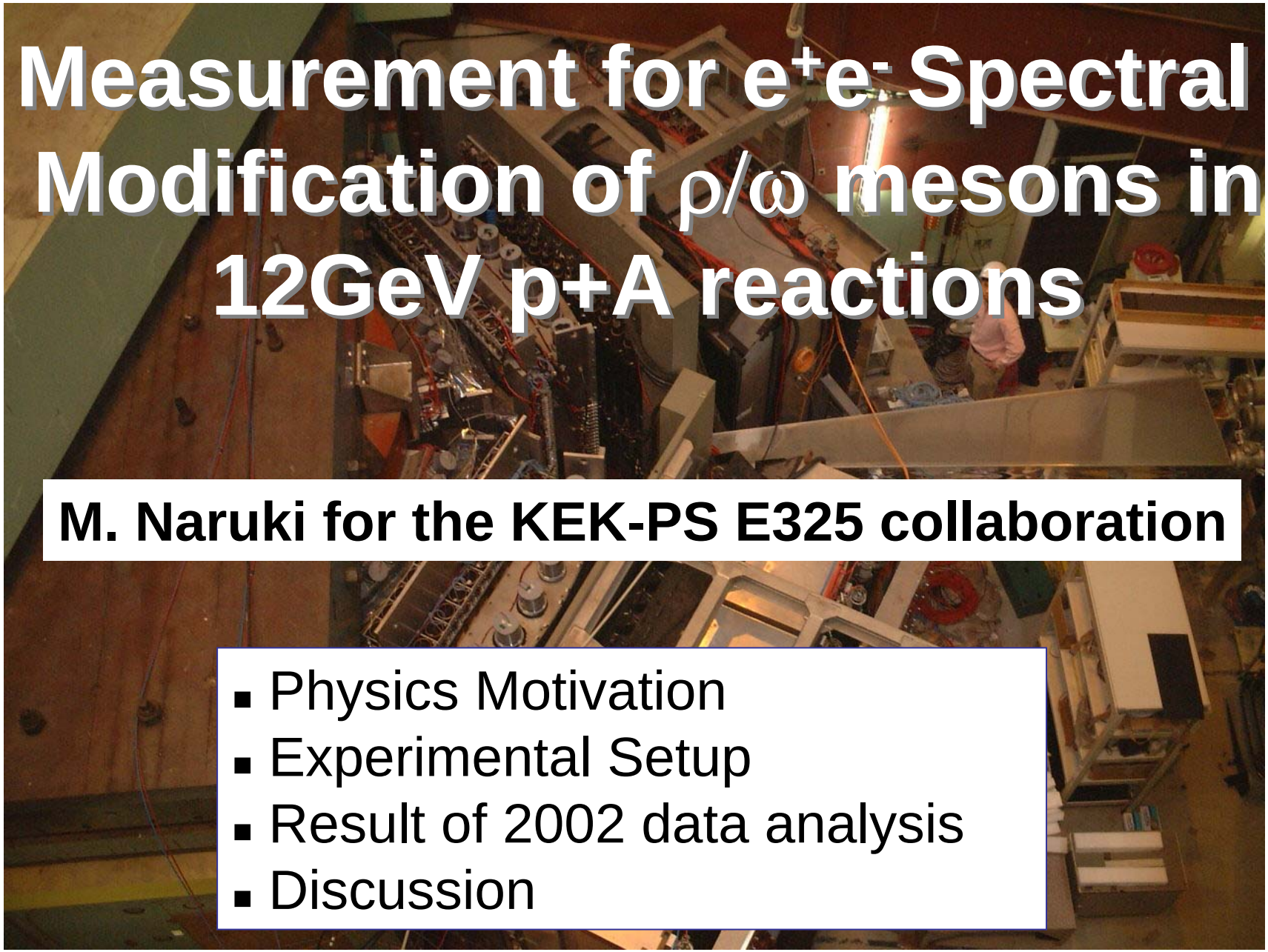


Measurement for e^+e^- Spectral Modification of ρ/ω mesons in 12GeV p+A reactions

M. Naruki for the KEK-PS E325 collaboration

- Physics Motivation
- Experimental Setup
- Result of 2002 data analysis
- Discussion

nucl-ex/0504016

E325 collaboration

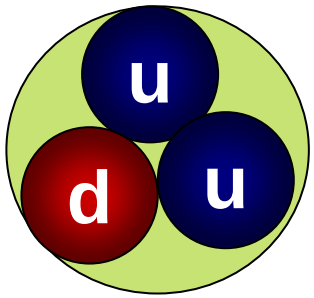
Kyoto Univ.$_a$, KEK$_b$, RIKEN$_c$, CNS Univ. of Tokyo$_d$,
ICEPP Univ. of Tokyo$_e$,Tohoku Univ.$_f$

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$_a$, M. Nomachi$_b$, K. Ozawa$_d$, F. Sakuma$_a$,
O. Sasaki$_b$, H.D. Sato$_a$, 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)

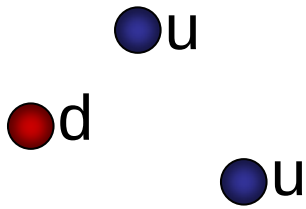
Physics Motivation

In Vacuum



Spontaneous Breaking of Chiral Symmetry

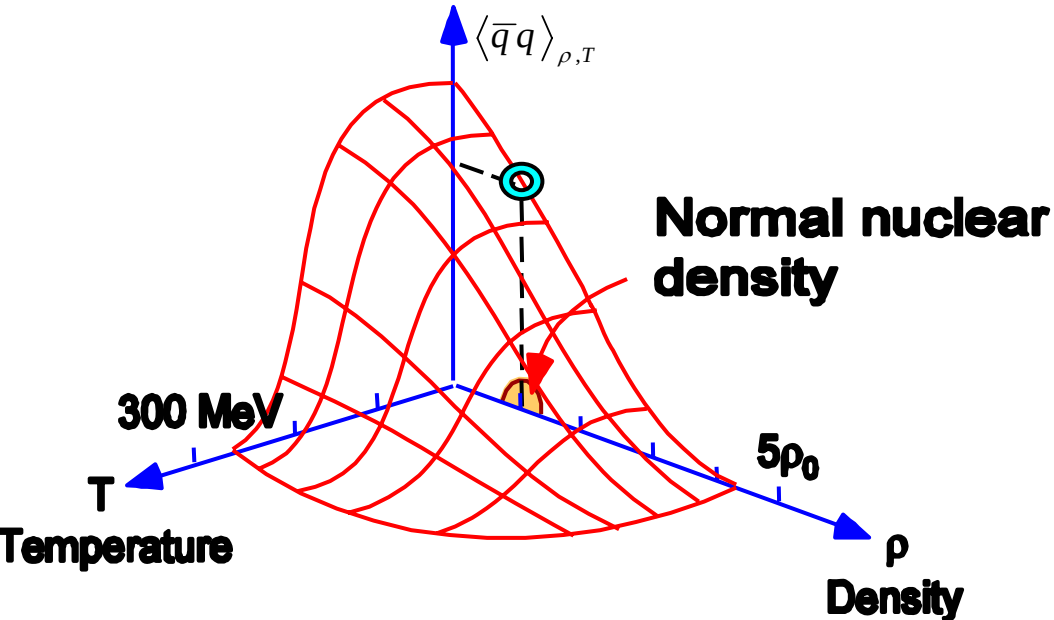
In Hot/Dense Matter



Hadrons ***~1GeV/c²***

Constituent quarks ***~300MeV/c²***

Current quarks ***~5MeV/c²***

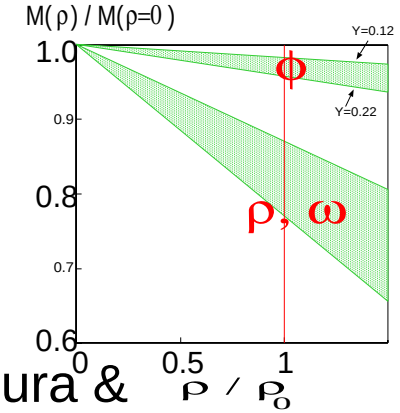


How to detect?

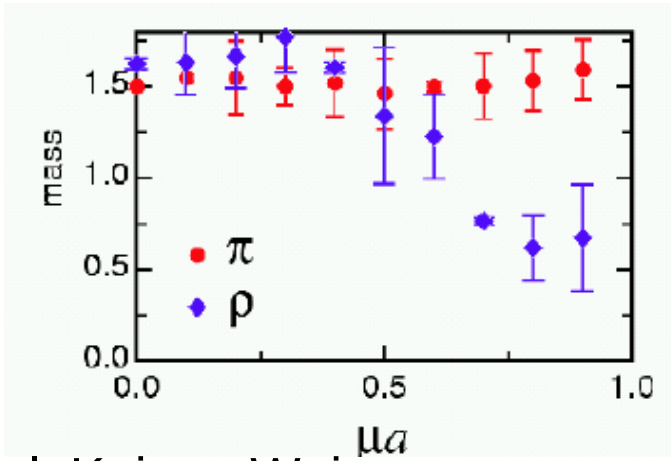
Vector meson mass at normal nuclear density

mass modification at finite density

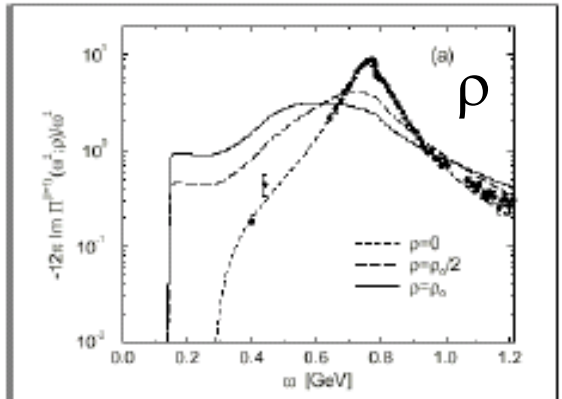
- dropping mass
  - $m^*/m = 0.8$ at $\rho = \rho_0$: Brown-Rho scaling ('91)
  - $m^*/m = 1 - 0.16\ \rho/\rho_0$:
    Hatsuda & Lee('92)

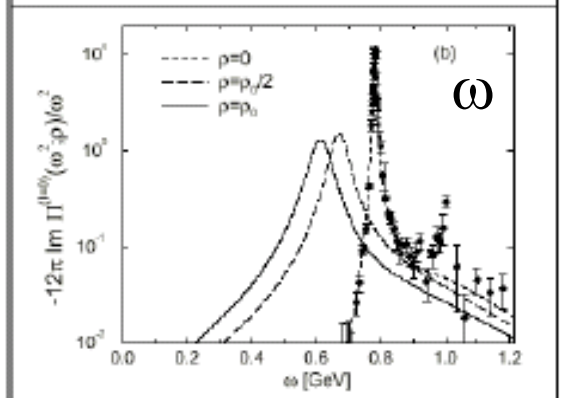


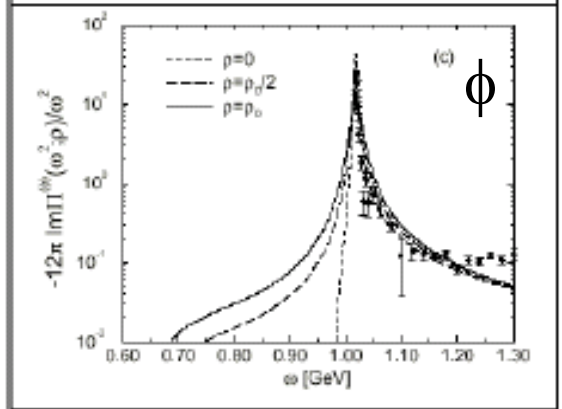
  - Lattice Calc. by Muroya, Nakamura & Nonaka('03)



