Electron pair spectrometer at J-PARC 50GeV-PS to mesure the meson modification

Satoshi Yokkaichi , RIKEN

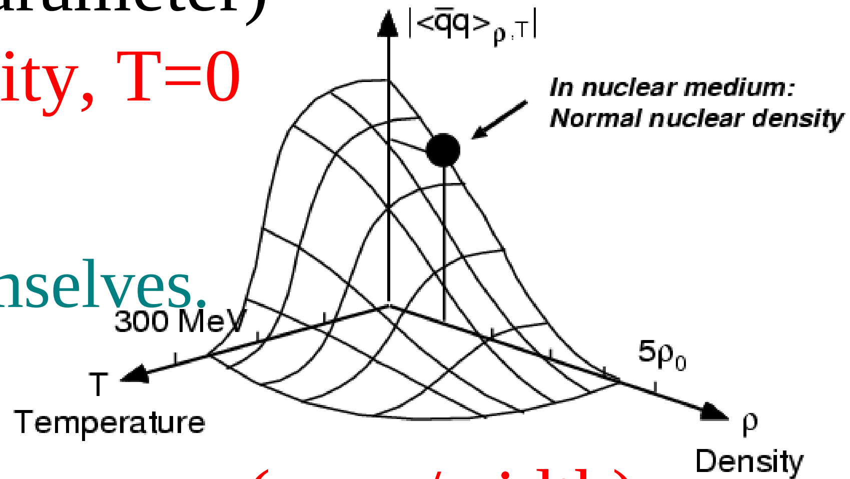
&

Kyoichiro Ozawa, CNS, U-Tokyo

- Physics : vector meson modification & chiral symmetry
- expected experimental signature in p+A reaction
- performed experiment KEK-PS E325
- Recent E325 Results : $\phi \to e^+e^-$ invariant mass spectra modification
- Proposed experiment at J-PARC

Chiral symmetry restoration in dense matter

- In hot/dense matter, chiral symmetry is expected to restore
  - hadron modification is expected in such matter
- quark-antiquark condensate (order parameter) ~2/3 even at the normal nuclear density, T=0
  - Achievable at KEK-PS in use of nuclear medium of target nuclei themselves.



- Many theoretical predictions of vector meson (mass/width) modification in dense medium, related (or not related) with CS
  - Brown & Rho ('91) : $m^*(\rho)/m_0 \sim f_\pi^*/f_\pi \sim 0.8$ at $\rho=\rho_0$
  - Hatsuda &Lee ('92) , Klingle, Keiser &Weise ('97), Muroya, Nakamura & Nonaka('03), etc.

Hatsuda and Lee, 92,96

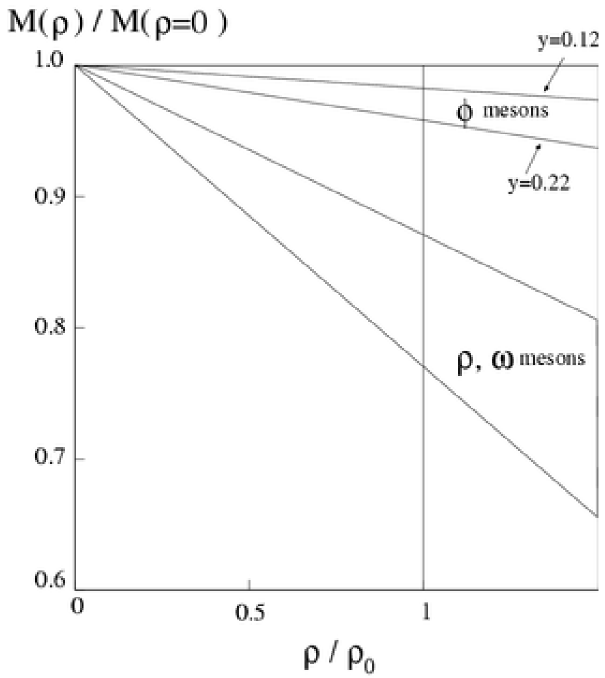
linear dependence on density

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

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

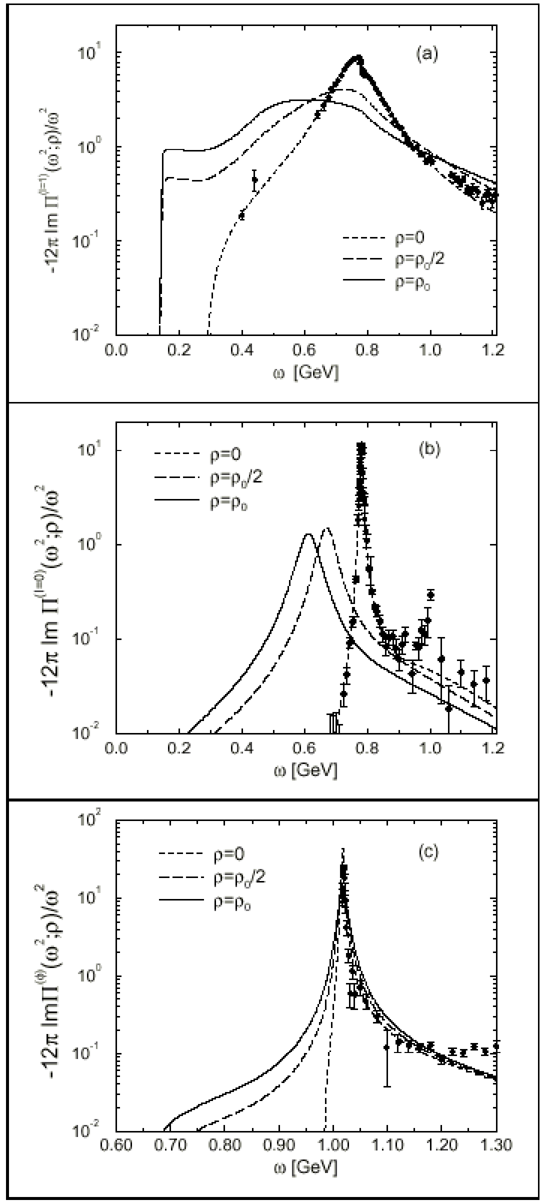


Klingle,Keiser,Weise, 97

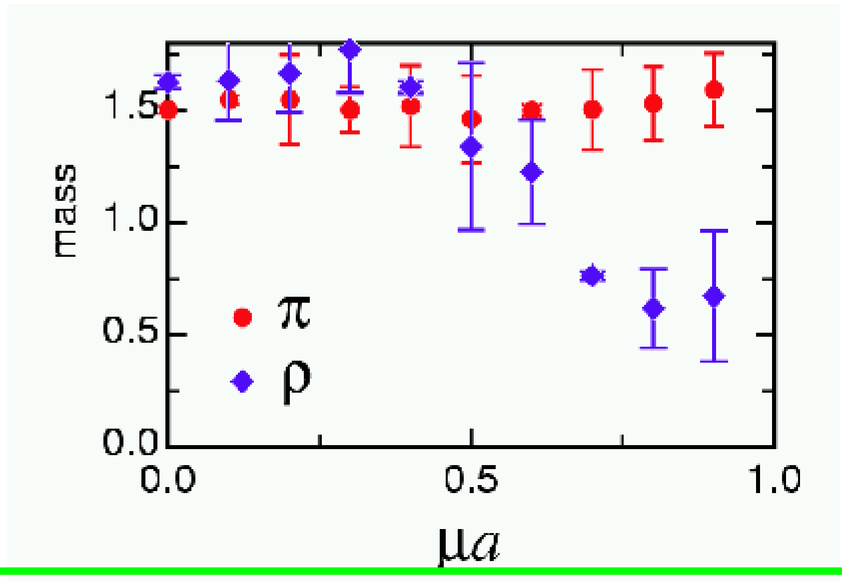
ρ

ω

φ

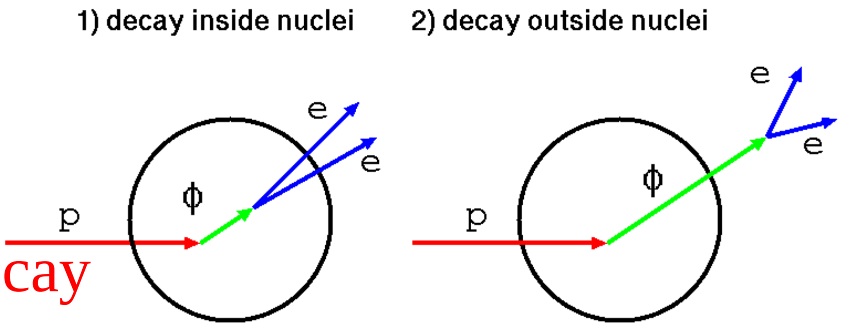


Muroya, Nakamura, Nonaka, 03



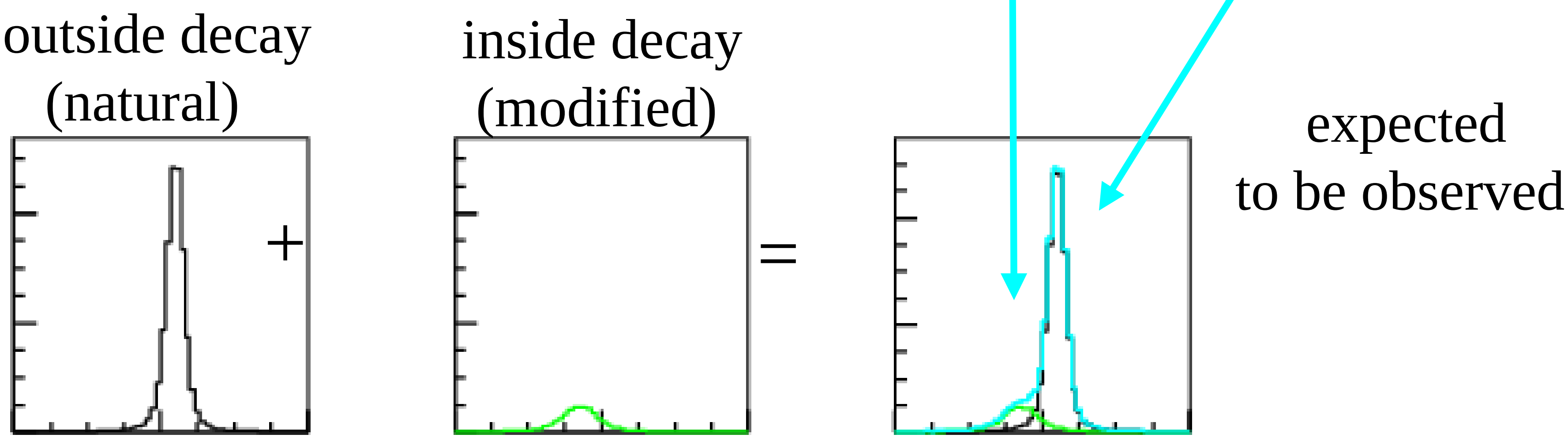
Expected Inv. e^+e^- mass spectra in p+A

- smaller FSI in e^+e^- decay channel rather than hadronic decay channel



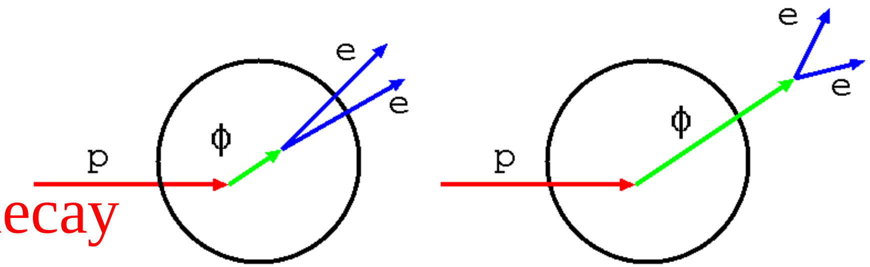
- double peak (or tail-like) structure
  - second peak is made by inside-nucleus decay (modified meson) : amount depend on the nuclear size and meson velocity
  - enhanced for slower mesons & larger nuclei

longer-life meson (ω(Γ=8.4MeV ~ 24 fm) & ϕ (Γ=4.3MeV ~ 46 fm)) cases :



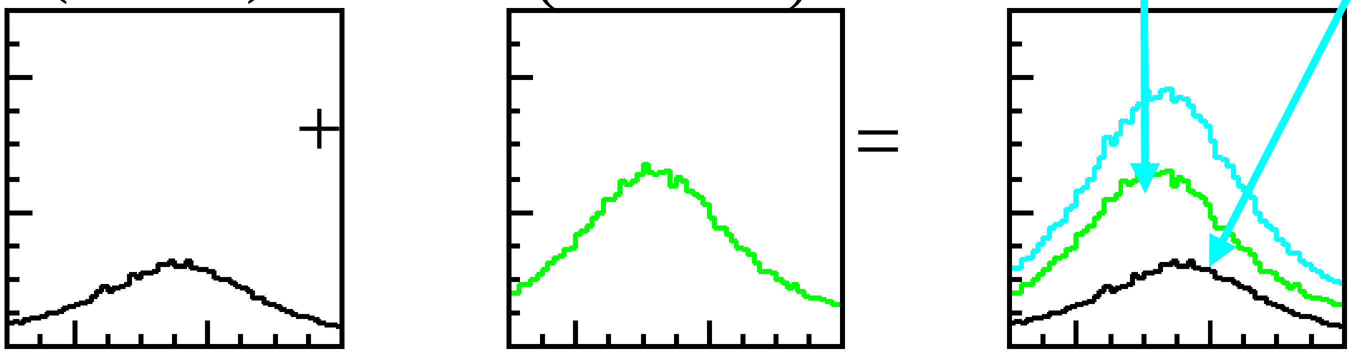
Expected Inv. e^+e^- mass spectra in p+A

- smaller FSI in e^+e^- decay channel rather than hadronic 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
  - enhanced for slower mesons & larger nuclei



shorter-life meson(ρ: Γ=150MeV ~ 1.3fm) cases

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



Experiment KEK-PS E325

- 12GeV p+A $\rightarrow \rho/\omega/\phi$ +X ($\rho/\omega/\phi \rightarrow e^+e^-$, $\phi \rightarrow K^+K^-$)
- Experimental key issues:
  - Very thin target to suppress the conversion electron background (typ. 0.1% interaction/0.2% radiation length of C)
  - To compensate the thin target, high intensity proton beam to collect high statistics (typ. 10^9 ppp $\rightarrow$ 10^6Hz interaction)
  - Large acceptance spectrometer to detect slowly moving mesons, which have larger probability decaying inside nuclei (1<$\beta\gamma$<3)

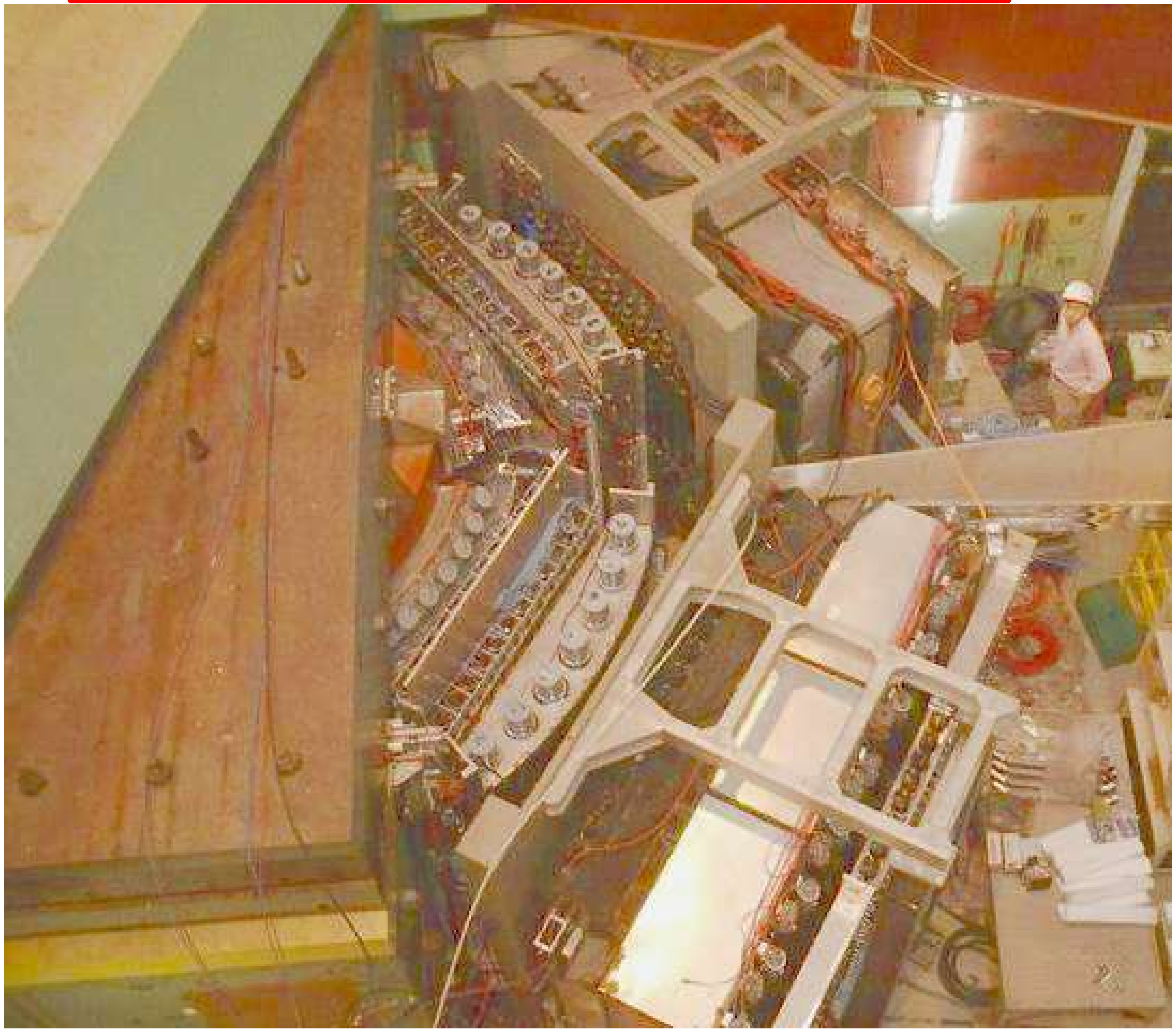
Collaboration

J. Chiba, H. En'yo, Y. Fukao, H. Funahashi, H. Hamagaki, M. Ieiri, M. Ishino, H. Kanda, M. Kitaguchi, S. Mihara, K. Miwa, T. Miyashita,T. Murakami, R. Muto, T. Nakura, M. Naruki, K.Ozawa, F. Sakuma, O. Sasaki, H.D.Sato, M.Sekimoto, T.Tabaru, K.H. Tanaka, M.Togawa, S. Yamada, S.Yokkaichi, Y.Yoshimura
(Kyoto Univ. , RIKEN, KEK, CNS-U.Tokyo, ICEPP-U.Tokyo, Tohoku-Univ.)

