

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

Satoshi Yokkaichi , RIKEN

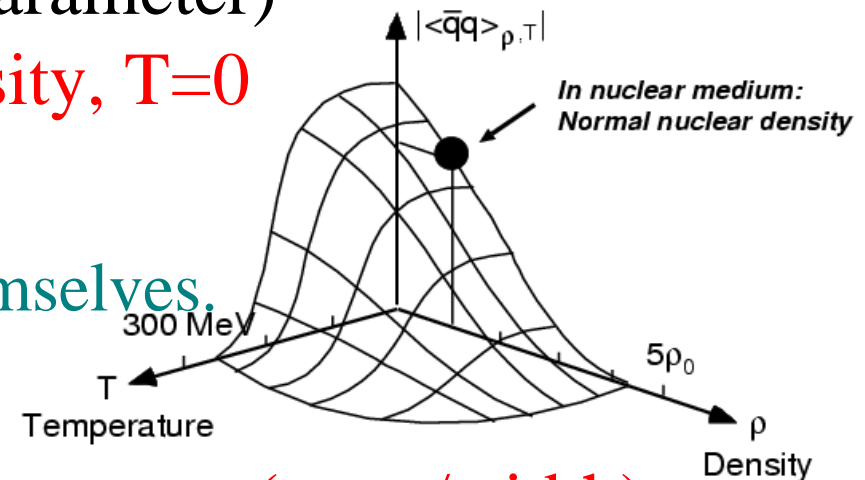
&

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 : $\phi \rightarrow e^+e^-$ 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)
 - $\sim 2/3$ 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), Klinge, Keiser & Weise ('97), Muroya, Nakamura & Nonaka('03), etc.



Hatsuda and Lee, 92,96
linear dependence on density

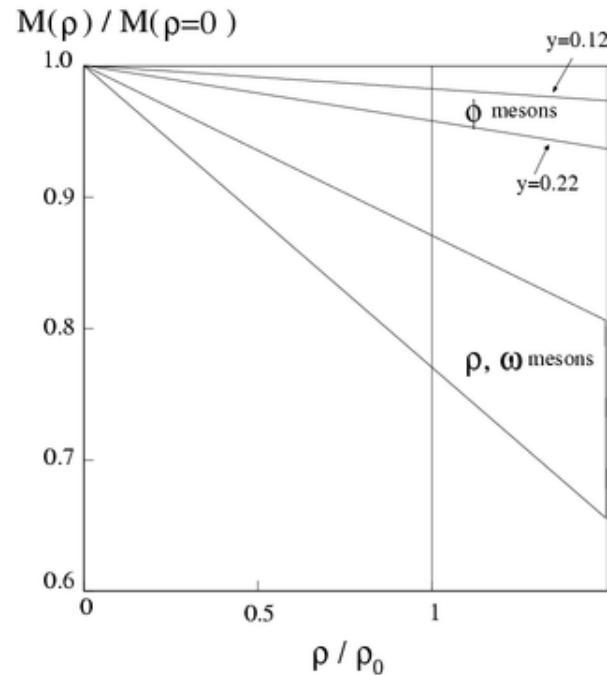
$$m^*/m_0 = 1 - k \rho/\rho_0$$

mass decreasing

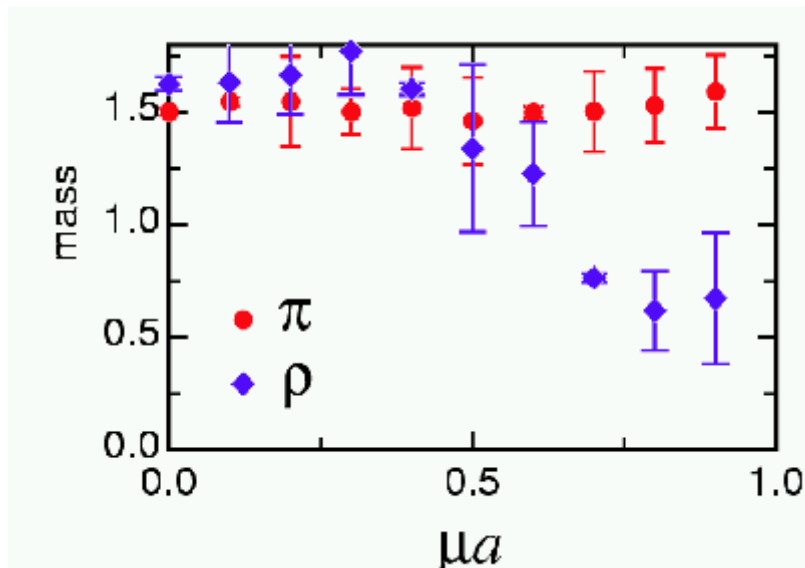
- 16(\pm 6)% for ρ/ω

- 0.15(\pm 0.05)*y
=2~4% for ϕ
(for y=0.22)

at the normal nuclear density

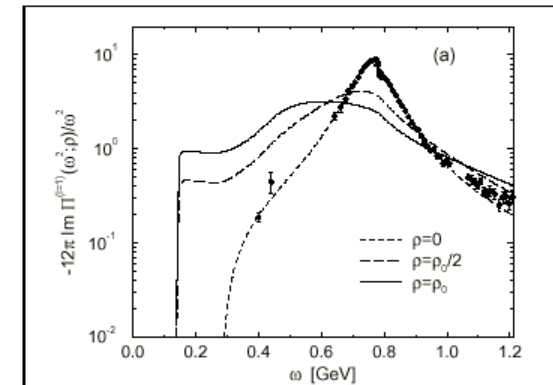


Muroya, Nakamura, Nonaka, 03

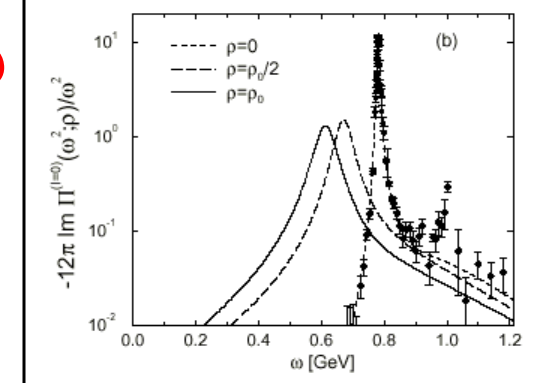


Klinge, Keiser, Weise, 97

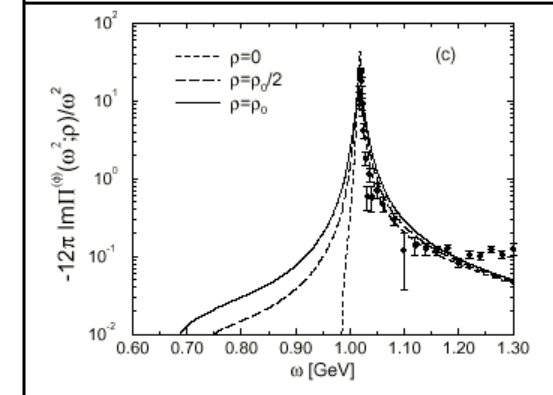
ρ



ω

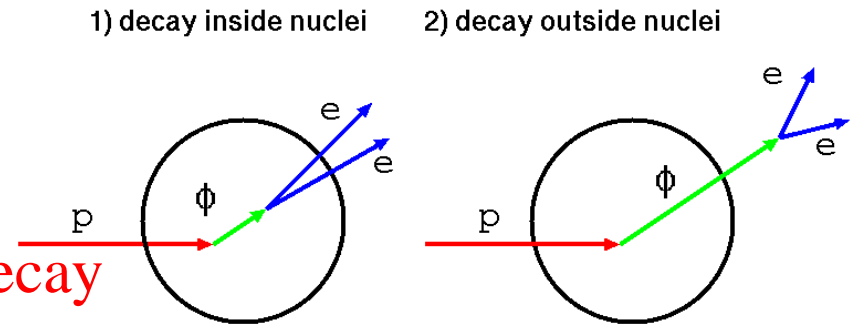


ϕ



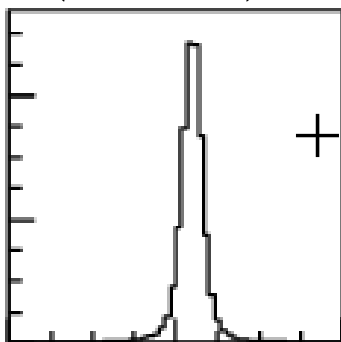
Expected Inv. e^+e^- mass spectra in p+A

- 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

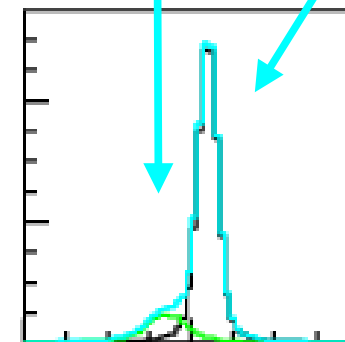
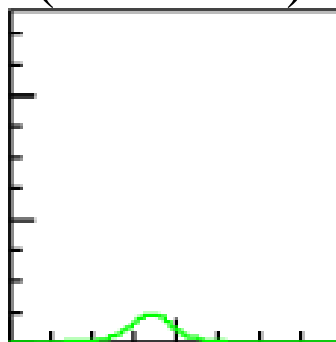


longer-life meson (ω ($\Gamma=8.4\text{MeV} \sim 24\text{ fm}$) & ϕ ($\Gamma=4.3\text{MeV} \sim 46\text{ fm}$)) cases :

outside decay
(natural)



inside decay
(modified)



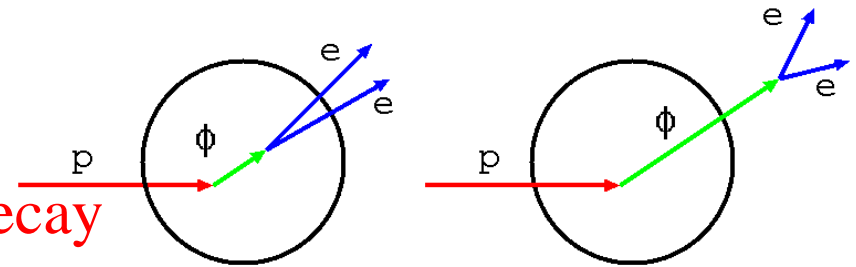
expected
to be observed

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

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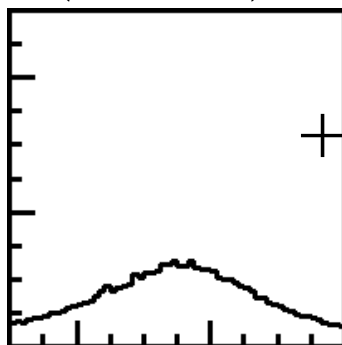
1) decay inside nuclei

2) decay outside nuclei

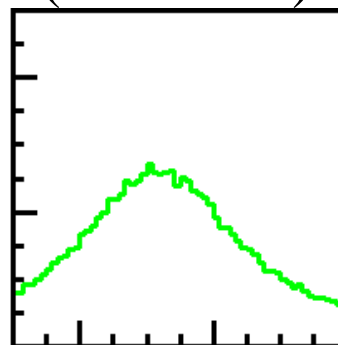


shorter-life meson(ρ : $\Gamma=150\text{MeV} \sim 1.3\text{fm}$) cases

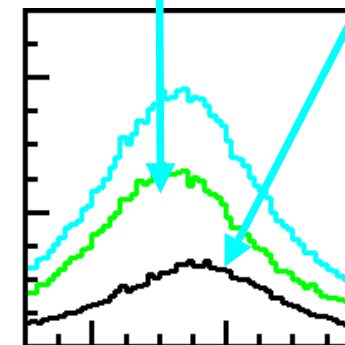
outside decay
(natural)



inside decay
(modified)



=



expected
to be observed

Experiment KEK-PS E325

- $12\text{GeV } p+A \rightarrow \rho/\omega/\phi + X$ ($\rho/\omega/\phi \rightarrow e^+e^-$, $\phi \rightarrow K^+K^-$)
- 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 **$10^6\text{Hz interaction}$**)
 - 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.)

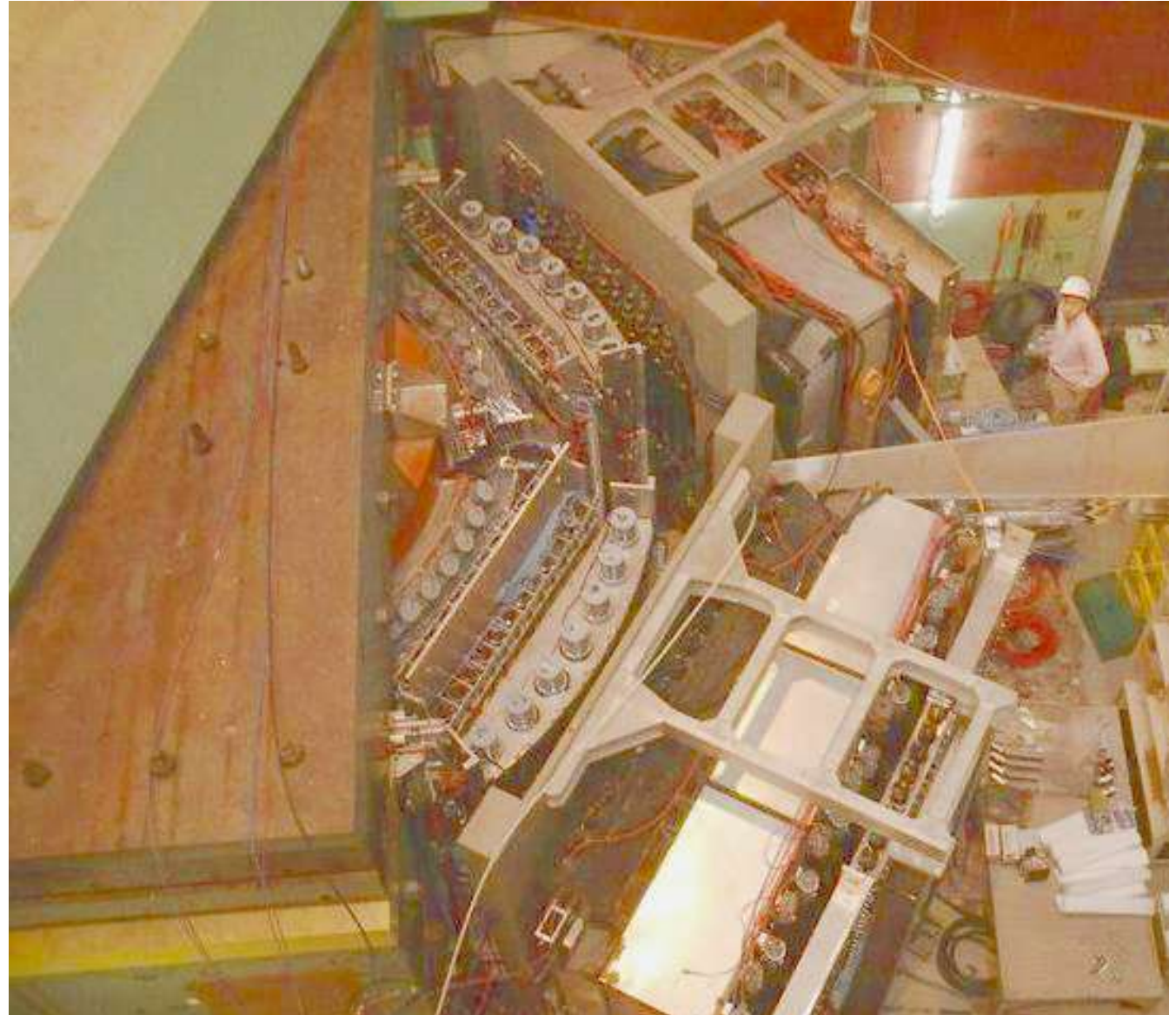
(Cont'd)

