Meson Photoproduction from Nuclei – Medium Modifications of Mesons Teilprojekt B4

SFB/TR16

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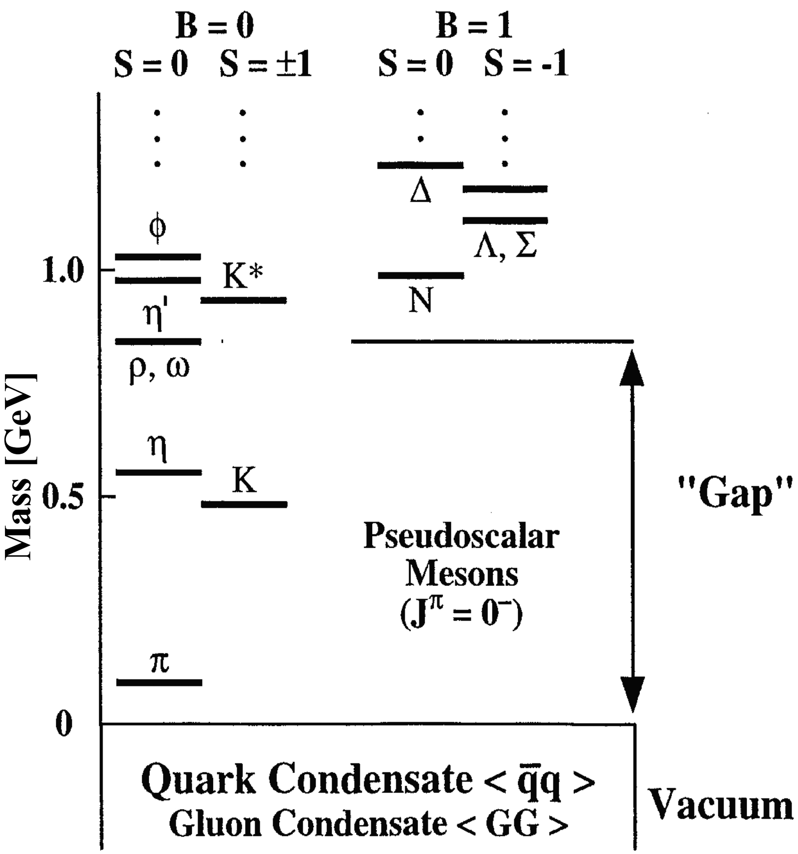
- motivation
- first observation of medium modifications of the ω meson:
  a.) mass shift
  b.) fragmentation of ω strength?
  b.) in-medium width
- first indication for an ω-nucleus bound state: ${}^{11}_{\omega}B$?
- modifications of ππ correlations in nuclei
- summary and outlook

SFB/TR16 Mitgliederversammlung
Bommerholz, 28.11.2006

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

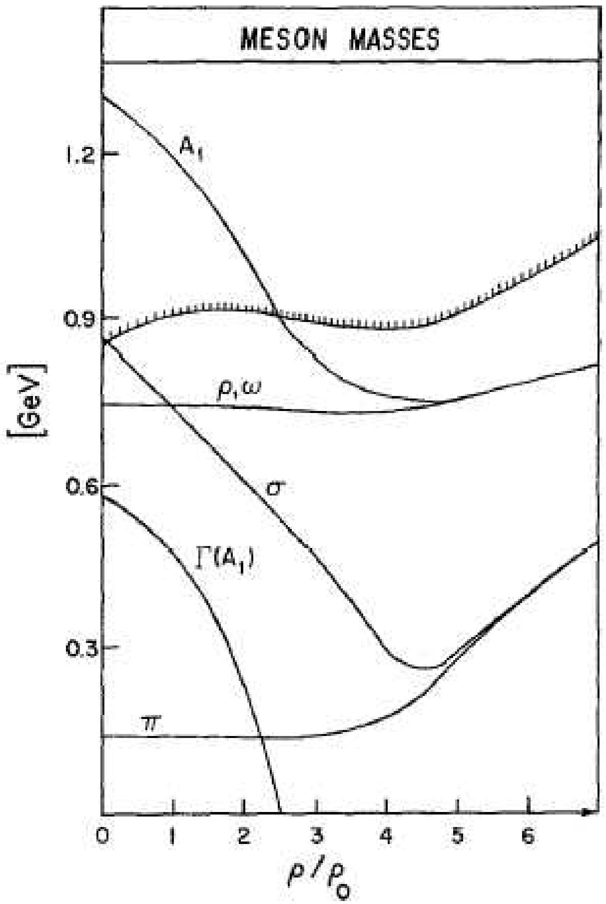
G.E.Brown and M. Rho, PRL 66 (1991) 2720 $\quad \frac{m^*}{m} \approx \frac{\langle \bar{q}q \rangle^*}{\langle \bar{q}q \rangle} \approx 0.8 \left(\rho \approx \rho_0\right)$

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

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

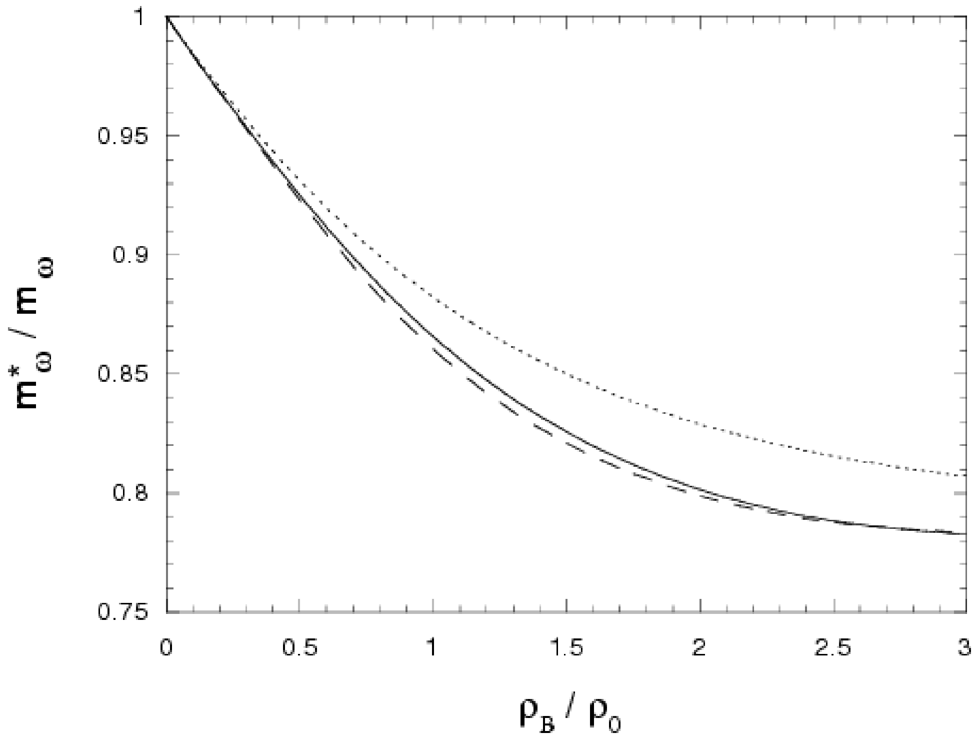
model predictions for in-medium masses of mesons

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



ω-mass roughly constant

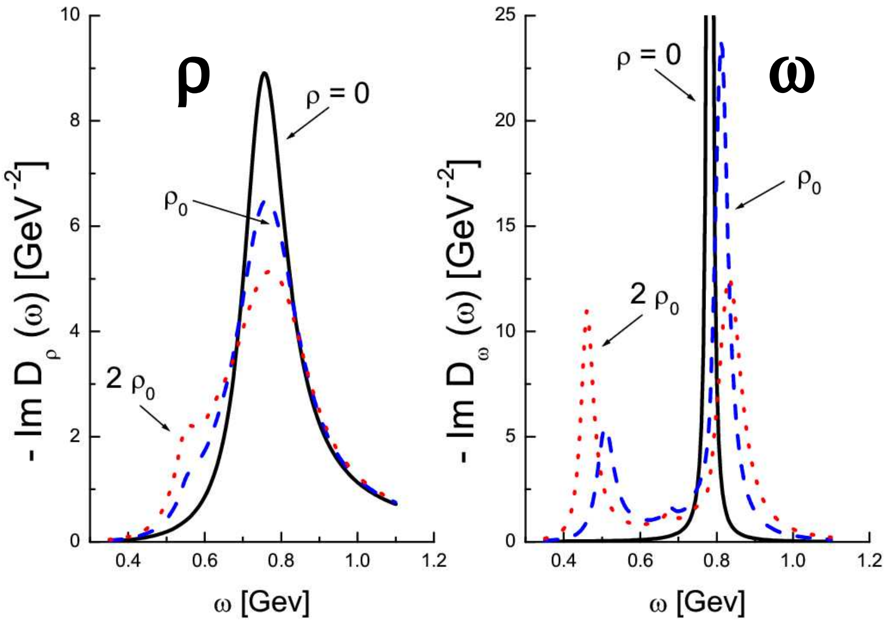
K. Saito, K. Tushima, and A.W. Thomas
PRC 55 (1997) 2637
Quark-meson coupling model (QMC)



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

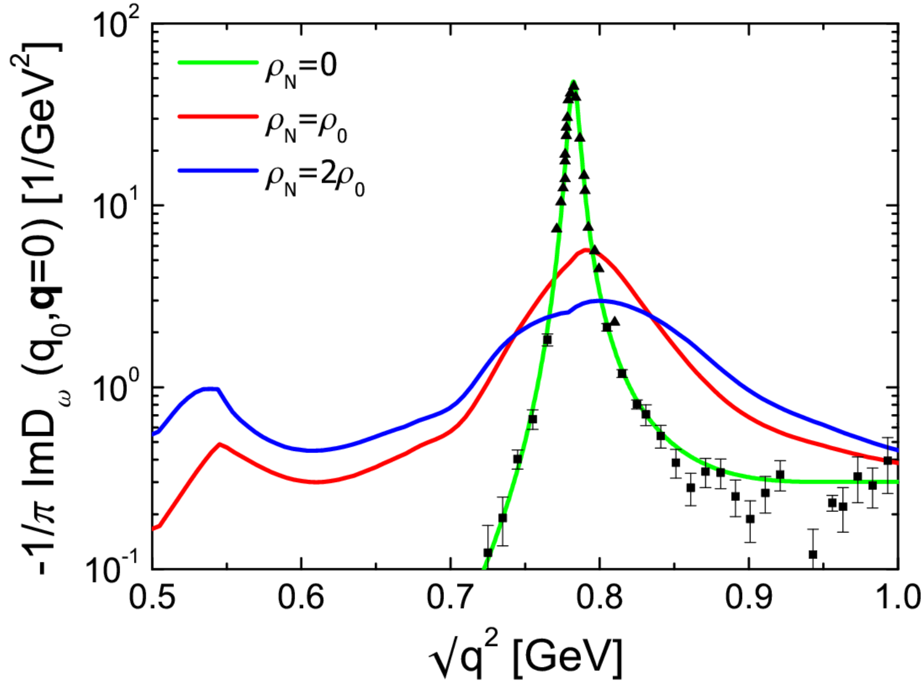
Model predictions for spectral functions of ρ and ω mesons

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



structure in spectral function due to coupling to baryon resonances

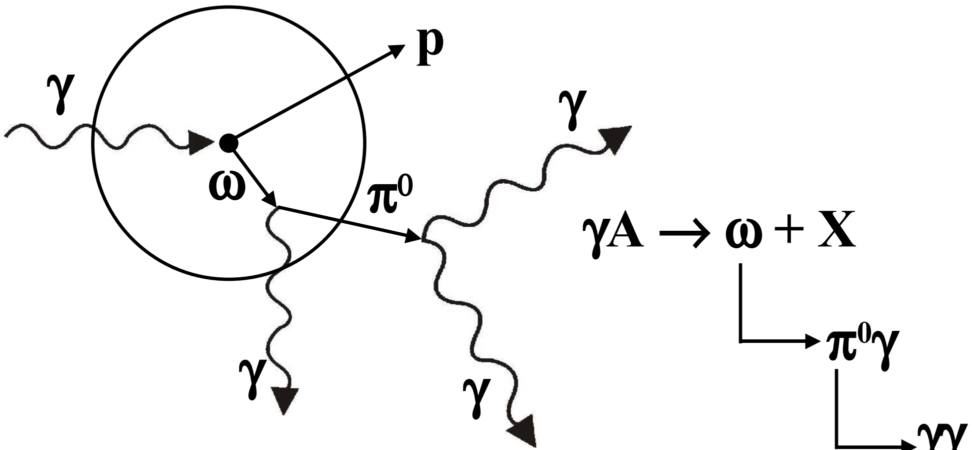
P. Mühlich, priv. com.



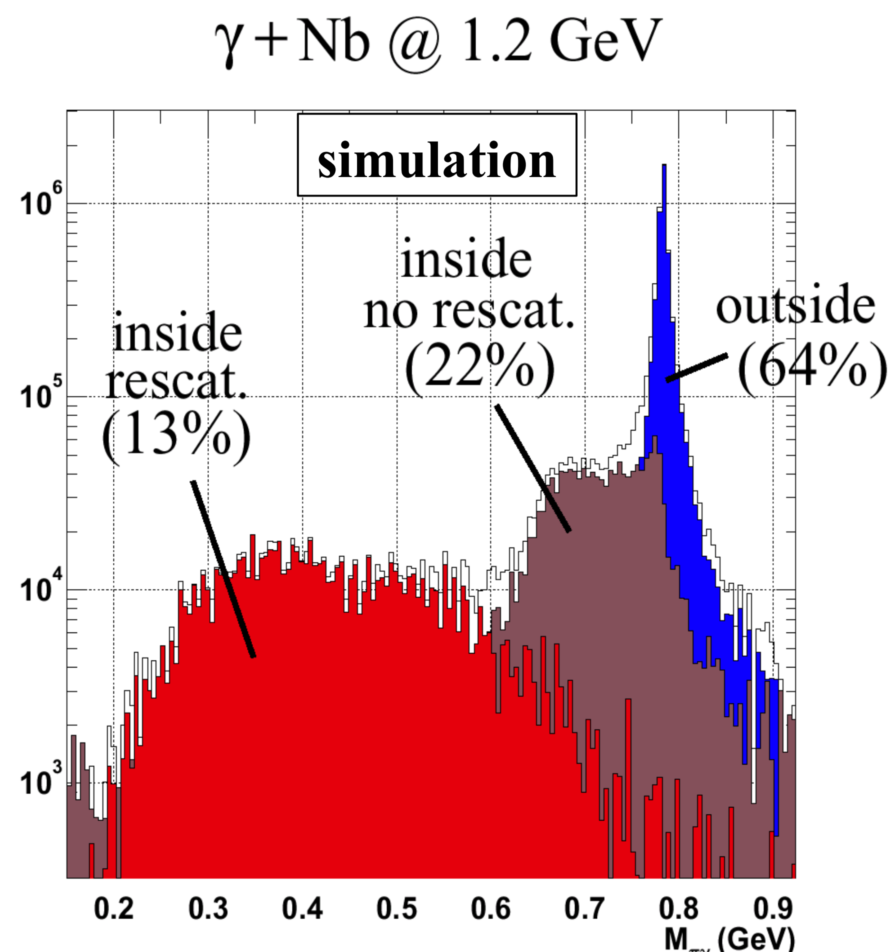
ω spectral function
(structure due to coupling to $S_{11,}P_{13}$ resonances)

ω-mass in nuclei from photonuclear reactions

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



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



advantage:

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

disadvantage:

- π^0-rescattering

no distortion by pion rescattering expected in mass range of interest; further reduced by requiring T_π>150 MeV

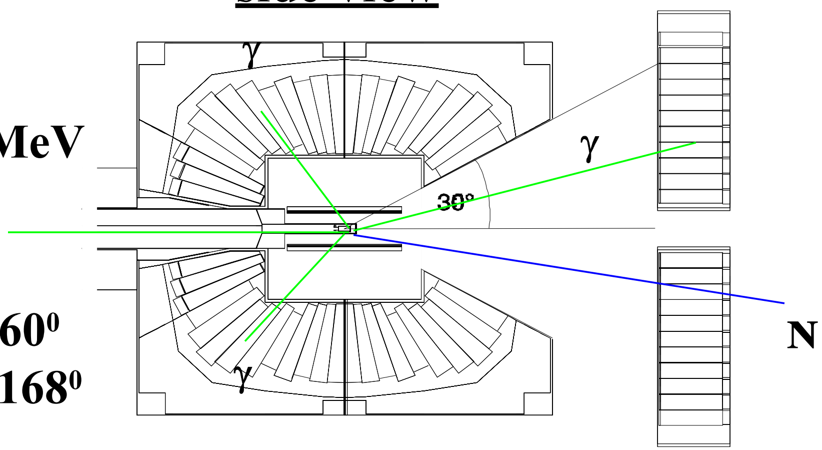
4 π detector system CB/TAPS @ ELSA

Crystal Barrel
1290 CsI

side view

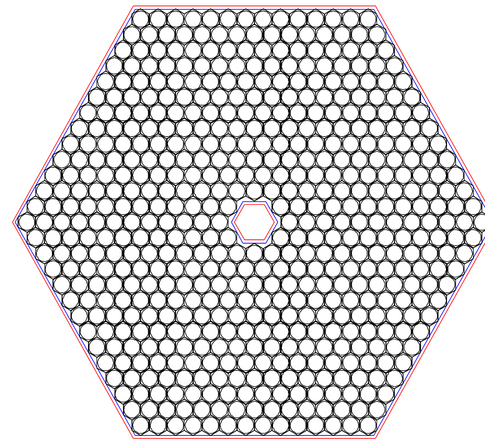
E_{γ}=
900-2200 MeV

Φ = 0^0 to 360^0
Θ = 30^0 to 168^0

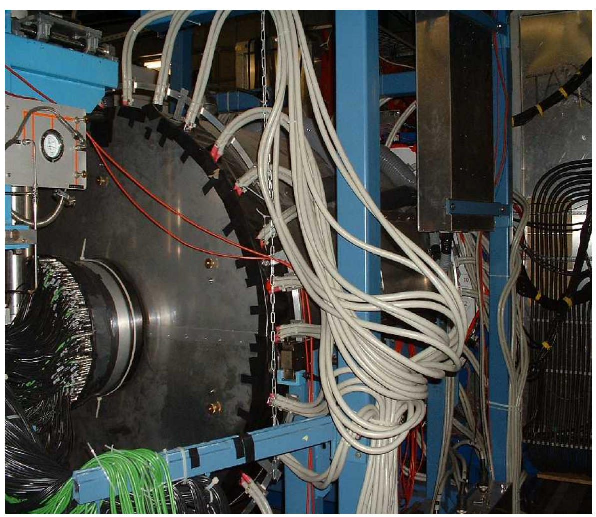


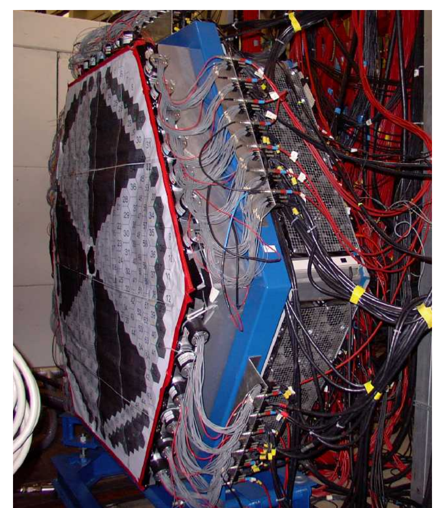
TAPS
528 BaF_2

front view of TAPS

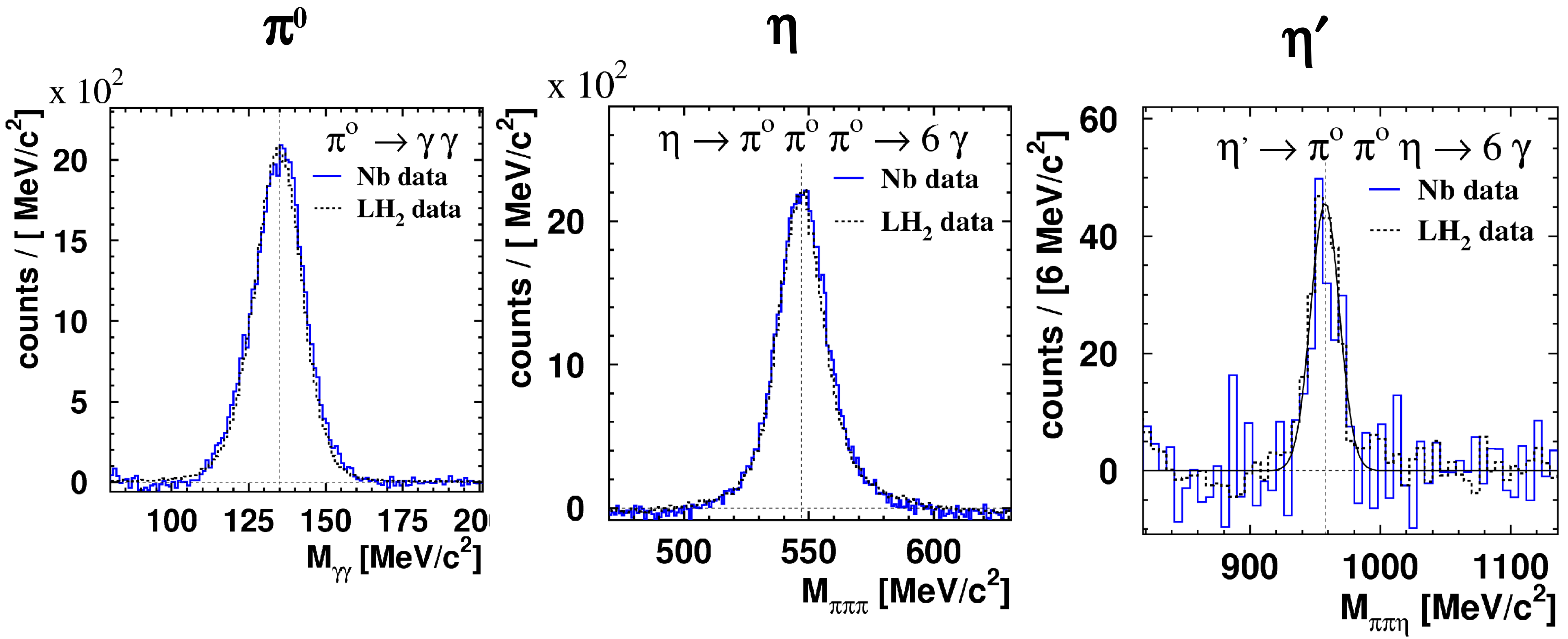


Φ = 0^0 to 360^0
Θ = 5^0 to 30^0





comparison of meson masses and lineshapes for LH_2 and nuclear targets after background subtraction

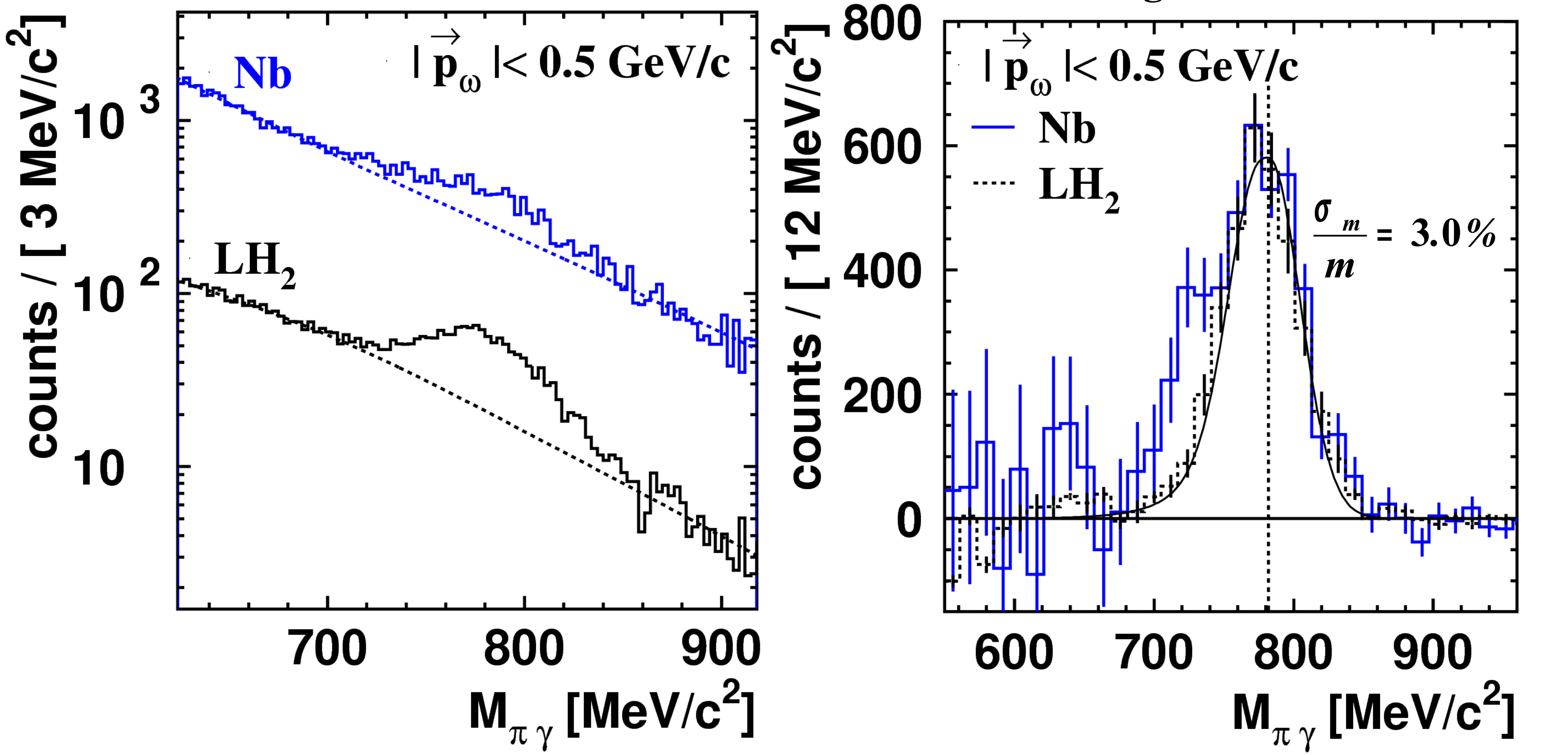


No change of mass and lineshape for longlived mesons (π^0, η, η') decaying outside nuclei

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

D. Trnka et al., PRL 94 (2005) 192203

after background subtraction

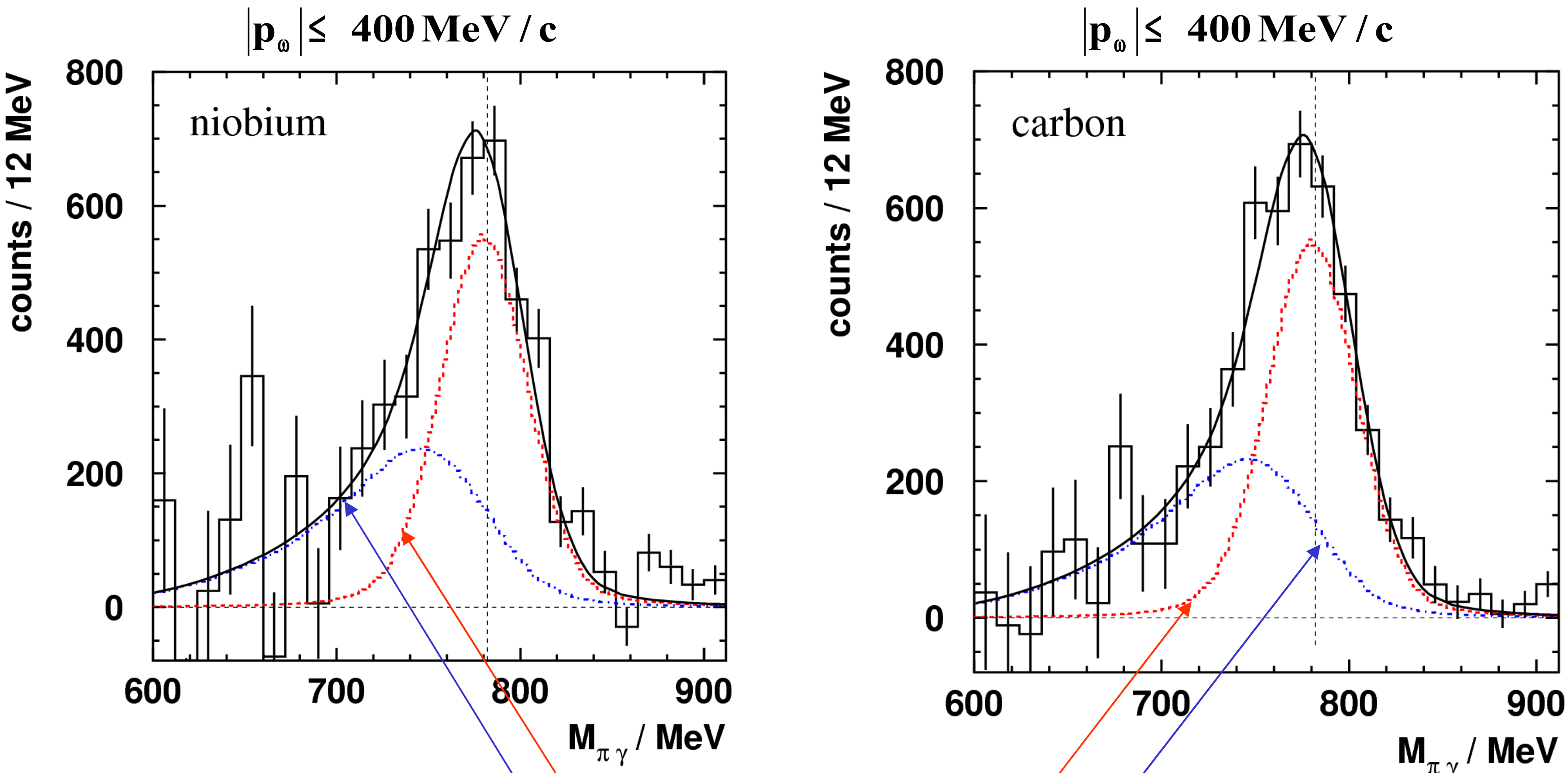


difference in line shape of ω signal for proton and nuclear target

consistent with $m_\omega = m_0 (1 - \alpha\, \rho/\rho_0)$ for $\alpha = 0.13$

D. Trnka, PhD thesis,
Univ. Giessen 2006

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



Nb: in-medium: 45%

vacuum contribution

in-medium contribution

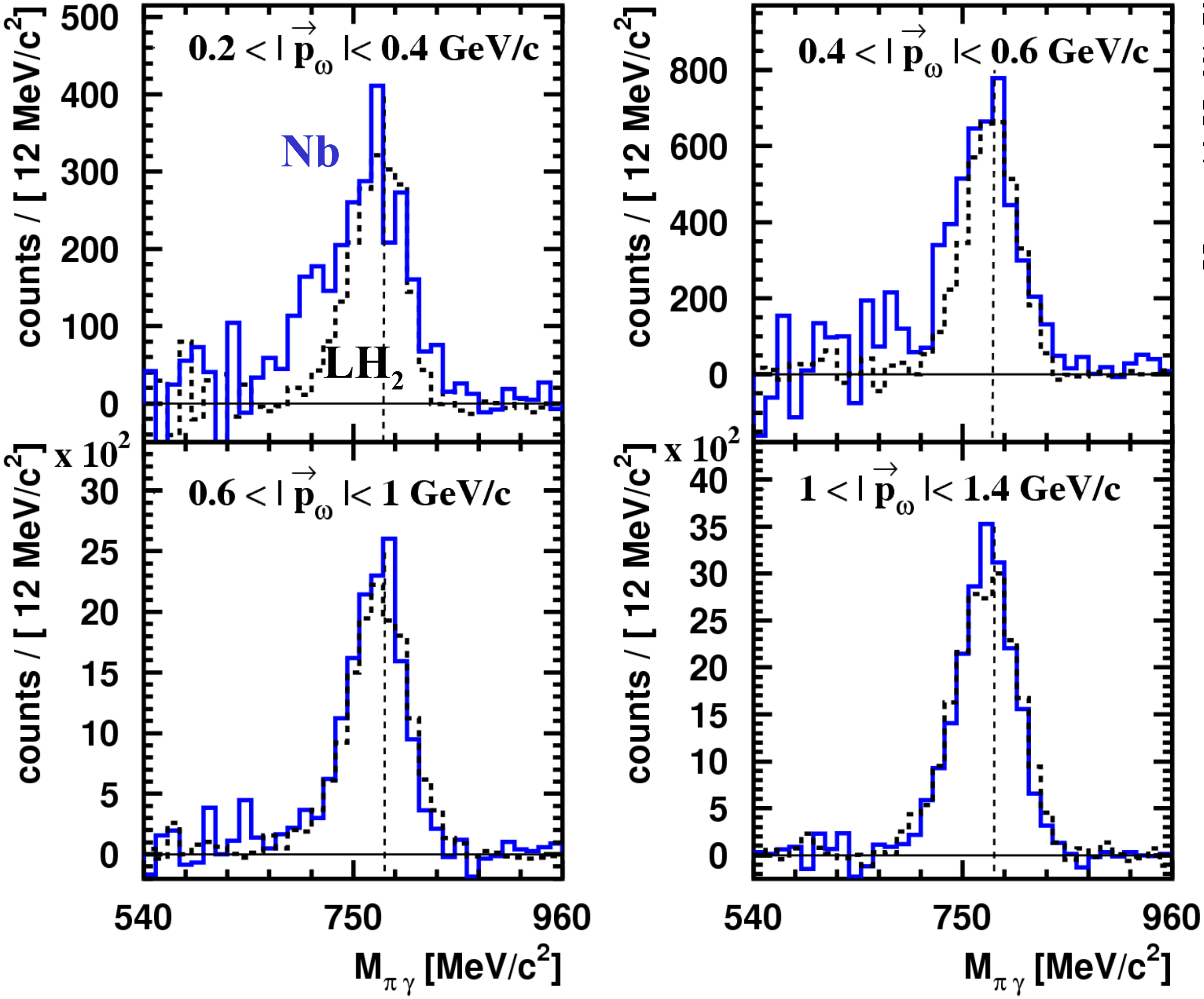
C: in-medium: 40%

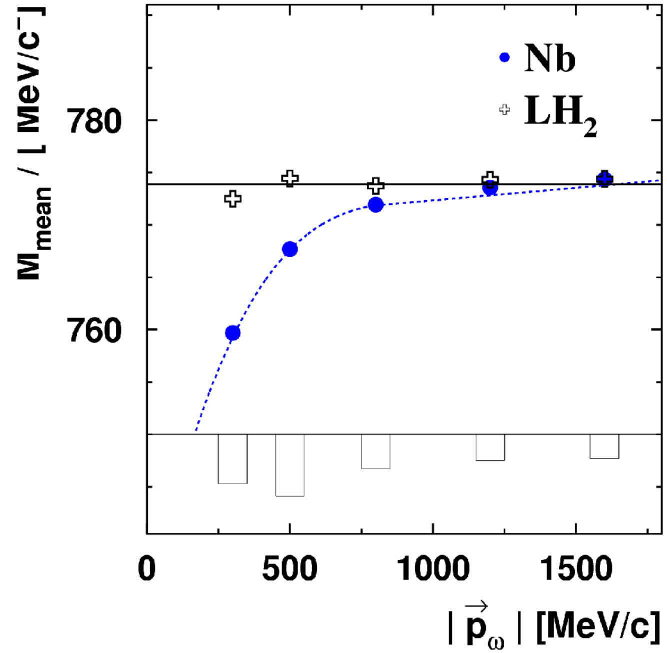
lineshape of vacuum contribution taken from LH_2 experiment