(Cont'd)

- History of E325
  - 1993 proposed
  - 1996 const. start
  - '97 data taking start
  - '98 first ee data
    - PRL86(01)5019
  - 99,00,01,02....
    - x100 statistics
      - nucl-ex/0504016
      - nucl-ex/0511019
  - '02 completed
  - spectrometer paper
    - NIM A516(04)390

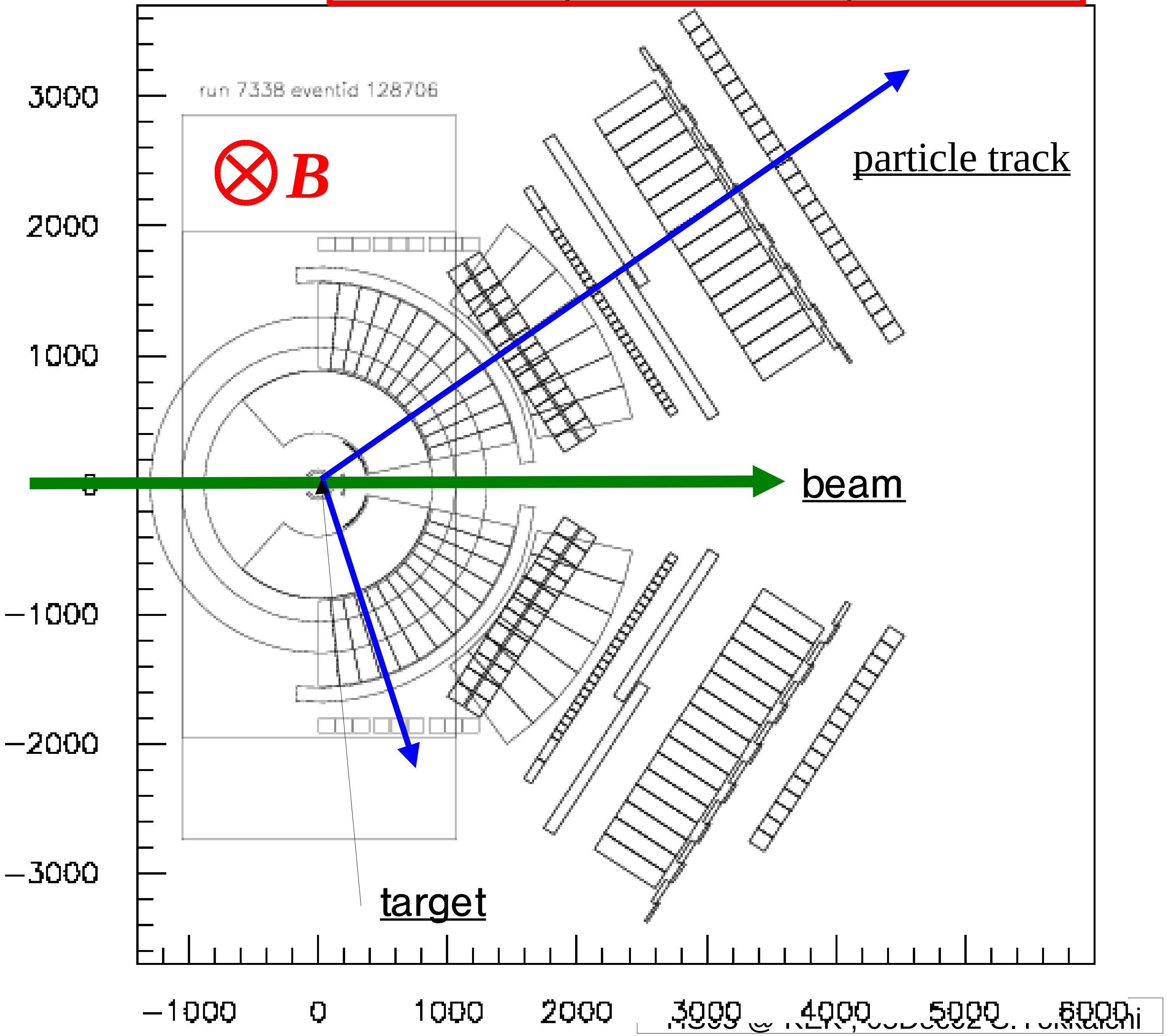
E325 spectrometer
located at KEK-PS EP1-B primary beam line



Experimental setup

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

schematic plan view of spectrometer



Experimental setup - Detectors

Electron ID counters

Gas Cherenkov &

Lead Glass EMC

total 3×10^{-4} π rejection

with 78% e efficiency

in two-stage operation

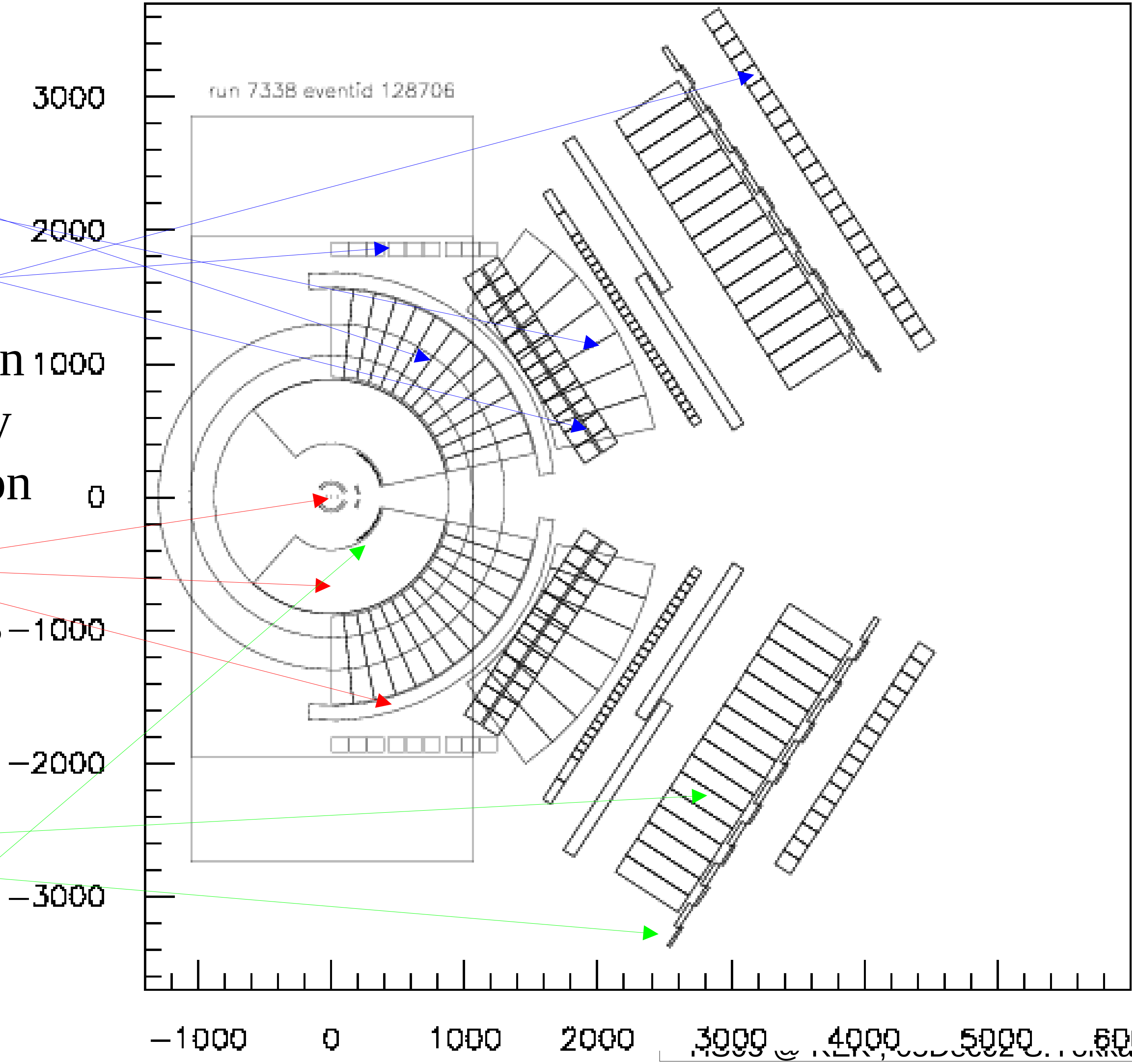
Tracker

Three Drift Chambers

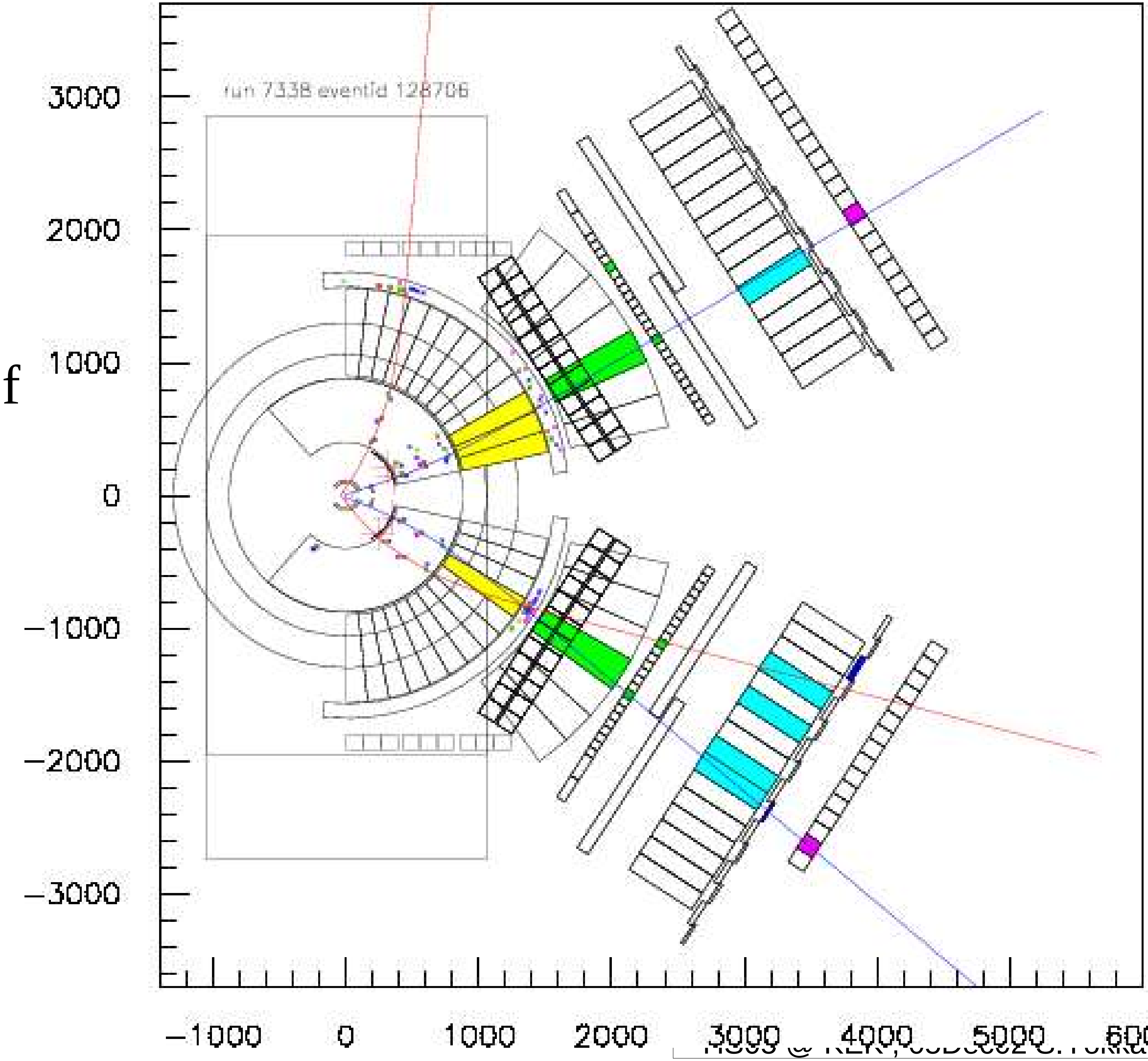
Kaon ID counters

Aerogel Cherenkov

& TOF



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



Vector meson measurements in the world

dilepton mesurement

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

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

already state 'modified'
running/in analysis
future plan

Result (1)

