Measurement of vector mesons in nuclei: J-PARC E16 experiment

Satoshi Yokkaichi
(RIKEN Nishina Center)

- physics
  - dilepton spectra
- precedent experiment E325
- proposed experiment E16
- status & schedule of construction
- summary

Collaboration

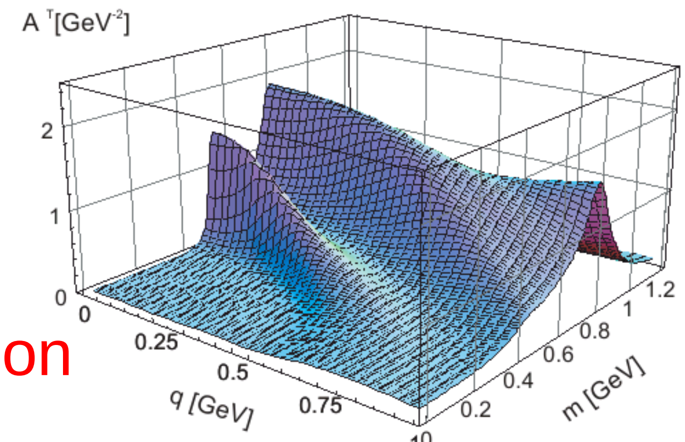
RIKEN	S.Yokkaichi, H. En'yo, F. Sakuma
KEK	K.Aoki, K.Ozawa, R. Muto, Y.Morino S. Sawada, M. Sekimoto
U-Tokyo	Y.Komatsu, S.Masumoto, K.Kanno, W.Nakai, Y.Obara, T.Shibukawa, H.Murakami
RCNP	T.N.Takahashi
CNS, U-Tokyo	H. Hamagaki
Kyoto-U	M. Naruki
Hiroshima-U	K. Shigaki
JASRI	A. Kiyomichi

spectral change of vector mesons

- hadron as the elementary excitation of QCD vacuum
  - elementary excitation on a ground state : changed when the ground state is changed
    - change of excitation reflects the vacuum
    - condensed matter examples
  - hadroninc spectral function could be changed in the hot and/or dense matter, different vaccum on the QCD phase diagram
    - various theoretical calculations
- vector meson : dilepton decay
  - spectral function probed by virtual photon
  - experimentally, smaller final-state interaction is expected
  - many dilepton measurements have been performed in the world
    - in hot matter : high-energy HI collision
    - in dense matter (nuclei) : γ+A, p+A reactions
  - ϕ meson is simple (while cross section is smaller)
    - isolated and narrow resonance unlike the ρ and ω mesons case (ρ/ω interfere, etc)
    - spectra is related $m_s \langle\bar{s}s\rangle_\rho$

In hadronic matter : vector meson spectra in dense nuclear matter (theory)

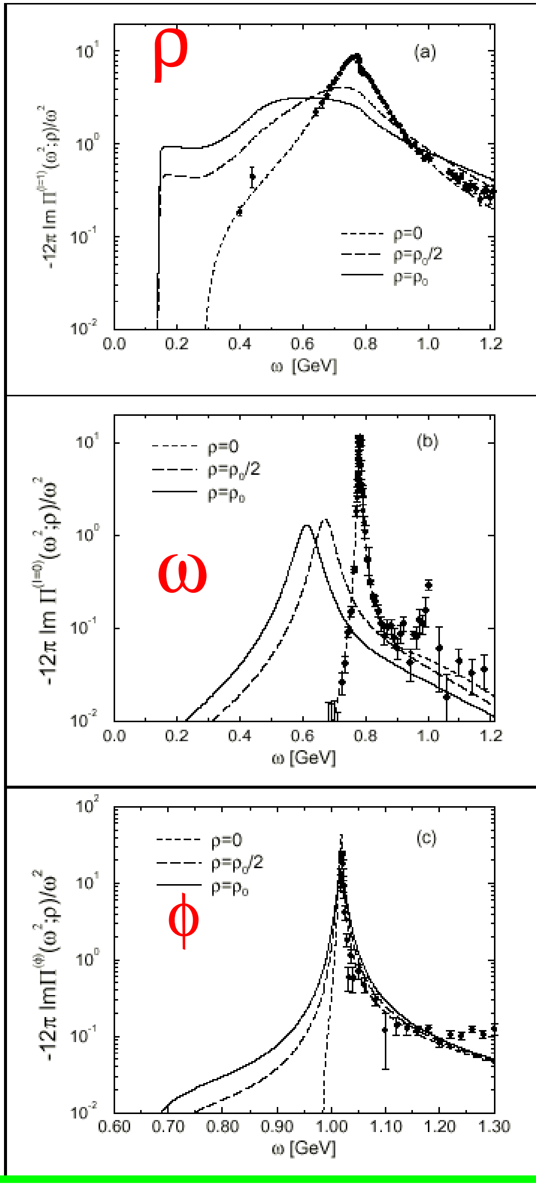
Post & Mosel [NPA699(02)169]



ρ-meson

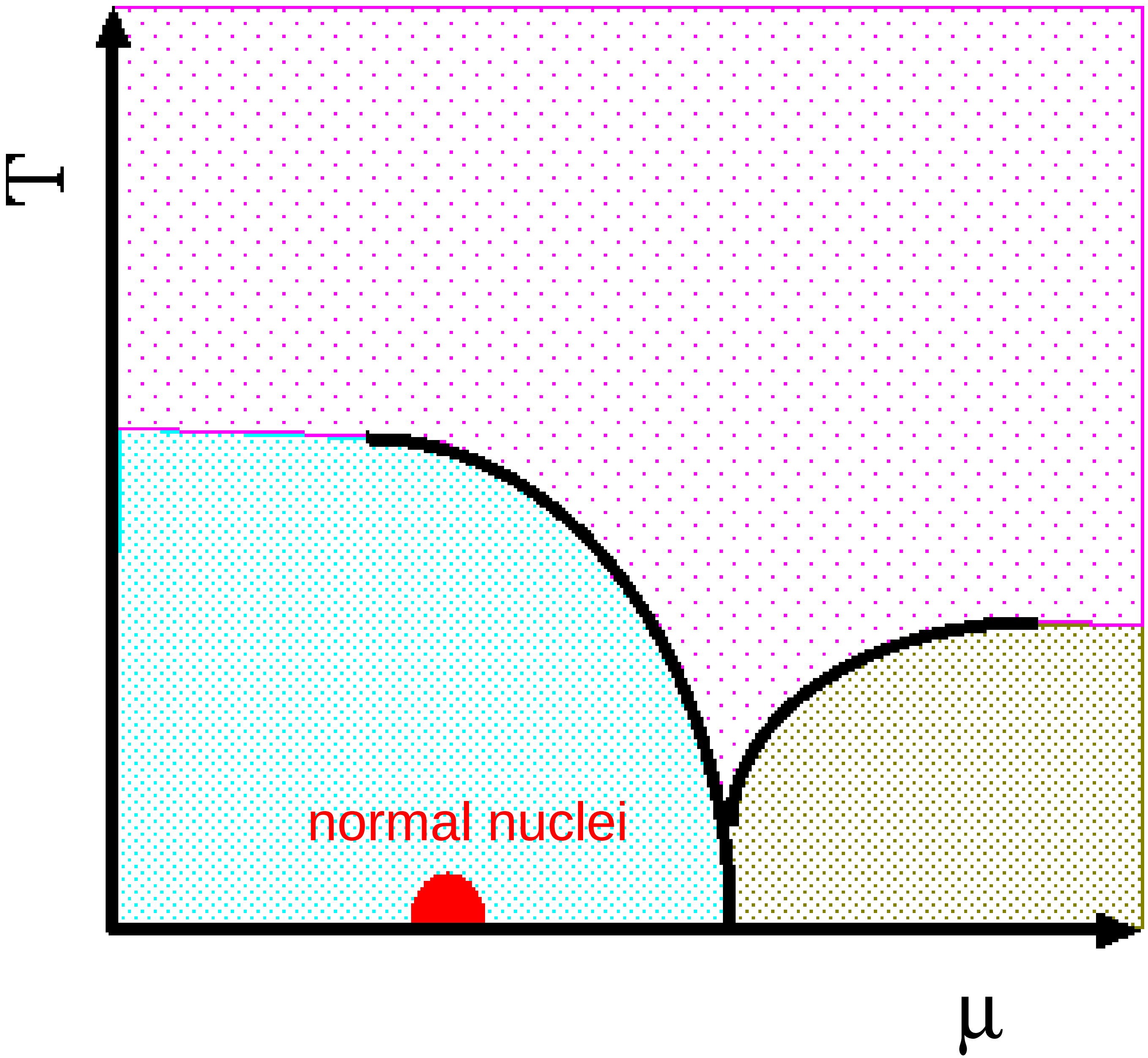
density $\rho = \rho_0$

Klingle,Kaiser,Weise
[NPA 624(97)527]
density $\rho = \rho_0/2$, ρ_0



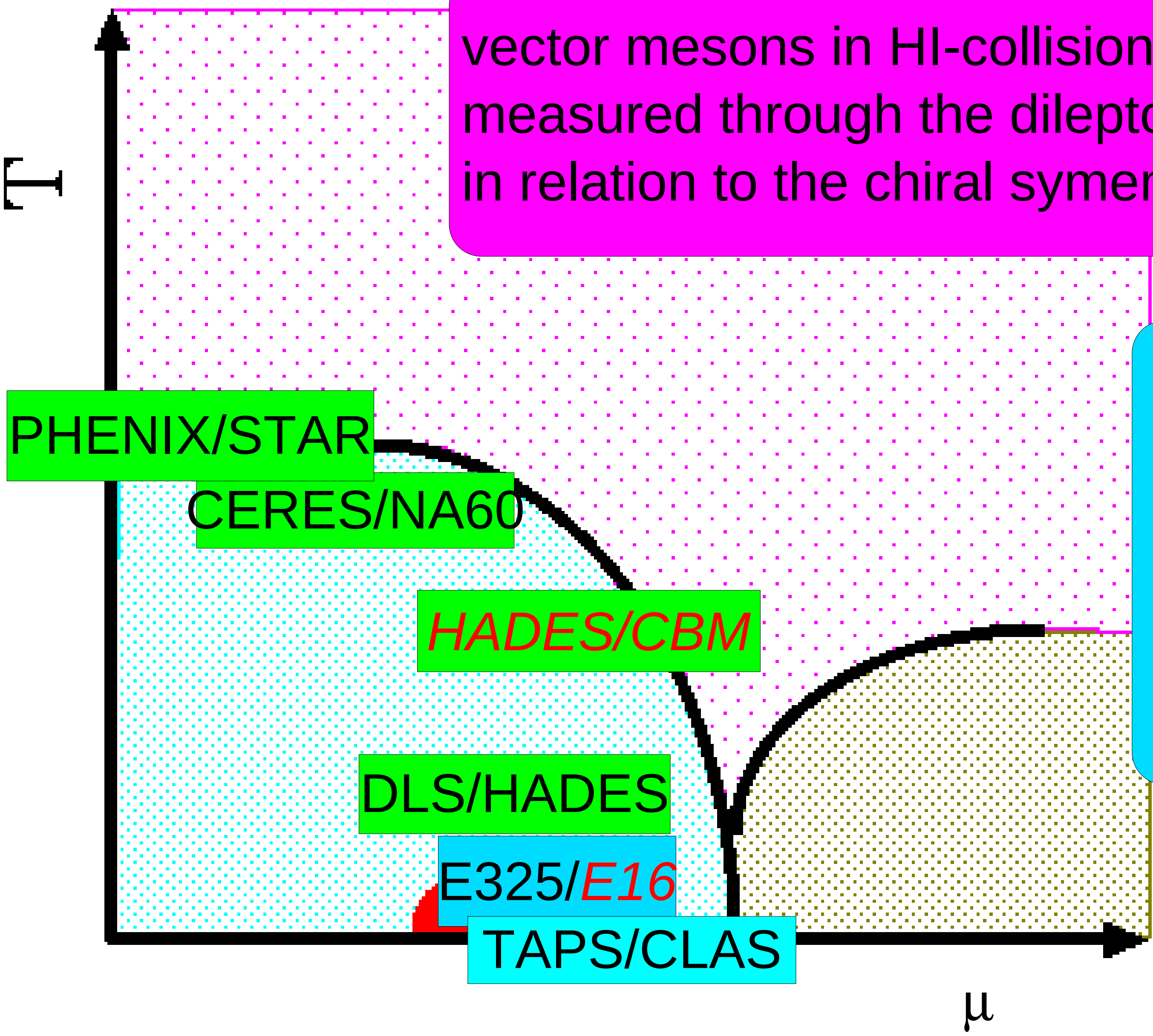
hadronic matter, changing density ρ,
excited by induced proton / γ / HI,
mass spectrum is measured by dilepton.

QCD phase diagram



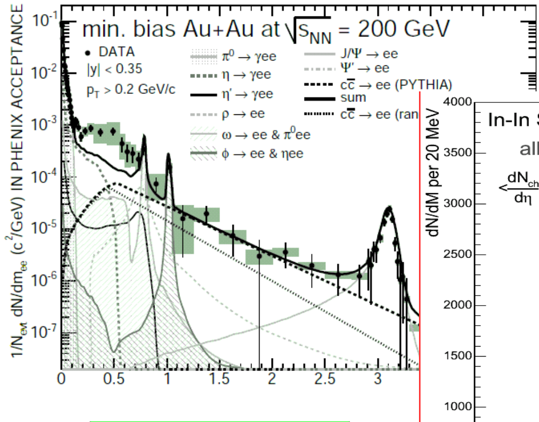
dilepton measurements in different vacuum

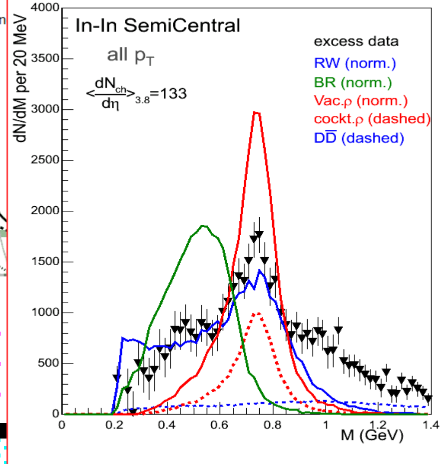
vector mesons in HI-collisions have been measured through the dilepton spectra in relation to the chiral symemtry restoration



In hot and dense matter, spectral modification of vector mesons (dilepton invariant mass) are observed in many experiments

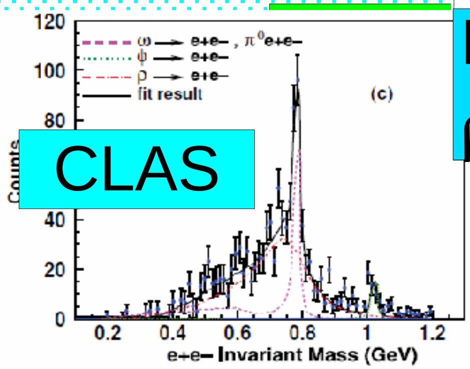
observed dilepton spectra in the world

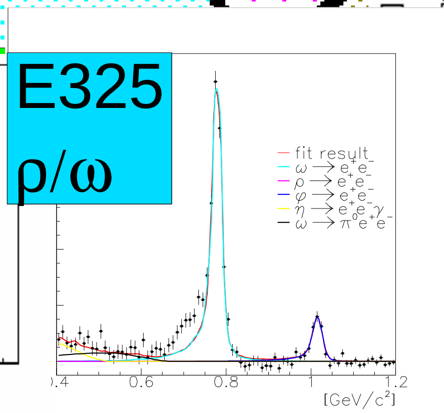


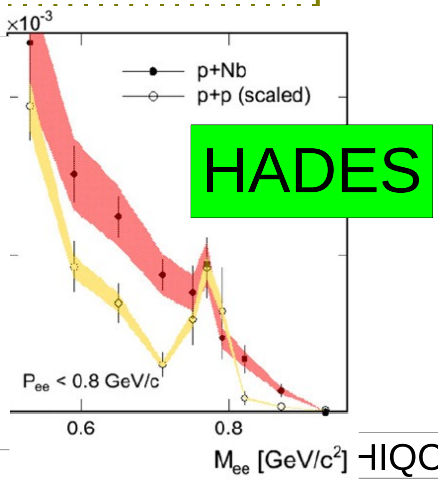


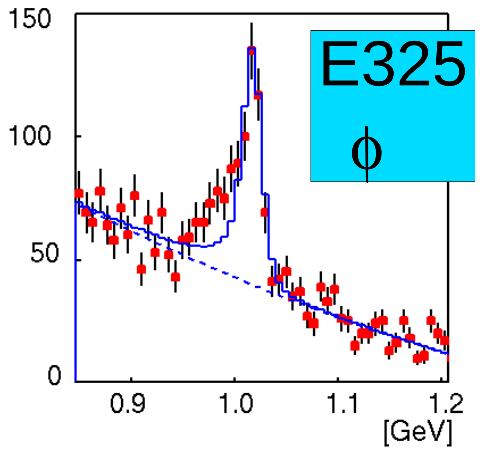
“low mass enhancement"
below the ω meson peak
in HI collisions
and HADES p+Nb

change of ϕ meson is
observed only by KEK-PS
E325 w/ best mass resolution
& high statistics



