Hadrons in Nuclei: Experiments and Perpectives

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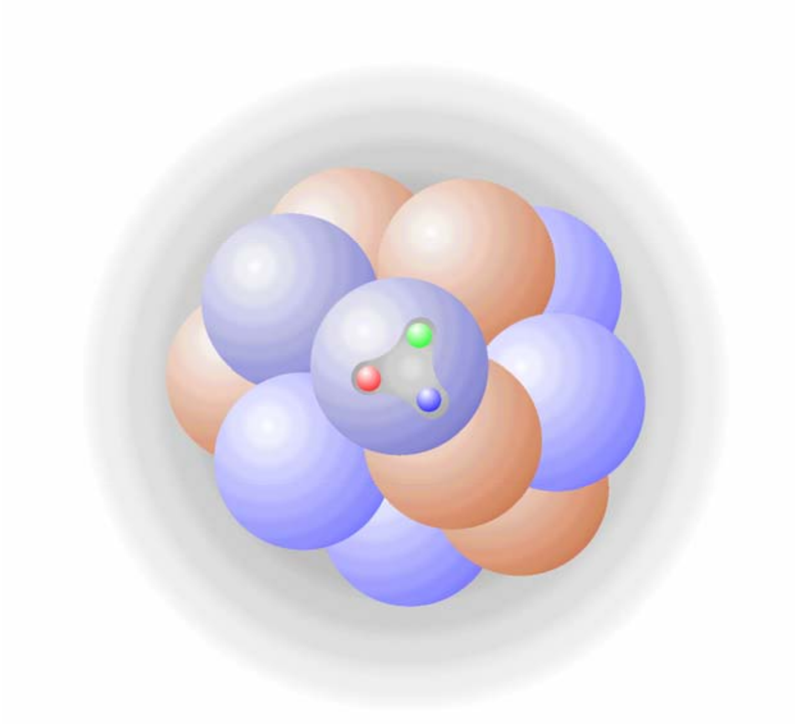
How does QCD (nature) *make* hadrons?

hadronic and electromagnetic probes →



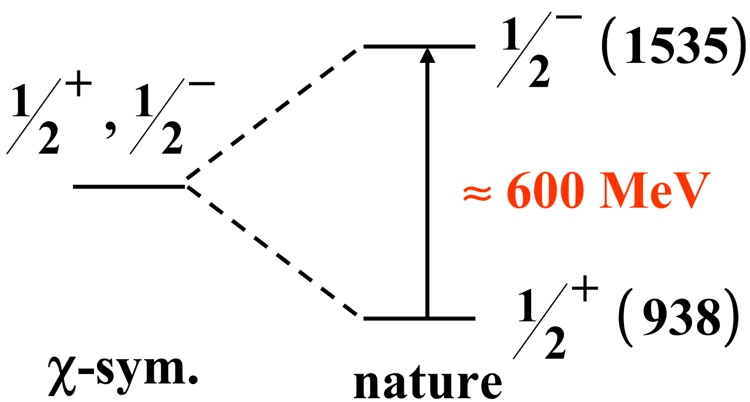
- confinement
- origin of mass

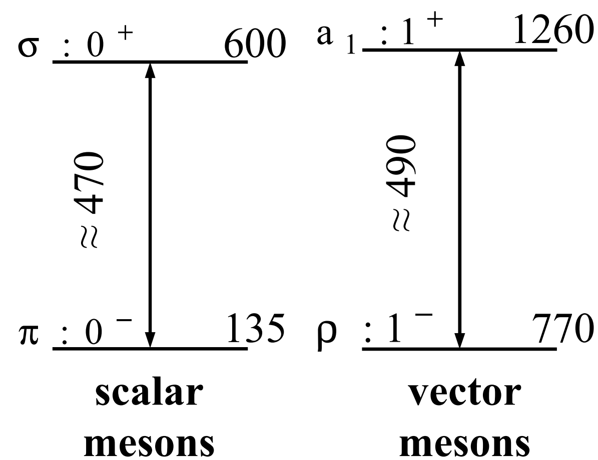
Hadron Physics

hadron properties
hadronic interactions

The Role of Chiral Symmetry Breaking

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





To understand the origin of mass:

can we (partially) restore chiral symmetry?

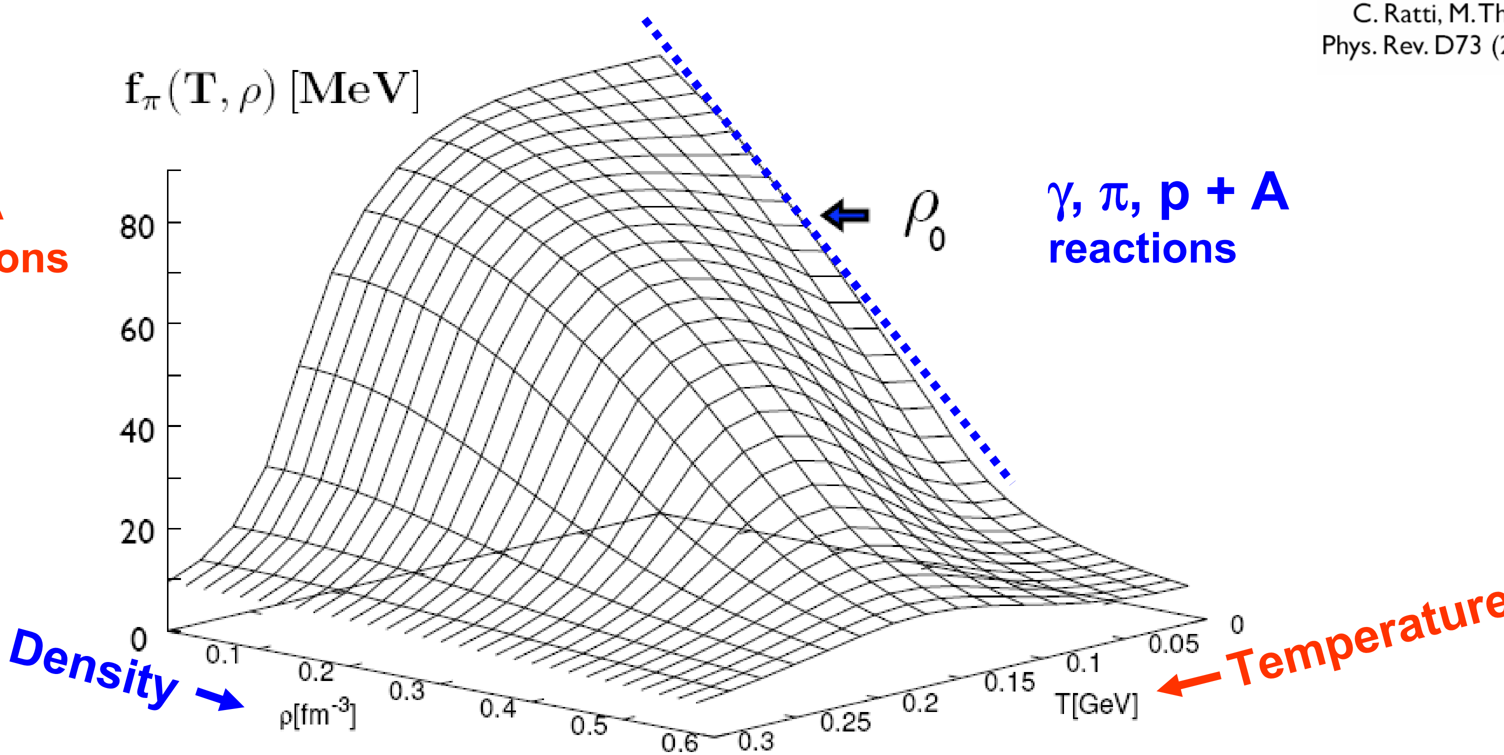
<u>changes of hadron properties in the nuclear medium</u>

