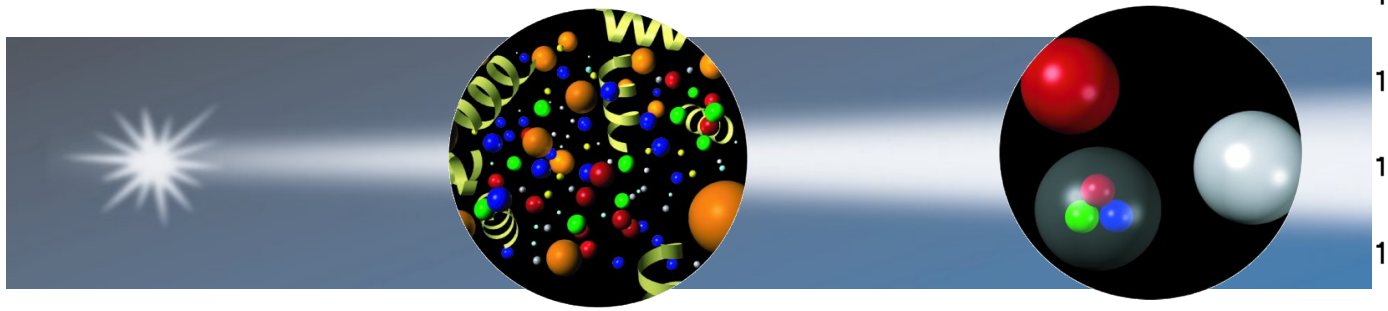
J-PARC E16
電子対測定実験の物理と実験計画

Satoshi Yokkaichi
(RIKEN Nishina Center)

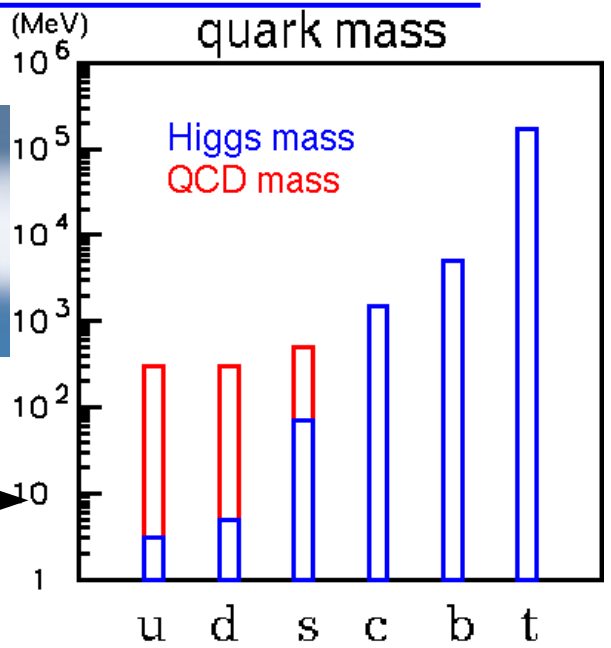
- Introduction
  - 核物質中でのカイラル対称性の回復と中間子の質量
  - 中間子質量の測定
- KEK-PS E325 実験
  - 核内での中間子質量変化の検出
- J-PARC E16 実験
  - 中間子質量変化の系統的測定

Mass and chiral symmetry in nuclear matter

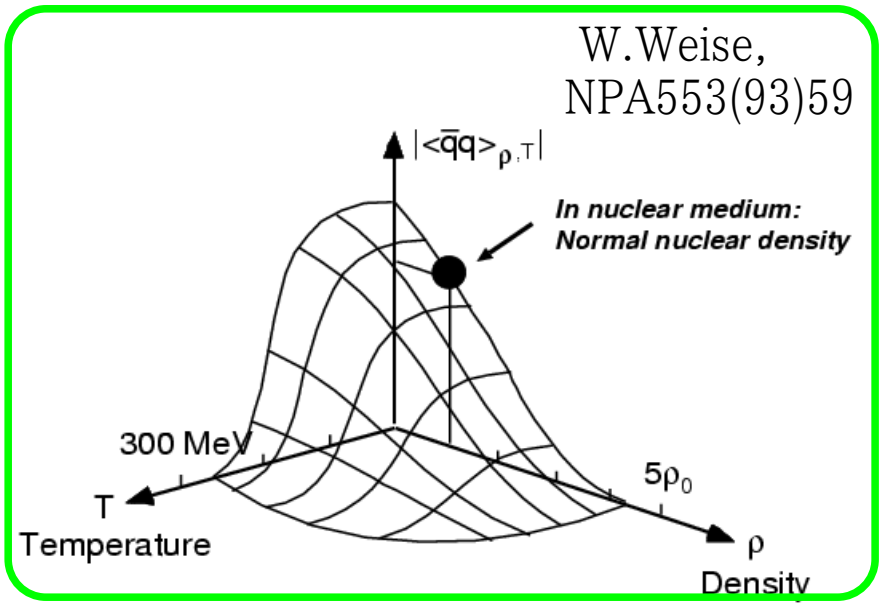


big bang　　10psec　　0.1msec

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...



Vector meson mass spectra in dense matter

- meson at rest (p=0)
- infinite-size nuclear matter

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

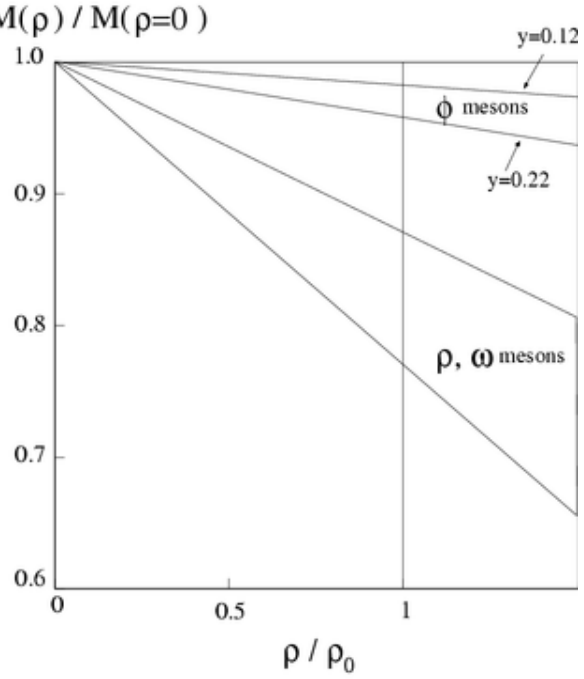
linear dependence on density

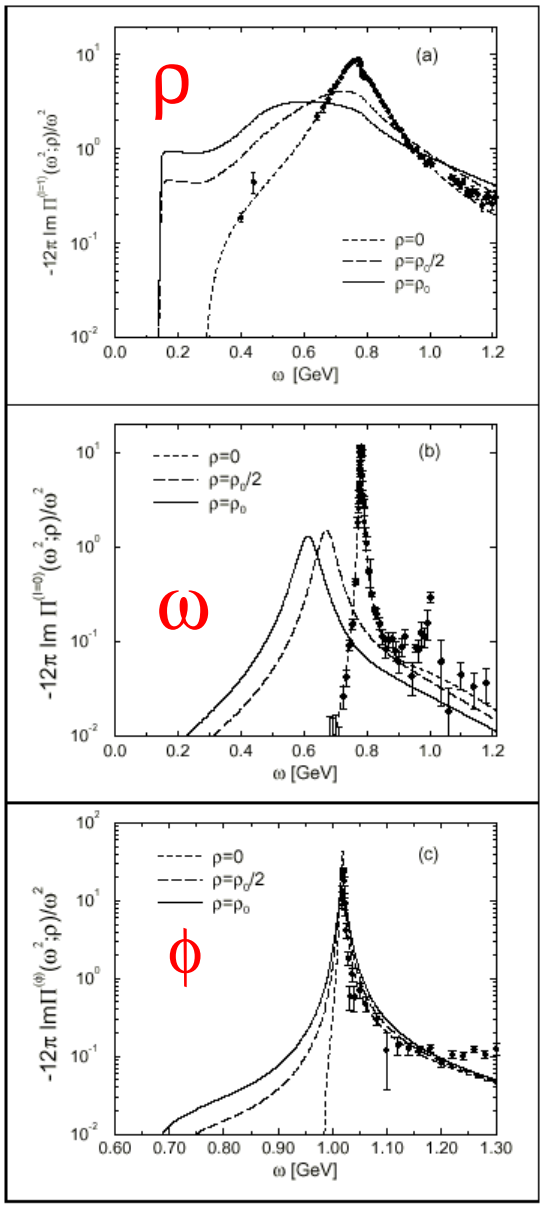
$m^*/m_0 = 1 - k\,\rho/\rho_0$

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

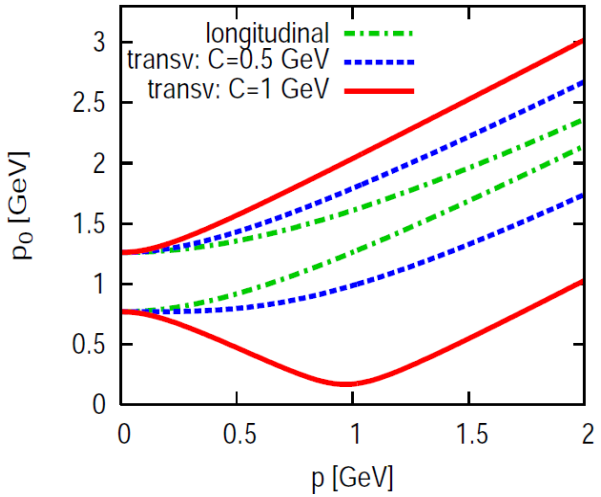




dispersion (mass VS momentum) in dense matter

- 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

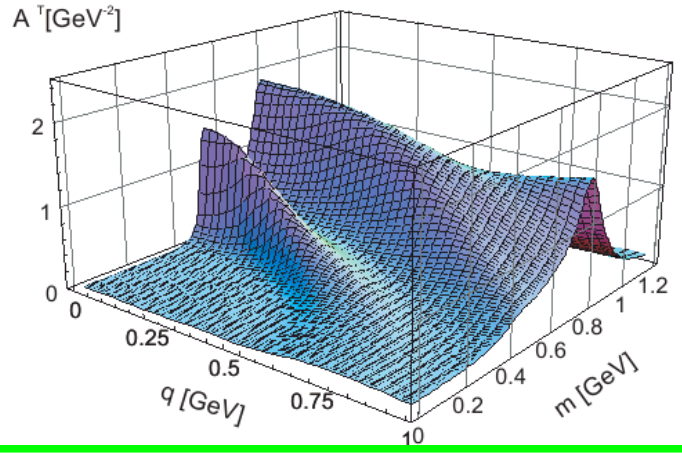
- Harada & Sasaki (arXiv:0902.3608v1)



a_1

ρ

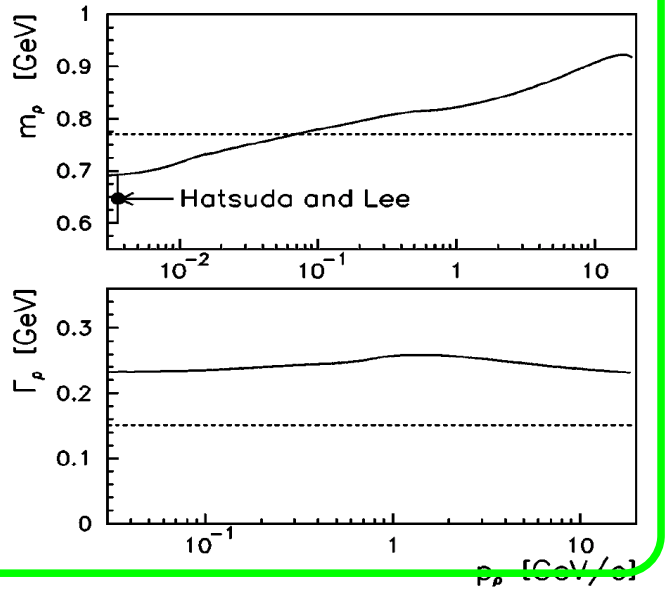
- Post & Mosel (NPA699(02)169)



ρ

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

ρ



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) 4.5GeV p+A/ 1-2GeV A+A
- CLAS-G7 (ee) 1~2 GeV γ+A
- *J-PARC E16* (ee) 30/50GeV p+A / ~20GeV A+A ?
- *CBM/FAIR* (ee) 20~30GeV A+A

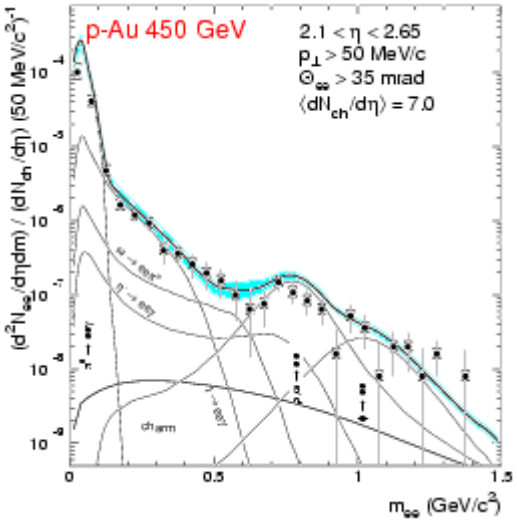
published/ 'modified'
published/ 'unmodified'
running/in analysis
future plan
as of 2008/Jul

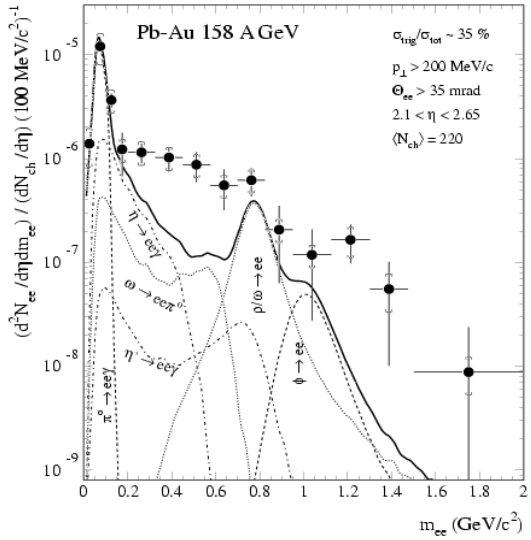
- TAGX (ππ) ~1 GeV γ+A
- STAR (ππ,KK) p+p/Au+Au
- LEPS (KK) 1.5~2.4 GeV γ+A
- CBELSA/TAPS ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb

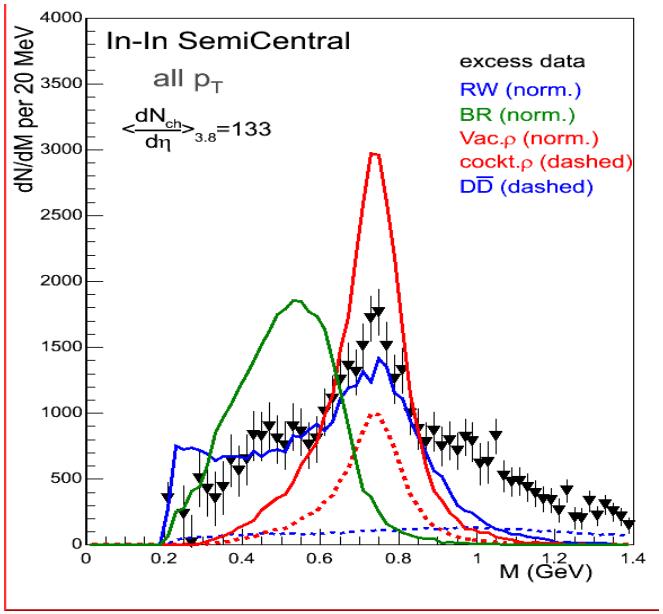
Vector meson measurements in HIC

- CERES : e^+e^- (EPJC 41('05)475)
  - anomaly at the 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'







- Discussion is continuing
  - mass dropping or broadening?

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 ($1<\beta\gamma<3$)

