

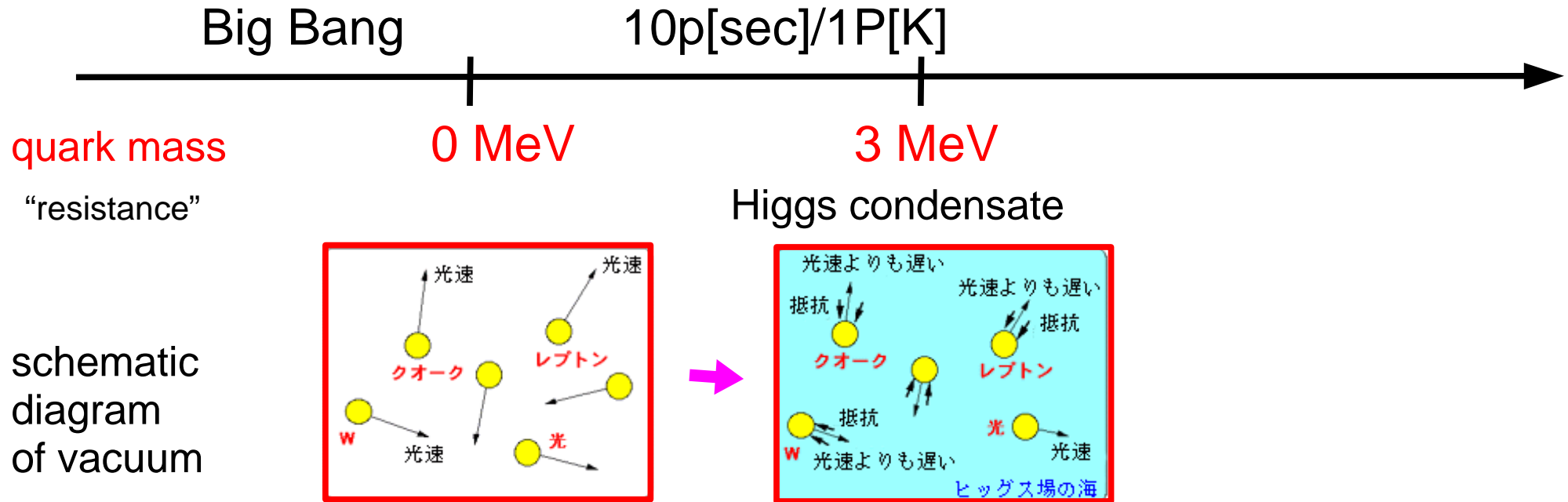
シンポジウム J-PARC ハドロン施設の近未来

核物質中での質量の変化と QCD での質量獲得機構

理研仁科センター 四日市 悟

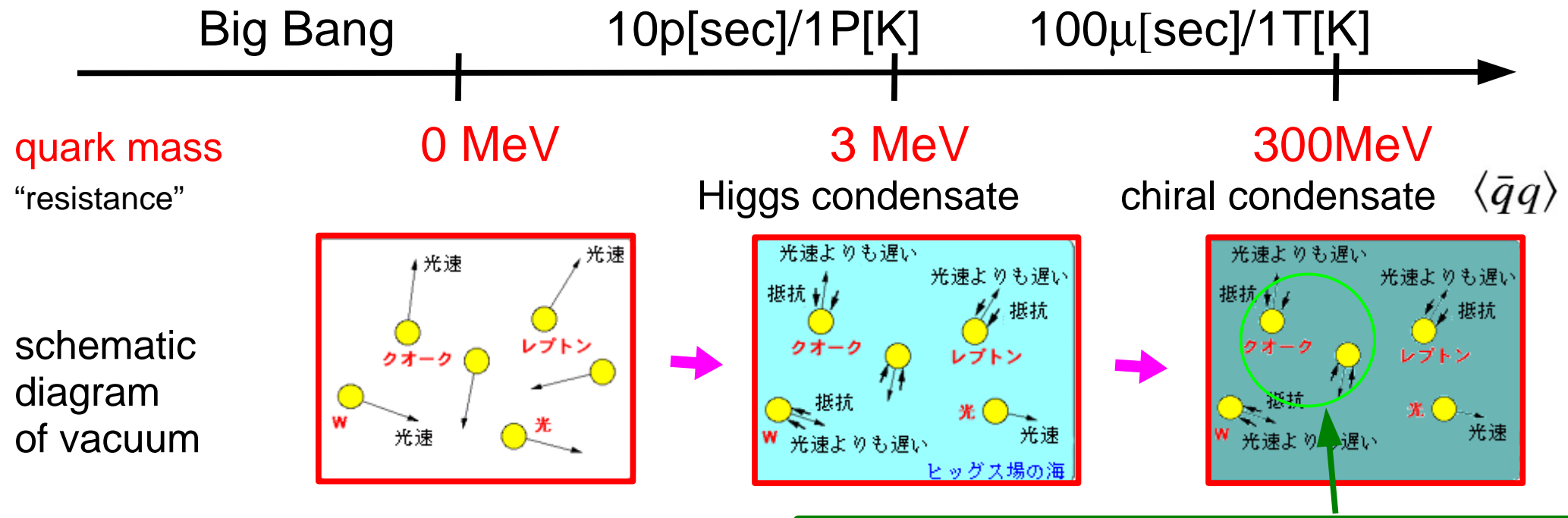
- physics motivation : hadron mass generation mechanism in QCD
- vector meson in nuclear matter : measurements in the world
- J-PARC E16 : invariant mass spectroscopy
- Related experiment at J-PARC

Origin of Mass (Higgs)



- Origin of lepton and quark mass: Higgs

Origin of Mass (QCD)



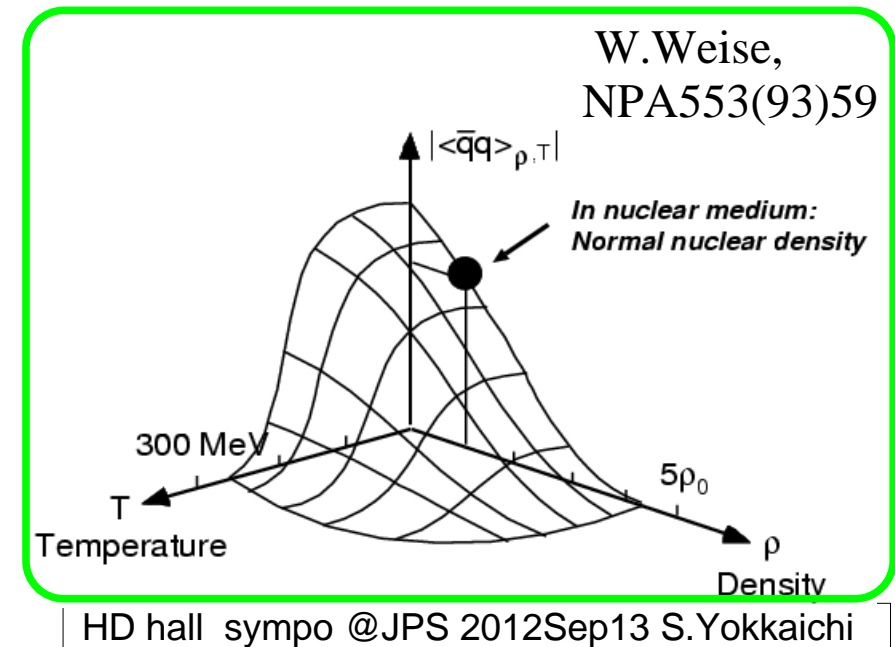
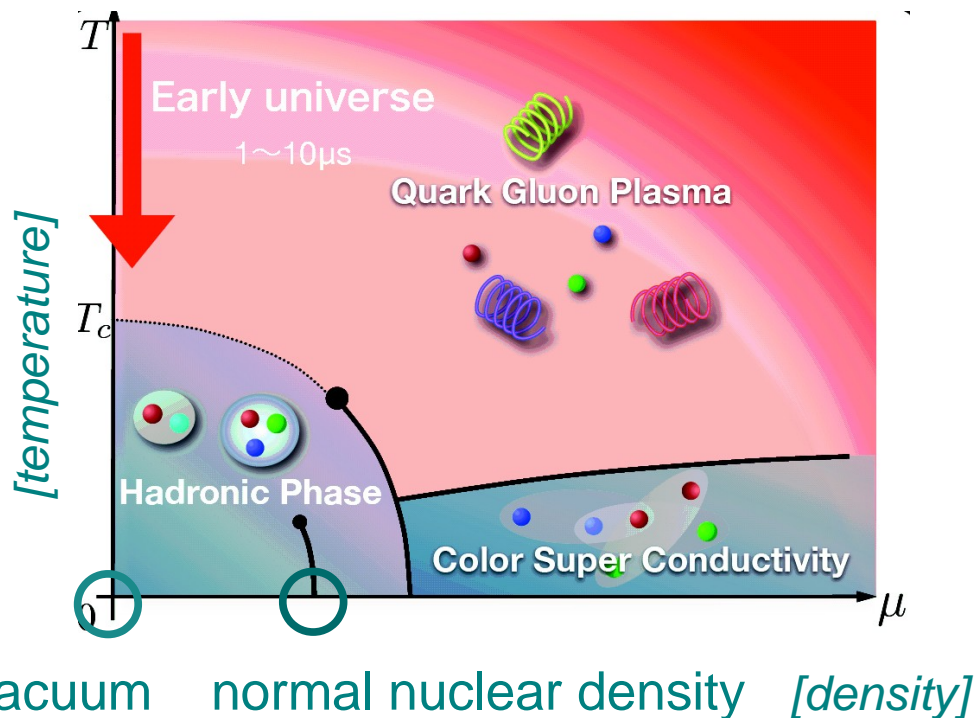
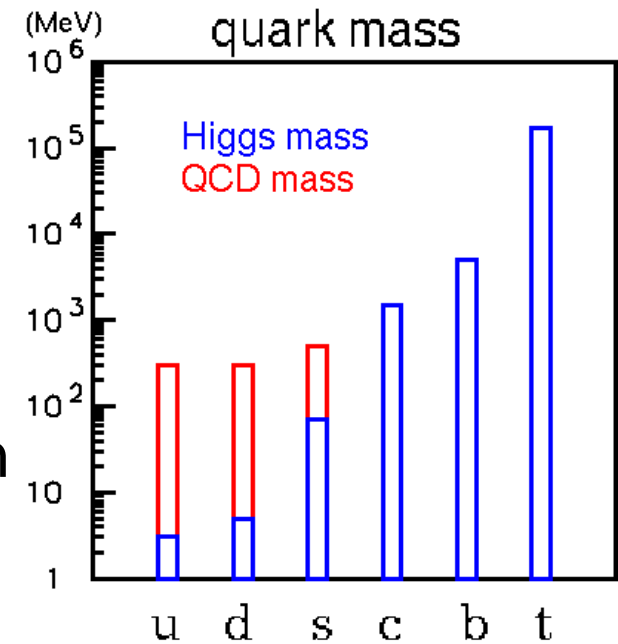
schematic diagram of vacuum

quark confinement : generation of hadrons (nucleon and mesons)

- Origin of lepton and quark mass: Higgs
- Origin of quark and hadron mass : spontaneous breaking of chiral symmetry, originally proposed by Nambu
 - Hadron mass could be modified in hot/dense matter, because of the chiral symmetry restoration is expected in such matter

Mass and chiral symmetry in nuclear matter

- Origin of quark and hadron mass : spontaneous breaking of chiral symmetry
- In hot/dense matter, chiral symmetry is expected to be restored
 - hadron spectral (mass , width) modification is also expected