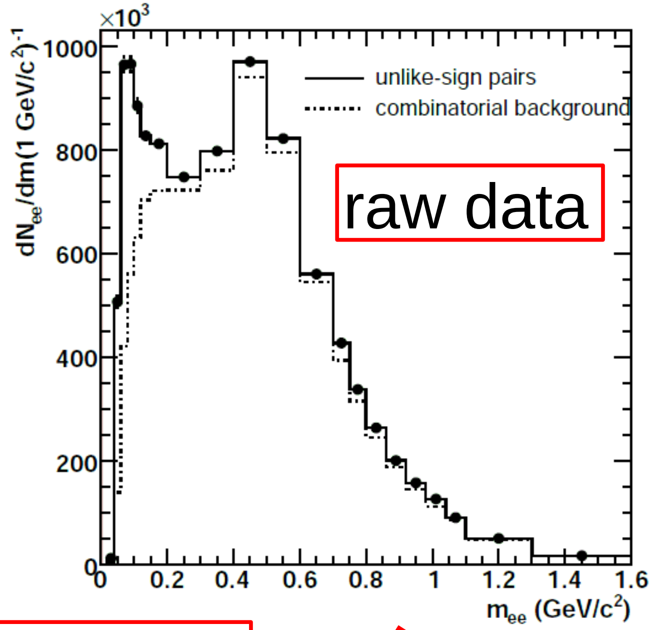




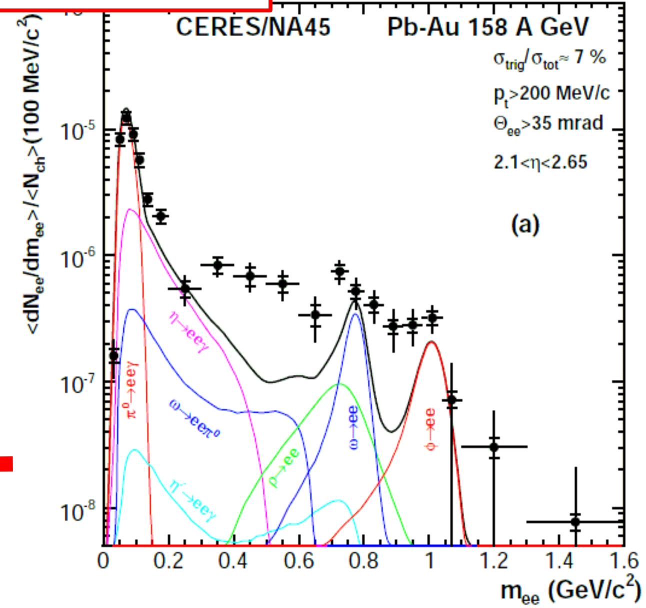


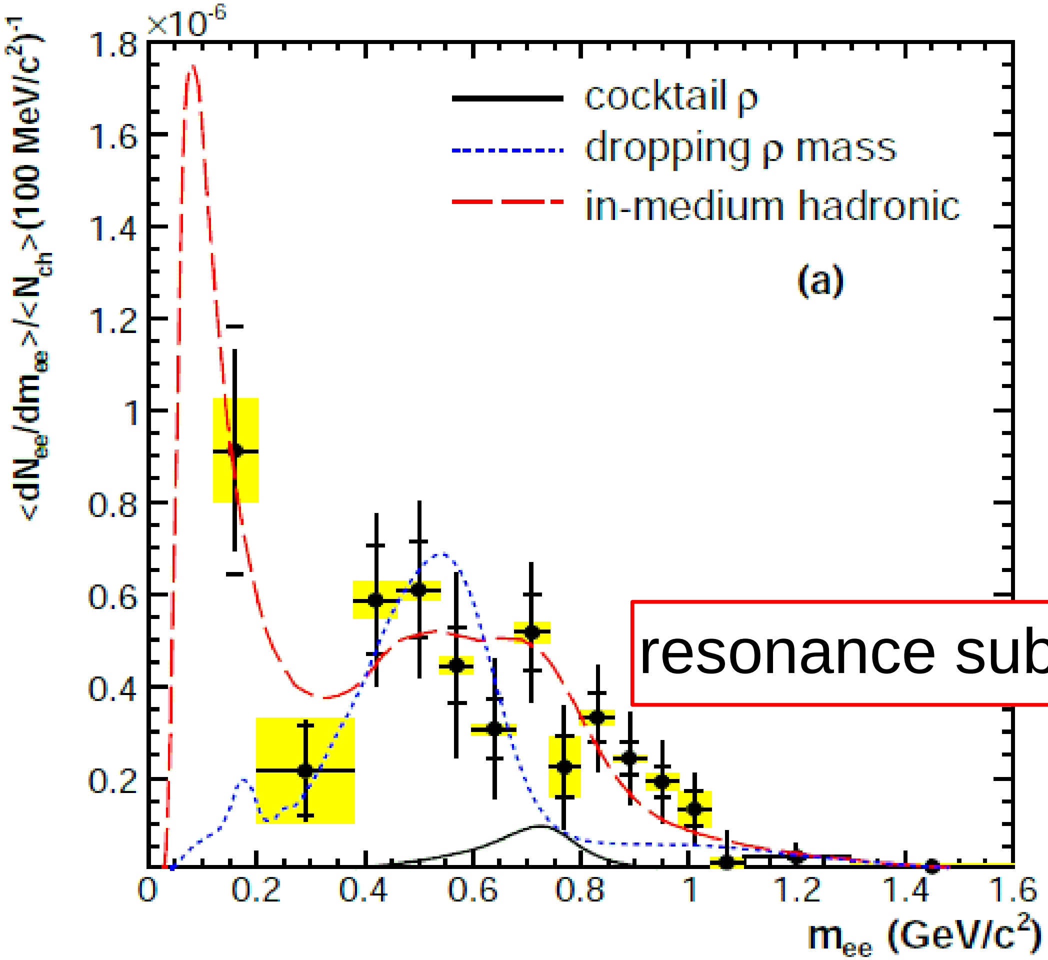
Dilepton spectrum in Heavy Ion Collision

- CERES@SPS : (PLB666(2008)425)
  - S/B = 1/22 @ m_{ee} > 0.2 GeV/c^2
  - “cocktail” with the thermal statistical model



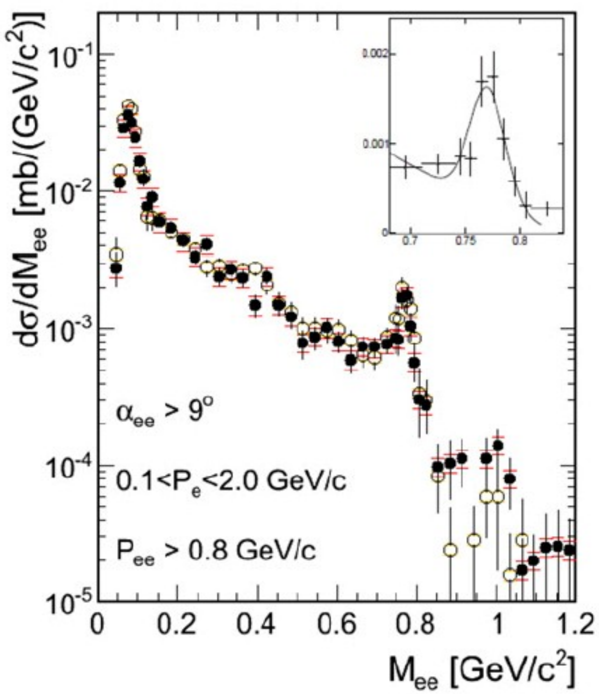
bkg subtracted

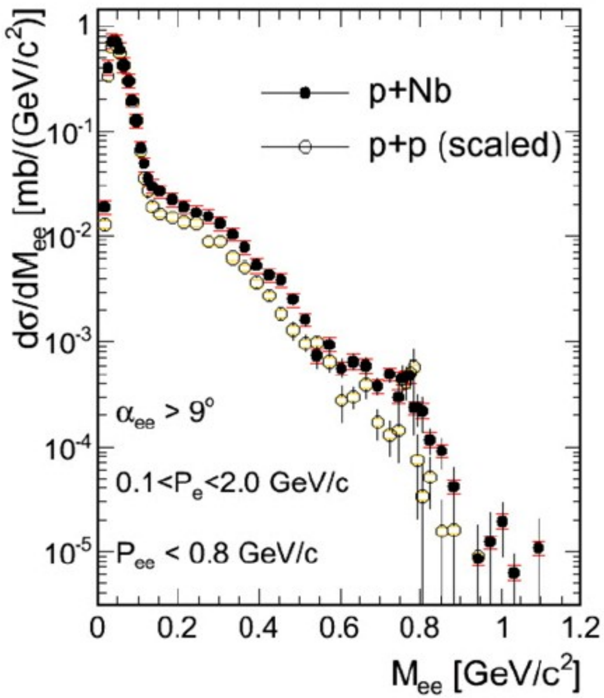




HADES 3.5GeV/c pp and pNb

[PLB715(2012)304]

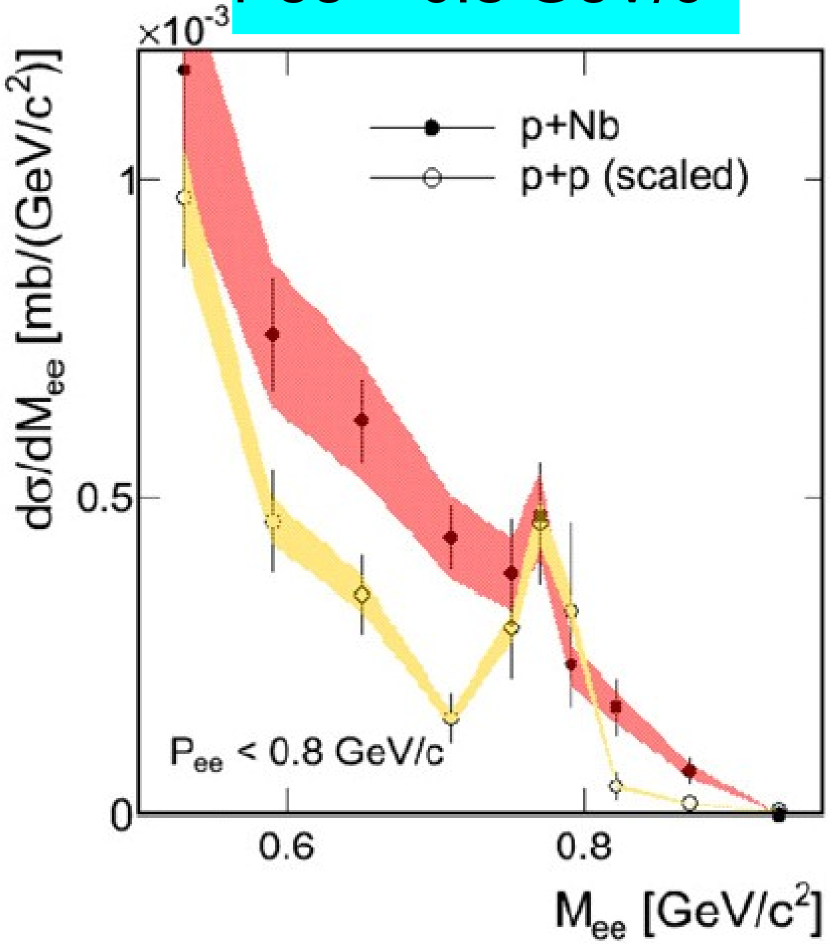




Fast : Pee > 0.8 GeV/c

Slow: Pee < 0.8 GeV/c

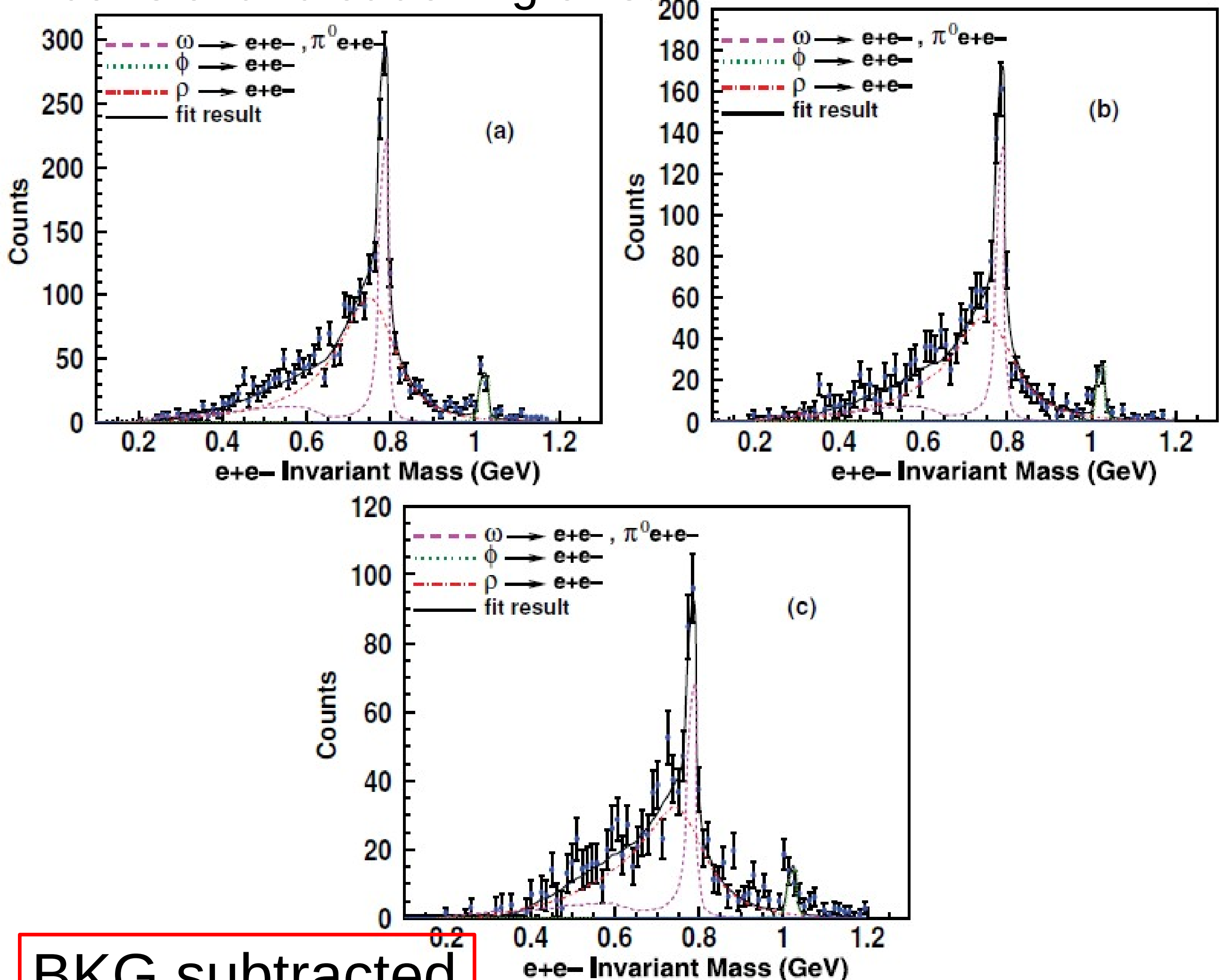
(zoomed) Slow: Pee < 0.8 GeV/c



- Excess in the slow component in the p+Nb data

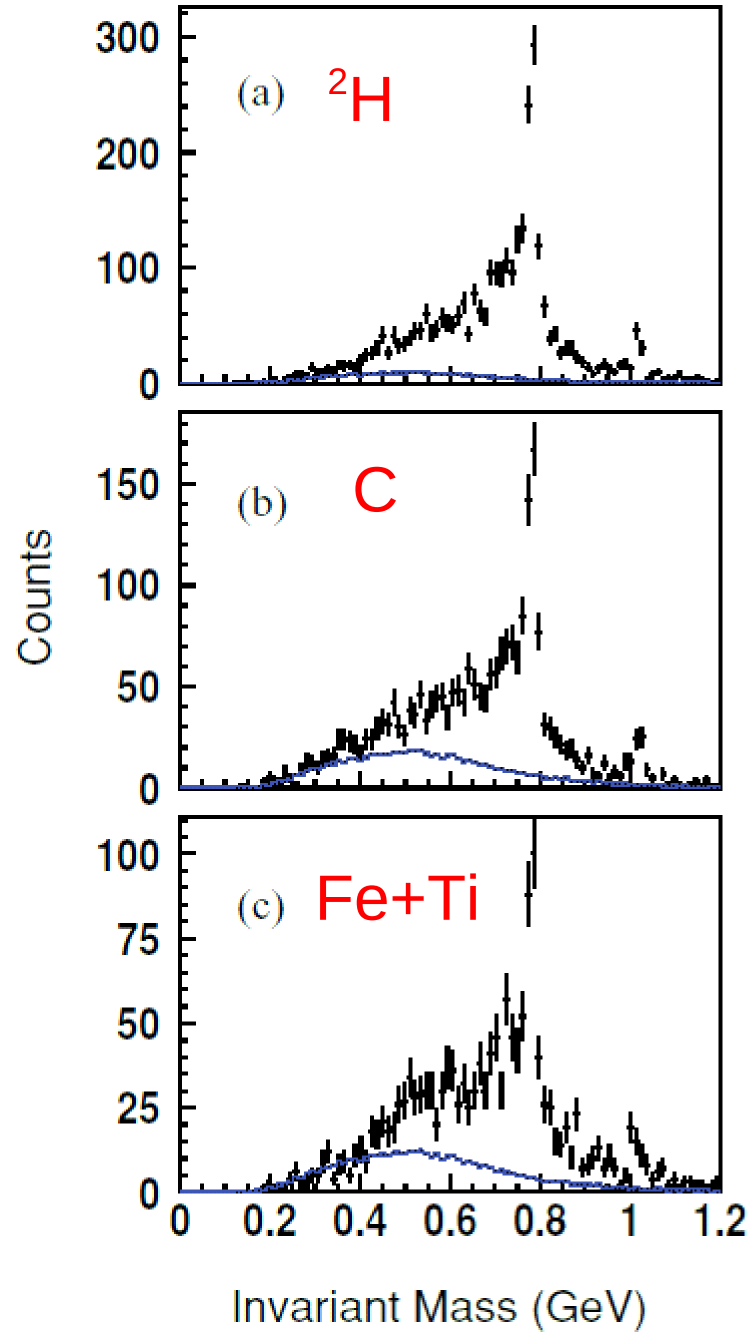
CLAS-G7(PRC78(2008)015201)

- $\gamma + A \rightarrow V \rightarrow e^+e^-$
- no anomaly for p >0.8GeV/c : while collisional broadening exist



BKG subtracted

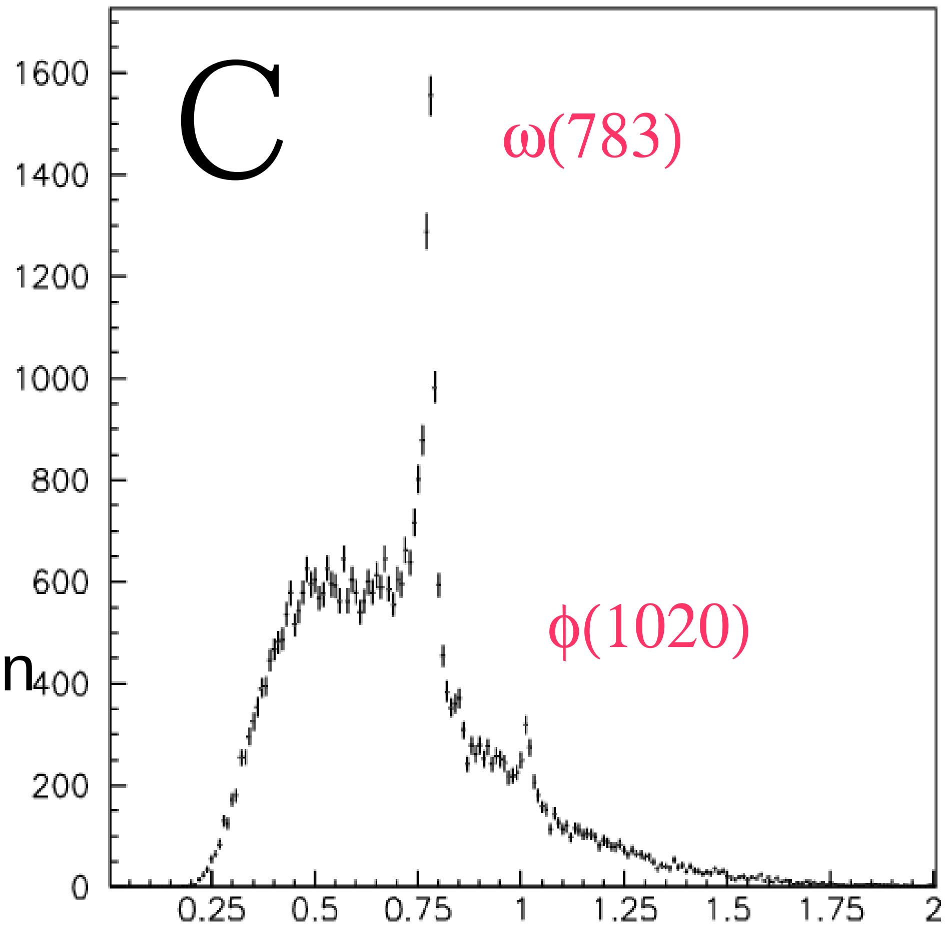
PRC78(2008)015201



Dilepton spectra measured at KEK-PS E325

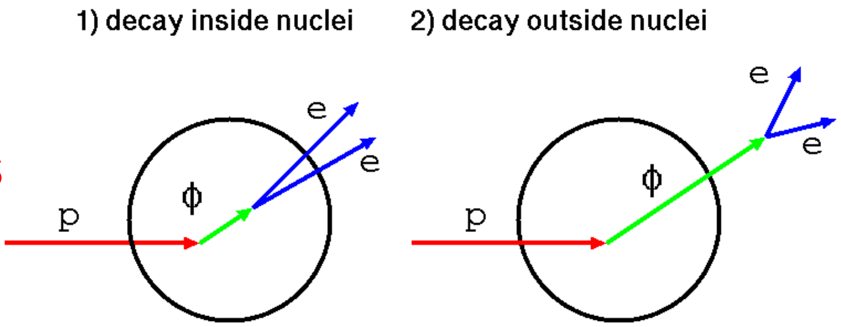
M. Naruki et al.,
PRL 96 (2006) 092301
R.Muto et al.,
PRL 98 (2007) 042501

