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

- recent results from KEK-PS E325 -

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for the KEK-PS E325 collaboration

vector meson modification & chiral symmetry

performed experiment

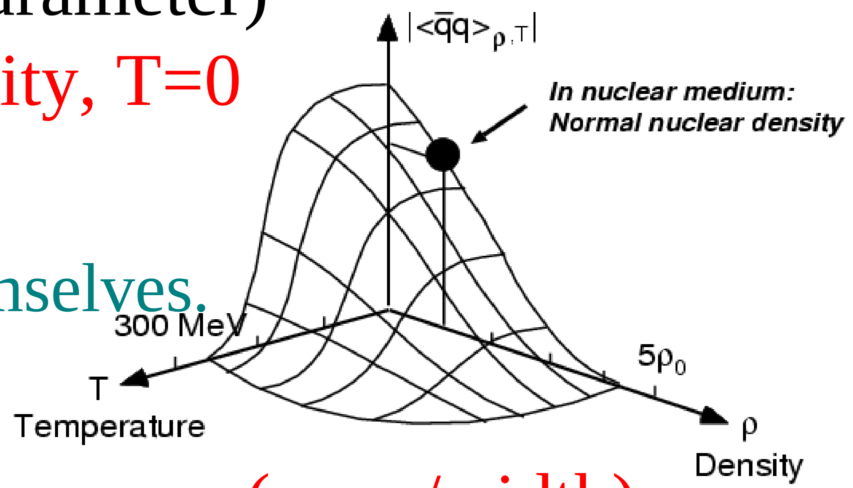
Results

– 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

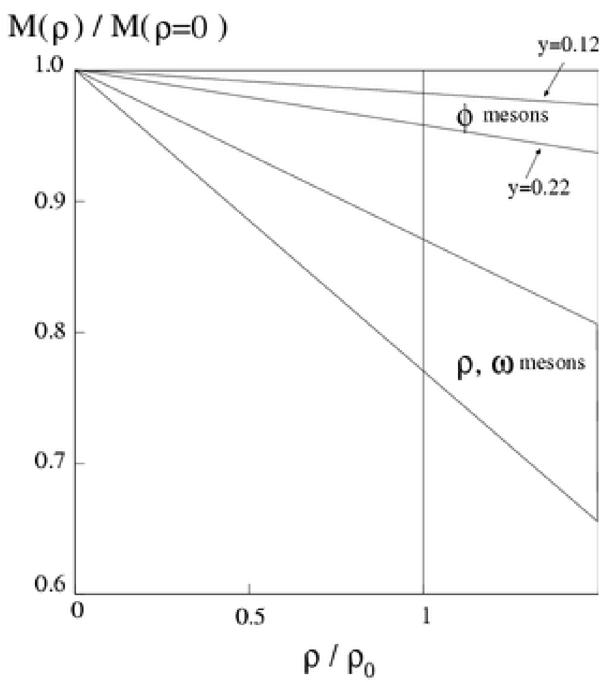
linear dependence on density

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

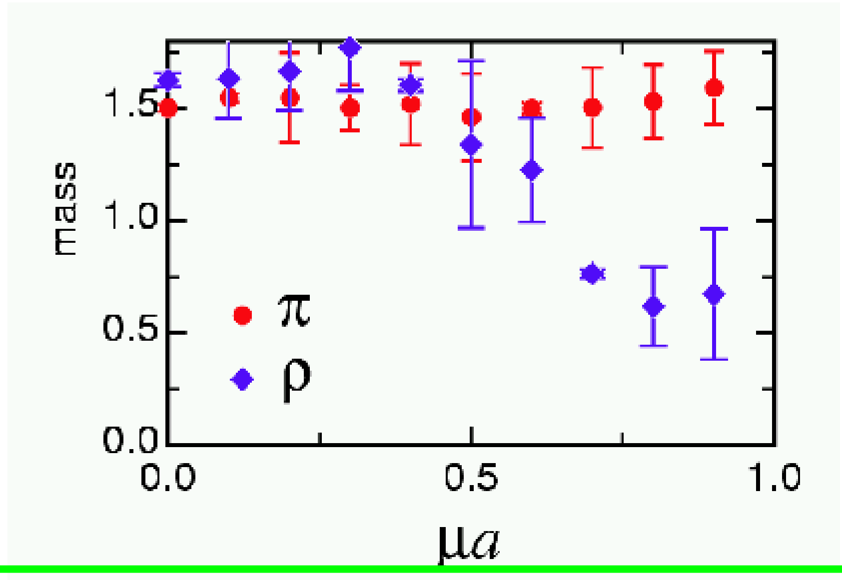
mass decreasing

- 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

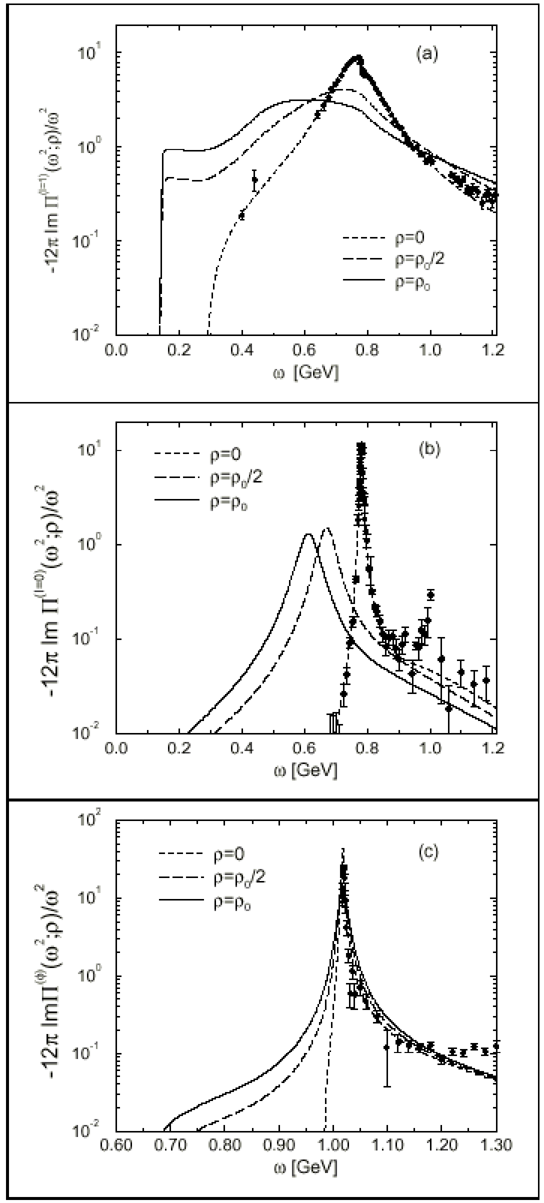


Klingle,Keiser,Weise, 97

ρ

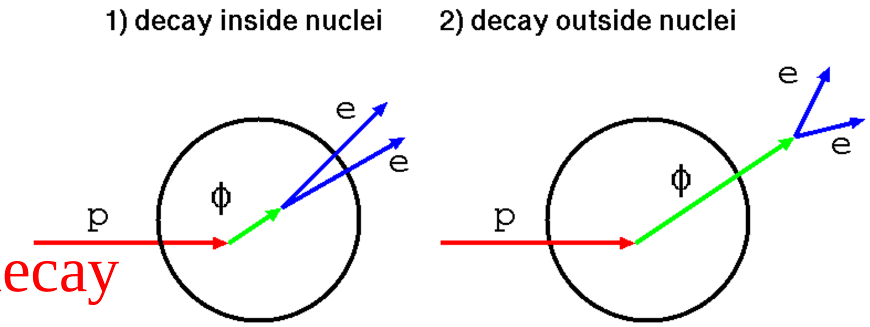
ω

φ



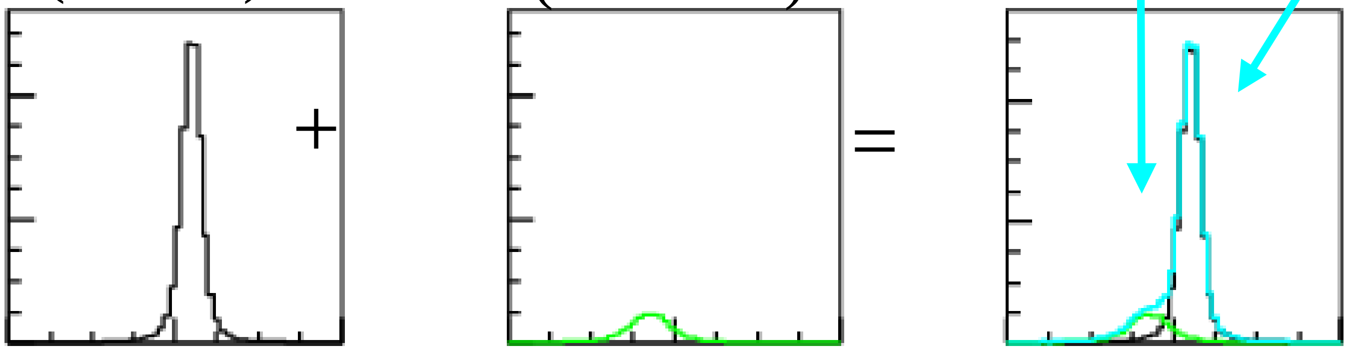
Expected Invariant mass spectra in e^+e^- channel

