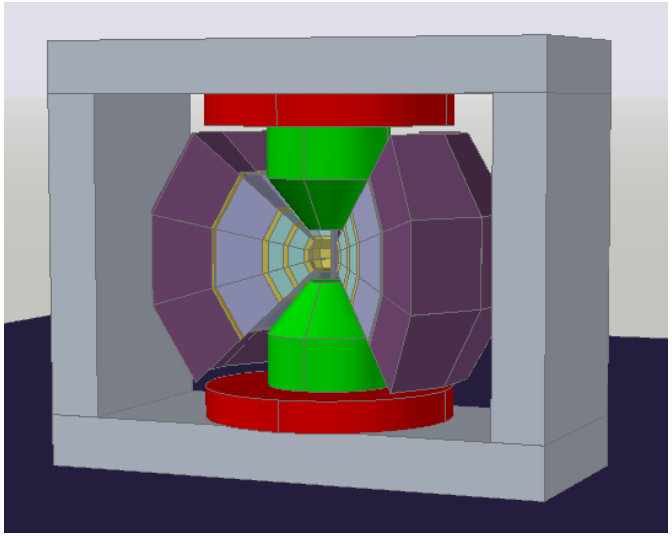
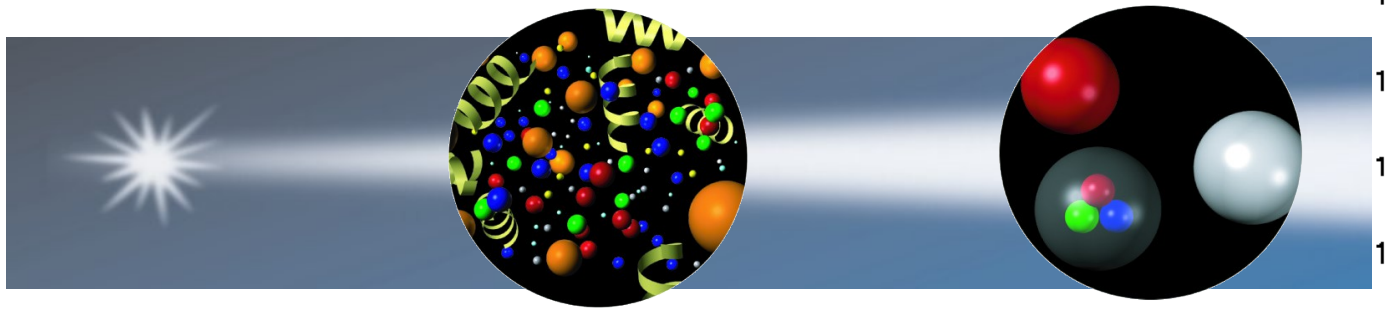
Vector meson measurements through the dilepton at KEK and J-PARC

Satoshi Yokkaichi
(RIKEN Nishina Center)

- Introduction
- Results of KEK-PS E325 experiment
  - observation of vector meson mass modification in nuclei
- J-PARC Hadron experimental facility
- Future : J-PARC E16 experiment
  - systematic study of mass modification of phi meson

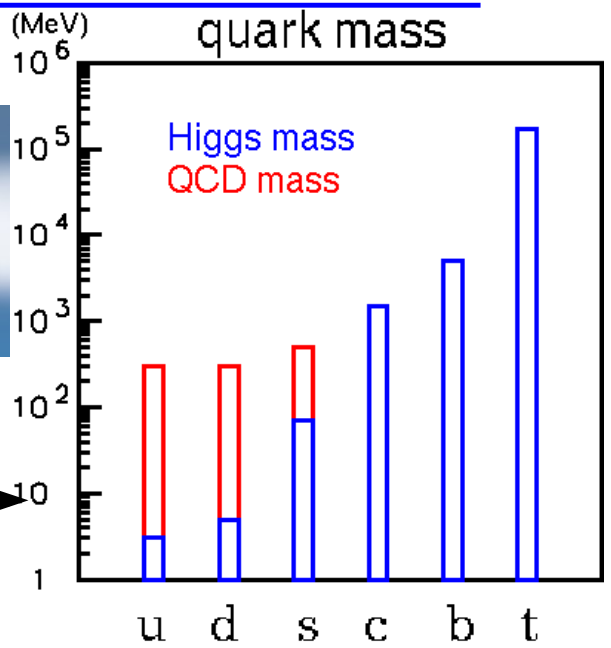


Mass and chiral symmetry in nuclear matter

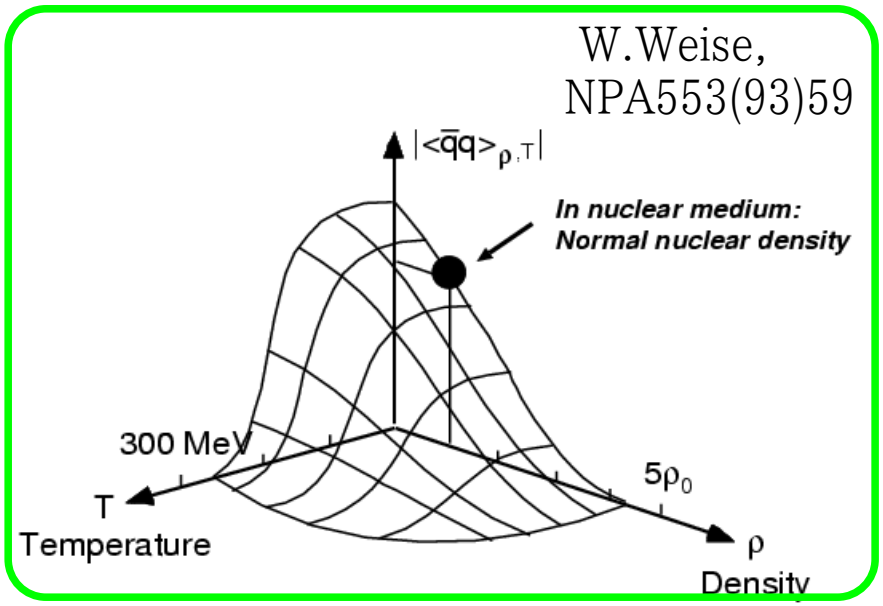


big bang 10psec 0.1msec

quark mass 0MeV 3MeV from Higgs 300MeV from chiral condensate $\langle\bar{q}q\rangle$



- Origin of hadron mass : spontaneous breaking of chiral symmetry
- In hot/dense matter, chiral symmetry is expected to be restored
  - hadron modification is also expected
  - many theoretical predictions, related CS restoration (or not); meson mass decreasing, width broadening, and so on.



Vector meson mass spectra in dense matter

Bronwn-Rho scaling
PRL 66(91)2720, etc

$$m_\rho^*/m_\rho \sim (\langle\bar{q}q\rangle^*/\langle\bar{q}q\rangle)^{1/2}$$

effective Lagrangian (chiral SU(3)+VMD)
Klingle,Kaiser,Weise,
NPA 624(97)527

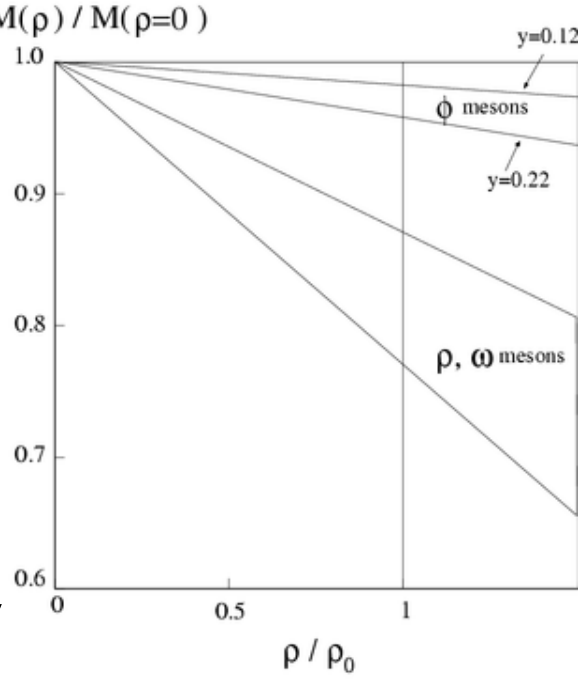
QCD sum rule
Hatsuda and Lee, PRC 46(92)R34, PRC 52(95)3364

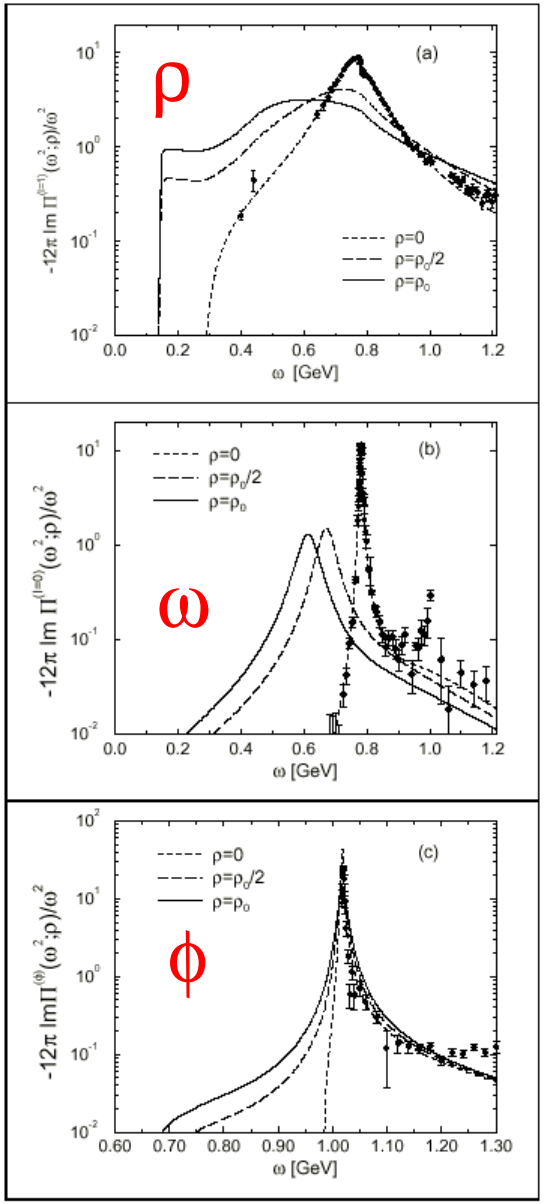
linear dependence on der

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

mass 'dropping'
- 16(±6)% for ρ/ω
- 0.15(±0.05)*y
  =2~4% for ϕ

for y=0.22
at the normal nuclear density

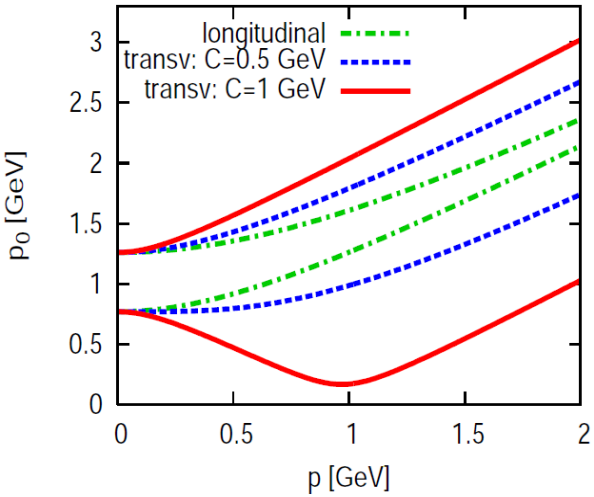




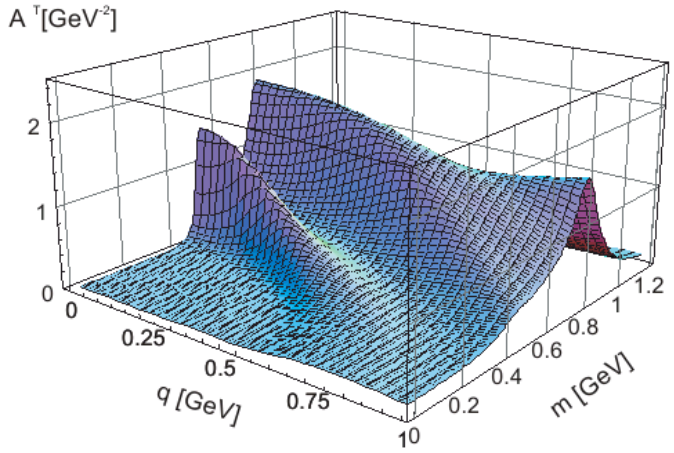
dispersion (mass VS momentum) in dense matter

- 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

- Harada & Sasaki (PRC80(09)054912)



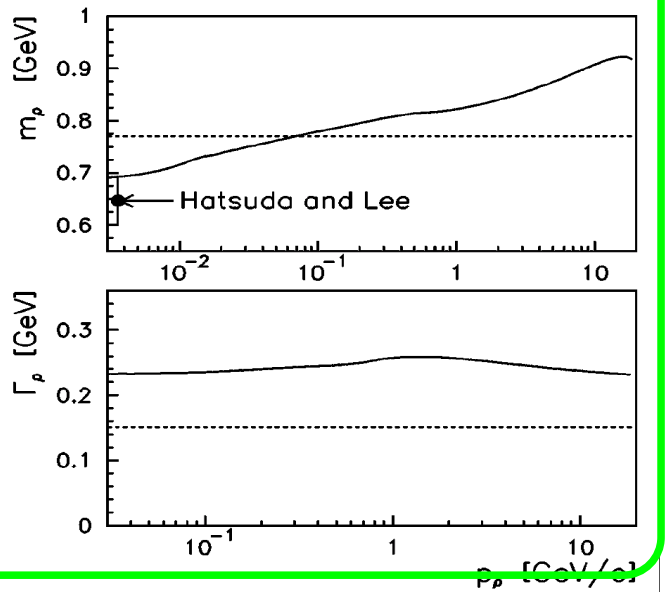
- Post & Mosel (NPA699(02)169)



ρ

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

ρ



Experiment KEK-PS E325

- 12GeV p+A $\rightarrow$ $\rho/\omega/\phi$ +X ($\rho/\omega/\phi \rightarrow e^+e^-$, $\phi \rightarrow K^+K^-$)
- Experimental key issues:
  - Very thin target to suppress the conversion electron background (typ. 0.1% interaction/0.2% radiation length of C)
  - To compensate the thin target, high intensity proton beam to collect high statistics (typ. 10^9 ppp $\rightarrow$ 10^6Hz interaction)
  - Large acceptance spectrometer to detect slowly moving mesons, which have larger probability decaying inside nuclei ($1<\beta\gamma<3$)

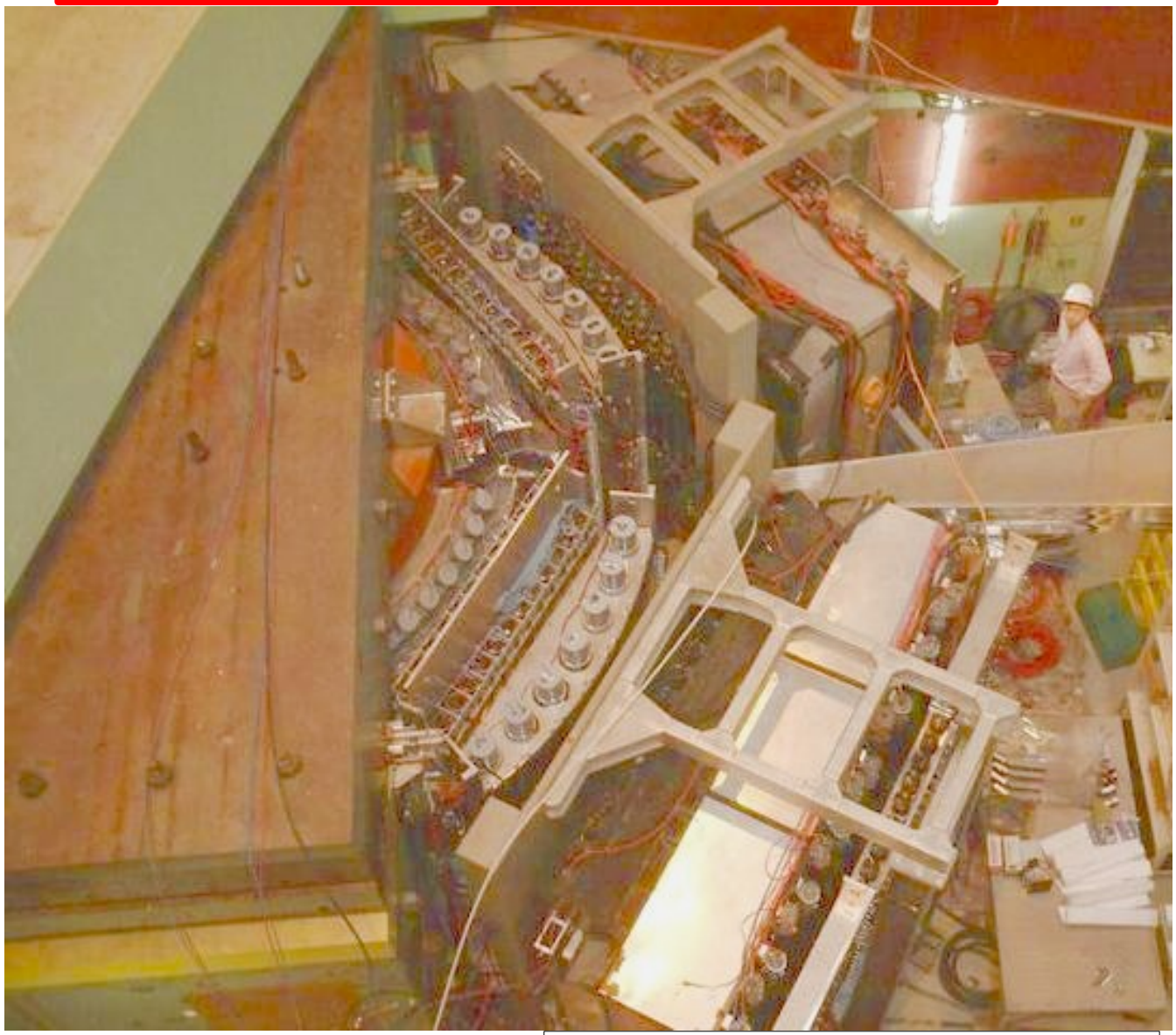
Collaboration

J. Chiba, H. En'yo, Y. Fukao, H. Funahashi, H. Hamagaki, M. Ieiri, M. Ishino, H. Kanda, M. Kitaguchi, S. Mihara, K. Miwa, T. Miyashita,T. Murakami, R. Muto, T. Nakura, M. Naruki, K.Ozawa, F. Sakuma, O. Sasaki, M.Sekimoto, T.Tabaru, K.H. Tanaka, M.Togawa, S. Yamada, S.Yokkaichi, Y.Yoshimura
(Kyoto Univ. , RIKEN, KEK, CNS-U.Tokyo, ICEPP-U.Tokyo, Tohoku-Univ.)

