

Evidence of ρ , ω and ϕ meson mass modification in nuclear medium measured in 12 GeV p+A reaction at KEK-PS E325

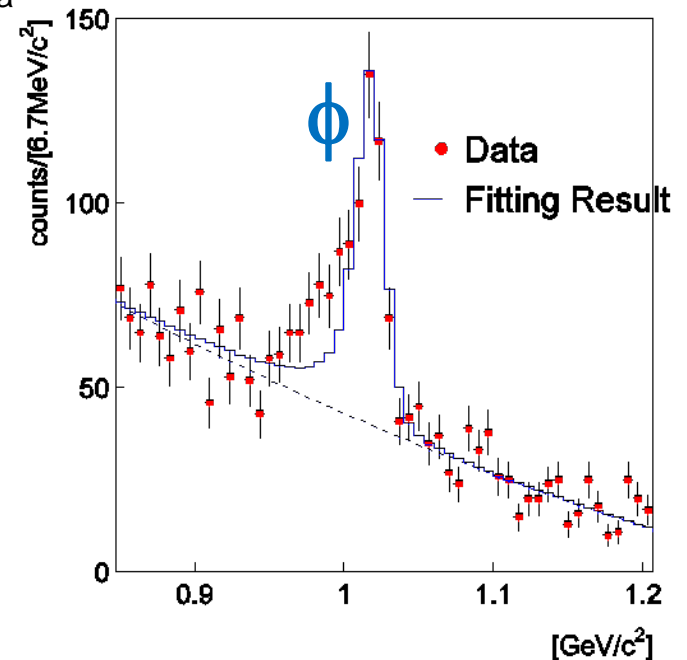
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(KEK-PS **E325** Collaboration)

- Introduction
- Result of $\rho/\omega \rightarrow e^+e^-$ analysis
- Result of $\phi \rightarrow e^+e^-$ analysis



Vector meson mass at finite density

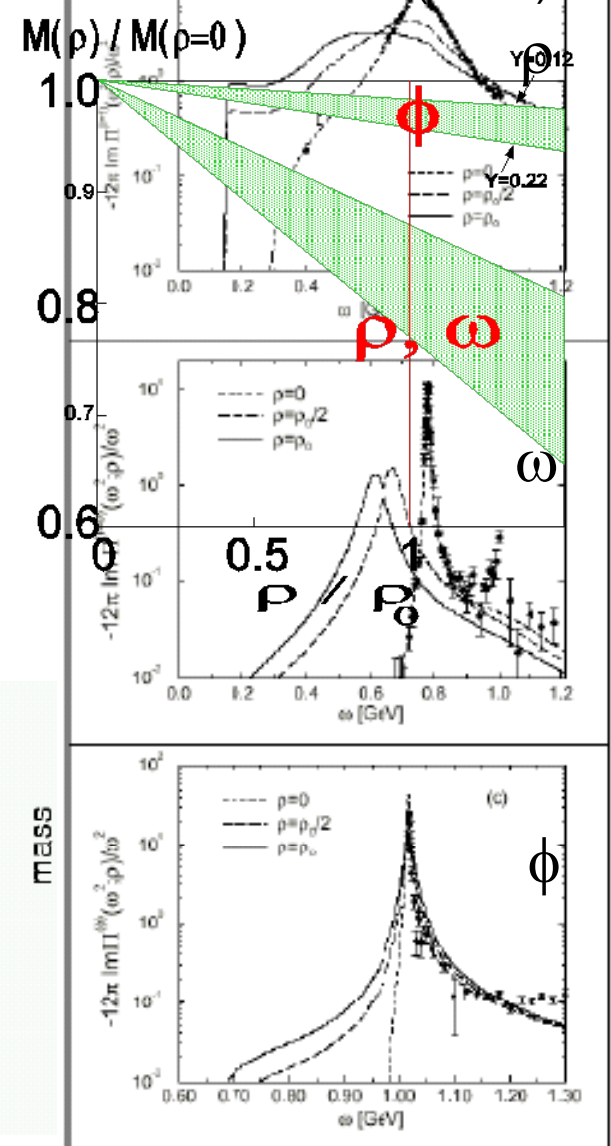
dropping mass

- Brown-Rho scaling ('91)
 - $m^*/m = 0.8$ at $\rho = \rho_0$
- QCD Sum Rule by Hatsuda & Lee ('92)
 - $m^*/m = 1 - 0.16 \rho/\rho_0$ for ρ/ω
 - $m^*/m = 1 - 0.03 \rho/\rho_0$ for ϕ
- Lattice Calc. by Muroya, Nakamura & Nonaka('03)

width broadening (at ρ_0)

- Klingl, Kaiser, Weise ('97-8)
 - $\Gamma^*/\Gamma \sim 10$ for $\rho/\omega/\phi$
- Rapp & Wambach ('99) : $\Gamma^*/\Gamma_\rho \sim 2$
- Oset & Ramos ('01) : $\Delta\Gamma_\phi = 22\text{MeV}$
- Cabrera & Vicente ('03) : $\Delta\Gamma_\phi = 33\text{MeV}$

Hatsuda & Lee PRC46(1992)R34



E325 experiment

Invariant Mass of e^+e^- , K^+K^-

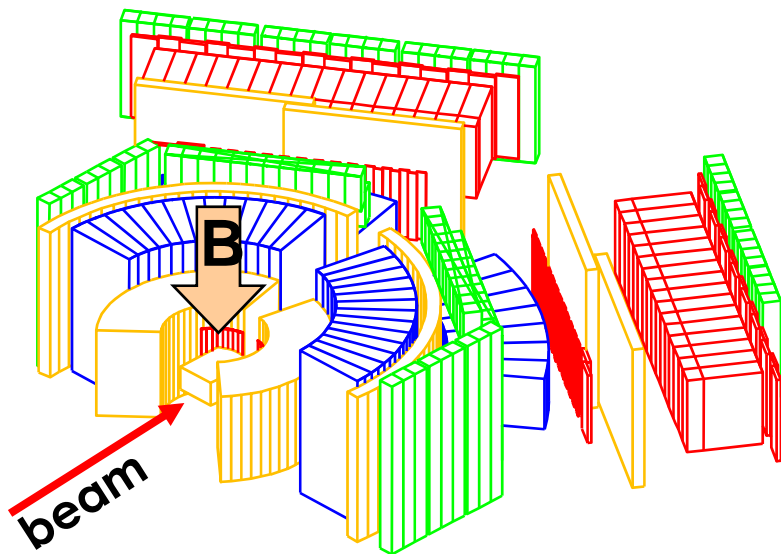
in $12\text{GeV } p + A \rightarrow \rho, \omega, \phi + X$

- Slowly moving ρ, ω, ϕ ($p_{\text{lab}} \sim 2\text{GeV}/c$)