- At the lower energy,
  - better S/N
  - smaller production cross section
  - possibly simpler environment
    (T=0, no time evolution)

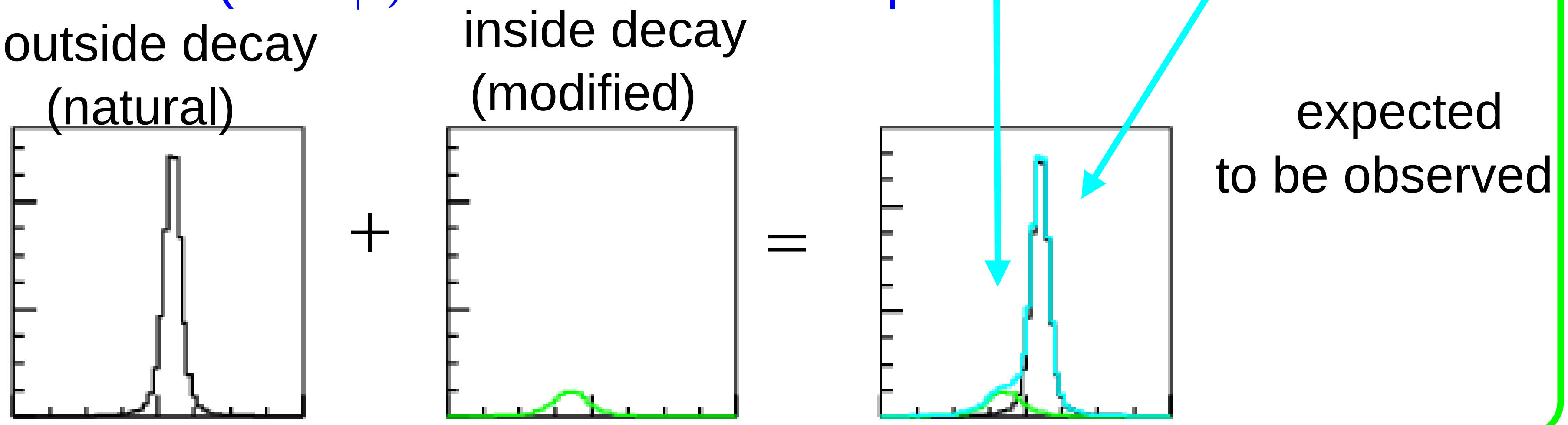


Expected Invariant mass spectra in ee

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

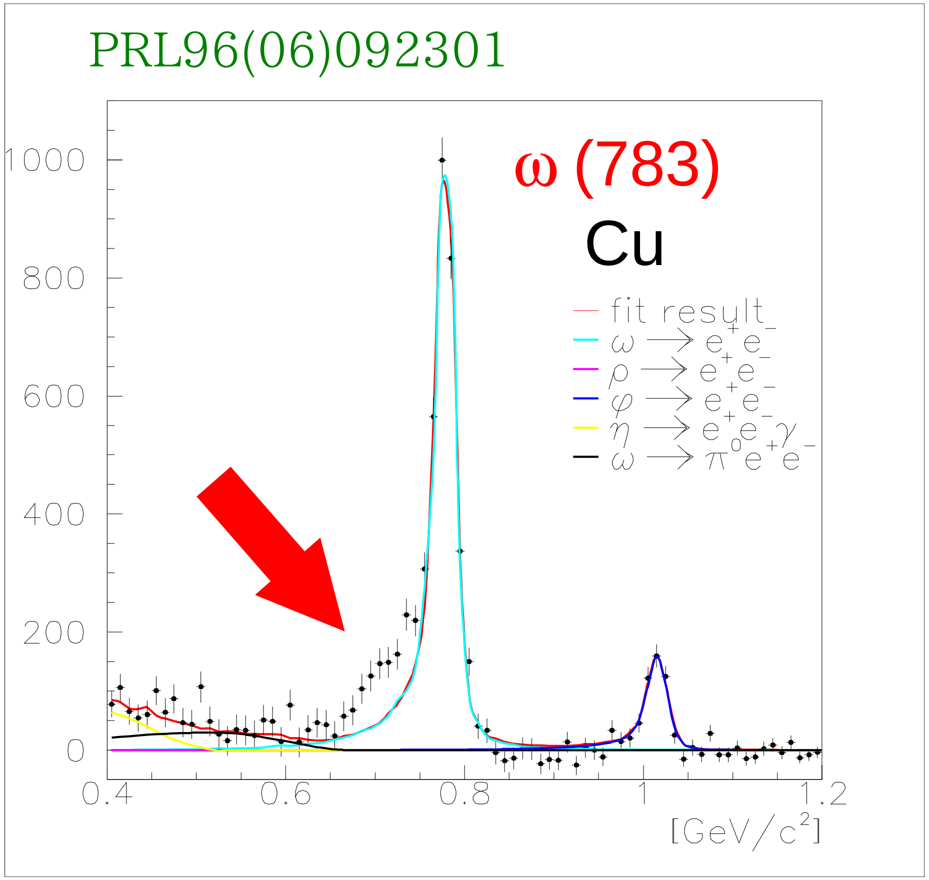


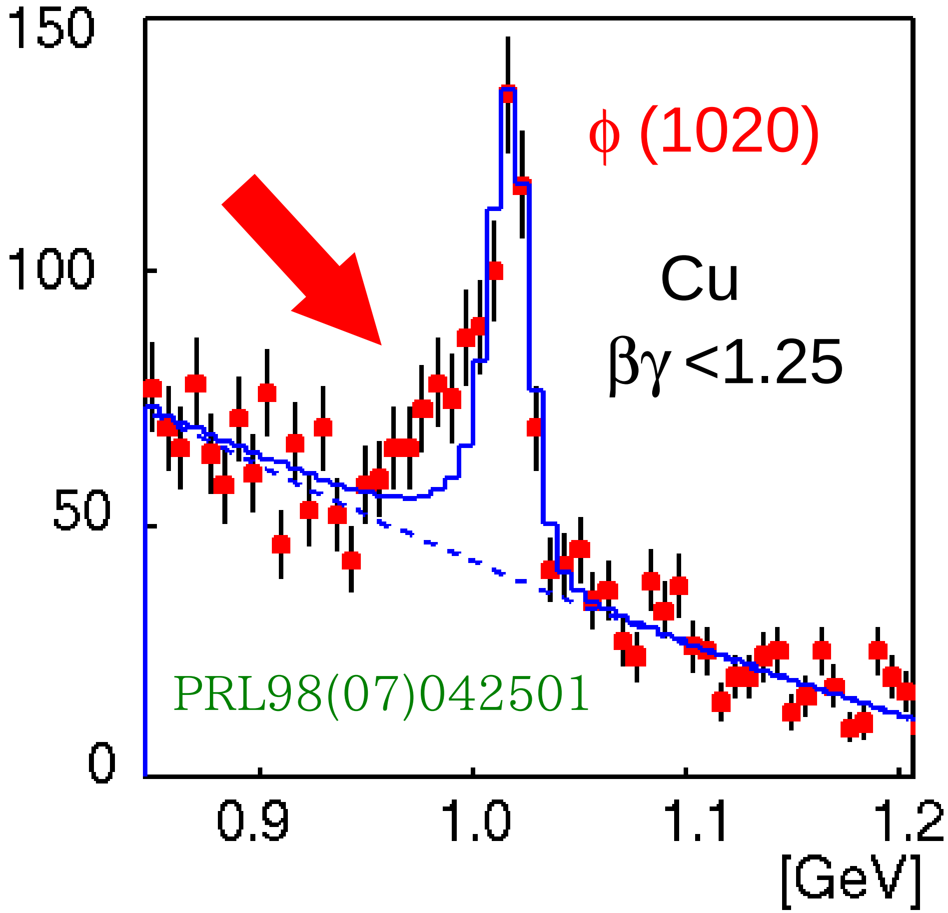
longer-life meson(ω & ϕ)cases : Schematic picture



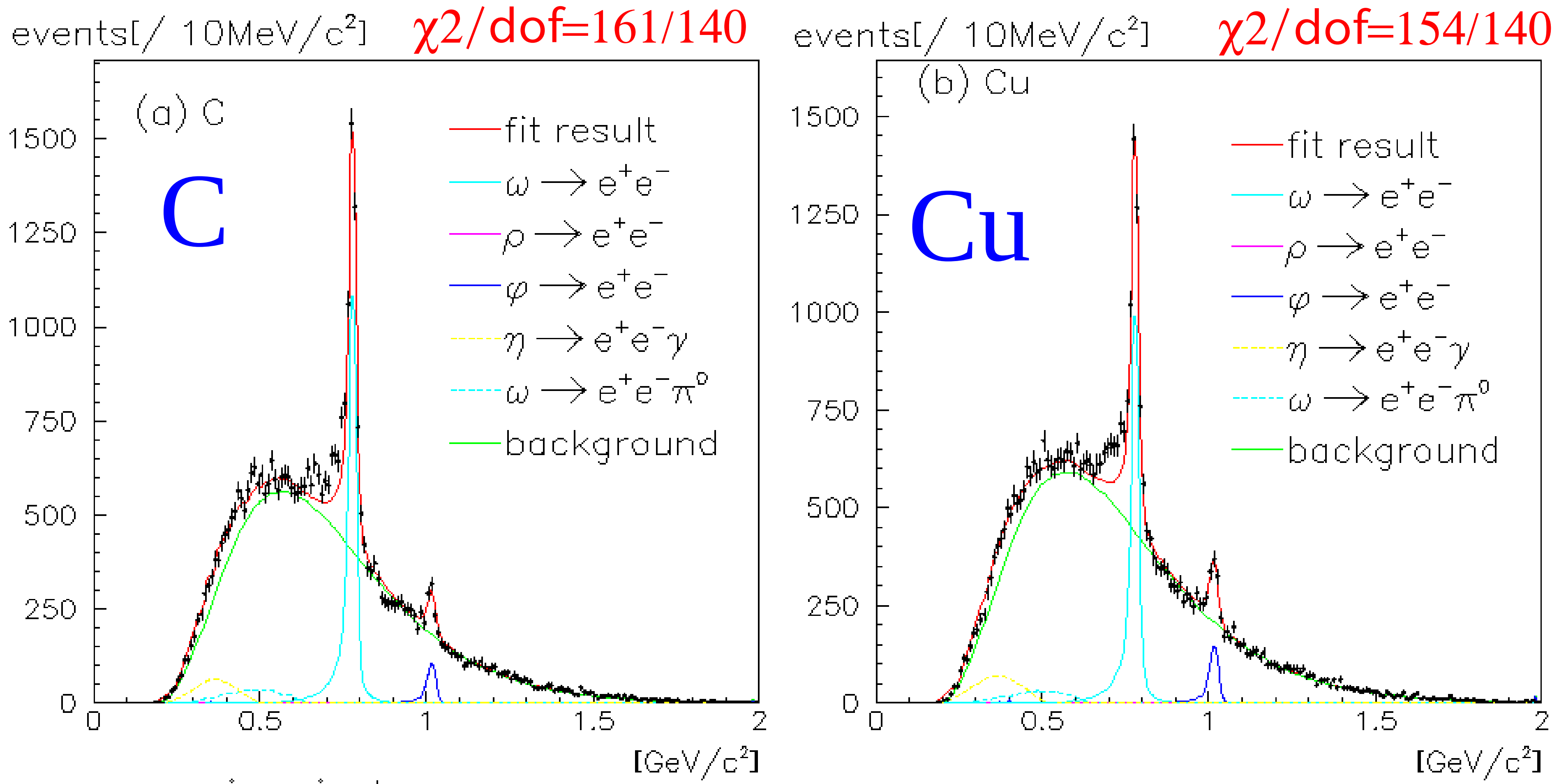
E325 observed the meson modifications

- 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)



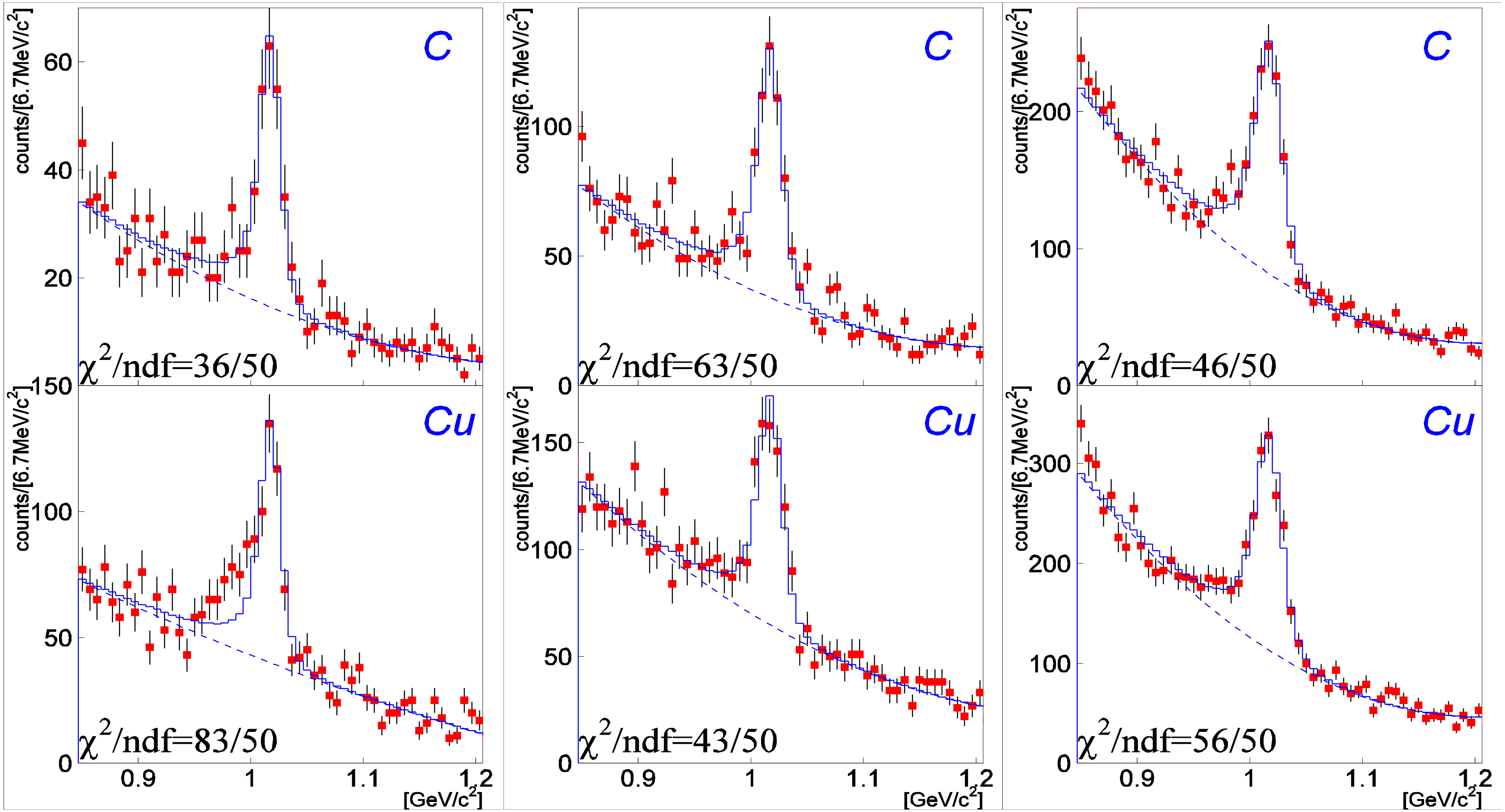
1) excess at the low-mass side of ω

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)

$e^{\pm}e^{-}$ spectra of ϕ meson (divided by $\beta\gamma$)

