Medium modifications on vector meson in 12GeV p+A reactions

Kyoto Univ.$_a$, KEK$_b$, RIKEN$_c$, CNS Univ. of Tokyo$_d$,

Megumi Naruki, RIKEN, Japan

J. Chiba$_b$, H. En'yo$_c$, Y. Fukao$_a$, H. Funahashi$_a$, H. Hamagaki$_d$, M. Ieiri$_b$, M. Ishino$_e$, H. Kanda$_f$, M. Kitaguchi$_a$, S. Mihara$_e$, K. Miwa$_a$, T. Miyashita$_a$, T. Murakami$_a$, R. Muto$_c$, T. Nakura$_a$, K. Ozawa$_d$, F. Sakuma$_a$, O. Sasaki$_b$, M. Sekimoto$_b$, T. Tabaru$_c$, K.H. Tanaka$_b$, M. Togawa$_a$, S. Yamada$_a$, S. Yokkaichi$_c$, Y. Yoshimura$_a$

(KEK-PS *E325* Collaboration)

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

Mass modification at finite density

dropping mass

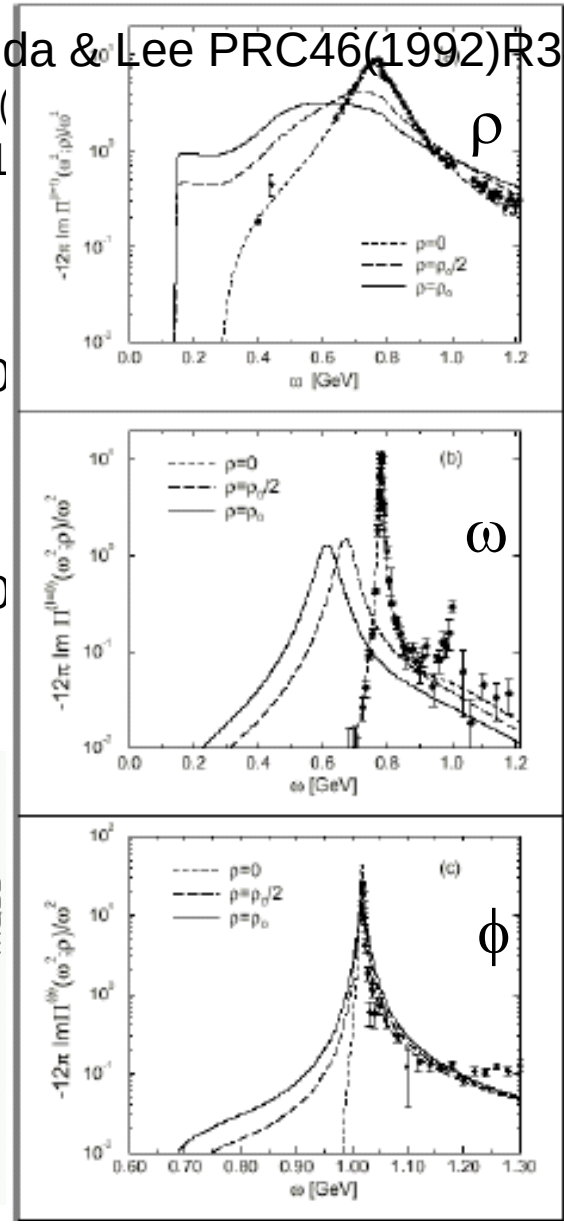
- Brown-Rho scaling (’91)
  - $m^*/m = 0.8$ at $\rho = \rho_0$
- QCD Sum Rule by Hatsuda & Lee (’92)
  - $m^*/m = 1 - 0.16\ \rho/\rho_0$ for ρ/ω
  - $m^*/m = 1 - 0.03\ \rho/\rho_0$ for ϕ
- Lattice Calc. by Muroya, Nakamura & Nonaka(’03)

width broadening (at ρ_0)

- Klingl, Kaiser, Weise (’97-8)

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

Hatsuda & Lee PRC46(1992)R34



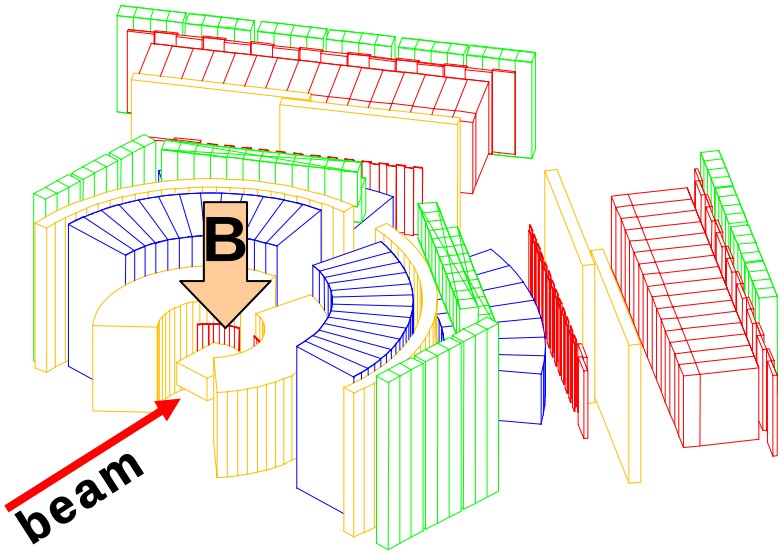
E325 experiment

Invariant Mass of e^+e^-, K^+K^-
in 12GeV p + A → ρ, ω, ϕ + X

- slowly moving ρ,ω,ϕ (p_{lab}~2GeV/c)

larger probability to decay inside nucleus

- primary proton beam ~10^9 ppp
- thin targets: 0.2%/0.05% (C/Cu)
  radiation length: 0.4/0.5%(C/Cu)



History

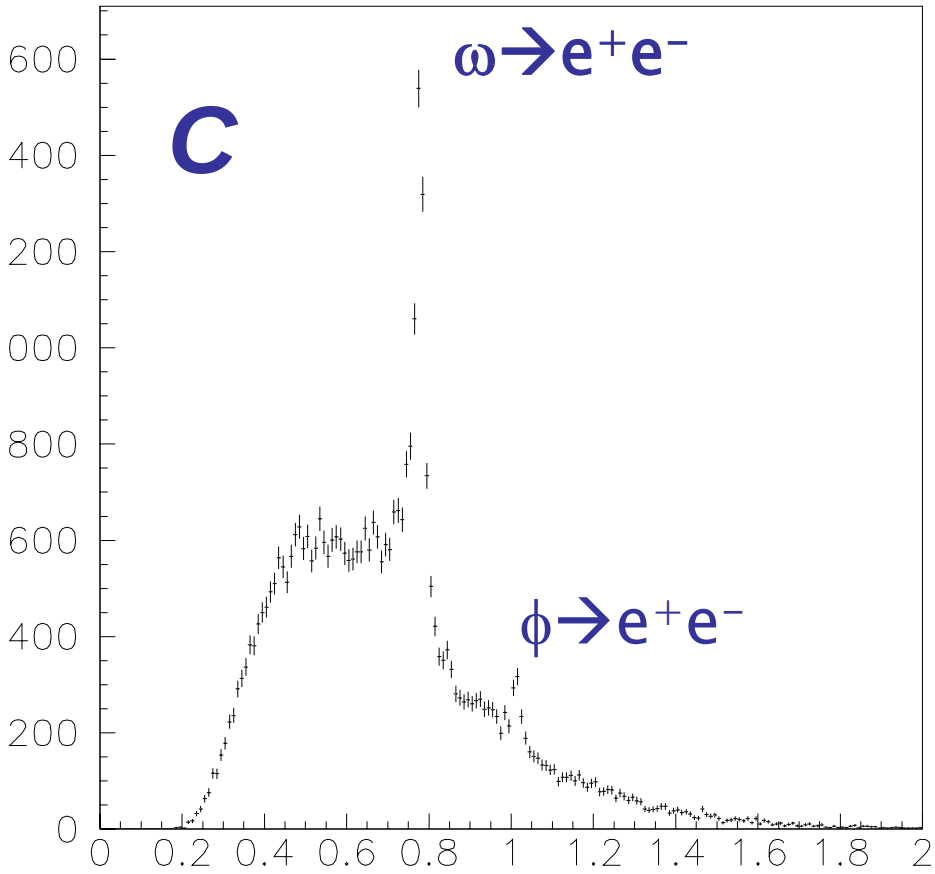
'93 proposed
'96 construction start
- ✓ *NIM, A457, 581 (2001).*
- ✓ *NIM, A516, 390 (2004).*