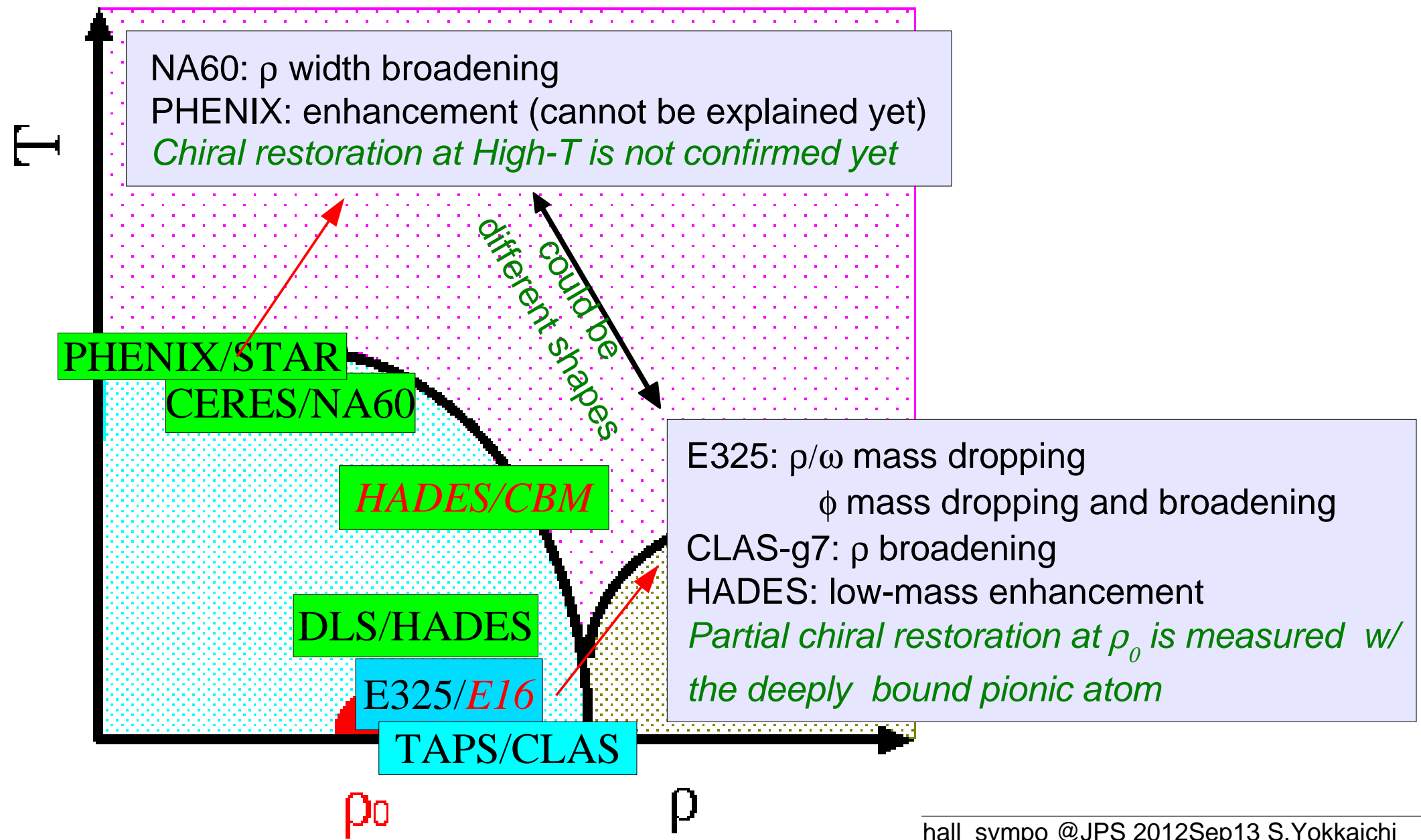
Vector meson measurements in the world

dilepton measurement

- HELIOS/3 (ee, $\mu\mu$) 450GeV p+Be / 200GeV A+A
 - DLS (ee) 1 GeV 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
 - STAR ($\pi\pi$, KK, ee) p+p/Au+Au
 - HADES (*) (ee) 1-4 GeV p+A/ 1-2GeV A+A
 - CLAS-G7 (*) (ee) 1~2 GeV γ +A
 - J-PARC E16 (ee) 30/50GeV p+A
 - HADES/FAIR (ee) 2~8GeV A+A
 - CBM/FAIR (ee) 20~30GeV A+A
-
- TAGX ($\pi\pi$) ~1 GeV γ +A
 - LEPS (KK) 1.5~2.4 GeV γ +A
 - CBELSA/TAPS(*) ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb
 - ANKE (KK) 2.83 GeV p+A

published/ 'modified'
 published/ 'unmodified'
 running/in analysis
 future plan
 as of 2012/Sep

Dilepton spectrum measurements in the world

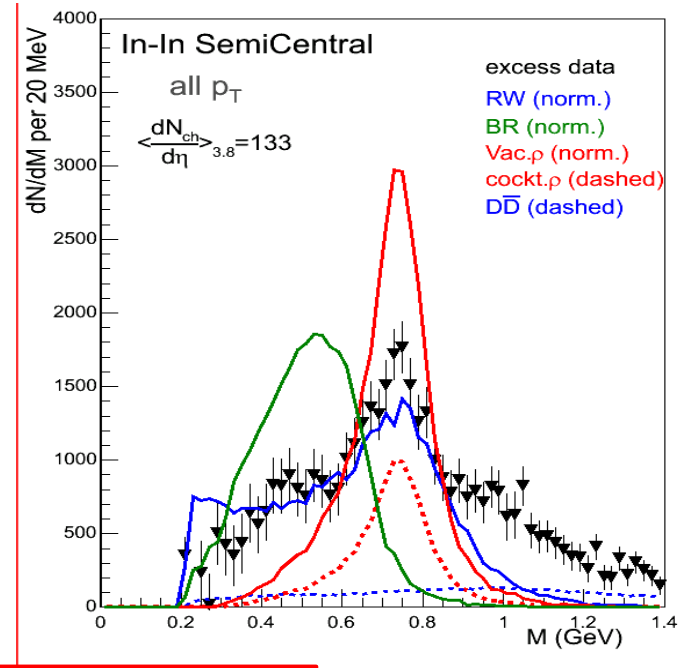


Dilepton spectrum measurements in the world

T

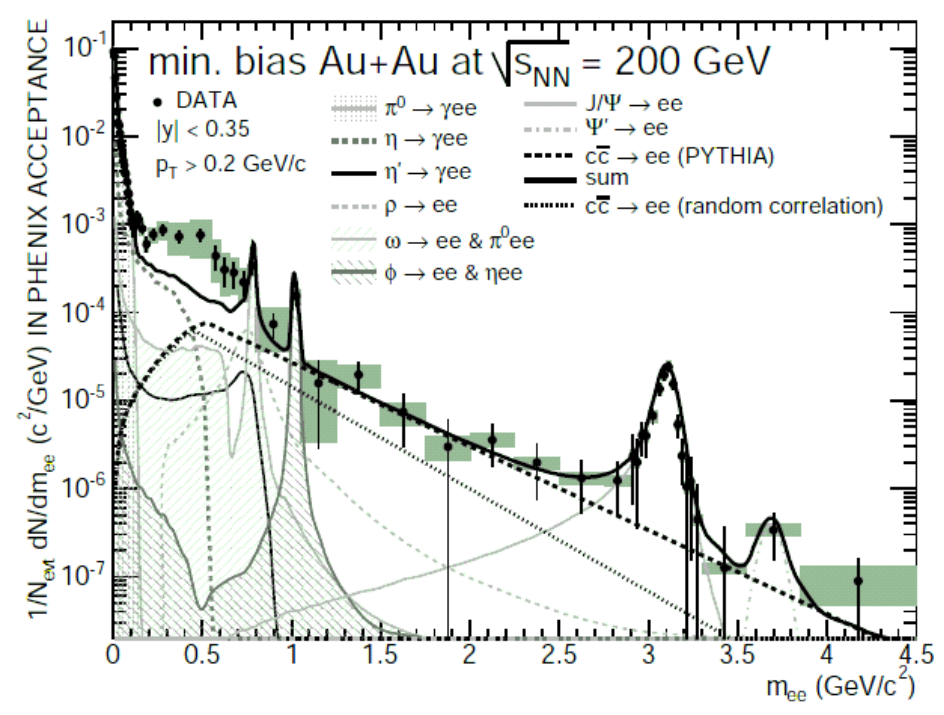
NA60: ρ width broadening
 PHENIX: enhancement (cannot be explained yet)
Chiral restoration at High-T is not confirmed yet

↑
 ↓
 differ. cont.



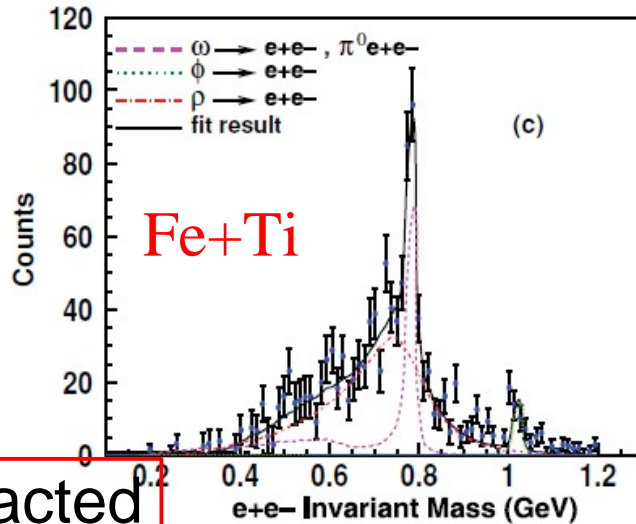
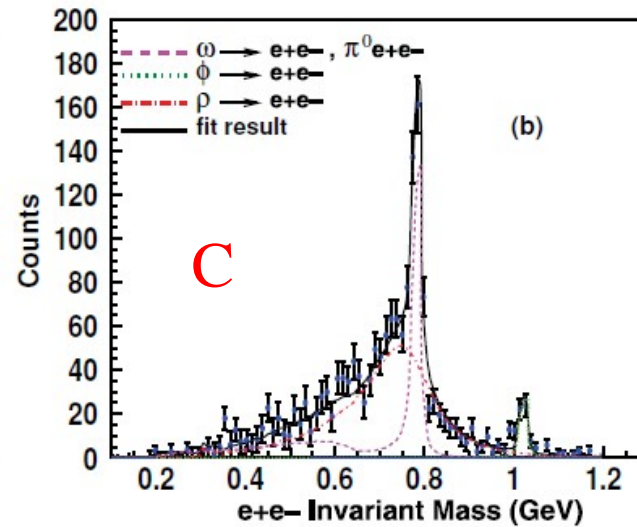
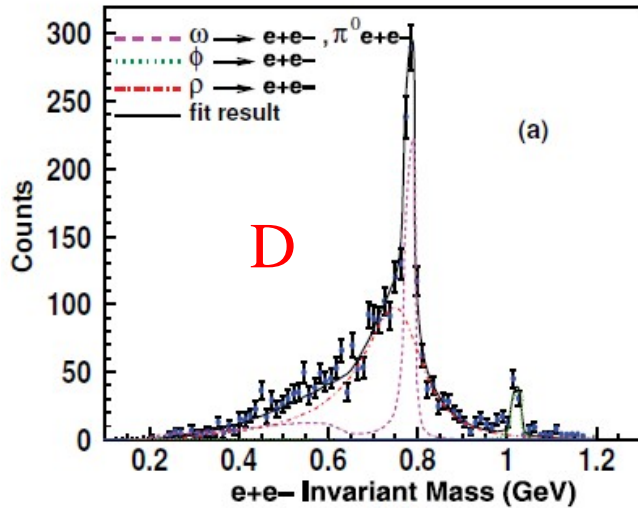
BKG subtracted