History of E325

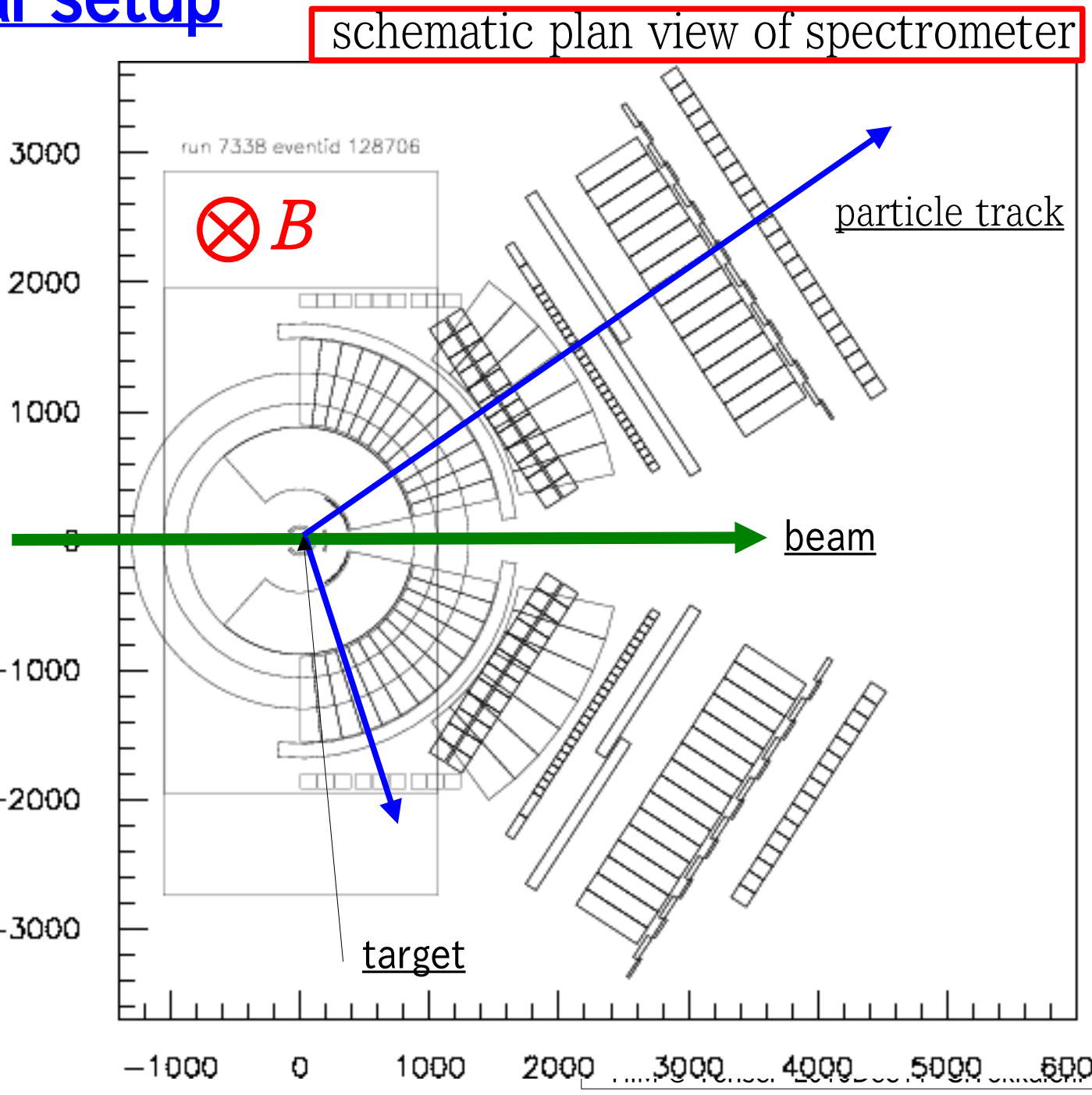
- 1993 proposed
- 1994 R&D start
- 1996 construction start
- '97 data taking start
- '98 first ee data
  - PRL86(01)5019 ρ/ω (ee)
- 99,00,01,02....
  - x100 statistics
  - PRL96(06)092301 ρ/ω (ee)
  - PRC74(06)025201 α (ee)
  - PRL98(07)042501 φ (ee)
  - PRL98(07)152302 φ (KK),α
- '02 completed
- spectrometer paper
  - NIM A457(01)581
  - NIM A516(04)390

E325 spectrometer
located at KEK-PS EP1-B primary beam line



Experimental setup

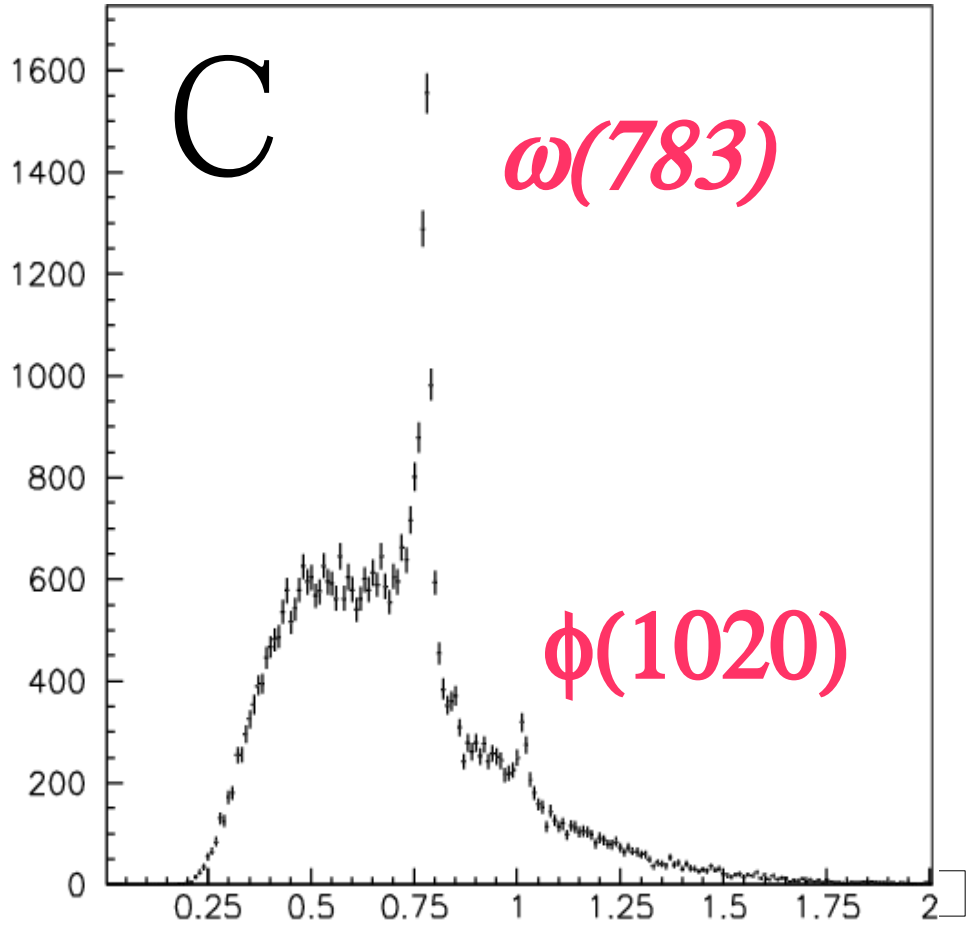
- Spectrometer Magnet
  - 0.71T at the center
  - 0.81Tm in integral
- Targets
  - at the center of the Magnet
  - C & Cu are used typically
  - very thin: ~0.1% interaction length
- Primary proton beam
  - 12.9 GeV/c
  - ~$1x10^9$ in 2sec duration, 4sec cycle



E325 Results (1)

e^+e^- invariant mass spectra

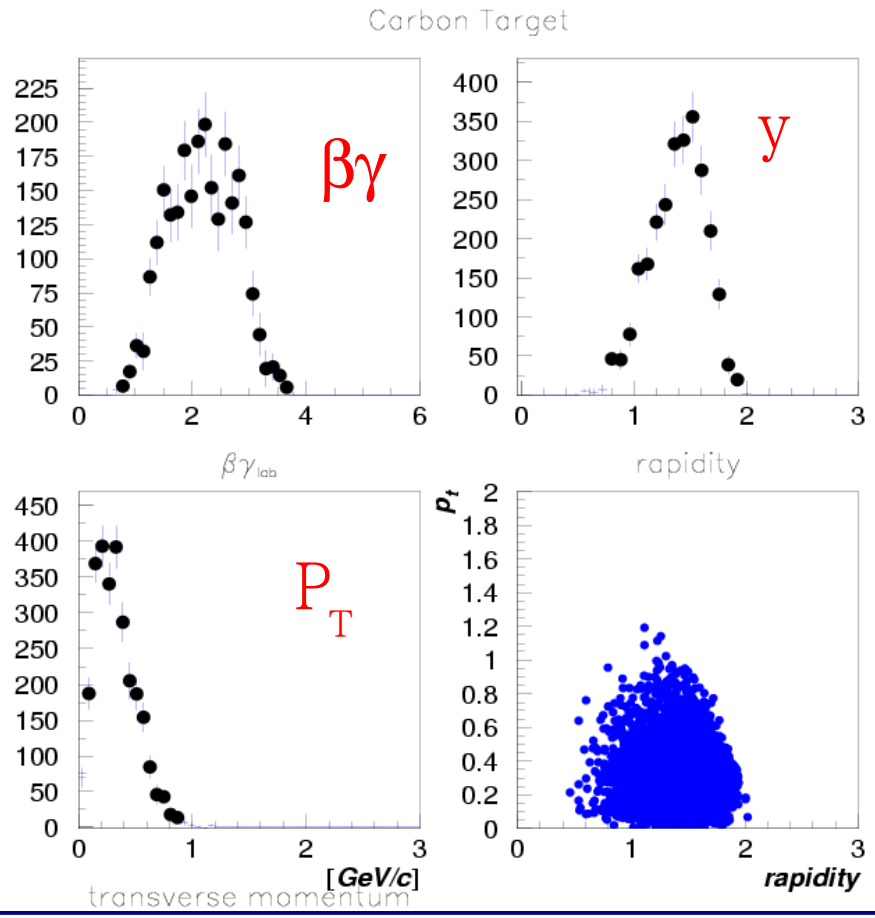
M. Naruki et al.,
PRL 96 (2006) 092301
R.Muto et al.,
PRL 98 (2007) 042501



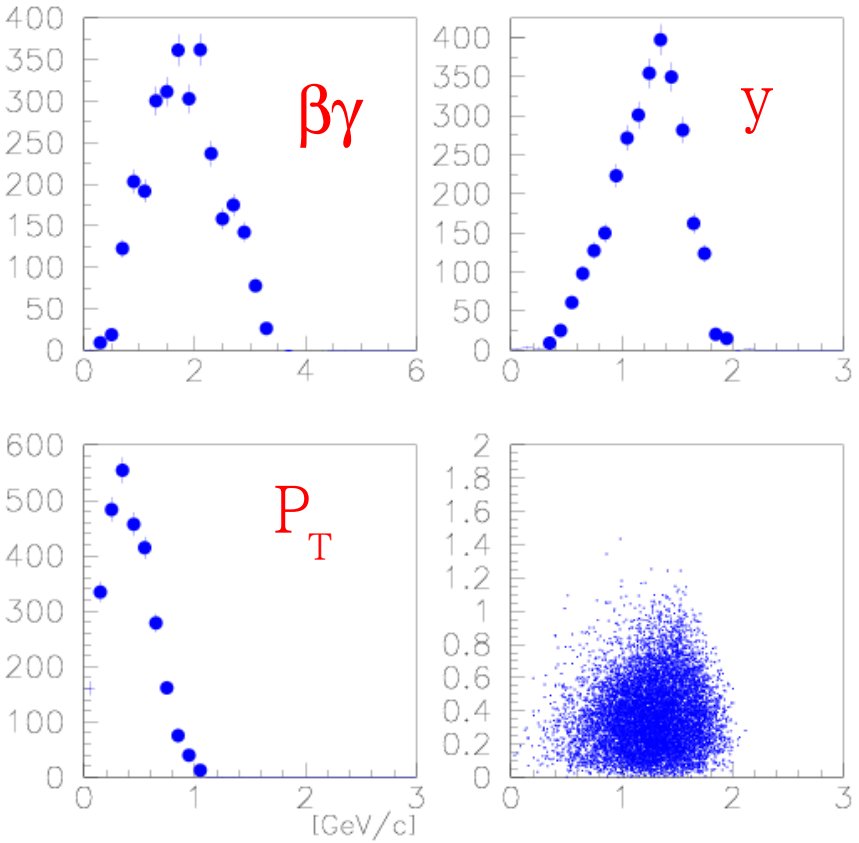
measured kinematic distribution of $\omega/\phi \rightarrow e^+e^-$

- $0 < P_T < 1$, $0.5 < y < 2$ (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)