Hadrons in the Nuclear Medium

S. Klimt, M. Lutz, W.W.
Phys. Lett. B249 (1990) 386

C. Ratti, M. Thaler, W.W.
Phys. Rev. D73 (2006) 014019

A + A reactions



γ, π, p + A reactions

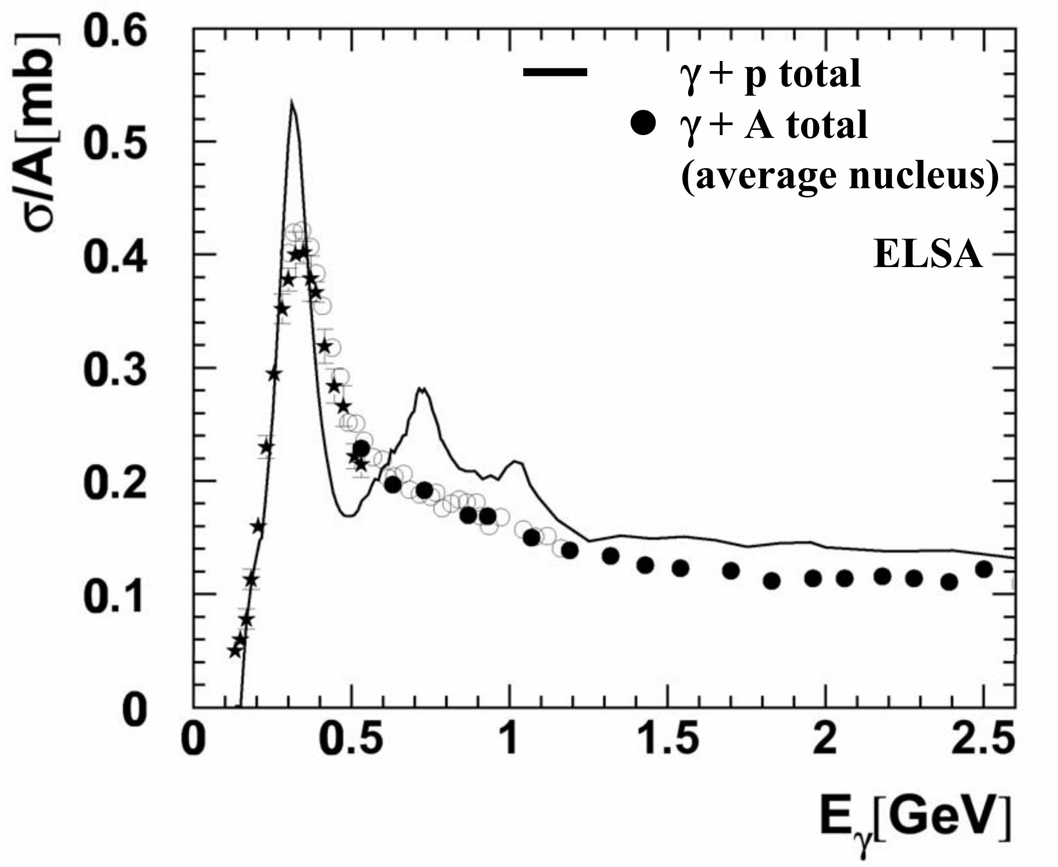
$$\frac{f_\pi^2(T,\rho)}{f_\pi^2(0)} \simeq \frac{\langle \bar{q}q \rangle_{T,\rho}}{\langle \bar{q}q \rangle_0} \simeq 1 - \frac{T^2}{8 f_\pi^2} - \frac{\sigma_N}{m_\pi^2 f_\pi^2}\,\rho + \ \dots$$

approximation for $\rho < 2\rho_o$: $m = m_o\,(1 - \alpha\,\rho/\rho_o)$

hadron masses modified in the nuclear medium: $m = f\,(|\langle qq \rangle|)$

Nuclear Photoabsorption: γ + A

total cross section <u>per nucleon</u>



evidence for medium modification:
no resonance structures
above 0.6 GeV

• $D_{13} \rightarrow N\rho$ decay branch
Mosel et al.

• modified $\pi\pi$ interaction/ interferences
Hirata et al.
Oset et al.

