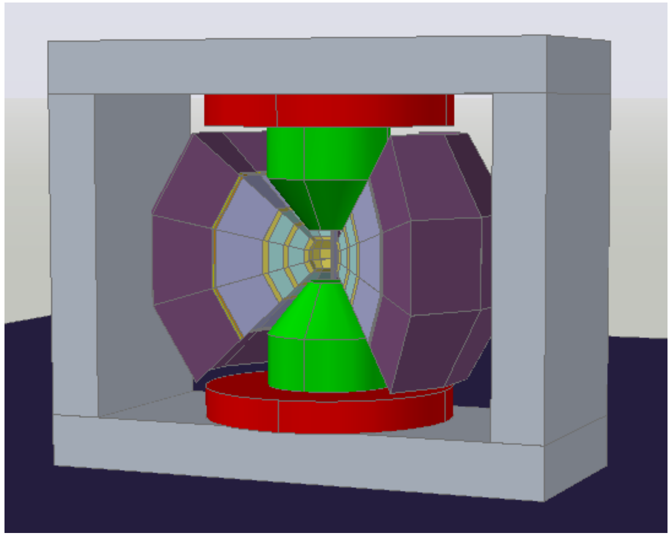
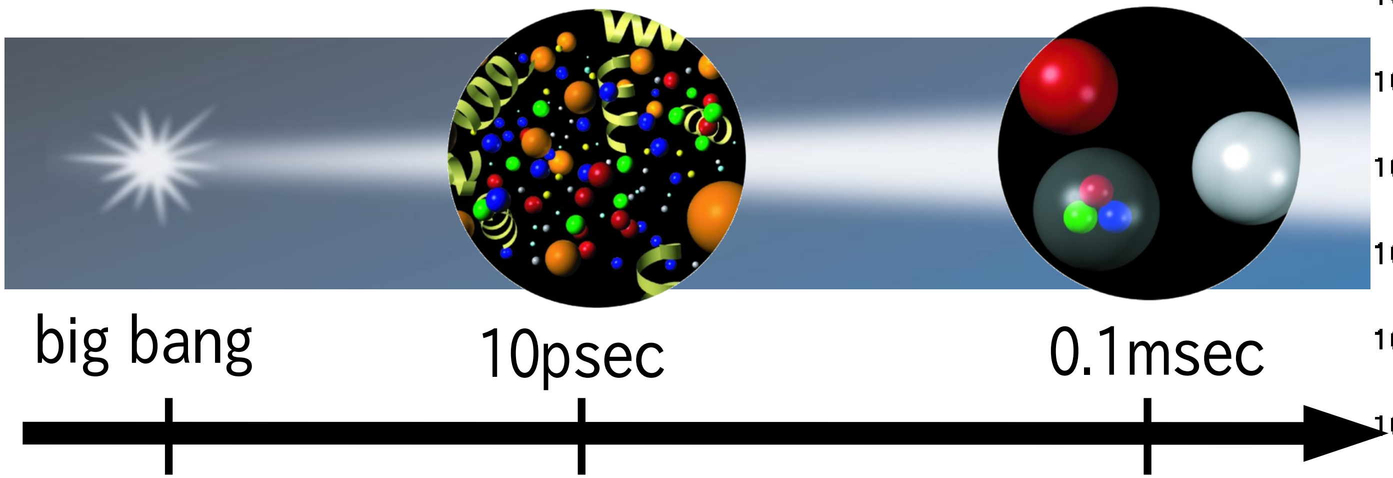
Vector meson measurements through dielectron : planned experiment at J-PARC

Satoshi Yokkaichi
(RIKEN Nishina Center)

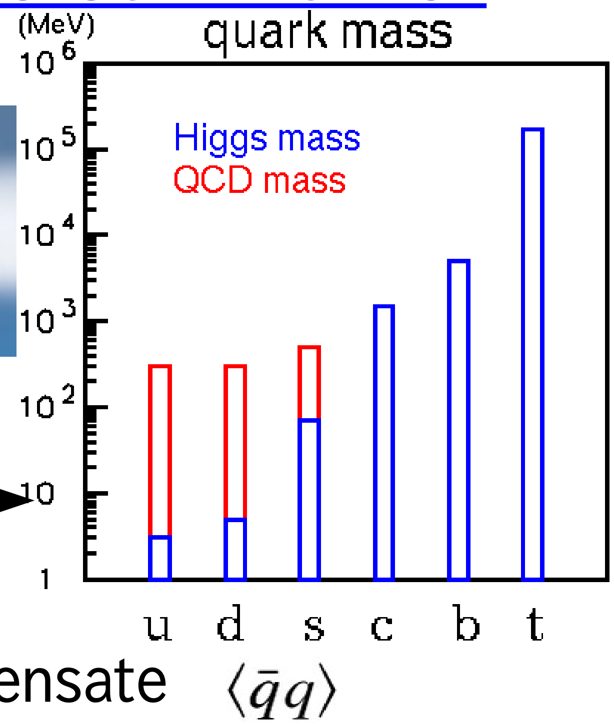
- Introduction
- Results of KEK-PS E325 experiment
  - observation of vector meson mass modification in nuclei
- J-PARC Hadron experimental facility
- Future : J-PARC E16 experiment
  - systematic study of mass modification of phi meson



Mass and chiral symmetry in nuclear matter

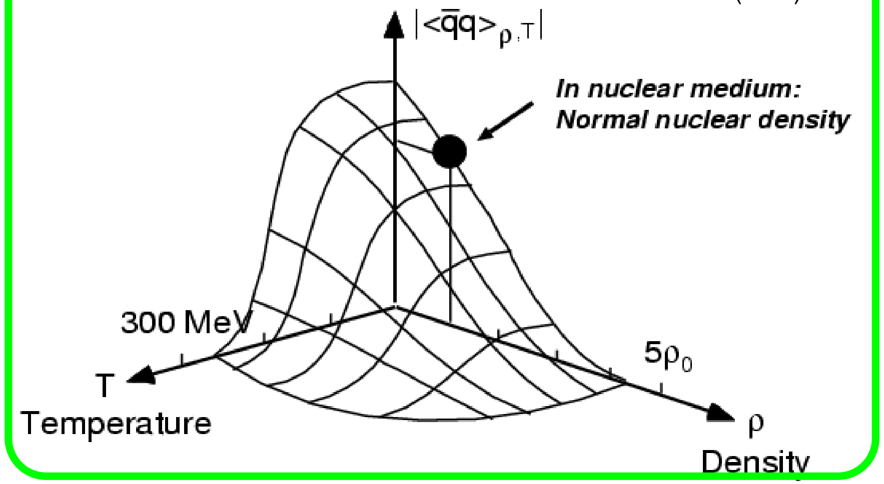


	big bang	10psec	0.1msec
quark mass	0MeV	3MeV from Higgs	300MeV from chiral condensate



- 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, related CS restoration (or not); meson mass decreasing, width broadening, and so on.

W.Weise, NPA553(93)59



Vector meson mass spectra in dense matter

Bronwn-Rho scaling
PRL 66(91)2720, etc

$$m_\rho^*/m_\rho \sim (\langle\bar{q}q\rangle^*/\langle\bar{q}q\rangle)^{1/2}$$

effective Lagrangian (chiral SU(3)+VMD)
Klingle,Kaiser,Weise,
NPA 624(97)527

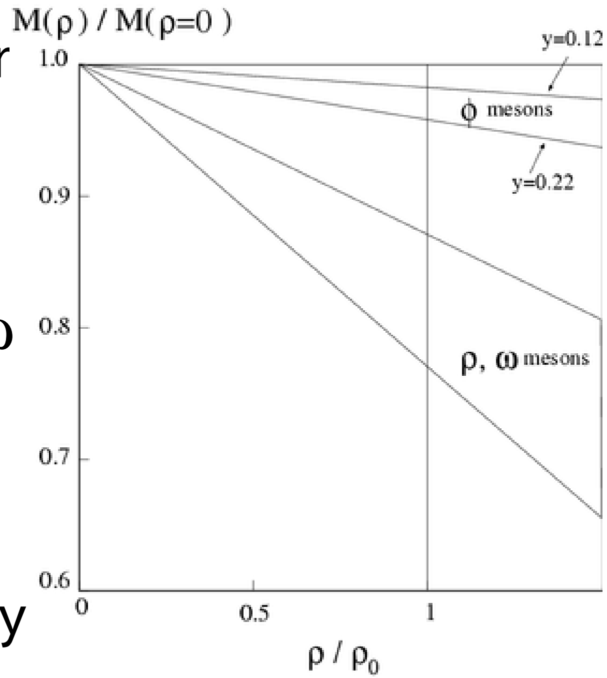
QCD sum rule
Hatsuda and Lee, PRC 46(92)R34, PRC 52(95)3364

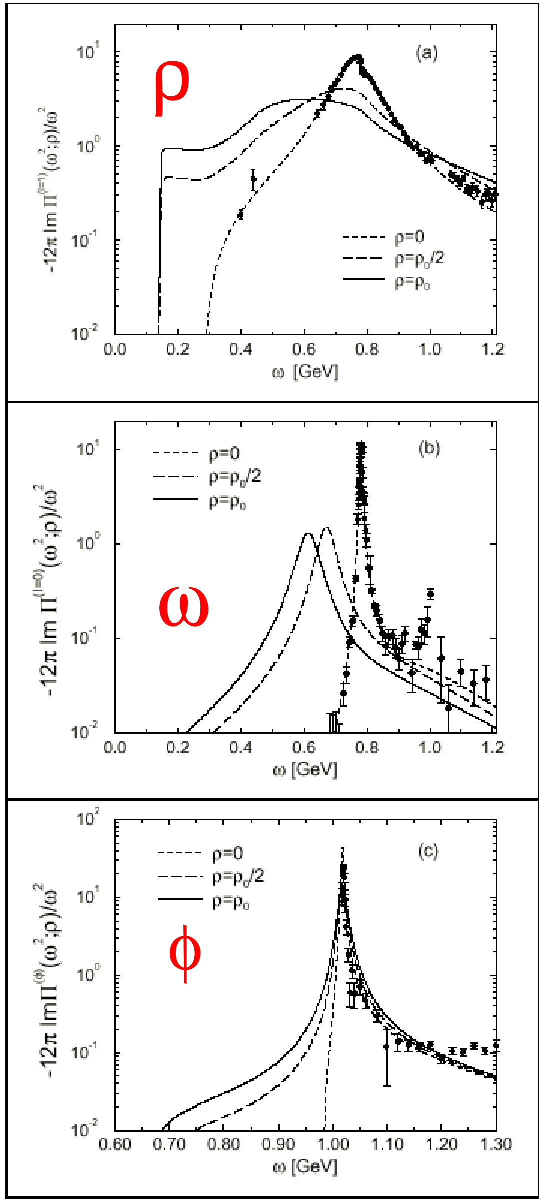
linear dependence on der

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

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

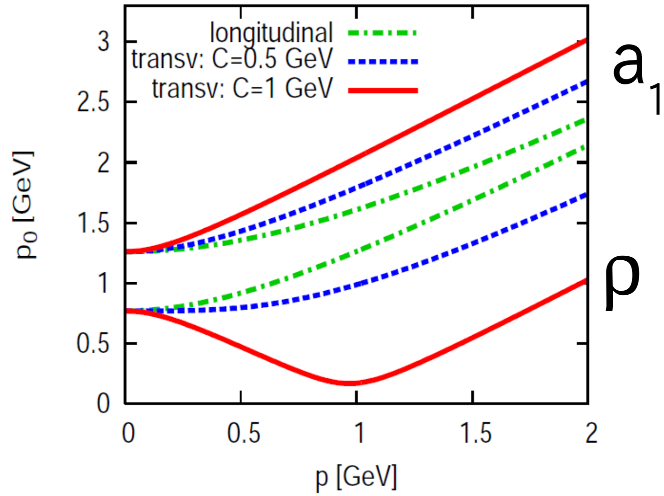




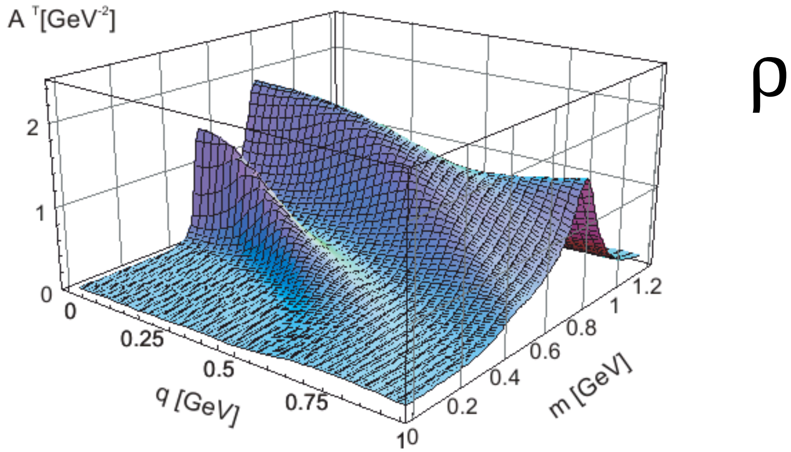
dispersion (mass VS momentum) in dense matter

- 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

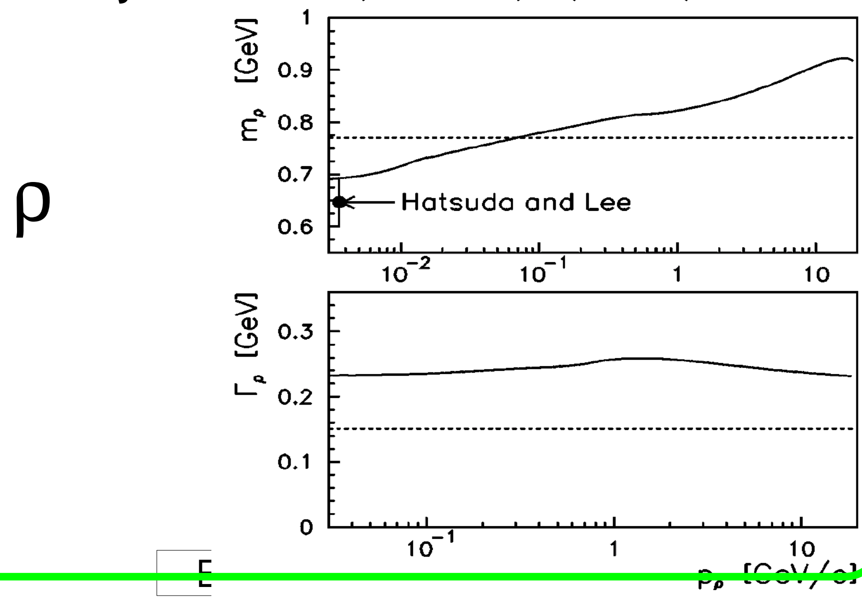
- Harada & Sasaki (PRC80(09)054912)



- Post & Mosel (NPA699(02)169)



- Kondratyuk et al. (PRC58(98)1078)



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

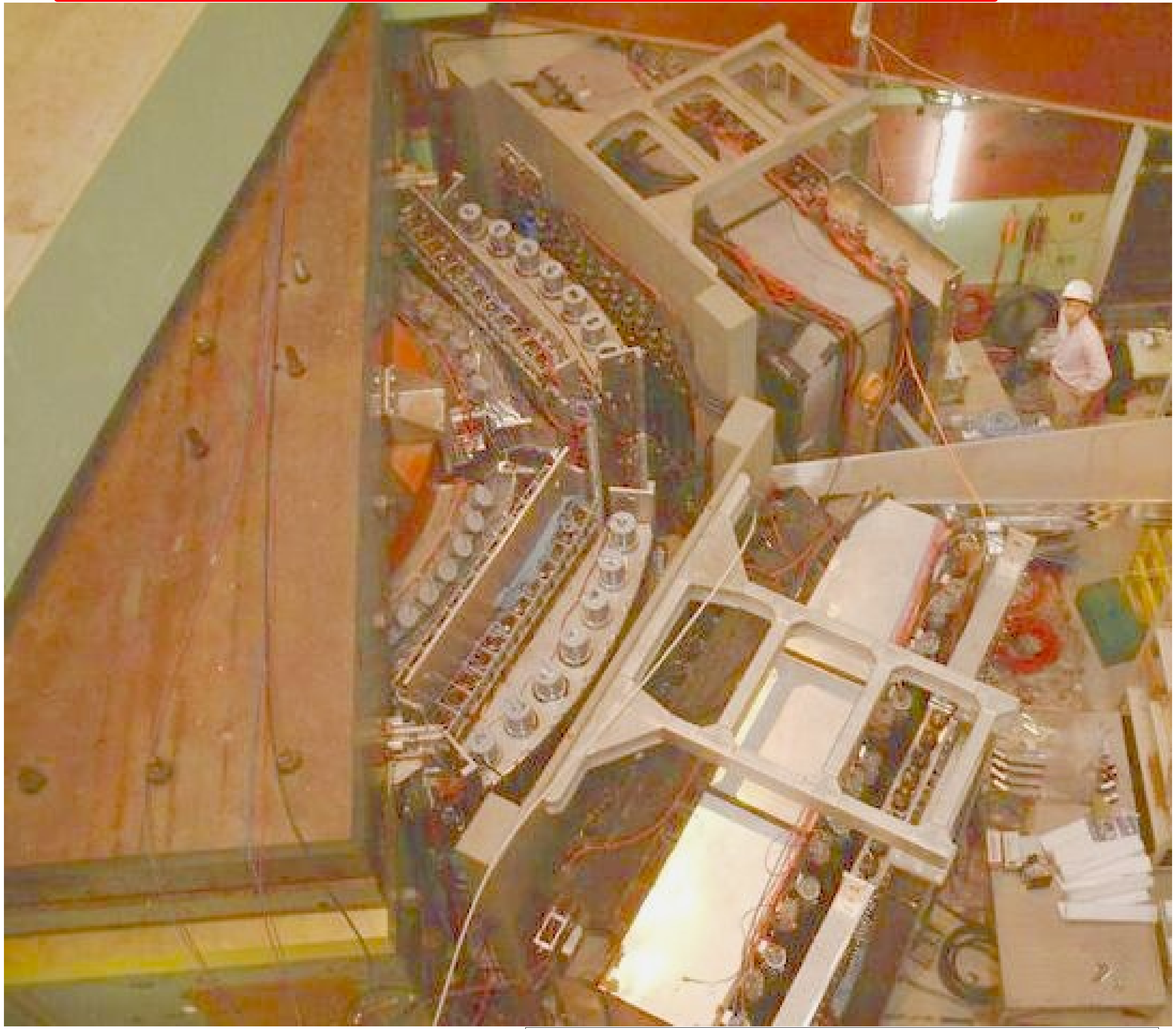
Collaboration

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.)

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

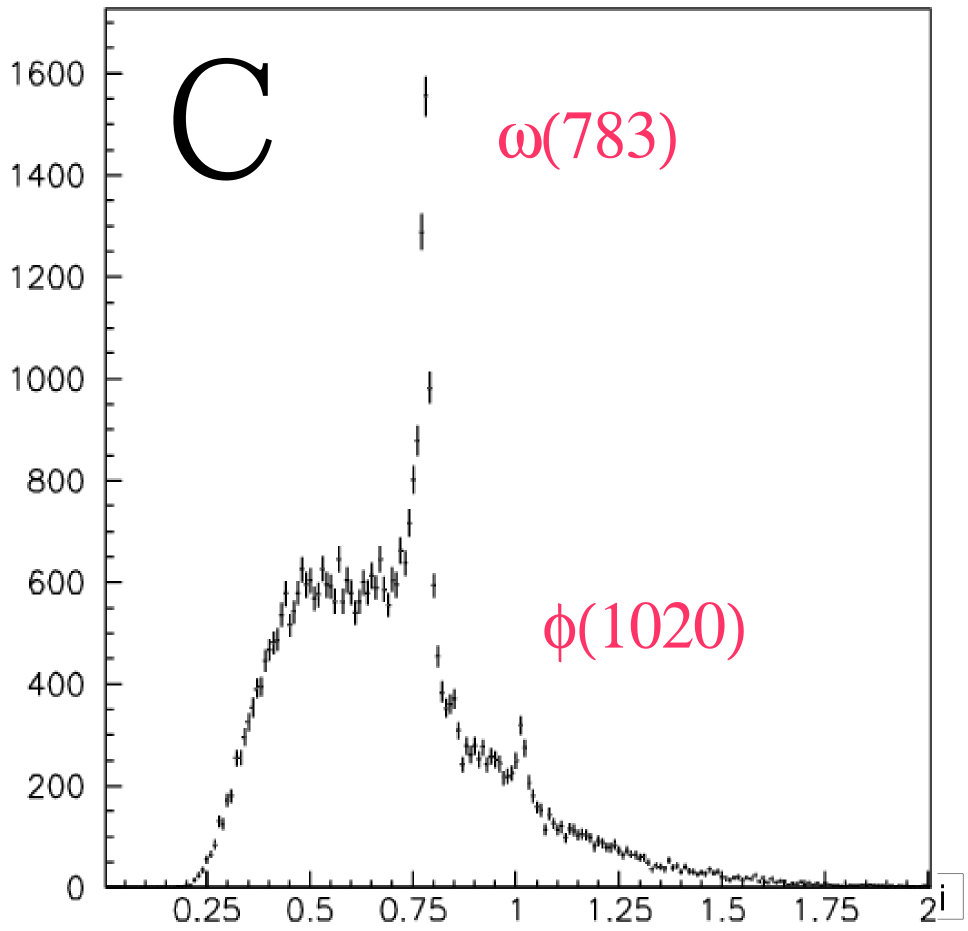
E325 spectrometer
located at KEK-PS EP1-B primary beam line



E325 Results (1)

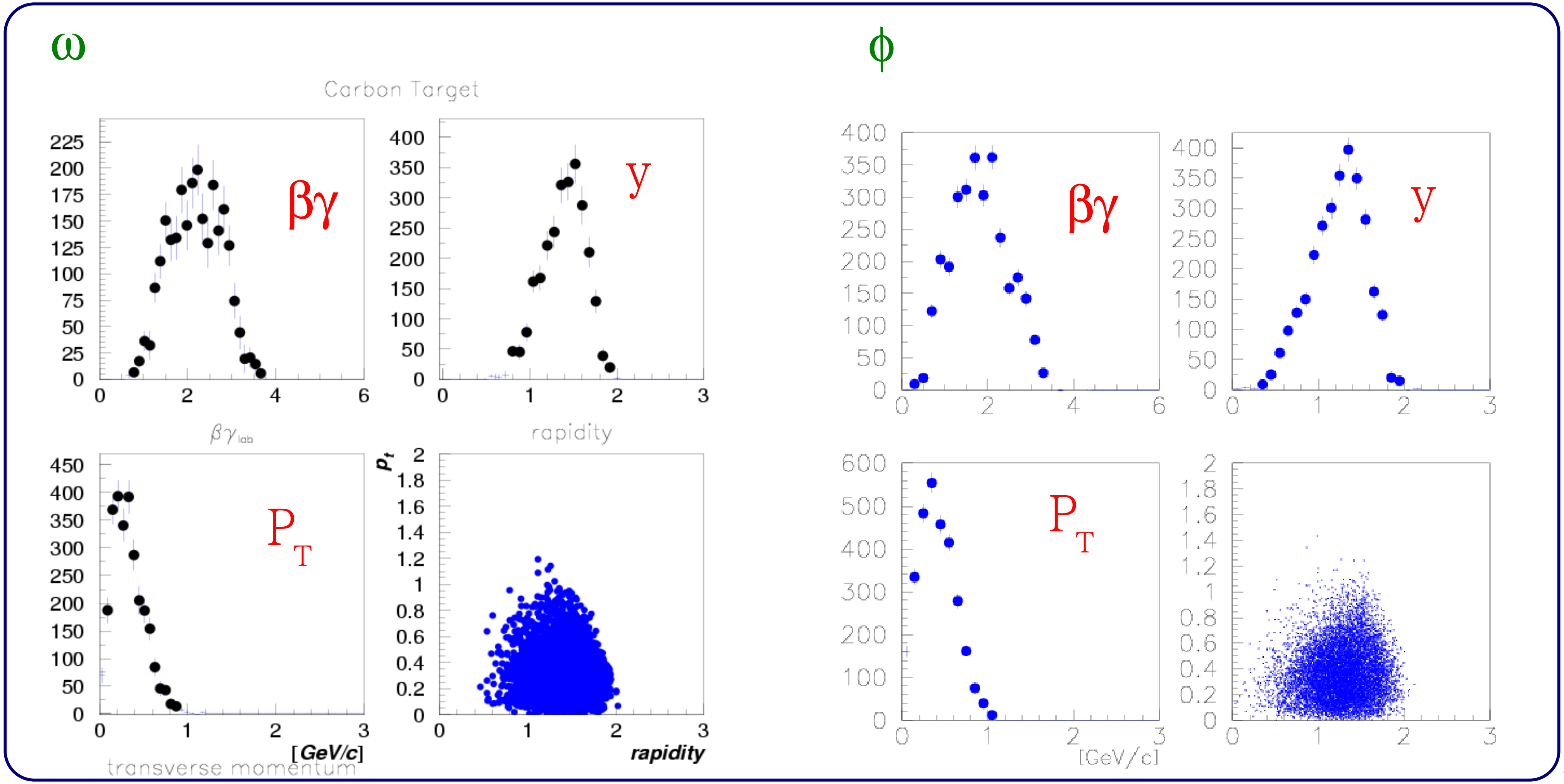
e^+e^- invariant mass spectra

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



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

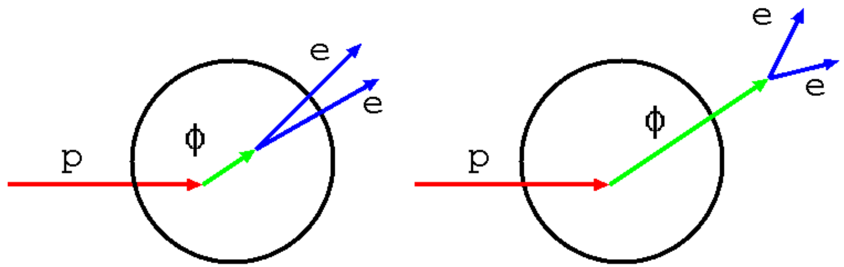
- $0 < P_T < 1$, $0.5 < y < 2$ (y_{CM}=1.66)
- $1 < \beta\gamma\,(=p/m) < 3$ (0.8<p<2.4GeV/c for ω, 1<p<3 GeV/c for ϕ)