- 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

schematic plan view of spectrometer

- **Spectrometer Magnet**

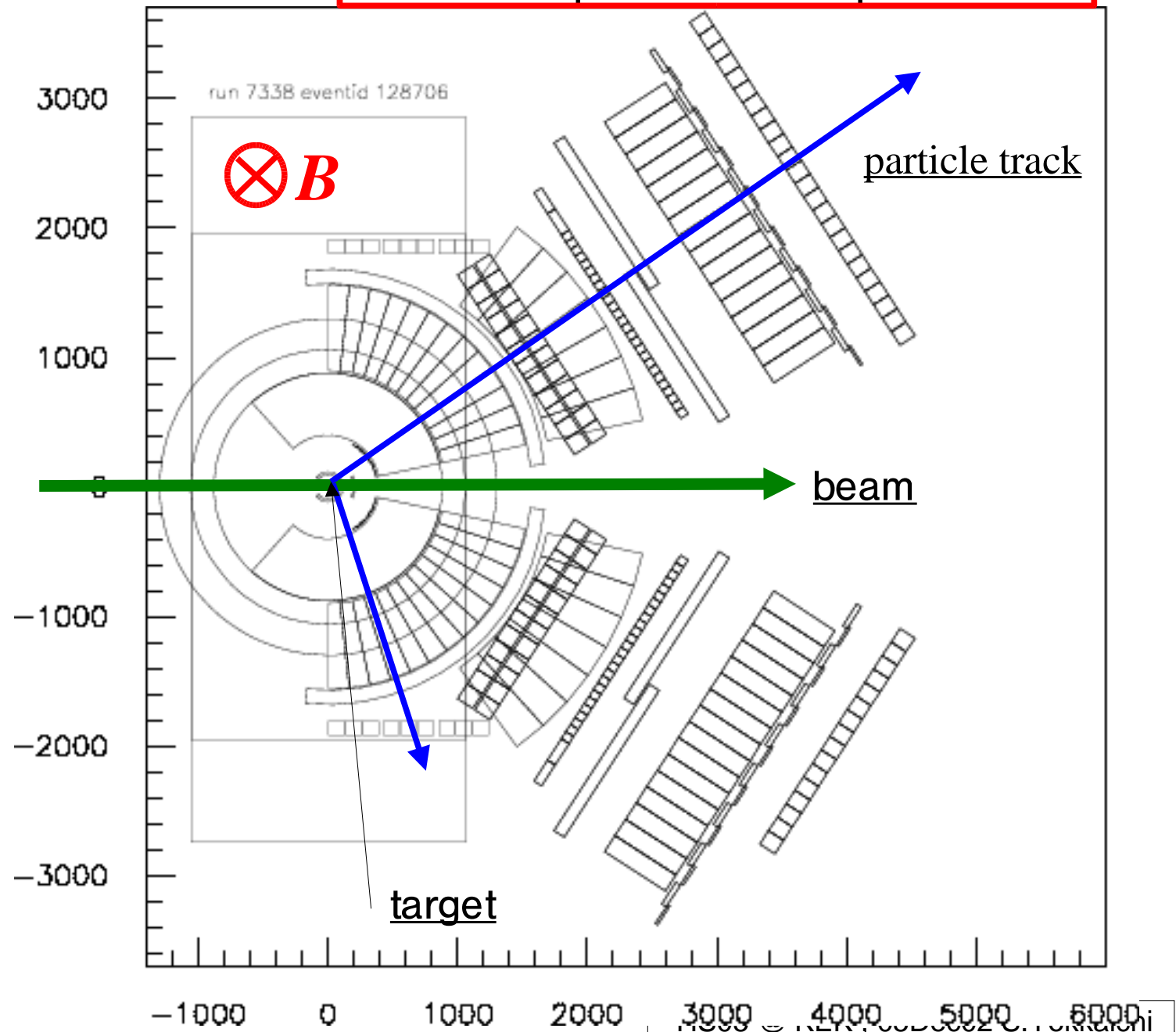
- 0.71T at the center
- 0.81Tm in integral

- **Targets**

- at the center of the Magnet
- C & Cu are used typically
- very thin: $\sim 0.1\%$ interaction length

- **Primary proton beam**

- 12.9 GeV/c
- $\sim 1 \times 10^9$ in 2sec duration, 4sec cycle



Experimental setup - Detectors

Electron ID counters

Gas Cherenkov &
Lead Glass EMC

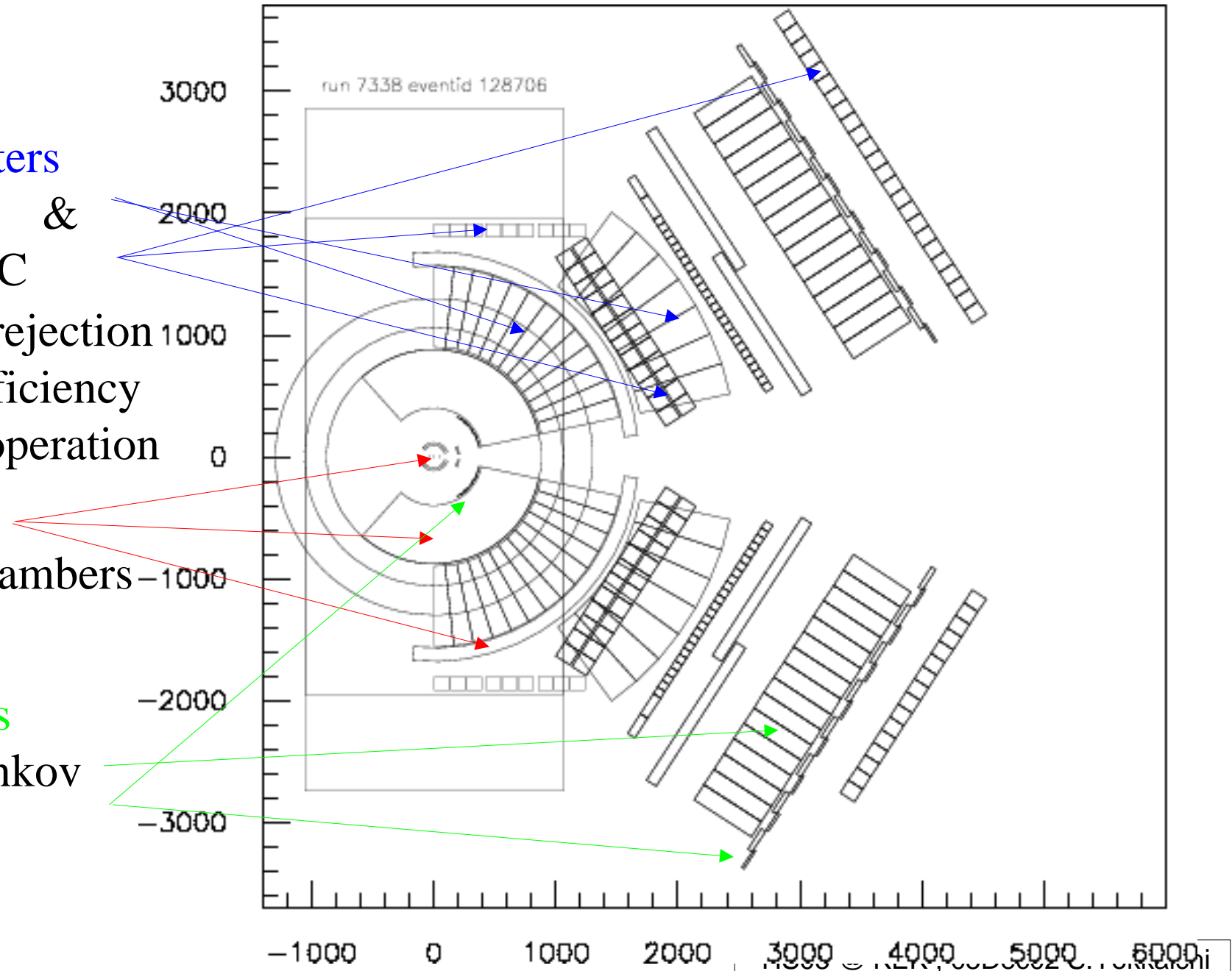
total 3×10^{-4} π rejection
with 78% e efficiency
in two-stage operation

Tracker

Three Drift Chambers

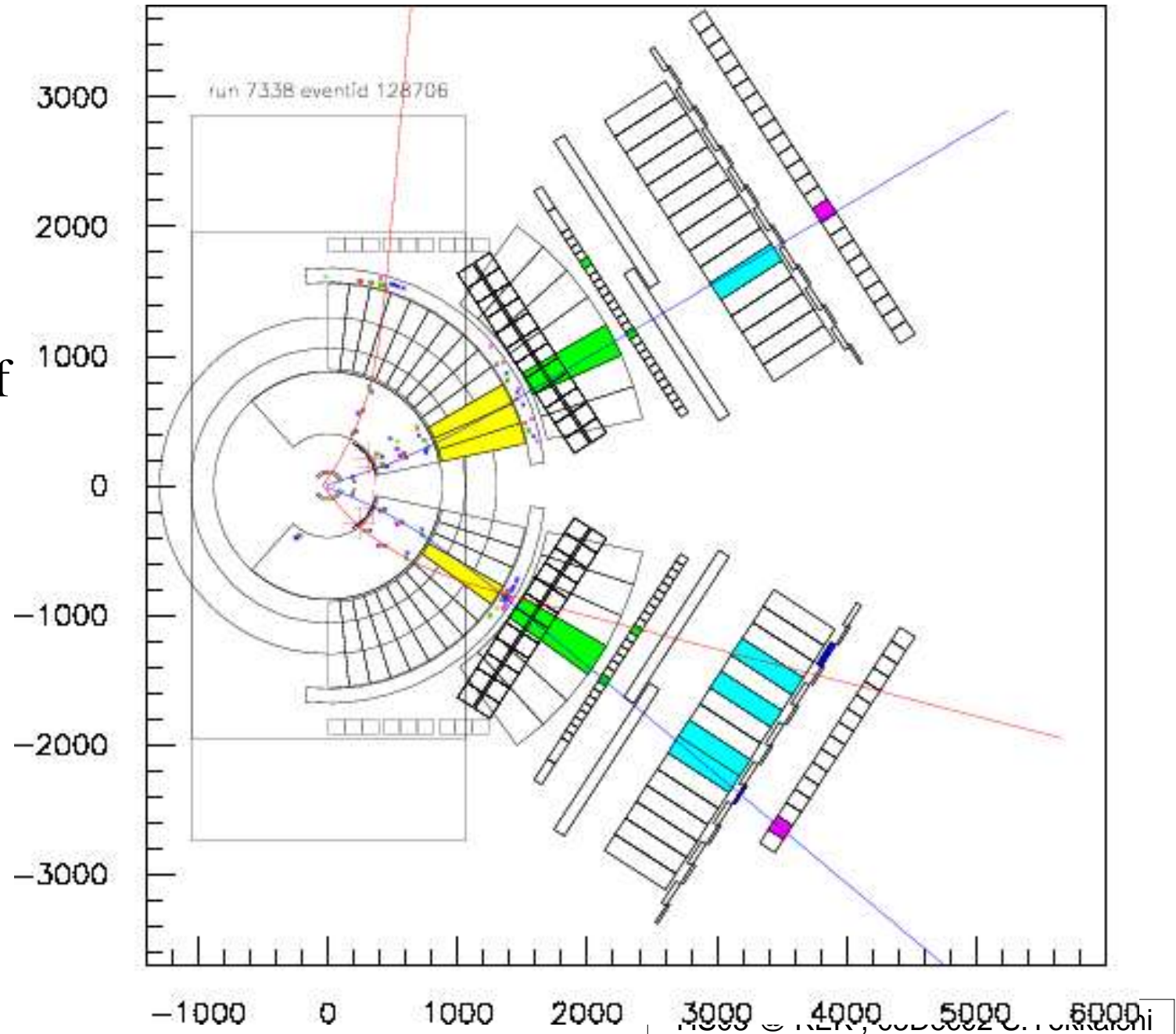
Kaon ID counters

Aerogel Cherenkov
& TOF



- Typical e^+e^- Event

- blue:electron
- red : other
- invariant mass of electron pair is calculated



Vector meson measurements in the world

dilepton measurement

- **HELIOS** (ee, $\mu\mu$) 450GeV p+Be / 200GeV A+A
 - **CERES** (ee) 450GeV p+Be/Au / 40-200GeV A+A
 - **E325** (ee, KK) 12GeV p+C/Cu
 - **NA60** ($\mu\mu$) 400GeV p+A/158GeV In+In
 - **PHENIX** (ee, KK) p+p/Au+Au
 - **HADES** (ee) 4.5GeV p+A/ 1-2GeV A+A
 - **CLAS** (ee) 1~2 GeV γ +A
 - **J-PARC** (ee) 30/50GeV p+A/ ~20GeV A+A
 - **CBM/FAIR**(ee) 20~30GeV A+A
-
- **TAGX** ($\pi\pi$) ~1 GeV γ +A
 - **STAR** ($\pi\pi$, KK) p+p/Au+Au
 - **LEPS** (KK) 1.5~2.4 GeV γ +A
 - **CBELSA** ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb

already state 'modified'
running/in analysis
future plan

Result (1)