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

momentum dependence of ω signal (Nb-target)

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





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

refined analysis requiring recoil proton and p-ω coplanarity

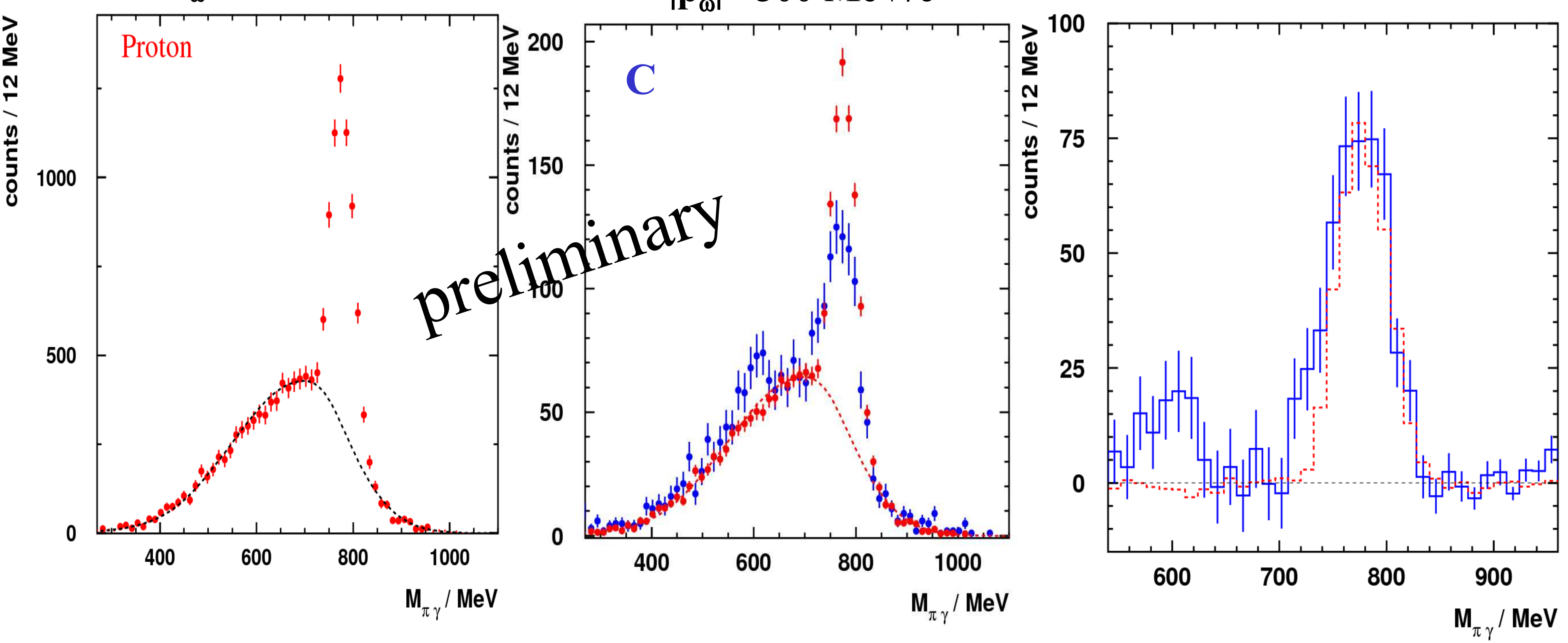
D. Trnka (Gießen) priv. com.

No background subtraction!!!

after LH_2 background subtraction

$|p_\omega| < 500$ MeV/c

$|p_\omega| < 500$ MeV/c



⇒ difference in ω - line shape for proton and nuclear target confirmed; no upward mass shift of ω meson!

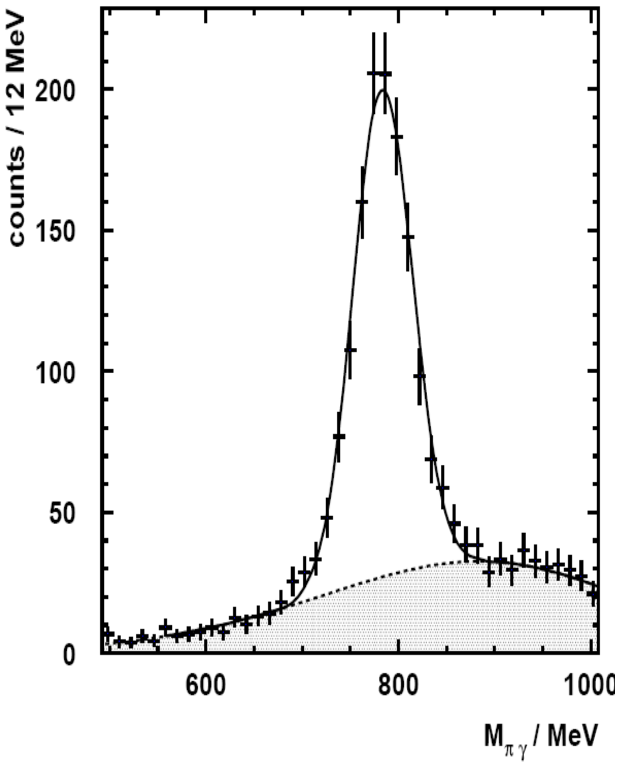
⇒ additional structure at ≈ 600 MeV!! (also seen for heavier targets) fragmentation of ω strength or background ??? under investigation

ω signal for high momenta

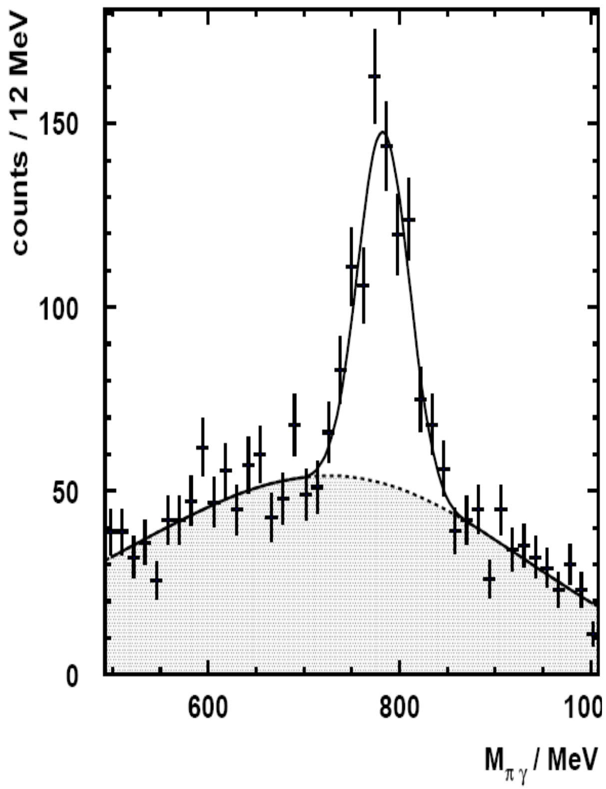
D. Trnka

$700\ \mathrm{MeV}/c < p_\omega < 1400\ \mathrm{MeV}/c$

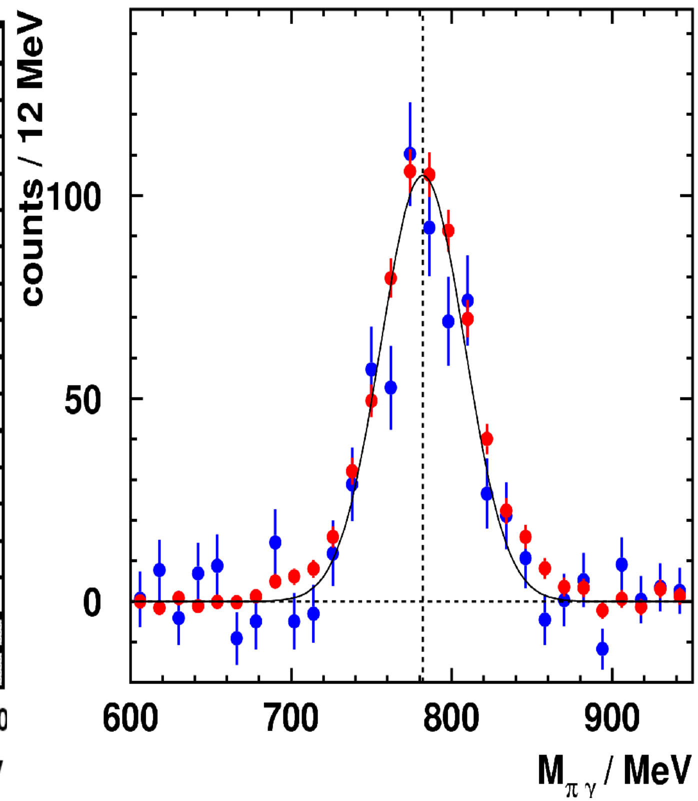
LH_2



carbon



after background subtraction

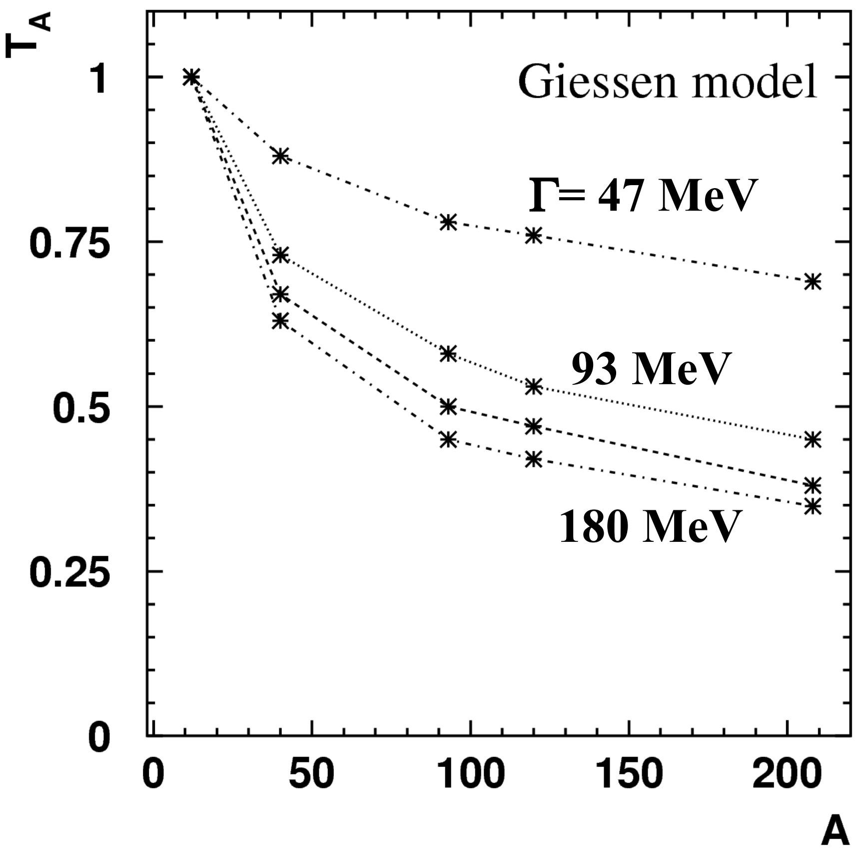


second structure at around 600 MeV/c² has dissappeared for high momentum ω mesons (mainly decaying outside nucleus)

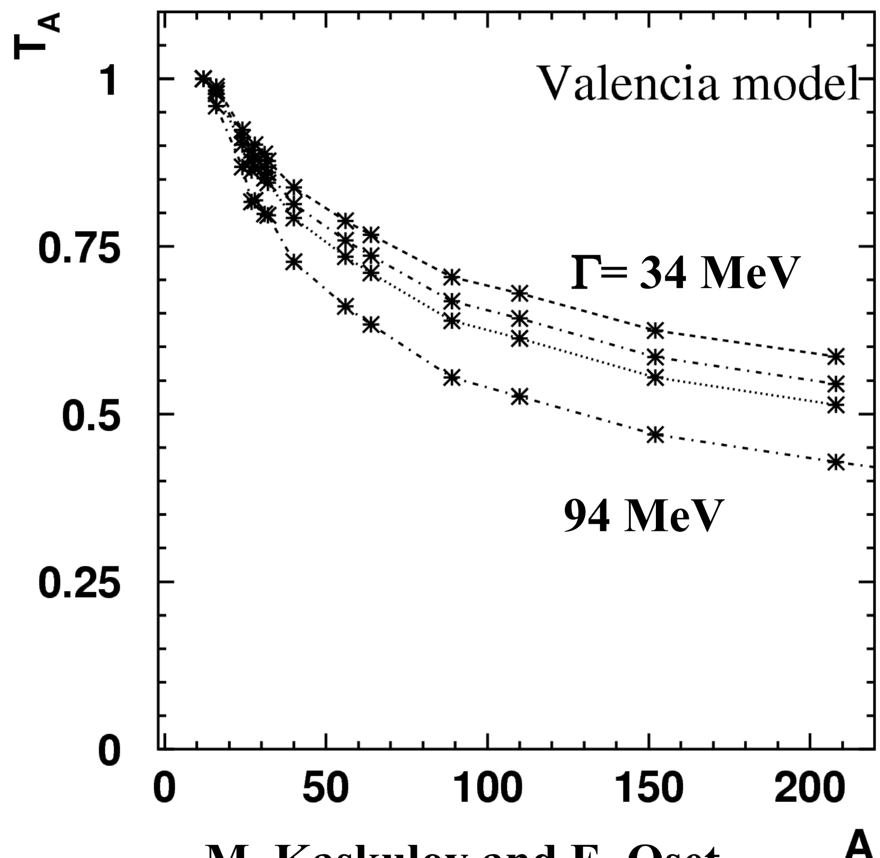
access to in-medium ω width

in-medium ω width proportional to ω absorption: $\Gamma(\rho,|\vec{p}_\omega|) \propto \rho v \sigma_{abs}$

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



P. Mühlich and U. Mosel
NPA (2006)

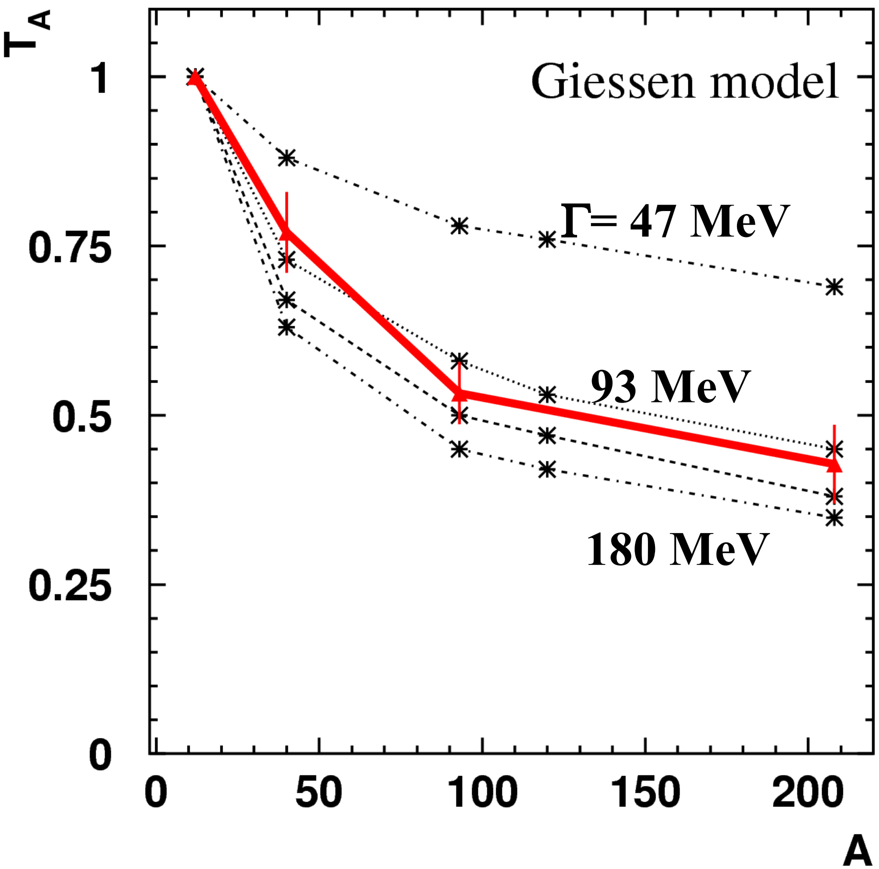


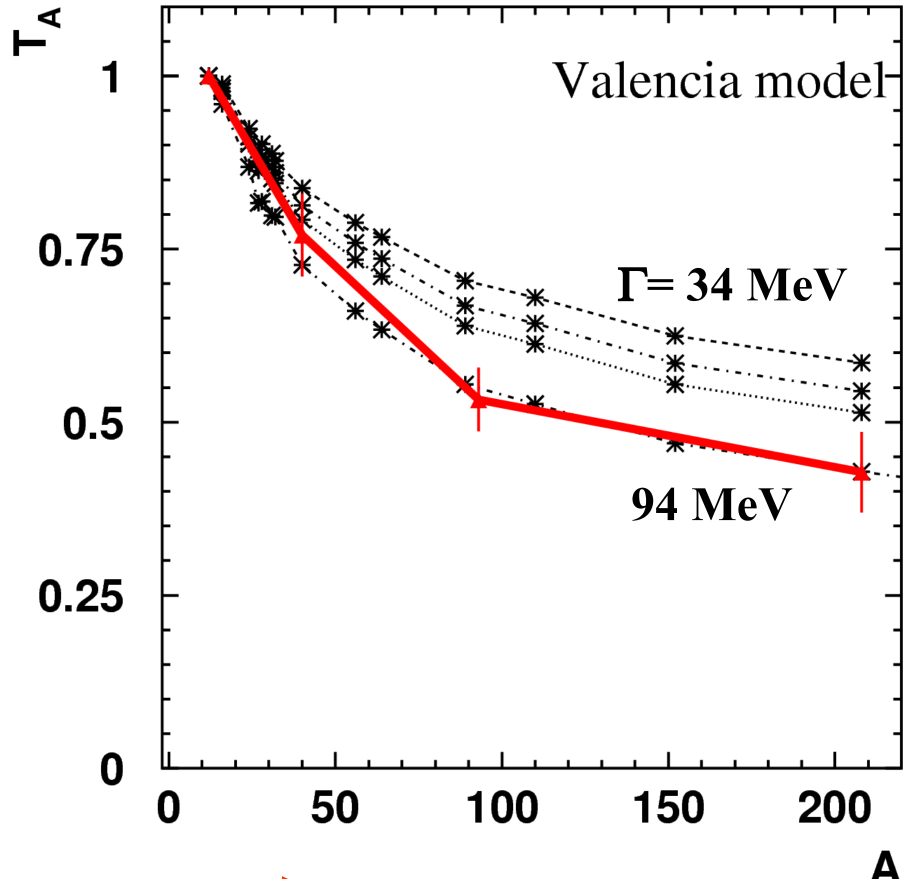
M. Kaskulov and E. Oset
priv. communication

access to in-medium ω width

in-medium ω width proportional to ω absorption: $\Gamma(\rho,|\vec{p}_\omega|) \propto \rho v \sigma_{abs}$

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

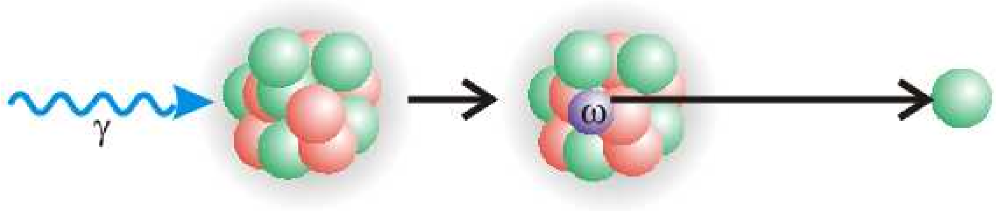




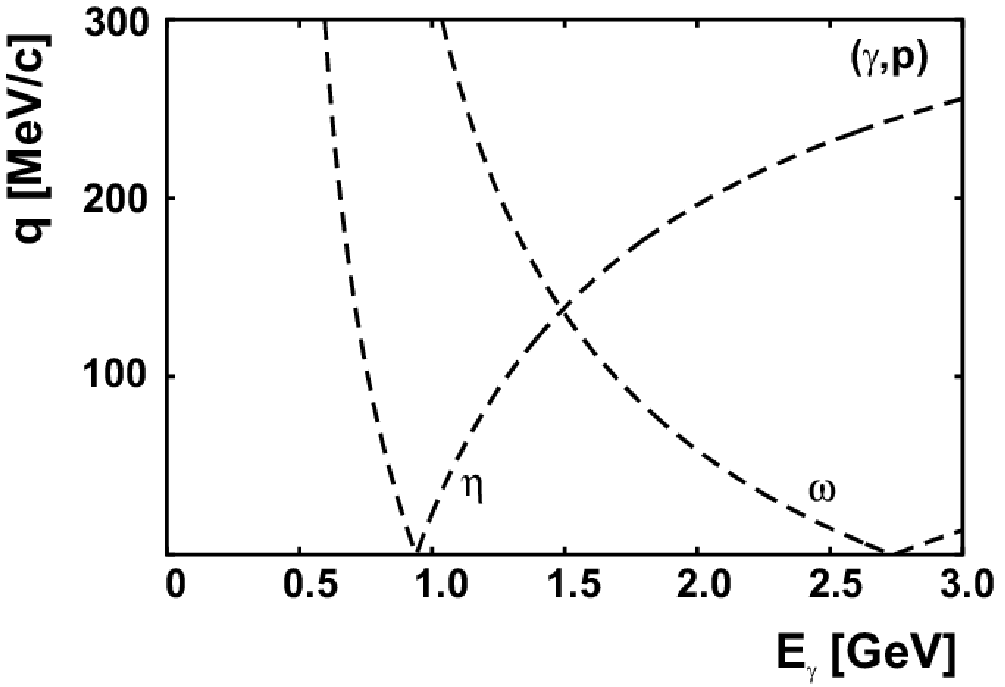
comparison to data (D.Trnka et al.(prelim.)) $\Gamma(\rho_0,\langle|\vec{p}_\omega|\rangle \approx 750\ \mathrm{MeV/c}) \approx 95$ MeV

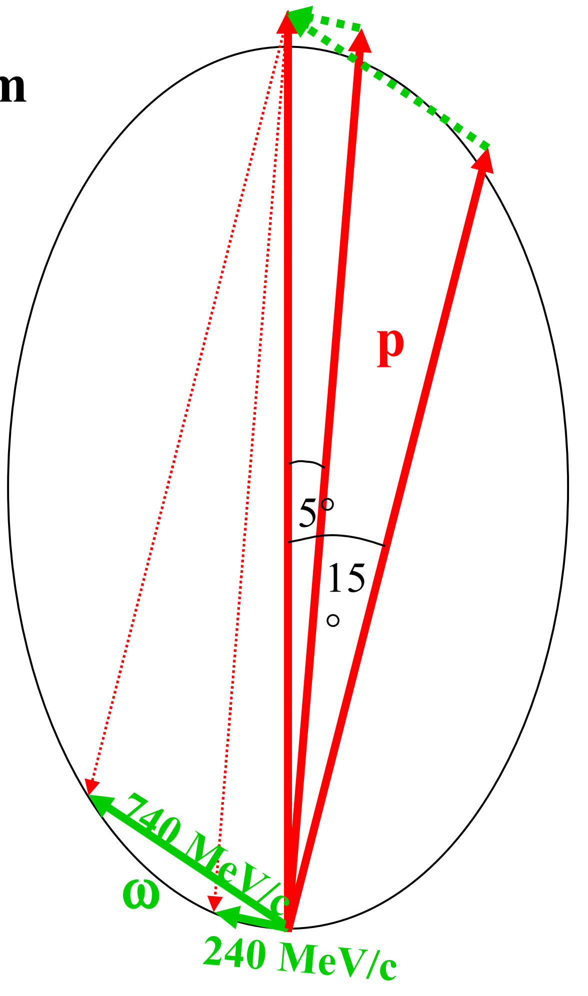
ω gets broadened in the medium by a factor 10!!

