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

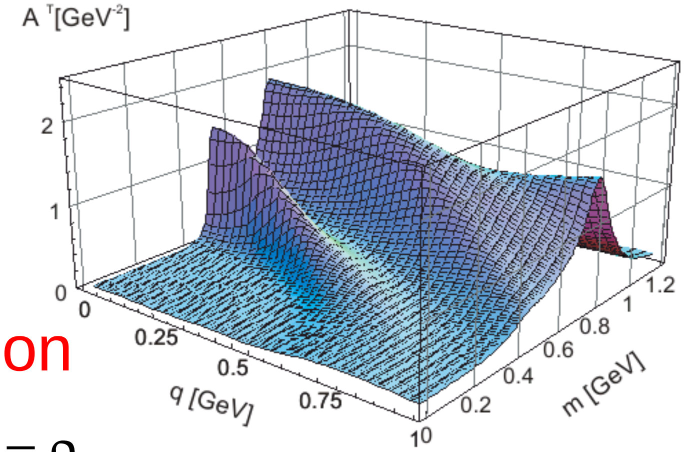
RIKEN	S.Yokkaichi, H. En'yo, F. Sakuma
KEK	K.Aoki, K.Ozawa, R. Muto, Y.Morino, S. Sawada, M. Sekimoto
U-Tokyo	Y.Komatsu, S.Masumoto, K.Kanno, W.Nakai, Y.Obara, T.Shibukawa, H.Murakami
RCNP	T.N.Takahashi
CNS, U-Tokyo	H. Hamagaki
Kyoto-U	M. Naruki
Hiroshima-U	K. Shigaki
JASRI	A. Kiyomichi

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]

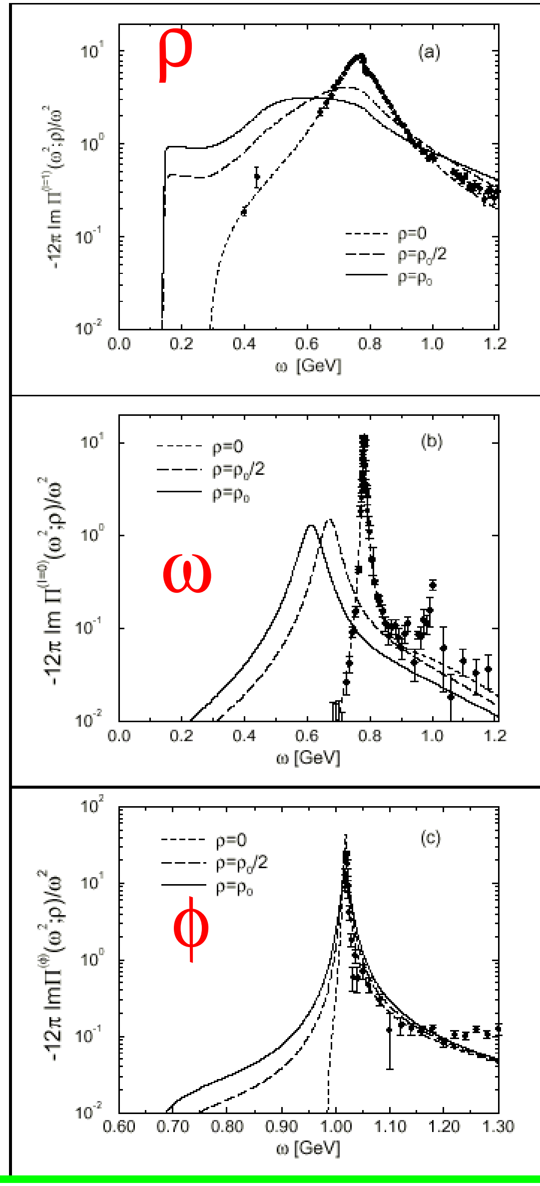


ρ-meson

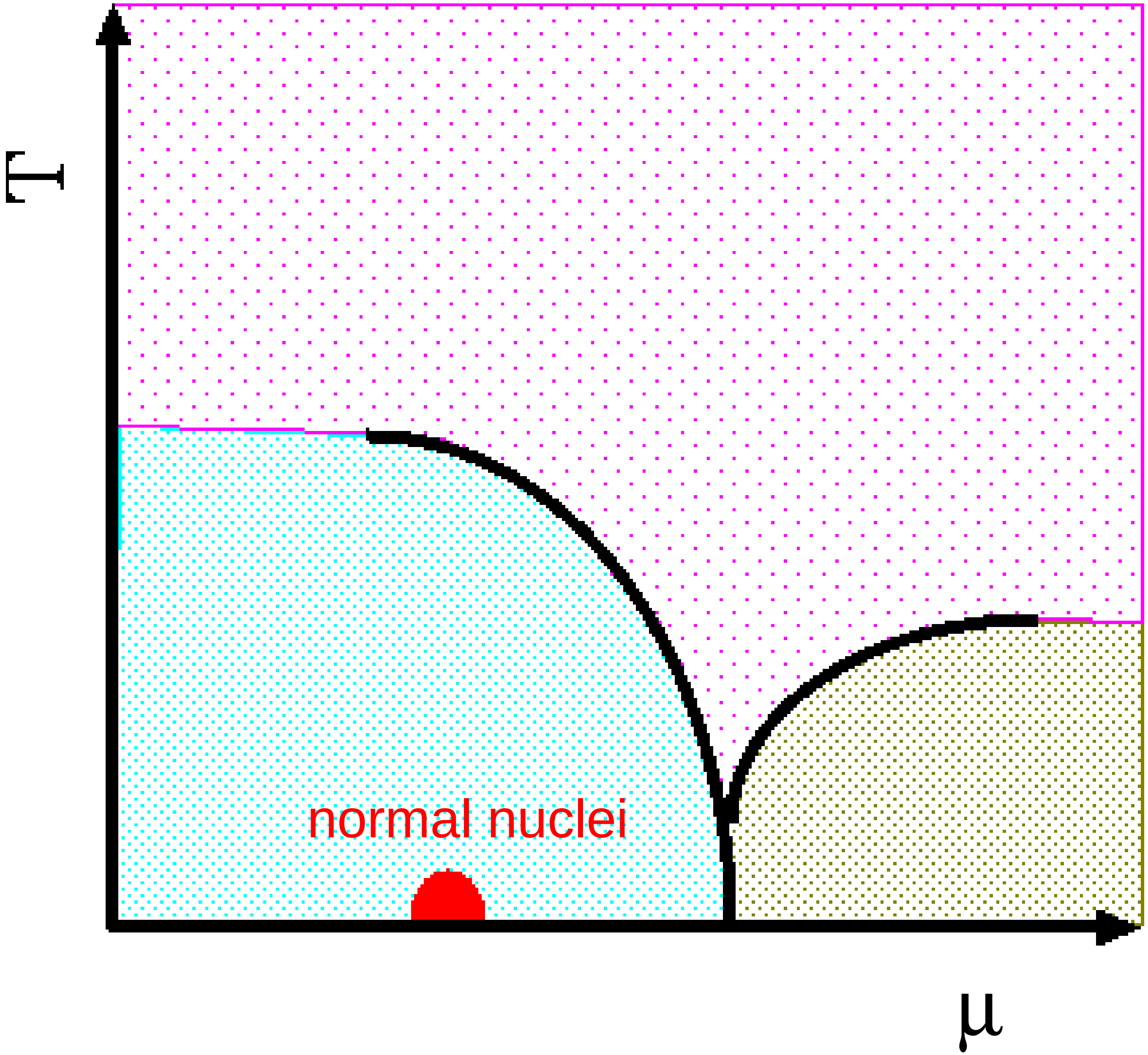
density $\rho = \rho_0$

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

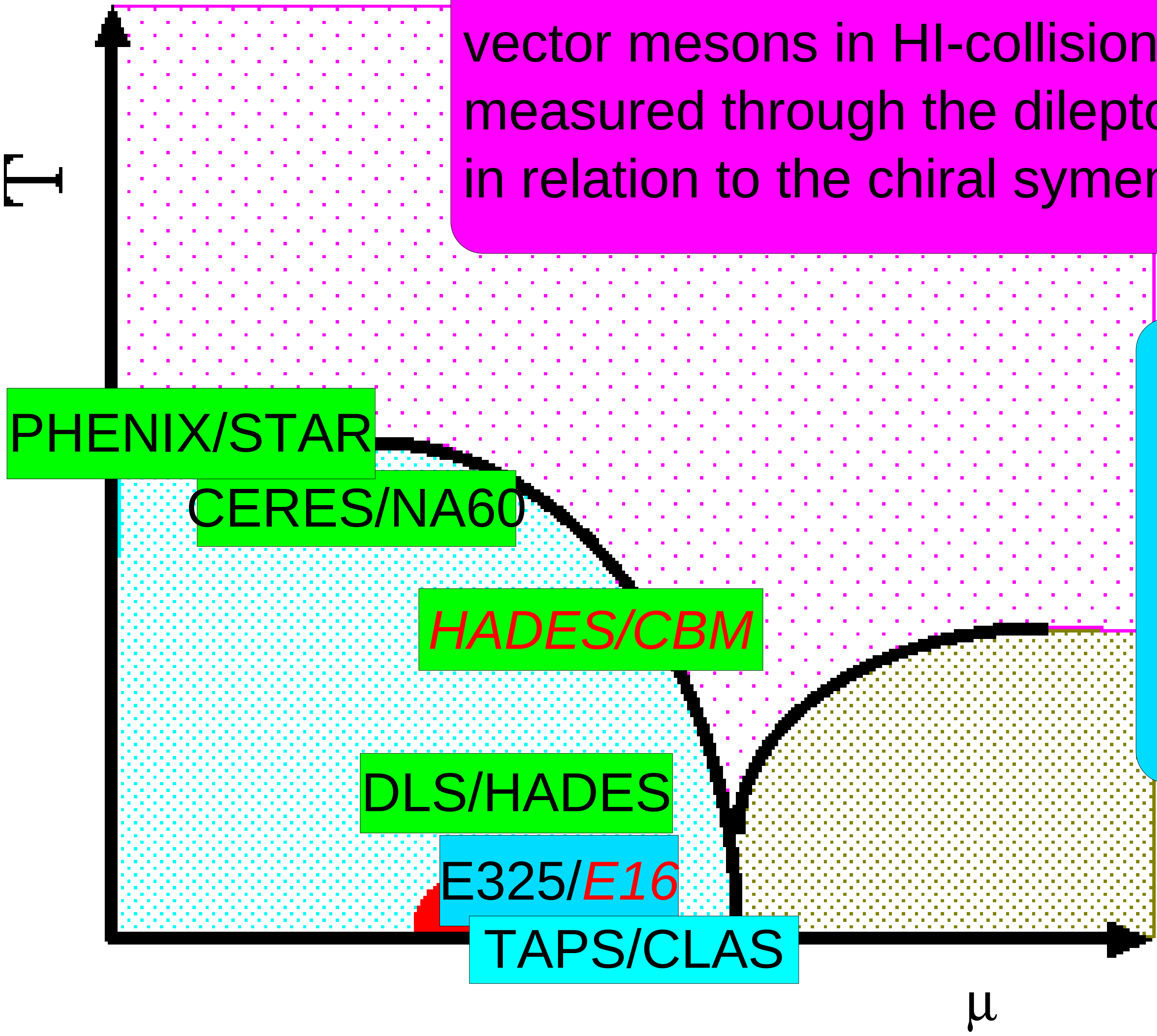


QCD phase diagram



dilepton measurements in different vacuum

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

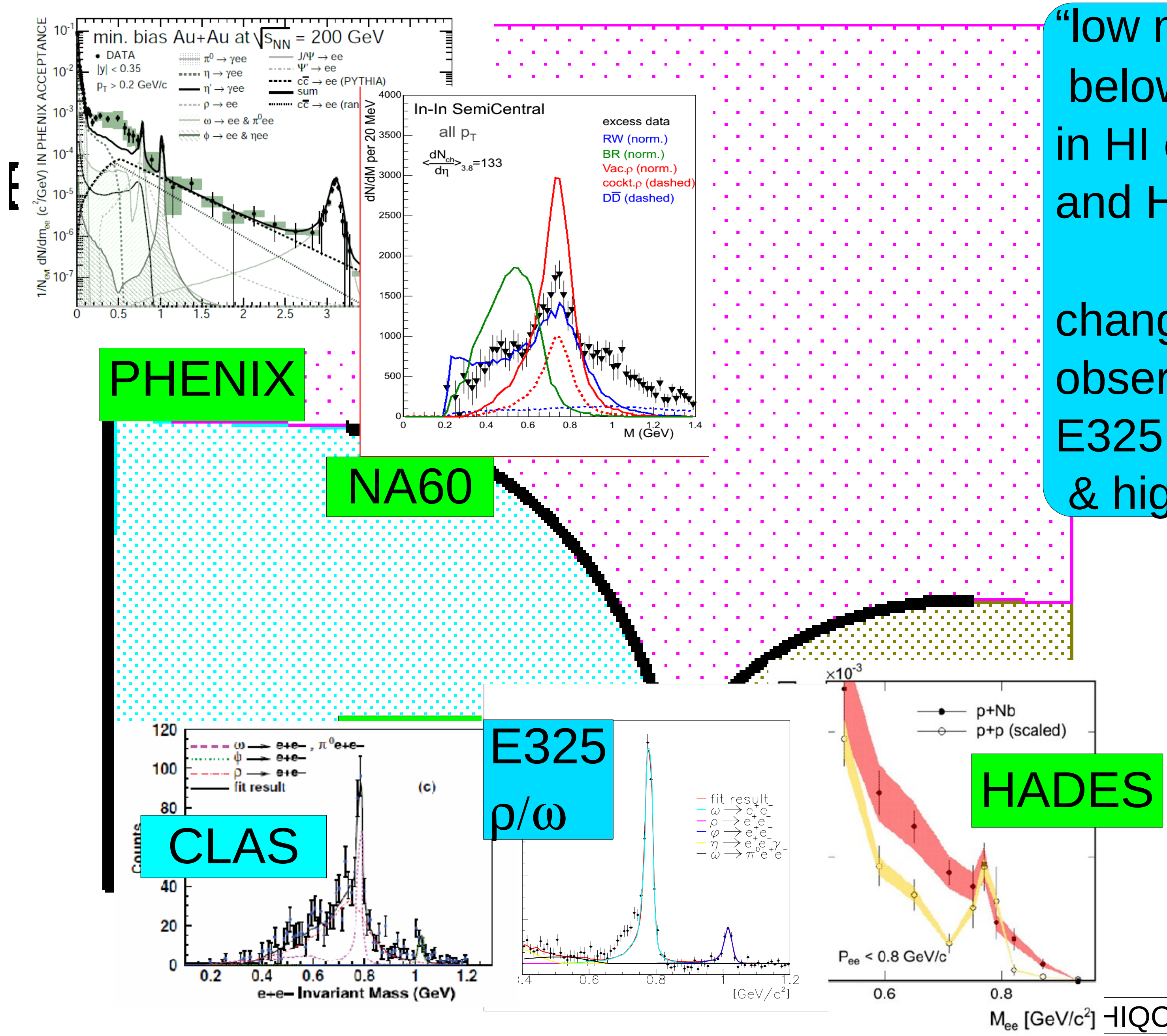


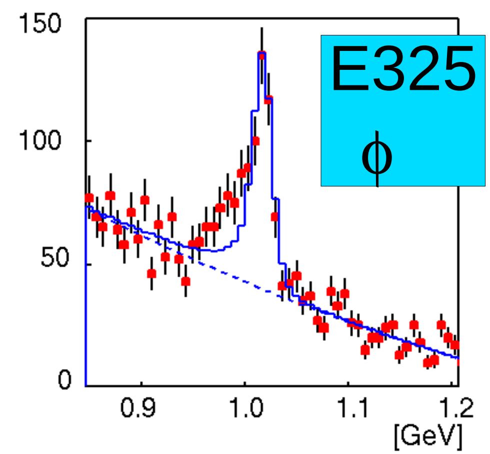
In hot and dense matter, spectral modification of vector mesons (dilepton invariant mass) are observed in many experiments

observed dilepton spectra in the world

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

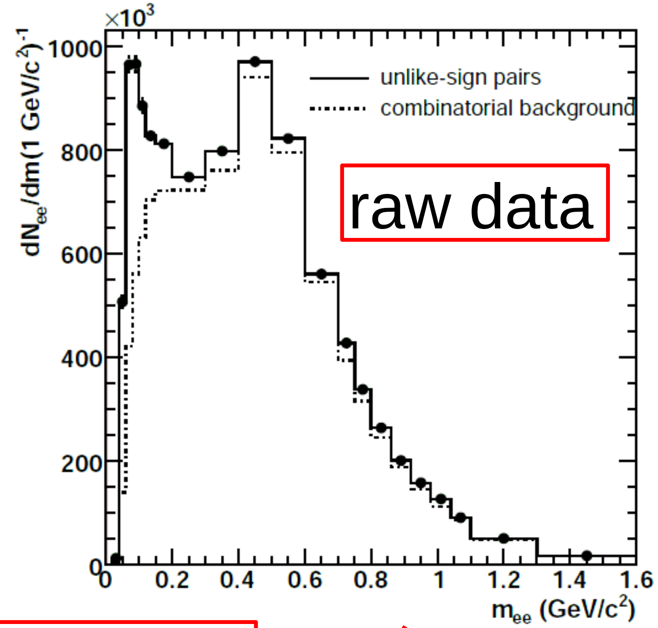
change of φ meson is
observed only by KEK-PS
E325 w/ best mass resolution
& high statistics





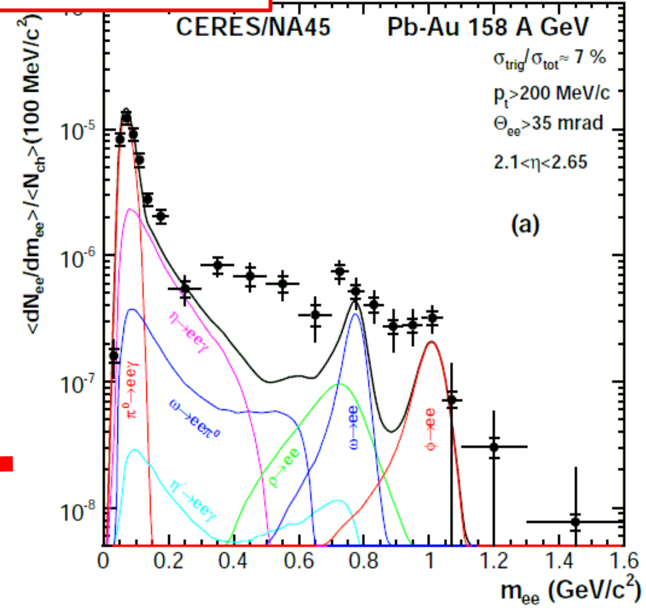
Dilepton spectrum in Heavy Ion Collision

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

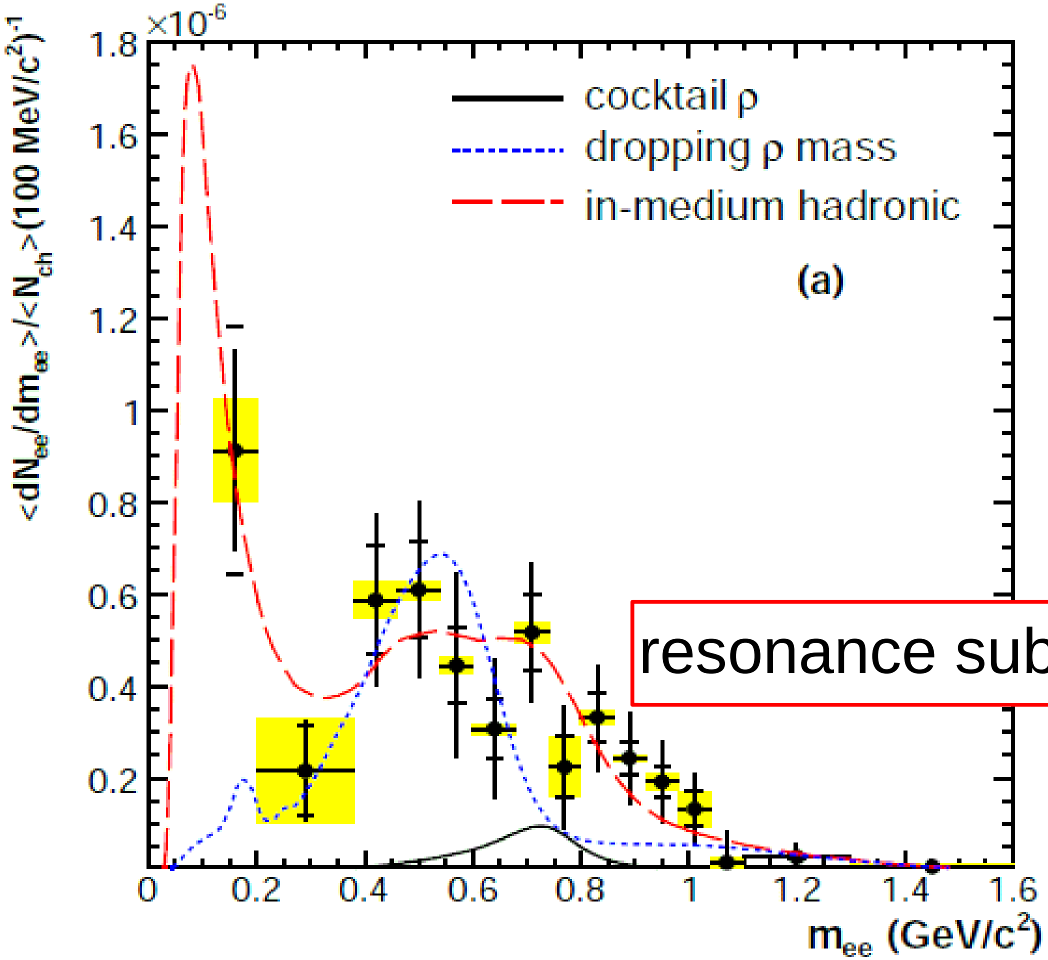


raw data

bkg subtracted

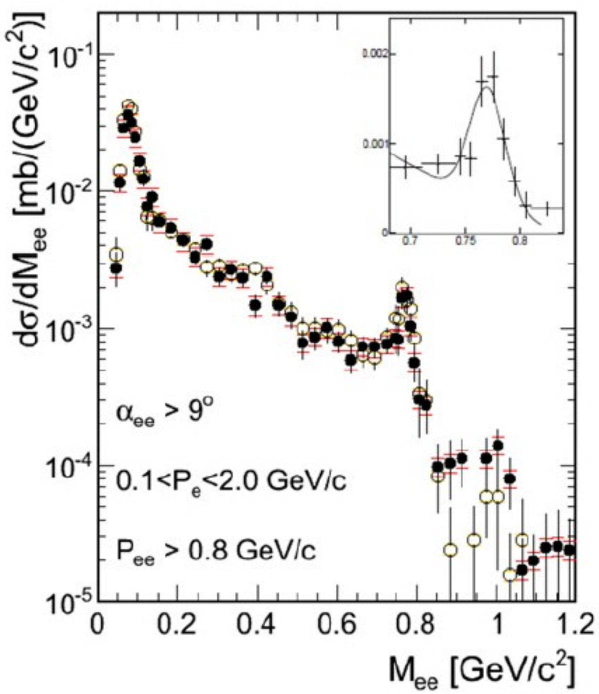


resonance subtracted

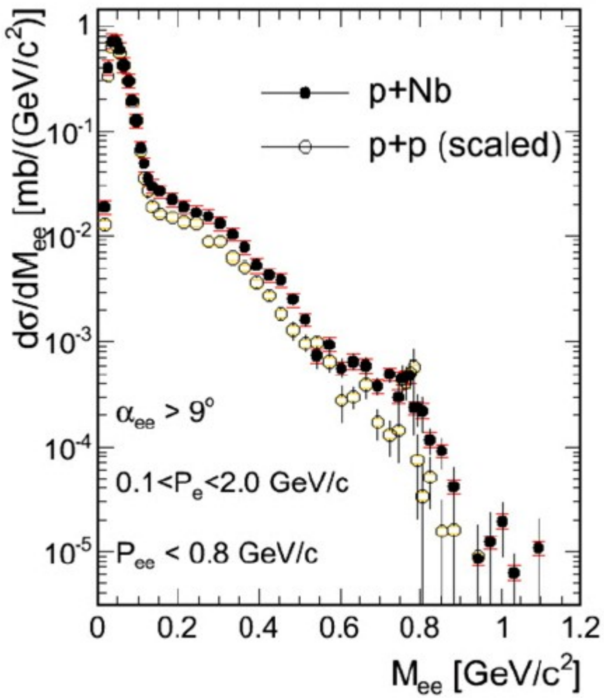


HADES 3.5GeV/c pp and pNb

[PLB715(2012)304]

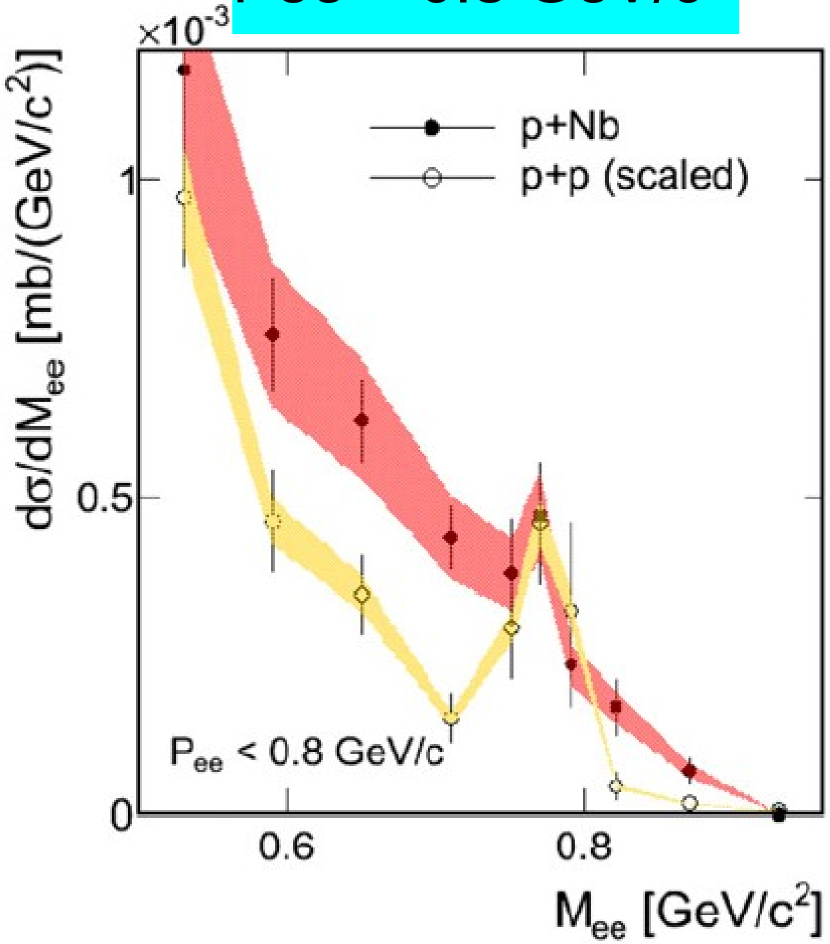


Fast :
Pee > 0.8 GeV/c



Slow:
Pee < 0.8 GeV/c

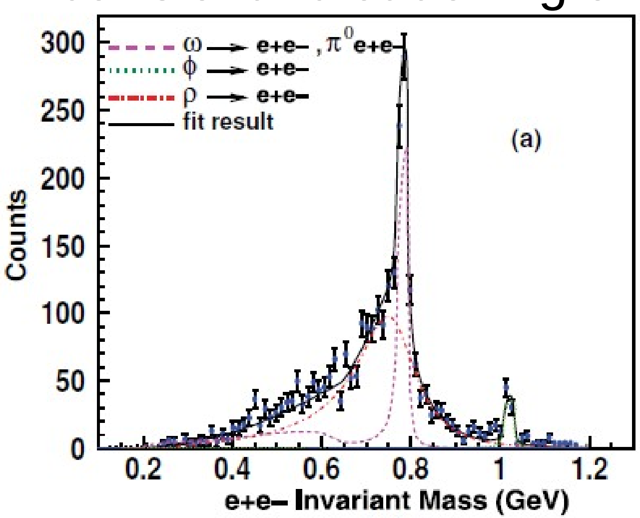
(zoomed)
Slow:
Pee < 0.8 GeV/c

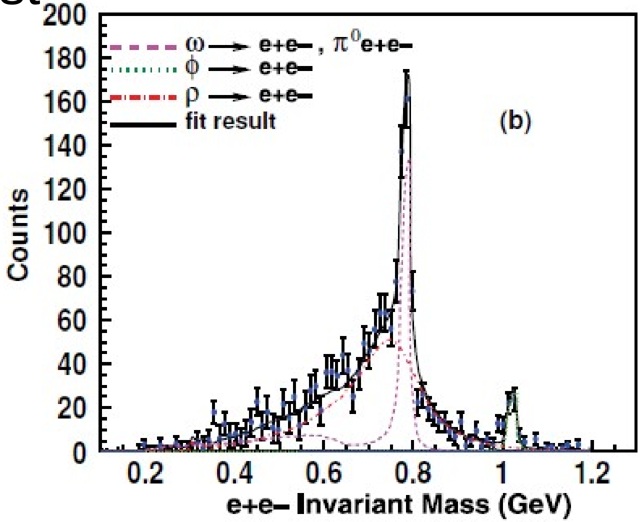


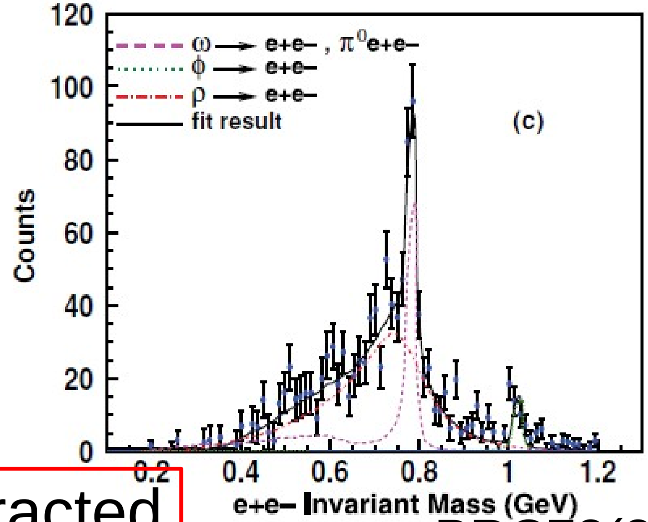
- Excess in the slow component in the p+Nb data

CLAS-G7(PRC78(2008)015201)

