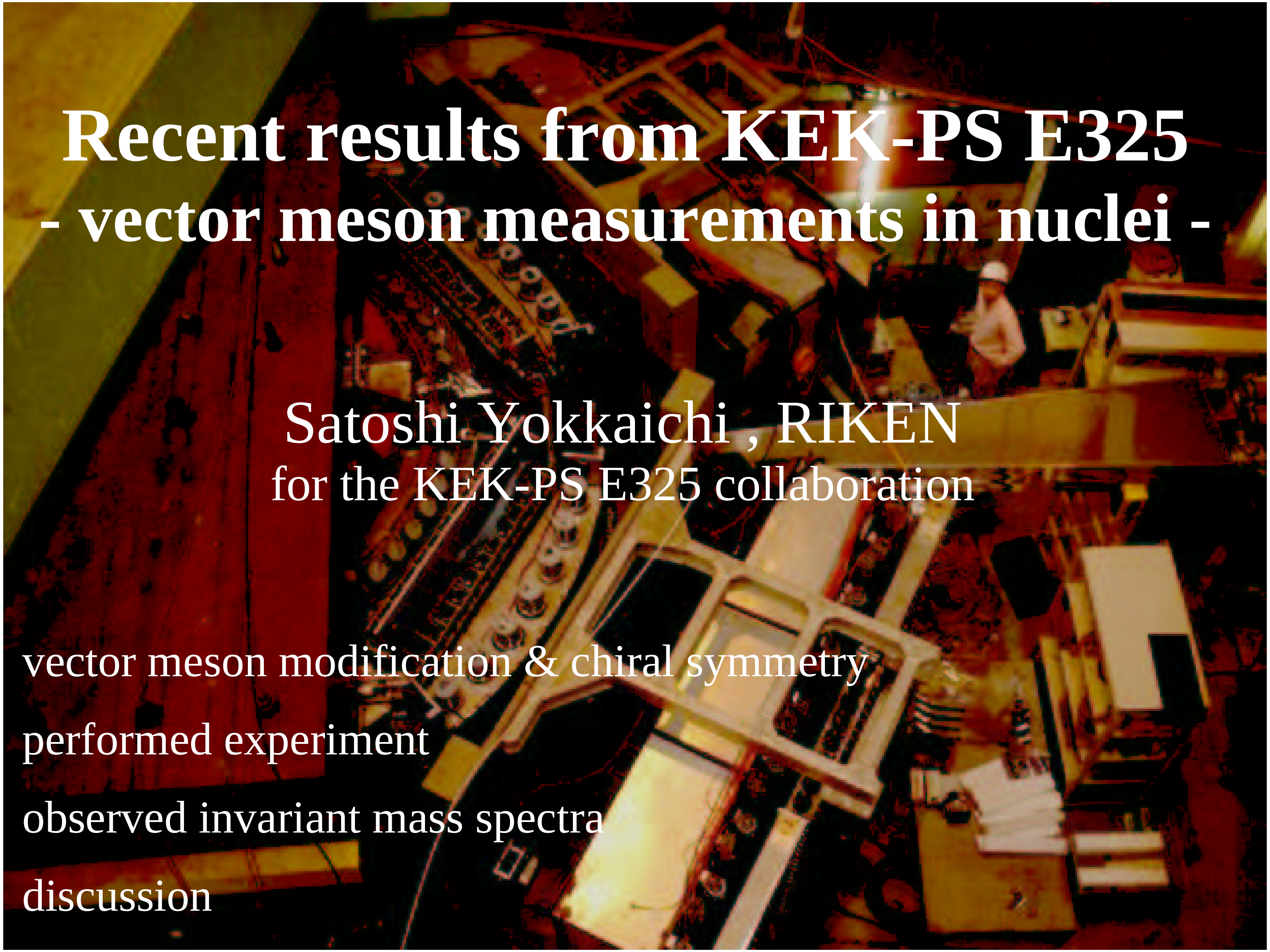


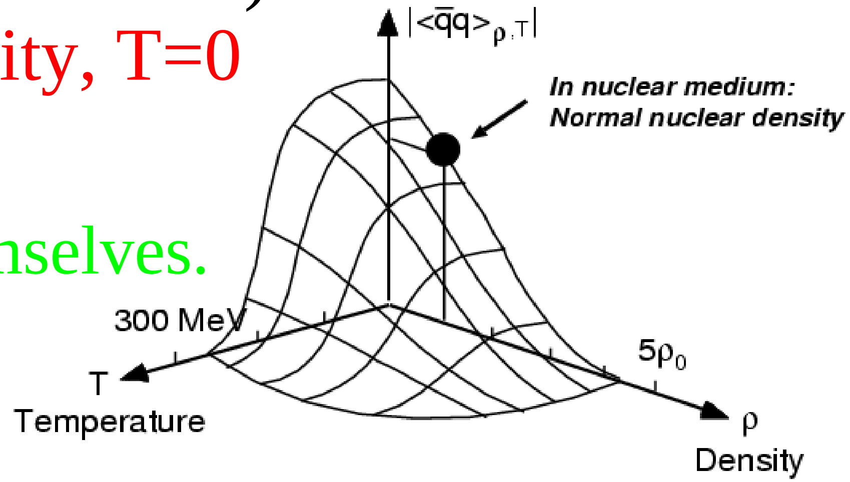
Recent results from KEK-PS E325
- vector meson measurements in nuclei -

Satoshi Yokkaichi , RIKEN
for the KEK-PS E325 collaboration

- vector meson modification & chiral symmetry
- performed experiment
- observed invariant mass spectra
- discussion

Chiral symmetry restoration in dense matter

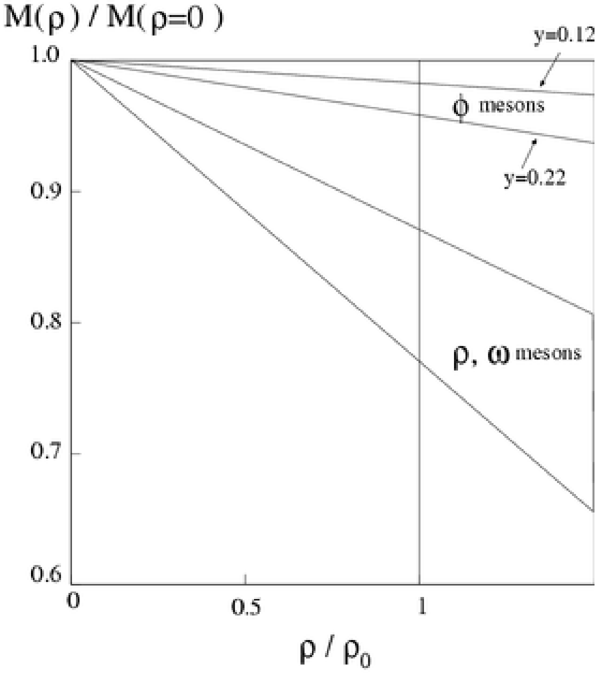
- In hot/dense matter, chiral symmetry is expected to restore
  - hadron modification is expected in such matter
- quark-antiquark condensate (order parameter) ~2/3 even at the normal nuclear density, T=0
  - Achievable at KEK-PS in use of nuclear medium of target nuclei themselves.



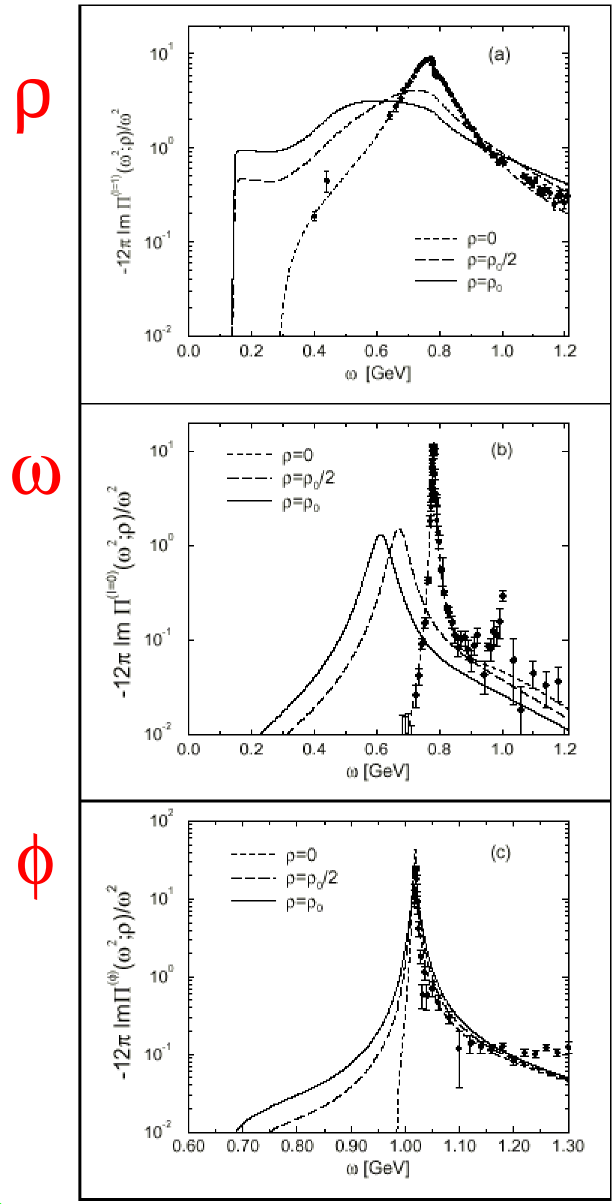
- Many theoretical predictions of vector meson (mass/width) modification in dense medium, related (or not related) with CS
  - Brown & Rho ('91) : $m^*(\rho)/m_0 \sim f_\pi^*/f_\pi \sim 0.8$ at $\rho=\rho_0$
  - Hatsuda &Lee ('92) , Klingle, Keiser &Weise ('97), Muroya, Nakamura & Nonaka('03), etc.

Hatsuda and Lee, 92,96

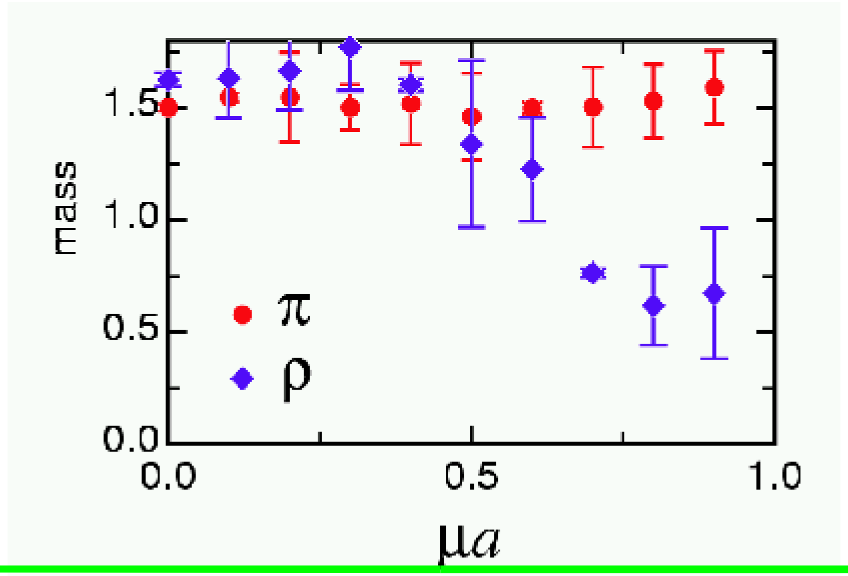
mass decreasing
~16(+-6)% for ρ/ω
~2-4% for ϕ
at the normal nuclear density



