In-medium modification of vector mesons measured at KEK-PS

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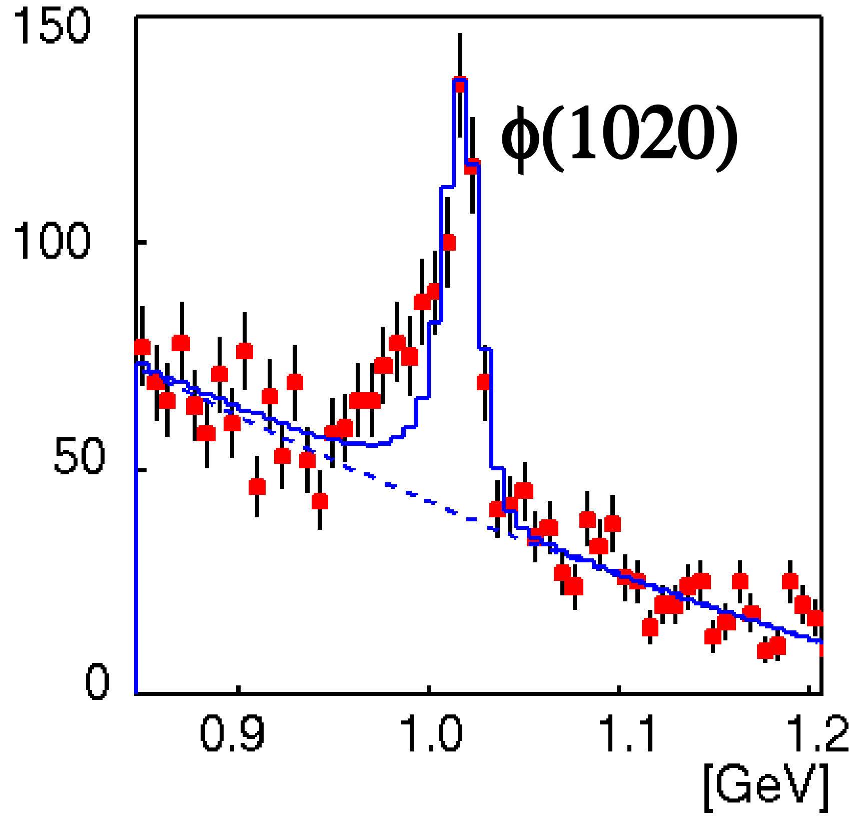
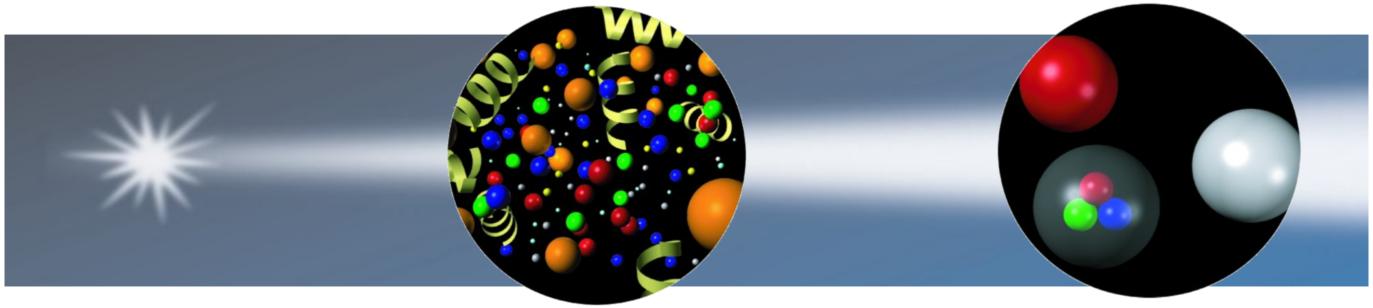
for the KEK-PS E325 collaboration
(RIKEN Nishina Center)

- **Introduction**
- **KEK-PS E325 Results**
  - 1) (ρ, ω and) $\phi \rightarrow e^+e^-$ spectra
  - 2) $\phi \rightarrow K^+K^-$ spectra /branching ratio

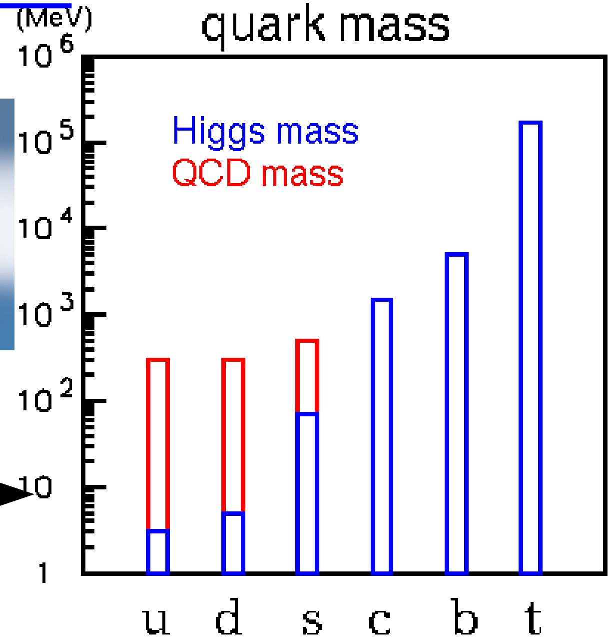


Chiral symmetry in dense matter



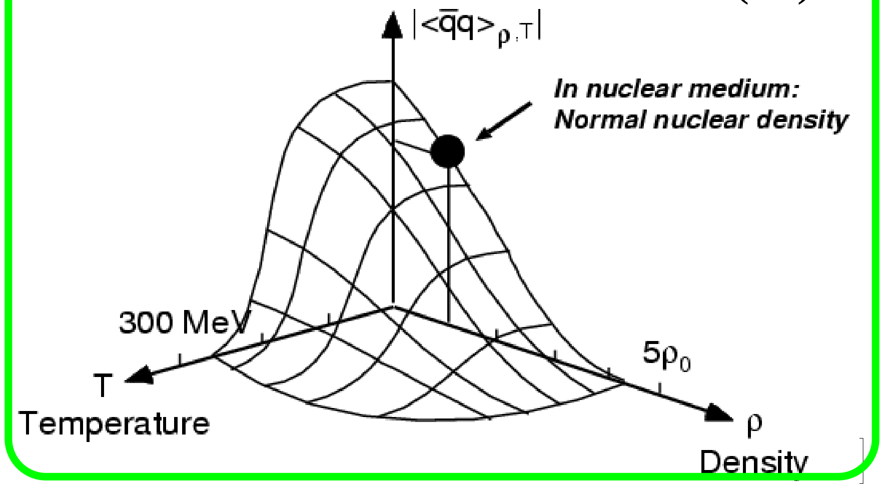
big bang — 10psec — 0.1msec

quark mass: 0MeV — 3MeV from Higgs — 300MeV from chiral condensate $\langle \bar{q}q \rangle$



- Origin of hadron mass : spontaneous breaking of chiral symmetry
- In hot/dense matter, chiral symmetry is expected to be restored
  - hadron modification is also expected
  - many theoretical predictions...

W.Weise, NPA553(93)59



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

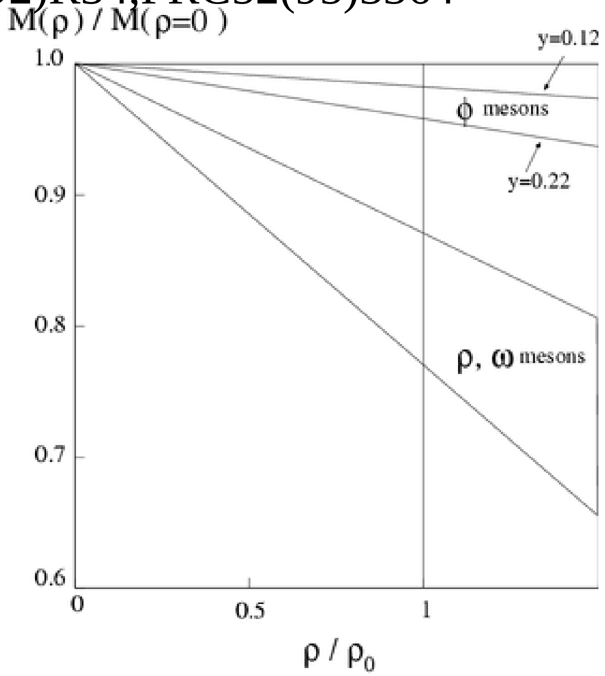
linear dependence on density

$m^*/m_0 = 1 - {\color{red}k}\ \rho/\rho_0$

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



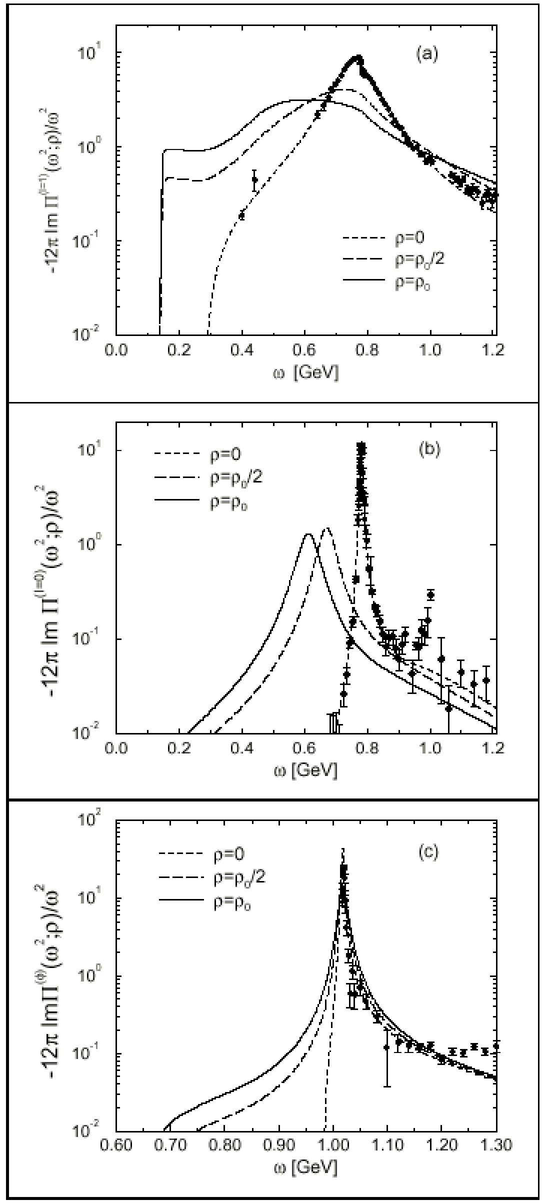
Klingle,Kaiser,Weise,

NPA624(97)527

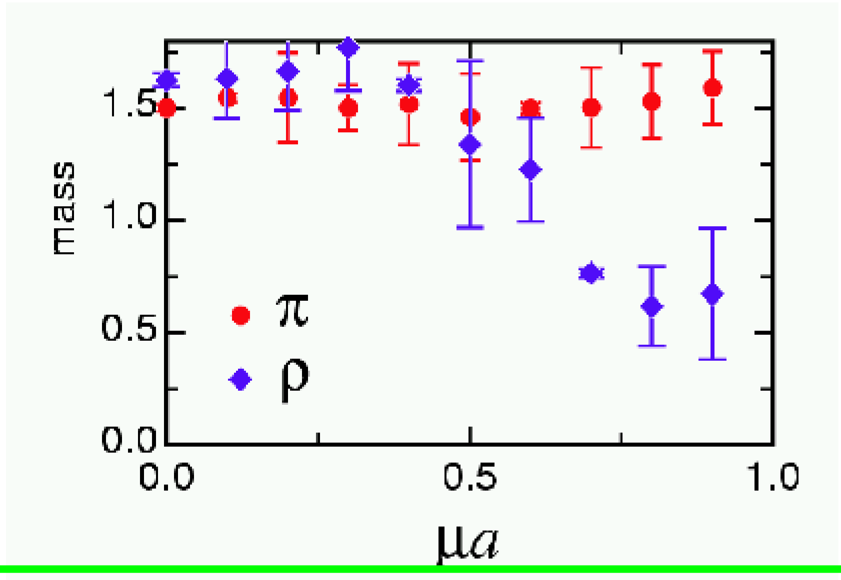
ρ

ω

φ

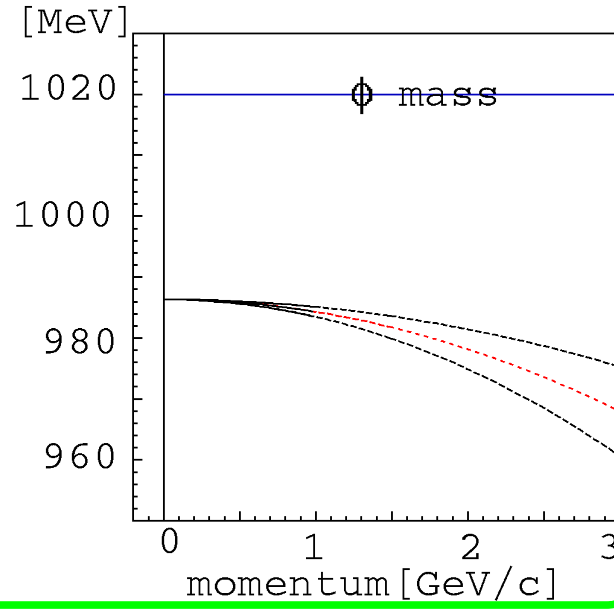


Muroya, Nakamura, Nonaka, PLB 551 (03) 305

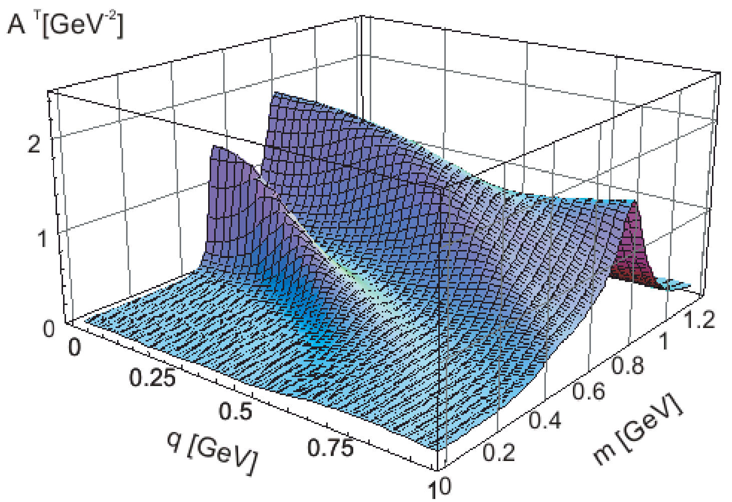


dispersion relation (mass VS momentum)

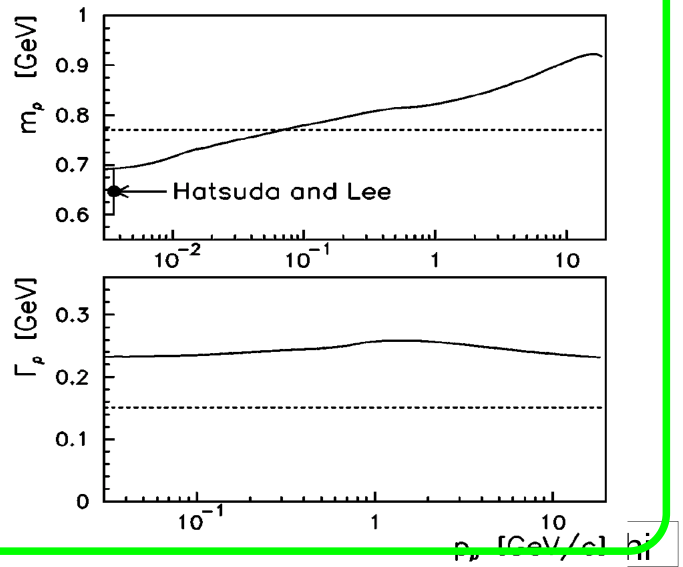
- S.H.Lee (PRC57(98)927) $m^*/m_0 = 1 - \textcolor{red}{k}\,\rho/\rho_0$
  - ρ/ω : $k=0.16\pm0.06+(0.023\pm0.007)(p/0.5)^2$
  - ϕ : $k=0.15(\pm0.05)*y + (0.0005\pm0.0002)(p/0.5)^2$
    - for p<1GeV/c



- Post & Mosel(NPA699(02)169) : ρ meson



- Kondratyuk et al. (PRC58(98)1078) : ρ meson



Experiment KEK-PS E325

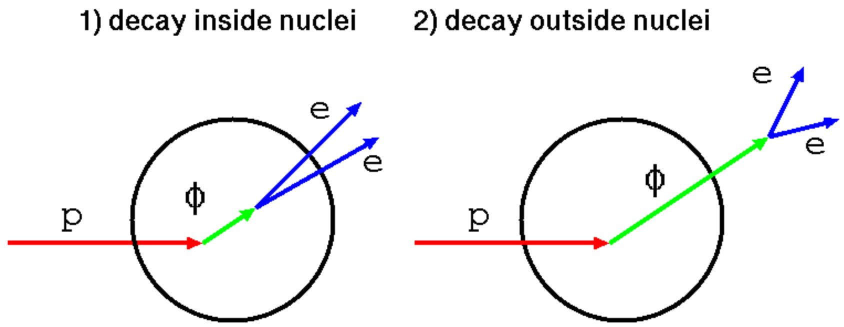
- 12GeV p+A $\rightarrow$ ρ/ω/φ +X (ρ/ω/φ $\rightarrow e^+e^-$, φ $\rightarrow K^+K^-$)
- Experimental key issues:
  - Very thin target to suppress the conversion electron background (typ. 0.1% interaction/0.2% radiation length of C)
  - To compensate the thin target, high intensity proton beam to collect 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<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, R. Muto, T. Nakura, M. Naruki, K.Ozawa, F. Sakuma, O. Sasaki, 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.)

Expected Invariant mass spectra in e^+e^-

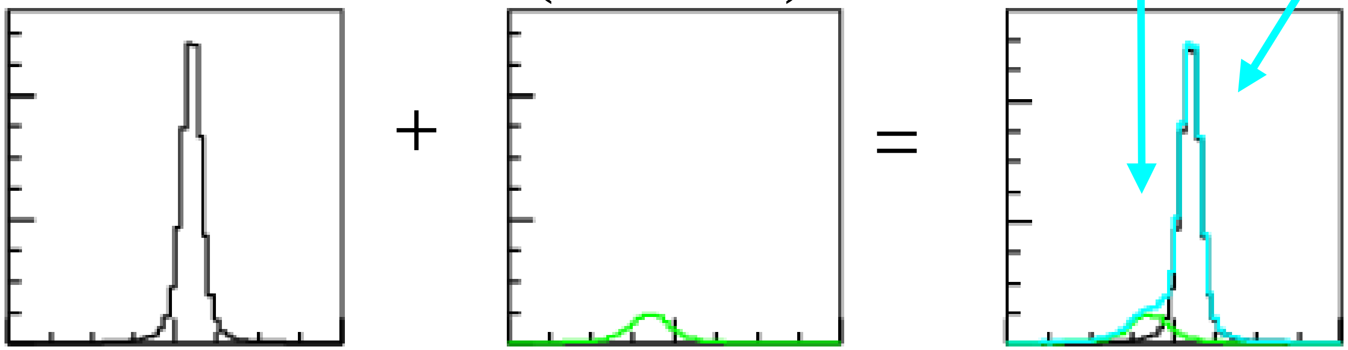
- smaller FSI in e^+e^- decay channel
- double peak (or tail-like) structure :
  - second peak is made by inside-nucleus decay (modified meson) : amount depend on the nuclear size and meson velocity
    - could be enhanced for slower mesons & larger nuclei



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

outside decay (natural)

inside decay (modified)



expected to be observed

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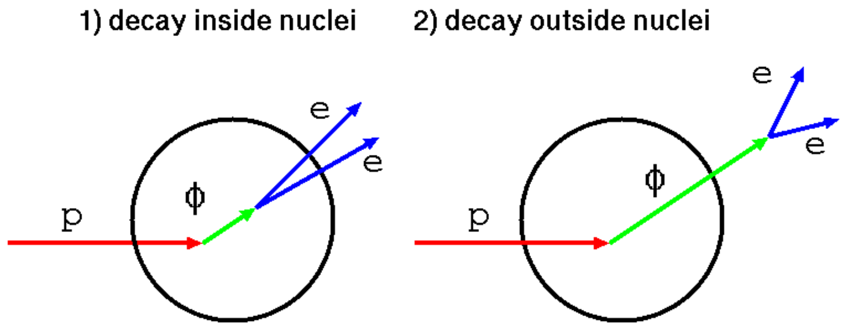
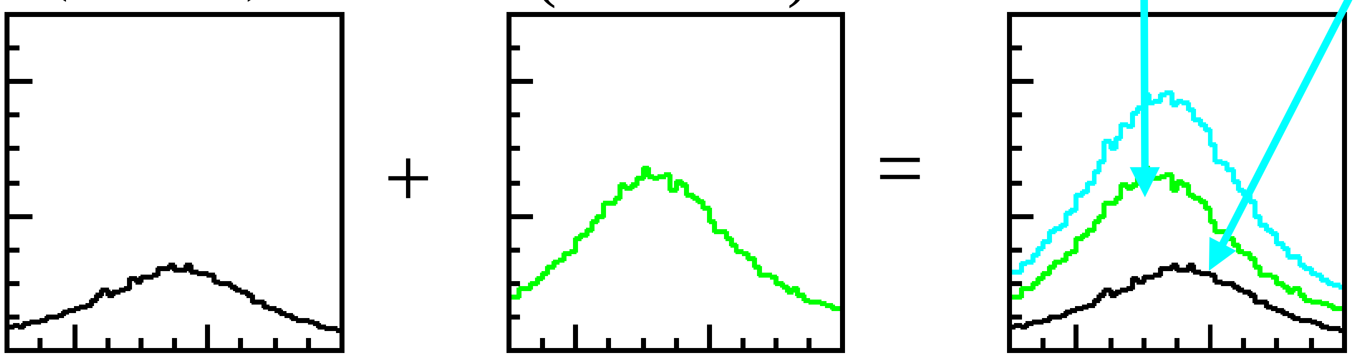


shorter-life meson(ρ) cases : Schematic picture

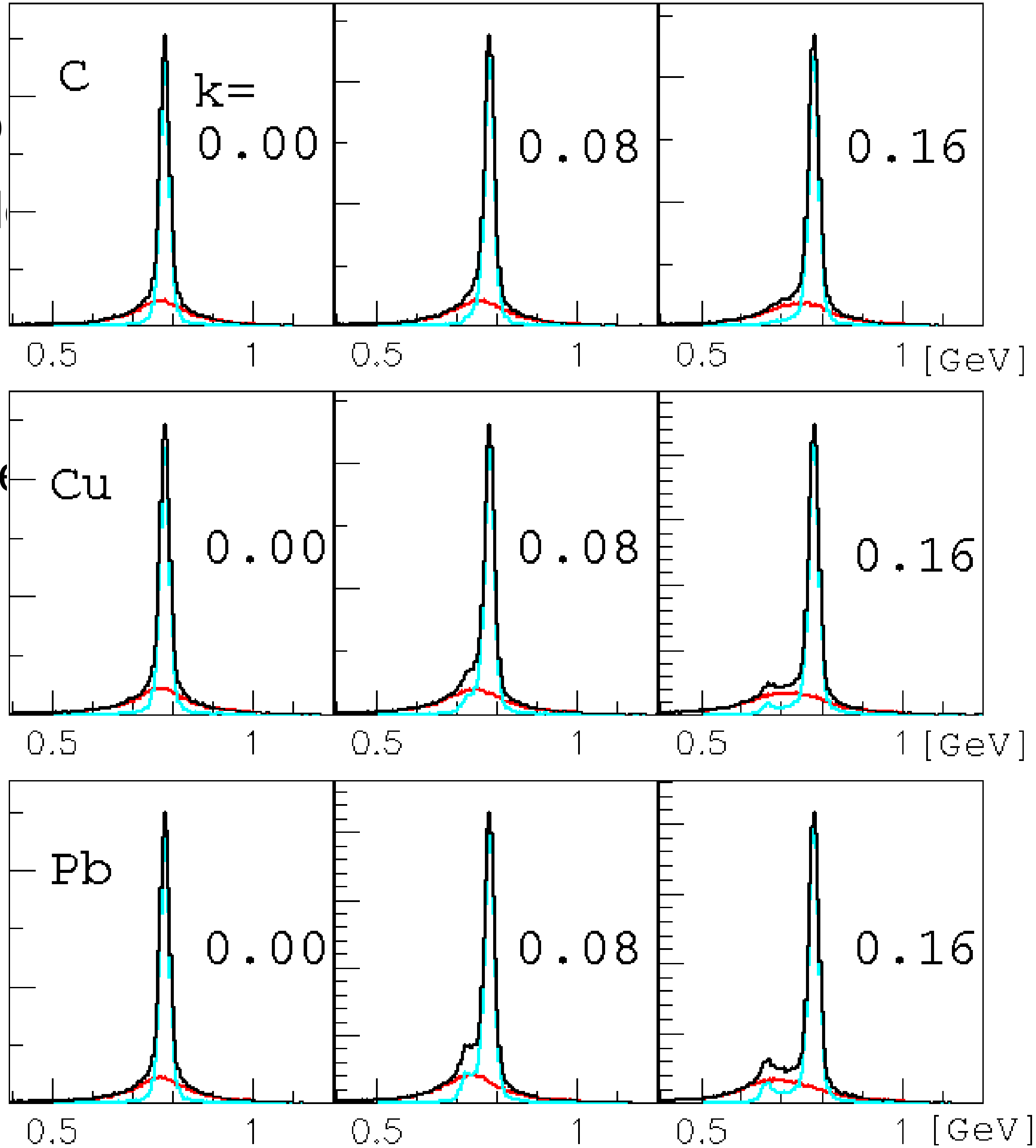
outside decay (natural) + inside decay (modified) = expected to be observed



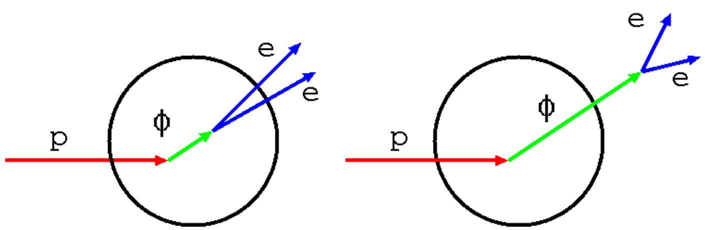
(Expected e^+e^- spectra)

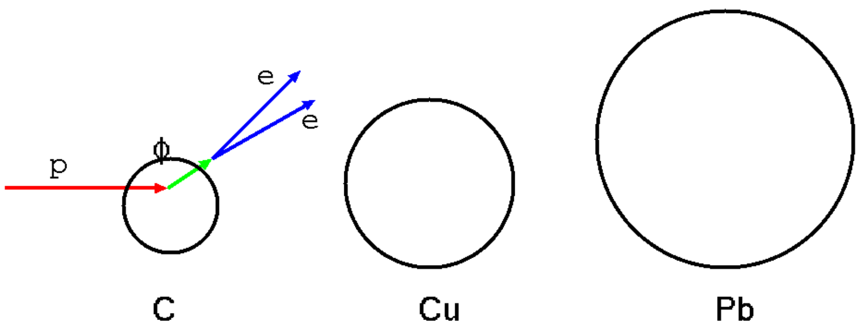
(toy model calc.)