- mass broadening
  - $\Gamma/\Gamma_0 = 10$ for ρ : Klingl, Kaiser, Weise
  - $\Delta\Gamma = 10\text{MeV}$: Rapp, Wambach







Vector Mesons ρ,ω,ϕ

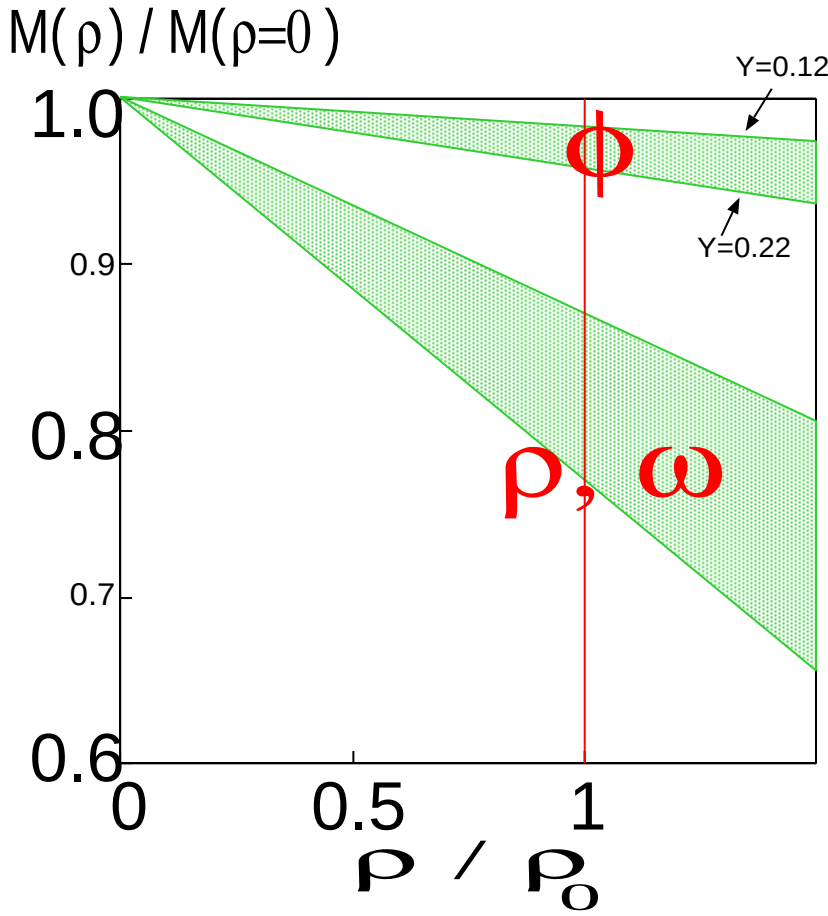
predictions of density dependence of vector meson mass
Hatsuda & Lee PRC46(1992)R34

ρ, ω

Large mass modification
~130MeV/c² at $\rho = \rho_0$
Large cross section

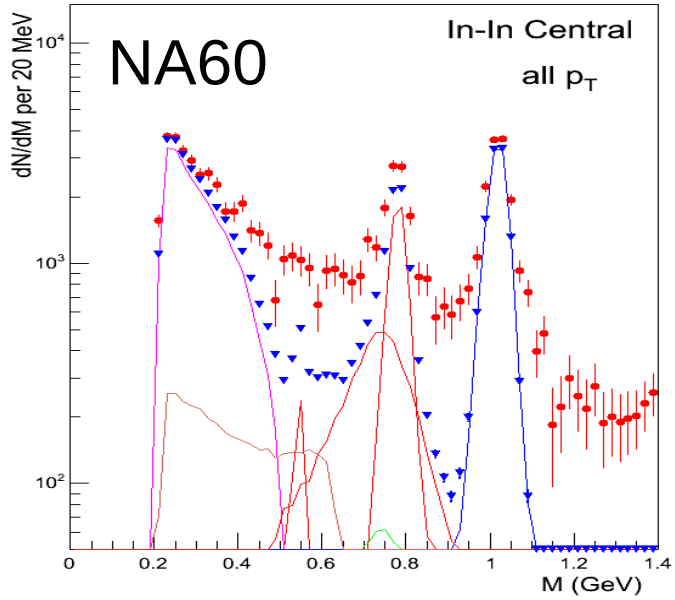
ϕ

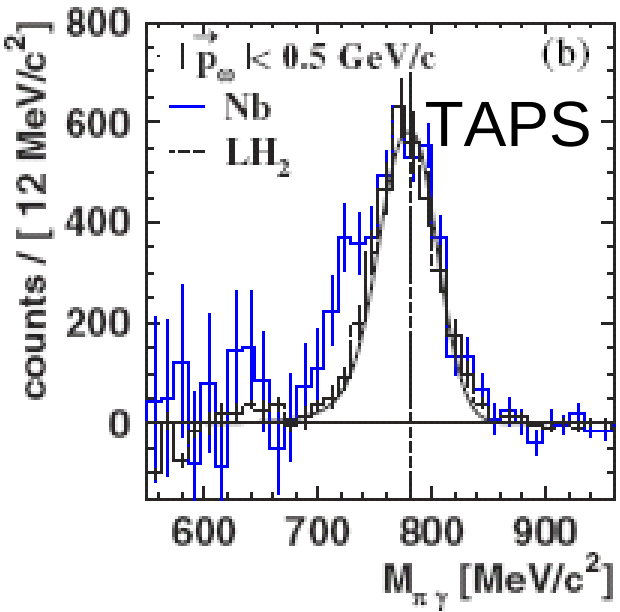
Mass modification **20 ~ 40MeV/c²**
: relatively small
Small decay width (**4.4MeV/c²**),
no other resonance nearby
: sensitive to small mass modification



Related Experiments

- *hot*
  - **CERES@SPS('93)** 158A GeV Pb – Au collisions; large enhancement observed in e^+e^- spectrum
  - **NA60@SPS/HADES@GSI/RHIC** dilepton measurements; on going
- *dense*
  - **TAGX@INS('03)** $^2H,^3He,^{12}C(\gamma\pi^+\pi^-)X$; ρ mass modified but final state interaction, sub threshold production may effect…
  - **TAPS@ELSA('05)** $\gamma+A\rightarrow\omega$, $\omega\rightarrow\pi^0\gamma$; 14% mass decrease





E325 experiment

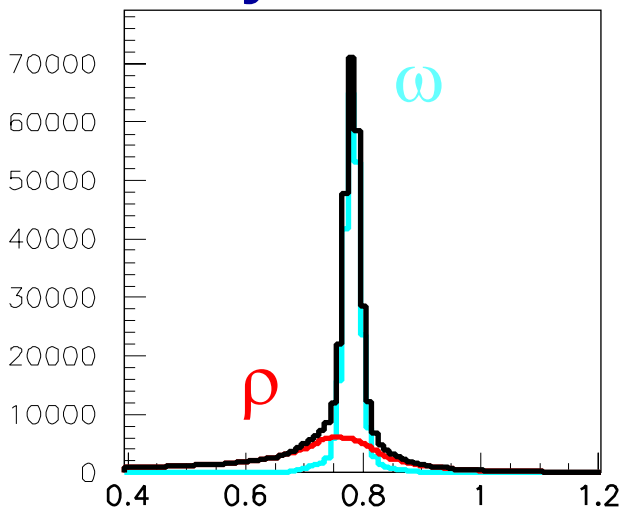
measures Invariant Mass of e^+e^-, K^+K^-
in 12GeV p + A → ρ , ω , ϕ + X reactions

- low energy : the mass modification at the normal nuclear density
- dilepton measurement : free from final state interactions

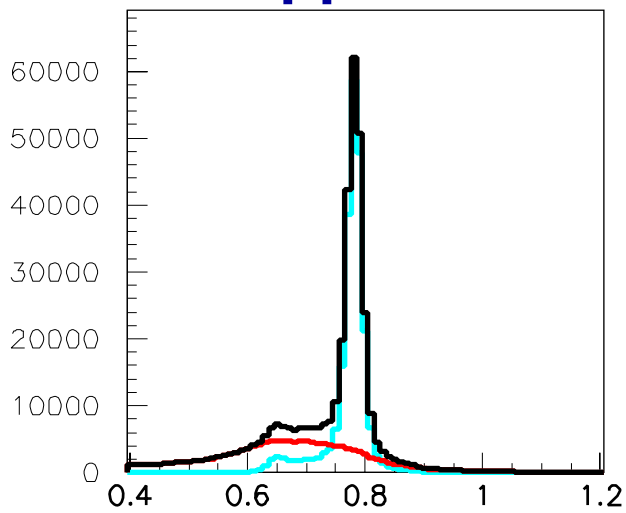
Expected Invariant Mass distribution of ρ and ω

mass modified by the formula
: $m^*/m=1-0.16\ \rho/\rho_0$
Prog.Theor.Phys.95(1996)1009

