J-PARC E16
Vector meson in nuclear matter

Satoshi Yokkaichi
(RIKEN Nishina Center)

- physics motivation
- dilepton measurements in the world
- E16 status and plan

Collaboration

RIKEN	S.Yokkaichi, K. Aoki, Y. Aramaki, H. En'yo, J. Kanaya, 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, A.Takagi, K.Kanno, W.Nakai
CNS, U-Tokyo	H. Hamagaki
Hiroshima-U	K. Shigaki
JASRI	A. Kiyomichi

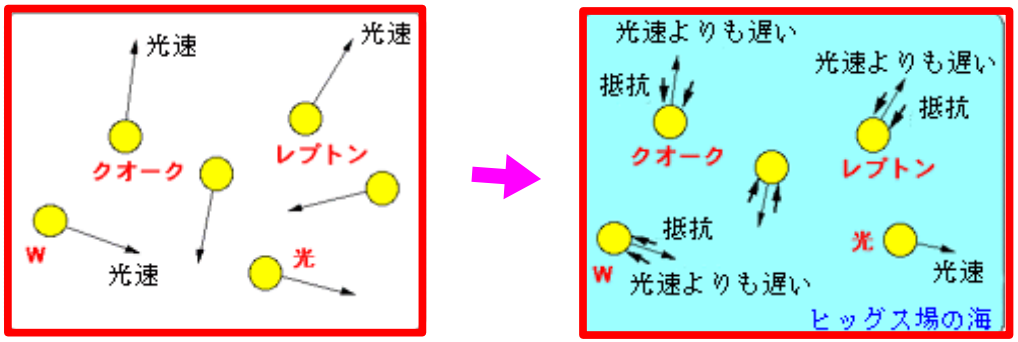
Origin of Mass (Higgs)

Big Bang — 10p[sec]/1P[K]

quark mass — 0 MeV — 3 MeV

"resistance" — Higgs condensate

schematic diagram of vacuum



- Origin of lepton and quark mass: Higgs

Origin of Mass (QCD)

Big Bang — 10p[sec]/1P[K] — 100μ[sec]/1T[K]

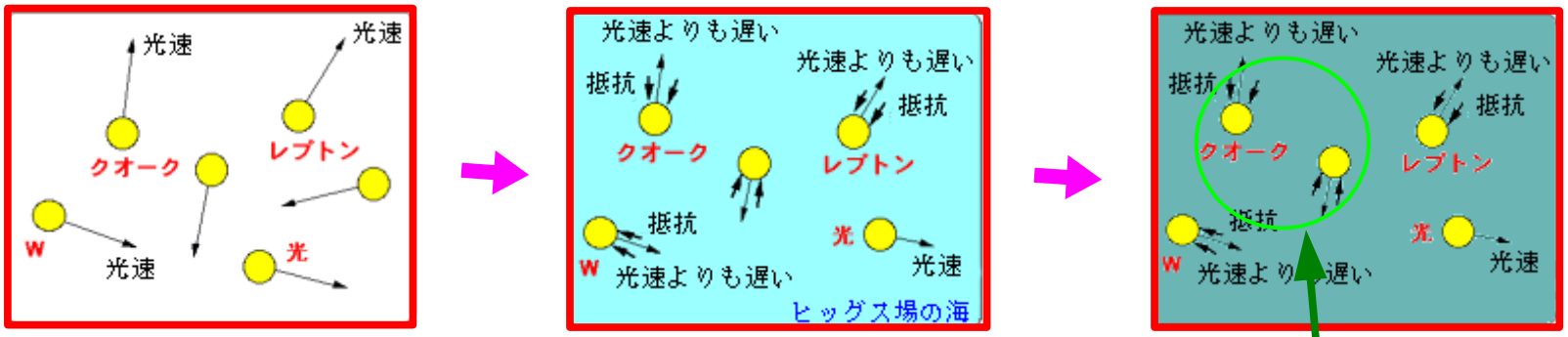
quark mass
"resistance"

0 MeV

3 MeV
Higgs condensate

300MeV
chiral condensate $\langle \bar{q}q \rangle$

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

Vector meson measurements in the world

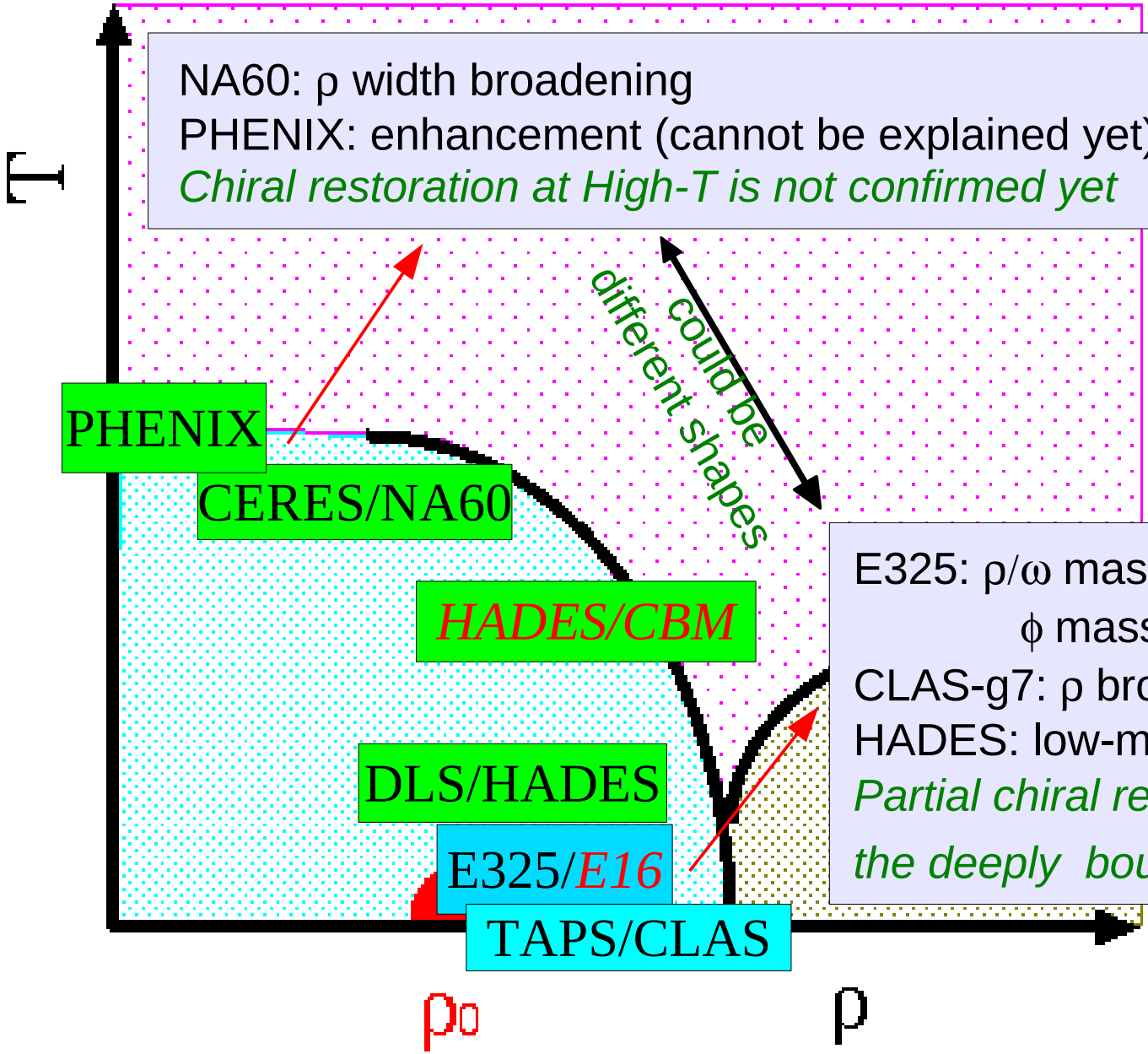
dilepton measurement

- HELIOS/3 (ee, μμ) 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 (μμ) 400GeV p+A/158GeV In+In
- PHENIX (ee,KK) 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

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

- TAGX (ππ) ~1 GeV γ+A
- STAR (ππ,KK) p+p/Au+Au
- 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

Dilepton spectrum measurements in the world



Open question:
Observed hadron modifications are signature of the chiral restoration / evidence of the QCD mass generation ?

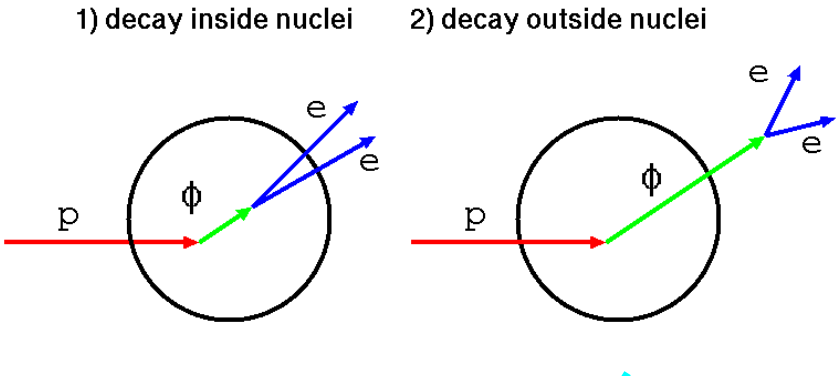
E325: ρ/ω mass dropping
ϕ mass dropping and broadening
CLAS-g7: ρ broadening
HADES: low-mass enhancement
Partial chiral restoration at ρ_0 is measured w/ the deeply bound pionic atom

Experimental methods:pros and cons

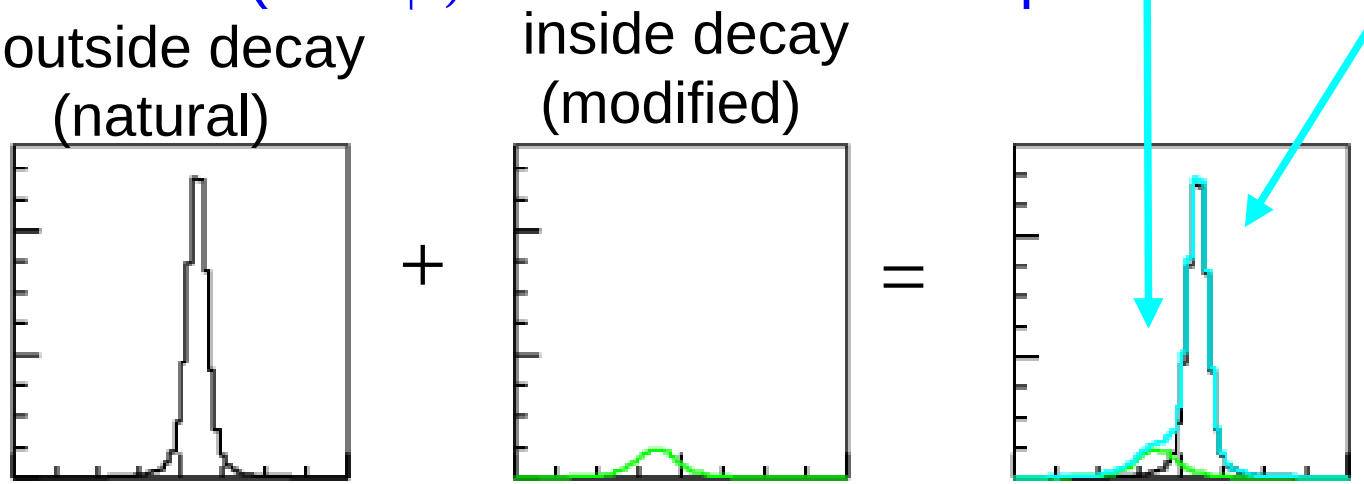
- leptonic decay VS hadronic decay
  - small FSI in the matter, but small branching ratio
- proton/photon induced VS heavy-ion collision
  - cold VS hot
  - static environment VS time evolution
  - S/N is better, production cross section is smaller
- ϕ VS ρ/ω
  - isolated and narrow, but production CS 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

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



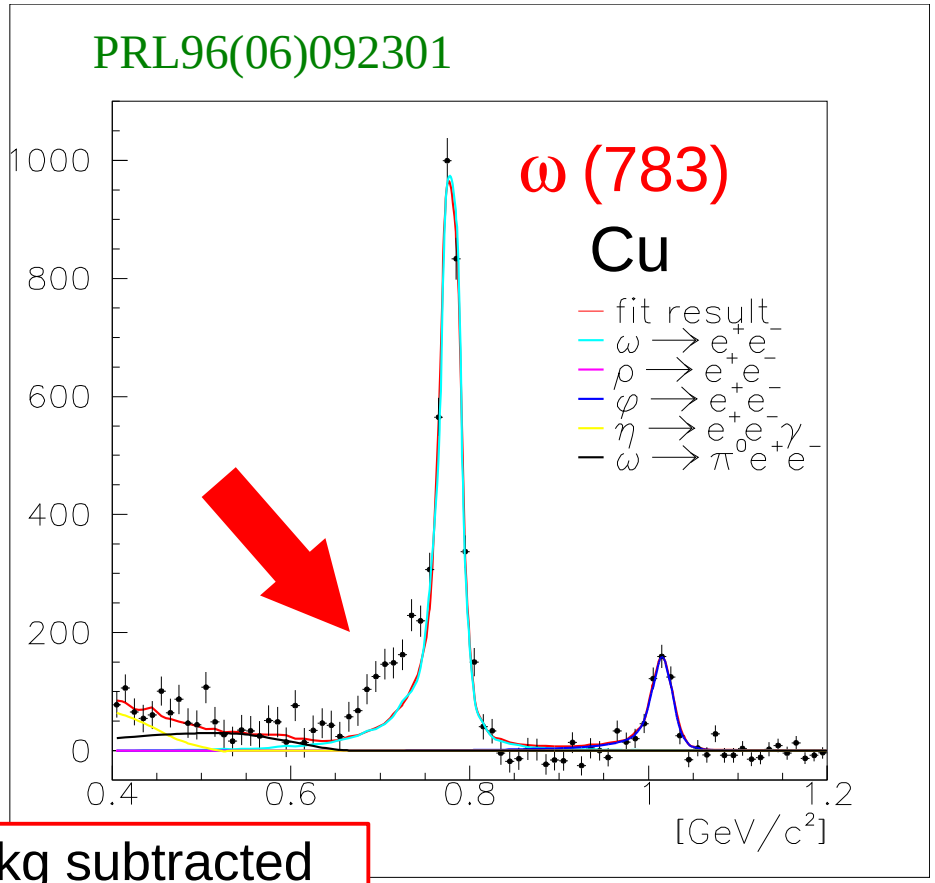
longer-life meson(ω & ϕ)cases : Schematic picture