ee invariant mass spectra

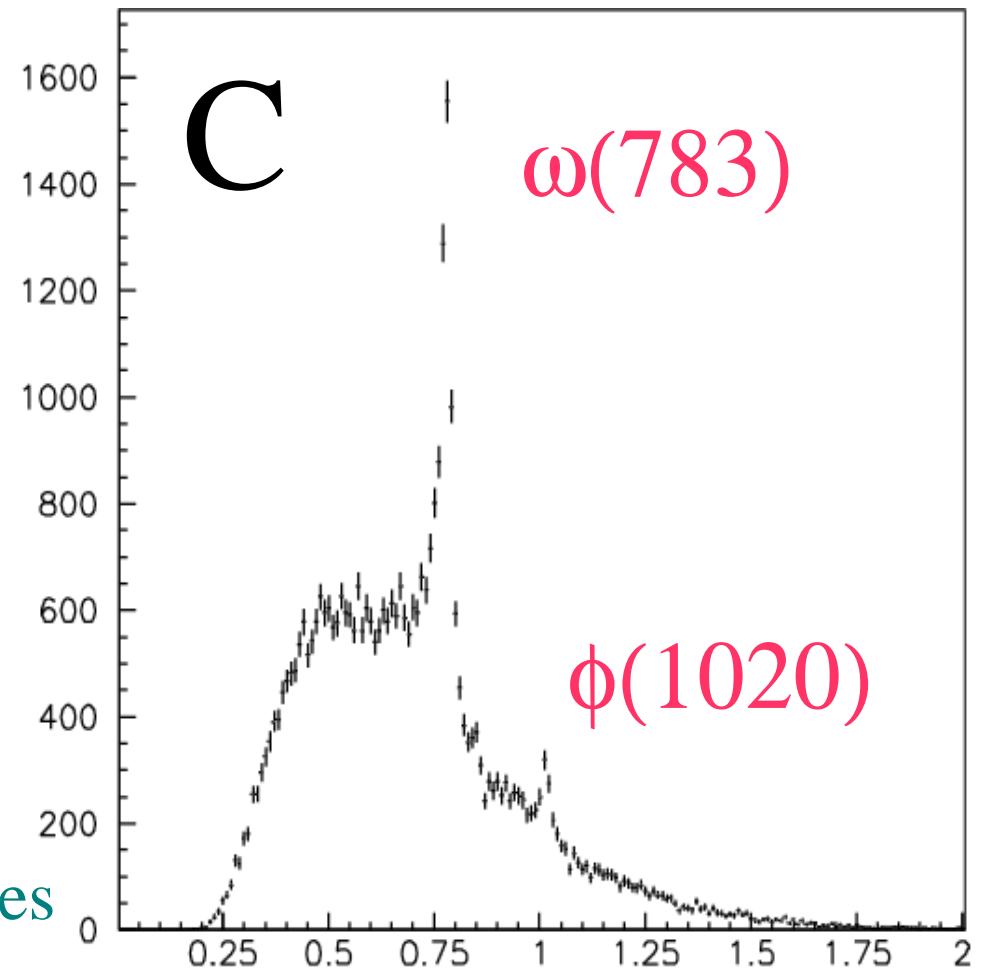
M. Naruki et al.,

nucl-ex/050416

Observed e^+e^- invariant mass spectra

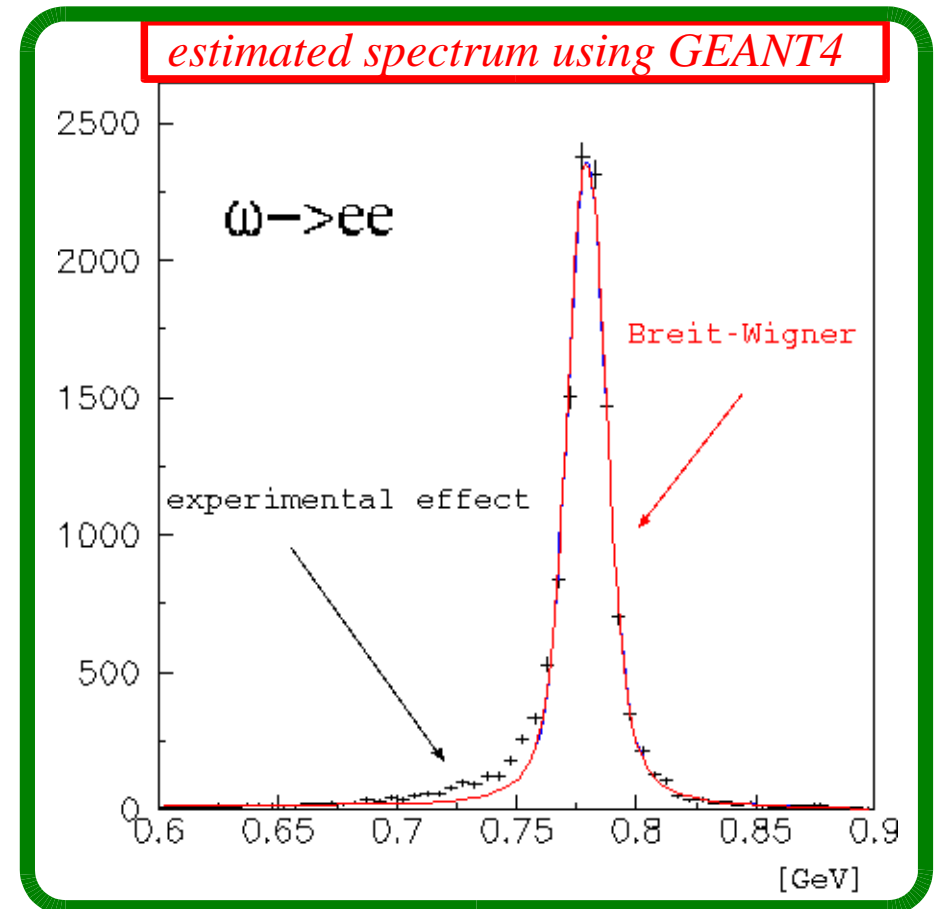
- from 2002 run data ($\sim 70\%$ of total data)
- C & Cu target
- clear resonance peaks
- $m < 0.2$ GeV is suppressed by detector acceptance
- acceptance uncorrected

→ fit the spectra with known sources

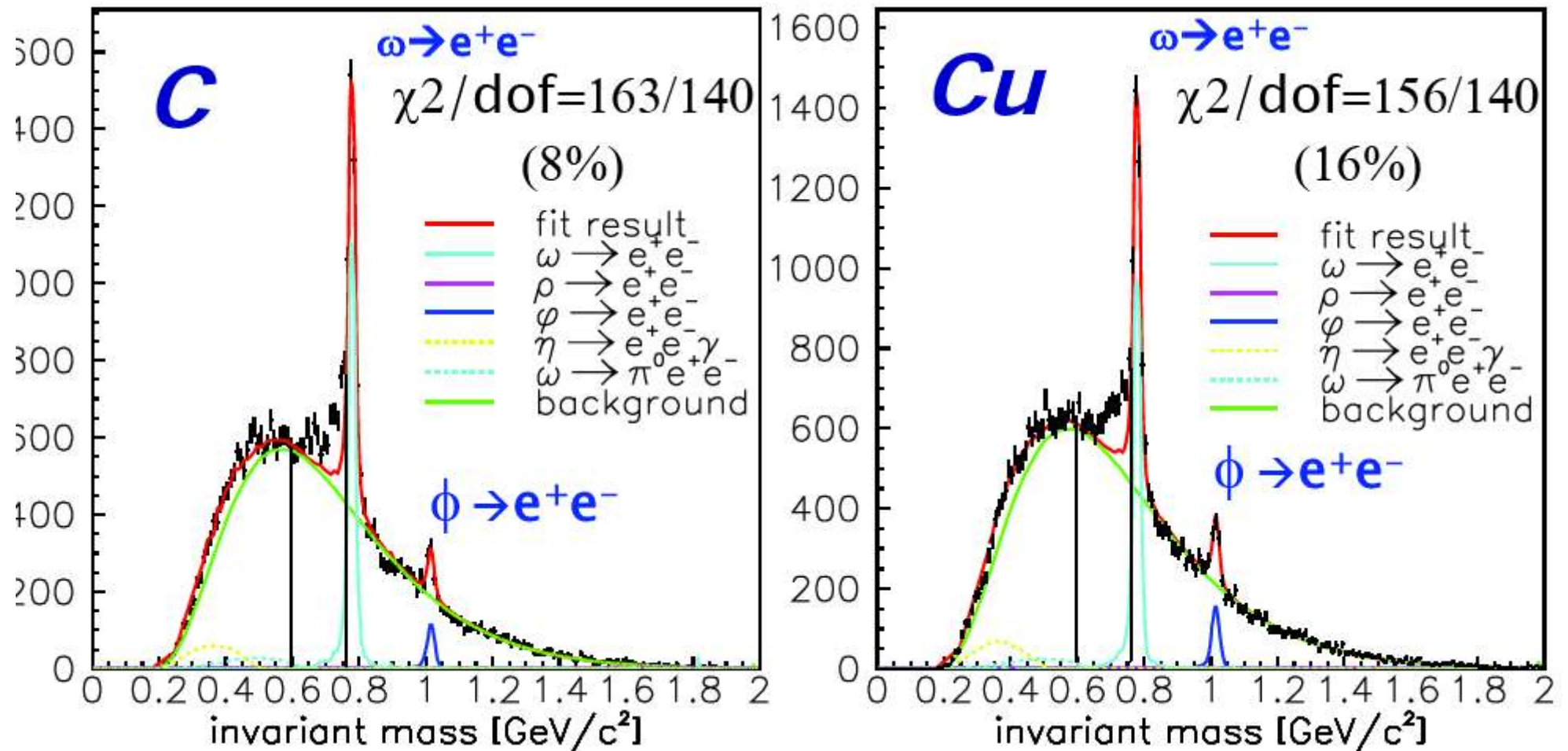


Fitting with known sources

- Hadronic sources of e^+e^- :
 - $\rho/\omega/\phi \rightarrow e^+e^-$, $\omega \rightarrow \pi^0 e^+e^-$,
 $\eta \rightarrow \gamma e^+e^-$
 - relativistic Breit-Wigner shape (without any modifications)
 - 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

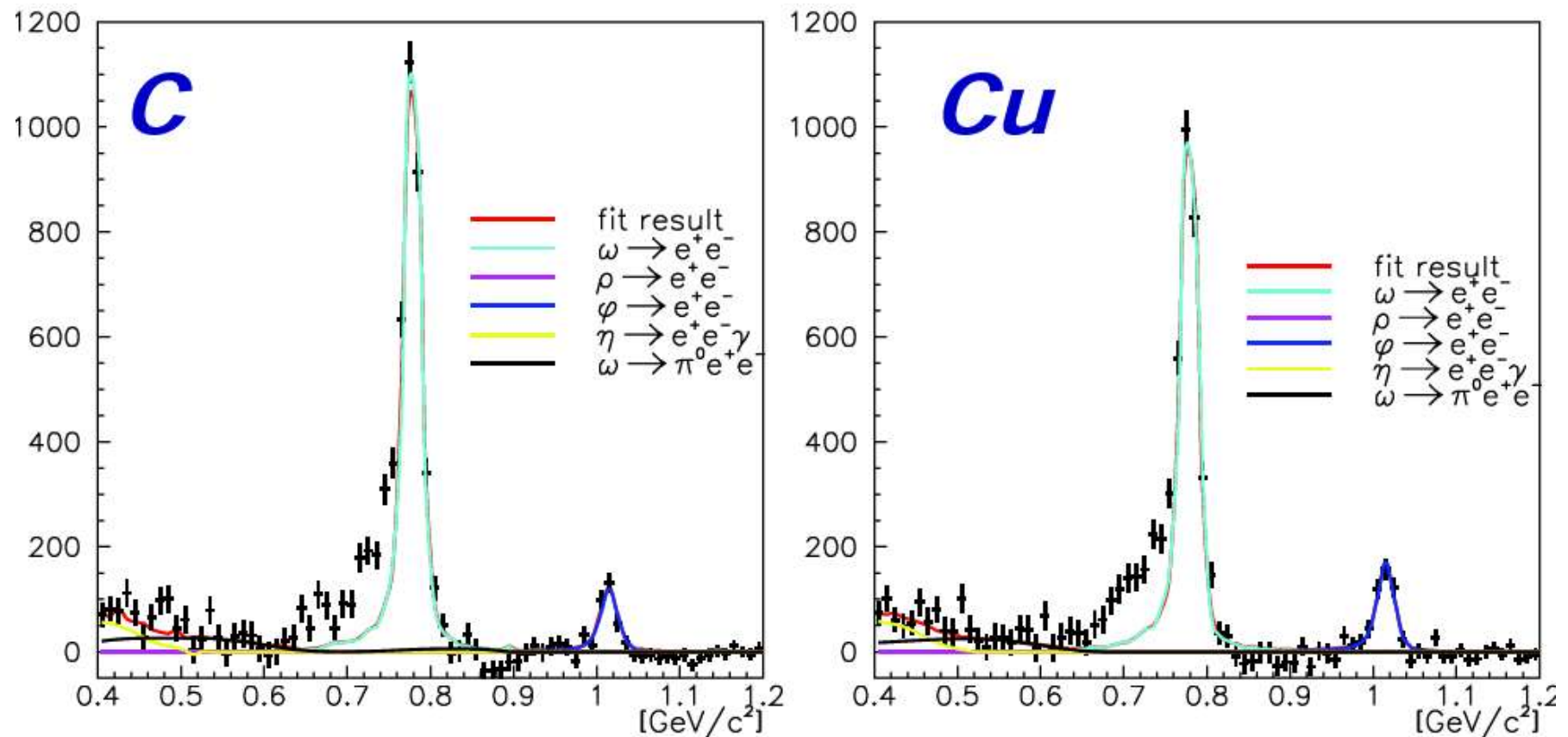


- 1) **excess** at the low-mass side of ω
 - To reproduce the data by the fitting, we have to exclude the excess region : 0.60~0.76 GeV
- 2) ρ -meson component seems to be **vanished** !

Fitting results (BKG subtracted)

$\rho/\omega < 0.15$ (for C),

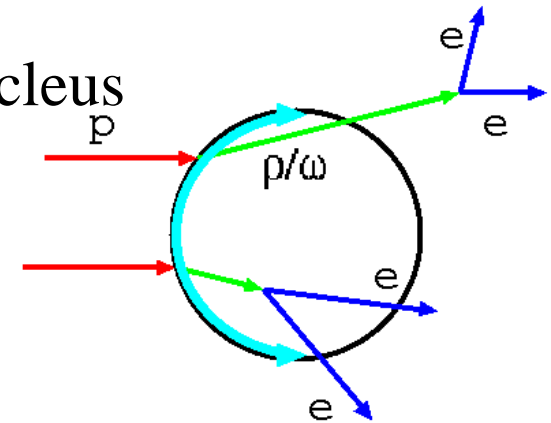
< 0.31 (for Cu)



- However, $\rho/\omega = 1.0 \pm 0.2$ in former experiment (p+p, 1974)
...suggests that the **origin of excess** is **modified ρ** mesons.

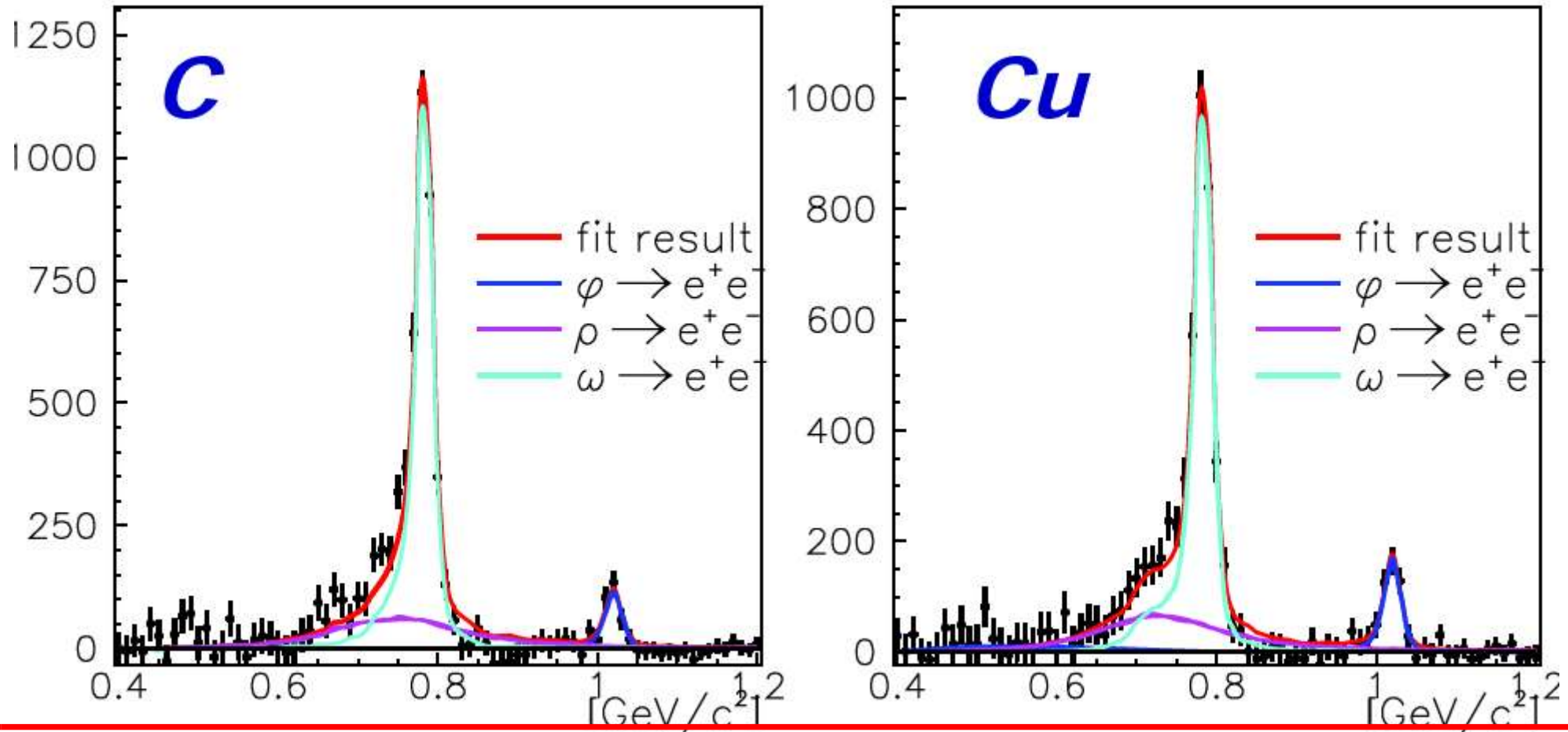
Toy model M.C. including modification

- 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
 - $\sim 0.8 \text{ GeV} < p < \sim 2.4 \text{ GeV}$ for ω
- nuclear density distribution : **Woods-Saxon** type
- modification form : $m^*/m_0 = 1 - k \rho/\rho_0$ for ρ & ω
 ($k=0.16 \pm 0.06$ 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 parameter k for ρ & ω is common for C & Cu