ee invariant mass spectra

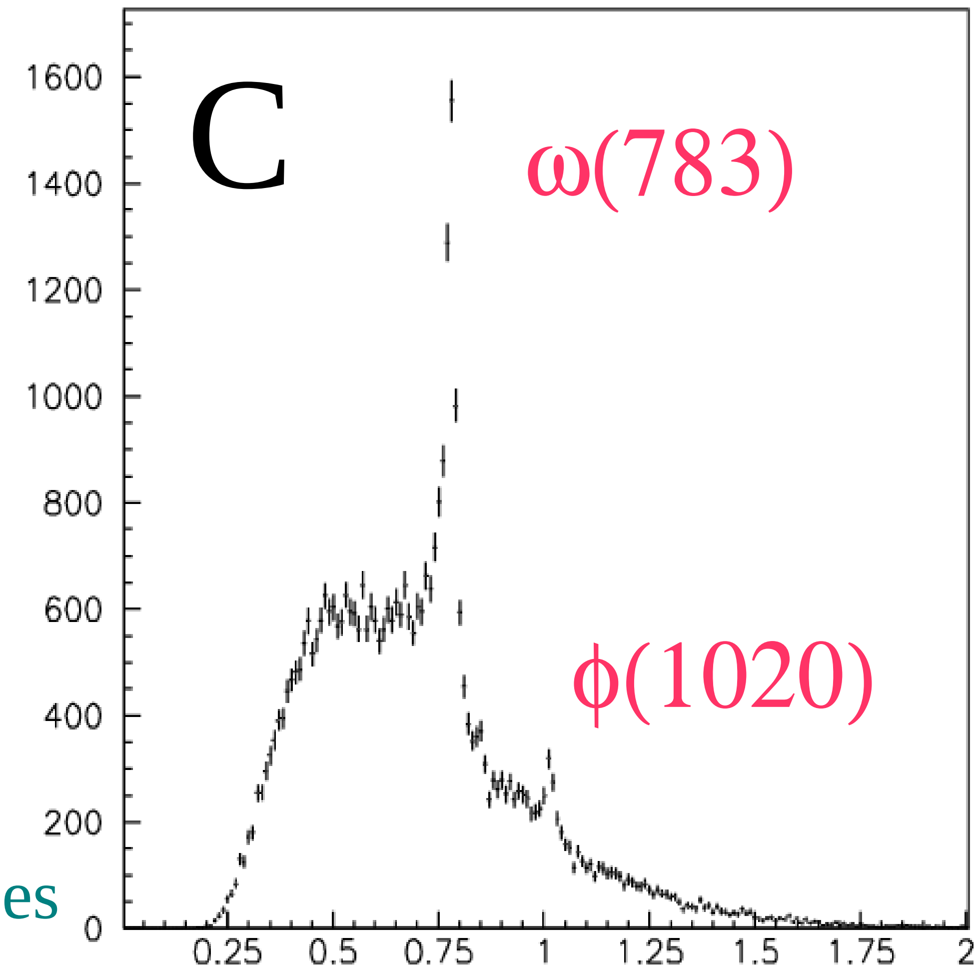
M. Naruki et al.,

nucl-ex/050416

Observed e^+e^- invariant mass spectra

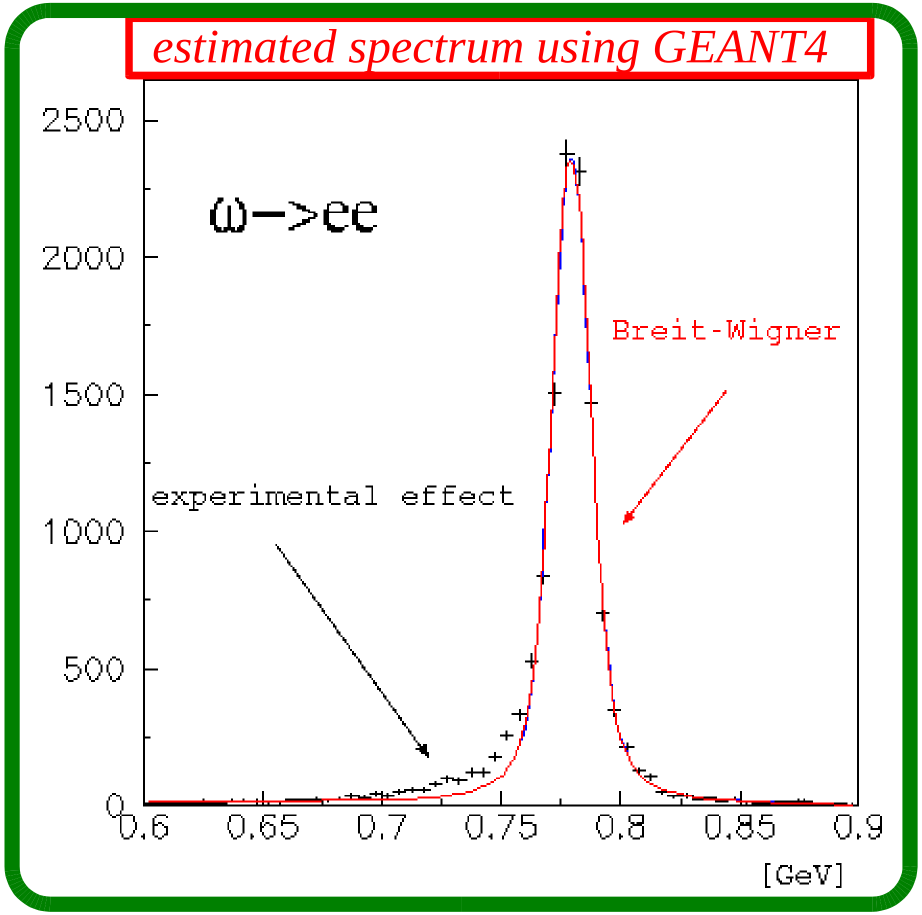
- from 2002 run data (~70% of total data)
- C & Cu target
- clear resonance peaks
- m<0.2 GeV is suppressed by detector acceptance
- acceptance uncorrected

→ fit the spectra with known sources

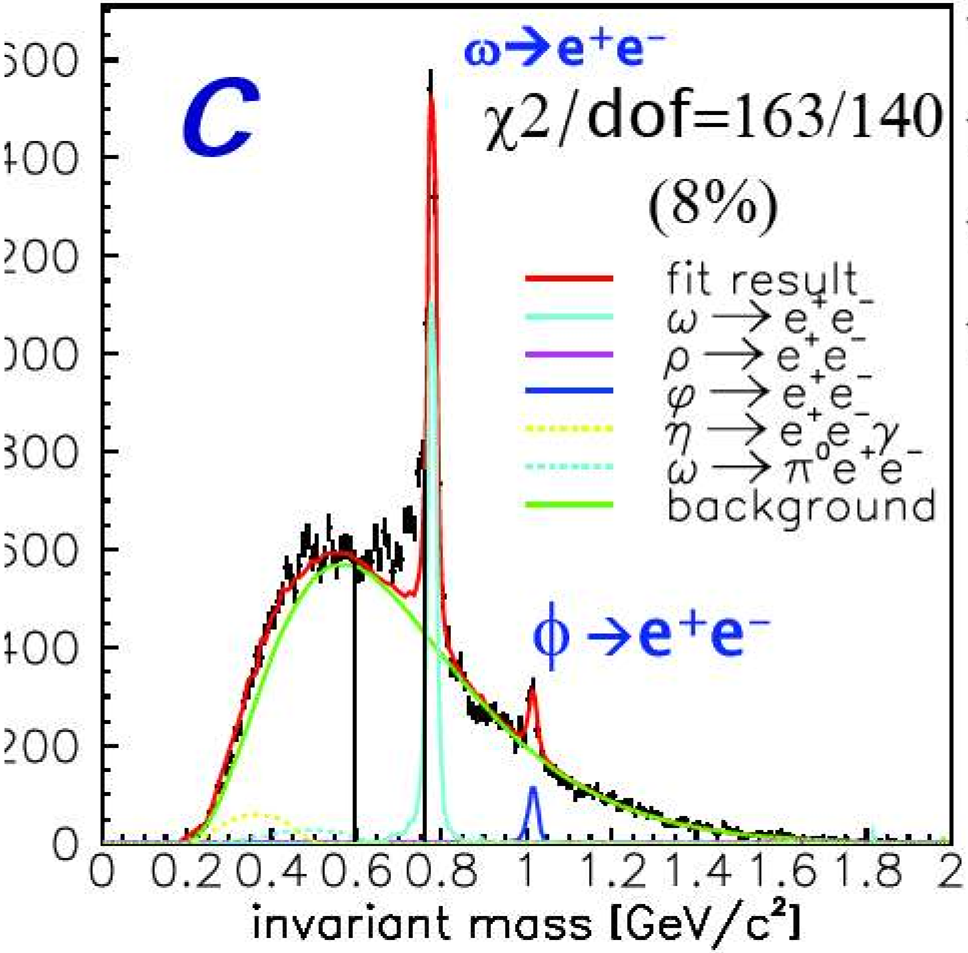


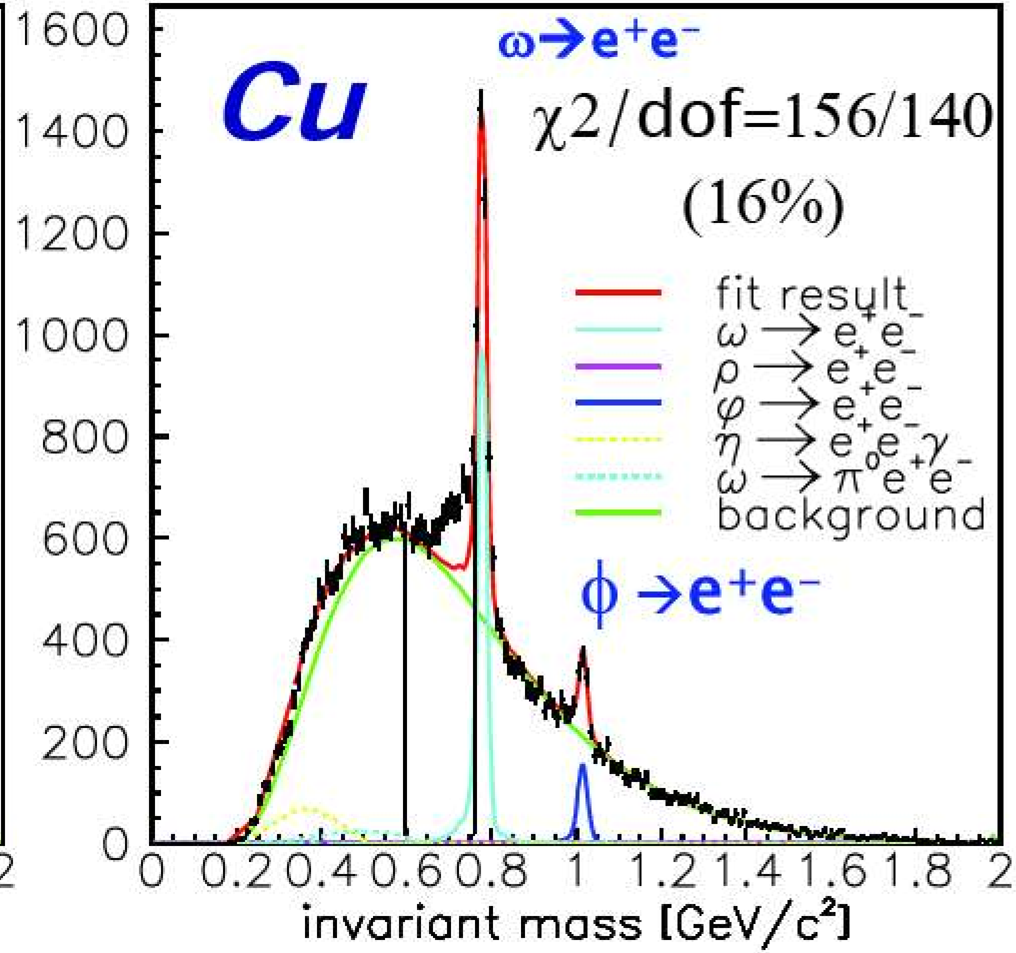
Fitting with known sources

- Hadronic sources of e^+e^-:
  - $\rho/\omega/\phi \to e^+e^-$, $\omega \to \pi^0 e^+e^-$, $\eta \to \gamma e^+e^-$
  - relativistic Breit-Wigner shape (without any modifications)
  - Geant4 detector simulation
    - multiple scattering and energy loss of e^+/e^- in the detector and the target materials
    - chamber resolutions
    - detector acceptance, etc.
- Combinatorial background : event mixing method
- Relative abundance of these components are determined by the fitting



Fitting results

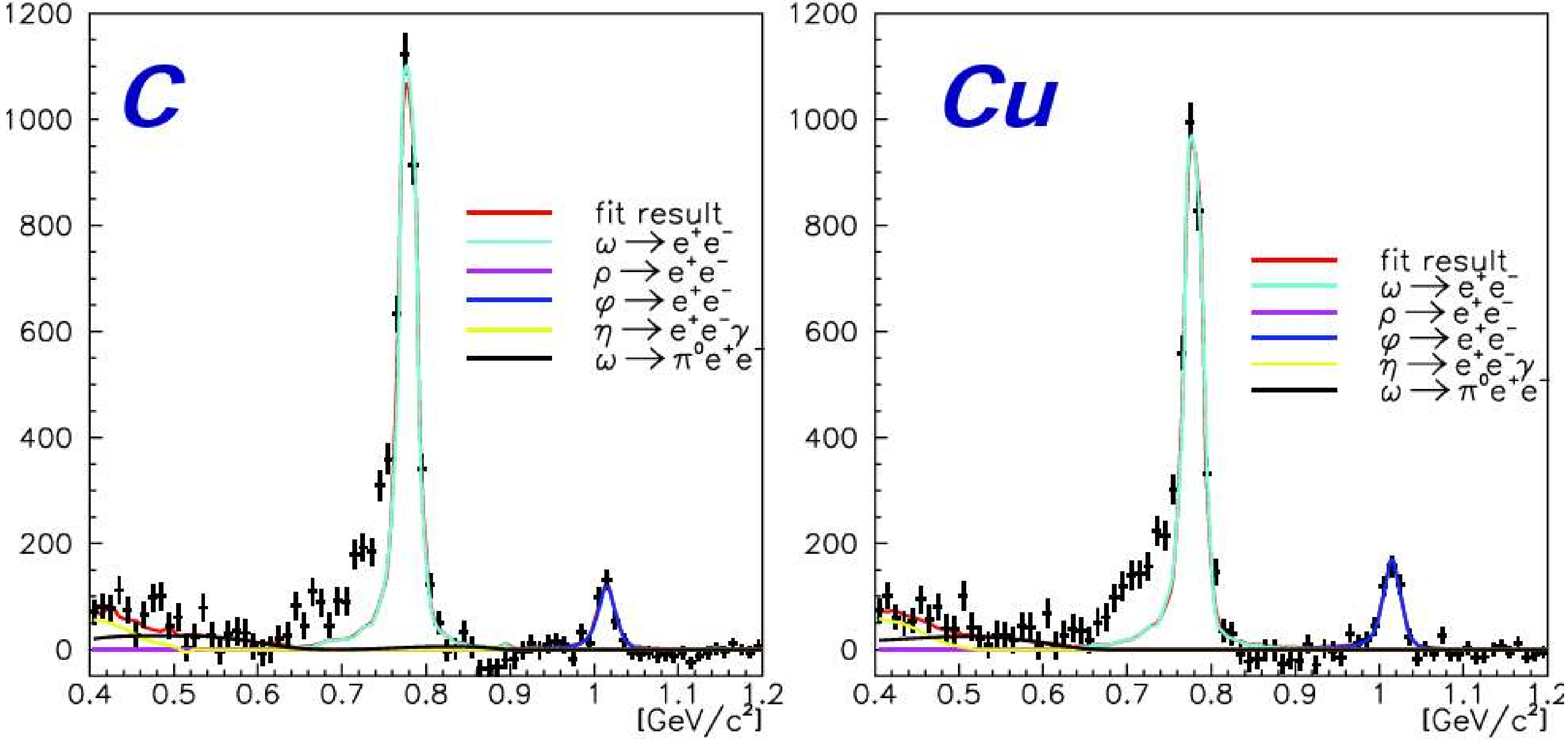




- 1) excess at the low-mass side of ω
  - To reploduce the data by the fitting, we have to exclude the excess region : 0.60~0.76 GeV
- 2) ρ–meson component seems to be vanished !

Fitting results (BKG subtracted)

ρ/ω < 0.15 (for C), < 0.31(for Cu)



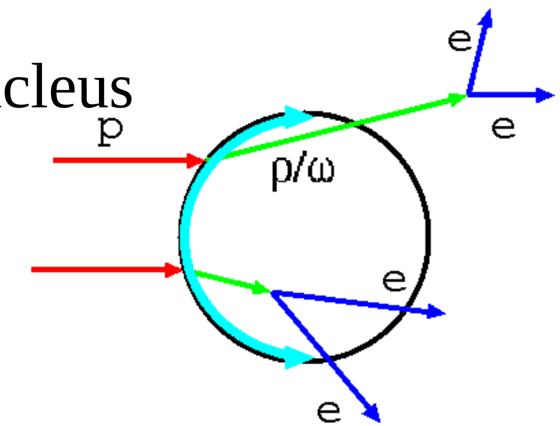
- However, ρ/ω =1.0±0.2 in former experiment (p+p, 1974)

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

Toy model M.C. including modification

- Assumptions to include the nuclear size effect in the fitting shape
  - mesons fly through the nucleus, decay with modified mass if the decay point is inside nucleus
    - meson production point : incident surface of nucleus
      - measured $\alpha \sim 0.68$ for ω
    - meson momentum :
      - measured distribution in our experiment
        - ~0.8 GeV < p < ~2.4GeV for ω
    - nuclear density distribution : Woods-Saxon type
    - modification form : $m^*/m_0 = 1 - k\,\rho/\rho_0$ for ρ & ω

