

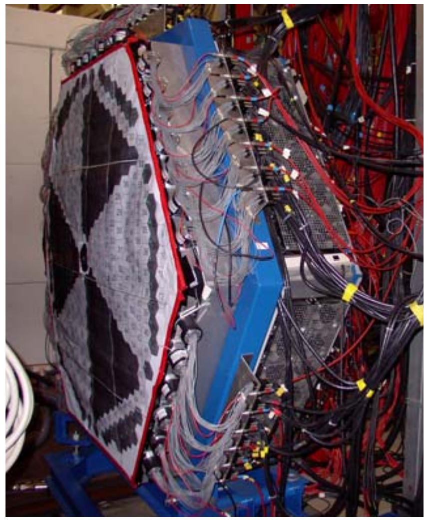
528 BaF_2

front view of TAPS



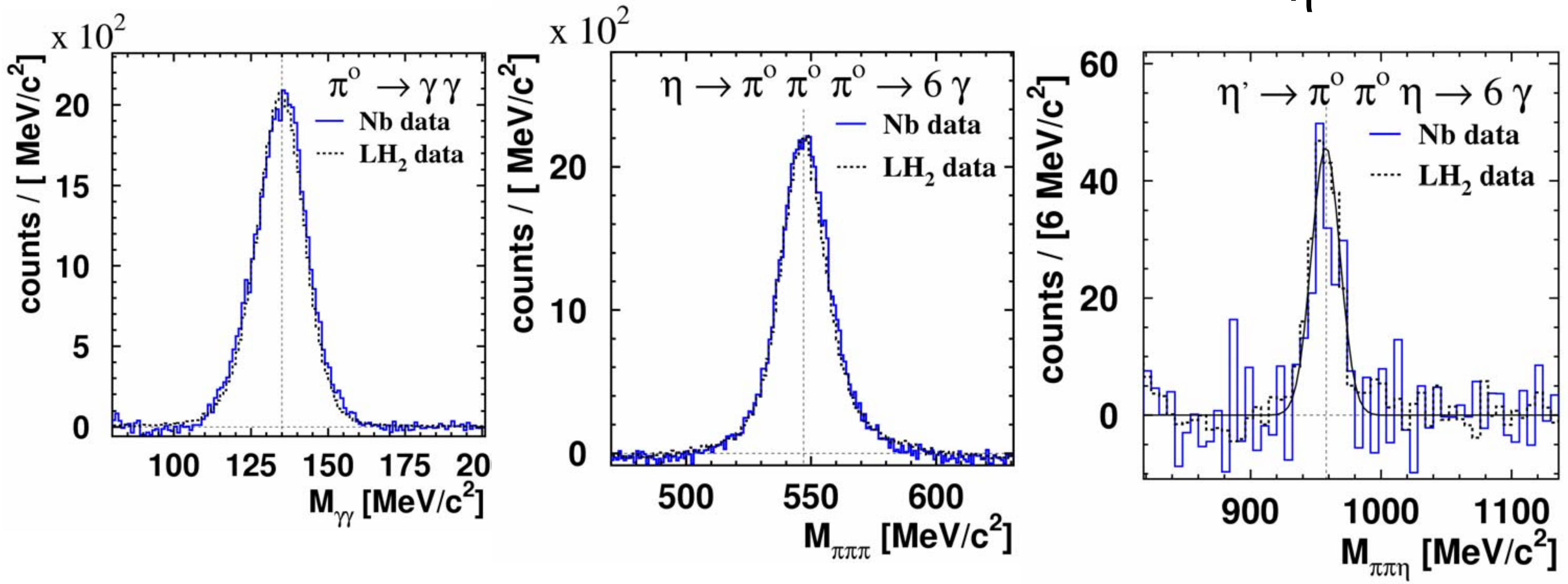
$\Phi = 0^0$ to 360^0
$\Theta = 5^0$ to 30^0





comparison of meson masses and lineshapes for LH_2 and nuclear targets

π^0 η η'