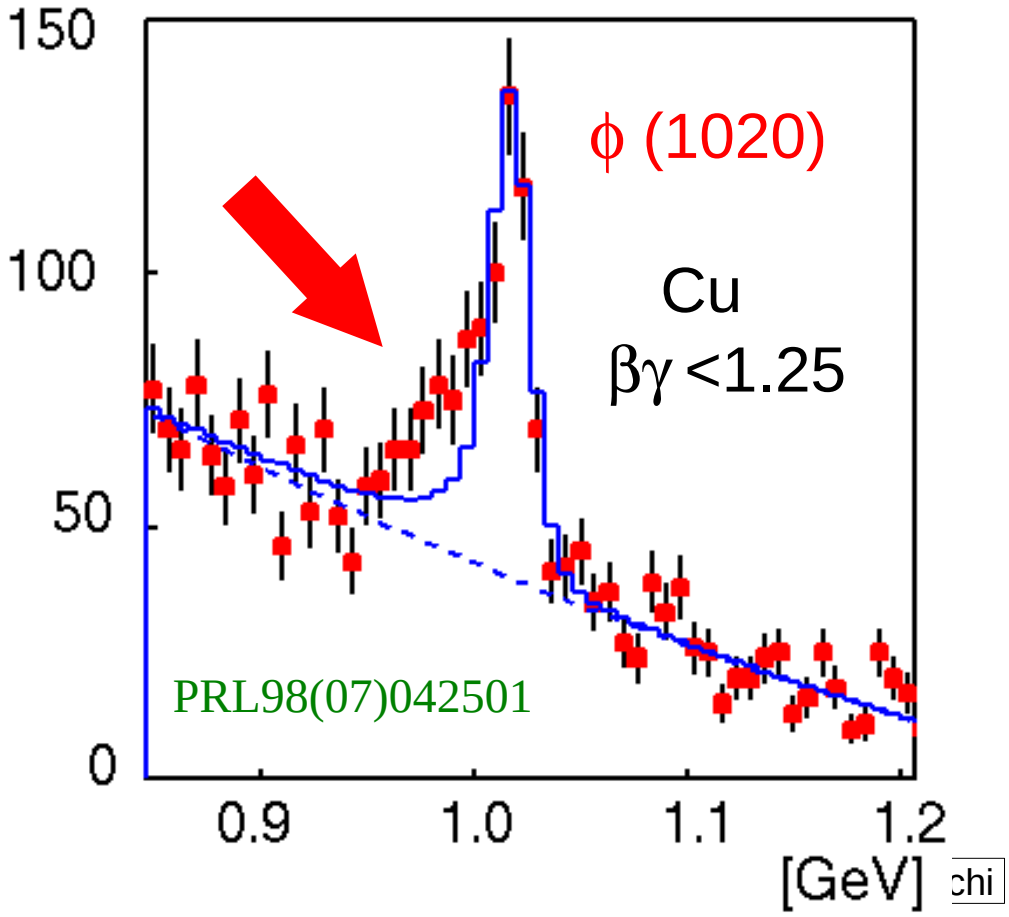


expected
to be observed

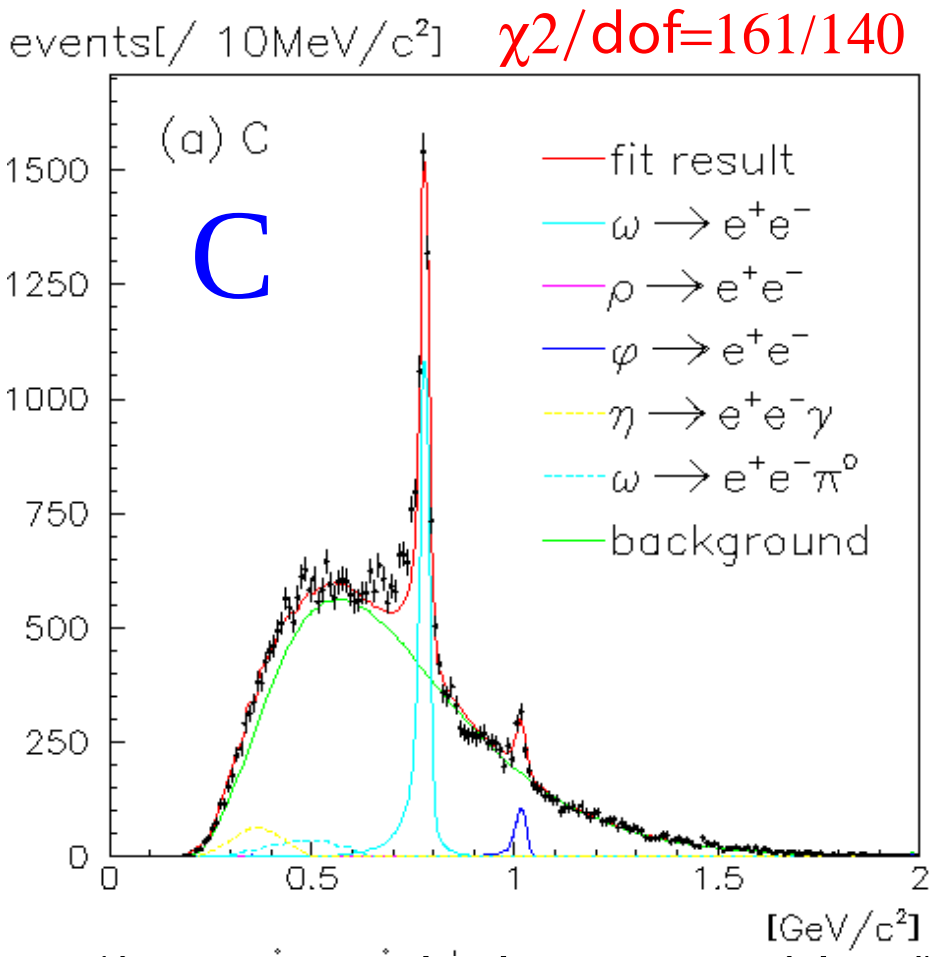
KEK-PS E325

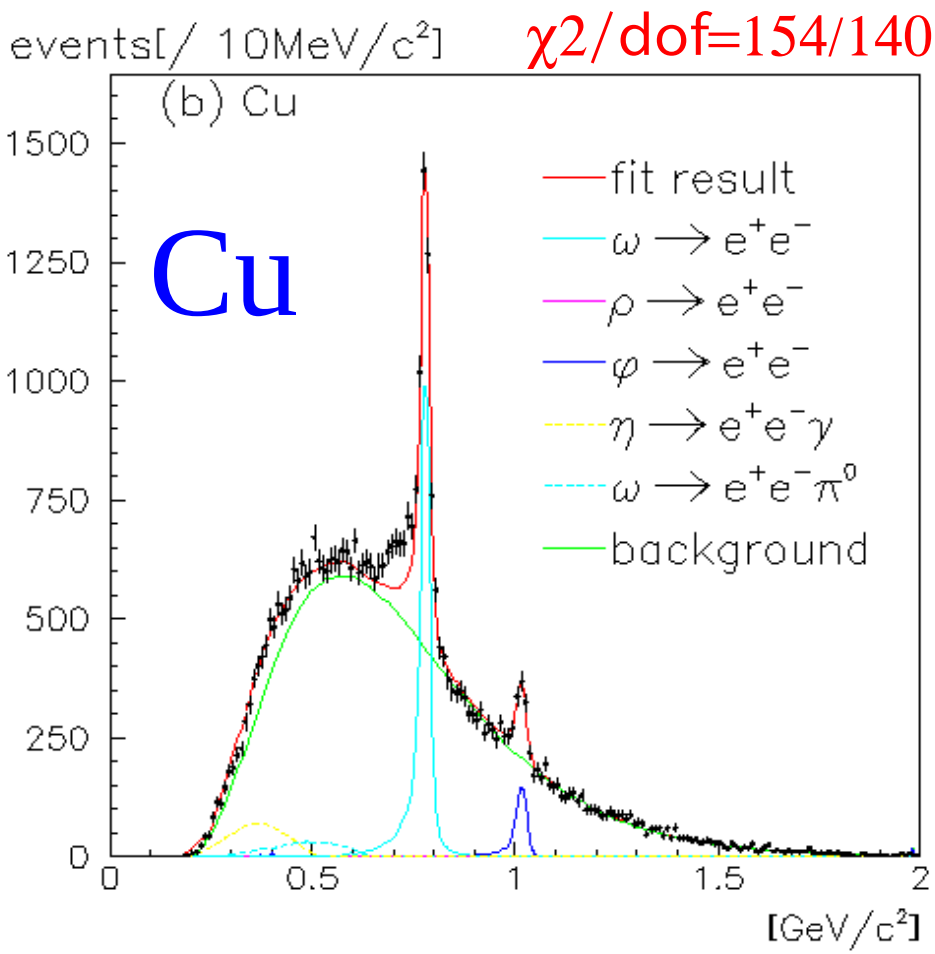
- 12GeV p+A (C/Cu) → ρ, ω, ϕ in the e^+e^- channel
- below the ω and ϕ peaks, statistically significant excesses over the known hadronic sources including experimental effects
- interpreted : mass dropping 9.2%(ρ, ω) , 3.4% (ϕ)





E325 Fitting results (ρ/ω)

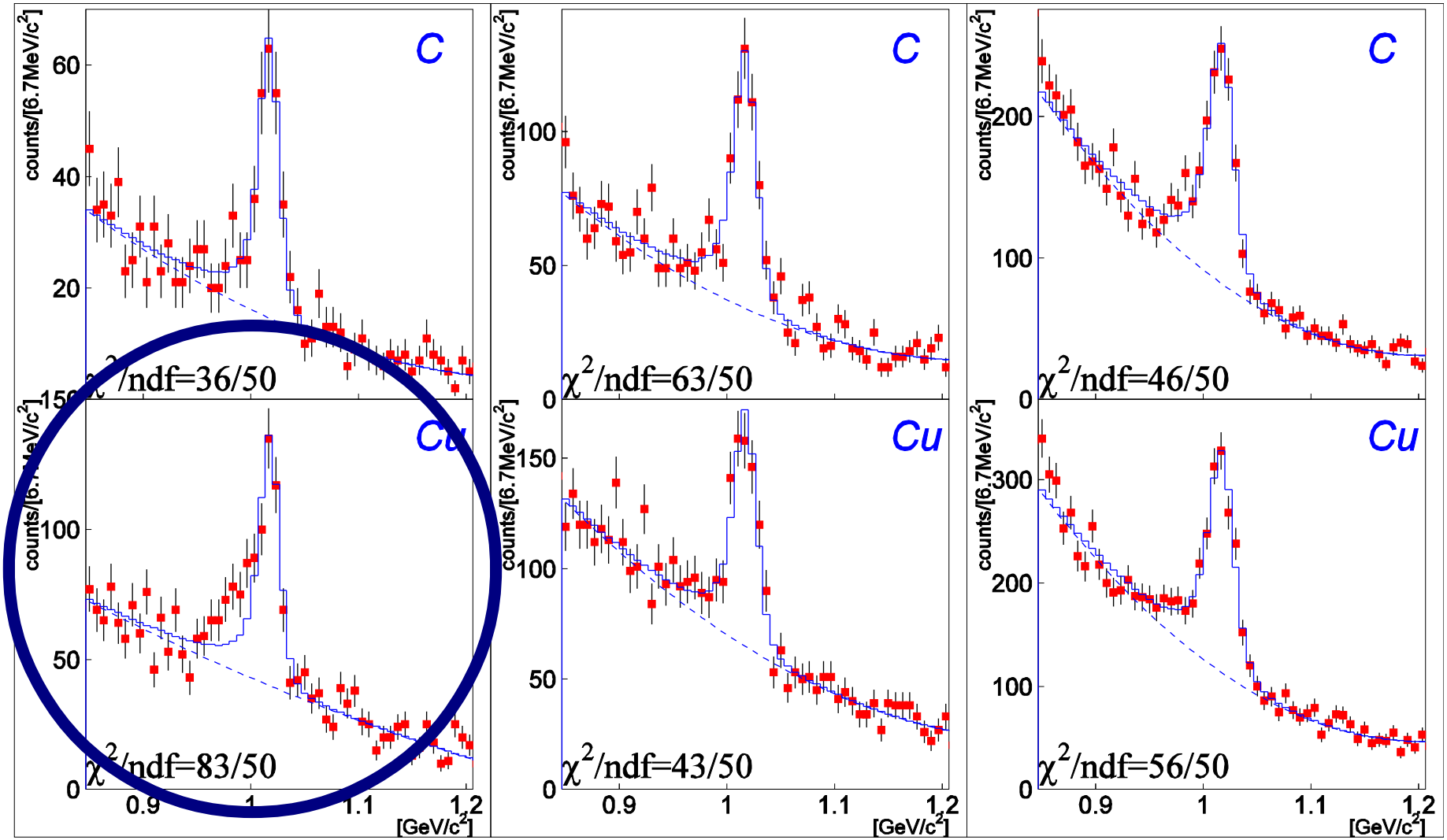




- 1) excess at the low-mass side of ω
  - To reproduce the data by the fitting, we have to exclude the excess region : 0.60~0.76 GeV
- 2) ρ–meson component seems to be vanished !

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% C.L.

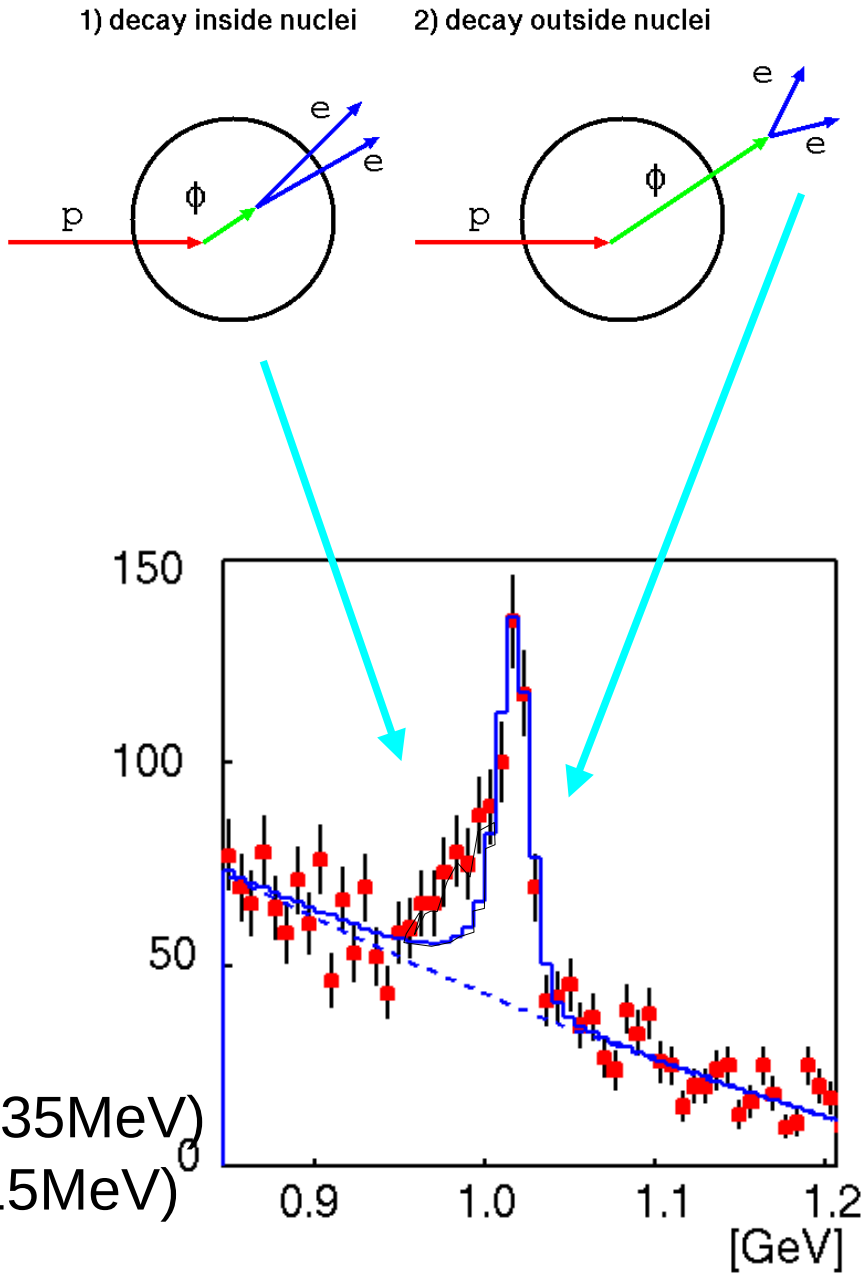
Discussion : modification parameters

- 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)

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

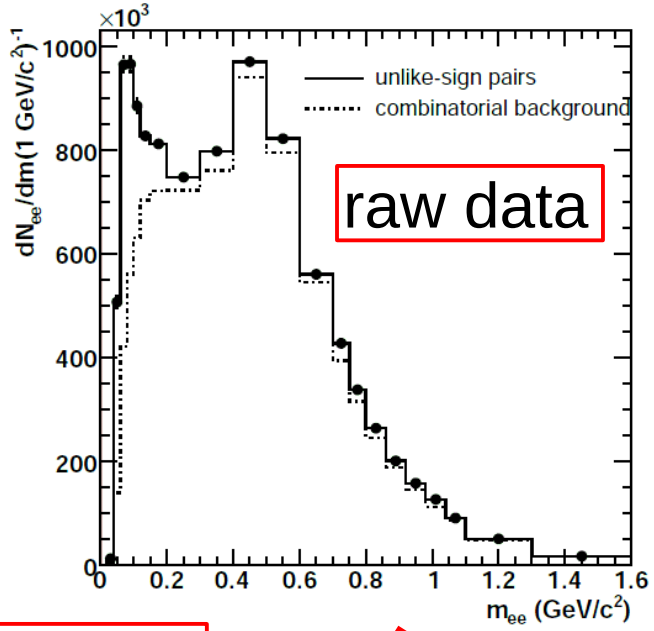
$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$