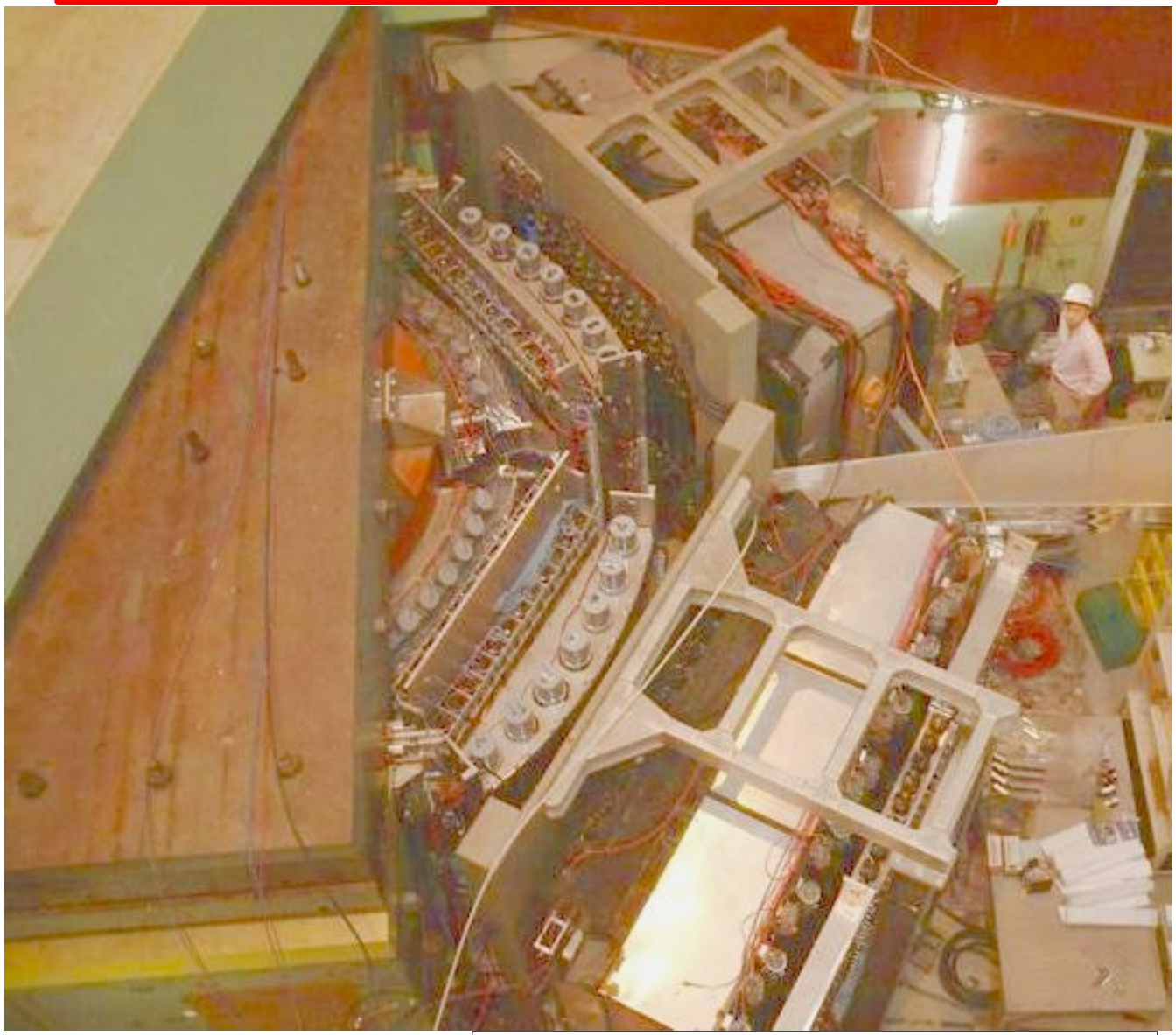
Collaboration

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

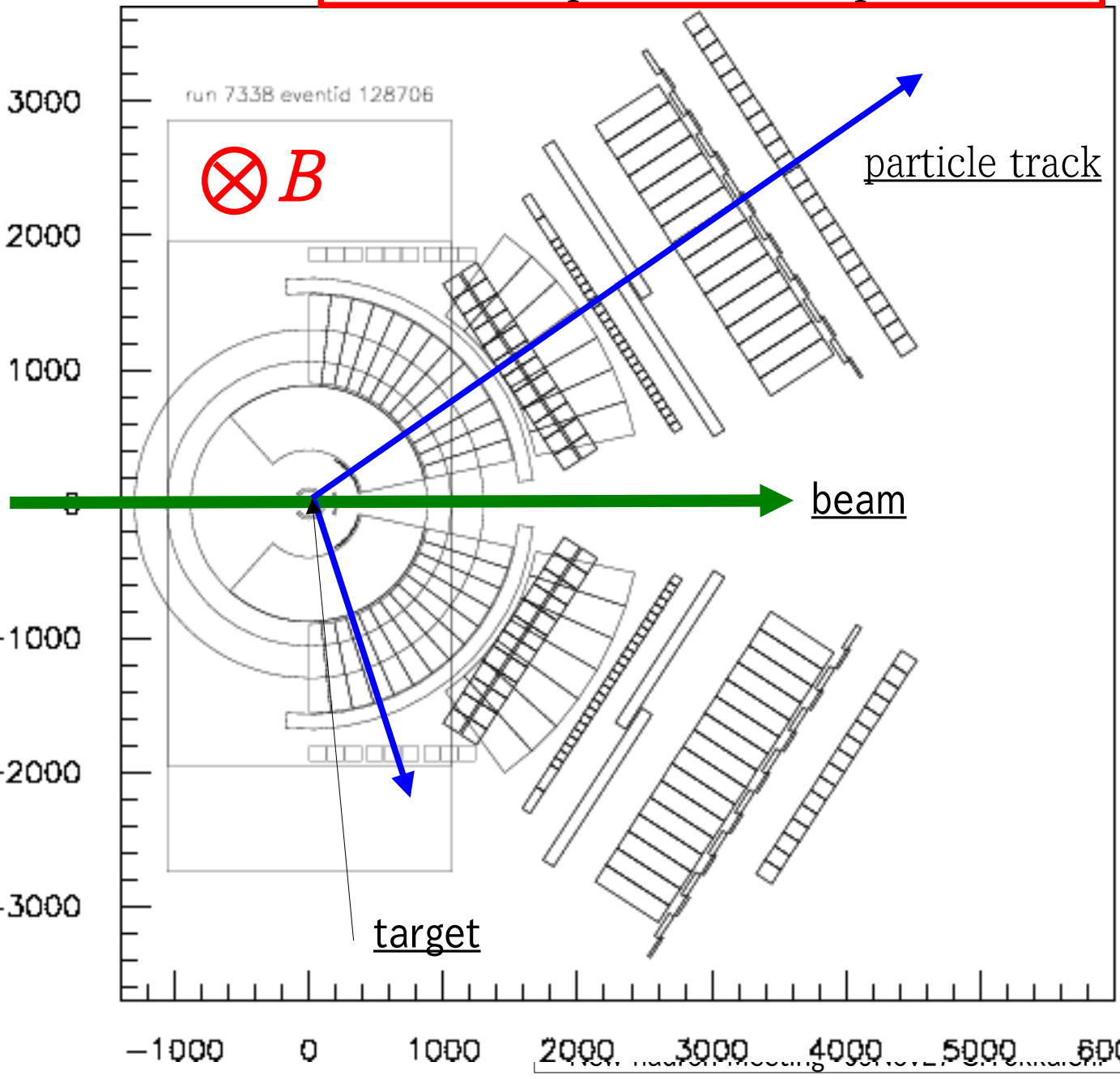
E325 spectrometer
located at KEK-PS EP1-B primary beam line



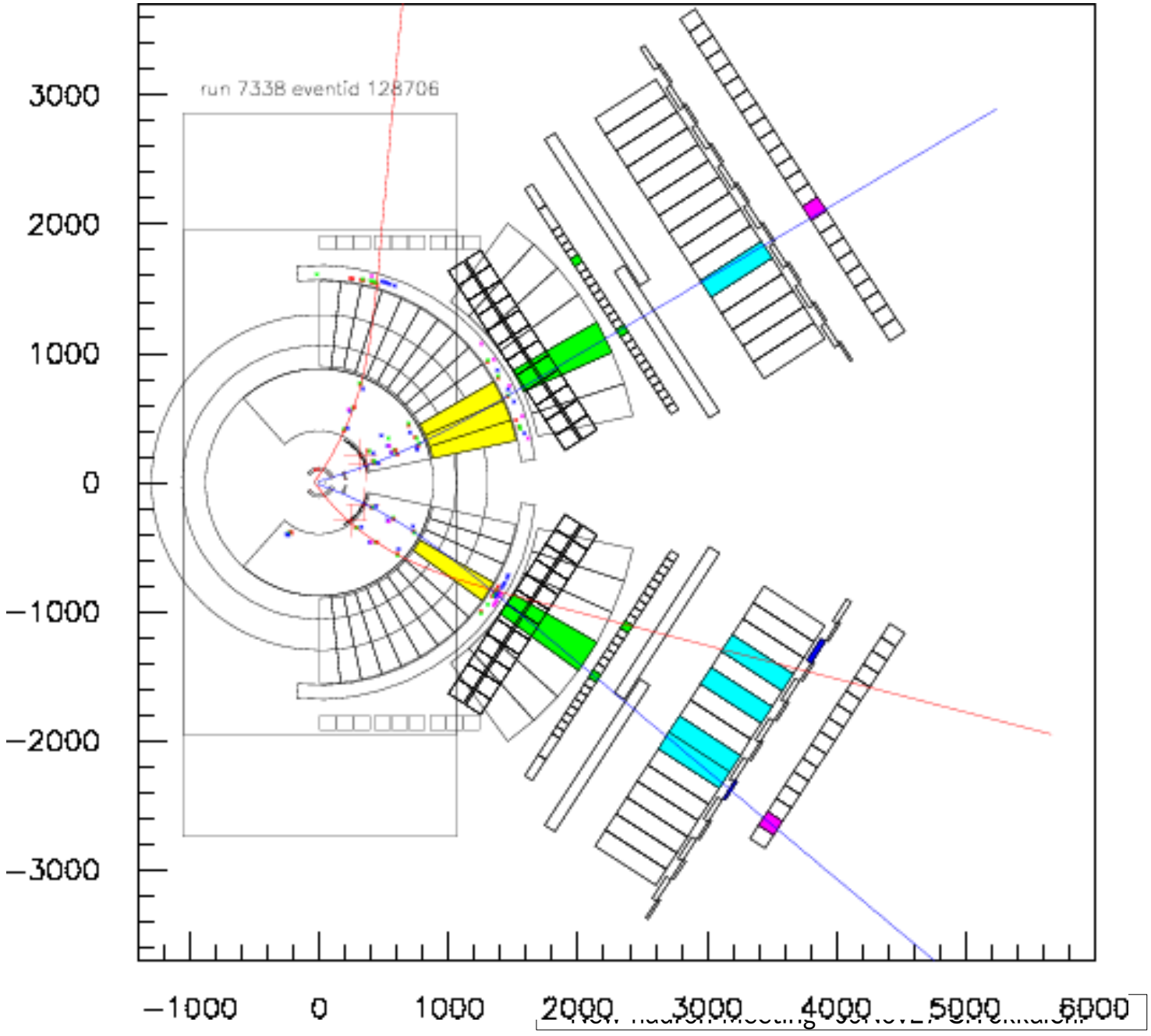
Experimental setup

- 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

schematic plan view of spectrometer



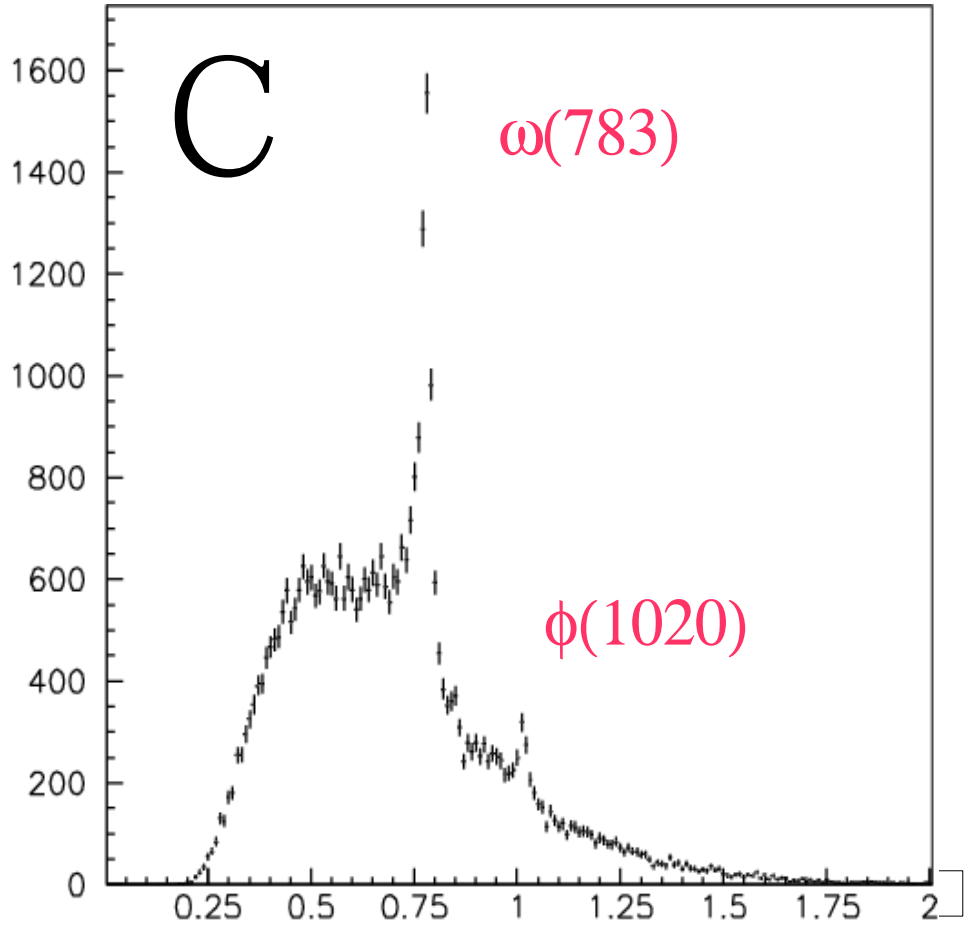
- Typical e^+e^- Event
  - blue:electron
  - red : other
  - invariant mass and momentum of mother particle can be calculated



E325 Results

e^+e^- invariant mass spectra

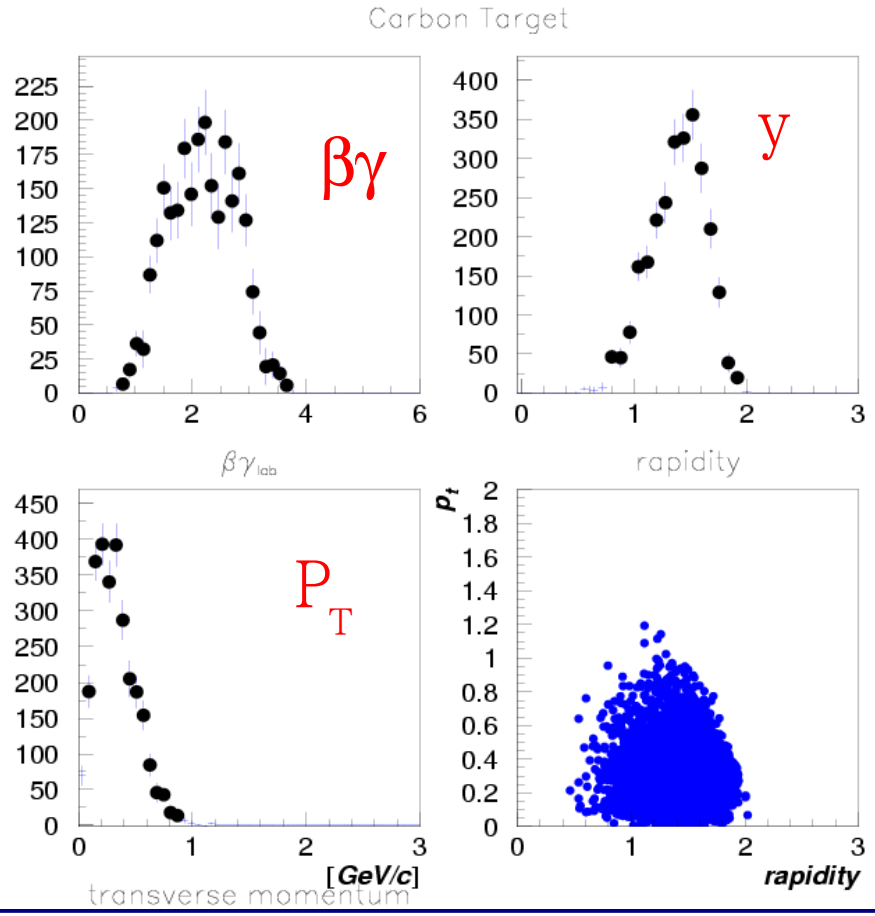
M. Naruki et al.,
PRL 96 (2006) 092301
R.Muto et al.,
PRL 98 (2007) 042501



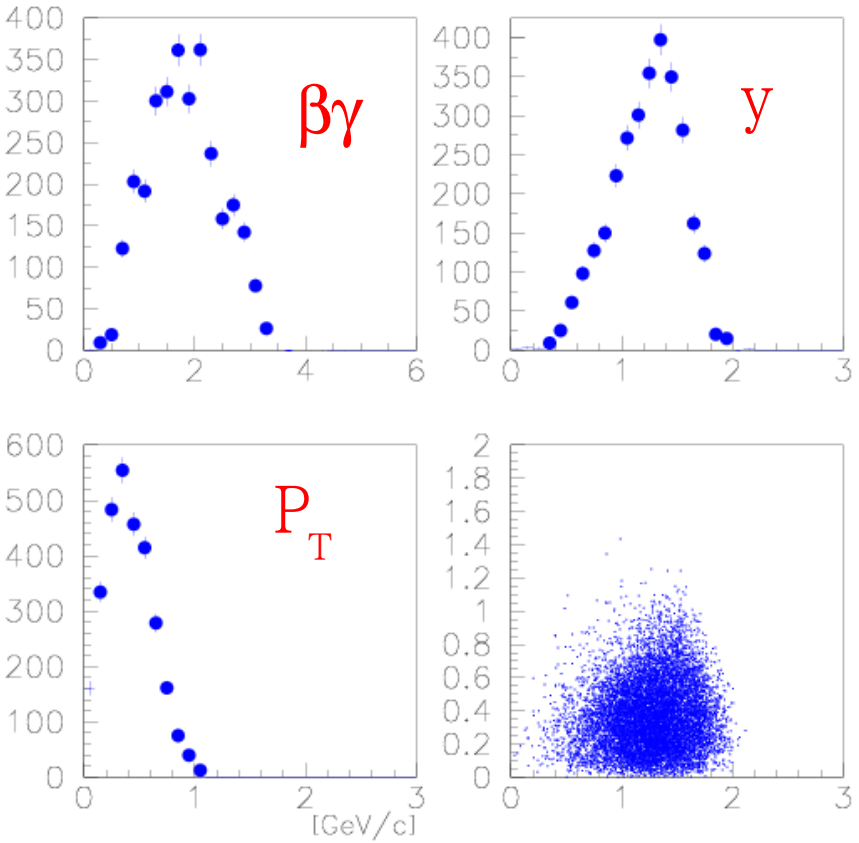
measured kinematic distribution of $\omega/\phi \rightarrow e^+e^-$

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

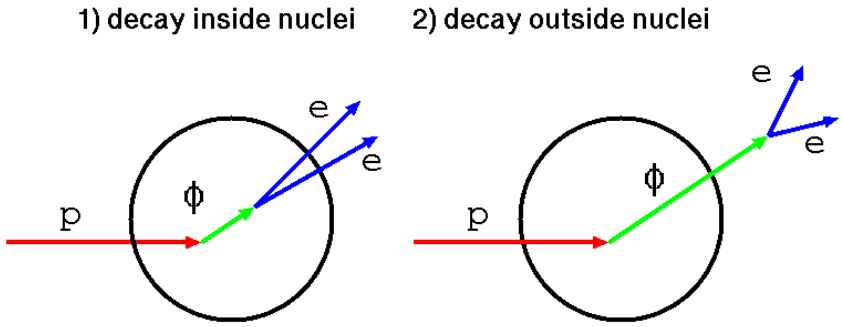


ϕ

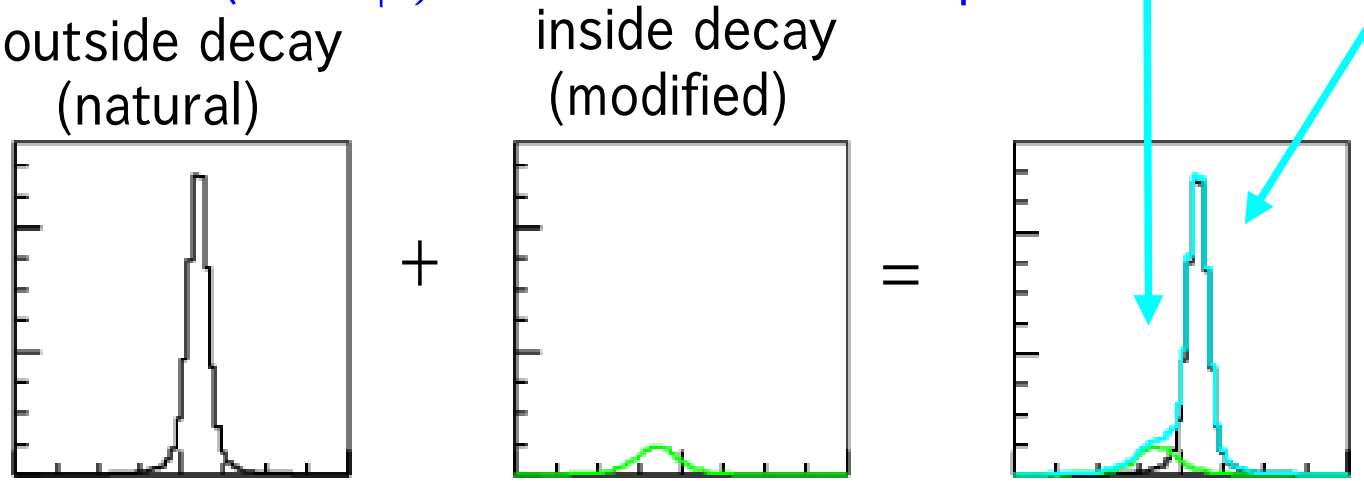


Expected Invariant mass spectra in e^+e^-

- 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



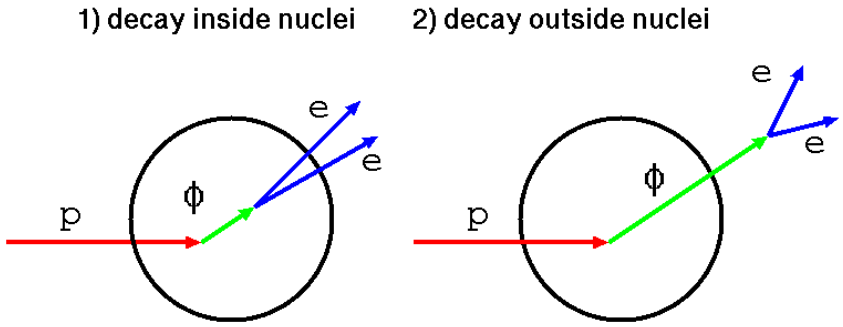
longer-life meson(ω & ϕ)cases : Schematic picture