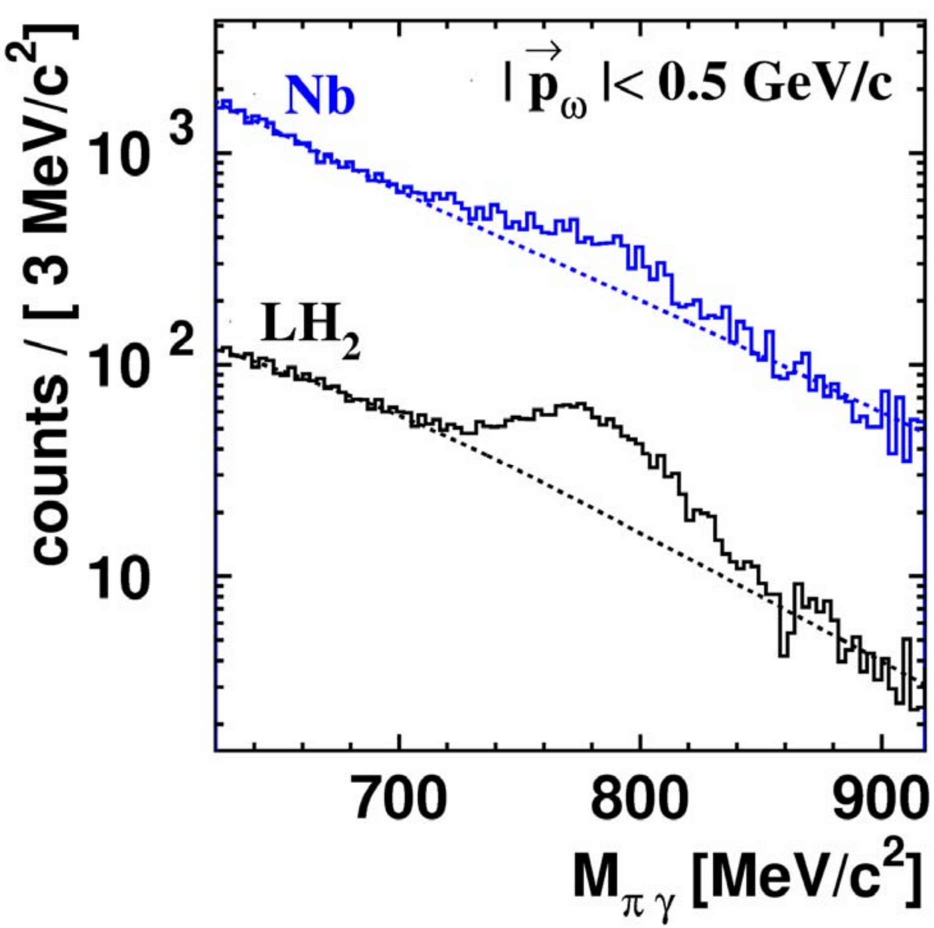


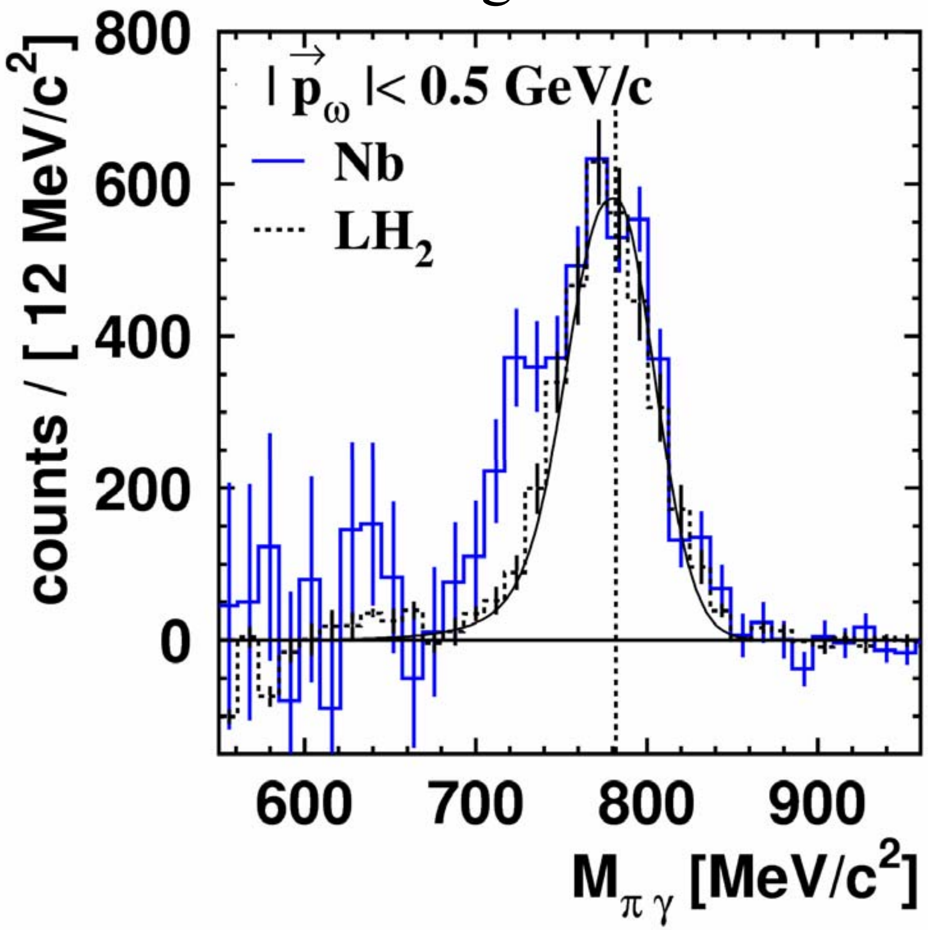
No change of mass and lineshape for longlived mesons (π^0, η, η') decaying outside nuclei

inclusive $\omega \to \pi^0 \gamma$ signal for LH_2 and Nb target

D. Trnka et al., PRL 94 (2005)192303

after background subtraction

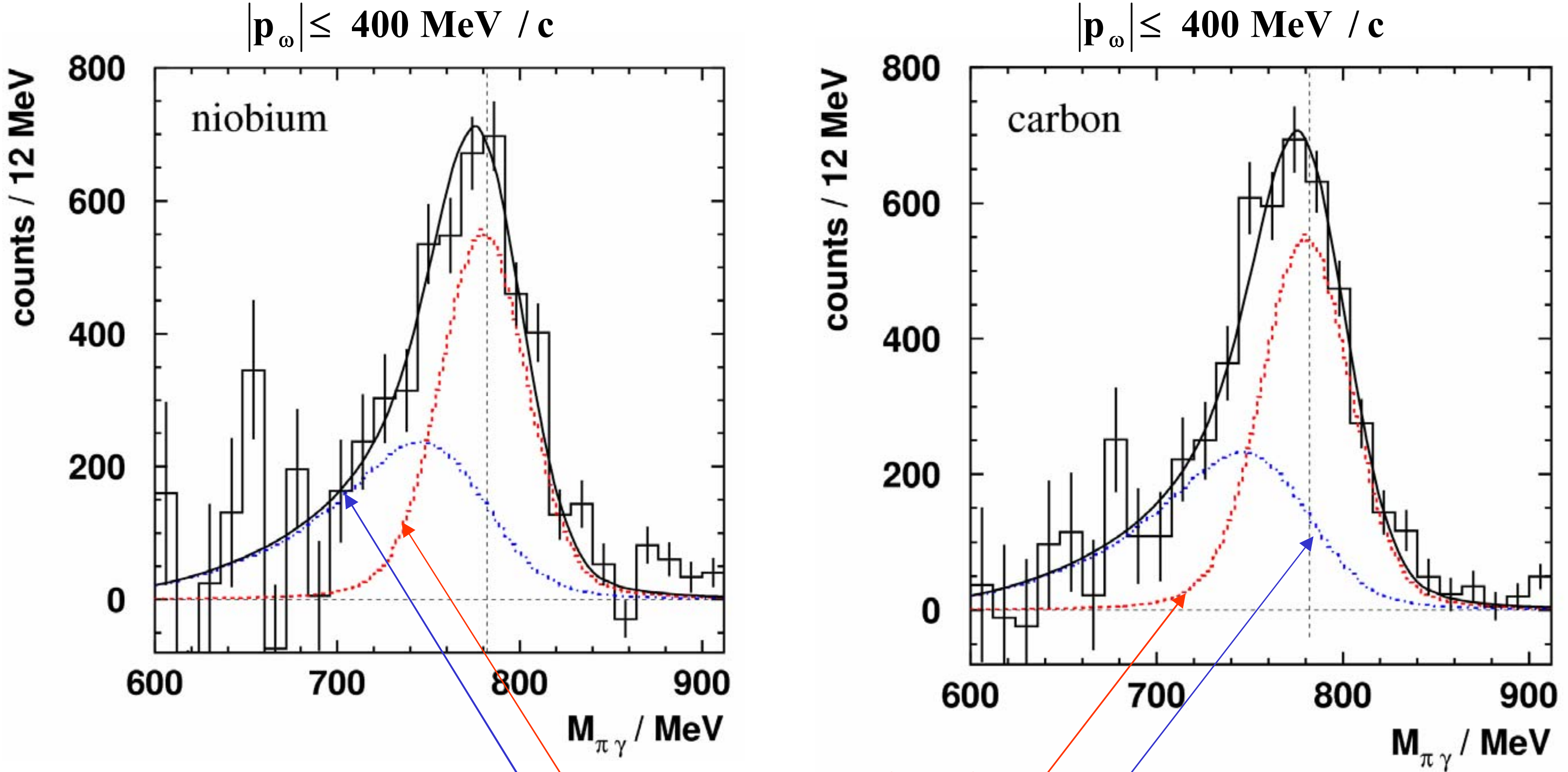




difference in line shape of ω signal for proton and nuclear target

$\langle m_\omega \rangle_{Nb}$ = 763 MeV; $\langle \rho \rangle \approx 0.11\rho_0$ consistent with $\mathbf{m_\omega = m_0 (1 - \alpha\, \rho/\rho_0)}$ **for** $\alpha = 0.13$