Klingle,Keiser,Weise, 97

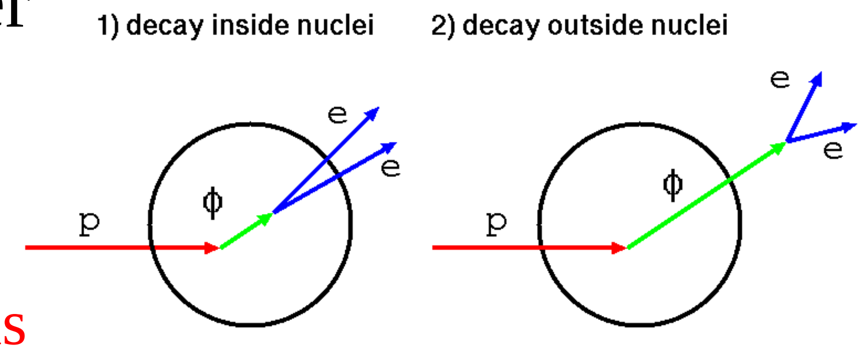


Muroya, Nakamura, Nonaka, 03



Expected Invariant mass spectra in e^+e^- channel

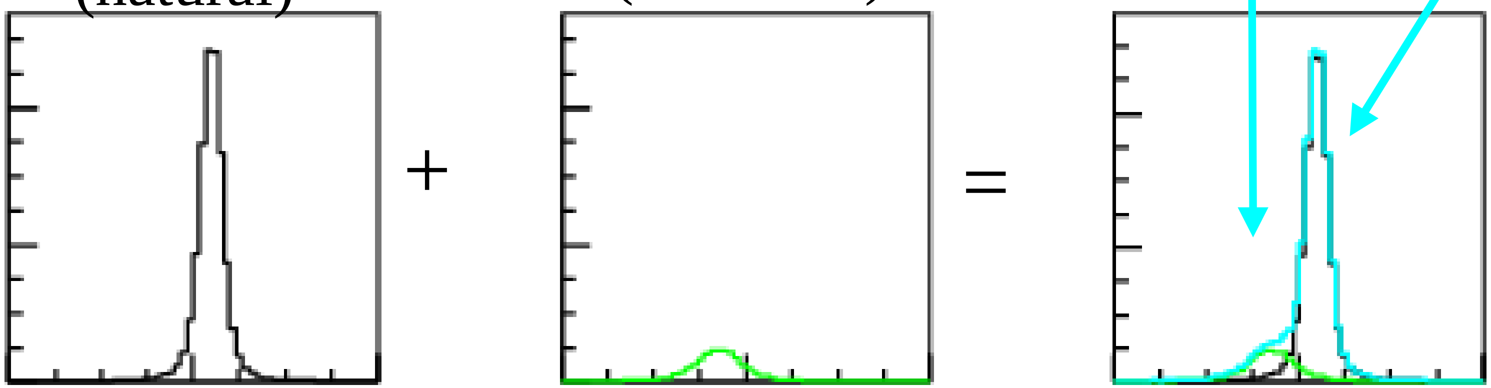
- smaller FSI in e^+e^- decay channel rather than hadronic decay channel
- double peak (or tail-like) structure
  - second peak is made by inside-nucleus decay (modified meson) : amount depend on the nuclear size



longer-life meson(ω & ϕ) cases : Schematic picture

outside decay (natural)

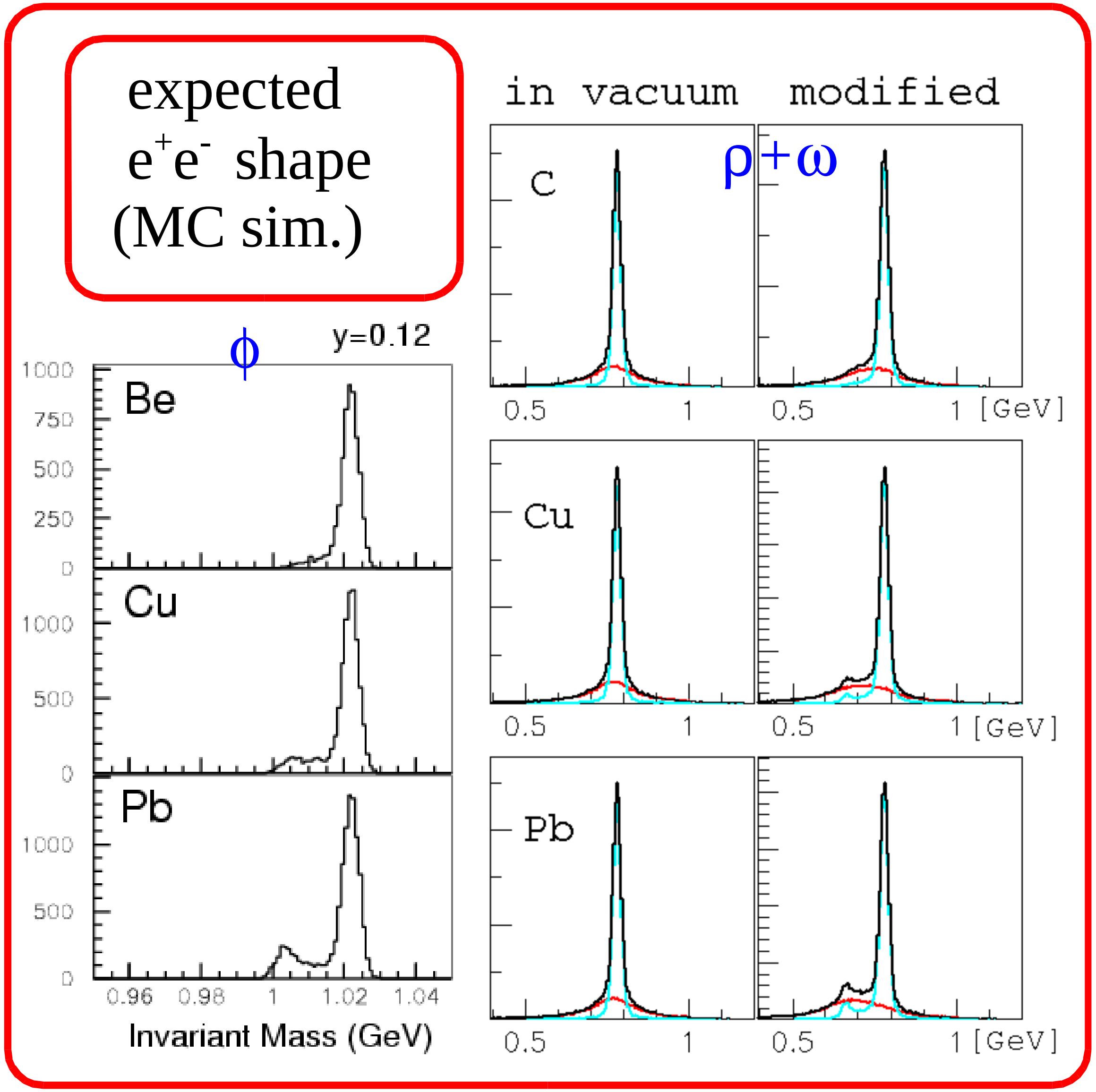
inside decay (modified)



expected to be observed

(Expected e^+e^- spectra)

- ρ (770) & ω(783) :
  - larger production cross section
  - larger decay prob. inside nuclei
  - cannot distinguish ρ & ω in e^+e^-
- ϕ (1020) : narrow width
  - smaller decay prob. inside nuclei
  - smaller production cross section



Experiment KEK-PS E325

- 12GeV p+A -> ρ/ω/φ +X (ρ/ω/φ ->e^+e^- , φ->K^+K^-)
- Experimental key issues:
  - Very thin target to suppress the conversion electron background (typ. 0.1% interaction/0.2% radiation length of C)
  - To compensate the thin target, high intensity proton beam to collect high statistics (typ. 10^9 ppp -> 10^6Hz interaction)
  - Large acceptance spectrometer to detect slowly moving mesons, which have larger probability decaying inside nuclei (1<βγ<3)

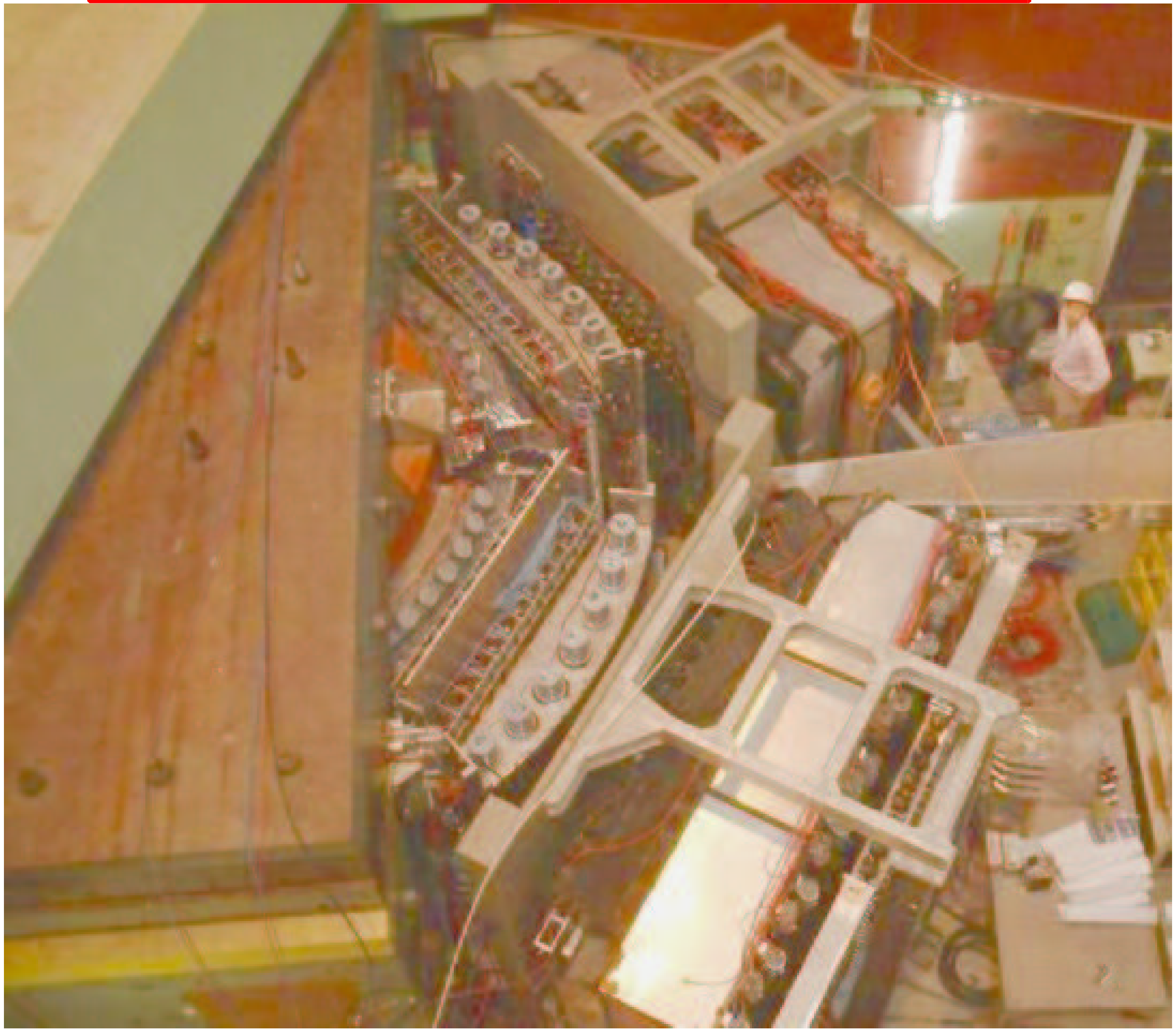
Collaboration

J. Chiba, H. En'yo, Y. Fukao, H. Funahashi, H. Hamagaki, M. Ieiri, M. Ishino, H. Kanda, M. Kitaguchi, S. Mihara, K. Miwa, T. Miyashita,T. Murakami, T. Nakura, M. Naruki, M. Nomachi, K.Ozawa, F. Sakuma, O. Sasaki, H.D.Sato, M.Sekimoto, T.Tabaru, K.H. Tanaka, M.Togawa, S. Yamada, S.Yokkaichi, Y.Yoshimura
(Kyoto Univ. , RIKEN, KEK, CNS-U.Tokyo, ICEPP-U.Tokyo, Tohoku-Univ.)

