Chiral symmetry in nuclear matter --from KEK-PS E325 to J-PARC E16--

Satoshi Yokkaichi
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1) Introduction

- How can we observe the chiral symmetry restoration ?
- Expected spectral modification of vector mesons in nuclear matter

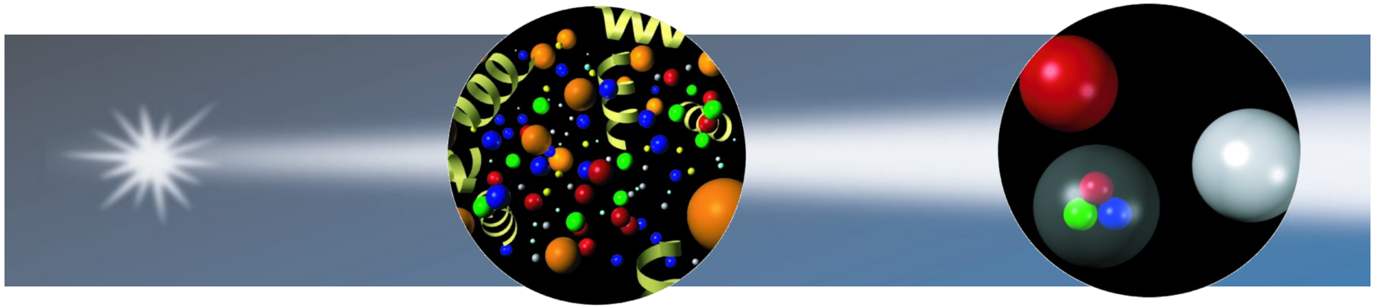
2) Experiment E325 at KEK-PS

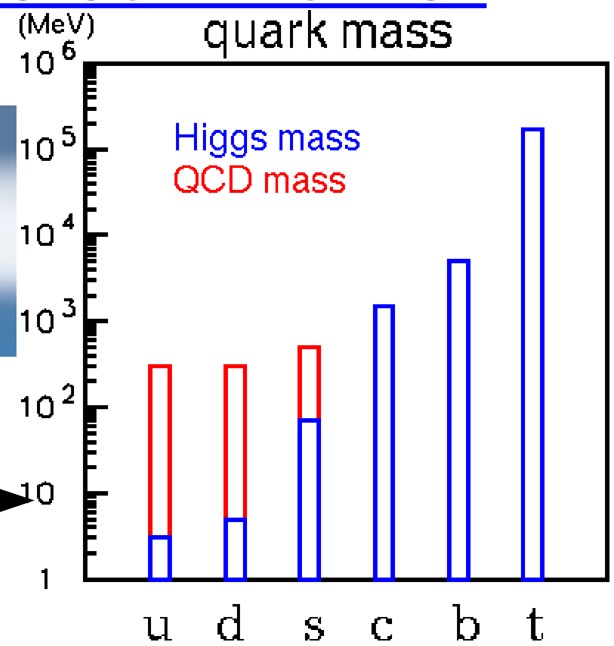
- Observed vector meson modification in nuclei

3) Future experiment E16 at J-PARC

- Systematic study of the modification of vector meson spectra

Mass and chiral symmetry in nuclear matter



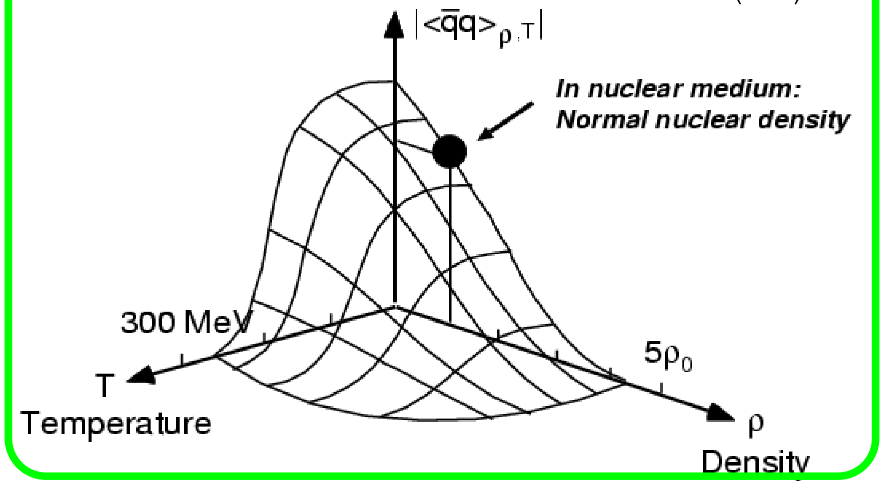


big bang | 10psec | 0.1msec

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...

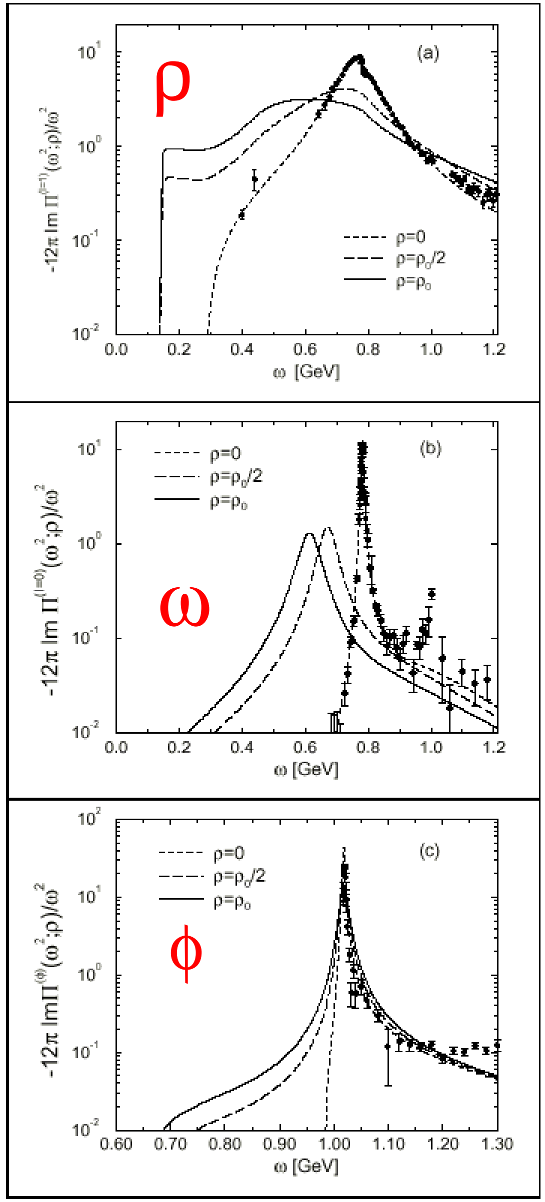
W.Weise, NPA553(93)59



Vector meson mass spectra in dense matter

effective Lagrangian
(chiral SU(3)+VMD)

Klingle,Kaiser,Weise,
NPA624(97)527



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

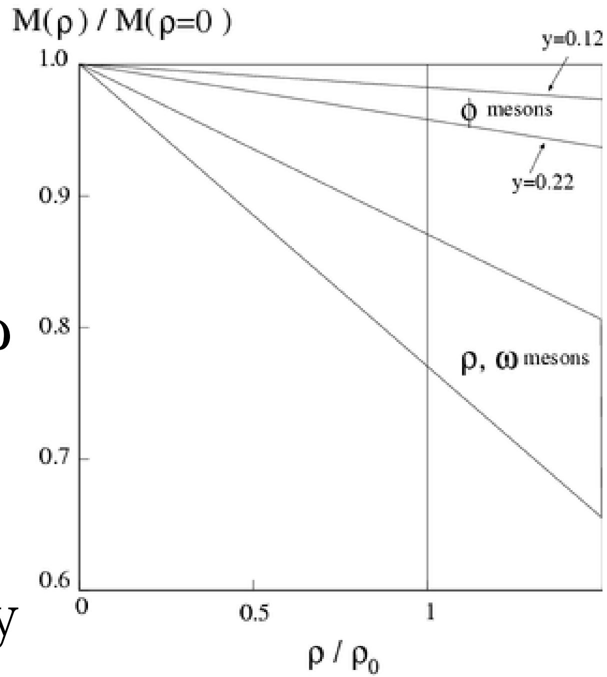
linear dependence on density

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

mass 'dropping'

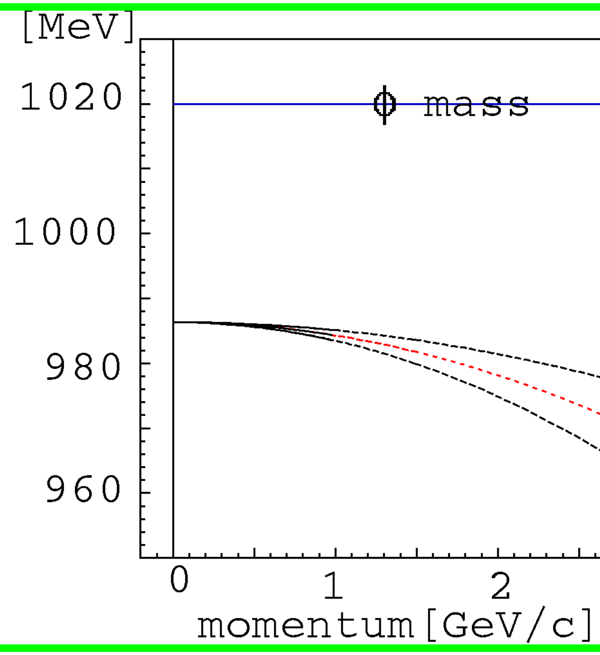
- 16(±6)% for ρ/ω
- 0.15(±0.05)*y
  =2~4% for ϕ
  (for y=0.22)

at the normal nuclear density

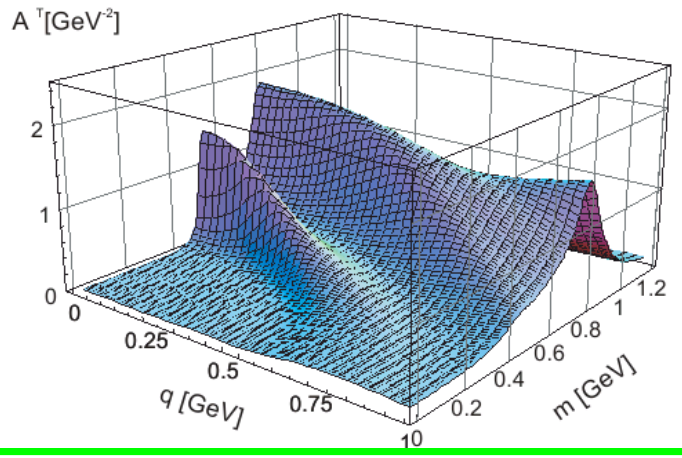


dispersion (mass VS momentum) in dense matter

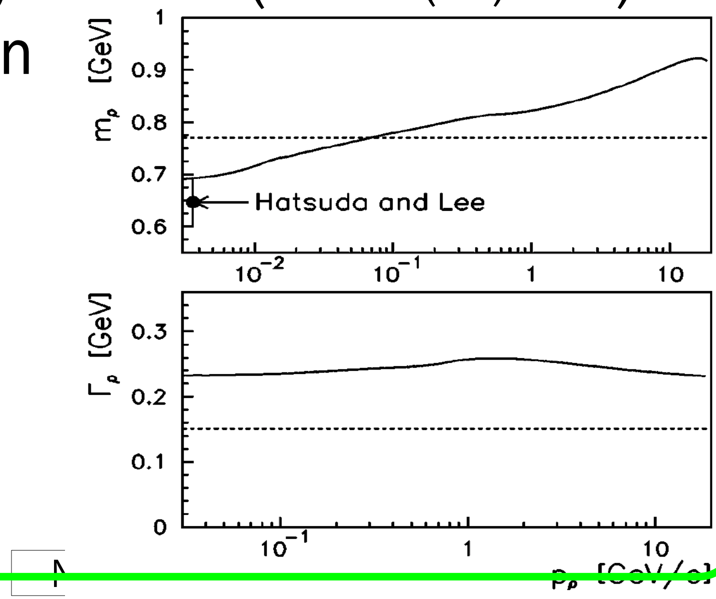
- S.H.Lee (PRC57(98)927) $m^*/m_0 = 1 - k\ \rho/\rho_0$
  - ρ/ω : $k=0.16\pm0.06+(0.023\pm0.007)(p/0.5)^2$
  - ϕ : $k=0.15(\pm0.05)*y + (0.0005\pm0.0002)(p/0.5)^2$
    - for p<1GeV/c



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



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



Vector meson measurements in hot/dense matter

dilepton measurement

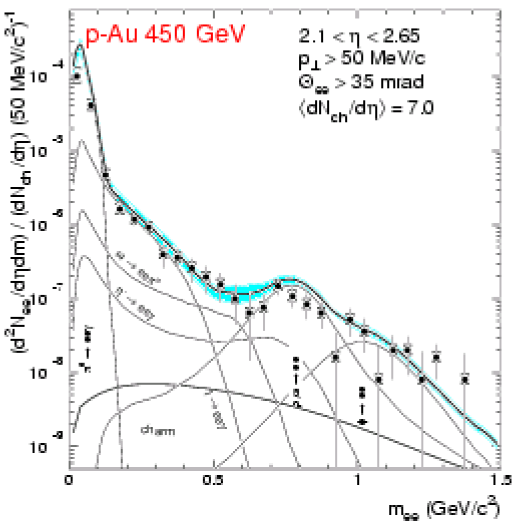
- HELIOS/3 (ee, μμ) 450GeV p+Be / 200GeV A+A
- DLS (ee) 1 GeV A+A
- CERES (ee) 450GeV p+Be/Au / 40-200GeV A+A
- E325 (ee,KK) 12GeV p+C/Cu
- NA60 (μμ) 400GeV p+A/158GeV In+In
- PHENIX (ee,KK) p+p/Au+Au
- HADES (ee) 4.5GeV p+A/ 1-2GeV A+A
- CLAS-G7 (ee) 1~2 GeV γ+A
- *J-PARC E16* (ee) 30/50GeV p+A / ~20GeV A+A ?
- *CBM/FAIR* (ee) 20~30GeV A+A

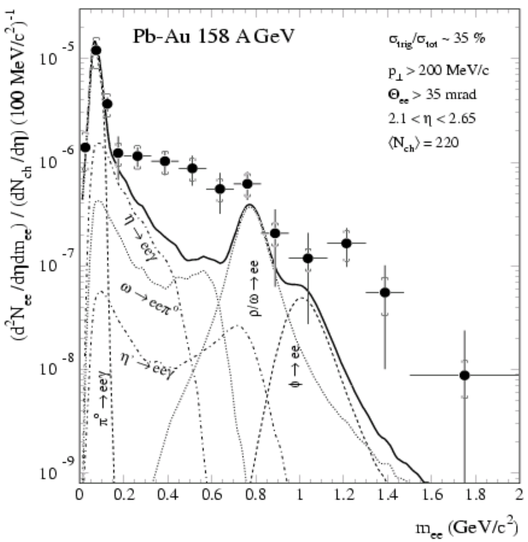
- TAGX (ππ) ~1 GeV γ+A
- STAR (ππ,KK) p+p/Au+Au
- LEPS (KK) 1.5~2.4 GeV γ+A
- CBELSA/TAPS ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb

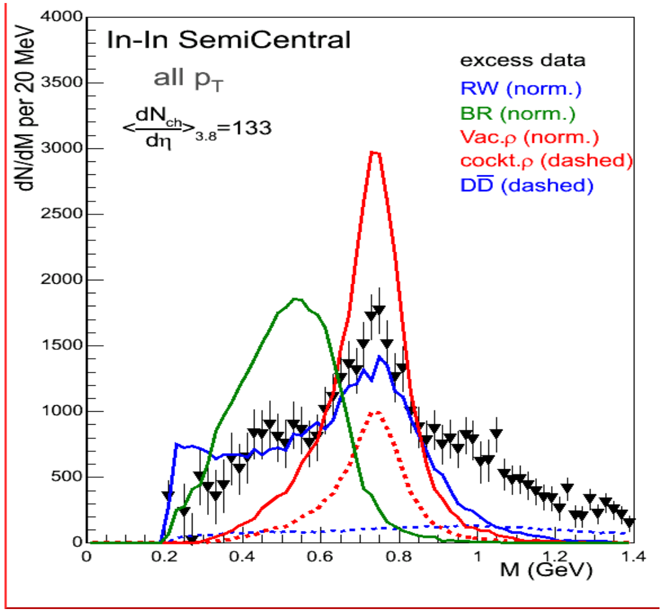
published/ 'modified'
published/ 'unmodified'
running/in analysis
future plan
as of 2008/Jul

Vector meson measurements in HIC

- CERES : e^+e^- (EPJC 41('05)475)
  - anomaly at the 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'







- Discussion is continuing
  - mass dropping or broadening?

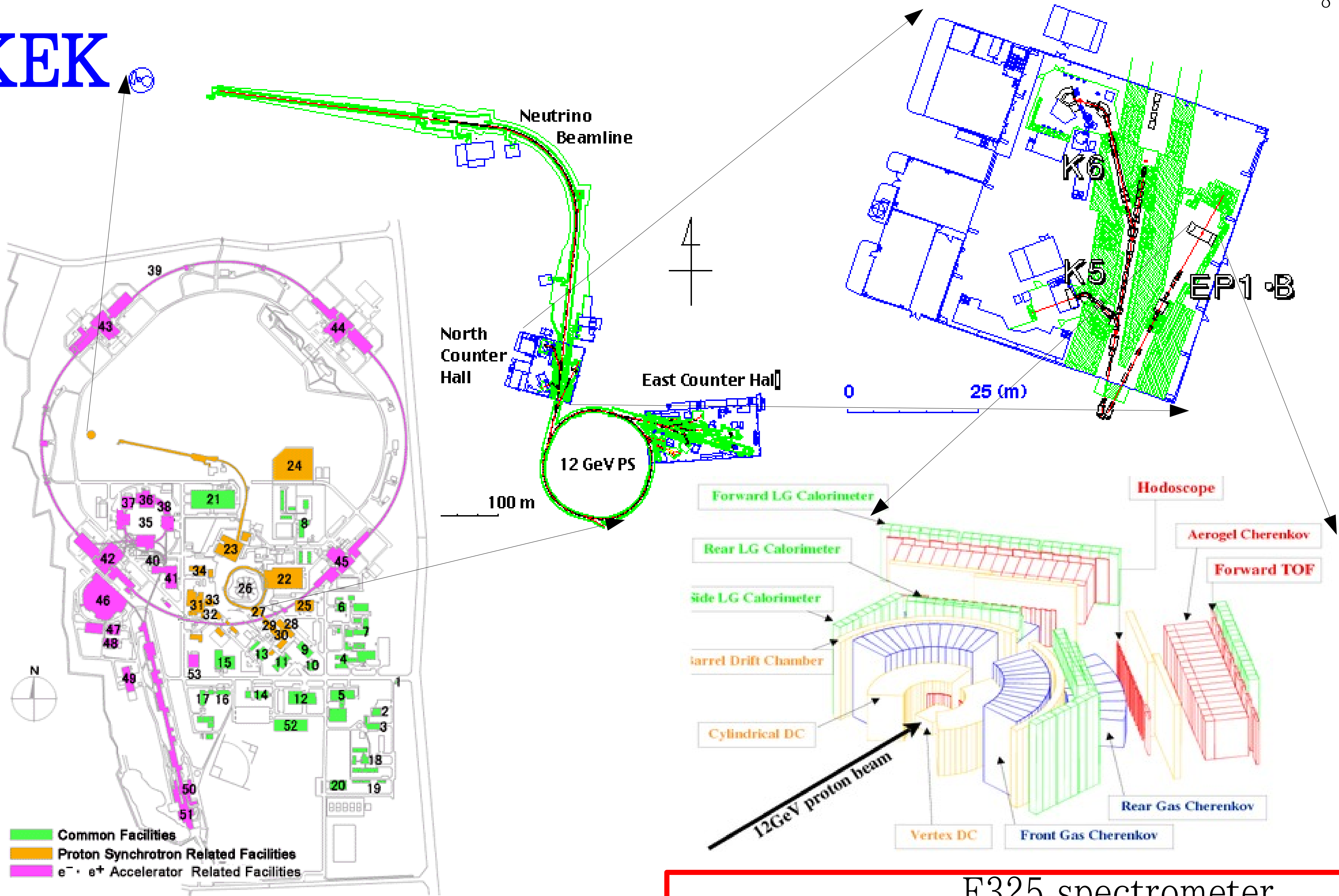
Experiment KEK-PS E325

- 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, 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.)

KEK



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

History of E325

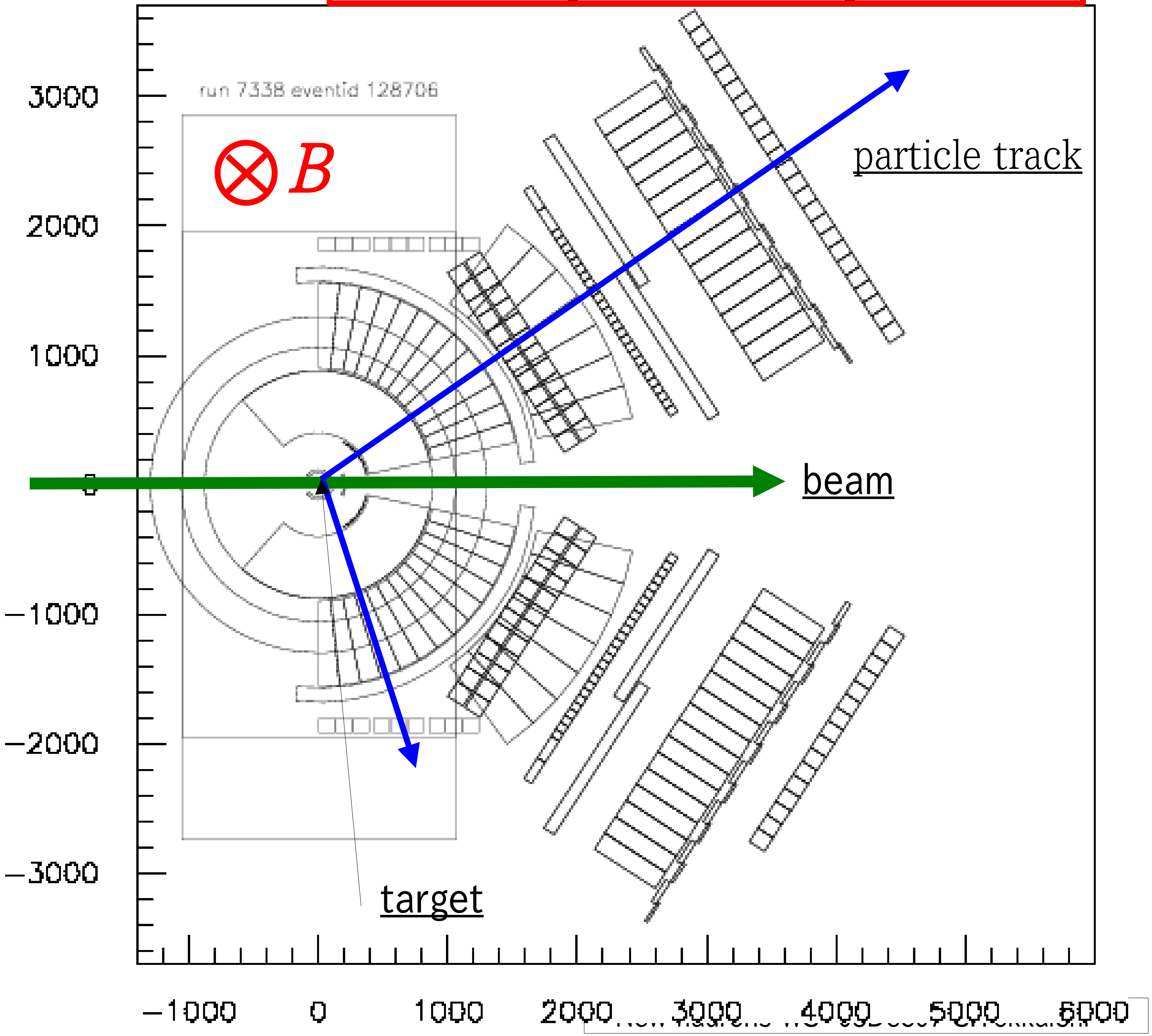
- 1993 proposed
- 1994 R&D start
- 1996 construction start
- '97 data taking start
- '98 first ee data
  - PRL86(01)5019 ρ/ω (ee)
- 99,00,01,02….
  - x100 statistics
  - PRL96(06)092301 ρ/ω (ee)
  - PRC74(06)025201 α (ee)
  - PRL98(07)042501 ϕ (ee)
  - PRL98(07)152302 ϕ (KK),α
- '02 completed
- spectrometer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

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

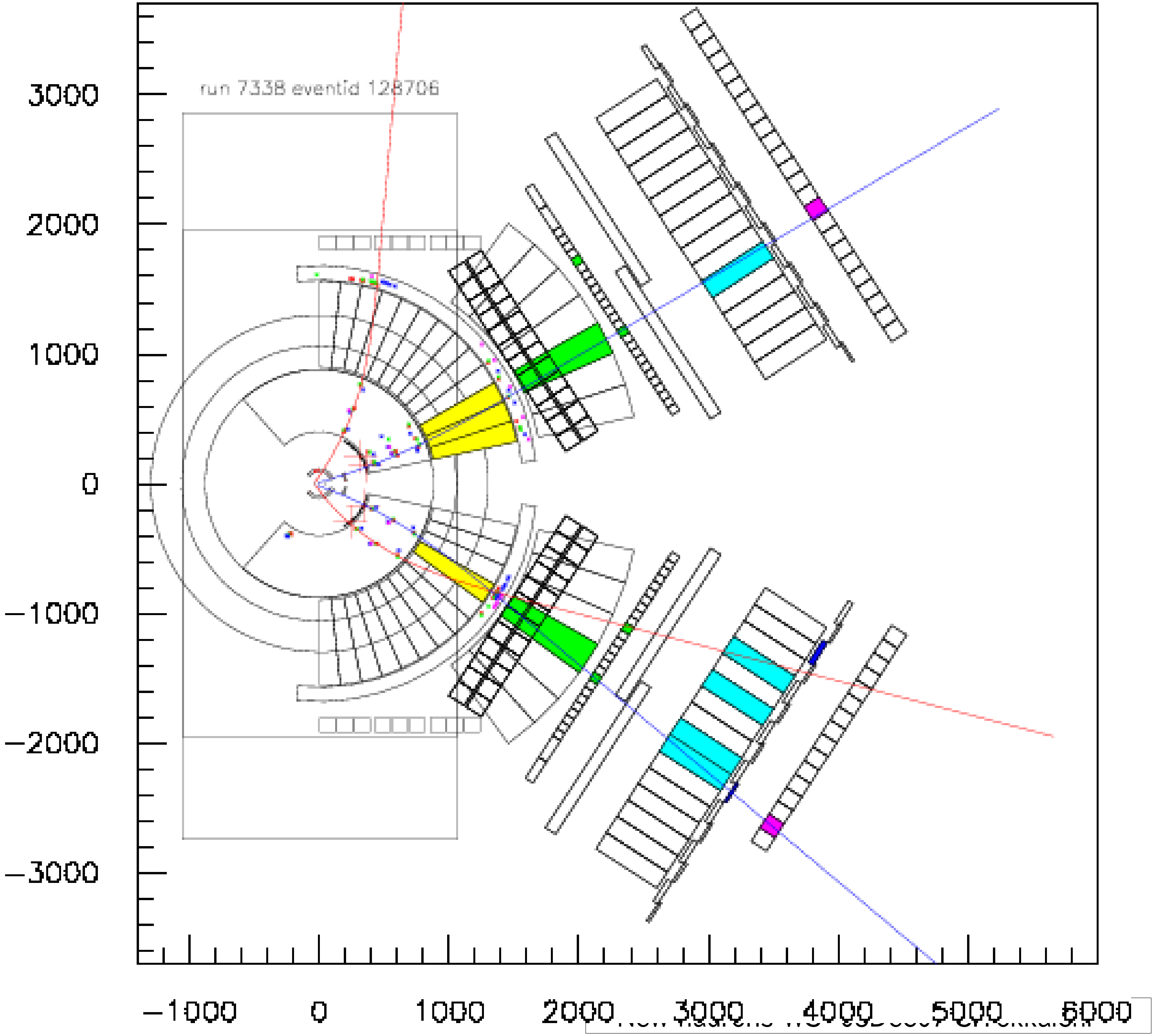
Experimental setup

- 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

schematic plan view of spectrometer



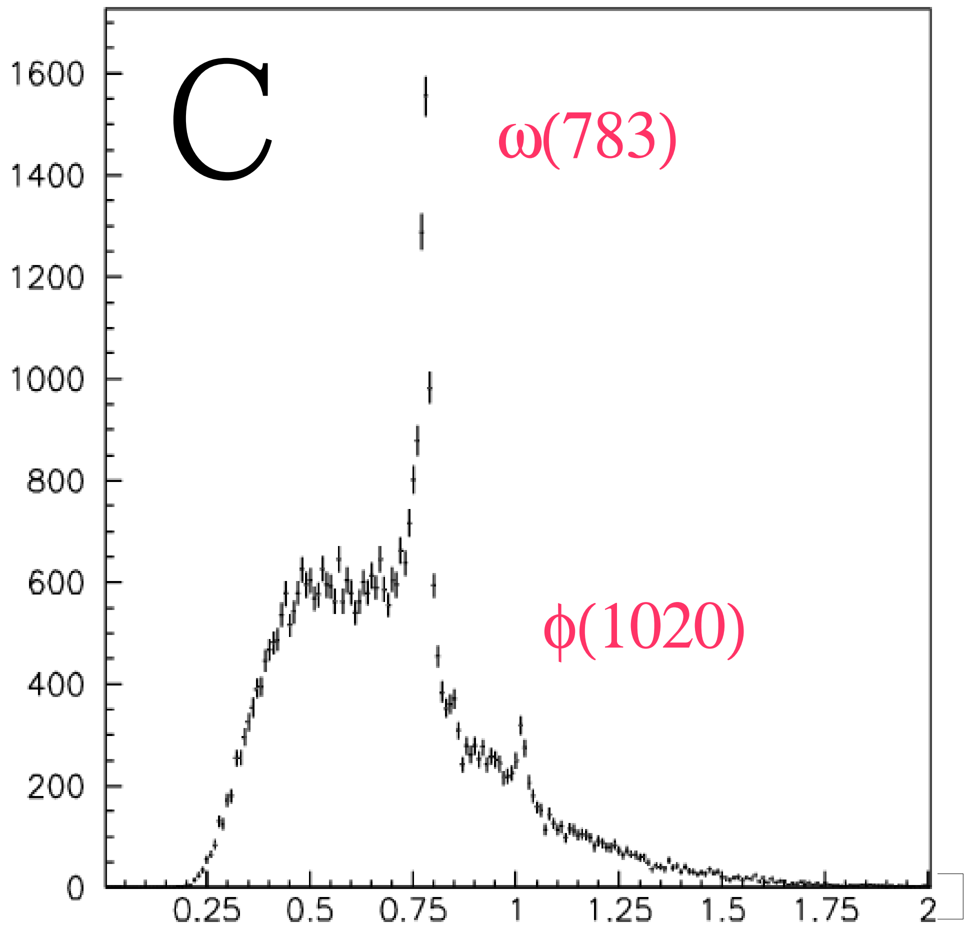
- Typical e^+e^- Event
  - blue:electron
  - red : other
  - invariant mass and momentum of mother particle can be calculated