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

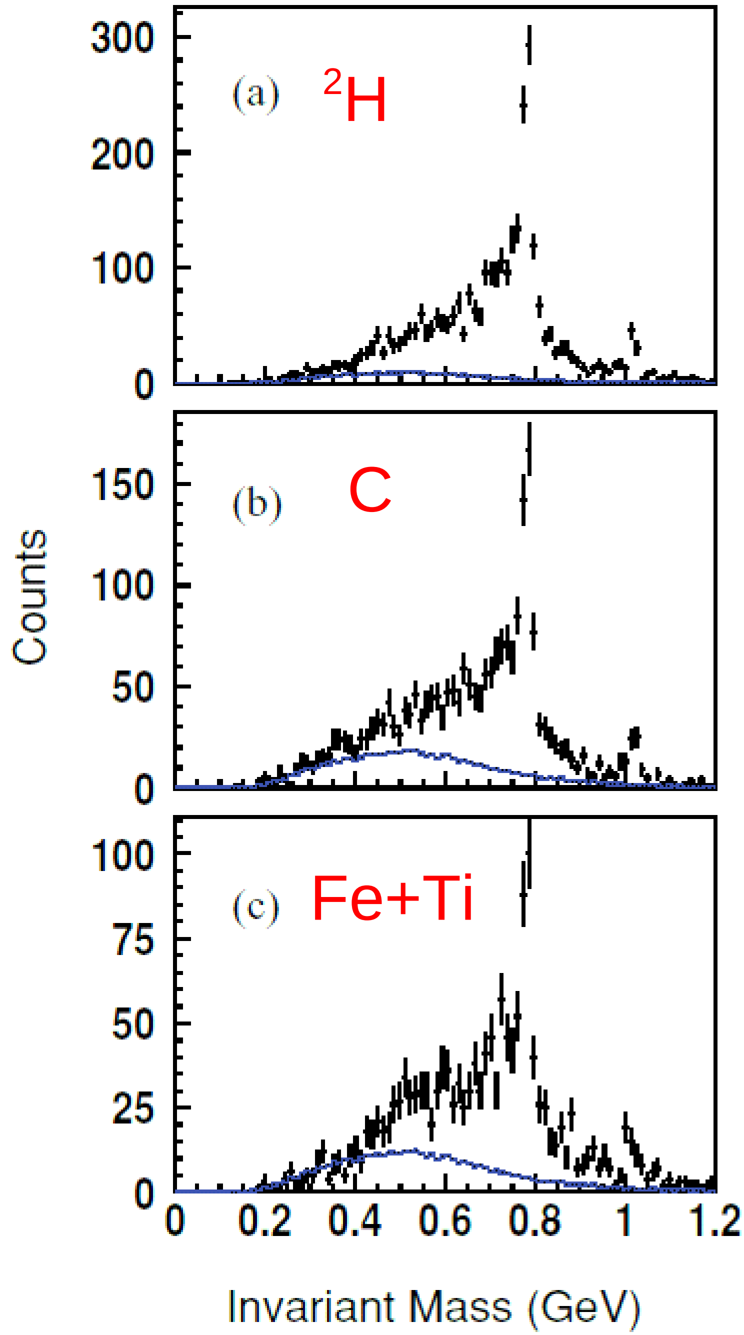






BKG subtracted

PRC78(2008)015201

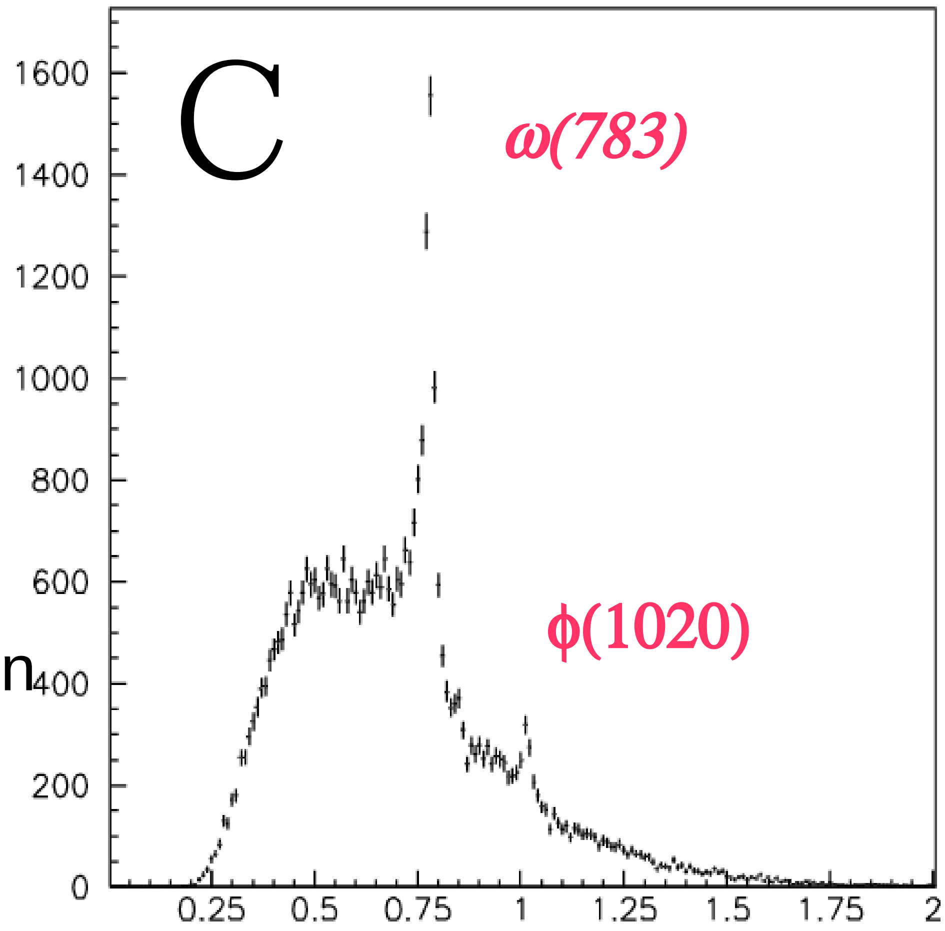


Dilepton spectra measured at KEK-PS E325

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

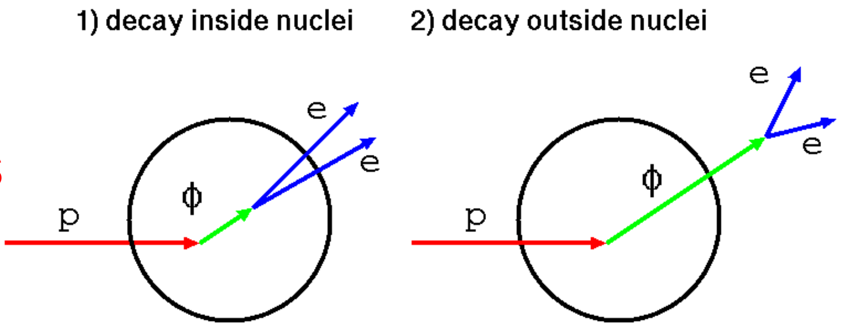
- At the lower energy,
  - better S/N
  - smaller production cross section
  - possibly simpler environment

    (T=0, no time evolution)

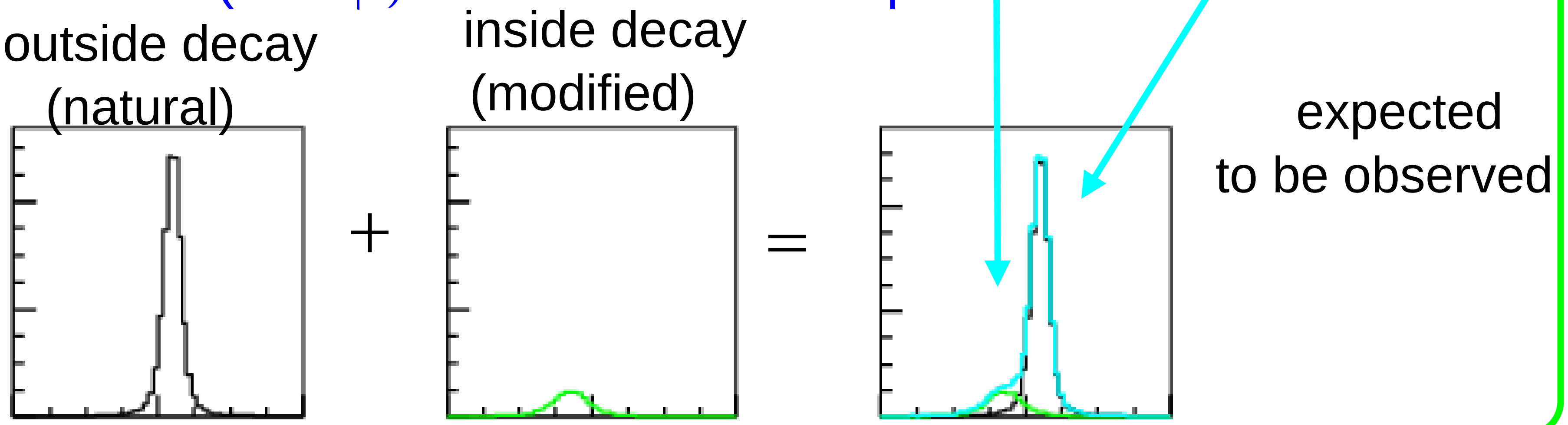


Expected Invariant mass spectra in ee

- 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

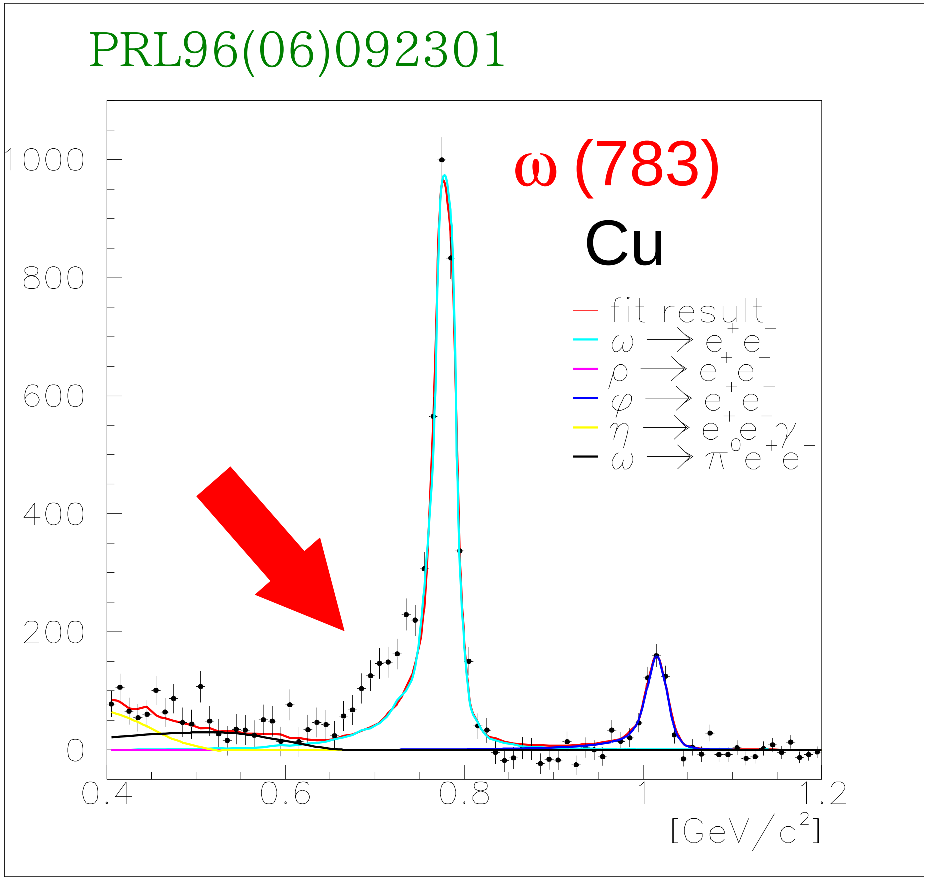


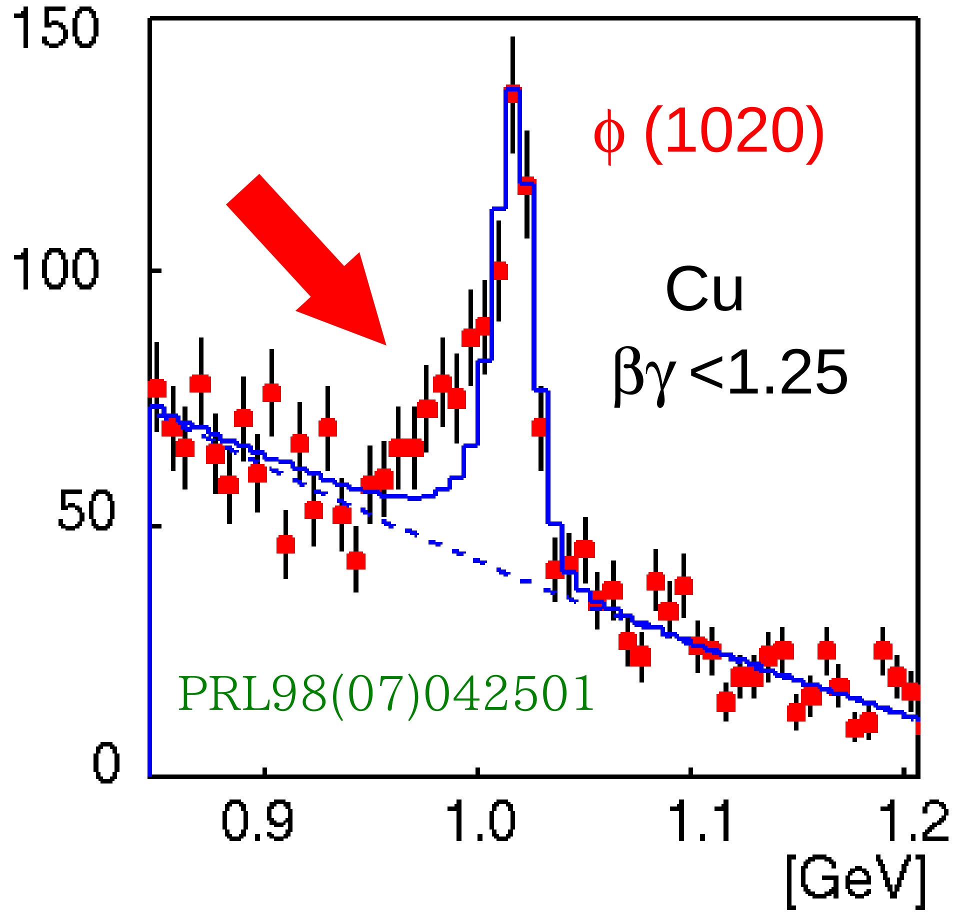
longer-life meson(ω & ϕ)cases : Schematic picture



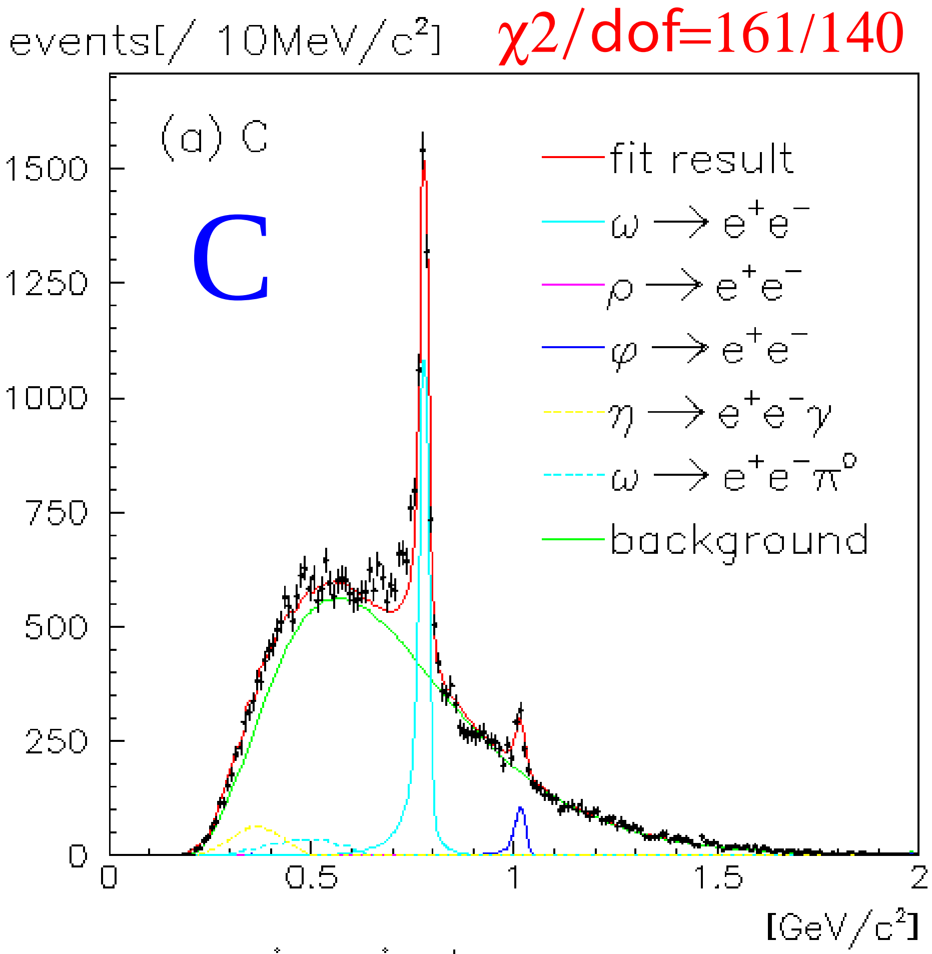
E325 observed the meson modifications

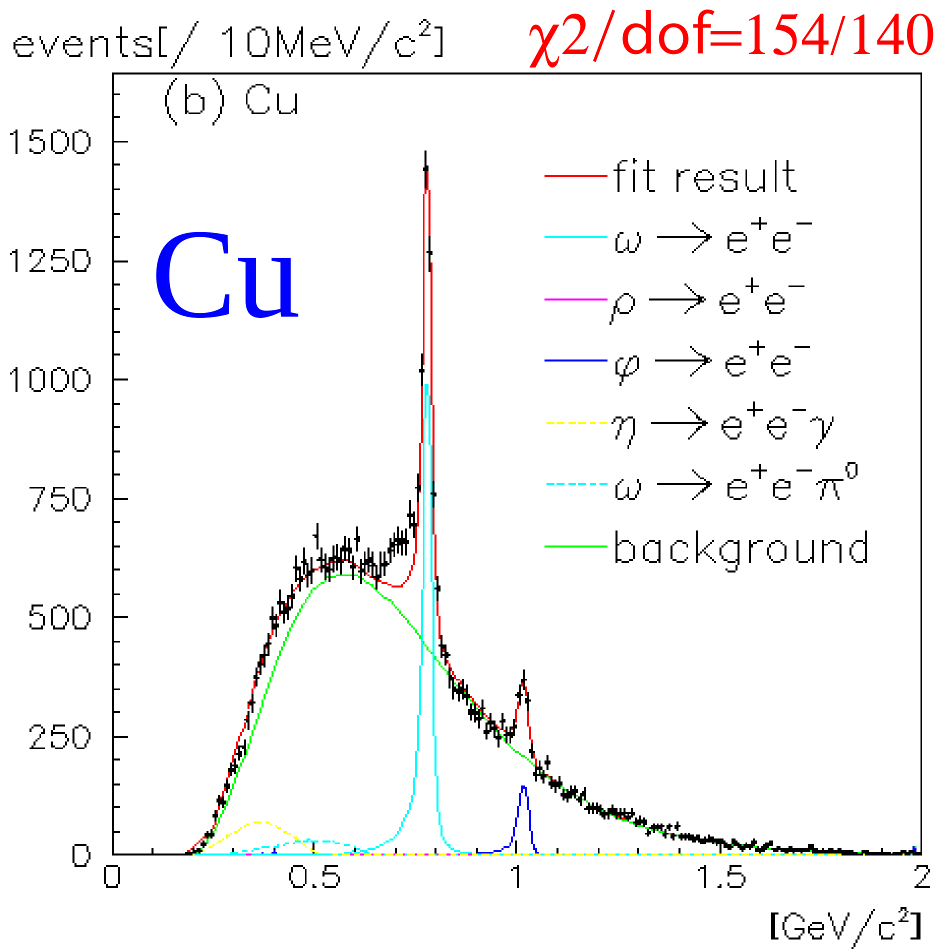
- in the e^+e^- channel
- below the ω and ϕ, statistically significant excesses over the known hadronic sources including experimental effects





Fitting results (ρ/ω)





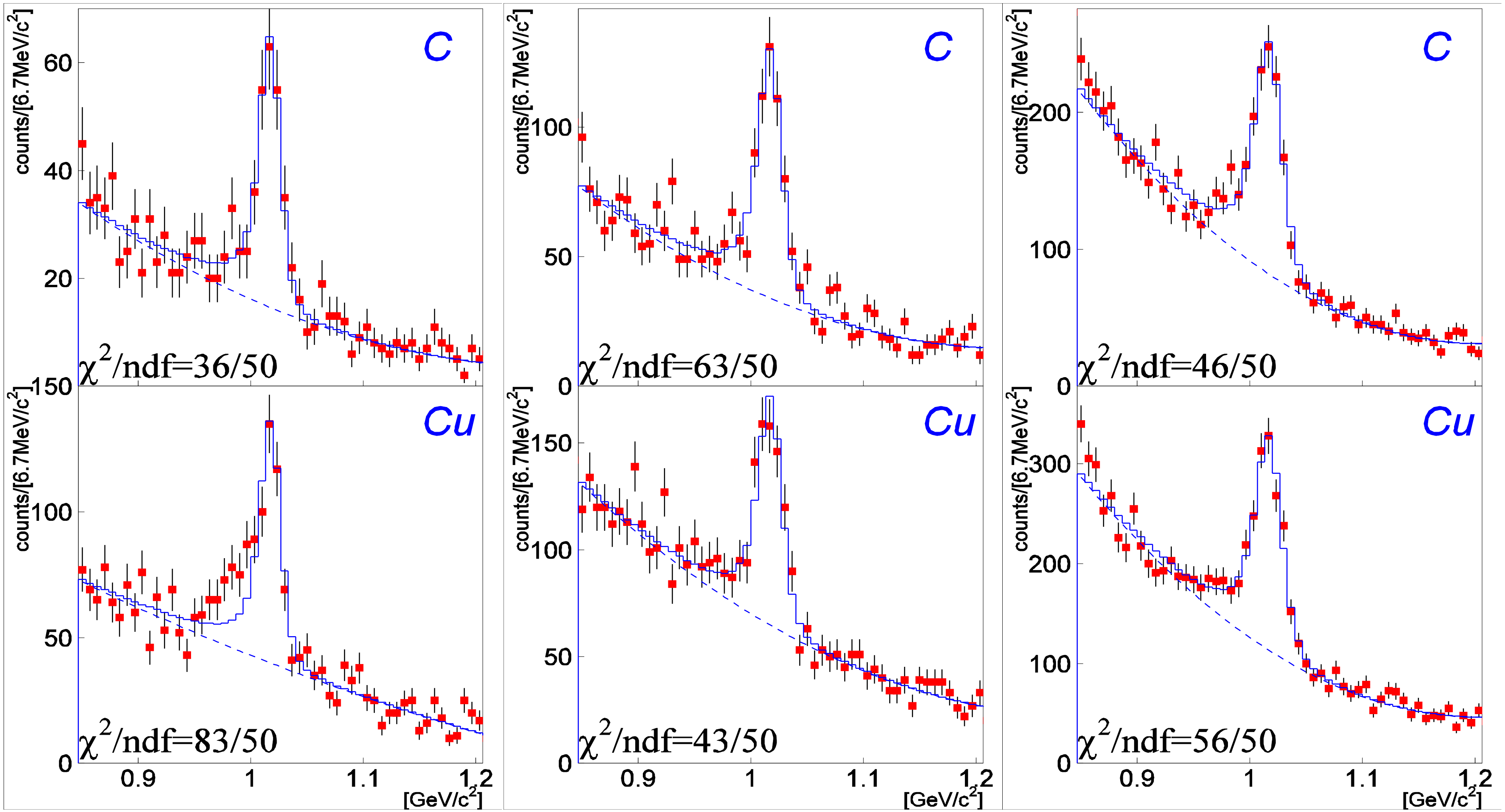
1) excess at the low-mass side of ω

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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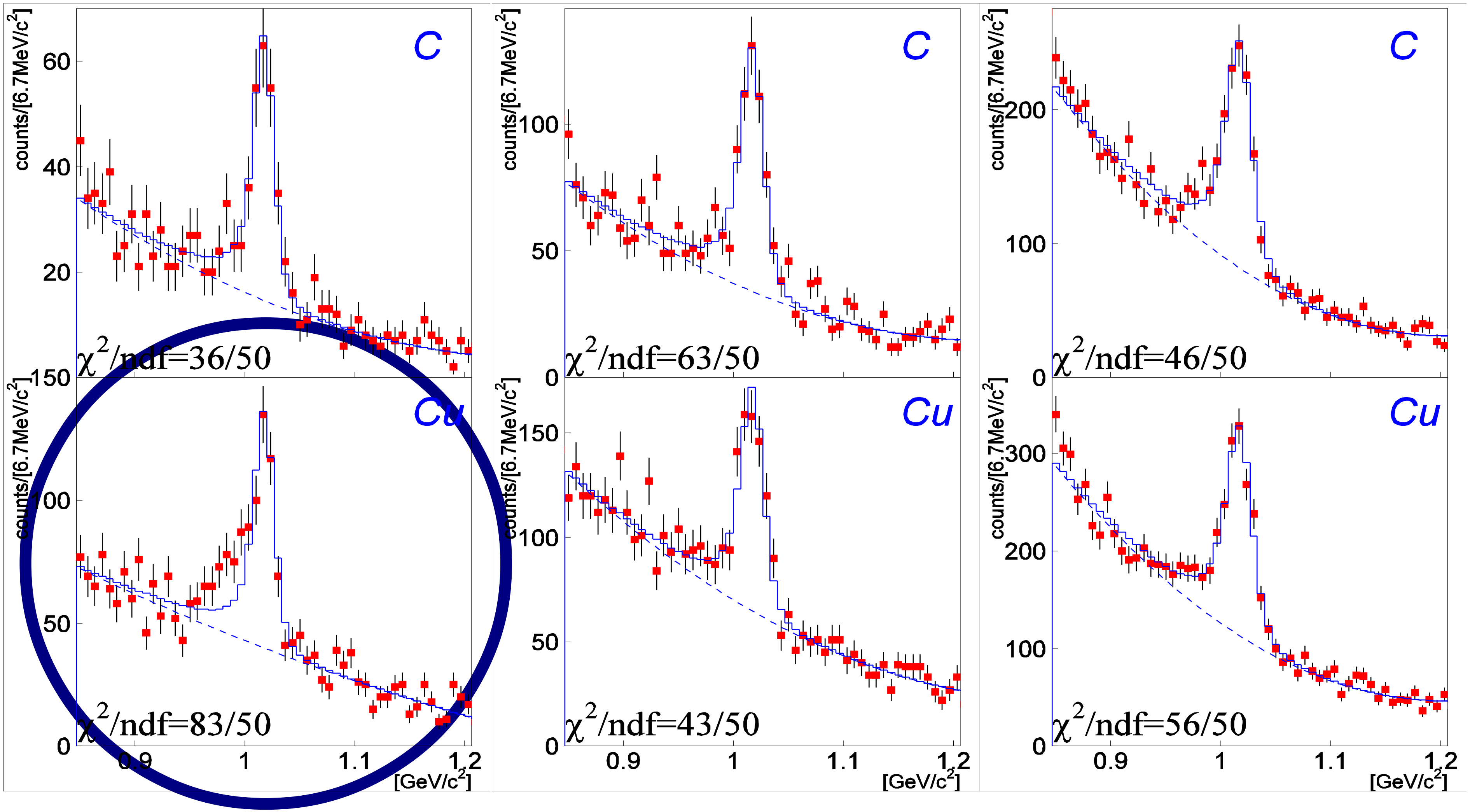
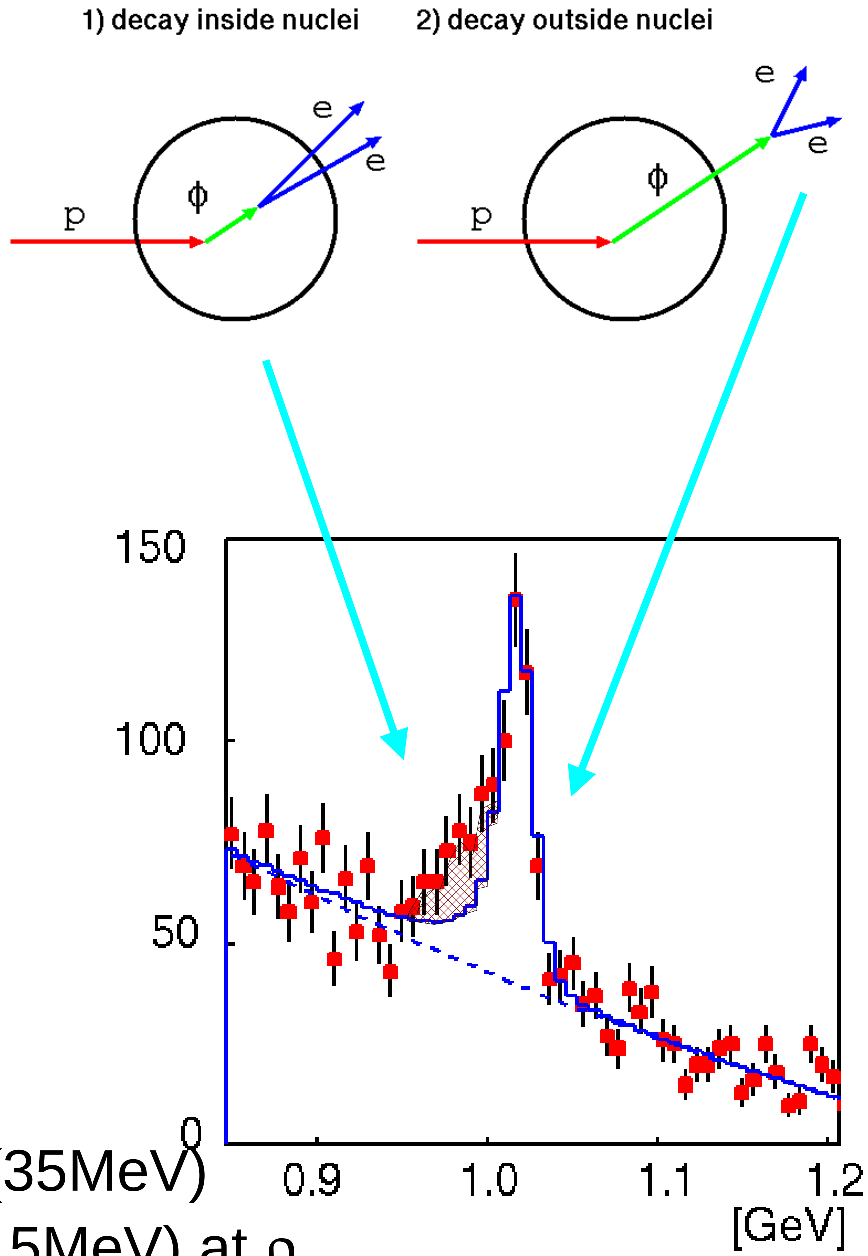


only slow/Cu is not reproduced in 99% C.L.

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)



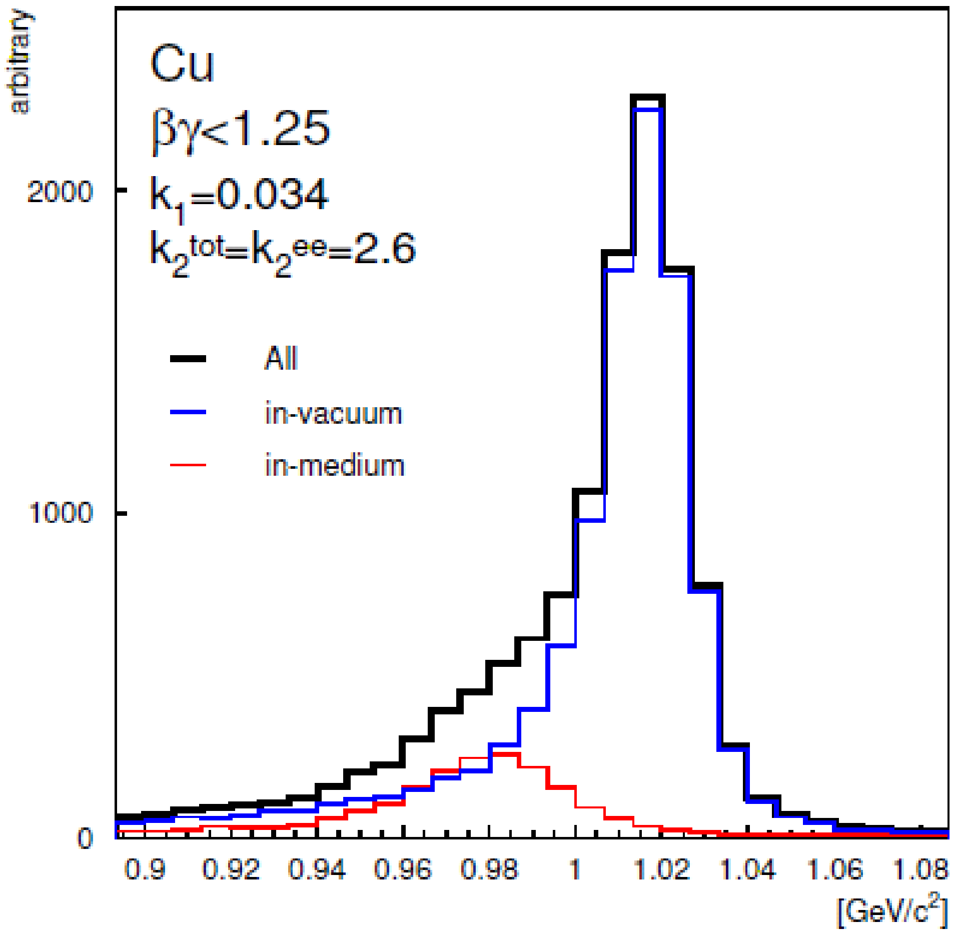
$$k_1 = 0.034^{+0.006}_{-0.007}$$

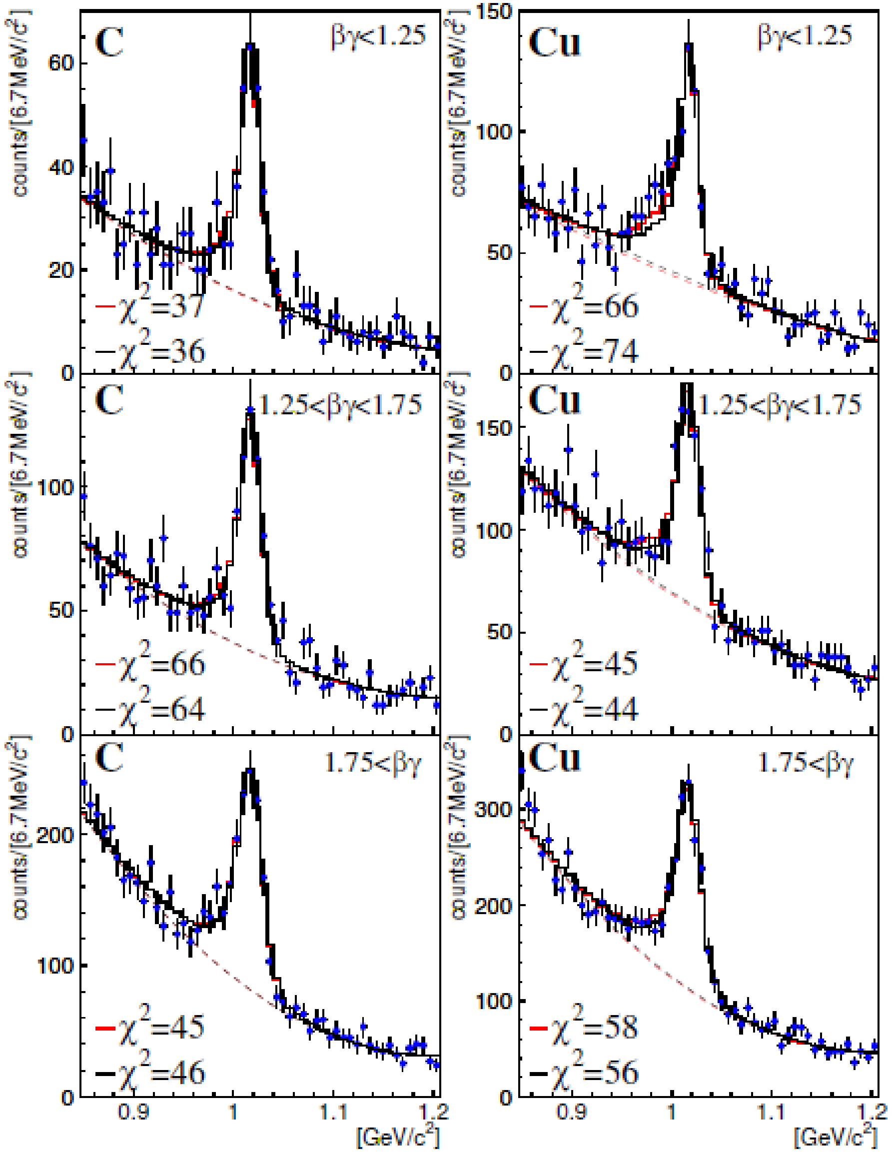
$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$