Expected Invariant mass spectra in e^+e^-

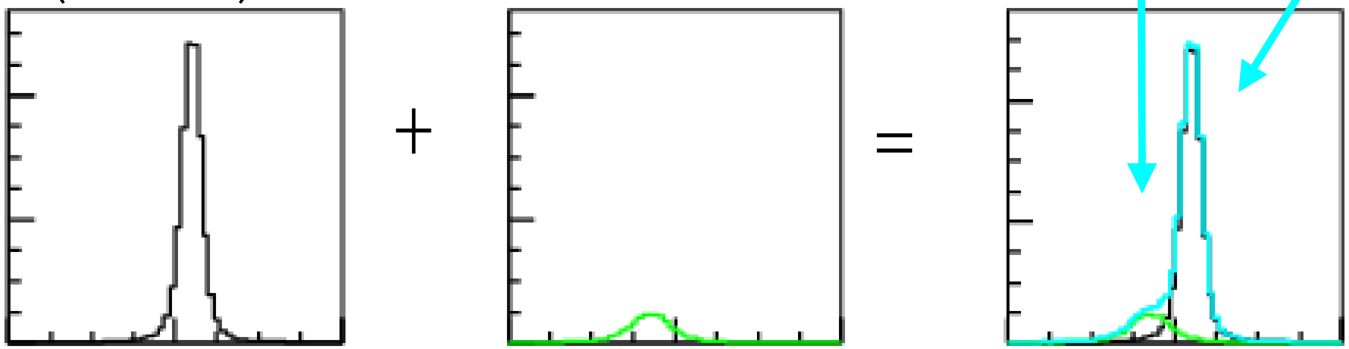
- smaller FSI in e^+e^- decay channel
- double peak (or tail-like) structure :
  - second peak is made by inside-nucleus decay (modified meson) : amount depend on the nuclear size and meson velocity
    - could be enhanced for slower mesons & larger nuclei

1) decay inside nuclei 2) decay outside nuclei



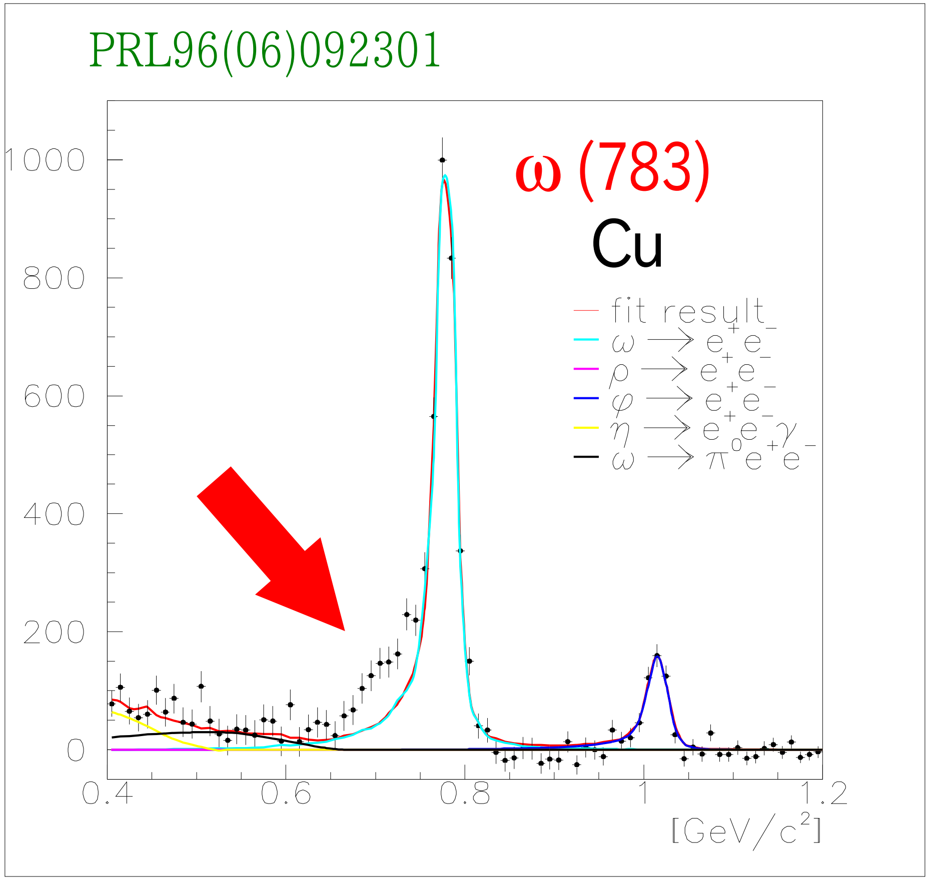
longer-life meson(ω & ϕ)cases : Schematic picture

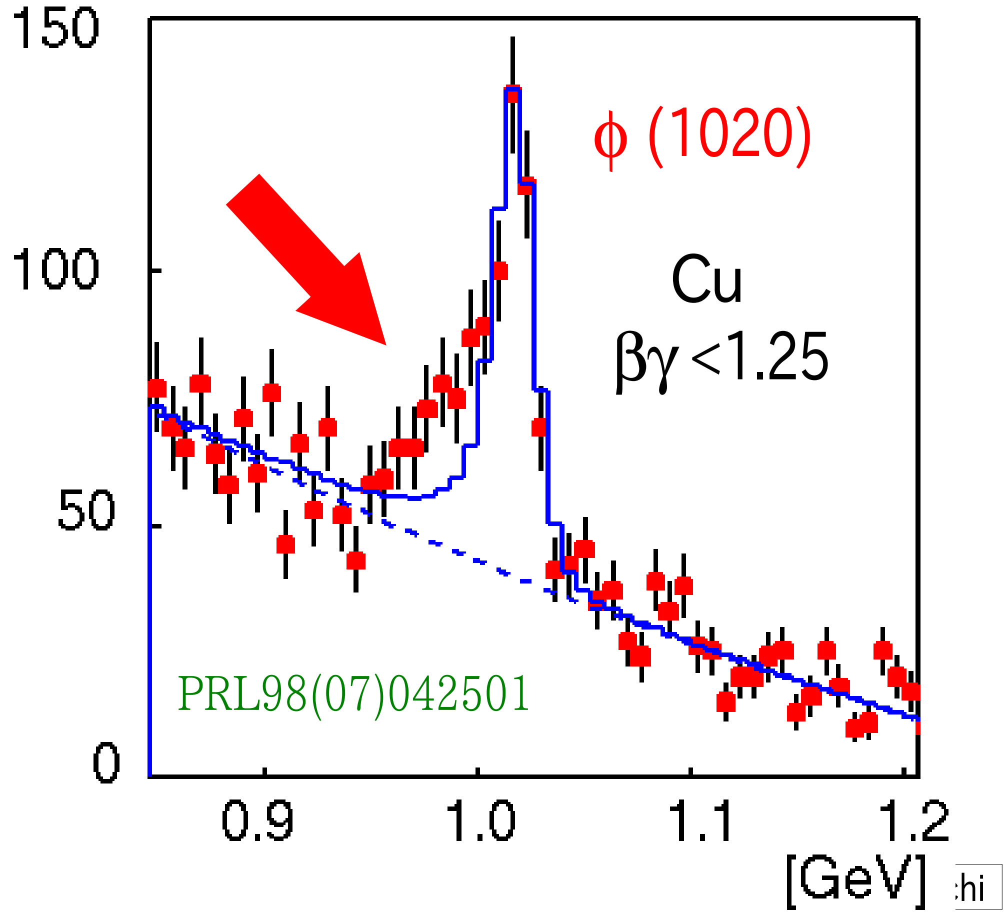
outside decay (natural) + inside decay (modified) = expected to be observed



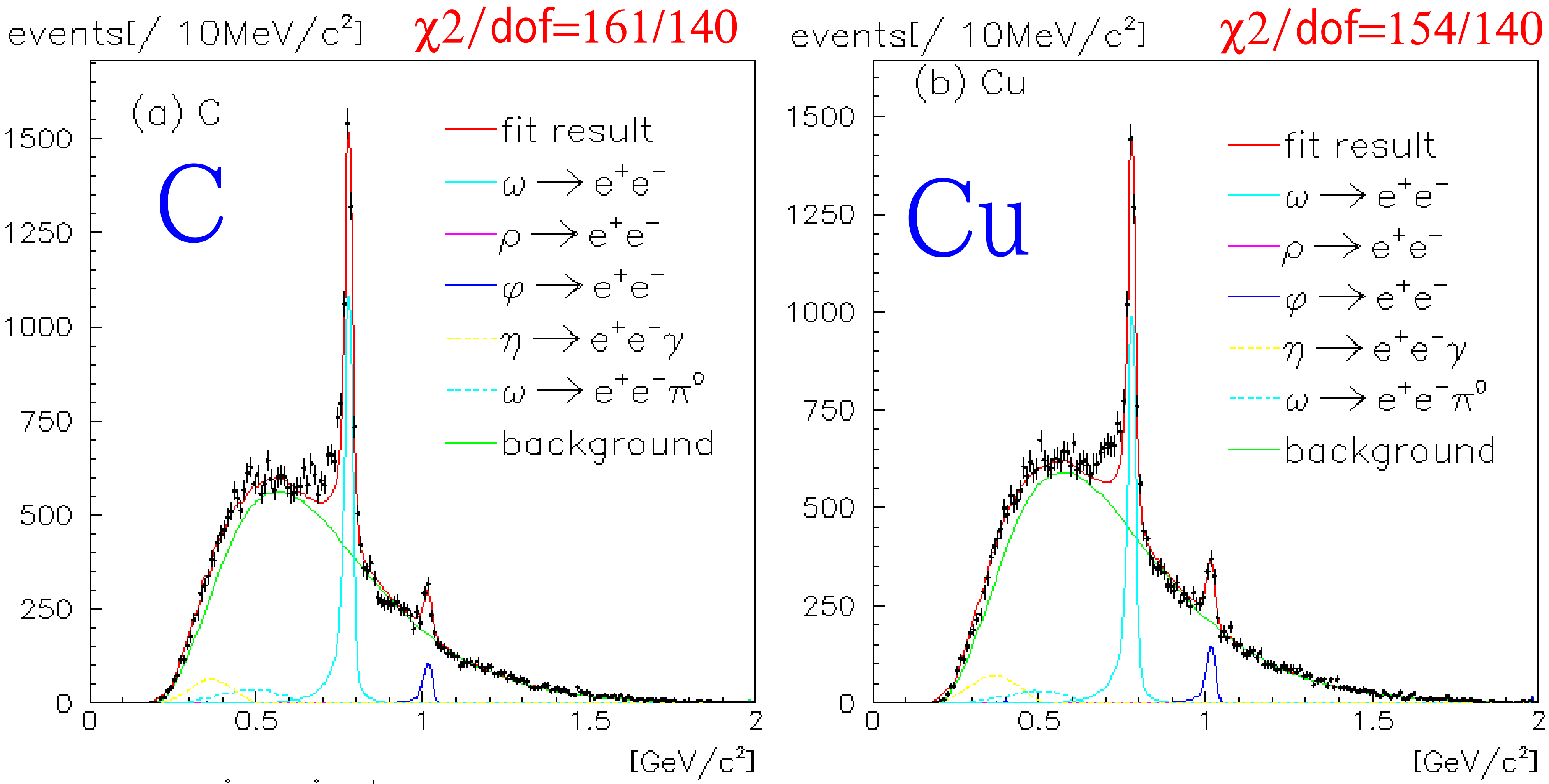
E325 observed the meson modifications

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





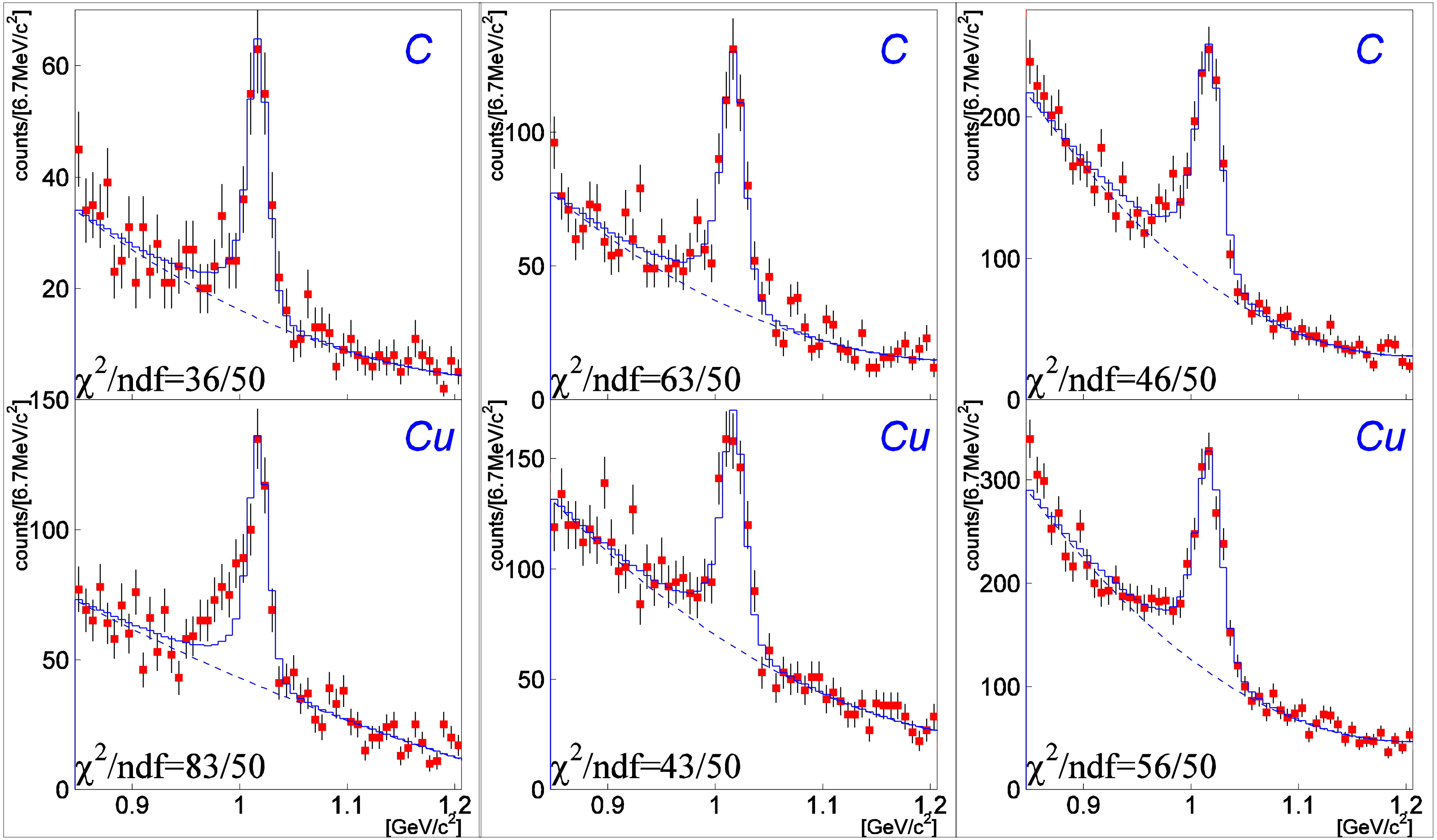
Fitting results (ρ/ω)



- 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. (ρ/ω =1.0±0.2 in a former experiment)

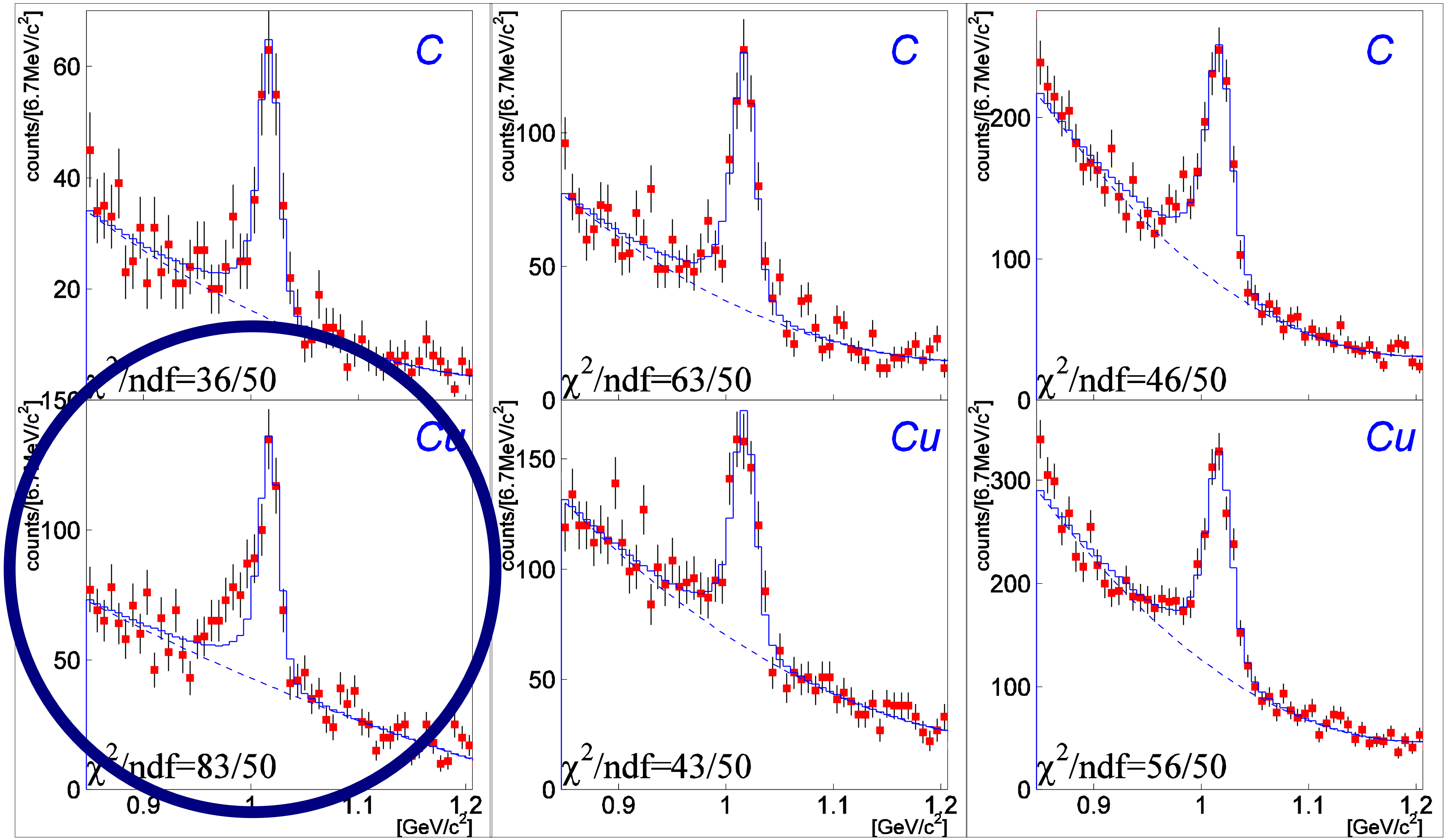
e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

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



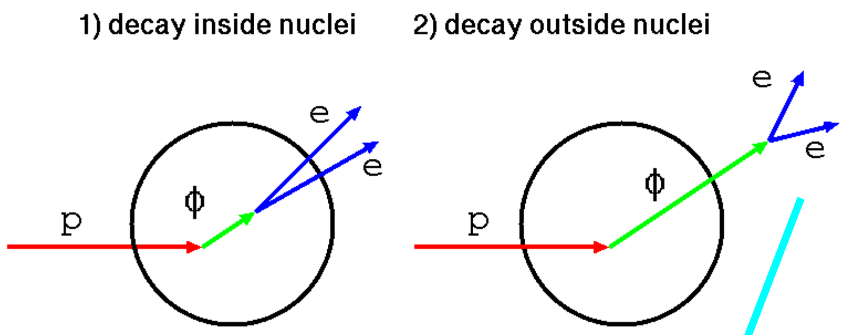
e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

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

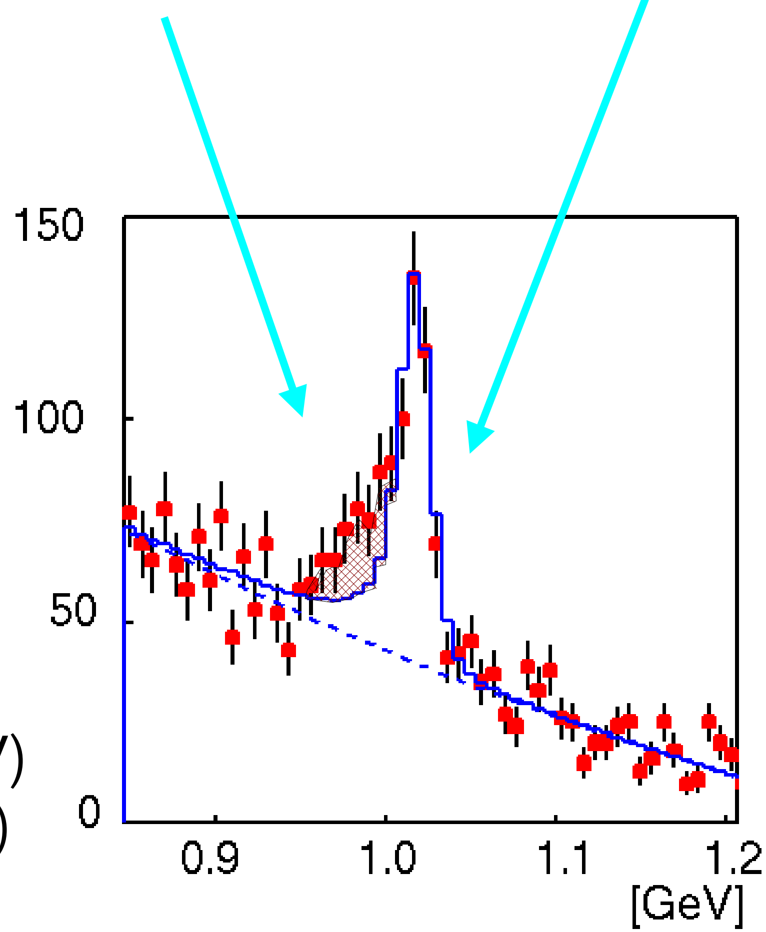


only slow/Cu is not reproduced in 99% C.L.

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 result with the predictions by Hatsuda & Lee (k_1) , Oset & Lamos (Γ)

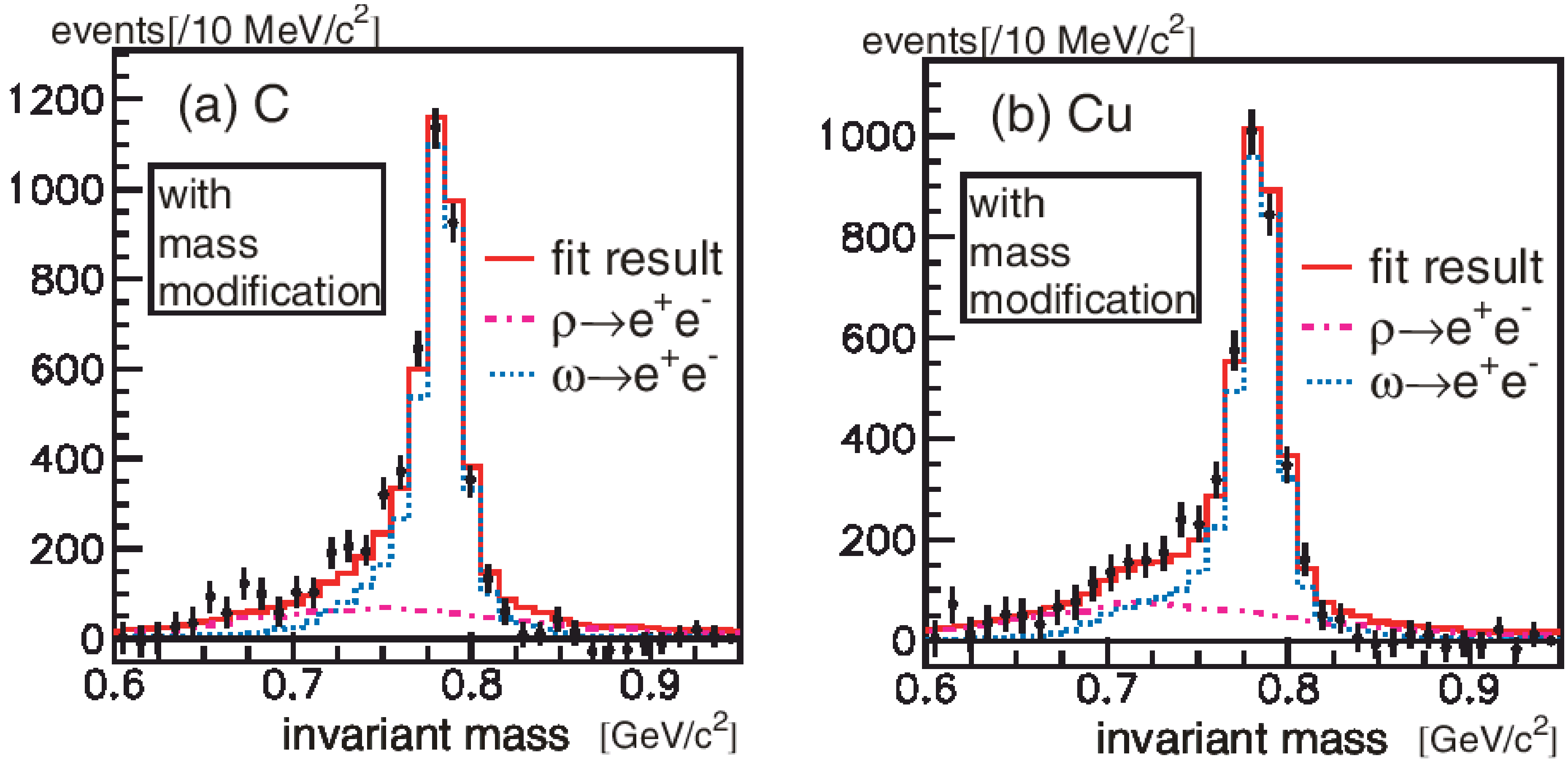


$$k_1 = 0.034^{+0.006}_{-0.007}$$
$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$

For ϕ, 3.4% mass reduction (35MeV)
3.6 times width broadening(15MeV)
at ρ_0

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 production ratio : 0.7± 0.1 (C), 0.9±0.2 (Cu) : … ρ meson returns.
Note: if k_ω is assumed to be 0 (*i.e.* not modified), k_ρ could be smaller.

