J-PARC E16 experiment and the hadron modification in nuclear matter

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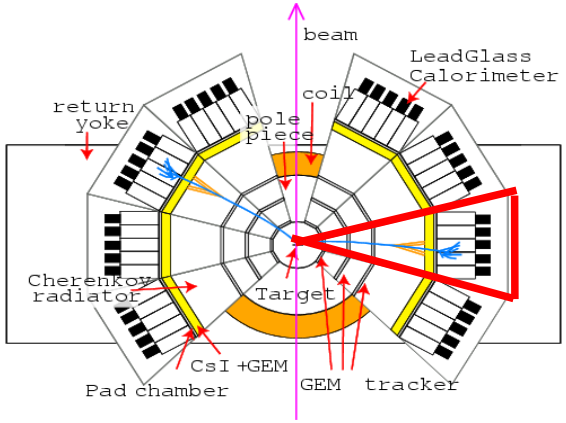
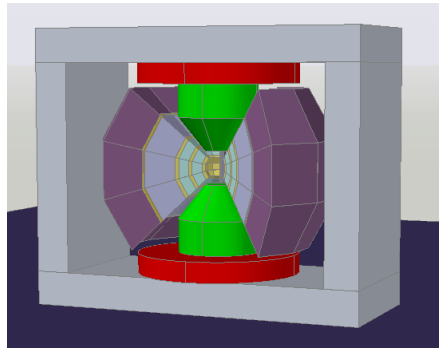
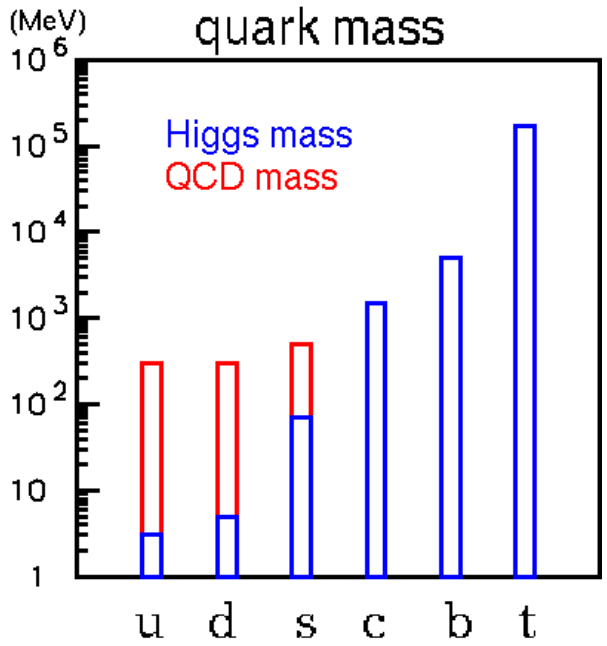
- Contents
  - Chiral restoration and hadron spectral modification in nuclear matter
  - Experiments so far : vector meson (dilepton) measurements
  - J-PARC E16 experiment

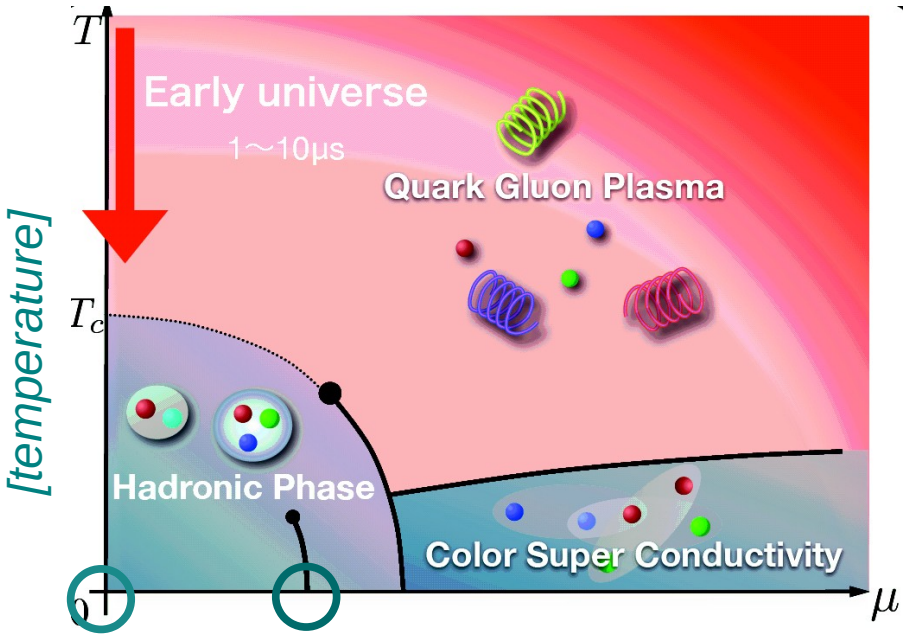




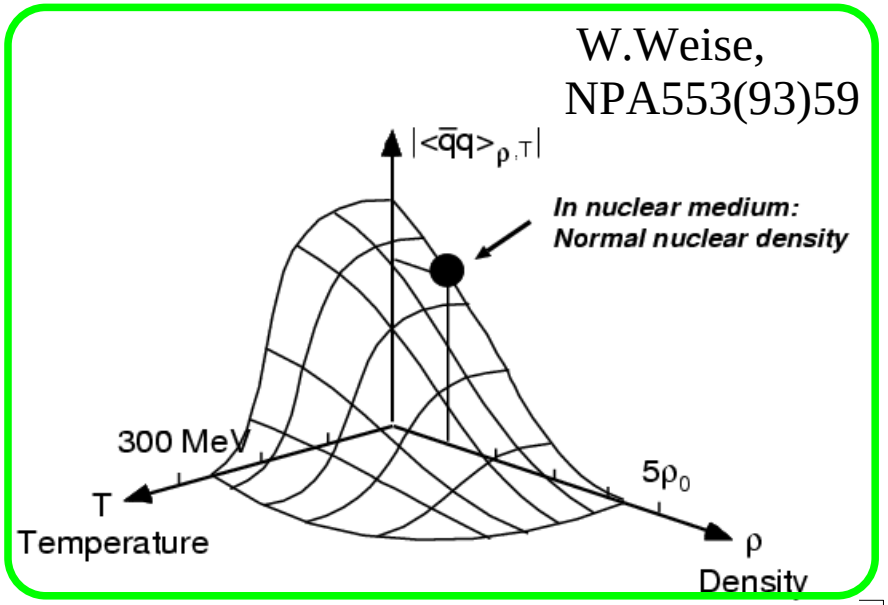
Mass and chiral symmetry in nuclear matter