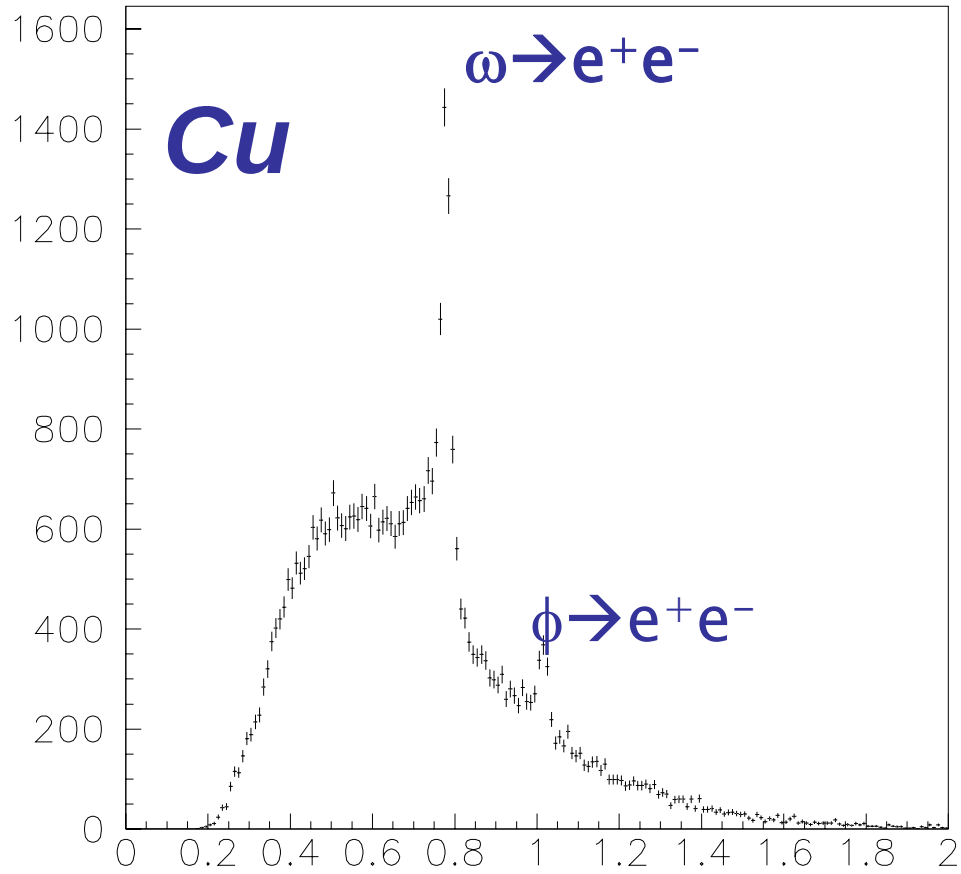
'97 first K^+K^- data
'98 first e^+e^- data
- ✓ *PRL, 86, 5019 (2001).*

'99~'02
x100 statistics in e^+e^-
- ✓ *ρ/ω: PRL 96, 092301 ('06).*
- ✓ *ϕ →ee: nucl-ex/0511019*
- ✓ *α : PRC, 75, 025201 ('06)*