E325 Results

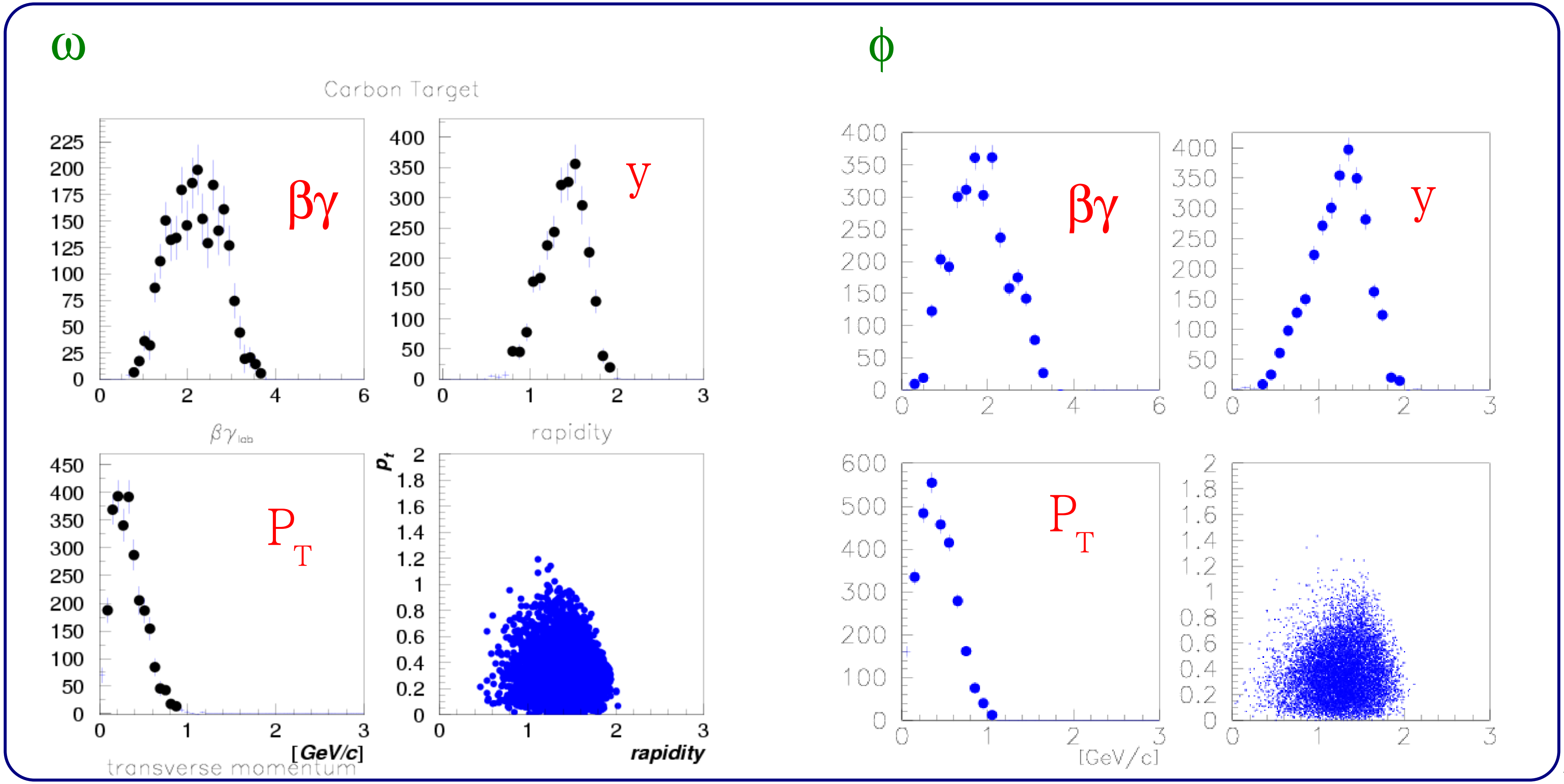
e^+e^- invariant mass spectra

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



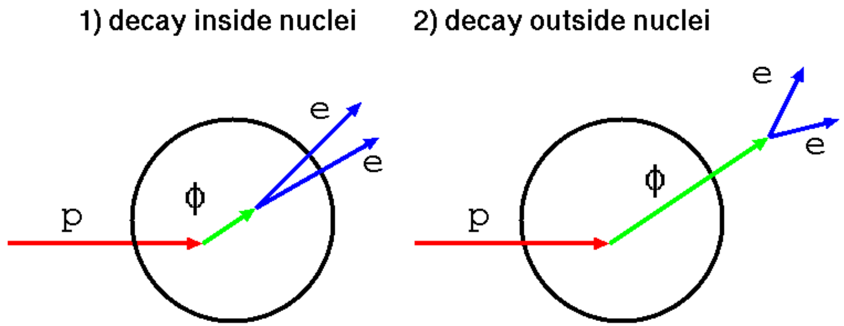
measured kinematic distribution of $\omega/\phi \rightarrow e^+e^-$

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



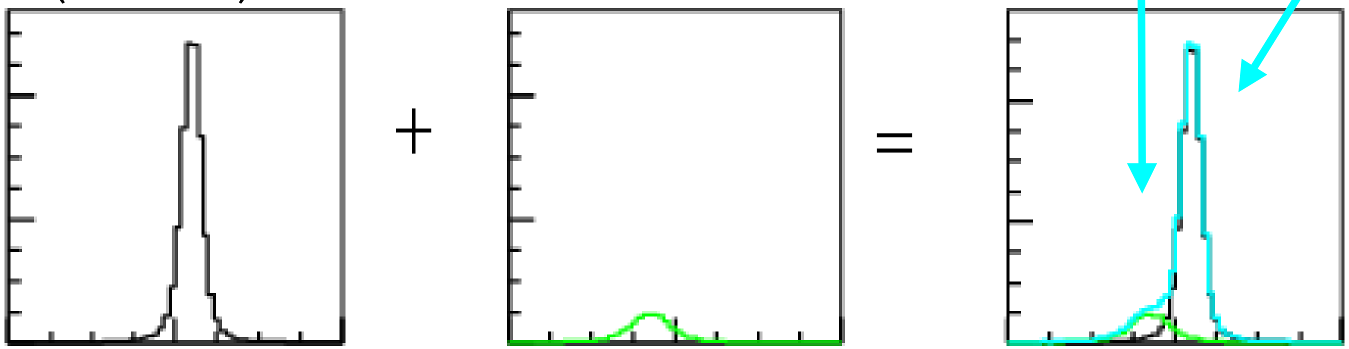
Expected Invariant mass spectra in e^+e^-

- 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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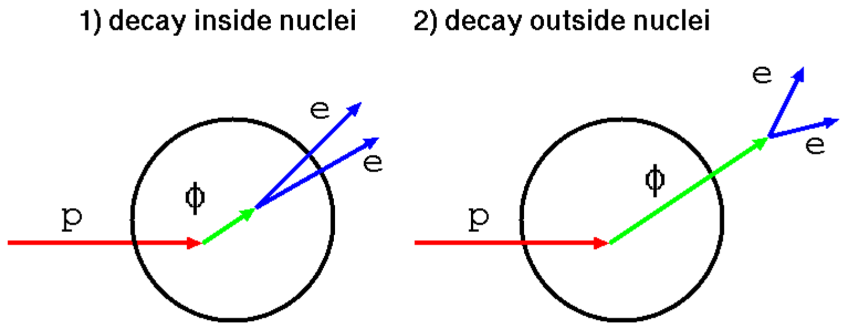
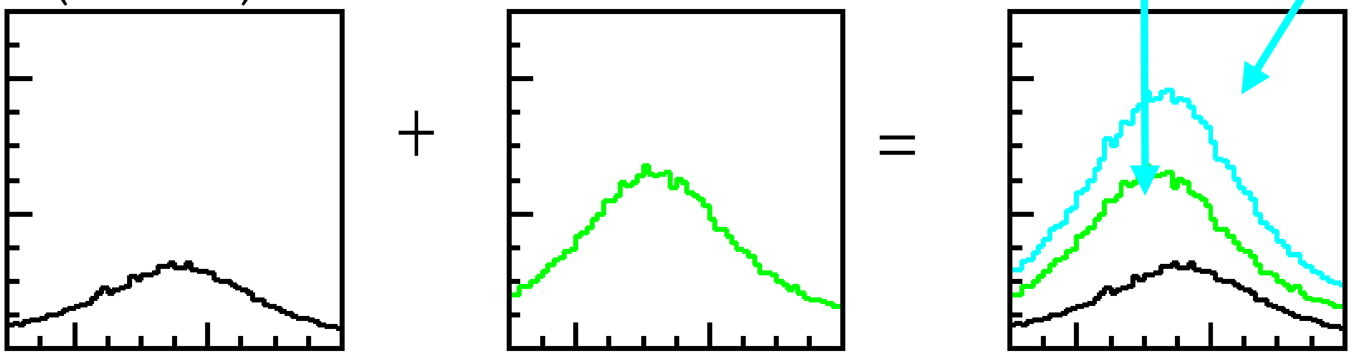


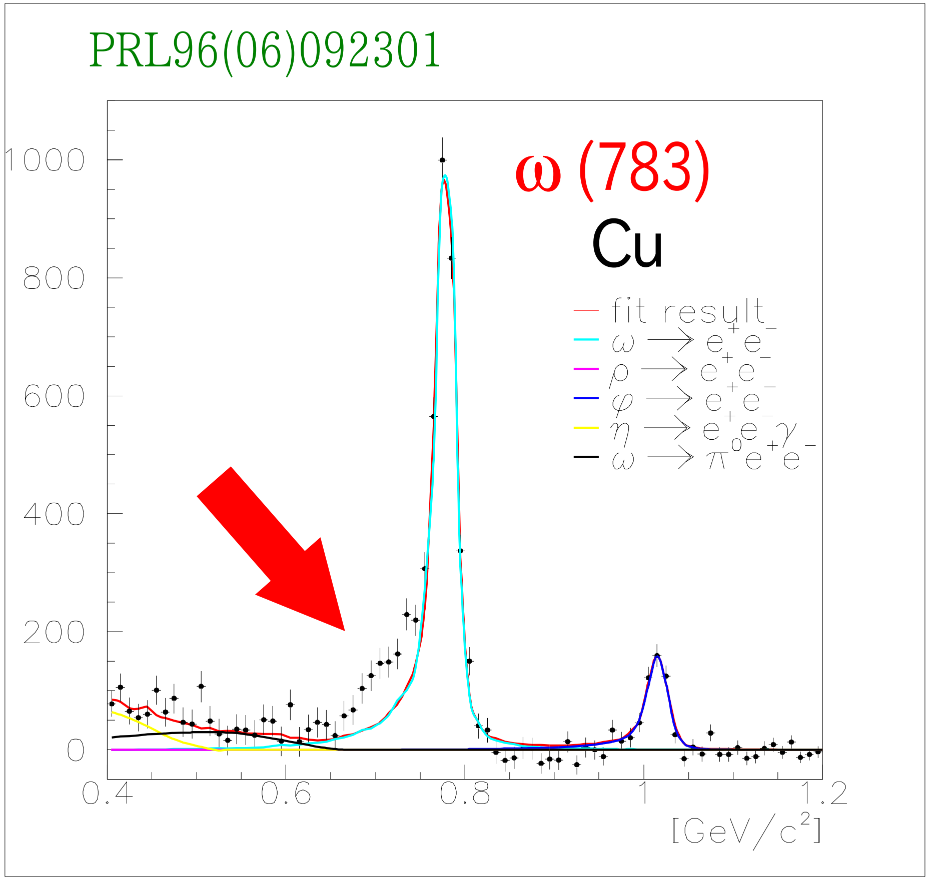
shorter-life meson (ρ)case : Schematic picture

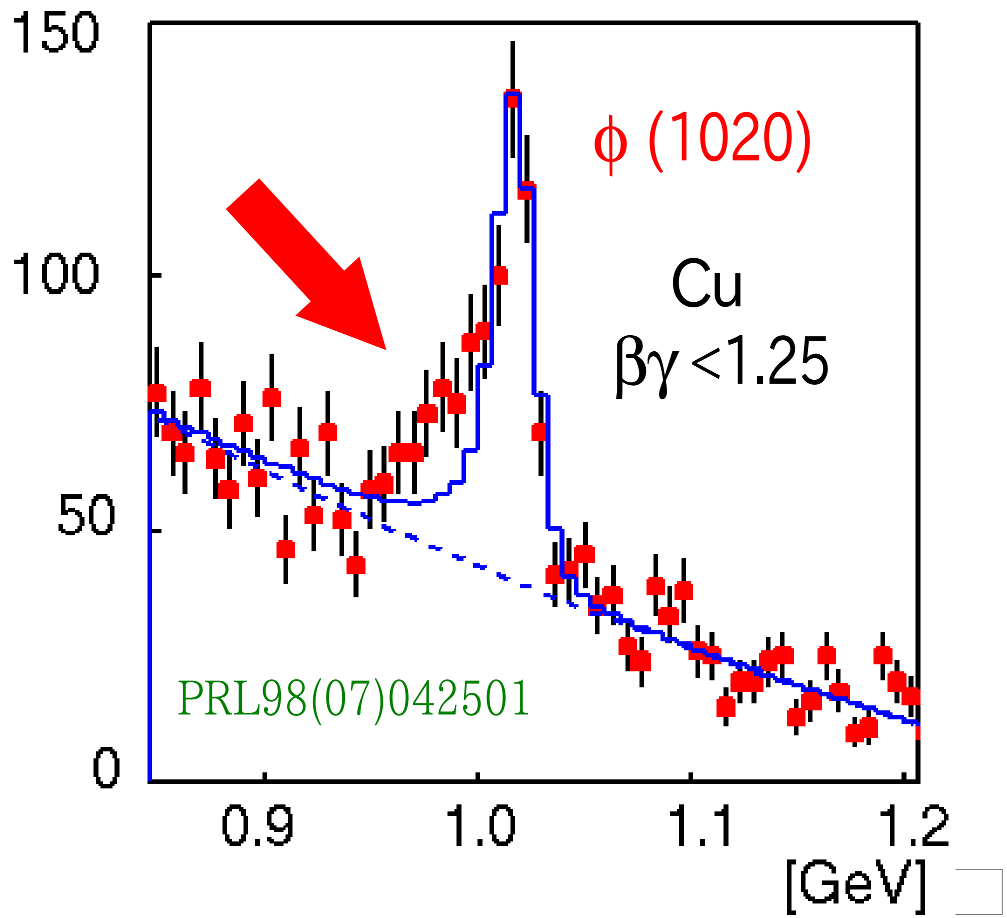
outside decay (natural) + inside decay (modified) = expected to be observed



E325 observed the meson modifications

- in the e^+e^- channel
- below the ω and ϕ, statistically significant excesses over the known hadronic sources including experimental effects

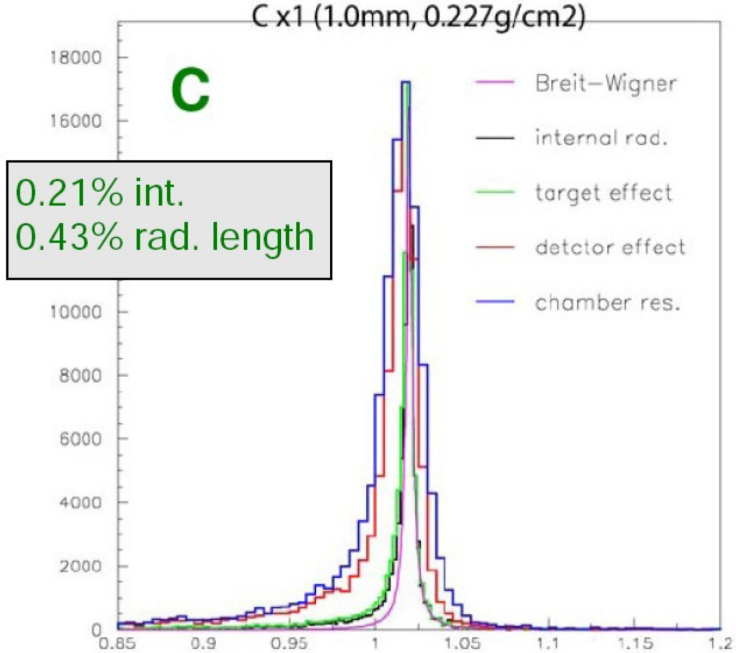




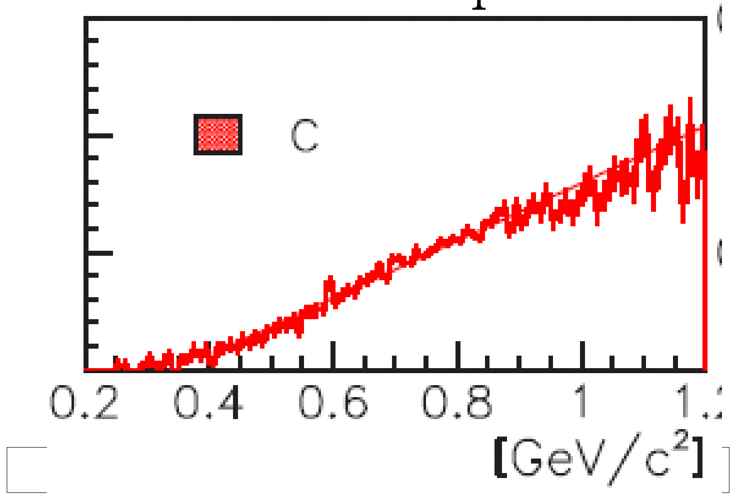
Analysis : Fitting with known sources

- 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

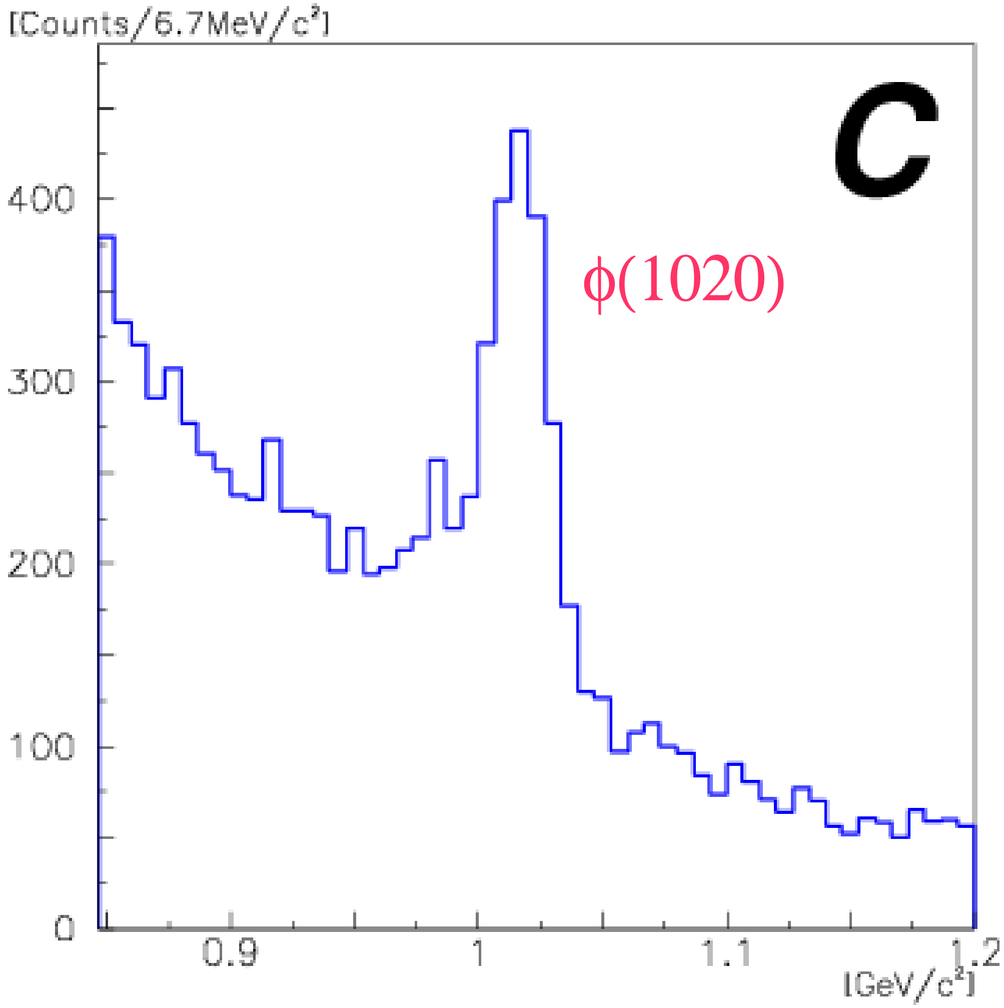


mass acceptance



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



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- from 2001/02 run data
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- fit with
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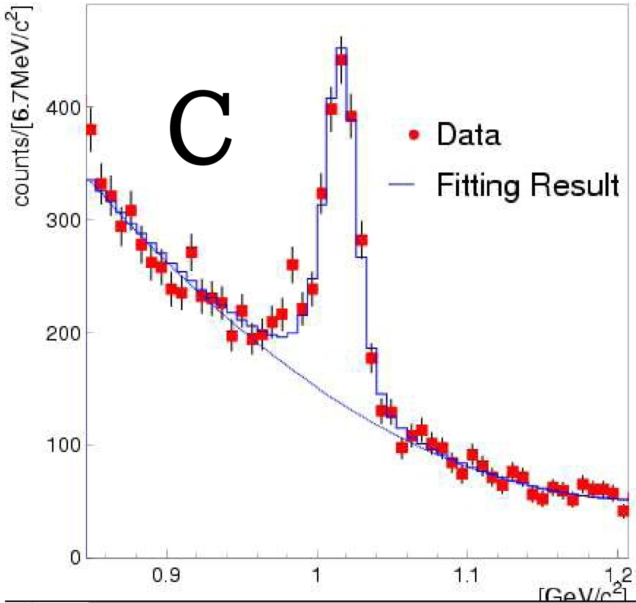
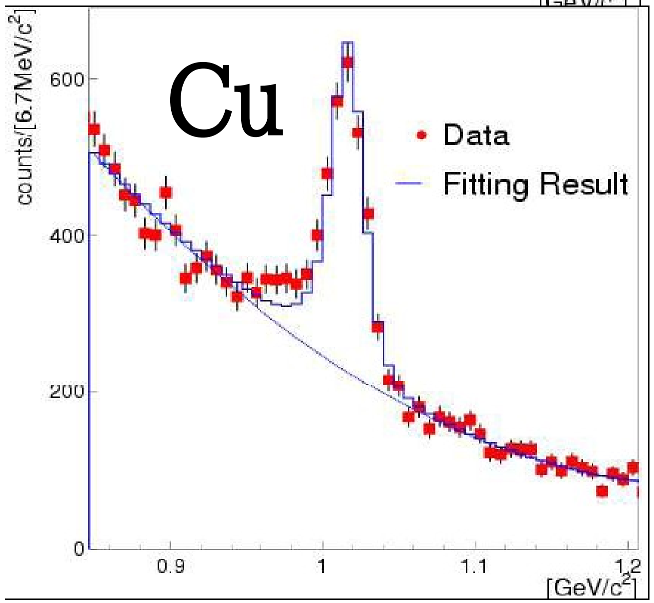
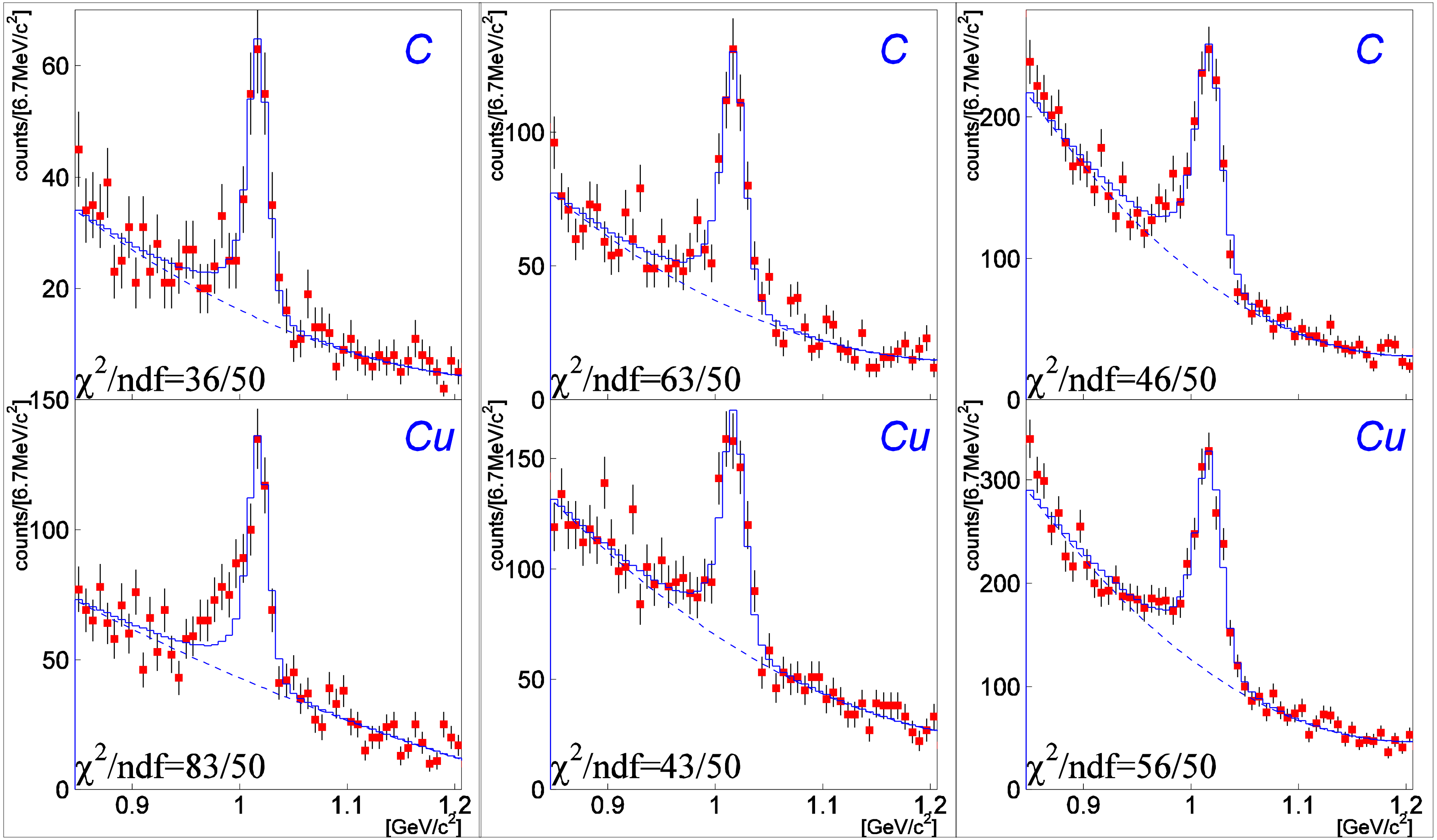
-
- examine the 'excess' is significant or not
  - check the $\beta\gamma$ dependence : excess could be enhanced for slowly moving mesons





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

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



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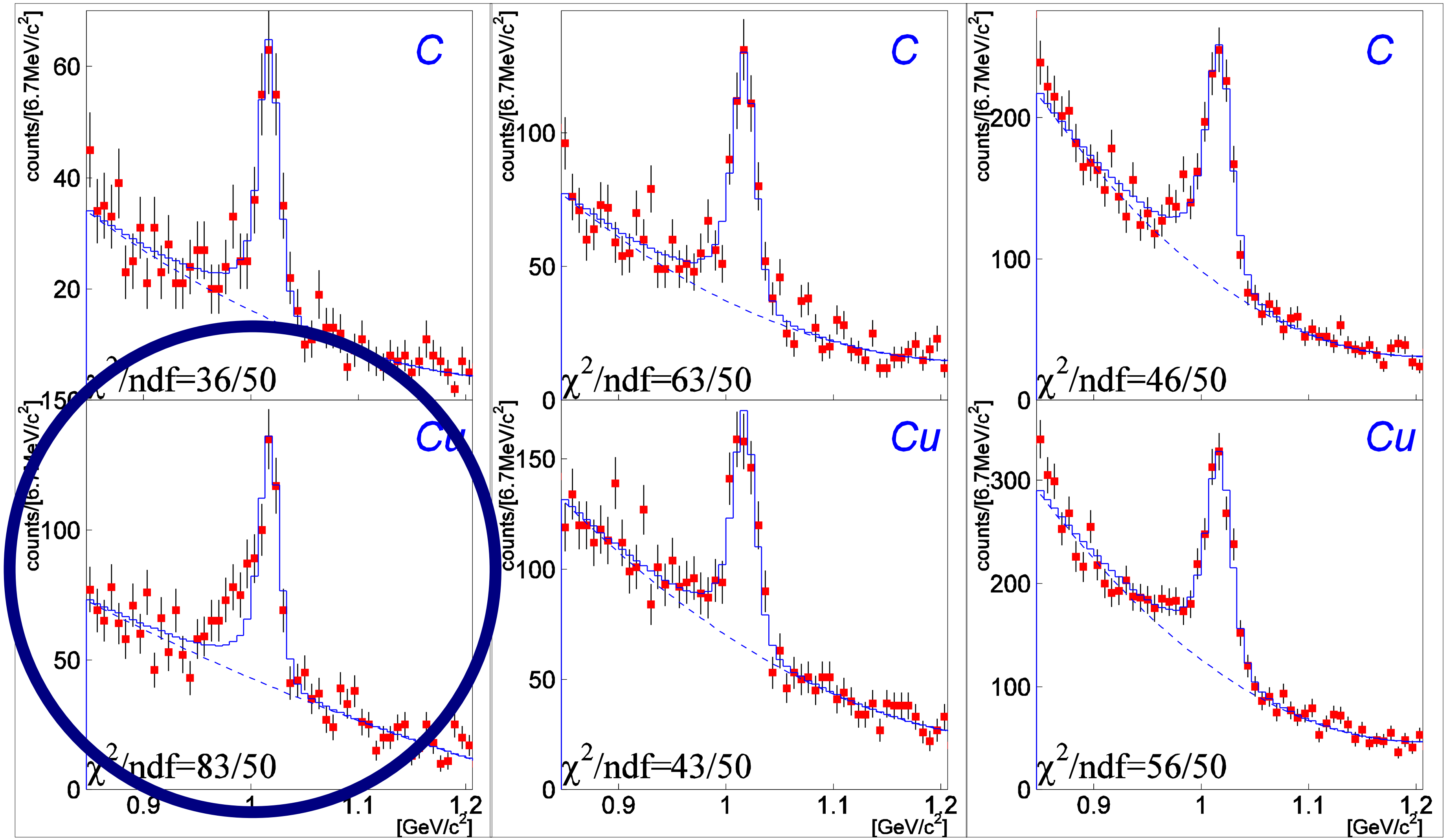
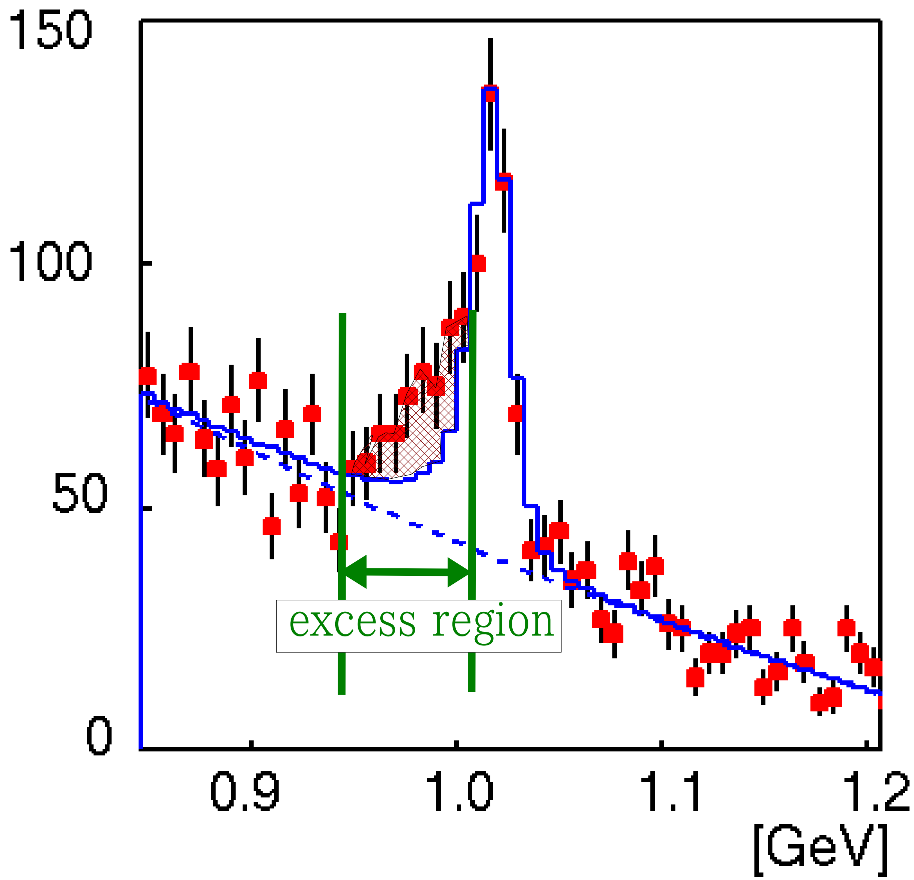


only slow/Cu is not reproduced in 99% C.L.