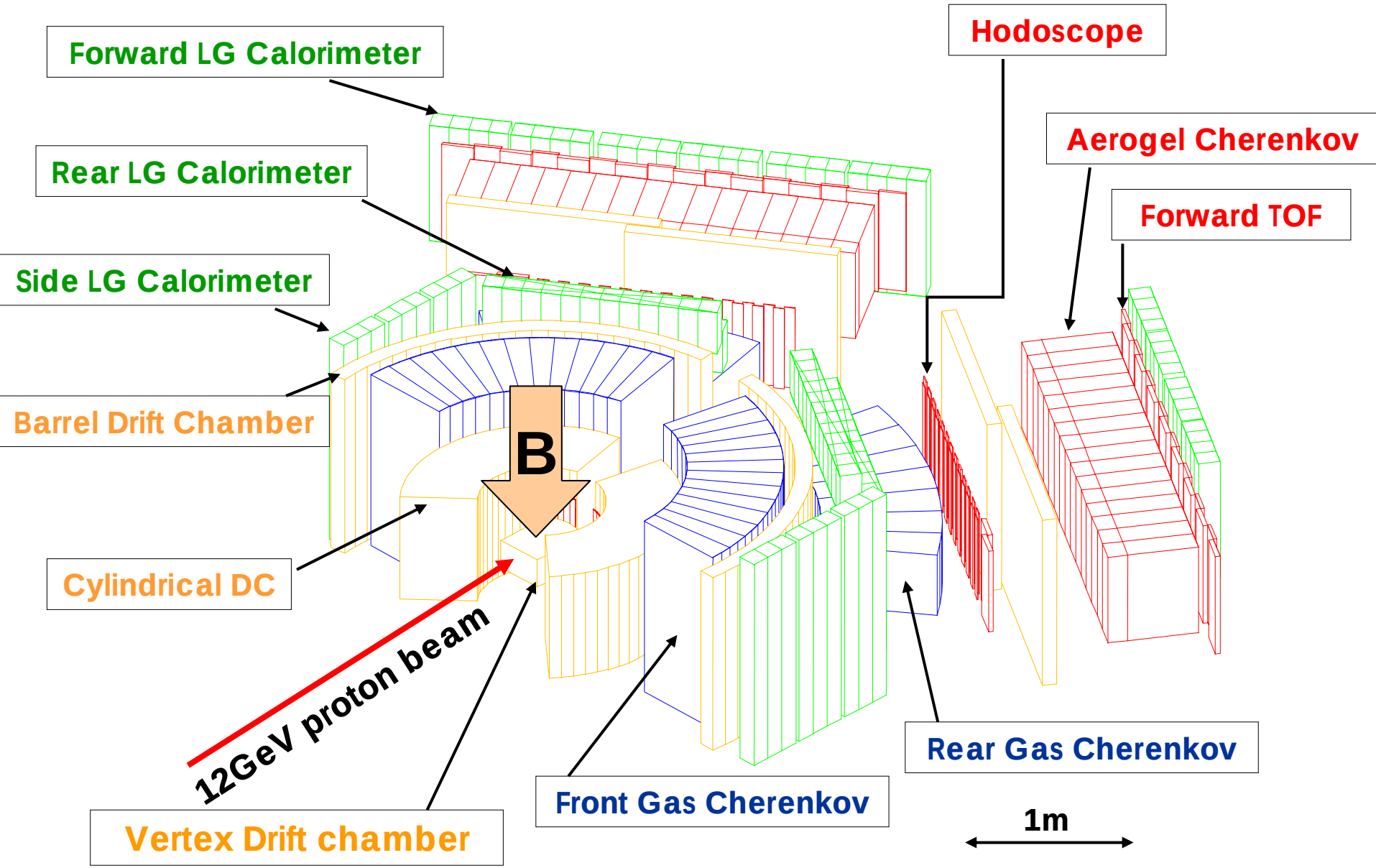
Decay in vacuum



In Copper Nuclei



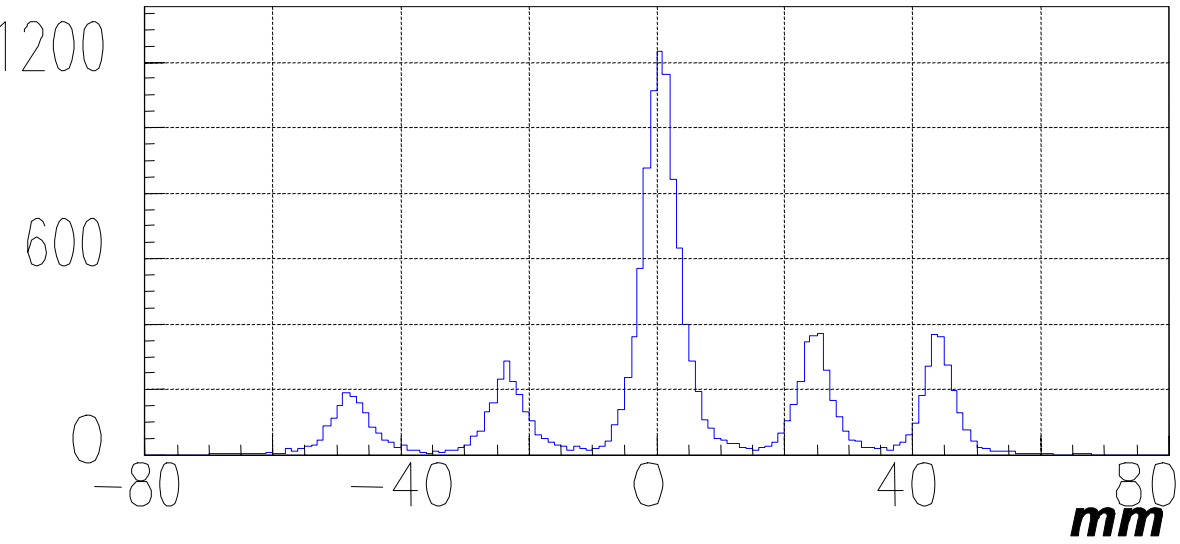
Detector Setup



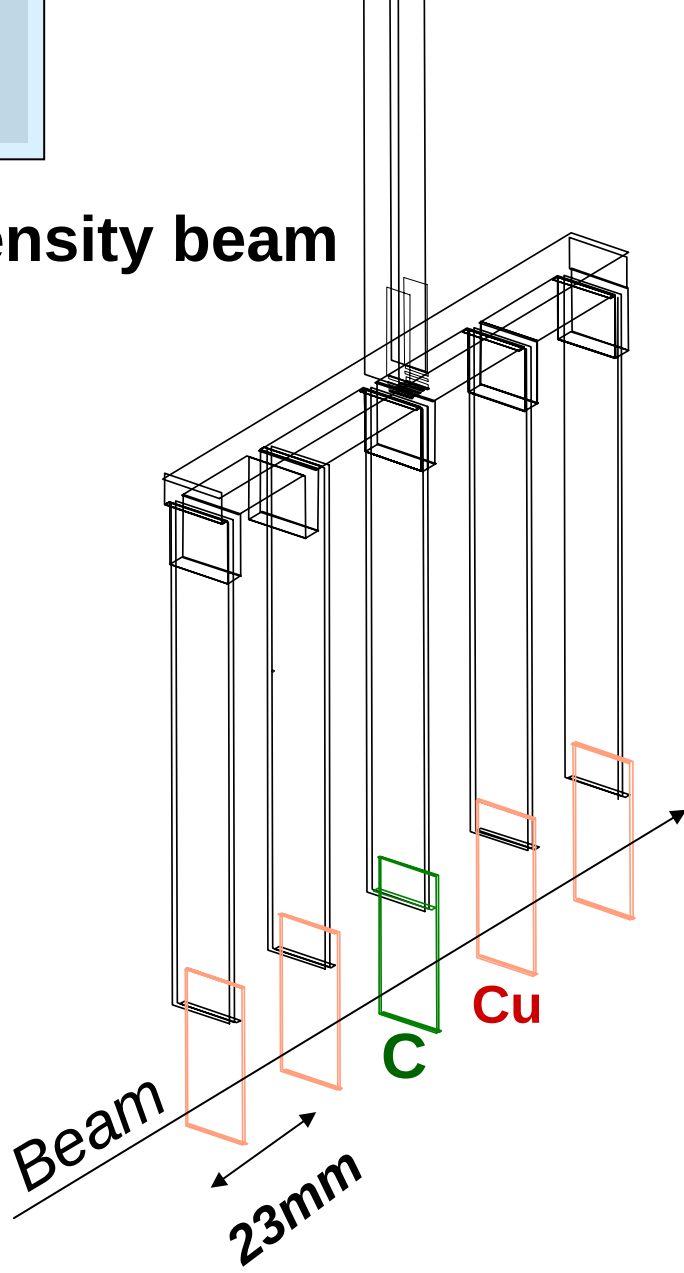
Target Configuration

Very thin target with clean and high intensity beam

material	beam intensity (p/spill)	Interaction length(%)	radiation length(%)
C	~1x10^9	0.2%	0.4%
CuX4	~1x10^9	0.05%X4	0.5%X4

