Measurements of Spectral Change of Vector Mesons in Nuclear Matter

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- physics
- precedent experiment E325
- proposed J-PARC E16
- status of E16
- expected results in the 1st stage
- summary

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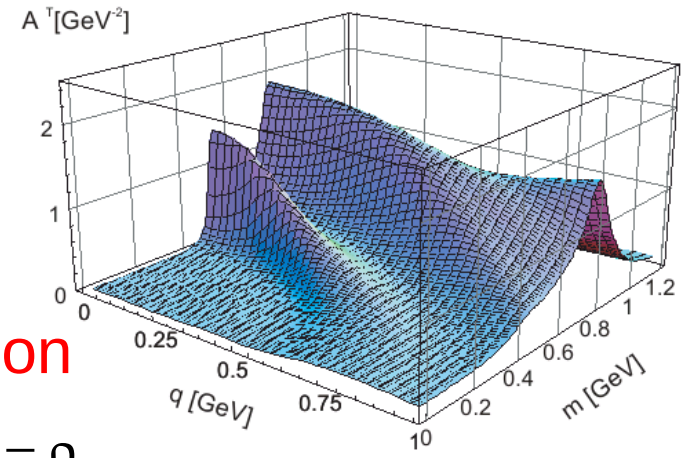
spectral change of vector mesons

- 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 nature : symmetry, phase
    - condensed matter: experimental examples, as the phonon softning in ferroelectric crystal around Tc
  - 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
  - theoretically, 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)

vector meson spectra in dense nuclear matter (theory)

Post & Mosel [NPA699(02)169]

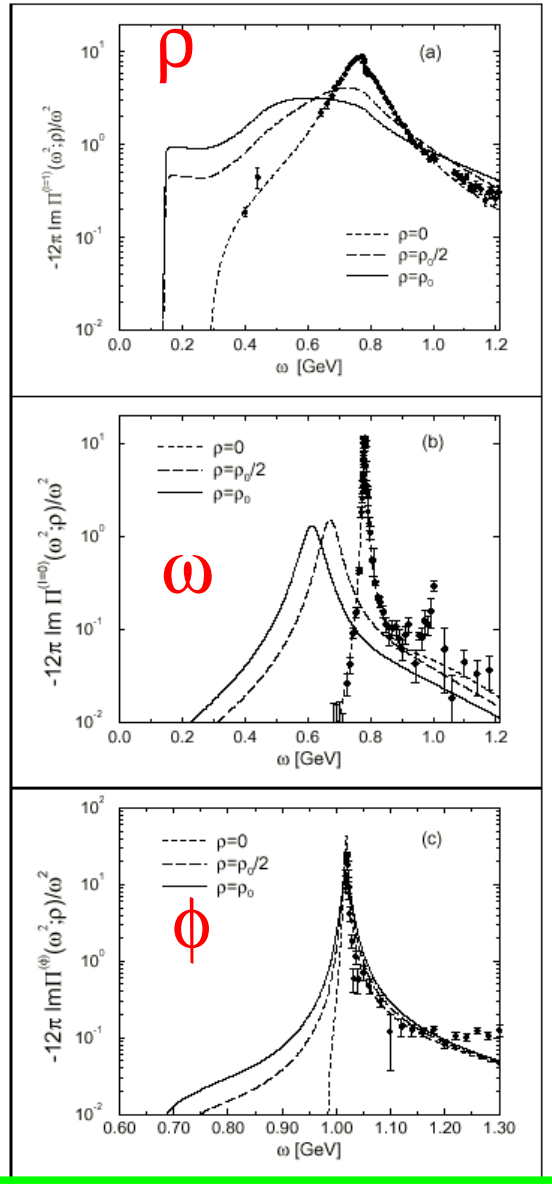


ρ-meson

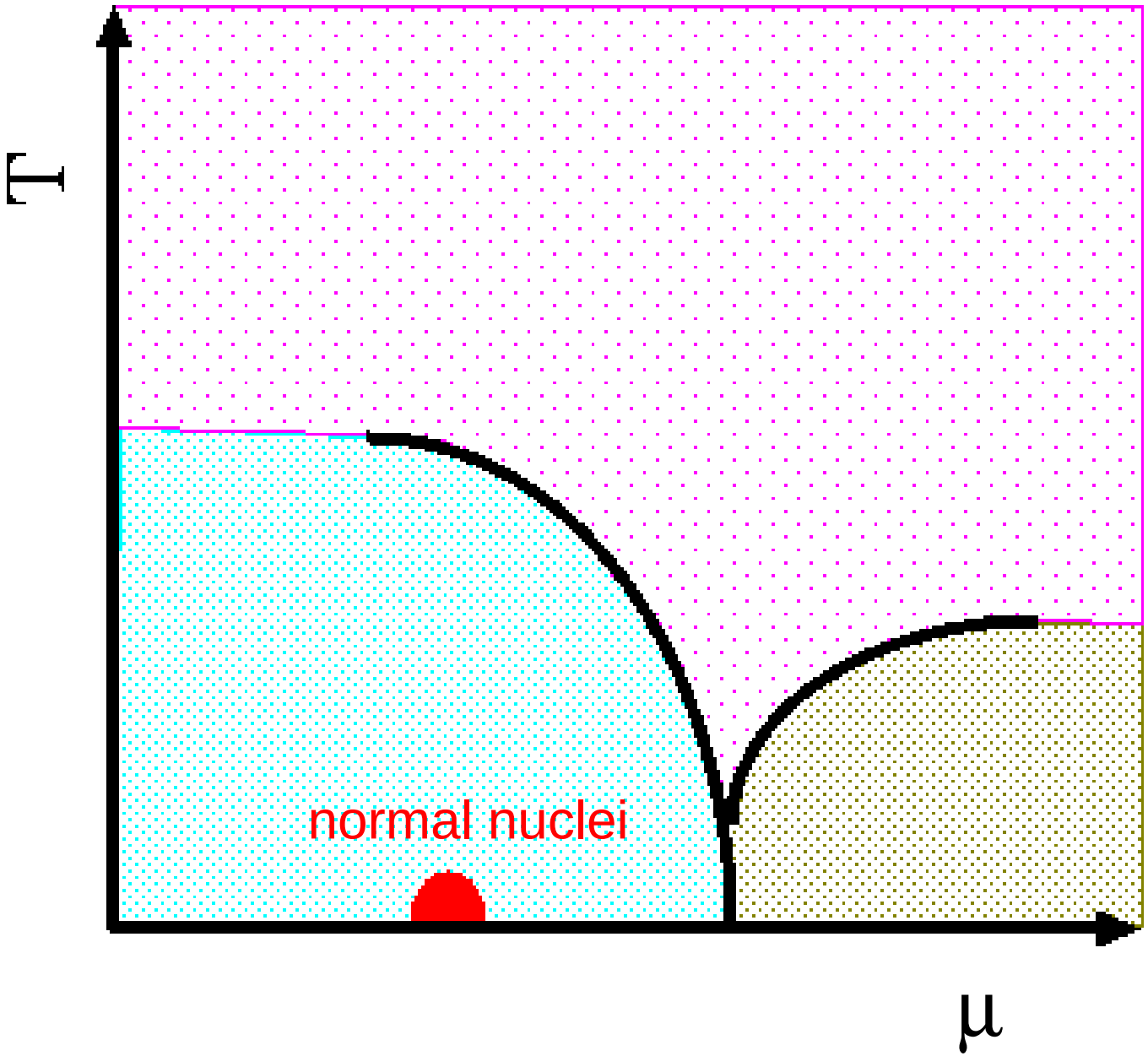
density $\rho = \rho_0$

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

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

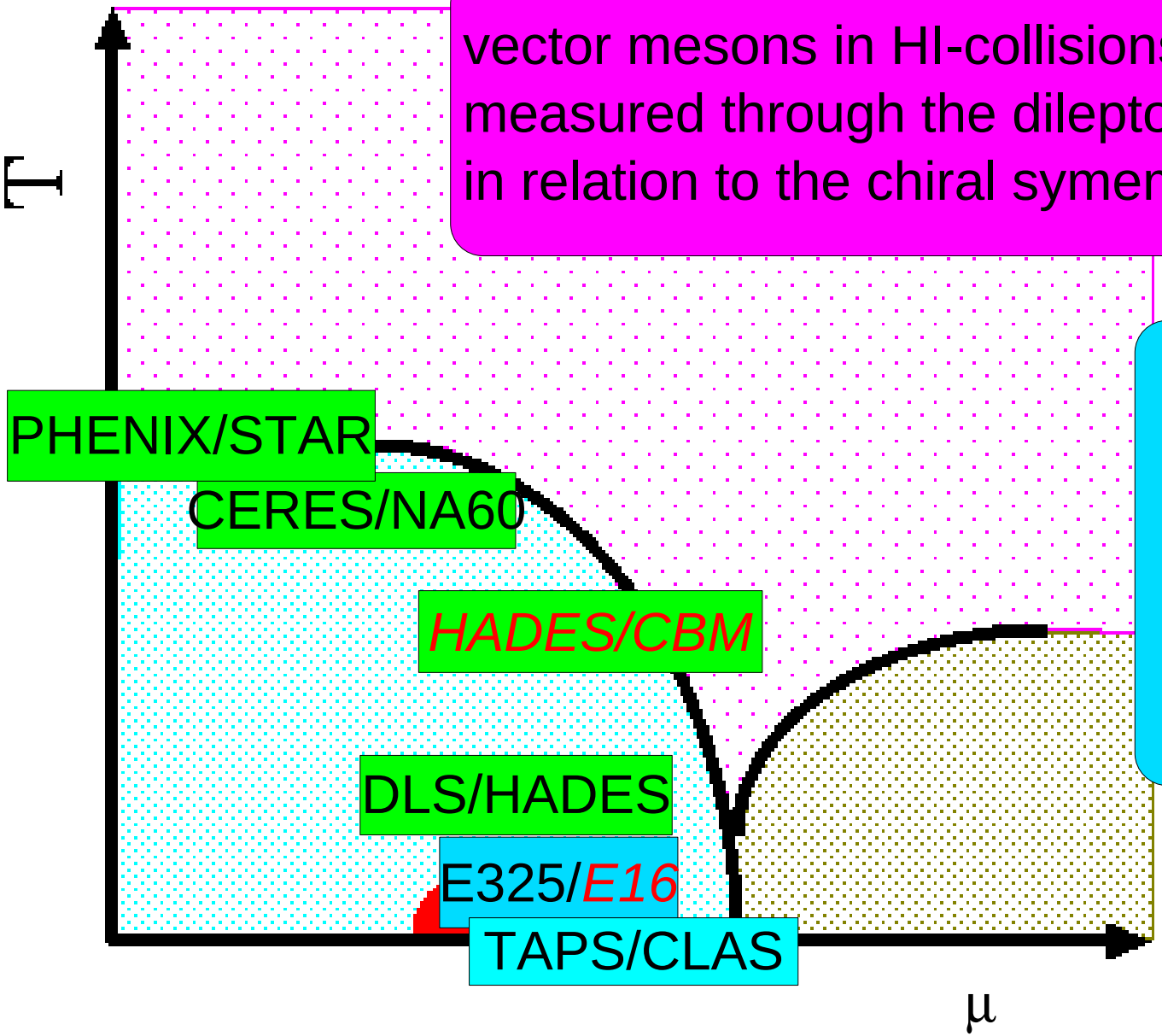


QCD phase diagram



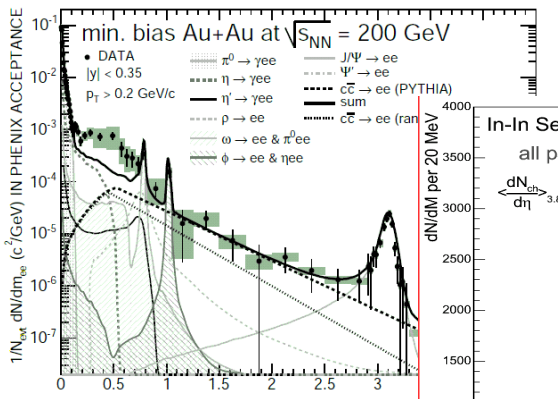
dilepton measurements in different vacuum

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

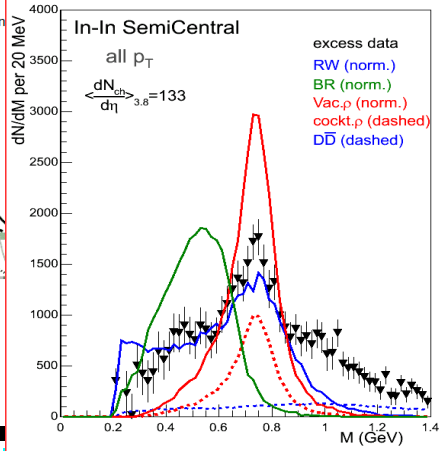


In hot and dense matter, spectral modification of vector mesons (dilepton invariant mass) are observed in many experiments

observed dilepton spectra in the world



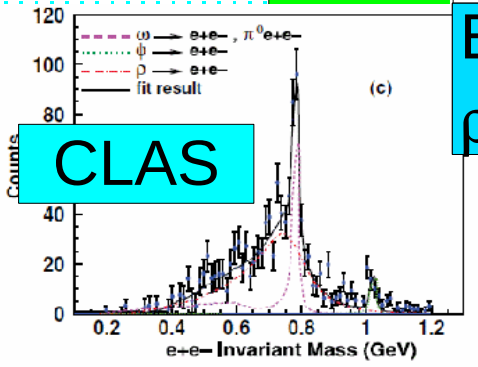
PHENIX



NA60

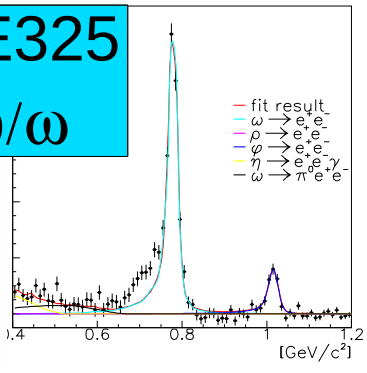
"low mass enhancement"
below the ω meson peak
in HI collisions
and HADES p+Nb

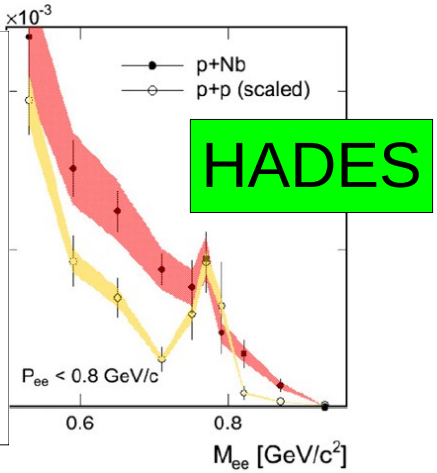
change of ϕ meson is
observed only by KEK-PS
E325 w/ best mass resolution
& high statistics