decomposition of ω signal into in-medium and vacuum decay contributions



Nb: in-medium: 45%

vacuum contribution

in-medium contribution

C: in-medium: 40%

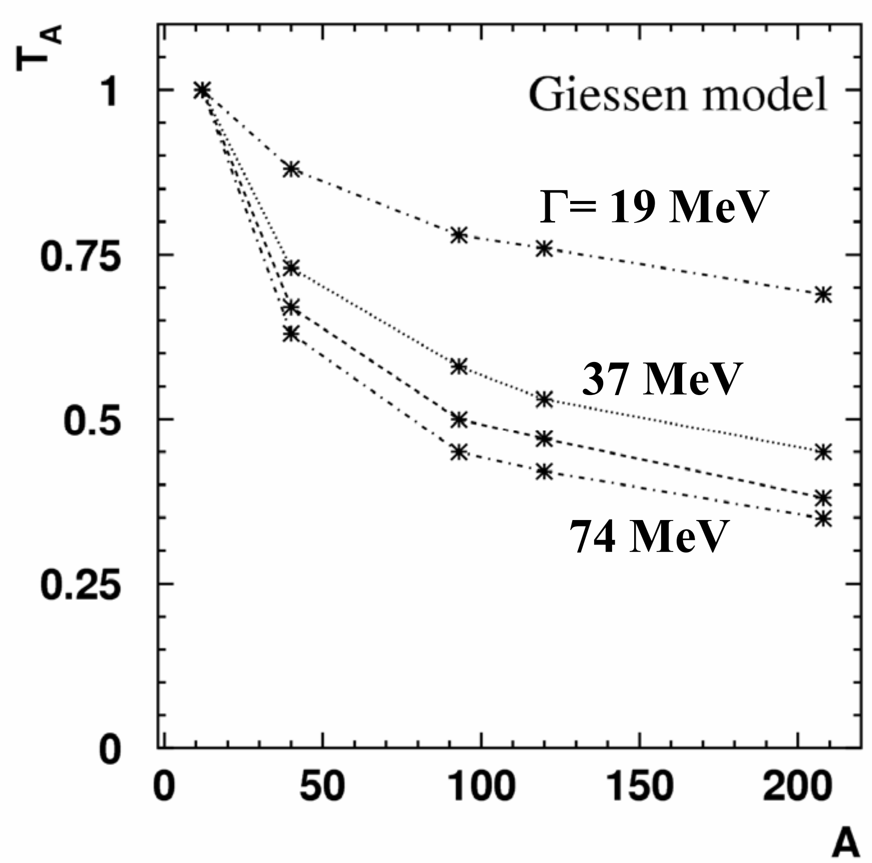
lineshape of vacuum contribution taken from LH_2 experiment

shape of in-medium contribution taken from BUU simulation (P. Mühlich and U. Mosel, NPA (2006)), assuming $m_\omega = m_0(1 - 0.16\ \rho/\rho_0)$

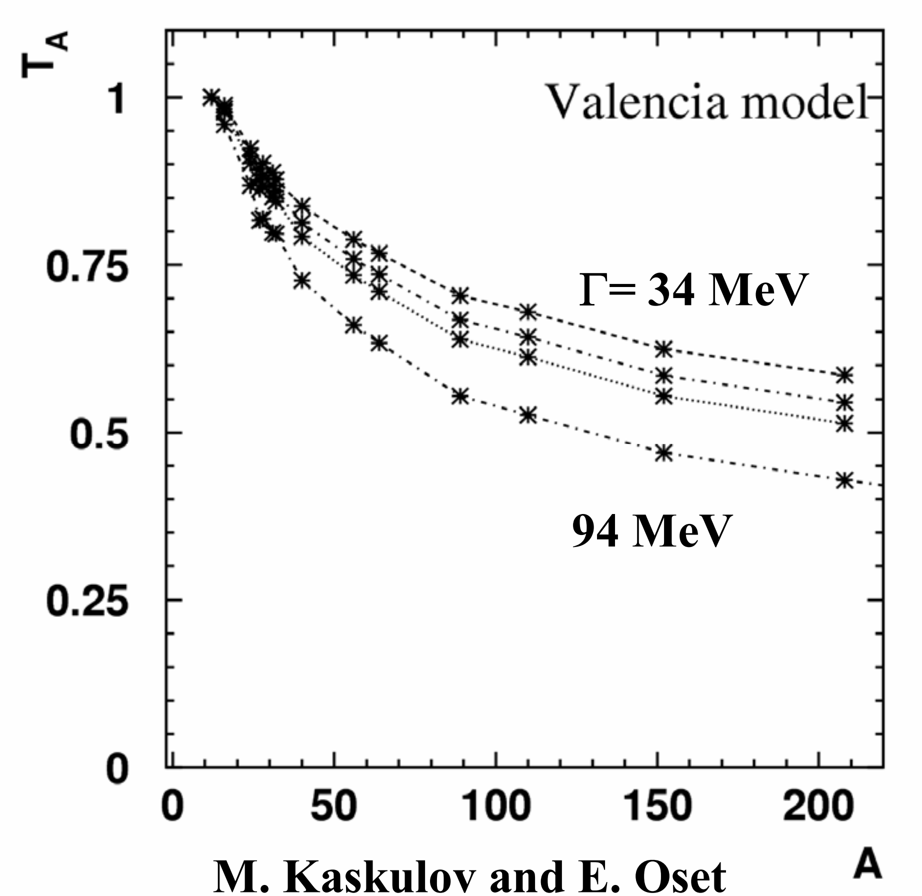
access to in-medium ω width

in-medium ω width proportional to ω absorption: $\Gamma \propto \rho v \sigma_{abs}$

transparency ratio: $T_A = \frac{\sigma_{\gamma A \to \omega X}}{A \cdot \sigma_{\gamma N \to \omega X}}$ normalization to C!!



