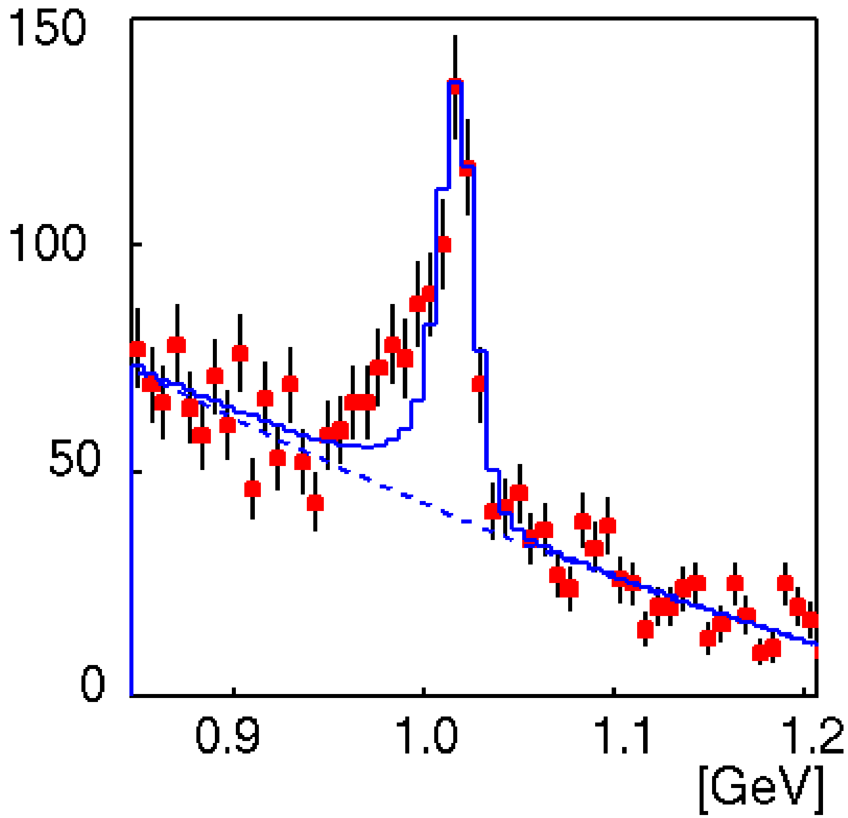
Medium modification of vector mesons in 12 GeV p+A reactions at KEK-PS

Satoshi Yokkaichi , RIKEN

for the KEK-PS E325 collaboration

- **Physics**
- **Expected experimental signature**
- **Performed experiment KEK-PS E325**
- **E325 Results**
  - 1) $\rho/\omega \rightarrow e^+e^-$ spectra
  - 2) $\phi \rightarrow e^+e^-$ spectra
  - 3) $\phi \rightarrow K^+K^-$ spectra
- **Future experiment at J-PARC**

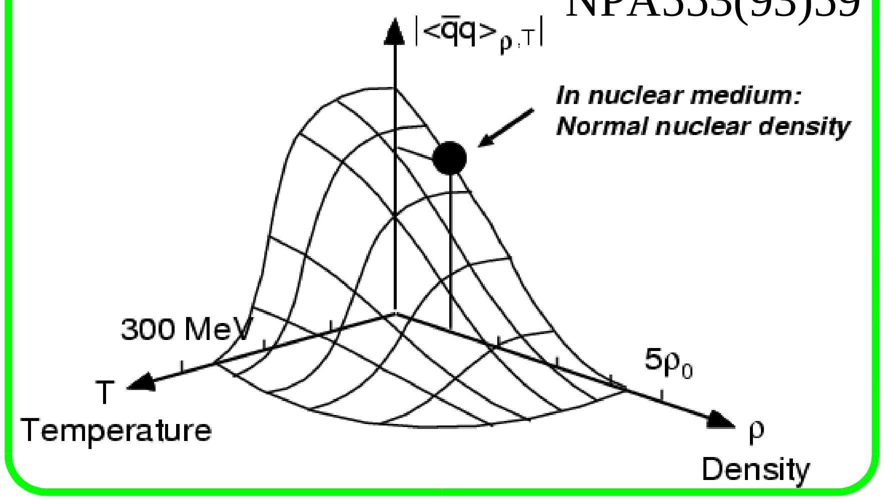


MESON2006 06Jun12 S.Yokkaichi

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.

W.Weise, NPA553(93)59



- 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, Kaiser &Weise ('97), Muroya, Nakamura & Nonaka('03), etc.

Hatsuda and Lee, PRC46(92)R34,PRC52(95)3364

linear dependence on density

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

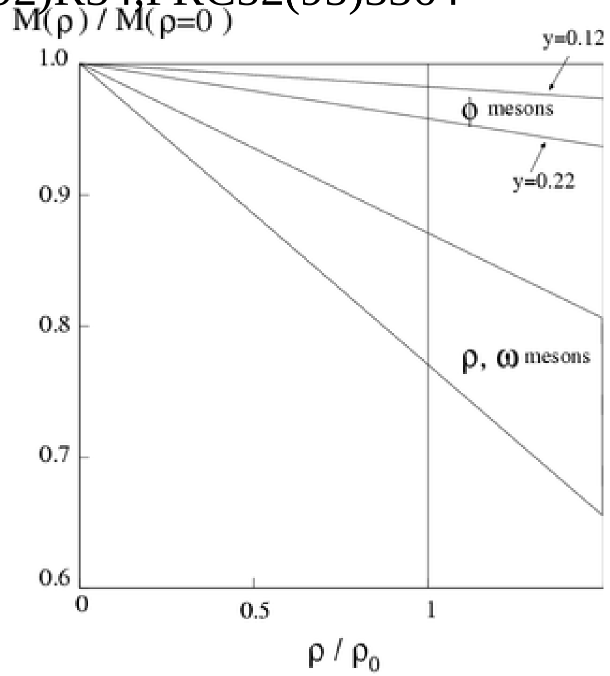
mass decreasing

- 16(±6)% for ρ/ω
- 0.15(±0.05)*y

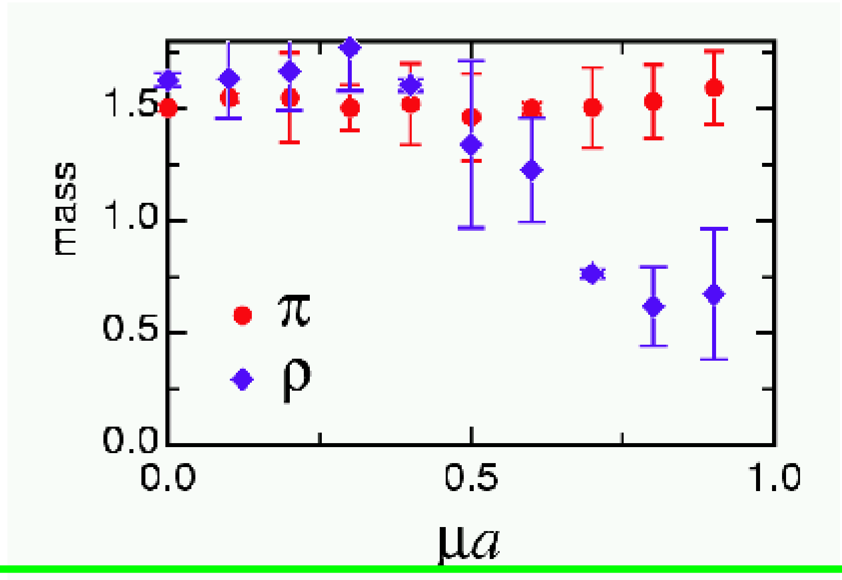
=2~4% for ϕ

(for y=0.22)

at the normal nuclear density



Muroya, Nakamura, Nonaka, PLB 551 (03) 305



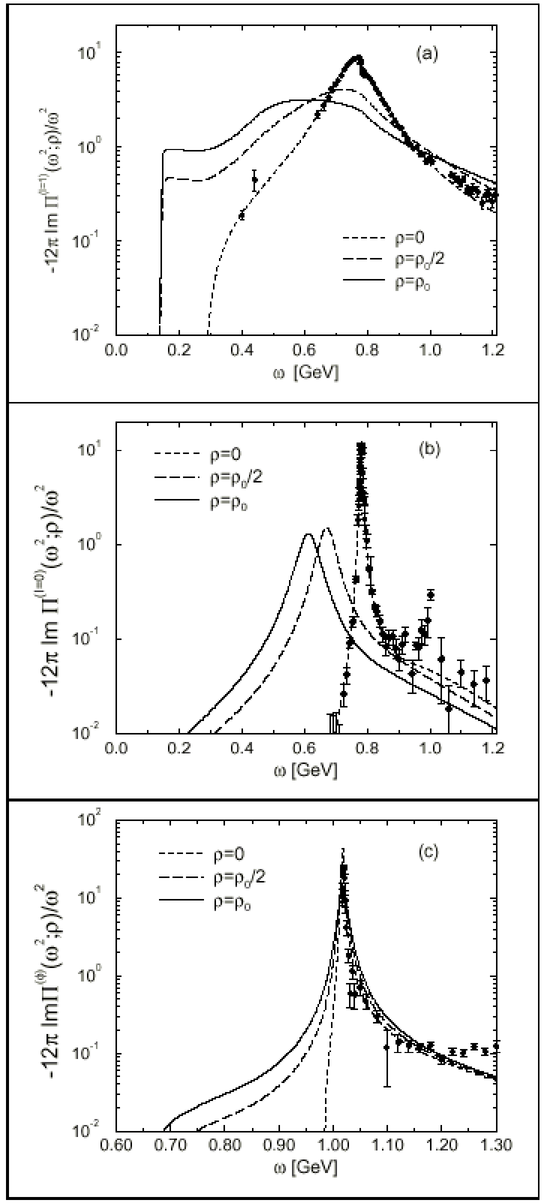
Klingle,Kaiser,Weise,

NPA624(97)527

ρ

ω

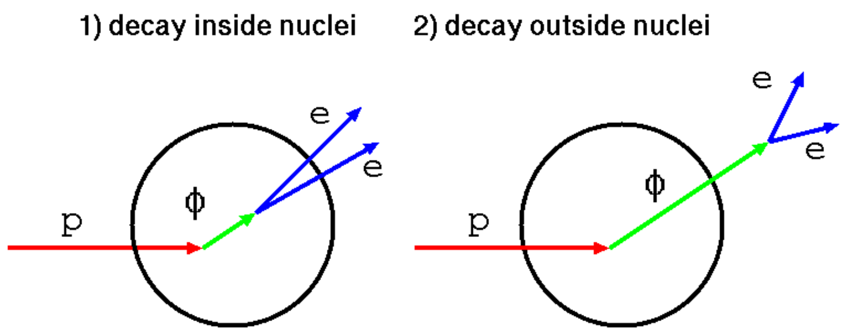
ϕ



Expected signal in p+A reaction in our energy region

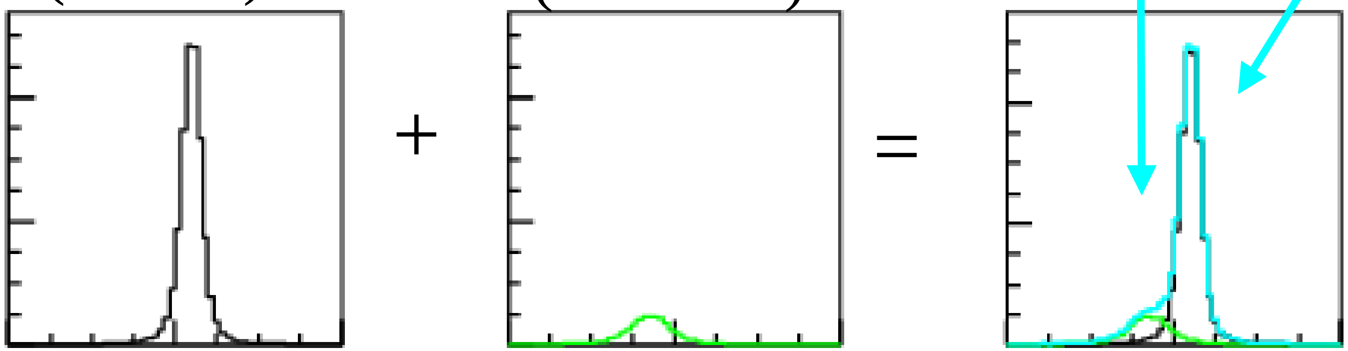
Expected Invariant mass spectra in e^+e^-

- smaller FSI in e^+e^- 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
    - could be enhanced for slower mesons & larger nuclei



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

outside decay (natural) + inside decay (modified) = expected to be observed



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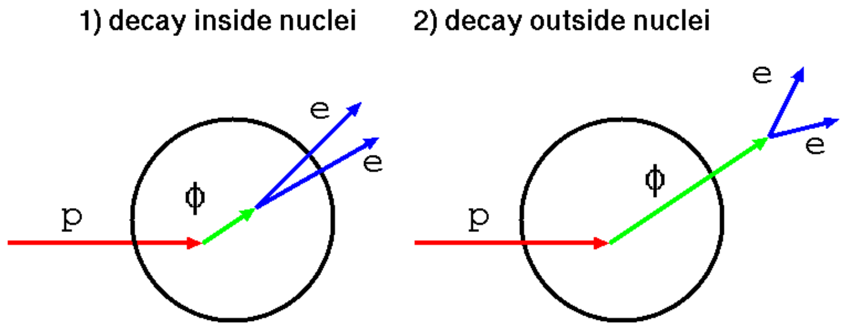
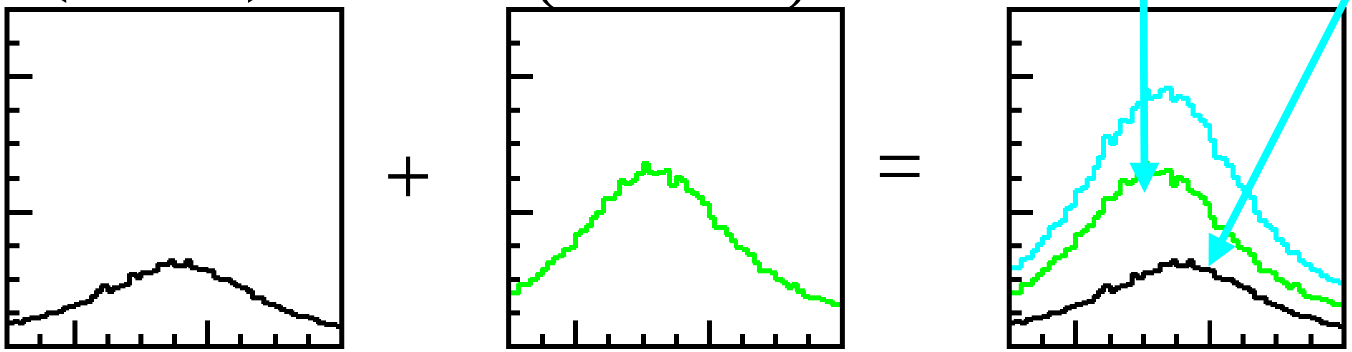


shorter-life meson(ρ) cases : Schematic picture

outside decay (natural)

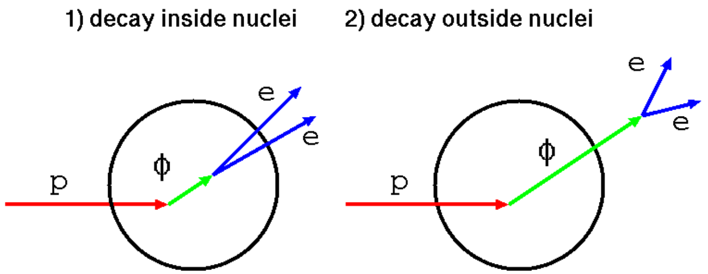
inside decay (modified)

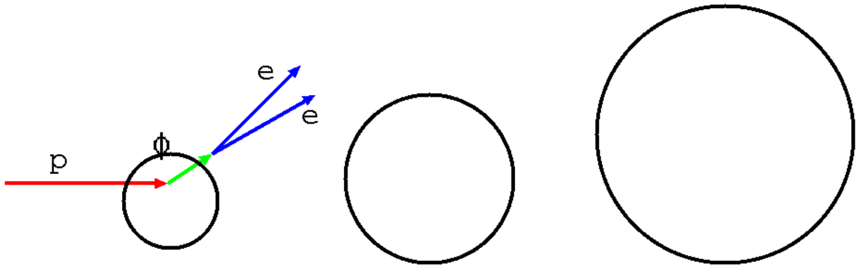


expected to be observed

(Expected e^+e^- spectra)