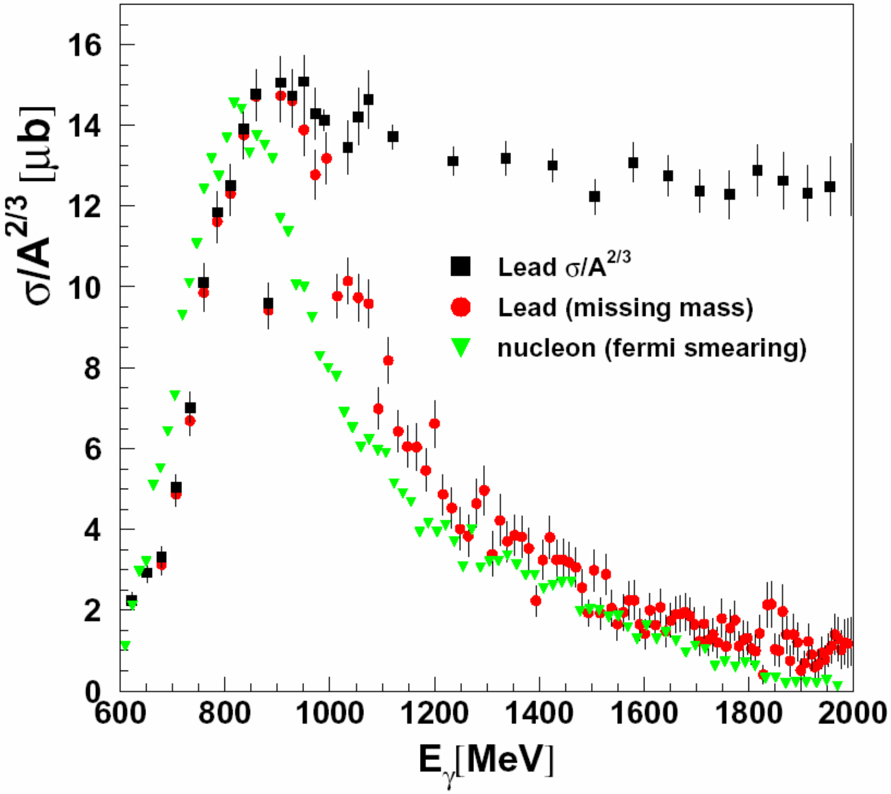
<u>resonance broadening in medium ?</u>

study in-medium **meson production** from nucleon resonance decays

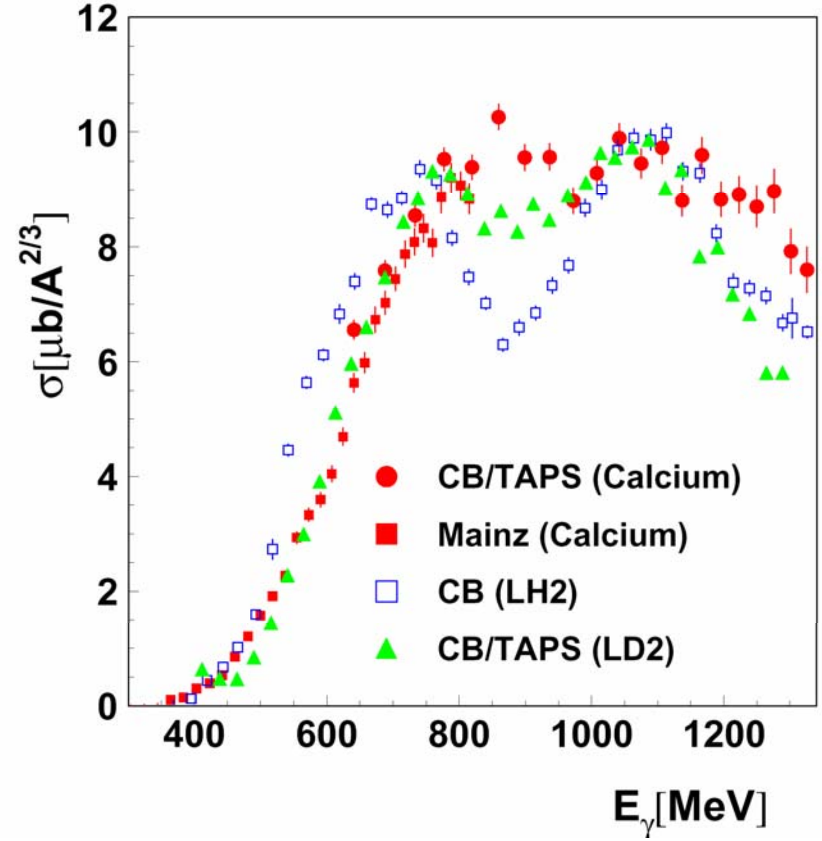
Meson Photoprodcution from Nuclei

B. Krusche, MESON2006, Cracow, June 2006

A(γ,η)



A(γ,π°π°)

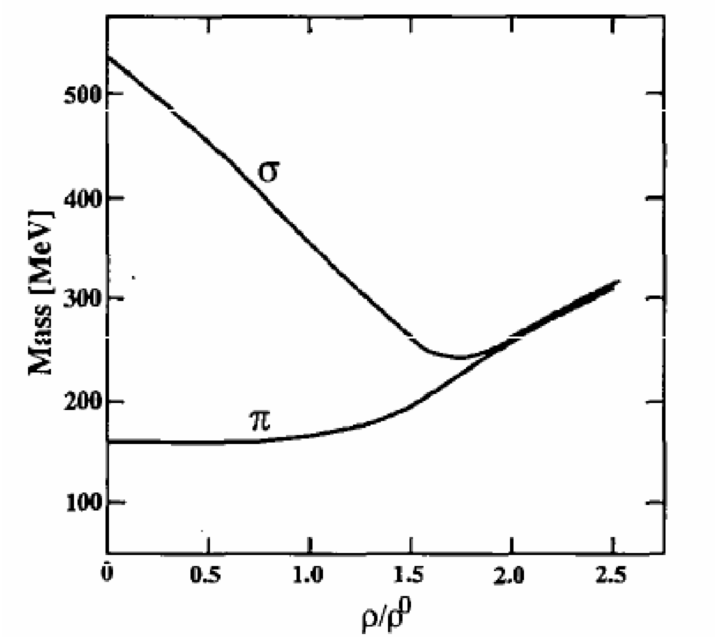


results for in-medium spectral functions of nucleon resonances consistent with preditions:

- no significant effect on S_{11} resonance
- possibly some suppression of D_{13} resonance (still under analysis)

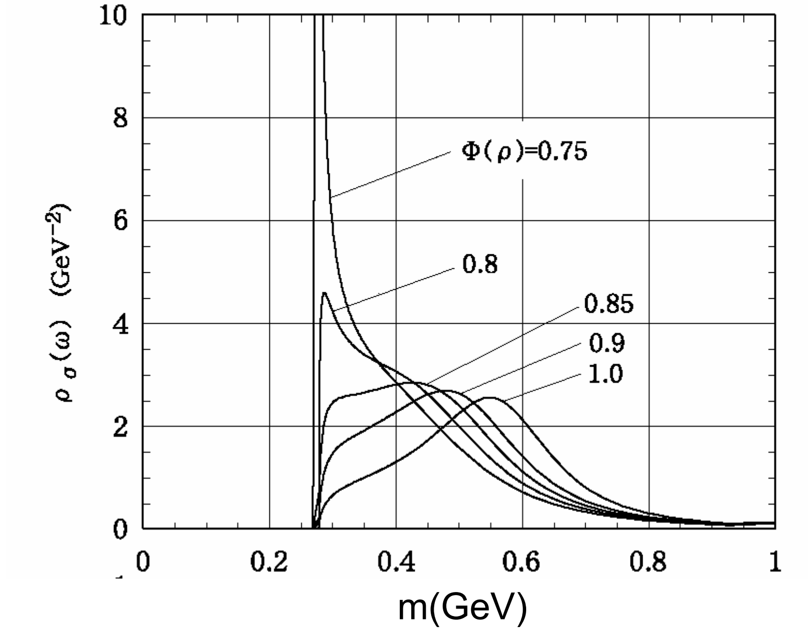
Scalar Mesons in Medium

V. Bernard et al., PLB 382 (1996) 19



masses of chiral partners become degenerate in the chiral limit

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



"σ"$\rightarrow \pi^o\pi^o$, $\pi^{\pm}\pi^o$

concentration of ππ strength near threshold

observable: pion-pion invariant mass

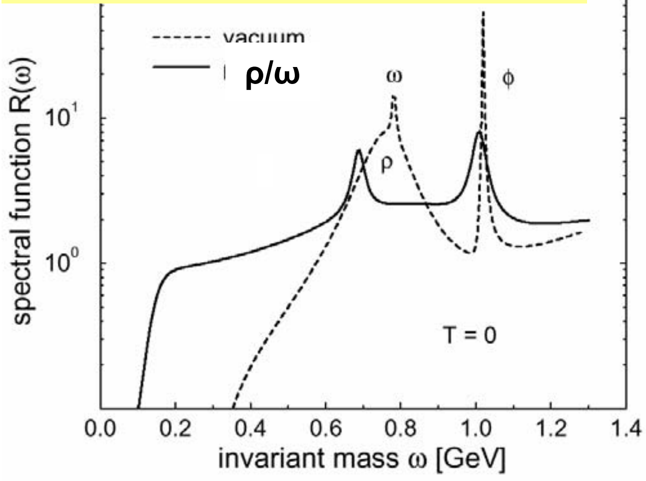
- pion induced $\pi^+\pi^-$ production (CHAOS@TRIUMF)
- pion induced $\pi^o\pi^o$ production (Crystal BAll@BNL)
- photon induced $\pi^o\pi^o$ production (TAPS@MAMI) →