→ Large acceptance

spectrometer

- Primary proton beam $\sim 10^9$ ppp
- Thin targets: 0.2%/0.05% (C/Cu)
radiation length: 0.4%/0.5% (C/Cu)



History

'93 proposed

'96 construction start

✓ *NIM*, A457, 581 (2001)

✓ *NIM*, A516, 390 (2004)

'97 first K^+K^- data

'98 first e^+e^- data

✓ *PRL*, 86, 5019 (2001)

'99~'02

x100 statistics in e^+e^-

✓ ρ/ω : *PRL* 96, 092301 ('06)

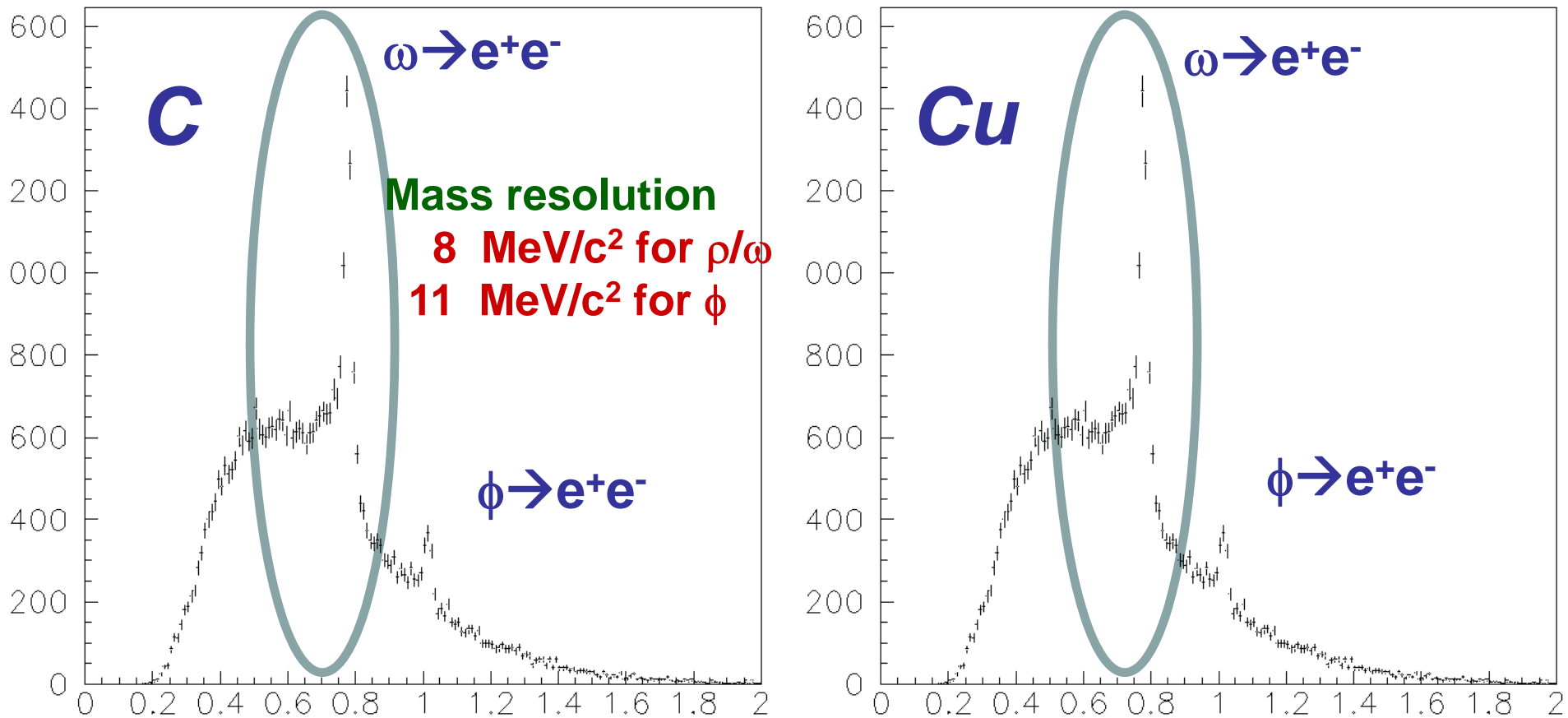
✓ $\phi \rightarrow ee$: *PRL* 98, 042501 ('07)

✓ α : *PRC*, 75, 025201 ('06)

