Vector Meson Measurement at KEK–12GeV PS

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for KEK–PS E325 collaboration

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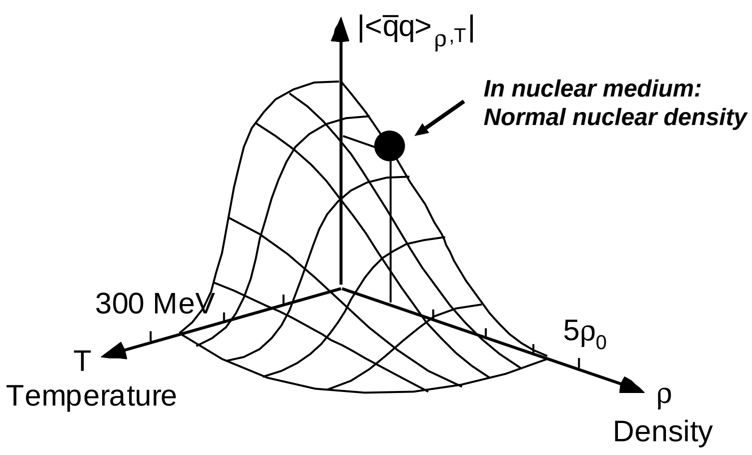
- Invariant mass spectra for $K^+K^-$and e^+e^-
- Nuclear dependence of production cross section
- New data taken in 2002
- Summary

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)

$$\Downarrow$$

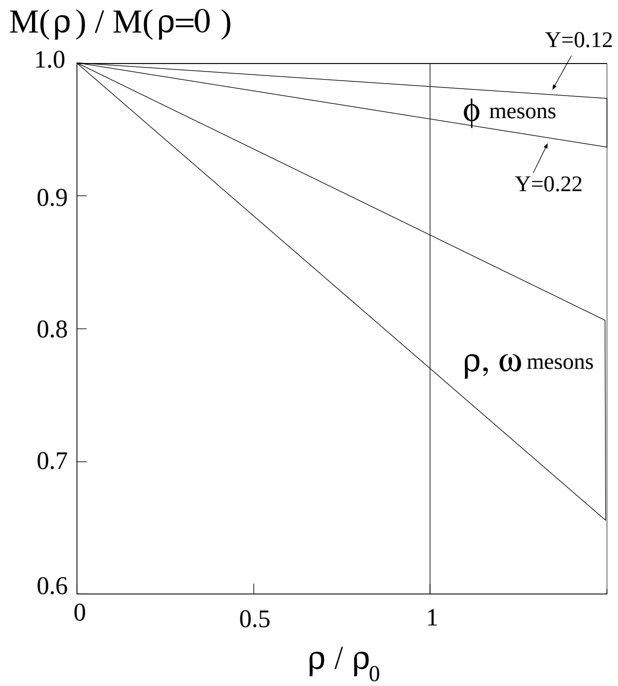
1/3 of restoration at the normal nuclear density

Vector meson modification in dense matter

For example,

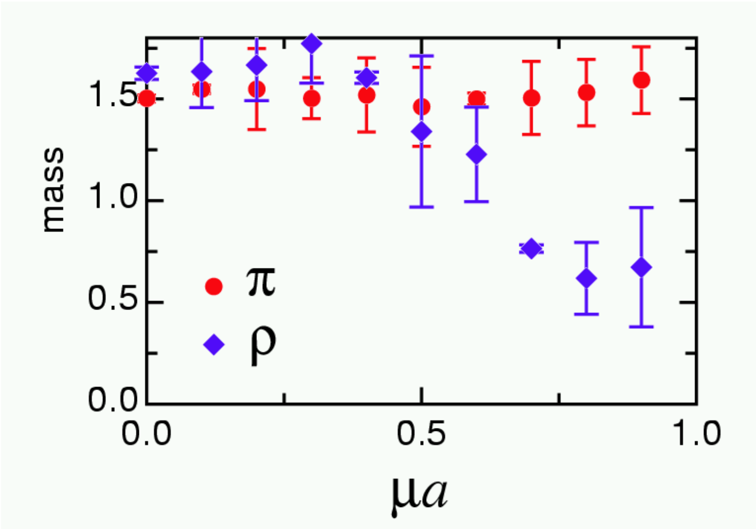
- Hatsuda and Lee(QCD sum rule)
  (PRC46(1992)R24)

  vector meson (ϕ, ρ and ω)mass shift in dence matter



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

  mass decreasing in vector channel, in finite chemical potential

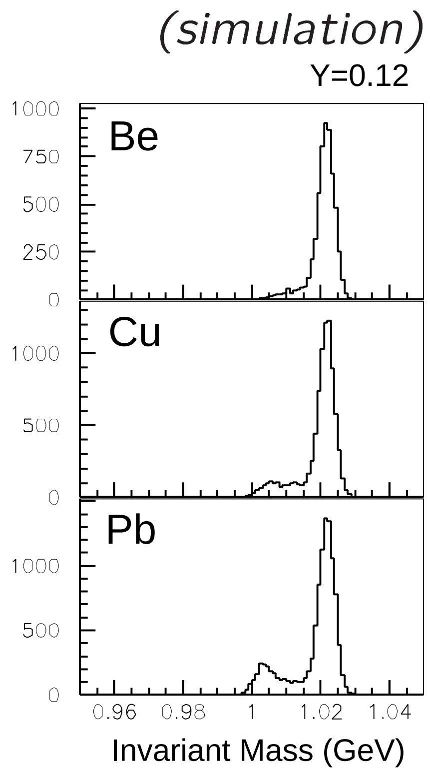


- many other:
  width changing, etc.

Experimental signal ∼ why ϕ ?