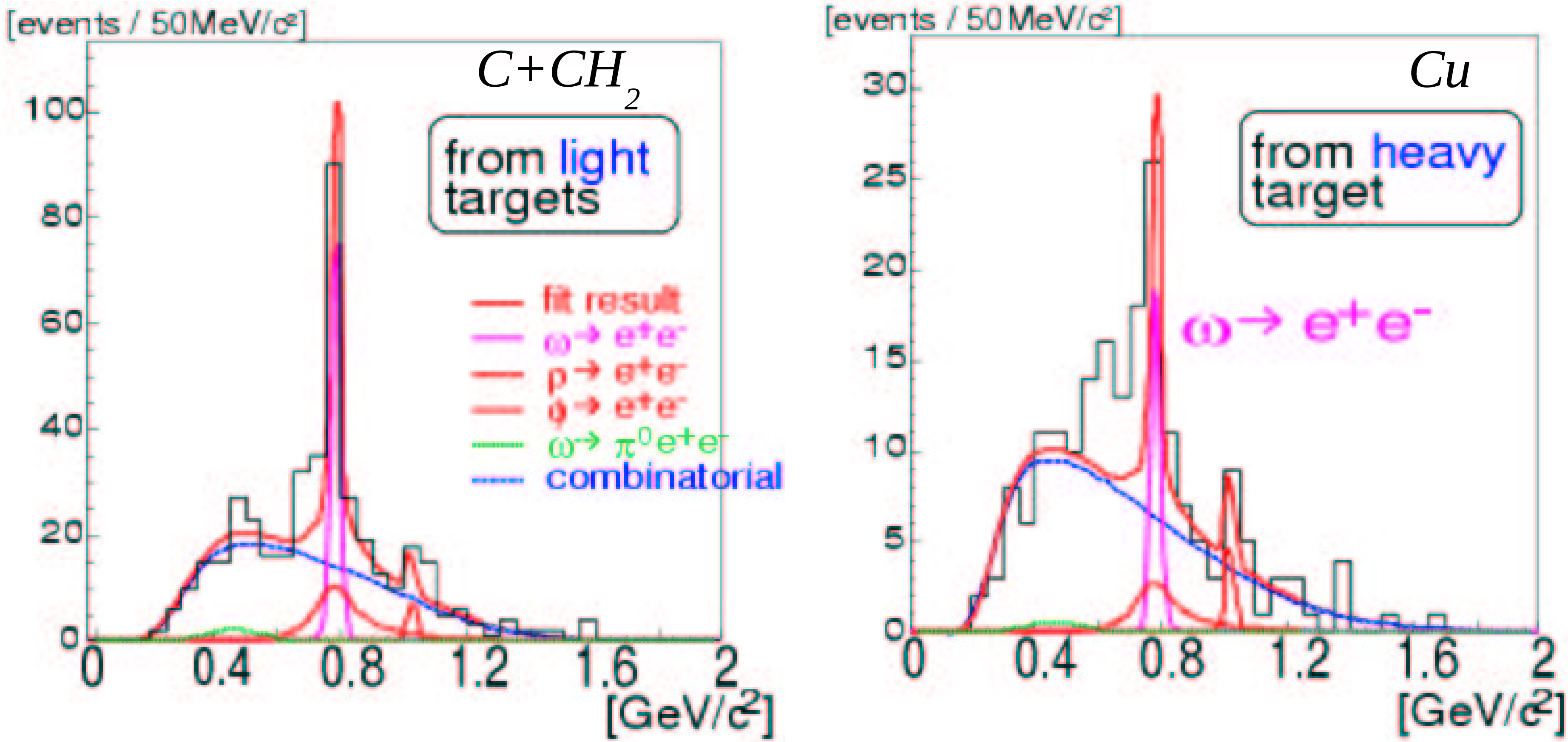
(Cont'd)

- History of E325
  - 1996 const. start
  - '97 data taking start
  - '98 first ee data
    - PRL86(01)5019
  - 99,00,01,02....
    - x100 statistics
      - presented today
  - '02 completed
  - spectrometer paper
    - NIM A516(04)390

E325 spectrometer
located at KEK-PS EP1-B primary beam line



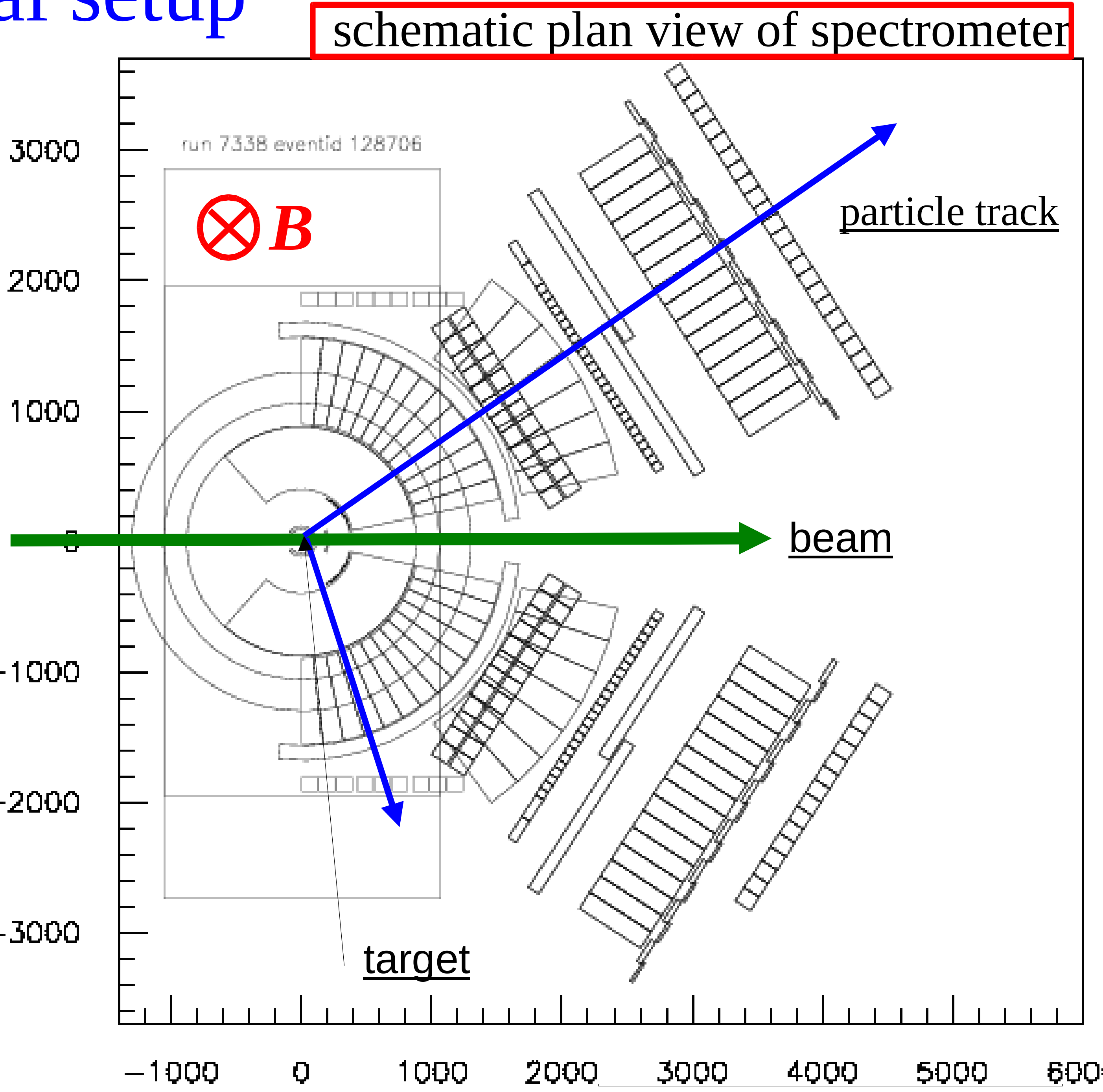
e^+e^- spectra in 1998 (published) data



- 'excess region' : 0.55-0.75 GeV
- N(excess)/N(ω) = 0.26+-0.16 (light), 1.48+-0.56 (heavy)

Experimental setup

- Spectrometer Magnet
  - 0.71T at the center
  - 0.81Tm in integral
- Targets
  - at the center of the Magnet
  - C & Cu are used typically
  - very thin: ~0.1% interaction length
- Primary proton beam
  - 12.9 GeV/c
  - ~1x10^9 in 2sec duration, 4sec cycle