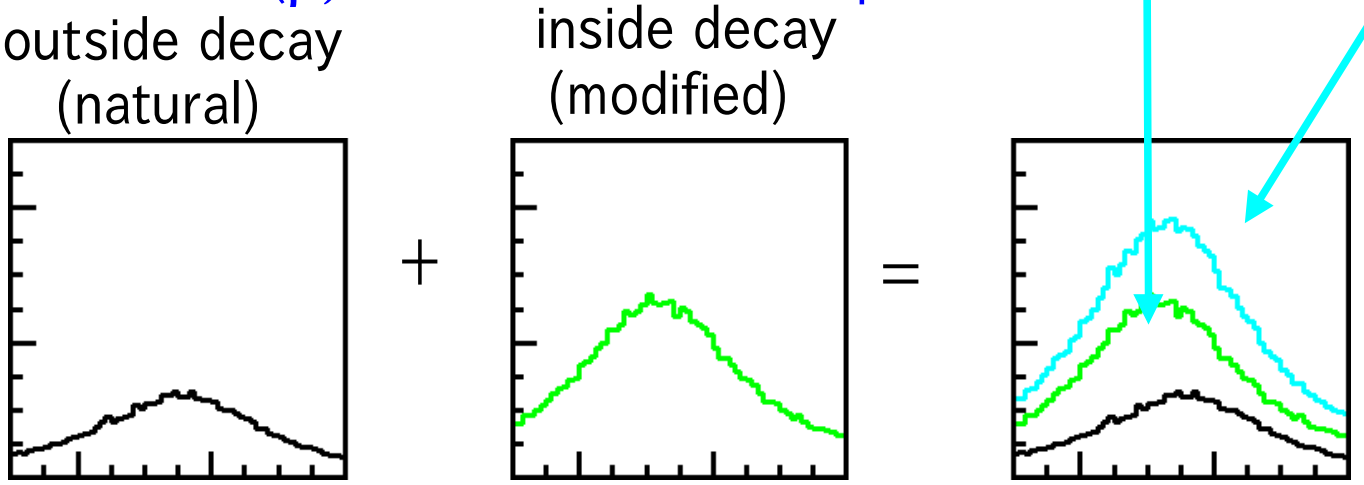
expected to be observed

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



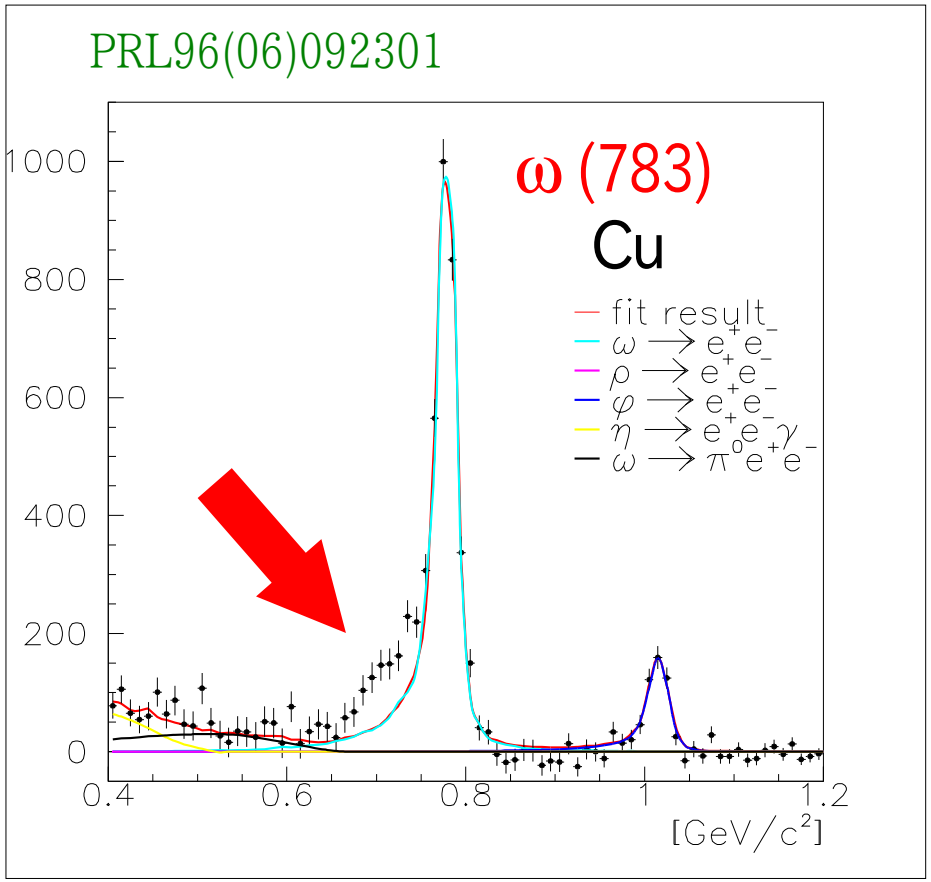
shorter-life meson (ρ)case : Schematic picture

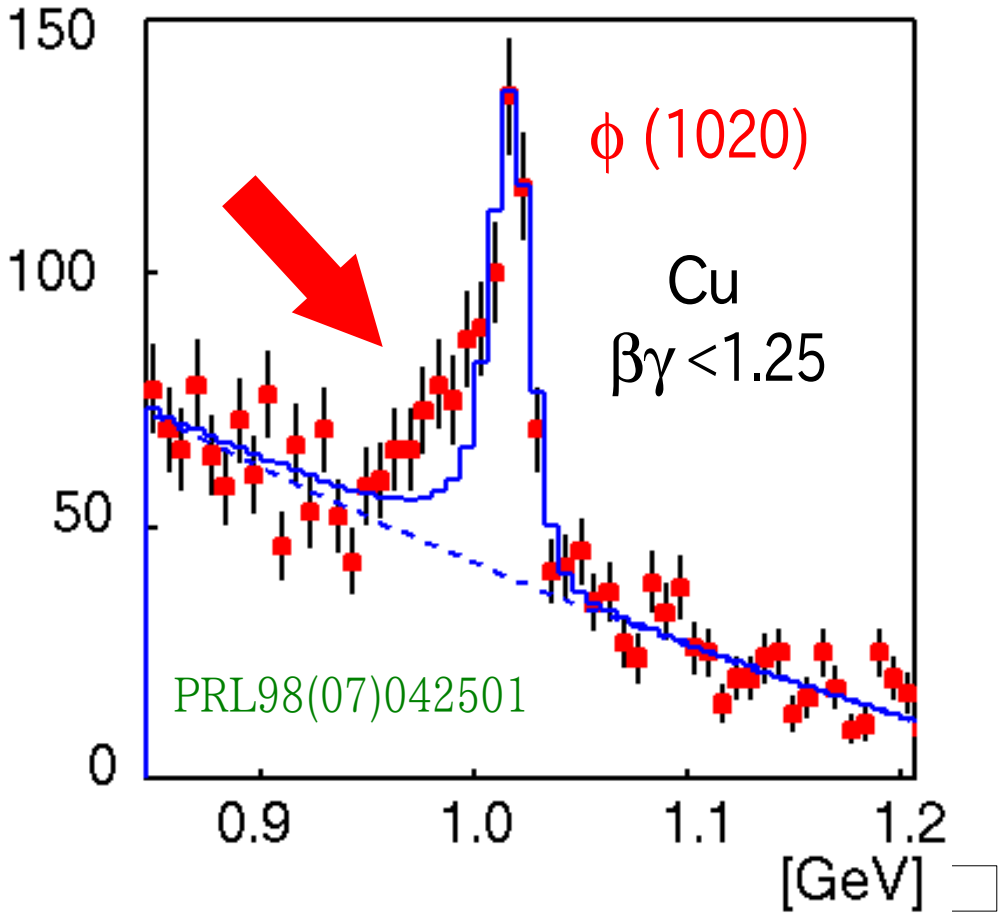


expected to be observed

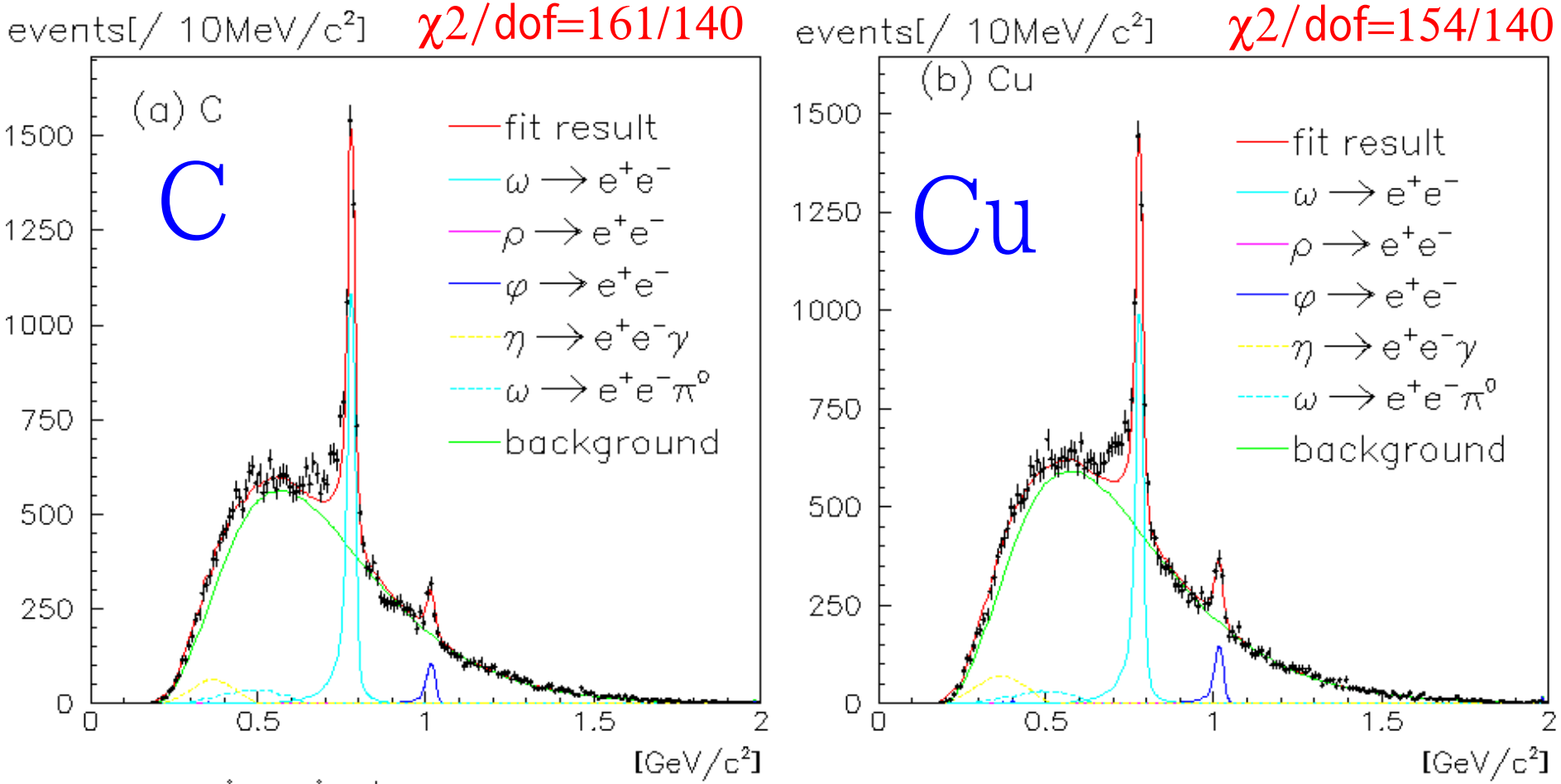
E325 observed the meson modifications

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





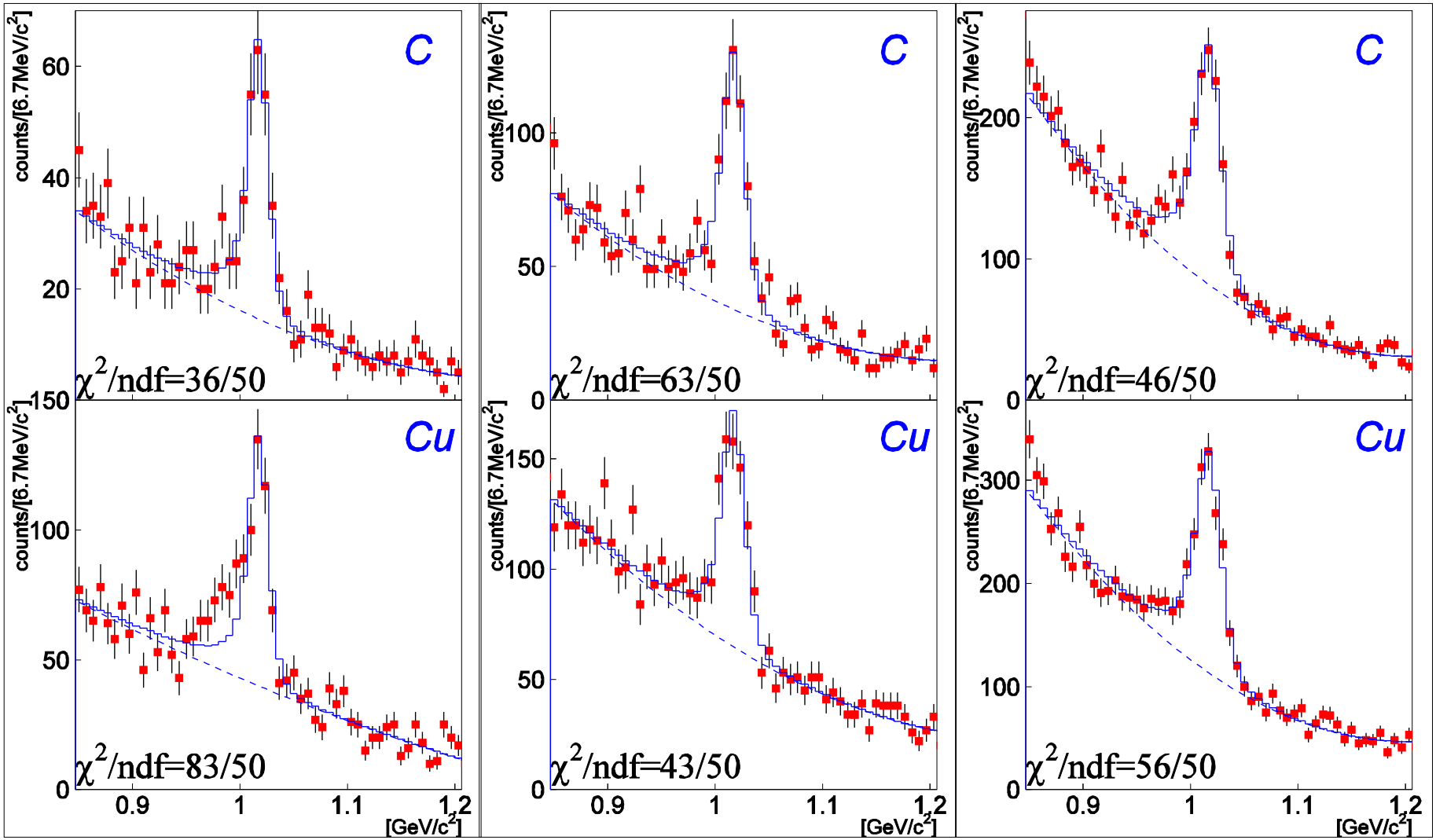
Fitting results (ρ/ω)



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

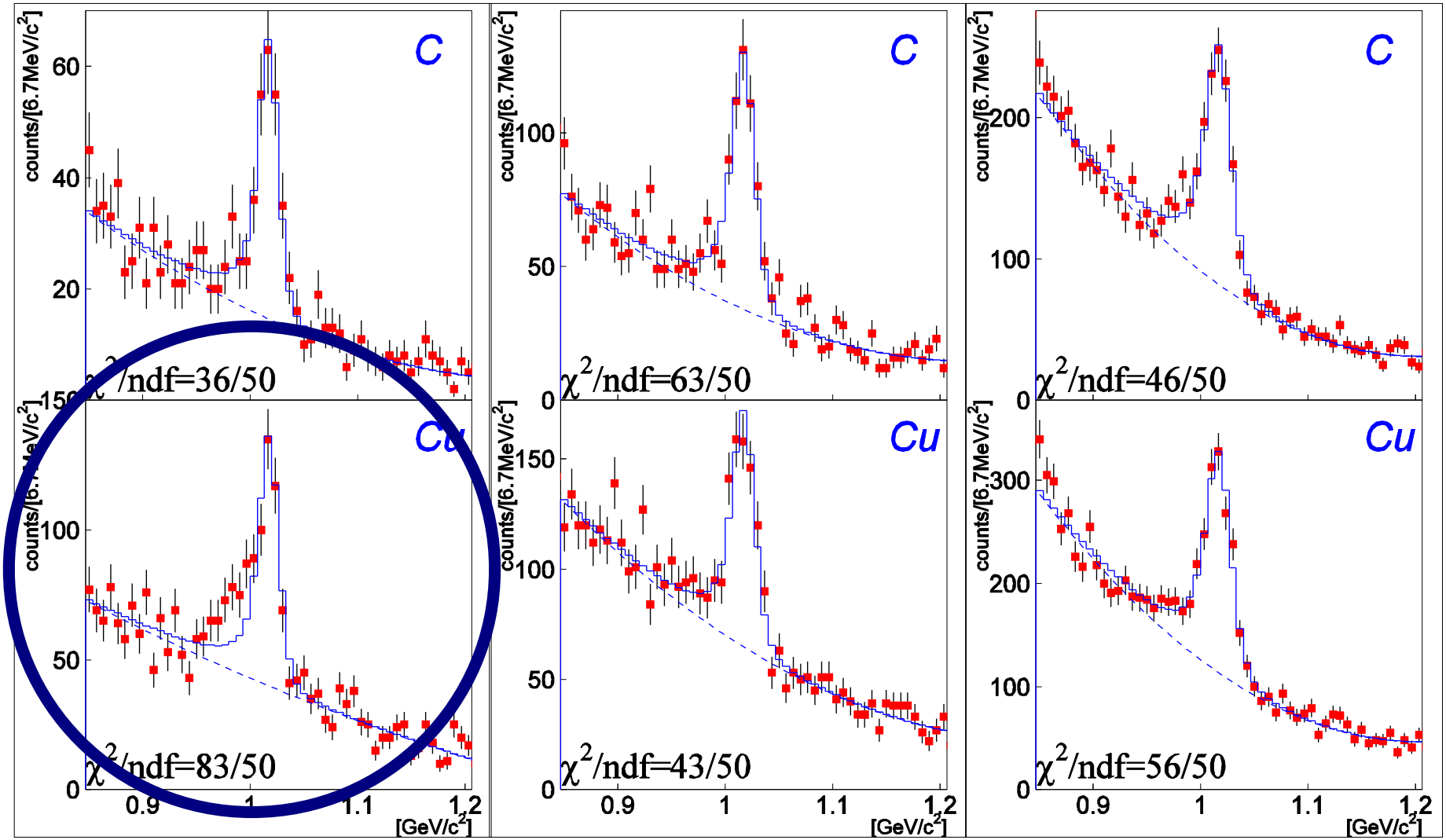
e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