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

Modified shape of ϕ

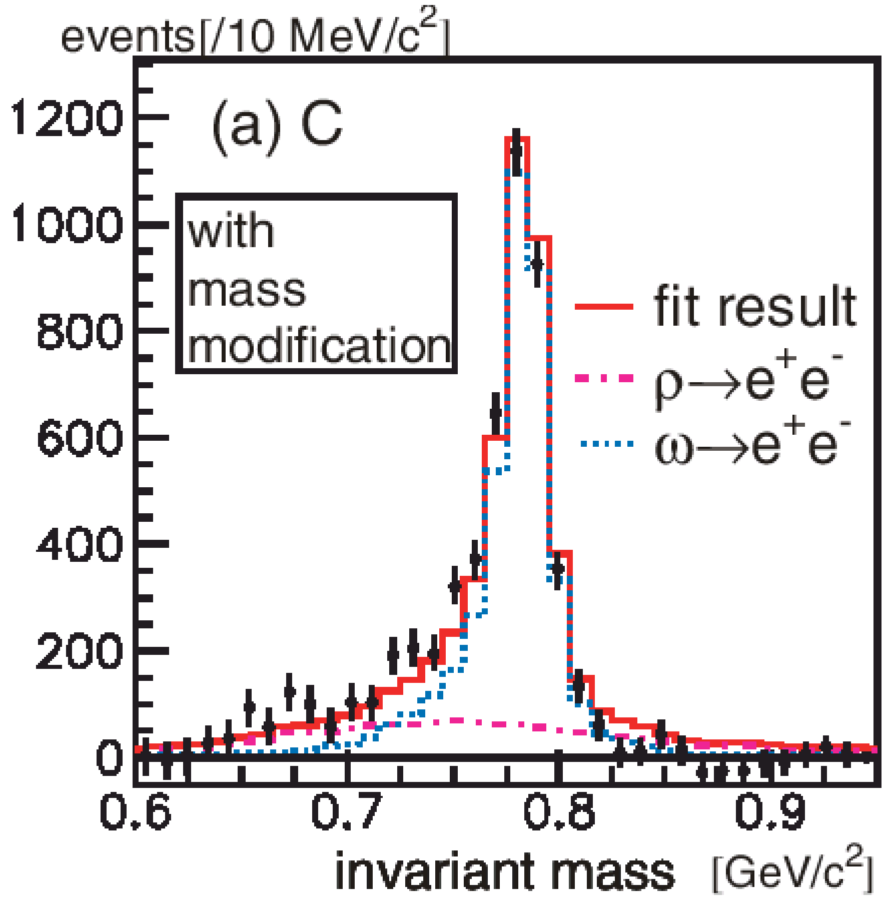
- Cu, $\beta\gamma < 1.25$,
- best fit values of k_1 and k_2

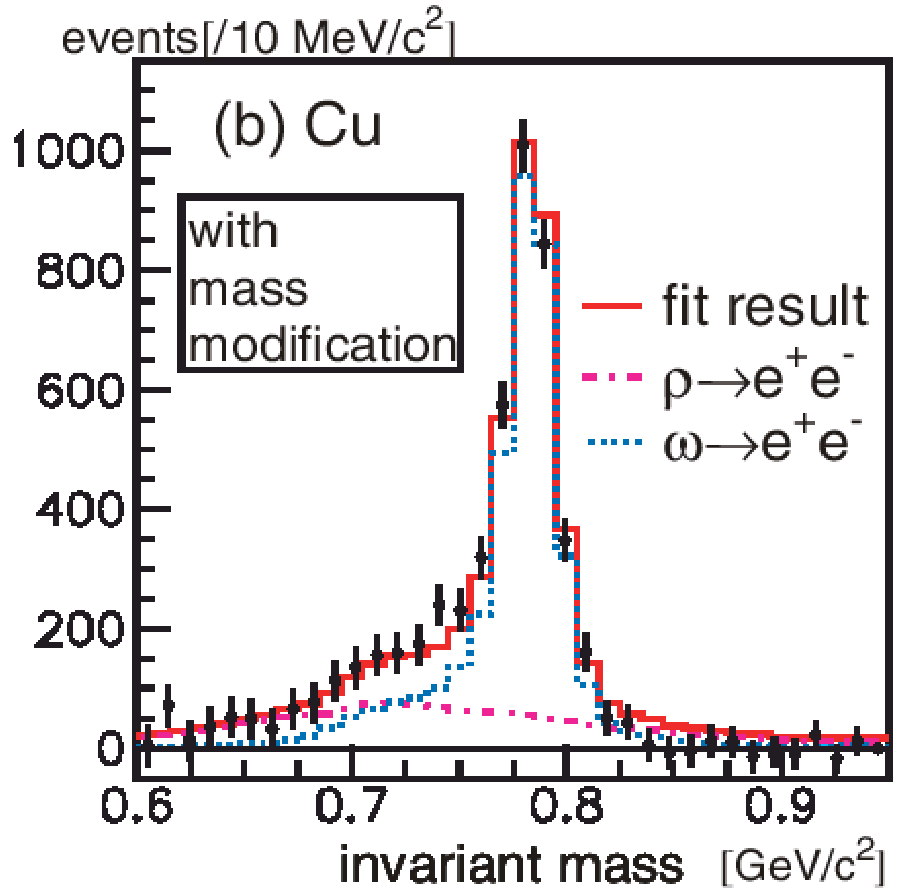




Discussion (ρ/ω)

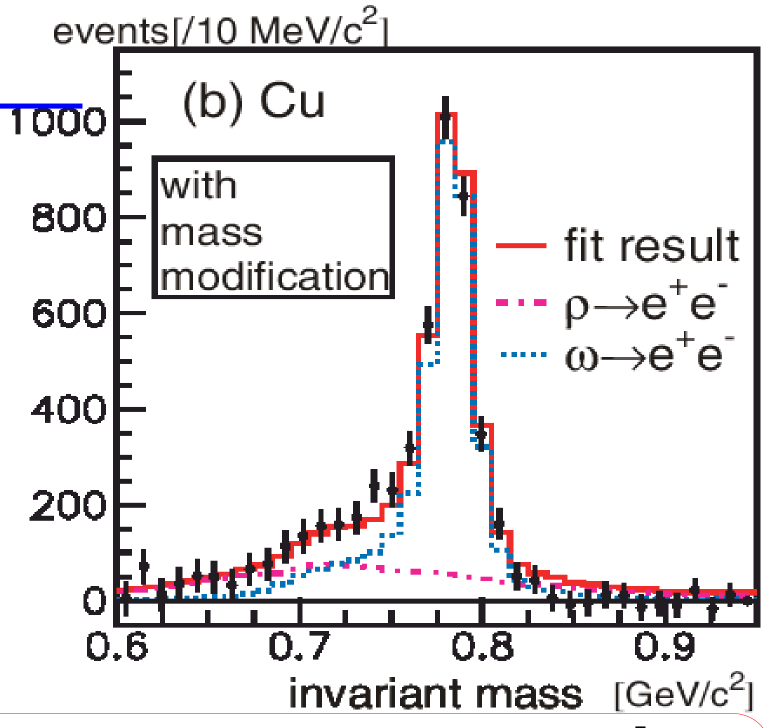
Free param.: - scales of background and hadron components for each C & Cu
- modification parameter k for ρ and ω is common to C & Cu



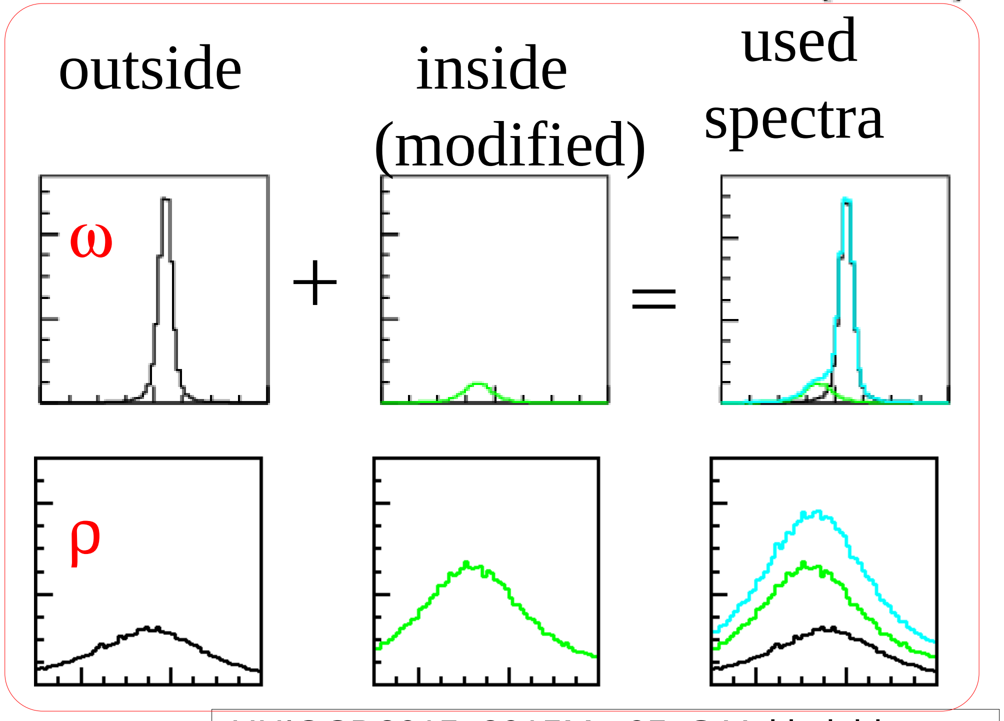


From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density
ρ/ω production ratio : 0.7± 0.1 (C), 0.9±0.2 (Cu) : ... ρ meson returns.
Note: if k_ω is assumed to be 0 (*i.e.* not modified), k_ρ could be smaller.

Remark on the model fitting



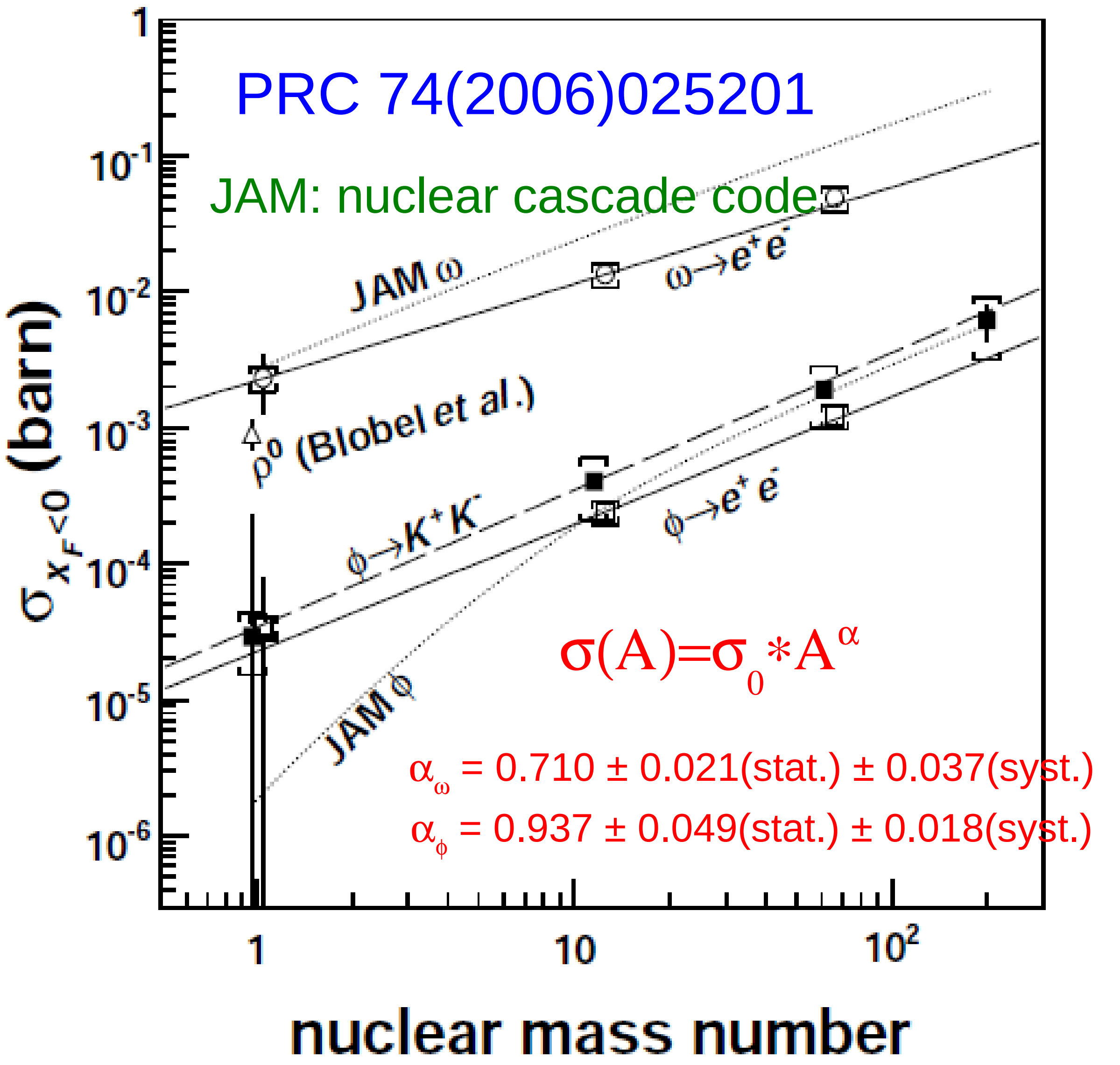
- constraint at right side of peak
  - Introducing the width broadening (x2 & x3) are rejected by this constraint
  - prediction of ' ρ mass increasing' is also not allowed.
- ρ (ω) decay inside nucleus : 46%(5%) for C, 61%(10%) for Cu
  - used spectrum is the sum of the modified and not-modified components.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

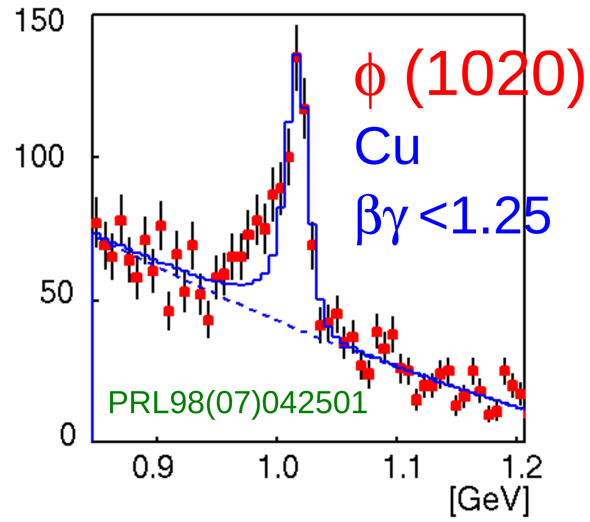
  Γ_ϕ=15MeV at m_ϕ=985MeV is consistent with Oset & Ramos (NPA679(2001)616)



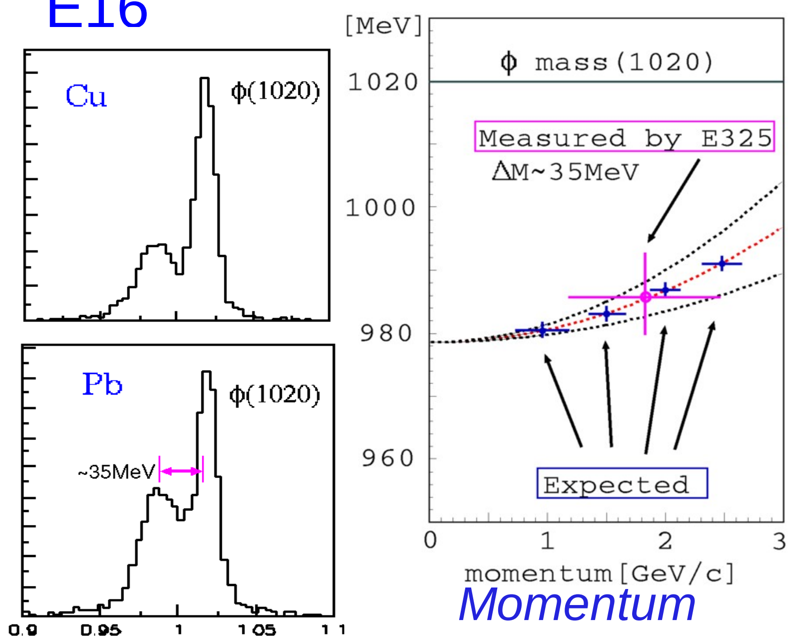
J-PARC E16

- 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 ϕ/ρ/ω 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

Precedent exp. E325



E16

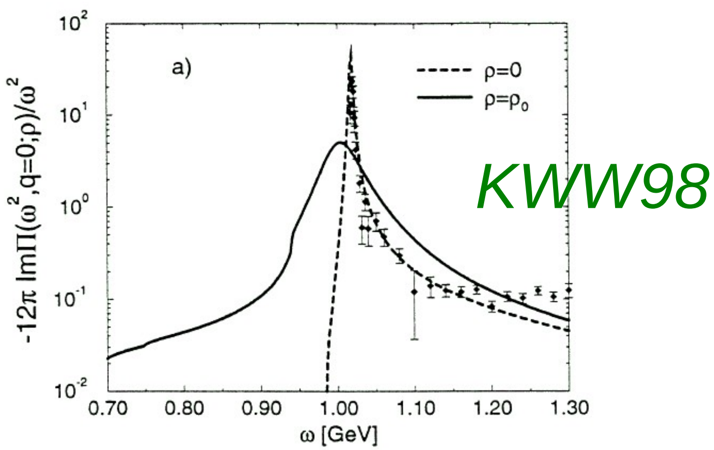


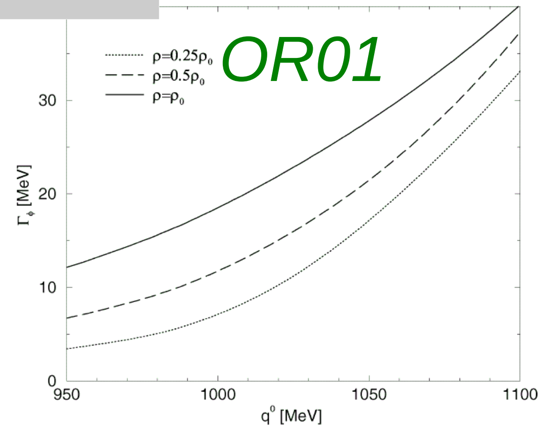
Nuclear dependence *Momentum dependence*

theory: spectral modification of ϕ at ρ_0

parametrize the predicted spectral change with m & Γ

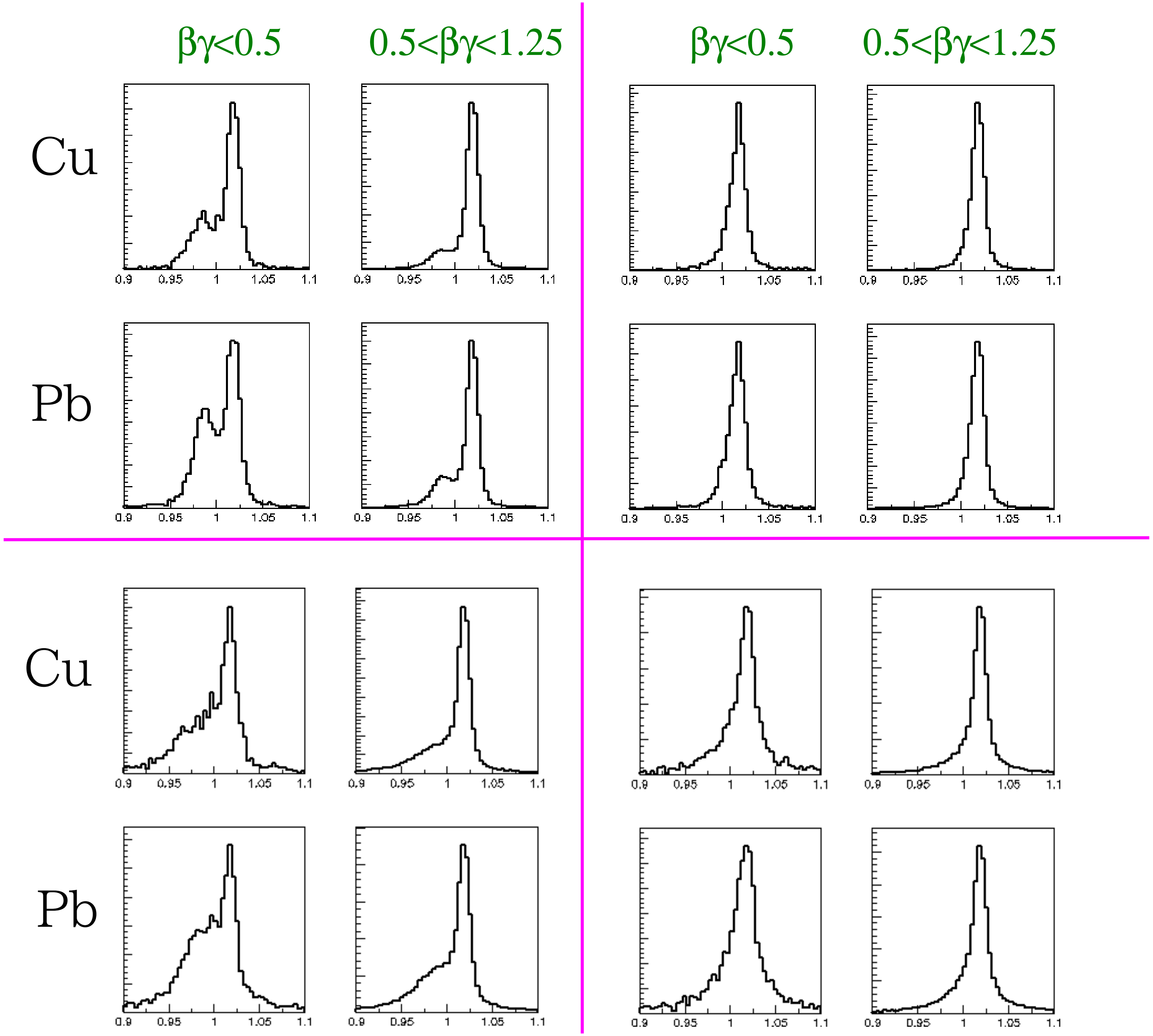
ϕ meson in vacuum	m = 1019.456 MeV	Γ= 4.26 MeV
KEK-PS E325 experiment PRL 98 (2007) 042501	Δm = –35(28~41) MeV	15 (10~23) MeV
Hatsuda & Lee PRC 46 (1992) R34	Δm = –(12-44)MeV	not estimated
Klingl, Waas, Weise PLB 431(1998) 254	Δm < – 10MeV	~45 MeV
Oset & Ramos NPA 679 (2001) 616	Δm < – 10MeV	~22 MeV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





expected shape w/ various parameters

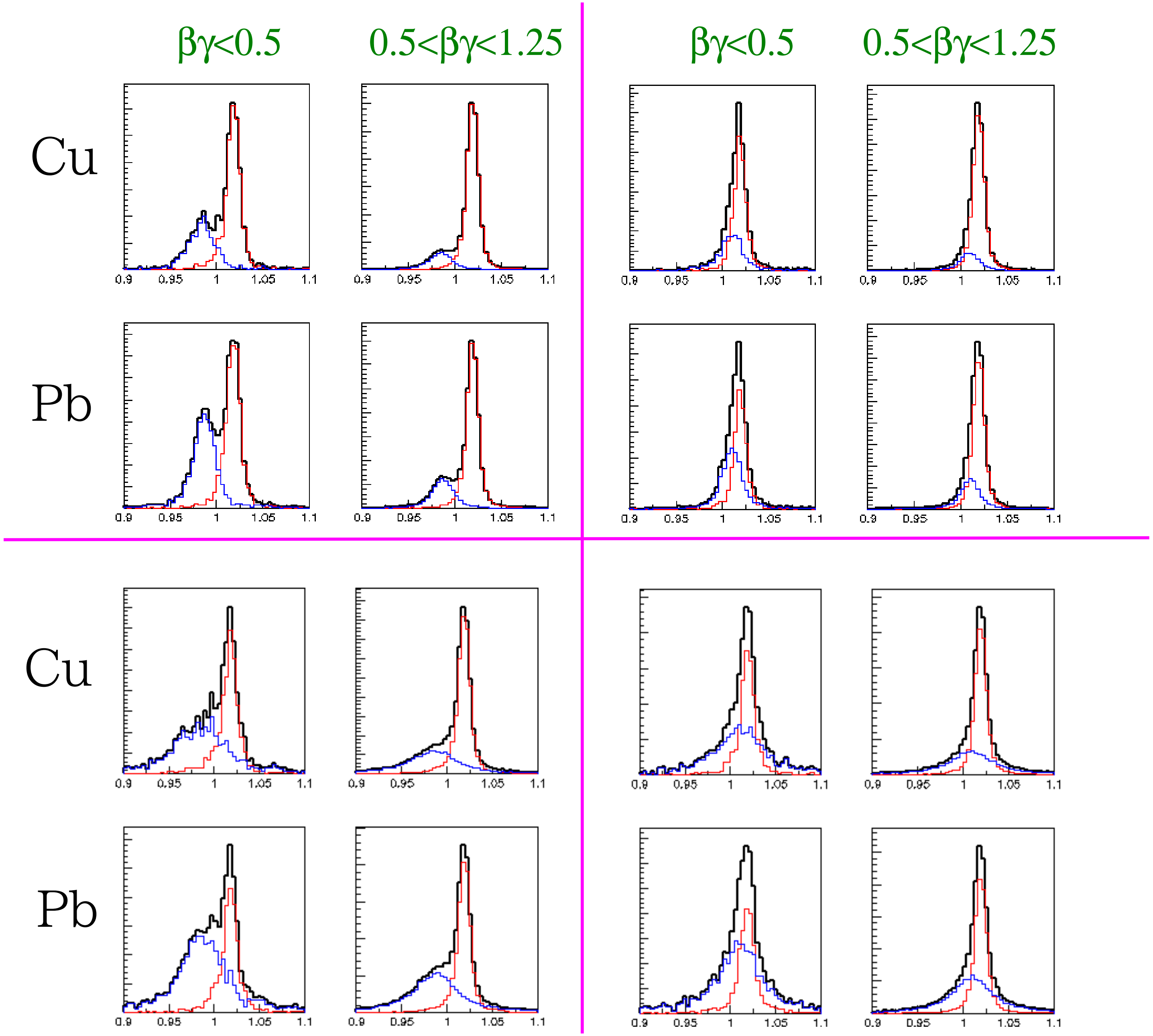
E325	OR-01
Δm : −35 MeV Γ : 15 MeV	Δm : −10 MeV Γ : 15 MeV
-	**KWW-98**
Δm : −35 MeV Γ : 50 MeV	Δm : −10 MeV Γ : 50 MeV



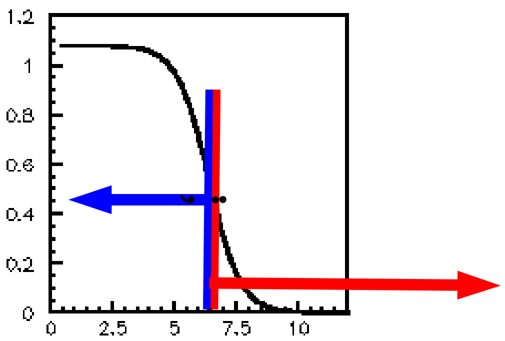
- using the parameters, spectra are approximated with the relativistic Breit-Wigner shape including experimental mass resolution

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

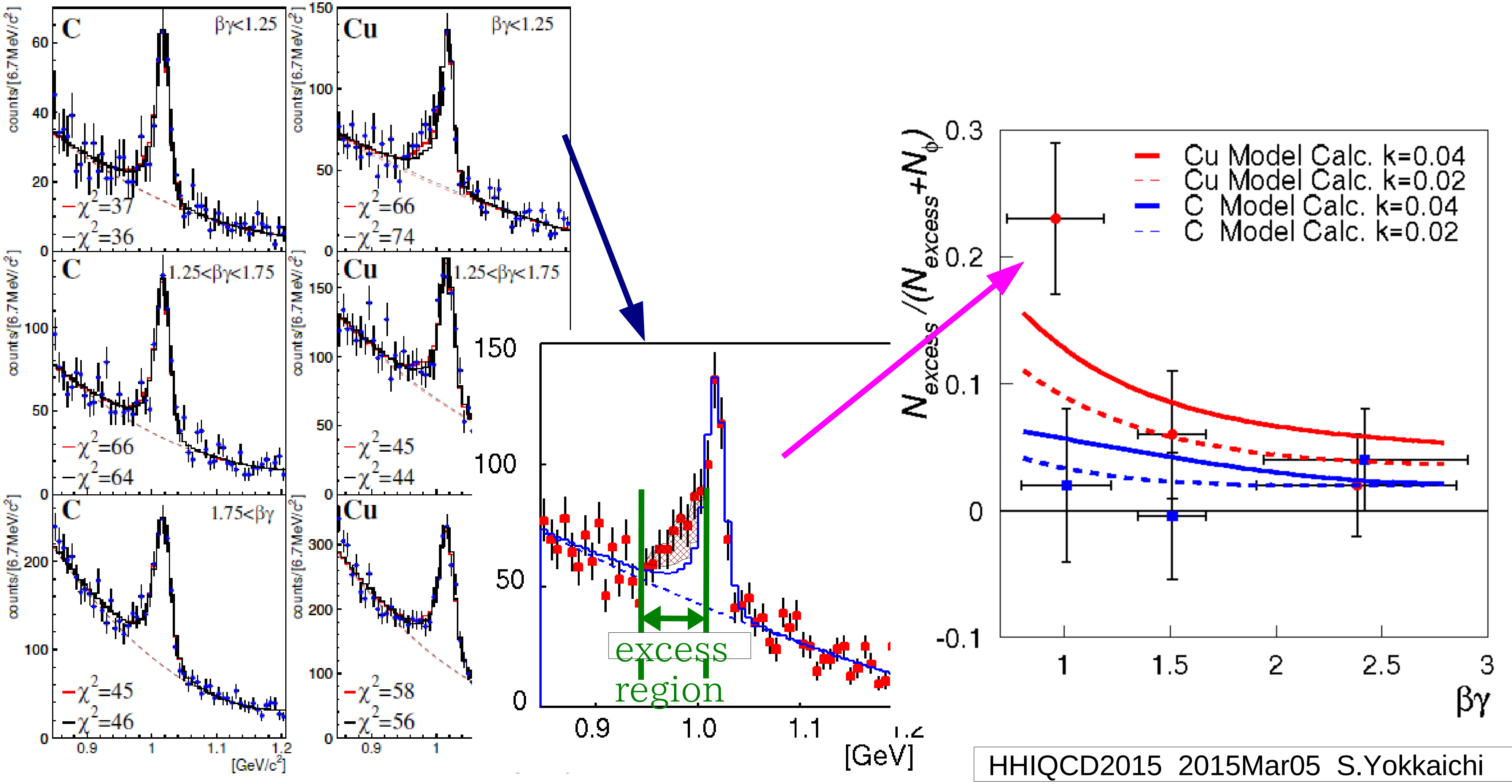


blue: decays inside the half-density radius of nuclei in the MC



velocity and nuclear size dependence

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



velocity and nuclear size dependence

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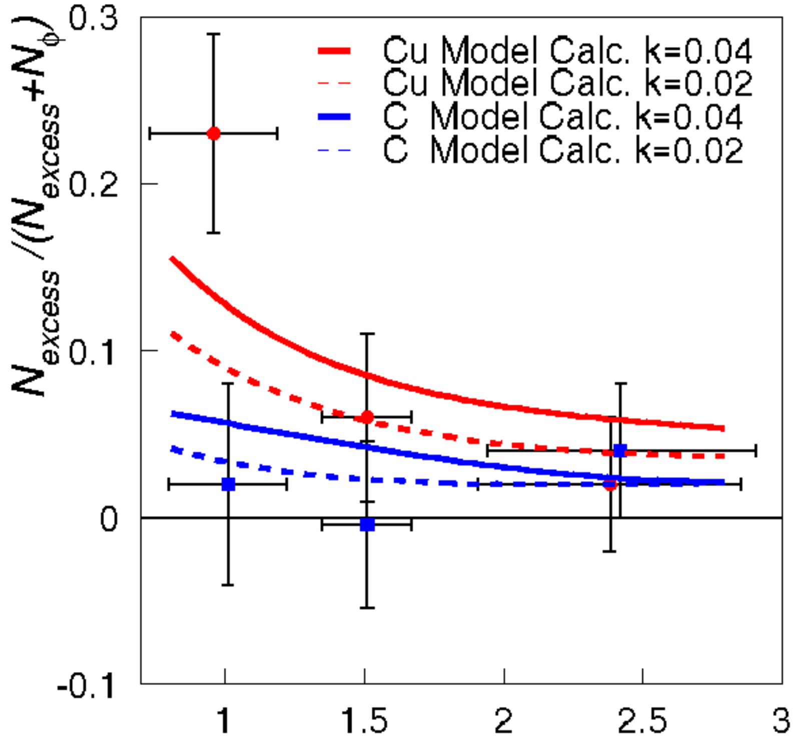
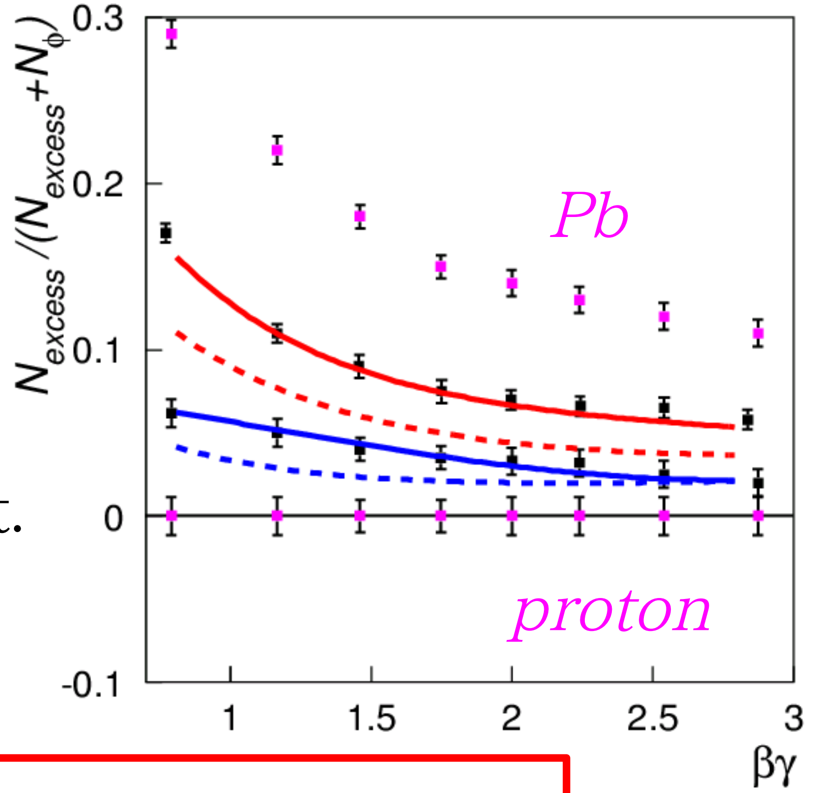
- systematic study : all the data should be explained the interpretation model



x 100 stat.