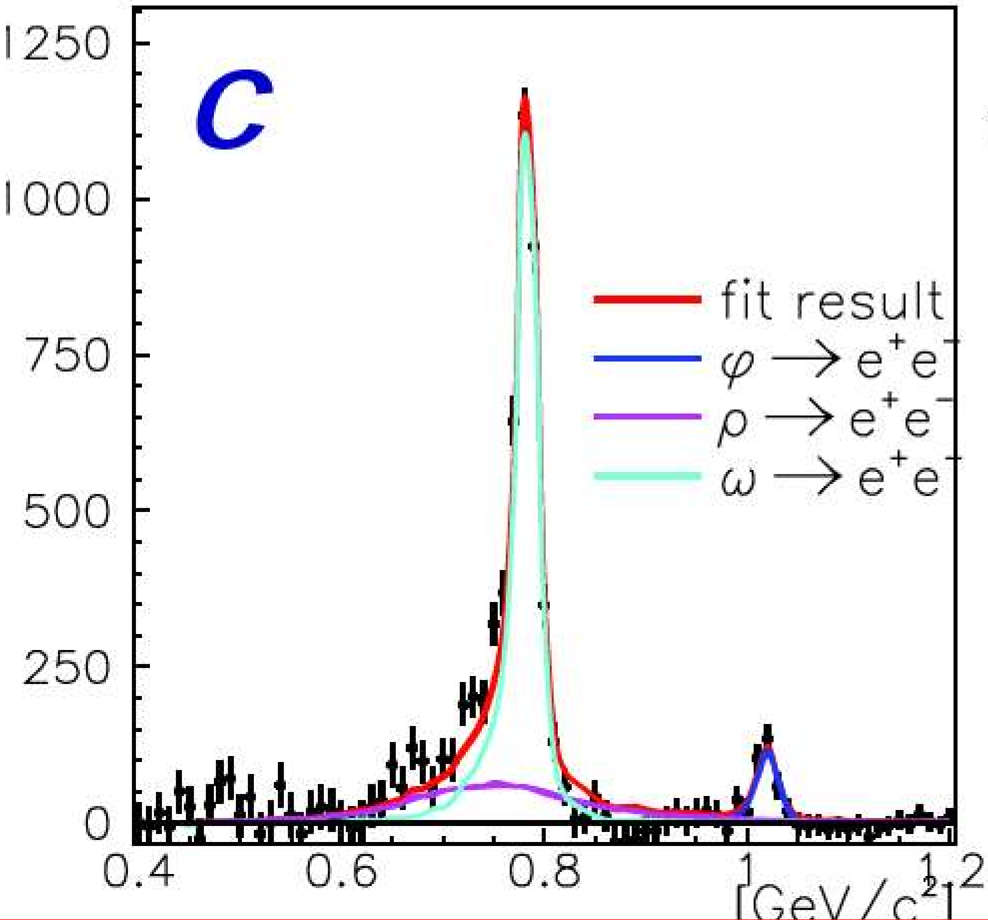
      (k=0.16±0.06 in Hatsuda & Lee, '92,'96)
    - (width modification & momentum dependence of modification are not taken into account this time)

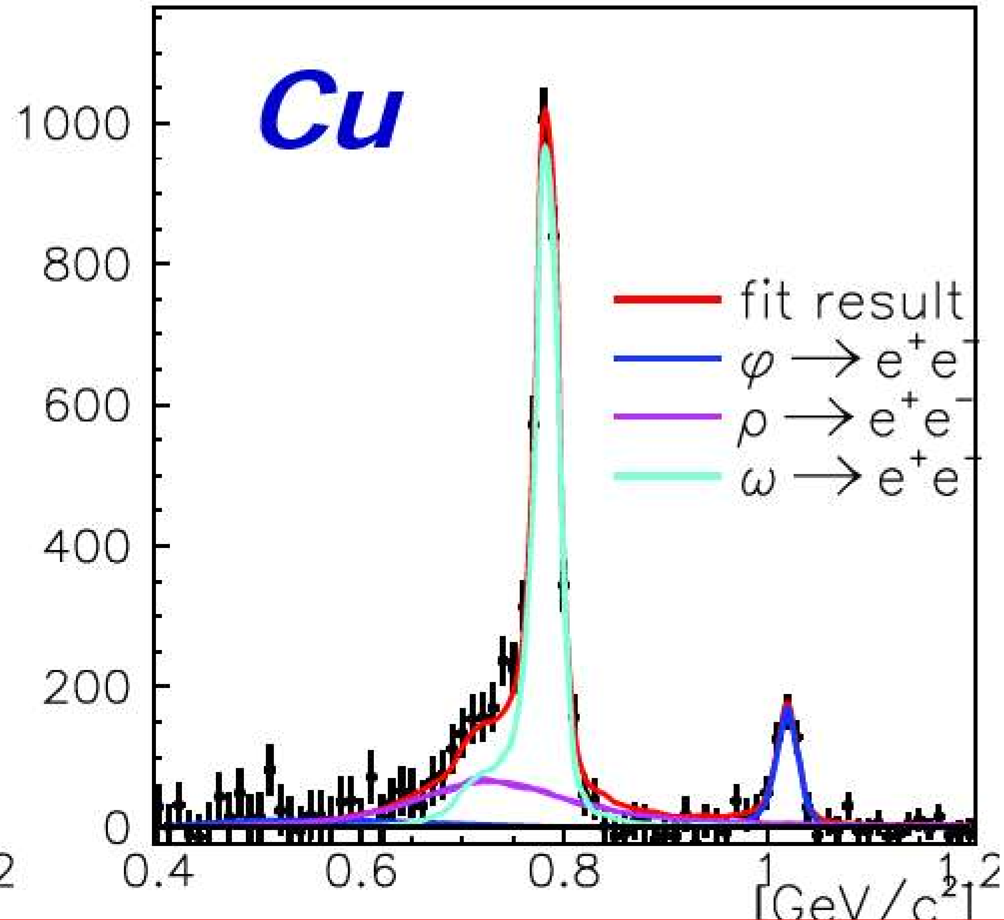


Fitting results by the toy model

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

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



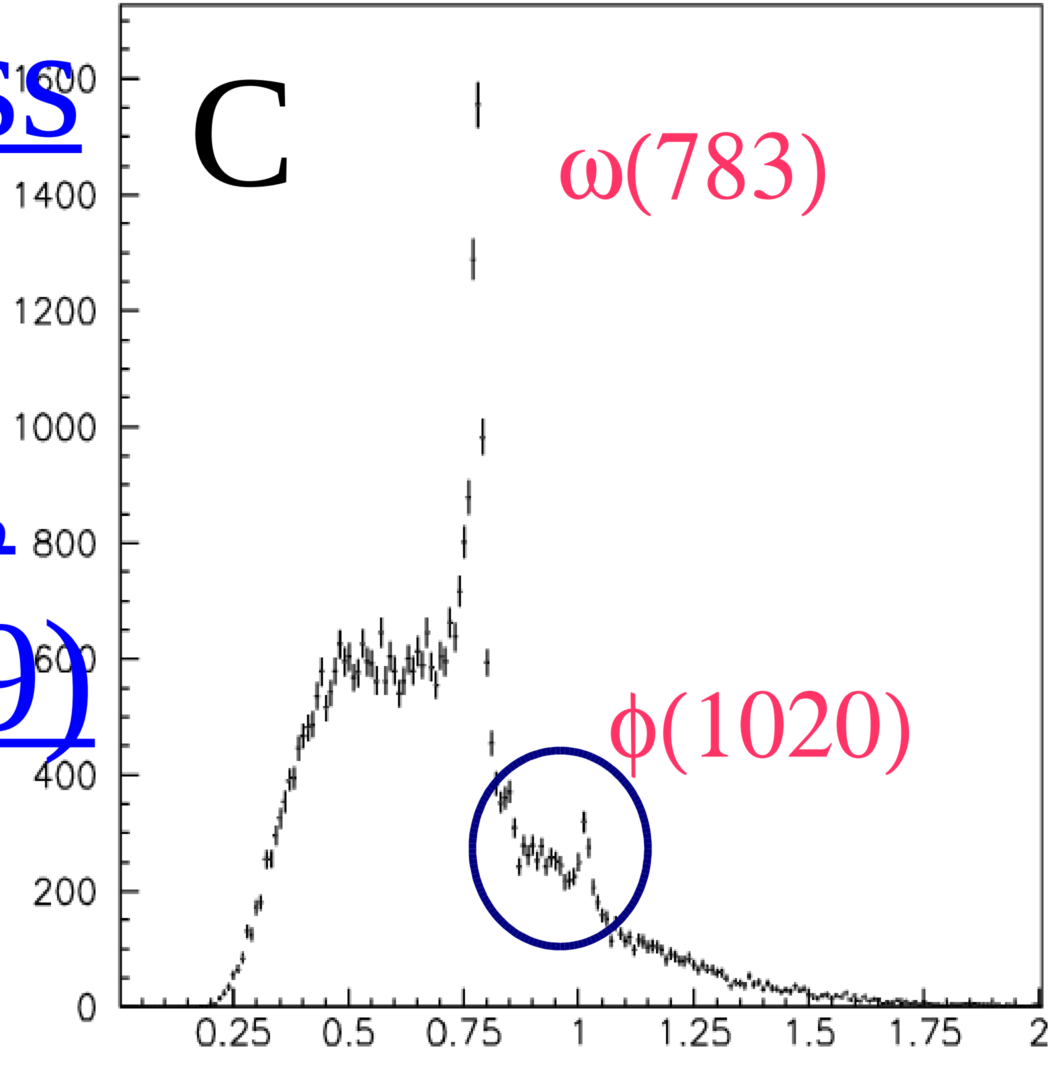


From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density

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

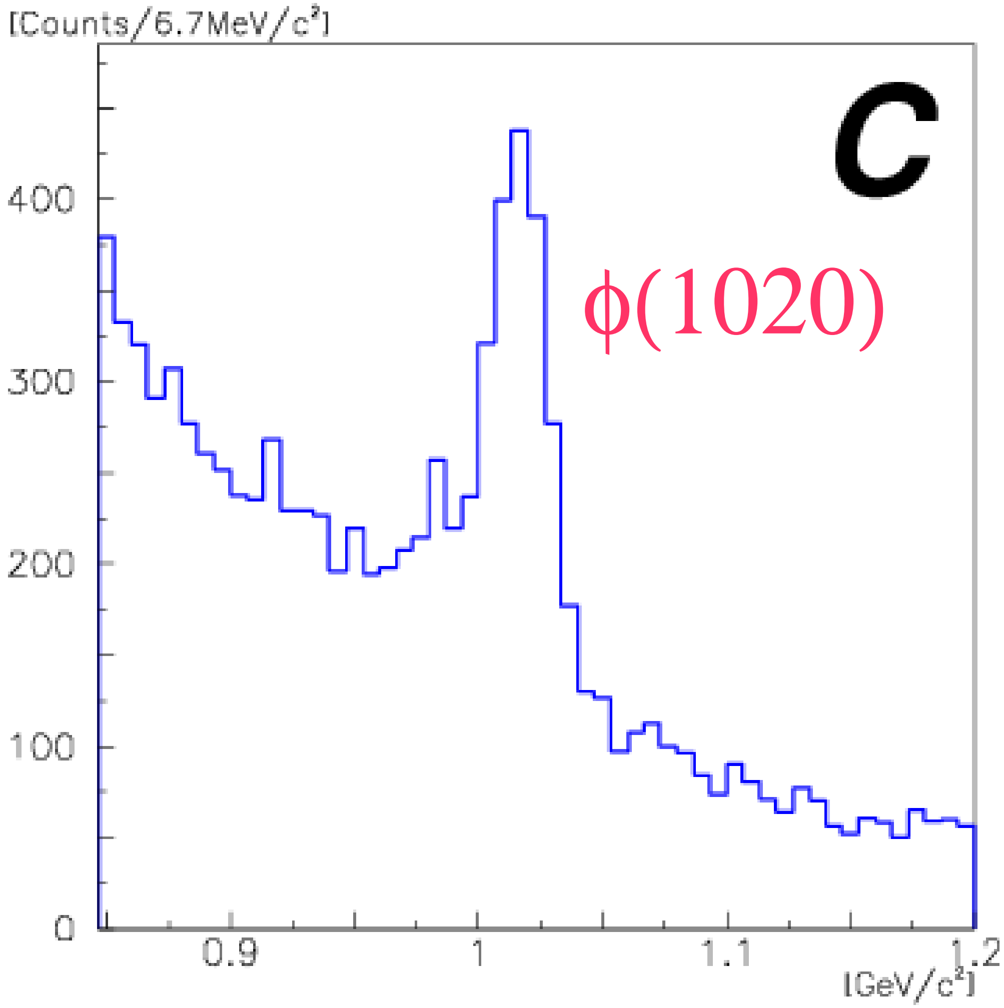
Result (2)

ee invariant mass spectra of ϕ (R. Muto et al., nucl-ex/0511019)



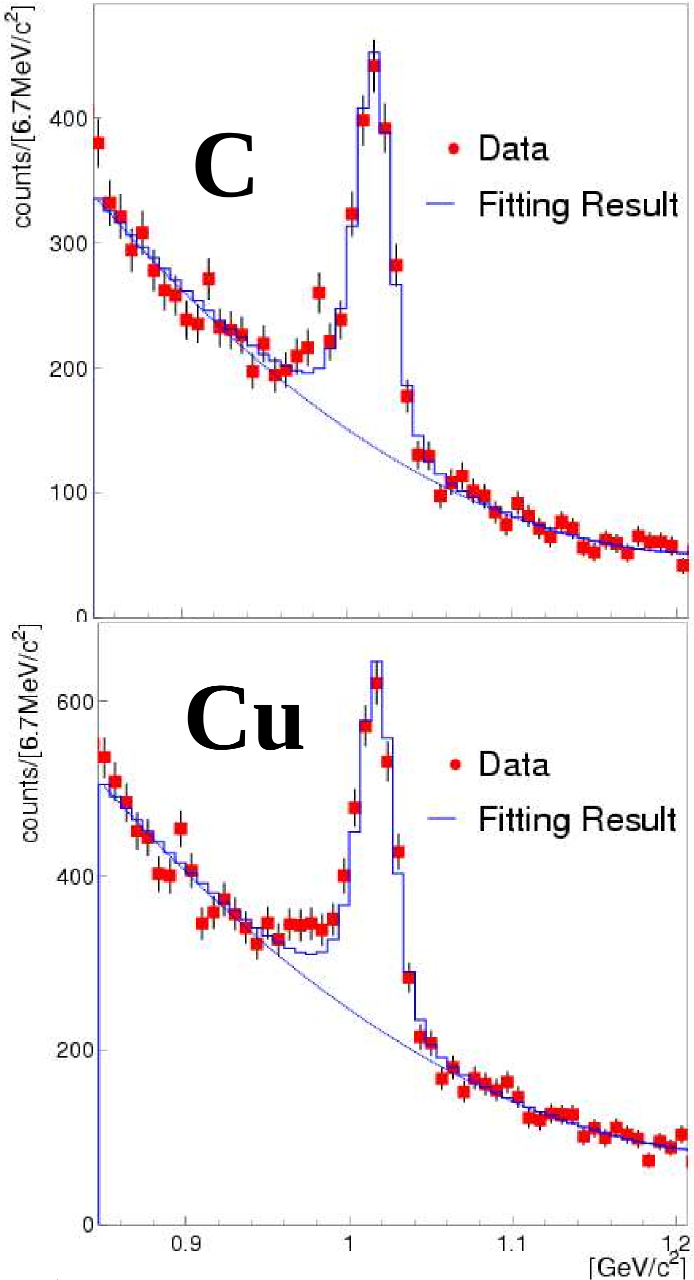
$\phi \rightarrow e^+e^-$ invariant mass spectra

- from 2001/02 run data
- C & Cu target
- acceptance uncorrected
- mass resolution :10.7MeV
- fit with
  - simulated mass shape of ϕ
    - (evaluated as same as ρ&ω)
  - polinomial curve background



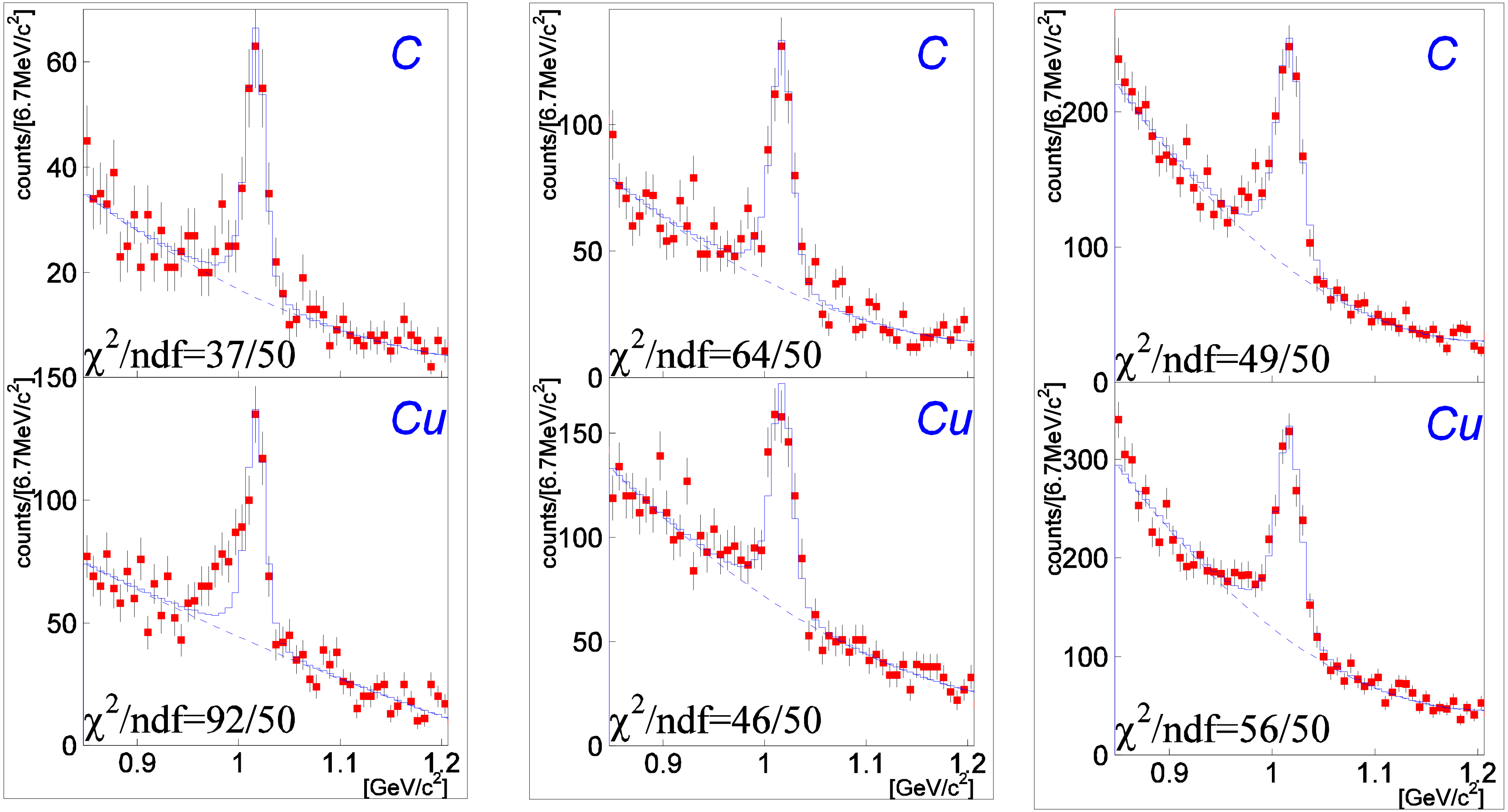
$\phi \rightarrow e^+e^-$ invariant mass spectra