- 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



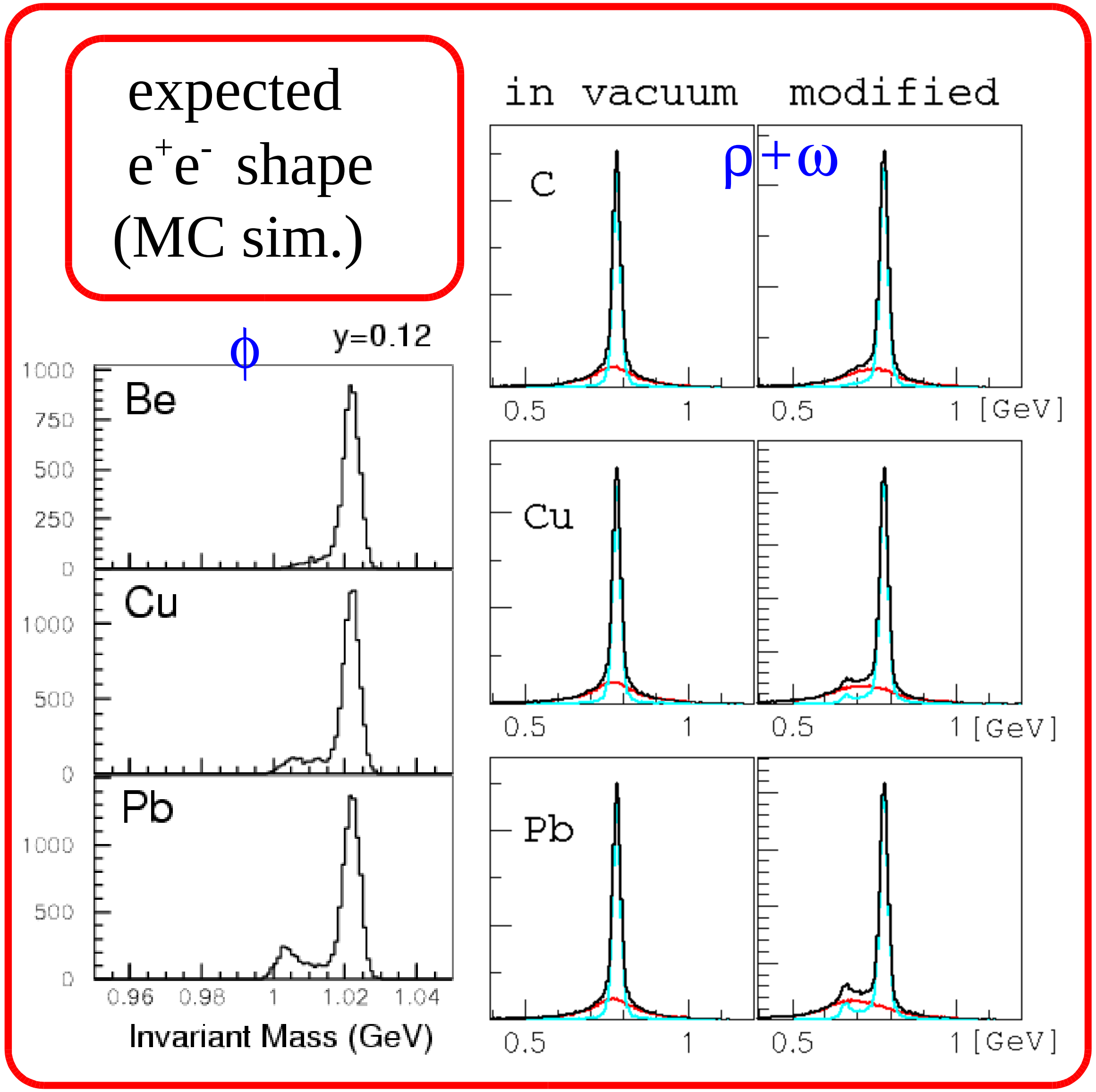
longer-life meson(ω & φ) cases : Schematic picture

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
    - 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 → 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

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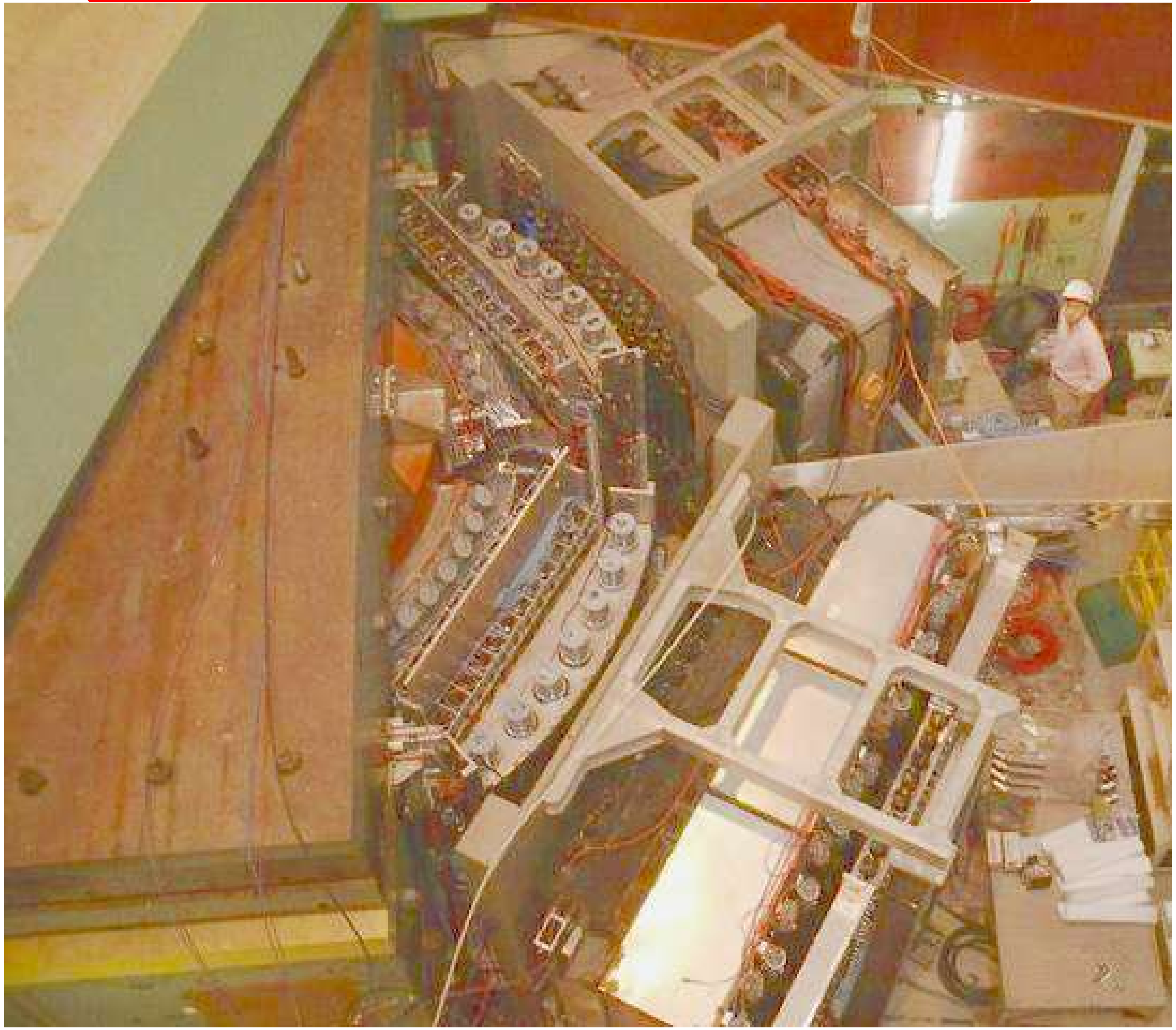
(Kyoto Univ. , RIKEN, KEK, CNS-U.Tokyo, ICEPP-U.Tokyo, Tohoku-Univ.)