x6 statistics in K^+K^-

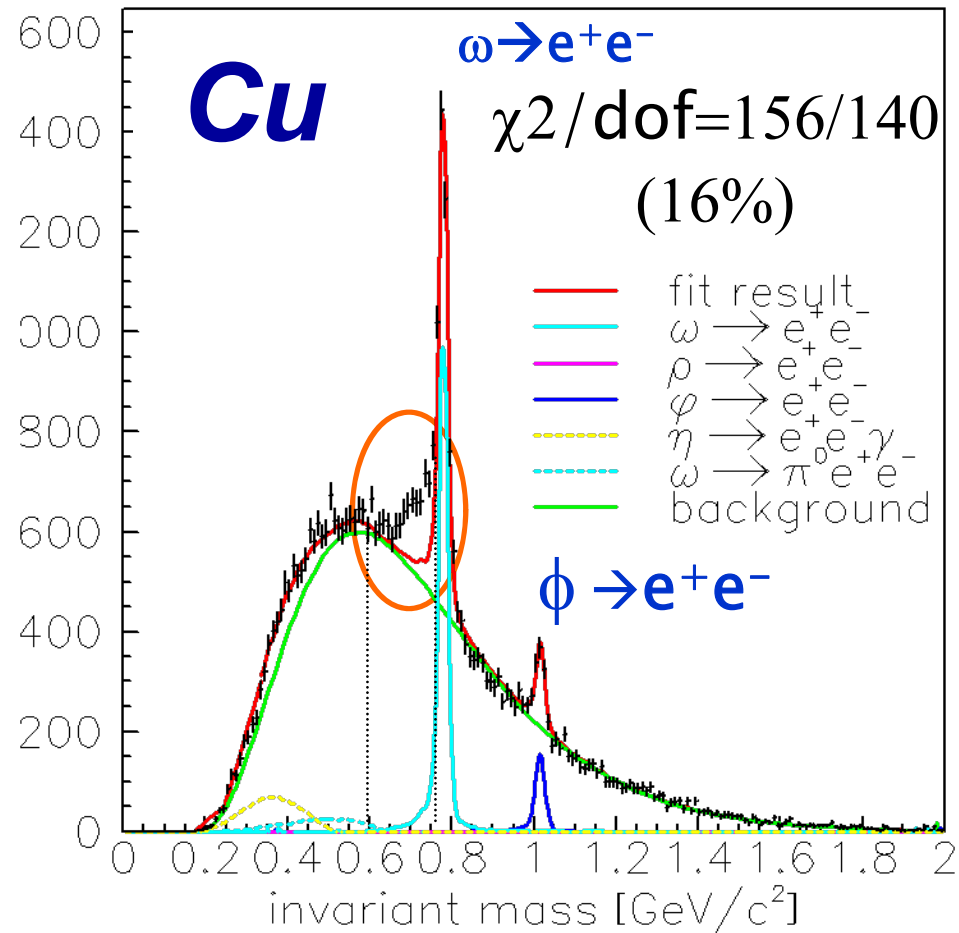
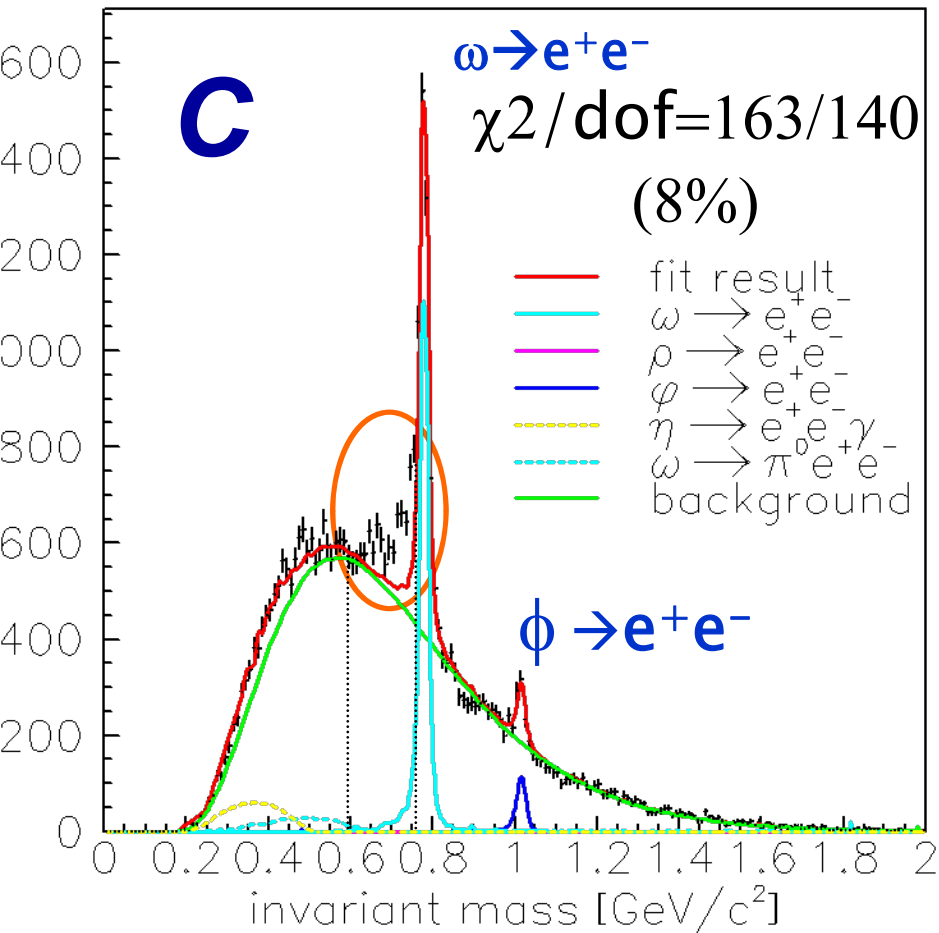
✓ $\phi \rightarrow KK$: *PRL* 98, 152302 ('07)

Invariant mass spectra of e^+e^-



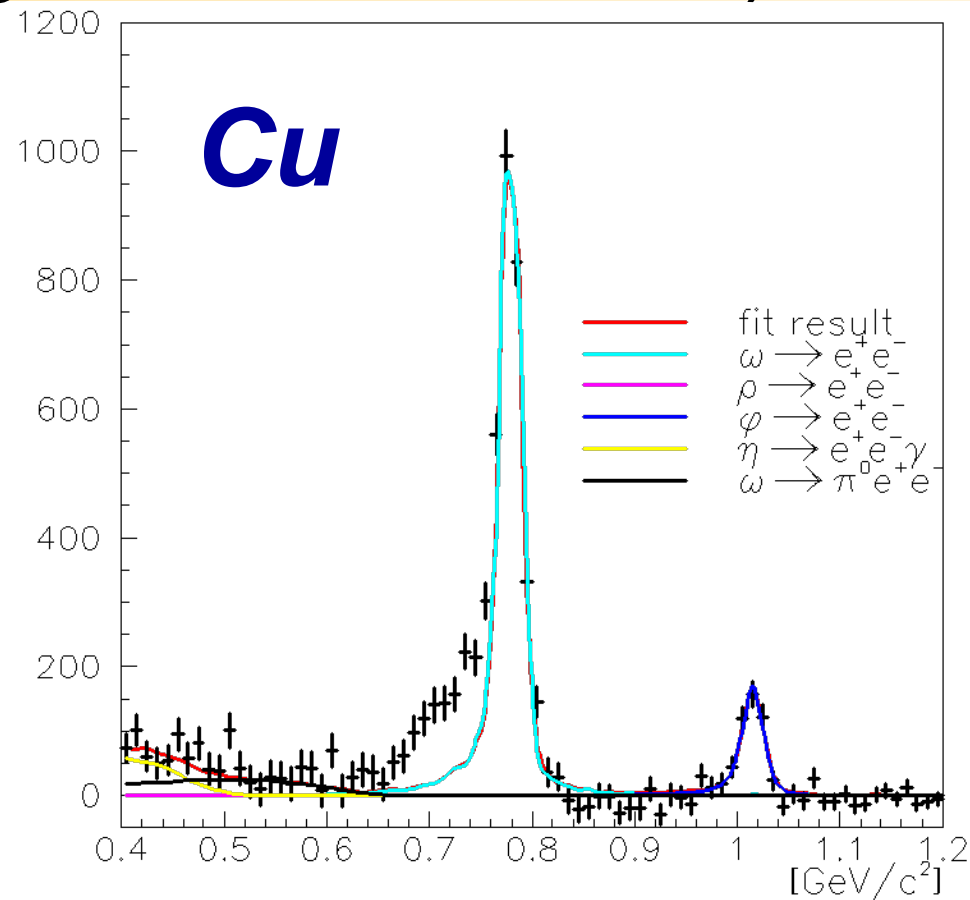
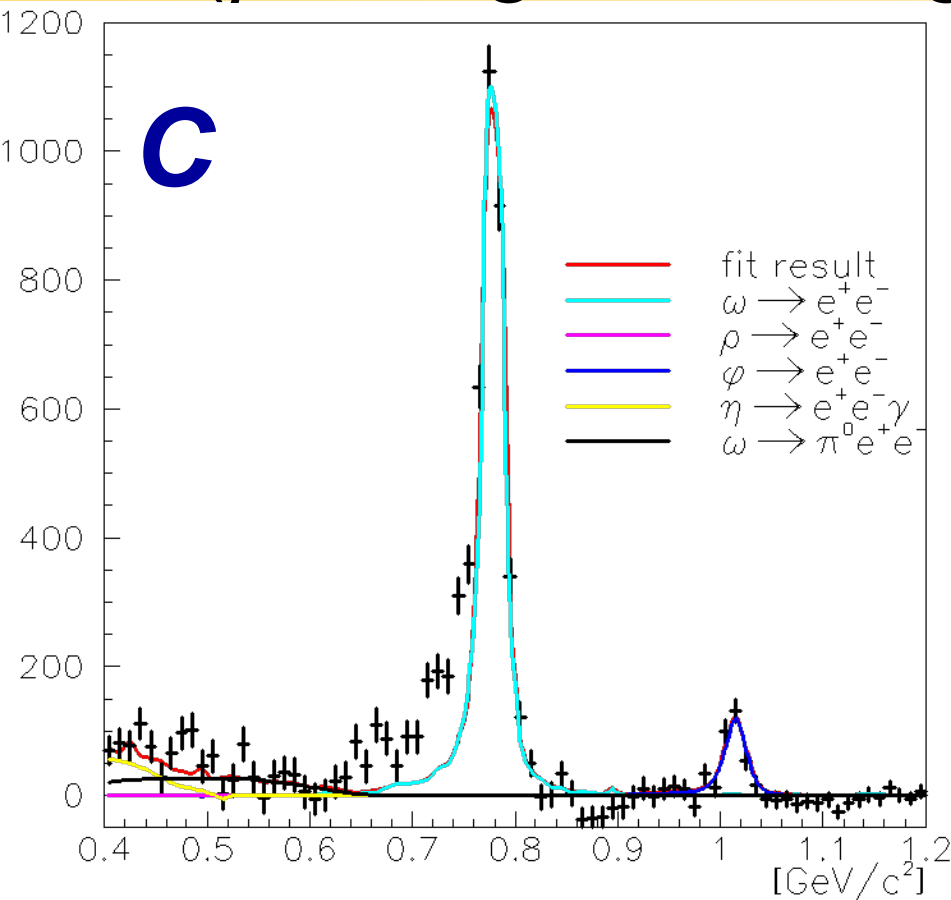
We examine how well the data are reproduced with known hadronic sources & combinatorial background