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



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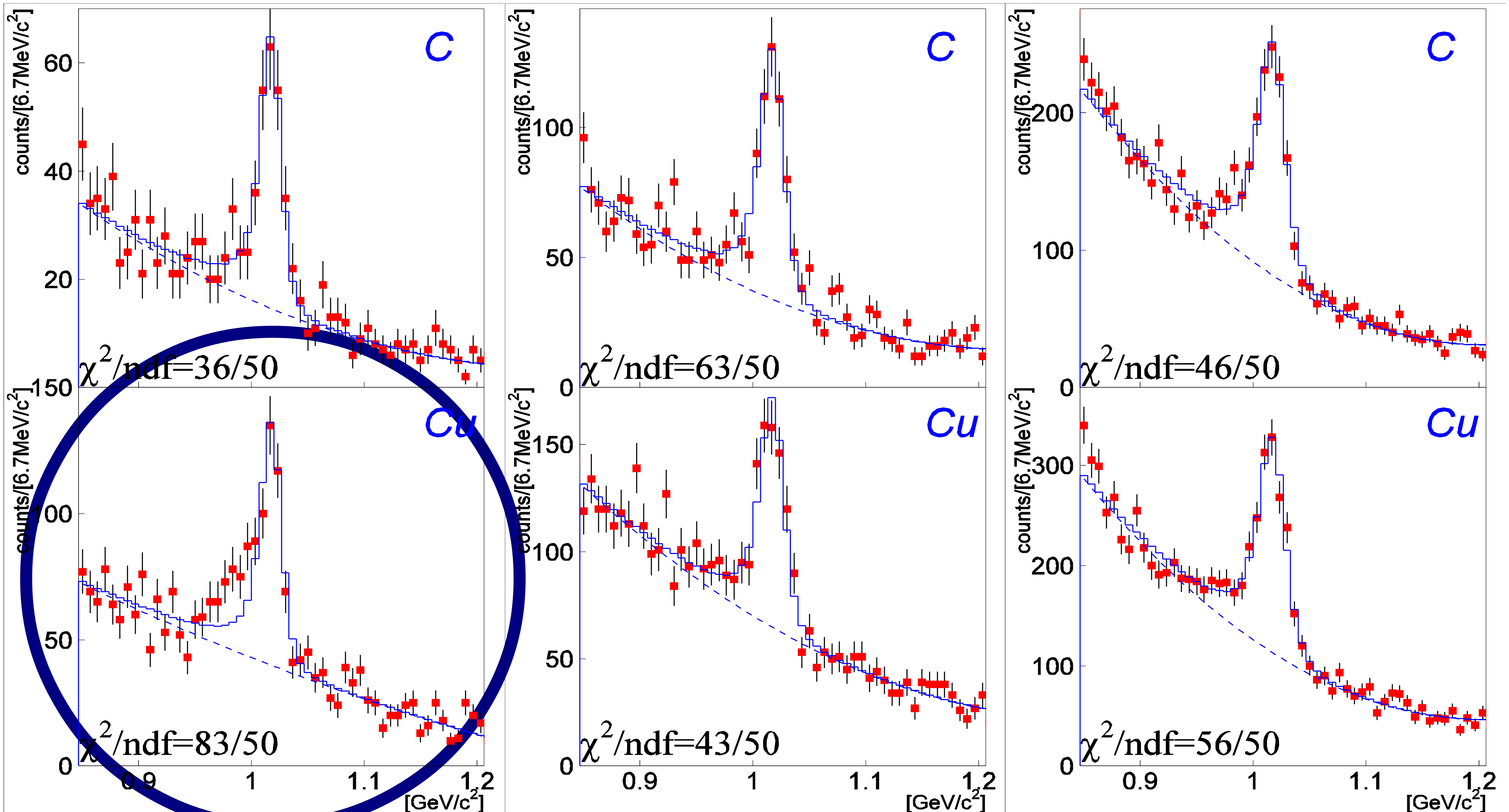
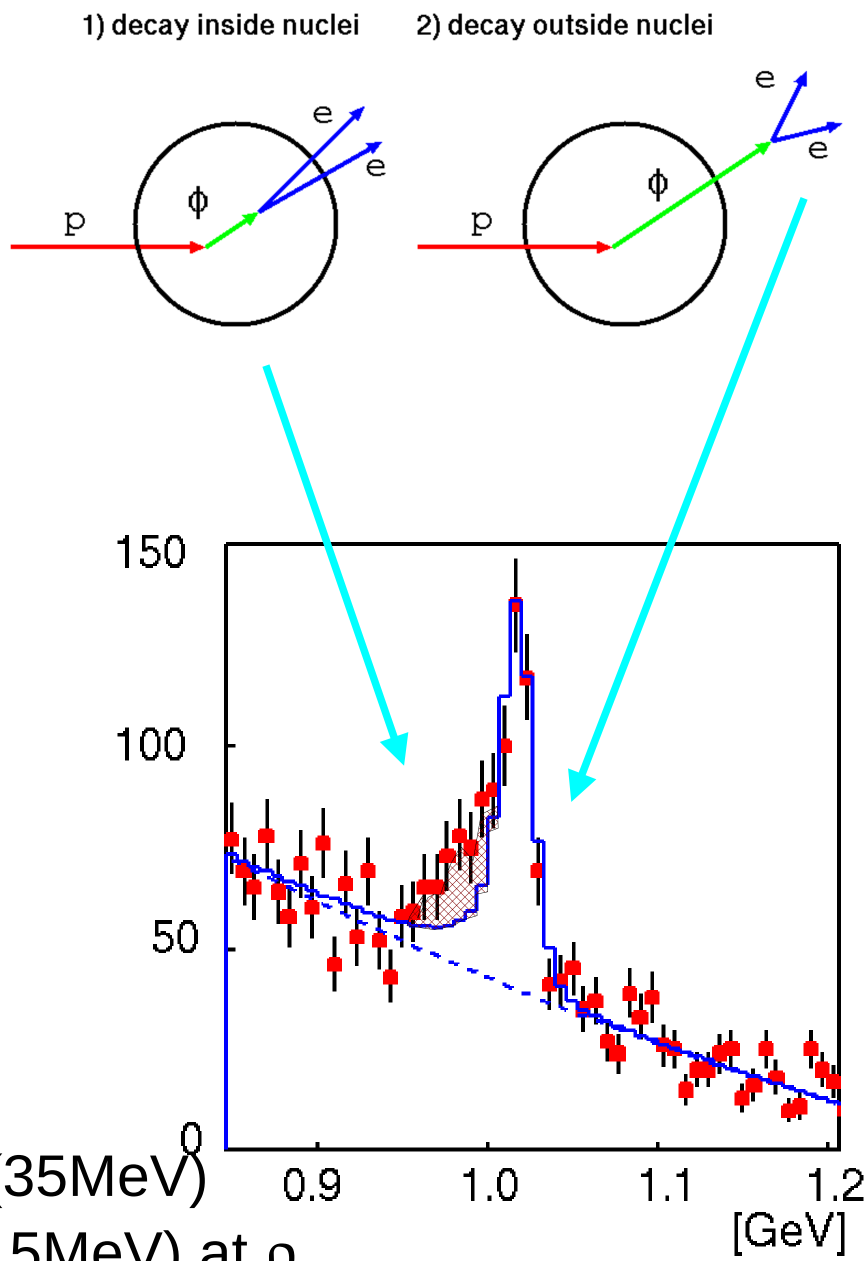


only slow/Cu is not reproduced in 99% C.L.

Discussion : modification parameter

- 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)



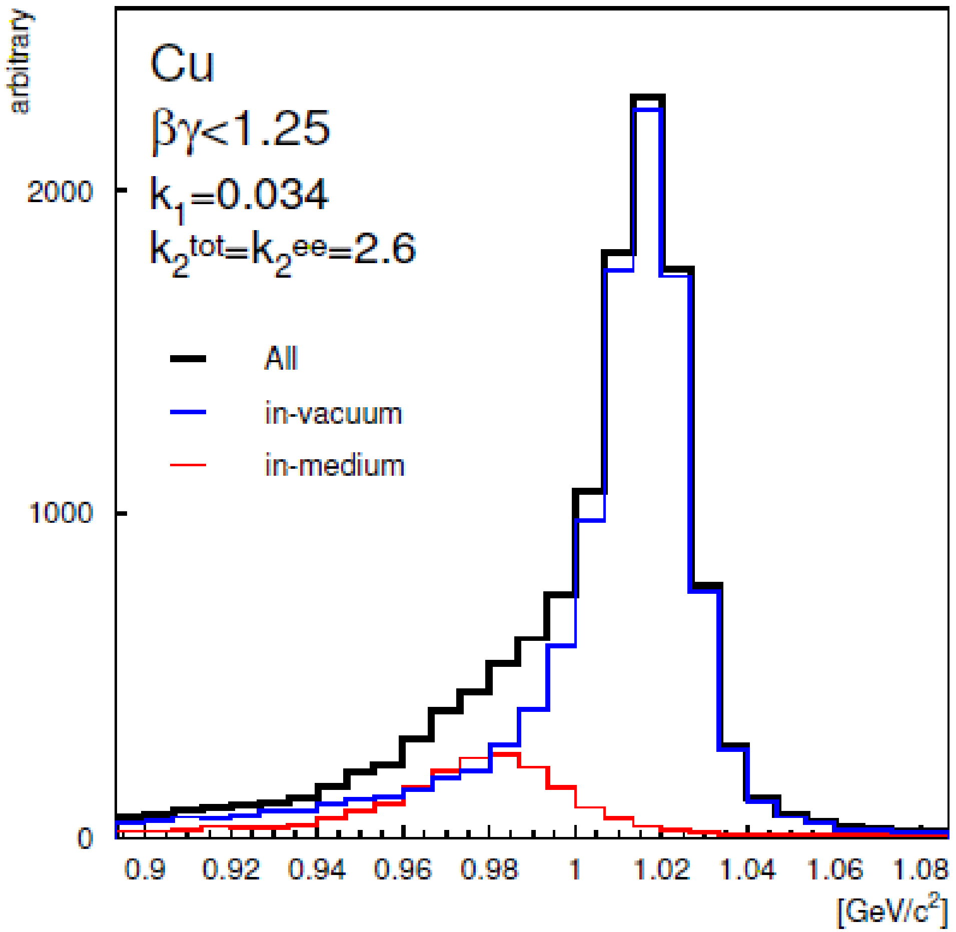
$$k_1 = 0.034^{+0.006}_{-0.007}$$

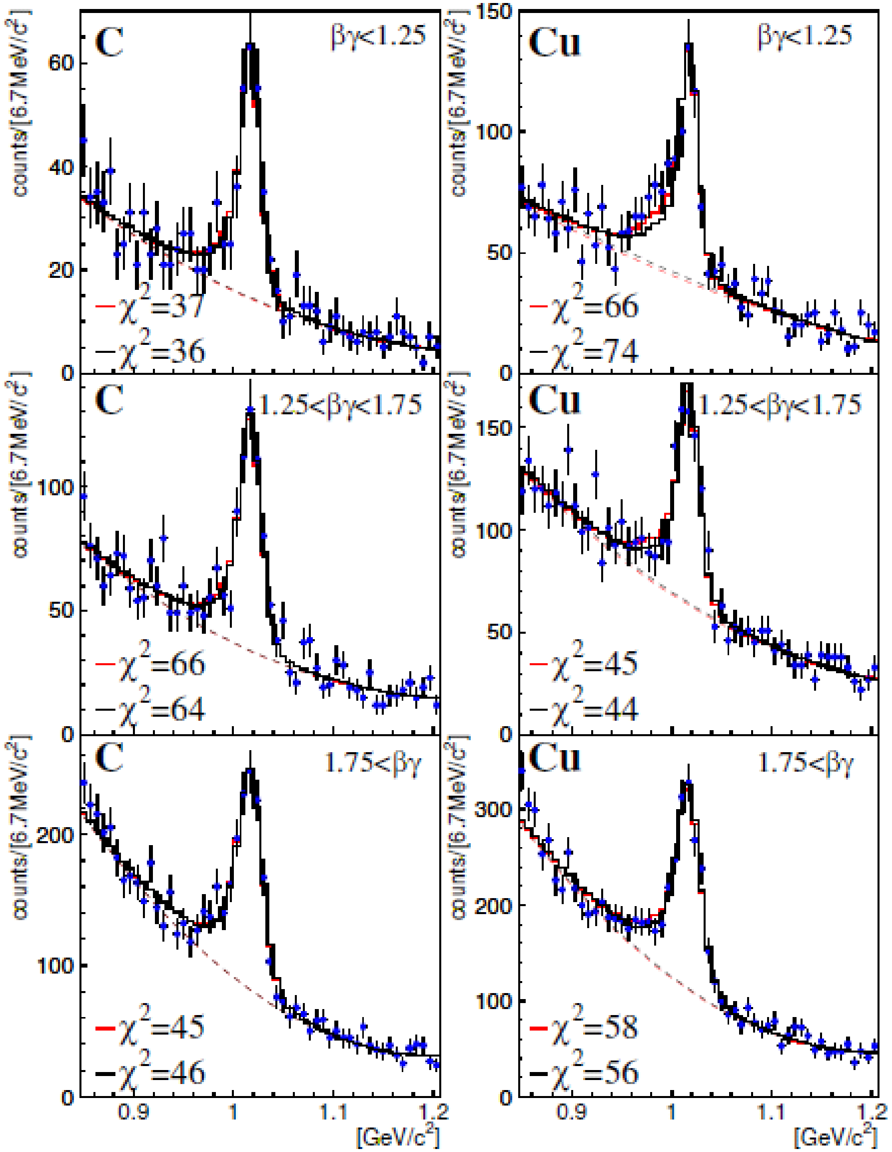
$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$

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

Modified shape of ϕ

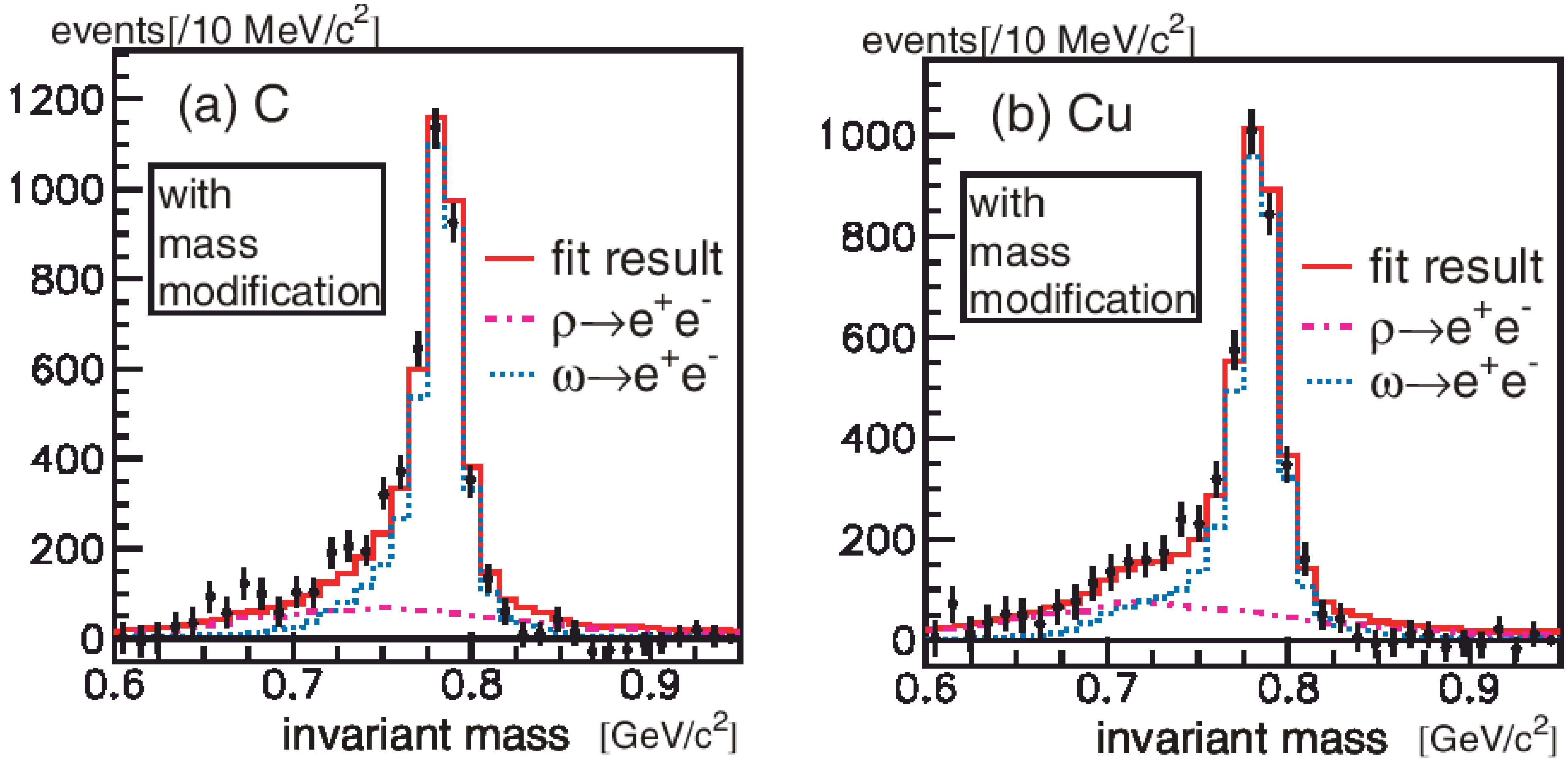
- Cu, $\beta\gamma$ <1.25,
- best fit values of k_1 and k_2





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

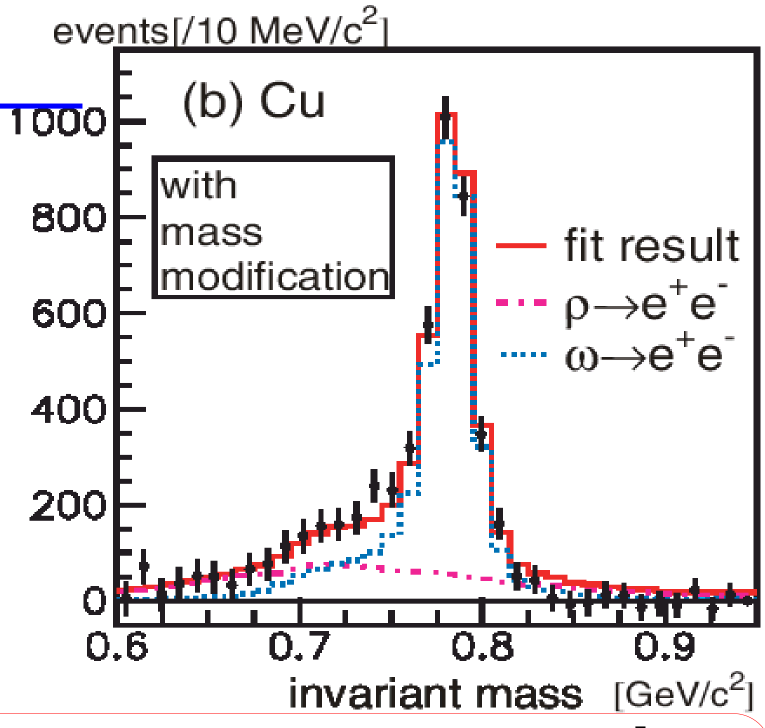


From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density

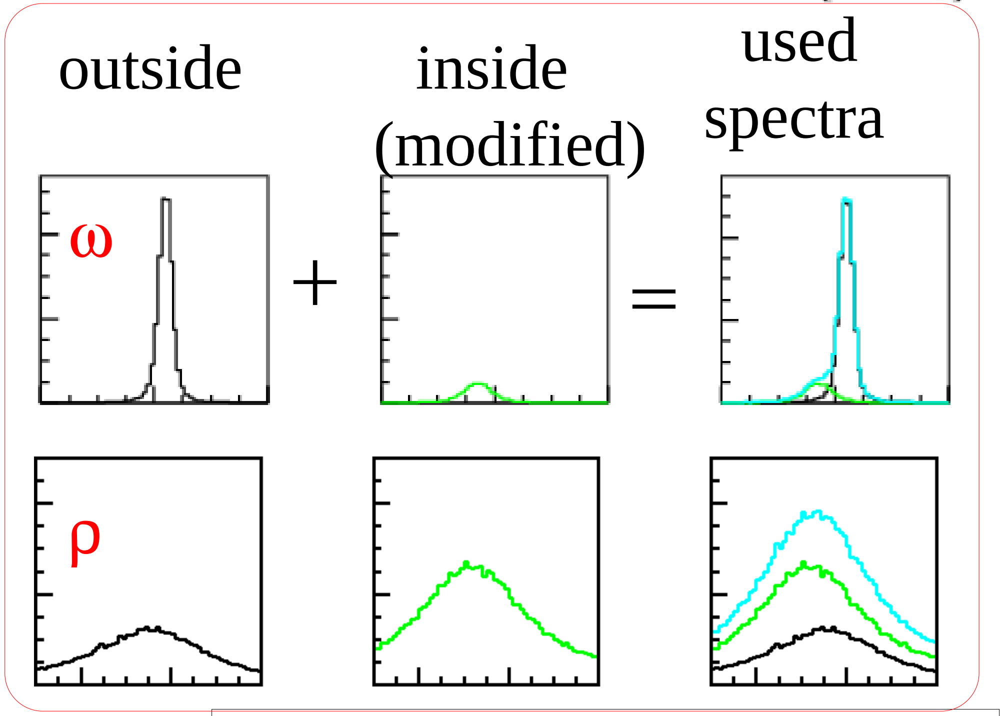
ρ/ω production ratio : 0.7± 0.1 (C), 0.9±0.2 (Cu) : ... ρ meson returns.

Note: if k_ω is assumed to be 0 (*i.e.* not modified), k_ρ could be smaller.