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



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

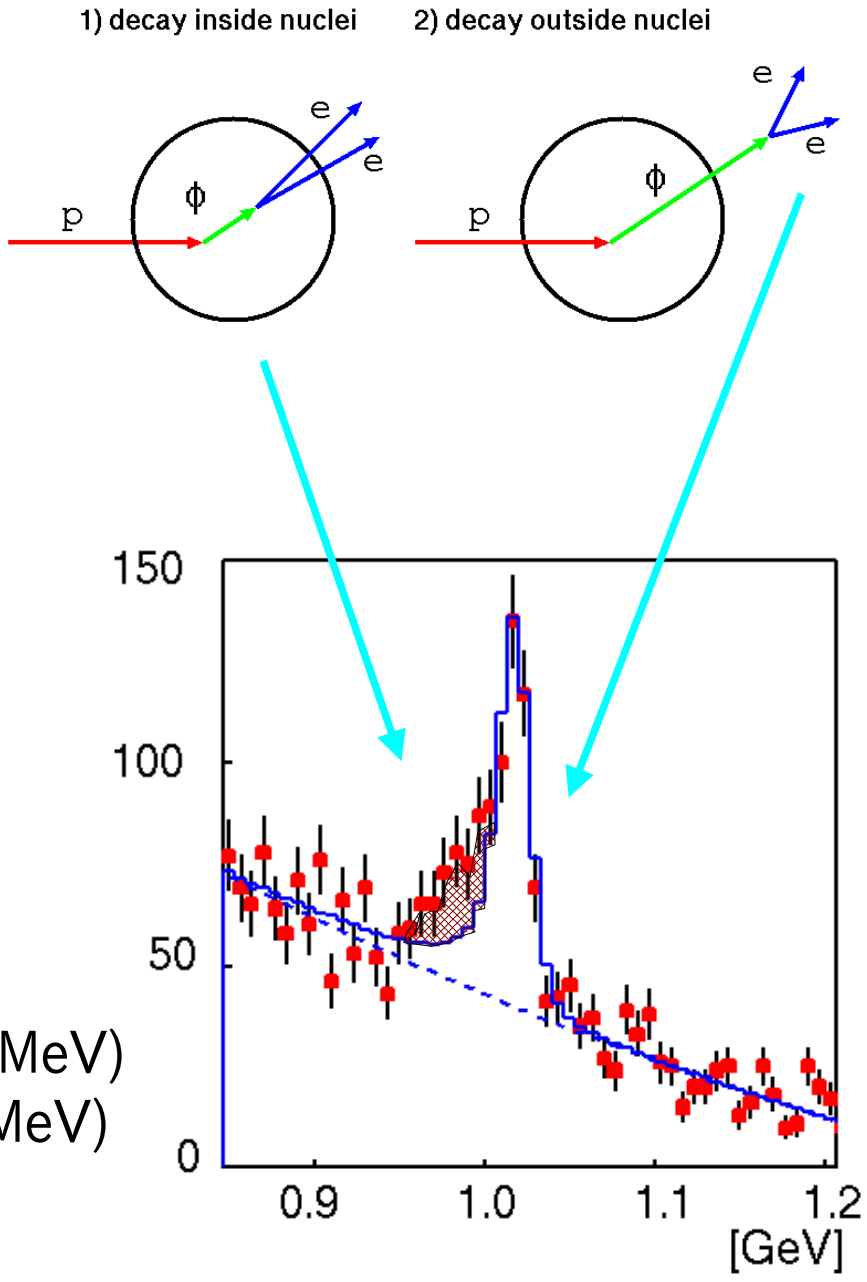
$\beta\gamma<1.25$ (Slow) $1.25<\beta\gamma<1.75$ $1.75<\beta\gamma$ (Fast)



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 with the predictions



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

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

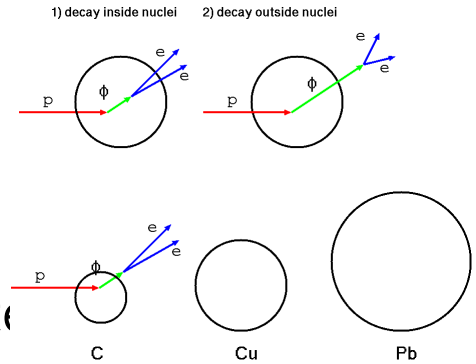
For ϕ, 3.4% mass reduction (35MeV)
3.6 times width broadening(16MeV)
at ρ_0
For ρ/ω , 9.2% mass reduction.

“mass modification” から physics へ

- 核物質中での中間子質量の変化は存在した (E325/CLAS-G7/(TAPS) at the lower energy, NA60/CERES/PHENIX in HI collision)
  - しかし、解釈は異なる
    - mass dropping and/or width broadening
    - 物質サイズ / 温度 / 密度の違いの影響を interpretation model に依存してはいないだろうか。
  - physics に決着がつかない
    - ハドロン多体効果か？ あるいは カイラル対称性の回復か？
- Next step in the invariant-mass approach
  - $\phi \longrightarrow e^+e^-$: に重点 ： ρ/ω より不定性が少ない
    - ρ's broad and complicated shape, ρ–ω interference, ρ/ω ratio, etc.
  - 質量分布変化の系統的測定
    - 核物質サイズ依存性： さらに大小の核， 衝突径数
    - 運動量依存性 ： 予言はあるが未だ測定されず
  - ... interpretation model の妥当性の check

J-PARC E16 experiment

- 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



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

J-PARC E16 experiment

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

Collaboration

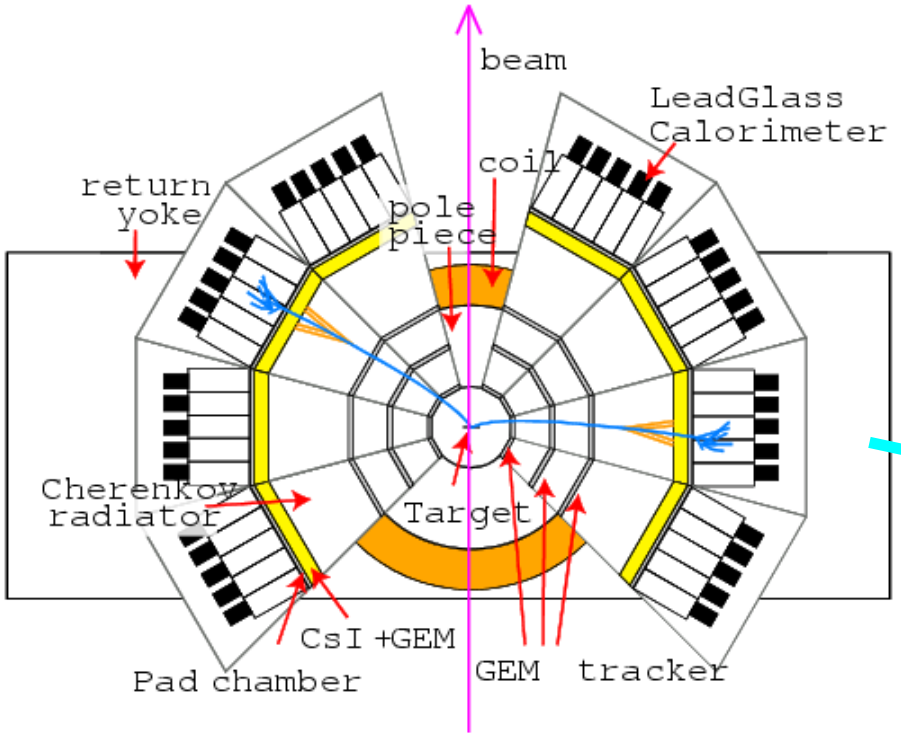
RIKEN S.Yokkaichi, H. En'yo, F. Sakuma, K. Aoki, J. Kanaya
U-Tokyo K. Ozawa, K. Utsunomiya, Y. Watanabe, Y.Komatsu, S.Masumoto
CNS, U-Tokyo H. Hamagaki Hiroshima-U K. Shigaki
KEK A.Kiyomichi, M. Naruki, R. Muto, S. Sawada, M. Sekimoto

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

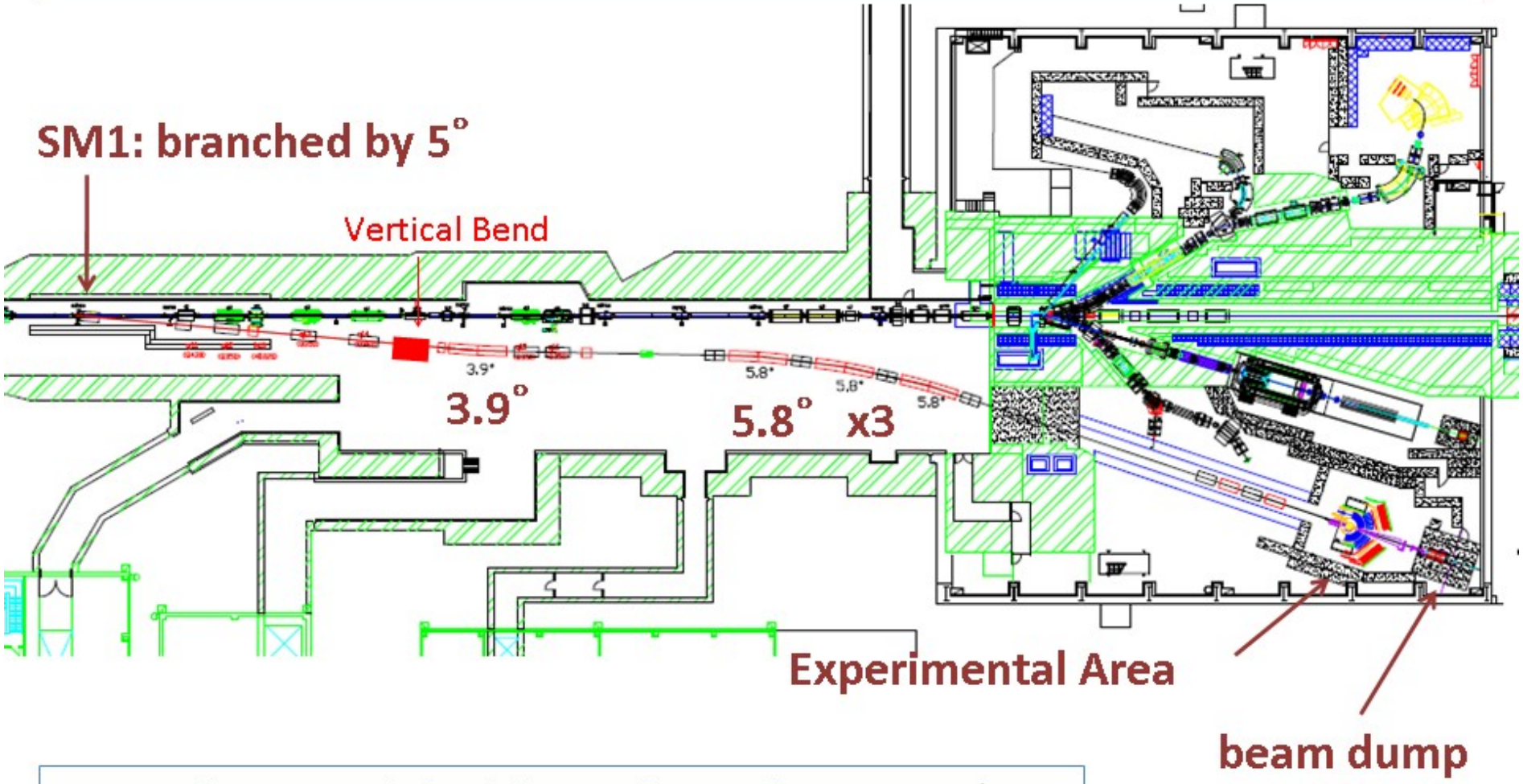
Scientific approval : 2007/3
... Detector R&D ...
Ready for beam : 2012/autumn

J-PARC E16 experiment

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



Location of E16 : High-momentum beam line



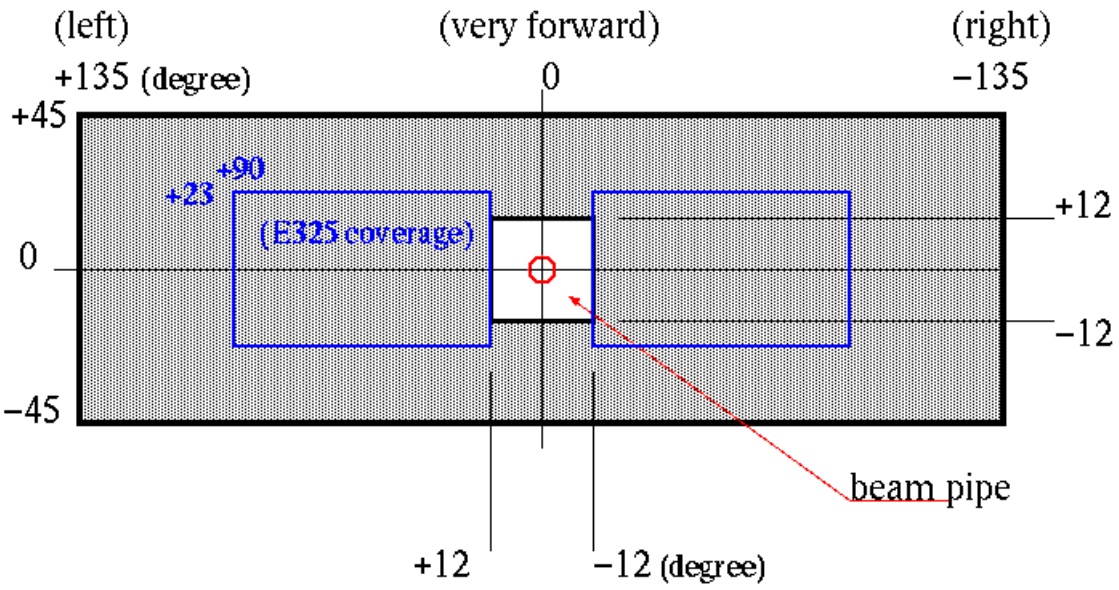
Beam dump and shields are for 10^{10} protons/s

by R. Muto

To collect high statistics

- 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

Geometrical (horizontal & vertical) coverage of the spectrometer



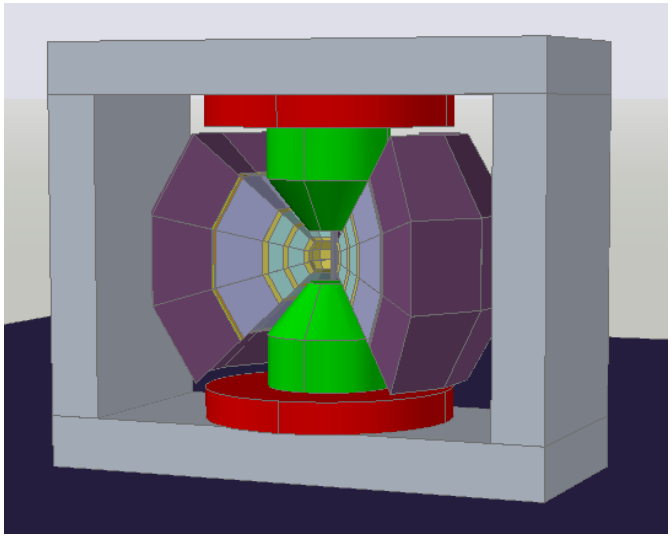
Target configuration

nuclei	interaction length(%)	radiation length(%)	thickness [μm]
C	0.05	0.1	200
CH_2	0.05	0.1	400
Cu	0.05	0.5	80
Pb	0.01	0.3	20

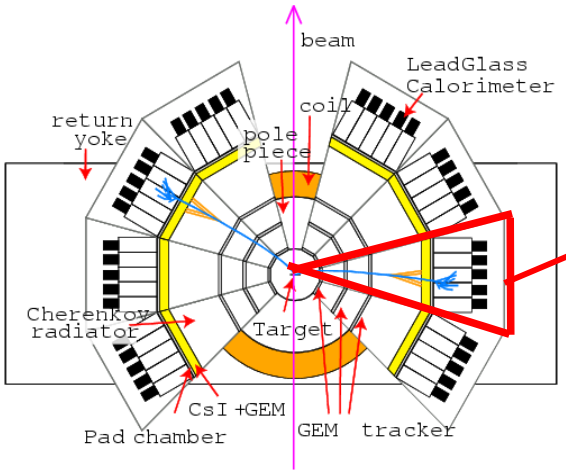
To collect high statistics

- 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)

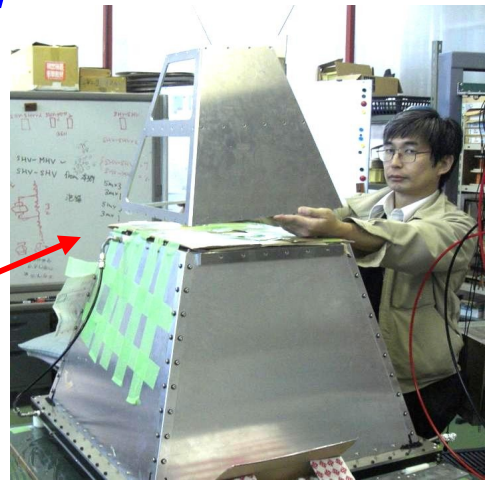
Proposed Spectrometer



Plan View

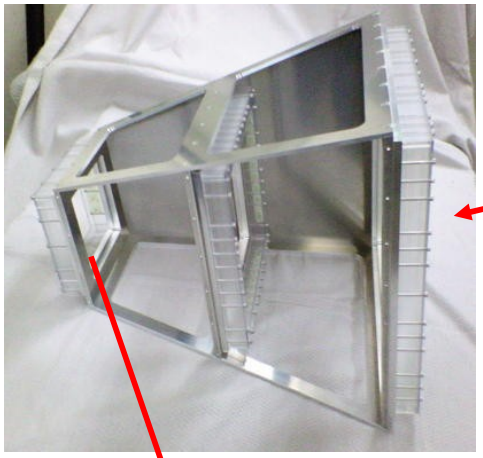


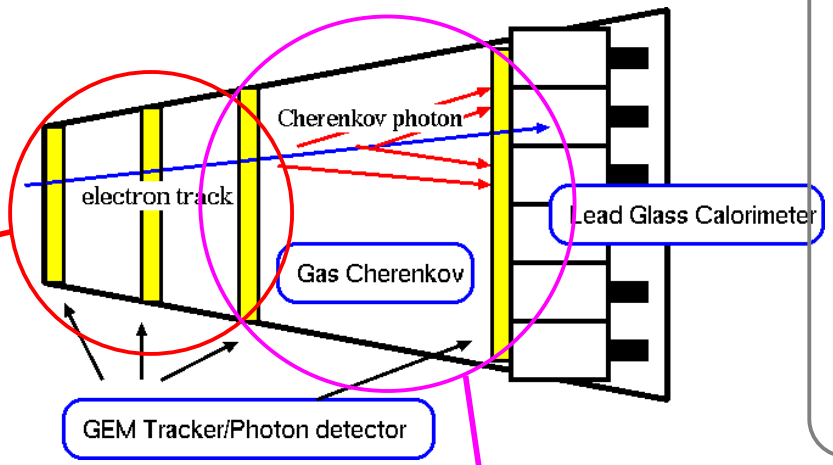
Prototype Module



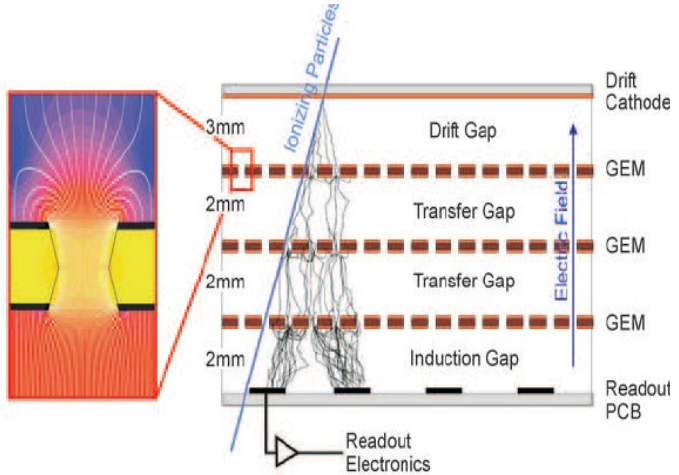
Detector R&D

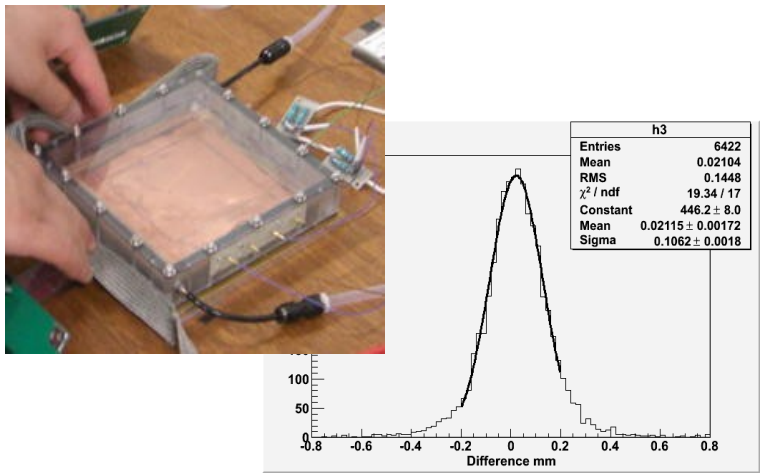
Beam test results of the Prototype Detector Module