F.Bloch et al., Eur.Phys.J.A32:219,2007 and

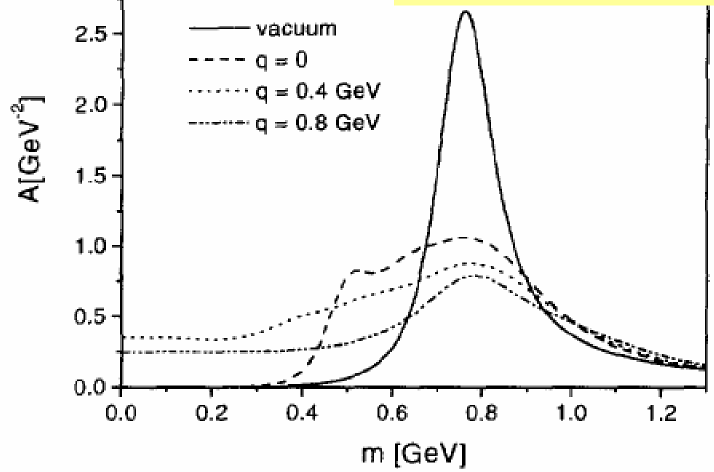
new + decisive data from Crystal Ball/TAPS at MAMI awaited

Model Predictions for ρ and ω Mesons

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

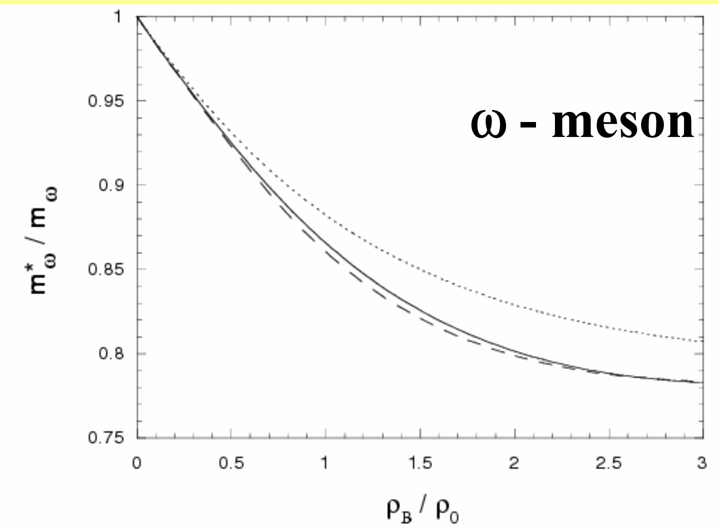


W. Peters et al., NPA 632 (1998) 109



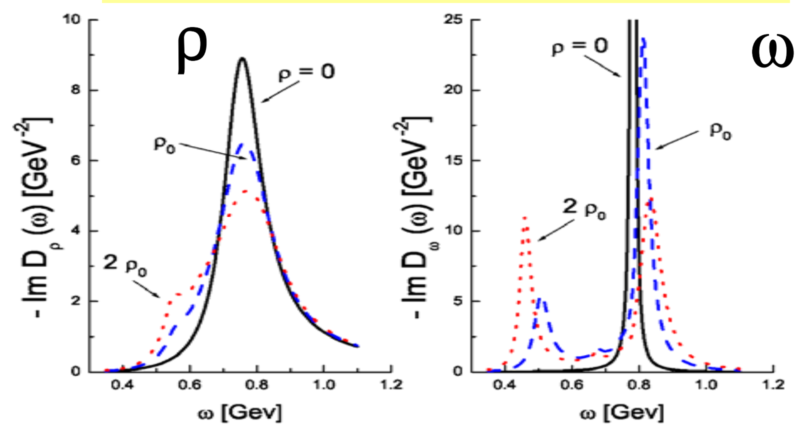
hadronic many body effects

K. Saito, K. Tushima, and A.W. Thomas, PRC 55 (1997) 2637



Quark-meson coupling model (QMC)

