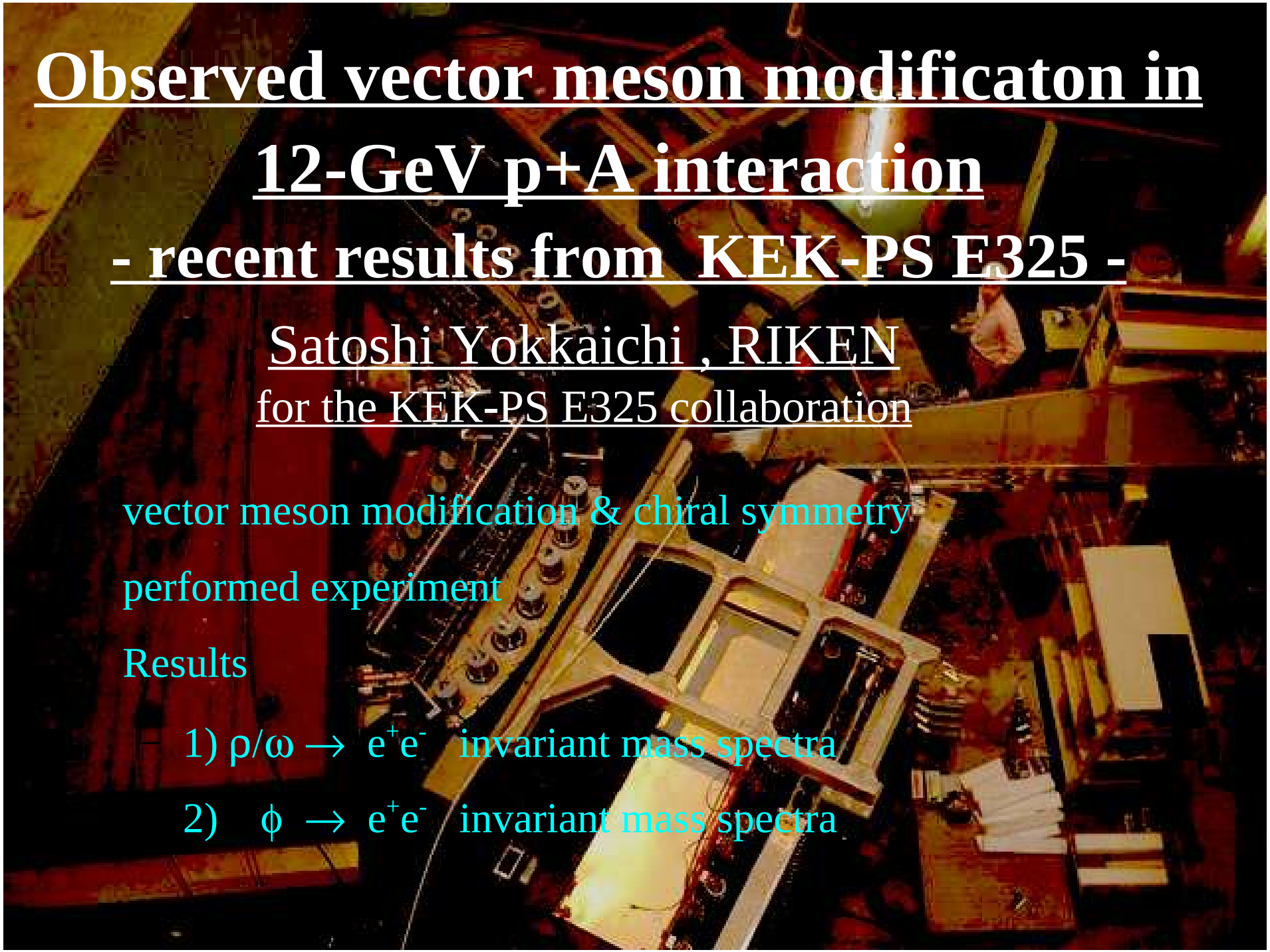
Observed vector meson modificaton in 12-GeV p+A interaction

- recent results from KEK-PS E325 -

Satoshi Yokkaichi , RIKEN
for the KEK-PS E325 collaboration



vector meson modification & chiral symmetry

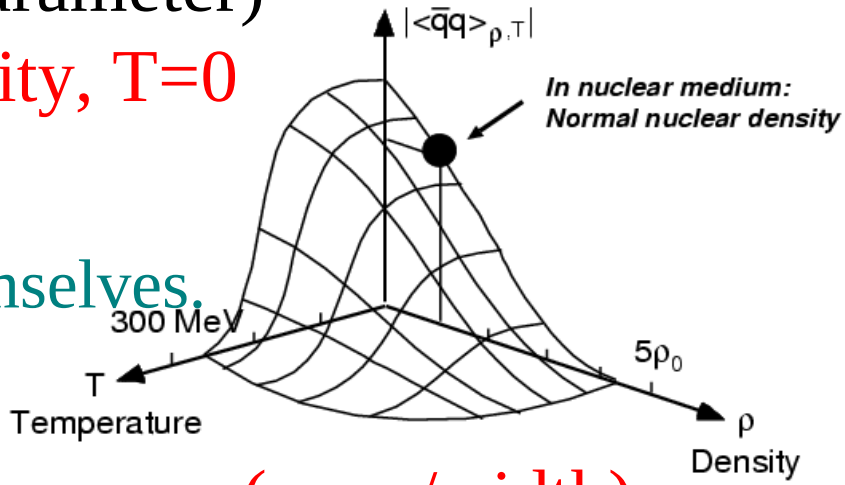
performed experiment

Results

- 1) $\rho/\omega \rightarrow e^+e^-$ invariant mass spectra
- 2) $\phi \rightarrow e^+e^-$ invariant mass spectra

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

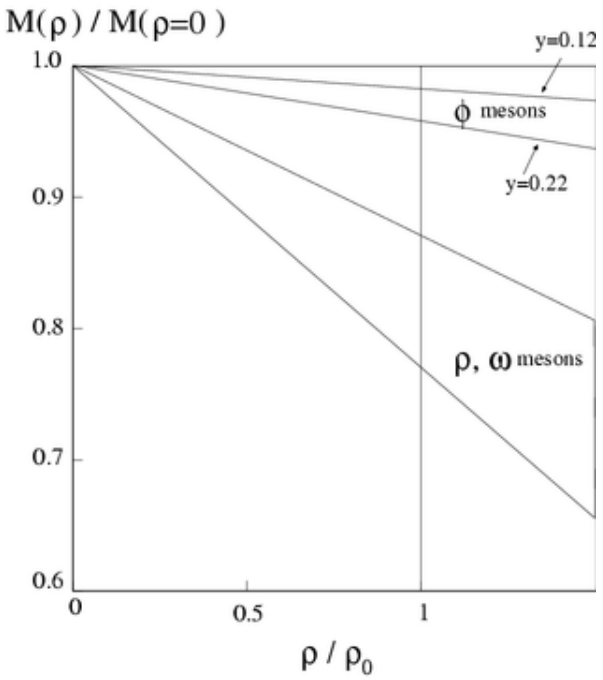
linear dependence on density

$m^*/m_0 = 1 - k\,\rho/\rho_0$

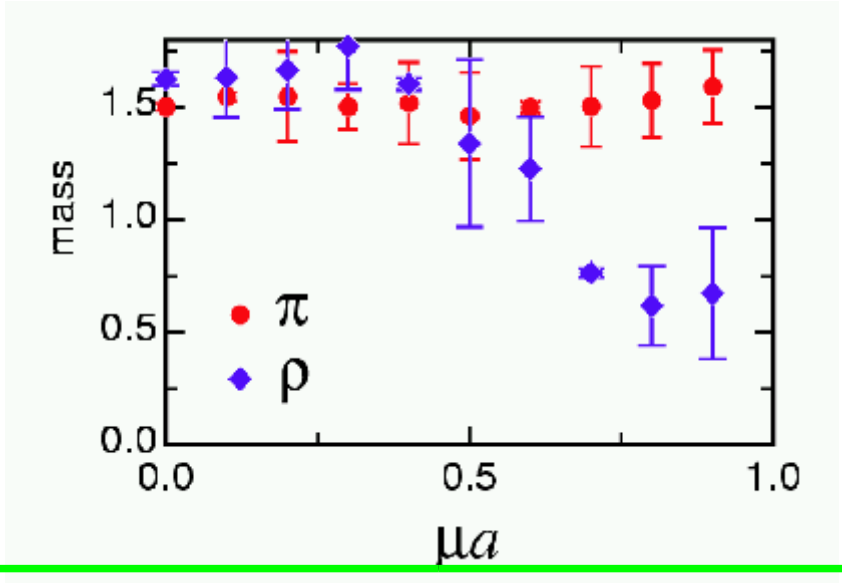
mass decreasing

- 16(±6)% for ρ/ω
- 0.15(±0.05)*y
  =2~4% for ϕ
  (for y=0.22)

at the normal nuclear density

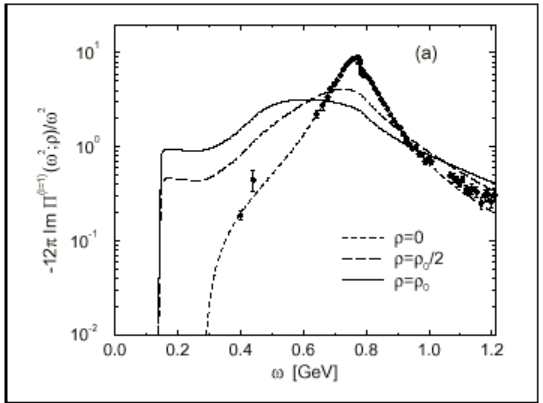


Muroya, Nakamura, Nonaka, 03

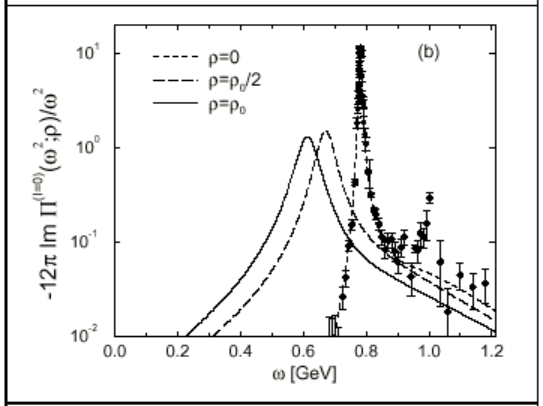


Klingle,Keiser,Weise, 97

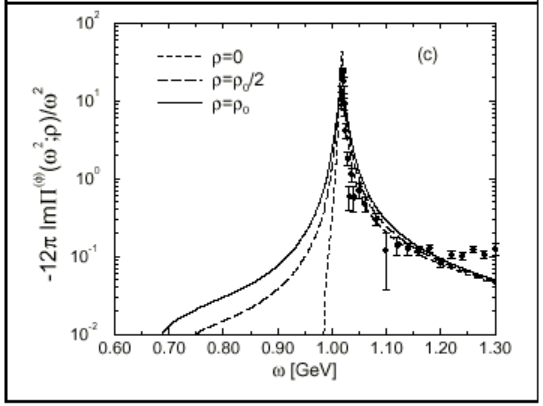
ρ



ω

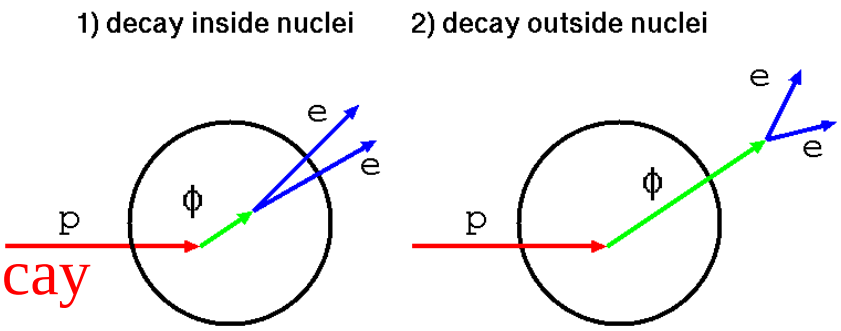


ϕ

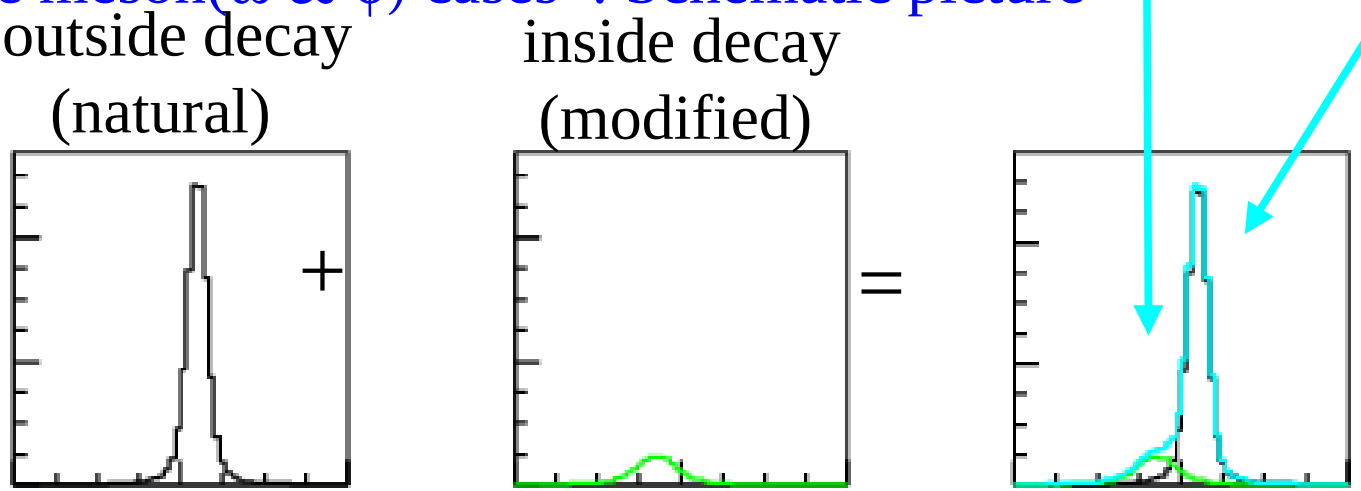


Expected Invariant mass spectra in e^+e^- channel

- 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 and meson velocity
  - enhanced for slower mesons & larger nuclei