P. Mühlich and U. Mosel
NPA (2006)

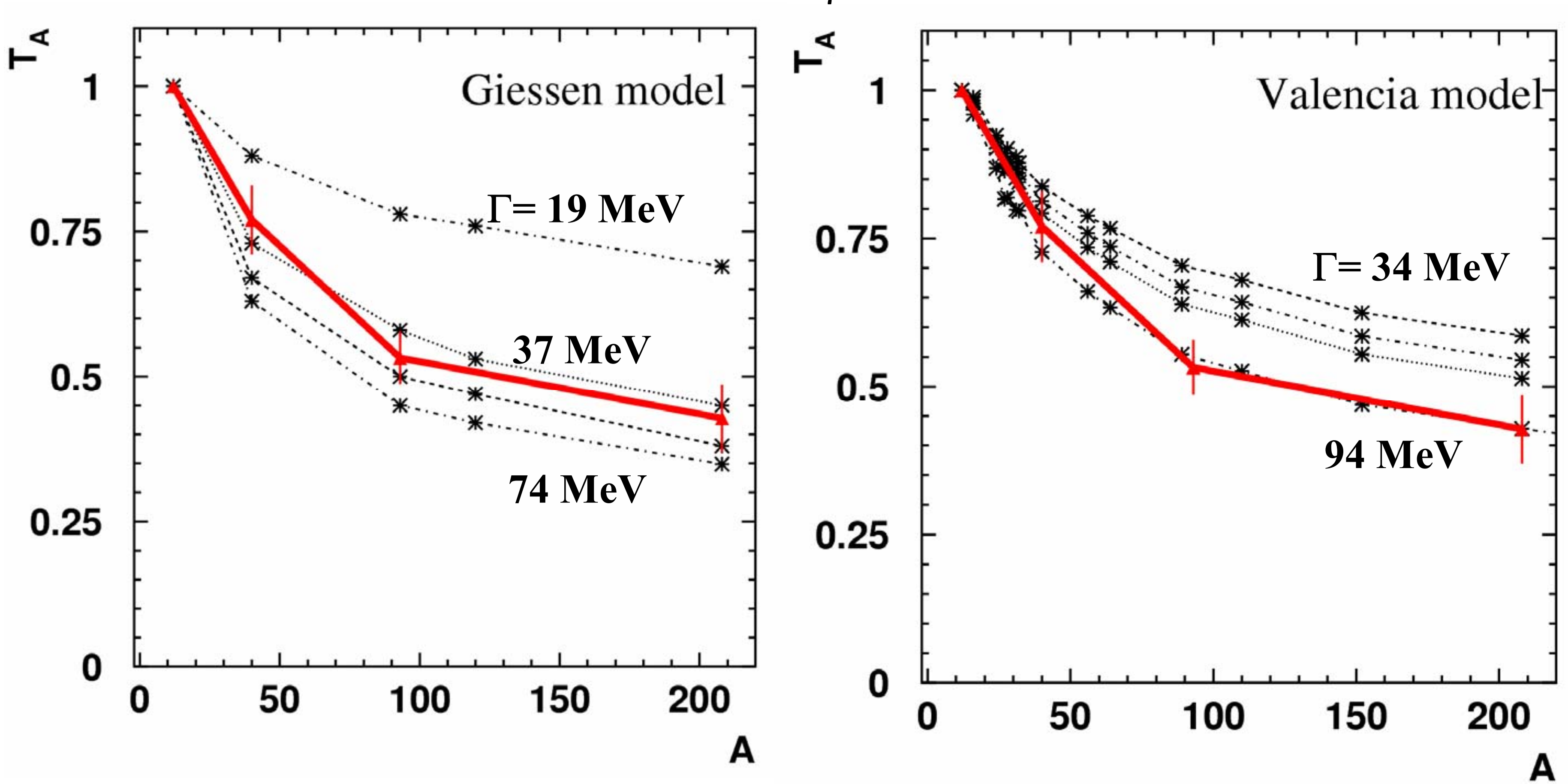


M. Kaskulov and E. Oset
priv. communication

access to in-medium ω width

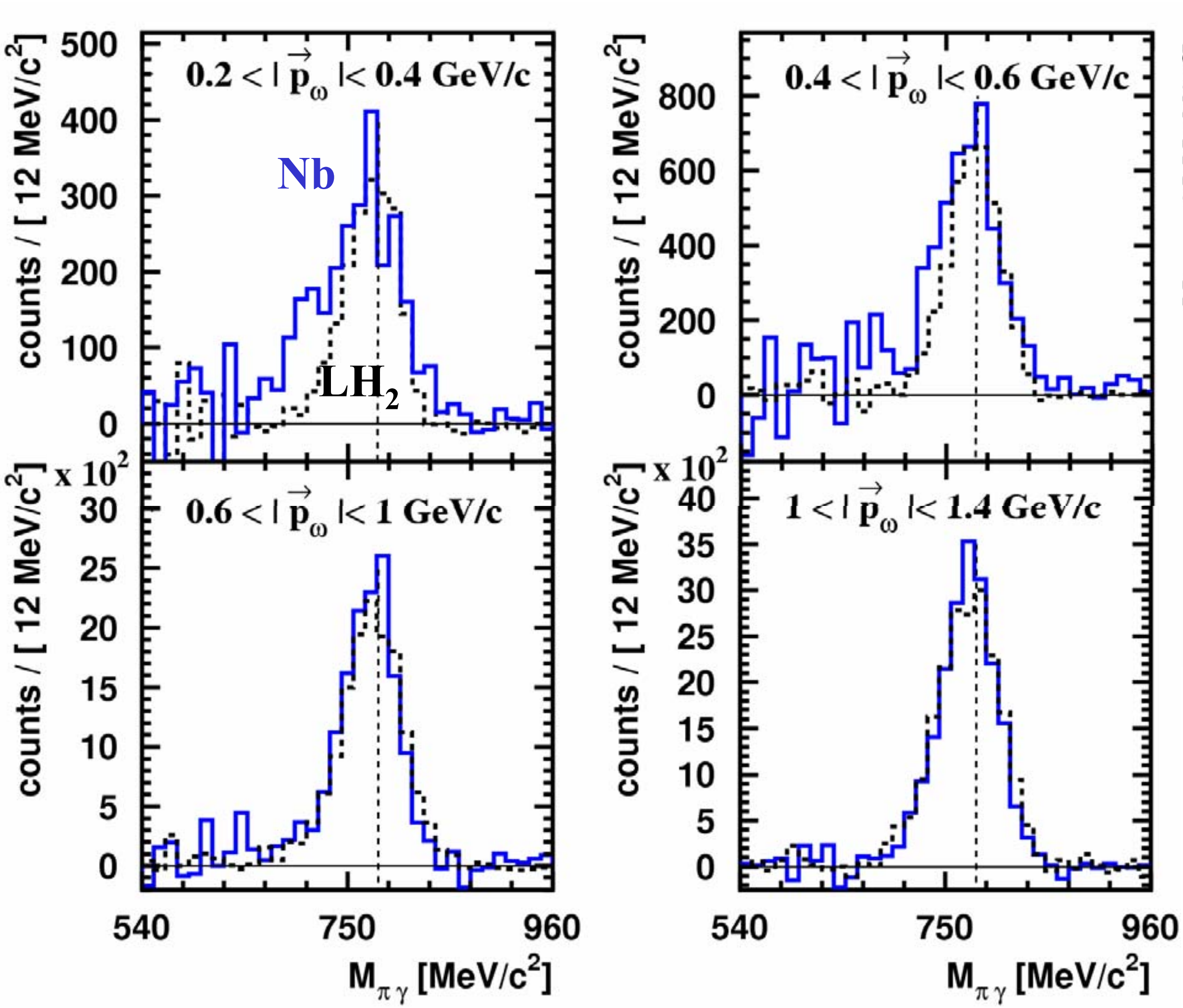
in-medium ω width proportional to ω absorption: $\Gamma \propto \rho v \sigma_{abs}$

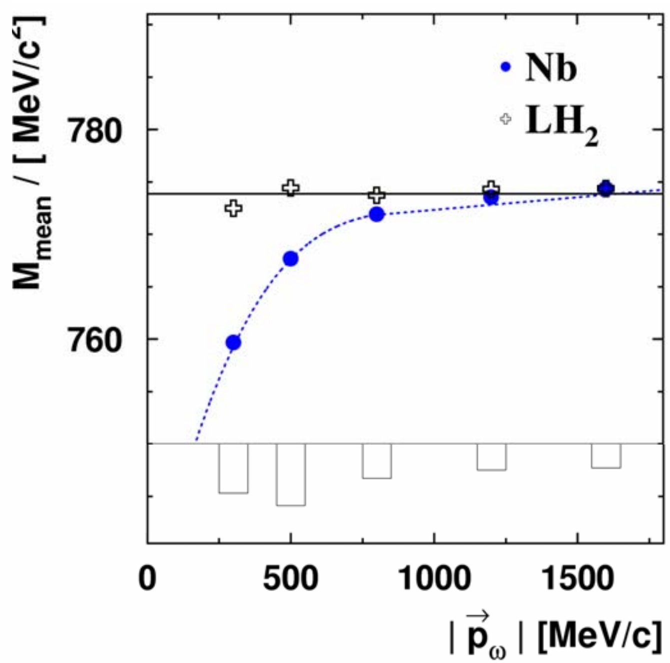
transparency ratio: $T_A = \dfrac{\sigma_{\gamma A \to \omega X}}{A \cdot \sigma_{\gamma N \to \omega X}}$ normalization to C!!



Comparison to data (D.Trnka et al.) $\Gamma(\rho_0) \approx 45 - 95$ MeV

momentum dependence of ω signal (Nb-target)





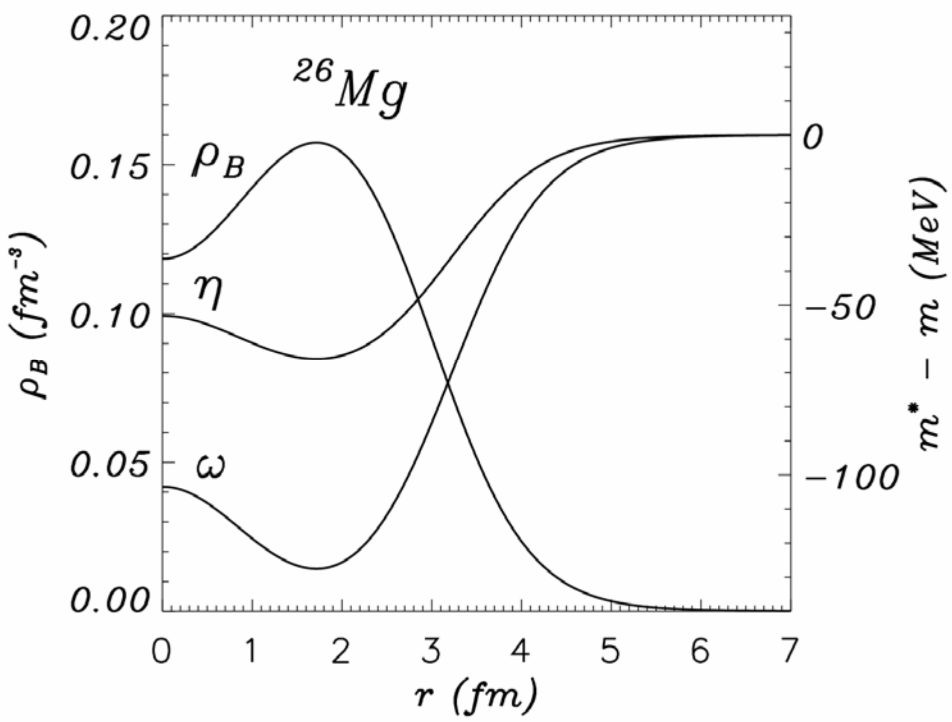
ω mass modification only for $p_\omega \leq 0.5$ GeV/c