Experimental setup - Detectors

Electron ID counters

Gas Cherenkov &

Lead Glass EMC

total $3x10^{-4}$ π rejection

with 78% e efficiency

in two-stage operation

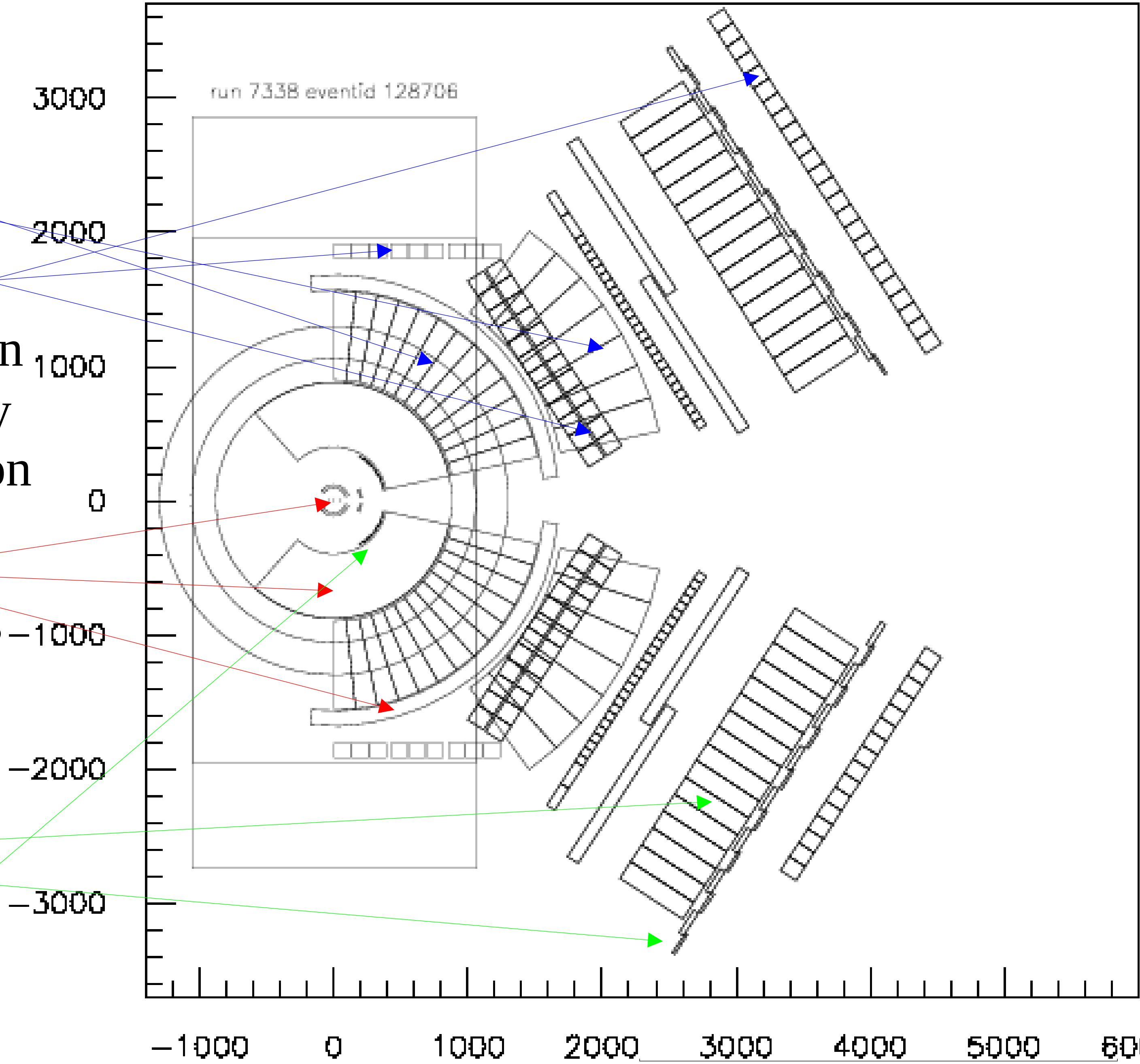
Tracker

Three Drift Chambers

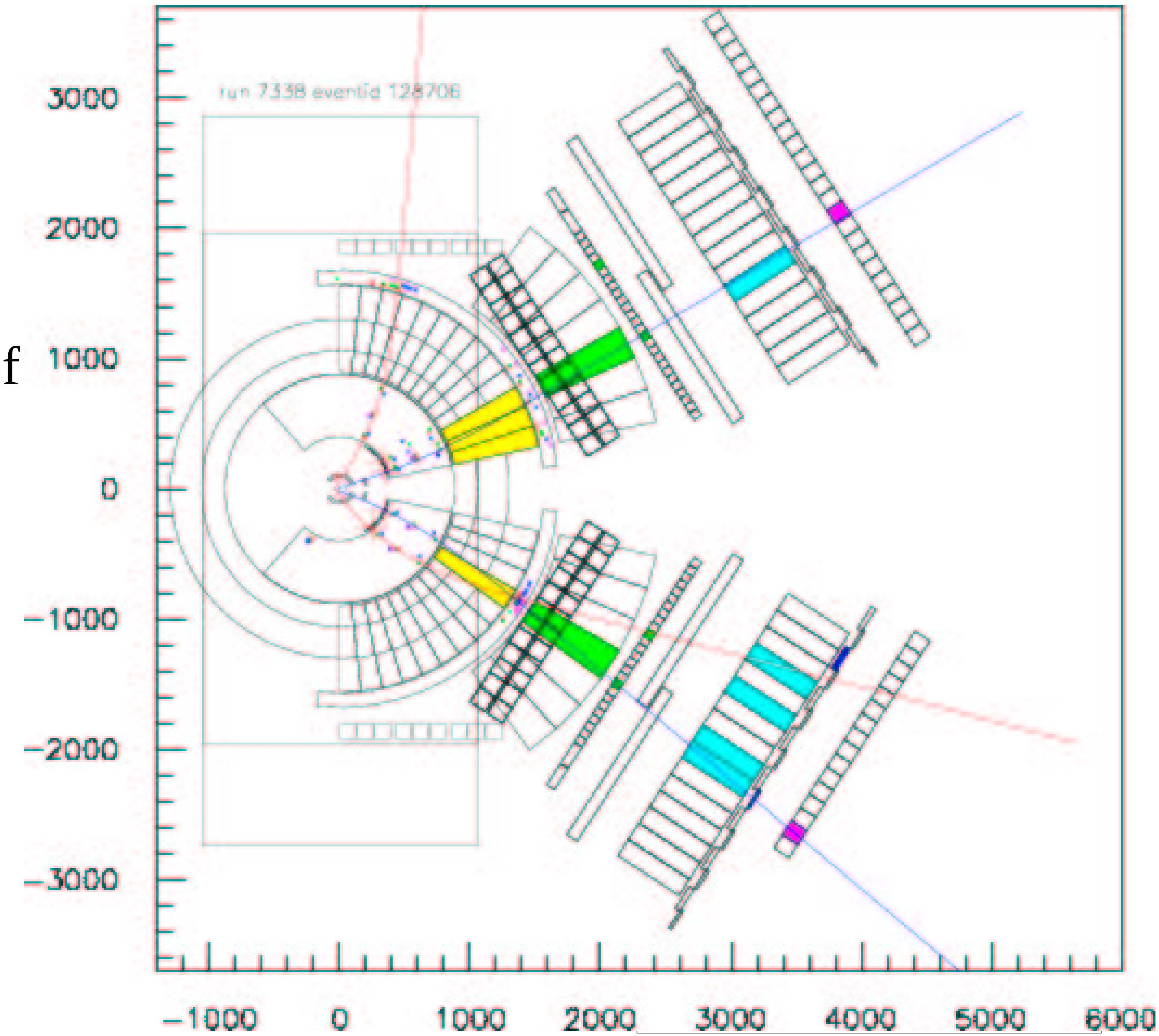
Kaon ID counters

Aerogel Cherenkov

& TOF



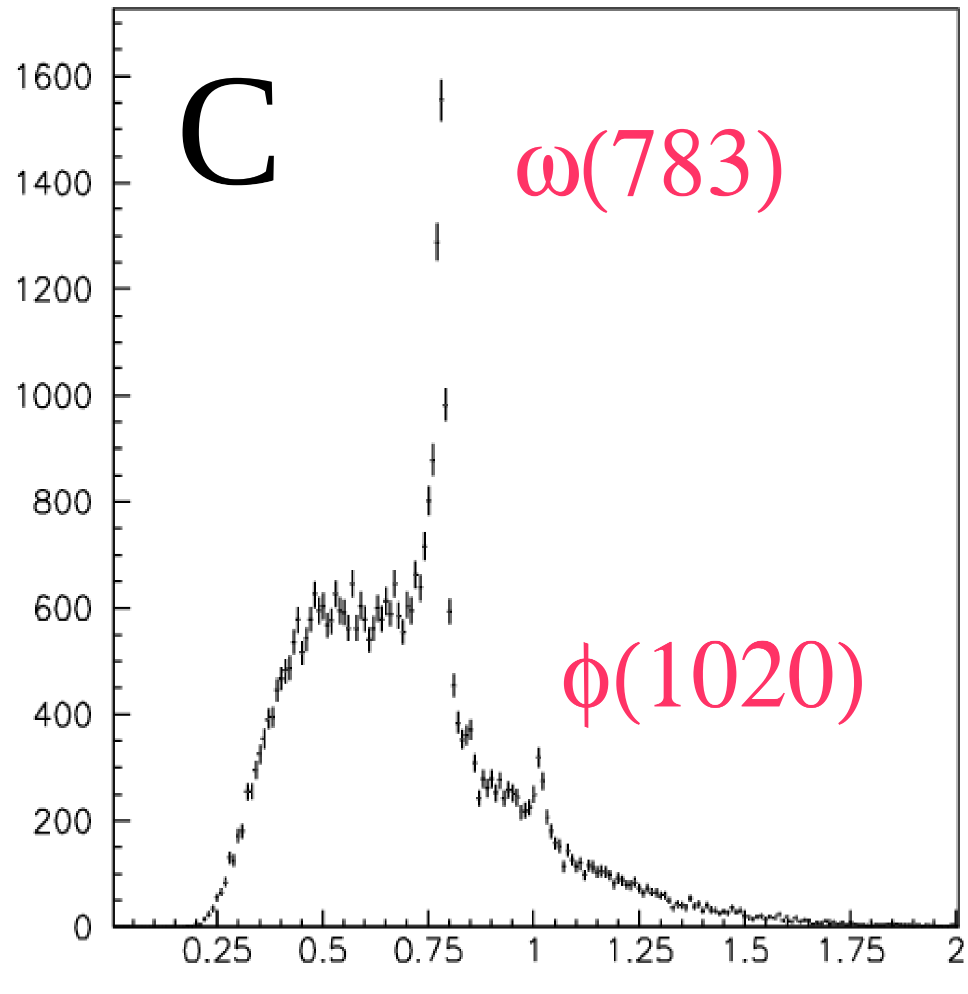
- Typical e^+e^- Event
  - blue:electron
  - red : other
  - invariant mass of eletron pair is calculated



Data
(ee invariant mass spectra)

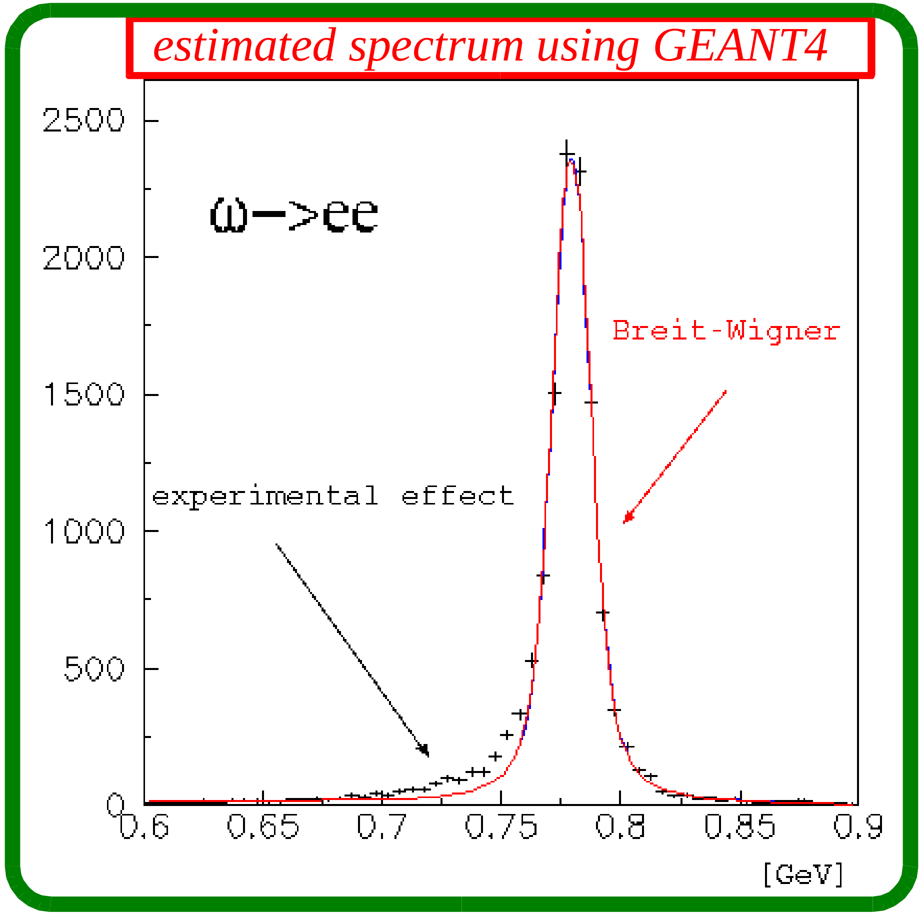
Observed e^+e^- invariant mass spectra

- from 2002 run data (~70% of total data)
- C & Cu target
- clear resonance peaks
- m<0.2 GeV is suppressed by detector acceptance
- acceptance uncorrected

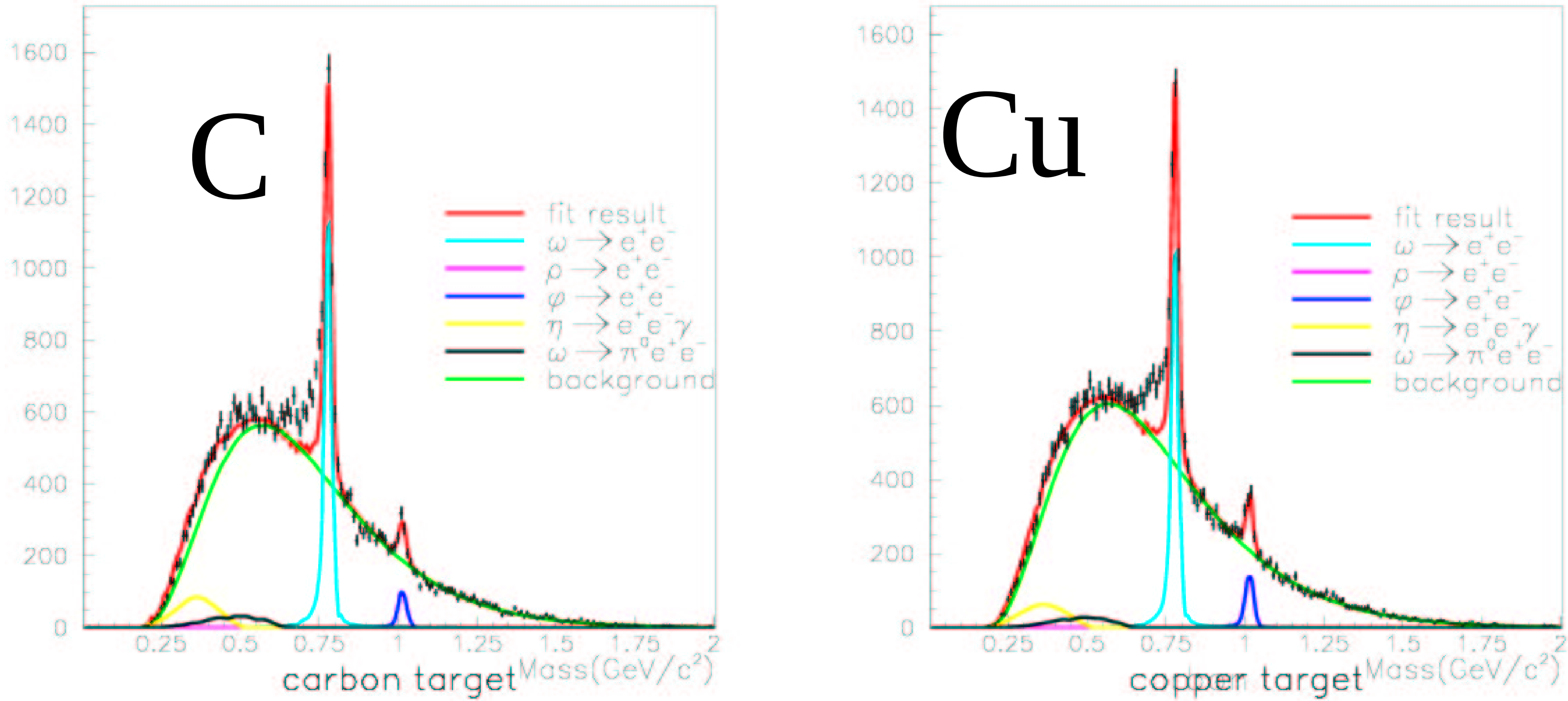


Fitting with known sources

- Hadronic sources of e^+e^-:
  - $\rho/\omega/\phi \to e^+e^-$, $\omega \to \pi^0 e^+e^-$, $\eta \to \gamma\, e^+e^-$
  - Breit-Wigner shape (no modification is assumed)
  - Geant4 detector simulation
    - multiple scattering and energy loss of e^+/e^- in the detector and the target materials
    - chamber resolutions
    - detector acceptance, etc.
- Combinatorial background : event mixing method
- Relative abundance of these components are determined by the fitting



