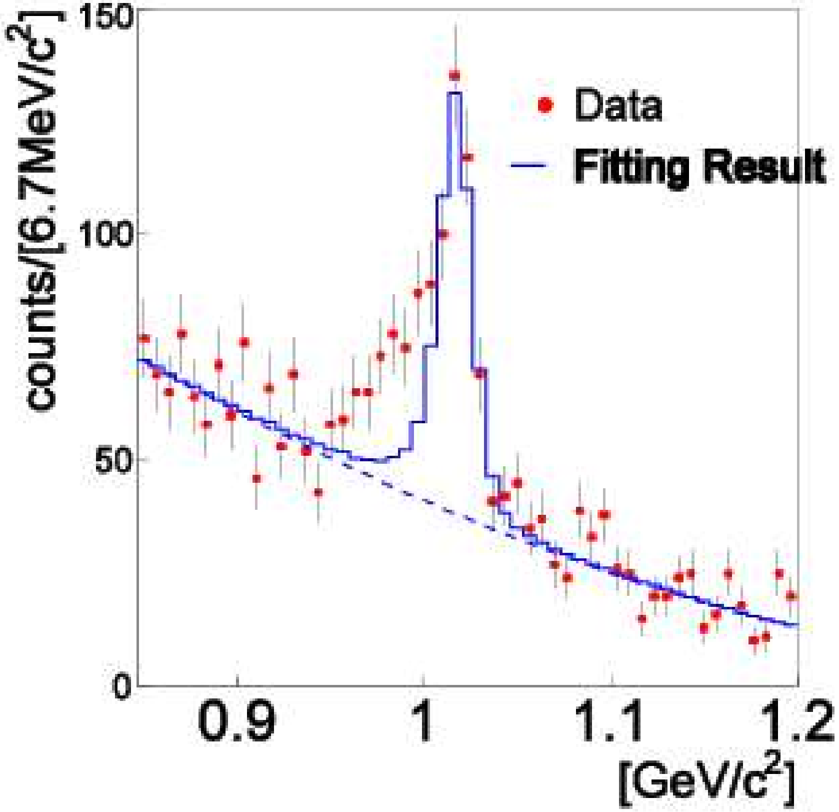
Vector meson spectrum measured in 12 GeV p+A reaction at KEK-PS

Satoshi Yokkaichi , RIKEN

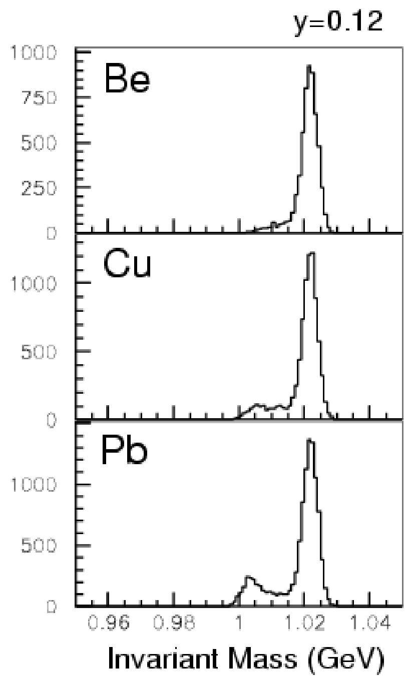
- Physics
- expected experimental signature
- performed experiment KEK-PS E325
- E325 Results
  - 1) $\rho/\omega \rightarrow e^+e^-$ spectra
  - 2) $\phi \rightarrow e^+e^-$ spectra
  - 3) $\phi \rightarrow K^+K^-$ spectra
- new experiment at J-PARC

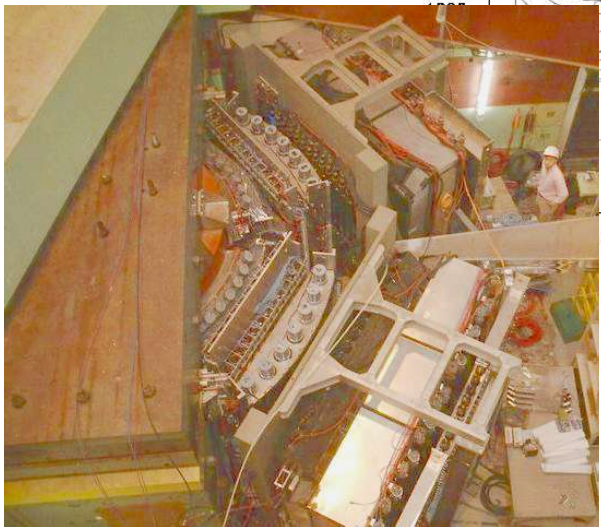


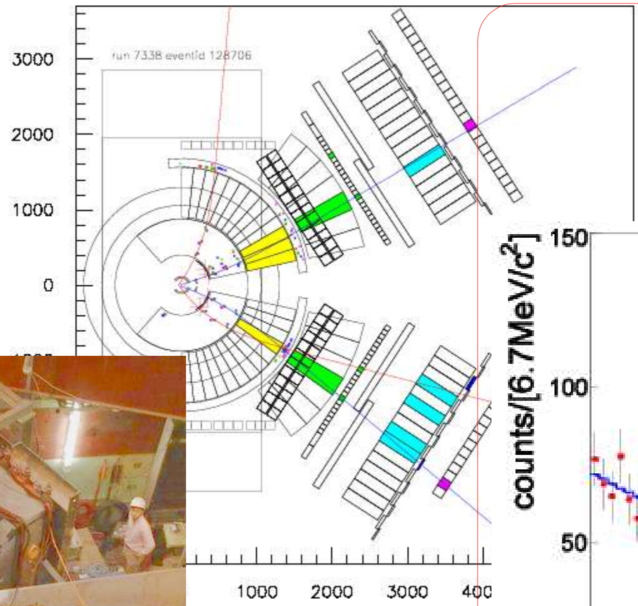
Vector meson measurements at KEK-PS

- To explore the chiral symmetry restoration in nuclear matter
  - vector meson (ρ/ω/ϕ) mass modification in nuclei
- performed experiment KEK-PS E325
  - detected vector meson modification

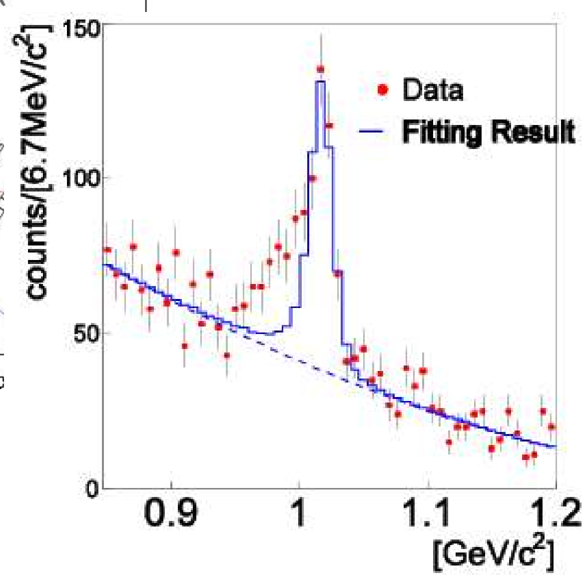
(Monte Carlo)





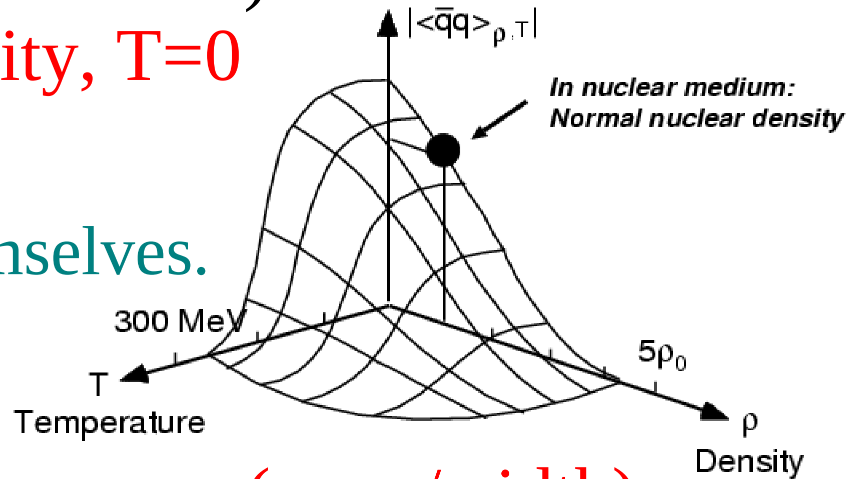


(Data)



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

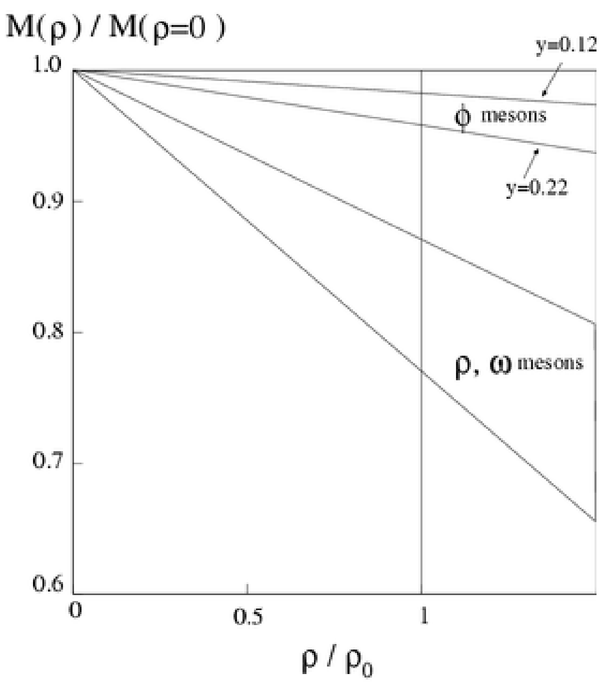
linear dependence on density

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

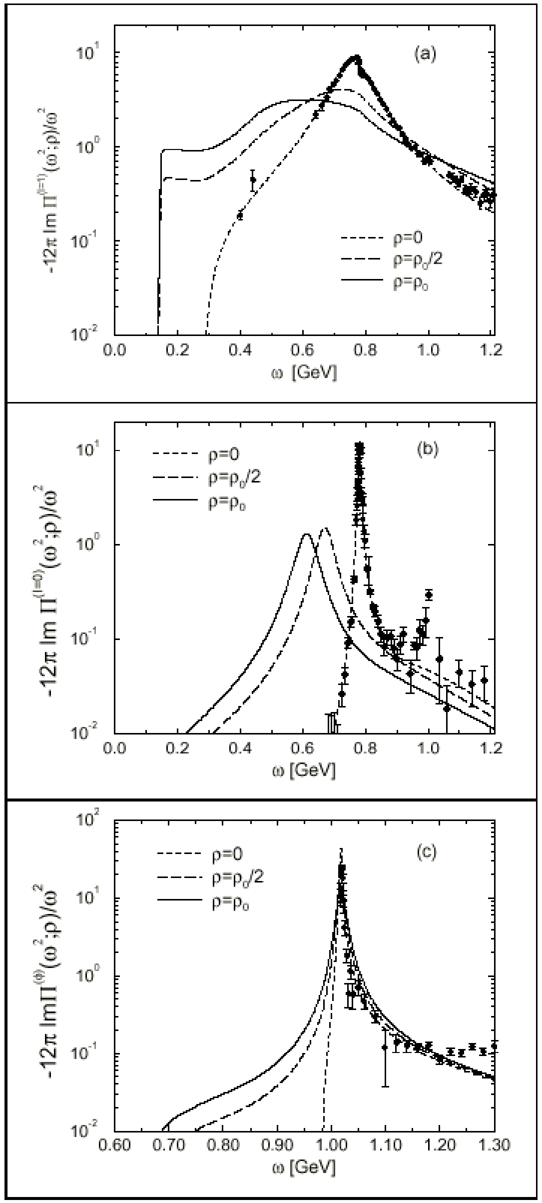
mass decreasing

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

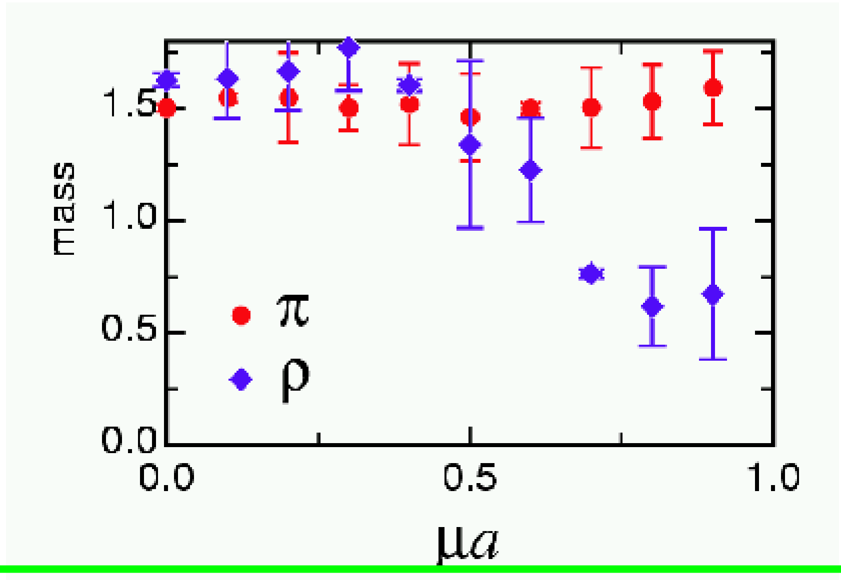
at the normal nuclear density



Klingle,Keiser,Weise, 97



Muroya, Nakamura, Nonaka, 03



Vector meson measurements in the world

dilepton mesurement

- HELIOS (ee, μμ) 450GeV p+Be / 200GeV A+A
- CERES (ee) 450GeV p+Be/Au / 40-200GeV A+A
- E325 (ee,KK) 12GeV p+C/Cu
- NA60 (μμ) 400GeV p+A/158GeV In+In
- PHENIX (ee,KK) p+p/Au+Au
- HADES (ee) 4.5GeV p+A/ 1-2GeV A+A
- CLAS (ee) 1~2 GeV γ+A
- *J-PARC* (ee) 30/50GeV p+A/ ~20GeV A+A
- *CBM/FAIR* (ee) 20~30GeV A+A

- TAGX (ππ) ~1 GeV γ+A
- STAR (ππ,KK) p+p/Au+Au
- LEPS (KK) 1.5~2.4 GeV γ+A
- CBELSA ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb

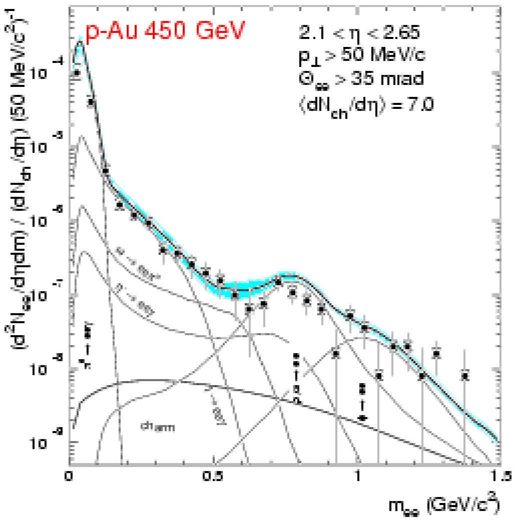
already state 'modified'
running/in analysis
future plan

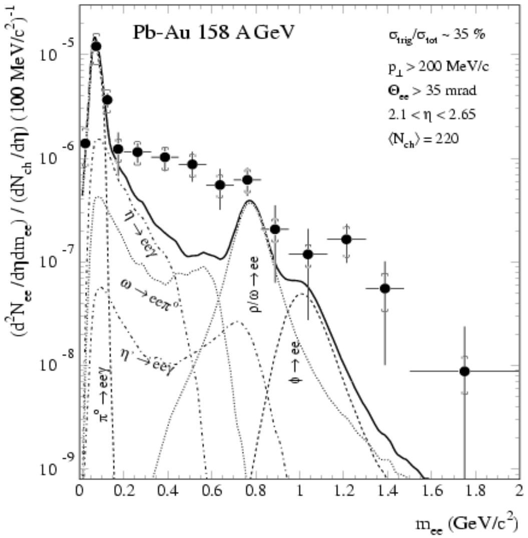
(Vector meson measurements)

