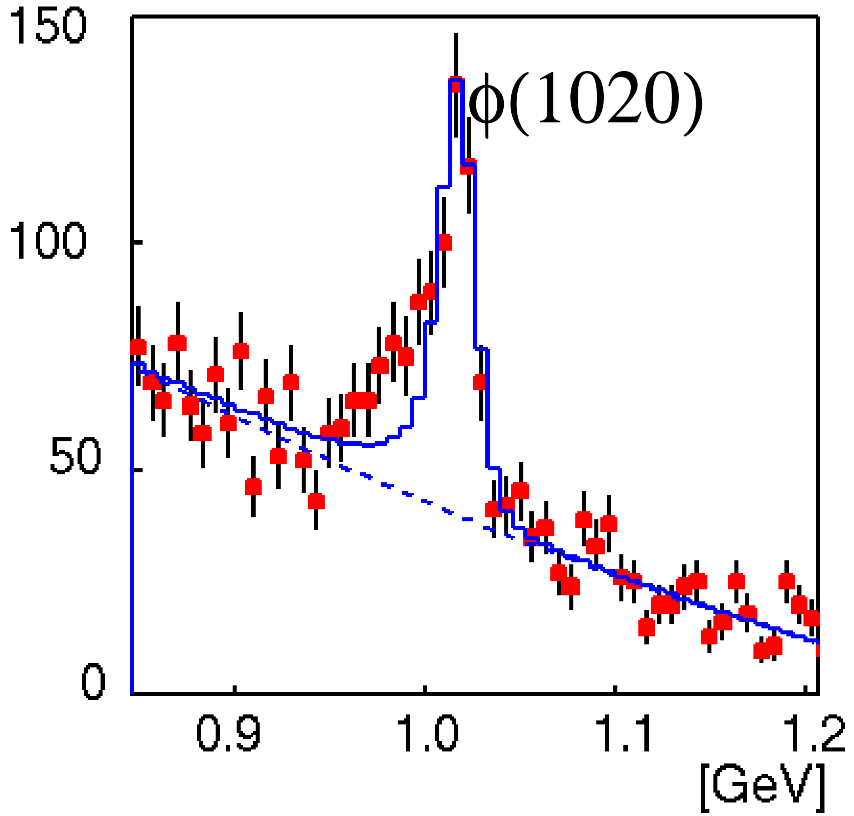
Modification of ρ/ω/φ mass spectra measured at the KEK 12GeV PS

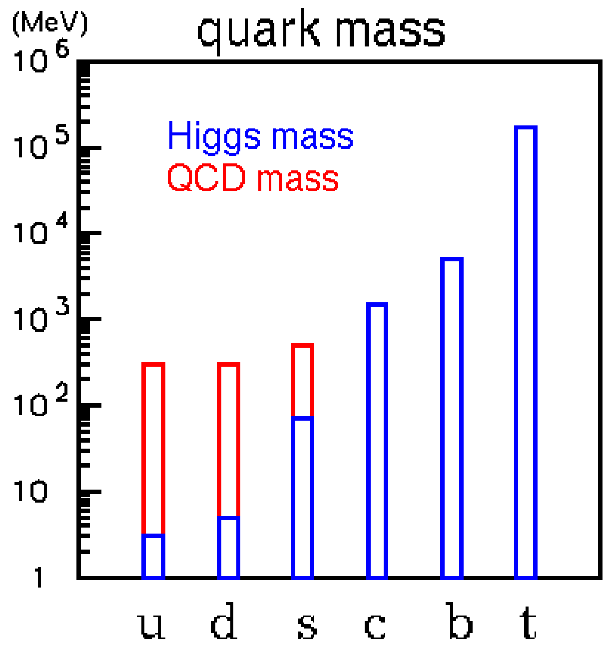
Satoshi Yokkaichi , RIKEN
for the KEK-PS E325 collaboration

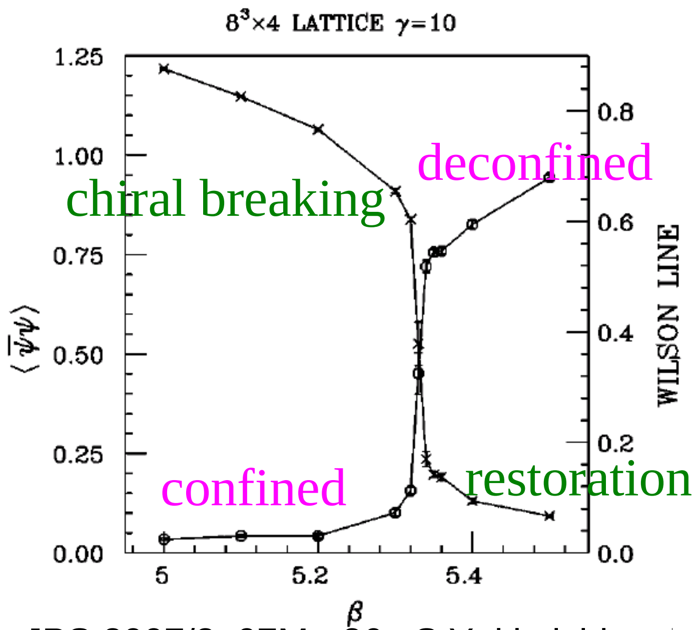
- Introduction
  - chiral symmetry restoration
  - experiments
- KEK-PS E325 Results
  - 1) $\rho/\omega/\phi \rightarrow e^+e^-$ spectra
  - 2) $\phi \rightarrow K^+K^-$ spectra



spontaneous chiral symmetry breaking in QCD

- Origin of hadron (nucleon) mass
  (and light quark mass in hadrons)
  - spontaneous breaking of the chiral symmetry
- confinement-deconfinement phase transition and chiral phase transition occur at the same temperature in lattice calc. (fig:PRD58(98)034504)

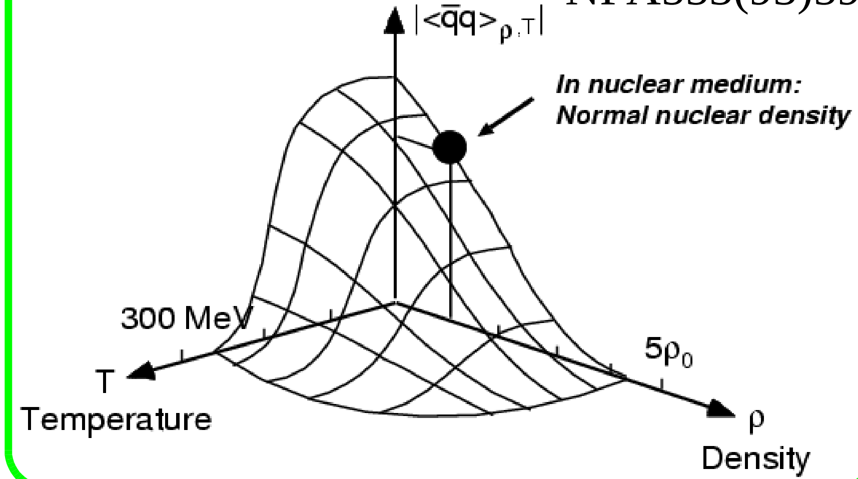




Chiral symmetry restoration in a medium

- quark-antiquark condensate (order parameter of the chiral symmetry) :

W.Weise, NPA553(93)59

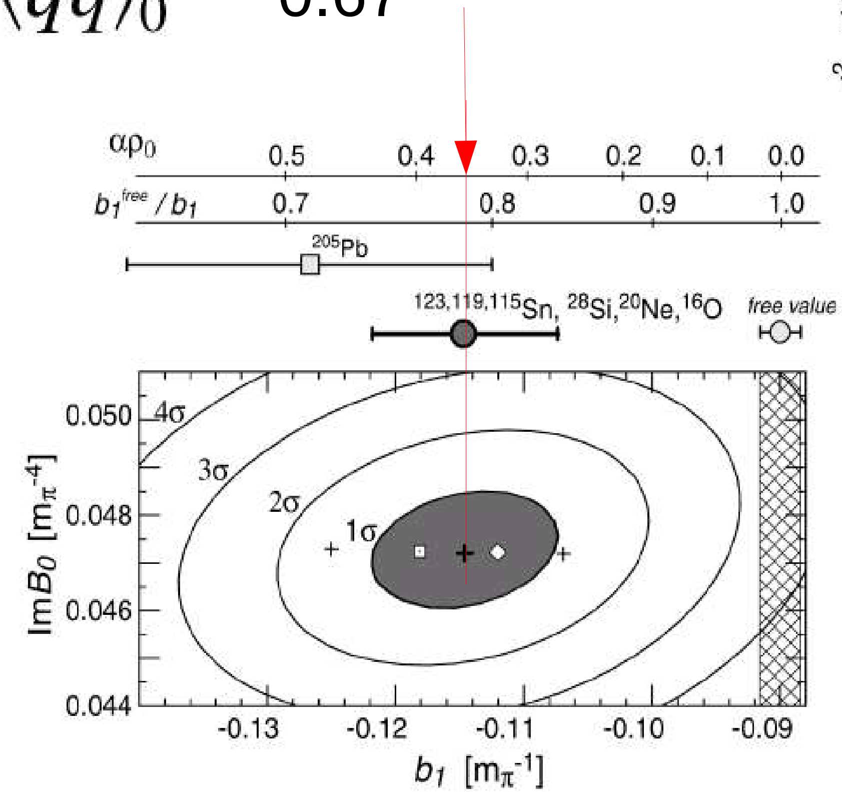


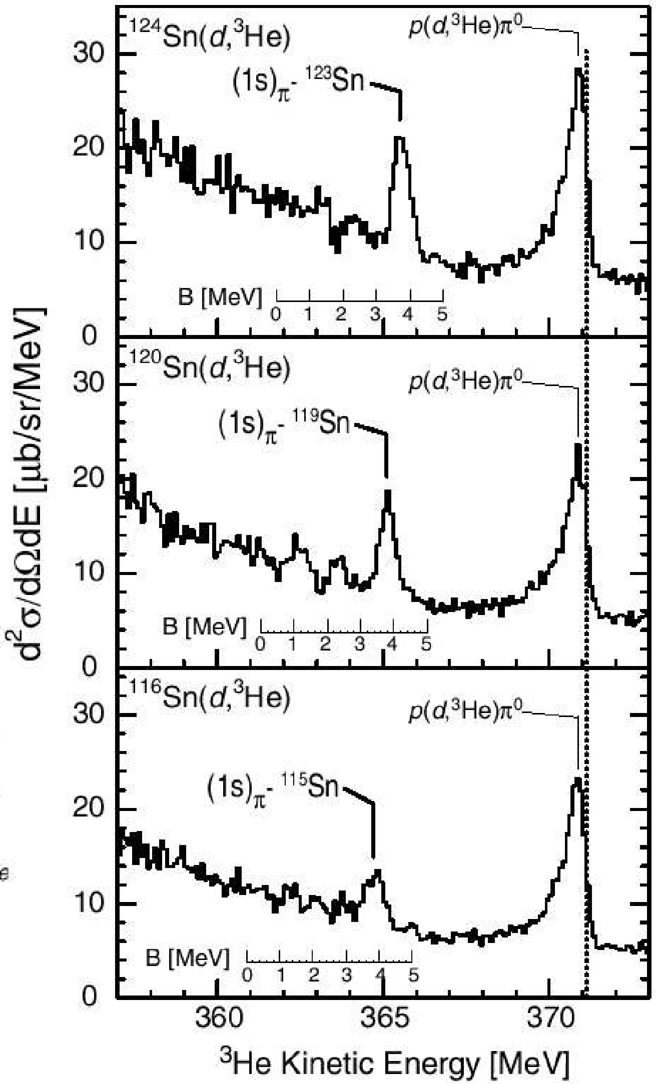
- In hot/dense matter, chiral symmetry is expected to restore
  - hadron modification is expected

- Experiments
  - Vector mesons (ρ / ω / φ), σ meson, S11(1535), etc.
  - deeply bound pionic atom

Deeply bound pionic atom

- optical potential b_1
  - $\rightarrow$ pion decay const.(TW)
  - $\rightarrow$ chiral condensate (GOR)
  - $\langle\bar{q}q\rangle_{\rho_0}/\langle\bar{q}q\rangle_0$ ~ 0.67

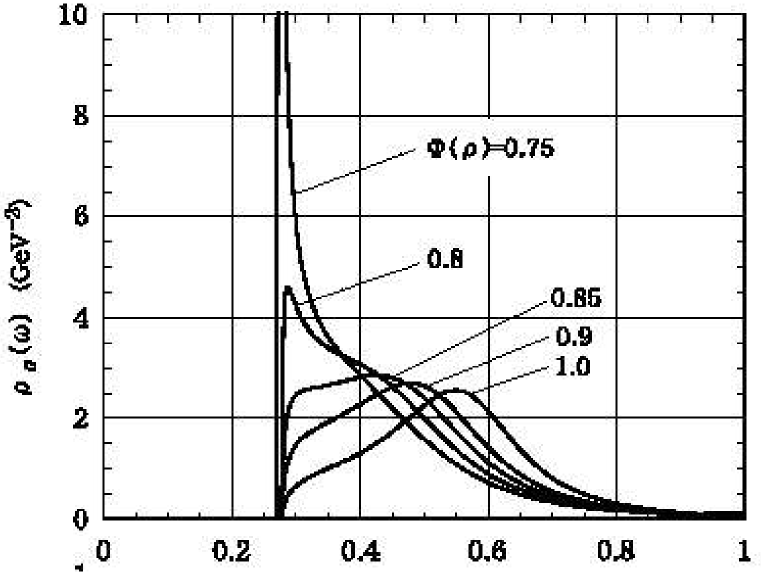




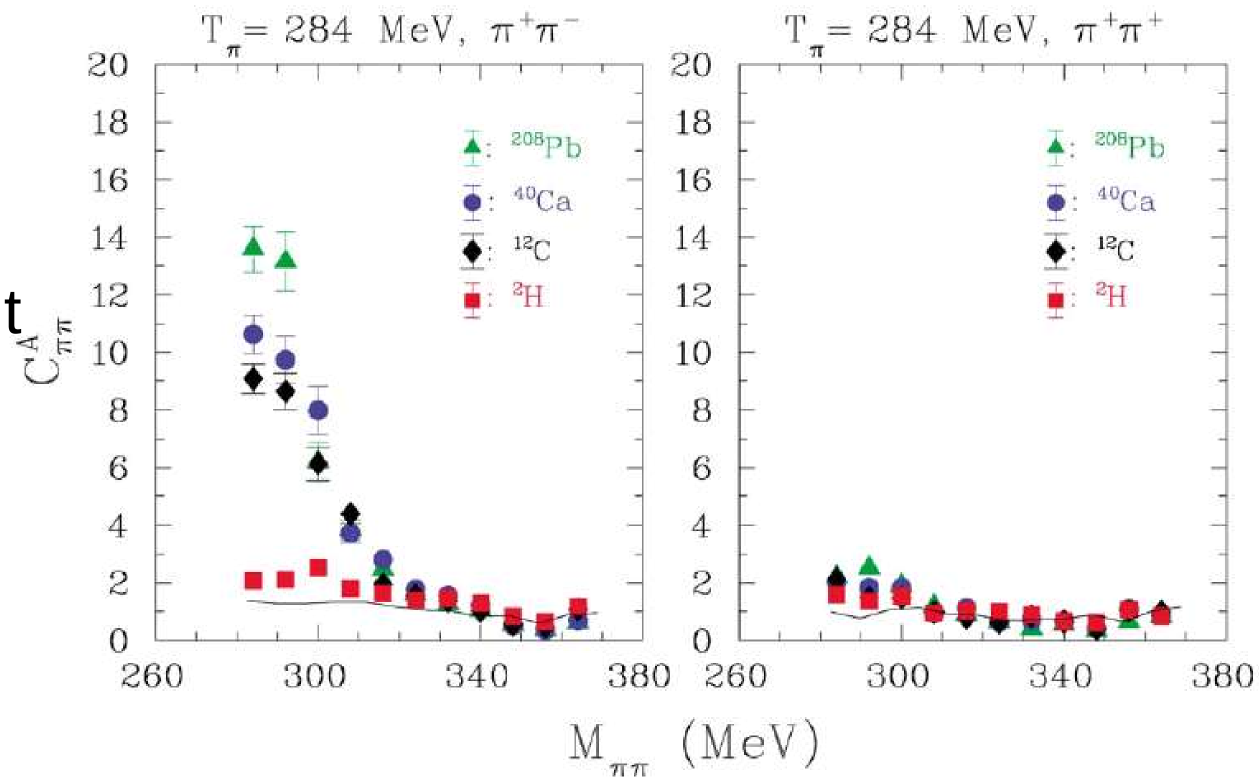
K.Suzuki et al, PRL92(04)072302

σ meson

- Hatsuda, Kunihiro, Shimizu (PRL63(99)2840)
  - prediction : in-medium σ meson spectrum



- CHAOS experiment (NPA763(05)80)
  - threshold enhancement in $\pi^+\pi^-$ channel



Vector meson measurements

dilepton measurement

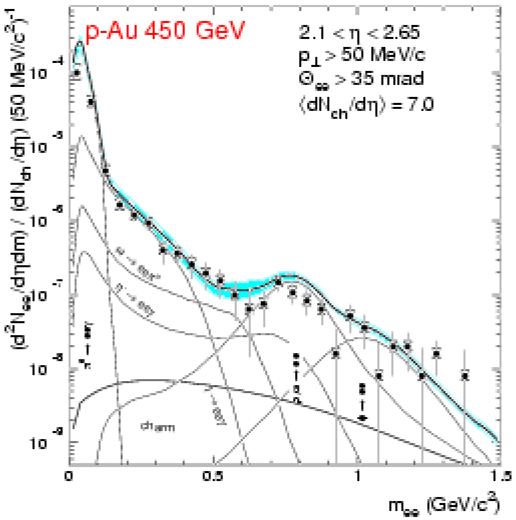
- HELIOS3 (ee, μμ) 450GeV p+Be / 200GeV A+A
- DLS (ee) 1 GeV A+A
- CERES (ee) 450GeV p+Be/Au / 40-200GeV A+A
- E325 (ee,KK) 12GeV p+C/Cu
- NA60 (μμ) 400GeV p+A/158GeV In+In
- PHENIX (ee,KK) p+p/Au+Au
- HADES (ee) 4.5GeV p+A/ 1-2GeV A+A
- CLAS-G7 (ee) 1~2 GeV γ+A
- *J-PARC* (ee) 30/50GeV p+A/ ~20GeV A+A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

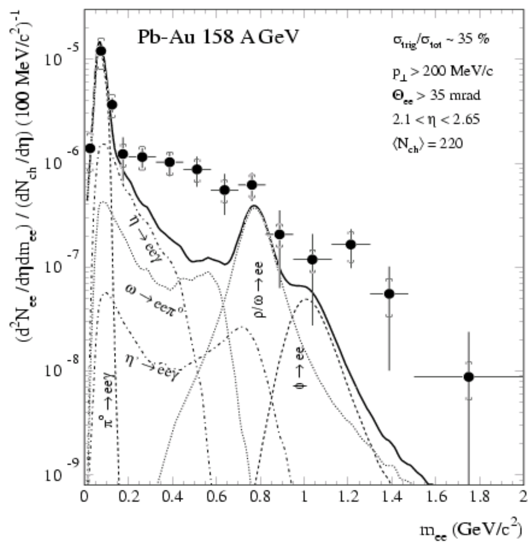
- TAGX (ππ) ~1 GeV γ+A
- STAR (ππ,KK) p+p/Au+Au
- LEPS (KK) 1.5~2.4 GeV γ+A
- CBELSA/TAPS ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb

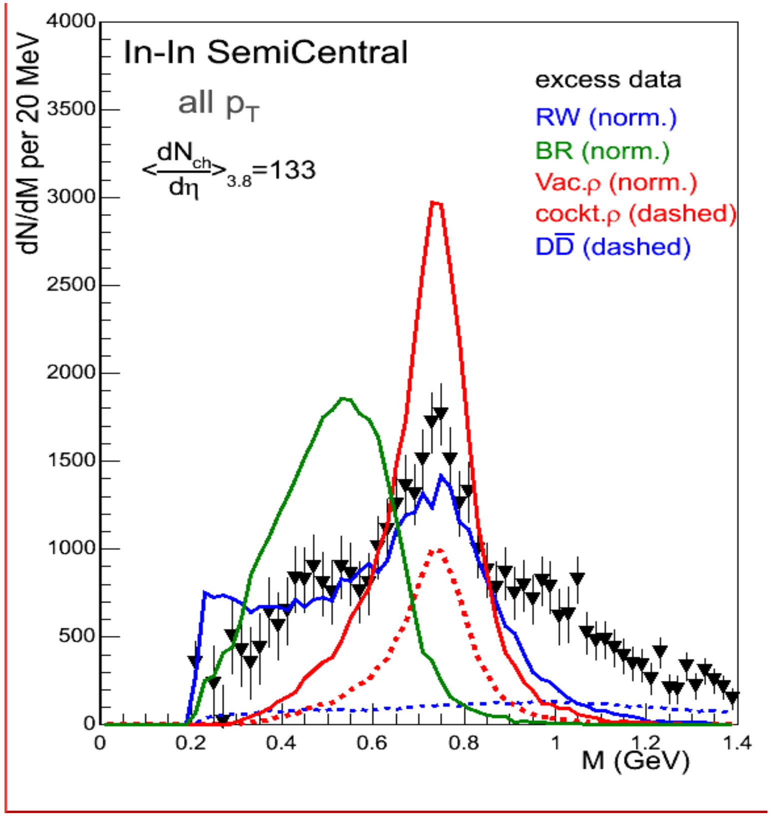
published/ 'modified'
running/in analysis
future plan

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)
  - $\rho \rightarrow \mu^+\mu^-$:
  - width broadening
  - 'BR scaling is ruled out'

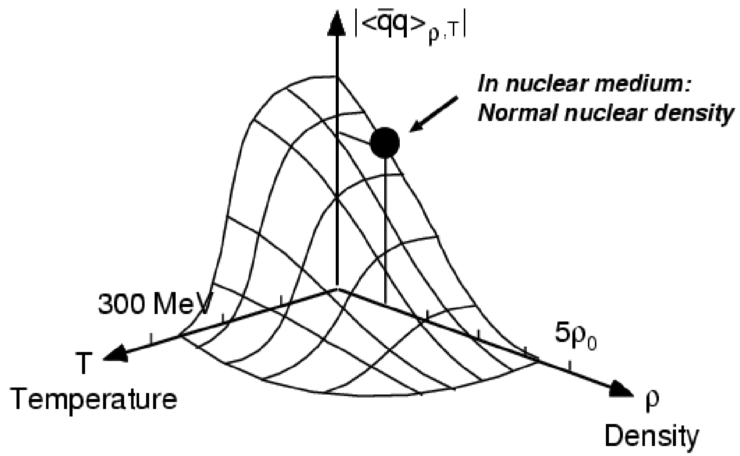






Predictions of vector meson modification

- quark-antiquark condensate (order parameter) : ~2/3 even at the normal nuclear density, T=0
  - could approach by p+A reaction