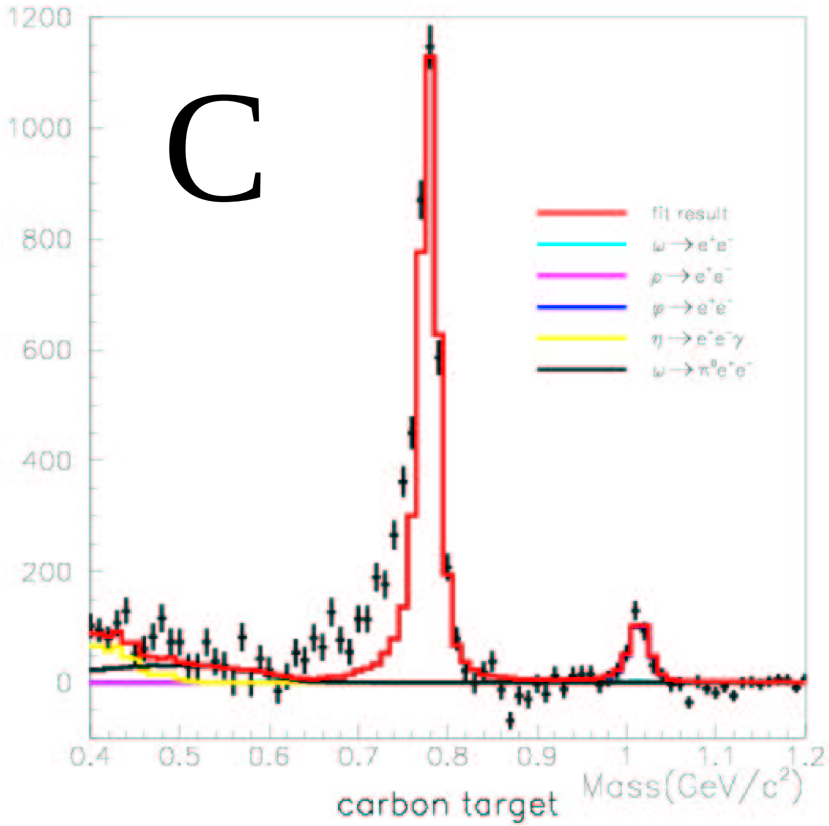
Fitting results

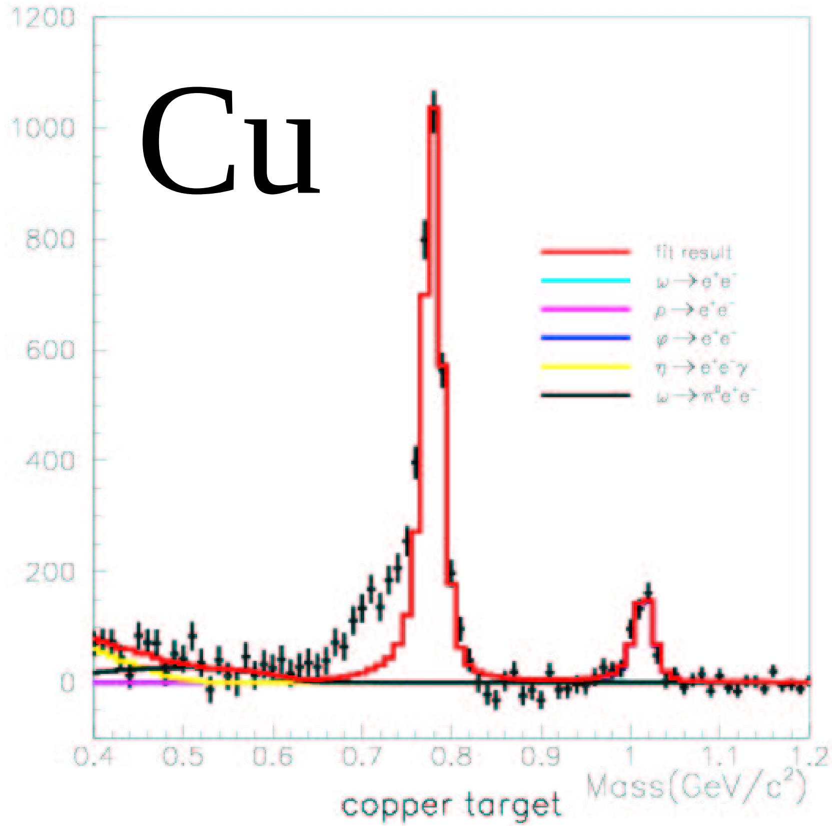


- excess at the low-mass side of ω
  - To reploduce the data by the fitting, we have to exclude the excess region : 0.65~0.77 GeV
- ρ–meson component seems to be vanished !

Fitting results (BKG subtracted)

ρ/ω=0.0+-0.02(stat.)+-0.26(sys.) , 0.0+-0.05(stat.)+-0.41(sys.)





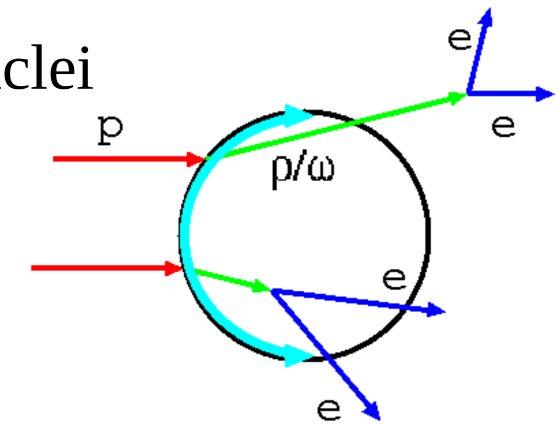
- However, ρ/ω =1.0+-0.2 in former experiment (p+p, 1974) ....suggests the origin of excess is modified ρ mesons.

Discussion: Toy model including modification

- Assumptions to include the nuclear size effect in the fitting shape
  - meson fly through the nucleus, decay with modified mass if the decay point is inside nuclei
    - meson production point : incident surface of nuclei
      - measured $\alpha \sim 0.68$ for ω
    - meson momentum :
      - measured distribution in our experiment
        - ~0.8 GeV < p < ~2.4GeV for ω
    - nuclear density distribution : Woods-Saxon type
    - modification as : $m^*/m_0 = 1 - k\, \rho^*/\rho_0$

      (k=0.16+-0.06 in Hatsuda & Lee, '92,'96)
    - (width modification & momentum dependence of modification

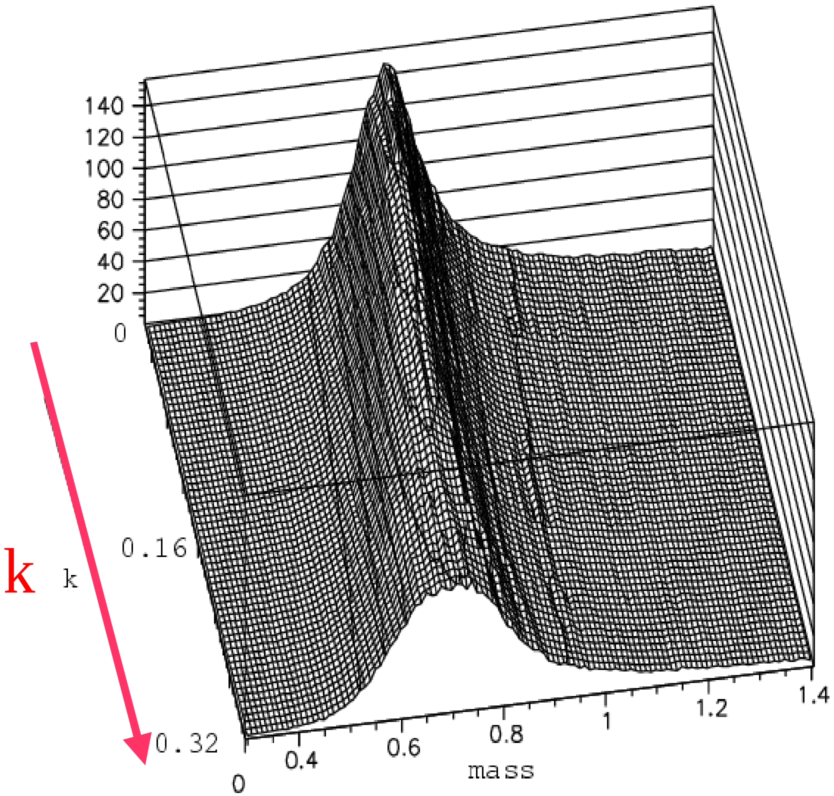
      are not taken into account this time)



Fitting with the model

- C and Cu spectra are fitted simultaneously
- free parameters :
  - shift parameter k
  - scale of background
  - scale of each hadron spectra
    - shape of ρ&ω are modified, parametrized by k
- Two cases for ρ/ω ratio
  - 1) free
  - 2) fixed to unity as measured in former experiment.

