# Vector Meson Measurement at KEK–12GeV PS

Satoshi Yokkaichi

RIKEN

for KEK–PS E325 collaboration

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- Invariant mass spectra for $K^+K^-$and $e^+e^-$
- Nuclear dependence of production cross section
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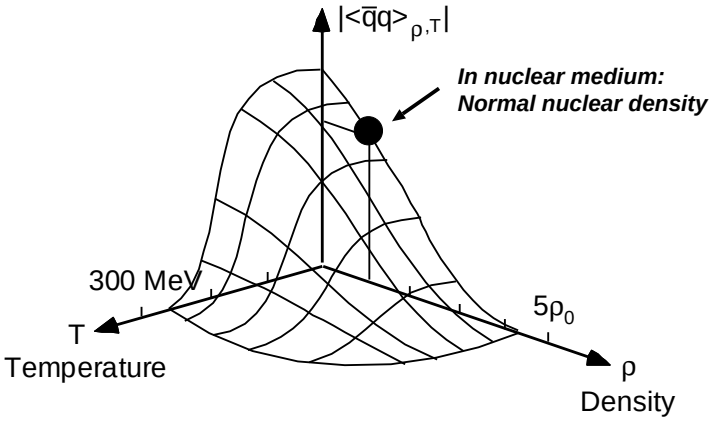
- Summary

# Chiral symmetry restoration

- constituent quark mass (∼350MeV) ∼ spontaneous braking of chiral symmetry
- quark condensate $\langle \bar{q}q \rangle$ is an order parameter of the chiral symmetry

$$\Downarrow$$

- In hot/dense matter,
  - the chiral symmetry restoration,
  - $\langle \bar{q}q \rangle$ decreasing,
  - hadron modification are expected




In dense matter

$$\frac{\langle \bar{q}q \rangle_\rho}{\langle \bar{q}q \rangle_0} = 1 - (0.34 \pm 0.05)\frac{\rho}{\rho_0}$$

(Drukarev *et al.*, 1991)

$$\Downarrow$$

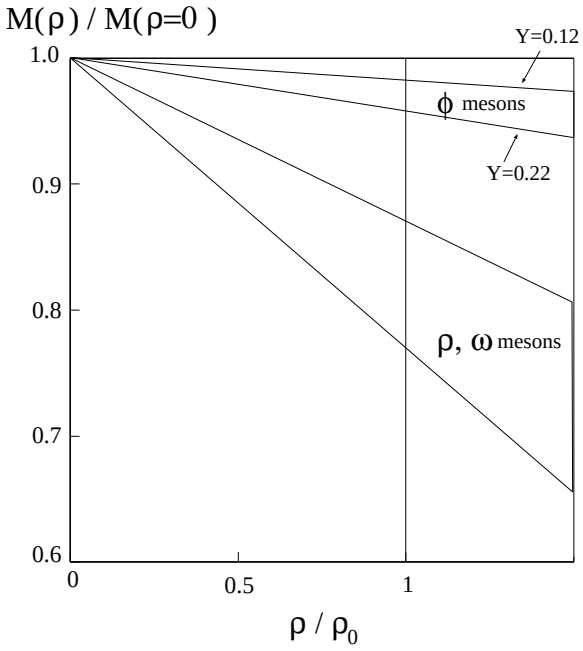
1/3 of restoration at the normal nuclear density

# Vector meson modification in dense matter

For example,

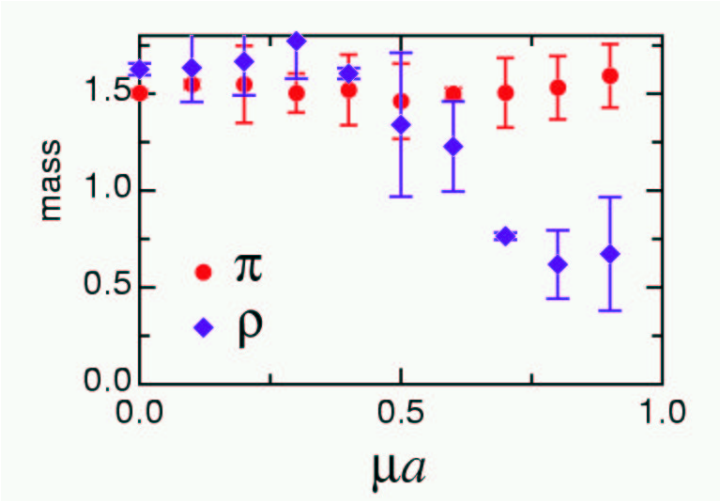
- Hatsuda and Lee(QCD sum rule) (PRC46(1992)R24)

  vector meson ( $\phi$, $\rho$ and $\omega$ )mass shift in dence matter




- Muroya, Nakamura and Nonaka (Lattice) (hep-lat/0208006)

  mass decreasing in vector channel, in finite chemical potential

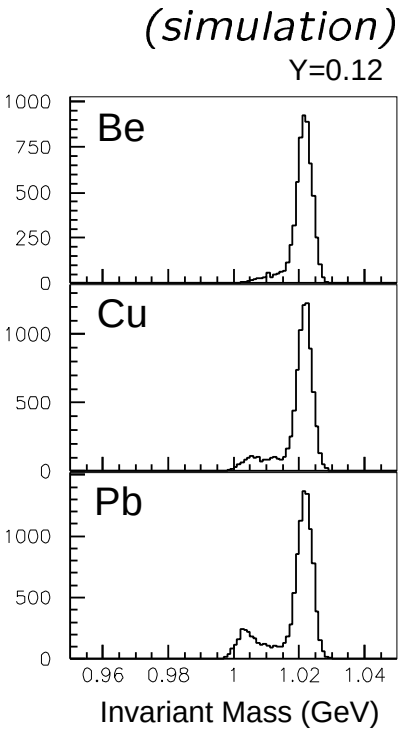



- many other: width changing, etc.

