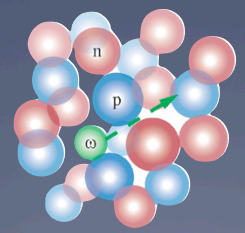
Vector Mesons in the Nuclear Medium

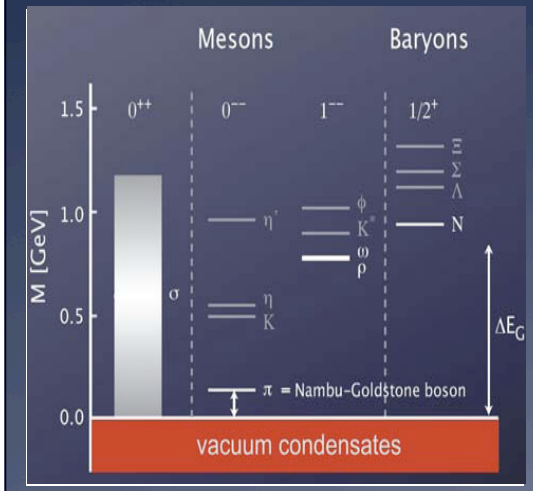
D.P. Weygand
R. Nasseripour, M. H. Wood, C. Djalali
and the CLAS Collaboration

R. Nasseripour *et al.* Jul 2007.**Phys.Rev.Lett.99:262302,2007**.

M.H. Wood, et al., Phys.Rev.C78:015201,2008.



The Nature of Mass



98% of mass is generated dynamically

The spontaneous breaking of Chiral Symmetry in vacuum is the origin of ~2% of the mass of hadrons

Changes of properties of hadrons in the nuclear medium may signal:
- -Chiral symmetry restoration
- -exotic state of matter,....

As $< q\bar{q} > \rightarrow 0$ chiral symmetry is restored.

and as a consequence, masses, coupling constants, widths of hadrons may change.

Model Predictions of Vector Meson Properties In Medium

Scale invariance in effective Lagrangian:

G.E. Brown and M Rho, *Phys. Rev Lett. 66 (1991) 2720*

$$\frac{m_V^*}{m_V} = \frac{m_N^*}{m_N} = \frac{f_\pi^*}{f_\pi} \approx 0.8 \quad \text{at } \rho_0$$

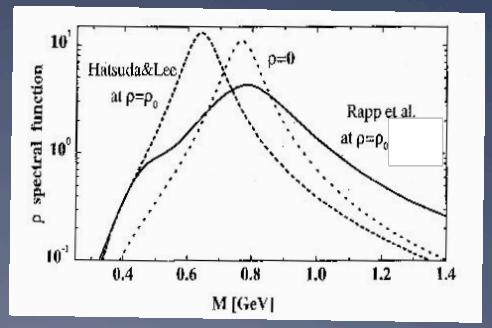
QCD sum rules:

T. Hatsuda and S. Lee *Phys. Rev. C46 (1992) R34*

$$\frac{m_V^*}{m_V} = 1 - \alpha \frac{\rho_B}{\rho_0} \qquad \alpha \approx 0.16 \pm 0.06$$

Many body effects:

B Friman, H.J. Pirner,
Nucl Phys. A617 (1997) 496
R. Rapp, G. Chanfray, J Wambach,
Nucl Phys. A617 (1997) 472

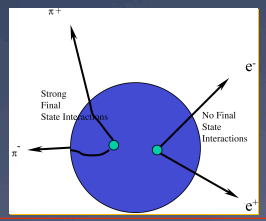


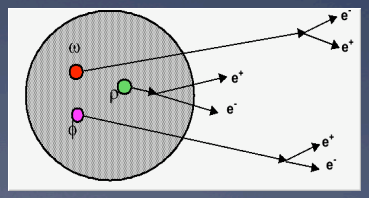
Medium modification of vector mesons

The predicted medium modifications are so large that even at normal nuclear density, they can be observed, so:

•Vector mesons can be produced in nuclei with probes that leave the nucleus in almost an equilibrium state γ,π,ρ,

• (probe) + A --> V X --> e^+e^- X (no FSI)





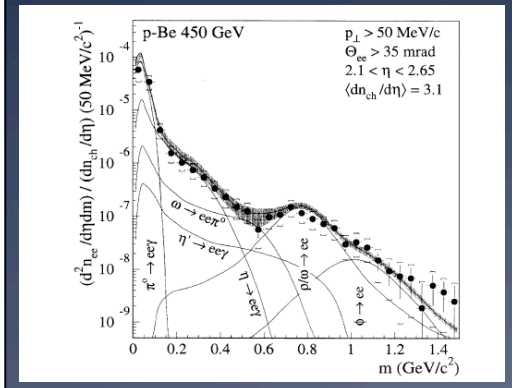
Vector mesons ρ: M=768 MeV Γ= 149 MeV $c\tau$~1.3 fm

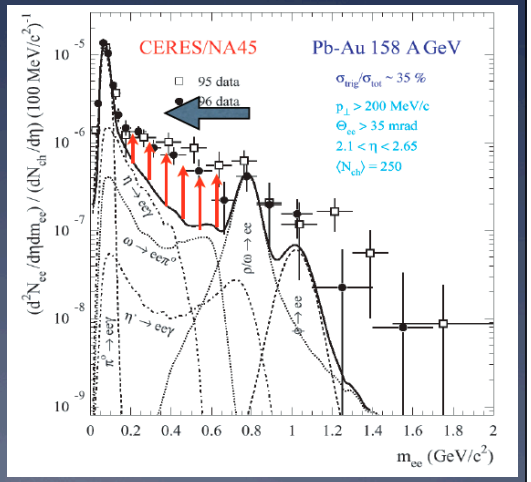
$J^P=1^-$ ω: M=782 MeV Γ = 8 MeV $c\tau$~23.4 fm

ϕ: M=1020 MeV Γ = 4 MeV

$c\tau$~44.4 fm

In RHI collisions (nuclear matter under extreme conditions)





KEK-PS E325 (ρ, ω)