- Origin of quark and hadron mass : spontaneous breaking of chiral symmetry
- In hot/dense matter, chiral symmetry is expected to be restored
  - hadron modification is also expected
  - many theoretical predictions...





vacuum normal nuclear density *[density]*



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) 3.5GeV 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 ?
- *HADES,CBM /FAIR* (ee) 2-8, 8-45 GeV A+A

published/ 'modified'
published/ 'unmodified'
running/in analysis
future plan
as of 2011/Jun

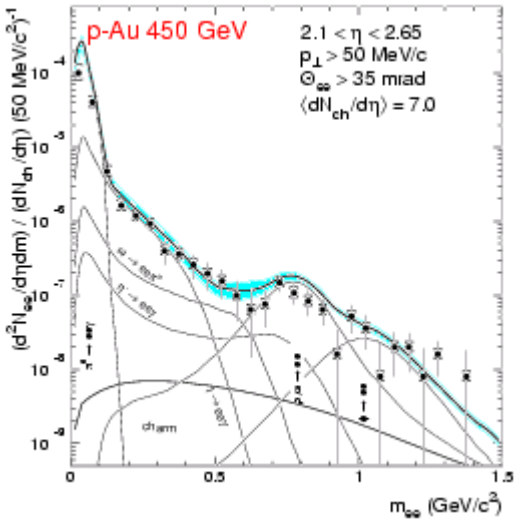
- TAGX (ππ) ~1 GeV γ+A
- STAR (ππ,KK) p+p/Au+Au
- LEPS (KK) 1.5~2.4 GeV γ+A
- CBELSA/TAPS(*) ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb

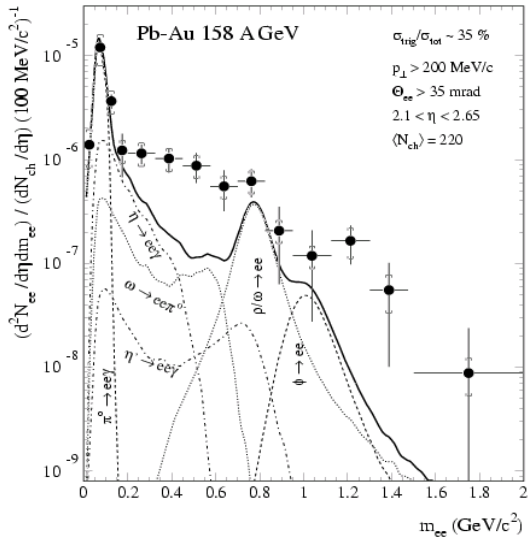
Tips

- Why Heavy Ion ?
  - Chiral restoration as a signal of QGP (hot matter)
  - Cold dense matter is also investigated using p+A and γ+A reactions
- Why dilepton (lepton pair : e^+e^- and $\mu^+\mu^-$)?
  - Smaller final state interaction (distortion of spectrum) in nuclear matter is expected than the hadronic decays
- Why vector mesons?
  - They decay into lepton pair
  - other mesons (e.g. σ, η, η' ...) are also investigated
  - Baryons are also important of course
- Why invariant mass?
  - Most straightforward
  - other approaches:
    - width (interaction CS) from the nuclear transparency ratio
    - Mesic nuclei → next talk by Ohnishi-san

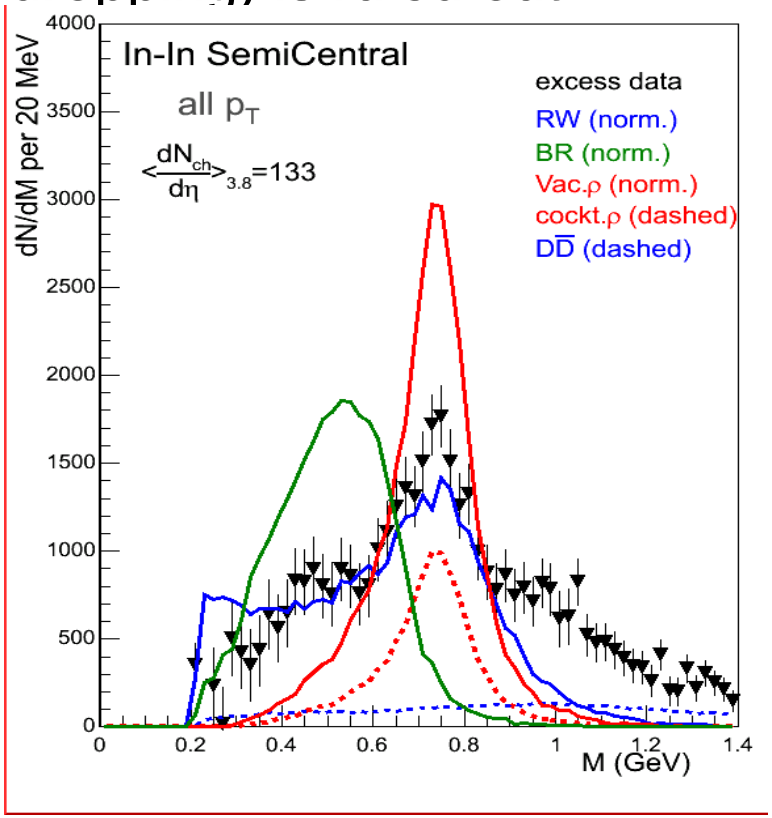
Dilepton spectra in Heavy Ion Collision

- CERES : e^+e^- (EPJC 41('05)475)
  - "low mass enhancement" : anomaly at the lower region of ρ/ω
    - in A+A, not in p+A
  - relative abundance is determined by their statistical model
  - Both "broadening" and "dropping" explain the data