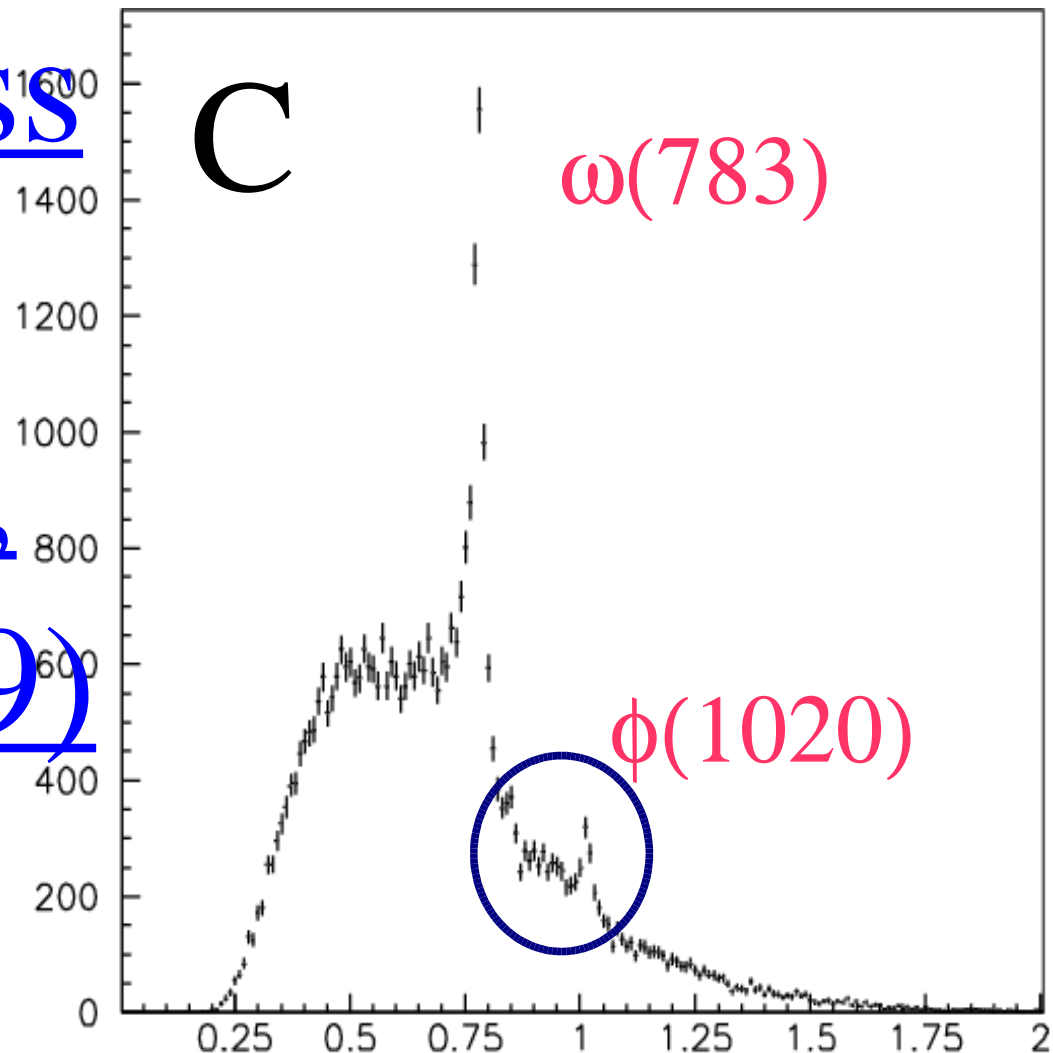


From the fit : $k=0.092 \pm 0.002$: $\sim 9\%$ reduced at normal nuclear density

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

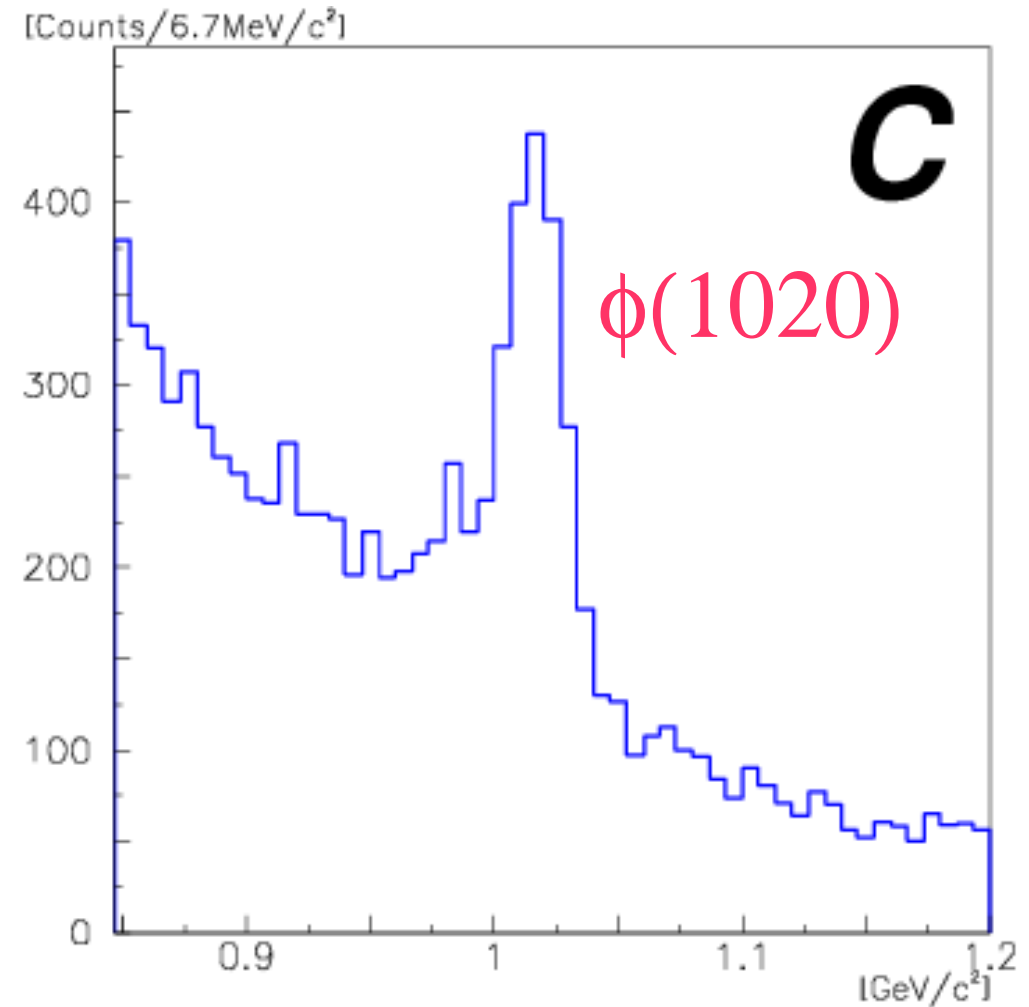
Result (2)

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



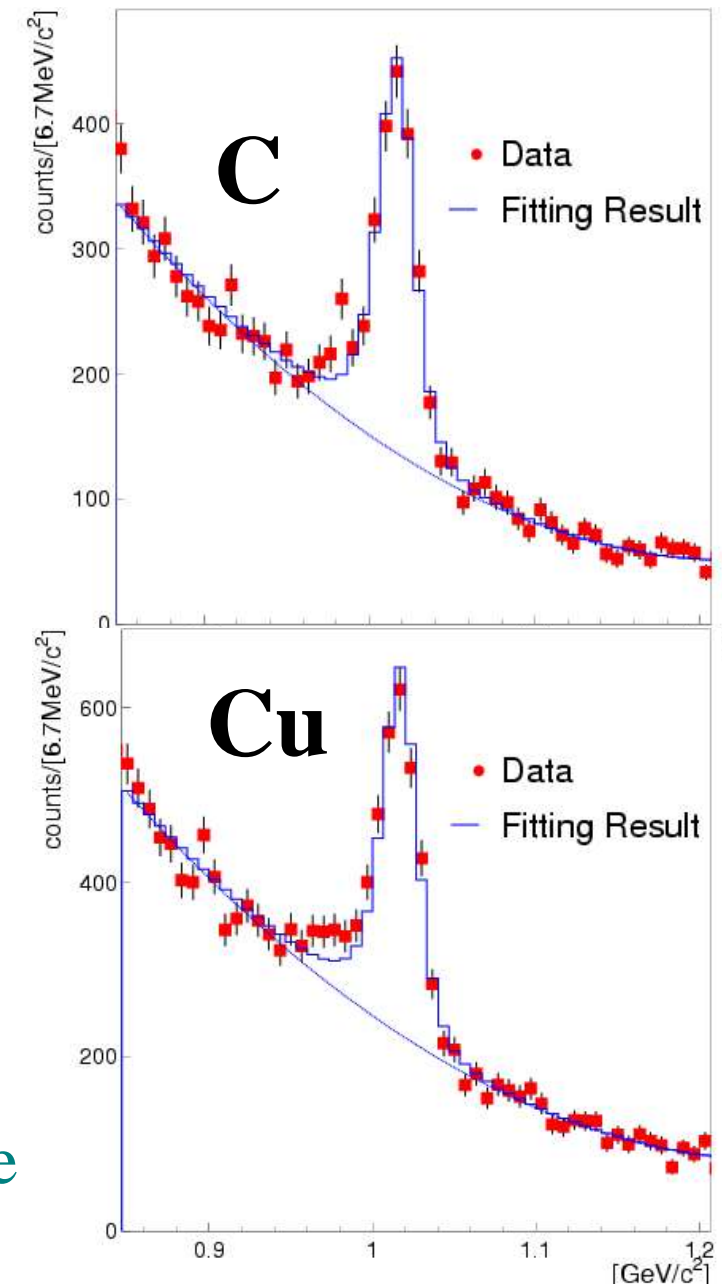
$\phi \rightarrow e^+e^-$ invariant mass spectra

- 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)
 - polynomial curve background



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

- from 2001/02 run data
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- acceptance uncorrected
- mass resolution : 10.7 MeV
- fit with
 - simulated mass shape of ϕ
 - (evaluated as same as ρ & ω)
 - polynomial curve background
- examine the 'excess' is significant or not.
 - \rightarrow see the $\beta\gamma$ dependence : excess could be enhanced for slowly moving mesons

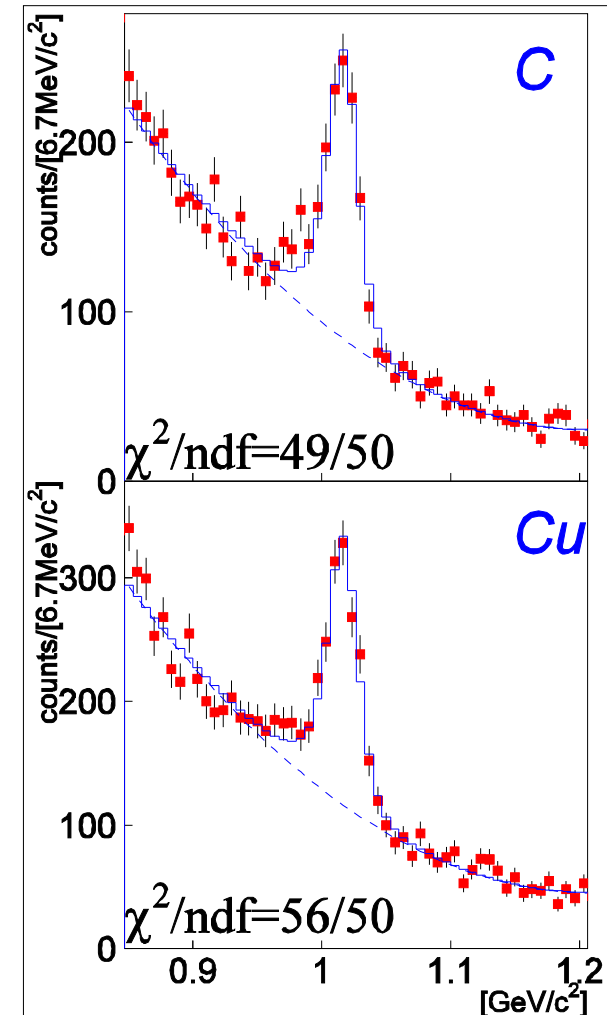
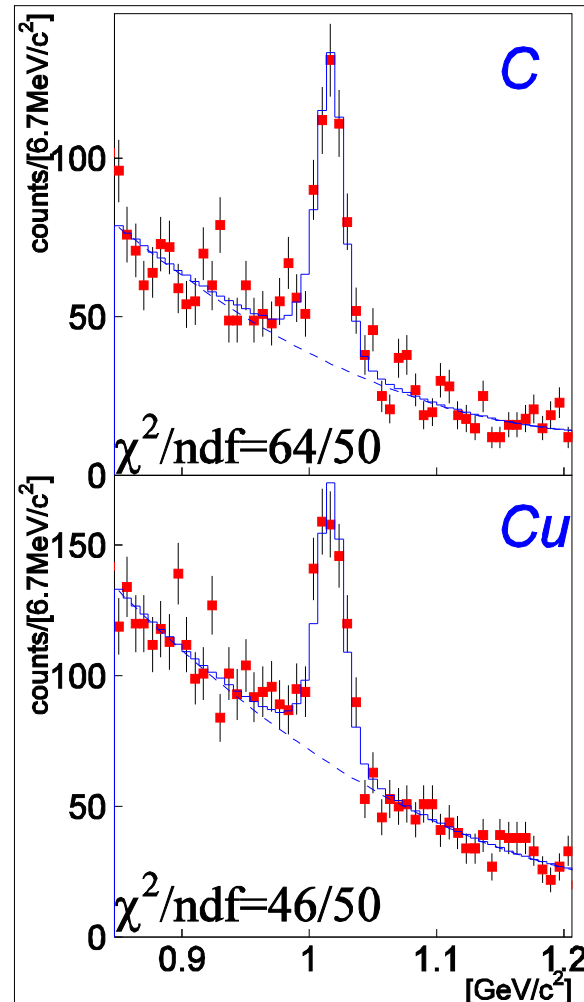
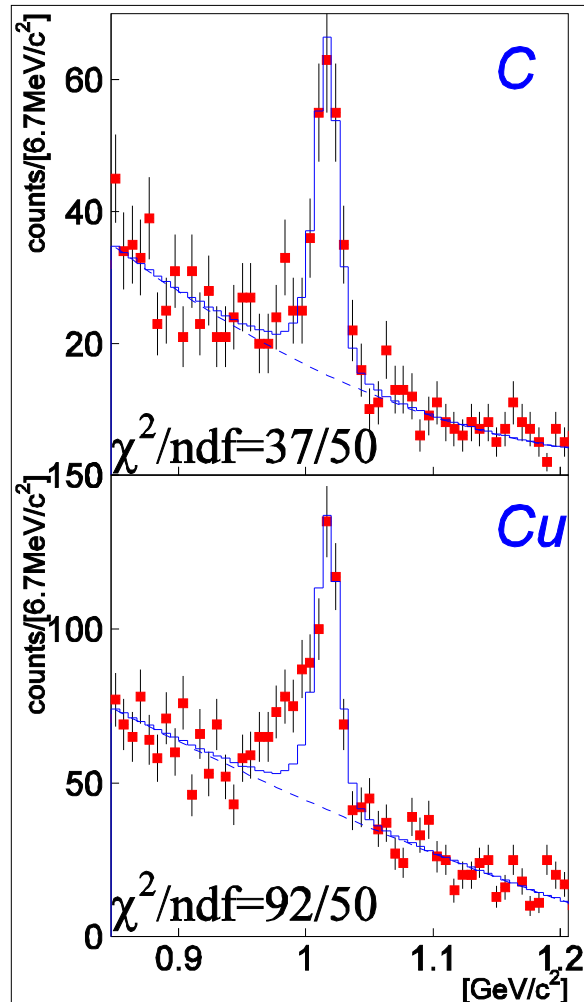


e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

$\beta\gamma < 1.25$ (Slow)