E325 Results (2)

KK invariant mass / branching ratio

F. Sakuma et al., PRL98(2007)152302
tendency of KK branch enhancement

Production Cross sections

T.Tabaru et al., PRC74(2006)025201
nuclear dependence of CS :

$\alpha_\omega = 0.710 \pm 0.021(\mathrm{stat.}) \pm 0.037(\mathrm{syst.})$

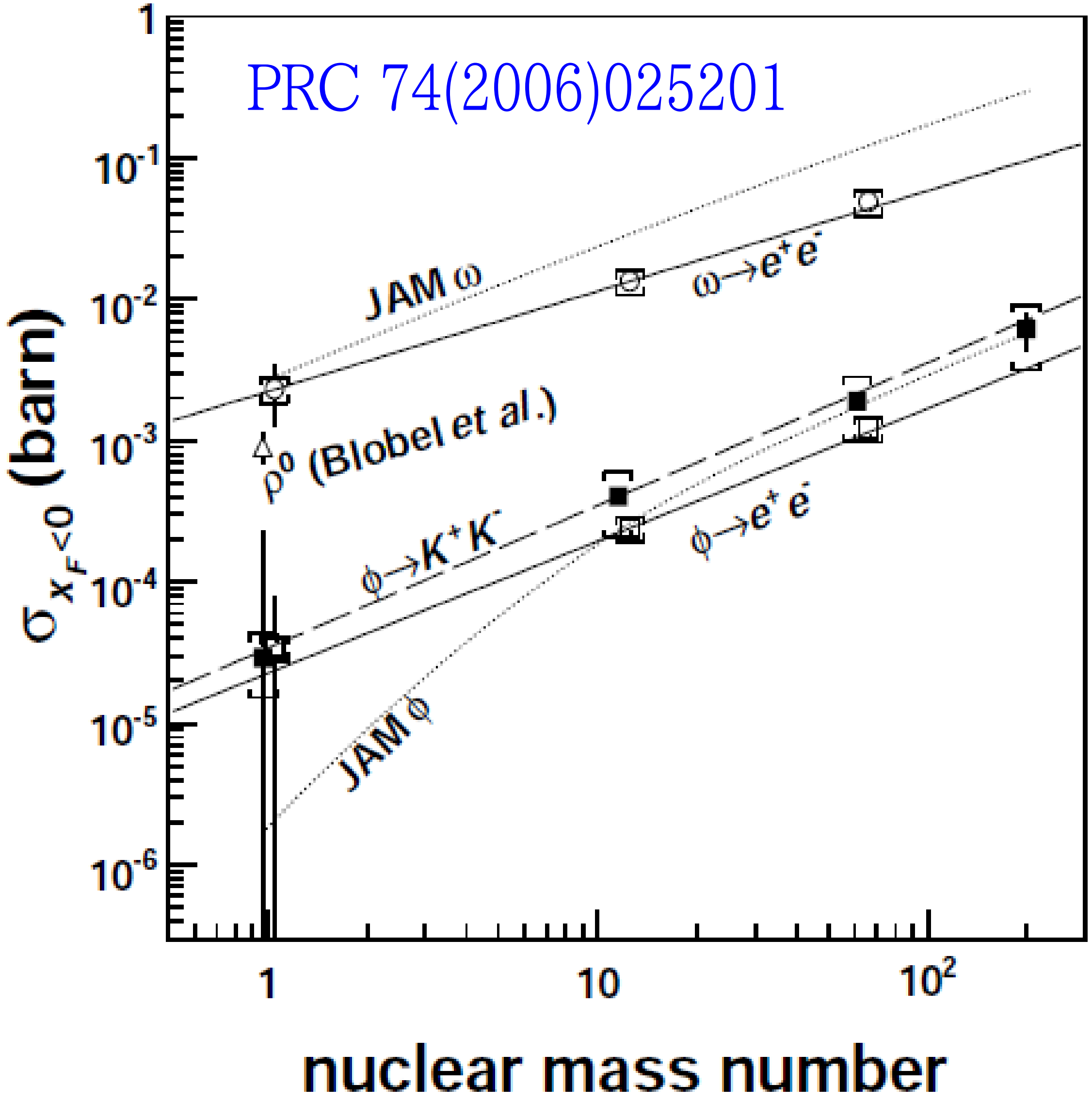
$\alpha_\phi = 0.937 \pm 0.049(\mathrm{stat.}) \pm 0.018(\mathrm{syst.})$

measured production CS by E325

- values for the CM backward
- consistent w/ the former measurement for ρ meson by Blobel (PLB48(1974)73)
- Nuclear dependence α_ϕ = 0.937 corresponds to about $\sigma_{\phi N}$=3.7mb (Sibirtsev et.al. EPJA 37(2008)287)

  additional Γ=12 MeV for 2 GeV/c ϕ (β=0.9) : consistent with Γ $=15^{+8}_{-5}$ MeV (i.e. $k_2=2.6^{+1.8}_{-1.2}$)
- Remark:

  Γ_ϕ=15MeV at m_ϕ=985MeV is consistent with Oset & Ramos (NPA679(2001)616)



Summary (1)

- E325 observed mass modification of vector mesons in nuclear matter
  - in $\rho/\omega \rightarrow e^+e^-$
    - in the e^+e^- channel, ρ and ω cannot be distinguished
  - in $\phi \rightarrow e^+e^-$
    - only one histogram has significance
  - in $\phi \rightarrow K^+K^-$, there is a hint in the branching ratio, but not significant
- Next step in the invariant-mass approach
  - $\phi \rightarrow e^+e^-$: less uncertain than the ρ/ω case
    - ρ's broad and complicated shape, ρ–ω interference, ρ/ω ratio, etc.
  - systematic study of the mass modification
    - matter-size dependence: larger/smaller nuclei, impact parameter
    - momentum dependence : never measured
  - check the interpretation models

J-PARC E16 experiment

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

Collaboration

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

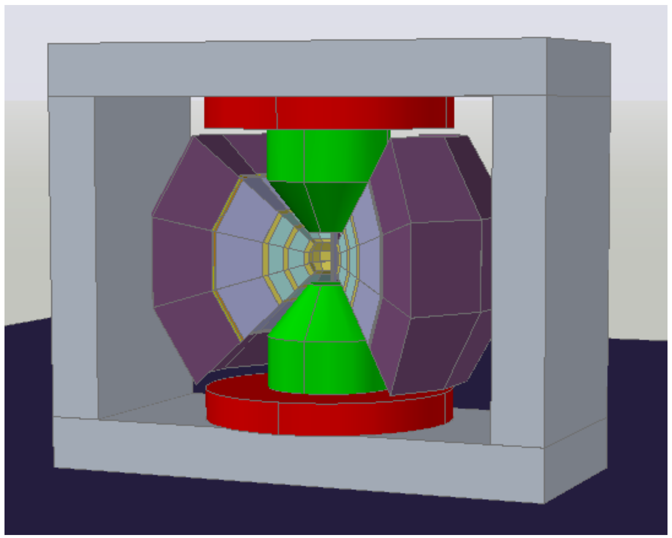
Proposal http://ribf.riken.jp/˜yokkaich/paper/jparc-proposal-0604.pdf

Scientific approval : 2007/3
... Detector R&D is on going (already supported)
... production is dependent on budget status
... beamline is also : budget requested by KEK/J-PARC
Goal of construction : 2012/autumn

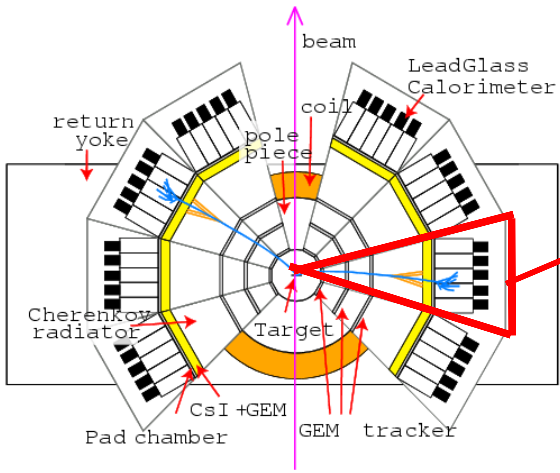
Collect high statistics for the systematic study

- 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 → 10^{10} /spill (1sec)) : x 10 (→ ~ 10MHz interaction on targets)

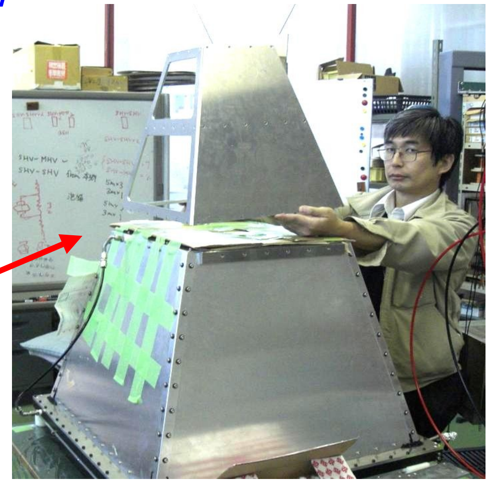
Proposed Spectrometer



Plan View

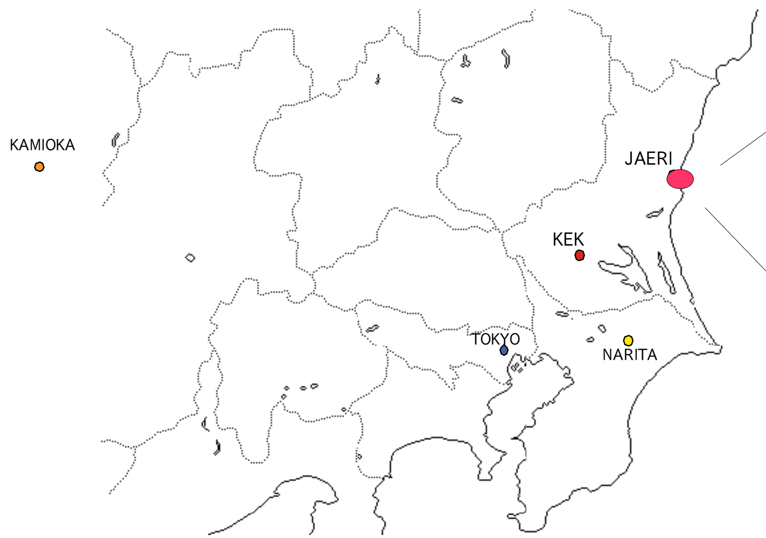


Prototype Module



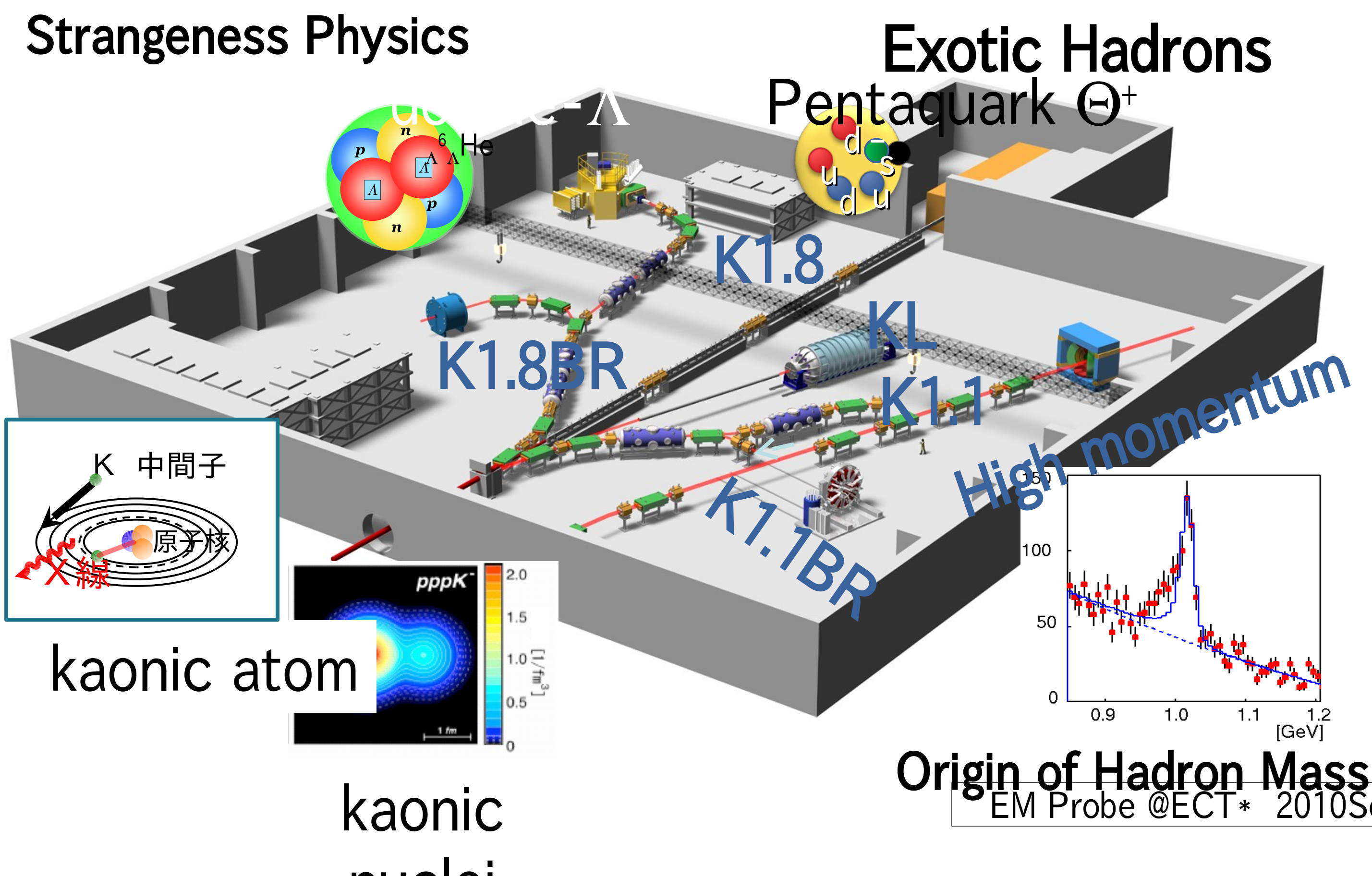
J-PARC : Japan Proton Accelerator Research Complex

- High Intensity Proton accelerator (3GeV and 50GeV rings) -> secondary beams
  - material & life science using neutron and muon beams
  - nuclear and hadronic physics using pion, kaon anti-proton and primary proton beams
  - neutrino beam to Kamioka
- At Tokai village, 2 hours from Tokyo by train and taxi

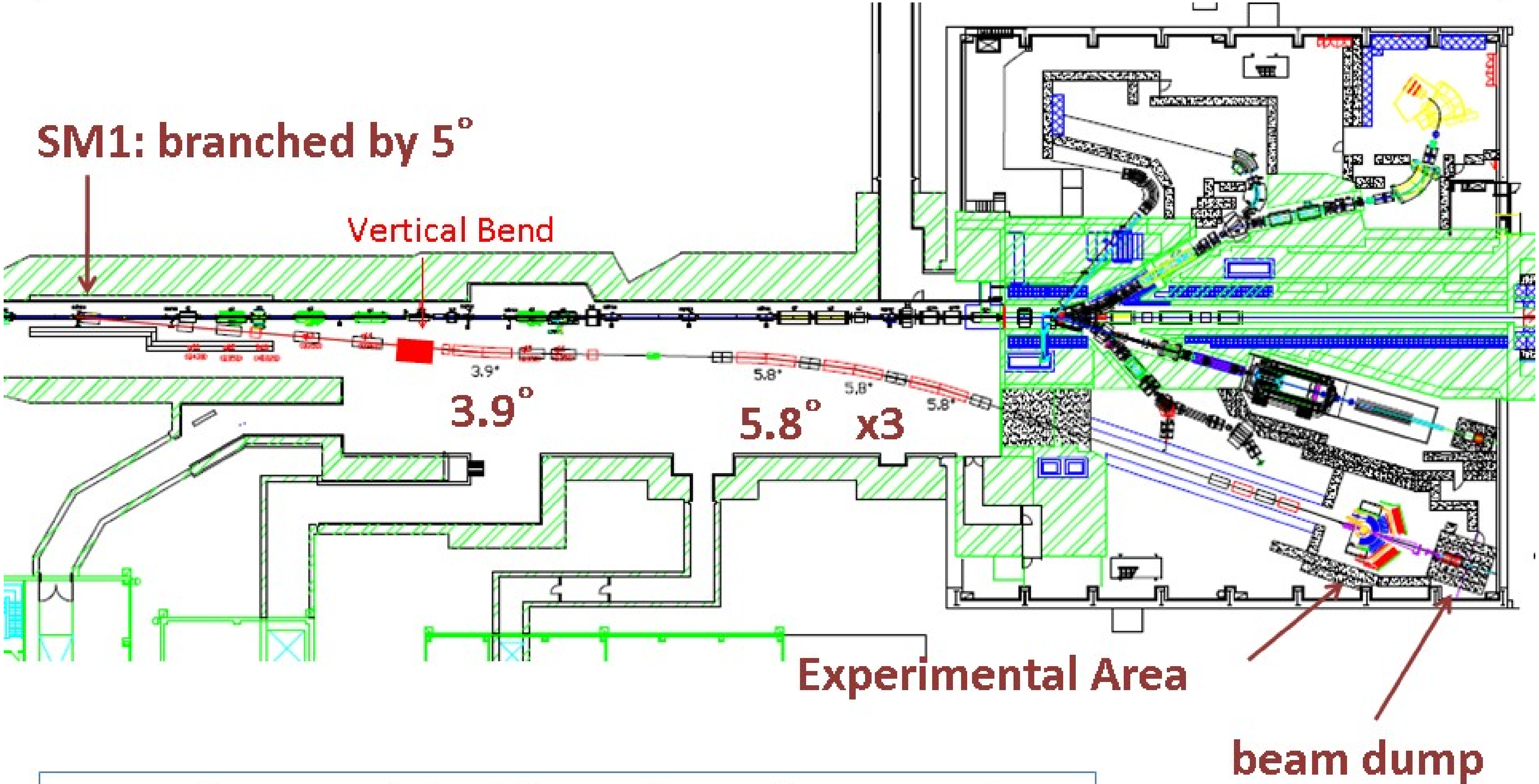


Hadron experimental facility in J-PARC

- 50GeV Main Ring (MR) is operated in 30GeV, first acceleration in 2008/12
- first slow extraction to Hadron experimental facility in 2009/1
  - first physics experiment (E19 :penta quark search), using 1.9GeV/c pion beam, is planned in 2010/10



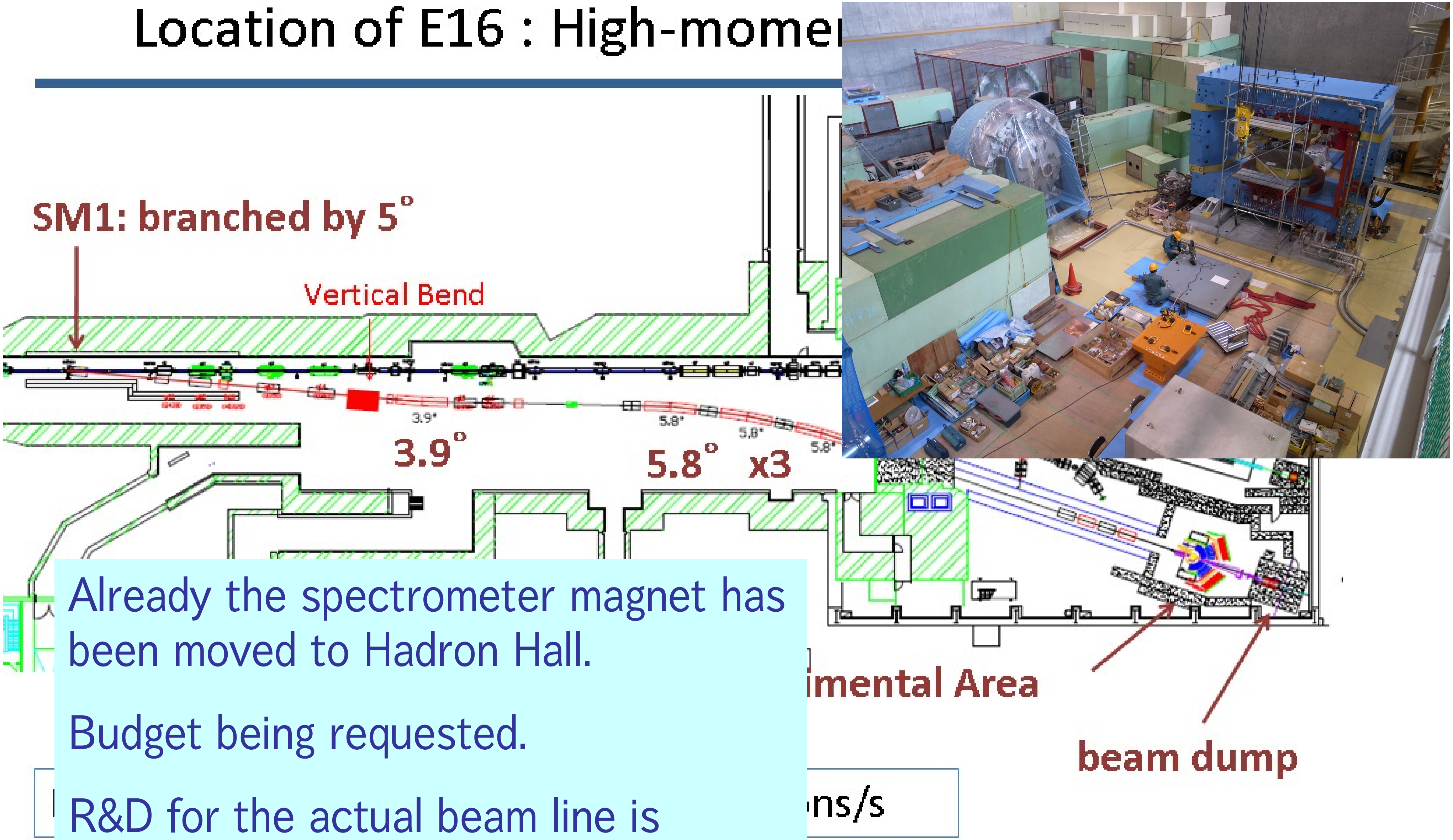
Location of E16 : High-momentum beam line



Beam dump and shields are for 10^{10} protons/s

by R. Muto

Location of E16 : High-momen



Already the spectrometer magnet has been moved to Hadron Hall.

Budget being requested.

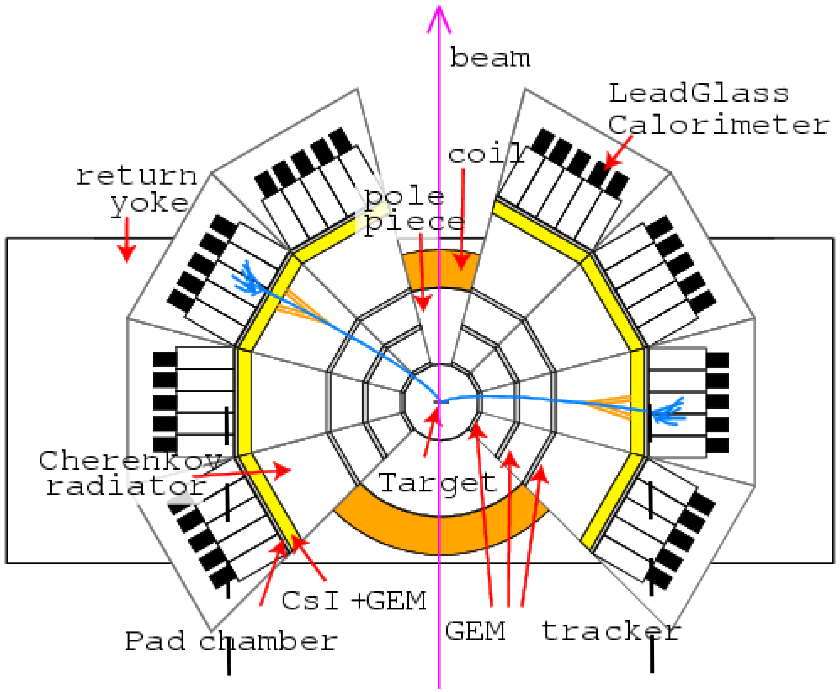
R&D for the actual beam line is underway.

by R. Muto

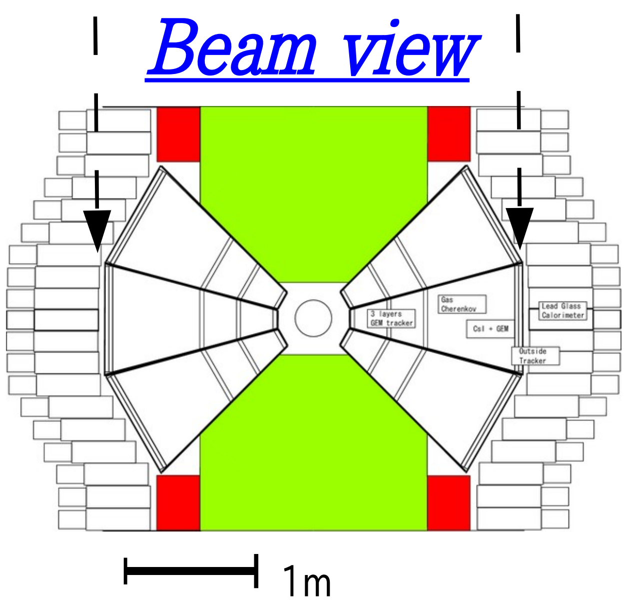
Proposed spectrometer

- Spectrometer Magnet : reuse E325 's
  - remodeling the pole / repairing the coil
  - stronger field for compact detector size
- GEM(Gas electron multiplier) Tracker
  - cope with high rate (5kHz/mm^2)
- Two-stage Electron ID (~10^{-4} π rejection)
  - Hadron Blind Detector (Gas Cherenkov)
    - GEM+CsI photocathode
    - hexagonal pad readout (~36mm 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