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



forward going nucleon takes over photon momentum

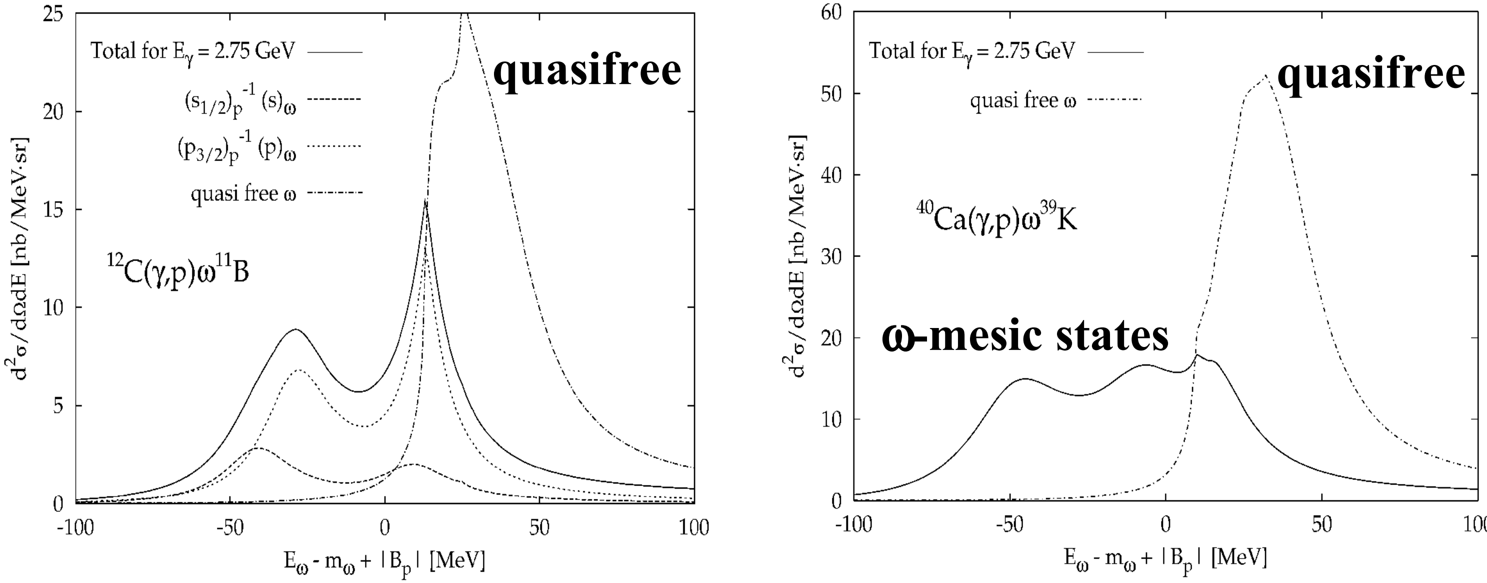




magic incident energies η: $E_\gamma \approx$ 930 MeV

ω: $E_\gamma \approx$ 2750 MeV

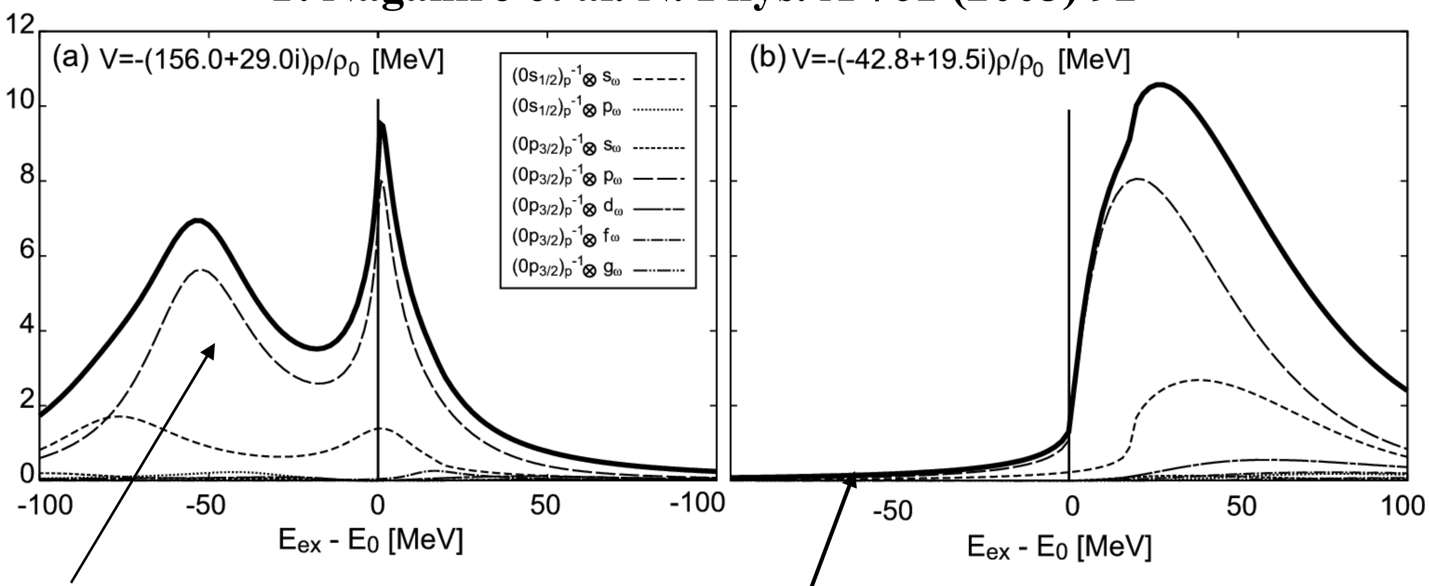
E. Marco and W. Weise, PLB 502 (2001) 59



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

attractive potential

repulsive potential



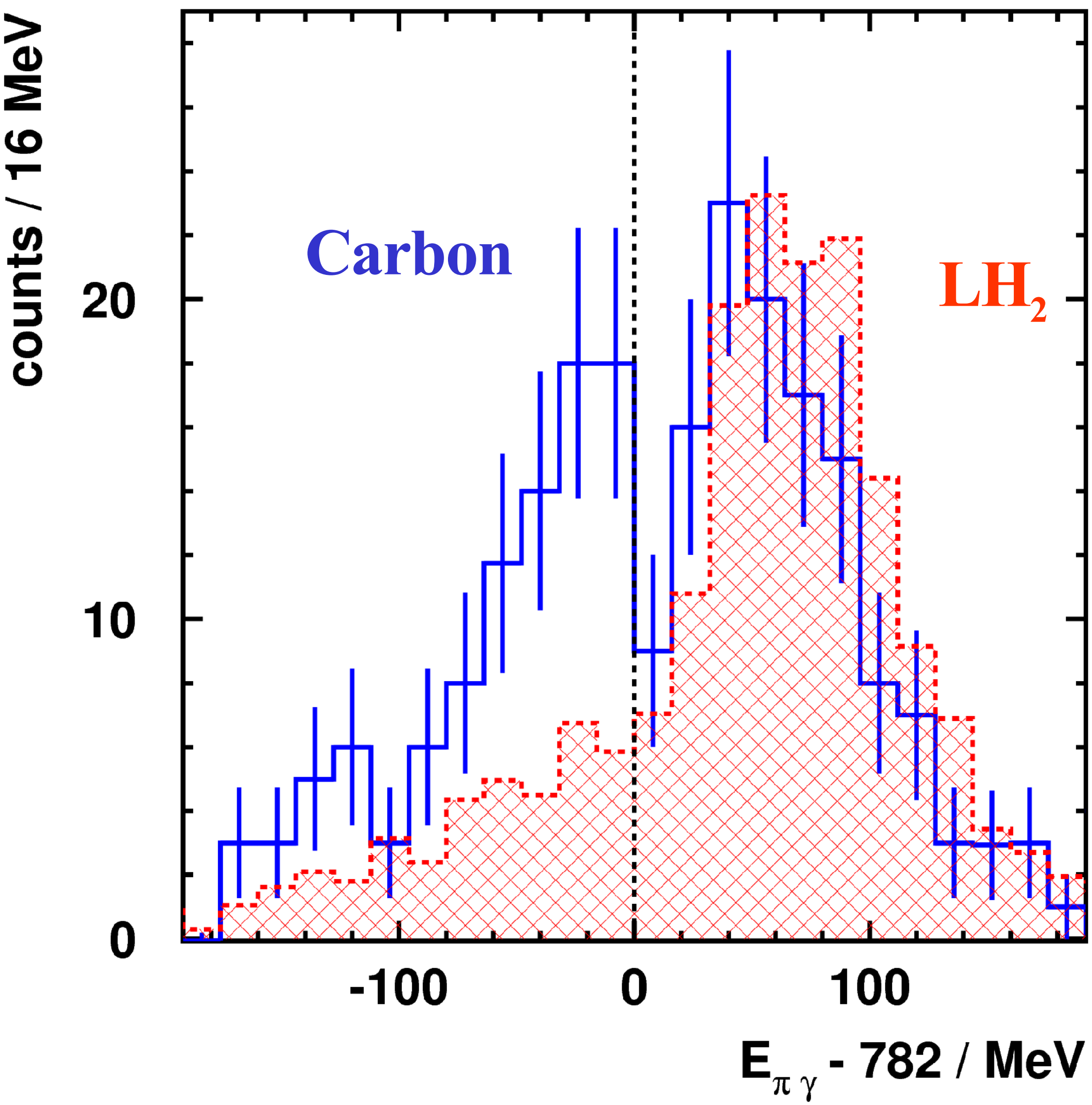
signature for ω - mesic states

no intensity for negative energies

comparison of carbon and LH_2 data

D. Trnka

1500 MeV < Eγ < 2200 MeV: $|\vec{p}_\omega| <$ 400 MeV/c
small proton angles: $6^0 < \Theta_p < 10^0$

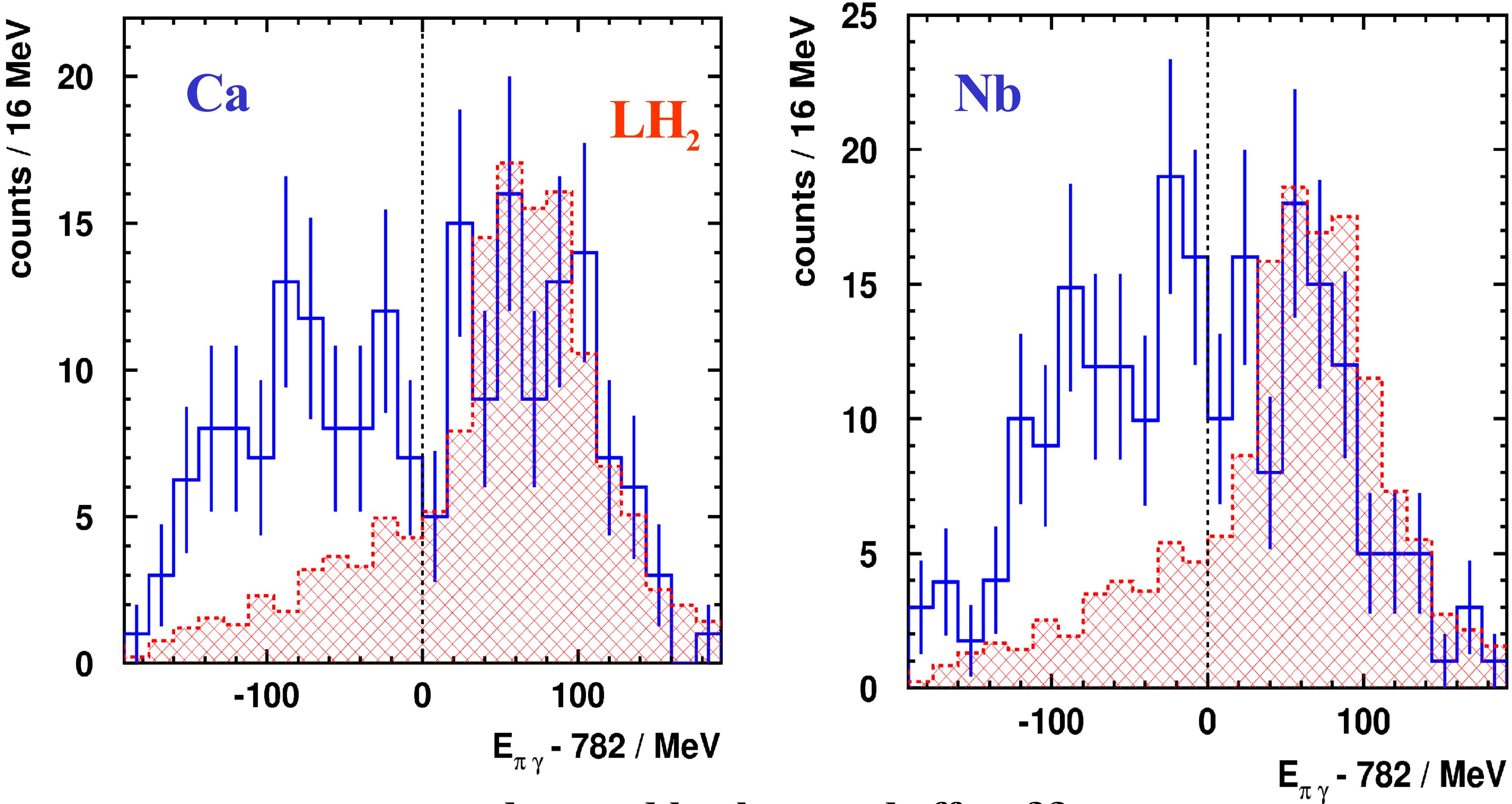


normalisation on quasi-elastic peak

excess yield relative to LH_2 reference spectrum for negative energies (bound state regime)

evidence for $^{11}_{\omega}B$??

evidence for ω -mesic states also in Ca and Nb??

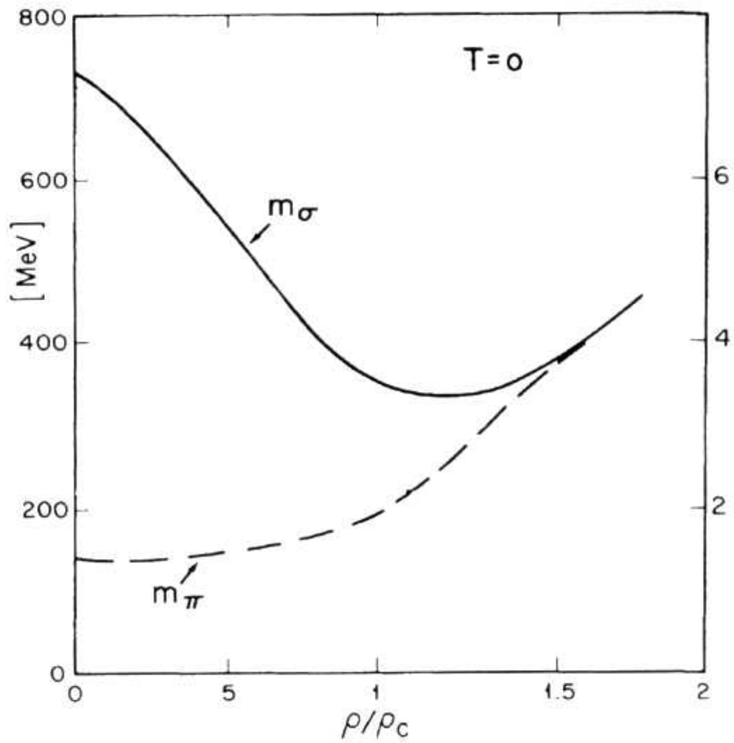


not understood background effect ??

improved experiment with Cerenkov detector for π/p discrimination
in preparation: K. Makonyi, T. Kuske

Partial chiral symmetry restoration in the nuclear medium

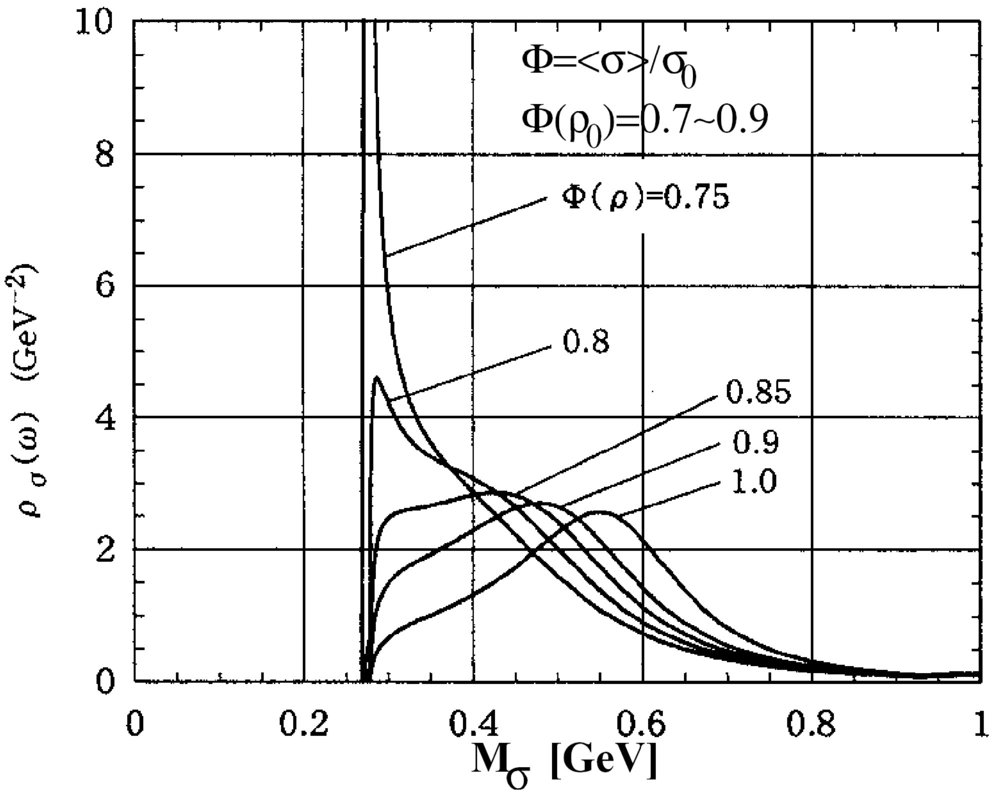
V. Bernard et al. PRL 59 (1987) 966



masses of chiral partners become degenerate in the chiral limit

$$m_\sigma = m_{\sigma 0}\left(1 - \alpha \frac{\rho}{\rho_0}\right)$$

$\sigma \rightarrow \pi^0\pi^0, \pi^+\pi^-$



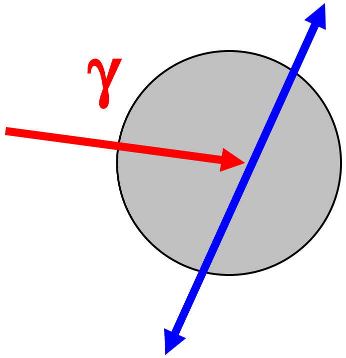
P. Schuck et al., nucl-th/0002031

T. Hatsuda et al., PRL 82 (1999) 2840

R. Rapp et al., PRC 59 (1999) 1237

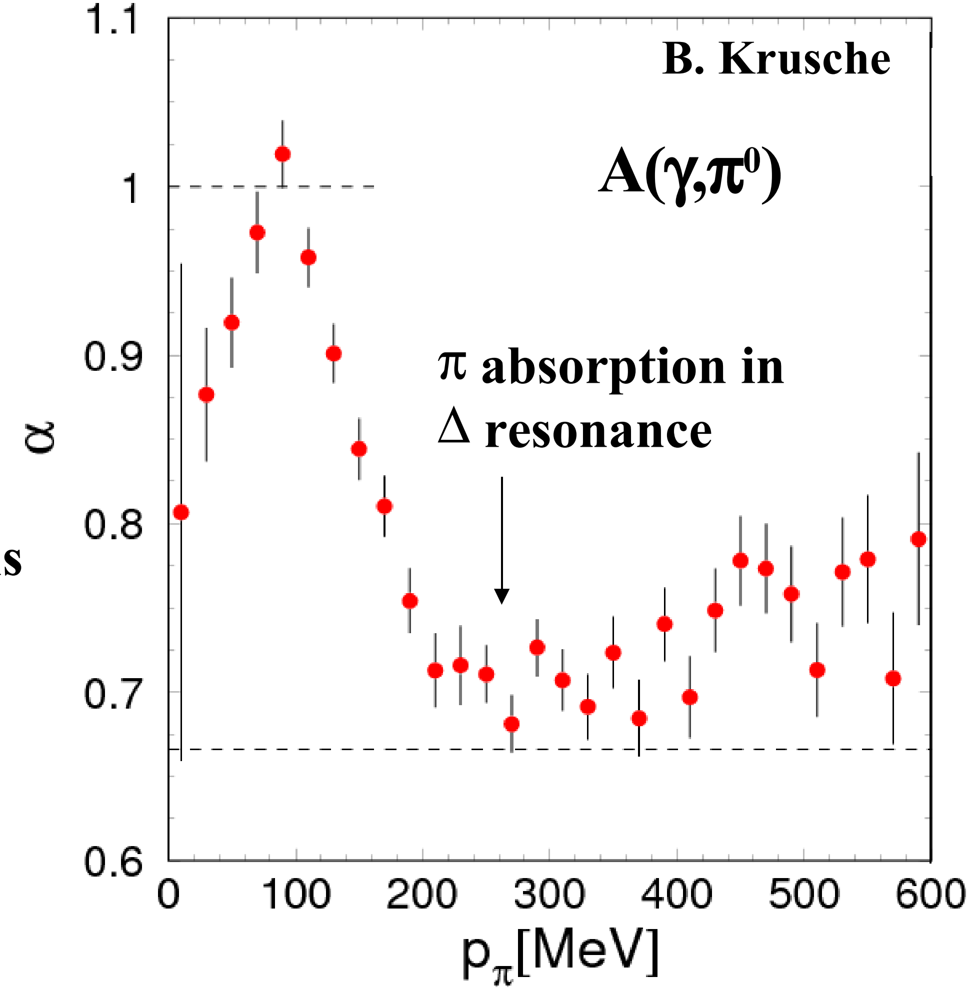
Pionabsorption

Outgoing pions should experience as little as possible final state interaction



$\rho \approx \rho_o$

$$\sigma_\pi = \sigma_p \cdot A^{\alpha(p_\pi)}$$



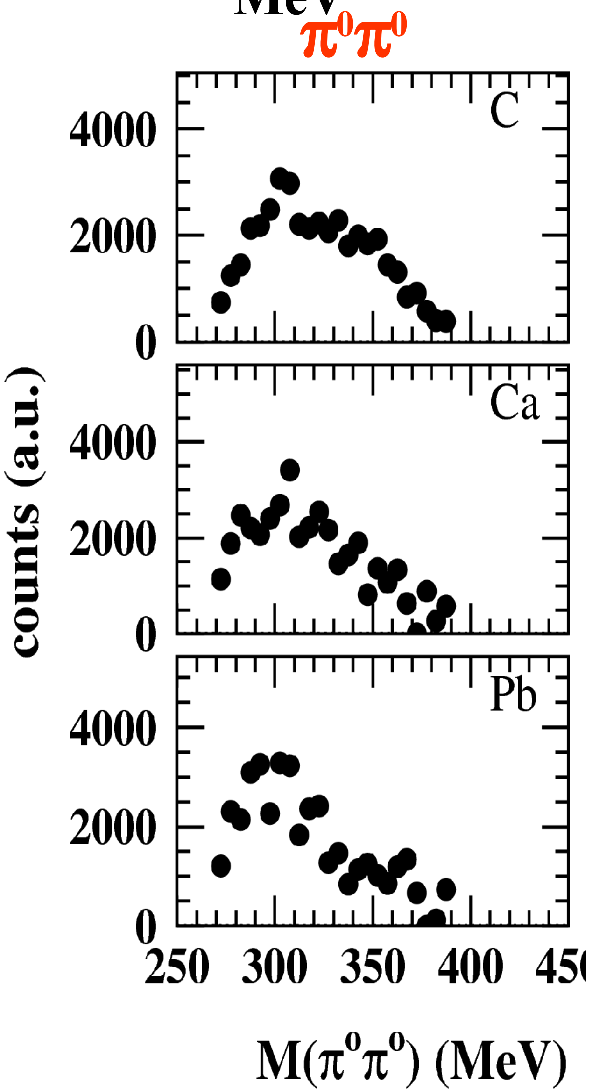
α =1 ⇔ nuclei transparent to pions

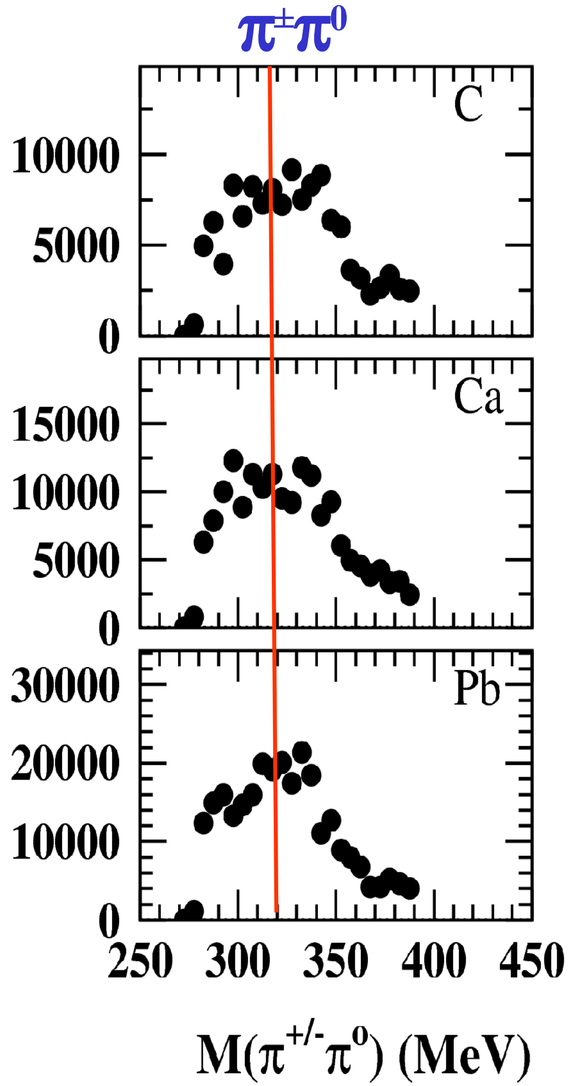
pions have relatively long mean free path for momentum range ≈ 50 – 150 MeV/c, i.e. for $T_\pi \approx 10 – 70$ MeV

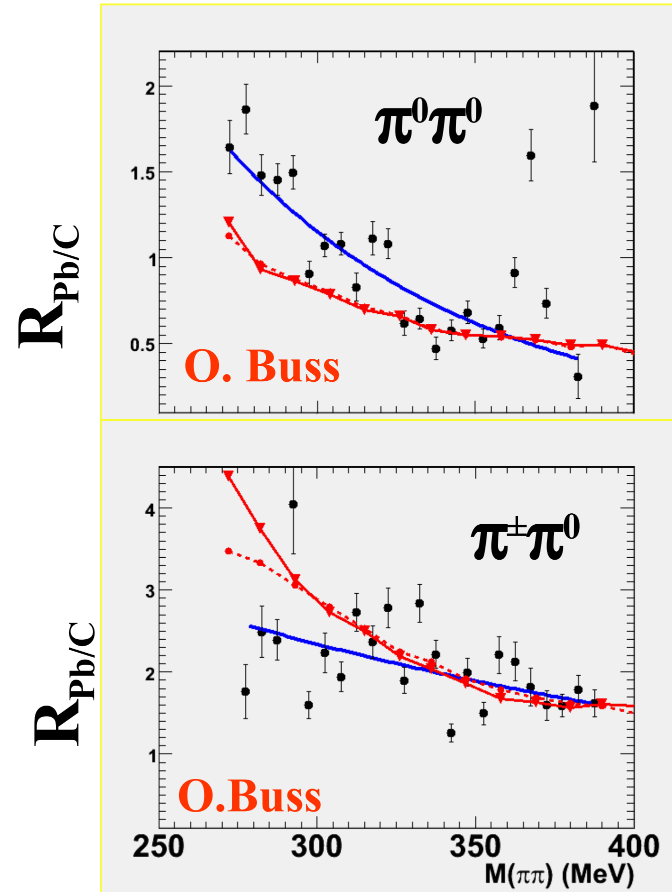
A (γ,ππ)

$E_\gamma = 400 – 460$ MeV

$$R_{Pb/C} = \frac{12\,\frac{d\sigma}{dM}(Pb)}{208\,\frac{d\sigma}{dM}(C)}$$







no quantitative agreement with BUU calculations

sizable mass shift with increasing A only observed for $\pi^0\pi^0$ channel, confirming J. Messchendorp et al.,PRL 89 (2002) 222302

summary

- **in-medium properties of the ω meson:**
  - evidence for dropping ω mass in the nuclear medium:
    $m_\omega = m_0(1 - 0.13\rho / \rho_0)$
  - possible evidence for fragmentation of ω strength?
  - in-medium ω width $\Gamma(\rho=\rho_0, \langle|p_\omega|\rangle \approx 750$ MeV/c$) \approx 95$ MeV
    → in-medium broadening by factor 10!
  - evidence for ω mesic nuclei?
    ongoing studies; improved experiment in preparation

- **in-medium ππ correlations**
  - sizabe concentration of $\pi^0\,\pi^0$ strength near 2π threshold with increasing nuclear mass number A observed, as theoretically predicted;
    similar shift not observed in $\pi^\pm\pi^0$ channel;
    detailed comparison with BUU-simulations (O. Buss, Giessen) ongoing

A3, B4 future prospects (next application period)

depending on successor!!!

- **magnetic moments of baryon resonances:**
  remeasurement of μ (Δ^+) using circular polarisation (P=70%)
  measurement of the magnetic moment of the S_{11}(1535) resonance via $\gamma\, p \rightarrow p\, \eta\, \gamma'$, exploiting linear polarization (ELSA)
- **2-π production on nuclei:**
  no further experiments planned
- **measurement of ω spectral function in nuclei:**
  further experiments likely (other nuclei, finer ω- momentum bins $\rightarrow$ momentum dependence of ω-nucleus potential), depending on outcome of approved experiment (MAMIC)
- **search for ω-mesic nuclei:**
  further experiments likely (other nuclei; better π/p-discrimination with Cerenkov-detector), depending on outcome of approved experiment (ELSA)

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Teilprojekte A3 und B4

Personnel: (3.5 BATIIa positions)

postdocs: M. Nanova (IIa), D. Trnka (IIa),

PhD-students: S. Lugert (B4),, M. Thiel (A3);

A1: K. Makonyi
from 1.1-30.6.2007: R. Gregor,
from 1.9.07 F. Hjelm)
from 1.8.07 H. Berghäuser

Sachmittel: 140 k€ for new BaF_2 and veto-electronics
30 k€: funds for electronics for 30 additional BaF_2 detectors

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:

  $\Gamma_\omega \approx 95\,\mathrm{MeV}$ at $\rho = \rho_0$ and $\langle|\vec{p}_\omega|\rangle \approx 750\,\mathrm{MeV/c}$

- first indication for the existence of ω mesic ^{11}B

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

⇒ higher statistics needed !!

⇒ improved experiments planned at MAMI and ELSA

CBELSA/TAPS collaboration

II. Physikalisches Institut, Universität Gießen:
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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

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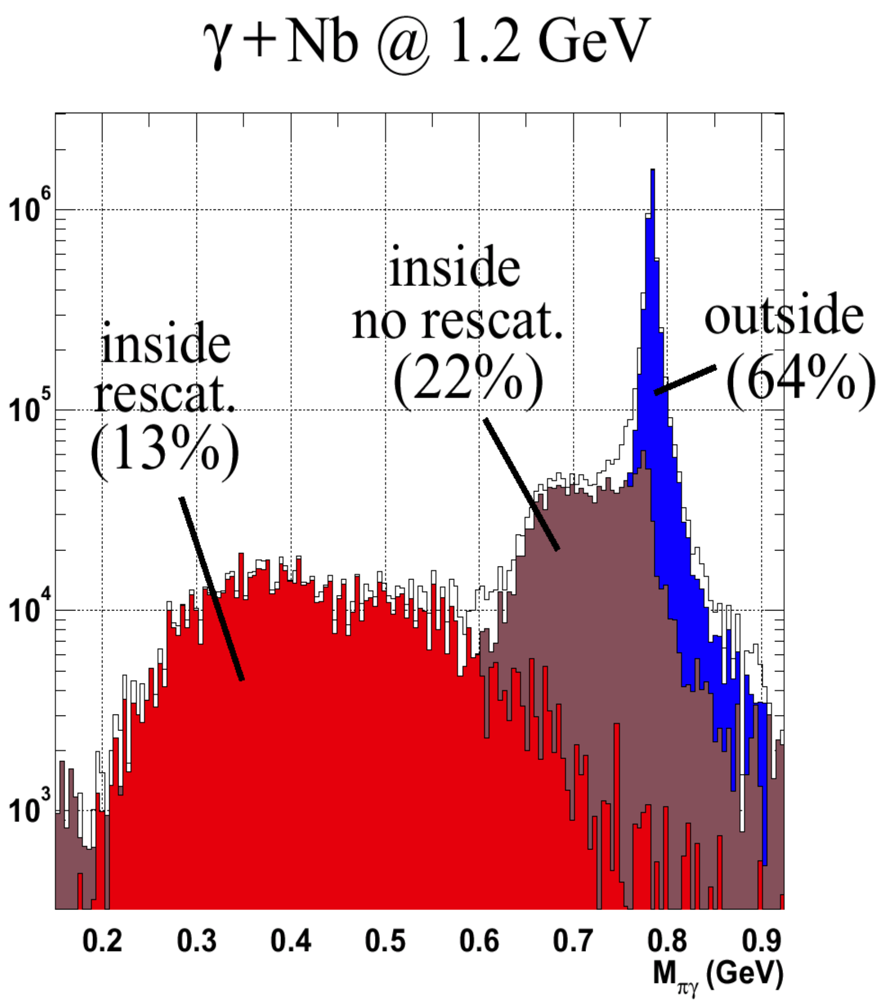
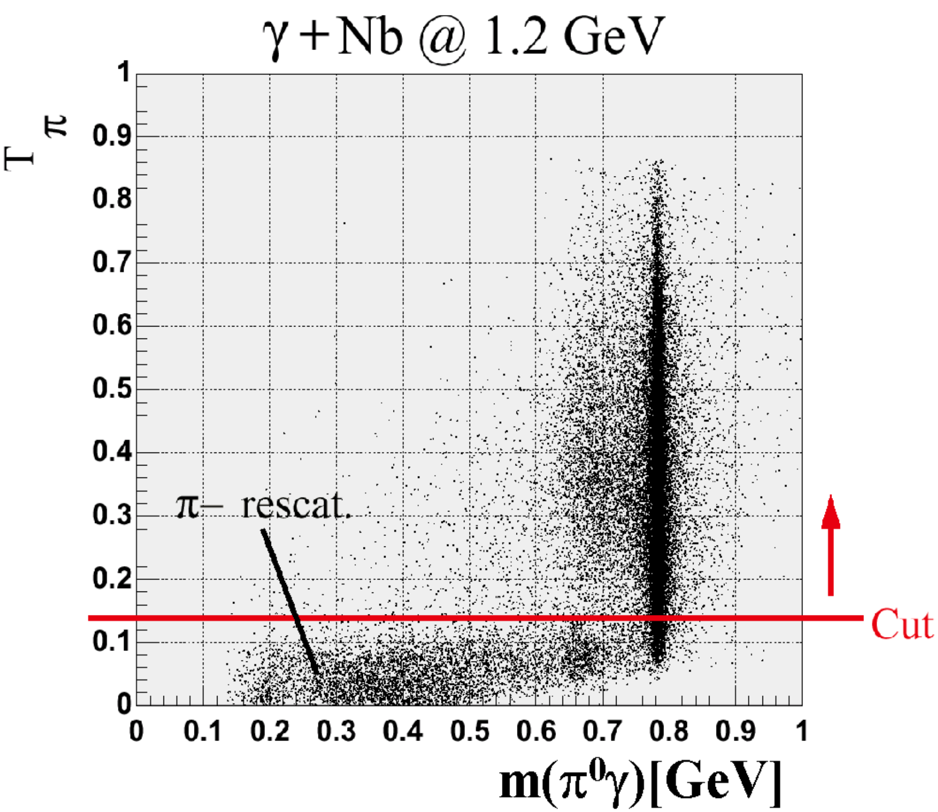
Expected ω in-medium signal