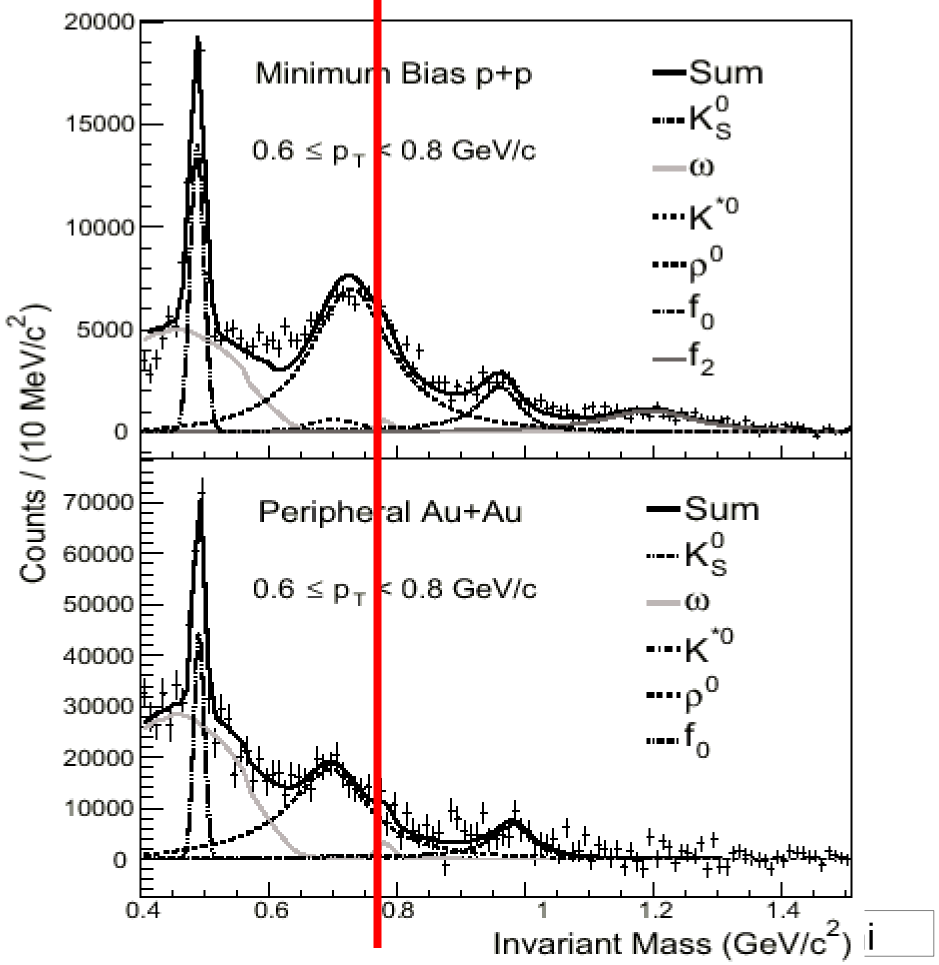
- CERES : e^+e^- (EPJC 41('05)475)
  - anomaly at lower region of ρ
    - in A+A, not in p+A
  - relative abundance is determined by their statistical model

- STAR : $\rho \to \pi^+\pi^-$ (PRL92('04)092301)
  - 'shift' in p+p & A+A peripheral
    - relative abundance is free parameter/ shape is BWxPS

~770MeV

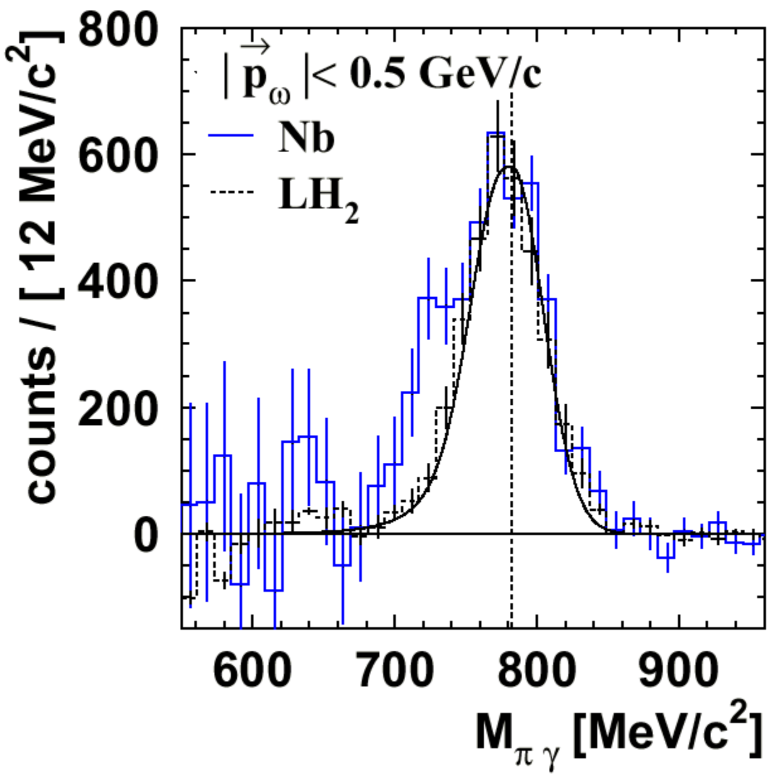




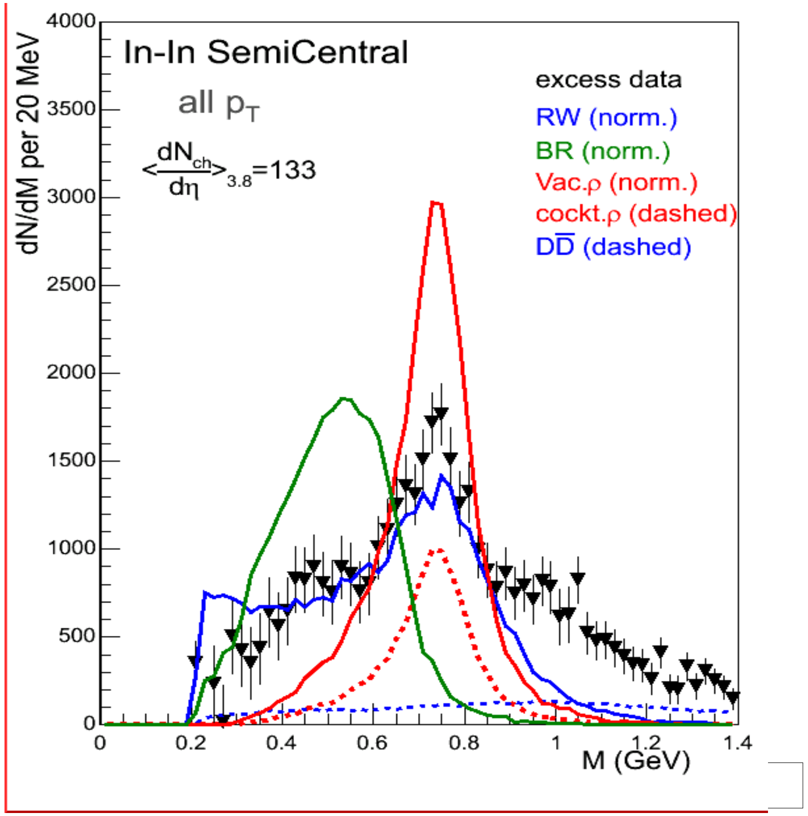


(Vector meson measurements)

- CBELSA/TAPS :(PRL94(05)192303)
  - $\omega \rightarrow \pi^0\gamma\,(\rightarrow \gamma\gamma\gamma)$
  - anomaly in γ+Nb, not in γ+p
    - direct comparison within the data
    - momentum dependence is seen



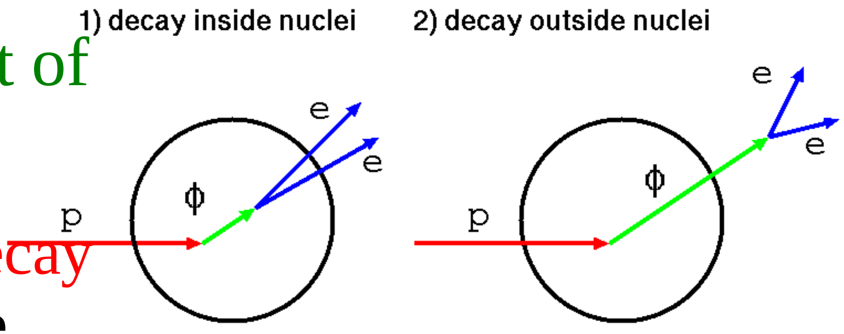
- NA60 : (nucl-ex/0510044)
  - $\rho \rightarrow \mu^+\mu^-$:
  - 'BR scaling is ruled out'



Expected signal in p+A reaction in our energy region

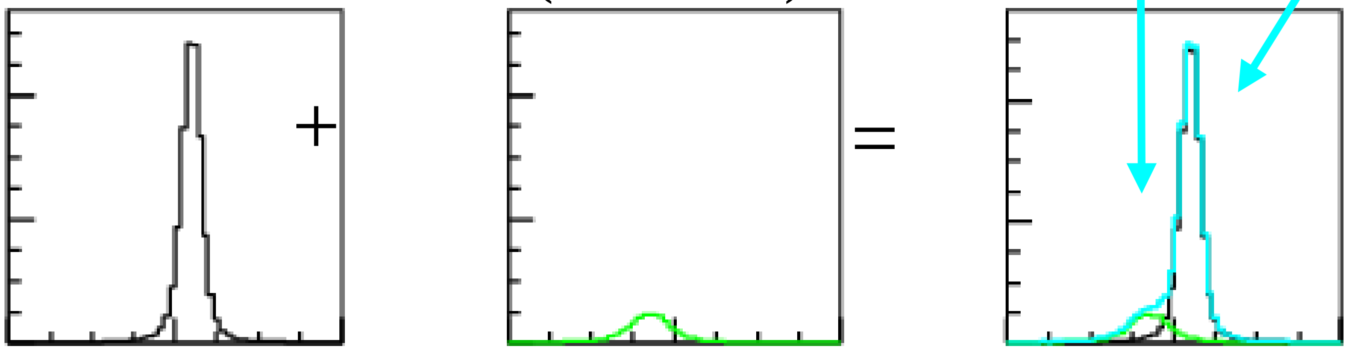
Expected Invariant mass spectra in e^+e^-

- smaller FSI in e^+e^- decay channel
- double peak (or tail-like) structure : Effect of meson life, velocity & size of nuclei :
  - 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



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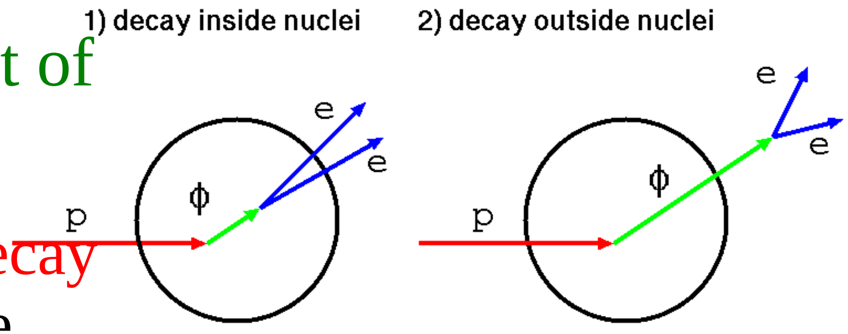
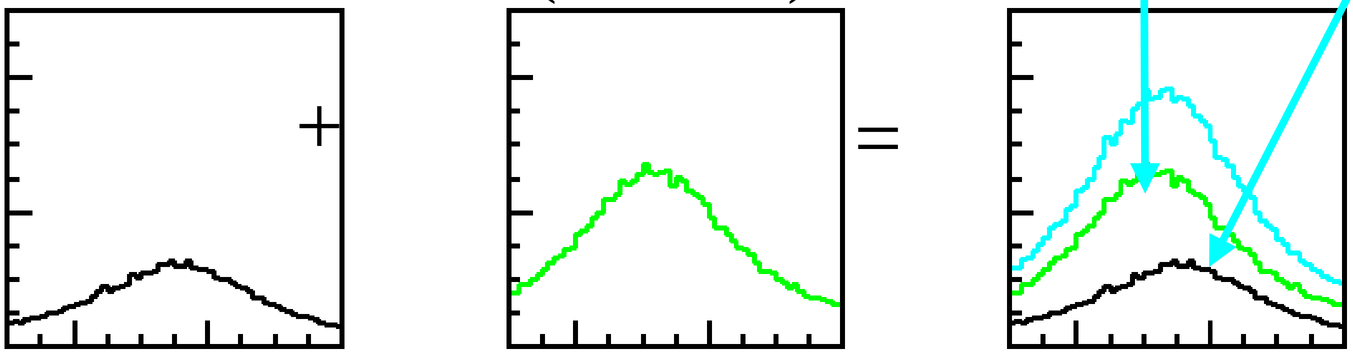


shorter-life meson(ρ) cases : Schematic picture

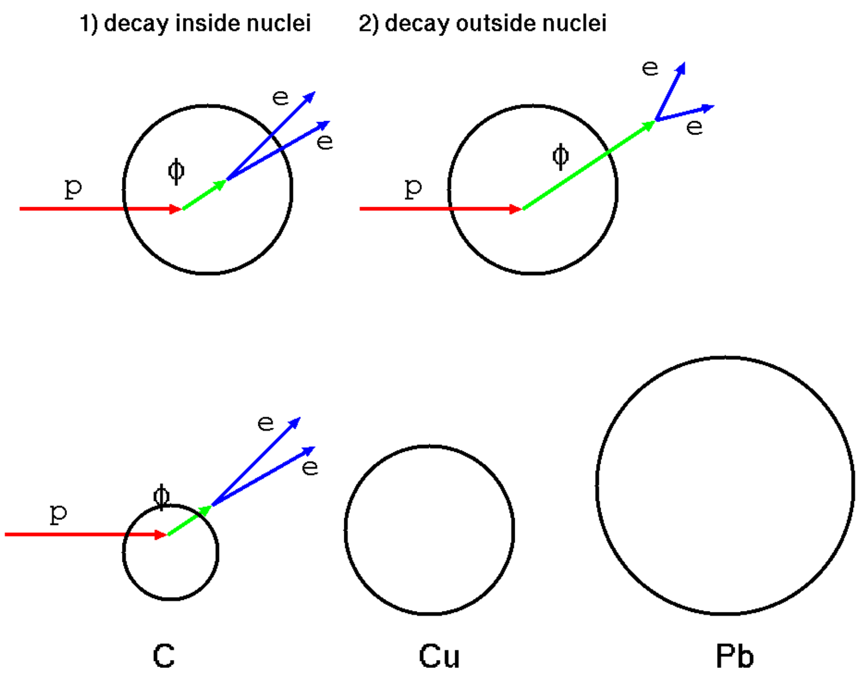
outside decay (natural) + inside decay (modified) = expected to be observed