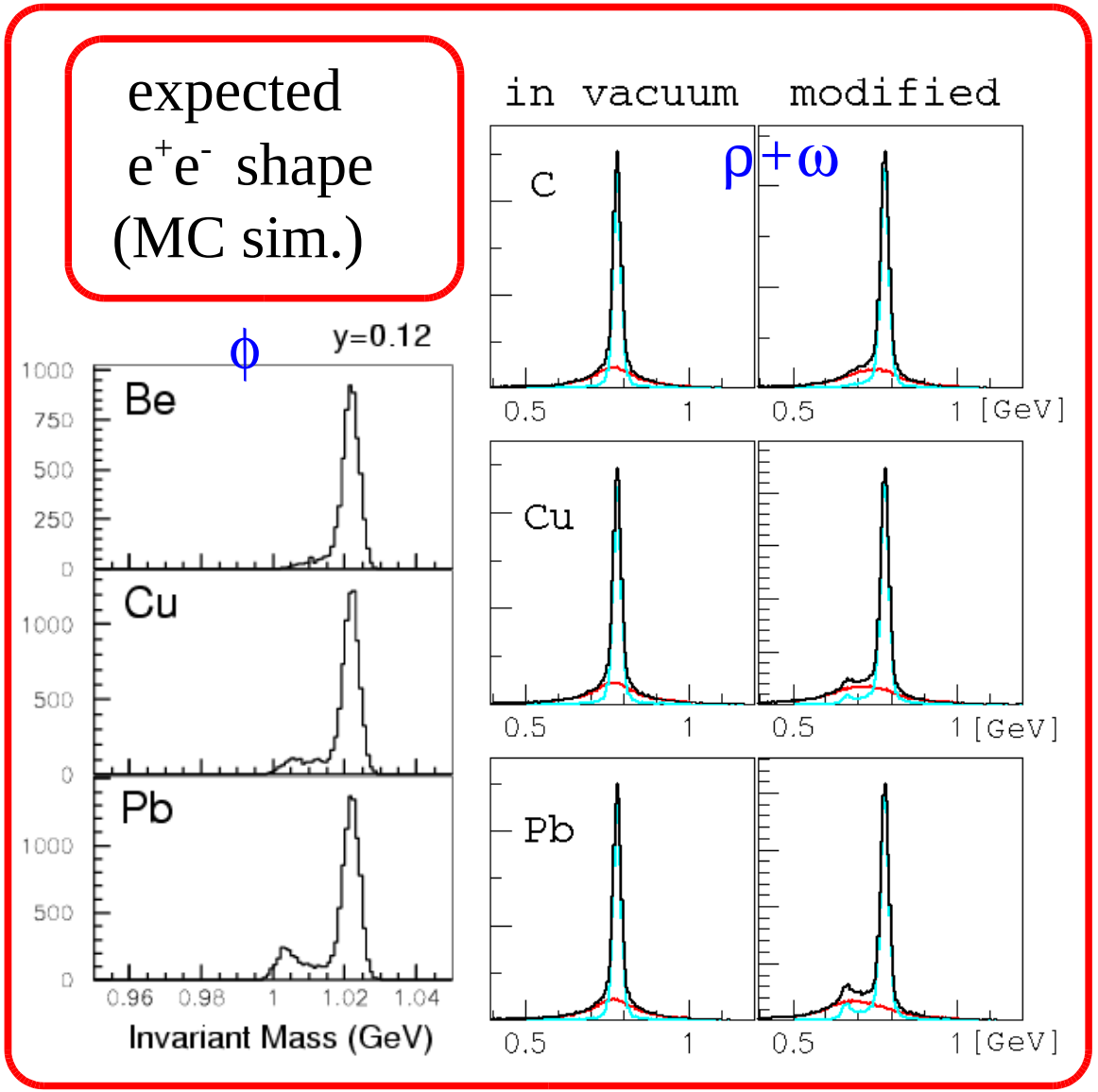
longer-life meson(ω & ϕ) cases : Schematic picture



expected to be observed

(Expected e^+e^- spectra)

- ρ (770) & ω(783) :
  - larger production cross section
  - larger decay prob. inside nuclei
    - ρ : Γ=150MeV ~ 1.3fm
    - ω : Γ=8.4MeV ~ 24 fm
  - cannot distinguish ρ & ω in e^+e^-
- φ (1020) : narrow width
  - smaller decay prob. inside nuclei
    - φ : Γ=4.3MeV ~ 46 fm
  - smaller production cross section



Experiment KEK-PS E325

- 12GeV p+A $\rightarrow \rho/\omega/\phi$ +X ($\rho/\omega/\phi \rightarrow e^+e^-$, $\phi \rightarrow K^+K^-$)
- 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 $\rightarrow$ 10^6Hz interaction)
  - Large acceptance spectrometer to detect slowly moving mesons, which have larger probability decaying inside nuclei ($1<\beta\gamma<3$)

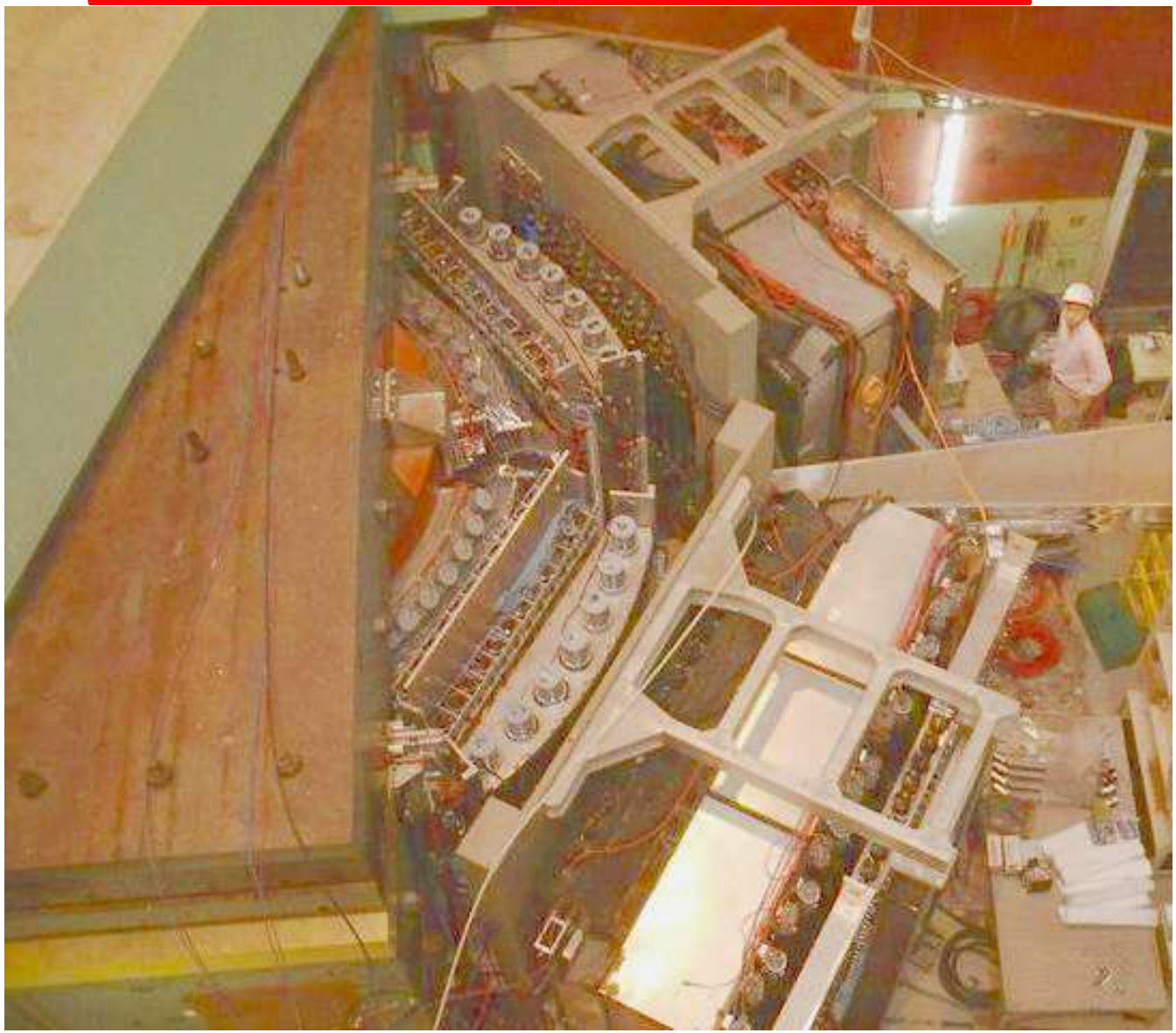
Collaboration

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, R. Muto, T. Nakura, M. Naruki, 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
  - 1993 proposed
  - 1996 const. start
  - '97 data taking start
  - '98 first ee data
    - PRL86(01)5019
  - 99,00,01,02....
    - x100 statistics
      - nucl-ex/0504016
      - presented today
  - '02 completed
  - spectrometer paper
    - NIM A516(04)390

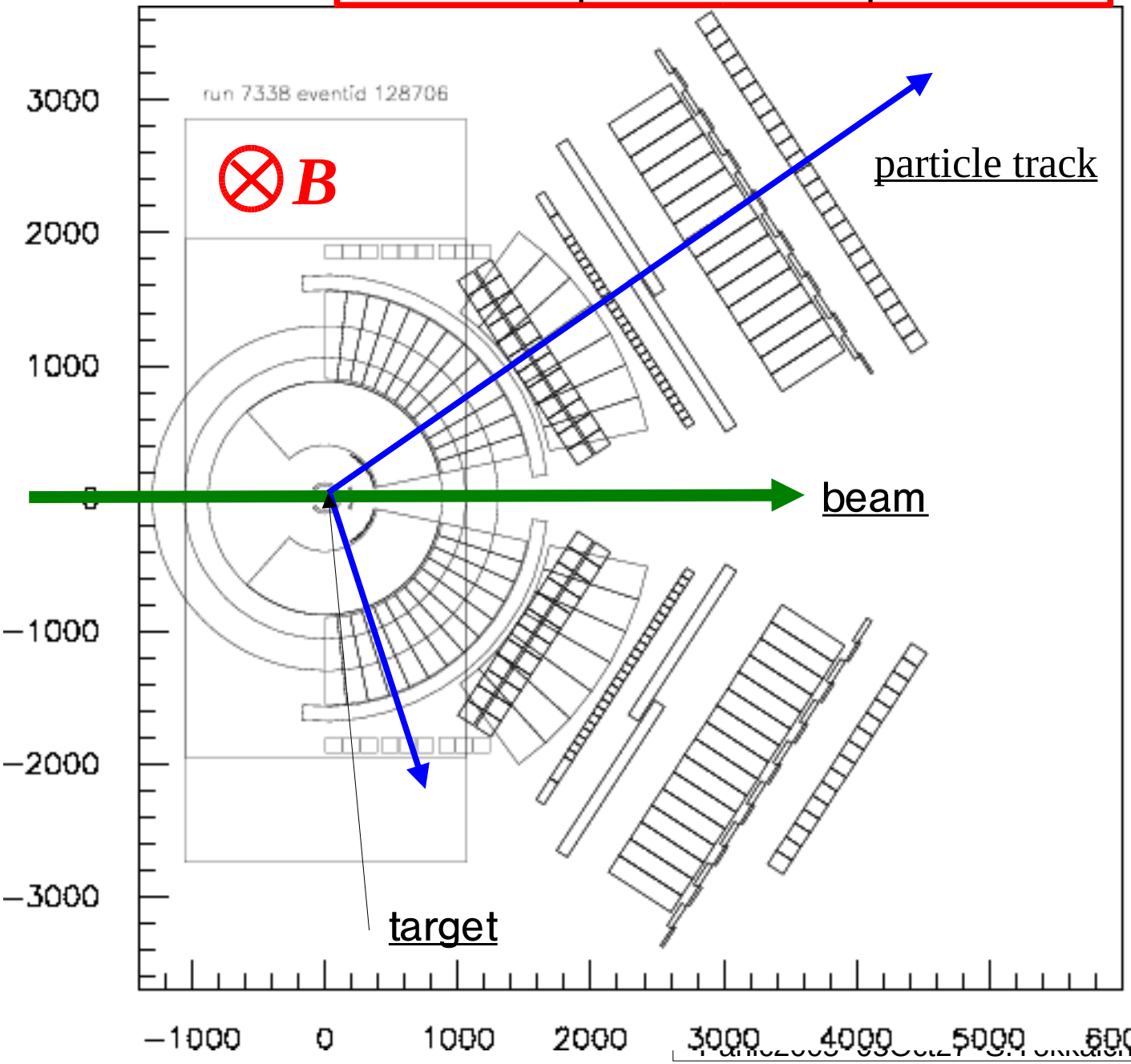
E325 spectrometer
located at KEK-PS EP1-B primary beam line



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

schematic plan view of spectrometer



Experimental setup - Detectors

Electron ID counters

Gas Cherenkov &
Lead Glass EMC

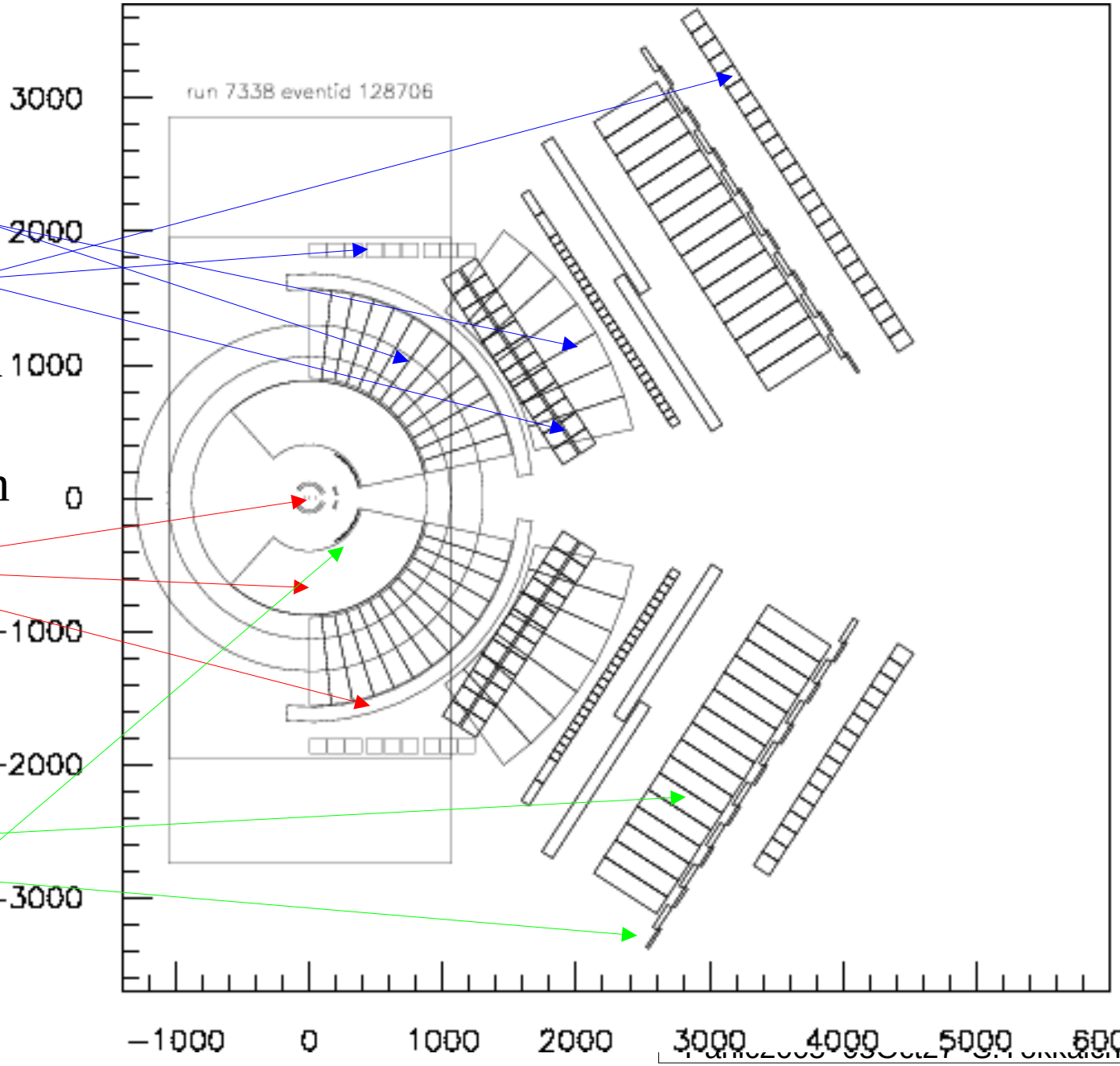
total 3×10^{-4} π rejection
with 78% e efficiency
in two-stage operation