- establish the modification
-

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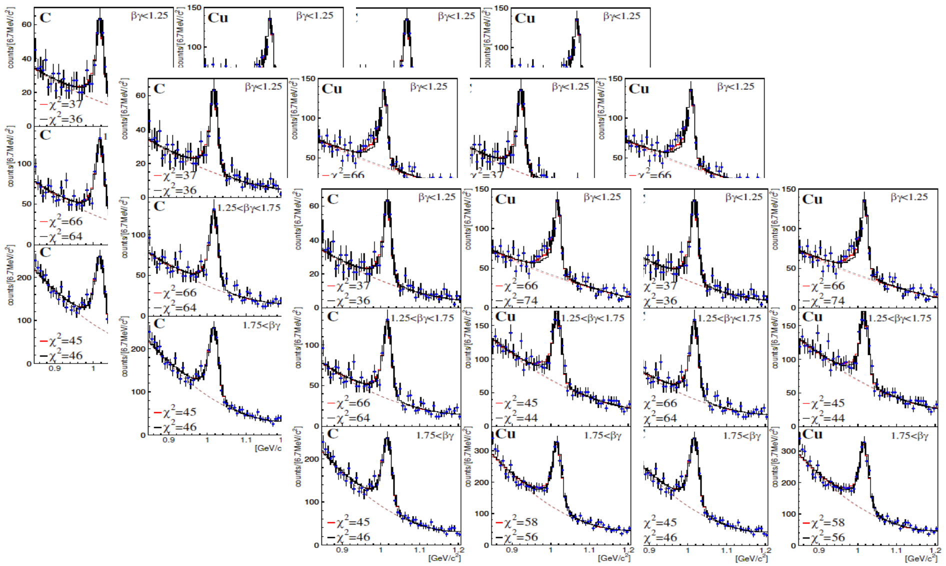
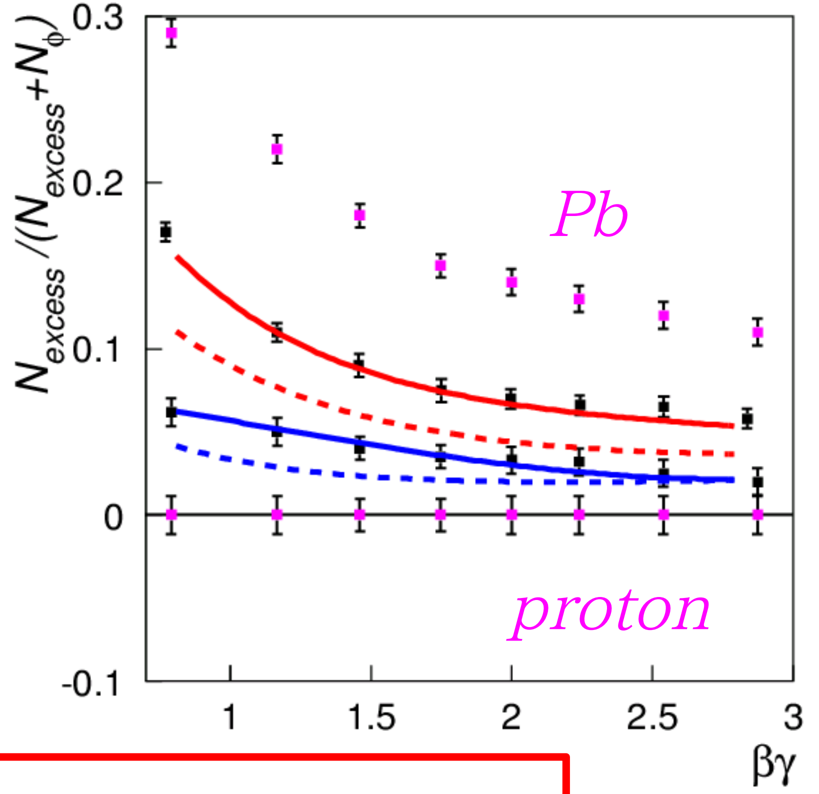
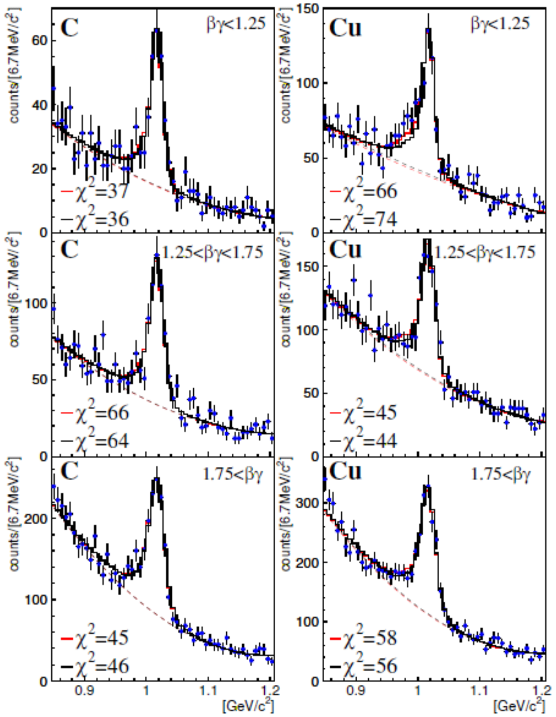


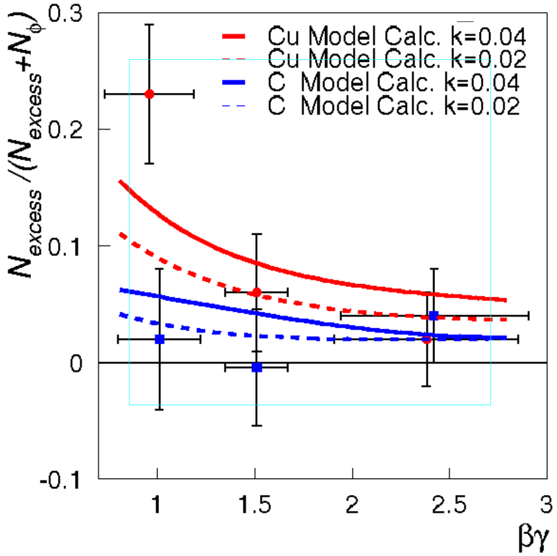


- establish the modification
- check the interpretation model with shape analysis for each histogram

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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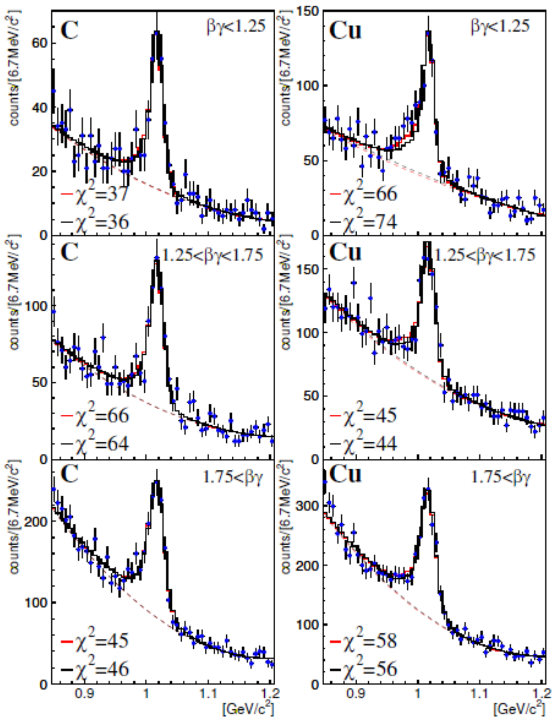
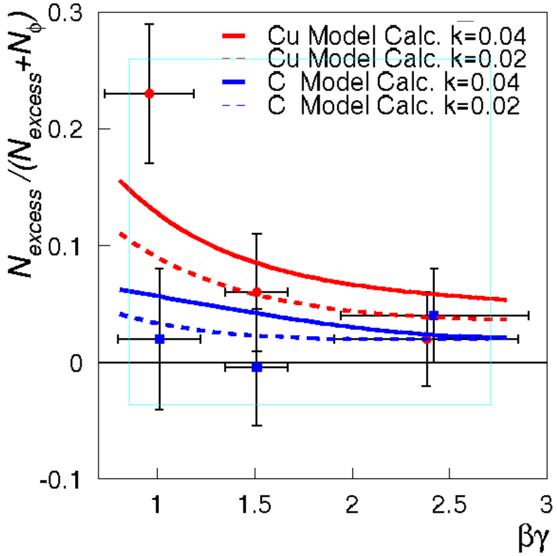
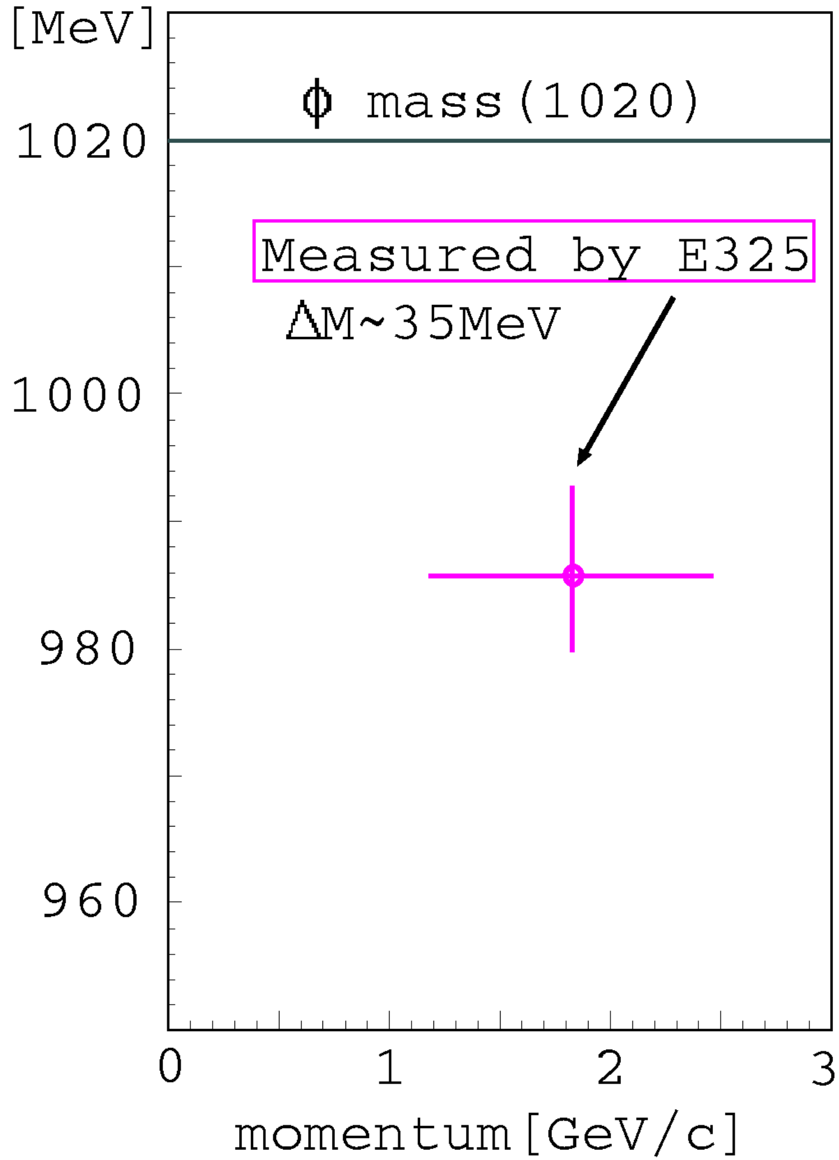
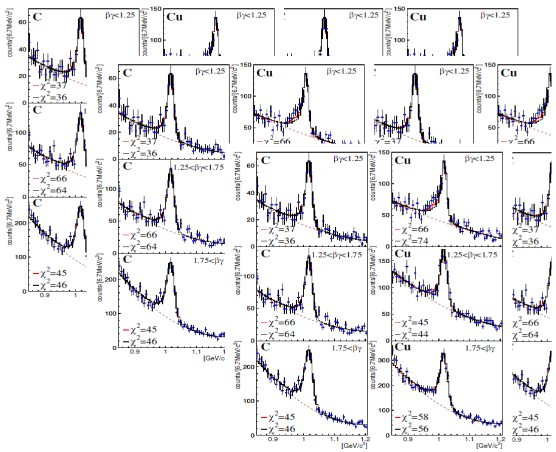


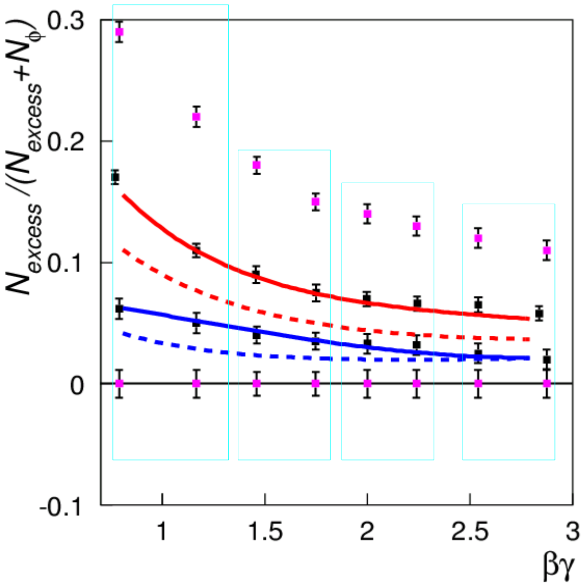


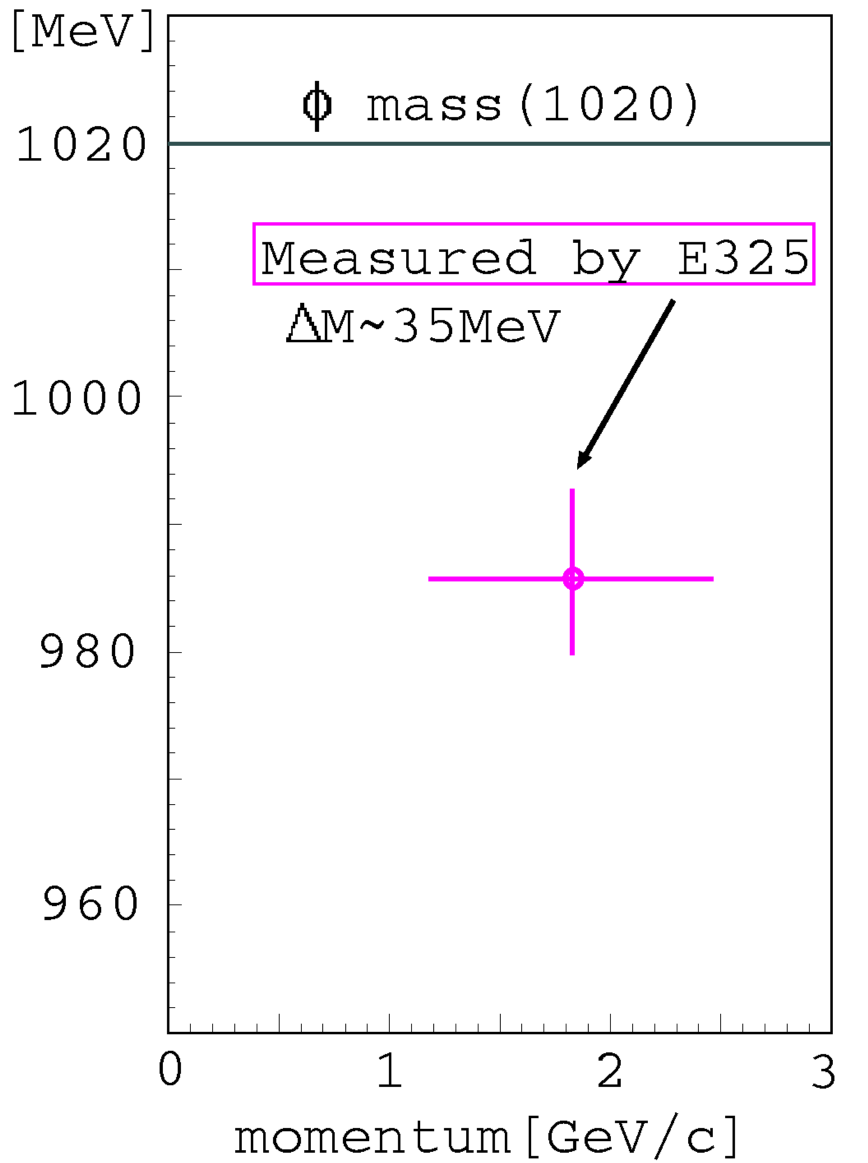


dispersion relation (mass VS momentum)

- 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







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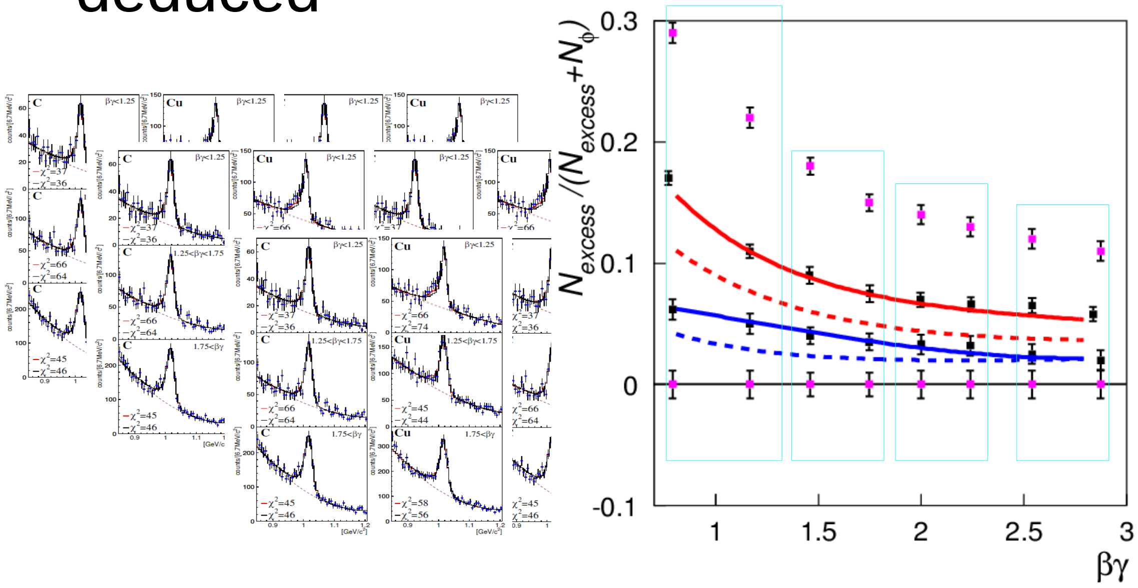
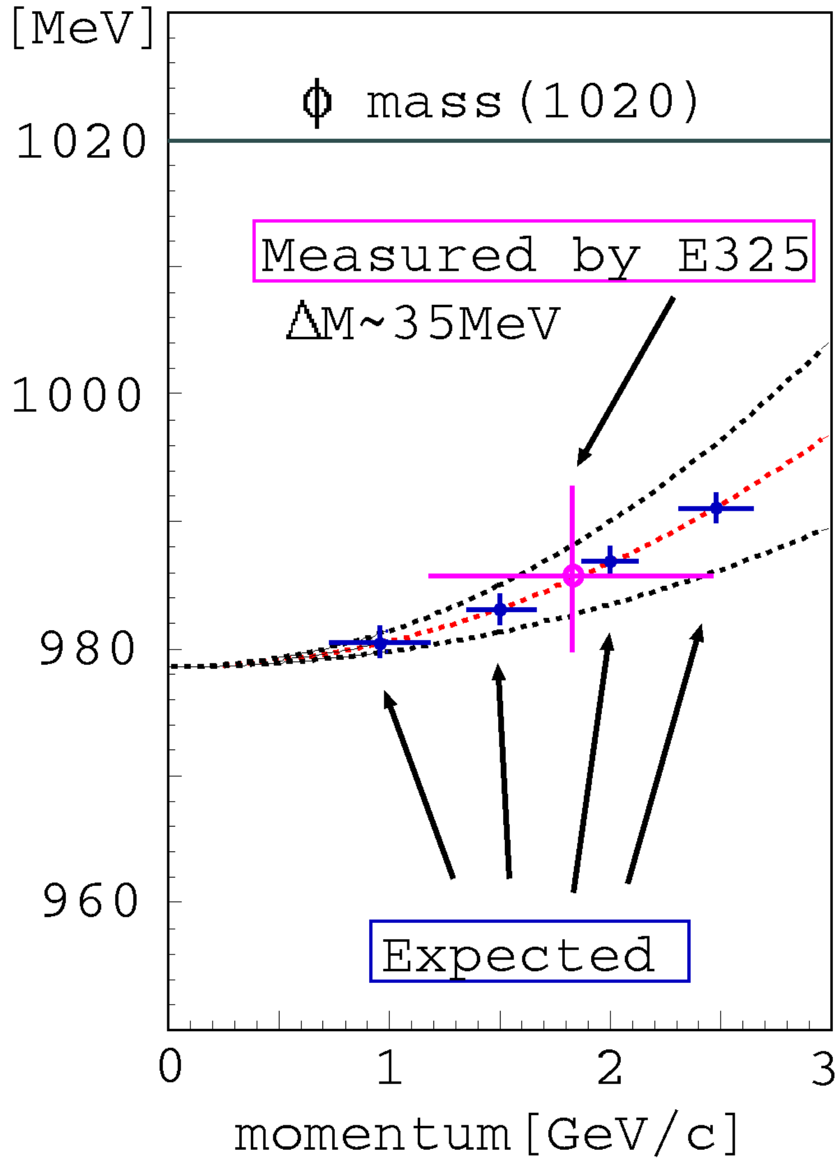
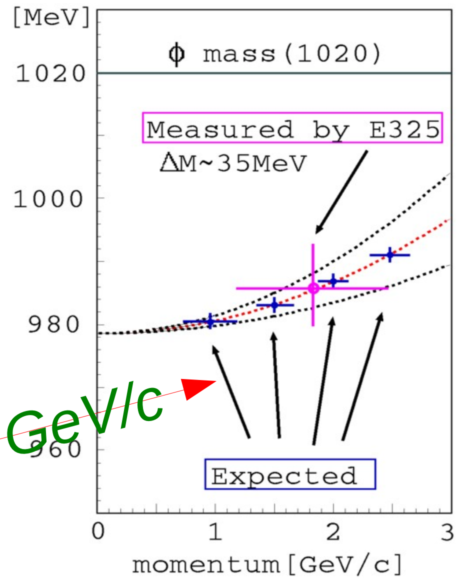


- prediction for ϕ by



momentum dependence

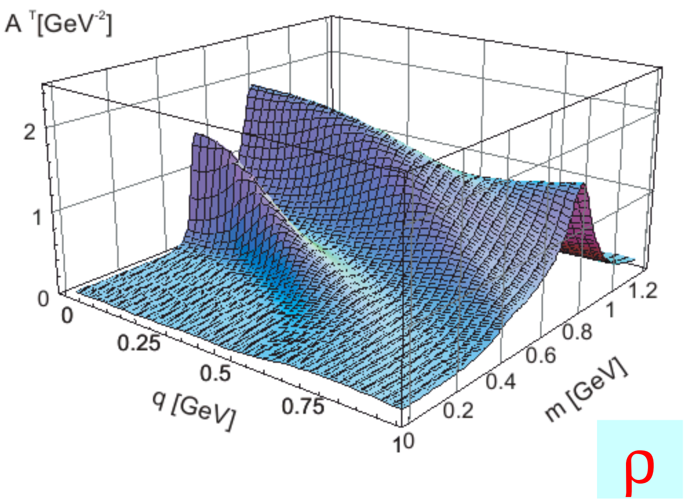
- many predictions are for the mesons at rest (p=0) while measurements are p>0
  - extrapolation to p=0 if it is a simple dependence



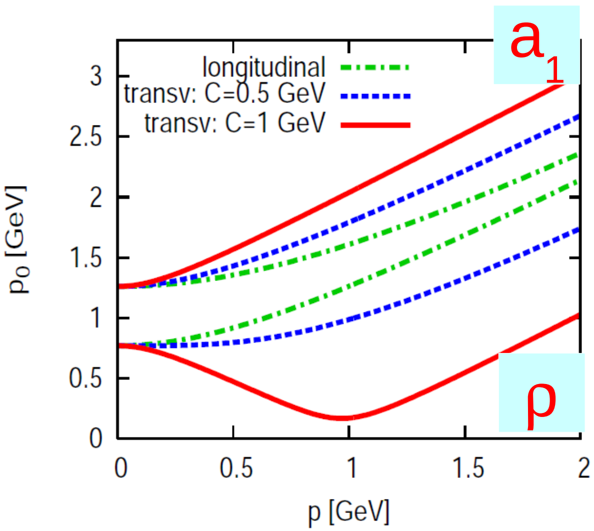
- S.H.Lee (PRC57(98)927) : $m^*/m_0 = 1- k\ \rho/\rho_0$ for p<1GeV/c
  - ρ/ω : $k=0.16\pm0.06+(0.023\pm0.007)(p/0.5)^2$
  - ϕ : $k=0.15(\pm0.05)*y +(0.0005\pm0.0002)(p/0.5)^2$

extraporate to 3 GeV/c

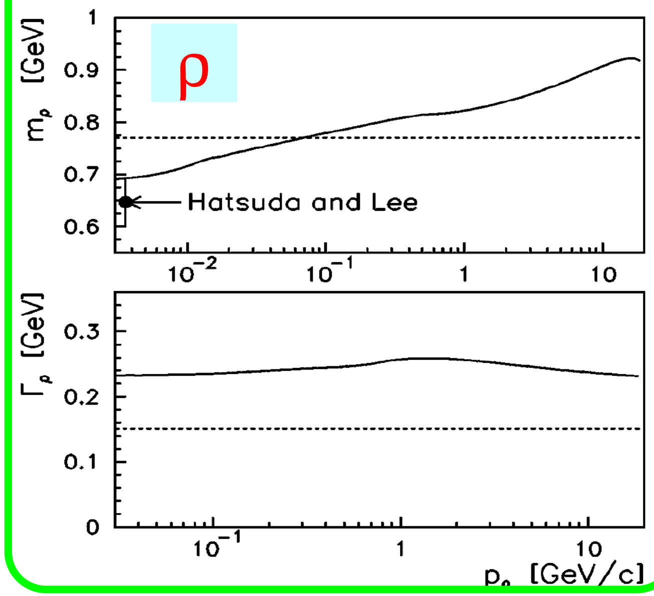
- Post &Mosel (NPA699(02)169)



- Harada & Sasaki (PRC80(09)054912)



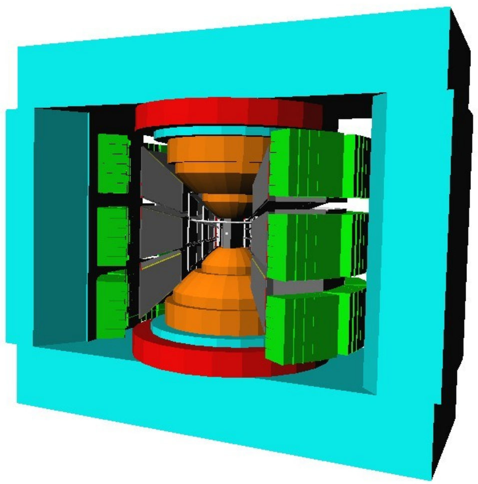
- Kondratyuk et al. (PRC58(98)1078)



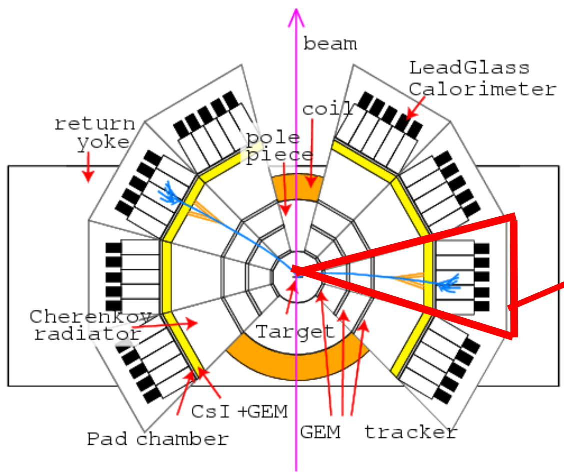
E16 Detectors

- ~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

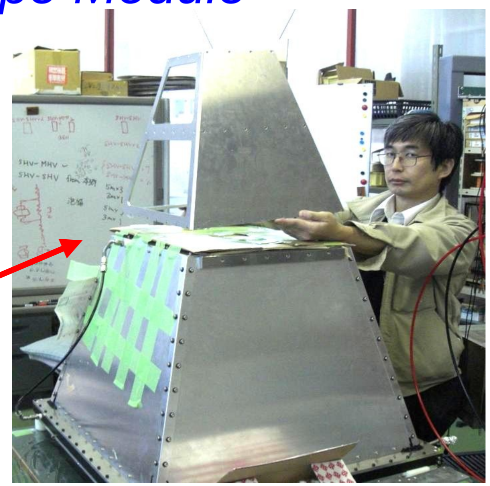
Proposed Spectrometer



Plan View



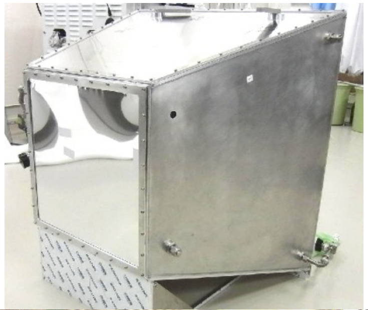
Prototype Module



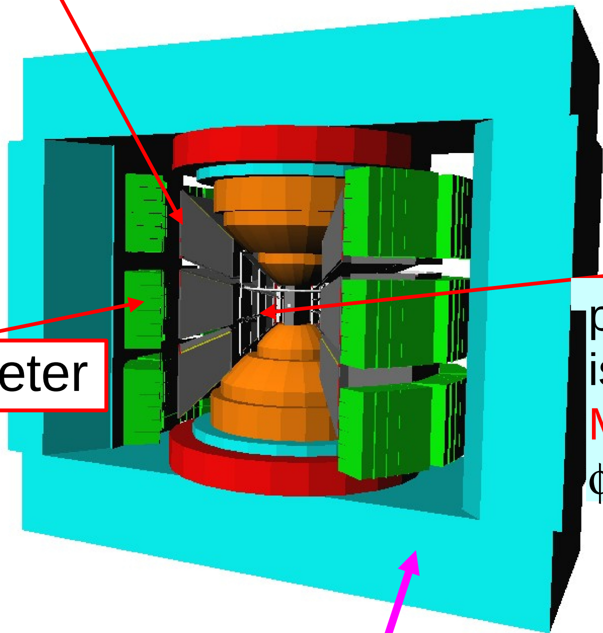
26 detector modules

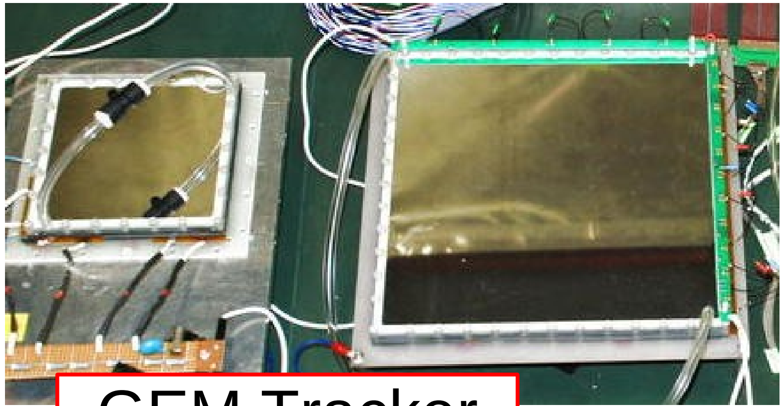
E16 : development & achieved performance