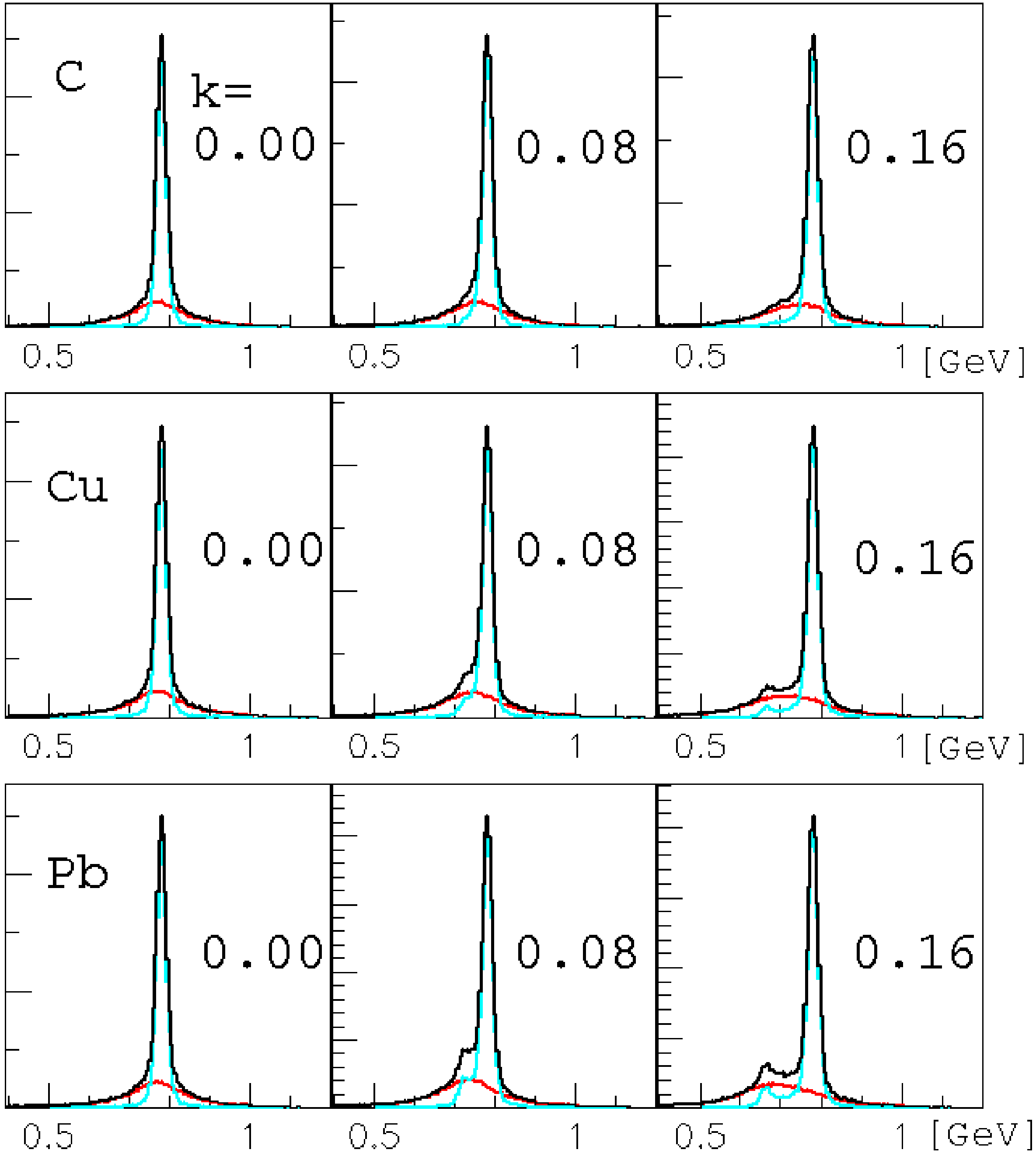


(Expected e^+e^- spectra)

(toy model calc.)

- 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^-

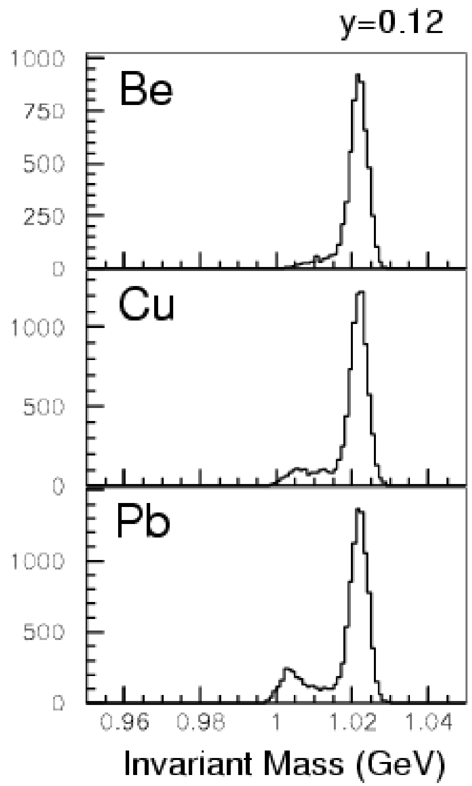


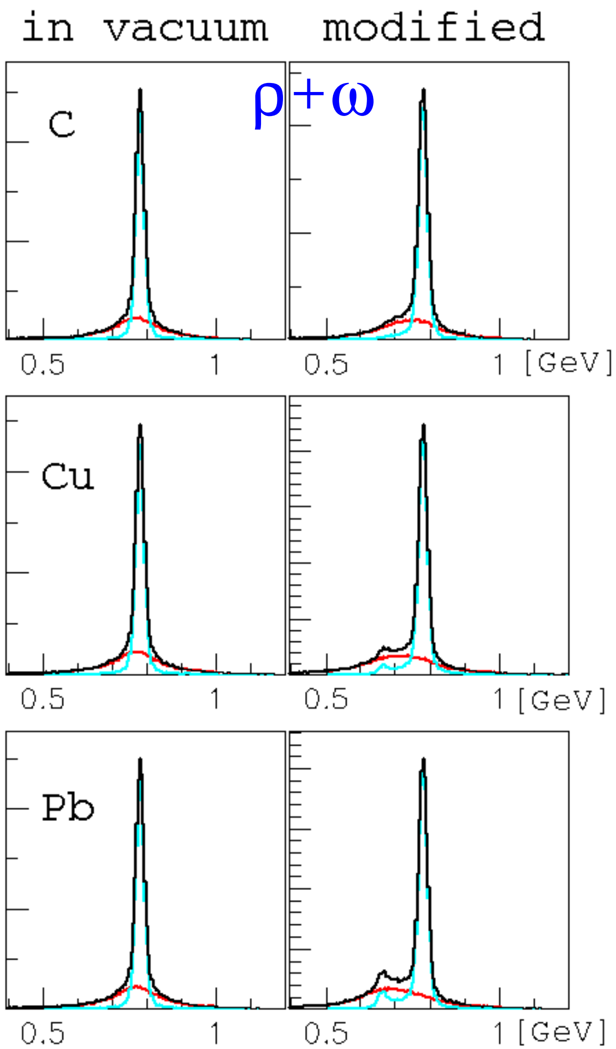


(Expected e^+e^- spectra)

- 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
-
- $L = \beta\gamma * c\tau = p/m * h/2\pi * c/\Gamma$

expected
e^+e^- shape
(MC sim.)





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

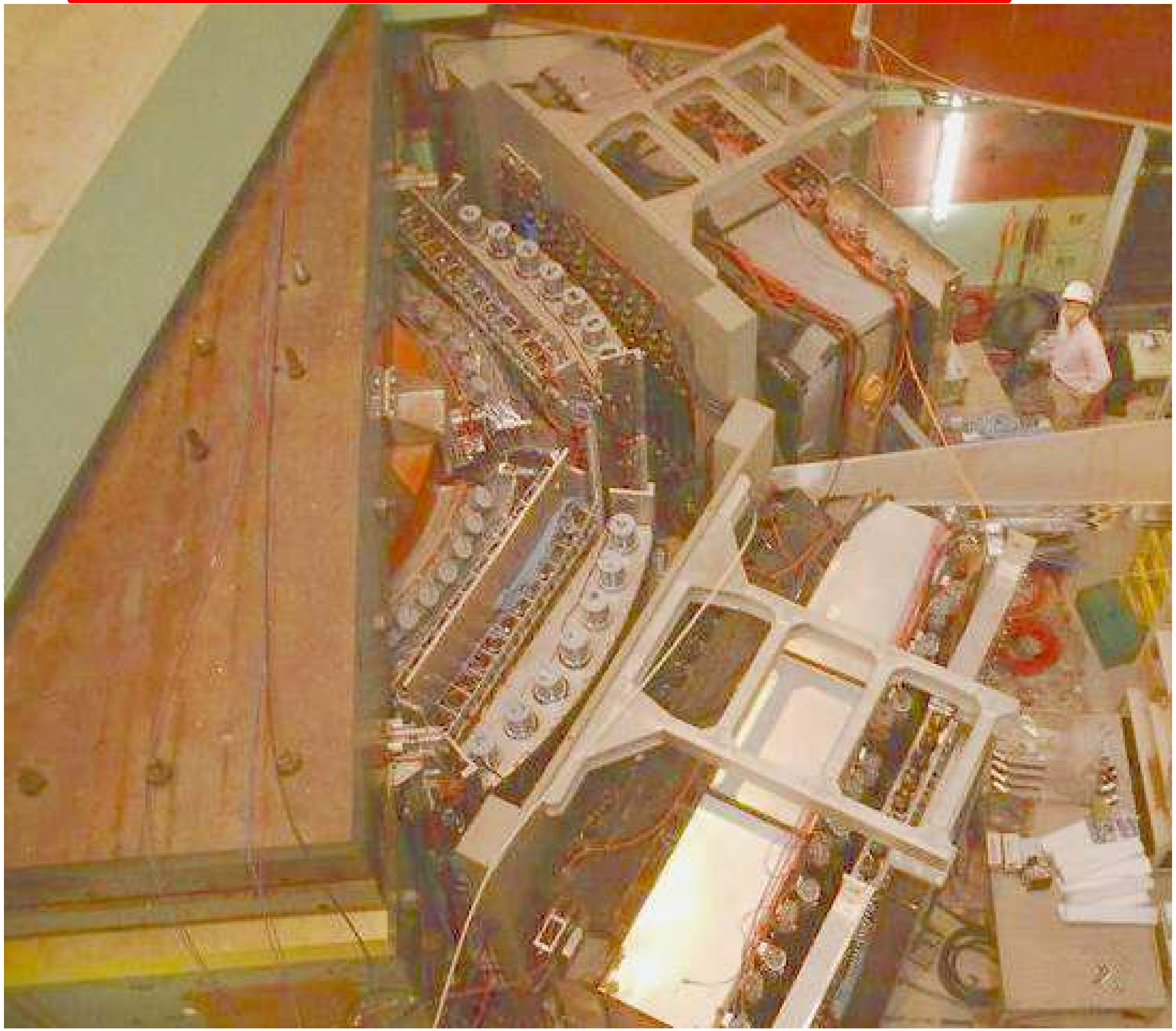
Collaboration

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

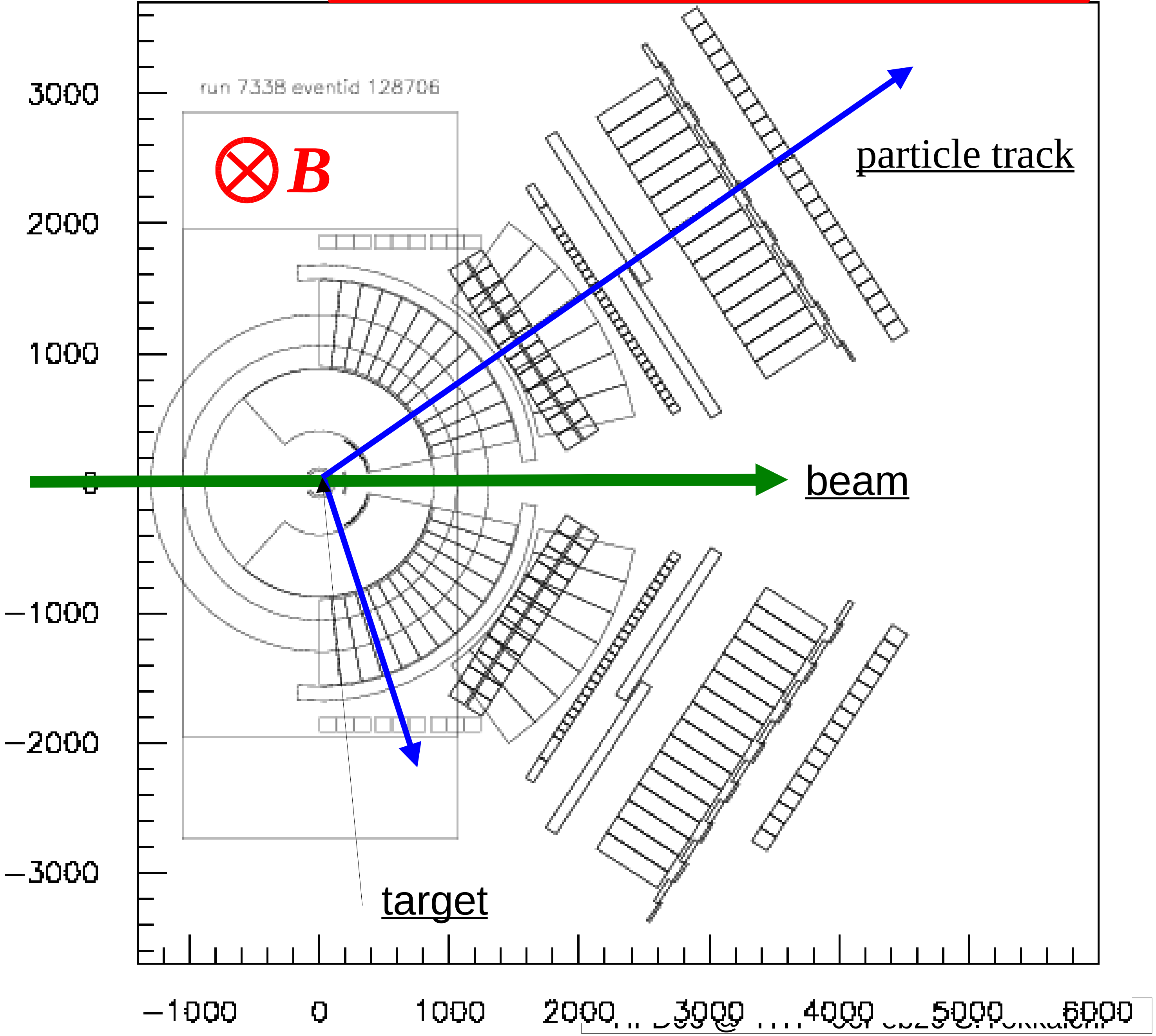
E325 spectrometer
located at KEK-PS EP1-B primary beam line