- from 2001/02 run data
- C & Cu target
- acceptance uncorrected
- mass resolution :10.7MeV
- fit with
  - simulated mass shape of ϕ
    - (evaluated as same as ρ&ω)
  - polinomial curve background
- 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 $\beta\gamma$)

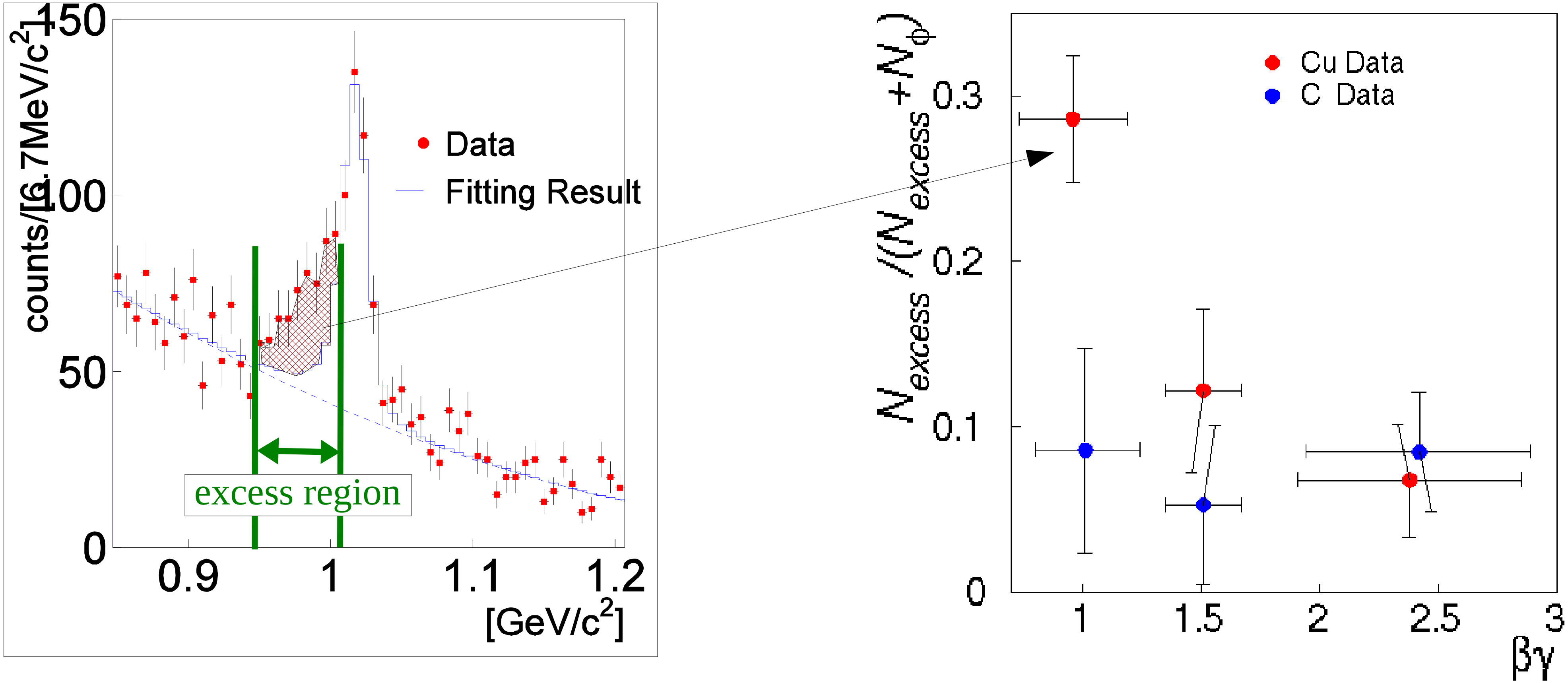
$\beta\gamma<1.25$ (Slow)	$1.25<\beta\gamma<1.75$	$1.75<\beta\gamma$ (Fast)



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

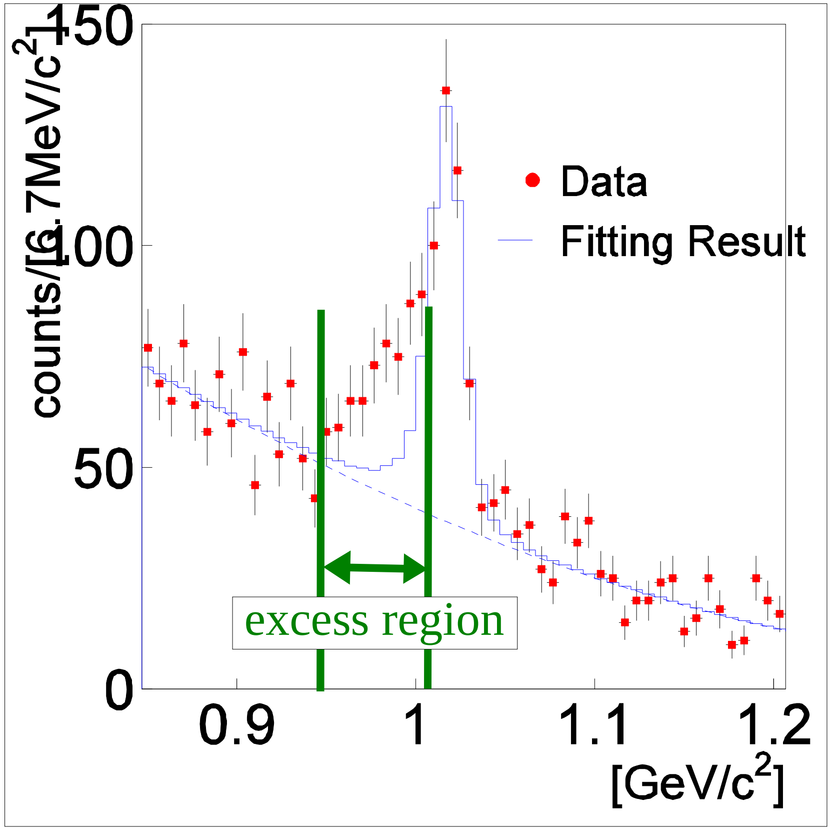
Amount of excess

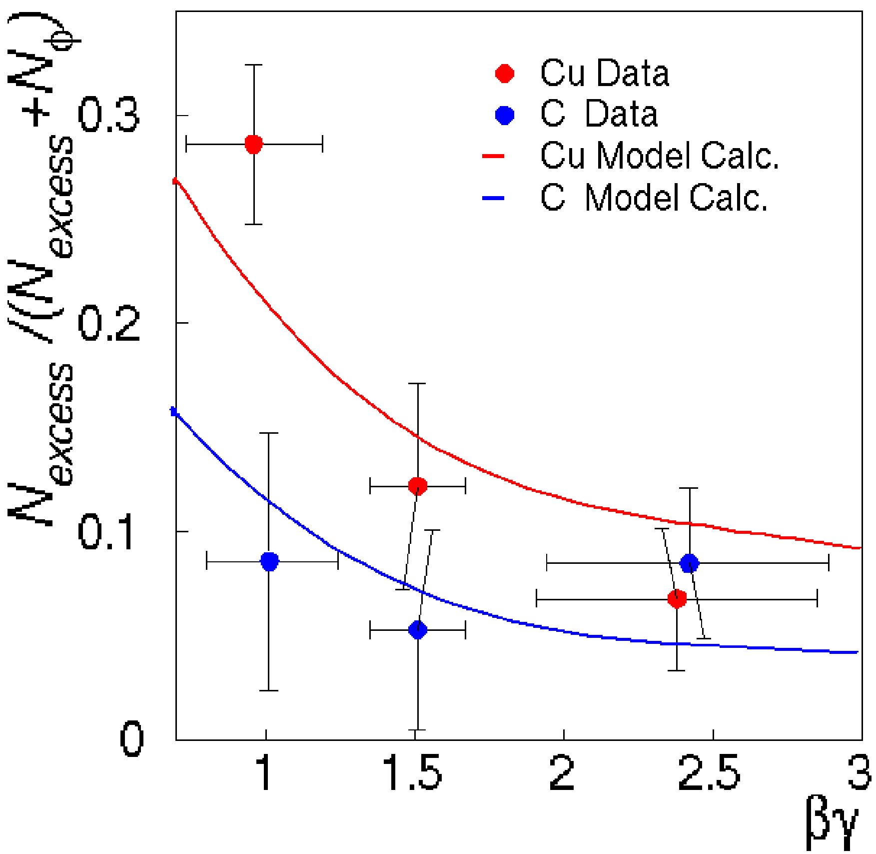
- To evaluate the amount of excess (N_{excess}), fit again excluding the excess region (0.95~1.01GeV) and integrate the excess area.



Amount of excess

- To evaluate the amount of excess (N_{excess}), fit again excluding the excess region (0.95~1.01GeV) and integrate the excess area.
- Model calculation reproduces the tendency of N_{excess} / (N_{excess} + N_{ϕ})

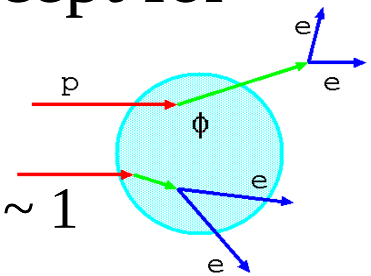




Toy model again for ϕ meson

$\beta\gamma$<1.25 (Slow), w/ unmodified

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



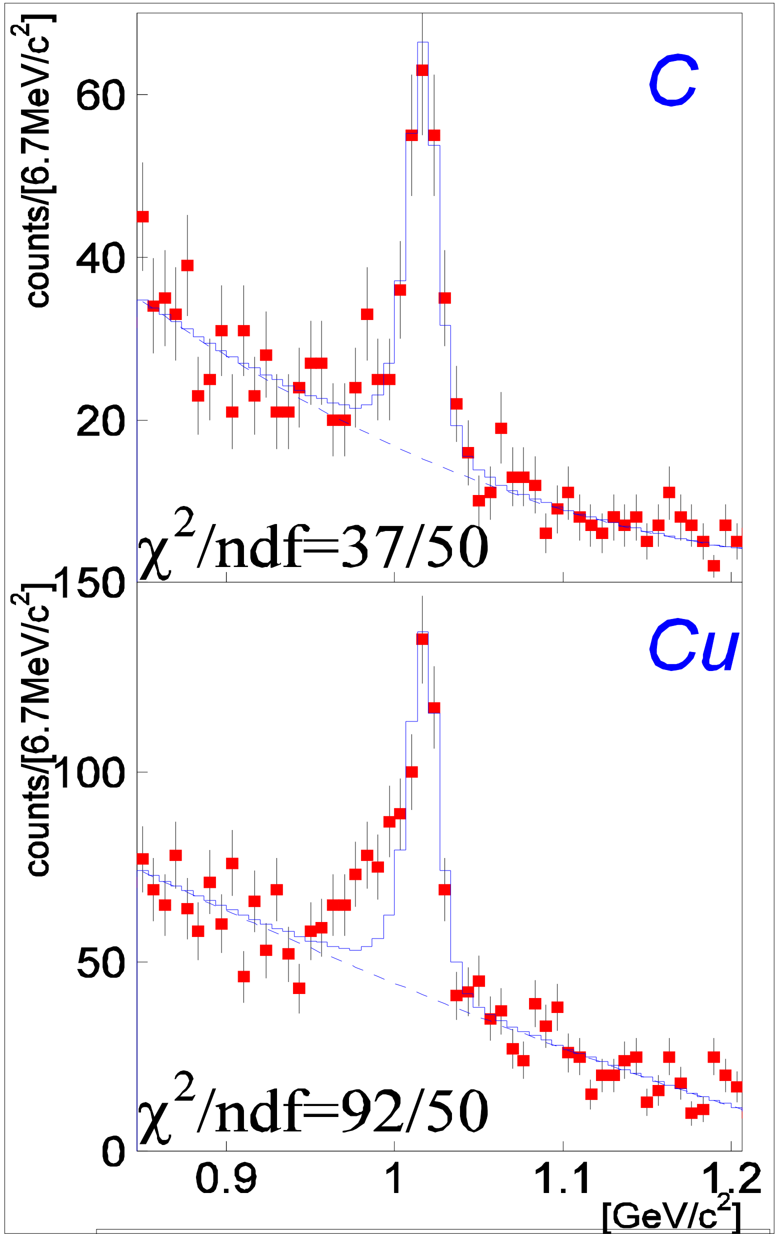
  - $m^{*}/m_{0} = 1-$ k_1 ρ/ρ_0

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

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

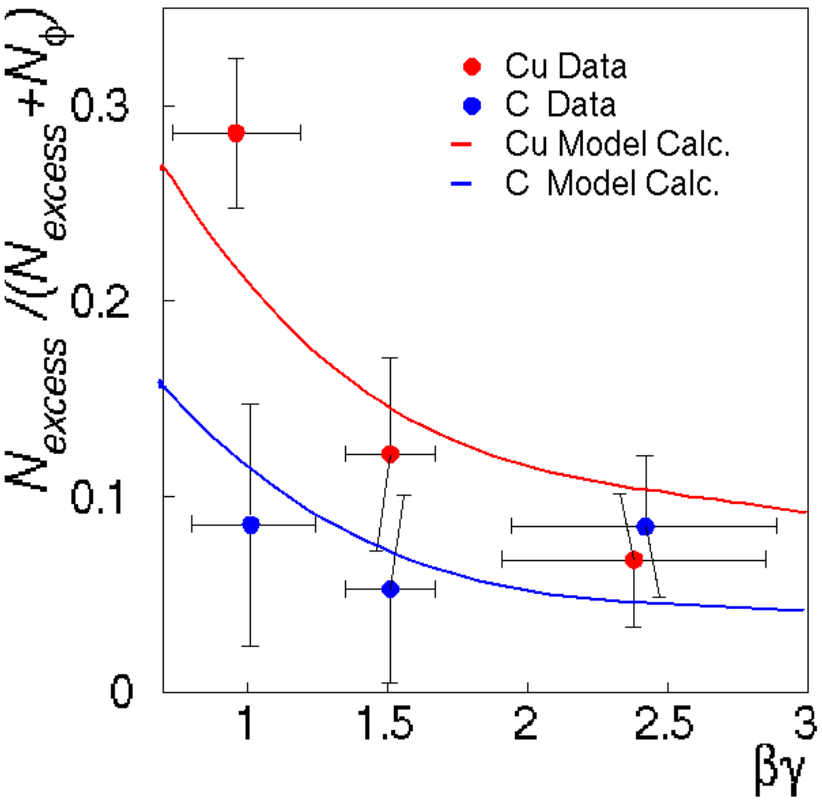
    (k_2=10, it means Γ_{tot}^{*}=~47MeV at ρ_0)

    (predicted value by Klingl *et al.*, '98)
    - e^+e^- branching ratio is not changed
      - $\Gamma^{*}_{e+e-}/\Gamma^{*}_{tot} = \Gamma^{0}_{e+e-}/\Gamma^{0}_{tot\ 0}$
  - k_1 & k_2 is not free param., but fixed.