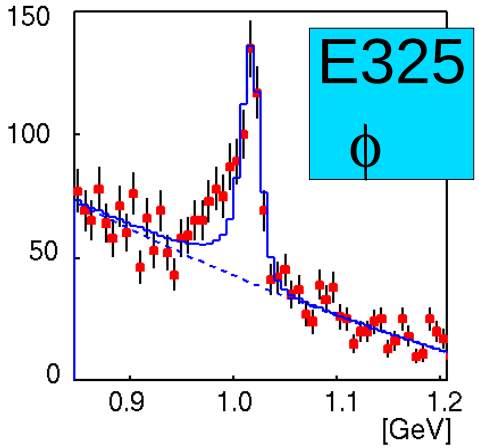
CLAS

E325
ρ/ω





HADES

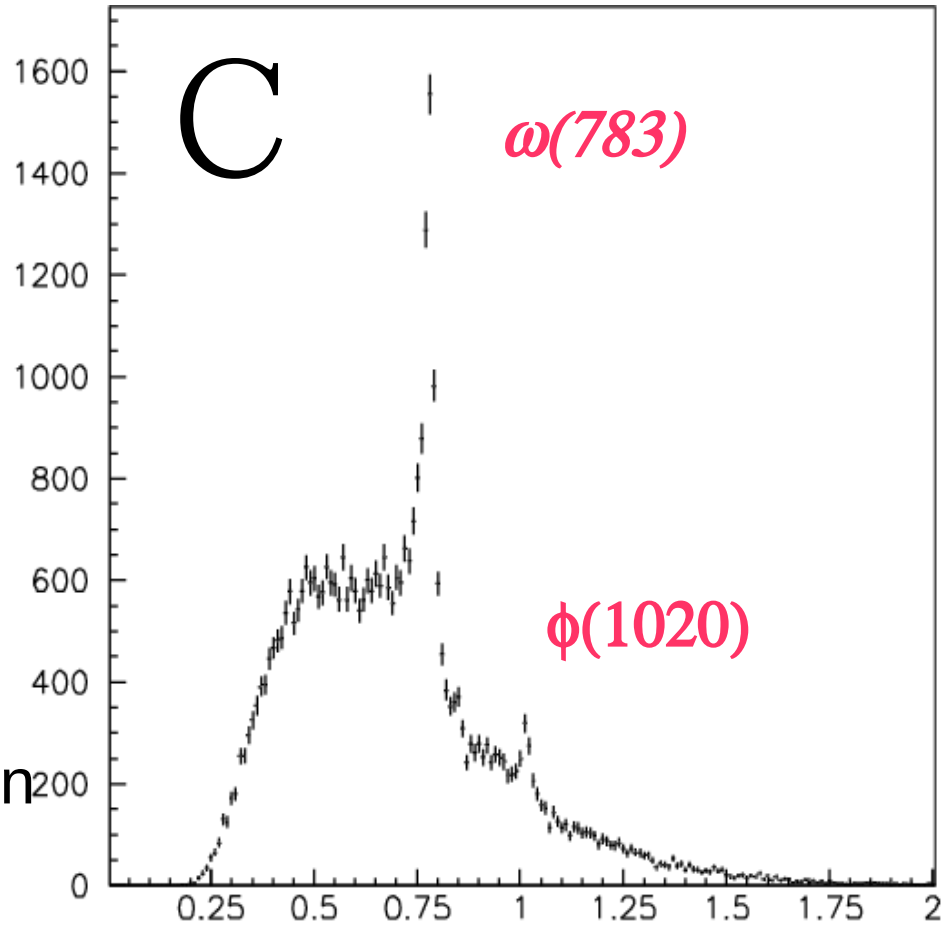


Dilepton spectra measured at KEK-PS E325

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

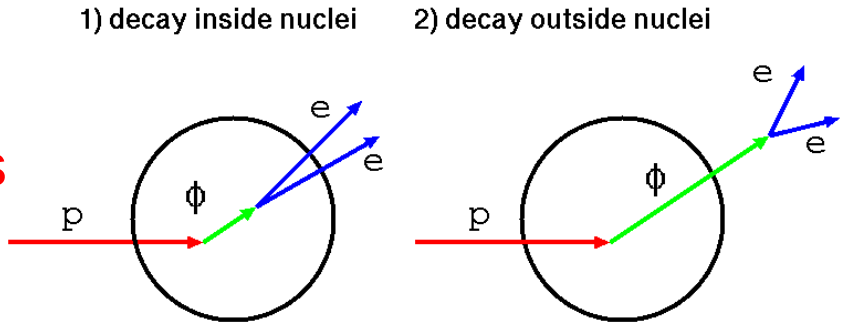
- 12GeV p+A → $\phi/\rho/\omega$ +X, $\phi/\rho/\omega \rightarrow e^+e^-$
- At the lower energy,
  - better S/N
  - smaller production cross section
  - possibly simpler environment

  (T=0, no time evolution)

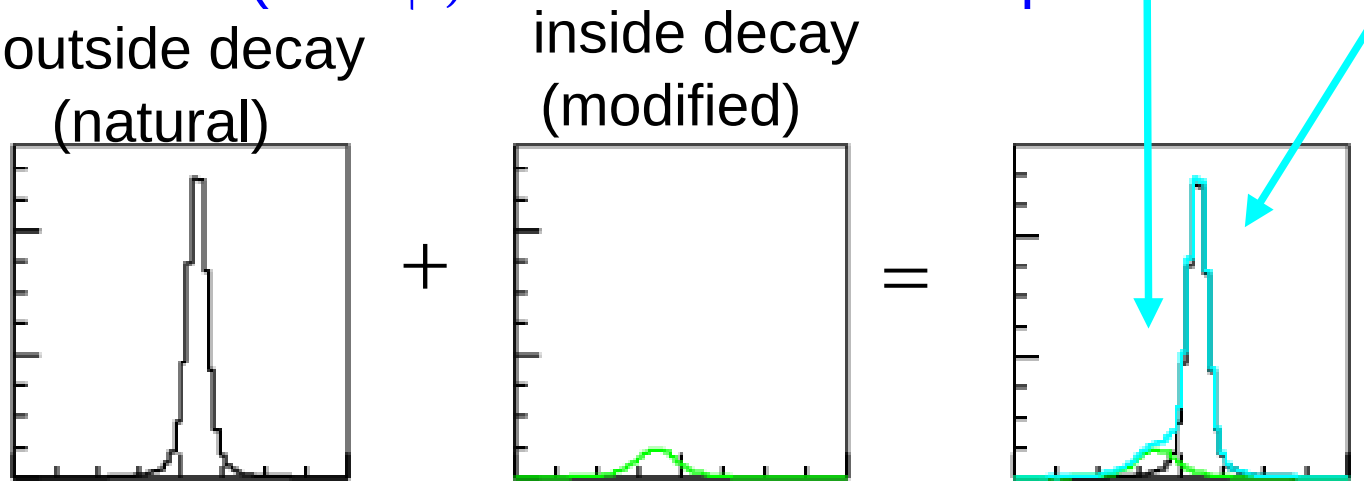


Expected Invariant mass spectra in ee

- 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



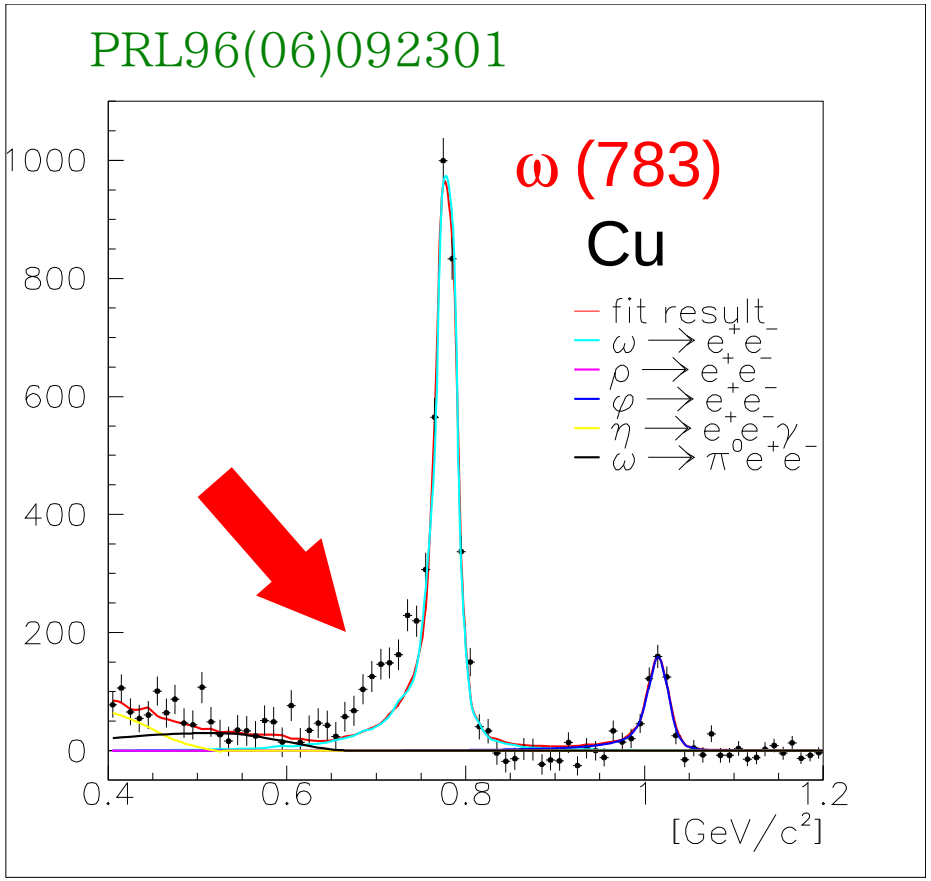
longer-life meson(ω & ϕ)cases : Schematic picture