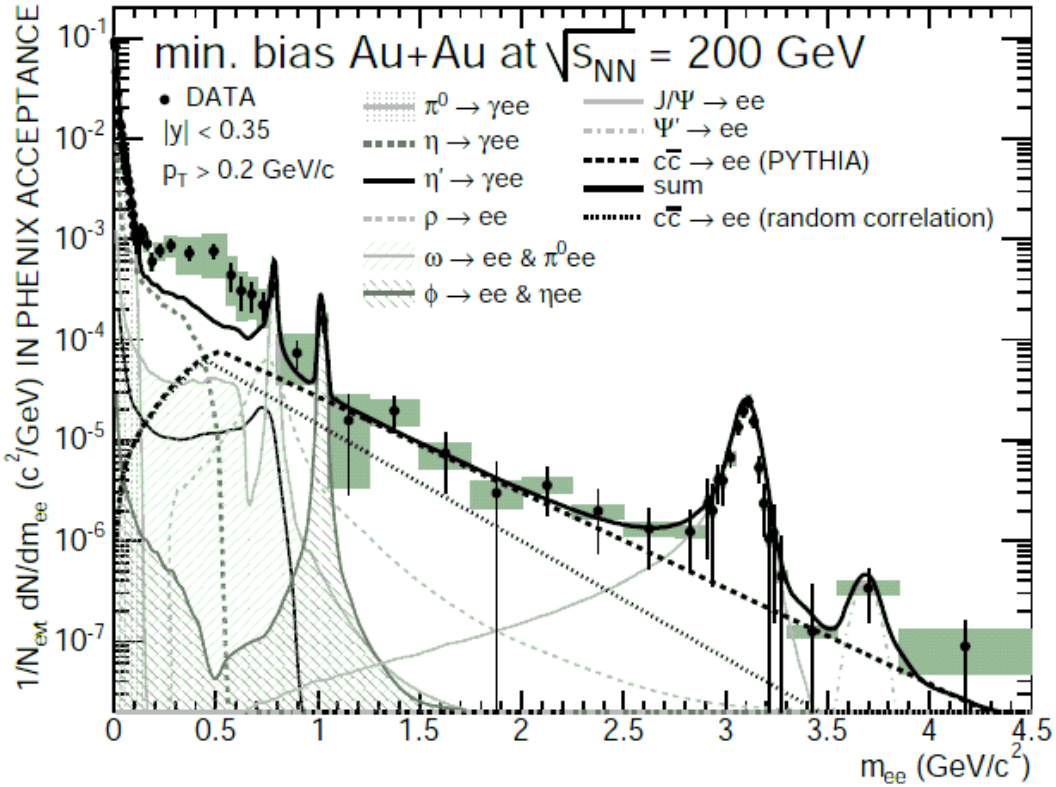


- NA60 : (PRL96(06)162302)
  - $\rho \rightarrow \mu^+\mu^-$:
  - width broadening of ρ
  - state 'BR scaling (mass dropping) is ruled out'



Dilepton spectra in Heavy Ion Collision

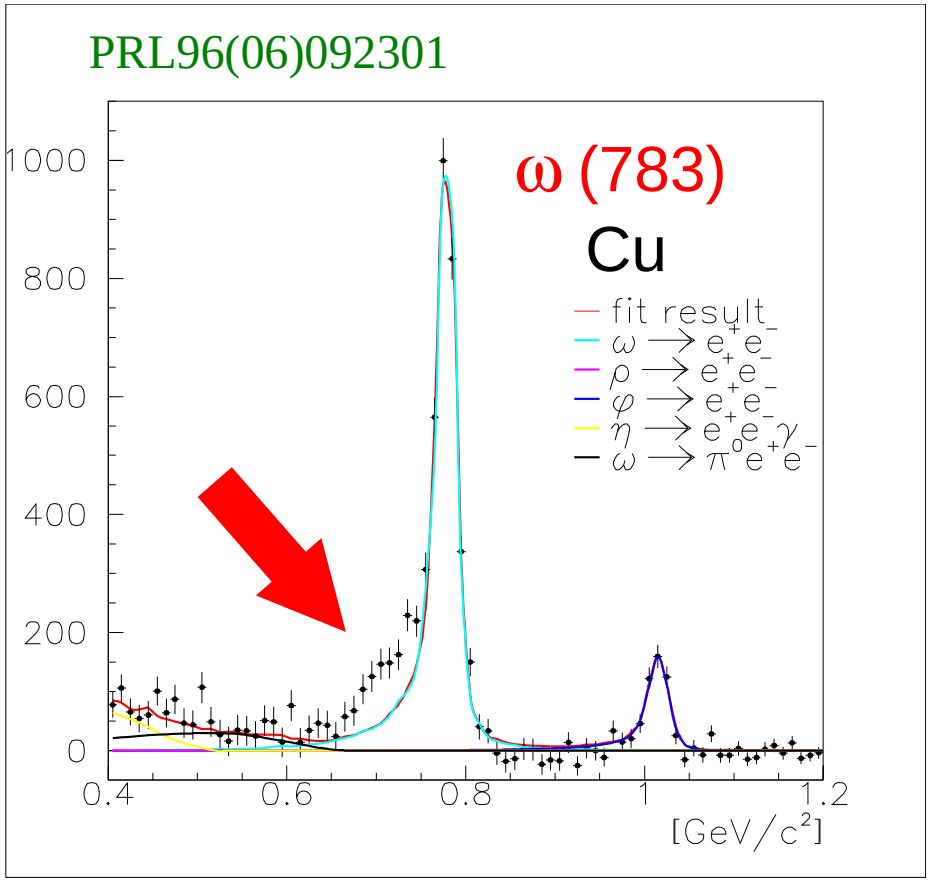
- PHENIX : (arXiv:0706.3034v1,0912.0244v1)
  - 200GeV /u Au+Au $\rightarrow e^+e^-$
  - enhancement below ω
  - cannot reproduced by any model at low pT
  - at high pT, thermal photons reproduce