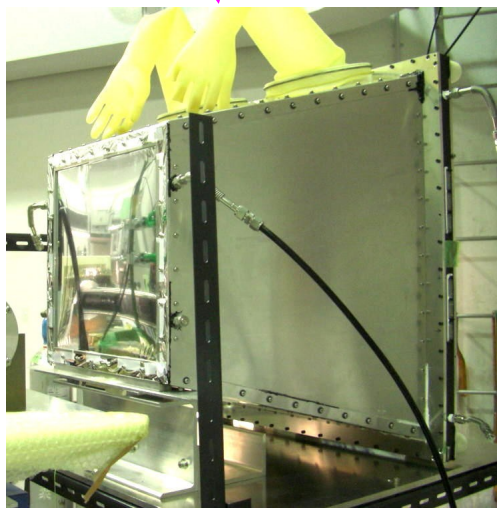




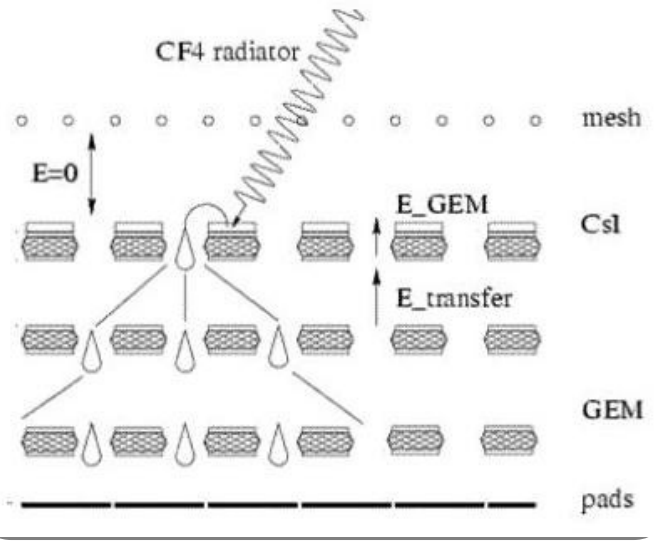
GEM & GEM chamber schematics







HBD(Hadron Blind Gas Cherenkov Detector)schematics



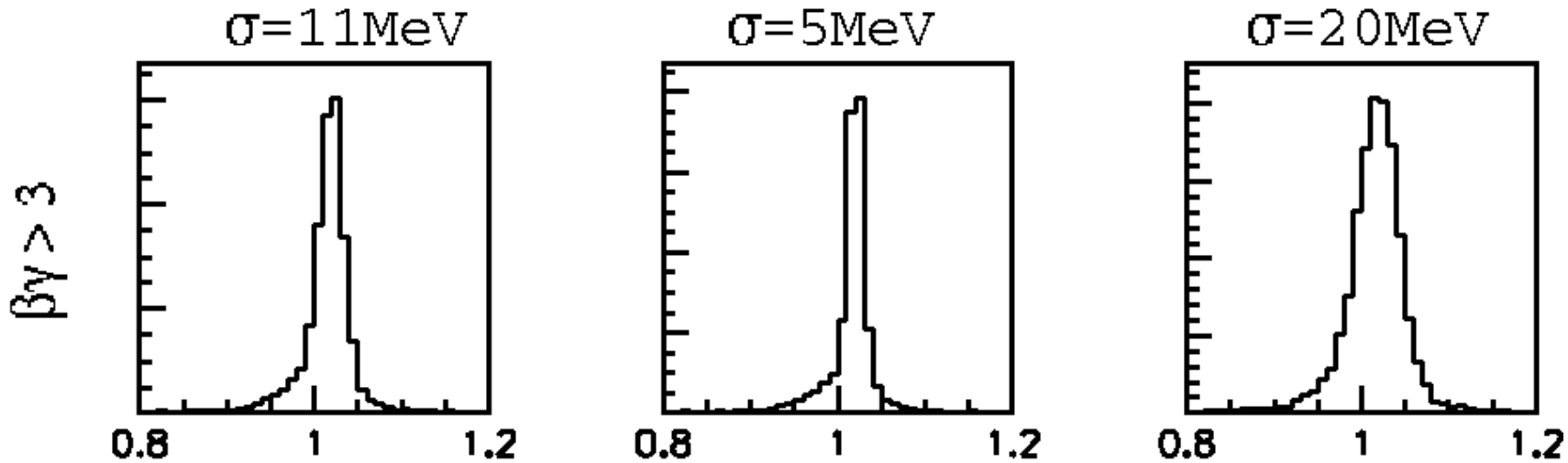
GEM Chamber :
required position resolution(~100μm) is achieved

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

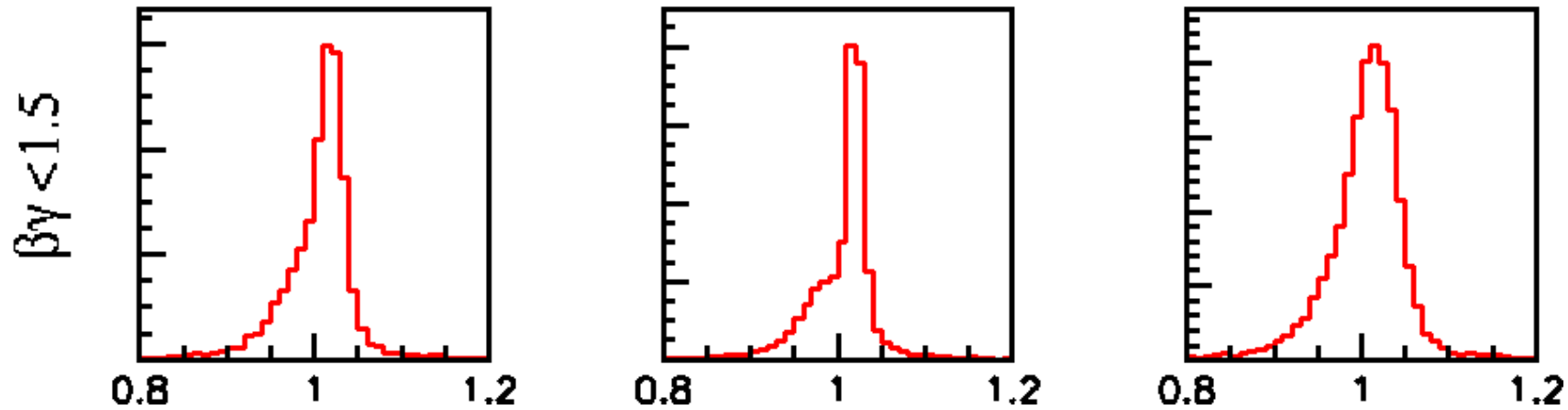
mass resolution requirement

- mass resolution should be kept less than ~10MeV

Fast



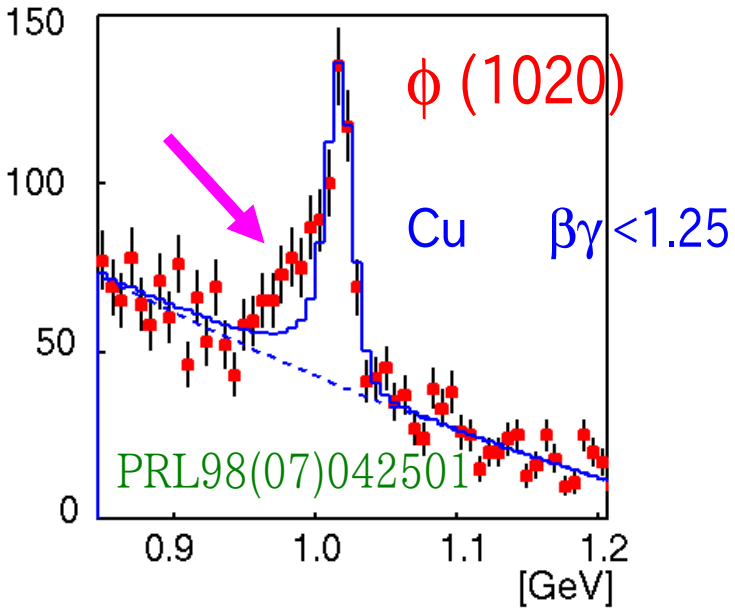
Slow



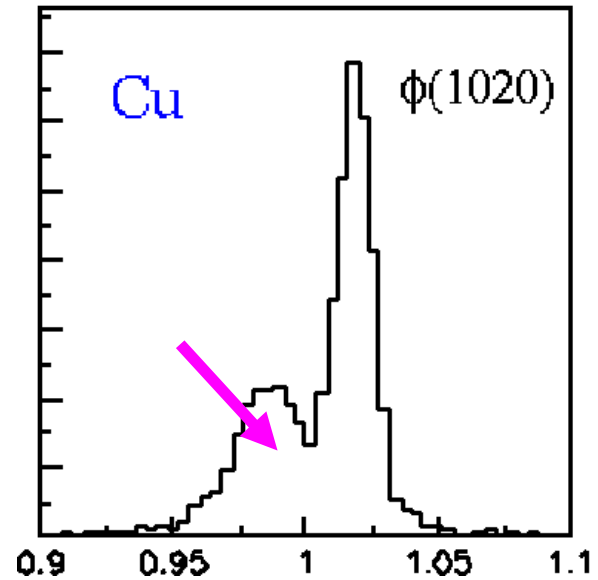
(model calc. for the Cu target)

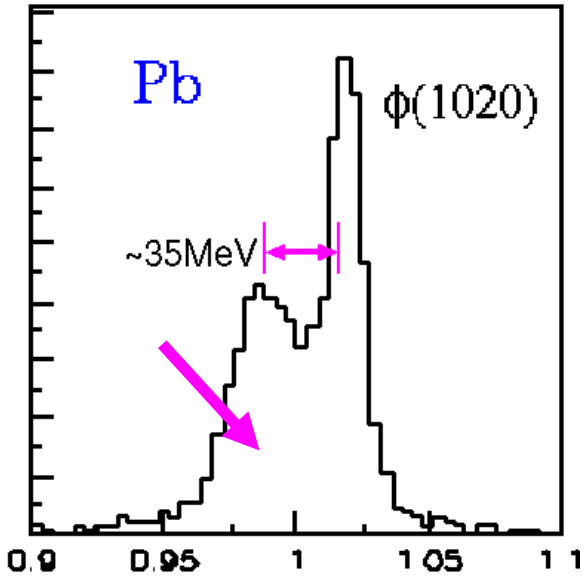
mass resolution requirement

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



βγ<0.5, σ=5 MeV

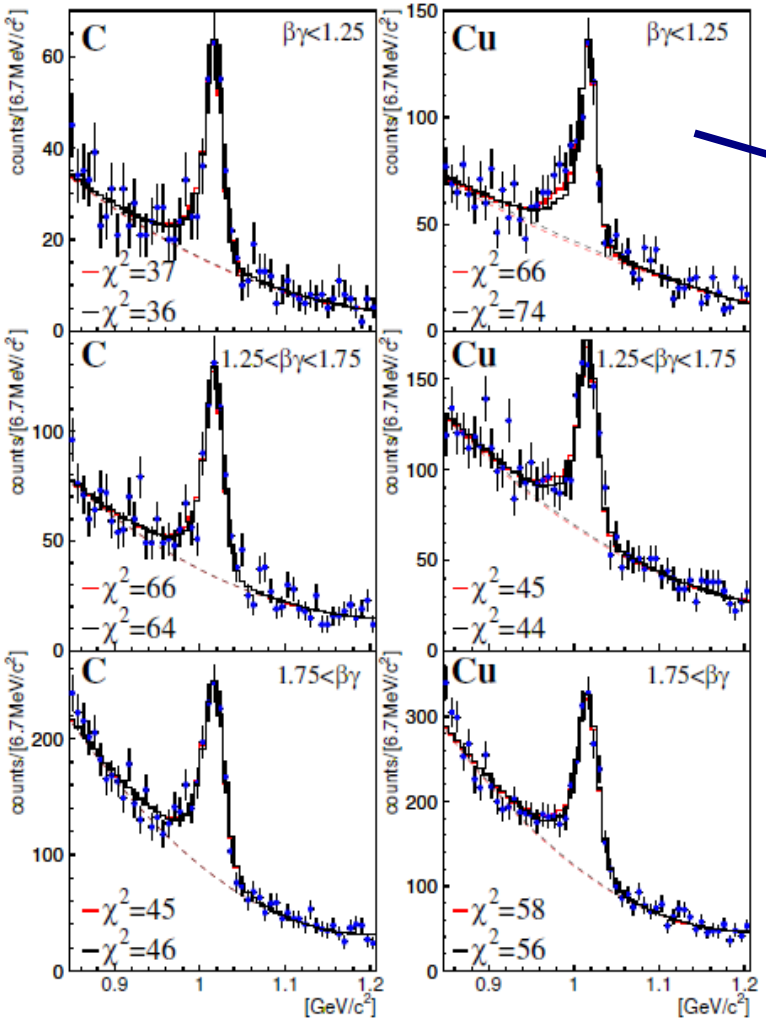


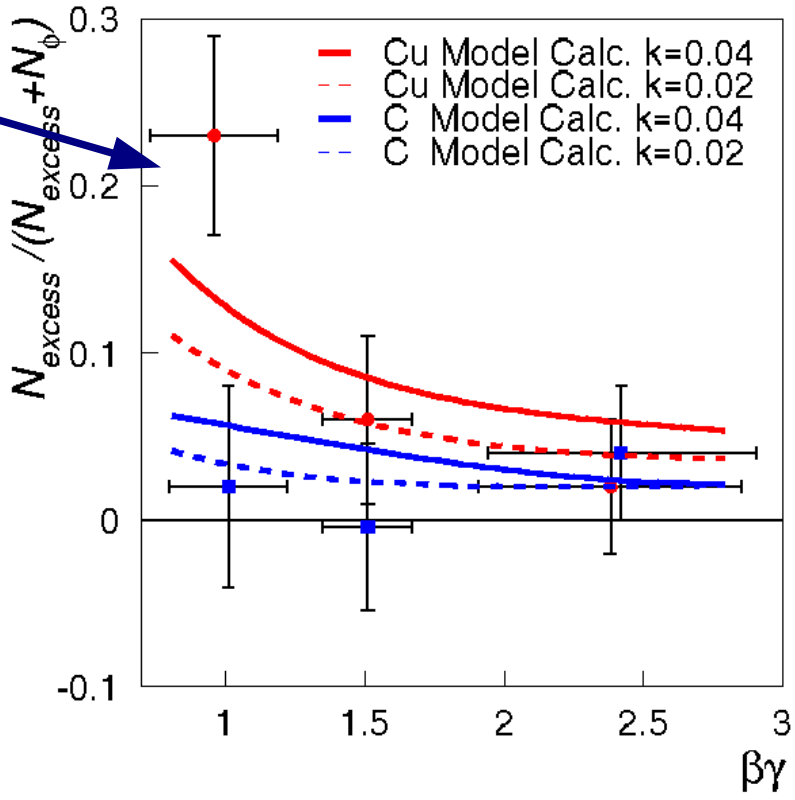


(model calc.)

velocity and nuclear size dependence

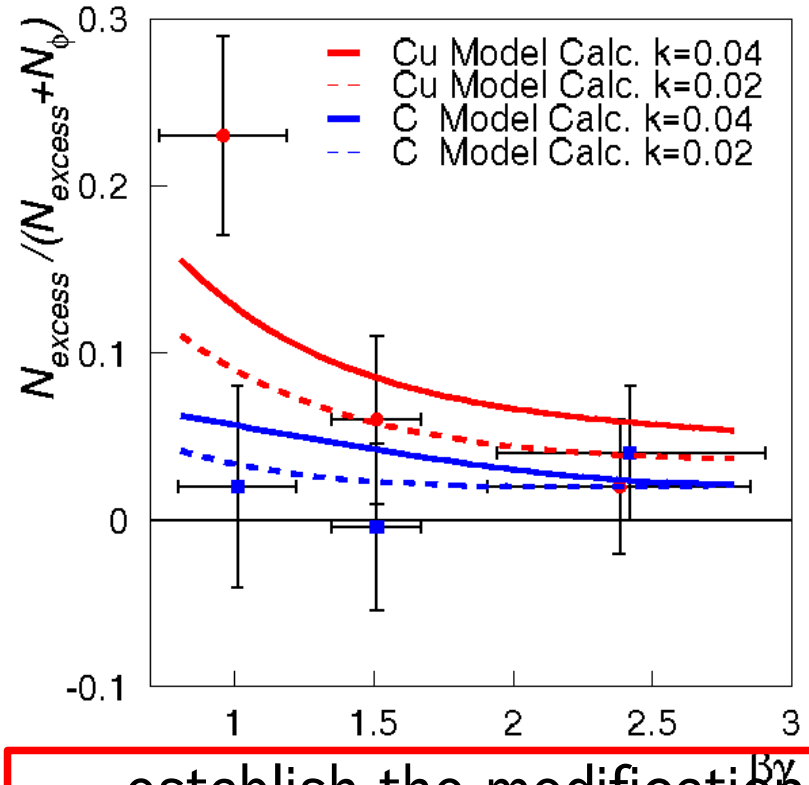
- velocity dependence of excesses ('modified' component)
- E325 only one data point for ϕ (slow/Cu) has significant excess



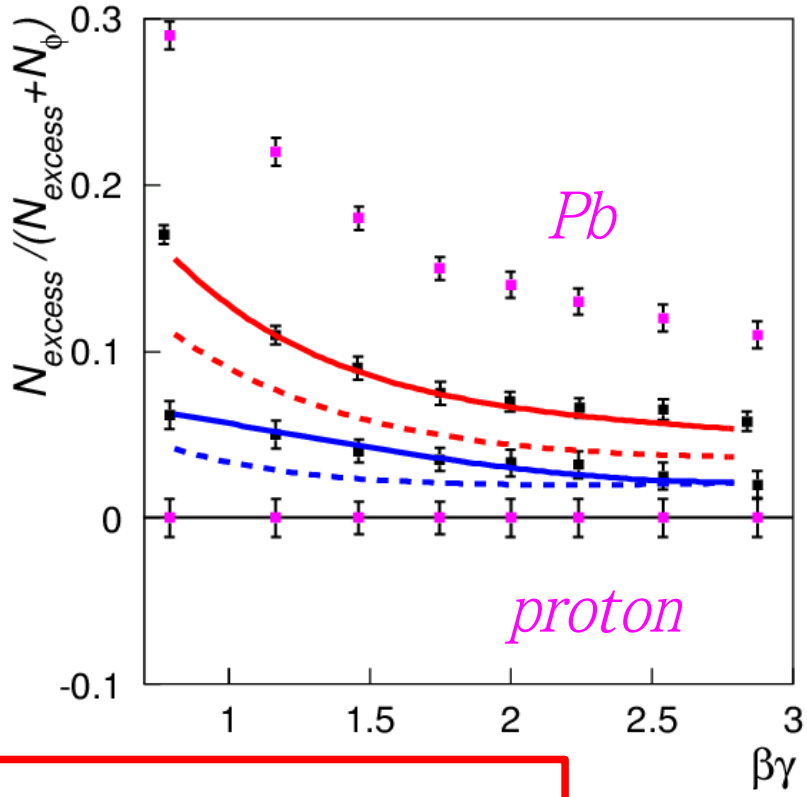


velocity and nuclear size dependence

- 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



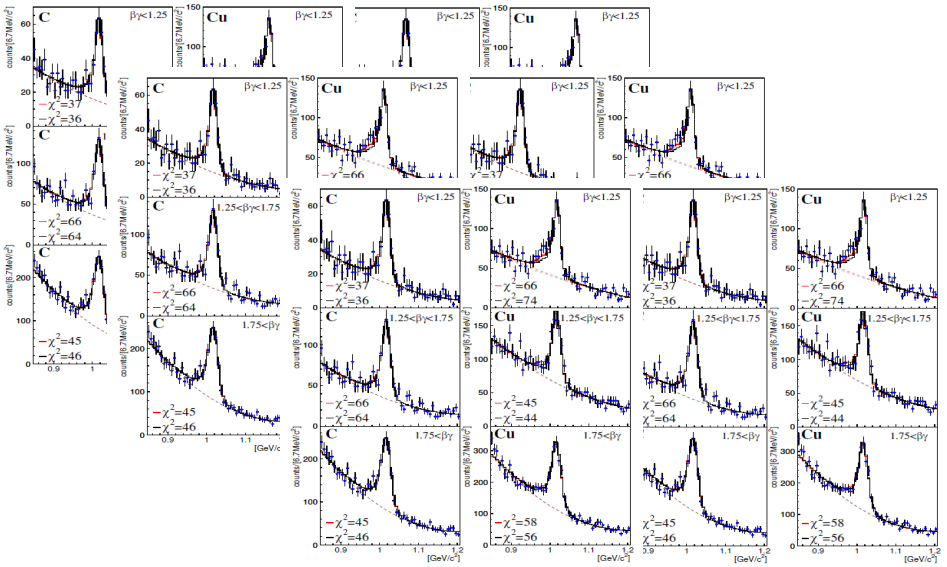
x 100 stat.