NA60



PHENIX

ments in the world



BKG subtracted

CLAS-g7

et)
t

mass dropping
mass dropping and broadening
broadening

DLS/HADES

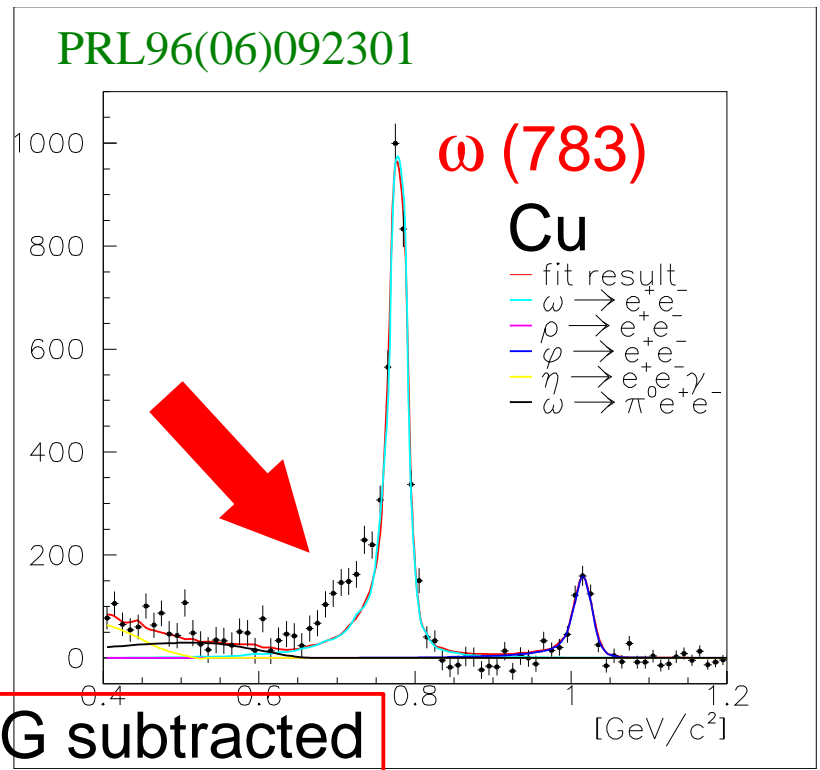
E325/E16

TAPS/CLAS

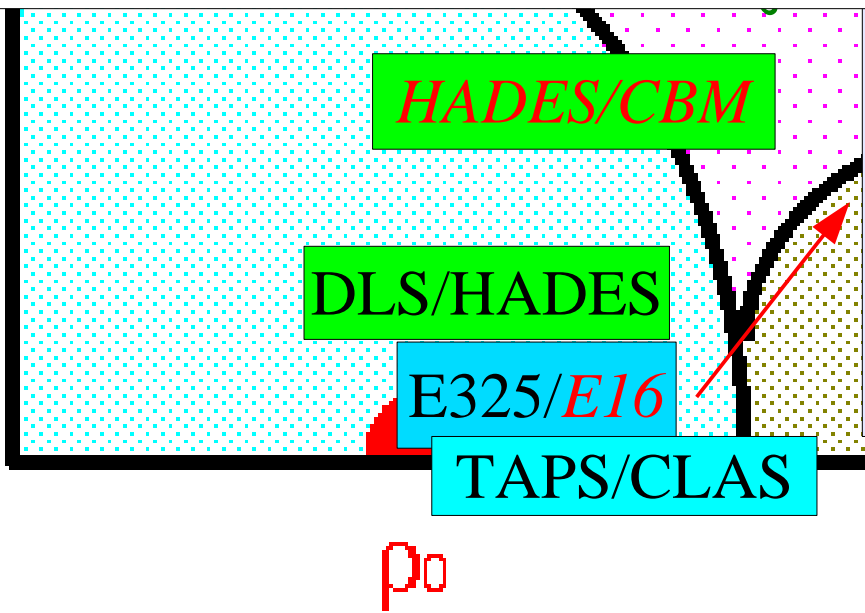
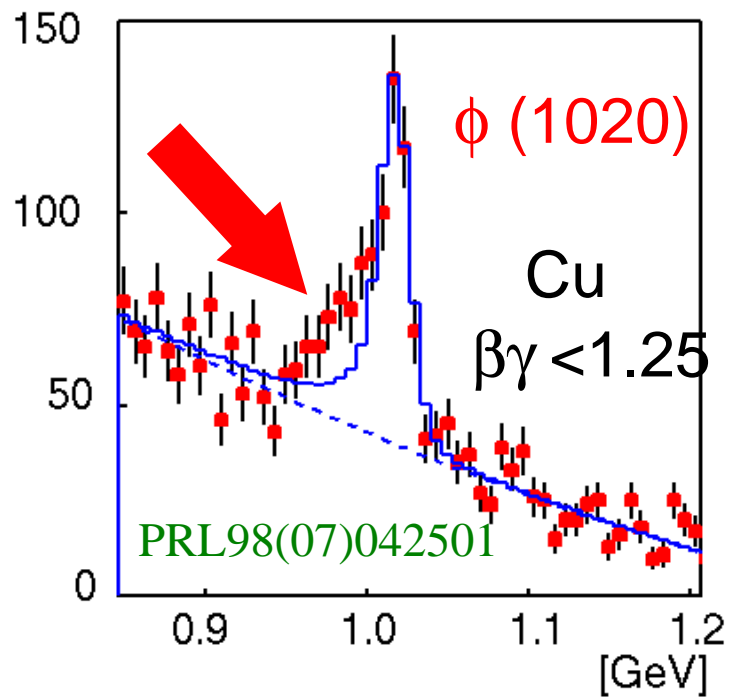
HADES: low-mass enhancement
*Partial chiral restoration at ρ_0 is measured w/
the deeply bound pionic atom*

ρ_0

ρ



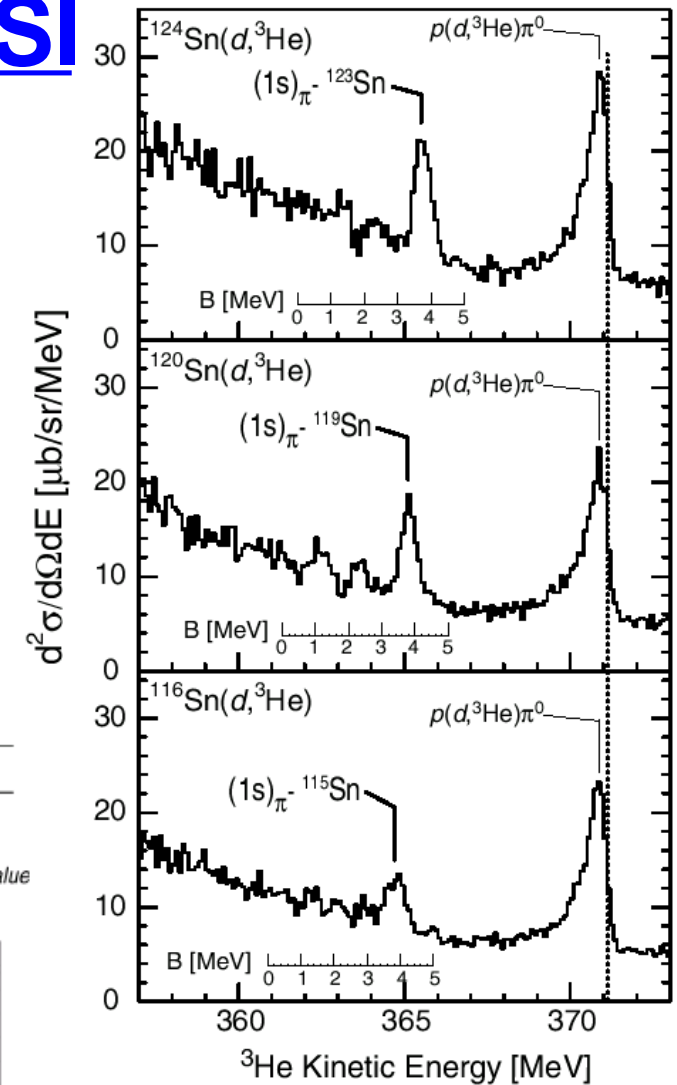
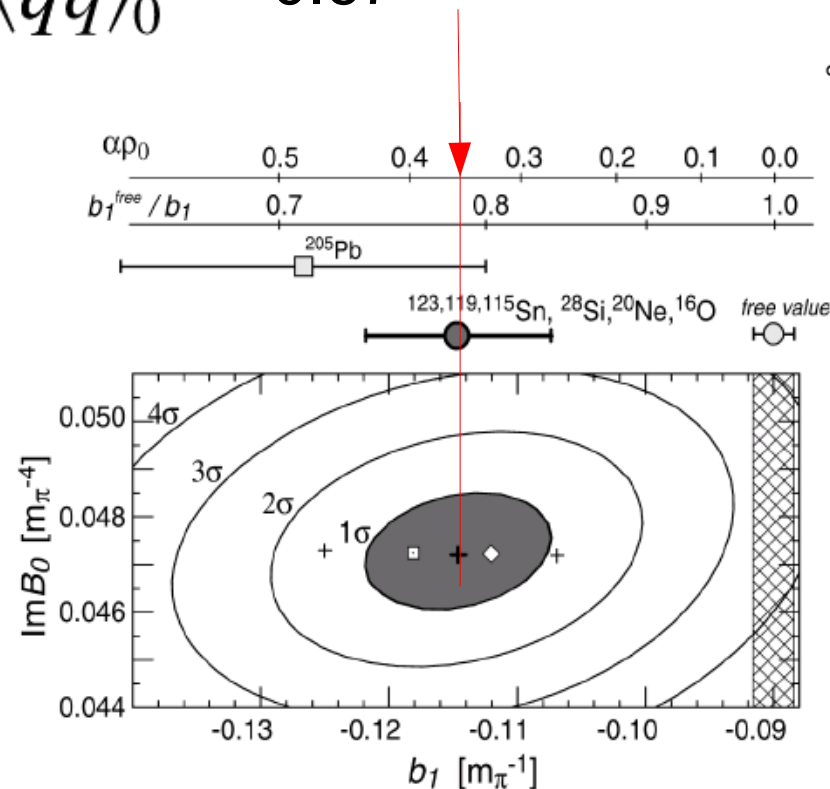
E325



E325: ρ/ω mass dropping
 ϕ mass dropping and broadening
 CLAS-g7: ρ broadening
 HADES: low-mass enhancement
Partial chiral restoration at ρ_0 is measured w/ the deeply bound pionic atom