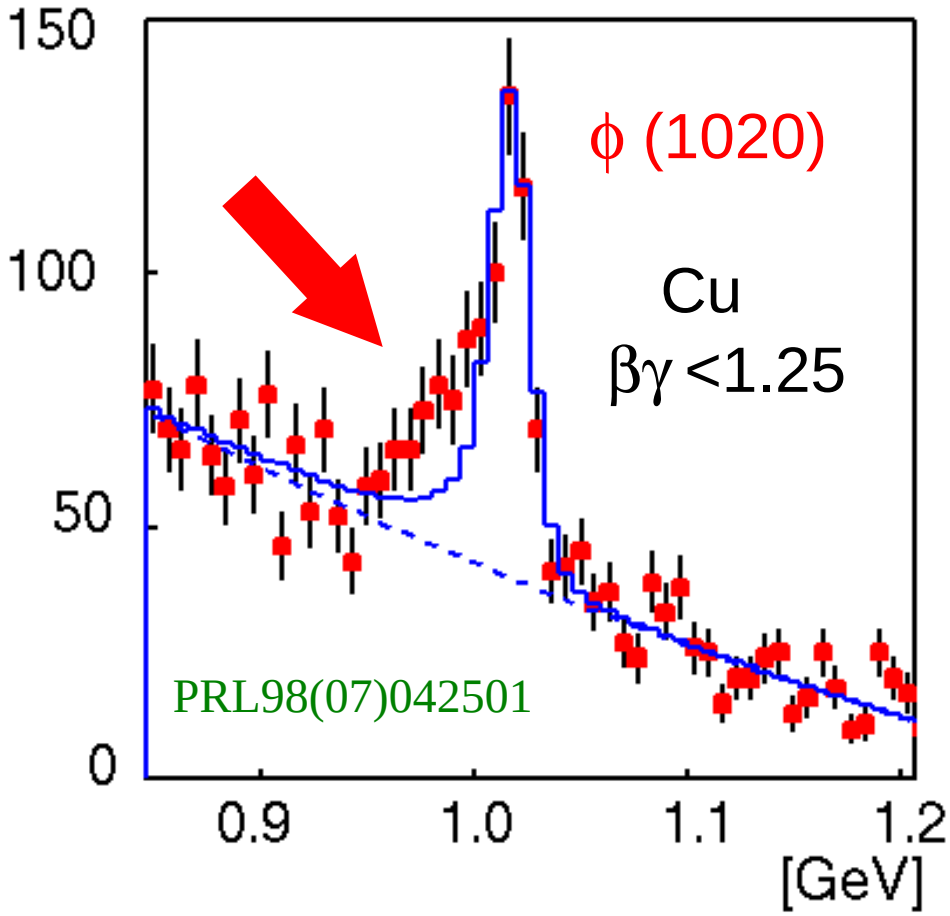


Dilepton spectra in p+A : KEK-PS E325

$12\mathrm{GeV}\ p+A(C,Cu) \rightarrow \rho/\omega/\phi\ +X\ \ (\ \rho/\omega/\phi \rightarrow e^+e^-\ ,\ \phi \rightarrow K^+K^-\ \ )$

- In the e^+e^- channel, below the ω and ϕ, statistically significant excesses over the known hadronic sources including experimental effects
- The excesses are consistent with “mass dropping” based on the chiral restoration in the normal nuclear matter predicted by Hatsuda and Lee





Status of dilepton measurements

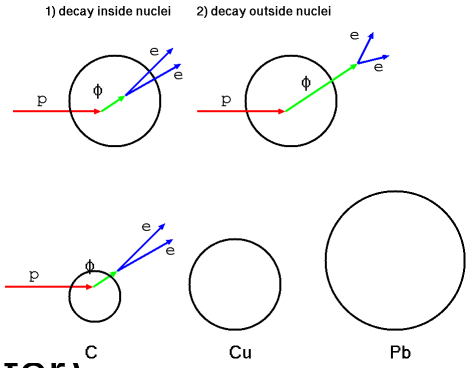
- low mass enhancement is found in the dilepton spectra in A+A (in comparison with p+p,p+A) from Bevalac to RHIC energy
  - DLS (Bevalac), Helios/3, CERES(SPS).... bad S/N ratio
  - NA60(SPS) : width broadening of ρ meson by hadronic calculation
  - PHENIX(RHIC) : not explained theoretically yet
- lower energy elementary reactions: finite density, better S/N
  - modification of resonance is found in dilepton spectra
    - E325(KEK-PS) : consistent w/ mass dropping in partial chiral restoration
    - CLAS-g7(JLab) : consistent w/ hadronic calc. (collisional broadening of ρ)
- Modification is observed, but discussion on the physics underlying the observed modification is not converged
  - hadronic many-body effect? chiral symmetry restoration?
  - interpretation model dependence ?
    - Assumption of the space-time evolution of the (T, ρ) of matter in the real world

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
- Mesic nuclei approach
  - the deeply bound pionic atom : success to deduce the chiral condensate in nuclei
  - static system : no space-time evolution
  - measure the decay of meson if possible : only inside-decay
  - another physics?
    - high density(K), chiral partner of N (η)