Hadron Blind Cherenkov Detector(HBD)



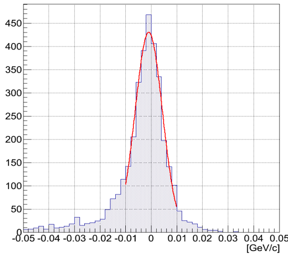
Lead-Glass EM Calorimeter



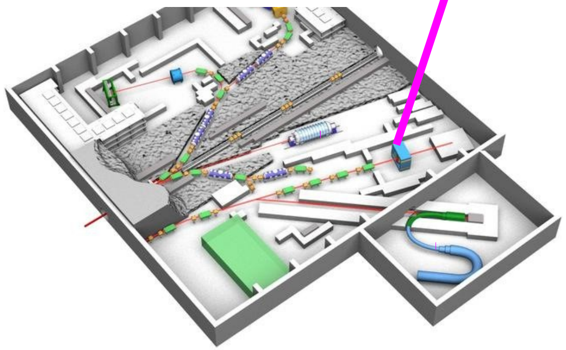


GEM Tracker

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



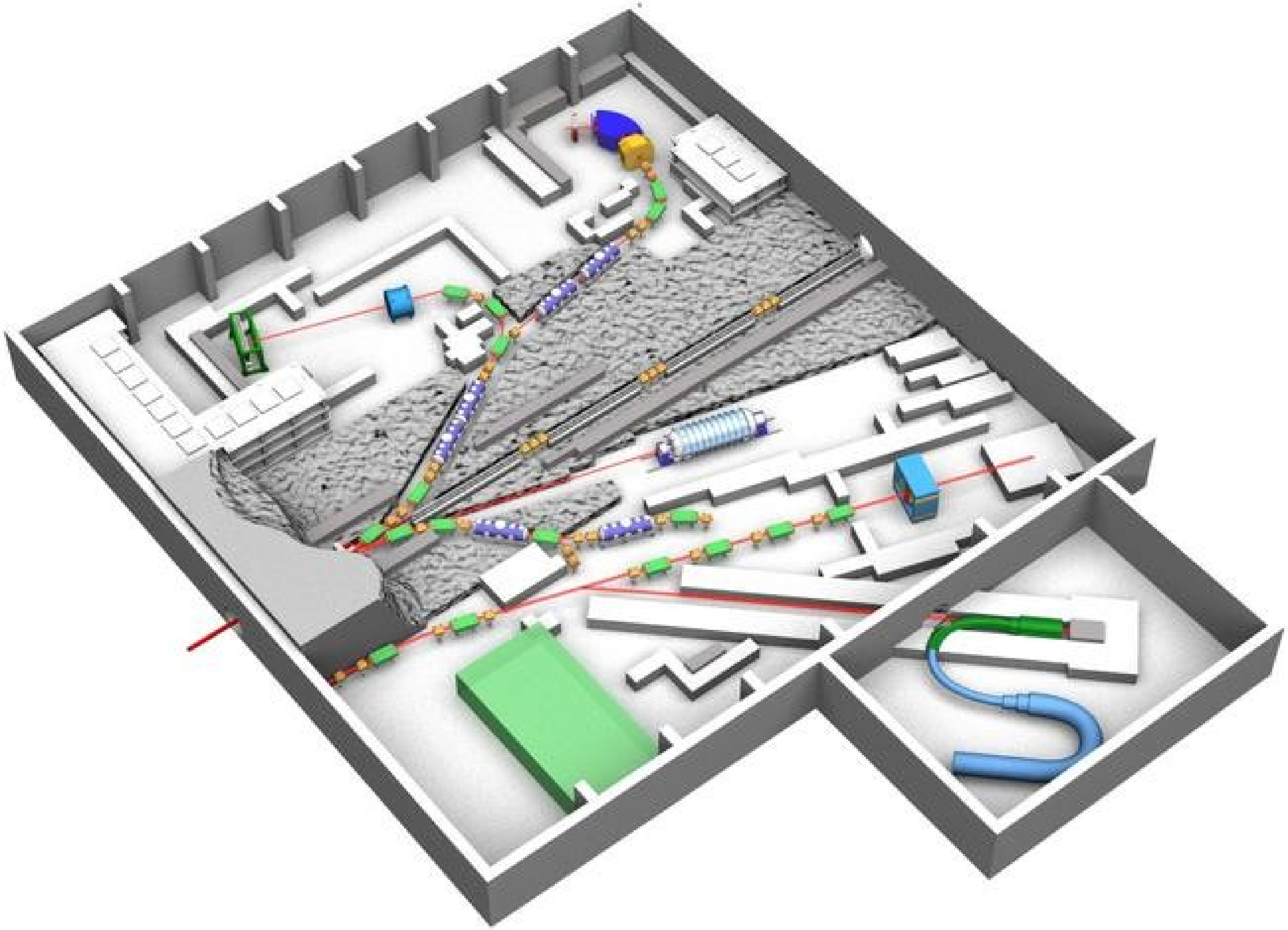
pion suppression down to ~0.1% is achieved with the combination of the two stage of electron-ID counters; HBD & LG



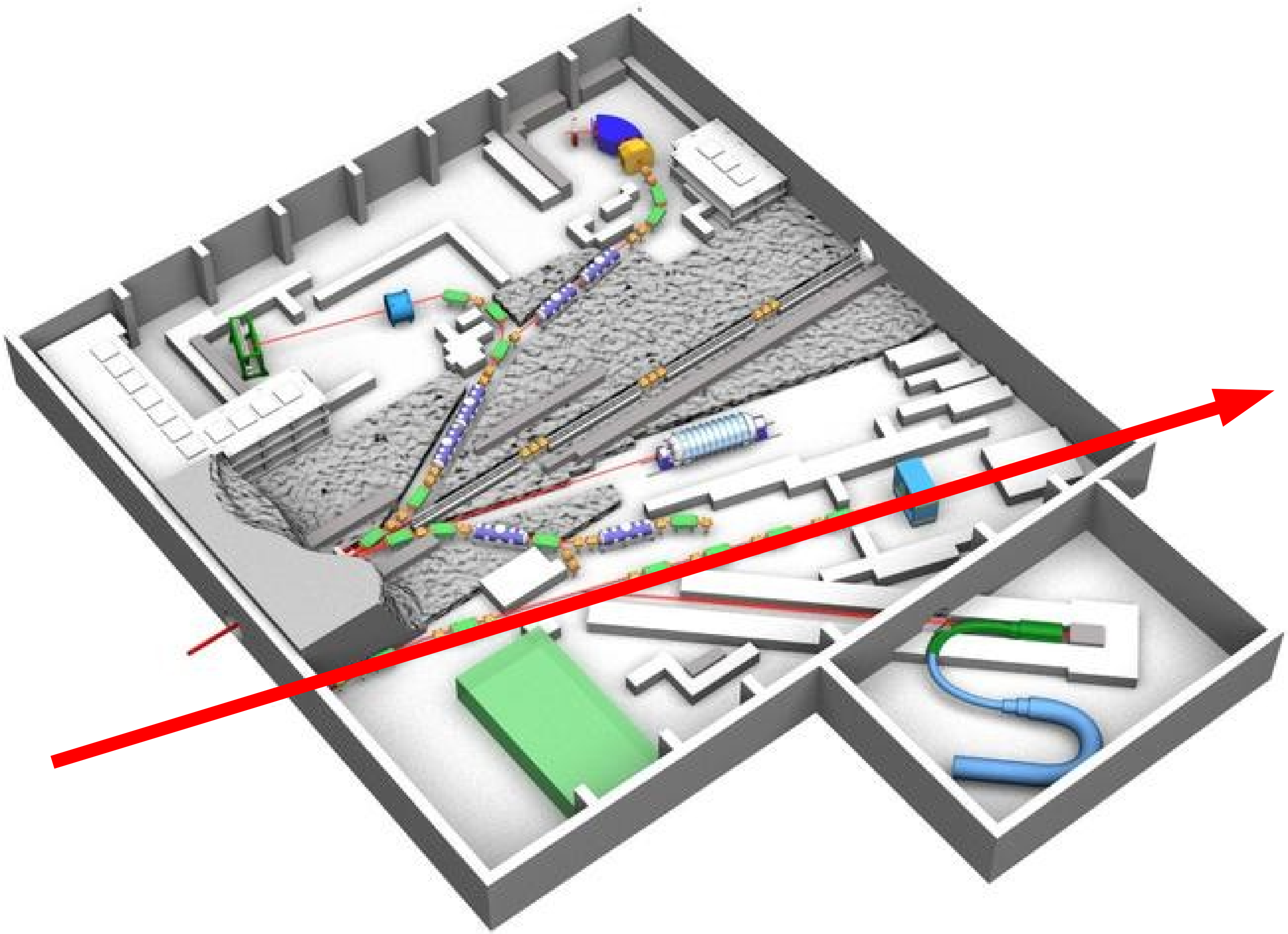
The spectromter magnet should be re-constructed and located at the new High-momentum beam line, which is under construction and completed in JFY 2016.

Experiment will start in early 2017.

Near future of the J-PARC Hadron hall

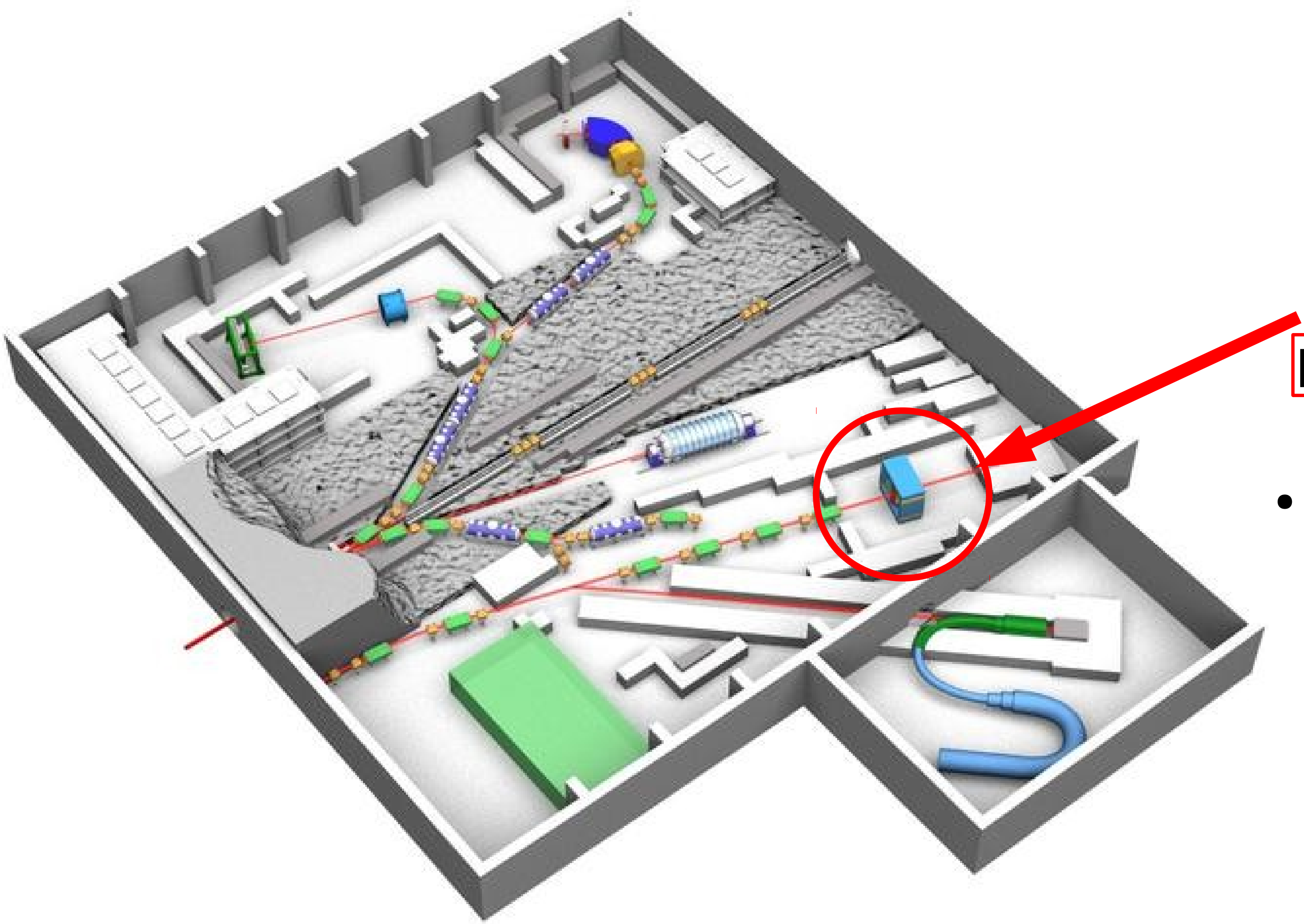


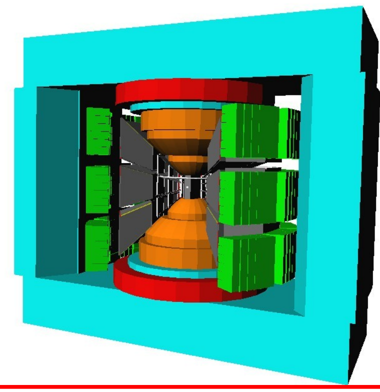
High-p line in the J-PARC Hadron hall



- High momentum line is under consturction

High-p line in the J-PARC Hadron hall





E16 spectrometer

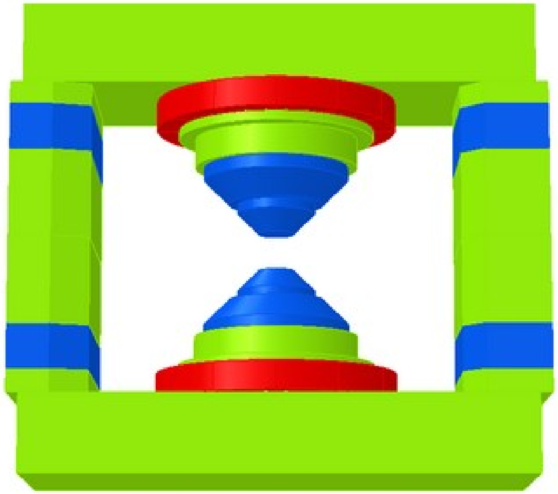
- magnet reassemble is started in Feb.

- High momentum line is under consturction

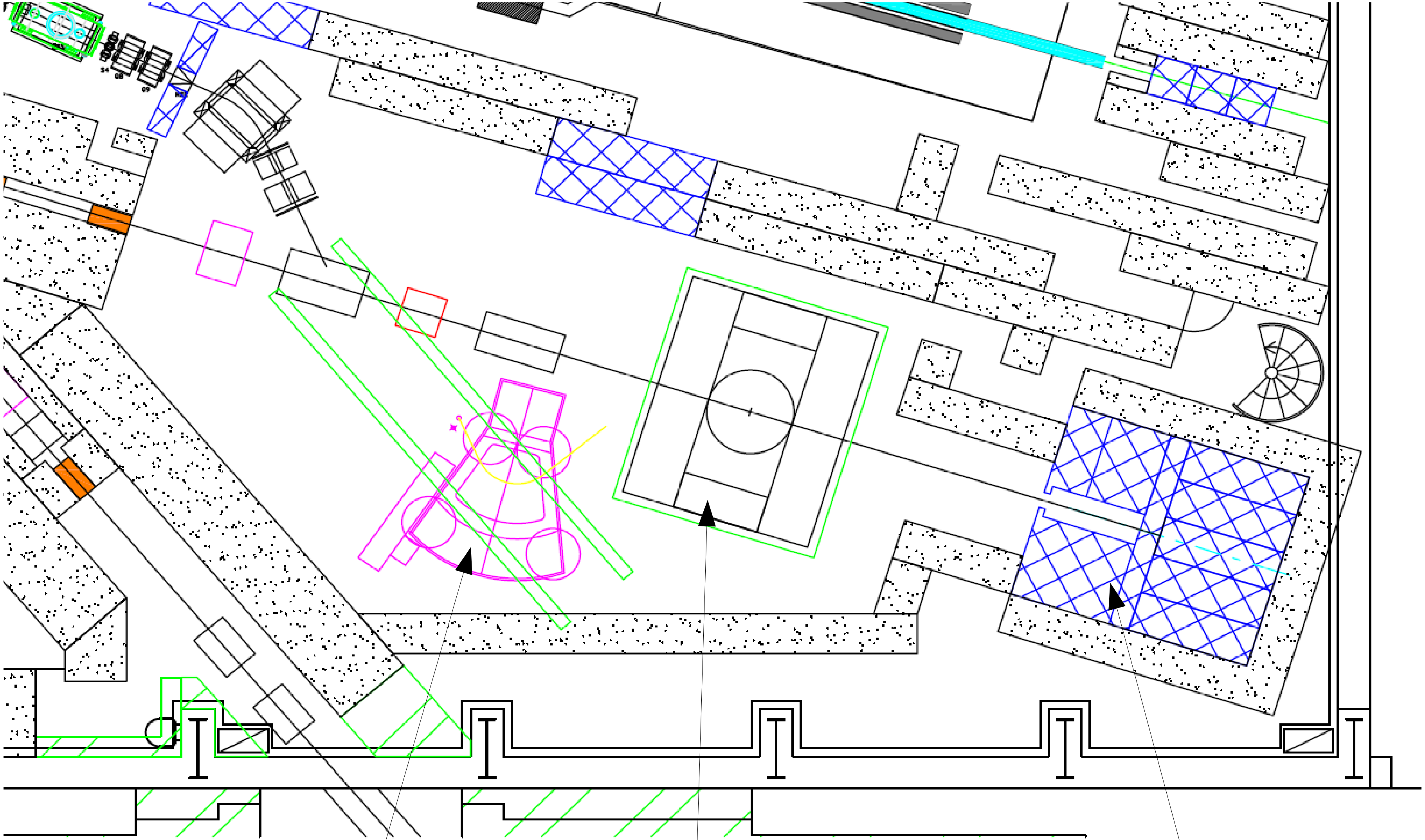
E16 Spectrometer Magnet

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

re-assemble with new parts (2015)



experimental area plan



SKS spectrometer
will be moved here

E16 spectrometer

beam dump of High-p lline

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.

Backup slides...

•

change of excitation in condensed matter

softening around Tc

- phonon frequency in the ferroelectric crystal, changed when T is approaching Tc [Kittel, v5]

- Higgs mode excitation in 2D-superfluid, changed when the order parameter j is approaching jc [nature487,454(2012)]

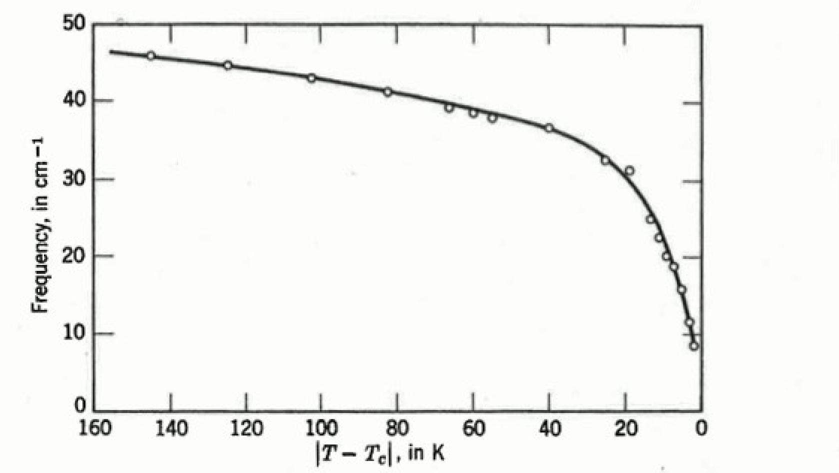
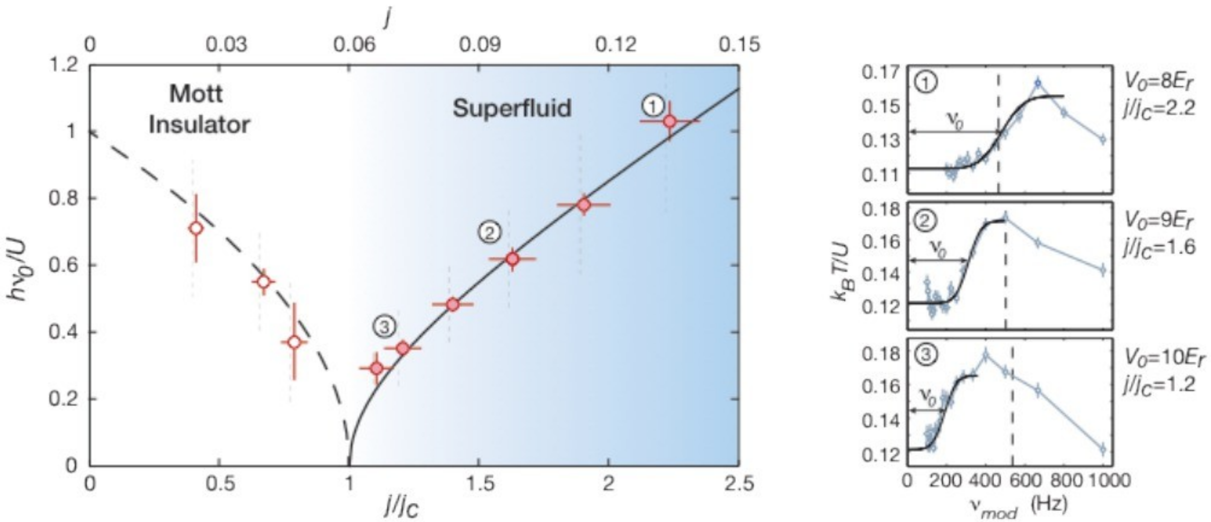


Figure 18 Decrease of a transverse phonon frequency as the Curie temperature is approached from below, in the ferroelectric crystal antimony sulphoiodide (SbSI). [After Raman scattering experiments by C. H. Perry and D. K. Agrawal, Solid State Comm. 8, 225 (1970).]



SbSI crystal, changing T, excited by laser, scattered photon is measured (Raman scattering)

Rb cold gas, changing coupling by optical lattice (j), excited by modulation(ν), and T is measured.

change of excitation in condensed matter

softening around critical point

- phonon frequency in the ferroelectric crystal, changed when T is approaching Tc [Kittel, v5]
- Higgs mode excitation in 2D-superfluid, changed when the order parameter j is approaching jc [nature487,454(2012)]

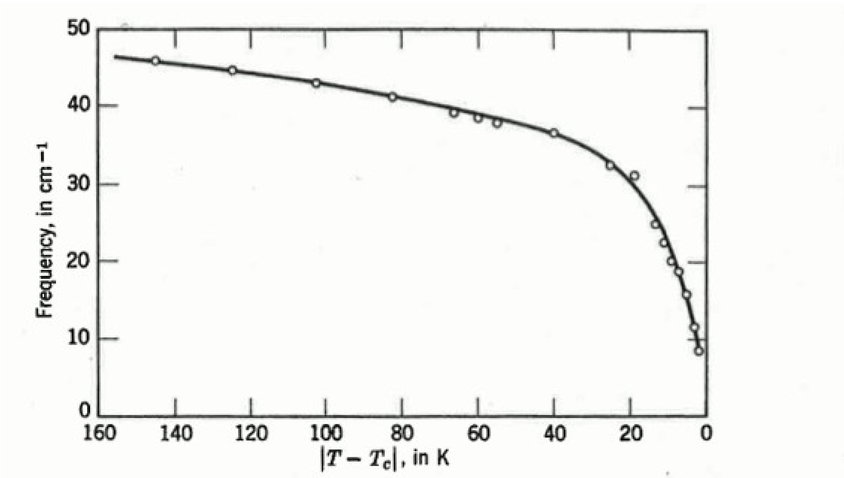
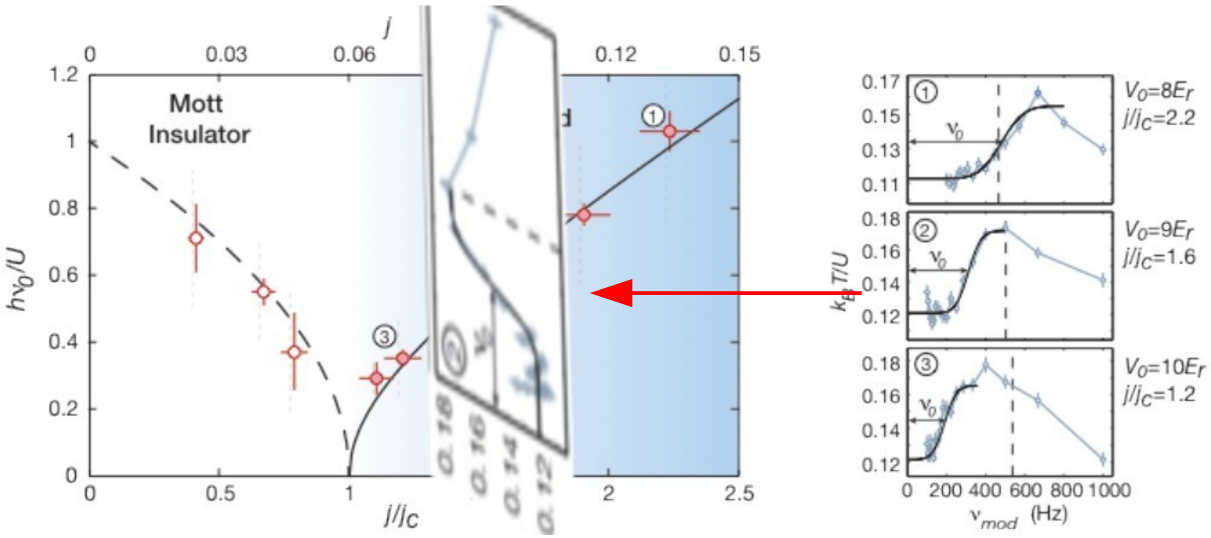


Figure 18 Decrease of a transverse phonon frequency as the Curie temperature is approached from below, in the ferroelectric crystal antimony sulpho-iodide (SbSI). [After Raman scattering experiments by C. H. Perry and D. K. Agrawal, Solid State Comm. 8, 225 (1970).]

SbSI crystal, changing T, excited by laser, scattered photon is measured (by Raman scattering)

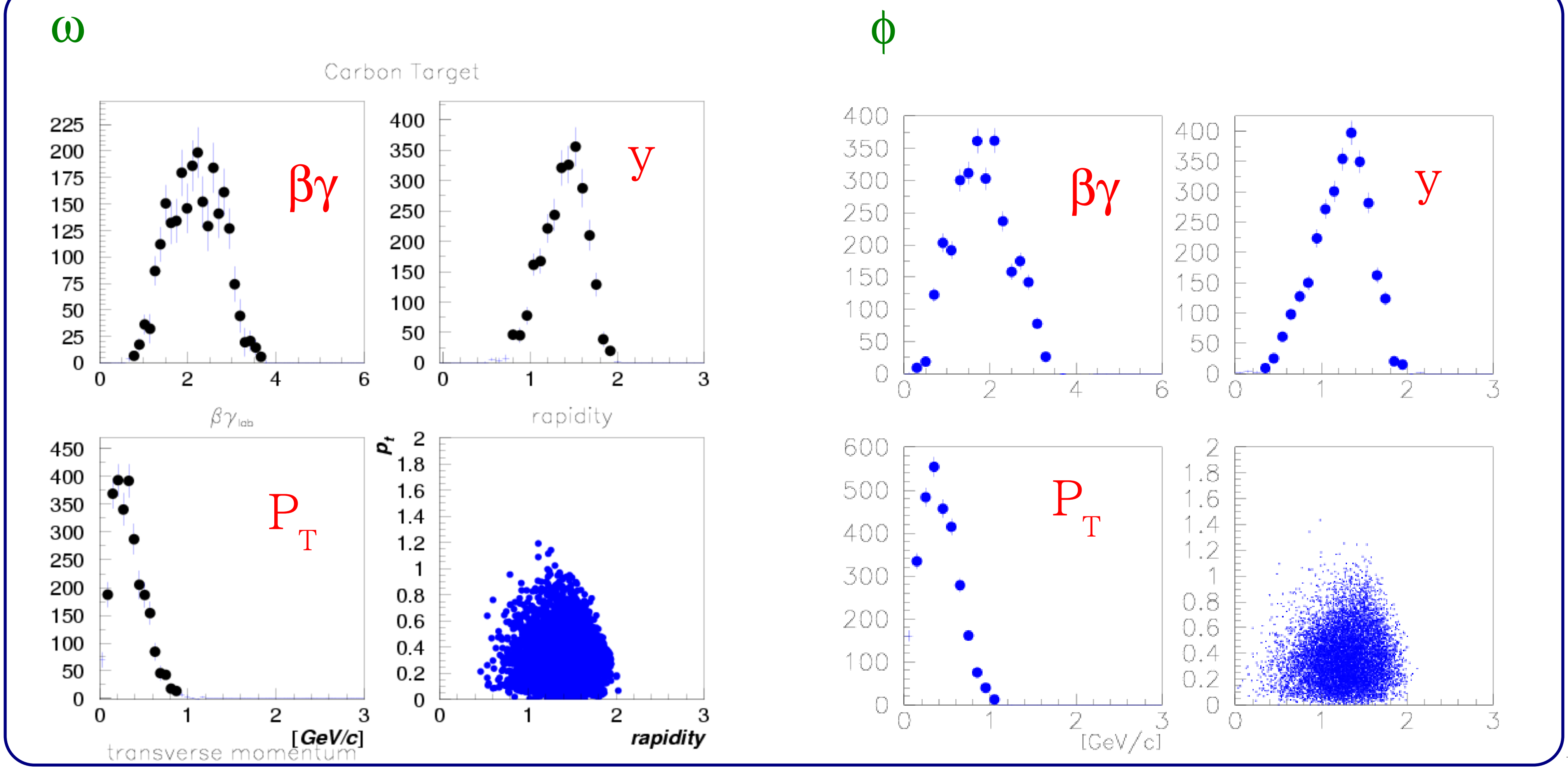


Rb cold gas, changing coupling by optical lattice (j), excited by modulation(ν), and T is measured.

measured kinematic distribution of $\omega/\phi \rightarrow ee$

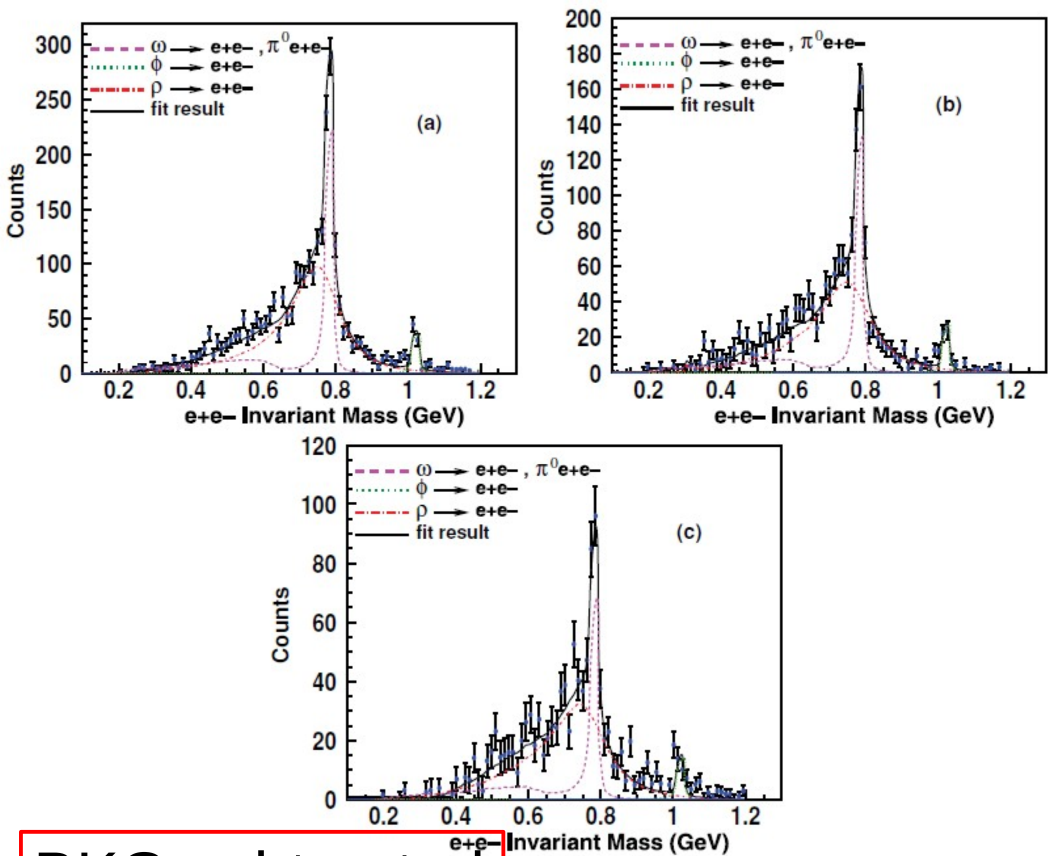
$0 < P_T < 1$ GeV/c, $0.5 < y < 2$ (y_{CM}=1.66)