- 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

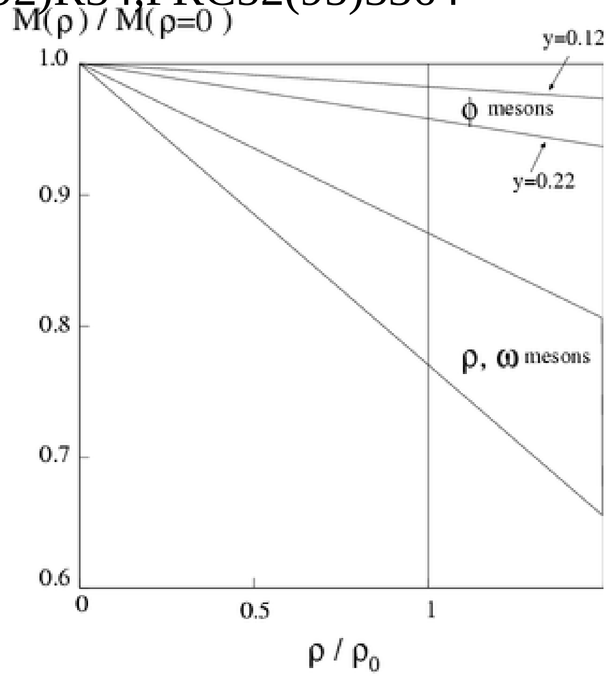
linear dependence on density

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

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



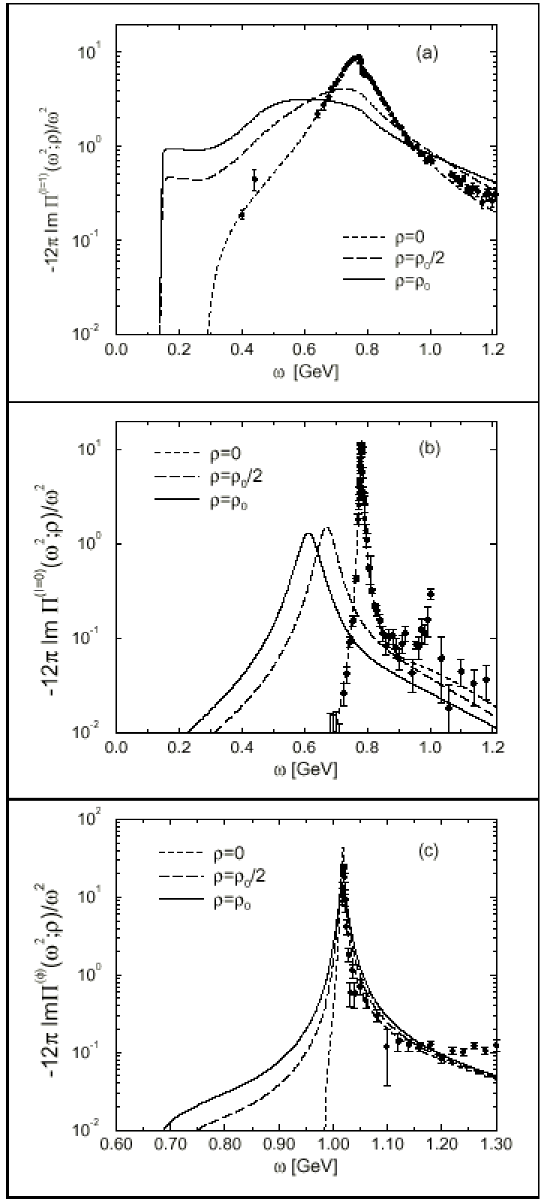
Klingle,Kaiser,Weise,

NPA624(97)527

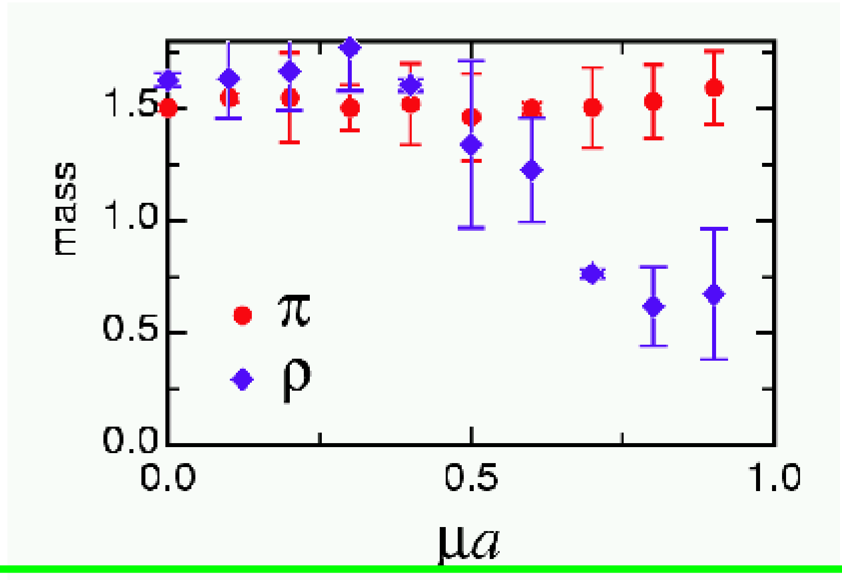
ρ

ω

φ

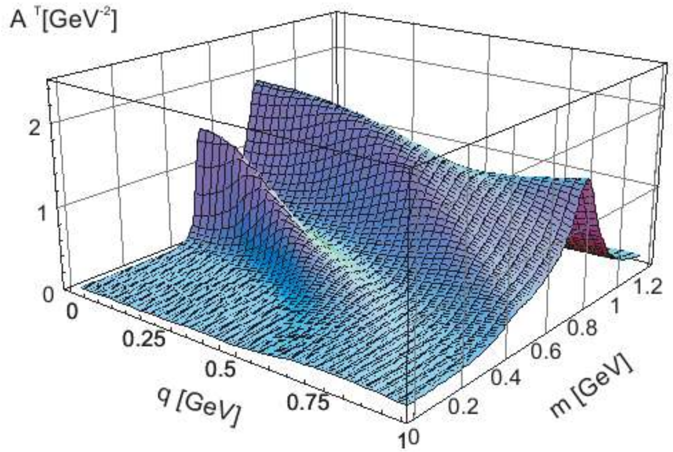


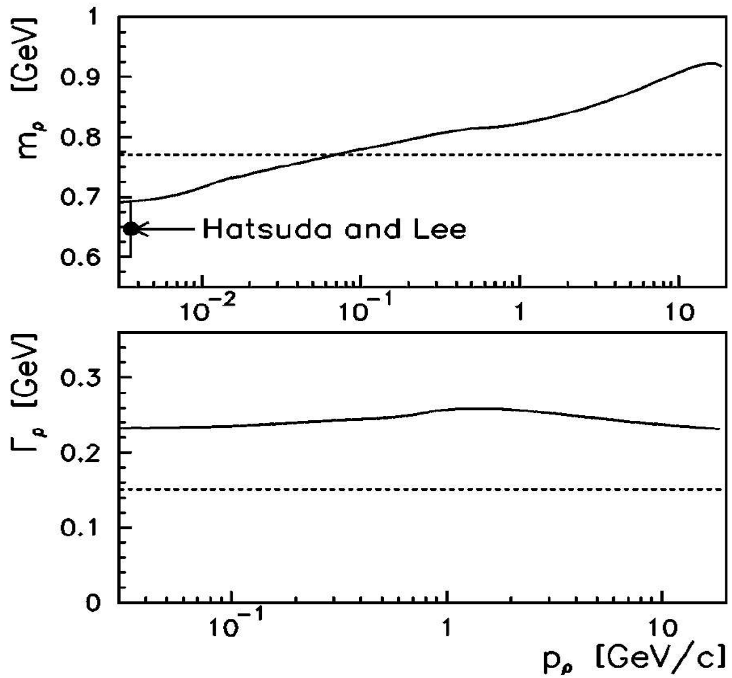
Muroya, Nakamura, Nonaka, PLB 551 (03) 305



non-trivial form of the dispersion relation (mass VS momentum)

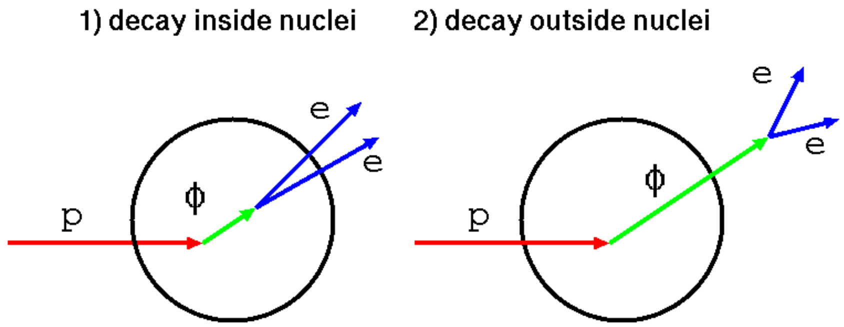
- S.H.Lee (PRC57(98)927) $m^*/m_0 = 1- k\ \rho/\rho_0$
  - ρ/ω : $k=0.16\pm0.06+(0.023\pm0.007)(p/0.5)^2$
  - ϕ : $k=0.15(\pm0.05)*y + (0.0005\pm0.0002)(p/0.5)^2$
  - for p<1GeV/c
- Kondratyuk et al. (PRC58(98)1078) : ρ meson
- Post & Mosel(NPA699(02)169) : ρ meson



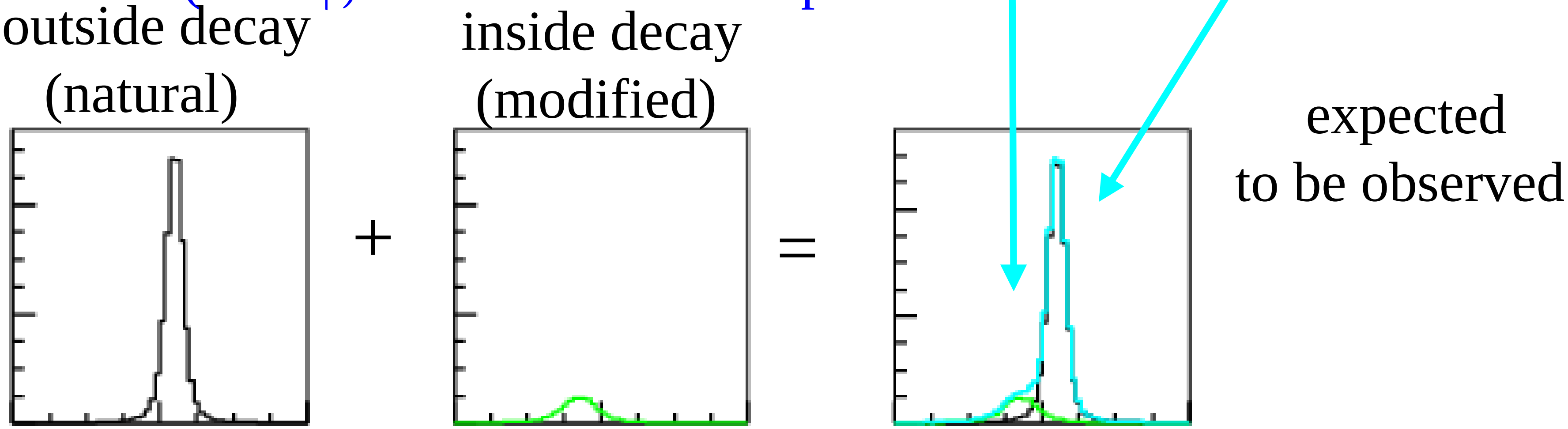


Expected Invariant mass spectra in e^+e^-

- 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



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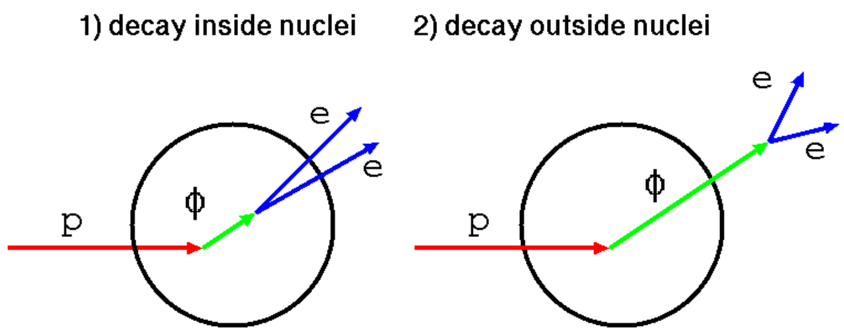
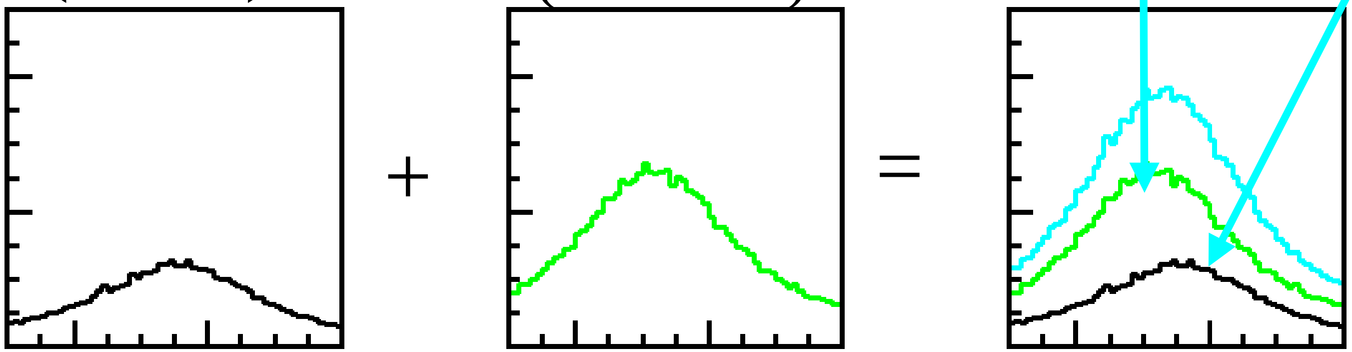


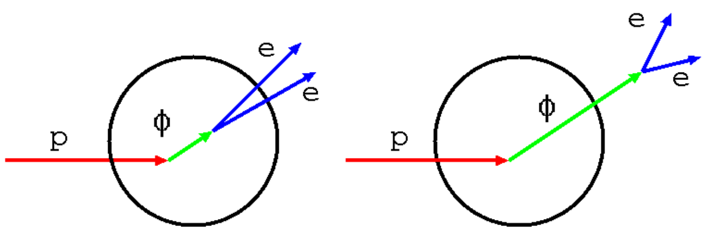
shorter-life meson(ρ) cases : Schematic picture

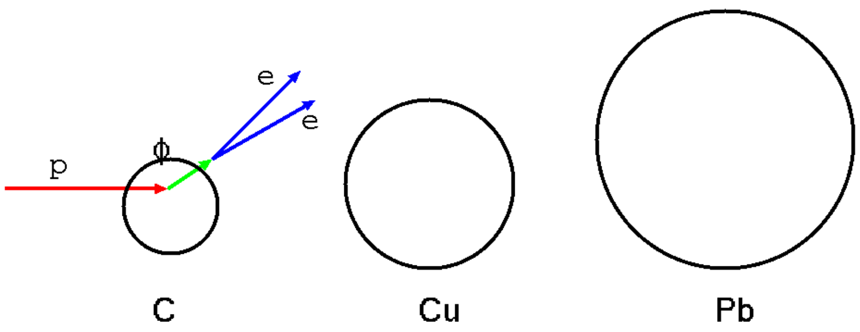
outside decay (natural) + inside decay (modified) = expected to be observed



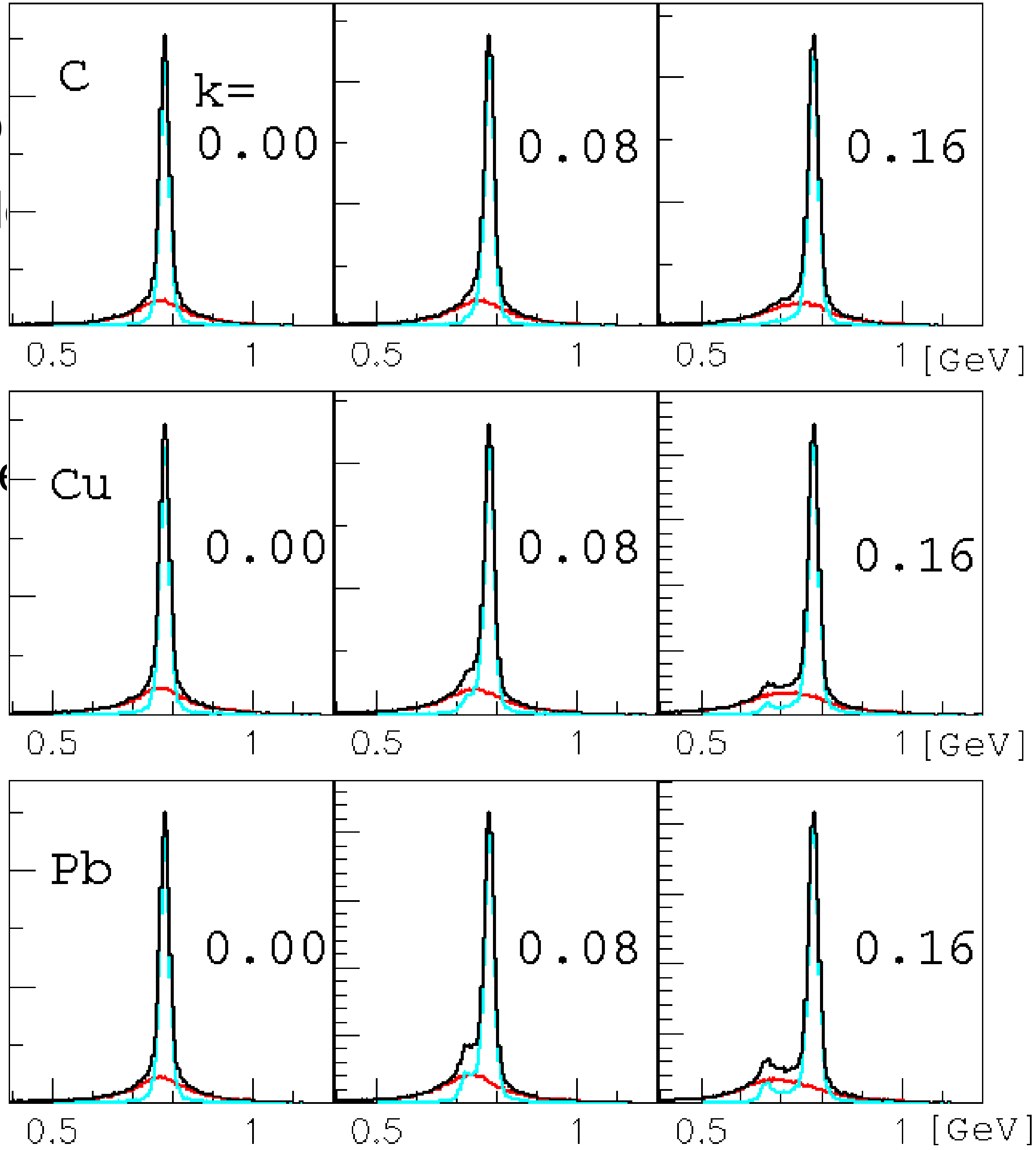
(Expected e^+e^- spectra)

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



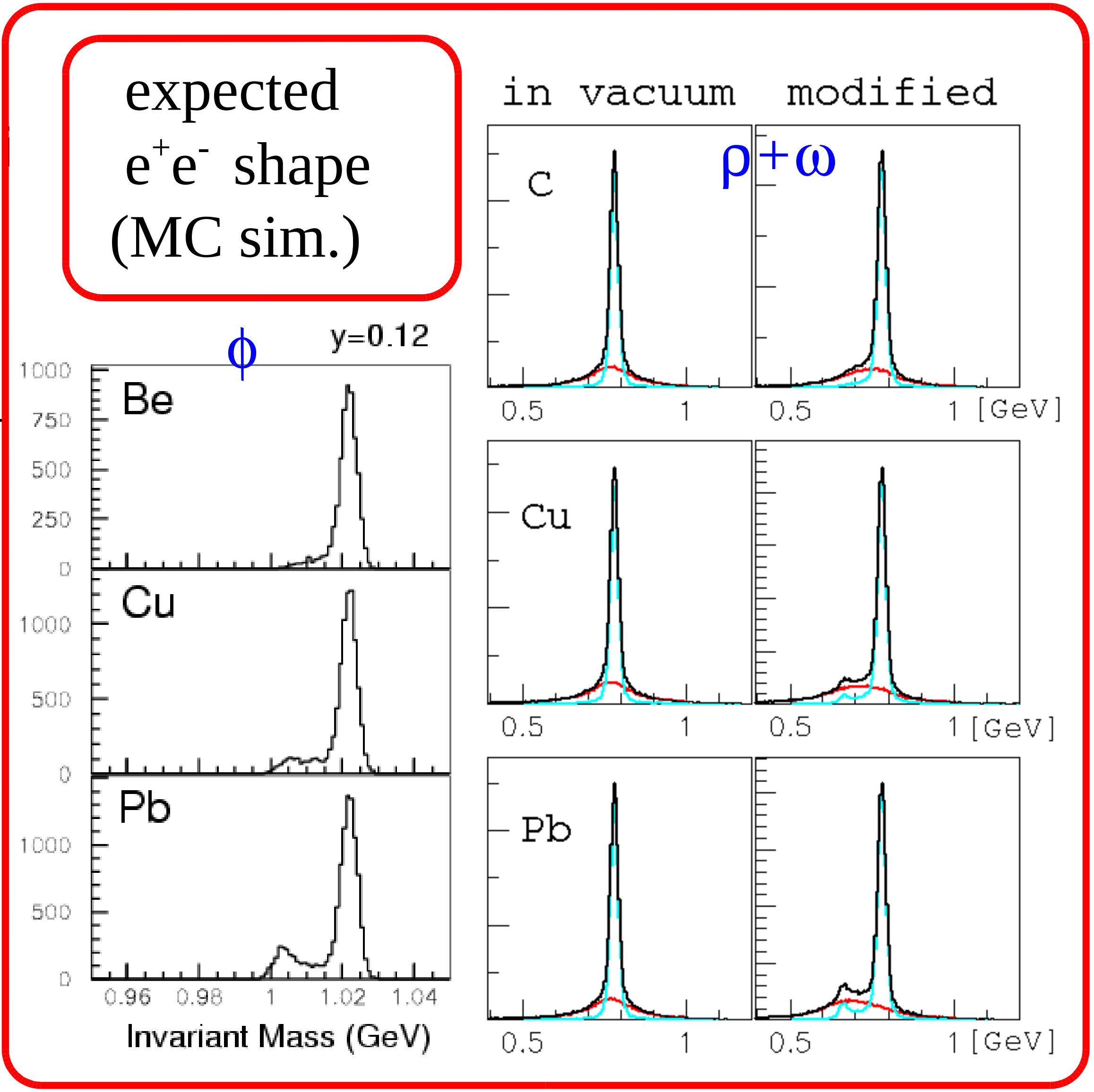


(toy model calc.)