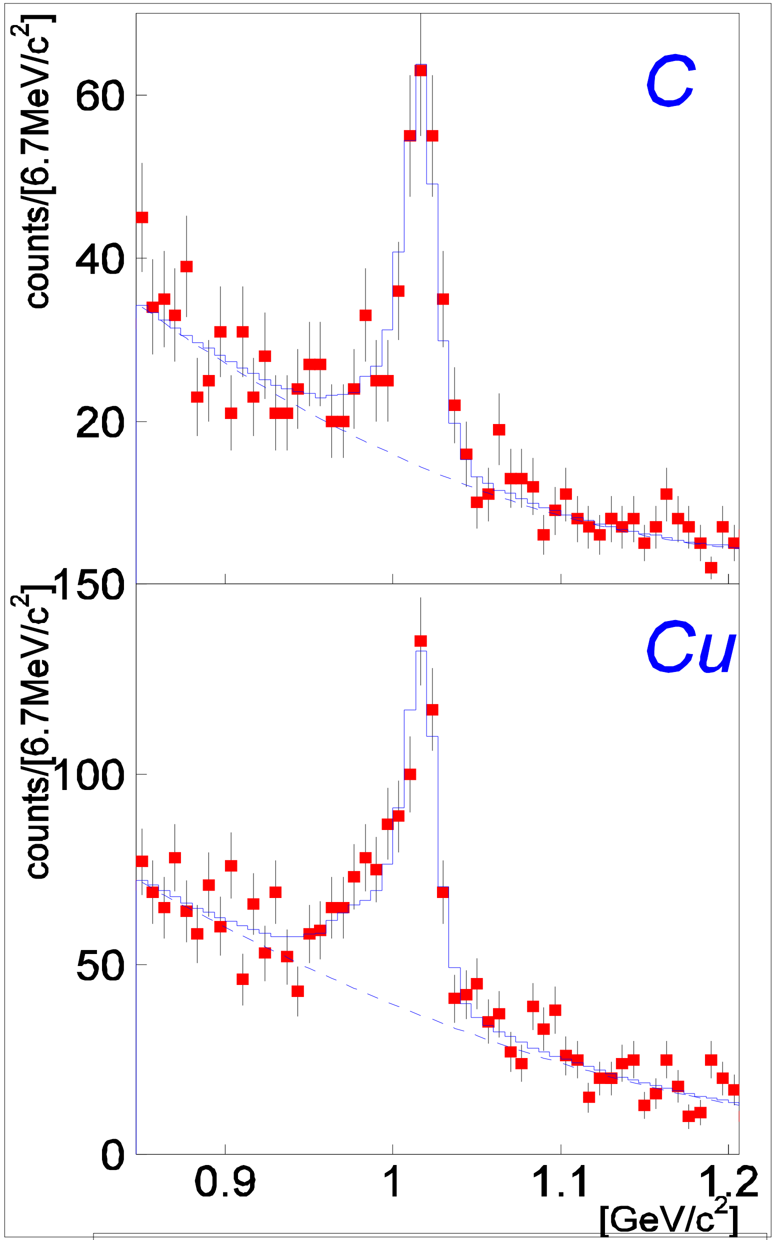


Toy model result for ϕ meson

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



βγ<1.25 (Slow), w/ modified



HS05 @ KEK , 05Dec02 S.Yokkaichi

Summary (1)

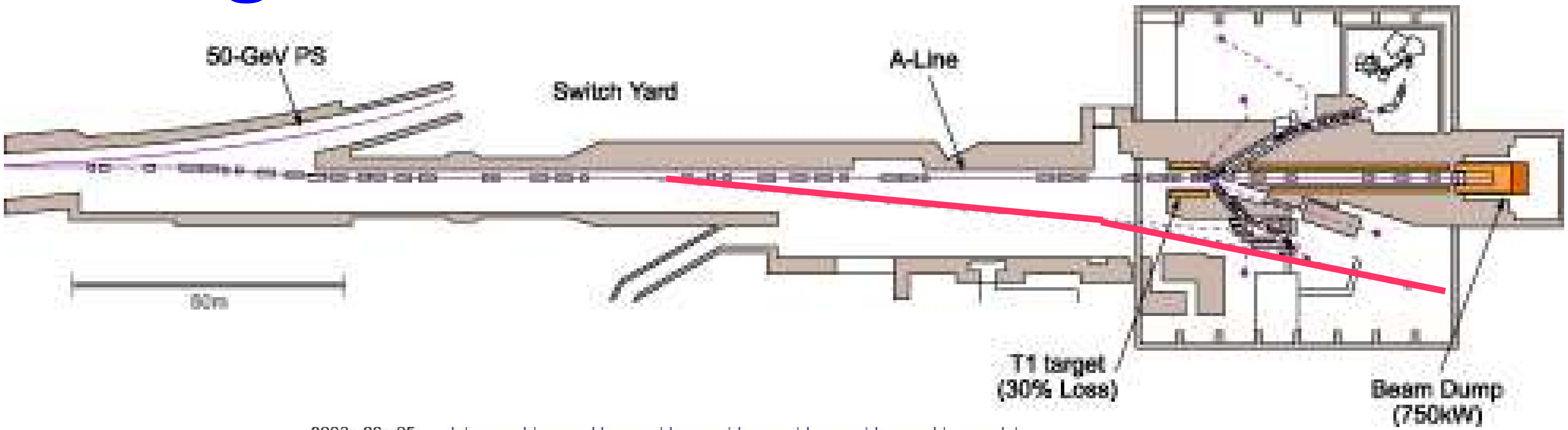
- KEK-PS E325 measured the e^+e^-(&K^+K^-) decay of slowly moving vector mesons in nuclei produced by 12-GeV proton beam, to explore the chiral symmetry restoration at the normal nuclear density.
- Observed e^+e^- invariant mass spectra have excesses below the ω meson peak, which cannot be explained 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 ϕ
  - First observation of the modification of ϕ meson
  - World best mass resolution for $\phi \to e^+e^-$
  - model calc. including mass shift and width broadning in nuclei also reproduces the data.

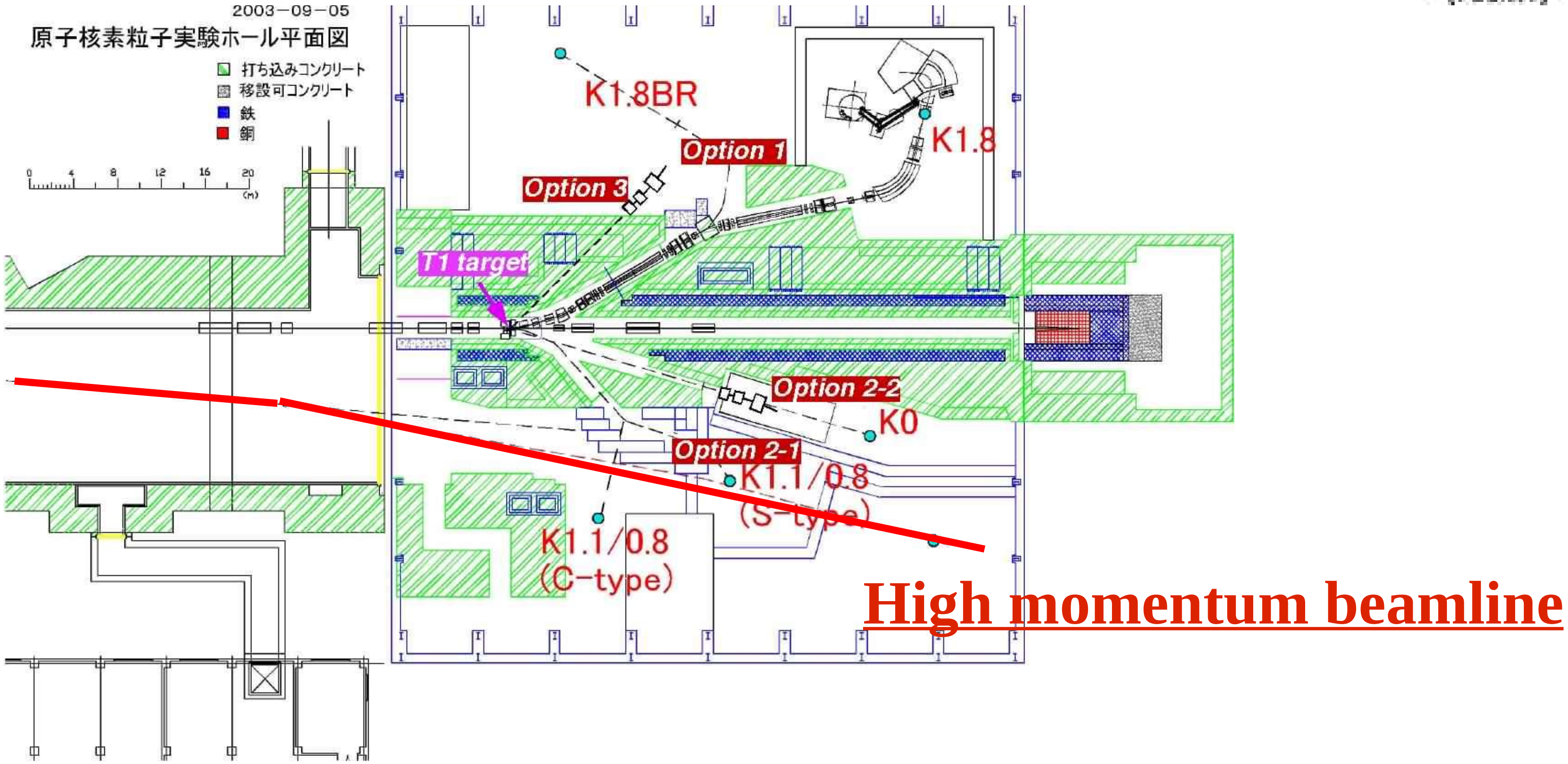
Proposed Experiment at J-PARC

Next generation experiment at J-PARC

- Same concept as E325
  - thin target / primary beam (10^9 ~10^{10} ppp)/ slowly moving mesons
- Main goal : collect 10^4 ~10^5 $\phi \rightarrow$ ee for each target in ~5 weeks
  - 10-100 times as large as E325
    - velocity dependence of 'modified' component
    - new nuclear targets : proton (CH_2 -C subtract), Pb
  - narrow width : sensitive to modification
  - mass resolution : less than ~10 MeV/c^2
- ω, ρ and J/ψ can be collected at the same time
  - higher statistics of ω, ρ than E325 with differ nuclear targets
  - 100-1000 J/ψ are expected in 50GeV operation
- Normal nuclear density (p+A)
  - but also high matter density (A+A, ~20GeV/u)

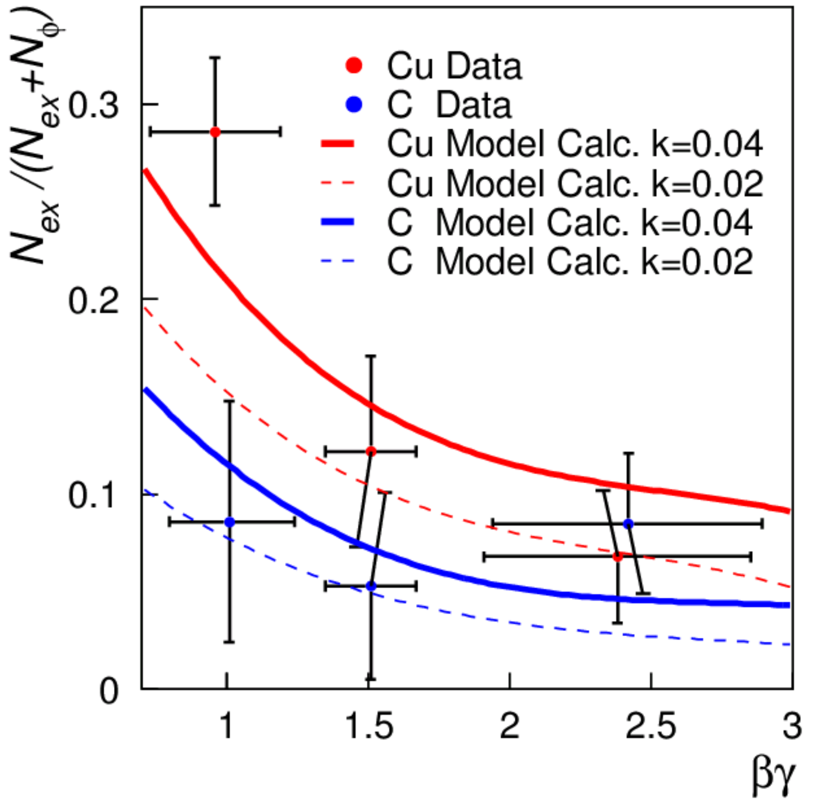
High momentum Beamline





high statistics

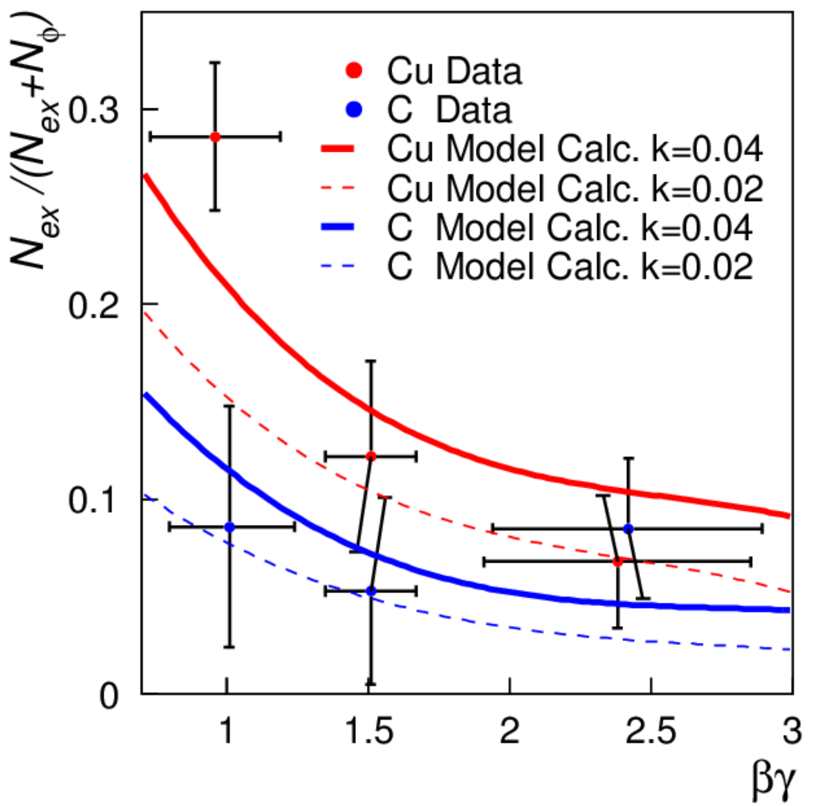
- Main goal : collect $10^4 \sim 10^5$ $\phi \rightarrow ee$ for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of 'modified' component



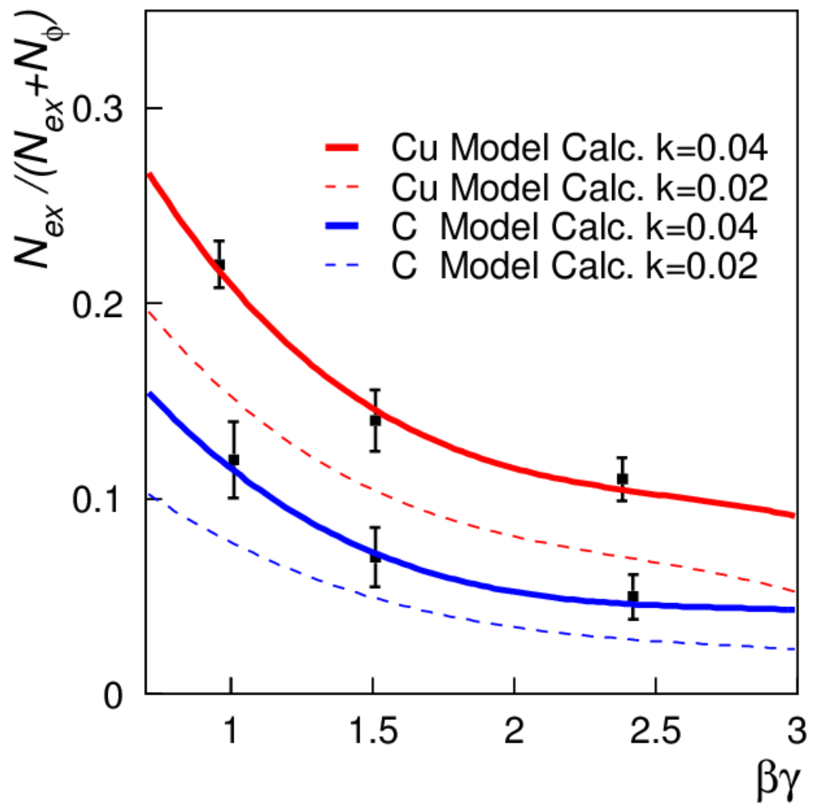
x 10 stat.