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

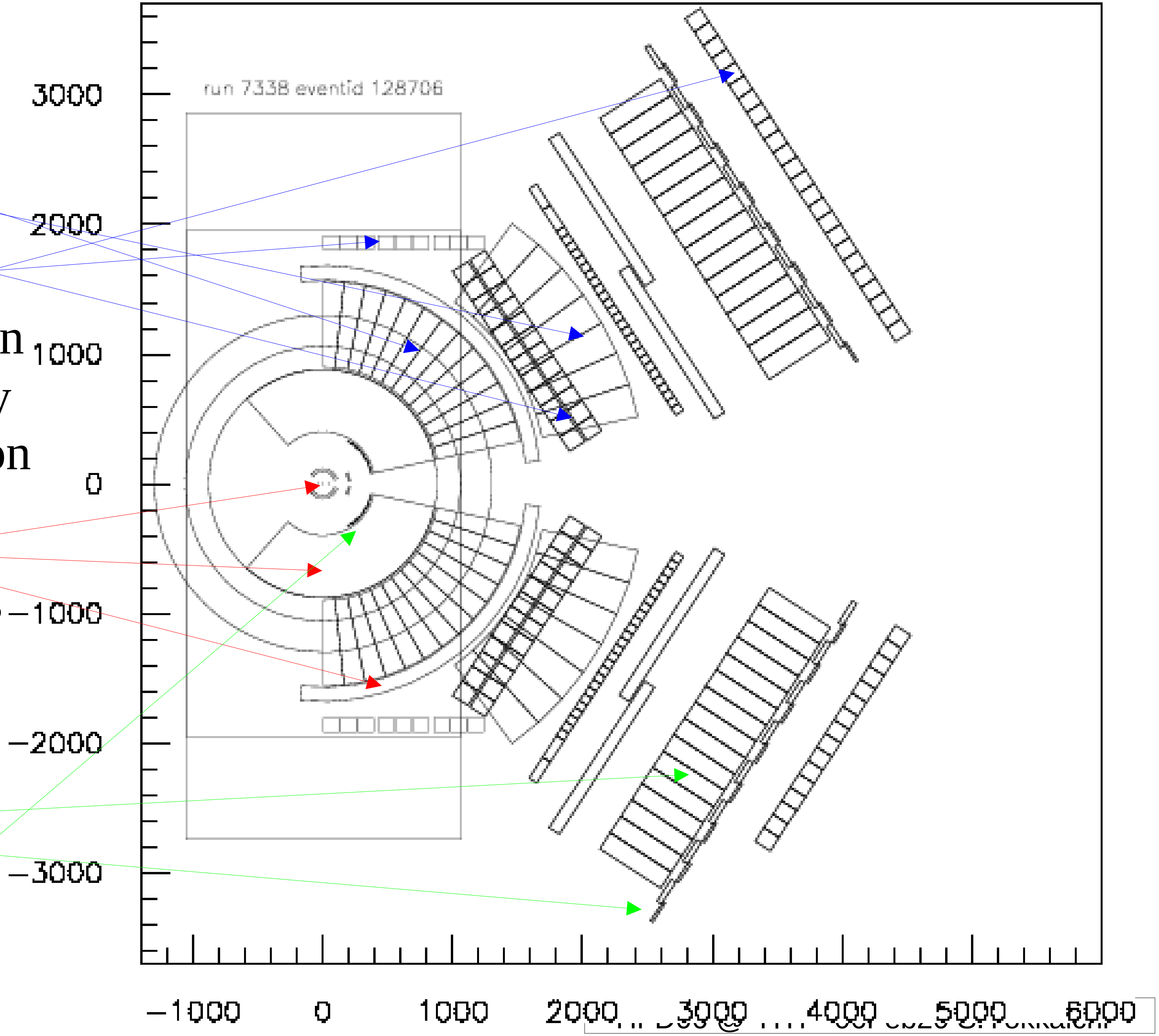
total 3×10^{-4} π rejection with 78% e efficiency in two-stage operation

Tracker

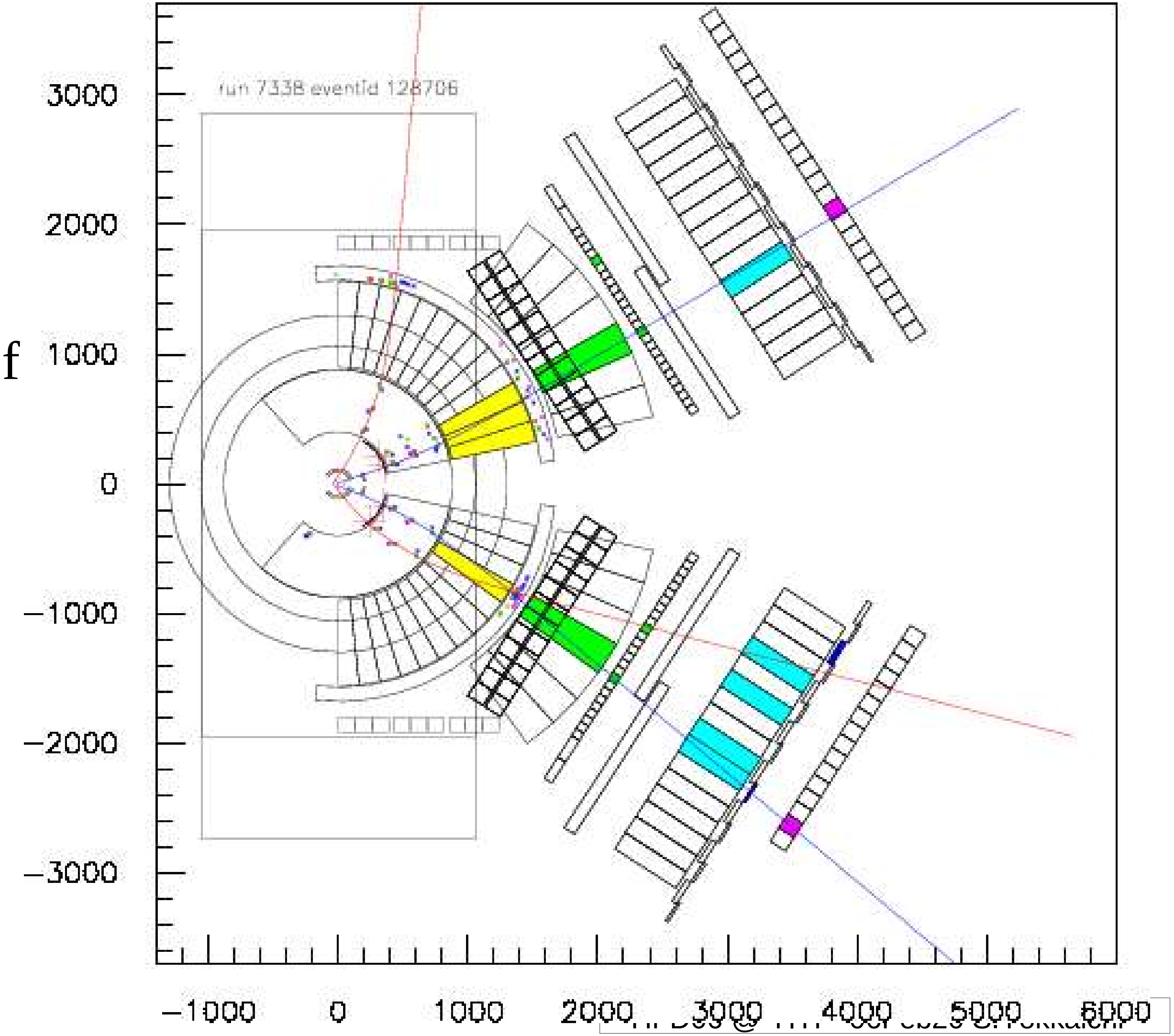
Three Drift Chambers

Kaon ID counters

Aerogel Cherenkov & TOF



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



Result (1)

ee invariant mass spectra

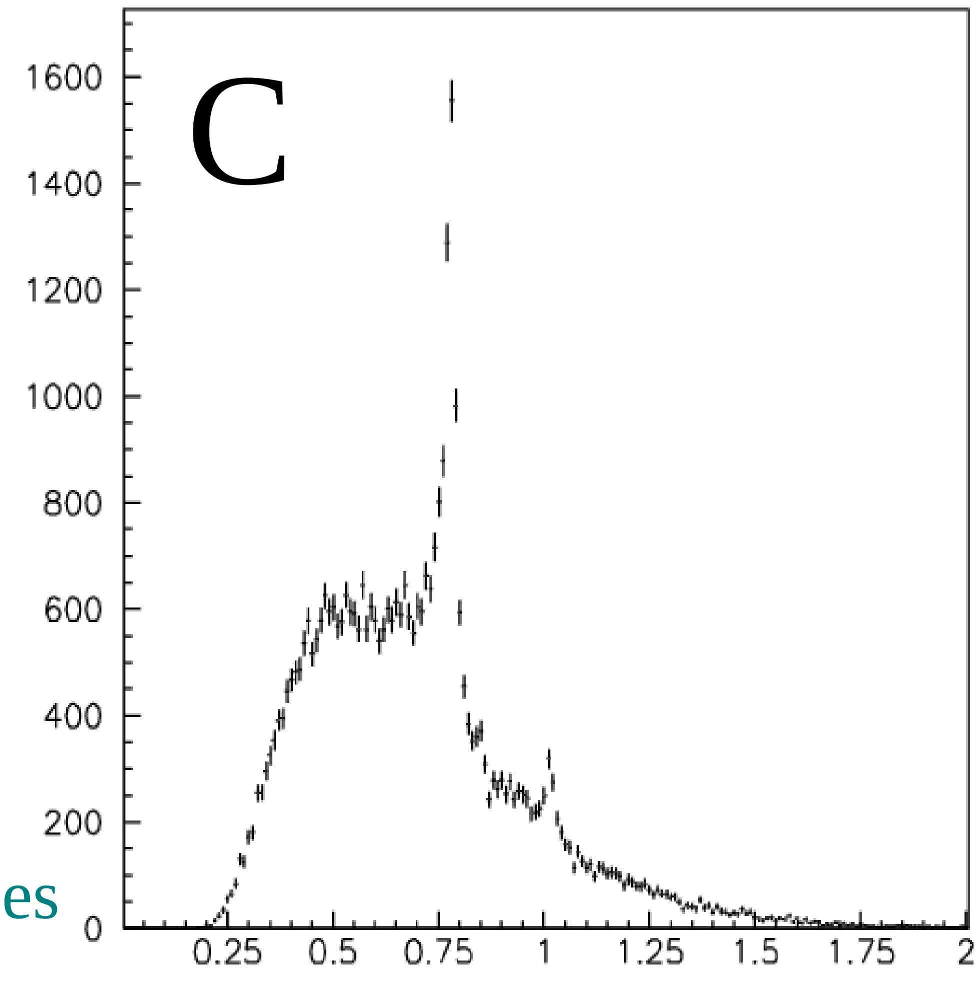
M. Naruki et al.,

nucl-ex/050416

(to be published in PRL)