Tracker

Three Drift Chambers

Kaon ID counters

Aerogel Cherenkov
& TOF



Result (1)

ee invariant mass spectra

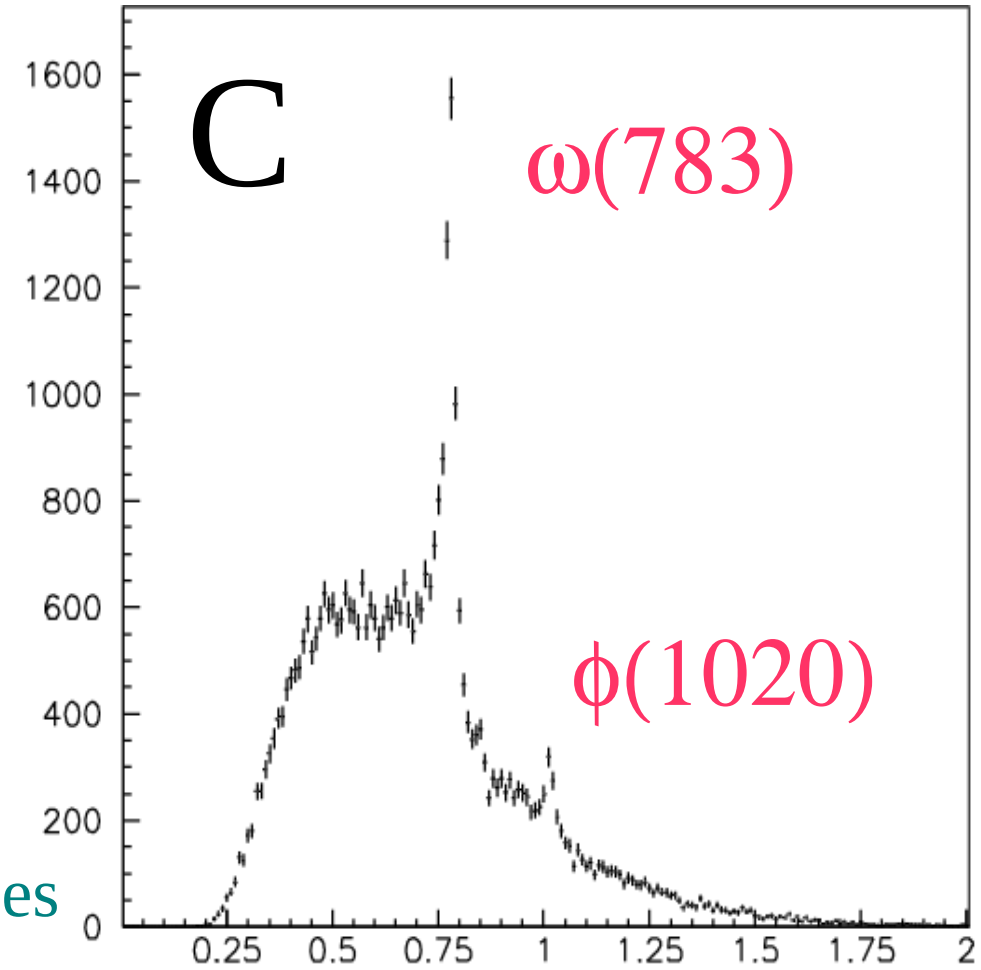
M. Naruki et al.,

nucl-ex/050416

Observed e^+e^- invariant mass spectra

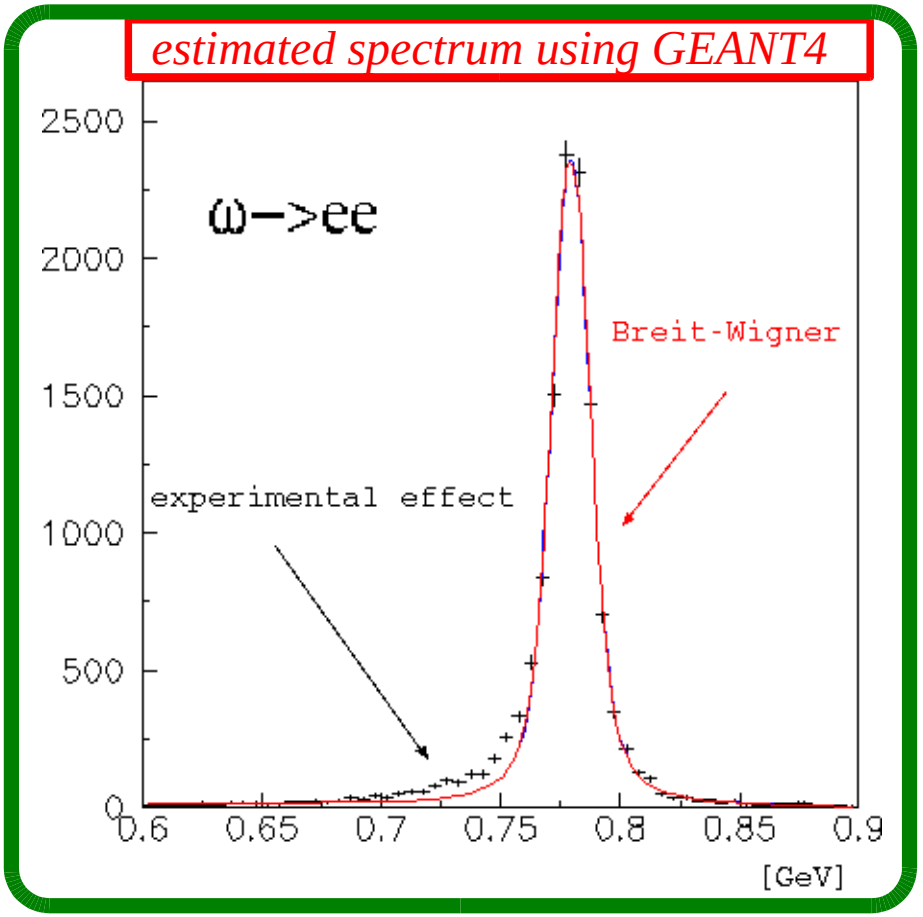
- from 2002 run data (~70% of total data)
- C & Cu target
- clear resonance peaks
- m<0.2 GeV is suppressed by detector acceptance
- acceptance uncorrected

→ fit the spectra with known sources

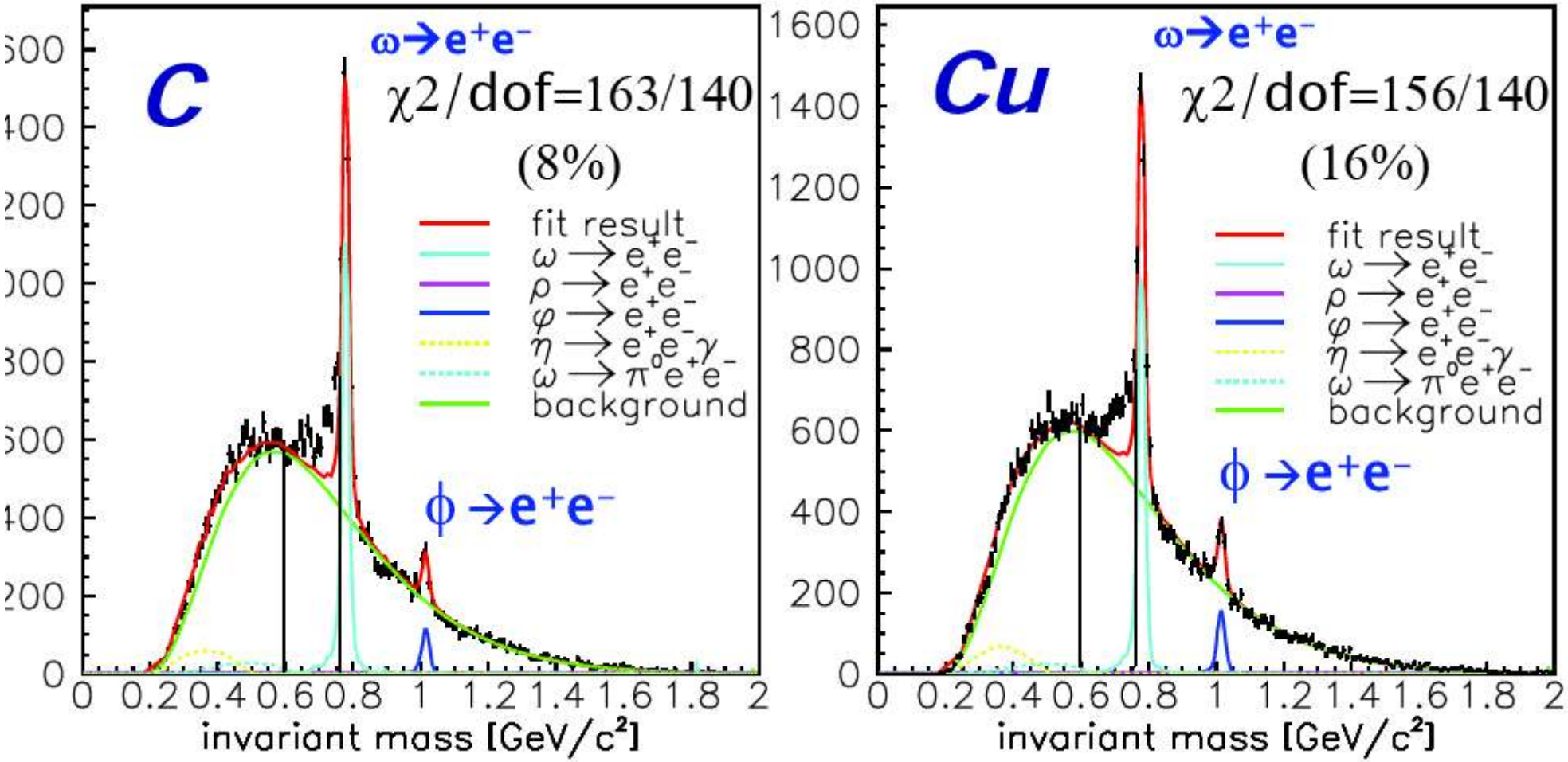


Fitting with known sources

- Hadronic sources of e^+e^-:
  - $\rho/\omega/\phi \rightarrow e^+e^-$, $\omega \rightarrow \pi^0 e^+e^-$, $\eta \rightarrow \gamma e^+e^-$
  - relativistic Breit-Wigner shape (without any modifications)
  - 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



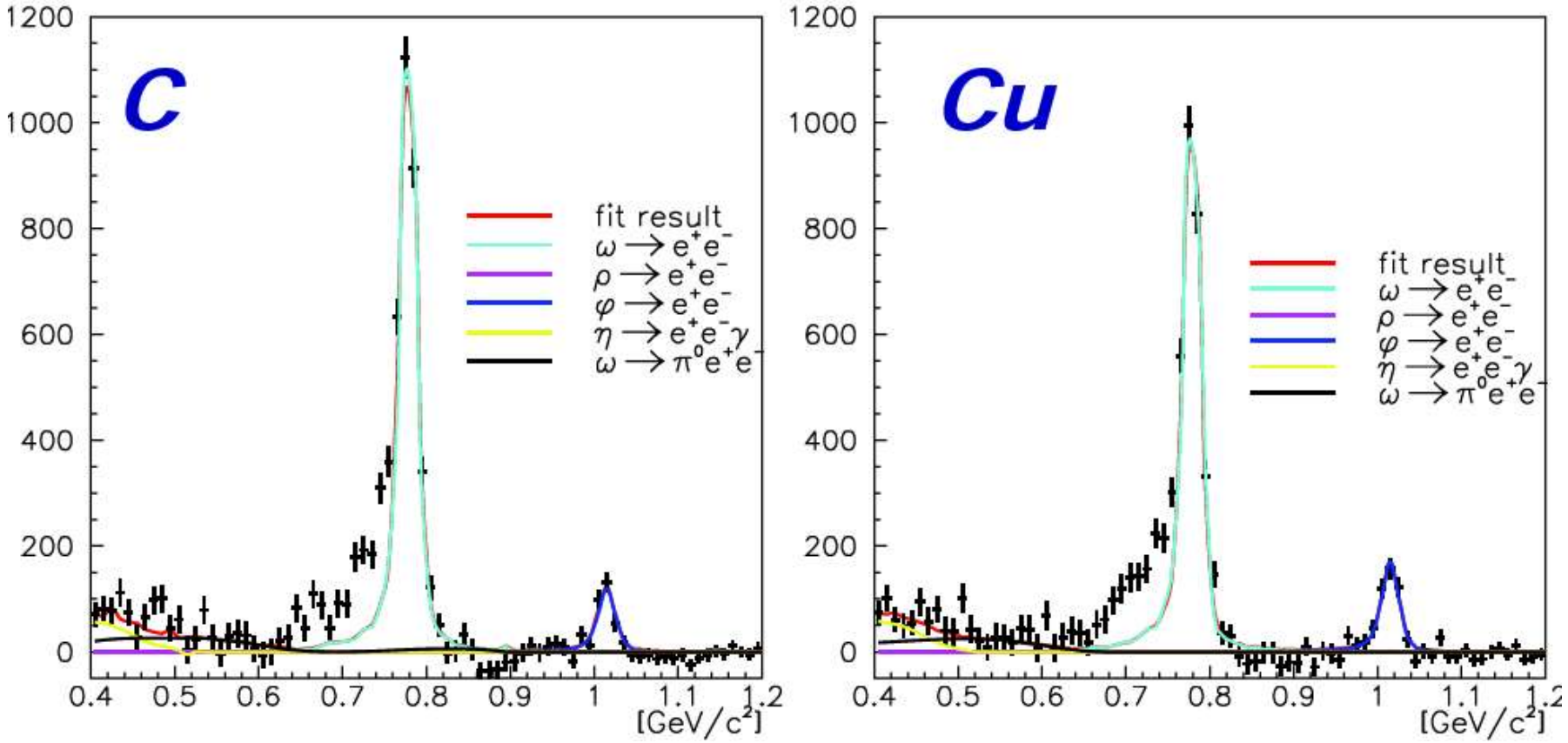
Fitting results



- 1) excess at the low-mass side of ω
  - To reploduce the data by the fitting, we have to exclude the excess region : 0.60~0.76 GeV
- 2) ρ–meson component seems to be vanished !

Fitting results (BKG subtracted)

ρ/ω=0.0±0.03(stat.)±0.11(sys.) , 0.0±0.04(stat.)±0.17(sys.)

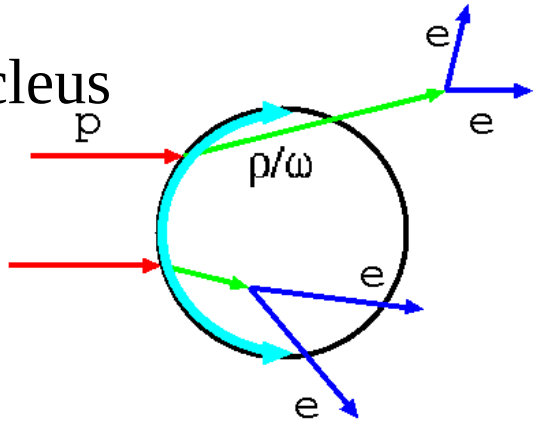


- However, ρ/ω =1.0±0.2 in former experiment (p+p, 1974)
  ...suggests that the origin of excess is modified ρ mesons.