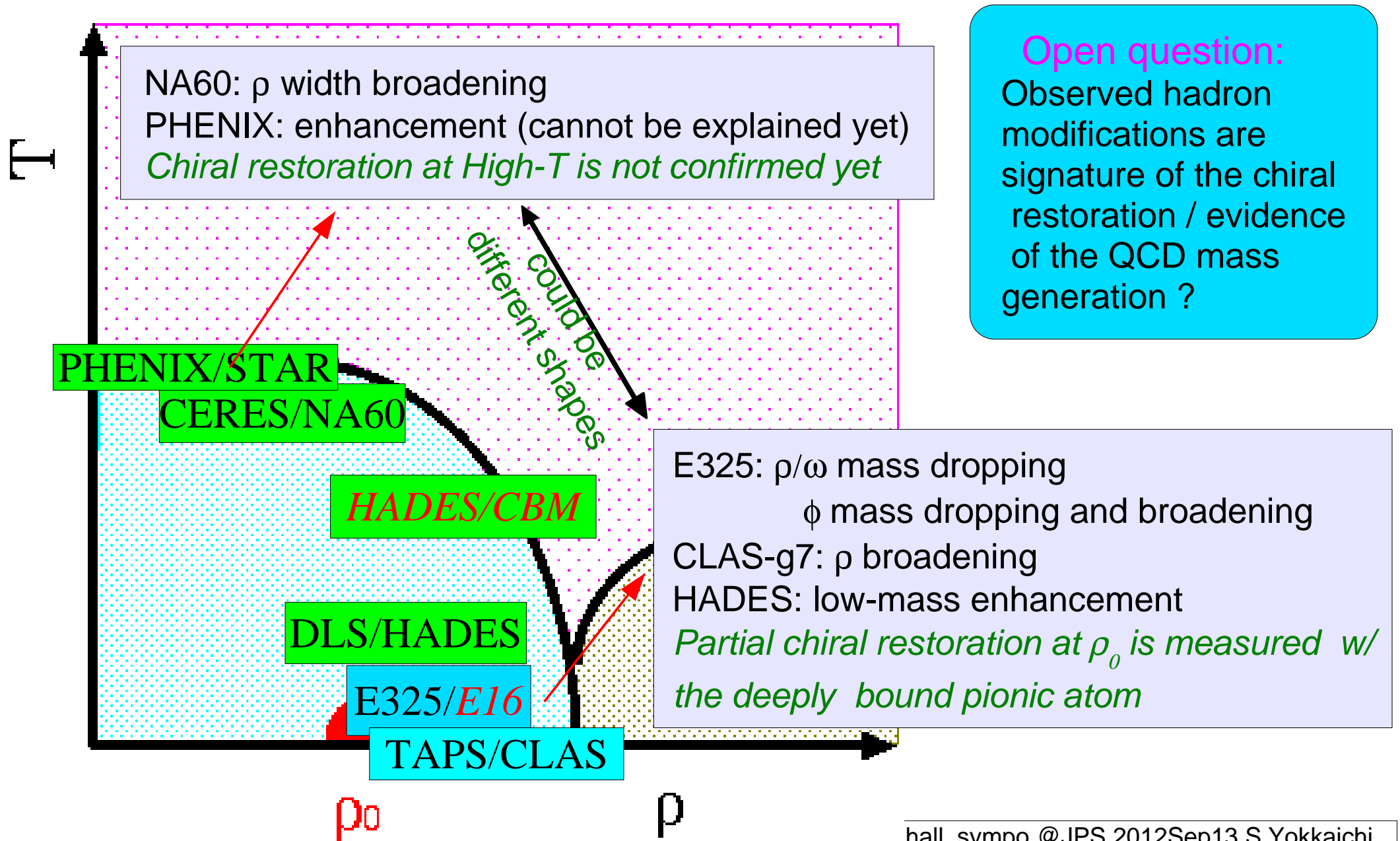
Deeply bound pionic atom @ GSI

- optical potential b_1
 - \rightarrow pion decay const.(TW)
 - \rightarrow chiral condensate (GOR)
 - $\langle \bar{q}q \rangle_{\rho_0} / \langle \bar{q}q \rangle_0 \sim 0.67$



K.Suzuki et al,
PRL92(04)072302

Dilepton spectrum measurements in the world



Experimental methods: pros and cons

- leptonic decay VS hadronic decay
 - small FSI in the matter, but small branching ratio
- proton/photon induced VS heavy-ion collision
 - cold VS hot
 - static environment VS time evolution
 - S/N is better, production cross section is smaller
- ϕ VS ρ/ω
 - isolated and narrow, but production CS is smaller
- Why only KEK-PS E325 can observe the ϕ modification?
 - proton induced : better S/N than the HI collisions
 - large stat. using a high intensity beam : cope with the small CS
 - good spectrometer keeps the good mass resolution and works under the higher interaction rate

J-PARC E16

Vector meson in nuclear matter

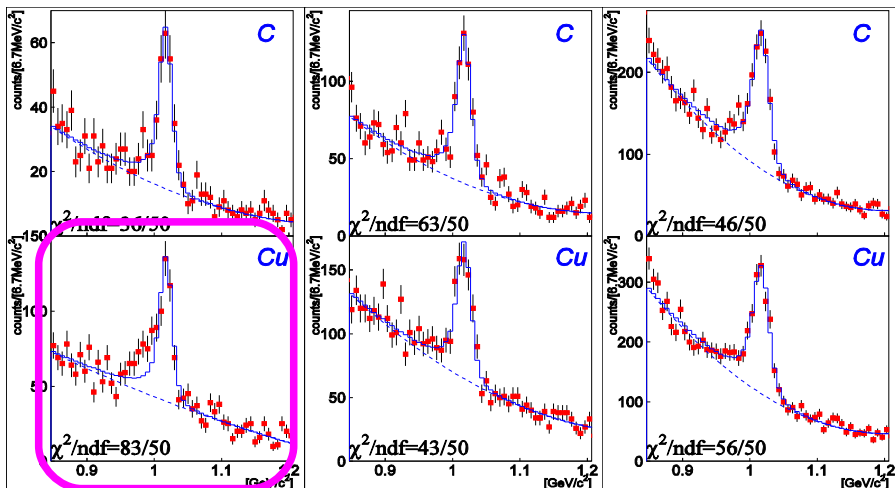
J-PARC E16 Collaboration

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

J-PARC E16 experiment

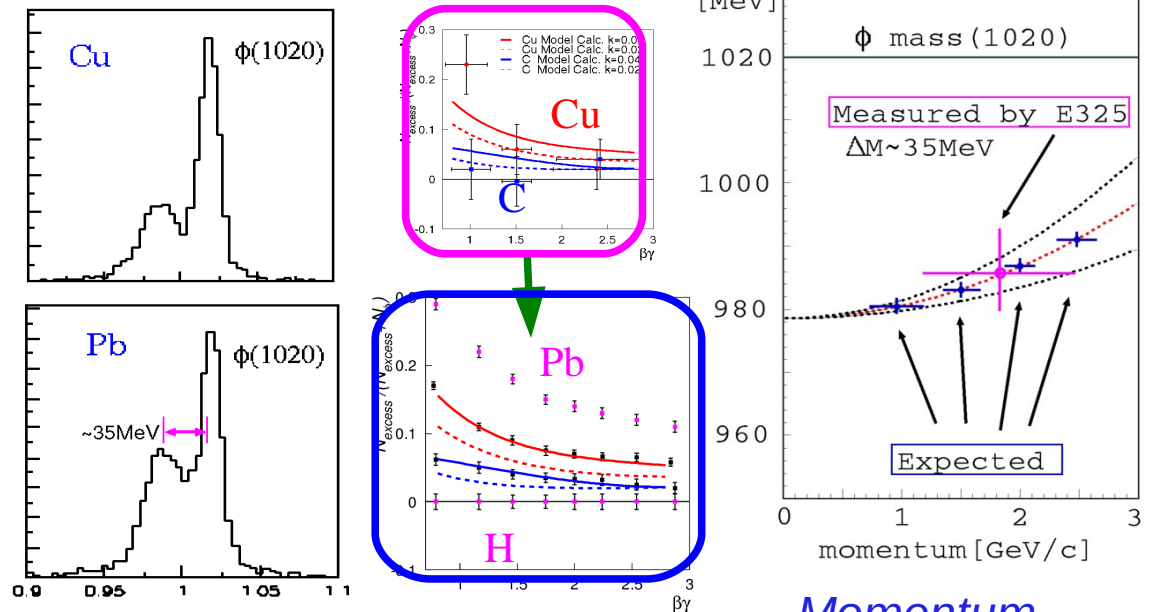
- Measure the vector-meson mass modification in nuclei systematically with the e^+e^- invariant mass spectrum
- A 30 GeV primary proton beam (10^{10} /spill) / 5 weeks of physics run to collect $\sim 10^5 \phi \rightarrow e^+e^-$ for each target
- confirm the E325 results, and provide new information as the matter size/momentum dependence of modification

Precedent exp.(KEK-PS E325)



ϕ -mass is modified in large nuclei for slowly moving mesons... consistent with the prediction based on the QCD sum rule

Proposed exp. E16



Nuclear matter size
dependence

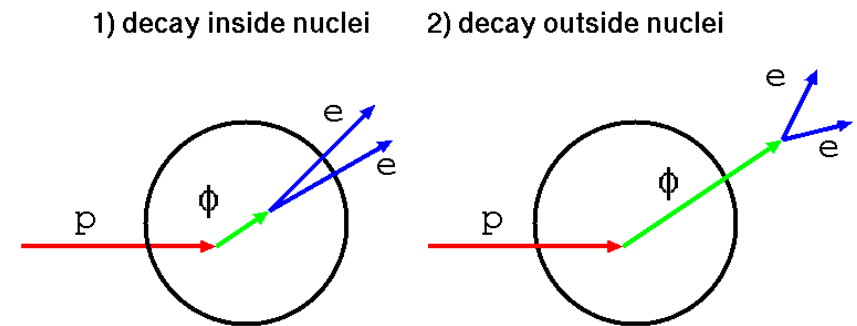
&

Momentum
dependence

of mass modification are measured

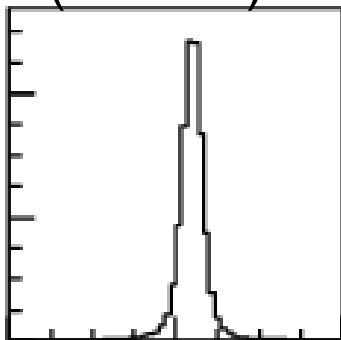
Expected Invariant mass spectra in e^+e^-

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



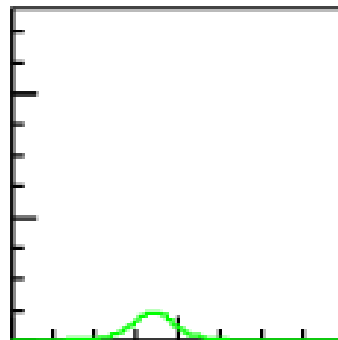
longer-life meson(ω & ϕ) cases : Schematic picture

outside decay
(natural)

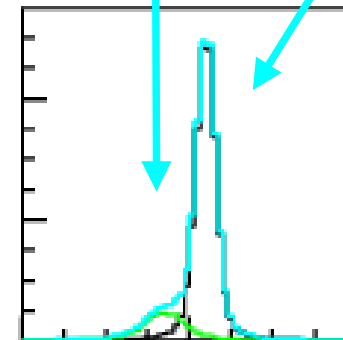


+

inside decay
(modified)



=

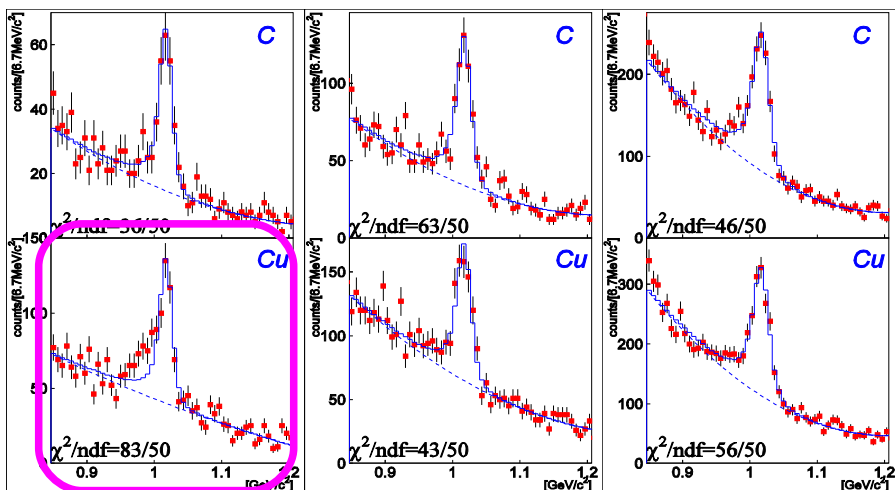


expected
to be observed

J-PARC E16 experiment

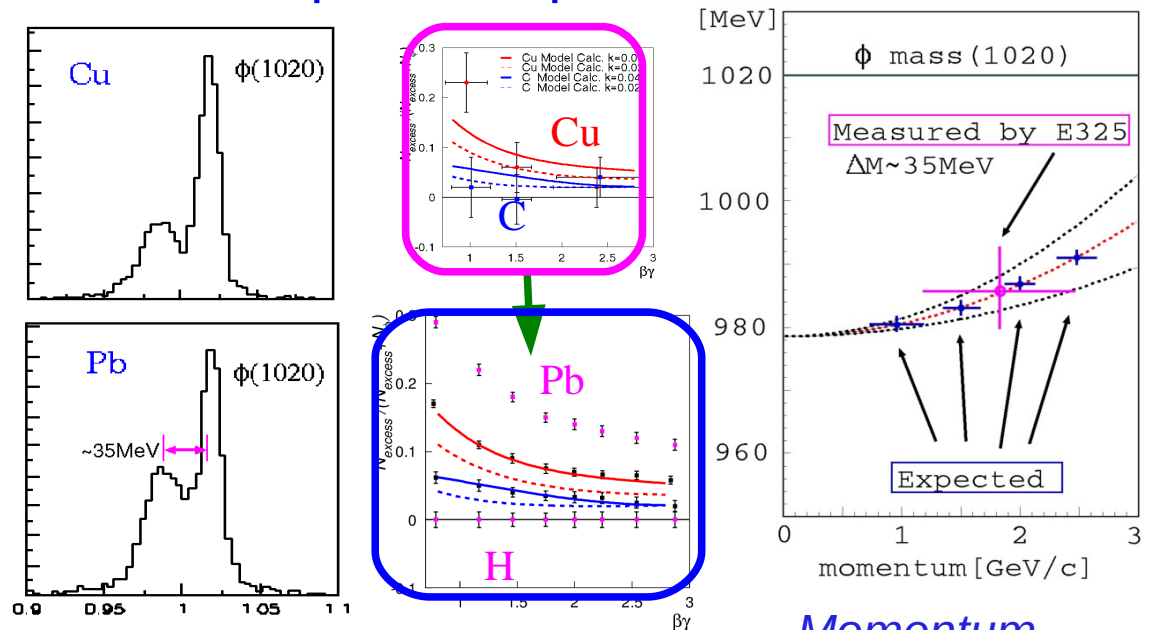
- Measure the vector-meson mass modification in nuclei systematically with the e^+e^- invariant mass spectrum
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Precedent exp.(KEK-PS E325)