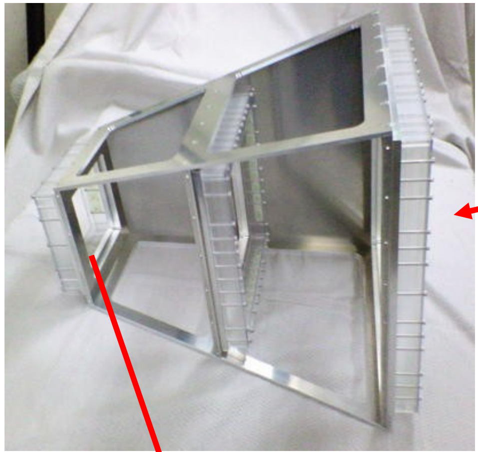


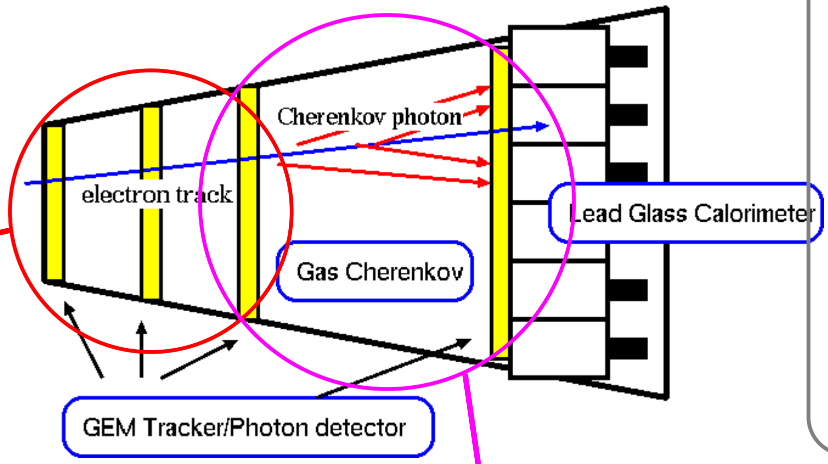
Beam view



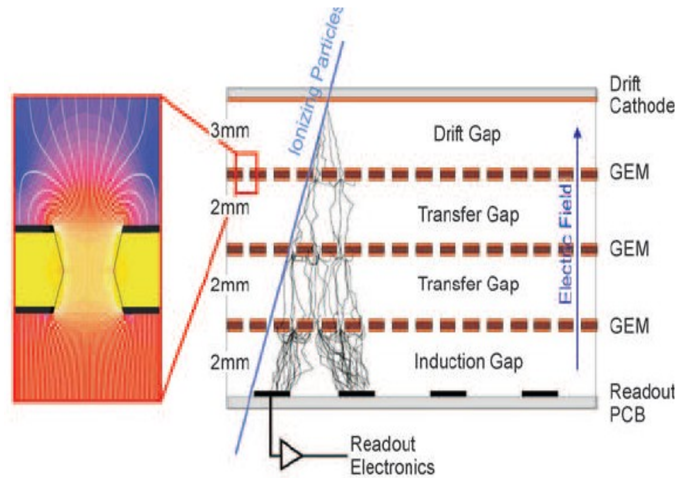
Detector R&D

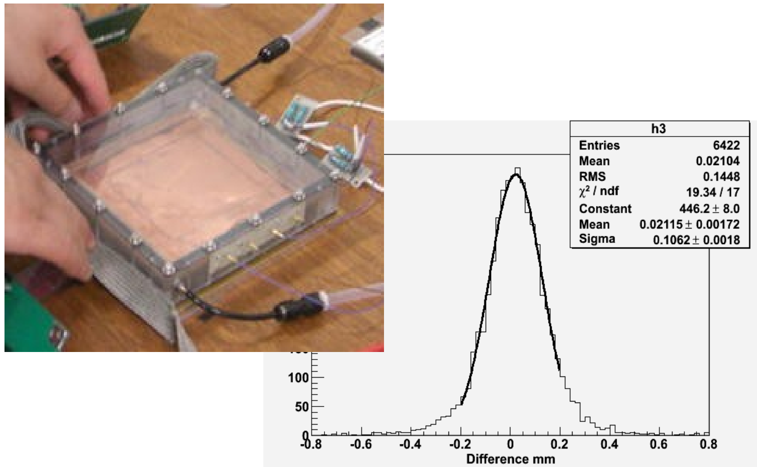
Beam test results of the Prototype Detector Module

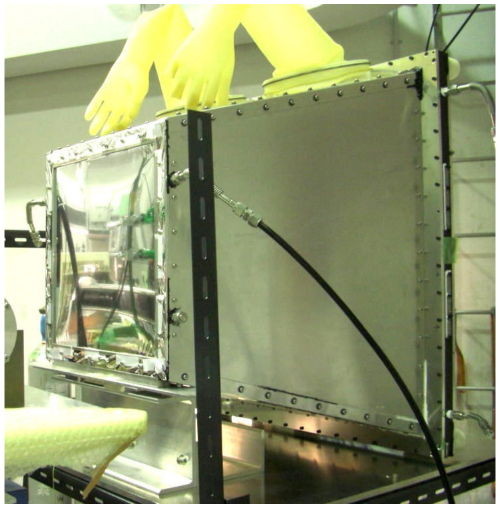




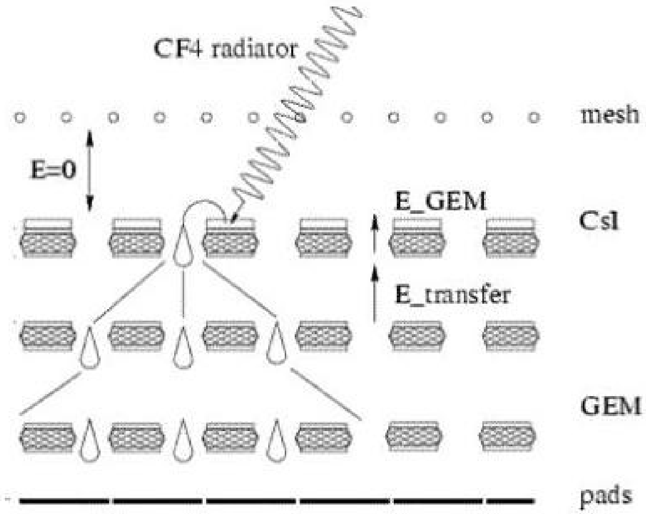
GEM & GEM chamber schematics







HBD(Hadron Blind Gas Cherenkov Detector)schematics

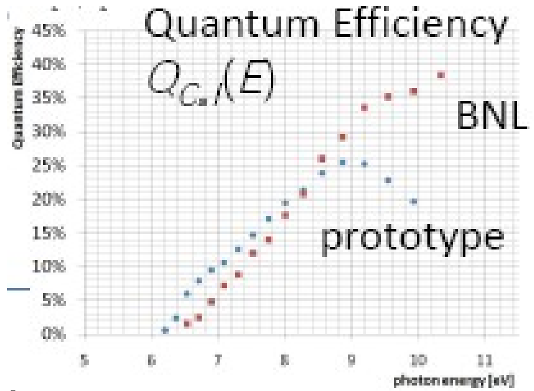


GEM Chamber :
required position resolution (~100μm) is achieved

Hadron Blind Detector :
UV Cherenkov photons from the electron beam are detected by CsI-GEM in CF4

Achievement in beam tests

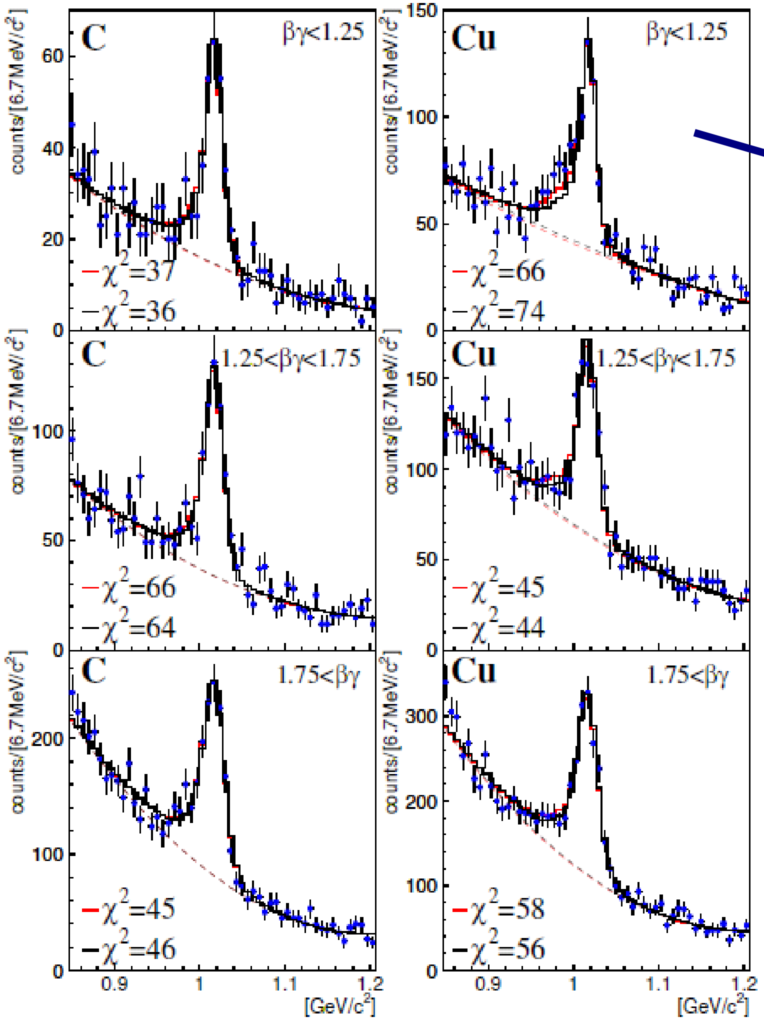
- GEM Tracker
  - GEM(PI 50um) by Raytech.Co.
    - 100mmx100mm, 200mm x 200mm, 300mm x300mm
  - R/O double sided strip PCB (PI 25um) by Raytech.Co
  - position resolution (using ArCO2/350um pitch strip) for angled tracks
    - 100um (for 0deg/15deg) – 140um(30deg) in 100mm x 100mm GEM
    - larger GEMs have enough gain, resolution will be checked in next beam test(2010/Nov.)
- HBD
  - developed thanks to Weizmann/Stony Brook
  - GEM(LCP 100um: higher gain) by Scienergy.Co.
  - CsI evaporaiton by Hamamatsu
  - 5-6 photoelectrons detected (cf. PHENIX ~20 p.e.)
    - gas purity and CsI q.eff. should be improved

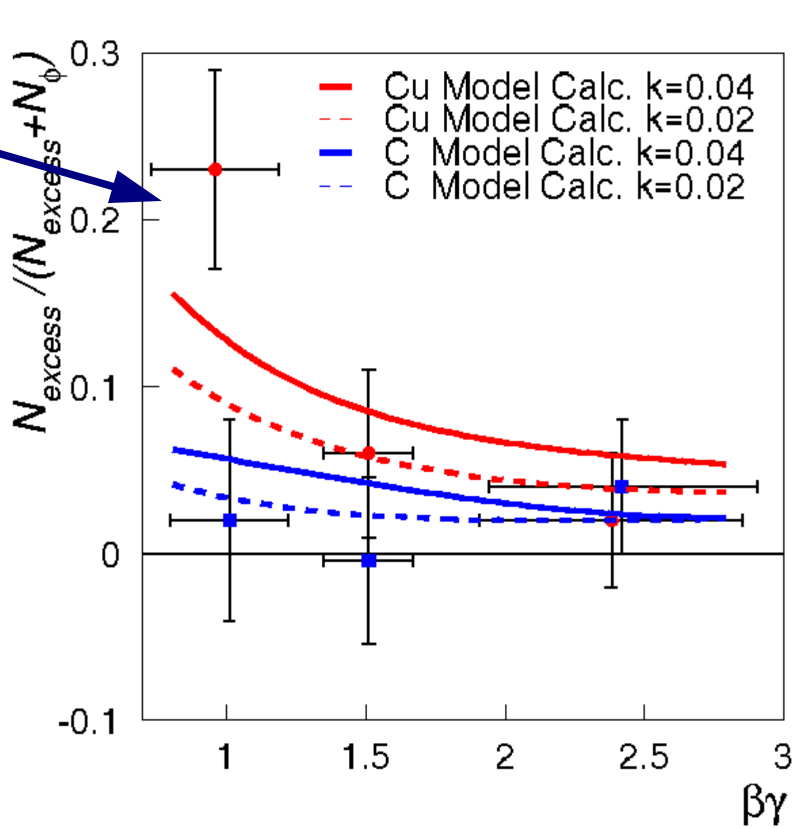


Expected signals in E16 high statistics

velocity and nuclear size dependence

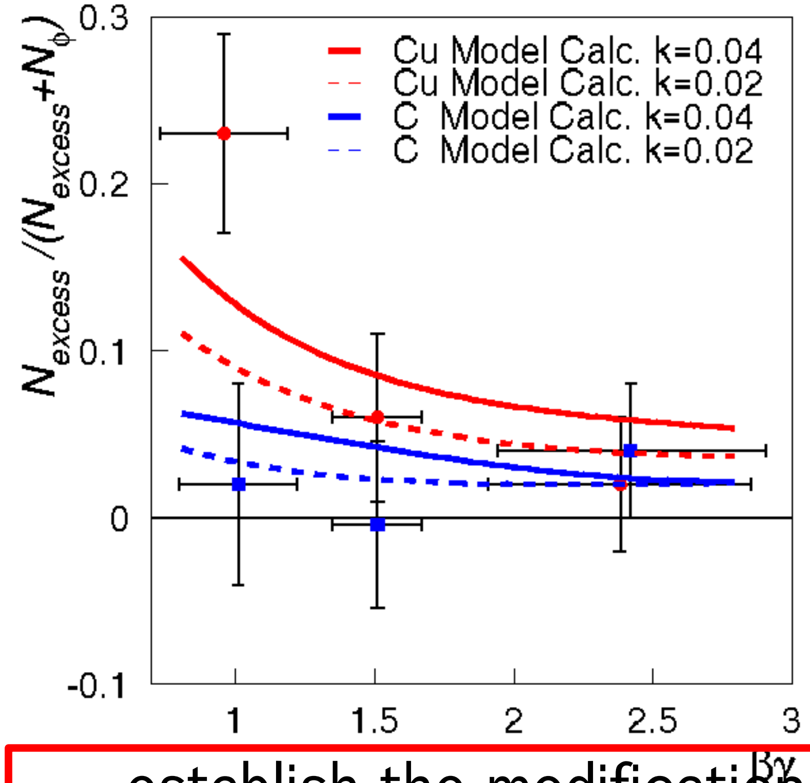
- velocity dependence of excesses ('modified' component)
- E325 only one data point for ϕ (slow/Cu) has significant excess



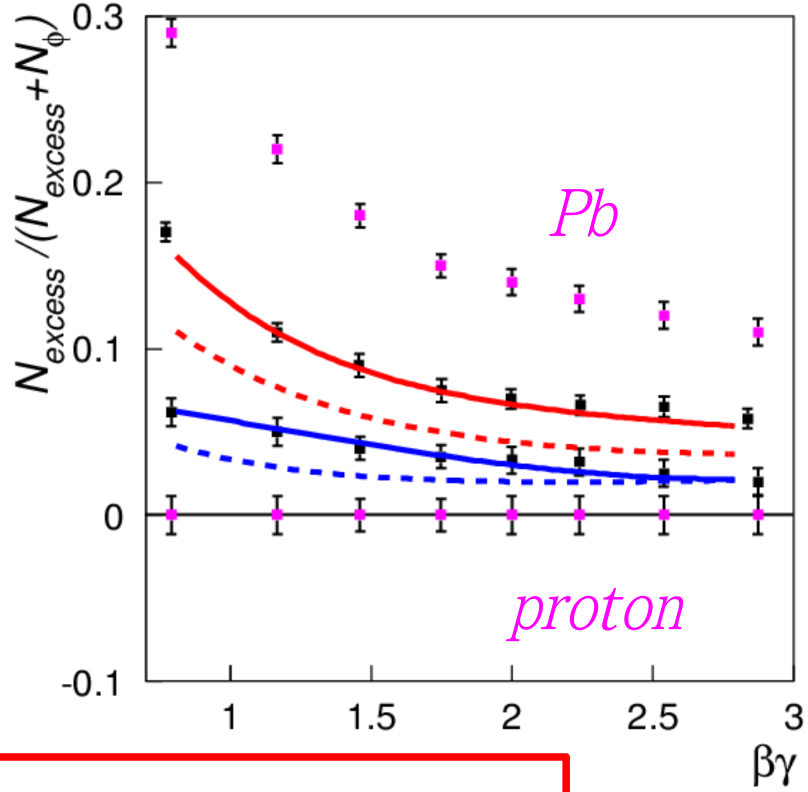


velocity and nuclear size dependence

- 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



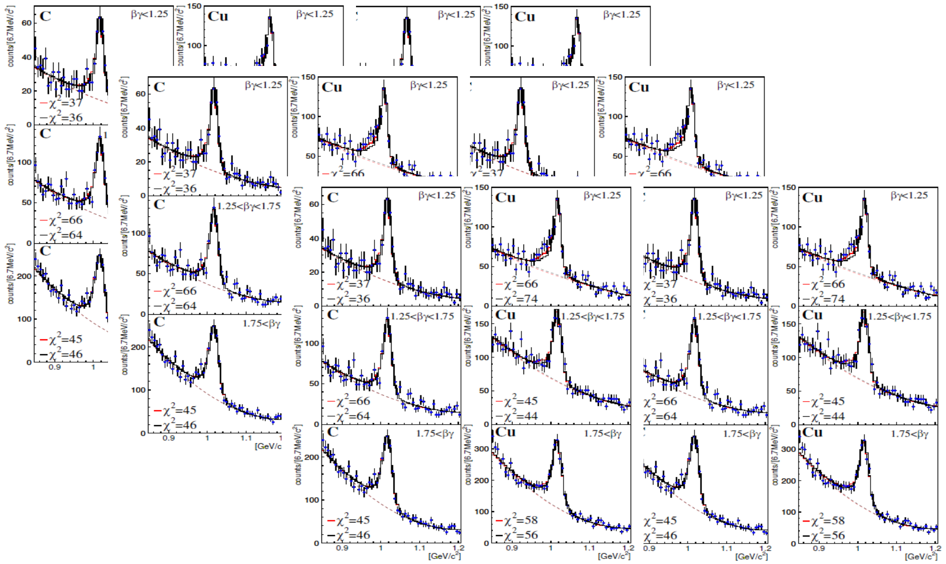
x 100 stat.

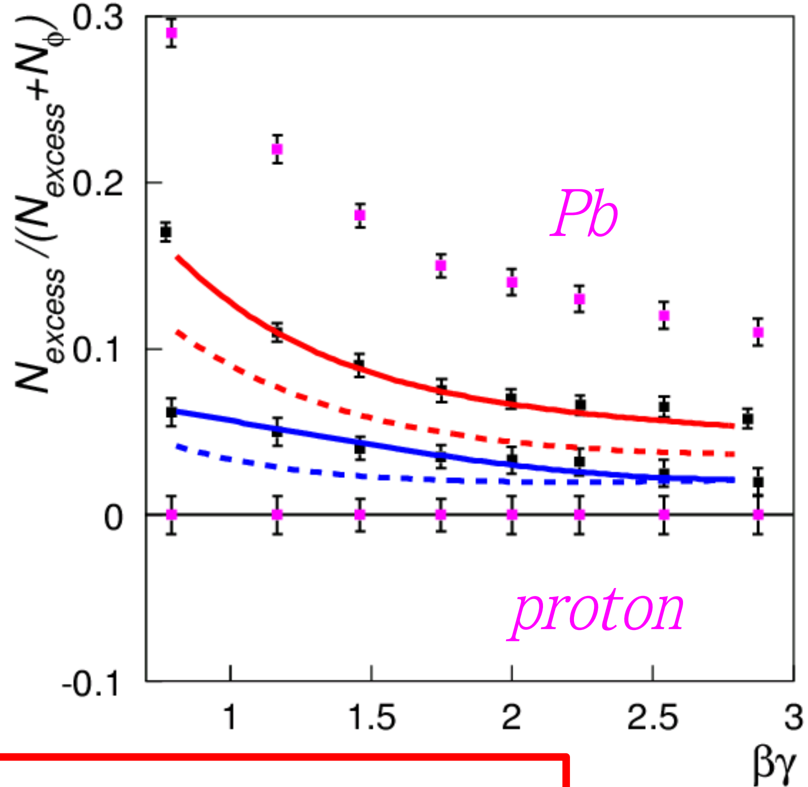


- establish the modification
-

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

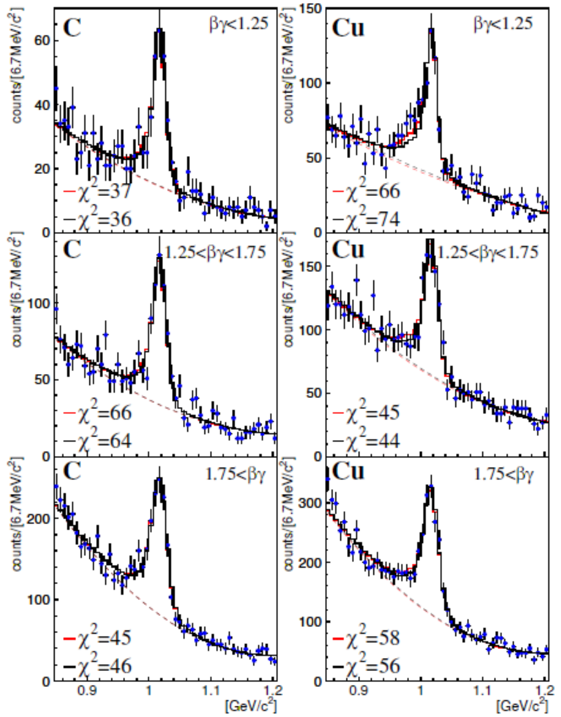


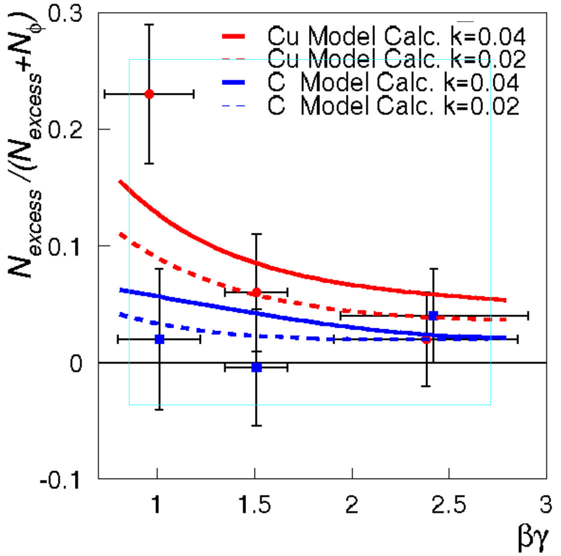


- establish the modification
- check the interpretation model with shape analysis for each histogram

dispersion relation (mass VS momentum)

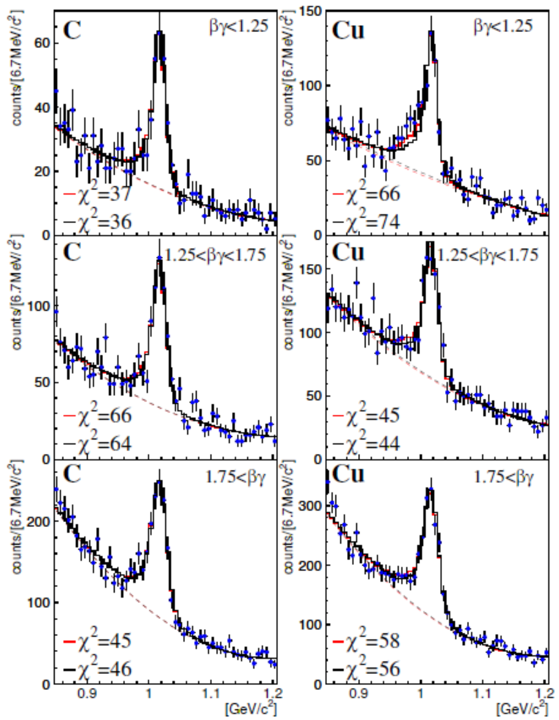
- prediction for ϕ by S.H.Lee(p<1GeV/c)
- current E325 analysis neglects the dispersion (limited by the statistics)

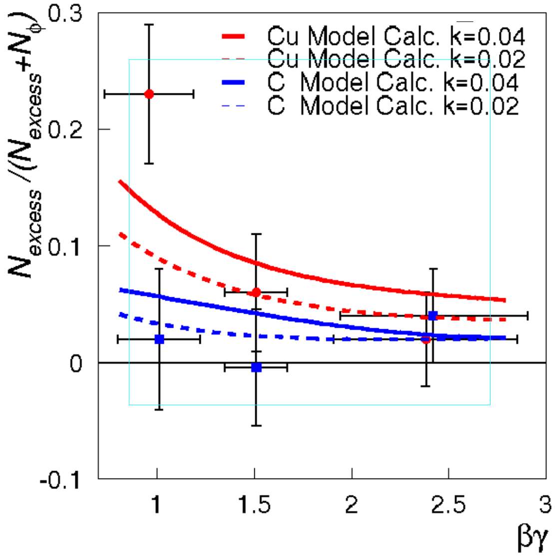


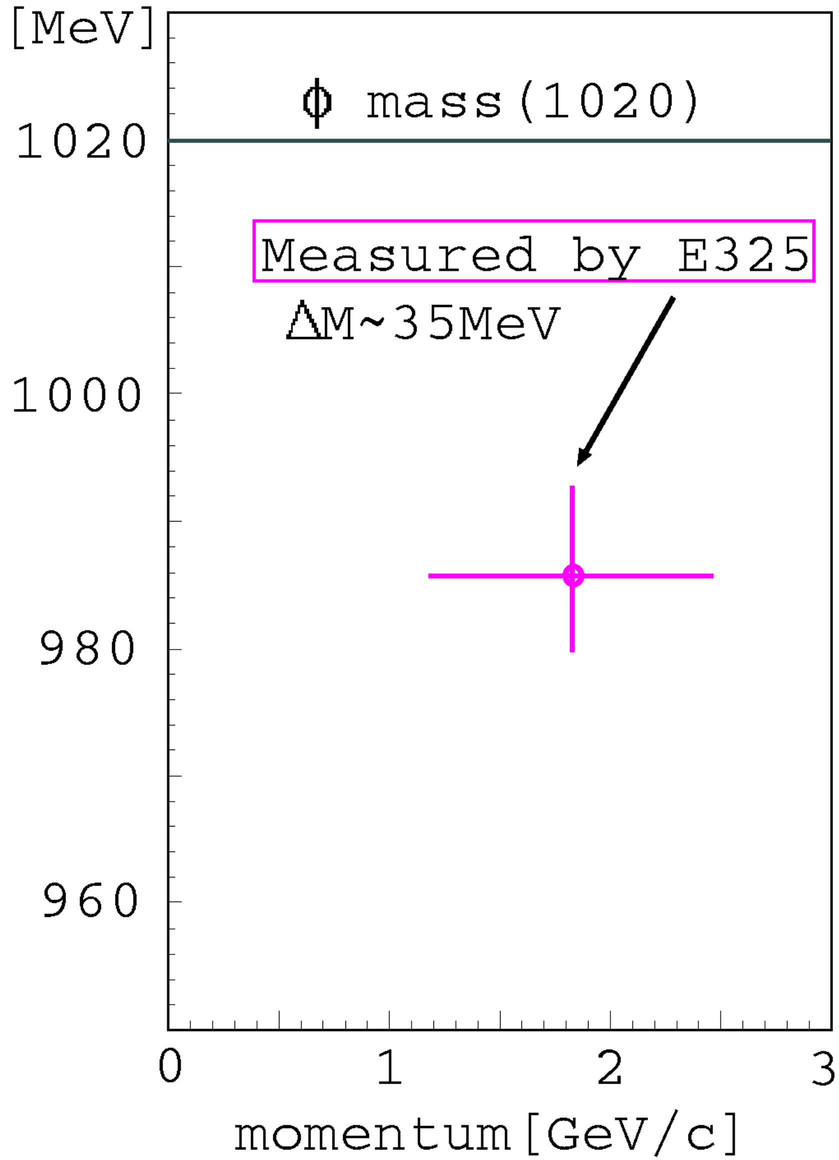


dispersion relation (mass VS momentum)