$1.25 < \beta\gamma < 1.75$

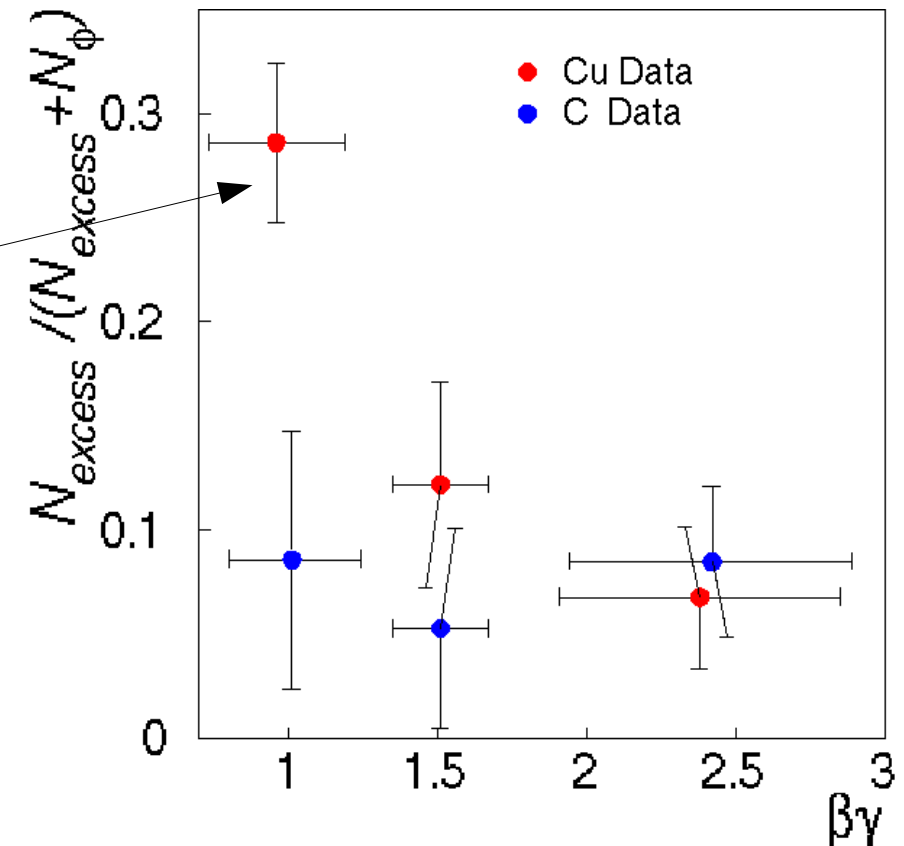
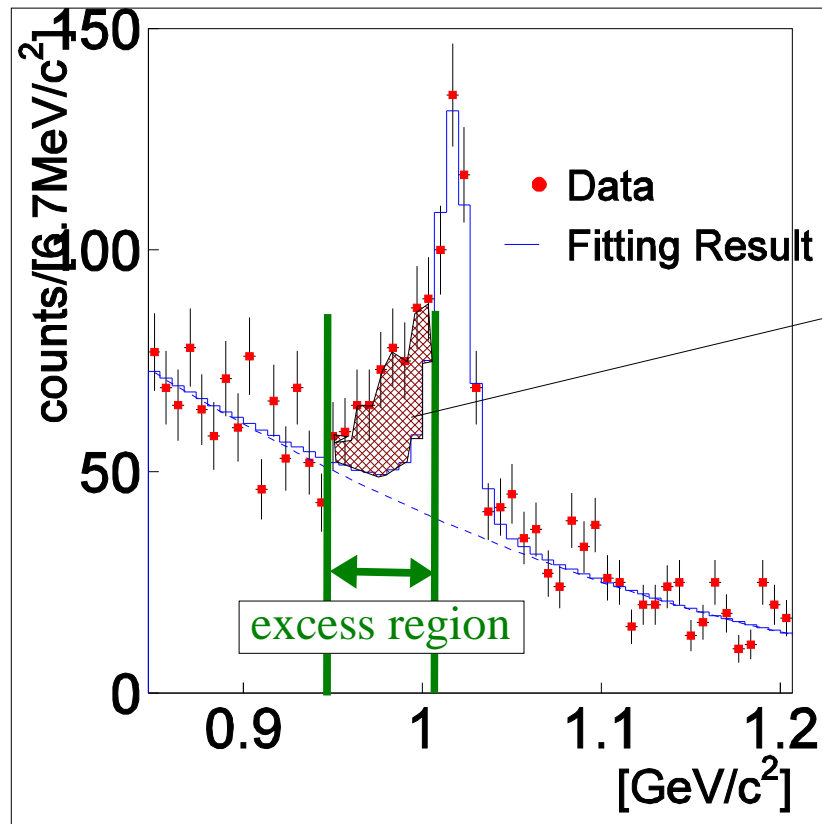
$1.75 < \beta\gamma$ (Fast)



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

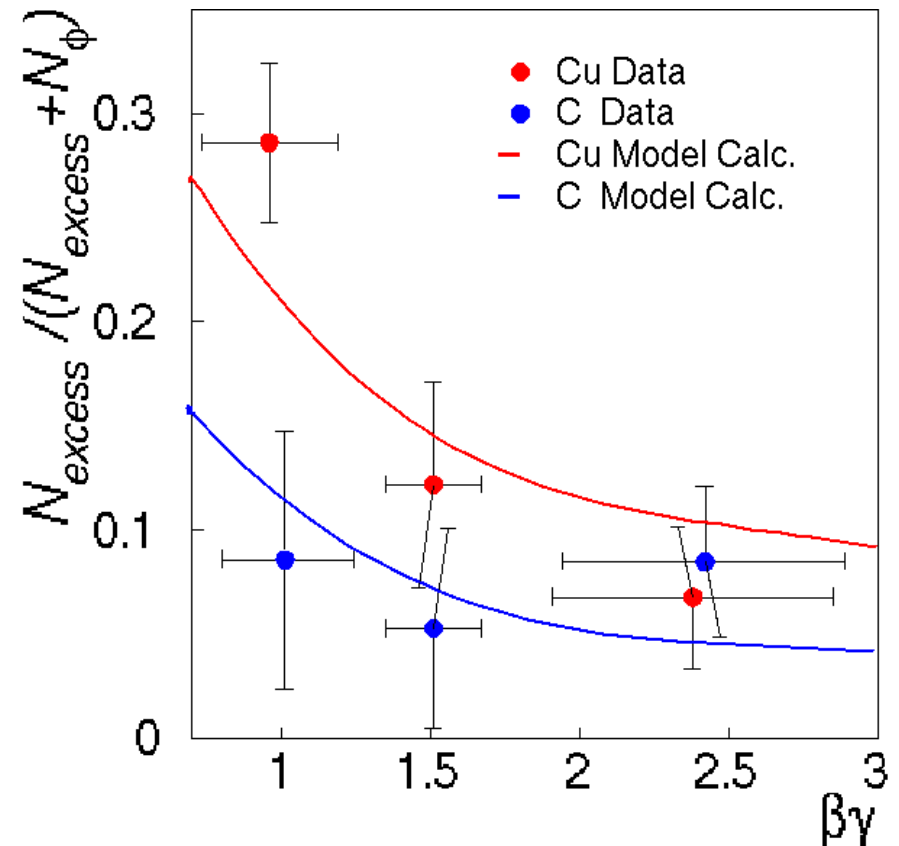
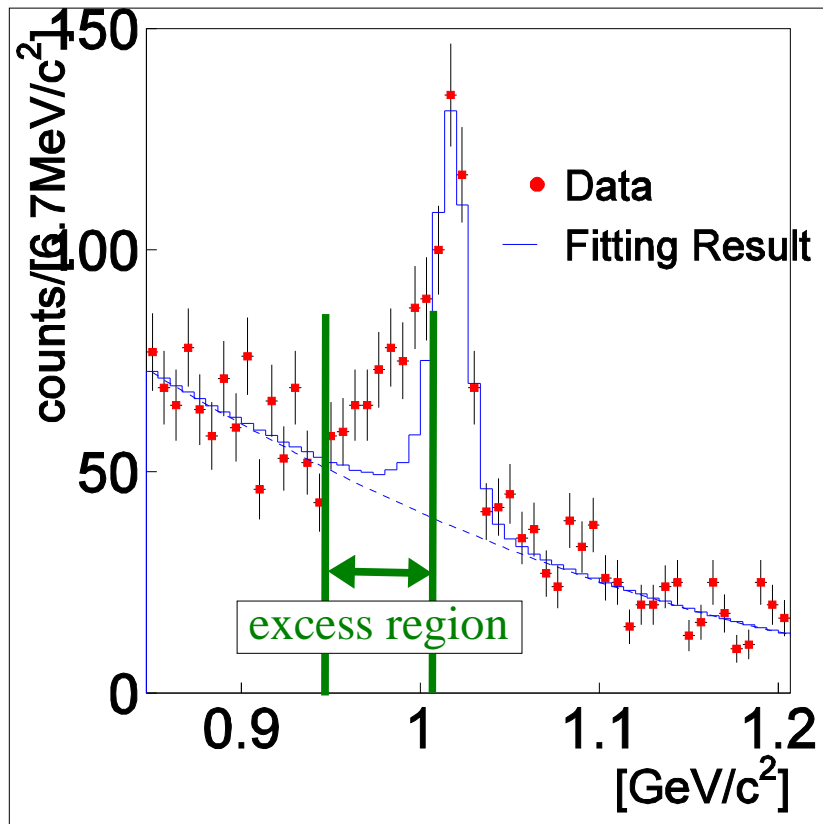
Amount of excess

- 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 $N_{\text{excess}} / (N_{\text{excess}} + N_{\phi})$



Toy model again for ϕ meson

- Toy model like ρ/ω case, except for

- uniformly made in nuclei

- measured α of ϕ production ~ 1

- $m^*/m_0 = 1 - k_1 \rho/\rho_0$

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

- To reproduce such amount of excess, linear-dependent **width broadening** is adopted :

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

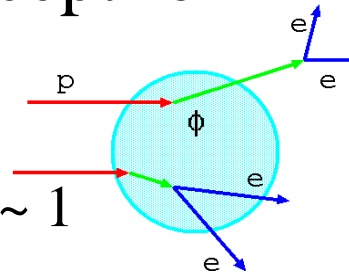
($k_2=10$, it means $\Gamma_{\text{tot}}^* \approx 47\text{MeV}$ at ρ_0)

(predicted value by Klingl *et al.*, '98)

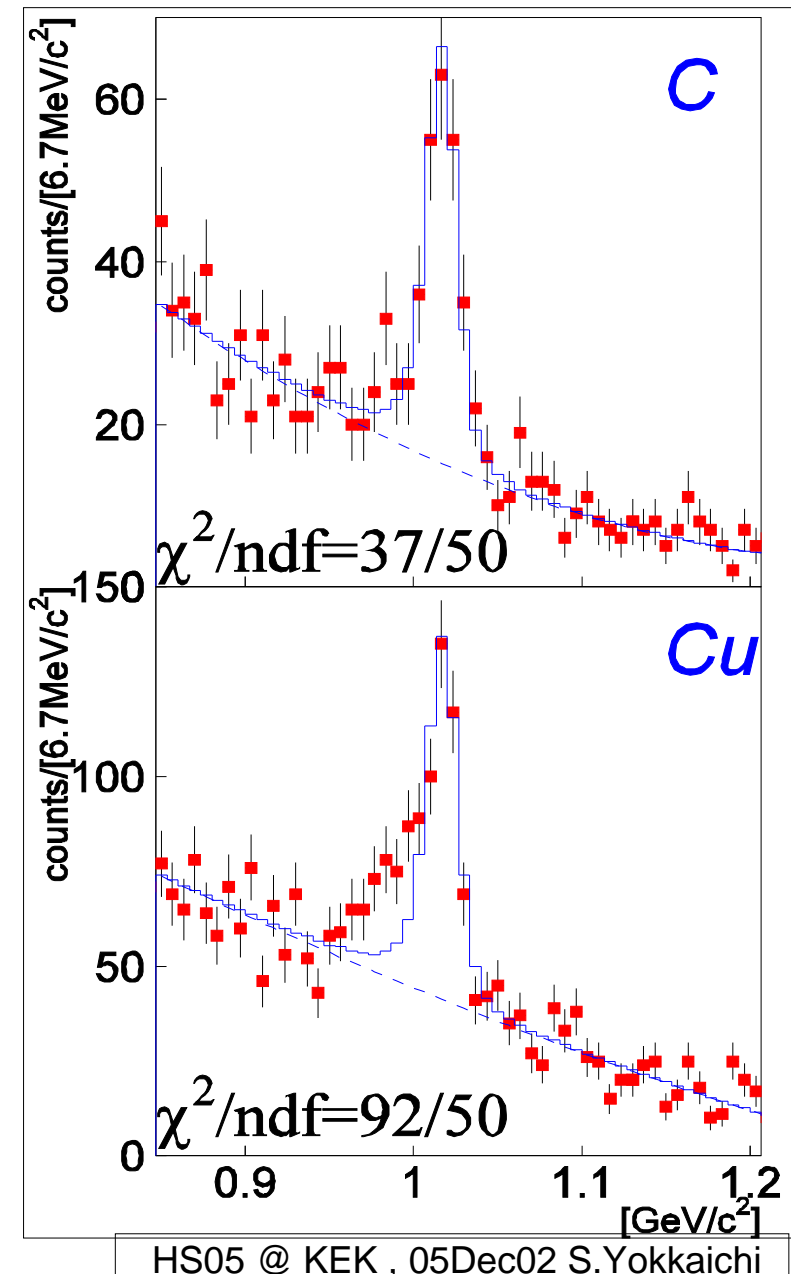
- e^+e^- branching ratio is not changed

$$\Gamma_{e^+e^-}^*/\Gamma_{\text{tot}}^* = \Gamma_{e^+e^-}^0/\Gamma_{\text{tot}0}^0$$

- k_1 & k_2 is not free param., but fixed.



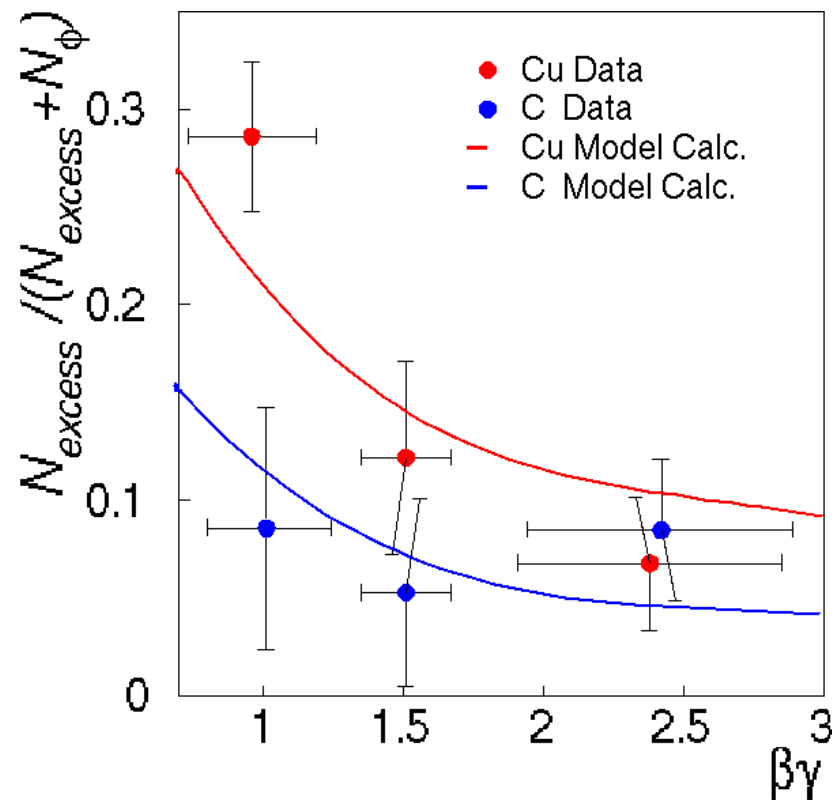
$\beta\gamma < 1.25$ (Slow), w/ unmodified