x6 statistics in K^+K^-
- ✓ *ϕ →KK : nucl-ex/0606029*

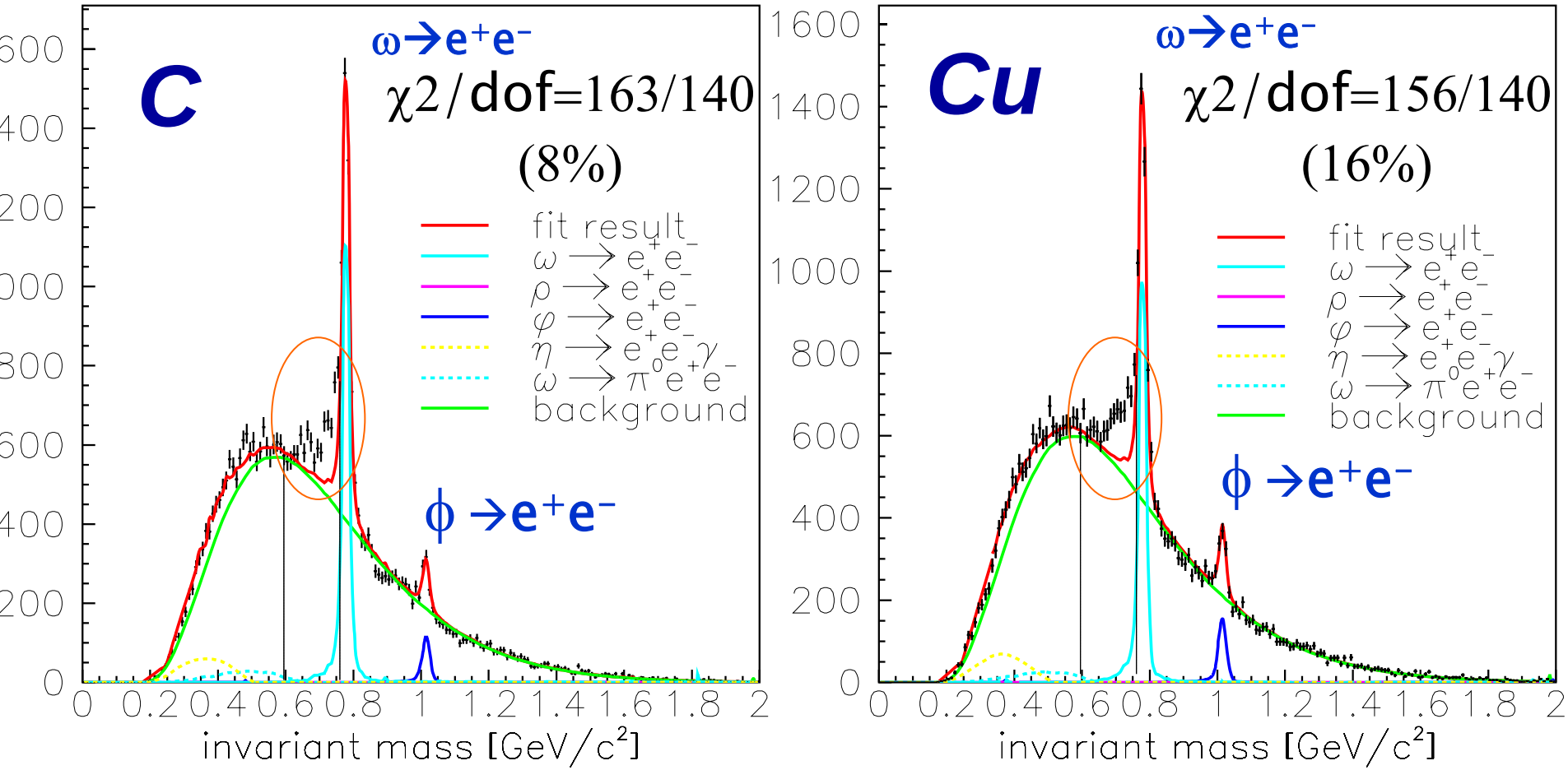
Invariant Mass Spectrum of e^+e^-





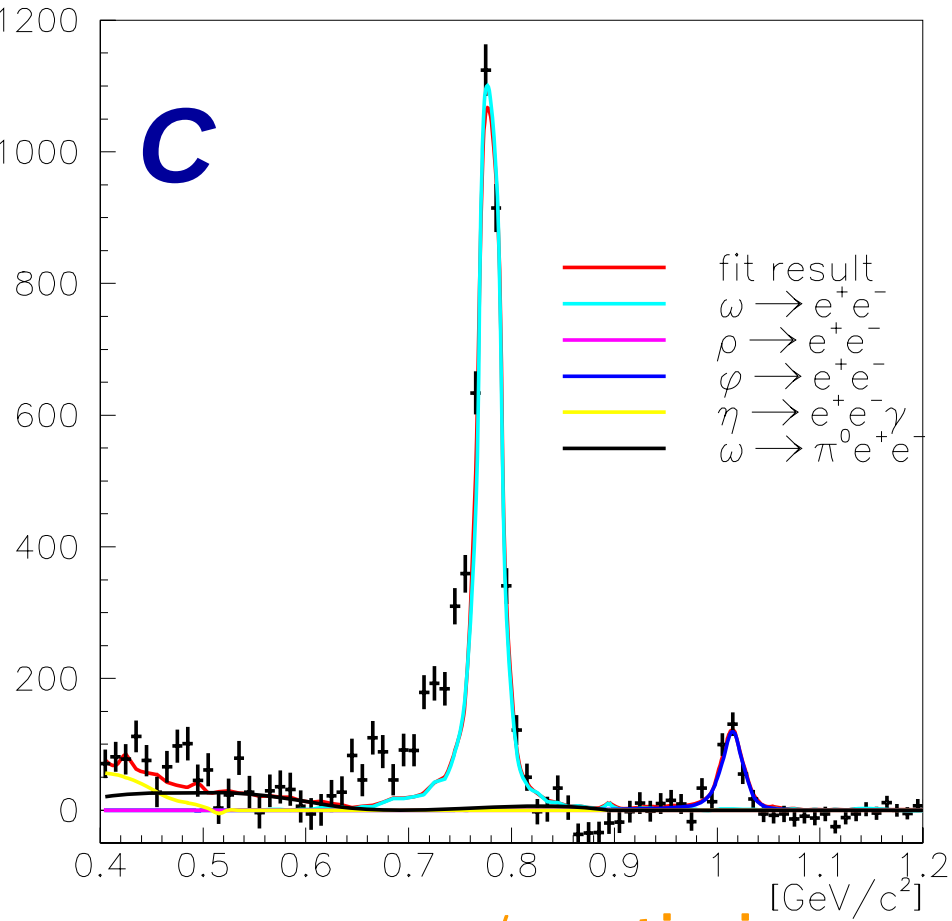
we examine how well the data are reproduced with known hadronic sources & combinatorial background

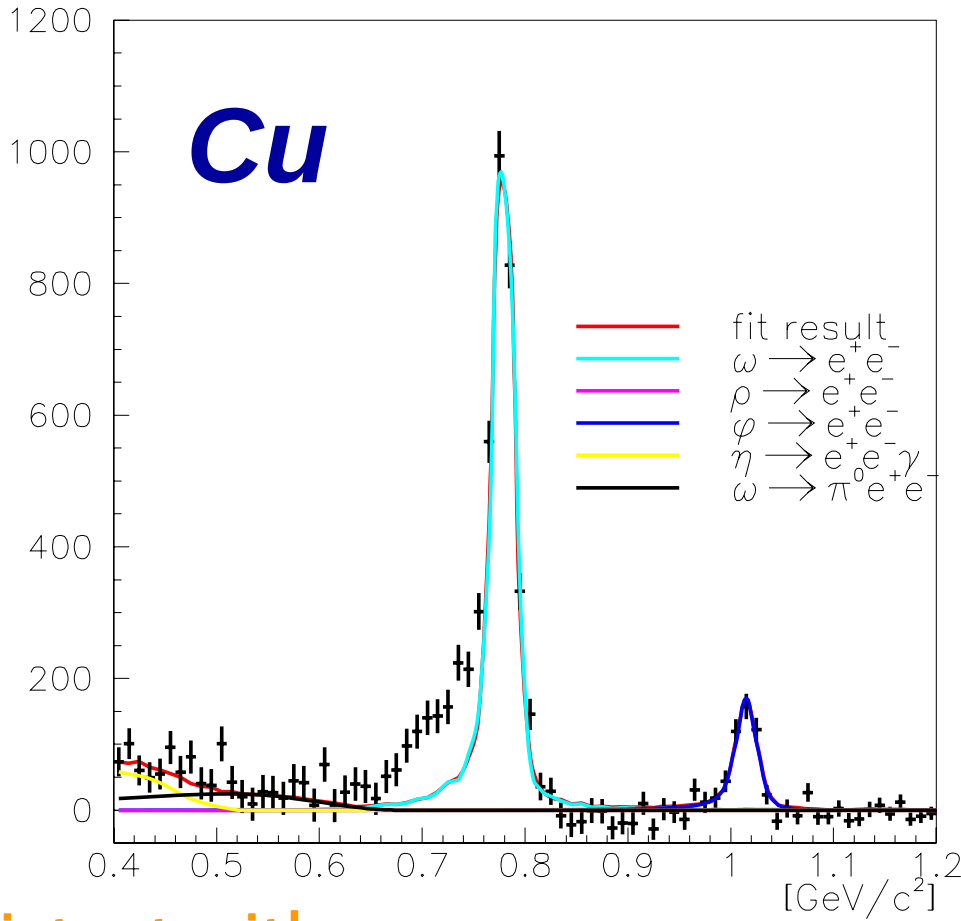
Invariant Mass Spectrum of e+e-



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

Invariant Mass Spectrum of e+e- (background subtracted)