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

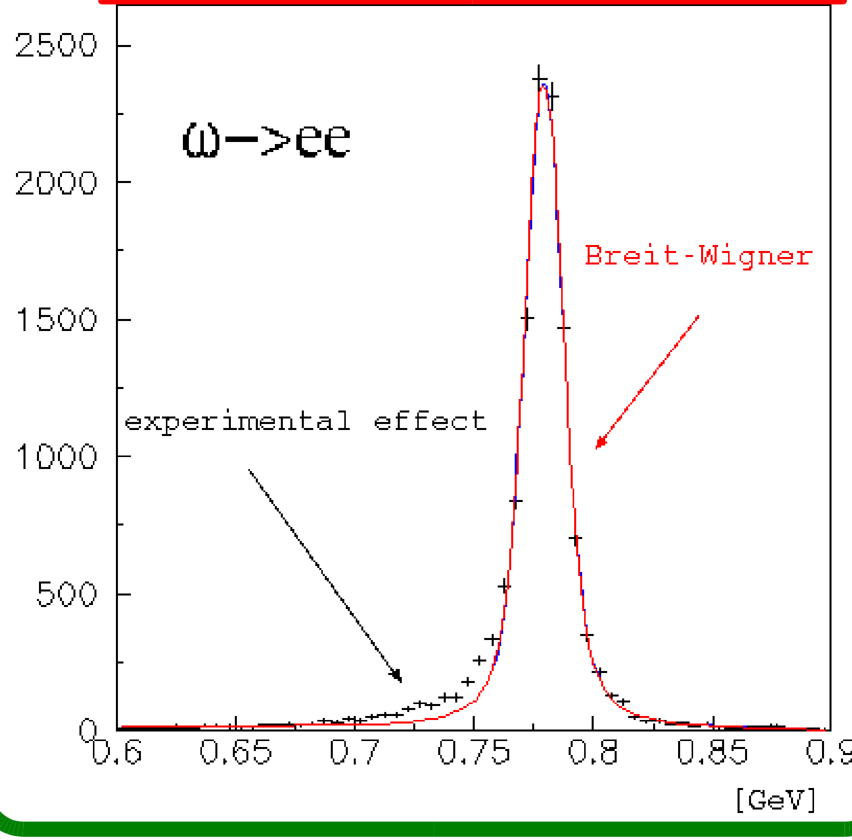


→ fit the spectra with known sources

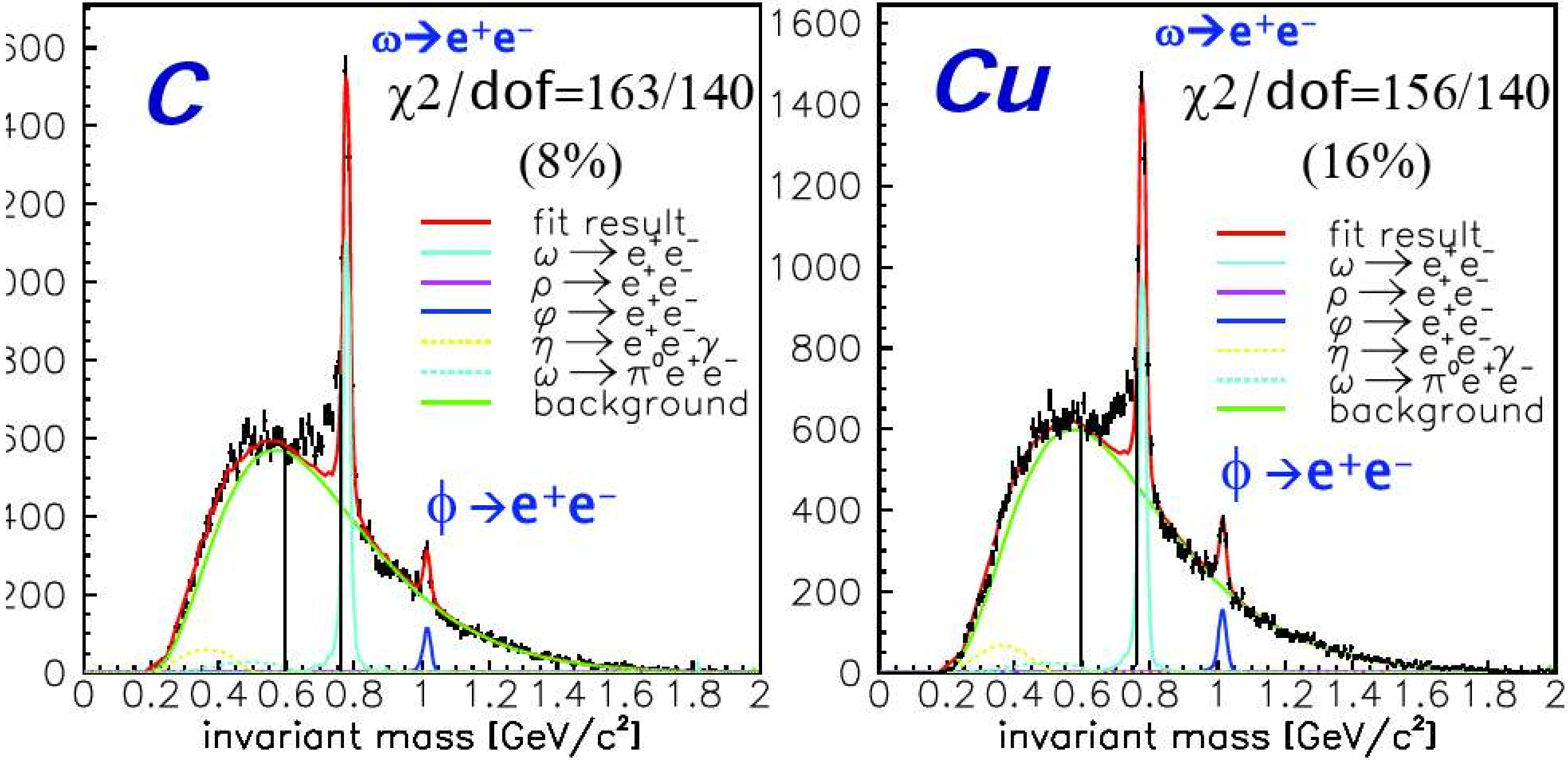
Fitting with known sources

- 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

estimated spectrum using GEANT4



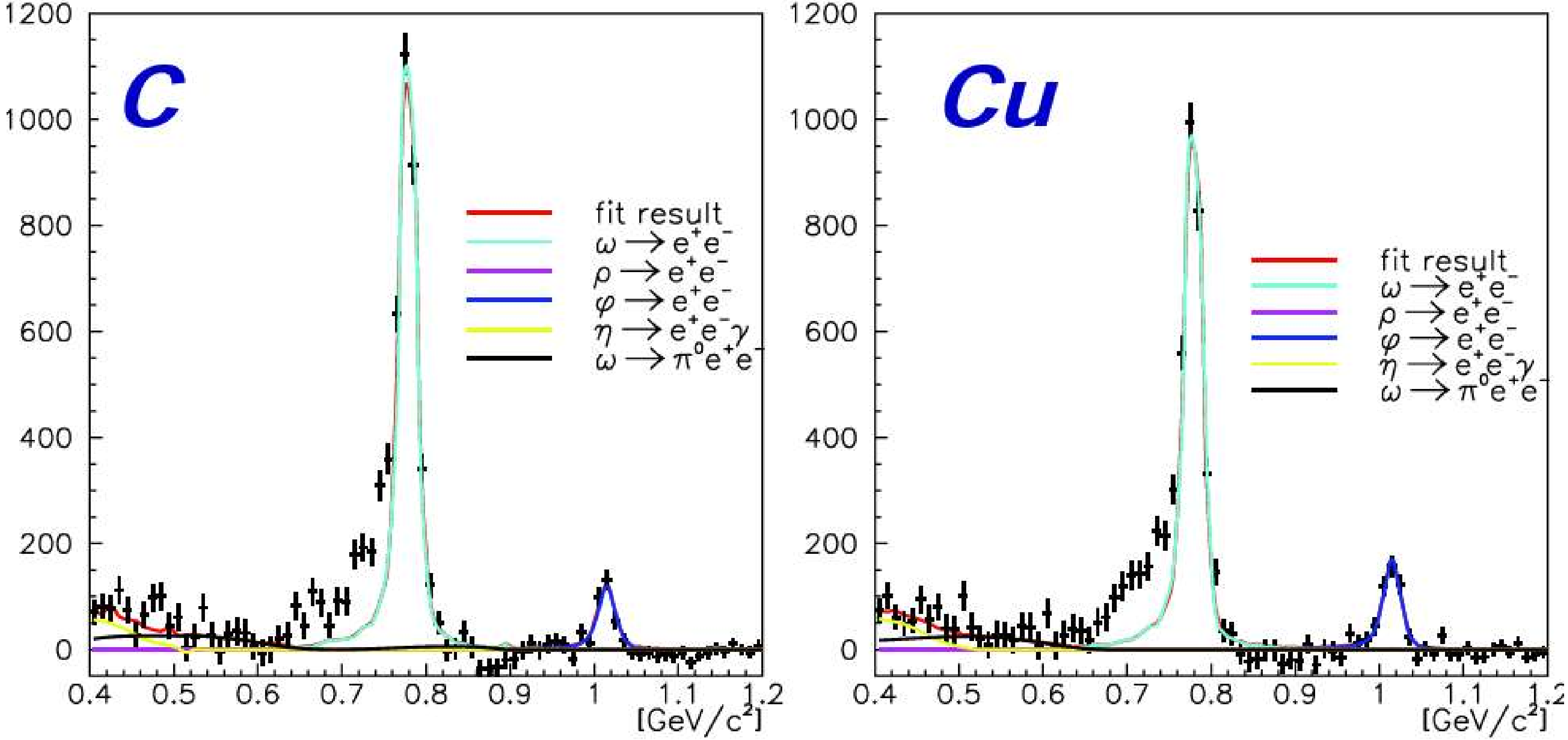
Fitting results



- 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	<0.15(for C)	<0.31(for Cu)



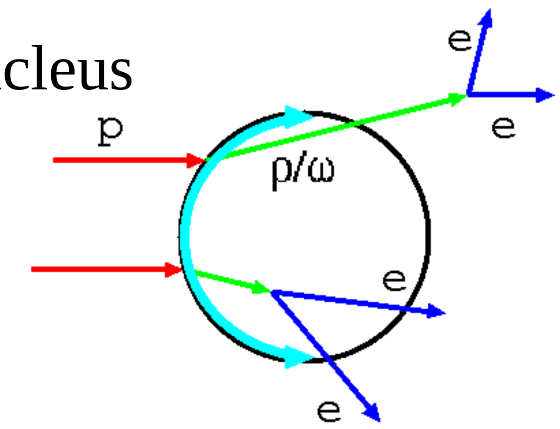
- However, $\rho/\omega = 1.0 \pm 0.2$ in former experiment (p+p, 1974)

...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 α~ 2/3 for ω
    - 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 : $m^*/m_0 = 1- k\ \rho/\rho_0$

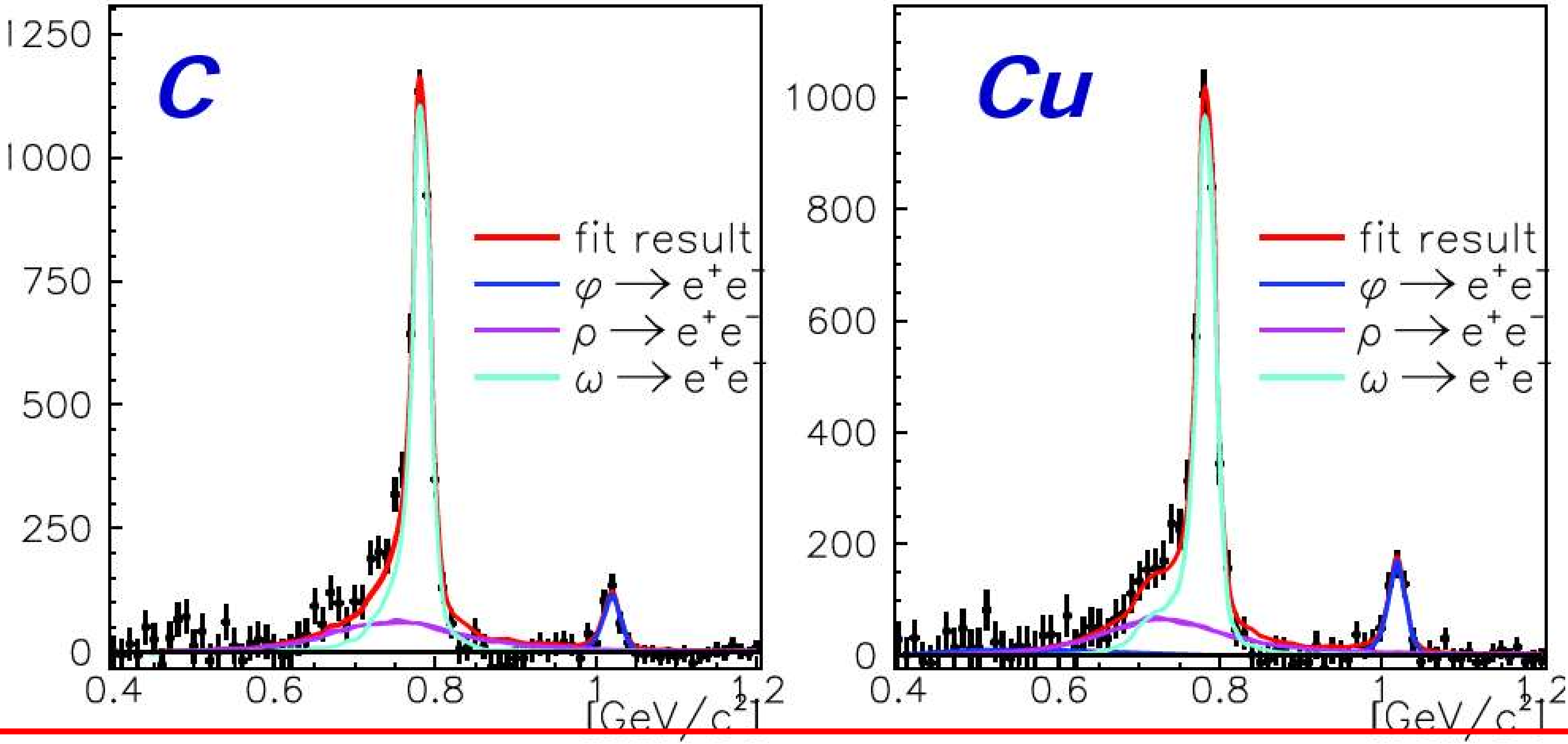
      (k=0.16±0.06 in Hatsuda & Lee, '92,'96)
    - (width modification & momentum dependence of modification are not taken into account this time)



Fitting results by the toy model

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

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

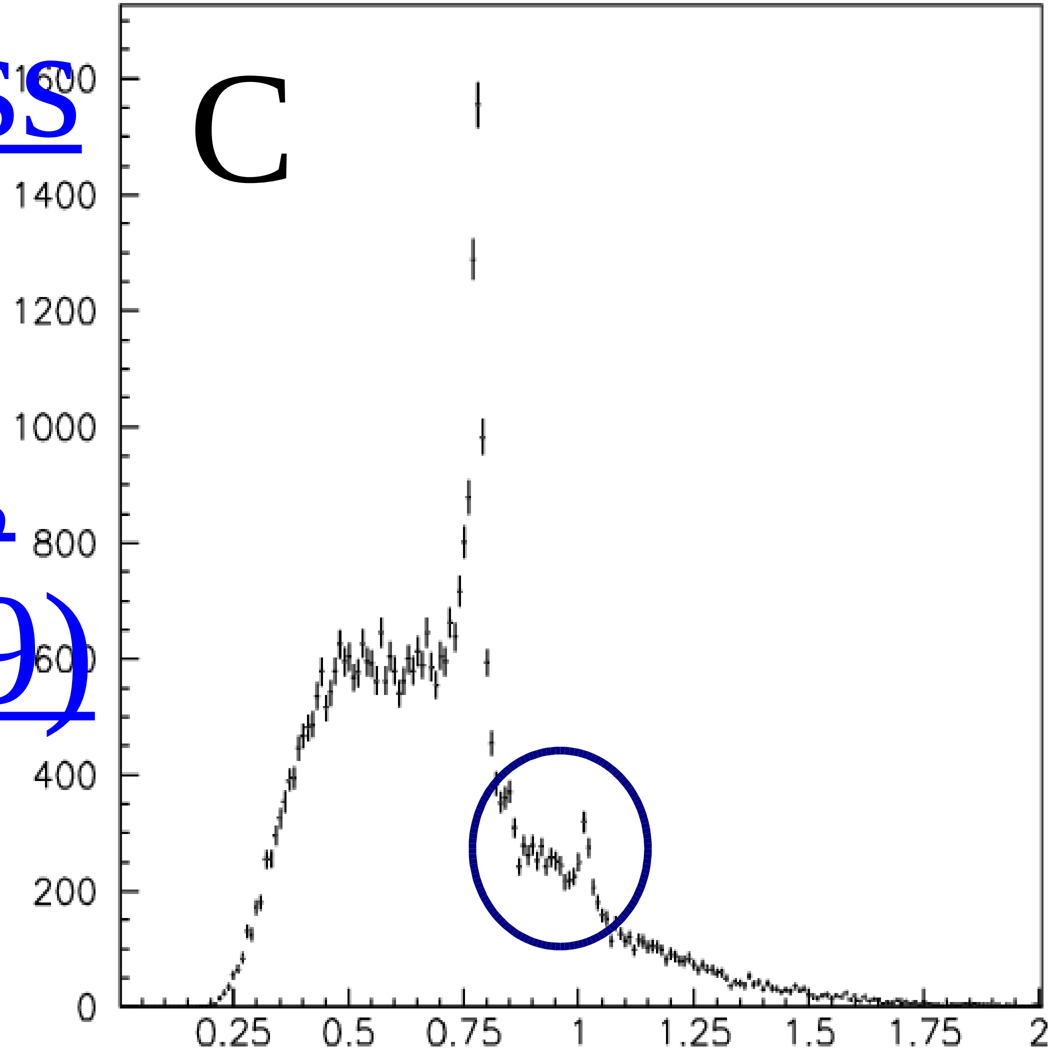


From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density

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

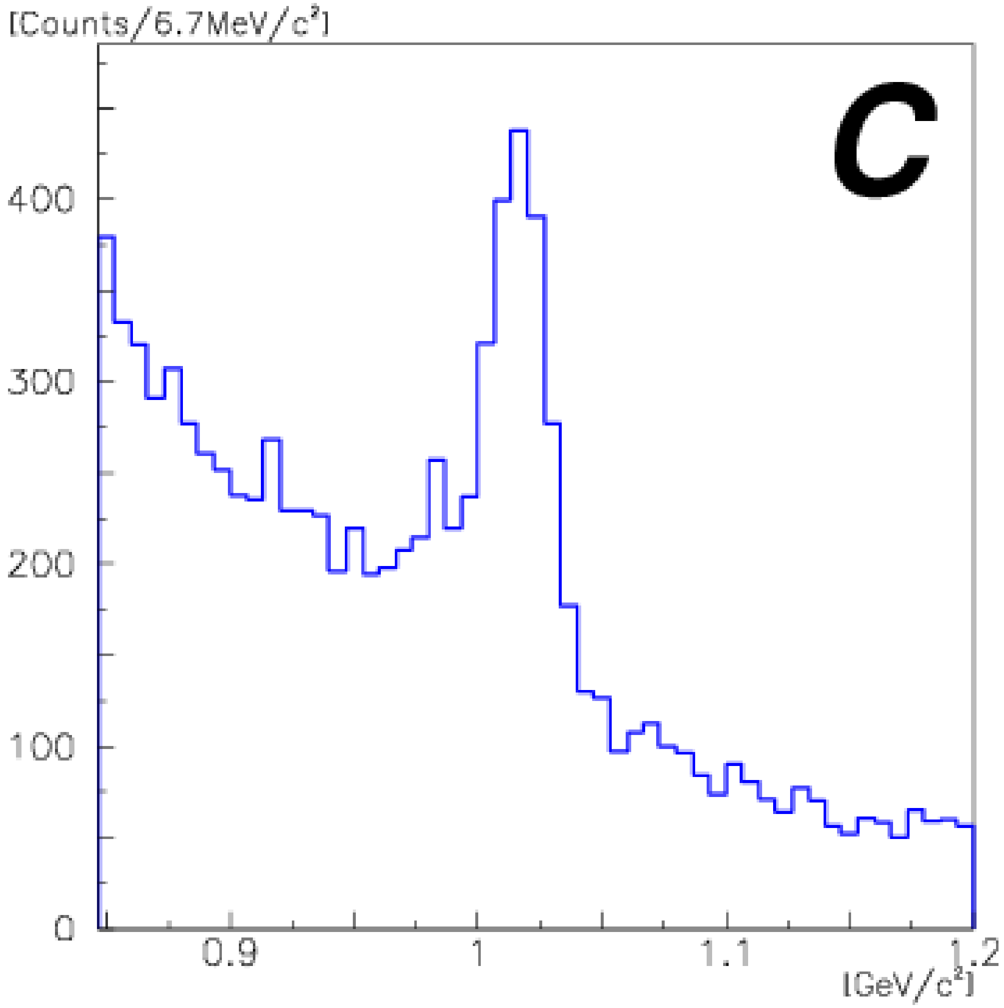
Result (2)