Invariant mass spectra of e^+e^-



the **excess over the known hadronic sources** on the low mass side of ω peak has been observed.

Invariant mass spectra of e^+e^- (ρ/ω region, background subtracted)



ρ/ω ratio is consistent with zero

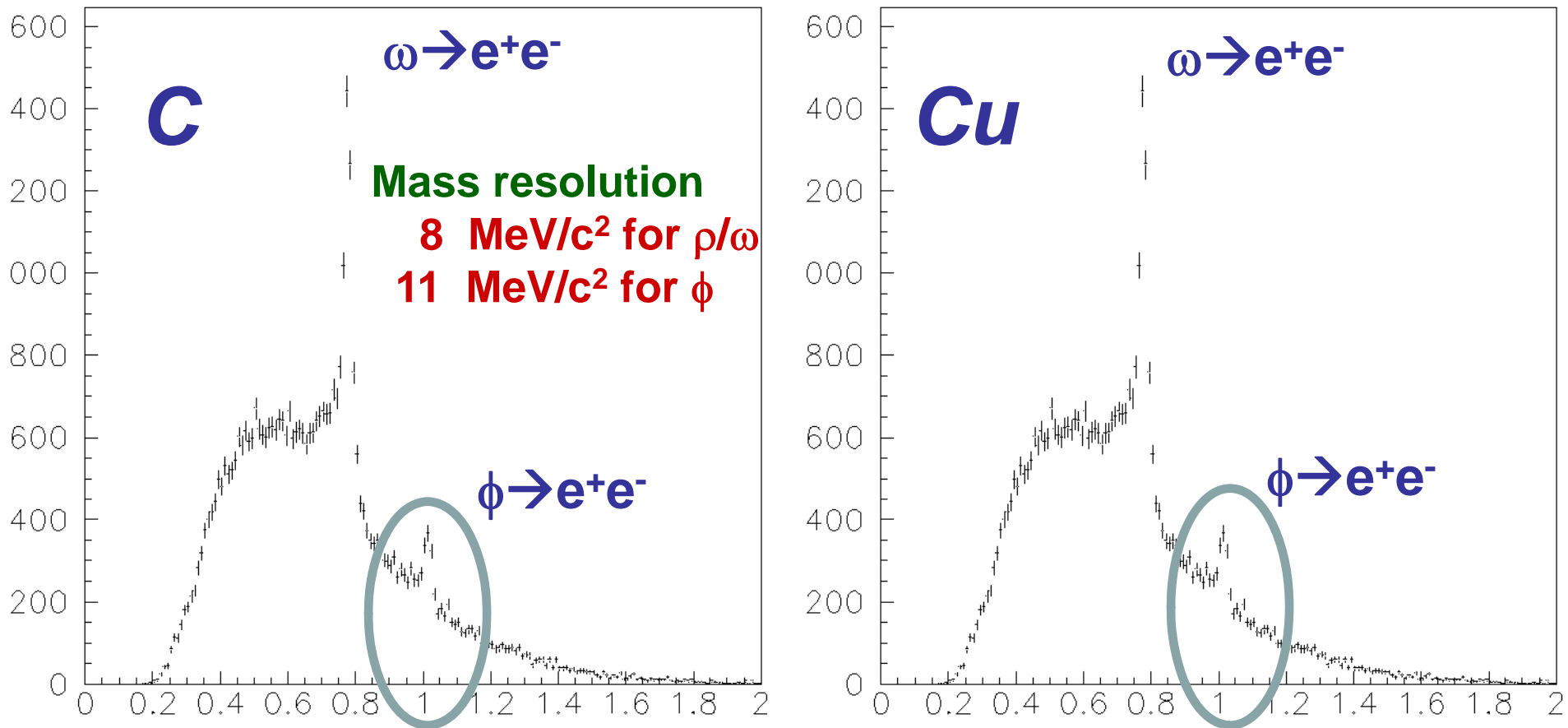
$$N_{\rho}/N_{\omega} = 0.0 \pm 0.02(\text{stat.}) \pm 0.2(\text{sys.})$$