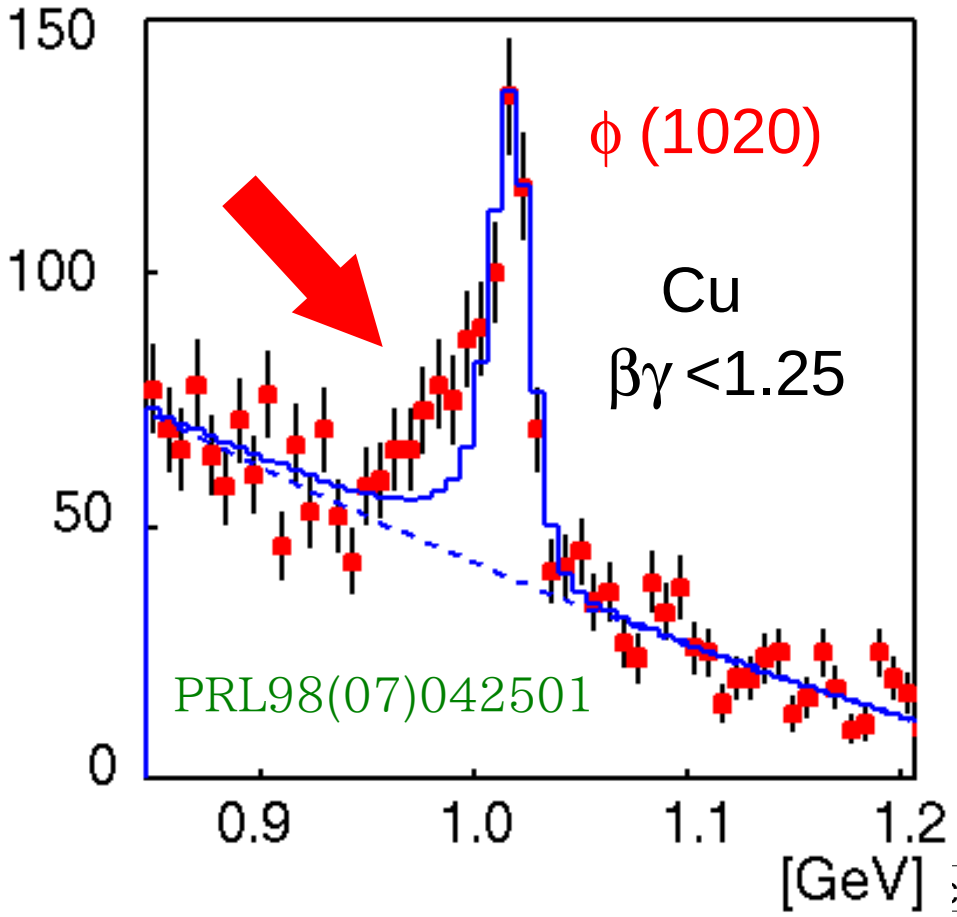


expected
to be observed

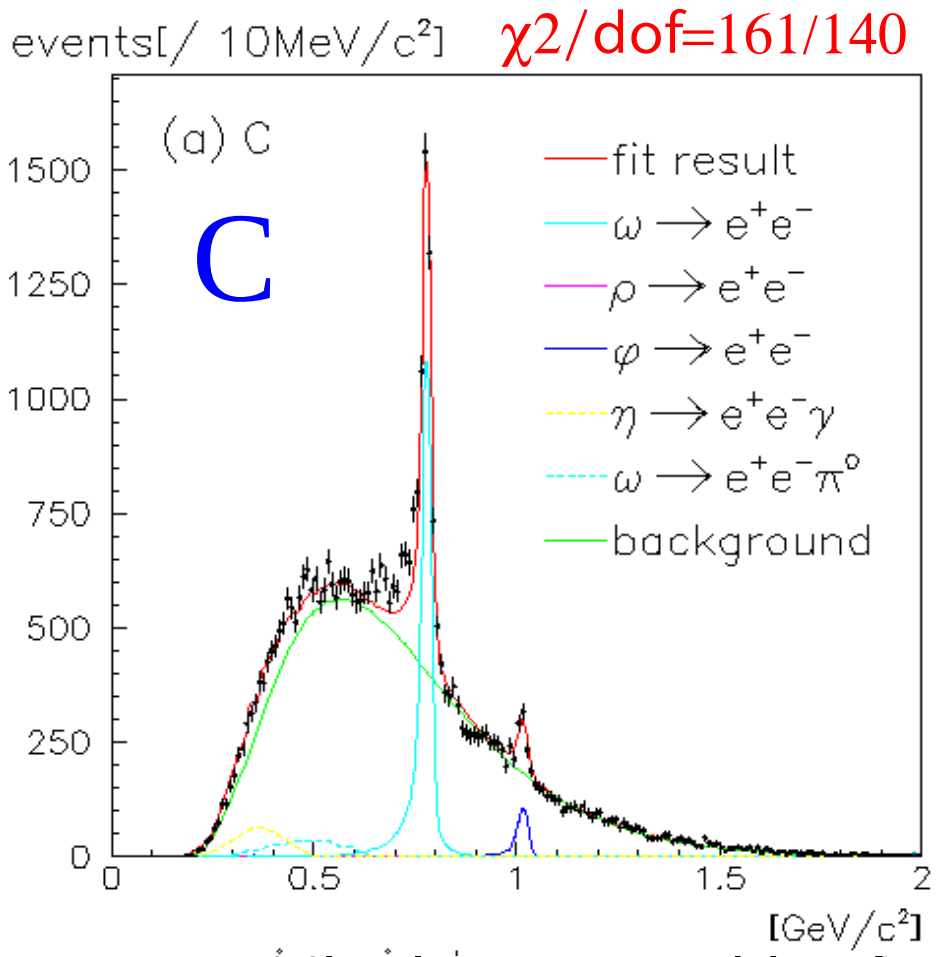
E325 observed the meson modifications

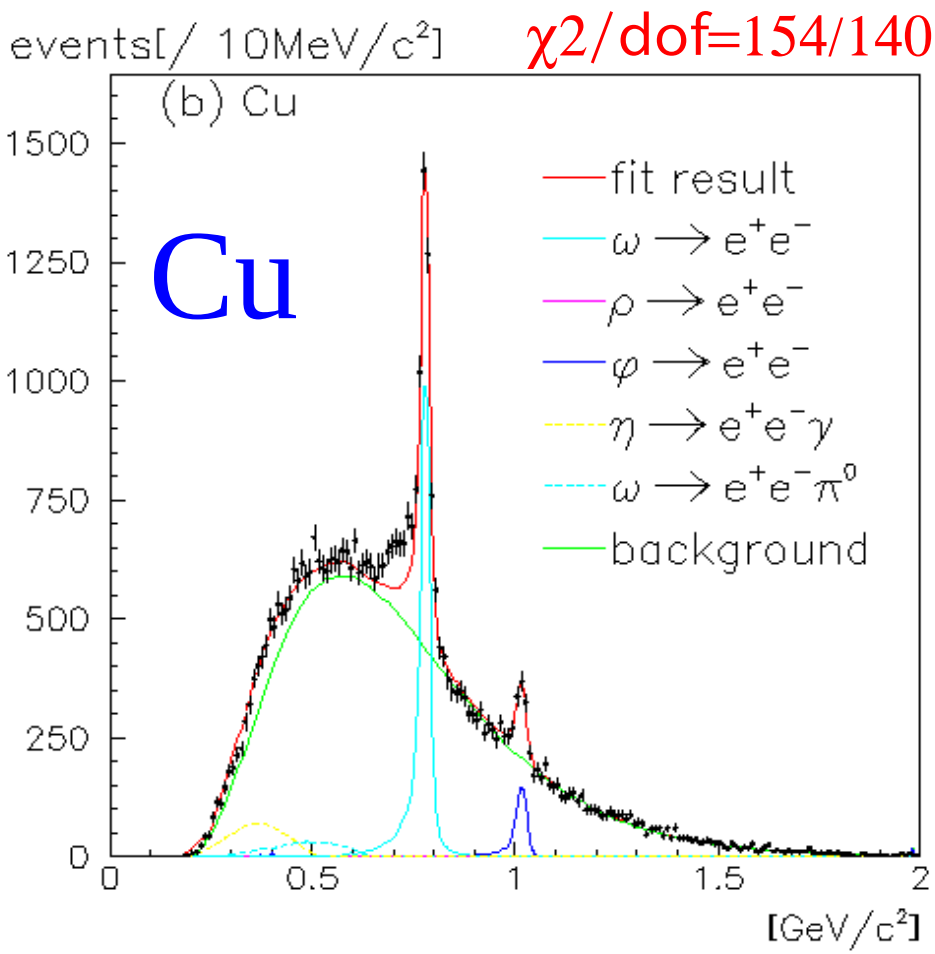
- in the e^+e^- channel
- below the ω and ϕ, statistically significant excesses over the known hadronic sources including experimental effects





Fitting results (ρ/ω)





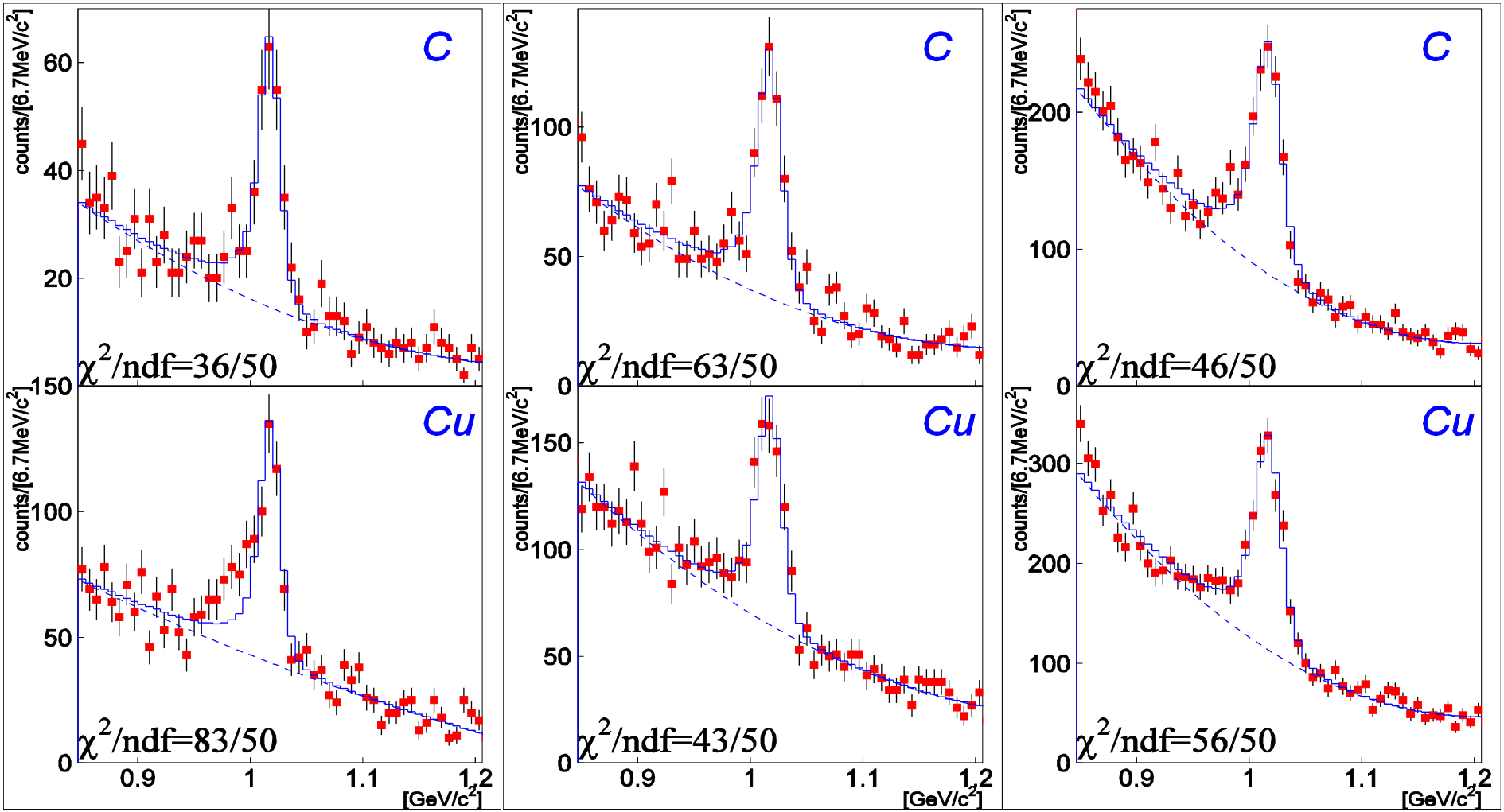
1) excess at the low-mass side of ω

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)



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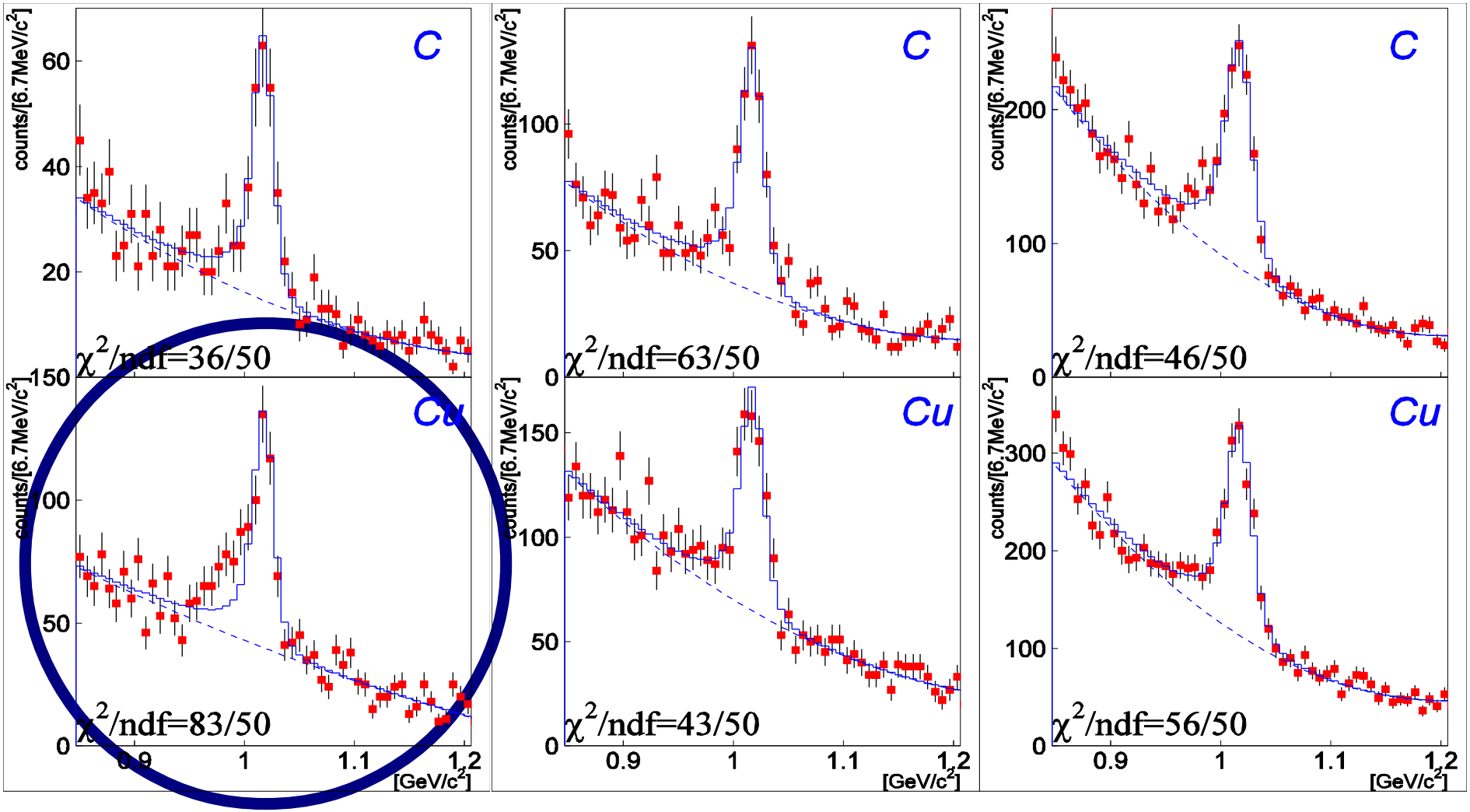
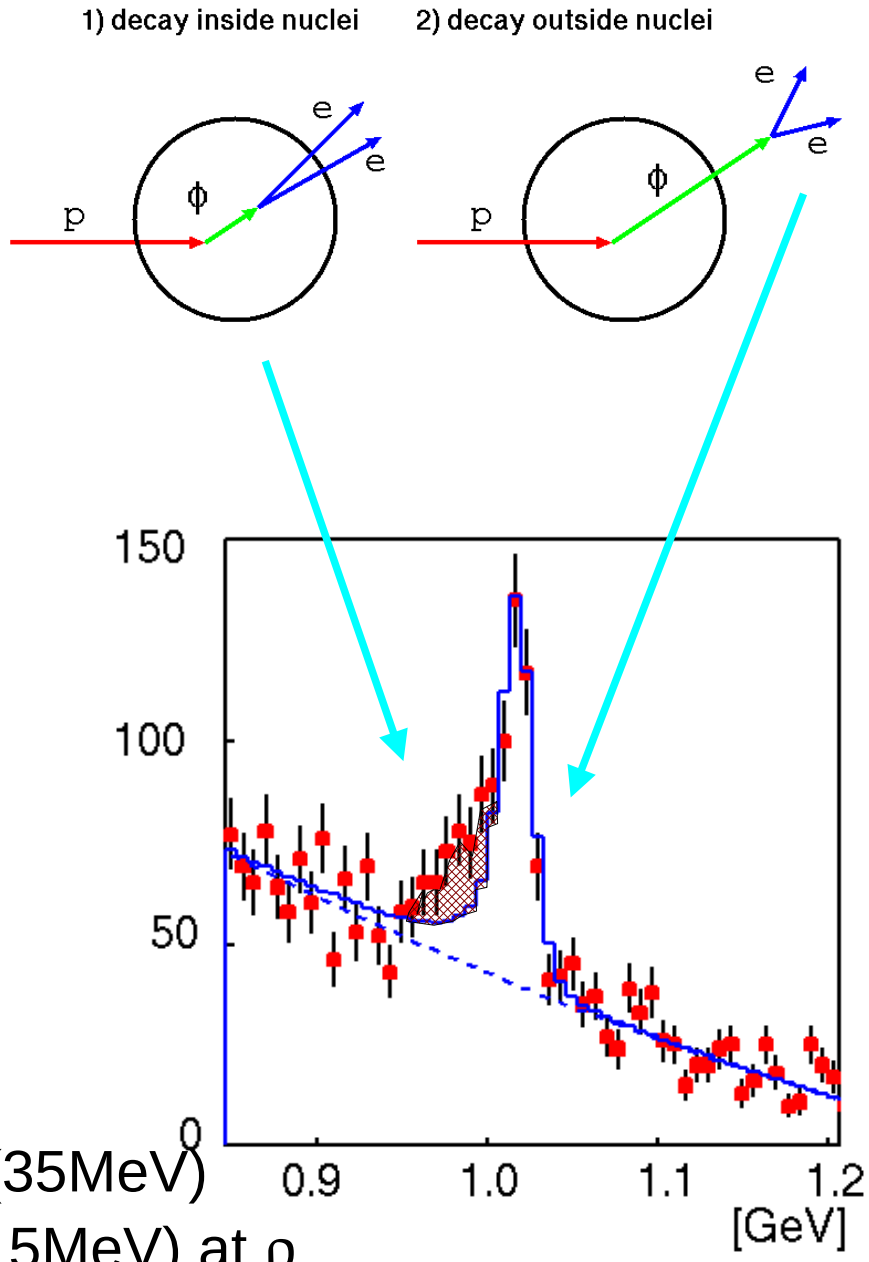


only slow/Cu is not reproduced in 99% C.L.