# Experimental signal ~ why $\phi$ ?

## 1. invariant mass spectra

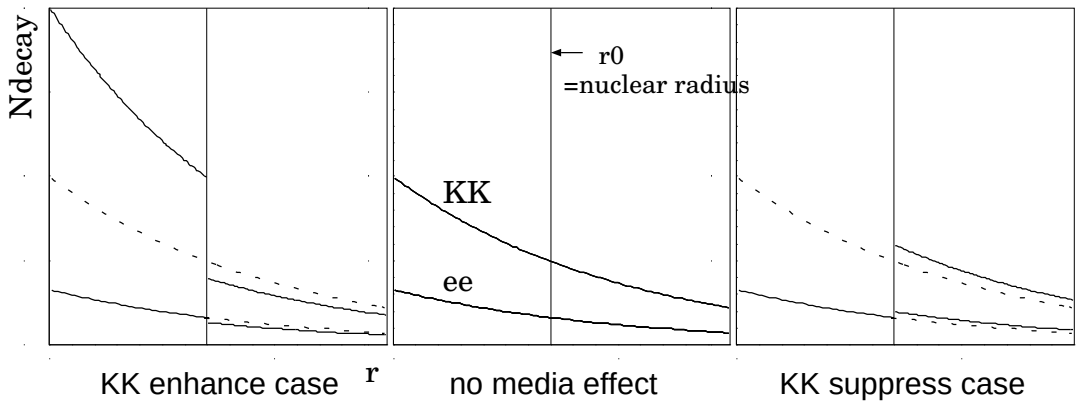
- second peak is made by $\phi$'s decaying in nuclei (no width-changing case)
- ee channel:
  - less final-state interaction
  - $\rho$ and $\omega$ can be collected at the same time
- KK channel:
  small Q-value(=32MeV/$c^2$ )
  $\Rightarrow$ possible width change in nuclei could be seen easier




## 2. branching ratio change

$\frac{br(\phi \to K^+K^-)}{br(\phi \to e^+e^-)}$ $\to$ compare with different nuclei

| Cu nuclei | KK enhance case ($\Gamma \sim 10MeV$) | normal | KK suppress case ($\Gamma \sim 0MeV$) |
|---|---|---|---|
| $\beta\gamma$=1.0 | 126% | 100% | 91% |



# KEK–PS E325 Collaboration

S. Yokkaichi[a], J. Chiba[b], H. En'yo[a], H. Funahashi[c], H. Hamagaki[d], M. Ieiri[b], M. Ishino[e], H. Kanda[f], M. Kitaguchi[c], S. Mihara[c], T. Miyashita[c], T. Murakami[c], R. Muto[c], M. Naruki[c], M. Nomachi[b], K. Ozawa[d], F. Sakuma[c], O. Sasaki[b], H.D. Sato[c], M. Sekimoto[b], T. Tabaru[a], K.H. Tanaka[b], S. Yamada[c] and Y. Yoshimura[c]

*a* RIKEN, *b* KEK, *c* Kyoto Univ., *d* CNS, *e* ICEPP *f* Tohoku Univ.

# History

| | | | (ee events) | (KK events) |
|---|---|---|---|---|
| 93 | 11 | proposal | | |
| 94 | 4 | test experiment start | | |
| 96 | 6 | construction start | | |
| 96 | 11 | first engineering run | | |
| 97 | 6 | first physics run | - | $\phi$:99 |
| 98 | 4/5 | 2nd physics run | $\omega$:95 | |
| | | | $\phi$:12 | |

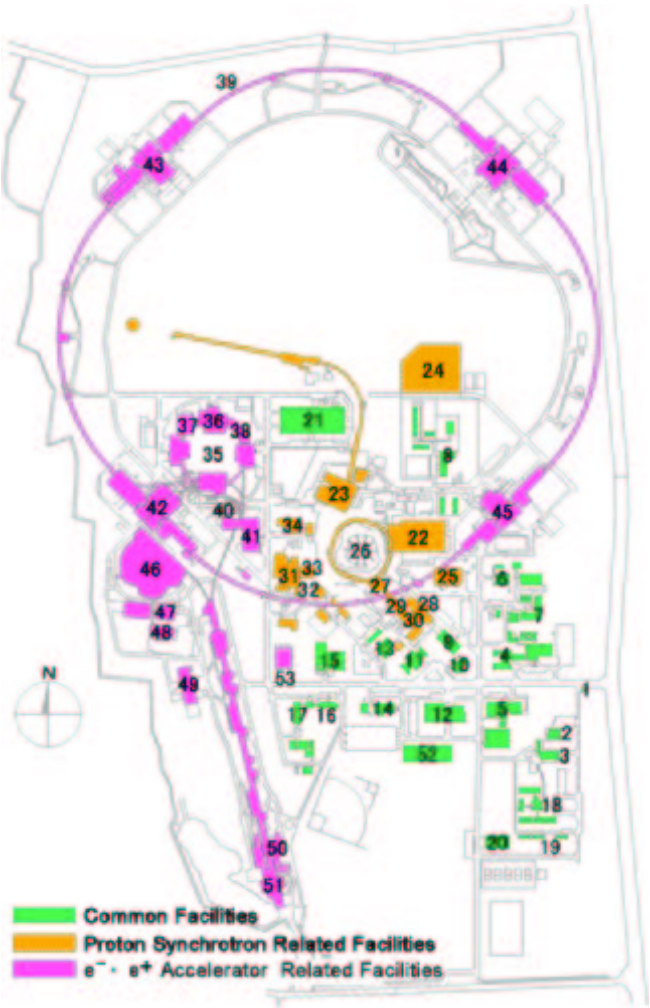
$\rho/\omega$ modification observed in ee invariant mass spectra
→published in PRL 86(2001)5019(K. Ozawa *et al.*)

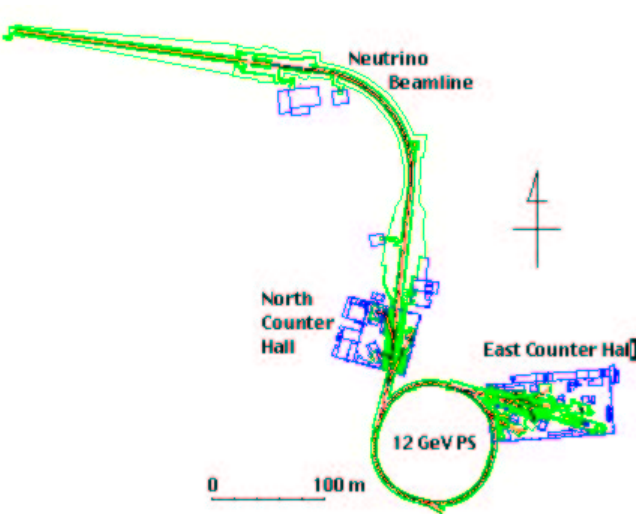
| | | | | |
|---|---|---|---|---|
| 99 | 7 | 3rd physics run | $\omega$ ∼700 | |
| | | | $\phi$:∼125 | :$\phi$:178 |