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

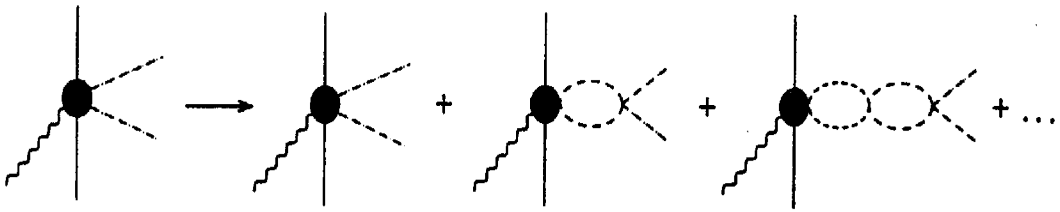


no distortion by pion rescattering expected in mass range of interest

ππ interaction in the chiral unitary model

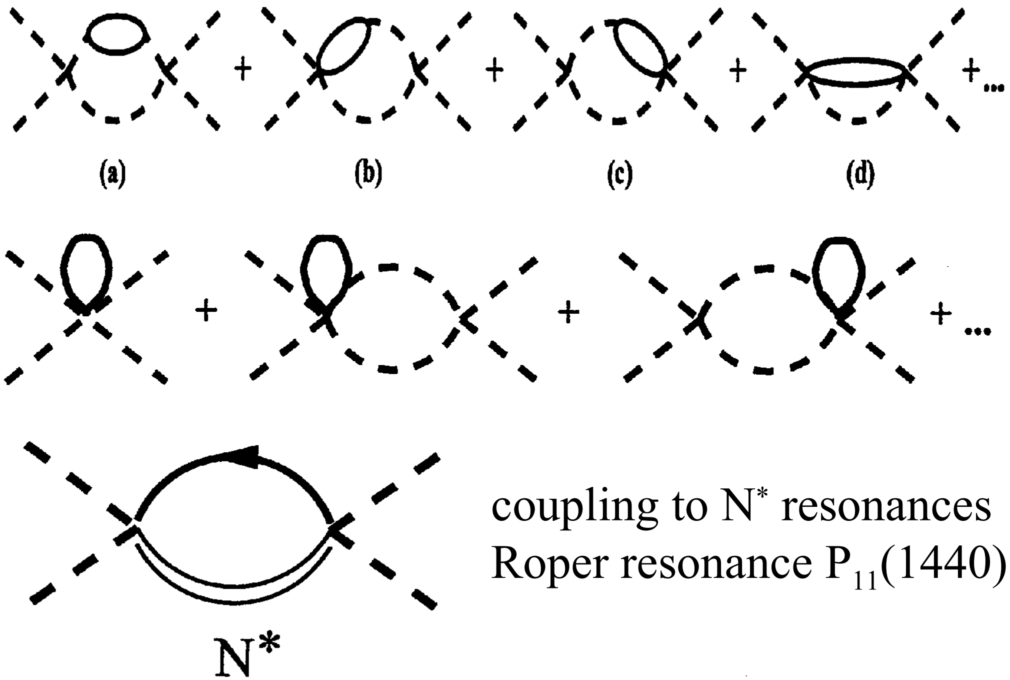
M.J. Vicente Vacas and E. Oset et al., nucl-th/0204055

ππ - interaction in vacuum:



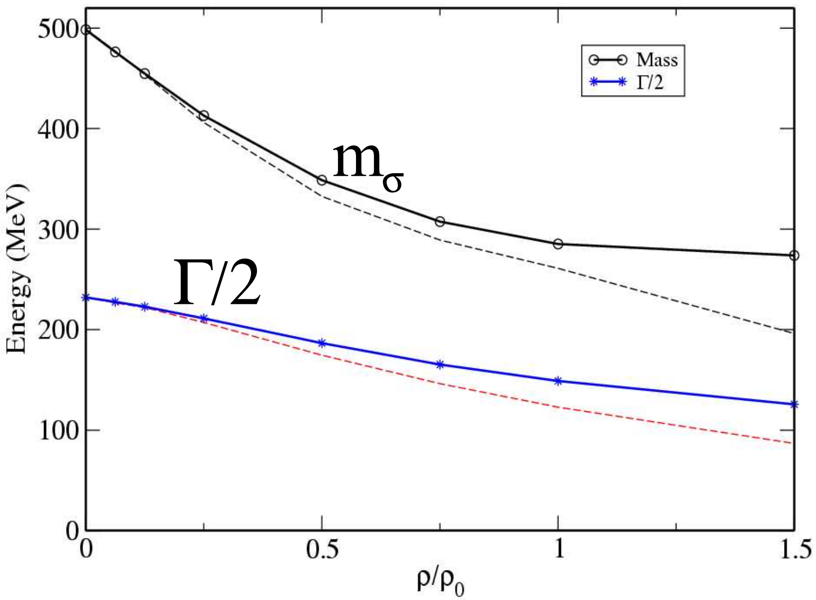
σ = resonance in ππ interaction

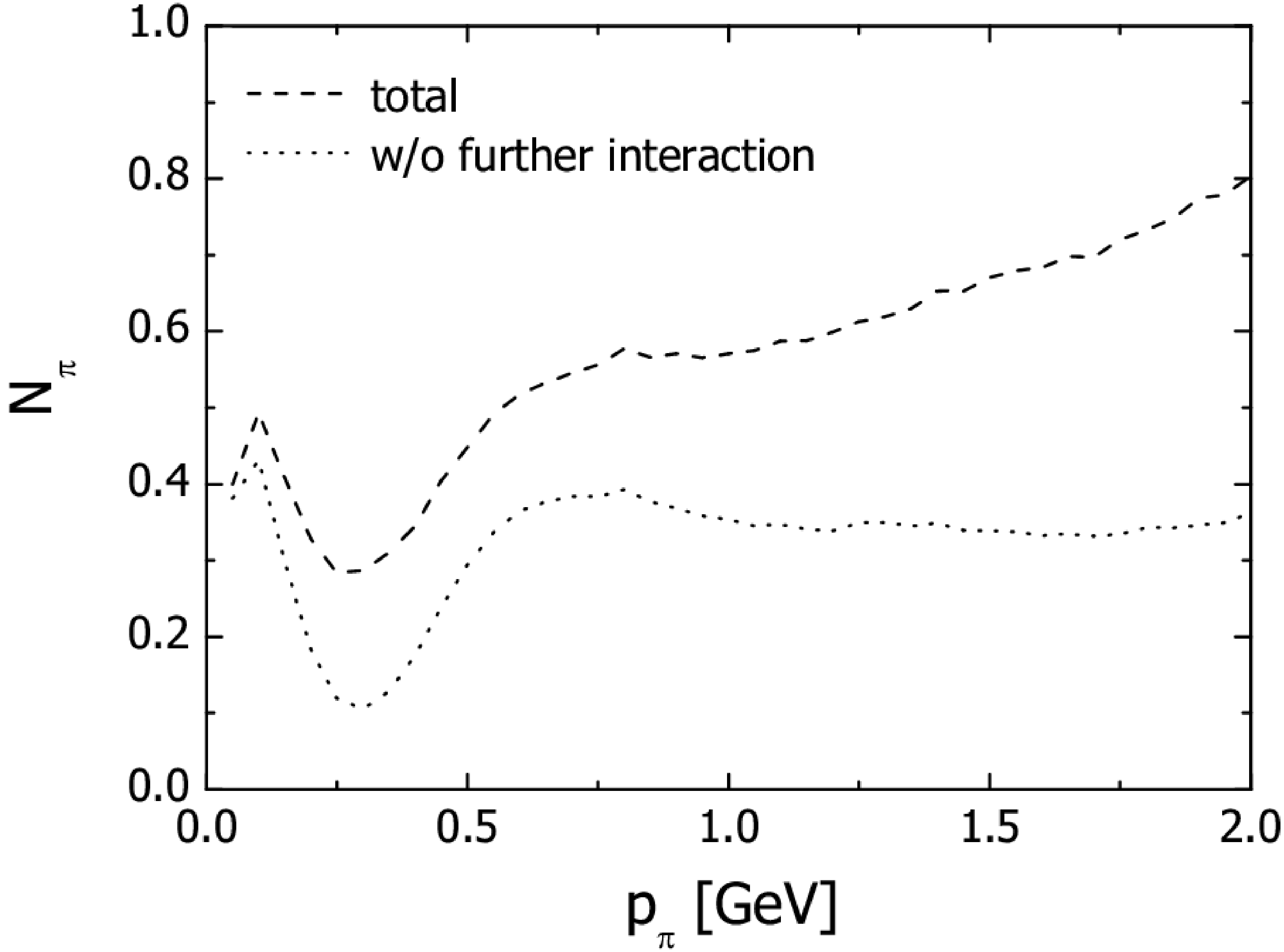
ππ - interaction in the nuclear medium:



coupling to N^* resonances
Roper resonance $P_{11}(1440)$

drop of σ mass and width with increasing nuclear density ρ

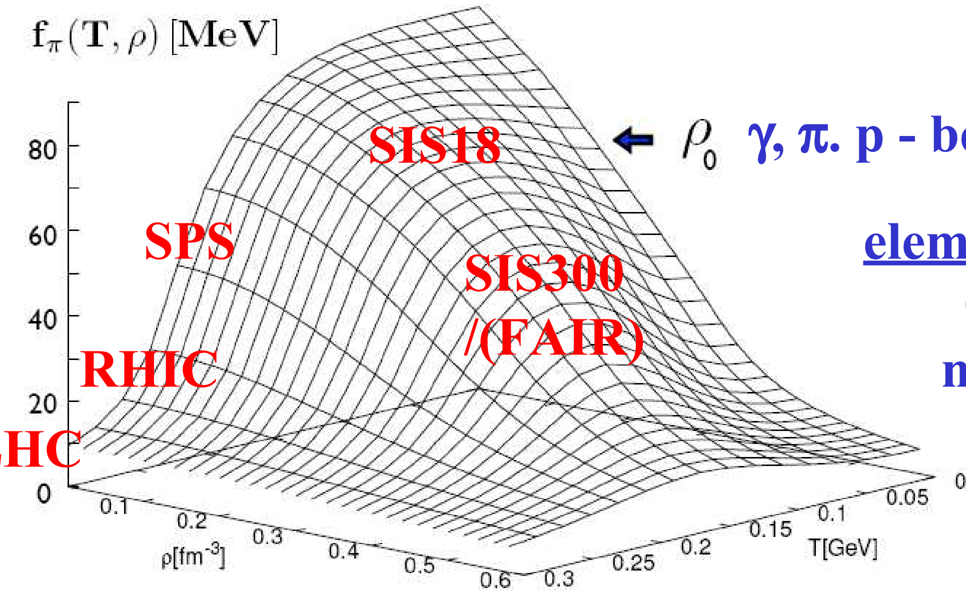




total
w/o further interaction
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
N_π
p_π [GeV]

chiral condensate as function of baryon density ρ_B and temperature T

C. Ratti, M. Thaler, W. Weise, PRD73 (2006) 014019



← ρ_0 γ, π. p - beams

heavy ion reactions:
A+A→V+X
$m_V(\rho >> \rho_0; T >> 0)$

elementary reaction:
γ, π → V+X
$m_V(\rho = \rho_0; T = 0)$

$$\frac{f_\pi^2(T,\rho)}{f_\pi^2(0)} \simeq \frac{\langle \bar{q}q \rangle_{T,\rho}}{\langle \bar{q}q \rangle_0} \simeq 1 - \frac{T^2}{8 f_\pi^2} - \frac{\sigma_N}{m_\pi^2 f_\pi^2} \rho + \ \ldots$$

$\langle q\bar{q} \rangle$ **is not an observable!!**

QCD sum rules: provide link between hadronic observables and condensates

$$\frac{Q^2}{24\pi^2} \int ds \frac{R(s)}{(s+Q^2)^2} = \frac{1}{16\pi^2}\left(1 + \frac{\alpha_s}{\pi}\right) + \frac{1}{Q^4}\left[m_q \langle \bar{q} q \rangle + \frac{1}{24} \left\langle \frac{\alpha_s}{\pi} G^2 \right\rangle \right] + \text{higher order terms}$$

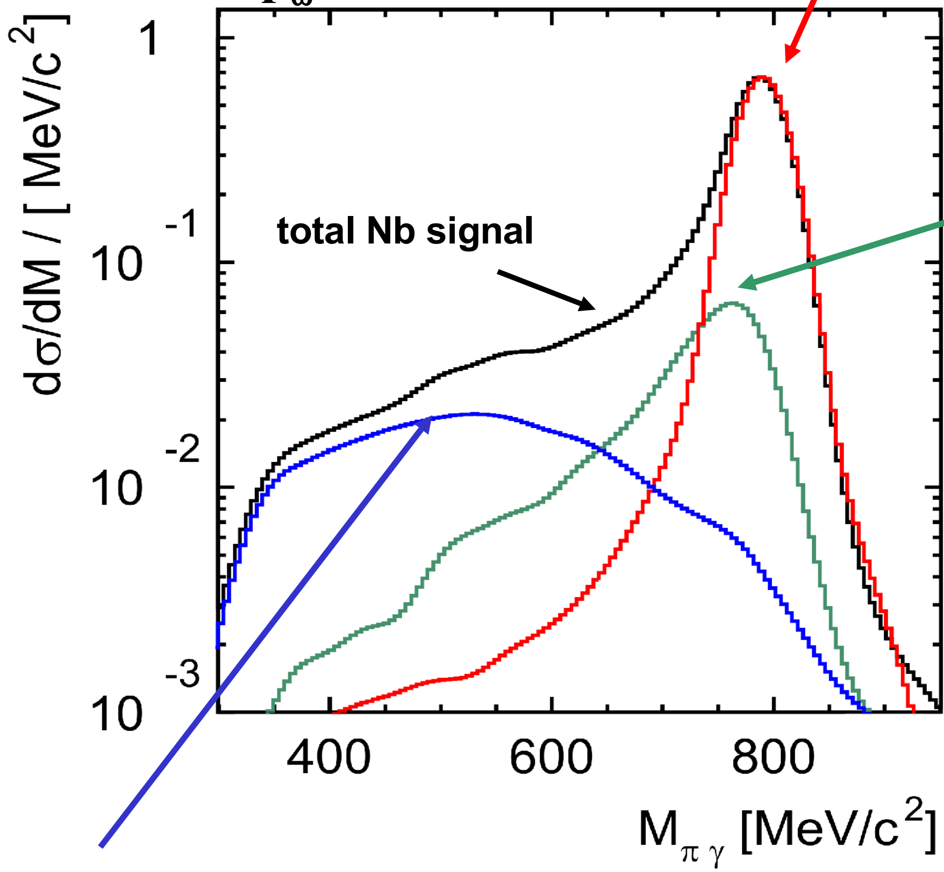
hadronic spectral function: $R(s) \sim F^2 \frac{1}{\pi} \frac{\sqrt{s}\,\Gamma(s)}{(s - M_\rho{}^2)^2 + s(\Gamma(s))^2}$

BUU calculation of $\gamma A \rightarrow \omega + X$

P. Mühlich (Gießen), priv. comm. (2005)

$E_\gamma < 2.5$ GeV,
$p_\omega < 500$ MeV/c

LH$_2$ reference



in-medium decays
⇒ peak around 750 MeV

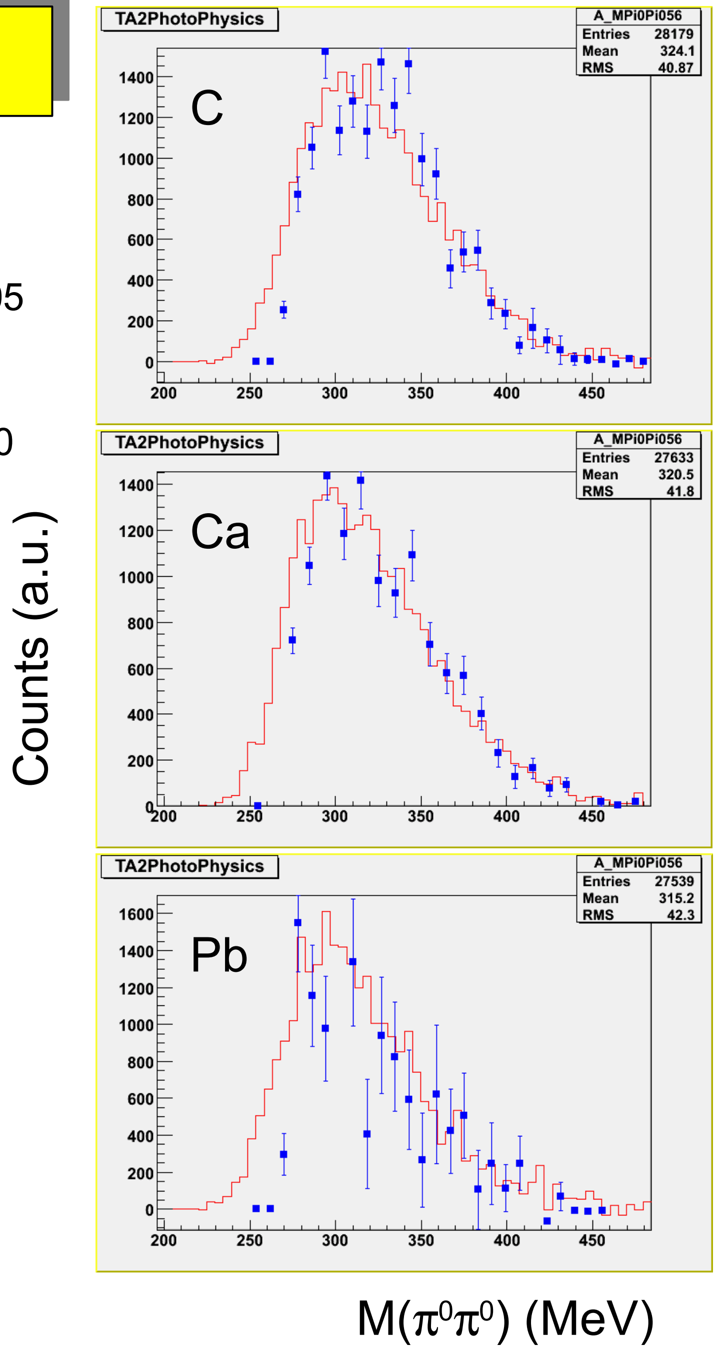
FSI distorted events
⇒ peak around 500 MeV

A (γ,$\pi^0\pi^0$)

red curve:
CB/TAPS@MAMI 05

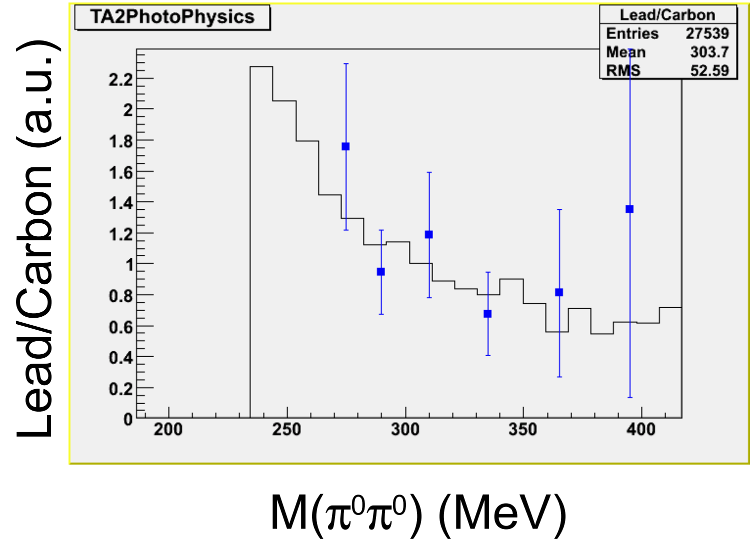
blue points:
TAPS@MAMI 99/00

E_γ = 400-500 MeV



Ralf Gregor
Stefan Lugert

E_γ = 400-500 MeV

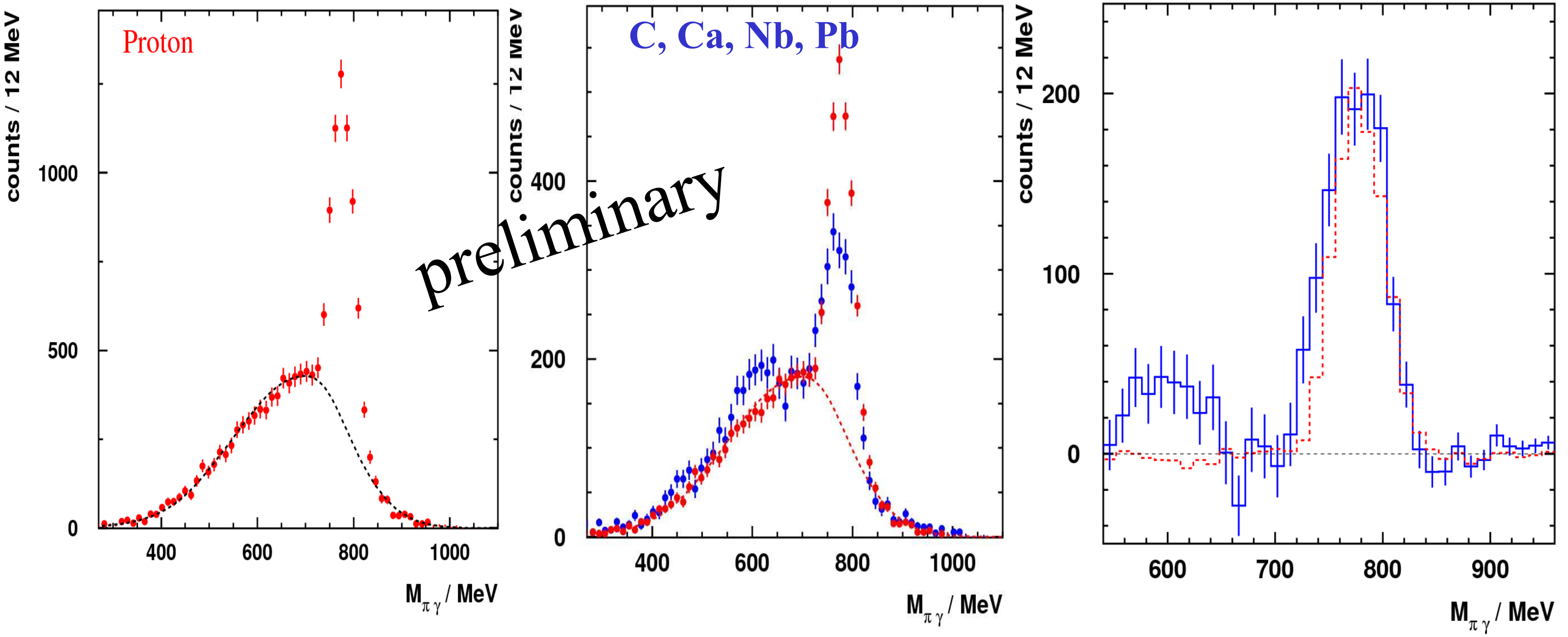


<- Old statistic ~ 150 datapoints
New statistic ~ 9000 datapoints
->improvement by a factor of >60

refined analysis requiring recoil proton and p-ω coplanarity

after LH_2 background subtraction

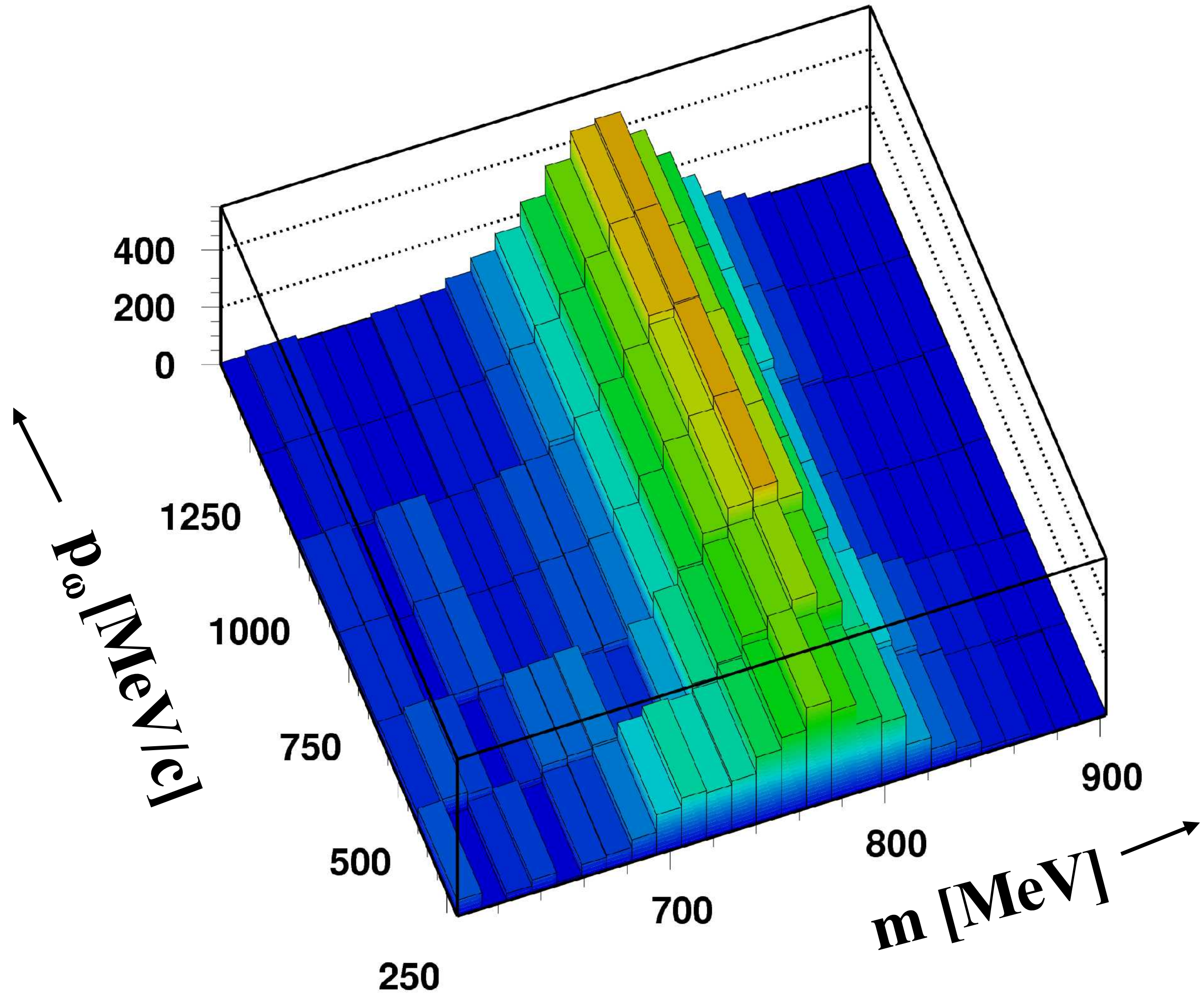
No background subtraction!!!



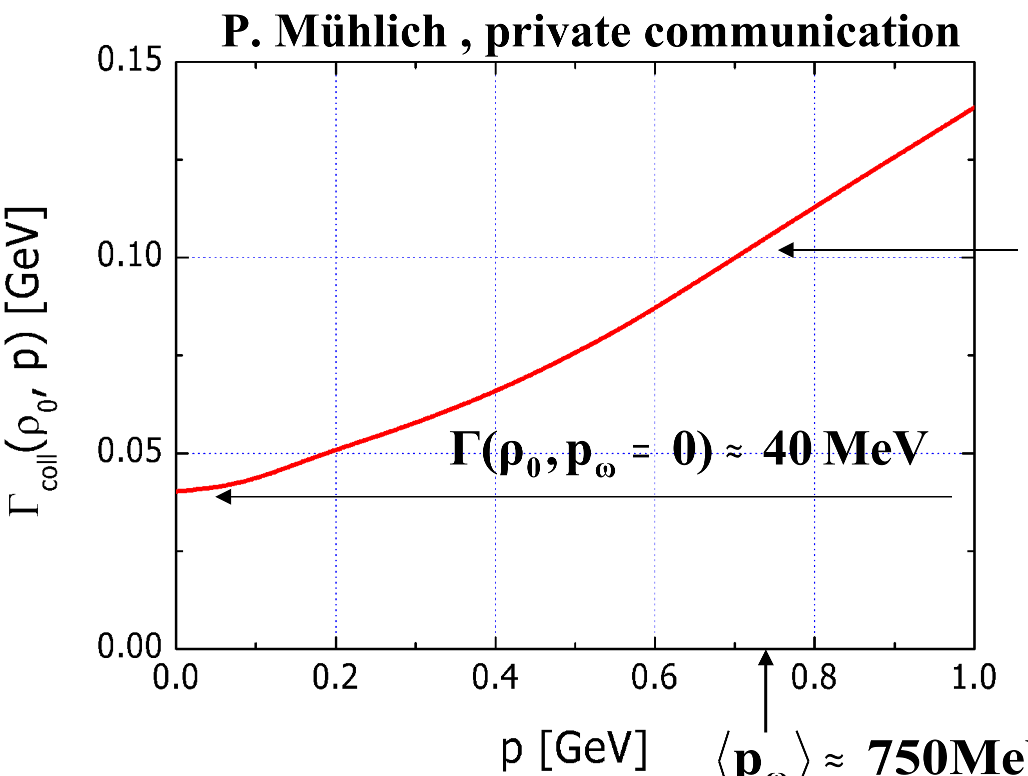
additional structure at ≈ 600 MeV!!

fragmentation of ω strength or background ???