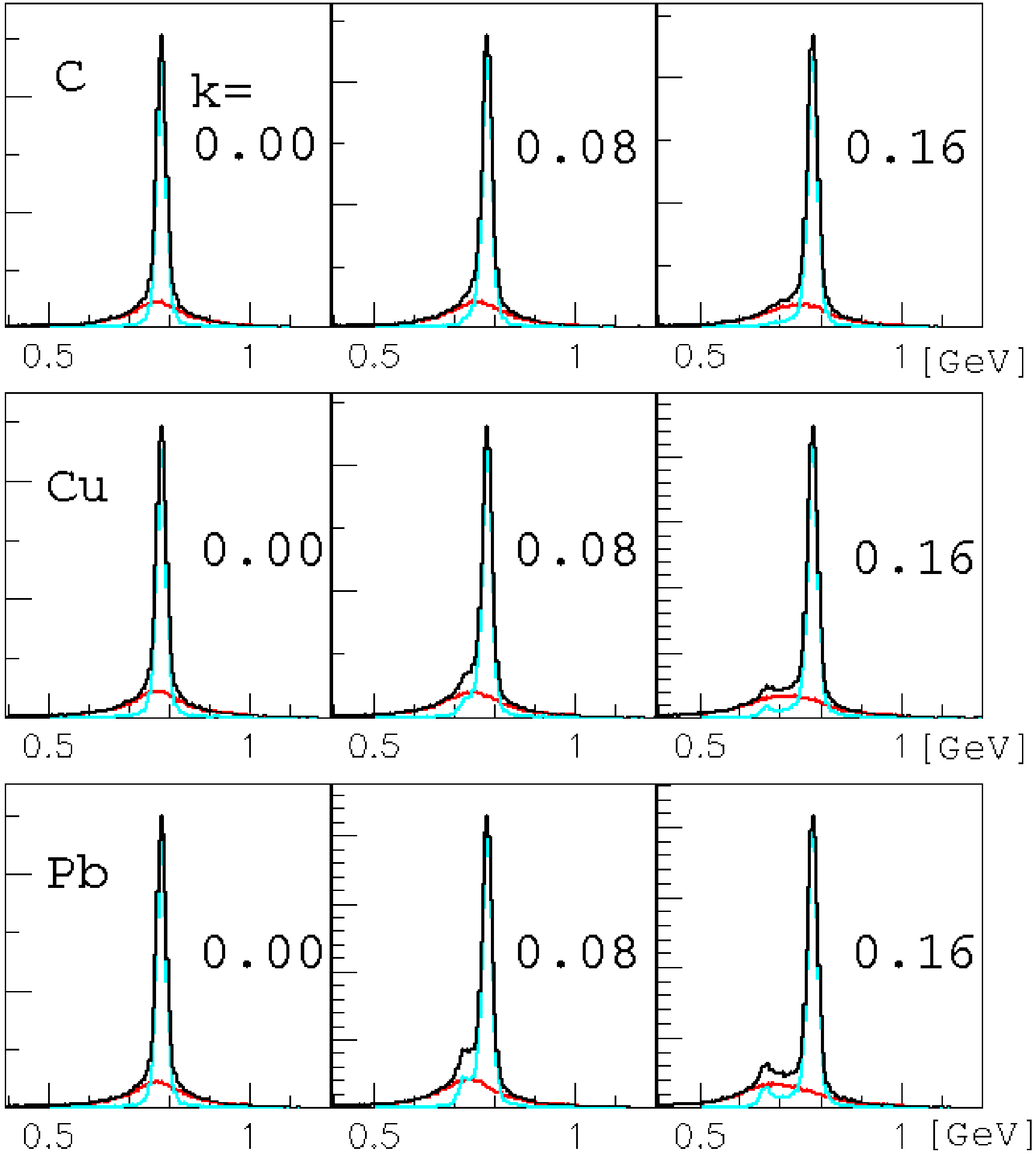
- ρ (770) & ω(783) :
  - larger production cross section
  - larger decay prob. inside nuclei
    - ρ : Γ=150MeV ~ 1.3fm
    - ω : Γ=8.4MeV ~ 24 fm
  - cannot distinguish ρ & ω in e^+e^-





C Cu Pb

(toy model calc.)



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  - larger production cross section
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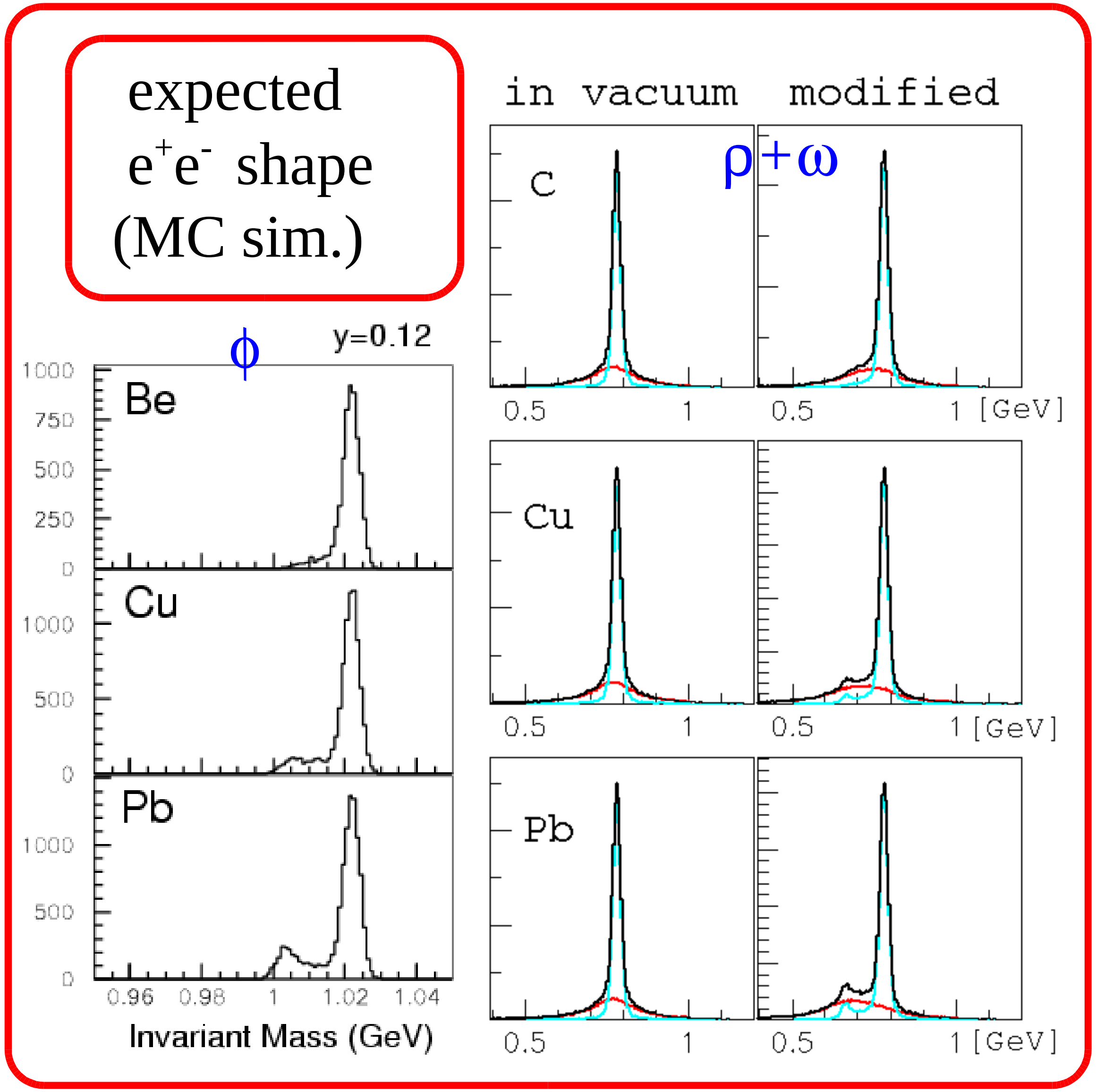
    - ρ : Γ=150MeV ~ 1.3fm
    - ω : Γ=8.4MeV ~ 24 fm
  - cannot distinguish ρ & ω in e^+e^-
- ϕ (1020) : narrow width
  - smaller decay prob. inside nuclei
    - ϕ : Γ=4.3MeV ~ 46 fm
  - smaller production cross section
-
- $L = \beta\gamma * c\tau = p/m * h/2\pi * c/\Gamma$



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 ($1<\beta\gamma<3$)

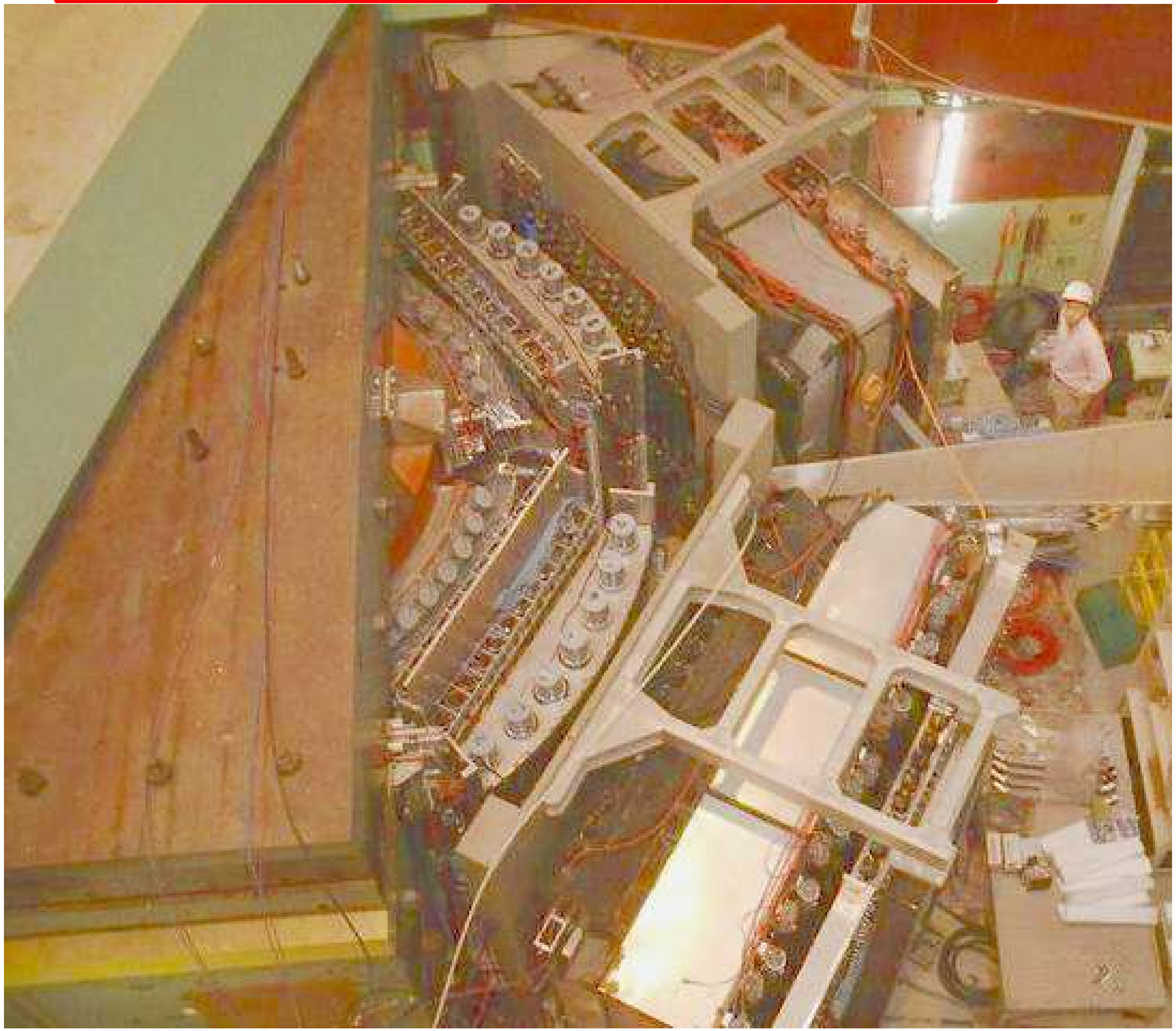
Collaboration

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
      - PRL96(06)092301
      - nucl-ex/0511019
  - '02 completed
  - spectrometer paper
    - NIM A516(04)390

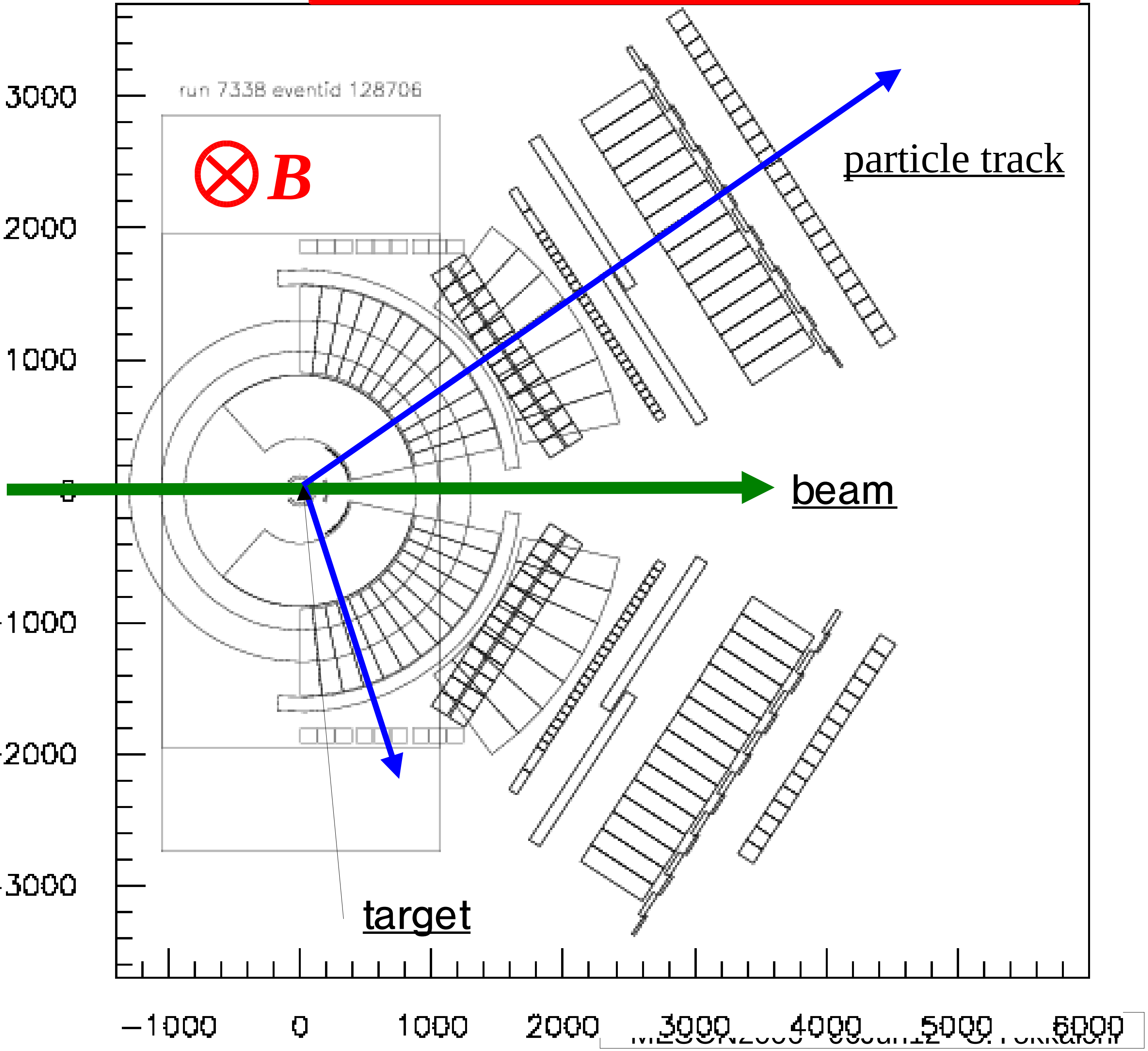
E325 spectrometer
located at KEK-PS EP1-B primary beam line