1. invariant mass spectra

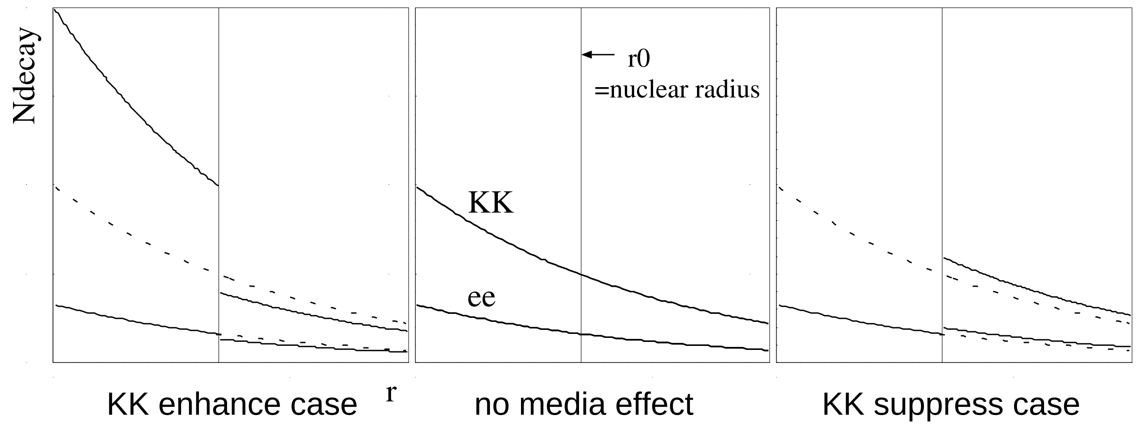
- second peak is made by ϕ's decaying in nuclei (no width-changing case)
- ee channel:
  - less final-state interaction
  - ρ and ω can be collected at the same time
- KK channel:
  small Q-value($=$32MeV$/c^2$)
  $\Rightarrow$ possible width change in nuclei could be seen easier



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

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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	-	ϕ:99
98	4/5	2nd physics run	ω:95 ϕ:12	

ρ/ω modification observed in ee invariant mass spectra
$\rightarrow$published in PRL 86(2001)5019(K. Ozawa *et al.*)

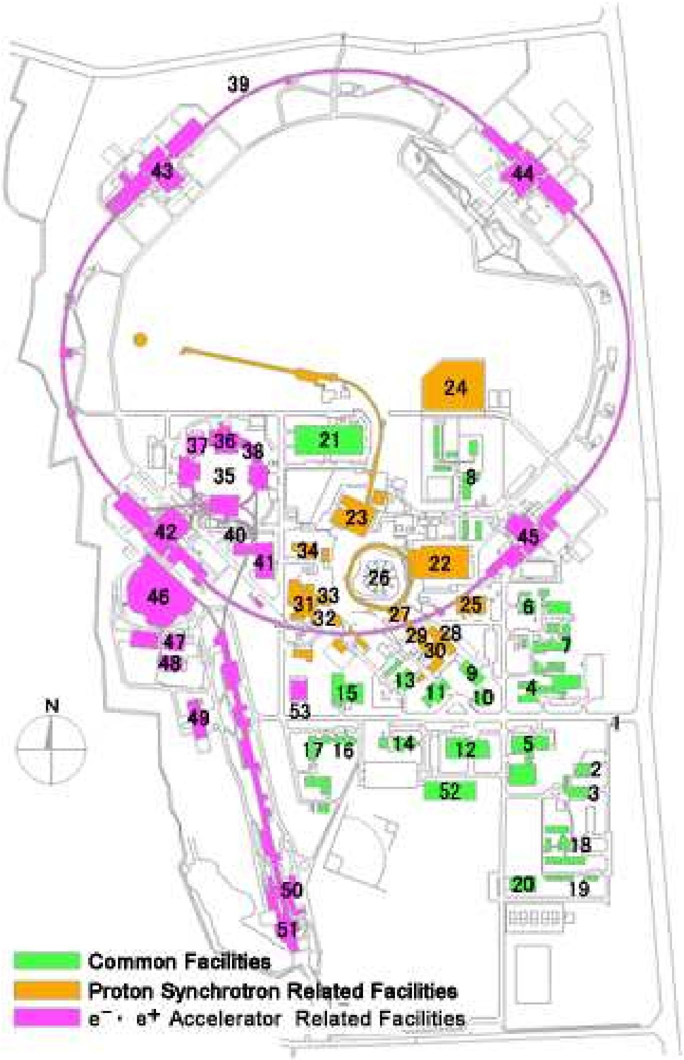
99	7	3rd physics run	ω ~700 ϕ:~125	:ϕ:178

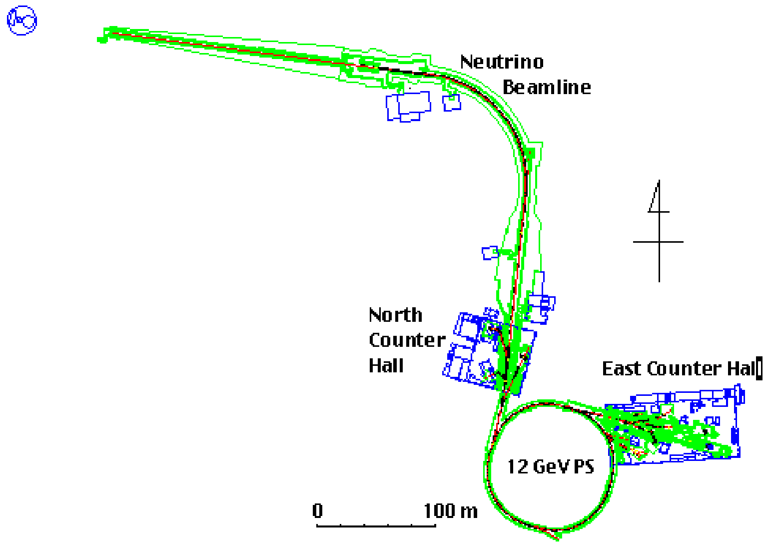
$\phi \rightarrow K^+K^-$ invariant mass spectra
cross sections of ϕ and ω are obtained
$\rightarrow$publication is in preparation

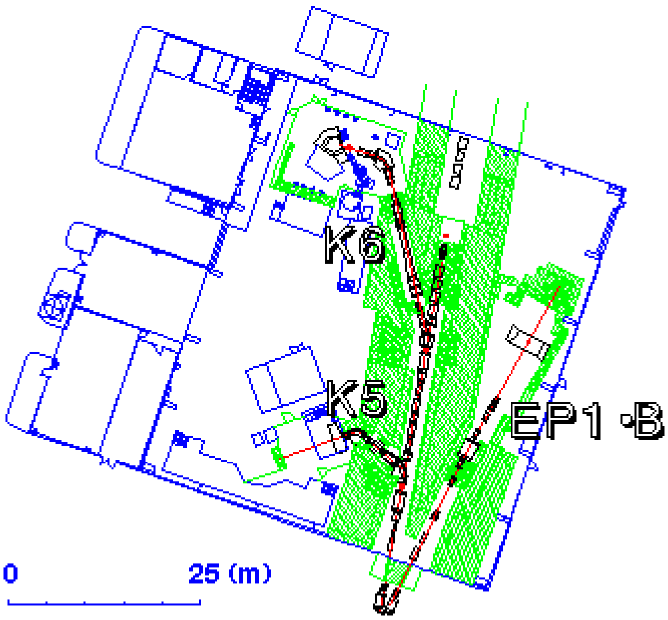
00	6/12	4th physics run	
01	11/12	5th physics run	
02	2/3	last physics run	