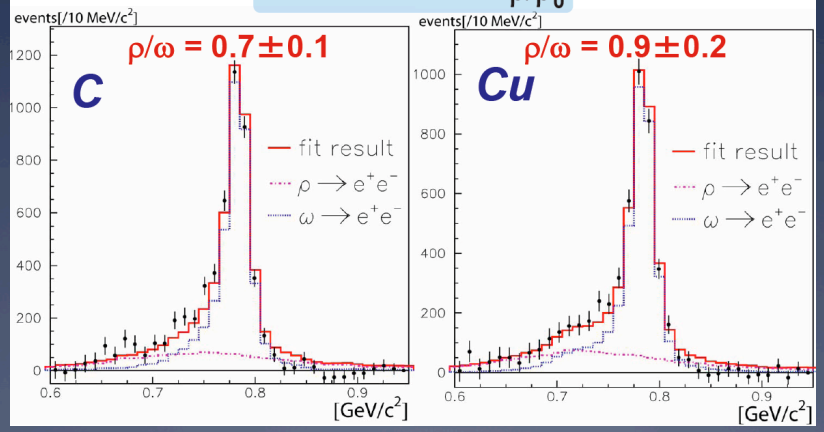
p+A → ρ,ω,ϕ+X (ρ,ω,ϕ → e+e-)

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

Subtract the background and constrain the ω/ρ ratio to include ρ

Using a model that predicts the probability for ρ mesons decaying inside the nucleus.

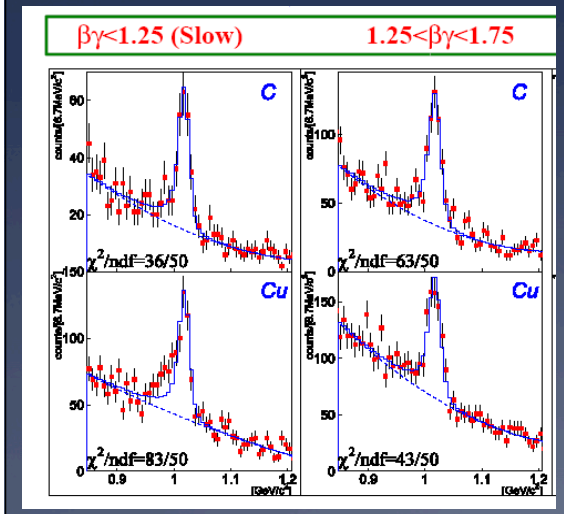
$m^*/m = 1 - 0.092\ \rho/\rho_0$



α = 0.092 +/- 0.002

"the fit … reproduces the data qualitatively well"

KEK-PS E325(ϕ)



mass shift for low recoil momenta ϕ in Cu

R.Muto et al., PRL 98 (2007) 042501

$$m^*/m = 1 - k_1\ \rho/\rho_0,$$

Best Fit Values

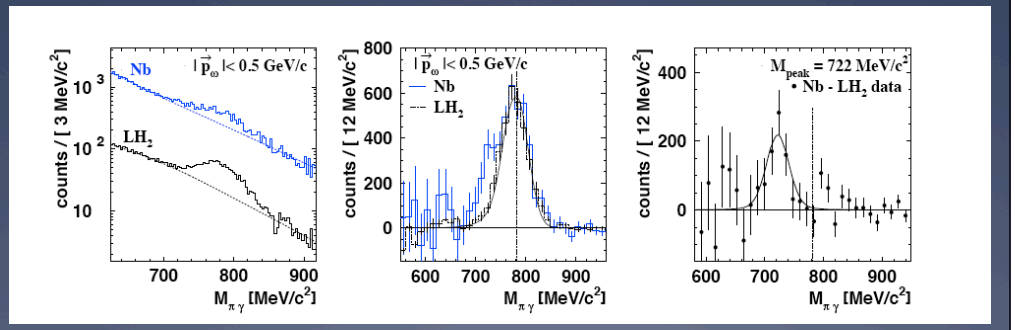
	ρ, ω	ϕ
k_1	9.2 ± 0.2%	$3.4^{+0.6}_{-0.7}$%
k_2	0 (fixed)	$2.6^{+1.8}_{-1.2}$

TAPS: CB-ELSA

$$\omega \rightarrow \pi^0 \gamma$$

$$p_\omega < 500\ \mathrm{MeV}/c^2$$

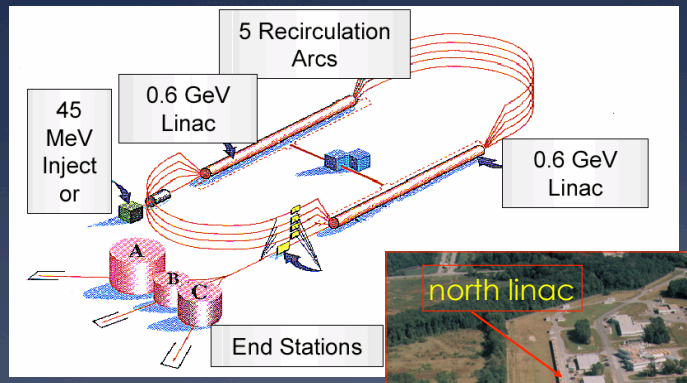
$$m = m\left(1 + 0.14\frac{\rho}{\rho_0}\right)$$