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

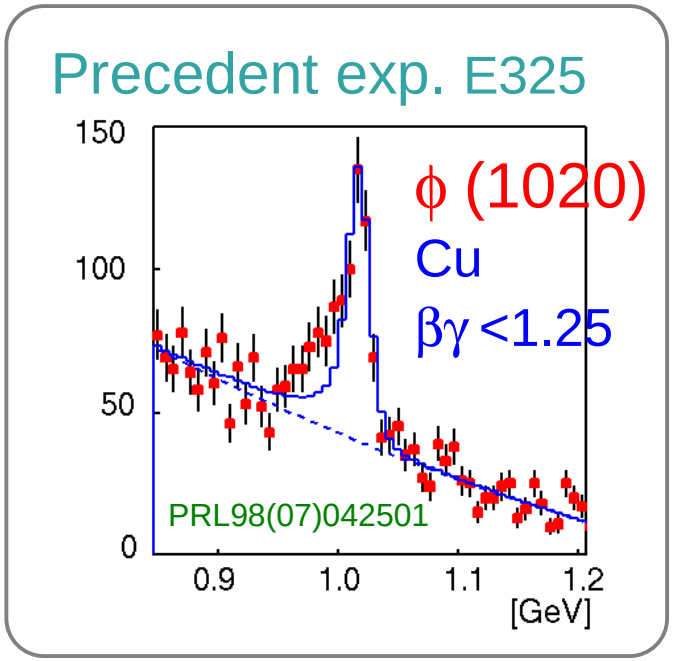
J-PARC E16

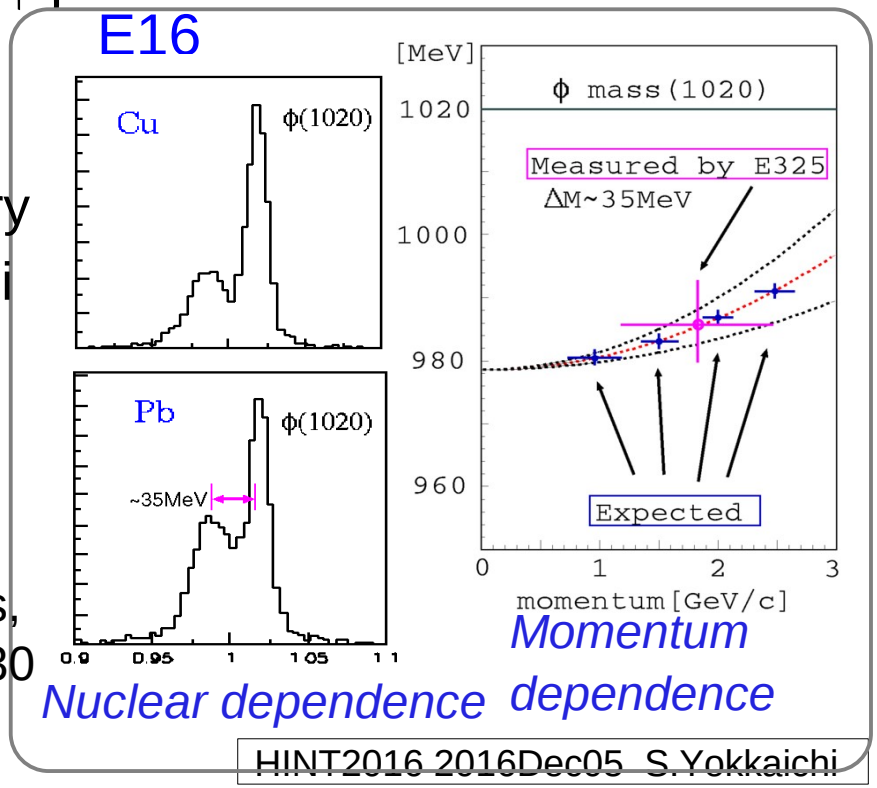
- Systematic measurements of the spectral change of ϕ (and ρ/ω) in nuclei throught the e^+e^- channel with highest statistics (100000 ϕ) & best mass resolution (~5 MeV) in the world

use 30GeV p+A → $\phi/\rho/\omega$ +X, $\phi/\rho/\omega \rightarrow e^+e^-$,

  - 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 ~10^{10} pps

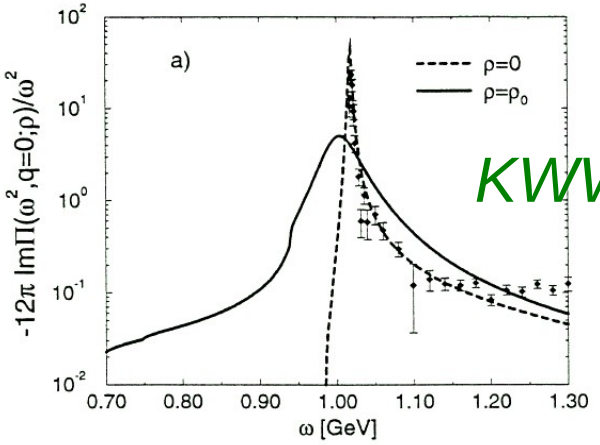




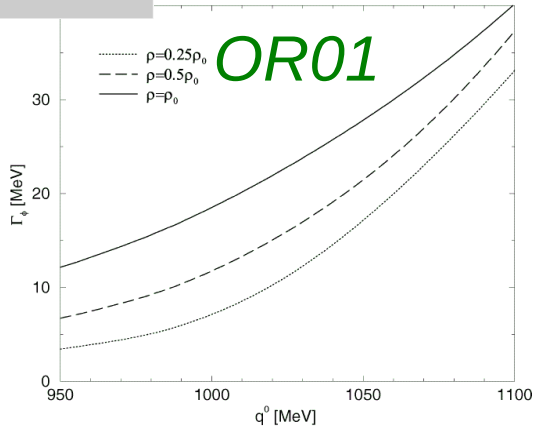
theory: spectral modification of ϕ at ρ_0

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



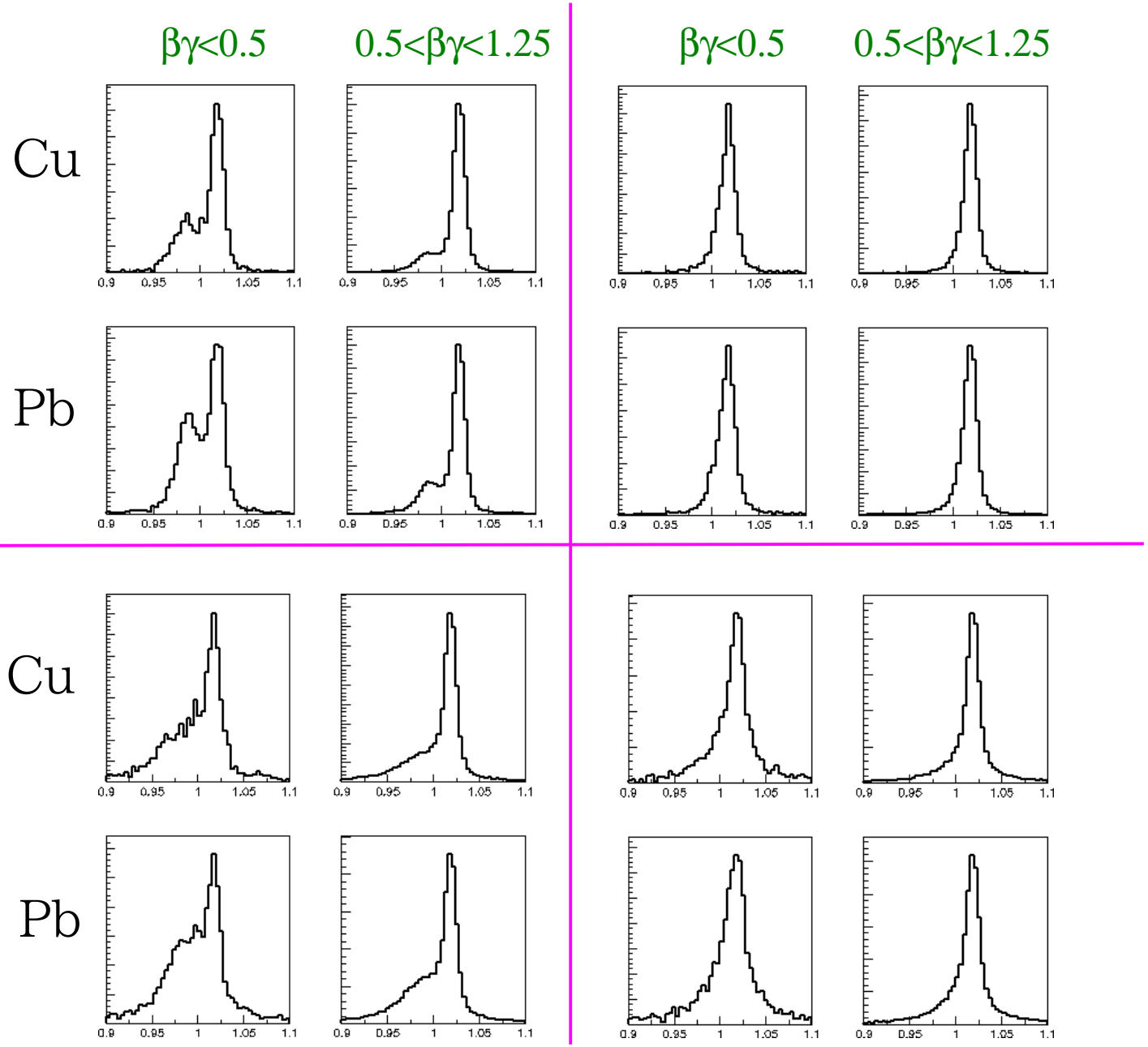
KWW98



OR01

expected shape w/ various parameters

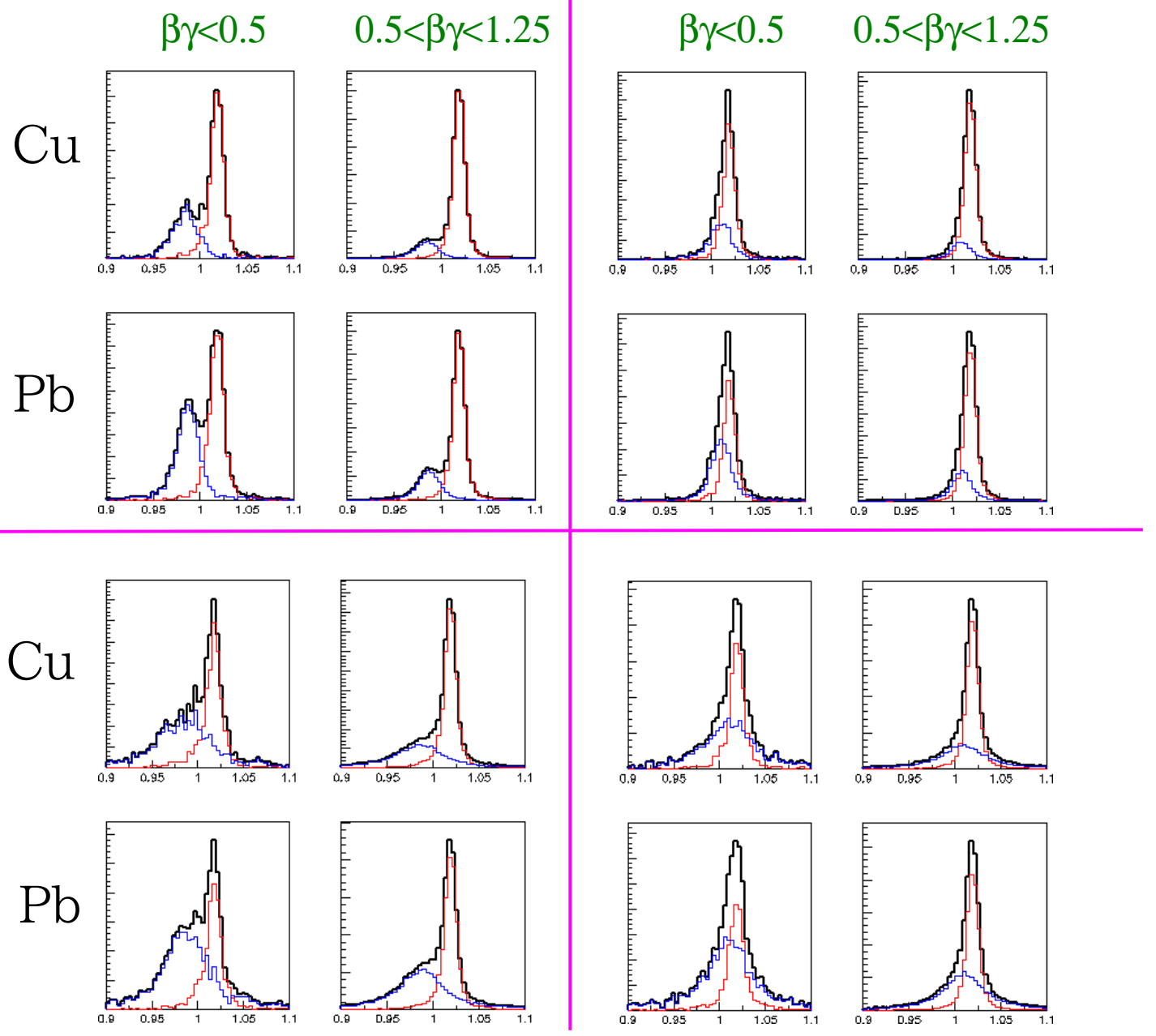
E325 Δm : −35 MeV Γ : 15 MeV	OR-01 Δm : −10 MeV Γ : 15 MeV
- Δm : −35 MeV Γ : 50 MeV	KWW-98 Δm : −10 MeV Γ : 50 MeV



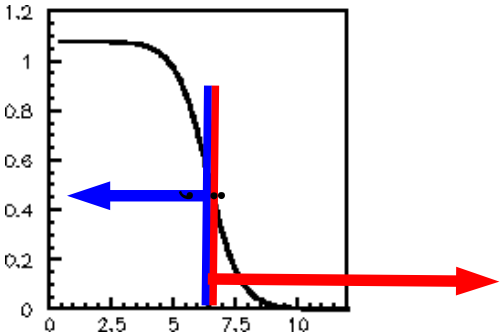
- using the parameters, spectra are approximated with the relativistic Breit-Wigner shape including experimental mass resolution

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



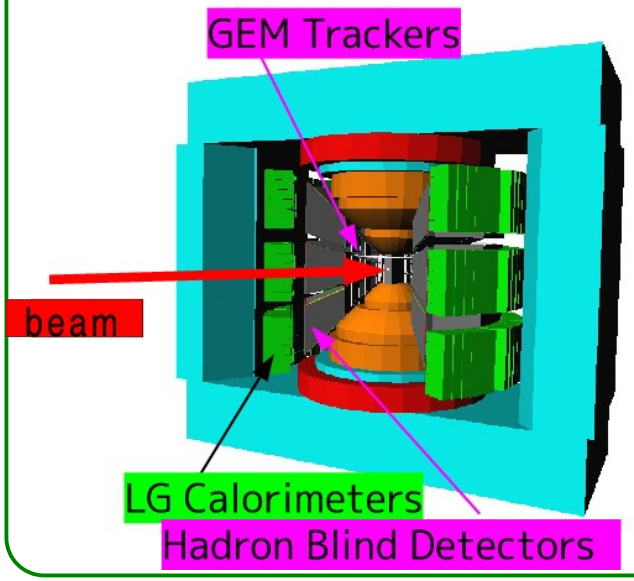
blue: decays inside the half-density radius of nuclei in the MC



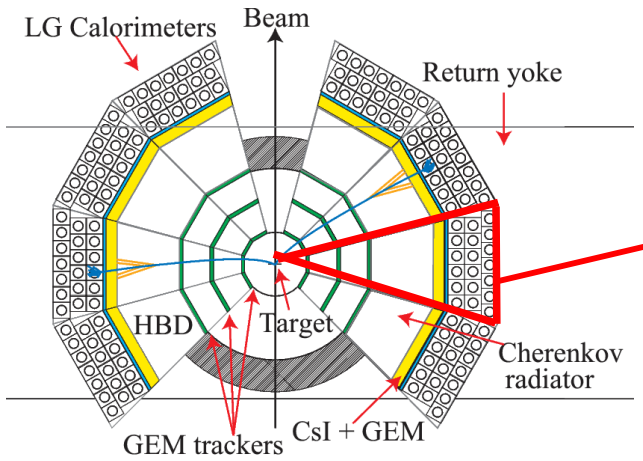
E16 Detectors

- ~10 MHz interaction at the targets with ~5 GHz of 30GeV proton beam
- Electron ID : Hadron Blind Detector(HBD) & lead glass EMC (LG)
- Tracking : GEM Tracker (3 layers of X&Y) / SSD (1layer of X, most inner)
  - 5kHz/mm^2 at the most forward, 100μm resolution(x) for 5 MeV/c^2 mass resolution
  - to avoid mistracking due to the accidental hits, SSD introduced
- Spectrometer Magnet : 1.77 T at the center, 0.78Tm for R=600 mm