$\rightarrow$recently analyzed data
(~60%of ee trigger) ω: ~10000
ϕ : ~1000

KEK 12GeV PS and EP1B primary beam line



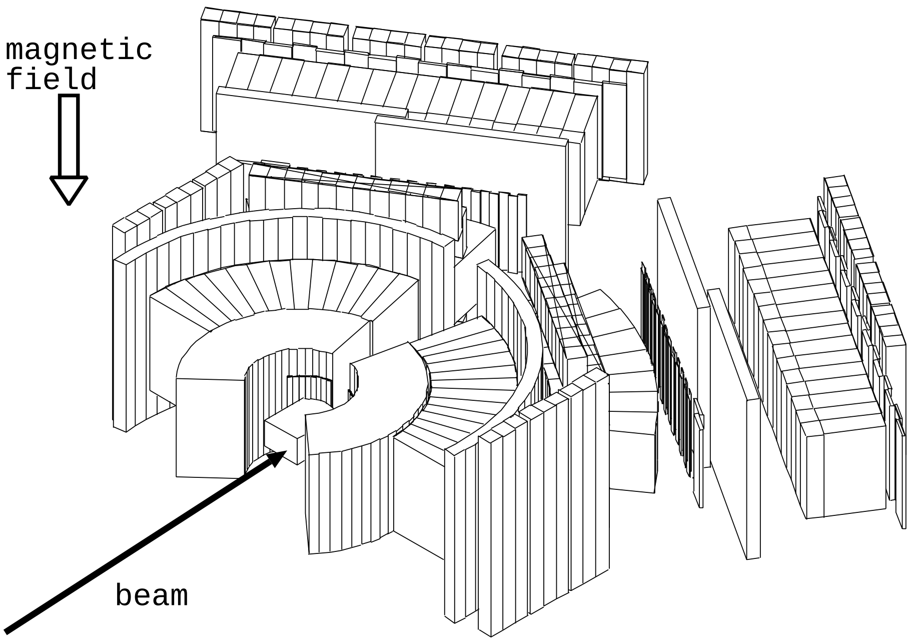




EP1B primary beam line

- available upto 4×10^9 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 ~ 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. 1×10^9 proton(12.9GeV/c)/pulse in 2sec duty
  $\Rightarrow$ typ. 1×10^6Hz interaction on targets

Kaon Arm

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

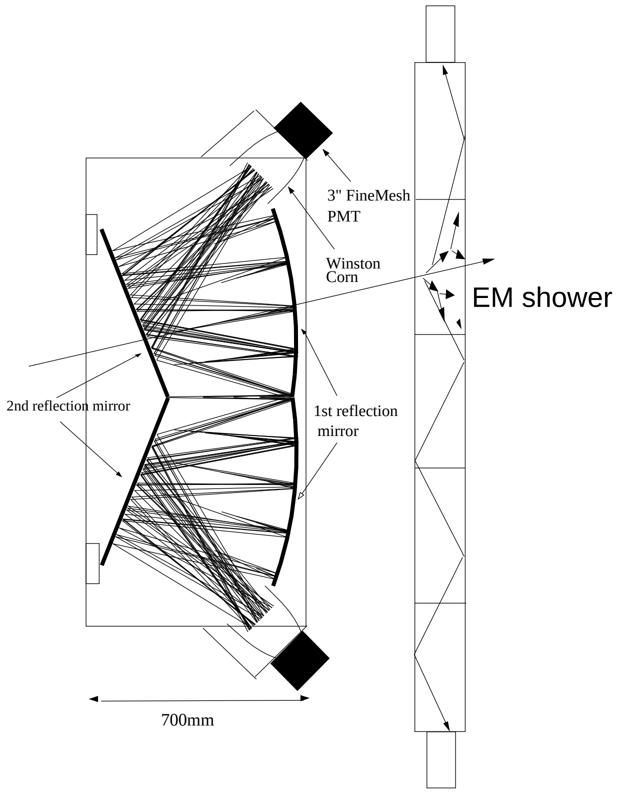
Electron Arm

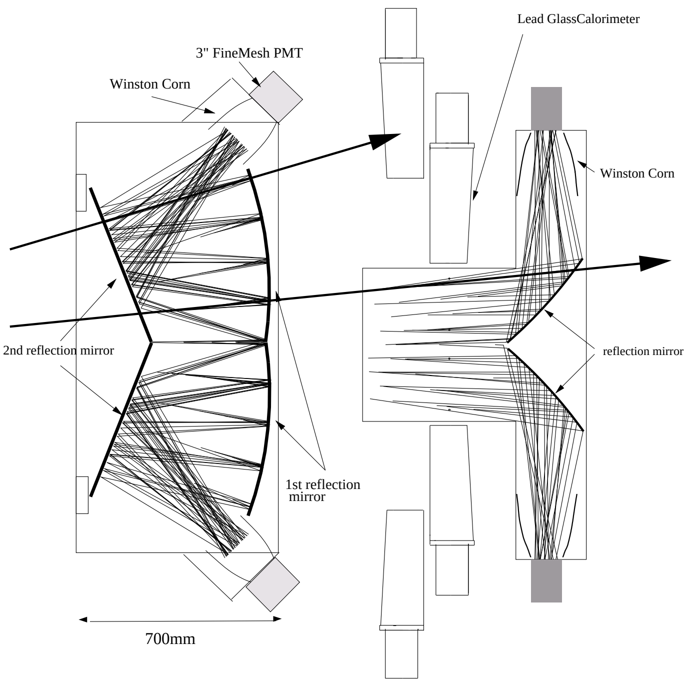
- vertical $\pm22^\circ$
  horizontal
  $\pm12^\circ \sim \pm90^\circ$
- FrontGC
- RearGC/RearLG/SideLG
- FrontLG