In-medium spectral function of the ω-meson



dependence of ω width on ω momentum



$\Gamma(\rho_0, p_\omega = 750\,\text{MeV/c}) \approx 100\,\text{MeV}$

$\langle p_\omega \rangle \approx 750\text{MeV/c}$

taking the momentum dependence of the ω width into account,both analyses agree:

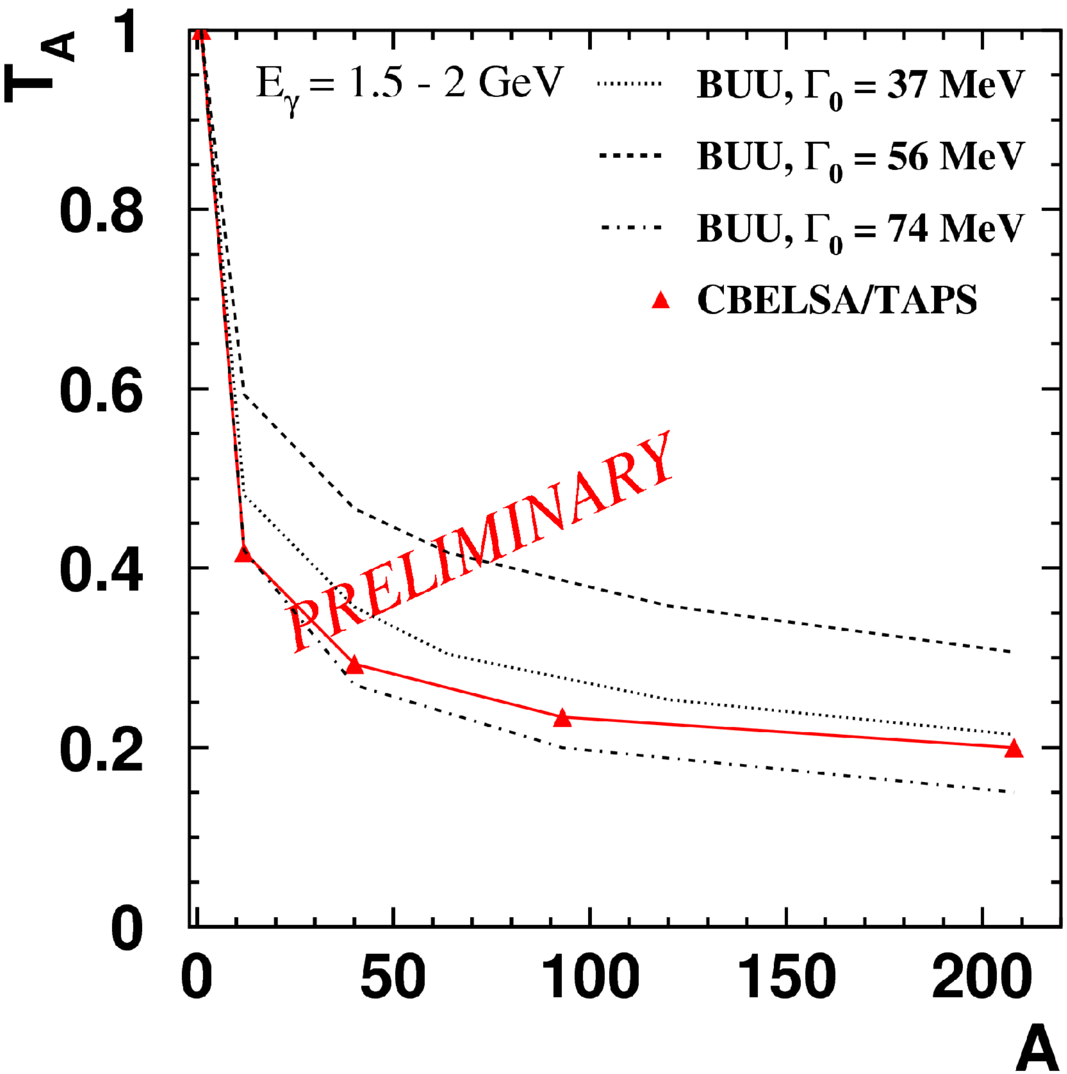
$\Gamma(\rho_0, p_\omega = 750\,\text{MeV/c}) \approx 100\,\text{MeV}$

- **ω gets broadened in the medium by a factor 10!!**
- **transparency ratio measurement also possible for charmed mesons in the nuclear medium ⇒ $\sigma_{inel}(p) \sim \Gamma(p)$; (J/ψ-suppression in AA collisions)**
- **experimental problem: luminosity $L \sim A^{-2/3}$ (for Au factor 30 !!)**

$\bar{p}$ - loss due to single Coulomb scattering $\sim Z^2$

access to in-medium ω width

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



transparency ratio:

$$T_A = \frac{\sigma_{\gamma A \rightarrow \omega X}}{A \cdot \sigma_{\gamma N \rightarrow \omega X}}$$

data: D. Trnka (CBELSA/TAPS)

transport calculation: P. Mühlich (Giessen)

$\Gamma \approx$ **60 MeV at** $\rho = \rho_0$

- need measurement on d for normalization
- need better statistics to separate coherent ω production

Prediction of ω mesic states

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

		$(\varepsilon_{nl}, \Gamma_{nl})$ [MeV]		
nucleus	n	$l = 0$	$l = 1$	$l = 2$
$^{6}_{\omega}\mathrm{He}$	(1)	$(-49, 36)$	$(-18, 33)$	–
$^{11}_{\omega}\mathrm{B}$	(1)	$(-66, 41)$	$(-40, 39)$	$(-13, 37)$
	(2)	$(-14, 34)$	–	–
$^{39}_{\omega}\mathrm{K}$	(1)	$(-88, 44)$	$(-73, 45)$	$(-57, 45)$
	(2)	$(-54, 45)$	$(-36, 44)$	$(-17, 44)$
	(3)	$(-16, 41)$	–	–

Prediction of ω mesic states in QMC and QHD models

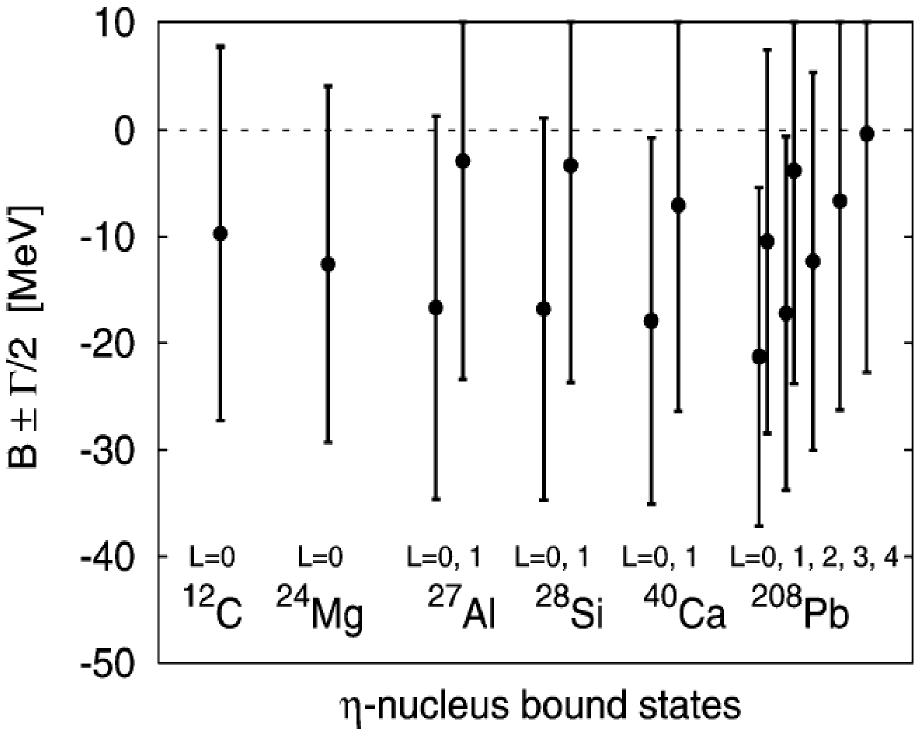
K. Saito, K. Tsushima, A.W. Thomas, hep-ph/0506314

		$\Gamma^0_\eta = 0$, $\gamma_\eta = 0.5$ (QMC)		$\Gamma^0_{\eta'} = 0$ (QMC)	$\Gamma^0_\omega = 8.43$ (MeV), γ_ω=0.2 (QMC)		$\Gamma^0_\omega = 8.43$ (MeV), $\gamma_\omega = 0.2$ (QHD)	
		E_η	Γ_η	$E_{\eta'}$	E_ω	Γ_ω	E_ω	Γ_ω
^6_jHe	1s	-10.7	14.5	*	-55.6	24.7	-97.4	33.5
$^{11}_j$B	1s	-24.5	22.8	*	-80.8	28.8	-129	38.5
$^{26}_j$Mg	1s	-38.8	28.5	*	-99.7	31.1	-144	39.8
	1p	-17.8	23.1	*	-78.5	29.4	-121	37.8
	2s	—	—	*	-42.8	24.8	-80.7	33.2
$^{16}_j$O	1s	-32.6	26.7	-41.3	-93.4	30.6	-134	38.7
	1p	-7.72	18.3	-22.8	-64.7	27.8	-103	35.5
$^{40}_j$Ca	1s	-46.0	31.7	-51.8	-111	33.1	-148	40.1
	1p	-26.8	26.8	-38.5	-90.8	31.0	-129	38.3
	2s	-4.61	17.7	-21.9	-65.5	28.9	-99.8	35.6
$^{90}_j$Zr	1s	-52.9	33.2	-56.0	-117	33.4	-154	40.6
	1p	-40.0	30.5	-47.7	-105	32.3	-143	39.8
	2s	-21.7	26.1	-35.4	-86.4	30.7	-123	38.0
$^{208}_j$Pb	1s	-56.3	33.2	-57.5	-118	33.1	-157	40.8
	1p	-48.3	31.8	-52.6	-111	32.5	-151	40.5
	2s	-35.9	29.6	-44.9	-100	31.7	-139	39.5

Search for η mesic states in heavier nuclei

C. Garcia-Recio et al., PLB 550 (2002) 47

unitarized chiral model



preferably only 1s-state

^{24}Mg: B=12.6 MeV; Γ=33 MeV

experiment at COSY (ENSTAR/Big-Karl):

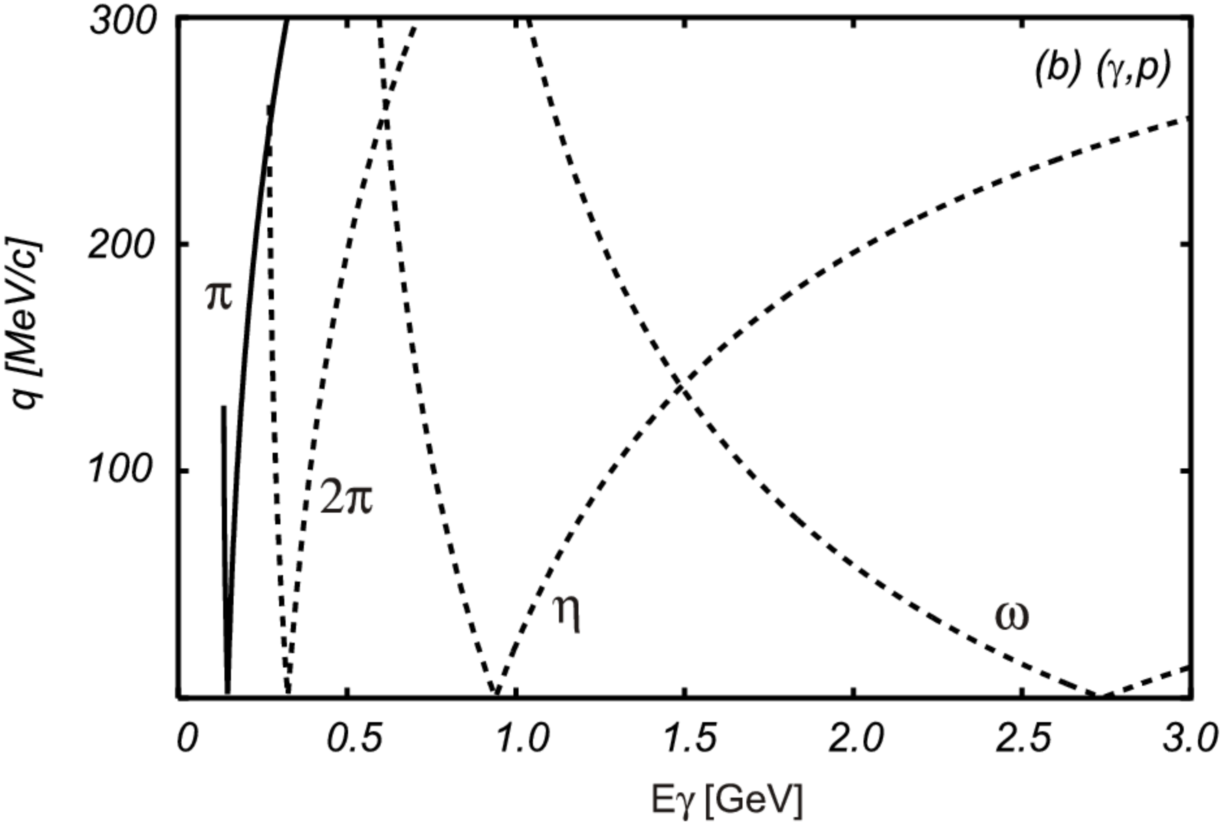
Roy et al. : p ^{12}C $\rightarrow$ ^{3}He + $_{\eta}{}^{10}$B; p ^{6}Li $\rightarrow$ ^{3}He + $_{\eta}{}^{4}$He

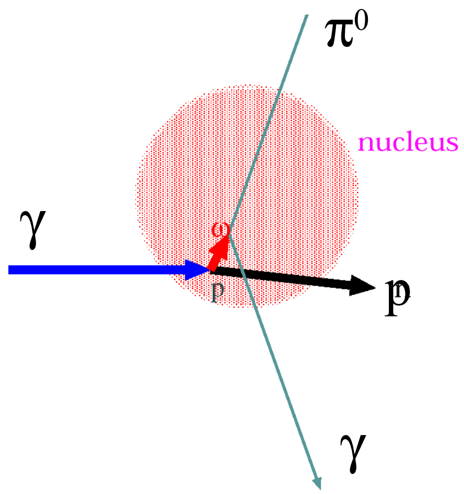
experiment at GSI:

Hayano et al., EPJ A6 (1999) 105; ^{7}Li(d,^{3}He)$_{\eta}{}^{6}$He; T_d = 3.6GeV

meson-nucleus bound states – recoilless meson photo production

forward going nucleon takes over photon momentum



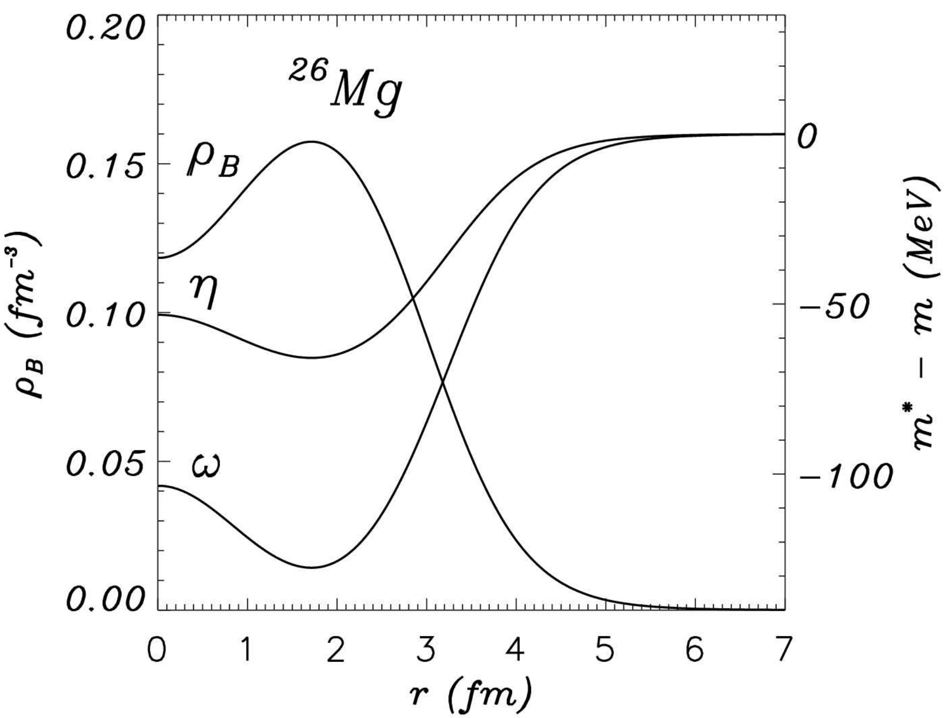


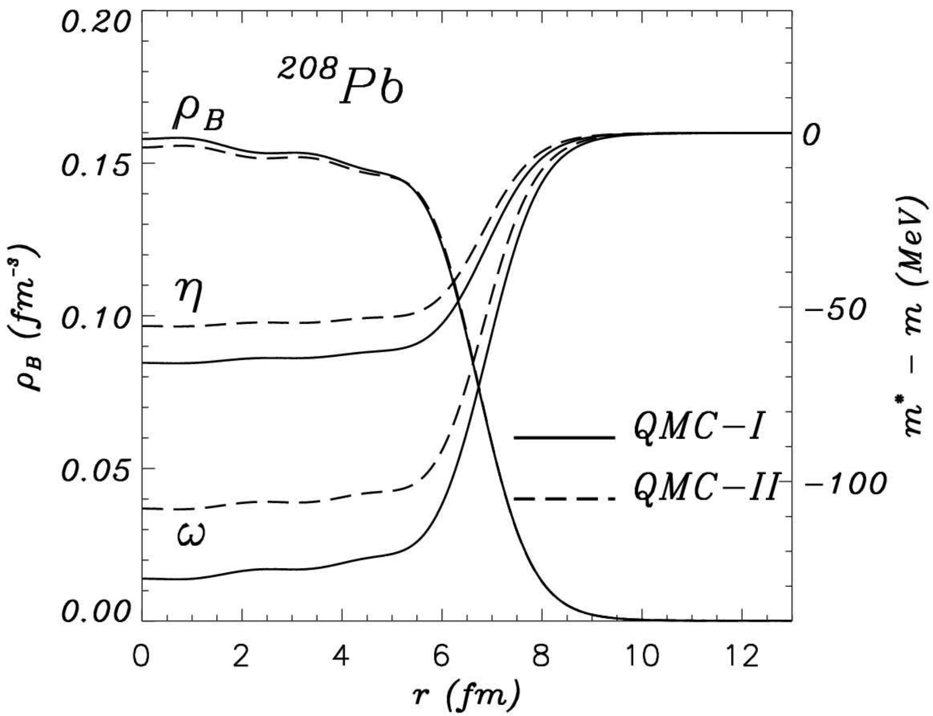
Magic incident energies η: $E_\gamma \approx$ 930 MeV, ω: $E_\gamma \approx$ 2750 MeV } (ELSA)

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

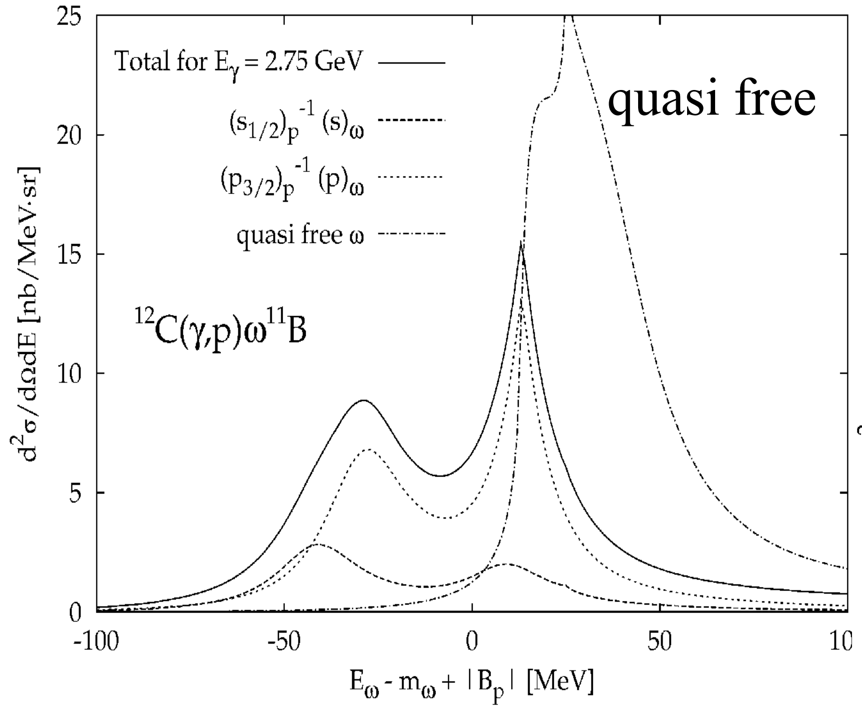
Search for ω-mesic nuclei

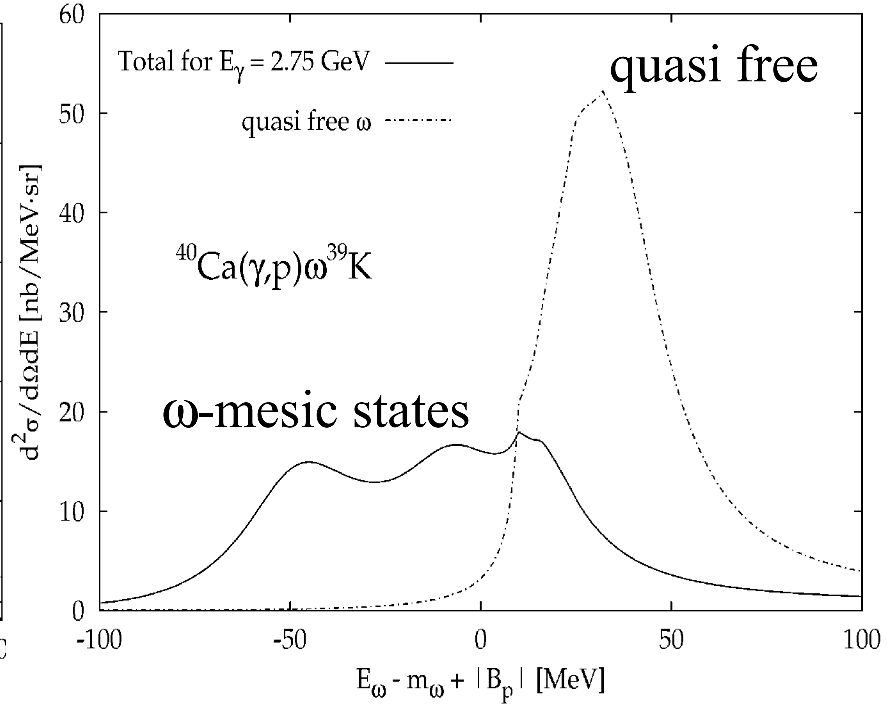
formation of ω-mesic nuclei in recoil-less quasi-free production:

magic energy: E_γ= 2.75 GeV;

forward going proton takes over photon momentum

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

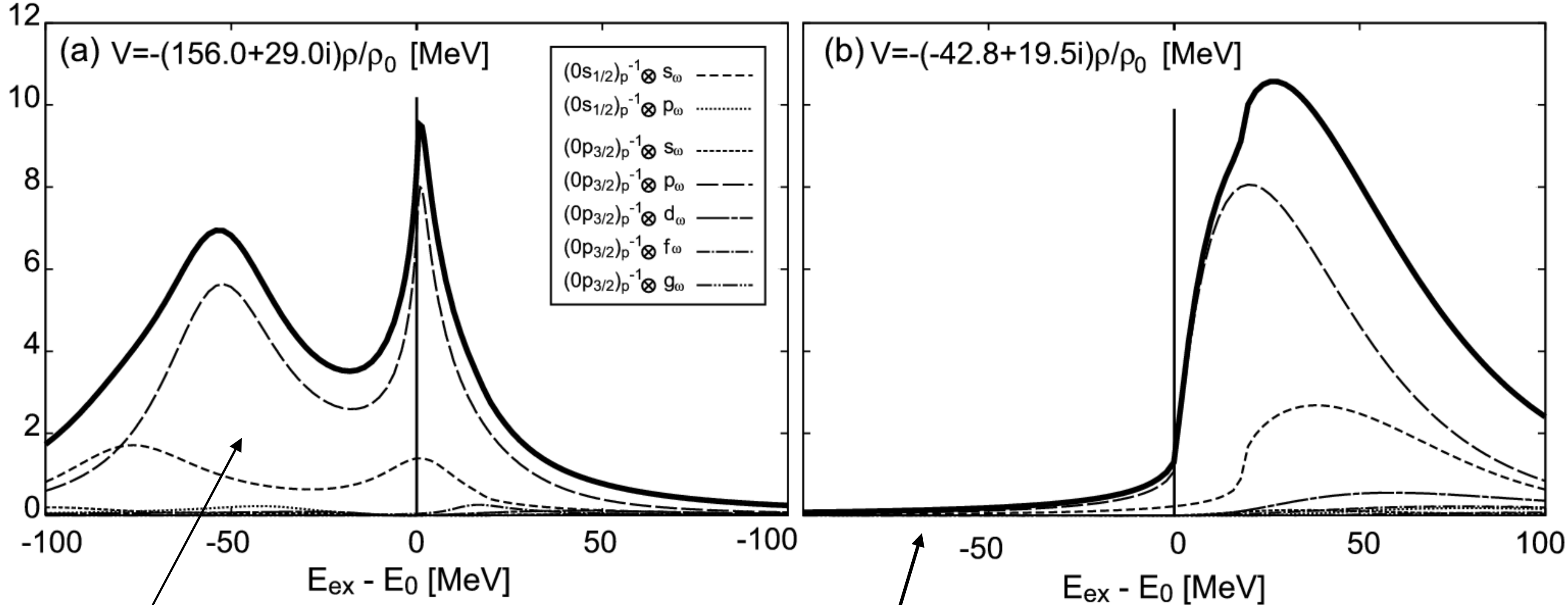




Predictions for different ω-nucleus potentials

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

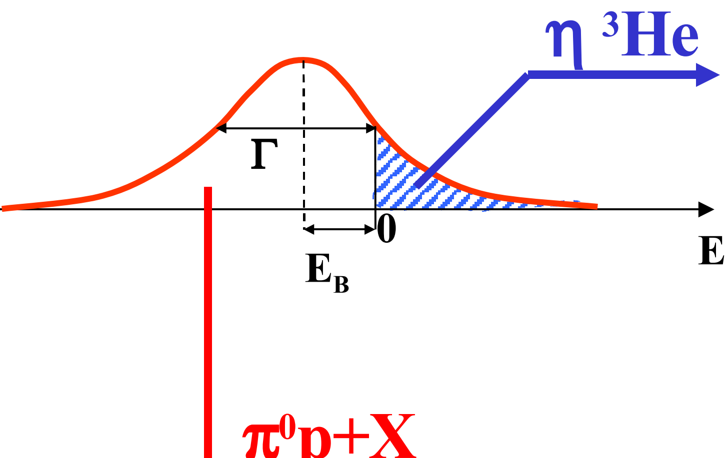
attractive potential **repulsive potential**

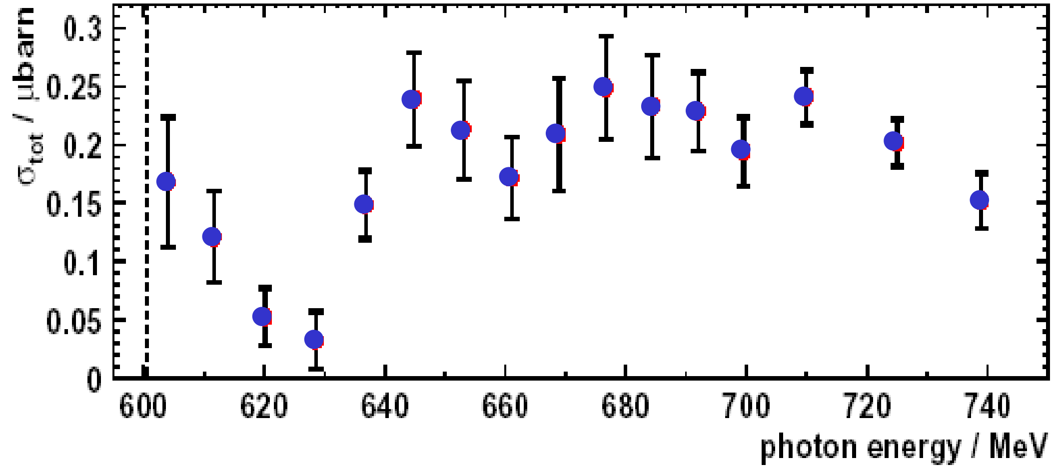


signature for ω - mesic states

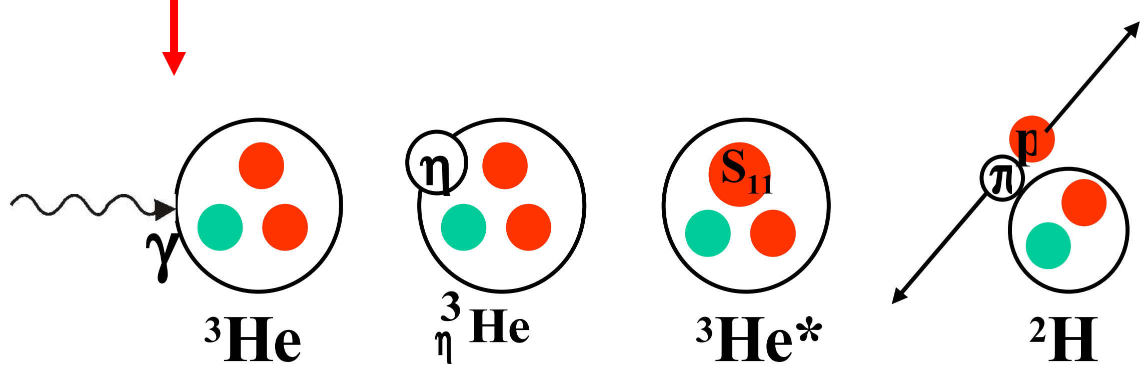
no intensity for negative energies

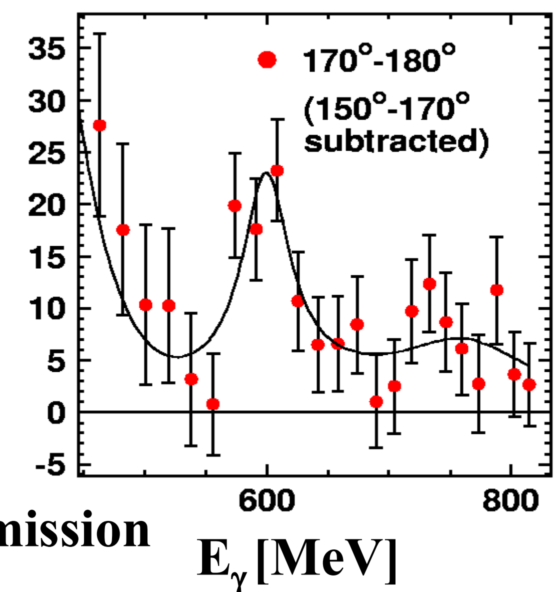
Decay of a bound η-mesic state: $^3_\eta He$





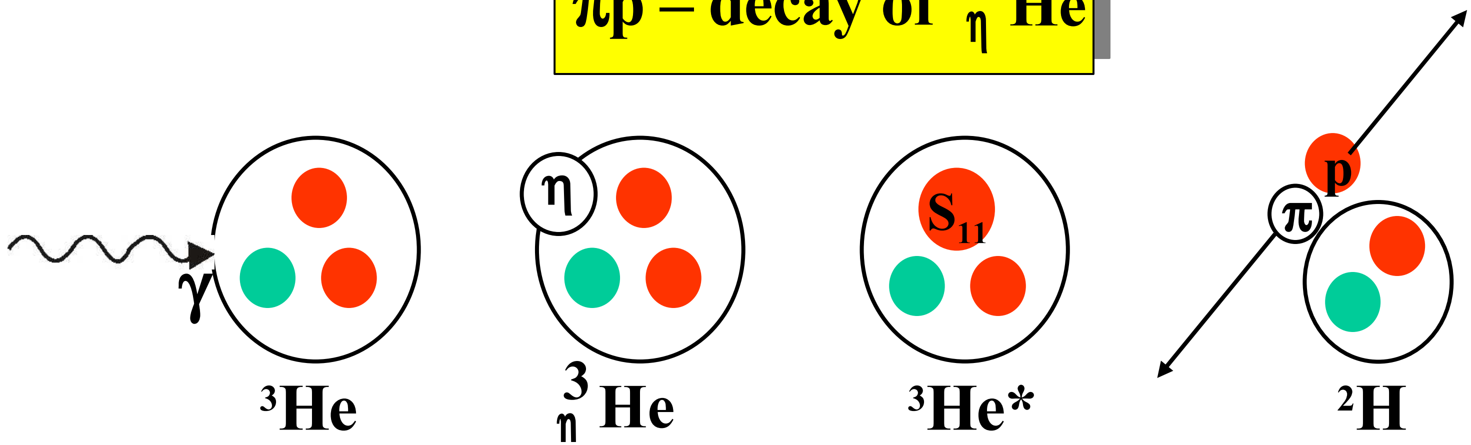
<u>**excitation function:**</u> **rise in cross section near threshold:**
η-mesic ^{3}He state ? (ηN-final state interaction?)