$1 < \beta\gamma$ (=p/m) < 3 (0.8<p<2.4GeV/c for ω, 1<p<3 GeV/c for ϕ)



CLAS-G7(PRC78(2008)015201)

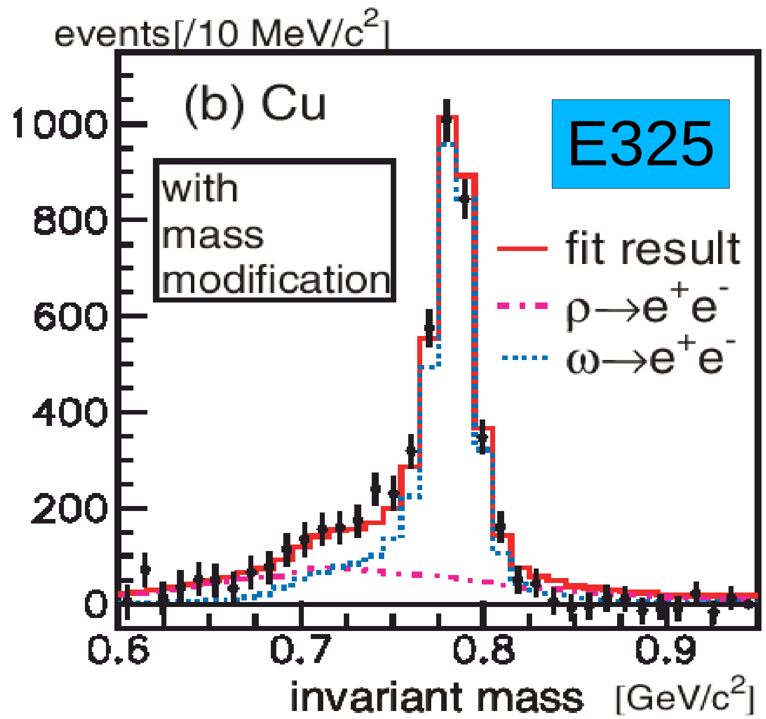
- $\gamma + A \rightarrow V \rightarrow e^+e^-$
- no anomaly for p >0.8GeV/c : ρ mass dropping <4% in 95%C.L.
  - ρ width broadening (up to ~45%) is consistent with the collisional broadening
  - ω modification is not included in the analysis



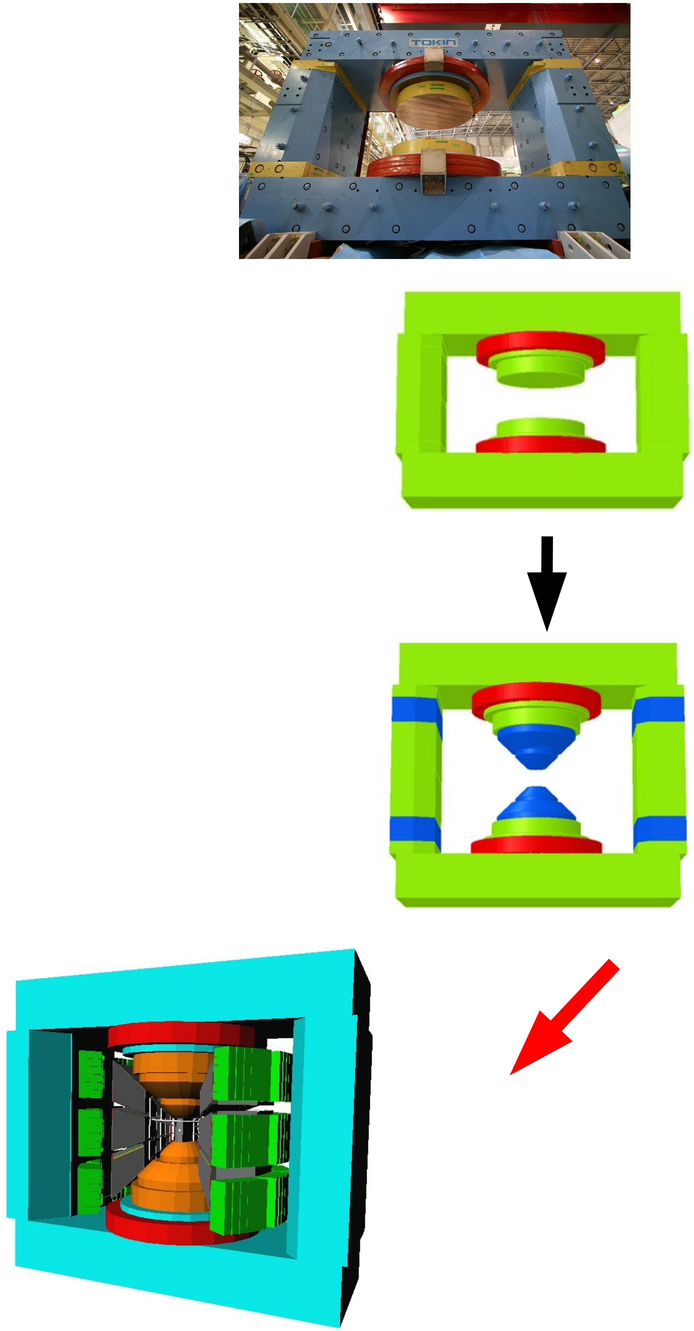
BKG subtracted

PRC78(2008)015201

ρ/ω mass dropping is 9%



Schedule



- 2007: stage1 approval
- 2008-2013 : detector R&D
- 2013 Jan : High-p construction budget is approved
- JFY 2014:
  - production of detectors, remaining tests of R/O circuits
- In the Hadron hall,
  - 2015 Apr-Jun : spectrometer magnet re-assemble
  - 2015 Jul-Dec. : detector installation in the magnet
  - 2016 Jan-Mar : detector commissioning w/ beam
    - measure the bkg particles and minimize the beam halo
- JFY2016 : 1st physics run with 8 modules
  - 80 shifts of physics run : 4000 ϕ for C/Cu
  - measure the distribution of vector mesons
    - effective trigger logic and additional modules

Schedule

		4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3
JFY		2013				2014				2015				2016			
Grant-in-Aid		Innovative area				kiban-A											
Magnet										re-assemble							
master's thesis					Obara				Murakami								
beam test			AVF	ELPH	AVF												
GTR																	
				production (GEM, R/O)													
							frame				install						
HBD																	
				production (GEM)													
									CsI evaporation								
							vessel					install					
LG		design															
							cut										
							frame		assemble		install						
R/O circuit																	
Trigger	UT3/FTS	test					test				install						
	MGR				v1												
	MGR-M						v1		test								
GTR	preamp		v2		test			production									
	ASIC	v1	sub	test			v2sub	test									
	ASD				v1		test										
HBD	preamp		SRS			test		purchase									
	ASIC			v1		sub	test										
	ASD					v1											
LG	FEM	test							v2								
High-p BL		construction											comissioning				

1st physics run

commissioning

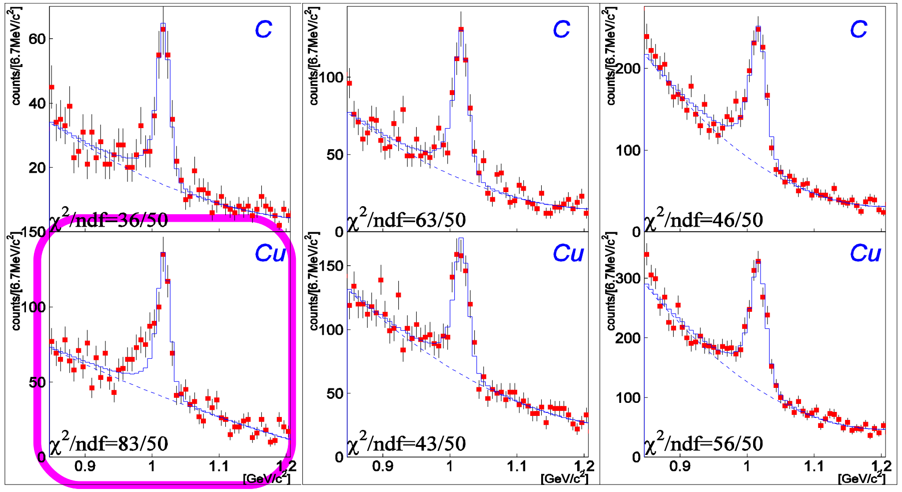
J-PARC E16 experiment

- Measure the spectral modification of vector-mesons in nuclei systematically with the e^+e^- invariant mass spectrum : ϕ and ρ/ω as the KEK-PS E325 experiment

- 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 with an improved mass resolution, 5MeV.

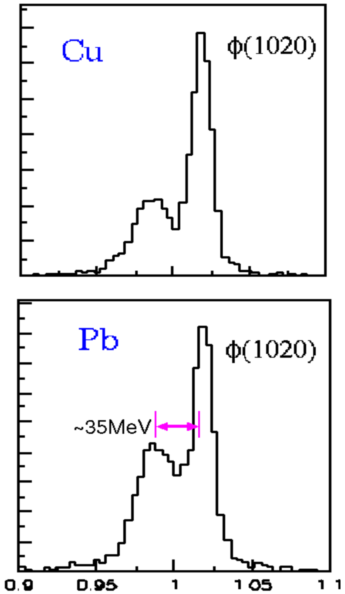
- confirm the E325 results, and provide new information as the matter size/momentum dependence of the spectral modification.

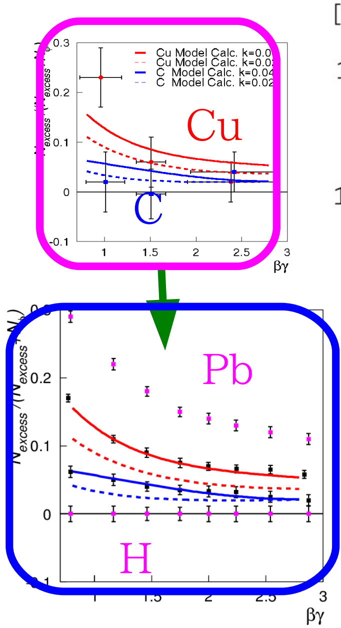
Precedent exp.(KEK-PS E325)

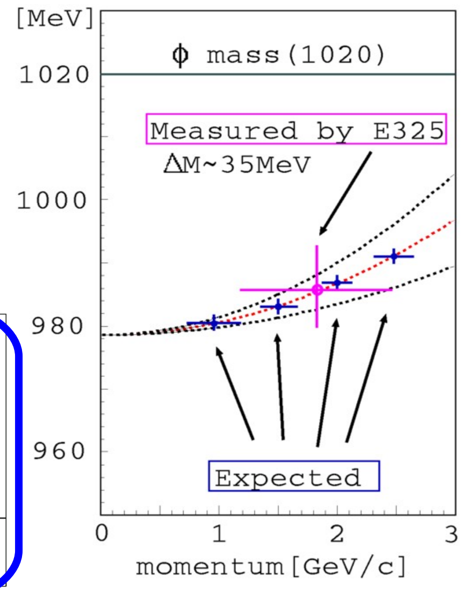


spectrum of ϕ is modified in large nuclei for slowly moving mesons... consistent with the prediction based on the QCD sum rule

Proposed exp. E16





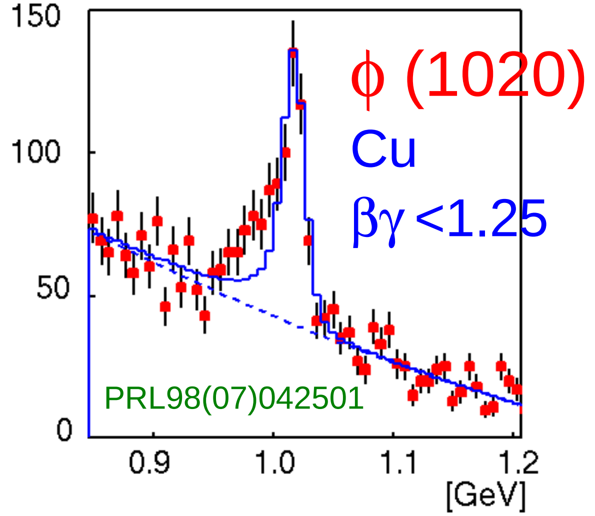


Nuclear matter size dependence & *Momentum dependence* of spectral modification are measured

J-PARC E16 experiment

- confirm the E325 results, and provide new information
  - check the interpretation model : explain the data for many nuclei, many velocity bins.
  - momentum dependence is measured for the first time.
  - 'mass shift' of ϕ is connected to the s-quark condensate $\langle \bar{s}s \rangle_\rho$ in finite-density medium.

Precedent exp.(KEK-PS E325)



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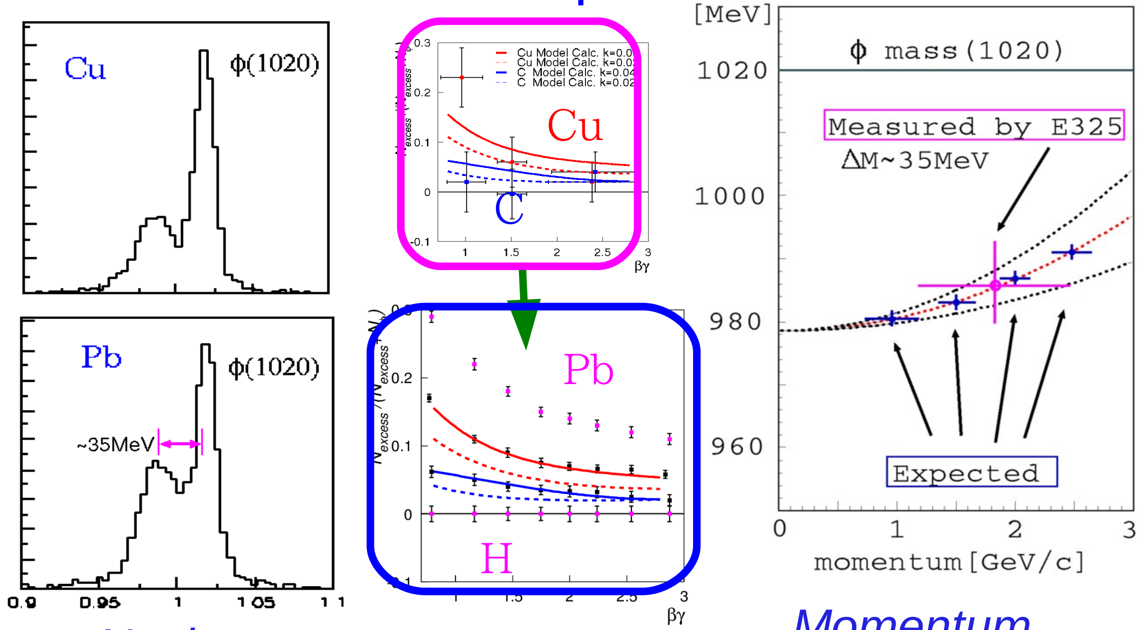


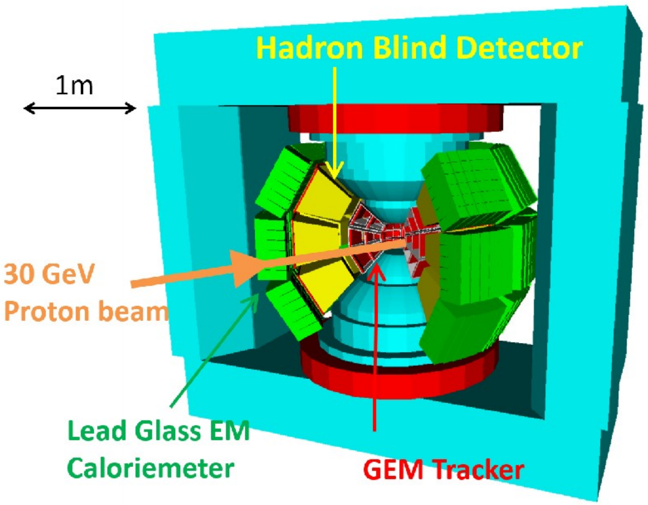
Nuclear matter size dependence & *Momentum dependence*

of spectral modification are measured

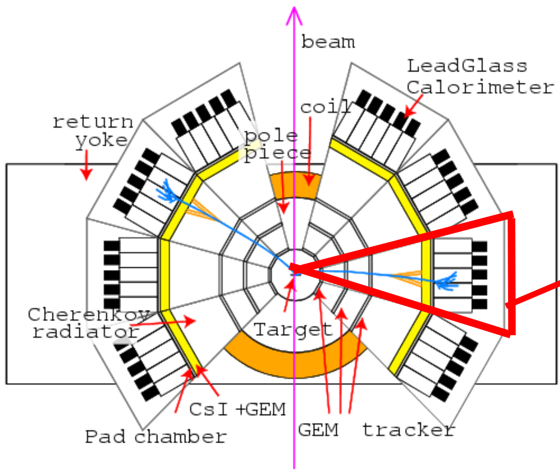
To collect high statistics

- 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.

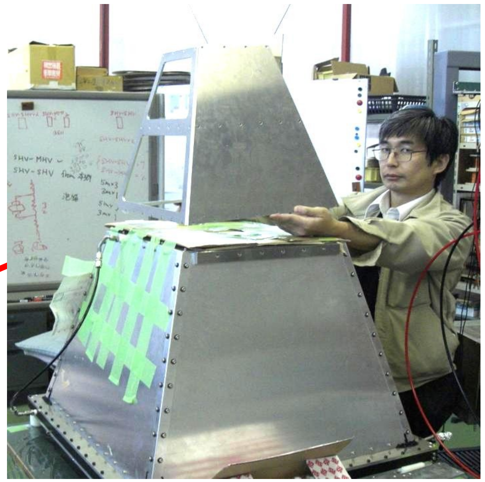
Proposed Spectrometer



Plan View

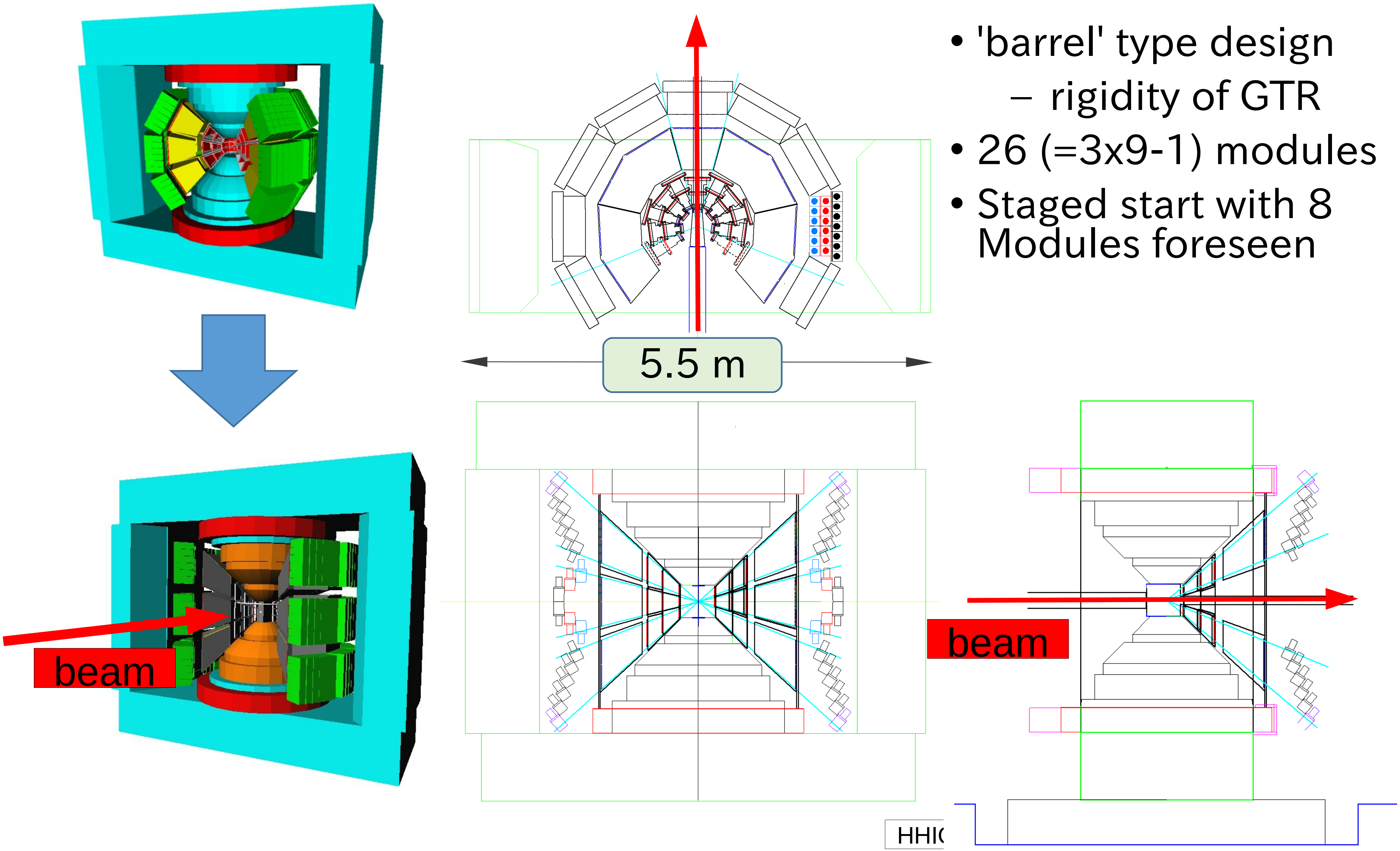


Prototype Module



26 detector modules

Spectrometer design

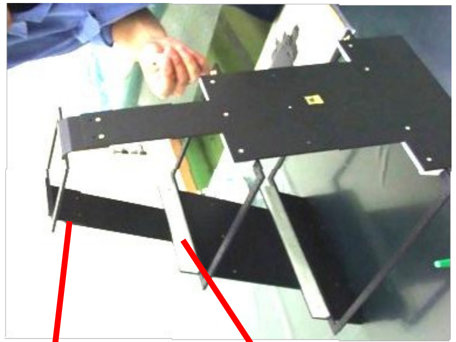


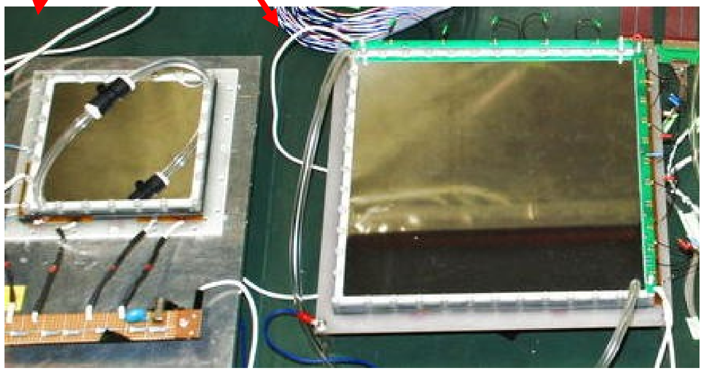
- 'barrel' type design
  - rigidity of GTR
- 26 (=3x9-1) modules
- Staged start with 8 Modules foreseen

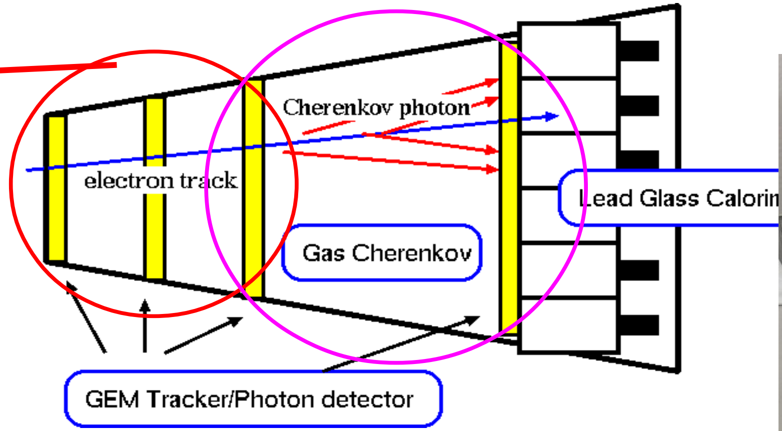
prototype to mass-production type

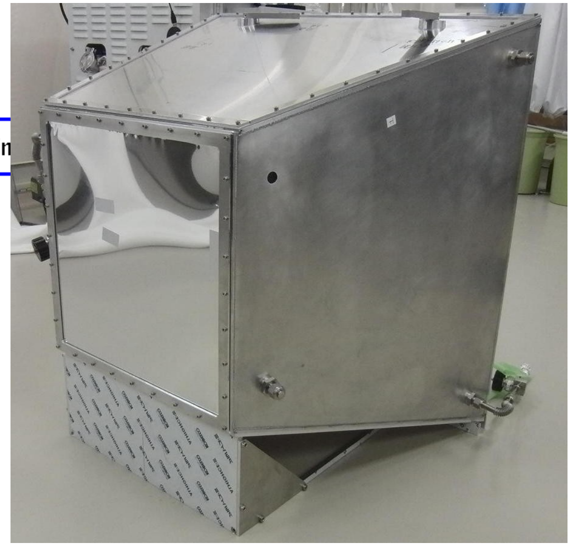
GEM Tracker

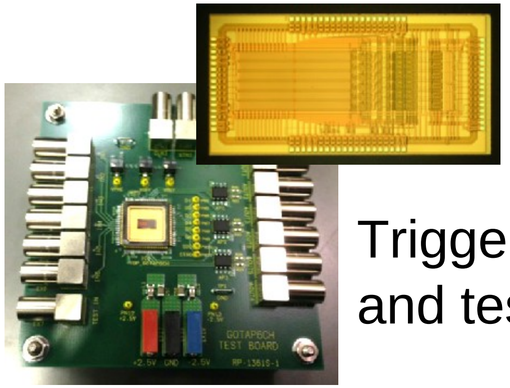
HBD (Hadron-Blind Cherenkov detector)









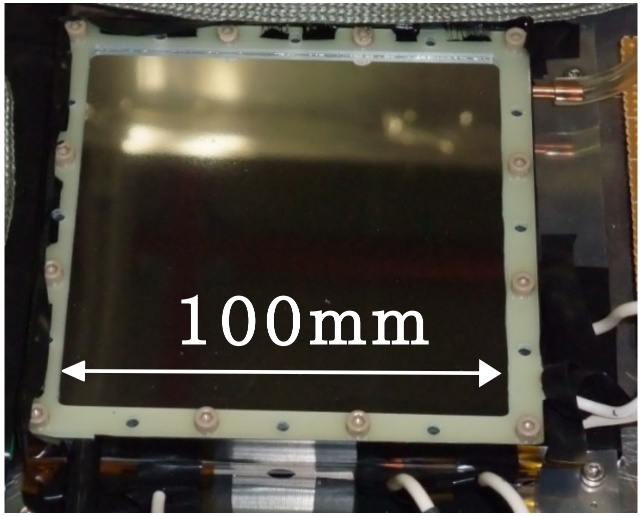


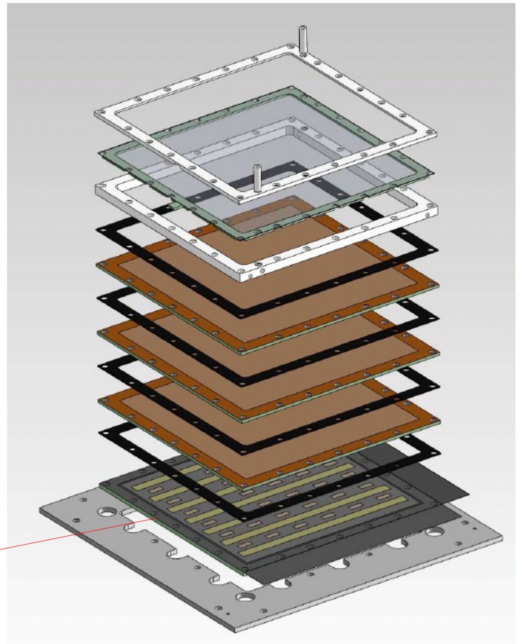
Trigger ASIC and test board

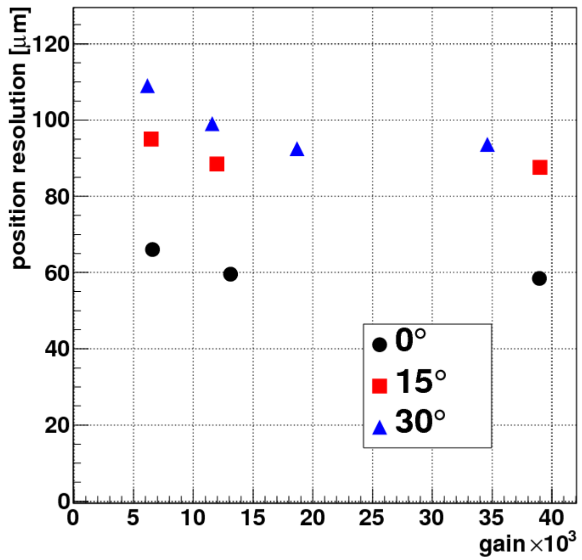
- Large size (upto 300x300mm) PI-GEM are successfully worked
  - LCP-GEM in the hadron-beam envirioment is gave up
- GEM Tracker is successfully worked with a new preamp board.
- GEM trigger ASIC is tested
- HBD optimization (gap size, pad size...) improves the pion-rejection factor.