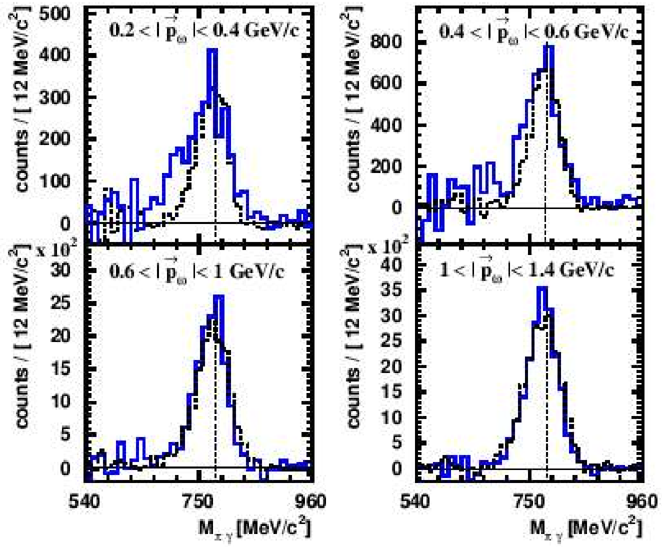
(Expected e^+e^- spectra)

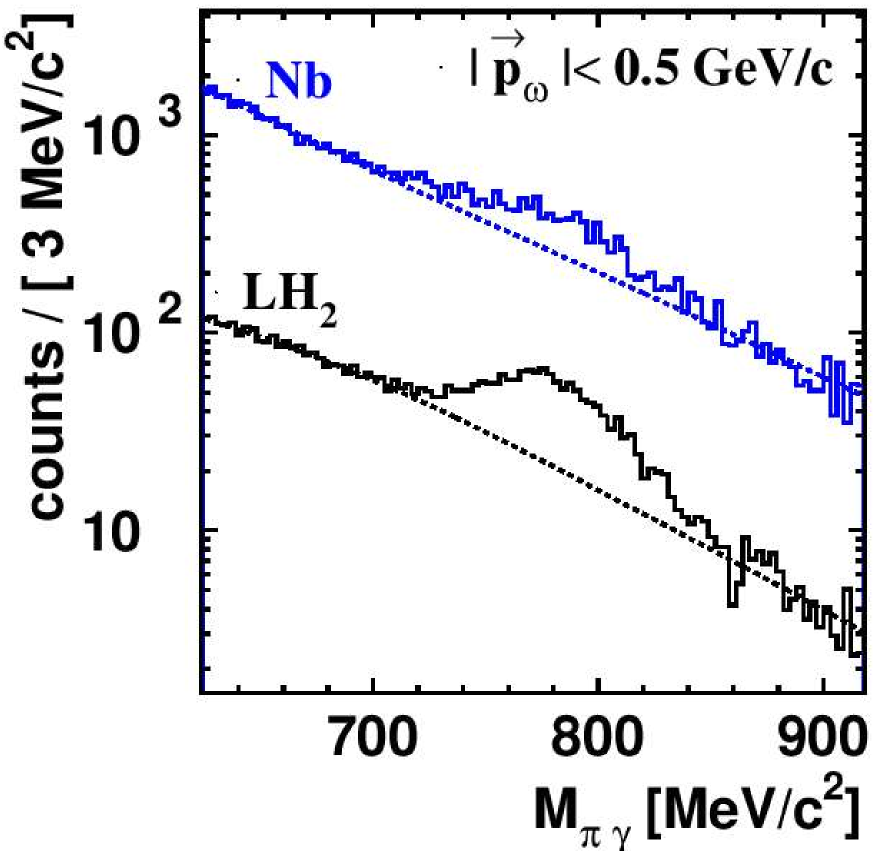
- ρ (770) & ω(783) :
  - larger production cross section
  - larger decay prob. inside nuclei
    - ρ : Γ=150MeV ~ 1.3fm
    - ω : Γ=8.4MeV ~ 24 fm
  - cannot distinguish ρ & ω in e^+e^-
- ϕ (1020) : narrow width
  - smaller decay prob. inside nuclei
    - ϕ : Γ=4.3MeV ~ 46 fm
  - smaller production cross section
-
- L = βγ*cτ= p/m * h/2π*c/Γ

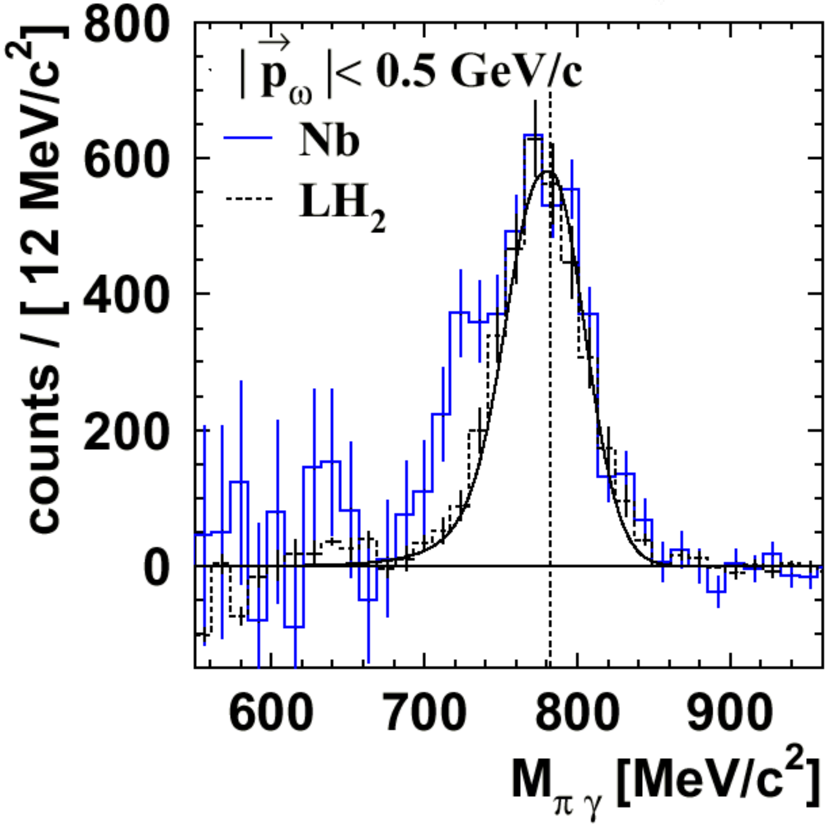


CBELSA/TAPS (PRL94(05)192303)

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

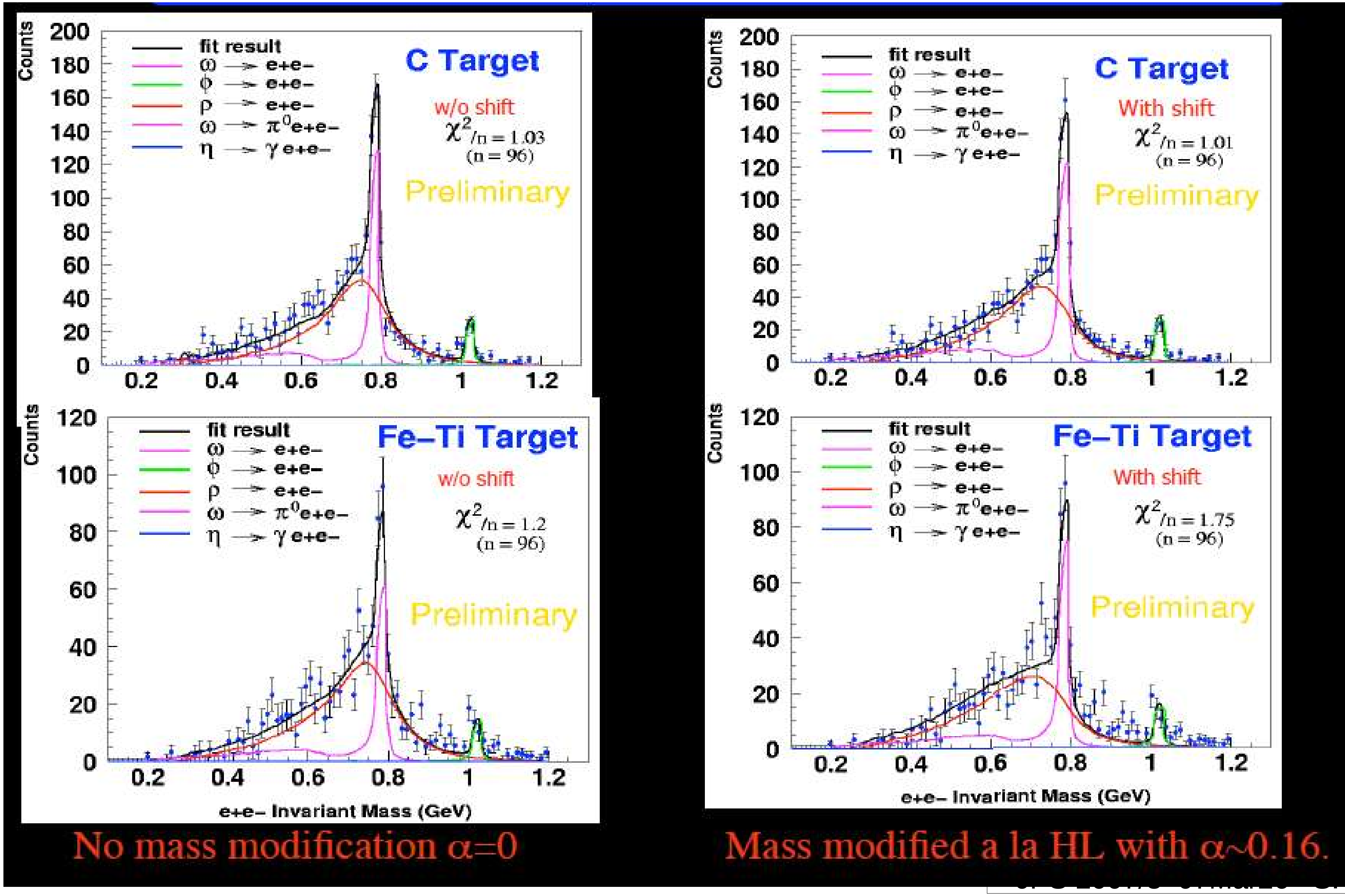






CLAS-G7 (preliminary , QM2006 etc.)

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

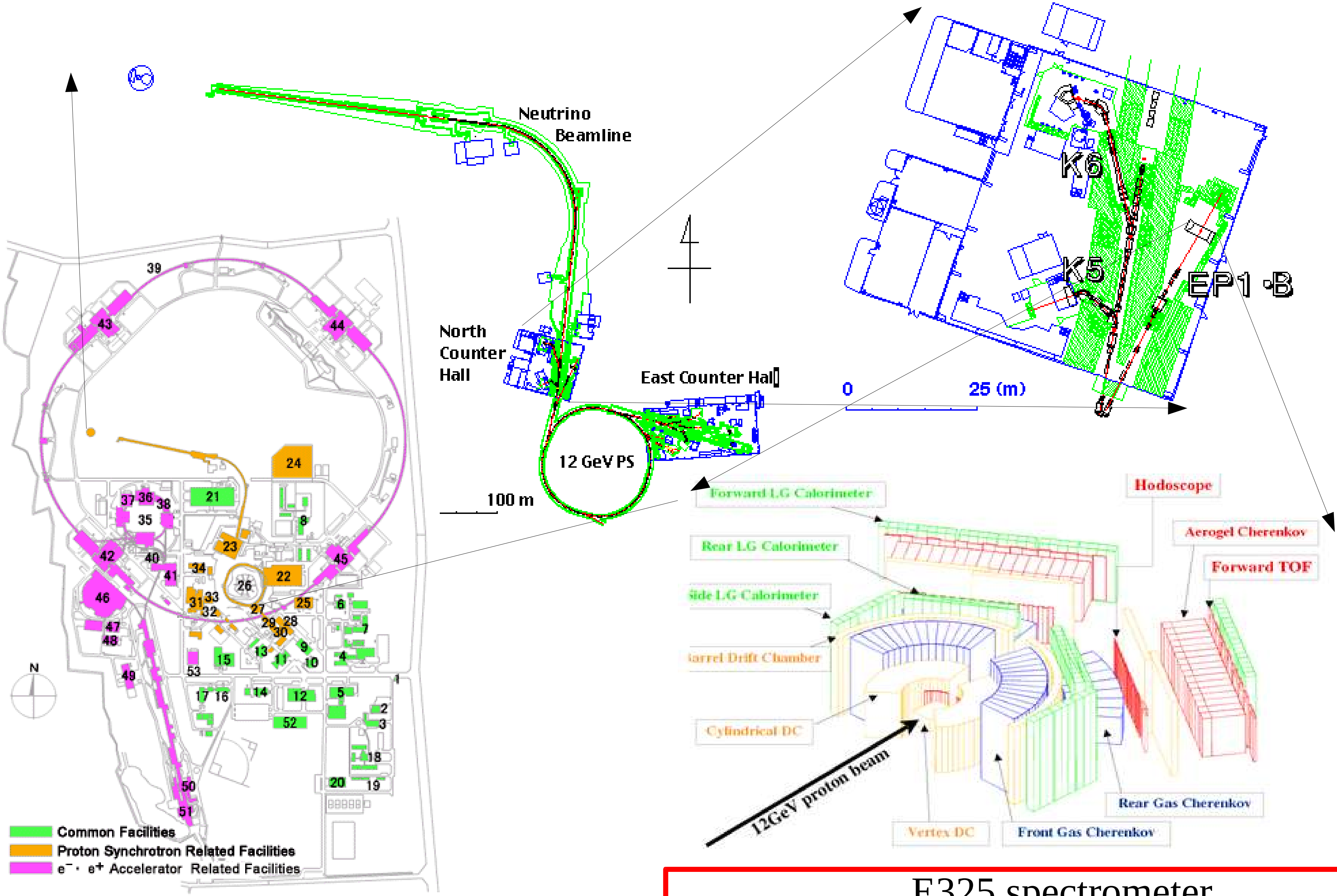


Experiment KEK-PS E325

- 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.)

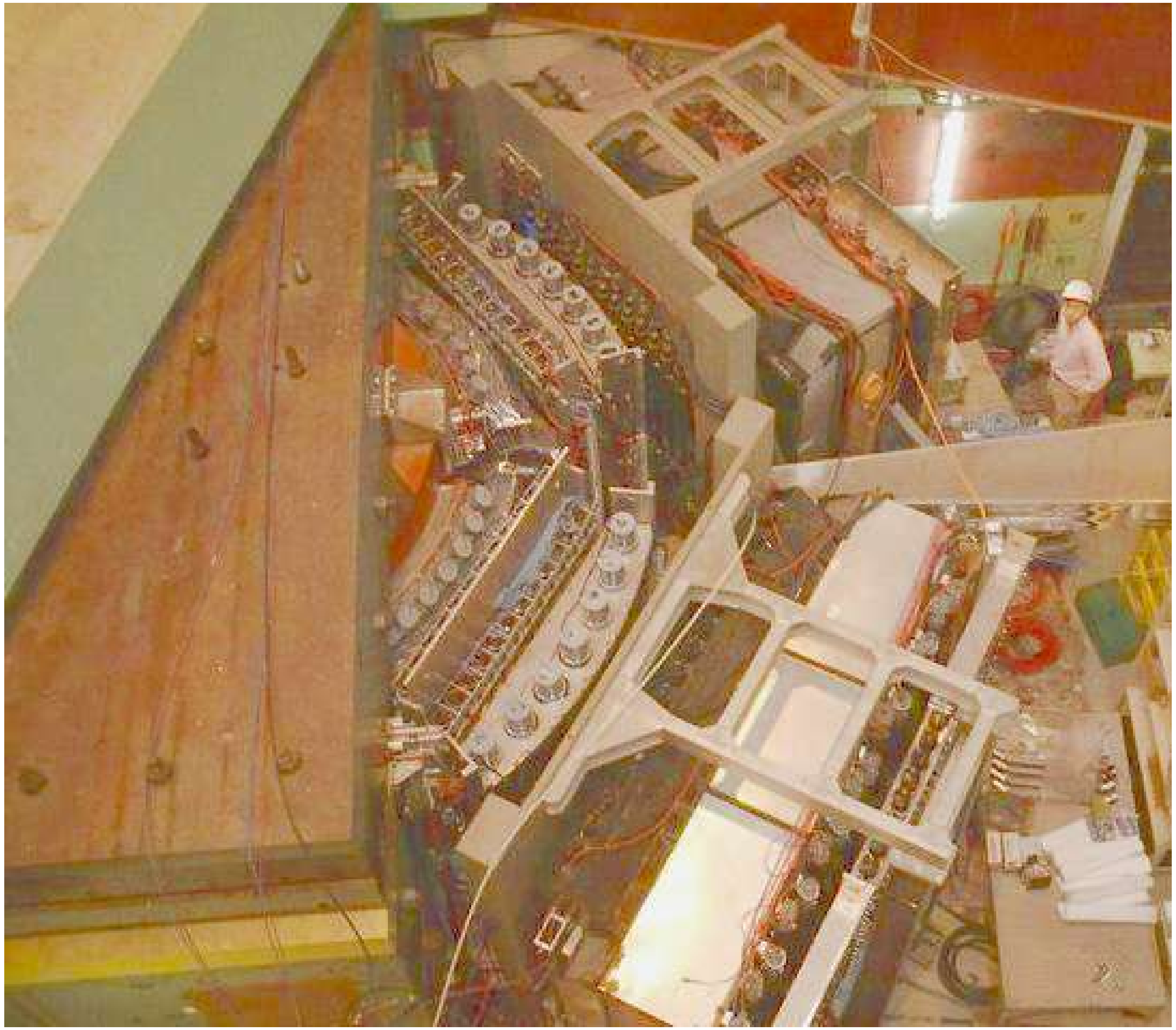


E325 spectrometer
located at KEK-PS EP1-B primary beam line

(Cont'd)

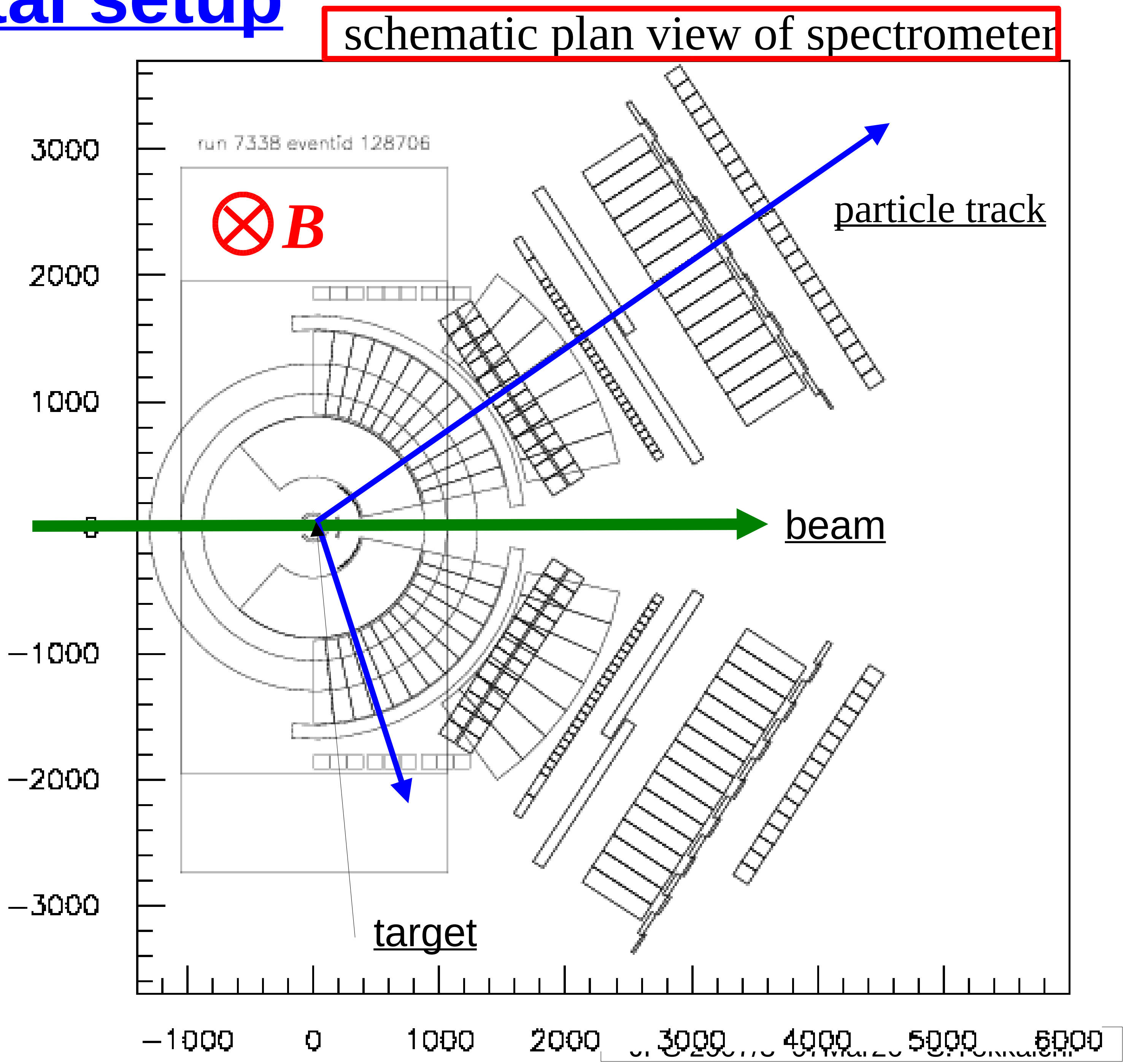
- History of E325
  - 1993 proposed
  - 1996 const. start
  - '97 data taking start
  - '98 first ee data
    - PRL86(01)5019
  - 99,00,01,02....
    - x100 statistics
      - PRL96(06)092301
      - PRL98(07)042501
      - PRC74(06)025201
      - nucl-ex/0606029(to be published in PRL)
  - '02 completed
    - NIM A516(04)390

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

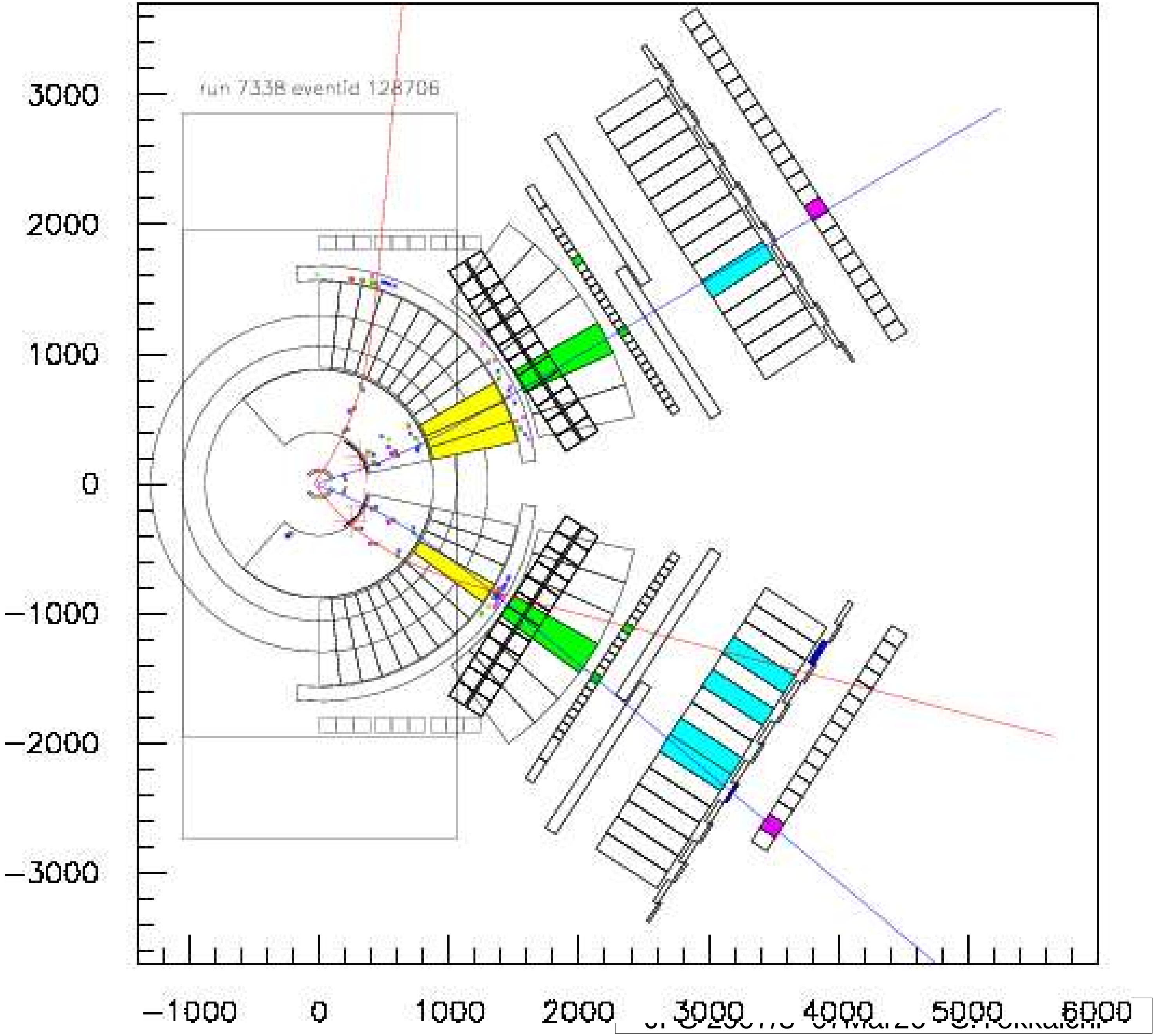


Experimental setup

- 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

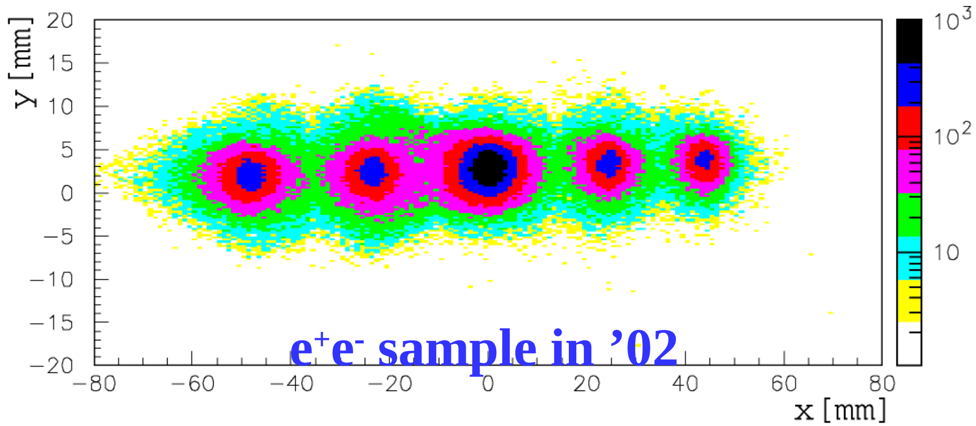


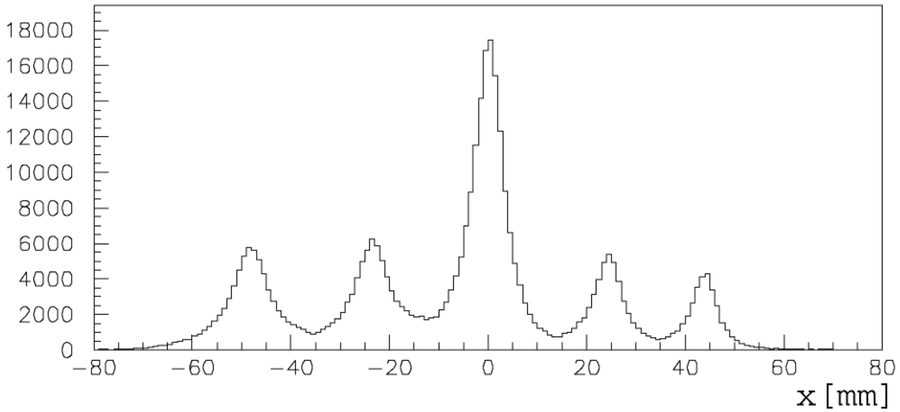
- Typical e^+e^- Event
  - blue:electron
  - red : other
  - invariant mass and momentum of mother particle can be calculated