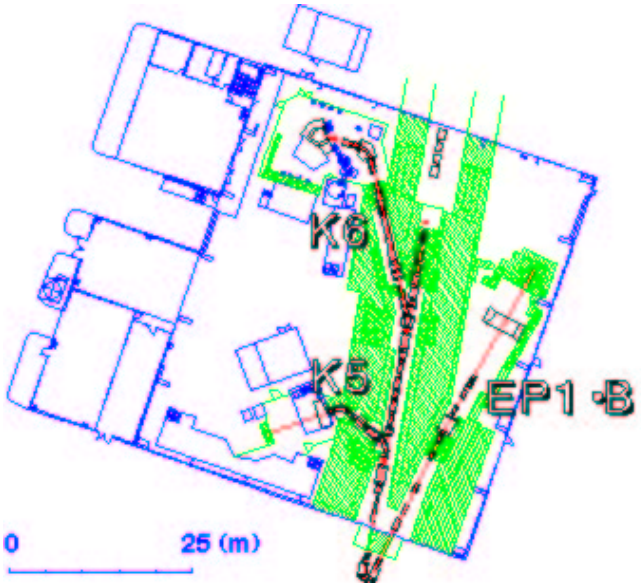
$\phi \to K^+K^-$ invariant mass spectra
cross sections of $\phi$ and $\omega$ are obtained
→publication is in preparation

| | | | | |
|---|---|---|---|---|
| 00 | 6/12 | 4th physics run | | |
| 01 | 11/12 | 5th physics run | | |
| 02 | 2/3 | last physics run | | |
| | | →recently analyzed data | | |
| | | (∼60%of ee trigger) | $\omega$: ∼10000 | |
| | | | $\phi$ : ∼1000 | |

# KEK 12GeV PS and EP1B primary beam line



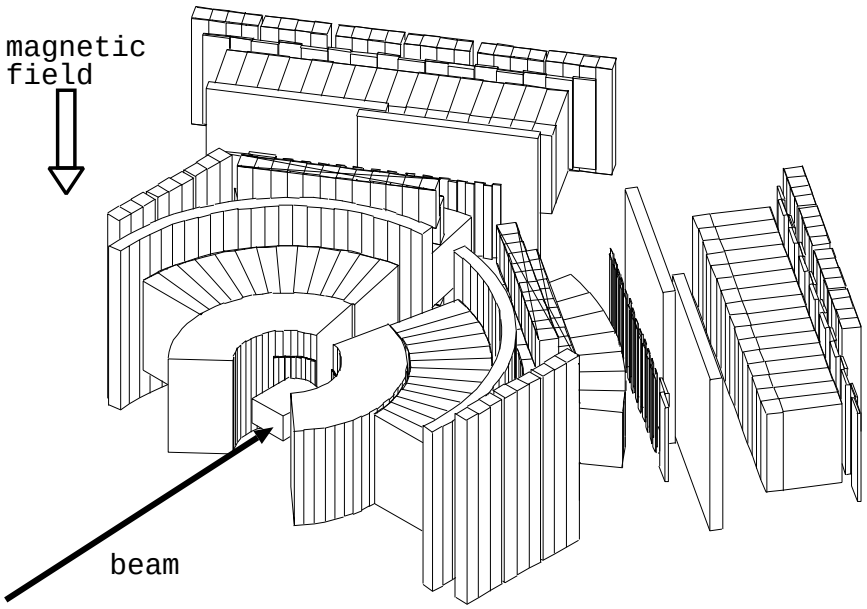




EP1B primary beam line

- available upto $4 \times 10^9$ proton per pulse(4 sec repitition/duty $\sim 50\%$)
- beam spot size:3mm FWHM

# Experimental Setup of E325




- $\int Bdl$=0.81 Tm (r= 0 $\sim$ 1600mm )/ 0.71T at r=0
- thin targets (to reduce conversion) placed in-line

| | $CH_2$ | C | Cu |
|---|---|---|---|
| interaction length (%) | 0.1 | 0.1 | 0.04 |
| radiation length(%) | 0.2 | 0.2 | 0.4 |

- typ. $1\times10^9$ proton(12.9GeV/c)/pulse in 2sec duty
  $\Rightarrow$ typ. $1\times10^6$Hz interaction on targets

## Kaon Arm

- vertical $\pm6^\circ$
  horizontal
  $\pm12^\circ \sim \pm54^\circ$
- STC–FTOF
- Aerogel
  Čerenkov counter

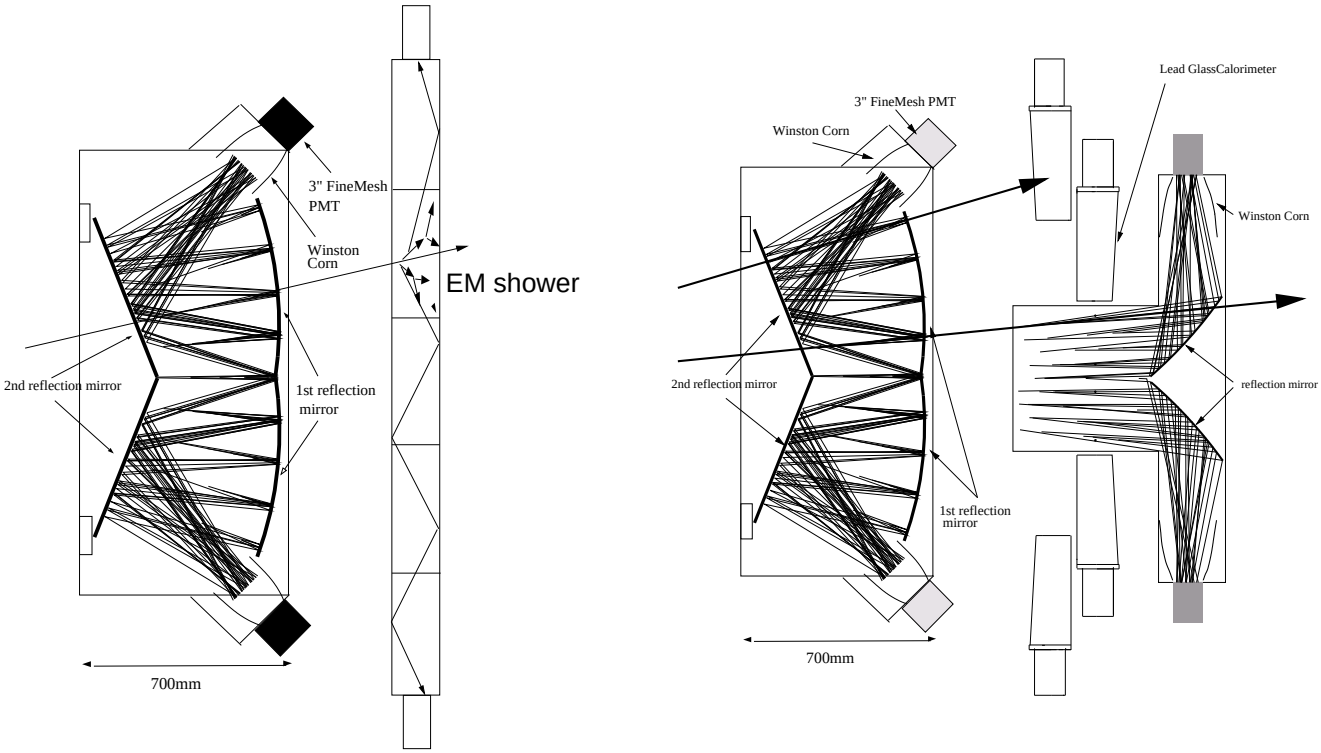
## Electron Arm

- vertical $\pm22^\circ$
  horizontal
  $\pm12^\circ \sim \pm90^\circ$
- FrontGC
- RearGC/RearLG/SideLG
- FrontLG