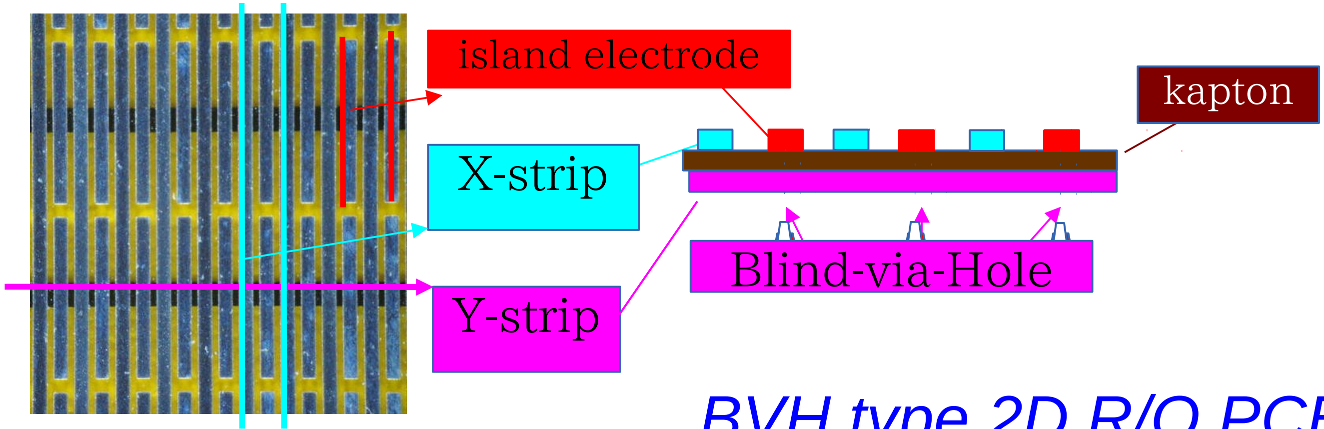
GEM Tracker : first prod. type is tested

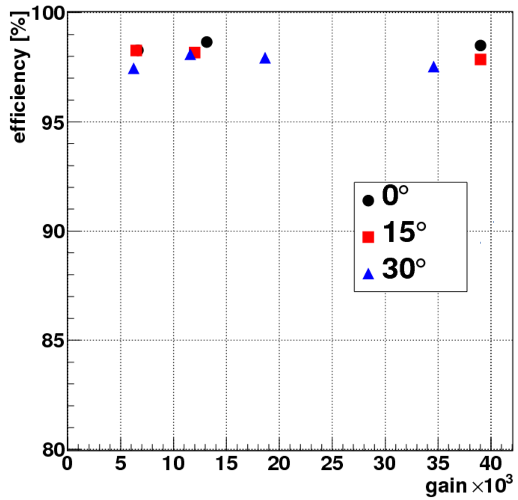
Y.Komatsu, NIM A 732(2013)241







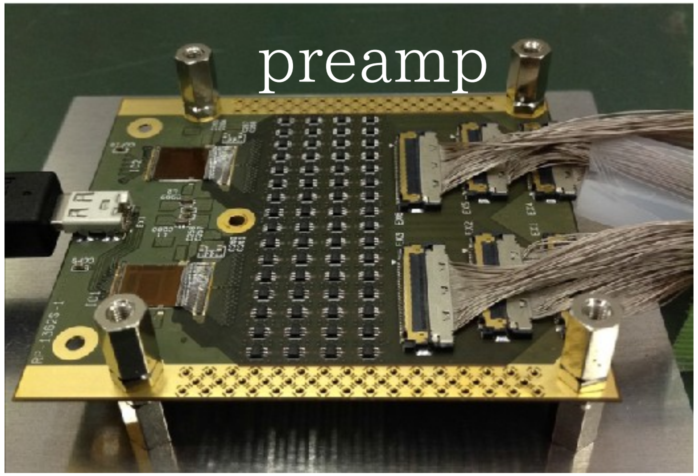


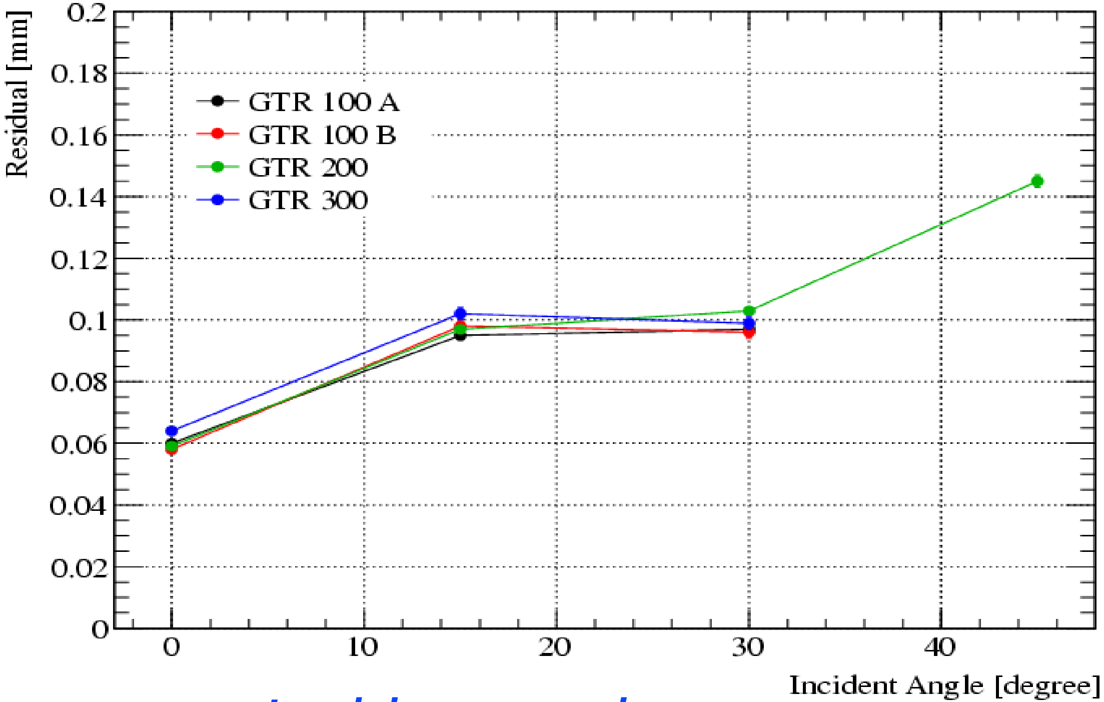


BVH type 2D R/O PCB

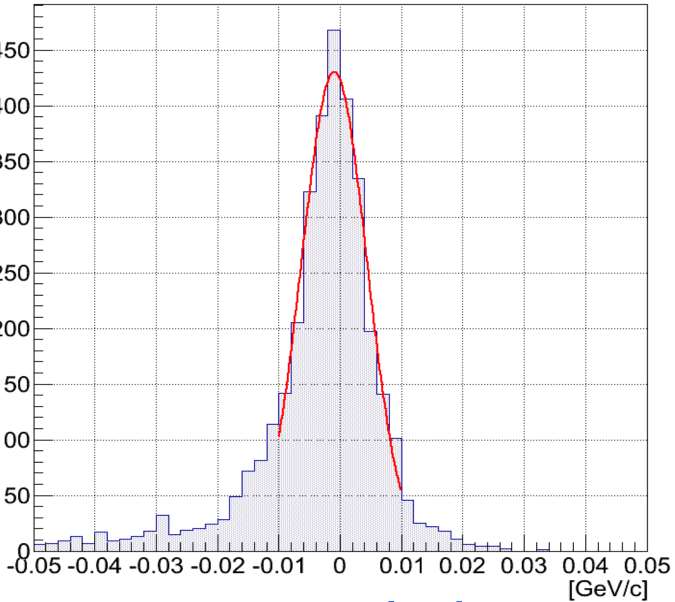
GEM Tracker

- Achieved Resolution 100um
  - for 100x100,200x200,300x300
  - for incident 30deg or less
  - using new preamp using APV25s1 chip
  - mass resolution 5.4 MeV including materials (Geant4 simulation)





Incident angle

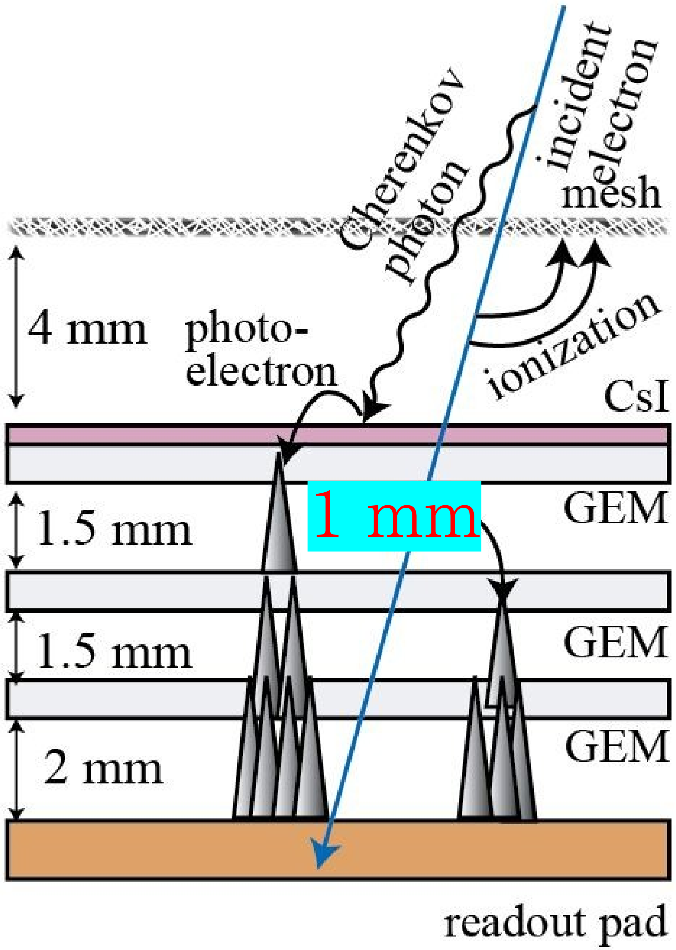


mass resolution

HBD : New configuration to improve the pion rejection

- gap length, gain, pad size are modified.
  - PI-GEM (t=50um), triple stack
  - 1st gap : 1.5 mm to 1 mm : to reduce the ionization by pion
  - 1st gap gain : 20 to 40 : to enhance the p.e. signal
  - readout pad size : a=16mm → 10mm : for the cluster analysis : cherenkov photons hit many pads while pion hits only one pad
- expected performance using the e-data (11.p.e) in the beam test in Dec.2013 and π–data in Jan. 2013
  - trigger : 2.0% π / 78 % e (68% for all the momenta)
  - offline : 0.6 % π / 75% e (63% for all the momenta)
    - using cluster analysis with the small pads

cf. PHENIX (20 p.e.) offline 1% π / 78% e



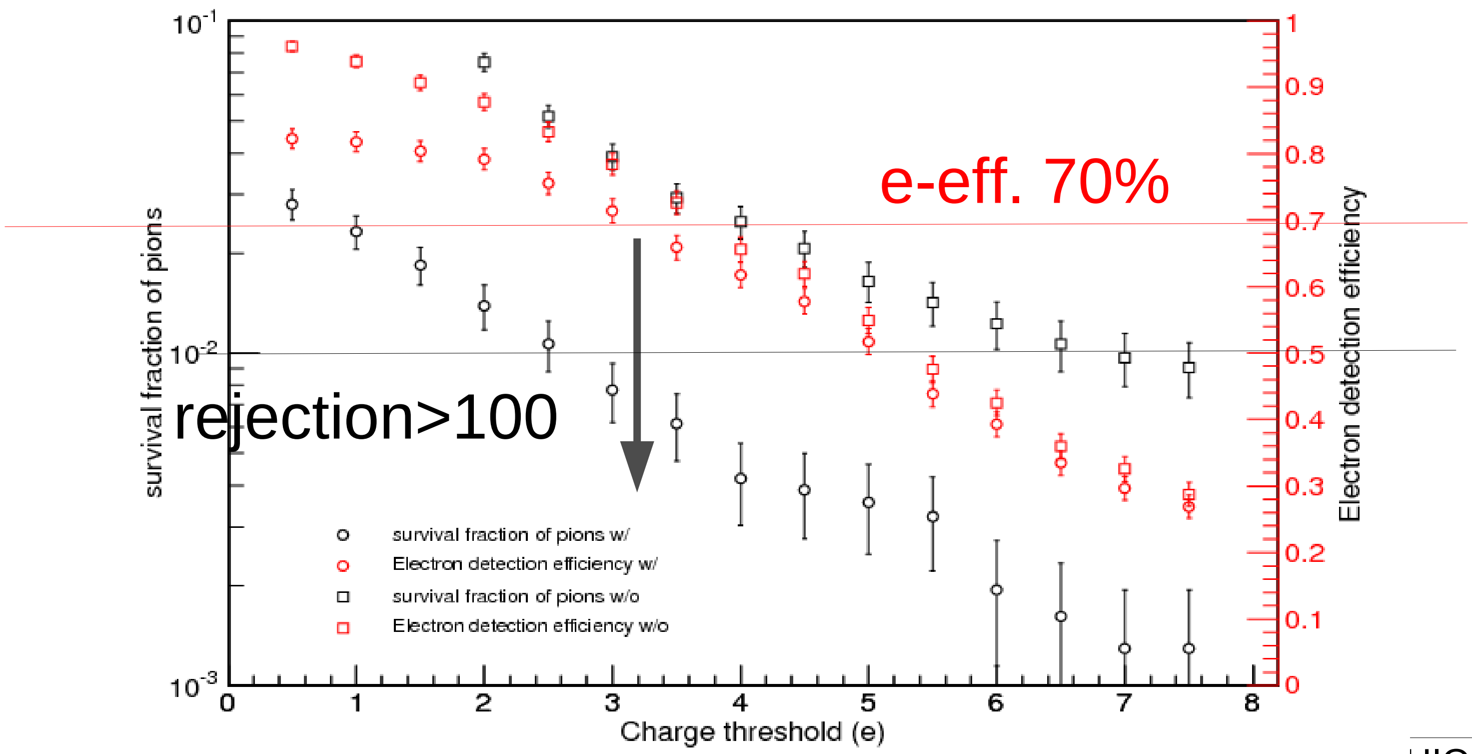
managed by K. Aoki & K.Kanno

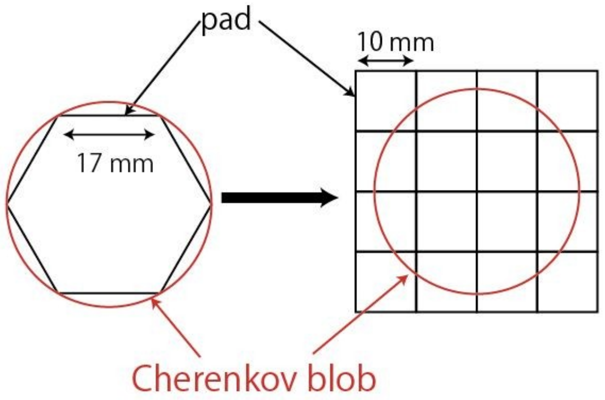
HBD (Hadron Blind Detector)

- Test @ J-PARC K1.1BR in 2013/Jan (T47)
  - pion rejection is improved with a higher gain of new PI-GEM and smaller-size readout pad
    - measure the distributed charge: selecting 3 fired pads or more

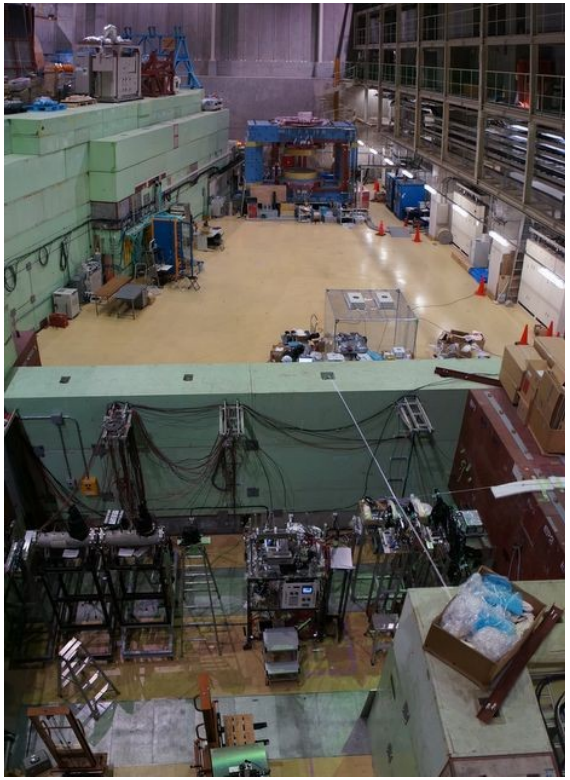
→ pion rejection factor 100 with e-efficiency 70% achieved, same level as PHENIX, in spite of the less #p.e.

w/ and w/o cluster size analysis





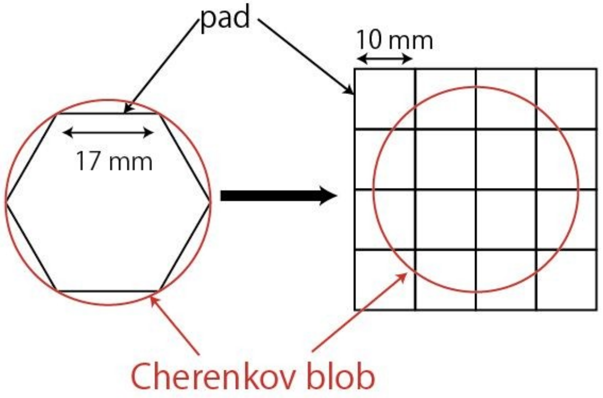
HBD (Hadron Blind Detector)



- Test @ J-PARC K1.1BR in 2012/Jun (T43)
  - #p.e. improvement : 10 → 13
    - QE , gas purity and HV config. optimization
    - however, still less than that of PHENIX (20 p.e.)
  - 300mm LCP-GEM double stack was unstable in the hadron beam environment : breakdown in an hour

- Test @ J-PARC K1.1BR in 2013/Jan (T47)
  - 100mm/50mm PI-GEM triple stack were stable, even for CF_4
  - pion rejection is improved with a higher gain of new PI-GEM and smaller-size readout pad
    - measure the distributed charge

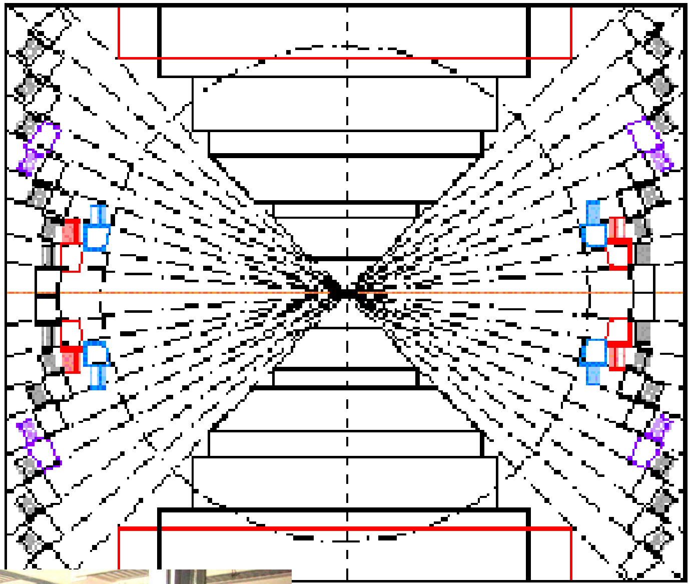
  → pion rejection factor 100 with e-efficiency 70% achieved, same level as PHENIX, in spite of the less #p.e.

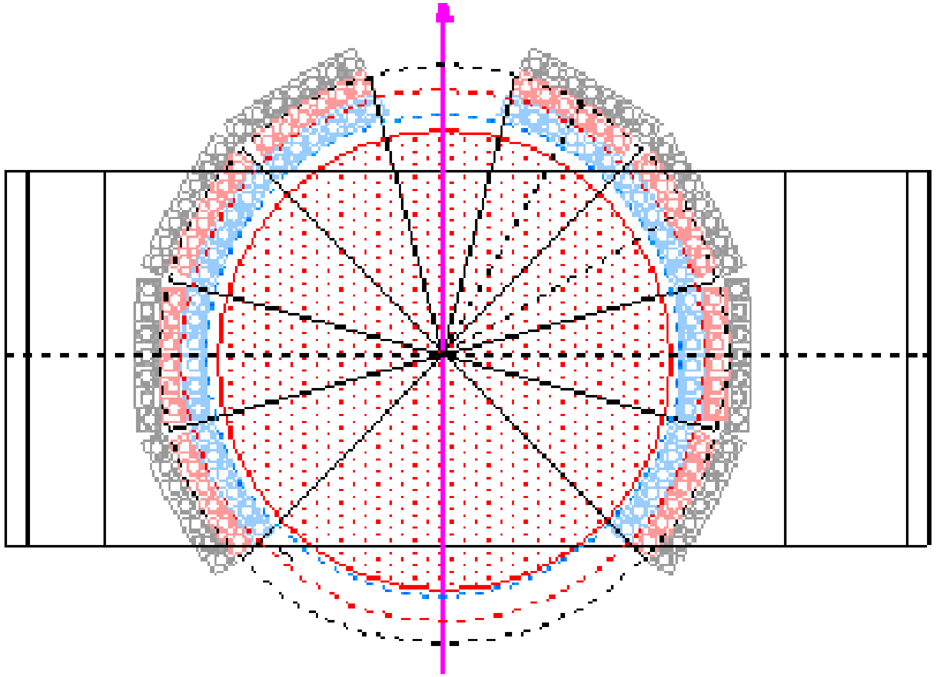


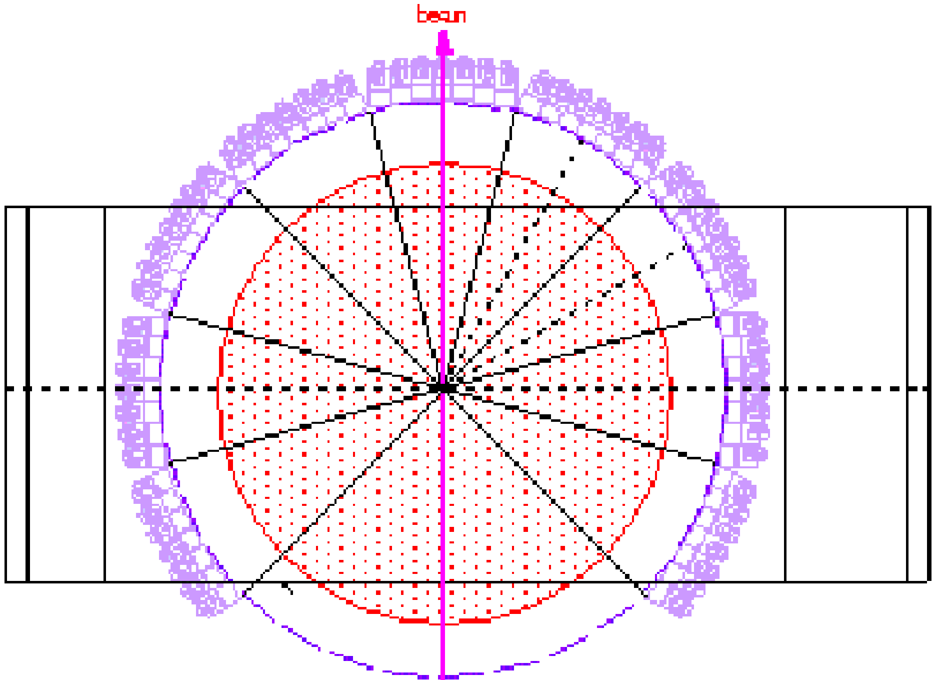
- Test using 300mm PI-GEM in 2013/June: canceled
  - stability is checked at RIKEN

managed by K. Aoki & K.Kanno

LG design in the spectrometer

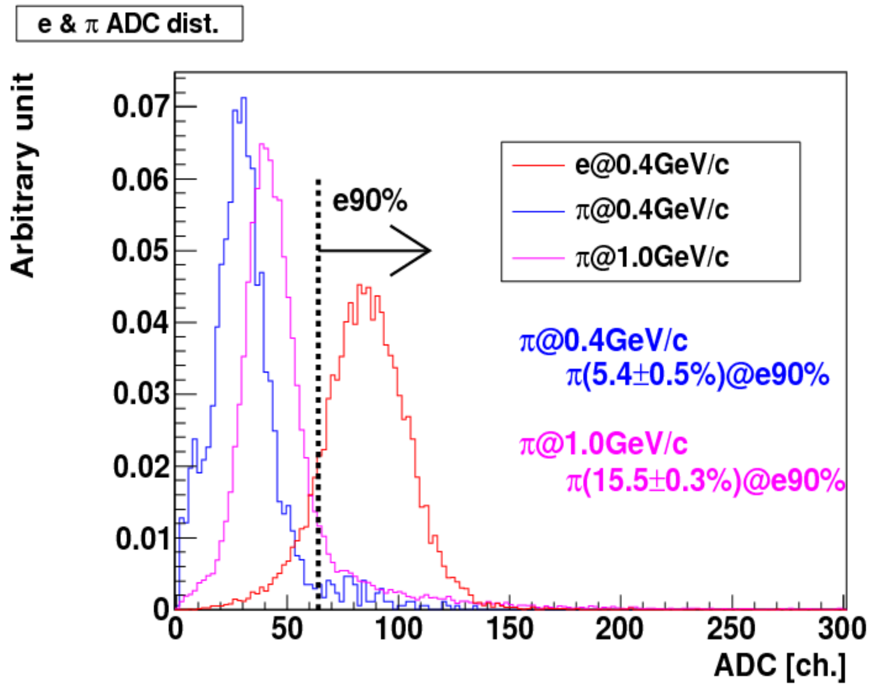




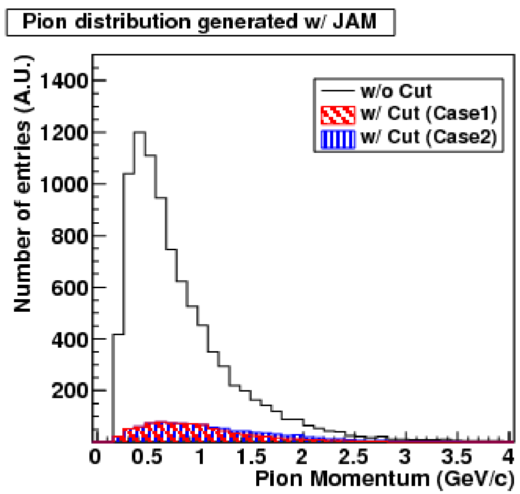


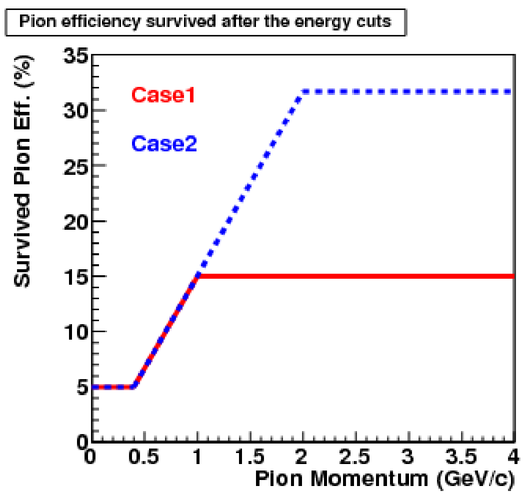
- ~ 1000 LG blocks of from TOPAZ are recycled

LG performance in the test (@J-PARC K1.1BR)

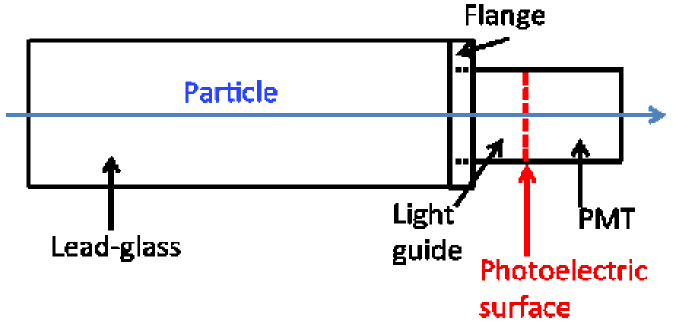


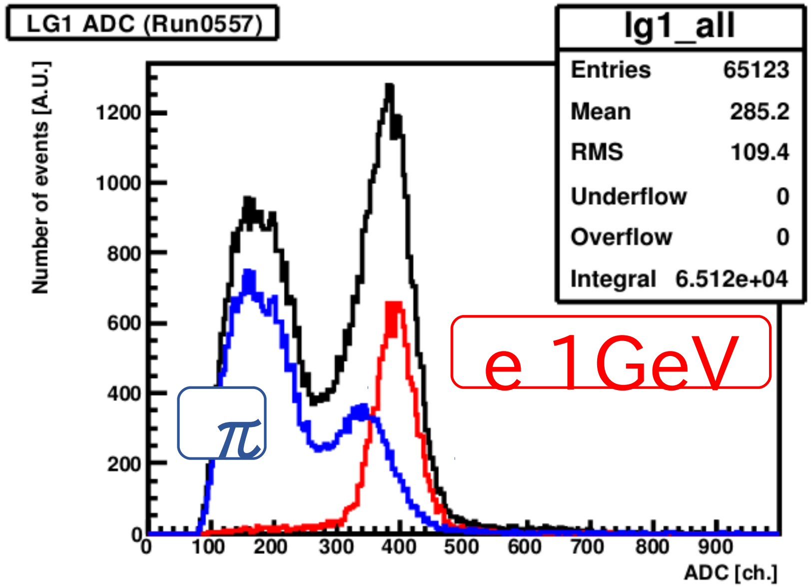
- Online
  - pion suppression down to 10% w/ the trigger threshold which keeps 90% of electron efficiency at 0.4GeV/c
- Offline
  - pion suppresion down to 5% (2%) at 0.4(1.0) GeV/c w/ 90% electron efficiency

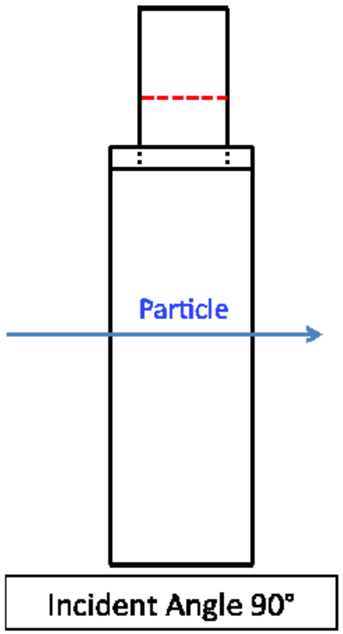


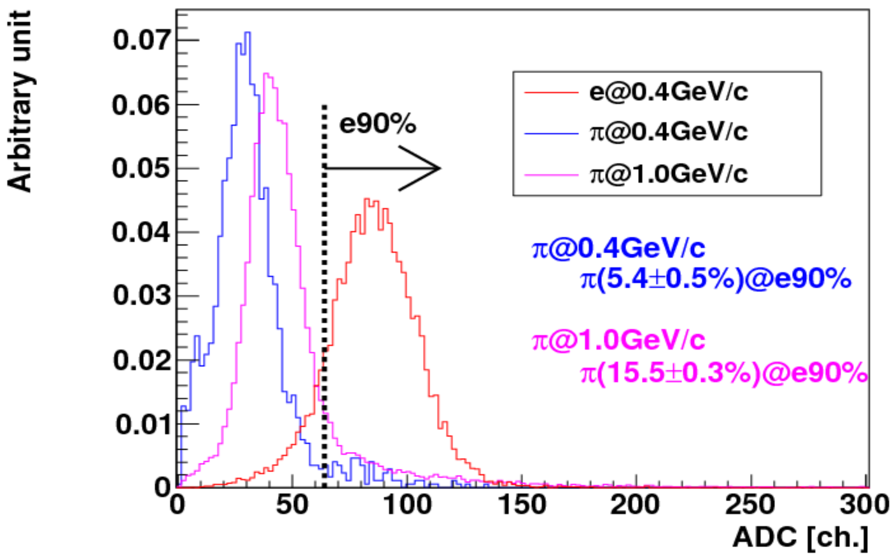


LG performance in the test (@J-PARC K1.1BR)

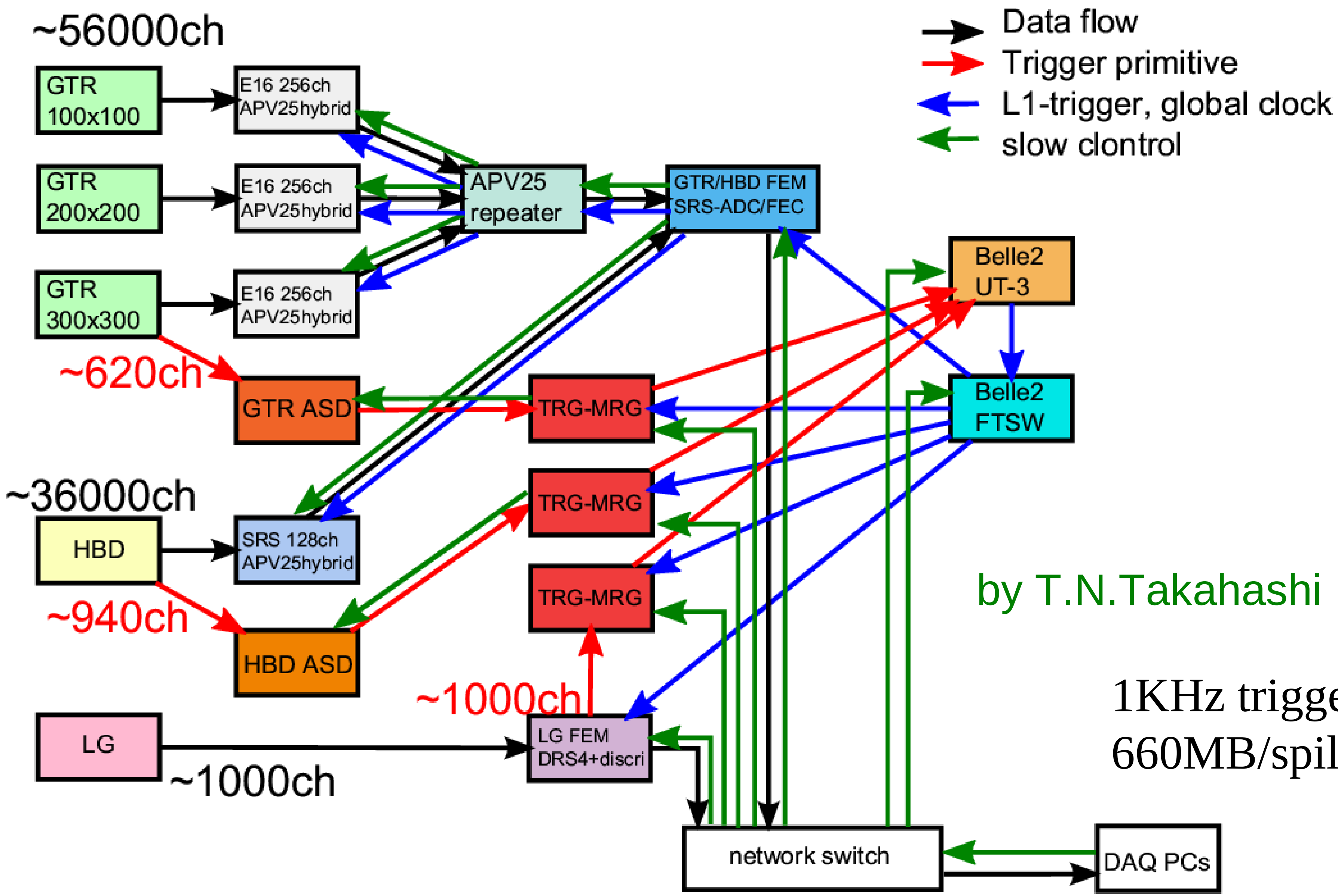






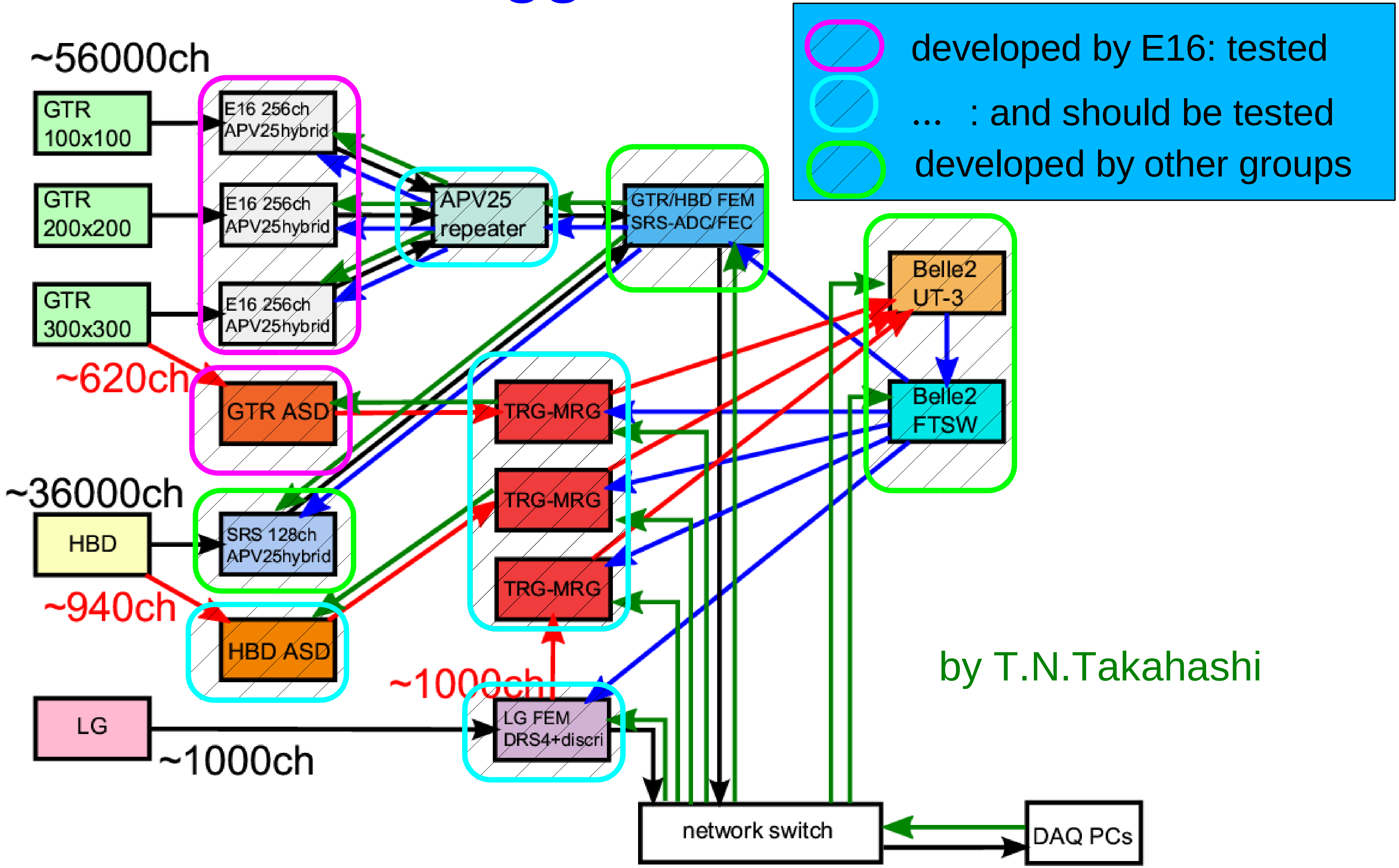


Data collection and trigger data flow



1KHz trigger
660MB/spill

R/O and trigger modules



by T.N.Takahashi

budgetary status

- cost
    - 5.2 oku-yen (~$5.2 M) for the full 26 modules
    - 8 modules + support frames at the beginning = 1.9 oku
        - 0.7 oku is already paid (shin-gakujutu/kiban-A)
- more 1.2 oku-yen is required for the 8 modules(+frames)
    - challenge other funds toward JFY2015
        - larger Grant-in-Aid (applied to kiban-S & shin-gakujutu)
        - competitive fund in RIKEN
    - if no new kakenhi, 6 GTR + 2 HBD + 2 LG will be ready for beam
- +3.3 oku-yen to full install
-
- expect that the magnet re-assemble will be performed by KEK
    - 0.3-0.4 oku-yen