Electron ID counter

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

	FGC	RGC	LG
elector ID eff.(%)	55	86	85
π rejection(with FGC)	-	3.9×10^{-4}	6.7×10^{-4}



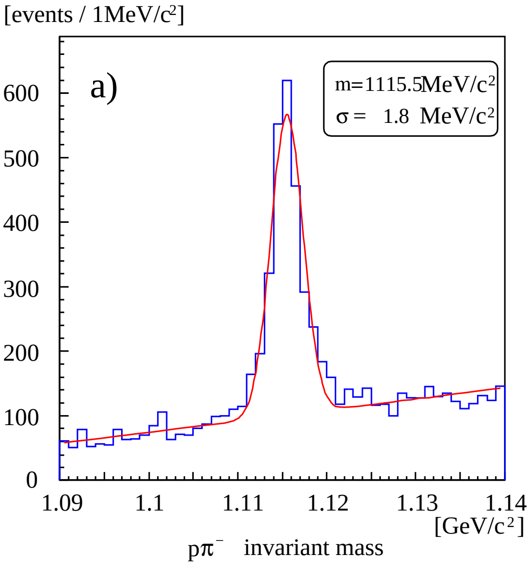


Tracking Performance

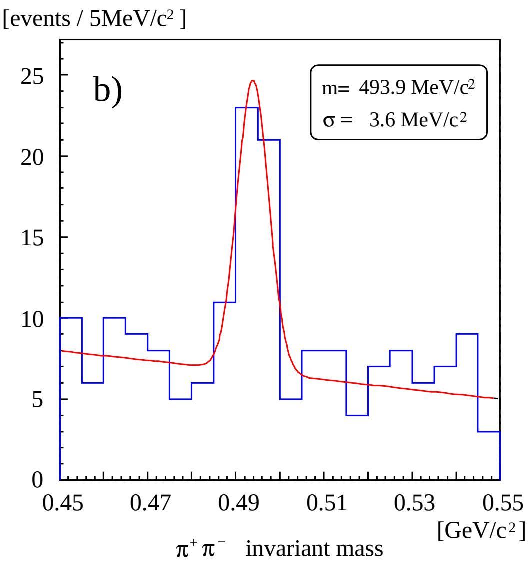
Cylindrincal DC/Barrel DC

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

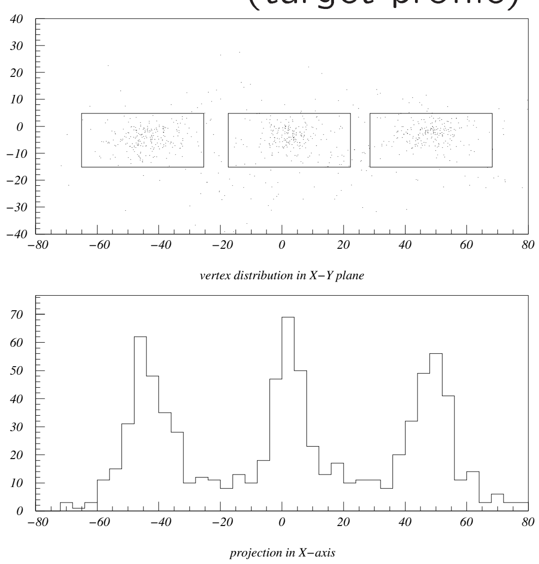
mass resolution of the spectrometer



	σ
Λ	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

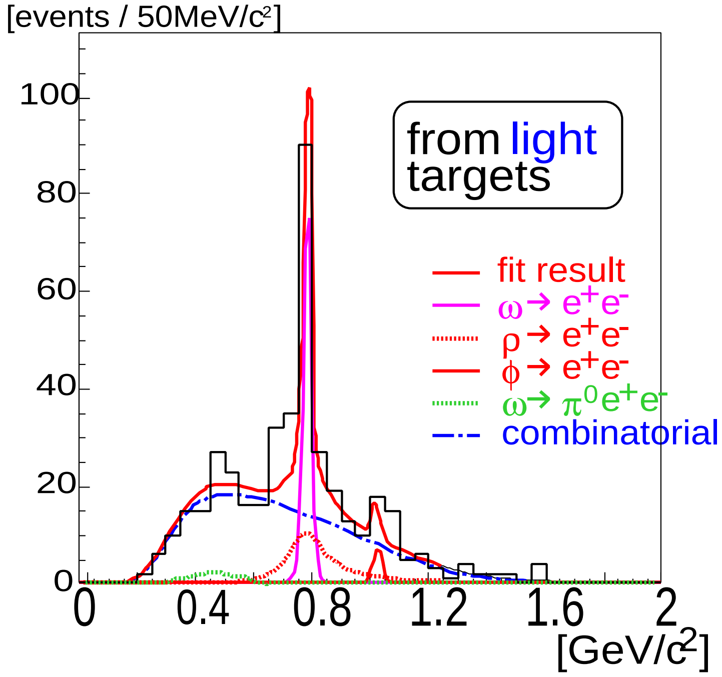


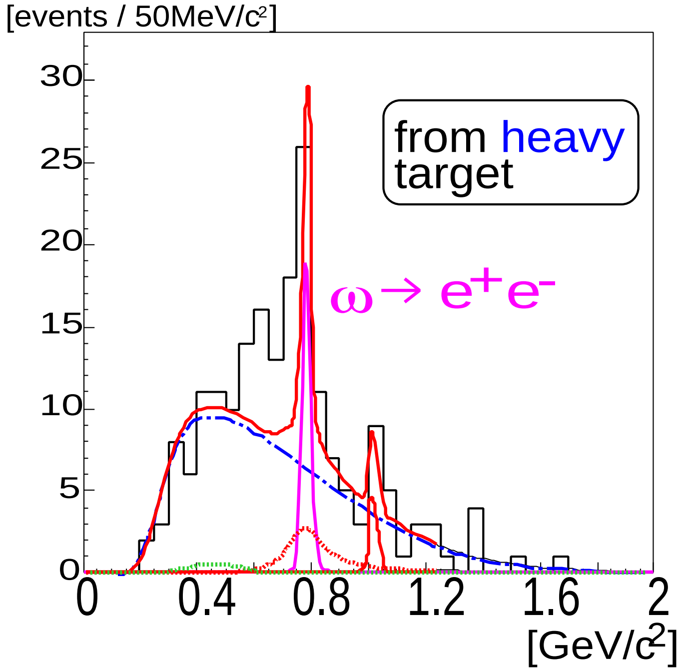
(target profile)



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:

f1,f2,f3 : (smeared) Breit-Wigner

f4,f5 : from the literature

f6 : event mixing

4 free parameters.