# Electron ID counter

- two stage: FrontGC + RearGC/RearLG/SideLG
- each segment covers about 6°
- GC : isobtane
- LG: lead glass SF6W (12cm depth=$\sim$ 7.1 radidation length)
- ForwardLG: 3rd stage covering RGC acceptance behind them
  $\rightarrow$ newly installed and used in analysis of new data

| | FGC | RGC | LG |
|---|---|---|---|
| elector ID eff.(%) | 55 | 86 | 85 |
| $\pi$ rejection(with FGC) | - | $3.9\times10^{-4}$ | $6.7\times10^{-4}$ |

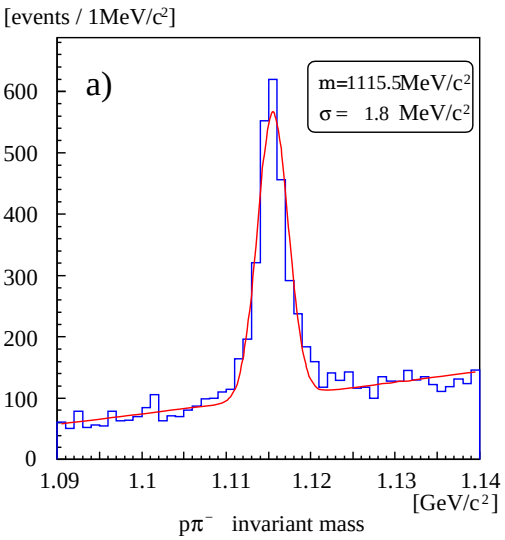


# Tracking Performance

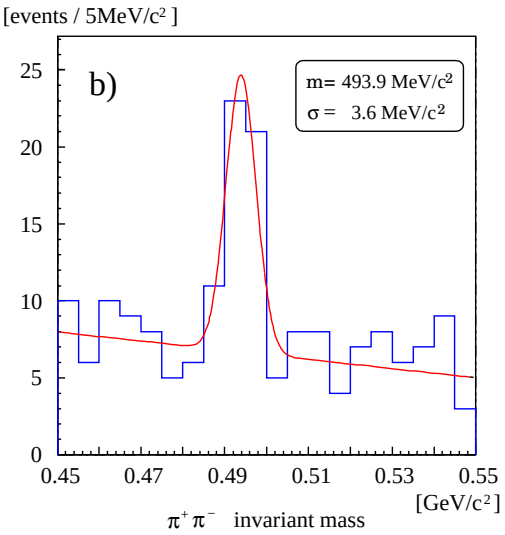
## Cylindrincal DC/Barrel DC

- CDC 10 layers
  (6 vertical and 4 stereo(∼0.1radian))
- BDC 4 layers
  (2 vertical and 2 stereo(∼0.1radian))
- typical position resolution ∼ 300$\mu$m

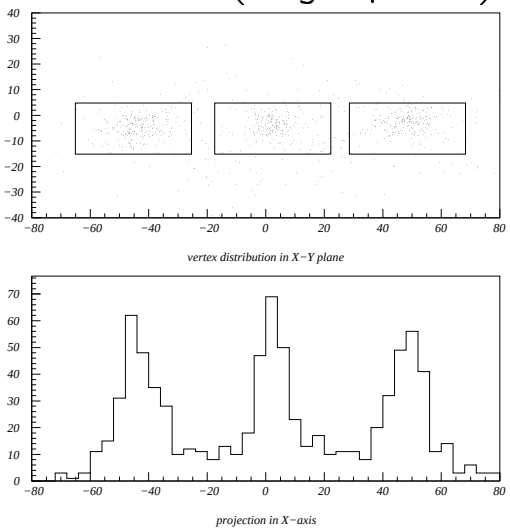
## mass resolution of the spectrometer




| | $\sigma$ |
|---|---|
| $\Lambda$ | 1.8MeV/$c^2$ |
| $K_s$ | 3.6MeV/$c^2$ |
| $\phi \to K^+K^-$ | 2.4MeV/$c^2$ |
| $\omega \to e^+e^-$ | 9.6MeV/$c^2$ |
| $\phi \to e^+e^-$ | 12.0MeV/$c^2$ |

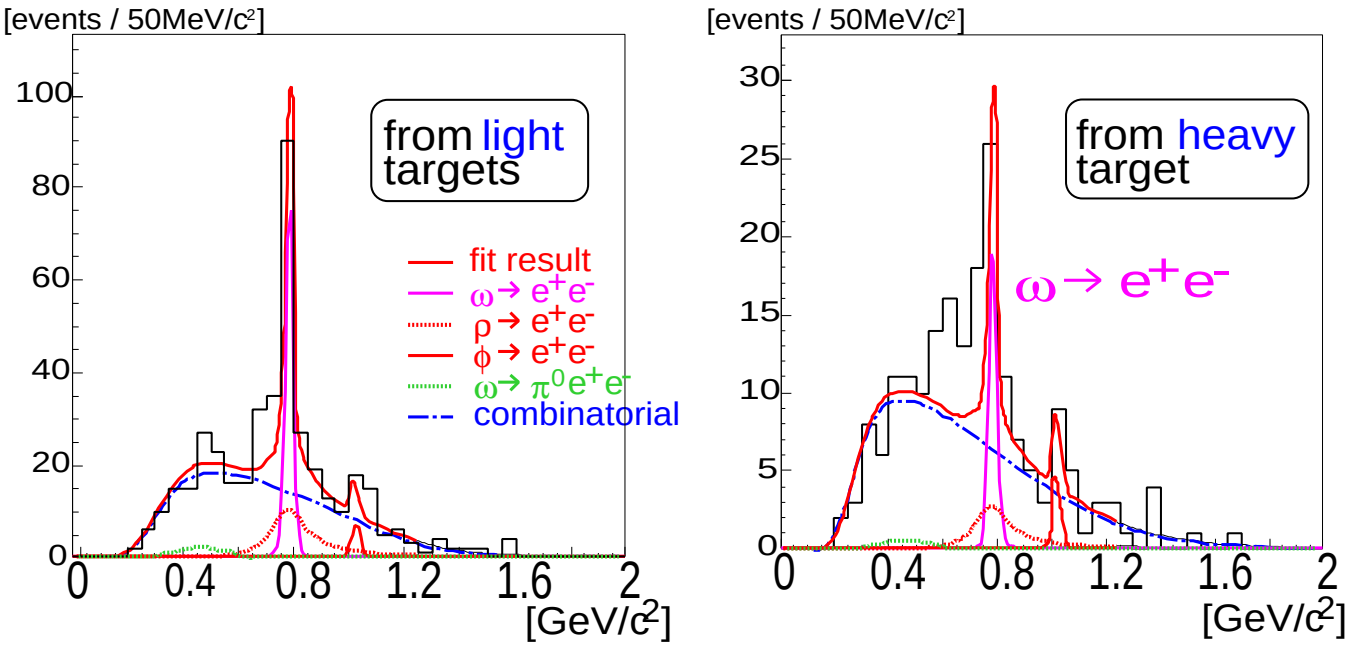



(target profile)