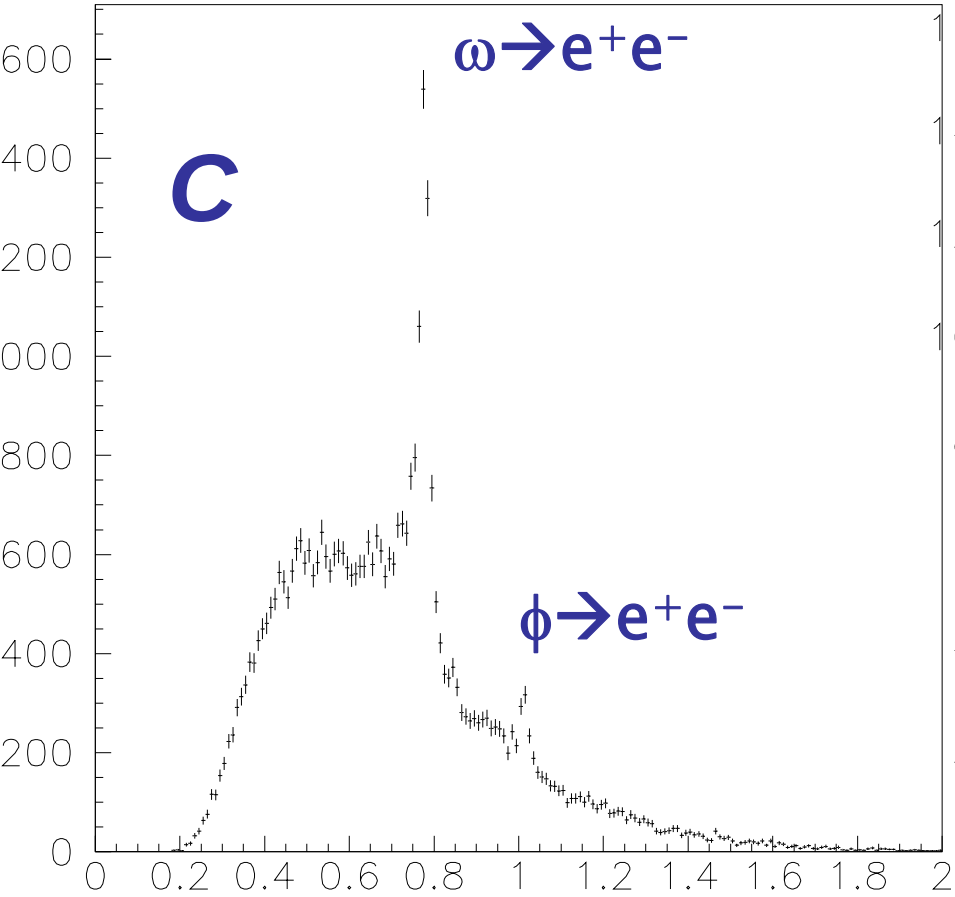


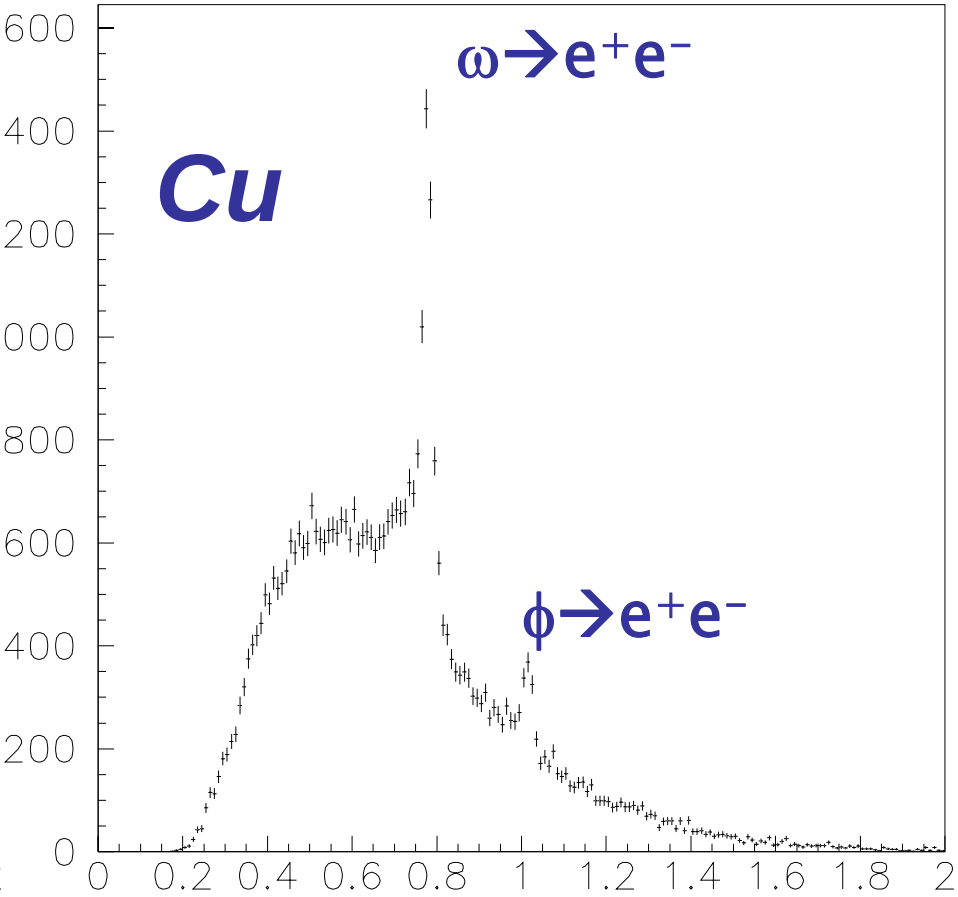
Vertex Distribution



Results

Invariant Mass Spectrum of e+e−





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

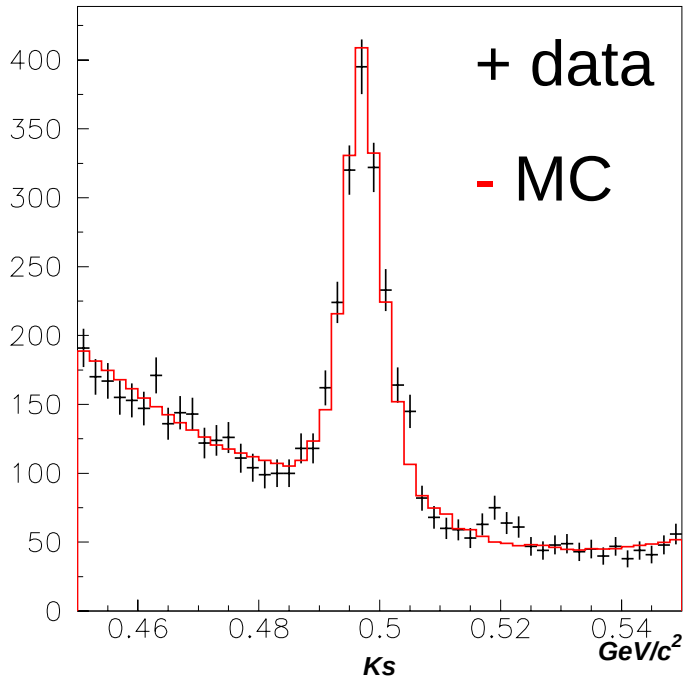
On the Fit

- **resonance**
  - relativistic Breit-Wigner shape
  - experimental effect estimated through Geant4 simulation – energy loss including Bremsstrahlung, multiple scattering, tracking performance and detector acceptance.
- **background**
  - combinatorial background obtained by mixed events.
- **fit parameters**
  - relative abundances of mesons (ρ,ω,ϕ) , η Dalitz and background are obtained by the fitting.

MC simulation : Mass Resolution

- mass resolution and scale are examined for observed $K_s \to \pi^+\pi^-$ decays.
- resolution and centroid are consistent with the detector simulation using Geant4.
- mass resolution for ω/ϕ are estimated to be 8.0/10.7 MeV/c^2

$K_s \to \pi^+\pi^-$



m = 497.1±0.2 MeV/c^2

(MC:497.0±0.1 MeV/c^2)

σ = 3.9±0.4 MeV/c^2

(MC: 3.5±0.1 MeV/c^2)

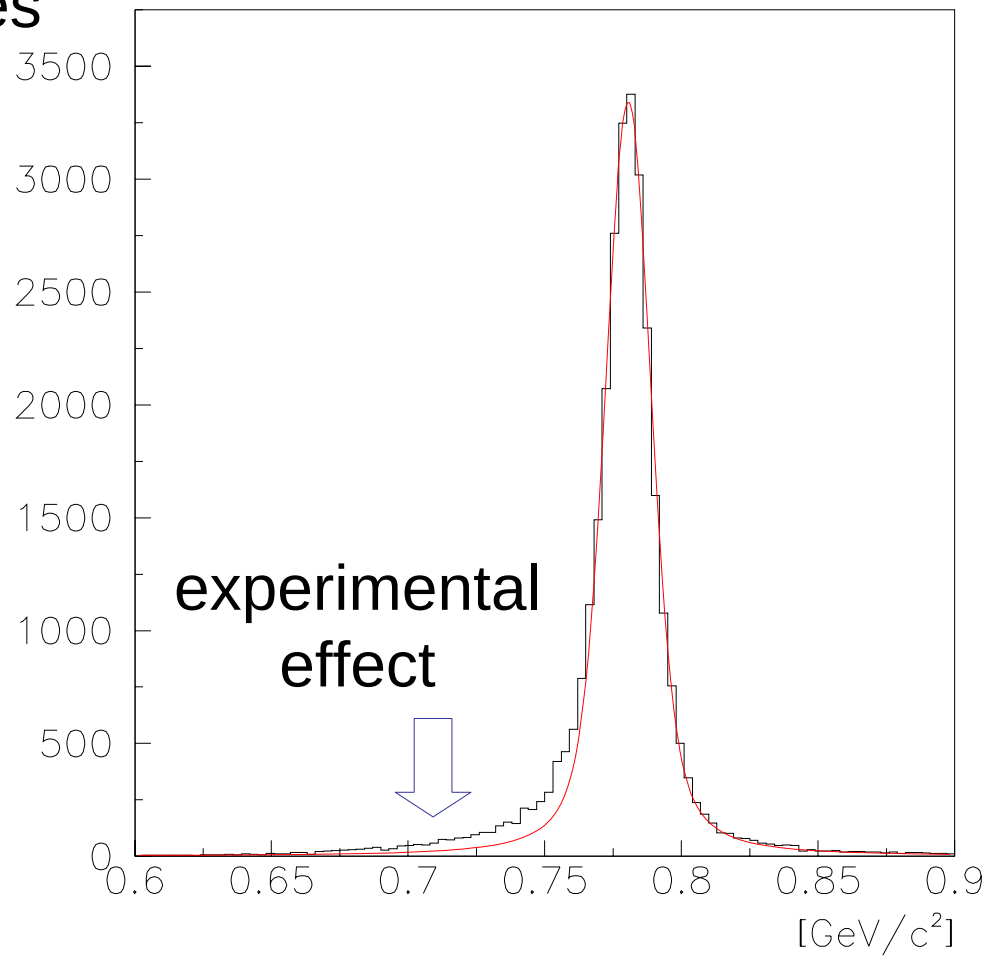
MC simulation : Energy Loss

– Monte Carlo shape

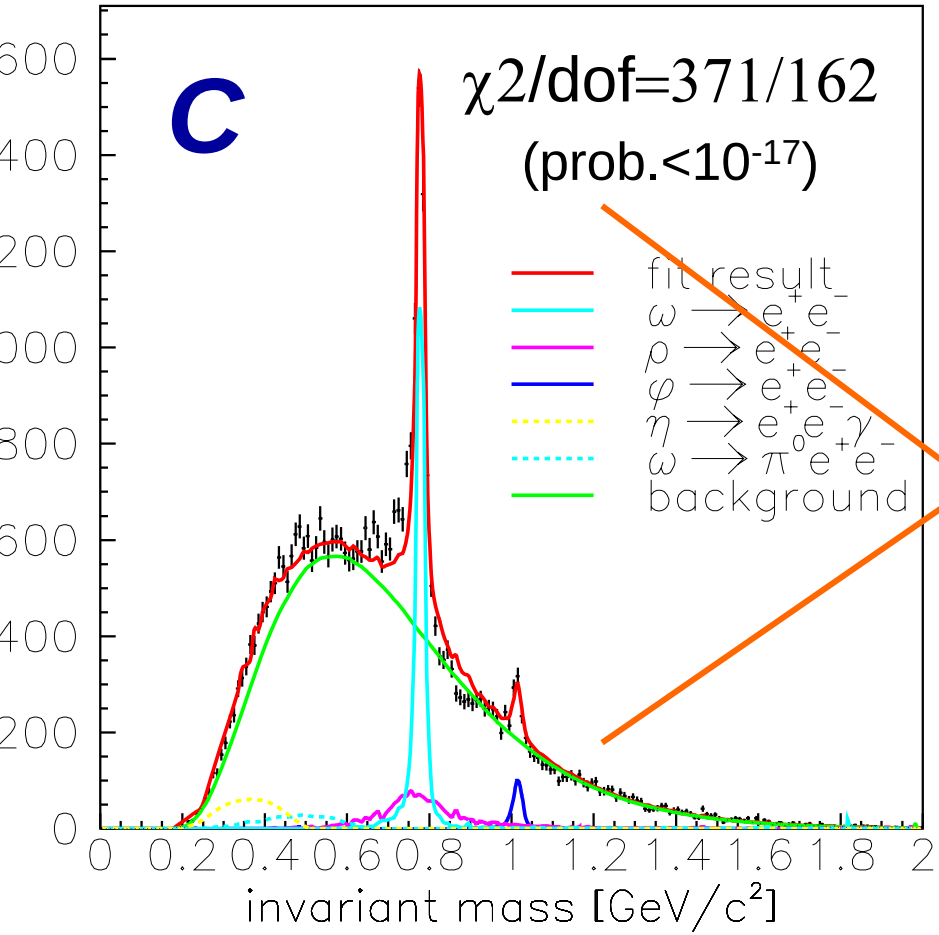
– relativistic Breit-Wigner ∗ Gaussian

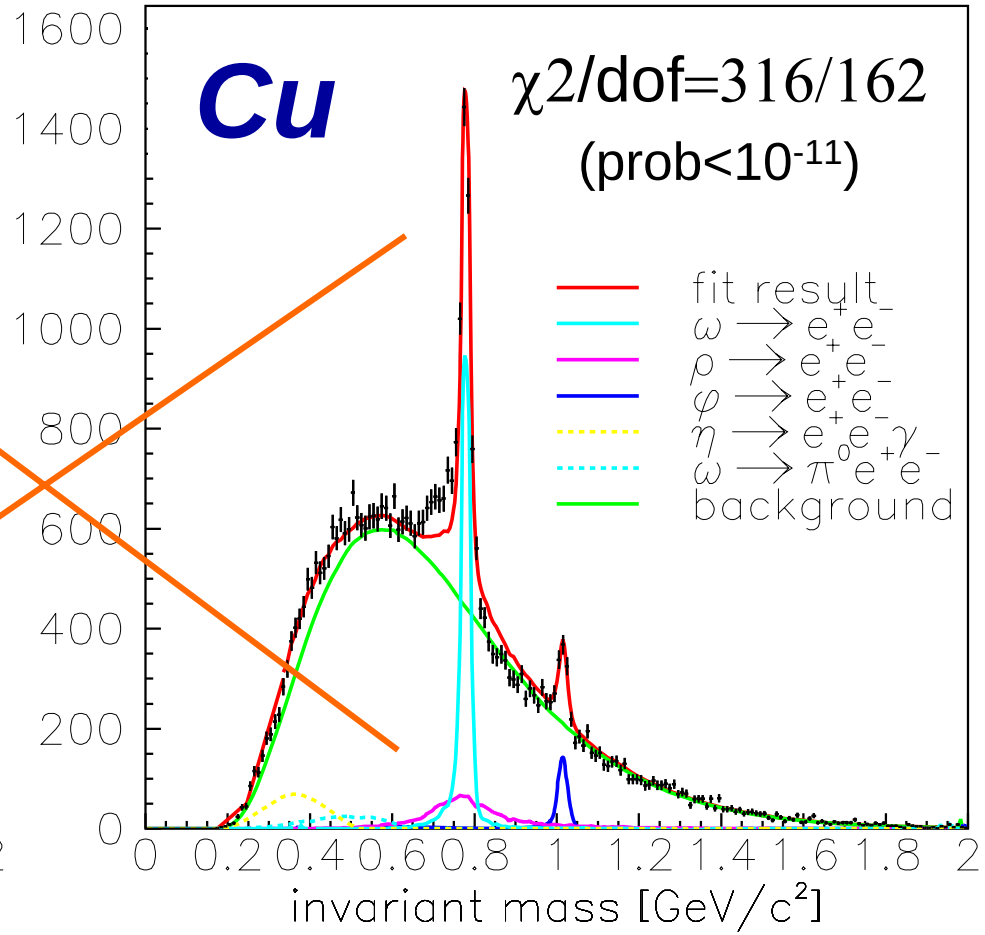
At low-mass side of the resonances, a long tail arises due to the energy loss of electrons (mainly by Bremsstrahlung).