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

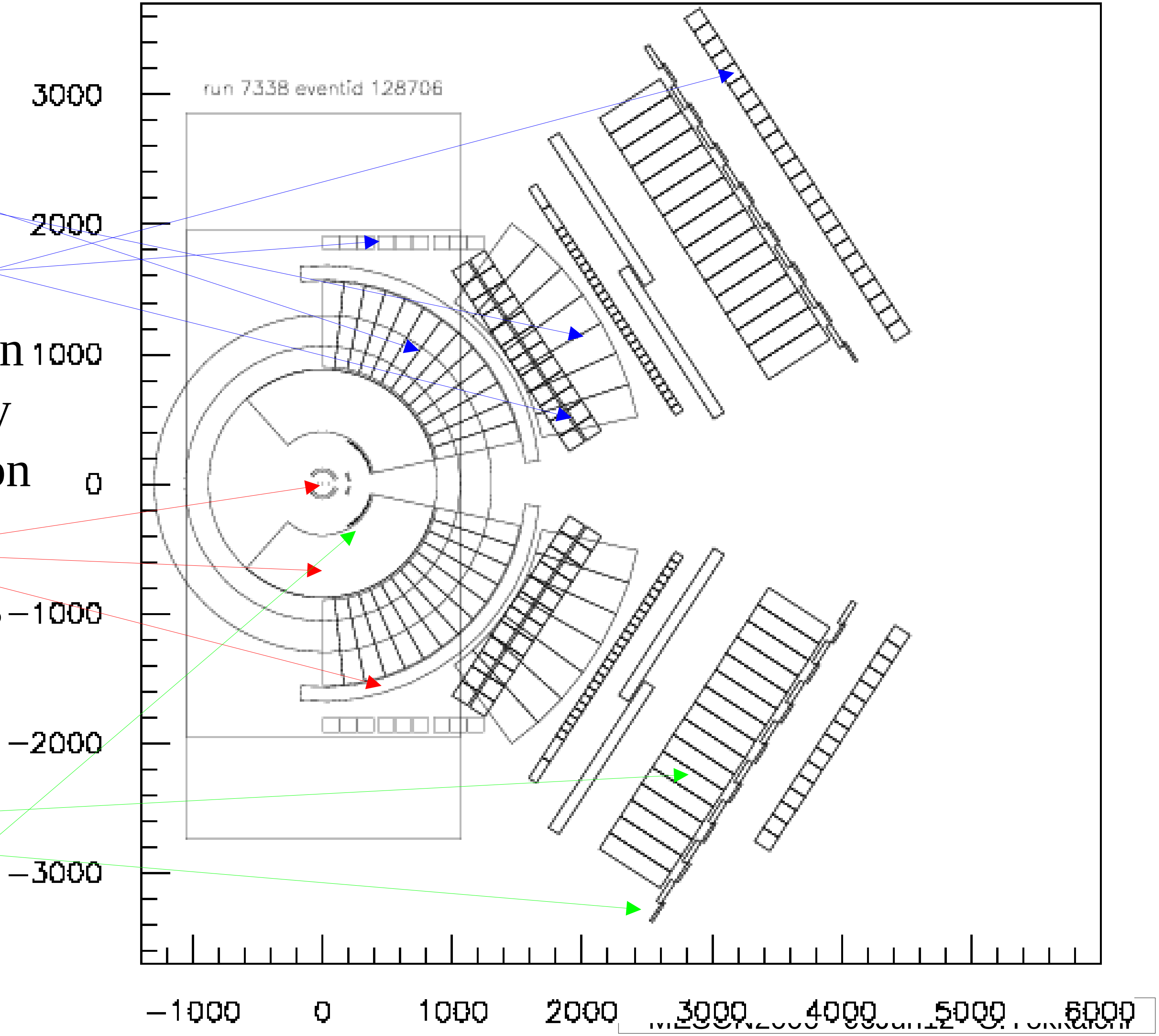
Tracker

Three Drift Chambers

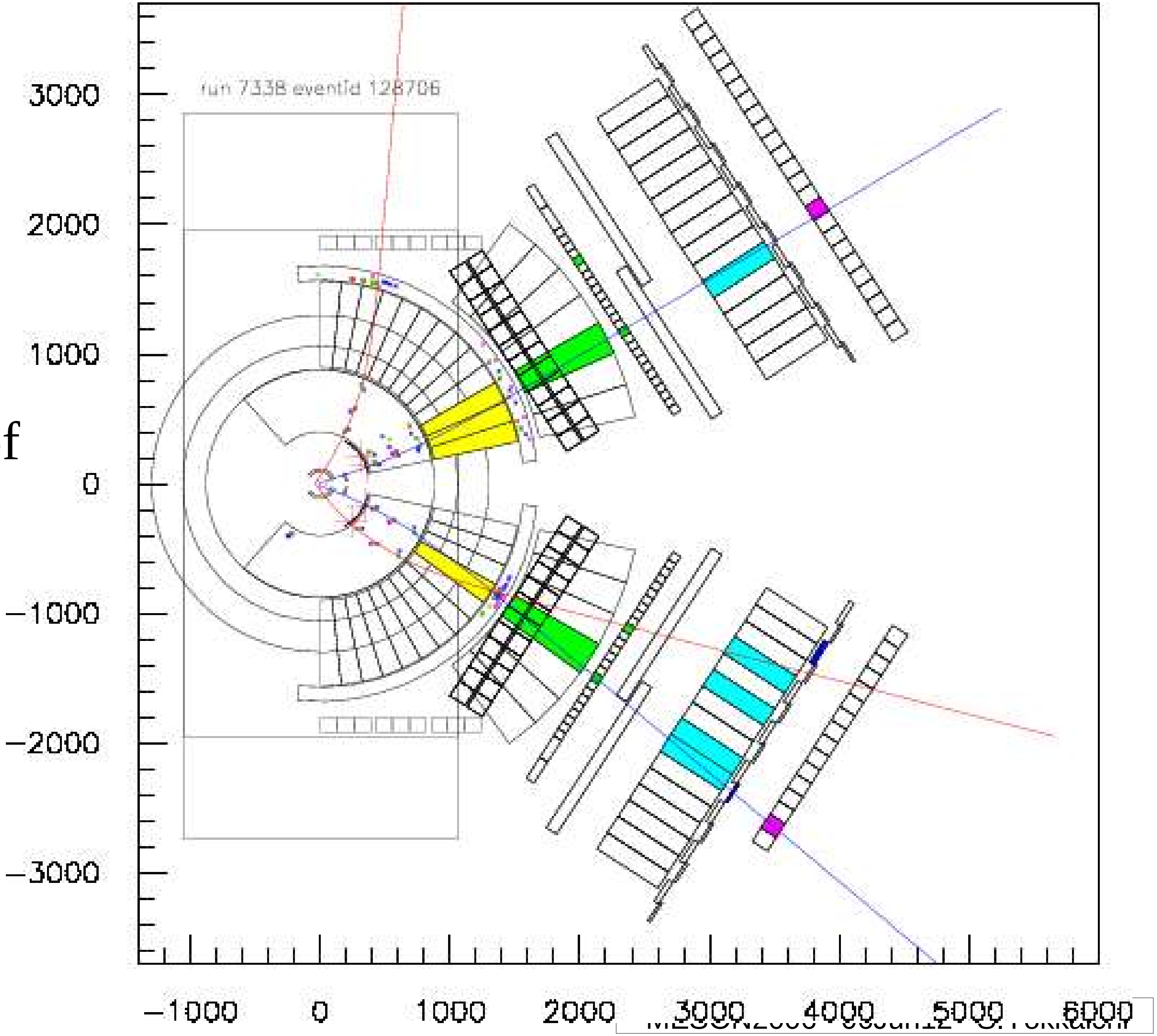
Kaon ID counters

Aerogel Cherenkov

& TOF



- Typical e^+e^- Event
  - blue:electron
  - red : other
  - invariant mass and momentum of mother particle can be calculated



Result (1)

ee invariant mass spectra

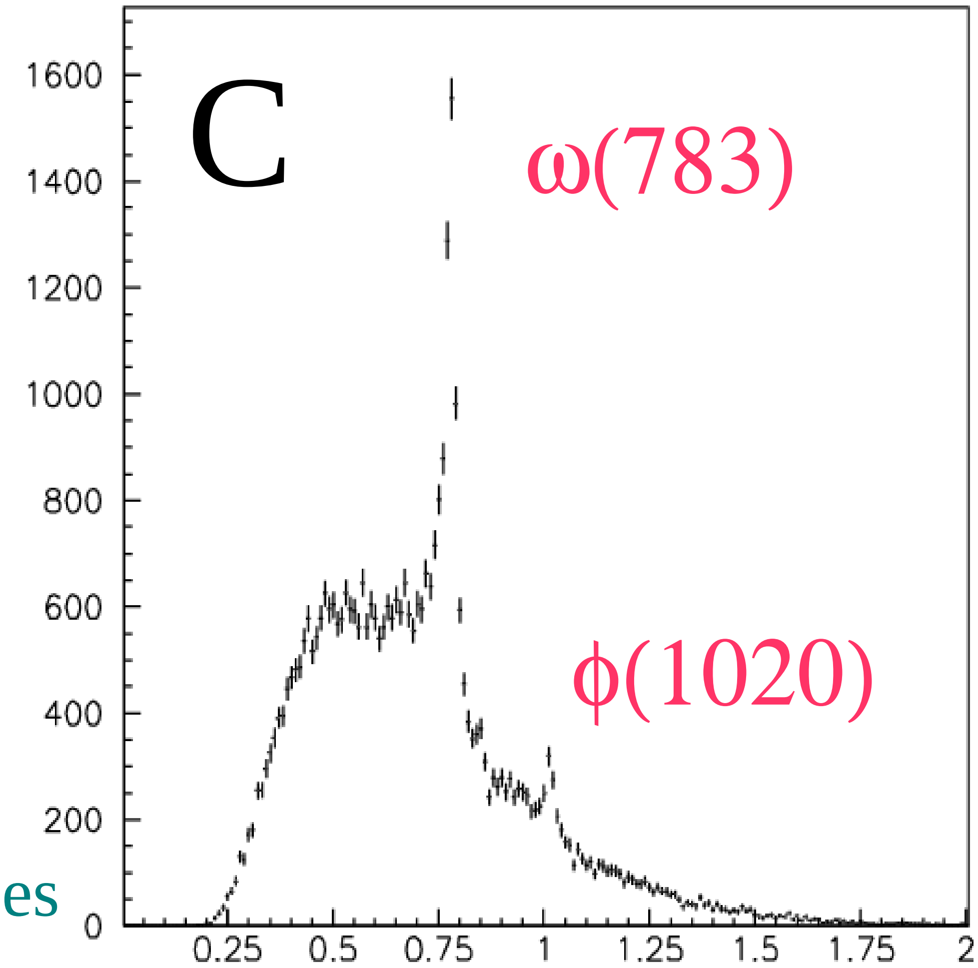
M. Naruki et al.,

PRL 96 (2006) 092301

(nucl-ex/050416)

Observed e^+e^- invariant mass spectra

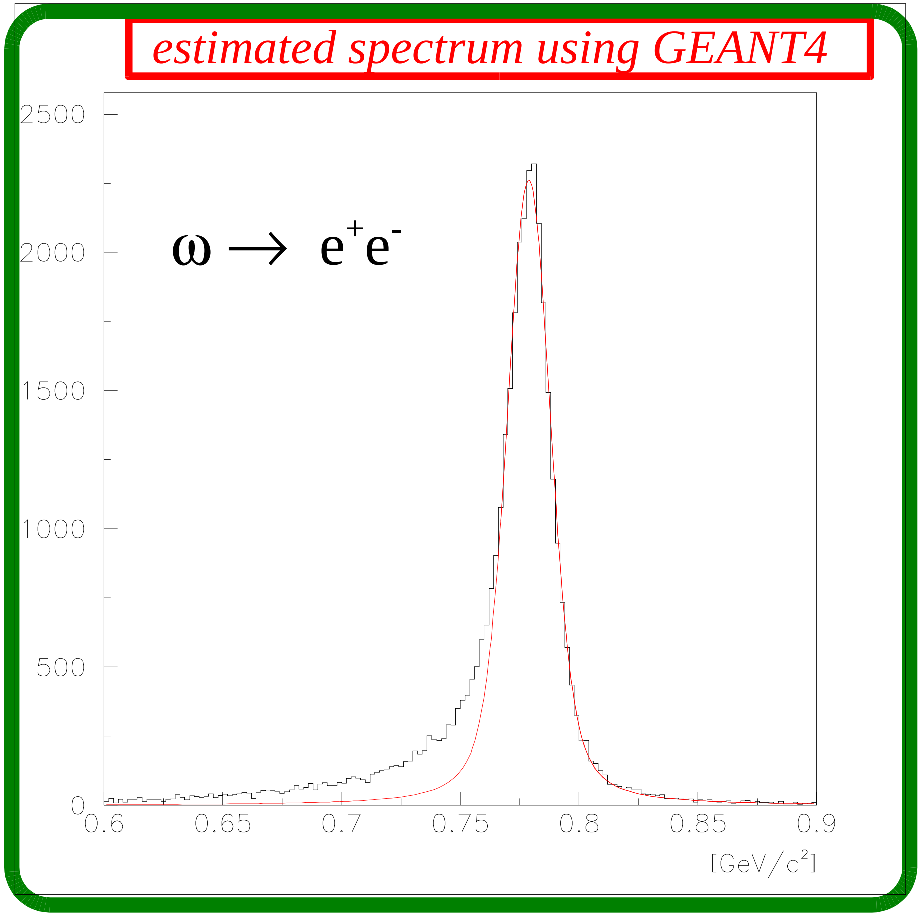
- from 2002 run data (~70% of total data)
- C & Cu target
- clear resonance peaks
- m<0.2 GeV is suppressed by detector acceptance
- acceptance uncorrected



→ fit the spectra with known sources

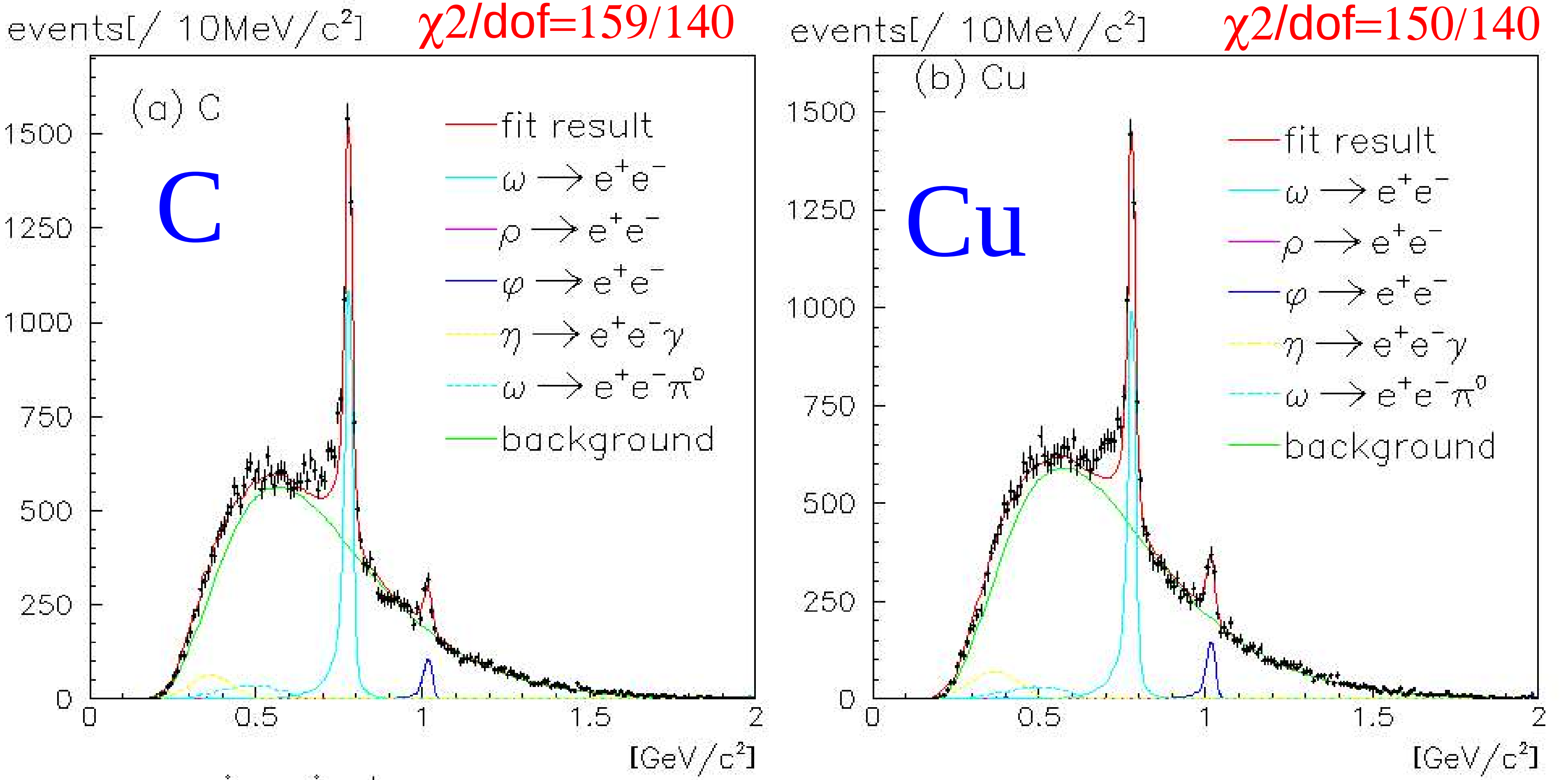
Fitting with known sources

- 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, but internal radiative corrections are included)
  - 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

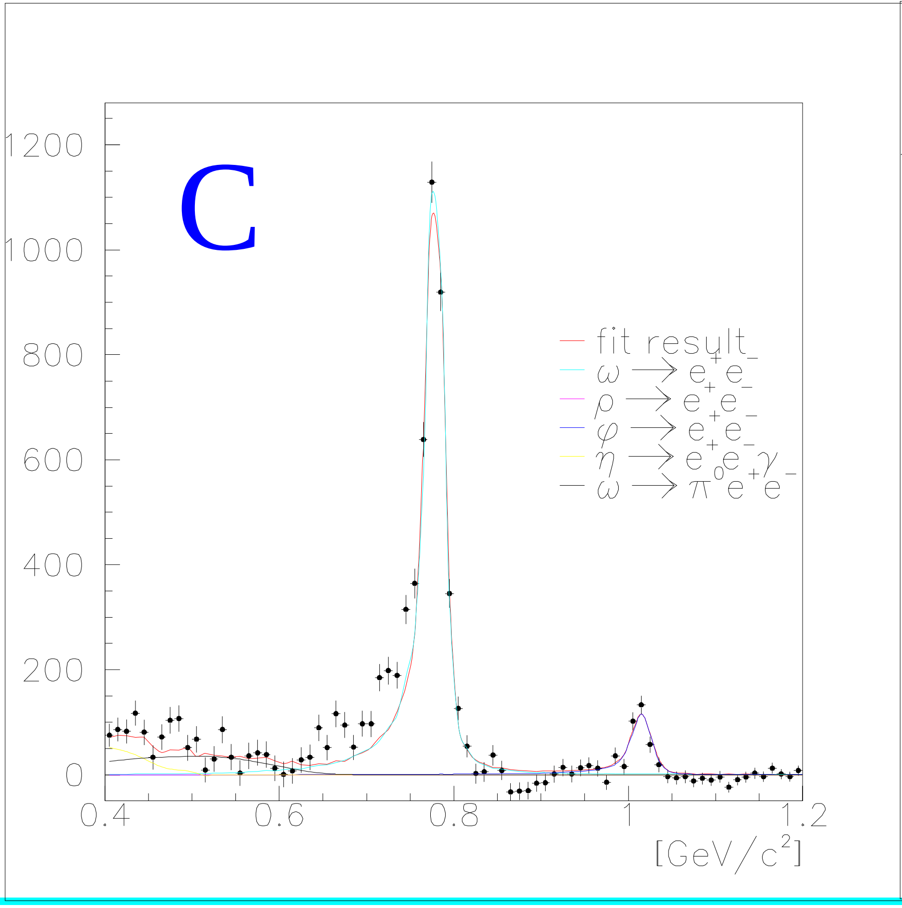
$\chi 2/dof=159/140$ $\chi 2/dof=150/140$