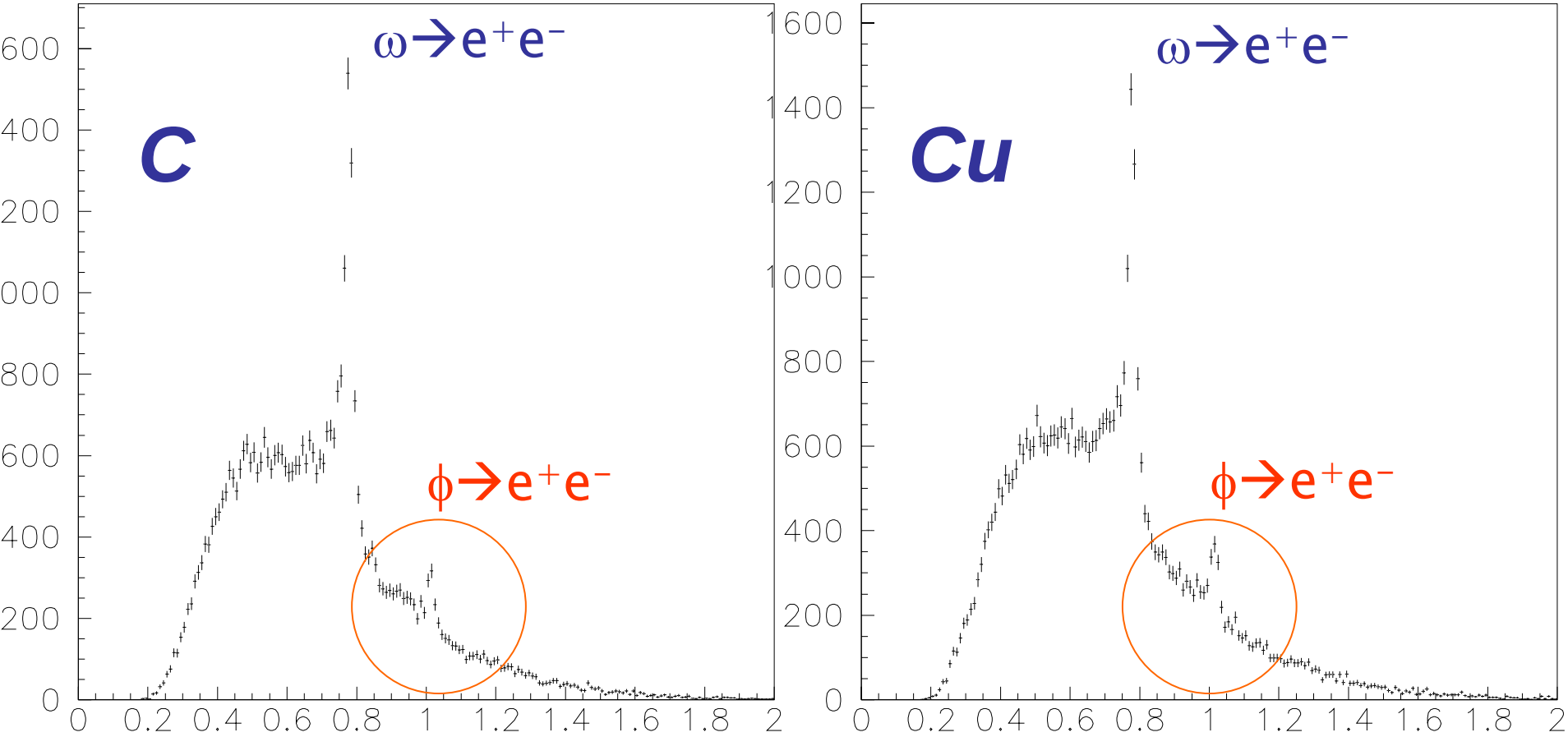


ρ/ω ratio is consistent with zero

Nρ/Nω=0.0±0.02(stat.)±0.2(sys.) 0.0±0.04(stat.)±0.3(sys.)

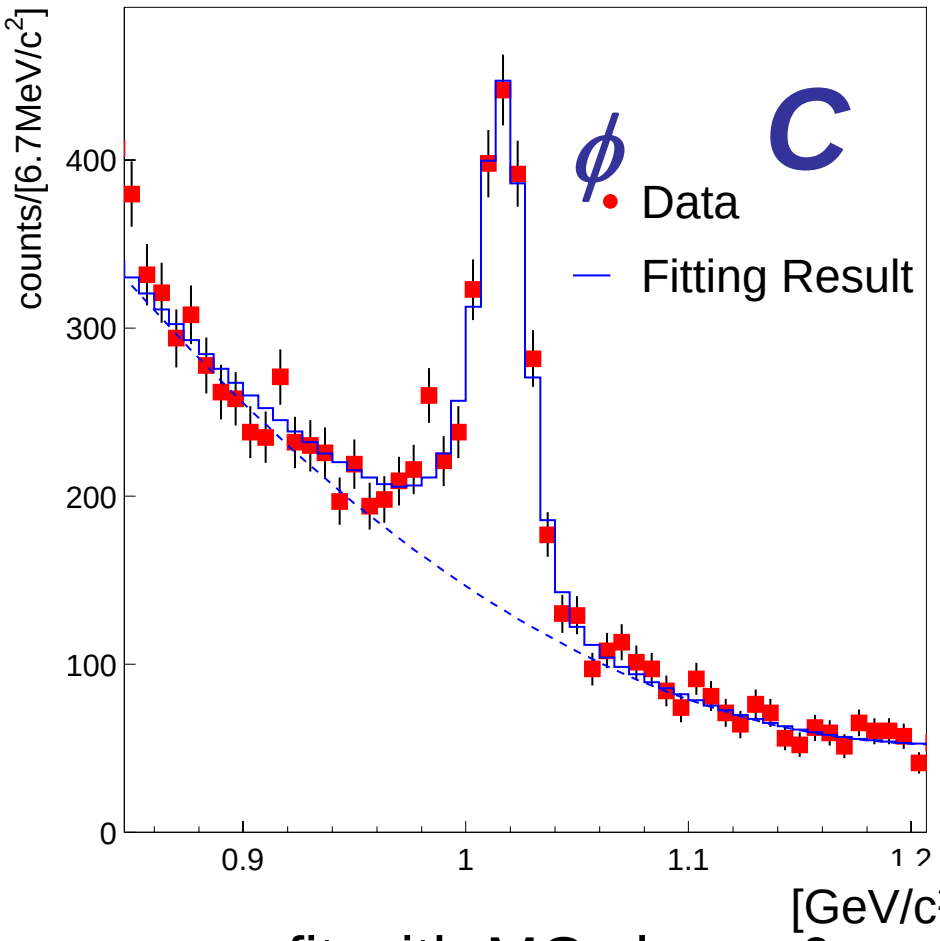
most of ρ decay in nucleus due to their short lifetime; τ ~ 1.3fm