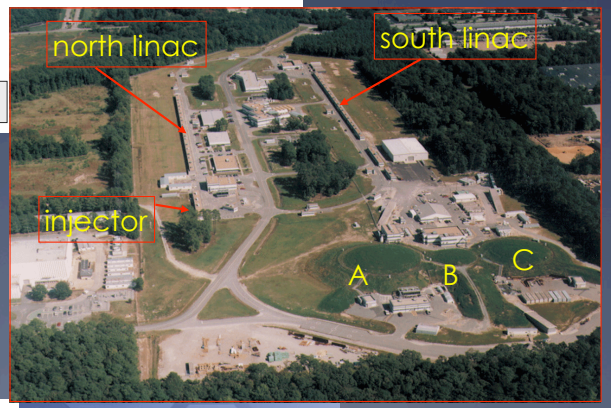


Experiment Reactions Results

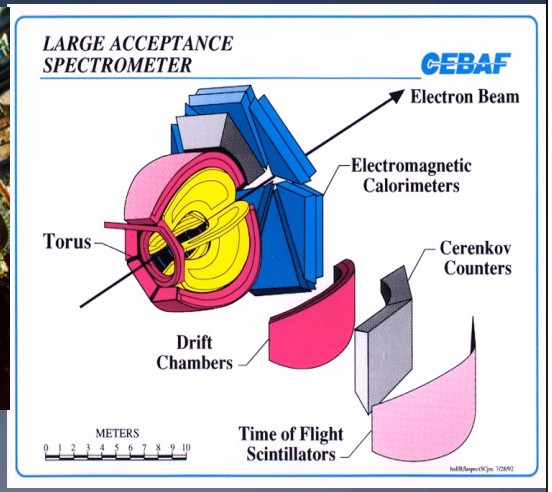
TAGX $\gamma + {}^3He \rightarrow \rho + X$ ($\rho \rightarrow \pi^+\pi^-$) full BR, $\alpha \sim 0.06$
KEK $p+A \rightarrow \rho,\omega,\phi+X$ ($\rho,\omega \rightarrow e^+e^-$) $\alpha = 0.092 \pm 0.002$
KEK $p+A \rightarrow \phi+X$ ($\phi \rightarrow e^+e^-$) $\alpha \sim 0.04$
SPring-8 $\gamma + A \rightarrow \phi + A^*$ ($\phi \rightarrow K^+K^-$) no effect
TAPS $\gamma+A \rightarrow \omega+X$ ($\omega \rightarrow \pi^0 \gamma$) $\alpha \sim 0.13$-015
JLab-g7a $\gamma+A \rightarrow (\rho,\omega,\phi)+A^*$ (VM$\rightarrow e^+e^-$) $\alpha = 0.02 \pm 0.02$
JPARC $p+A \rightarrow \rho,\omega,\phi+X$ ($\rho,\omega,\phi \rightarrow e^+e^-$) proposal #16
HADES $p+p,d \rightarrow \rho,\omega,\phi+X$ ($\rho,\omega,\phi \rightarrow e^+e^-$) (running)

-Only g7 with EM interaction in entrance and exit channels
-TAGX, Spring8 and TAPS have hadronic FSI.


5 Recirculation Arcs
0.6 GeV Linac
45 MeV Inject or
0.6 GeV Linac
A
B
C
End Stations

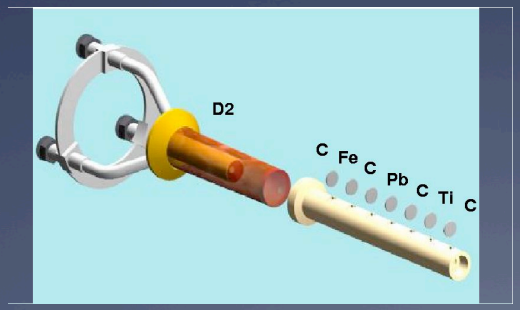

north linac
south linac
injector
A
B
C

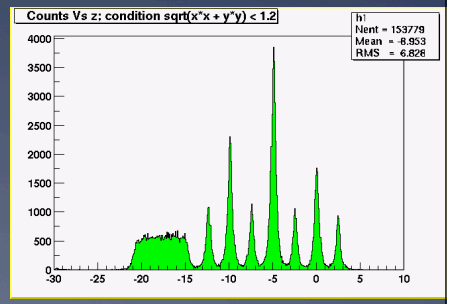
Particle Detection In CLAS



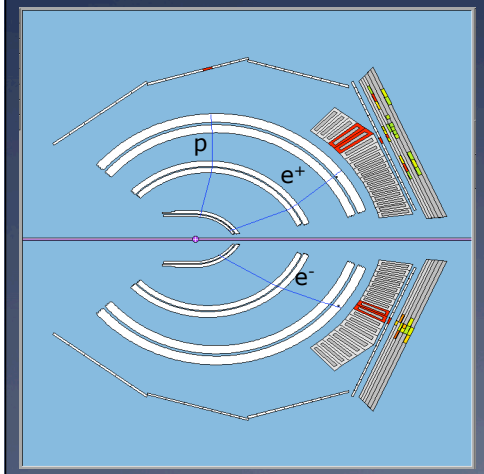
Segmented Target

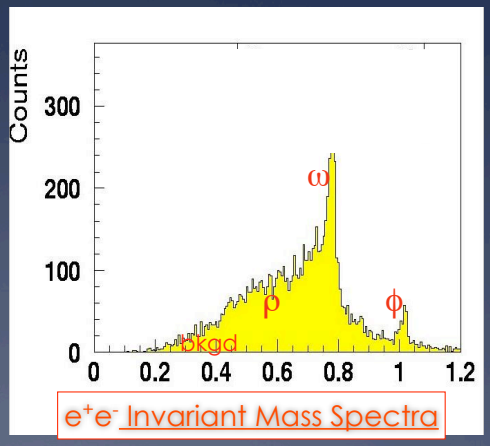
- Foils of Carbon, Iron, Titanium, and Lead
- LD2 (LH2) as control





Excellent π/e Rejection



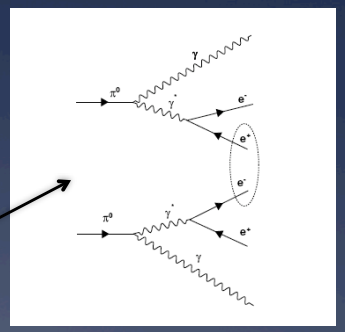


e^+e^- Invariant Mass Spectra

Excellent π/e discrimination: 5.4×10^{-4} for one and 2.9×10^{-7} for two arms.

Backgrounds

Correlated:
Monte-Carlo simulations using a model (BUU) by Mosel et al. (Nucl. Phys. A671, 503) including various decay channels and nuclear effects, and CLAS detector simulation package (GSIM) Simulations with BUU includes all the e+e- decay channels with same strength.