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

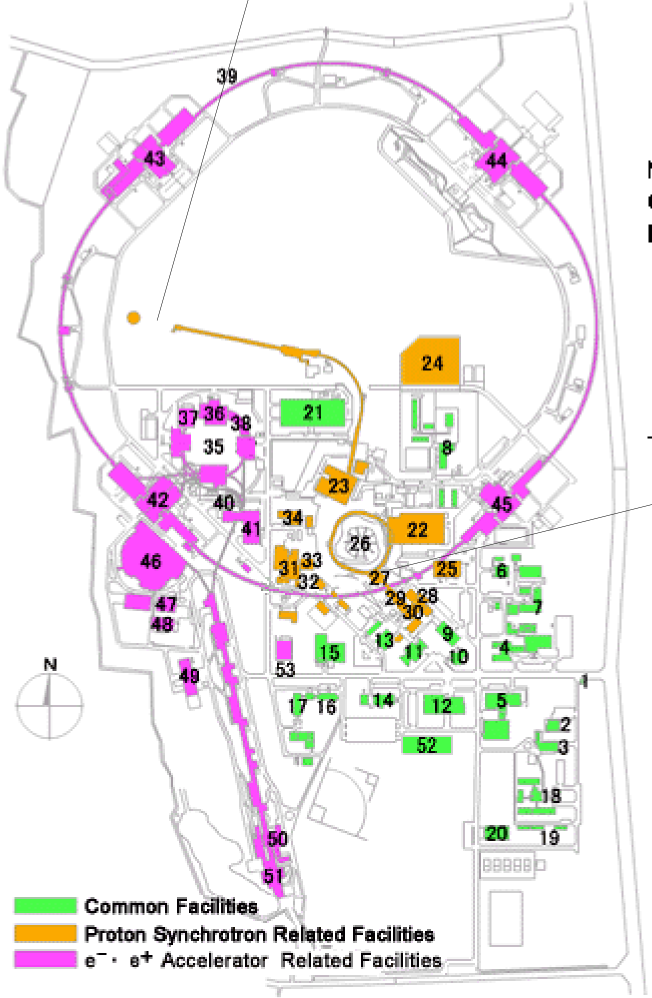


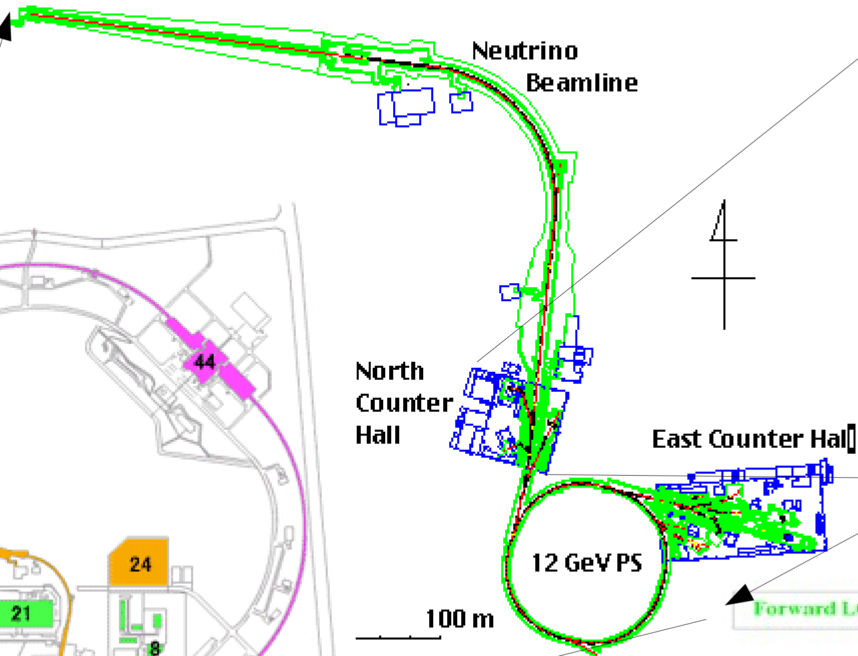
1) decay inside nuclei 2) decay outside nuclei

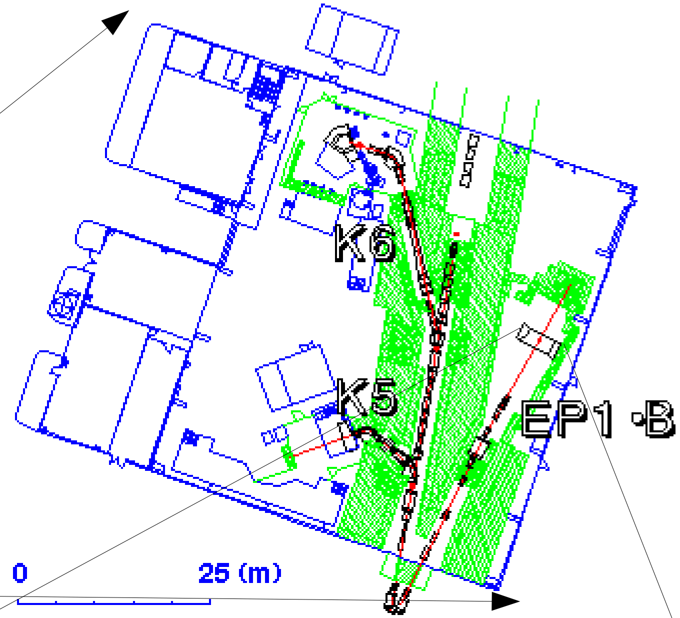


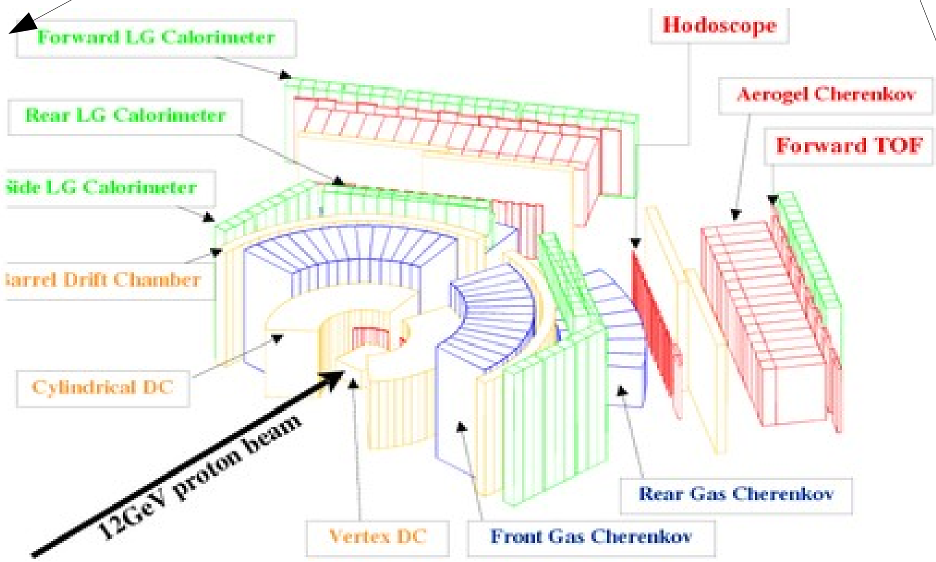


KEK









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

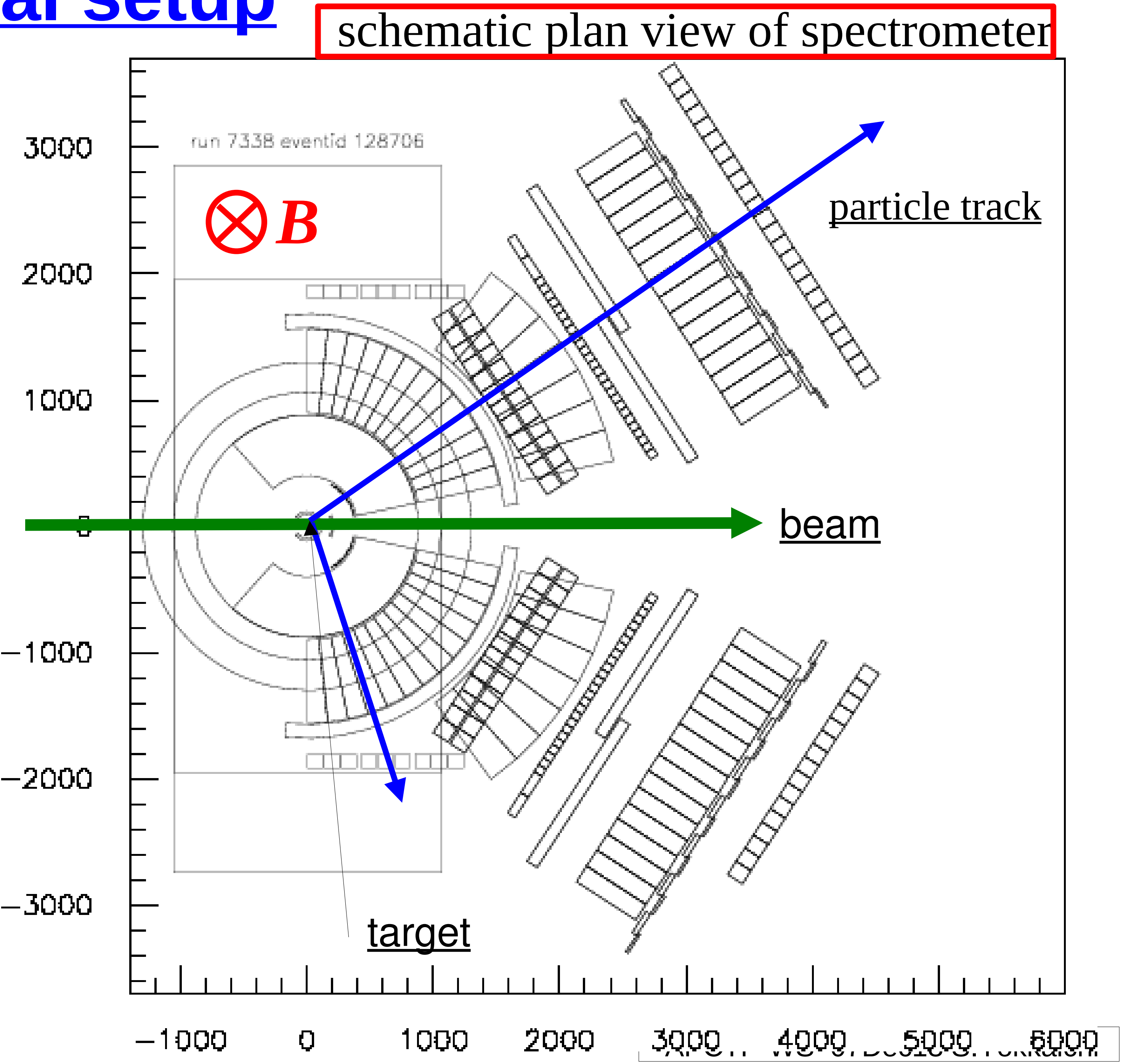
History of E325

- 1993 proposed
- 1994 R&D start
- 1996 construction start
- '97 data taking start
- '98 first ee data
  - PRL86(01)5019 ρ/ω (ee)
- 99,00,01,02....
  - x100 statistics
  - PRL96(06)092301 ρ/ω (ee)
  - PRC74(06)025201 α (ee)
  - PRL98(07)042501 ϕ (ee)
  - PRL98(07)152302 ϕ (KK),α
- '02 completed
- spectrometer paper
  - NIM A457(01)581
  - NIM A516(04)390

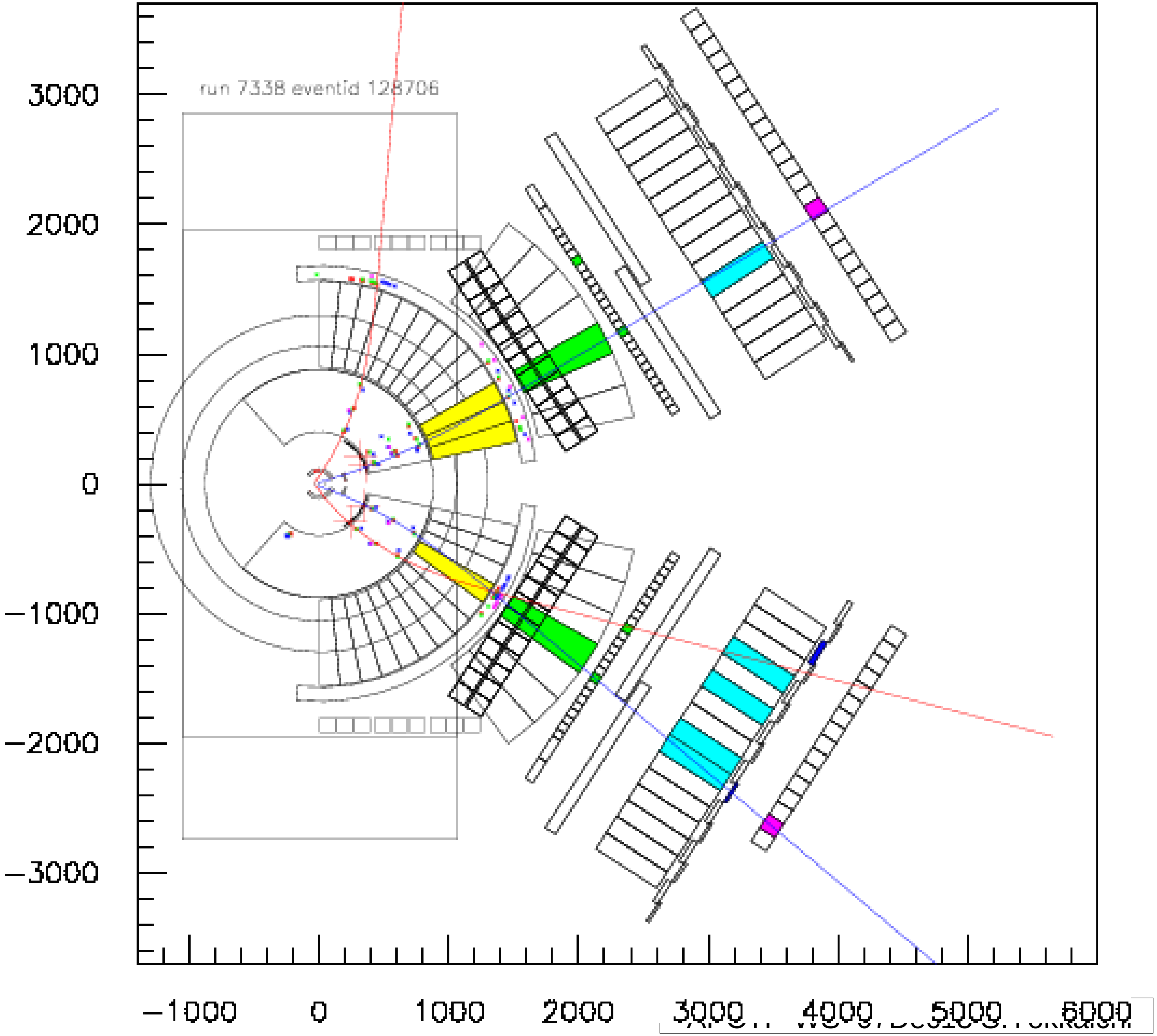
E325 spectrometer
located at KEK-PS EP1-B primary beam line

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



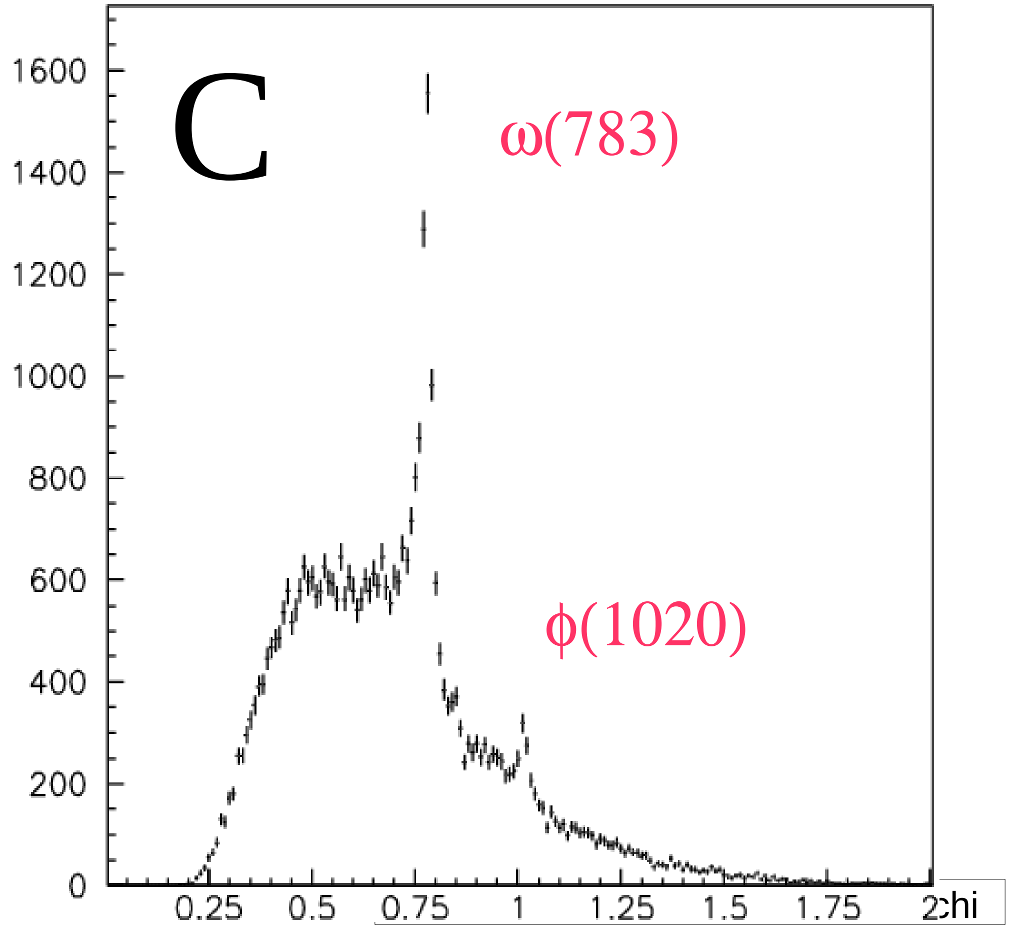
- Typical e^+e^- Event
  - blue:electron
  - red : other
  - invariant mass and momentum of mother particle can be calculated



E325 Results (1)

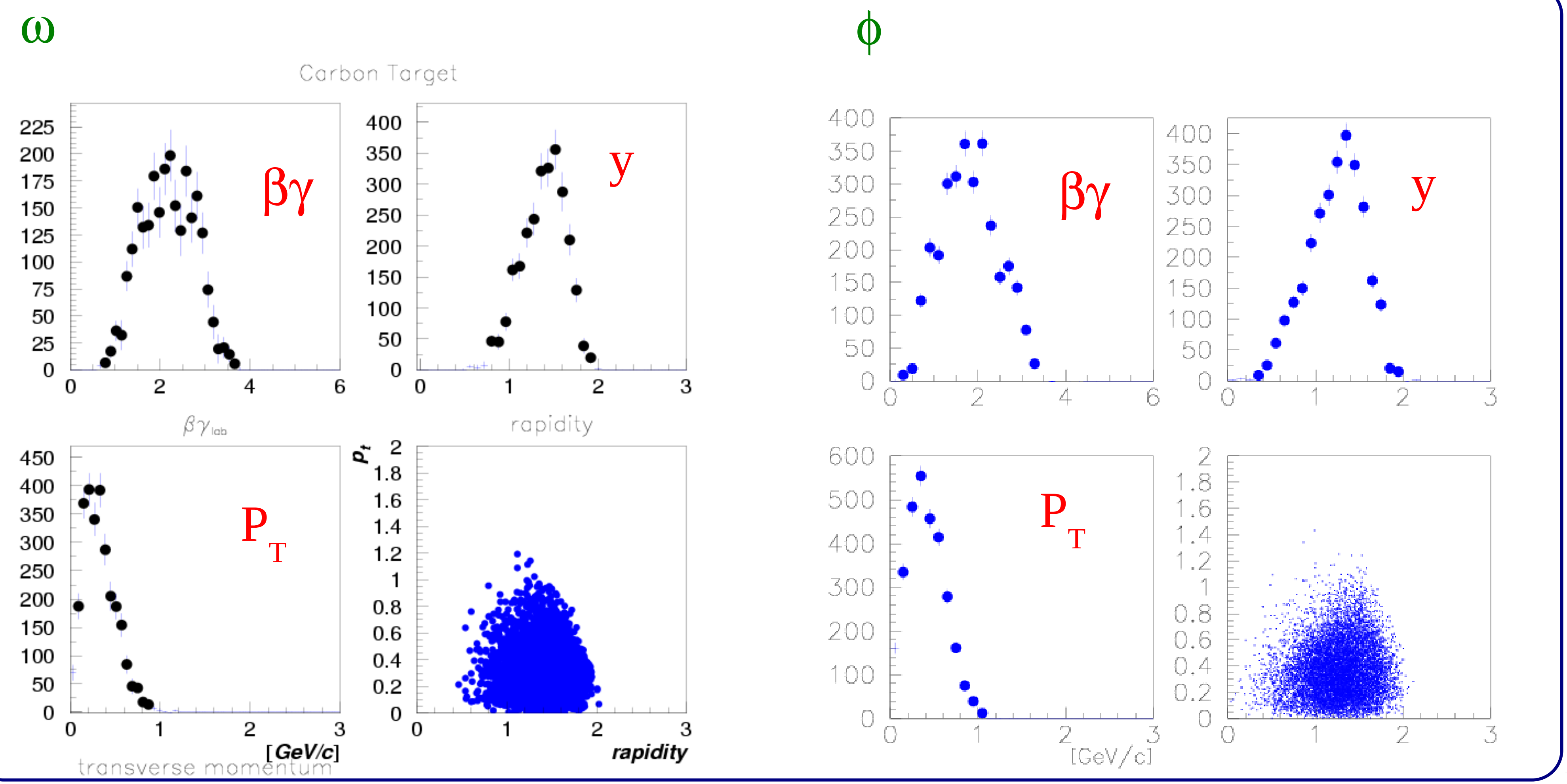
ee invariant mass spectra

M. Naruki et al.,
PRL 96 (2006) 092301
R.Muto et al.,
PRL 98 (2007) 042501



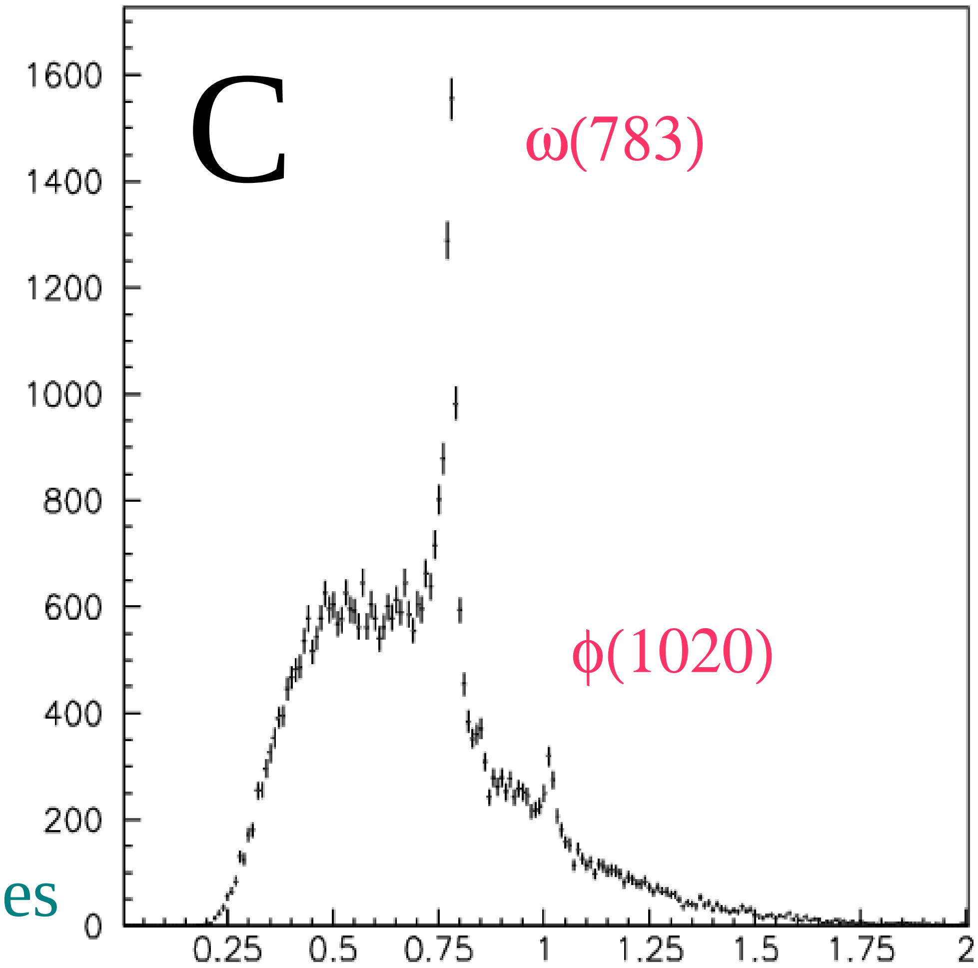
measured kinematic distribution of $\omega/\phi \rightarrow e^+e^-$

- $0 < P_T < 1$, $0.5 < y < 2$ (y_{CM}=1.66)
- $1 < \beta\gamma$ (=p/m) < 3 (0.8<p<2.4GeV/c for ω, 1<p<3 GeV/c for ϕ)