$$0.0 \pm 0.04(\text{stat.}) \pm 0.3(\text{sys.})$$

→ the excesses are mainly due to modified ρ mesons

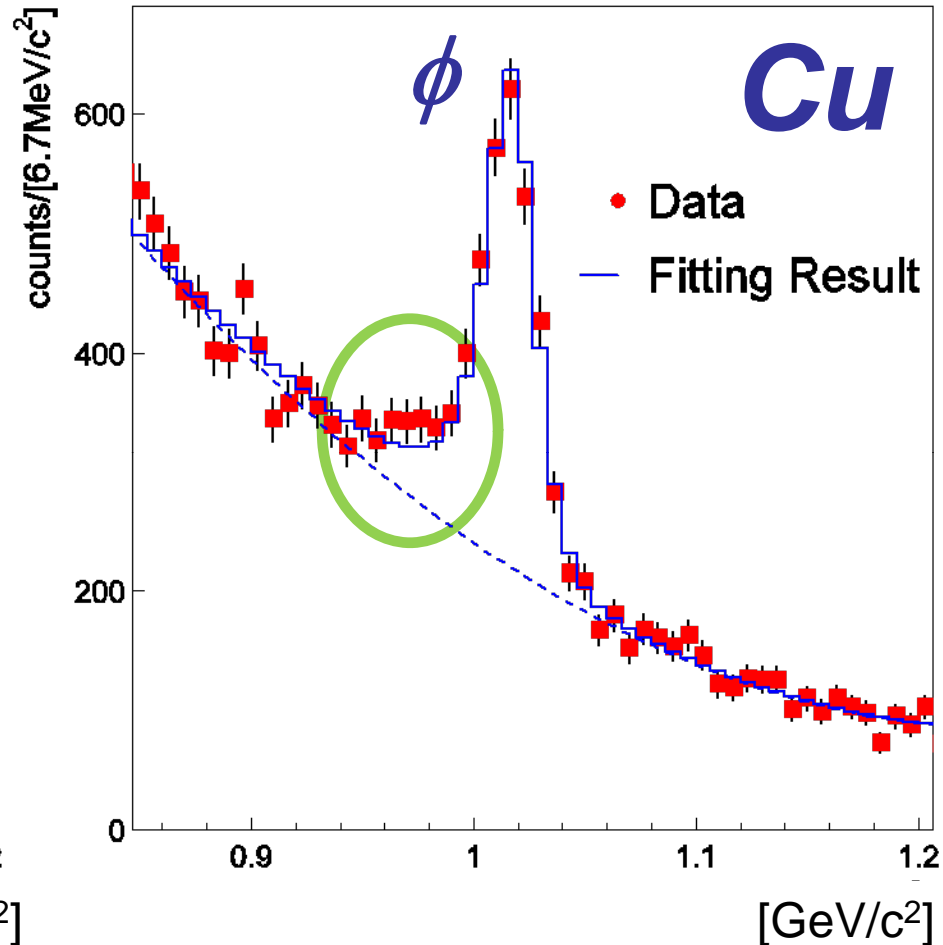
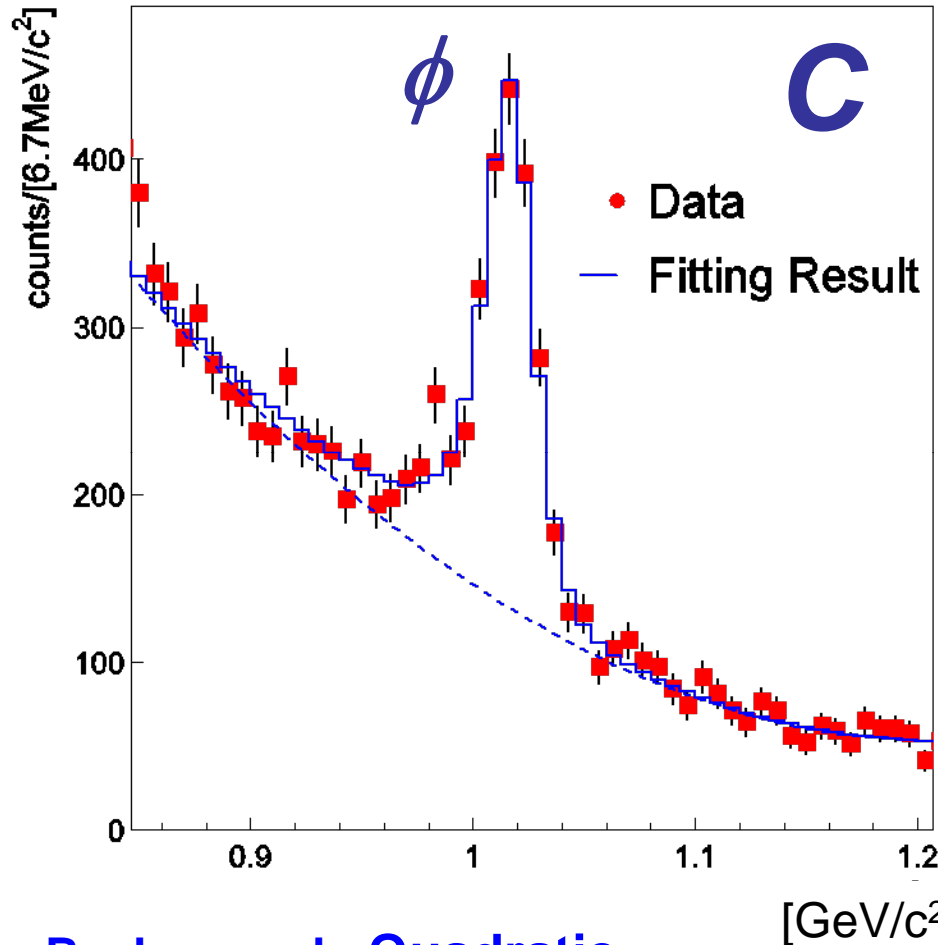
Lifetime of ρ : $c\tau \sim 1.3\text{fm}$ → excess can be observed in both C & Cu

Invariant mass spectra of e^+e^-



We examine how well the data are reproduced with known hadronic sources & quadratic background