# $e^+e^-$ invariant mass spectra('98)

(K. Ozawa et.al., PRL 86(2001)5019)




low mass region is suppressed due to the detector acceptance

fit funciton:

$$N_1 f_1(\phi \to e^+e^-) + N_2 f_2(\rho \to e^+e^-) + N_3 f_3(\omega \to e^+e^-) + N_4 f_4(\omega \to \pi^0 e^+e^-) + N_5 f_5(\eta \to e^+e^-\gamma) + N_6 f_6(\text{combinatorial})$$

where

function shapes are determined as:

$f_1, f_2, f_3$ : (smeared) Breit-Wigner

$f_4, f_5$ : from the literature

$f_6$ : event mixing

4 free parameters.

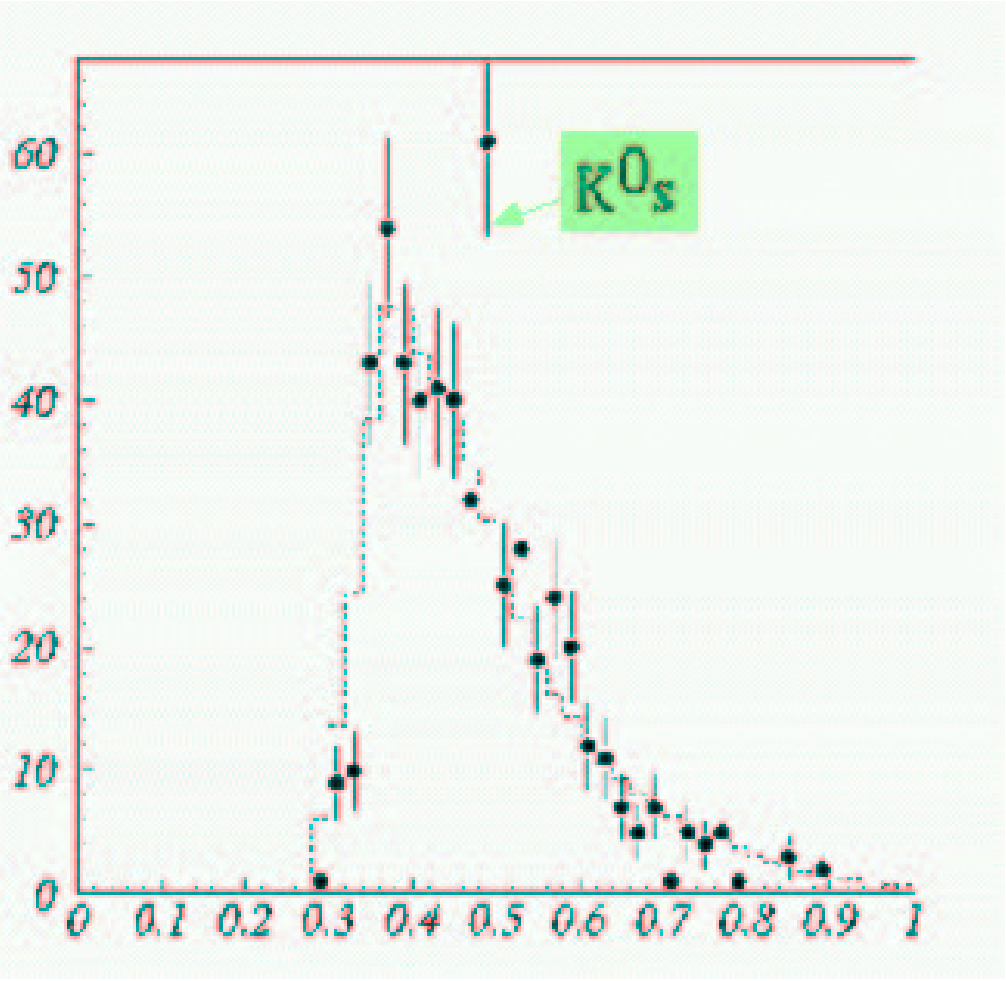
$N_1, N_3, N_5$ and $N_6$

significant excess (550 MeV/$c^2$ ~ 750 MeV/$c^2$ ) is seen :

⇒ meson mass modification

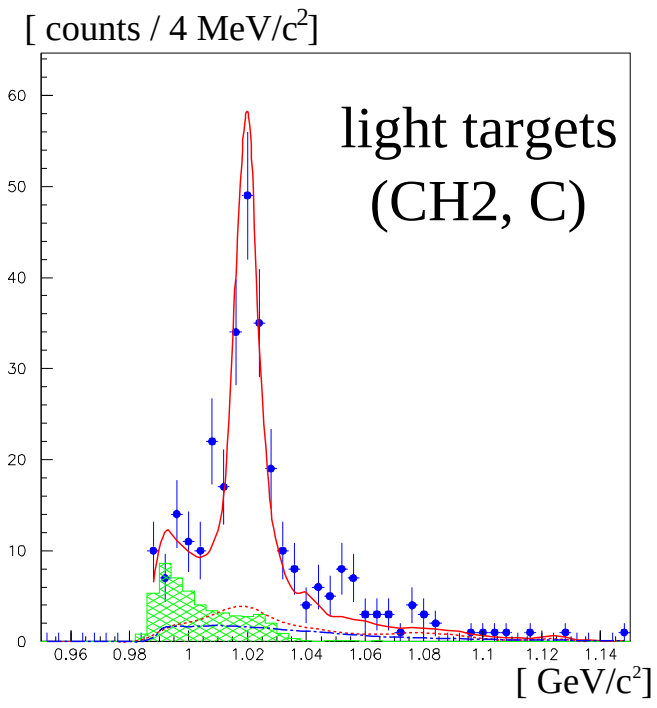
# Background estimation using event mixing

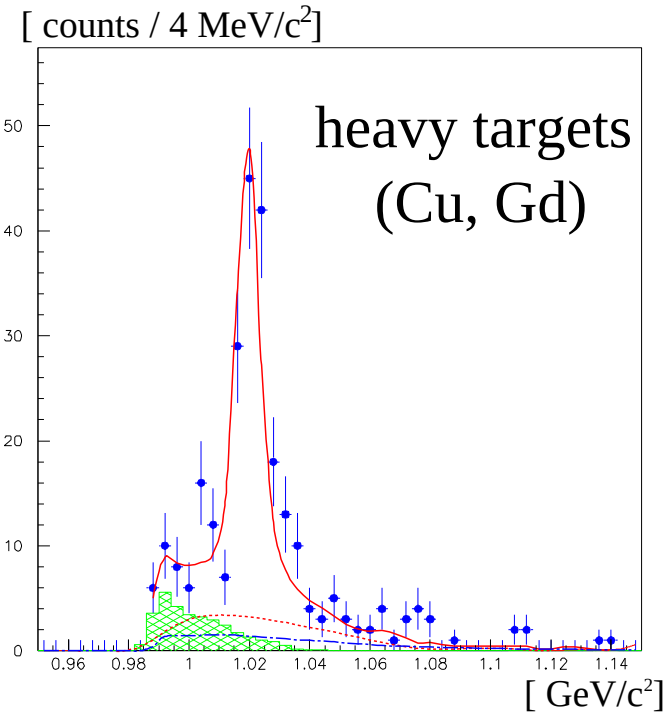
$\pi^+\pi^-$ invariant spectrum is described using mixed event