ω

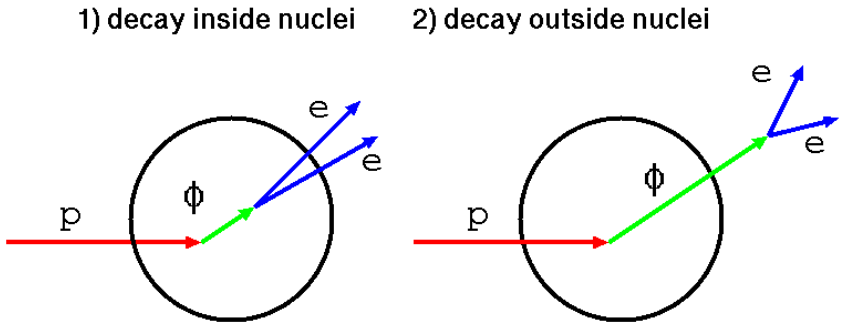


ϕ

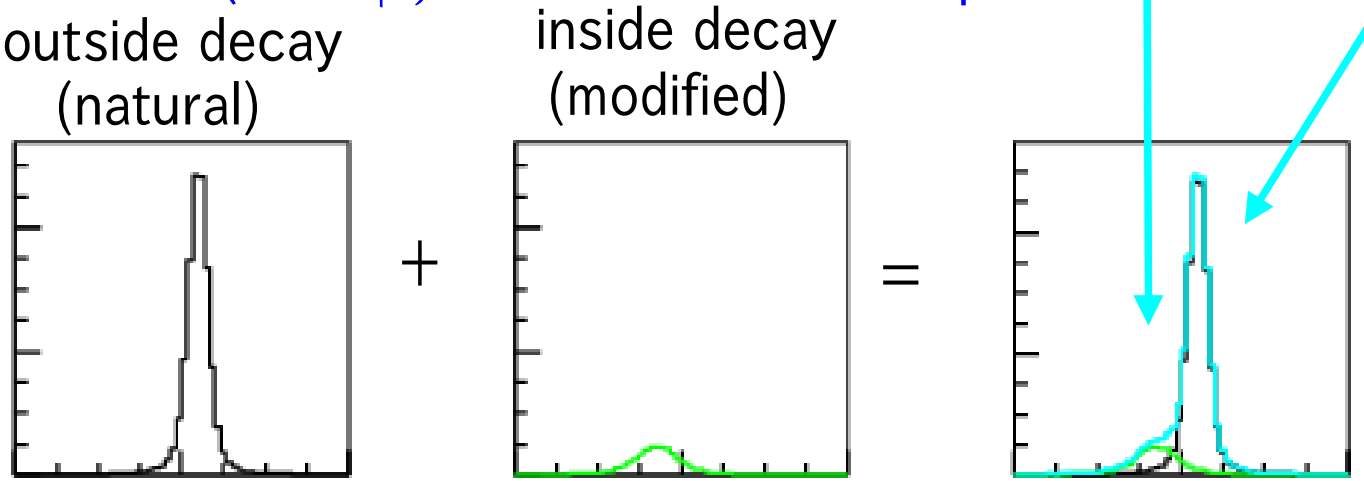


Expected Invariant mass spectra in e^+e^-

- 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



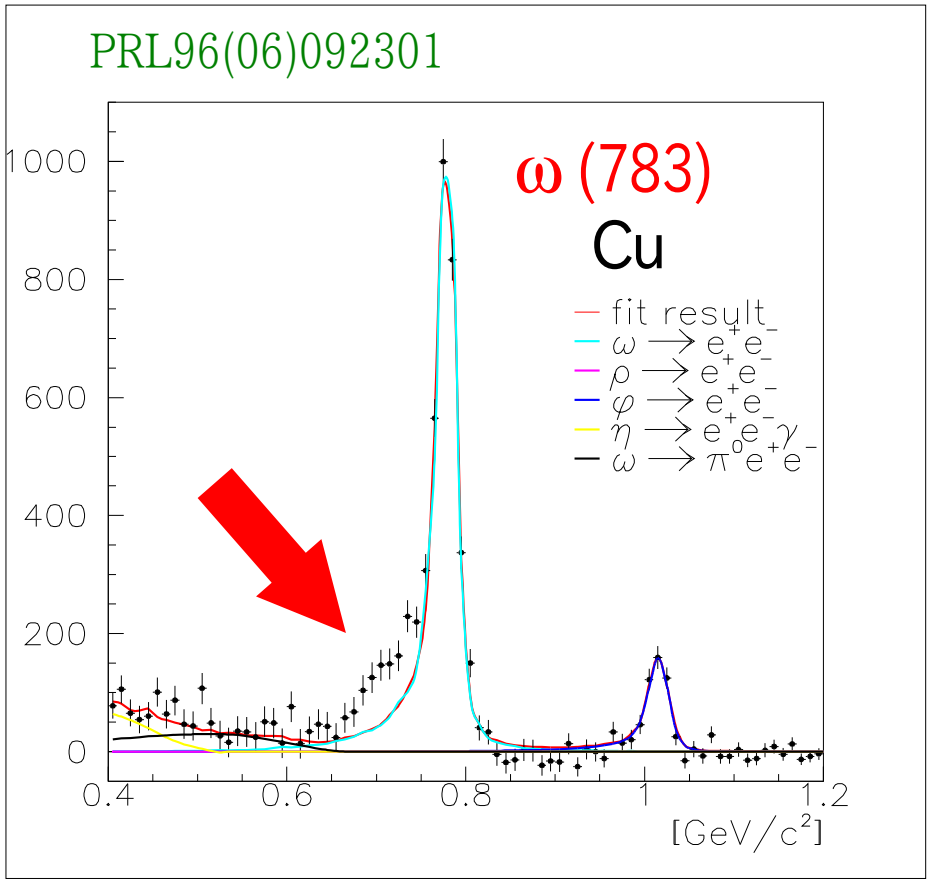
longer-life meson(ω & ϕ)cases : Schematic picture

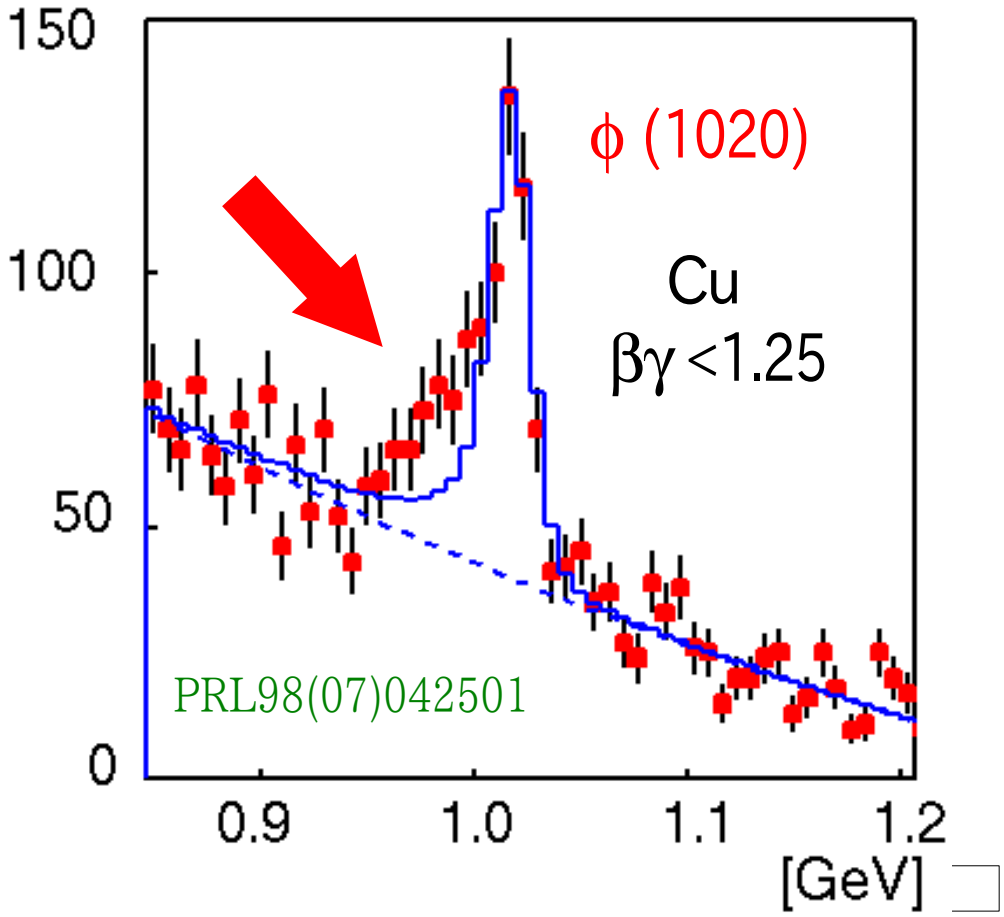


expected
to be observed

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

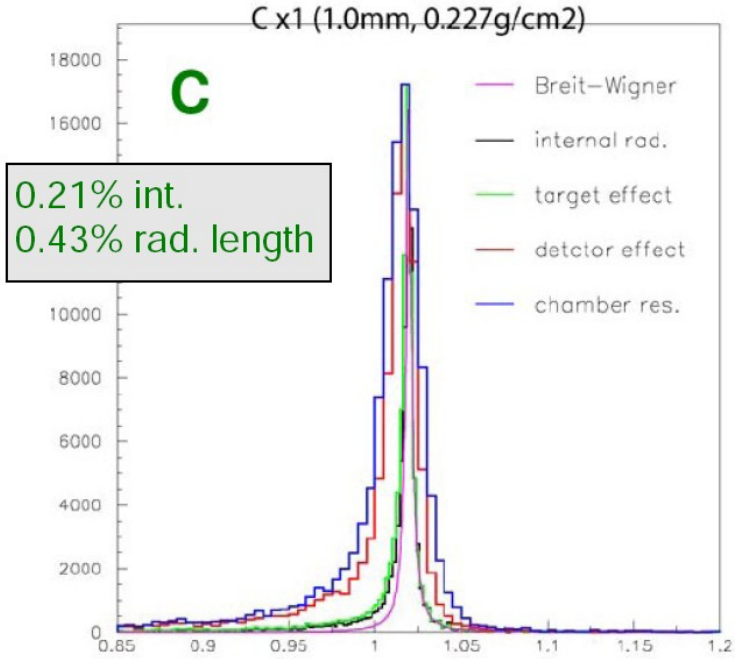




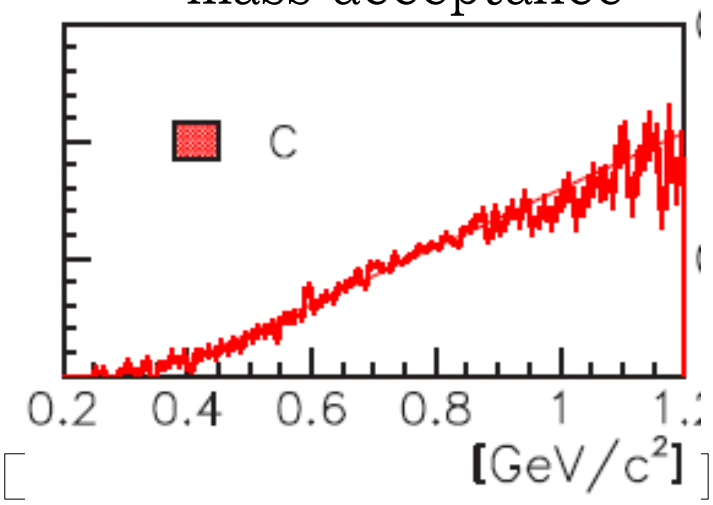
Analysis : Fitting with known sources

- Hadronic sources of e^+e^-:
  - $\rho/\omega/\phi \rightarrow e^+e^-$, $\omega \rightarrow \pi^0 e^+e^-$, $\eta \rightarrow \gamma e^+e^-$
  - relativistic Breit-Wigner shape (without any modifications, but internal radiative corrections are included)
  - Geant4 detector simulation
    - multiple scattering and energy loss of e^+/e^- in the detector and the target materials
    - chamber resolutions
    - detector acceptance, etc.
- Combinatorial background :event mixing method
- Relative abundance of these components are determined by the fitting

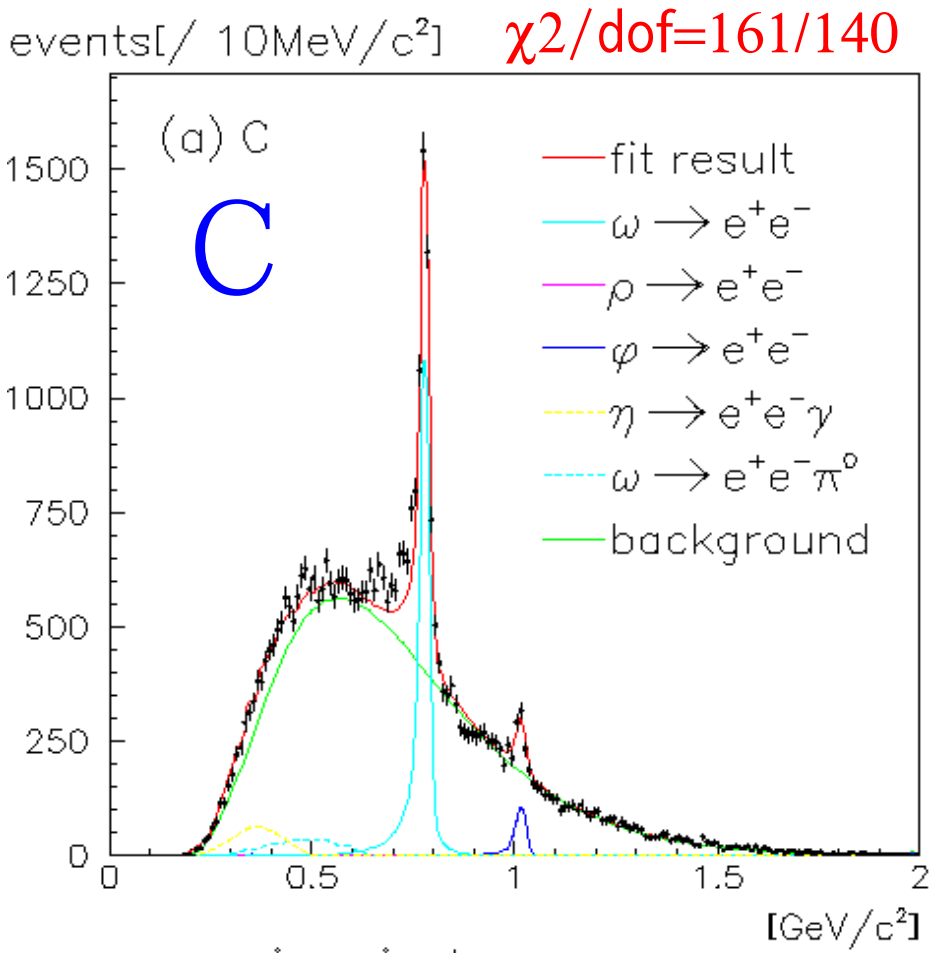
experimental effects

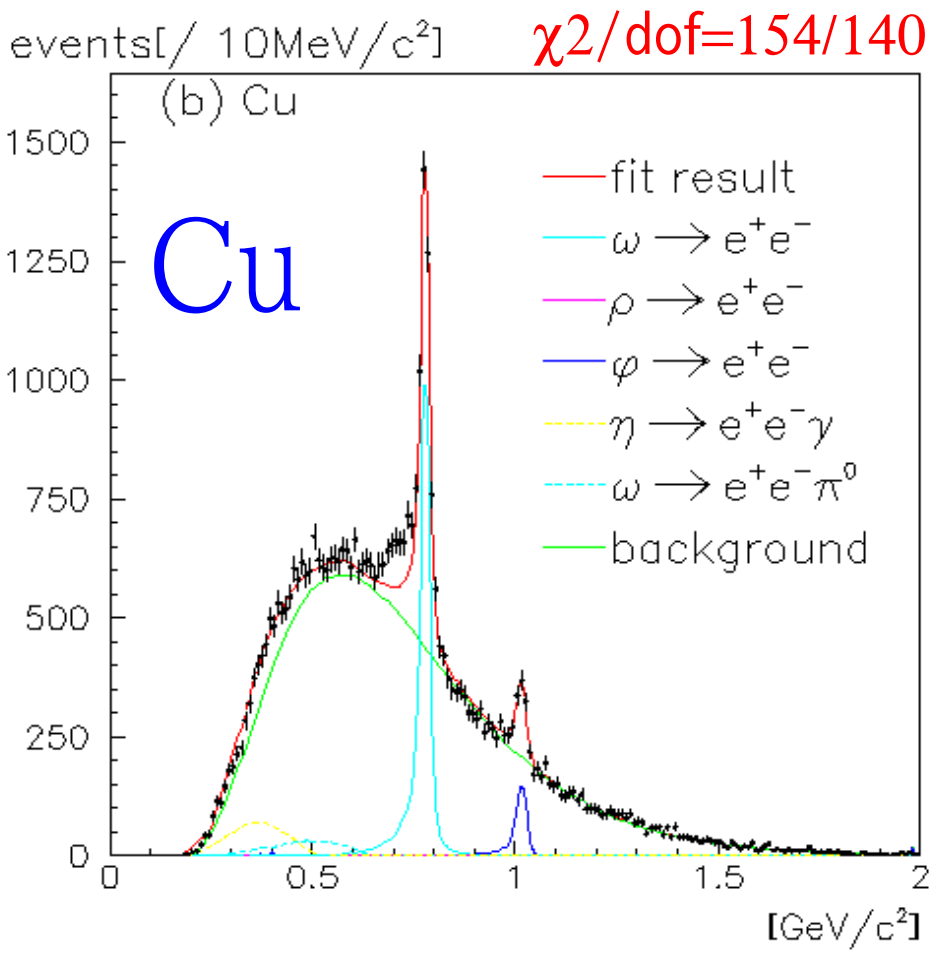


mass acceptance



Fitting results (ρ/ω)

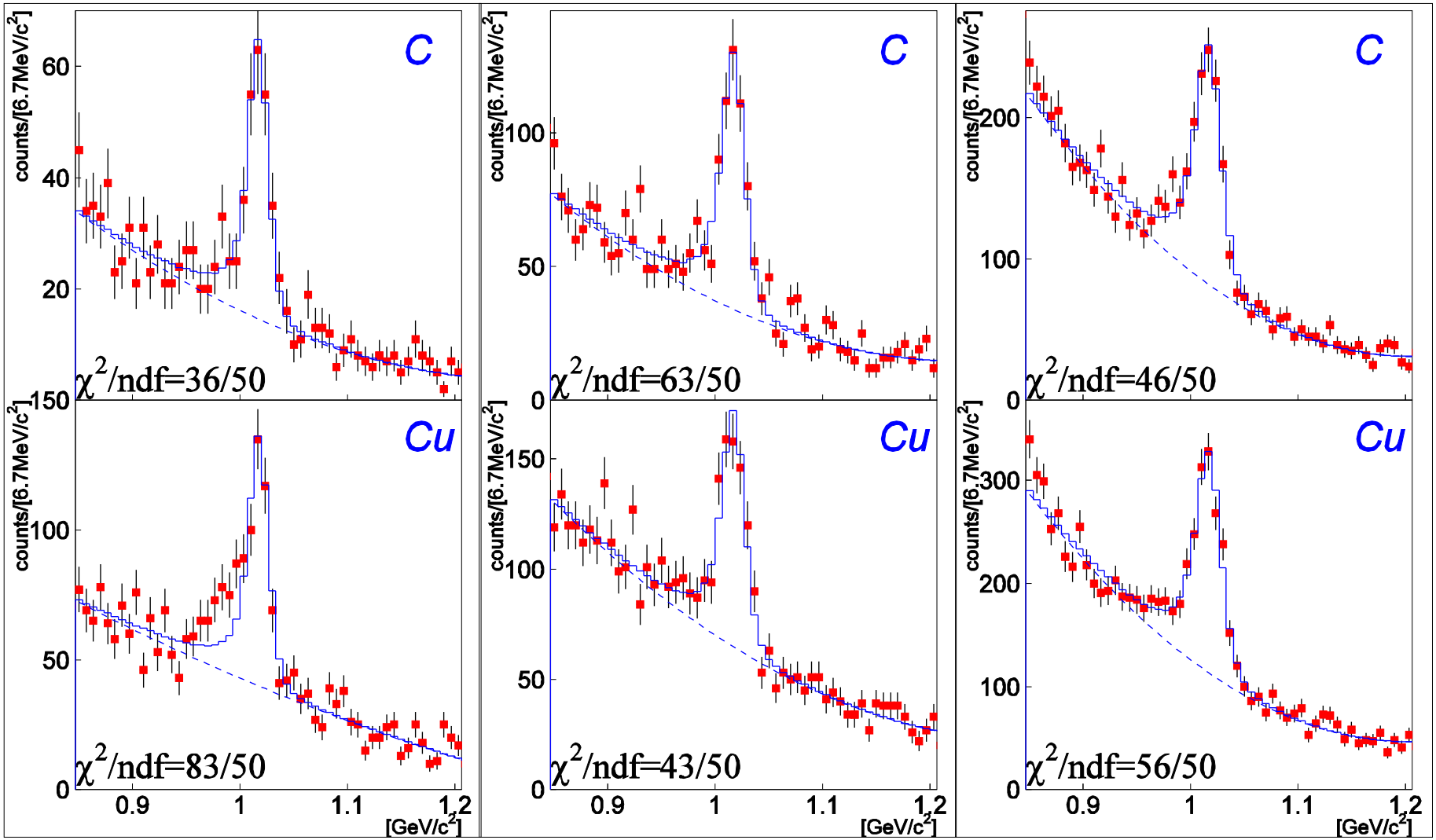




- 1) excess at the low-mass side of ω
  - To reproduce the data by the fitting, we have to exclude the excess region : 0.60-0.76 GeV
- 2) ρ meson component seems to be vanished. (ρ/ω =1.0±0.2 in a former experiment)