Invariant mass spectra of $\phi \rightarrow e^+e^-$



Background : Quadratic curve

Some hints on the low mass side of the ϕ meson peak in Cu data

Slowly moving ϕ has larger probability to decay inside nucleus

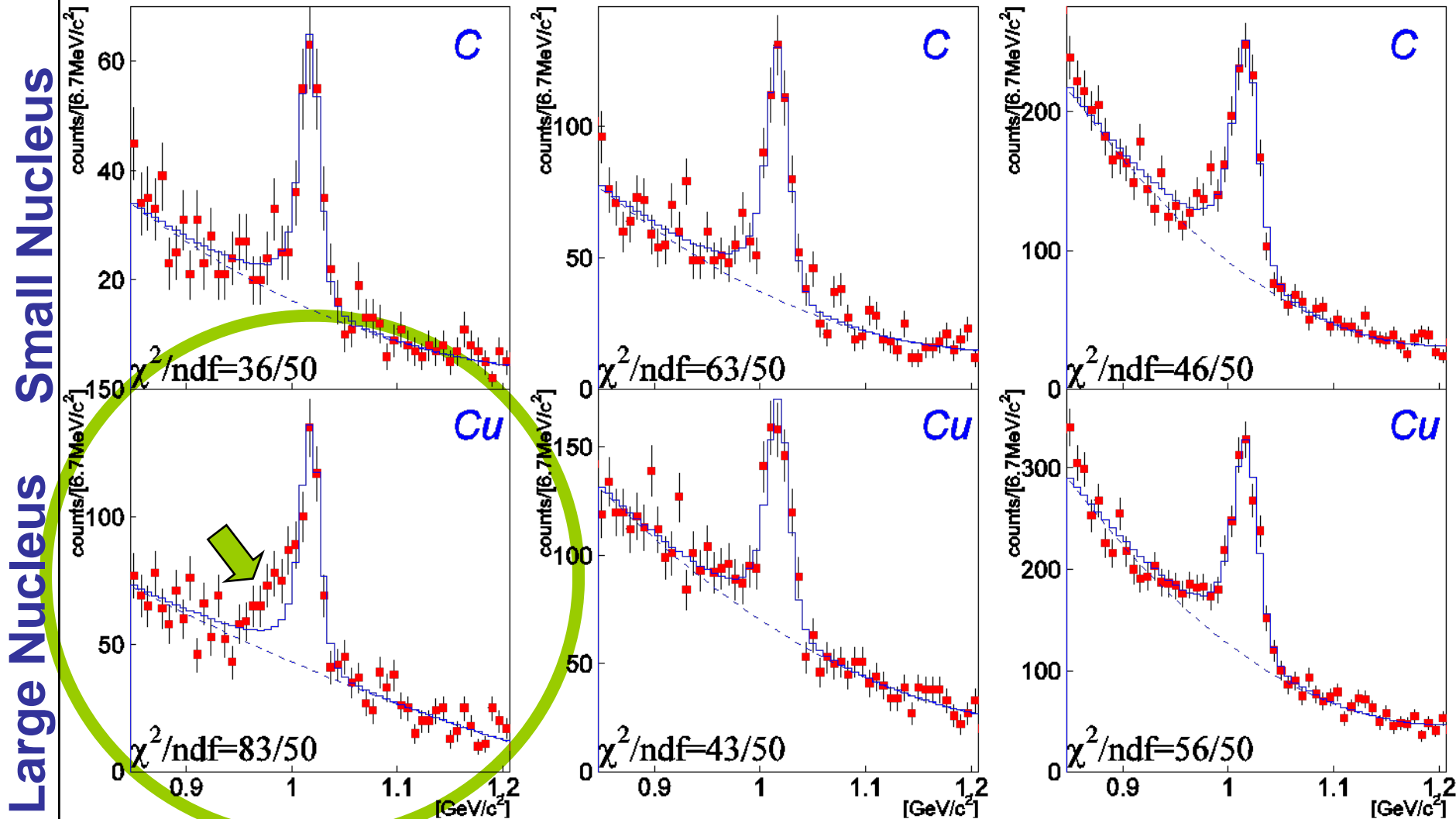
→ We divided the data by $\beta\gamma$ (= p/m)

Invariant mass spectra of $\phi \rightarrow e^+e^-$

$\beta\gamma < 1.25$ (Slow)

$1.25 < \beta\gamma < 1.75$

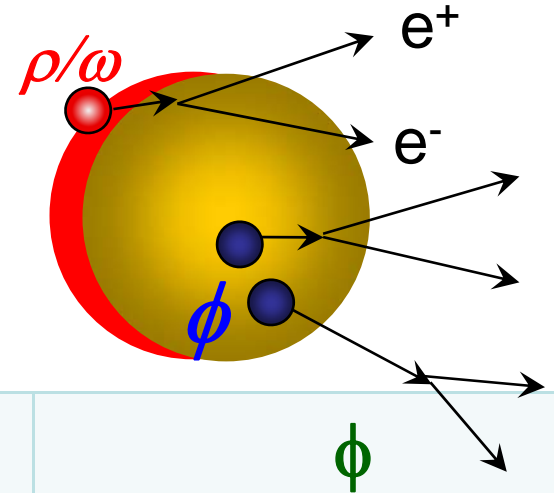
$1.75 < \beta\gamma$ (Fast)



Rejected at 99% confidence level

Model calc. including mass modification

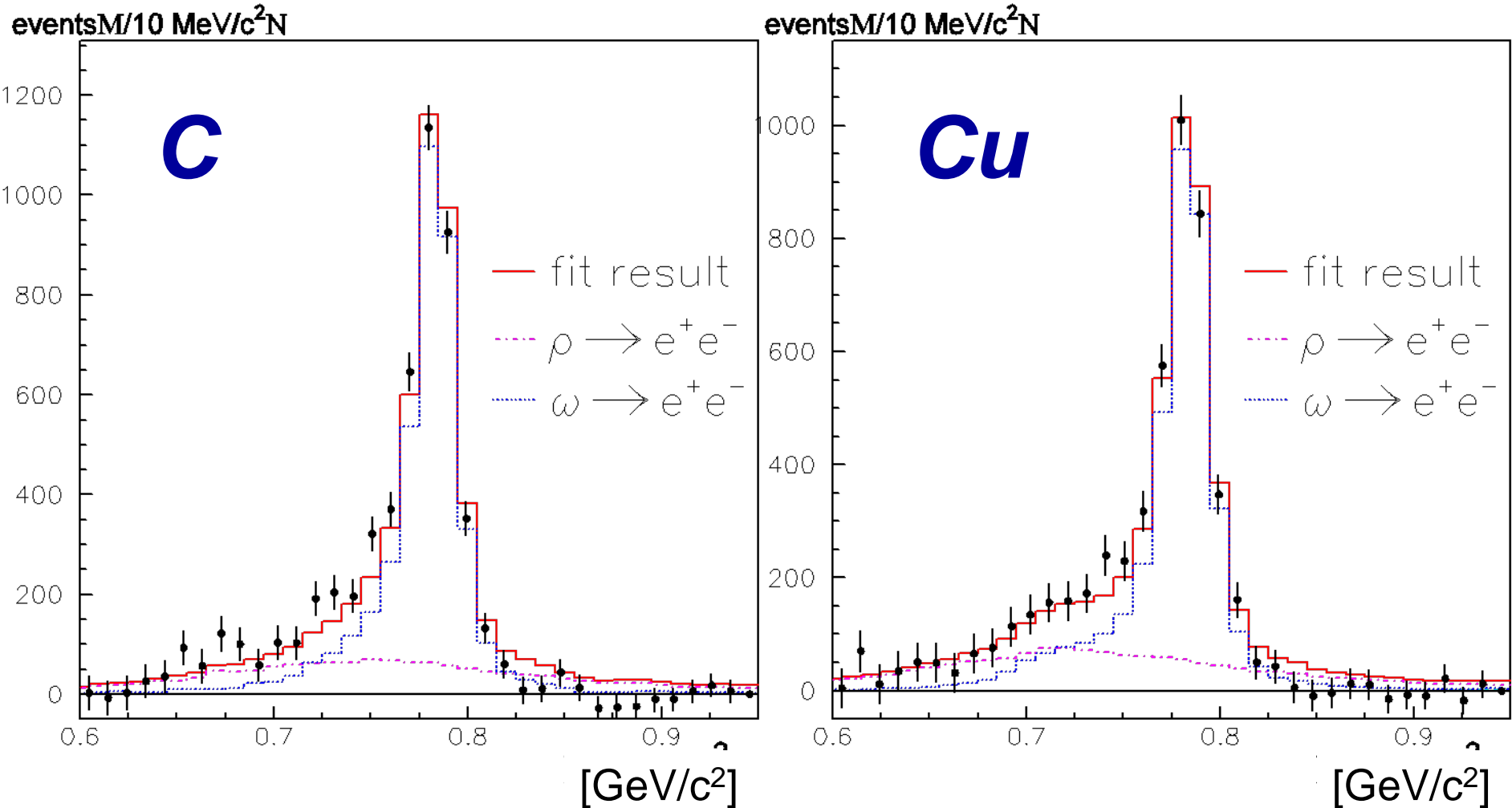
We attempt to reproduce the observed spectra with model calculation including mass modification