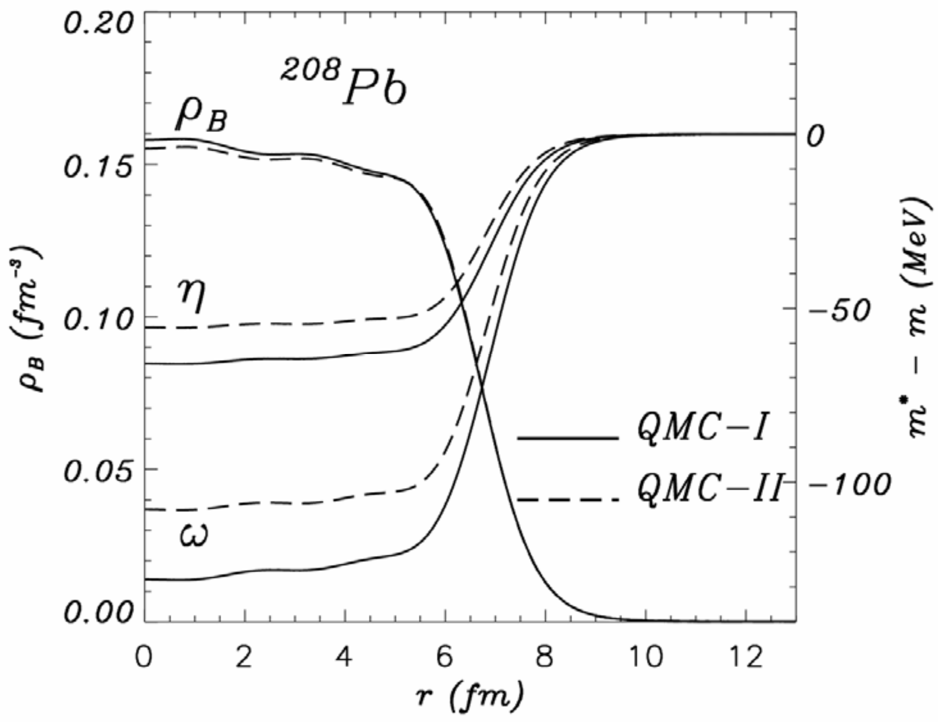
determination of momentum dependence of ω - nucleus potential requires finer momentum bins ⇒ improved 2nd. generation experiment

η-, ω-meson-nucleus potential

K. Saito, K. Tsushima, A.W. Thomas, hep-ph/0506314

predictions within the quark meson coupling model (QMC)

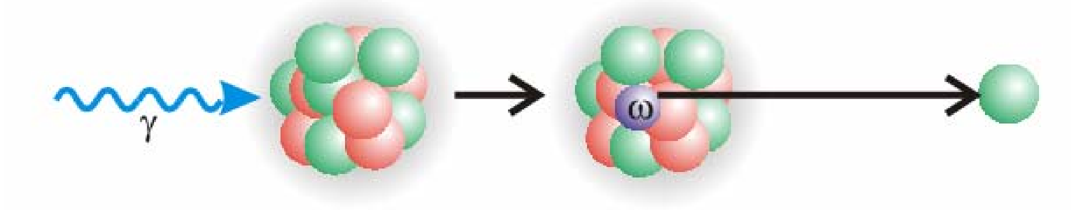




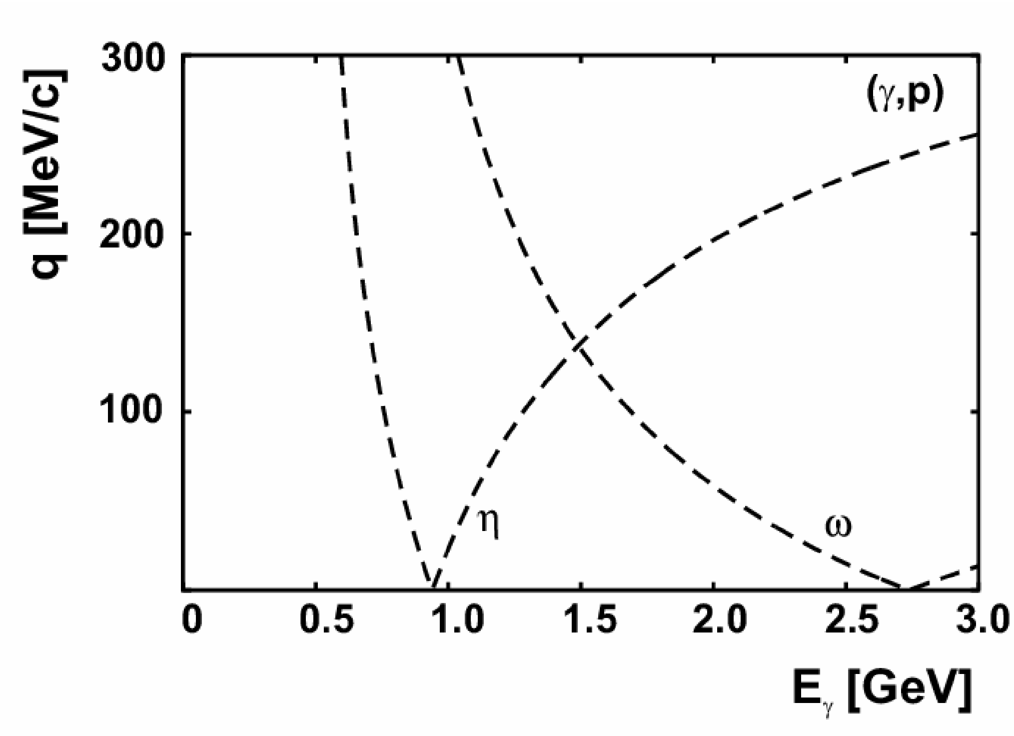
η: E(1s) = -39 MeV; Γ= 29 MeV
ω: E(1s) = -100 MeV; Γ= 31 MeV