Toy model M.C. including modification

- Assumptions to include the nuclear size effect in the fitting shape
  - mesons fly through the nucleus, decay with modified mass if the decay point is inside nucleus
    - meson production point : incident surface of nucleus
      - 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 form : $m^*/m_0 = 1 - k\,\rho/\rho_0$

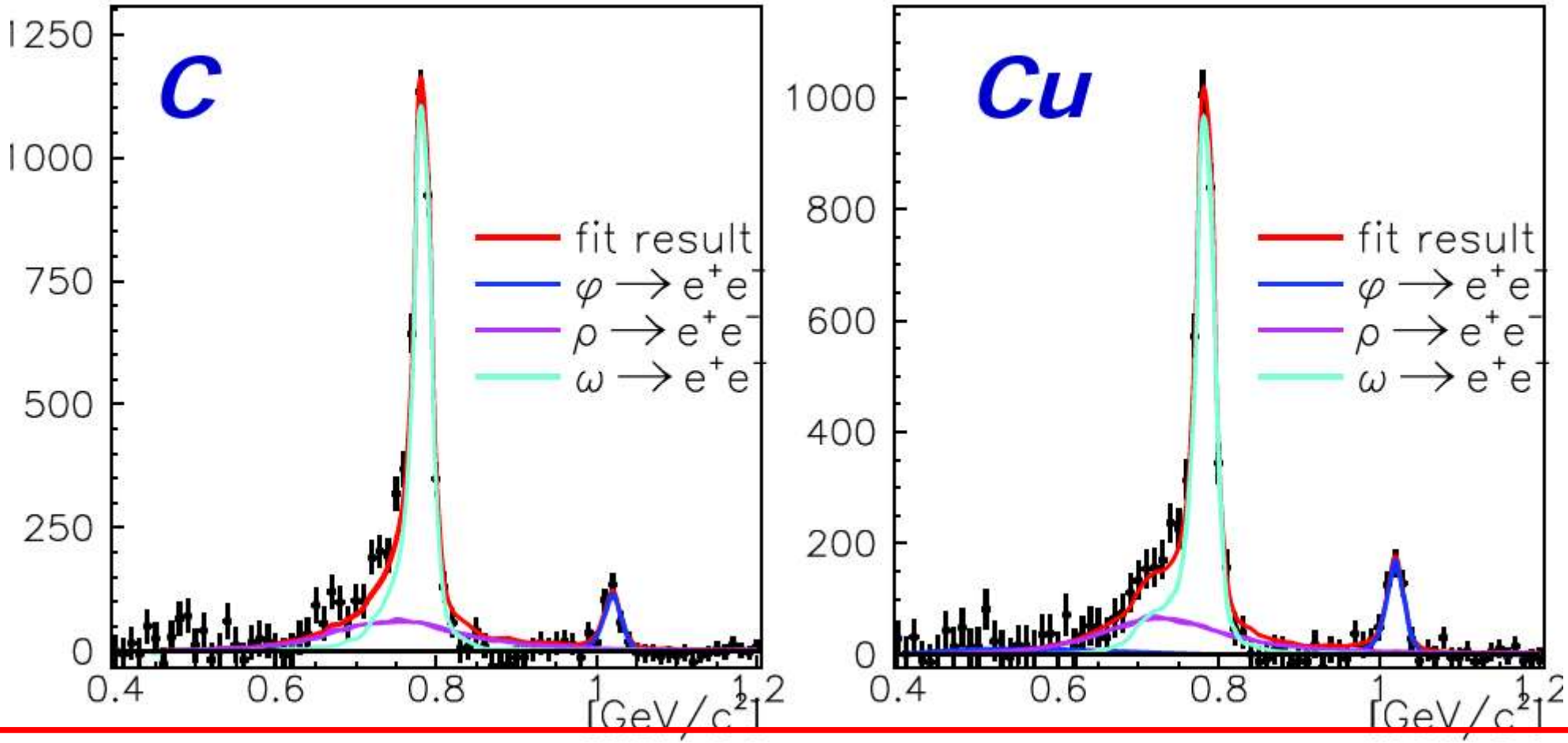
      (k=0.16±0.06 in Hatsuda & Lee, '92,'96)
    - (width modification & momentum dependence of modification are not taken into account this time)



Fitting results by the toy model

Free param.: - scales of background and hadron components for each C & Cu

- modification paramter k for ρ/ω is common for C & Cu

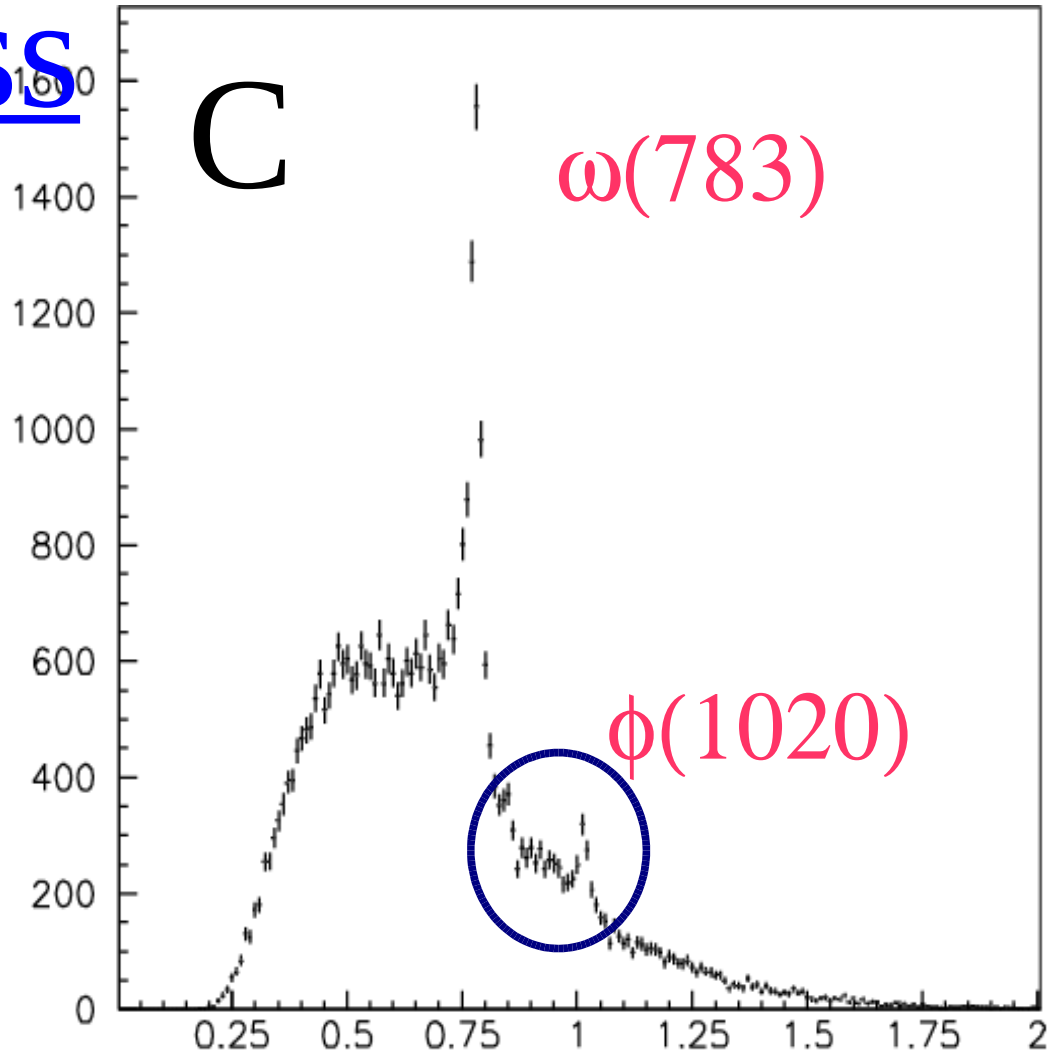


From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density

ρ/ω ratio : 0.7± 0.1 (C), 0.9±0.2 (Cu) : ... ρ meson returns.

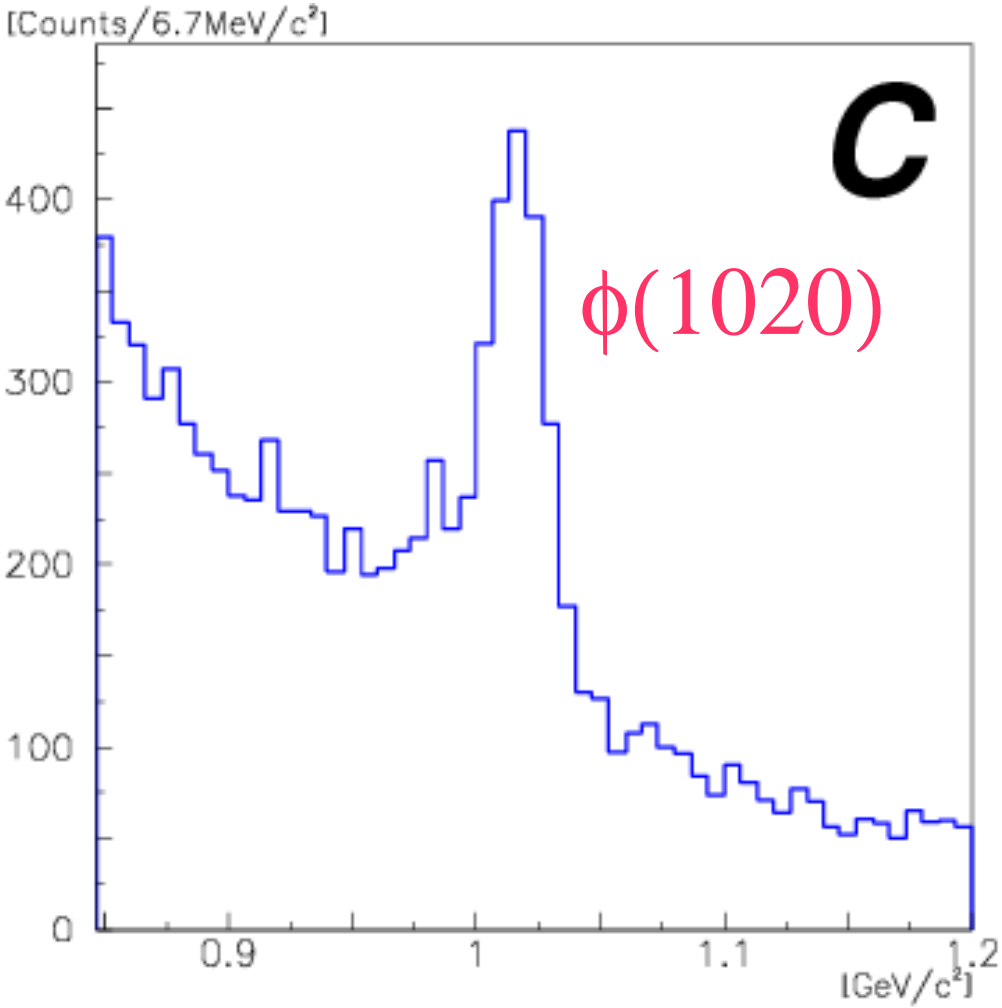
Result (2)

ee invariant mass spectra of ϕ



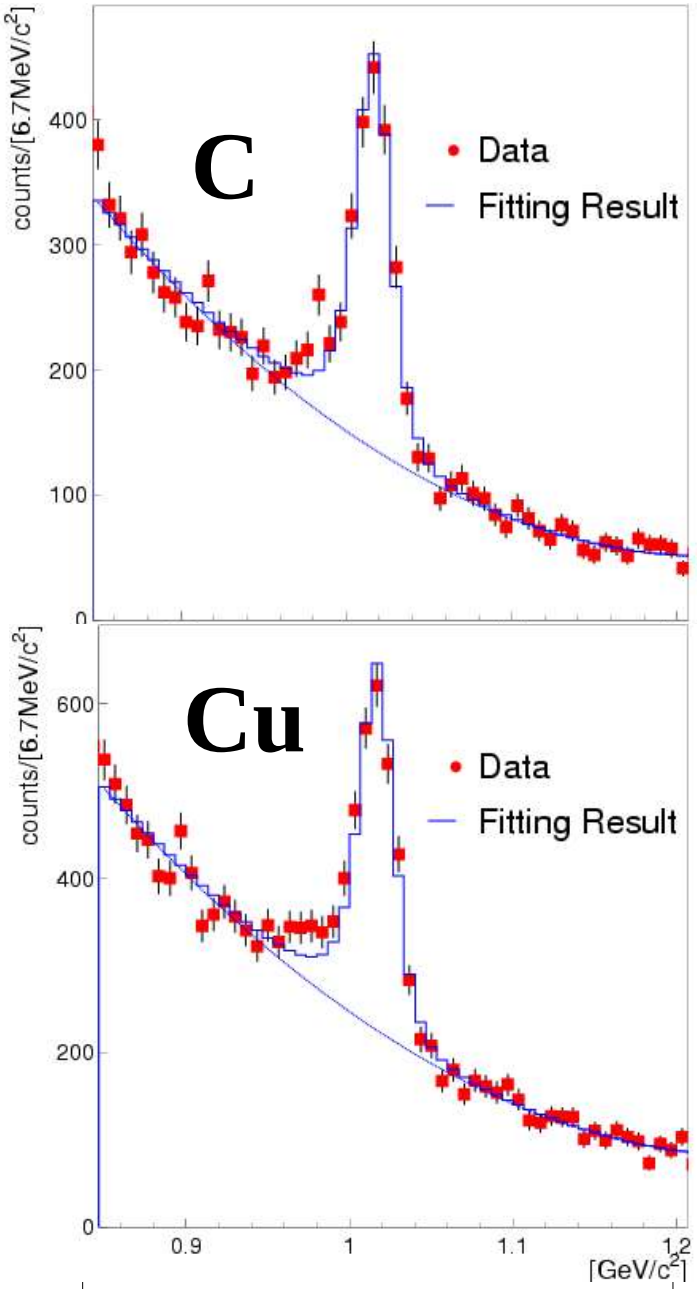
$\phi \rightarrow e^+e^-$ invariant mass spectra

- from 2001/02 run data
- C & Cu target
- acceptance uncorrected
- mass resolution :10.7MeV
- fit with
  - simulated mass shape of ϕ
    - (evaluated as same as ρ&ω)
  - polinomial curve background