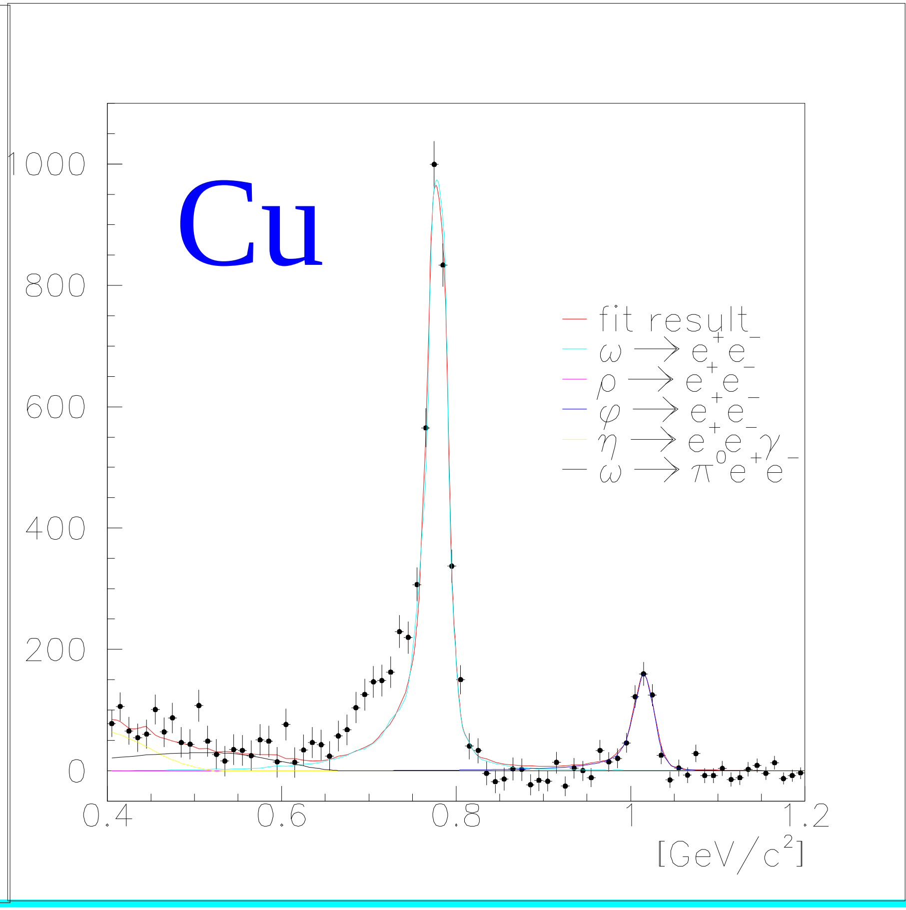


- 1) excess at the low-mass side of ω
  - To reploduce the data by the fitting, we have to exclude the excess region : 0.60~0.76 GeV
- 2) ρ–meson component seems to be vanished !

Fitting results (BKG subtracted)

ρ/ω <0.06 +0.09(syst.) , <0.08 + 0.21(syst.) (95%CL)





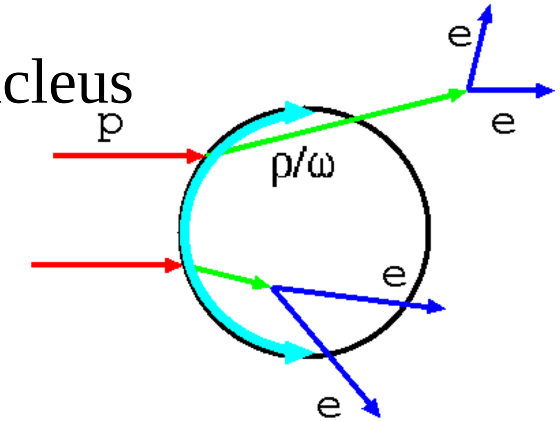
- However, ρ/ω =1.0±0.2 in former experiment (p+p, 1974)

...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 $\alpha \sim 2/3$ for ω [nucl-ex/0603013]
    - meson momentum :
      - measured distribution in our experiment
        - ~0.8 GeV < p < ~2.4GeV for ω
    - nuclear density distribution : Woods-Saxon type
    - ρ & ω meson modification form : $m^*/m_0 = 1 - k\, \rho/\rho_0$

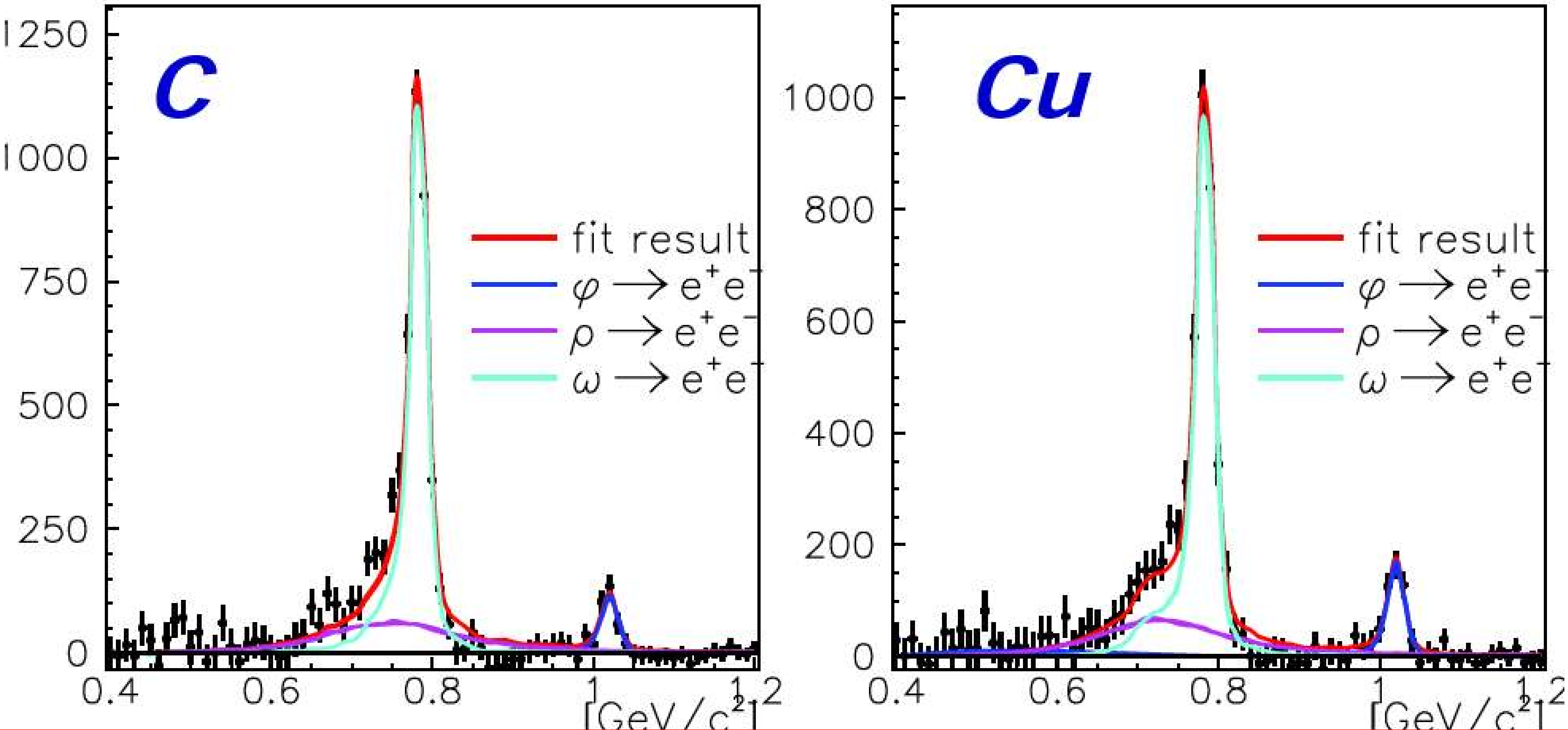
      (k=0.16±0.06 in Hatsuda & Lee, '92,'96)
    - (width modification & momentum dependence of modification are not taken into account this time)



Fitting results by the toy model

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

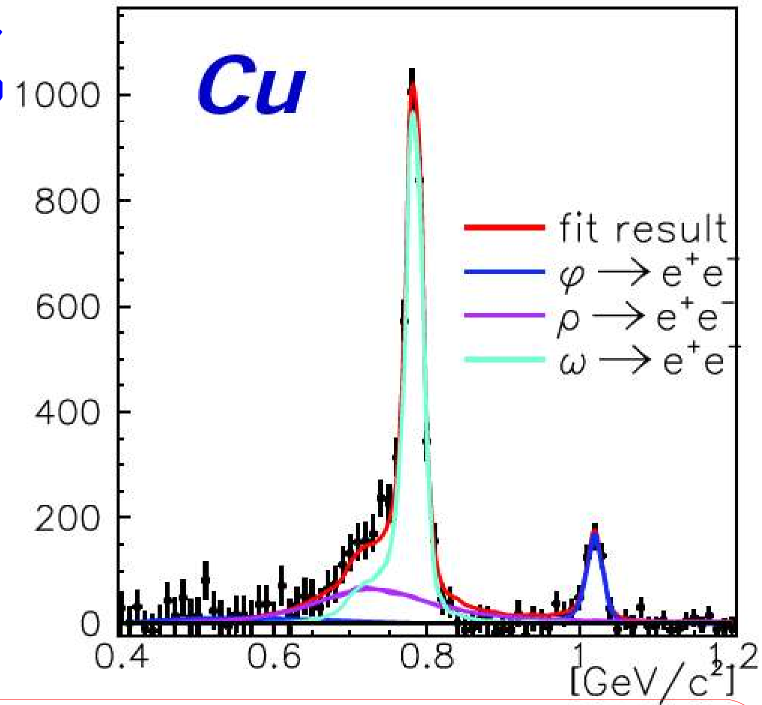
- modification paramter k for ρ and ω is common for C & Cu



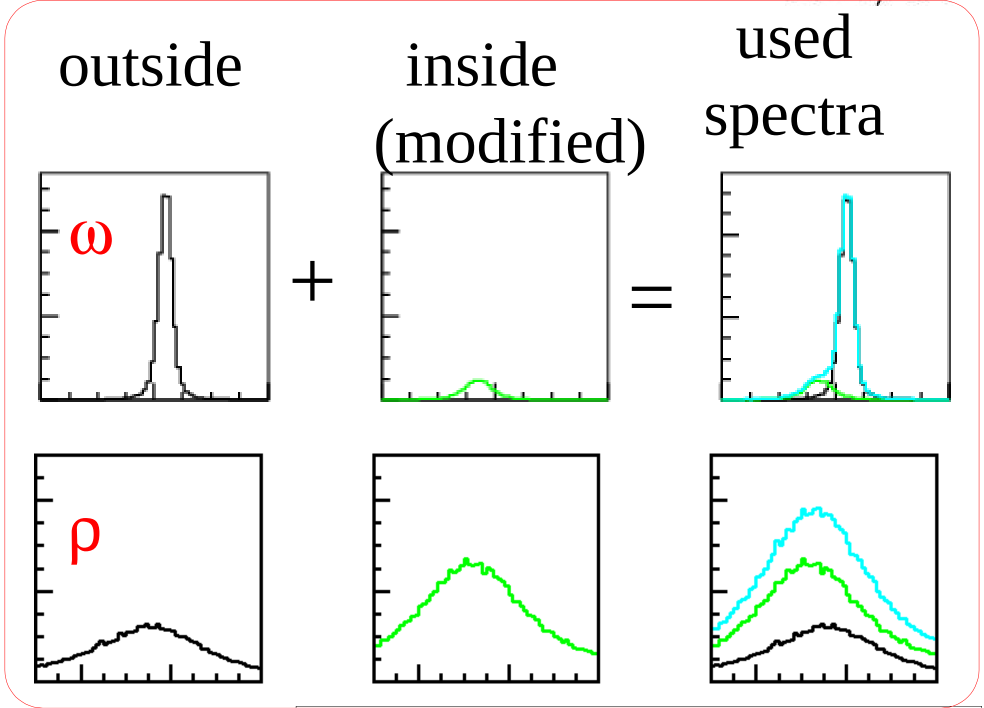
From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density

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

Remark on the model fitting

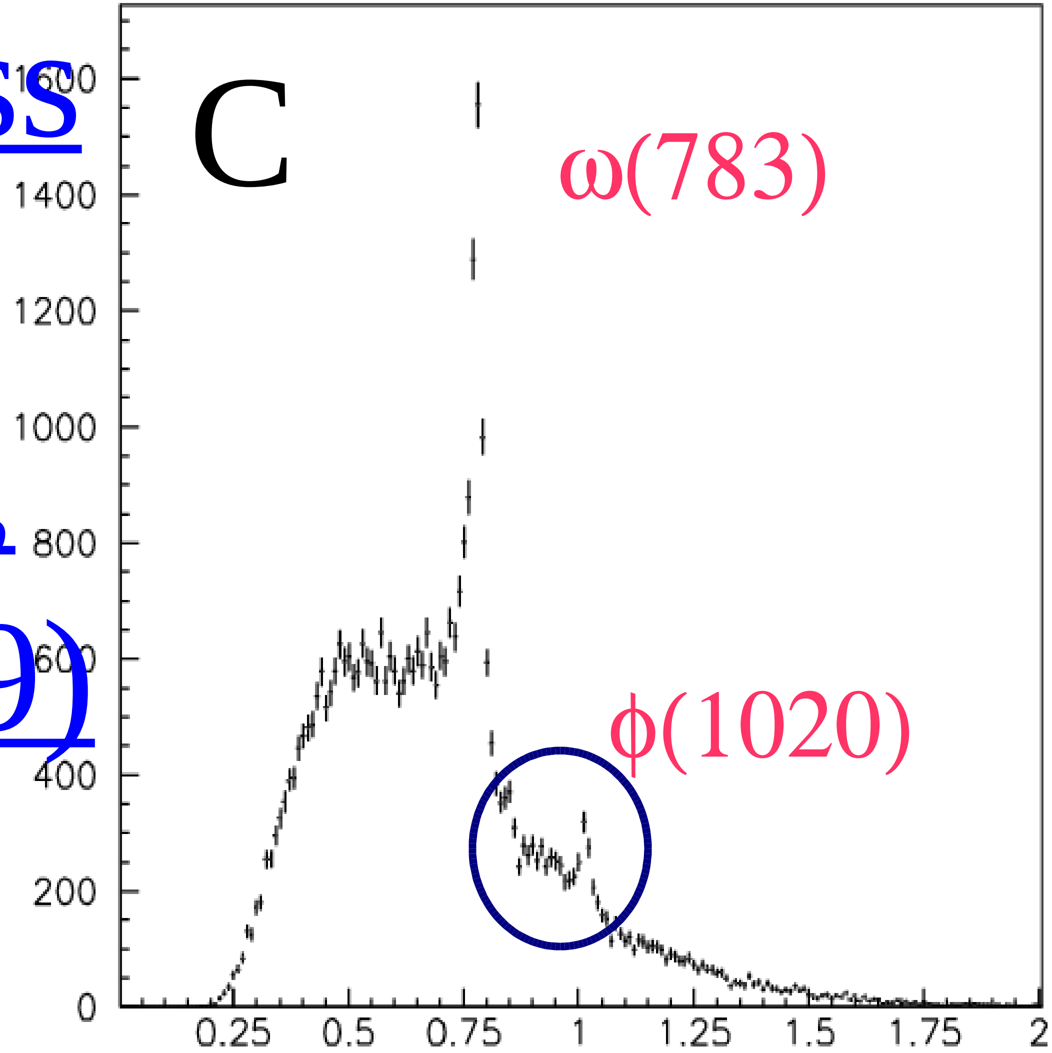


- constraint at right side of peak
  - Intoducing the width broadning (x2 & x3) are rejected by this costraint.
  - prediction of ' ρ mass increasing' is also not allowed.
- ρ (ω) decay inside nucleus : 46%(5%) for C, 61%(10%) for Cu
  - used spectrum is the sum of the modified and not-modified components.
- momentum dependence of mass shift is not included.(But typical p =1.5GeV/c)