Amount of excess

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



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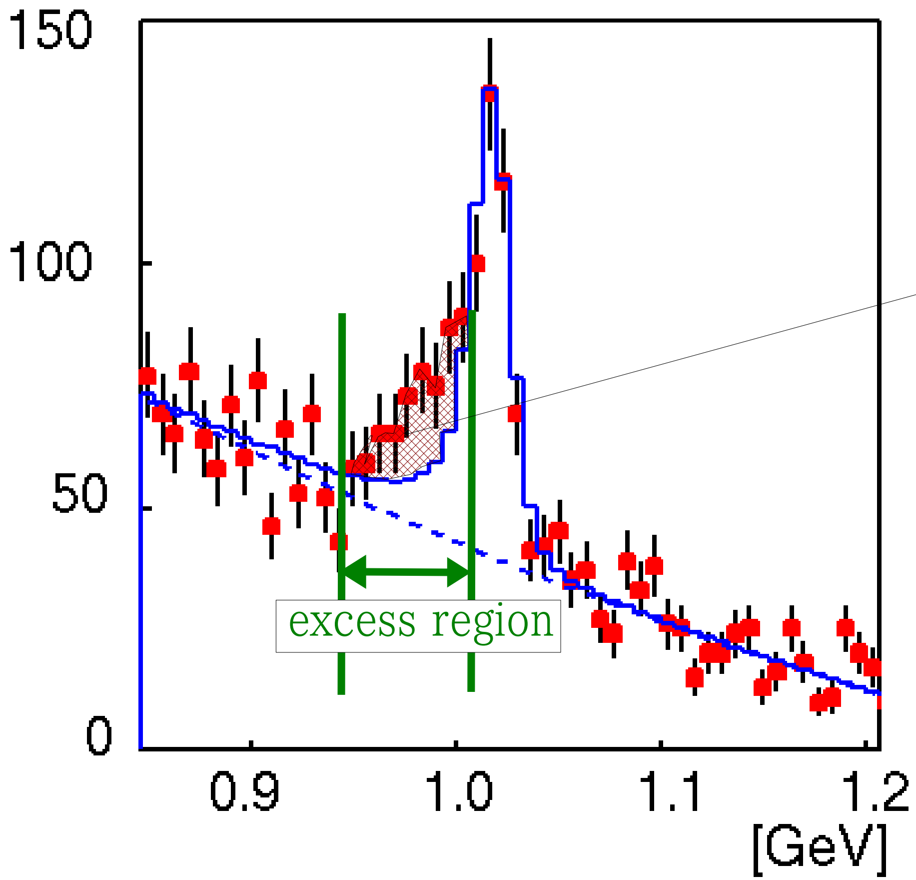
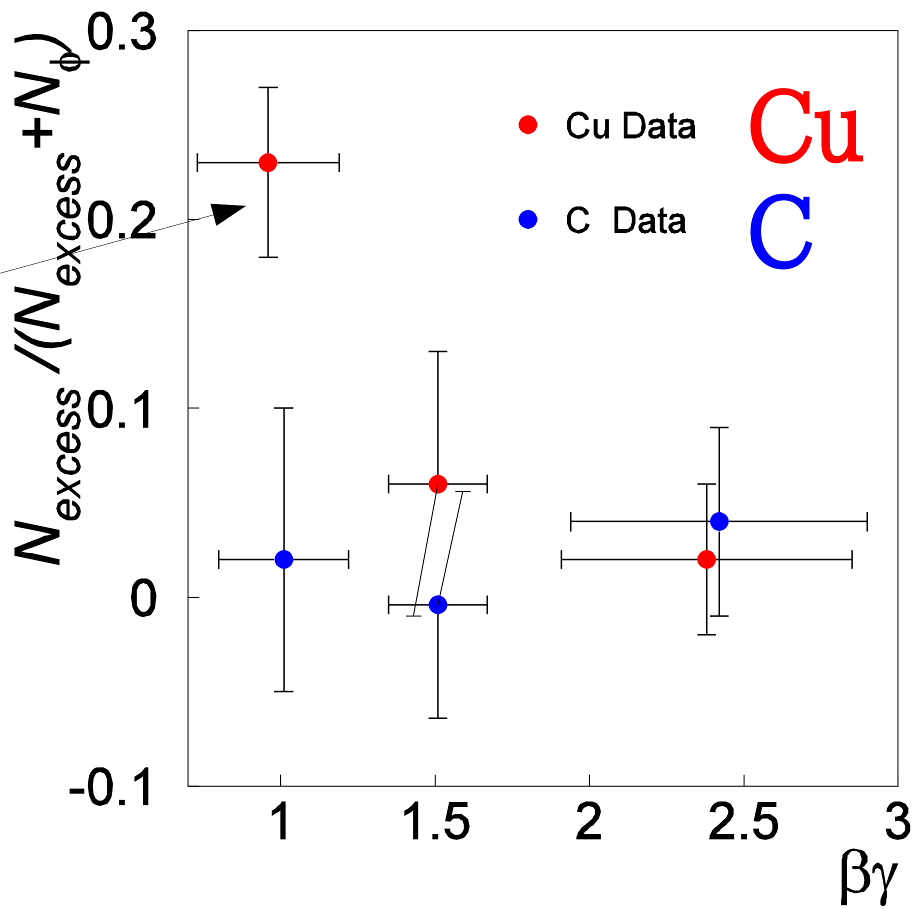
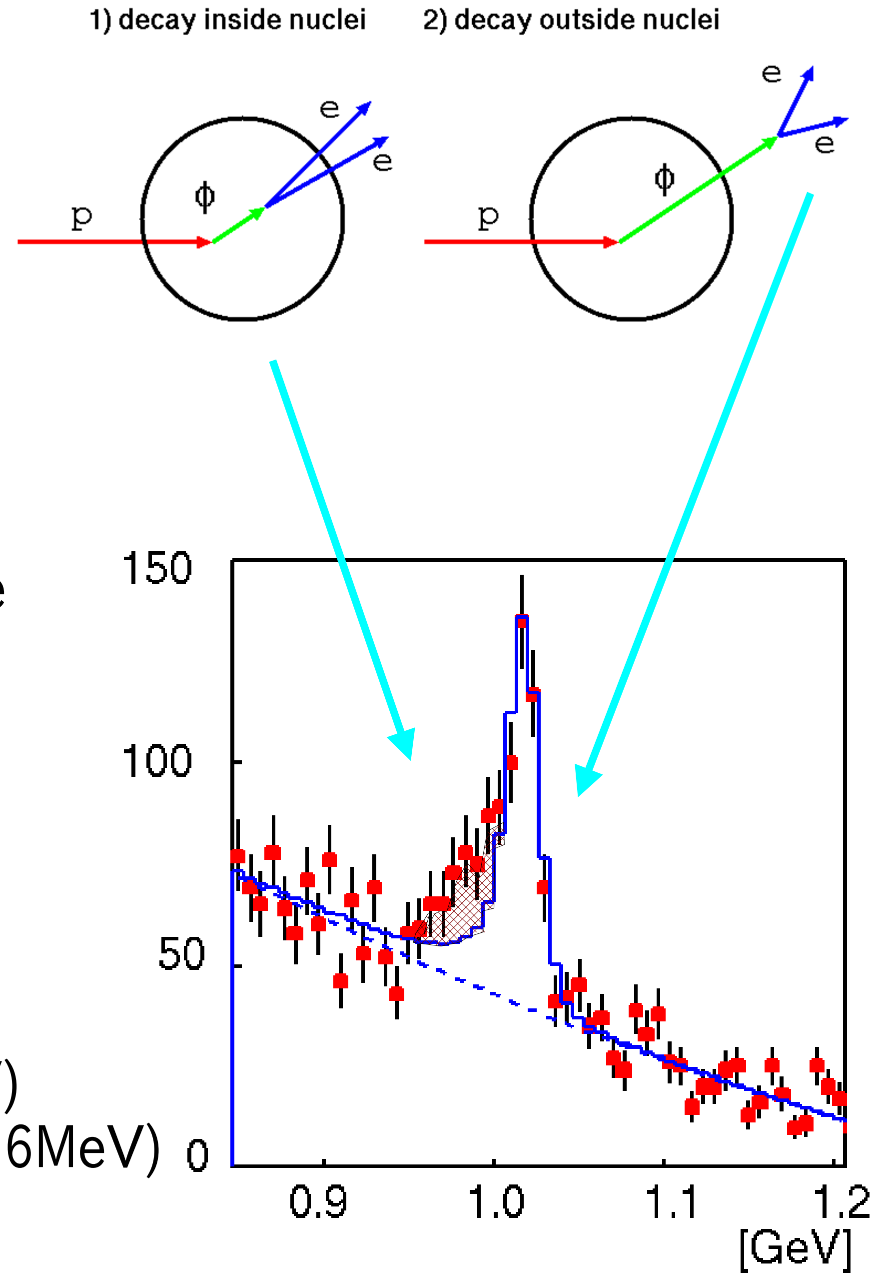




Discussion : modification parameters

- MC type model analysis to include the nuclear size/meson velocity effects
  - generation point : uniform for ϕ meson
    - from the measured A-dependence
  - measured momentum distribution
  - Woods-Saxon density distribution
  - decay in-flight : linearly dependent on the density of the decay point
    - dropping mass: $M(\rho)/M(0) = 1 - k_1 (\rho/\rho_0)$
    - width broadening: $\Gamma(\rho)/\Gamma(0) = 1 + k_2 (\rho/\rho_0)$
- consistent with the predictions



$$k_1 = 0.034^{+0.006}_{-0.007}$$
$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$

3.4% mass reduction (35MeV)
3.6 times width broadening(16MeV)
at ρ_0

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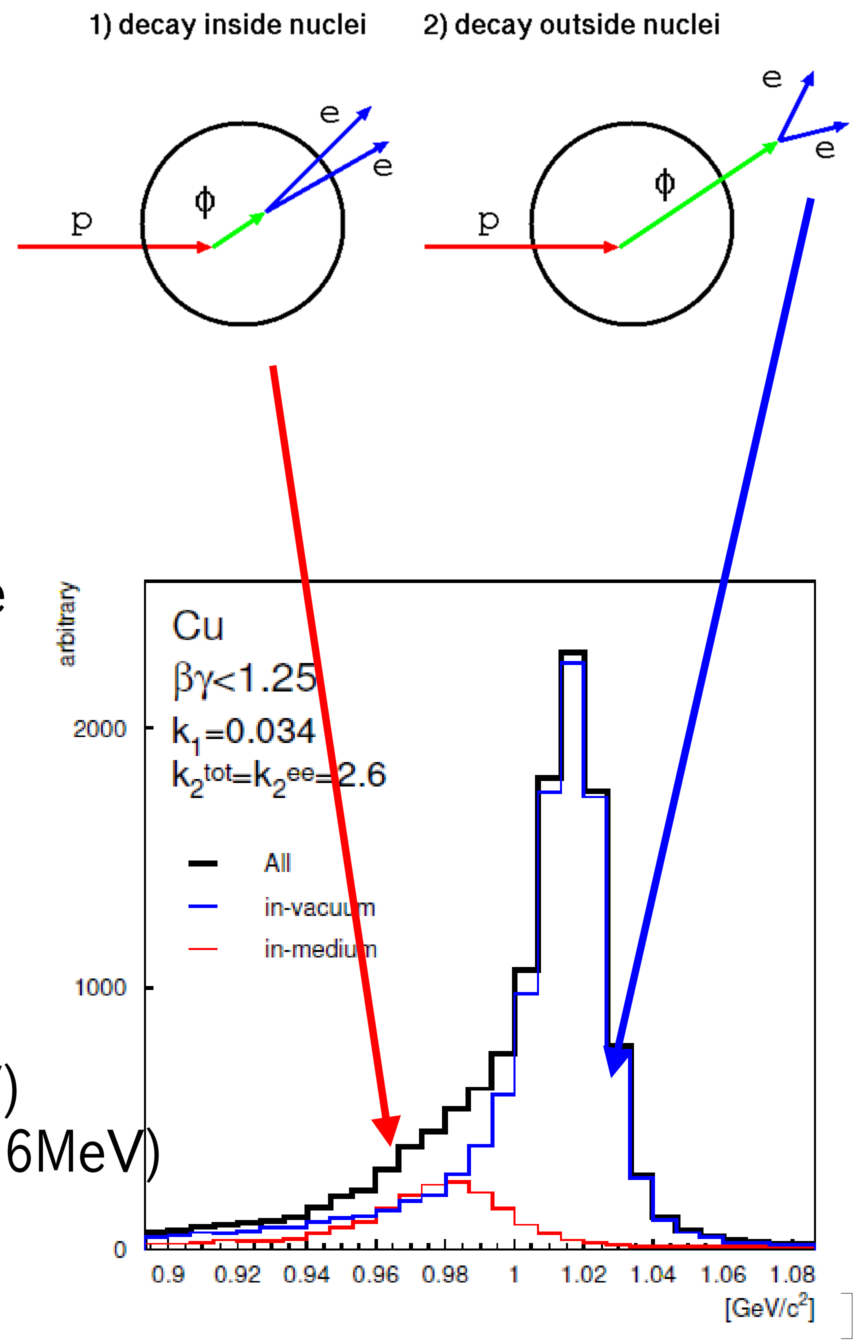

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Summary (1)

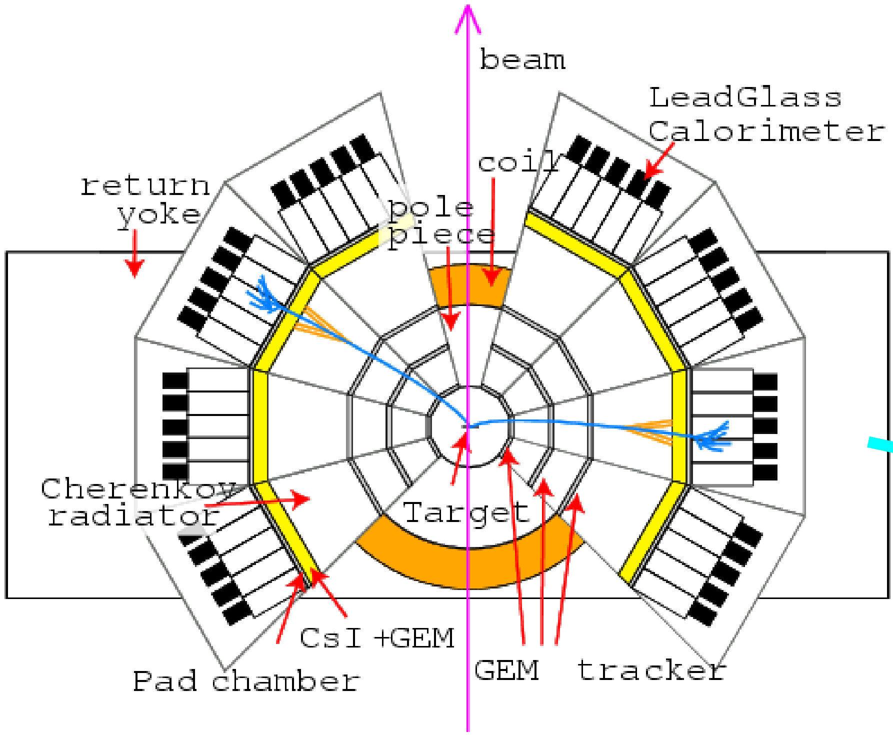
- KEK-PS E325 measured the e^+e^- & K^+K^- decay of slowly moving vector mesons in nuclei produced by 12-GeV proton beam to explore the chiral symmetry restoration at the normal nuclear density, T=0.
- Observed e^+e^- invariant mass spectra have excesses below the ω meson peak, which cannot be explained by known hadronic sources in normal (unmodified) shape. These suggest modification of ρ (and ω) meson.
  - Simple model calculation including predicted modification of ρ & ω reproduces the observed spectra. (~9% of mass reduction)
- $\phi \rightarrow e^+e^-$ also have excess, for the larger target, slowly moving component : the first result in the world for the ϕ-meson spectral modification
  - model calc. including mass shift and width broadening in nuclei also reproduces the data. (~3.4% of mass reduction & ~3.6-times broadening)
- Deduced modification parameters are almost consistent with the theoretical prediction using in-medium QCD sum rule.

From "mass modification" to physics

- Mass shape modification of vector mesons in medium looks to be established by many experimental results (E325/CLAS-G7/TAPS at the lower energy, NA60/CERES in HI collision)
  - statements contradict each other
    - mass dropping and/or width broadening
    - depending on the interpretation models to include the matter size effect
  - physics
    - only hadronic effects ? or chiral restoration ?
- Next step in the invariant-mass approach
  - put an emphasis on $\phi \rightarrow e^+e^-$: less ambiguous than ρ/ω case
    - ρ's broad and complicated shape, ρ–ω interference, ρ/ω ratio, etc.
  - systematic study of the shape modification
    - nuclear matter size dependence : larger/smaller nuclei, collision geometry
    - momentum dependence : predicted, but not measured yet

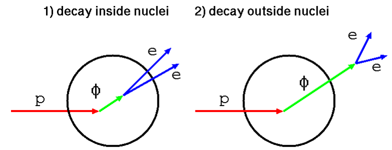
J-PARC E16 experiment

Future experiment :
Systematic study of the modification of vector meson spectra in nuclei
to approach the chiral symmetry restoration

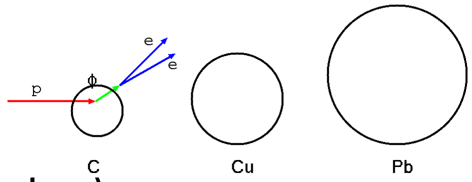


J-PARC E16 experiment

- Status : 2007/3 : stage1 (physics) approval / Detector R&D is on going
- Main goal : collect ˜1-2 x 10^5 $\phi \rightarrow e^+e^-$ for each target in 5 weeks
  using 30 (or 50) GeV p +A (C/CH_2/Cu/Pb) reactions



  - statistics : ˜100 times as large as E325
  - **systematic study of the modification**
    - velocity & nuclear size (0˜10 fm) dependence
      - proton/Pb targets / collision geometry (impact parameter)



    - momentum dependence (dispersion relation)
  - mass resolution : < 10 MeV (E325 : 10.7 MeV for φ)

Collaboration

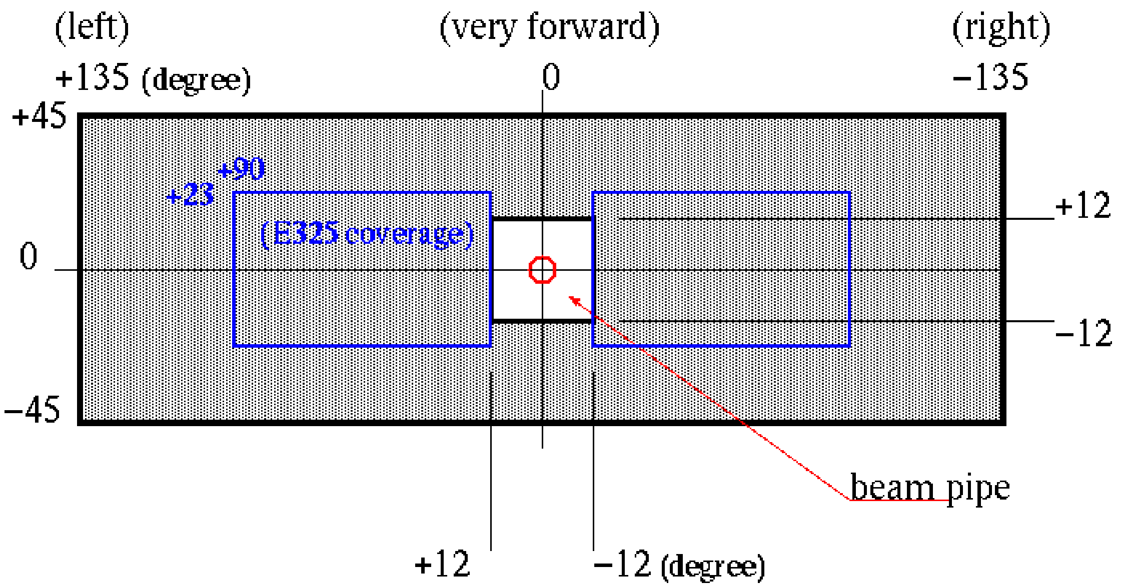
RIKEN	S.Yokkaichi, H. En'yo, F. Sakuma, K. Aoki	Hiroshima-U	K. Shigaki
U-Tokyo	K. Ozawa, K. Utsunomiya, Y. Watanabe	CNS, U-Tokyo	H. Hamagaki
KEK	A.Kiyomichi, M. Naruki, R.Muto, S. Sawada, M. Sekimoto		

Proposal http://ribf.riken.jp/˜yokkaich/paper/jparc-proposal-0604.pdf

To collect high statistics

- For the statistics 100 times as large as E325, new spectrometer is required.
  - To cover larger acceptance : x˜ 5
  - Higher energy beam (12 → 30/50 GeV) : x ˜2 of production
  - Higher intensity beam ($10^9 \rightarrow 10^{10}$ /spill (1sec)) : x 10 (→ 10MHz interaction on

Geometrical (horizontal & vertical) coverage of the spectrometer

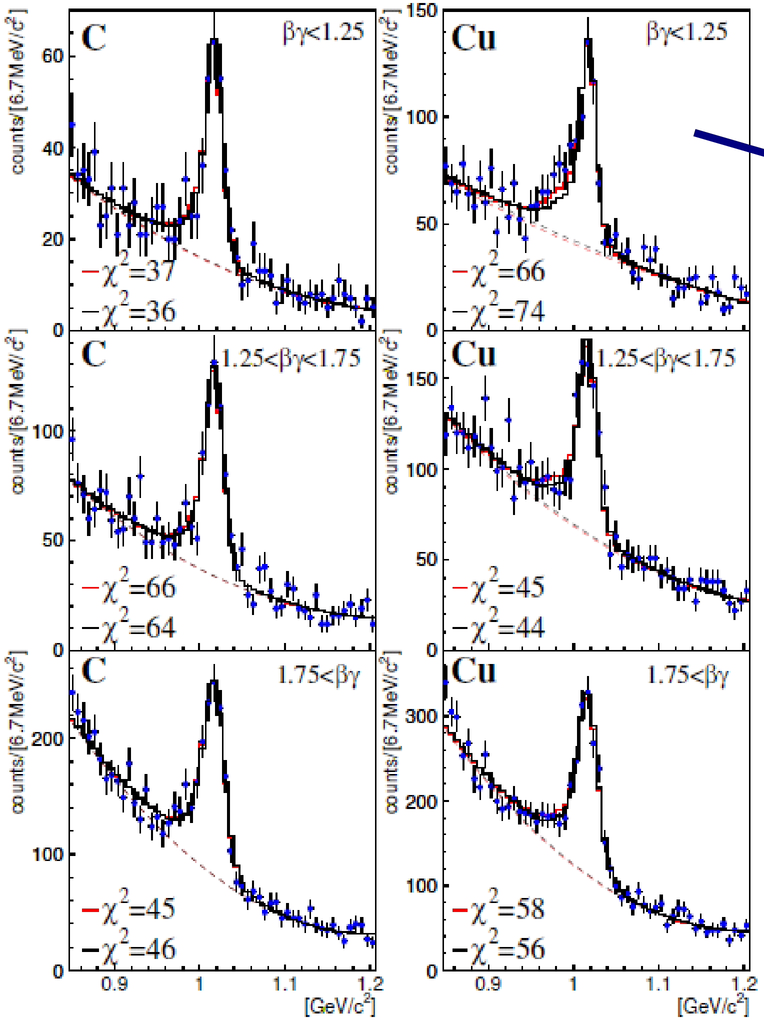


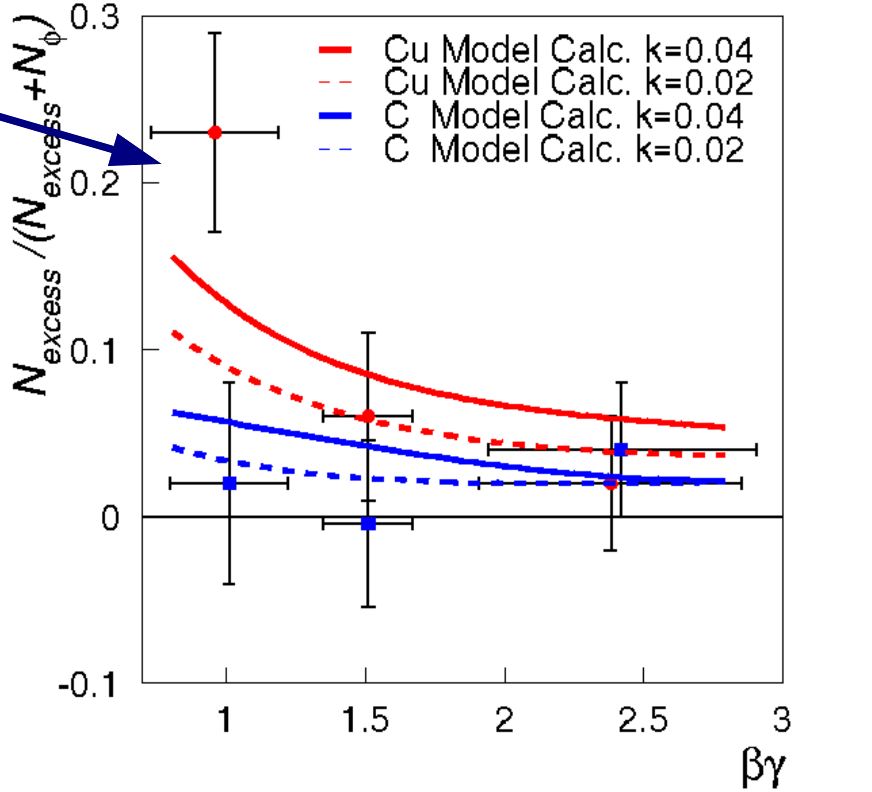
Target configuration

nuclei	interaction length(%)	radiation length(%)	thickness [μm]
C	0.05	0.1	200
CH_2	0.05	0.1	400
Cu	0.05	0.5	80
Pb	0.01	0.3	20

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)
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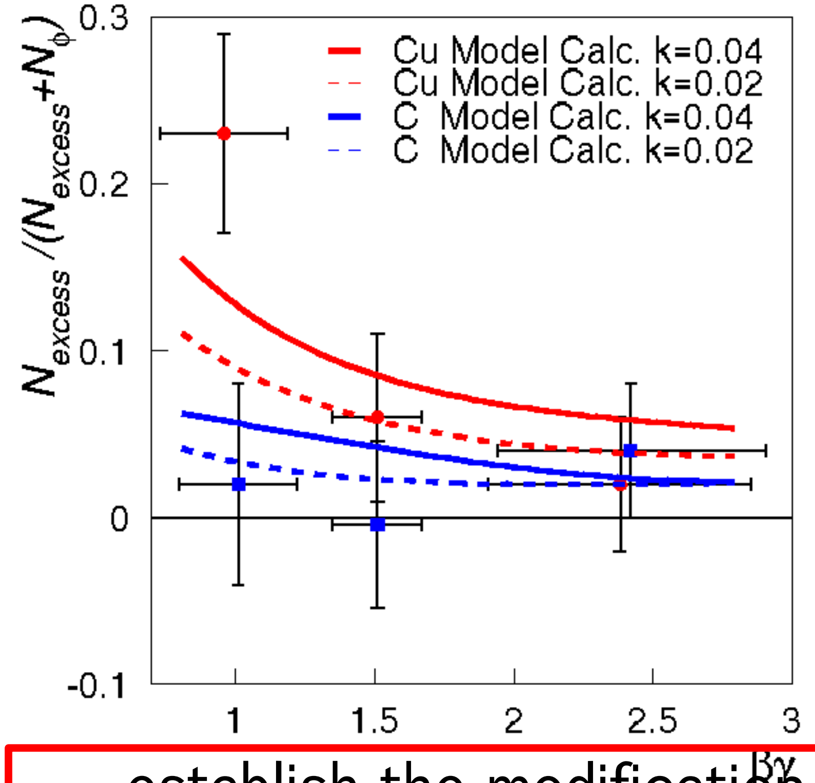
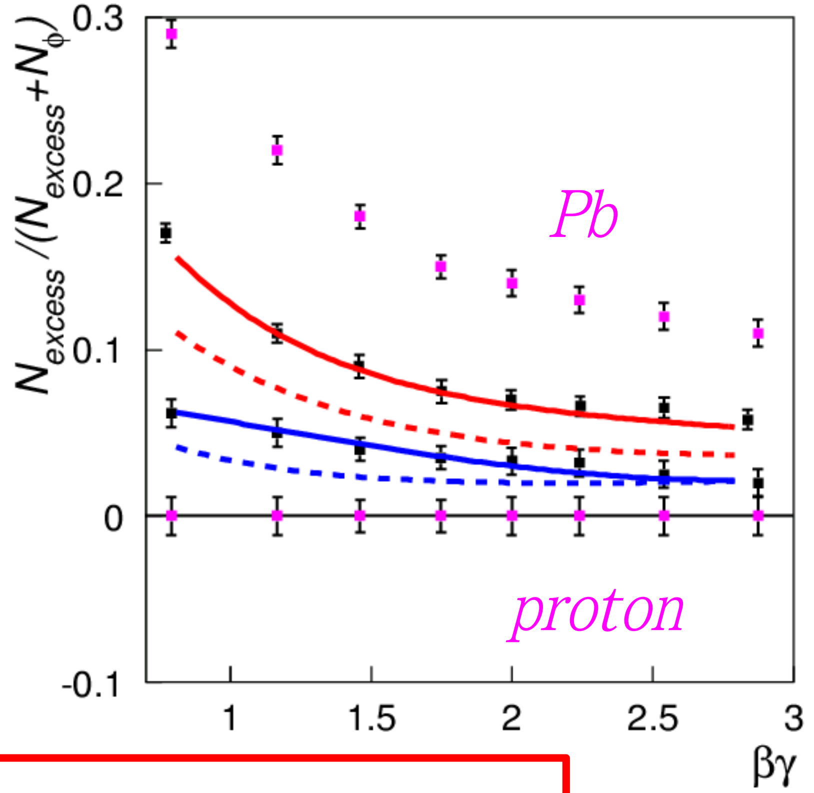
- systematic study : all the data should be explained the interpretation model



x 100 stat.