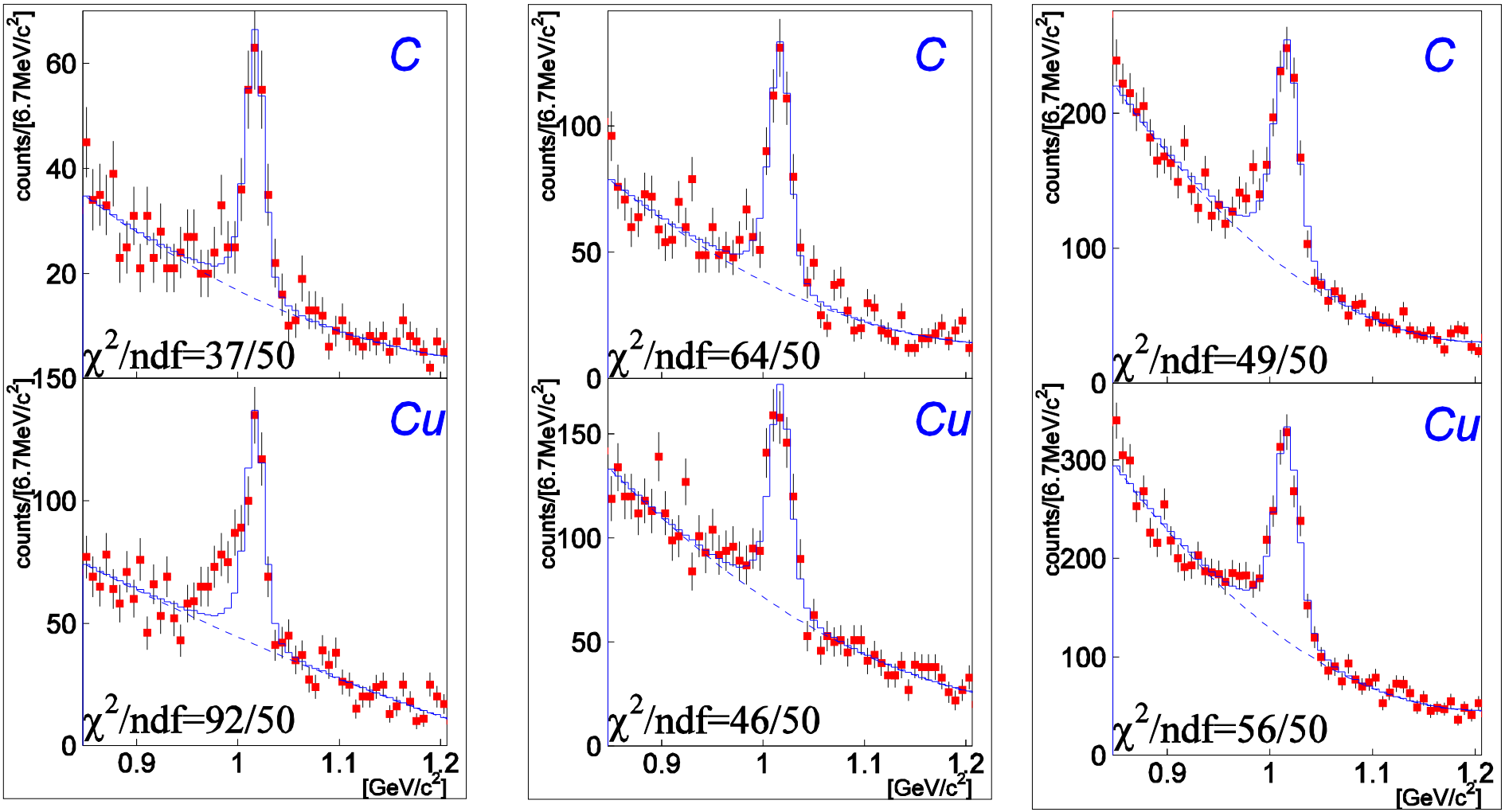
$\phi \rightarrow e^+e^-$ invariant mass spectra

- from 2001/02 run data
- C & Cu target
- acceptance uncorrected
- mass resolution :10.7MeV
- fit with
  - simulated mass shape of ϕ
    - (evaluated as same as ρ&ω)
  - polinomial curve background
- examine the 'excess' is significant or not.
  - $\rightarrow$ see the $\beta\gamma$ dependence : excess could be enhanced for slowly moving mesons



e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

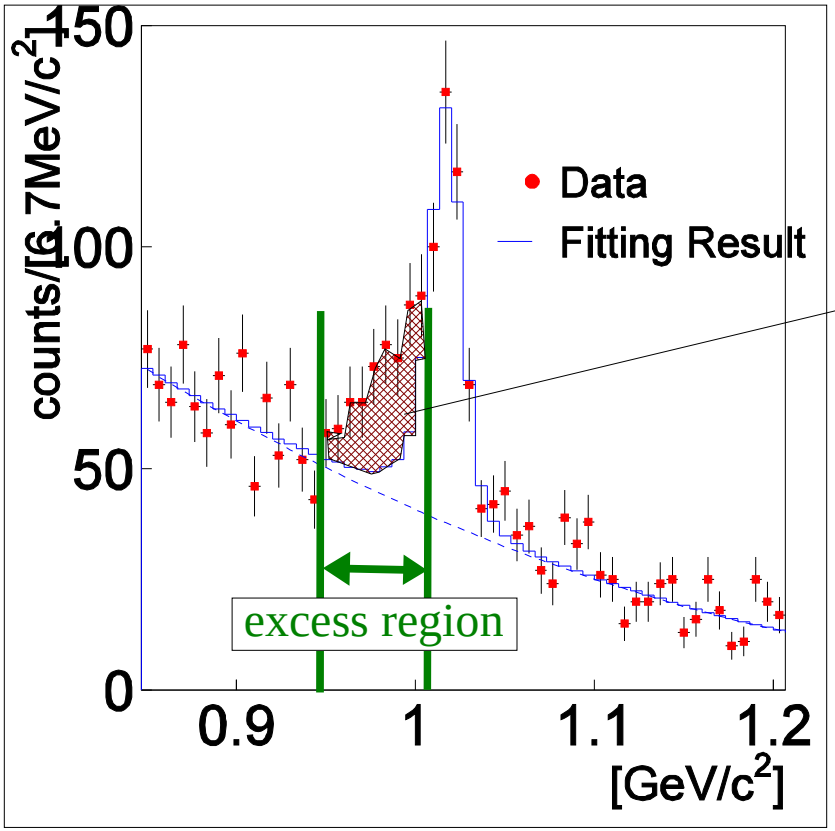
$\beta\gamma$<1.25 (Slow)	1.25<$\beta\gamma$<1.75	1.75<$\beta\gamma$ (Fast)

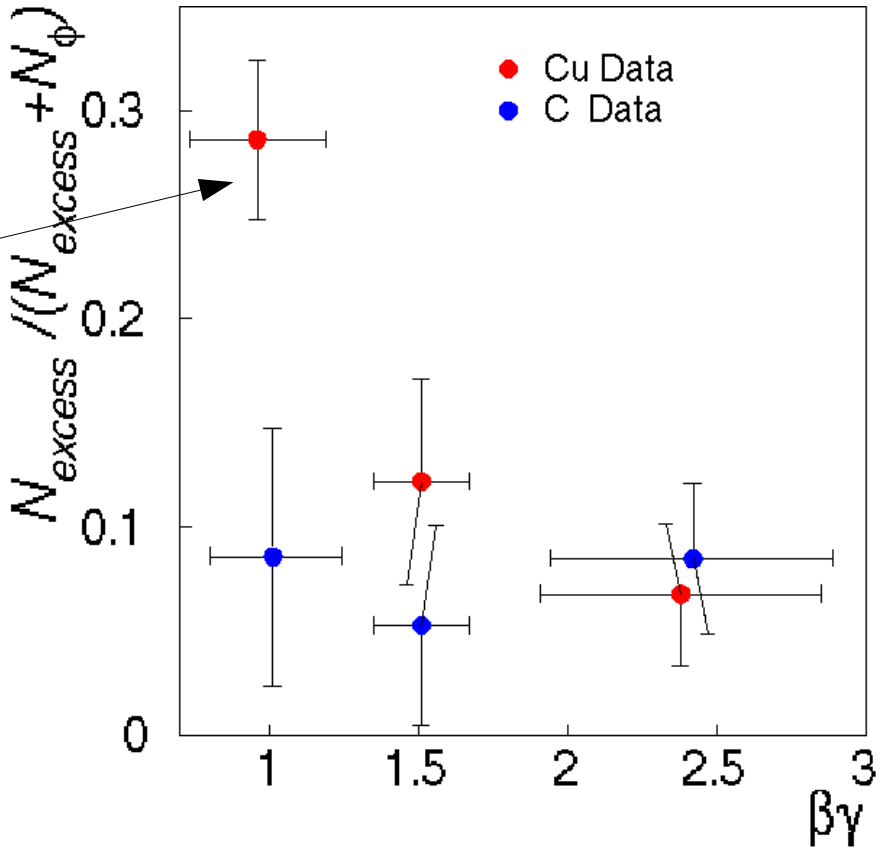


- Only slow/Cu is not reproduced in 99% CL.

Amount of excess

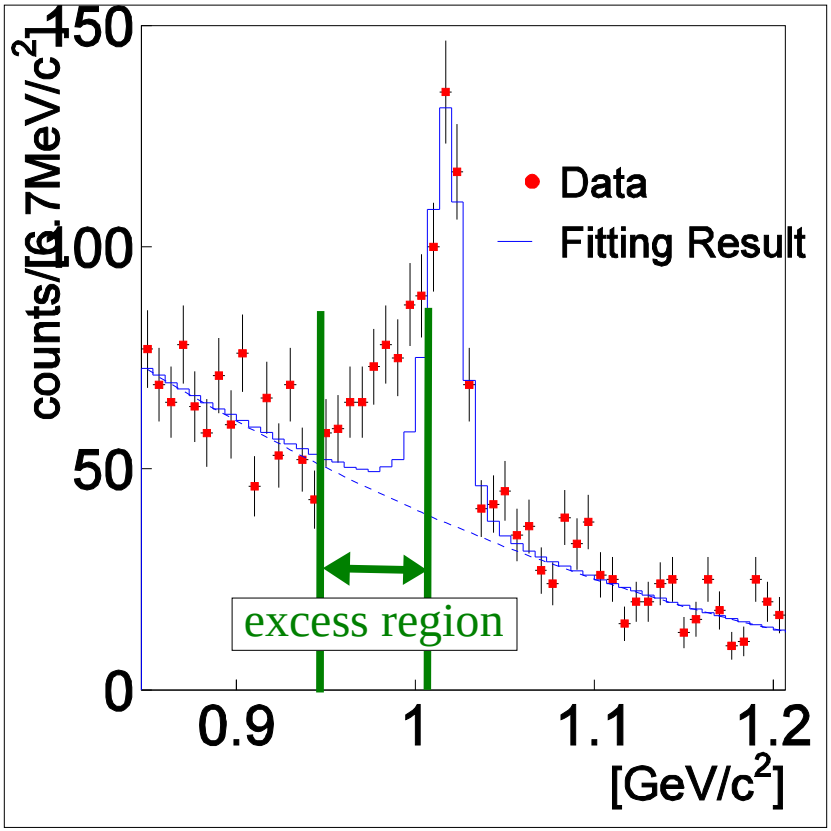
- To evaluate the amount of excess (N_{excess}), fit again excluding the excess region (0.95~1.01GeV) and integrate the excess area.

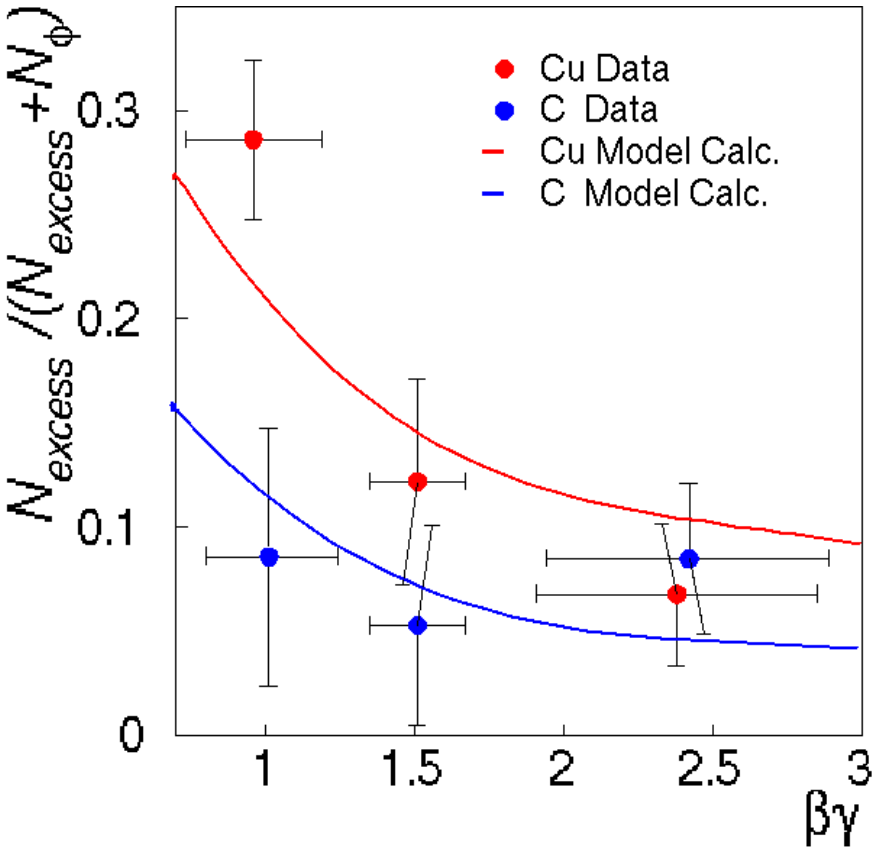




Amount of excess

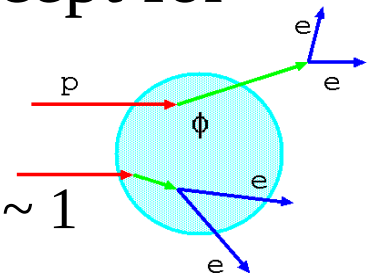
- To evaluate the amount of excess (N_{excess}), fit again excluding the excess region (0.95~1.01GeV) and integrate the excess area.
- Model calculation reproduces the tendency of $N_{excess} / (N_{excess} + N_{\phi})$





Toy model again for ϕ meson

- Toy model like ρ/ω case, except for
  - uniformly made in nuclei
    - measured α of ϕ production ~ 1



  - $m^*/m_0 = 1- k_1 \rho/\rho_0$

    (k_1=0.04, Hatsuda & Lee, '92,'96)

  - To reproduce such amount of excess, linear-dependent width broadning is adopted :

    $\Gamma_{tot}^*/\Gamma_{tot\ 0} = 1+ k_2 \rho/\rho_0$

    (k_2=10, it means Γ_{tot}^*=~47MeV at ρ_0)