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

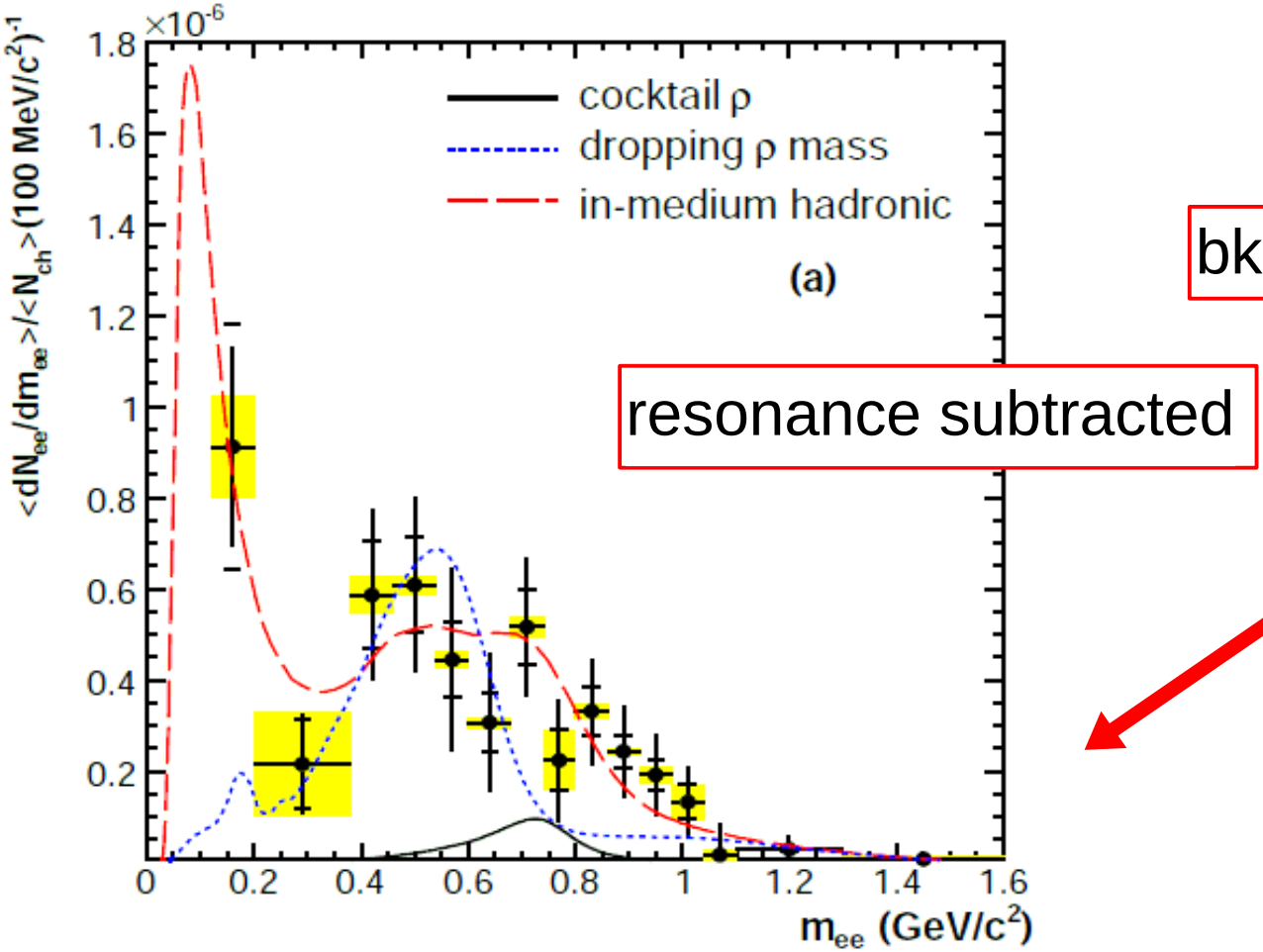


Vector meson measurements in Heavy Ion Collision

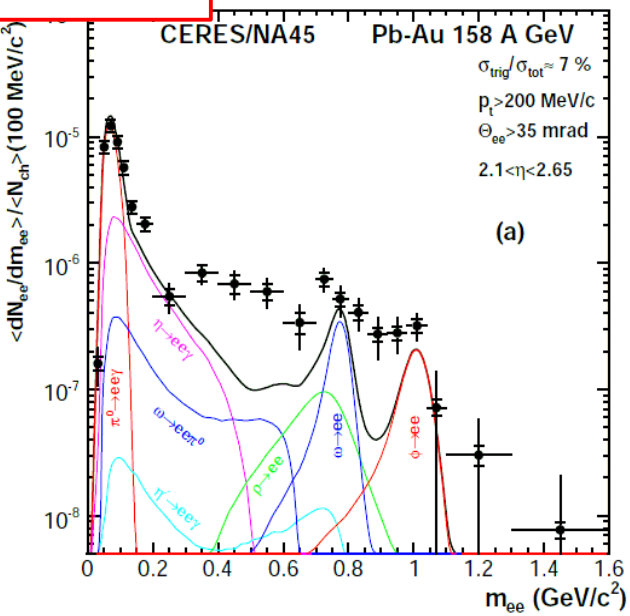
- CERES : (PLB666(2008)425)
  - “broadening by hadronic effect “ is favored



bkg subtracted



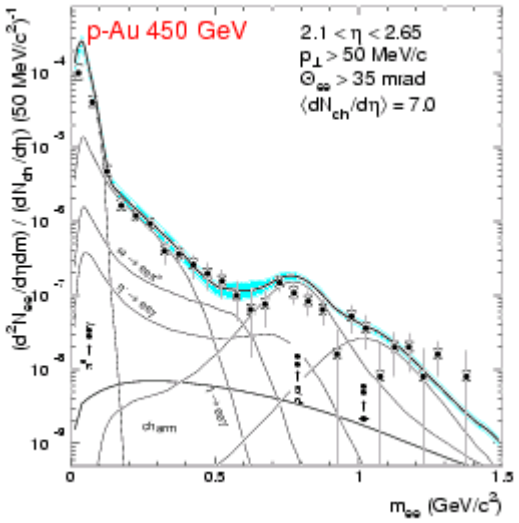
resonance subtracted

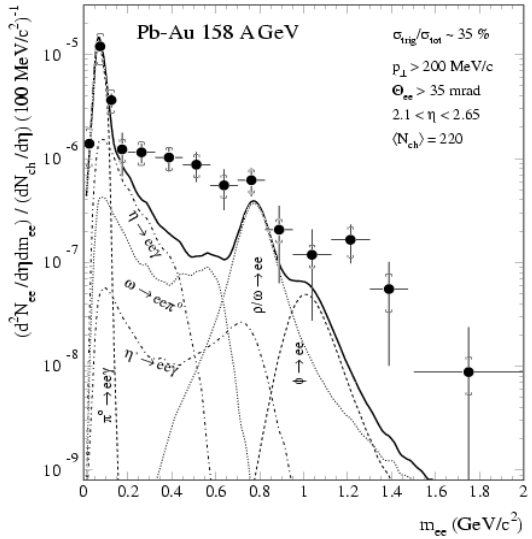


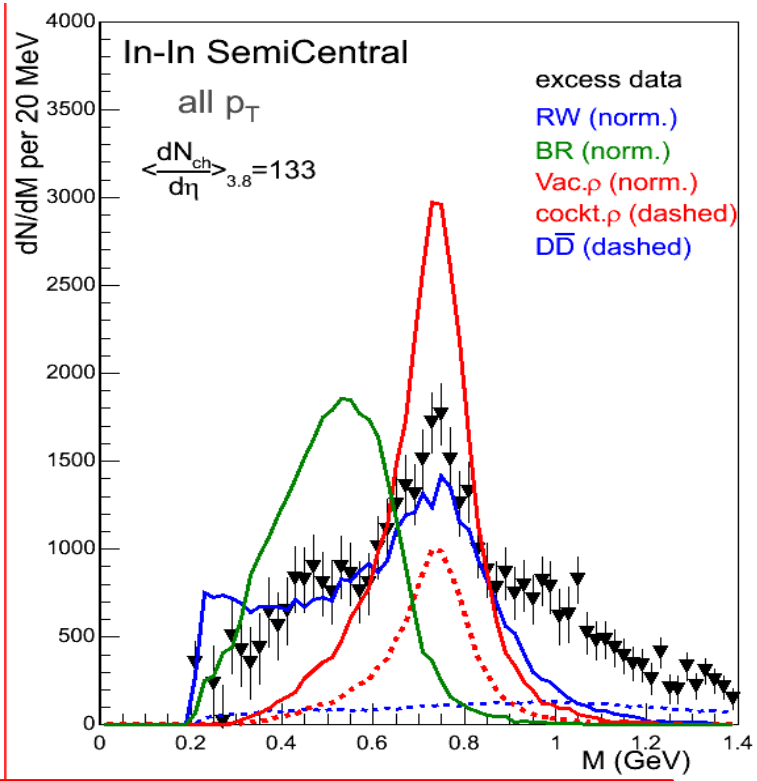
Vector meson measurements in HIC

- CERES : e^+e^- (EPJC 41('05)475)
  - anomaly at lower region of ρ/ω
    - in A+A, not in p+A
  - relative abundance is determined by their statistical model
- NA60 : (PRL96(06)162302)
  - $\rho \rightarrow \mu^+\mu^-$:
  - width broadening
  - 'BR scaling is ruled out'

bkg subtracted



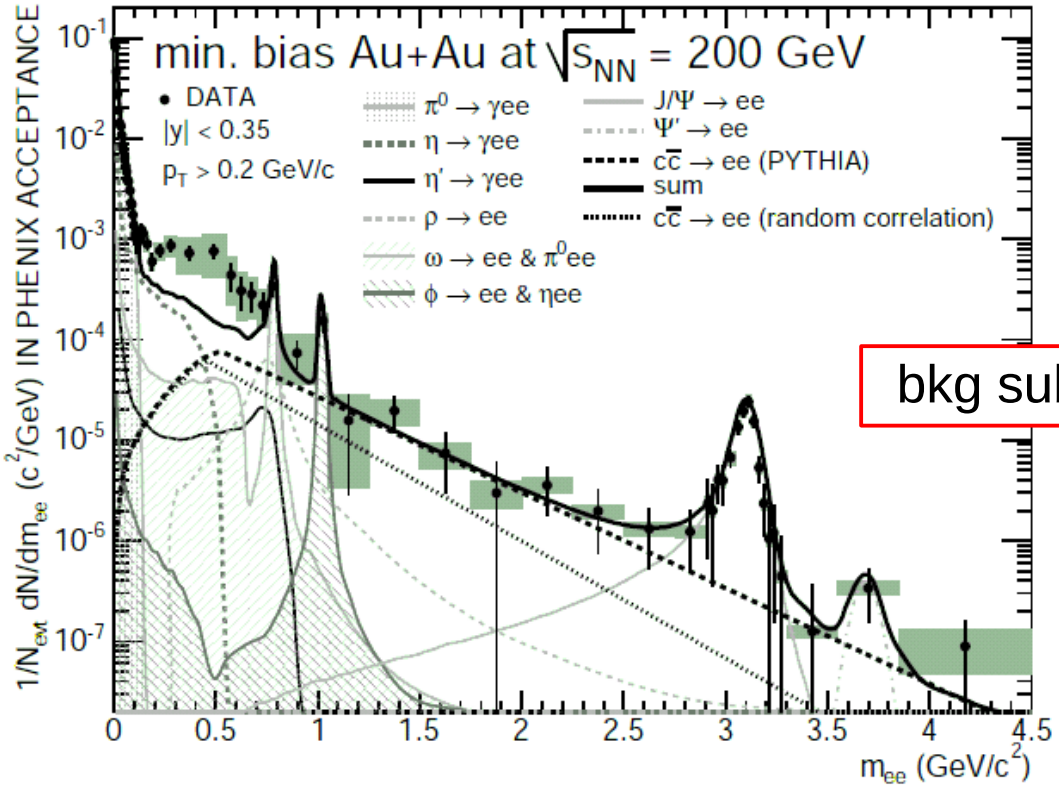




bkg & resonance subtracted

Vector meson measurements in Heavy Ion Collision

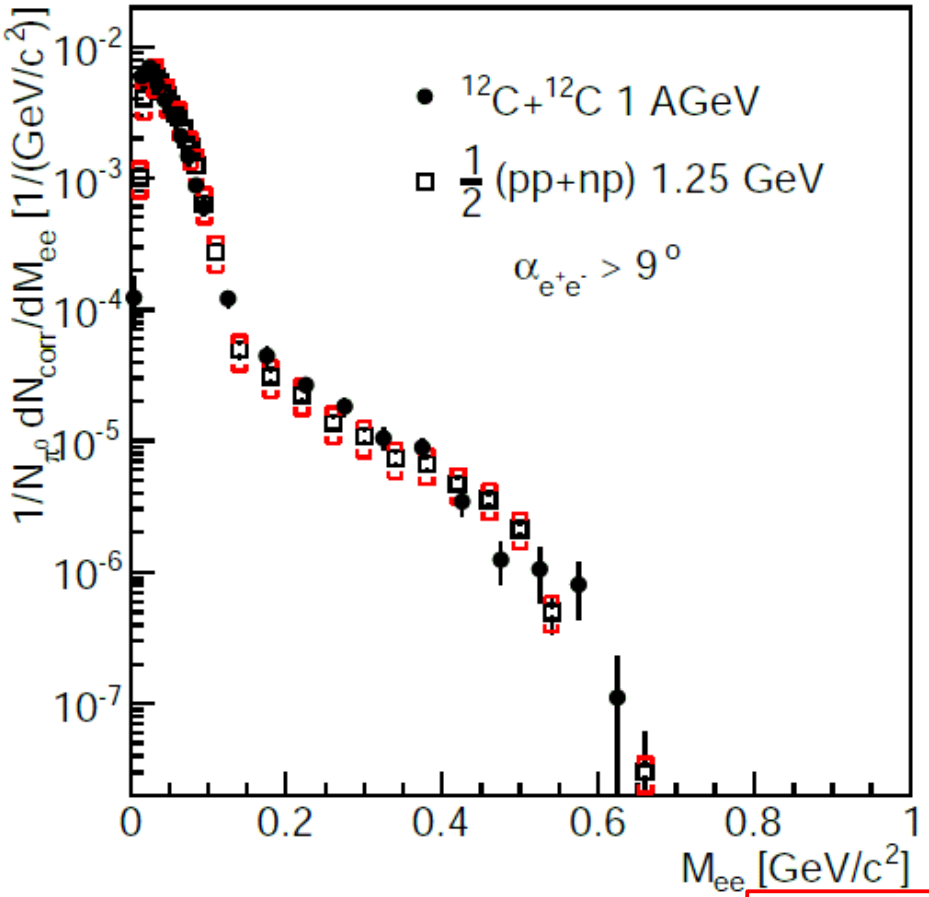
- PHENIX : (arXiv:0706.3034v1,0912.0244v1)
  - 200GeV /u Au+Au → e^+e^-
  - enhancement below ω
  - cannot reproduced by any model at low pT
  - at high pT, thermal photons reproduce

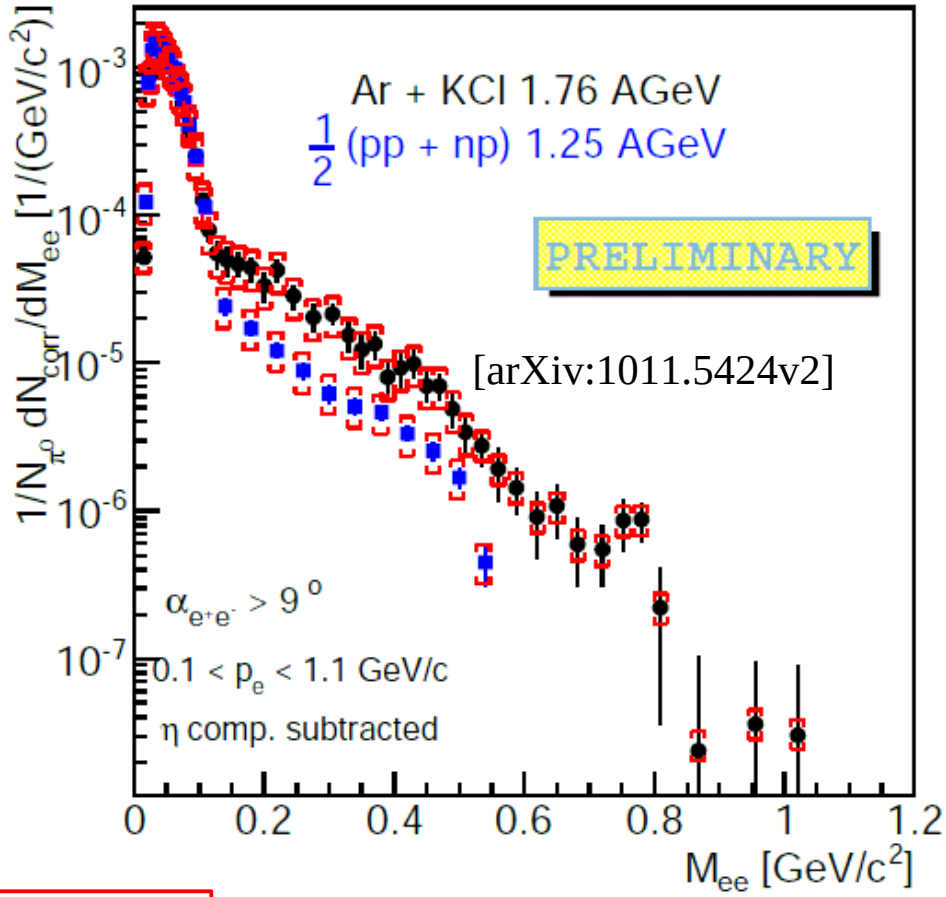


bkg subtracted

HADES

- lower energy HI collisions : A+A $\rightarrow e^+e^-$
- DLS data is confirmed, and the puzzle in C+C is resolved by (pp+np)[PLB690(10)118]
- However, Ar+KCl have enhancement over the (pp+np) estimation [PRC84(11)014902]