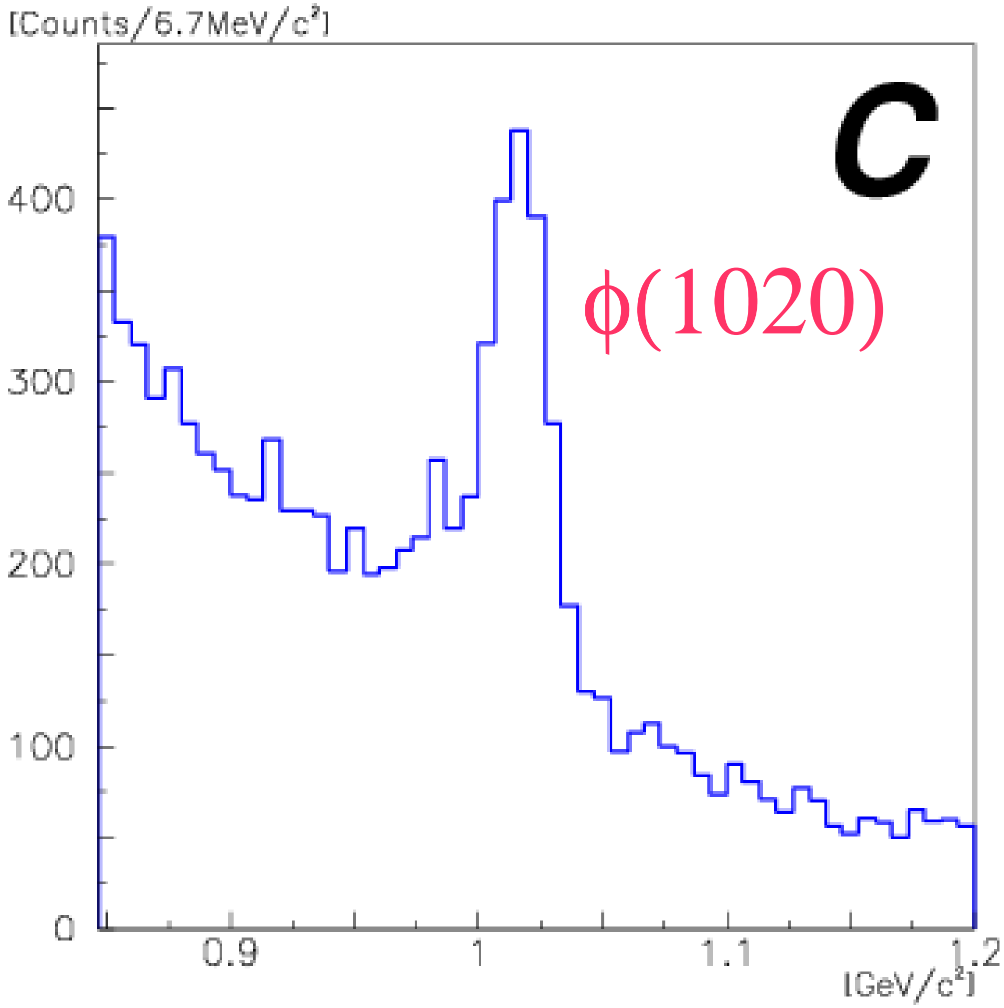
Result (2)

ee invariant mass spectra of ϕ (R. Muto et al., nucl-ex/0511019)



$\phi \rightarrow e^{+}e^{-}$ 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



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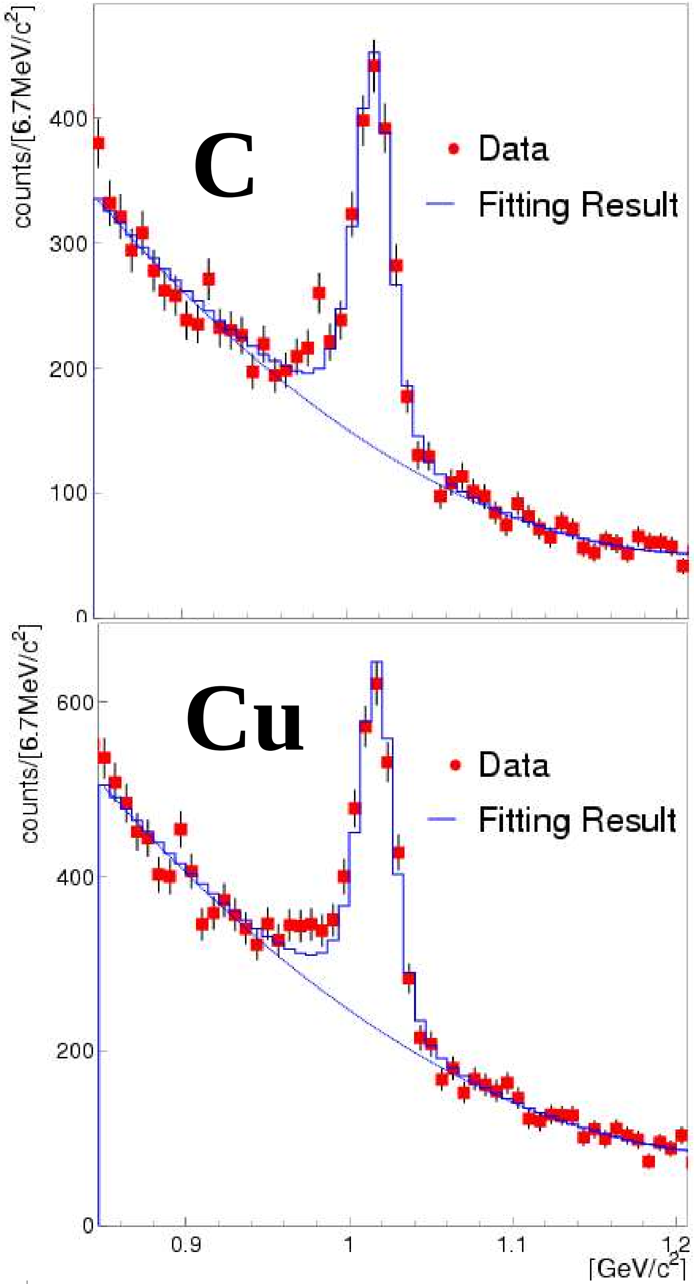
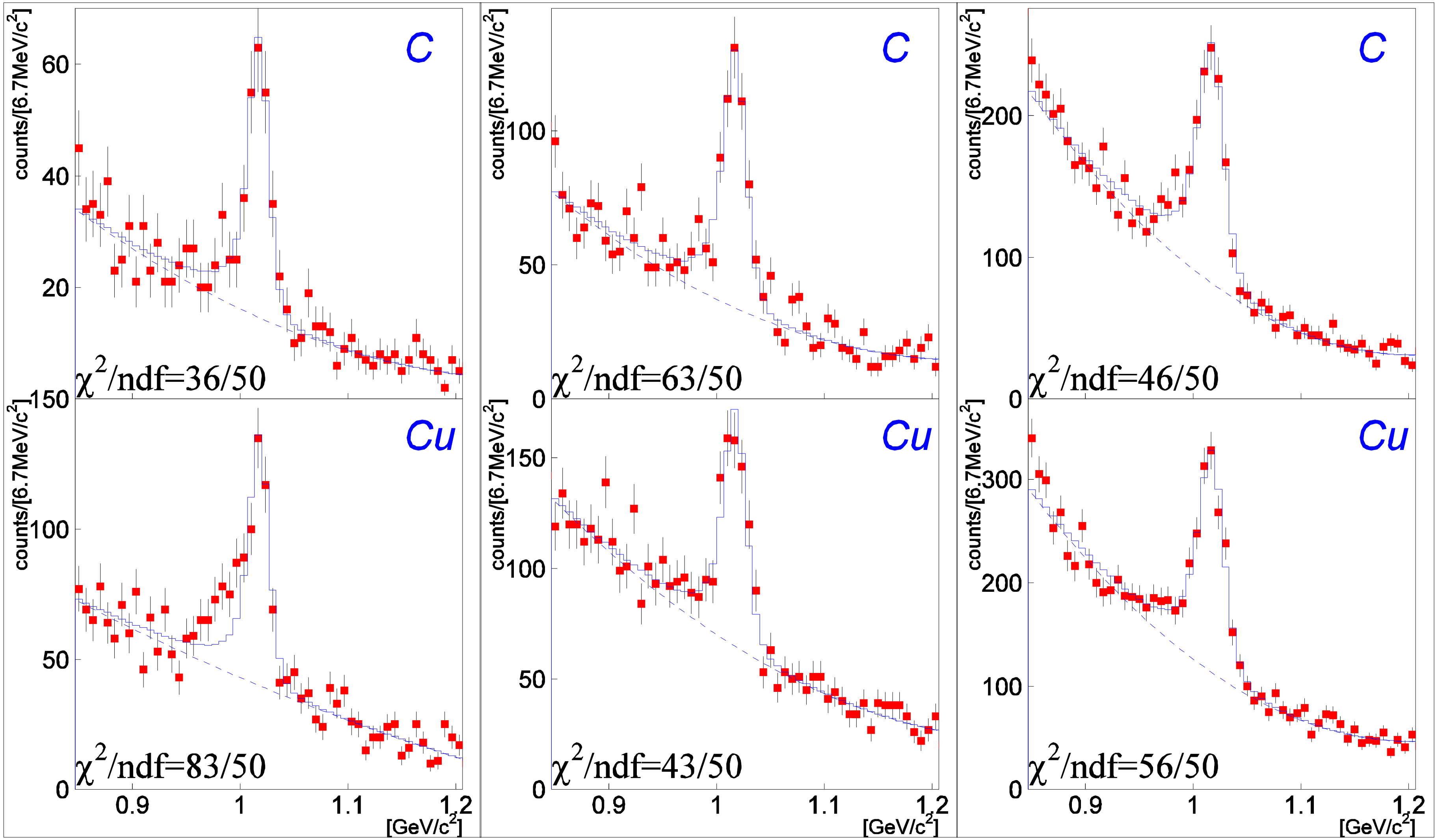
  - polinomial curve background
- examine the 'excess' is significant or not.
  - $\rightarrow$ see the $\beta\gamma$ dependence : excess could be enhanced for slowly moving mesons



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)



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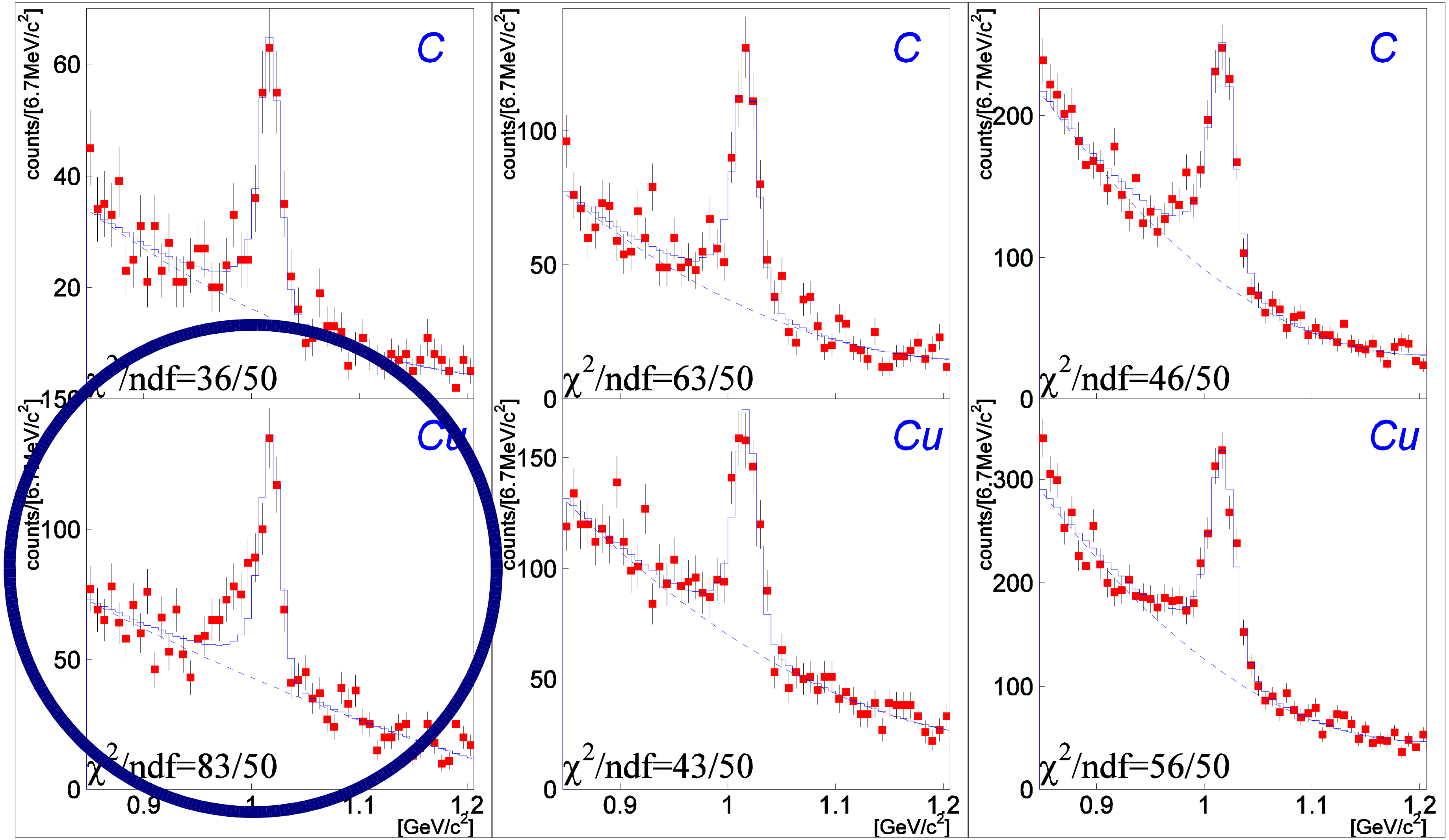
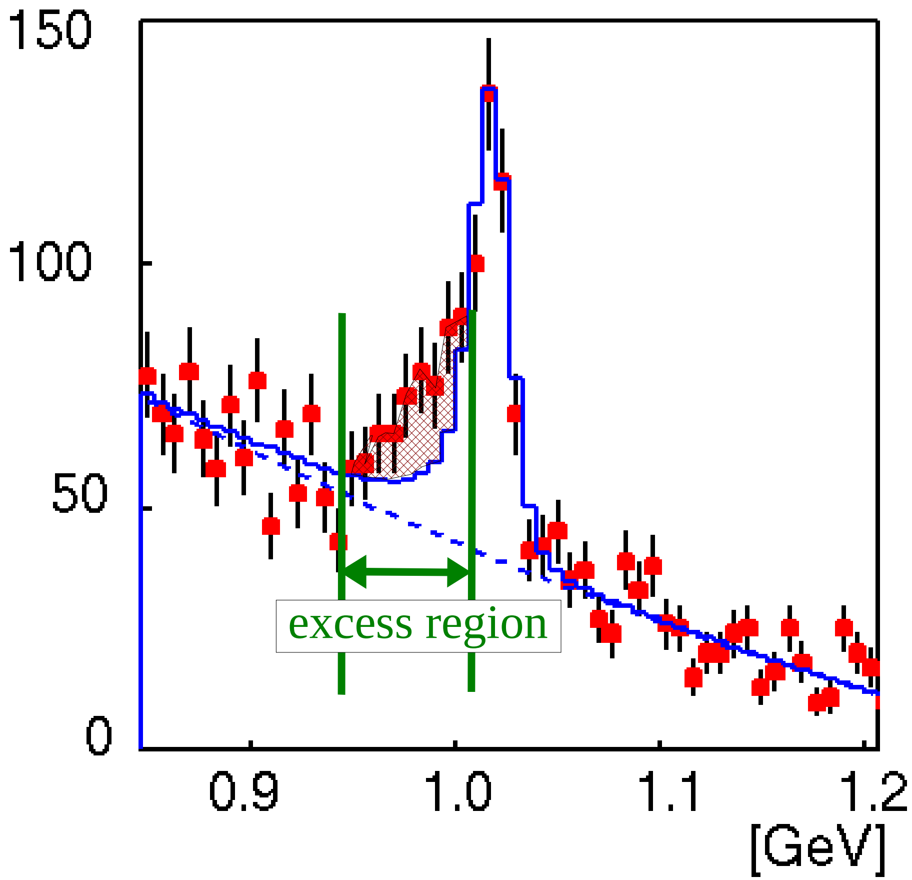


only slow/Cu is not reproduced in 99% C.L.

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.