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



Invariant Mass Spectrum of e^+e^-



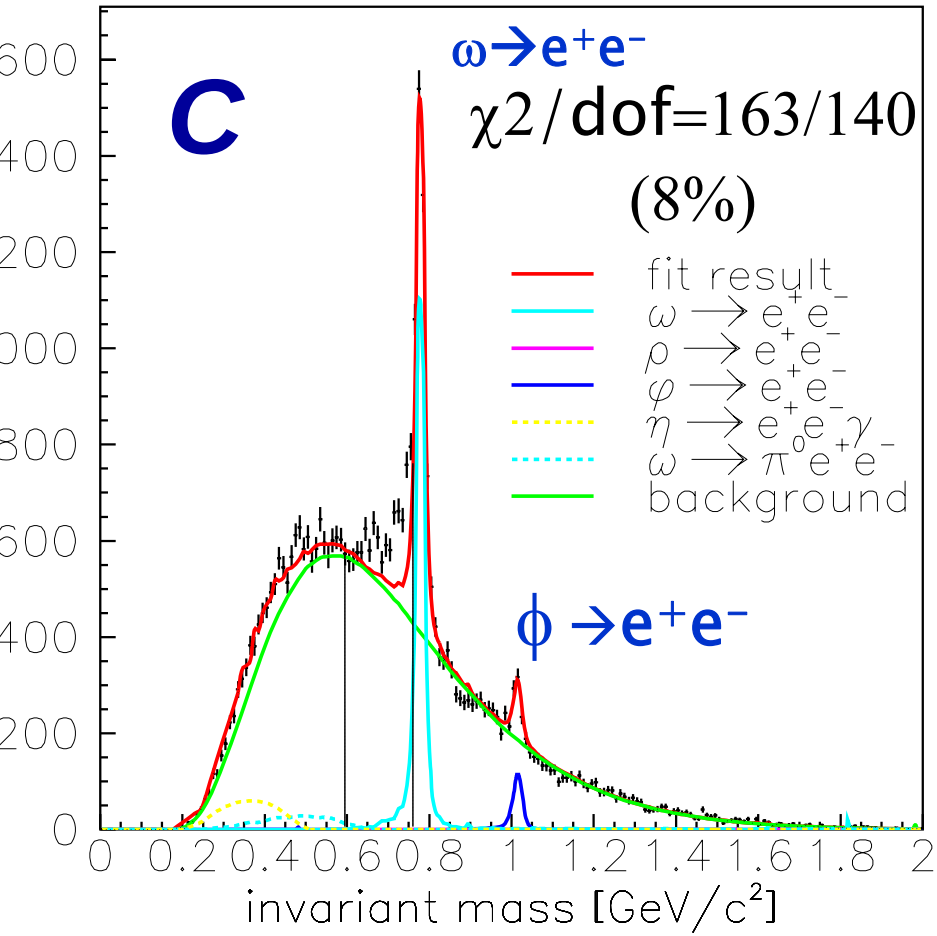


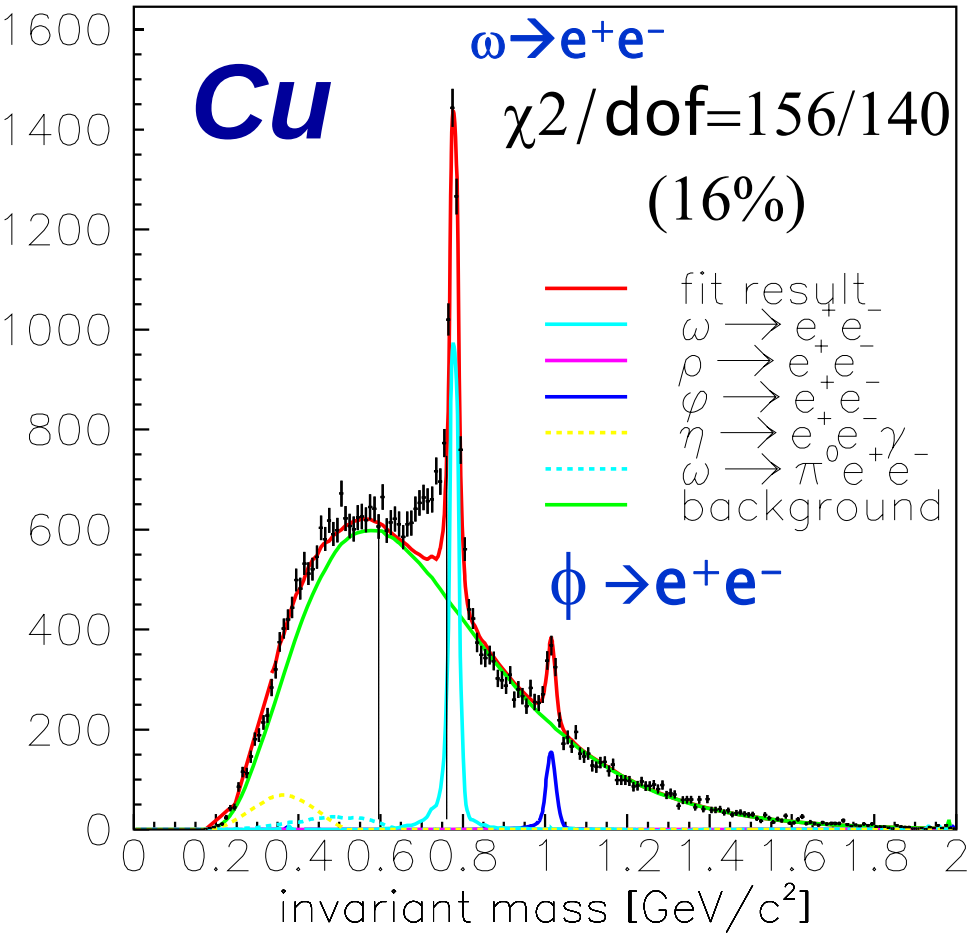
the data can not be reproduced by the expected shapes when we include the all region to the fit

→something exotic exists in 0.60–0.76GeV/c^2!

Invariant Mass Spectrum of e^+e^-

the region 0.60-0.76GeV/c^2 is excluded from the fit.

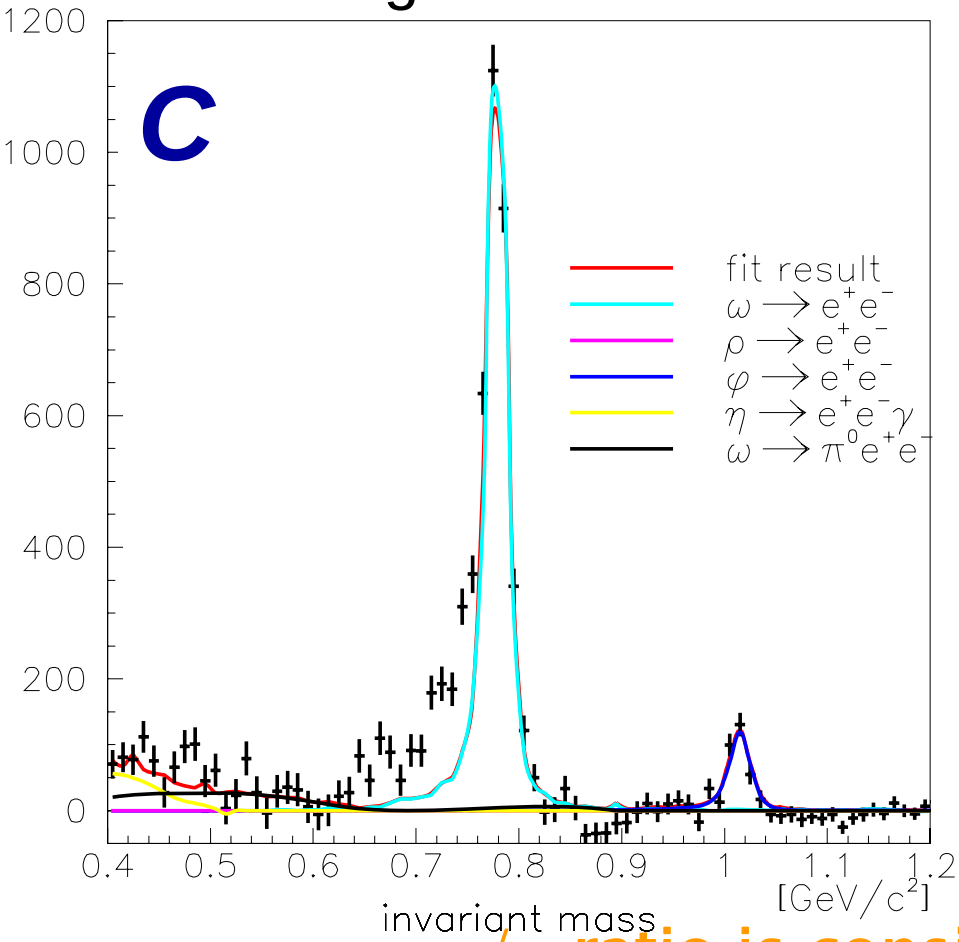


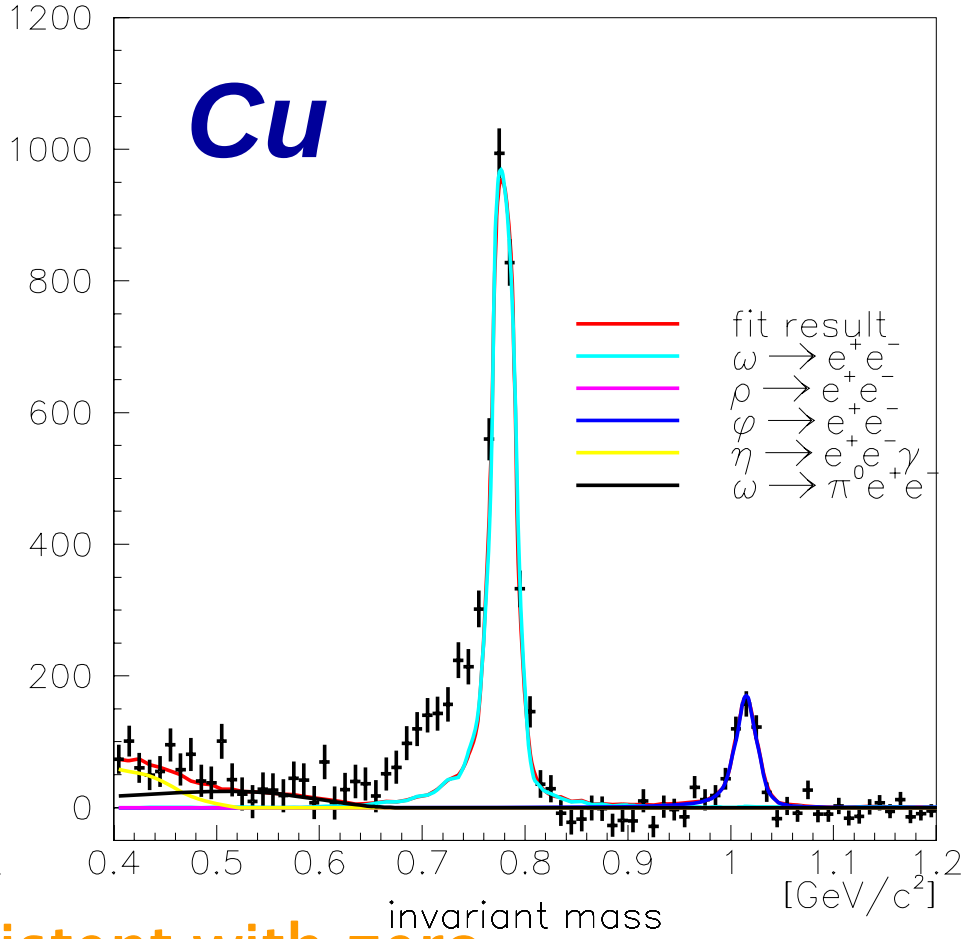


the excess over the known hadronic sources on the low mass side of ω peak has been observed.