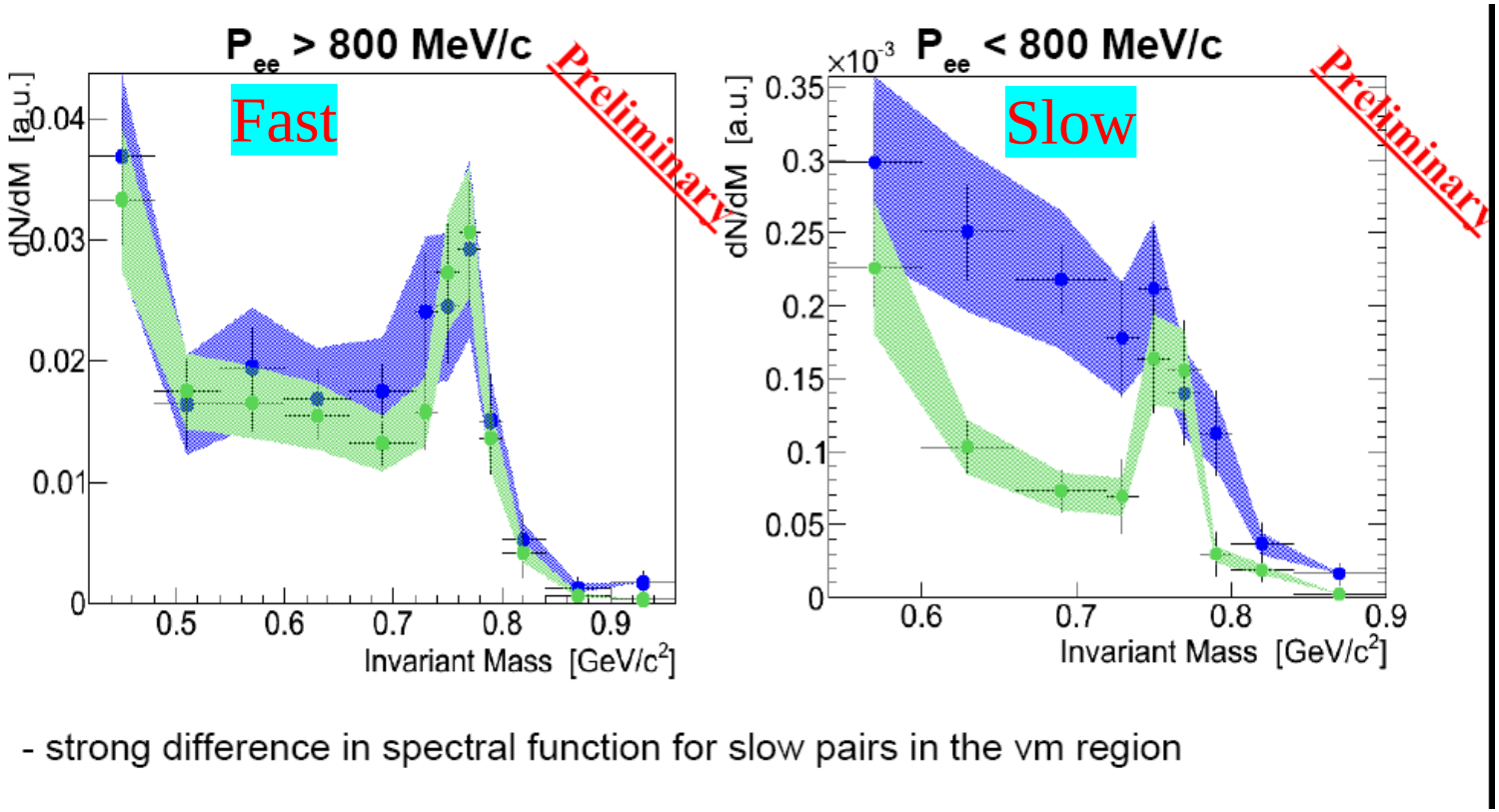


bkg subtracted

HADES 3.5GeV pp and pNb

- Selecting slower mesons, an excess is seen below the ω peak in the larger nuclei data (preliminary)

HADES **p+p** vs **p+Nb** @ 3.5 GeV(E_{kin}/u)



- strong difference in spectral function for slow pairs in the vm region

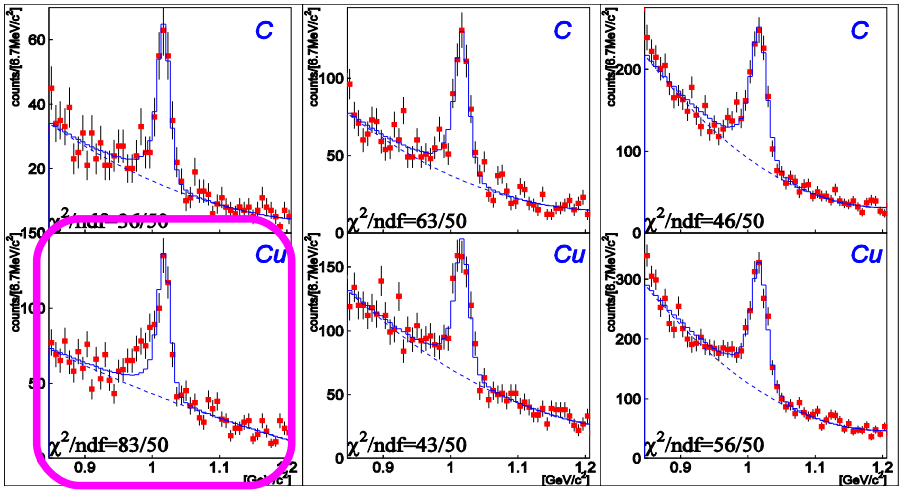
(P.Salabura,cracow)

J-PARC E16

J-PARC E16 experiment

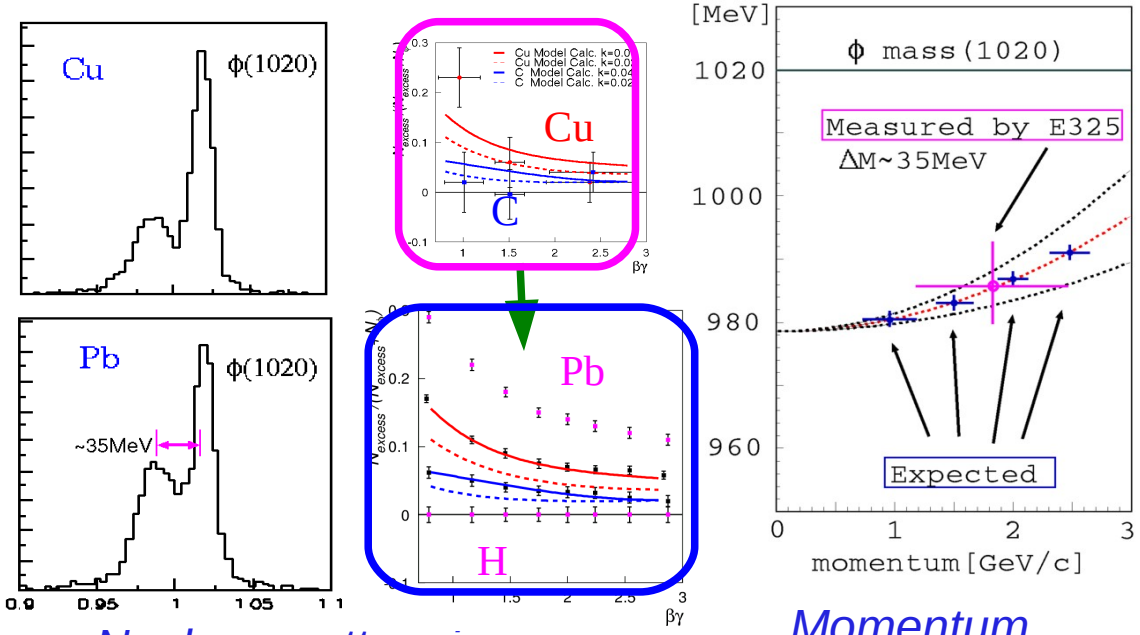
- Measure the vector-meson mass modification in nuclei systematically with the e^+e^- invariant mass spectrum
- A 30 GeV primary proton beam (10^{10}/spill) / 5 weeks of physics run to collect ~10^5 $\phi \rightarrow e^+e^-$ for each target
- confirm the E325 results, and provide new information as the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

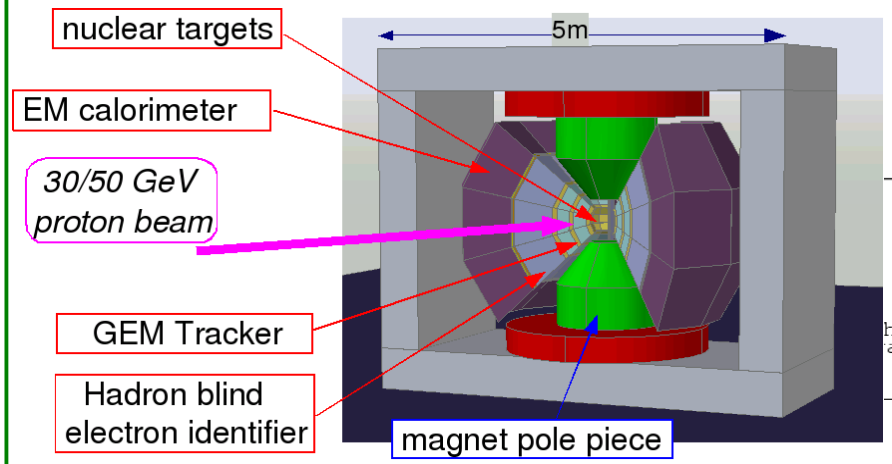


Nuclear matter size dependence & *Momentum dependence* of mass modification are measured

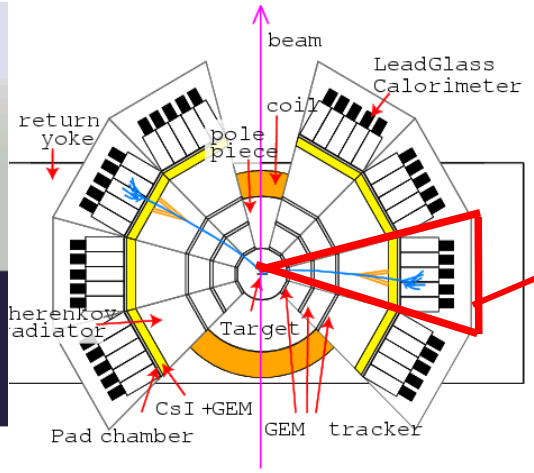
To collect high statistics

- 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~ 5
  - Higher energy beam (12 → 30/50 GeV) : x ~2 of production
  - Higher intensity beam ($10^9 \rightarrow 10^{10}$ /spill (1sec)) : x 10 (→ 10MHz interaction on targets)
  - to cope with the high rate, new detectors (GEM Tracker & HBD) are required.

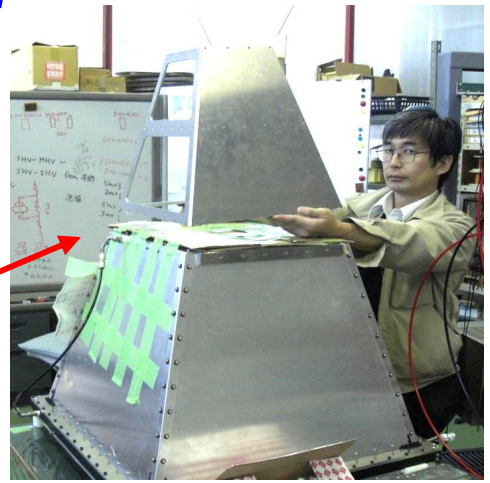
Proposed Spectrometer



Plan View



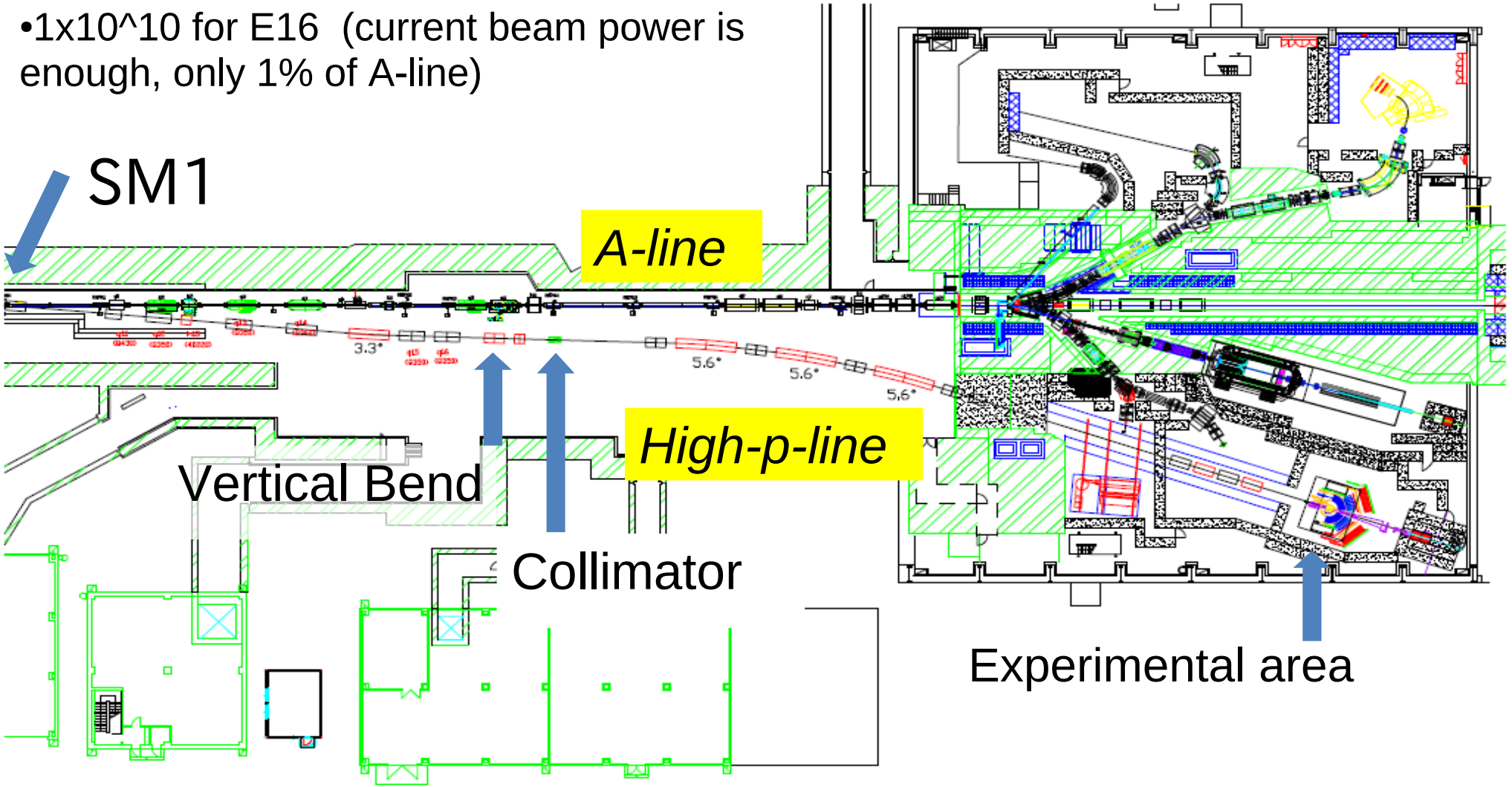
Prototype Module



26 detector modules

High-p line in the Hadron hall

•1x10^10 for E16 (current beam power is enough, only 1% of A-line)



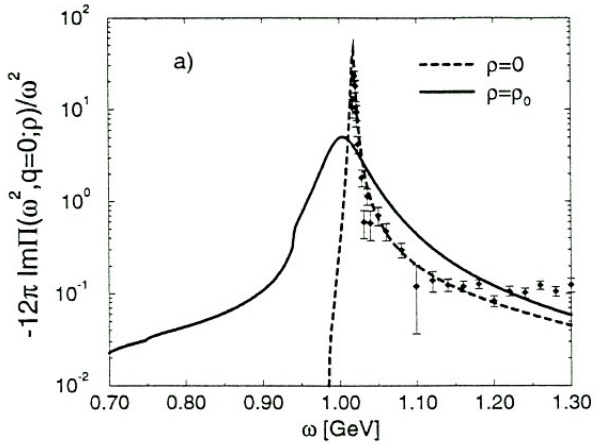
- 3 years plan of the construction : budget requested by KEK to MEXT

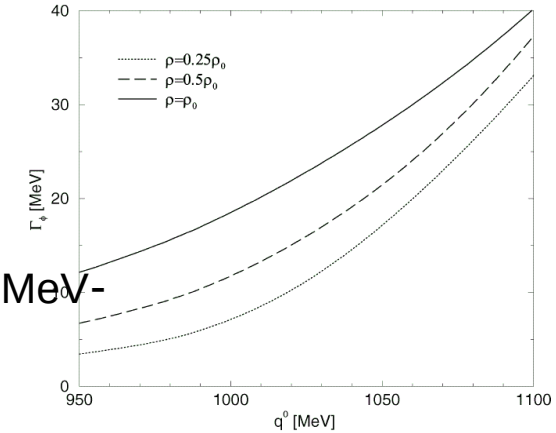
ϕ-mass modification at ρ_0 –

- (vacuum value : m(0)=1019.456MeV, $\Gamma(0)$= 4.26MeV)
  - **$m(\rho)/m(0) = 1 - k_1(\rho/\rho_0)$, $\Gamma(\rho)/\Gamma(0) = 1 + k_2(\rho/\rho_0)$**
- 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 : –12~44 MeV (k=(0.15±0.05)y, y=0.12~0.22),
  - 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=1020MeV, ~16MeV for m=985 MeV-
- Cabrera and Vacas [PRC 67(2003)045203] OR01+ *hadronic*
  - Δm : – 8 MeV, Γ : ~30 MeV for m=1020MeV