- establish the modification
-

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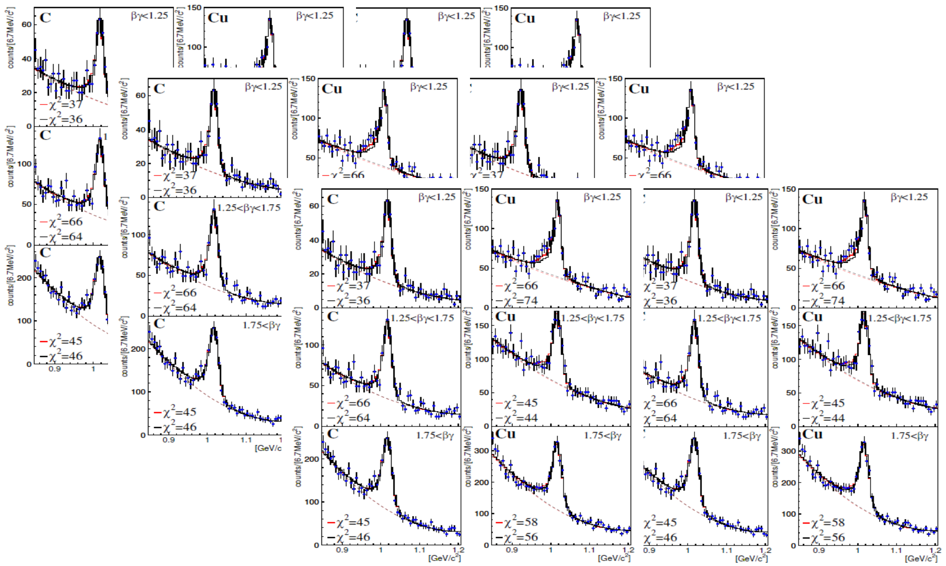
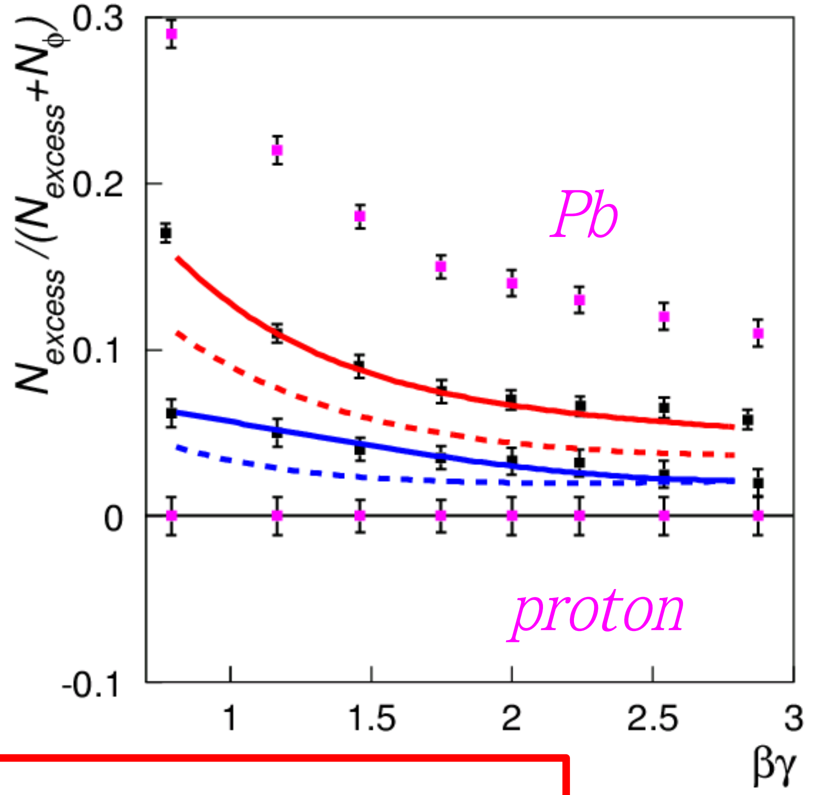
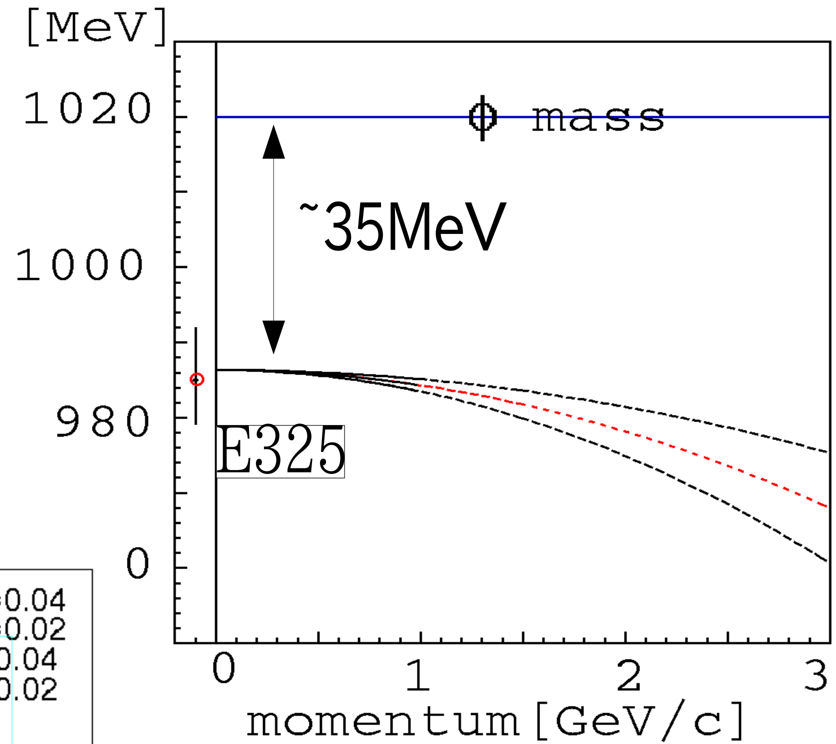


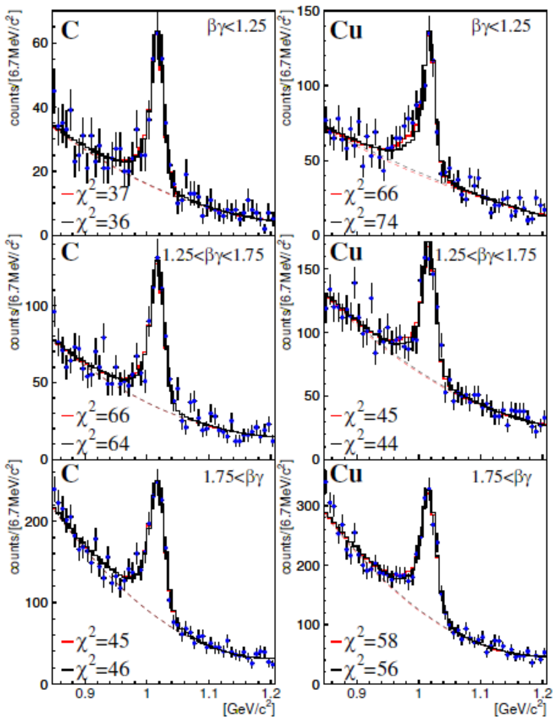


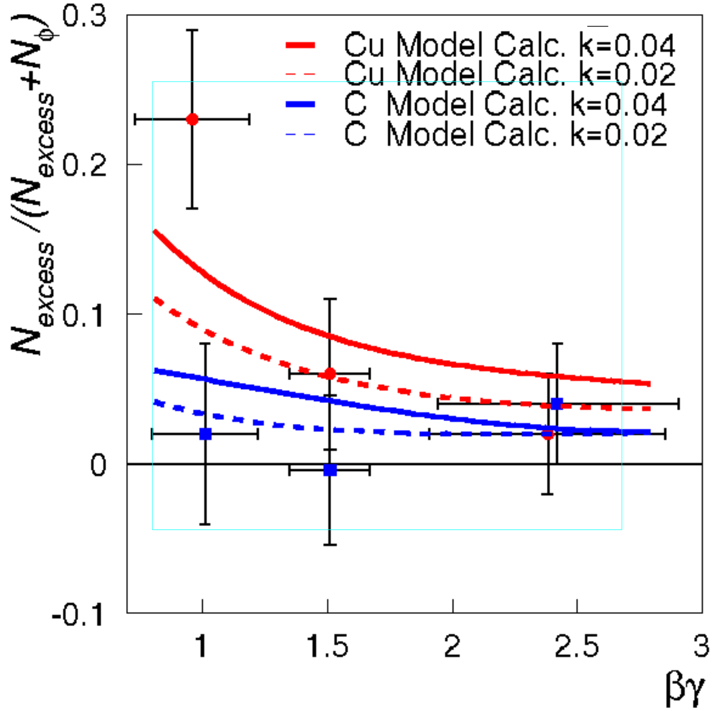
- establish the modification
- check the interpretation model with shape analysis for each histogram

dispersion relation (mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV)
- current E325 analysis neglects the dispersion (limited by the statistics)

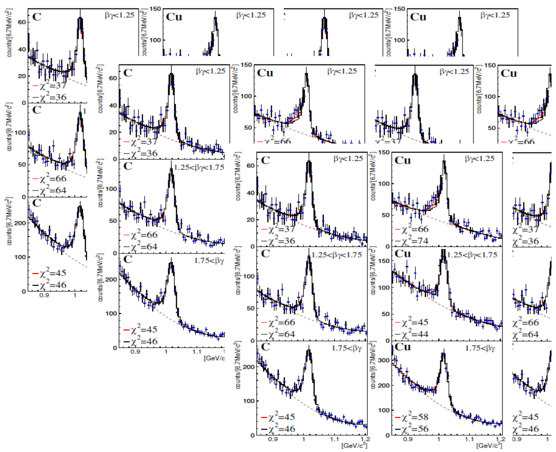


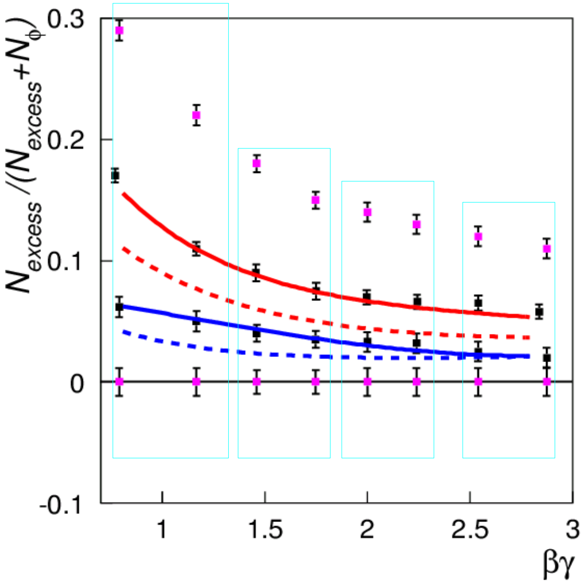


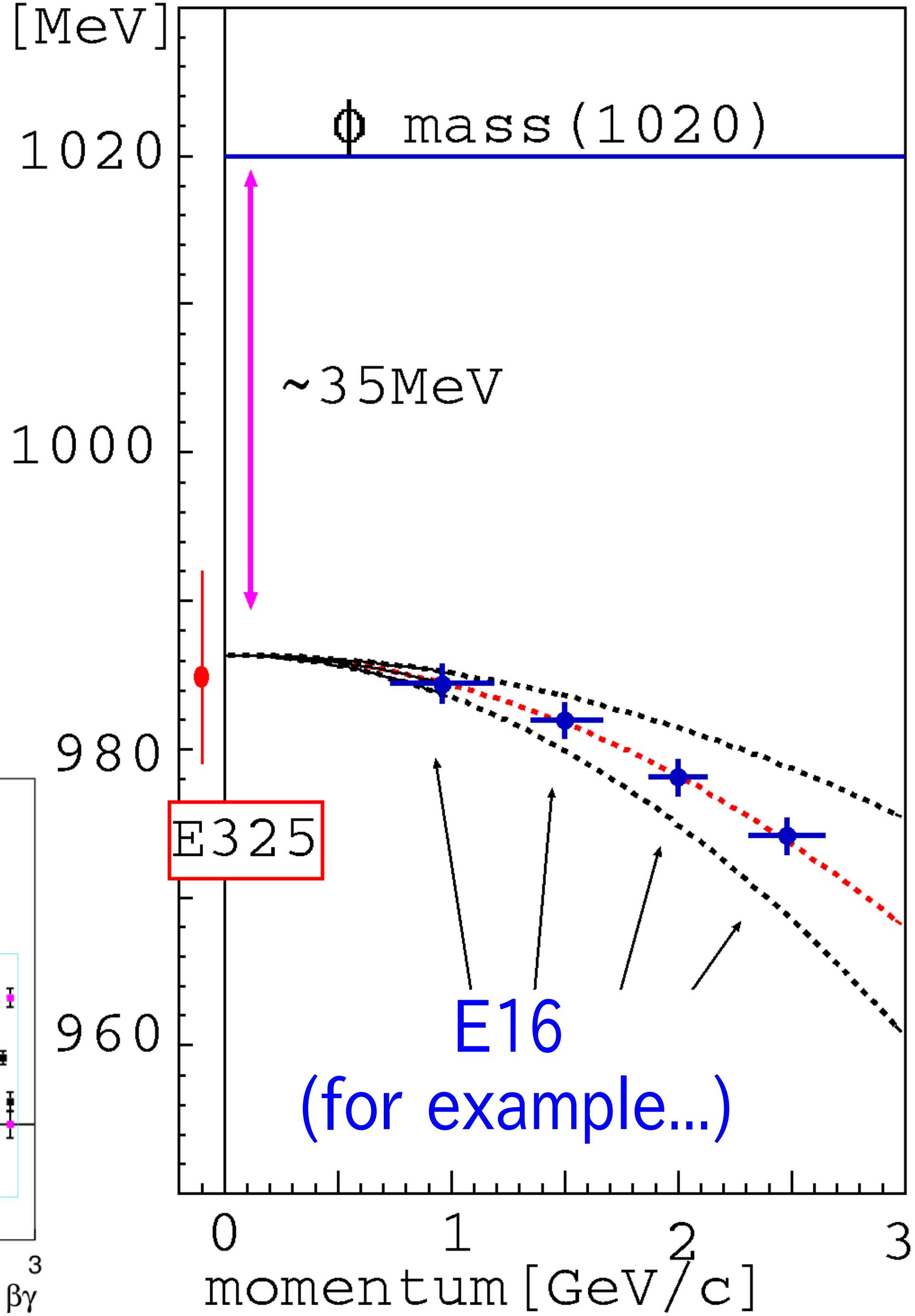


dispersion relation (mass VS momentum)

- 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



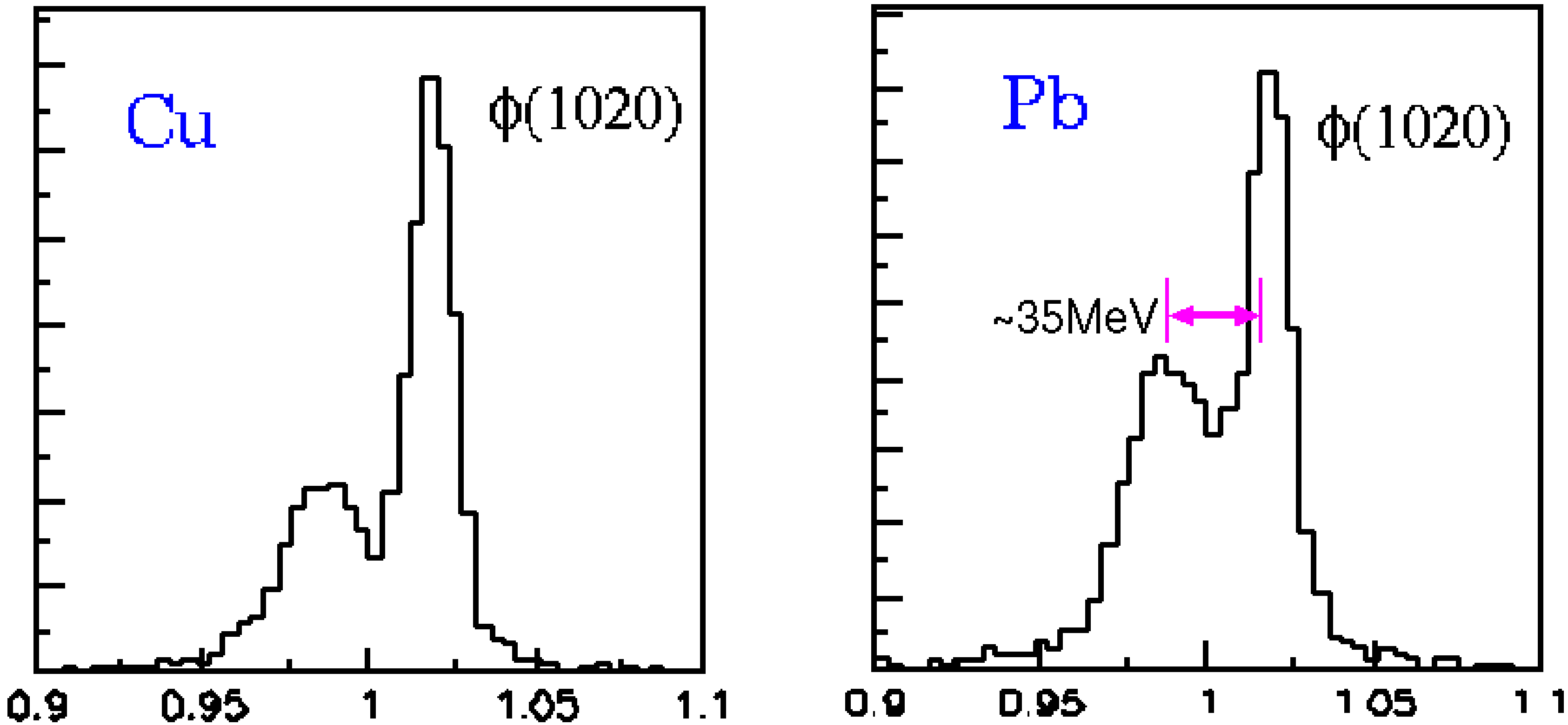




mass resolution requirement

- mass resolution should be kept less than ~10MeV
- Very ideal case : very slow mesons w/ best mass resolution:

$\beta\gamma<0.5$, $\sigma=5$ MeV



(model calc.)

Summary (2)

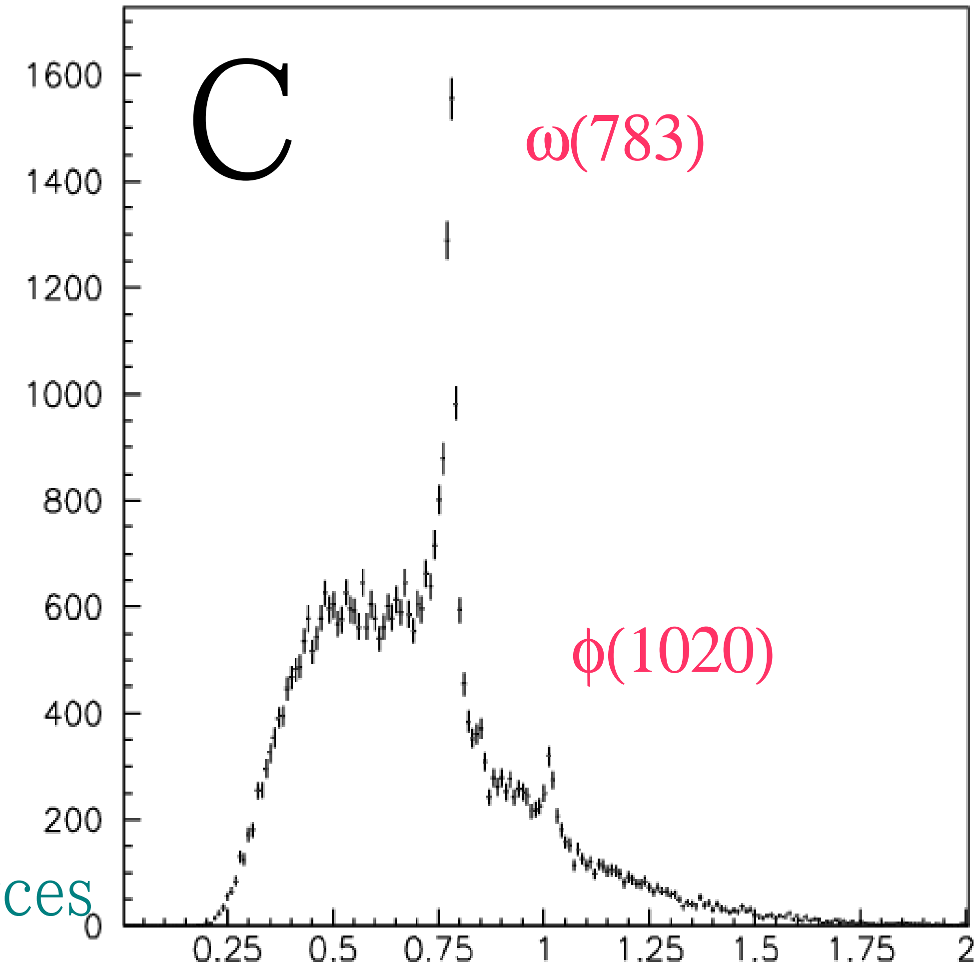
- Spectral modification of vector mesons are observed in nuclei (and also in heavy ion collisions).
  - under discussion about the physics behind such phenomena
- Next step at J-PARC : E16 exp.
  - systematic measurements of matter size (0˜10 fm) and momentum dependences of the modification of ϕ meson
-
- Possible further steps :
  - measurements of meson decays from mesic nuclei
    - ω (ϕ) bound state in nuclei using π (pbar) beam at J-PARC
  - density dependence using heavy-ion collisions
    - GSI, J-PARC

Backup slides…

-

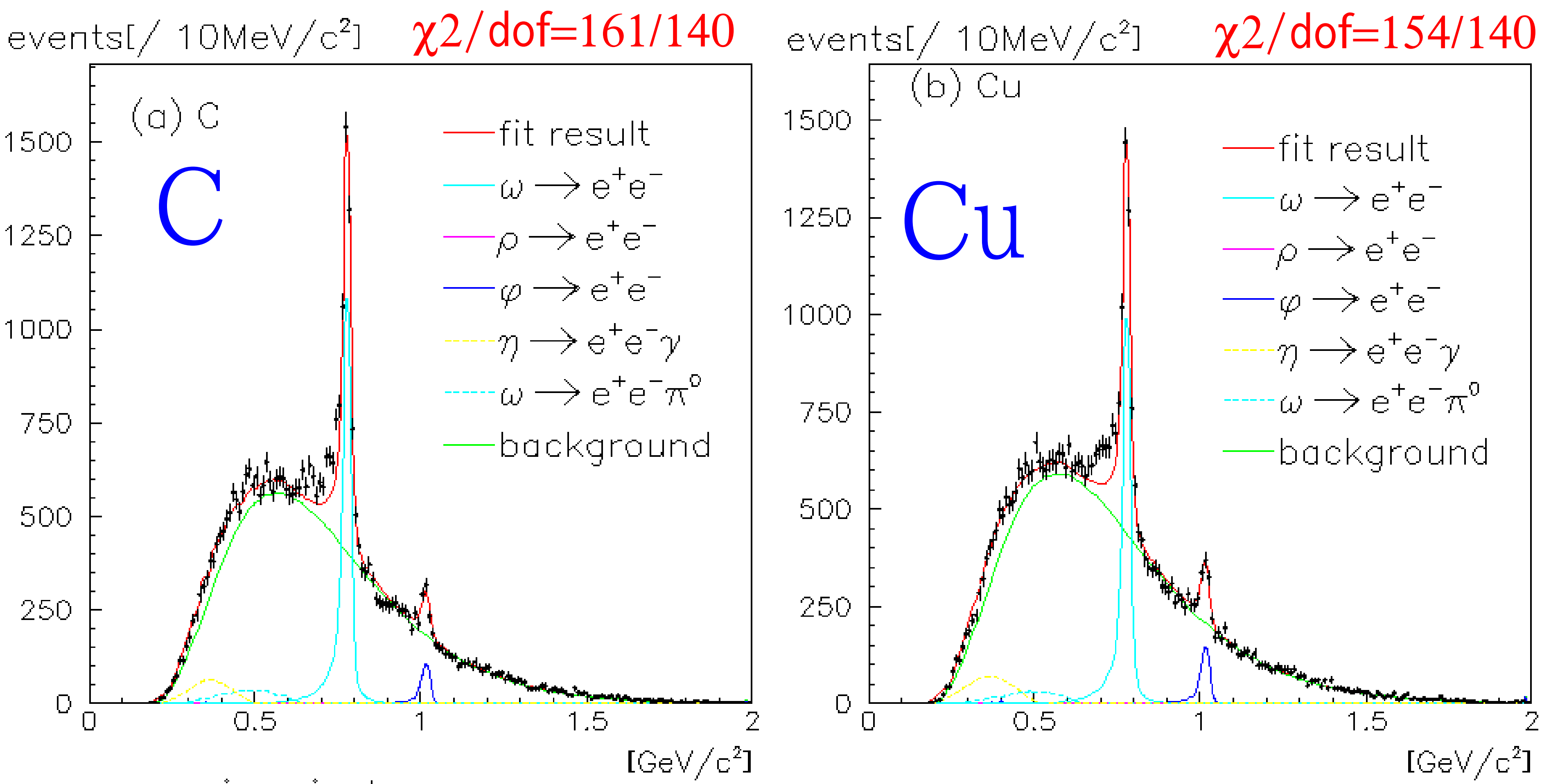
Observed e^+e^- invariant mass spectra

- 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

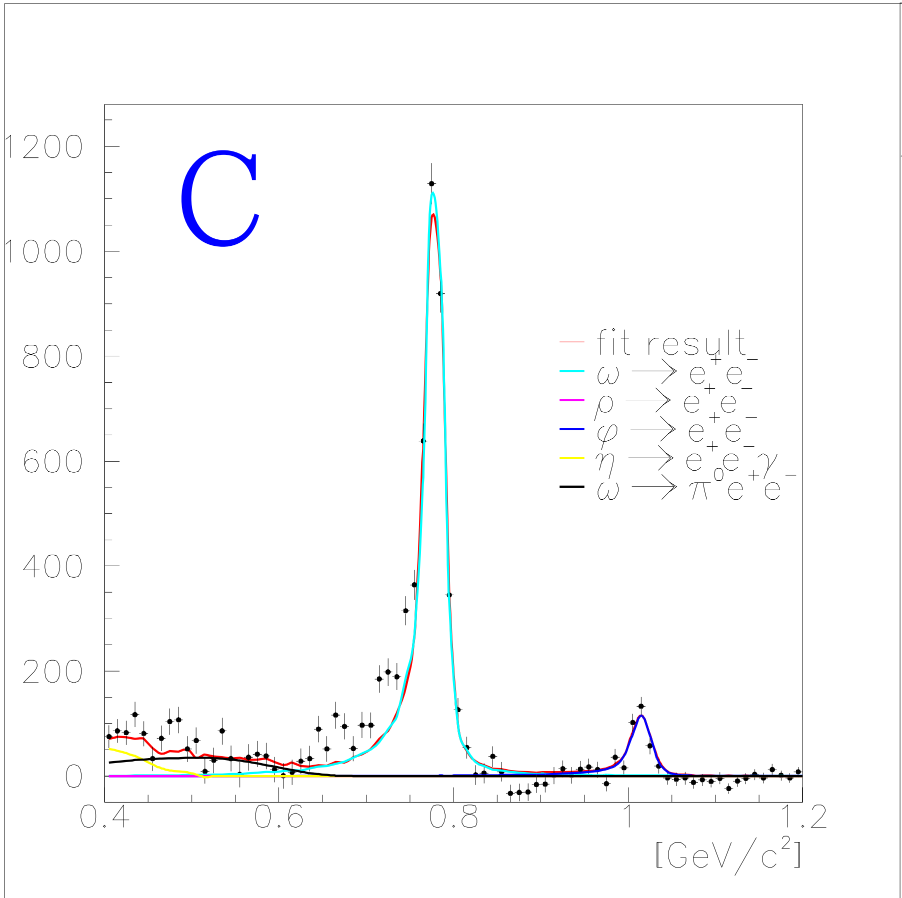
Fitting results (ρ/ω)