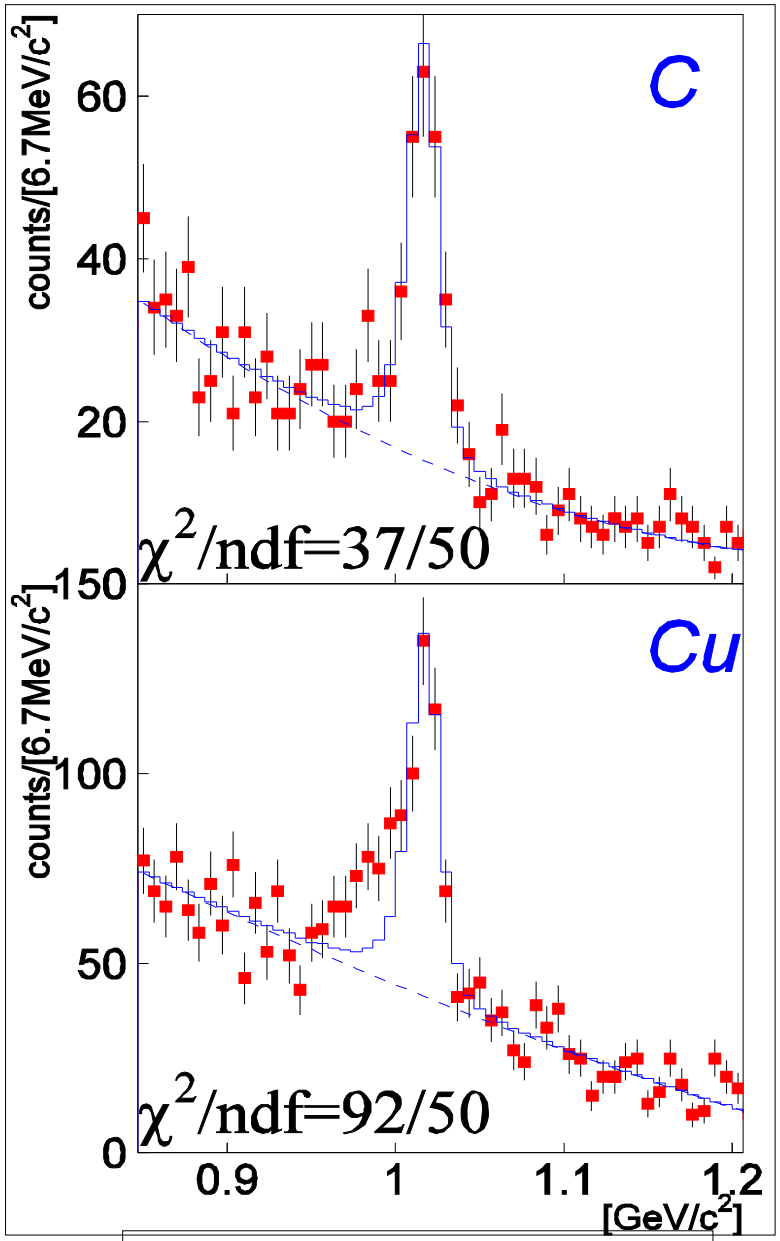
    (predicted value by Klingl *et al.*, '98)

    - e^+e^- branching ratio is not changed

      $\Gamma_{e+e-}^*/\Gamma_{tot}^* = \Gamma_{e+e-\ 0}/\Gamma_{tot\ 0}$

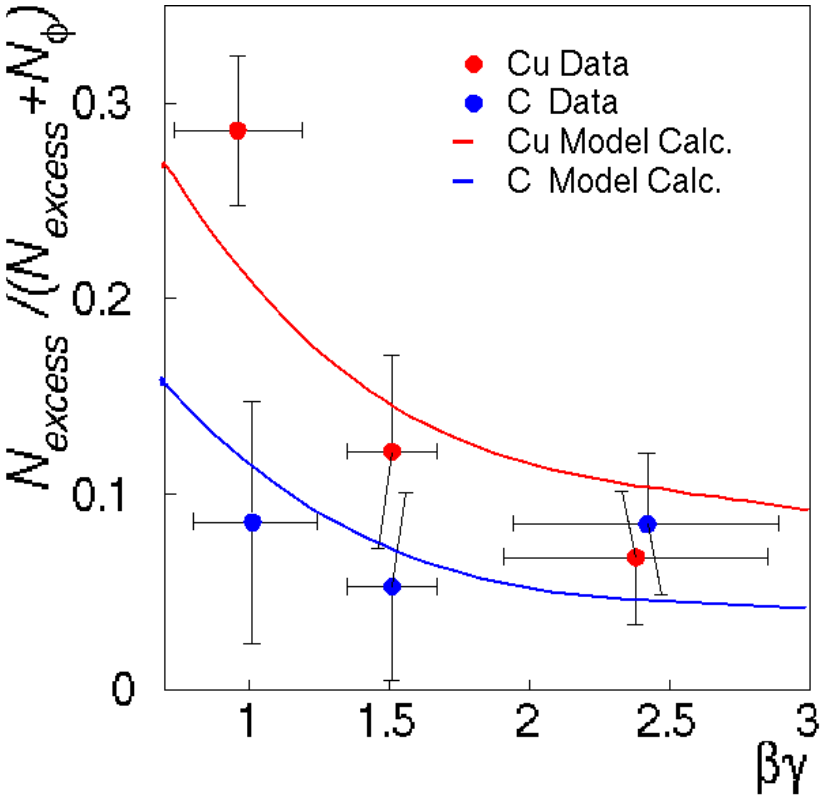
  - k_1 & k_2 is not free param., but fixed.

βγ<1.25 (Slow), w/ unmodified

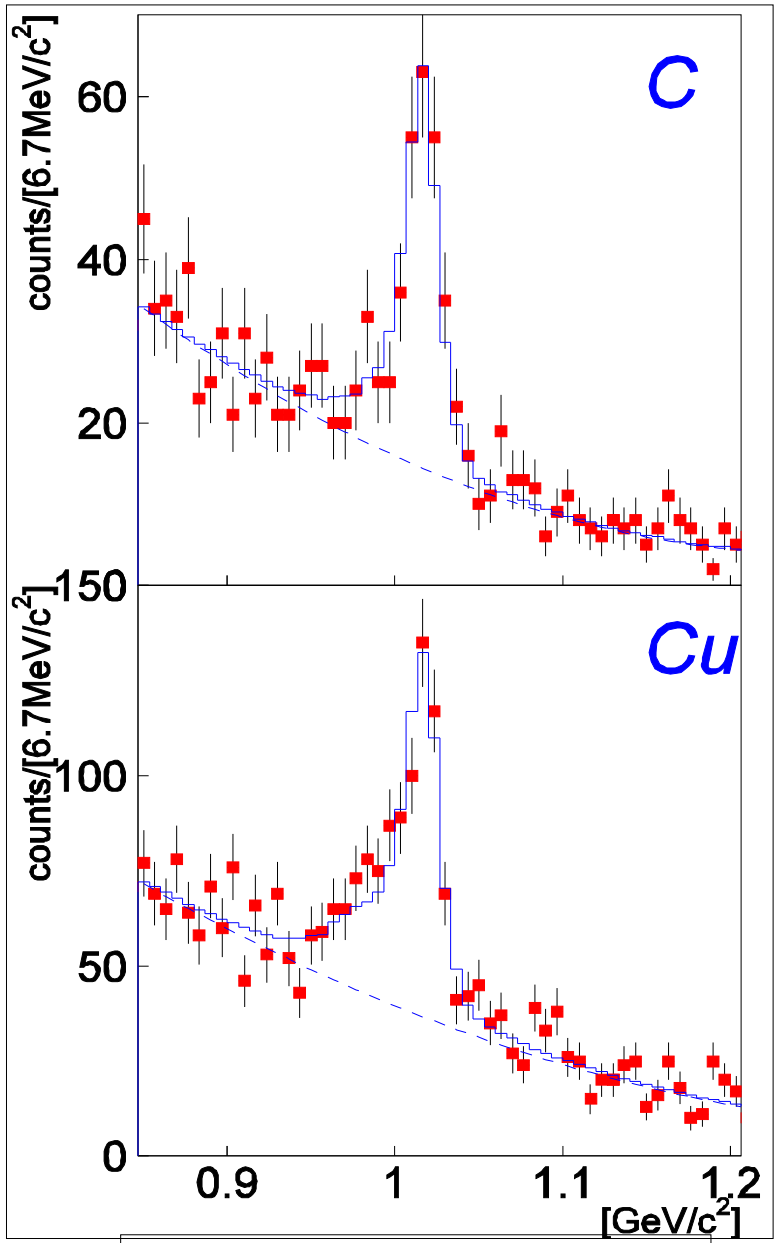


Toy model result for φ meson

- modified (model) shapes well reproduce the data, even slow/Cu
- modified shapes are analyzed with unmodified shape to evaluate the $N_{excess} / (N_{excess} + N_{\phi})$



βγ<1.25 (Slow), w/ modified



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 of ρ & ω reproduces the observed spectra.
- $\phi \rightarrow e^+e^-$ also have excess, for the larger target, slowly moving φ
  - model calc. including mass shift and width broadning in nuclei also reproduces the data.
- (Analysis of nuclear dependence of $\phi \rightarrow K^+K^-$ & $\phi \rightarrow e^+e^-$ is also on going to investigate $\Gamma_{K+K-}/\Gamma_{e+e-}$ changing in nuclei.)

Backup slides...

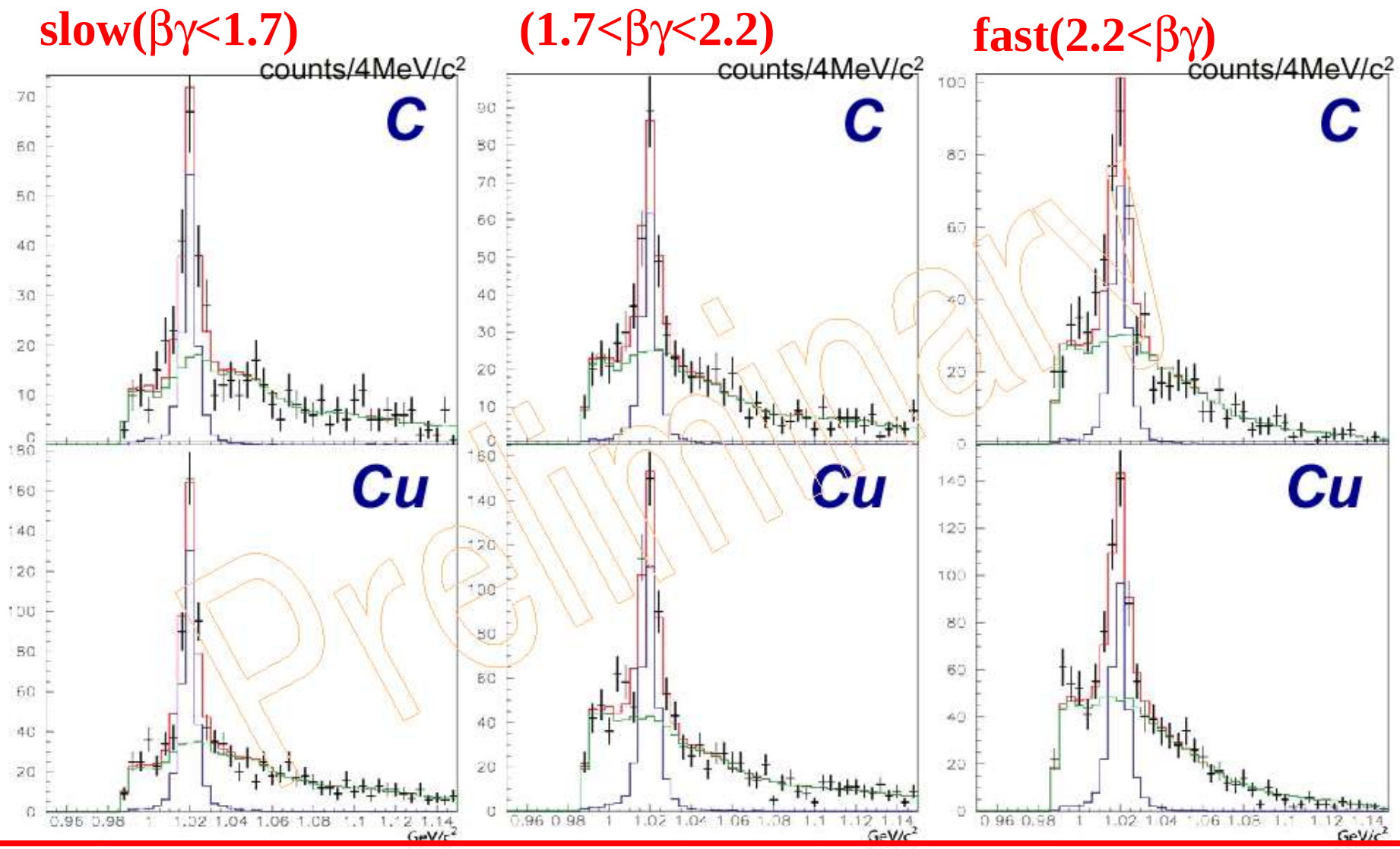
Number of 'excess' in e^+e^- spectra

	C	Cu
– ρ/ω for all sample		
• N(ω)	3594± 91	3224 ± 88
• N(excess)	1502 ±147	1412±149
• N(excess)/N(ω)	(42±4)%	(44 ± 5)%
– ϕ for slow component (βγ<1.25)		
• N(ϕ)	221± 21	392 ± 32
• N(excess)	21 ±16	158±26
• N(excess)/[N(ϕ) +N(excess)]	(9±6)%	(29 ± 4)%

Data (3)

(KK invariant mass spectra & nuclear dependence α)

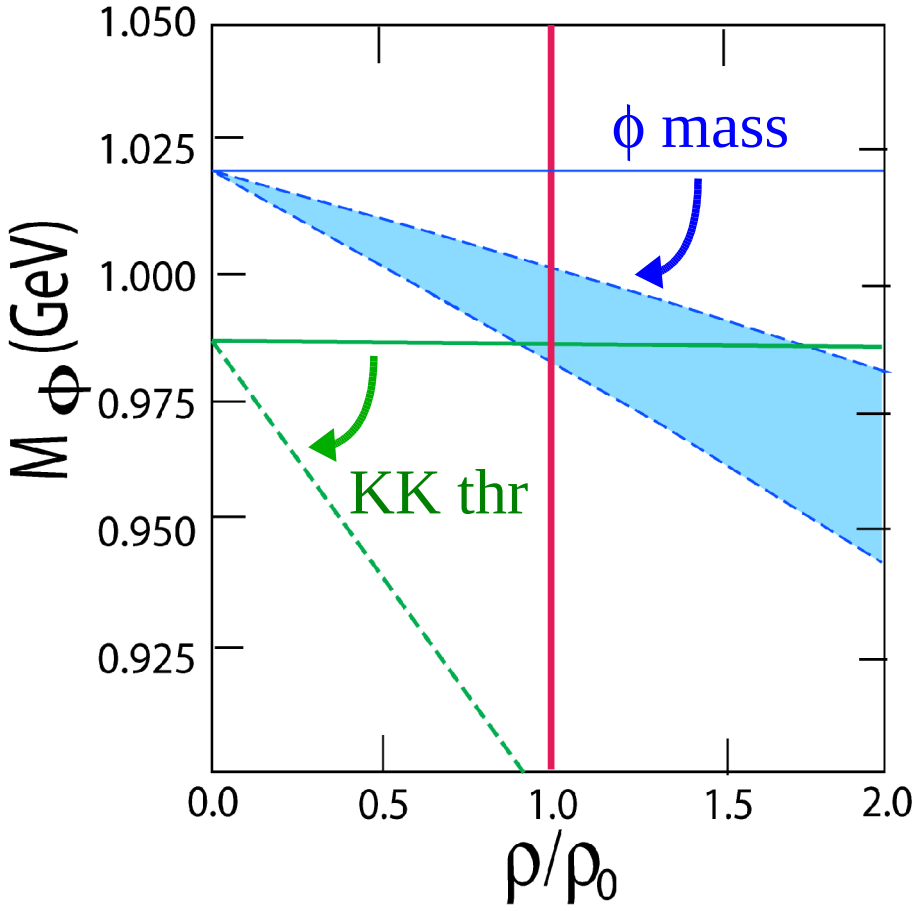
K^+K^- spectra of ϕ meson



- mass modification is NOT statistically significant (very low statistics in $\beta\gamma < 1.25$ where modification is observed in $\phi \rightarrow e^+e^-$)