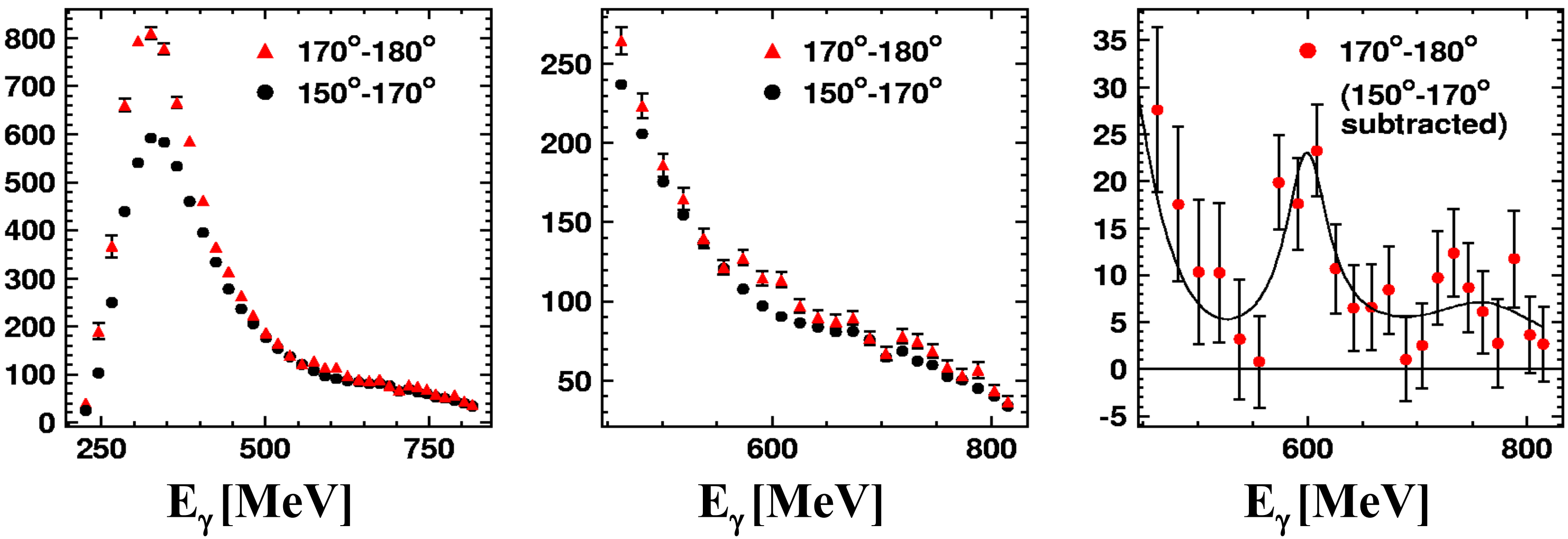




structure in excitation function for π^0 p back-to-back emission

πp – decay of $^{3}_{\eta}$He



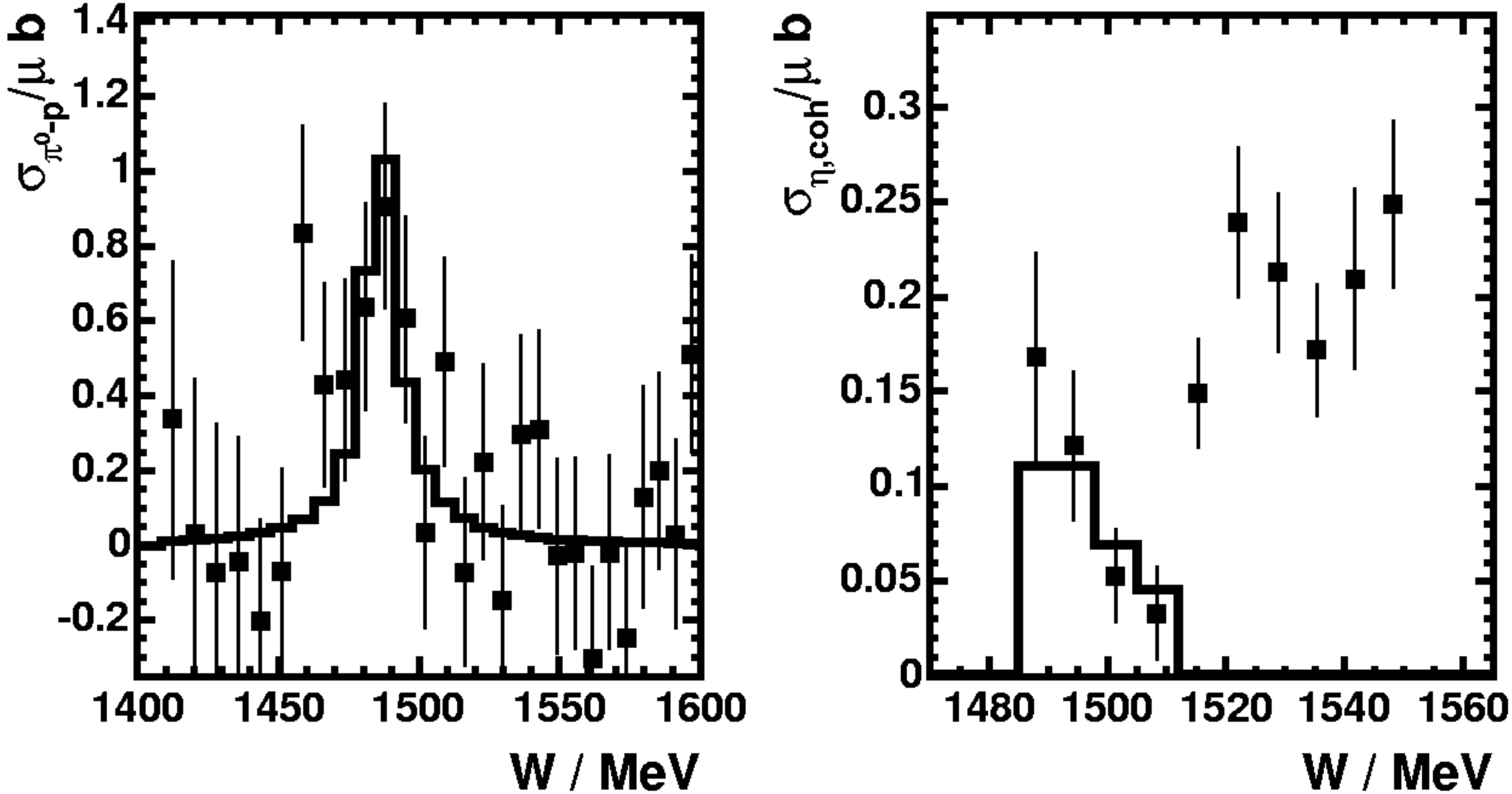


structure in excitation function of π^0p back-to-back emission near η-threshold: $B_\eta(^3$He$)= (5.5 \pm 5)$ MeV; $\Gamma = (39 \pm 21)$ MeV

Flatte fit to TAPS data

M. Pfeiffer et al., PRL 94 (2005)

finer energy binning



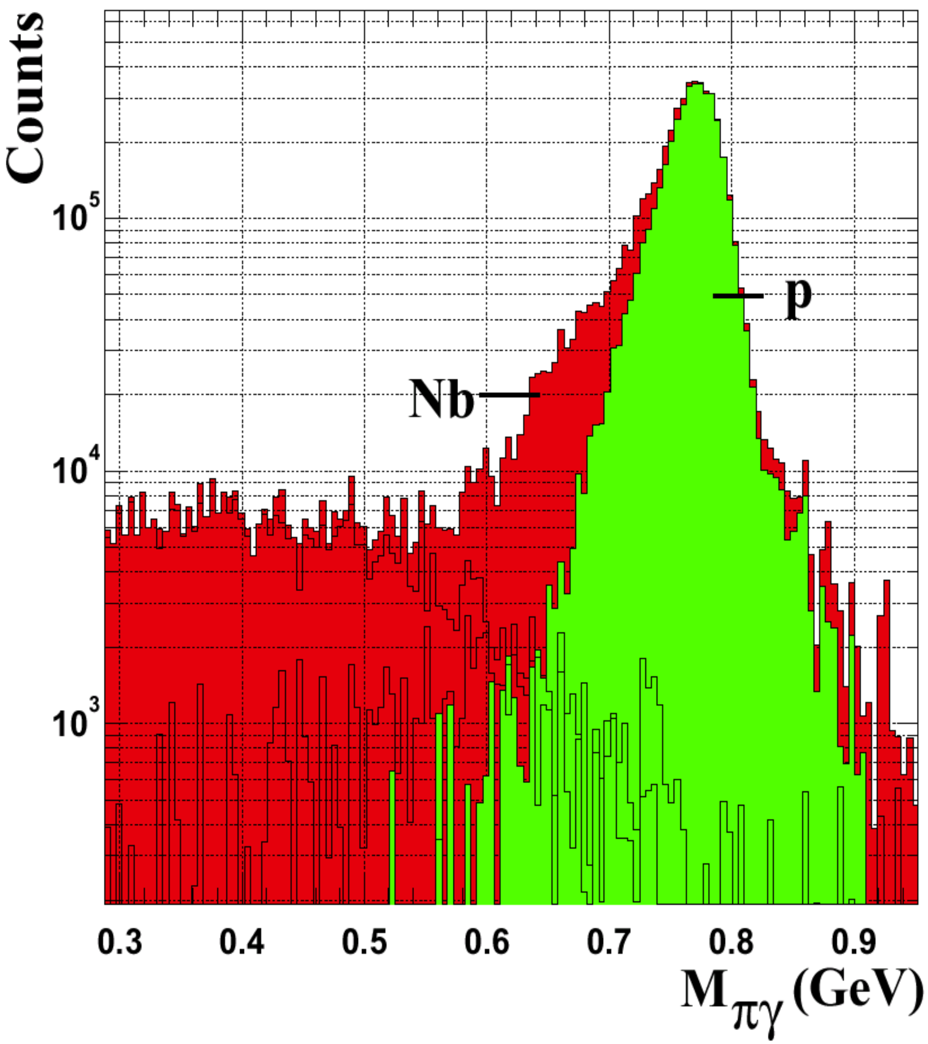
$$\sigma_{fi} = \left(\frac{16\pi}{s}\right)\left(\frac{\rho_f}{\rho_i}\right)\left|\hat{T}_{fi}\right|^2 \qquad \hat{T}_{p\pi^0,\eta} = \frac{m_0\Gamma_0 \cdot A_{\pi^0,\eta}}{m_0^2 - m^2 - im_0\left(\rho_{p\pi^0}\Gamma_0\gamma^2_{p\pi^0} + \rho_{p\eta}\Gamma_0\gamma^2_{p\eta}\right)}$$

2 poles: m-$i\Gamma/2$ = (1487.7-i4.8) MeV; (1483.9-i8.9) MeV

expected mass distribution for p, Nb

(including detector resolution and $2\pi^0$ background)

$\gamma + (p, Nb) @ 1.2$ GeV



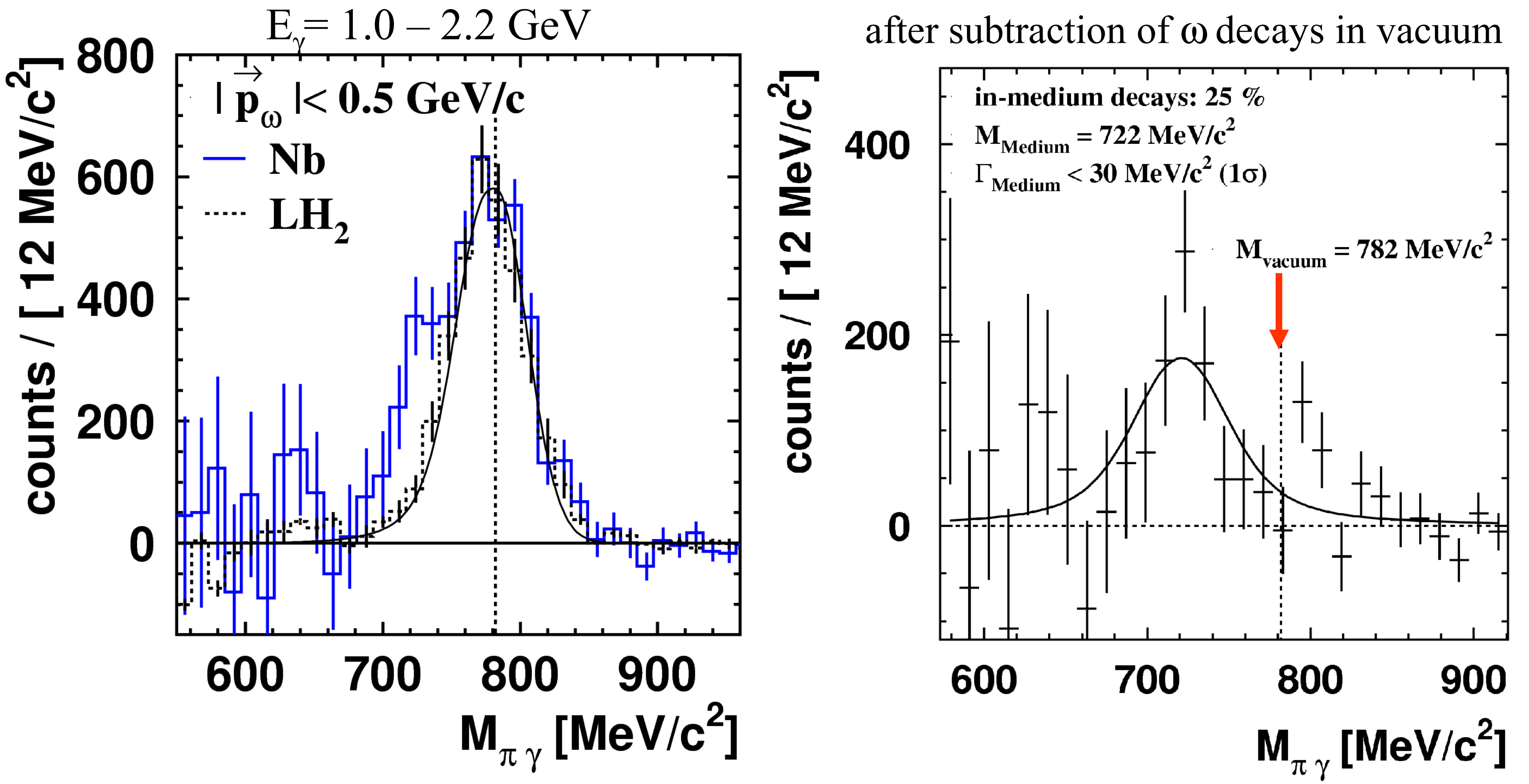
after cut on π^0 kinetic energy

within $0.6 < M_{\pi^0\gamma} < 0.8$:

outside	**76%**
inside no π^0-rescat.	**22%**
inside π^0-rescat.	**1%**
double-π^0	**1%**

First observation of in-medium modifications of the ω-meson

D. Trnka et al., PRL 94 (2005) 192303; experiment at ELSA

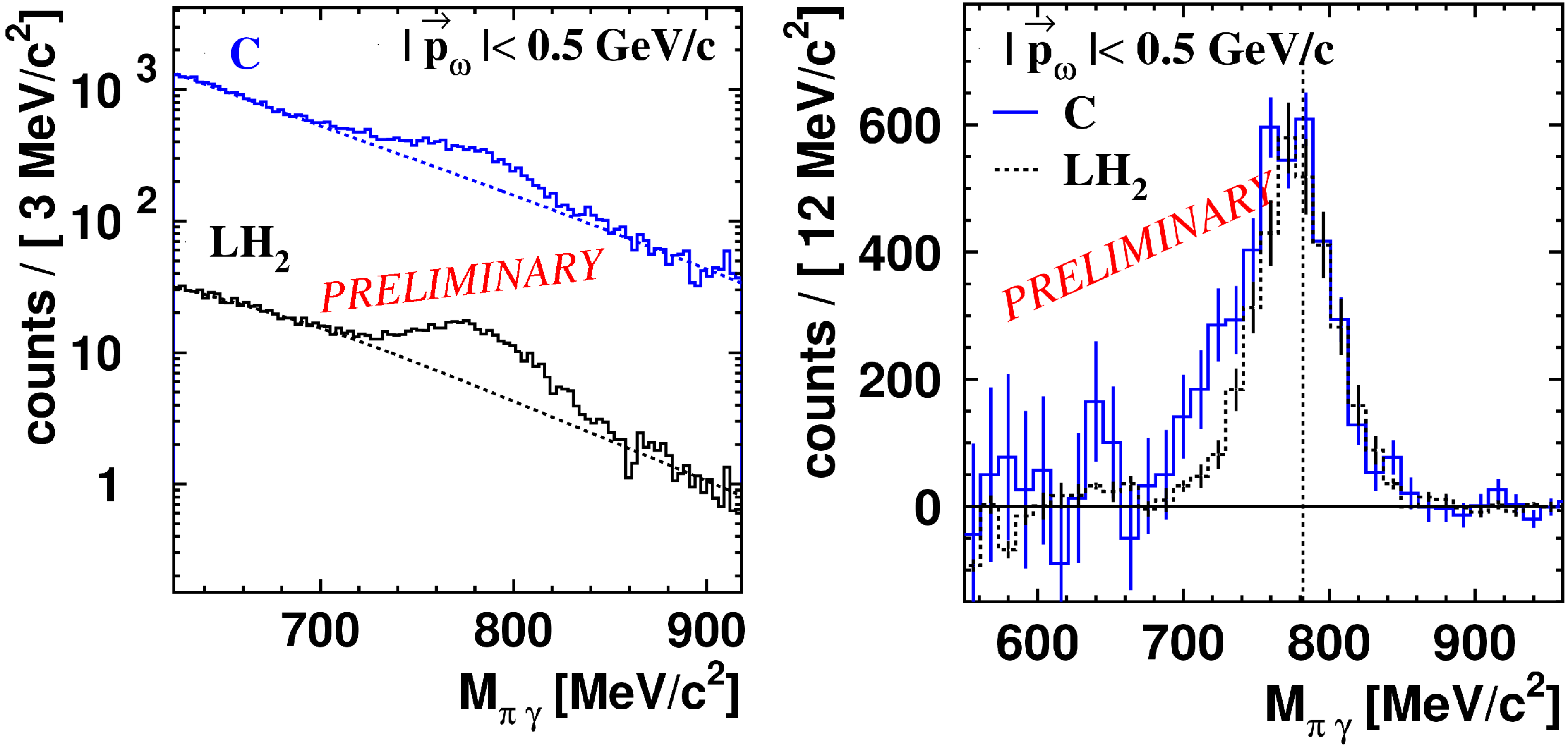


ω in-medium mass: 720^{+35}_{-5} MeV/c² consistent with $m_\omega = m_0\,(1 - 0.14\,\rho/\rho_0)$

Open questions: 1.) in-medium ω width? 2.) structure at 630 MeV/c² ?

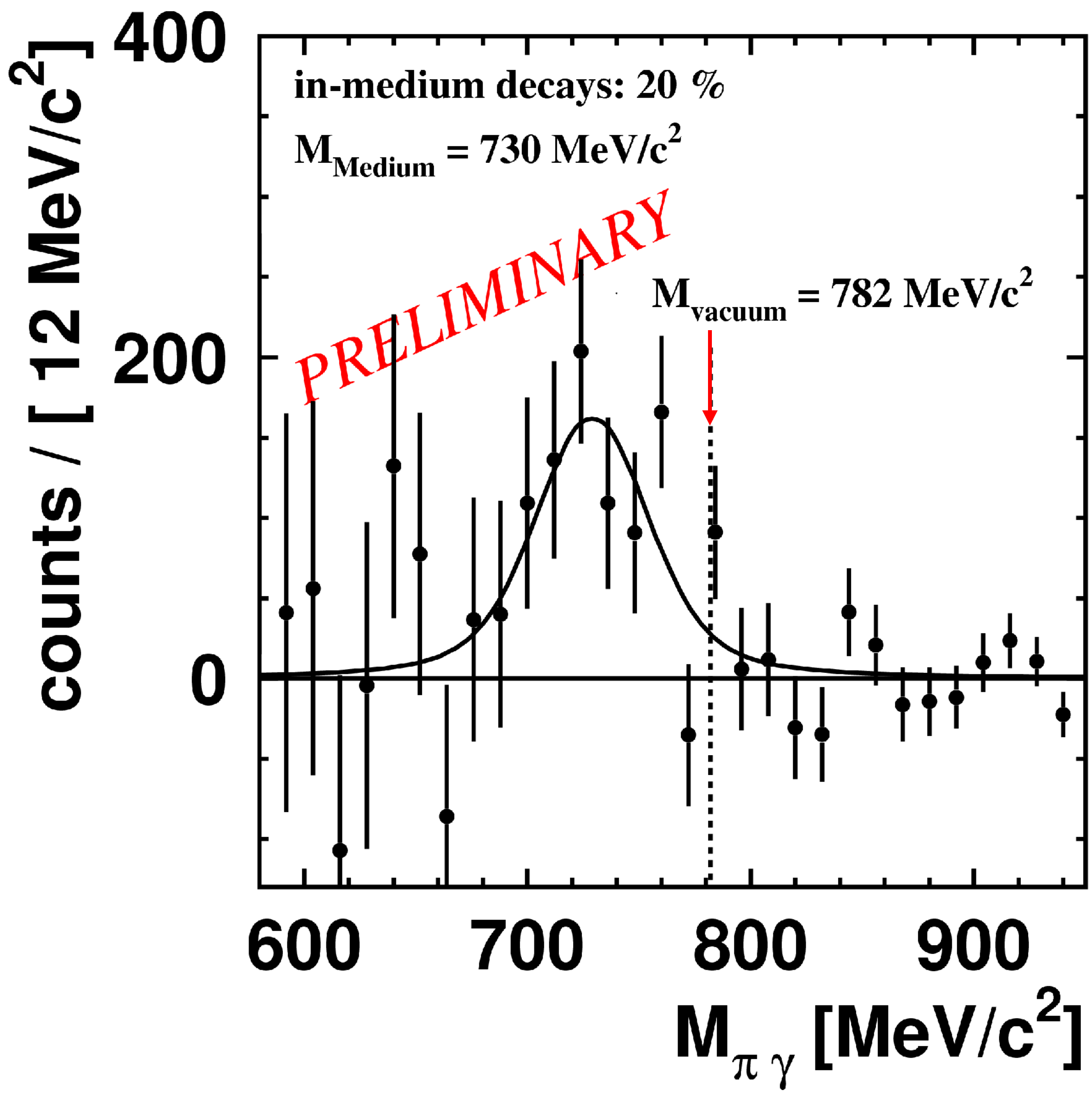
ω photo production off C and LH_2

David Trnka (Giessen) et al.



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

contribution from ω in-medium decays (C-target)



In-medium ω-signal after subtracting vacuum decay contribution (80%)

ω in-medium strength centered around 730 MeV

⇒ mass drop by about 6% at estimated baryon density of about 0.45 ρ_0

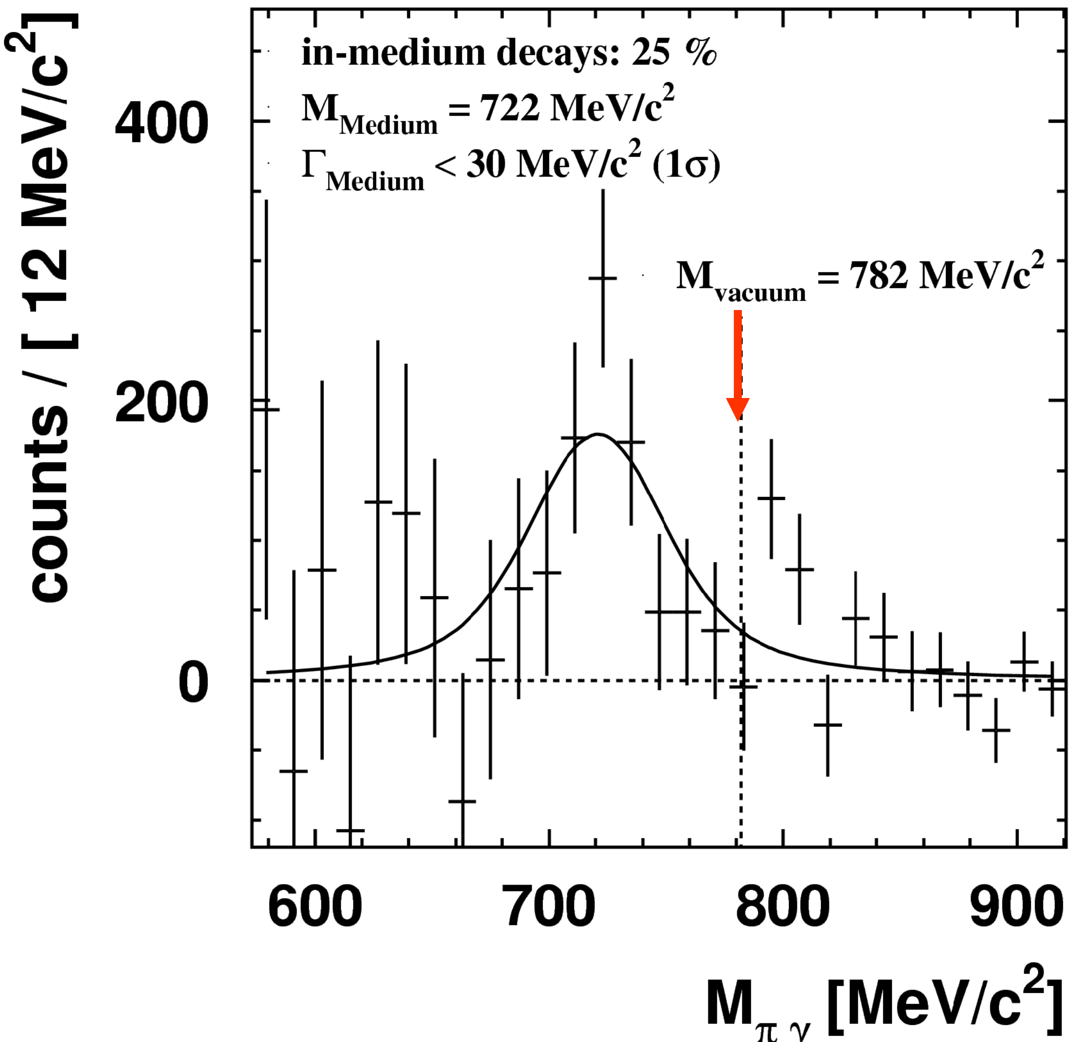
consistent with

$m_\omega = m_0 (1 - \alpha\, \rho/\rho_0)$;

for $\alpha = 0.14$

contribution from ω in-medium decays

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



ω decays in vacuum removed by subtracting ω mass distribution measured with LH_2 target (75%)

strength of in-medium ω decays concentrated around masses of 720 MeV (systematic error due to normalization: +35, -5 MeV)

⇒ mass drop by about 7% at estimated baryon density of about 0.55 ρ_0

width governed by experimental resolution!

consistent with

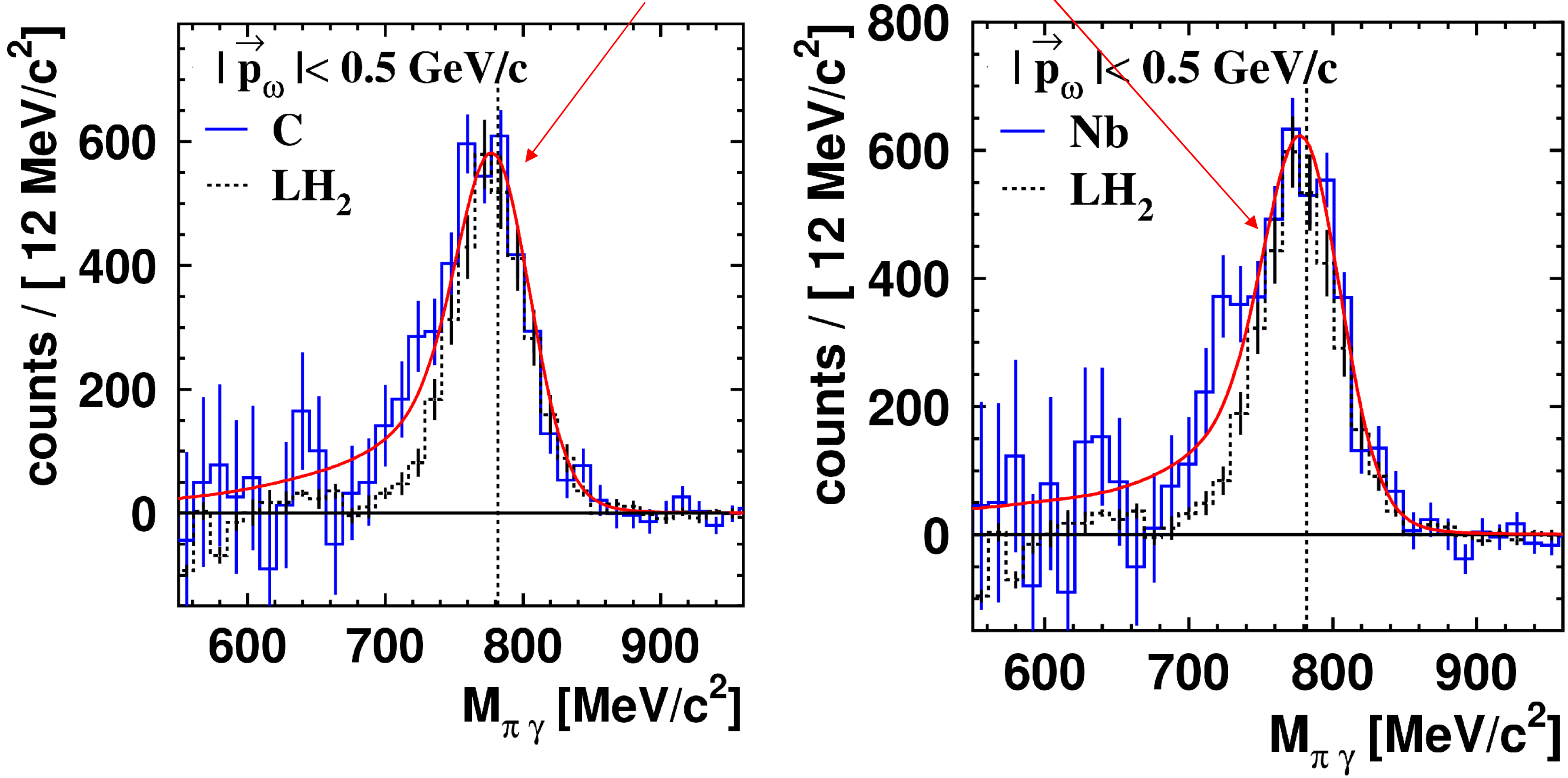
$m_\omega = m_0 (1 - \alpha \rho/\rho_0)$;

for $\alpha = 0.14$

Comparison with BUU calculations

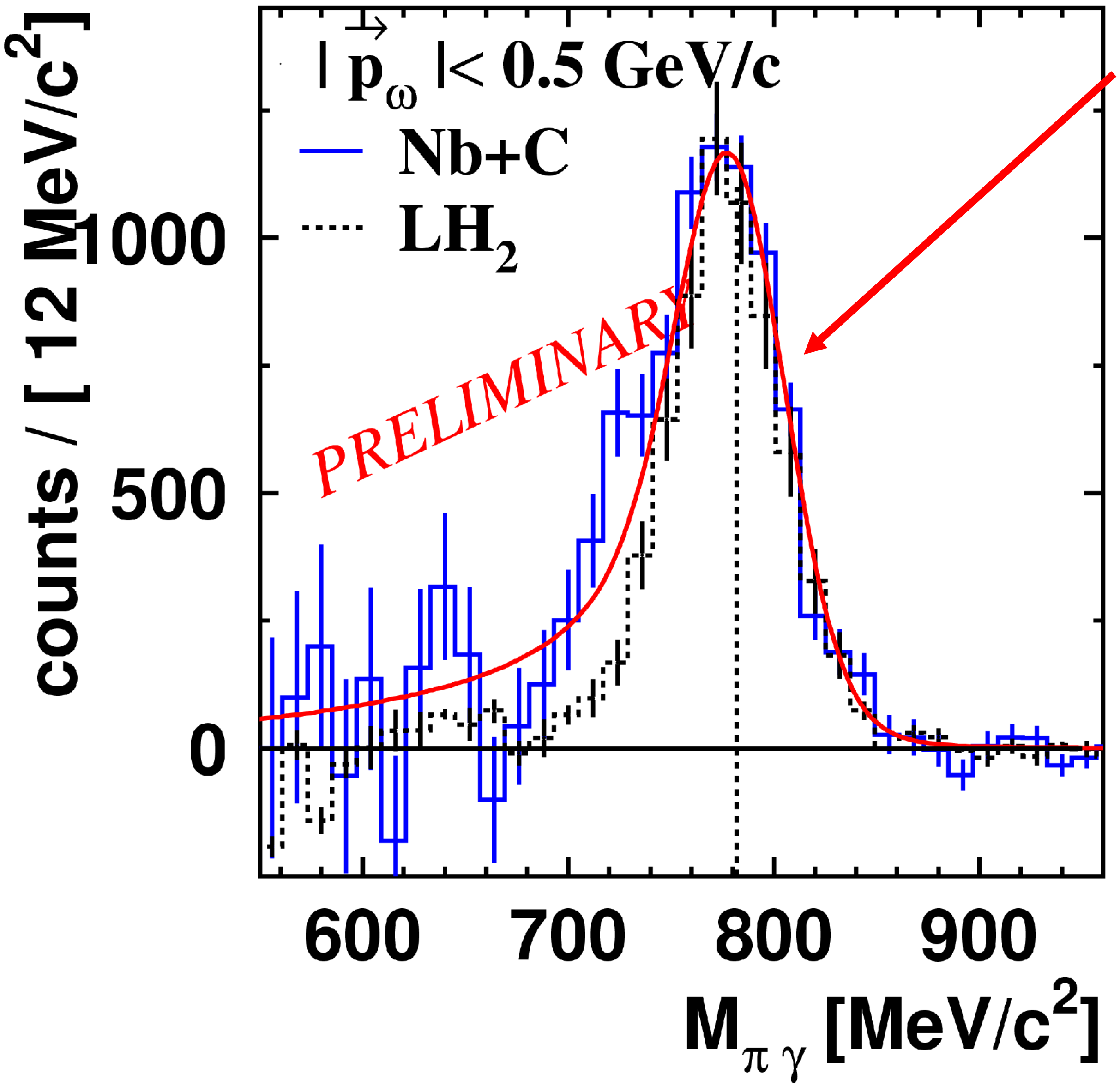
P. Mühlich (Giessen) priv. communication