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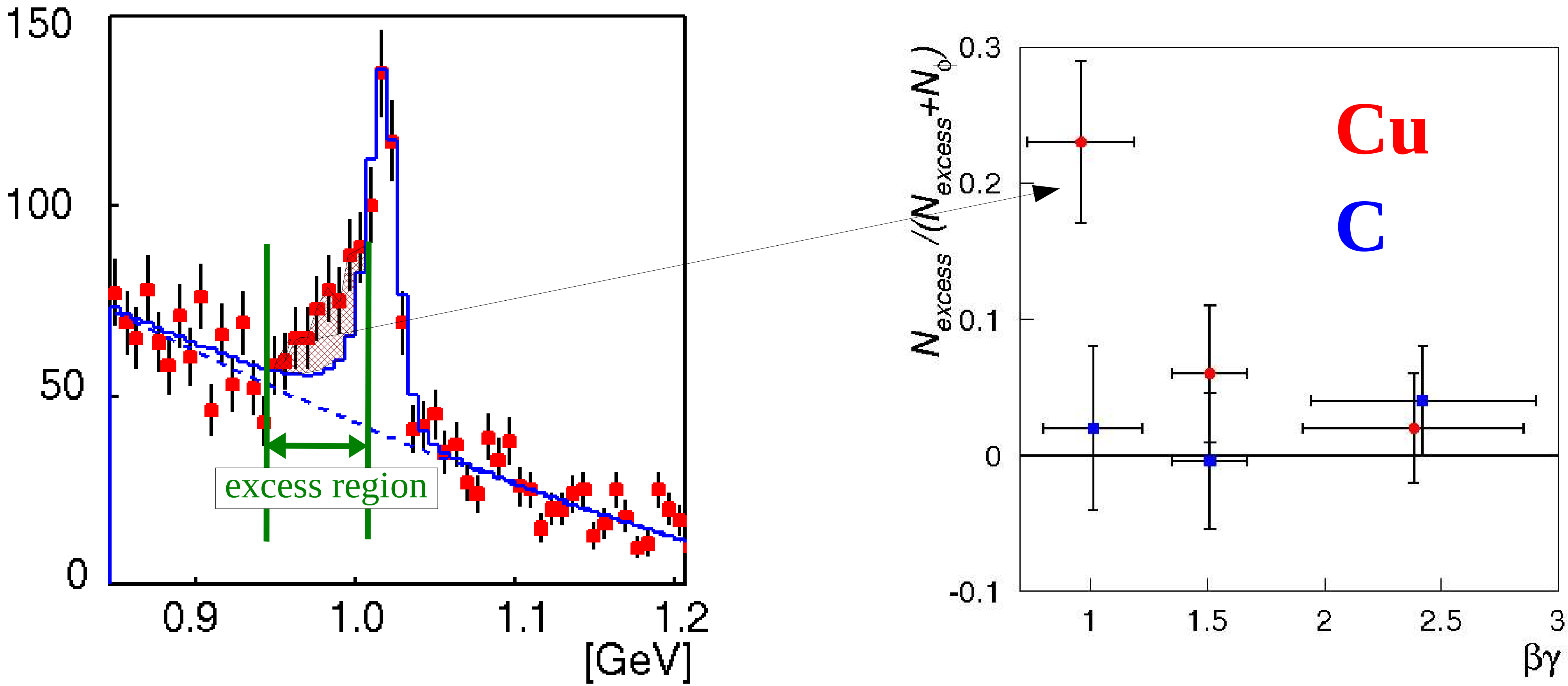

Amount of excess

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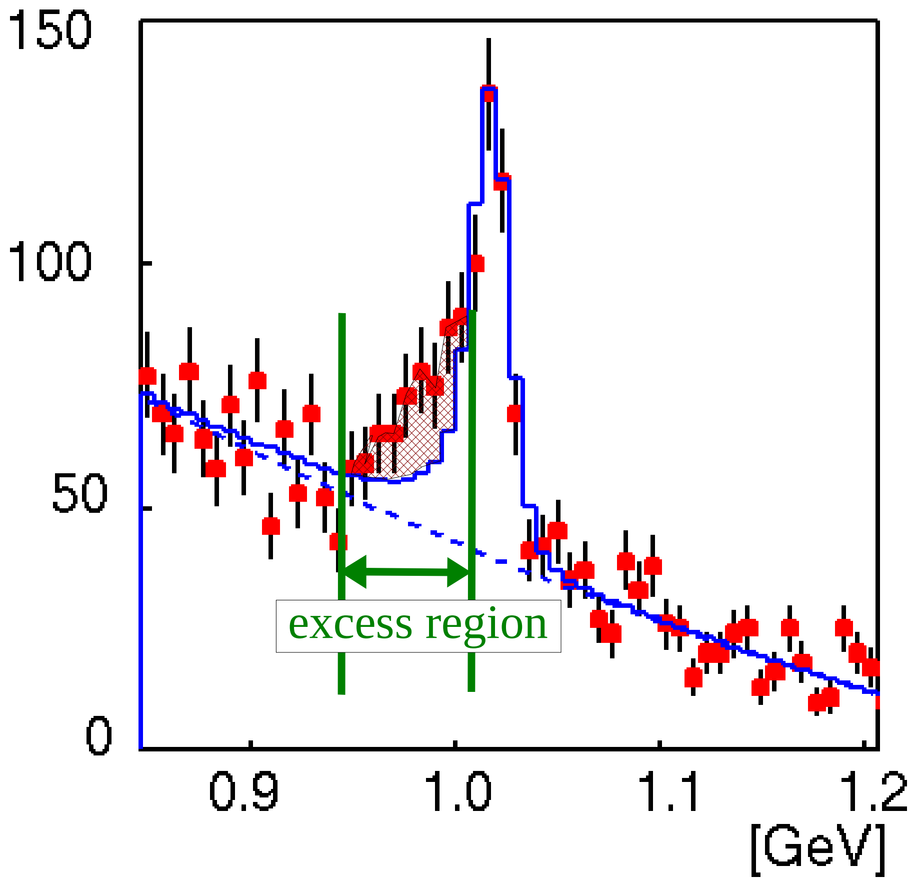
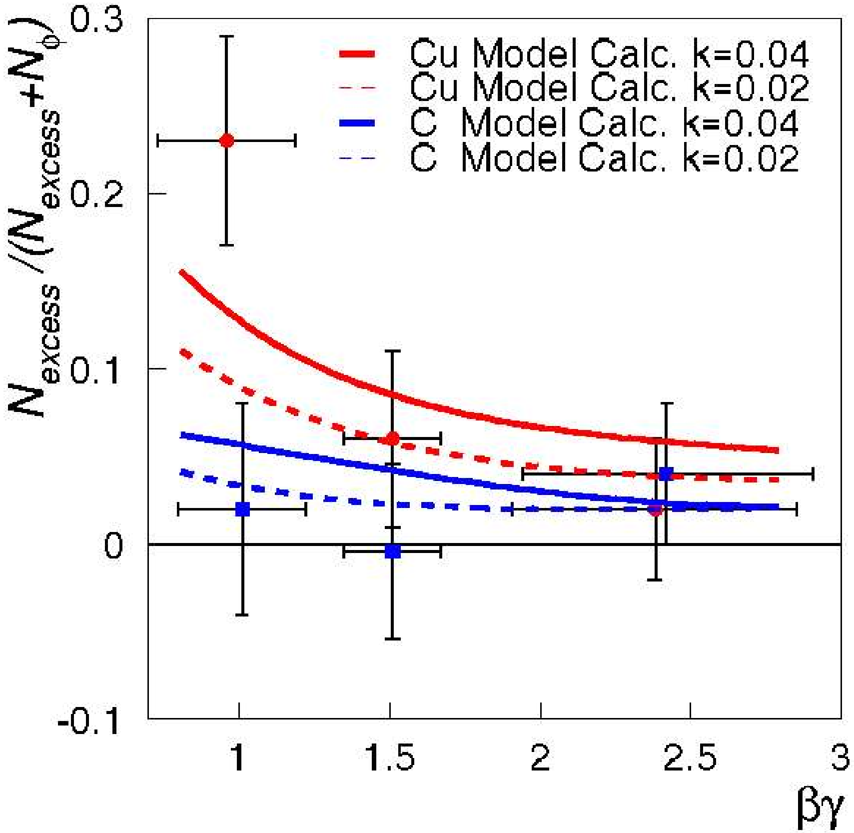
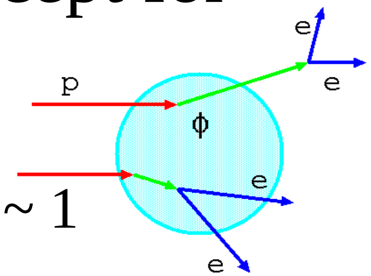
- Model calculation reproduces the tendency of N_{excess} / (N_{excess} + N_{ϕ})





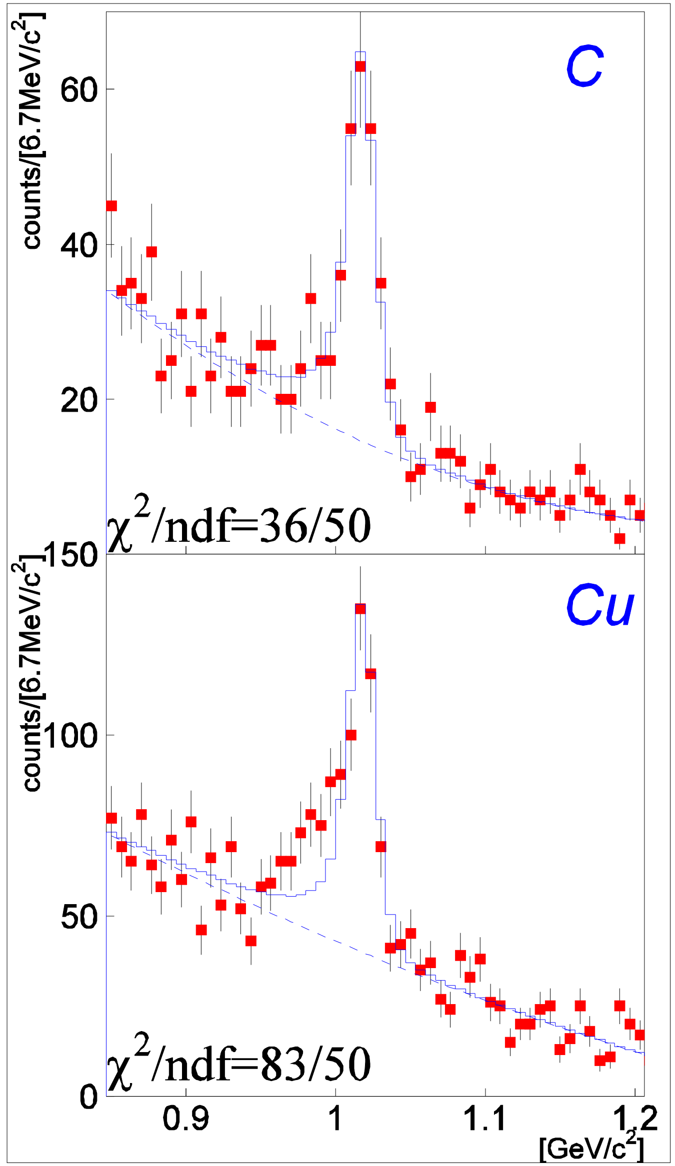
Toy model again for ϕ meson

- 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 broadening is adopted :
    $\Gamma_{tot}^{*}/\Gamma_{tot}^{0} = 1 + k_2\ \rho/\rho_0$
    - e^+e^- branching ratio is not changed
      - $\Gamma^*_{e+e-}/\Gamma^*_{tot} = \Gamma^0_{e+e-}/\Gamma^0_{tot}$
  - k_1 & k_2 is not free param., but fixed.
    - fits were done with many combinations of (k_1 , k_2) and data were well reproduced

βγ<1.25 (Slow) k_1=0,k_2=0



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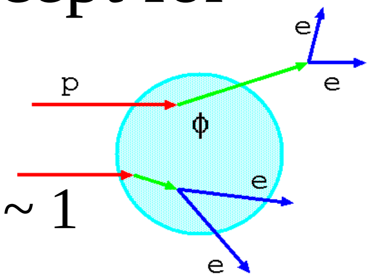

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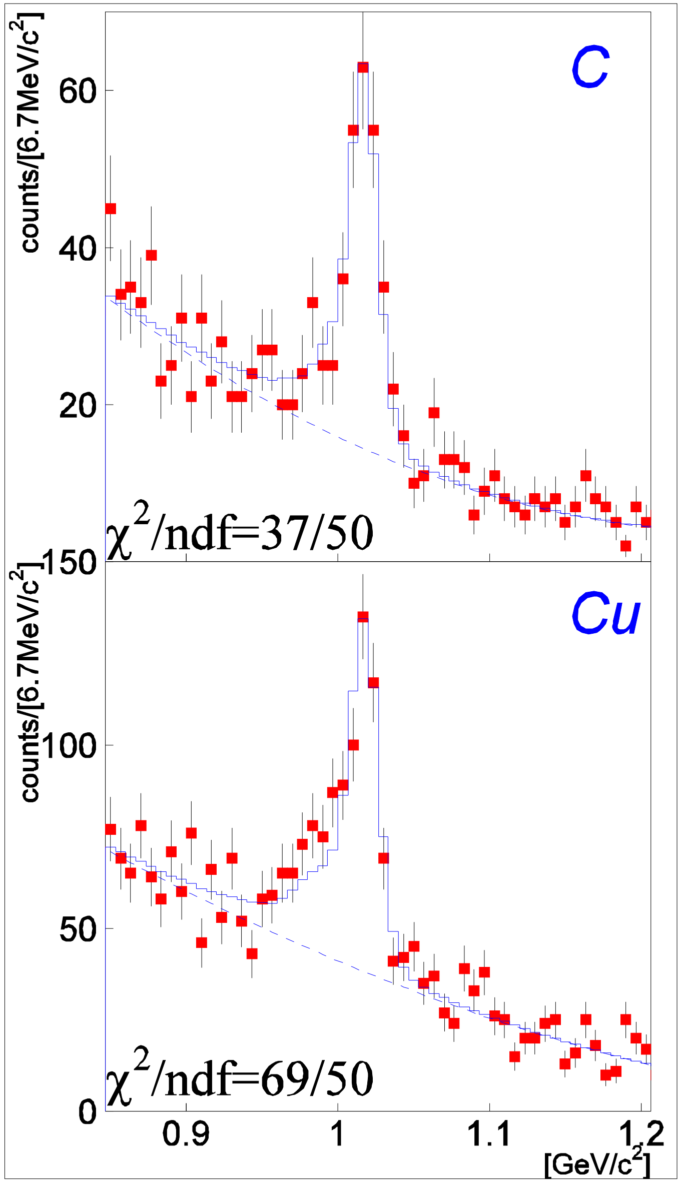
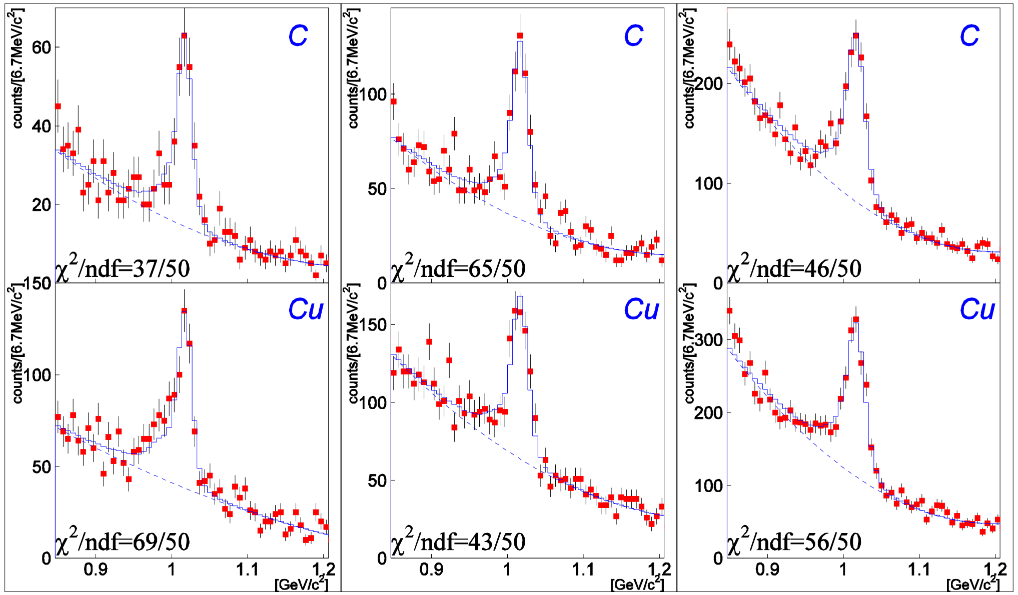
$\beta\gamma$<1.25 (Slow) k_1=0.04,k_2=2



Model fitting : parameter k_1 and k_2

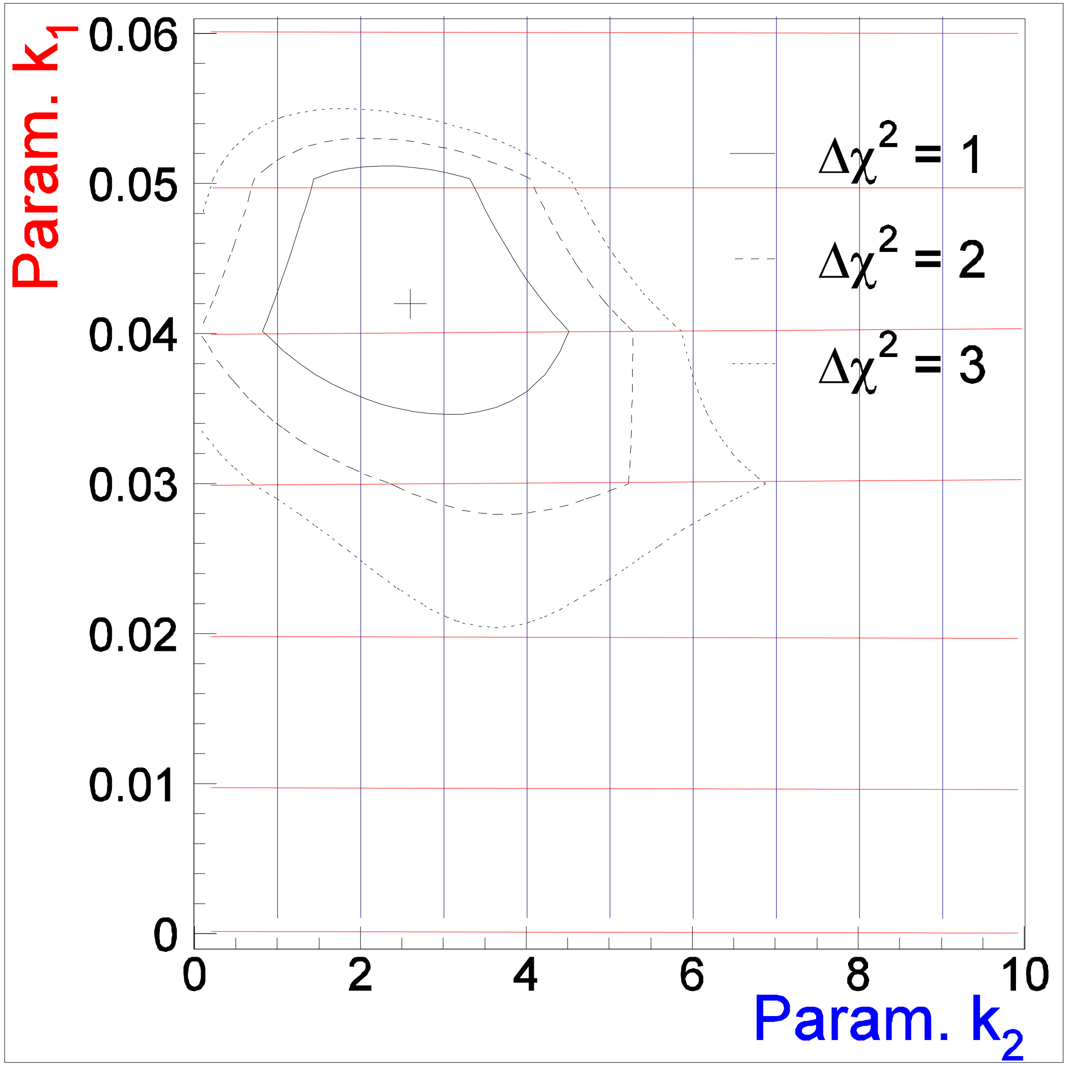
- To determine the shift parameters...
  - $m^*/m_0 = 1 - k_1\, \rho/\rho_0$
  - $\Gamma_{tot}^{*}/\Gamma^{0}_{tot} = 1 + k_2\, \rho/\rho_0$
- We fit the observed 6 mass spectra (C/Cu, slow/mid/fast) with modified MC shapes and calculate the χ^2 as the sum of 6 spectra