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

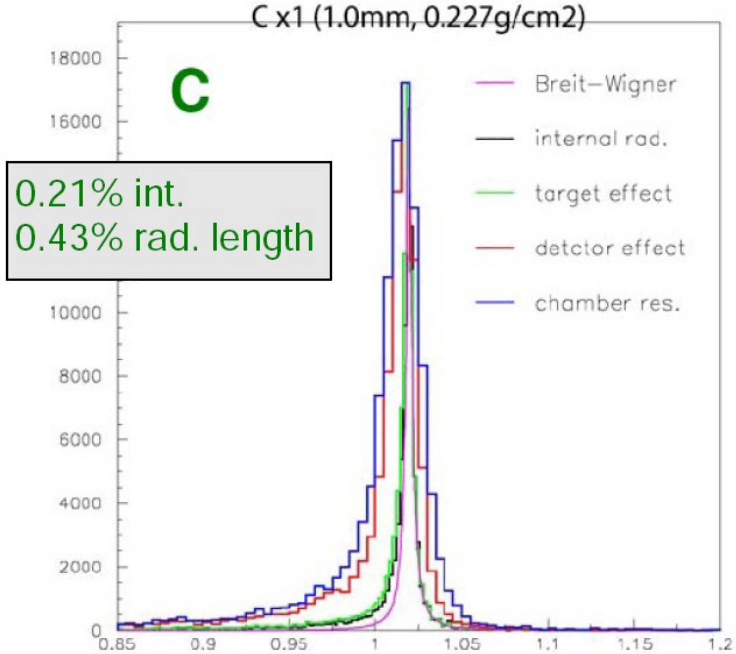


→ fit the spectra with known sources

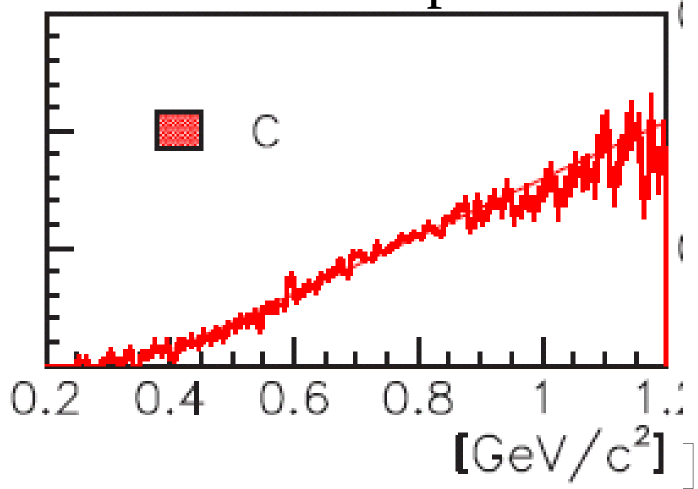
Analysis : Fitting with known sources

- 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

experimental effects

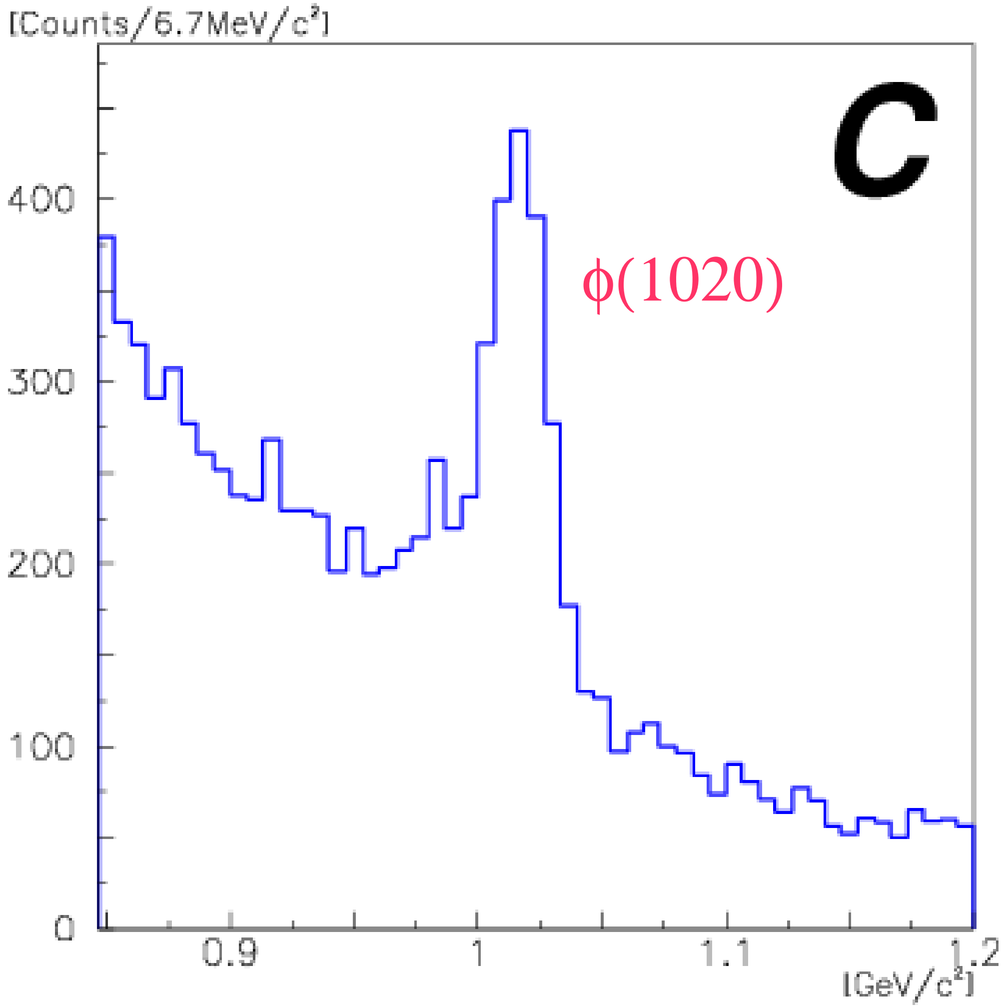


mass acceptance



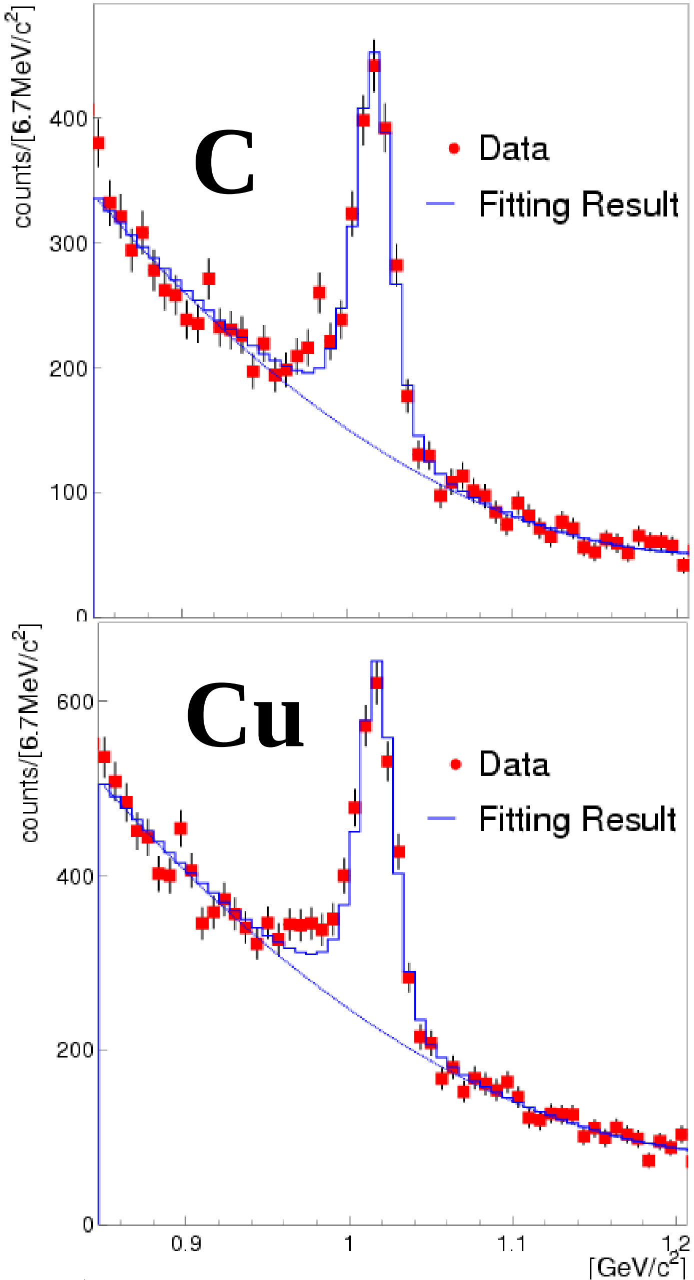
$\phi \rightarrow e^+e^-$ invariant mass spectra

- from 2001/02 run data
- C & Cu target
- acceptance uncorrected
- mass resolution :10.7MeV
- fit with
  - simulated mass shape of ϕ
  - polynomial curve background



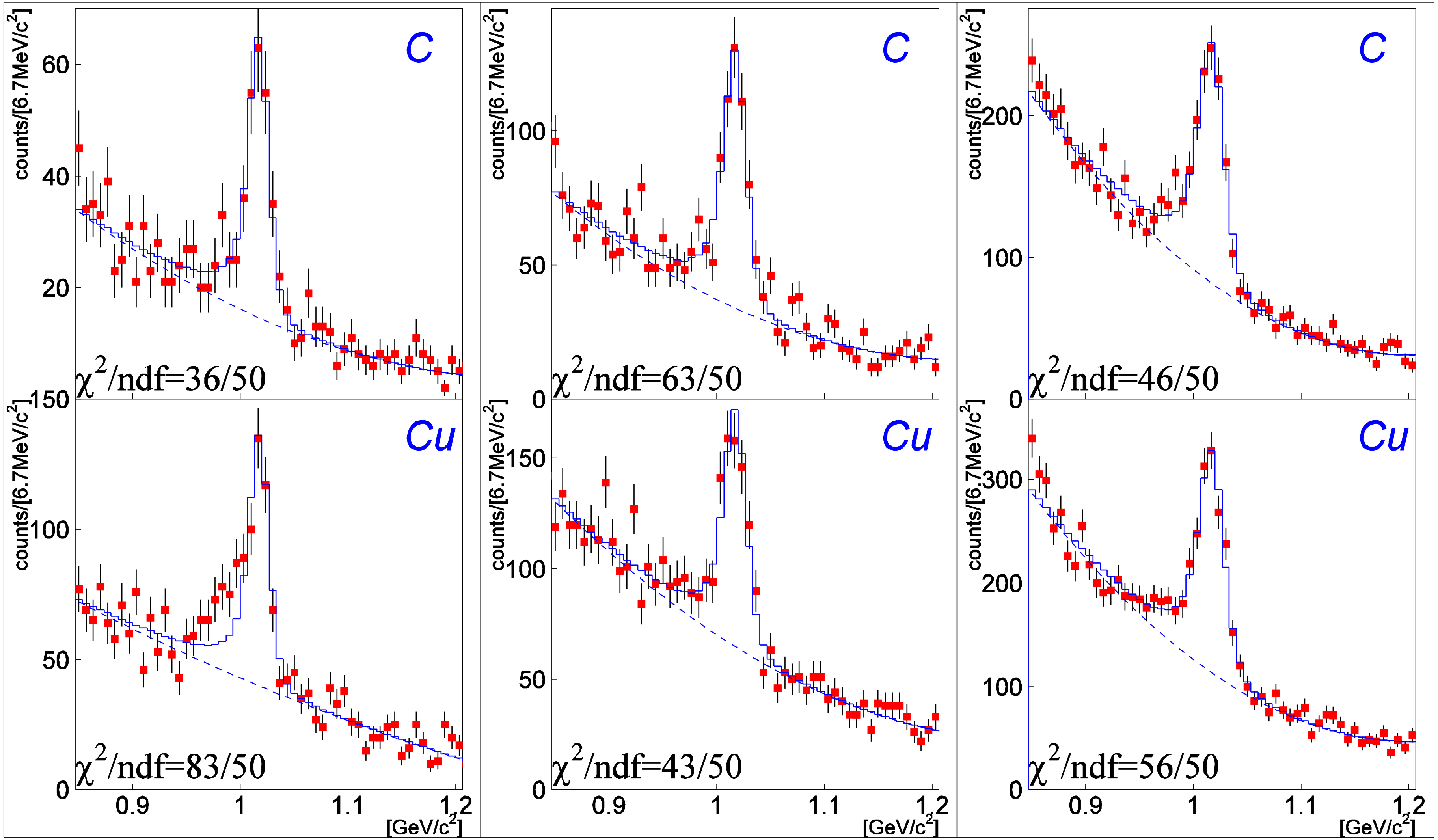
$\phi \rightarrow e^+e^-$ invariant mass spectra

- 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)
  - polynomial curve background
- examine the 'excess' is significant or not.
  - $\rightarrow$ see the $\beta\gamma$ dependence : excess could be enhanced for slowly moving mesons



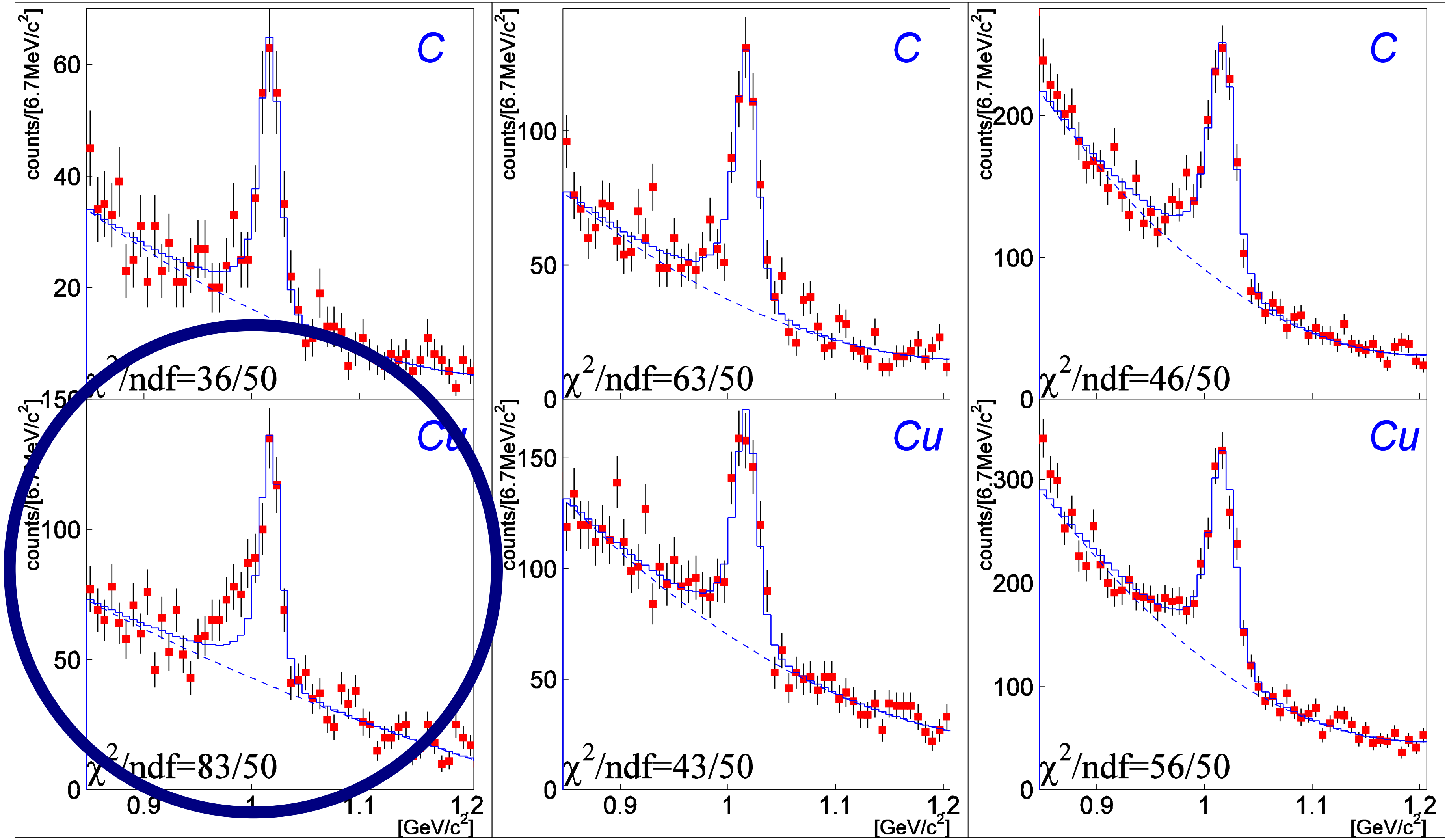
e^+e^- spectra of φ meson (divided by βγ)

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



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

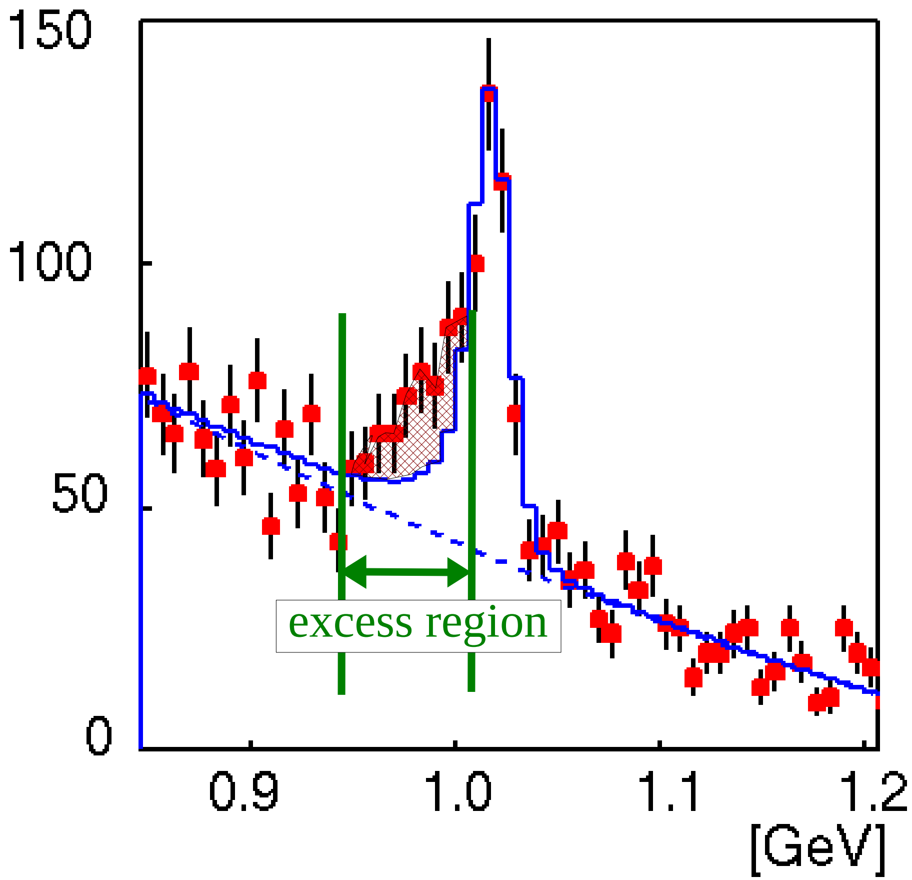
$\beta\gamma<1.25$ (Slow) | $1.25<\beta\gamma<1.75$ | $1.75<\beta\gamma$ (Fast)



only slow/Cu is not reproduced in 99% 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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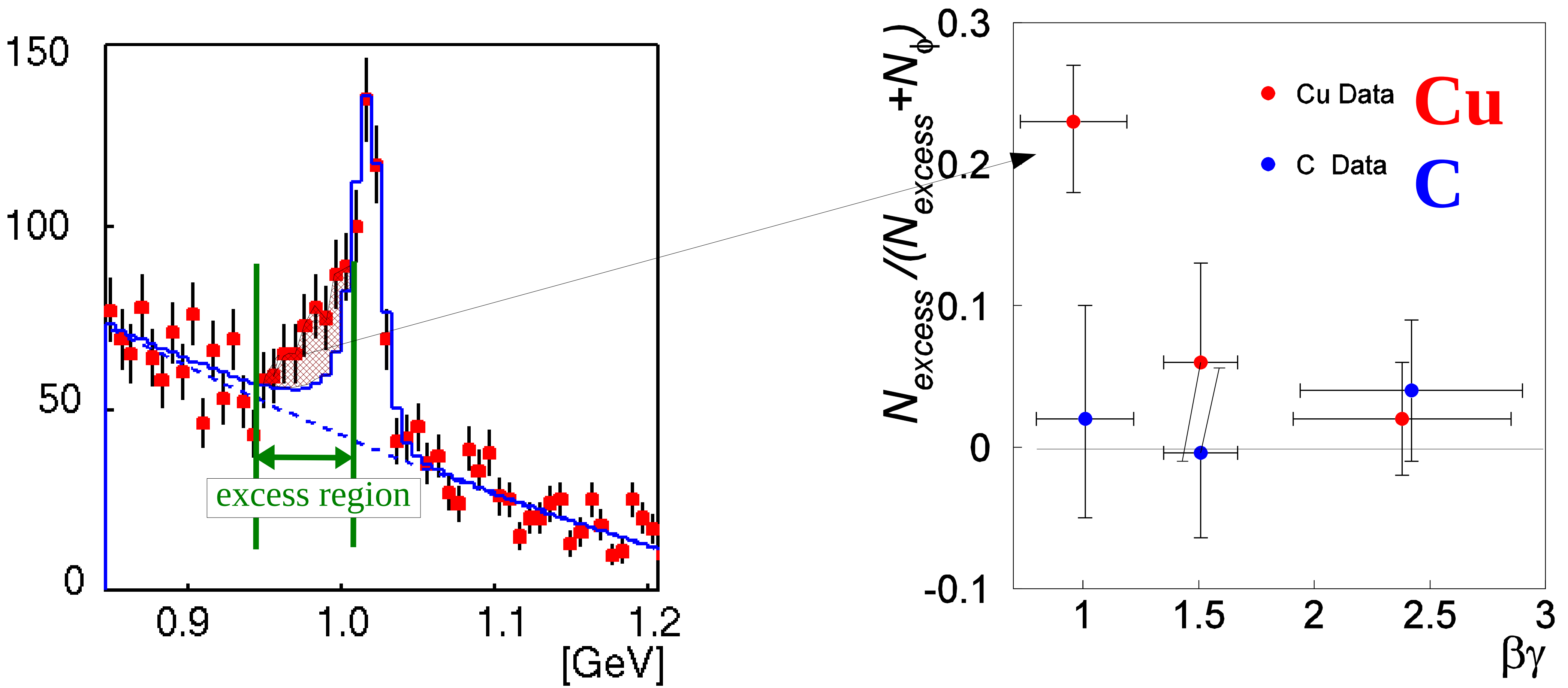
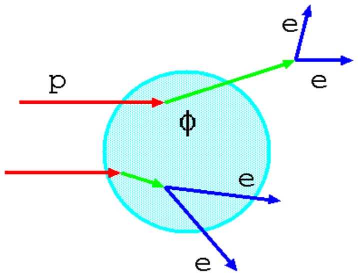
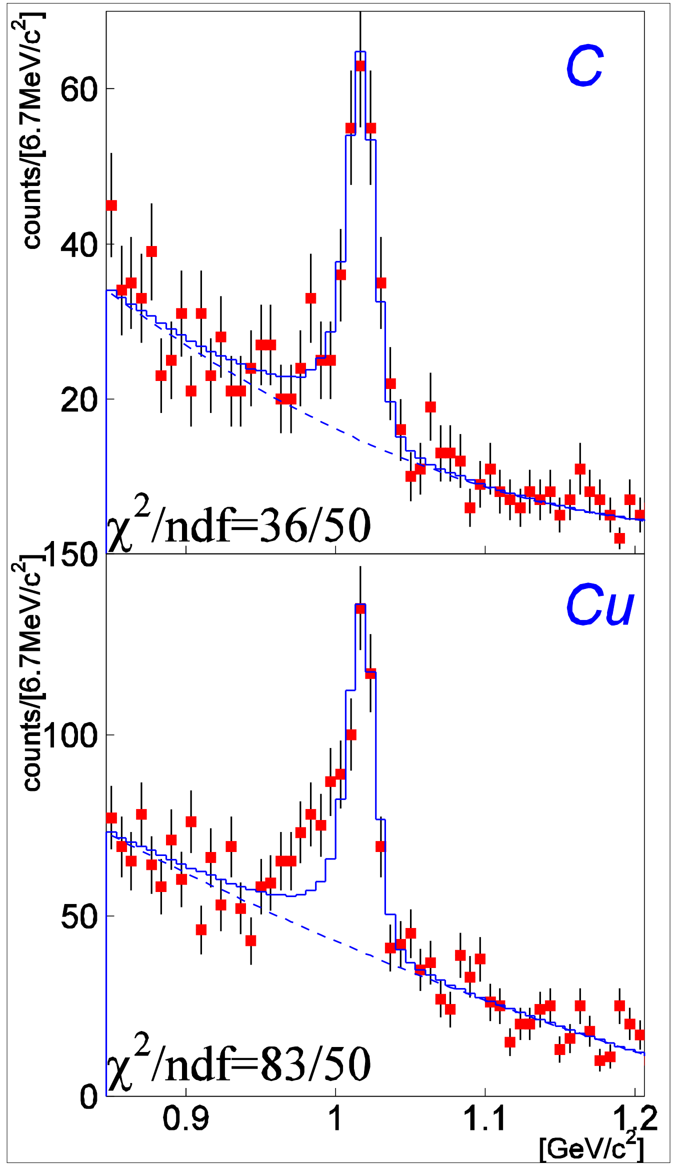


Fit using modified mass shapes

βγ<1.25 (Slow) k_1=0, k_2=0

- MC type calc. : mesons are generated,flied and modified
  - observed momentum dist.
  - 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 (i.e. partial width is changed)
      - $\Gamma^{*}_{e+e-} / \Gamma^{*}_{tot} = \Gamma^{0}_{e+e-} / \Gamma^{0}_{tot}$
  - many combinations of (k_1 , k_2)





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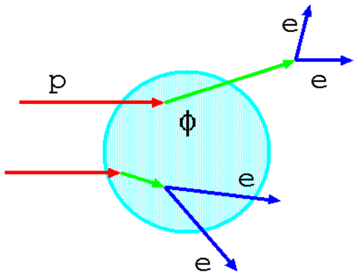
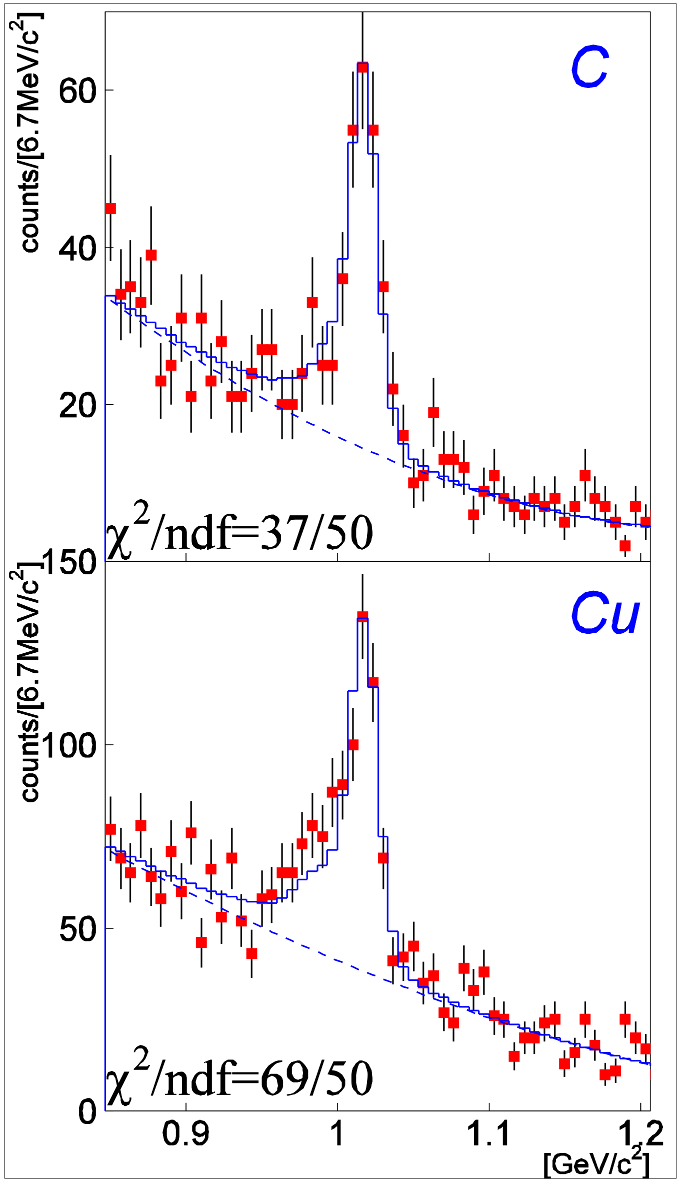


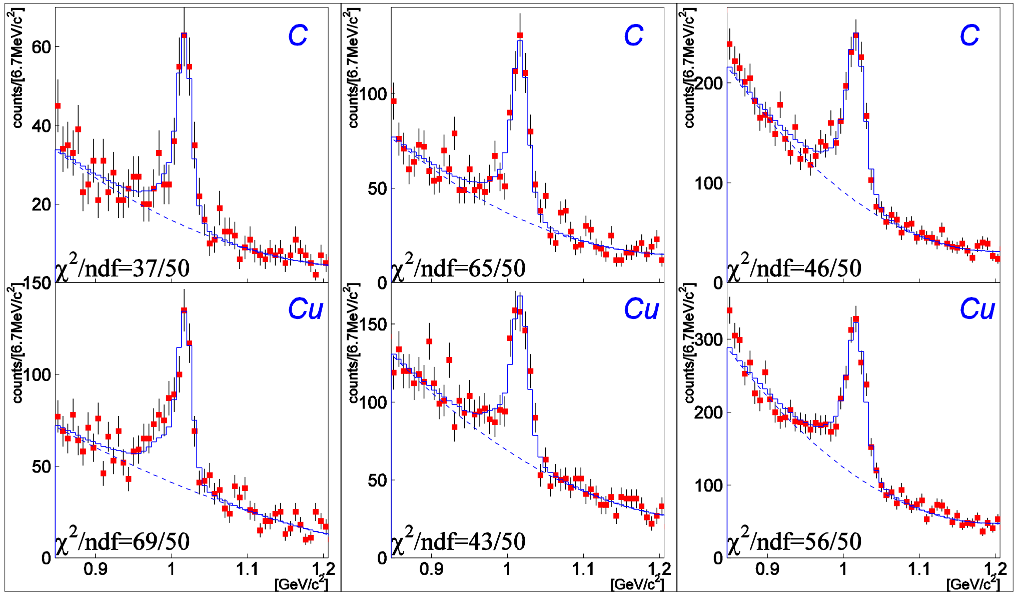
  - $m^*/m_0 = 1 - k_1 \rho/\rho_0$
    (k_1=0.04, Hatsuda & Lee, '92,'96)
  - To reproduce such amount of excess, linear-dependent width broadening is adopted :
    $$\Gamma_{tot}^{*}/\Gamma_{tot}^{0} = 1 + k_2 \rho/\rho_0$$
    - e^+e^- branching ratio is not changed (i.e. partial width is changed)
      $$-\Gamma^*_{e+e-} / \Gamma^*_{tot} = \Gamma^0_{e+e-} / \Gamma^0_{tot}$$
  - many combinations of (k_1 , k_2)