J-PARC E16 experiment

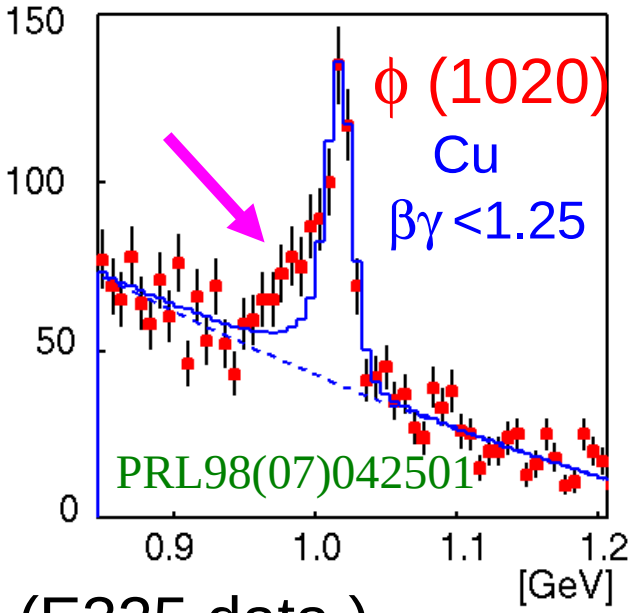
- Main goal : collect ~1-2 x 10^5 $\phi \rightarrow e^+e^-$ for each target in 5 weeks using 30 (or 50) GeV p +A (C/CH_2/Cu/Pb) reactions



  - 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 : σ < 10 MeV (E325 : 10.7 MeV for ϕ)
    - double peak structure can be seen w/ $\beta\gamma$ < 0.5, σ ~5-6 MeV
  - ρ, ω, J/ψ 's also can be measured at the same time
  - Confirm the modification observed in E325, and provide new information about the mass of hadrons

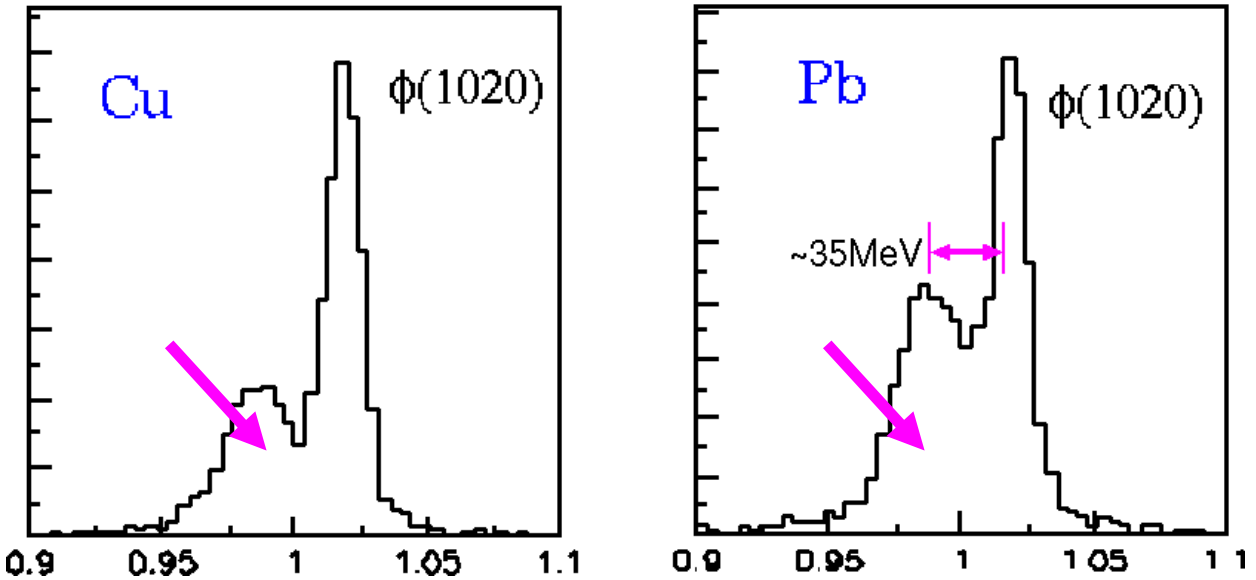
E16 : mass resolution requirement

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



(E325 data)