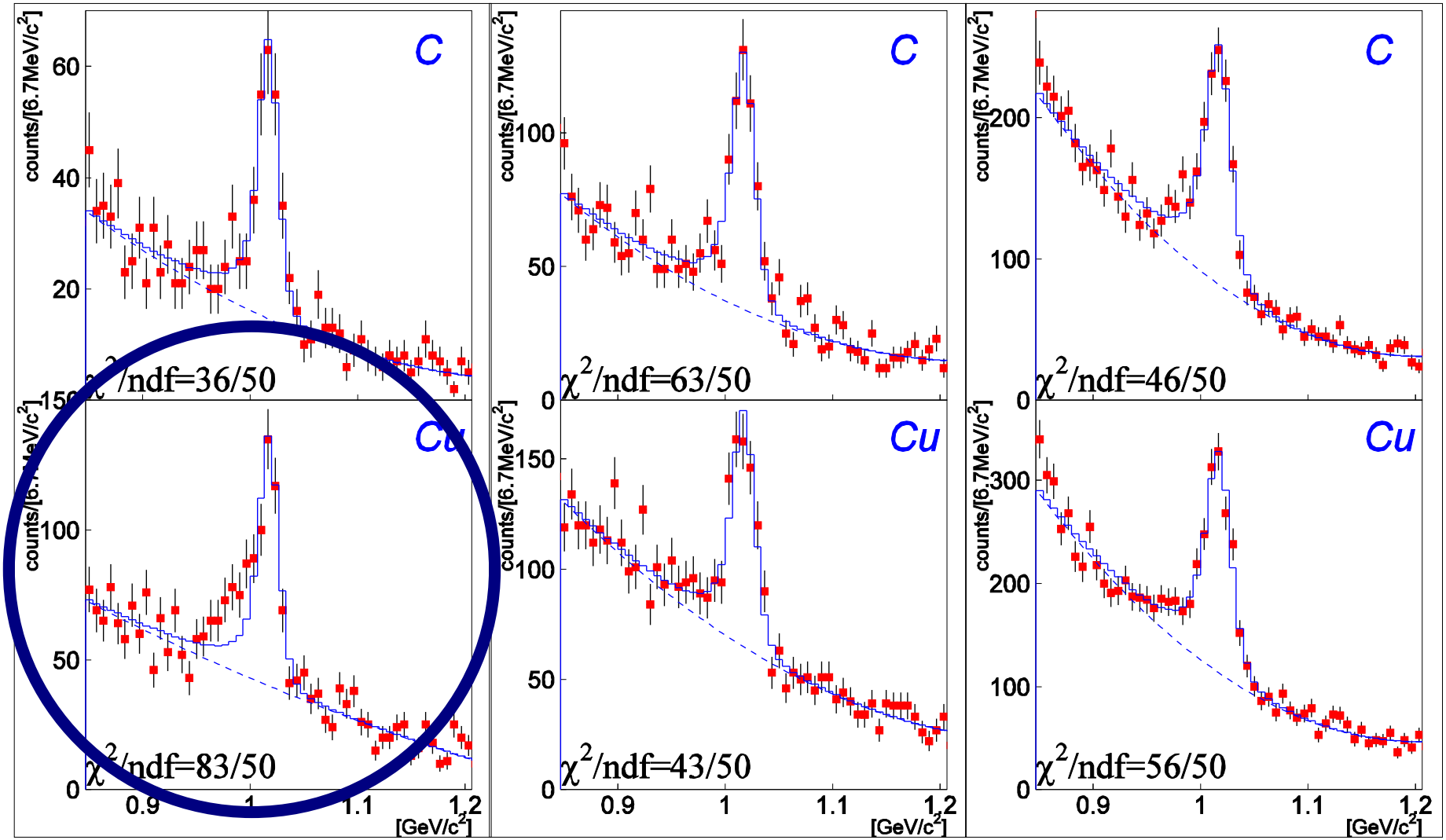
e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

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



e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

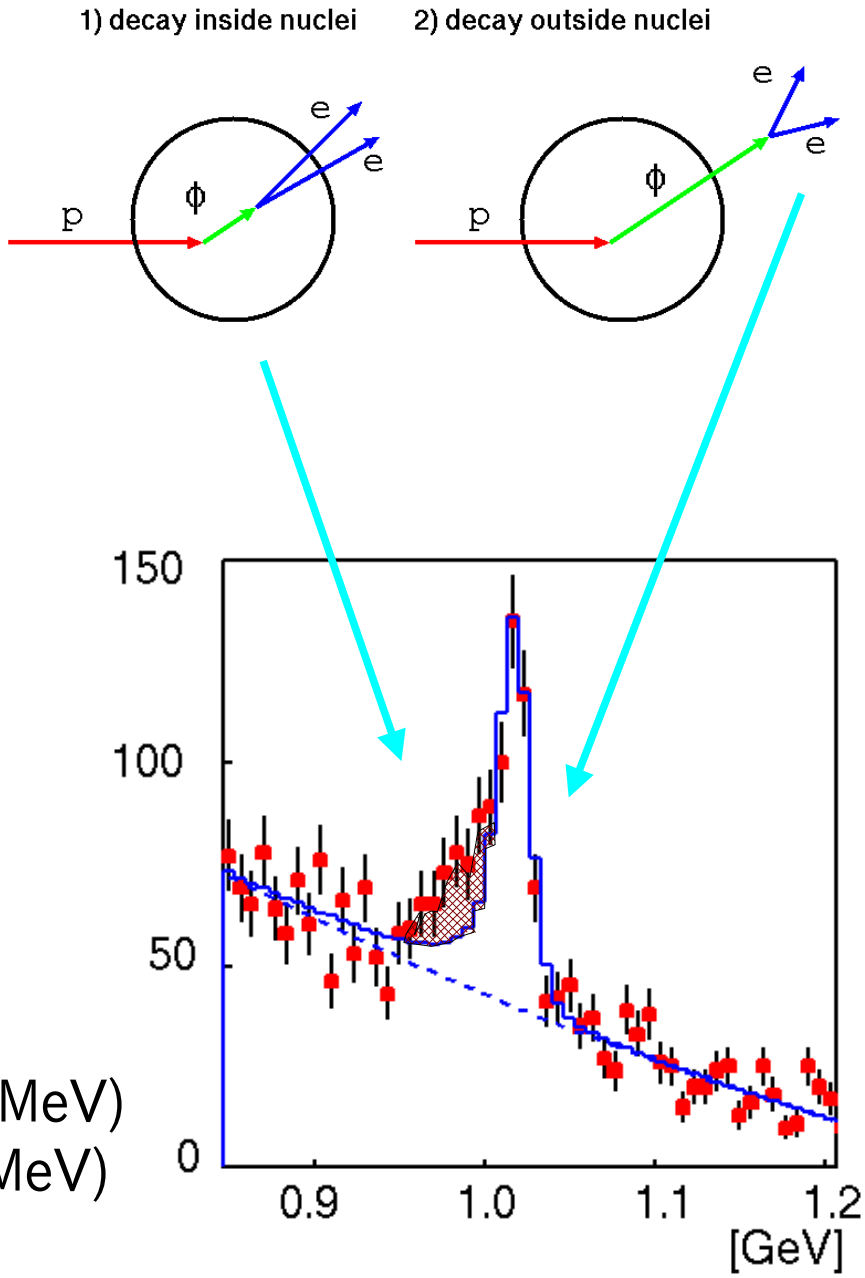
$\beta\gamma$<1.25 (Slow) | 1.25<$\beta\gamma$<1.75 | 1.75<$\beta\gamma$ (Fast)



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)



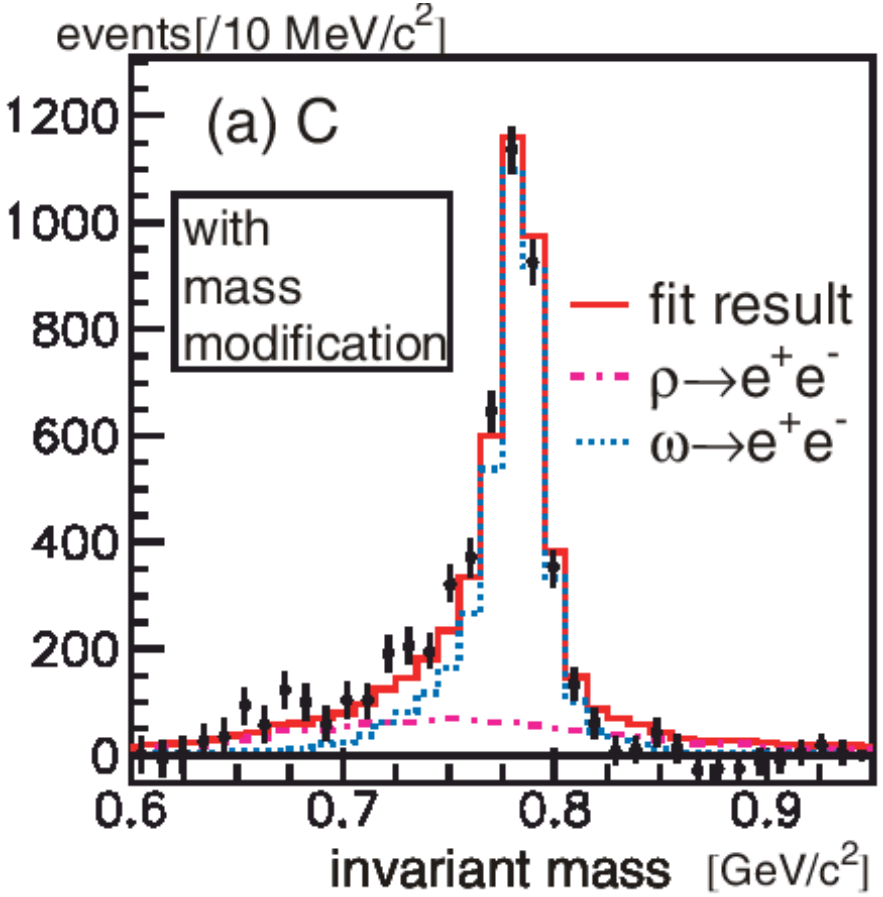
$$k_1 = 0.034^{+0.006}_{-0.007}$$

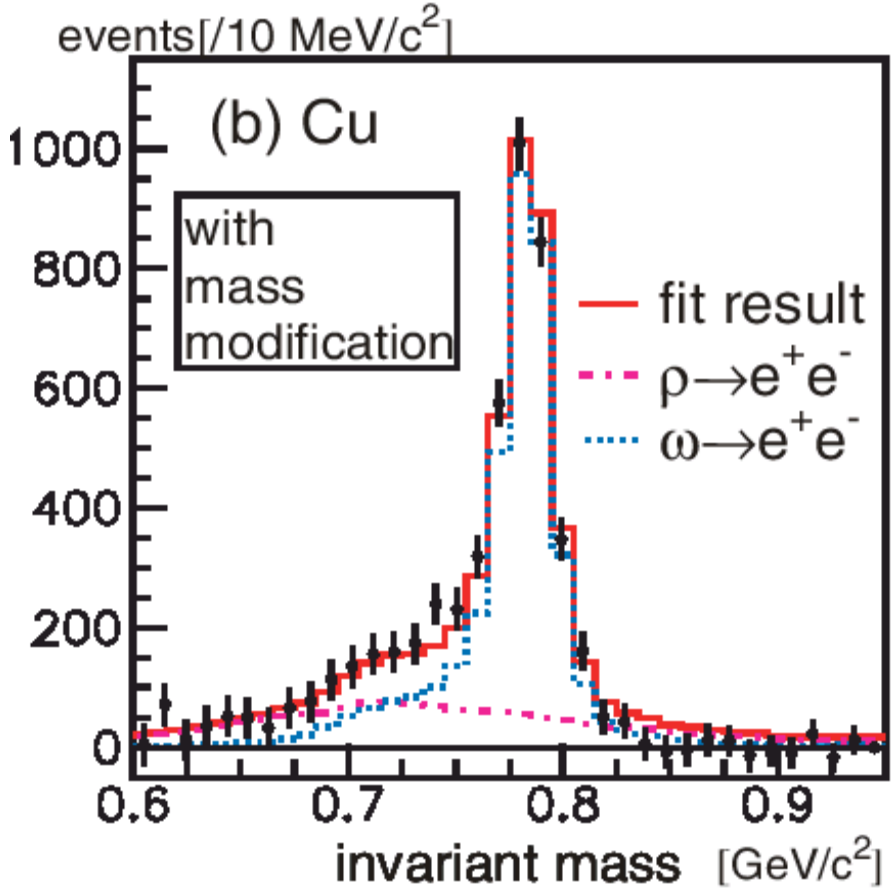
$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$

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

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 kω is assumed to be 0 (*i.e.* not modified), kρ could be smaller.

E325 Results (2)

KK invariant mass / branching ratio

F. Sakuma et al., PRL98(2007)152302
tendency of KK branch enhancement

Production Cross sections

T.Tabaru et al., PRC74(2006)025201
nuclear dependence of CS : $\sigma(A)=\sigma_0\times A^{\alpha}$

α_ω = 0.710 ± 0.021(stat.) ± 0.037(syst.)

α_ϕ = 0.937 ± 0.049(stat.) ± 0.018(syst.)

Summary (1)

- E325 observed mass modification of vector mesons in nuclear matter
  - in $\rho/\omega \rightarrow e^+e^-$
    - in the e^+e^- channel, ρ and ω cannot be distinguished
  - in $\phi \rightarrow e^+e^-$
    - only one histogram has significance
  - in $\phi \rightarrow K^+K^-$, there is a hint in the branching ratio, but not significant
- Next step in the invariant-mass approach
  - $\phi \rightarrow e^+e^-$: less uncertain than the ρ/ω case
    - ρ's broad and complicated shape, ρ–ω interference, ρ/ω ratio, etc.
  - systematic study of the mass modification
    - matter-size dependence: larger/smaller nuclei, impact parameter
    - momentum dependence : never measured
  - check the interpretation models

J-PARC E16 experiment

Systematic study of the modification of vector meson spectra in nuclei to approach the chiral symmetry restoration

Collaboration

RIKEN S.Yokkaichi, H. En'yo, F. Sakuma, K. Aoki, J. Kanaya
U-Tokyo K. Ozawa, K. Utsunomiya, Y.S. Watanabe, Y.Komatsu, S.Masumoto, A.Takagi, K. Kanno
CNS, U-Tokyo H. Hamagaki Hiroshima-U K. Shigaki
KEK A.Kiyomichi, M. Naruki, R. Muto, S. Sawada, M. Sekimoto

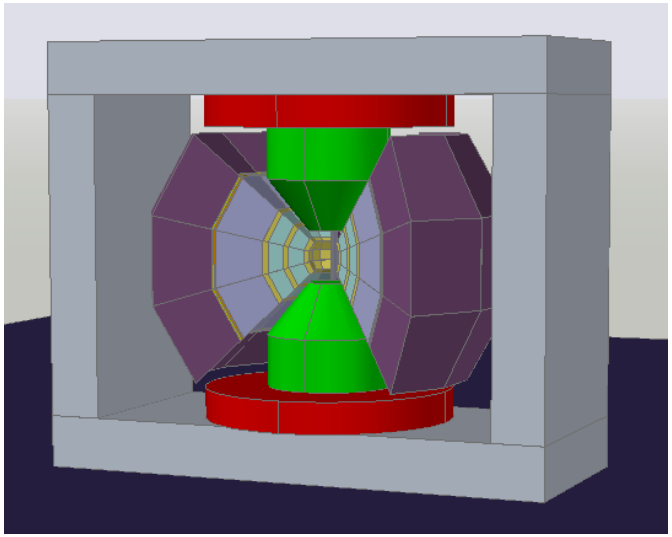
Proposal http://ribf.riken.jp/~yokkaich/paper/jparc-proposal-0604.pdf

Scientific approval : 2007/3
... Detector R&D is on going (already supported)
... production is dependent on budget status
... beamline is also : budget requested by KEK/J-PARC
Goal of construction : 2012/autumn