	ρ/ω	ϕ
$m(\rho)/m(0)$ (mass dropping)	$1 - k_1 \rho/\omega$ (ρ/ρ_0) (Hatsuda & Lee)	$1 - k_1 \phi$ (ρ/ρ_0) (Hatsuda & Lee)
$\Gamma(\rho)/\Gamma(0)$ (width broadening)	1	$1 + k_2$ (ρ/ρ_0)
generation point	surface	uniform
$\leftarrow \alpha$ ($\sigma(A) \propto A^\alpha$)	0.710 ± 0.021	0.937 ± 0.049
momentum dist.	measured	
density distribution	Woods-Saxon, radius: C:2.3fm/Cu:4.1fm	

Fit results of model calculation for ρ/ω

$$k_1 = 0.092 \quad (m^*/m = 1 - 0.092 \rho/\rho_0)$$



the excesses for both C and Cu are well reproduced by the model including the **9%** mass decrease at ρ_0 .

Fit result of model calculation for $\phi \rightarrow e^+e^-$

$$k_1=0.034, \quad k_2=2.6$$

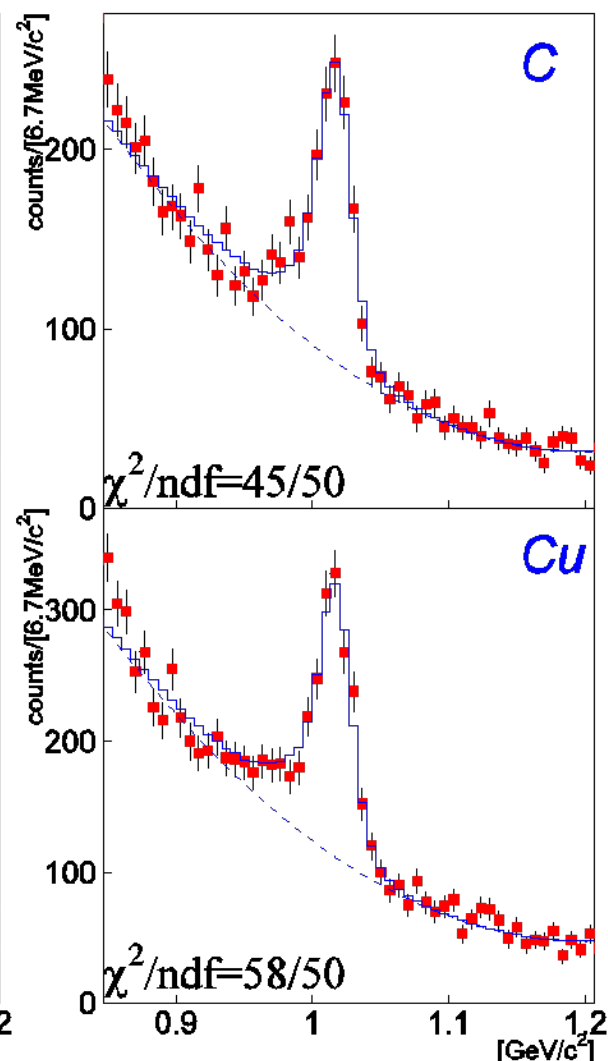
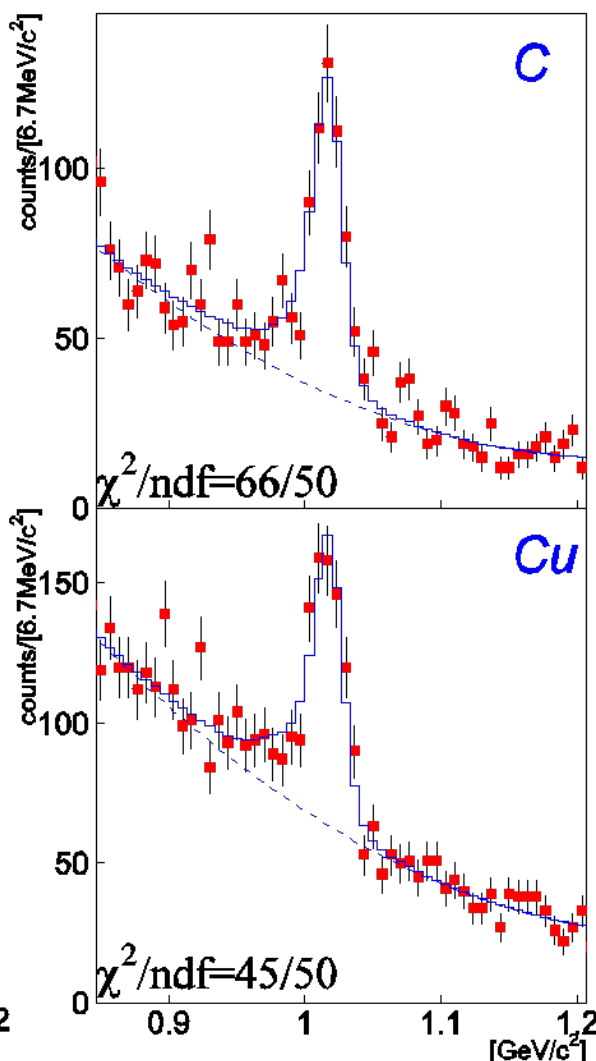
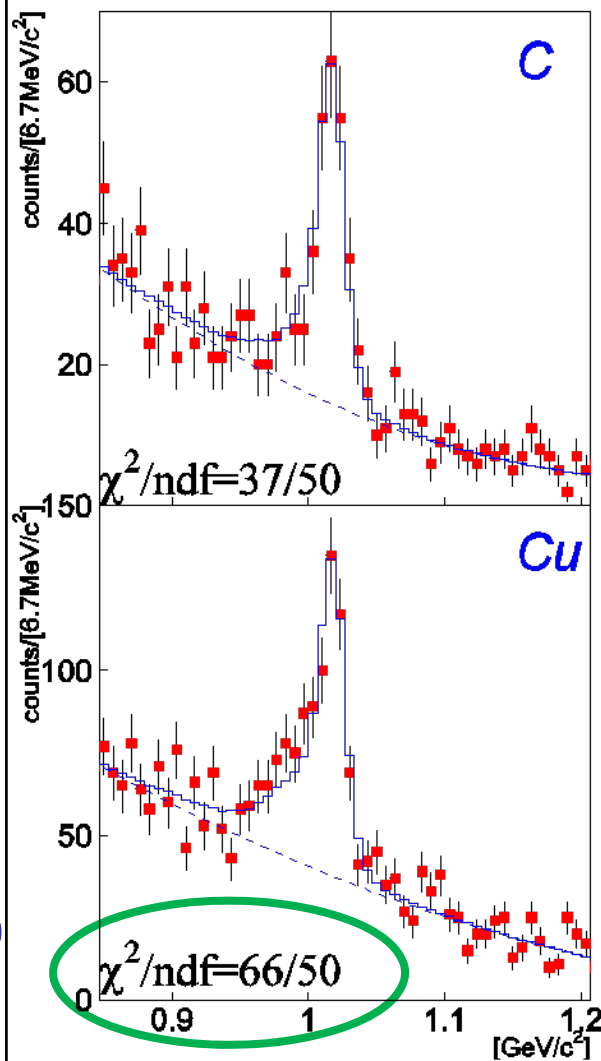
$\beta\gamma < 1.25$ (Slow)