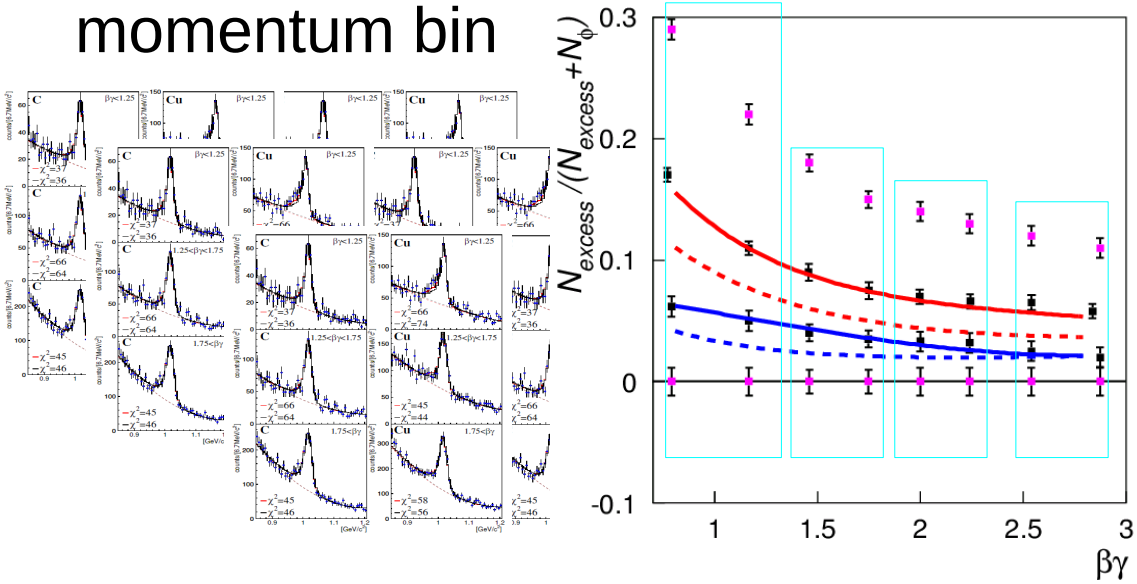
βγ<0.5, σ=5 MeV

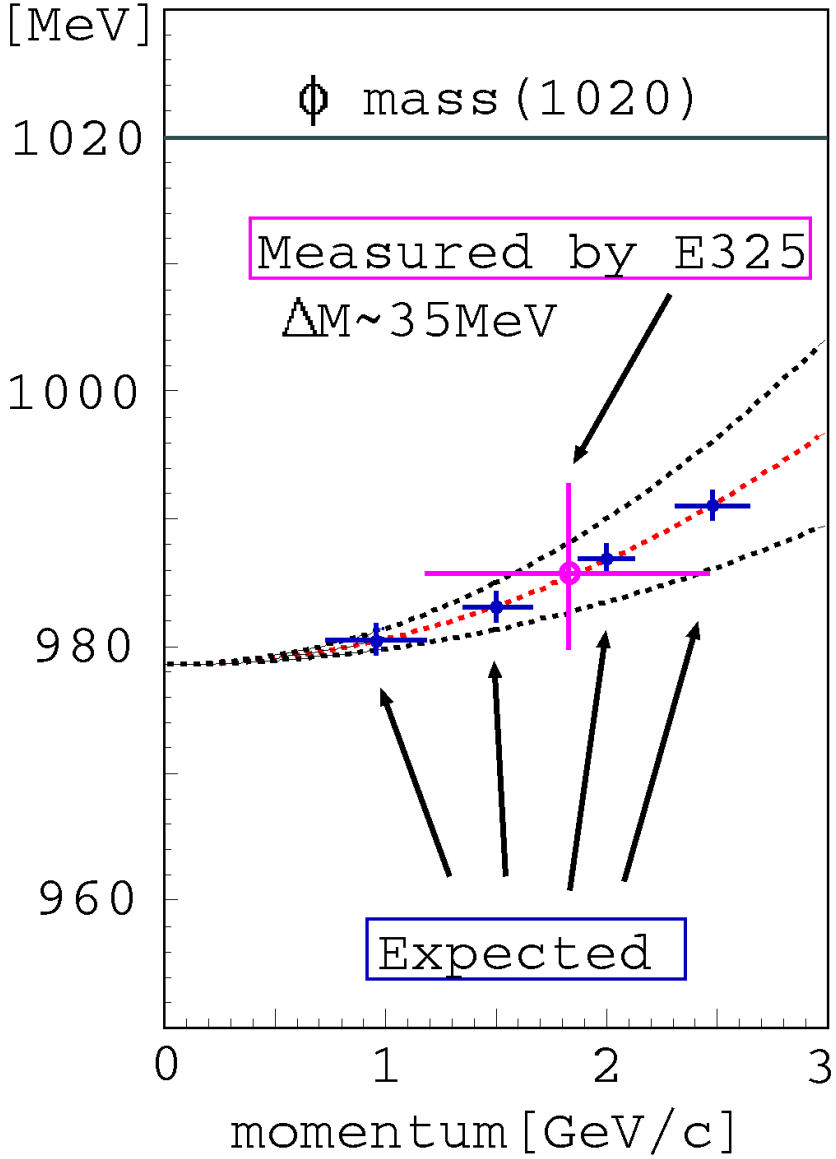


(model calc.)

E16 : 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



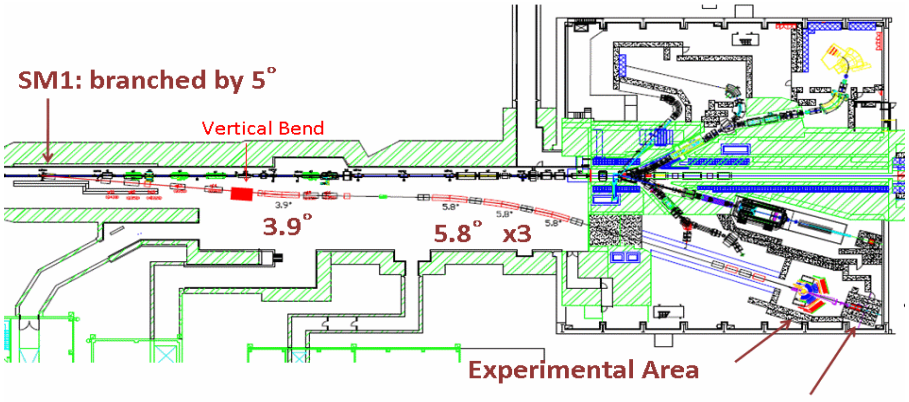


E16 : schedule

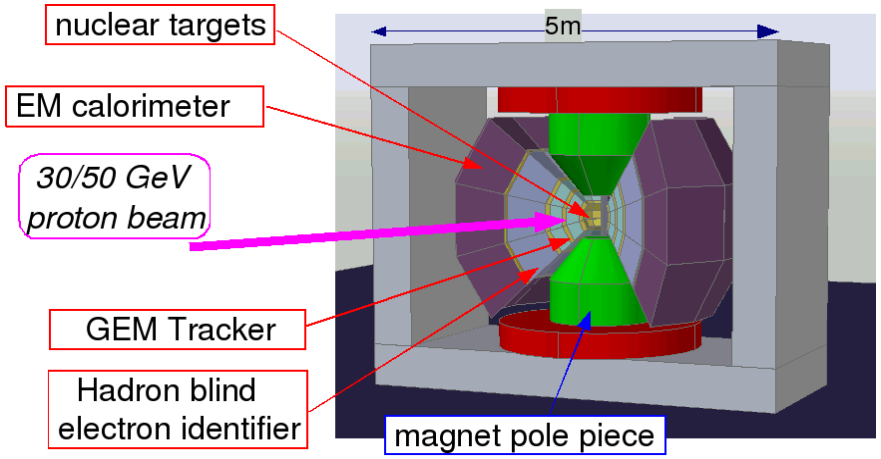
- 2007: stage1(scientific) approval
- 2008-2010 : development of prototype detectors
  - GEM Tracker and HBD
  - w/ Grant-in-Aid (2007-8, 2009-13 ($2.4M))
- 2011 : additional parts of the spectrometer magnet , R/O circuit development
  - budget of beamline construction (2012-14) is requested by KEK
- 2013 : Goal of the spectrometer construction