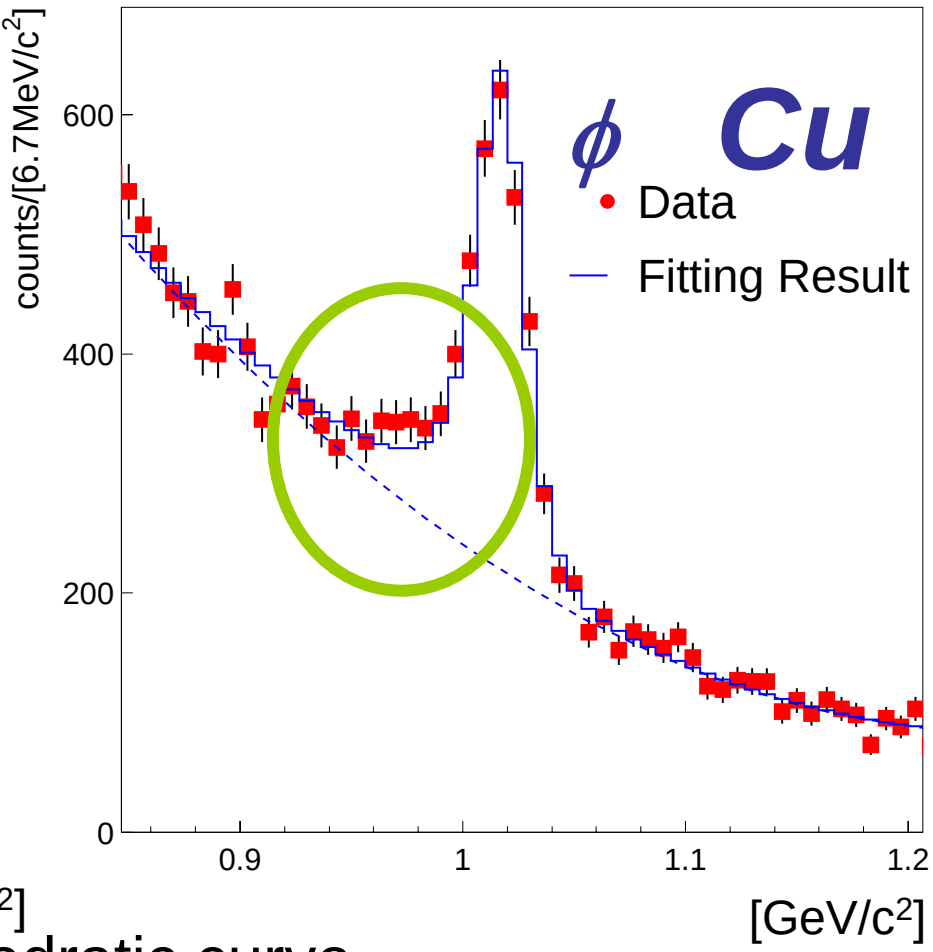
Invariant Mass Spectrum of e^+e^-



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

e^+e^- Invariant Mass Distributions





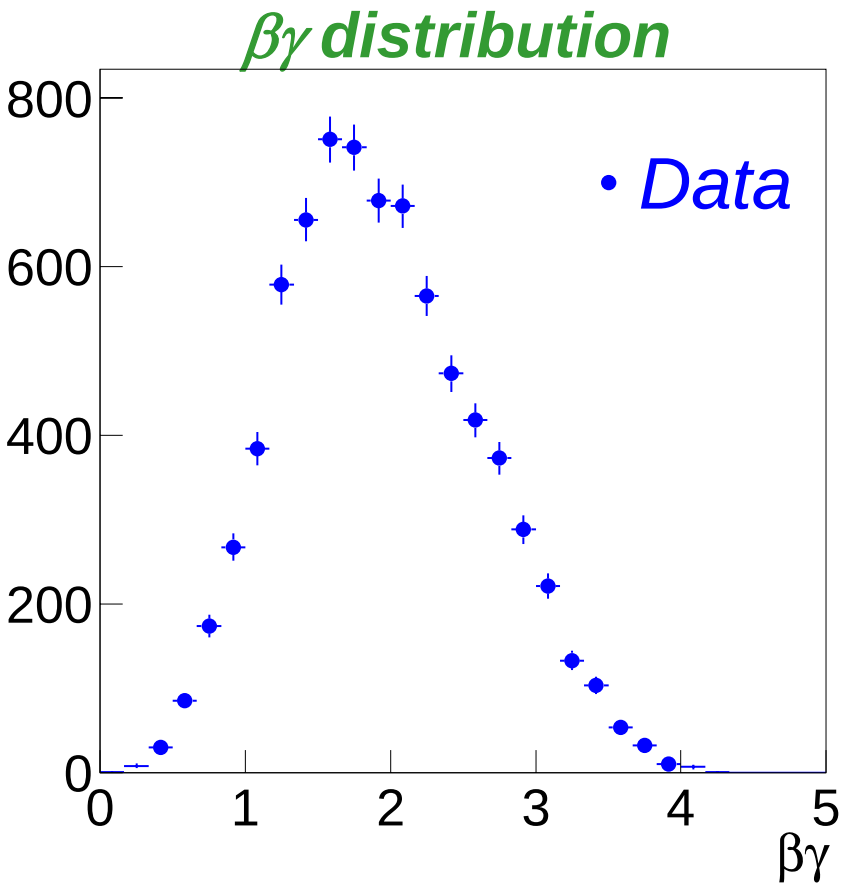
- fit with MC shape & quadratic curve
- a hint on the spectrum of Cu data.
- longer lifetime; τ~50fm → kinematical dependence

To see βγ dependence

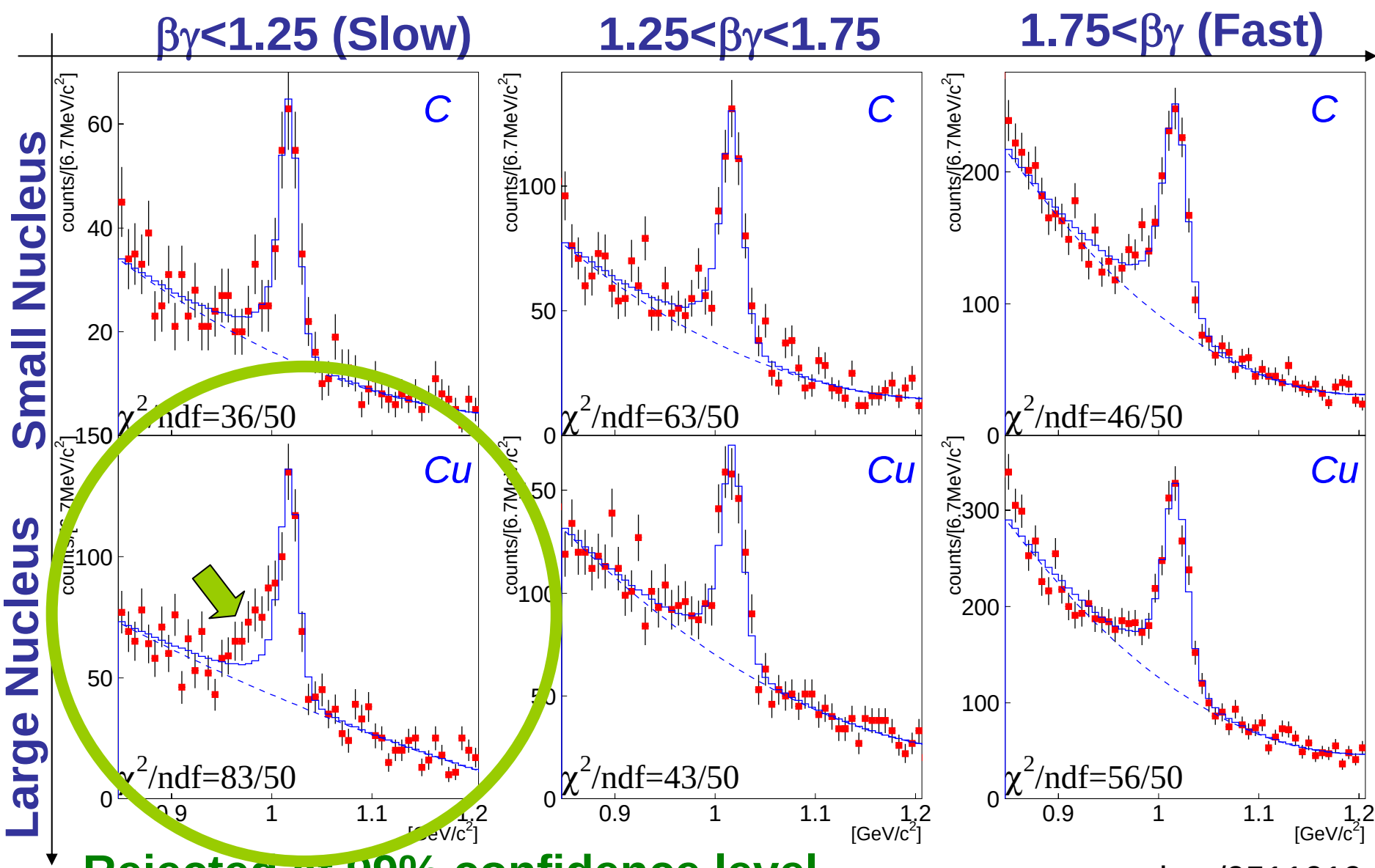
Slowly moving ϕ mesons have a larger probability to decay inside the target nucleus.

We divided the data into three by βγ (= p/m);

$\beta\gamma<1.25$, $1.25<\beta\gamma<1.75$ and $1.75<\beta\gamma$.