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

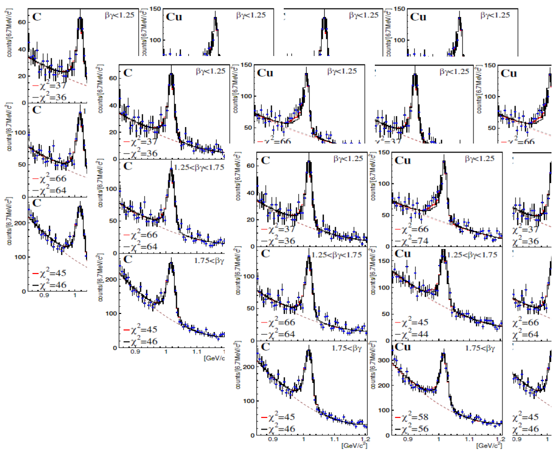


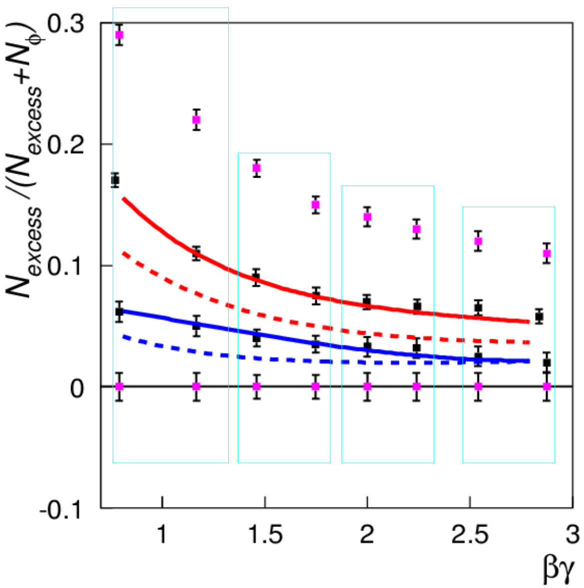


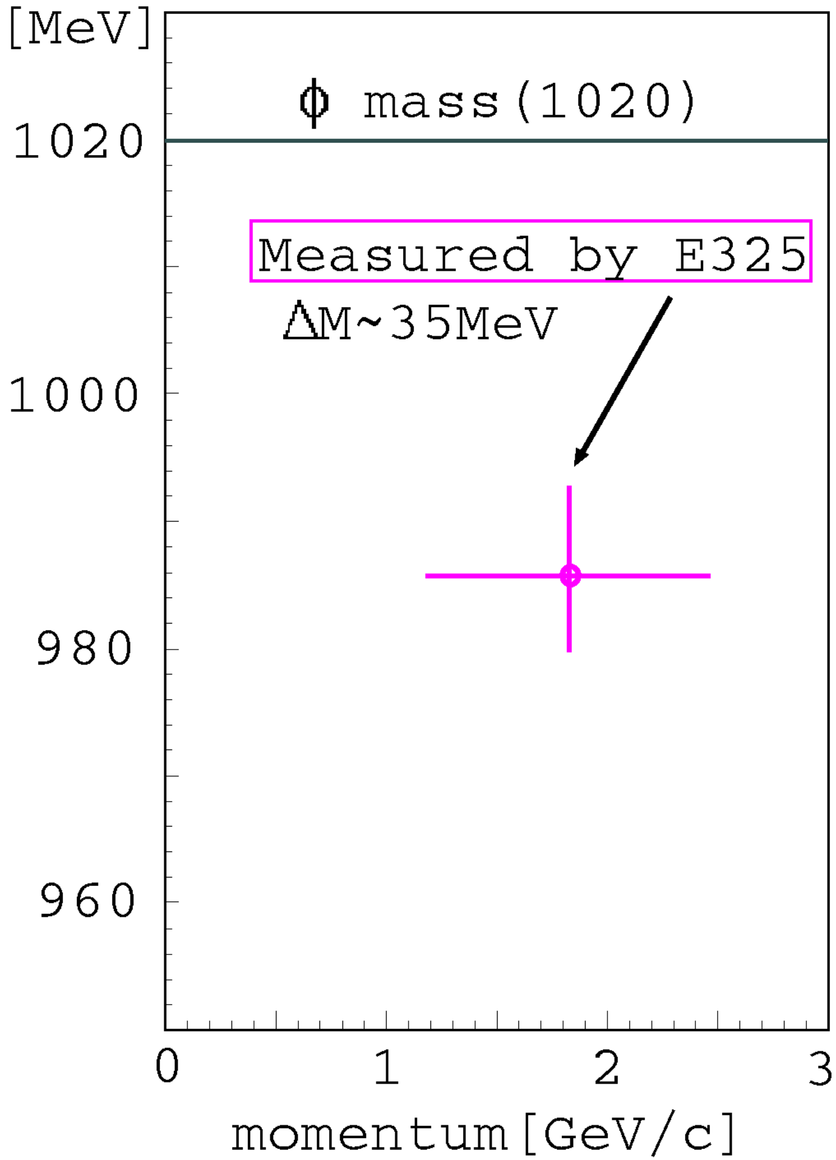


dispersion relation (mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV/c)
- 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

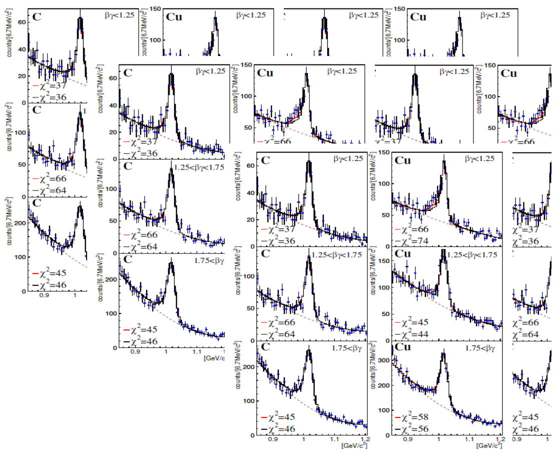


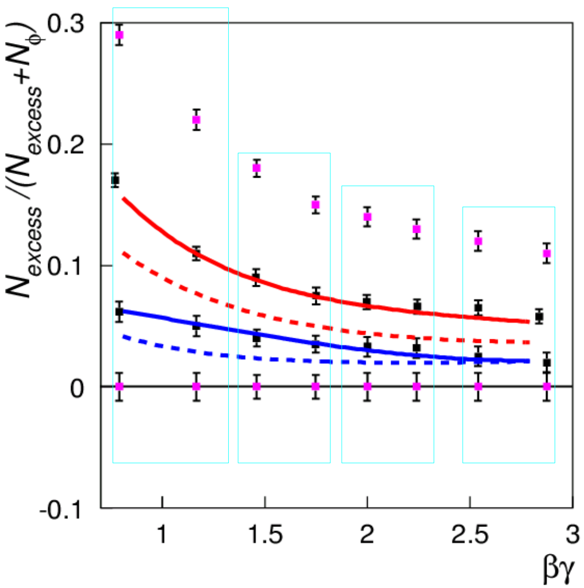


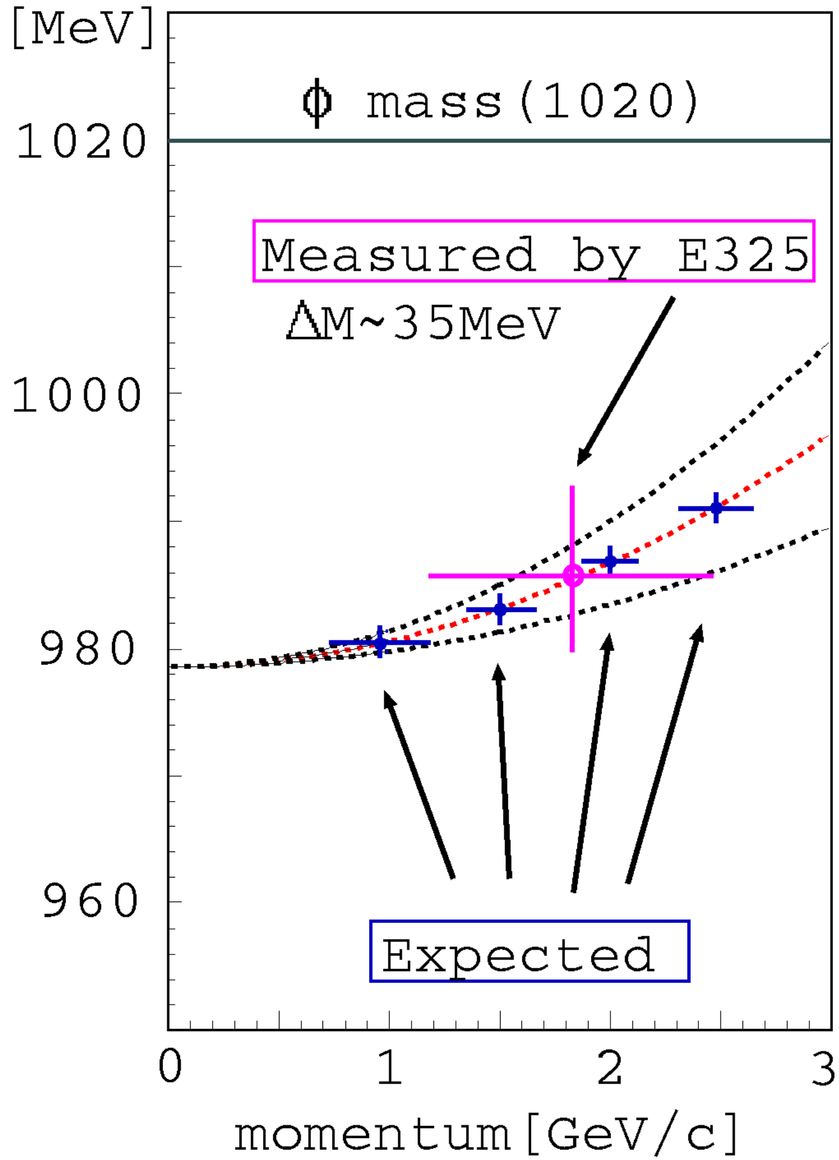


dispersion relation (mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV/c)
- 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

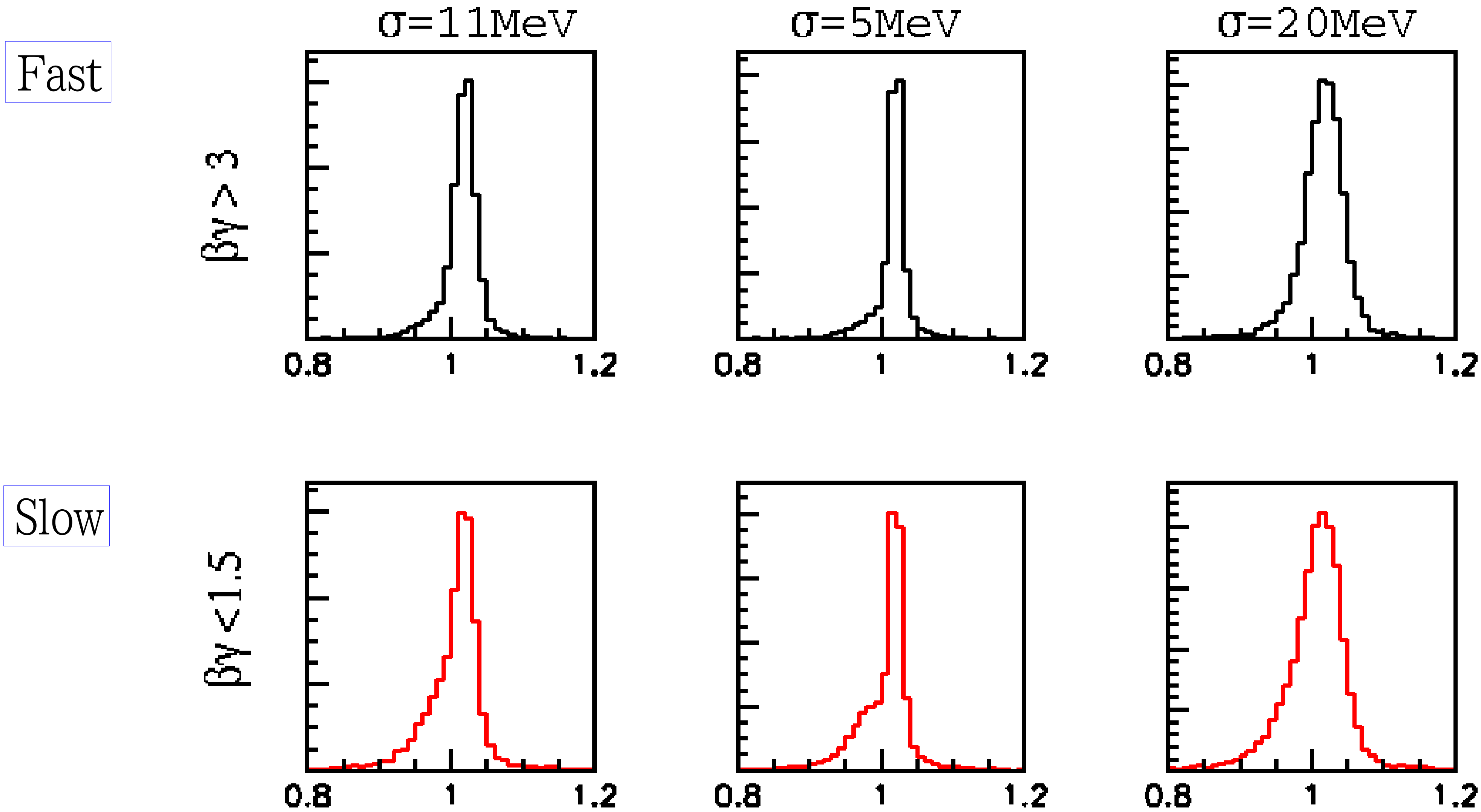






mass resolution requirement

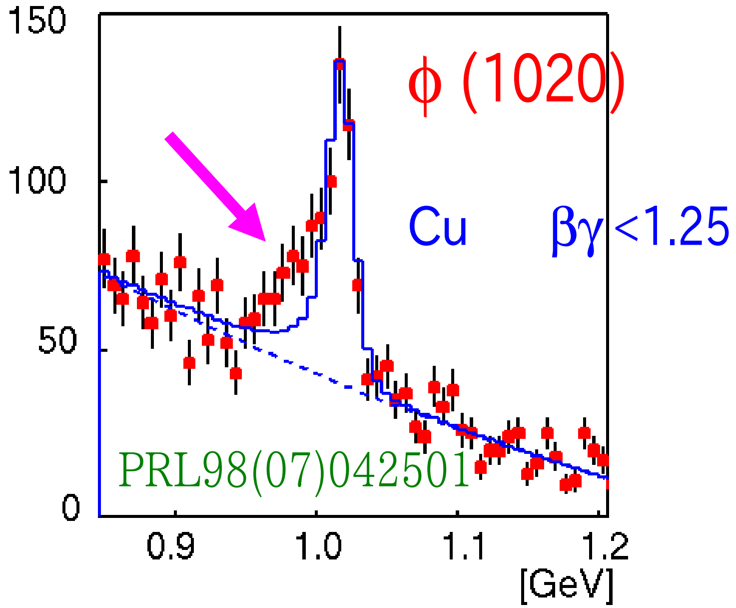
- mass resolution should be kept less than ~10MeV



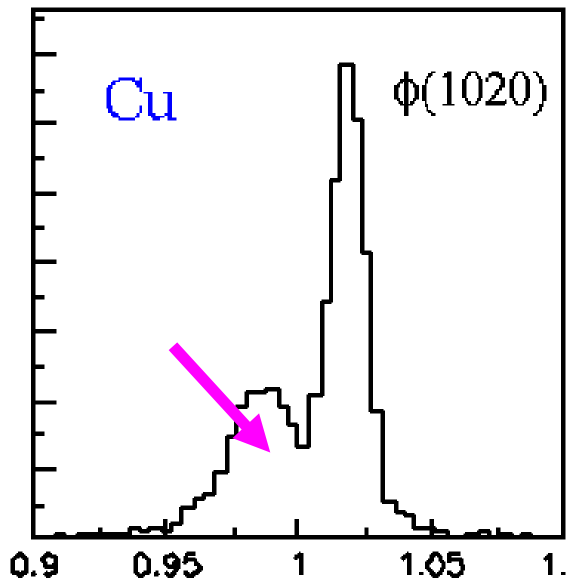
(model calc. for the Cu target)

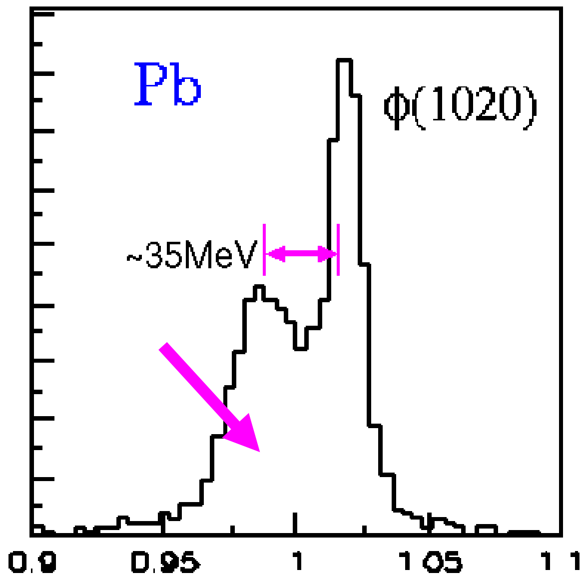
mass resolution requirement

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



βγ<0.5, σ=5 MeV





(model calc.)

50GeV is necessary for charmonium @E16

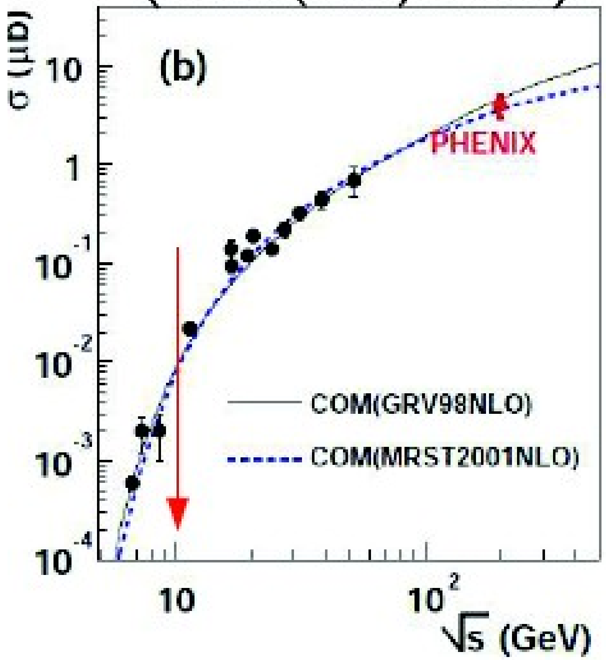
- charmonium mass is governed by the gluon condensate
  - small modification is expected for J/ψ
    - even narrow width (no in-medium decays)
  - width broadening (~10MeV) for χ_c, $\psi(2s)$ and mass decreasing (~10-100MeV)
- very rough estimation w/ the production CS ratio

	ϕ		J/ψ	ratio	ψ (3686)
	12GeV	50GeV	50GeV		
pp	70ub		0.01ub		
pCu	1mb	5mb*1	0.5ub*2	1/10000	?
ee branch	0.03%		6%	200	0.7%
yield		100000	2000	1/50	<200

- *1 : JAM & empirical formula, from 12GeV data
- *2 : nuclear dependence ~A , from pp
- 10^{10} ppp, 0.1% int. target

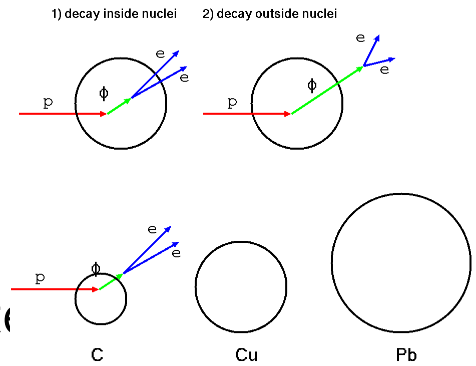
$p+p \rightarrow J/\psi + X$

(PRL92(2004)051802)



Summary(2) :J-PARC E16

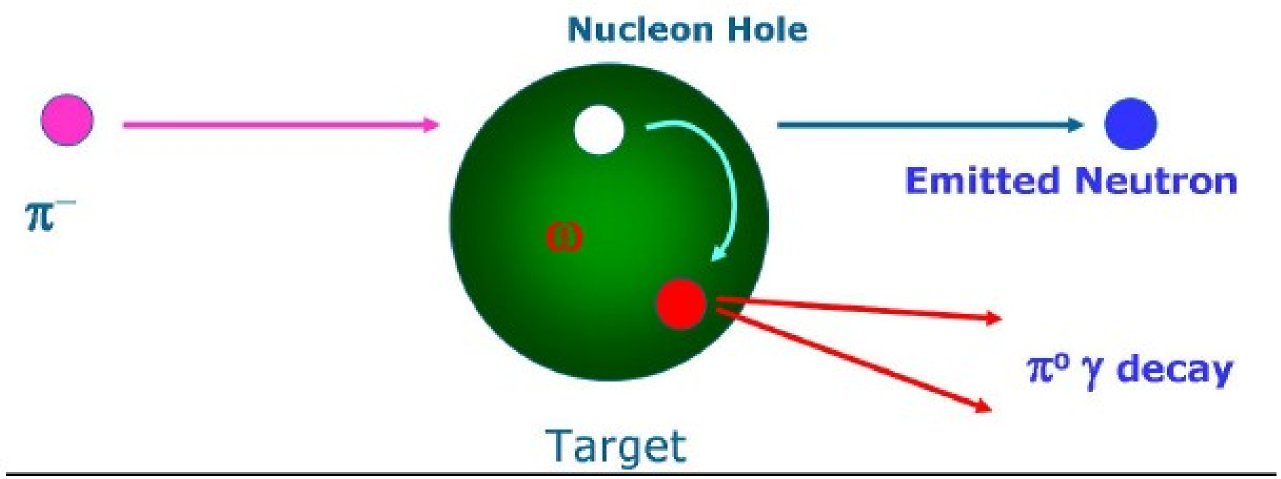
- Main goal : collect ~1-2 x 10^5 $\phi \rightarrow e^+e^-$ for each target in 5 weeks using 30 (or 50) GeV p +A (C/CH_2/Cu/Pb) reactions
  - statistics : ~100 times as large as E325
  - **systematic study of the modification**
    - velocity & nuclear size (0~10 fm) dependence
      - proton/Pb targets / collision geometry (impact paramet
    - momentum dependence (dispersion relation)
  - mass resolution : < 10 MeV (E325 : 10.7 MeV for ϕ)
    - double peak structure with σ ~ 5 MeV, selecting $\beta\gamma$ < 0.5 (vely slow)
- Confirm the modification observed in E325, and provide new information about the mass of hadrons



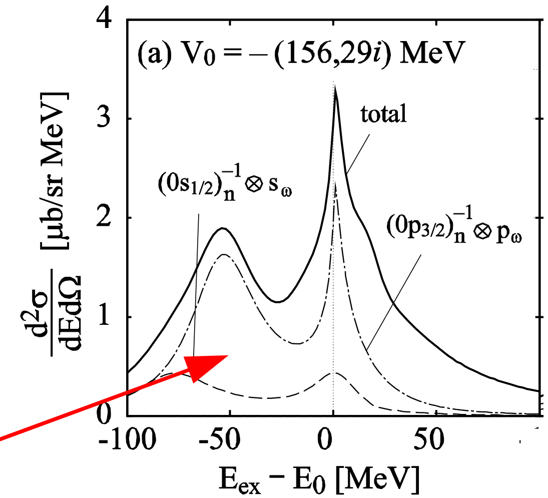
Backup slides…

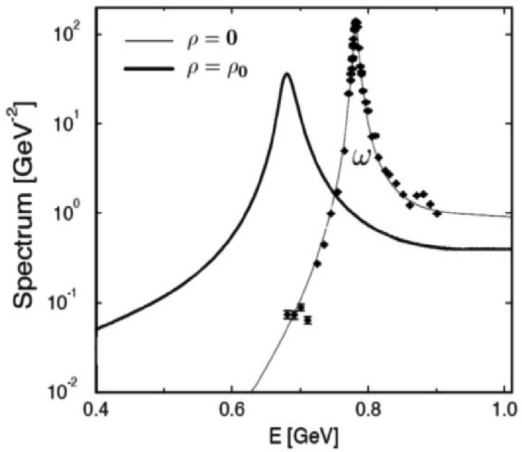
•

meson bound state in nuclei



theoretical predictions of missingmass and invariant mass



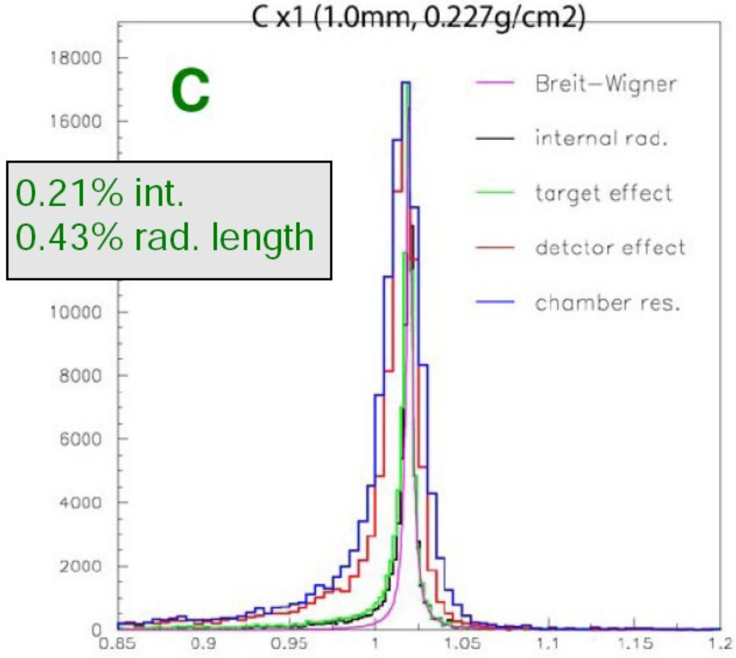


- ω bound state (P26 Ozawa)
  - missing mass spectroscopy in π^-+ A reaction – select the bound state
    - elementary : ~2 GeV/c $\pi^- + p \rightarrow \omega + n$
  - and measure the ω decay to $\pi^0\gamma$
    - Pω is low, and decay in nuclear matter