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

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





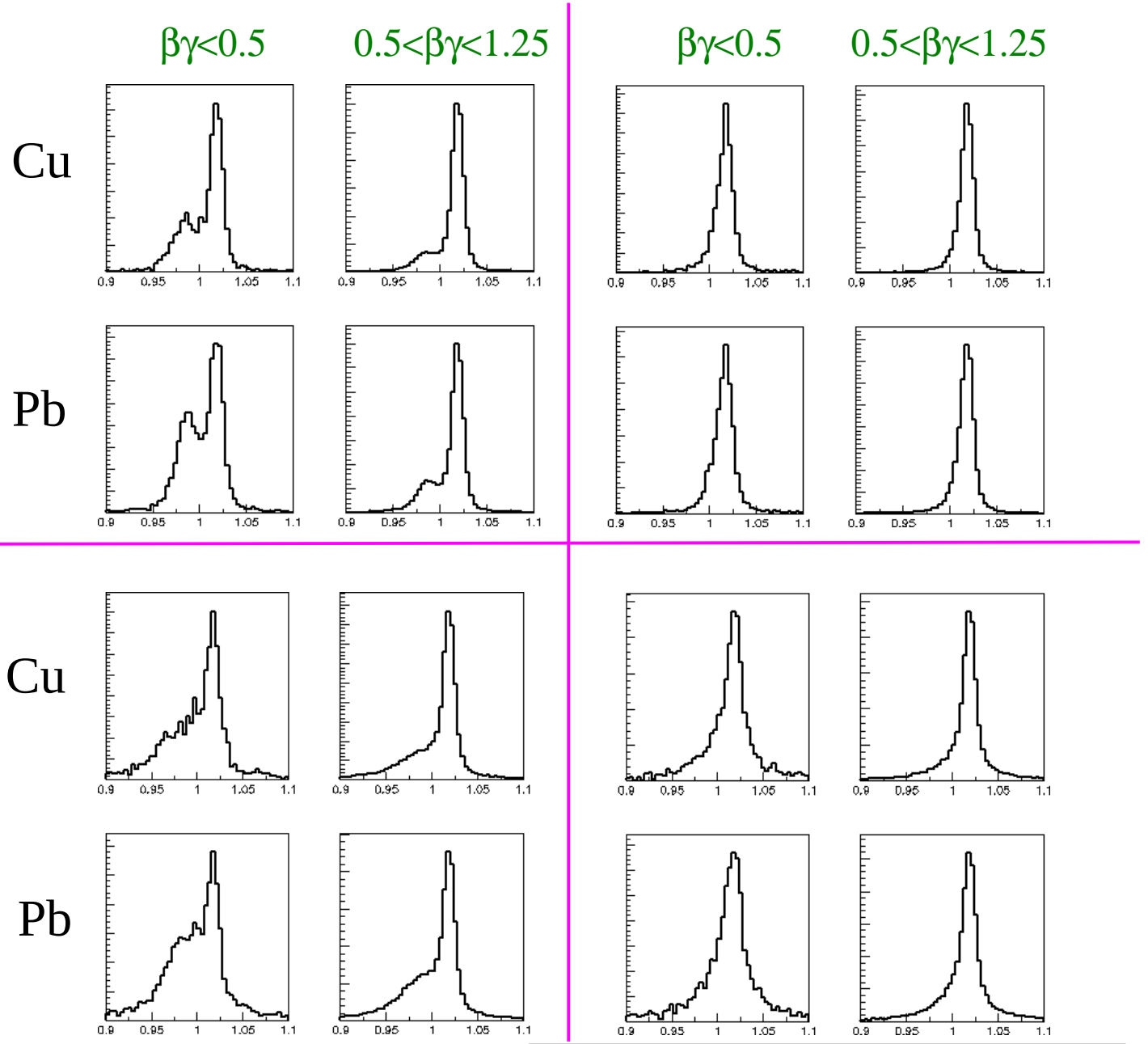
expected shape w/ various parameters

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

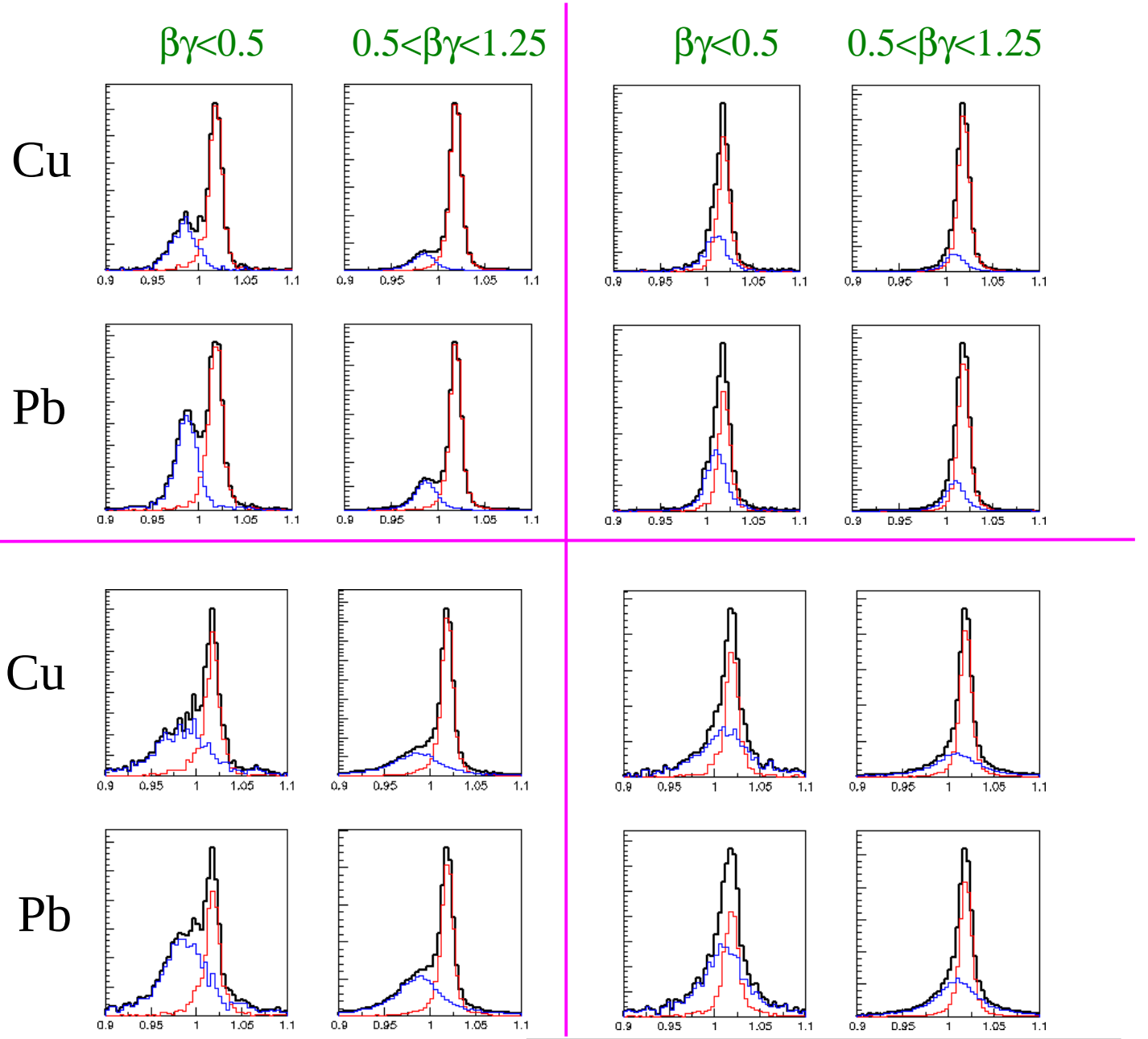
Δm = –35 or –10 MeV

Γ = 15 or 50 MeV

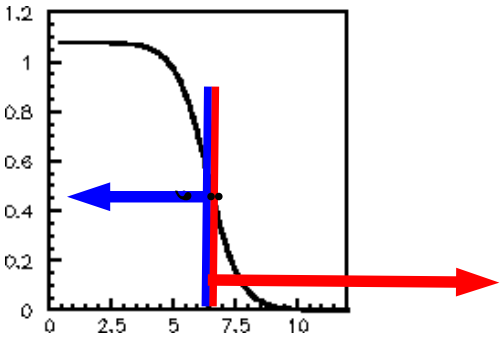


expected shape w/ various parameters

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

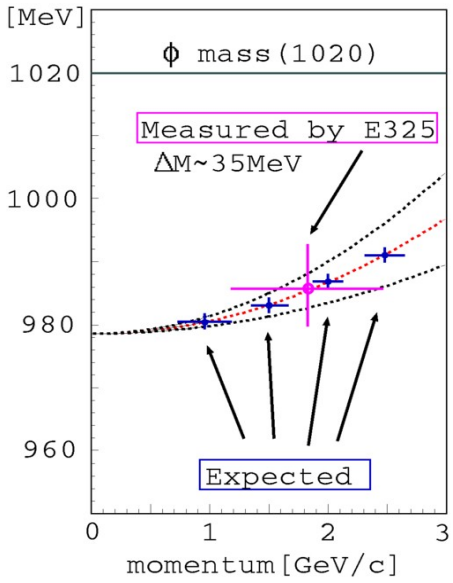


blue: decays inside the half-density radius of nuclei in the MC

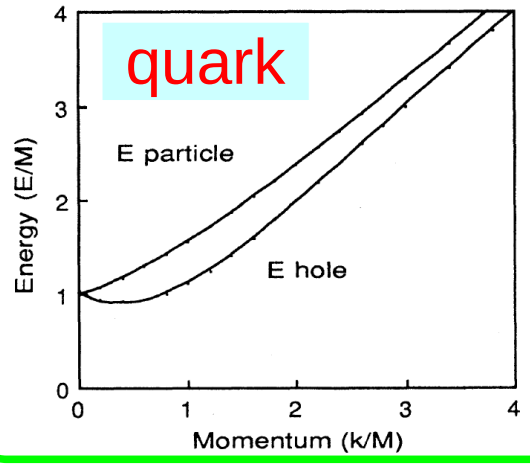


momentum dependence

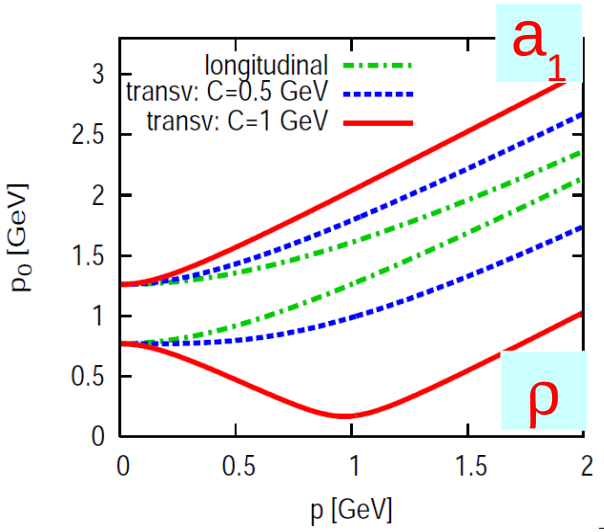
- From the view point of experimentalists
  - many predictions are for the mesons at rest (p=0)
    - extrapolation to p=0 if it is a simple dependence
- From the view point of theorists
  - dispersion relation of quasi particles are characteristic
  - other effects



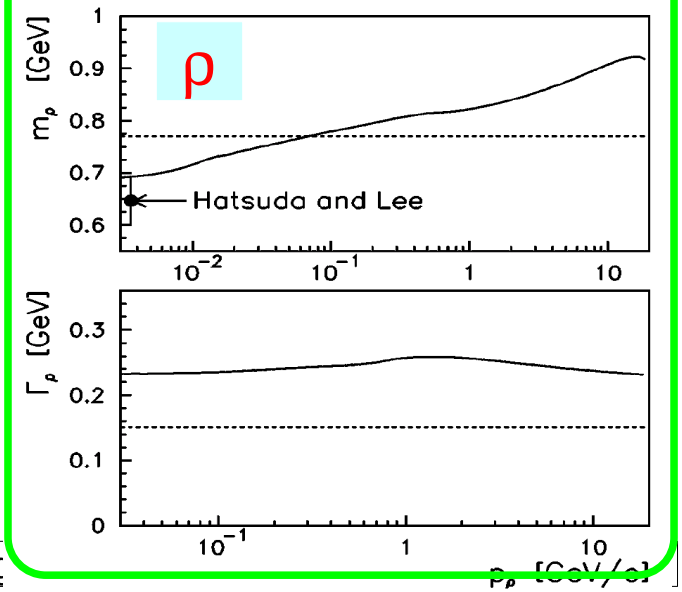
- Weldon (PRD40(89)2410)



- Harada & Sasaki (PRC80(09)054912)



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



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

– 1st module of production type (GT and HBD)

• test using pion beam @ J-PARC

•2012 : magnet re-construction

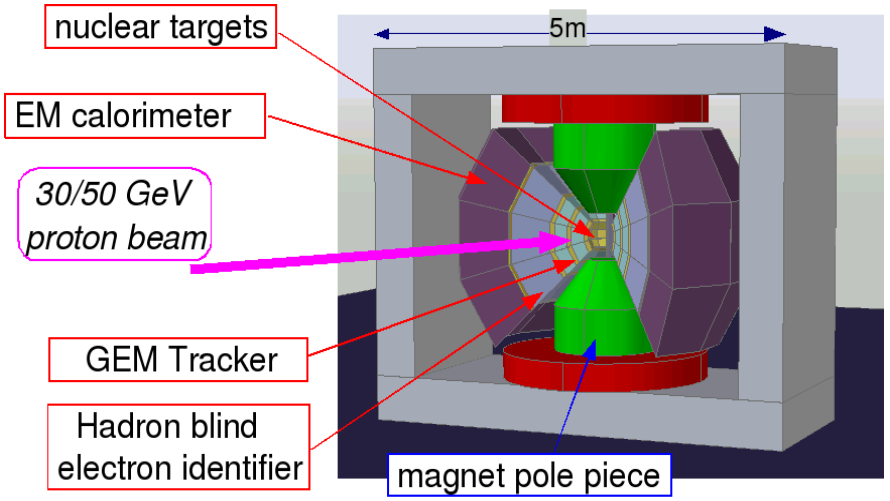
• all the detectors are installed in the magnet

– 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)



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 π 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 (10^7Hz) 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.