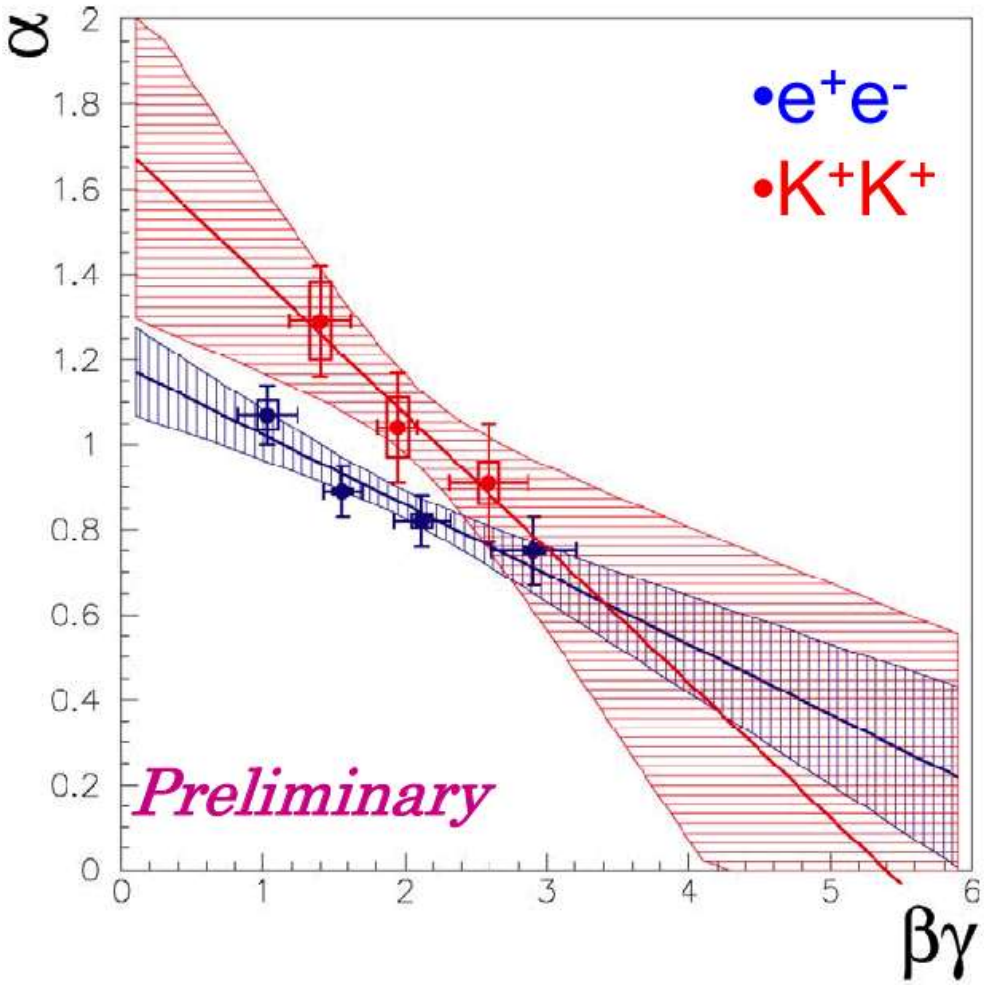
mass modification and ϕ branching ratio

- small decay Q value (= 32MeV) for $\phi \rightarrow K^+K^-$
  - branching ratio is sensitive to ϕ and K mass modification
    - when ϕ mass decrease : Γ_{K+K-} decrease
    - when K mass decrease : Γ_{K+K-} increase
- change of the ratio : Γ_{K+K-} / Γ_{e+e-} can be studied by mesurement of α parameter : the nuclear dependence of production cross section
  - measure both $\phi \rightarrow K^+K^-$ & $\phi \rightarrow e^+e^-$ simultaneously
  - => NEXT



nuclear dependence α of the production CS of φ in K^+K^- & e^+e^- channel

- nuclear dependence α:
  - $\sigma(A) = A^{\alpha} \times \sigma(1)$
- α and Γ : for example
  - $\Gamma_{K+K-}/\Gamma_{e+e-}$ increases in nuclei, N_{K+K-}/N_{e+e-} becomes larger
  - larger modification expected in larger nuclei
  - then, $\alpha_{K+K-} > \alpha_{e+e-}$, especially for slowly moving mesons

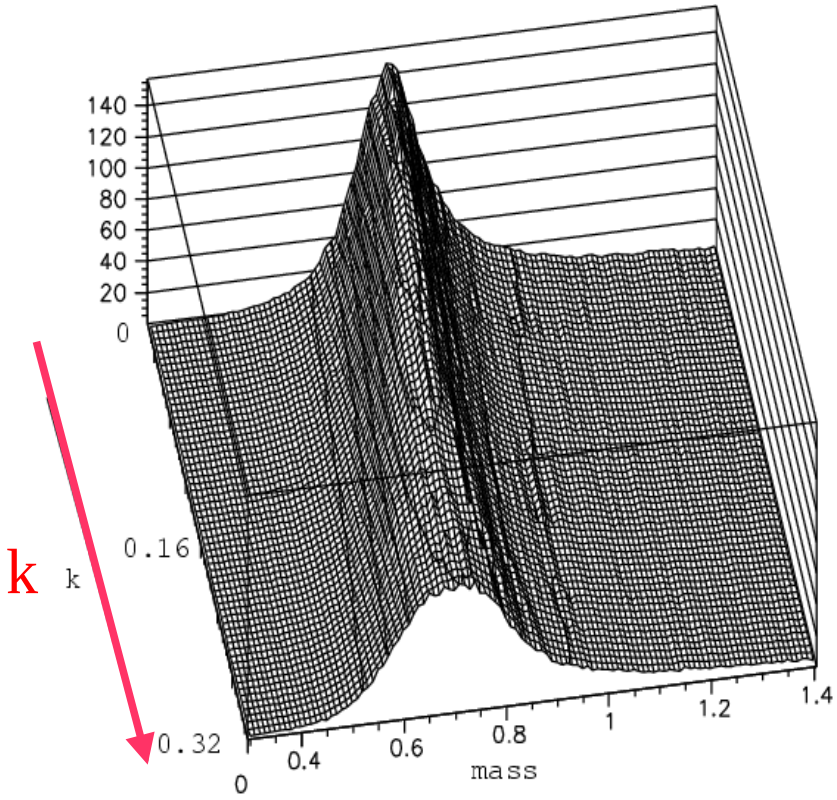


- In our data, α_{K+K-} looks like larger than α_{e+e-} , in lower βγ.

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
- ρ/ω ratio is free and not common between C and Cu

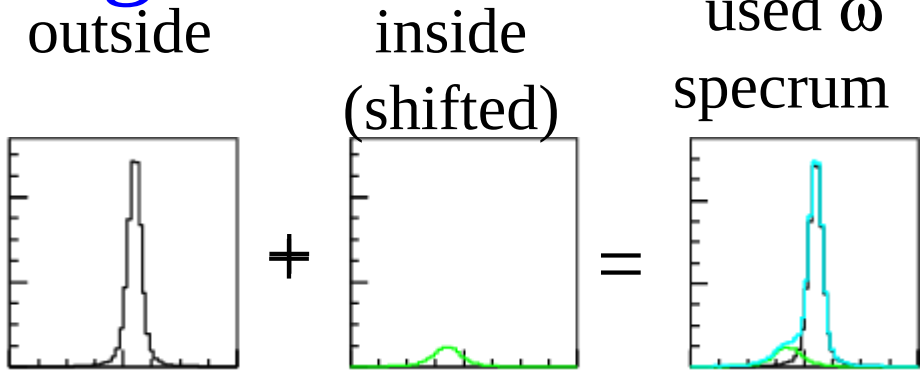
parametrization of ρ spectrum

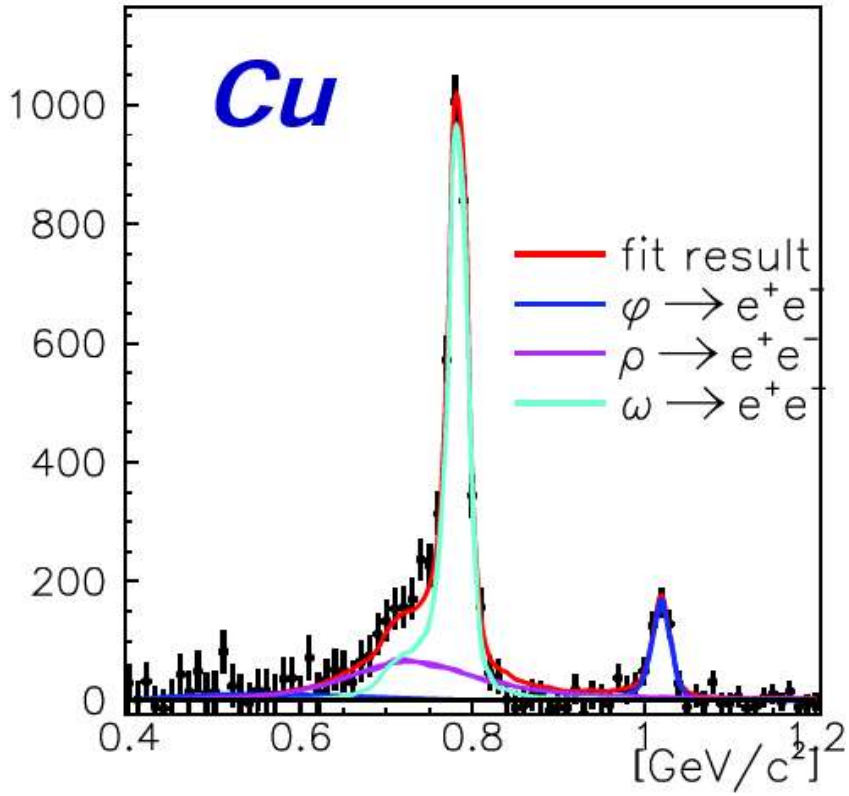


mass

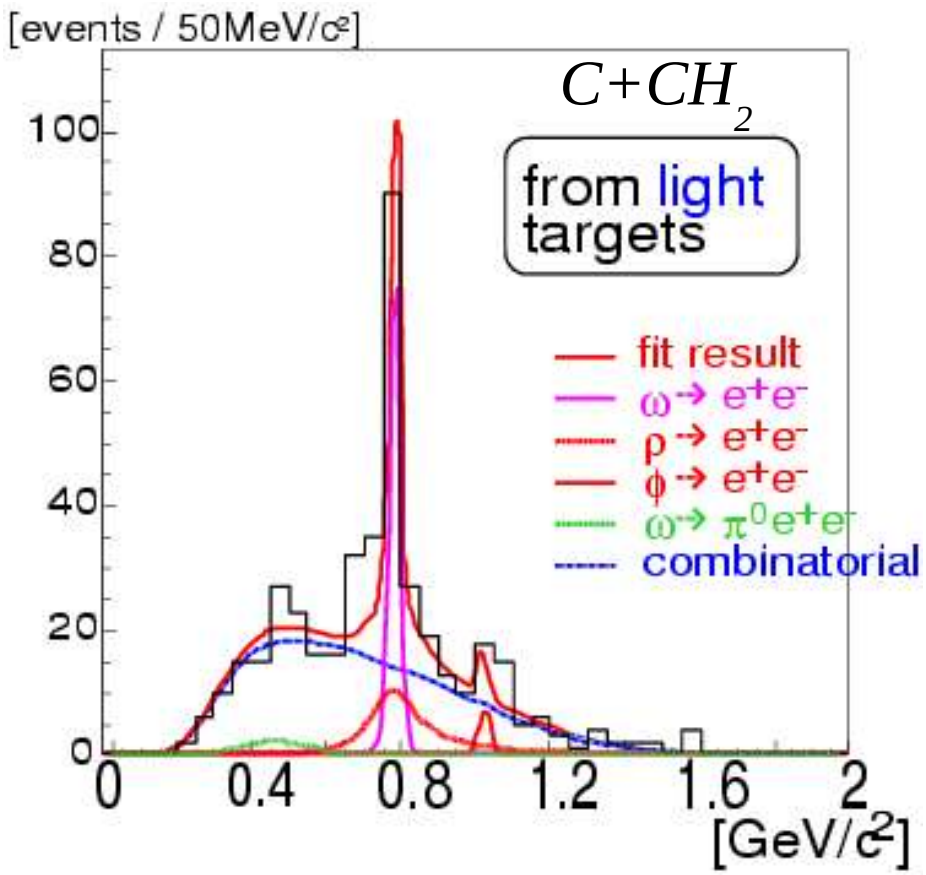
Remark on the model fitting

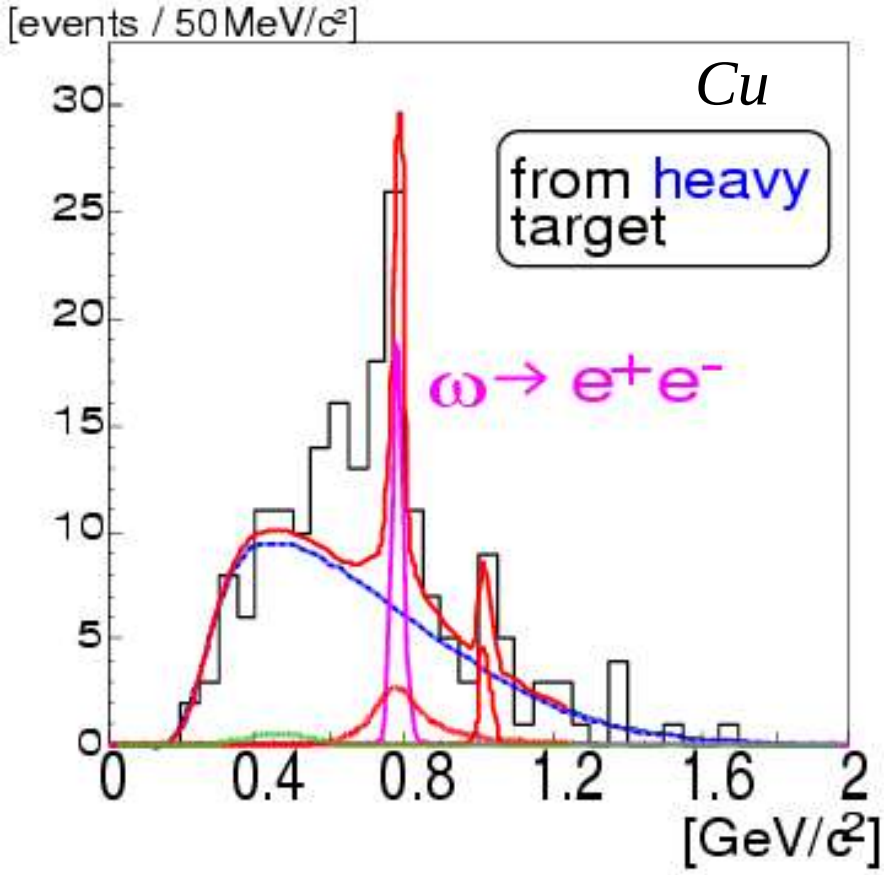
- ρ (ω) decay inside nucleus : 52% (5%) for C, 66%(10%) for Cu
  - used spectrum is the sum of the shifted and not-shifted components.
- constraint at right side of peak
  - Intoducing the width broadning (x2,x3) are rejected by the right side costraint.
  - prediction of ' mass increasing' is not allowed.
- momentum dependence of mass shift is not included.(But typical p =1.5GeV)