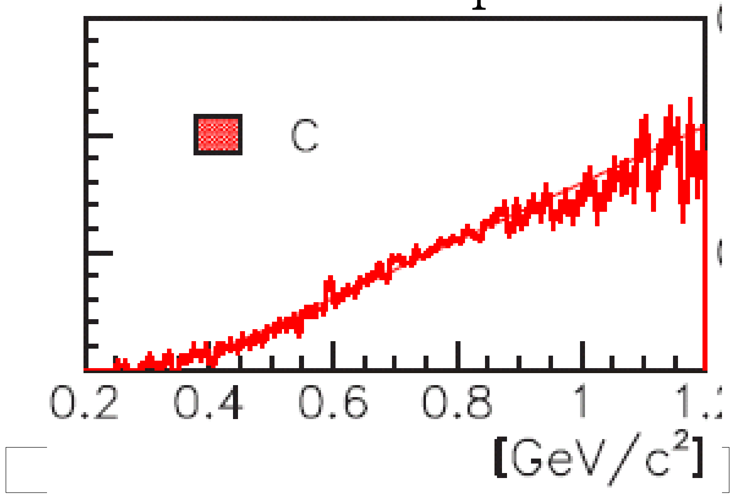
Analysis : Fitting with known sources

- 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

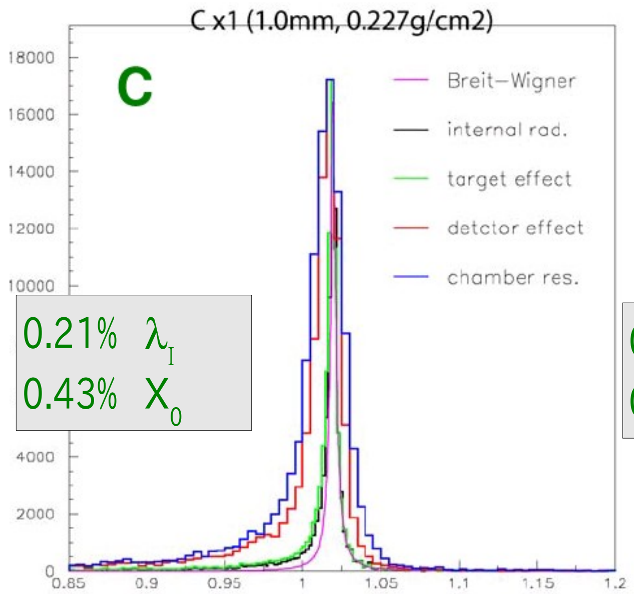


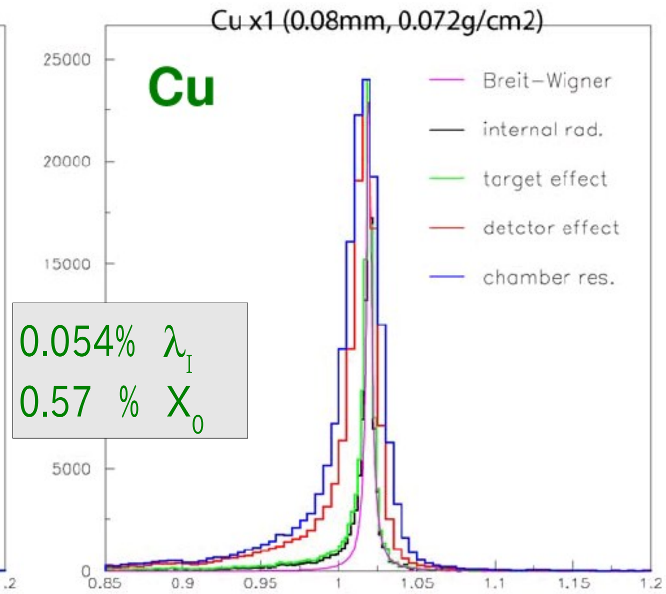
mass acceptance



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

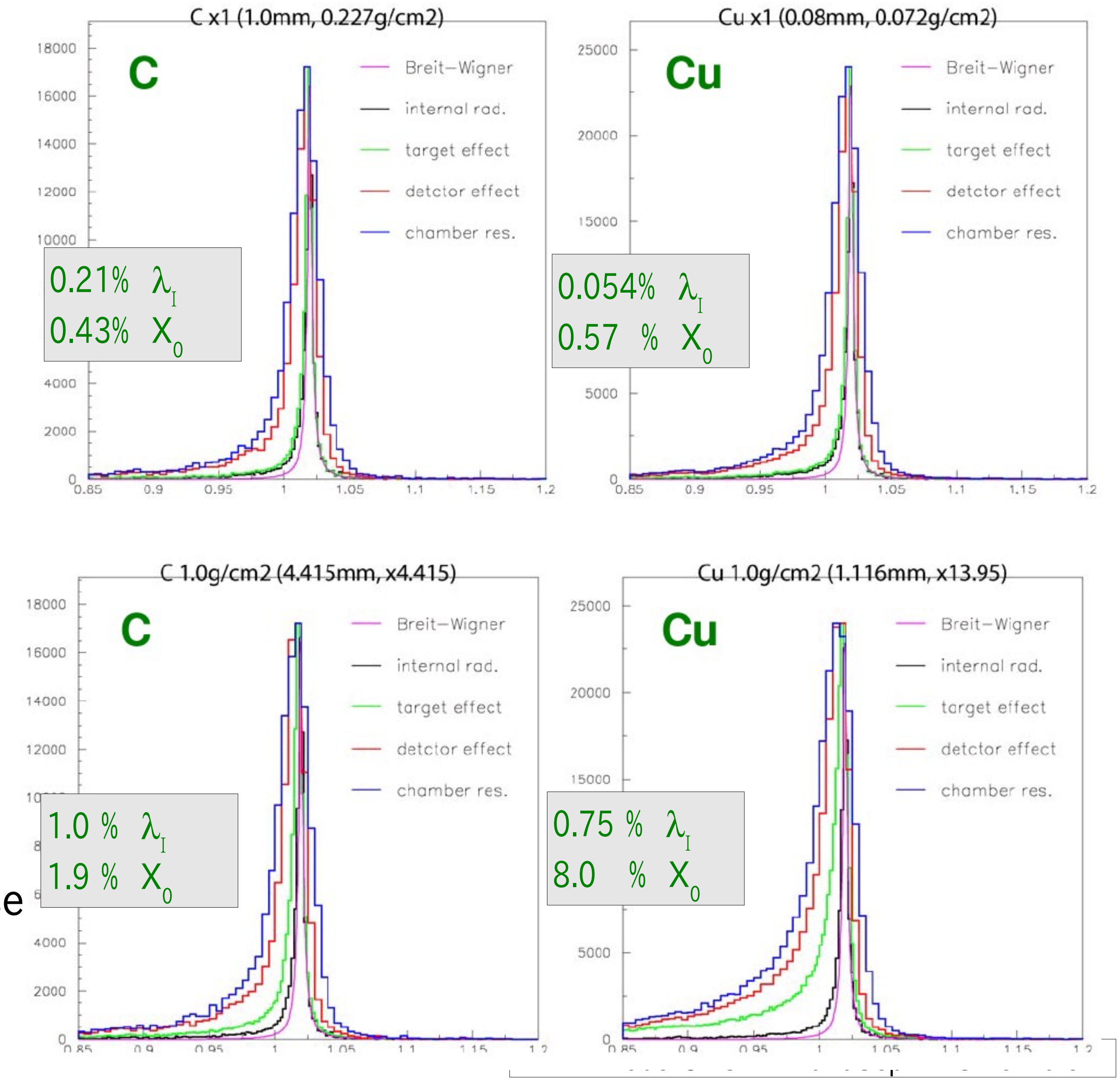




experimental effects on the BW shape (E325)

- 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

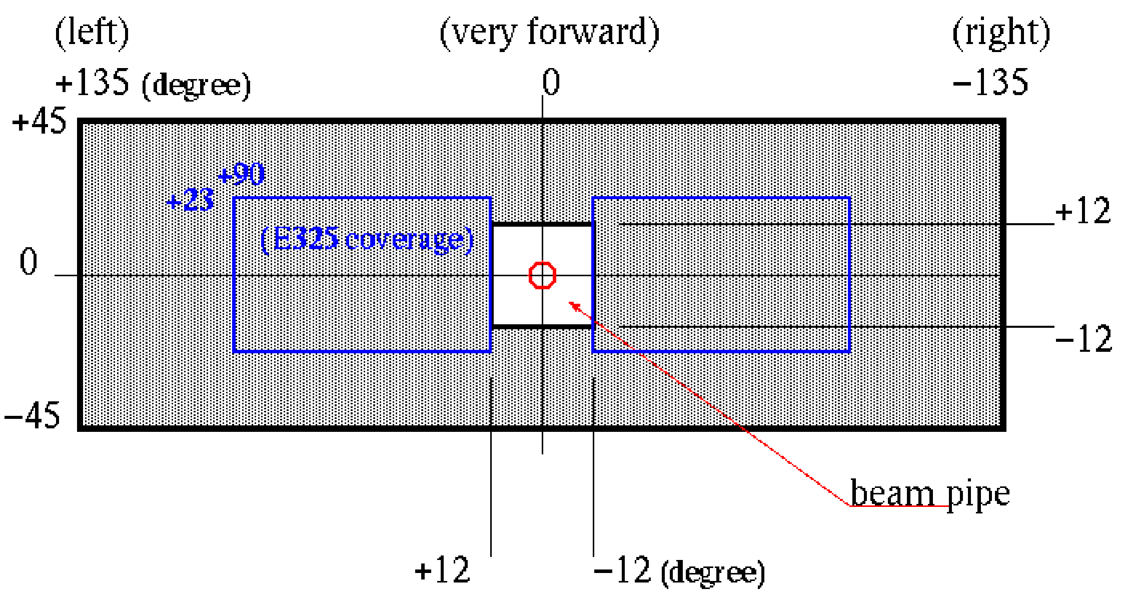
- In the case of the thick targets : 1g/cm^2
  - bremsstrahlung in target is so large for the Cu case



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 $\rightarrow$ 30/50 GeV) : x ˜2 of production
  - Higher intensity beam ($10^9 \rightarrow 10^{10}$ /spill (1sec)) : x 10 ($\rightarrow$ ~10MHz interaction on targets)

Geometrical (horizontal & vertical) coverage of the spectrometer

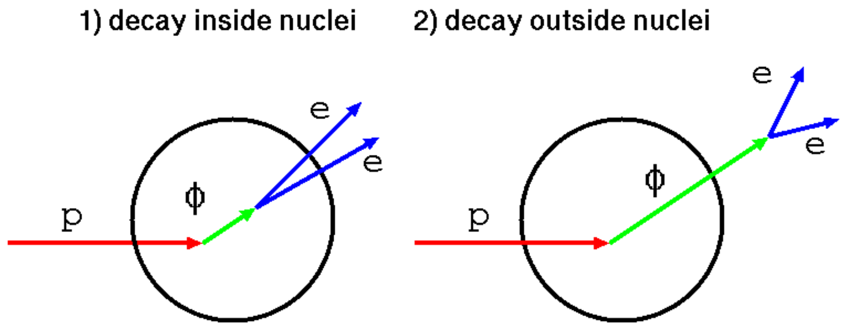


Target configuration

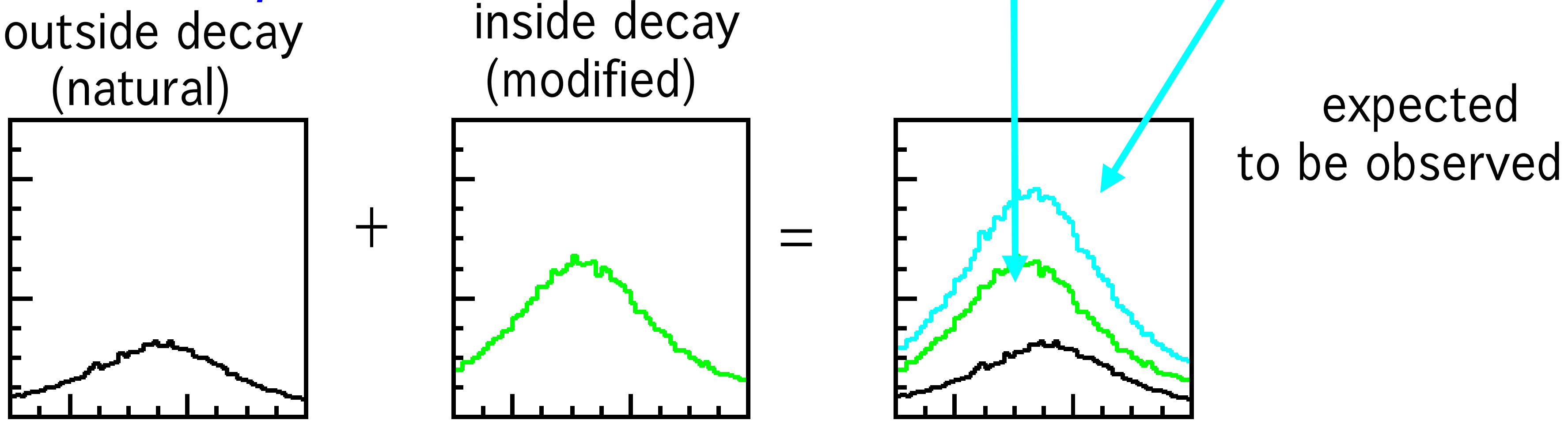
nuclei	interaction length(%)	radiation length(%)	thickness [μm]
C	0.05	0.1	200
CH_2	0.05	0.1	400
Cu	0.05	0.5	80
Pb	0.01	0.3	20

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



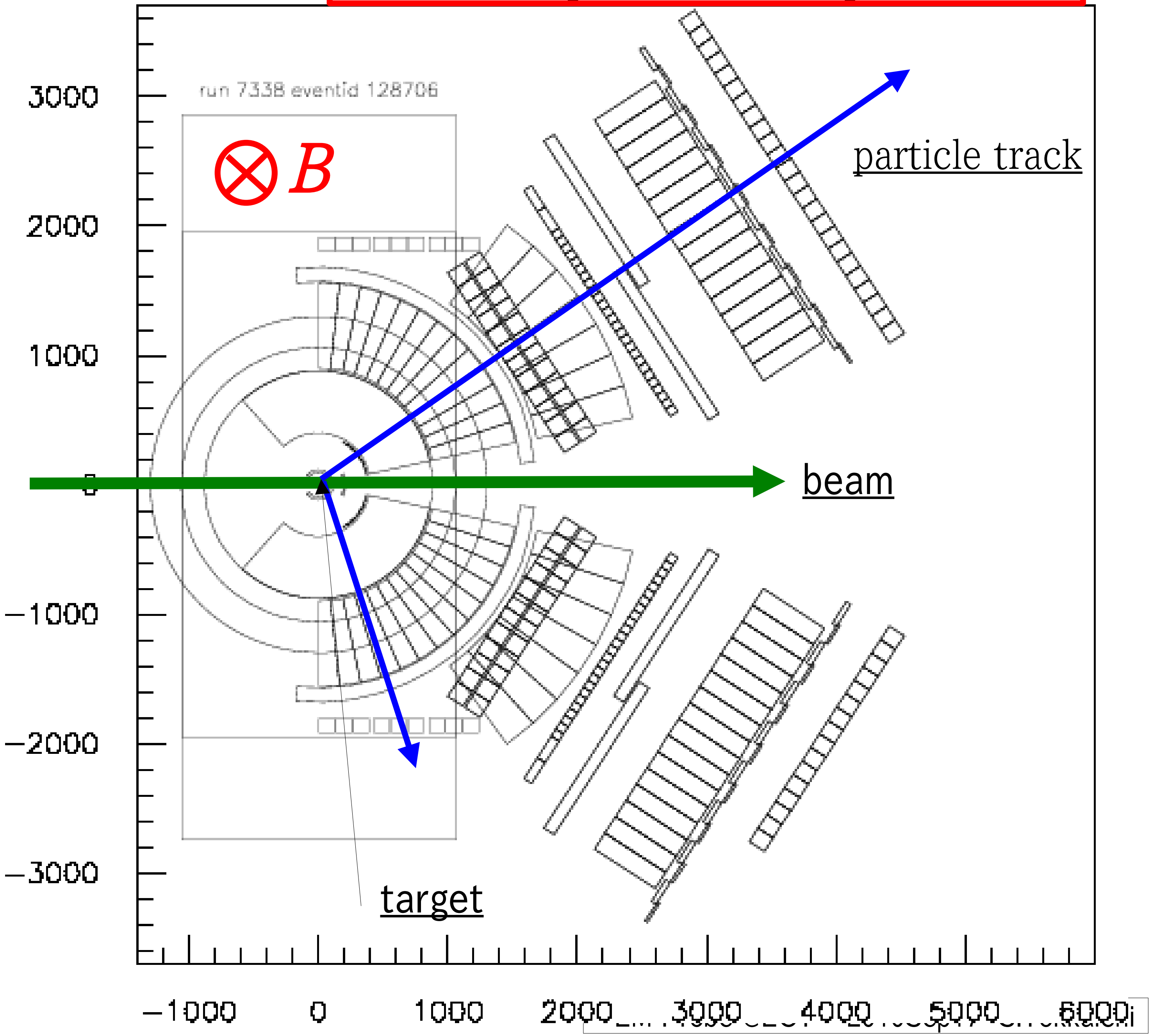
shorter-life meson (ρ)case : Schematic picture



Experimental setup

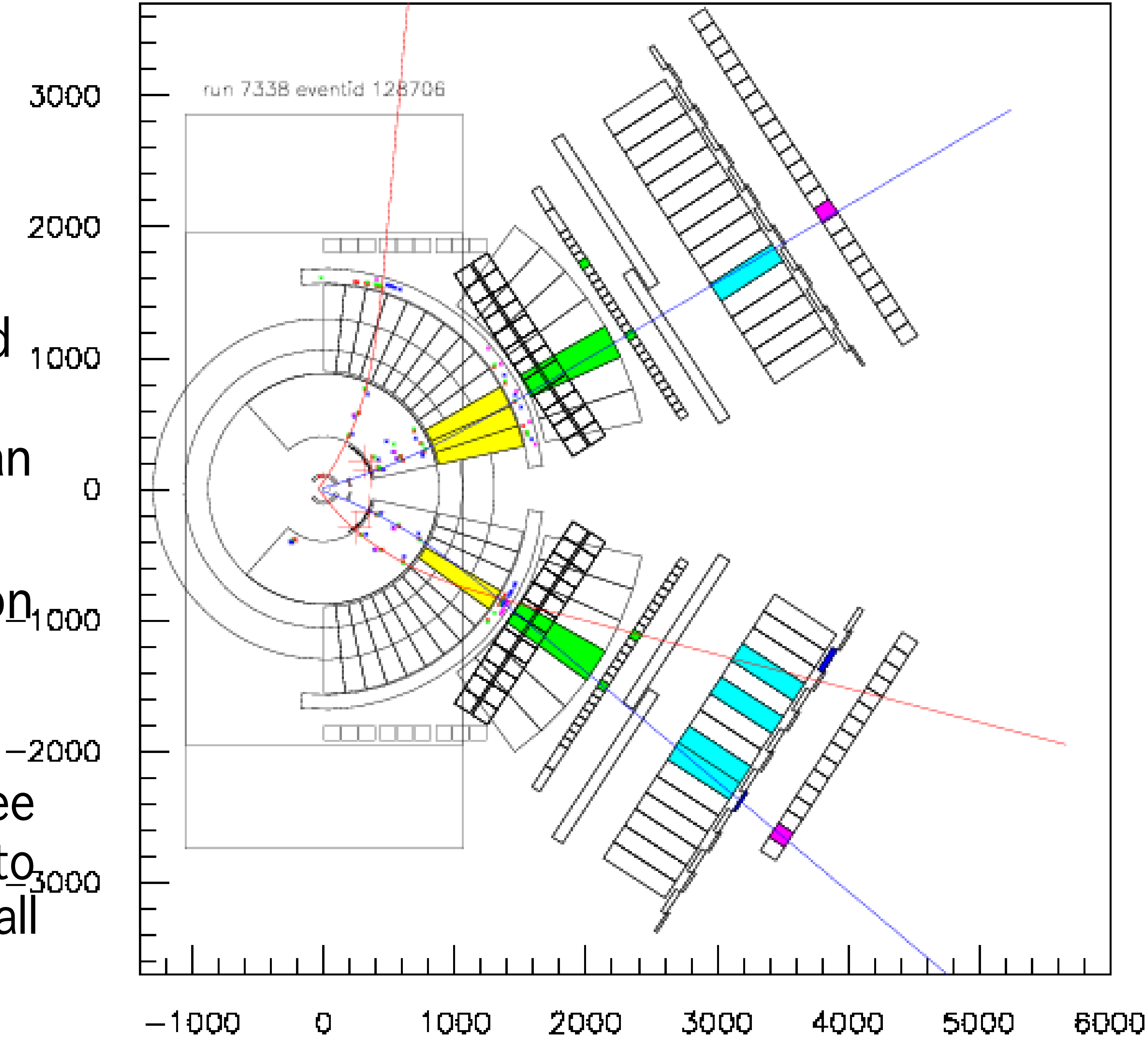
- Spectrometer Magnet
  - 0.71T at the center
  - 0.81Tm in integral
- Targets
  - at the center of the Magnet
  - C & Cu are used typically
  - very thin: ˜0.1% interaction length
- Primary proton beam
  - 12.9 GeV/c
  - ˜1x10^9 in 2sec duration, 4sec cycle

schematic plan view of spectrometer

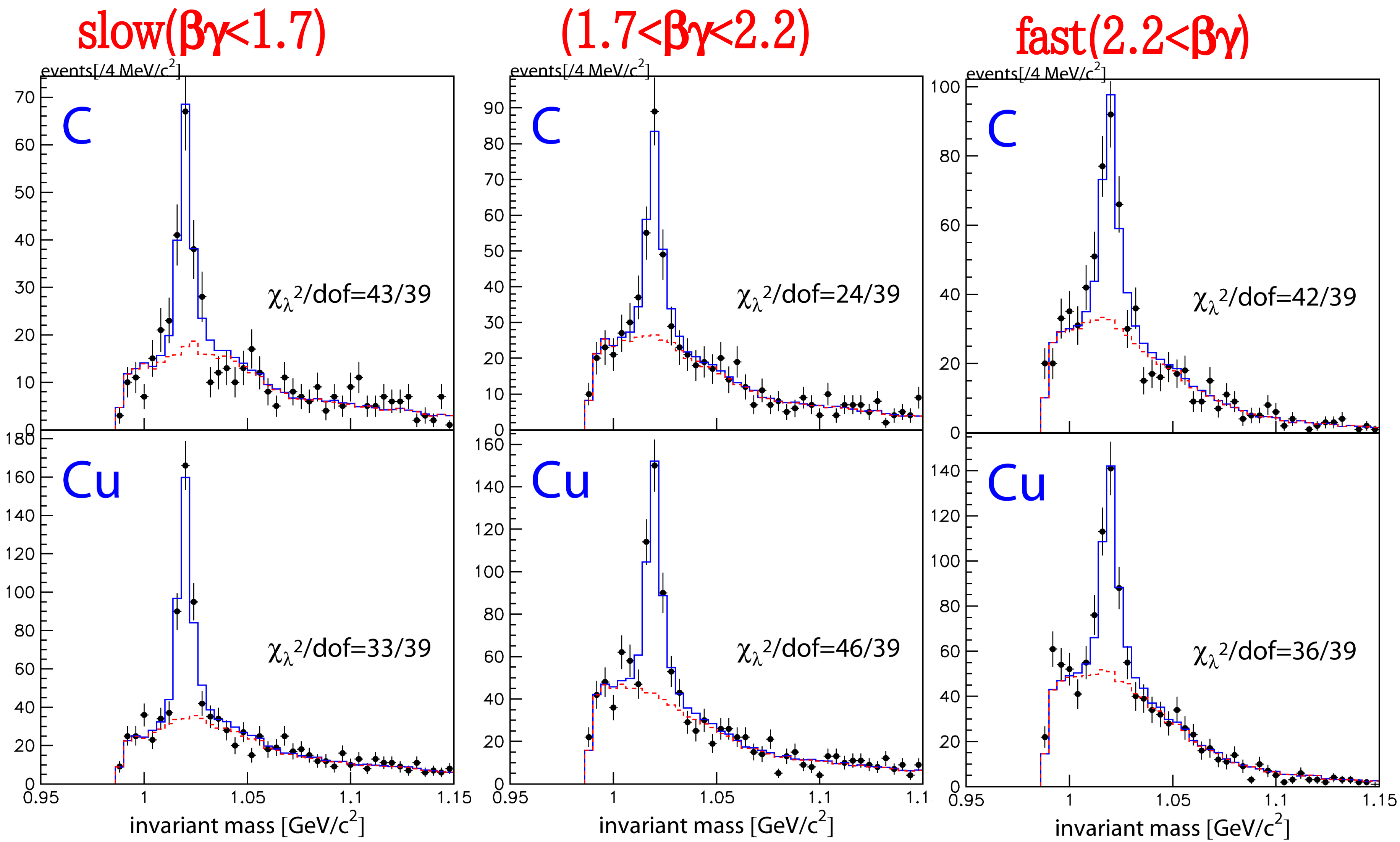


Experimental setup

- Typical e^+e^- Event
  - blue:electron
  - red : other
  - invariant mass and momentum of mother particle can be calculated
- Experimental condition
  - 1GHz proton beam, 1MHz interaction, 1K ϕ mesons, 0.3 ee decays, 9% come into detector, 10% overall efficiency, ...