Proposed Spectrometer

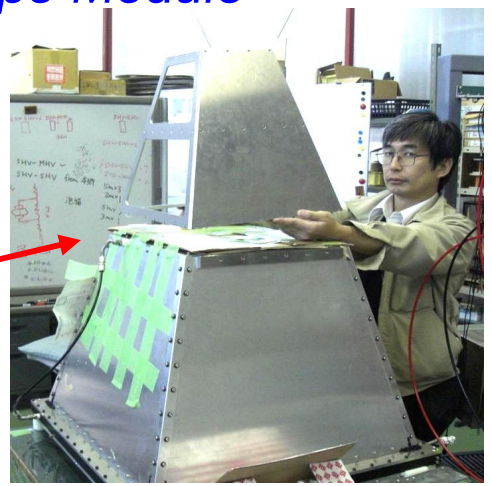


Plan View



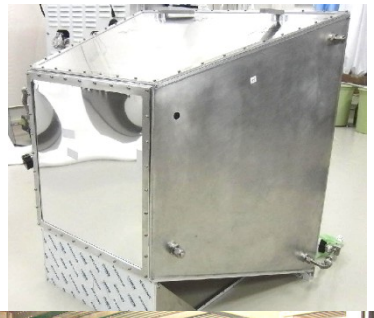
26 detector modules

Prototype Module



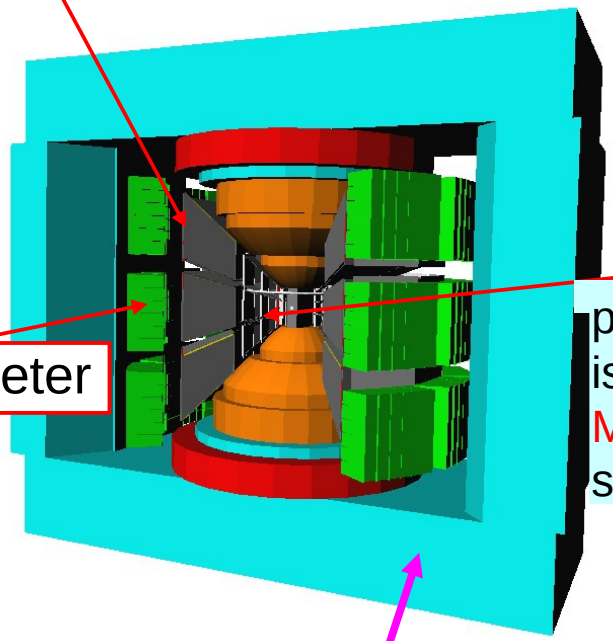
E16 : development & achieved performance

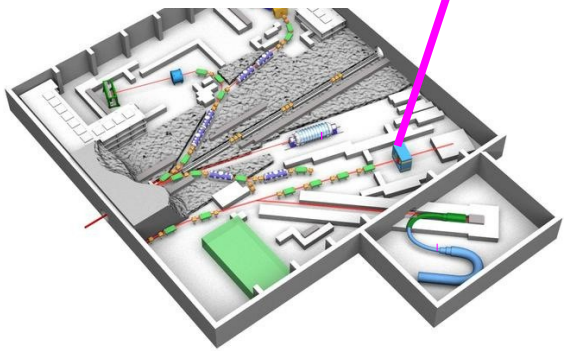
Hadron Blind Cherenkov Detector(HBD)

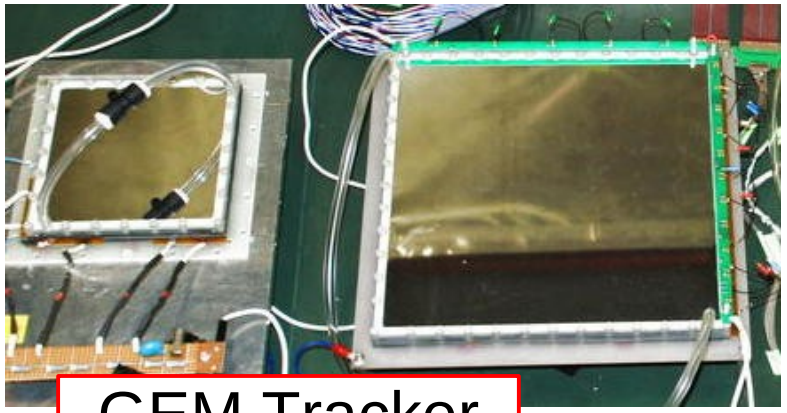


Lead-Glass EM Calorimeter

pion suppression down to ~0.03% is achieved with the combination of the two stage of electron-ID counters; HBD & LG

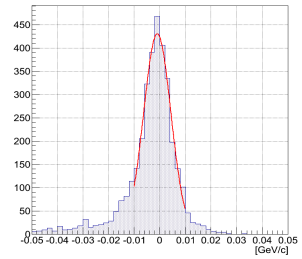






GEM Tracker

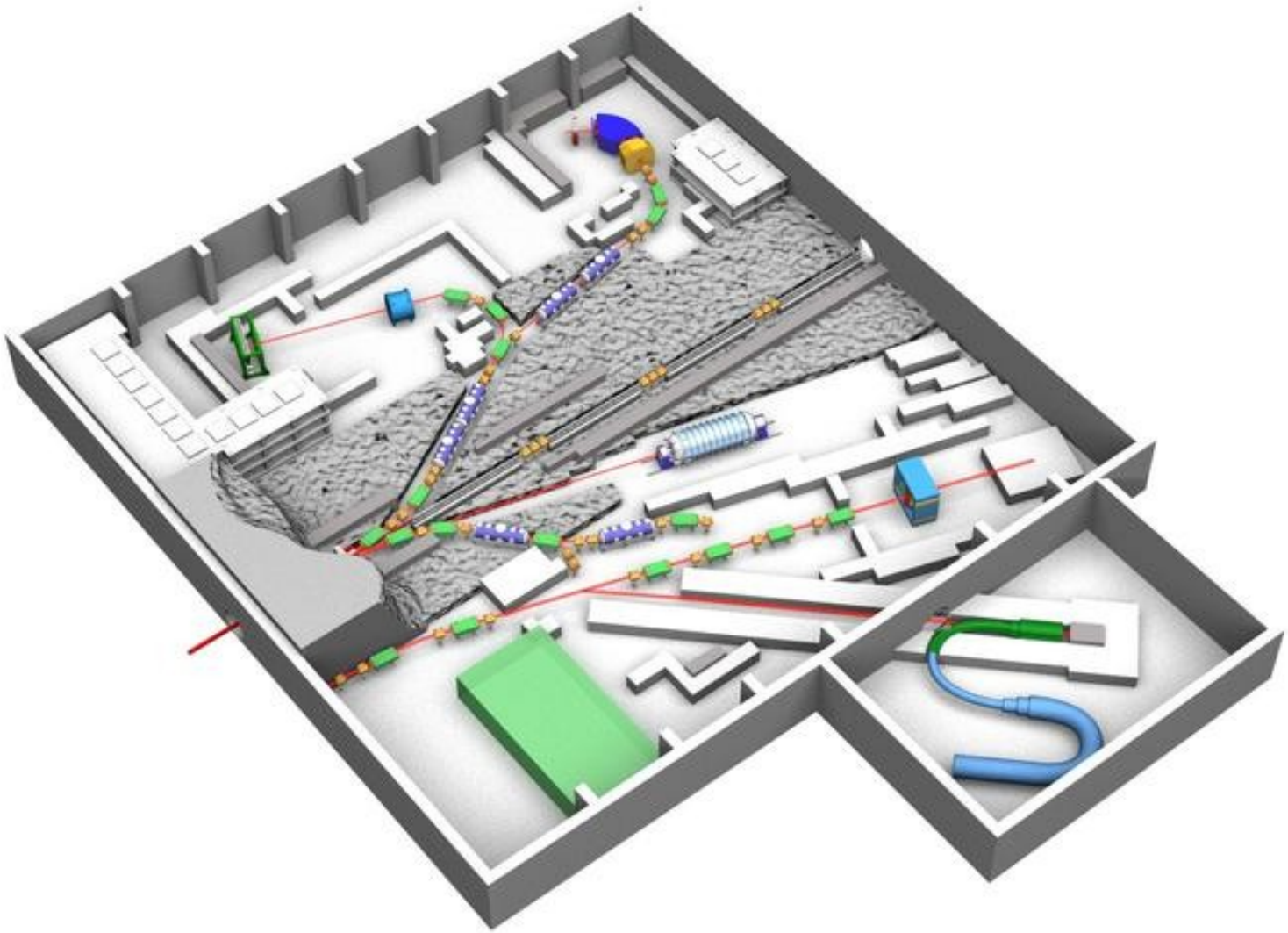
position resolution 100 μm is achieved to keep the 5-6 MeV mass resolution for the slowly moving ϕ mesons.



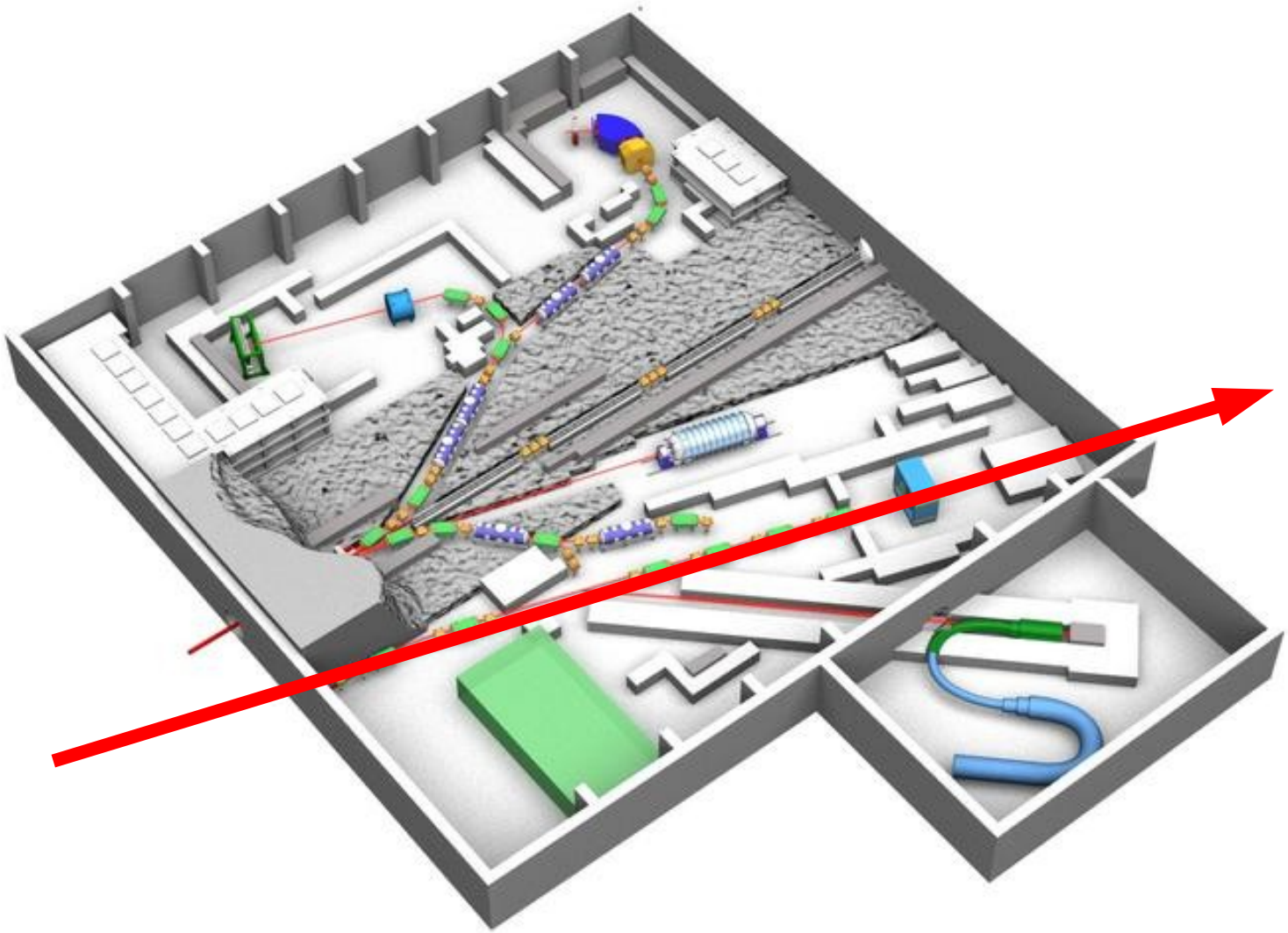
The spectromter magnet has been re-constructed and located at the new High-momentum beam line, which is under construction and completed in early 2019.

Experiment will start in early 2019.