(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

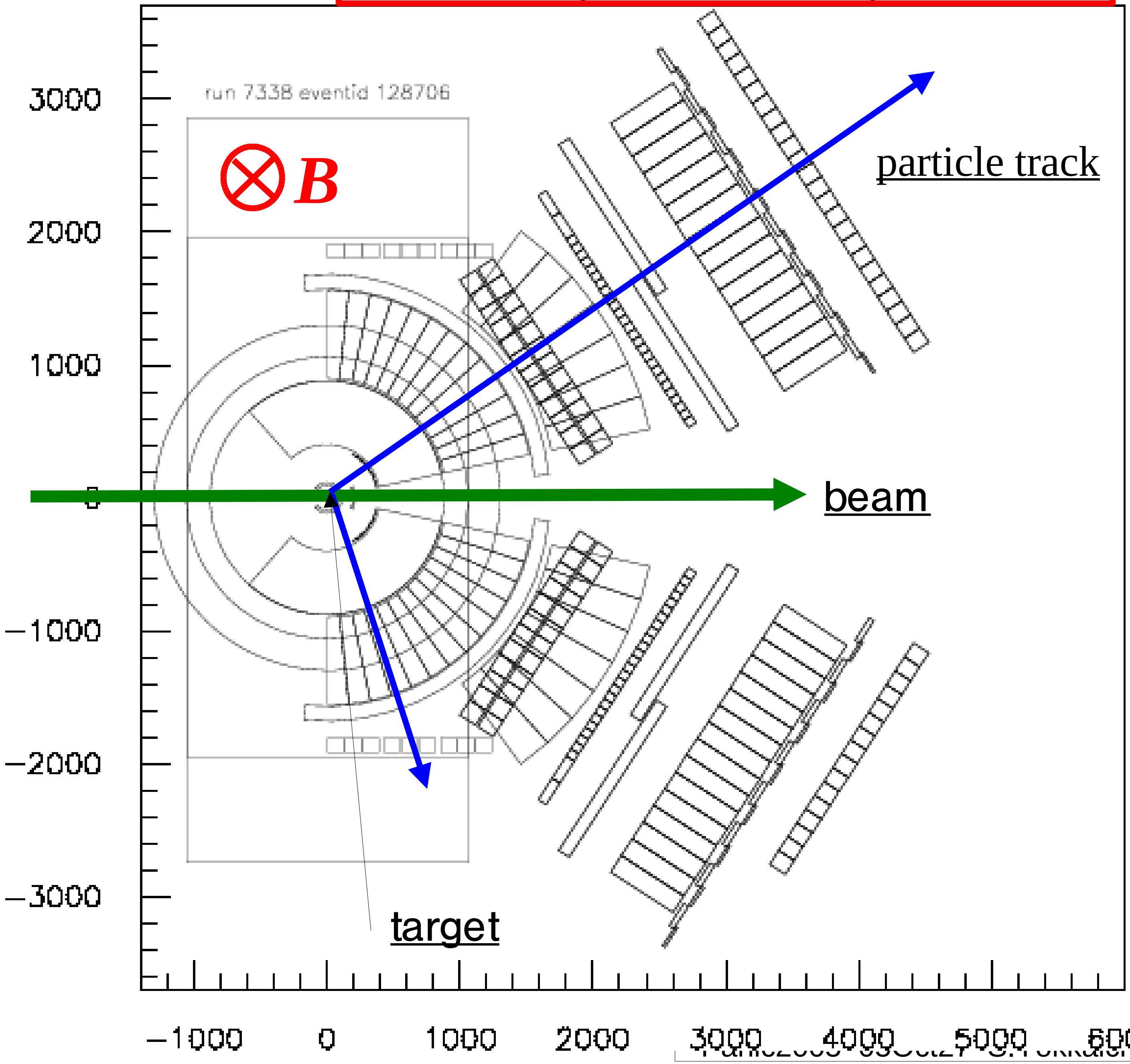
E325 spectrometer
located at KEK-PS EP1-B primary beam line



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 $3\text{x}10^{-4}$ π rejection

with 78% e efficiency

in two-stage operation

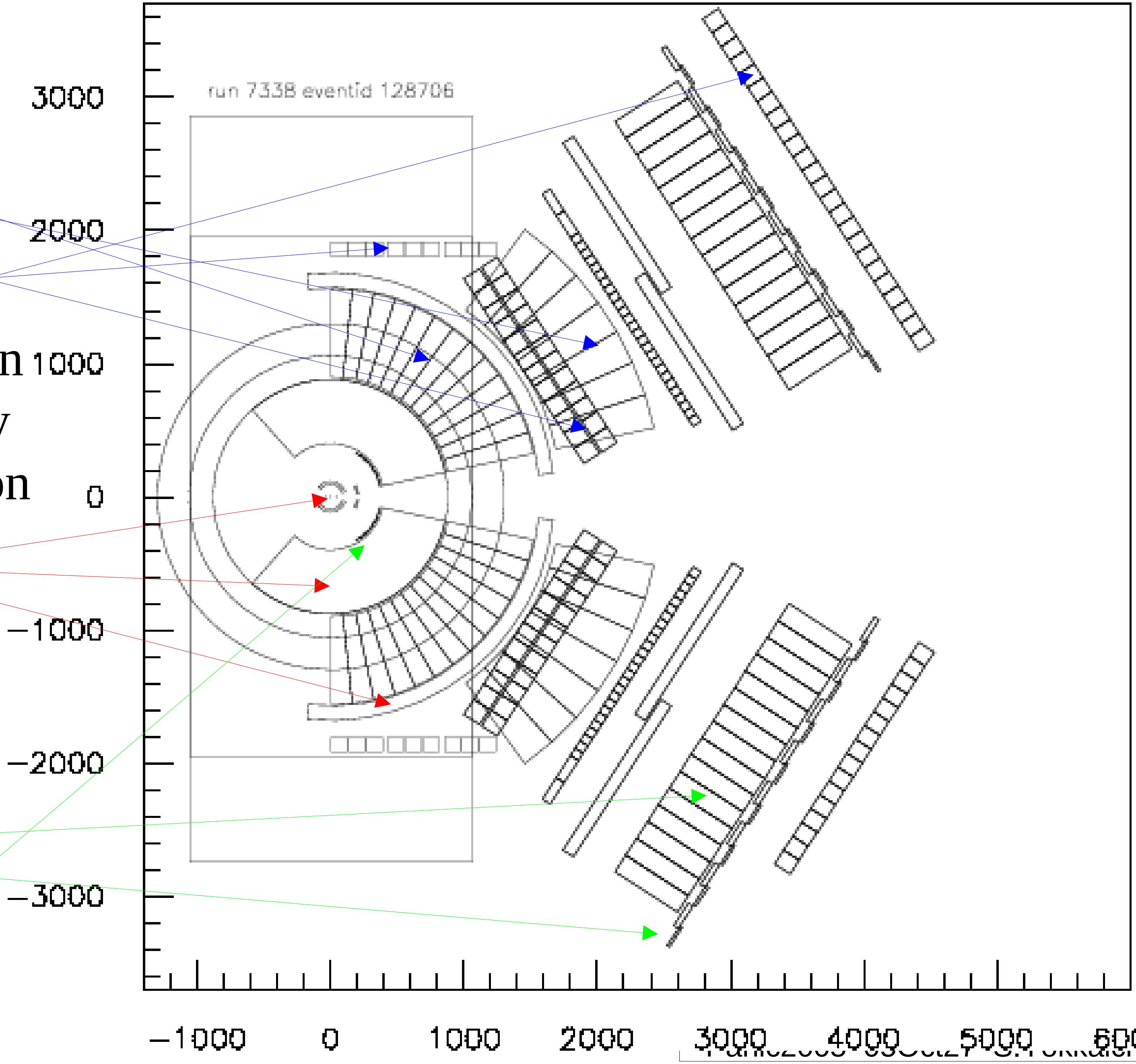
Tracker

Three Drift Chambers

Kaon ID counters

Aerogel Cherenkov

& TOF



Result (1)