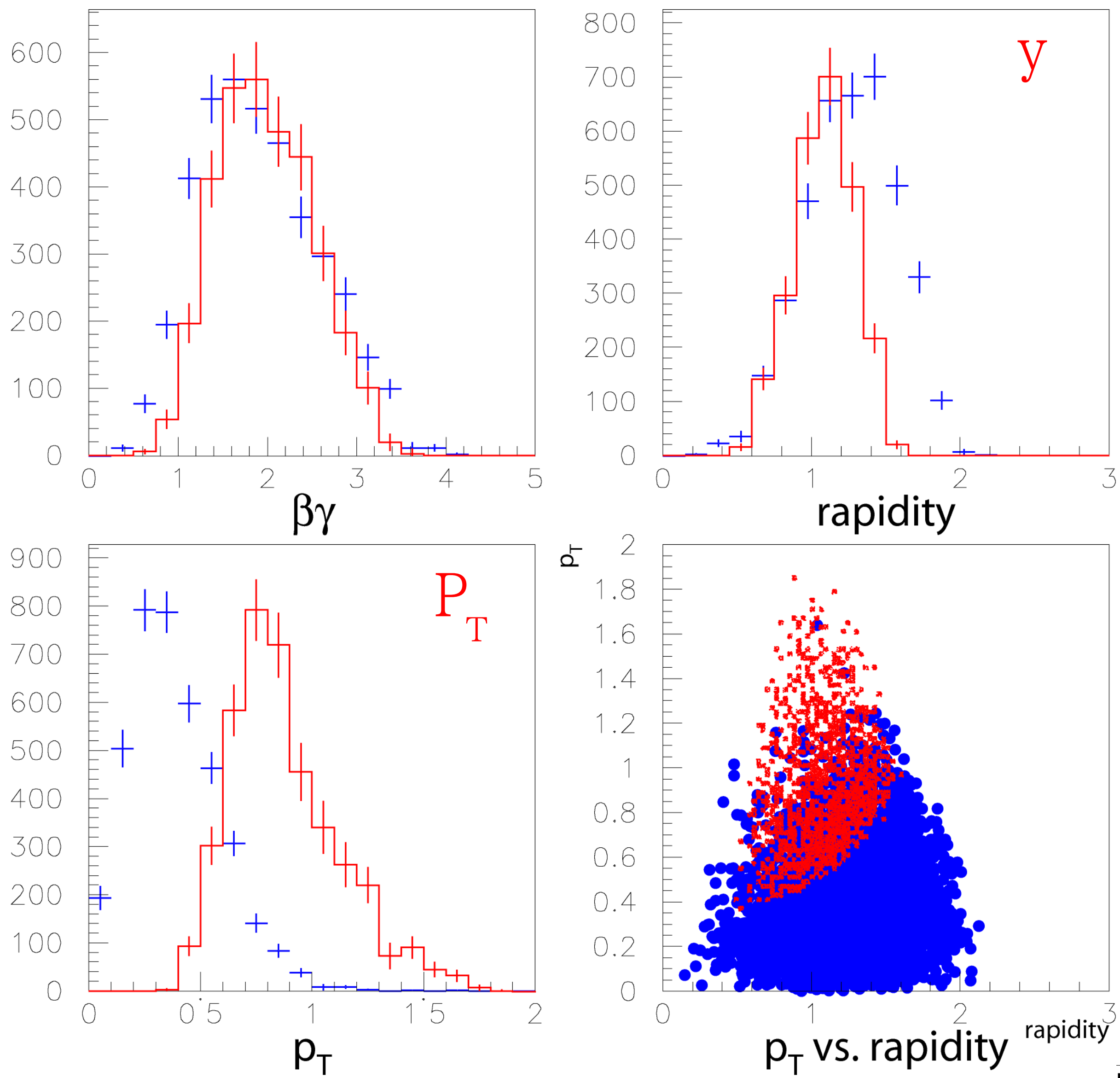
K^+K^- spectra of ϕ meson



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

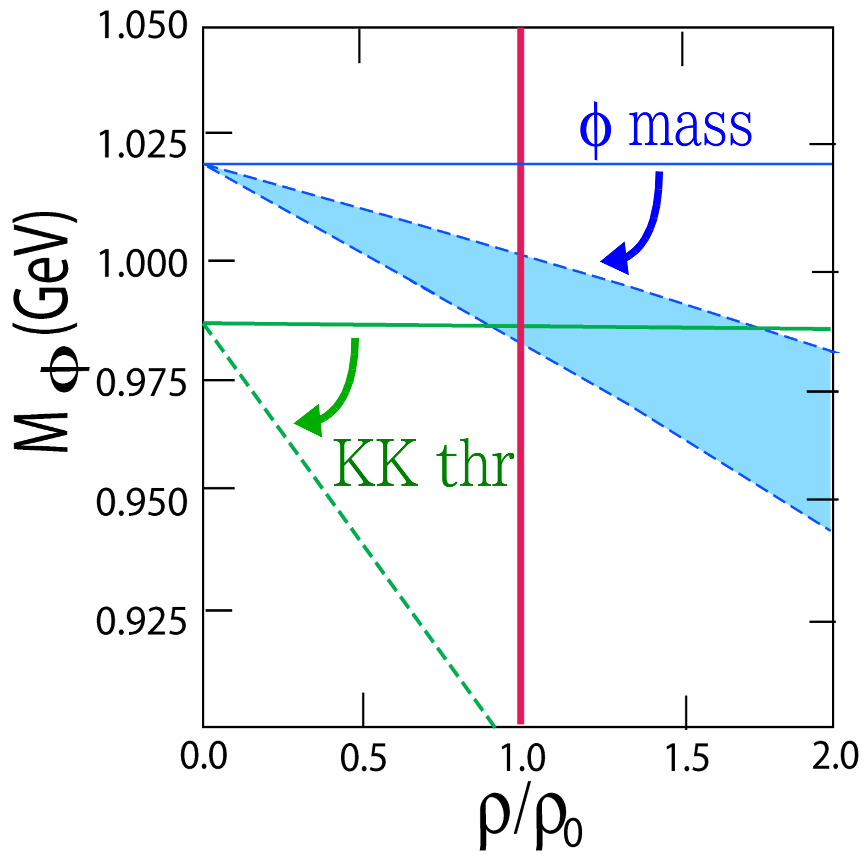
measured kinematic distribution of $\phi \rightarrow K^+K^-$ & $\phi \rightarrow e^+e^-$

- $0.5 < y < 1.5$
- $1 < \beta\gamma < 3$
- $0.5 < P_T < 1.5$
- 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 parameter : the nuclear dependence of production cross section
  - measure both $\phi \to K^+K^-$ & $\phi \to e^+e^-$ simultaneously
  - => NEXT

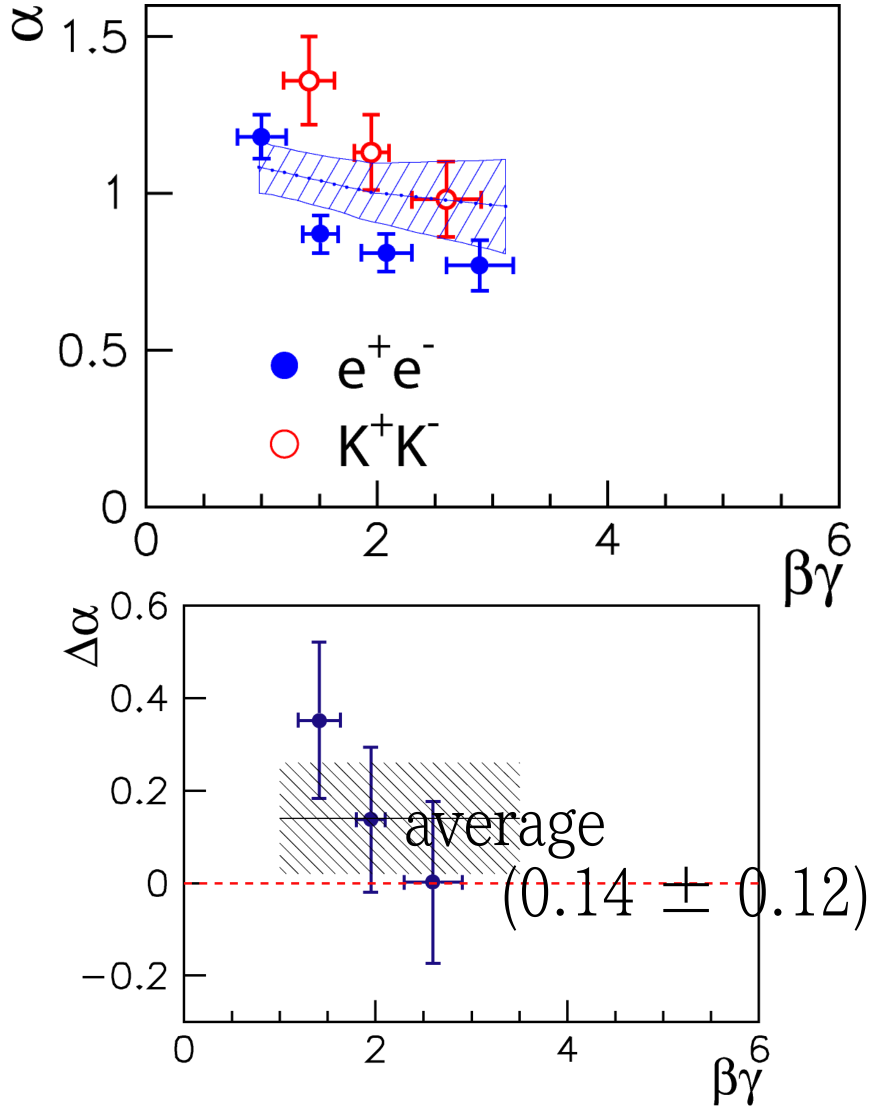
nuclear dependence α of the prod. CS of ϕ in K^+K^- & e^+e^- channel

- 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

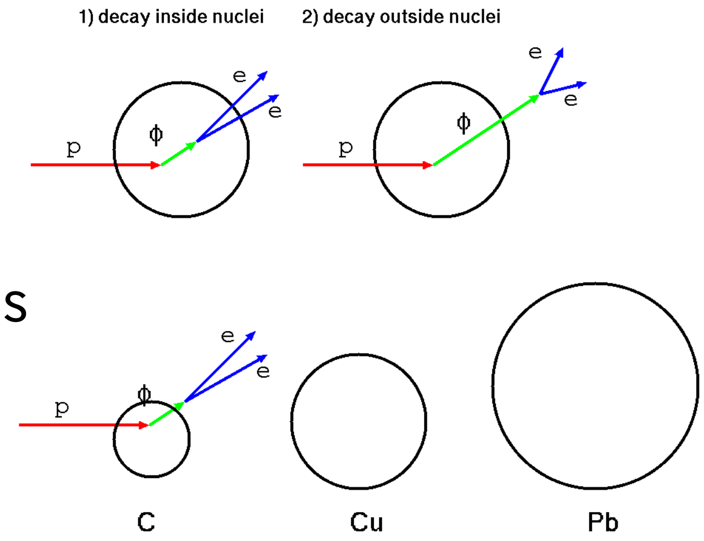
- nuclear dependence α:
  - $\sigma(A) = \sigma_0 \times A^{\alpha}$
- α and Γ : for example
  - $\Gamma_{K+K-} / \Gamma_{e+e-}$ increases in nuclei, N_{K+K-} / N_{e+e-} becomes larger
  - larger modification expected in larger nuclei
  - then, $\alpha_{K+K-} > \alpha_{e+e-}$, especially for slowly moving mesons
- ...looks such tendency of KK enhancement but consistent within the errors :

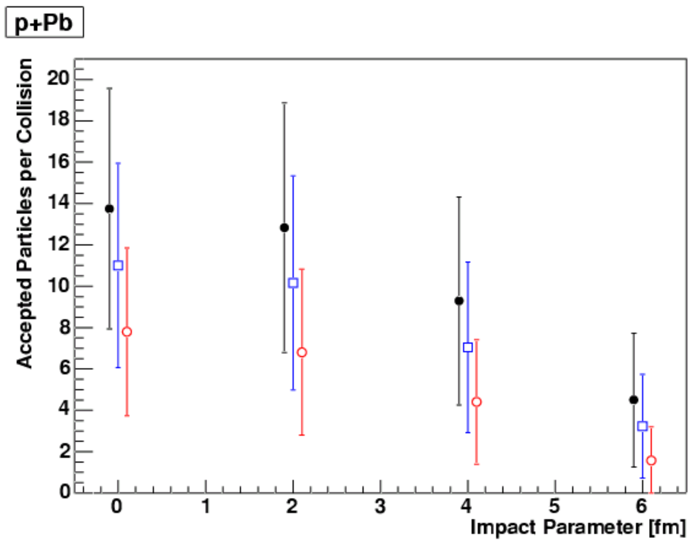
  $\alpha_{K+K-} - \alpha_{e+e-} = 0.14 \pm 0.12$



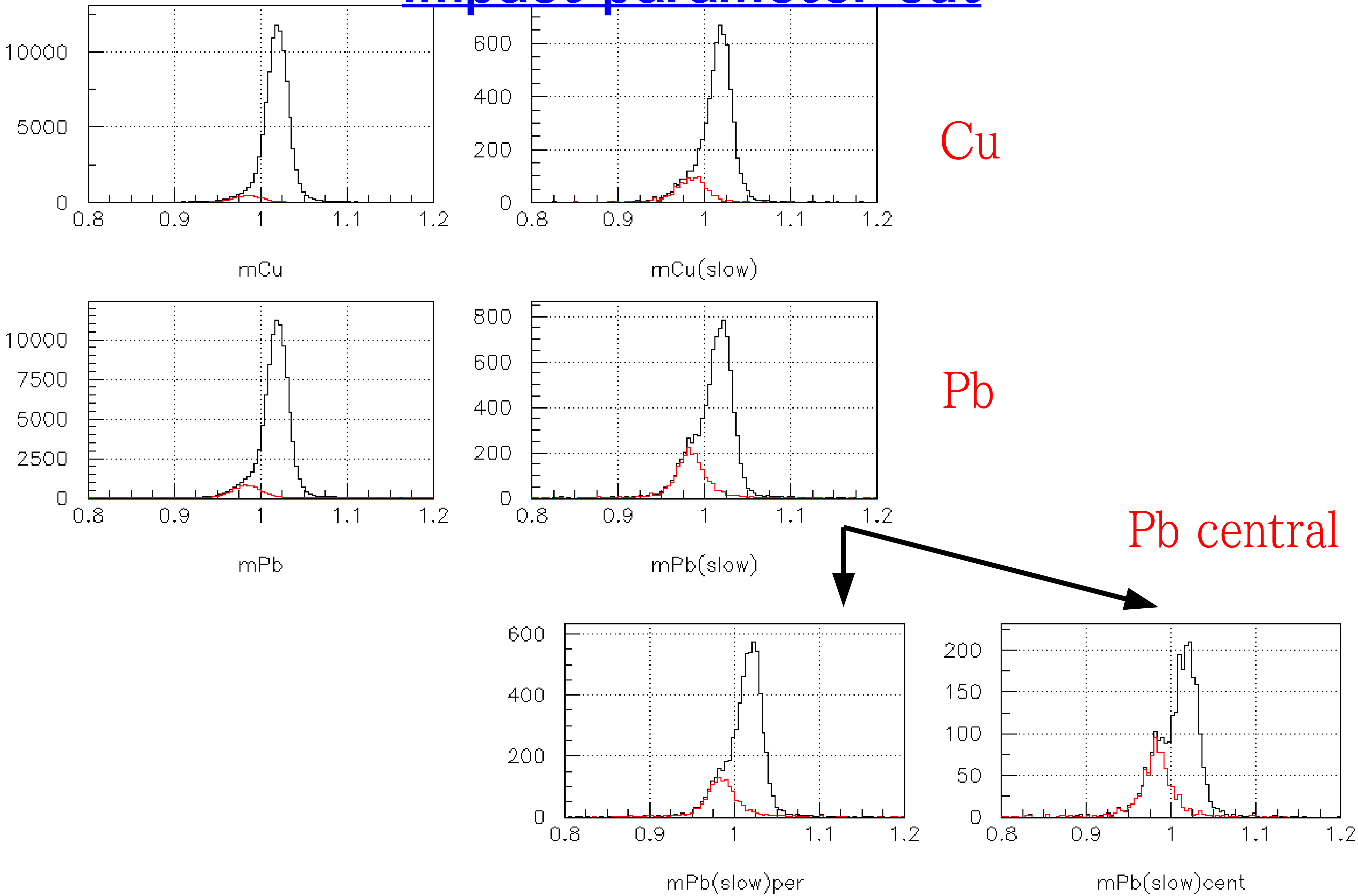
New nuclear targets with larger statistics

- 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.



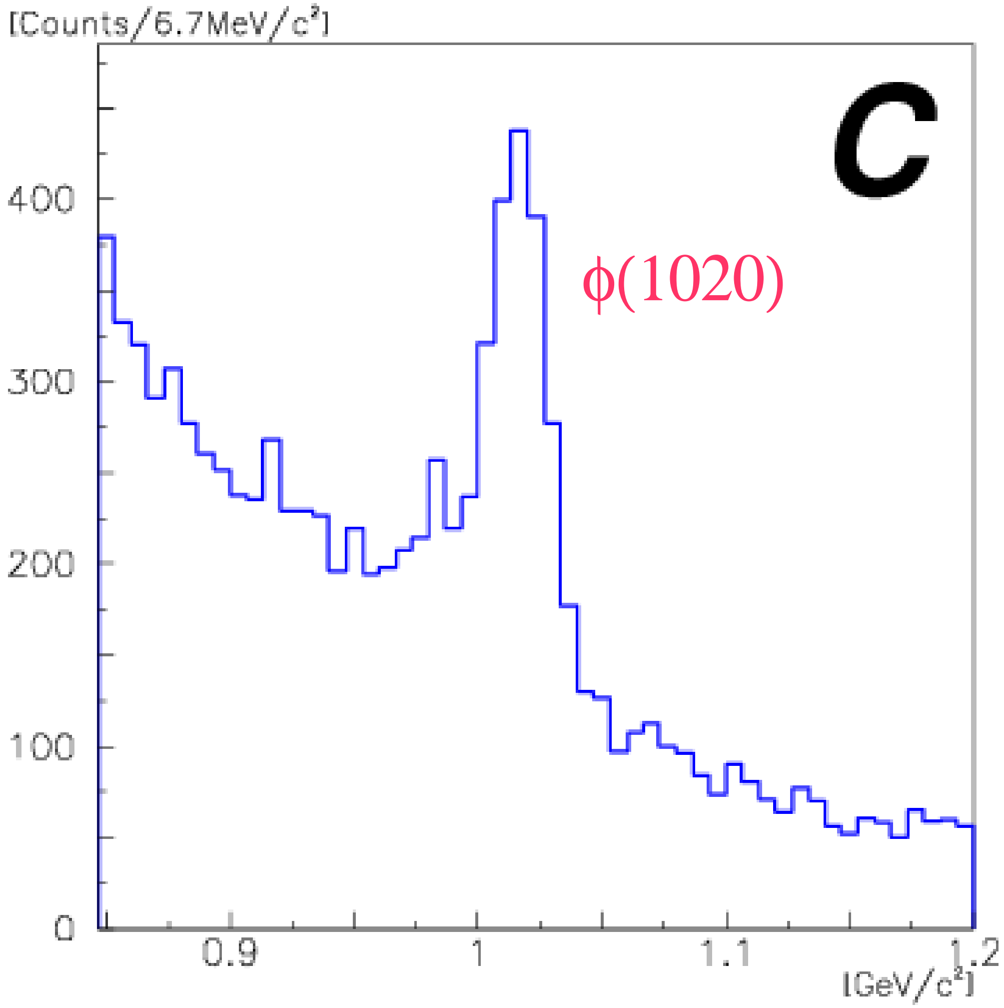


Impact parameter cut



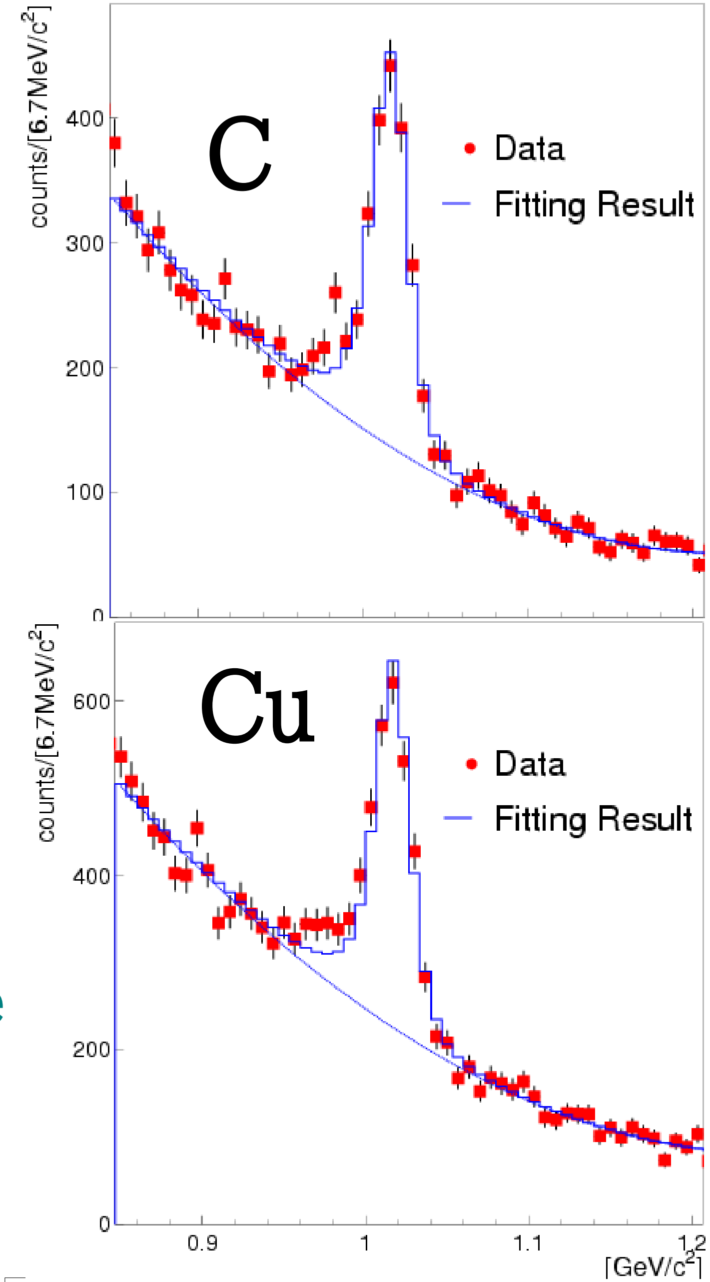
$\phi \rightarrow e^+e^-$ invariant mass spectra

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



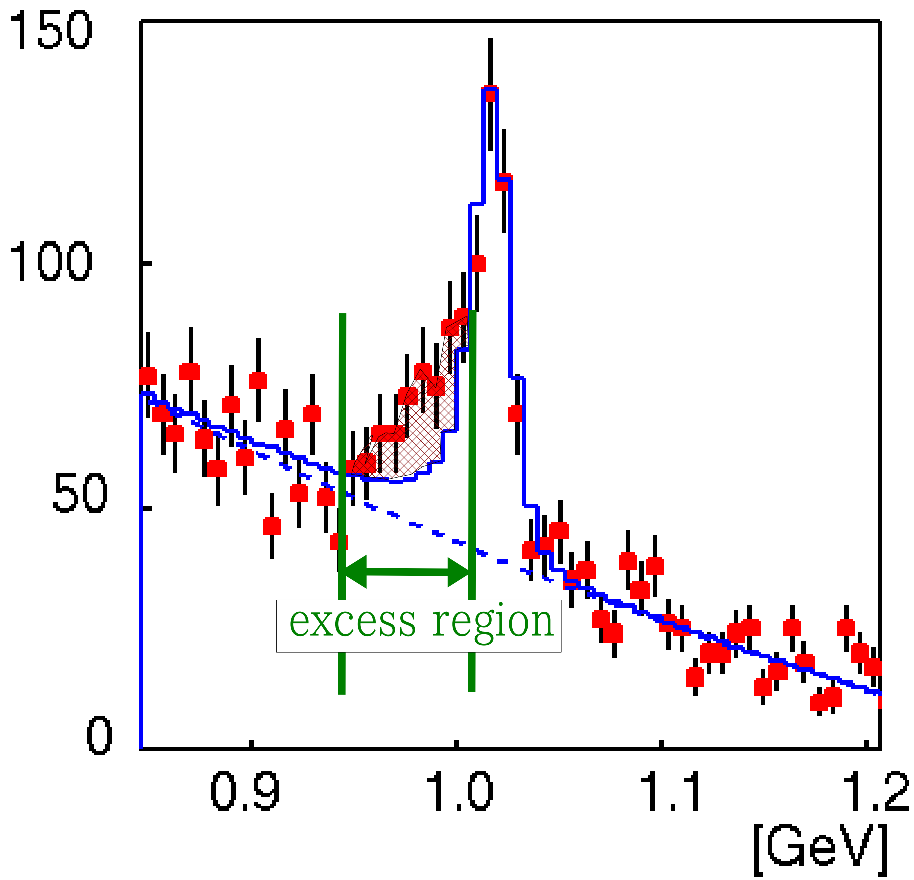
$\phi \rightarrow e^+e^-$ invariant mass spectra