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





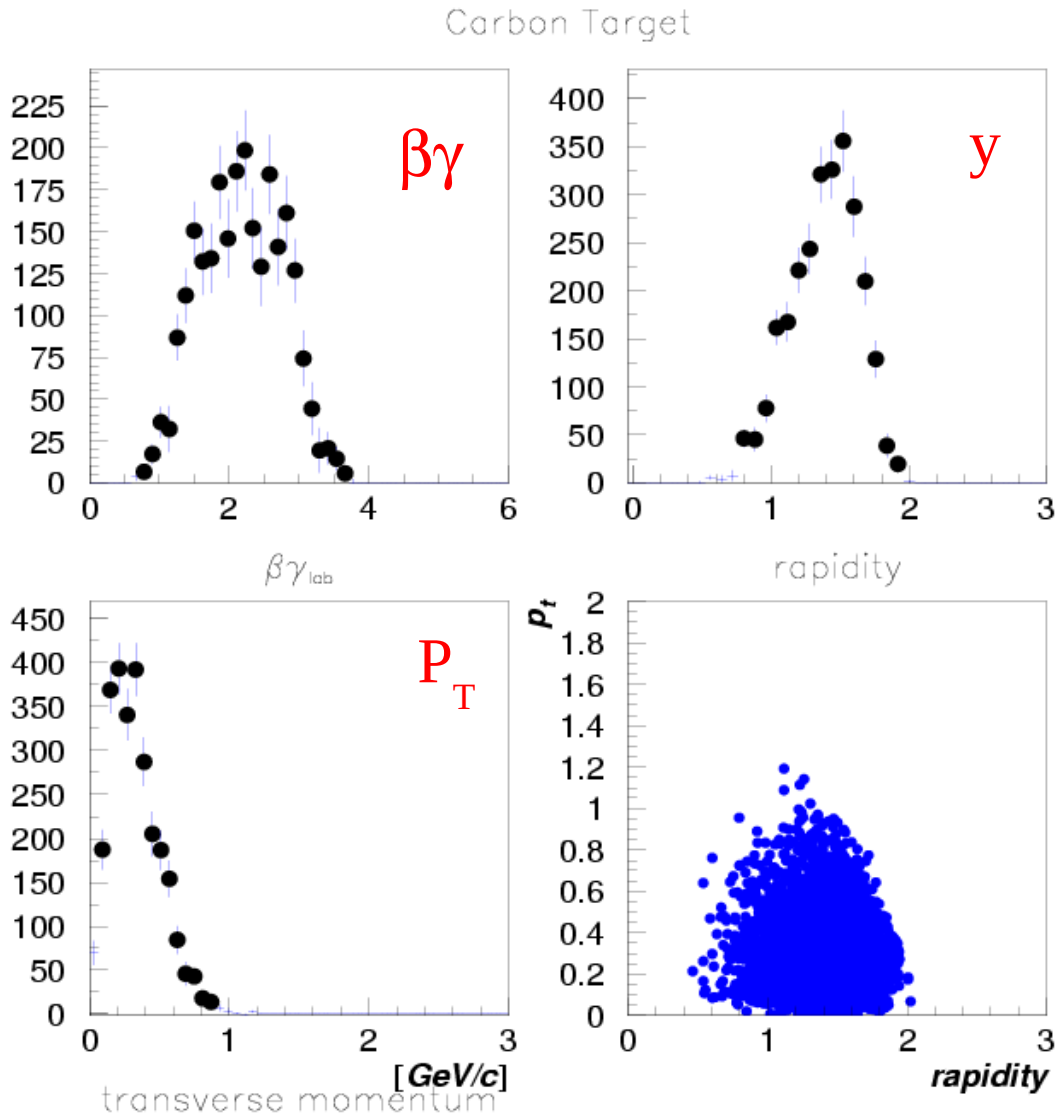
- 'excess region' : 0.55~0.75 GeV
- N(excess)/N(ω) = 0.26±0.16 (light), 1.48±0.56 (heavy)

Target material

	thickness		inteaction length	radiation length	
• 2002					
– C	0.184	g/cm^2 :	0.21 %	0.43%	x1
– Cu	0.0727	g/cm^2 :	0.054%	0.57%	x4

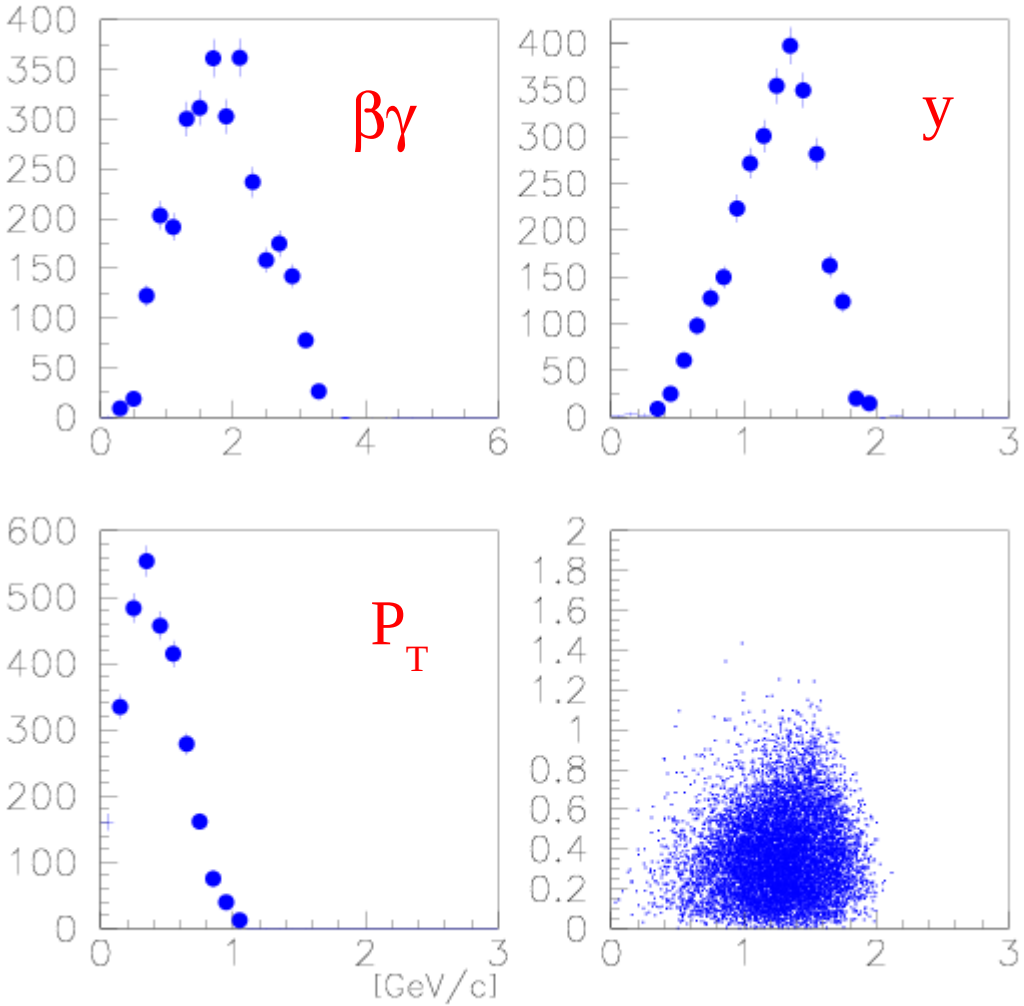
measured kinematic distribution of $\omega \rightarrow e^+e^-$

- $0.5 < y < 2$
- $1 < \beta\gamma < 3$
  - $(0.8<p<2.4)$
- $0 < P_T < 1$



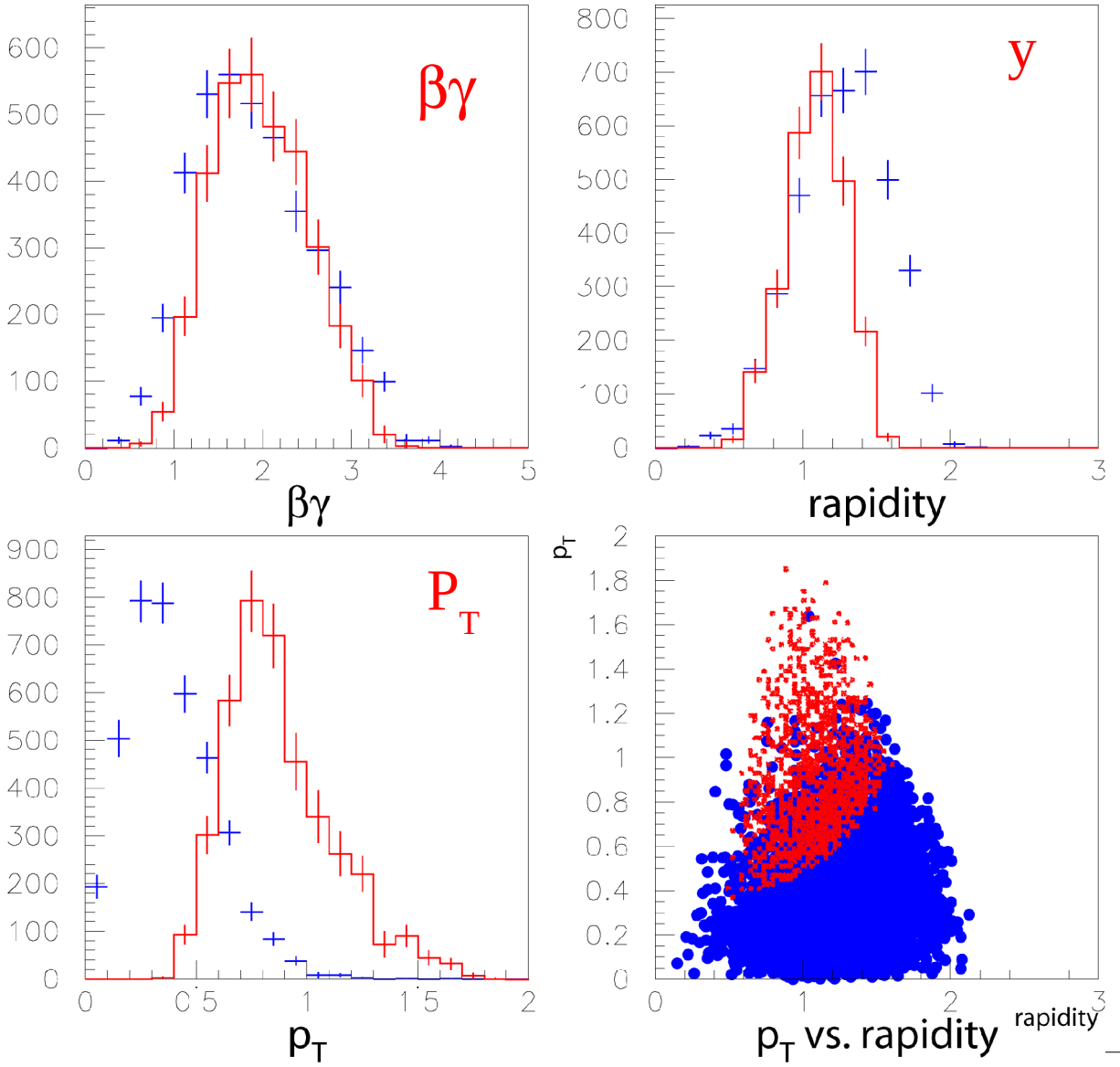
measured kinematic distribution of $\phi \rightarrow e^+e^-$

- $0.5 < y < 2$
- $1 < \beta\gamma < 3$
- $0 < P_T < 1$



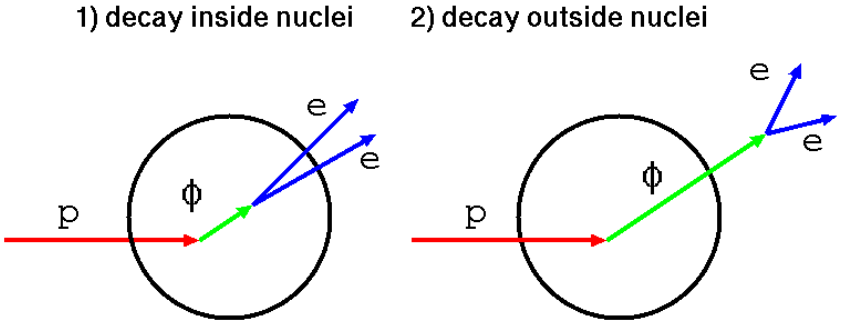
measured kinematic distribution of $\phi \rightarrow K^+K^-$ & $\phi \rightarrow e^+e^-$

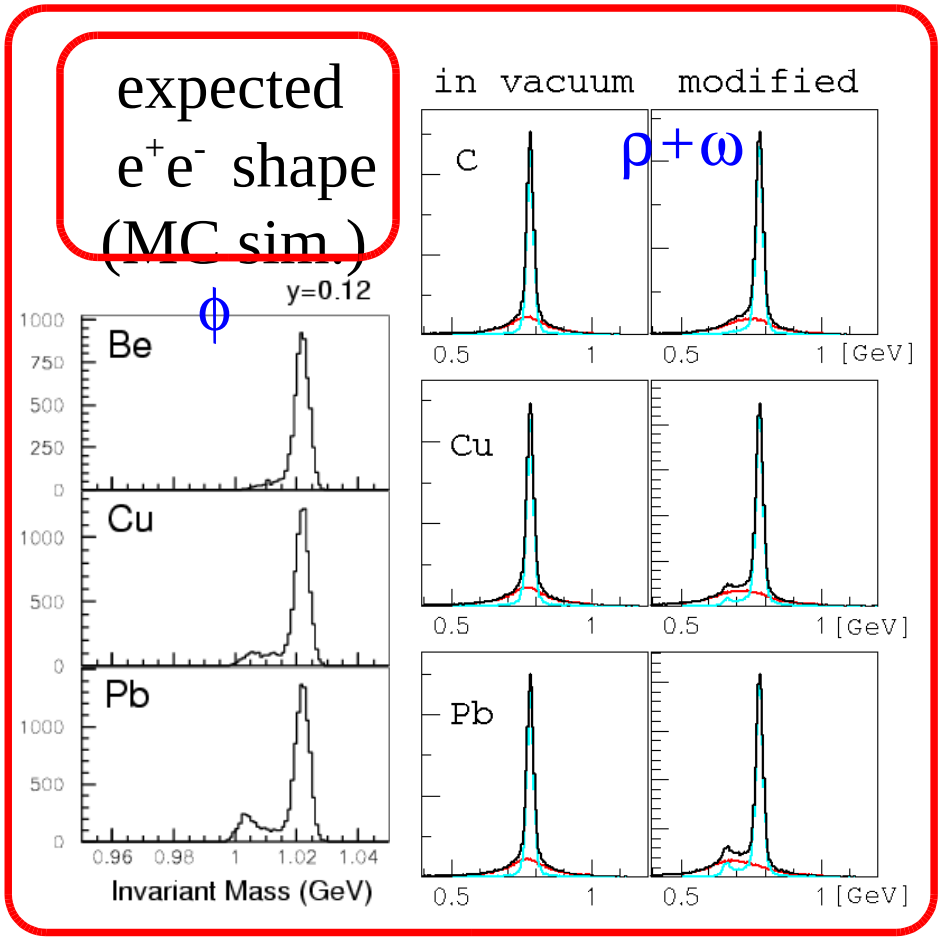
- $0.5 < y < 1.5$
- $1 < \beta\gamma < 3.5$
- $0.5 < P_T < 1.5$
- overlayed
  - $\phi \rightarrow K^+K^-$
  - $\phi \rightarrow e^+e^-$



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

- smaller FSI in e^+e^- decay channel
- double peak or tail-like structure
  - second peak is made by inside-nucleus decay (modified meson)
- comparison of ρ and ϕ
  - 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





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