(k_1=0.04, k_2=2, χ^2=316)

Model fitting : parameter k_1 and k_2

- To determine the shift parameters...
  - $m^*/m_0 = 1 - k_1\ \rho/\rho_0$
  - $\Gamma_{tot}^{*}/\Gamma^0_{tot} = 1 + k_2\ \rho/\rho_0$
- We fit the observed 6 mass spectra (C/Cu, slow/mid/fast) with modified MC shapes and calculate the χ^2 as the sum of 6 spectra for each (k_1,k_2) combination on the grid and make the χ^2 contour



Best Fit Value:

k_1 = 0.042 +/- 0.008

(4.2 % mass decreasing at ρ_0)

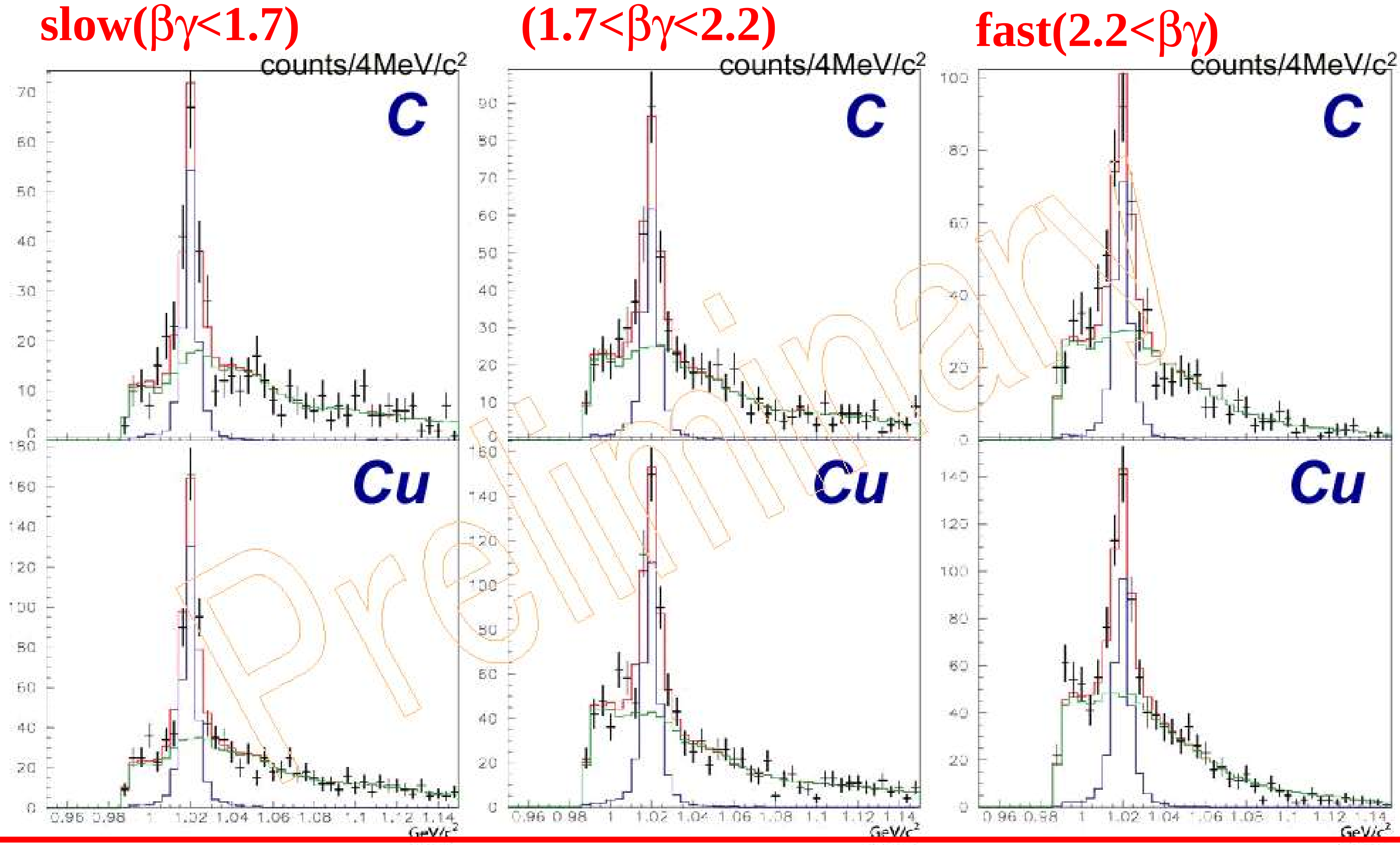
k_2 = 2.6 +/- 1.9

(3.6 times width broadening at ρ_0)

Result (3)

(KK invariant mass spectra by F. Sakuma)

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 $\phi \rightarrow e^+e^-$)

Proposed Experiment at J-PARC

What is J-PARC ?

(Japan Proton Accelerator Reserch Complex)

- KEK/JAERI joint project
- 50 GeV proton synchrotron is under construction at Tokai, Japan
  - first beam is planned in 2008
- Proposed experiments
    - hypernuclei
    - deeply bound K-nuclei and tribaryon
    - Pentaquark search
    - dimuon production mesurements
    - Neutrino physics
    - .... etc.
    - And our project : **electron pair spectrometer**

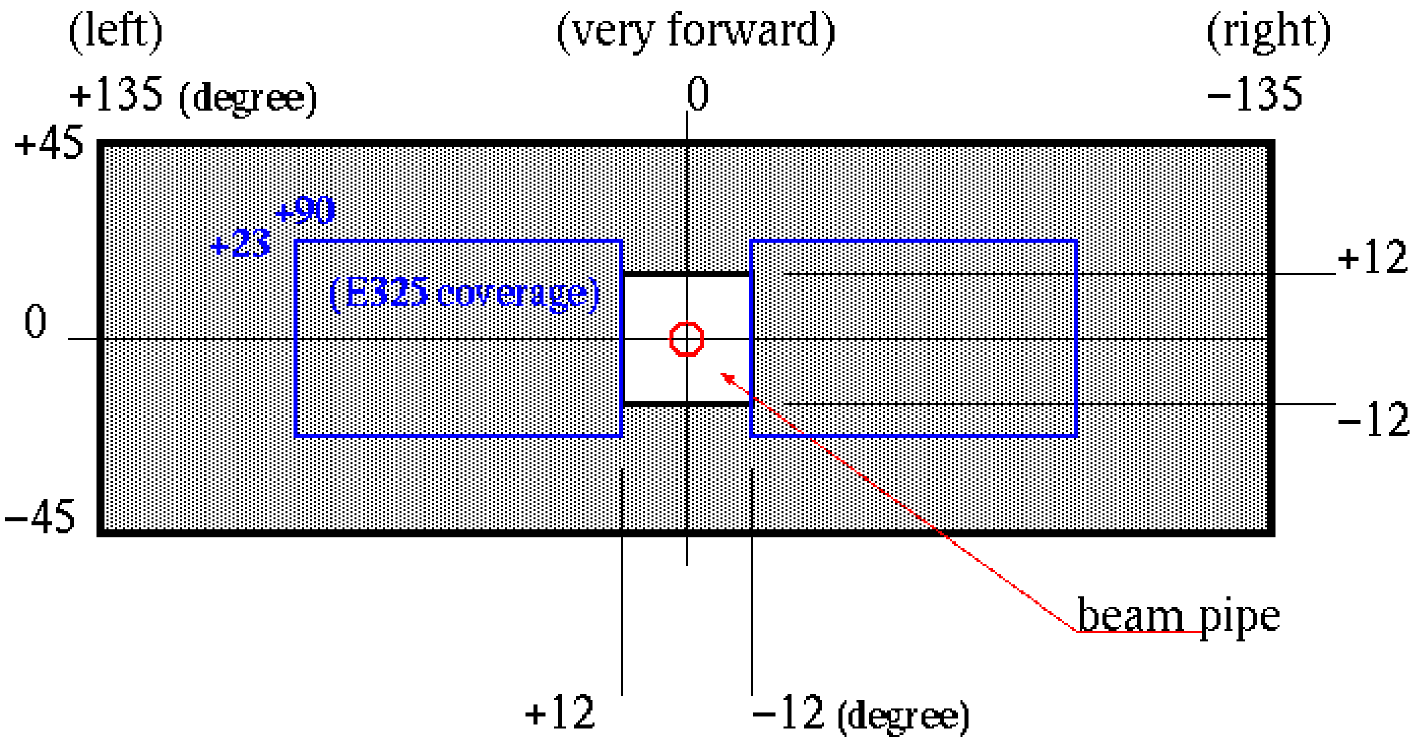
Next generation experiment at J-PARC

- Same concept as E325
  - thin target / primary beam (10^9 ~10^{10} ppp)/ slowly moving mesons
- Main goal : collect ~1 x 10^5 $\phi \rightarrow ee$ for each target in 5 weeks
  - ~100 times as large as E325
    - velocity dependence of 'modified' component
    - new nuclear targets : proton (CH_2 -C subtraction), Pb
    - collision geometry for larger nucleus target
  - narrow width -> sensitive to modification
- ρ ,ω and J/ψ can be collected at the same time
  - higher statistics of ρ and ω than E325 with different nuclear targets
  - 100-1000 J/ψ are expected in 50GeV operation
- Normal nuclear density (p+A)
  - but also high matter density (A+A, ~20GeV/u)

To collect high statistics

- To cover larger acceptance : x5
- Higher energy beam (12 → 30/50 GeV) : x2
- Higher intensity beam ($10^9 \rightarrow 10^{10}$ Hz) : x10

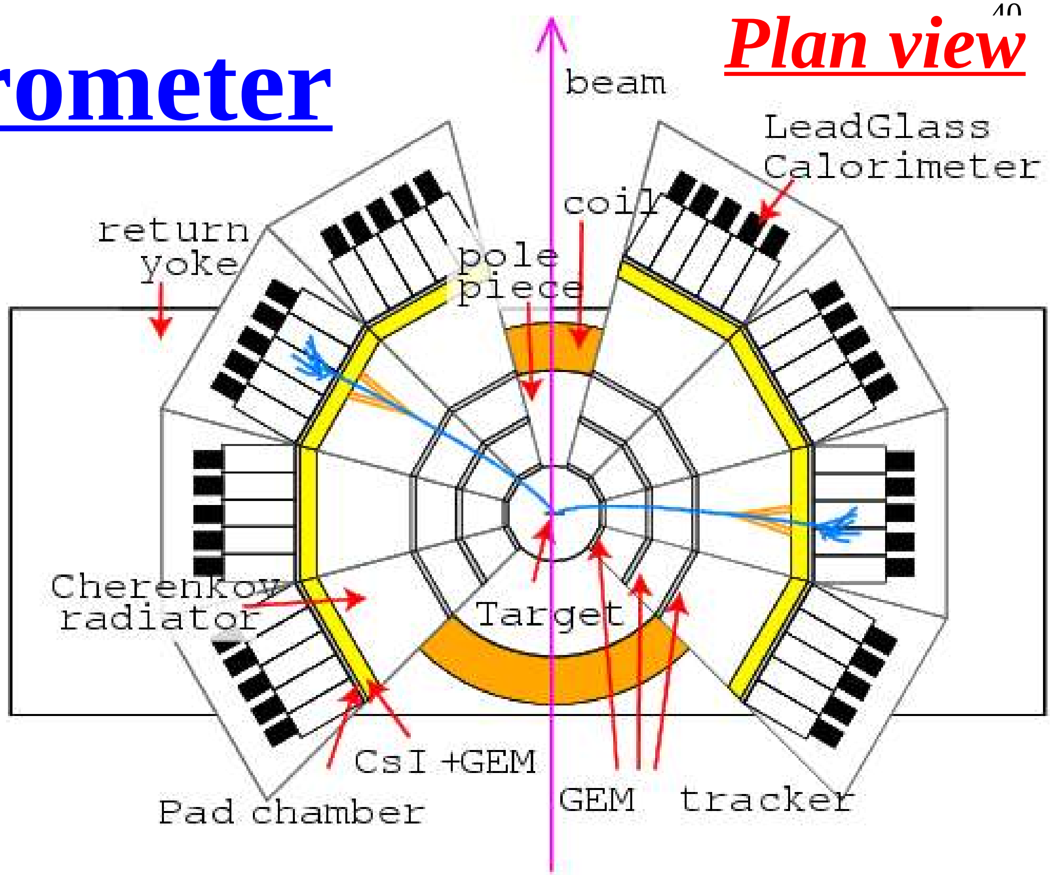
Geometrical (horizontal & vertical) coverage
of the spectrometer

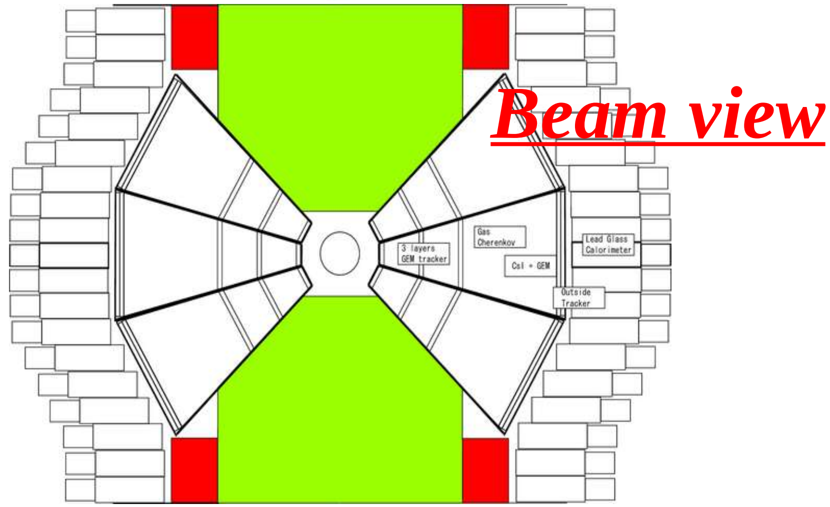


Proposed spectrometer

- Tracking Device
  - GEM(Gas electron multiplier)
    - 0.7mm pitch strip readout
- Two-stage Electron ID
  - Gas Cherenkov
    - GEM+CsI photocathode
      - pad readout
  - Leadglass EMC
- ~70K Readout Channels (in 27 units)
  - E325: 3.6K, PHENIX:~300K
- Cost : ~$5M (including $2M electronics)
  - 2 times of E325