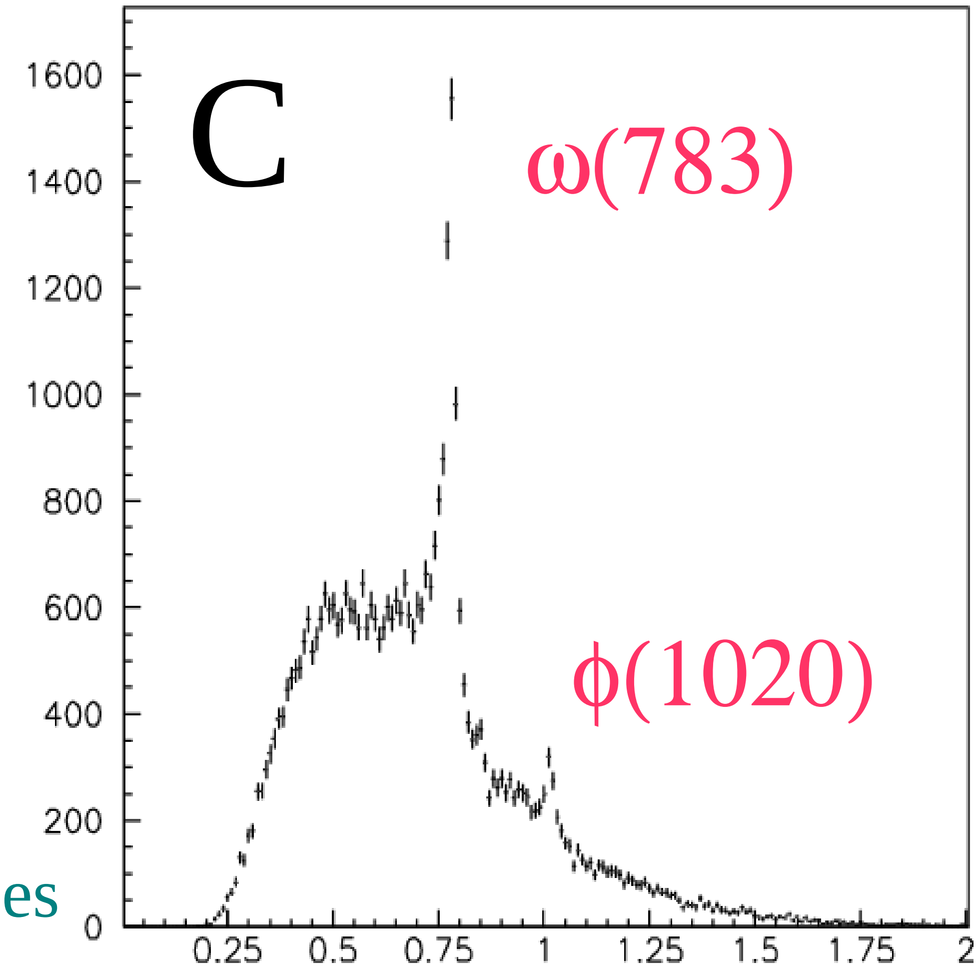
ee invariant mass spectra

M. Naruki et al.,

nucl-ex/050416

Observed e^+e^- invariant mass spectra

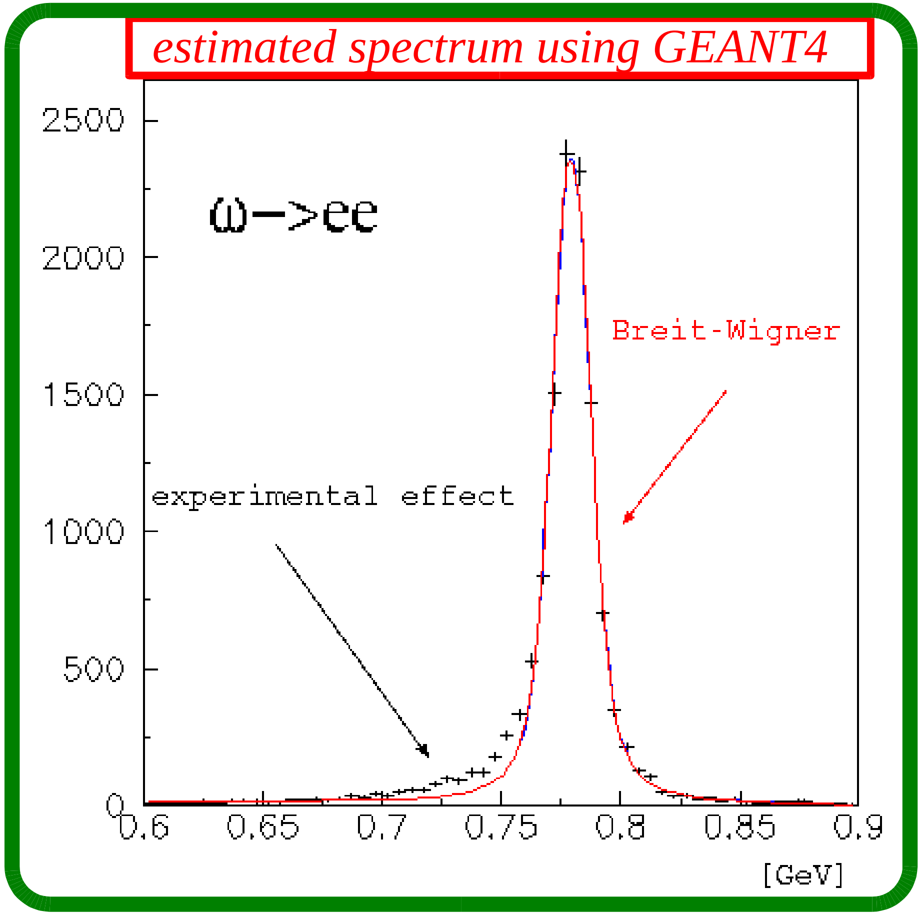
- from 2002 run data (~70% of total data)
- C & Cu target
- clear resonance peaks
- m<0.2 GeV is suppressed by detector acceptance
- acceptance uncorrected