# $K^+K^-$ invariant mass spectra('99)

(M. Ishino et.al., PRL in prep.)




fit funciton is

$$N_1 f_1(\phi) + N_2 f_2(a_0/f_0) + N_3 f_3(non-resonant) + N_4 f_4(missID)$$

where

function shapes are determined as:

$f_1, f_2, f_3$ : JAM simulation

$f_4$ : event mixing

parameters are

$N_3/N_1$ by JAM

$N_4/(N_1+N_2+N_3+N_4)$ by expelimentally

then, $N_1/N_2$ and overall normarization are two free parameters of the fit

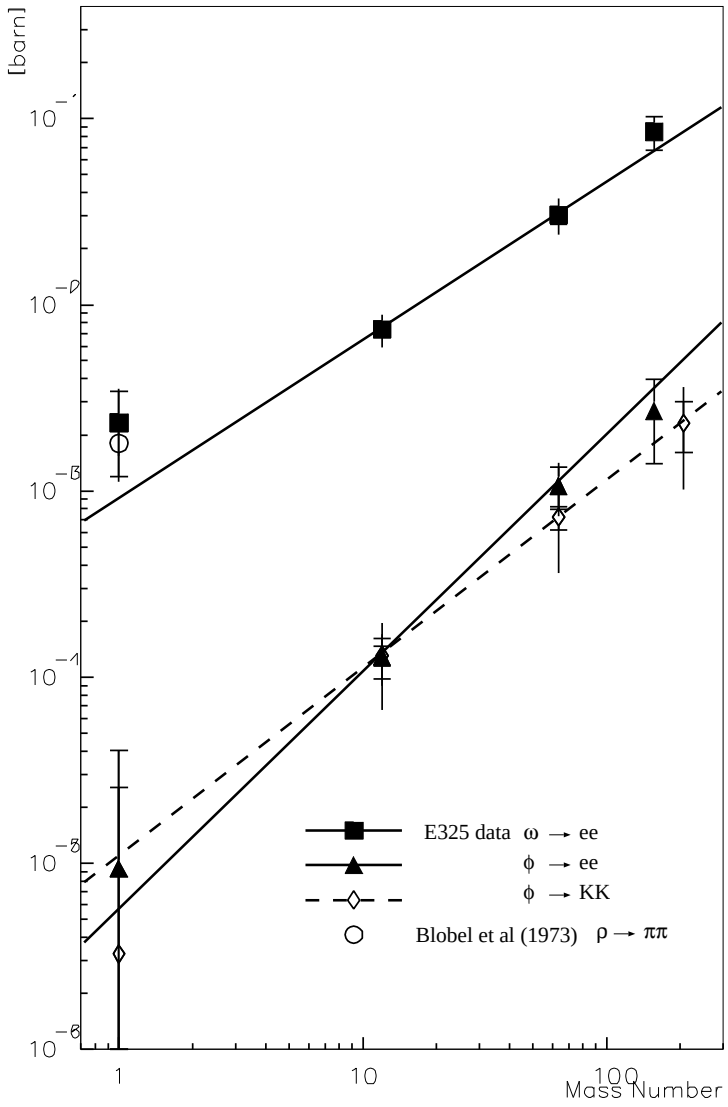
well reproduced by introducing scaler meson.

$\Rightarrow$ no significant spectral modification of $\phi$.

# Cross Section of $\omega$ and $\phi$ ('99 data)

production cross section

- $\omega$ : consistent with other experiment
- $\phi$ : ee and KK are consistent



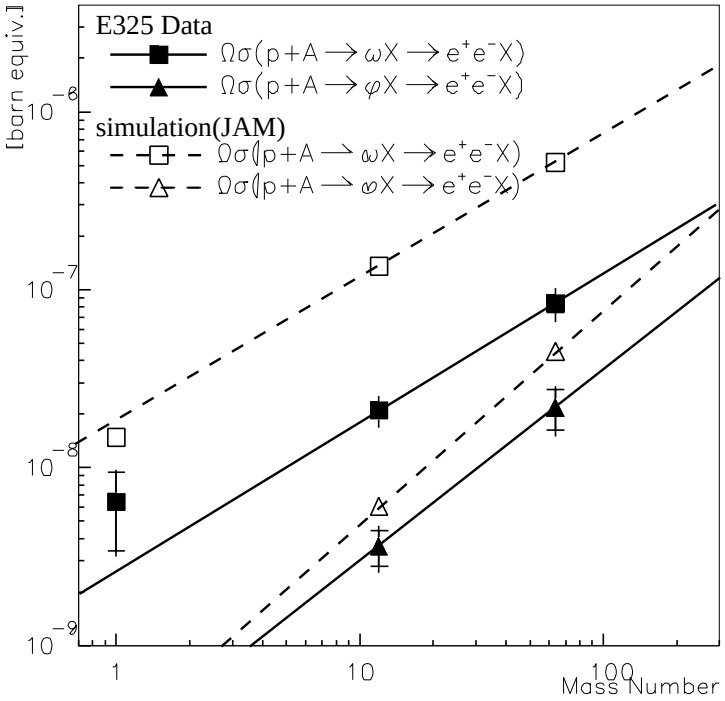

nuclear dependence $\alpha$ : $(\sigma(A) = \sigma(1) \times A^{\alpha})$

- $\omega \to e^+e^-$ : $\alpha = 0.85 \pm 0.08$
- $\phi \to e^+e^-$ : $\alpha = 1.27 \pm 0.21$
- $\phi \to K^+K^-$ : $\alpha = 1.01 \pm 0.09$

– too strong dependence for $\phi$ ?