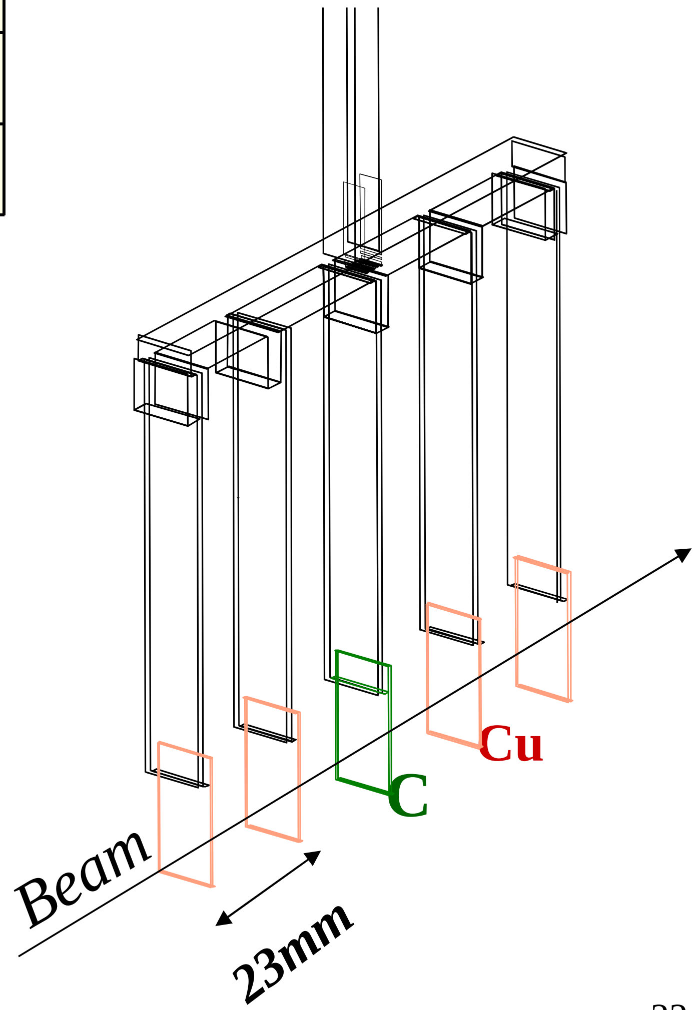
Experimental setup - targets

material	beam intensity (p/spill)	Interaction length(%)	radiation length(%)
C	~1x10⁹	0.2%	0.4%
Cu X 4	~1x10⁹	0.05%X4	0.6%X4



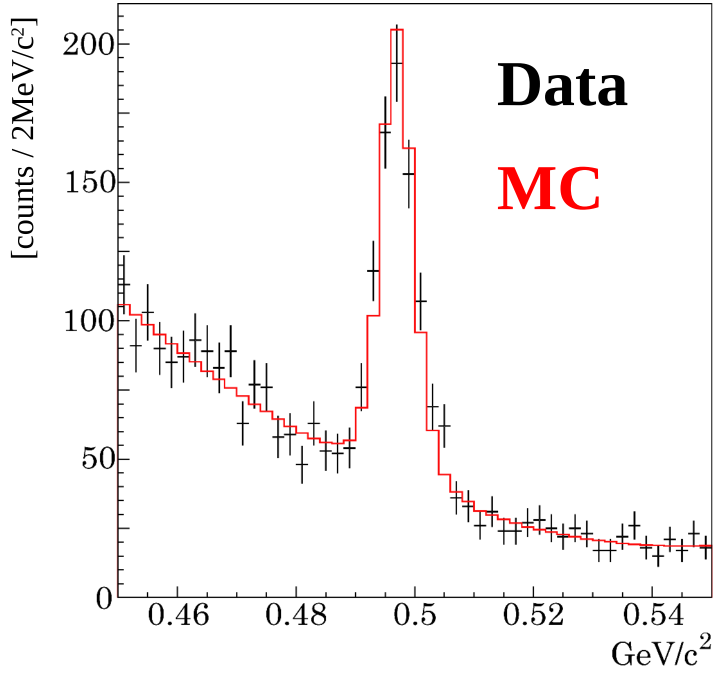


targets in 2002

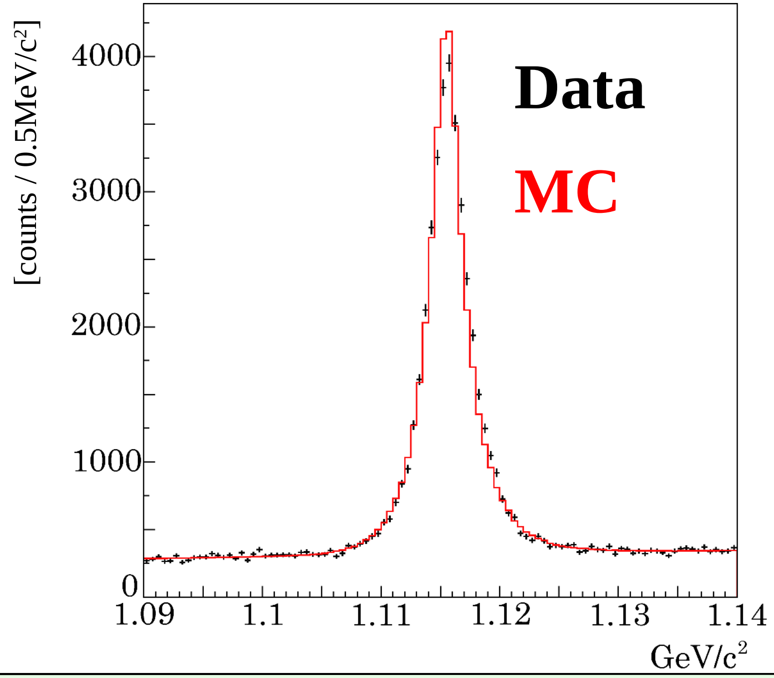


Spectrometer performance

$K^0_s \rightarrow \pi^+\pi^-$



$\Lambda \rightarrow p\pi^-$



M = 496.8±0.2 (MC 496.9) MeV/c²

= 3.9±0.4 (MC 3.5) MeV/c²

M = 1115.71±0.02 (MC 1115.52) MeV/c²

= 1.73±0.04 (MC 1.63) MeV/c²

mass resolution for ϕ-meson decays

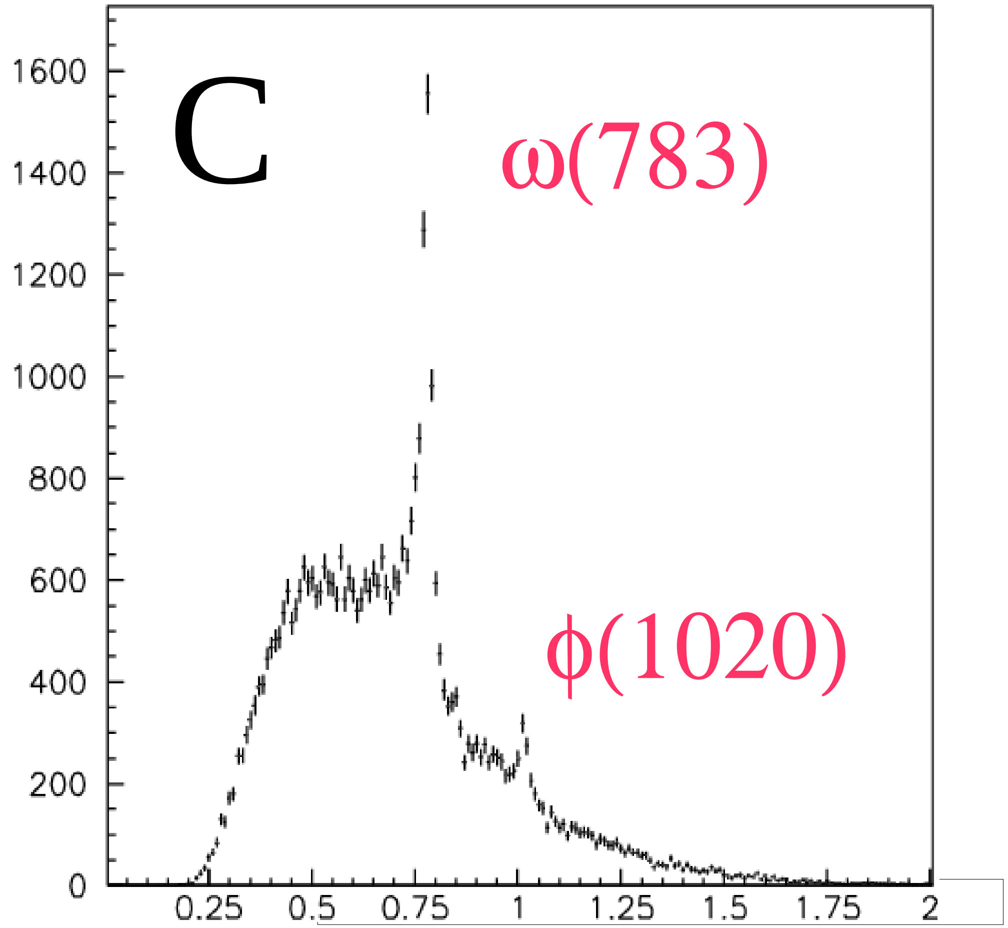
$\phi \rightarrow e^+e^-$: 10.7 MeV/c²

$\phi \rightarrow K^+K^-$: 2.1 MeV/c²

E325 Results (1)

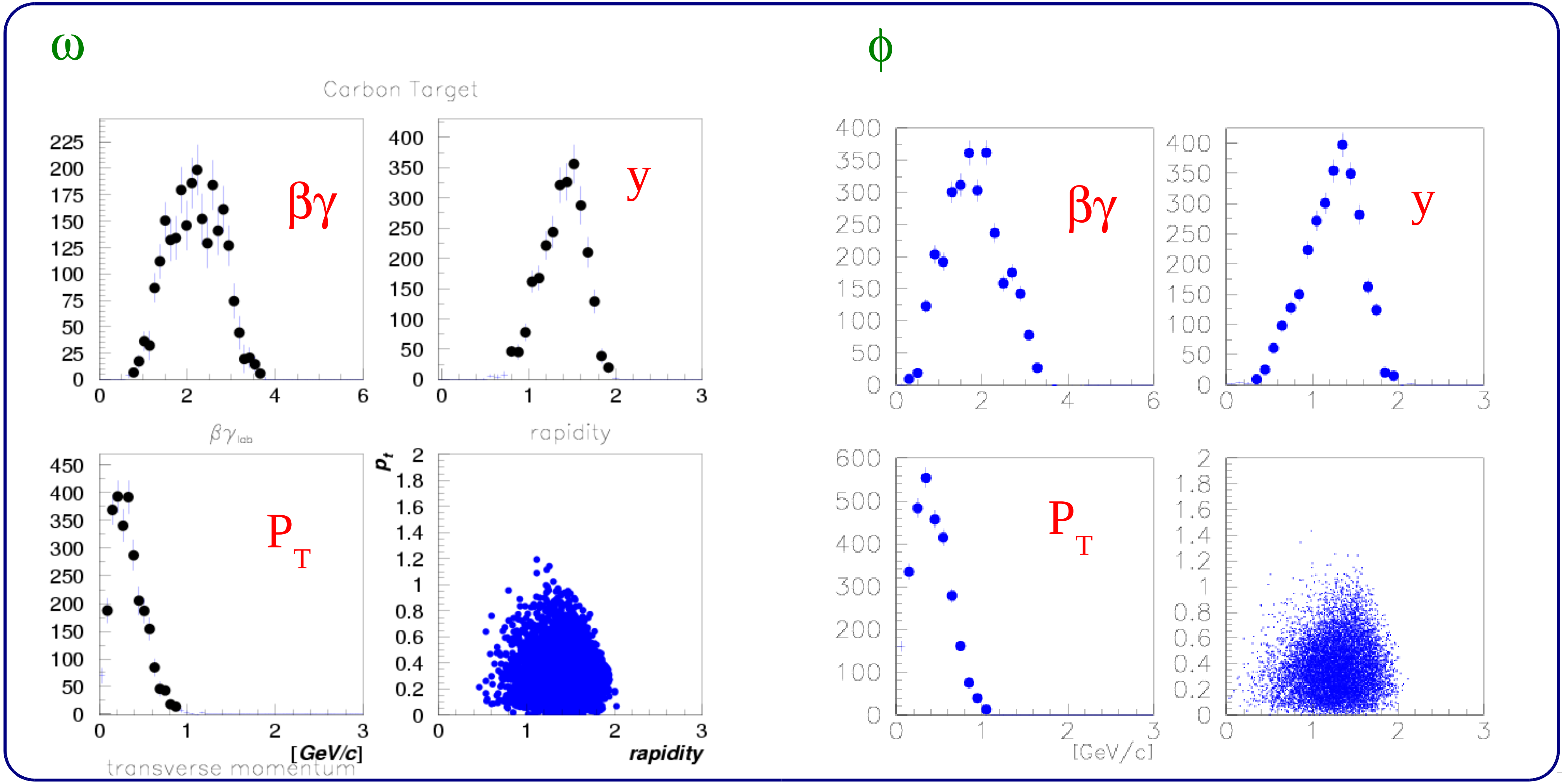
ee invariant mass spectra

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



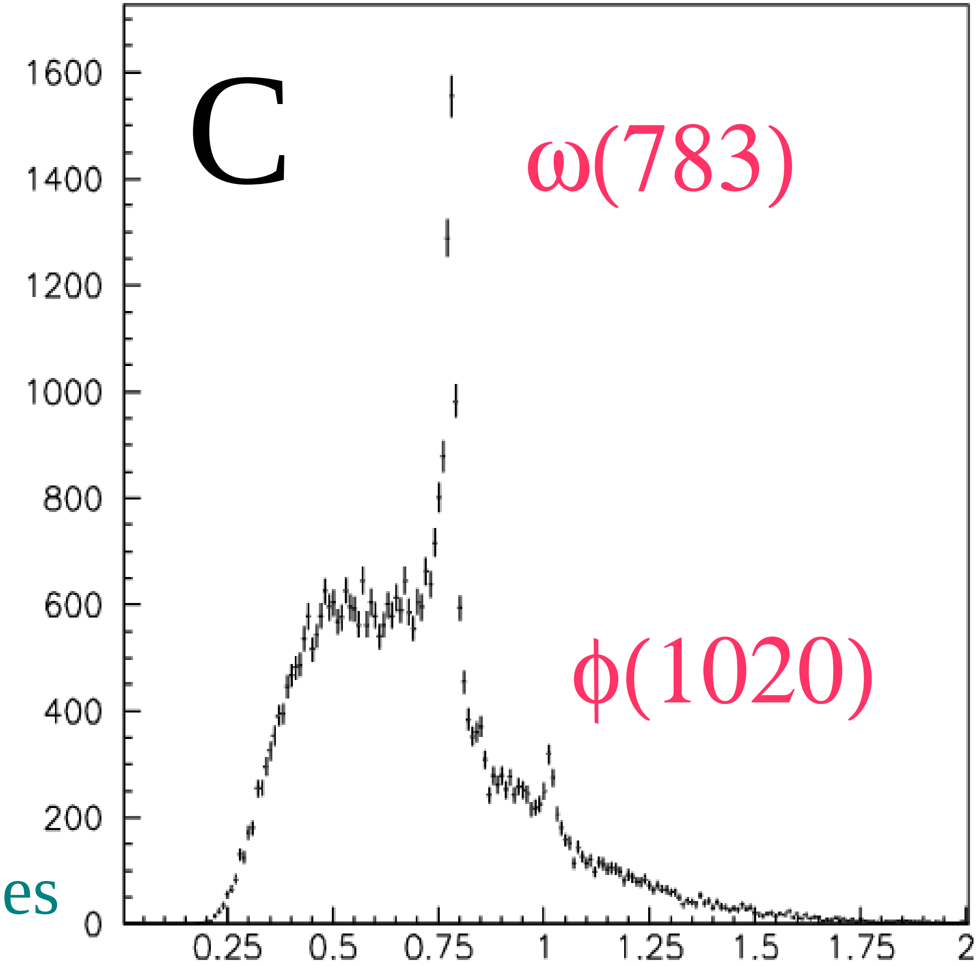
measured kinematic distribution of ω/φ → e^+e^-

- $0 < P_T < 1$, $0.5 < y < 2$ (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

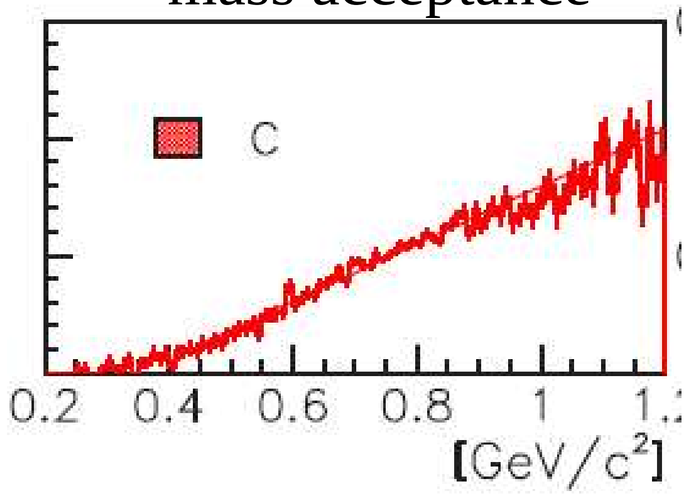


→ fit the spectra with known sources

Fitting with known sources

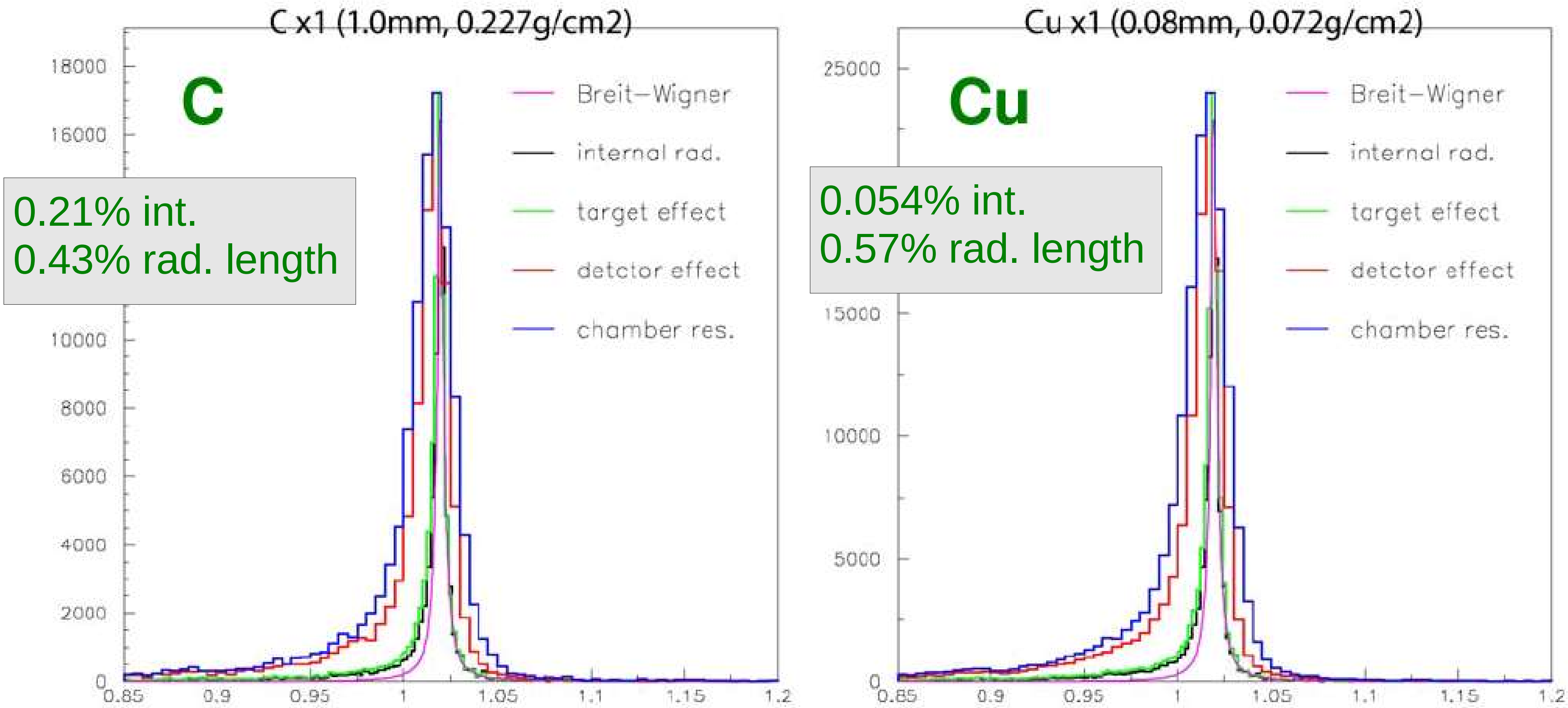
- Hadronic sources of e^+e^-:
  - $\rho/\omega/\phi \rightarrow e^+e^-$, $\omega \rightarrow \pi^0 e^+e^-$,
    $\eta \rightarrow \gamma e^+e^-$
  - relativistic Breit-Wigner shape
    (without any modifications, but internal radiative corrections are included)
  - Geant4 detector simulation
    - multiple 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

mass acceptance

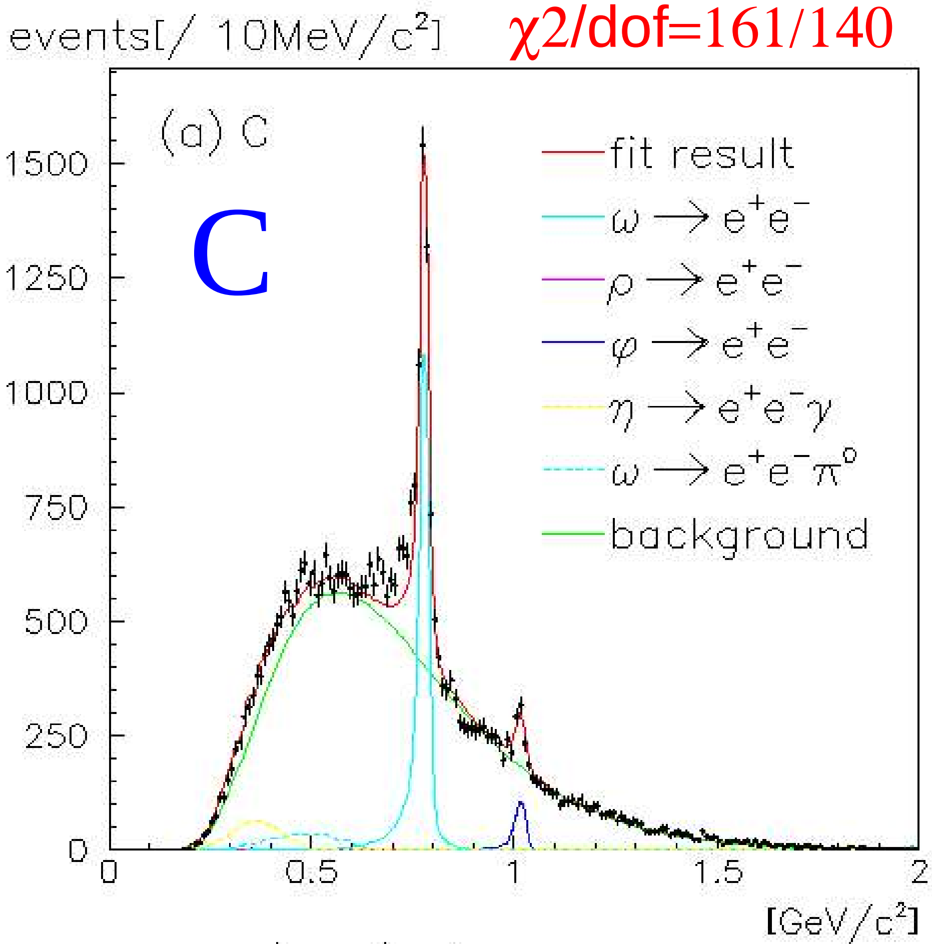


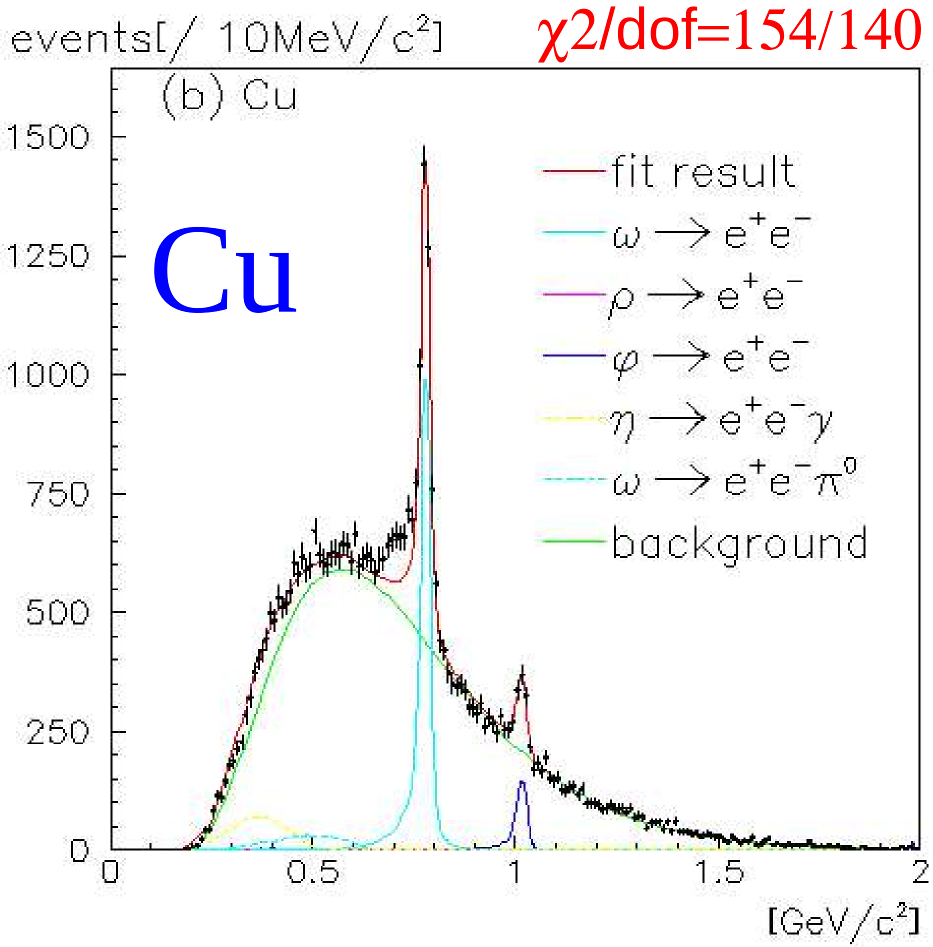
experimental effects on the resonance shape