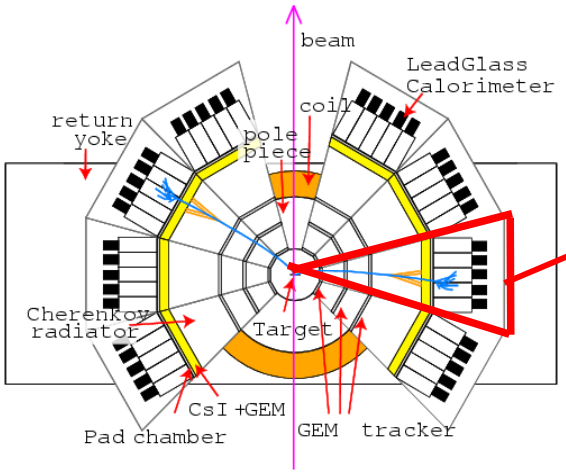
Collect high statistics for the systematic study

- For the statistics 100 times as large as E325, new spectrometer is required.
  - To cover larger acceptance : x~ 5
  - Higher energy beam (12 → 30/50 GeV) : x ~2 of production
  - Higher intensity beam (10^9 →10^{10} /spill (1sec)) : x 10 (→ ~ 10MHz interaction on targets)

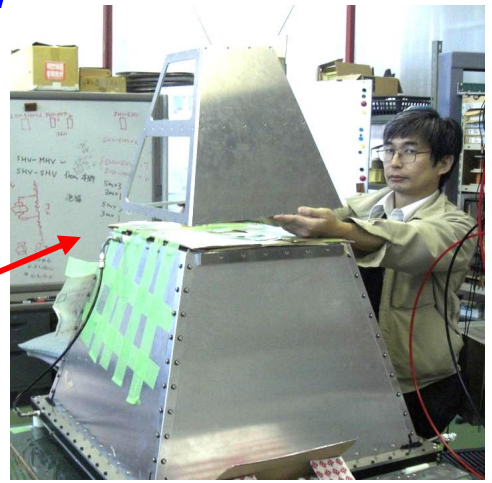
Proposed Spectrometer



Plan View

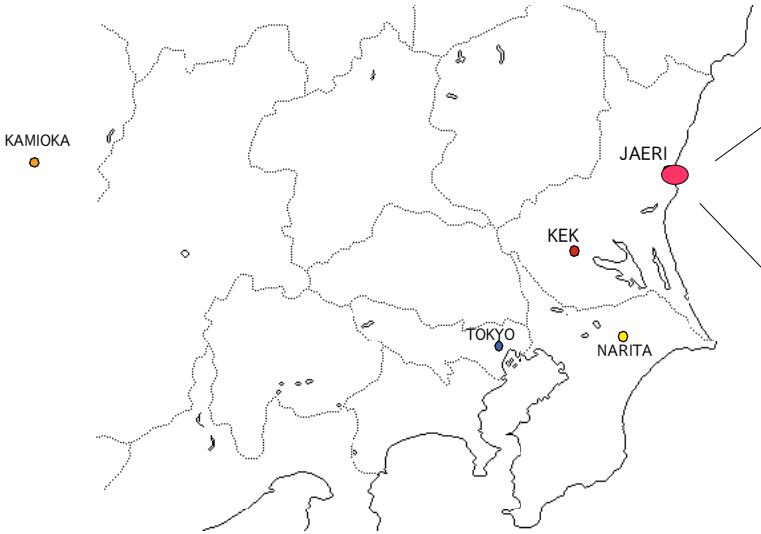


Prototype Module



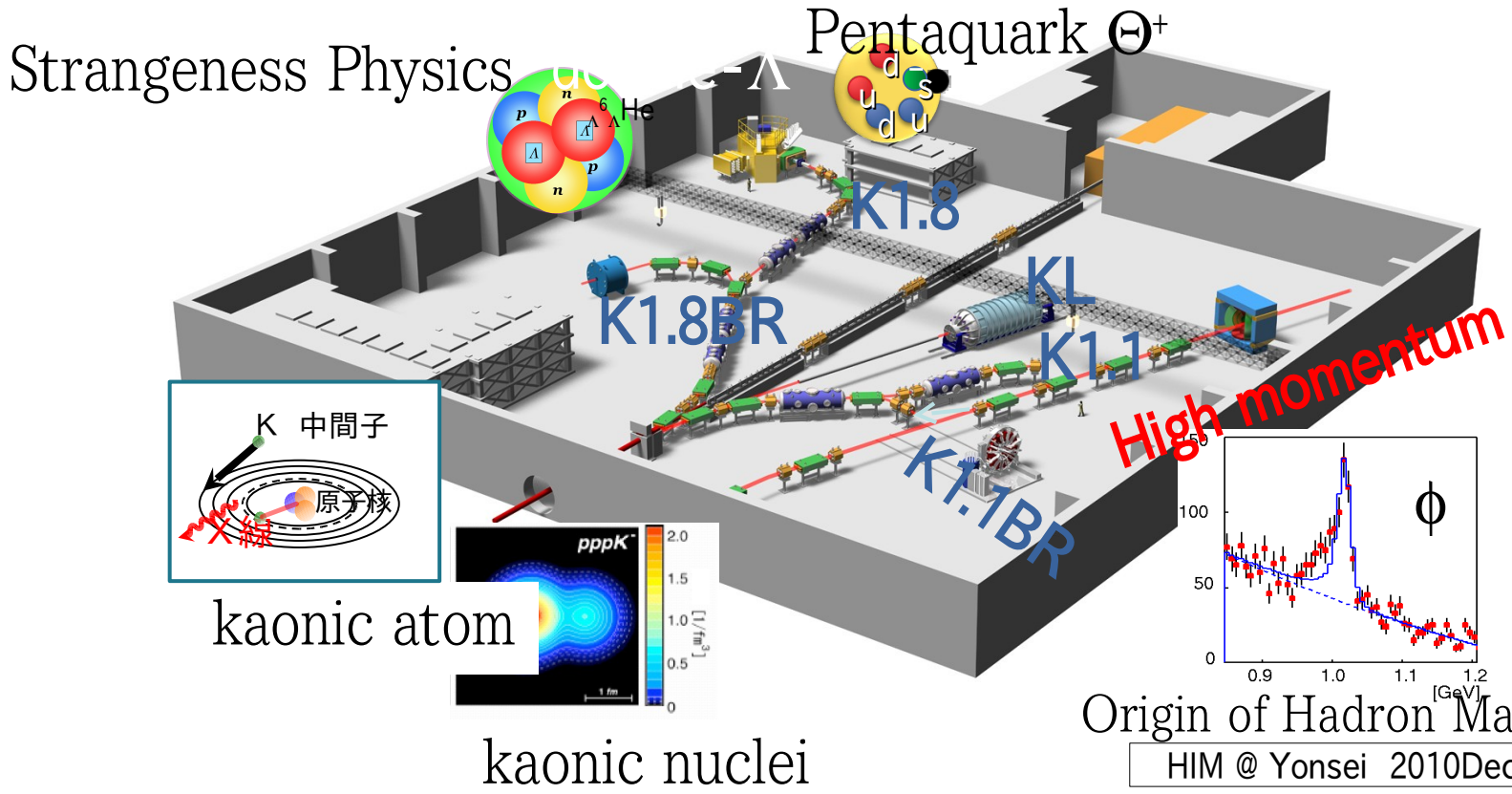
J-PARC : Japan Proton Accelerator Research Complex

- High Intensity Proton accelerator (3GeV and 50GeV rings) -> secondary beams
  - material & life science using neutron and muon beams
  - nuclear and hadronic physics using pion, kaon, anti-proton and primary proton beams
  - neutrino beam to Kamioka
- At Tokai village, 2 hours from Tokyo by train and taxi

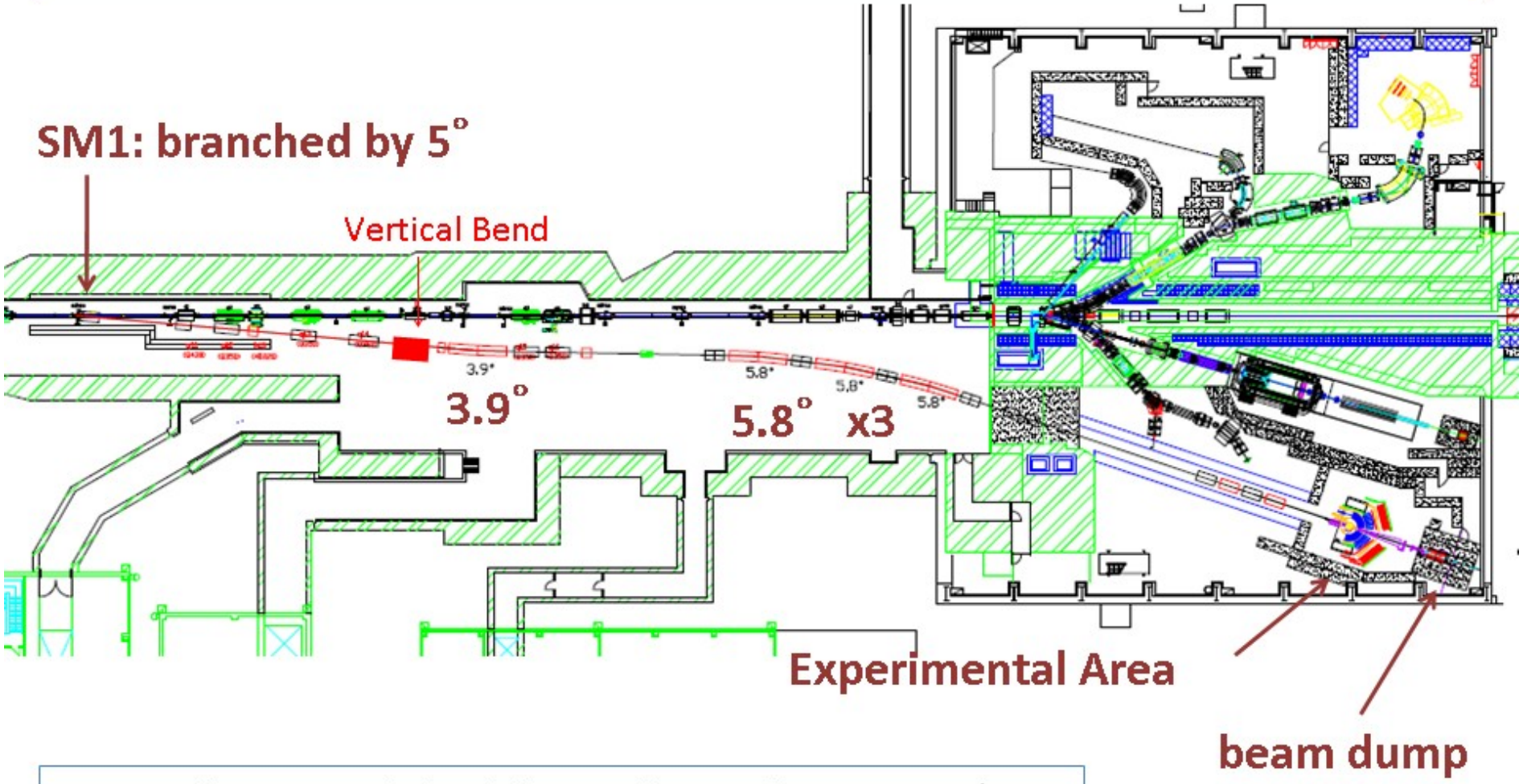


Hadron experimental facility in J-PARC

- 50GeV Main Ring (MR) is operated in 30GeV, first acceleration in 2008/12
- first slow extraction to Hadron experimental facility in 2009/1
  - first physics experiment (E19 : pentaquark search), using 1.9 GeV/c pion beam, was executed in 2010/10-11

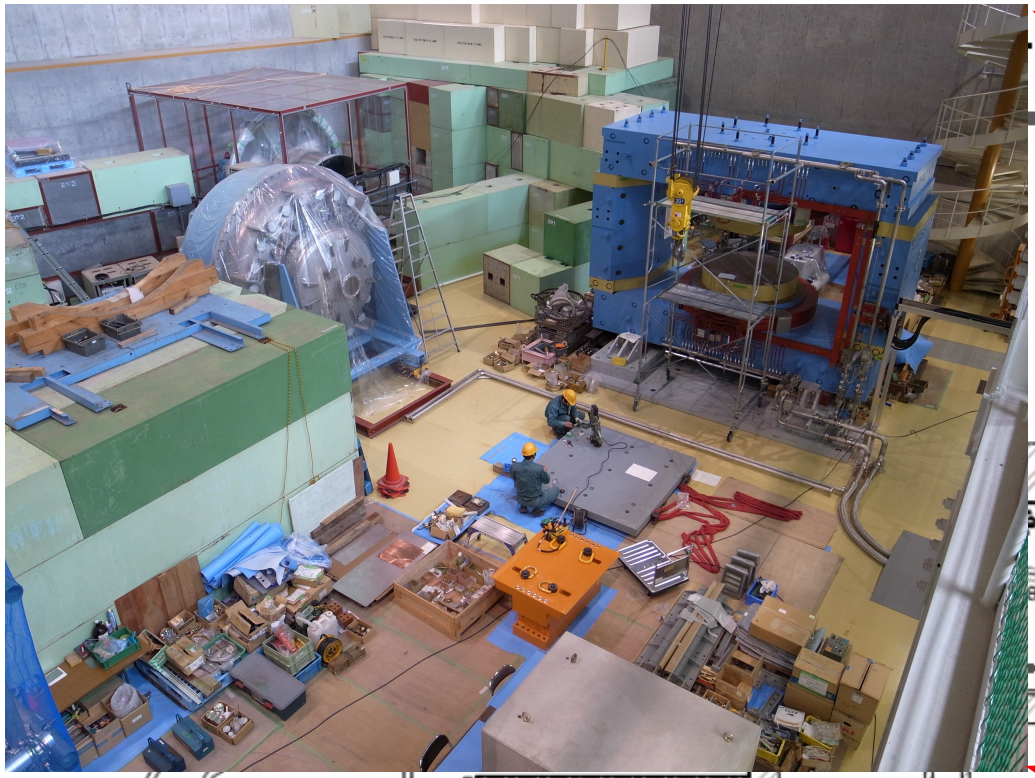


Location of E16 : High-momentum beam line



Beam dump and shields are for 10^{10} protons/s

by R. Muto



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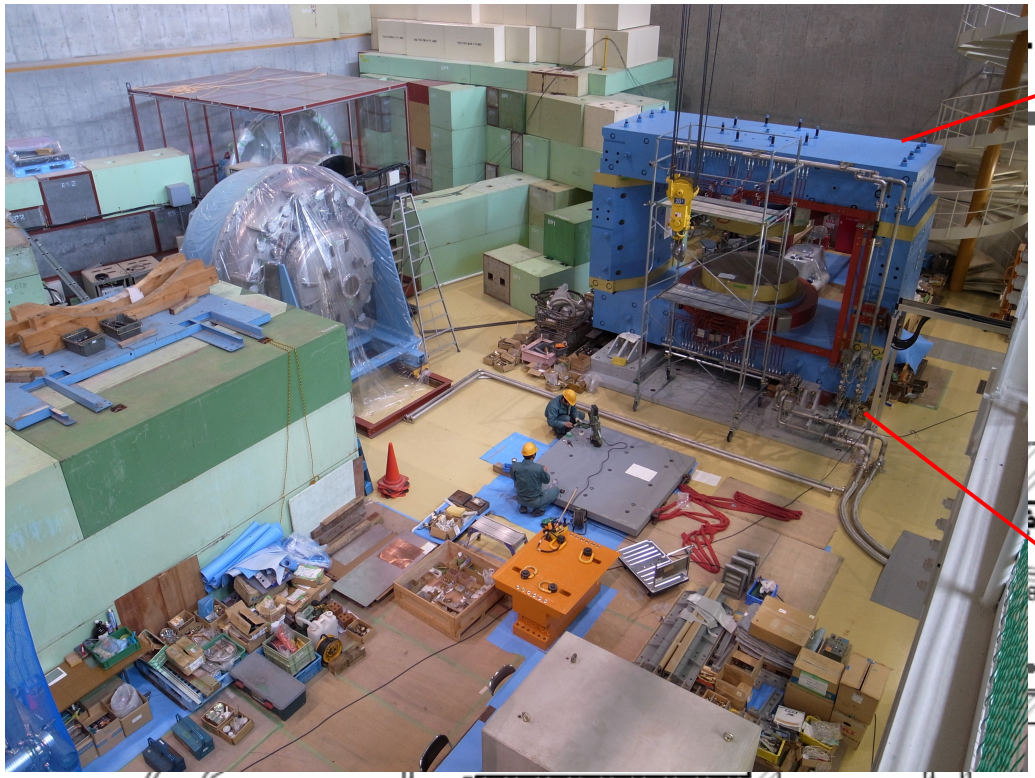


Already the spectrometer magnet has been moved to Hadron Hall.