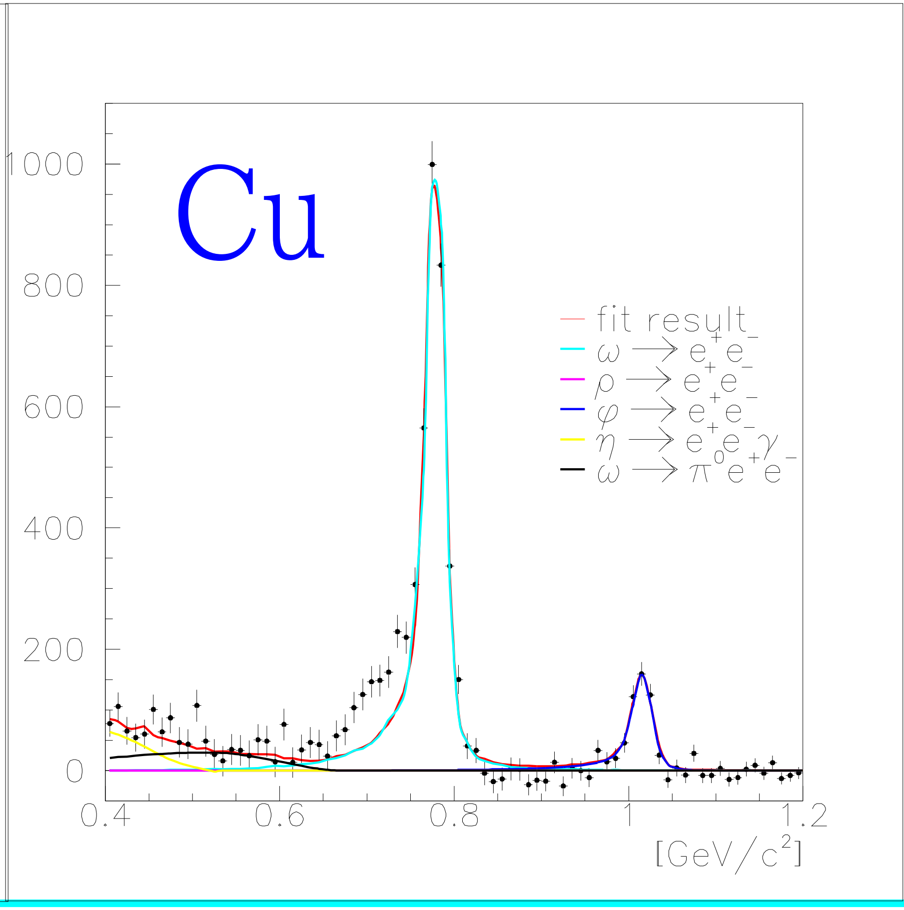


- 1) excess at the low-mass side of **ω**
  - To reproduce the data by the fitting, we have to exclude the excess region : **0.60~0.76** GeV
- 2) ρ–meson component seems to be vanished !

Fitting results (BKG subtracted)

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



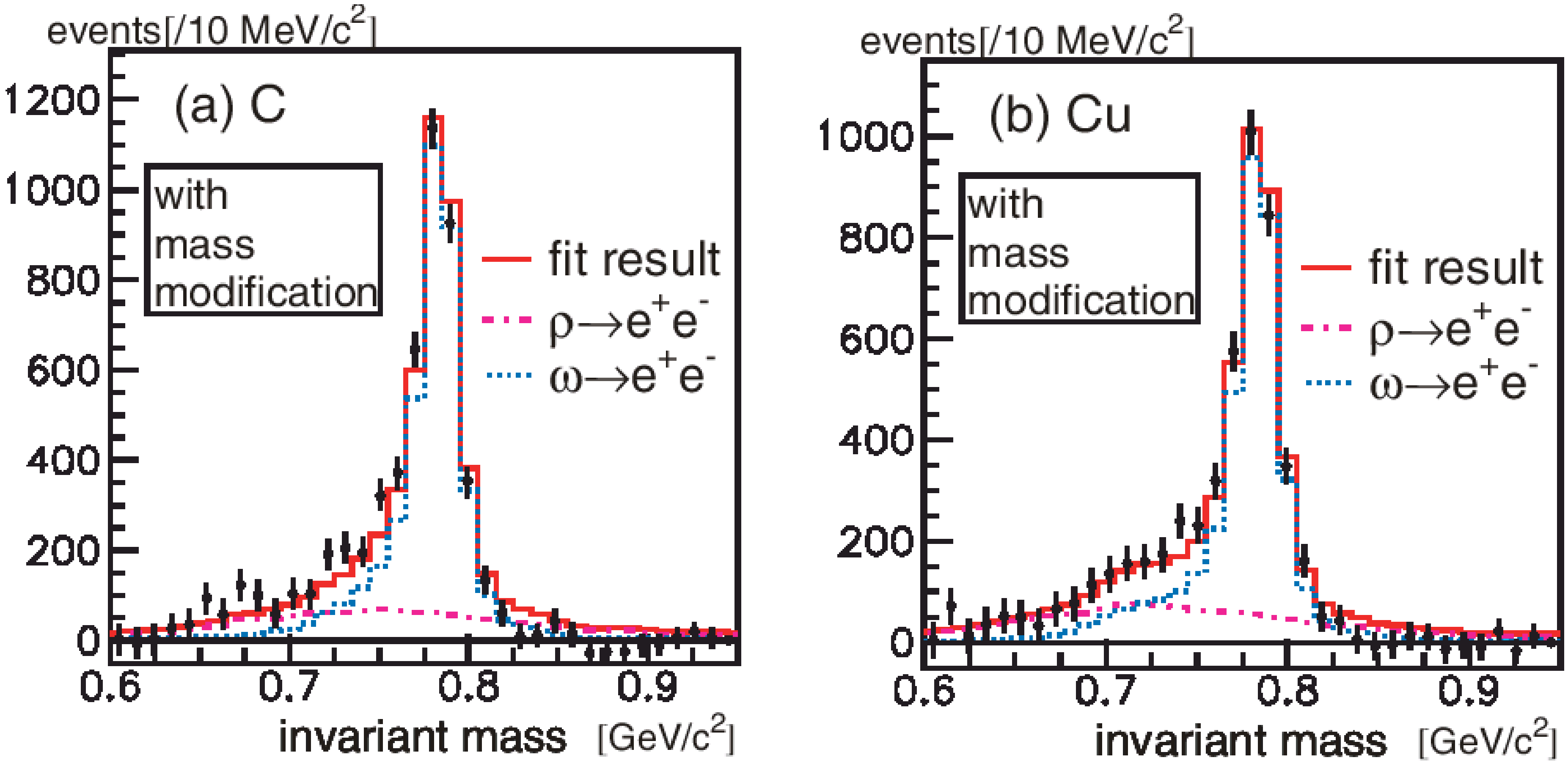


- However, ρ/ω =1.0±0.2 in former experiment (p+p, 1974)

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

Discussion (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



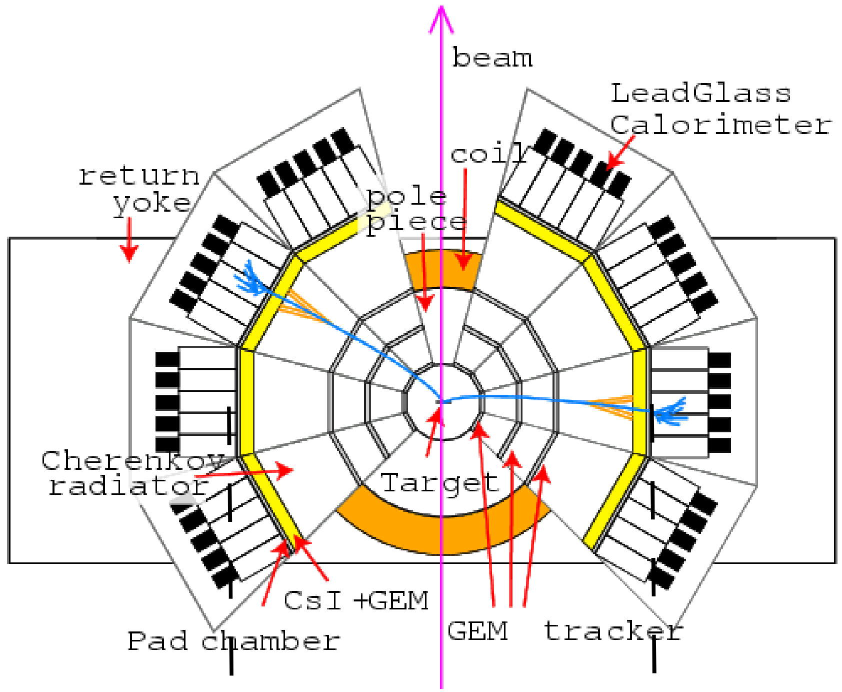
From the fit : k=0.092 ± 0.002 : ˜ 9 % reduced at normal nuclear density

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

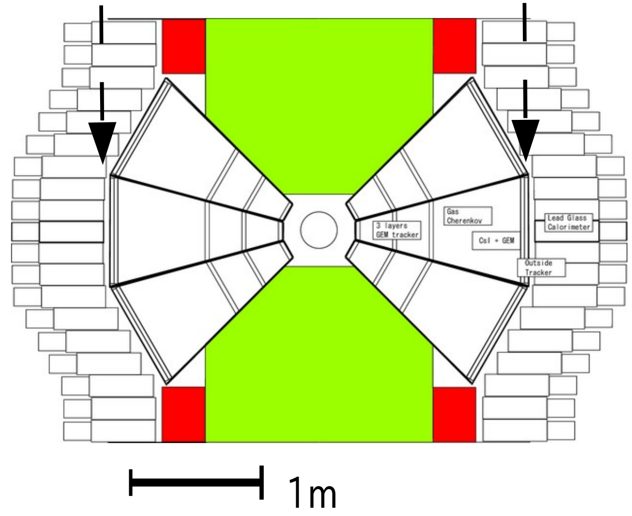
Proposed spectrometer

- Spectrometer Magnet : reuse E325 's
  - remodeling the pole / repairing the coil
  - stronger field for compact detector size
- GEM(Gas electron multiplier) Tracker
  - 0.7mm pitch strip readout
- Two-stage Electron ID (10^{-4} π rejection)
  - Hadron Blind Detector (Gas Cherenkov)
    - GEM+CsI photocathode
    - hexagonal pad readout (~30mm ϕ)
  - Leadglass EMC: reuse of TOPAZ
- ~70K Readout Channels (in 26 segments)
  - cf. E325: 3.6K, PHENIX:~300K (w/o VTX)
- Cost : ~$5M (including ~$2M electronics)
  - cf. E325: $2M not including electronics

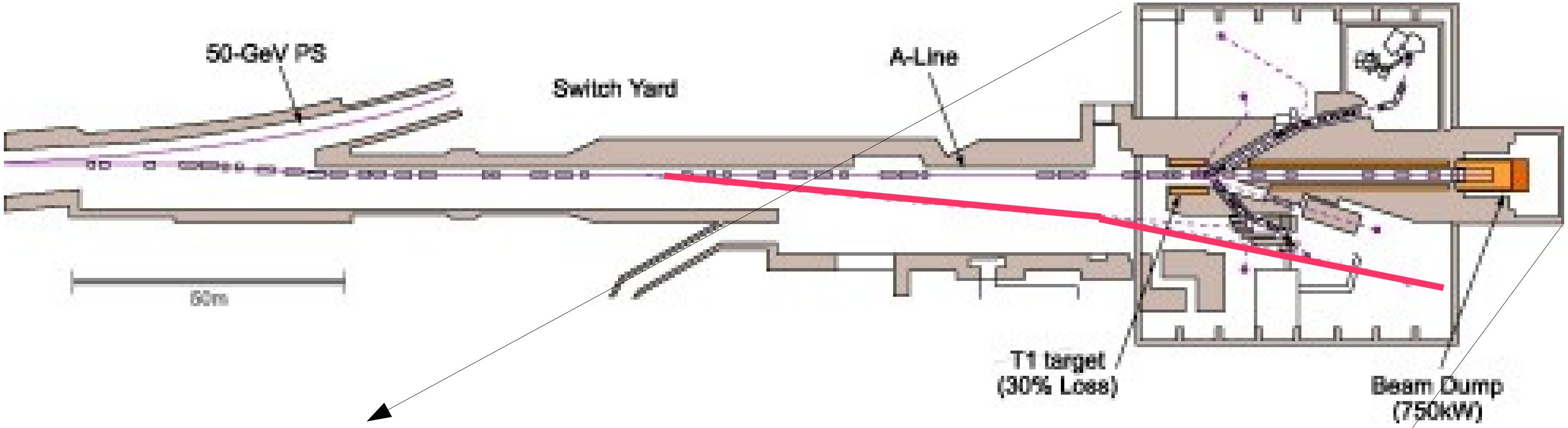
Plan view

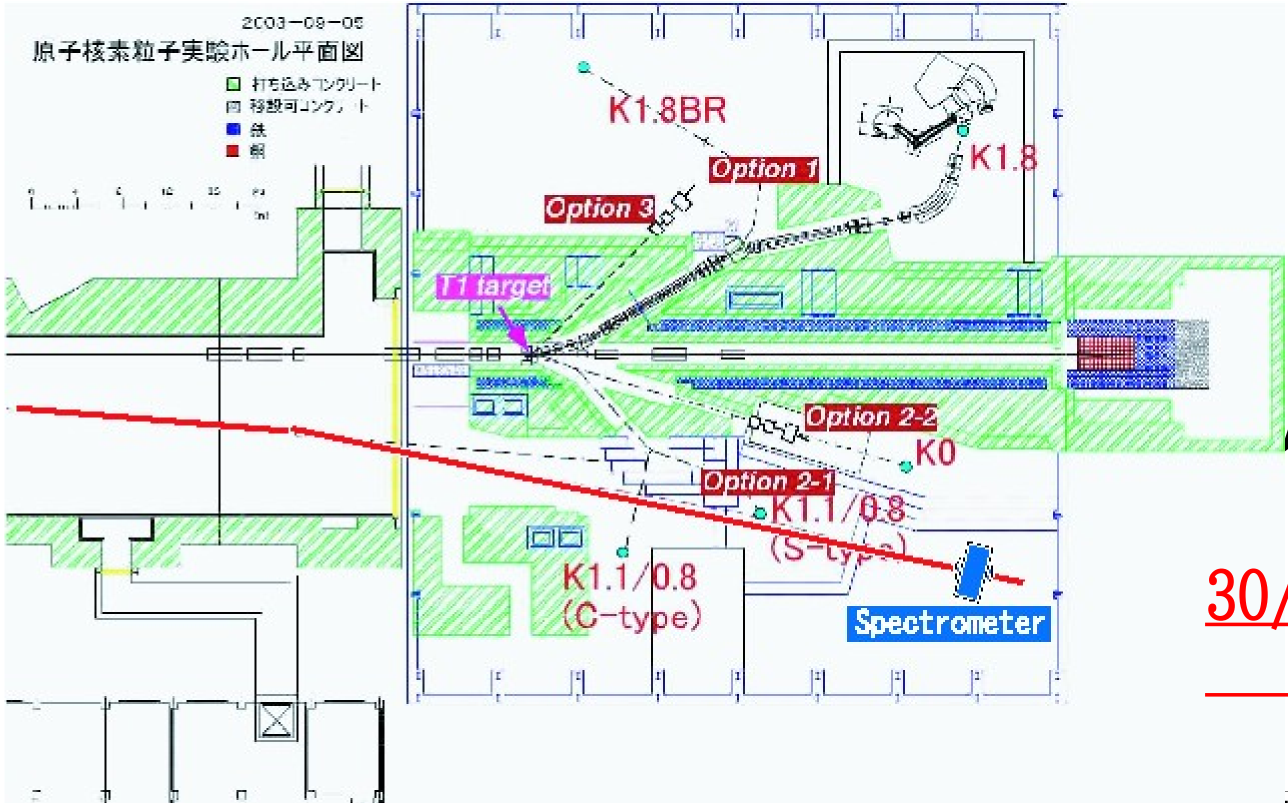


Beam view



High momentum Beamline

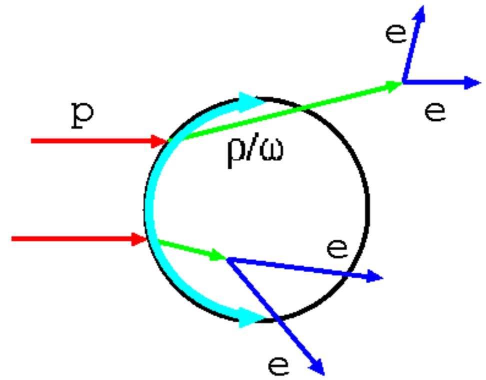




30/50GeV proton beam
(upto 10^{12} /sec)

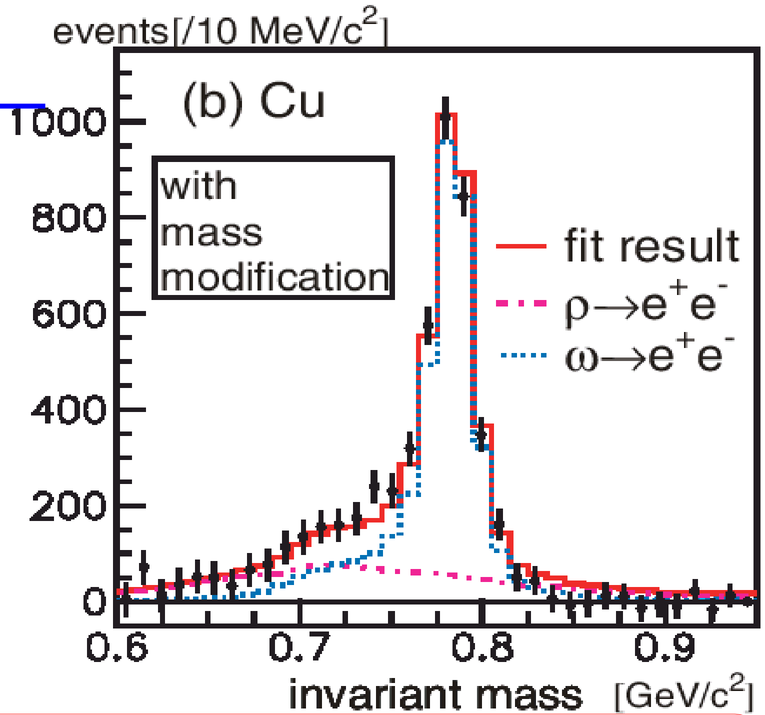
Discussion : fit with modification

- 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)

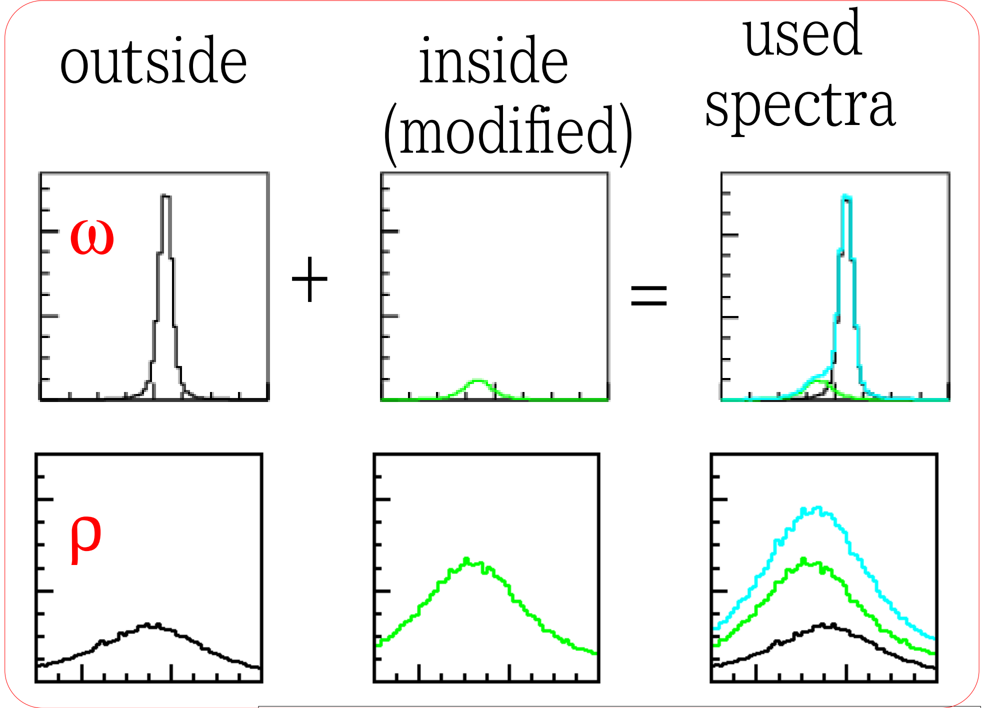


	ρ, ω	φ
m*/m	$1 - k_1^{\rho/\omega} \rho/\rho_0$	$1 - k_1^{\phi} \rho/\rho_0$
Γ*/Γ	1	$1 + k_2 \rho/\rho_0$
generation point	surface	uniform
α ($\sigma(A) \propto A^{\alpha}$) [PRC74(06)025201]	0.710±0.021	0.937±0.049
momentum dist.	measured	
density distribution	Woods-Saxon, R= C:2.3fm/Cu:4.1fm	

Remark on the model fitting

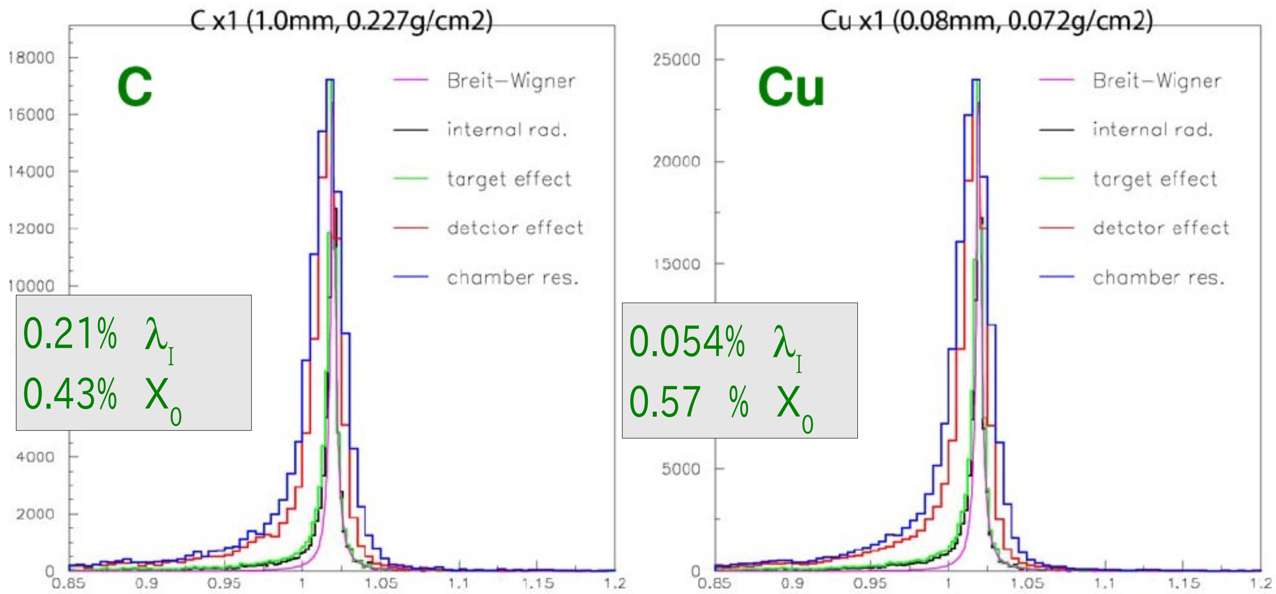


- constraint at right side of peak
  - Introducing the width broadening (x2 & x3) are rejected by this constraint
  - prediction of ' ρ mass increasing' is also not allowed.
- ρ (ω) decay inside nucleus : 46%(5%) for C, 61%(10%) for Cu
  - used spectrum is the sum of the modified and not-modified components.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



experimental effects on the BW shape (E325)

- E325 Detector Sim.
  - target material is negligible for ~0.5% radiation length (X_0)
  - detectors :up to 4.5 % X_0 in the tracking region



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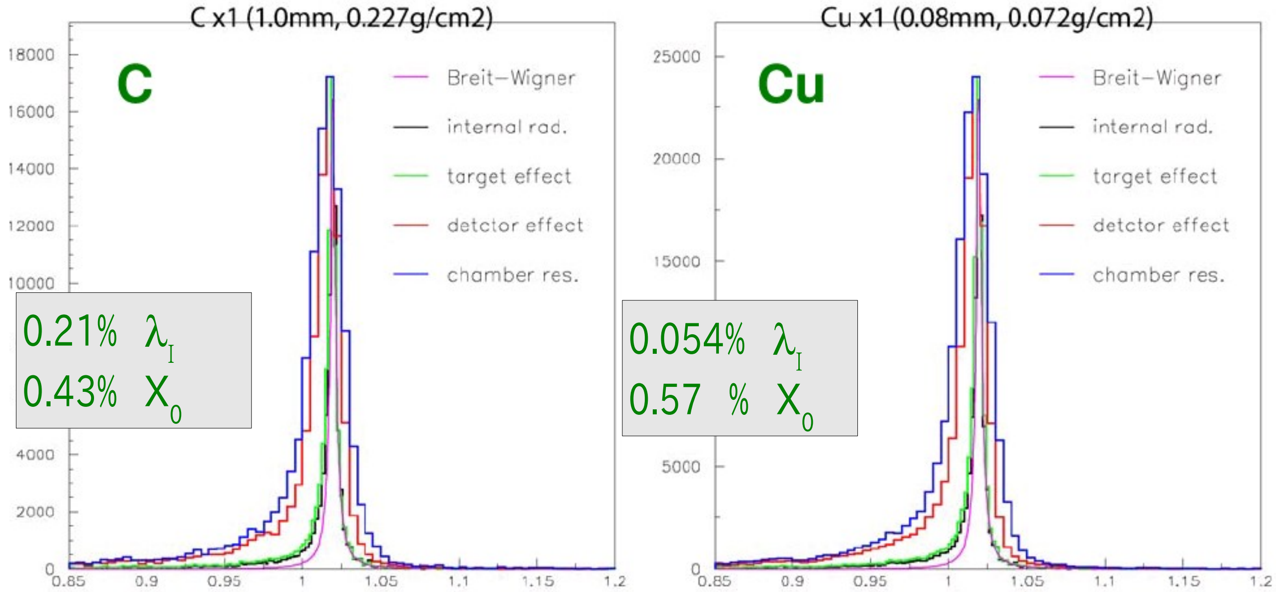
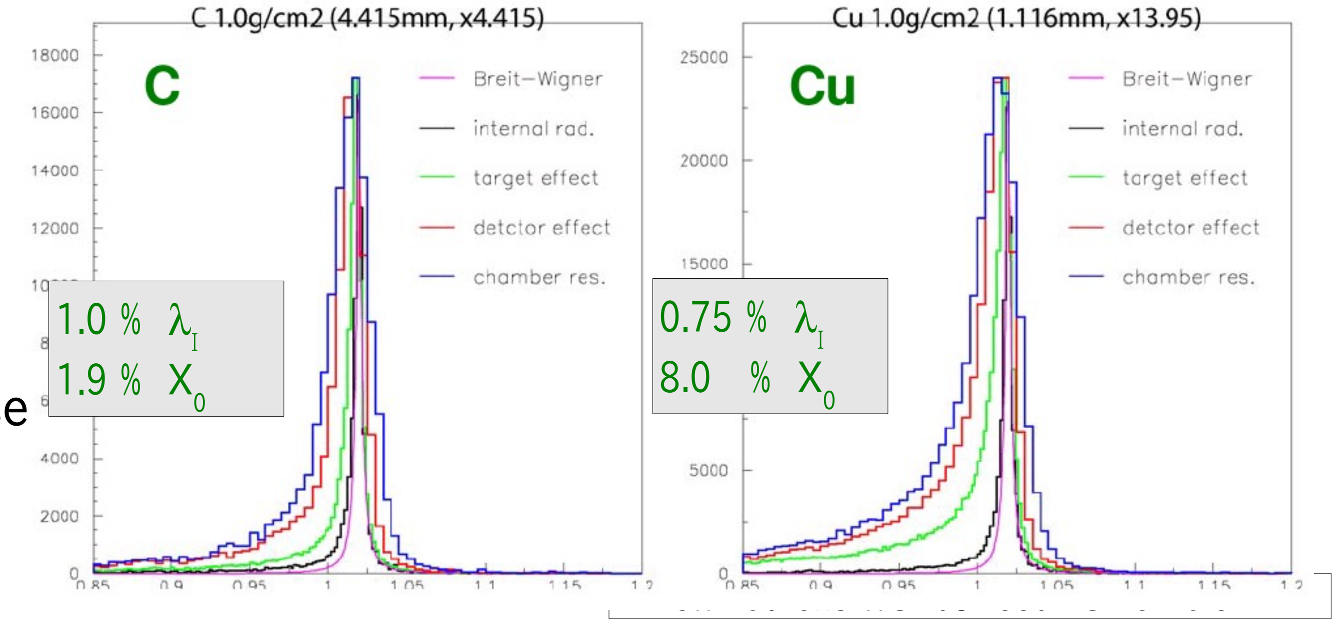