Schedule

2012-05-15																	
						1	2	3	4	5	6	7	8	9	10	11	12
		理研2期						理研3期					理研4期				
JFY		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	
		H20	H21	H22	H23	H24	H25	H26	H27	H28	H29	H30	H31	H32	H33	H34	
J-PARC hadron		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
RJC plan						1	1	2	3	4	5	1	2	3	4	5	
BNL MOU																	
RHIC PHENIX		8	9	10	11	12	13	14	15	16							
sPHENIX										1?	2	3	4	5	6		
ePHENIX															1	2	
eRHIC															1	2	
LHC ALICE				1	2	3	4	5	6	7	8	9	10	11	12	13	
GSI FAIR											1	2	3	4	5	6	
HADES run												0?	1	2	3	4	
High-p line							1	2	3	1	2	3	4	5			
E16 construction																	
E16 run									0	1	2	3					

This year(JFY)

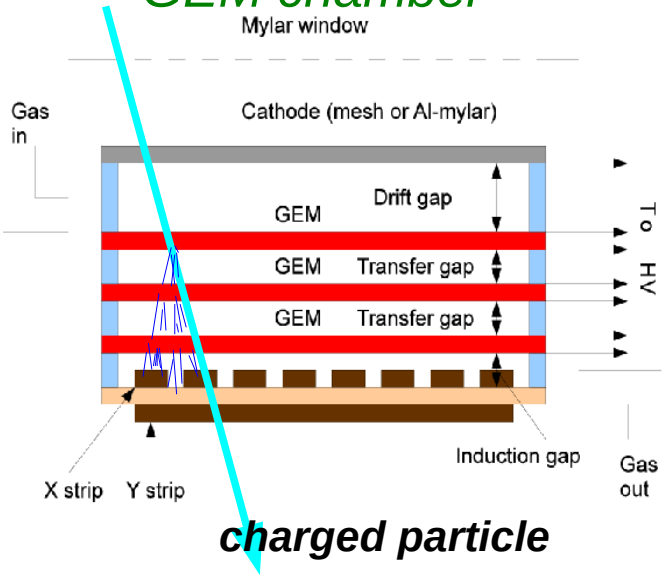
possibly compete with HADES/FAIR

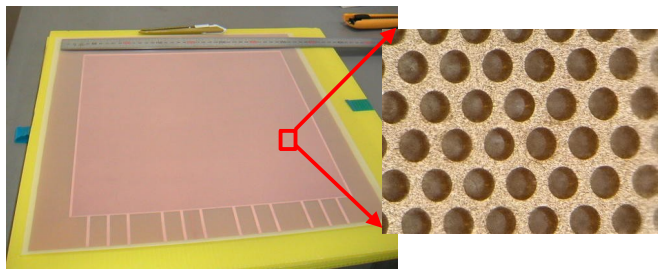
E16 Detector R&D

GEM R&D for Tracker/HBD

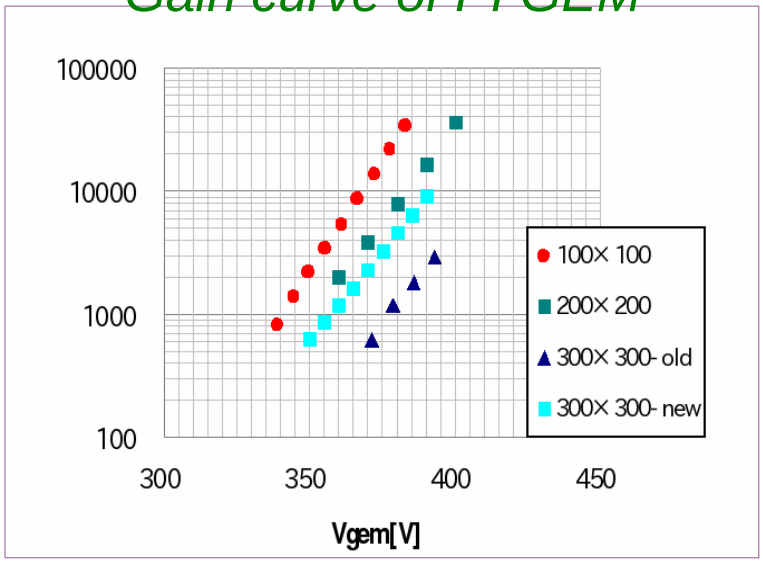
- GEM Tracker to cope with the high rate
  - Ar+CO_2(70:30)
  - angled injection, 2D readout,etc.
  - required position resolution 100um is achieved for angled tracks w/ FADC R/O
- Hadron Blind Detector to trigger the electrons
  - CsI photocathode, CF_4 gas purity, etc.
- Domestic Large size (300mmx300mm) GEM
  - kapton (Polyimide, PI) t=50um for GT
  - LCP , t=100 um for HBD

GEM chamber



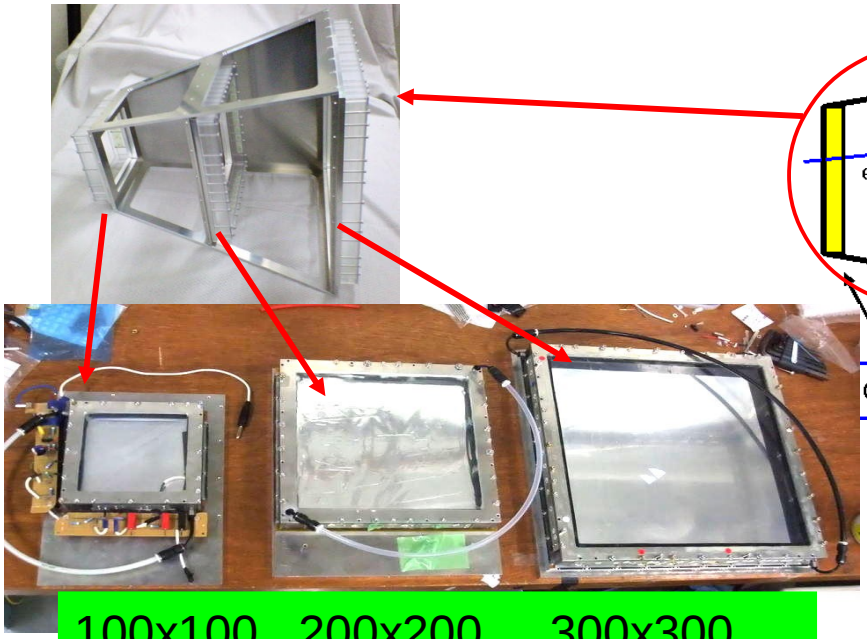


Gain curve of PI GEM



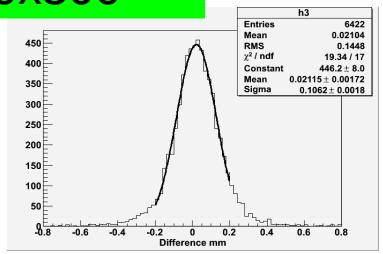
Beam test results of prototype detectors

GEM Tracker

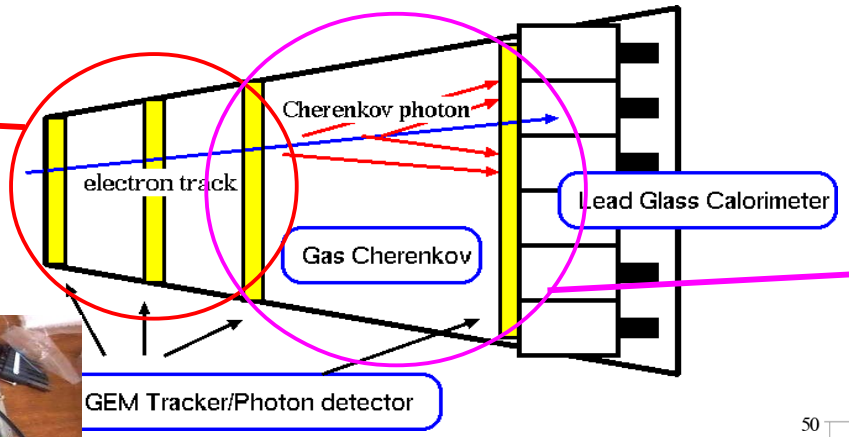


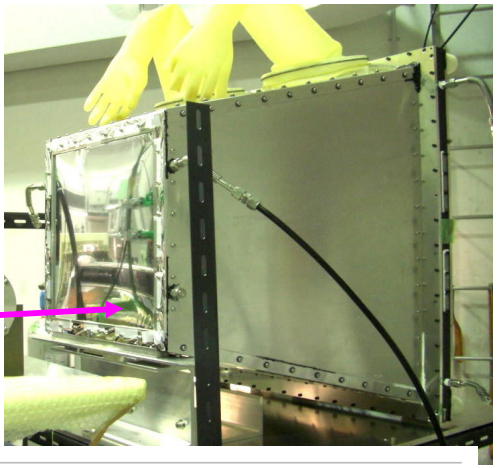
100x100 200x200 300x300

Required position resolution (~100μm) is achieved

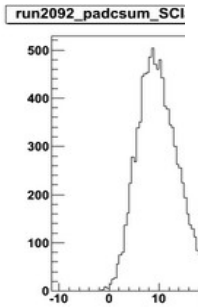


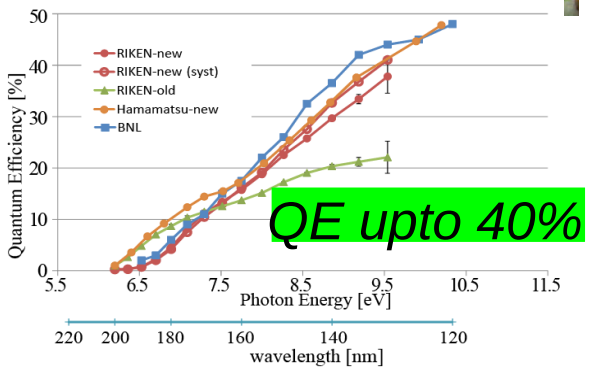
HBD (Hadron-Blind Cherenkov detector)





UV Cherenkov photons are detected with CsI-evaporated LCP-GEM and CF_4 gas





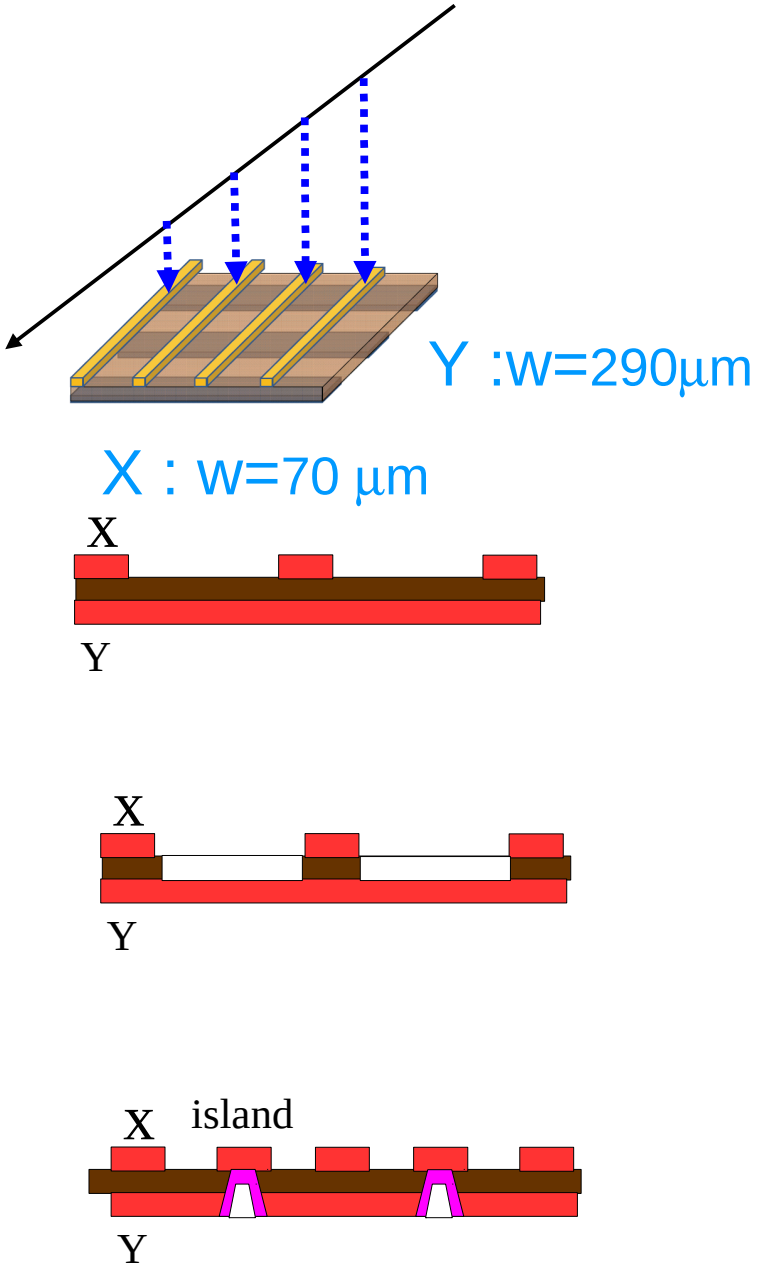
QE upto 40%

10 p.e.

- Large size (300x300mm) PI- and LCP-GEM are successfully worked for a electron beam
  - Stability for a pion beam should be checked. : Test @ J-PARC at June.
- GEM Tracker is successfully worked.
- Improvement of the photo-detection efficiency of HBD is on going

Three types of 2D-R/O board of GEM Tracker

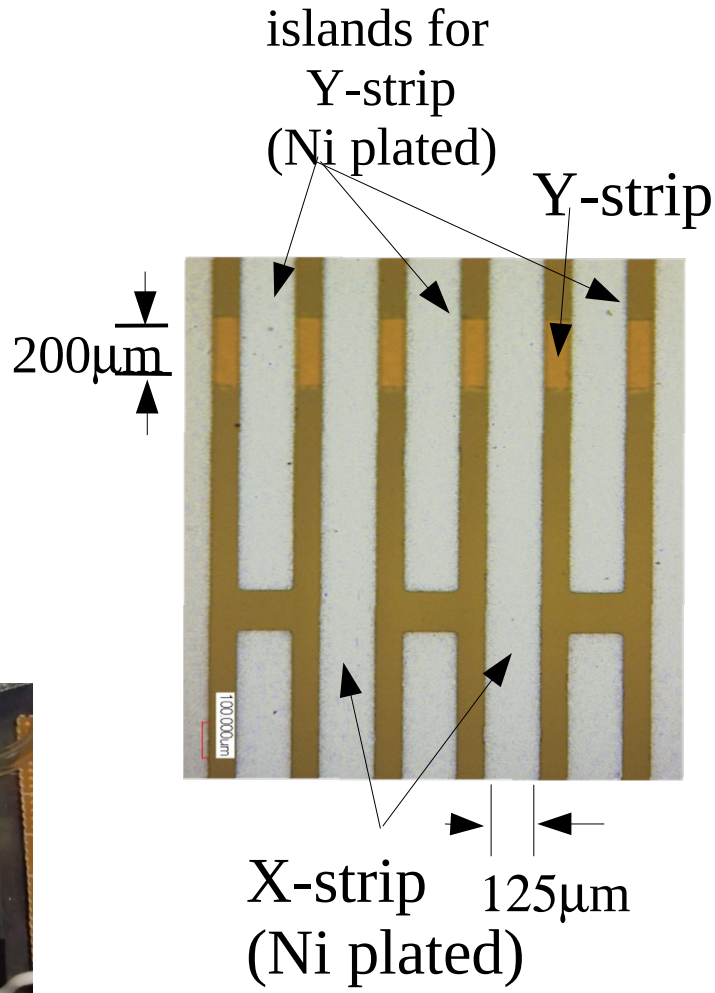
- thin two-dimensional read out board
  - base: t=25 um kapton
  - strip pitch : X: 350 um, Y:350 um
  - required resolution X:100um , Y: 700um
    - double side type
      - Y- efficiency is bad (~80%)
    - mesh type
      - amplified electrons can reach both X and Y strips by etching-out of base kapton
      - expensive and fragile
    - BVH (blind-via-hole) type
      - island electrodes between X strips to transport the electrons to Y strips via holes
      - pitch of Y is changed: 1400um
      - tested in Oct. 2011, works well

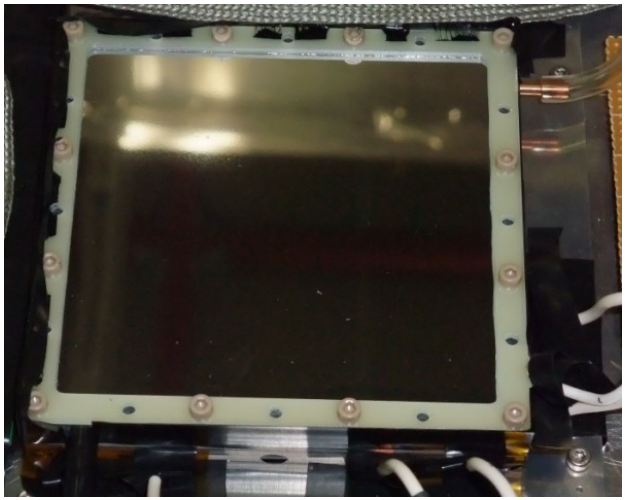


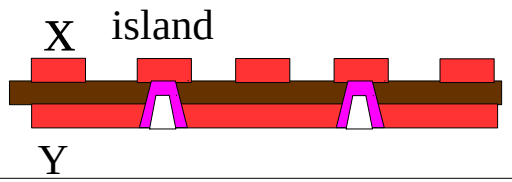
GEM Tracker test @ LEPS

- 1st 100mm x 100mm production type Tracker
  - BVH-type R/O board
  - Al-mylar cathode
  - gas-tight is kept by the GEM frame, Al-mylar and the R/O board
  - resolution (efficiency) under the gain=5000
    - 105μm (98%) for X
    - 310 μm (93%) for Y : can be improved by gain=10000