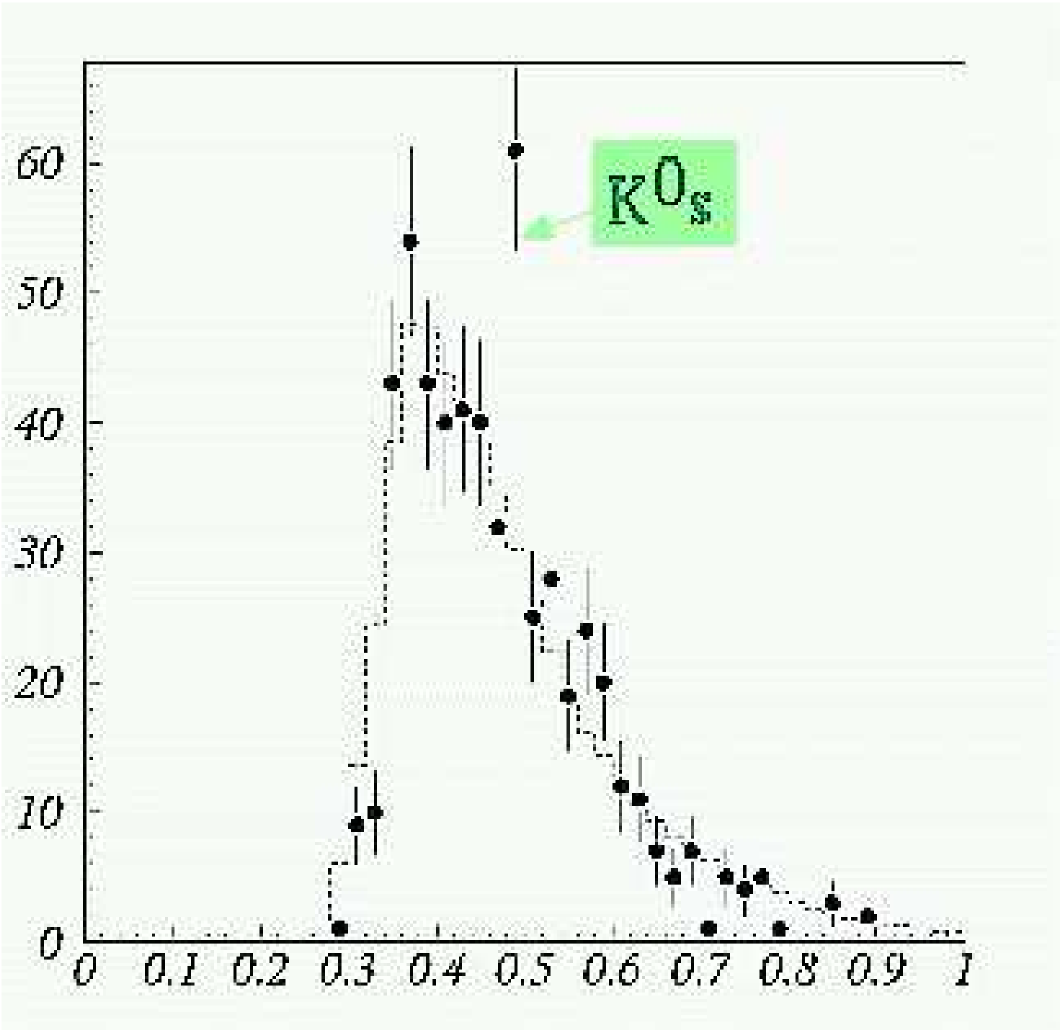
N1,N3,N5 and N6

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

⇒ <u>meson mass modification</u>

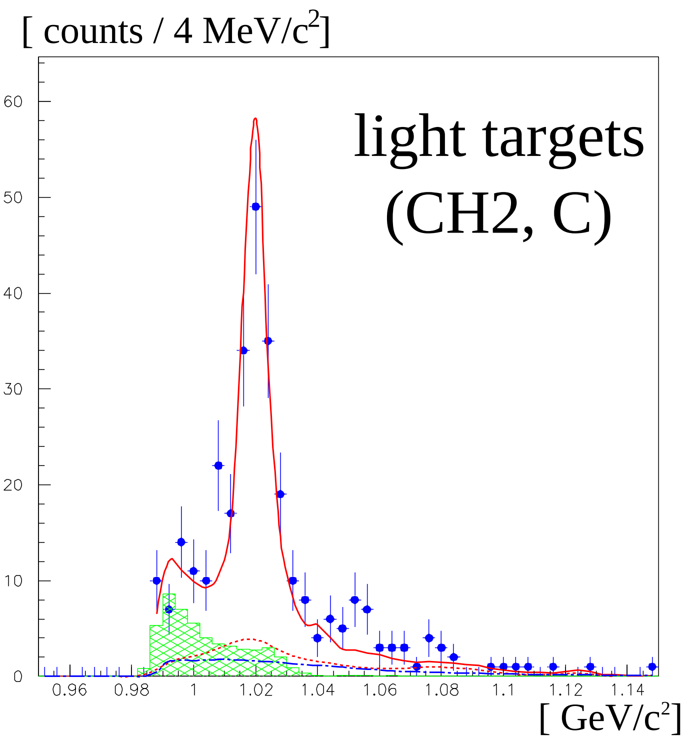
Background estimation using event mixing