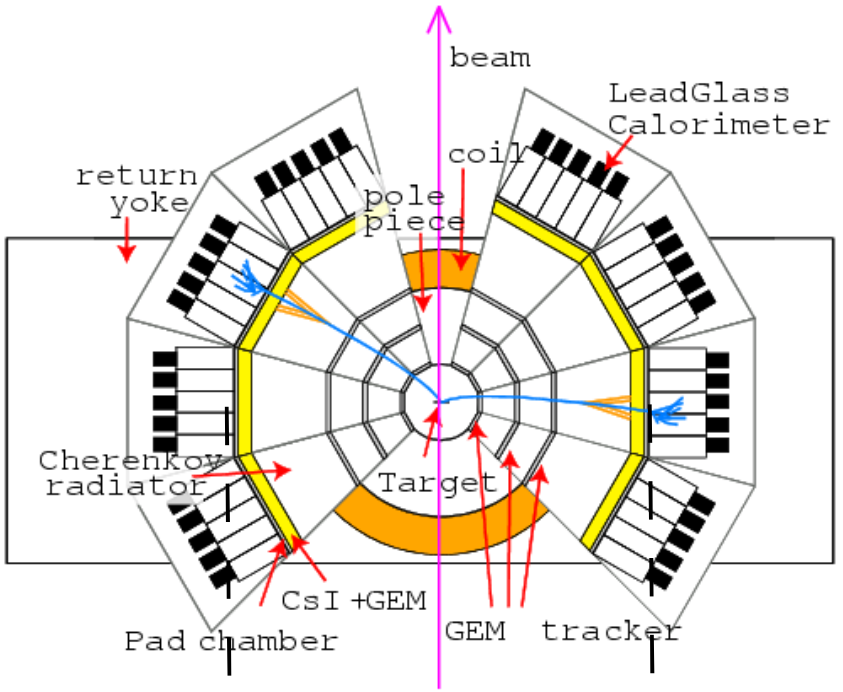
Beamline construction budget is being requested.

R&D for the actual beam line is underway.

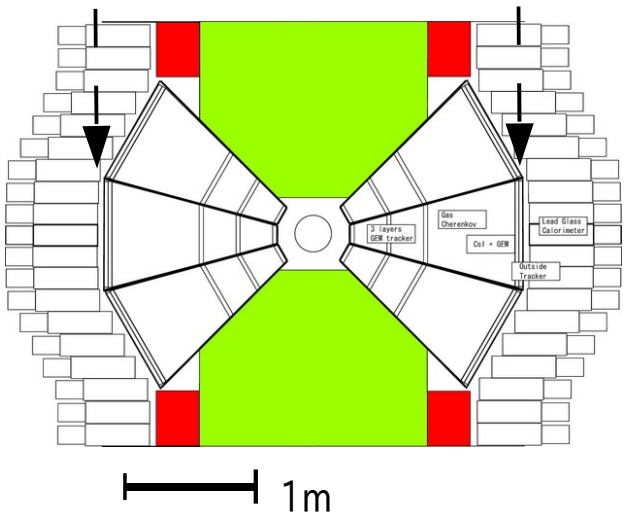
Proposed spectrometer

- Spectrometer Magnet : reuse E325 's
  - remodeling the pole / repairing the coil
  - stronger field for compact detector size
- GEM(Gas electron multiplier) Tracker
    - cope with high rate (5kHz/mm^2)
- Two-stage Electron ID (~10^{-4} π rejection)
  - Hadron Blind Detector (Gas Cherenkov)
    - GEM+CsI photocathode
    - hexagonal pad readout (~36mm ϕ)
  - Leadglass EMC: reuse of TOPAZ
- ~70K Readout Channels (in 26 segments)
  - cf. E325: 3.6K, PHENIX:~300K (w/o VTX)
- Cost : ~$5M (including ~$2M electronics)
  - cf. E325: $2M not including electronics

Plan view

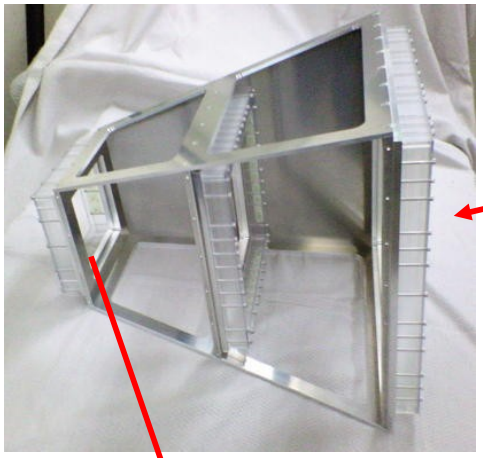


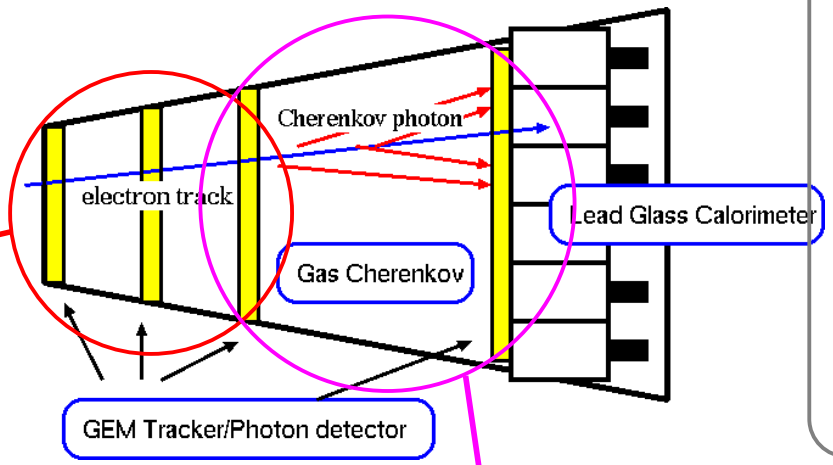
Beam view



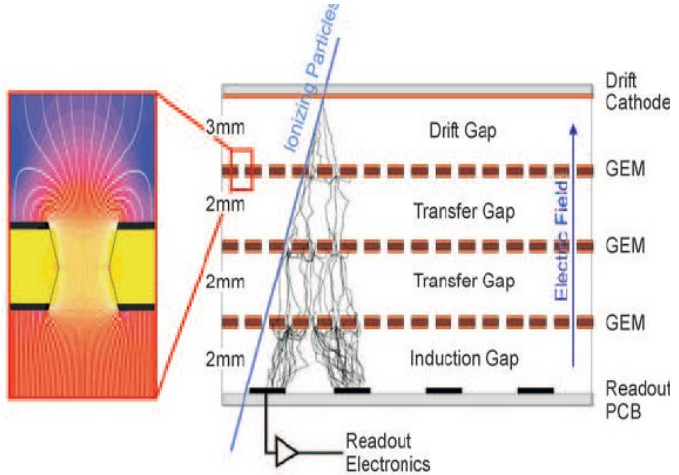
Detector R&D

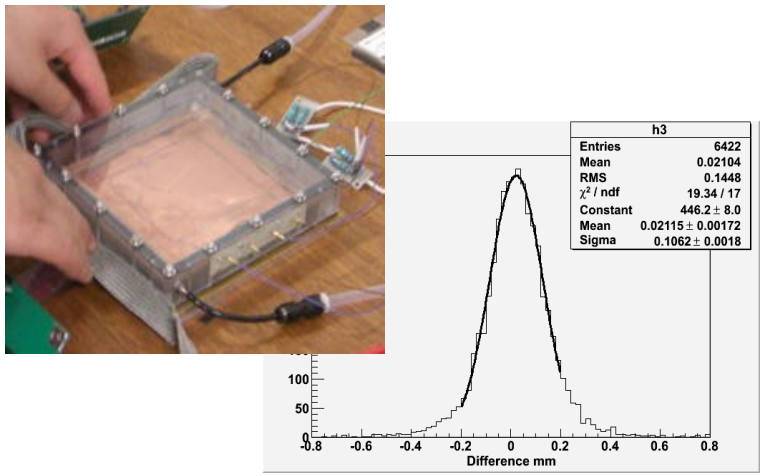
Beam test results of the Prototype Detector Module

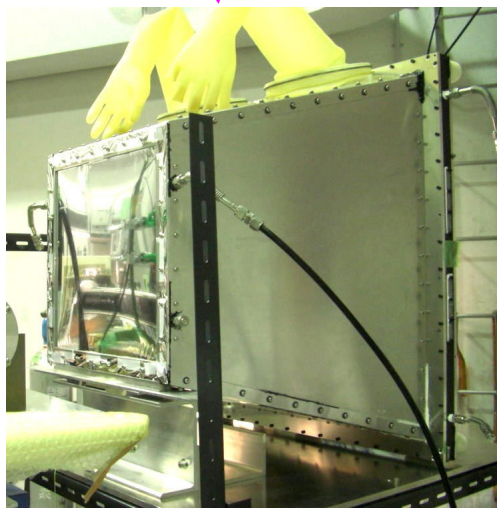




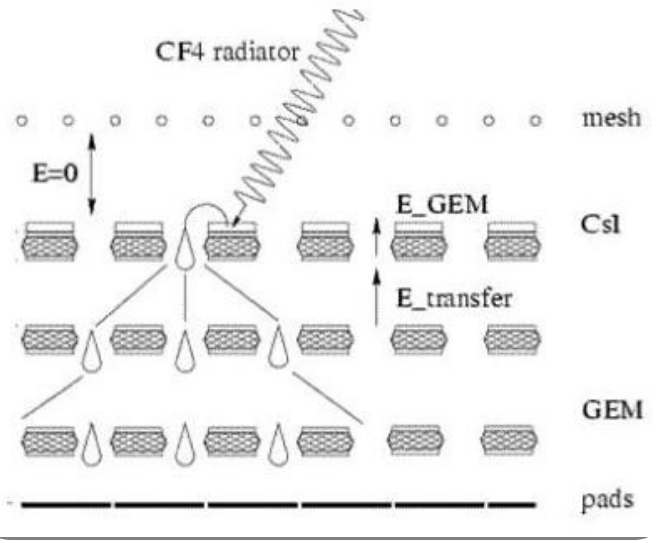
GEM & GEM chamber schematics





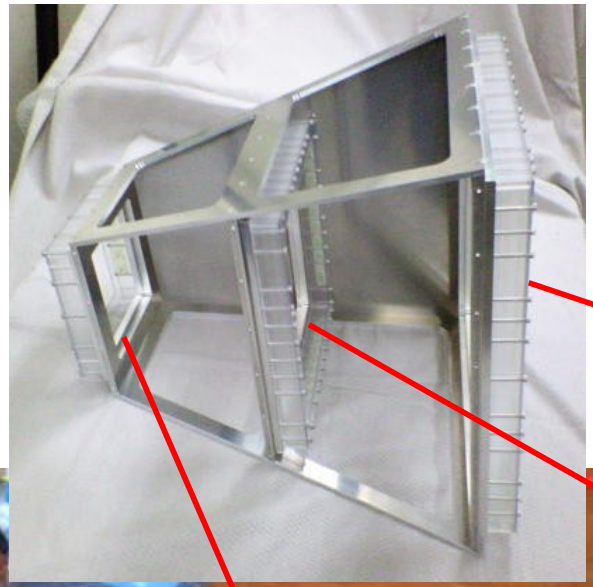


HBD(Hadron Blind Gas Cherenkov Detector)schematics



GEM Chamber :
required position resolution (~100μm) is achieved

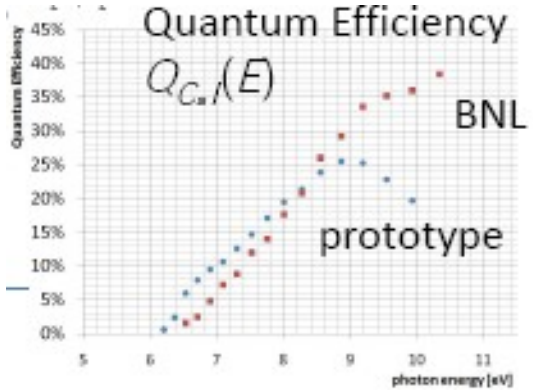
Hadron Blind Detector :
UV Cherenkov photons from the electron beam are detected by CsI-GEM in CF4



100x100 200x200 300x300

Achievements in beam tests

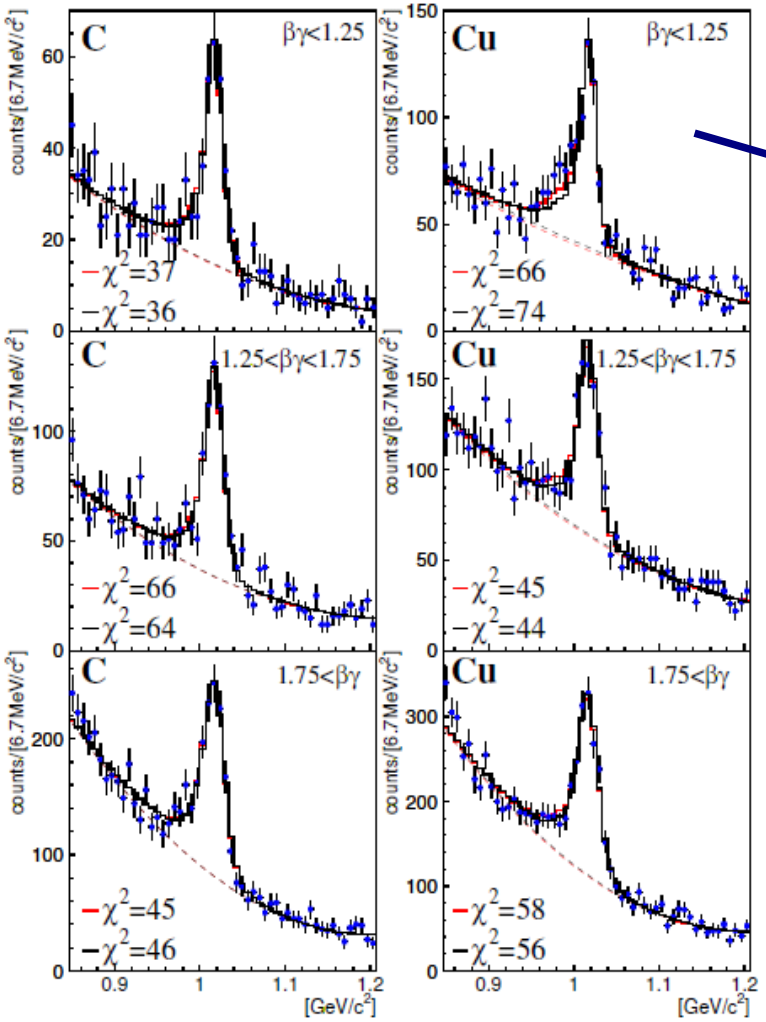
- GEM Tracker
  - GEM(PI 50um) by Raytech.Co.
    - 100mmx100mm, 200mm x 200mm, 300mm x300mm
  - R/O double sided strip PCB (PI 25um) by Raytech.Co
  - position resolution (using ArCO2/350um pitch strip) for angled tracks
    - 100um (for 0deg/15deg) – 140um(30deg) in 100mm x 100mm GEM
    - larger GEMs were also checked in the beam test(2010/Nov.)
- HBD(Gas Cherenkov)
  - developed thanks to Weizmann/Stony Brook(PHENIX)
  - CsI evaporaiton by Hamamatsu
  - 5-6 photoelectrons detected (cf. PHENIX ~20 p.e.)
    - Improvement of gas purity and CsI q.eff. is underway

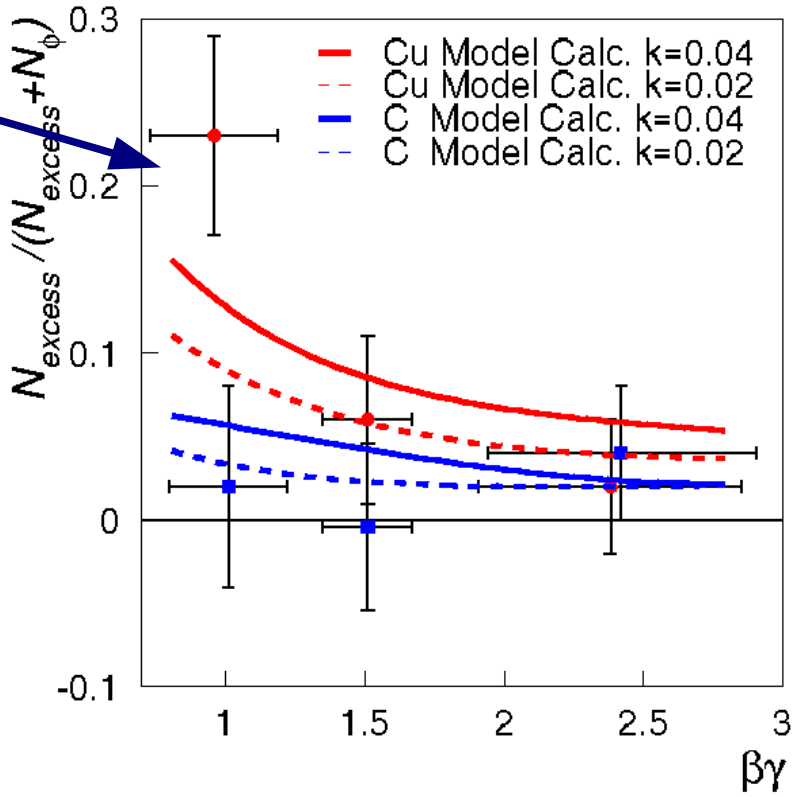


Expected signals in E16 high statistics

velocity and nuclear size dependence

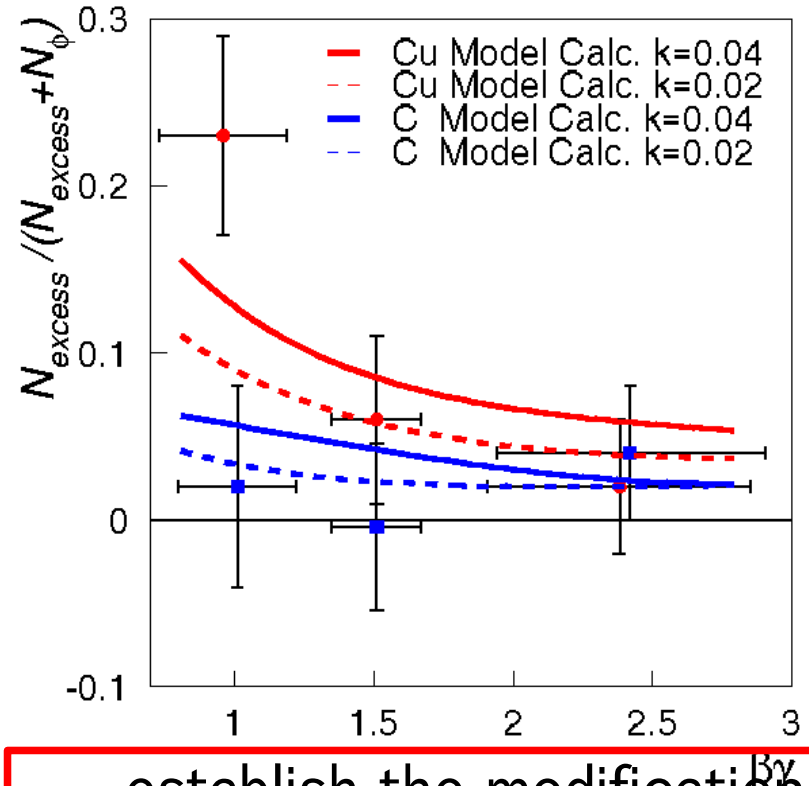
- velocity dependence of excesses ('modified' component)
- E325 only one data point for ϕ (slow/Cu) has significant excess