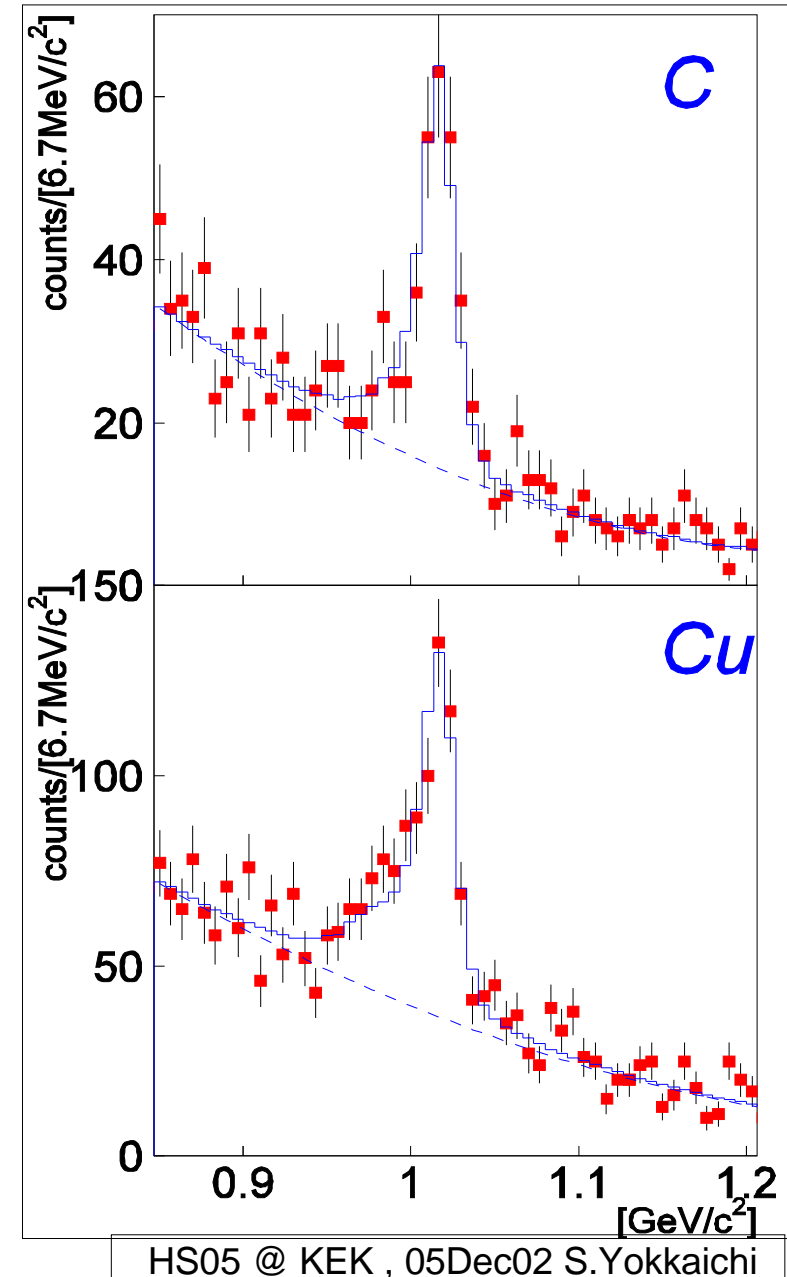
Toy model result for ϕ meson

- modified (model) shapes well reproduce the data, even slow/Cu
- modified shapes are analyzed with unmodified shape to evaluate the

$$N_{\text{excess}} / (N_{\text{excess}} + N_{\phi})$$



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



Summary (1)

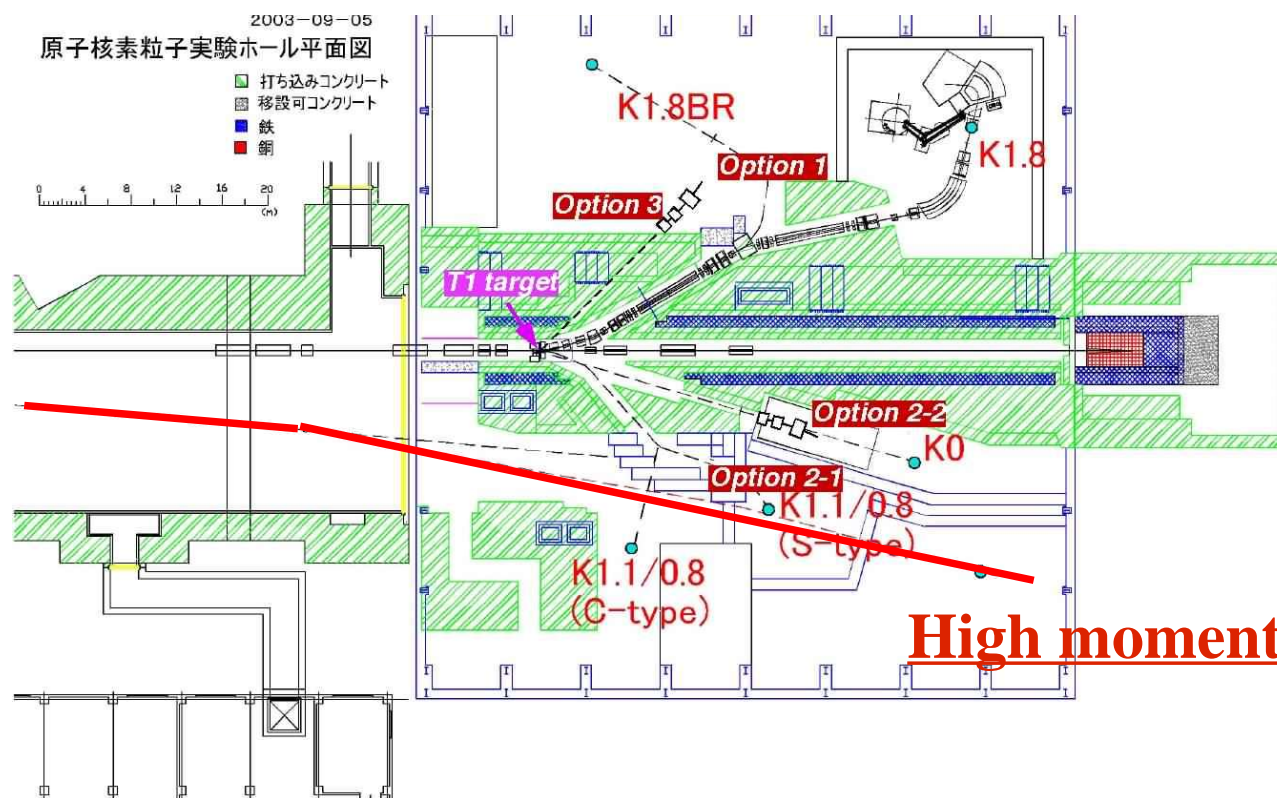
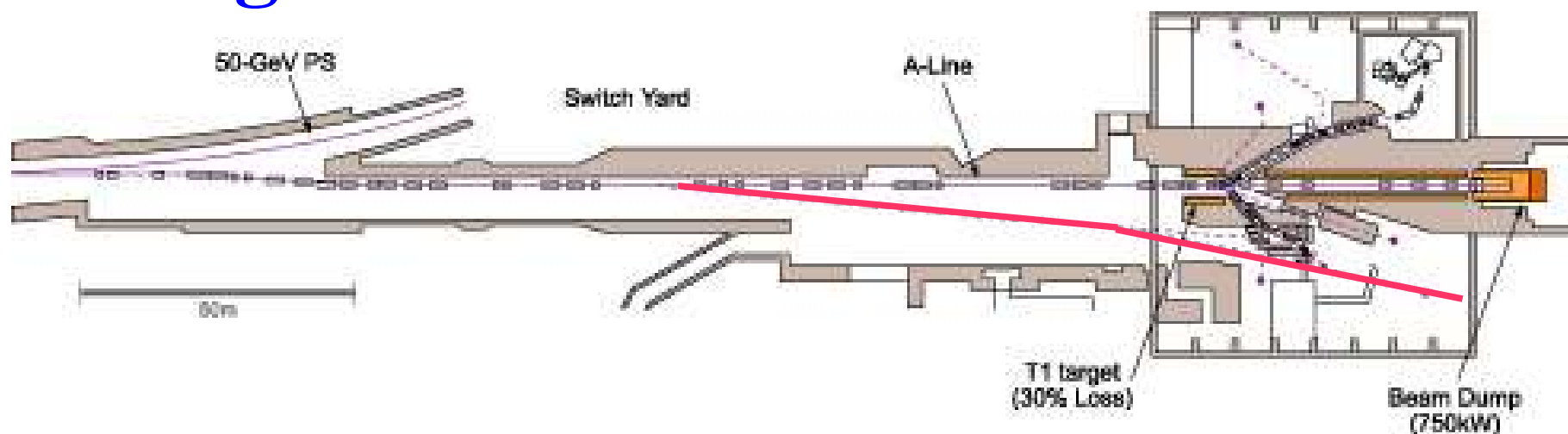
- KEK-PS E325 measured the $e^+e^-(&K^+K^-)$ decay of slowly moving vector mesons in nuclei produced by 12-GeV proton beam, to explore the **chiral symmetry restoration** at the **normal nuclear density**.
- Observed **e^+e^- invariant mass spectra** have **excesses** below the ω meson peak, which cannot 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.
- **$\phi \rightarrow e^+e^-$** also have **excess**, for the **larger** target, **slowly** moving ϕ
 - First observation of the modification of ϕ meson
 - World best mass resolution for $\phi \rightarrow e^+e^-$
 - model calc. including mass shift and width **broadening** 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 ($10^9 \sim 10^{10}$ ppp)/ slowly moving mesons
- **Main goal** : collect $10^4 \sim 10^5$ $\phi \rightarrow ee$ 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 $\sim 10 \text{ MeV}/c^2$
- **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, $\sim 20 \text{ GeV}/u$)

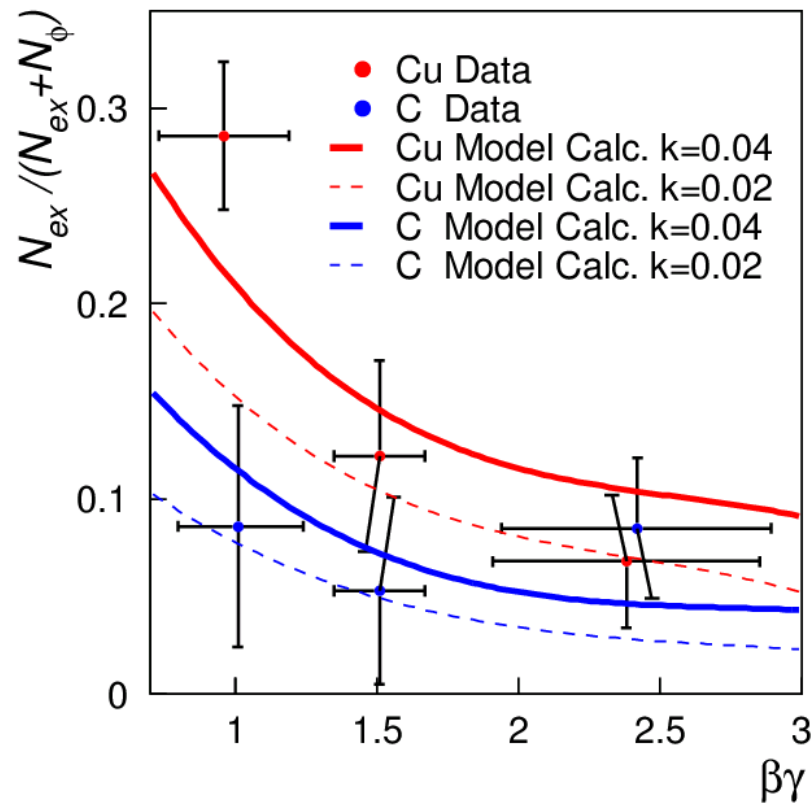
High momentum Beamline



High momentum beamline

high statistics

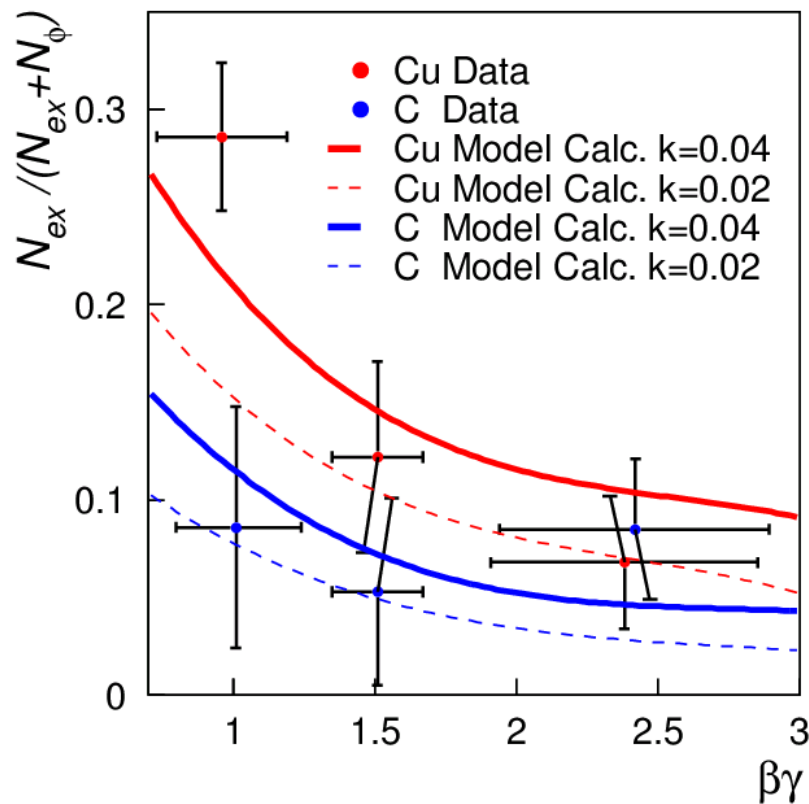
- **Main goal** : collect $10^4 \sim 10^5$ $\phi \rightarrow ee$ for each target in 5 weeks
 - **100 times** as large as E325
 - **velocity dependence** of 'modified' component



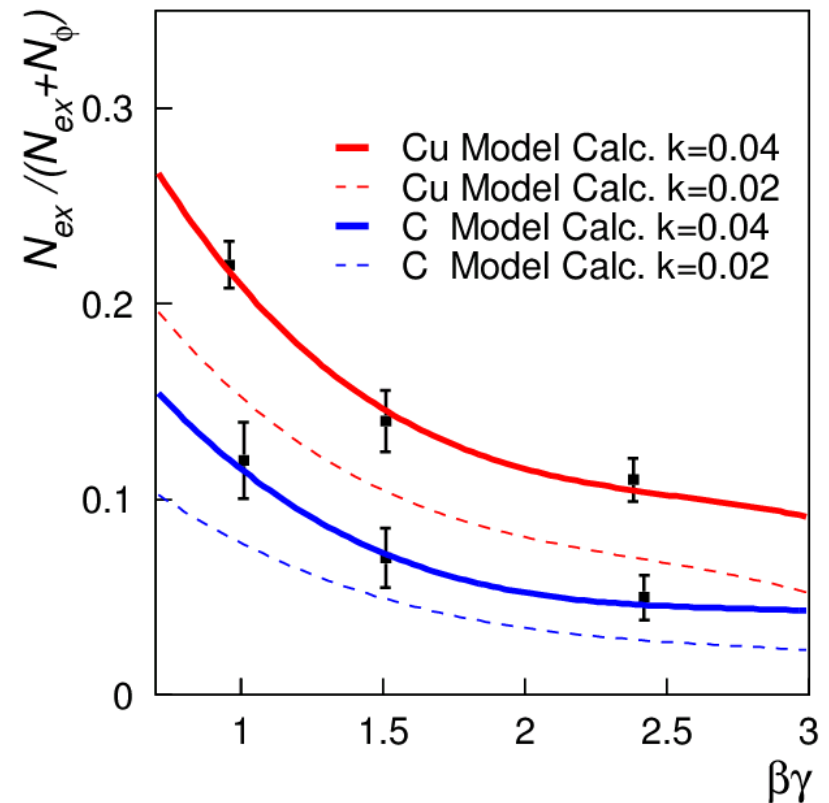
x 10 stat.

high statistics

- **Main goal** : collect $10^4 \sim 10^5$ $\phi \rightarrow ee$ for each target in 5 weeks
 - **100 times** as large as E325
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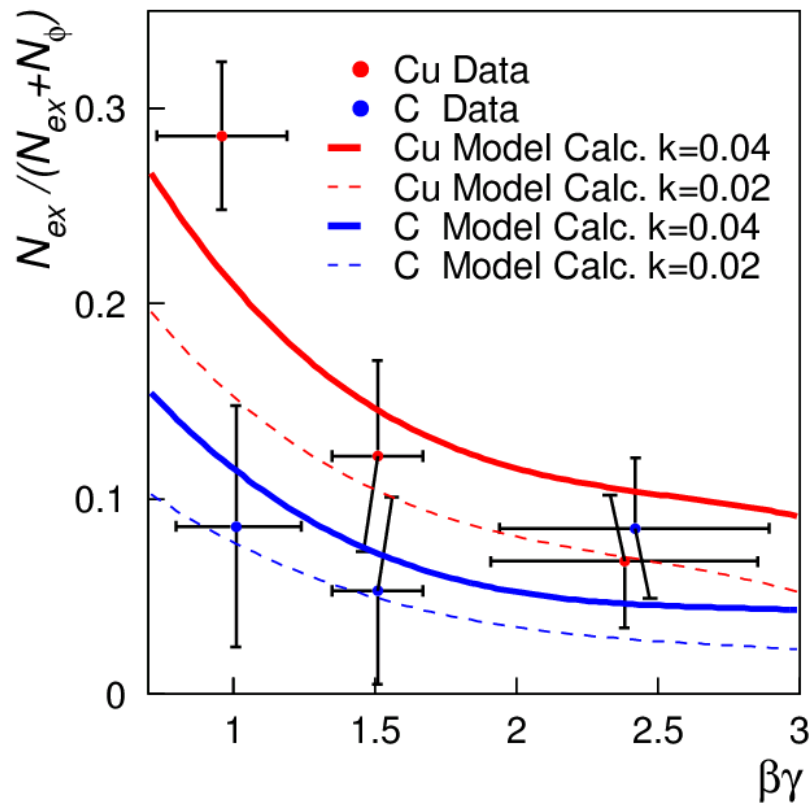
x 10 stat.