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



Model fitting : parameter k_1 and k_2

- To determine the shift parameters...
  - $m^*/m_0 = 1 - k_1\, \rho/\rho_0$
  - $\Gamma_{tot}^*/\Gamma_{tot}^0 = 1 + k_2\, \rho/\rho_0$
- 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

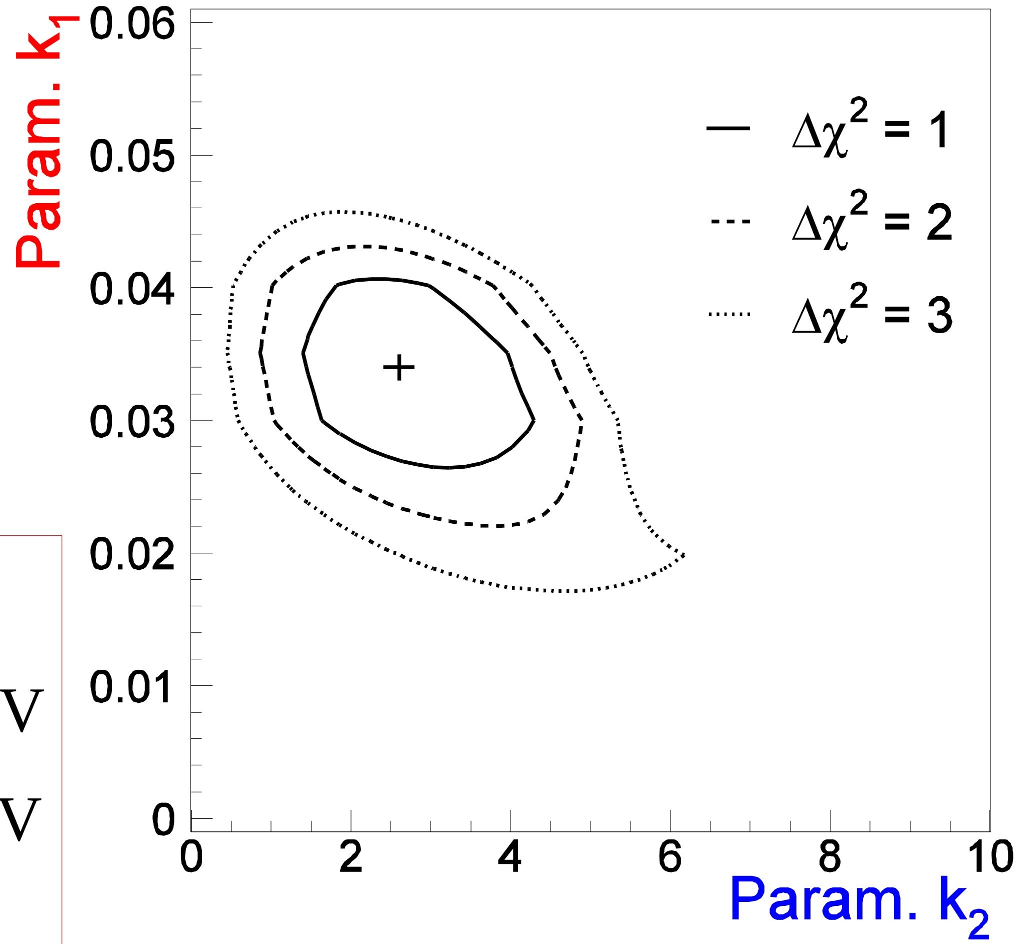
- To determine the shift parameters...
  - $m^*/m_0 = 1 - k_1\ \rho/\rho_0$
  - $\Gamma_{tot}^{*}/\Gamma^0_{tot} = 1 + k_2\ \rho/\rho_0$
- We fit the observed 6 mass spectra (C/Cu, slow/mid/fast) with modified MC shapes and calculate the χ^2 as the sum of 6 spectra for each (k_1,k_2) combination on the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

Best Fit Value:

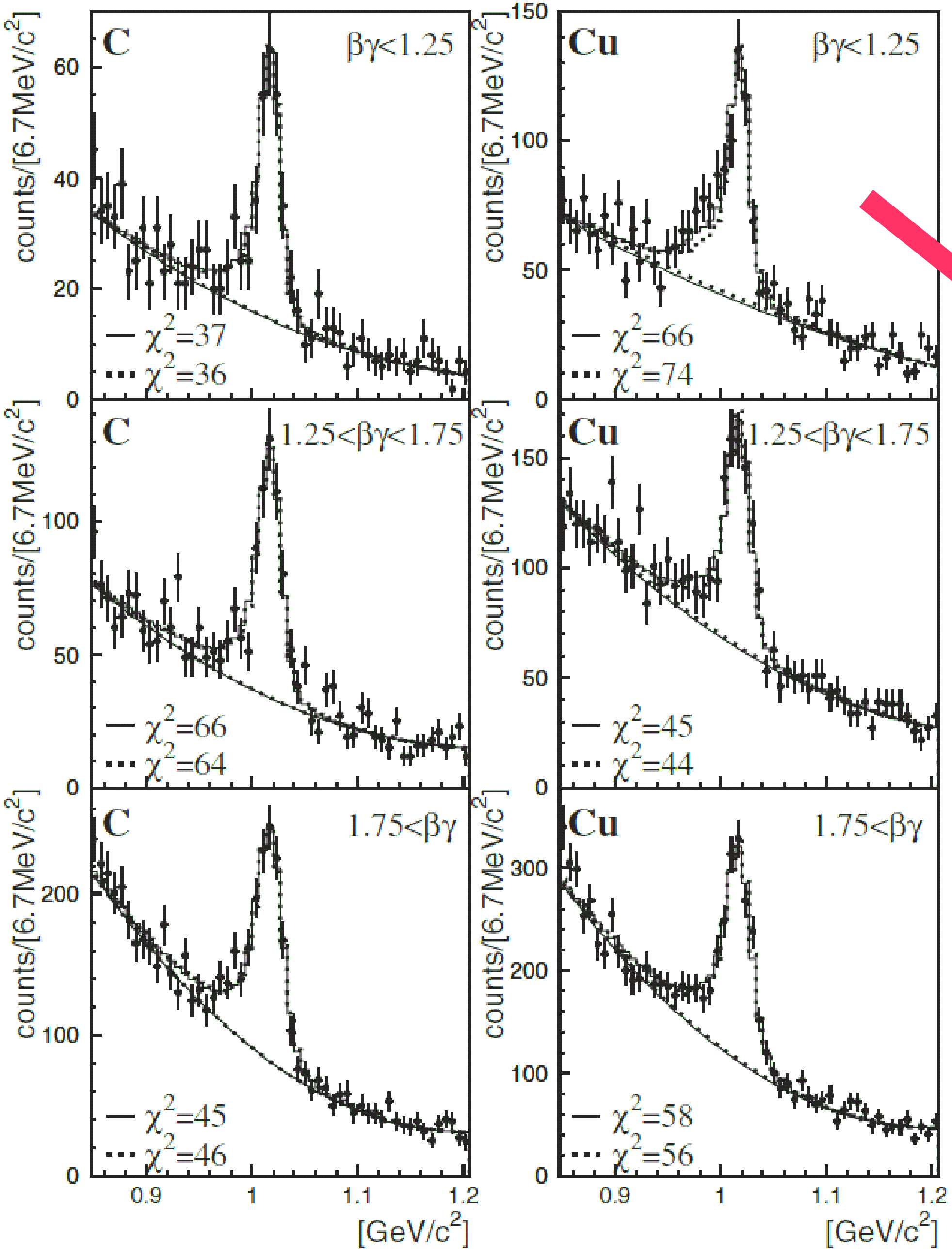
$$k_1 = 0.034^{+0.006}_{-0.007}$$ – m^* =985MeV

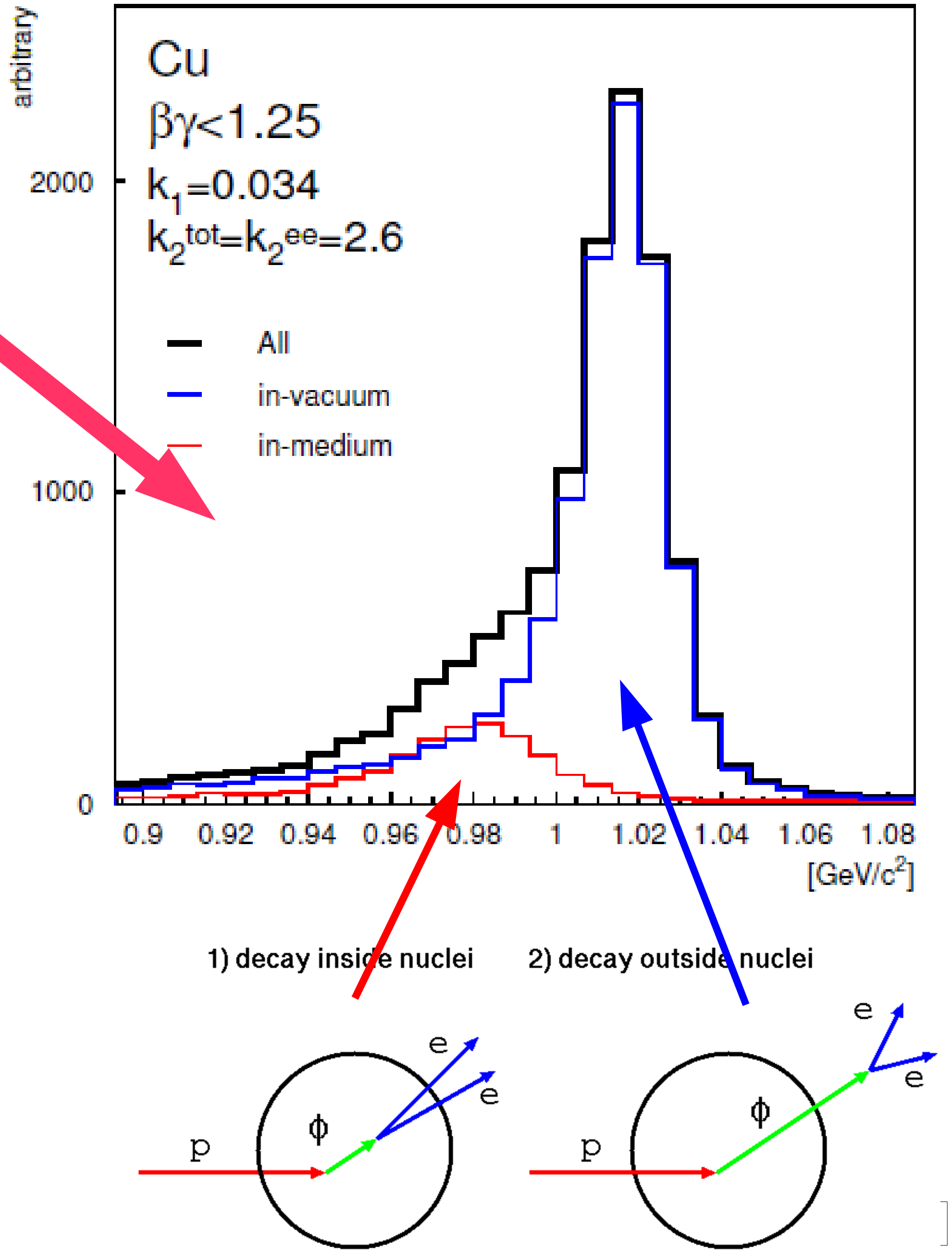
$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$ – Γ_{tot}^{*} = 16MeV

(3.6 times width broadening at ρ_0)

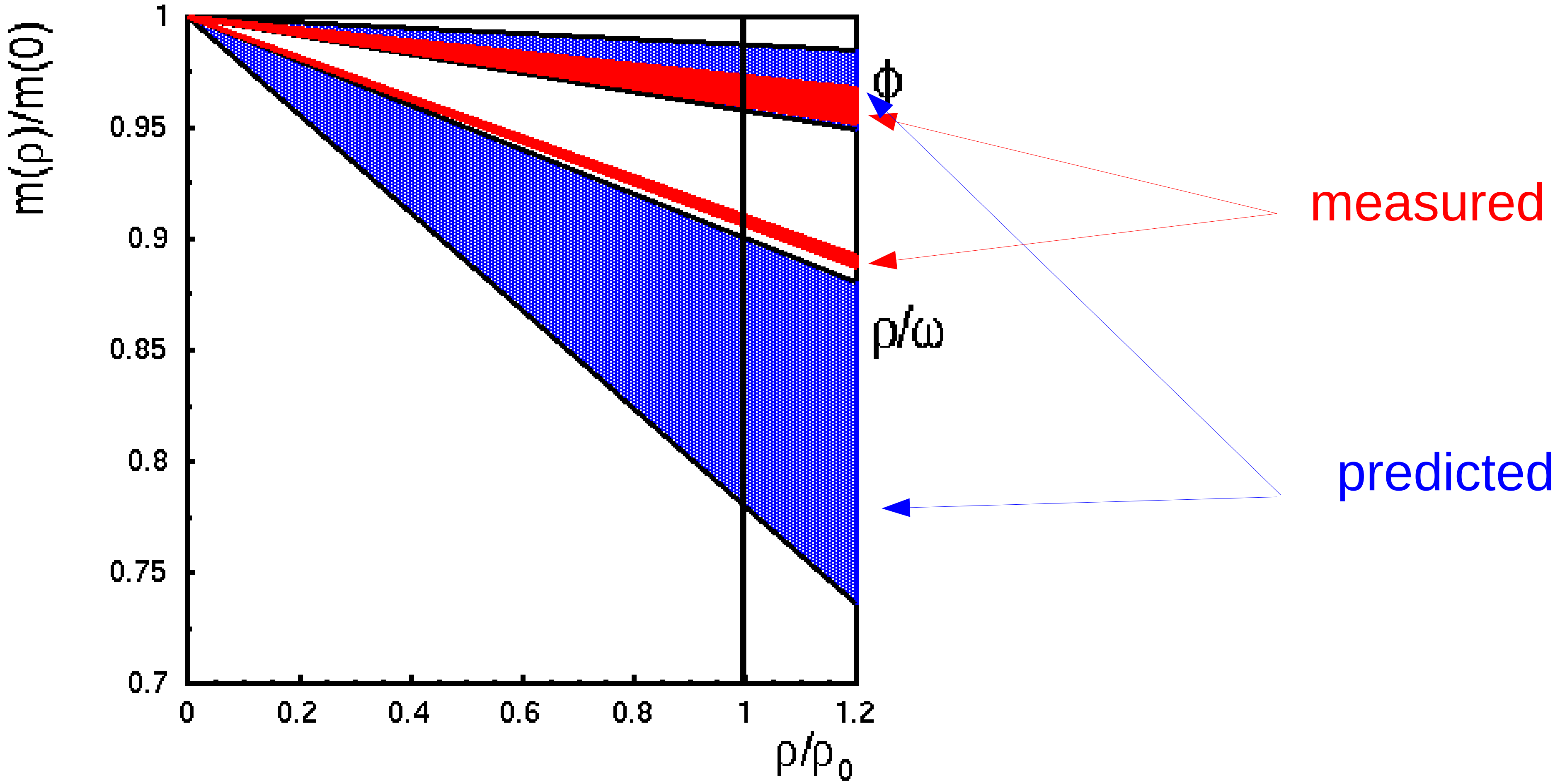


Typical modified shape of ϕ used for the fit





comparison w/ the prediction by Hatsuda & Lee

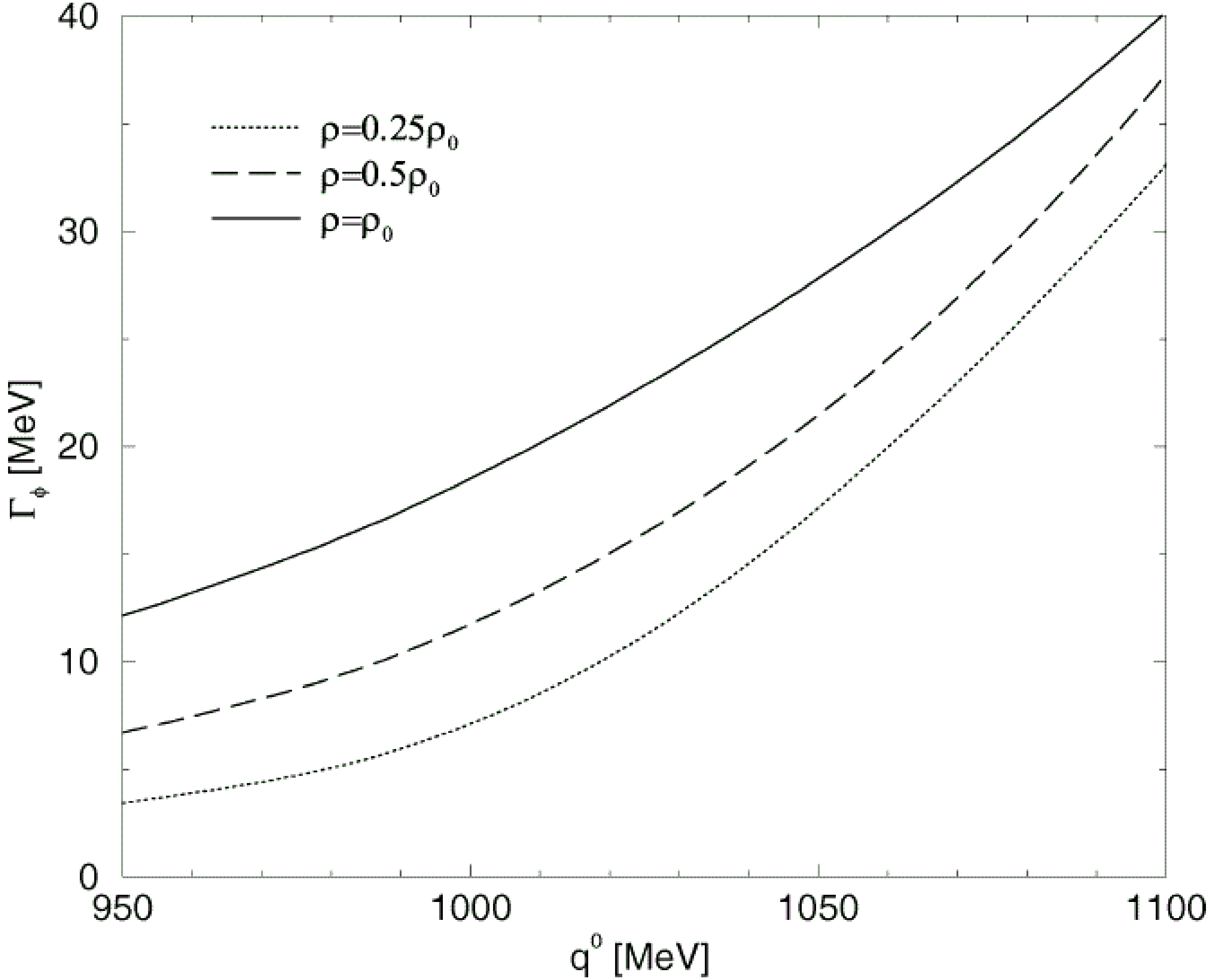


comparison w/ the prediction by Oset & Lamos

mass-dependent width in medium

NPA 679 (01) 616

ϕ mass shift
< 1%
width broadening
x5 (22MeV) at ρ_0



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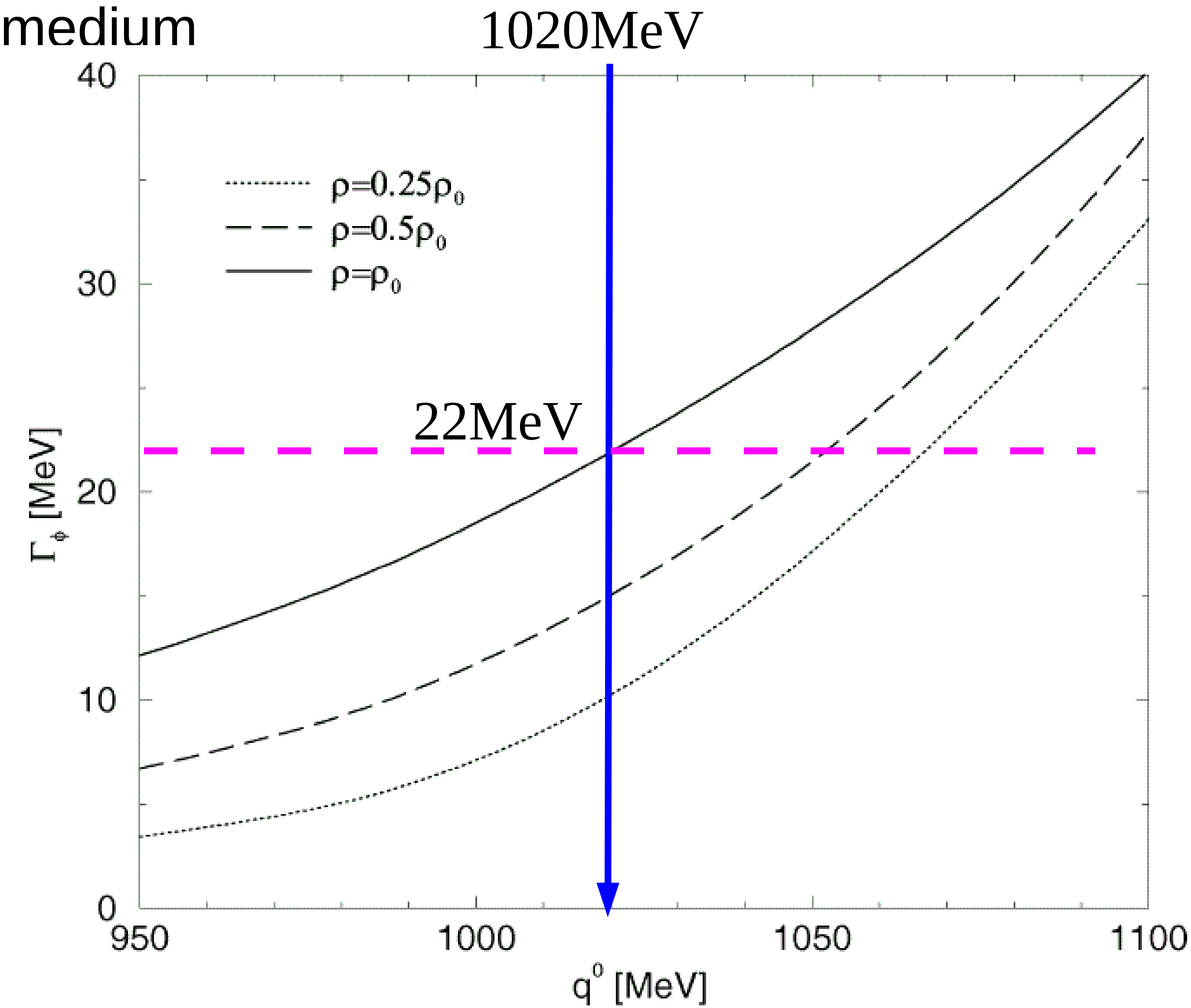