η: E(1s) = -56 MeV; Γ= 33 MeV
ω: E(1s) = -118 MeV; Γ= 33 MeV

The population of meson-nucleus bound states in recoil-free kinematics

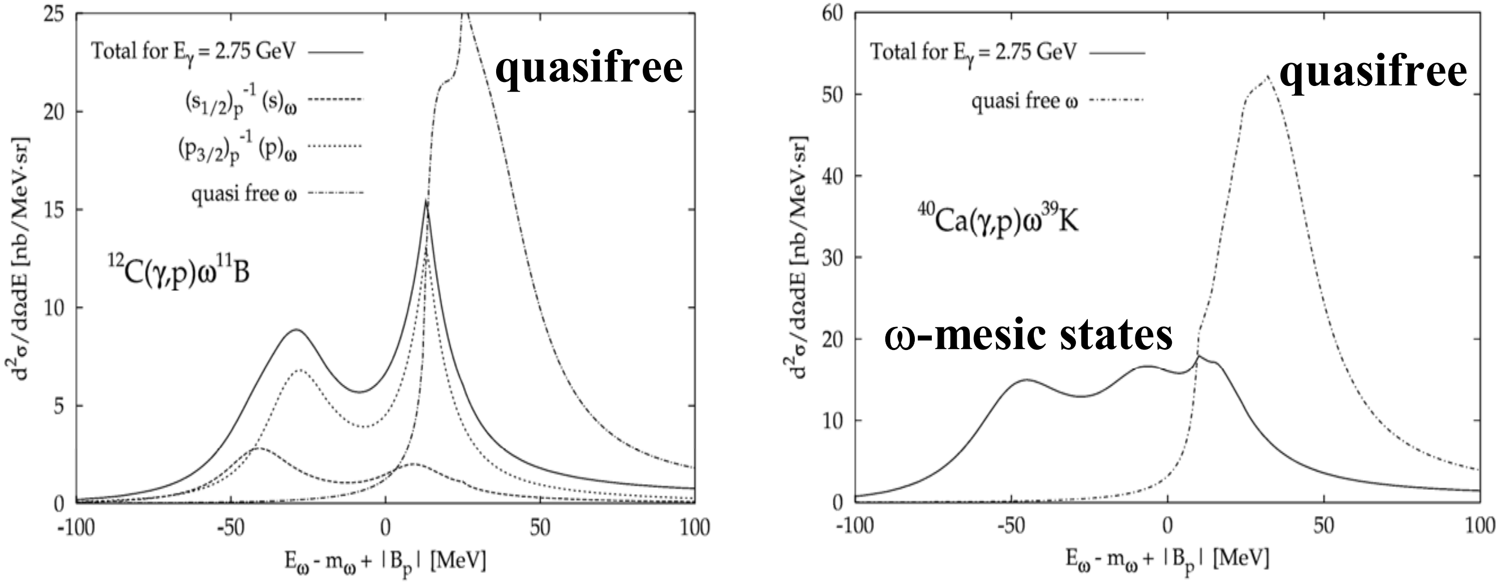


forward going nucleon takes over photon momentum



magic incident energies η: $E_\gamma \approx$ 930 MeV; ω: $E_\gamma \approx$ 2750 MeV } (ELSA)

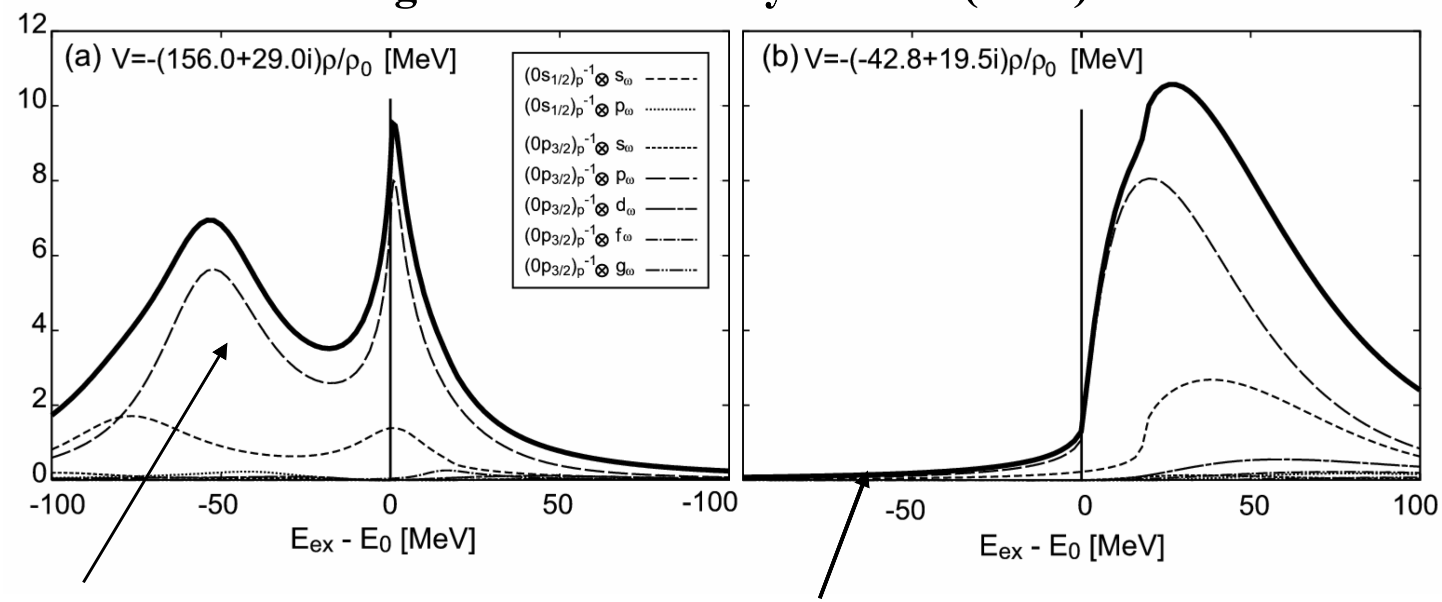
E. Marco and W. Weise, PLB 502 (2001) 59