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



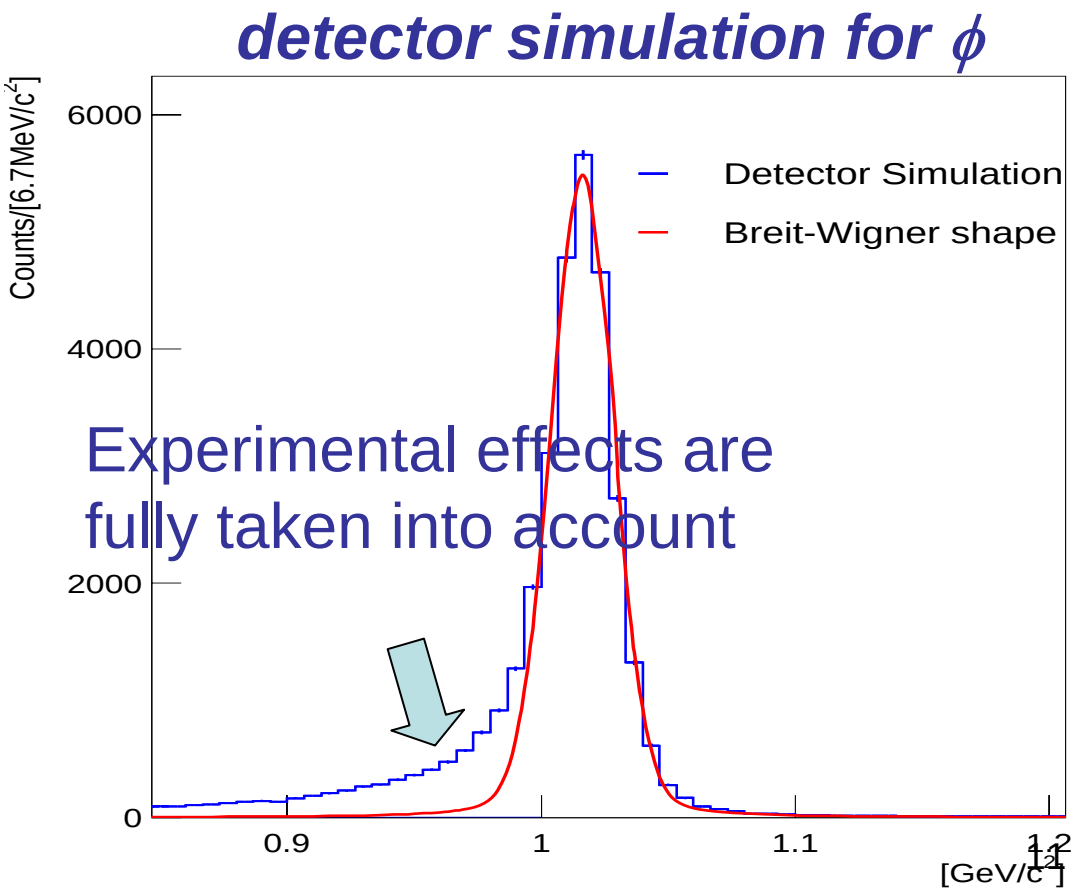
nucl-ex/0511019

Energy Loss

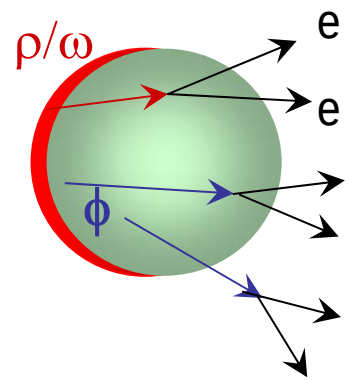
Resonance Shape : Breit-Wigner + internal radiative correction
experimental effect estimated by Geant4 simulation
– energy loss, mass resolution, mass acceptance etc.

- **Blue** histogram : Detector Simulation
- **Red** line : Breit-Wigner (gaussian convoluted) fitting result

we fit the data by the simulated shape, which fully includes the experimental effect



Model Calculation w/ medium modification

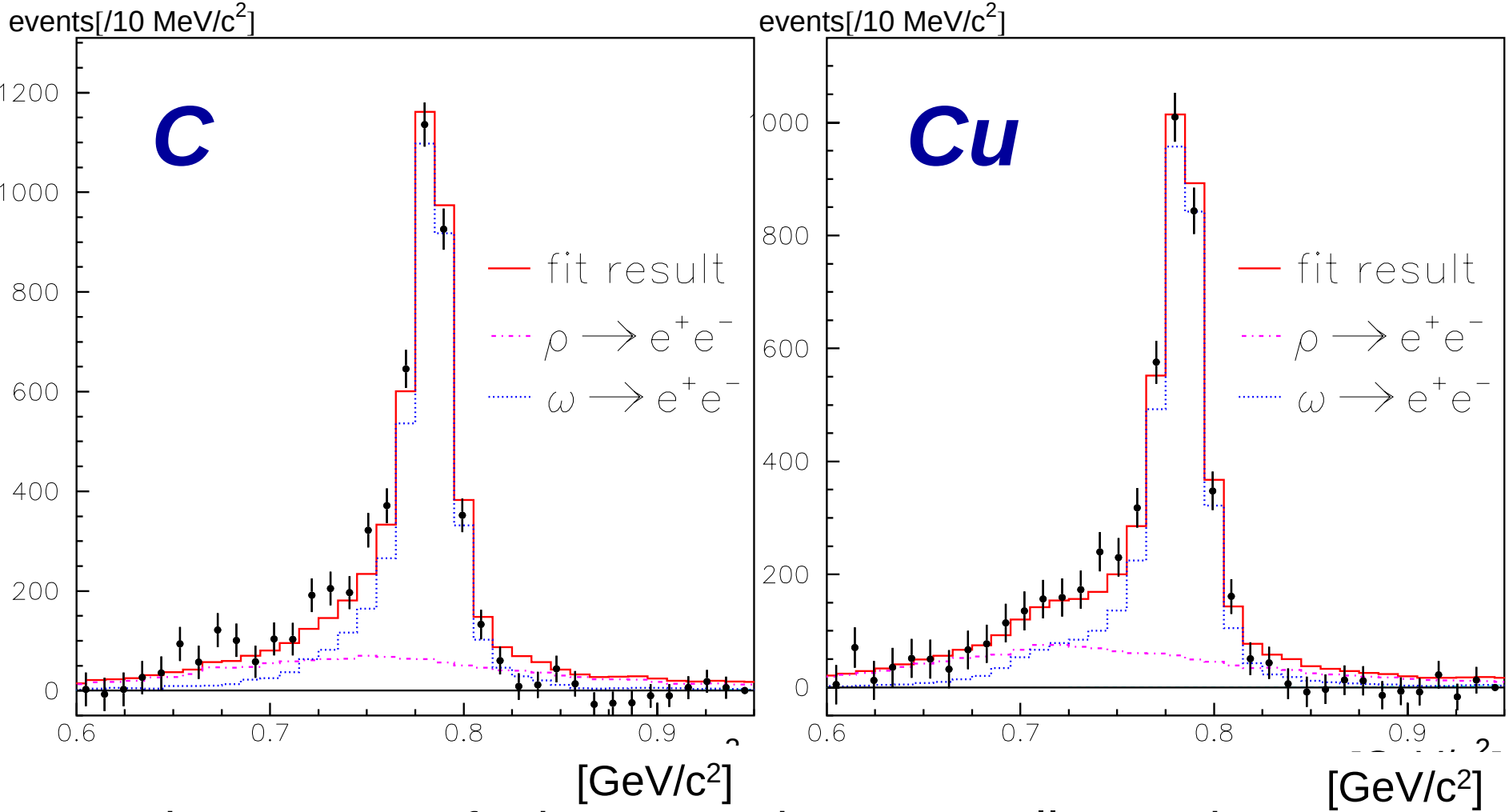


- dropping mass: $M(\rho)/M(0) = 1 - k_1 (\rho/\rho_0)$ (Hatsuda & Lee)
- width broadening: $\Gamma(\rho)/\Gamma(0) = 1 + k_2 (\rho/\rho_0)$ (k_2~10 (Klingl *et.al*))

	ρ, ω	ϕ
m*/m	**$1 - k_1^{\rho/\omega} \rho/\rho_0$**	**$1 - k_1^{\phi} \rho/\rho_0$**
Γ^*/Γ	**1**	**$1 + k_2 \rho/\rho_0$**
generation point	surface	uniform
← α ($\sigma(A) \propto A^{\alpha}$) [PRC74(06)025201]	0.710 ± 0.021	0.937 ± 0.049
momentum dist.	measured	
density distribution	Woods-Saxon, radius: C:2.3fm/Cu:4.1fm	