Near future of the J-PARC Hadron hall

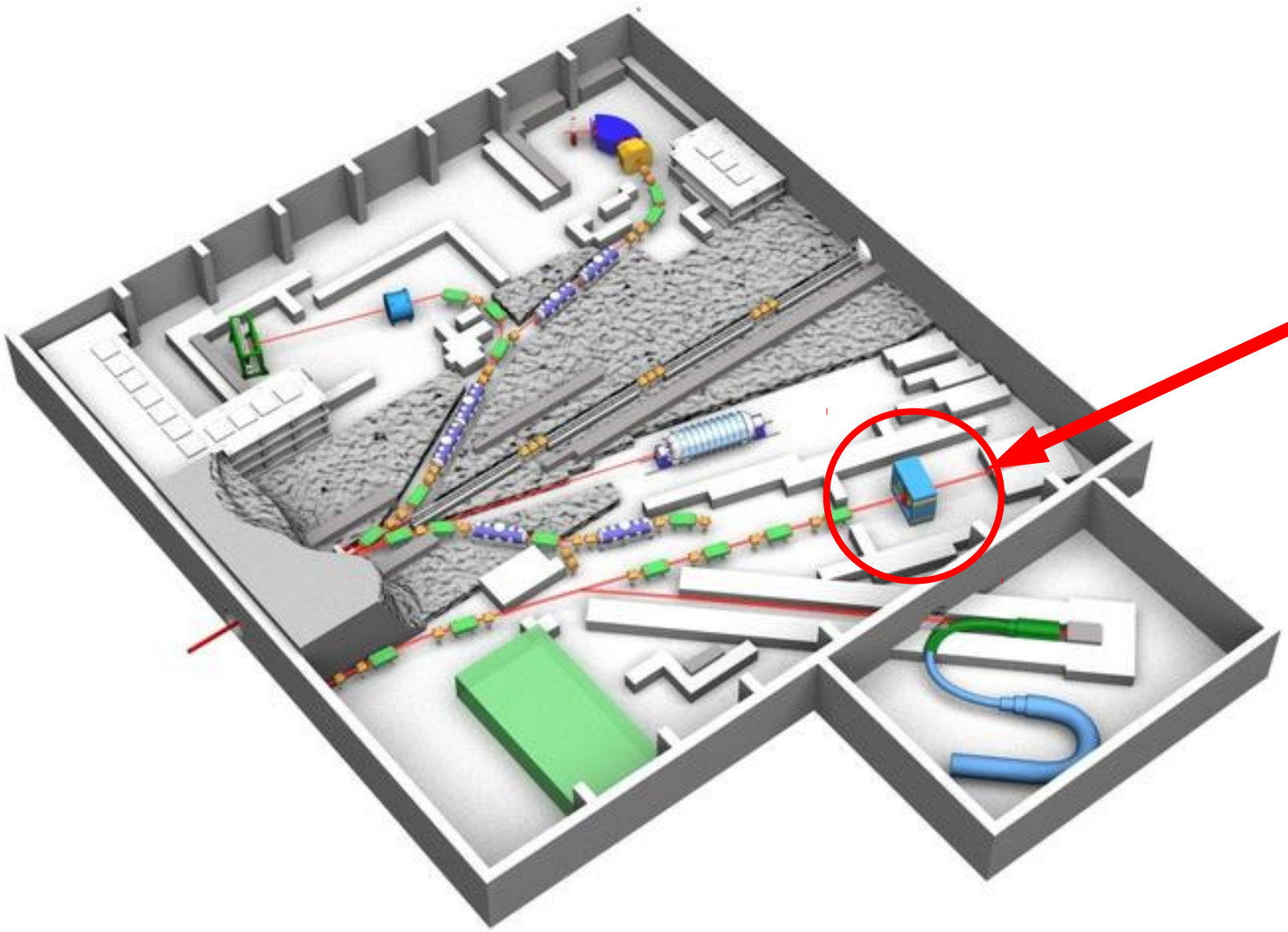


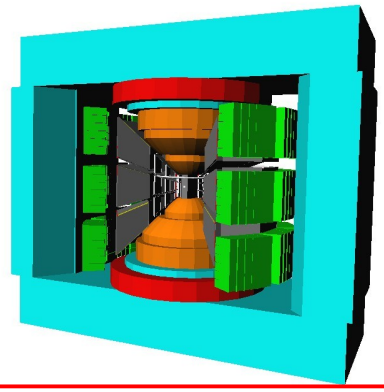
High-p line in the J-PARC Hadron hall



- High momentum line is under consturction

High-p line in the J-PARC Hadron hall



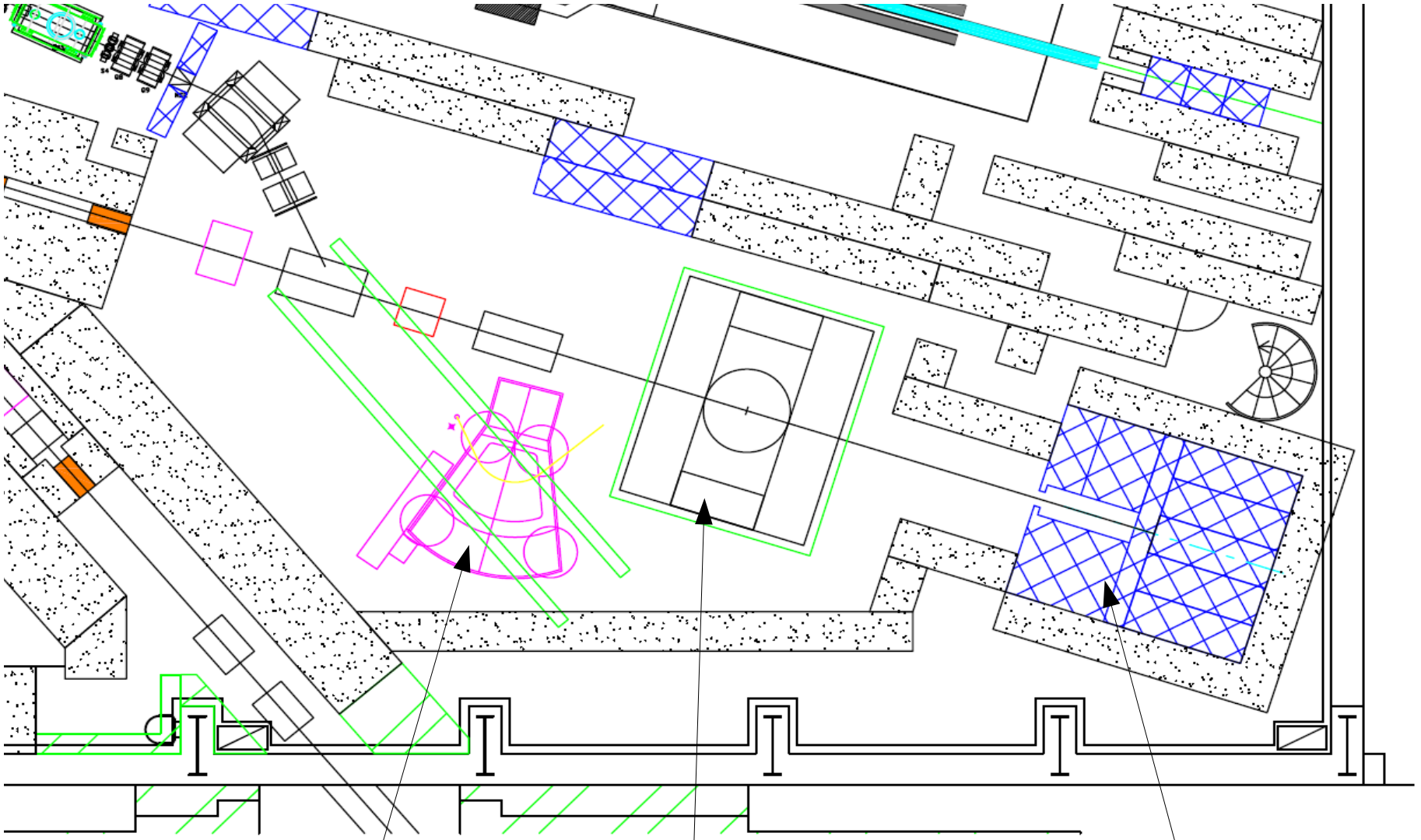


E16 spectrometer

- magnet reassemble is completed

- High momentum line is under consturction
- completed in early 2019

experimental area plan

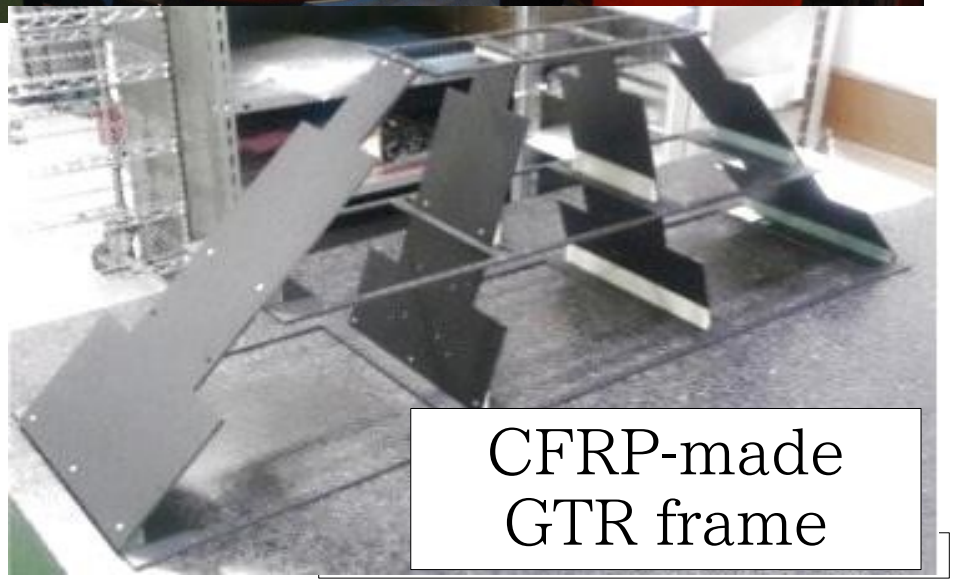


SKS spectrometer
will be moved here

E16 spectrometer

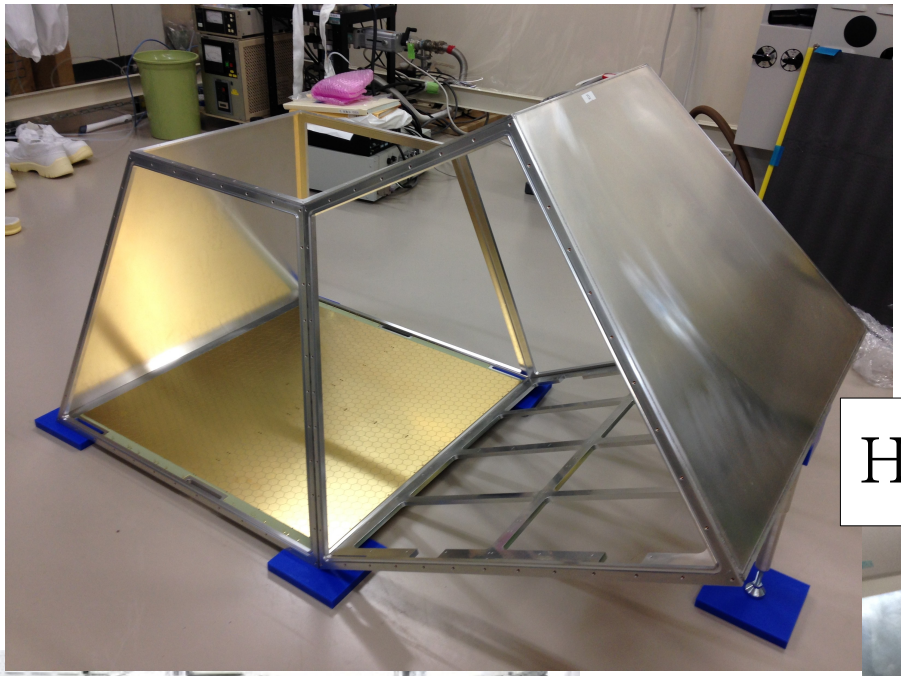
beam dump of High-p lline

Detectors:GTR frame in the magnet

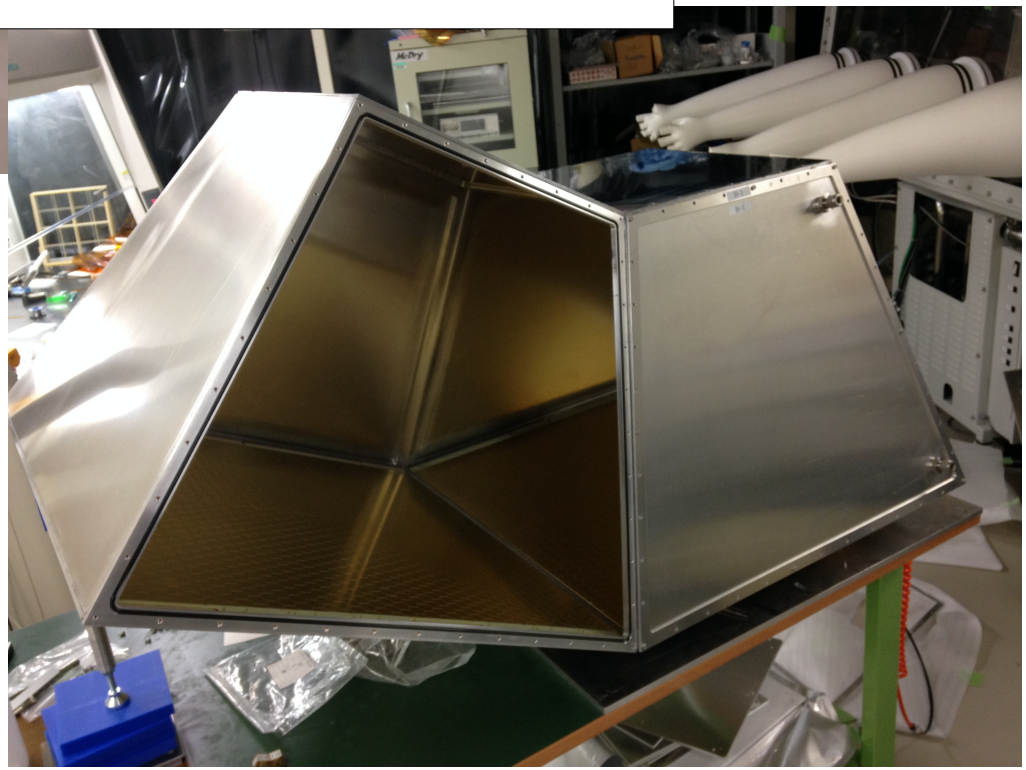


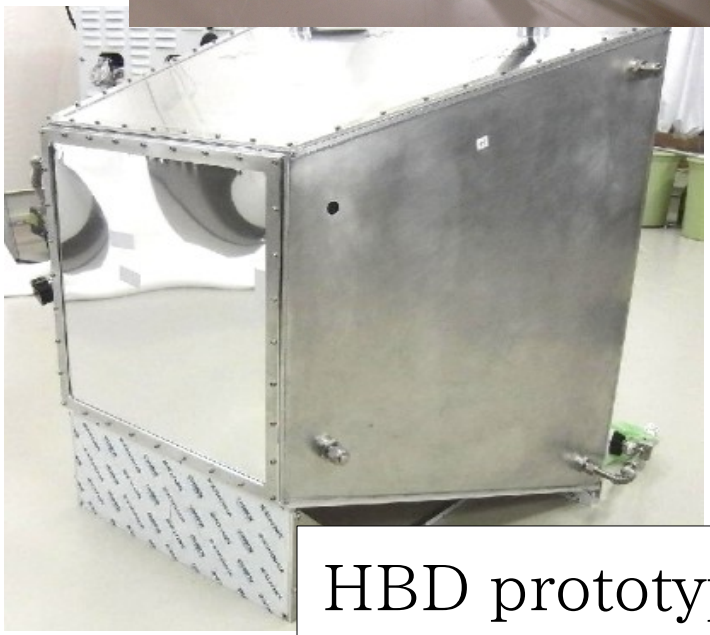
CFRP-made
GTR frame

Detectors: HBD



HBD dual type vessel



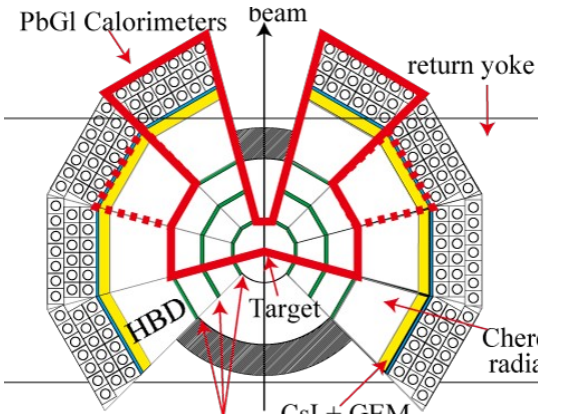


HBD prototype

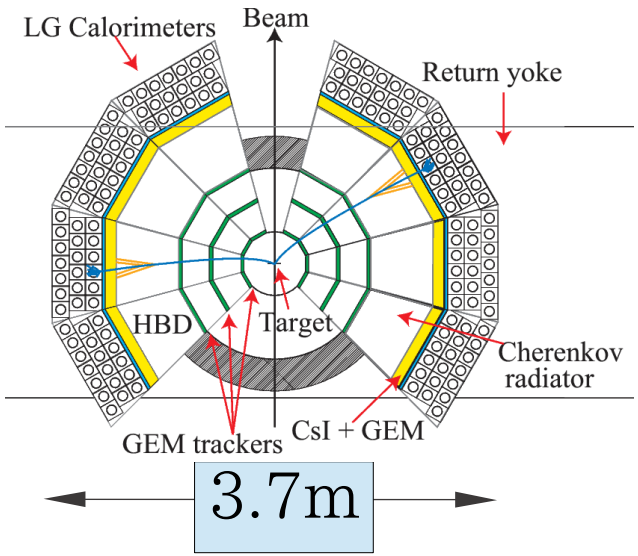
Preparation status as of 2016/Dec.