$m_\omega = m_0 (1 - 0.16\, \rho/\rho_0)$;



almost quantitative agreement between experiment and calculation

Summed spectra (C+Nb)

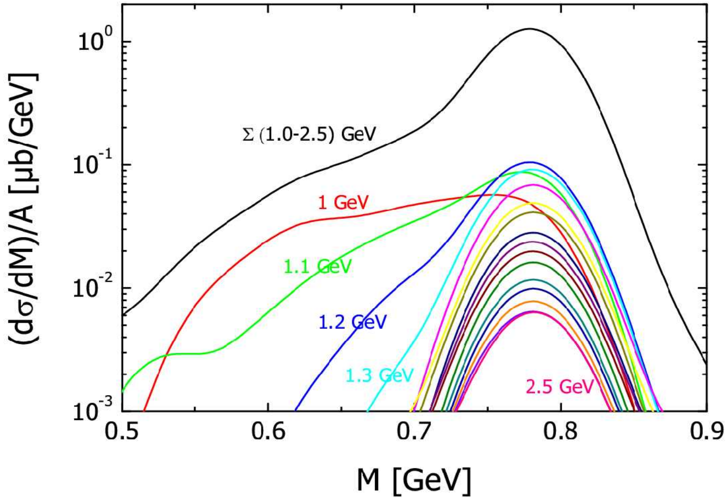


P. Mühlich (priv. comm.)

Structure around 640 MeV ?

important to clarify in view of theoretical predictions for structures in the in-medium spectral function of the ω meson

countrate estimate for improved 2nd. generation experiment at MAMI C (A2-1)



P. Mühlich (priv. com.)
most of the medium modifications occur for $E_\gamma \leq 1.3$ GeV
$\Rightarrow$ MAMI C

targets	p	d	C	Ca	Nb	Pb
photon flux (0.8-1.4 GeV) [10^6/s]	13	13	13	11	10	8
target thickness [cm]	5	5	2	1	0.1	0.06
running time [h]	50	50	100	100	400	500
number of events	17 000	34 000	20 000	10 000	20 000	4 500
effective number of events	7 000	14 000	3 600	1 500	3 600	450

Total requested runng time 1300 h (including 100 h of no-target runs)

countrate estimate
for 2nd. generation experiment at ELSA (E5)

for ω mesic nuclei

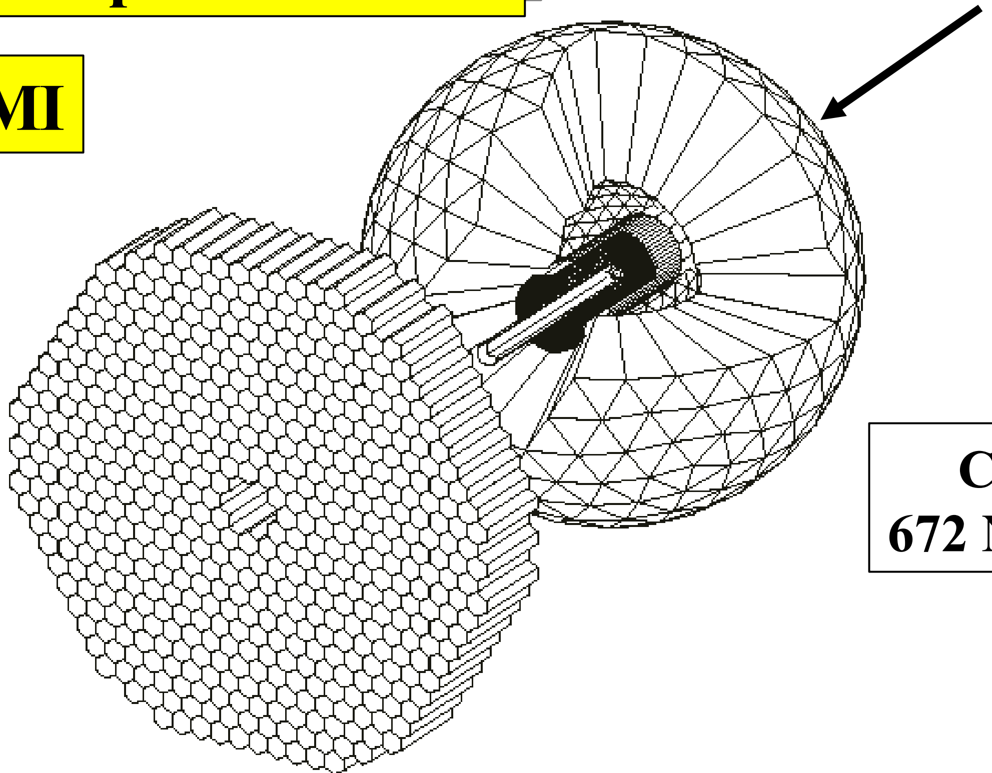
targets	C	Ca	Nb
photon flux (0.8-2.9 GeV) [10^6/s]	10	10	8
target thickness [cm]	2	1	0.1
running time [h]	200	300	500
number of events	300	300	300
effective number of events	150	120	100

- look for η-mesic nuclei in recoilless production
  around magic photon energy: $E_\gamma \approx 930$ MeV
  decay mode: $\eta N \rightarrow N\pi^0$ (back-to-back emission)

Total requested running time 1100 h (including no-target runs of 100 h)

Proposed setup for experiment A2-1

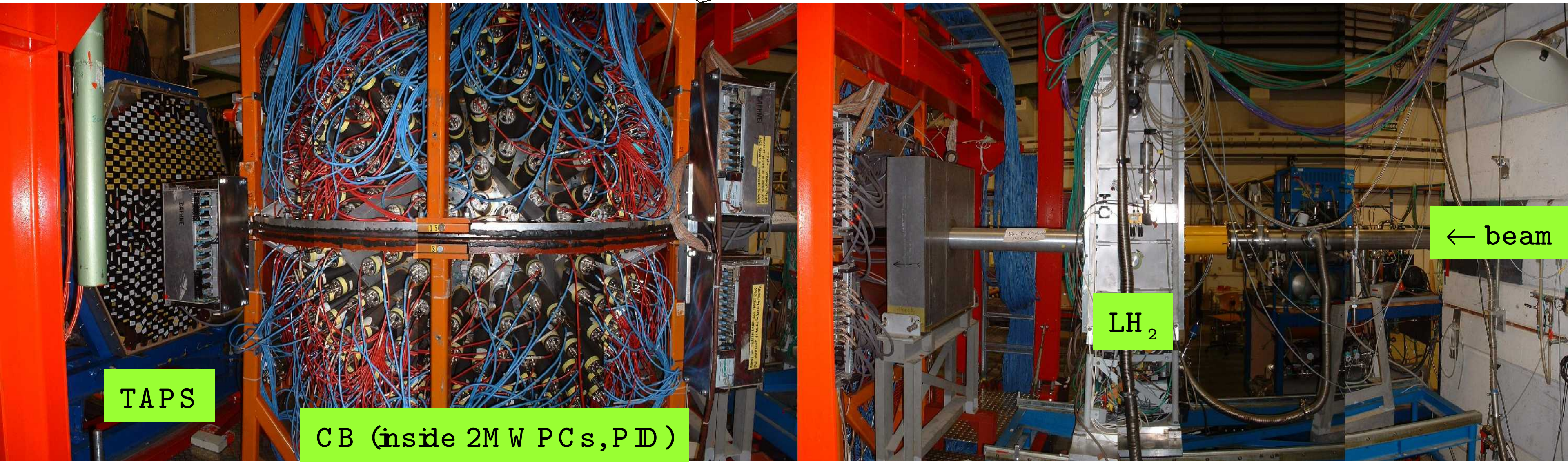
CB/TAPS@MAMI



γ-beam

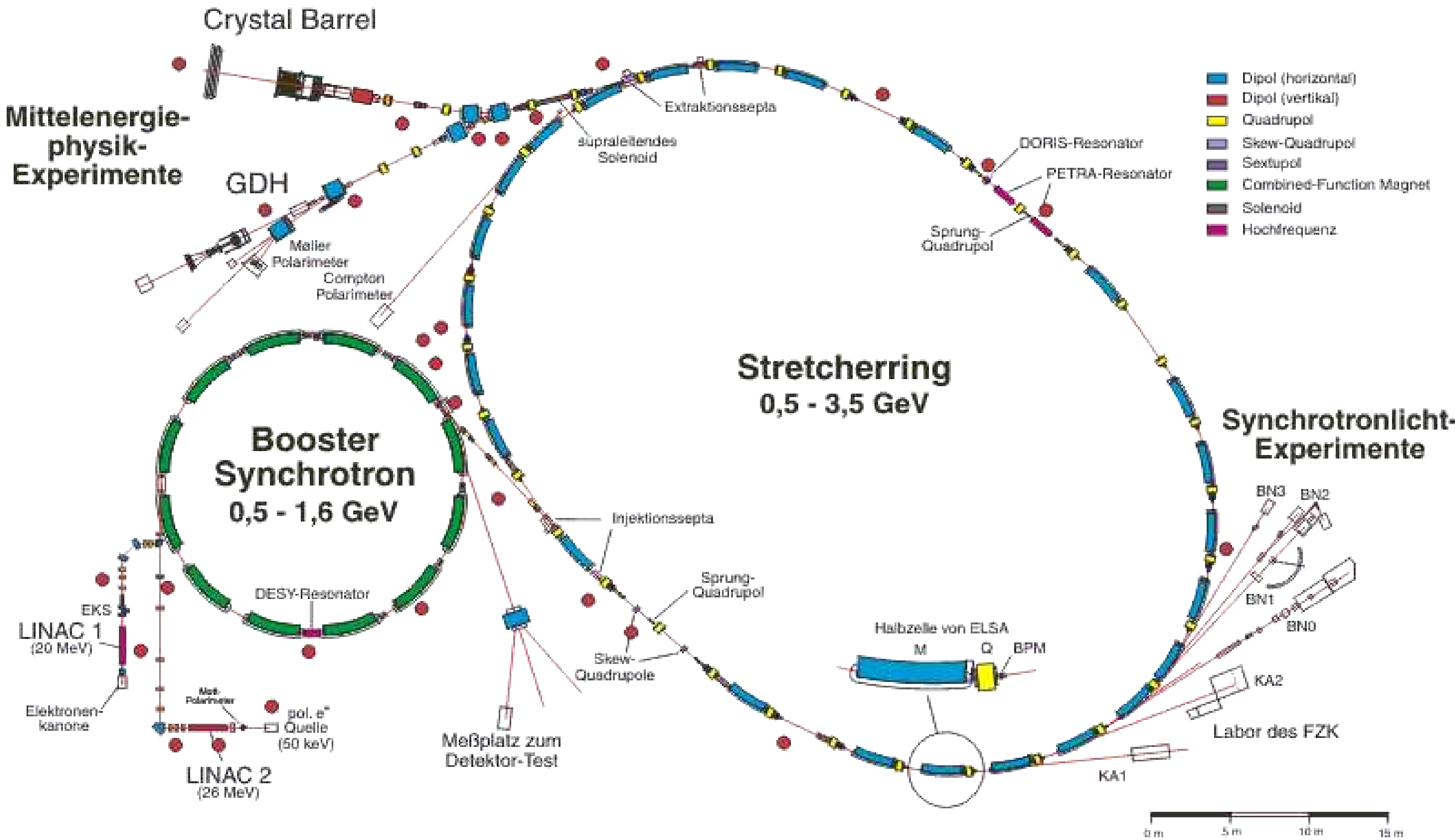
TAPS forward wall
384 BaF_2 modules
distance: 150 cm
angles: $1.1^0 – 20.0^0$

Crystal Ball
672 NaI - modules

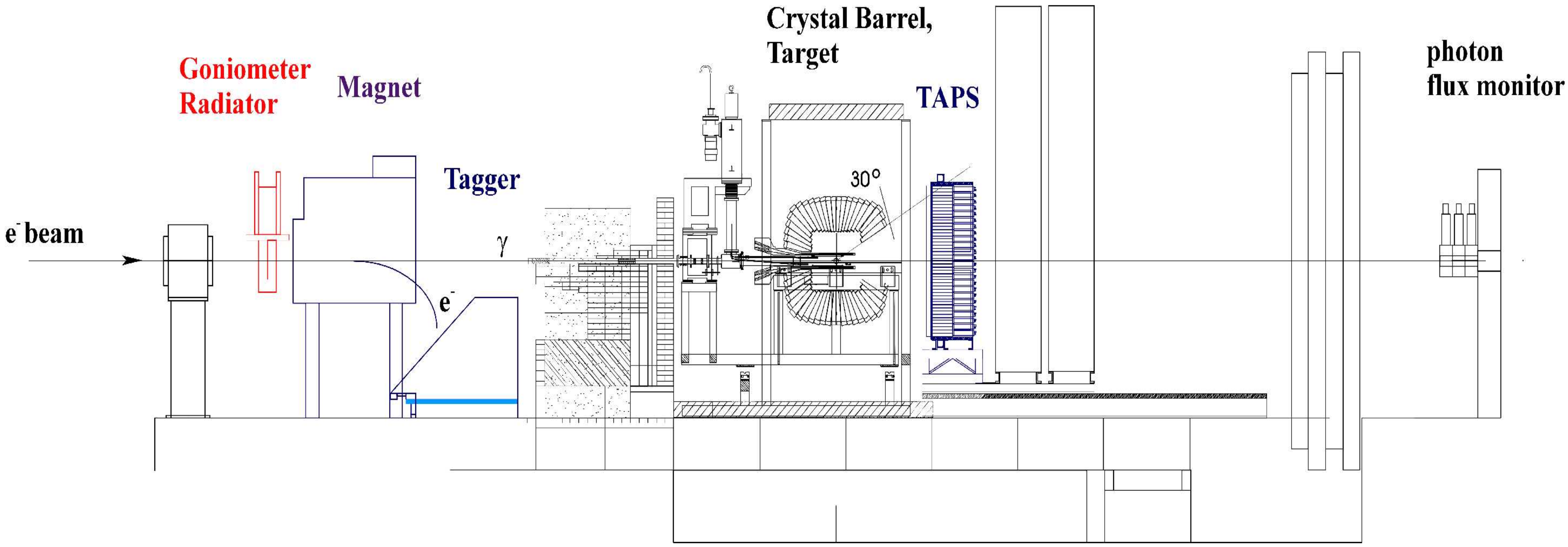


The accelerator facility ELSA at Bonn

ELSA = Elektron Strecher Anlage



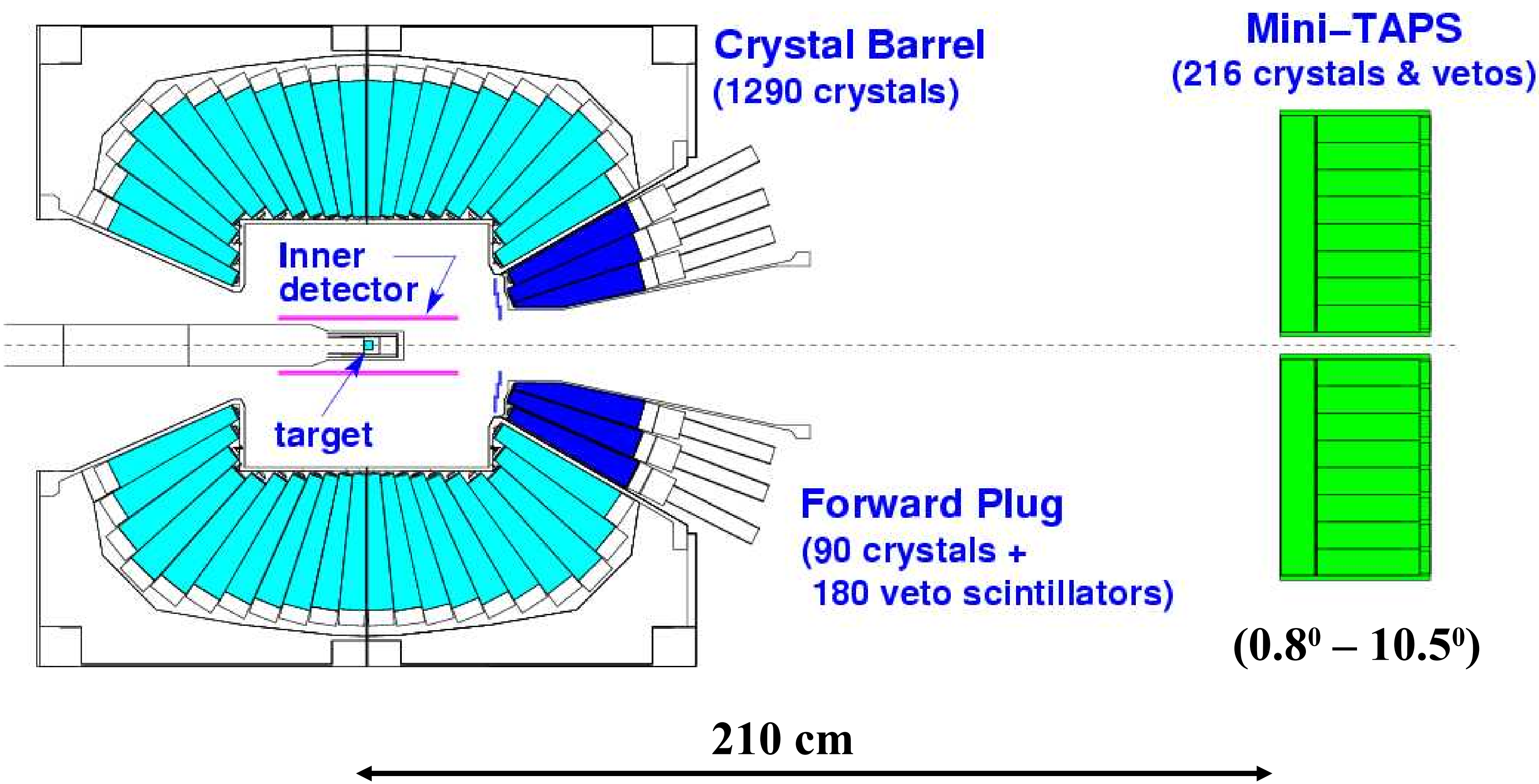
The Crystal Barrel/ TAPS detector @ELSA



tagging spectrometer:
tagging range: 31% -94% of E_{beam}
$E_\gamma = E_{beam} - E_e$

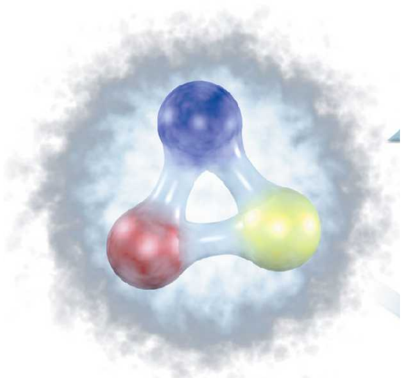
CB: 1290 CsI modules
TAPS: 528 BaF_2 modules

Proposed experimental setup for experiment E5



hadrons: strongly interacting composite particles

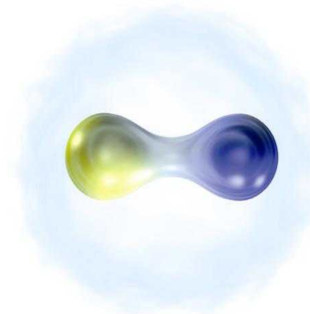
Baryons (qqq)



proton: (uud) $J^{\pi} = \frac{1}{2}^{+}$, ↑↓↑

neutron: (udd) $J^{\pi} = \frac{1}{2}^{+}$, ↑↓↑

Mesons ($q\bar{q}$)



<u>pseudoscalar mesons</u>: $J^{\pi} = 0^{-}$, ↑↓

$\boldsymbol{\pi}^{+}(u\bar{d})$, $\boldsymbol{\pi}^{0}(u\bar{u}-d\bar{d})/\sqrt{2}$, $\boldsymbol{\pi}^{-}(d\bar{u})$

<u>vector mesons</u>: $J^{\pi} = 1^{-}$, ↑↑

$\boldsymbol{\rho}^{+}(u\bar{d})$, $\boldsymbol{\rho}^{0}(u\bar{u}-d\bar{d})/\sqrt{2}$, $\boldsymbol{\rho}^{-}(d\bar{u})$

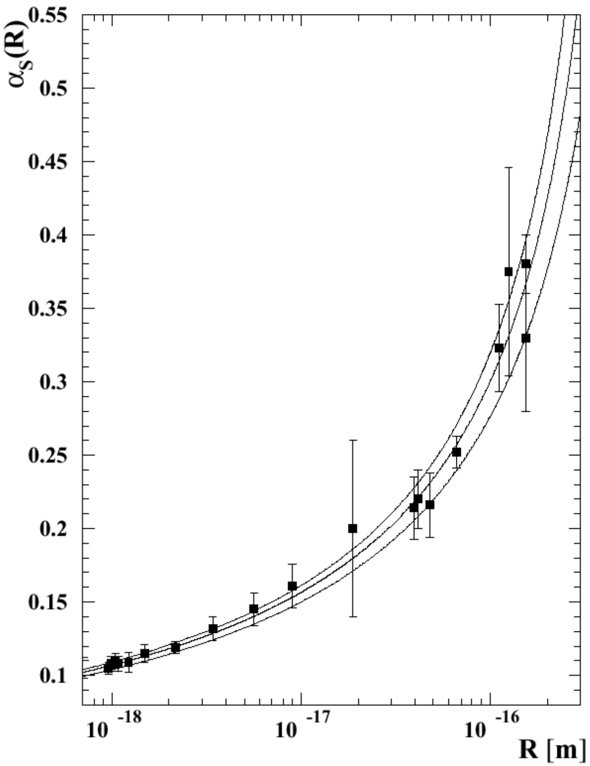
$\boldsymbol{\omega}(u\bar{u}-d\bar{d})/\sqrt{2}$, $\boldsymbol{\phi}(s\bar{s})$

<u>scalar mesons</u>: $J^{\pi} = 0^{+}$, ↑↓

$\boldsymbol{\sigma}$, $(\boldsymbol{\pi\pi})_{l=0}$

how is the mass of the nucleon generated?

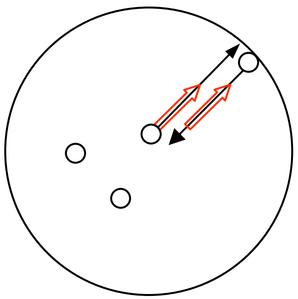
$m_N = 938$ MeV >> $m_q \approx 5 - 10$ MeV

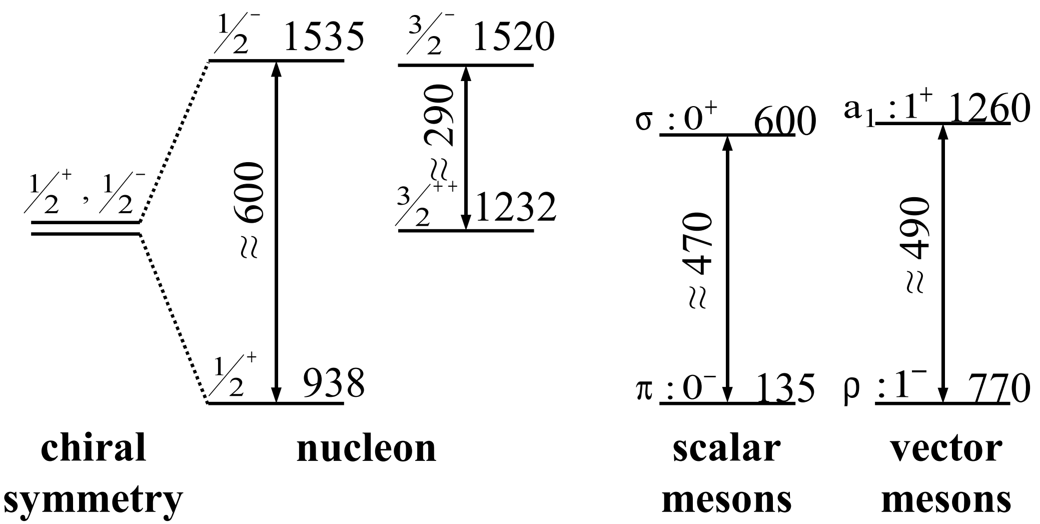


the interaction among quarks has to become so strong that it overcomes their quantum mechanical resistance to localization (Wilczek)

the role of chiral symmetry breaking

- **chiral symmetry = fundamental symmetry of QCD for massless quarks**
- **chiral symmetry broken on hadron level**

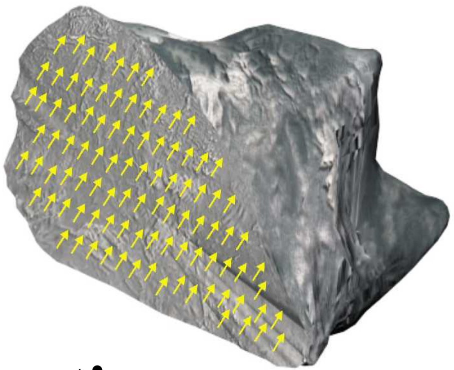


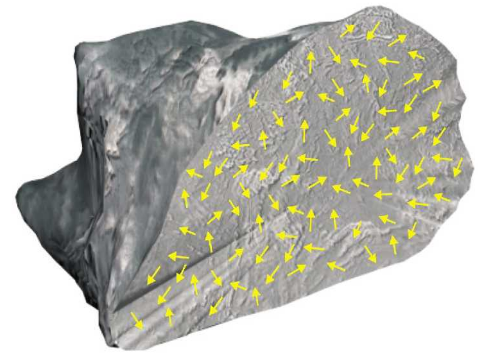


mass split comparable to hadron masses !

phase transition: ferromagnetism → paramagnetism

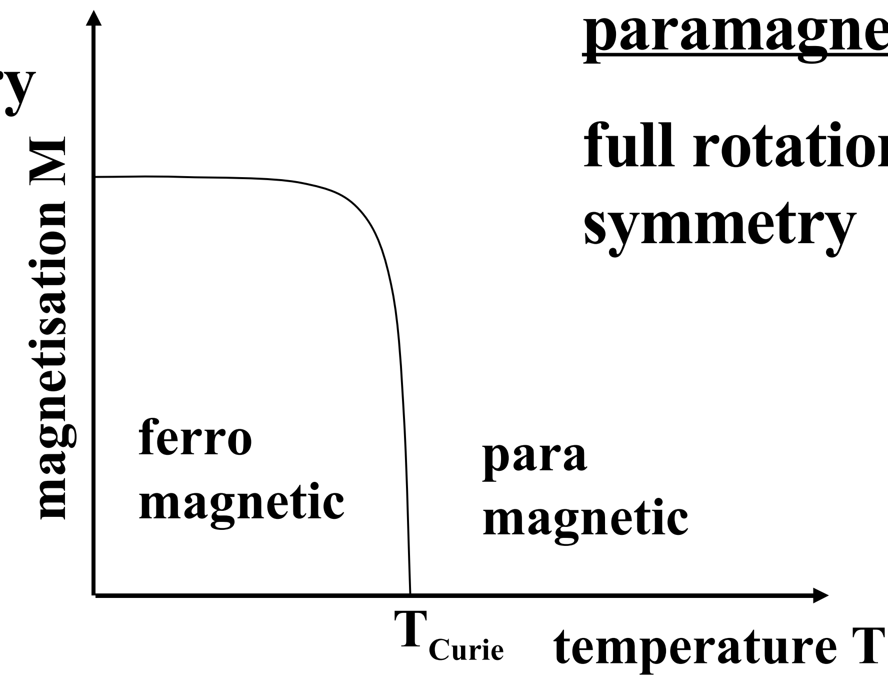
restoration of full rotational symmetry





ferromagnetic:

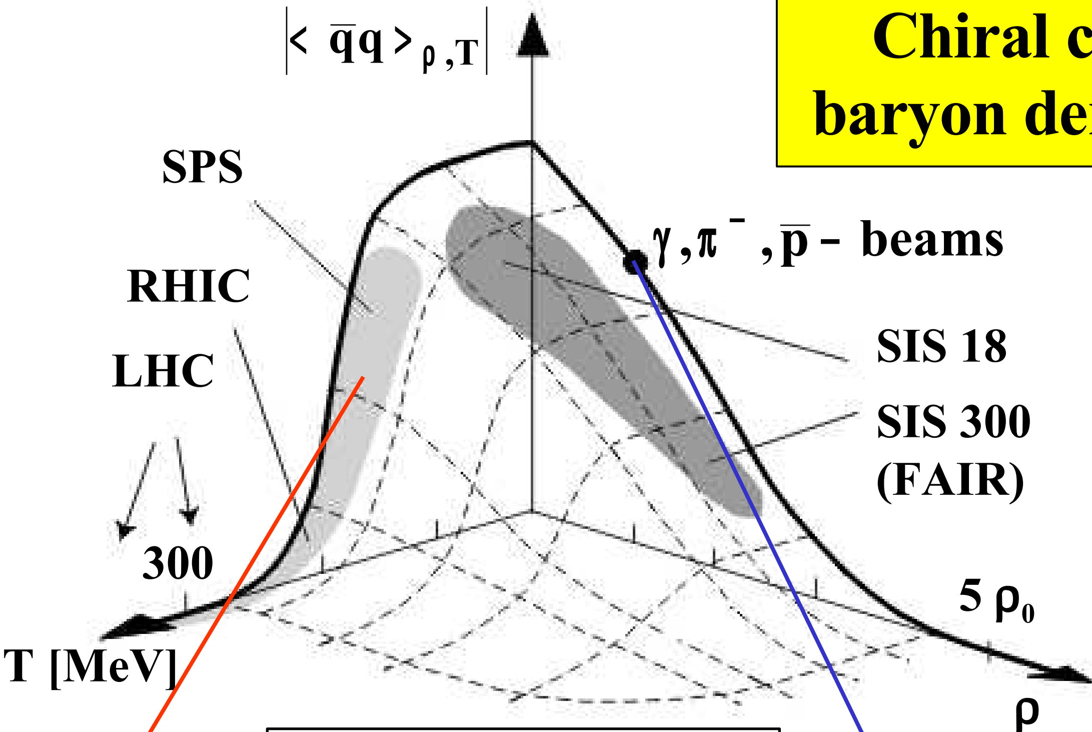
rotational symmetry about 1 axis



paramagnetic:

full rotational symmetry

Chiral condensate as function of baryon density ρ_B and temperature T



NJL - model :