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Proposed exp. E16

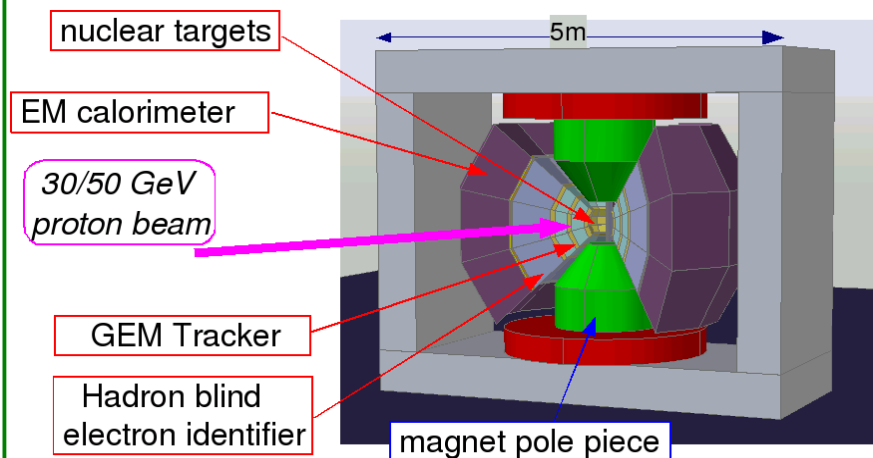


Nuclear matter size & Momentum dependence of mass modification are measured

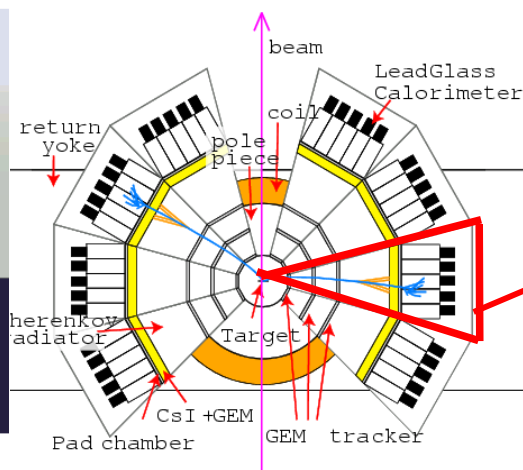
To collect high statistics

- For the statistics 100 times as large as E325, a **new spectrometer** and a **primary beam in the High-p line** are required.
 - To cover larger acceptance : $x \sim 5$
 - Higher energy beam (12 \rightarrow 30/50 GeV) : $x \sim 2$ of production
 - Higher intensity beam ($10^9 \rightarrow 10^{10}$ /spill (1sec)) : $x 10$ (\rightarrow 10MHz interaction on targets)
 - to cope with the high rate, new detectors (GEM Tracker & HBD) are required.

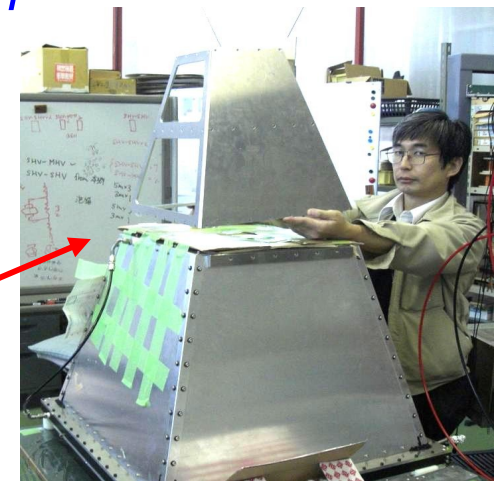
Proposed Spectrometer



Plan View



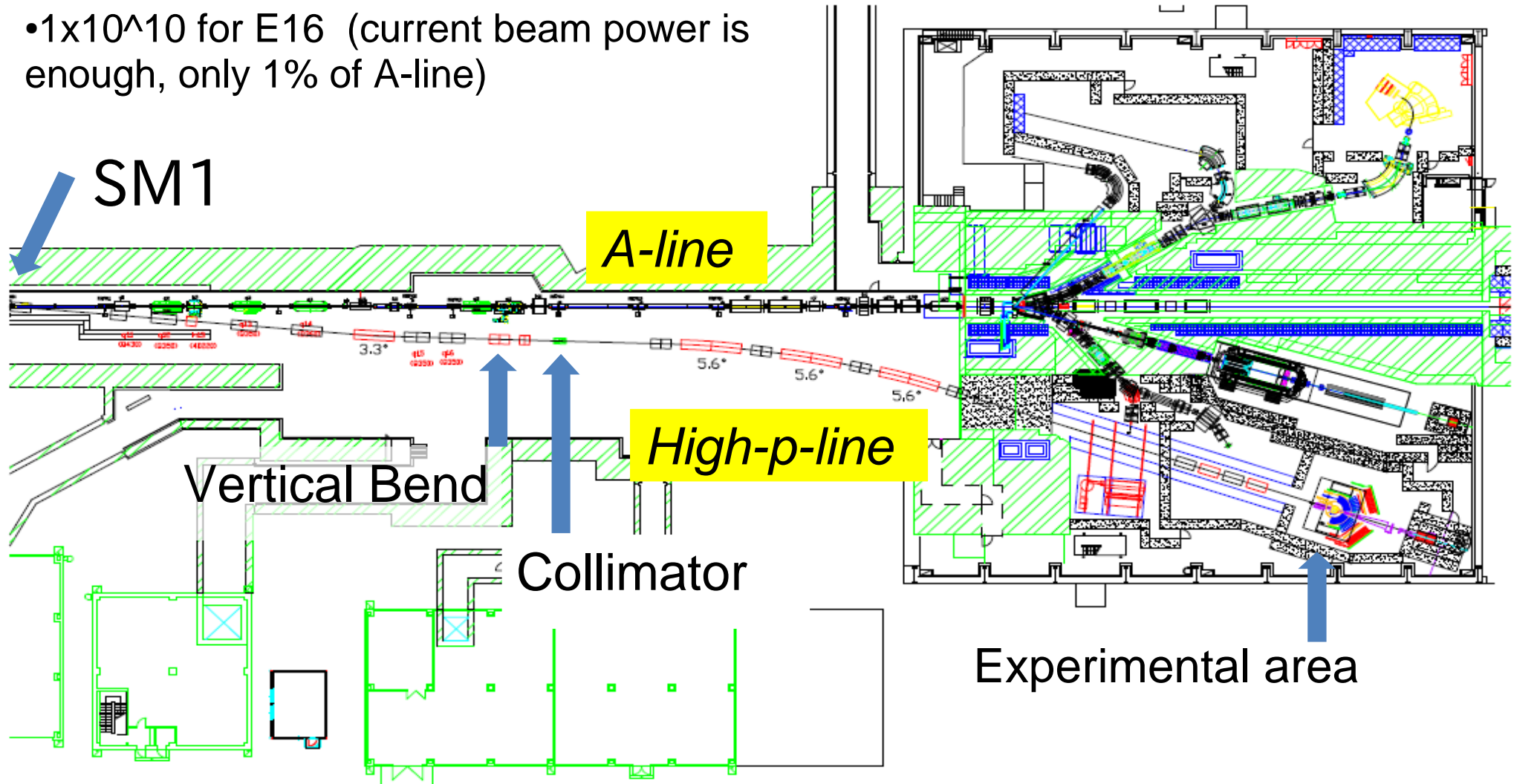
Prototype Module



26 detector modules

High-p line in the Hadron hall

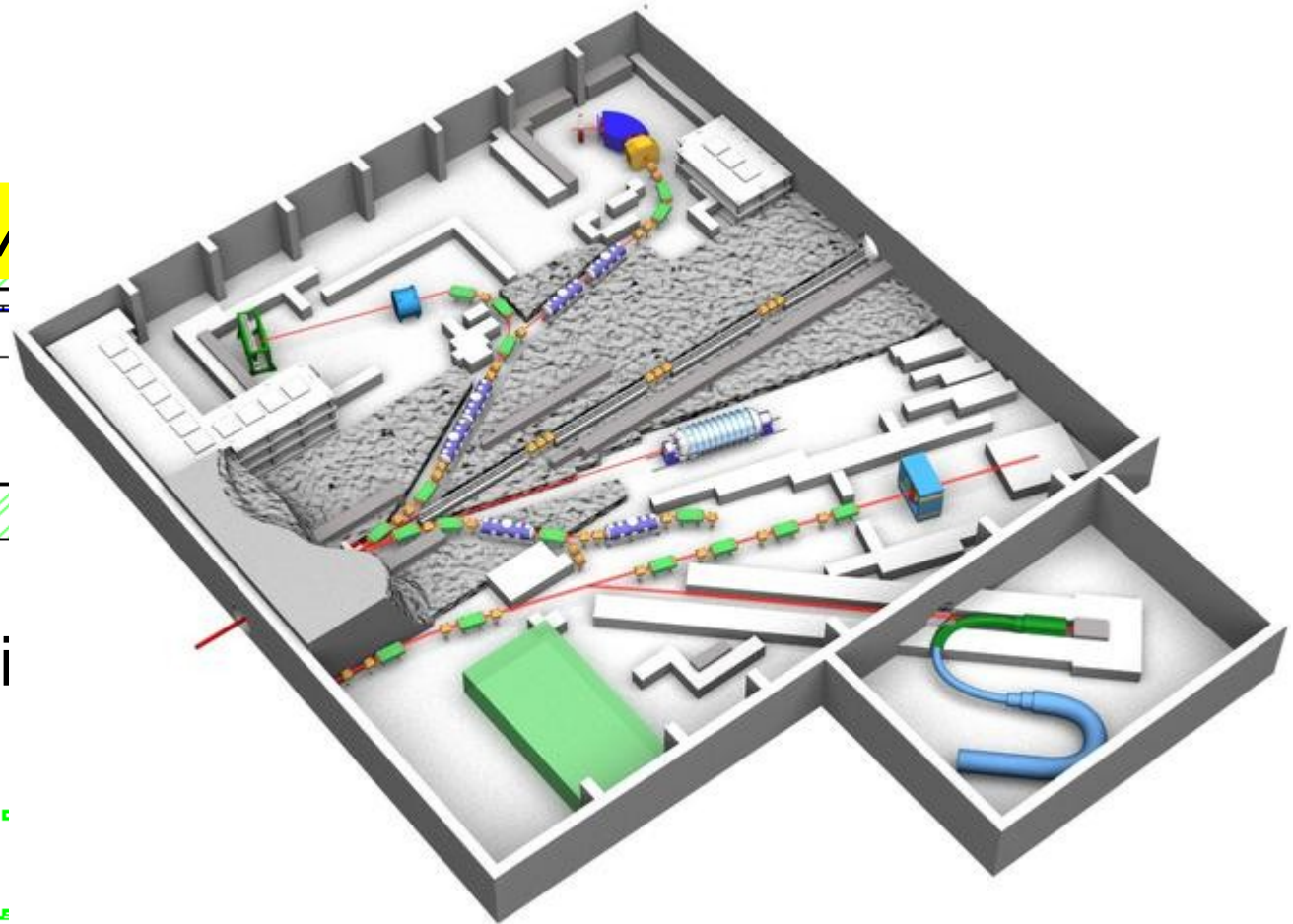
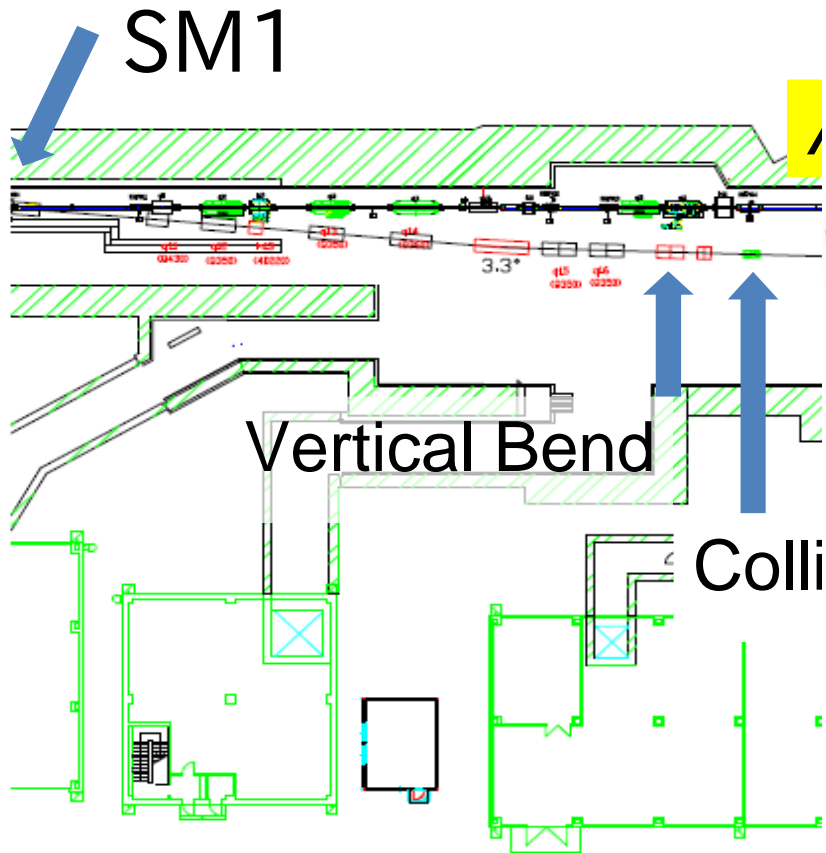
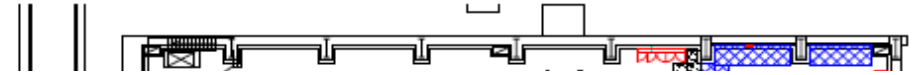
- 1×10^{10} for E16 (current beam power is enough, only 1% of A-line)