Remark on the model fitting



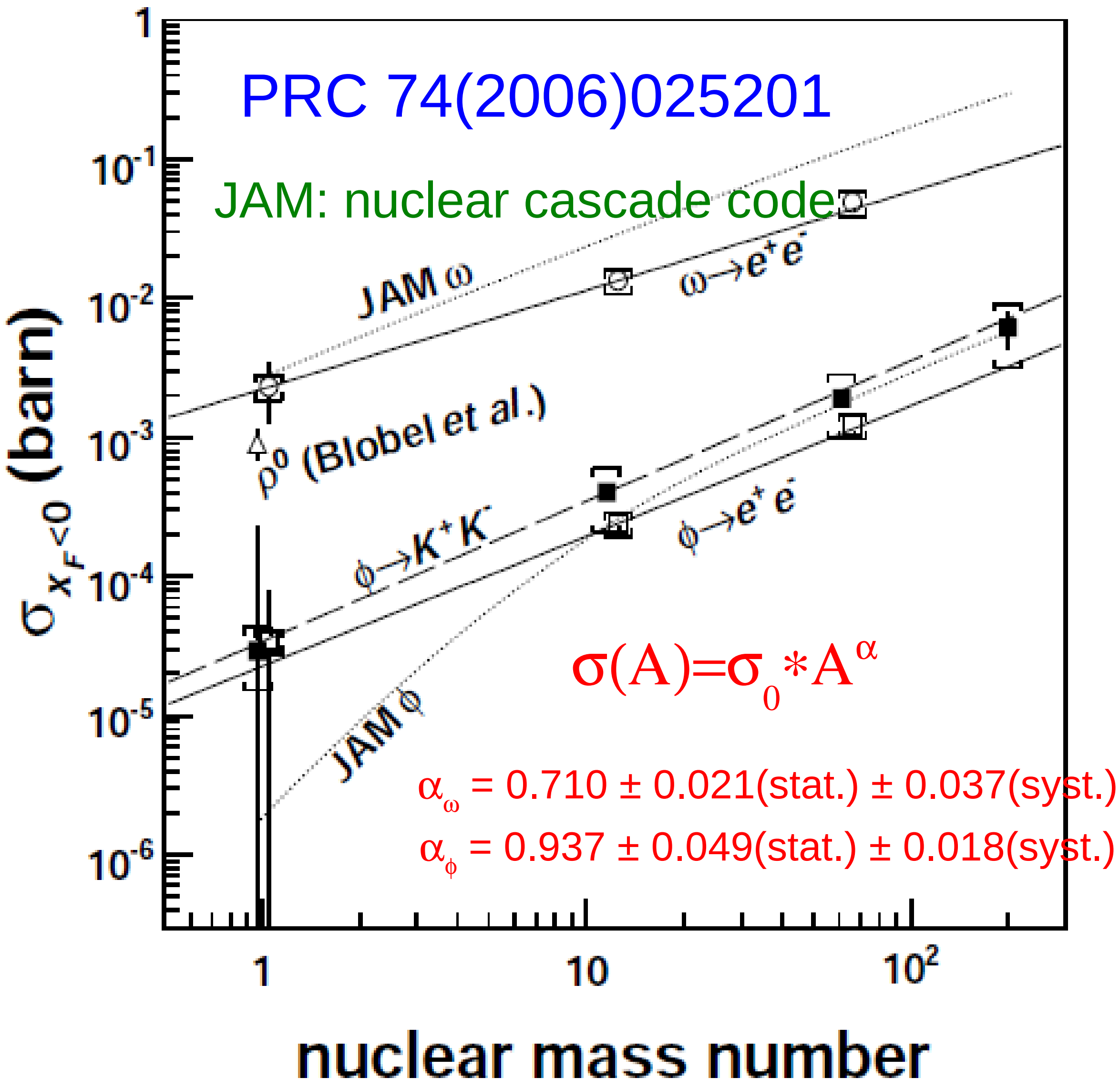
- constraint at right side of peak
  - Introducing the width broadening (x2 & x3) are rejected by this constraint
  - prediction of ' ρ mass increasing' is also not allowed.
- ρ (ω) decay inside nucleus : 46%(5%) for C, 61%(10%) for Cu
  - used spectrum is the sum of the modified and not-modified components.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



measured production CS of ω & ϕ

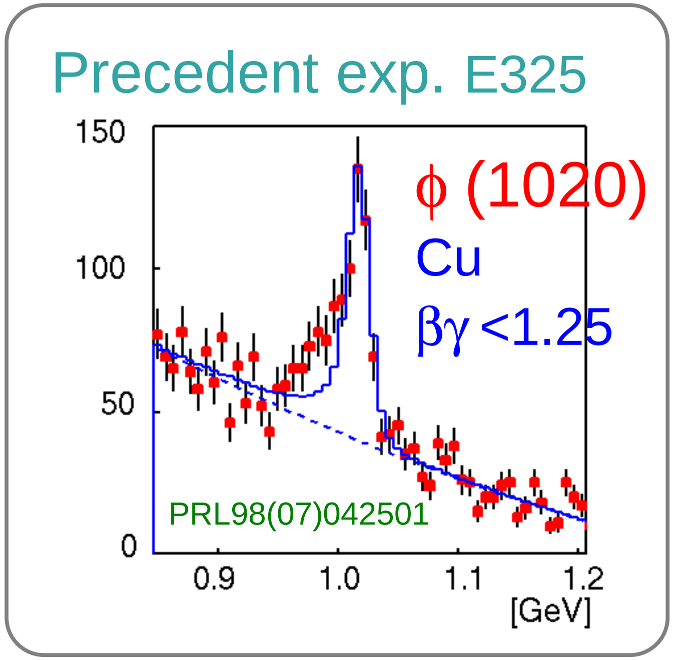
- values for the CM backward
- consistent w/ the former measurement for ρ meson by Blobel (PLB48(1974)73)
- Nuclear dependence α_ϕ = 0.937 corresponds to about $\sigma_{\phi N}$=3.7mb (Sibirtsev et.al. EPJA 37(2008)287)
- additional Γ=12 MeV for 2 GeV/c ϕ (β=0.9) : consistent with $\Gamma=15^{+8}_{-5}$ MeV (i.e. $k_2=2.6^{+1.8}_{-1.2}$)
- Remark:

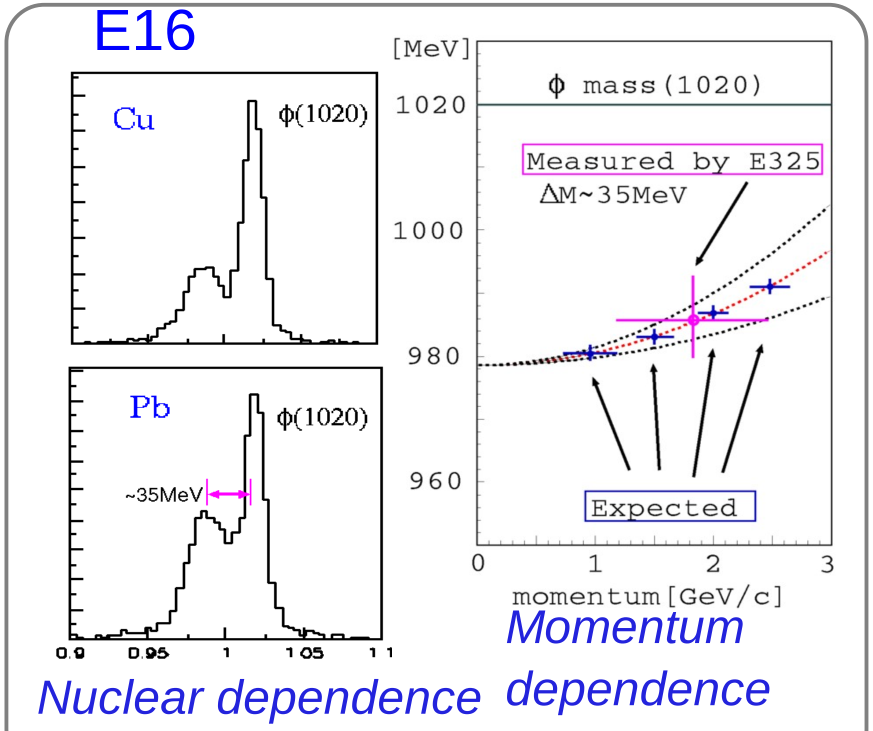
  Γ_ϕ=15MeV at m_ϕ=985MeV is consistent with Oset & Ramos (NPA679(2001)616)



J-PARC E16

- Systematic measurements of the spectral change of ϕ (and ρ/ω) in nuclei throught the e^+e^- channel with highest statistics (100000 ϕ) & best mass resolution (5 MeV) in the world
  - confirm the results of precedent exp. KEK-PS E325, establish the spectral change of $\phi/\rho/\omega$ in nuclei w/ higher statistics
  - nuclear matter size dependence (H, C, Cu, Pb) : double-peak shape for the very slowly-moving ϕ mesons in larger nuclei
  - first measurement of the momentum dependence (dispersion relation) in nuclear matter
- New spectrometer is required to collect high statistics, to cope with the 10MHz interactions at the target w/ 30 GeV primary proton beam of $\sim 10^{10}$ pps

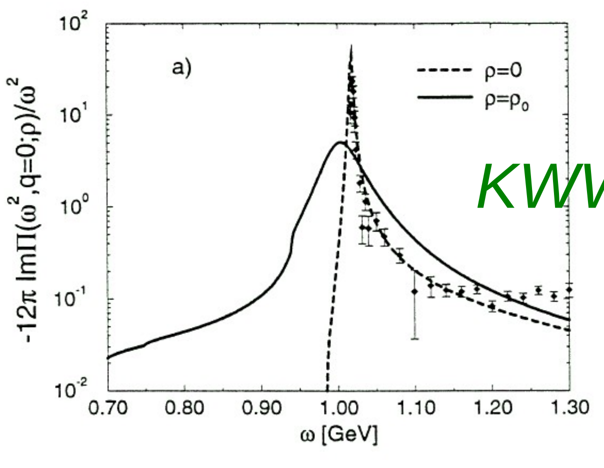




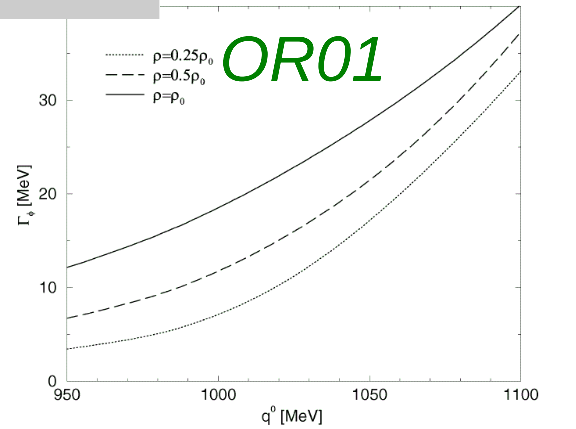
theory: spectral modification of ϕ at ρ_0

parametrize the predicted spectral change with m & Γ

ϕ meson in vacuum	m = 1019.456 MeV	Γ= 4.26 MeV
KEK-PS E325 experiment PRL 98 (2007) 042501	Δm = –35(28~41) MeV	15 (10~23) MeV
Hatsuda & Lee PRC 46 (1992) R34	Δm = –(12-44)MeV	not estimated
Klingl, Waas, Weise PLB 431(1998) 254	Δm < – 10MeV	~45 MeV
Oset & Ramos NPA 679 (2001) 616	Δm < – 10MeV	~22 MeV @ m=1020 ~16 MeV @ m=985
Cabrera & Vacas PRC 67 (2004) 045203	Δm = – 8MeV	~30 MeV @ m=1020



KWW98

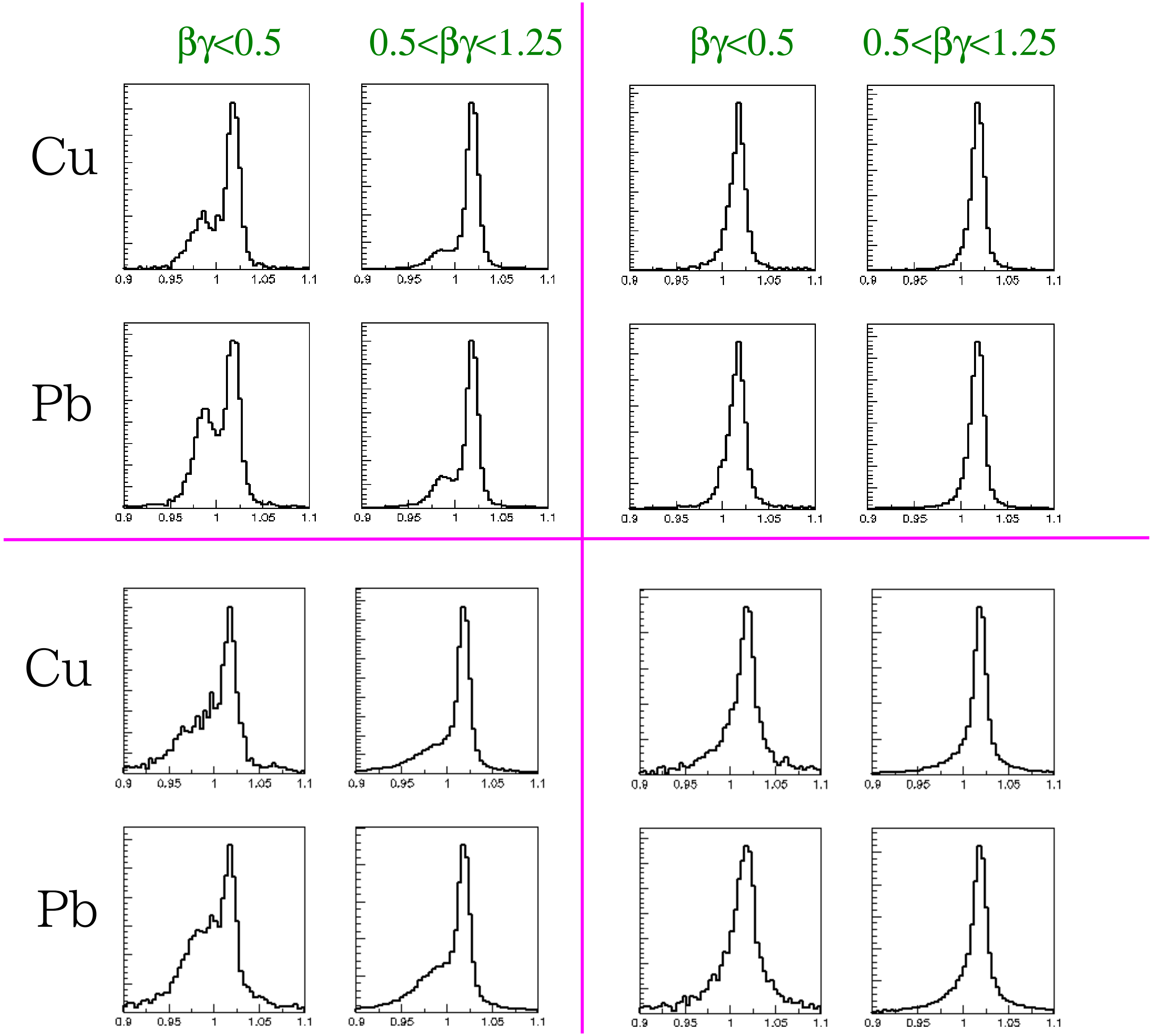


OR01

expected shape w/ various parameters

E325 Δm : -35 MeV Γ : 15 MeV	OR-01 Δm : -10 MeV Γ : 15 MeV
- Δm : -35 MeV Γ : 50 MeV	KWW-98 Δm : -10 MeV Γ : 50 MeV

- using the parameters, spectra are approximated with the relativistic Breit-Wigner shape including experimental mass resolution



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E325	OR-01
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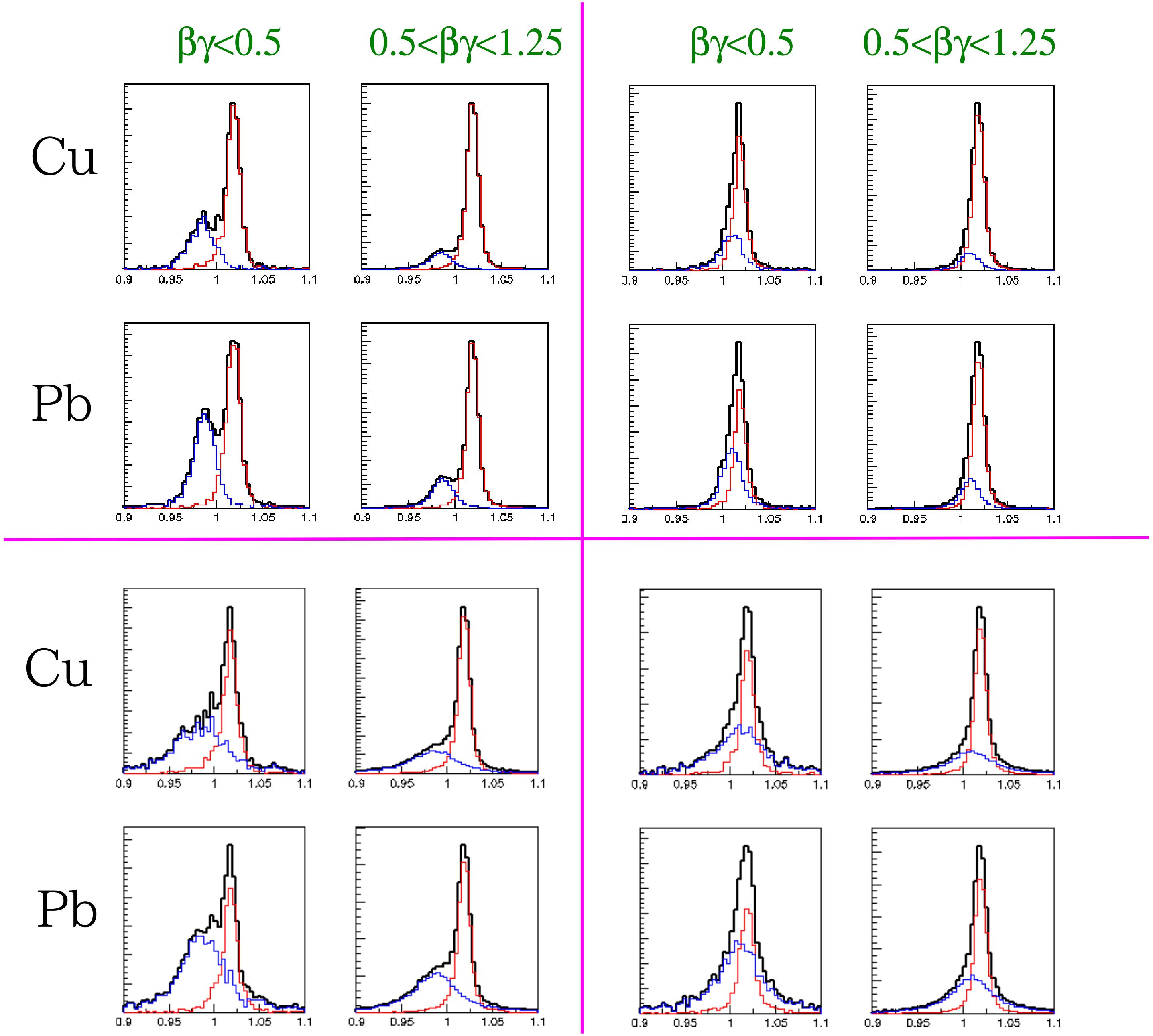
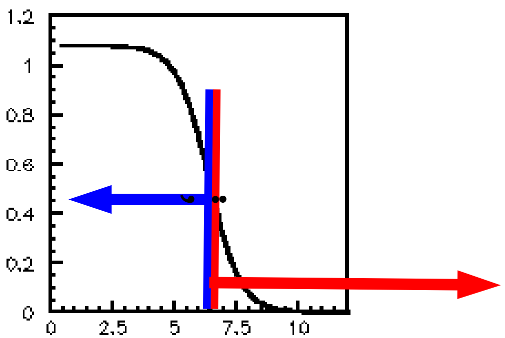
-	KWW-98
Δm : −35 MeV Γ : 50 MeV	Δm : −10 MeV Γ : 50 MeV