- 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 are almost ready.

- Spectrometer magnet reassemble is completed.
- R/O circuits
  - GTR preamp is OK. HBD preamp w/SRS is also OK.
    - SRS-ATCA is worked basically
  - GTR trigger ASIC is OK, circuit board v2 is delivered
    - discharge protection
  - LG-ADC will be made in this JFY.
  - HBD trigger ASIC & trigger logic modules in tests.



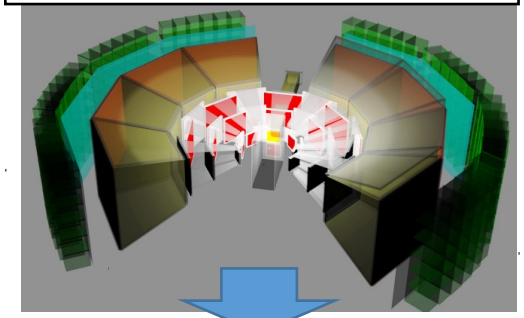
E16: staged construction plan



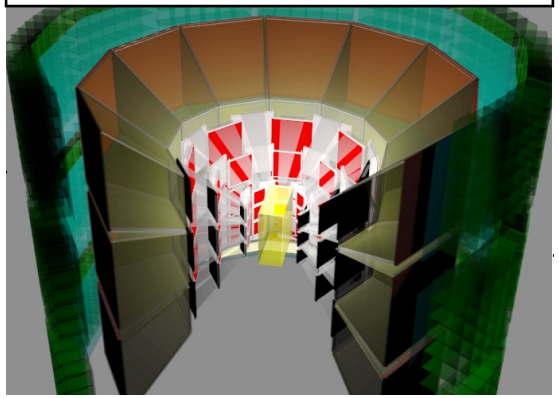
The spectrometer consists of 26 (=3x9-1) detector modules in a triple-decker

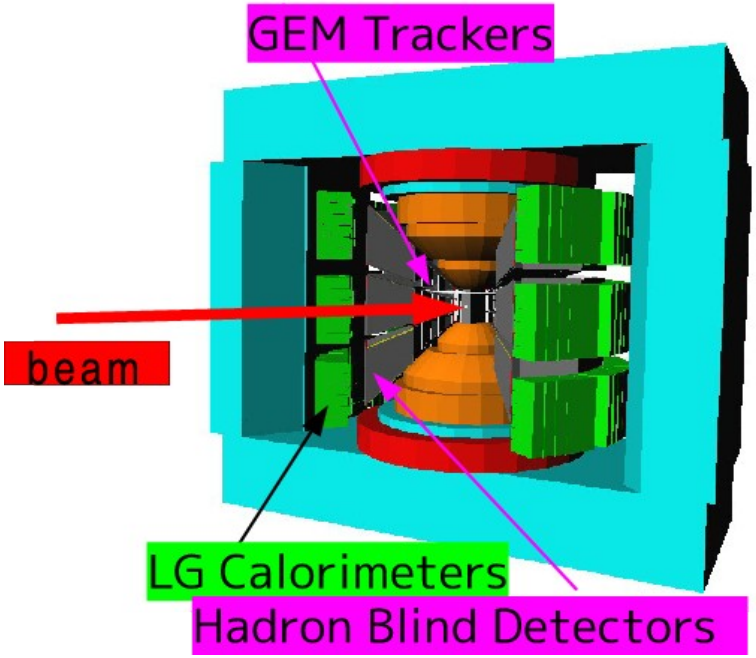
→ start with 8 modules in the middle deck

(8 modules)

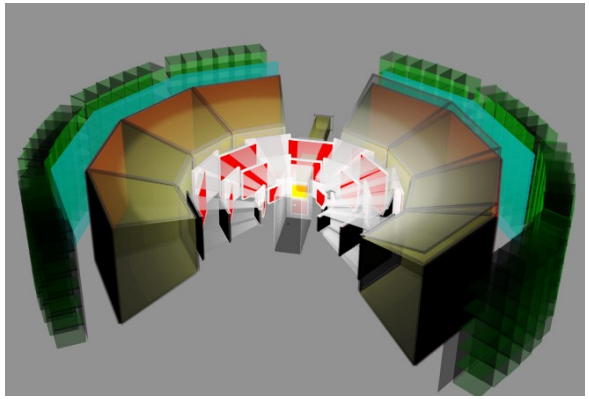


(26 modules)



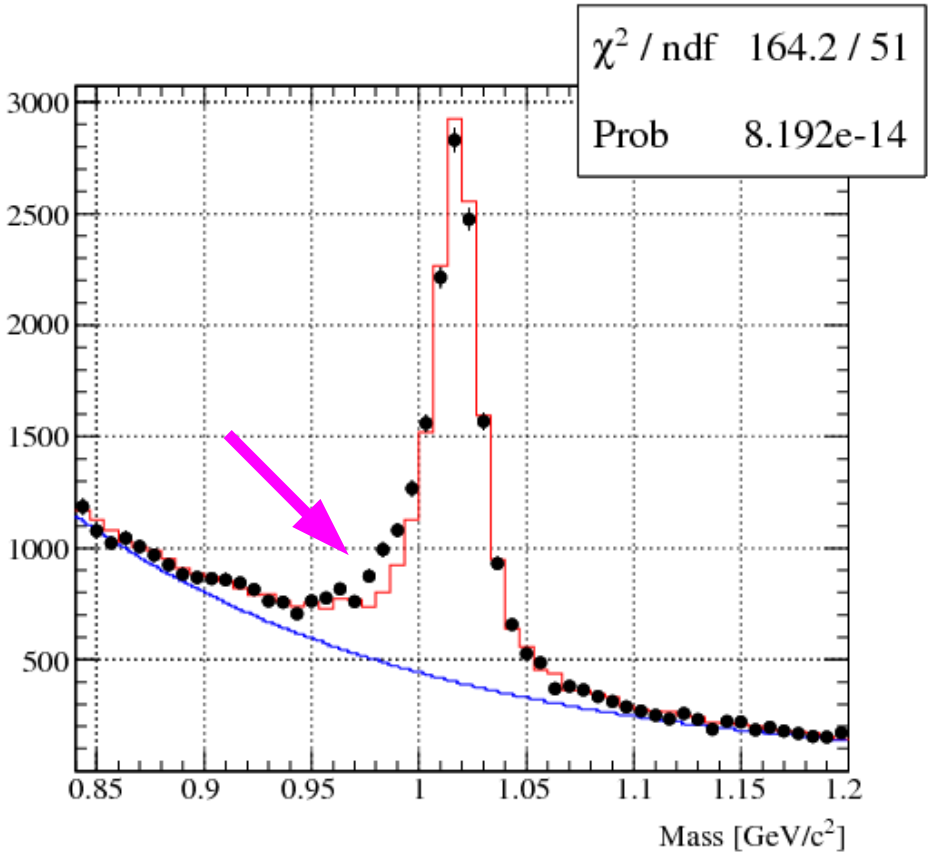


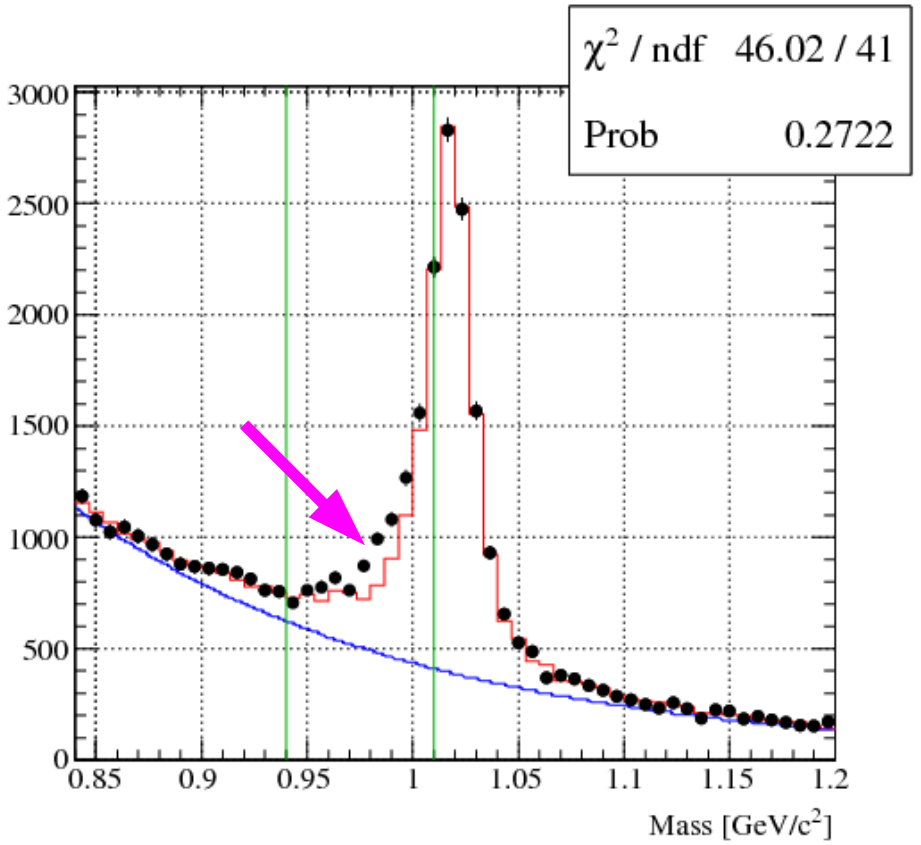
E16: simulation



- Geant4 detector simulation
  - including detector performance
    - pion rejection 0.6%(5%) by HBD(LG)
    - electron efficiency 63%(90%) by HBD(LG)
    - GTR charge response which reproduces the resolution 100um
      - simulate the accidental hits in GTR: up to 5 kHz/mm^2
    - SSD used in test exp. : resolution 30um/4ns, X_0=0.3%
- simple model of spectral change: k_1=0.034, k_2=2.6
  - modified $\phi \rightarrow$ ee : input to Geant4 simulation, w/ accidental hits on trackers
  - compared with the vacuum (Briet-Wigner) shape
- background tracks in the e^+e^- spectra in the ϕ–mass region
  - pion misID, e^+e^- from Dalitz decay & γ conversoin: pions from JAM
- Cu target (80um x 2), 1x10^{10} pps, 8 modules

E16: expected spectrum for Cu w/ bkg

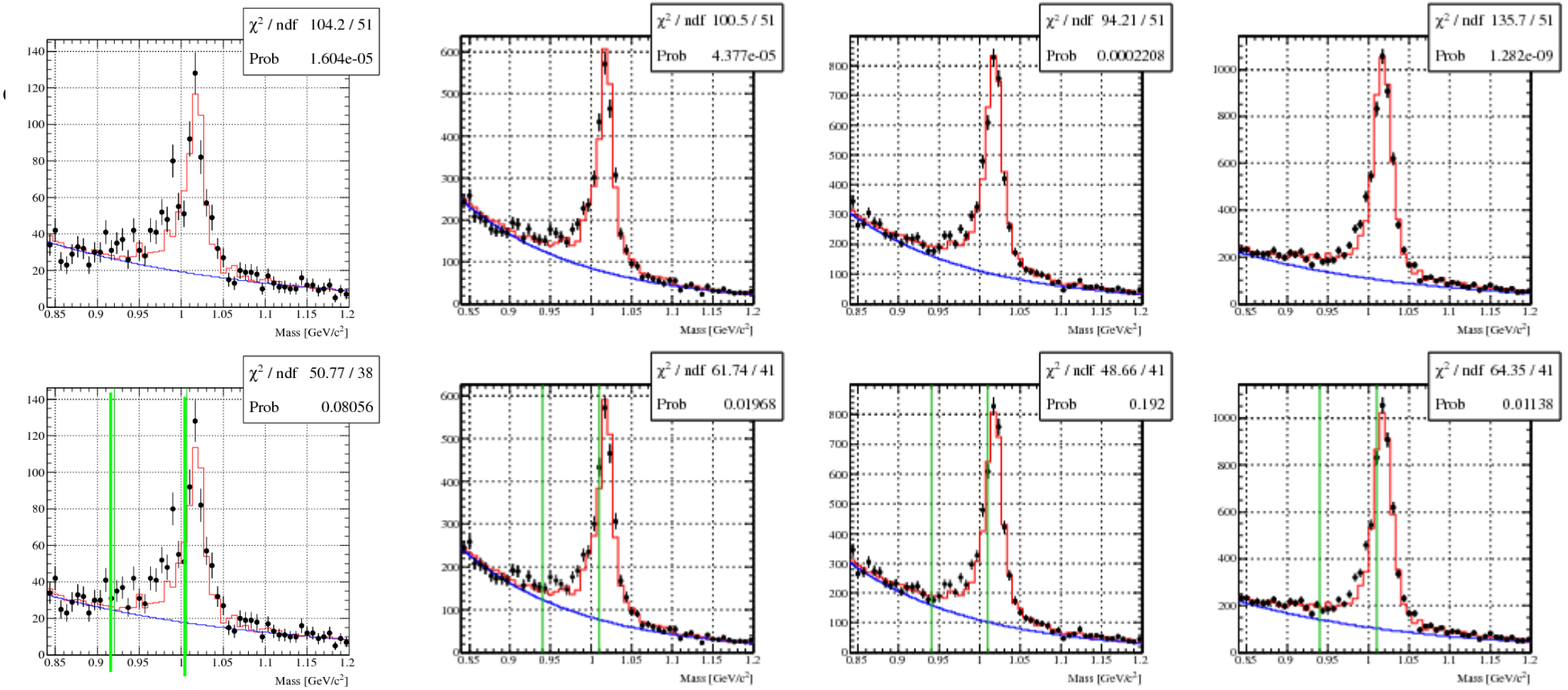




- ~15000 ϕ for Cu target in 160 shifts (53 days),1x10^{10} pps, 8 modules
- significant change: fit with [vacuum shape+exponential bkg] fails, due to the excess left side of the peak
- excluding the excess region(0.94-1.01GeV/c^2), fit succeeds