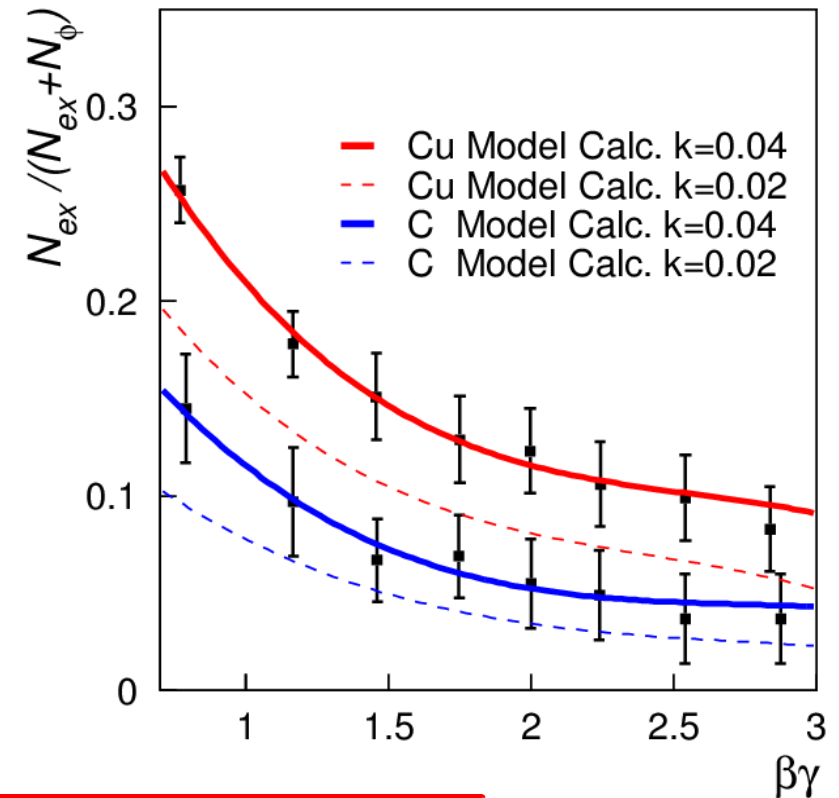
error bars can be shrunk (data points are moved around the model curve)

high statistics

- **Main goal** : collect $10^4 \sim 10^5$ $\phi \rightarrow ee$ for each target in 5 weeks
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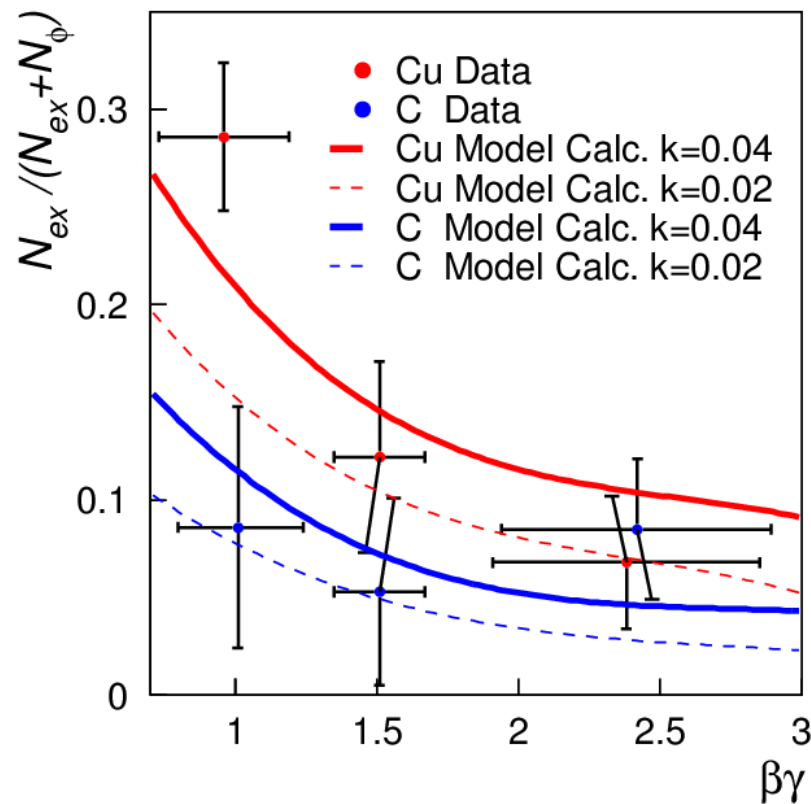
x 10 stat.



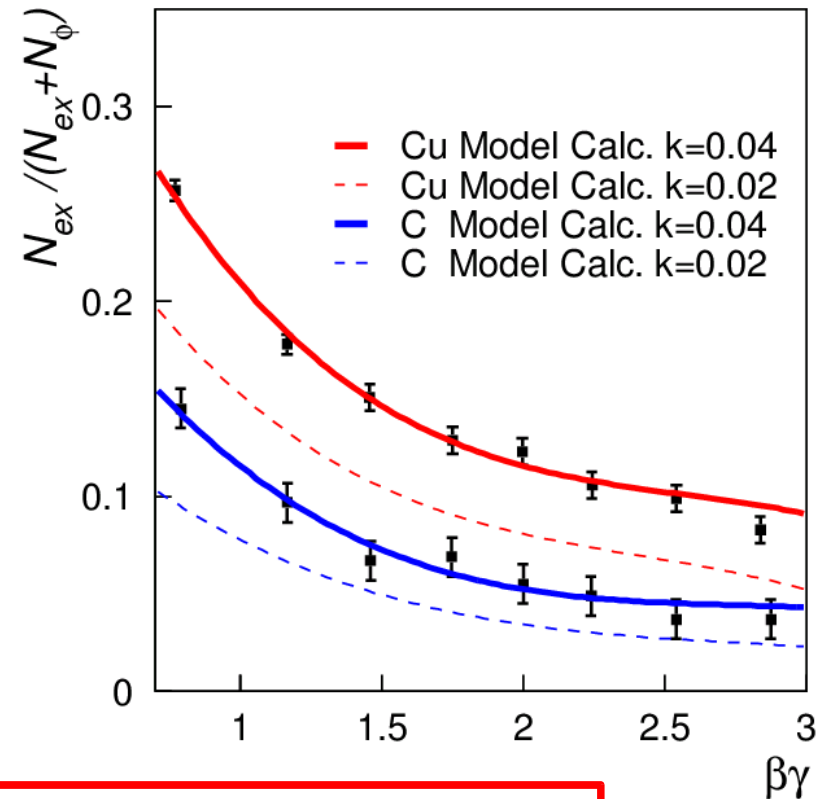
$\beta\gamma$ bin can be divided

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 100 stat.



error bars are shrunk again

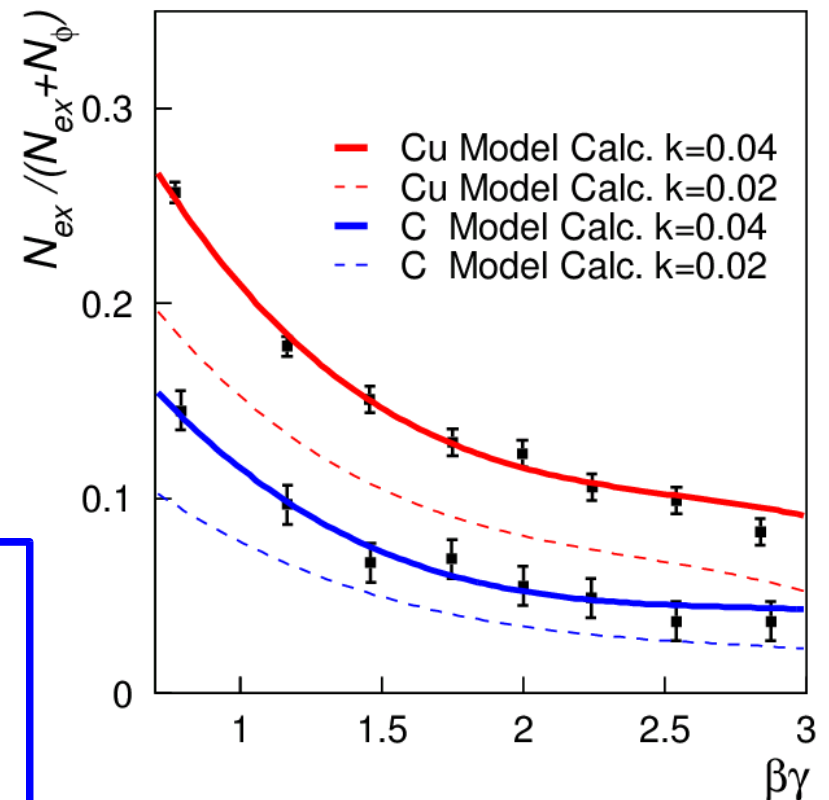
high statistics

- **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.

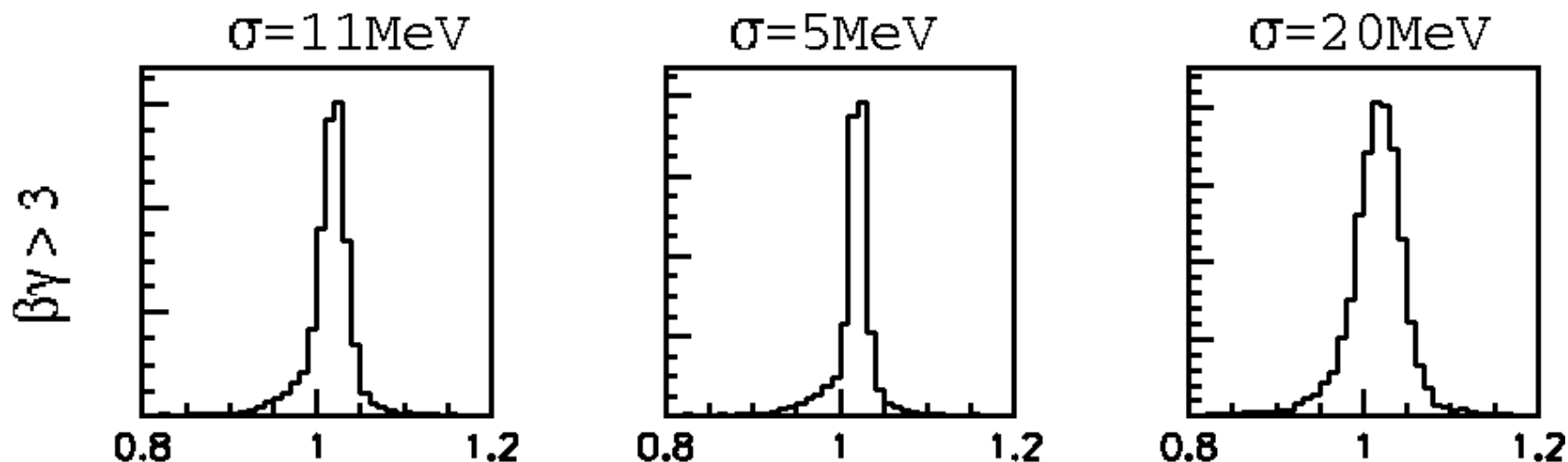
Advance of the theoretical works is also needed to solve the puzzle:
 in finite size nuclear matter, possible time evolution of the density, density/momentum dependence of the mass/width changing, etc.



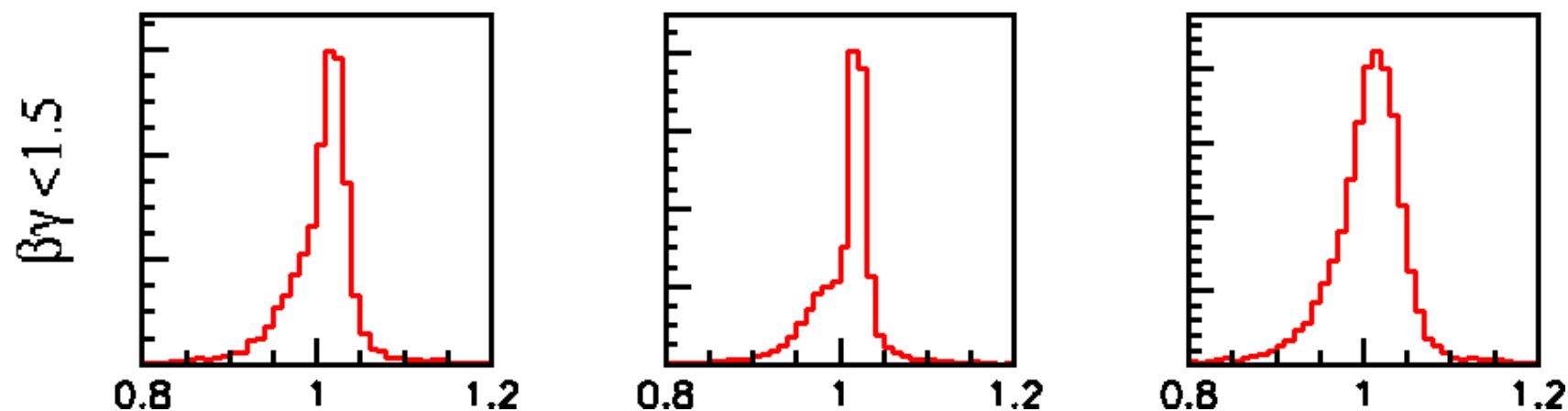
high mass resolution

- mass resolution should be less than $\sim 10\text{MeV}$

Fast



Slow



(model calc. with $k=0.05/\Gamma=x10/E325$ spectrometer)

To collect the high statistics

A) Reuse of E325 spectrometer

or

B) New larger acceptance spectrometer

(coverage : $\pm 45^\circ$ (vert.), $\pm 12^\circ \sim 132^\circ$ (holi.))

expected ϕ yield for two options (using JAM)

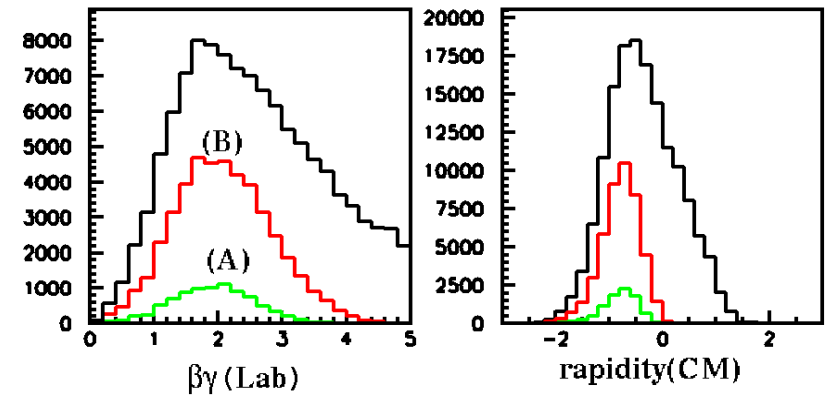
beam energy		12 GeV	30 GeV	50 GeV
ϕ production CS (p+Cu)		1.0 mb	3.0 mb	5.1 mb
detector acceptance	case A	8.8%	6.0%	4.5%
	case B	45%	31%	23%
normalized yield by E325	case A	1	2.0	2.6
	case B	5.1	10.0	12.7