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

the region 0.60-0.76 GeV/c^2 is excluded from the fit.





ρ/ω ratio is consistent with zero

$N\rho/N\omega = 0.0 \pm 0.02(stat.) \pm 0.2(sys.)$ $0.0 \pm 0.04(stat.) \pm 0.3(sys.)$

It is pretty much surprising because the ρ/ω is known to be unity in pp interactions (Blobel et. al, PLB48('74)73)

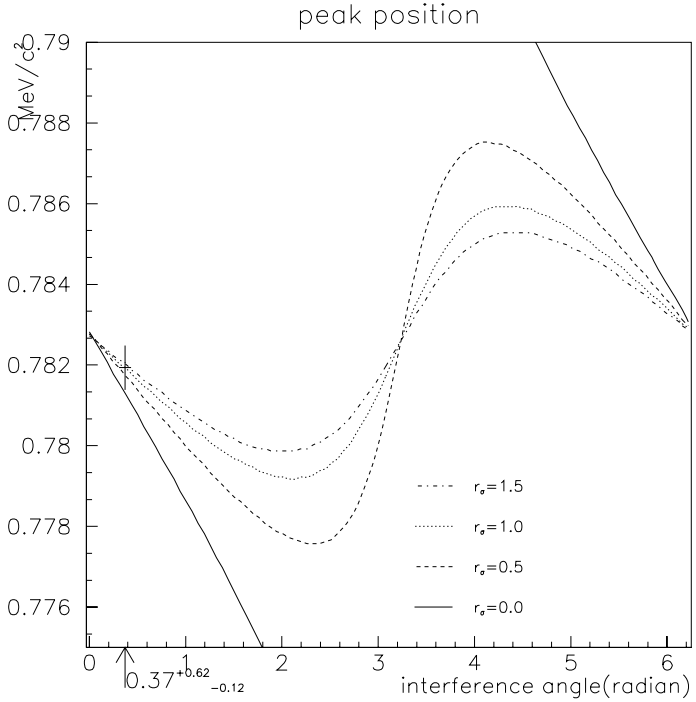
Discussion

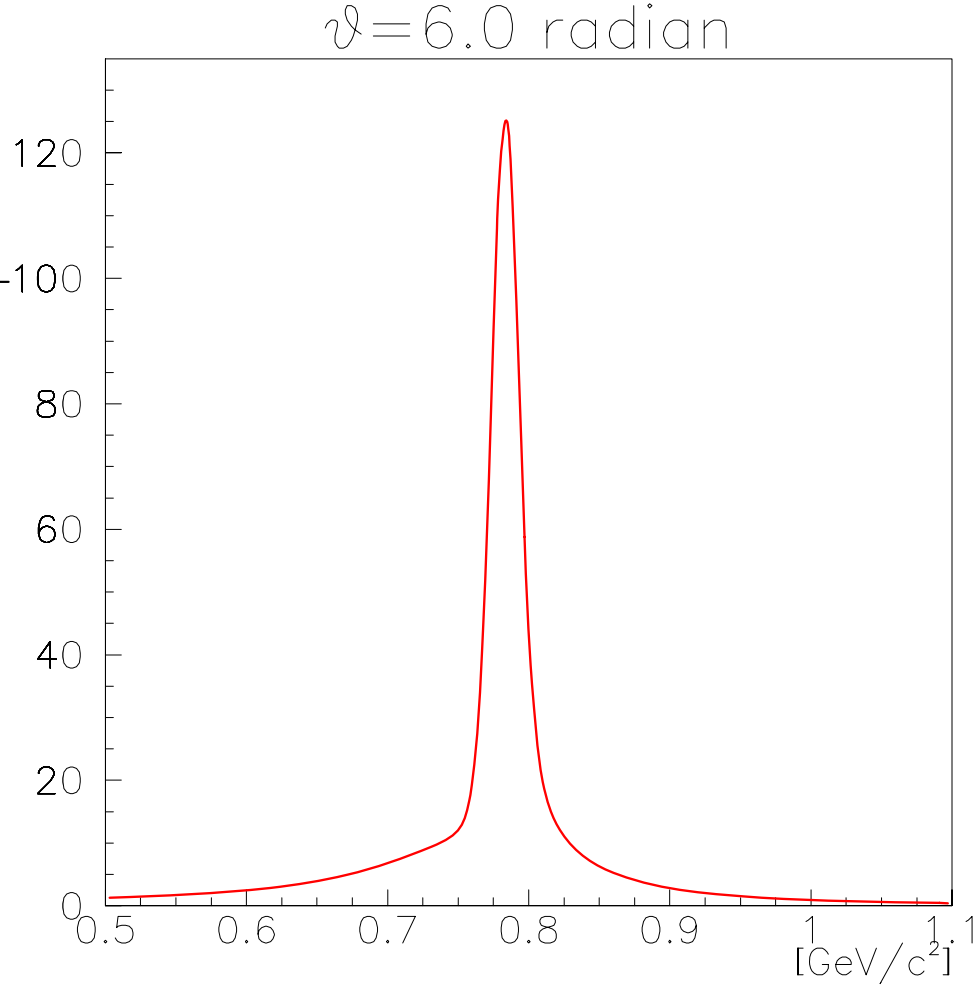
ρ–ω interference?

ρ–ω interfering resonance shape:

$$F^2 = \left|F_\rho + RF_\omega\right|^2,\ F_V = \frac{1}{m^2 - m_V{}^2 + im\Gamma_V}$$

$$R = \frac{\langle ee|\omega\rangle\langle\omega|pA\rangle}{\langle ee|\rho\rangle\langle\rho|pA\rangle} = \sqrt{\frac{m_\omega\Gamma_{\omega\to ee}}{m_\rho\Gamma_{\rho\to ee}}}\sqrt{\frac{\sigma_\omega}{\sigma_\rho}}e^{i\theta}$$





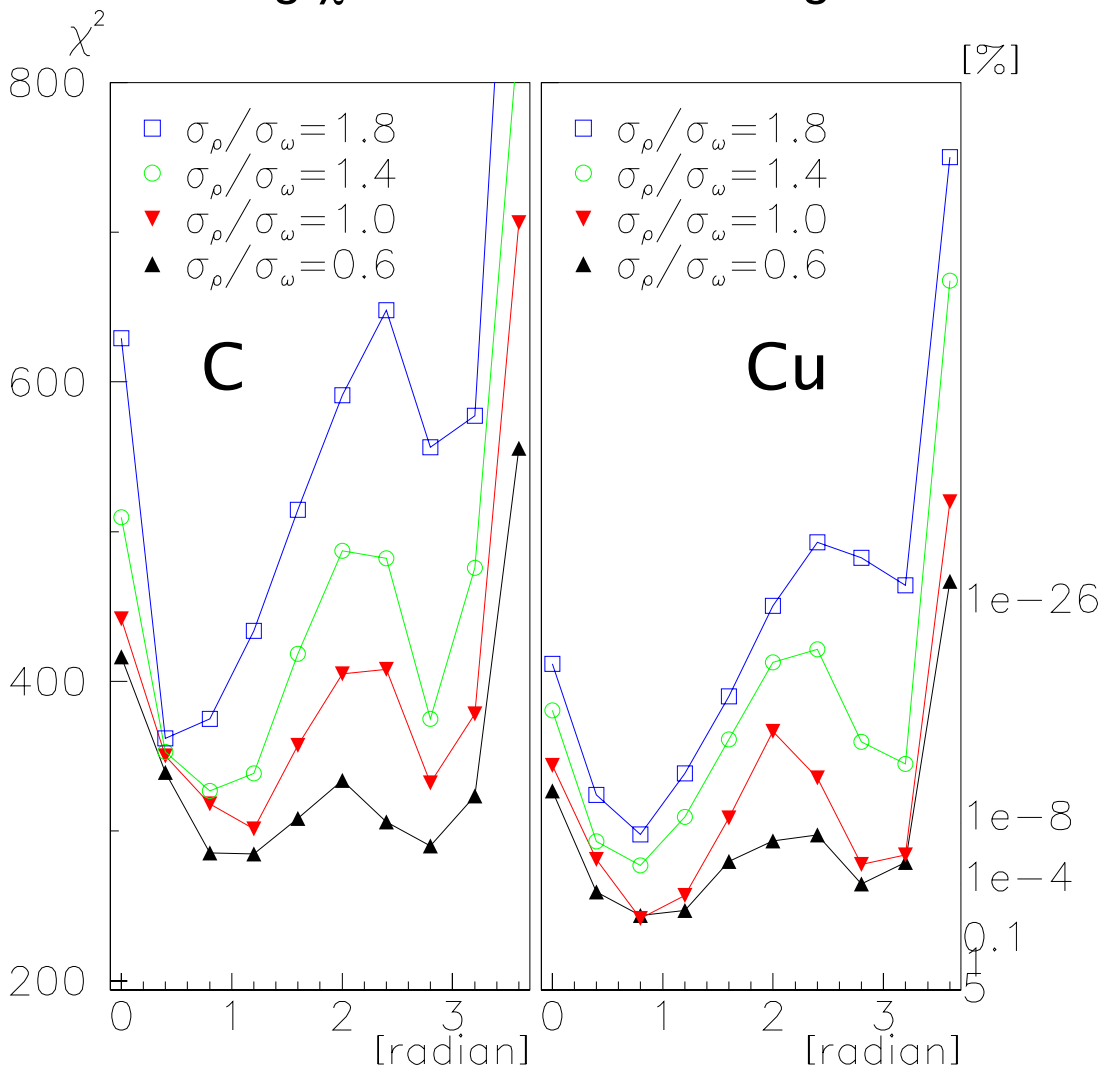
Is the ρ–ω interference possible explanation for the modified spectra?

ρ–ω interference?