BVH type R/O board







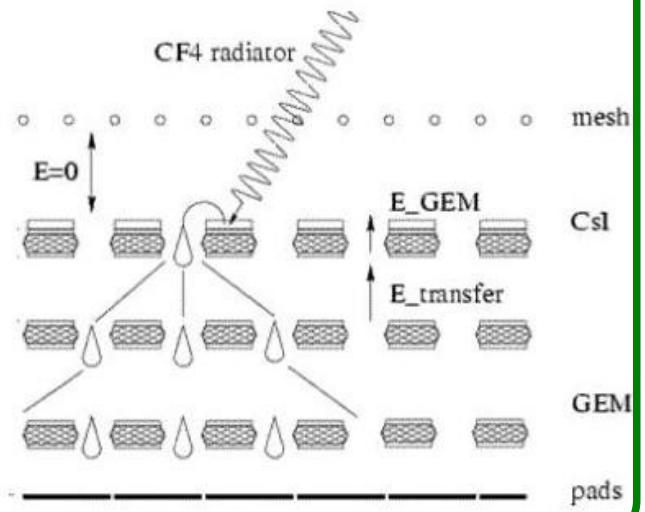
managed by Y. Komatsu & W.Nakai

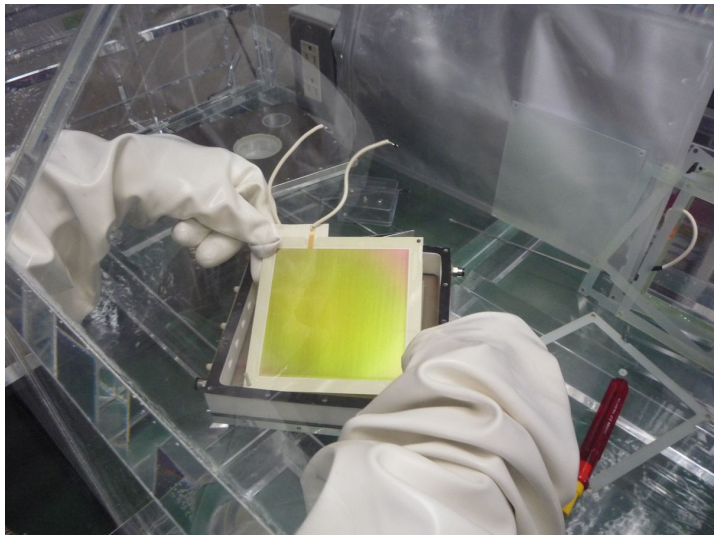
HBD (Hadron Blind Detector)

- HBD (Thr. type Gas Cherenkov)
  - developed thanks to Weizmann/Stony Brook
  - 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 photons.
      - (1/100 of pion rejection)
  - GEM (LCP 100um: higher gain) by Scienergy.Co.
  - CsI evaporation by Hamamatsu & RIKEN
  - QE improved at RIKEN : beam test at 2011/3
    - 10 photoelectrons detected (cf. PHENIX ~20 p.e.)
    - Improvement of gas purity and GEM HV config. are required
  - Test @ J-PARC in June
    - pion rejection & p.e. improvement

managed by K. Aoki & K.Kanno

Concept of HBD





High-p WS@KEK 2012May16 S.Yokkaichi

Lead Glass from TOPAZ / E362

17 frames were decomposed
at KEK warehouse
by Y. Aramaki & S. Sekimoto
(Apr. 2012)

FM magnet re-modeling

Hadron hall

yoke extension

additional pole piece

delivered in Feb.2012
(managed by R. Muto)

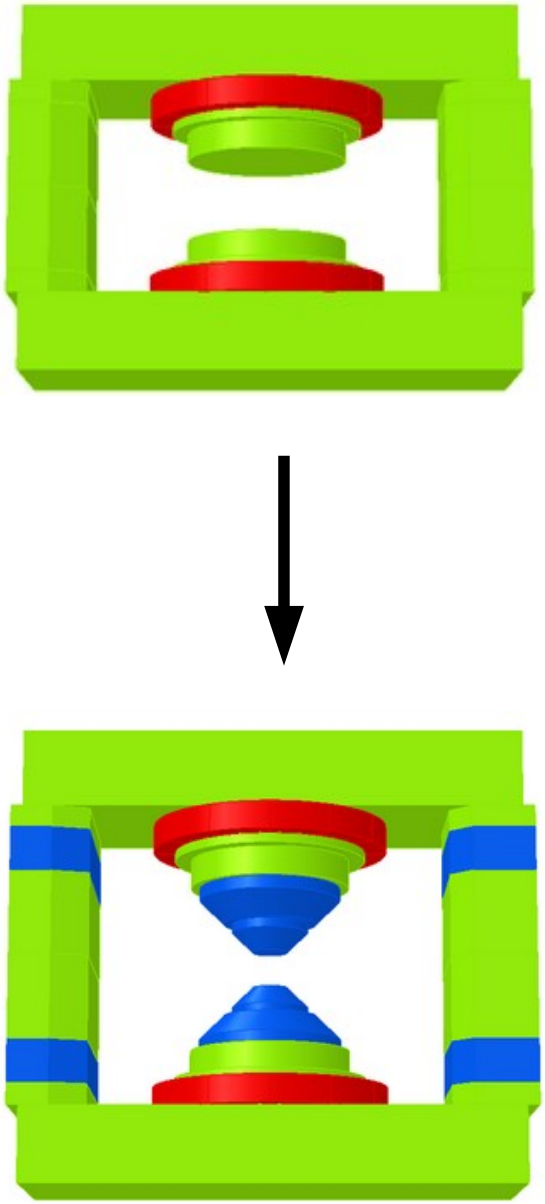
Summary

- 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
  - establish the QCD-originated mass
  - preparation is underway
  - Staged Goal of construction : the end of JFY 2013

back up

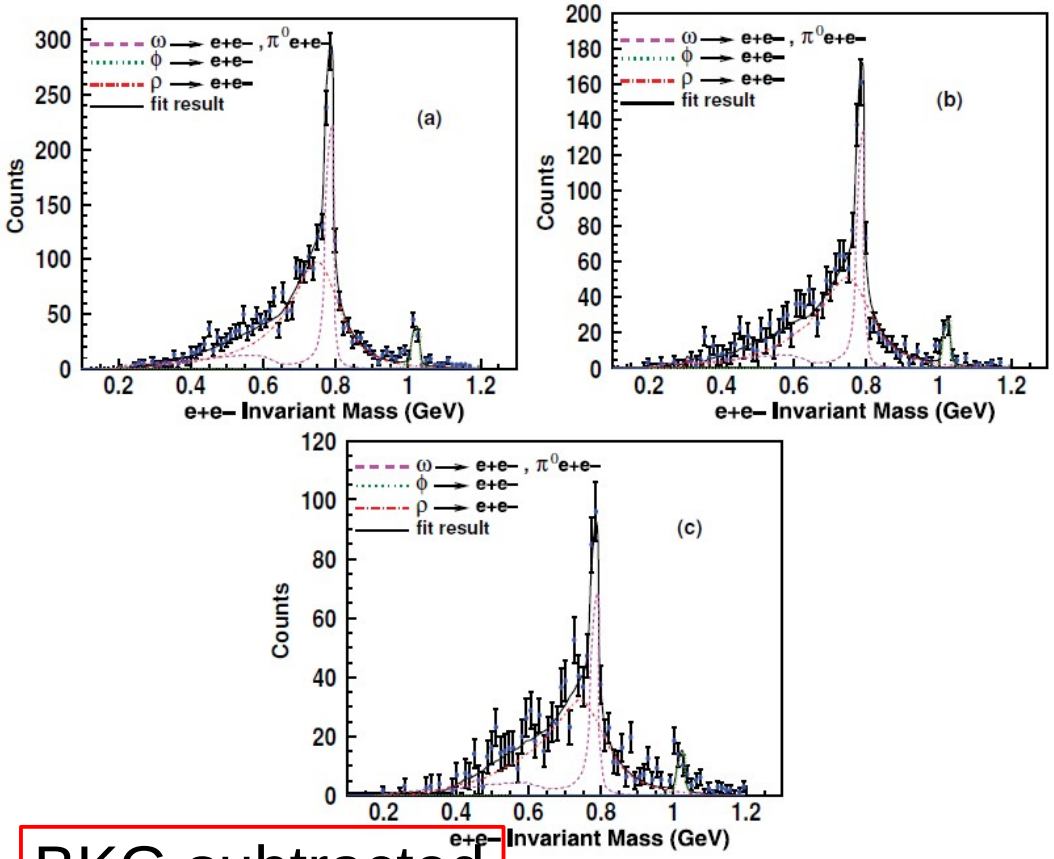
Spectrometer Magnet re-construction

- FM magnet (used by KEK-PS E325)
  - additional poles and yokes
    - larger acceptance/stronger field
  - decompose -> proper location on the High-p line -> re-construction with new parts
  - a pit (digging of the floor concrete) is required under the magnet
    - cannot be managed by Grant-in-Aid : at least, 'overhead' of grants should be used.
  - takes 6-8 months
    - scheduling of the area and overhead crane usage
  - by the end of JFY2012
- detector installation in JFY2013
  - all the detectors are installed in the Magnet



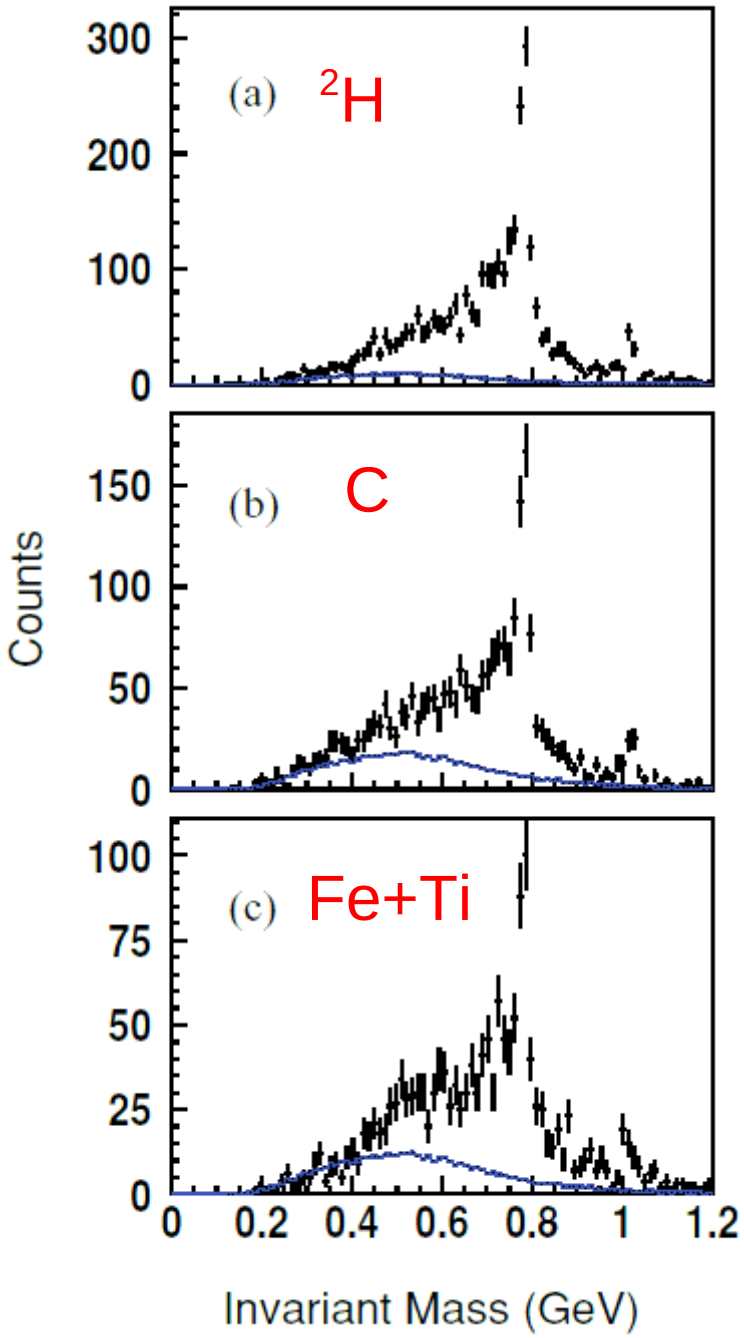
CLAS-G7 (PRC78(2008)015201)

- $\gamma + A \rightarrow V \rightarrow e^+e^-$
- no anomaly for p >0.8GeV/c



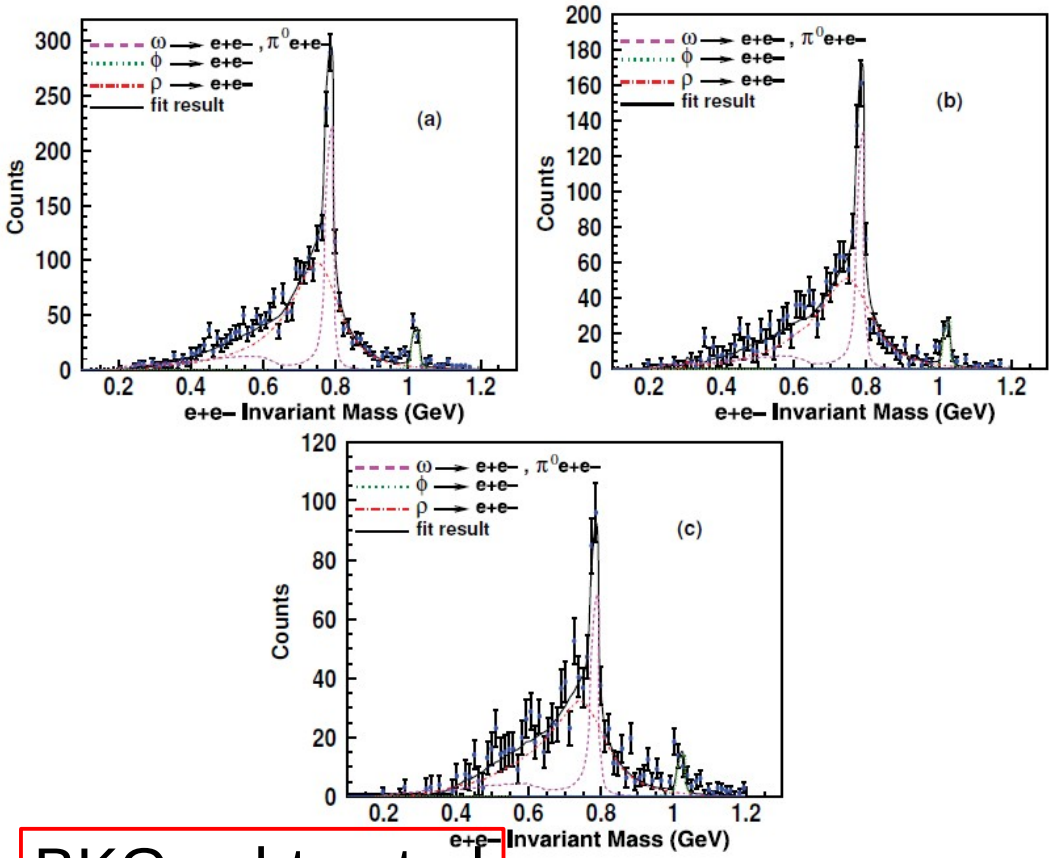
BKG subtracted

PRC78(2008)015201



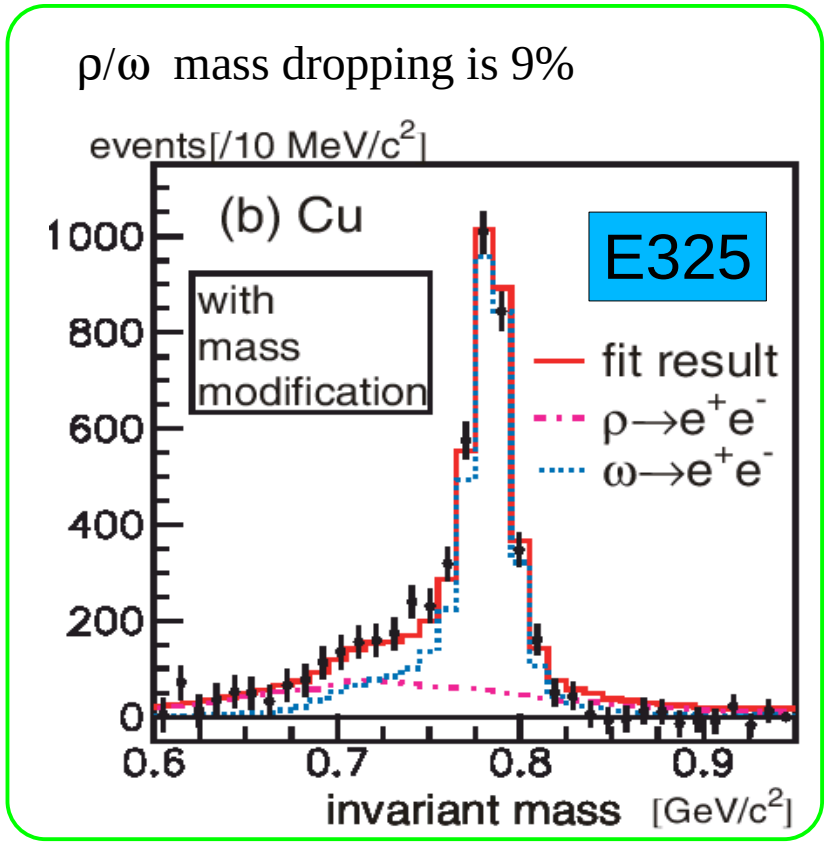
CLAS-G7(PRC78(2008)015201)

- $\gamma + A \rightarrow V \rightarrow e^+e^-$
- no anomaly for p >0.8GeV/c : ρ mass dropping <4% in 95%C.L.
  - ρ width broadening (up to ~45%) is consistent with the collisional broadening
  - ω modification is not included in the analysis