- 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



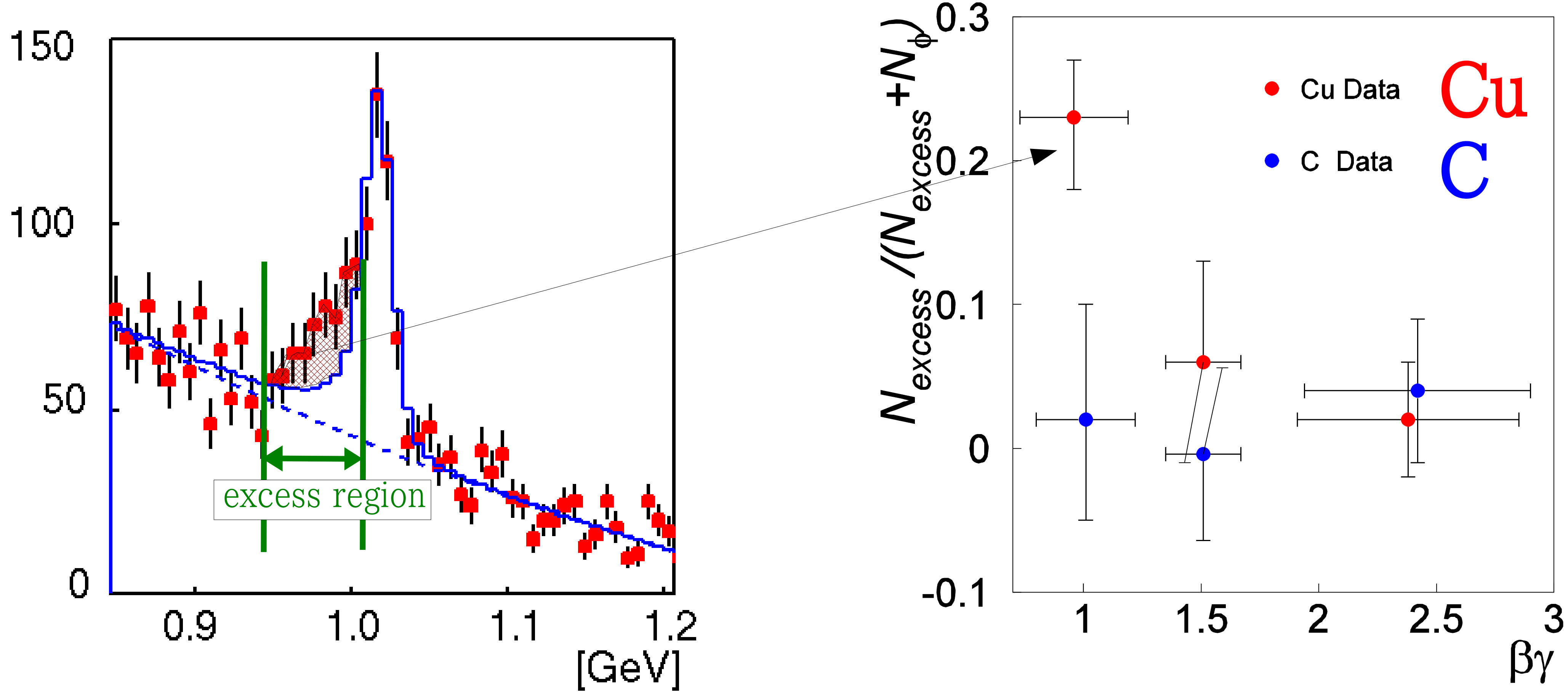
Amount of excess

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



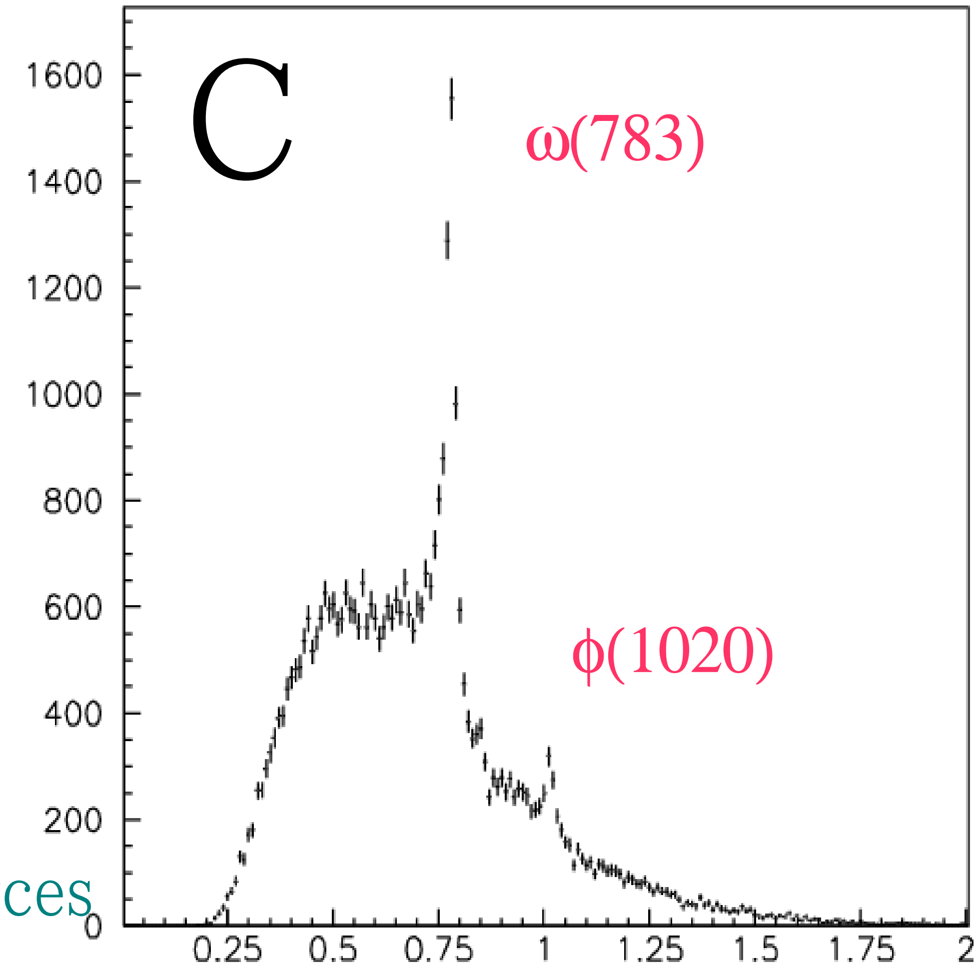
Amount of excess

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



Observed e^+e^- invariant mass spectra

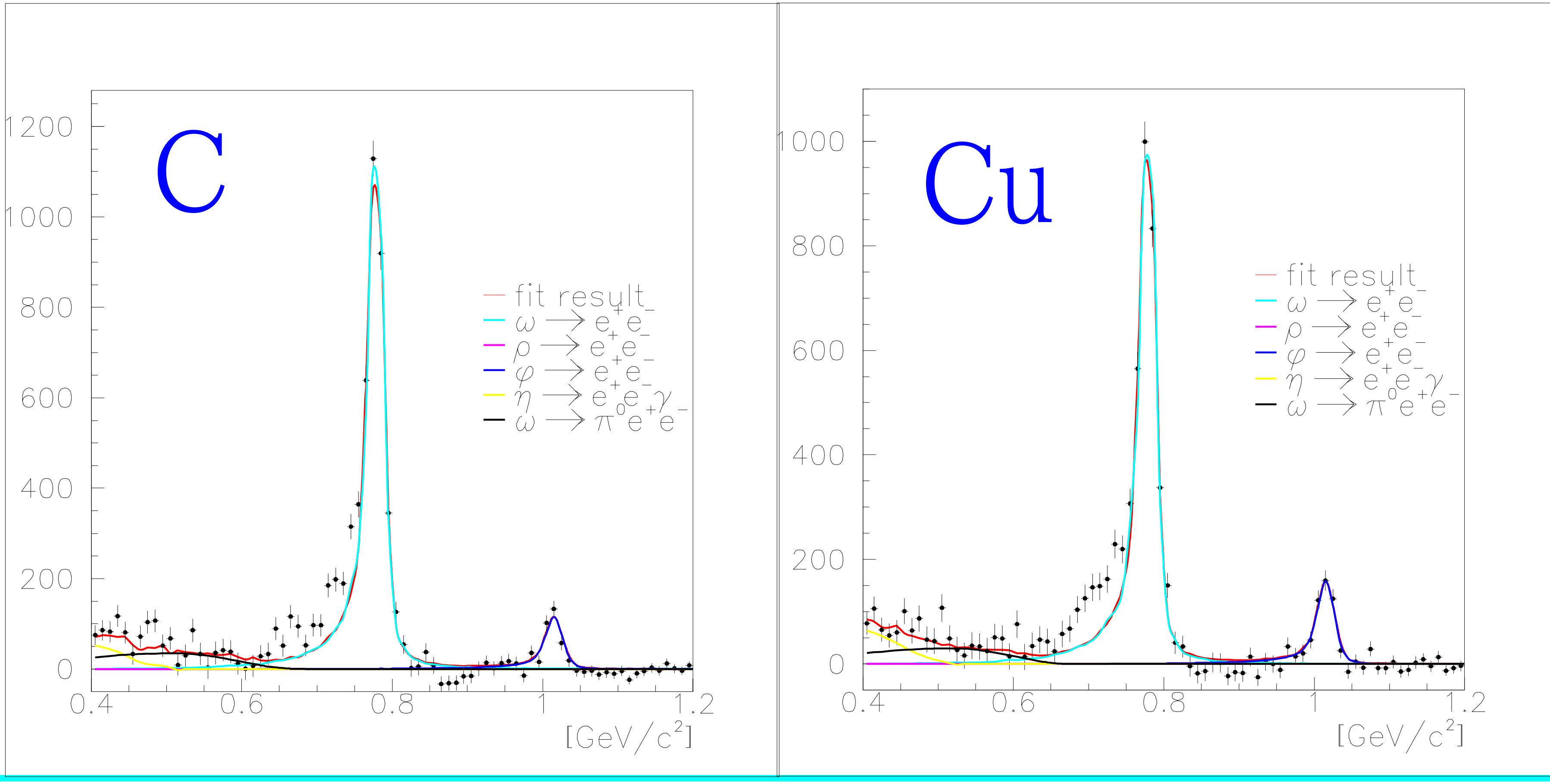
- from 2002 run data (~70% of total data)
- C & Cu target
- clear resonance peaks
- m<0.2 GeV is suppressed by detector acceptance
- acceptance uncorrected



→ fit the spectra with known sources

Fitting results (BKG subtracted)

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

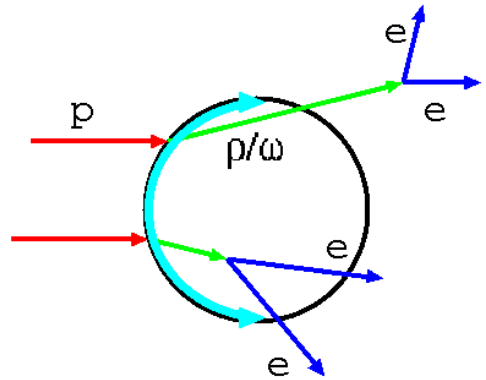


- However, ρ/ω =1.0±0.2 in former experiment (p+p, 1974)

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

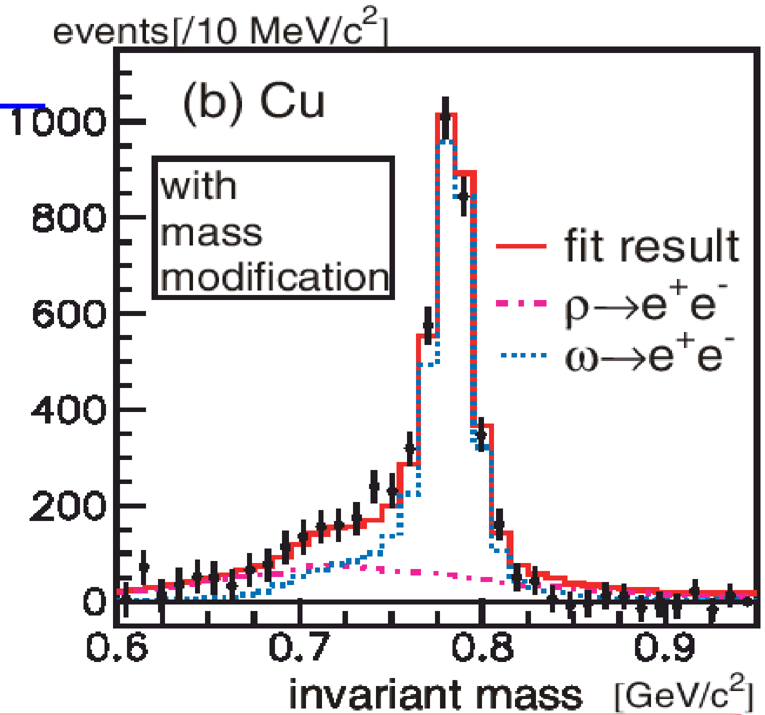
Discussion : fit with modification

- 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)

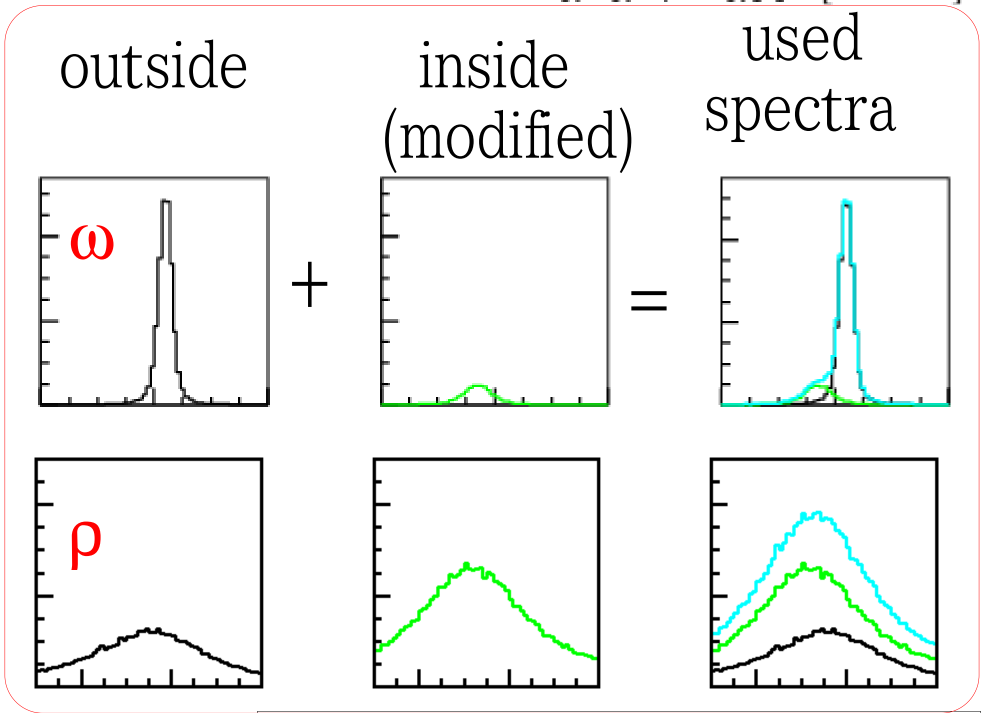


	ρ, ω	ϕ
m*/m	$1 - k_1^{\rho/\omega} \rho/\rho_0$	$1 - k_1^{\phi} \rho/\rho_0$
Γ^*/Γ	1	$1 + k_2 \rho/\rho_0$
generation point	surface	uniform
α ($\sigma(A) \propto A^\alpha$) [PRC74(06)025201]	0.710±0.021	0.937±0.049
momentum dist.	measured	
density distribution	Woods-Saxon, R= C:2.3fm/Cu:4.1fm	

Remark on the model fitting

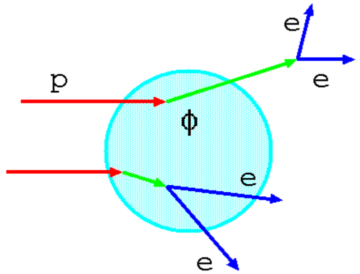


- constraint at right side of peak
  - Introducing the width broadening (x2 & x3) are rejected by this constraint
  - prediction of ' ρ mass increasing' is also not allowed.
- ρ (ω) decay inside nucleus : 46%(5%) for C, 61%(10%) for Cu
  - used spectrum is the sum of the modified and not-modified components.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

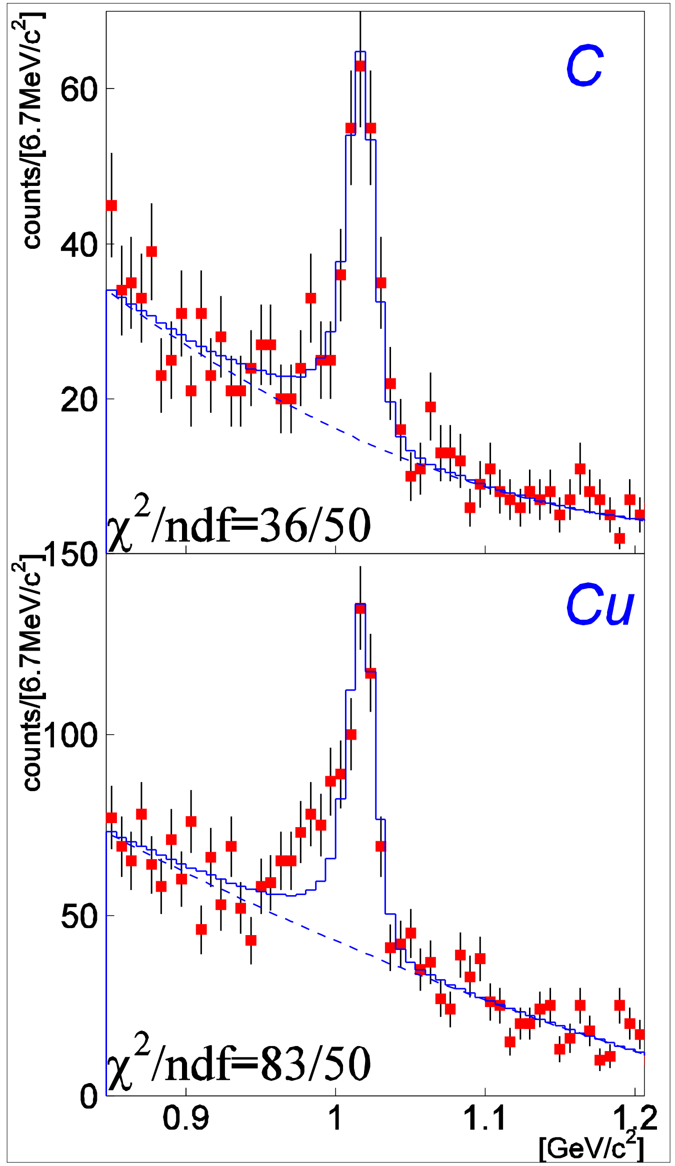


Fit using modified mass shapes

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

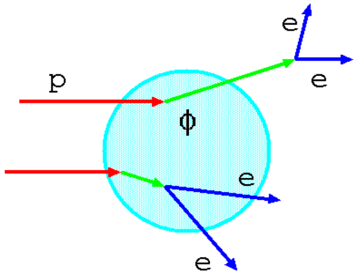


$\beta\gamma$<1.25 (Slow) k_1=0,k_2=0

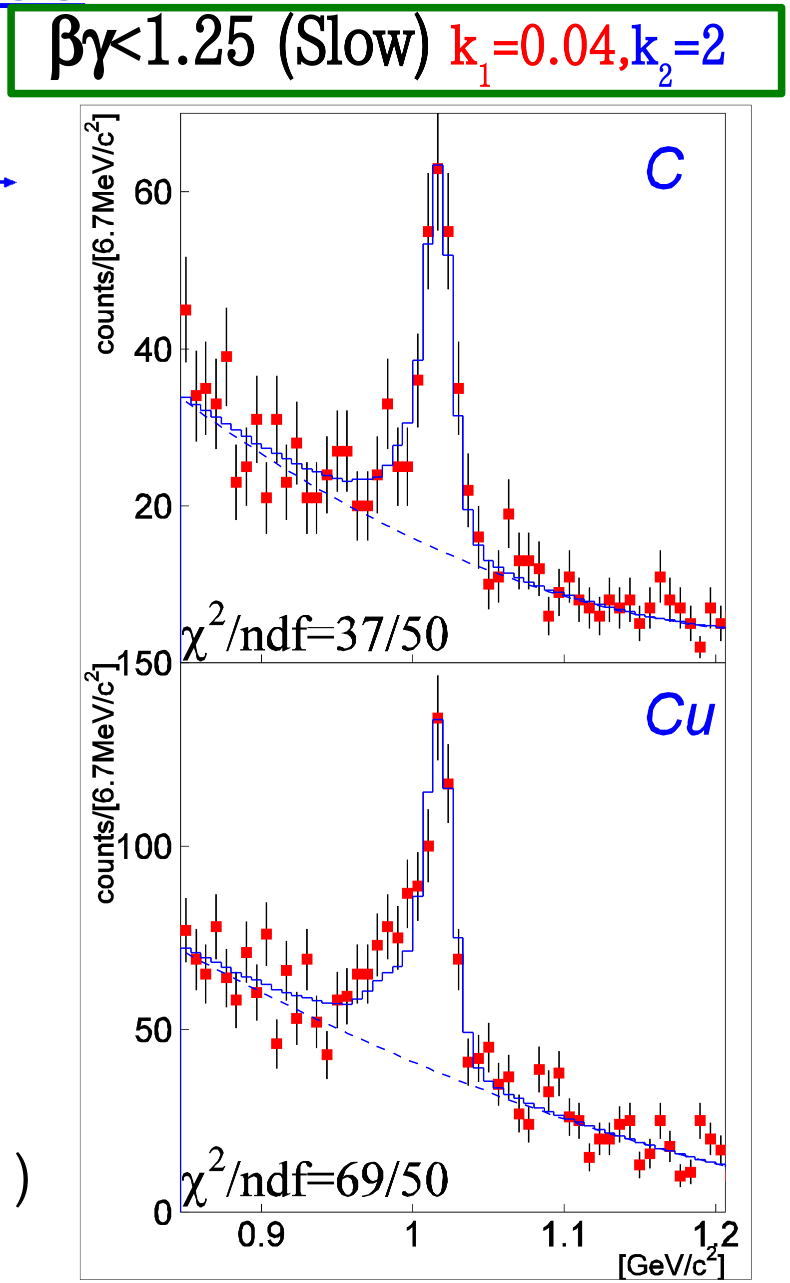


Fit using modified mass shapes

- MC type calc. : mesons are generated,flied and modified
  - observed momentum dist.
  - uniformly made in nuclei
    - measured α of ϕ production ~ 1

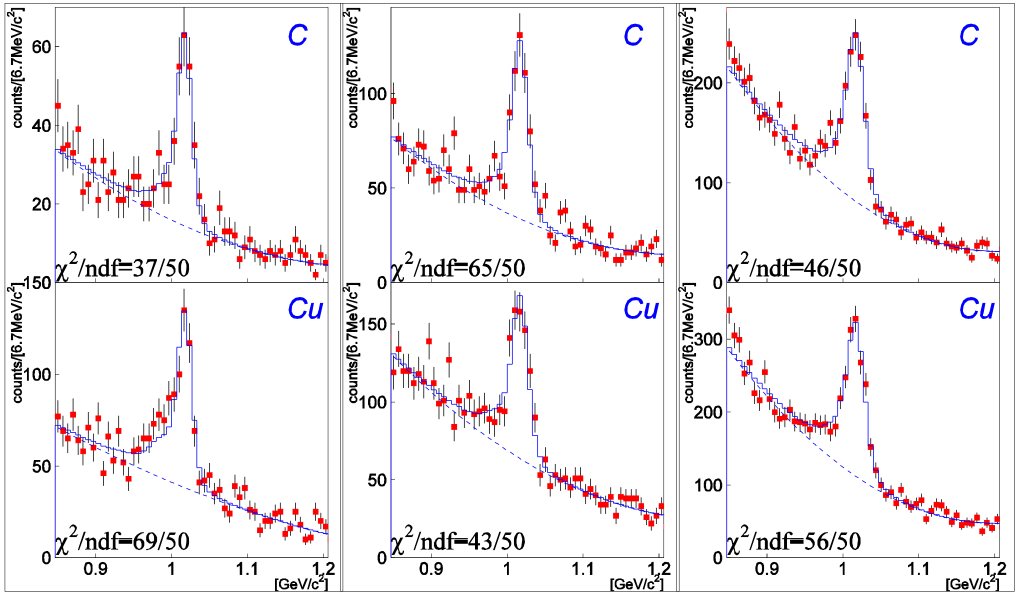


  - $m^*/m_0 = 1 - k_1\ \rho/\rho_0$
    (k_1=0.04, Hatsuda & Lee, '92,'96)
  - To reproduce such amount of excess, linear-dependent width broadening is adopted :
    $\Gamma_{tot}^{*}/\Gamma^{0}_{tot} = 1 + k_2\ \rho/\rho_0$
    - e^+e^- branching ratio is not changed
      - $\Gamma^{*}_{e+e-}\ /\ \Gamma^{*}_{tot}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



Model fitting : parameter k_1 and k_2

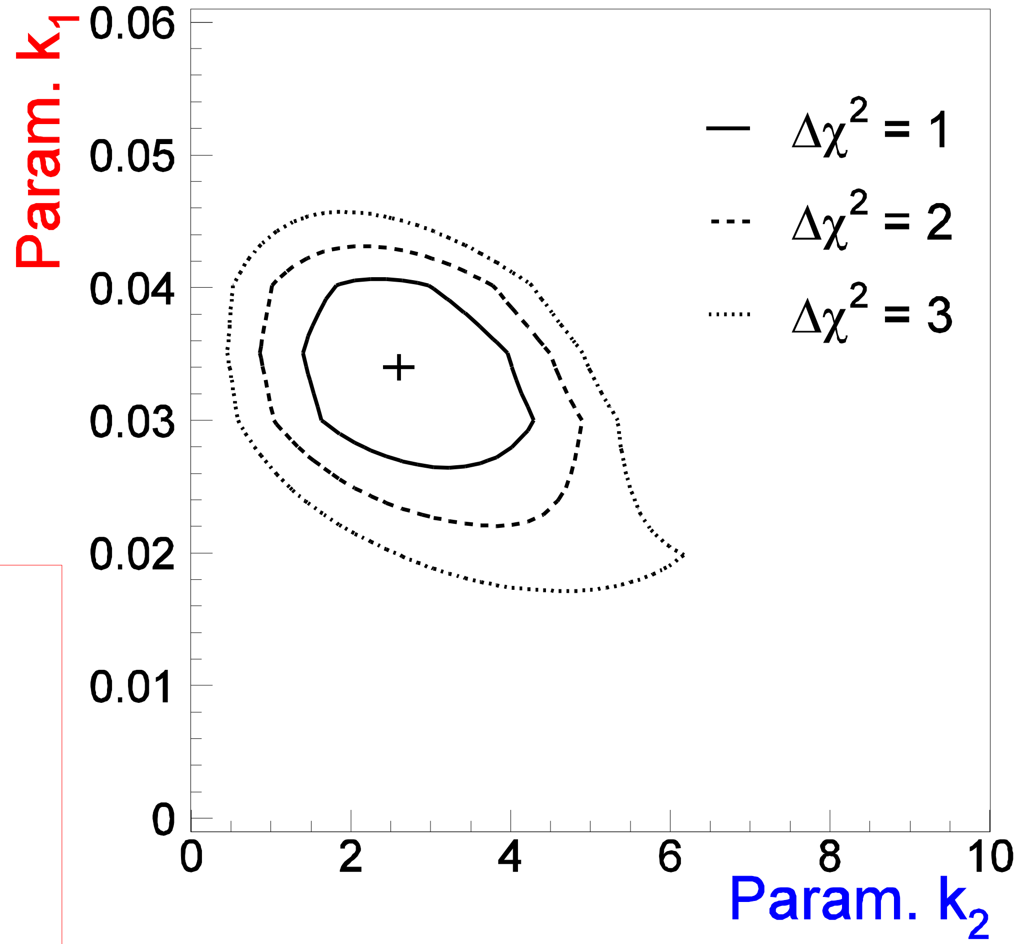
- To determine the shift parameters...
  - $m^*/m_0 = 1 - k_1 \rho/\rho_0$
  - $\Gamma_{tot}^*/\Gamma^0_{tot} = 1 + k_2 \rho/\rho_0$
- We fit the observed 6 mass spectra (C/Cu, slow/mid/fast) with modified MC shapes and calculate the χ^2 as the sum of 6 spectra



(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:

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

$$k_2^{tot} = 2.6^{+1.8}_{-1.2} \qquad \Gamma_{tot}^{\ *} = 15\,\mathrm{MeV}$$

(3.6 times width broadening at ρ_0)