Further, for 10 times higher intensity beam (10^{10})
(i.e. high interaction rate : 10MHz)

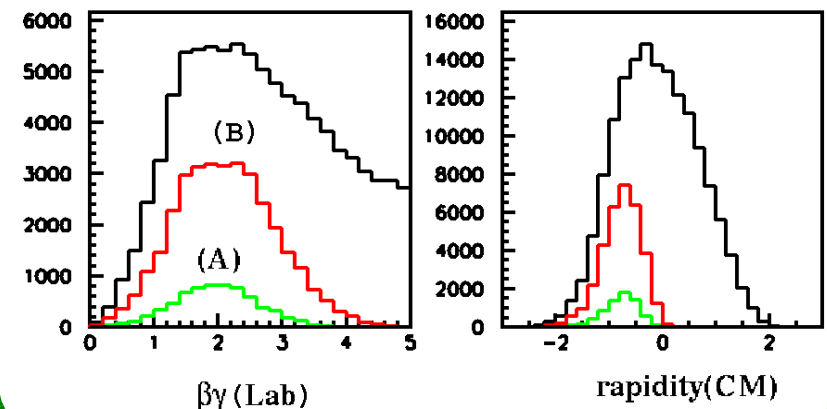
to collect higher statistics (100 times of E325 = $10^5 \phi$), (B) is needed

spectrometer acceptance $\phi \rightarrow ee$
(estimated by JAM)

30GeV p+Cu $\rightarrow \phi (+X) \rightarrow ee$

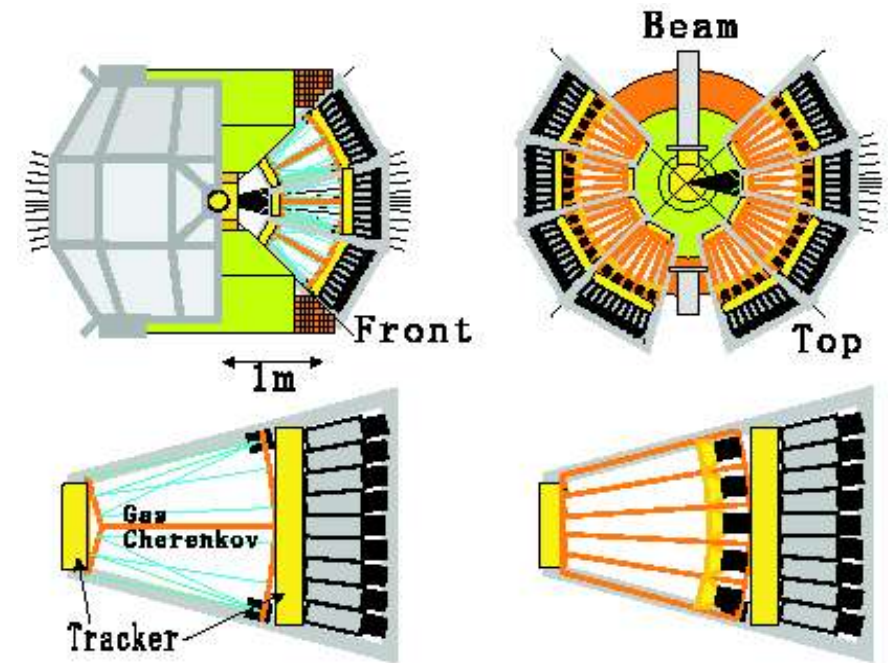


50GeV p+Cu $\rightarrow \phi (+X) \rightarrow ee$

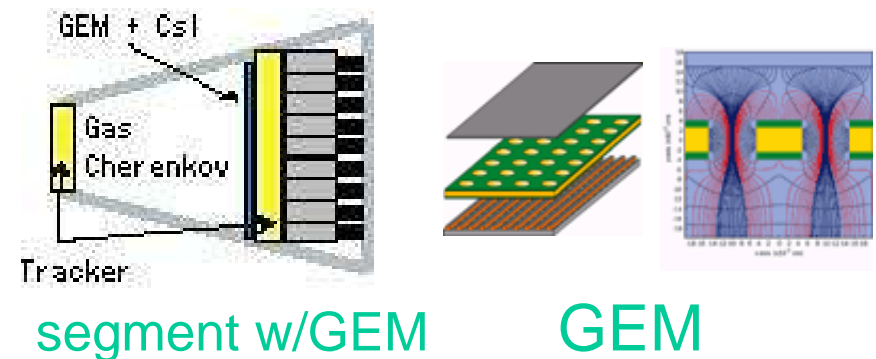


Proposed New spectrometer

- Cover the large acceptance
 - $\pm 45^\circ$ (vert.), $\pm 12^\circ \sim 132^\circ$ (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)

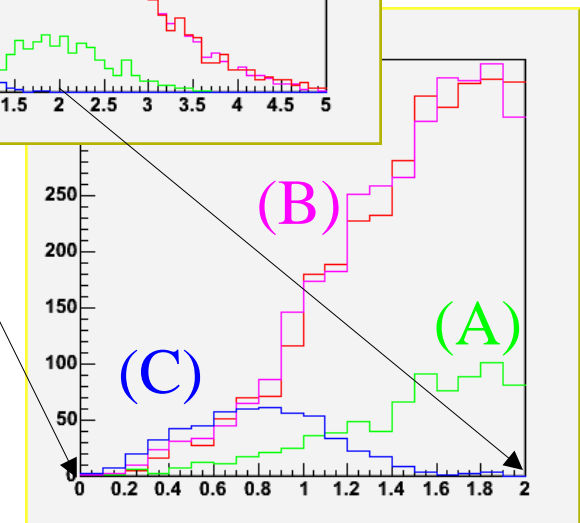
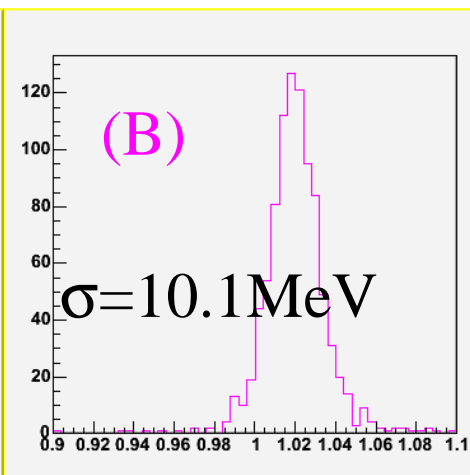
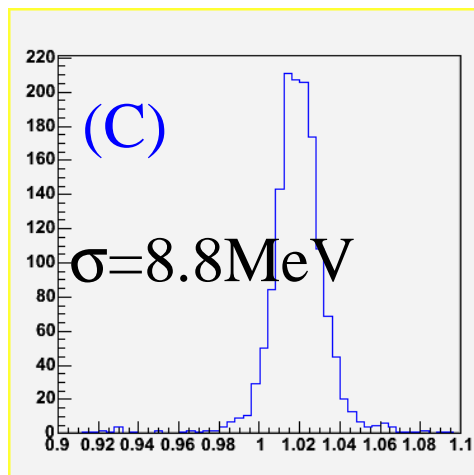
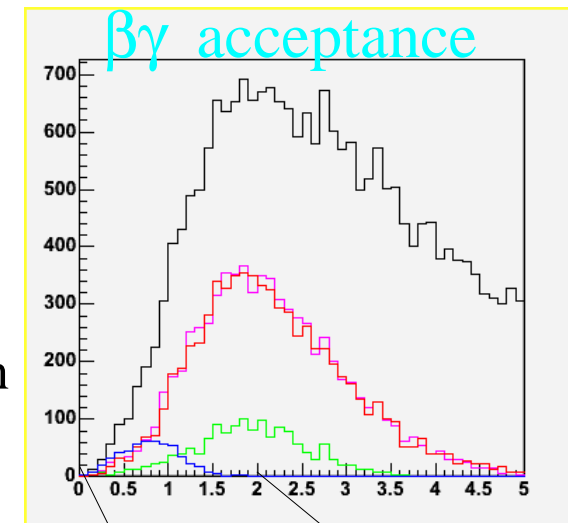
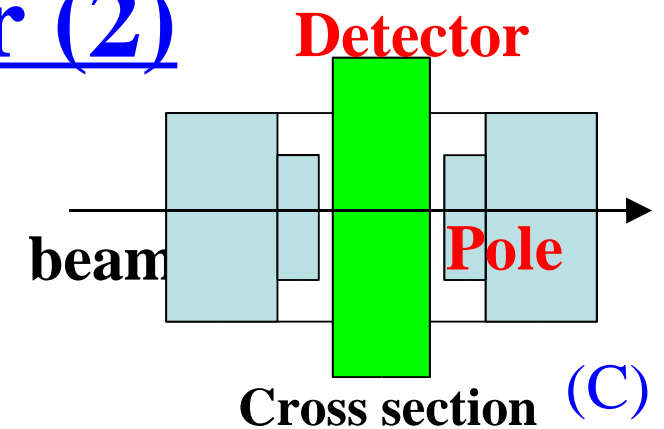


Schematic view of spectrometer



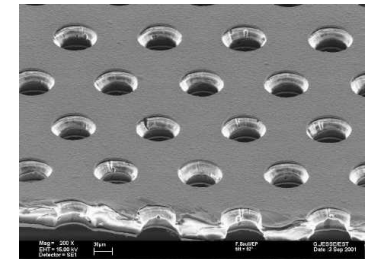
Proposed New spectrometer (2)

- 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 $\beta\gamma < 1.25$
 - can be operated in more higher rate?
 - operation capability with the dimuon experiment : $\sim 10^{12}$ ppp beam
- Mass resolutions are less than ~ 10 MeV/ c^2 in the simulation



Detector R&D item

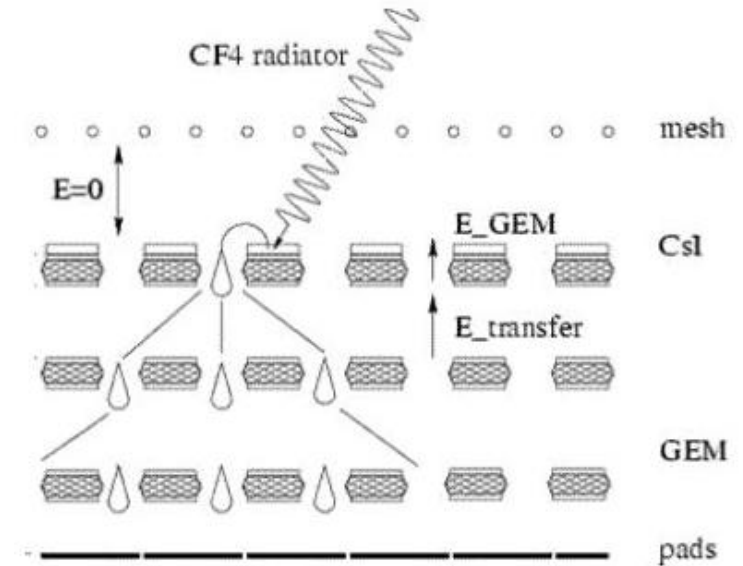
- Environment with primary beam ($10^9 \sim 10^{10}$ ppp)
 - high interaction rate (1~10MHz)
 - beam halo is origin of trigger background & saturation of forward detector
- Tracker should cope with high beam / interaction rate
 - GEM tracker in forward region : works 10KHz/mm²
- Electron ID : 10^{-4} π rejection
 - lead glass EMC (recycled from TRISTAN) : $< 10^{-1}$
 - Gas Cherenkov : $\sim 10^{-3}$
 - HBD (Hadron Blind Detector)
 - GC with GEM/CsI photocathode & pad readout / CF₄ radiator/amplification gas
 - No mirror, No segment, No window : No photon loss with reflection efficiency
 - Flexible trigger capability



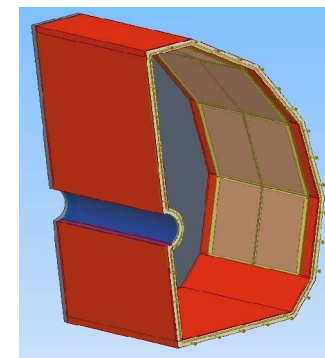
GEM

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



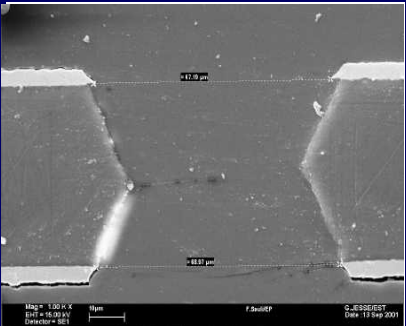
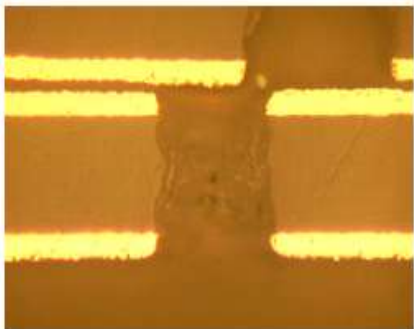
Concept of HBD



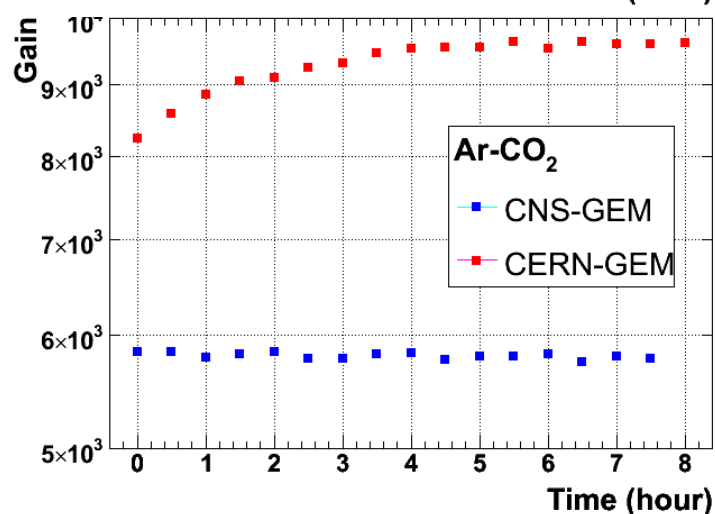
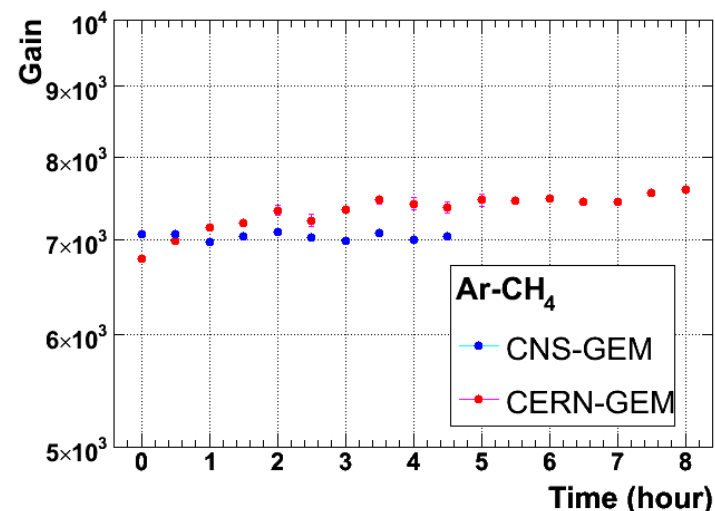
Proposed structure for PHENIX HBD

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	 <u>double-conical</u> shape	 <u>cylindrical</u> 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** ($1 \times 10^9 \sim 1 \times 10^{10}$ /sec) on thin targets ($\sim 0.1\%$ int.length) to reduce electron background
 - especially collect $10^4 \sim 10^5$ $\phi \rightarrow e^+e^-$ in p+A reaction in 100 shift (~ 5 weeks) operation
 - 10 \sim 100 times as large as E325's statistics
- New spectrometer using new technology (GEM tracker/HBD)
 - mass resolution : less than 10 MeV/c²
 - larger incident energy/larger acceptance \rightarrow 10 times larger statistics.
 - higher rate capability \rightarrow more 10 times stat. using higher intensity beam
- Prototype Detector with new technology is being developed.
 - GEM made in Japan works well
 - CsI photocathode & CF₄ operation are next hurdle in Japan