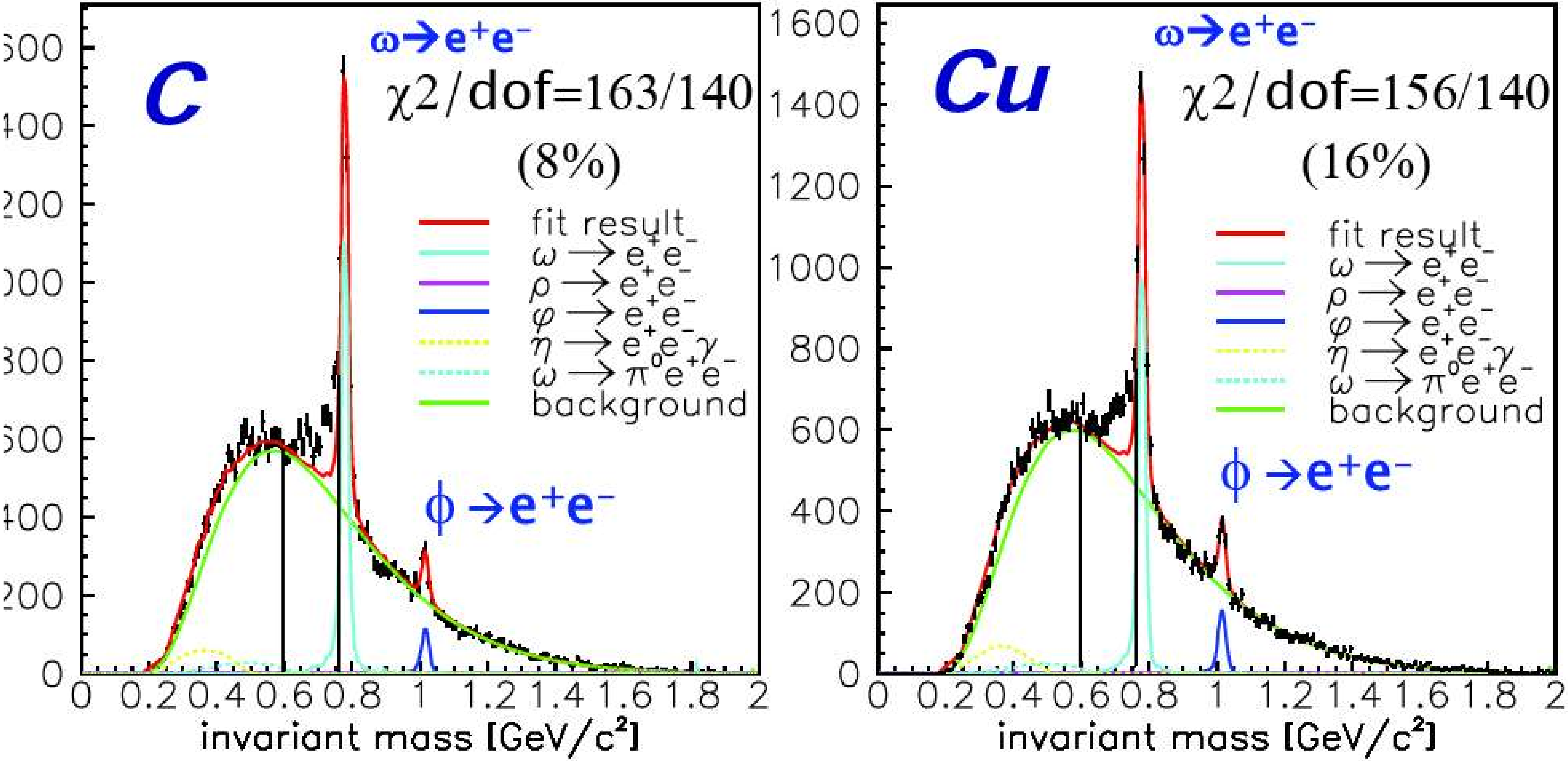
→ fit the spectra with known sources

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



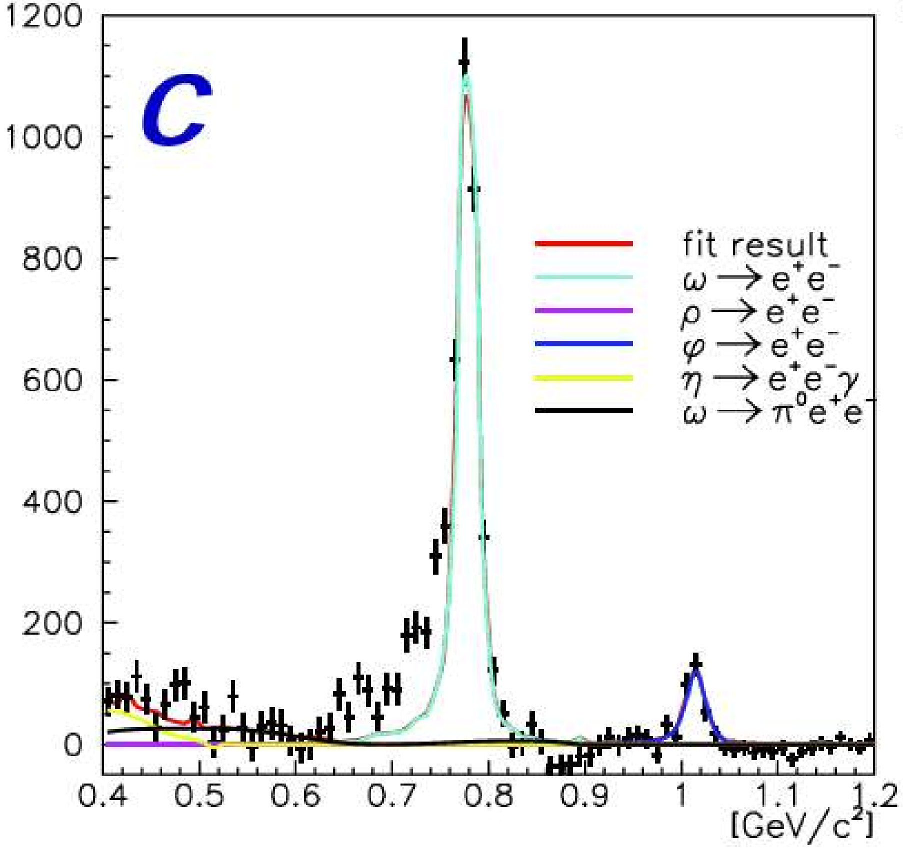
Fitting results

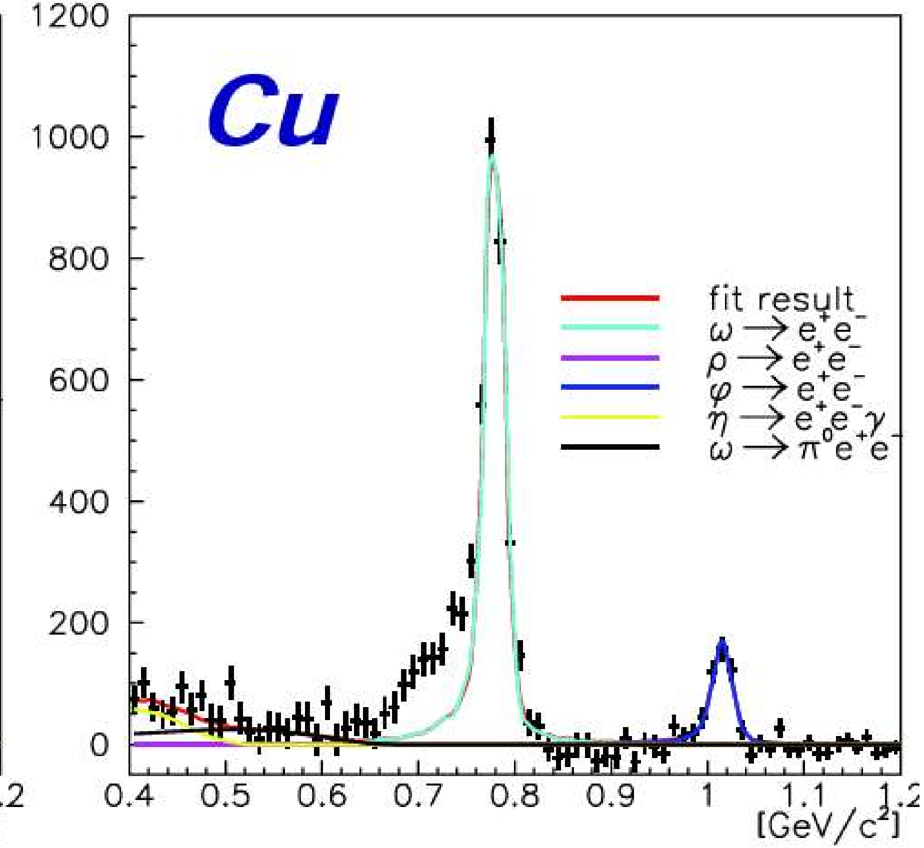


- 1) excess at the low-mass side of ω
  - To reploduce the data by the fitting, we have to exclude the excess region : 0.60~0.76 GeV
- 2) ρ−meson component seems to be vanished !

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)

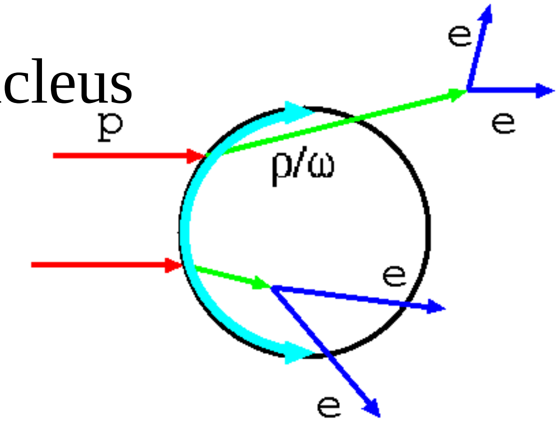
...suggests that the origin of excess is modified ρ mesons.

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

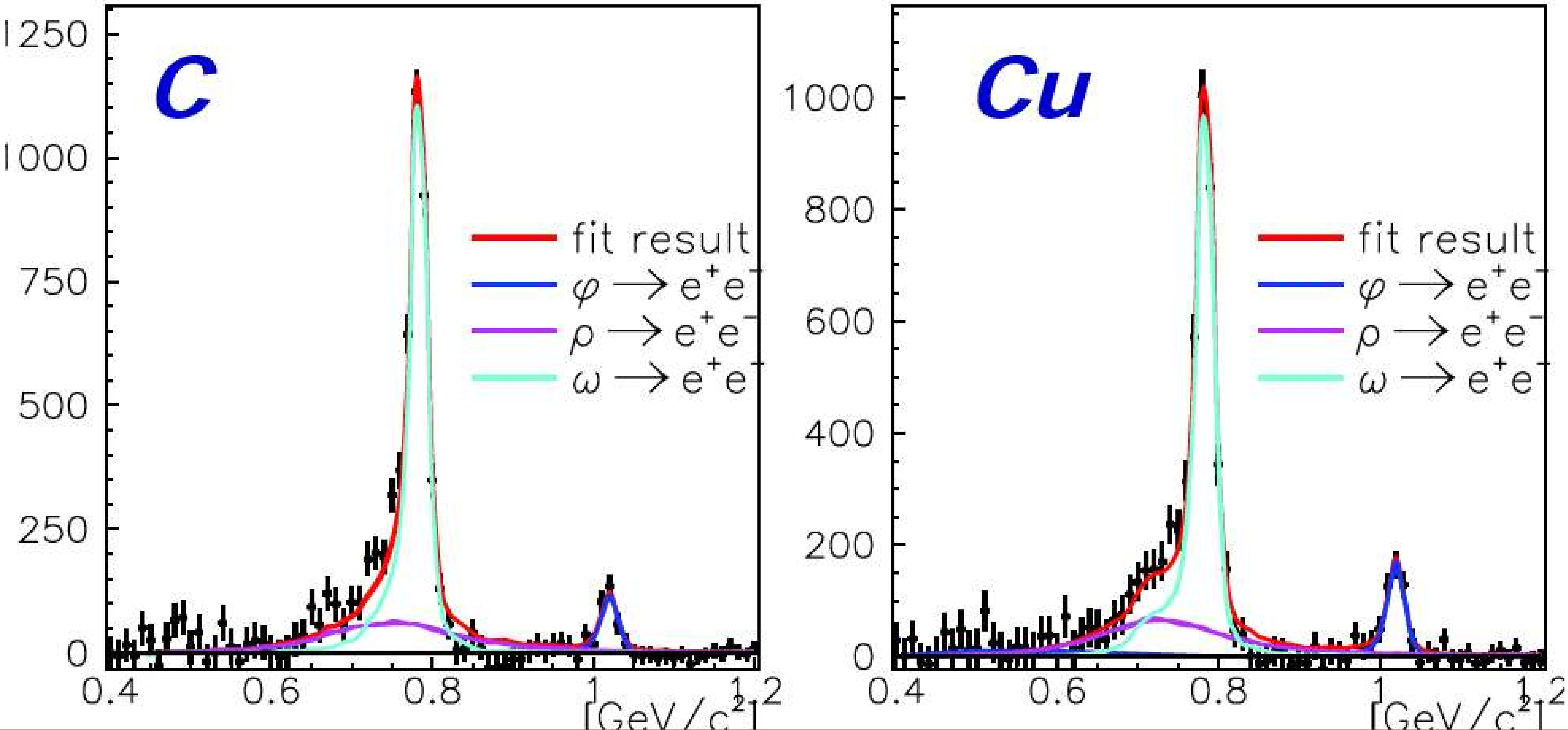
      are not taken into account this time)