E16: expected spectra

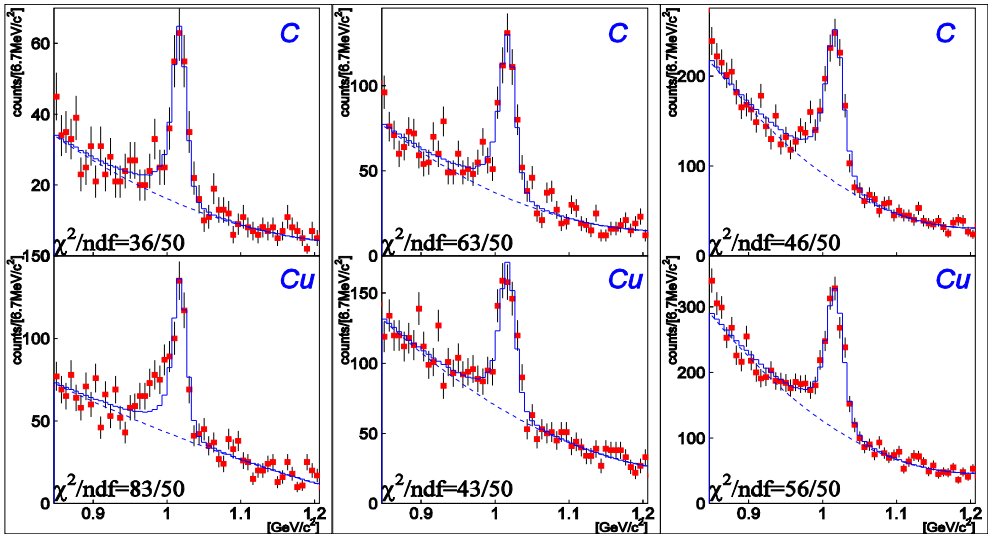
βγ<1.25, 1.25<βγ<1.75, 1.75<βγ<2.5, 2.5<βγ

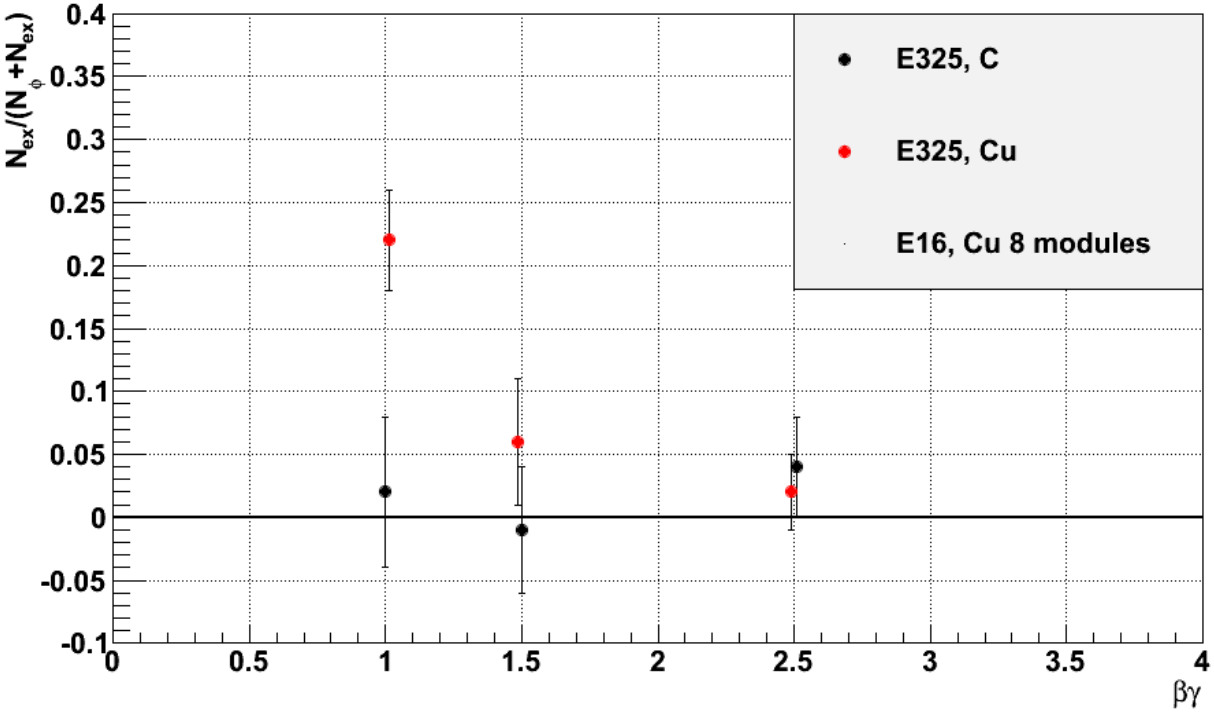


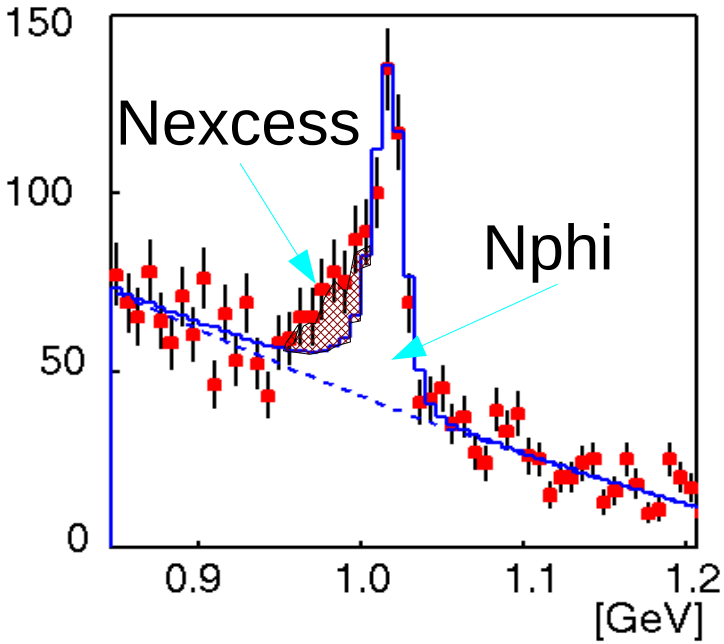
- divide to four βγ regions
- βγ dependence is examined → next

excess ratio in E325

- Nexcess/(Nexcess+Nphi)

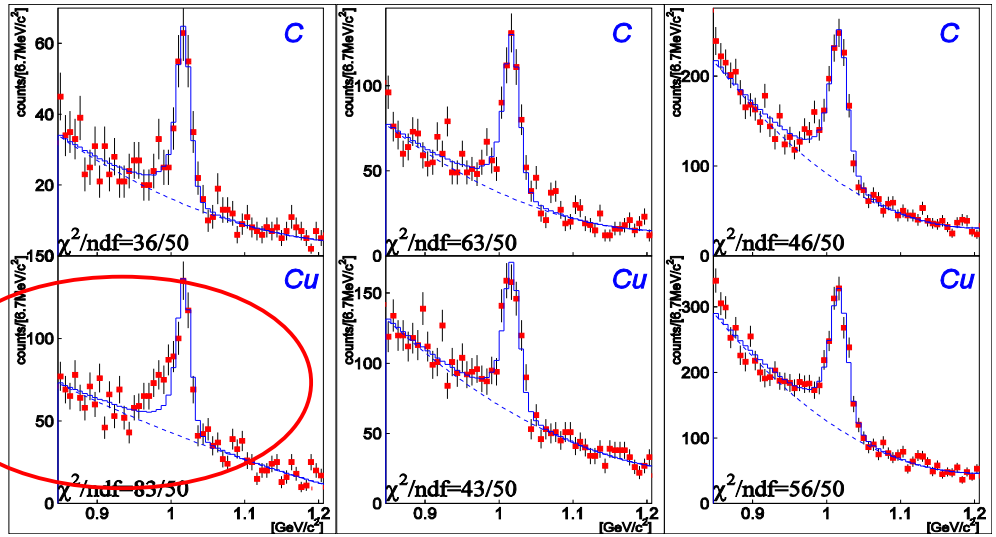


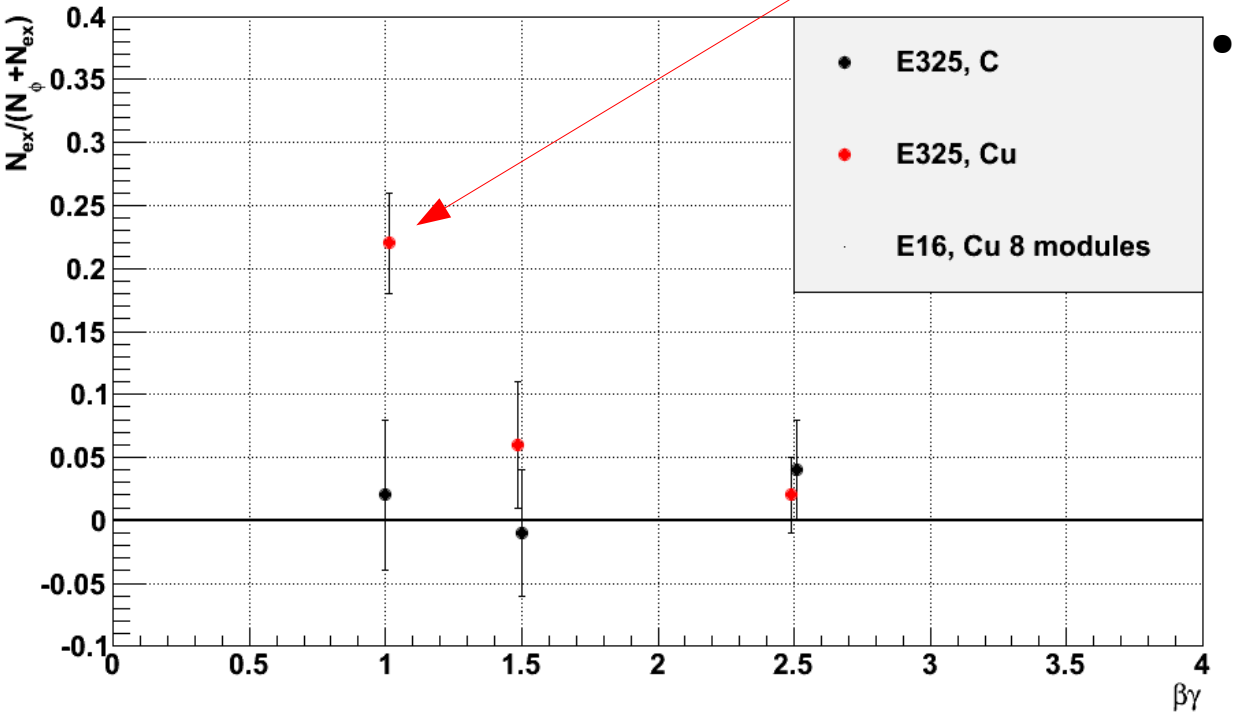




excess ratio

- Nexcess/(Nexcess+Nphi)
  - only slow Cu is significant in E325

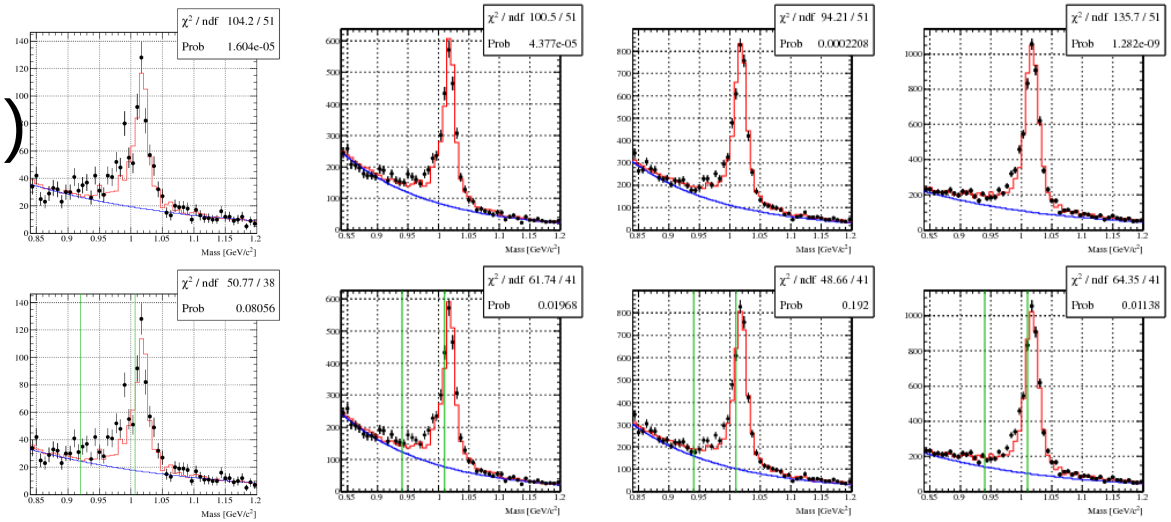


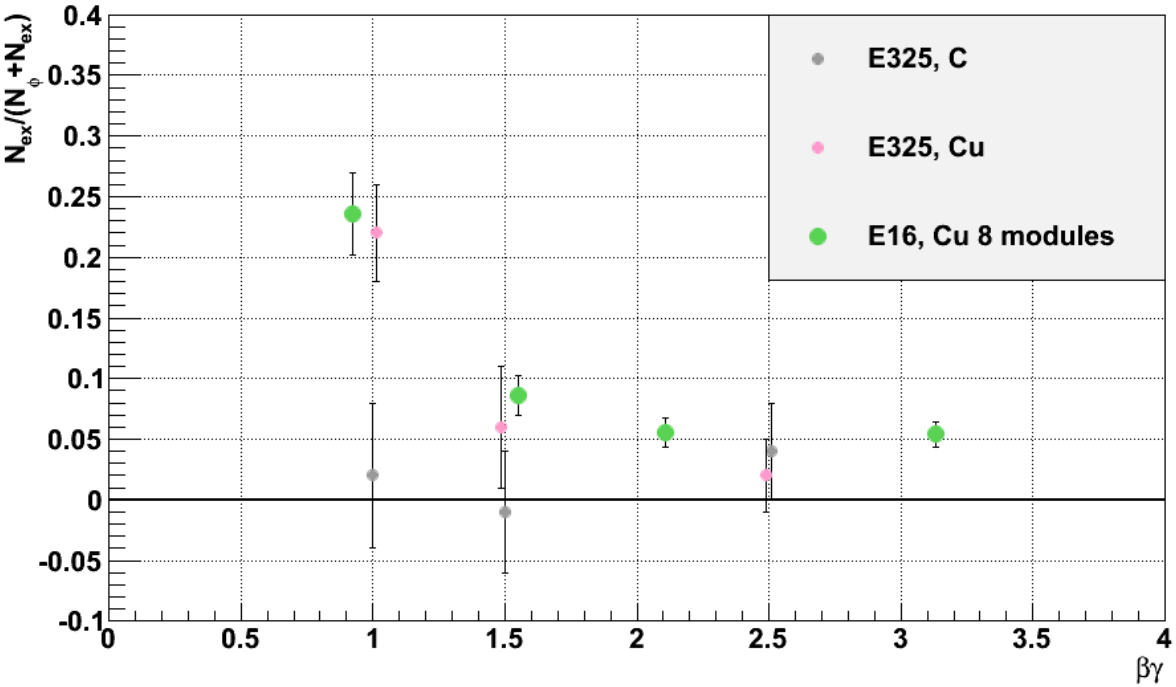


- larger excess in lower βγ (slower) bin : consistent with the modification in nuclei

excess ratio E16

- Nexcess/(Nexcess+Nphi)
  - all bins for Cu are significant in E16





- larger excess in lower βγ (slower) bin :

  the tendency become more clear and significant

  than that of E325.

Summary

- spectral change of hadrons reflects QCD vacuum nature.
- dilepton spectra in medium have been measured, and spectral change 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.
    - expected spectra for Cu target in the first stage are presented.
      - confirm the E325 results clearly even in the limited acceptance and stat.
  - beamline construction is also on-going, possibly completed in early 2019.