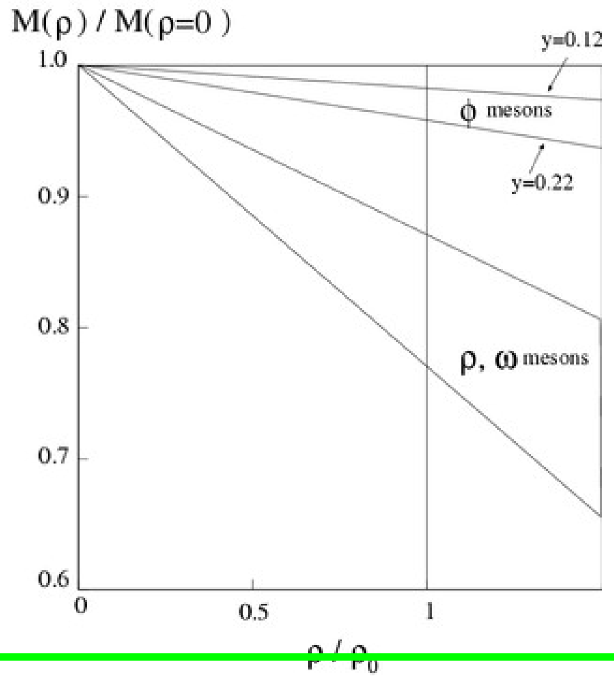
QCDSR analysis on vector mesons

Hatsuda & Lee
PRC 46(92)R34, PRC 52(95)3364

approximately linear dependence on density

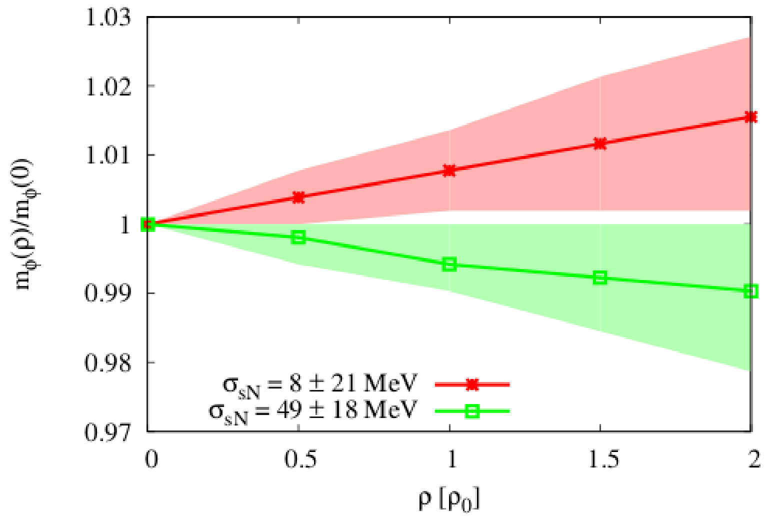
$m^*/m_0 = 1- k\ \rho/\rho_0$

Δm at the normal nuclear density
- 16(±6)% for ρ/ω
- 0.15(±0.05)*y =2~4% for ϕ



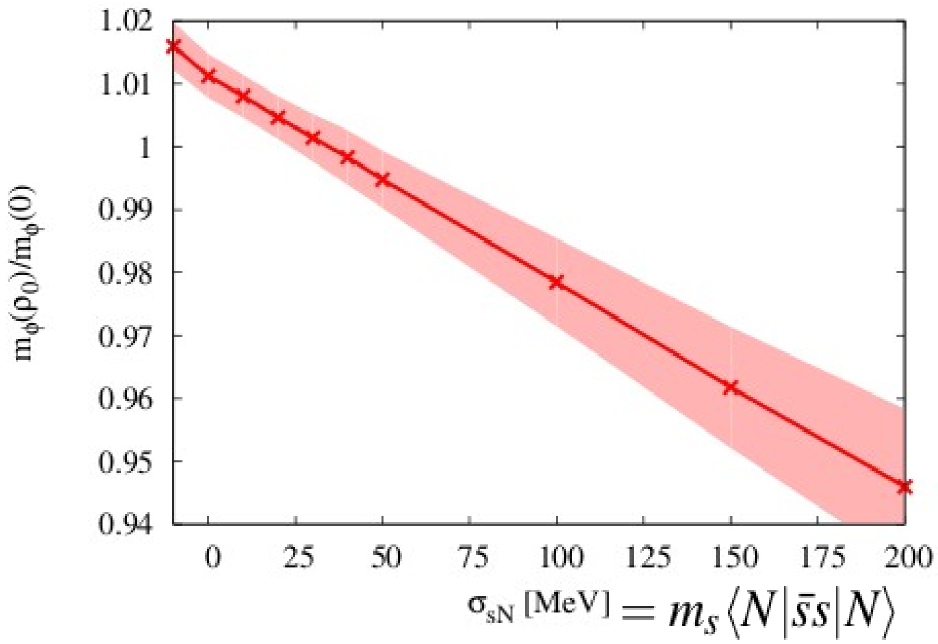
Gubler & Ohtani
arxiv:1404.7701
PRD90(2014)094002

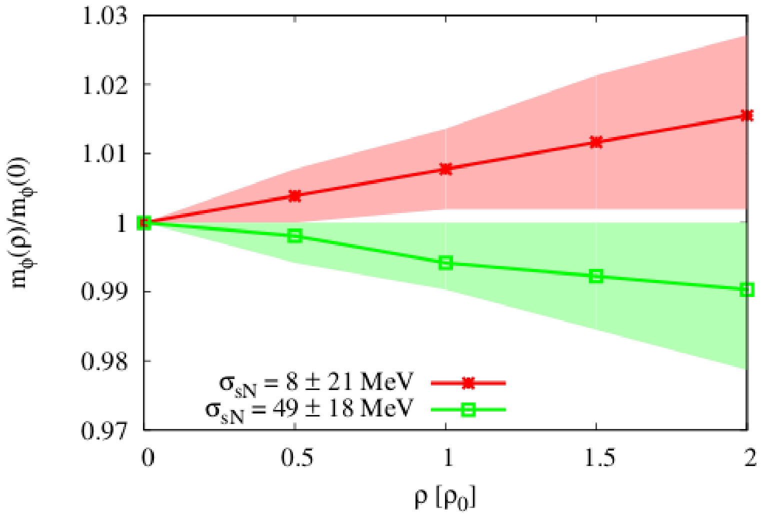
using recent Lattice $m_s\langle N|\bar{s}s|N\rangle$
- Δm =~1% for ϕ



<s̄s> & ϕ-meson mass

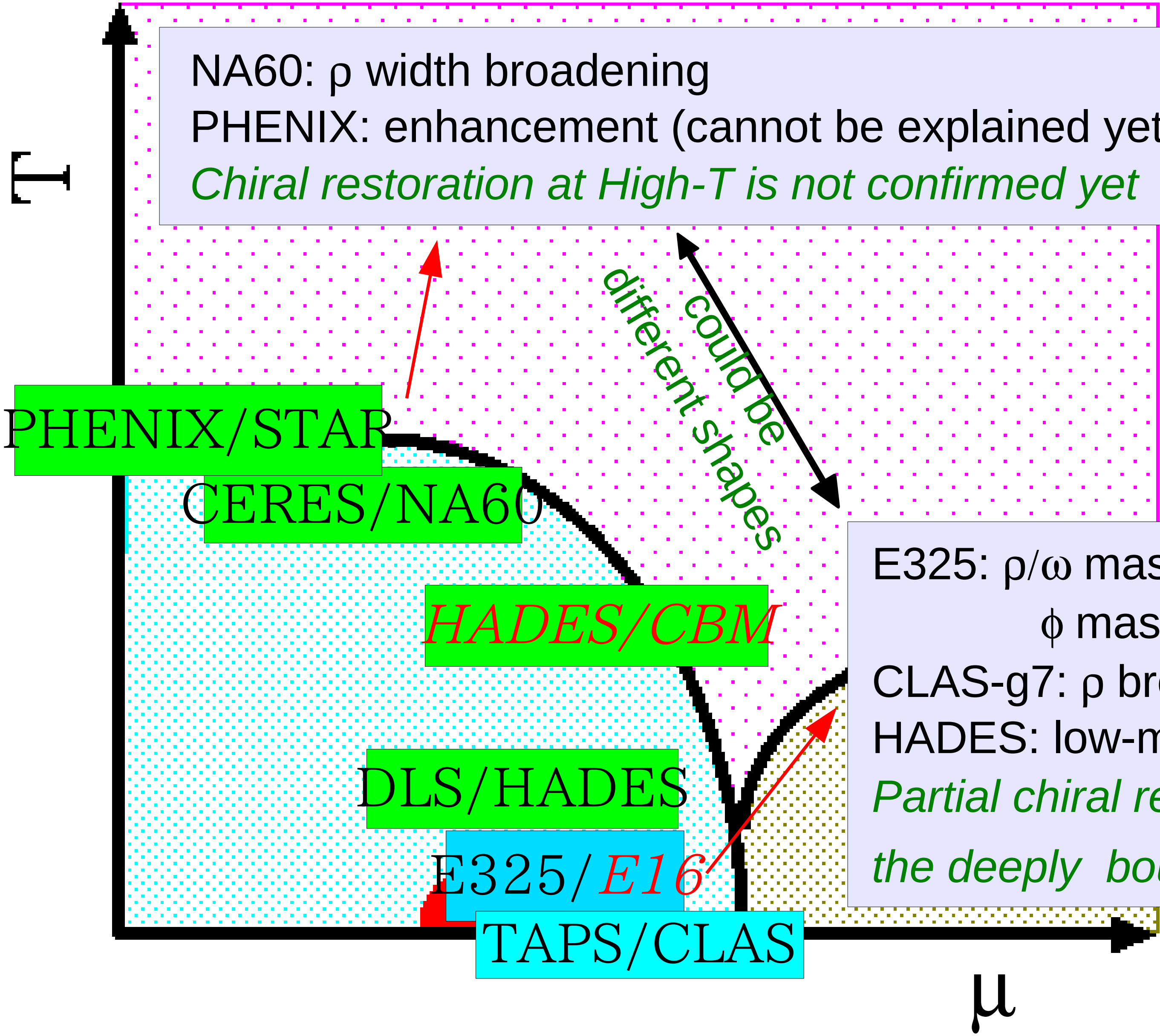
- <s̄s>$_\rho$ (s̄s condensate in medium whose density is ρ) is relevant the ϕ mass in nuclear matter under the QCD sum rule analysis
  - linear approximation : <s̄s>$_\rho$ = <s̄s>$_{vac}$ + <N|s̄s|N> ∗ρ
  - <N|s̄s|N> should be determined by experimental data
  - Recently <N|s̄s|N> (so called " strangeness content in nucleon") is calculated with Lattice QCD
  - Recent QCDSR analysis by Gubler & Ohtani [arXiv:1404.7701]





Dilepton spectrum measurements in the world

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

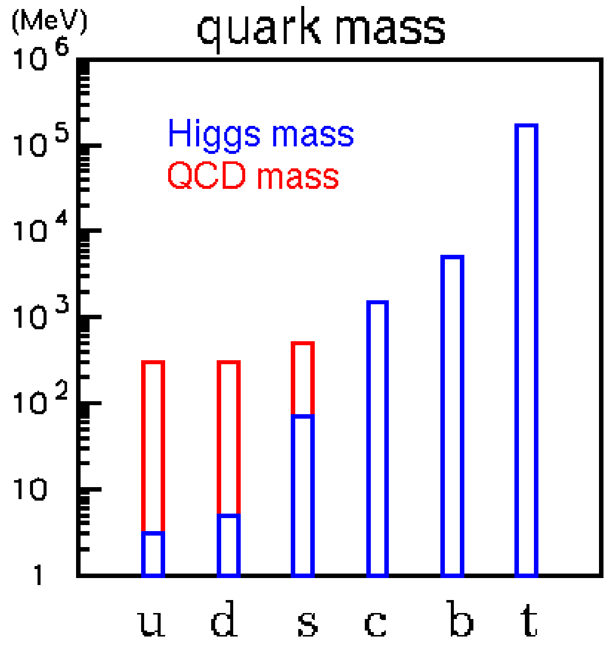


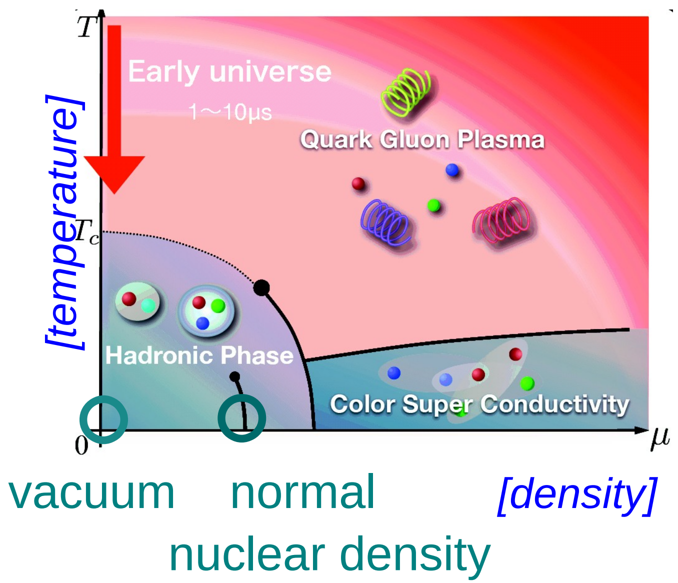
E325: ρ/ω mass dropping
ϕ mass dropping and broadening
CLAS-g7: ρ broadening
HADES: low-mass enhancement
Partial chiral restoration at ρ_0 is measured w/ the deeply bound pionic atom

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

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 modification is also expected
  - many theoretical and experimental approaches
- Hadron modification is observed in many experiments, but the origin is not determined
  - NA60(SPS), PHENIX(RHIC) : ρ and/or low mass
  - CLAS-g7(JLab) : ρ
  - E325(KEK-PS) : ρ/ω, and φ
    - best mass resolution and high statistics
- Next Step ...
  - put an emphasis on φ : not ambiguous like ρ/ω



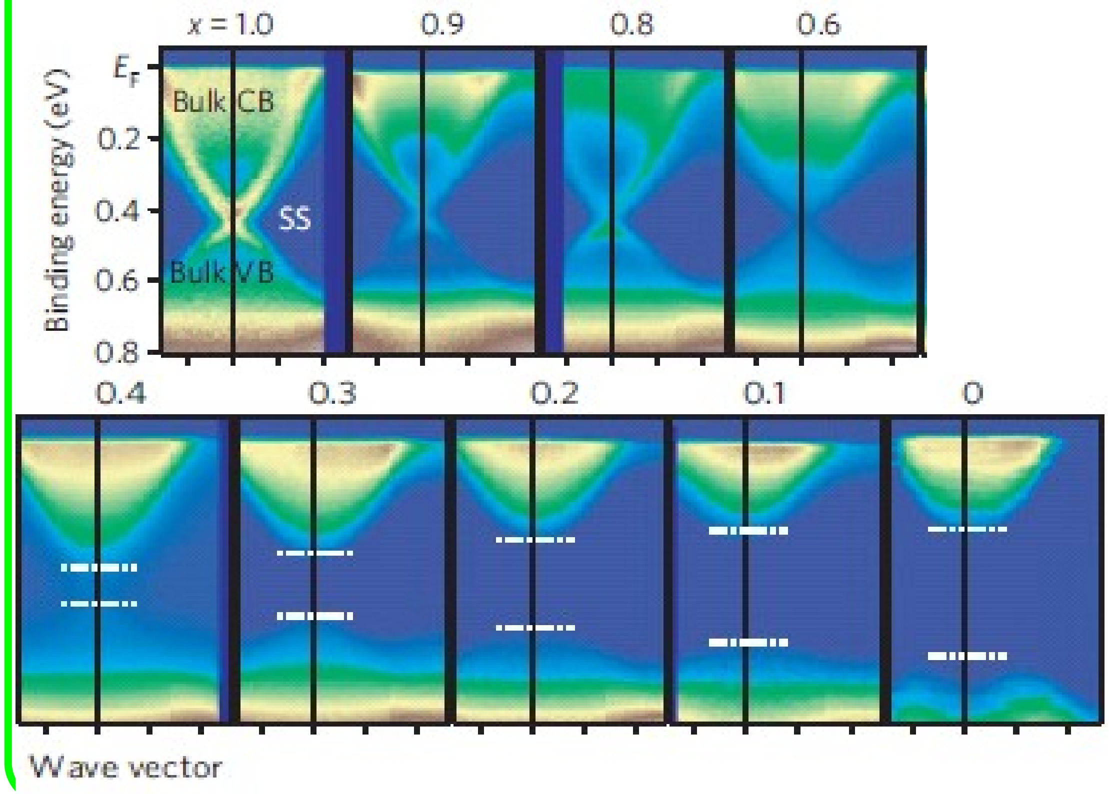


dispersion of elementary excitation in condensed matter

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

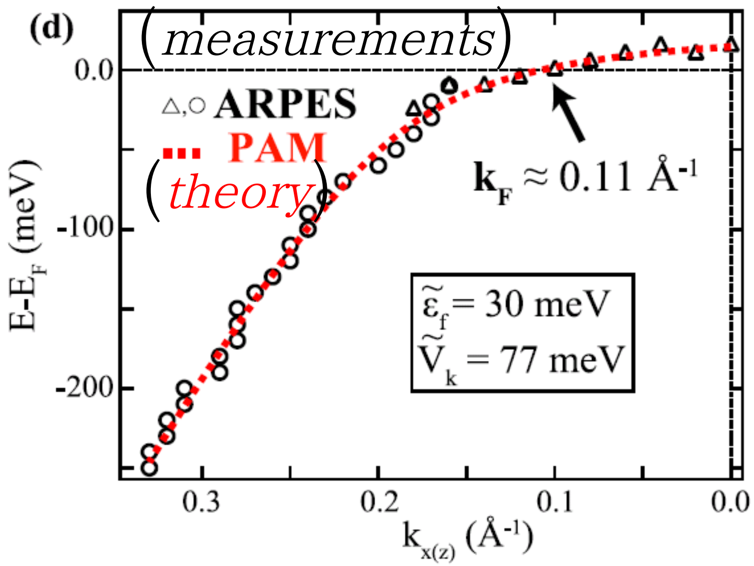
Sato et al.

(n.phys 7(2011)840)



Im et al.

(PRL100(2008)176402)



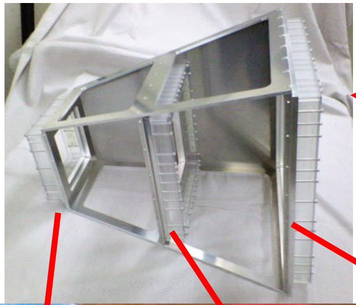
Schedule

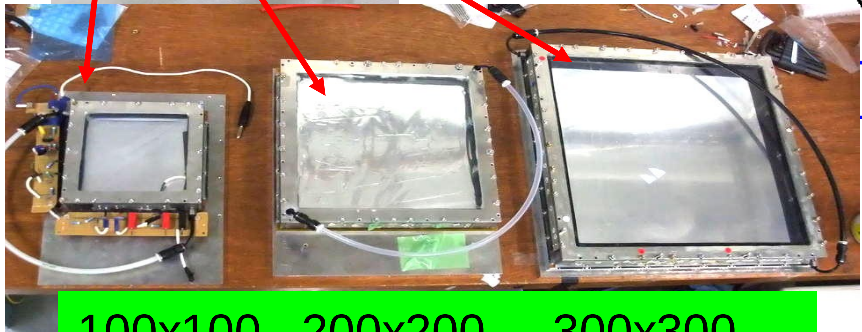
		4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3
JFY		2009				2010				2011				2012				2013				2014				2015			
Grant-in-Aid																													
Magnet		moved to J-PARC						design			manufactured															re-assemble			
master's thesis					Watanabe-M				Komatsu-M								Kanno/Nakai				Obara				Murakami				
beam test			ELPH		ELPH			ELPH	ELPH			LEPS			J-PARC		J-PARC		AVF	ELPH	AVF								
GTR					FADC			200/300				100-BVH			preamp		APV/foil-trig			final									
			angled track					charge share							gain					production (GEM, R/O)									
																							frame				install		
HBD			3p.e		6p.e			-	10p.e.						pion		cluster analysis			final									
			1st vessel				QE improvement						2nd vessel		LCP breakdown					production (GEM)									
																									CsI evaporation				
																							vessel					install	
LG												test			pion		90deg	design											
														decomposition			check						cut						
																							frame				install		
R/O circuit										total design																			
Trigger	UT3/FTSW															purchase		test					test				install		
	MGR															design	firmware				v1		v2						
	MGR-M																						v1						
GTR	preamp														v1		test		v2		test								
	ASIC																	v1	sub	test			v2sub	test					
	ASD																				v1		test						
HBD	preamp																		SRS			test		purchase					
	ASIC																			v1		sub	test						
	ASD																					v1							
LG	FEM														v1			test						v2					
High-p BL																		construction											comissioning

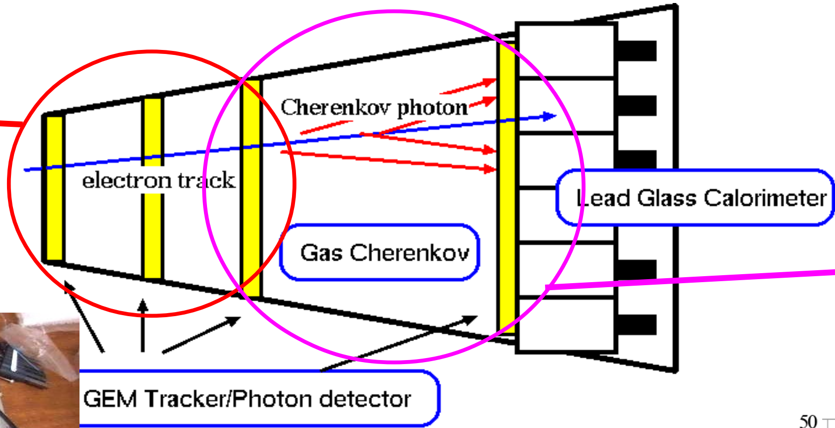
Beam test results of prototype detectors (2012)

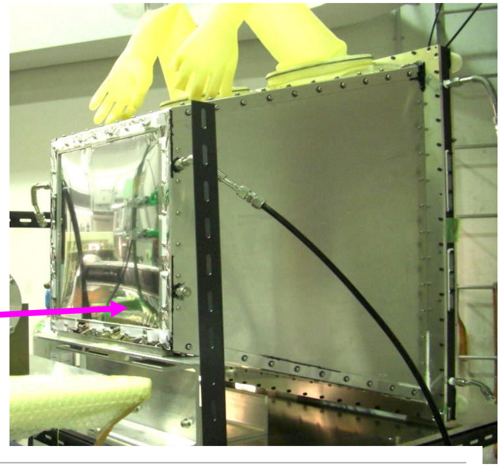
GEM Tracker

HBD (Hadron-Blind Cherenkov detector)



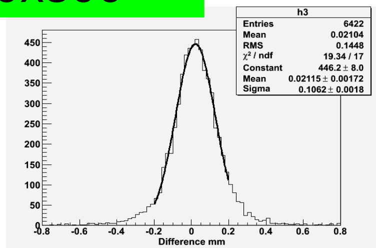




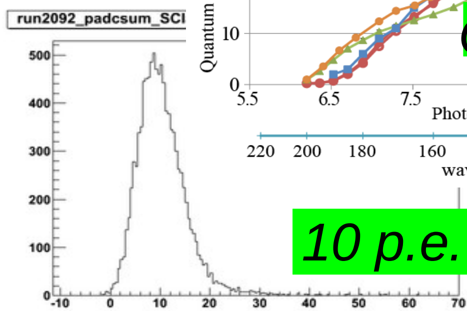


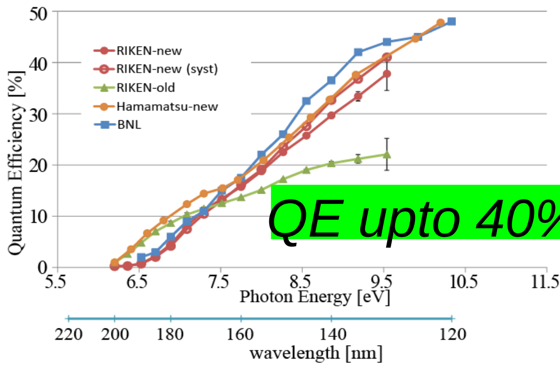
100x100 200x200 300x300

Required position resolution (~100µm) is achieved



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





QE upto 40%

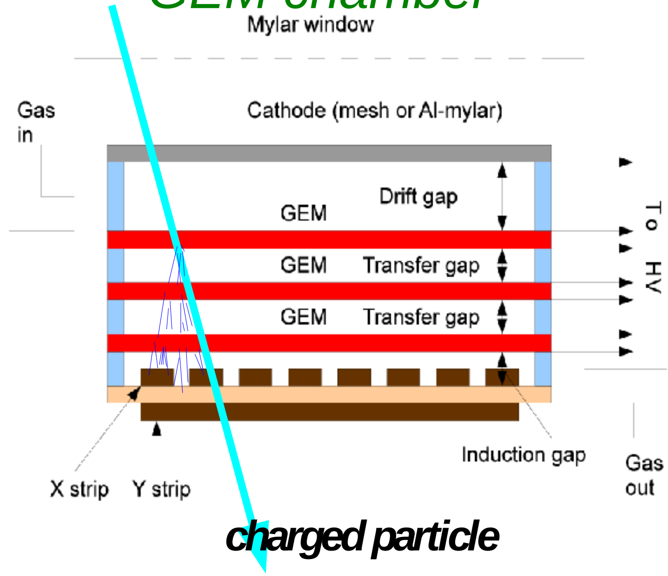
10 p.e.

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

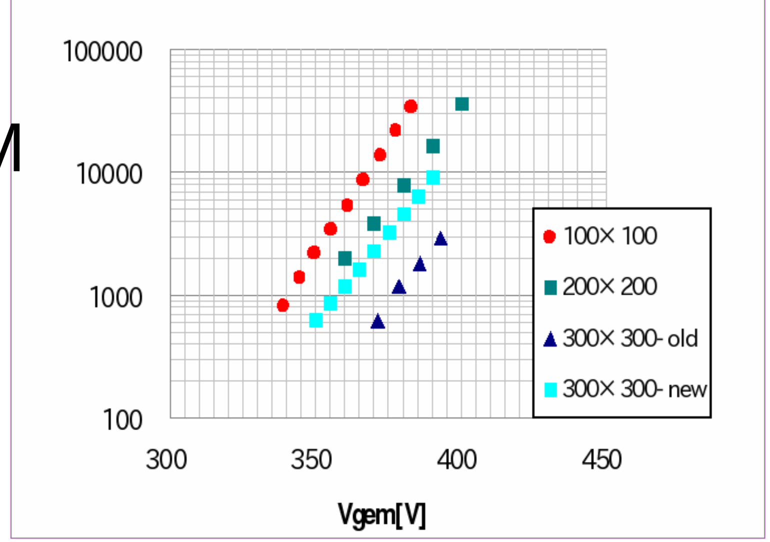
Detector R&D

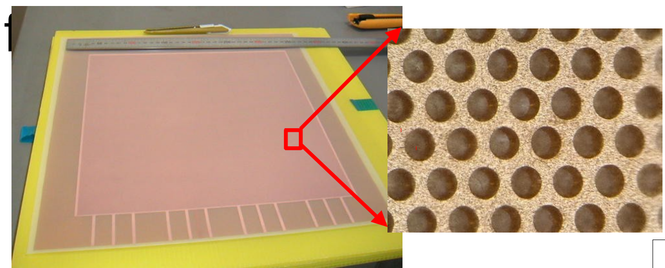
- GEM Tracker to cope with the high rate
  - Ar+CO_2(70:30)
  - angled injection, 2D readout,etc.
  - required position resolution 100um is achieved for angled tracks w/ FADC R/O
- Hadron Blind Detector to trigger the electrons
  - CsI photocathode, CF_4 gas purity, etc.
  -
- Domestic Large size (300mmx300mm)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

GEM chamber

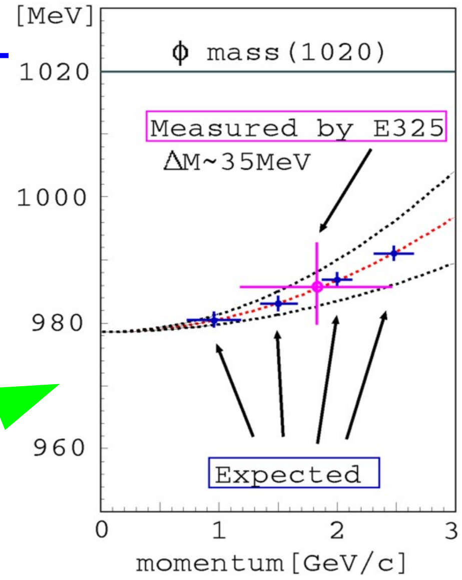


Gain curve of PI GEM





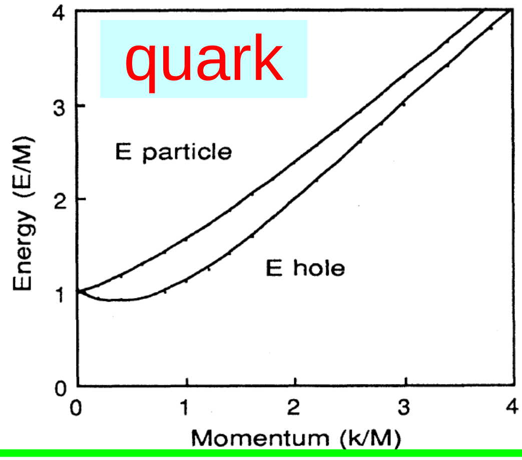
momentum dependence



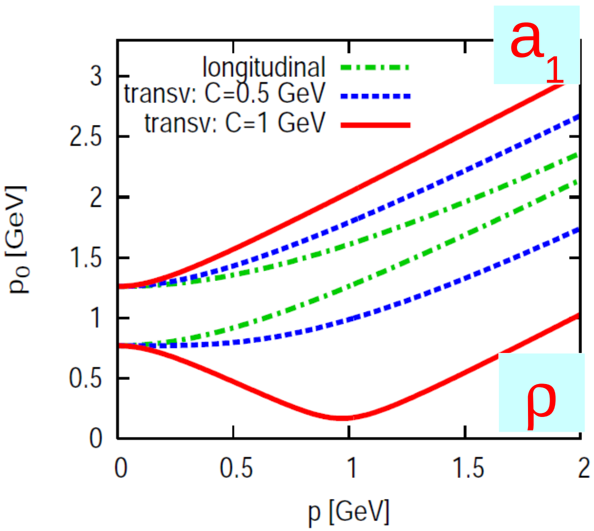
- From the view point of experimentalists
  - many predictions are for the mesons at rest (p=0)
    - extrapolation to p=0 if it is a simple dependence

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

- Weldon (PRD40(89)2410)



- Harada & Sasaki (PRC80(09)054912)



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