T. Nagahiro et al. N. Phys. A 761 (2005) 92

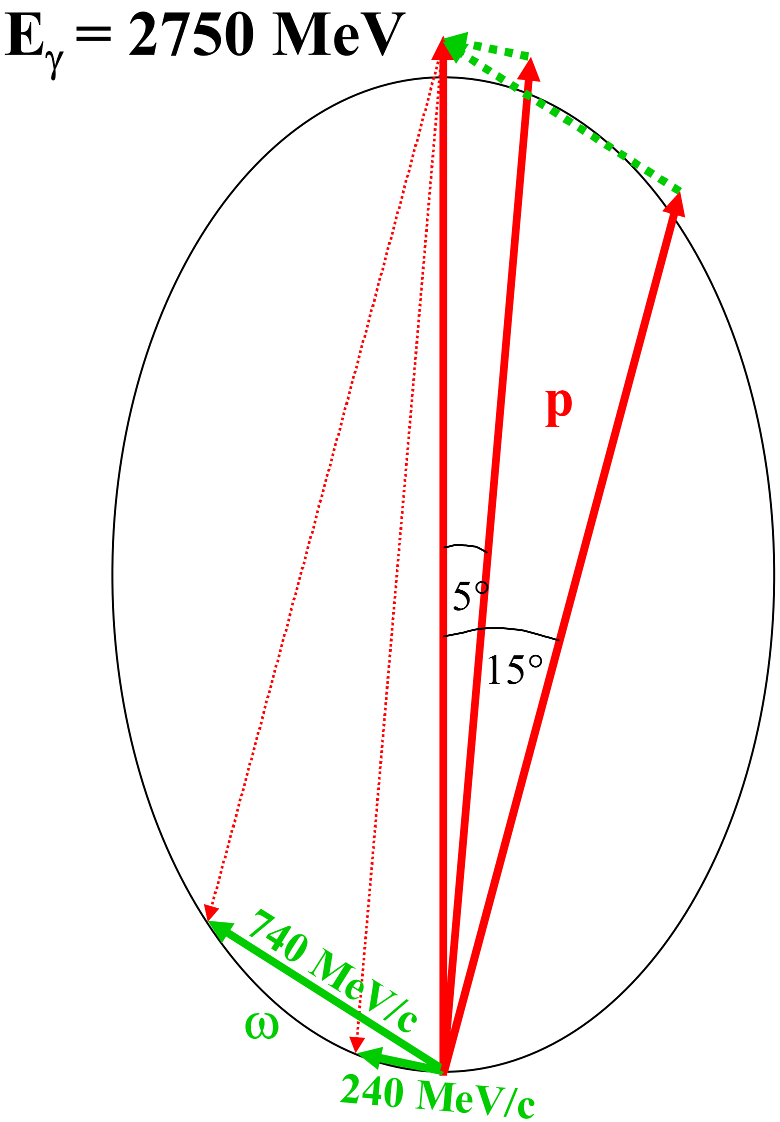
attractive potential

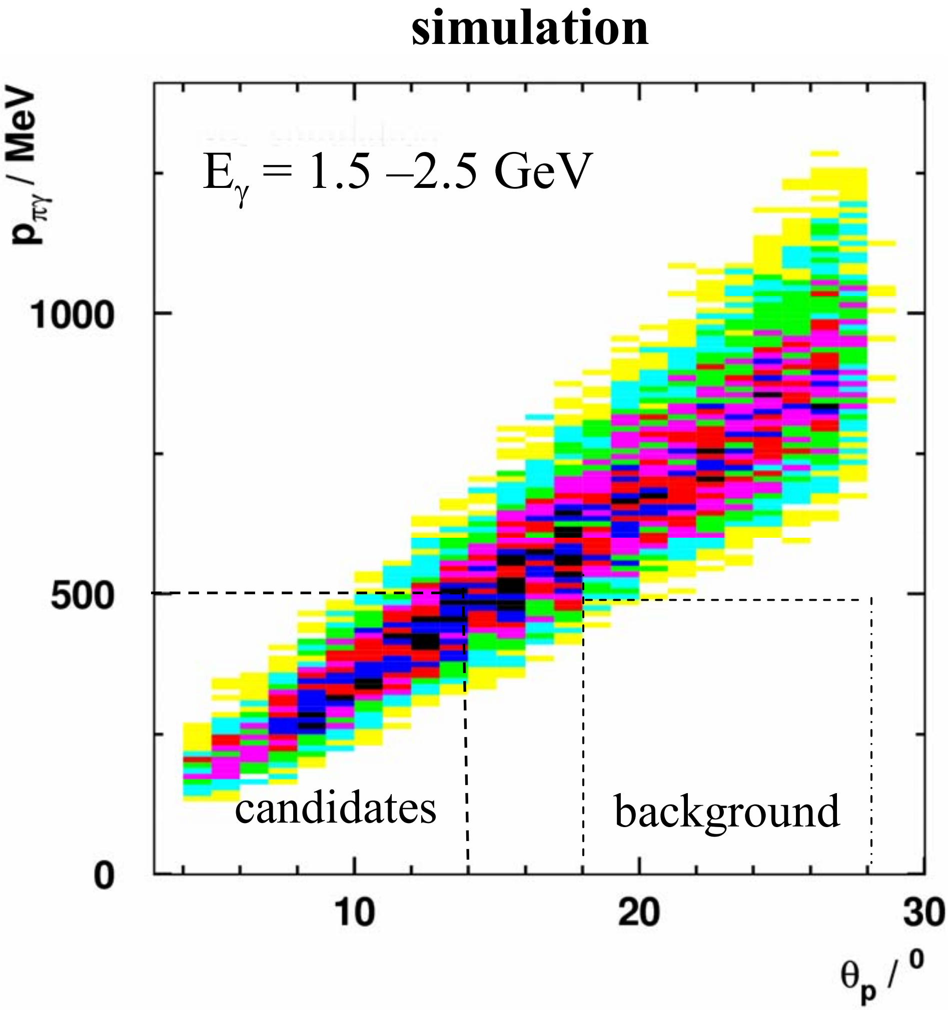
repulsive potential



signature for ω - mesic states **no intensity for negative energies**

correlation between ω momentum and proton angle



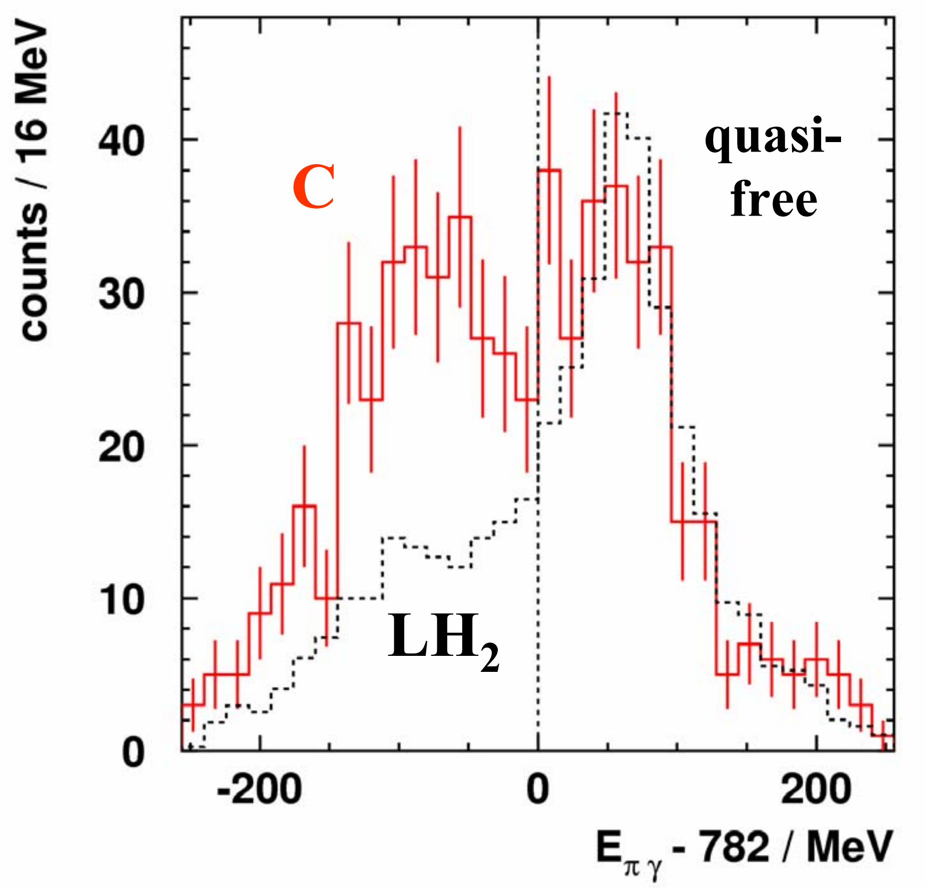


$|p_\omega| < 500$ MeV/c for $\theta_p < 14^0$

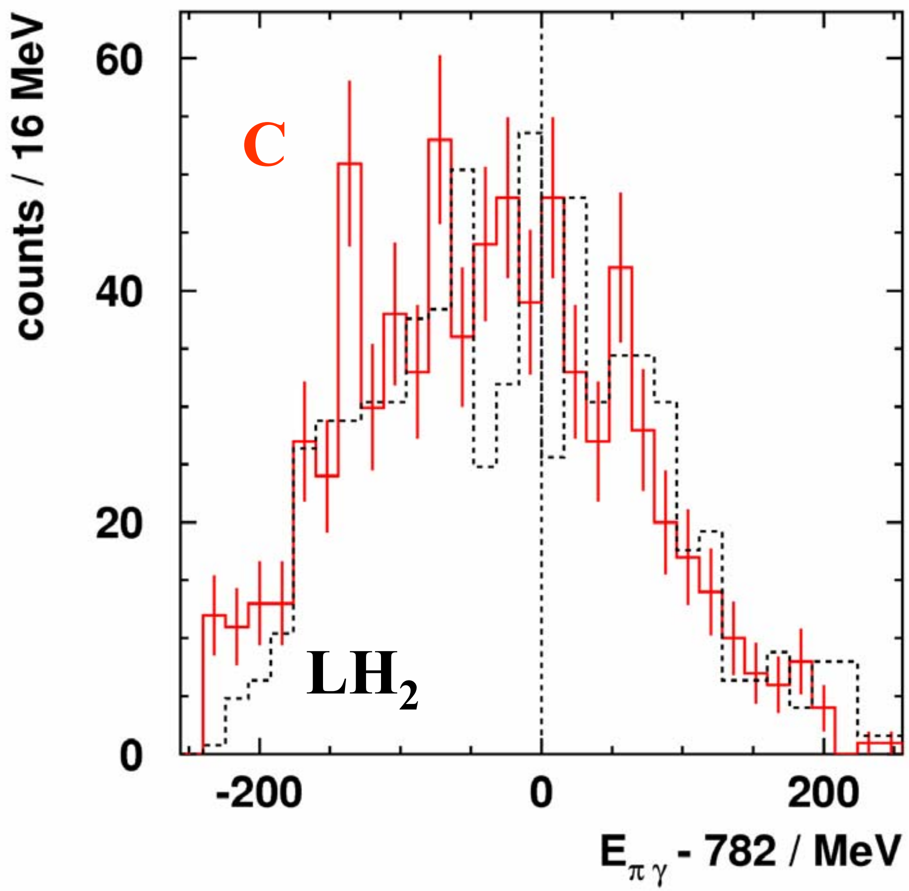
bound states expected for $\theta_p < 14^0$