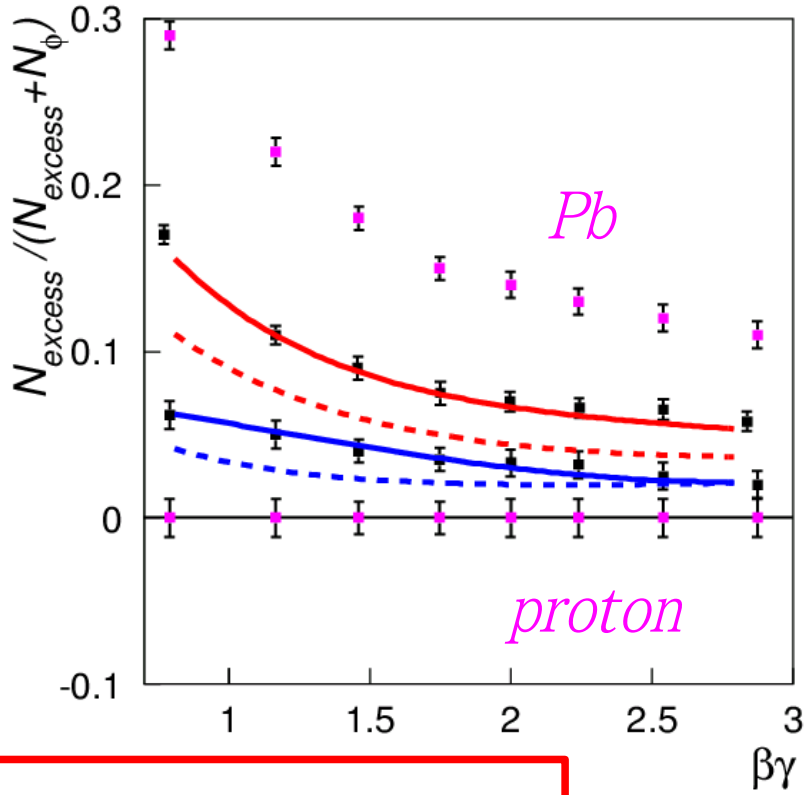


velocity and nuclear size dependence

- velocity dependence of excesses ('modified' component)
- E325 only one data point for ϕ (slow/Cu) has significant excess
- systematic study : all the data should be explained the interpretation model



x 100 stat.



- establish the modification
-

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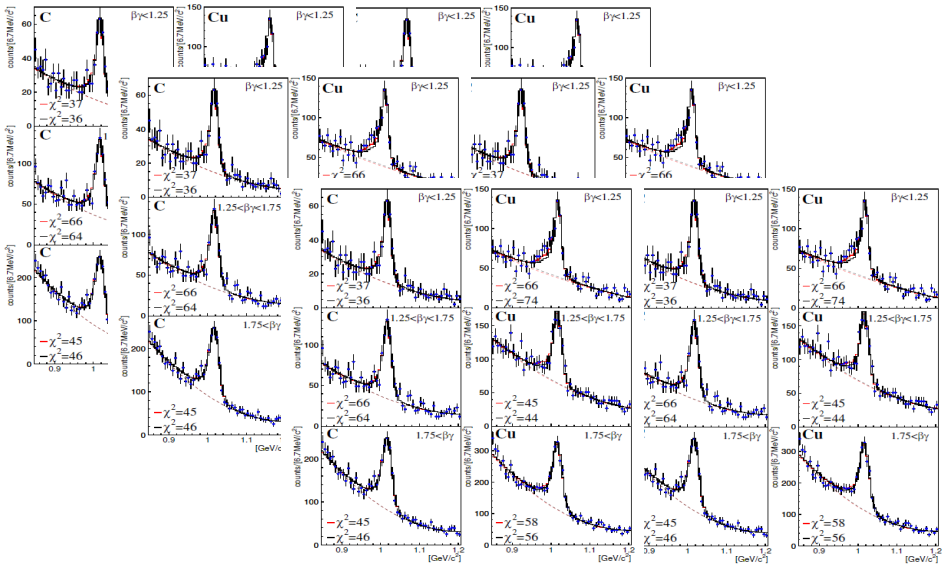
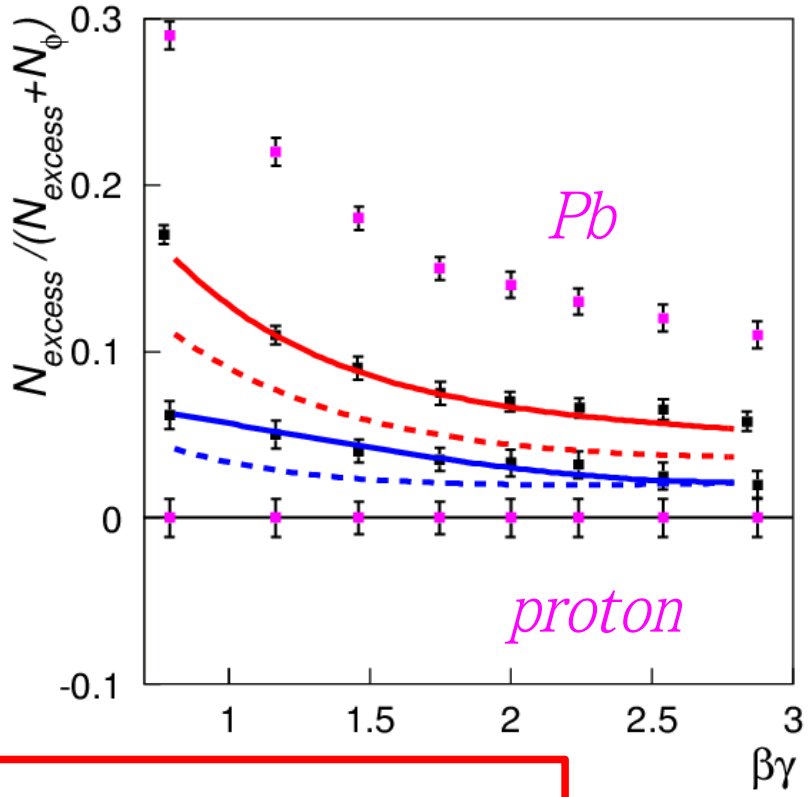
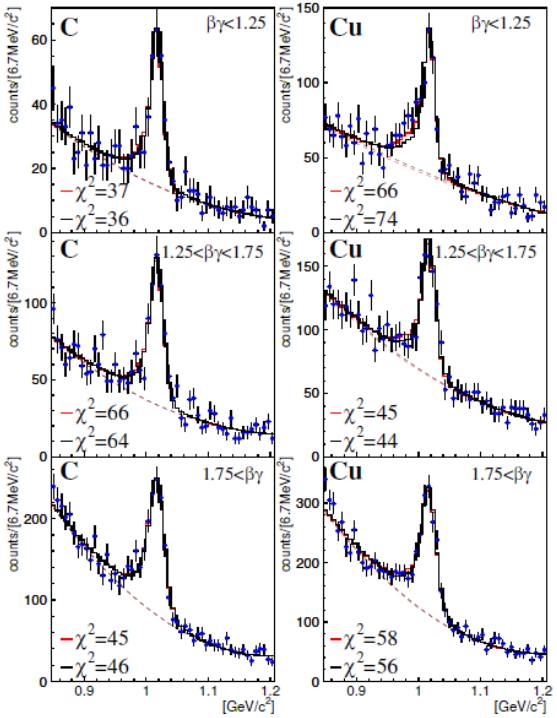


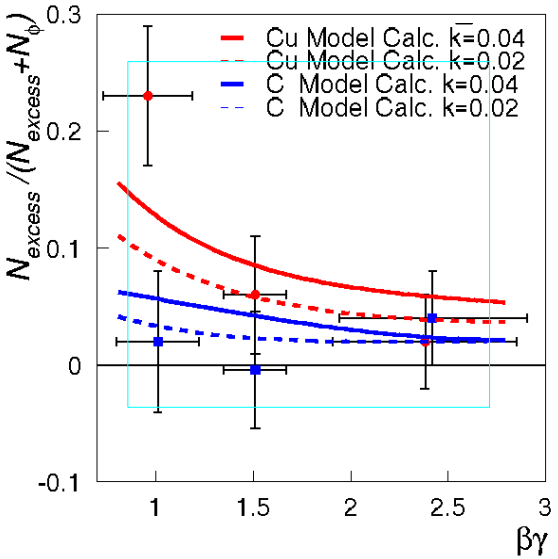


- establish the modification
- check the interpretation model with shape analysis for each histogram

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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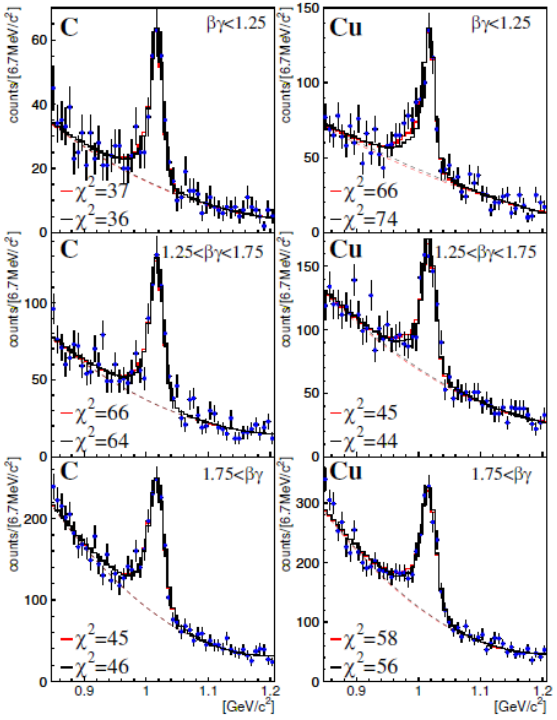