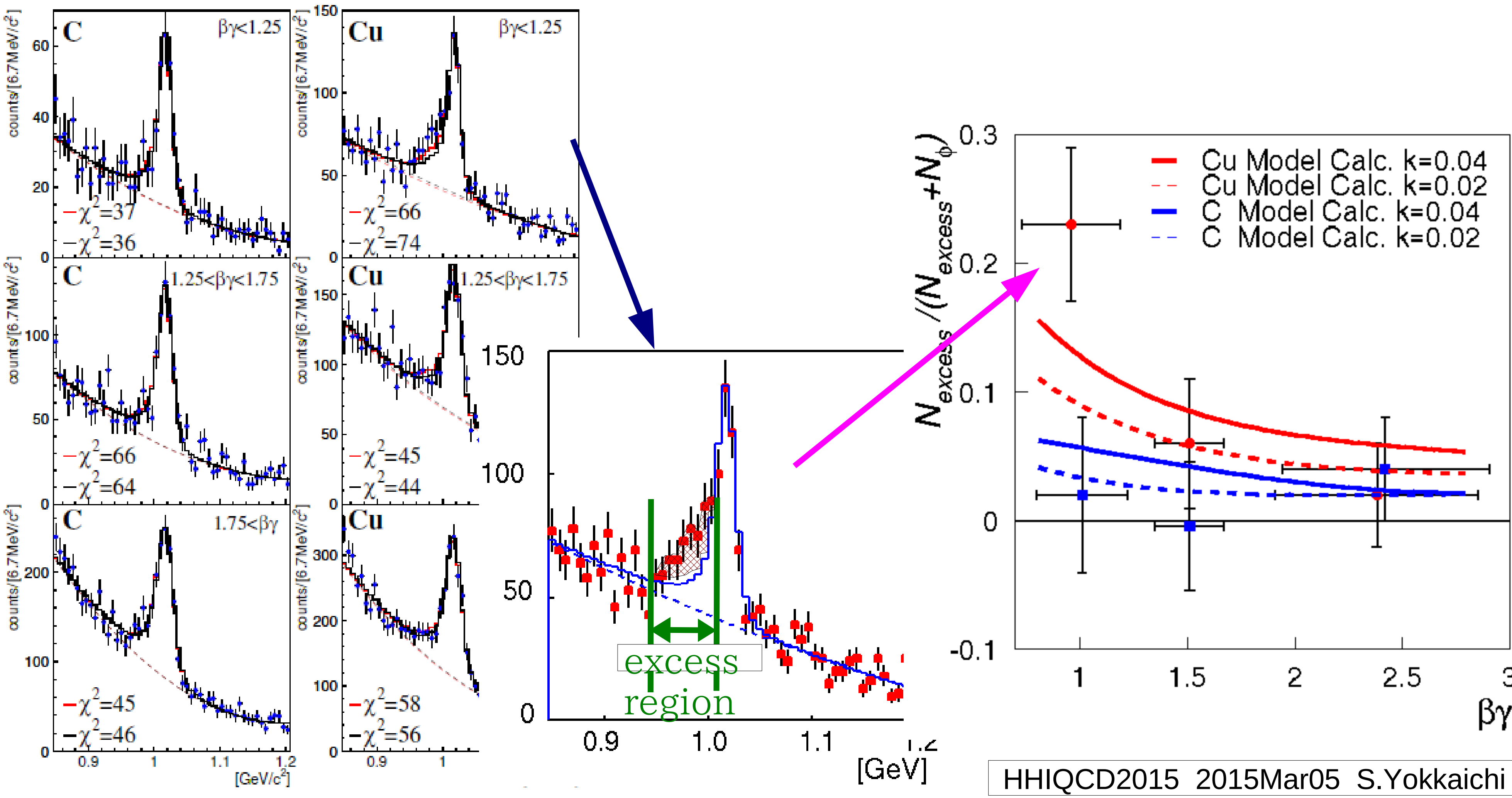


blue: decays inside the half-density radius of nuclei in the MC



velocity and nuclear size dependence

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



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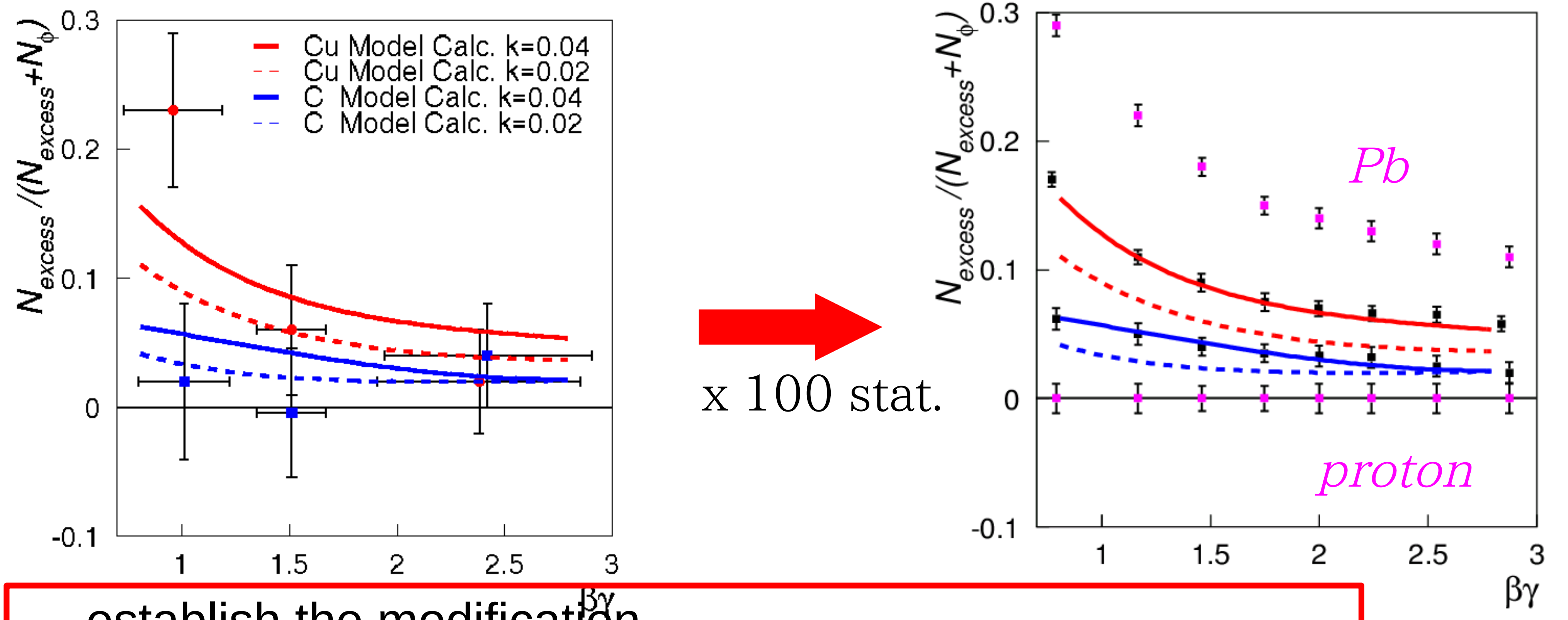
- systematic study : all the data should be explained the interpretation model



- establish the modification
-

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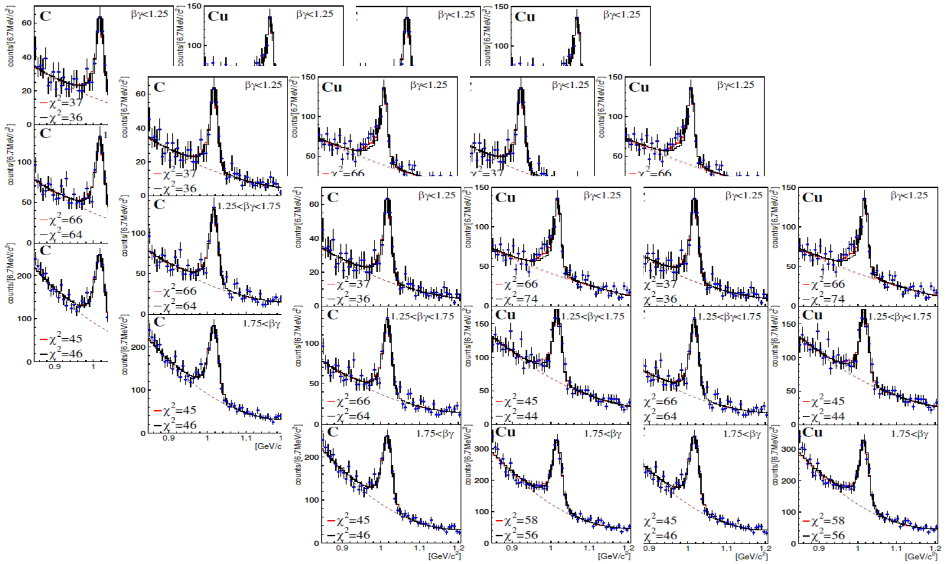
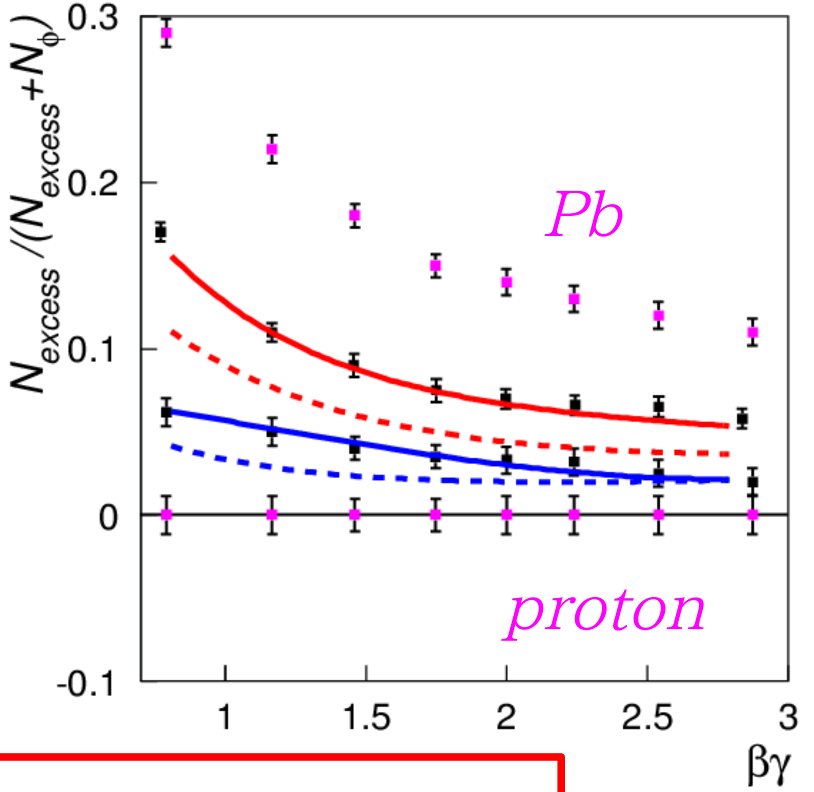
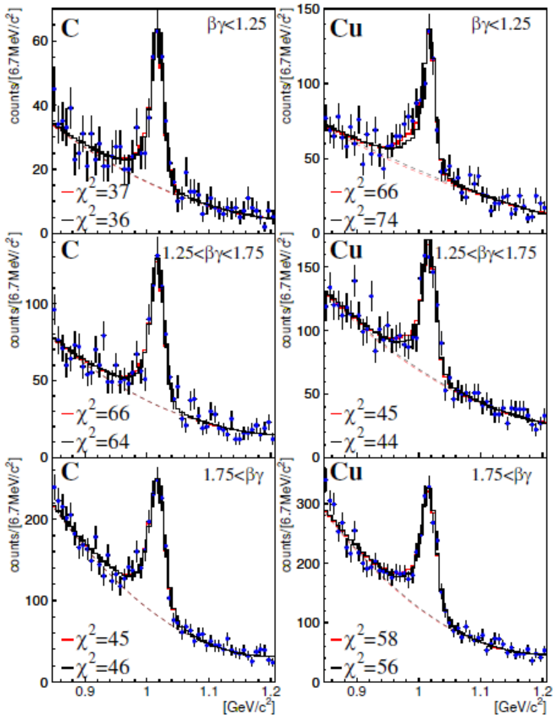


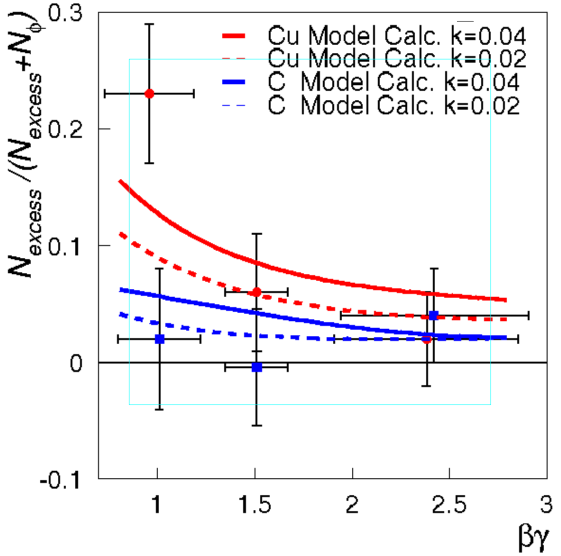


- establish the modification
- check the interpretation model with shape analysis for each histogram

dispersion relation (mass VS momentum)

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





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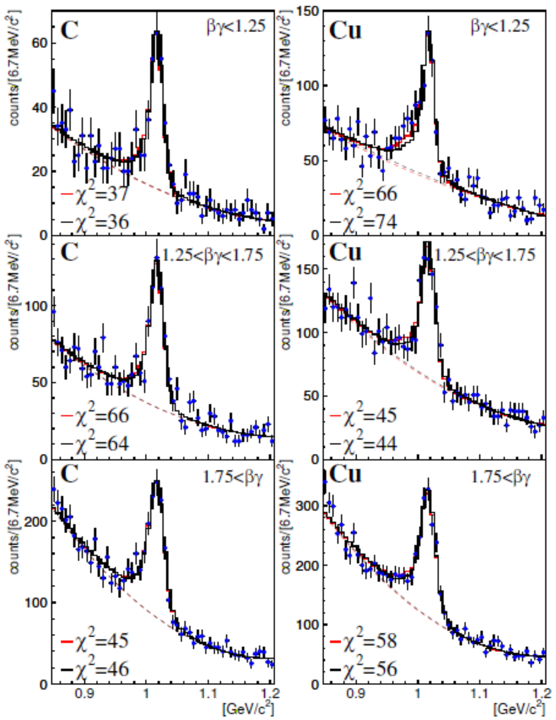
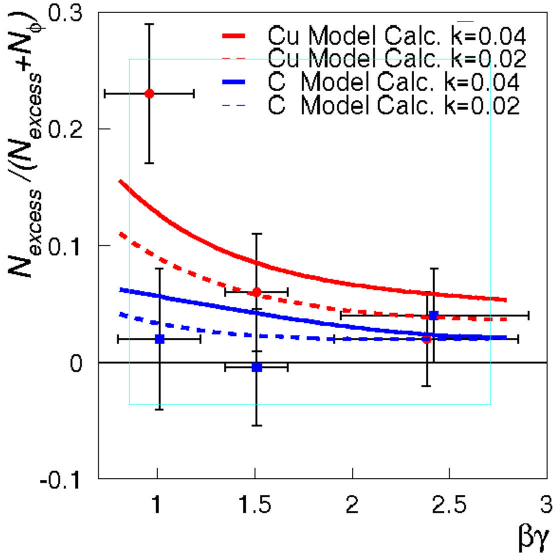
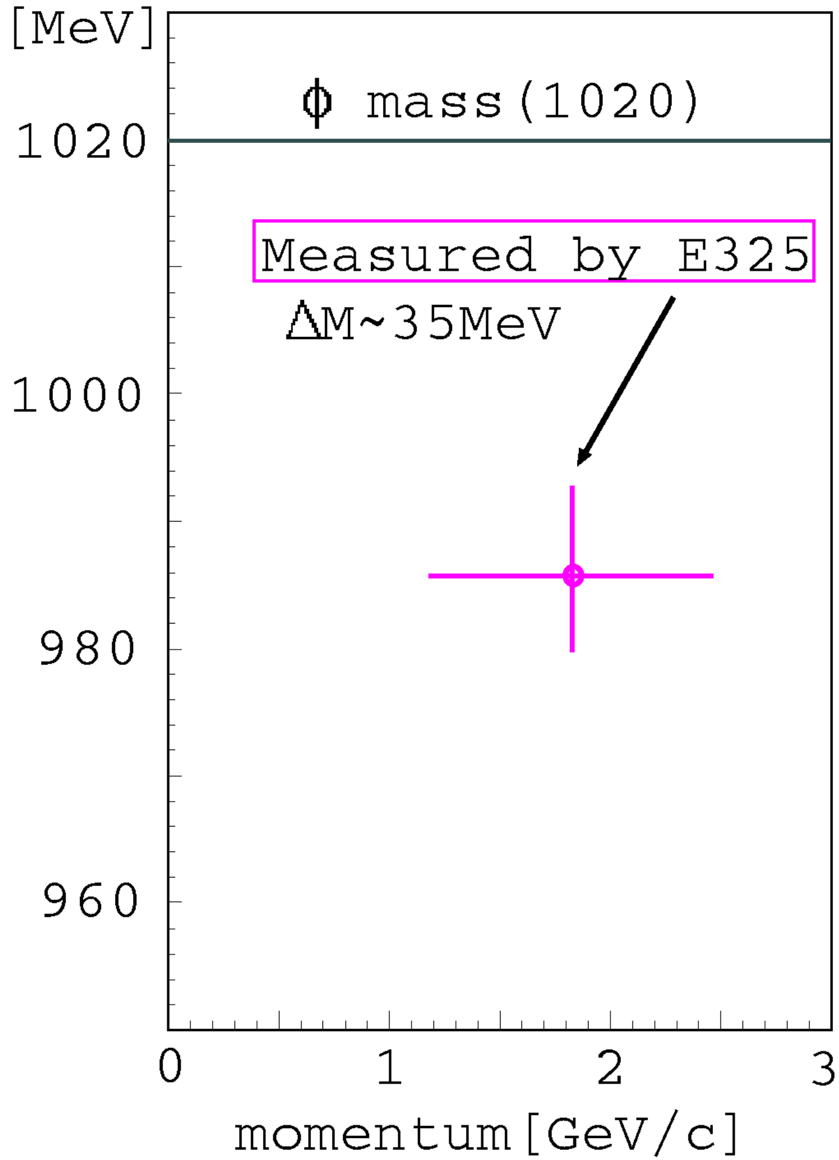
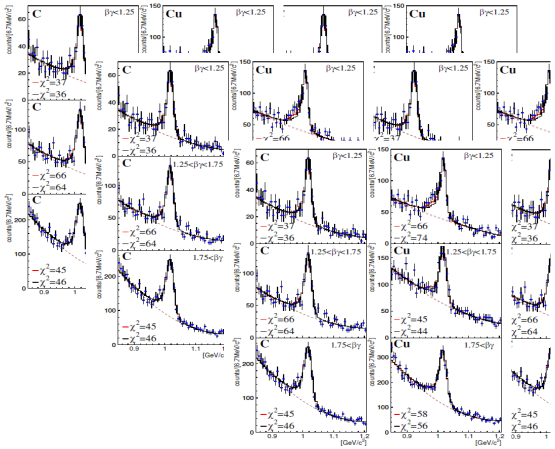