# CS:Comparison with simulation – Production mechanism

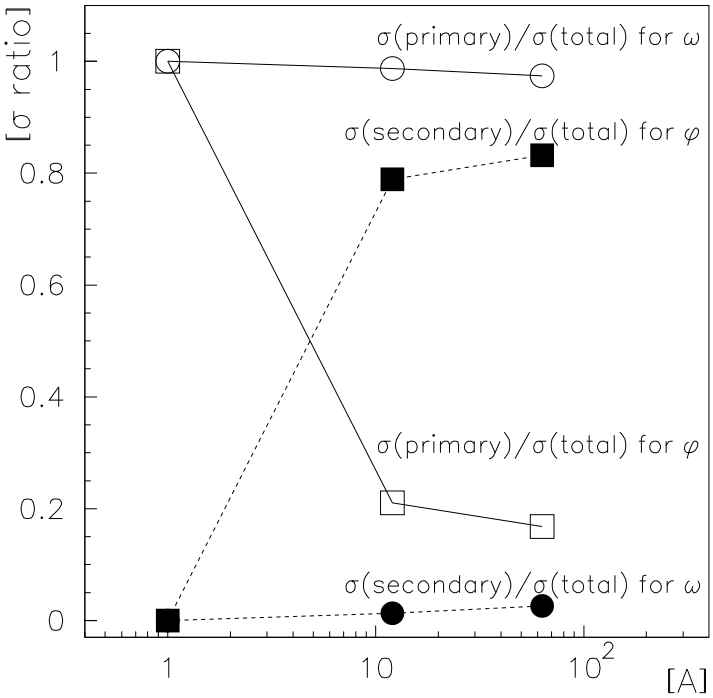
nuclear cascade code JAM:
absolute values are not reproduced
but tendency of mass number dependence.




## production mechanism in JAM

dominated by:

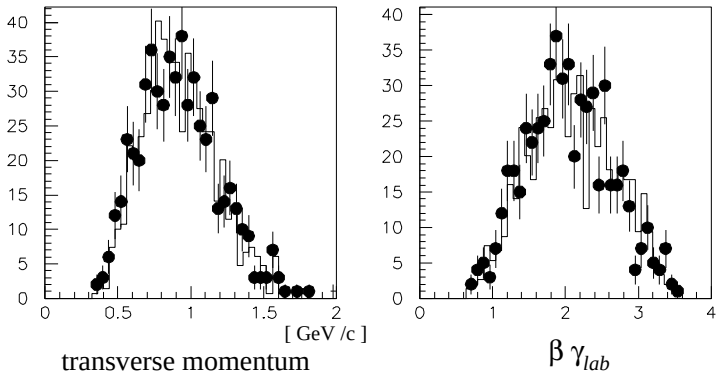
- $\omega$ : primary fragmentation
- $\phi$ : secondary collision




Knowlegde of the production mechanism could help to analysis the modification in nuclei.

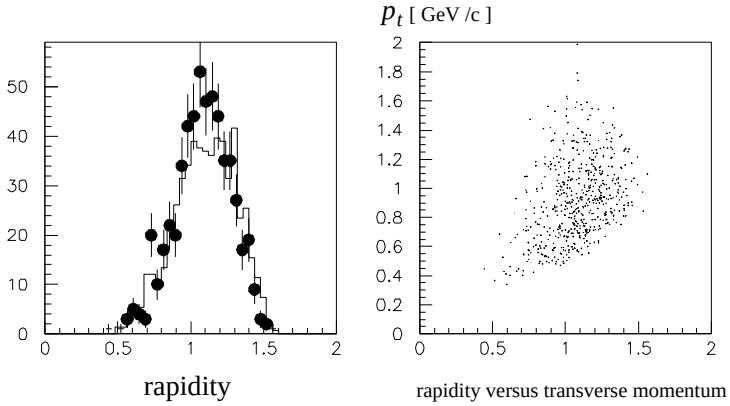
# Kinematics for detected $\phi \to K^+K^-$ & $\phi \to e^+e^-$

$\phi \to K^+K^-$ for all targets('99)



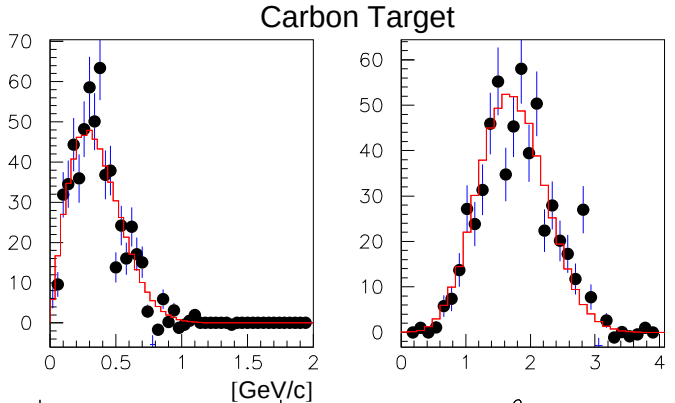

$P_T$ $\beta\gamma$

rapidity(y) $P_T$ VS y



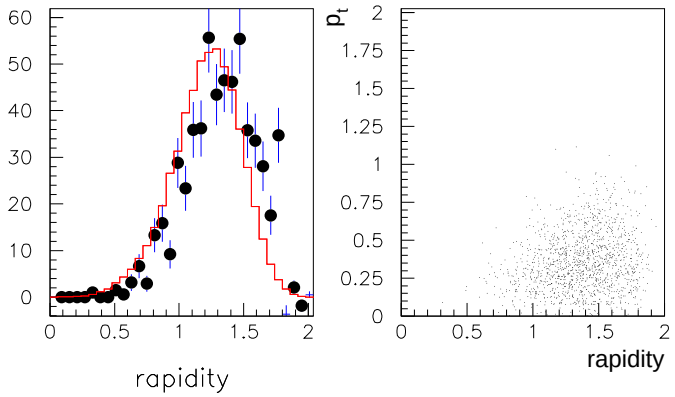

$\phi \to e^+e^-$ for C('02)

(preliminary)