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

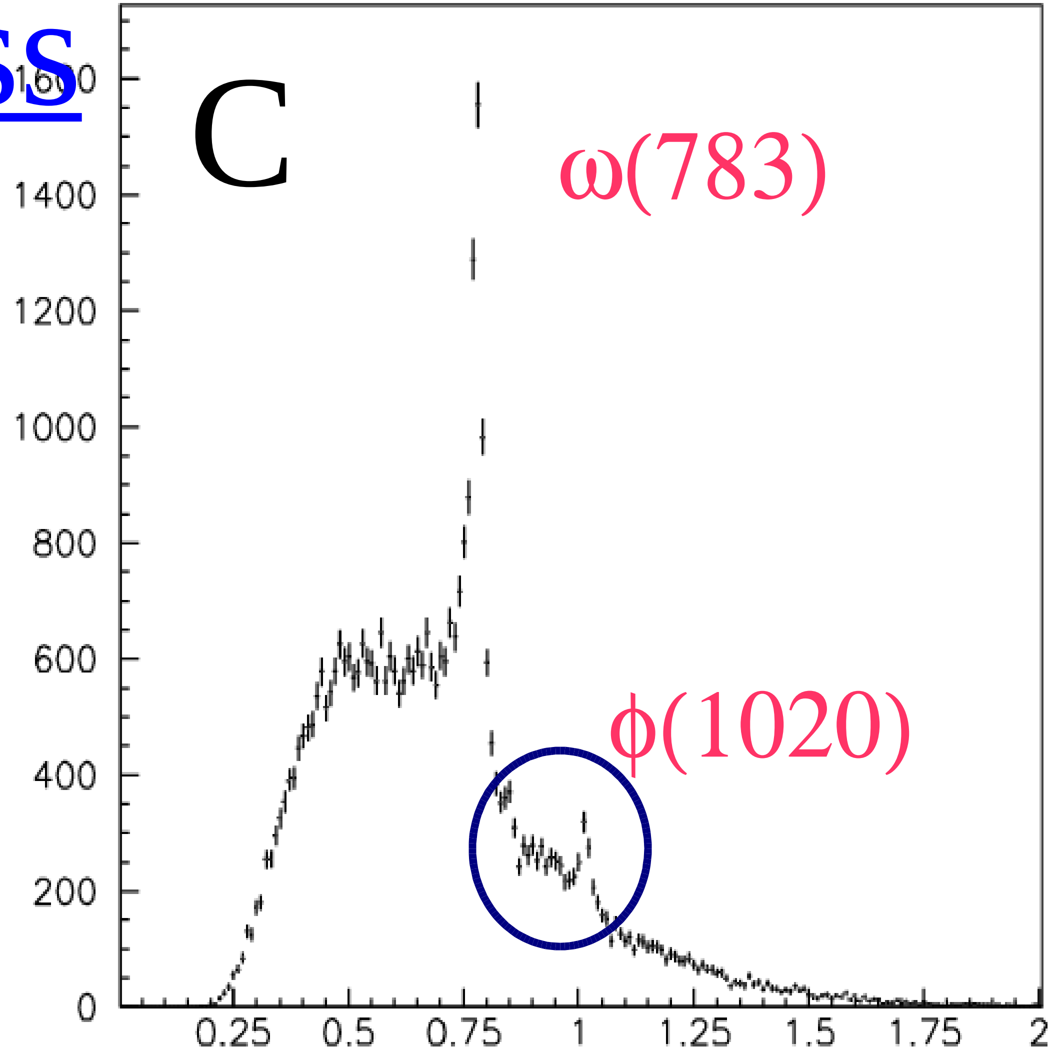


From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density

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

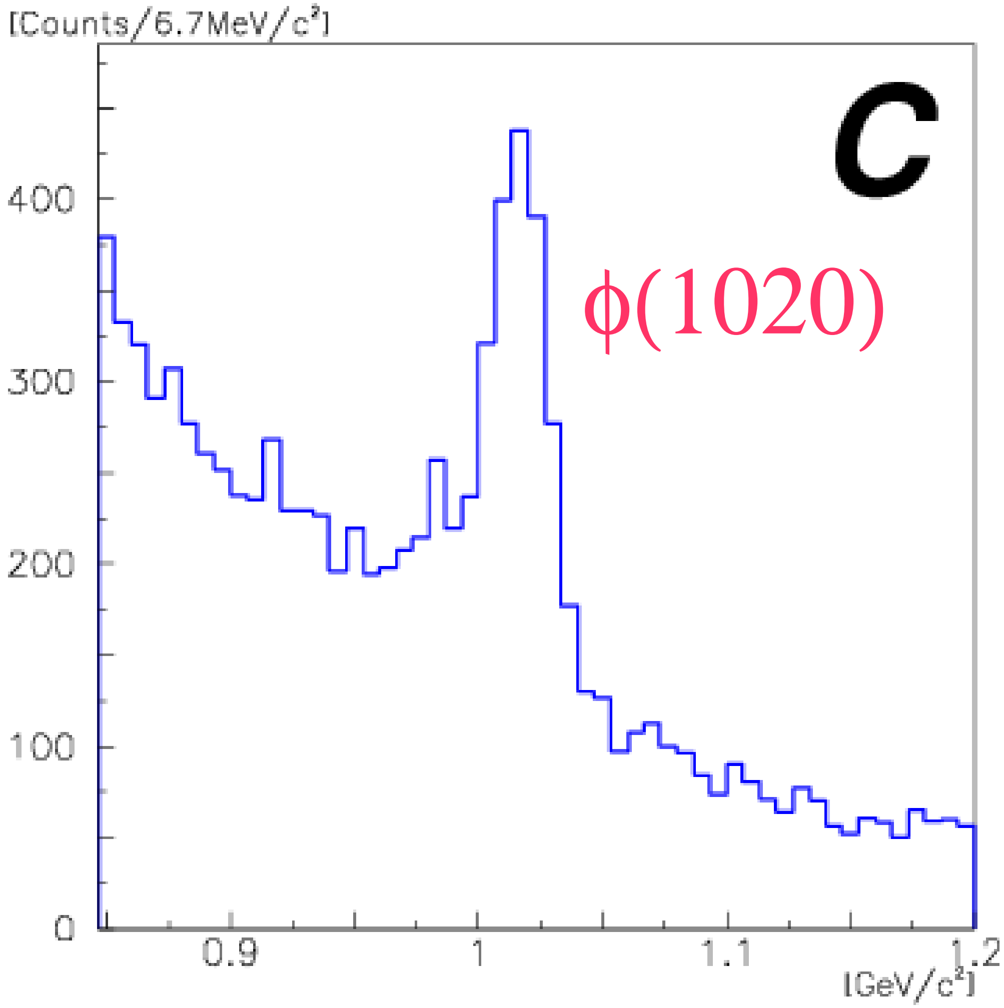
Result (2)

ee invariant mass spectra of ϕ



$\phi \to e^+e^-$ 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

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- fit with
  - simulated mass shape of ϕ
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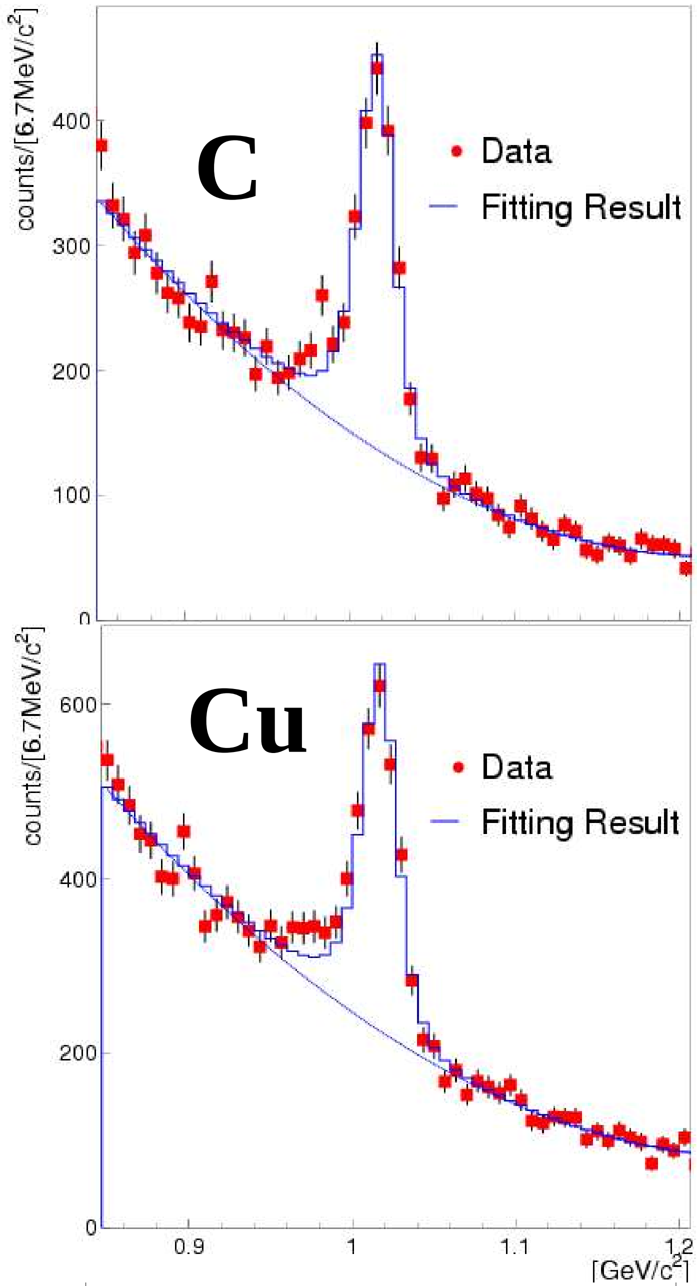
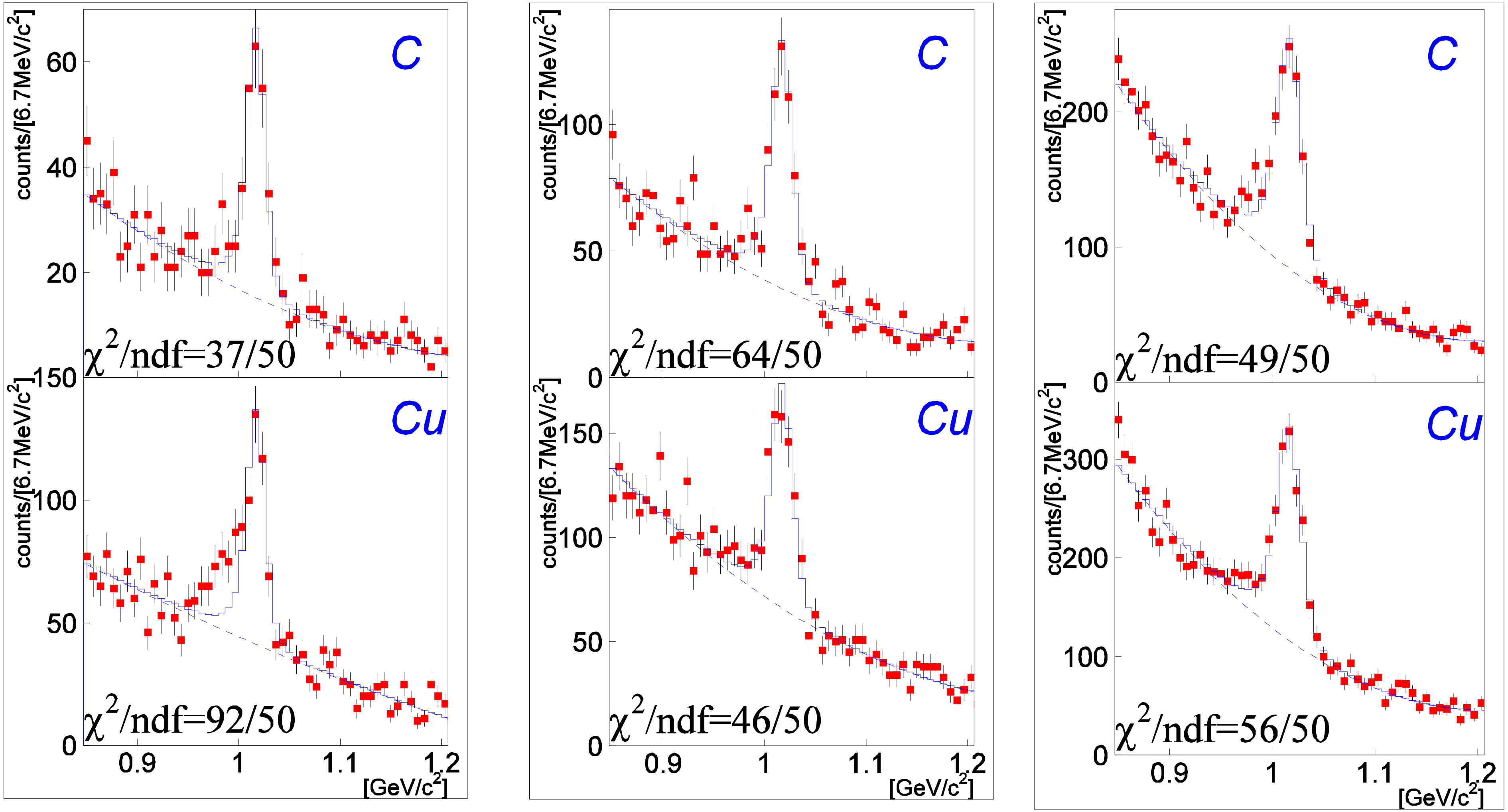
  - polinomial curve background
- examine the 'excess' is significant or not.
  - $\rightarrow$ see the $\beta\gamma$ dependence : excess could be enhanced for slowly moving mesons