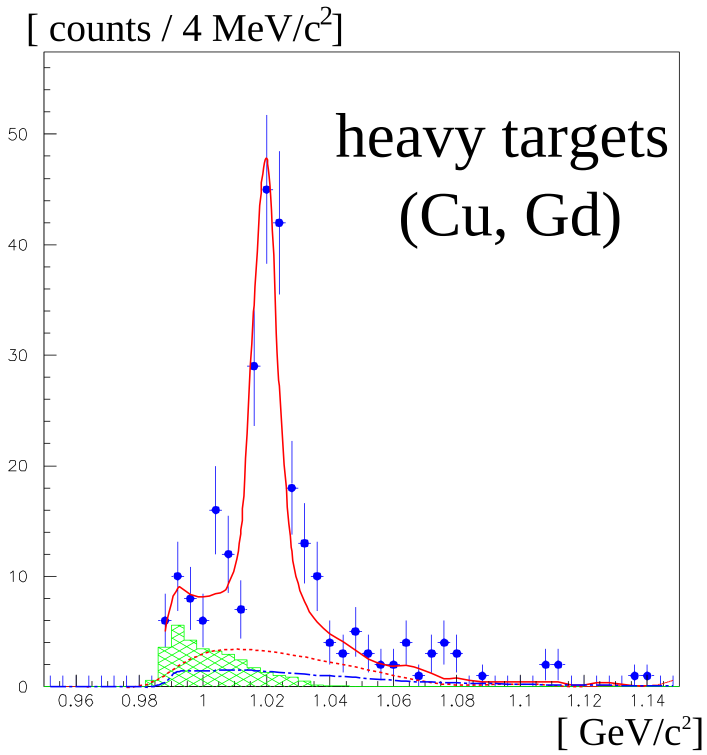
$\pi^+\pi^-$invariant spectrum is described using mixed event



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

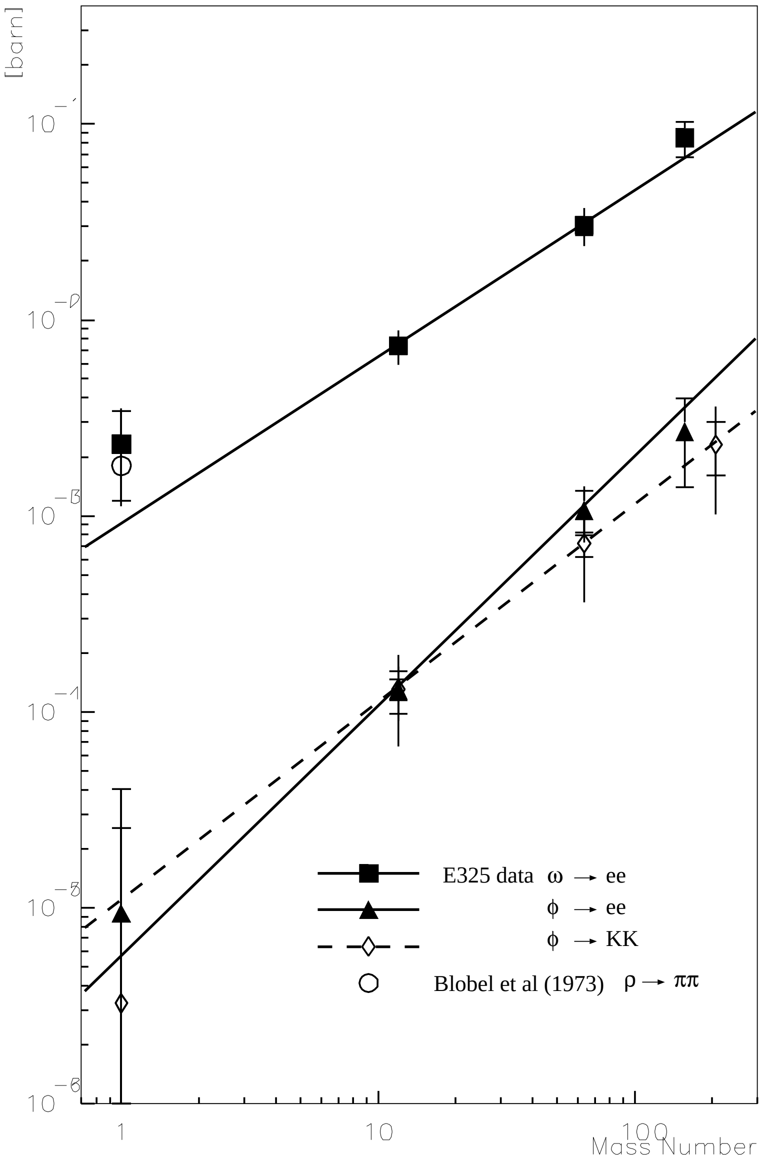
then, N_1/N_2 and overall normarization are two free parameters of the fit

well reproduced by introducing scaler meson.

$\Rightarrow$ no significant spectral modification of ϕ.

Cross Section of ω and ϕ ('99 data)

production cross section



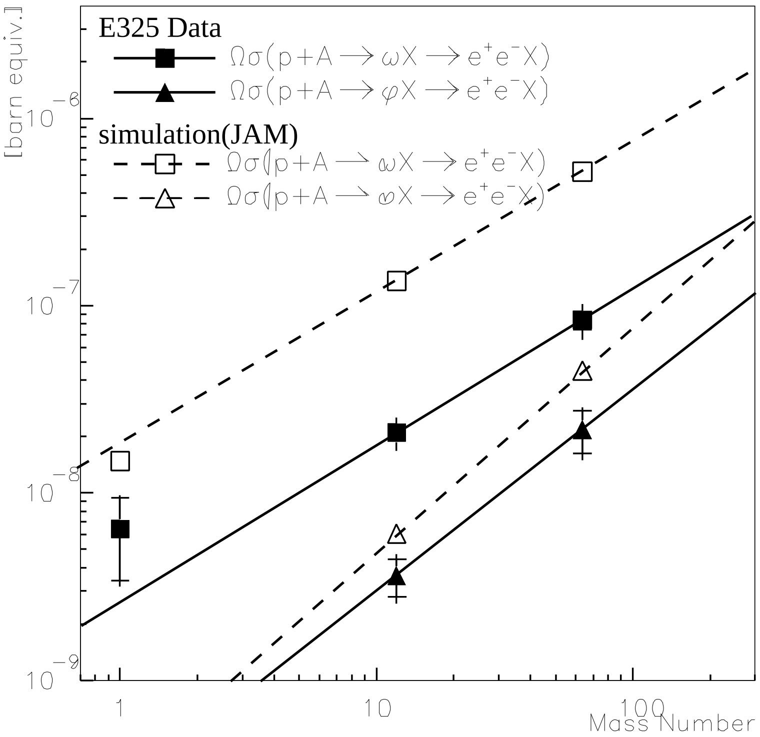
- ω : consistent with other experiment
- ϕ : ee and KK are consistent