Semi-correlated":
Bethe-Heitler
$\gamma A \rightarrow \pi^0 \pi^0 X \rightarrow \gamma$ e+e- γ e+e-
$\pi^0 \rightarrow$ e+e- e+e-

calculated by Mosel's group → negligible
2 π^0 Dalitz decay mixed → negligible
double Dalitz → low mass

Uncorrelated:
Mixed event technique. Pairs of identical (e+e+, e-e-) leptons, which are produced only by combinatorial background provide a natural normalization and samples of uncorrelated particles.

Uncorrelated Background

$$P(r,\mu) = \frac{\mu^r}{r!}e^{-\mu}$$

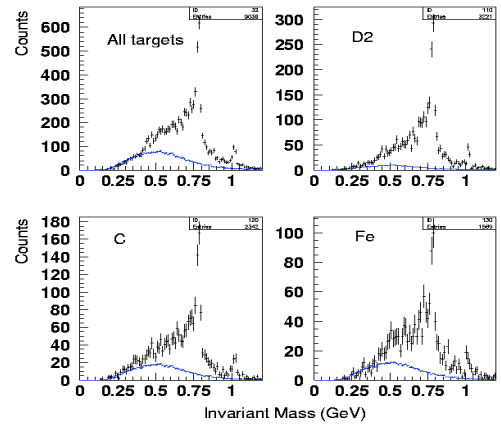
$$P_+ = P(1,\mu_+) = \mu_+ e^{-\mu_+}$$
$$P_- = P(1,\mu_-) = \mu_- e^{-\mu_-}$$

$$P_{++} = P(2,\mu_+) = \frac{1}{2}\mu_+^2 e^{-\mu_+}$$
$$P_{--} = P(2,\mu_-) = \frac{1}{2}\mu_-^2 e^{-\mu_-}$$
$$P_{+-} = P_+ P_-$$

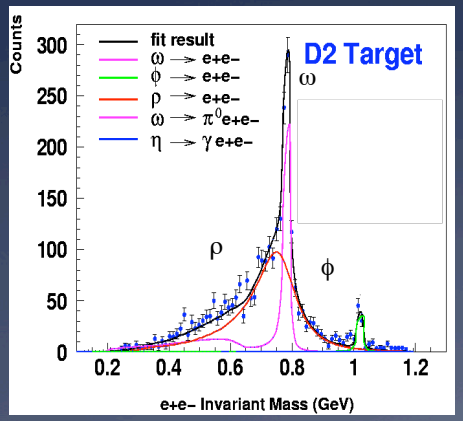
$$P_{++} = \frac{1}{2}\mu_+^2 e^{-\mu_+} = \frac{1}{2}\mu_+ e^{-\mu_+}\mu_+ e^{-\mu_+} e^{\mu_+} = \frac{1}{2}P_+^2 e^{\mu_+}$$
$$P_{--} = \frac{1}{2}P_-^2 e^{\mu_-}$$