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ϕ mass shift
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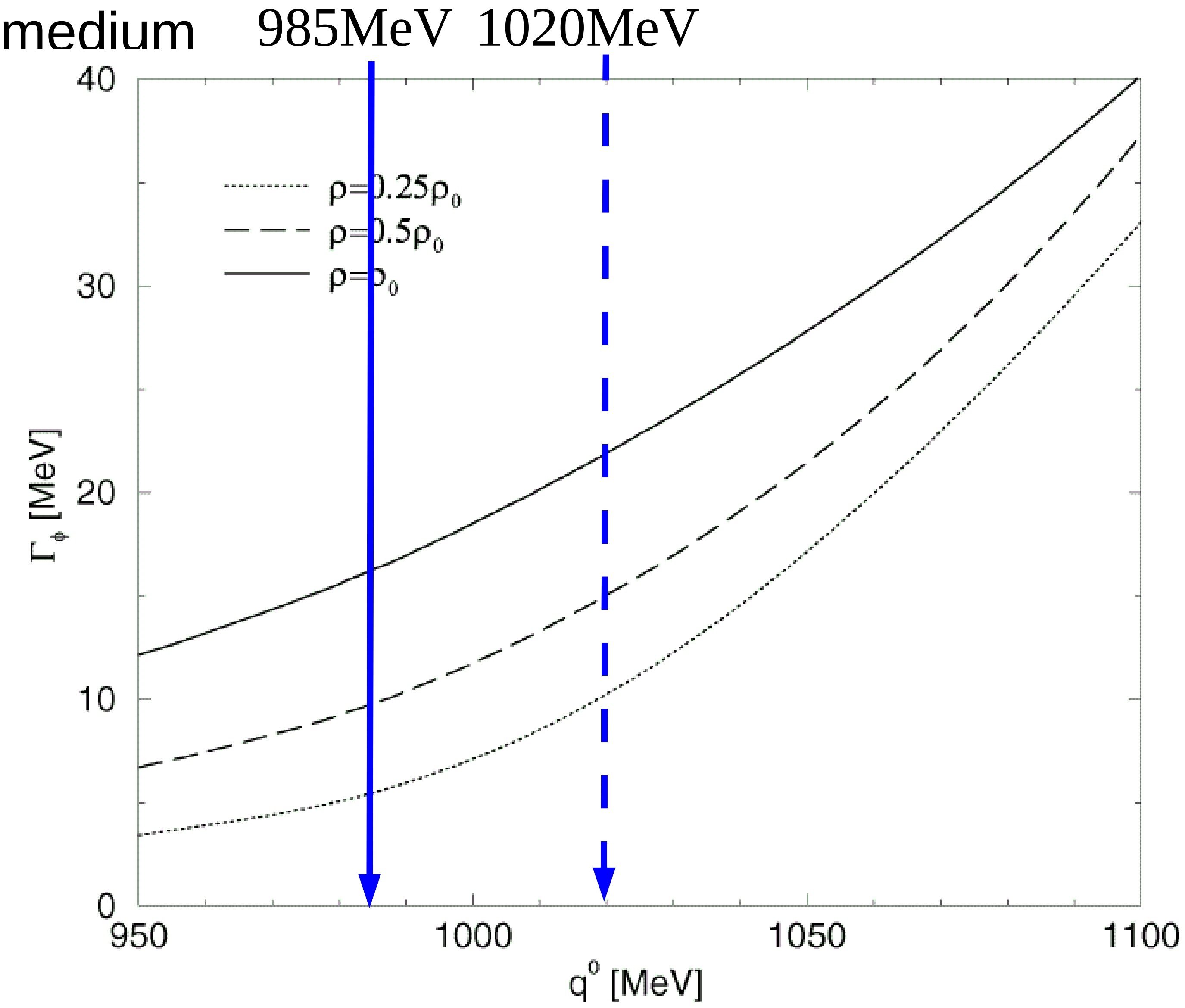
E325 measurements
mass ~ 985 MeV
width ~ 16 MeV



comparison w/ the prediction by Oset & Lamos

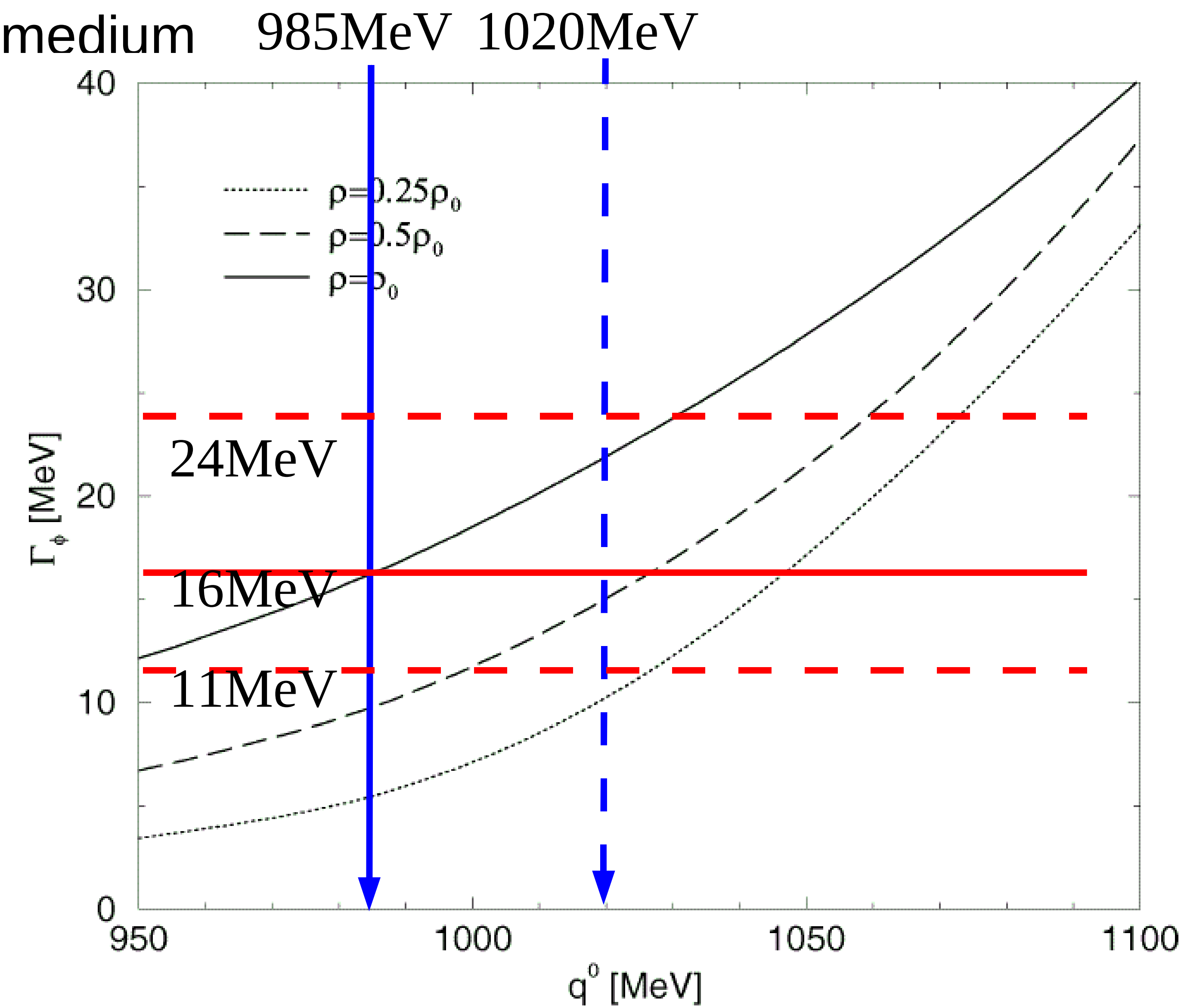
mass-dependent width in medium

NPA 679 (01) 616

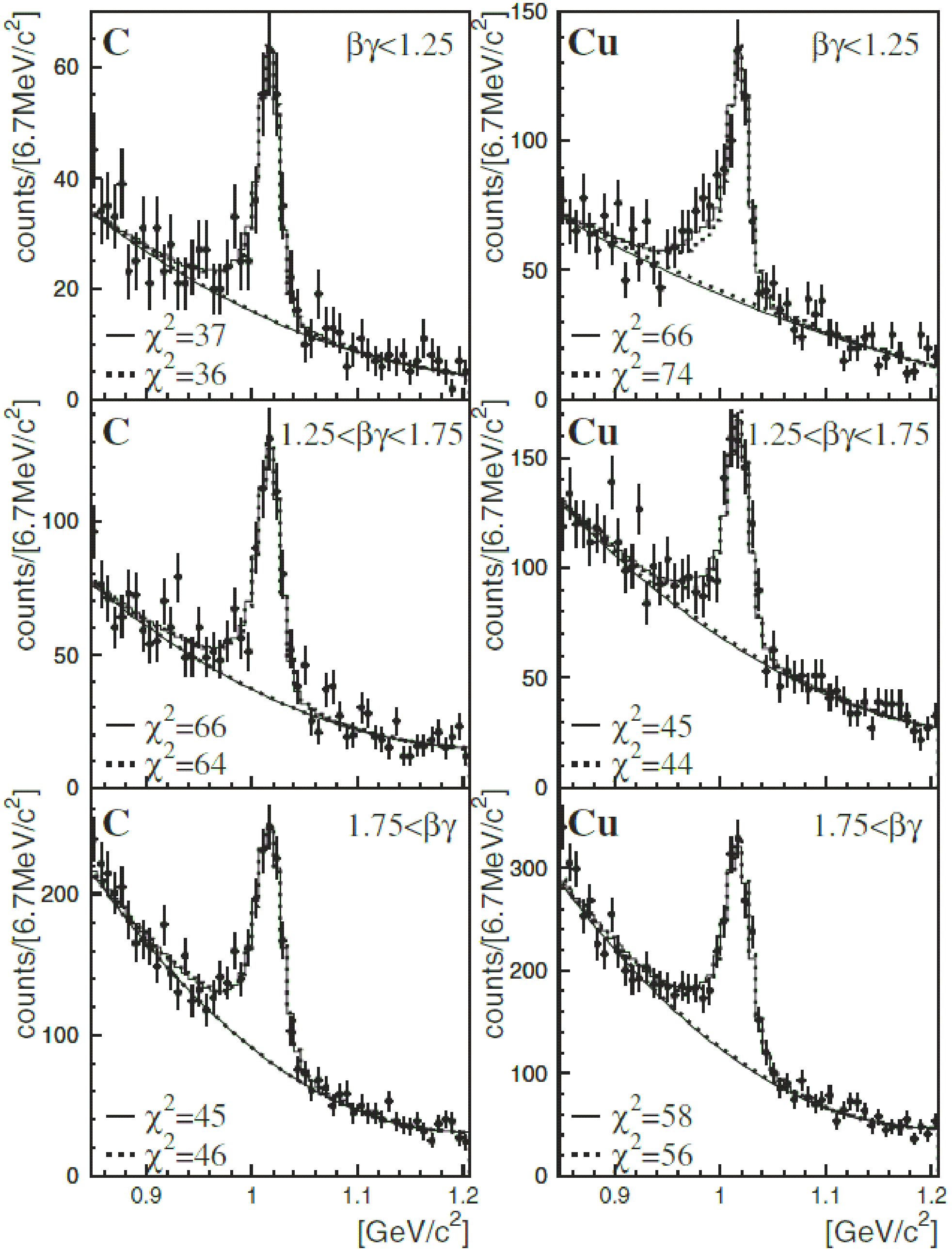
ϕ mass shift
< 1%
width broadening
x5 (22MeV) at ρ_0

E325 measurements
mass ~ 985 MeV
width ~ 16 MeV

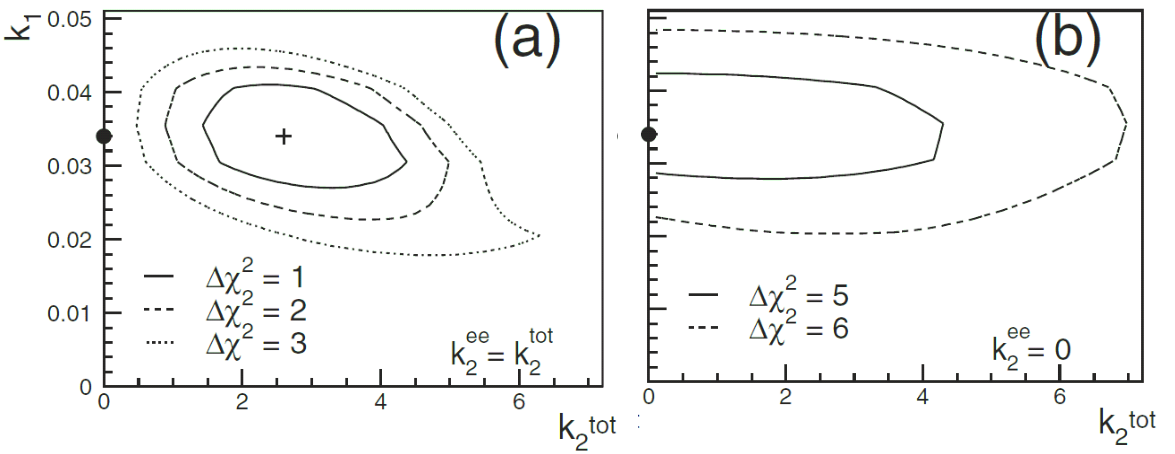
consistent w/ the curve
(still error is so large)



Partial width for ee decay



- solid(a) : $\Gamma^{*}_{e+e-} \propto \Gamma^{*}_{tot}$
- dashed(b) : Γ_{e+e-} fixed



(a) is favored (if only slow Cu data, (b) is rejected in 99% C.L.)

It suggests
the partial decay width to ee channel is changed in nuclei ?

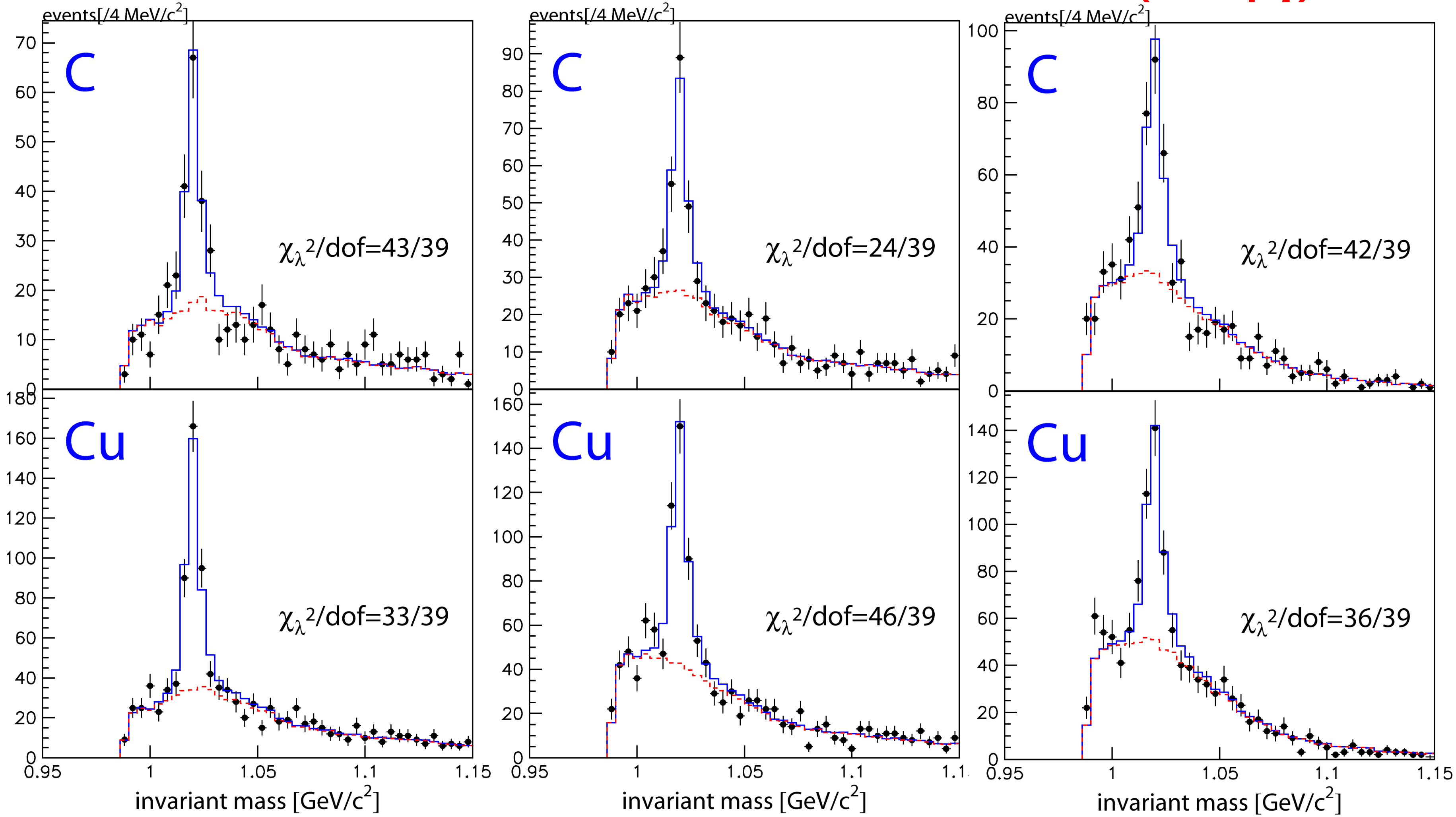
E325 Results (2)

KK invariant mass spectra and branching ratio

F. Sakuma et al., PRL98(2007)152302

K^+K^- spectra of ϕ meson

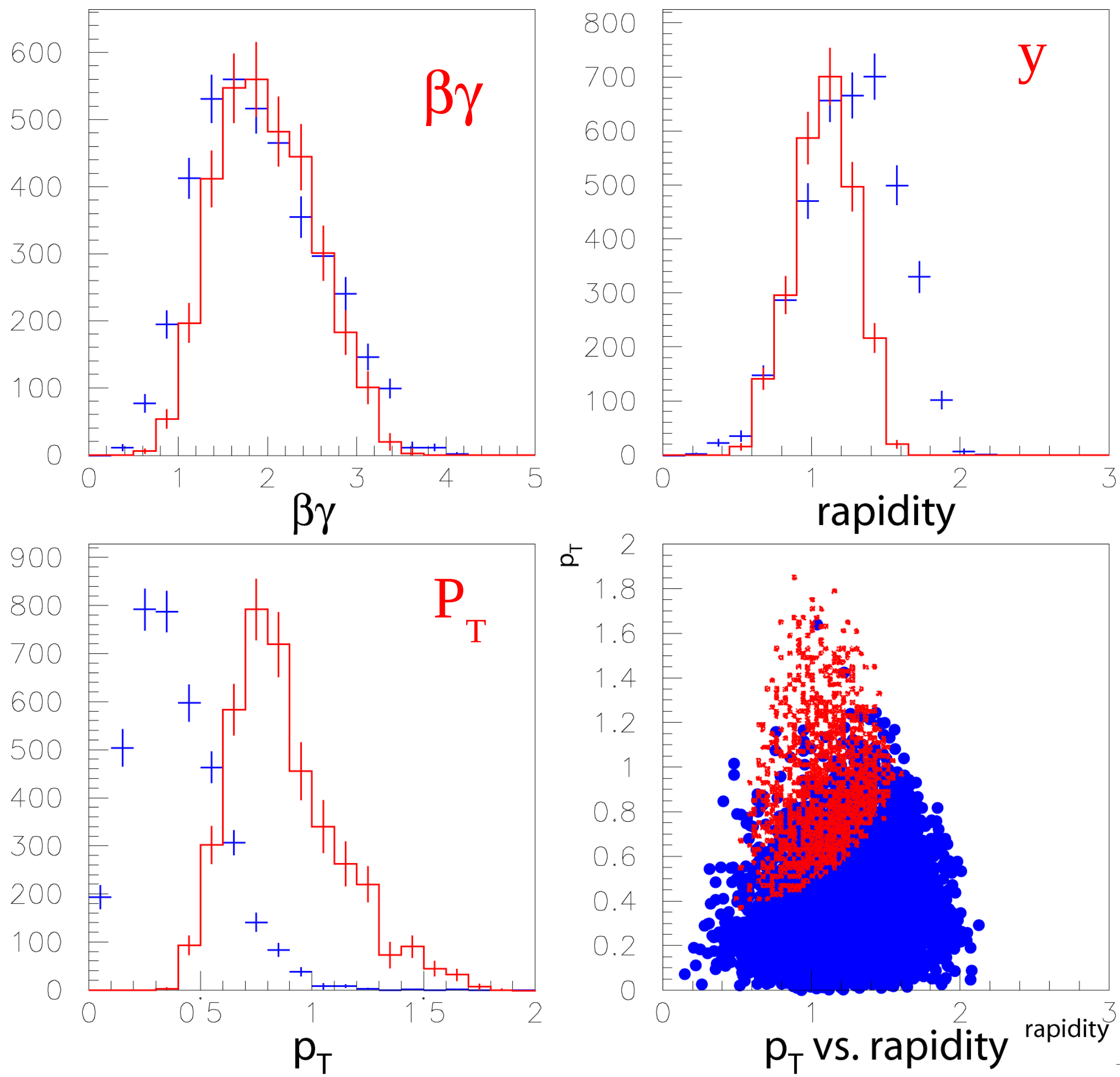
slow($\beta\gamma$<1.7) **(1.7<$\beta\gamma$<2.2)** **fast(2.2<$\beta\gamma$)**



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

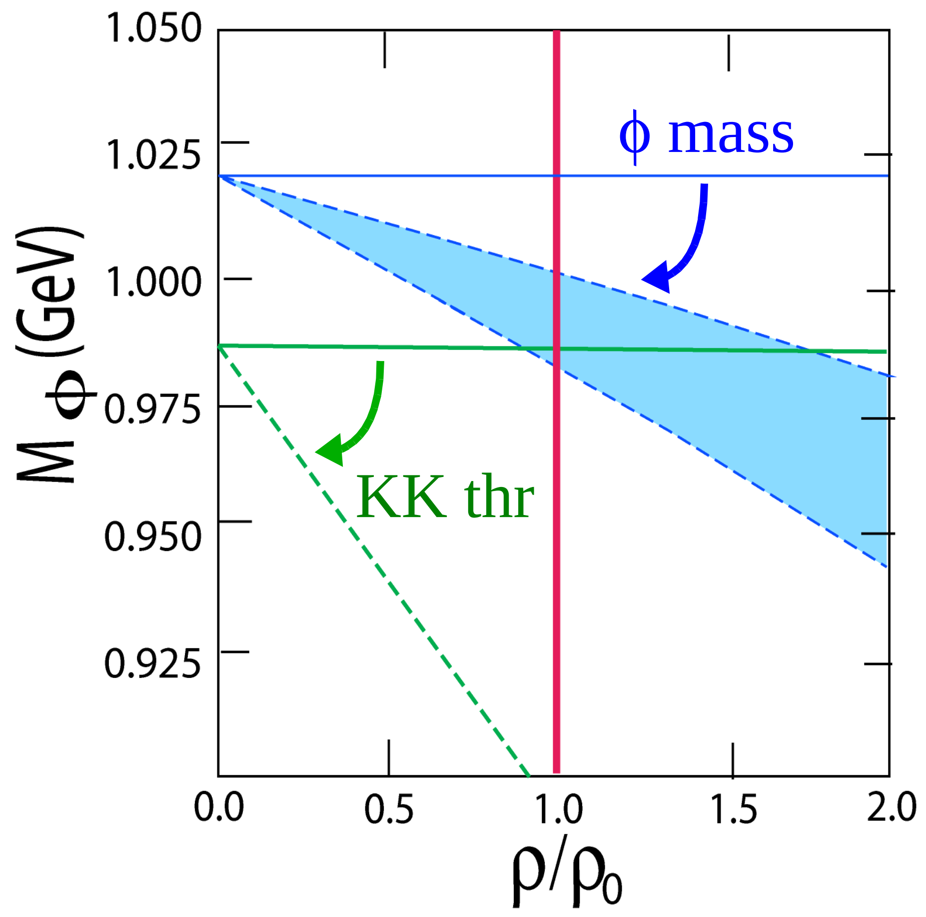
measured kinematic distribution of $\phi \rightarrow K^+K^-$ & $\phi \rightarrow e^+e^-$

- $0.5 < y < 1.5$
- $1 < \beta\gamma < 3$
- $0.5 < P_T < 1.5$
- overlayed
  - $\phi \rightarrow K^+K^-$
  - $\phi \rightarrow e^+e^-$



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 measurement 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 prod. CS of φ in K^+K^- & e^+e^- channel

- nuclear dependence α:
  - $\sigma(A) = \sigma_0 \times A^{\alpha}$
- α , Γ : for example
  - $\Gamma_{K+K-} / \Gamma_{e+e-}$ increases in nuclei, N_{K+K-} / N_{e+e-} becomes larger
  - larger effect is expected in larger nuclei
  - then, $\alpha_{K+K-} > \alpha_{e+e-}$, especially for slowly moving mesons

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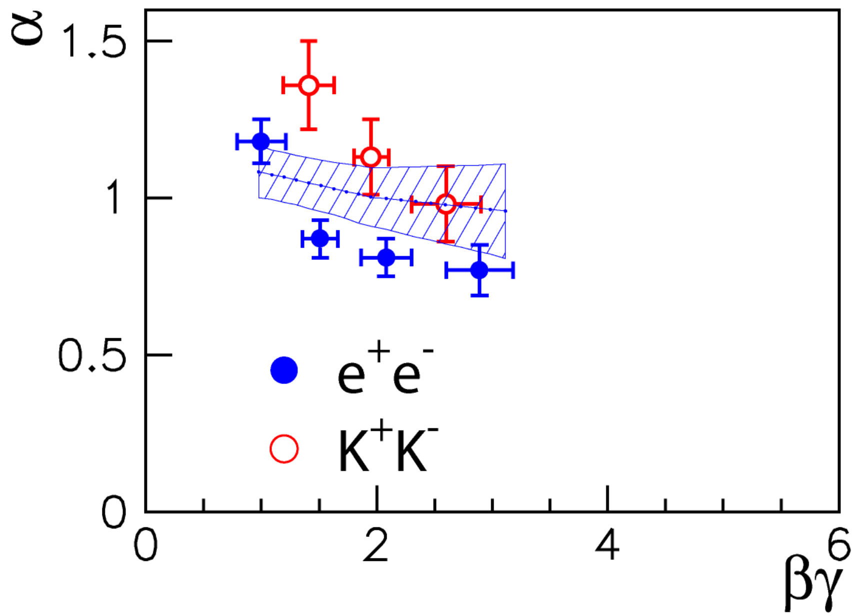
- ...looks such tendency ...



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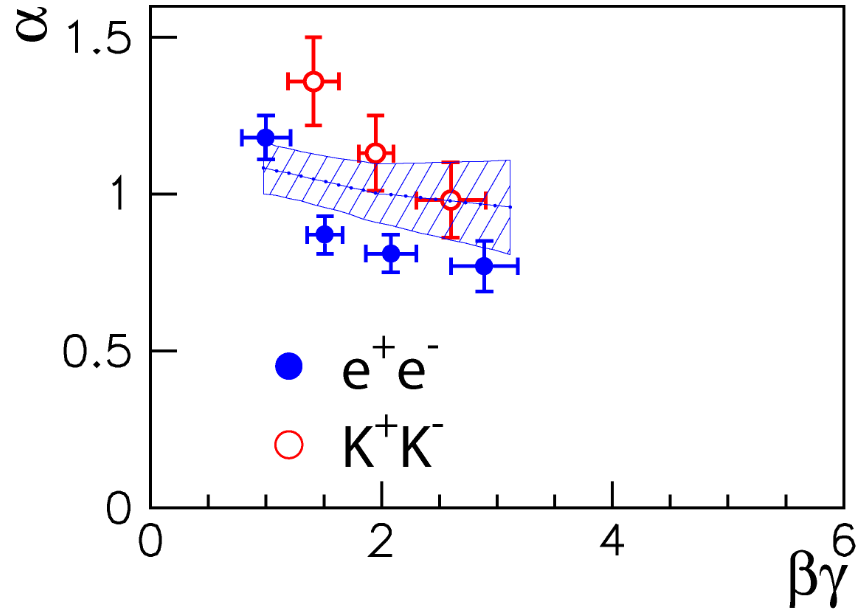
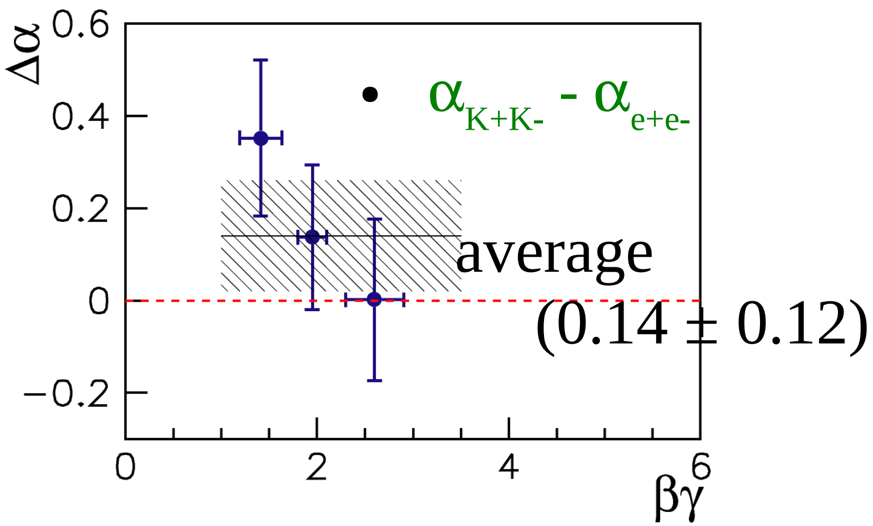
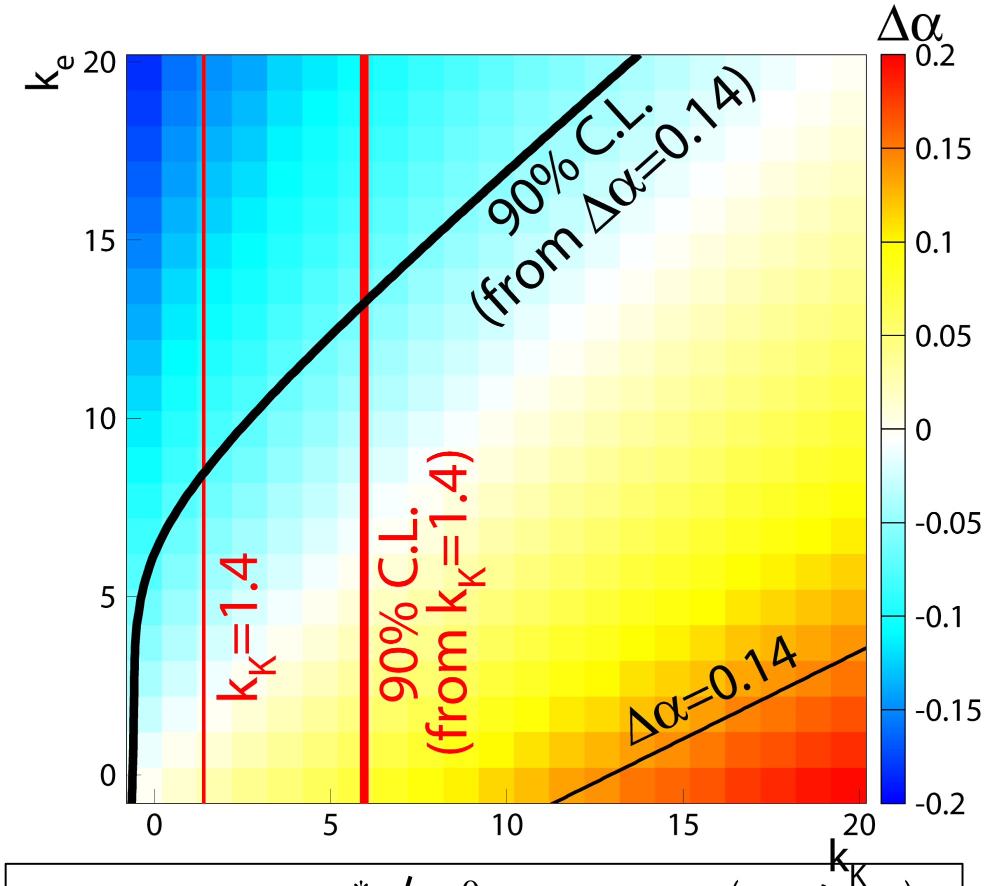
  - larger effect is expected in larger nuclei
  - then, $\alpha_{K+K-} > \alpha_{e+e-}$, especially for slowly moving mesons
- ...looks such tendency but consistent within the errors : $\alpha_{K+K-} - \alpha_{e+e-} = 0.14 \pm 0.12$