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



Fitting results

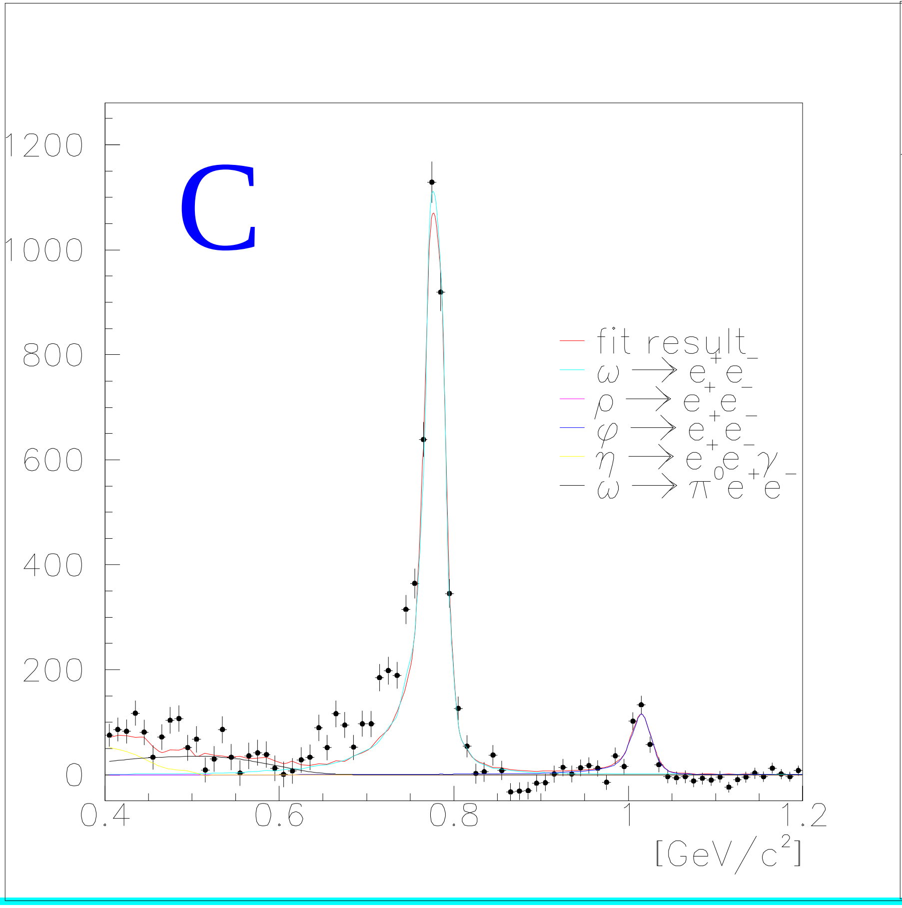


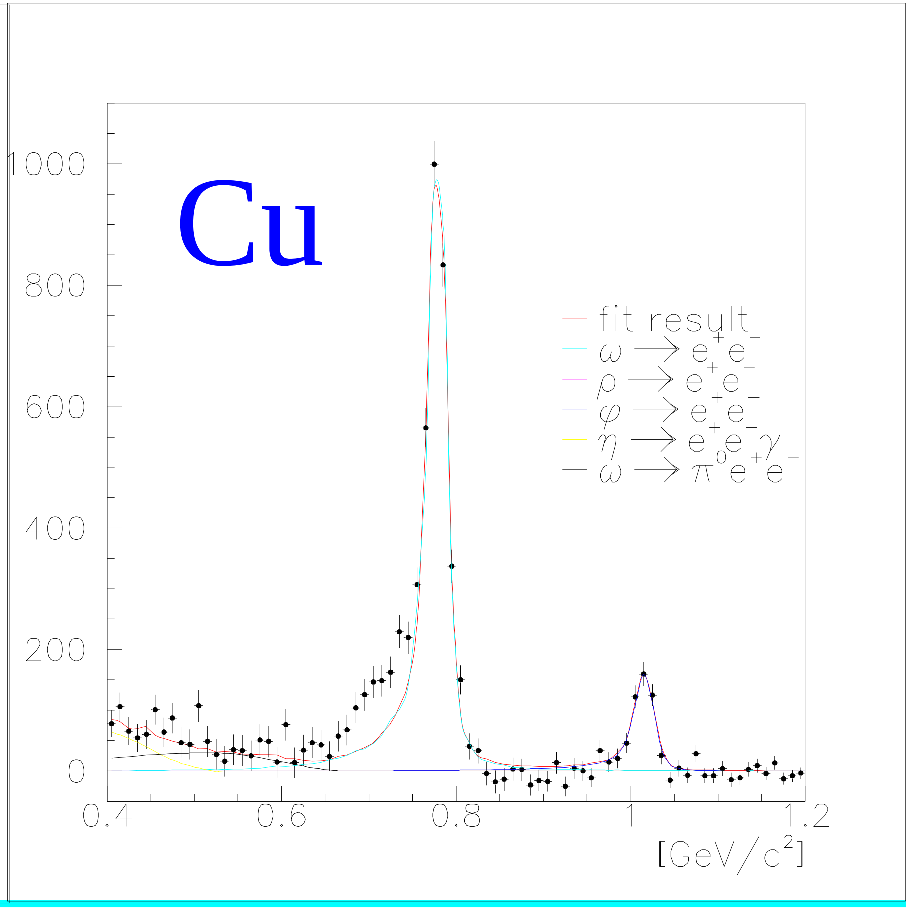


- 1) excess at the low-mass side of ω
  - To reproduce the data by the fitting, we have to exclude the excess region : 0.60~0.76 GeV
- 2) ρ–meson component seems to be vanished !

Fitting results (BKG subtracted)

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

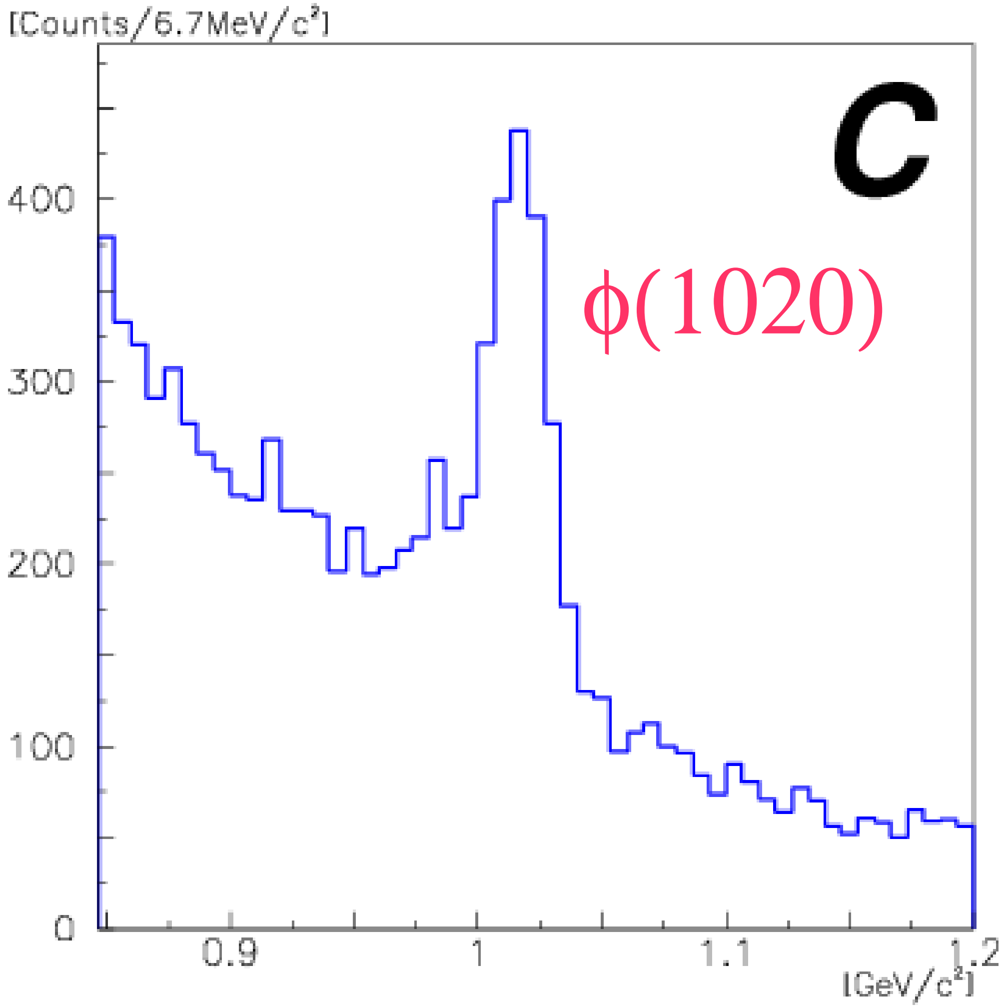




- However, ρ/ω =1.0±0.2 in former experiment (p+p, 1974)
  ...suggests that the origin of excess is modified ρ mesons.

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



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

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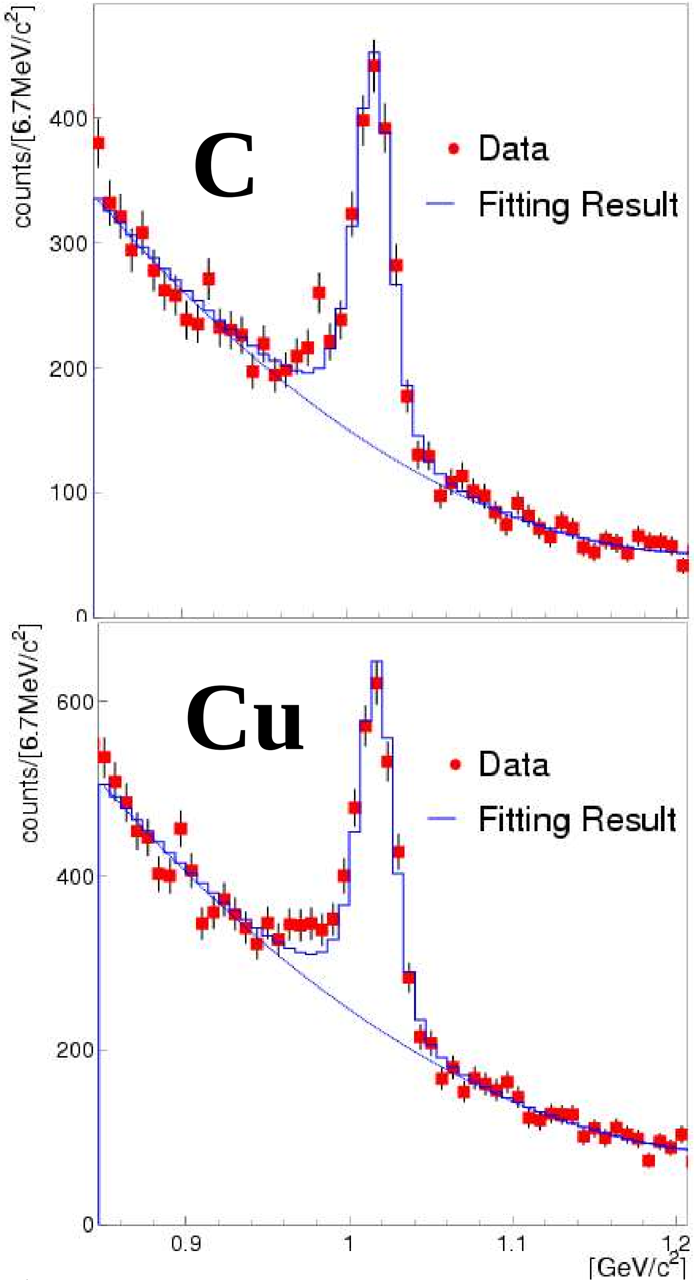
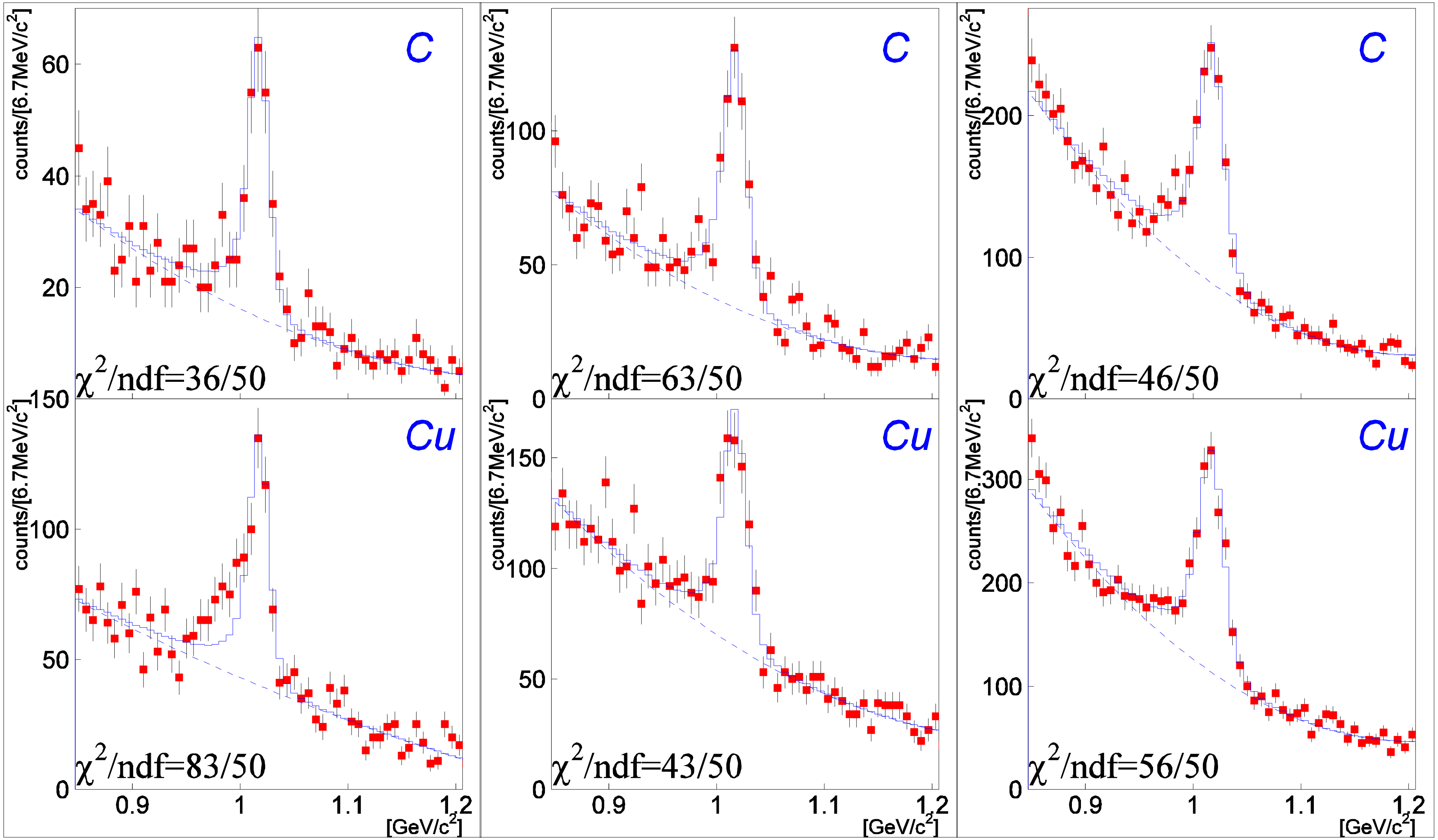
- C & Cu target
- acceptance uncorrected
- mass resolution :10.7MeV
- fit with
  - simulated mass shape of ϕ
    - (evaluated as same as ρ&ω)
  - polynomial curve background
- examine the 'excess' is significant or not.
  - $\rightarrow$ see the $\beta\gamma$ dependence : excess could be enhanced for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



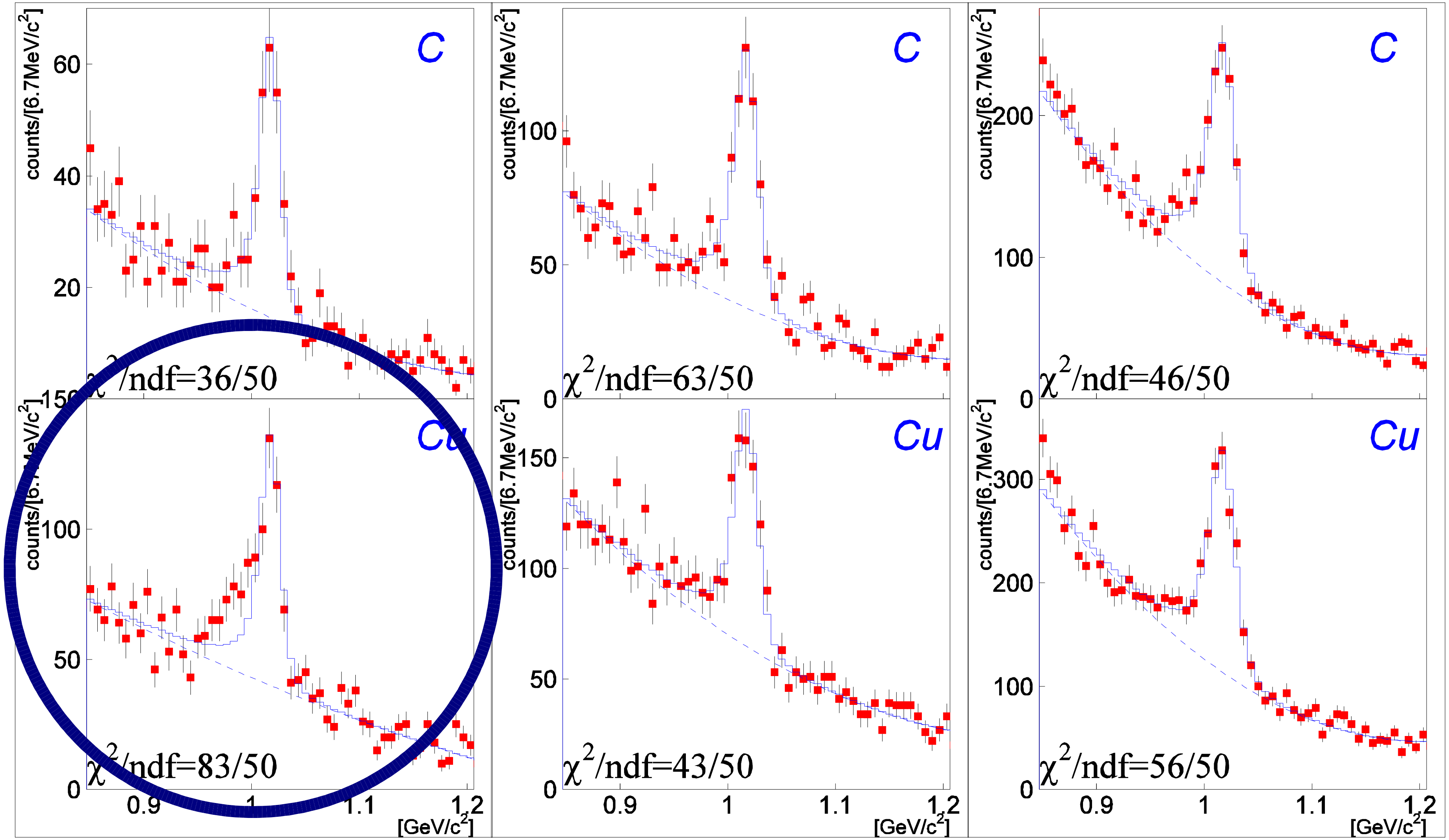
e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

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



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

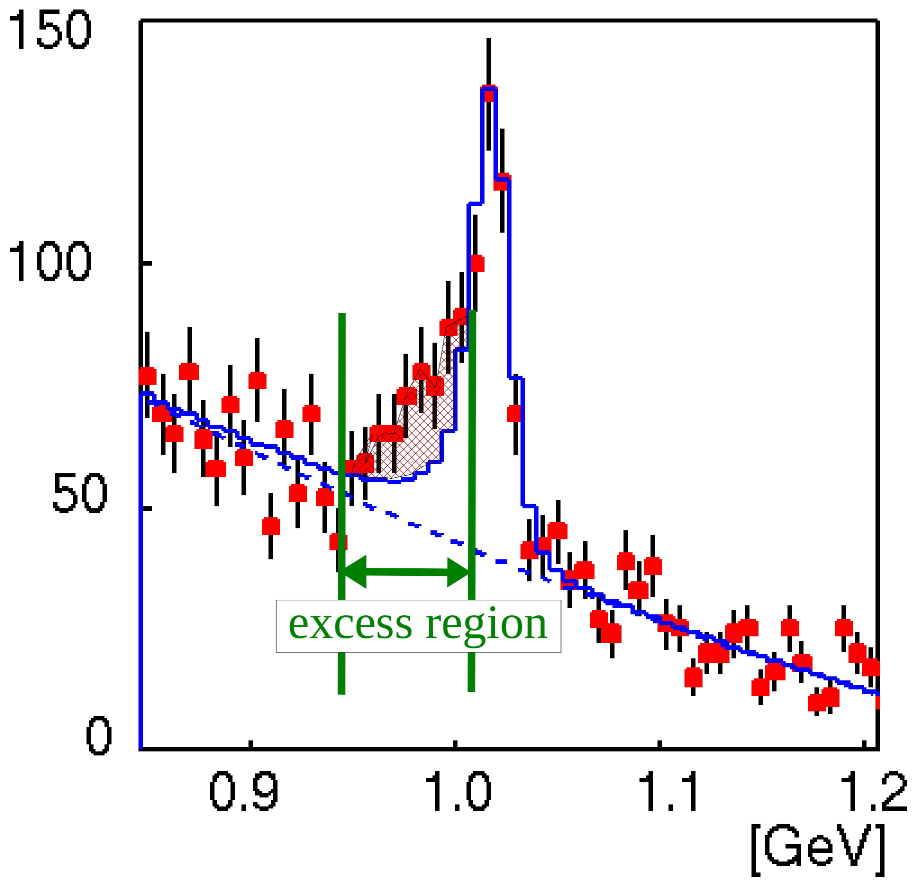
$\beta\gamma$<1.25 (Slow) | 1.25<$\beta\gamma$<1.75 | 1.75<$\beta\gamma$ (Fast)