high statistics

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



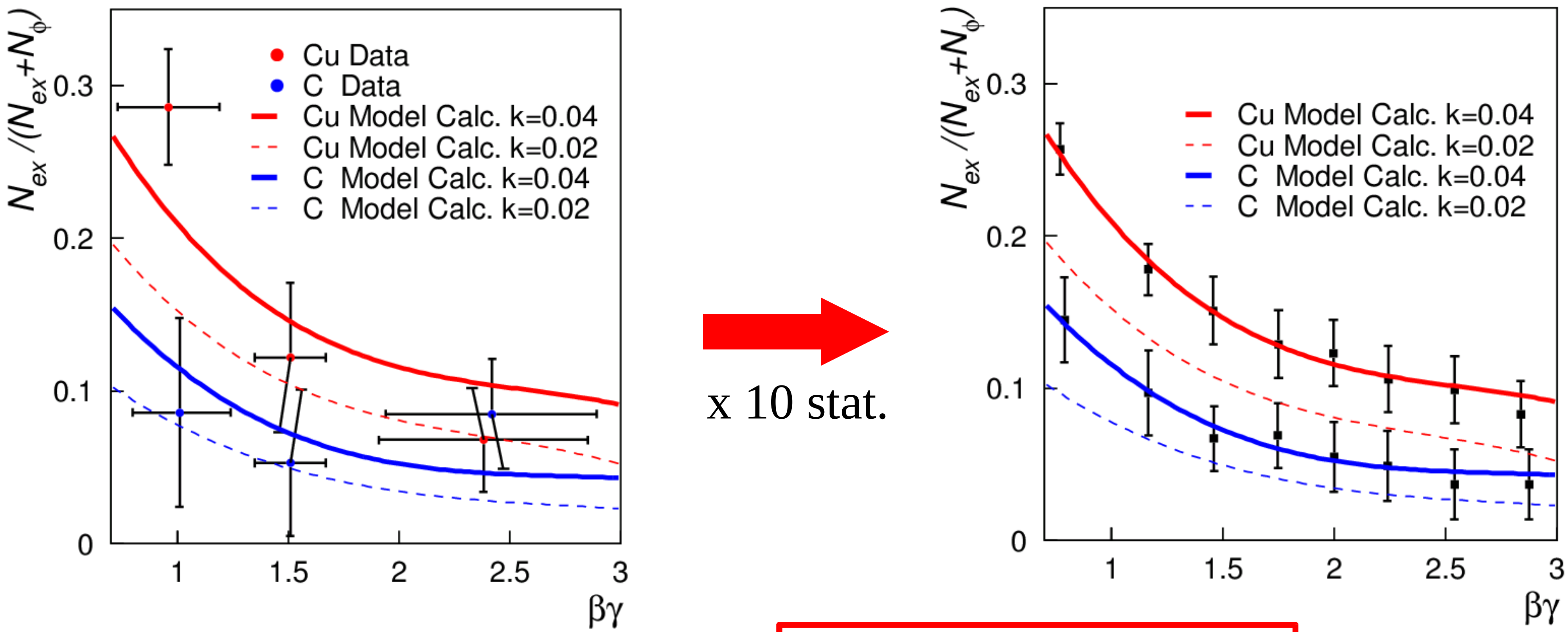
x 10 stat.



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

high statistics

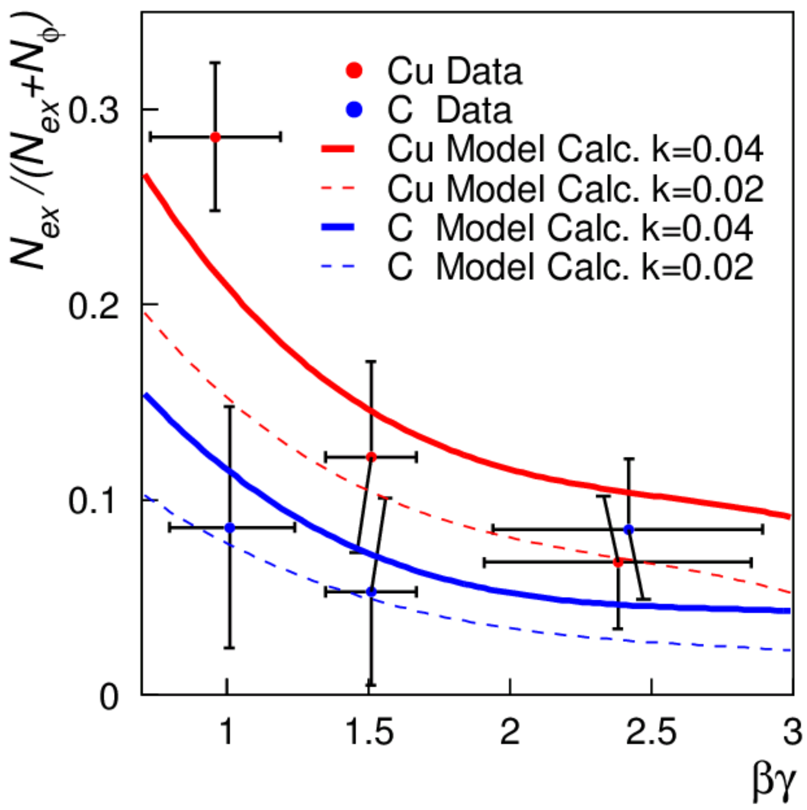
- Main goal : collect 10^4 ~10^5 $\phi \rightarrow ee$ for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of 'modified' component



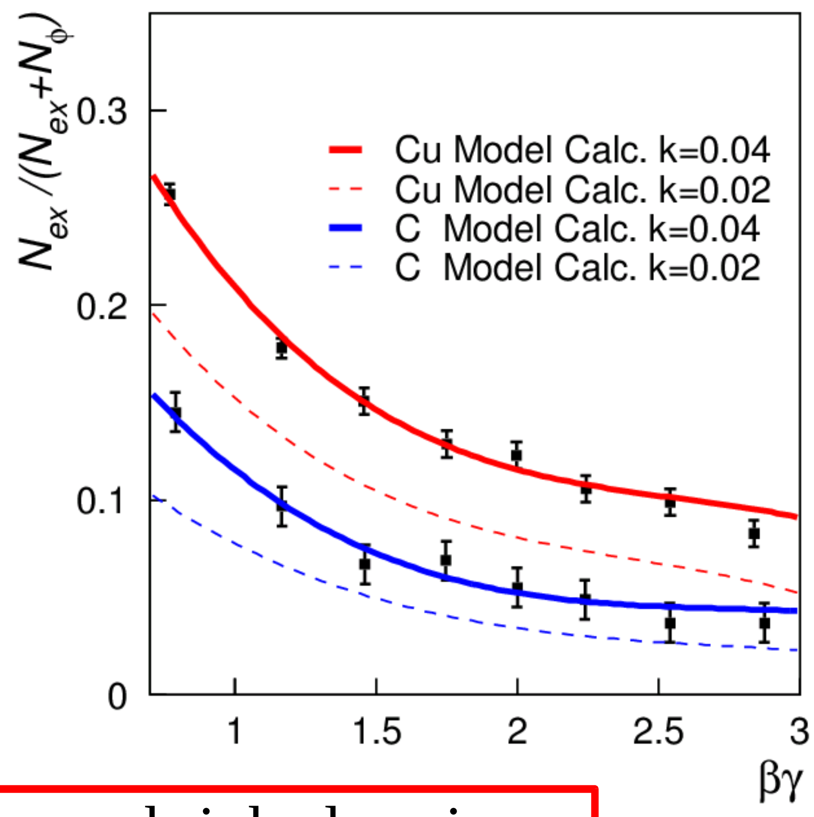
βγ bin can be divided

high statistics

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



x 100 stat.



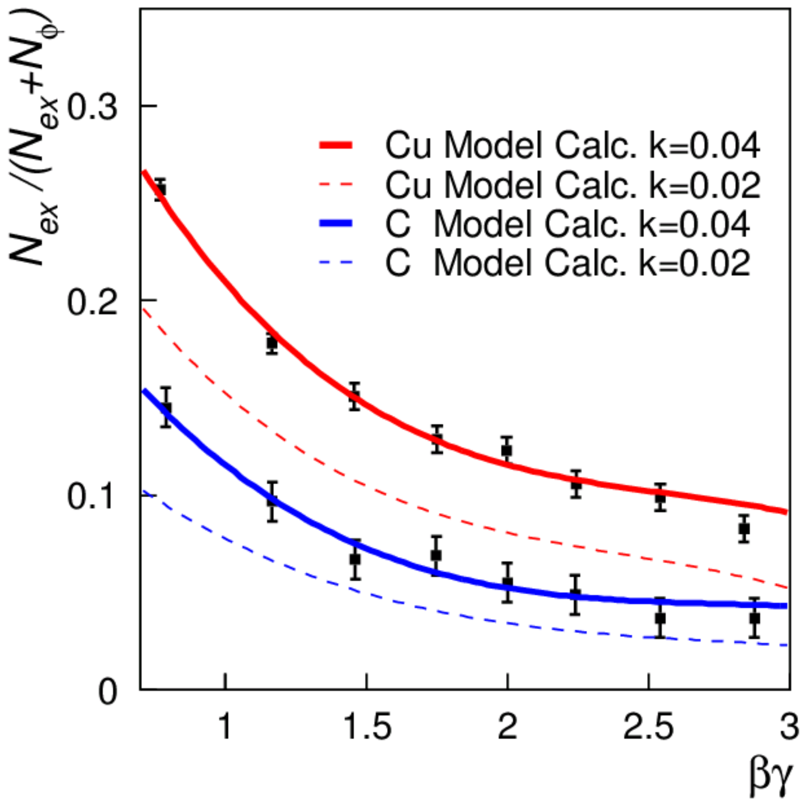
error bars are shrinked again

high statistics

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

We can compare the data with theoretical predictions more precisely, and we can approach the puzzle that the modification is due to the chiral symmetry restoration or not.

x 100 stat.



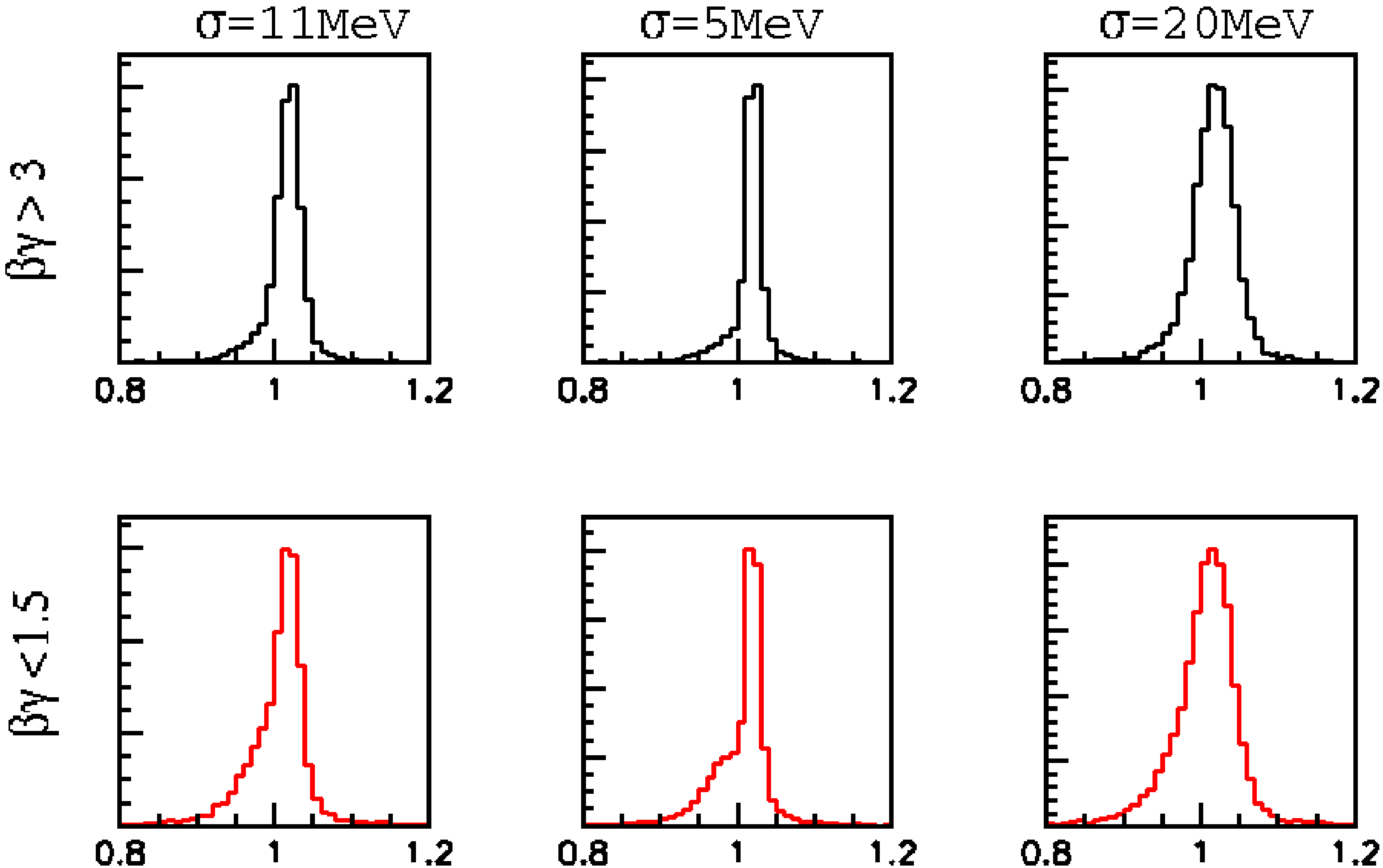
Advance of the theoretical works is also needed to solve the puzzle....

high mass resolution

- mass resolution should be less than ~10MeV

Fast

Slow



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

To collect the high statistics

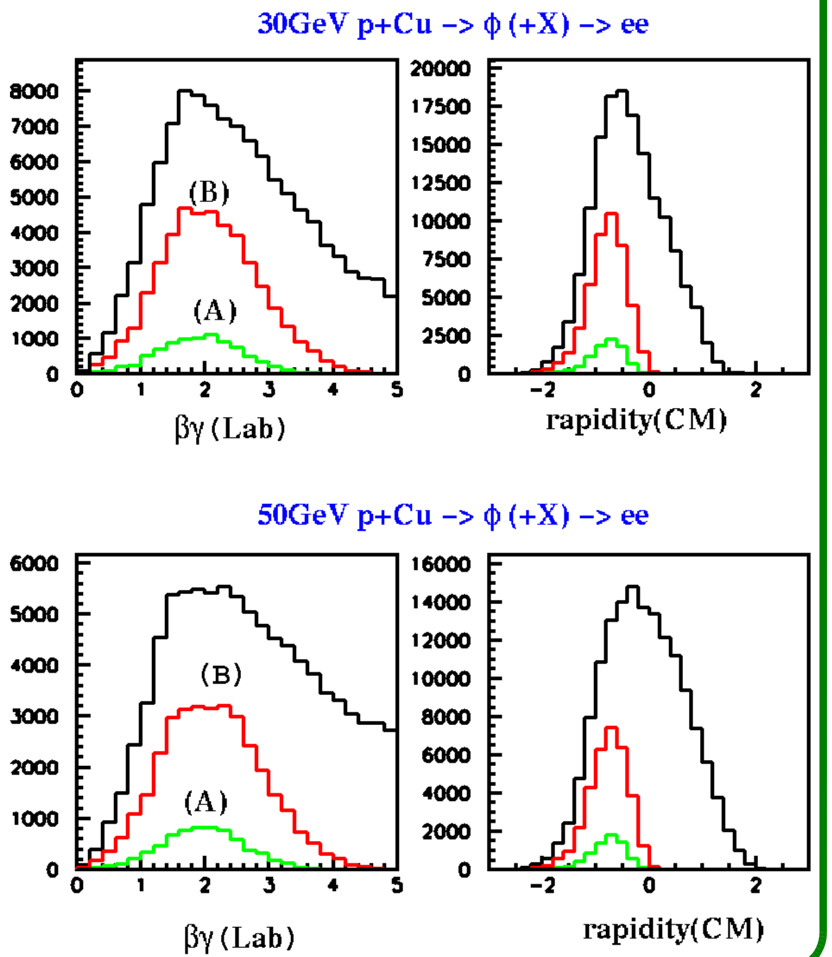
A) Reuse of E325 spectrometer

or

B) New larger acceptance spectrometer

(coverage : ±45° (vert.), ±12° ~132° (holi.))

spectrometer acceptance φ–>ee
(estimated by JAM)