Limit to the φ width in k_K - k_e space

- 1) limitation from the Δα:
  - k_K and k_e (black line)



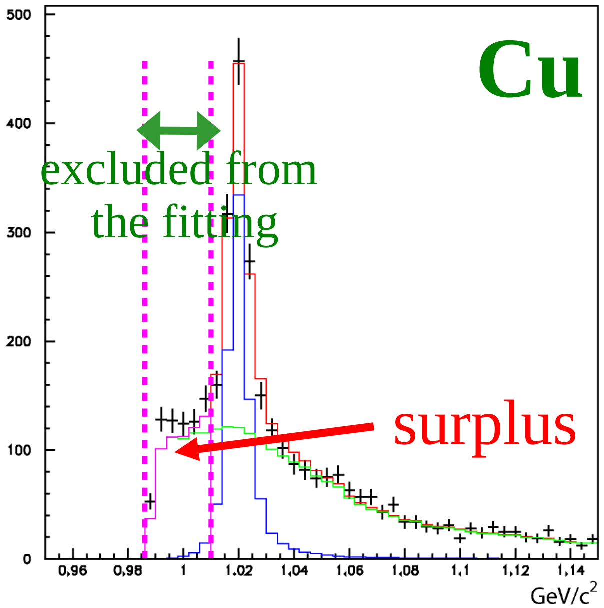
$$\Gamma^*_\phi / \Gamma^0_\phi = 1 + k_{tot}(\rho/\rho_0),$$

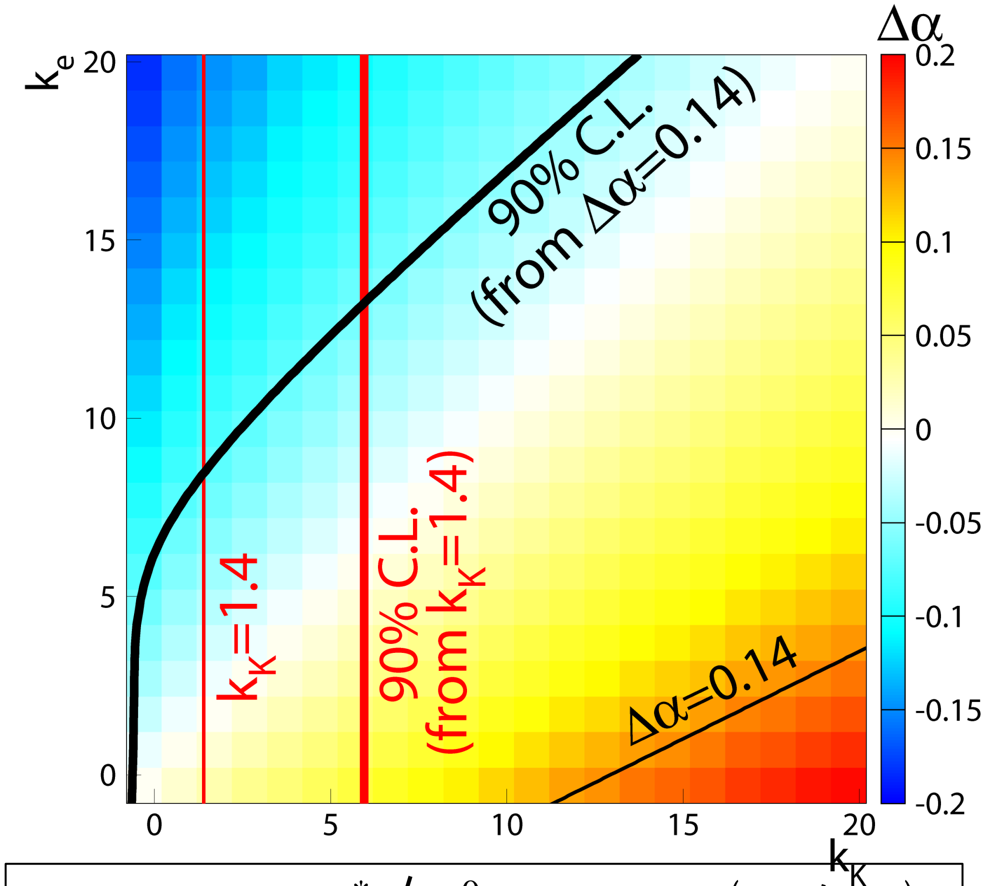
$$\Gamma^*_{\phi \; K^+K^-} / \Gamma^0_{\phi \; K^+K^-} = 1 + k_K(\rho/\rho_0),$$

$$\Gamma^*_{\phi \; e^+e^-} / \Gamma^0_{\phi \; e^+e^-} = 1 + k_e(\rho/\rho_0)$$

Limit to the ϕ width in k_K - k_e space

- 1) limitation from the $\Delta\alpha$:
  - k_K and k_e (black line)
- 2) limitation from the KK spectra
  - $k_K < 6.0$ (90%CL) (red line)





$$\Gamma^*_\phi / \Gamma^0_\phi = 1 + k_{tot}(\rho/\rho_0),$$
$$\Gamma^*_{\phi\ K^+K^-} / \Gamma^0_{\phi\ K^+K^-} = 1 + k_K(\rho/\rho_0),$$
$$\Gamma^*_{\phi\ e^+e^-} / \Gamma^0_{\phi\ e^+e^-} = 1 + k_e(\rho/\rho_0)$$

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 component
  - Model calc. including mass shift and width broadening in nuclei also reproduces the data. Change of the partial width to ee is favored.
- In $\phi \rightarrow K^+K^-$ spectra, no modification is observed. Limits to the width broadening are set.. They are consistent with $\phi \rightarrow e^+e^-$ results.

Remark

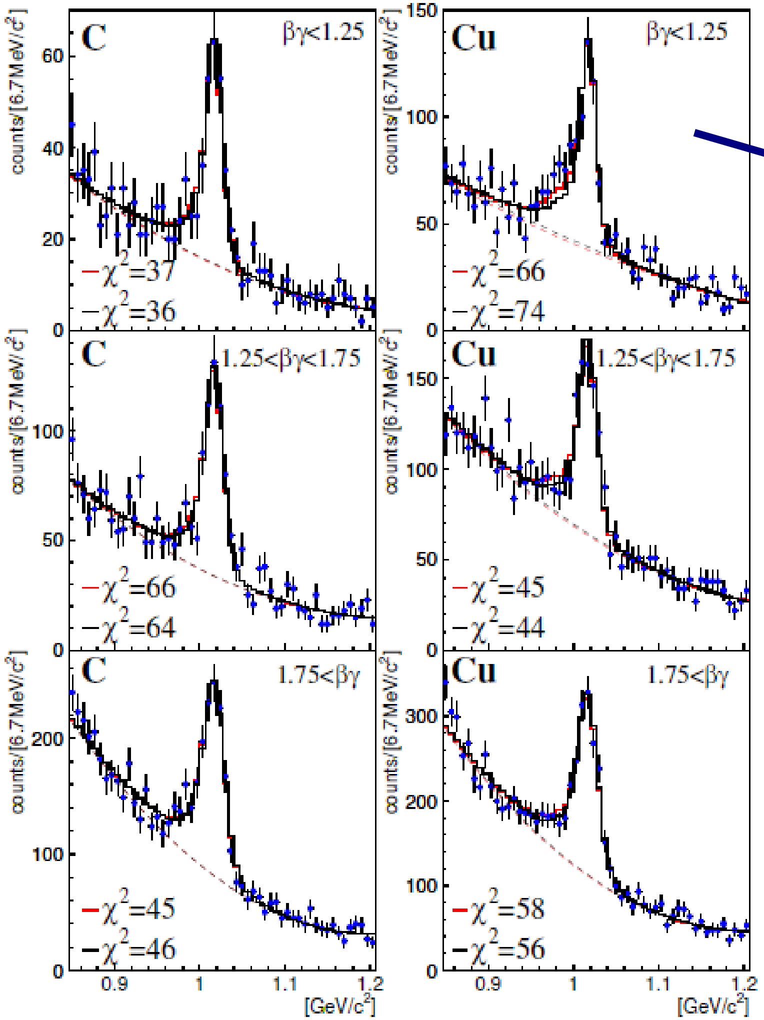
- We detected the mass modifiction in the inv. mass spectra.
- We may exclude some predictions like upward mass-shift
- In our analysis, we ignore :
  - finite-size nuclei <-> infinite nuclear matter
  - Possible time evolution of the density of nuclei in the reaction
    - our model is just toy model...
    - transport calculation like BUU ?
  - momentum dependence of 'mass shift' & 'width broadening'
- How can we connect the results with chiral symmetry restoration?
-
- We have a project to study more systematically at J-PARC.
  - larger nuclei, high statistics, mom. dependence, etc.

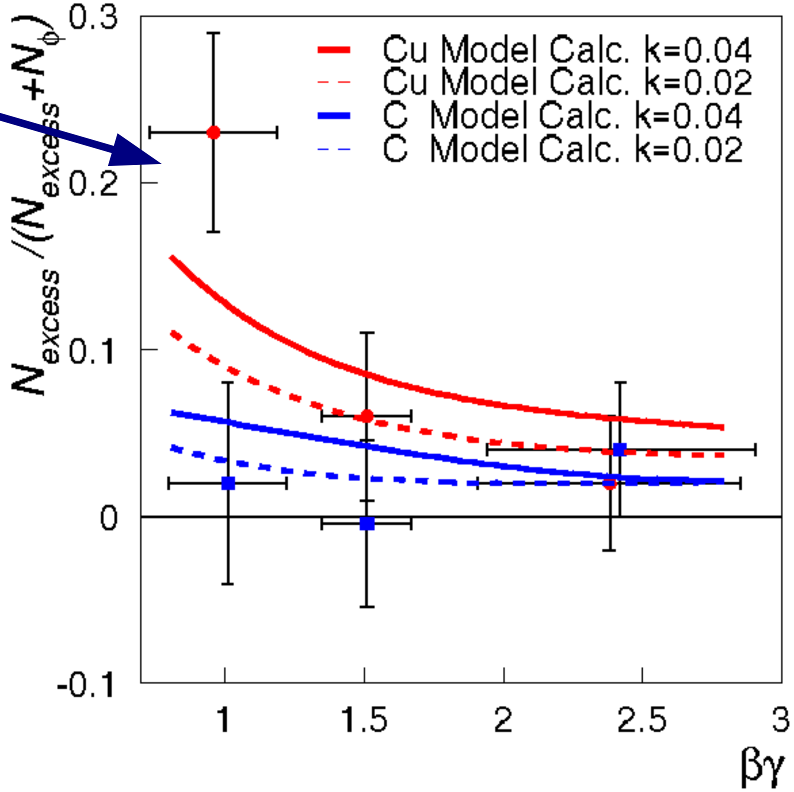
J-PARC E16 experiment

- Same concepts as KEK-PS E325
  - thin target (0.1% interaction) / primary beam (~10^{10} /sec)/ slowly moving vector mesons in the ee channel
- Main goal : collect ~1-2 x 10^5 $\phi \rightarrow$ ee for each target in 5 weeks
  - ~100 times as large as E325
    - new nuclear targets : proton (CH_2 -C subtraction), Pb
    - collision geometry for Pb target (by multiplicity)
  - **systematic study** of the velocity & nuclear size dependence of excess ('modified' component)
    - check the interpretation models
    - extract the dispersion relation
  - mass resolution : keep ~ 10 MeV
- ρ ,ω and J/ψ can be collected at the same time
- 2007/3 : stage1 (physics) approval / R&D is on going

velocity and nuclear size dependence

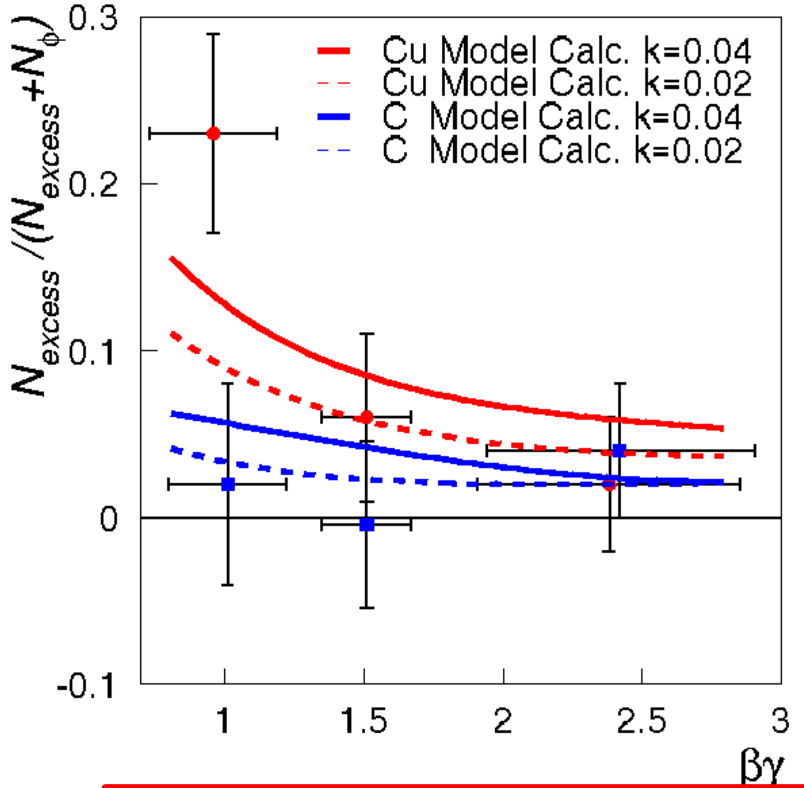
- velocity dependence of excesses ('modified' component)
- E325 only one data point for ϕ (slow/Cu) has significant excess



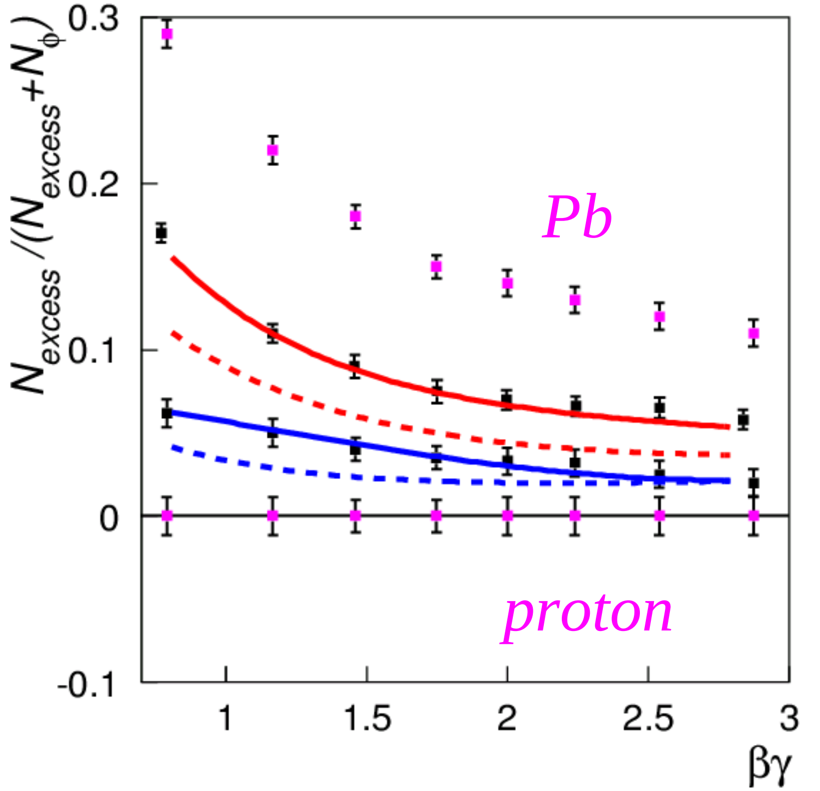


velocity and nuclear size dependence

- velocity dependence of excesses ('modified' component)
- E325 only one data point for ϕ (slow/Cu) has significant excess
- systematic study : all the data should be explained the interpretation model



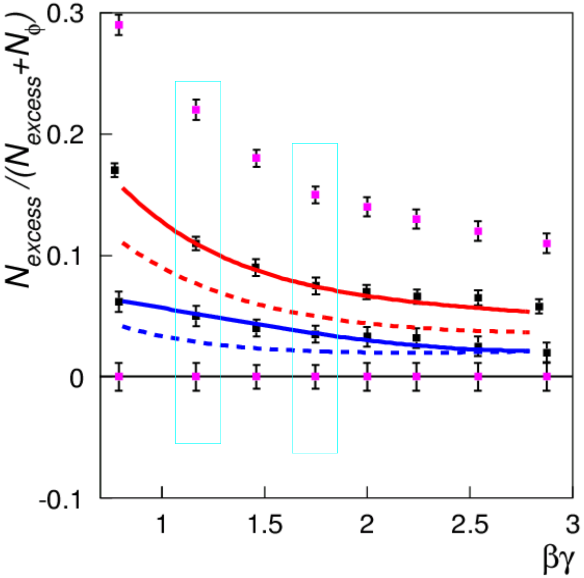
x 100 stat.

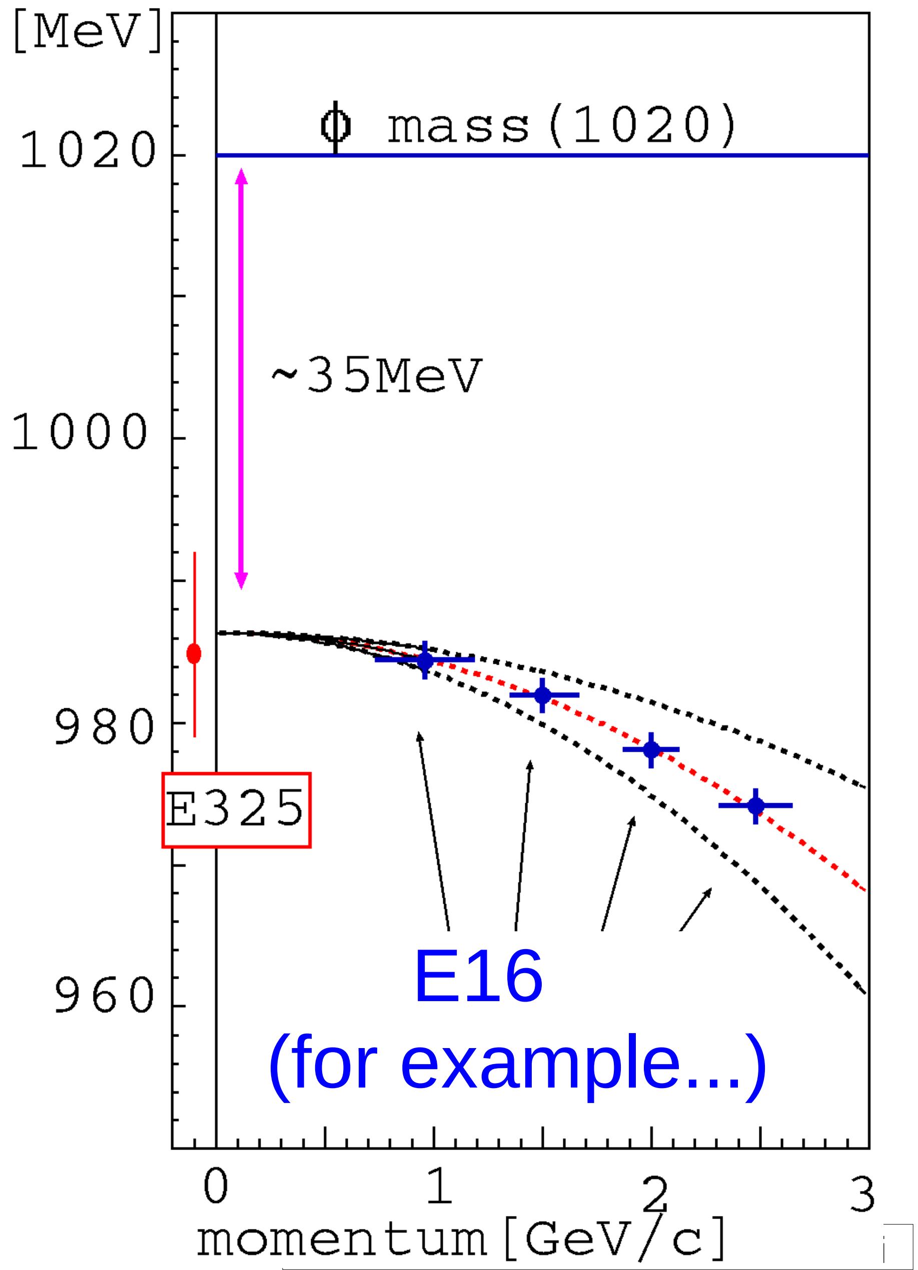


- establish the modification
- check the interpretation model w/ shape analysis

dispersion relation(mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV)
- current E325 analysis neglects the dispersion (limited by the statistics)
- fit with common shift parameter $k_1(p)$, to all nuclear targets in each momentum bin



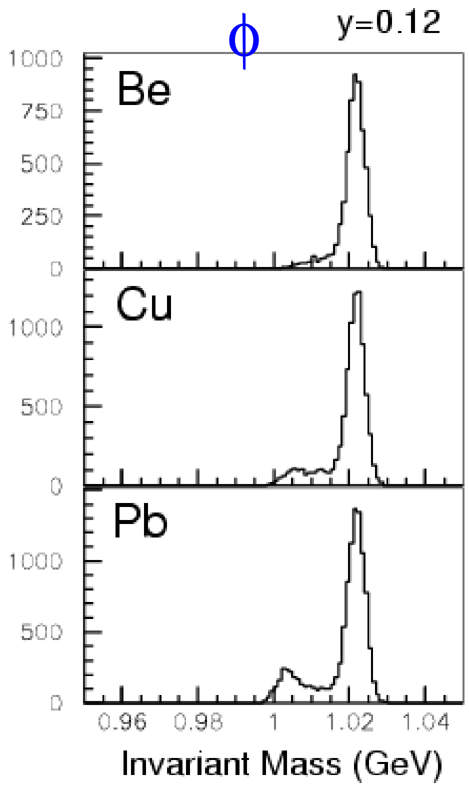


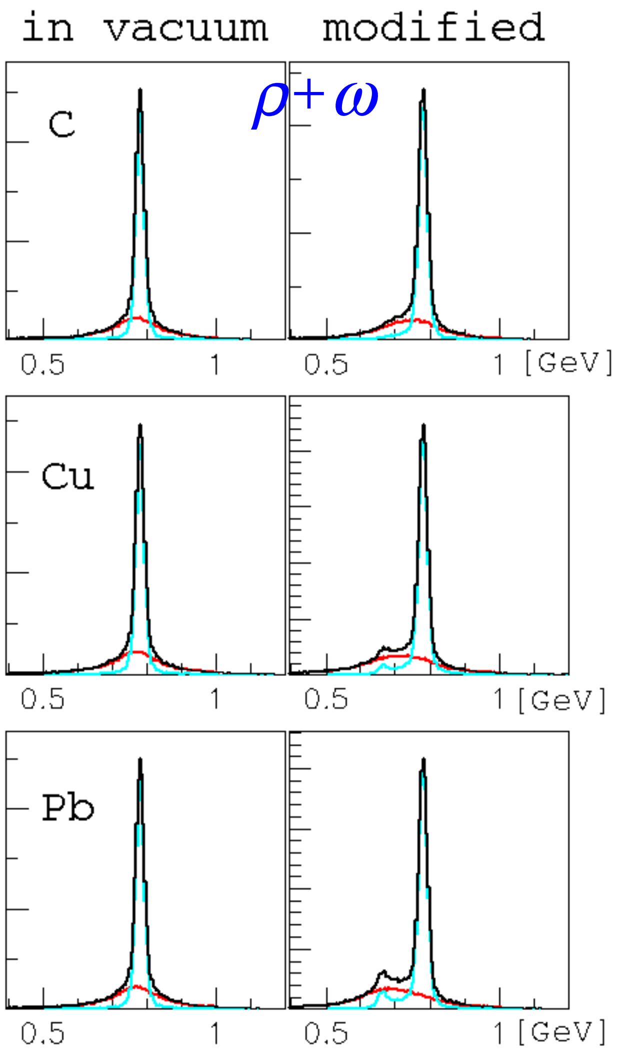
Backup slides...

(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 = βγ∗cτ= p/m ∗ h/2π∗c/Γ

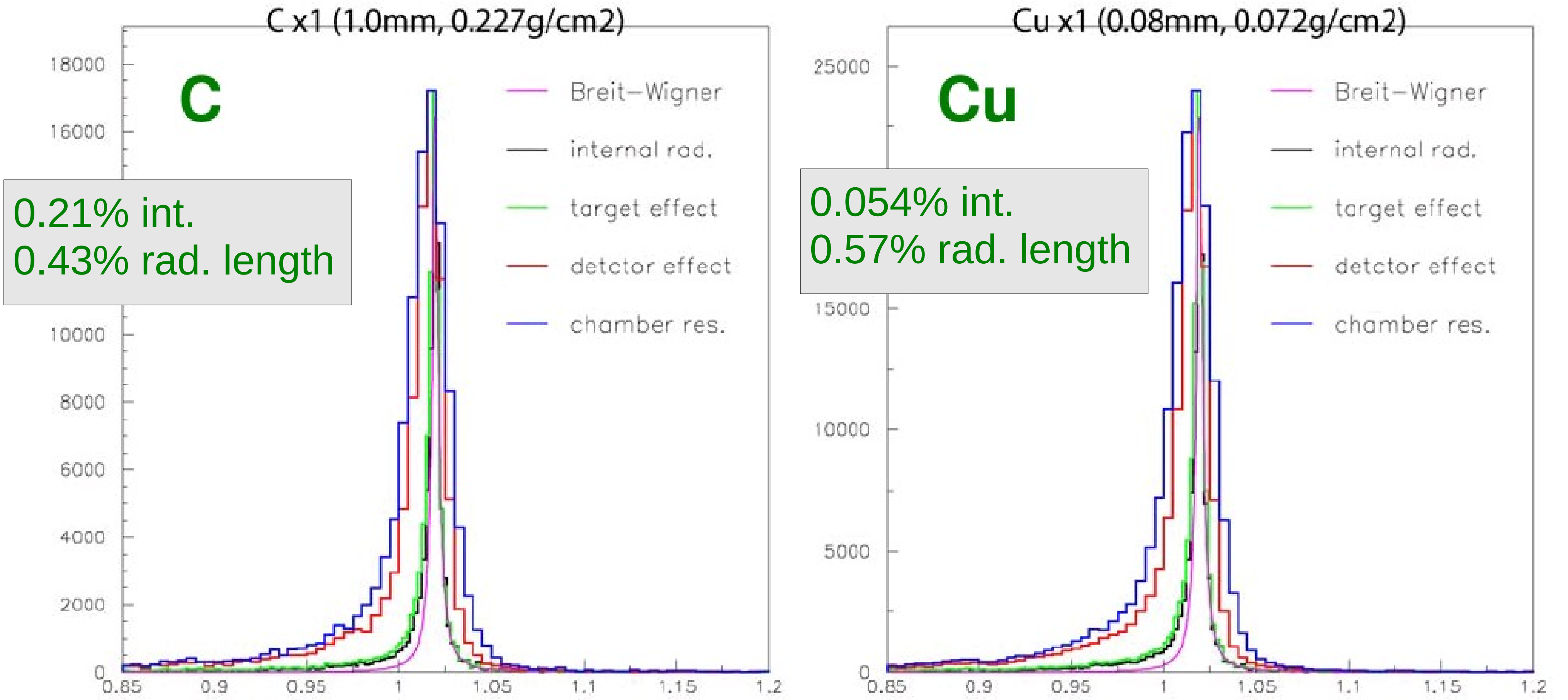
expected
e^+e^- shape
(MC sim.)