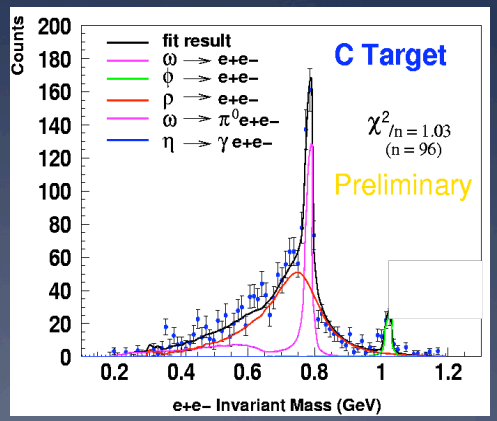
$$\mu \ll 1 \Rightarrow e^{\mu} \to 1$$

$$P_{+-} = 2\sqrt{P_{++}P_{--}}$$

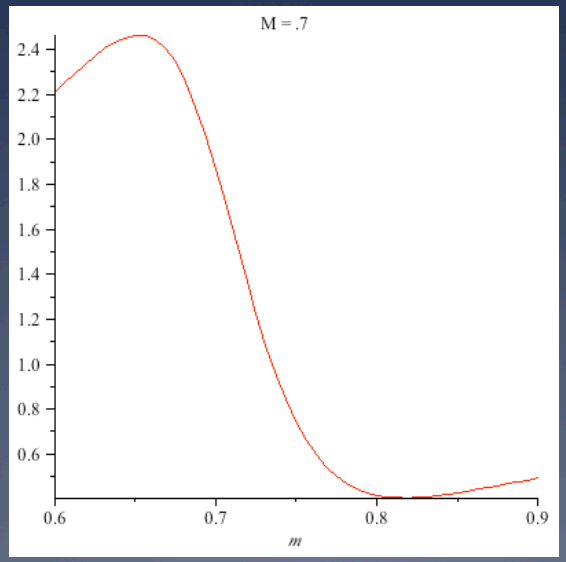


$e^+ e^-$ Spectra: Background Subtracted Fit Results

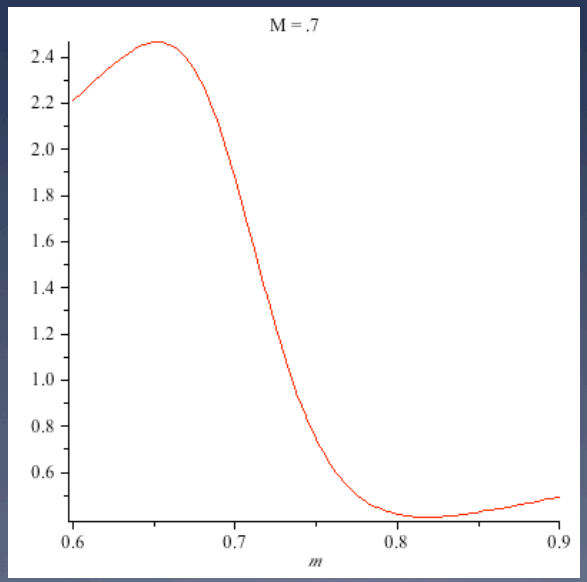




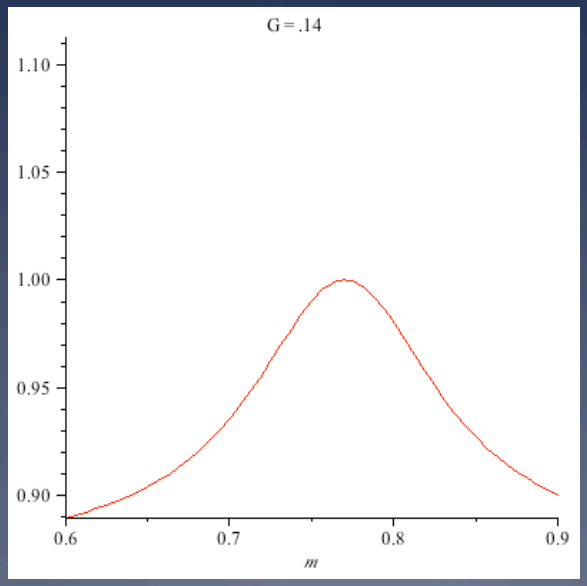
Ratio A/^{2}H: Varying pole mass



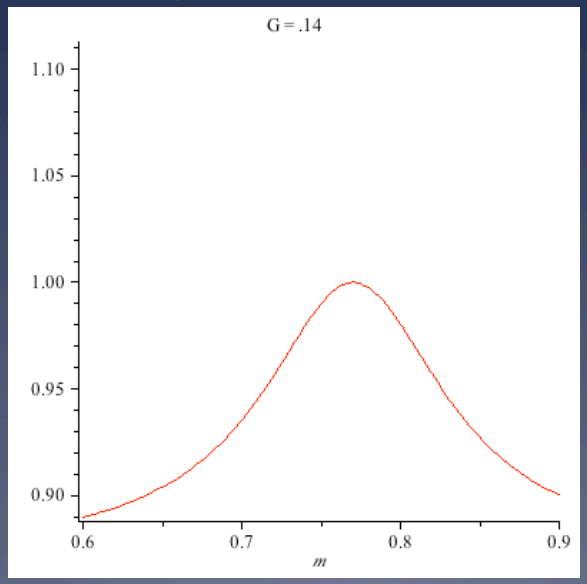
Ratio A/^{2}H: Varying pole mass

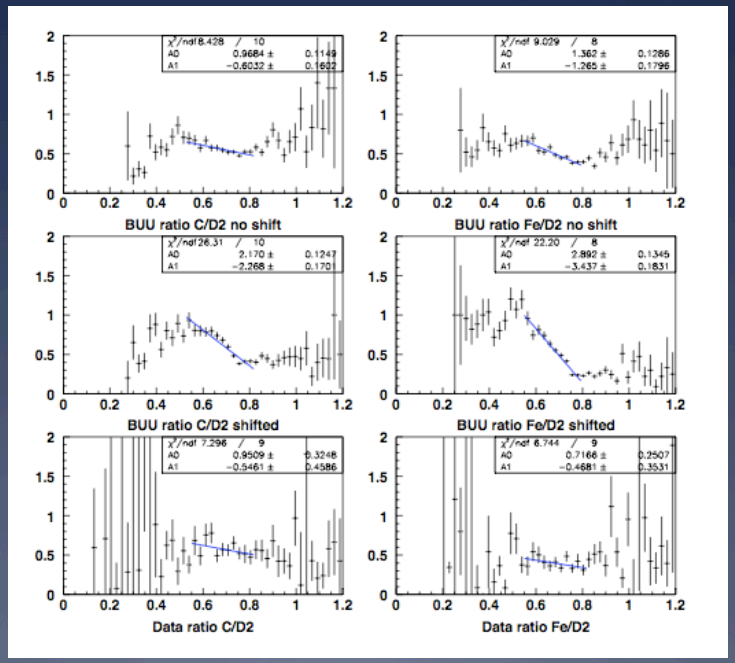


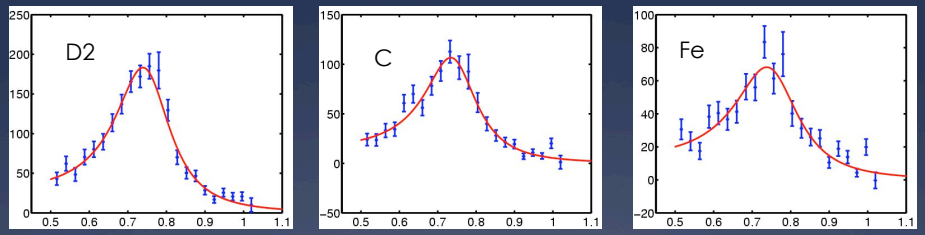
Ratio A/^{2}H: Varying width



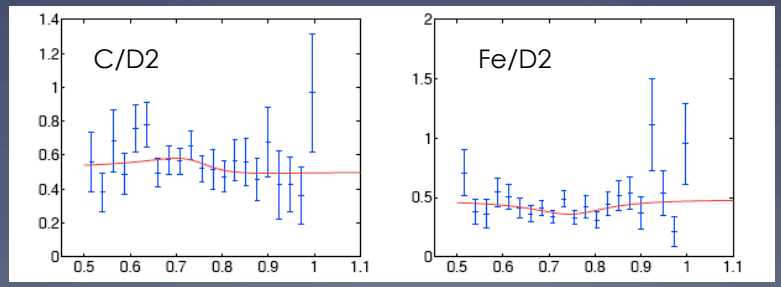
Ratio A/^{2}H: Varying width




χ²/ndf 8.428 / 10
A0 0.9684 ± 0.1149
A1 −0.6032 ± 0.1602
BUU ratio C/D2 no shift
χ²/ndf 9.029 / 8
A0 1.362 ± 0.1286
A1 −1.265 ± 0.1796
BUU ratio Fe/D2 no shift
χ²/ndf 26.31 / 10
A0 2.170 ± 0.1247
A1 −2.268 ± 0.170
BUU ratio C/D2 shifted
χ²/ndf 22.20 / 8
A0 2.892 ± 0.1345
A1 −3.437 ± 0.1831
BUU ratio Fe/D2 shifted
χ²/ndf 7.296 / 9
A0 0.9509 ± 0.3248
A1 −0.5461 ± 0.4586
Data ratio C/D2
χ²/ndf 6.744 / 9
A0 0.7166 ± 0.2507
A1 −0.4681 ± 0.3531
Data ratio Fe/D2



e^+e^- Invariant Mass (GeV)