Collaboration

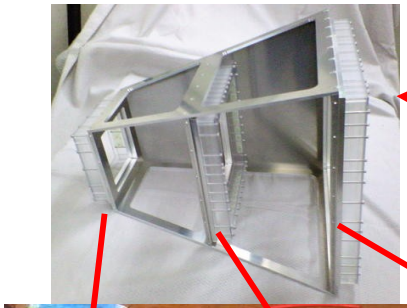
RIKEN	S.Yokkaichi, H. En'yo, F. Sakuma, K. Aoki, J. Kanaya, Y.Aramaki, T.Takahashi
KEK	K.Ozawa, M. Naruki, R. Muto, S. Sawada, M. Sekimoto
U-Tokyo	Y.S. Watanabe, Y.Komatsu, S.Masumoto, A.Takagi, K.Kanno, W.Nakai
CNS, U-Tokyo	H. Hamagaki
Hiroshima-U	K. Shigaki
JASRI	A.Kiyomichi

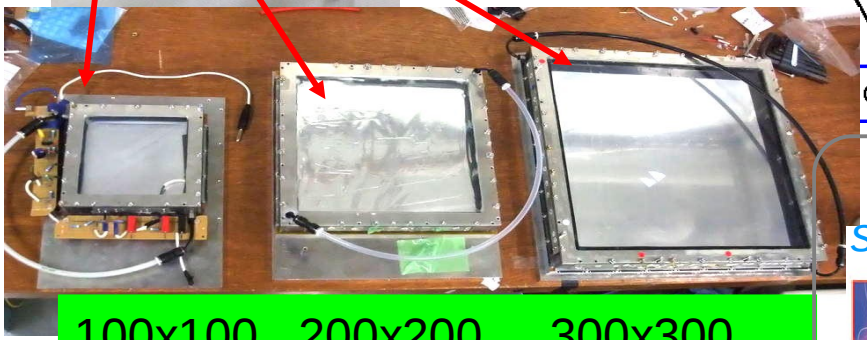


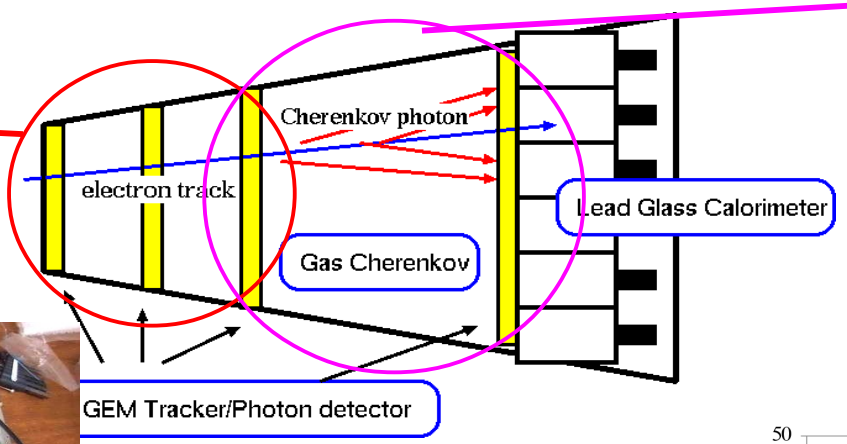
Beam dump and shields are for 10^{10} protons/s