$1.25 < \beta\gamma < 1.75$

$1.75 < \beta\gamma$ (Fast)

Small Nucleus

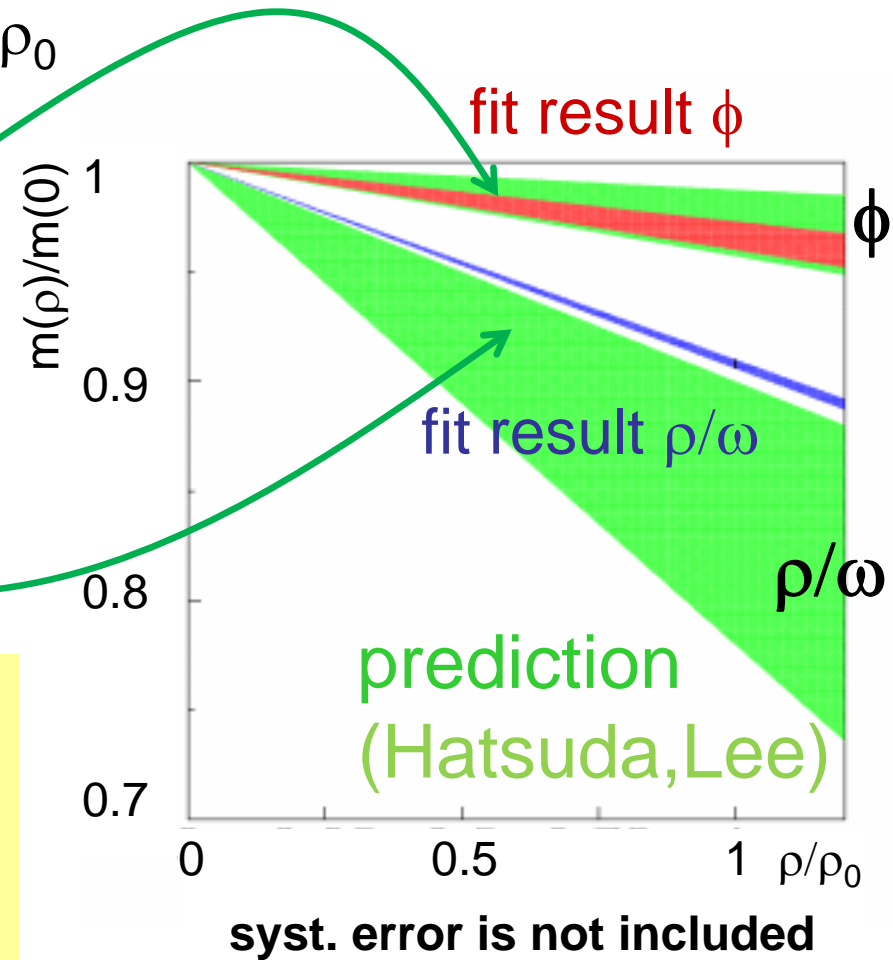
Large Nucleus



Comparison with the theoretical prediction

$$m^*/m = 1 - k_1 \rho/\rho_0, \Gamma^*/\Gamma = 1 + k_2 \rho/\rho_0$$

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



The data were well reproduced with the model;

$m_{\rho/\omega}$ decreases by 9.2%,
 m_{ϕ} decreases by 3.4% and
 Γ_{ϕ} increases by 3.6 at ρ_0

Summary

- We have observed significant excesses over the known hadronic sources both in $\rho/\omega \rightarrow e^+e^-$ and $\phi \rightarrow e^+e^-$ distributions in 12 GeV p+A reactions
- The excesses were well reproduced by the model calculation including mass modification,
 - ρ/ω : **9% mass decrease**
 - ϕ : **3% mass decrease** and **width broadening** by a factor of **3.6** at ρ_0 .
- **From $\phi \rightarrow K^+K^-$ analyses** we have obtained limits on the in-medium decay width broadenings for both $\phi \rightarrow e^+e^-$ and $\phi \rightarrow K^+K^-$ decay channels
 - **See Poster by Fuminori Sakuma (Tomorrow)**
- We are planning next experiment at **J-PARC** which will achieve statistics 100 times as large as the present experiment
 - **See Poster by Satoshi Yokkaichi (Tomorrow)**