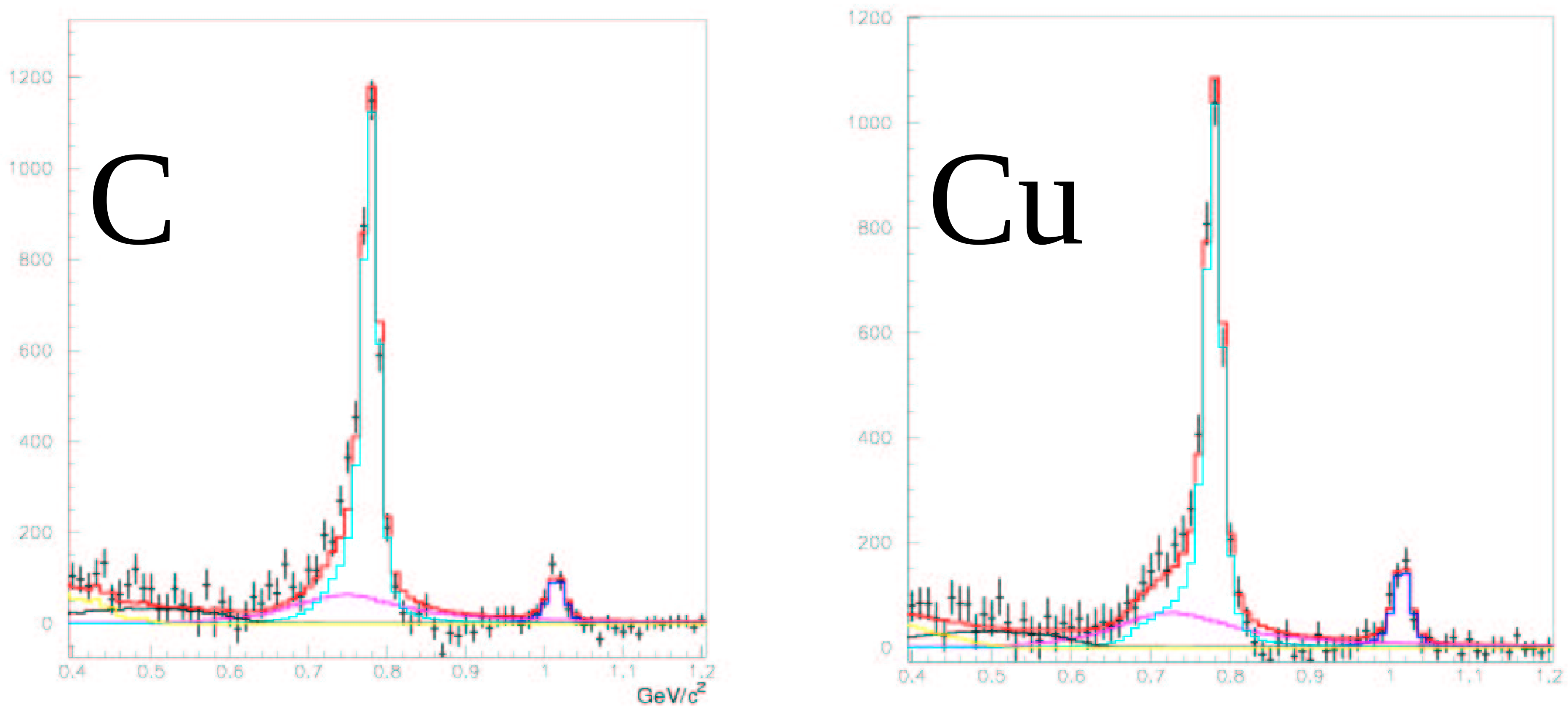
parametrization of ρ spectrum



k

mass

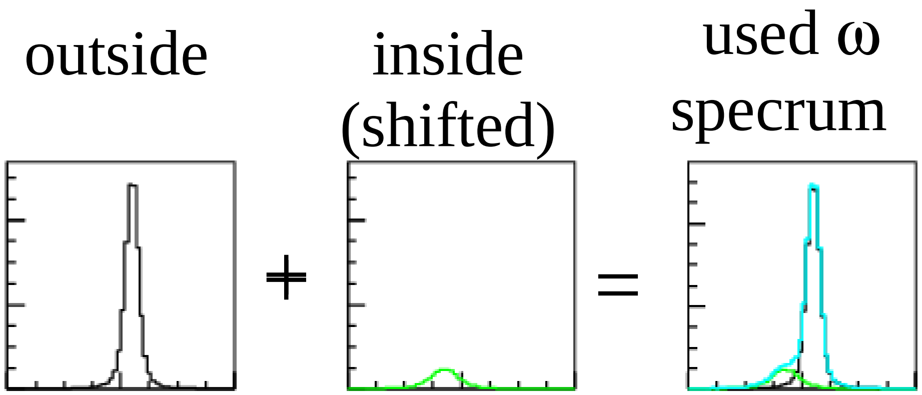
Fitting results by the toy model

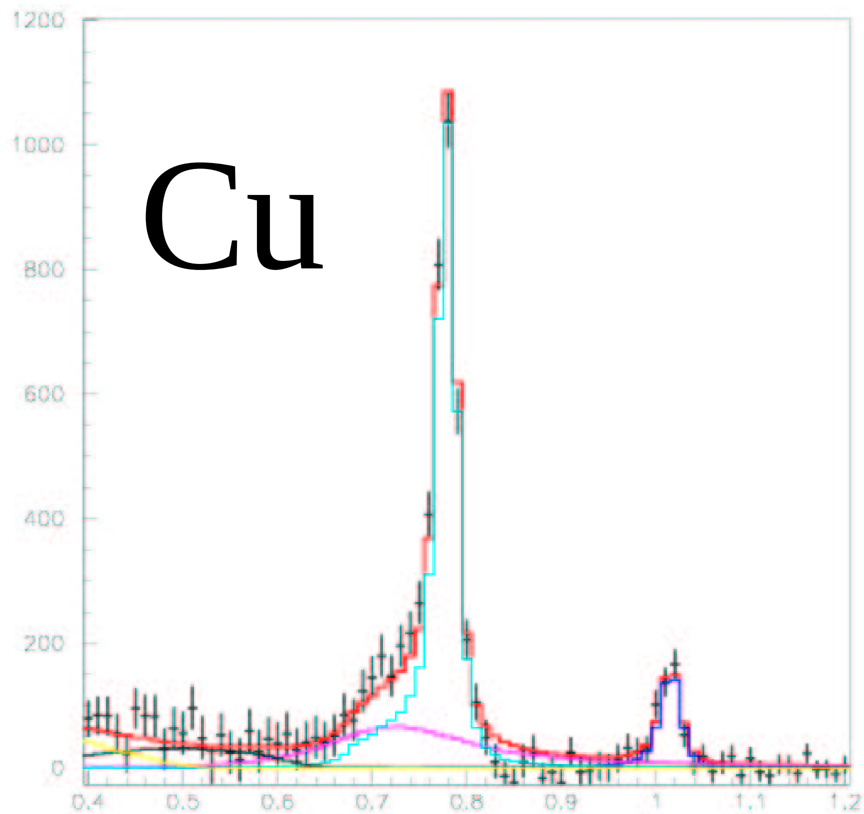


- 1) k = 0.101 +- 0.007 : ~ 10% reduced at the normal nuclear density
  - ρ/ω ratio : 0.63 +- 0.12 (C), 0.79+-0.14 (Cu) : ... ρ meson returns.
- 2) k=0.106 +- 0.007 (ρ/ω =1 fixed)

Remark on the fitting

- ρ (ω) decay inside nucleus :
  52%(5%) for C, 66%(10%) for Cu
  - used spectrum is the sum of the shifted and the not-shifted components.
- constraint at right side of peak
  - Intoducing the width broadning may enlarge the ρ decay probability inside nuclei and the fitting may be refined.
  - prediction of ' mass increasing' is not allowed.
- momentum dependence of mass shift is not included.(But typical p =1.5GeV)

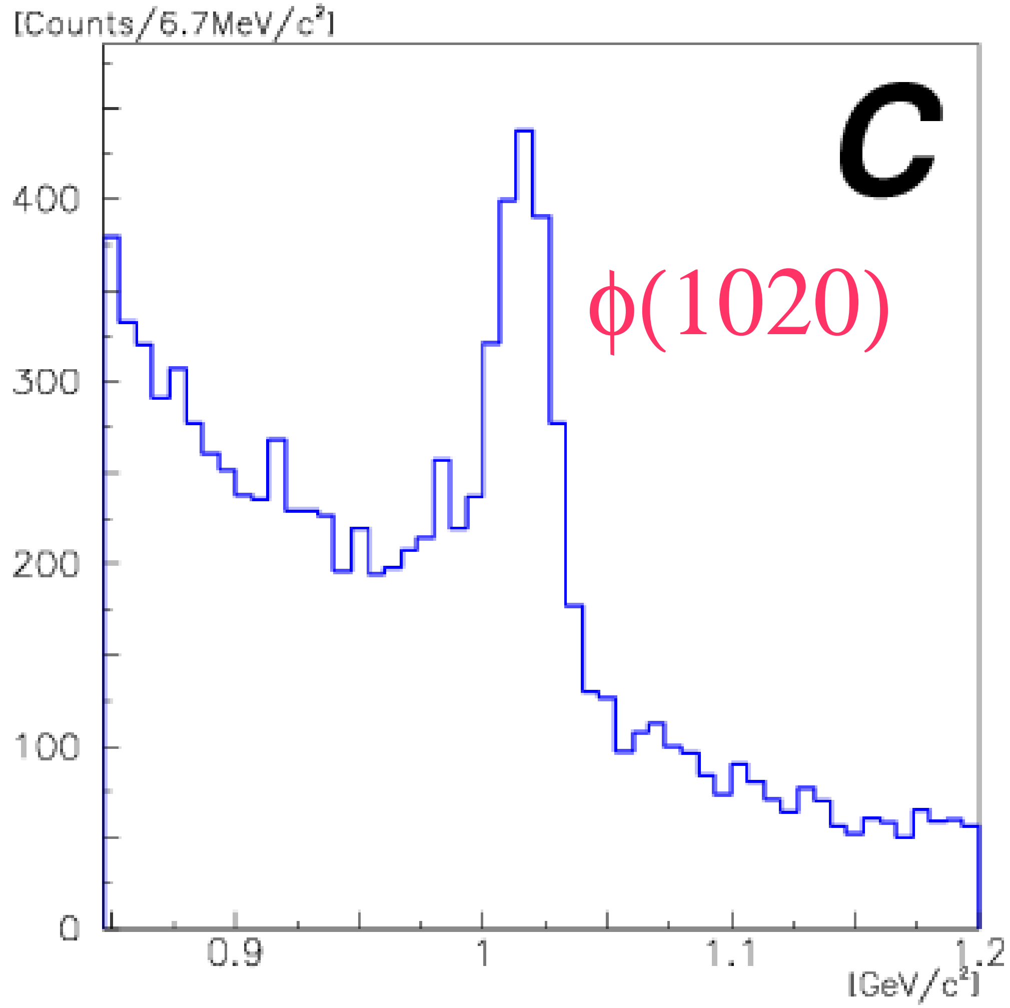




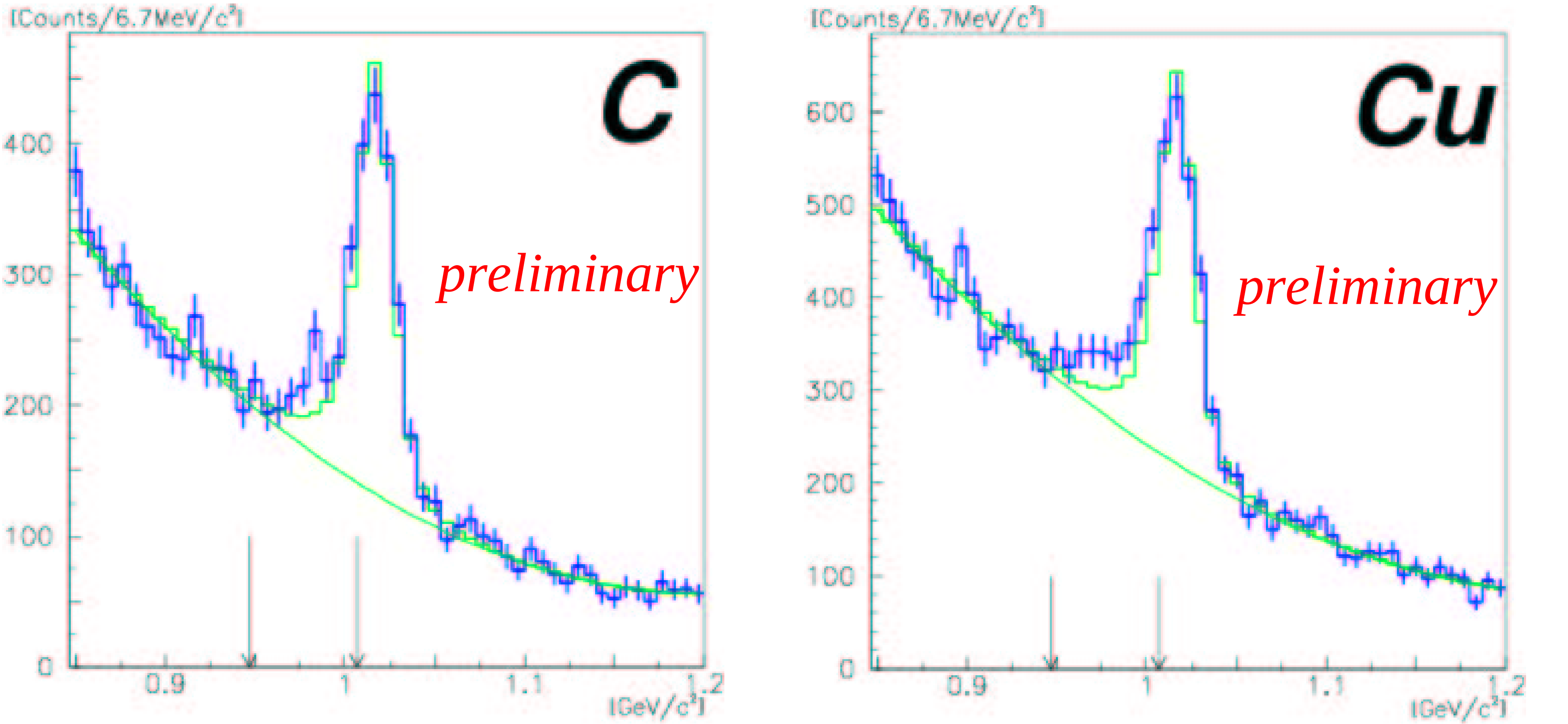
Preliminary Data
(phi meson)

$\phi \to e^+e^-$ invariant mass spectra

- from 2001/02 run data
- C & Cu target
- acceptance uncorrected
- mass resolution : 9MeV
- fit with
  - simulated mass shape of ϕ (evaluated as same as ρ&ω)
  - polinomial curve background
- examine the 'excess' is significant or not.