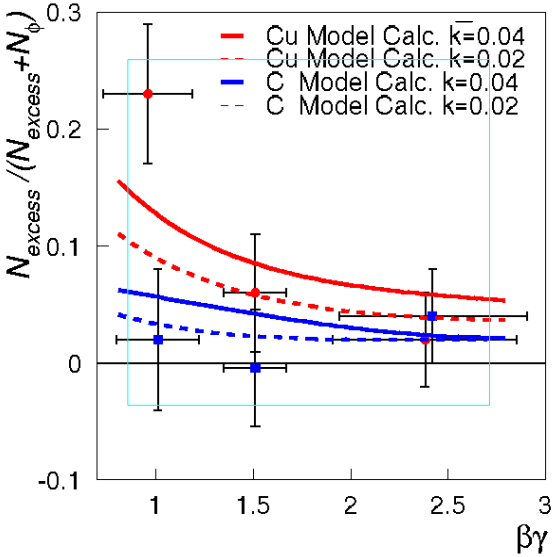

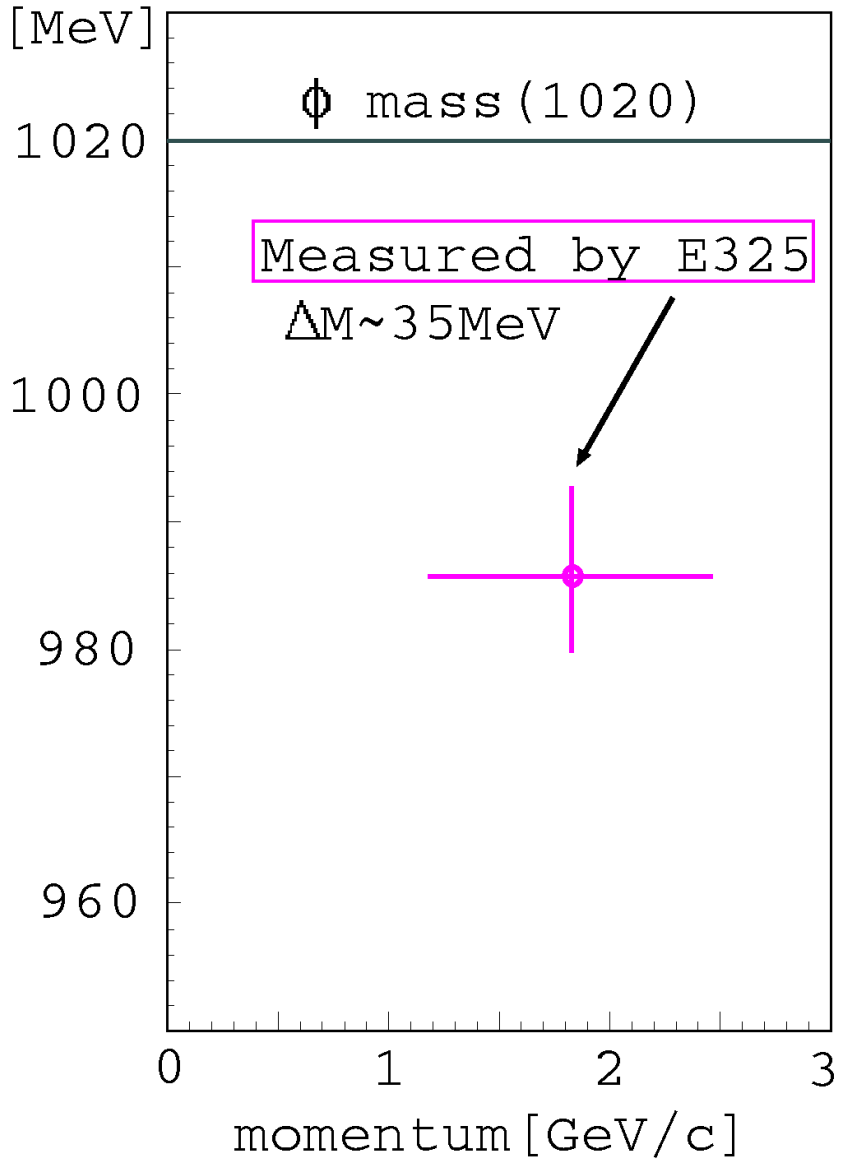

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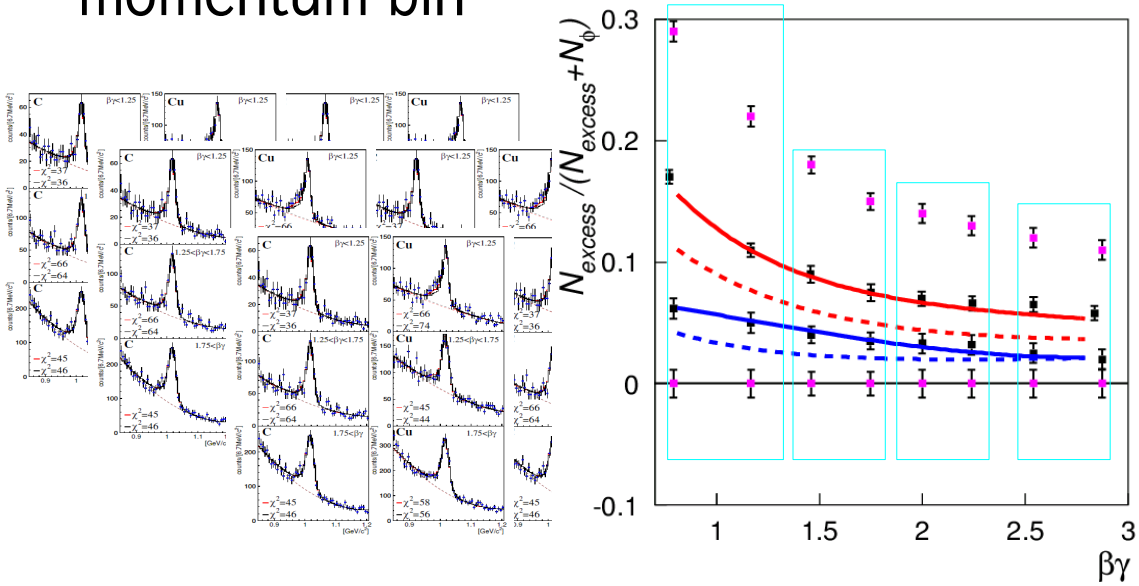
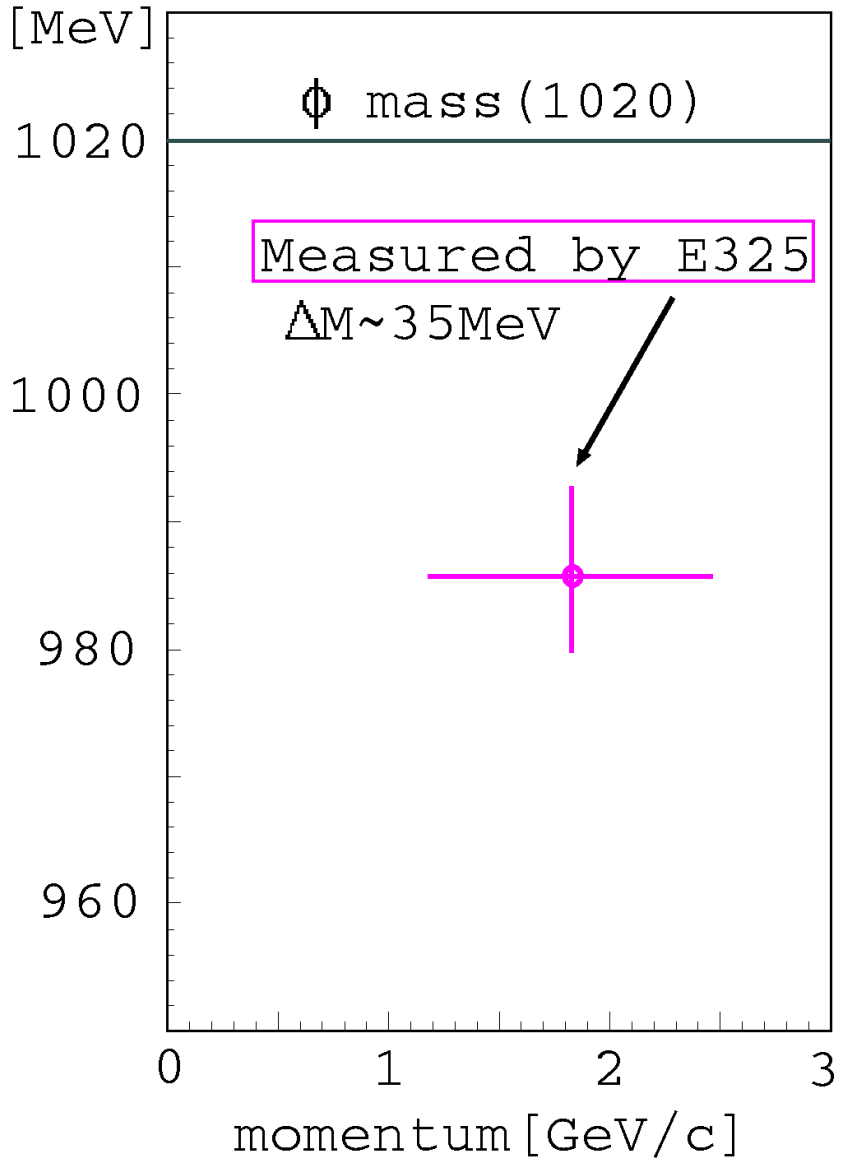
- fit with common shift parameter $k_1(p)$, to all nuclear targets in each momentum bin





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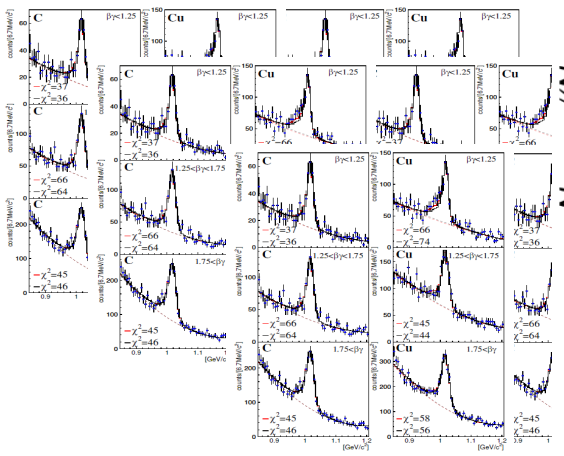
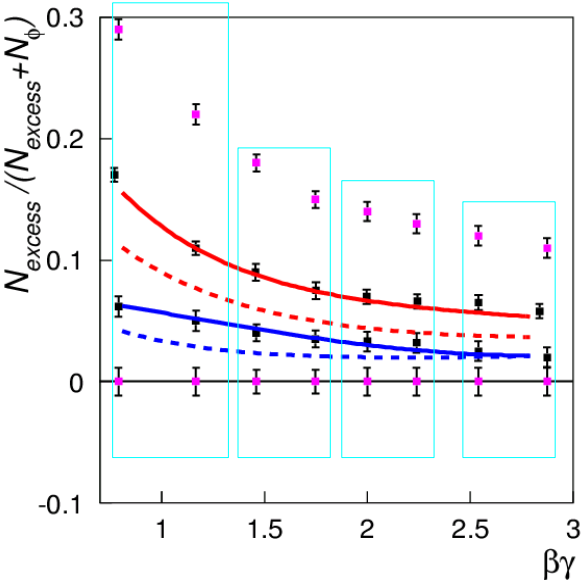
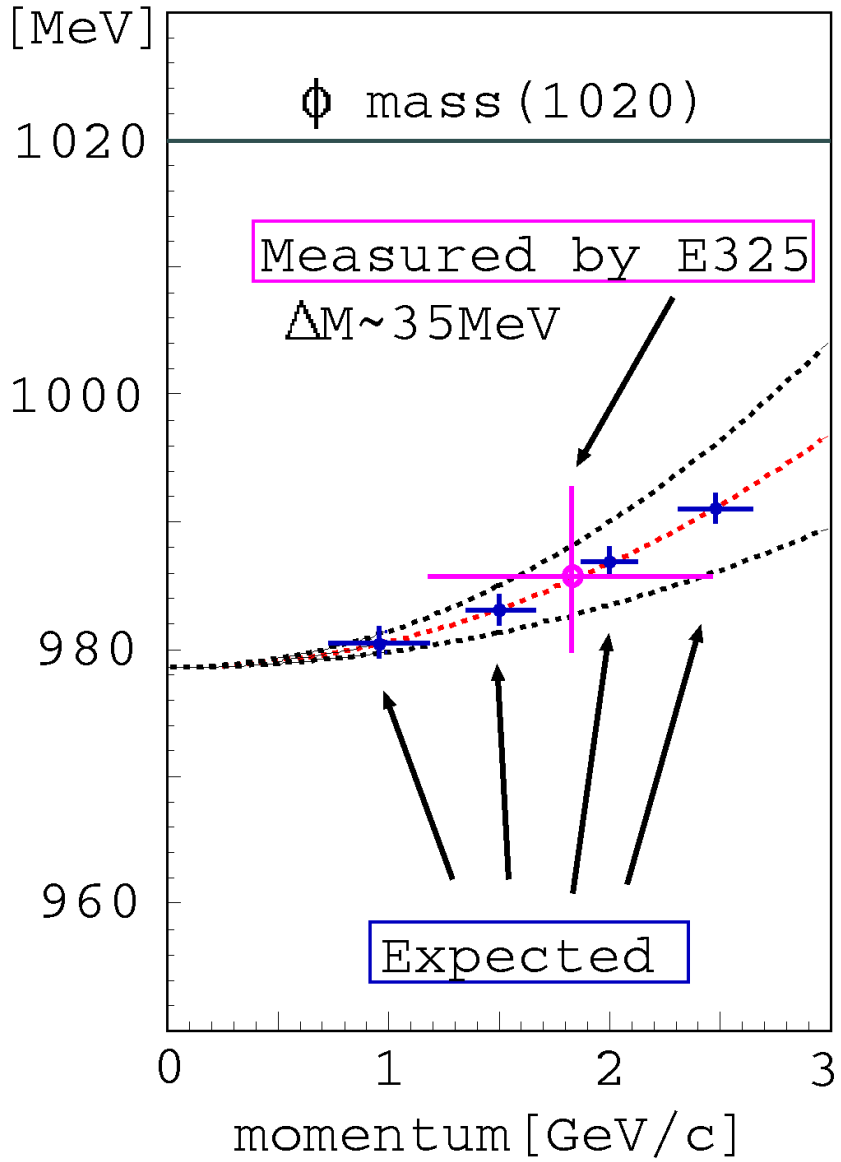




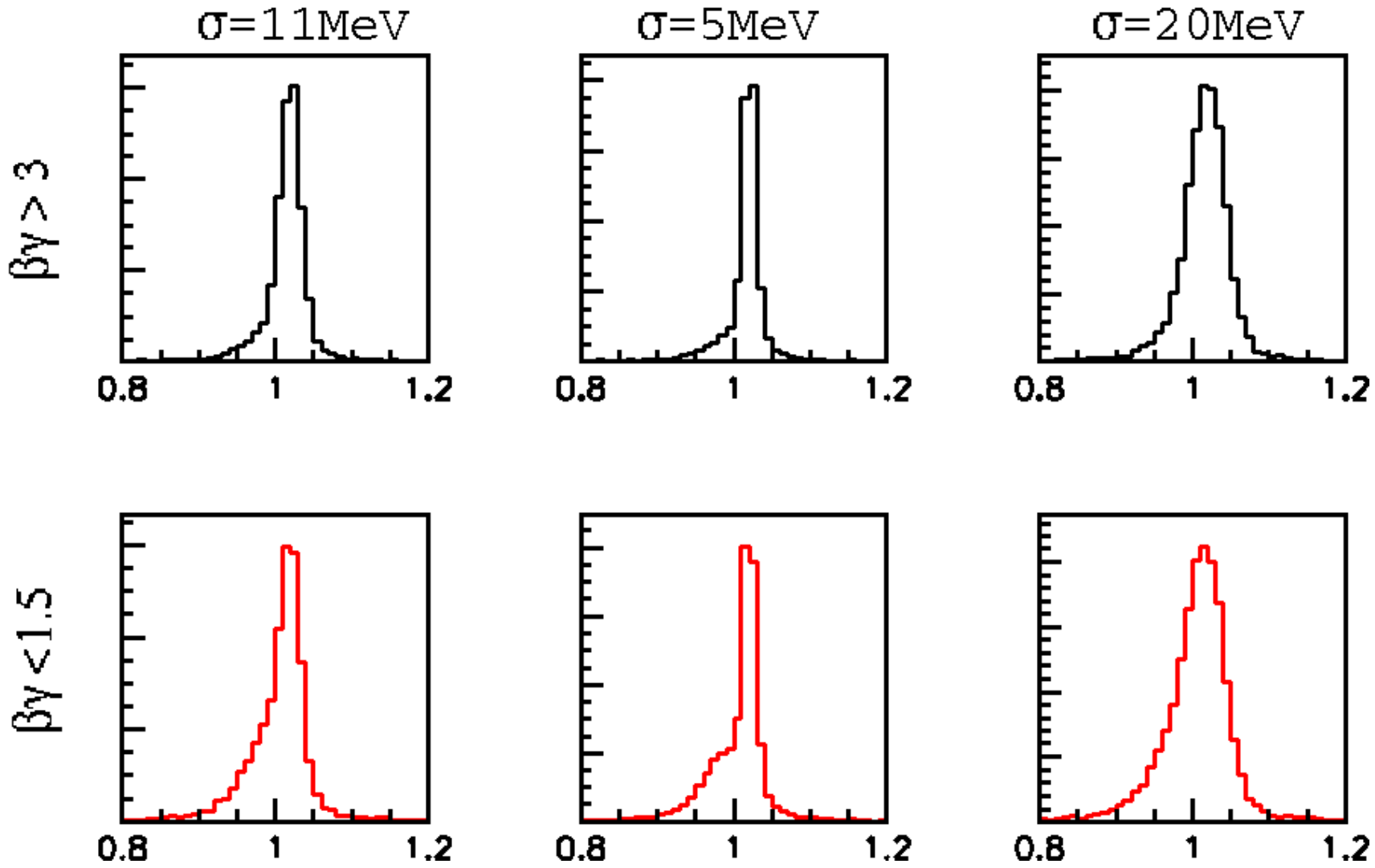


mass resolution requirement

- mass resolution should be kept less than ~10MeV

Fast

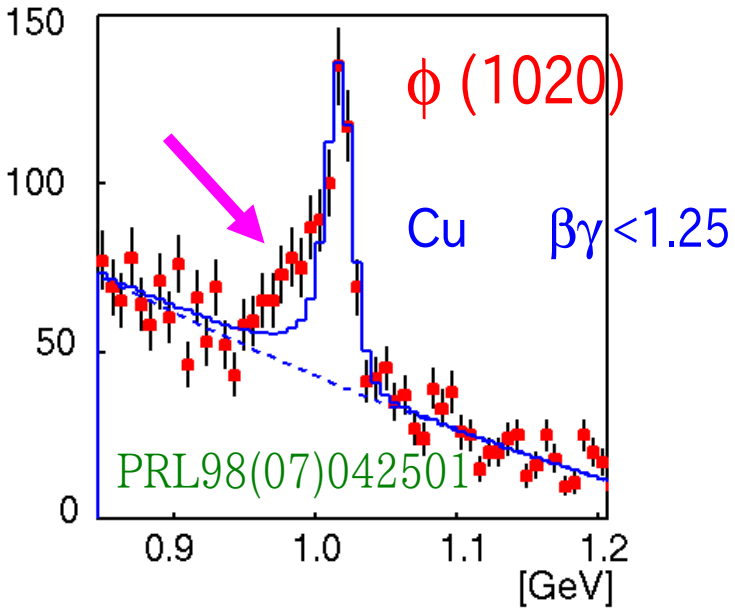
Slow



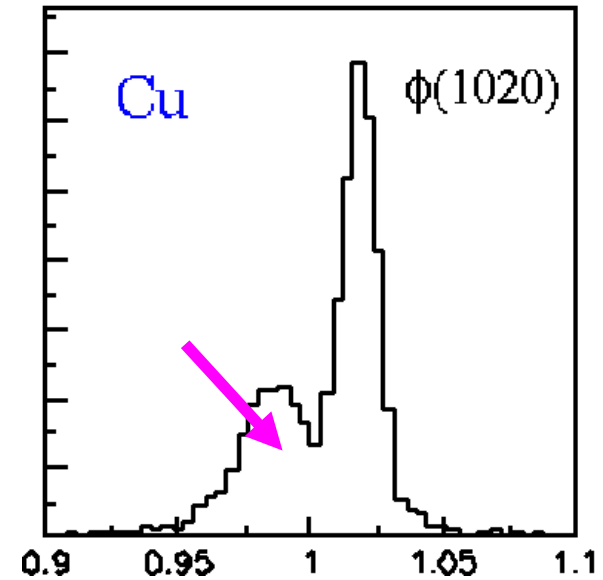
(model calc. for the Cu target)

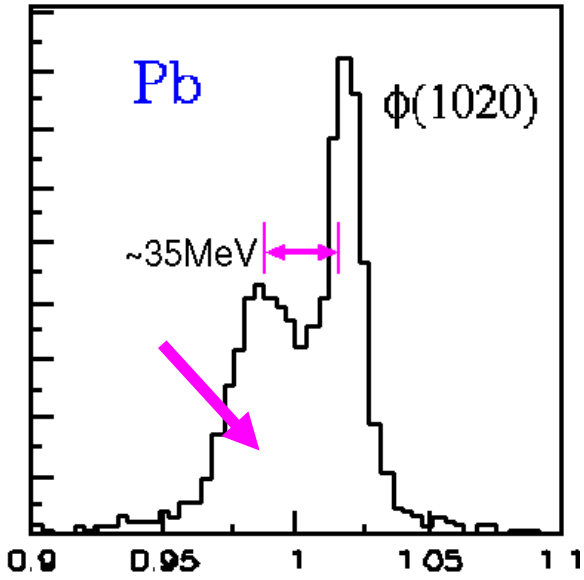
mass resolution requirement

- mass resolution should be kept less than ~10MeV
- Very ideal case : very slow mesons w/ best mass resolution:



βγ<0.5, σ=5 MeV

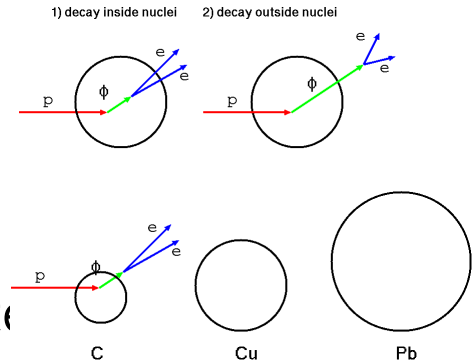




(model calc.)

Summary(2) :J-PARC E16

- Main goal : collect ~1-2 x 10^5 $\phi \rightarrow e^+e^-$ for each target in 5 weeks
  using 30 (or 50) GeV p +A (C/CH_2/Cu/Pb) reactions
  - statistics : ~100 times as large as E325
  - **systematic study of the modification**
    - velocity & nuclear size (0~10 fm) dependence
      - proton/Pb targets / collision geometry (impact parameter)
    - momentum dependence (dispersion relation)
  - mass resolution : < 10 MeV (E325 : 10.7 MeV for ϕ)
    - double peak structure with σ ~ 5 MeV, selecting $\beta\gamma < 0.5$ (vely slow)



- Confirm the modification observed in E325, and provide new information about the mass of hadrons