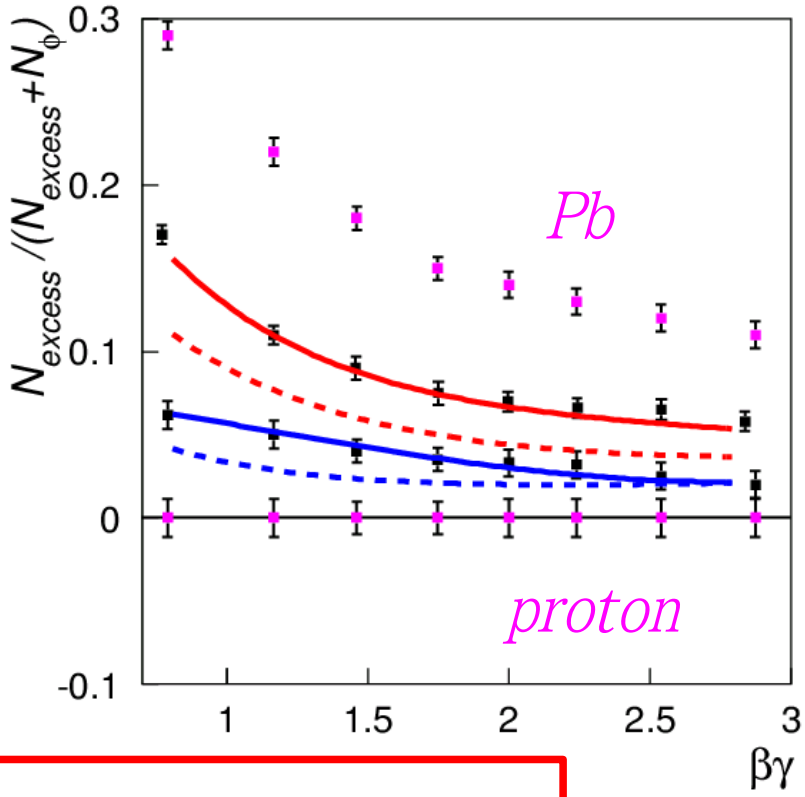


- establish the modification
-

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

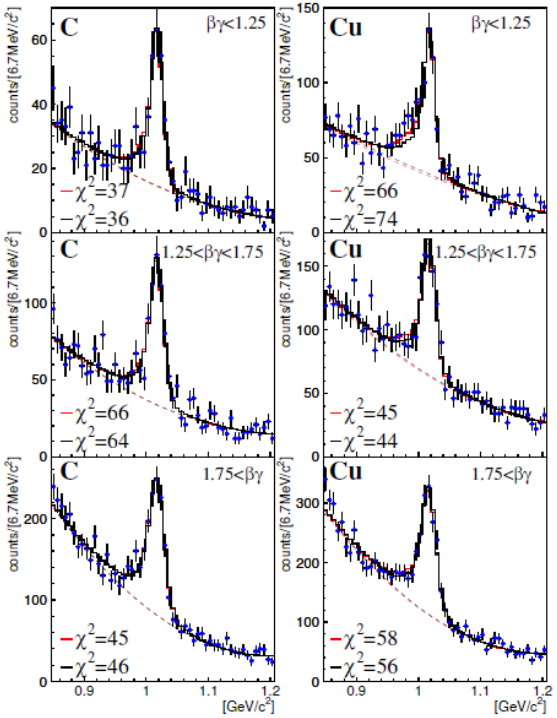


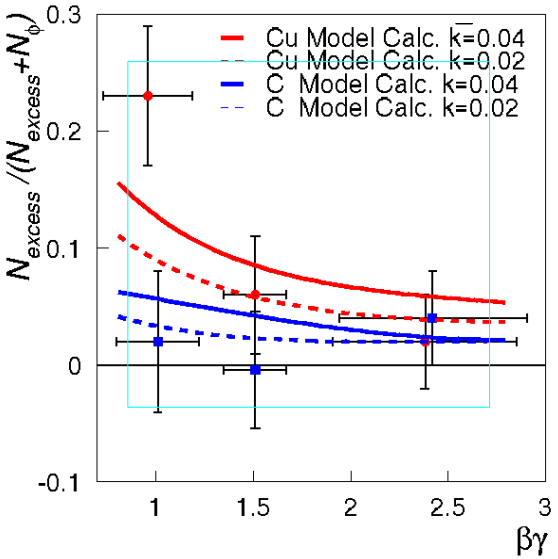


- establish the modification
- check the interpretation model with shape analysis for each histogram

dispersion relation (mass VS momentum)

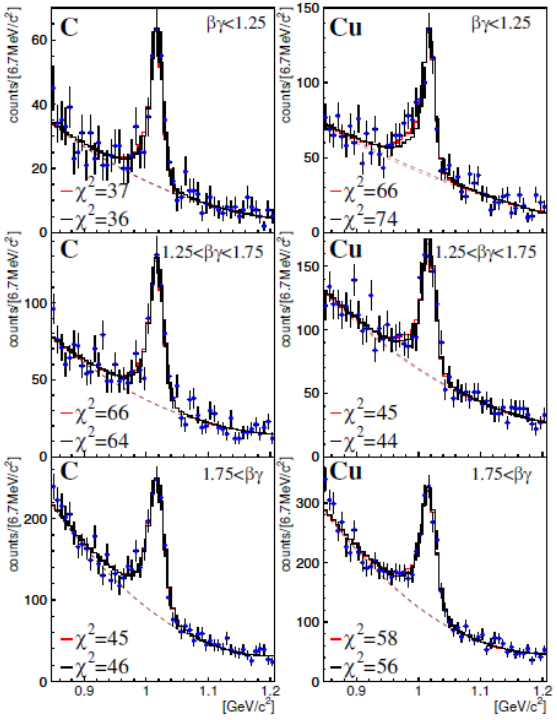
- prediction for ϕ by S.H.Lee(p<1GeV/c)
- current E325 analysis neglects the dispersion (limited by the statistics)

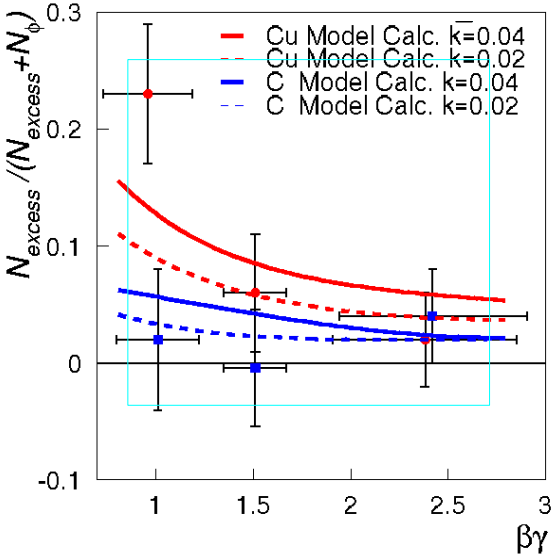


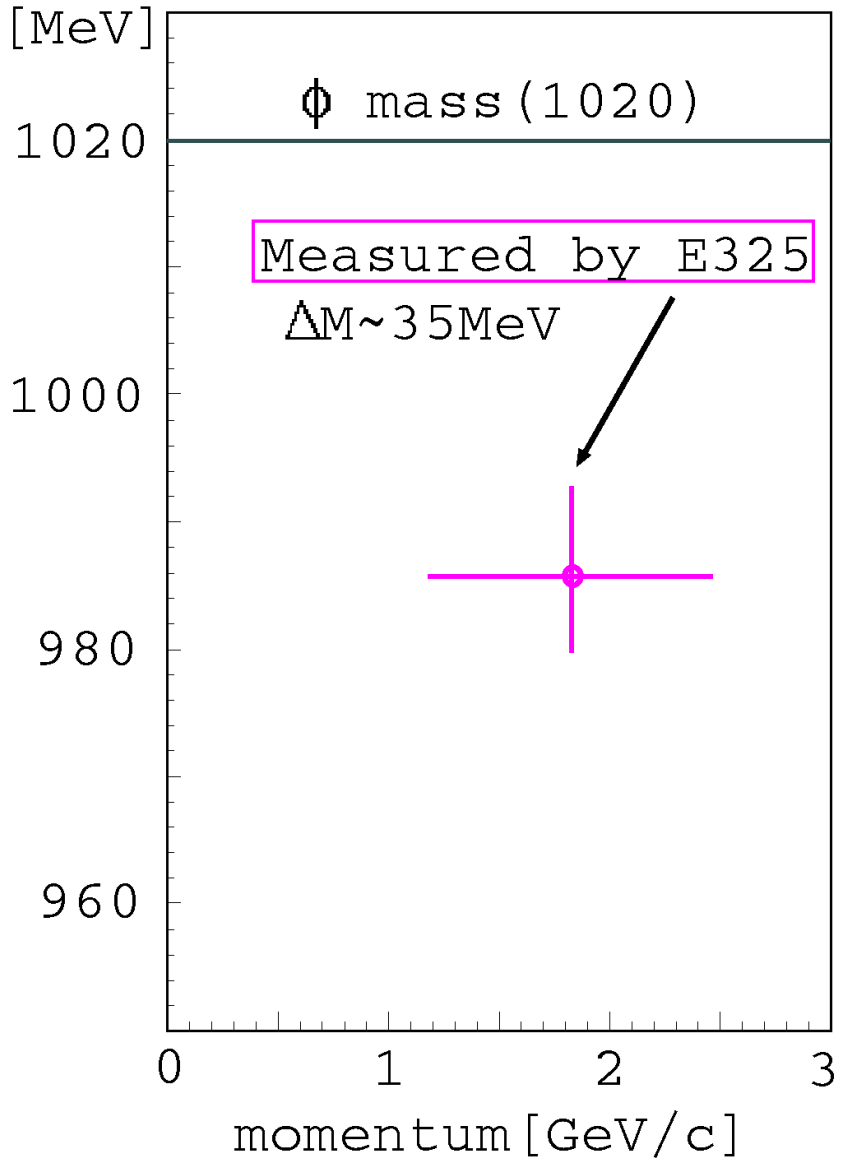


dispersion relation (mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV/c)
- current E325 analysis neglects the dispersion (limited by the statistics)



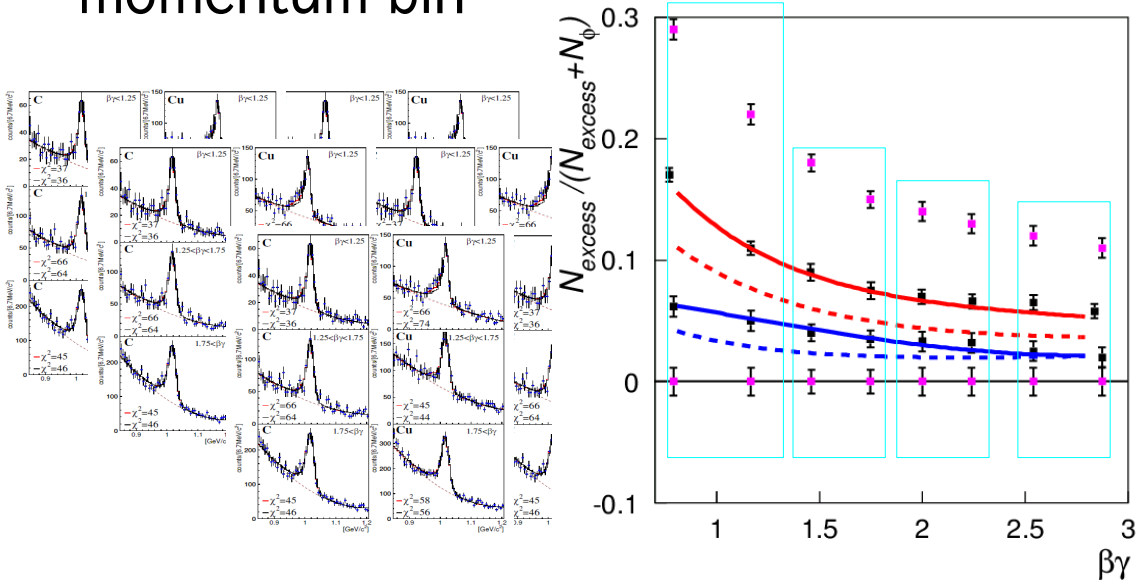


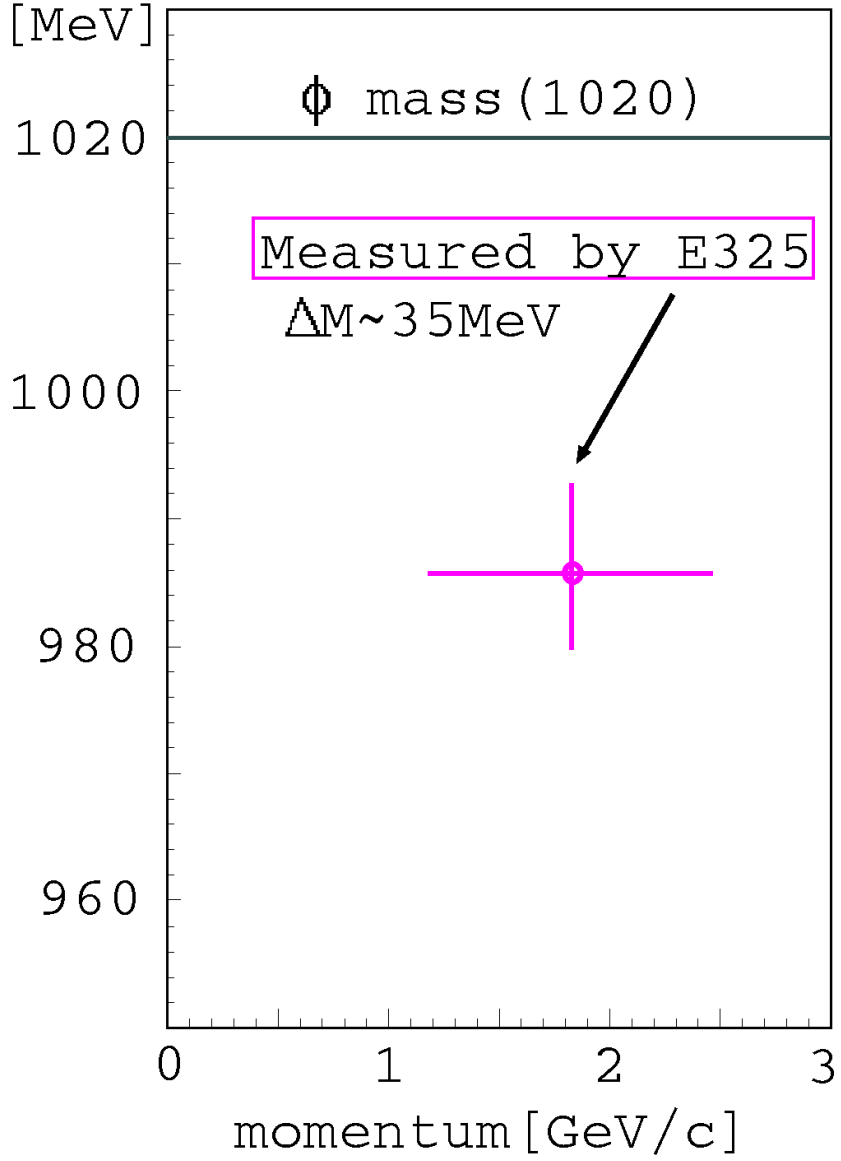


New hadron Meeting 09Nov27 S.Yokkaichi

dispersion relation (mass VS momentum)

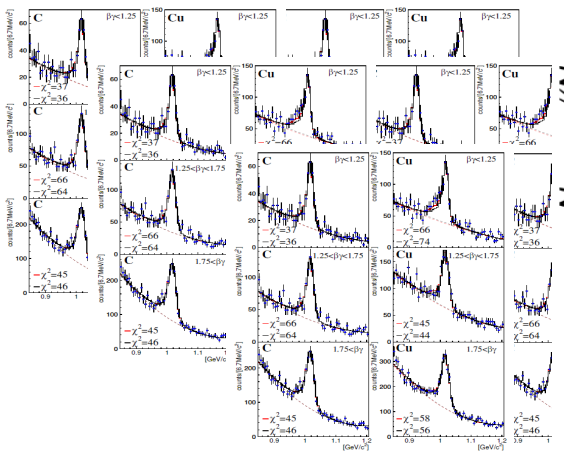
- prediction for ϕ by S.H.Lee(p<1GeV/c)
- current E325 analysis neglects the dispersion (limited by the statistics)
- fit with common shift parameter $k_1(p)$, to all nuclear targets in each momentum bin