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



structure in spectral function due to coupling to baryon resonances

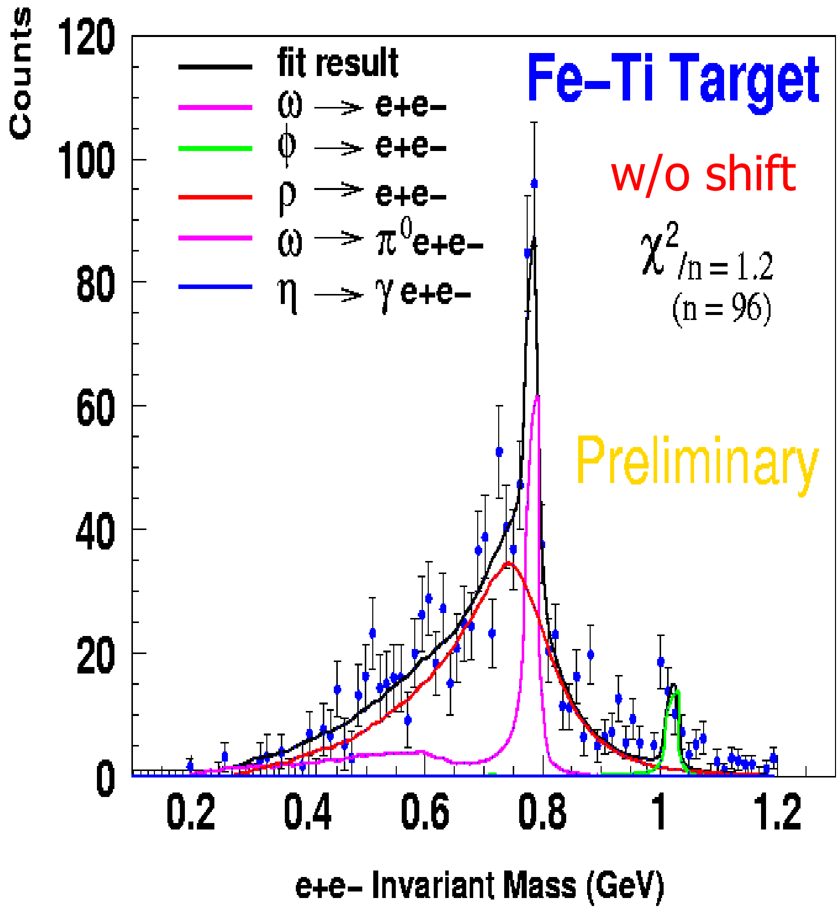
Experimental Approach

dilepton spectroscopy: $\rho, \omega, \phi \rightarrow e^+e^-$

vector mesons deay via dileptons, free of final state interaction

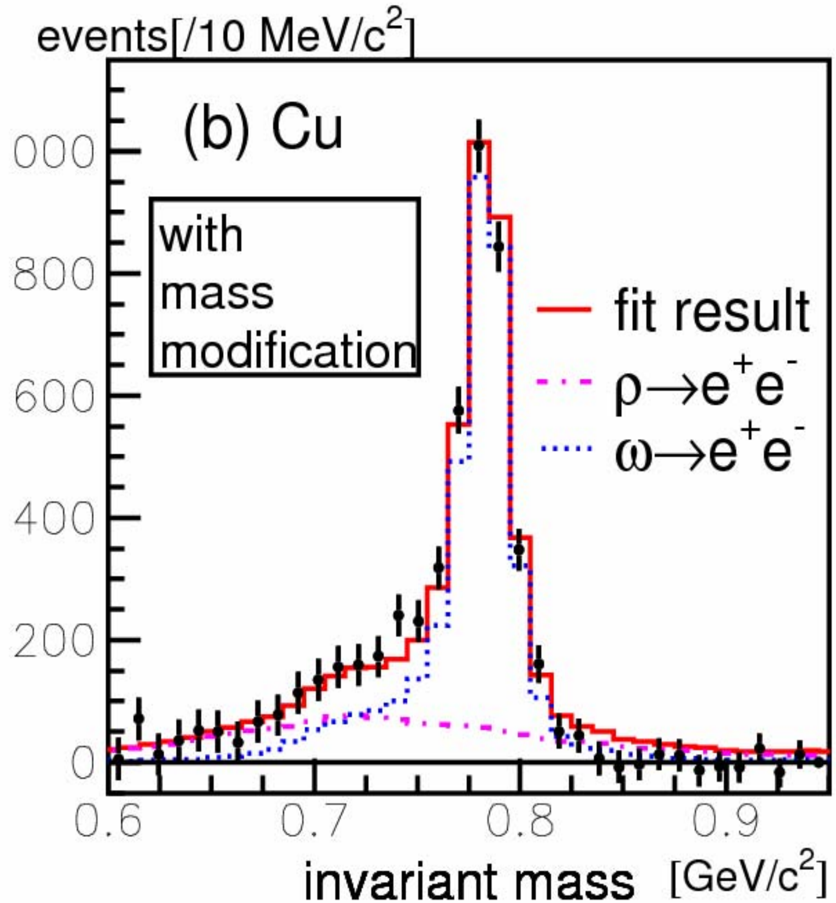
- **γ+A CLAS**
- **p+A KEK** ***(see talk by R. Muto)***
- **p+A HADES** ***(see talk by J. Pietraszko)***
- **A+A HADES** ***(see talk by J. Pietraszko)***
- **and others...**

JLAB-CLAS: G7 $\gamma A \rightarrow e^{+}e^{-} + X$



ρ slightly broadened;
no mass shift

KEK-E325: p (12 GeV) A→ ρ, ω +X



ρ shifted in mass:
no broadening

$$m_\rho = m_0\left(1 - 0.092\frac{\rho}{\rho_0}\right);$$

Chaden Djalali
Berekely School, May 21-26, 2007

M. Naruki et al., PRL 96 (2006) 092301

Experimental Approach

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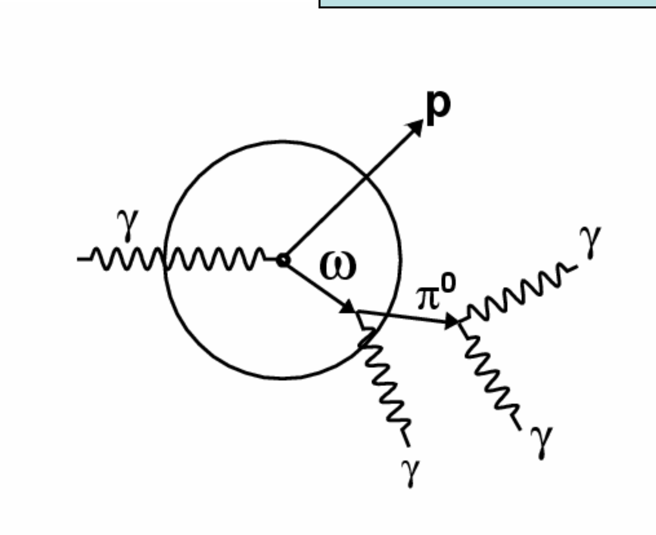
alternative approach: ω Dalitz decay in γ+A TAPS
(*see talk by M.Kotulla*)

ω-mass in nuclei from photonuclear reactions

J.G.Messchendorp et al., EPJ A11 (2001) 95

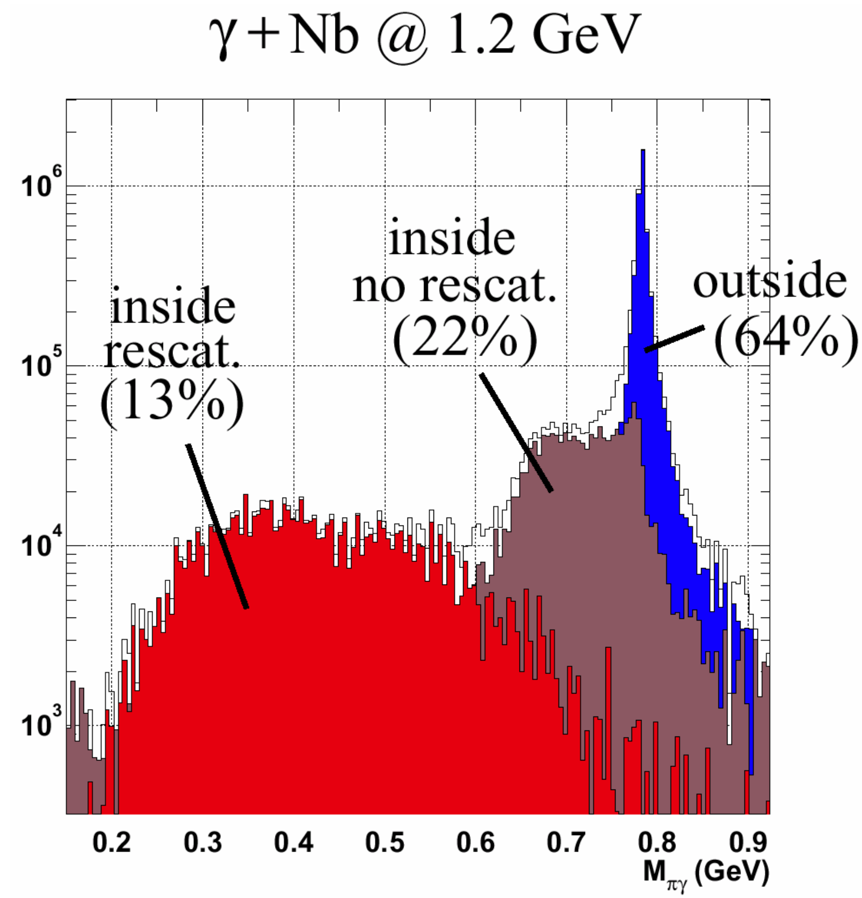


advantage:

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

disadvantage:

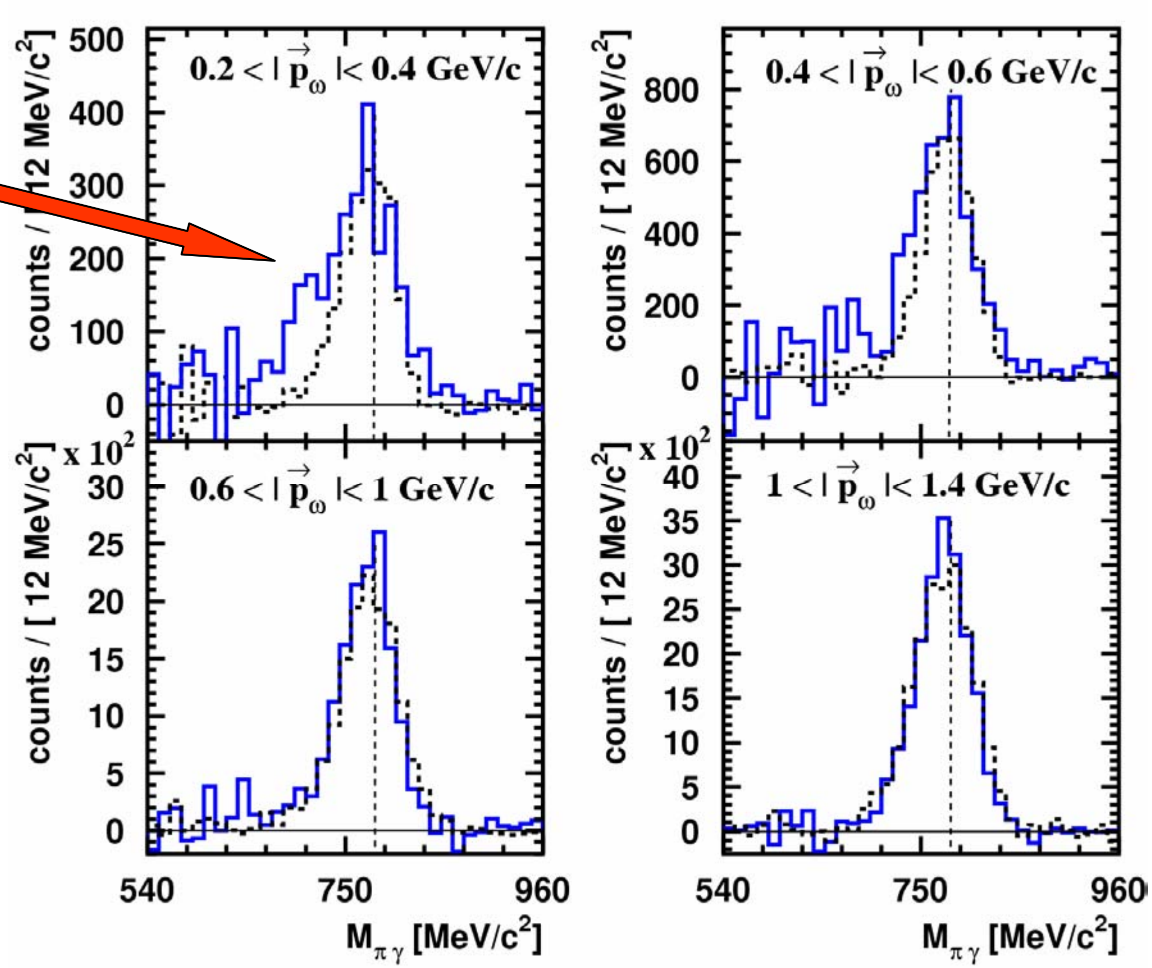
- π^o-rescattering
- background reactions: $\gamma A \to 2\,\pi^o + X$
- mass resolution



momentum dependence of ω signal

D. Trnka et al. PRL (2005) 192303

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



the latest news:
see talk by M.Kotulla

indication for an in-medium modification of the ω meson mass

2001 - 2003

Further perspective: Vector Mesons in p+A reactions with WASA-at-COSY

ω, ρ line shapes in nuclear medium
Φ meson in medium

• dilepton production (elementary reactions: Stepaniak et al)

• simultaneous measurement of Dalitz decay ($\pi^o\gamma$) of ω meson

• comparison to photon induced reactions (CBELSA/TAPS) and elementary and heavy ion dilepton production (HADES), etc

note:
• $\omega \to \pi^o\gamma$ was suggested in:

Studying the ω properties in pA collisions via the $\omega \to \pi^0\gamma$ decay ☆
A. Sibirtsev [a], V. Hejny [b], H. Ströher [b], W. Cassing [a]
Physics Letters B 483 (2000) 405–409

• and in:

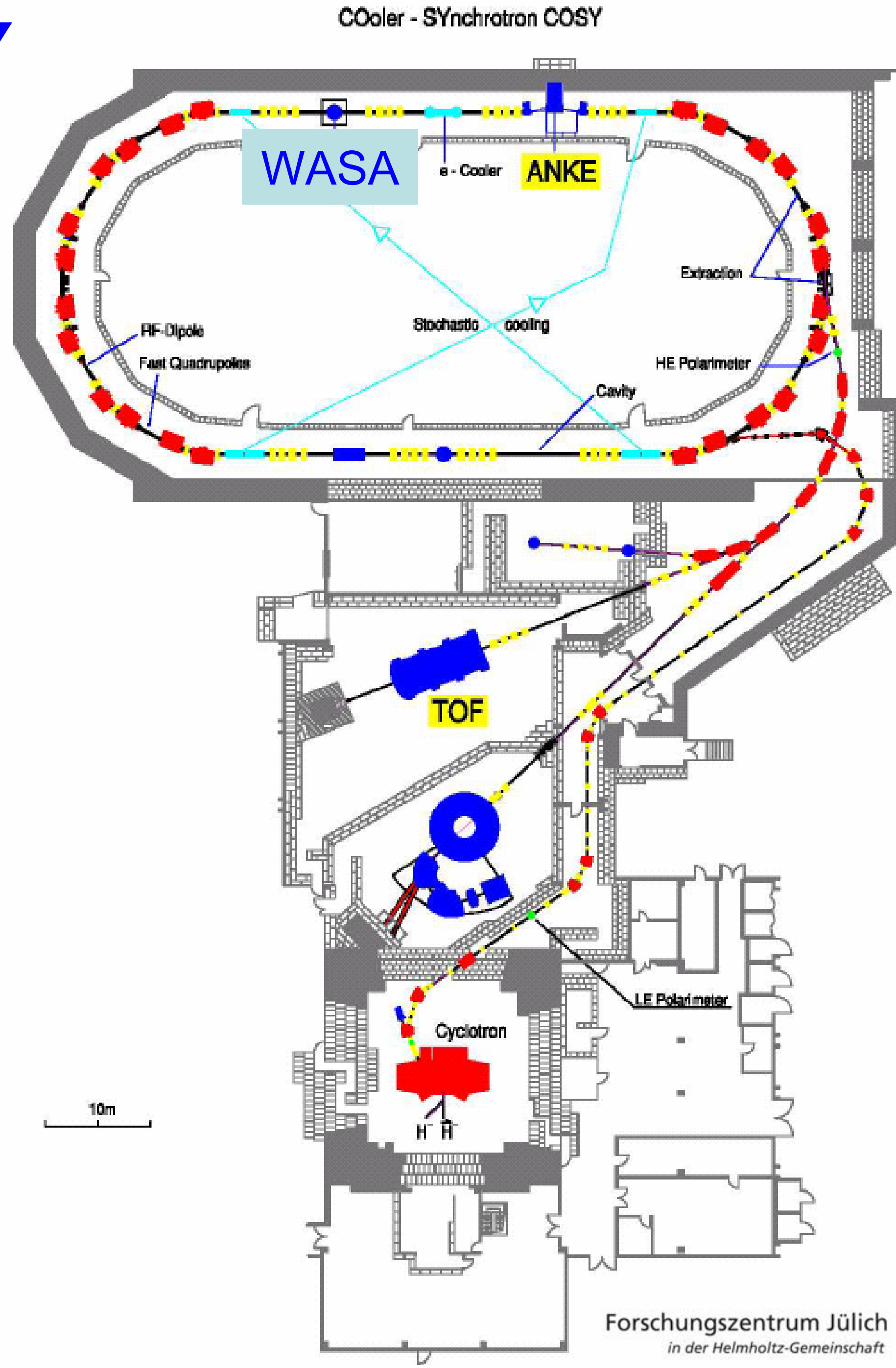
Studying the ω mass in-medium in $\gamma + A \to \pi^0\gamma + X$ reactions
Eur. Phys. J. A **11**, 95–103 (2001)
J.G. Messchendorp[1,a], A. Sibirtsev[2,3], W. Cassing[2], V. Metag[1], and S. Schadmand[1]