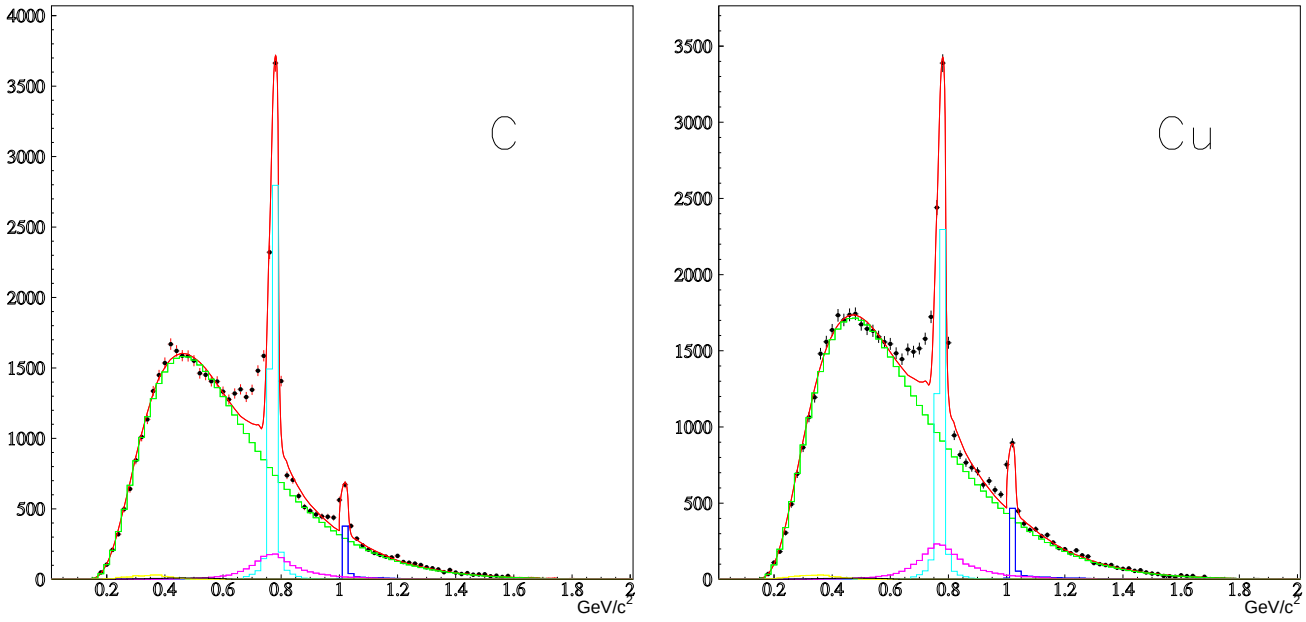

$P_T$ $\beta\gamma$

rapidity(y) $P_T$ VS y




nuclear cascade code JAM (histogram) well reproduce the data

# $e^+e^-$ invariant mass spectra('02/preliminary)




(low mass region is suppressed due to the detector acceptance)

fit funciton:

$$N_1 f_1(\phi \to e^+e^-) + N_2 f_2(\rho \to e^+e^-) + N_3 f_3(\omega \to e^+e^-) + N_4 f_4(\omega \to \pi^0 e^+e^-) + N_5 f_5(\eta \to e^+e^-\gamma) + N_6 f_6(\text{combinatorial})$$

where

function shapes are determined as:

$f_1, f_2, f_3$ : based on JAM simulation

$f_4, f_5$ : from the literature

$f_6$ : event mixing

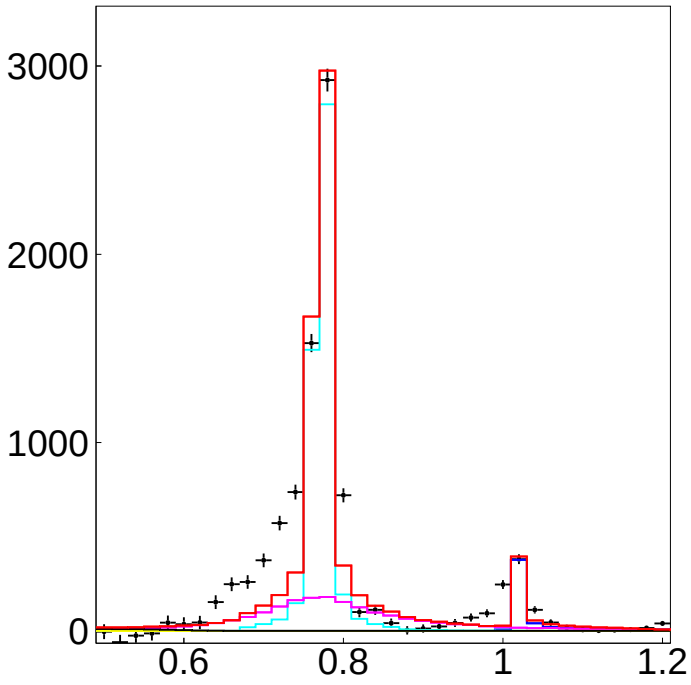
5 free parameters.($\rho/\omega$ ratio is not fixed)

$N_1, N_2, N_3, N_5$ and $N_6$

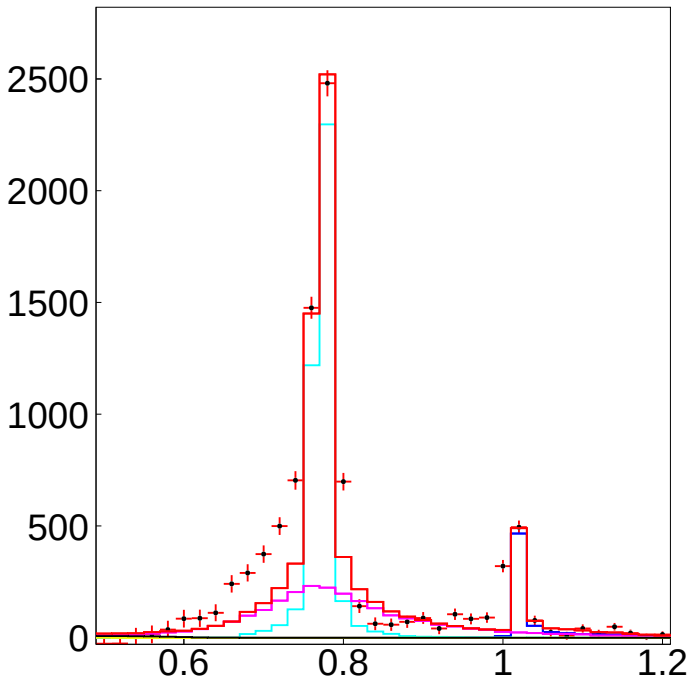
excesses are still seen below the $\omega$ peak in both targets

# $e^+e^-$ invariant mass spectra('02/preliminary) (background subtracted)

C target




Cu target




In the result of fitting, $\rho/\omega$ ratio is smaller than unity.
(other experiment, $\rho/\omega \sim 1$ in 12GeV pp reaction)
$\rightarrow$ suggests rho meson modification.
Difference over different target is not so clear becasue of shorter life of $\rho$.

# Summary

- KEK-PS E325 is designed to explore the chiral symmetry restoration at normal nuclear density.
- measure $\phi \to e^+e^-$ , $\rho/\omega \to e^+e^-$ and $\phi \to K^+K^-$
- using high intensity proton beam and thin targets, large acceptance spectrometer to detect slowly moving mesons in ee decay channel.
- data taking was finished at this spring.
- the modification of $e^+e^-$invariant mass spectra is observed, which cannot be explained by known hadronic sources. It supports the $\rho$ meson modification.
- Some hints for $\phi$ meson modification is also seen.
- $K^+K^-$invariant mass spectra can be understood without modification taking account of scaler mesons ($a_0$ and $f_0$)
- mass number dependence of production cross section and kinematical ditribution of detected mesons are consistent with the JAM simulation

## Outlook

- About 2 times larger statistics will be available in near future in $e^+e^-$channel, and also more 3 times larger statistics for $K^+K^-$channel are expected.
- Momentum dependence of spectra should be analyzed. (In slowly moving component, modification may be enhanced.)