Summary on the ρ meson

Target	Mass (MeV)	Width (MeV)	Mass Giessen BUU	Width Giessen BUU
^2H	770.3 +/- 3.2	185.2 +/- 8.6	-	-
C	762.5 /- 3.7	176.4 +/- 9.5	773.8 +/- .9	177.6 +/- 2.1
Fe	779.0 +/- 5.7	217.7 +/- 14.5	773.8 +/- 5.4	202.5 +/- 11.6

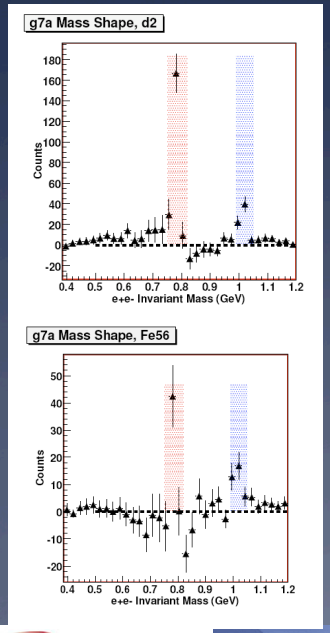
Summary on the ρ meson

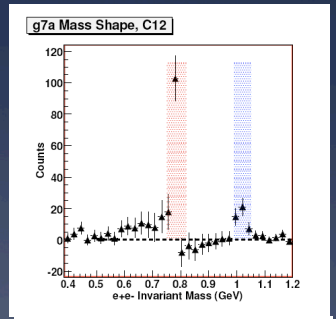
Our result (α =0.02 ± 0.02) is consistent with no mass shift
Result does not confirm the KEK results (α ~0.09).
Rule out ΔM à la Brown/Rho (20%) and Hatsuda/Lee (α ~0.16)
width reproduced by GiBUU

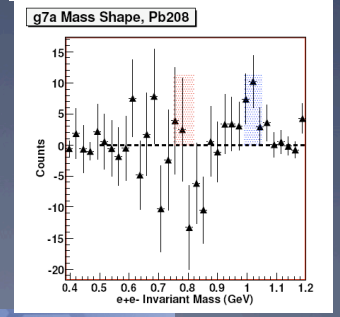
momentum of ρ limited between 0.8 and 2 GeV

- PRL published – R. Nasseripour *et al.*, PRL 99 (2007) 262302
- PRC submitted February 2008. M. Wood *et al.*, arXiv:0803.0492v1 [nucl-ex]

ω/ϕ Absorption



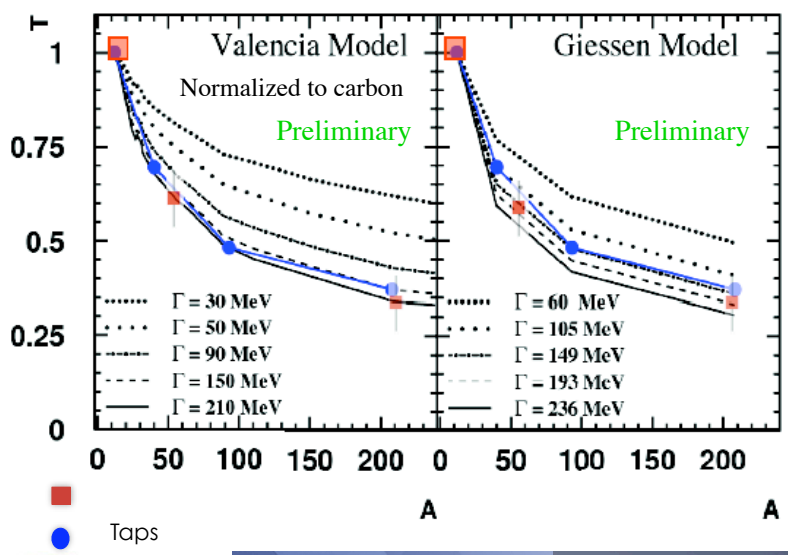




ω absorption

The in-medium width is $\Gamma=\Gamma_0+\Gamma_{coll}$ where $\Gamma_{coll} = \gamma\rho v\sigma^*_{VN}$

Kaskulov, Hernandez & Oset EPJ A 31 (2007) 245 P. Mühlich and U. Mosel NPA 773 (2006) 156

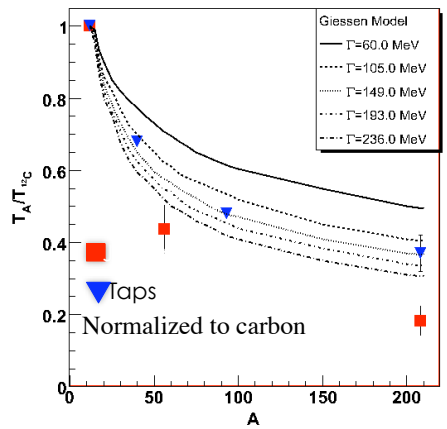


ω Absorption

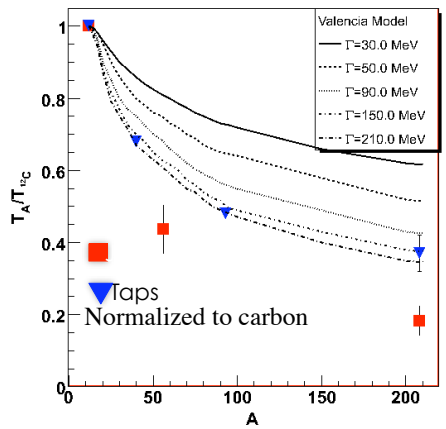
The in-medium width is
$\Gamma=\Gamma_0+\Gamma_{coll}$ where $\Gamma_{coll} = \gamma\rho v\sigma^*_{VN}$