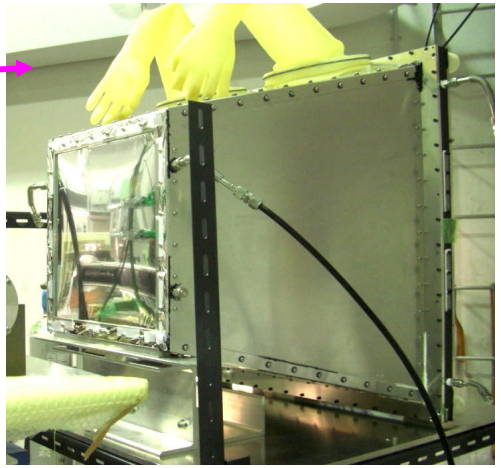


E16: Beam test results of prototype detectors

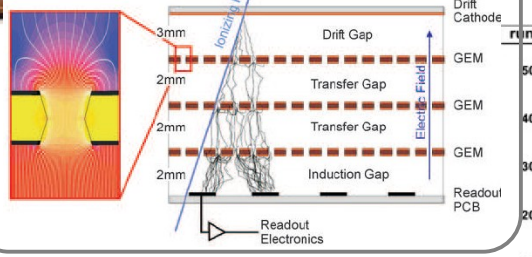


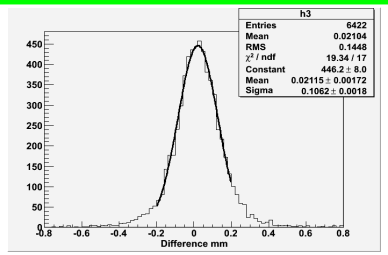


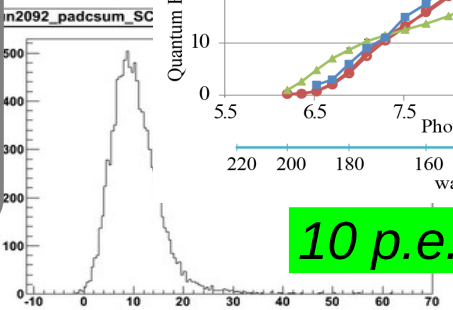




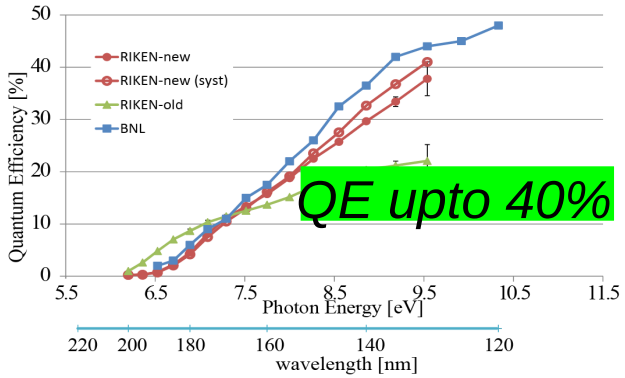
GEM & GEM Tracker schematics







10 p.e.



QE upto 40%

GEM Tracker :

Required position resolution (~100μm) is achieved with large-size PI-GEM(300mm x 300mm)

Hadron-Blind Gas Cherenkov detector

UV Cherenkov photons (10 photoelectrons) are detected for an electron track with CsI-evaporated LCP-GEM and CF_4 gas

Summary

- Investigation of the hadron spectral modification in nuclear matter
  - is a study of the origin of mass (spontaneous breaking of the chiral symmetry, and its possible restoration)
  - i.e., a study of the nature of QCD vacuum
- Spectral modification of hadrons is observed in hot / dense nuclear matter through the dilepton invariant mass spectra
  - but discussion is not converged : chiral restoration or not
- J-PARC E16 will measure the vector meson modification in nuclei with the ee decay channel, using 30GeV primary proton beam.
  - confirm the observation by KEK-PS E325 and provide more systematic information of the mass modification
  - Goal of spectrometer construction : the end of 2013

Backup slides...

-

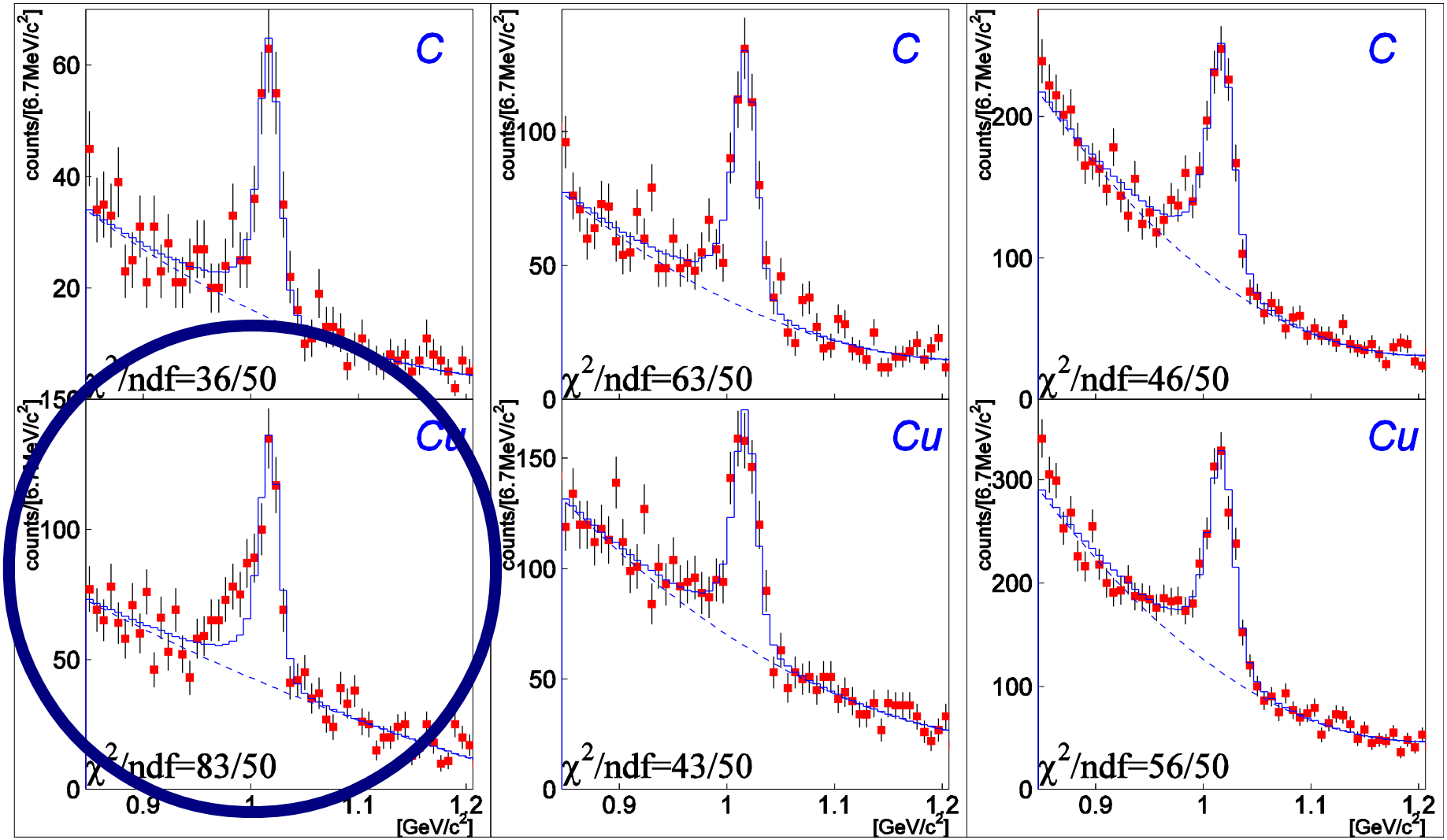
History of E325

- 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

E325 φ meson (divided by βγ)

βγ<1.25 (Slow) 1.25<βγ<1.75 1.75<βγ (Fast)



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