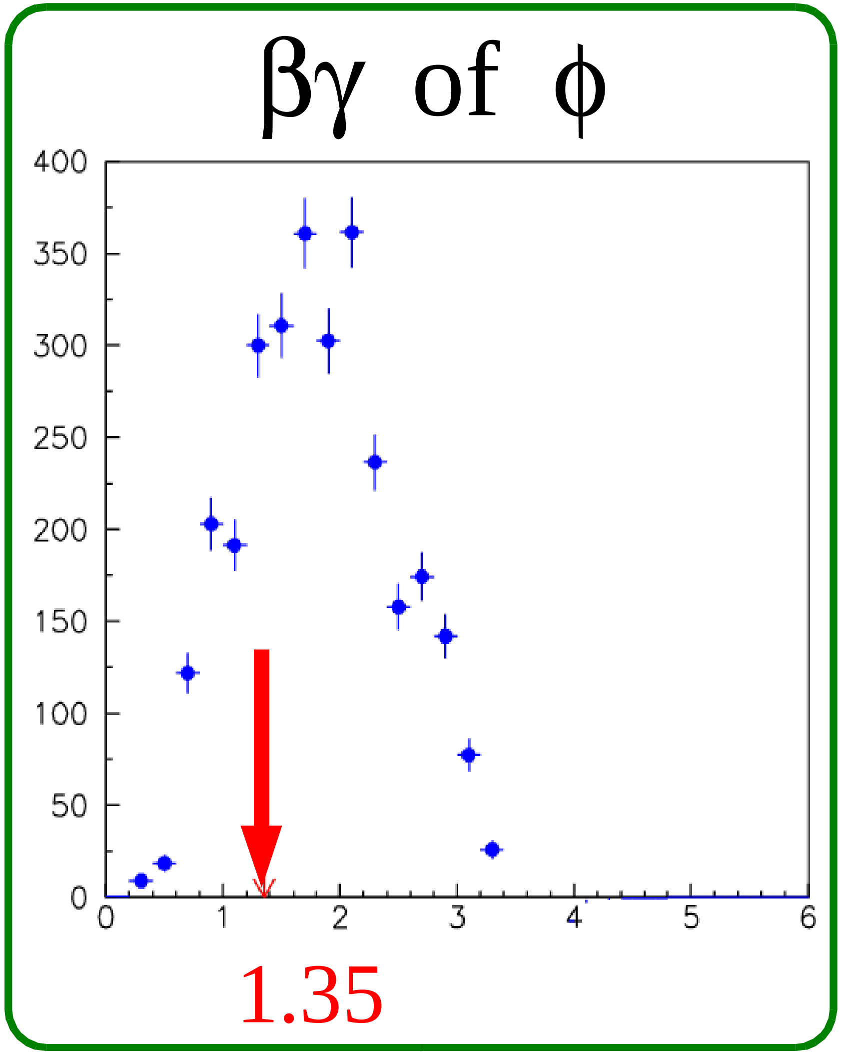
e^+e^- spectra of ϕ meson (2001/02 data)



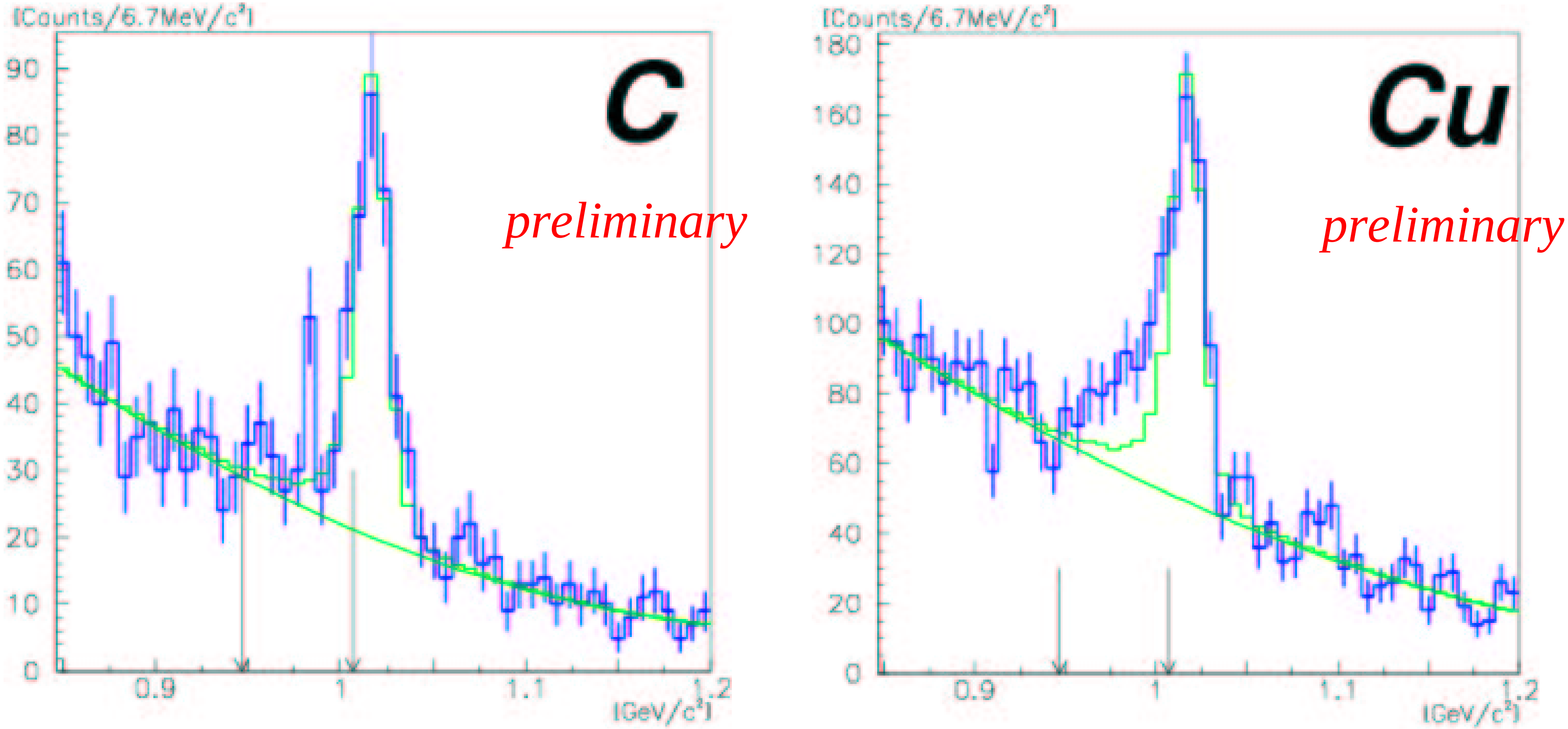
- To reploduce the data, we have to exclude the region shown by two arrows (0.946-1.007GeV) from the fit for the Cu data.
  - C data can be reploduced in both case (excluding/including)

$\beta\gamma$ dependence : slowly moving ϕ ?

- select the slowly moving component of the data.
  - excess should be enhanced, if our view is correct. Because larger probability of inside-decay is expected.
  - cut at $\beta\gamma = 1.35$
    - p[GeV/c]~ $\beta\gamma$ for ϕ, because $p = m\beta\gamma$ and $m(\phi)$ =1.02GeV



slowly moving ϕ ($\beta\gamma$<1.35)



- excess seems enhanced in this slow component , for Cu
  - it is consistent with our view : mass shift in nuclei.

Number of 'excess' in e^+e^- spectra of ϕ

– for all sample

	C	Cu
• $N(\phi)$	1550 +- 64	1985 +- 77
• N(excess)	159 +- 95	300 +-121
• N(excess)/(N(ϕ)+N(excess))	(9+- 7)%	(13 +- 7)%
• significance of excess *[=N(excess)/σ(fit)]*	1.9 σ	2.8 σ

– for slow component ($\beta\gamma$<1.35)

	C	Cu
• $N(\phi)$	271+-24	481+-34
• N(excess)	46 +-36	161+-57
• N(excess)/(N(ϕ)+N(excess))	(15+-15)%	(25+-12)%
• significance of excess	1.5 σ	3.2 σ

Preliminary

- significant excess for Cu, while marginal for C
- "enhancement of excess in slow component " is 1σ for Cu
- N(excess)/N(ϕ) seems so large : Γ broadning ?

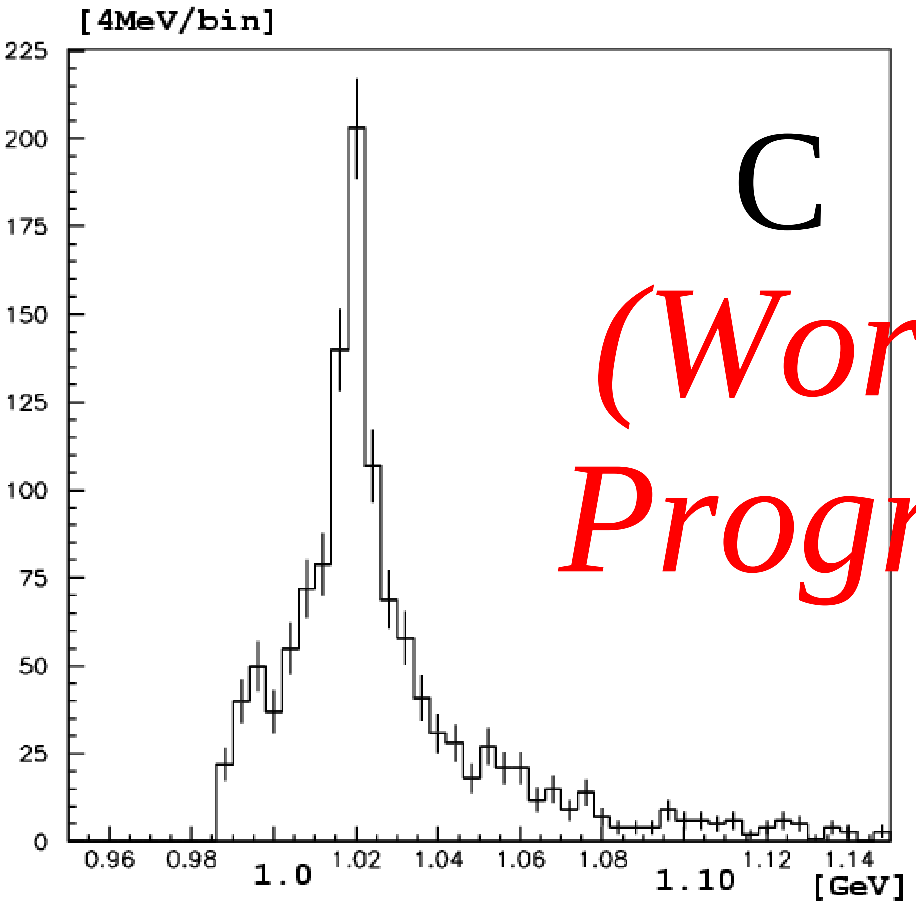
Toy model again : Width broadning of ϕ ?