comparison of data on LH_2 and C

small proton angles
$7^0 < \Theta_p < 14^0$

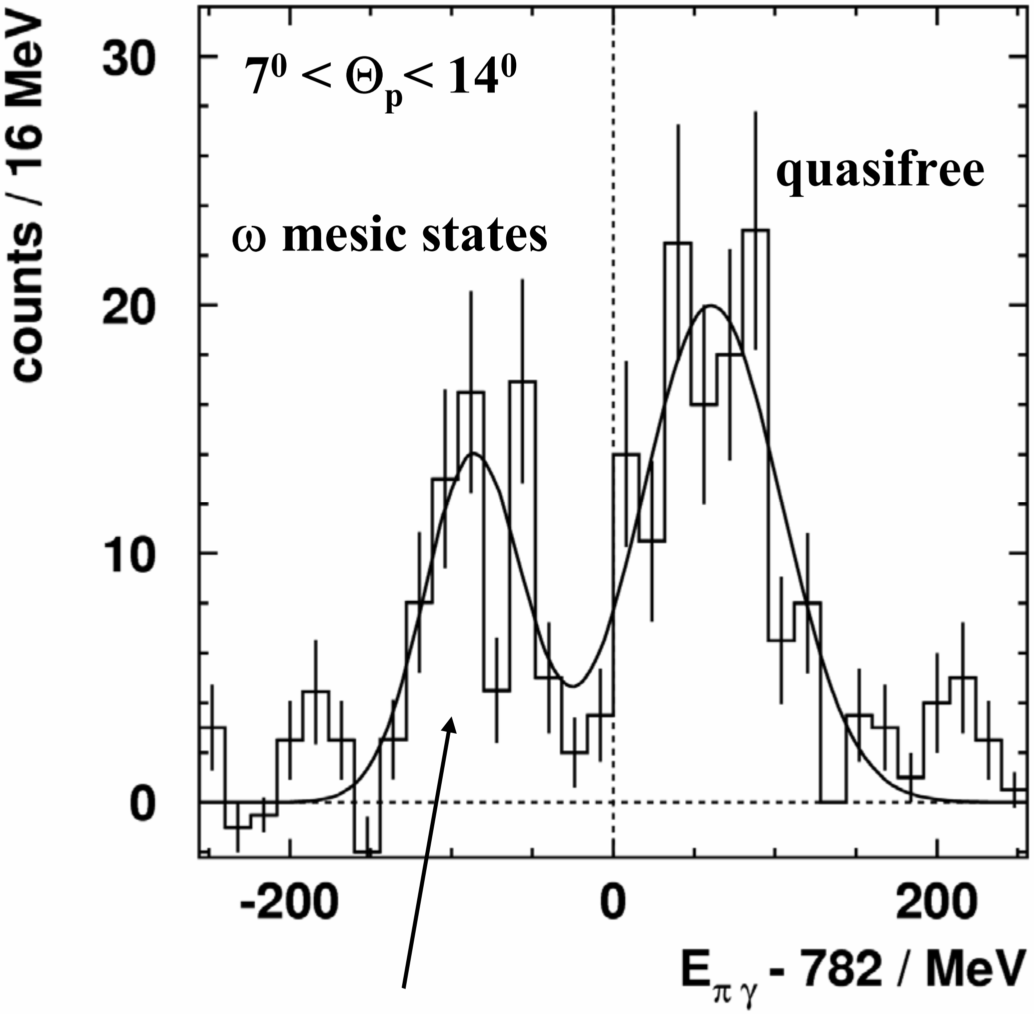


large proton angles
$18^0 < \Theta_p < 28^0$



- for small proton angles: difference between C and LH_2 data for negative energies
- for large proton angles: similar background distributions for C and LH_2 data

Evidence for $^{11}_{\omega}B$



$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} \approx \frac{1.4\ \mu b}{sr}$$

carbon data after background subtraction

theoretical prediction
E.Marco and W.Weise
PLB 502 (2001) 59

$$\left(\frac{d\sigma}{d\Omega}\right)_{theo} = \frac{550\ nb}{sr}$$

first evidence for the existence of an ω-nucleus bound state:
here: $^{11}_{\omega}B$

Summary and outlook

- An in-medium dropping of the ω meson mass has been observed consistent with $m_\omega(\rho) = m_0\left(1 - 0.14 \cdot \frac{\rho}{\rho_0}\right)$

major step forward towards understanding the origin of hadron masses

- first information on in-medium ω width: $\Gamma_\omega \approx 40 - 100$ MeV at $\rho = \rho_0$

- first evidence for ω mesic ^{11}B

- remaining open questions
  - $\Rightarrow$ momentum dependence of ω-nucleus potential?
  - $\Rightarrow$ structure in ω strength function?
  - $\Rightarrow$ confirm existence of ω mesic states in heavier nuclei

$\Rightarrow$ higher statistics needed !!

$\Rightarrow$ improved experiments planned at MAMI and ELSA

CBELSA/TAPS collaboration

II. Physikalisches Institut, Universität Gießen:
R. Gregor, S. Lugert, V. Metag, M. Nanova, R. Novotny, L.M. Pant, H. van Pee, M. Pfeiffer, A. Roy, S. Schadmand, D. Trnka, R. Varma

Physikalisches Institut, Universität Erlangen:
G. Anton, R. Bogendörfer, J. Hößl, G. Suft

Kernfysisch Versneller Instituut, Groningen:
J. Bacelar, R. Castelijns, H. Löhner, J. Messchendorp, S. Shende

Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn:
O. Bartholomy, V. Credé, A. Ehmanns, K. Essig, I. Fabry, M. Fuchs, C. Funke, E. Gutz, P. Hoffmeister, I. Horn, J. Junkersfeld, H. Kalinowsky, E. Klempt , J. Lotz, C. Schmidt, T. Szczepanek, U. Thoma, C. Weinheimer, C. Wendel

Physikalisches Institut, Universität Bonn:
H. Dutz, D. Elsner, R. Ewald, R. Gothe, S. Höffgen, F. Klein, F. Klein, M. Konrad, J. Langheinrich, D. Menze, C. Morales, M. Ostrick, H. Schmieden, B. Schoch, A. Süle, D. Walther

Institut für Kern- und Teilchenphysik, TU Dresden
B. Kopf

Institut für Physik, Universität Basel:
I. Jaeglé, M. Kotulla, B. Krusche, T. Mertens

Petersburg Nuclear Physics Institute:
D. Bayadilov, Y. Beloglazov, A. Gridnev, I. Lopatin, A. Radkov, V. Sumachev