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

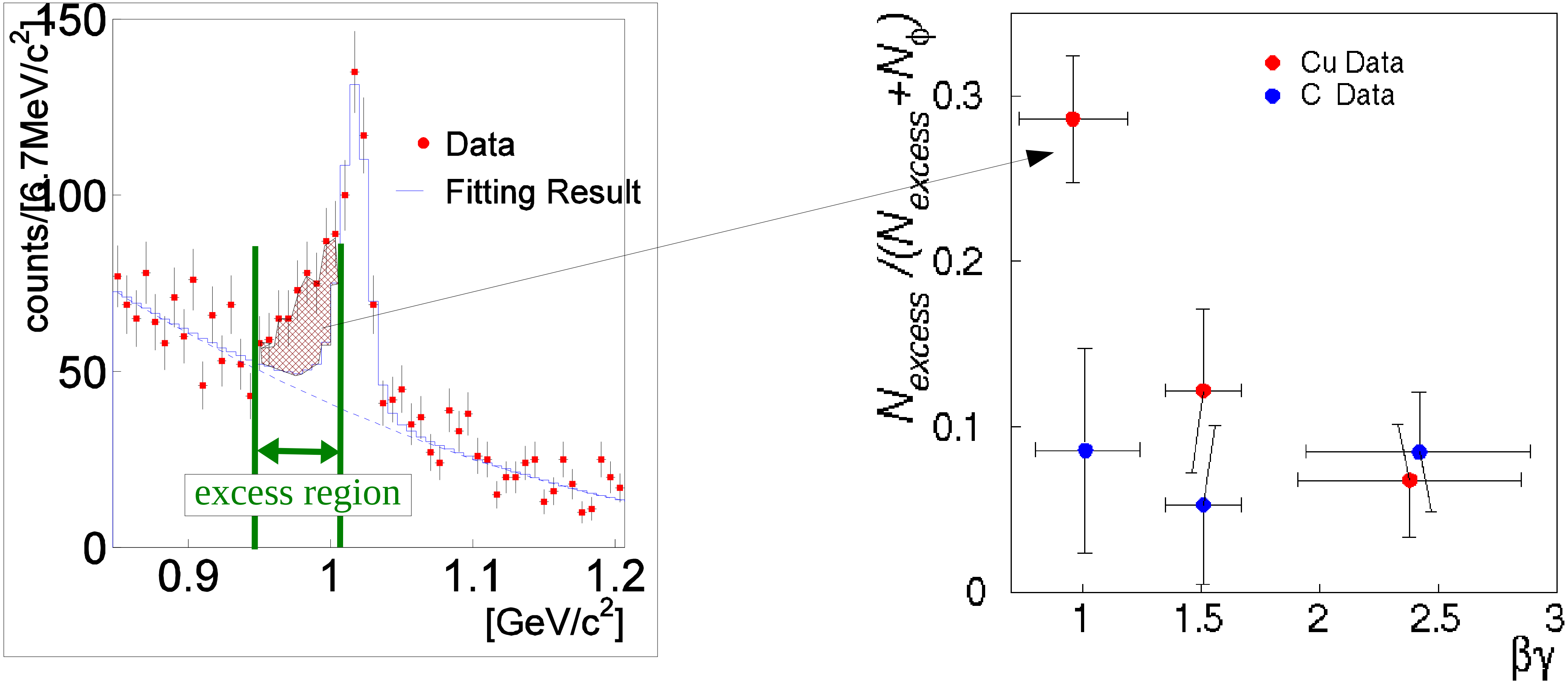
$\beta\gamma$<1.25 (Slow)	1.25<$\beta\gamma$<1.75	1.75<$\beta\gamma$ (Fast)



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

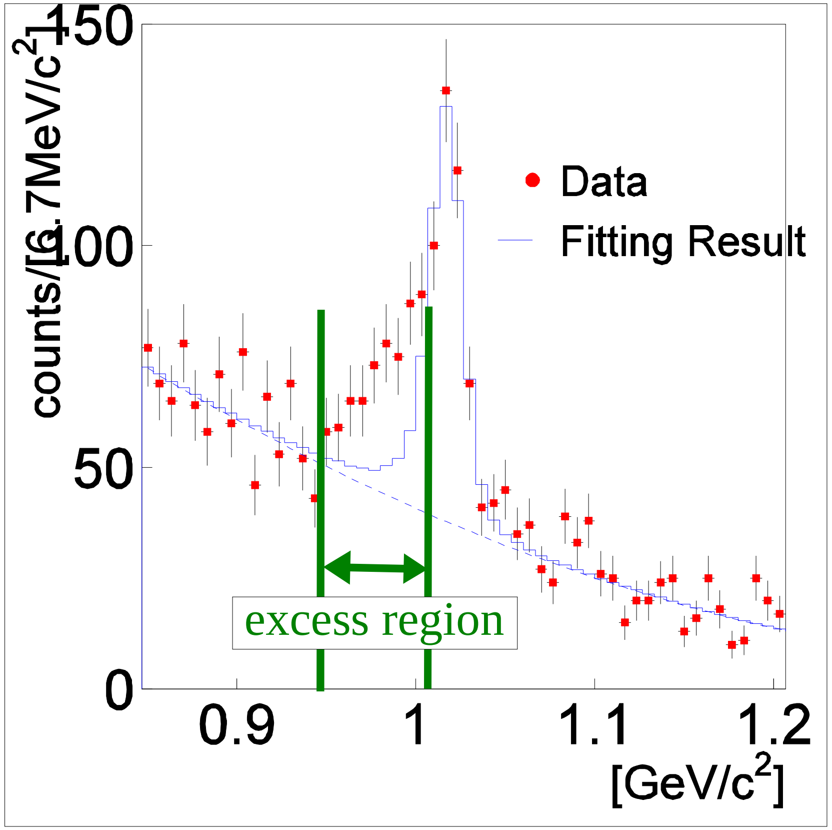
Amount of excess

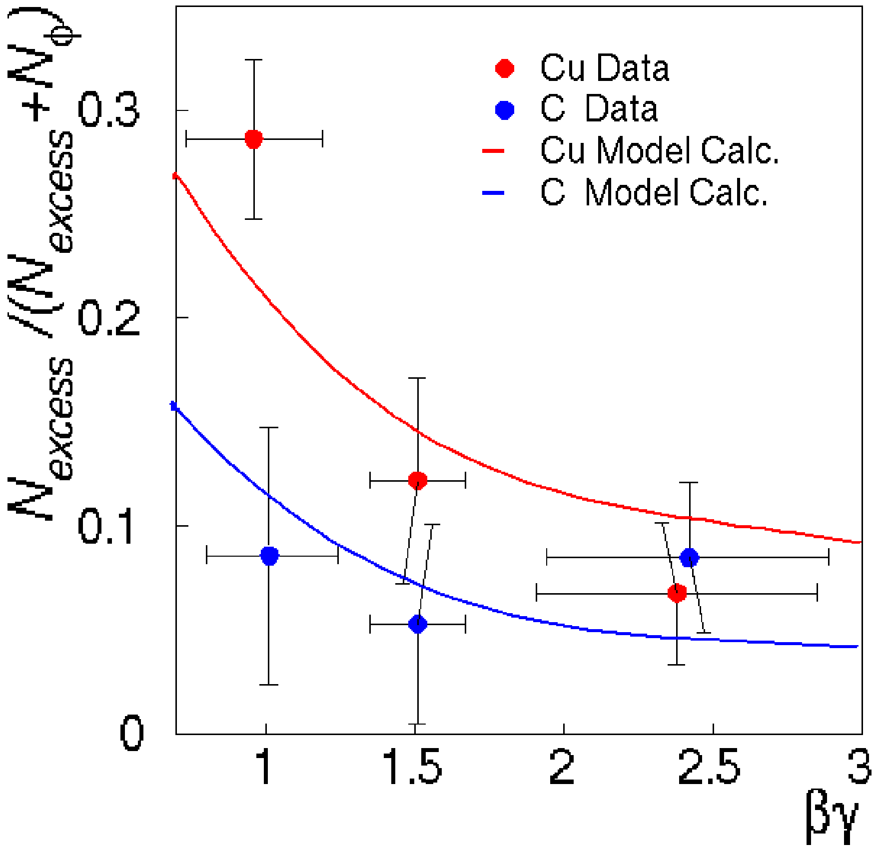
- To evaluate the amount of excess (N_{excess}), fit again excluding the excess region (0.95~1.01GeV) and integrate the excess area.