ee invariant mass spectra of ϕ (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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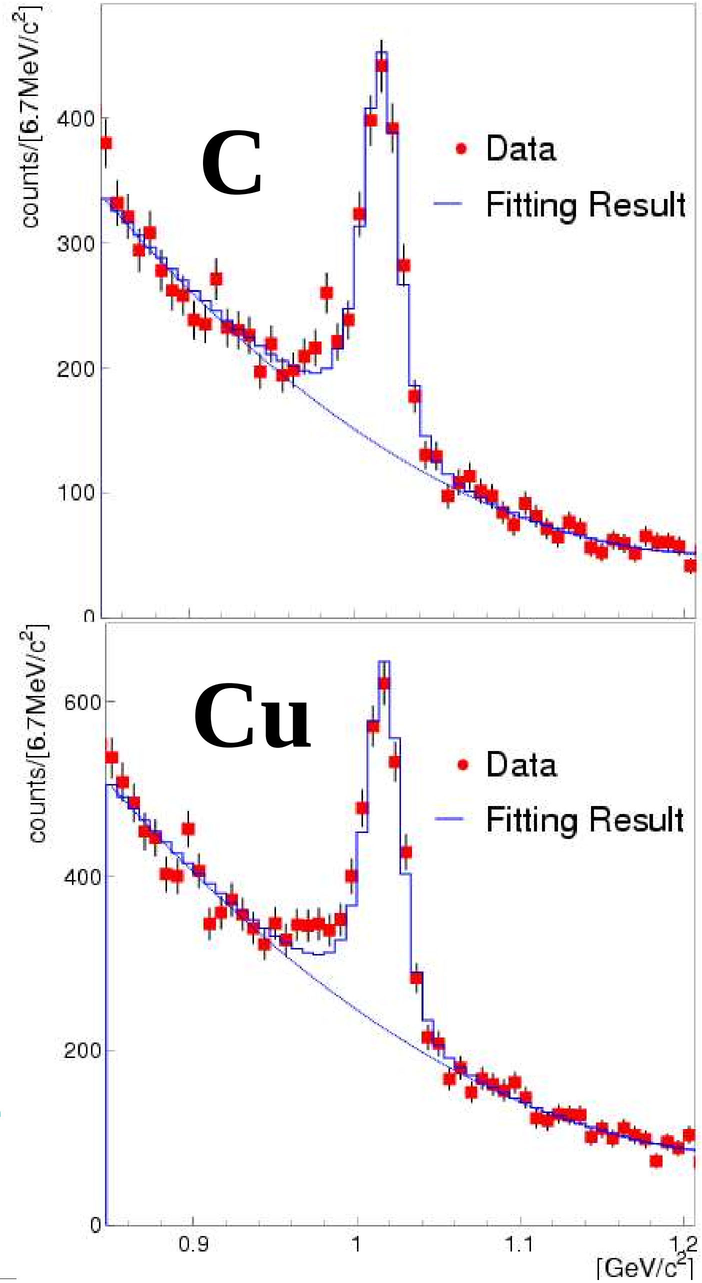
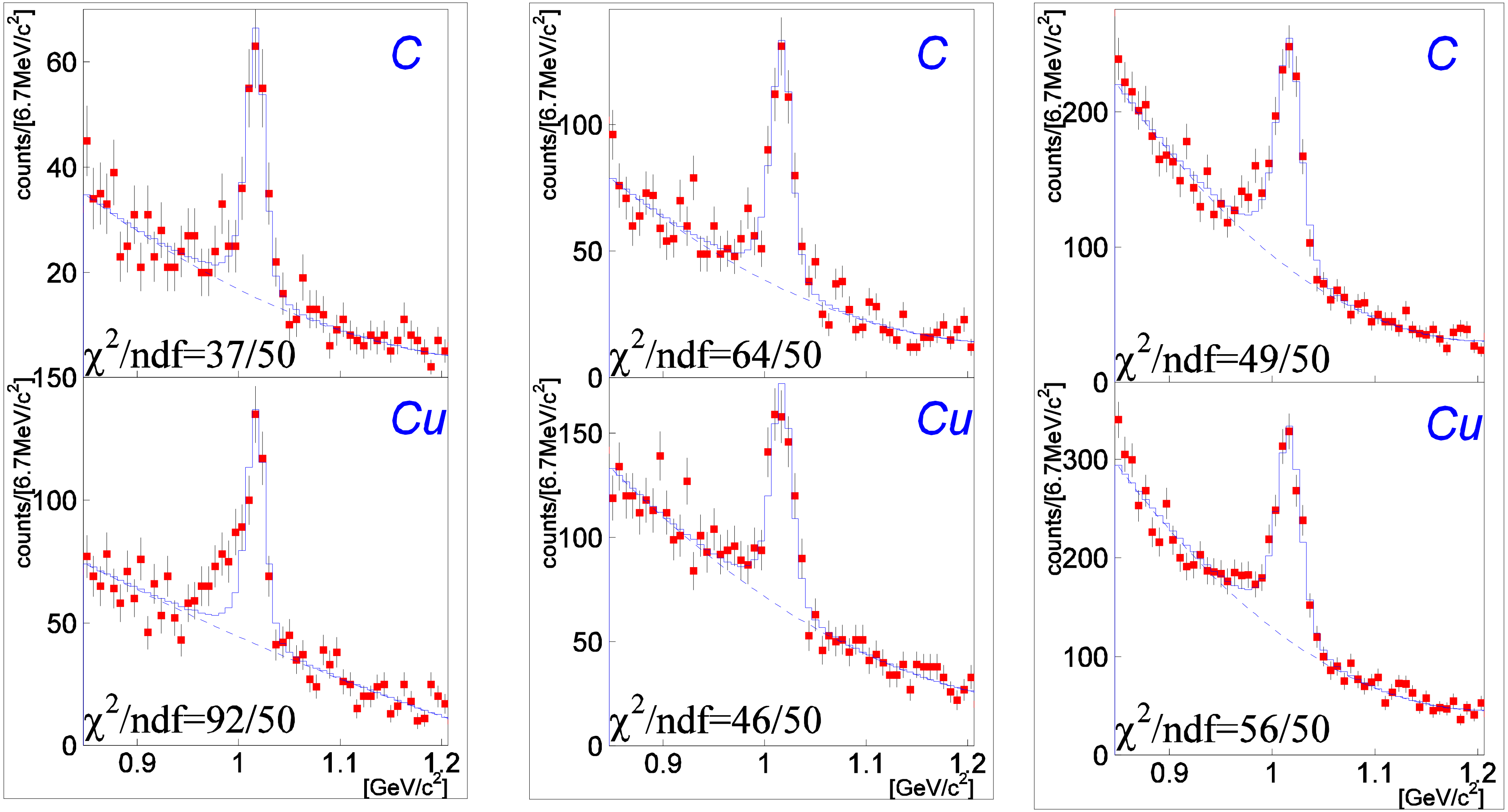
- fit with
  - simulated mass shape of ϕ
    - (evaluated as same as ρ&ω)
  - polinomial curve background
- examine the 'excess' is significant or not.
  - $\rightarrow$ see the $\beta\gamma$ dependence : excess could be enhanced for slowly moving mesons



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

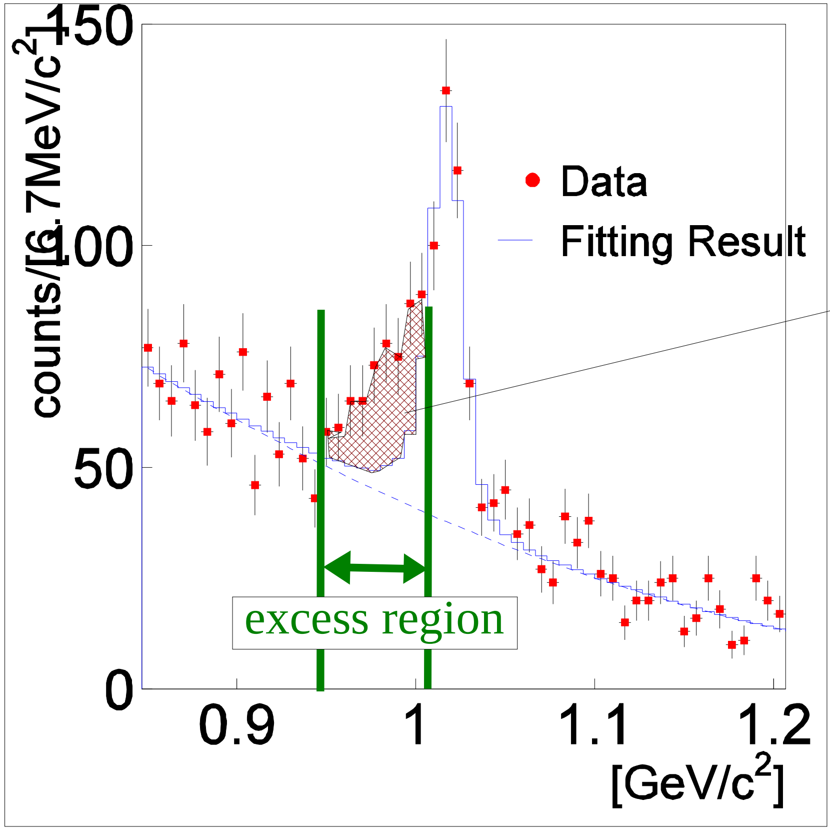
βγ<1.25 (Slow) 1.25<βγ<1.75 1.75<βγ (Fast)

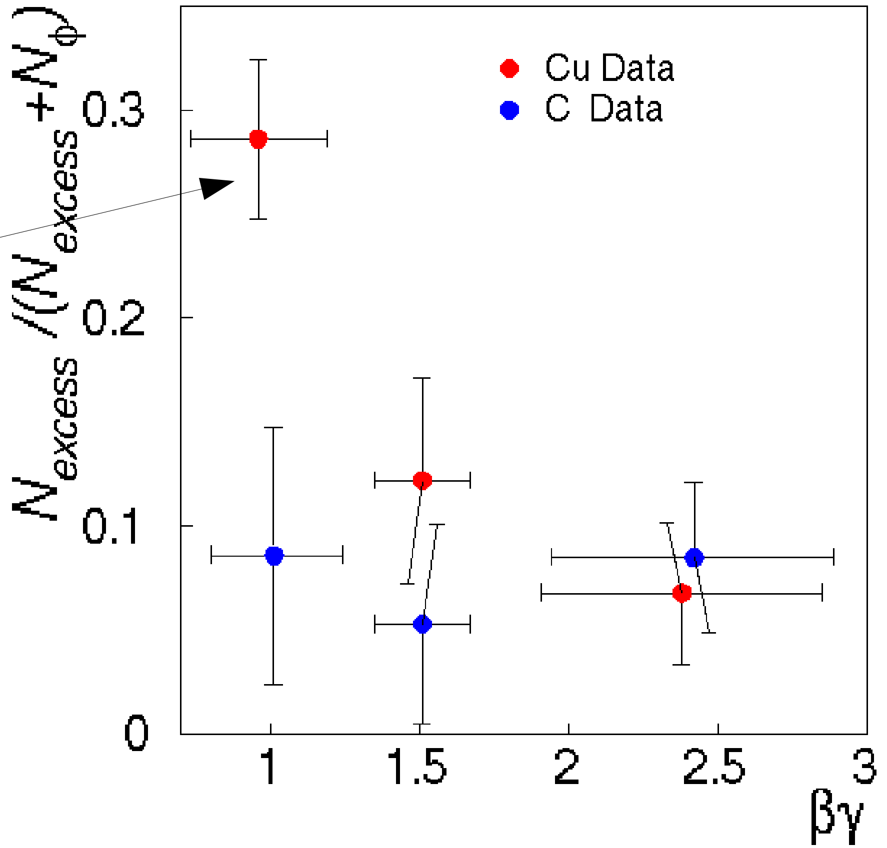


- Only slow/Cu is not reproduced in 99% CL.

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

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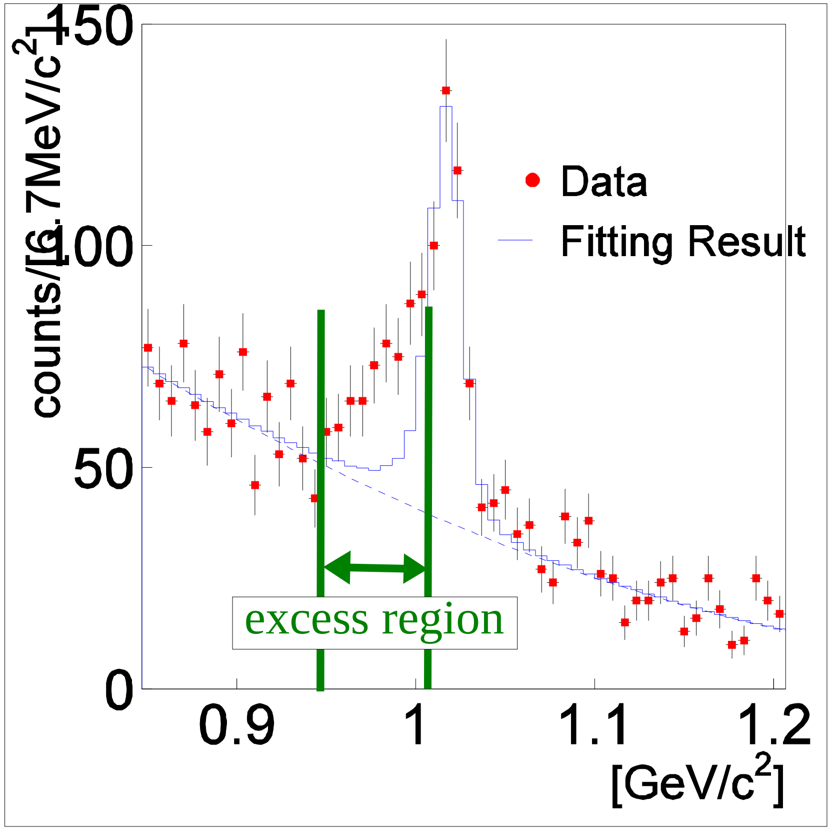
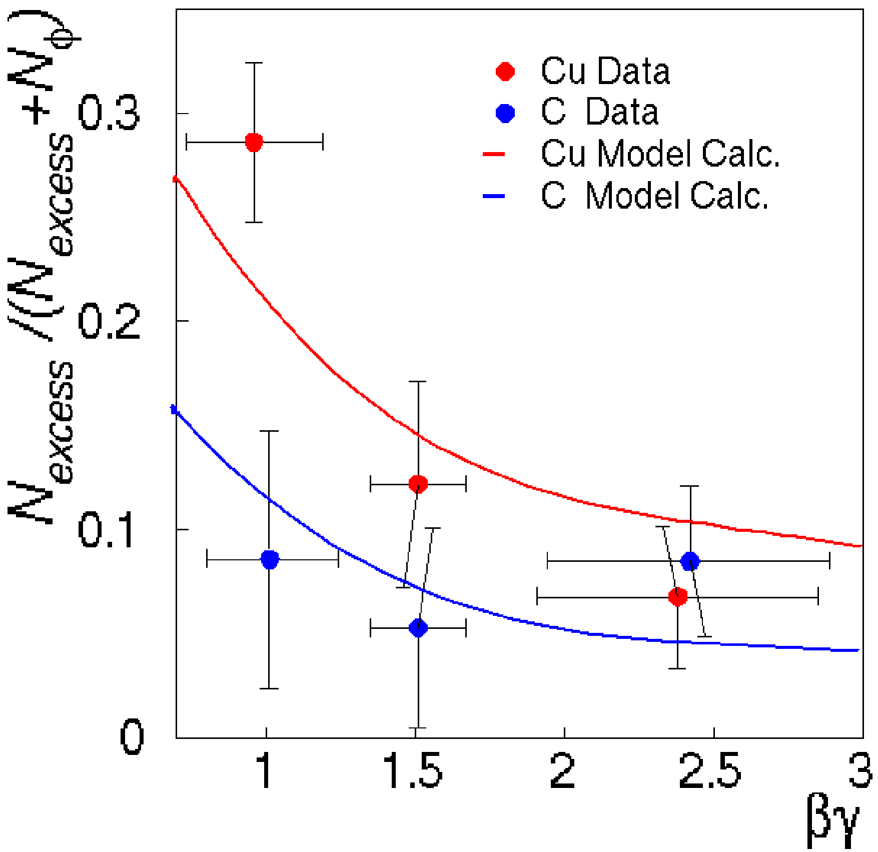
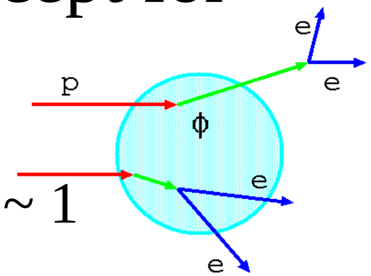
- Model calculation reproduces the tendency of N_{excess} / (N_{excess} + N_{ϕ})