- In the case of the thick targets : 1g/cm^2
  - bremsstrahlung in target is so large for the Cu case



E325 Results (2)

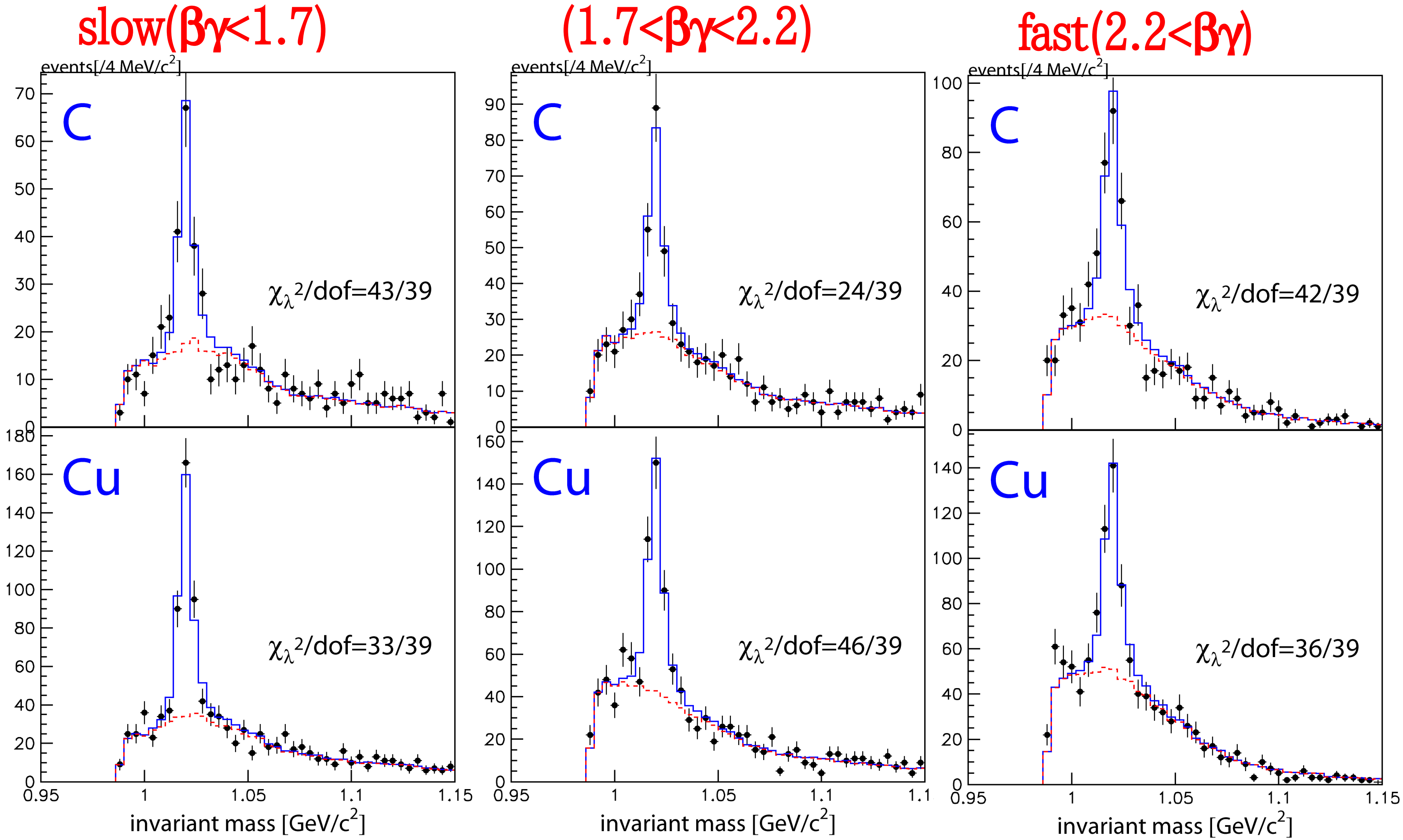
KK invariant mass spectra

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

Production Cross sections

T.Tabaru et al., PRC74(2006)025201

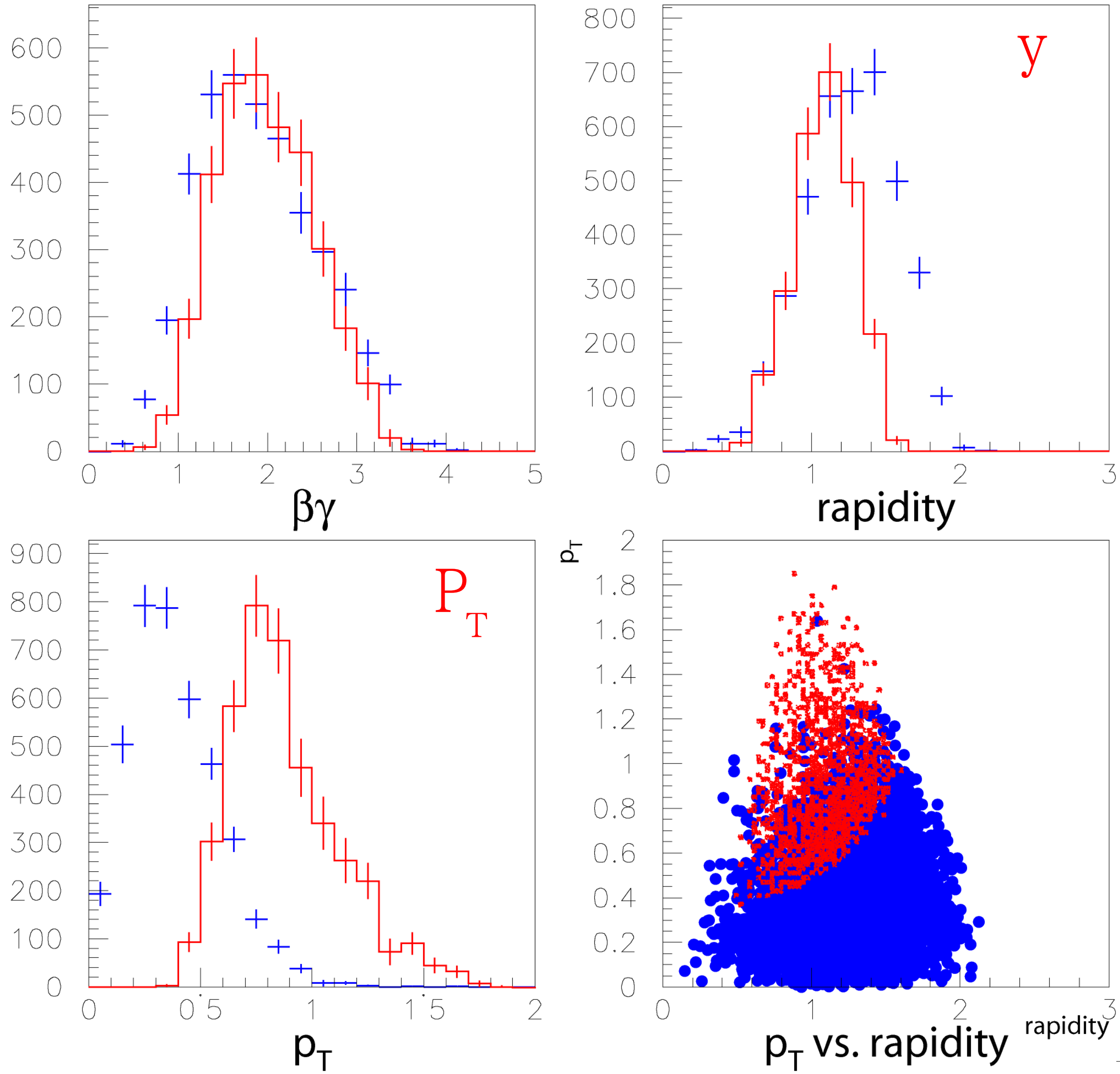
K^+K^- spectra of ϕ meson



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

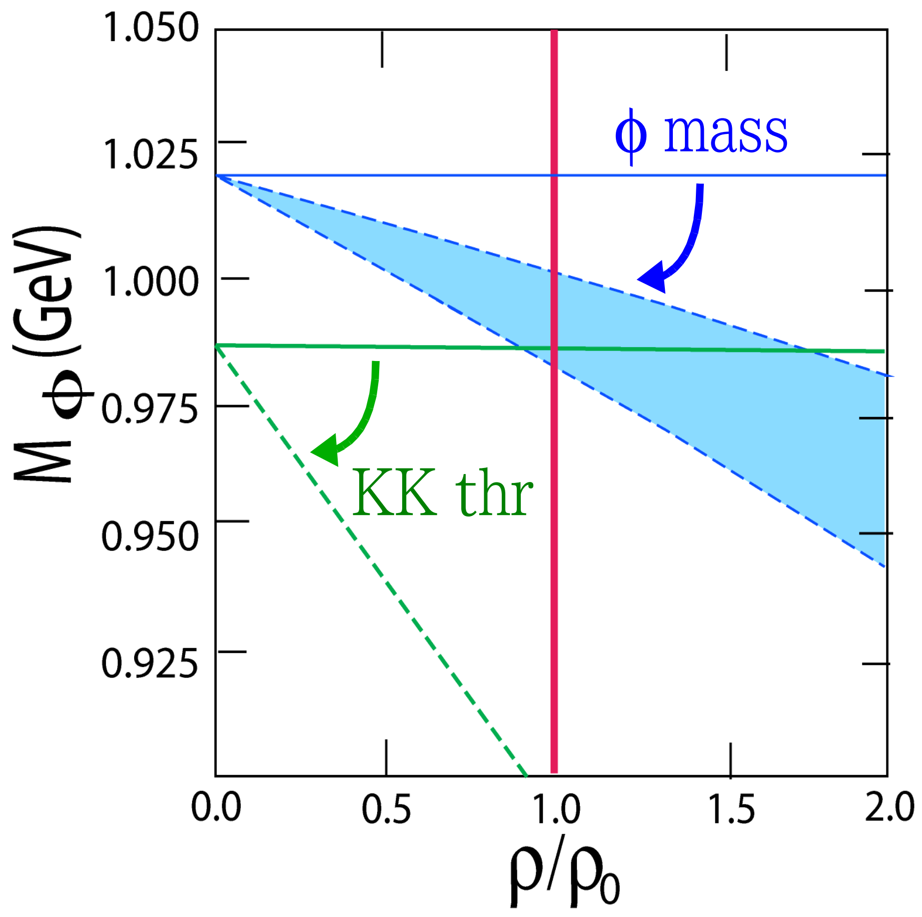
measured kinematic distribution of $\phi \to K^+K^-$ & $\phi \to e^+e^-$

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



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-} decreas
    - when K mass decrease : Γ_{K+K-} increase
- change of the ratio : Γ_{K+K-} / Γ_{e+e-} can be studied by measurement of parameter : the nuclear dependence of production cross sectic
  - 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

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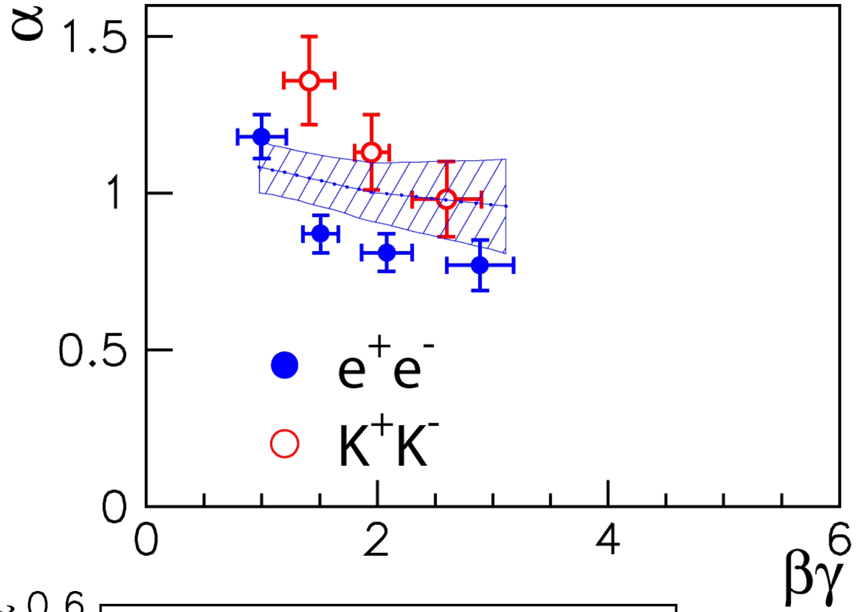
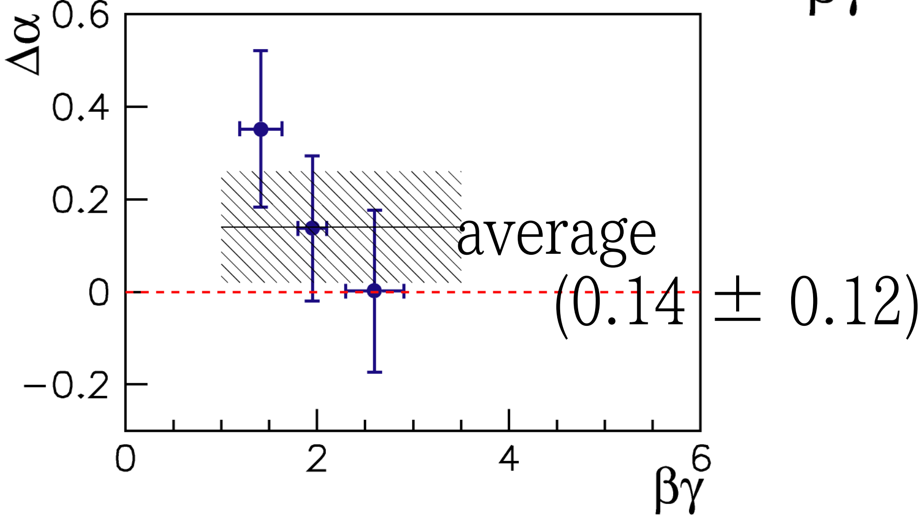
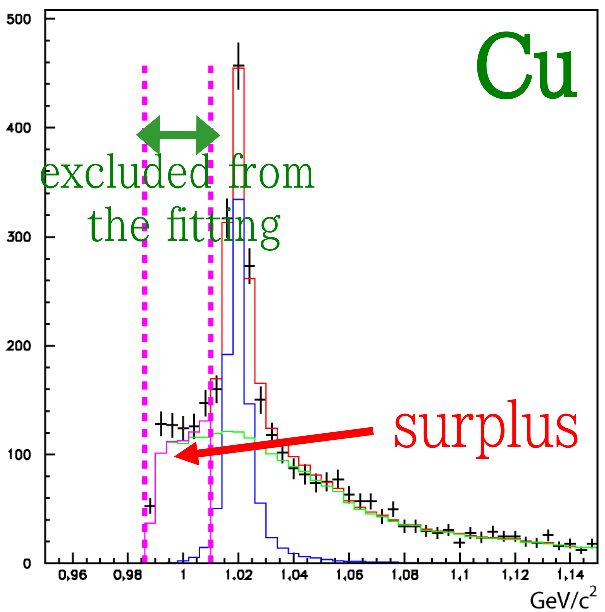
  - larger modification expected in larger nuclei
  - then, $\alpha_{K+K-} > \alpha_{e+e-}$, especially for slowly moving mesons
- ...looks such tendency but consistent within the errors : $\alpha_{K+K-} - \alpha_{e+e-} = 0.14 \pm 0.12$

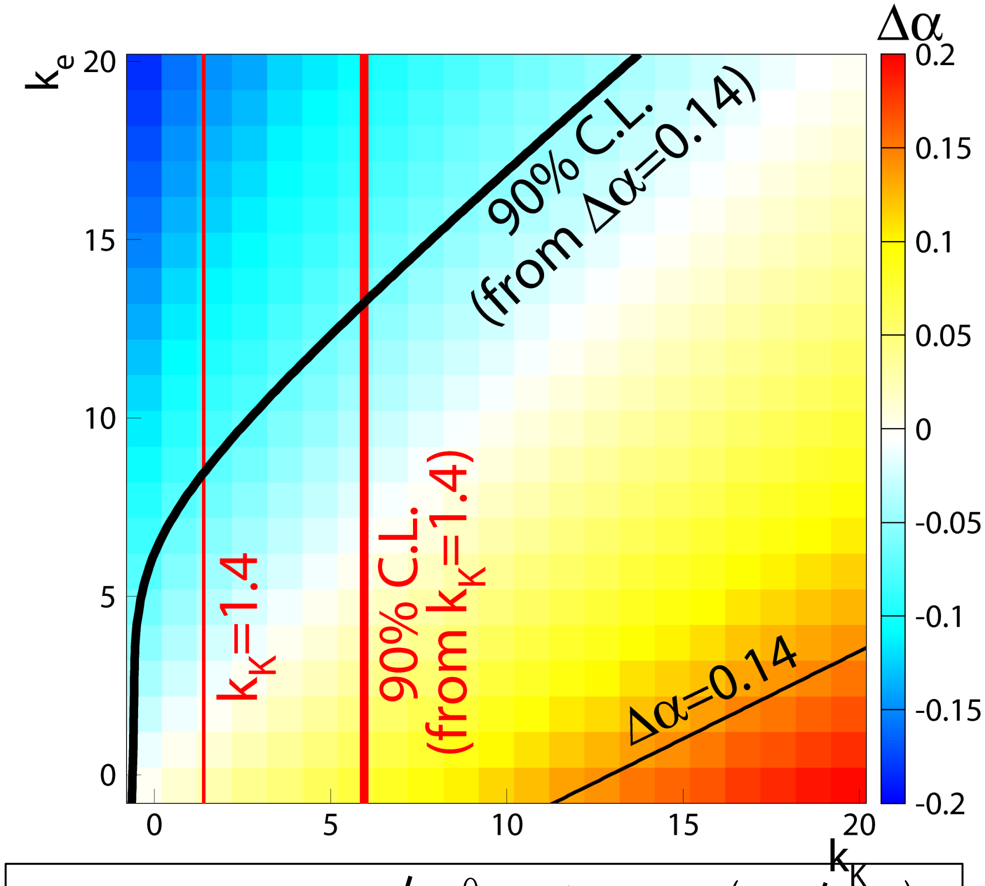




Limit to the ϕ width broadening

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





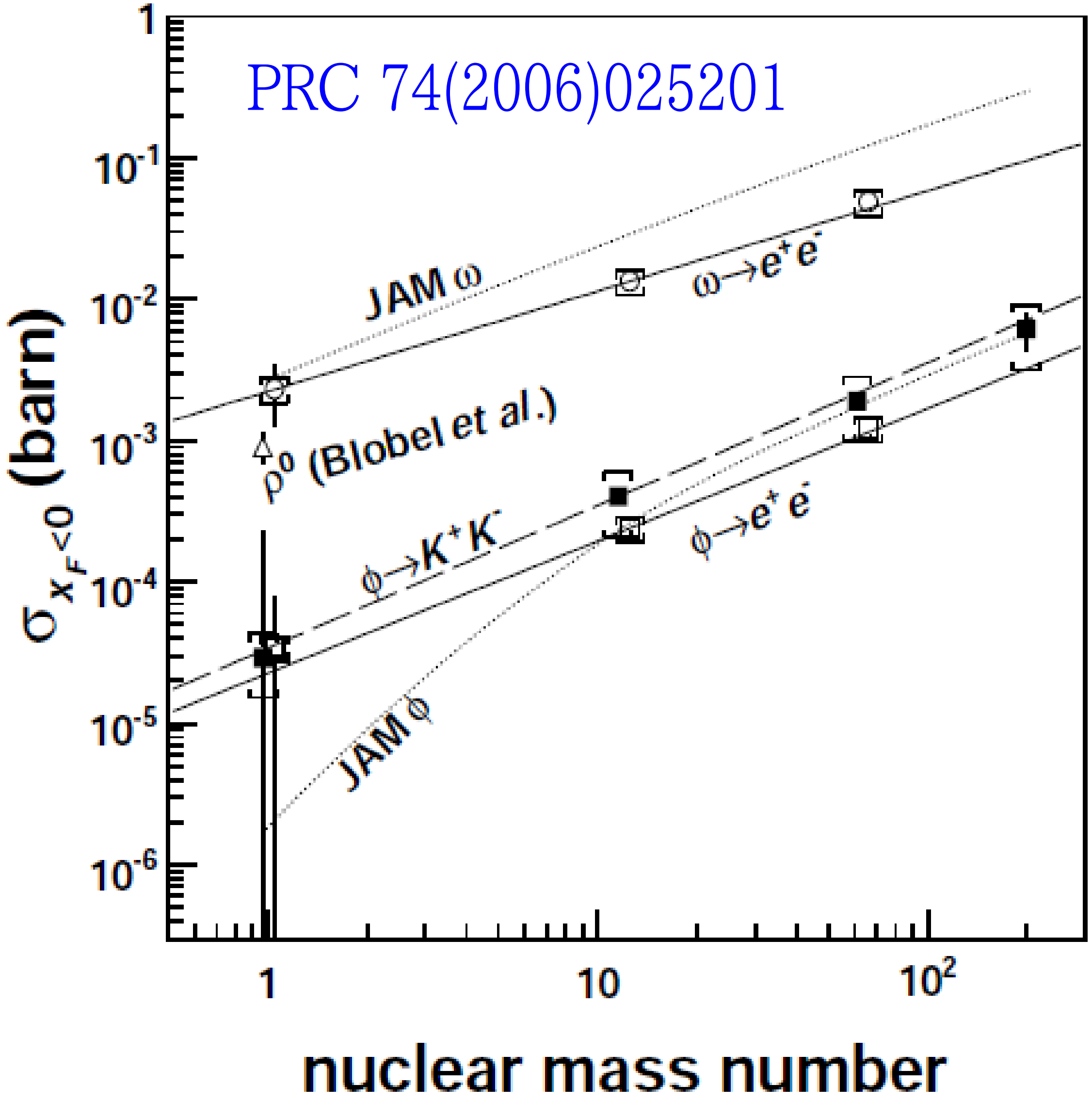
$$\Gamma^*_\phi / \Gamma^0_\phi = 1 + k_{tot} \left(\rho / \rho_0 \right),$$

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

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

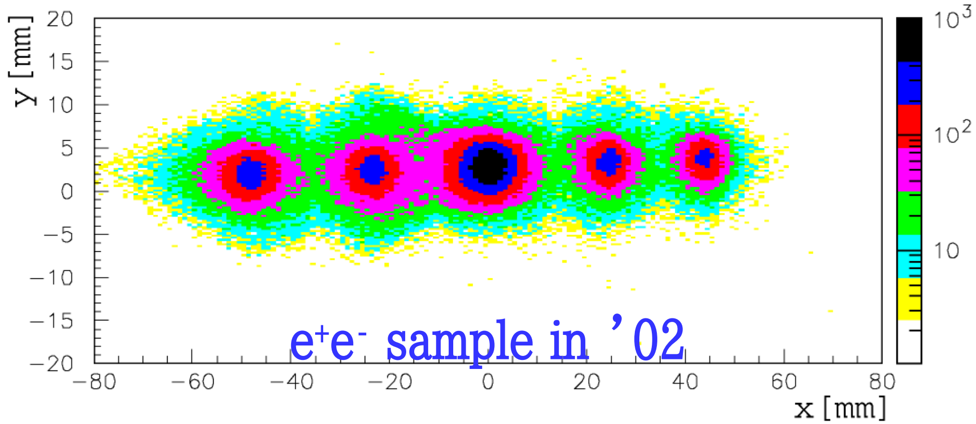
measured production CS by E325

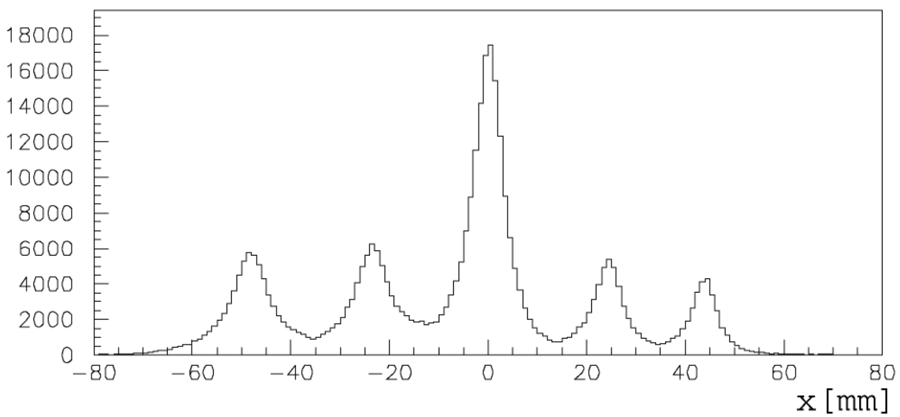
- values for the CM backward
- consistent w/ the former measurement for ρ meson by Blobel (PLB48(1974)73)



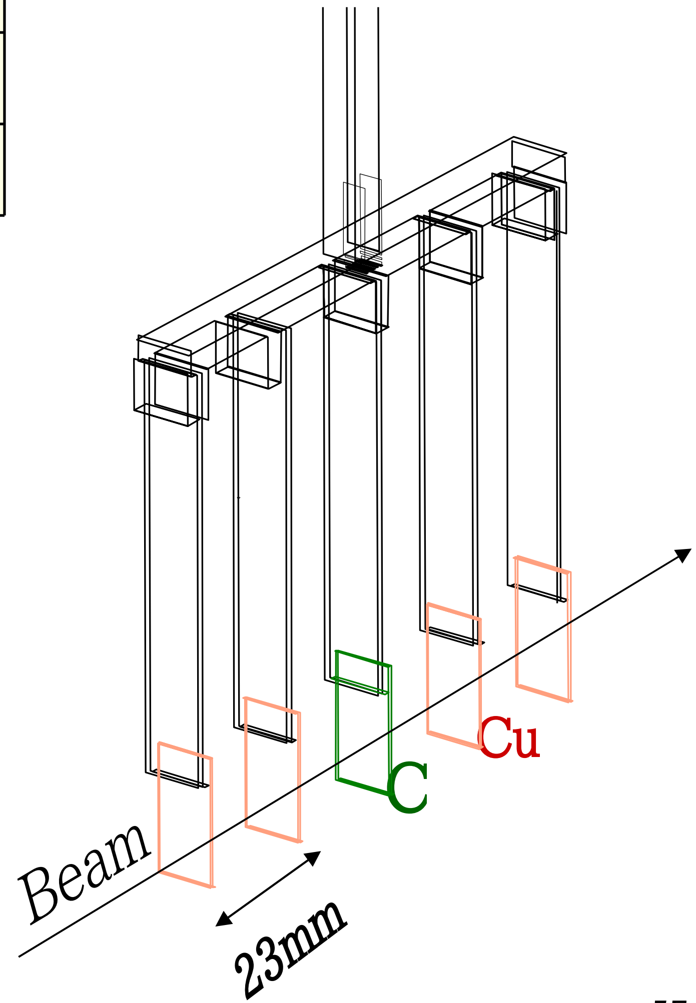
Experimental setup - targets

material	beam intensity (p/spill)	Interaction length(%)	radiation length(%)
C	~$1x10^9$	0.2%	0.4%
Cu X 4	~$1x10^9$	0.05%X4	0.6%X4



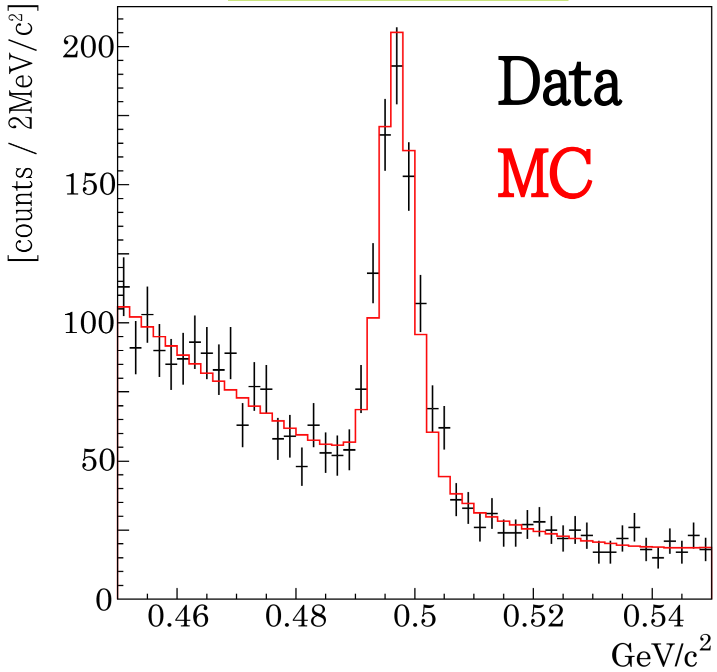


targets in 2002

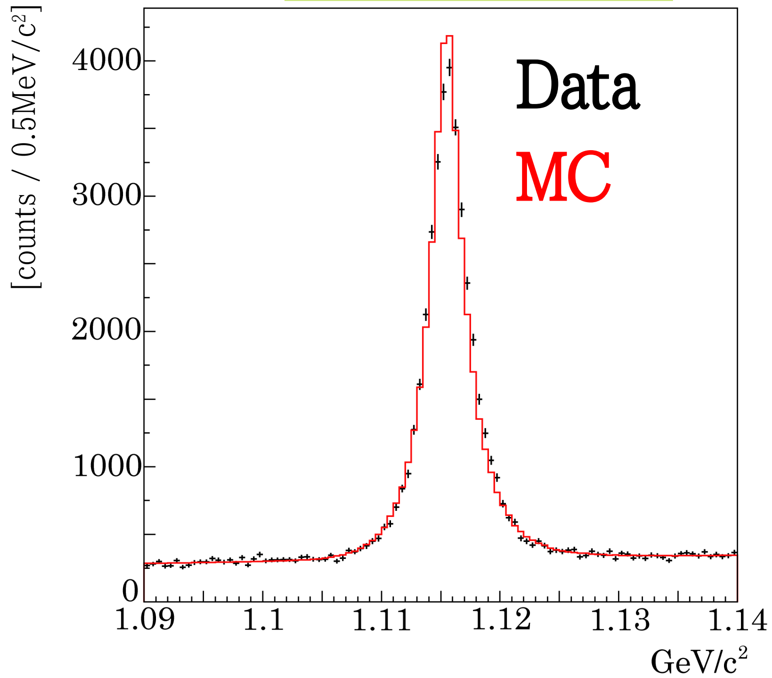


Spectrometer performance

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



$\Lambda \to p\pi^-$



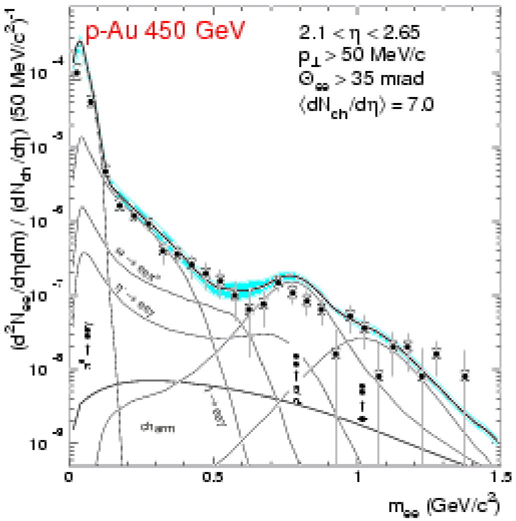
M = 496.8±0.2 (MC 496.9) MeV/c²
σ = 3.9±0.4 (MC 3.5) MeV/c²