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

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

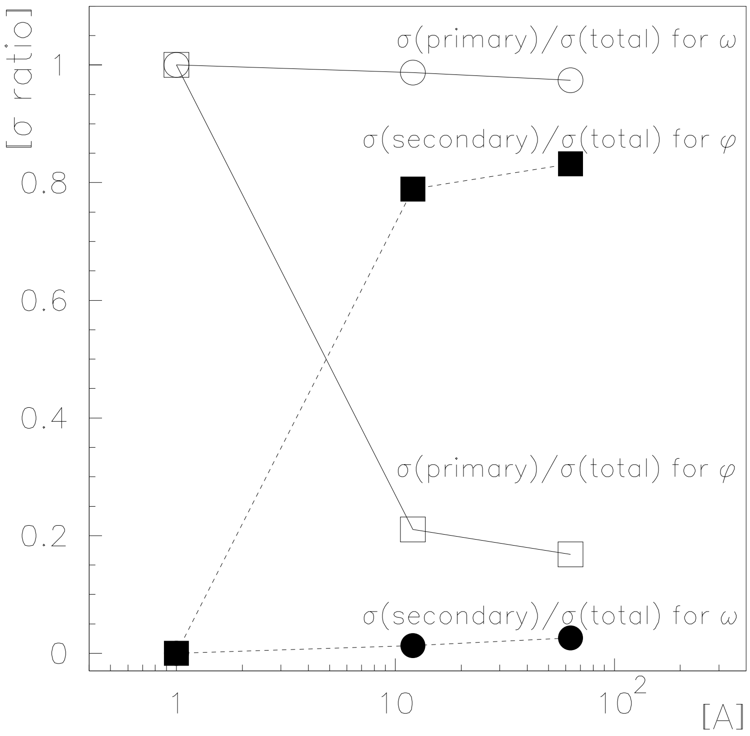
– too strong dependence for ϕ ?

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:

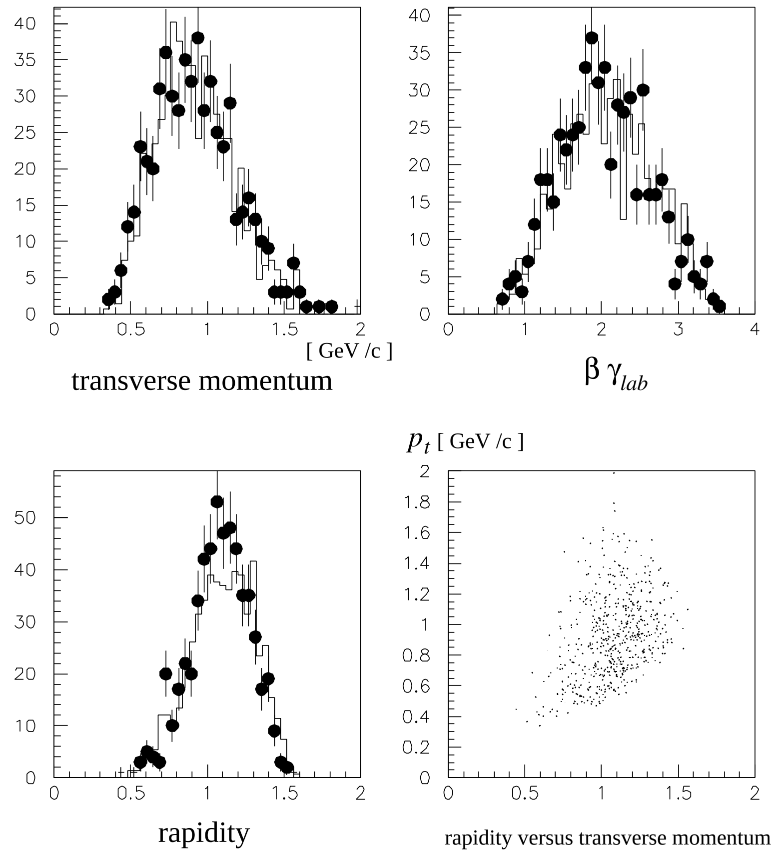
- ω : primary fragmentation
- ϕ : secondary collision

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)