BKG subtracted

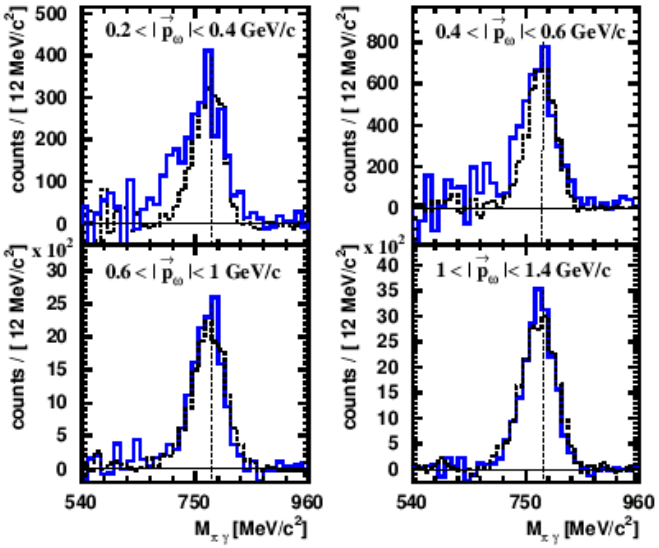
PRC78(2008)015201

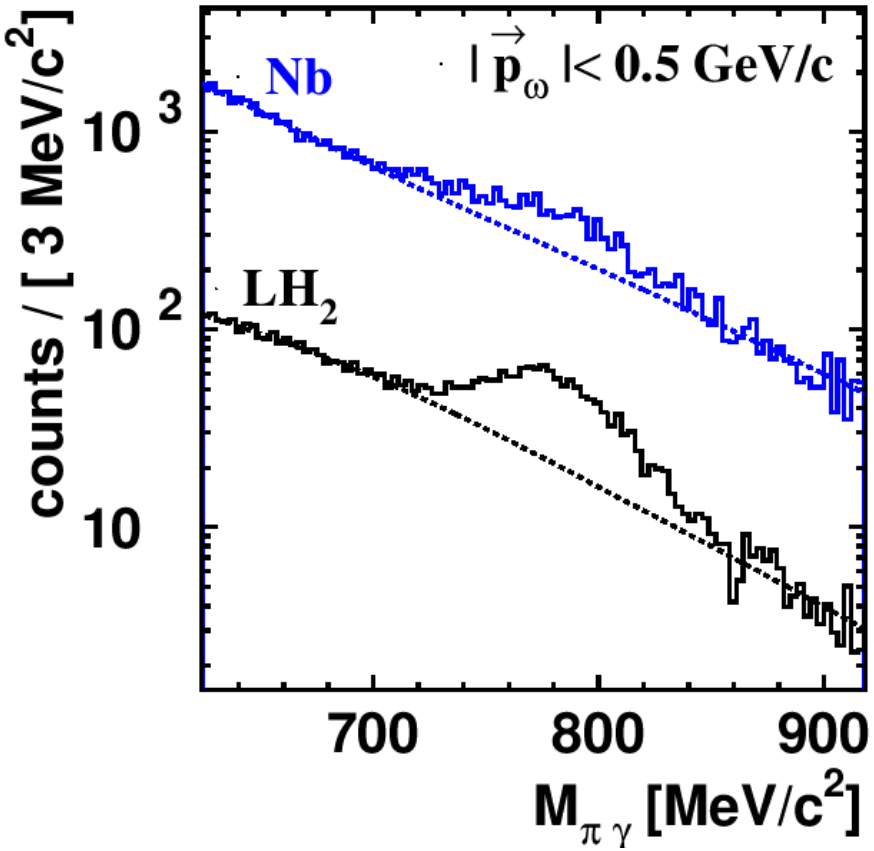


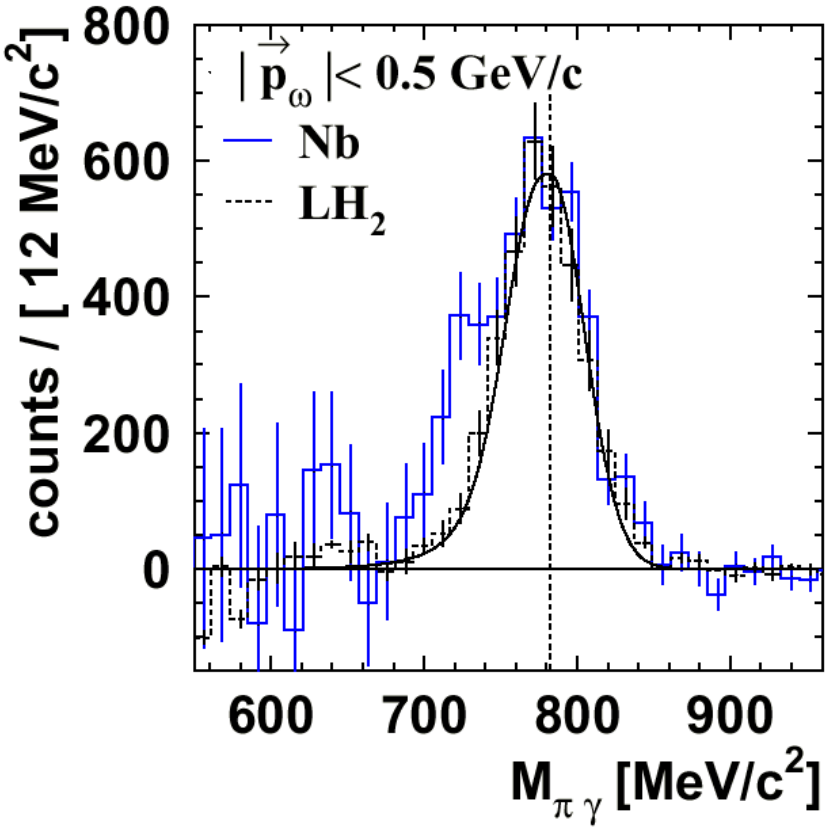
High-p WS@KEK 2012May16 S.Yokkaichi

CBELSA/TAPS (PRL94(05)192303)

- $\omega \to \pi^0\gamma\,(\to \gamma\gamma\gamma)$
- anomaly in γ +Nb, not in γ +p
  - shift param. k~0.14

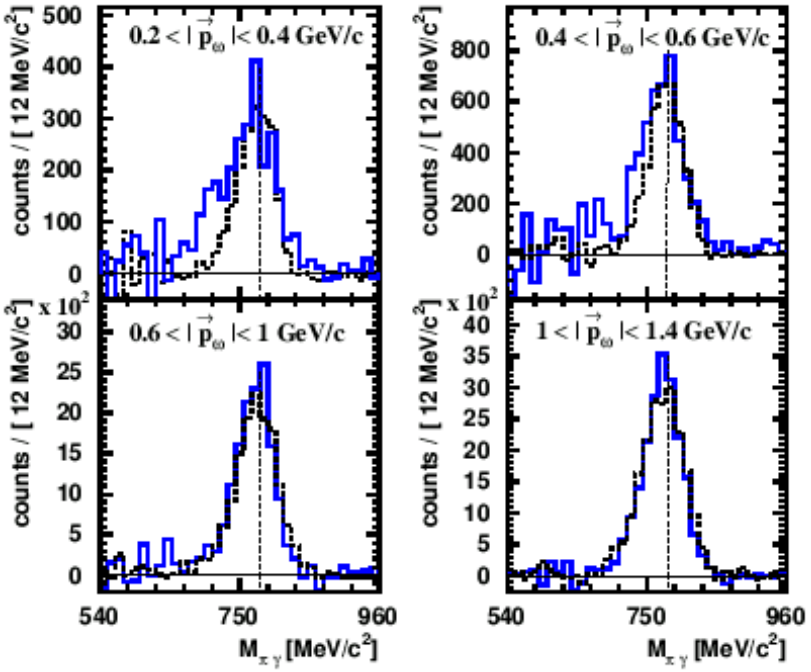




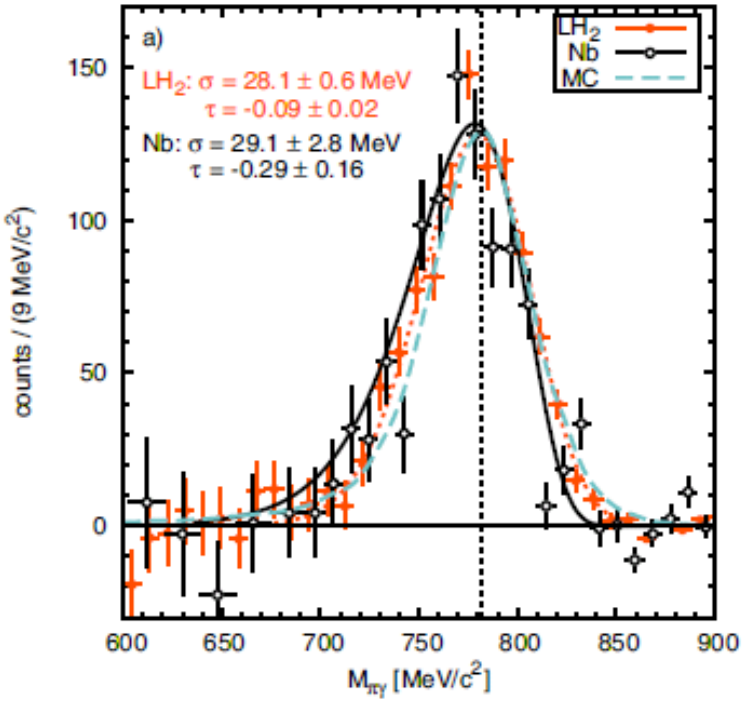


CBELSA/TAPS

- $\gamma + A \rightarrow \omega \rightarrow \pi^0\gamma\,(\rightarrow \gamma\gamma\gamma)$
- excess in γ +Nb, not in γ +p
  [PRL94(05)192303]



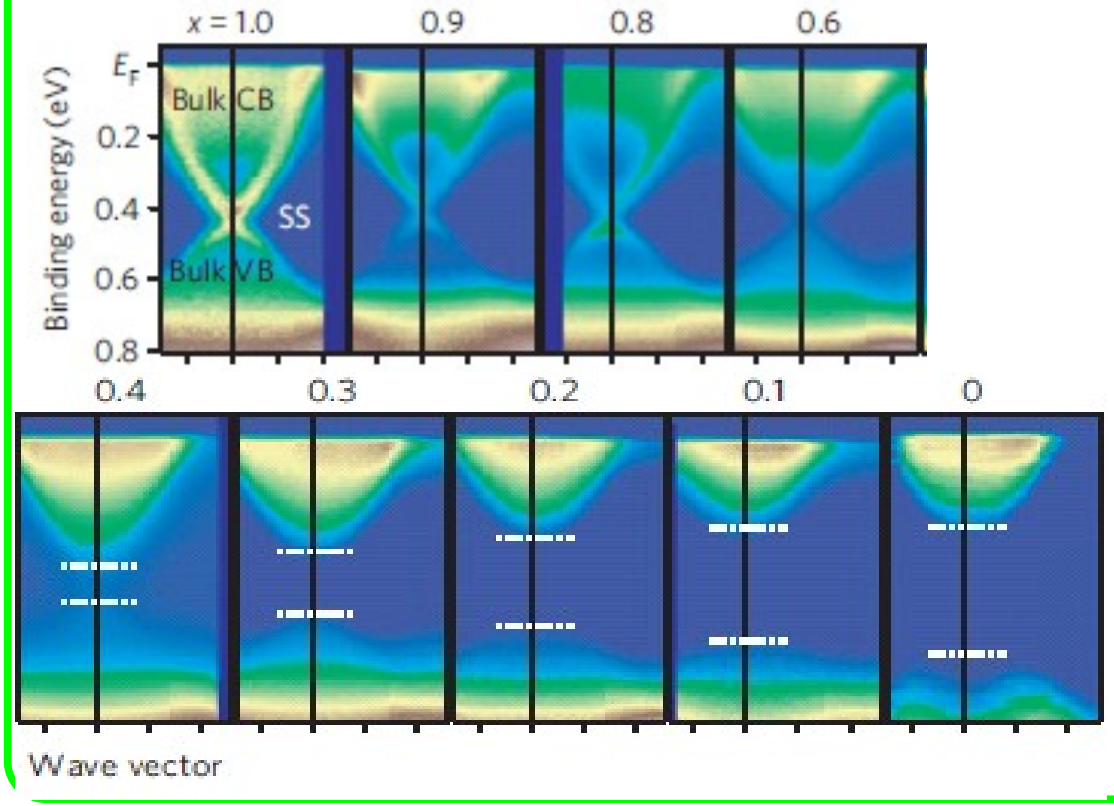
-
- excess is not reproduced significantly by the following experiment [EPJA47(11)16]



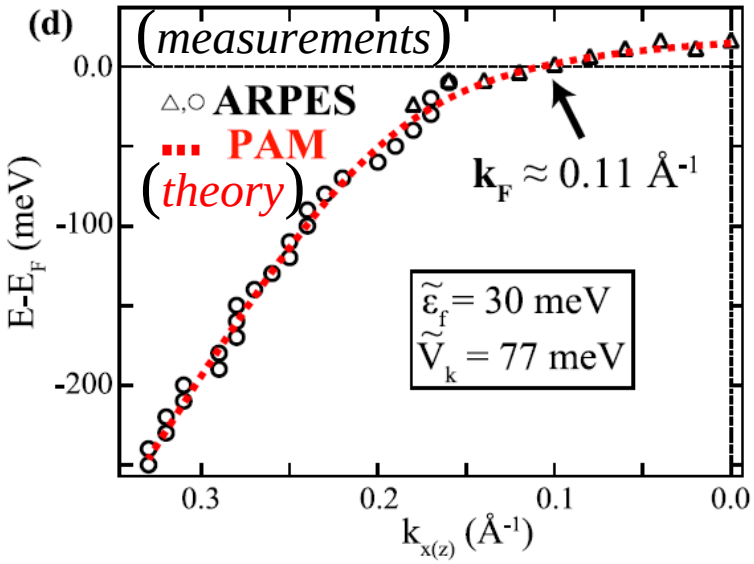
dispersion of quasi particle in condensed matter

- ARPES (angle-resolved photoemission spectroscopy) measurements
  - Mass acquisition of Dirac electron in the topological insulator
  - heavy electron w/ Kondo-effect in $CeCoGe_{1.2}Si_{0.8}$

- Sato et al.
  (n.phys 7(2011)840)



- Im et al.
  (PRL 100(2008)176402)

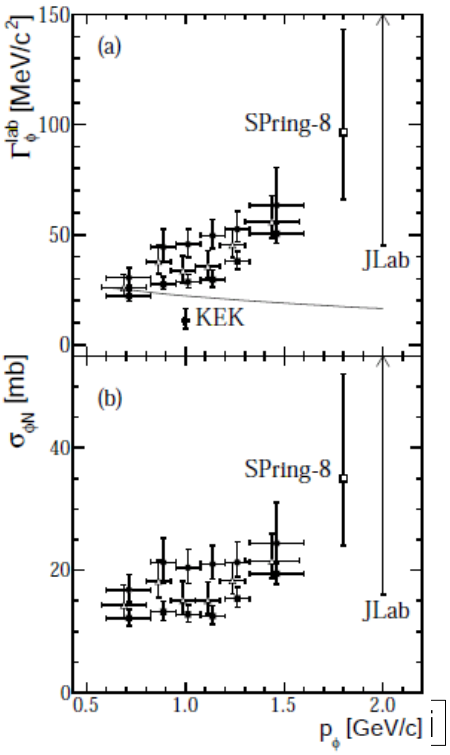


Note: shape and its nuclear matter size / momentum dependence

- size of “mass shift” or “mass dropping” (Δm)
  - proportional to the density : physics
  - could be dependent on the momentum : physics
- number of “shifted” meson
  - proportional to the matter size : experimental viewpoint : use larger nuclei
  - depend on the meson life
    - $\beta\gamma$ of mesons : experimental viewpoint: select slower
    - decay width change : physics
- observed shape
  - depend on the “shift”, width, and density distribution of the nuclei

width broadening by absorption

- Attenuation measurements:
  - absorption in nuclei evaluated from the A-dependence of production CS using theoretical models (Glauber, Valencia, Giessen...)
  - additional width: $\Gamma_{abs} = \hbar\rho\beta c\sigma_{abs}$
- LEPS : ϕ : σ_{abs} = 35mb, p=1.8 GeV/c [PLB608(05)215] ($\rightarrow \Gamma$= ~100 MeV)
- TAPS : ω : σ_{abs} = 70mb, p=1.1GeV/c , Γ=~150 MeV [PRL100(08)192302]
- CLAS : ϕ : 16-70mb, 2 GeV/c , Γ=23-100MeV [PRL105(10)112301]
  - A-dependence of ω (p=1.7GeV/c) is not reproduced by any model
- ANKE : ϕ : 14-21mb, 0.6-1.6GeV/c, 50-70MeV [arXiv:1201.3517v1]
    - 2.83 GeV p+A
- Note:
  - different from the old higher-energy photo-production data
  - No one measured the width directly through the mass shape



E325 A-dependence of the meson production cross sections

- 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 (cf. Sibirtsev et.al. EPJA 37(2008)287)

  additional Γ=12 MeV for 2 GeV/c φ (β=0.9) : consistent with Γ=15 MeV (i.e. k_2=2.6)
- Remark:
  Γ_ϕ=15 MeV at m_ϕ=985MeV is consistent with Oset & Ramos et.al (NPA679(2001)616)