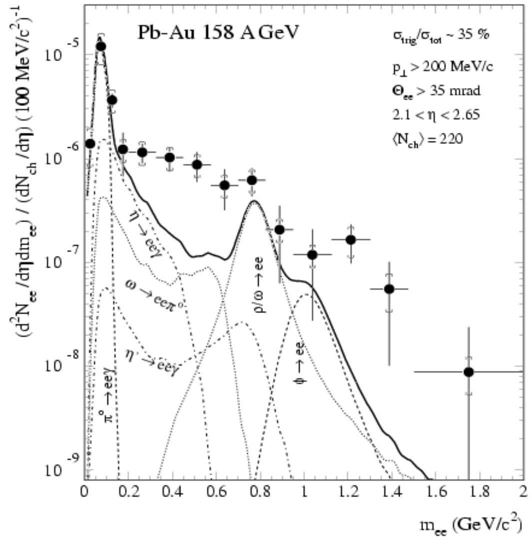
M = 1115.71±0.02 (MC 1115.52) MeV/c²
σ = 1.73±0.04 (MC 1.63) MeV/c²

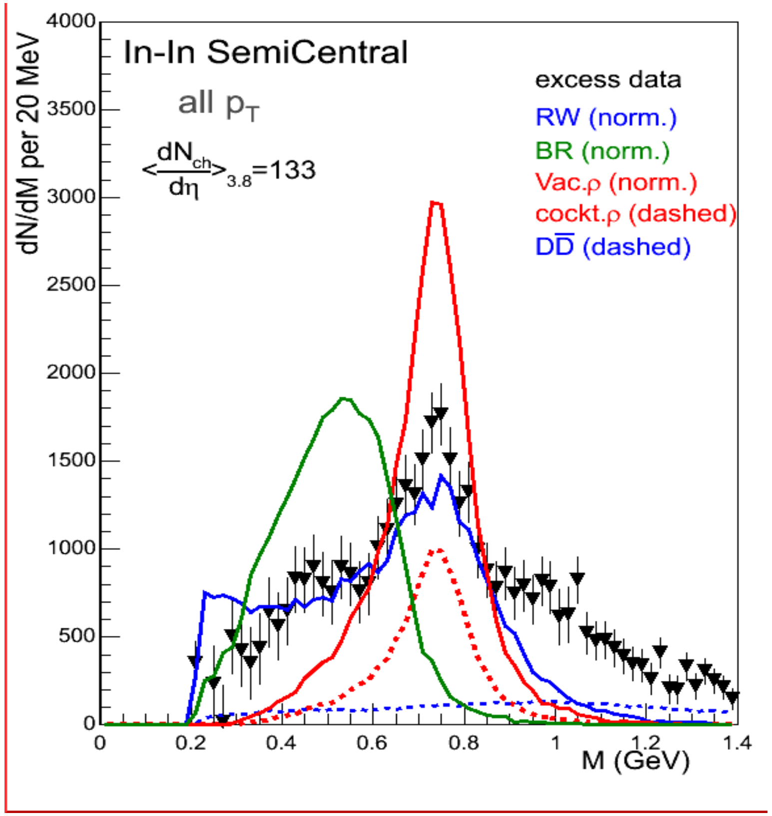
mass resolution for ϕ-meson decays
$\phi \to e^+e^-$: 10.7 MeV/c²
$\phi \to K^+K^-$: 2.1 MeV/c²

Vector meson measurements in HIC

- CERES : e^+e^- (EPJC 41('05)475)
  - anomaly at the 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'

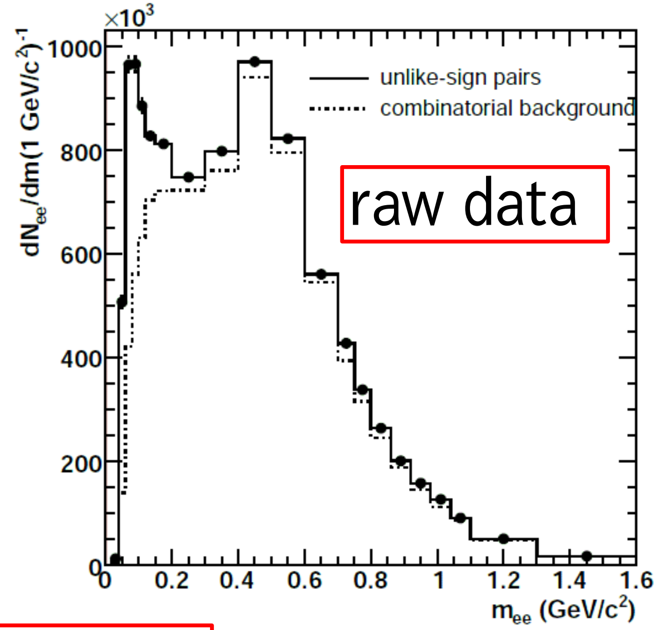






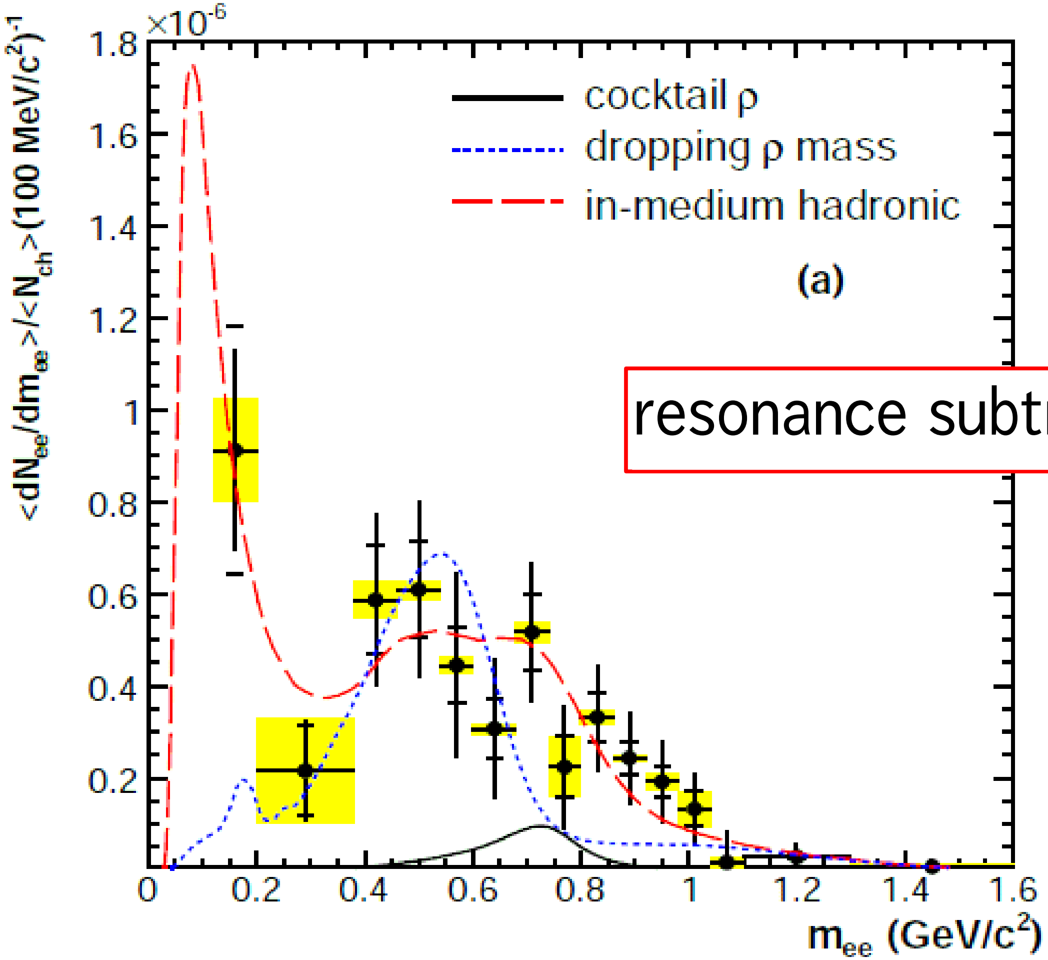
Vector meson measurements in HIC

- CERES : (arXiv: 0611022v3)
  - "broadening by hadronic effect " is favored

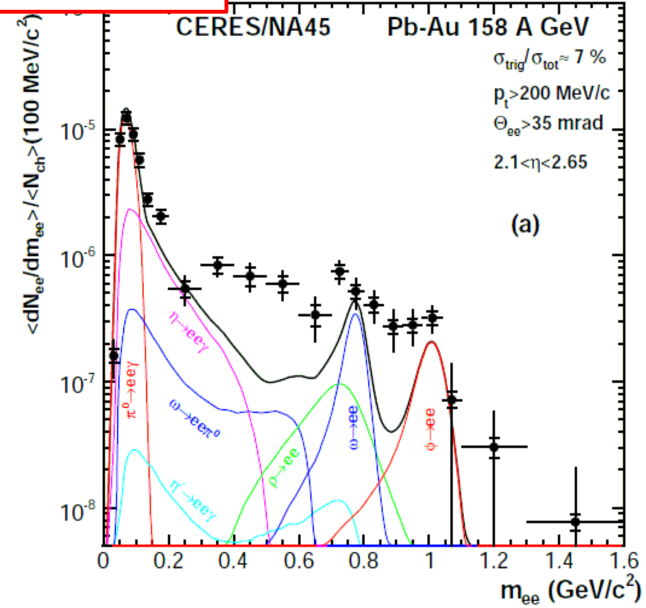


raw data

bkg subtracted

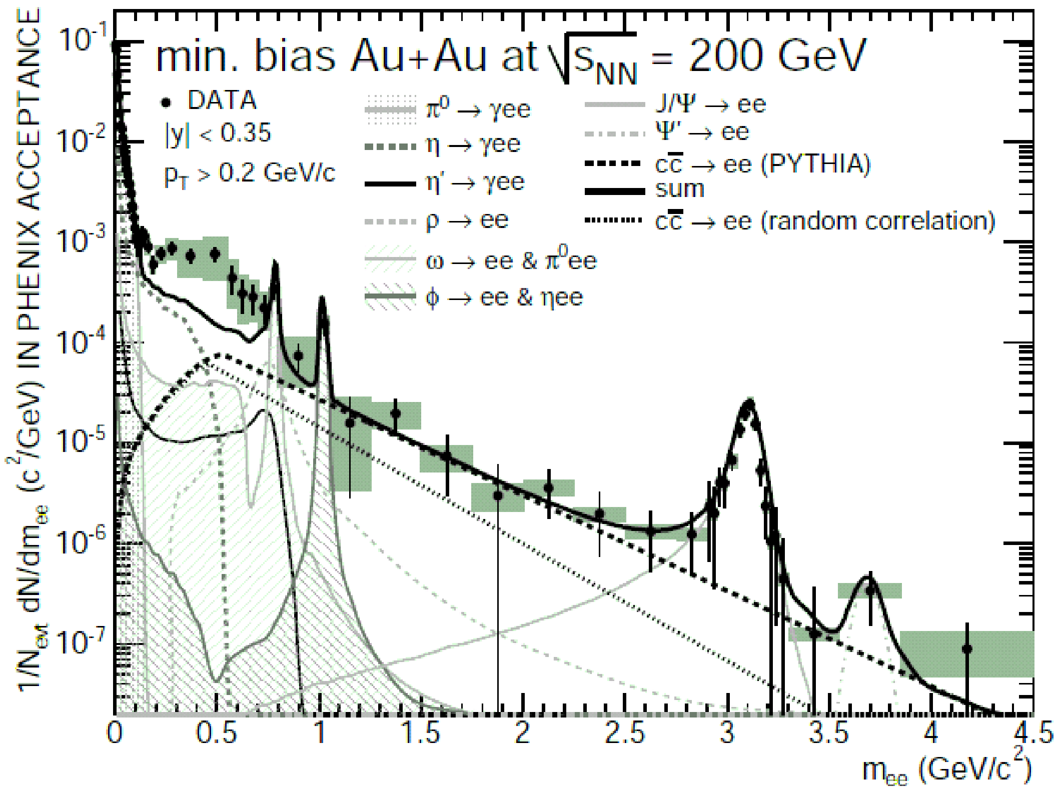


resonance subtracted



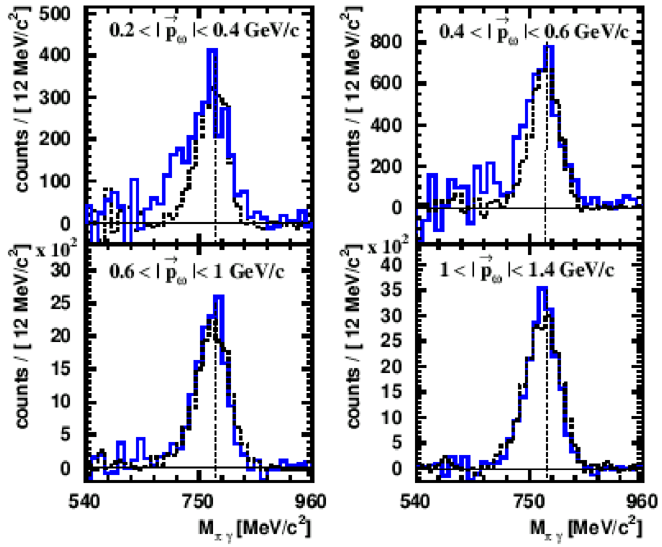
Vector meson measurements in HIC

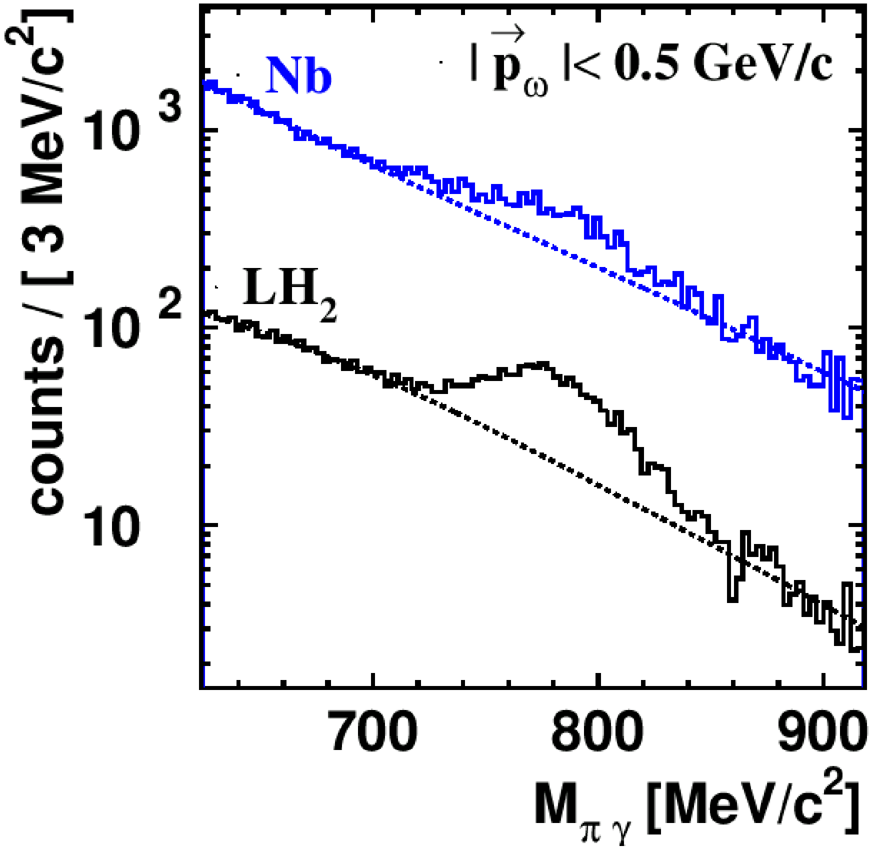
- PHENIX : (arXiv:0706.3034v1)
  - 200GeV /u Au+Au → e^+e^-
  - enhancement below ω

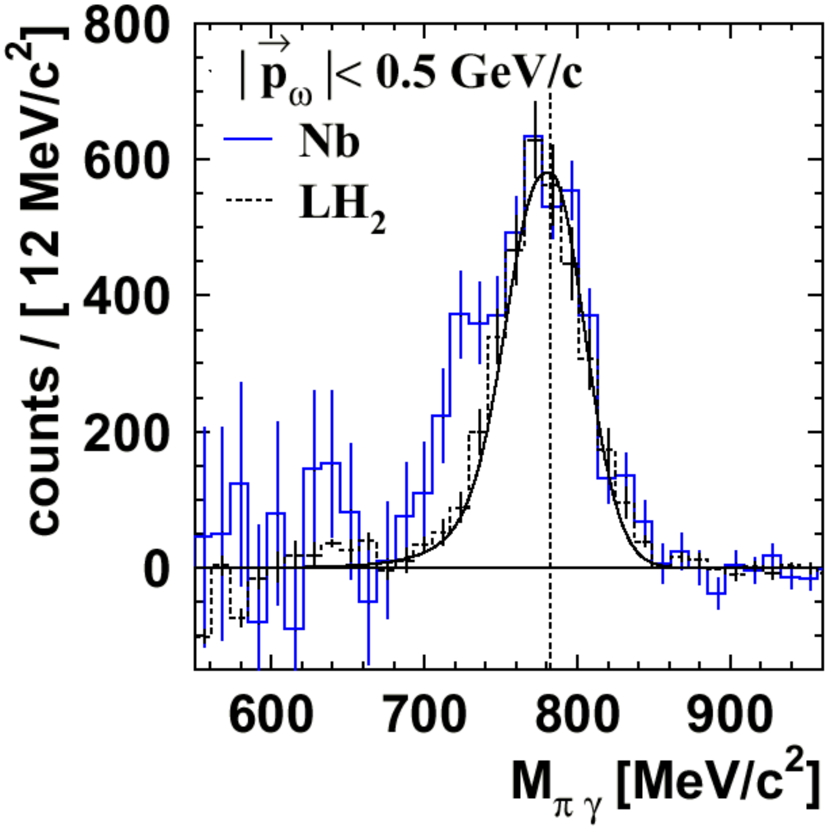


CBELSA/TAPS (PRL94(05)192303)

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

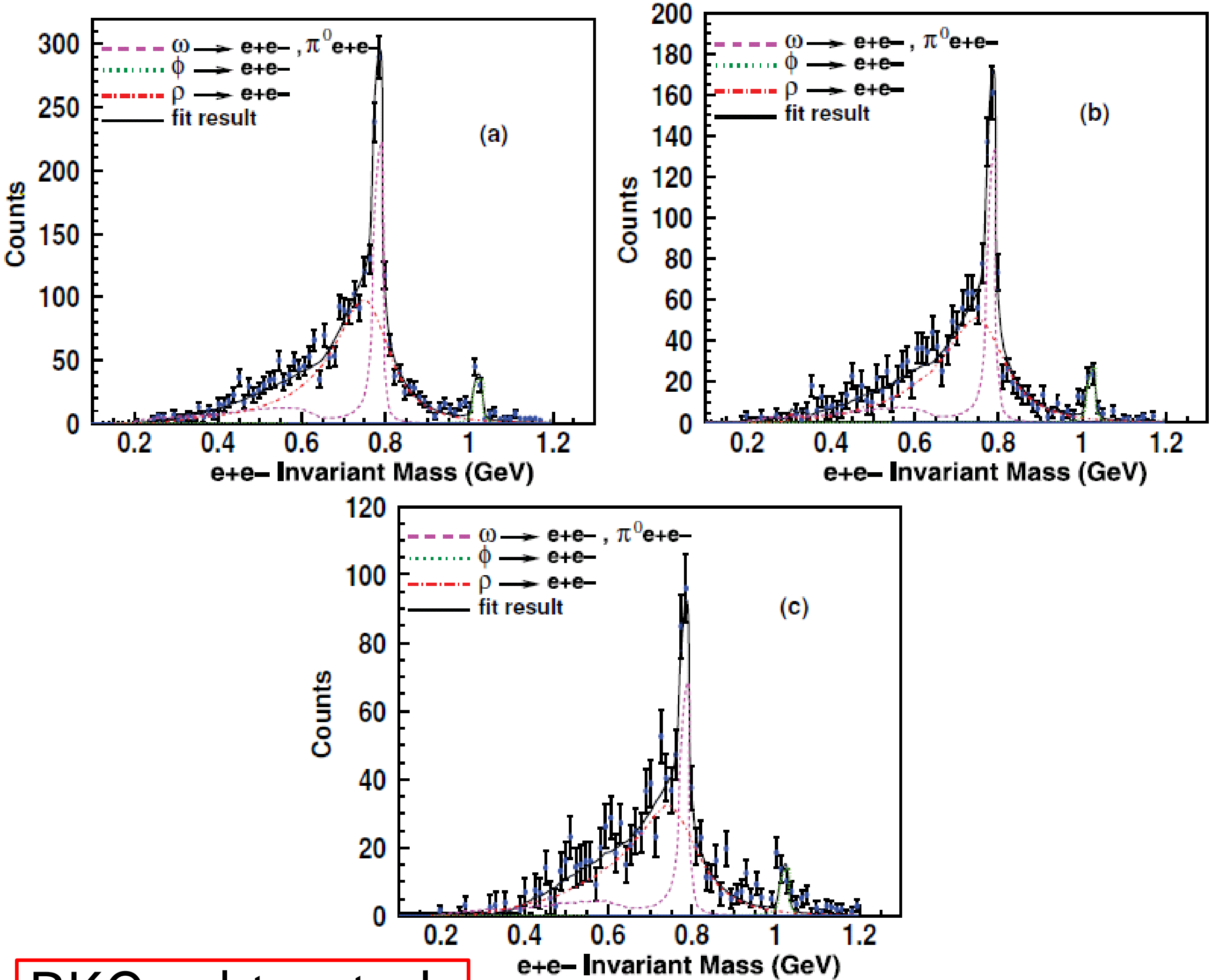






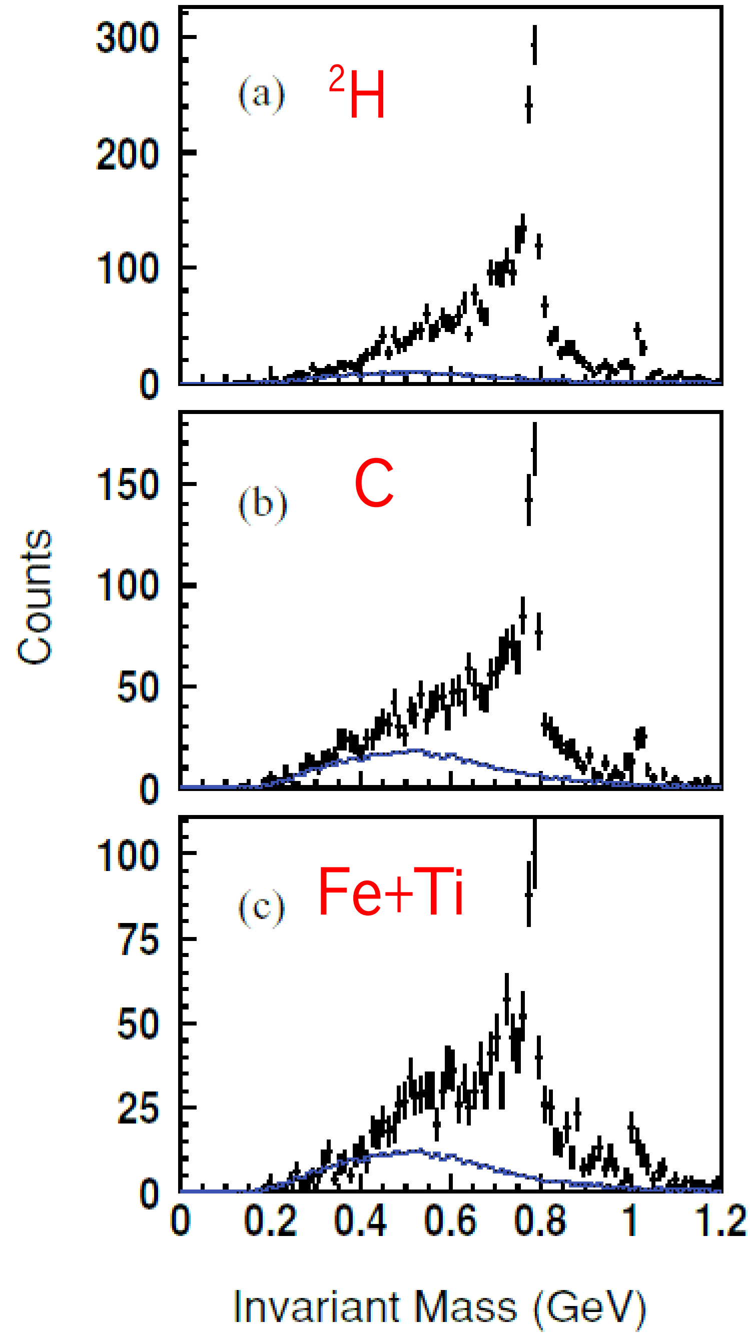
CLAS-G7(PRC78(2008)015201)

- $\gamma + A \rightarrow V \rightarrow e^+e^-$
- no anomaly for p >0.8GeV/c



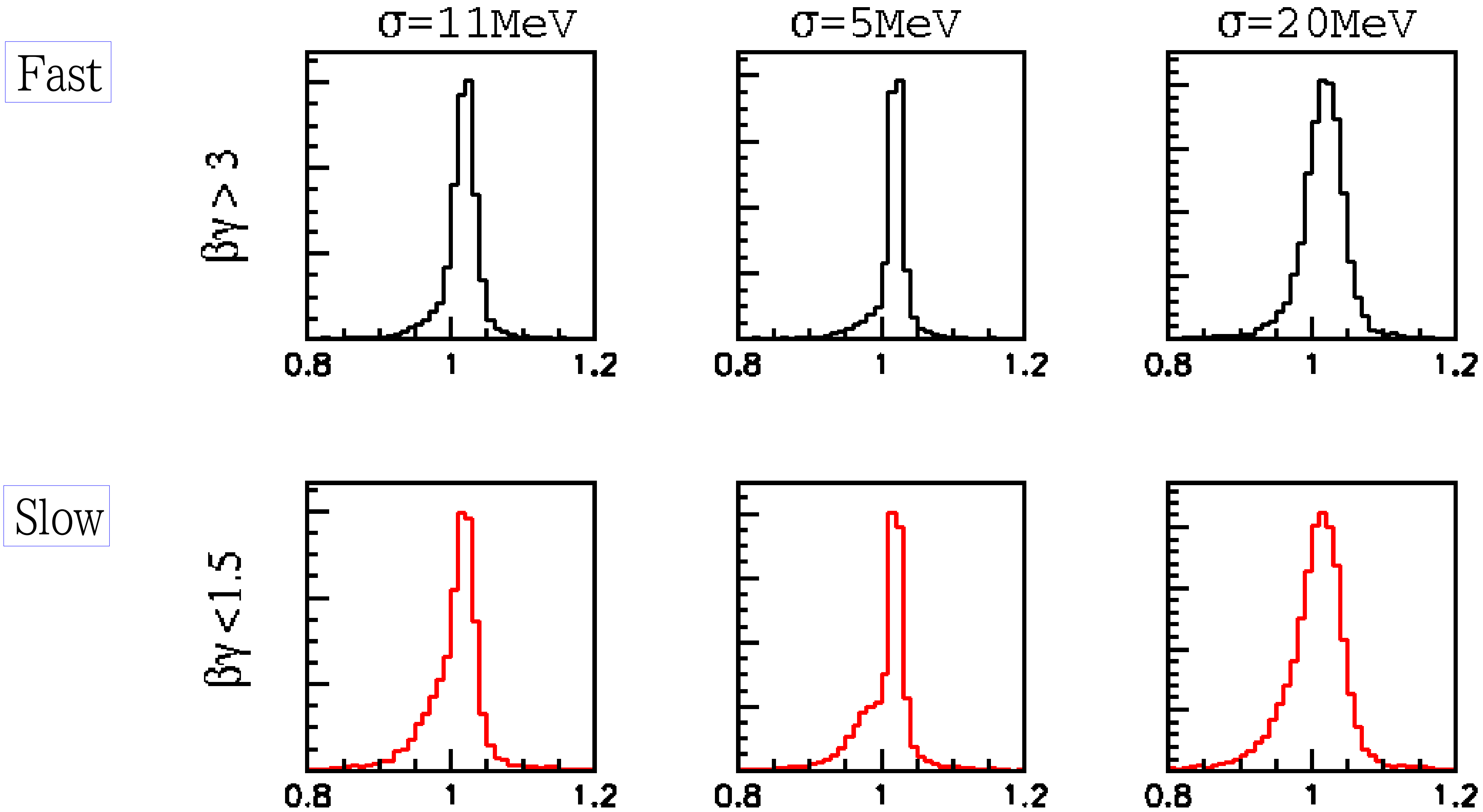
BKG subtracted

PRC78(2008)015201



mass resolution requirement

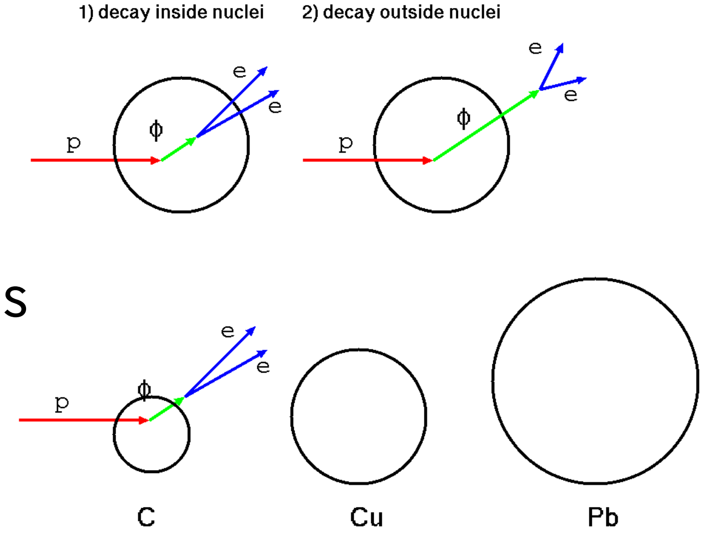
- mass resolution should be kept less than ~10MeV