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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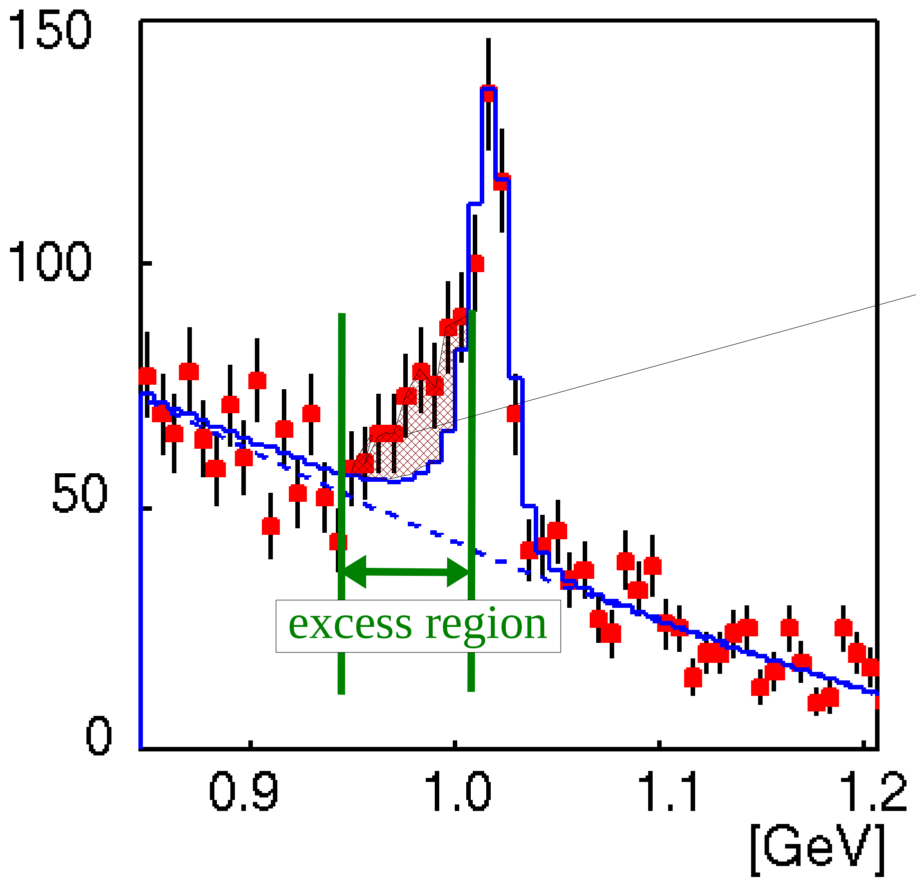
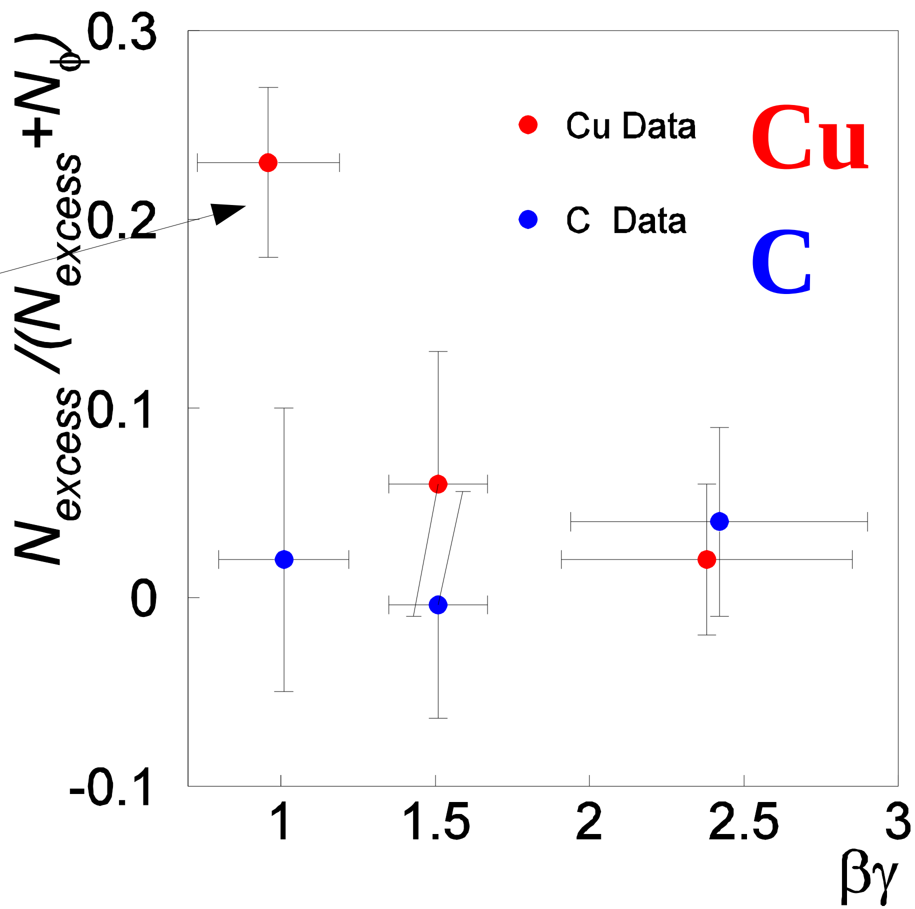
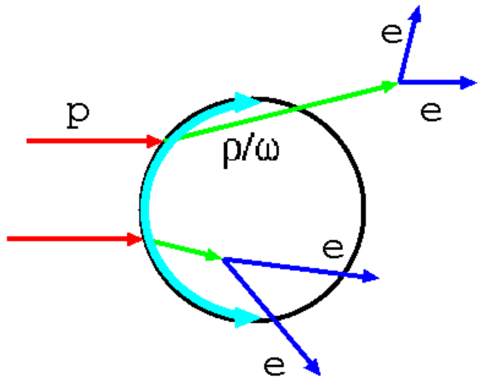




Discussion : fit with modification

- 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)

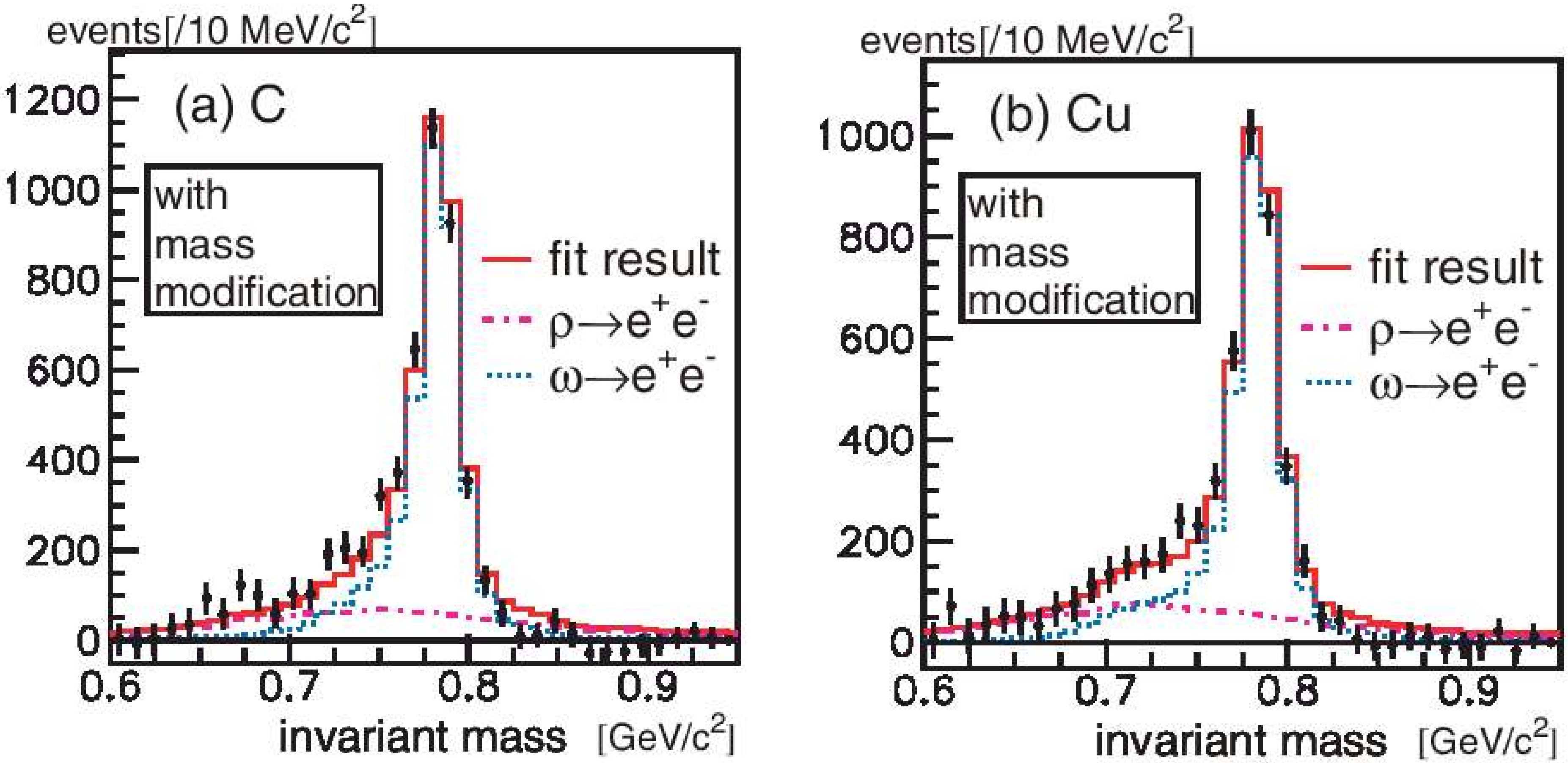


	ρ, ω	ϕ
m*/m	**$1 - k_1^{\rho/\omega} \rho/\rho_0$**	**$1 - k_1^{\phi} \rho/\rho_0$**
Γ*/Γ	**1**	**$1 + k_2 \rho/\rho_0$**
generation point	surface	uniform
α ($\sigma(A) \propto A^{\alpha}$) [PRC74(06)025201]	0.710±0.021	0.937±0.049
momentum dist.	measured	
density distribution	Woods-Saxon, R= C:2.3fm/Cu:4.1fm	

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

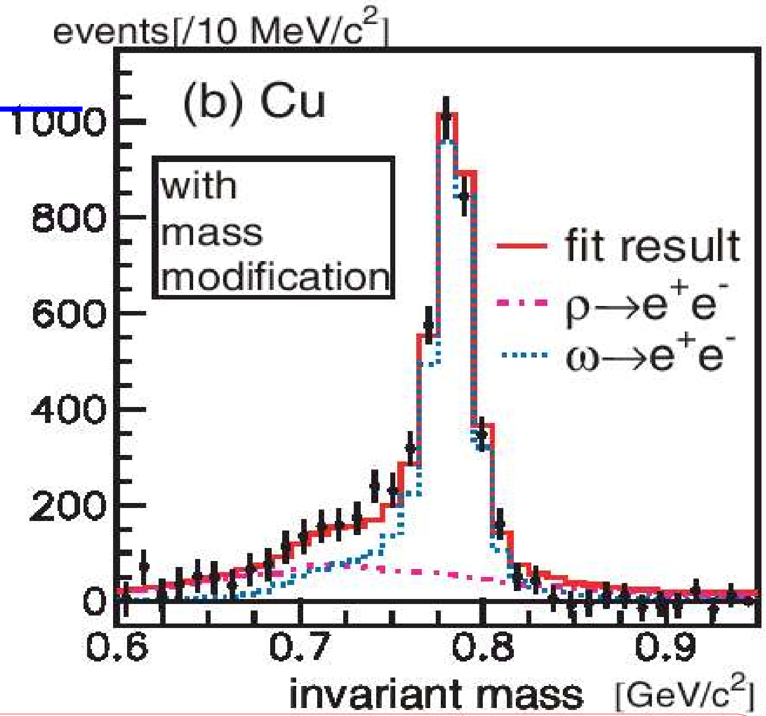


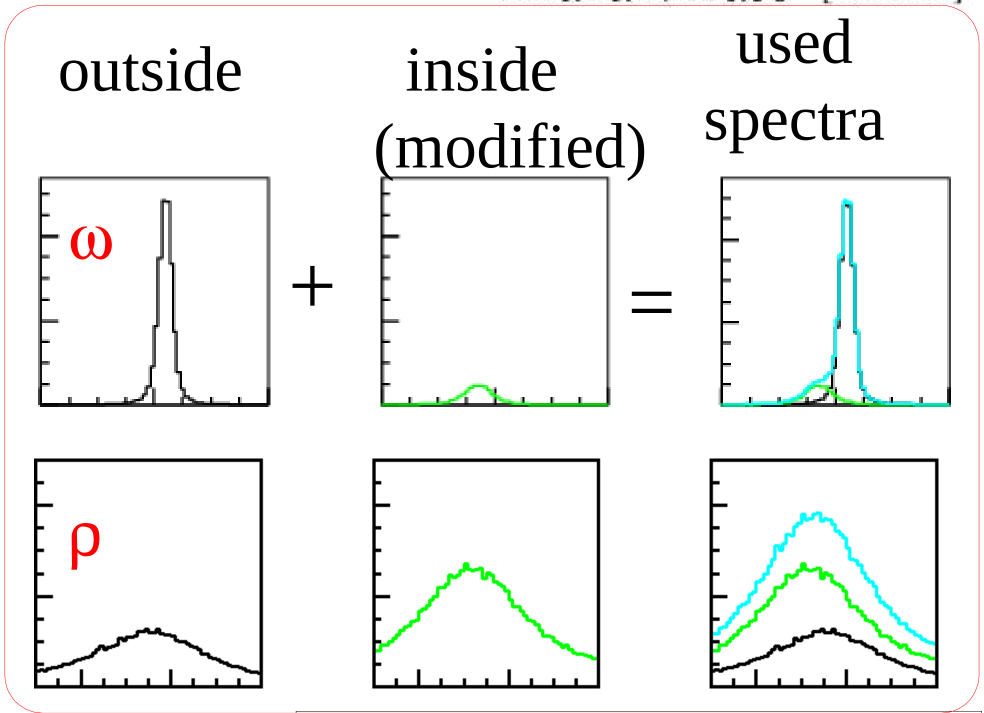
From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density

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

Remark on the model fitting

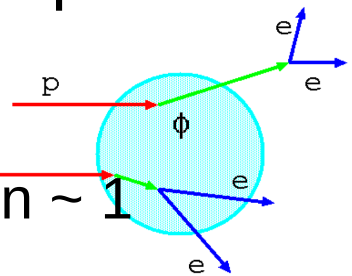
- constraint at right side of peak
  - Introducing the width broadening (x2 & x3) are rejected by this constraint
  - prediction of ' ρ mass increasing' is also not allowed.
- ρ (ω) decay inside nucleus : 46%(5%) for C, 61%(10%) for Cu
  - used spectrum is the sum of the modified and not-modified components.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





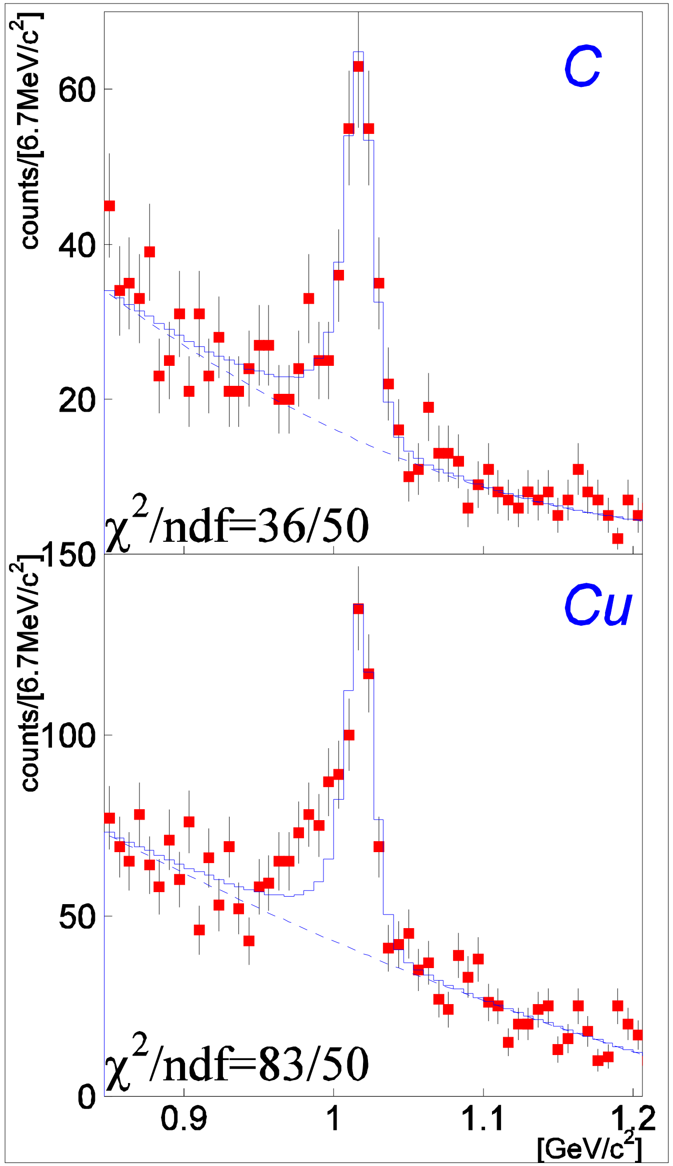
Toy model again for ϕ meson

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

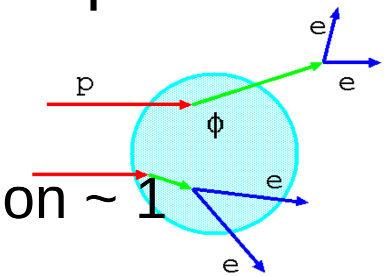
$\beta\gamma$<1.25 (Slow) k_1=0,k_2=0



Toy model again for ϕ meson

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

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



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

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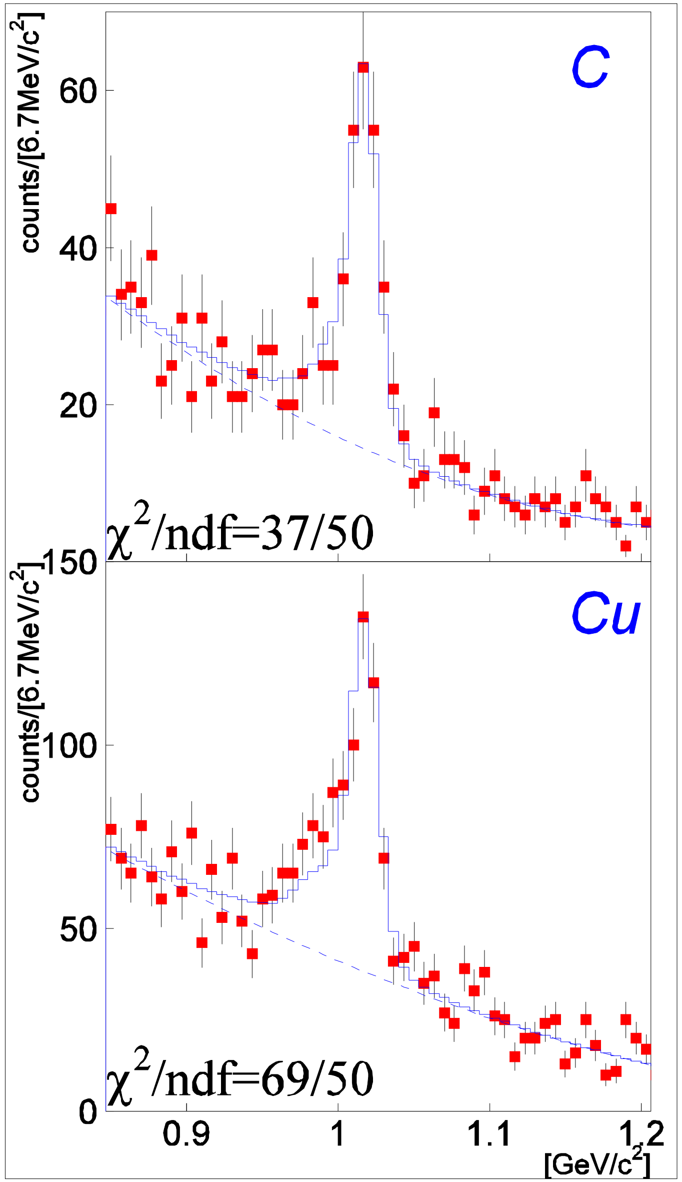
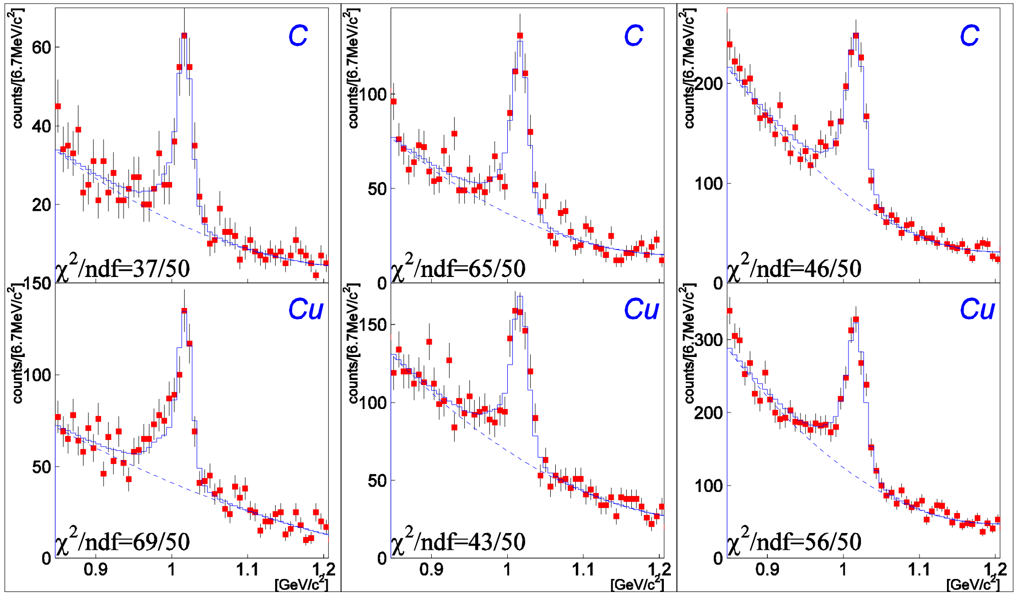
    - fits were done with many combinations of (k_1 , k_2) and data were well reproduced



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

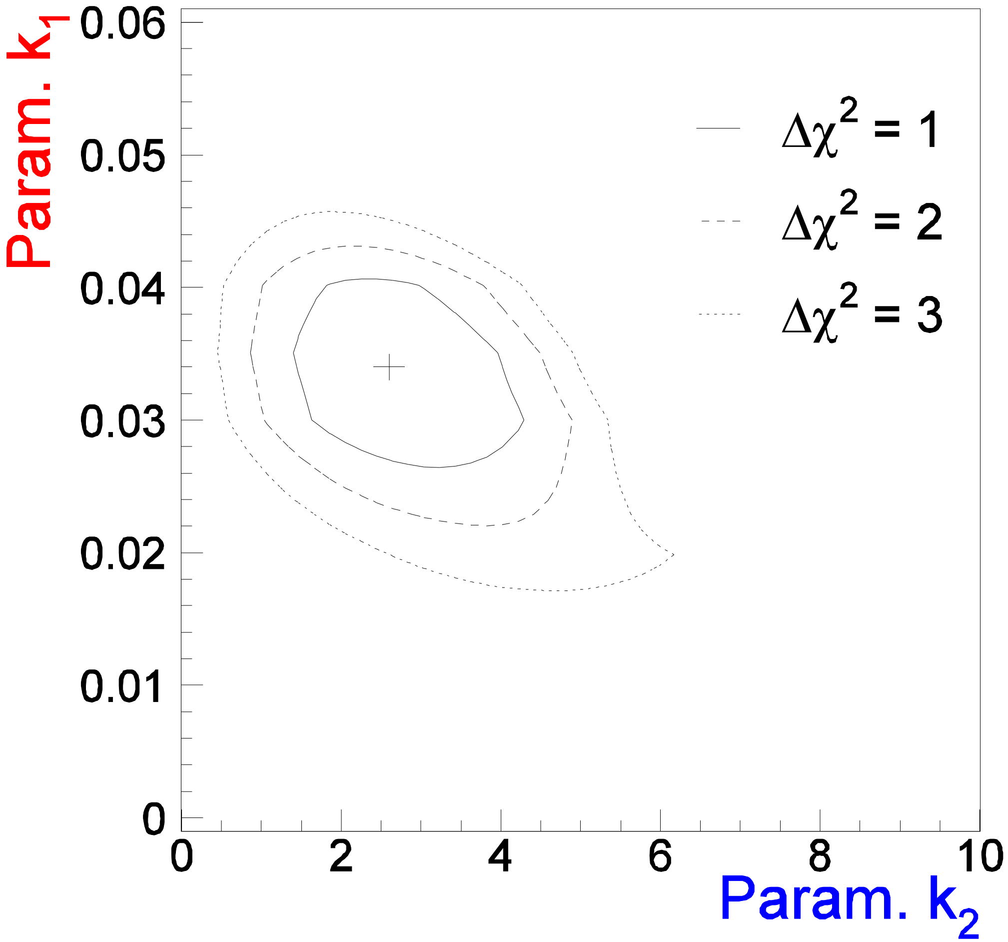
- To determine the shift parameters...
  - $m^*/m_0 = 1 - k_1\ \rho/\rho_0$
  - $\Gamma_{tot}^*/\Gamma^0_{tot} = 1 + k_2\ \rho/\rho_0$
- We fit the observed 6 mass spectra (C/Cu, slow/mid/fast) with modified MC shapes and calculate the χ^2 as the sum of 6 spectra for each (k_1,k_2) combination on the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