CBELSA/TAPS
PRL **94,** 192303 (2005)

possible:
second generation WASA-at-COSY experiments with nuclear targets

WASA at COSY

- p beams up to p=3.7 GeV/c
- d beams
- polarized beams
- beam cooling
- high luminosity
- charged and neutral particle detection



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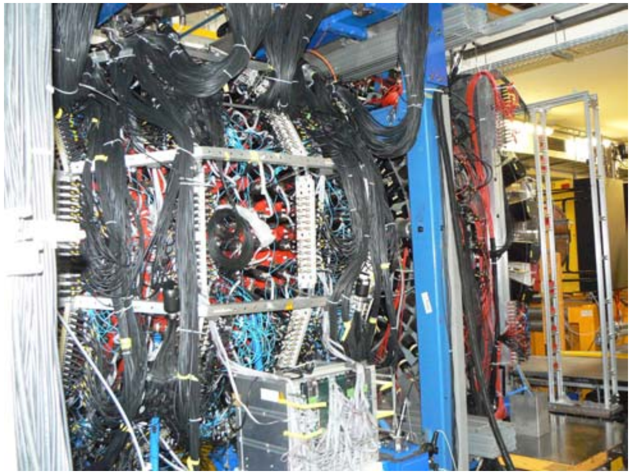
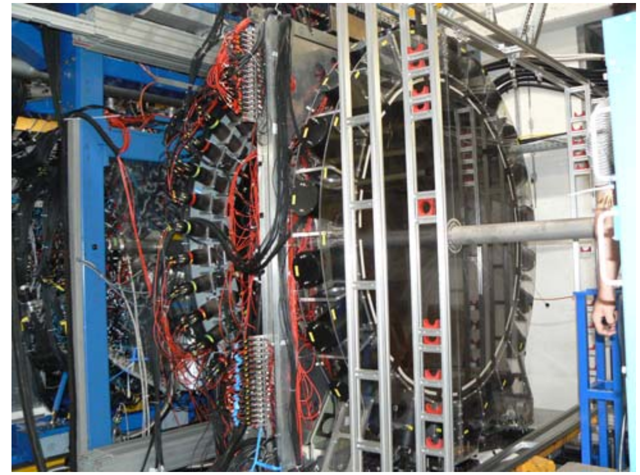
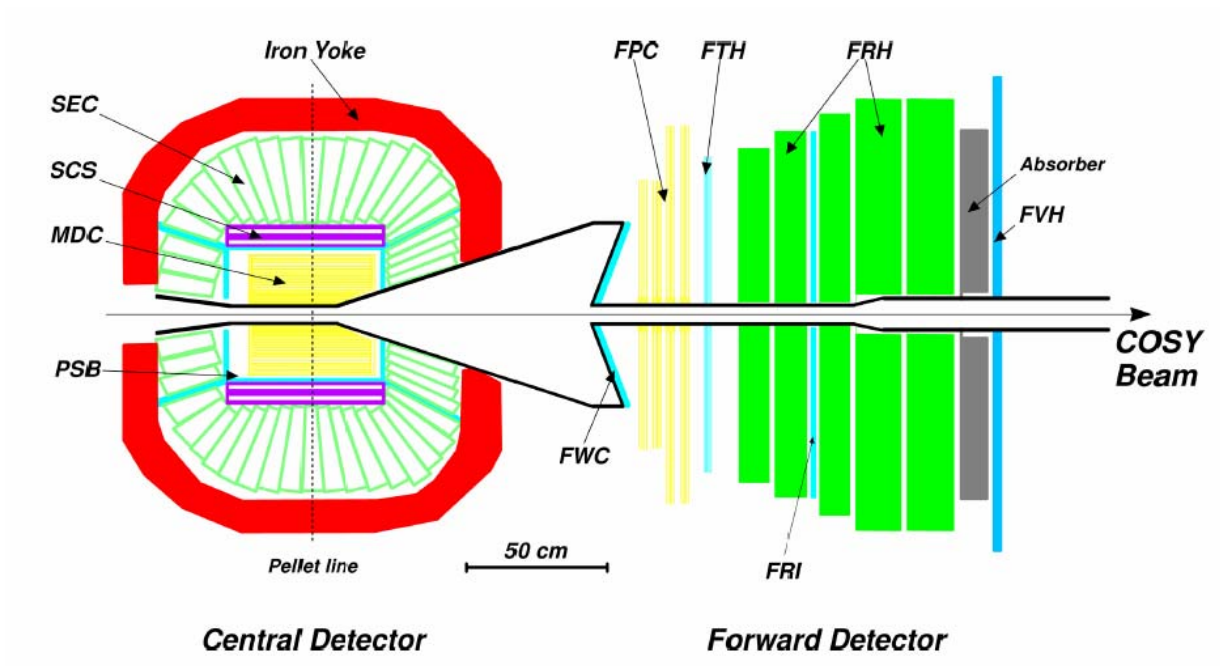
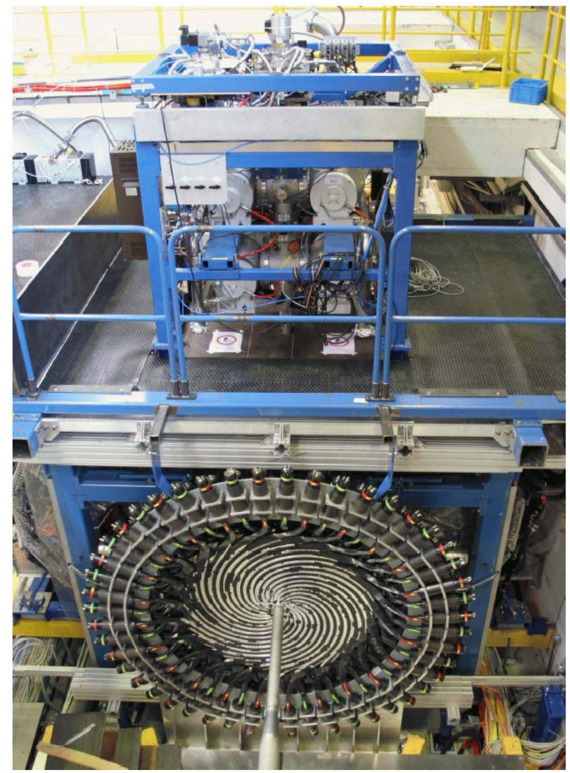
WASA at COSY