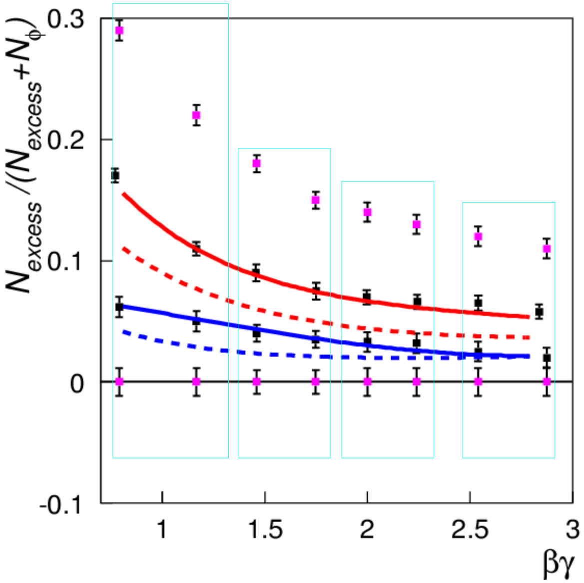


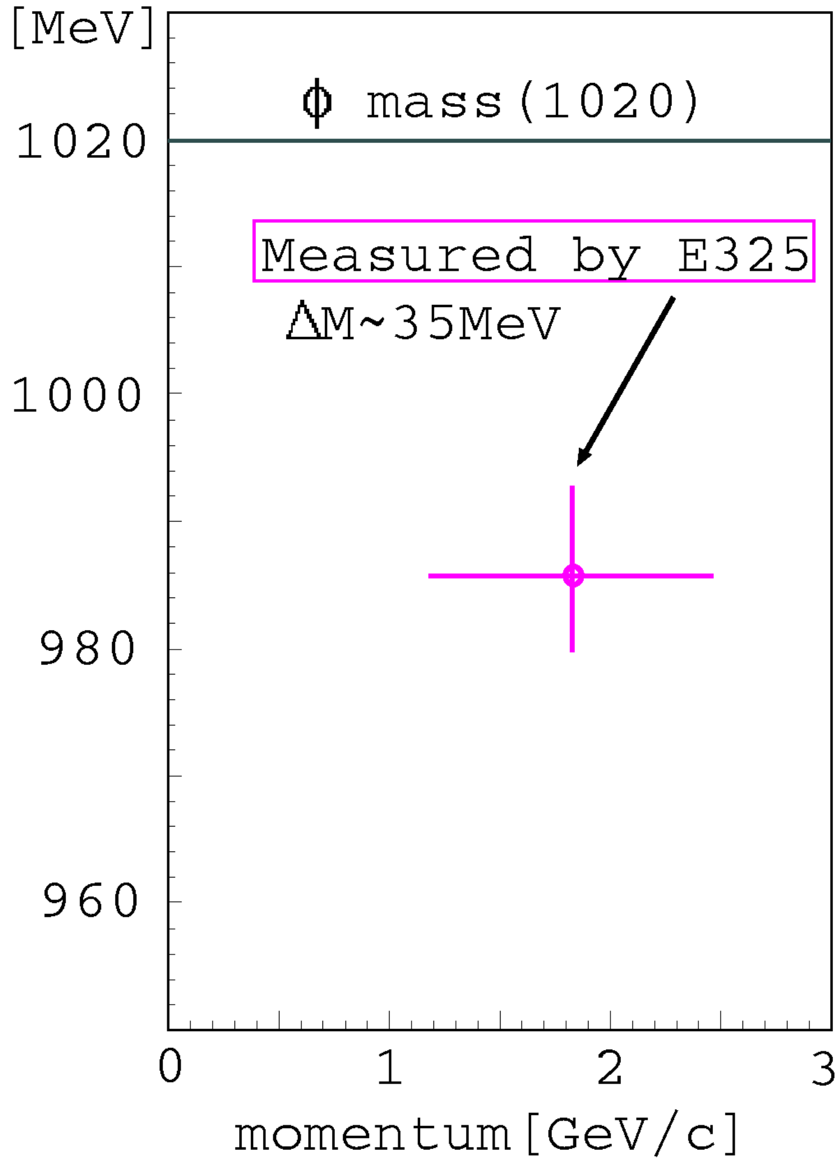


dispersion relation (mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV/c)
- current E325 analysis neglects the dispersion (limited by the statistics)
- In E16, momentum-dependent $k_1(p)$, can be deduced

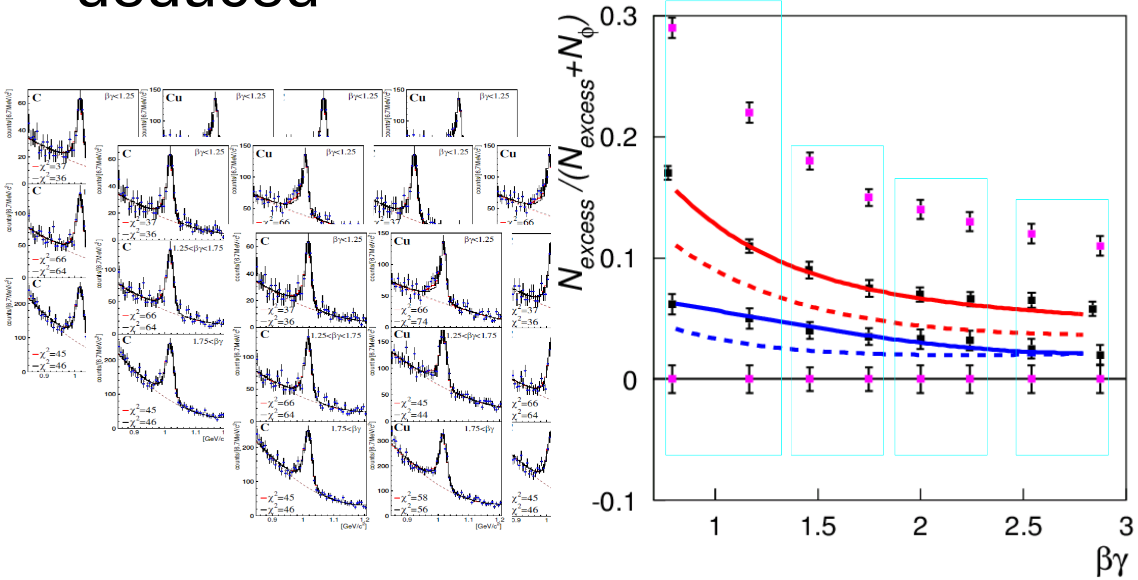




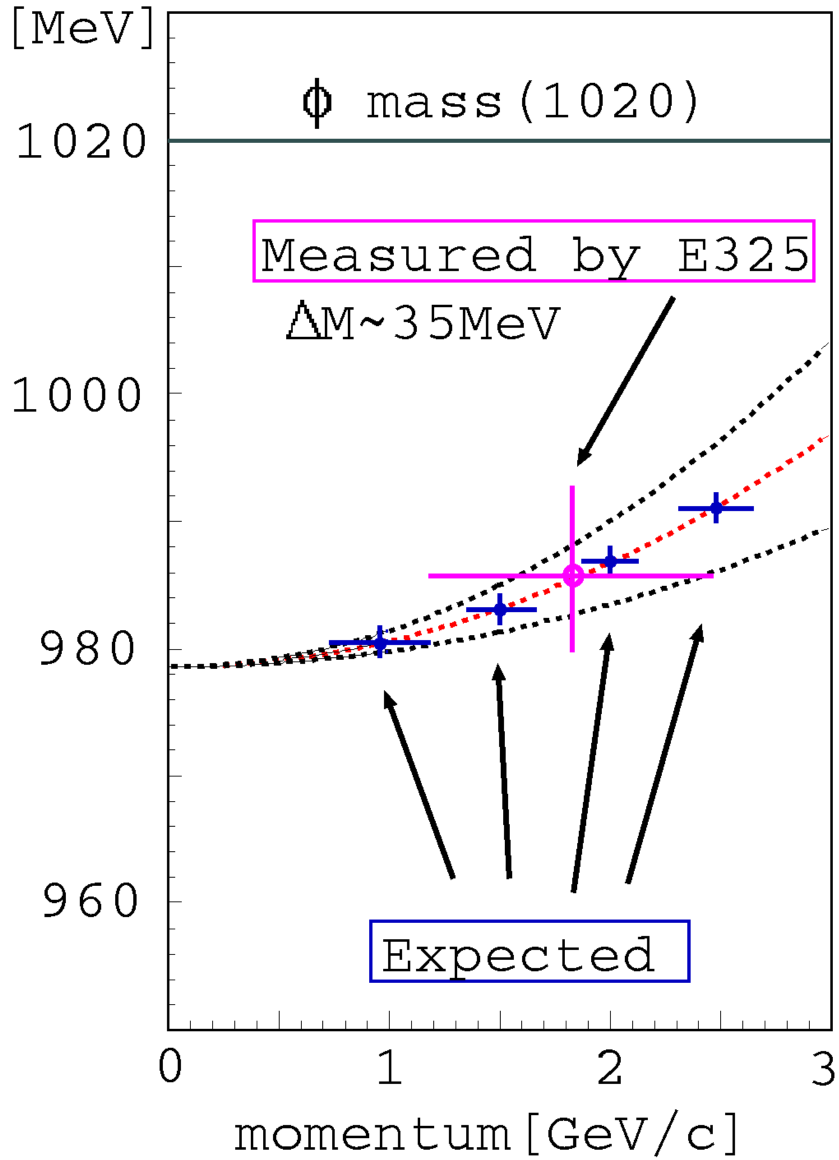


dispersion relation (mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV/c)
- current E325 analysis neglects the dispersion (limited by the statistics)
- In E16, momentum-dependent $k_1(p)$, can be deduced

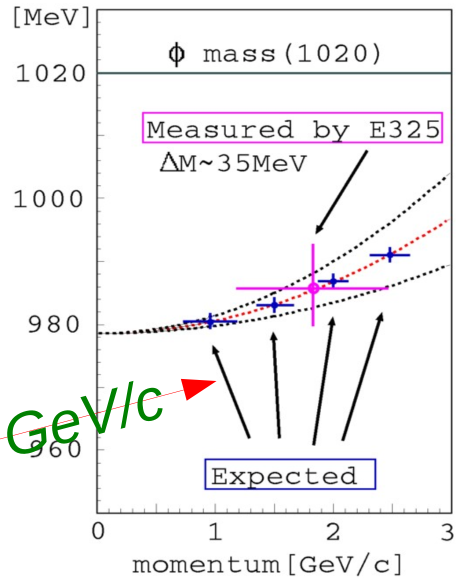


- prediction for ϕ by



momentum dependence

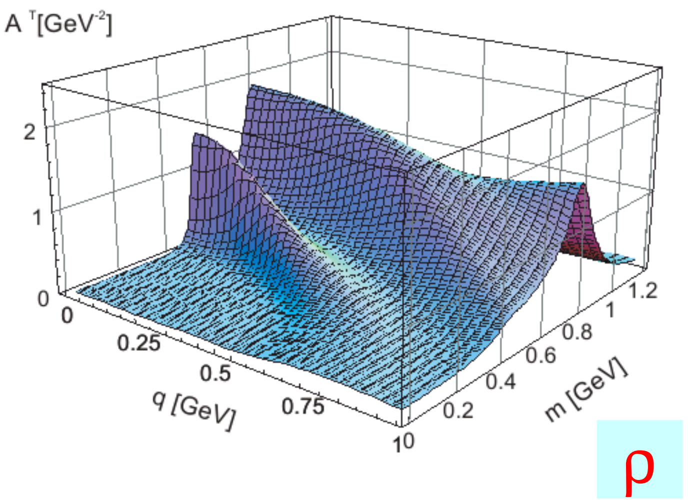
- many predictions are for the mesons at rest (p=0) while measurements are p>0
  - extrapolation to p=0 if it is a simple dependence



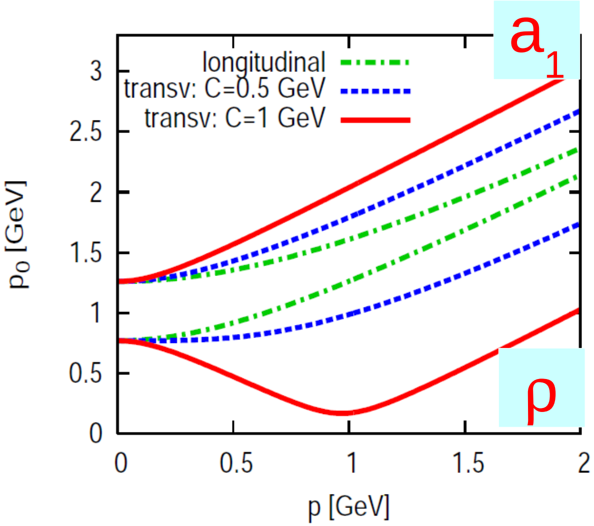
- S.H.Lee (PRC57(98)927) : $m^*/m_0 = 1 - k\ \rho/\rho_0$ for p<1GeV/c
  - ρ/ω : $k=0.16\pm0.06+(0.023\pm0.007)(p/0.5)^2$
  - ϕ : $k=0.15(\pm0.05)*y + (0.0005\pm0.0002)(p/0.5)^2$

extraporate to 3 GeV/c

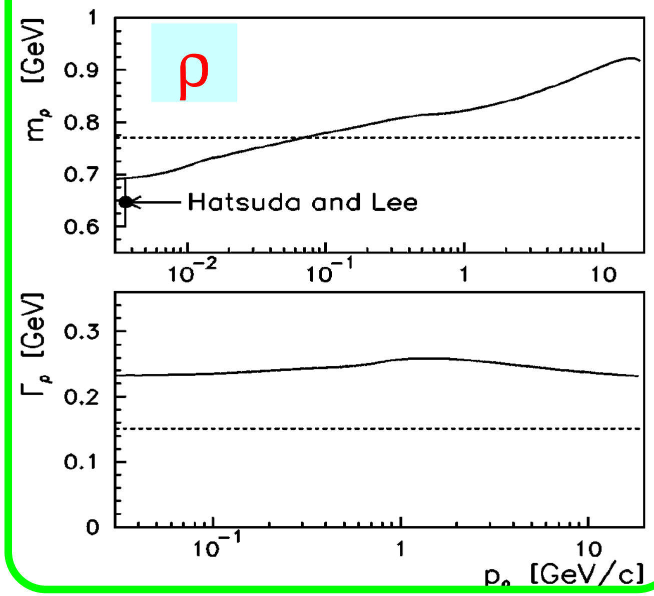
- Post &Mosel (NPA699(02)169)



- Harada & Sasaki (PRC80(09)054912)



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

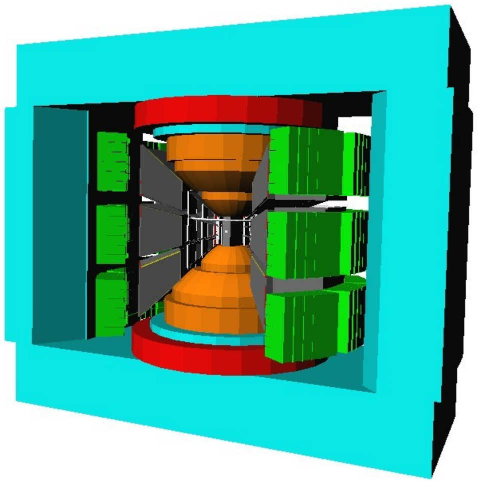


HHIÇ

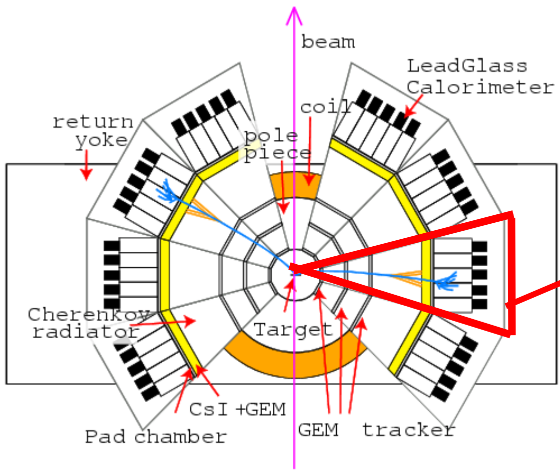
E16 Detectors

- ~10 MHz interaction at the targets with ~5 GHz of 30GeV proton beam
- Tracking : GEM Tracker (3 layers of X&Y)
  - 5kHz/mm^2 at the most forward, 100µm resolution(x) for 5MeV/c^2 mass resolution
- Electron ID : Hadron Blind Detector(HBD) & lead glass EMC (LG)
- Spectrometer Magnet : 1.77 T at the center, 0.78Tm for R=600 mm

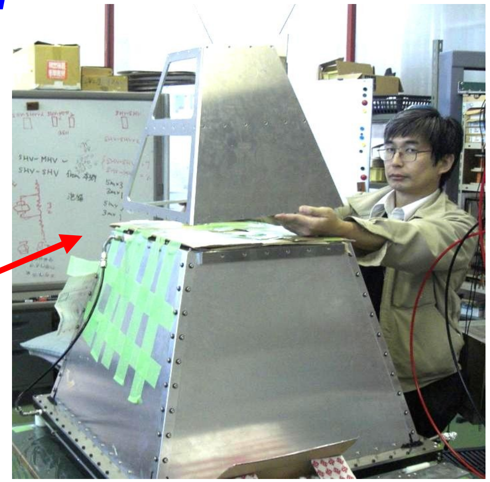
Proposed Spectrometer



Plan View



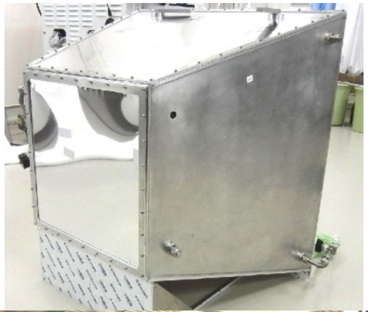
Prototype Module



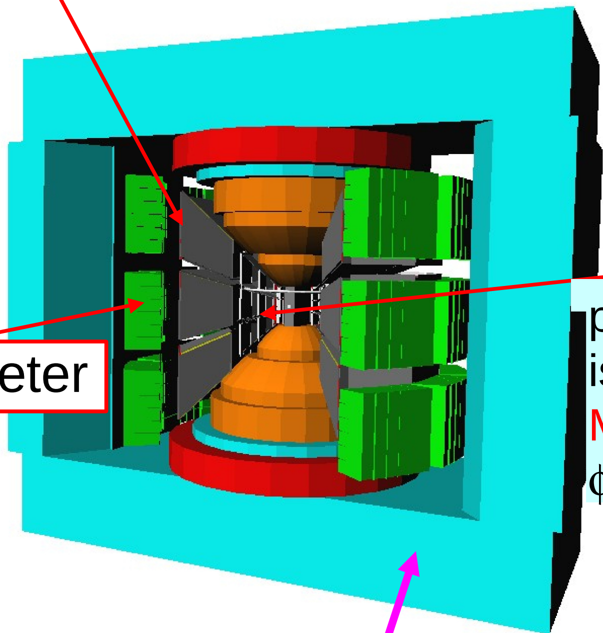
26 detector modules

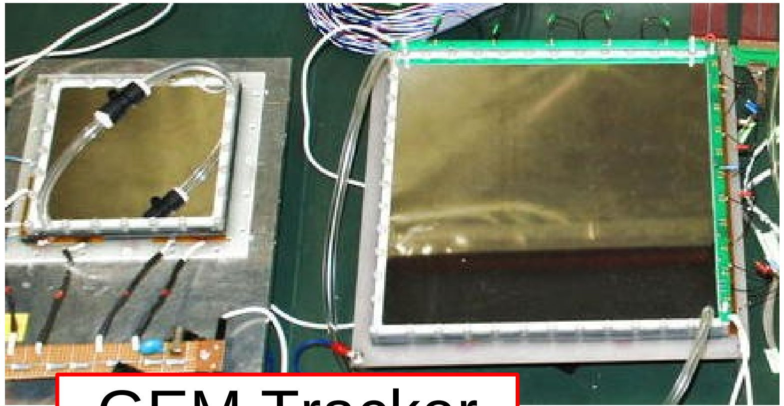
E16 : development & achieved performance

Hadron Blind Cherenkov Detector(HBD)



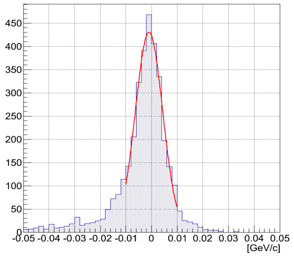
Lead-Glass EM Calorimeter



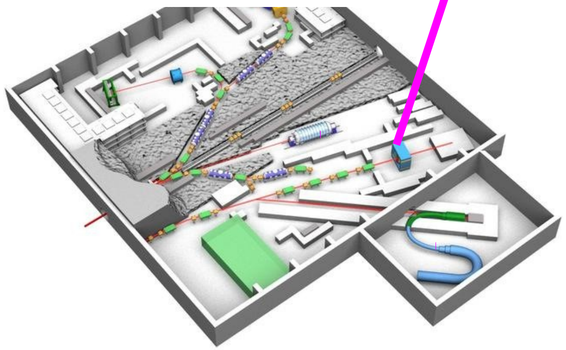


GEM Tracker

position resolution 100 μm is achieved to keep the ~5 MeV mass resolution for the ϕ mesons.