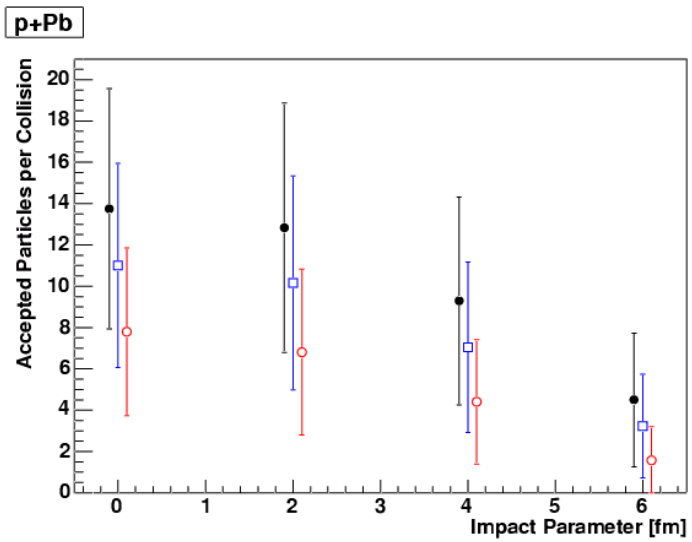


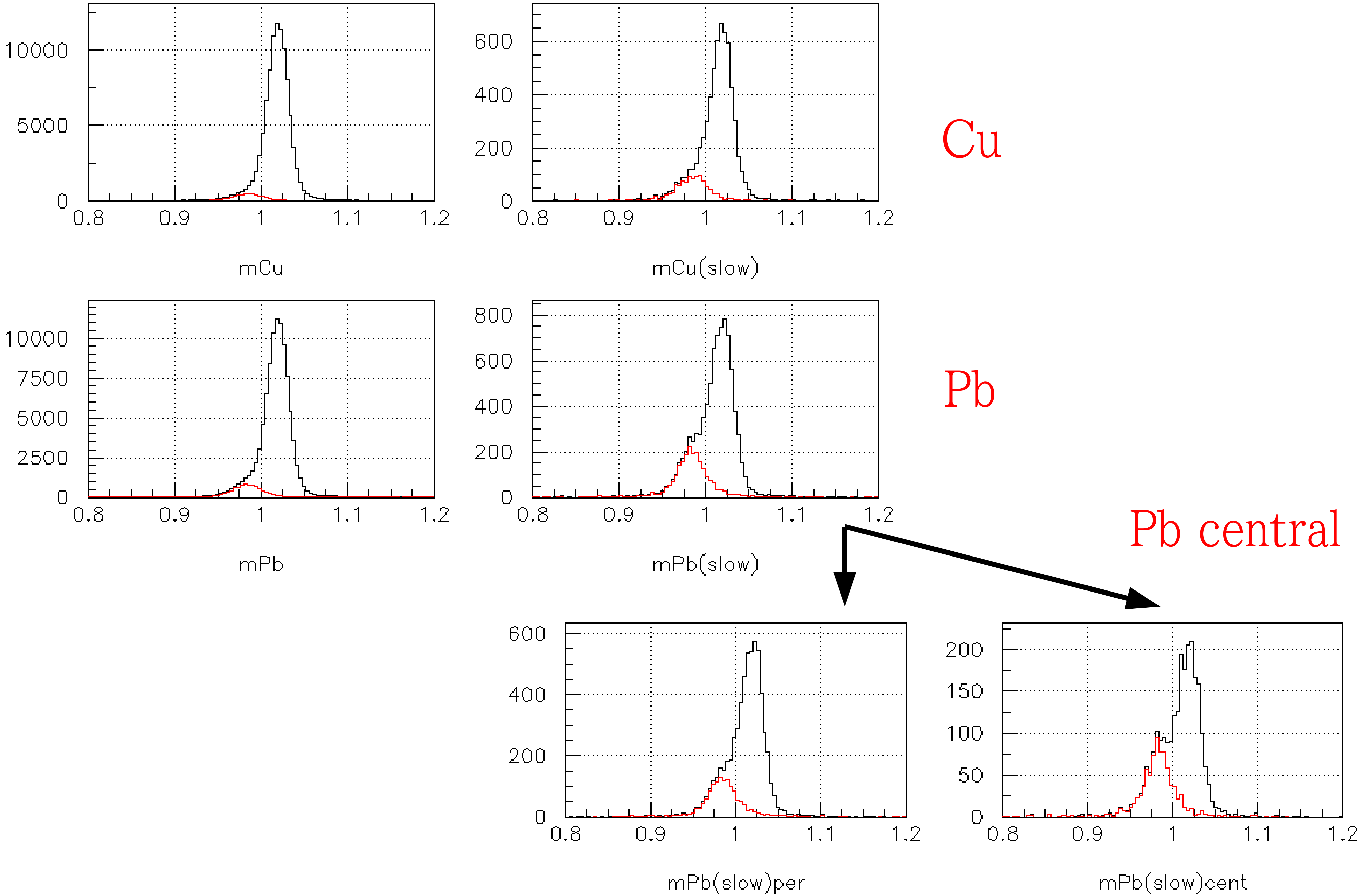
(model calc. for the Cu target)

New nuclear targets with larger statistics

- Smaller nuclear target :
  - proton as reference(CH_2 -C subtraction)
  - LH target cannot be used because of the materials
- Larger nuclear target as Pb
  - larger nuclear matter
  - collision geometry ("impact parameter") study using multiplicity (PRC60 024902 (18GeV p+A))
    - can be divided to at least two regions
    - another type of the matter size effect
  - larger radiation length for heavier target
    → more thiner foil target to keep S/N
    - high statistics capability is required.

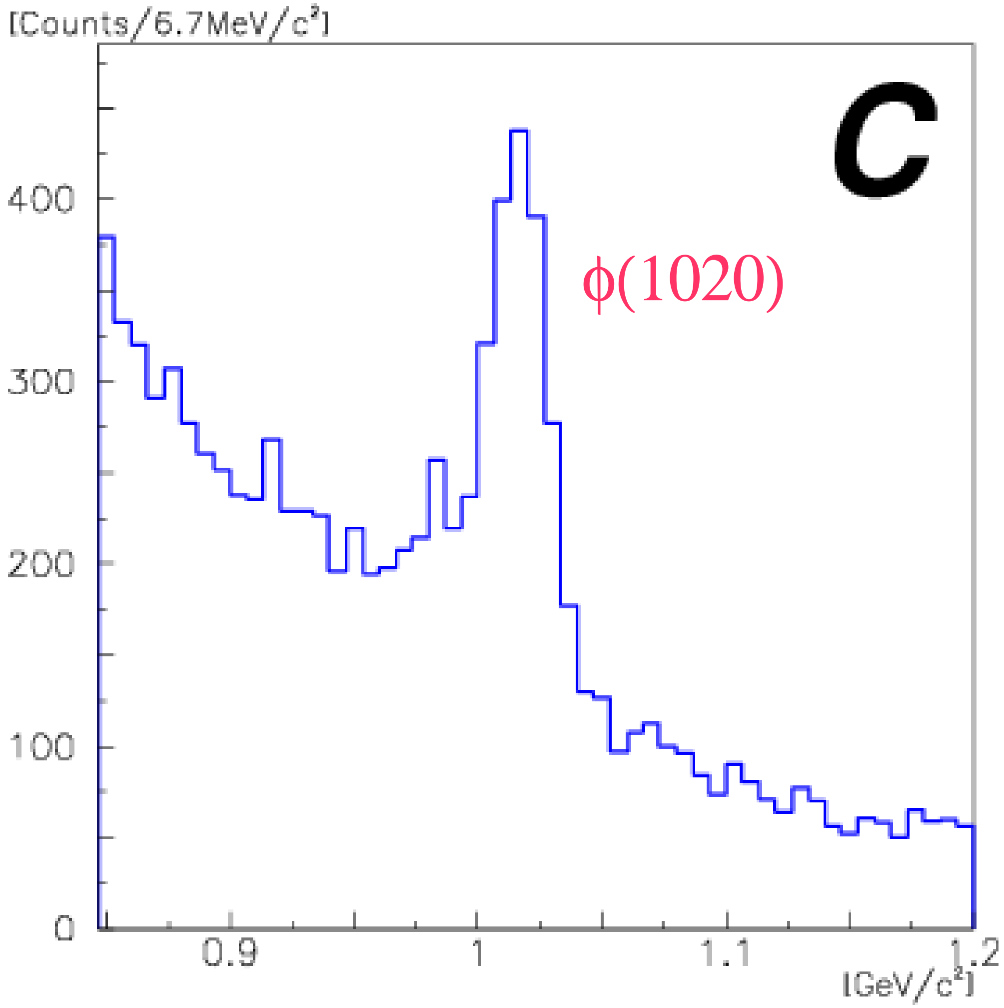





mCu
mCu(slow)
Cu
mPb
mPb(slow)
Pb
Pb central
mPb(slow)per
mPb(slow)cent

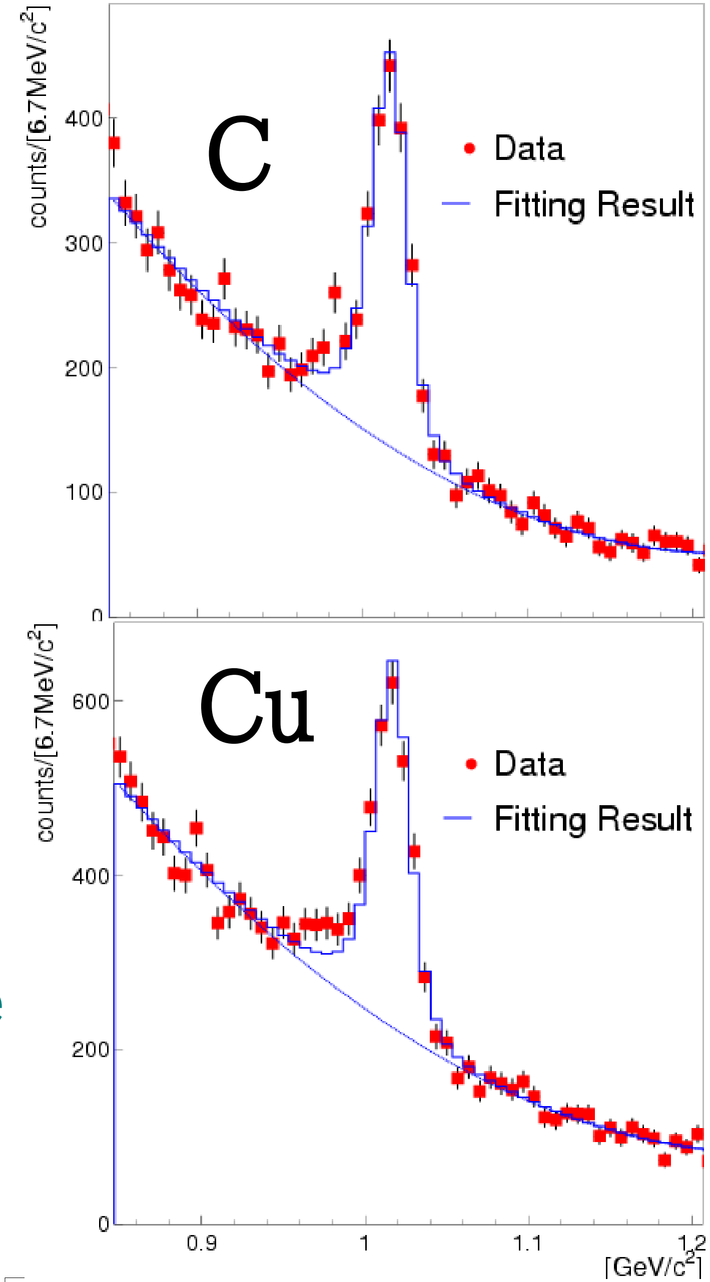
$\phi \rightarrow e^+e^-$ invariant mass spectra

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



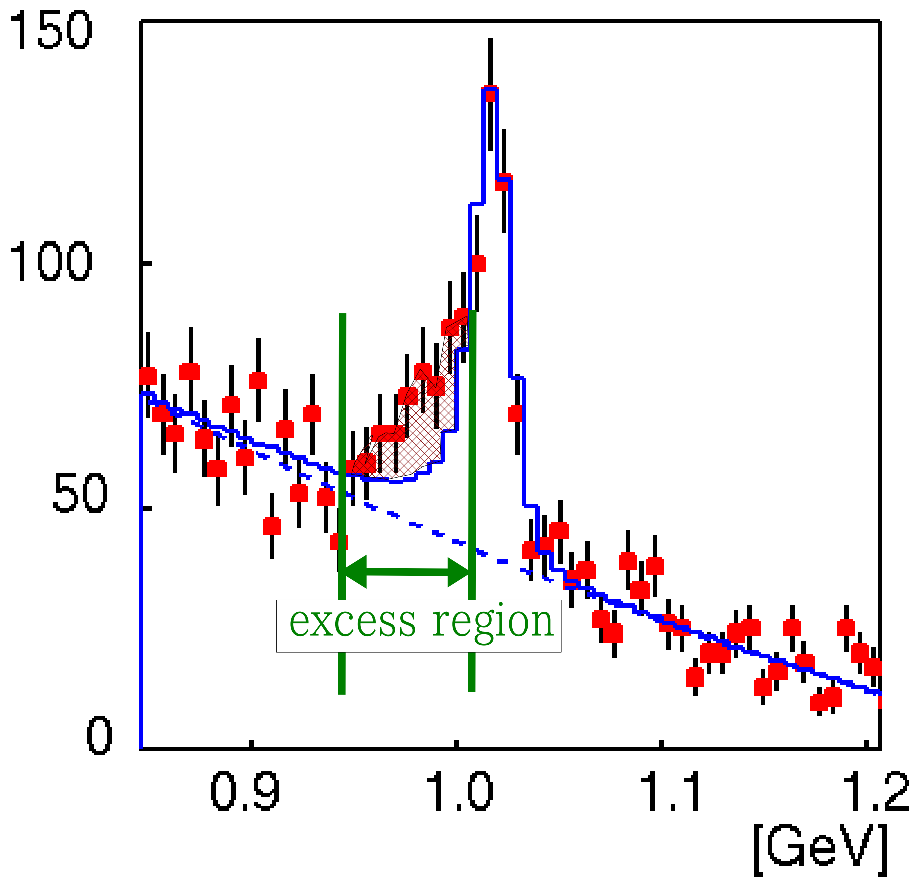
$\phi \rightarrow e^+e^-$ invariant mass spectra

- 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



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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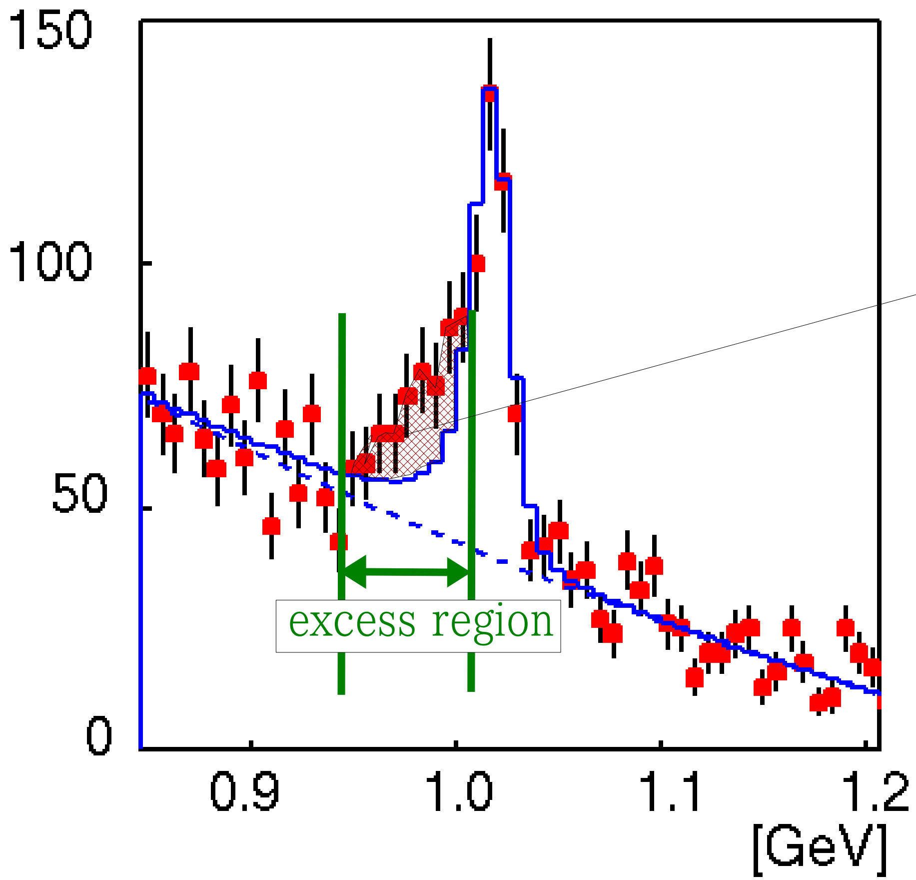
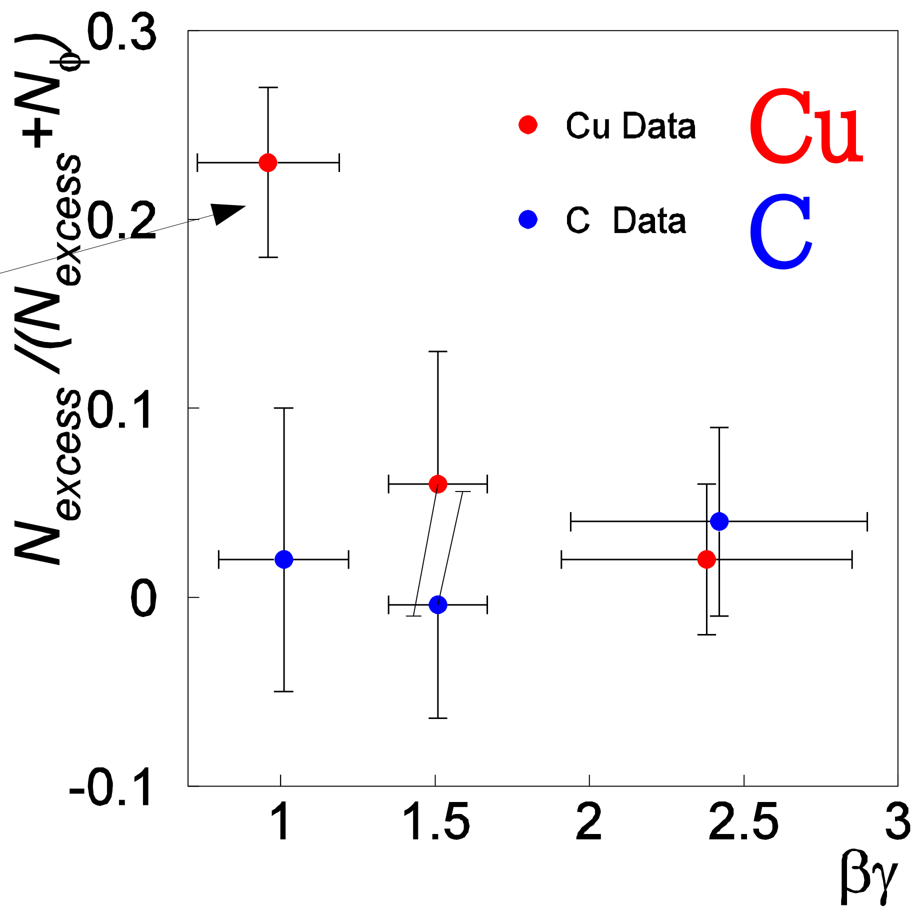
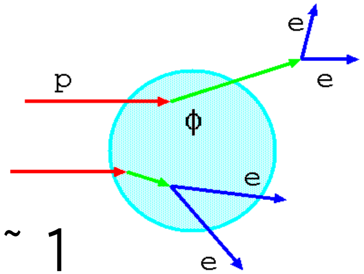




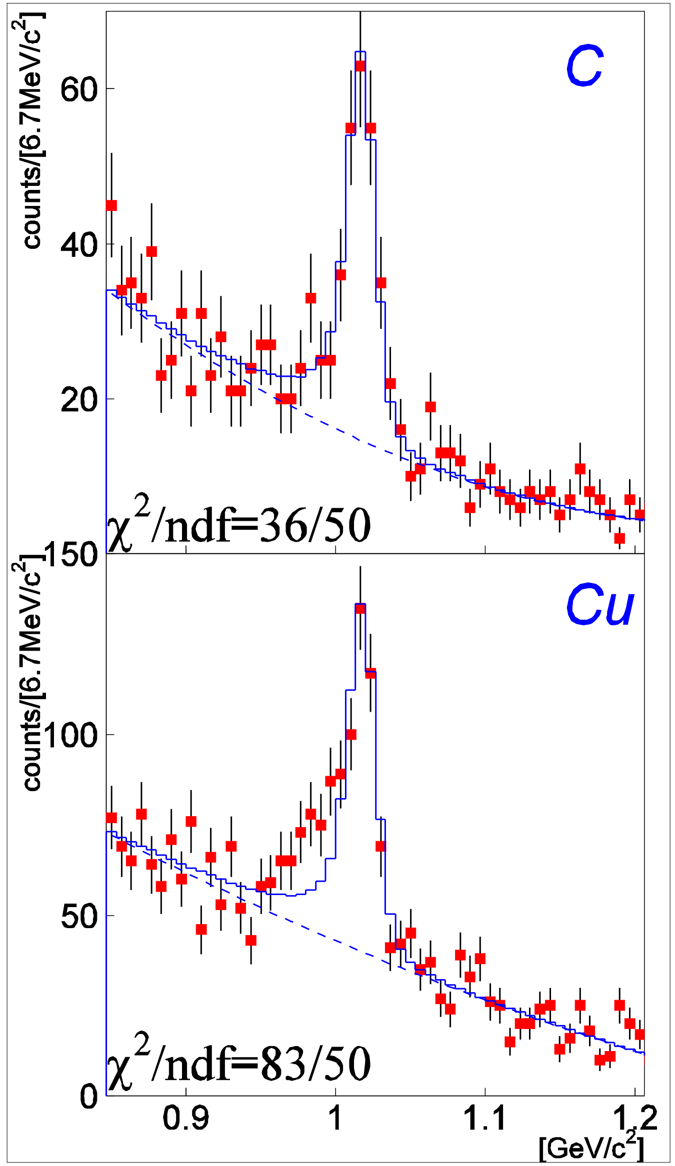
Fit using modified mass shapes

- MC type calc.: mesons are generated, fied 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 :
    $\Gamma^*_{tot}/\Gamma^0_{tot} = 1 + k_2\ \rho/\rho_0$
    - e^+e^- branching ratio is not changed
      - $\Gamma^*_{e+e-}\ /\ \Gamma^*_{tot} = \Gamma^0_{e+e-}\ /\ \Gamma^0_{tot}$
  - fits were done with many combinations of (k_1 , k_2)

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



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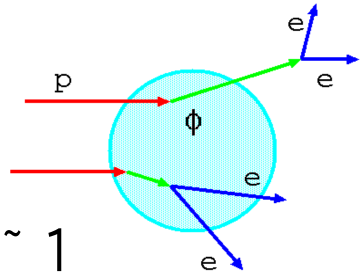

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    (k_1=0.04, Hatsuda & Lee, '92,'96)
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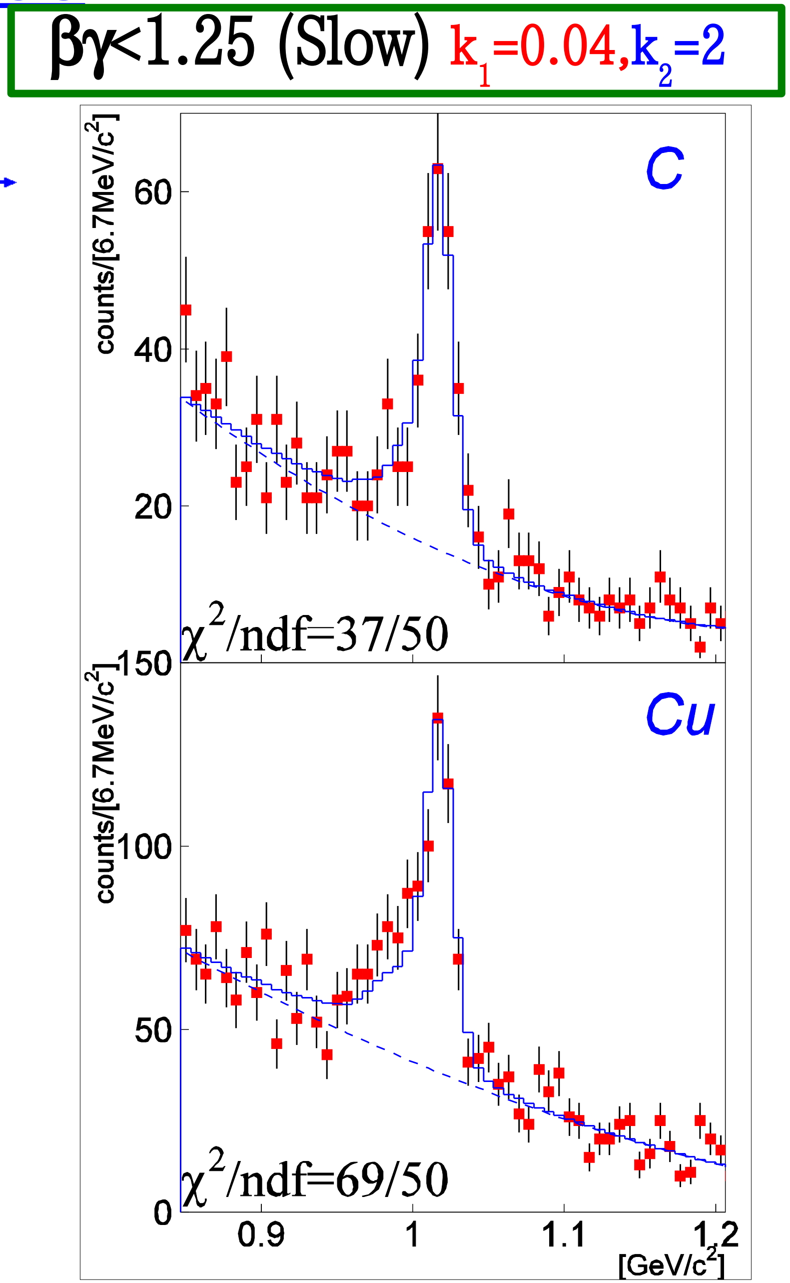
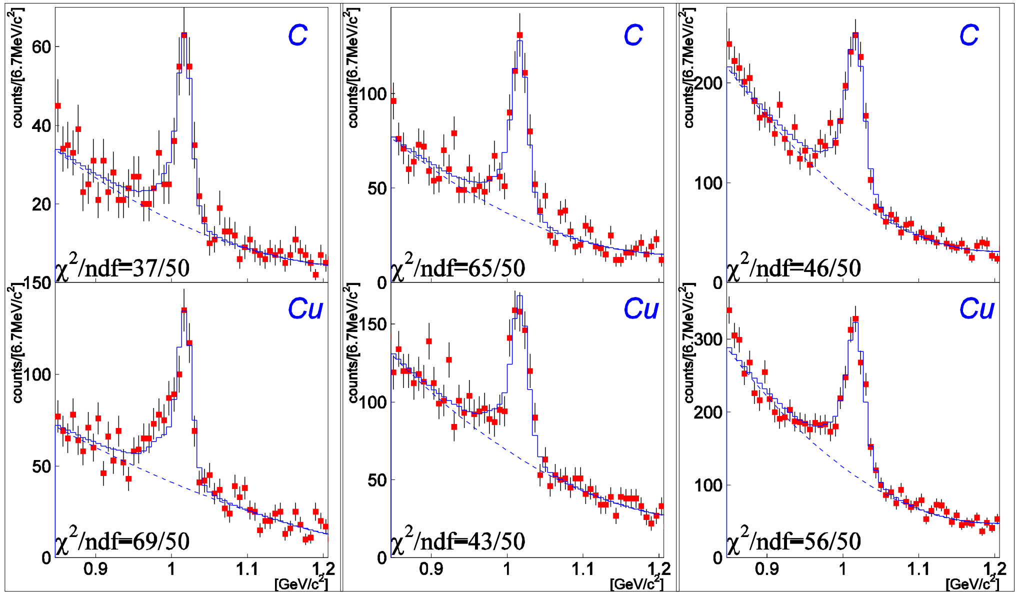


Model fitting : parameter k_1 and k_2

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



(k_1=0.04, k_2=2, χ^2=316)

Model fitting : parameter k_1 and k_2

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

Best Fit Value:

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

$k_2^{tot} = 2.6^{+1.8}_{-1.2}$ $\Gamma_{tot}^* = 16\text{MeV}$

(3.6 times width broadening at ρ_0)