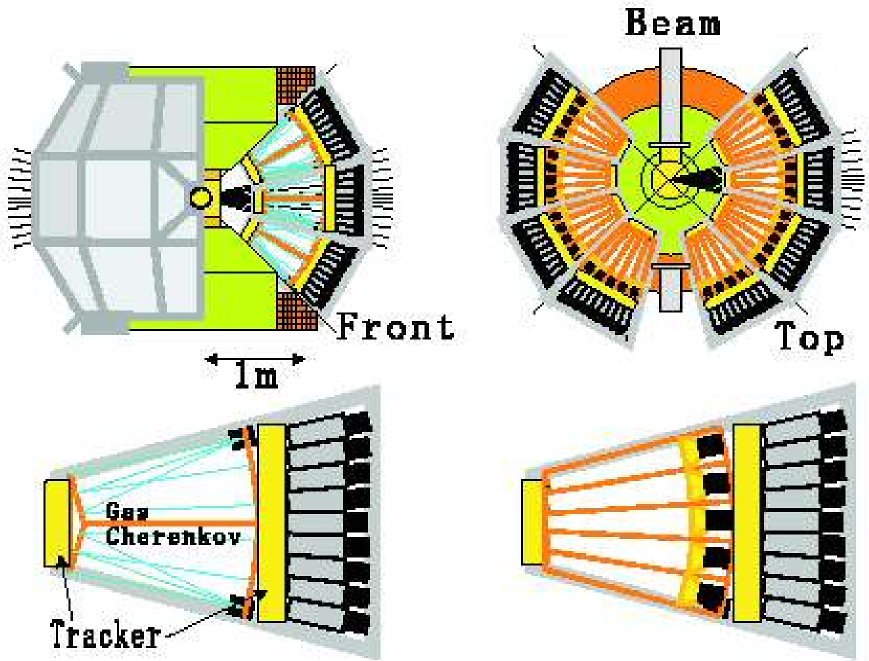
expected ϕ yield for two options(using JAM)

		12 GeV	30 GeV	50 GeV
beam energy		12 GeV	30 GeV	50 GeV
ϕ production CS (p+Cu)		1.0 mb	3.0 mb	5.1 mb
detector acceptance	case A	8.8%	6.0%	4.5%
	case B	45%	31%	23%
normalized yield by E325	case A	1	2.0	2.6
	case B	5.1	10.0	12.7

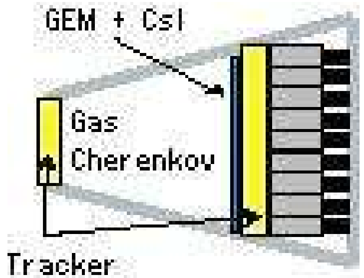
Further, for 10 times higher intensity beam (10^{10})
(i.e. high interaction rate : 10MHz)
to collect higher statistics (100 times of E325 =10^5 φ), (B) is needed

Proposed New spectrometer

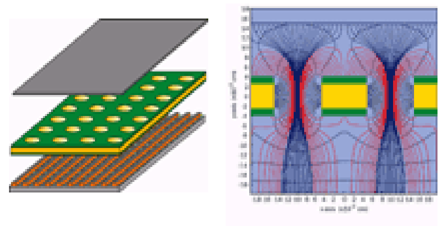
- Cover the large acceptance
  - ±45° (vert.), ±12° ~132° (holi.)
- Tracking Device
  - Drift Chamber
  - GEM(Gas electron multiplier)
- Two-stage Electron ID
  - Gas Cherenkov
    - PMT+2 mirrors
    - GEM+CsI photocathode
  - Leadglass EMC
- ~30K Readout Channels (in 20 units)
  - E325: 3.6K, PHENIX:~300K
- Cost : ~$5M (including $2M electronics)



Schematic view of spectrometer

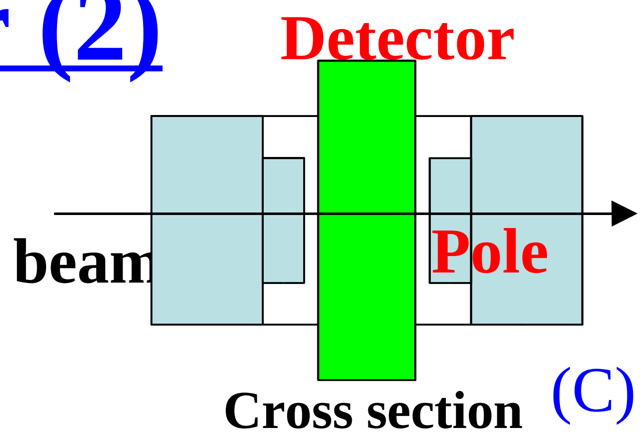


segment w/GEM

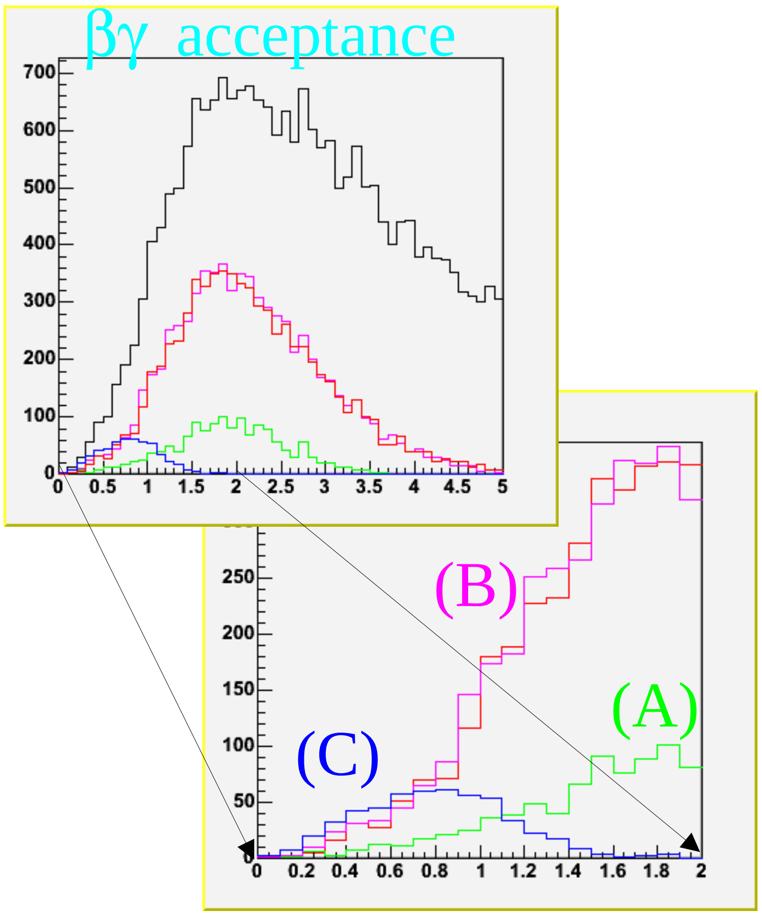


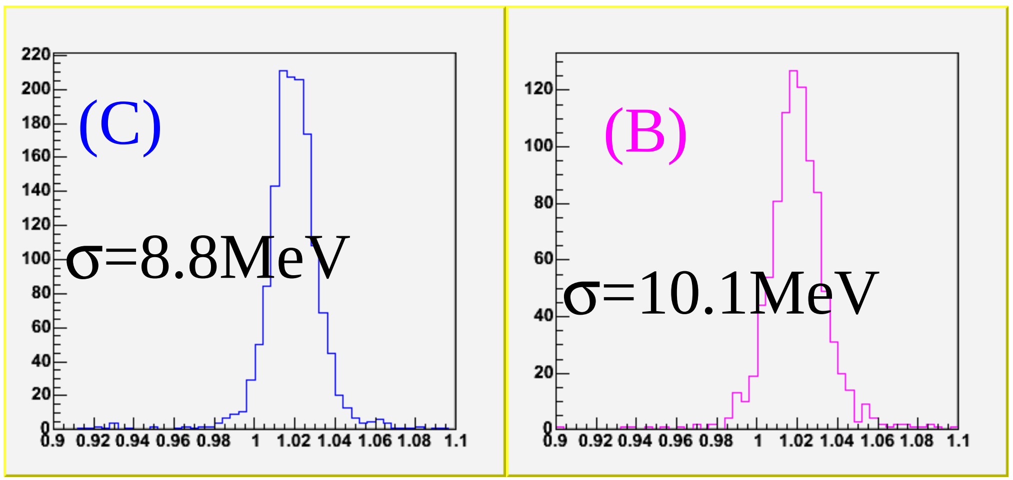
GEM

Proposed New spectrometer (2)



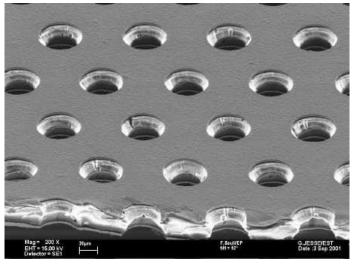
- Focus to the very backward region:(option C)
  - rotate the spectrometer (B) with 90 degree
  - 2π acceptance
  - acceptance is 2 times as E325(A) in βγ<1.25
  - can be operated in more higher rate?
    - operation capability with the dimuon experiment : 10^{12} ppp beam
- Mass resolutions are less than ~10 MeV/c^2 in the simulation





Detector R&D item

- Environment with primary beam (10^9~10^{10} ppp)
  - high interaction rate (1~10MHz)
  - beam halo is origin of trigger background & saturation of forward detector
- Tracker should cope with high beam / interaction rate
  - GEM tracker in forward region : works 10KHz/mm^2

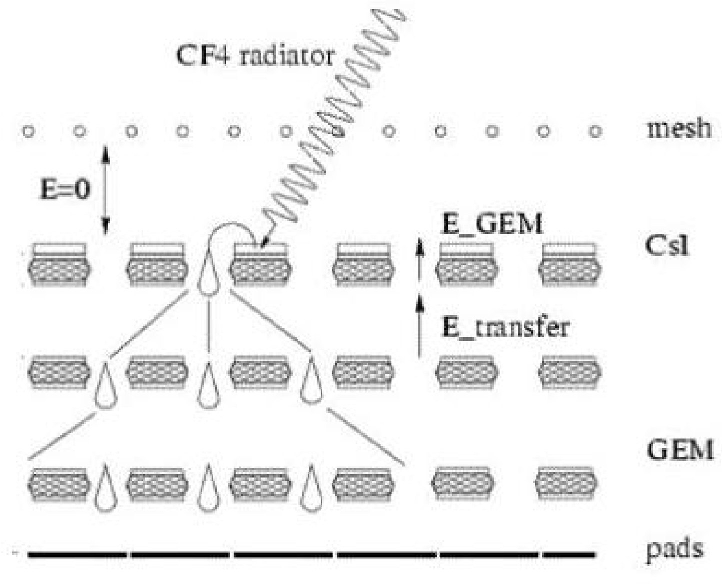


GEM

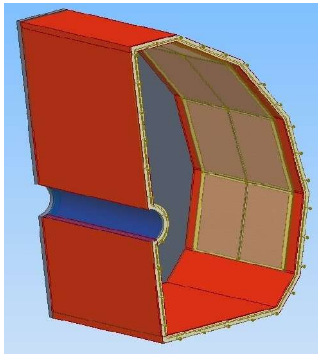
- Electron ID : 10^{-4} π rejection
  - lead glass EMC (recycled from TRISTAN) : < 10^{-1}
  - Gas Cherenkov : ~ 10^{-3}
  - HBD (Hadron Blind Detector)
    - GC with GEM/CsI photocathode & pad readout / CF_4 radiator/amplification gas
    - No mirror, No segment, No window : No photon loss with reflection efficiency
    - Flexible trigger capability

HBD (Hadron Blind Detector)

- HBD : Thr. type Gas Cherenkov Counter
  - CsI photocathode : UV photon sensitive
  - Triple GEM with pad readout
    - low granularity/low gain
  - Ionized electrons are collected by mesh
    - photoelectrons are amplified by 3 stages
    - ionized electrons are amp. by only last 2 stages
    - -> can detect only particles with cherenkov photon.
- Joint project with Weitzman Institute
  - originally for PHENIX upgrade plan
  - GEM with CsI
- Beam Test was done in 2004 at KEK-PS
  - NIM A 546(2005)466



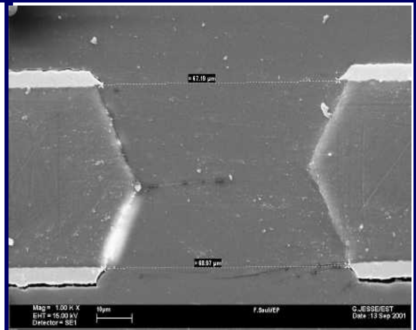
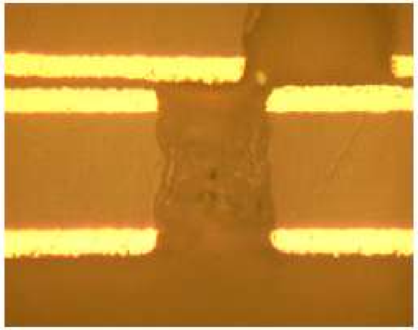
Concept of HBD

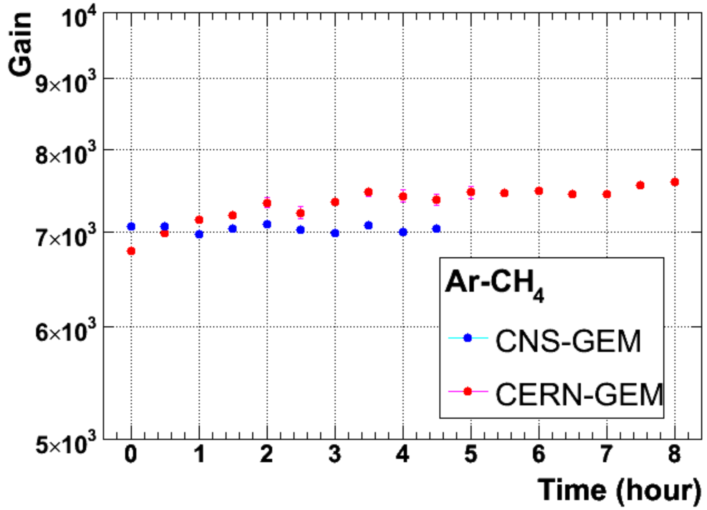


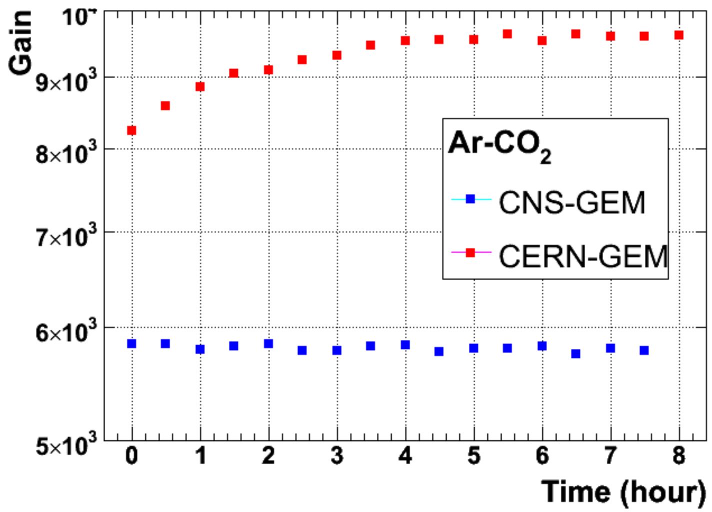
Proposed structure for PHENIX HBD

Development of GEM in CNS, U-Tokyo

We succeeded in fabricating a new type of GEM (CNS-GEM) using a dry etching method.

	CERN-GEM	CNS-GEM
Etching method	**wet** etching	**dry** etching
The cross section of a hole	 **double-conical** shape	 **cylindrical** shape





- Gain stability of CNS-GEM is better than that of CERN-GEM.
  - The shape of holes of GEM significantly affect gain stability.
  - stability for more longer time range (~1week) is also under study

Summary (2)

- Vector meson measurements in e^+e^- channel at J-PARC
  - use primary proton beam ($1x10^9$ ~$1x10^{10}$ /sec) on thin targets (~0.1% int.length) to reduce electron background
  - especially collect 10^4 ~10^5 $\phi \rightarrow e^+e^-$ in p+A reaction in 100 shift (~5weeks) operation
    - 10 ~100 times as large as E325's statistics
- New spectrometer using new technology (GEM tracker/HBD)
  - mass resolution : less than 10 MeV/c^2
  - larger incident energy/larger acceptance → 10 times larger statistics.
  - higher rate capability → more 10 times stat. using higher intensity beam
- Prototype Detector with new technology is being developed.
  - GEM made in Japan works well
  - CsI photocathord & CF_4 operation are next hurdle in Japan