- 3 years plan of the construction : budget requested by KEK to MEXT

High-p line in the Hadron hall

- 1×10^{10} for E16 (current beam power is enough, only 1% of A-line)



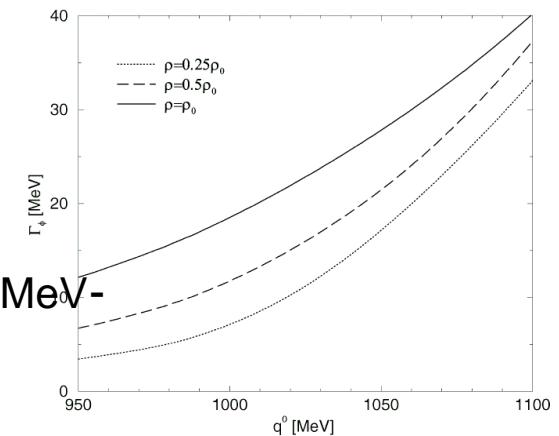
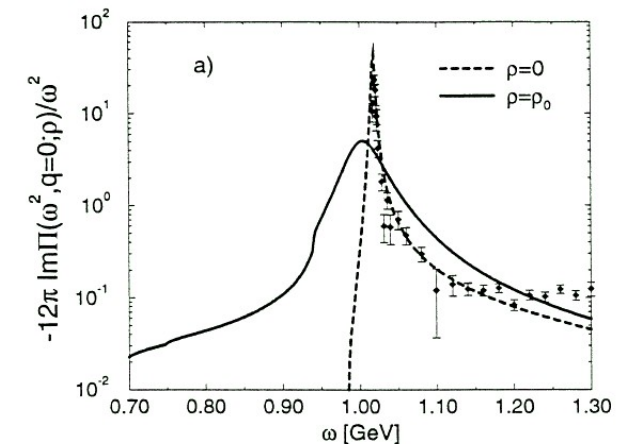
- 3 years plan of the construction : budget requested by KEK to MEXT

ϕ -mass modification at ρ_0

- (vacuum value : $m(0)=1019.456\text{MeV}$, $\Gamma(0)=4.26\text{MeV}$)
 - $m(\rho)/m(0) = 1 - k_1 (\rho/\rho_0)$, $\Gamma(\rho)/\Gamma(0) = 1 + k_2 (\rho/\rho_0)$
- determined by E325 (PRL98(2007)042581)
 - Δm : -35 (28~41) MeV, Γ : 15 (10~23) MeV
- Hatsuda, Lee [PRC46(1992)34] *QCD sum rule*
 - Δm : $-12\sim 44$ MeV ($k=(0.15\pm 0.05)y$, $y=0.12\sim 0.22$),
 - Γ : not estimated
- Klingl, Waas, Weise [PLB431(1998)254] *hadronic*
 - taking account of K-mass modification
 - Δm : < -10 MeV, Γ : ~ 45 MeV
- Oset , Ramos [NPA 679 (2001) 616] *hadronic*
 - different approach for K-mass
 - Δm : < -10 MeV, Γ : ~ 22 MeV for $m=1020\text{MeV}$, $\sim 16\text{MeV}$ for $m=985$ MeV-
- Cabrera and Vacas [PRC 67(2003)045203] OR01+ *hadronic*
 - Δm : -8 MeV, Γ : ~ 30 MeV for $m=1020\text{MeV}$

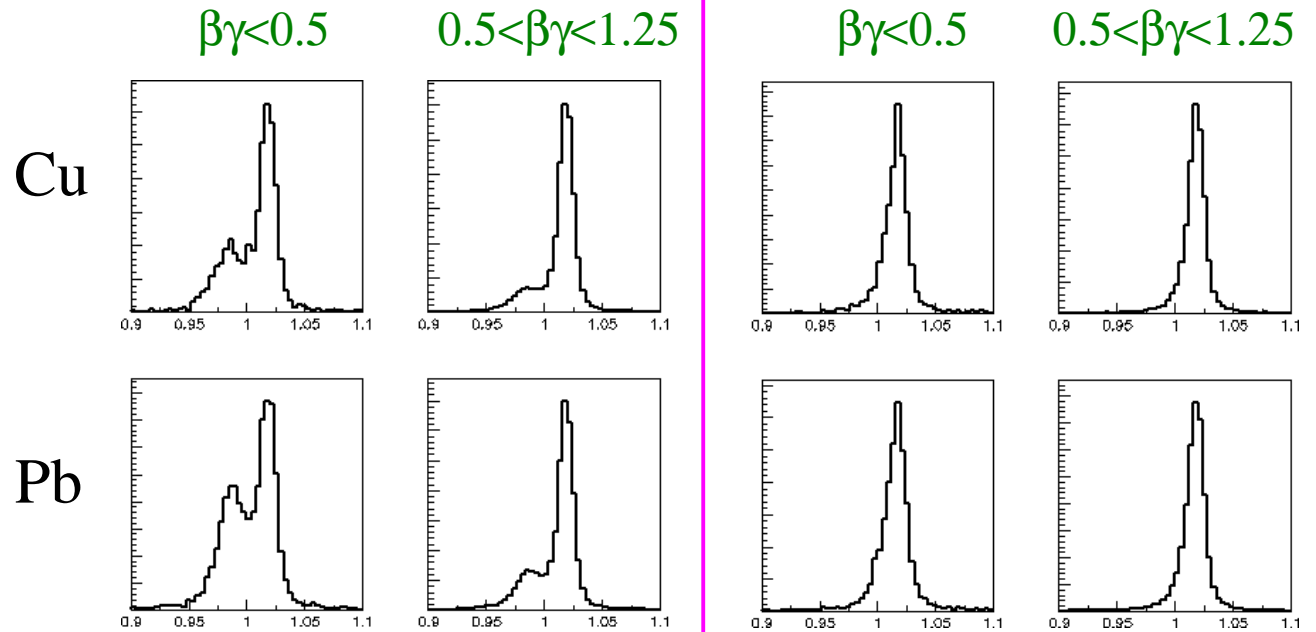
$$k_1 = 0.034^{+0.006}_{-0.007}$$

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



expected shape w/ various parameters

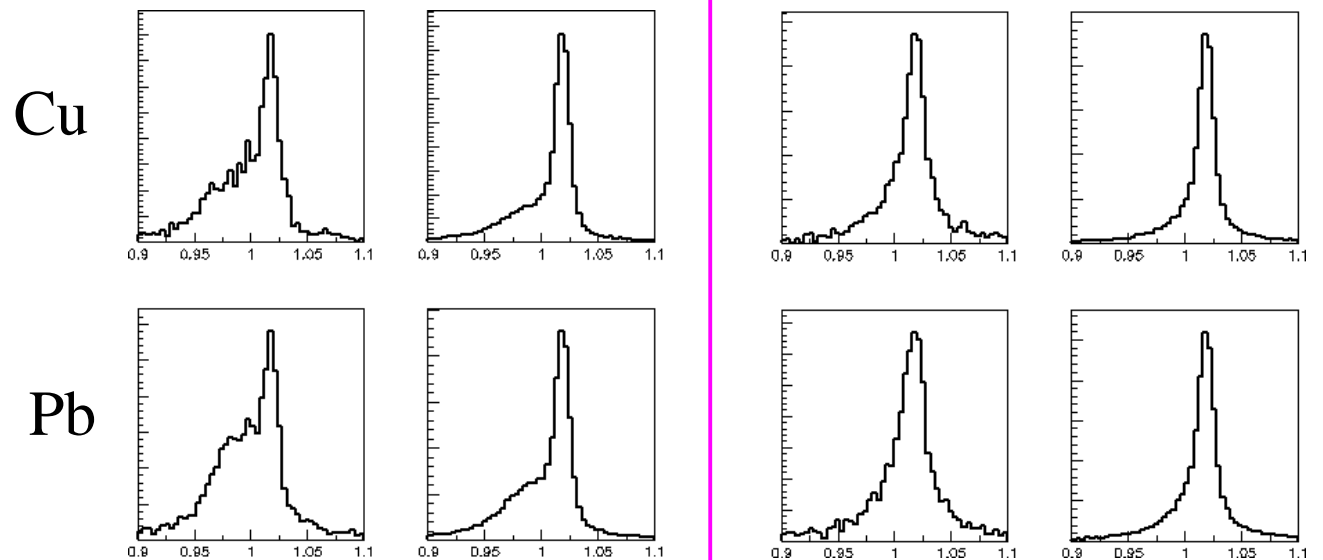
E325 Δm : -35 MeV Γ : 15 MeV	OR-01 Δm : -10 MeV Γ : 15 MeV
- Δm : -35 MeV Γ : 50 MeV	KWW-98 Δm : -10 MeV Γ : 50 MeV