Best Fit Value:

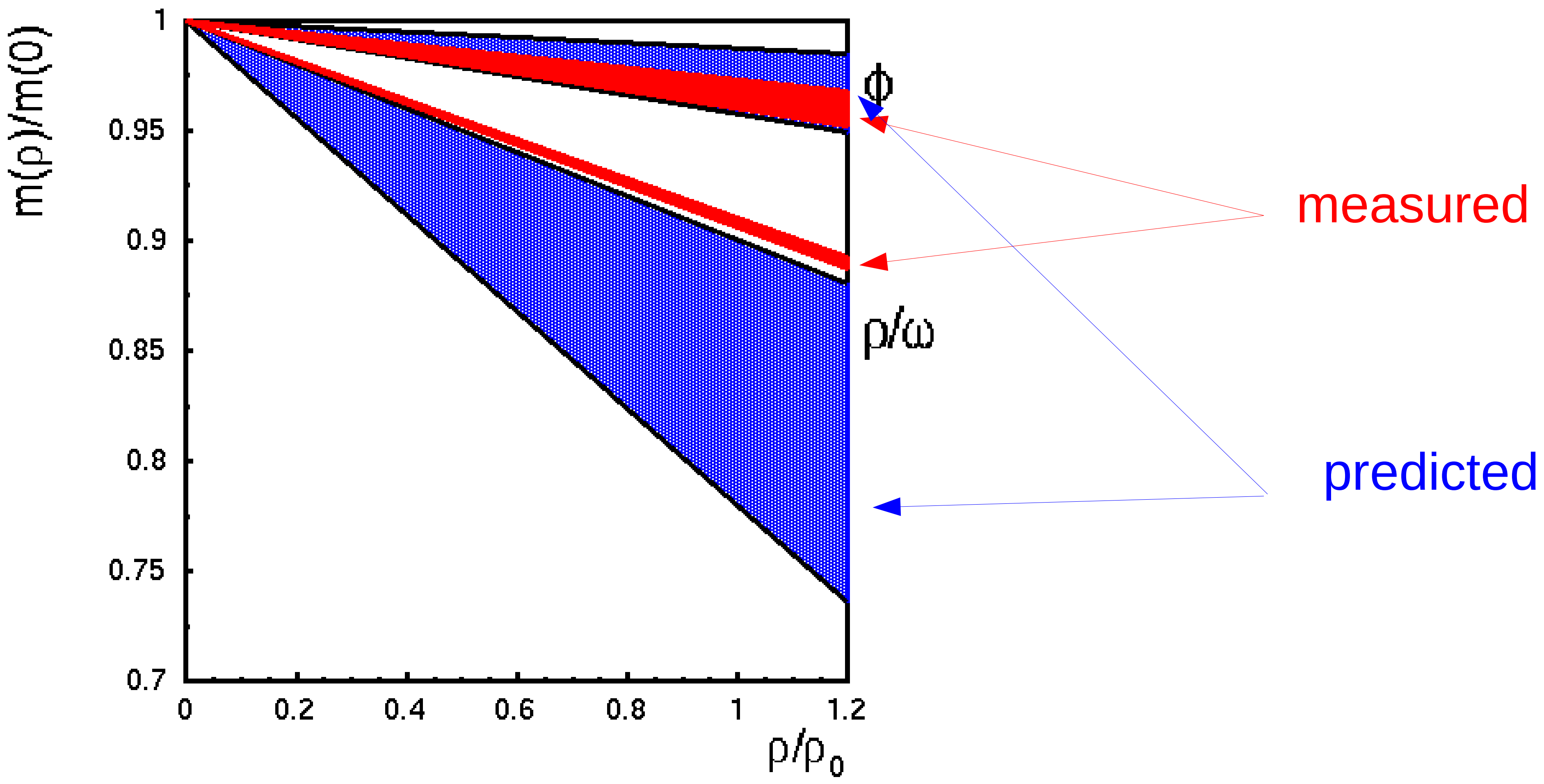
$$k_1 = 0.034^{+0.006}_{-0.007}$$

$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$

(3.6 times width broadening at ρ_0)



comparison w/ the prediction by HL

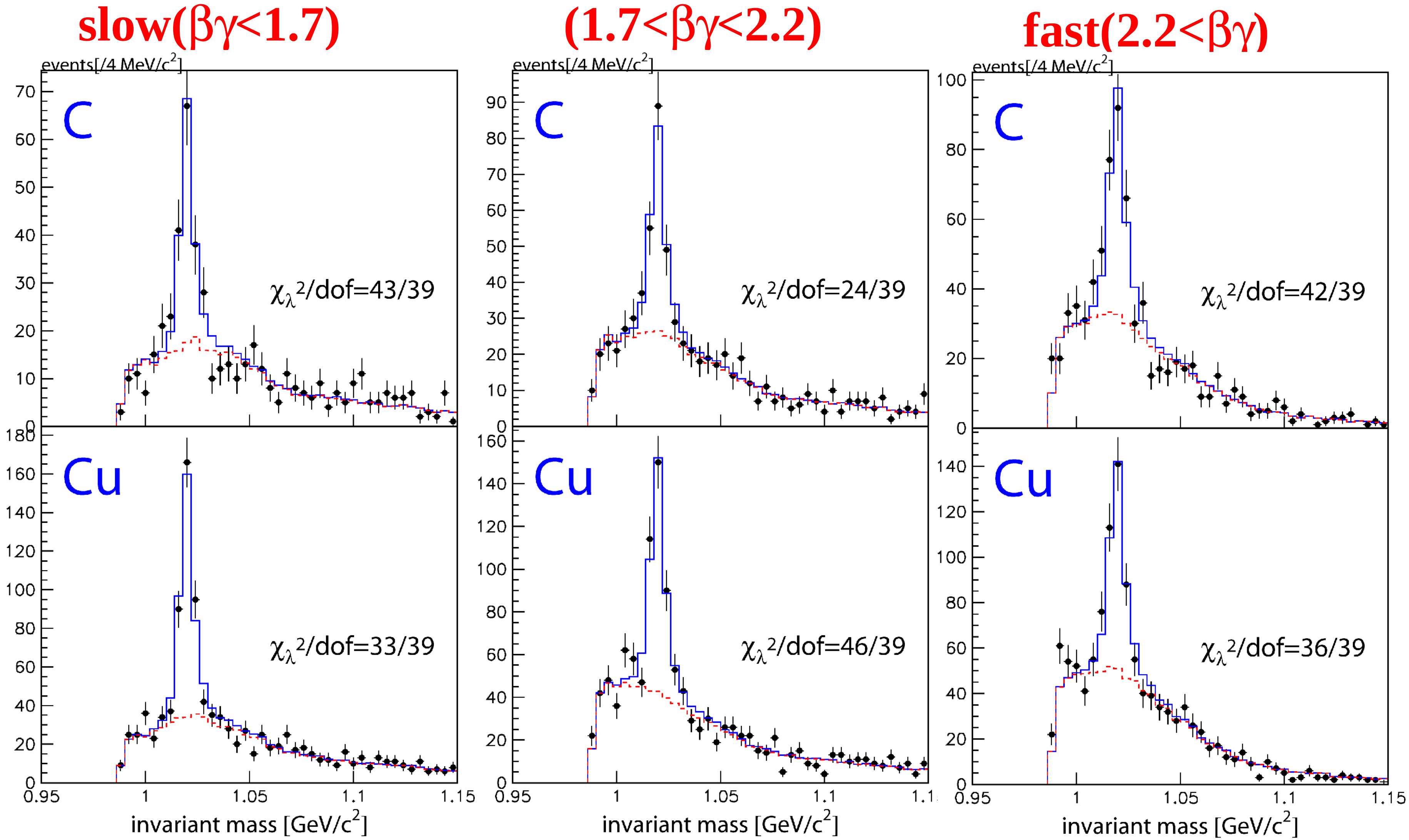


E325 Results (2)

KK invariant mass spectra

F. Sakuma et al., nucl-ex/0606029
(to be published in PRL)

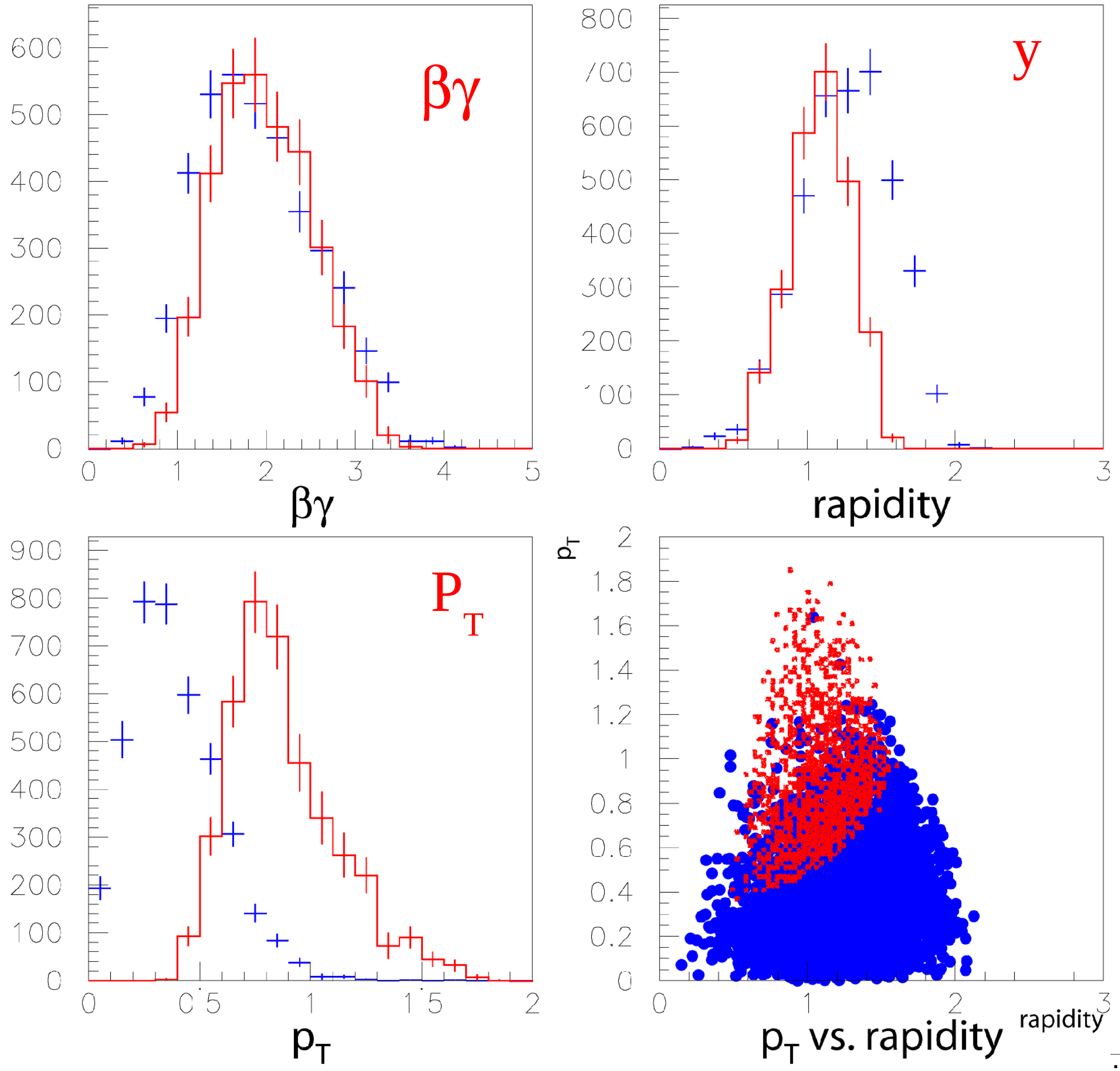
K^+K^- spectra of ϕ meson



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

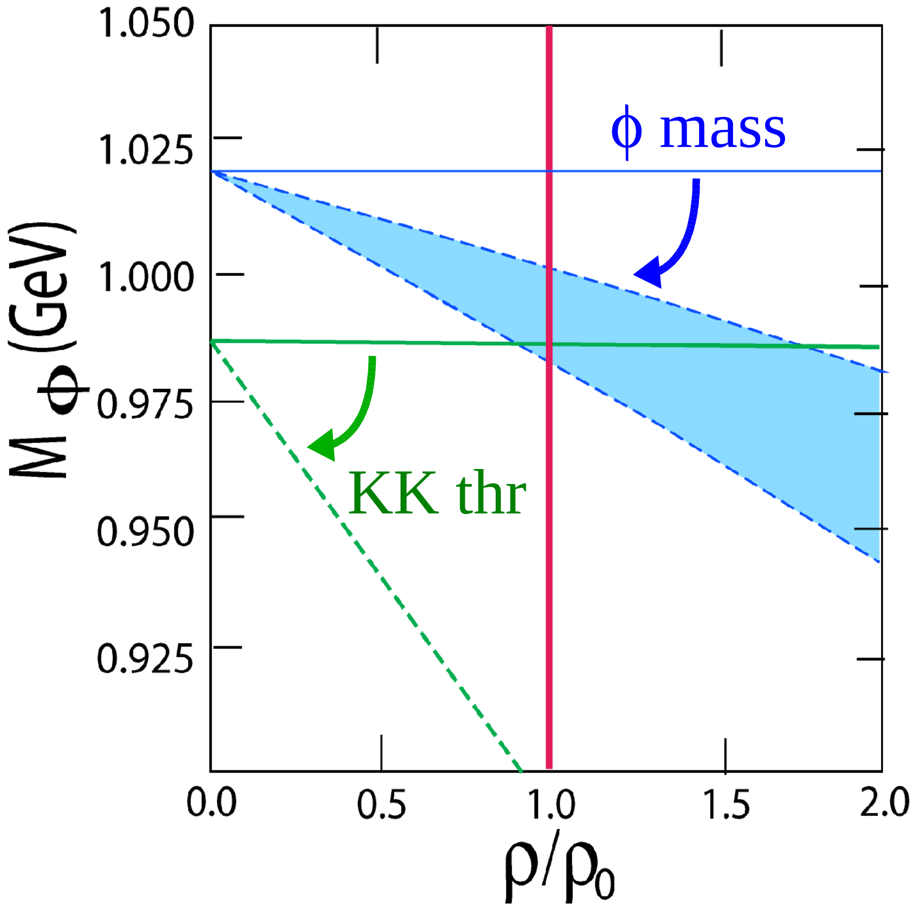
measured kinematic distribution of $\phi \rightarrow K^+K^-$ & $\phi \rightarrow e^+e^-$

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



mass modification and ϕ branching ratio

- small decay Q value (= 32MeV) for $\phi \to K^+K^-$
  - 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 $\phi \to K^+K^-$ & $\phi \to e^+e^-$ 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 and Γ : for example
  - $\Gamma_{K+K-} / \Gamma_{e+e-}$ increases in nuclei, N_{K+K-} / N_{e+e-} becomes larger
  - larger modification expected in larger nuclei
  - then, $\alpha_{K+K-} > \alpha_{e+e-}$, especially for slowly moving mesons
- ...looks such tendency but consistent within the errors

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

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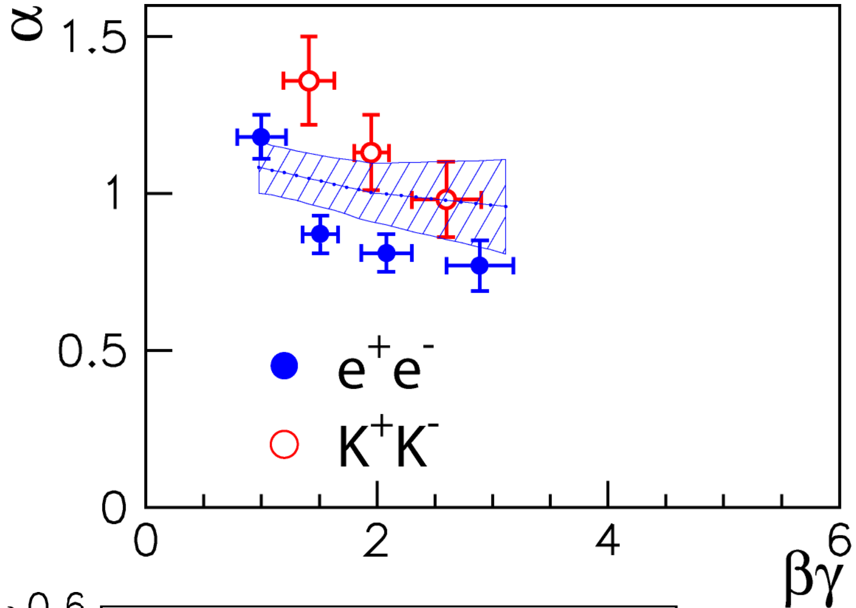
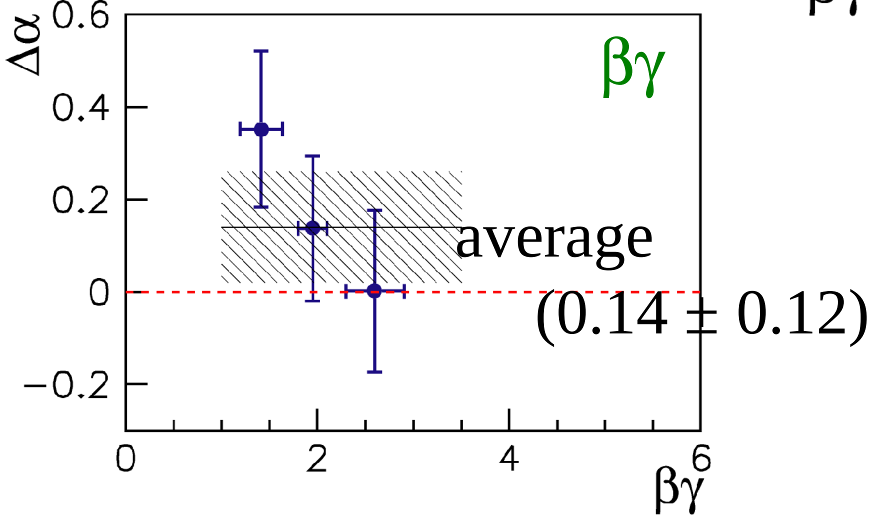
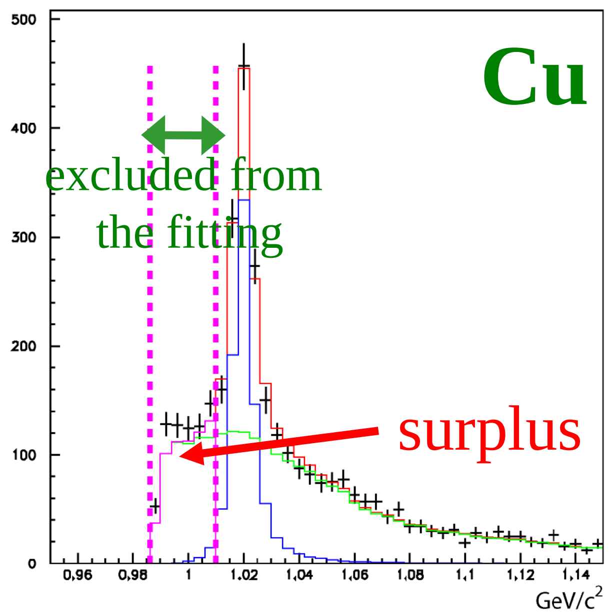
- α and Γ : for example
  - $\Gamma_{K+K-} / \Gamma_{e+e-}$ increases in nuclei, N_{K+K-} / N_{e+e-} becomes larger
  - larger modification expected in larger nuclei
  - then, $\alpha_{K+K-} > \alpha_{e+e-}$, especially for slowly moving mesons
- ...looks such tendency but consistent within the errors : $\alpha_{K+K-} - \alpha_{e+e-} = 0.14 \pm 0.12$

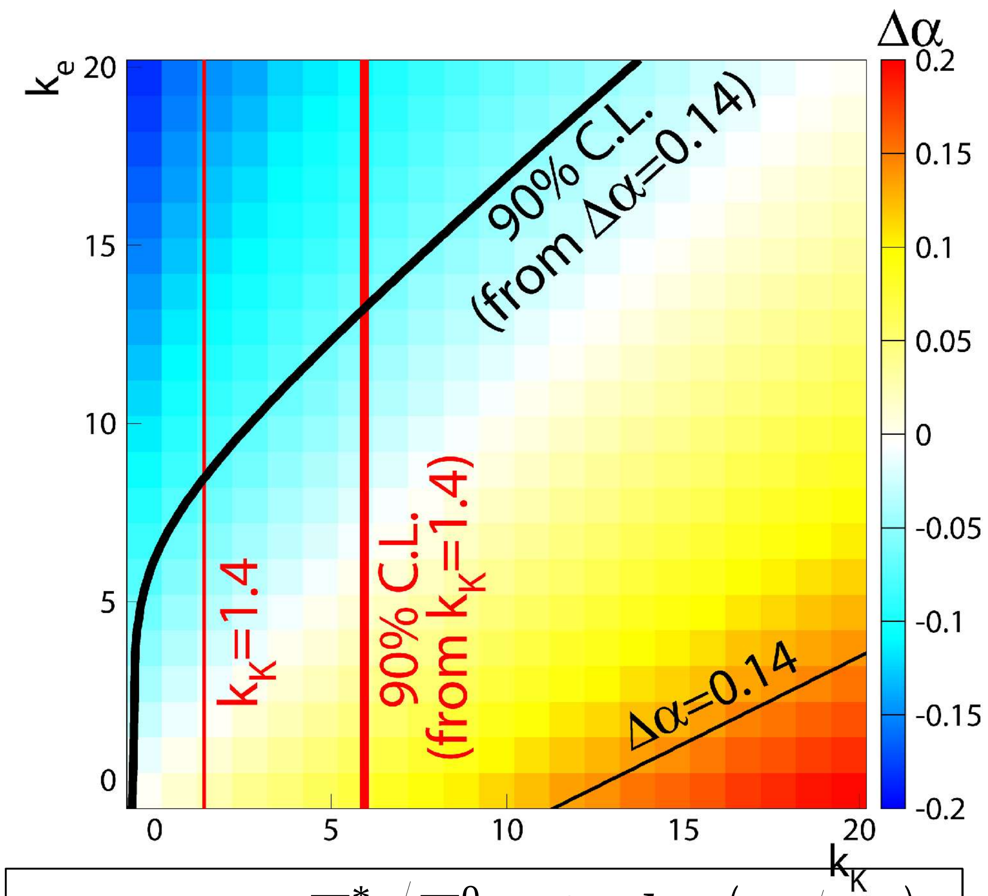




Limit to the ϕ width broadening

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





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

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.
- $\phi \to e^+e^-$ 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. Limit to the width broadening is set.