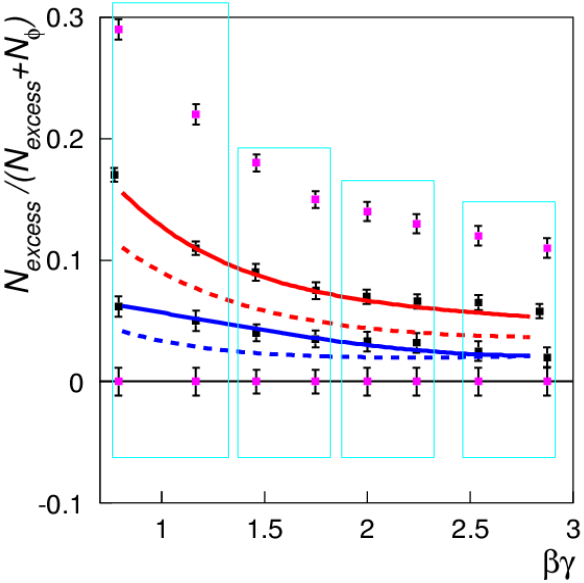


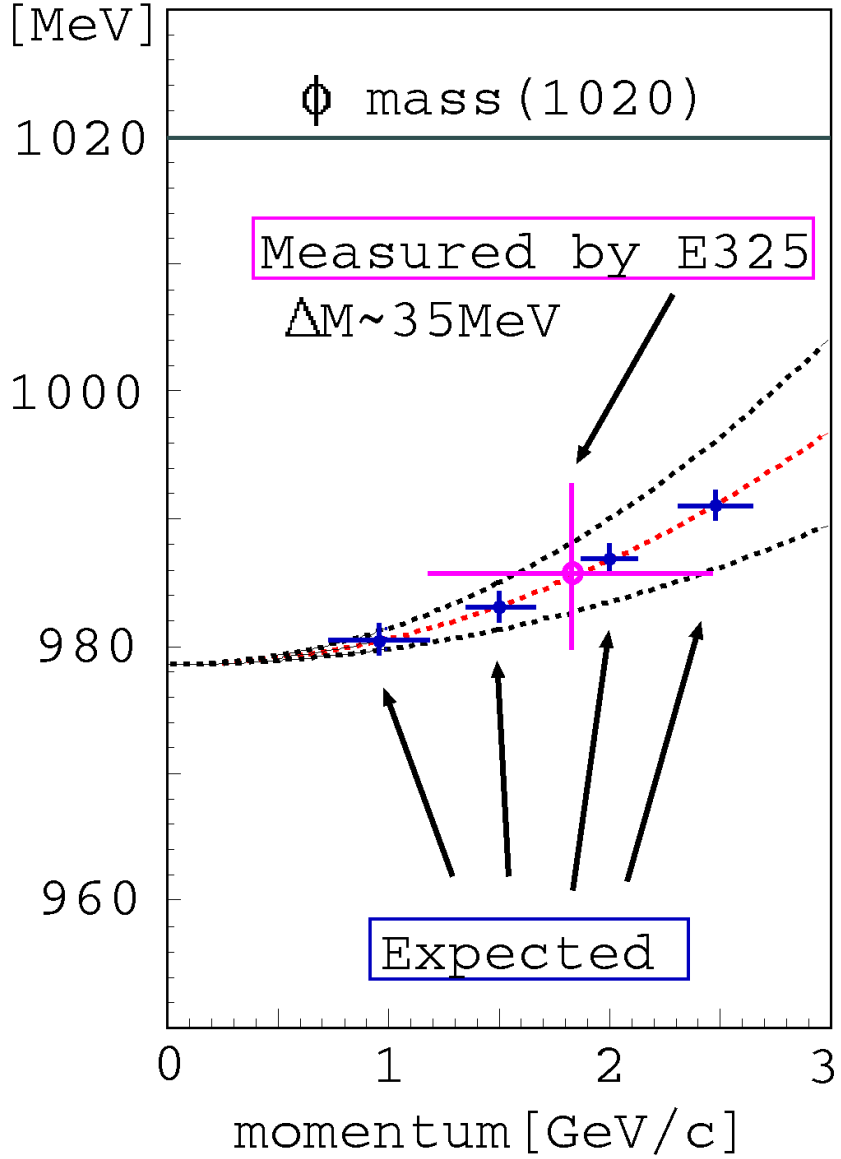


dispersion relation (mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV/c)
- current E325 analysis neglects the dispersion (limited by the statistics)
- fit with common shift parameter $k_1(p)$, to all nuclear targets in each momentum bin







Summary

- 高温（重イオン衝突）および 原子核密度中（原子核標的実験）での 中間子の不変質量スペクトルの変化は存在した。
- それがカイラル対称性の回復のせいであるかどうかは 議論がつづいている。
- 次の一手
  - 実験： @J-PARC
    - 質量変化の系統的測定 (E16) 30/50 GeV p+A
    - 中間子束縛核からの中間子崩壊 ~2GeV/c π +A, pbar+A
    - 密度依存性：高密度@重イオン衝突？ A+A ？
  - 理論： 実験室の不変質量分布と QCD を結ぶ枠組 ？
    - 現象論 ： 解析上の”バックグラウンド”
      - 系の時間発展、原子核サイズ効果， FSI ： BUU?
      - mixing などの 不変質量分布への影響
    - 第一原理 ： “無限核物質中に静止した中間子”の次
      - 運動量依存性
      - QCDSR/Lattice in 有限サイズ核？

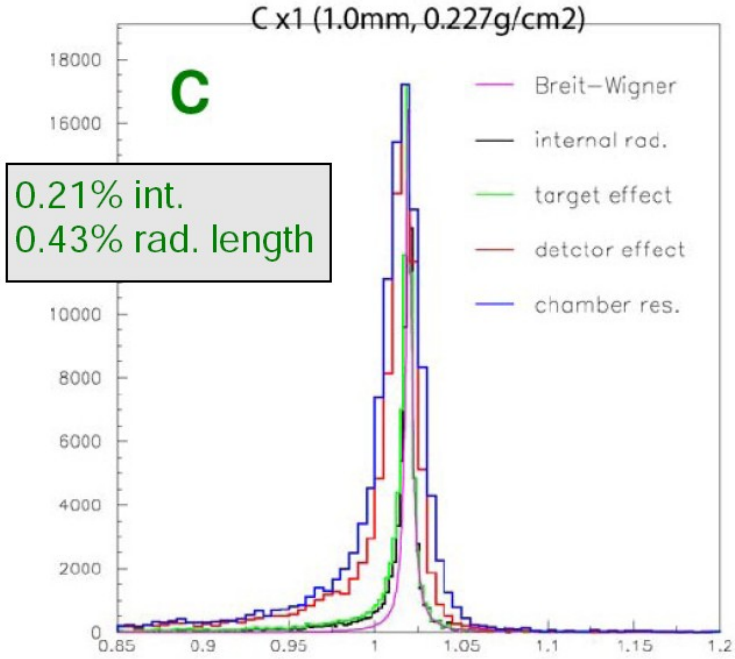
Backup slides...

-

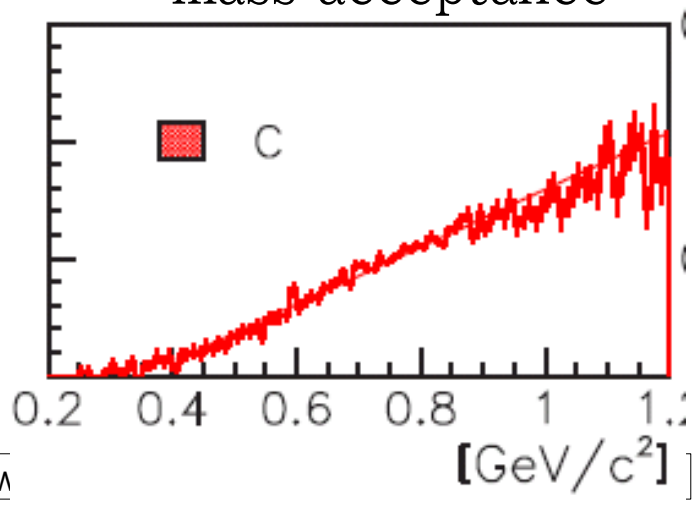
Analysis : Fitting with known sources

- 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



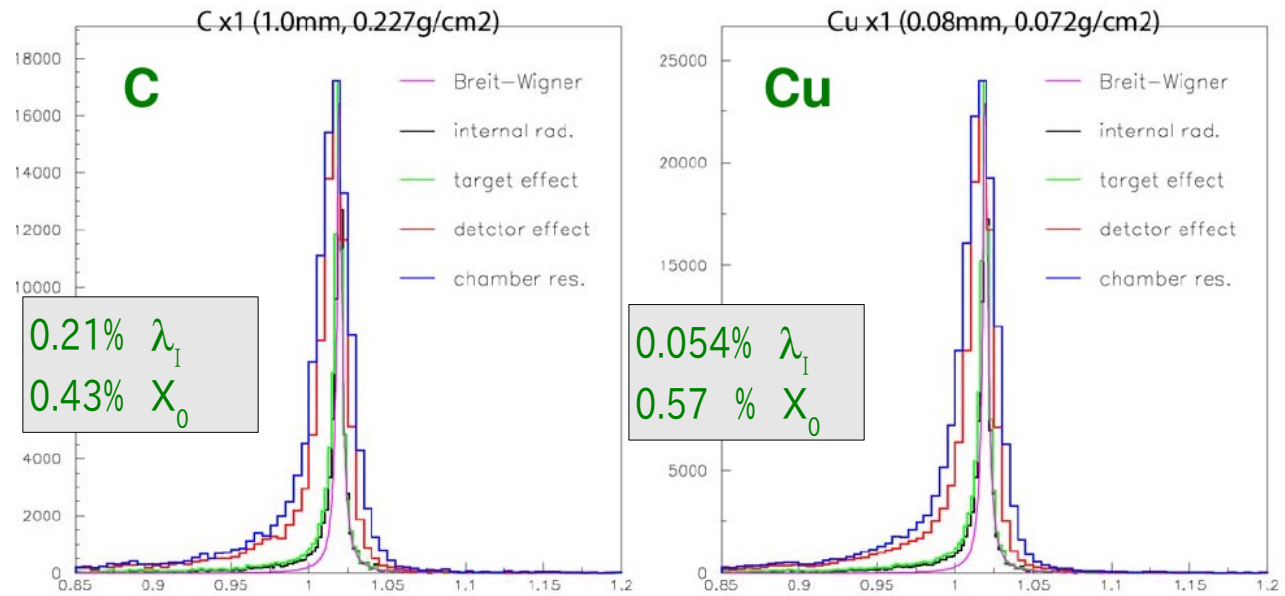
mass acceptance



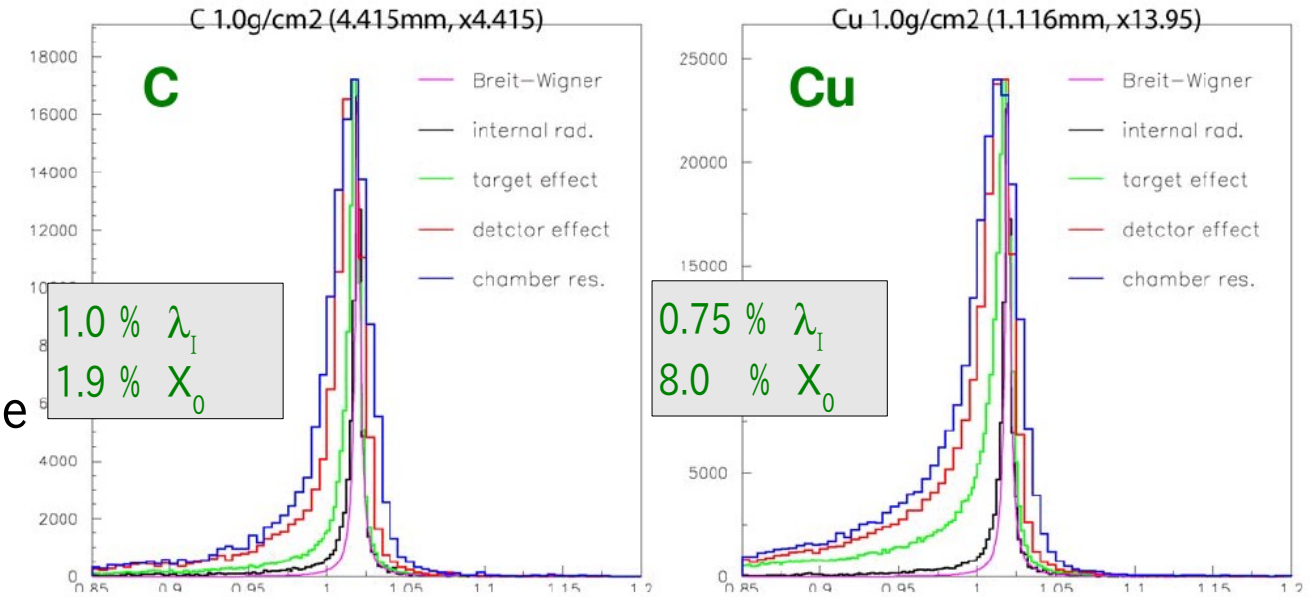
New

experimental effects on the BW shape (E325)

- E325 Detector Sim.
  - target material is negligible for ~0.5% radiation length (X_0)
  - detectors :up to 4.5 % X_0 in the tracking region

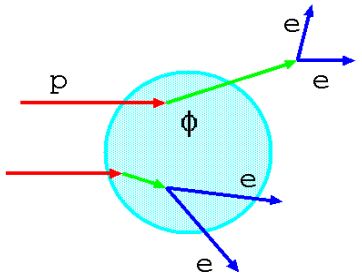


- In the case of the thick targets : 1g/cm^2
  - bremsstrahlung in target is so large for the Cu case

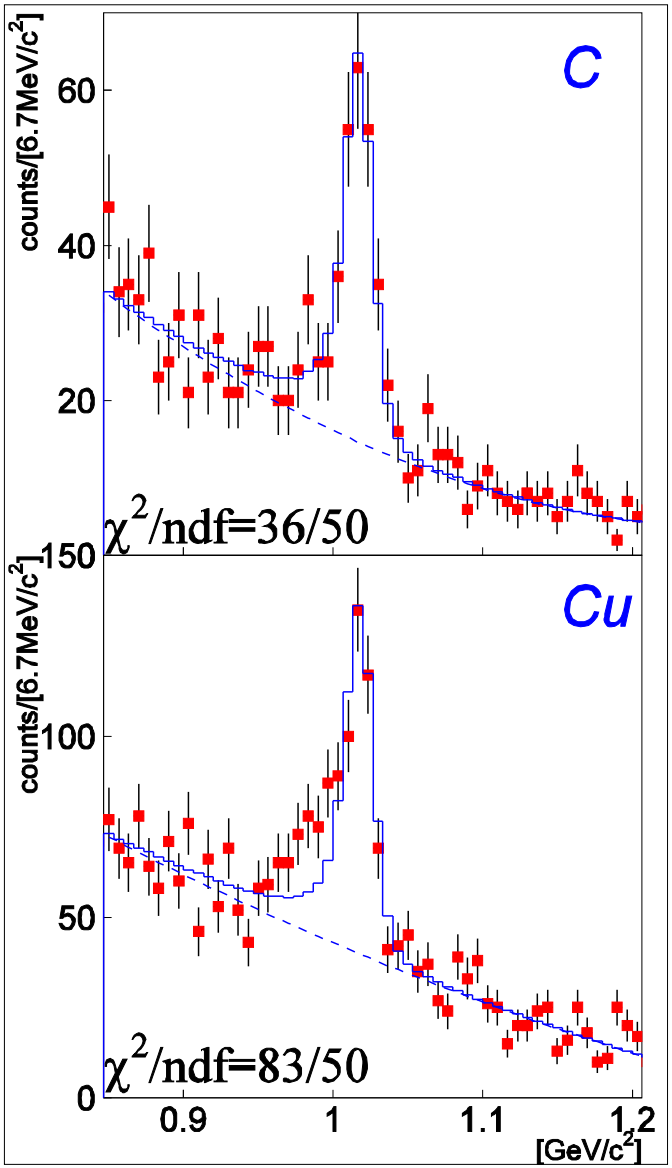


Fit using modified mass shapes

- MC type calc. : mesons are generated,flied and modified
  - observed momentum dist.
  - uniformly made in nuclei
    - measured α of ϕ production ~ 1
  - $m^*/m_0 = 1 - k_1\ \rho/\rho_0$
    (k_1=0.04, Hatsuda & Lee, '92,'96)
  - To reproduce such amount of excess, linear-dependent width broadening is adopted :
    $\Gamma_{tot}^{*}/\Gamma^{0}_{tot} = 1 + k_2\ \rho/\rho_0$
    - e^+e^- branching ratio is not changed
      - $\Gamma^{*}_{e+e-} / \Gamma^{*}_{tot} = \Gamma^{0}_{e+e-} / \Gamma^{0}_{tot}$
  - fits were done with many combinations of (k_1,k_2)

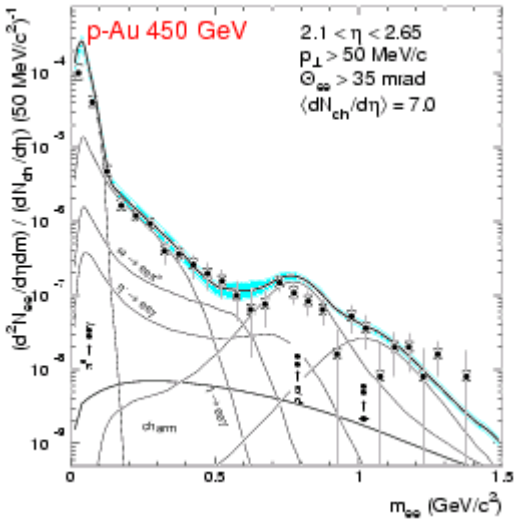


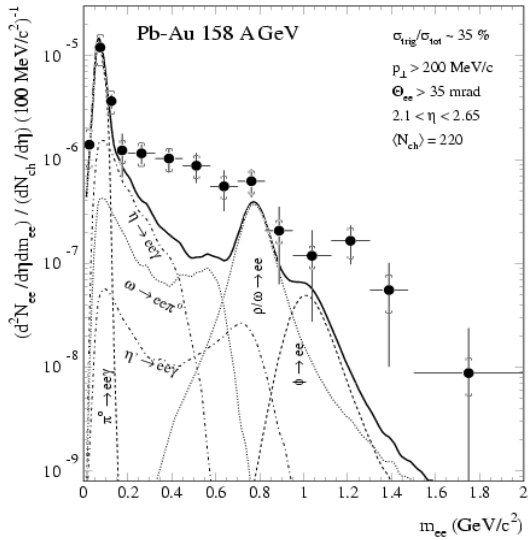
$\beta\gamma$<1.25 (Slow) k_1=0,k_2=0

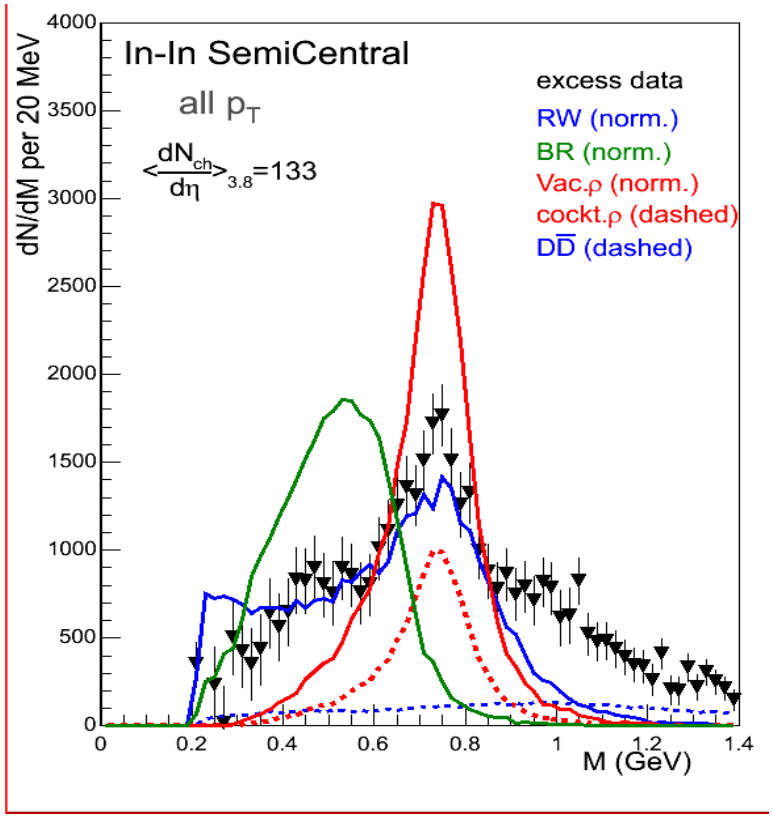


Vector meson measurements in HIC

- CERES : e^+e^- (EPJC 41('05)475)
  - anomaly at the 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'