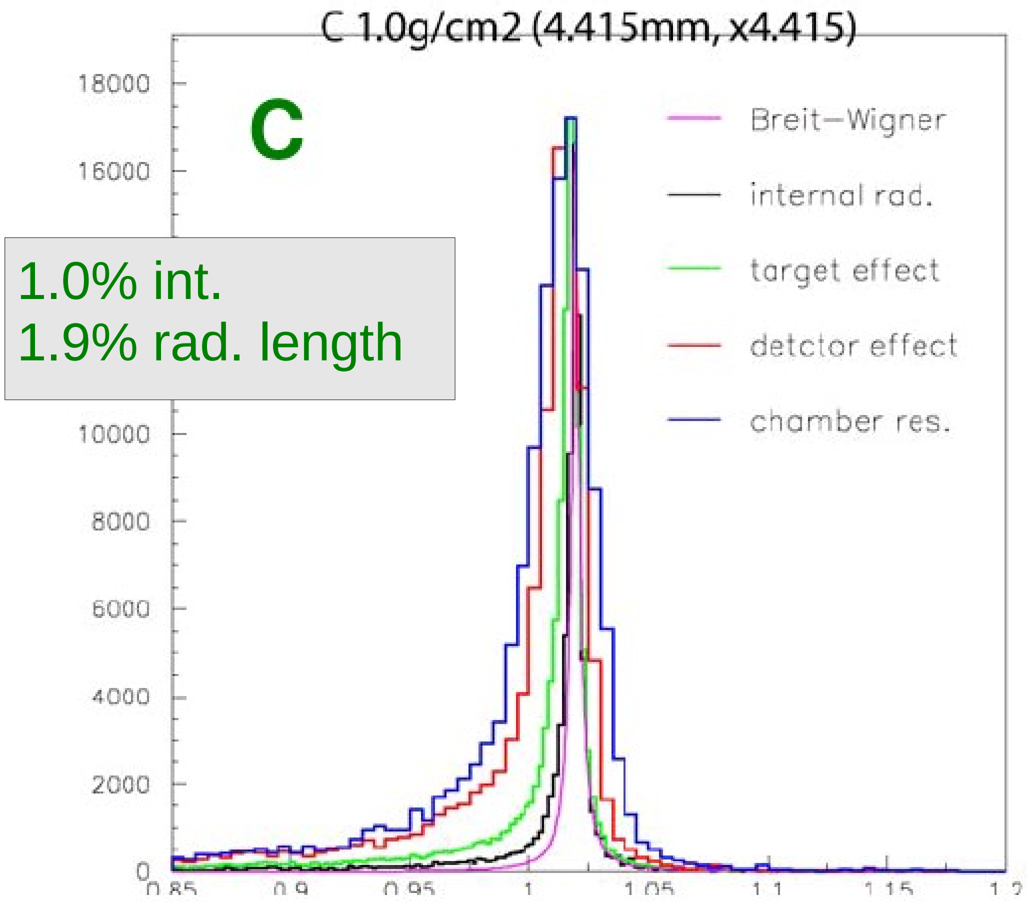
experimental effects on the resonance shape

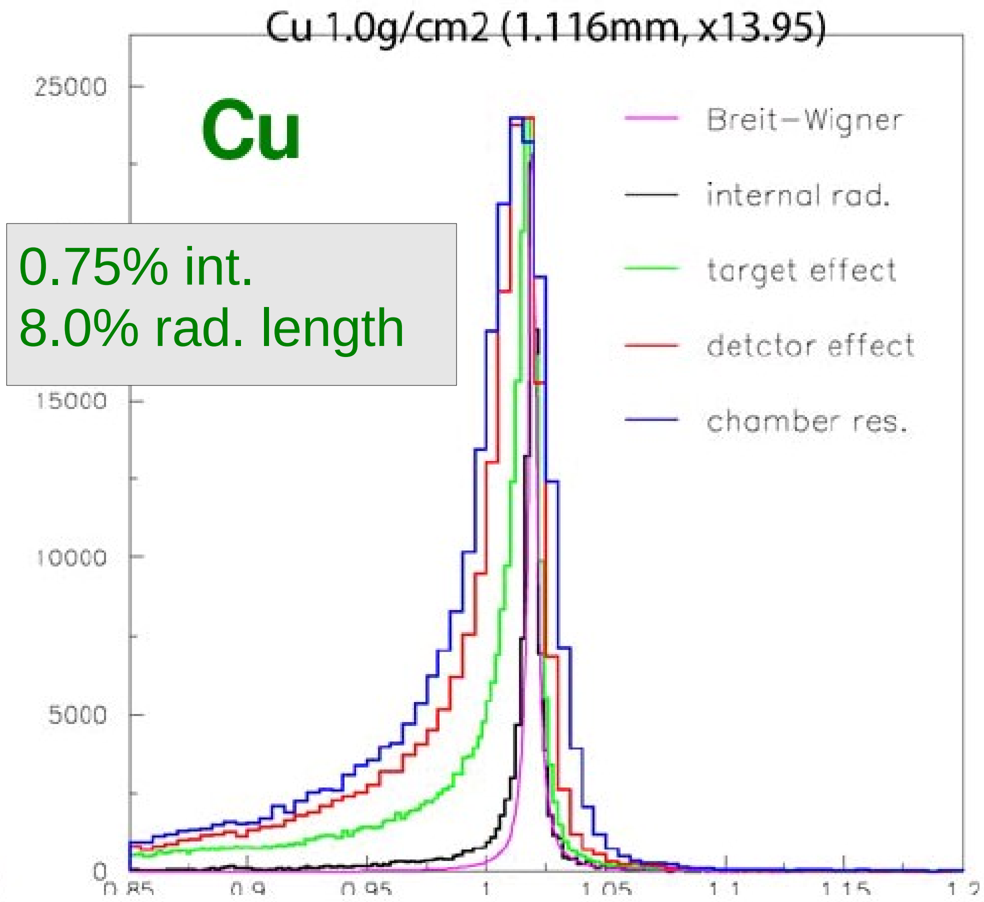
- target material is negligible for ~0.5% radiation length
- detectors :up to 4.5 % rad. length for the tracking region



(experimental effects on the BW shape)

- thick target effect : 1g/cm^2

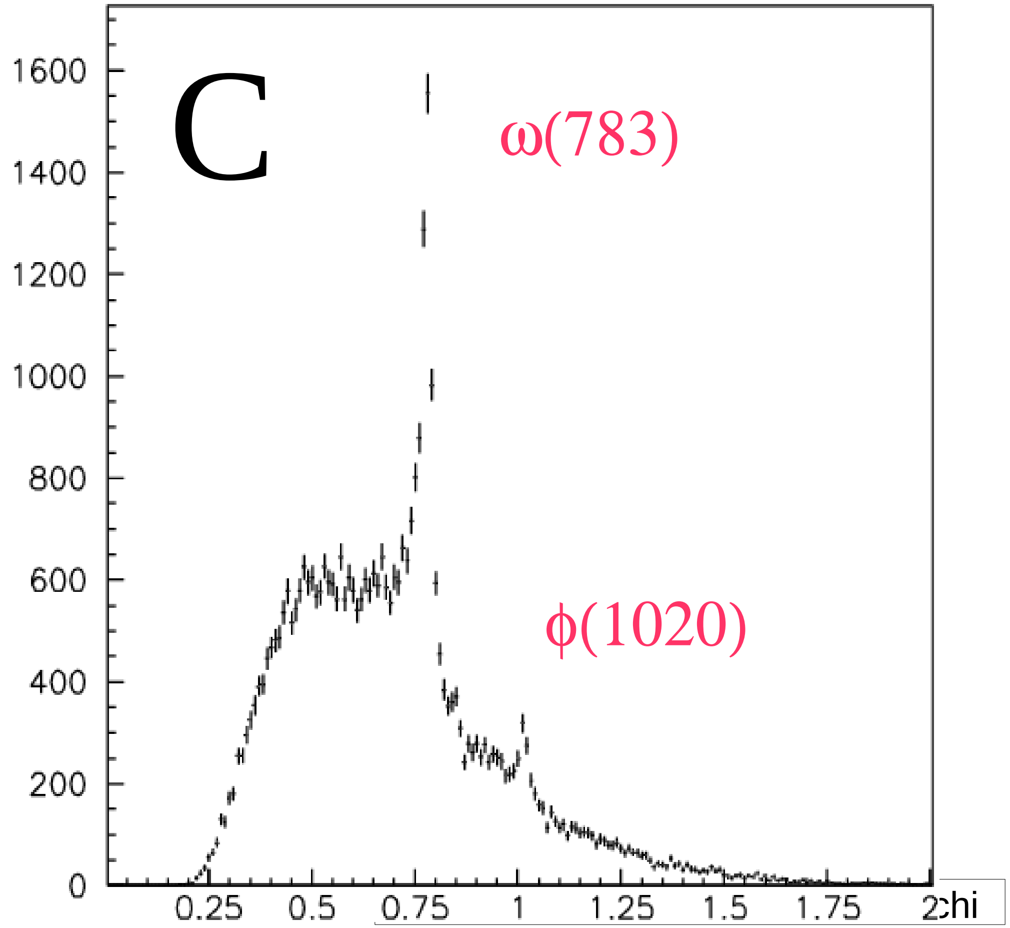




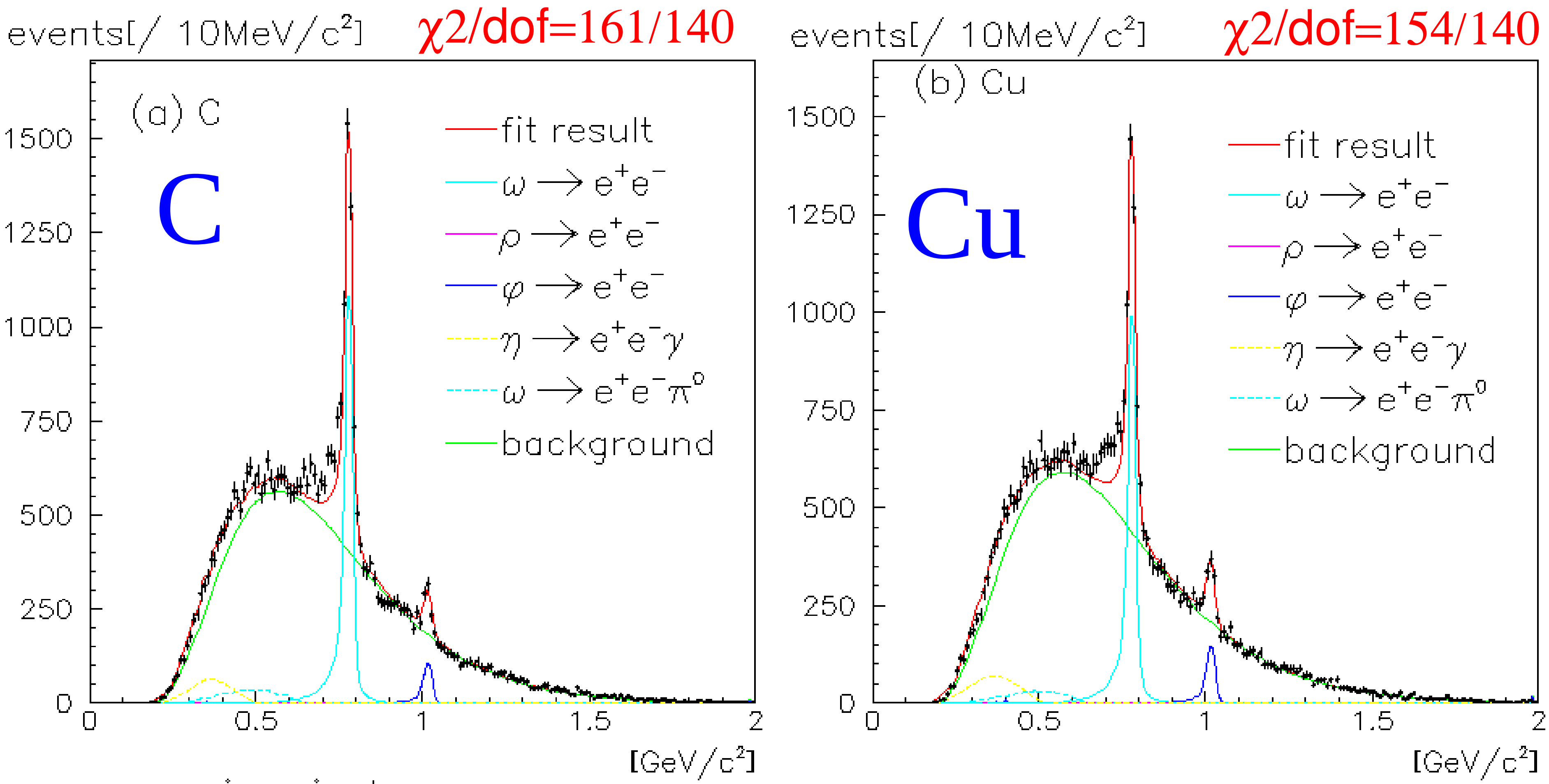
E325 Results (3)

ee invariant mass spectra(ρ/ω)

M. Naruki et al.,
PRL 96 (2006) 092301



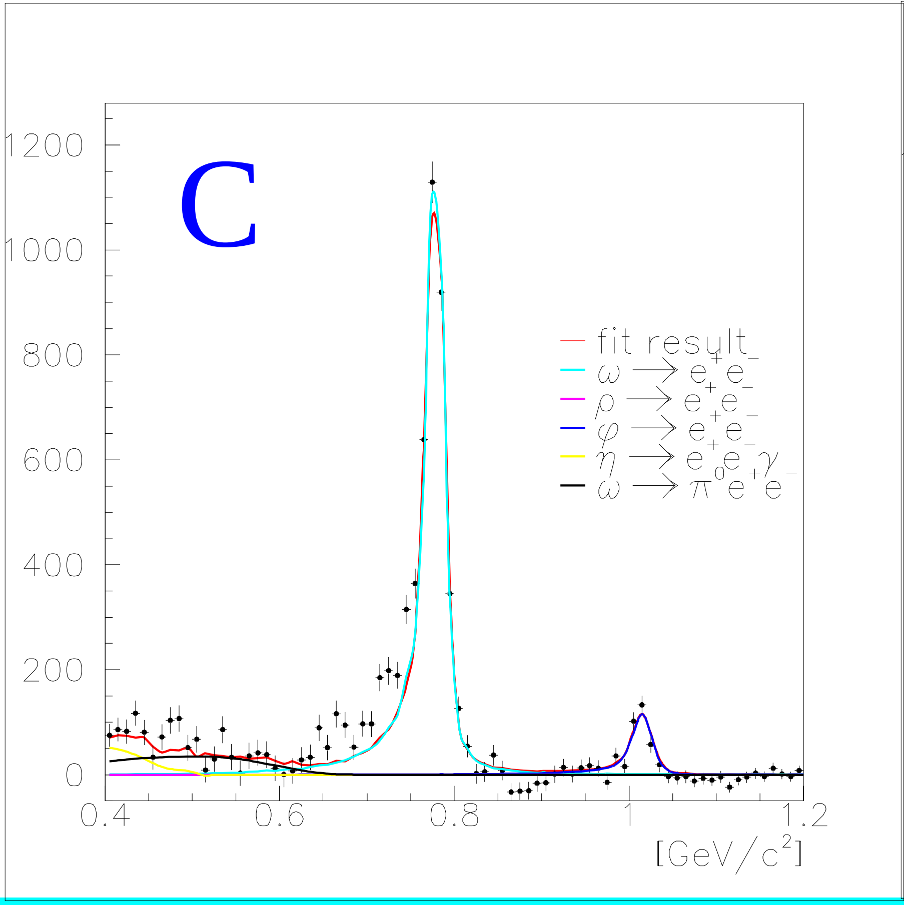
Fitting results

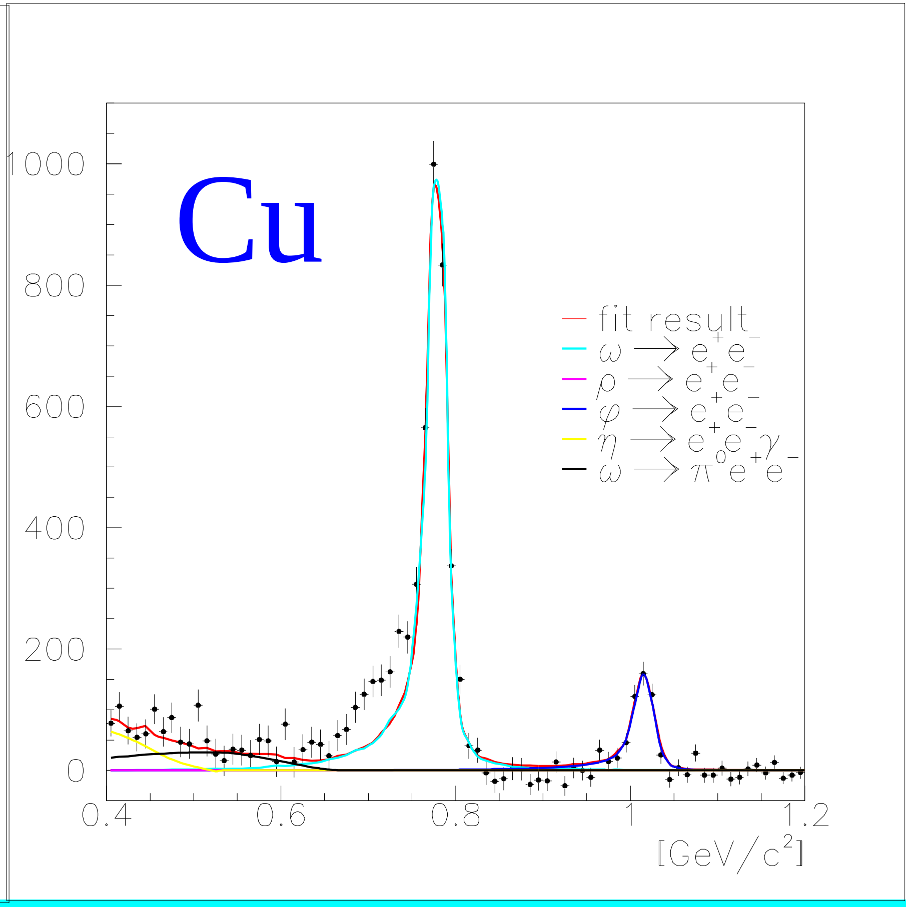


- 1) excess at the low-mass side of ω
  - To reproduce the data by the fitting, we have to exclude the excess region : 0.60~0.76 GeV
- 2) ρ−meson component seems to be vanished !

Fitting results (BKG subtracted)

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



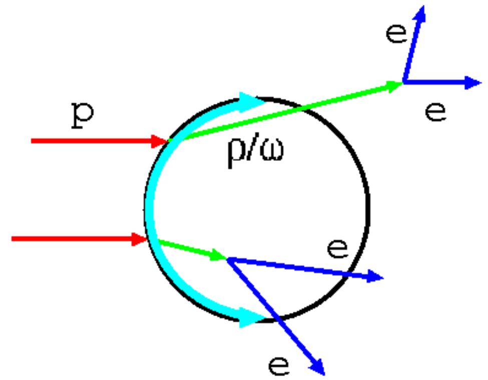


- However, ρ/ω =1.0±0.2 in former experiment (p+p, 1974)

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

Discussion : fit with modification

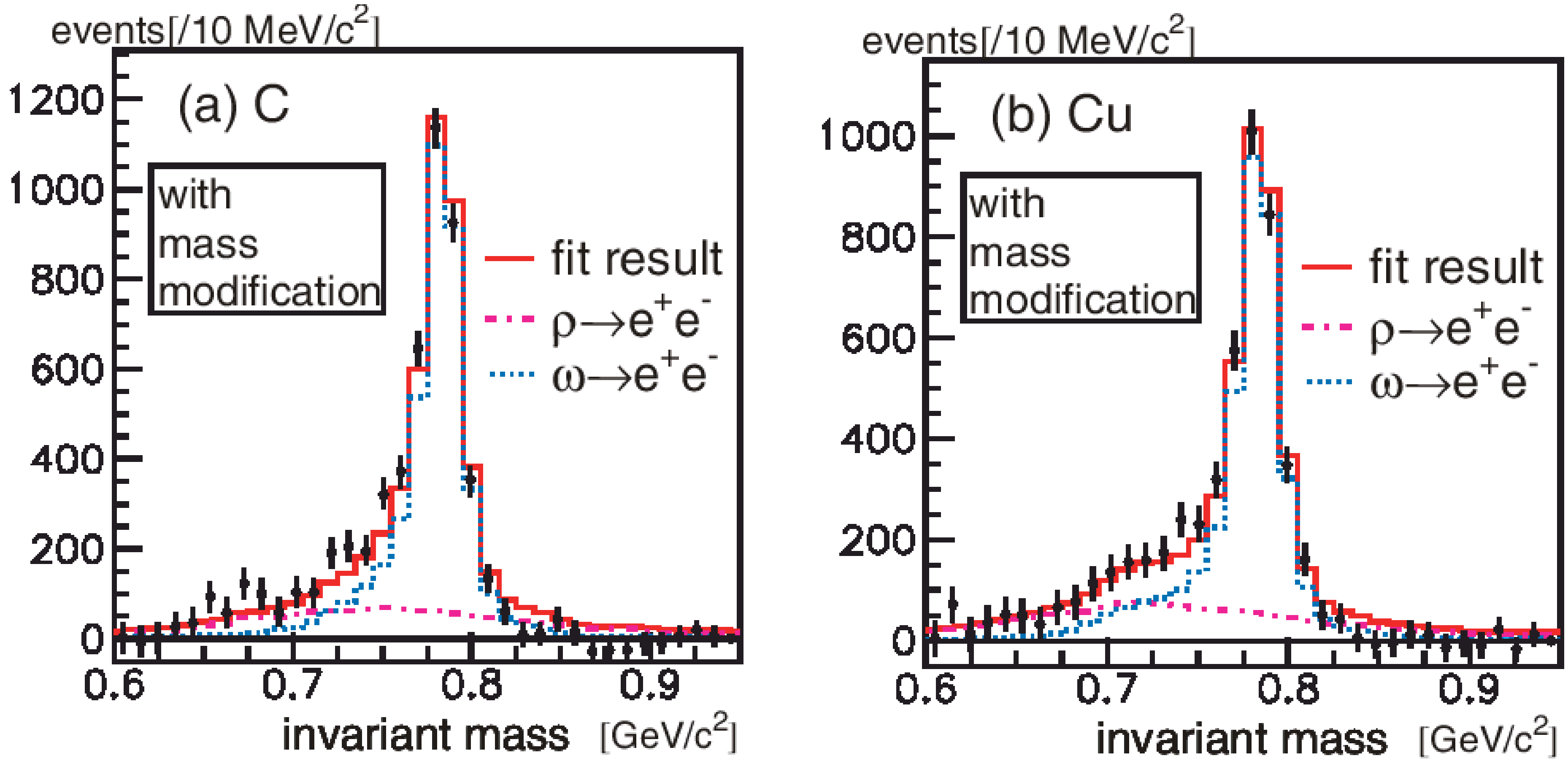
- Assumptions to include the nuclear size effect in the fitting shape
  - dropping mass: **$M(\rho)/M(0) = 1 - k_1 (\rho/\rho_0)$**
    (Hatsuda & Lee, k=0.16±0.06)
  - width broadening: **$\Gamma(\rho)/\Gamma(0) = 1 + k_2 (\rho/\rho_0)$**
    (~* Oset &Ramos)
    (momentum dependence of modification
    is not taken into account this time)



	ρ, ω	φ
m*/m	**$1 - k_1^{\rho/\omega} \rho/\rho_0$**	**$1 - k_1^{\phi} \rho/\rho_0$**
Γ*/Γ	**1**	**$1 + k_2 \rho/\rho_0$**
generation point	surface	uniform
α ($\sigma(A) \propto A^{\alpha}$) [PRC74(06)025201]	0.710±0.021	0.937±0.049
momentum dist.	measured	
density distribution	Woods-Saxon, R= C:2.3fm/Cu:4.1fm	

Fitting results by the model (ρ/ω)

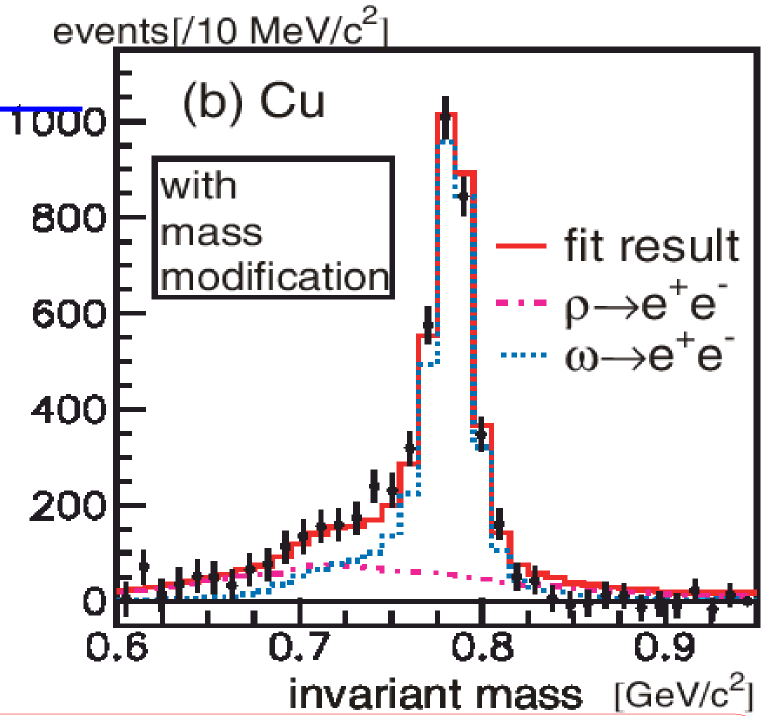
Free param.: - scales of background and hadron components for each C & Cu
- modification parameter k for ρ and ω is common to C & Cu



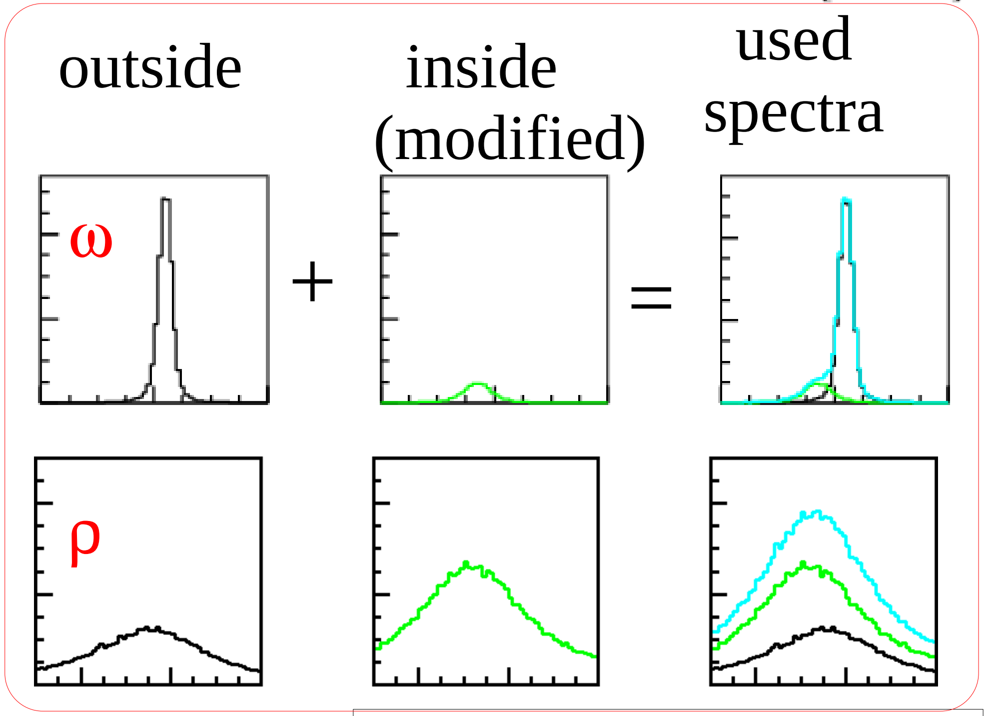
From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density