Iron Yoke
SEC
SCS
MDC
PSB
FPC
FTH
FRH
Absorber
FVH
FWC
COSY Beam
Pellet line
50 cm
FRI
Central Detector
Forward Detector



WASA-at-COSY

- is a 4π detection system
- can detect neutral and charged decays, even dileptons
- can handle high rates
- can have nuclear targets

very suited for studies of ω meson production and decays

Medium Effects on Hadrons

- absorption/rescattering of mesons
- modified hadron-hadron interaction
- partial chiral symmetry restoration
- meson-baryon coupling
- meson-nucleus attractive potential

- mass shift
- broadening
- bound states

Experiments are in accordance with theoretical scenarios for changes of hadron properties in the nuclear medium.

Some controversy to be resolved.

Studying the in-medium behavior of hadrons is a promising approach to learn more about the origin of their mass.

Outlook

16:25 - 16:40
Ryotaro Muto (KEK)
Evidence of rho, omega and phi Meson Mass Modification in Nuclear Medium Measured in 12C

16:40 - 16:55
Jerzy Pietraszko (GSI)
Dielectron Production in C+C Collisions with HADES

16:55 - 17:10
Martin Kotulla (Giessen)
New Results on the omega Meson in the Nuclear Medium

17:10 - 17:25
Tatiana Skorodko (Tübingen) *WASA d+d*
Two-pion Production in the Delta Delta Region - Approaching the ABC Puzzle by Exclusive and ...

17:25 - 17:40
Daisuke Jido (Kyoto):
In-medium Properties of Pion and Partial Restoration of Chiral Symmetry in Nuclear Medium

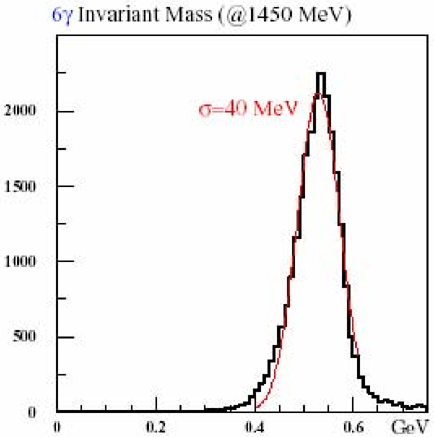
17:40 - 17:55
Hideko Nagahiro (Osaka):
Formation Spectra of eta-Mesic Nuclei by (pi+,p) Reaction at J-PARC and Chiral Symmetry for Baryons

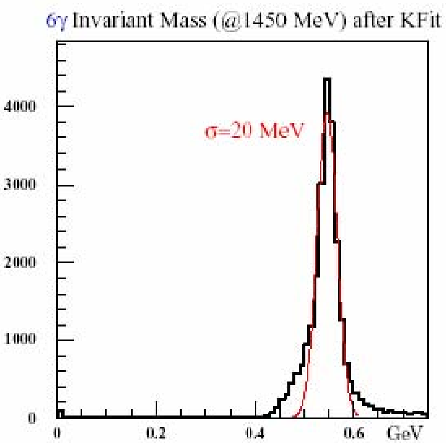
and poster sessions.

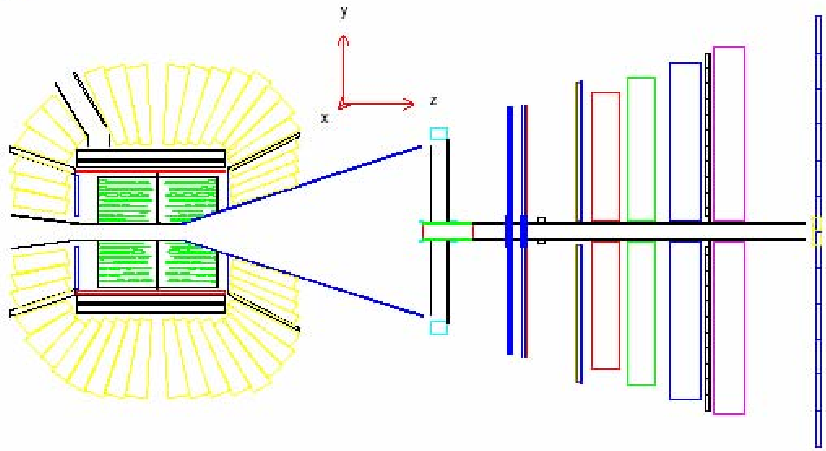
WASA Central Detector

Performance

neutral η ($\rightarrow 3\pi^0 \rightarrow 6\gamma$) decays







particle identification:
ΔE-E, ΔE-P

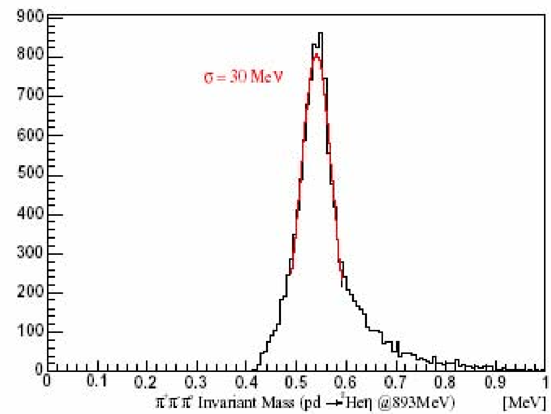
θ range: 20° - 169°

ϕ range: 0° - 180°

σ_E/E for γ: 8 %

σ_P/P for $\pi^{\pm}/p$: 4%/9%

charged η ($\rightarrow \pi^0\pi^+\pi^-$) decays



future modifications:

plastic barrel upgrade
$\rightarrow$ scintillating fibre detector

Status WASA-at-COSY

first **η production** beam time: April 2 - May 6, 2007 (ongoing)

		with improved DAQ
data rate:	2000/s	→ 8000/s (with ca. 40 MB/s, presently limited by writing to disk)
dead time:	>= 80μs	→ 20-30 μs
events per pellet:	~1	→ 3-4

goal: 10^8 η decays

status 25Apr07: **estimated $8 \cdot 10^5$ $\eta \rightarrow \pi^o \pi^o \pi^o$**

conclusion: it's working!!!