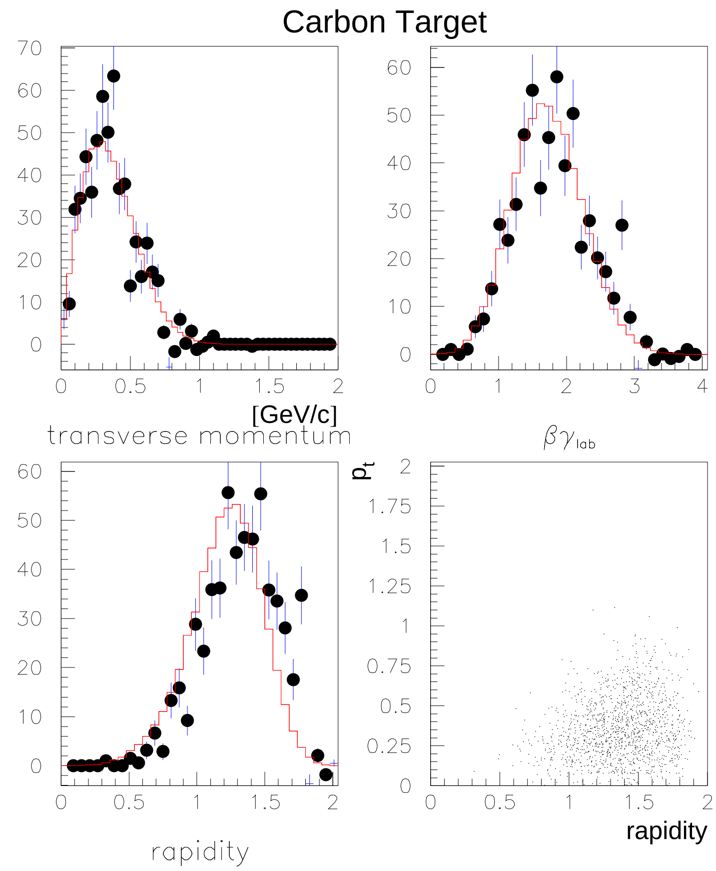
P_T	$\beta\gamma$
rapidity(y)	P_T VS y



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

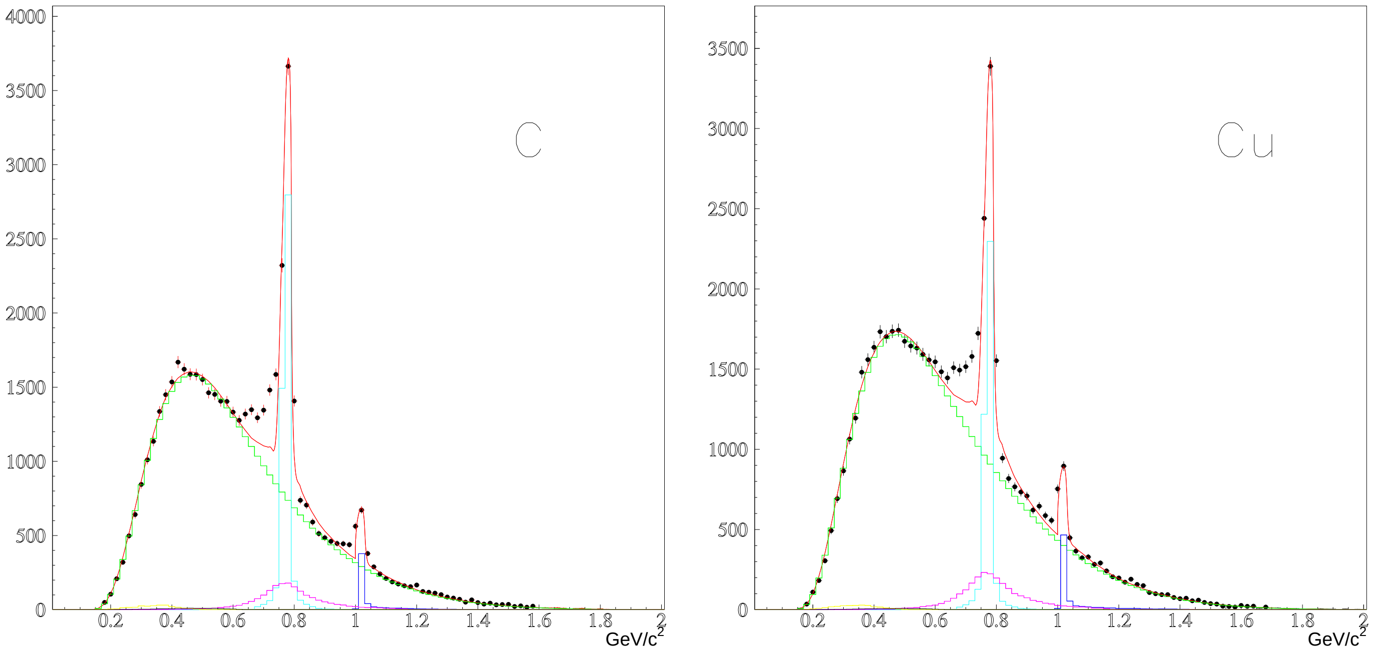
(preliminary)

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

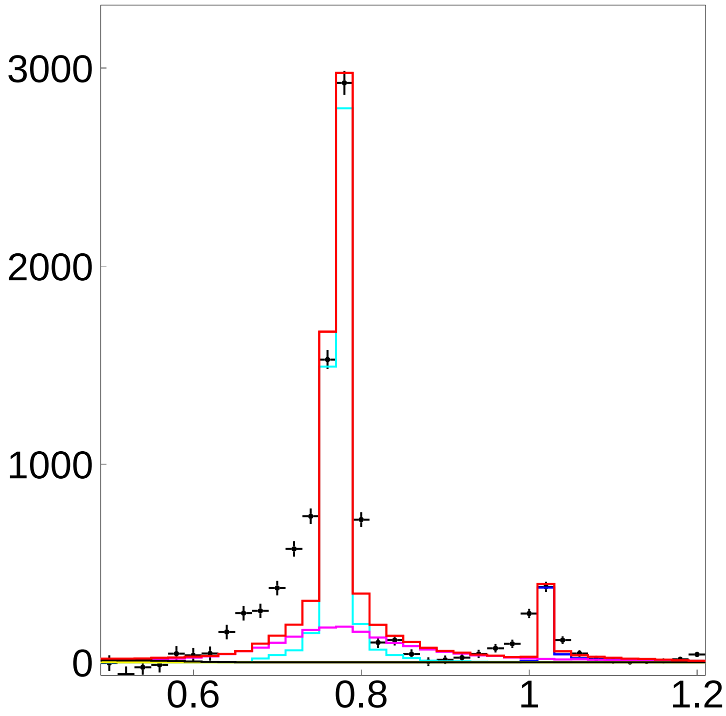
5 free parameters.(ρ/ω ratio is not fixed)

N_1, N_2, N_3, N_5 and N_6

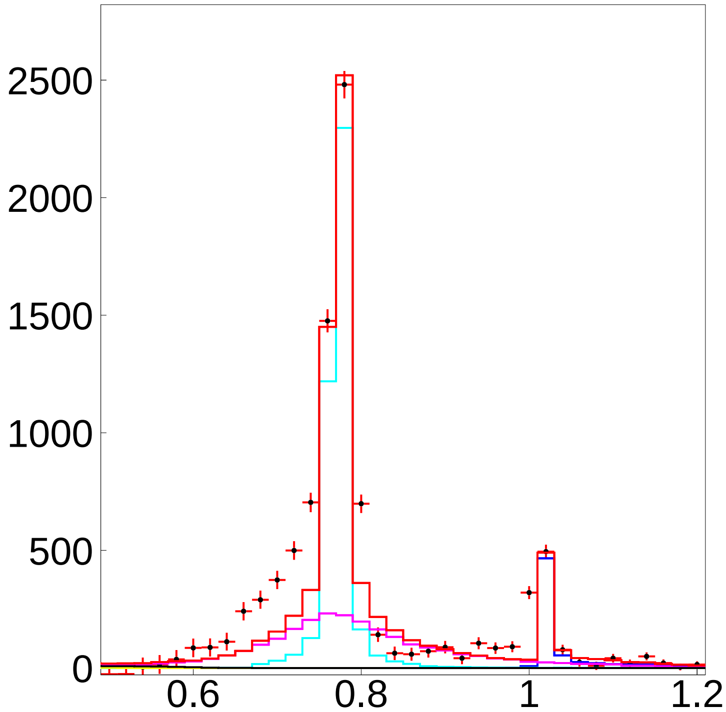
excesses are still seen below the ω peak in both targets

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

C target



Cu target



In the result of fitting, ρ/ω 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 ρ.

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 ρ meson modification.
- Some hints for ϕ 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.)