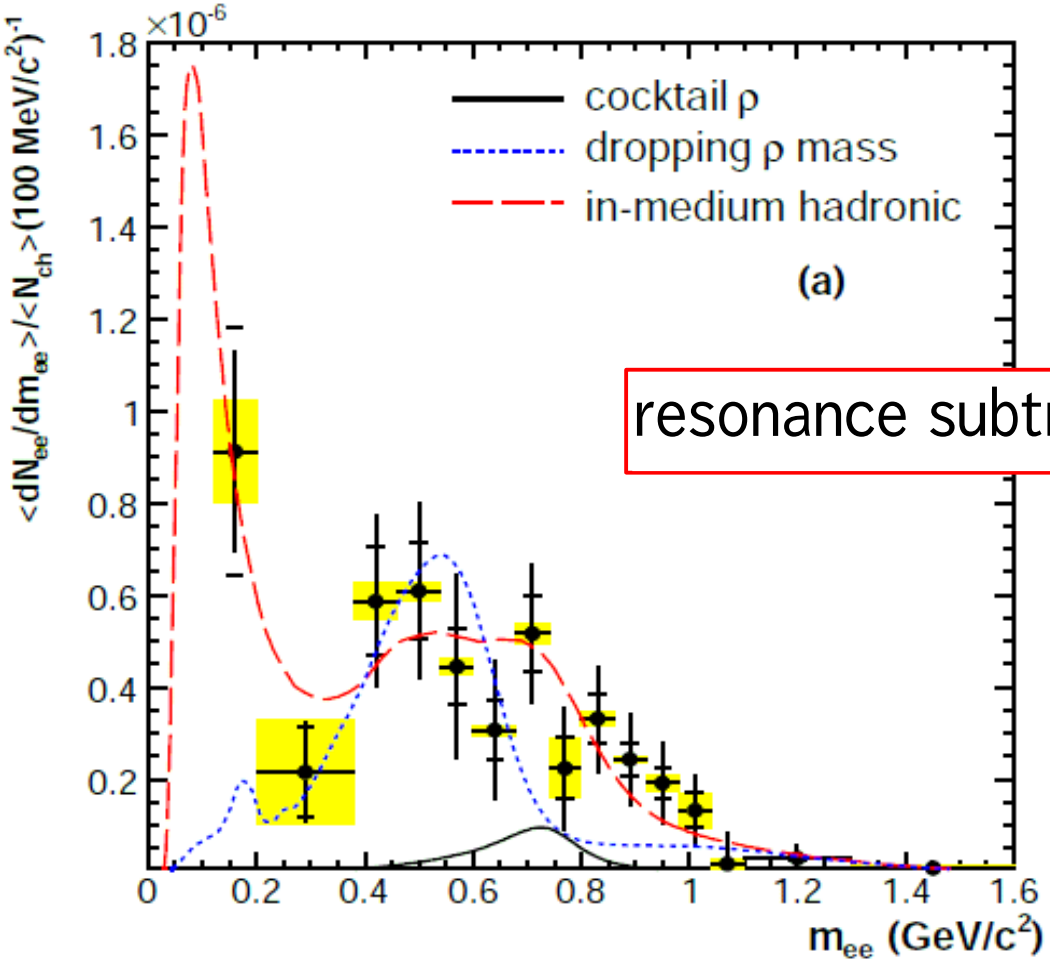




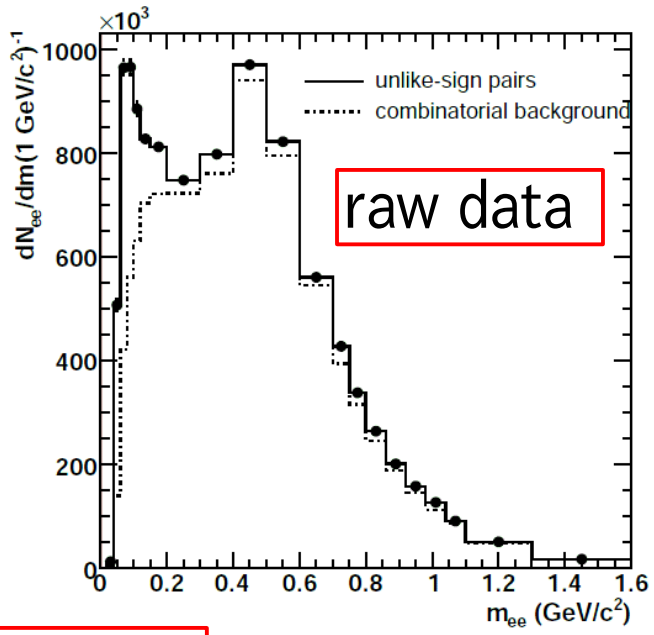


Vector meson measurements in HIC

- CERES : (arXiv: 0611022v3)
  - "broadening by hadronic effect " is favored

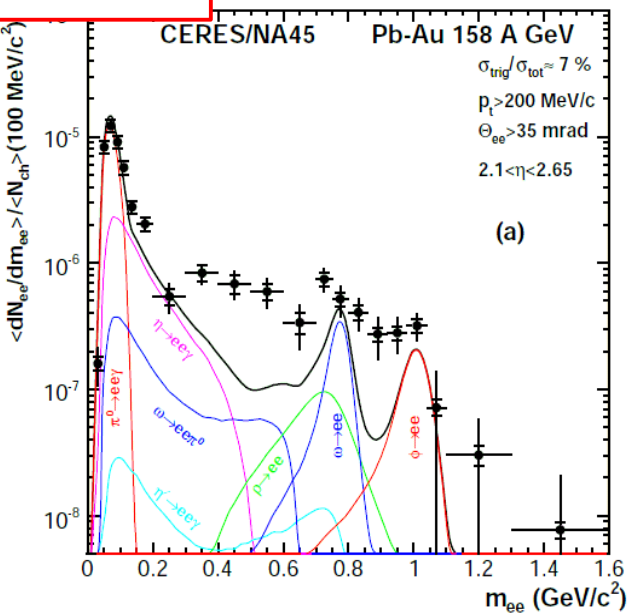


resonance subtracted



raw data

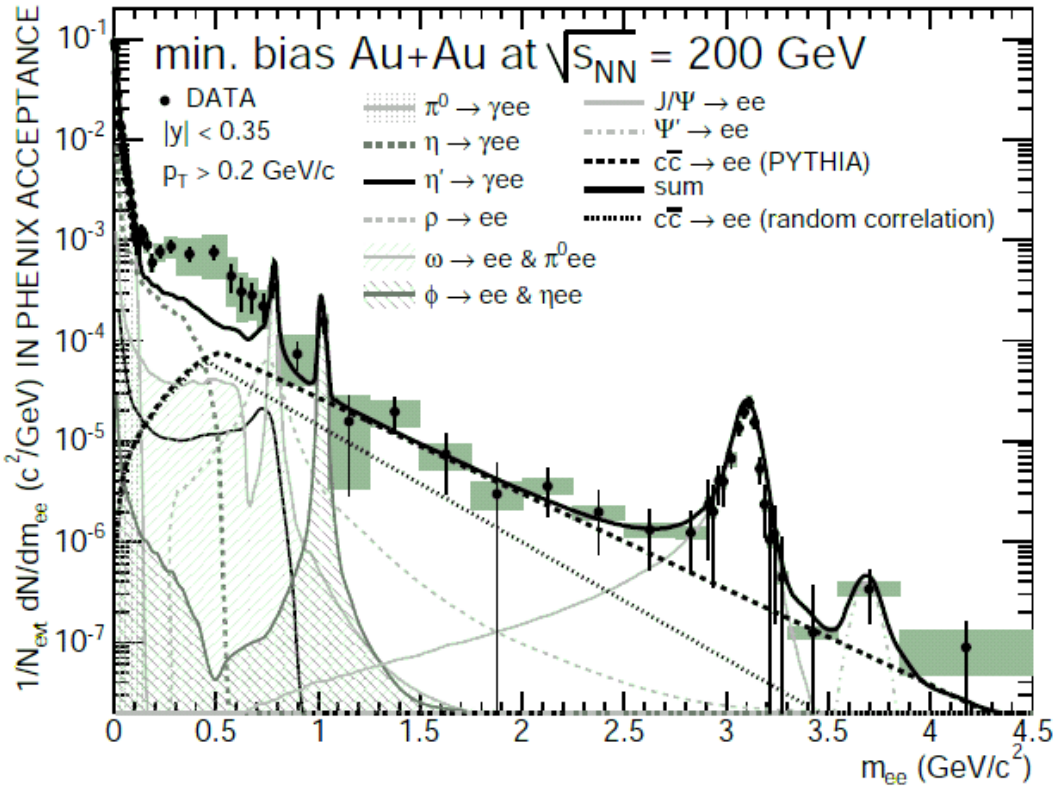
bkg subtracted



New hadron Meeting 09Nov27 S.Yokkaichi

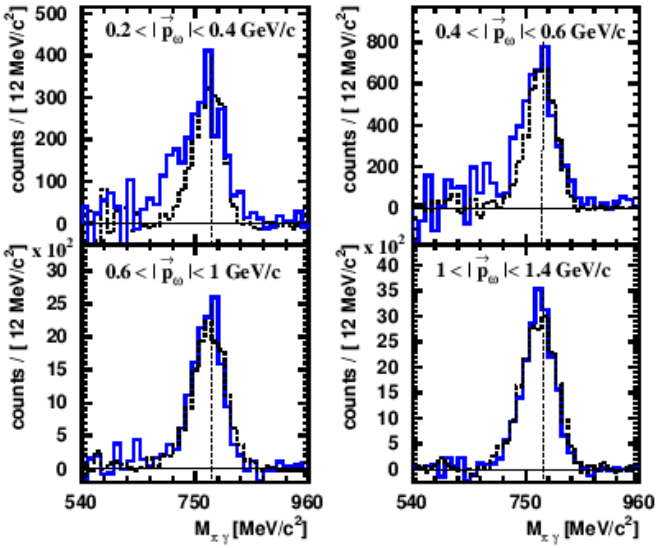
Vector meson measurements in HIC

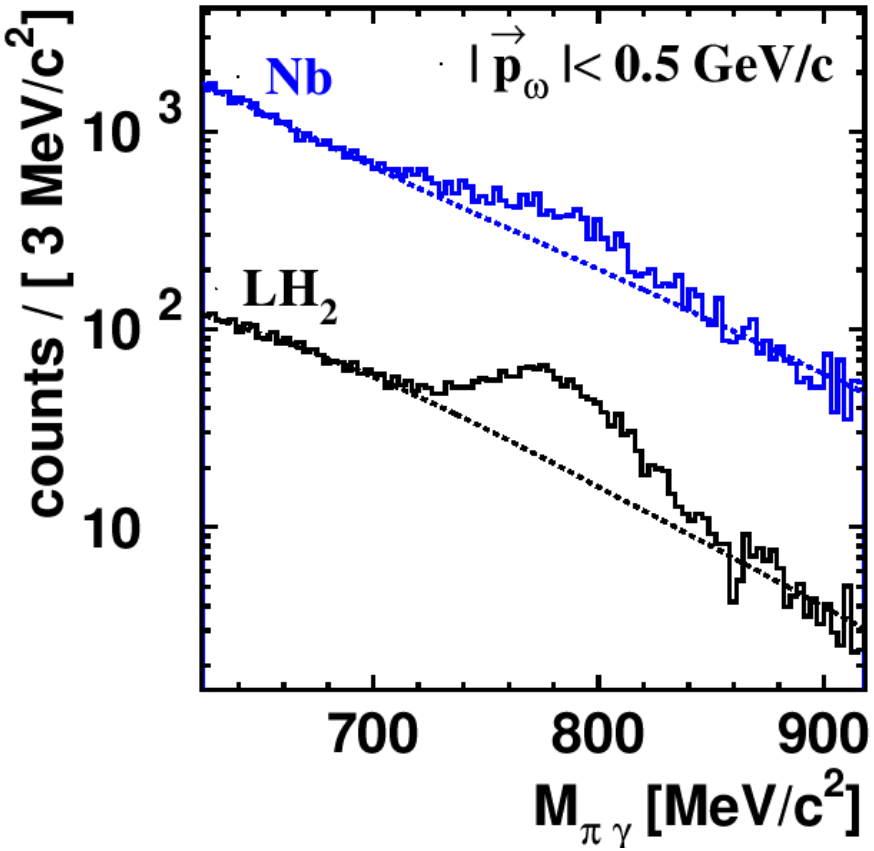
- PHENIX : (arXiv:0706.3034v1)
  - 200GeV /u Au+Au $\rightarrow e^+e^-$
  - enhancement below ω

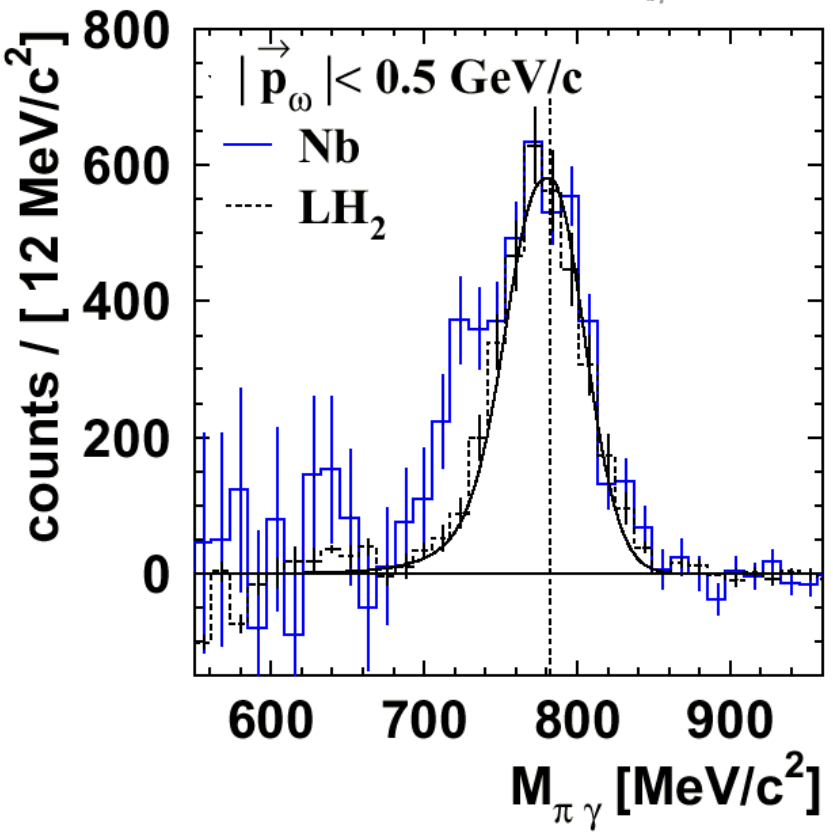


CBELSA/TAPS (PRL94(05)192303)

- $\omega \to \pi^0\gamma\,(\to \gamma\gamma\gamma)$
- anomaly in γ+Nb, not in γ+p
  - shift param. k~0.13



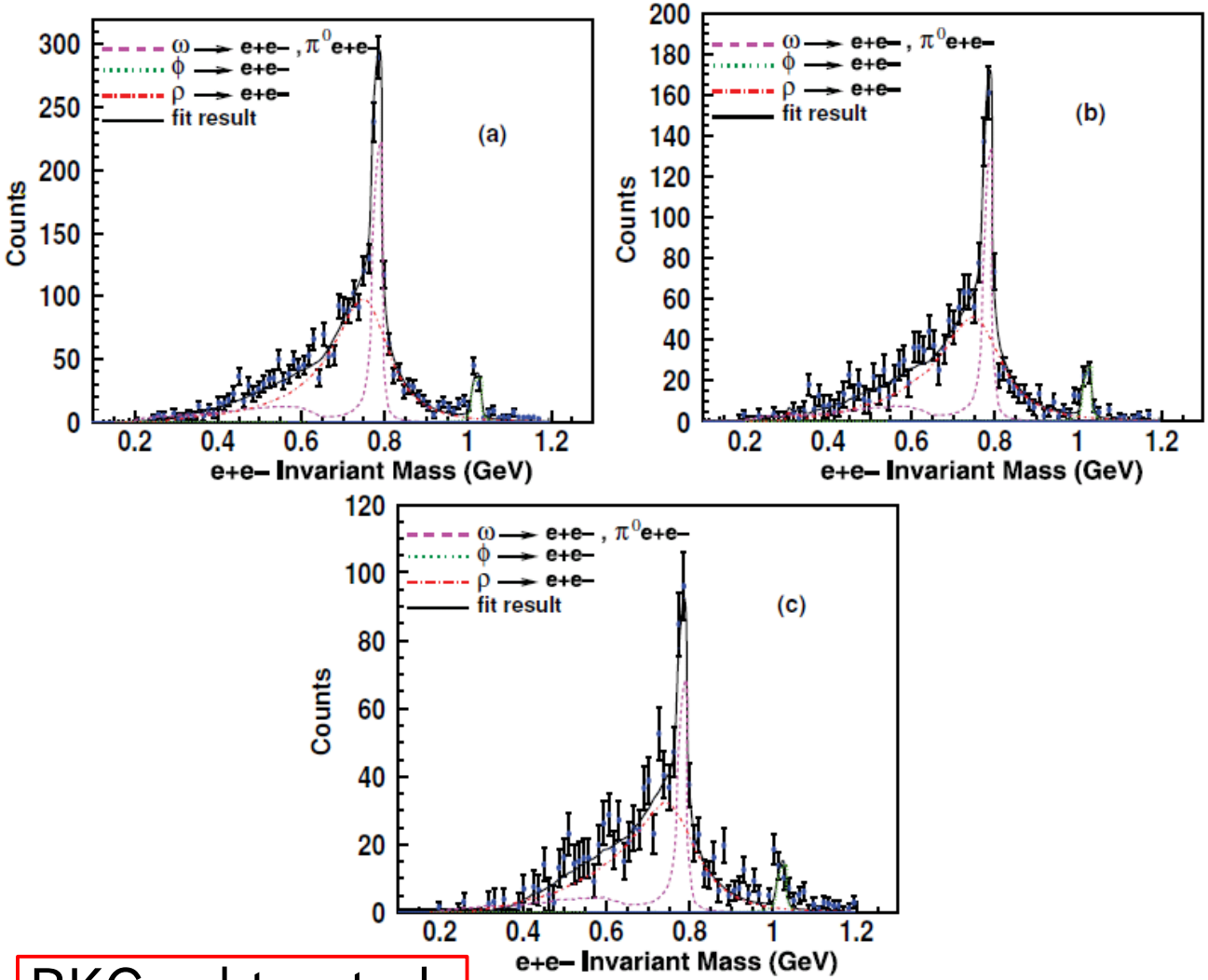




S.Yokkaichi

CLAS-G7 (PRC78(2008)015201)

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



BKG subtracted

PRC78(2008)015201