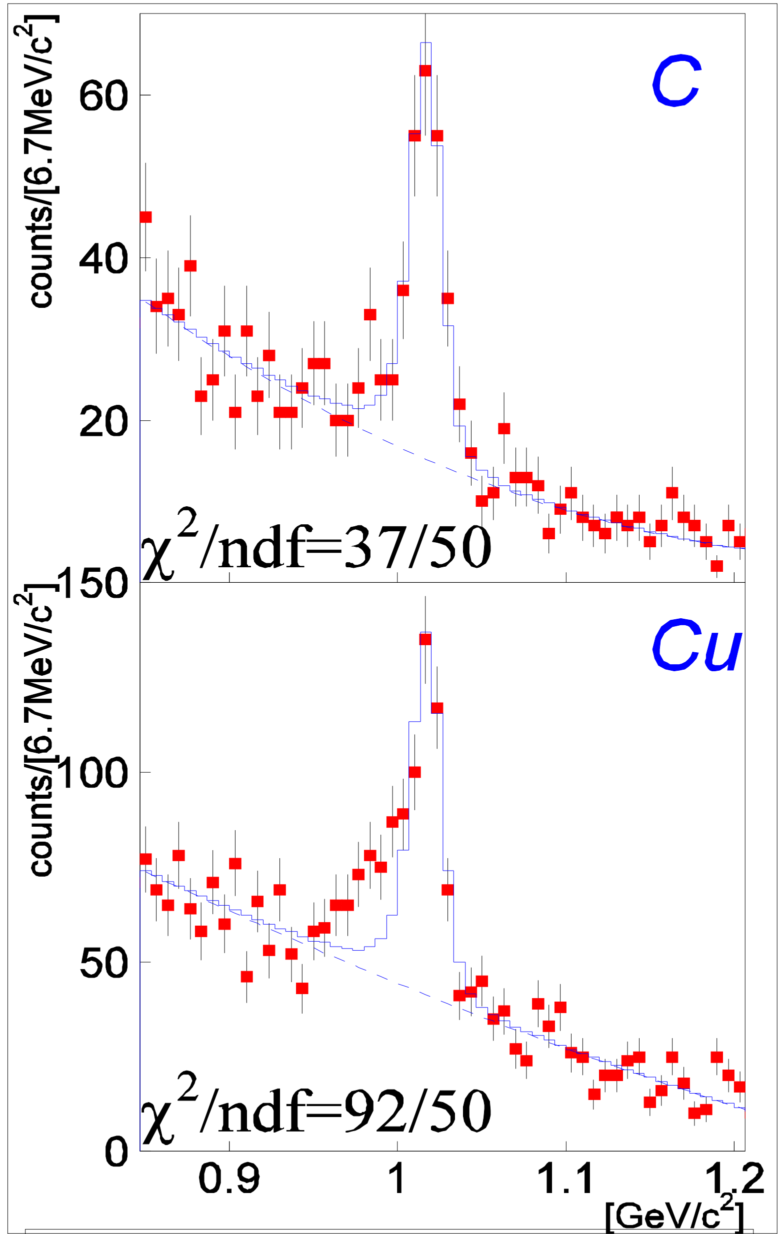
Toy model again for ϕ meson

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



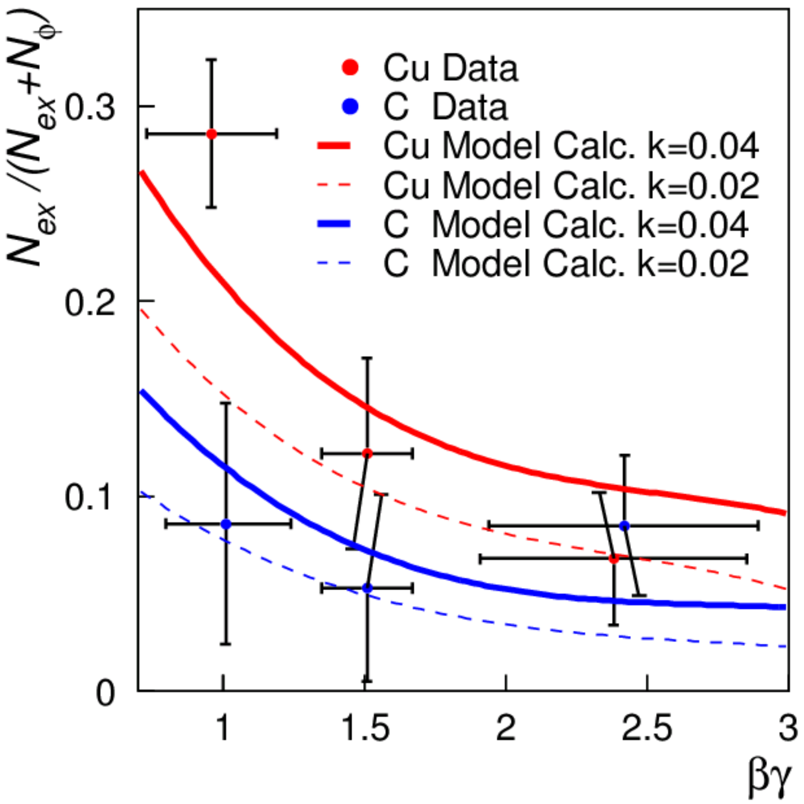
  - $m^*/m_0 = 1- k_1 \rho/\rho_0$
    (k_1=0.04, Hatsuda & Lee, '92,'96)
  - To reproduce such amount of excess, linear-dependent width broadning is adopted :
    $\Gamma_{tot}^*/\Gamma_{tot\,0} = 1+ k_2 \rho/\rho_0$
    (k_2=10, it means Γ_{tot}^* =~47MeV at ρ_0)
    (predicted value by Klingl *et al.*, '98)
    - e^+e^- branching ratio is not changed
      - $\Gamma^*_{e+e-} / \Gamma^*_{tot} = \Gamma^0_{e+e-} / \Gamma^0_{tot}$
  - k_1 & k_2 is not free param., but fixed.

βγ<1.25 (Slow), w/ unmodified

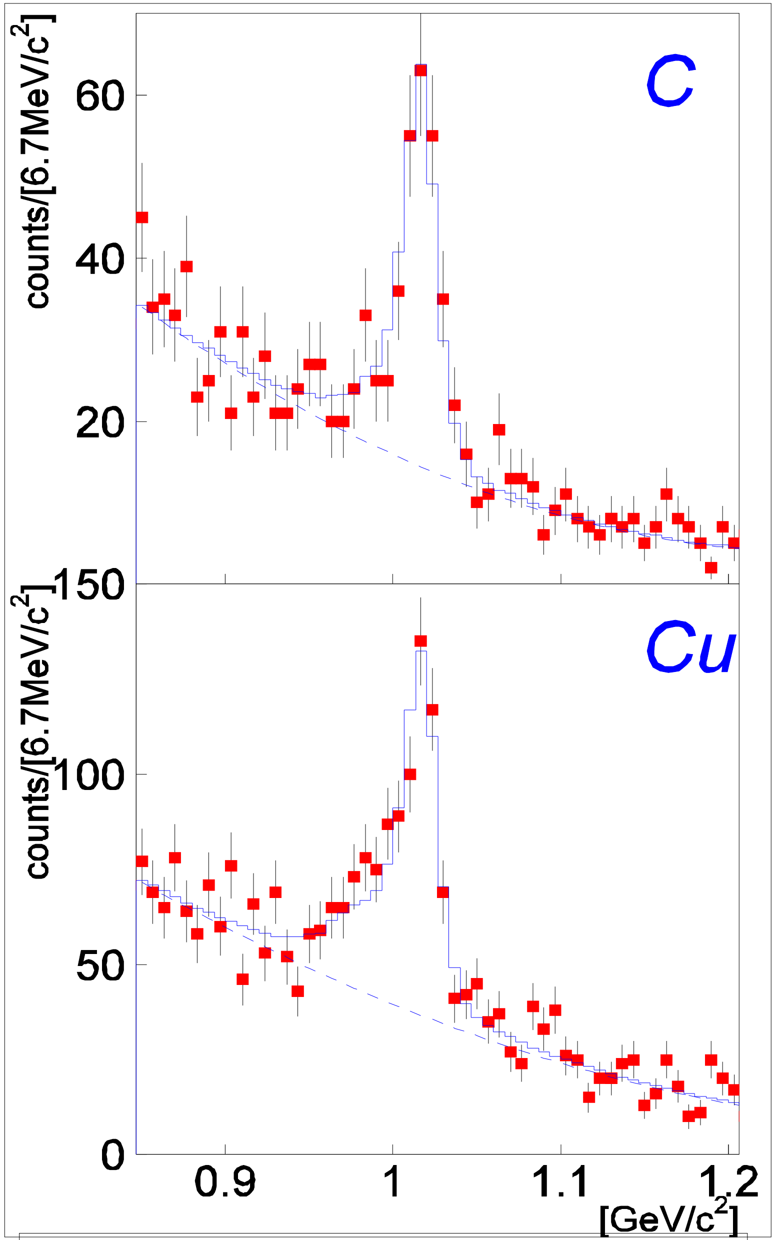


Toy model result for ϕ meson

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



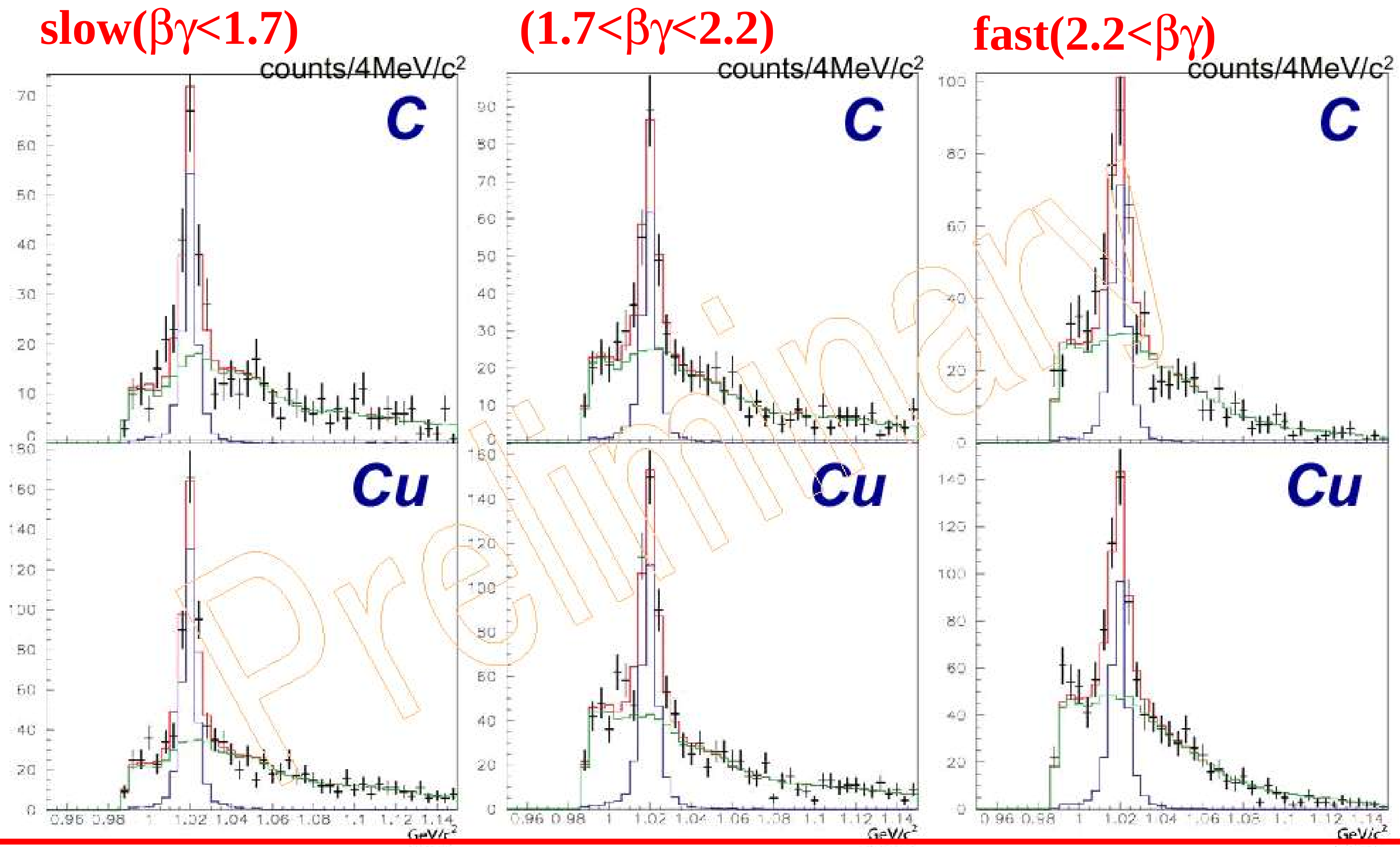
βγ<1.25 (Slow), w/ modified



Result (3)

(KK invariant mass spectra & nuclear dependence α 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 $\phi \rightarrow e^+e^-$)

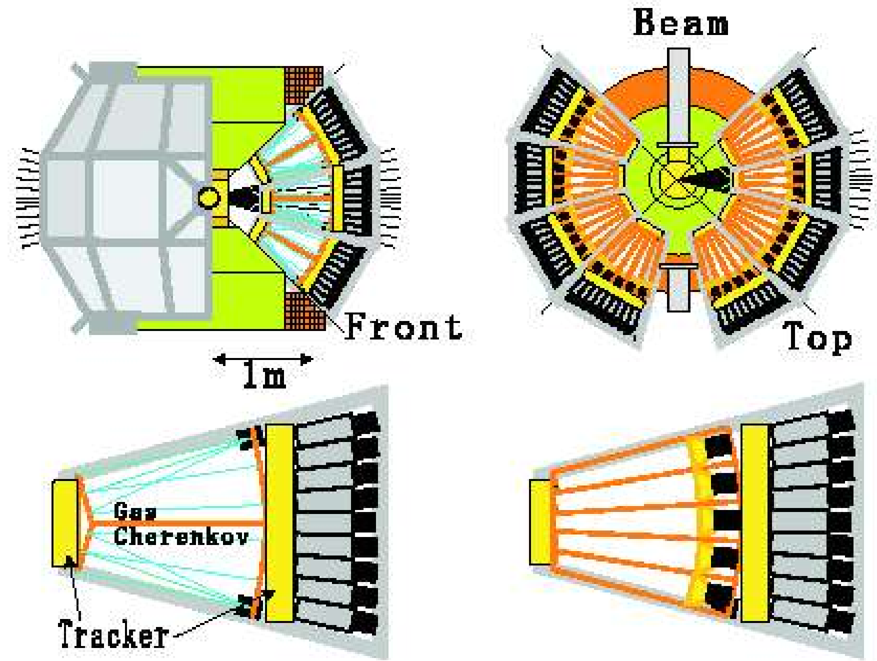
Proposed Experiment at J-PARC

Next generation experiment at J-PARC

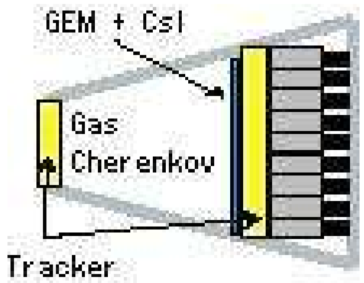
- Same concept as E325
    - thin target / primary beam (10^9 ~10^{10} ppp)/ slowly moving mesons
- Main goal : collect 1x (10^4 ~10^5) $\phi \rightarrow ee$ for each target in 5 weeks
    - 10-100 times as large as E325
        - velocity dependence of 'modified' component
        - new nuclear targets : 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)

Proposed spectrometer

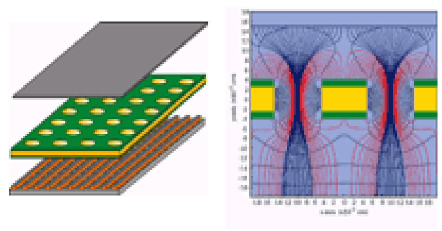
- Tracking Device
  - Drift Chamber
  - GEM(Gas electron multiplier)
    - strip readout
- Two-stage Electron ID
  - Gas Cherenkov
    - PMT+2 mirrors
    - GEM+CsI photocathode
      - pad readout
  - Leadglass EMC
- ~30K Readout Channels (in 20 units)
  - E325: 3.6K, PHENIX:~300K
- Cost : ~$5M (including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