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

Remark on the model fitting

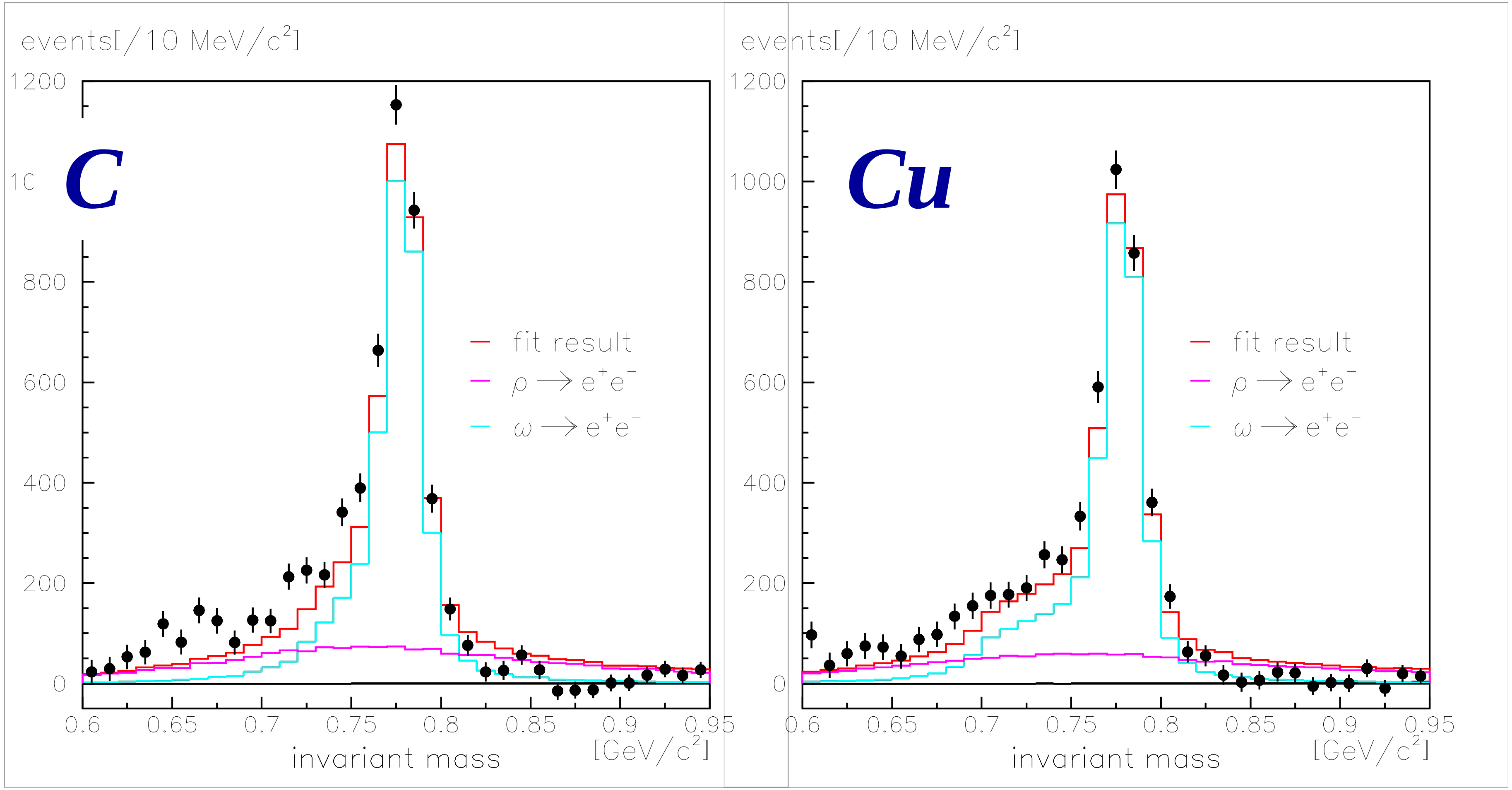


- constraint at right side of peak
  - Introducing the width broadening (x2 & x3) are rejected by this constraint
  - prediction of ' ρ mass increasing' is also not allowed.
- ρ (ω) decay inside nucleus : 46%(5%) for C, 61%(10%) for Cu
  - used spectrum is the sum of the modified and not-modified components.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



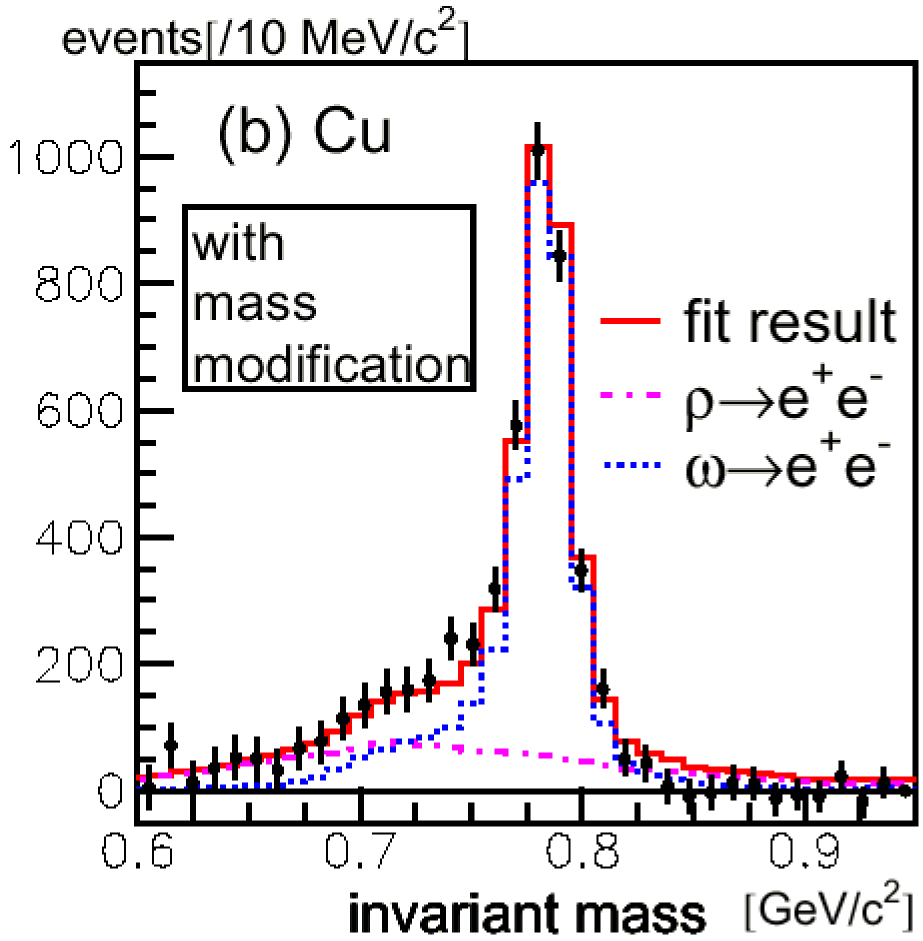
toy model including width broadening

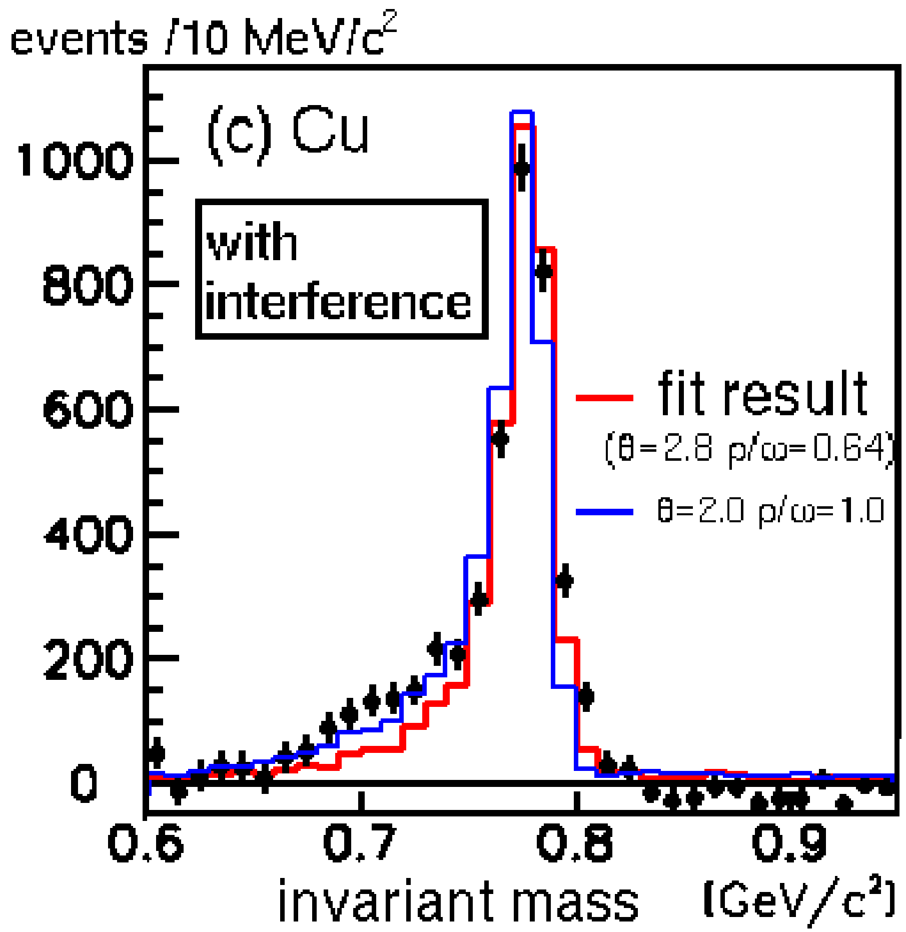
In the case : k=0.08, x2 broadening



- simple broadening increases the high-mass tail of ω

ρ–ω Interference ?



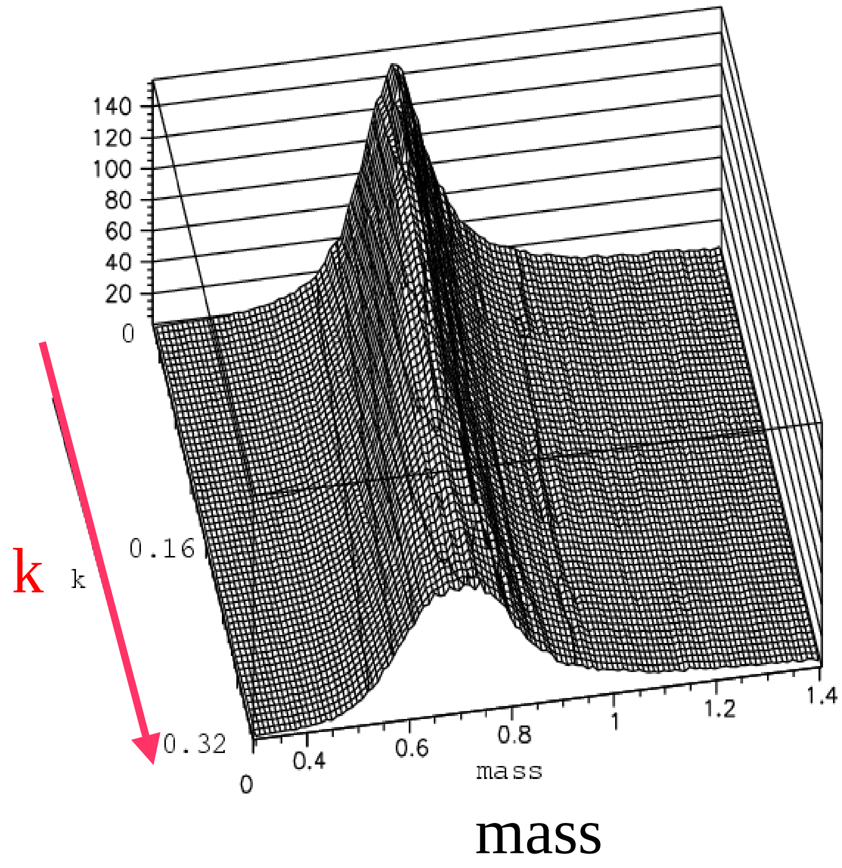


- interfere-shape cannot describe the data in any interference angle and any ρ/ω ratio (0.2~2.6).

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



Vector meson measurements

dilepton measurement

- HELIOS3 (ee, $\mu\mu$) 450GeV p+Be / 200GeV A+A
- DLS (ee) 1 GeV A+A
- CERES (ee) 450GeV p+Be/Au / 40-200GeV A+A
- E325 (ee,KK) 12GeV p+C/Cu
- NA60 ($\mu\mu$) 400GeV p+A/158GeV In+In
- PHENIX (ee,KK) p+p/Au+Au
- HADES (ee) 4.5GeV p+A/ 1-2GeV A+A
- CLAS-G7 (ee) 1~2 GeV γ+A
- *J-PARC E16* (ee) 30/50GeV p+A/ ~20GeV A+A
- *CBM/FAIR* (ee) 20~30GeV A+A

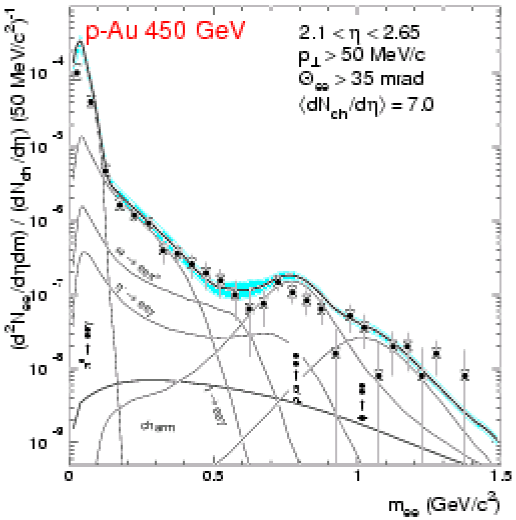
- TAGX ($\pi\pi$) ~1 GeV γ+A
- STAR ($\pi\pi$,KK) p+p/Au+Au
- LEPS (KK) 1.5~2.4 GeV γ+A
- CBELSA/TAPS ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb

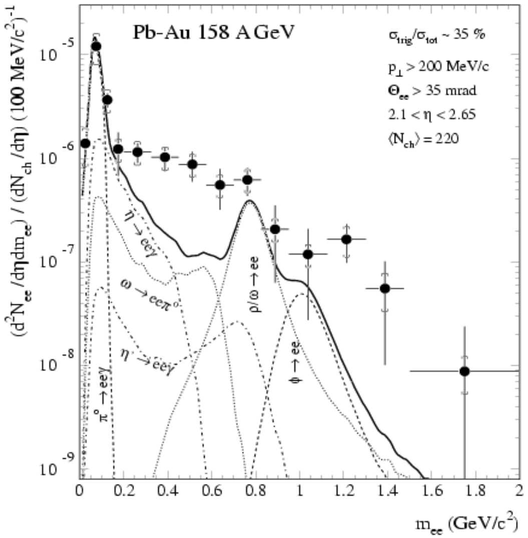
published/ 'modified'
running/in analysis
future plan

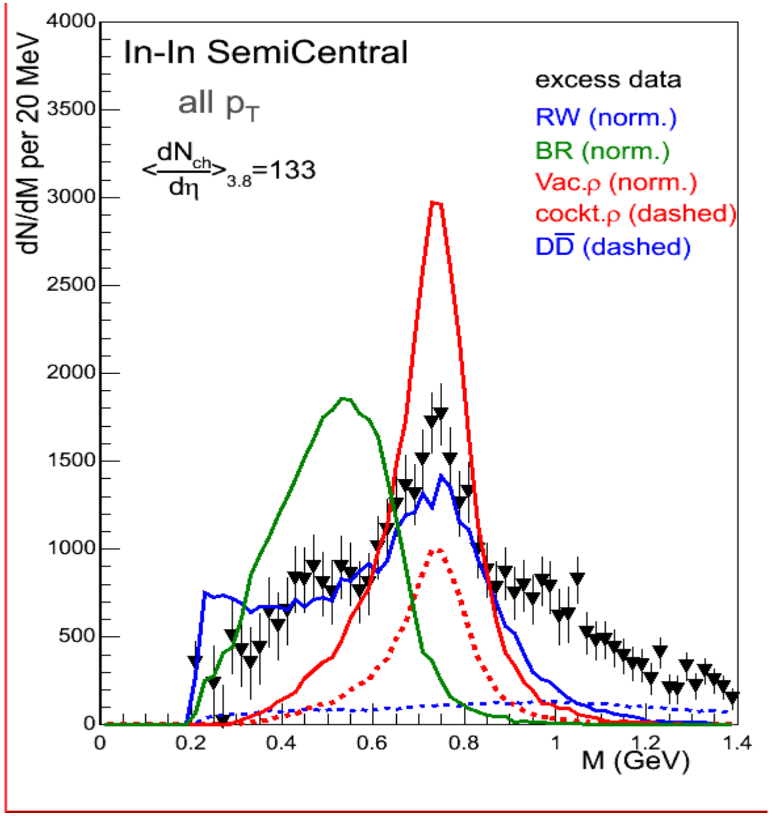
Vector meson measurements in HIC

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

- NA60 : (PRL96(06)162302)
  - $\rho \to \mu^+\mu^-$:
  - width broadening
  - 'BR scaling is ruled out'

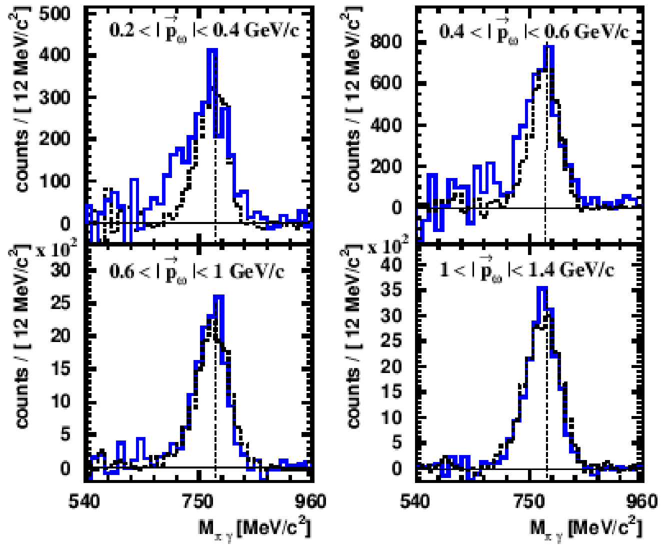


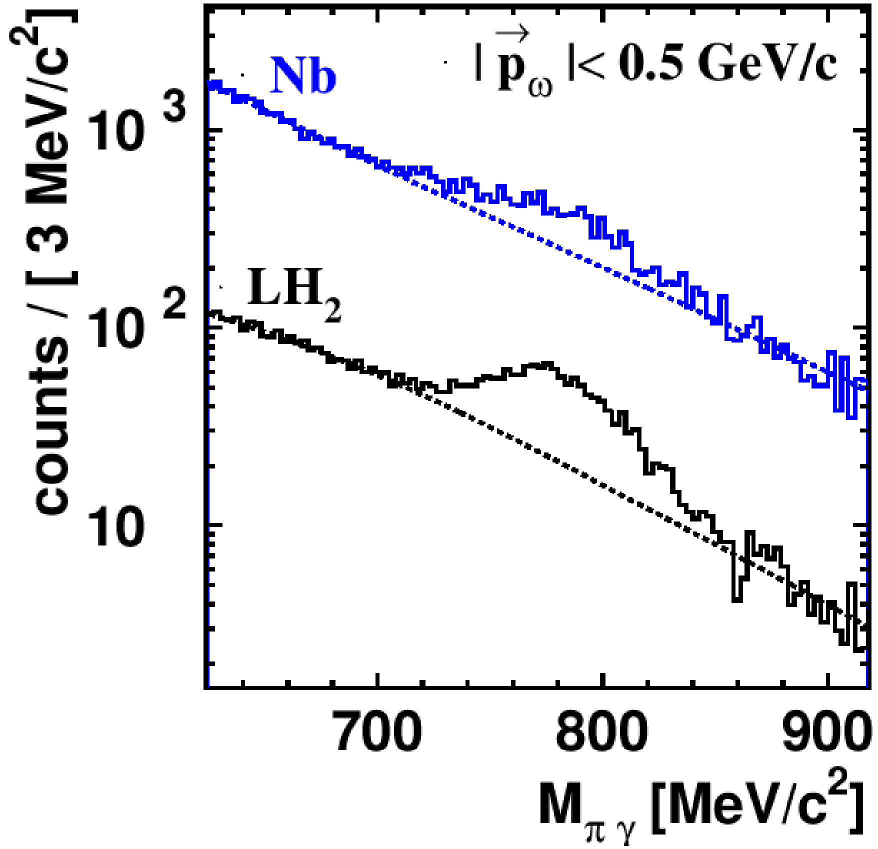


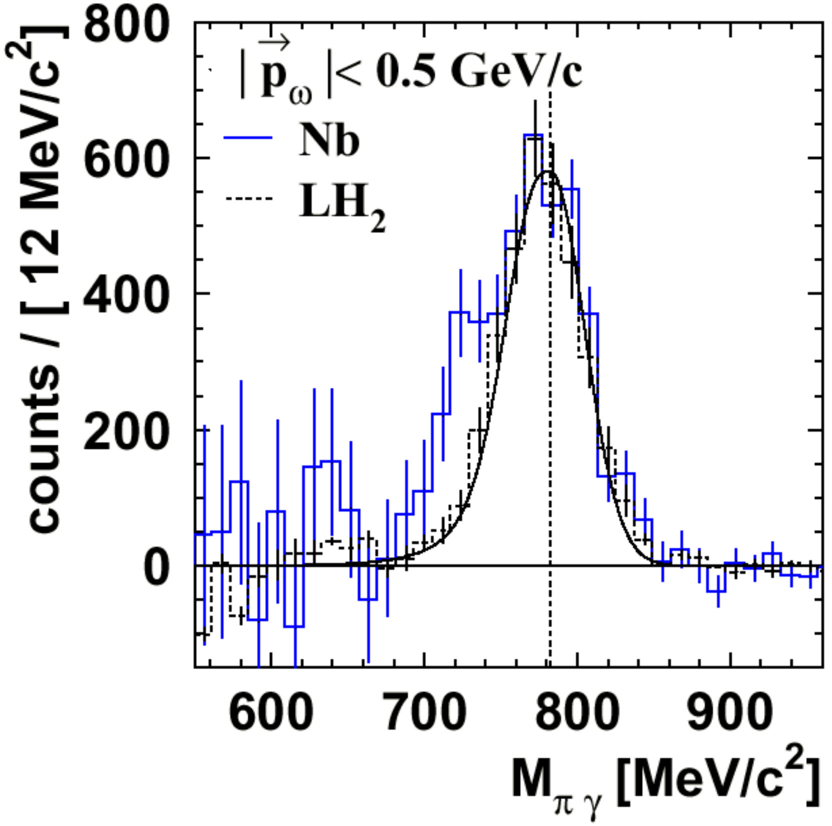


CBELSA/TAPS (PRL94(05)192303)

- $\omega \rightarrow \pi^0\gamma\,(\rightarrow \gamma\gamma\gamma)$
- anomaly in γ+Nb, not in γ+p
  - shift param. k~0.13

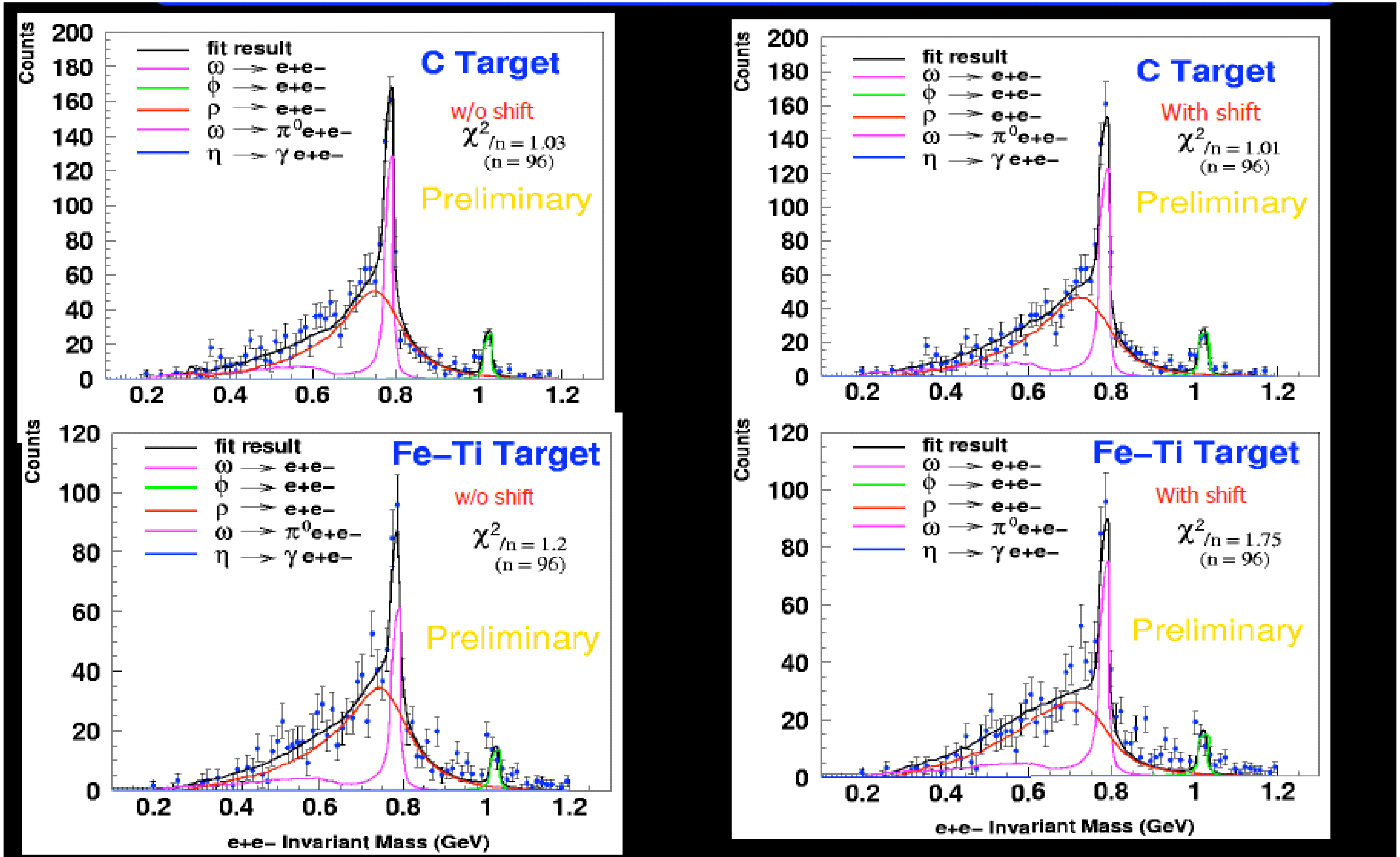






CLAS-G7 (preliminary , QM2006 etc.)

- $\rho \rightarrow e^+e^-$: no modification (k=0.02±0.02)   w/ Giessen BUU



No mass modification α=0

Mass modified a la HL with α~0.16.