can distinguish

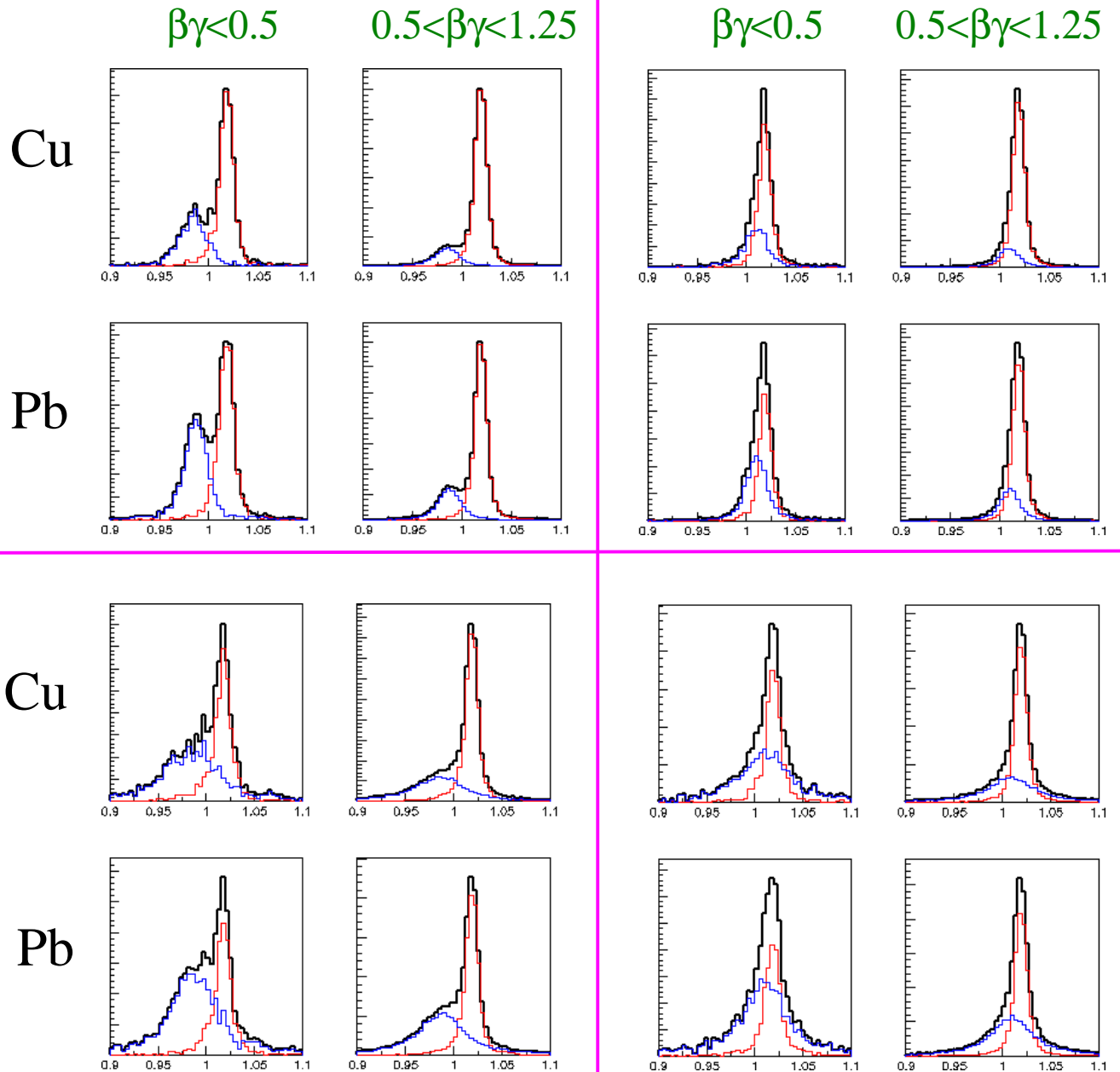
$\Delta m = -35$ or -10 MeV

$\Gamma = 15$ or 50 MeV

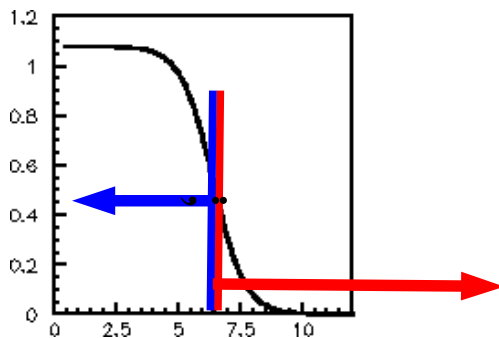


expected shape w/ various parameters

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

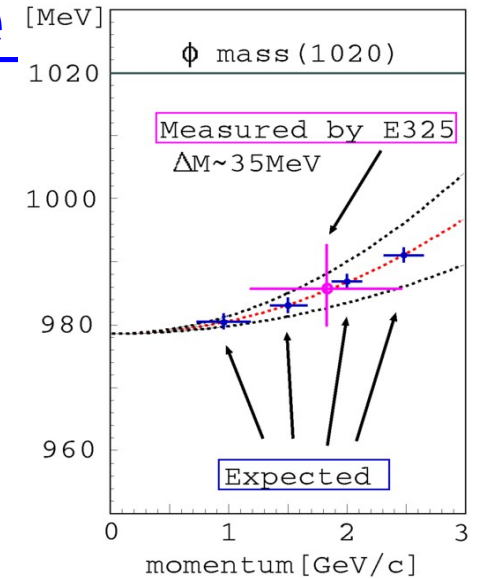


blue: decays inside the half-density radius of nuclei in the MC

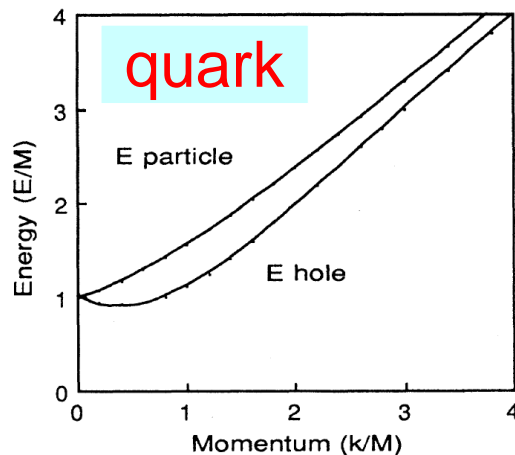


momentum dependence

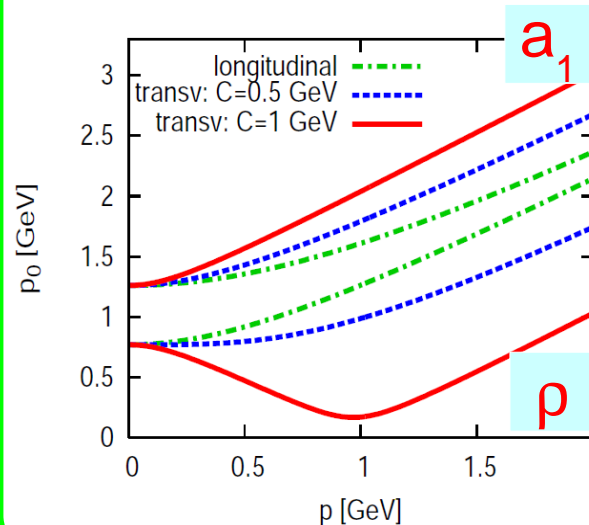
- From the view point of experimentalists
 - many predictions are for the mesons at rest ($p=0$)
 - extrapolation to $p=0$ if it is a simple dependence
- From the view point of theorists
 - dispersion relation of quasi particles are characteristic
 - other effects



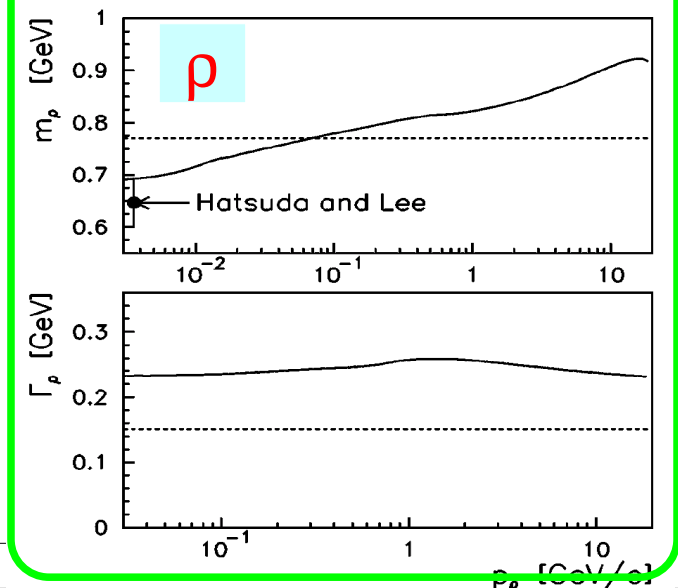
- Weldon
(PRD40(89)2410)



- Harada & Sasaki
(PRC80(09)054912)

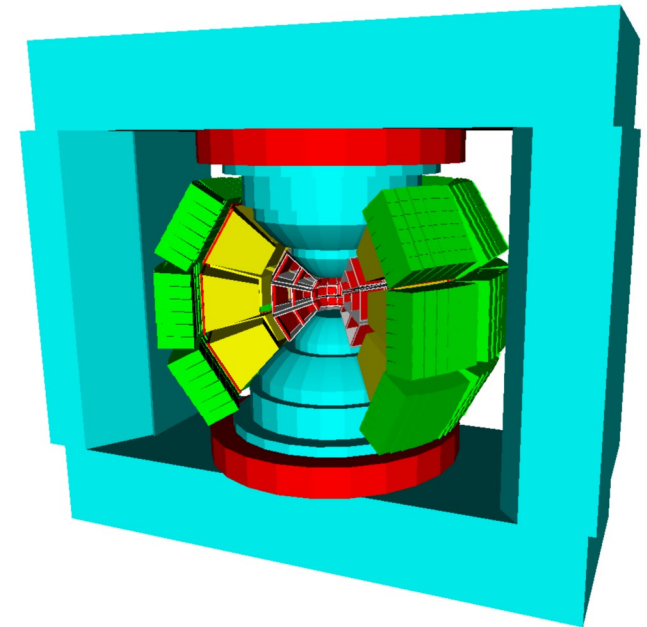


- Kondratyuk et al.
(PRC58(98)1078)



E16 Schedule

- 2007: stage1 approval
- 2008-2010 : development of prototype detectors w/ Grant-in-Aid(2007-8, 2009-13)
- 2011 : additional parts of the spectrometer magnet ,
R/O circuit development
- 2012 : magnet re-construction
 - all the detectors are installed in the magnet
 - production of the detectors/circuits
- 2013 : staged goal of the spectrometer construction
(w/ 8 detector modules) : **ready for the beam**
 - **(beam power is enough for 10^{10} /spill at High-p)**
- 2014-15 : production of detector modules (depending on the budget)
- High-p construction : 3-years plan : 2013-15