Summary Table (V.Metag, QM2006)

	KEK	Jlab	CBELSA/TAPS	CERES	NA 60
ω	–	–	mass shift: -14% $\Gamma_\omega(\rho=\rho_0)\approx100$MeV	–	–
ρ	mass shift: -9% no broadening	no mass shift some broadening	–	broadening favored over density dependent mass shift	no mass shift strong broadening
Φ	mass shift: -4% $\Gamma_\phi(\rho_0)=47$MeV	–	–	–	–

Summary Table (SY)

E325 CLAS-G7

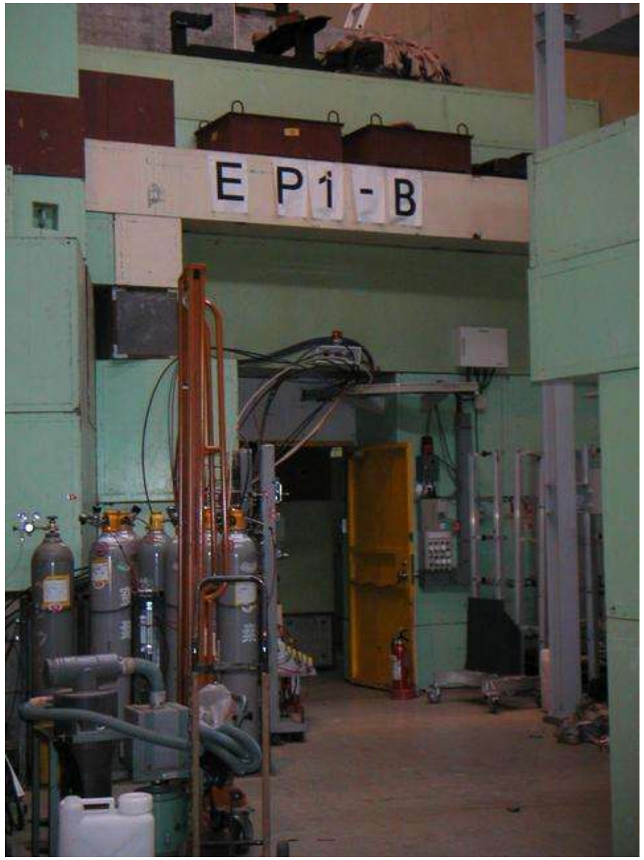
	KEK	Jlab	CBELSA/TAPS	CERES	NA 60
ω		–	mass shift: -14% $\Gamma_\omega(\rho=\rho_0)\approx 100$MeV	–	–
ρ	mass shift: -9% no broadening	no mass shift some broadening	–	broadening favored over density dependent mass shift	no mass shift strong broadening
Φ	mass shift: -4% $\Gamma_\phi(\rho_0)=$ ~~47MeV~~ ~16MeV	–	–	–	–

Remark

- We detected the mass modifiction in the inv. 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 like BUU ?
  - momentum dependence of 'mass shift' & 'width broadening'
- We expect the precise prediction to be compared with coming high statistics result.
- <u>How can we connect the results with chiral symmetry restoration?</u>

Acknowledgments

- Thank you for the support by all staffs of KEK, including the PS beam channel group, the PS floor staffs, the online group, the electronics division, the computing division and the accelerator division.
- Thanks to the members of Kyoto Univ, RIKEN, etc.



Acknowledgments

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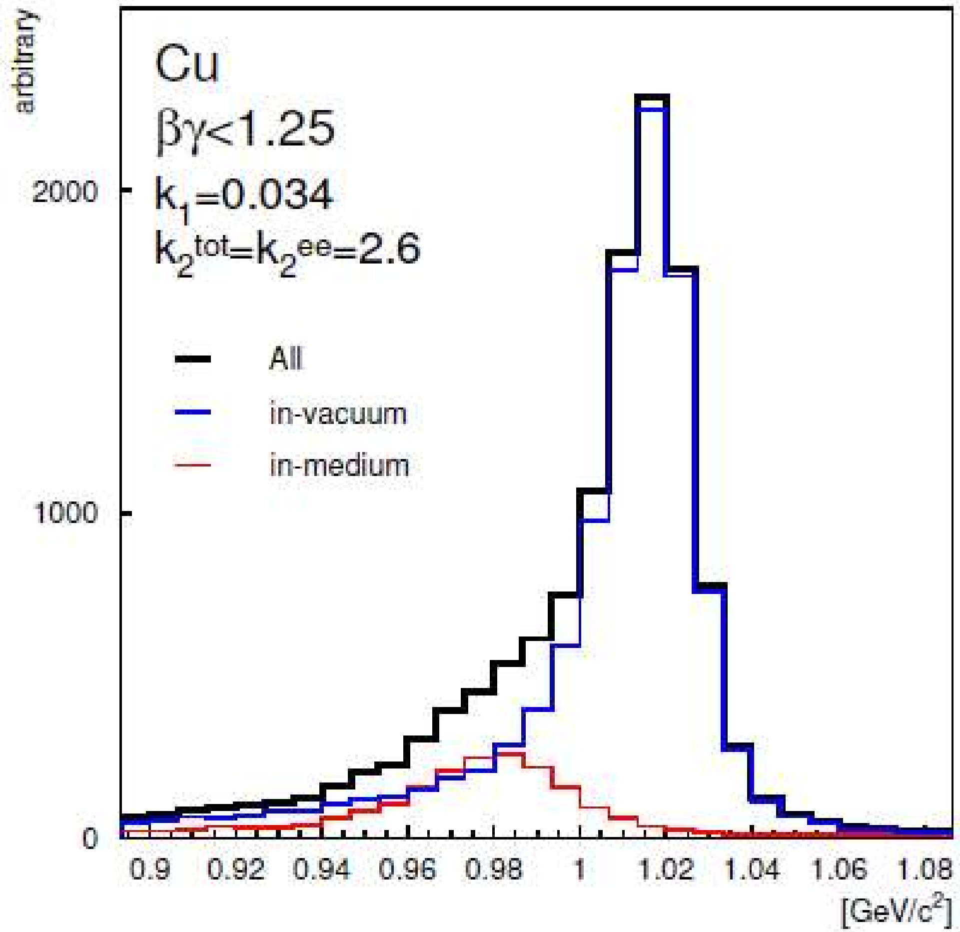
- Thanks to the members of Kyoto Univ, RIKEN, etc.

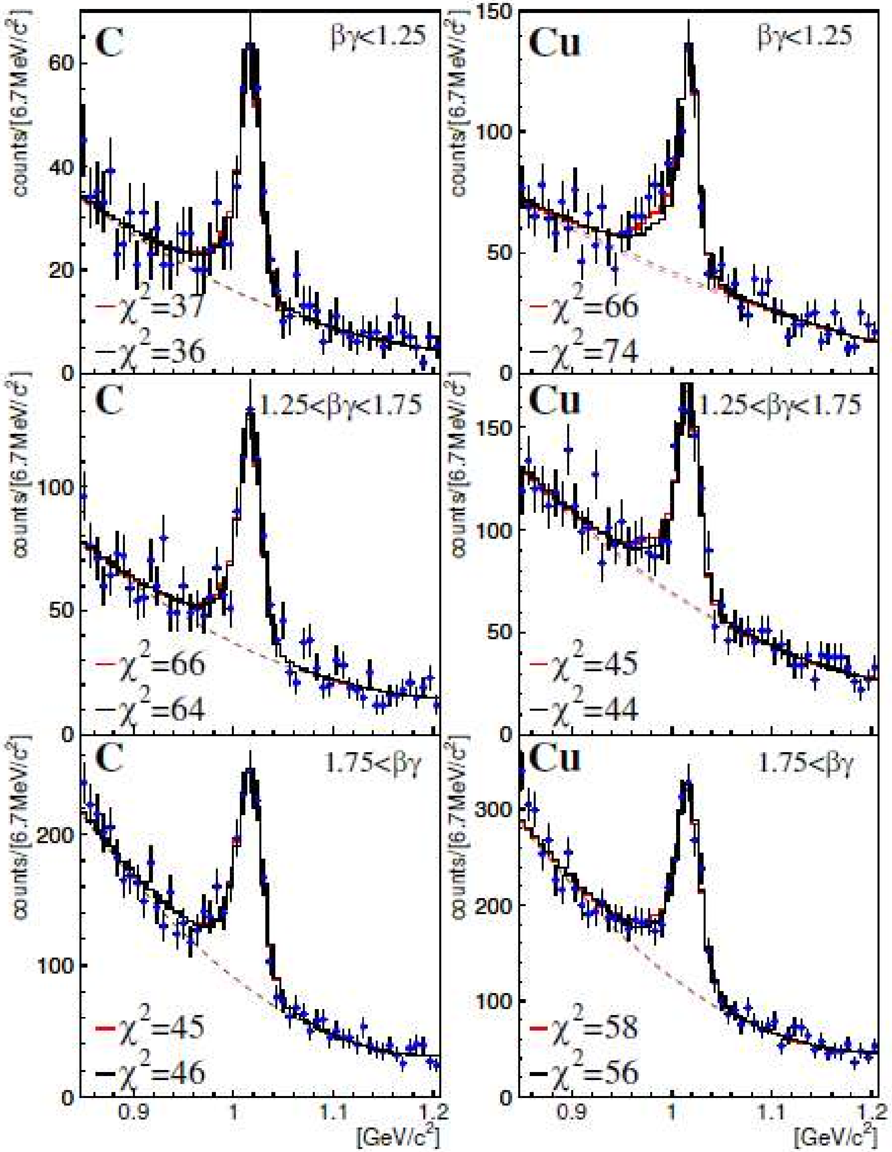
- Let's Go to the next experiment at J-PARC !

Backup slides...

Modified shape of ϕ

- Cu, $\beta\gamma$ <1.25,
- best fit values of k_1 and k_2



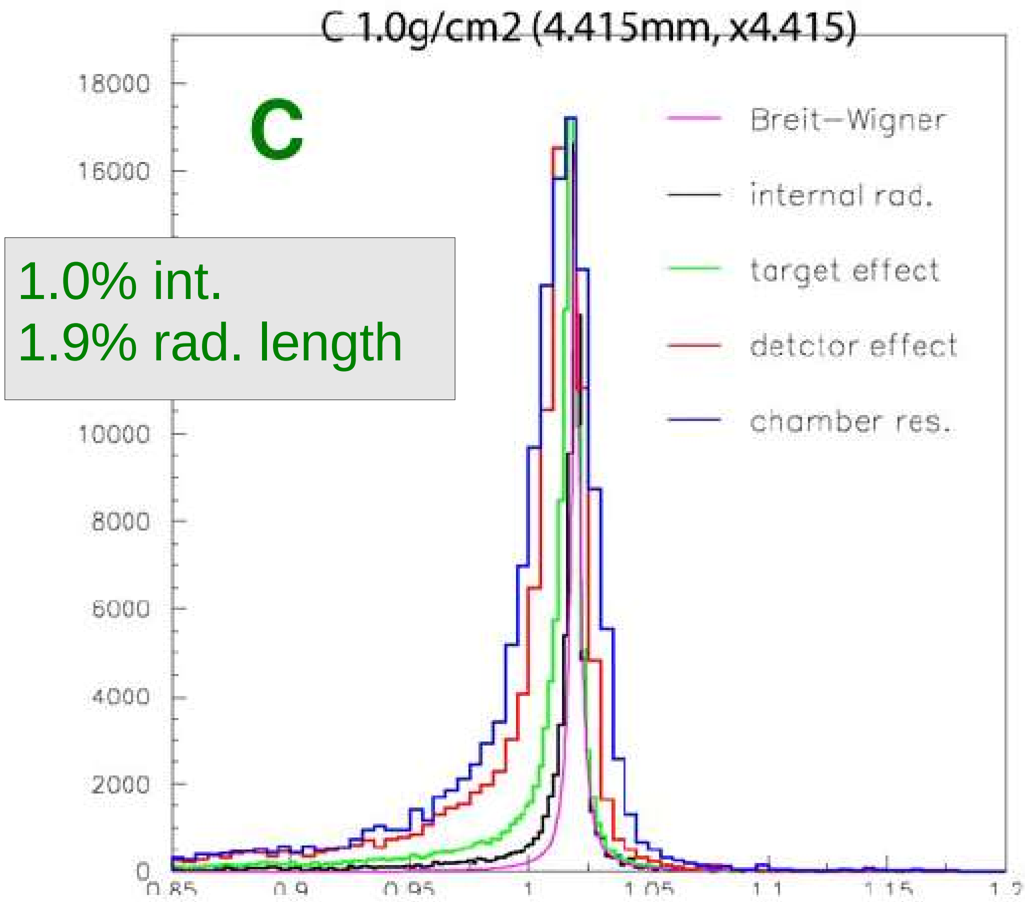


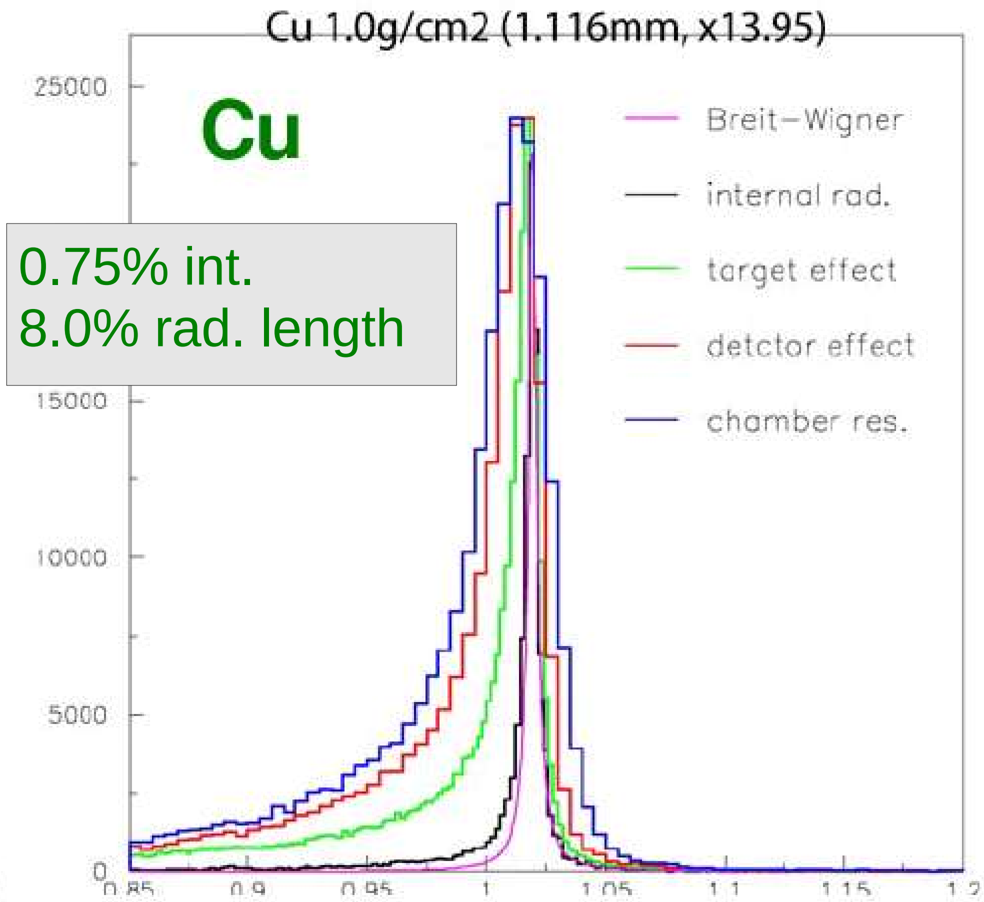
Summary Table (H.En'yo, YKIS2006)

	Proton induced		induced (Eγ GeV)			
E_{inc}	12GeV		0.6-2.5	0.8-1.1	1.5-2.4	0.6-3.8
Exp	KEK		TAPS	TAGX	LEPS	CLAS
A	12, 64 0.18˜0.07g/cm2		1, 93 0.37-0.85g/cm2	2, 3, 12	7, 12, 27, 64 5.4,8.2,6.5,2.6 g/cm2	2,12,48,56, 207. 1g/cm2
φ	e^+e^-	K^+K^-			K^+K^-	e^+e^-
	Shift 3.4 ±0.6%	No hint in IMS. Limits on Γ*			No hint in IMS In-media broadening ?	seen No report yet
ω	e^+e^-		$\pi^0\gamma$			e^+e^-
	Shift 9.2 ± 0.2% Not very sensitive for ω mod.		Shift 14%			No shift 2±2%(1σ) Not very sensitive for ω mod.
ρ				$\pi^+\pi^-$ Shift 5~8%		

(experimental effects on the BW shape)

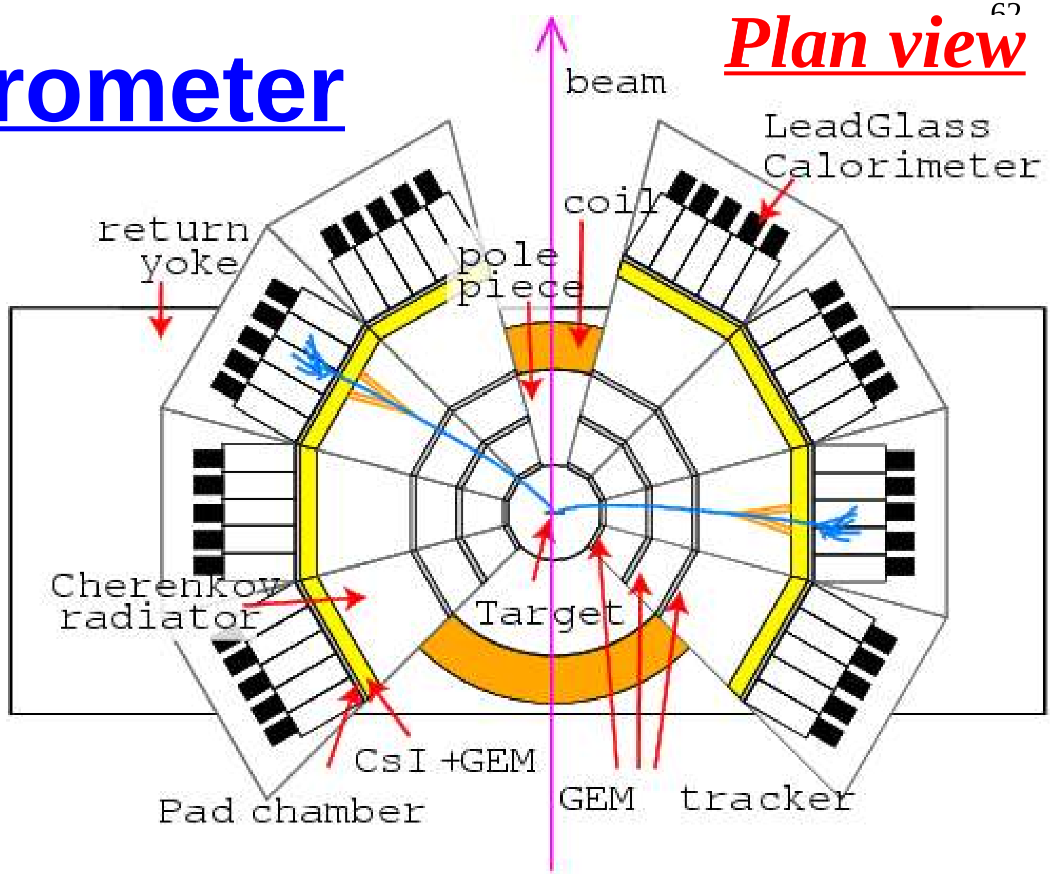
- thick target effect : 1g/cm^2

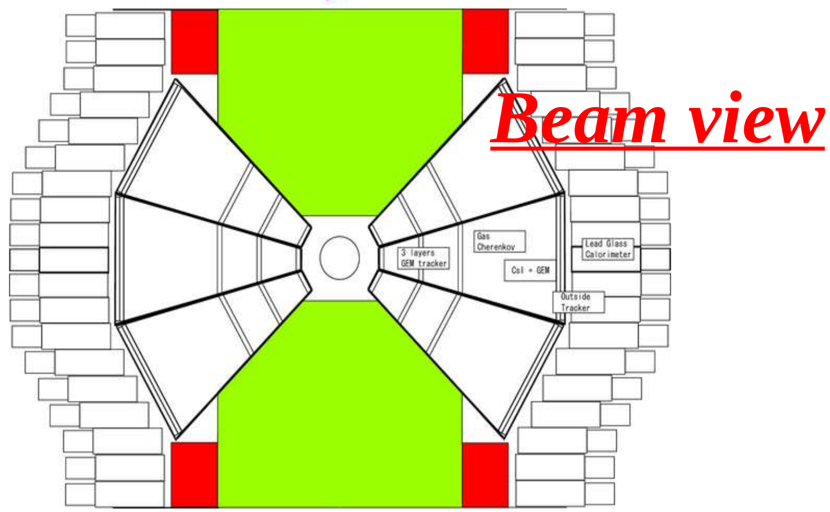




Proposed spectrometer

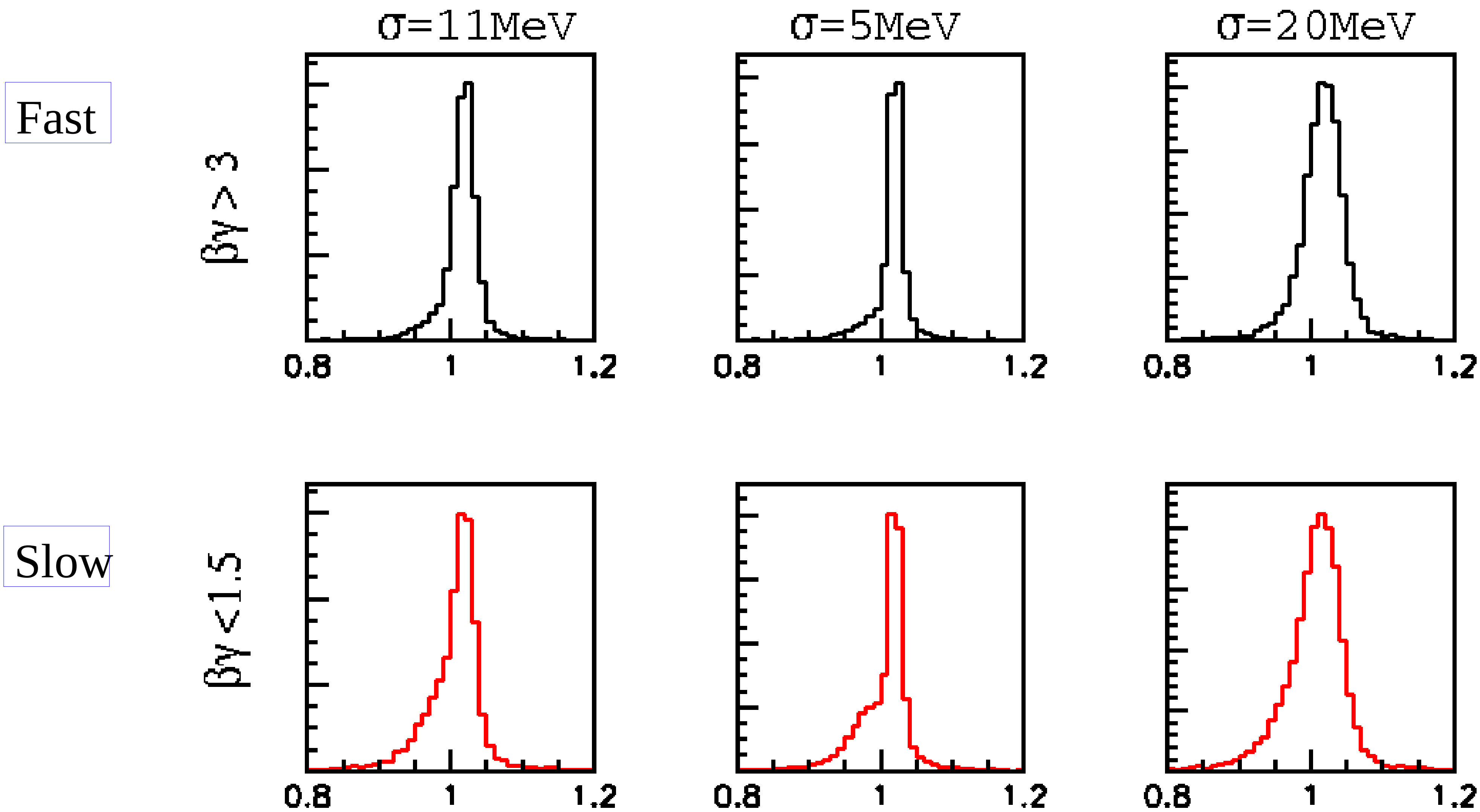
- Tracking Device
  - GEM(Gas electron multiplier)
    - 0.7mm pitch strip readout
- Two-stage Electron ID
  - Gas Cherenkov
    - GEM+CsI photocathode
      - pad readout
  - Leadglass EMC
- ~70K Readout Channels (in 27 units)
  - E325: 3.6K, PHENIX:~300K
- Cost : ~$5M (including $2M electronics)
 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





high mass resolution

- mass resolution should be less than ~10MeV



(model calc. with k=0.05/Γ=x10 /E325 spectrometer)