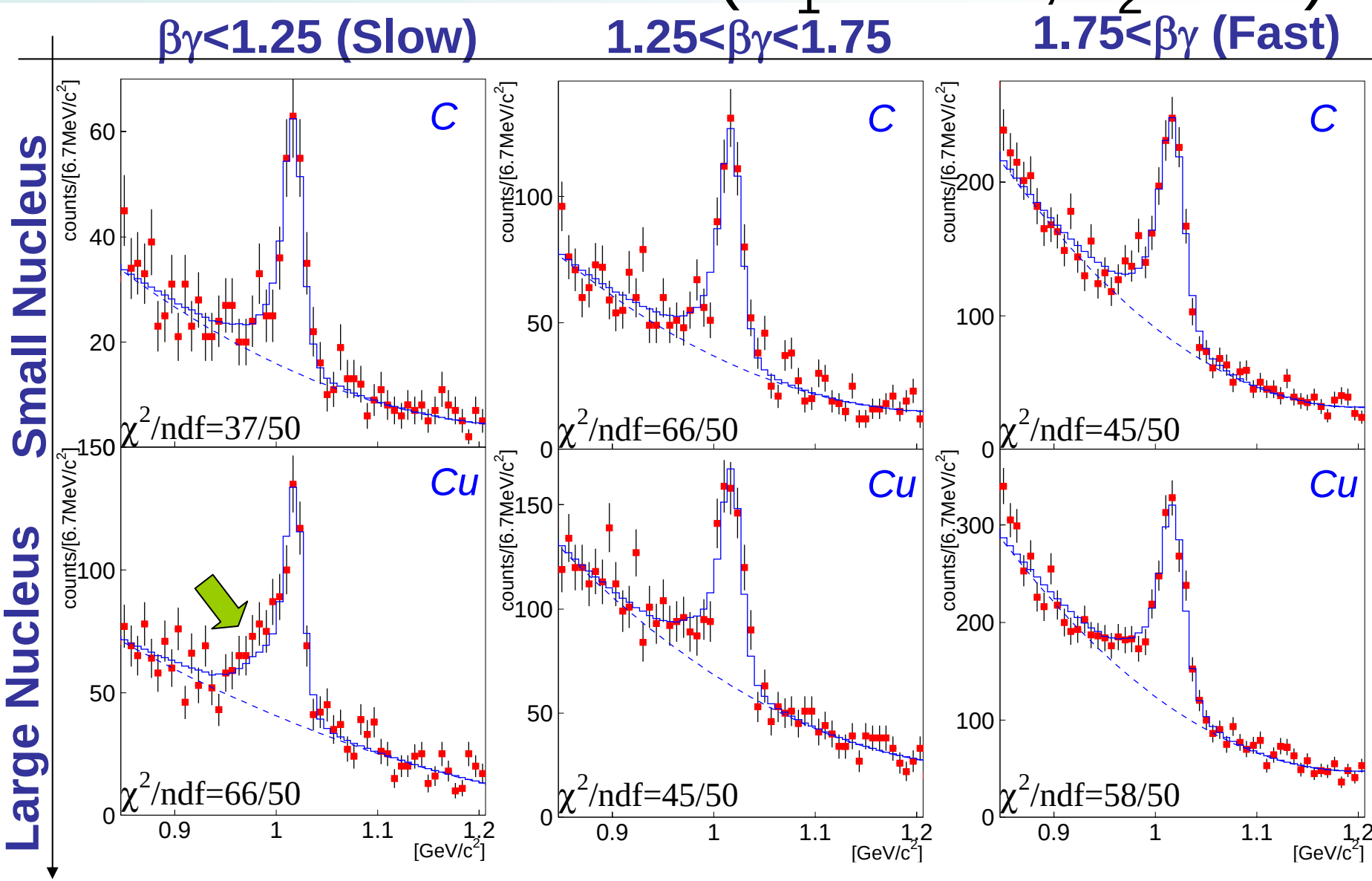
Fit Results of Model Calculation

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



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

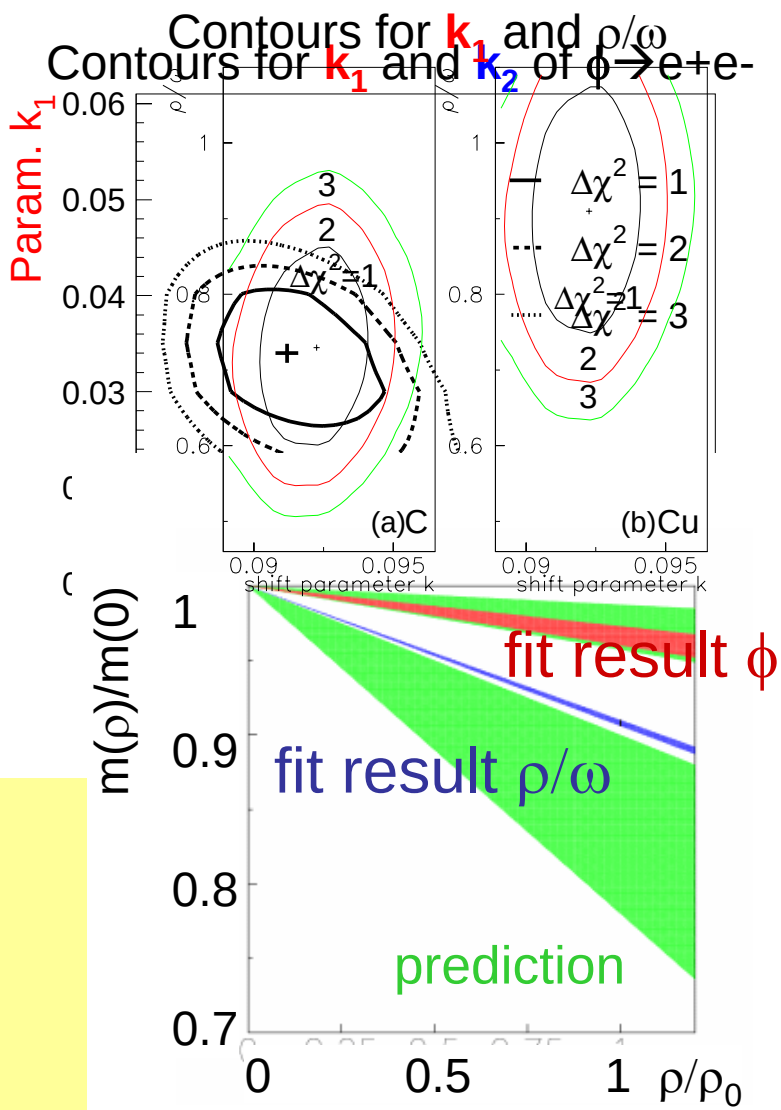
Invariant spectra of $\phi \rightarrow e^+e^-$ fit with modified M.C. (k_1=0.034, k_2=2.6)



Fit Results of model calculation

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

Best Fit Values		
	ρ, ω	ϕ
k_1	$9.2 \pm 0.2\%$	$3.4^{+0.6}_{-0.7}\%$
k_2	0 (fixed)	$2.6^{+1.8}_{-1.2}$
ρ/ω	0.7 ± 0.1 (C) 0.9 ± 0.2 (Cu)	-