Schematic view of spectrometer



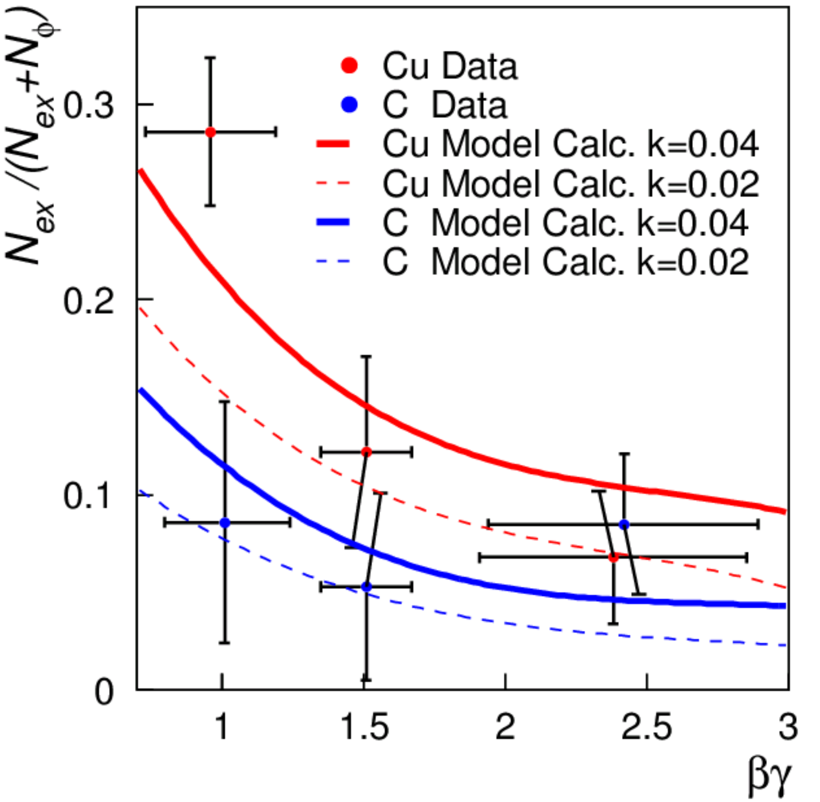
segment w/GEM



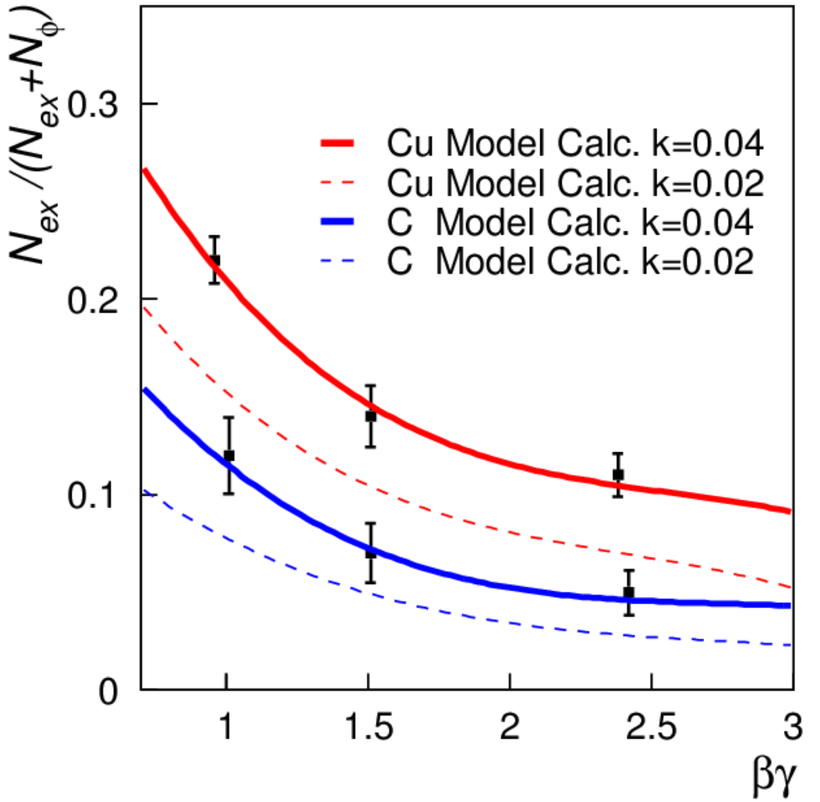
GEM

high statistics

- Main goal : collect 10^4 ~10^5 $\phi \rightarrow ee$ for each target in 5 weeks
    - 100 times as large as E325
        - velocity dependence of 'modified' component



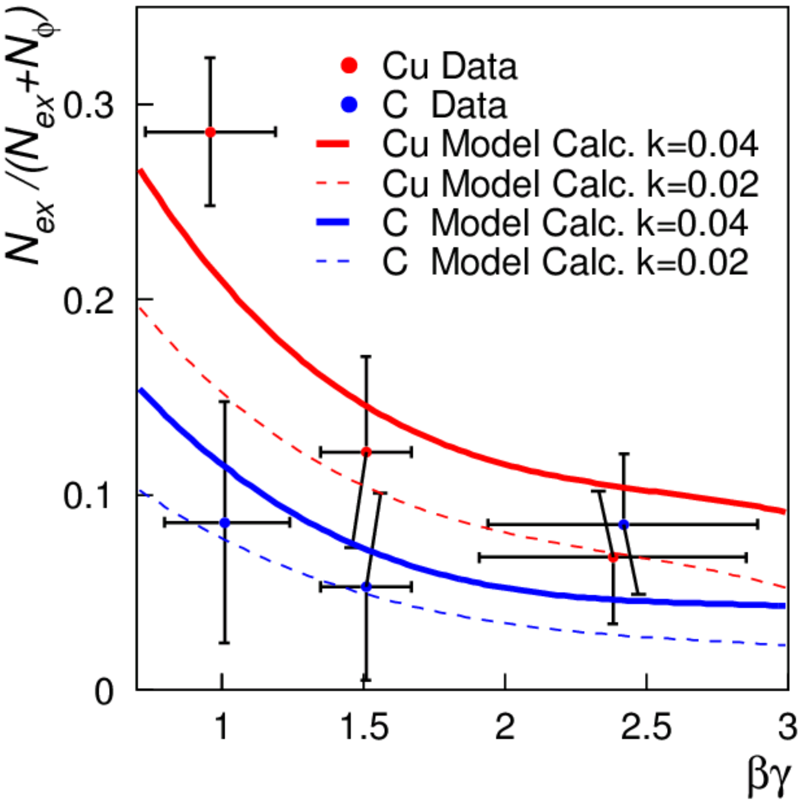
x 10 stat.



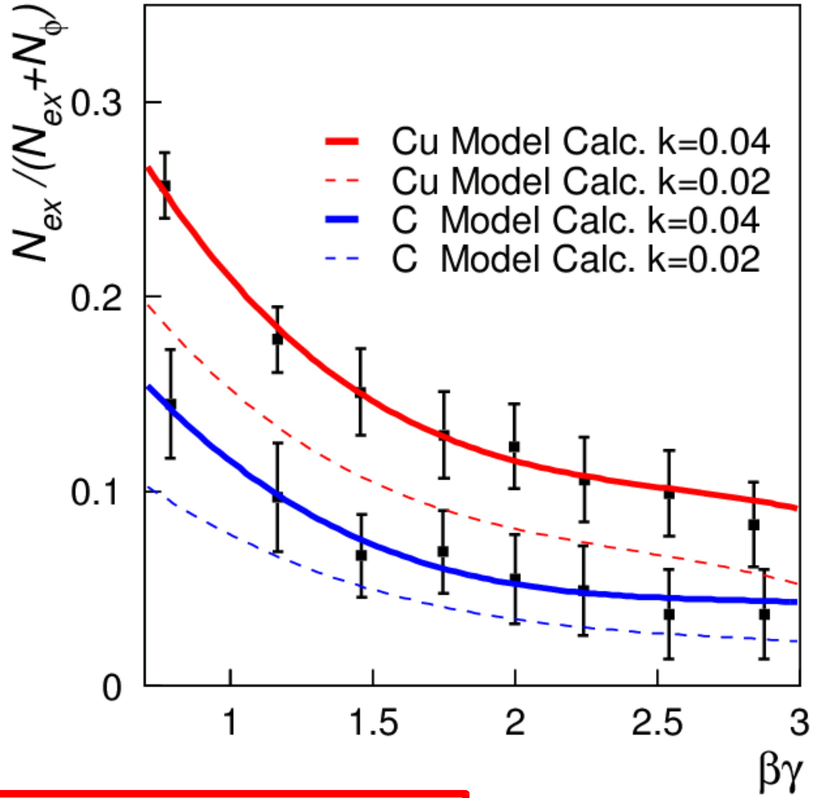
error bars can be shrinked (data points are moved around the model curve)

high statistics

- Main goal : collect $10^4 \sim 10^5$ $\phi \rightarrow ee$ for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of 'modified' component



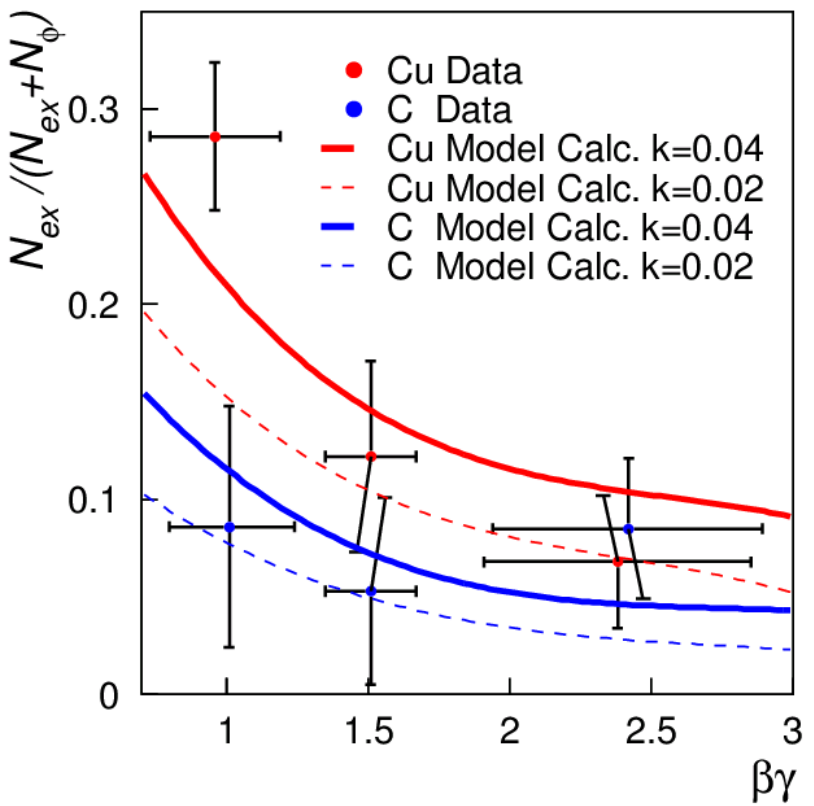
x 10 stat.



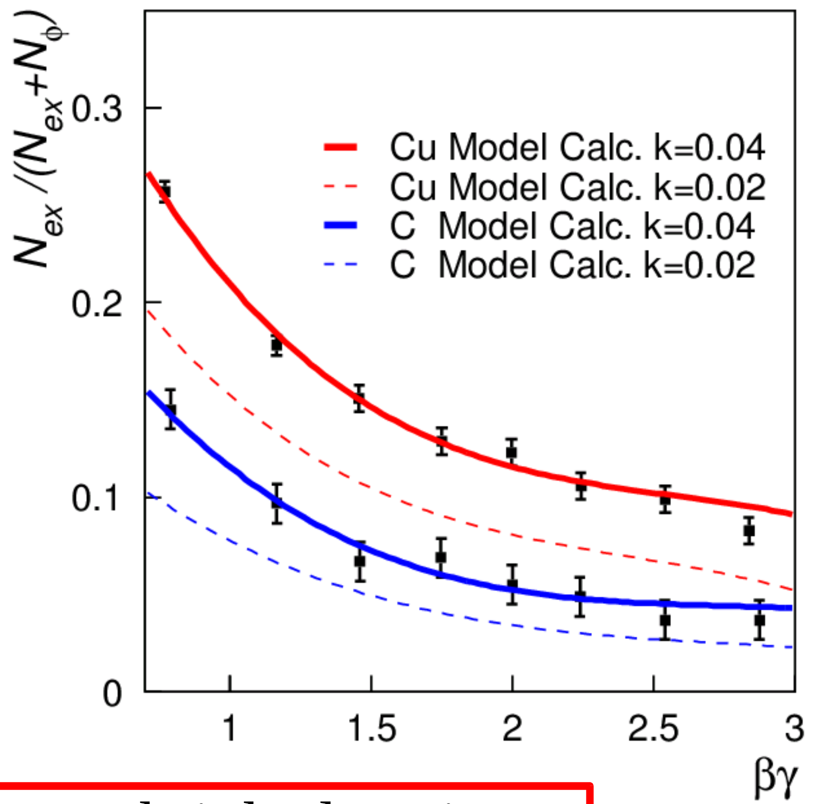
βγ bin can be divided

high statistics

- Main goal : collect $10^4 \sim 10^5$ $\phi \rightarrow ee$ for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of 'modified' component



x 100 stat.



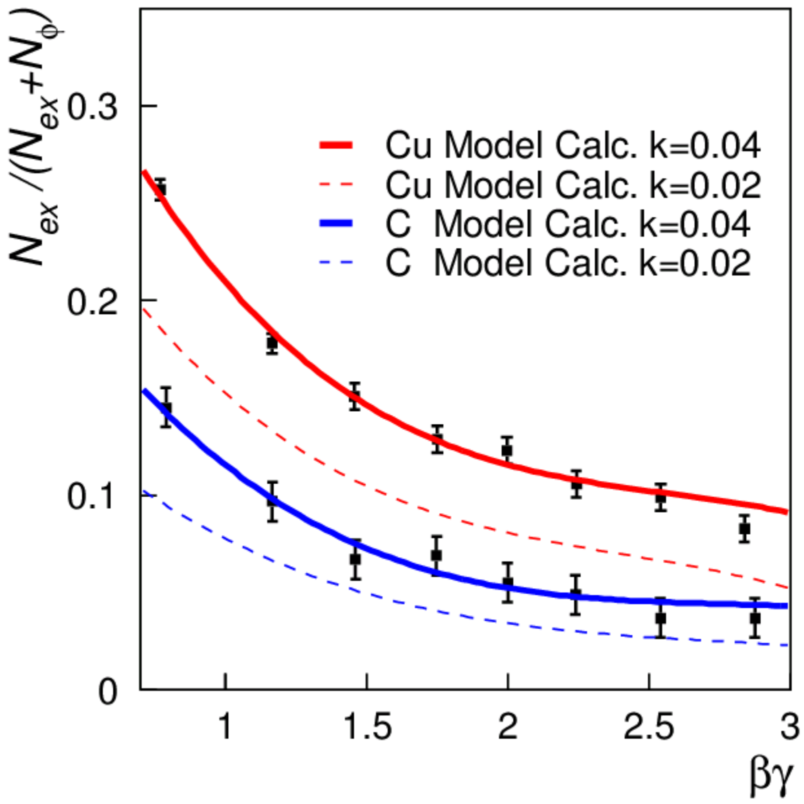
error bars are shrinked again

high statistics

- Main goal : collect $10^4 \sim 10^5$ $\phi \rightarrow ee$ 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.

x 100 stat.



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.
  - analysis of the verocity dependence of the excesses are on going.
- $\phi \to e^+e^-$ 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 $\phi \to K^+K^-$ & $\phi \to e^+e^-$ is also on going to investigate $\Gamma_{K+K-} / \Gamma_{e+e-}$ changing in nuclei.