Access to the cross section
$T_A=\sigma_A/A\sigma_N$

P. Mühlich and U. Mosel NPA 773 (2006) 156

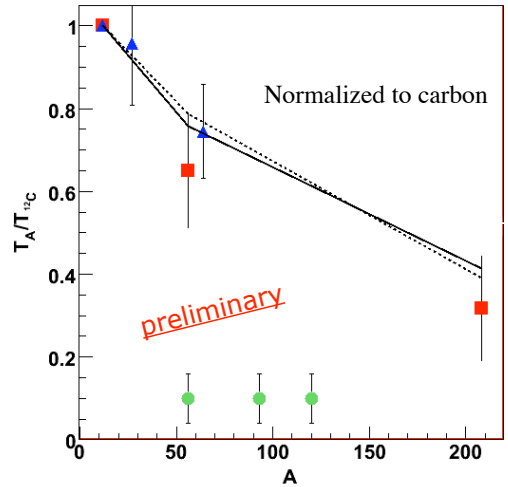


Kaskulov, Hernandez & Oset EPJ A 31 (2007) 245



ϕ Absorption

Spring8 γ A $\rightarrow \phi$ A′ $\rightarrow$ K^+K^- A′ ($E\gamma$=1.5-2.4 GeV)



Giessen calculations

Giessen calculations w/ Spring8 absorption strengths

JLab (preliminary)

Spring8
T. Ishikawa et al. Phys. Lett. B 608, 215 (2005)

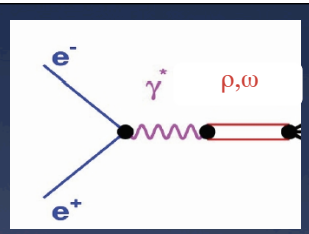
Proposed JLab data

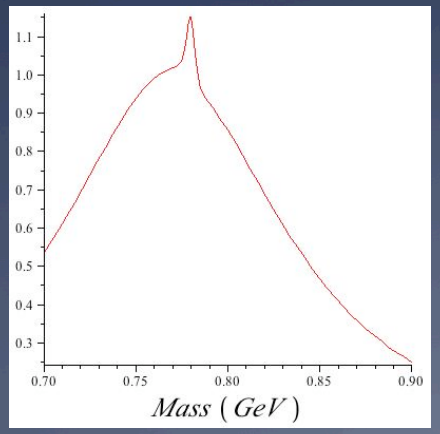
$$\sigma_{\phi N} \sim 25 - 55\mathrm{m}b$$

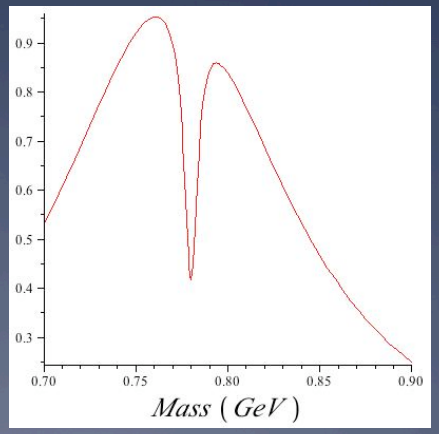
$$\Gamma_{coll} \sim 11 - 25\ MeV$$

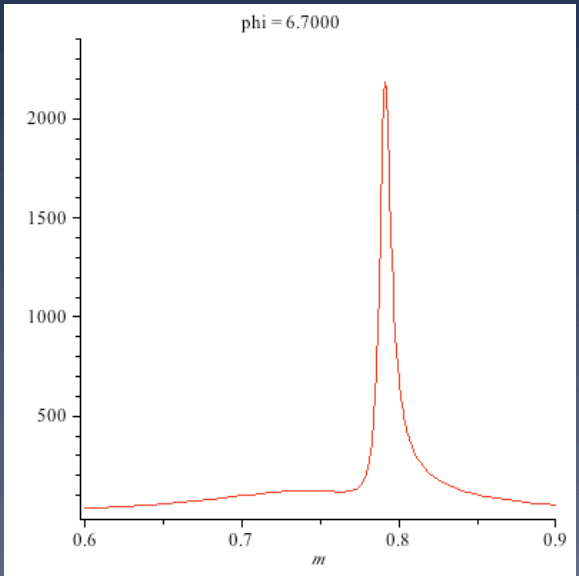
Large statistical error bars.