- data was fitted with the interfering ρ–ω shape for various $\sigma_\rho/\sigma_\omega$ and angle
- best case
  - ✓ $\sigma_\rho/\sigma_\omega$=0.6, θ=0.8rad
  - ✓ $\chi 2$=285/163(C) ,242/163(Cu)
  - ✓ probability<1x10^{-4}

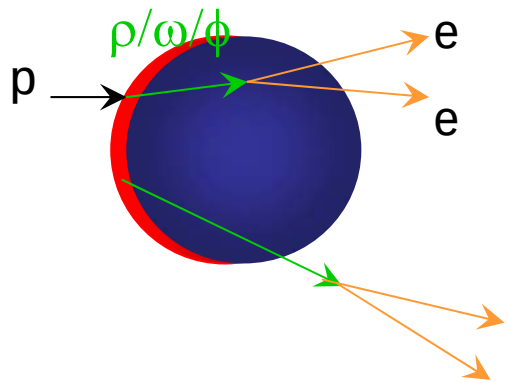
no solution to reproduce the excess

fitting χ^2 vs interference angle

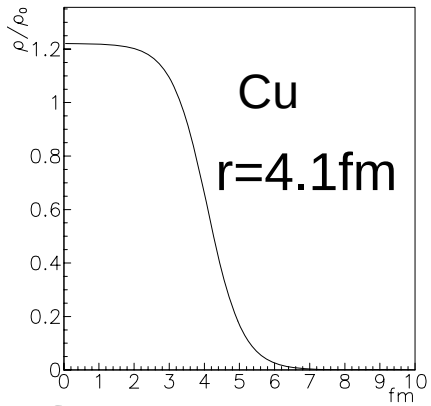


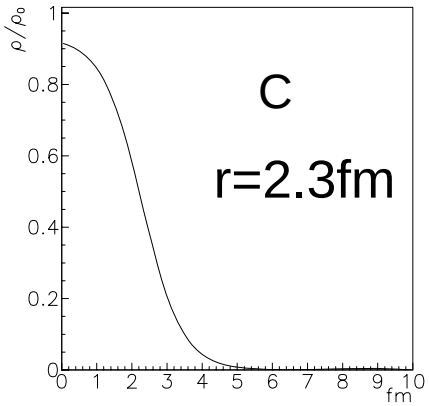
Toy Model Calculation

- generated at surface of forward hemisphere of target nucleus
  - $\alpha_\omega = 0.68 \pm 0.04$
    ($\alpha_\phi = 0.93 \pm 0.15$)
  - decay inside nucleus:



	C	Cu
ρ	52%	66%
ω	5%	10%

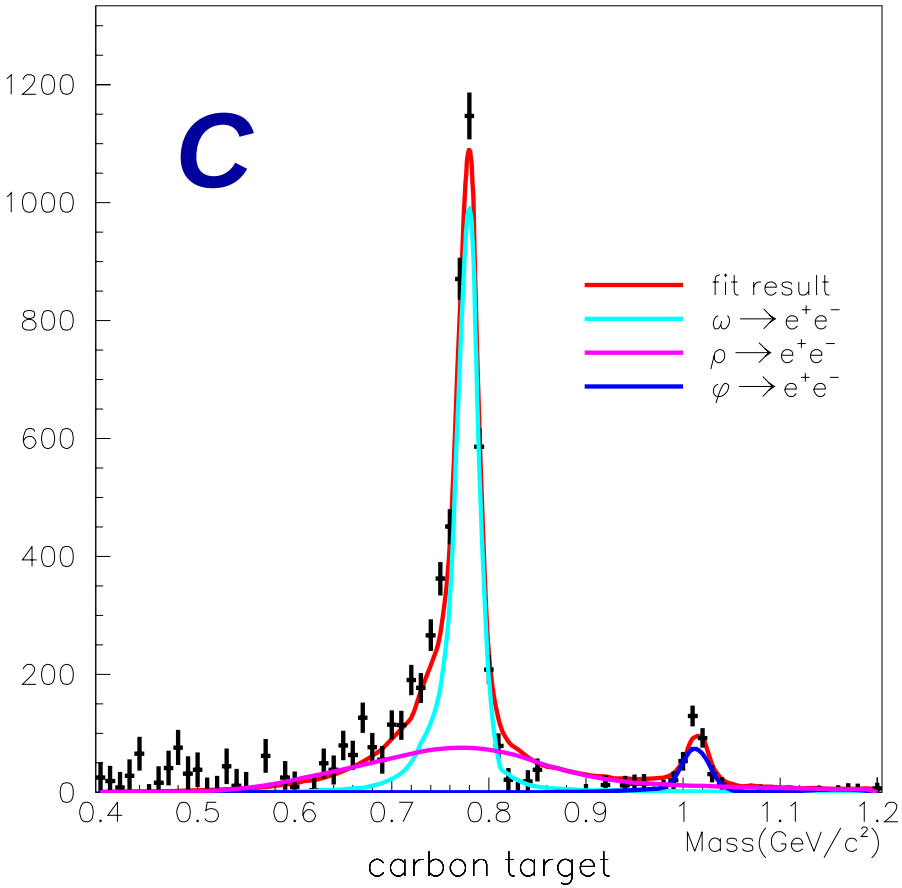


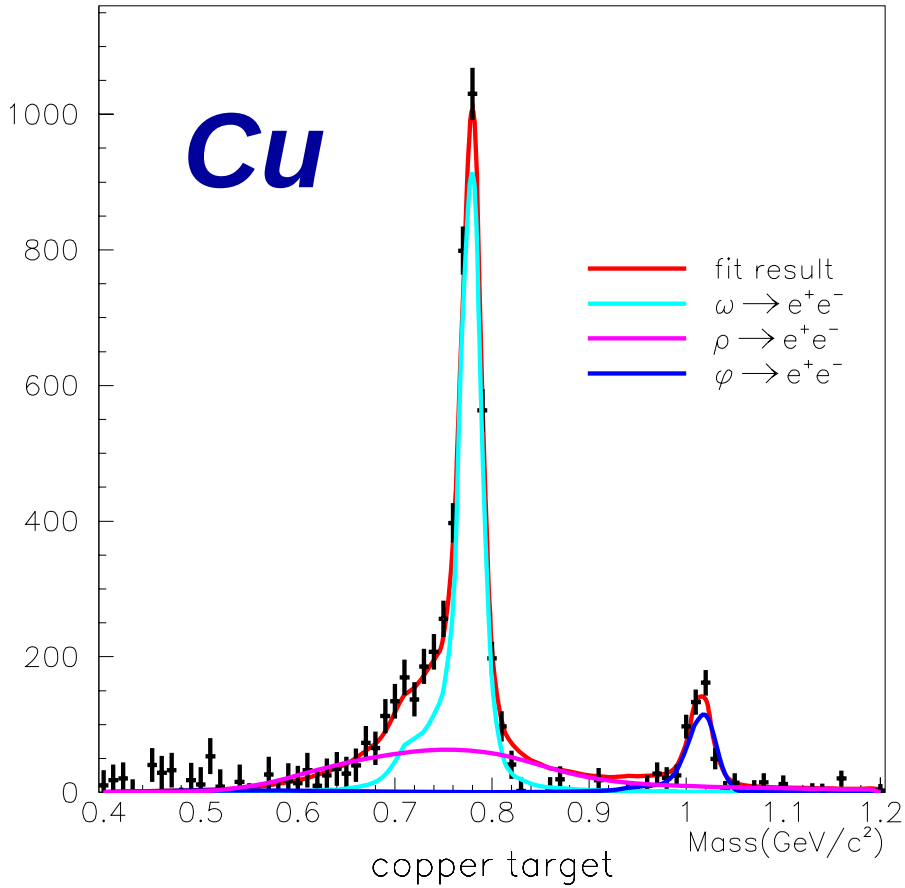


- density distribution - Woods-Saxon
- mass spectrum: relativistic Breit-Wigner Shape
- pole mass: $\frac{m^*}{m} = 1 - k\frac{\rho}{\rho^0}$ (Hatsuda-Lee formula)
- no width modification

Model Calculation

With the formula : $m^*/m=1-k\rho/\rho_0$

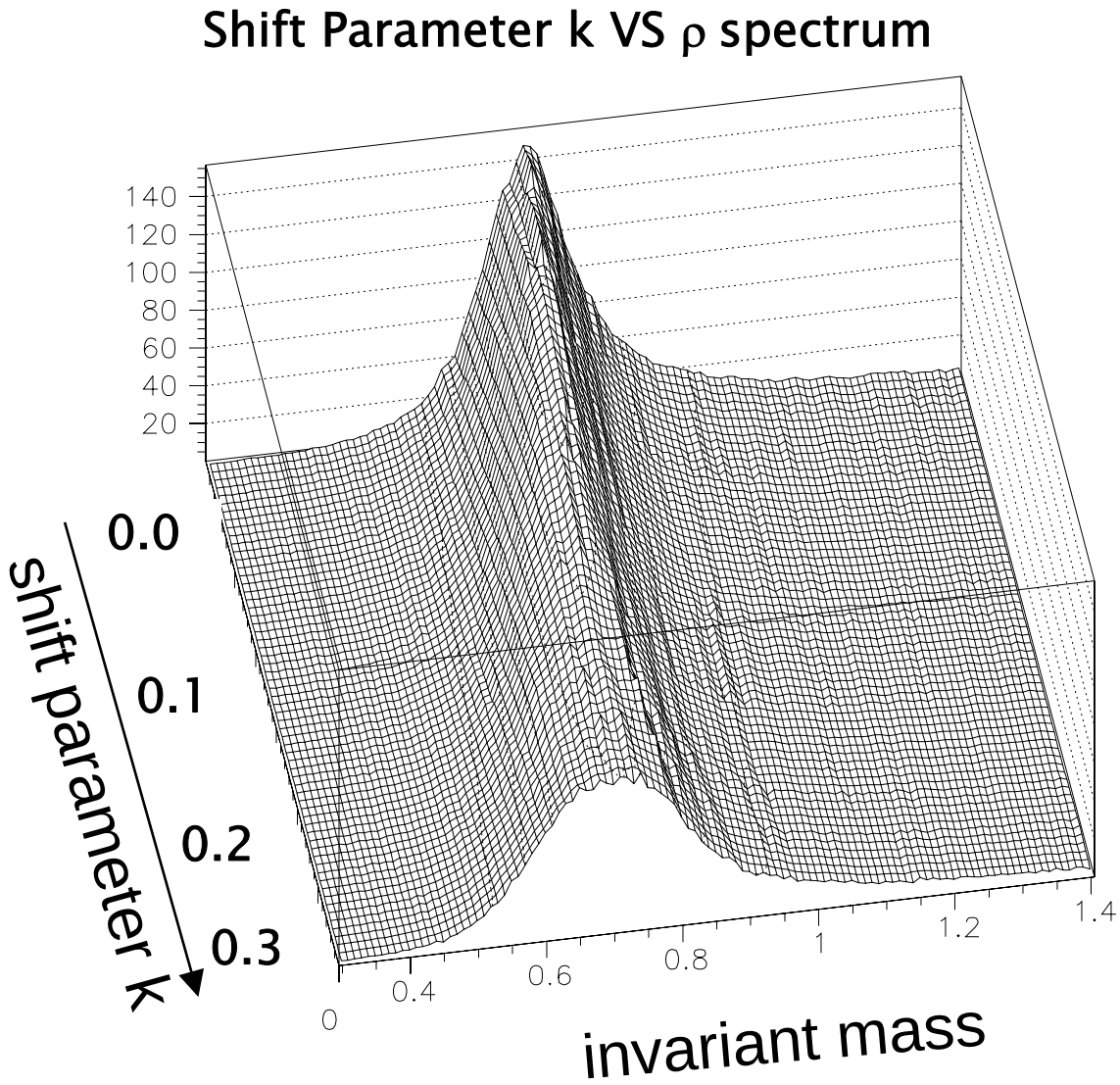




k = 0.08 → seems to fit the data

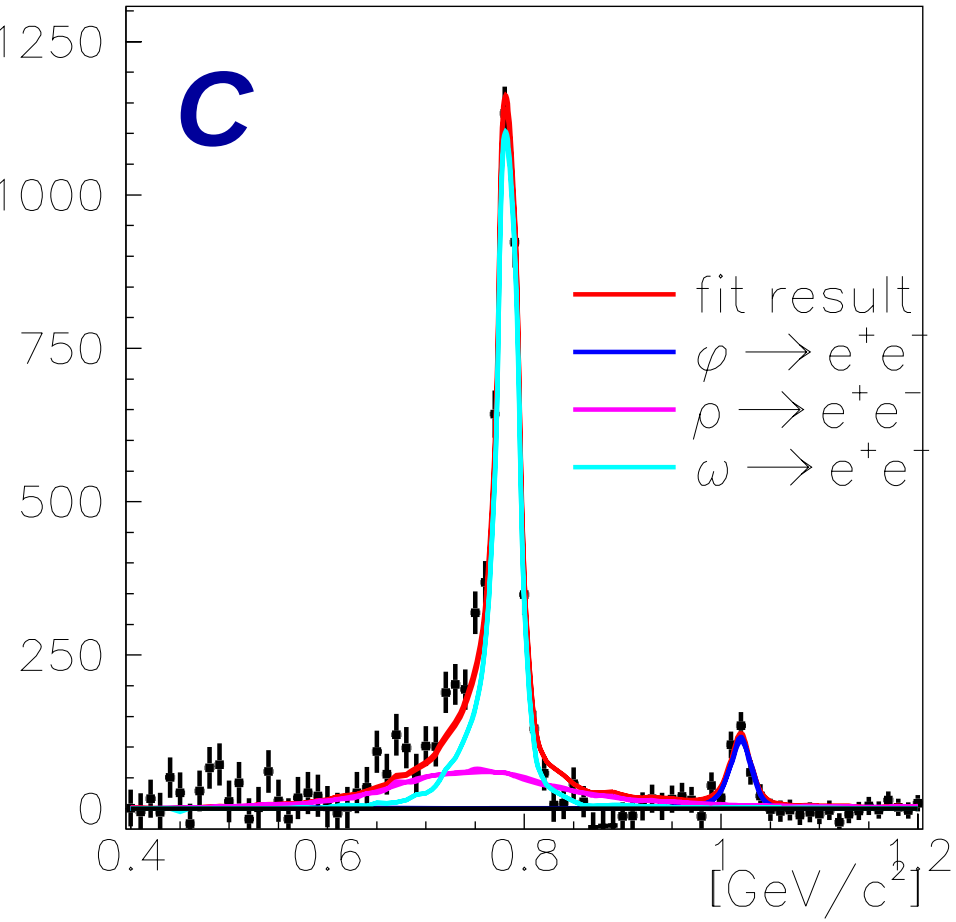
ρmeson spectrum for various k
m*/m=1-k ρ/ρ$_0$