Amount of excess

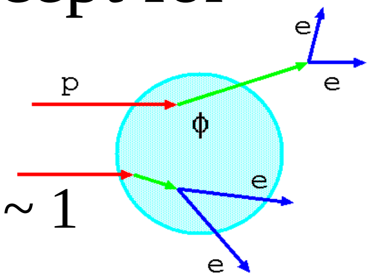
- To evaluate the amount of excess (N_{excess}), fit again excluding the excess region (0.95~1.01GeV) and integrate the excess area.
- Model calculation reproduces the tendency of N_{excess} / (N_{excess} + N_{ϕ})





Toy model again for ϕ meson

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



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

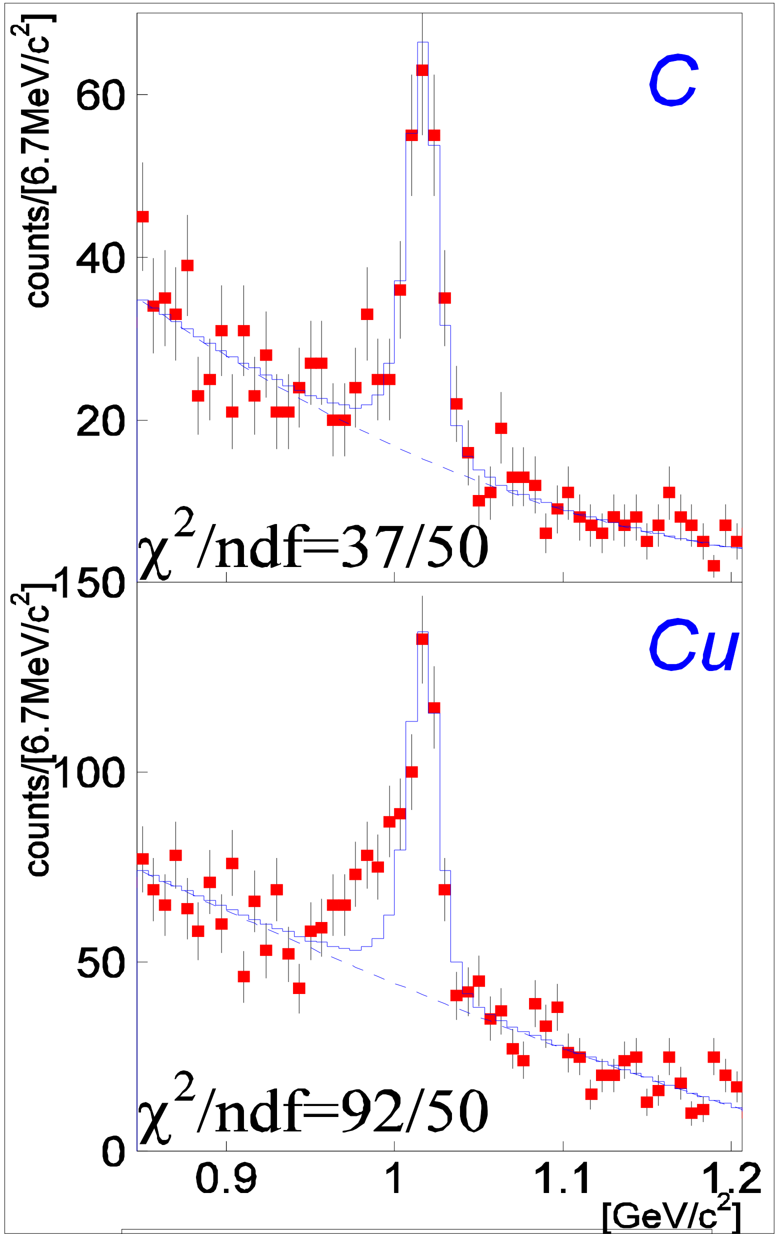
    (k_1=0.04, Hatsuda & Lee, '92,'96)
  - To reproduce such amount of excess, linear-dependent width broadning is adopted :

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

    (k_2=10, it means $\Gamma_{tot}^{\ *}$ =~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.

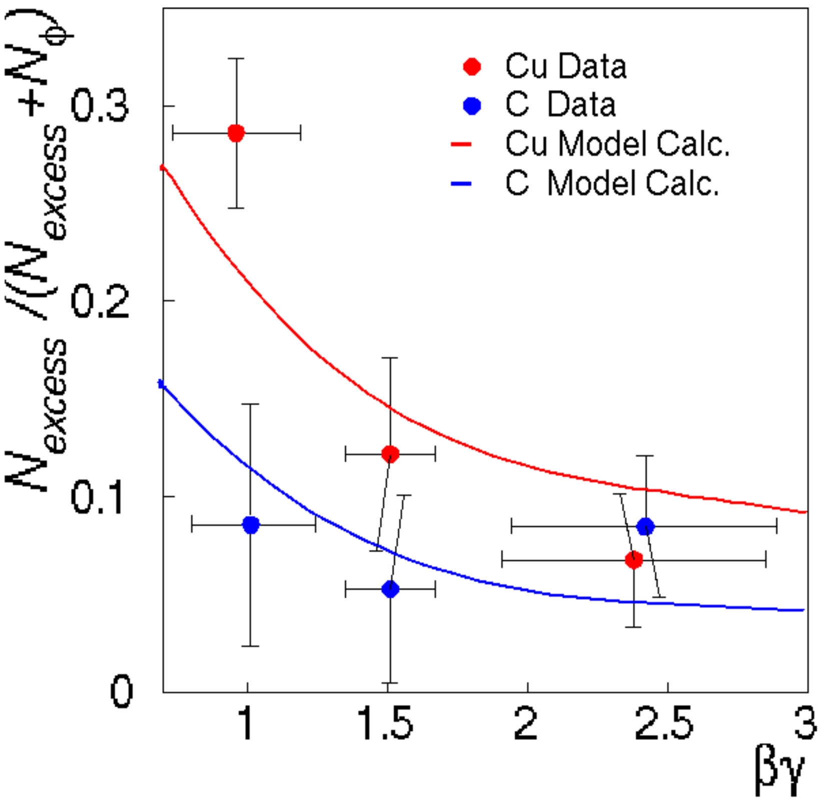
$\beta\gamma$<1.25 (Slow), w/ unmodified

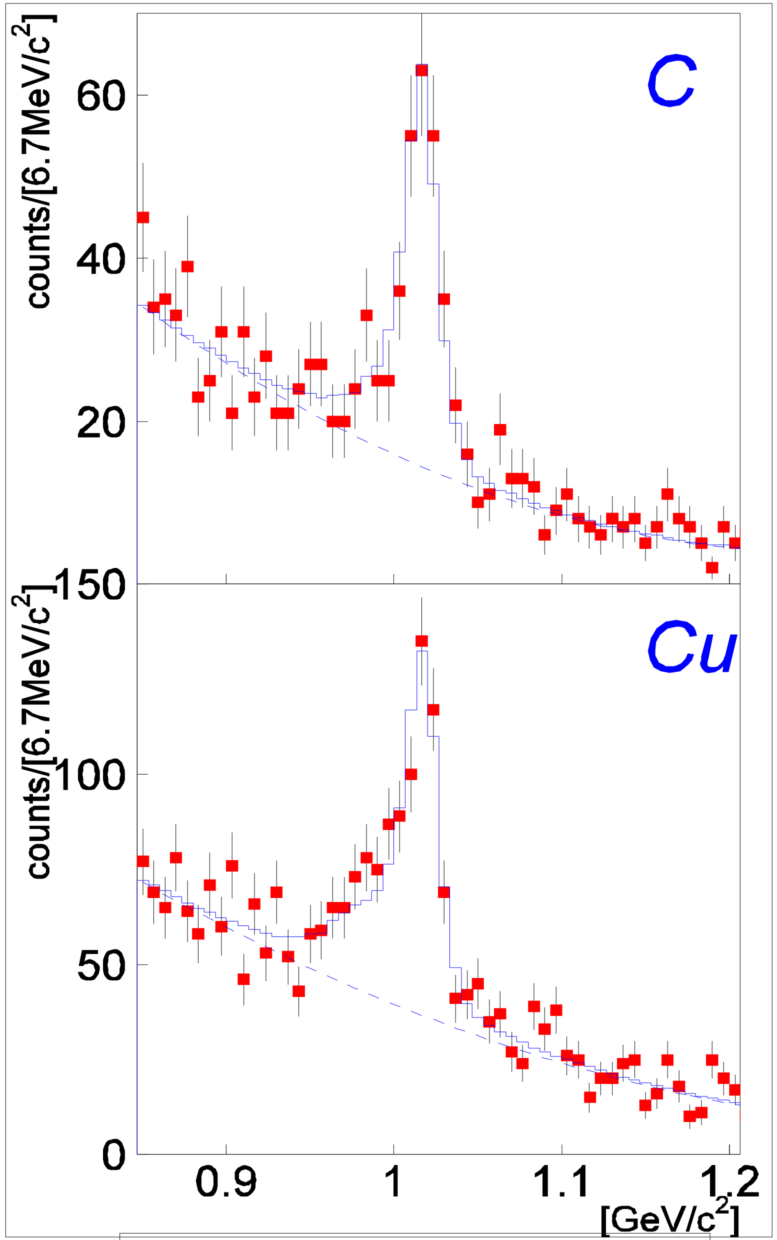


Toy model result for φ meson

- 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.)