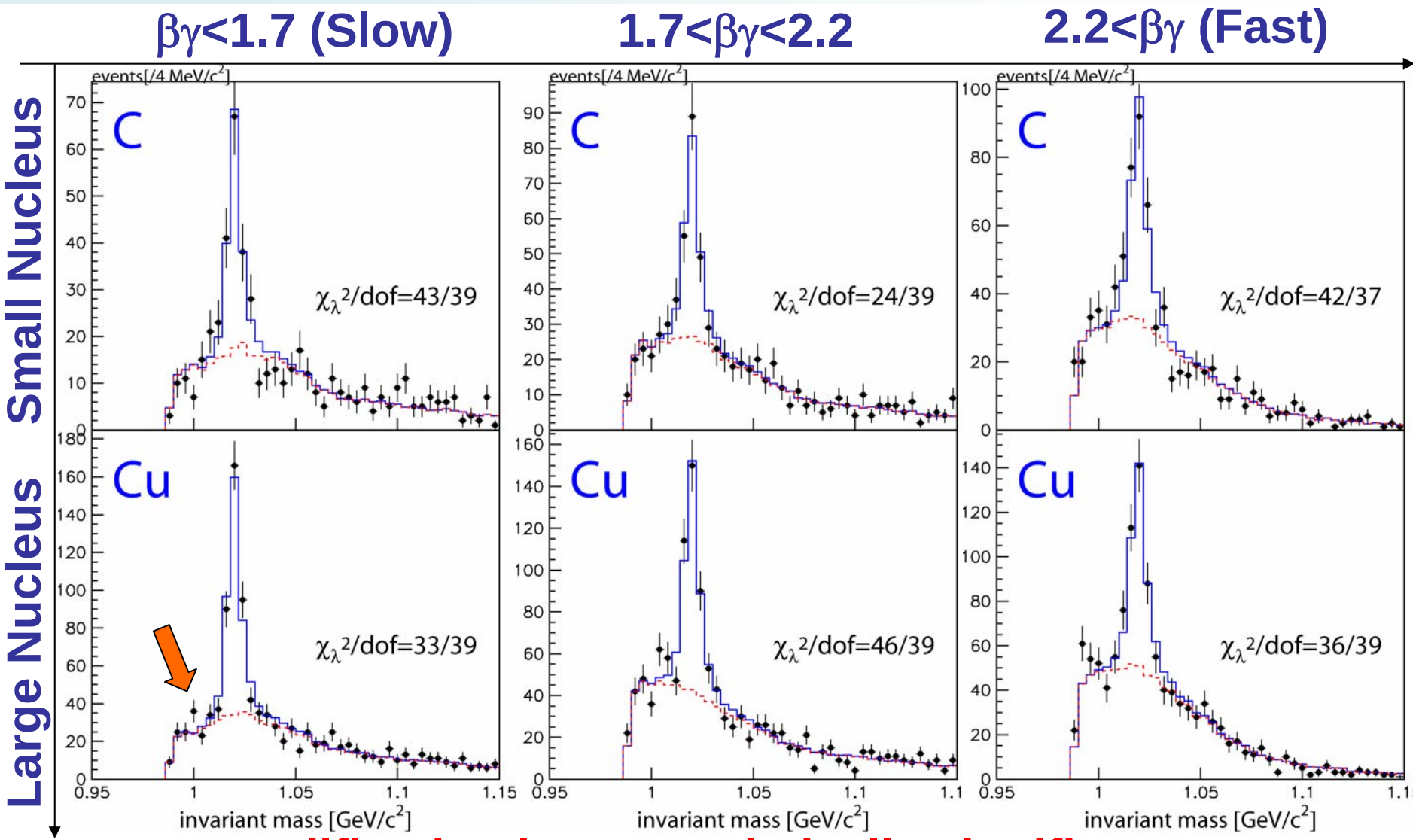


The data were well reproduced with the model;

$m_{\rho/\omega}$ decreases by 9%,
m_ϕ decreases by 3% and
Γ_ϕ increases by 3.6 at ρ_0

syst. error is not included

Fitting Results of $\phi \rightarrow K^+K^-$



modification is not statistically significant

Our statistics in the K+K- decay mode are very limited in the βγ region in which we find the excess in the e+e- mode

nuclear mass number dependence of $\Gamma_{\phi\to K^+K^-} / \Gamma_{\phi\to e^+e^-}$

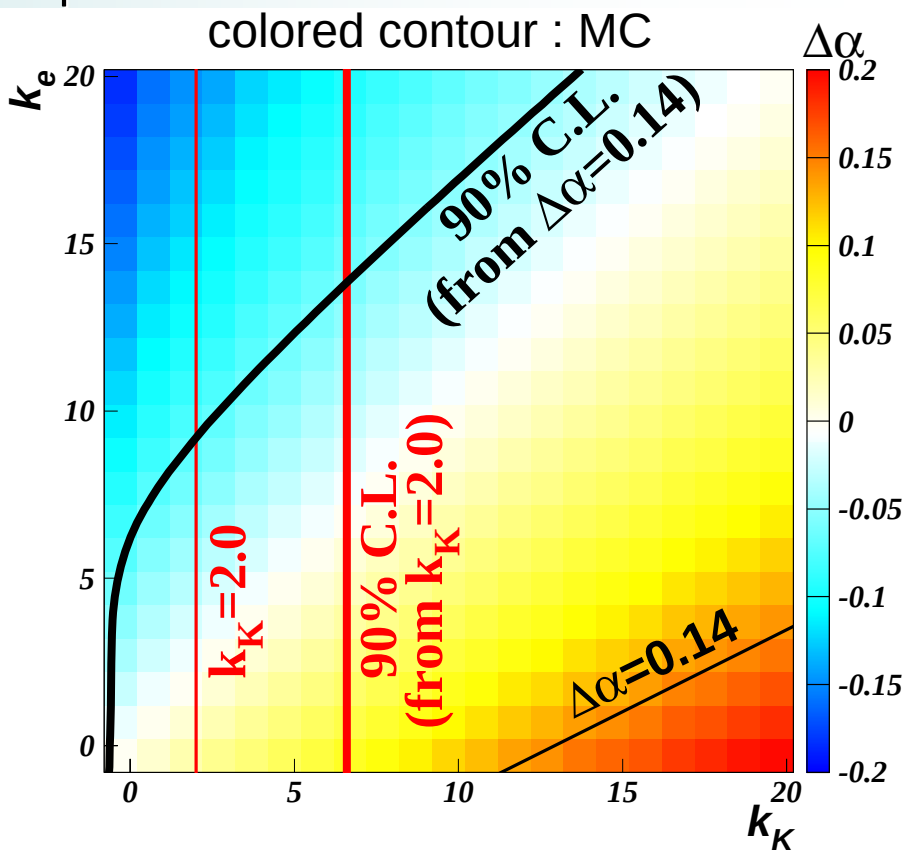
$$\Gamma^*_{KK} / \Gamma^0_{KK} = 1 + k_K(\rho/\rho_0)$$

$$\Gamma^*_{ee} / \Gamma^0_{ee} = 1 + k_e(\rho/\rho_0)$$

$$\Gamma^*_{tot} / \Gamma^0_{tot} = 1 + k_{tot}(\rho/\rho_0)$$

$$\Delta\alpha = \alpha_{KK} - \alpha_{ee} \propto \ln \frac{\Gamma_{KK}(A_2)}{\Gamma_{KK}(A_1)} / \frac{\Gamma_{ee}(A_2)}{\Gamma_{ee}(A_1)}$$

- $k_{K/e}$ was obtained from the amount of excess.
  $k_K = 2.0 \pm 1.1(\text{stat.}) \pm 2.2(\text{syst.})$
- The measured $\Delta\alpha$ provides constraints on k_K and k_e.



F. Sakuma, nucl-ex/0606029

the first experimental limits of the in-medium broadening of the partial decay widths

Summary

- We have observed the excess over the known hadronic sources at the low-mass side of ω. Obtained ρ / ω ratio indicates that the excess is mainly due to the modification of ρ .
- We also observed the excess at the low-mass side of ϕ, only at the low $\beta\gamma$ region of Cu data.
- The data were well reproduced by the model calculation based on the mass modification. The fit results show that;
  - ✓ ρ/ω : the mass decreases by 9% at ρ_0 .
  - ✓ ϕ : the mass decreases by 3%, and the width increases by a factor of 3.6 at ρ_0.
- The mass modification is not statistically significant for the **K+K-** invariant mass distributions.
- The observed **nuclear mass-number dependences** of $\phi \rightarrow e^+e^-$ and $\phi \rightarrow K^+K^-$ are consistent.
  - We have obtained **limits on the in-medium decay width broadenings** for both the $\phi \rightarrow e^+e^-$ and $\phi \rightarrow K^+K^-$ decay channels.