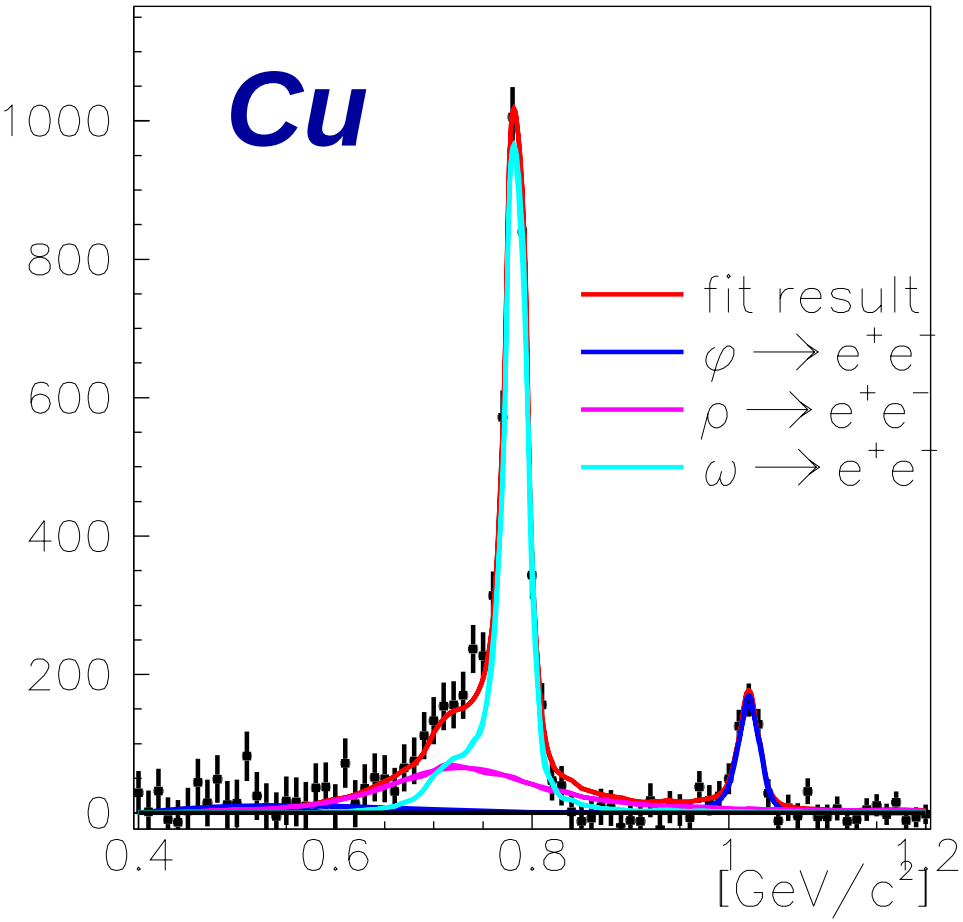
- We fit the data to determine the shift parameter k
- C/Cu data are fitted simultaneously
- fit parameters:
  - shift parameter k
  - relative abundances of ϕ, ω and background
  - ρ/ω ratio



Fit Results of Model Calculation

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





the tendency of the excess for C and Cu are well reproduced by the model including the mass modification.

Confidence ellipsoids for k
$m^*/m = 1 - k\,\rho/\rho_0$

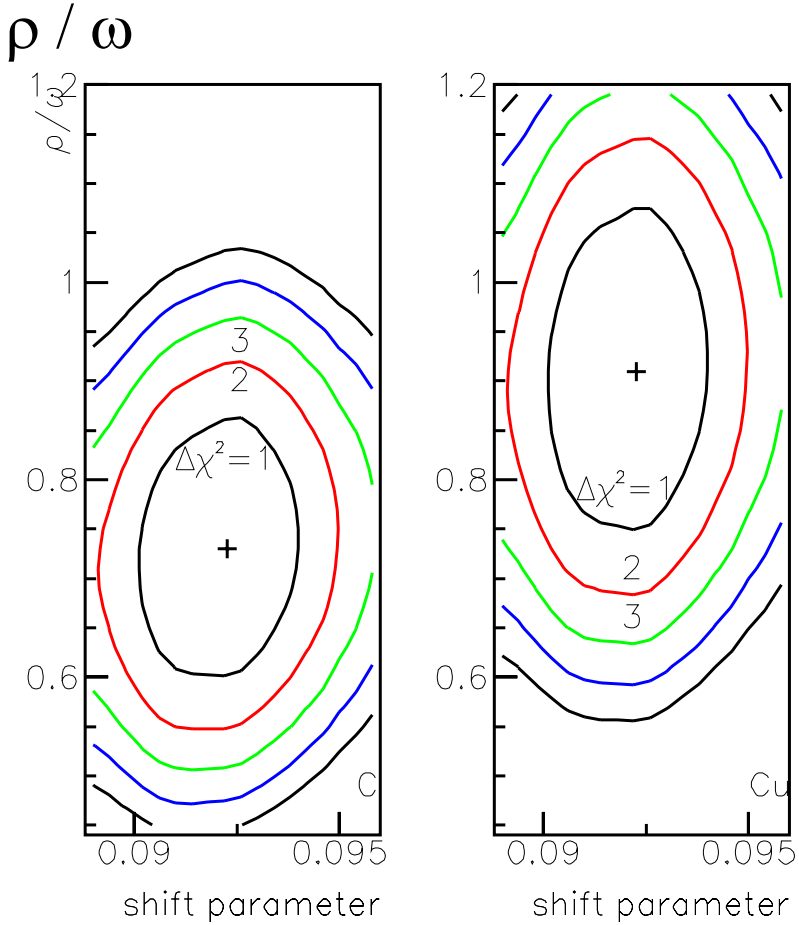
- production ratio ρ/ω VS shift parameter k
- Best-Fit value is

$k = 0.092 \pm 0.002$

$\rho/\omega = 0.7 \pm 0.1$ (C)

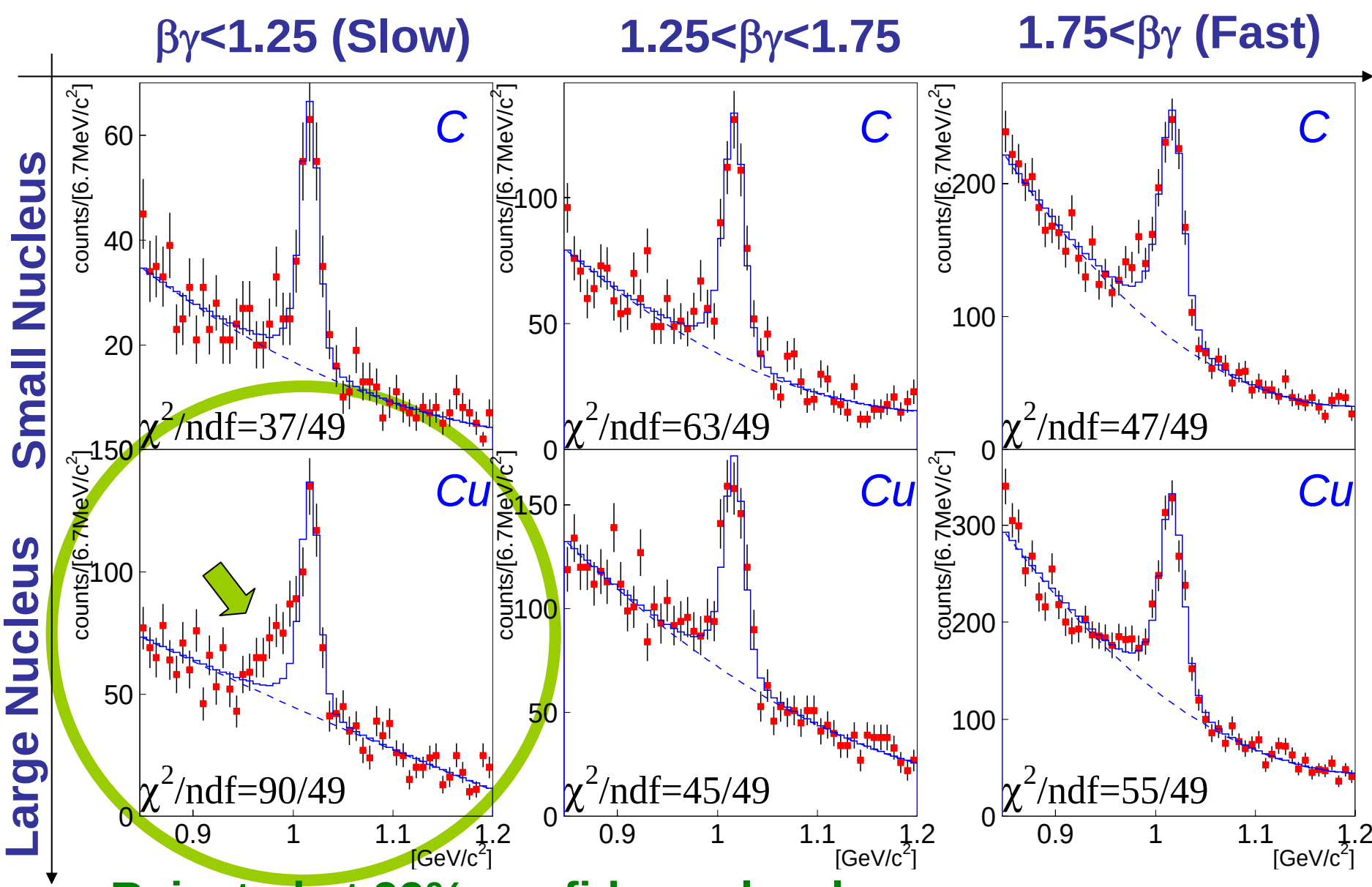
0.9 ± 0.2 (Cu)

→ mass of ρ / ω meson decrease 9% at normal nuclear density.



shift paramter k

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



Summary

- KEK PS-E325 experiment measured e^+e^- pairs in 12GeV p+A reactions to investigate invariant mass of vector mesons decaying in nuclear matter.
- We have observed the excess over the known hadronic sources at low-mass side of ω. Obtained ρ / ω ratio indicates that the excess is mainly due to the modification of ρ mesons.
- ρ–ω interference does not explain our data.
- Model calculation based on the mass modification reproduced the tendency of the data. The fit result shows that the mass of ρ/ω decreases by 9% at the normal nuclear density.