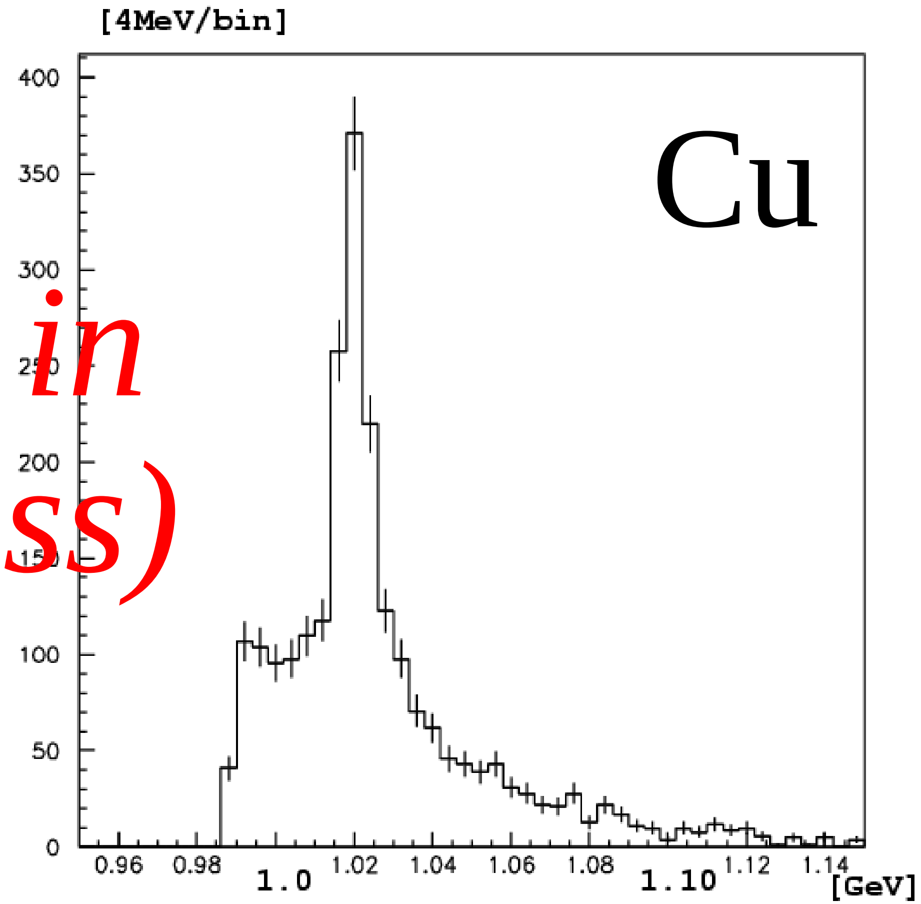
- Many theoretical predeictions ...
  - Γ=22MeV, Δm=0 at $\rho=\rho_0$ (Oset et.al,2001)
  - Γ=30MeV, Δm=8MeV at $\rho=\rho_0$ (Cabrera et.al, 2003)
- Toy model like ρ&ω, including width (=decay prob.) change
- Inside-nucleus decay (=at $\rho > 0.5\ \rho_0$) probability for ϕ

	C	Cu
– natural width (Γ=4.4MeV)		
• all our acceptances	1 %	3%
• slow ($\beta\gamma < 1.35$)	2 %	6%
– Γ=30MeV at $\rho=\rho_0$		
• all	5 %	18%
• slow	9 %	32%
– Observation : N(excess)/(N(excess)+N(ϕ))		
• all	(9+-7) %	(13+-7)%
• slow	(15+-15) %	(25+-12)%

- $\Gamma^*/\Gamma_0 = 1+$ 6 ρ^*/ρ_0
  4.4 *7~30MeV at $\rho=\rho_0$)
  - no theoretical basis

K^+K^- spectra of ϕ meson (2001 data)





(Work in Progress)

- There is shape difference between C and Cu ?
- However, precise analysis is on going...

Summary

- KEK-PS E325 measured the e^+e^-(&K^+K^-) decay of slowly moving vector mesons in nuclei produced by 12-GeV proton beam, to explore the chiral symmetry restoration at the normal nuclear density.
- Observed e^+e^- invariant mass spectra have excesses below the ω meson peak, which cannot be explained by known hadronic sources in normal (unmodified) shape. These suggest modification of (at least) ρ meson.
  - Simple model calculation including predicted modification reproduces the observed spectra qualitatively.
- ϕ ->e^+e^- have excess, at least for the Cu target.
  - enhancement of excess in the slow component is 1σ.
  - hint for the width broadning
- Analysis on ϕ ->K^+K^- is also on going.

Proposed Experiment at J-PARC

Proposed Experiment at J-PARC

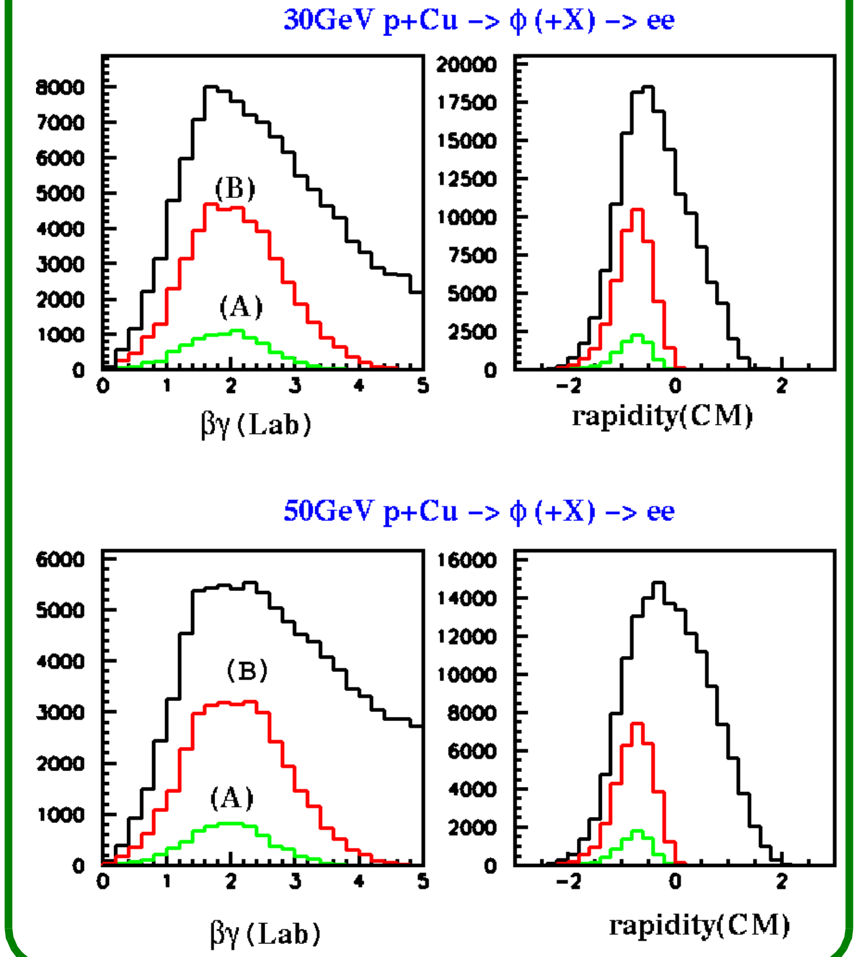
- Same concept as E325
  - thin target / primary beam ($10^9 \sim 10^{10}$ ppp)/ slowly moving mesons
- Main goal : collect $10^4 \sim 10^5$ ϕ -> ee for each target in 5 weeks
  - 10-100 times as large as E325
    - velocity dependence of 'modified' component
    - new nuclear targets : proton (CH_2 -C subtract), Pb
  - narrow width -> sensitive to modification
  - free from ω–ρ interference
- ω, ρ and J/ψ can be collected at the same time
  - higher statistics of ω, ρ than E325 with differ A targets
  - 100-1000 J/ψ are expected in 50GeV operation
- Normal nuclear density (p+A)
  - but also high matter density (A+A, ~20GeV/u) in the future

examine the modification from various view points

Spectrometer : two options

A) Reuse of E325 spectrometer
or
B) Newly constructed larger acceptance spectrometer
using Gas Electron Multiplier (GEM) as a Cherenkov photon sensor and/or tracker

spectrometer acceptance $\phi \rightarrow ee$
(estimated by JAM)



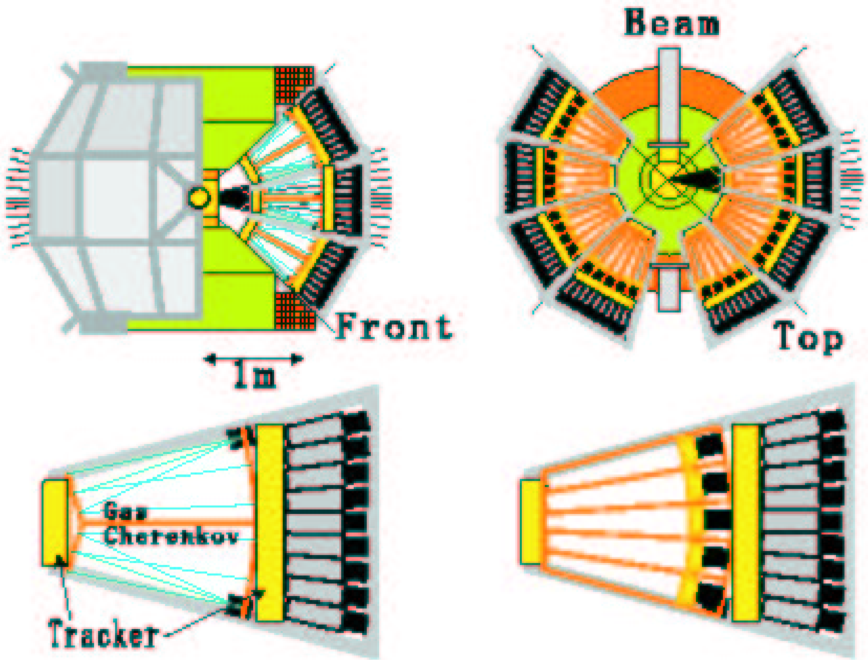
expected ϕ yield for two options(using JAM)

		12 GeV	30 GeV	50 GeV
beam energy		12 GeV	30 GeV	50 GeV
ϕ production CS (p+Cu)		1.0 mb	3.0 mb	5.1 mb
detector acceptance	case A	8.8%	6.0%	4.5%
	case B	45%	31%	23%
normalized yield by E325	case A	1	2.0	2.6
	case B	5.1	10.0	12.7

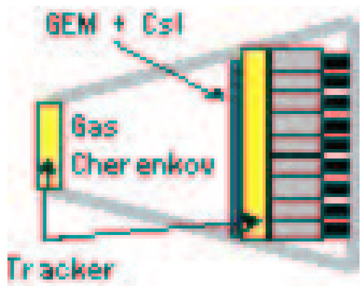
Further, for 10 times higher intensity beam (10^{10})
(i.e. high interaction rate : 10MHz)
to collect higher statistics (100 times of E325 $=10^5$ ϕ), (B) is needed

Proposed new spectrometer

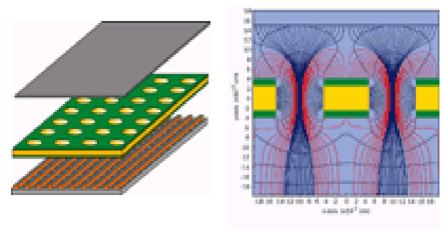
- Tracking Device
  - Drift Chamber
  - GEM(Gas electron multiplier)
    - strip readout
- Two-stage Electron ID
  - Gas Cherenkov
    - PMT+2 mirrors
    - GEM+CsI photocathode
      - pad readout
  - Leadglass EMC
- ~30K Readout Channels (in 20 units)
  - E325: 3.6K, PHENIX:~300K
- Cost : ~$5M (including $2M electronics)



Schematic view of spectrometer



GEM segment



GEM

Summary(2)

- E325- type experiment at J-PARC
  - use primary proton beam (1×10^{9} ~1×10^{10} /sec) on thin targets (~0.1% int.length) to reduce electron background
  - especially collect 10^4 ~10^5 $\phi \to e^+e^-$ in p+A reaction in 100shift(1month)
    - (10-100 times as large as E325's statistics)
  - Using old E325 spectrometer, 2-3 times larger statistics than E325 with 30~50GeV proton beam
- New spectrometer using new technology (GEM tracker/HBD)
  - better mass resolution : ~5 MeV/c^2
  - larger acceptance -> 10 times larger statistics.
  - higher rate capability -> more 10 times stat. using higher intensity beam
- Test Detector with new technology is being developed. Beam test was done in 2004 and also planned in 2005.