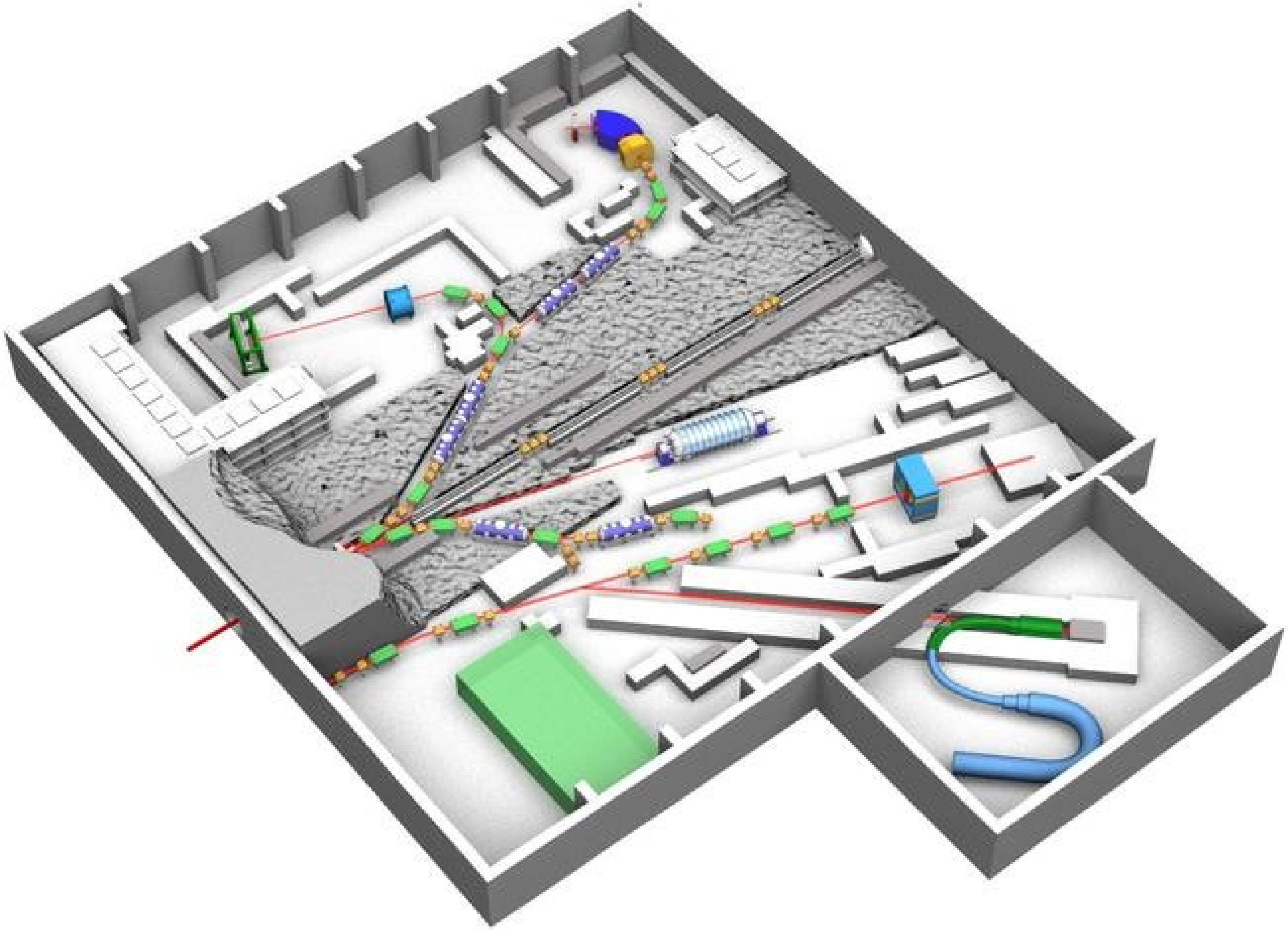
pion suppression down to ~0.1% is achieved with the combination of the two stage of electron-ID counters; HBD & LG



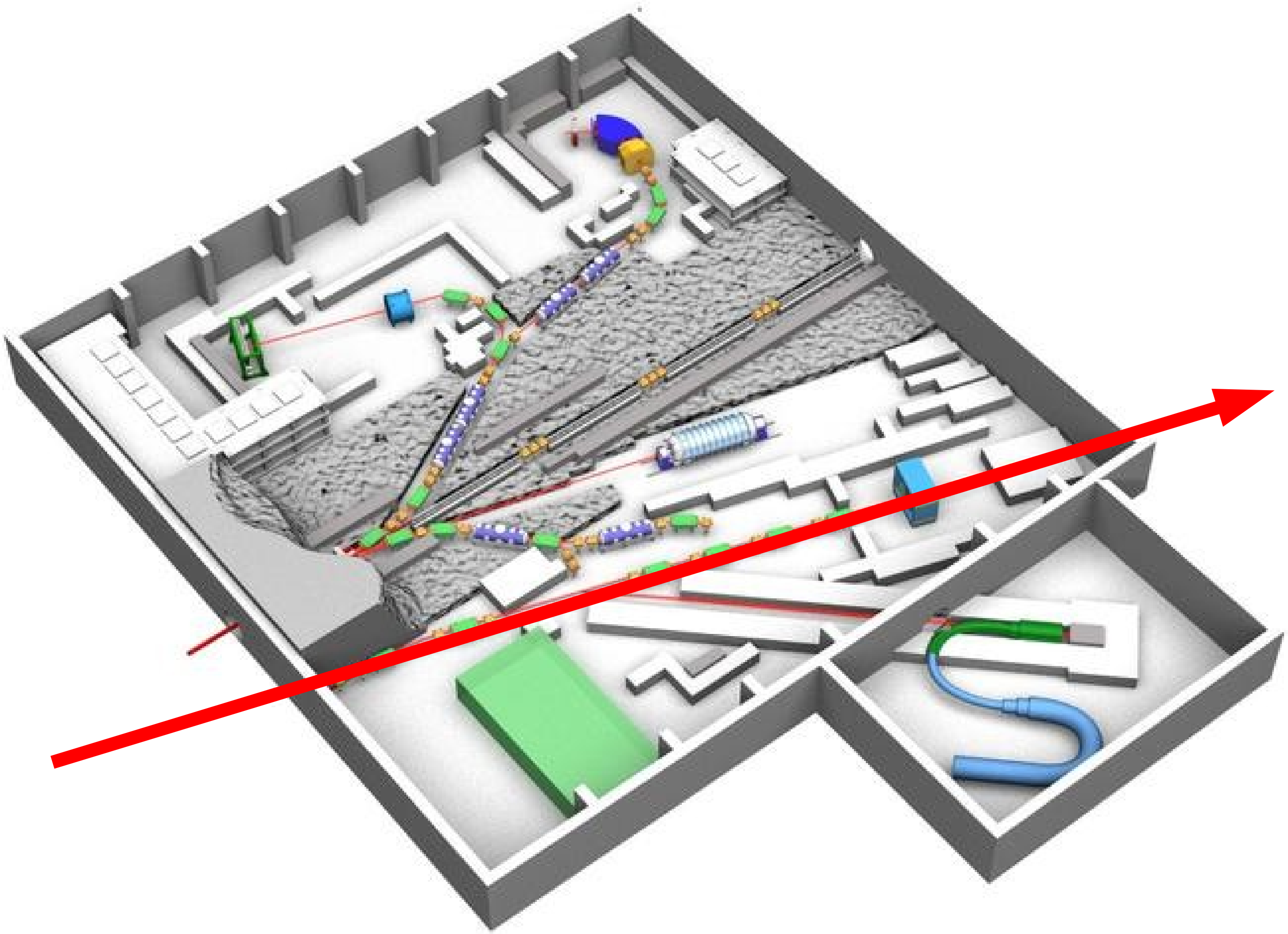
The spectromter magnet should be re-constructed and located at the new High-momentum beam line, which is under construction and completed in JFY 2016.

Experiment will start in early 2017.

Near future of the J-PARC Hadron hall

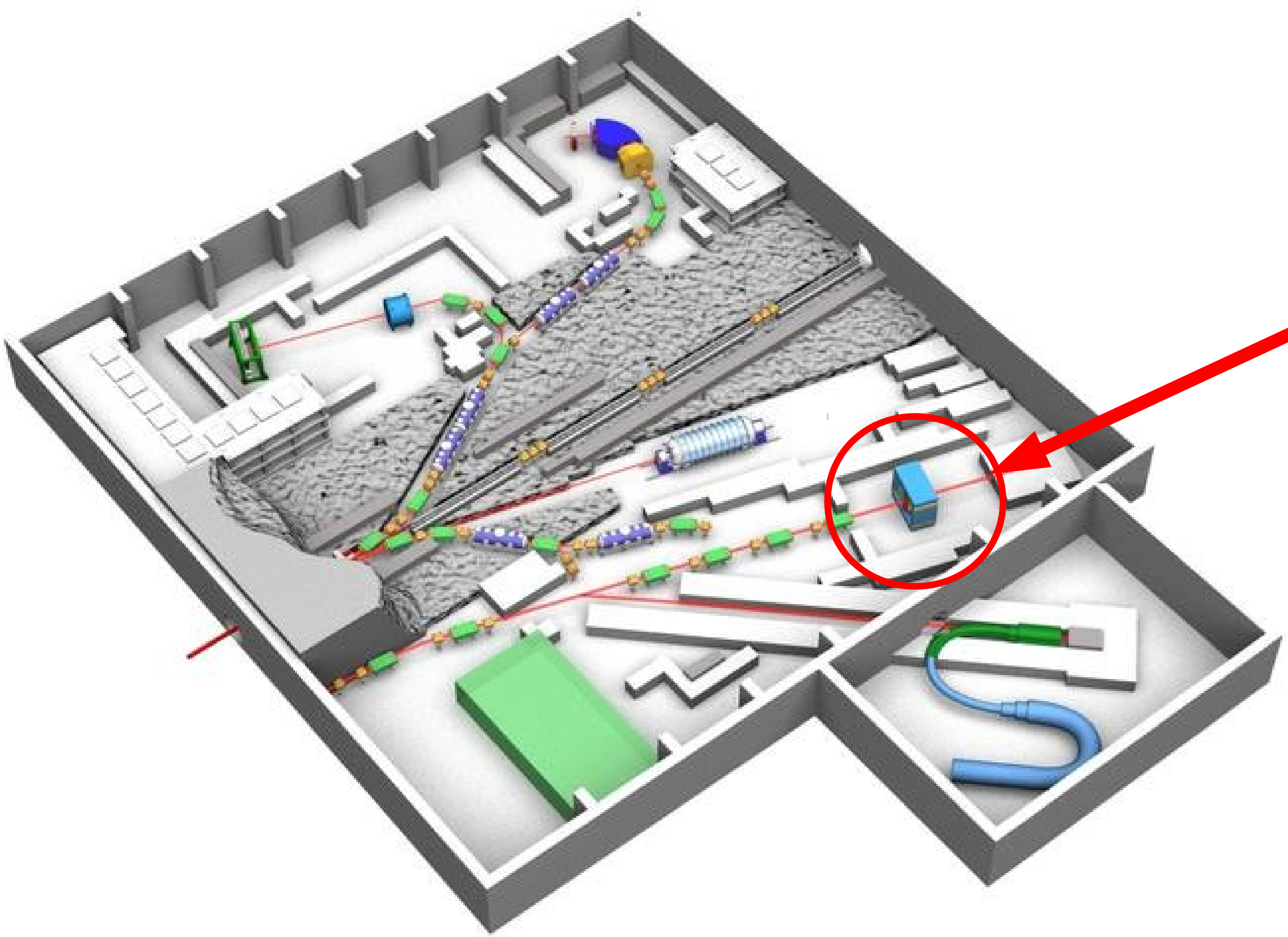


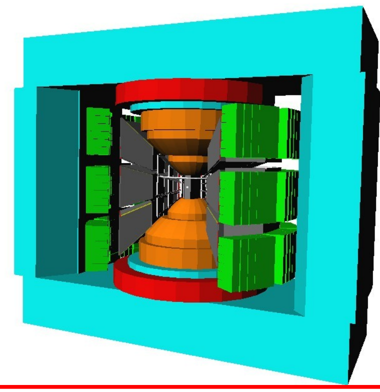
High-p line in the J-PARC Hadron hall



- High momentum line is under consturction

High-p line in the J-PARC Hadron hall





E16 spectrometer

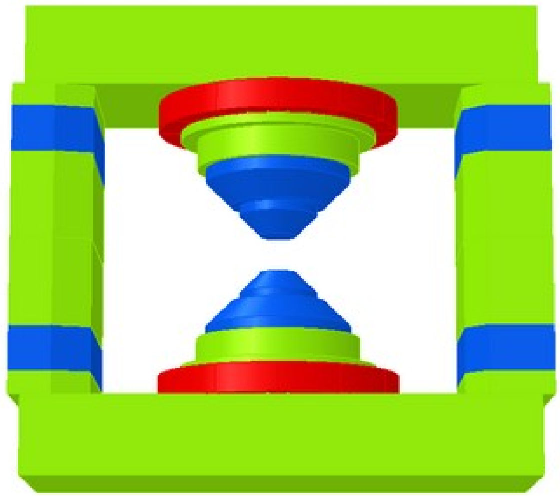
- magnet reassemble is started in Feb.

- High momentum line is under consturction

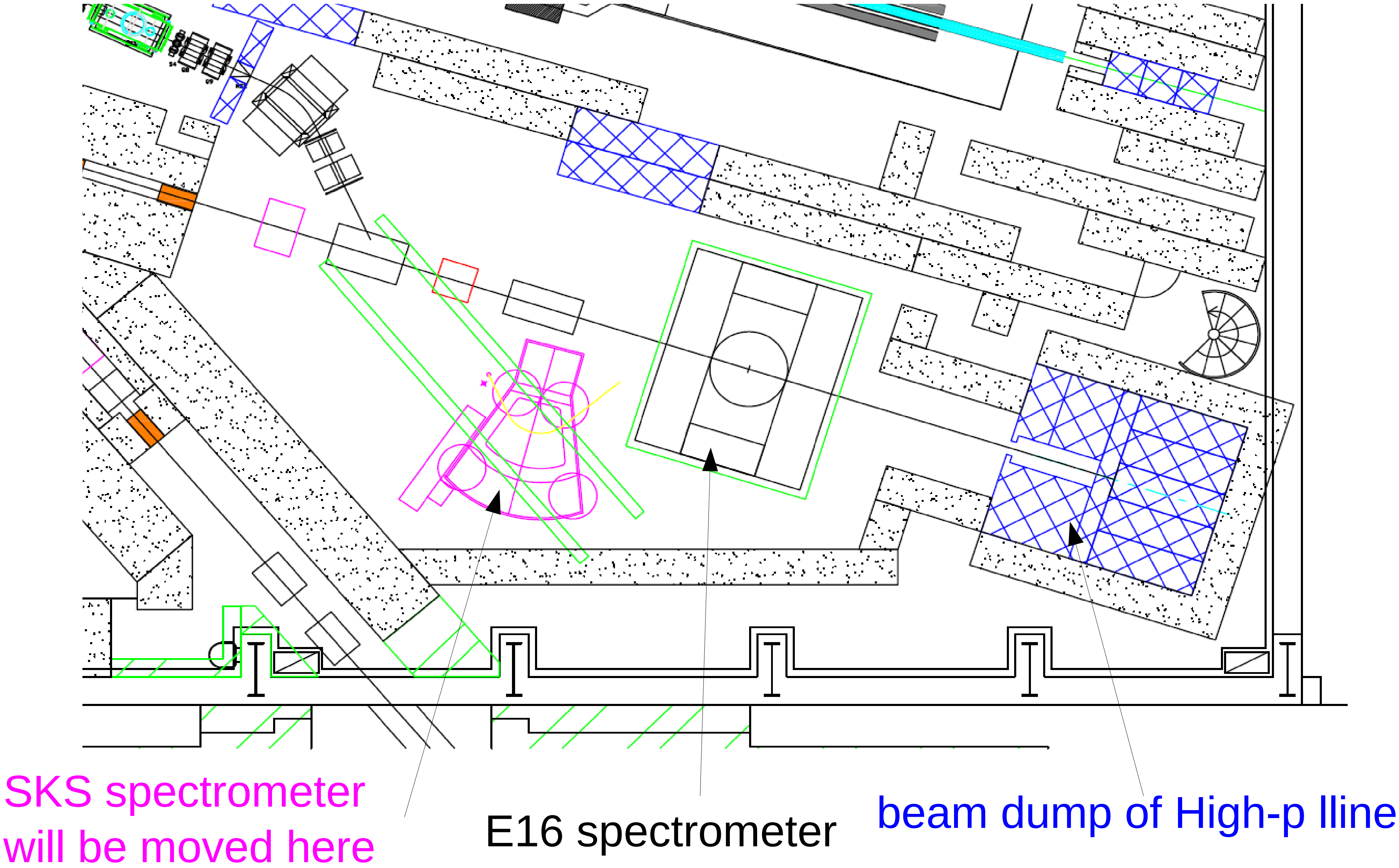
E16 Spectrometer Magnet

new parts are delivered in 2012 (by R. Muto)

re-assemble with new parts (2015)



experimental area plan



E16 preparation status

- Basic performance of GTR/HBD/LG is confirmed
  - Production of parts is started (GEM, R/O board) & LG
    - parts for 6 GTR & 2 HBD, 8 LG modules will be ready in Mar.
  - Design of support frames will be completed till Mar.
- Spectrometer magnet re-assemble
  - by KEK, started 2015 Feb., 2-3 months
  - after that, we will install LG, GTR and HBD in the magnet
    - target day is July 1st for the support structure delivery
- R/O circuits
  - GTR preamp is OK. HBD preamp w/SRS is also OK.
    - ready in Mar. for 8 modules
  - GTR/HBD trigger ASD are in the test.
  - test of trigger logic circuits is also being tested.
  - Goal : ready for production by Mar. 2015

Summary

- dilepton spectra in medium have been meausred, and spectral modification is observed in many experiments, including KEK-PS E325.
- J-PARC E16 will measure the spectral change of vector mesons in nuclei with the ee decay channel, using 30GeV proton beam at the newly constructed high-momentum beam line in the J-PARC hadron hall.
  - confirm the observation by E325 and provide more systematic information of the spectral modification (as nuclear-size dependence, momentum dependence, etc) of vector mesons in the finite density matter.
  - preparation is underway and detector mass-production was started.
  - Staged goal of construction : 8 modules out of 26.
  - beamline construction is also on-going, possibly delayed to JFY2016.
- calculation of spectral function of vector mesons in real nuclei (N/Z asymmetric) with finite momentum is expected.