V.Bernard and U.G.Meißner
Nucl. Phys. A 489 (1988) 647

S. Klimt et al.
Phys. Lett. B 249 (1990) 386

$$m_V = f\left(|\langle q\bar{q} \rangle|\right)$$

partial restoration of chiral symmetry ?

heavy ion reactions:

$$AA \rightarrow V + x$$

$$\rightarrow \quad m_V\left(\rho_B >> \rho_0;\ T > 0\right)$$

elementary reactions:

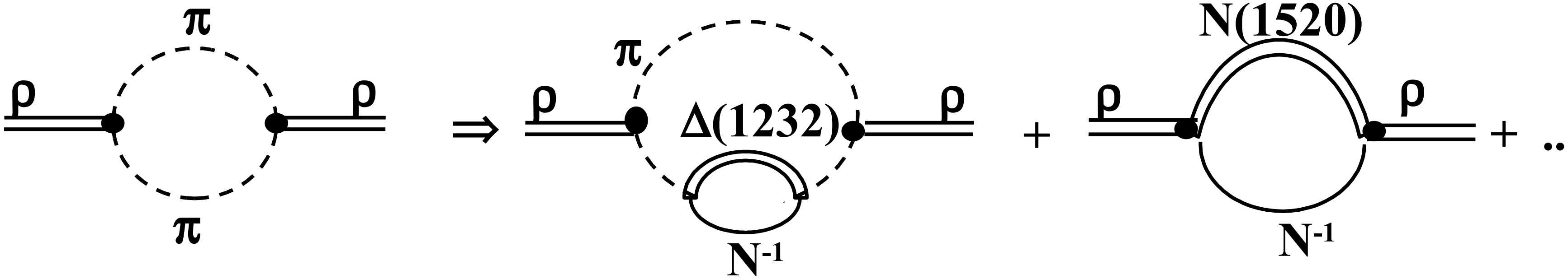
$$\gamma, \pi \ \ A \rightarrow V + x$$

$$\rightarrow \quad m_V\left(\rho_B = \rho_0;\ T = 0\right)$$

medium modifications of vector mesons in heavy ion reactions and elementary processes

In-medium modifications through hadronic many body effects

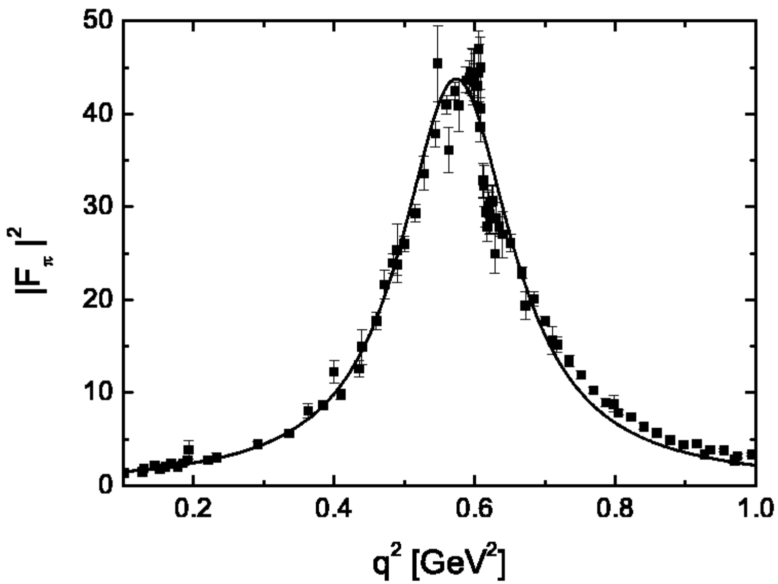
in vacuum | **in medium**



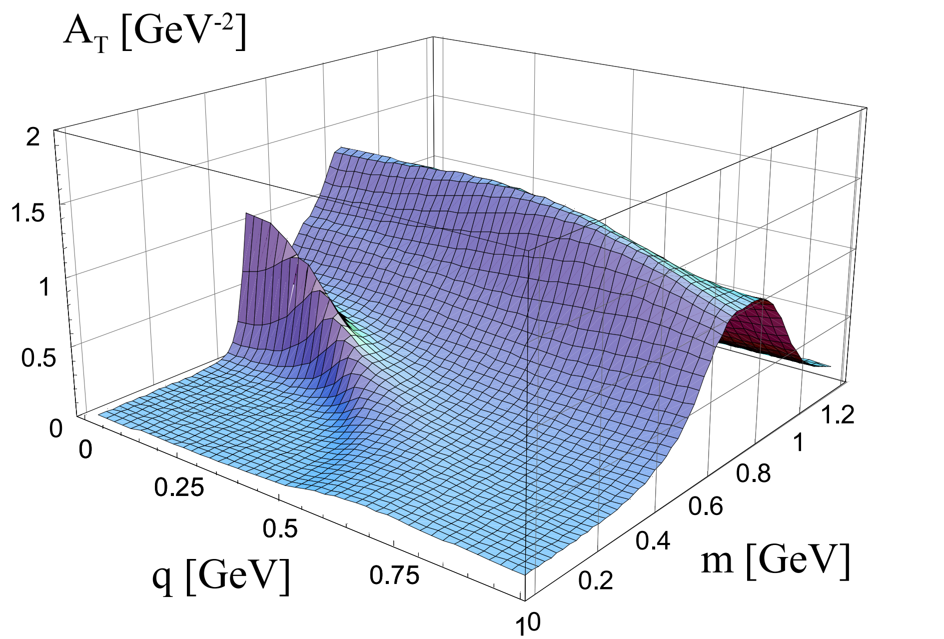
propagator: $D = \dfrac{1}{p^2 - m^2 - \Pi_{vac}} \Rightarrow D = \dfrac{1}{p^2 - m^2 - \Pi_{vac} - \Pi_{med}}$

spectral function: $= \dfrac{1}{\pi} \, Im \, D$

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



⇒



Link between hadronic and QCD-description: QCD sum rules

hadronic side

QCD -side

$$\frac{Q^2}{\pi}\int_0^\infty ds \frac{\Im m\Pi(s)}{s(s+Q^2)} = -\frac{1}{8\pi^2}\left(1+\frac{\alpha_s}{\pi}\right)\ln\frac{Q^2}{\Lambda^2}$$

$$+\frac{m_q\langle\bar{q}q\rangle}{Q^4}+\frac{1}{24}\frac{\left\langle\frac{\alpha_s}{\pi}G^2\right\rangle}{Q^4}-\frac{112}{81}\alpha_s\pi\frac{\langle\bar{q}q\rangle^2}{Q^6}+\ldots$$

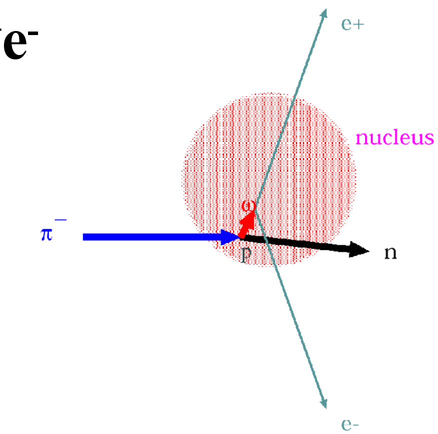
No direct relation between in medium properties of hadrons and the quark condensate but an indirect one via QCD sum rules

ω-mass in nuclei

W. Schön et al.
Act. Phys. Pol. B 27 (96) 2959

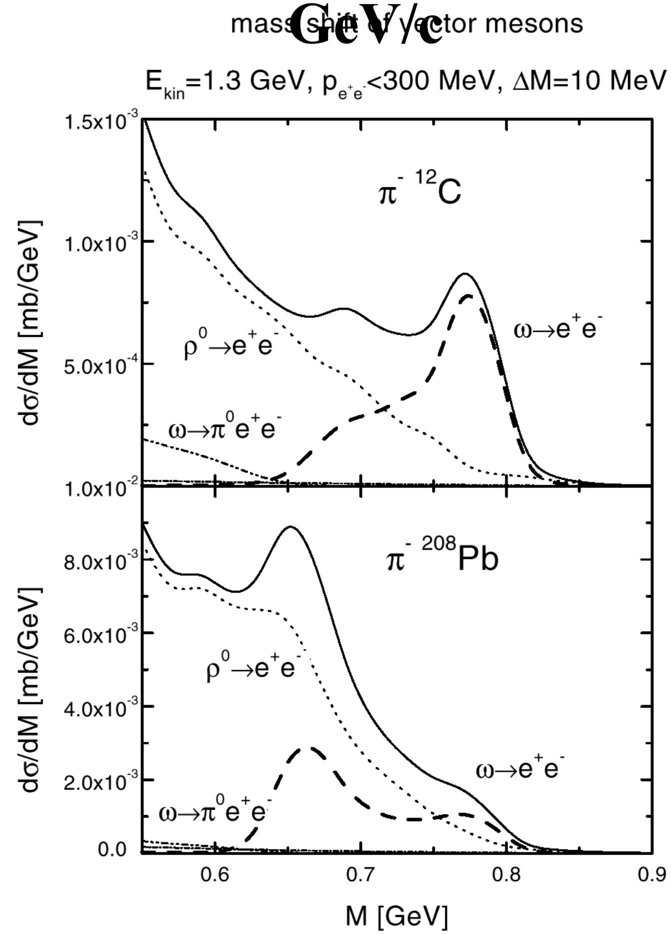
$\pi^- p_{bound} \rightarrow n\omega_{at\ rest} \rightarrow ne^+e^-$

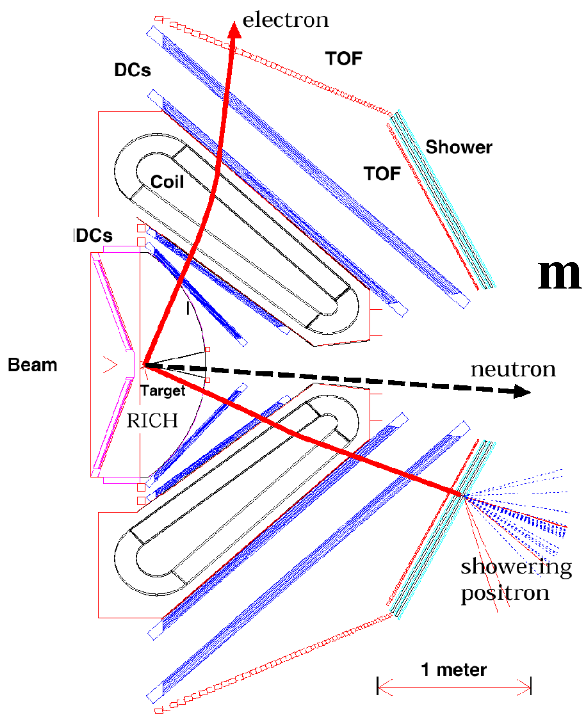
"at rest: $|\vec{p}_\omega| \leq |\vec{p}_F|$



M. Effenberger et al.
PRC 60 (1999) 044614

expected signal:
$\pi^- A$ at $p_\pi = 1.3$ GeV/c





exp: detect e^+e^-

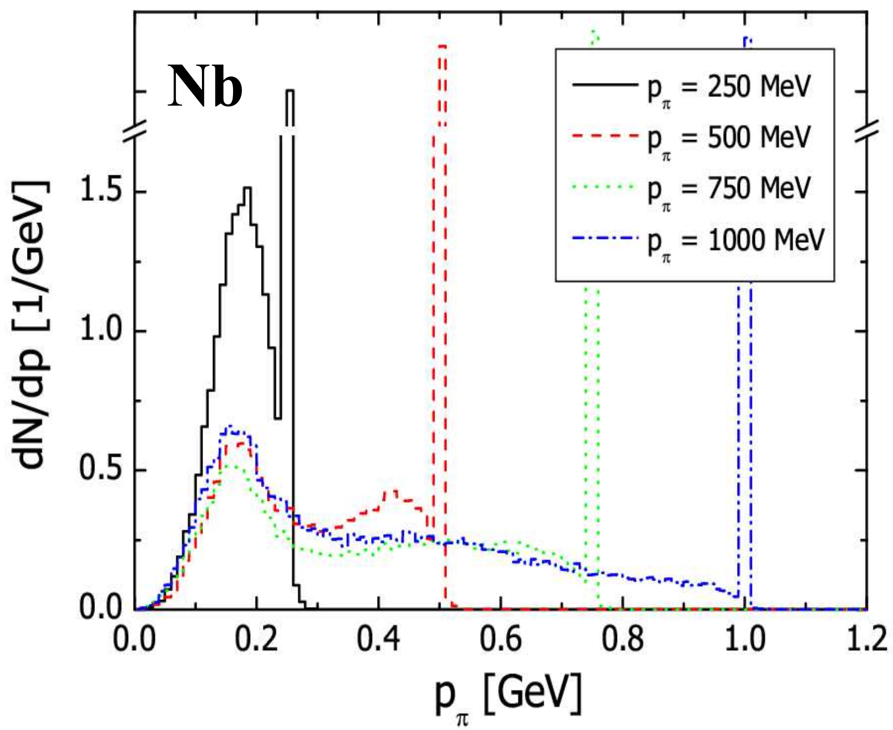
$$m_\omega = \sqrt{\left(\sum E_i\right)^2 - \left(\sum p_i\right)^2}$$

HADES

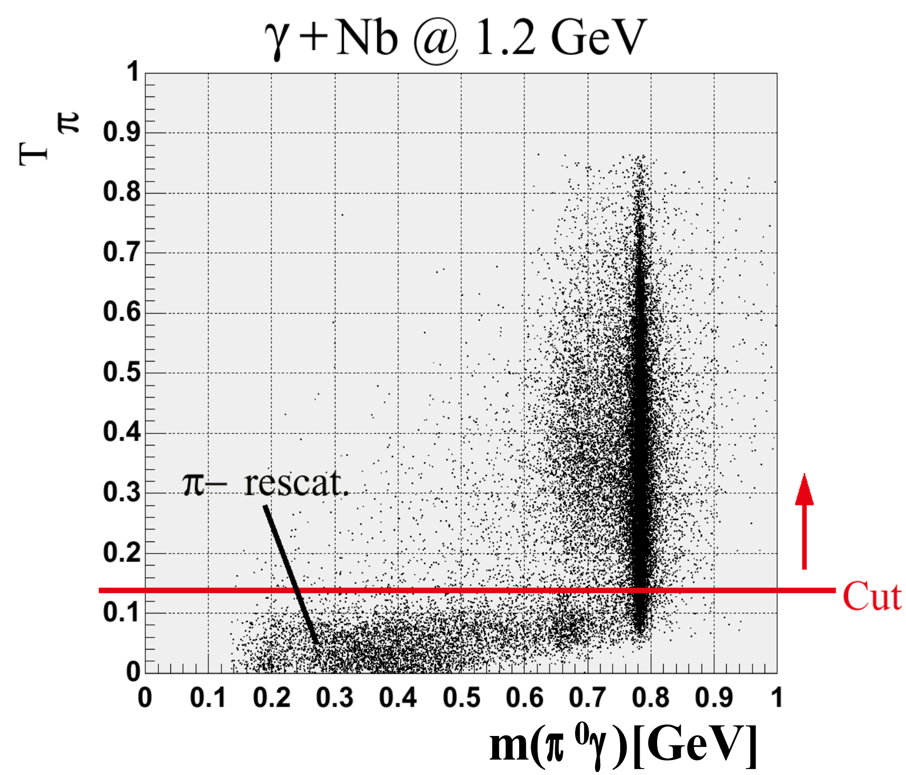
Suppression of π^0 rescattering events

after rescattering π^0 kinetic energy below 150 MeV ≅ 250 MeV/c
(Δ -decay kinematics) ⇒ cut on π^0 kinetic energy

P. Mühlich (Giessen)
nucl-th/0310067

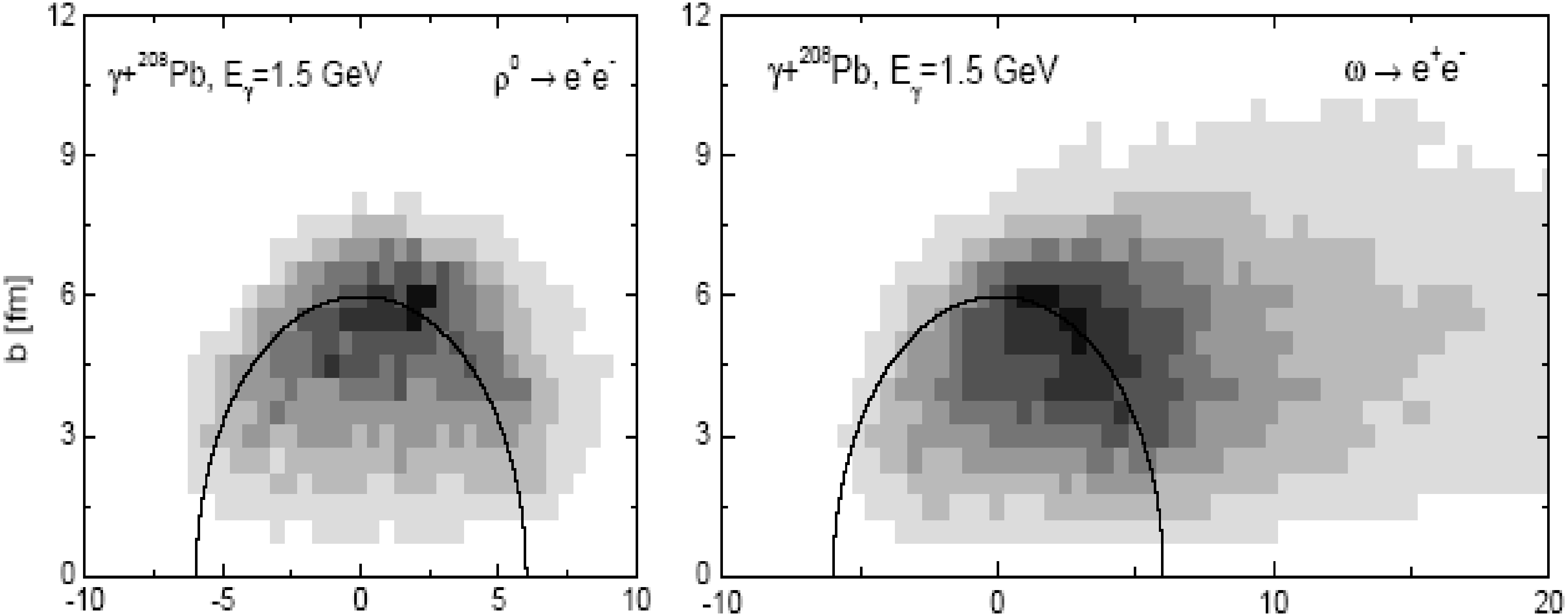


J.G.Messchendorp et al.
Eur. Phys. J. A11 (2001) 95



photoproduction of ρ, ω mesons off nuclei

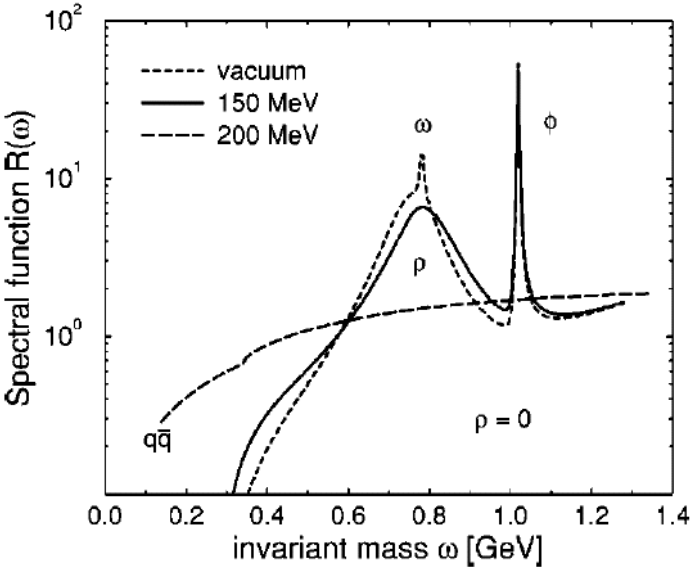
distribution of decay sites (M. Effenberger et al.)

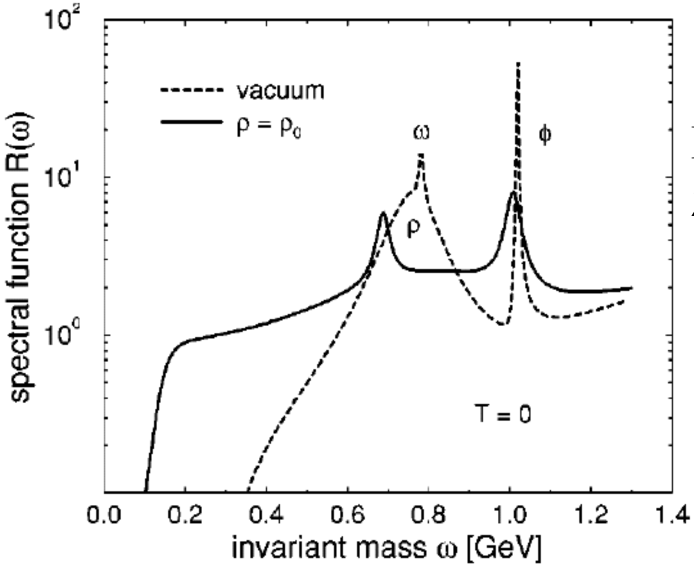


a sizable fraction of ω mesons decay outside of the nucleus

average baryon density at ω decay points $\langle\rho\rangle = 0.11\ \rho_0$

theoretical predictions for mass changes of vector mesons in the nuclear medium





F.Klingl et al., Z.Phys.A356 (1996)193

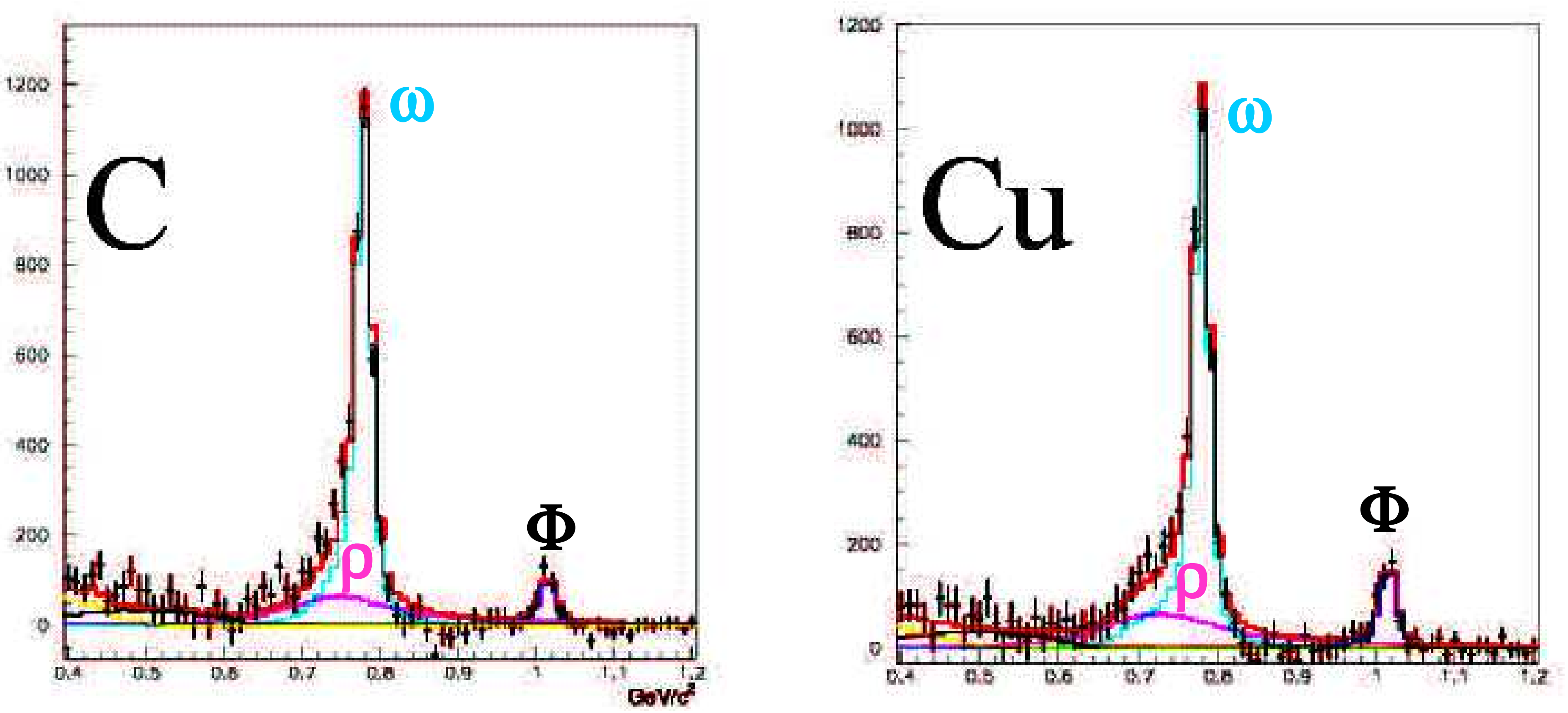
T. Renk et al., PRC 66 (2002) 014902

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

} **for ρ_B↗, T ↗**

e^+e^- invariant mass spectrum from p A→ ρ, ω, Φ +X at 12 GeV

S. Yokkaichi, Chiral-2005, Japan, KEK-E325



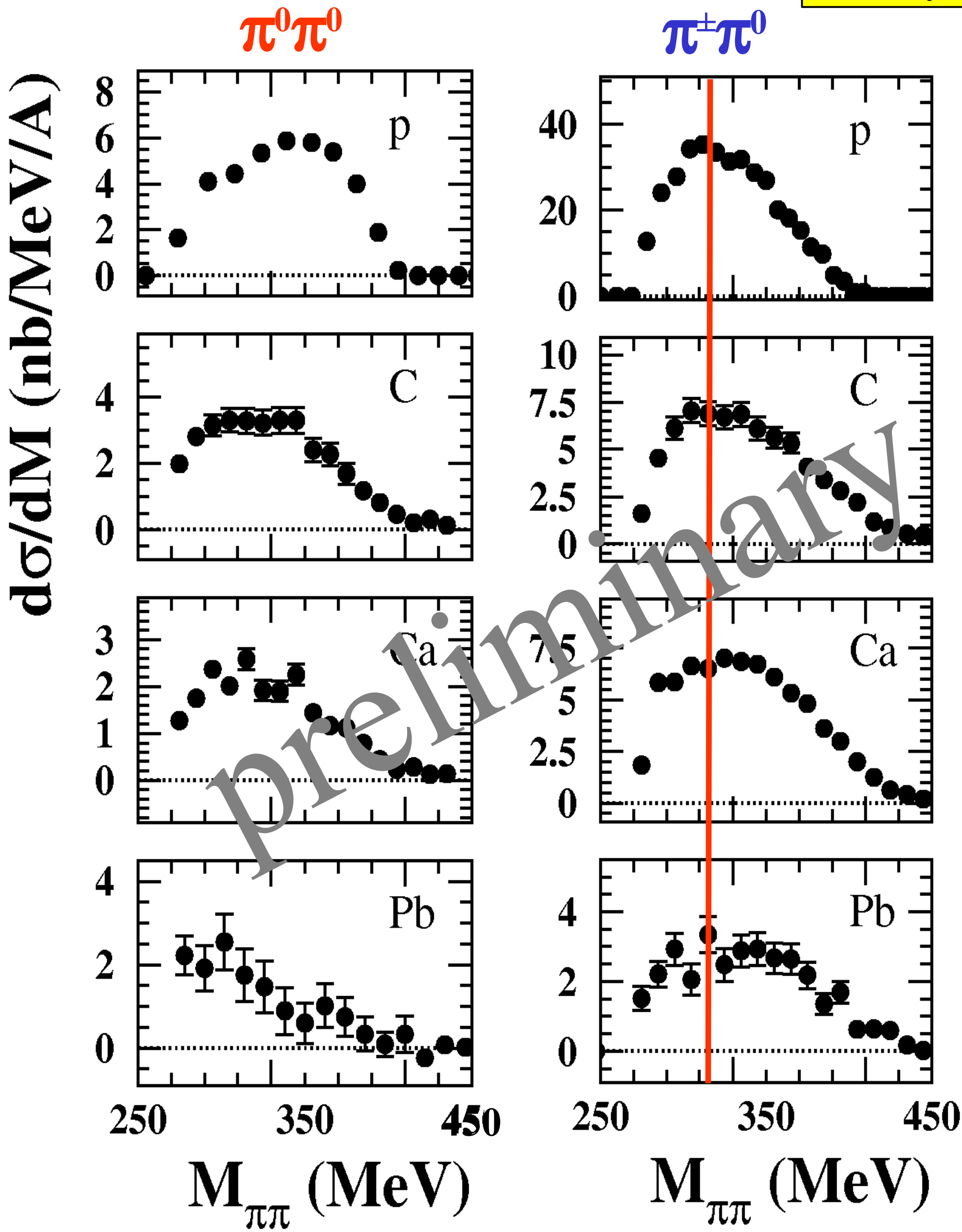
Comparison to model calculation assuming $m^* = m_0(1 - 0.10\,\rho/\rho_0)$

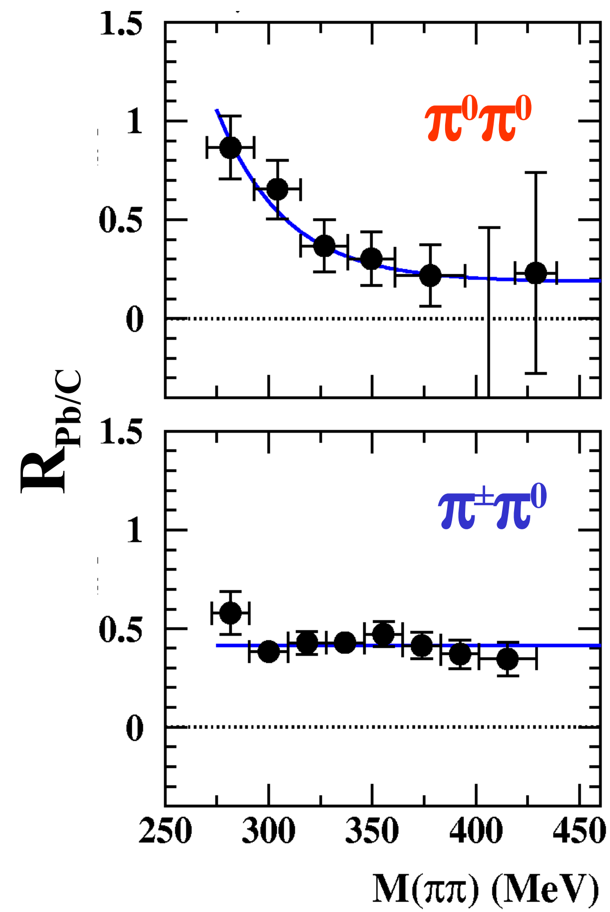
⇒ modification of ρ (ω) spectral function

$E_\gamma = 400 - 500$ MeV

A (γ,ππ)

$$R_{Pb/C} = \frac{12\,\frac{d\sigma}{dM}(\mathrm{Pb})}{208\,\frac{d\sigma}{dM}(\mathrm{C})}$$





mass shift with increasing A only observed for $\pi^0\pi^0$ channel

J. Messchendorp et al., PRL 89 (2002) 222302