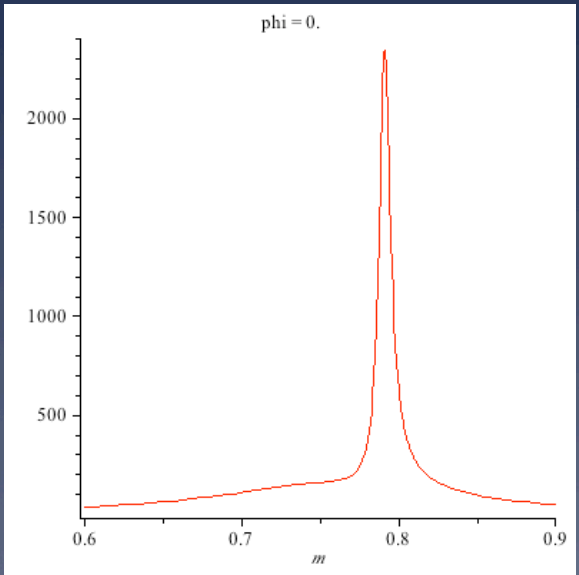
ρ–ω Interference



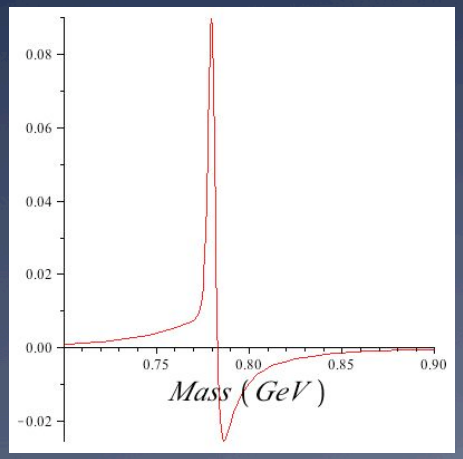


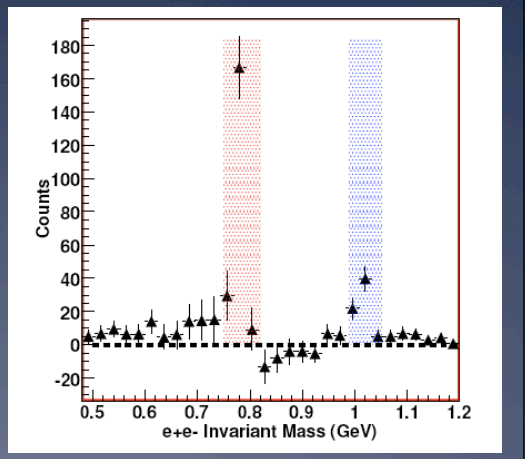



phi = 6.7000
2000
1500
1000
500
0.6
0.7
0.8
0.9
m


phi = 0.
2000
1500
1000
500
0.6
0.7
0.8
0.9
m

ρ–ω Interference





Summary and Conclusions (Medium Modifications)

CLAS was an excellent tool for these studies:

- e^+e^- from rare leptonic decay of light vector mesons are identified.
- Clear ρ, ω and ϕ signals in the invariant mass spectrum.
- "Mixed-event" technique gives both shape and normalization of the combinatorial background.

The ρ meson (Final):

- Correct mass shape is extracted.
- No mass shift and width increased by 40% in Fe (as predicted by GiBUU)

The ω meson (preliminary):

- From transparency ratios, width at least ~ 150 MeV!

The ϕ meson (preliminary):

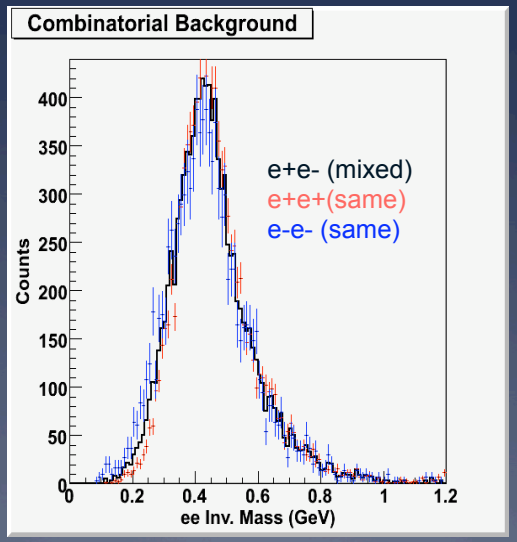
- From transparency ratios, in medium total cross section ~ 30 mb

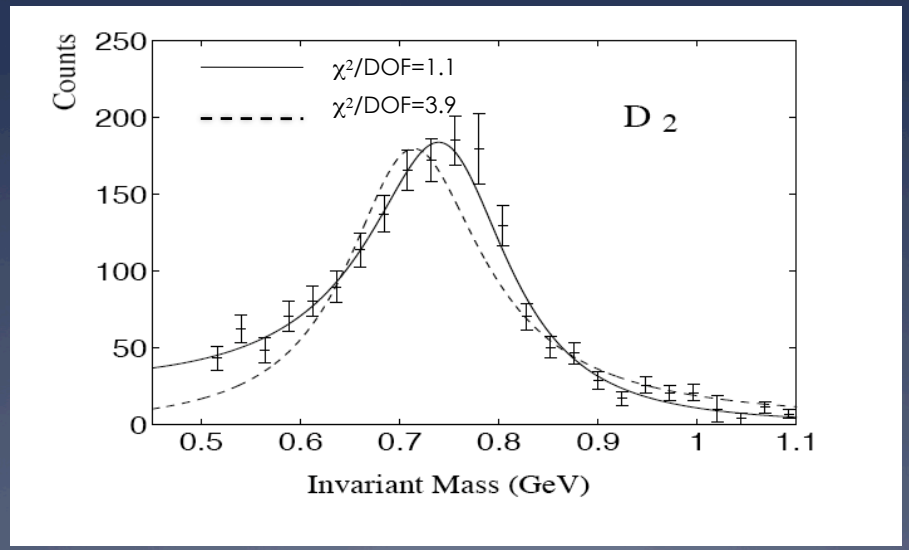
Next at Jlab by g7 group:

- High Statistics measurement of e^+e^- production on H_2 g_{12} 70 pb^{-1}
- Conditionally approved g_{7b} high statistics data on LD_2, C, Fe, Nb and Sn

The End

Extra Slides


Combinatorial Background
Counts
ee Inv. Mass (GeV)
e+e- (mixed)
e+e+(same)
e-e- (same)
0
50
100
150
200
250
300
350
400
0
0.2
0.4
0.6
0.8
1
1.2


Counts
250
200
150
100
50
0
0.5
0.6
0.7
0.8
0.9
1
1.1
Invariant Mass (GeV)
χ²/DOF=1.1
χ²/DOF=3.9
D 2

Systematic errors on α

TABLE II: Summary of systematic uncertainties in the mass shift parameter α. For the total error, the individual contributions were added in quadrature.

Source	Description	$\Delta\alpha$
Vertex Cuts	Radial Position	0.003
	z Position	0.001
	Time	0.002
Corrections	Momentum Corrections	0.0015
	Target Energy Loss	0.001
Target Position	z Dependence	0.006
Background Sub.	Mixed-Event Normalization Factor	0.001
Fit Range	Table III	0.007
Total	Sum of individual sources	0.01