Impact of E16

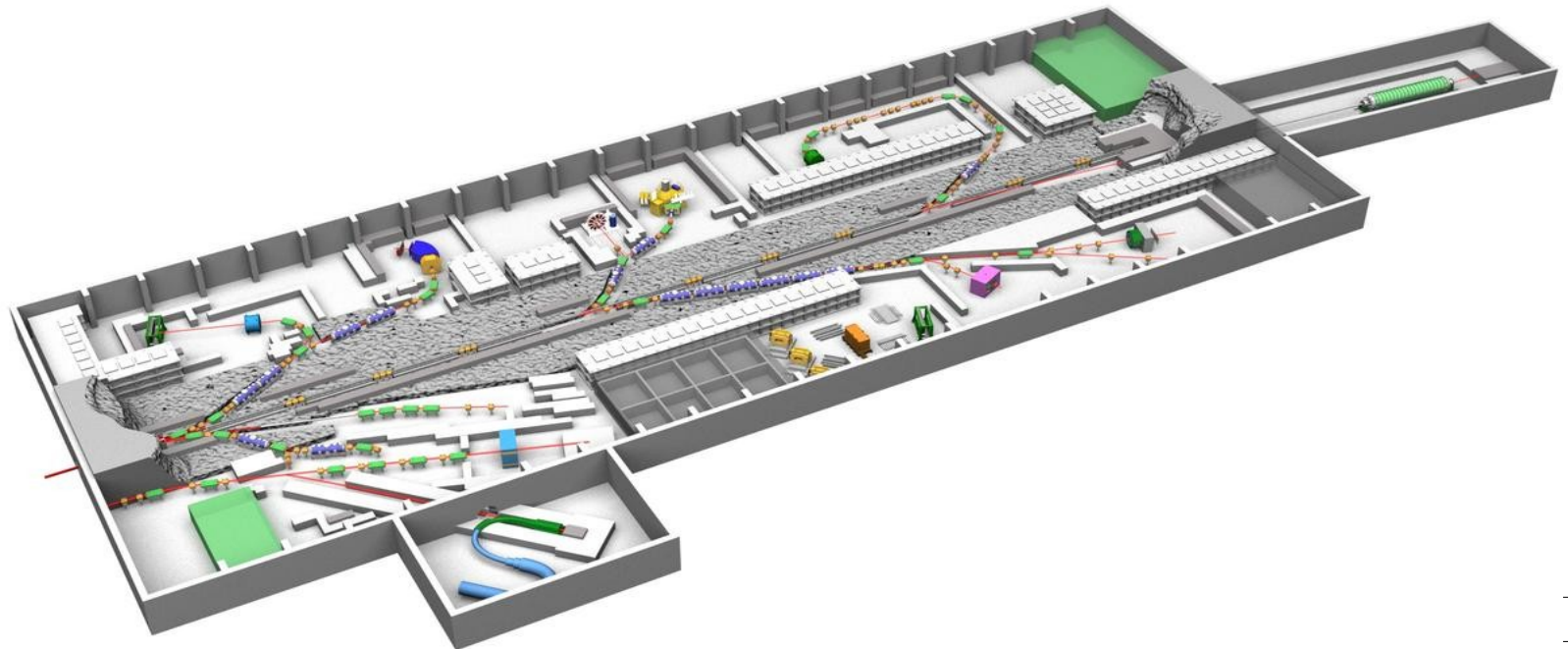
- hadron modification are observed in several experiments but interpretation is not converged : “mass dropping or broadening?”
 - theoretically the question is oversimplified : T- dependence, momentum dependence
 - analysis difficulties in ρ/ω in the dilepton decay channel
 - small statistics and small data sets
- pin down the phenomena for the vector meson in nuclei ($\rho=\rho_0, T=0$) using ϕ meson
 - confirm the E325 observation with improved resolution(x2) and statistics (x100)
 - matter-size dependence and momentum dependence will be examined systematically
 - first measurement of the dispersion relation of hadrons in nuclear matter
- establish the QCD effect
 - mass generation due to the chiral symmetry breaking
- Further Step (future experiment)
 - slow ϕ at HIHR beam line with $10^9 \pi$ beam, $\mu\mu$ pair measurement, etc.
 - higher density state using medium-energy HI collisions
 - chiral phase transition in the high-density region

International competition

- FAIR (GSI upgrade: new accelerator SIS 100 is funded)
 - Two spectrometers for the heavy-ion collisions are funded
 - HADES : 2-8 GeV : start ~2018
 - detectors will be moved from SIS 18 to SIS 100, as the 1st experiment
 - CBM : 15-30 GeV : probe the high-density state
 - newly constructed
 - Detector acceptances for the A+A : relatively forward
 - not suitable to detect slower mesons in p+A reactions
 - however, a clue is seen in 3.5 GeV p+A in HADES
 - design value of the interaction rate (10^7 Hz) is as high as E16
- We strongly urge the construction start of High-p line
 - If even a part of magnets are constructed in the JFY 2012, they can be aligned in the long shutdown in 2013 and thus the earlier completion is expected.

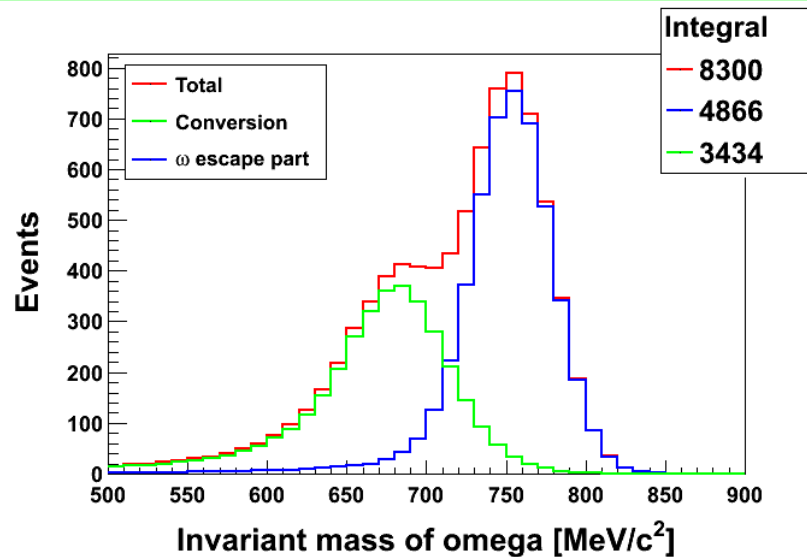
Related experiments at J-PARC

- ω bound state/invariant mass (E26) : K1.8 or High-p
- ϕ bound state (E29) : K1.1 or K10
- η bound state and N(1535) (LoI) : K1.8BR or HIHR
- magnetic moment of Λ at finite density
- dilepton decay of slow ϕ using $10^9 \pi$ beam at HIHR



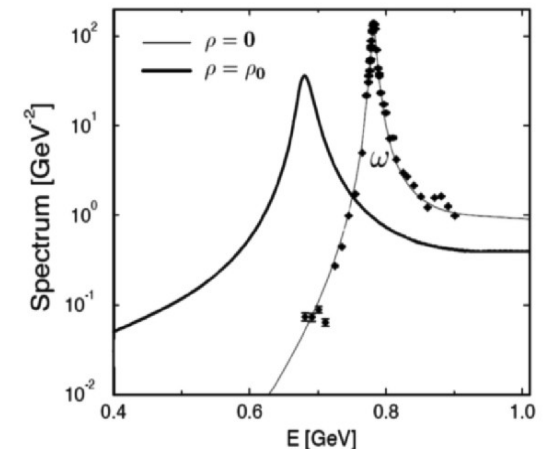
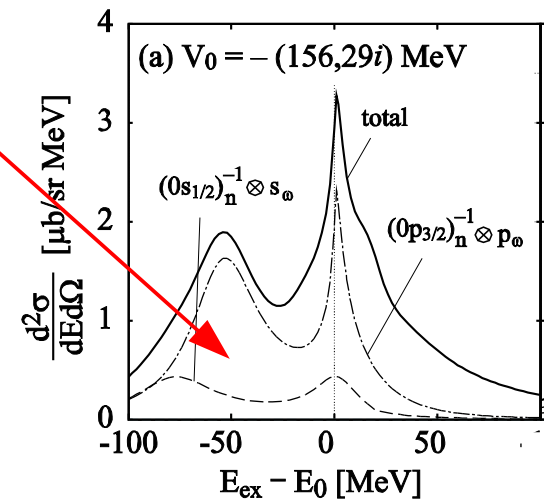
meson bound state in nuclei : E26 (ω)

- ω bound state (J-PARC E26 Ozawa)
 - missing mass spectroscopy in $\pi^- + A$ reaction – **select the bound state**
 - elementary : $\sim 2 \text{ GeV}/c$ $\pi^- + p \rightarrow \omega + n$
 - and measure the ω decay to $\pi^0 \gamma$
 - P_ω is low, and decay in nuclear matter



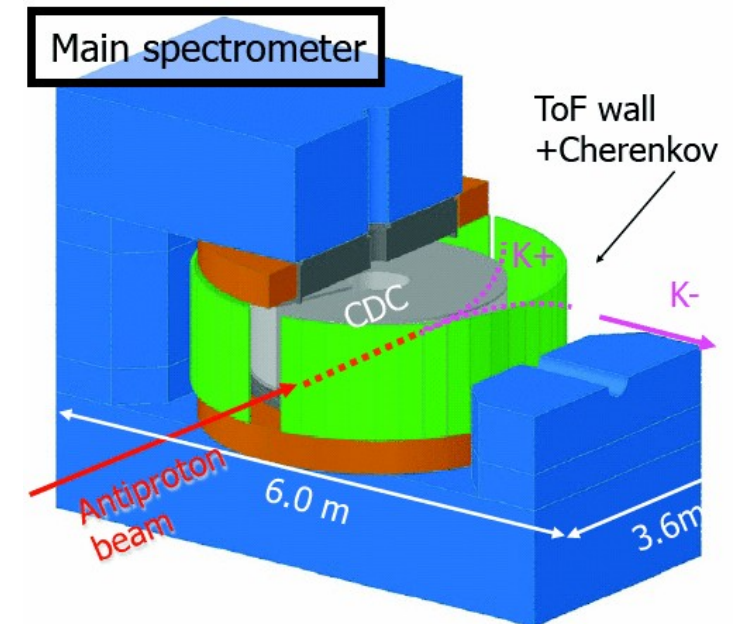
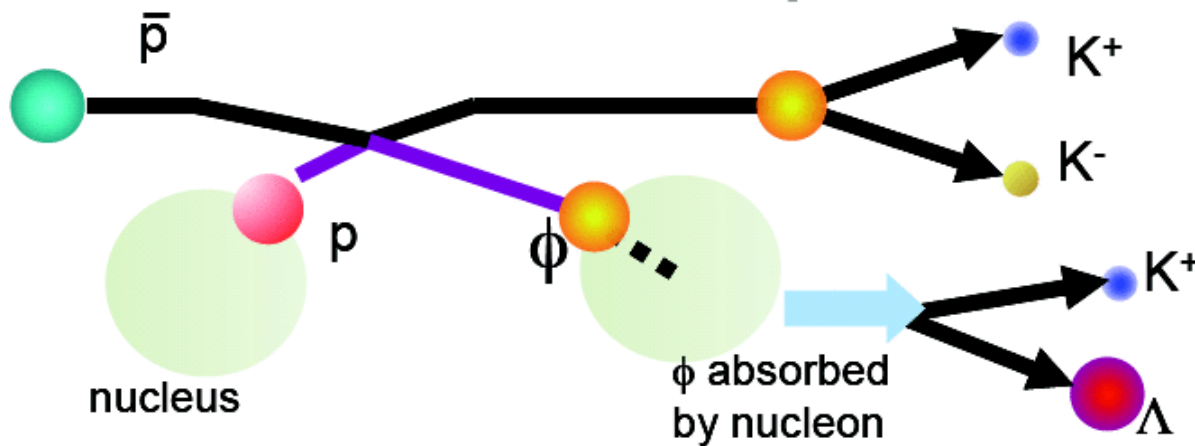
Expected modified ω spectrum

Theoretical predictions of *missing mass* and *invariant mass*



meson bound state in nuclei: E29 (ϕ)

- ϕ bound state : (J-PARC E29 Ohnishi)
 - **missing mass** spectroscopy in $p\bar{p} + A / \pi^- + A$ reaction
 - elementary: $\sim 1.3 \text{ GeV}/c \text{ } p\bar{p} + p \rightarrow \phi + \phi$
 - (or $\sim 2 \text{ GeV}/c \text{ } \pi^- + p \rightarrow \phi + n$)
 - measurements of the dilepton decay of ϕ is difficult



Summary

- Investigation of the hadron spectral modification in nuclear matter is a study of the nature of QCD vacuum
 - A major origin of hadron mass is the spontaneous breaking of chiral symmetry and the spectral modification could be a signal of the chiral restoration
 - Spectral modification of hadrons is observed in hot (HI collisions) and dense (nuclei) matter in the dilepton invariant mass spectra
 - but discussion is not converged : chiral restoration or not
- J-PARC E16 will measure the vector meson modification in nuclei with the ee decay channel, using 30GeV primary proton beam at the High-p line.
 - confirm the observation by KEK-PS E325 and provide more precise information of the mass modification
- E26, E29, etc. will be performed at new beam lines in the Hadron hall, to explore the chiral symmetry at finite density