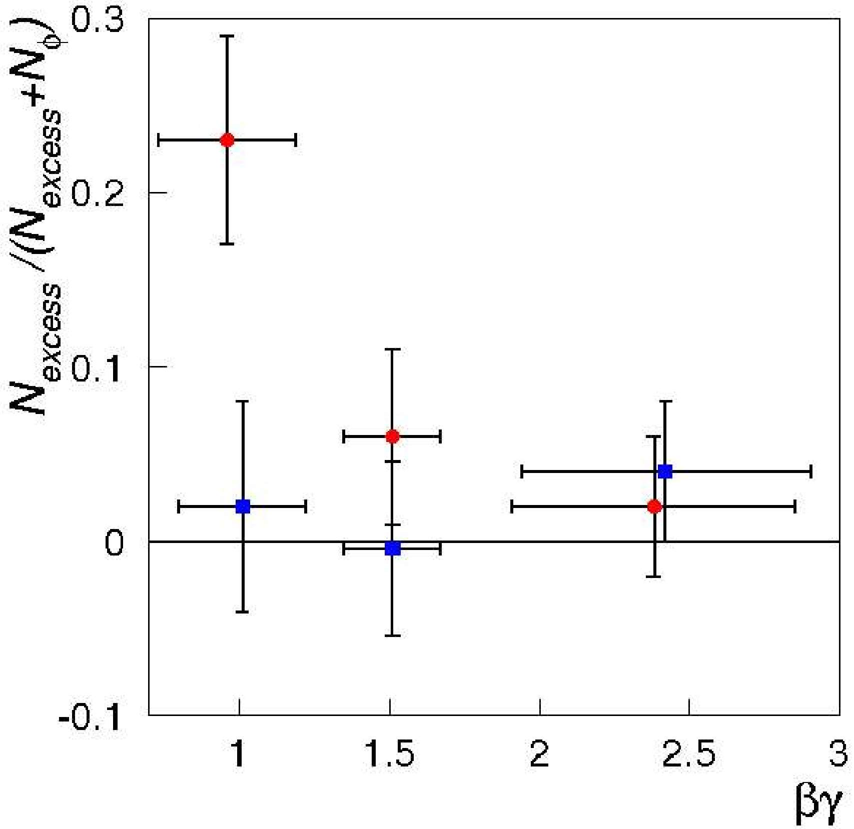
Plan view





high statistics

- Main goal : collect ~1×10^5 $\phi \rightarrow ee$ for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of 'modified' component



high statistics

- Main goal : collect ~1x10^5 $\phi \rightarrow ee$ for each target in 5 weeks
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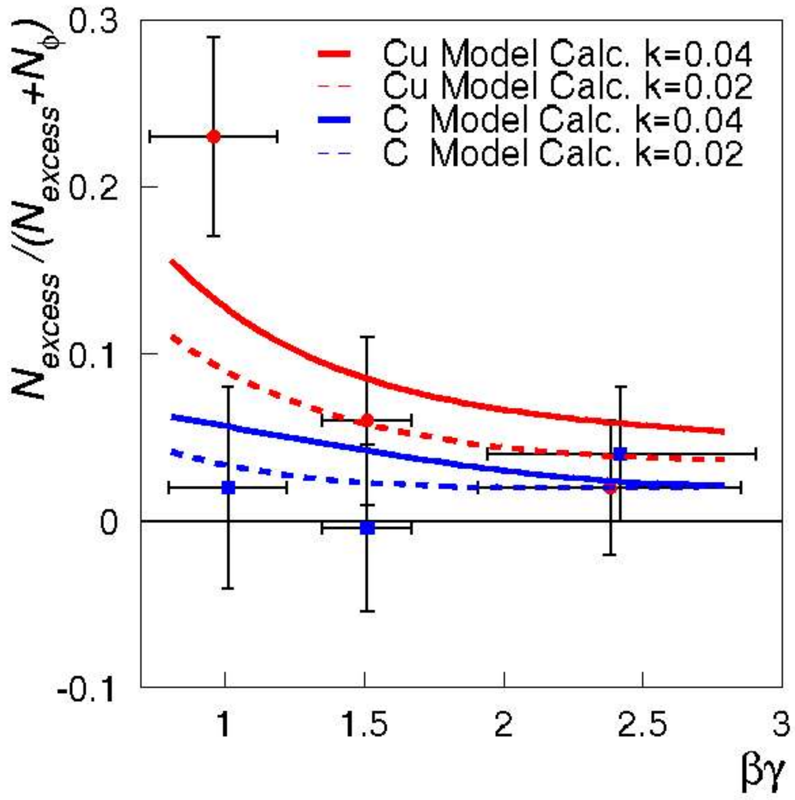

high statistics

- Main goal : collect ~1x10^5 $\phi \rightarrow ee$ for each target in 5 weeks
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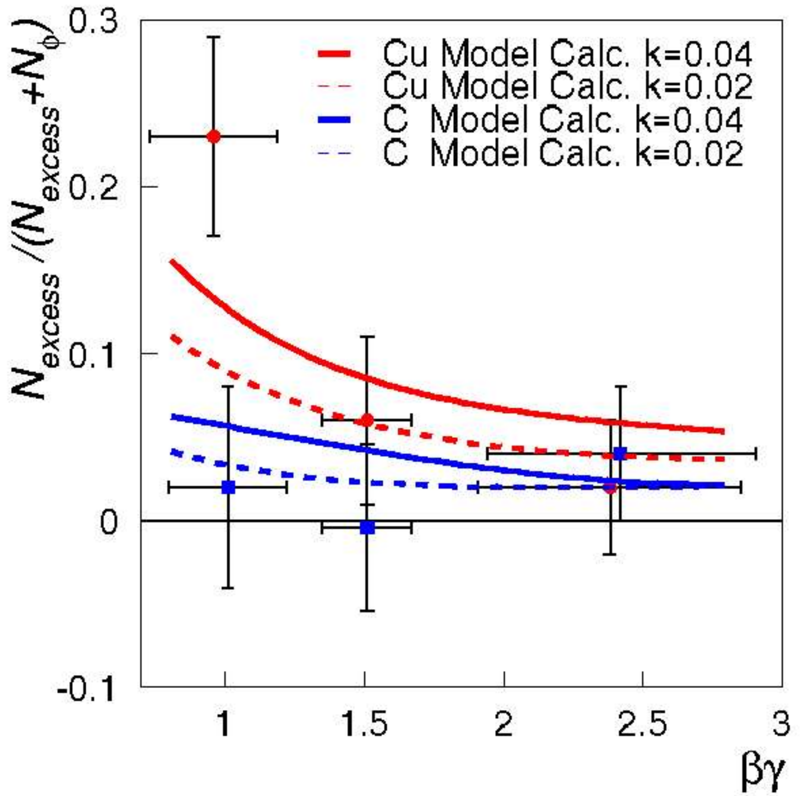
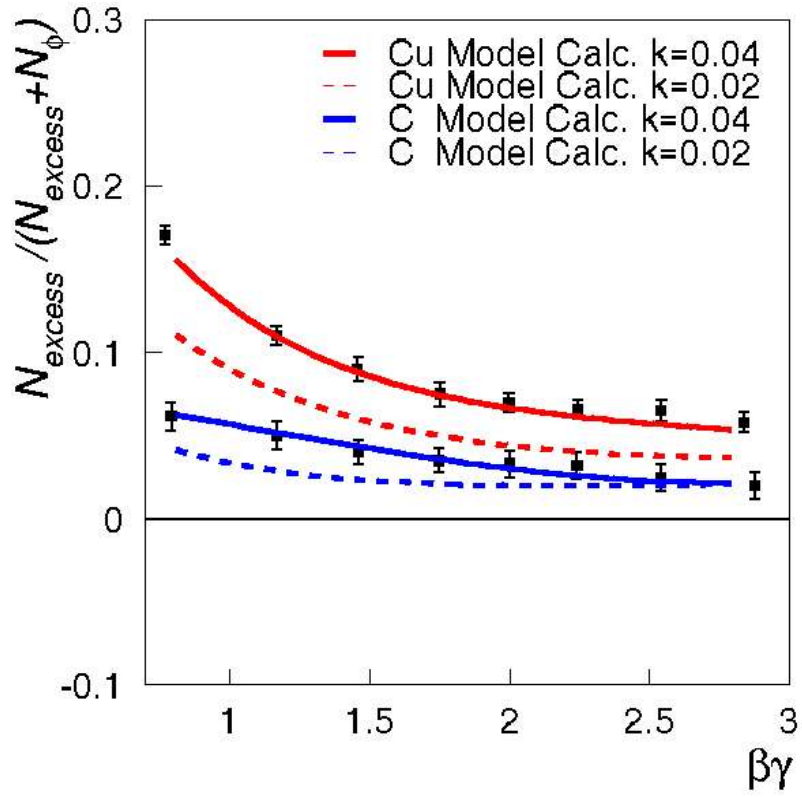


x 100 stat.

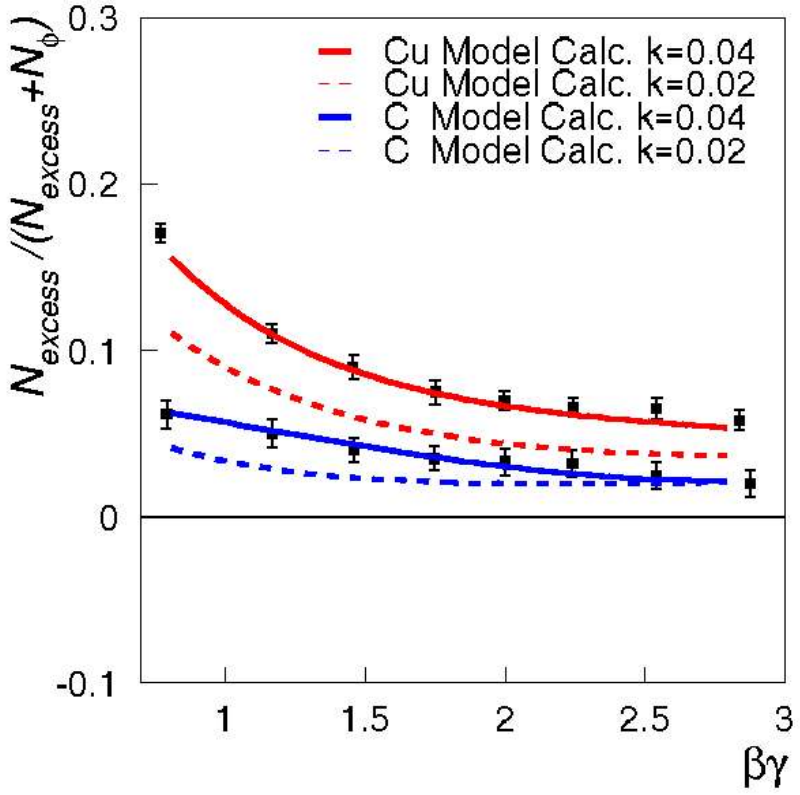


error bars are shrunk and βγ bin can be divided

high statistics

- Main goal : collect ~1x10^5 $\phi \rightarrow ee$ for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of 'modified' component

We can compare the data with theoretical predictions more precisely, and we could approach the puzzle that the modification is due to the chiral symmetry restoration or not.



Advance of the theoretical works is also required to solve the puzzle.
- in finite-size nuclear matter
- possible time evolution of the density
- density/momentum dependence of the mass/width modification, etc.

We detected the mass modification in the invariant mass spectra...

- We may exclude some predictions like upward mass-shift
- Now we ignore :
  - finite-size nuclei <-> infinite nuclear matter
  - Possible time evolution of the density of nuclei in the reaction
    - our model is just toy model...
    - transport calculation?
  - momentum dependence of 'mass shift' & 'witdh broadening'
- We expect the precise prediction to be compared with coming high statistics result.
- How can we connect the results with chiral symmetry restoration?

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.
- $\phi \to e^+e^-$ also have excess, for the larger target, slowly moving component
  - model calc. including mass shift and width broadening in nuclei also reproduces the data.
- In $\phi \to K^+K^-$ spectra, no modification is observed, however, the data are relatively fast component

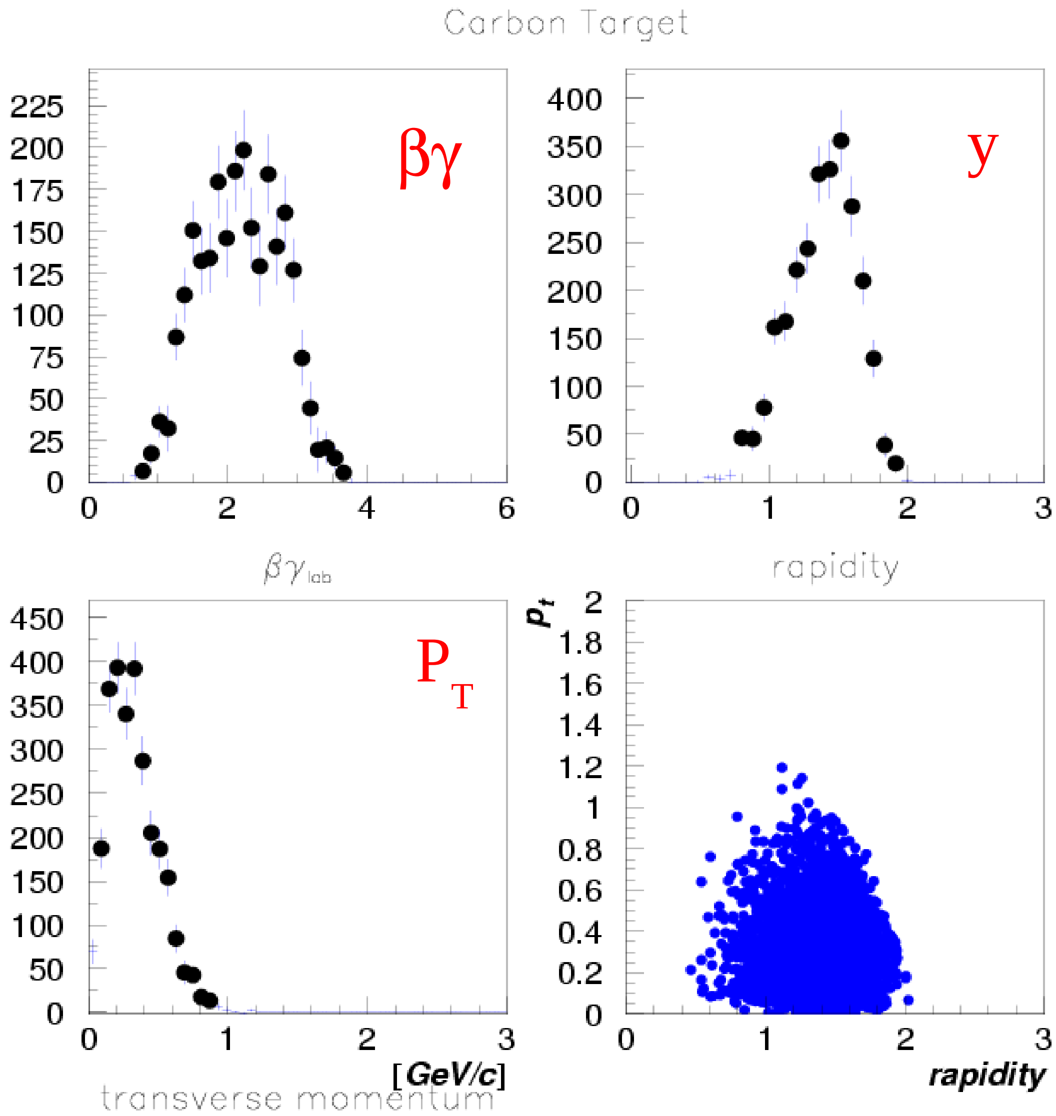
Outlook

- production cross section of ω & ϕ and their nuclear dependence :
  - nucl-ex/0603013 (to be published in PRC)
- Analysis of nuclear dependence of $\phi \rightarrow K^+K^-$ & $\phi \rightarrow e^+e^-$ is on going to investigate $\Gamma_{K+K-} / \Gamma_{e+e-}$ changing in nuclei.
  - paper is in preparation
- Analysis of $\beta\gamma$ dependence of ρ & ω data is also on going.
-
-
- ... and next generation experiment at J-PARC has been proposed.

Backup slides...

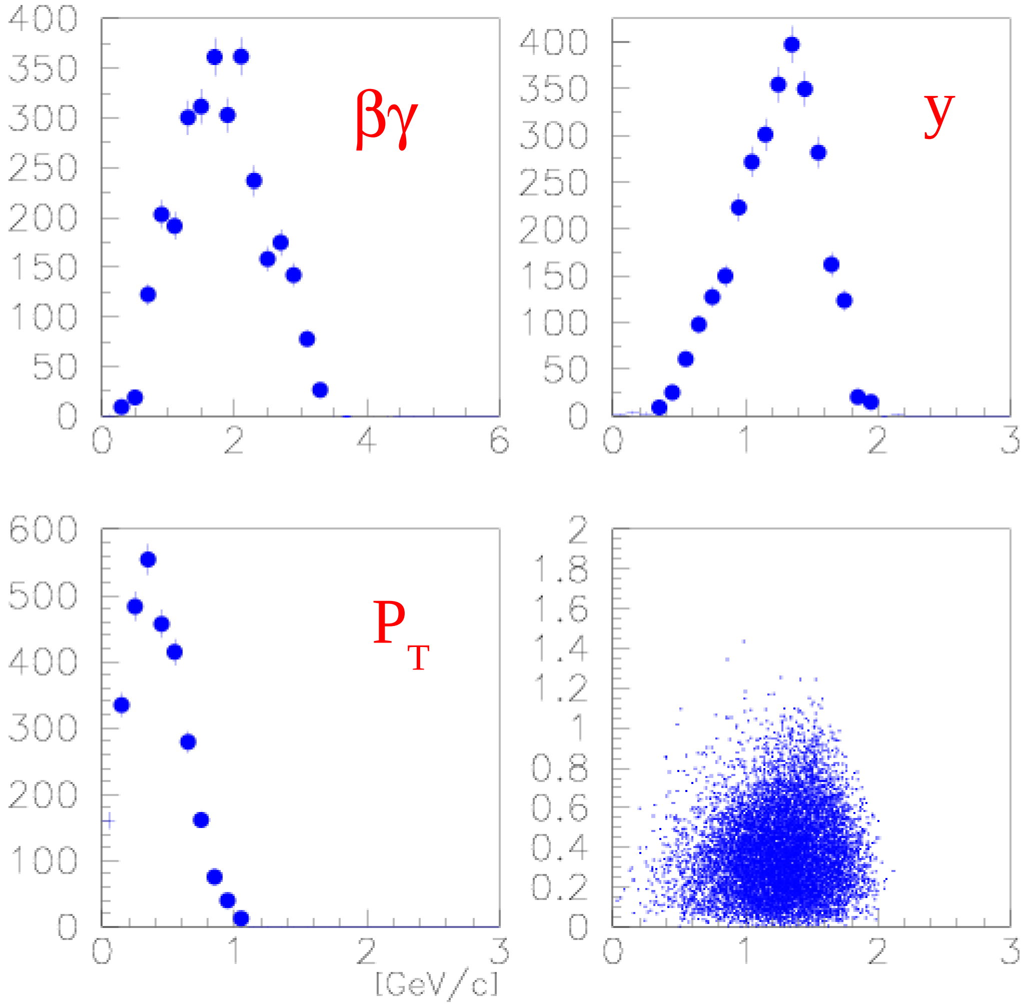
measured kinematic distribution of $\omega \rightarrow e^+e^-$

- $0.5 < y < 2$
- $1 < \beta\gamma < 3$
  - $(0.8<p<2.4\mathrm{GeV}/c)$
- $0 < P_T < 1$



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

- $0.5 < y < 2$
- $1 < \beta\gamma < 3$
  - ($1<p<3$ GeV/c)
- $0 < P_T < 1$



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
  - $\phi \rightarrow K^+K^-$
  - $\phi \rightarrow e^+e^-$