vector mesonの媒質中での崩壊の測定とその解釈

Satoshi Yokkaichi
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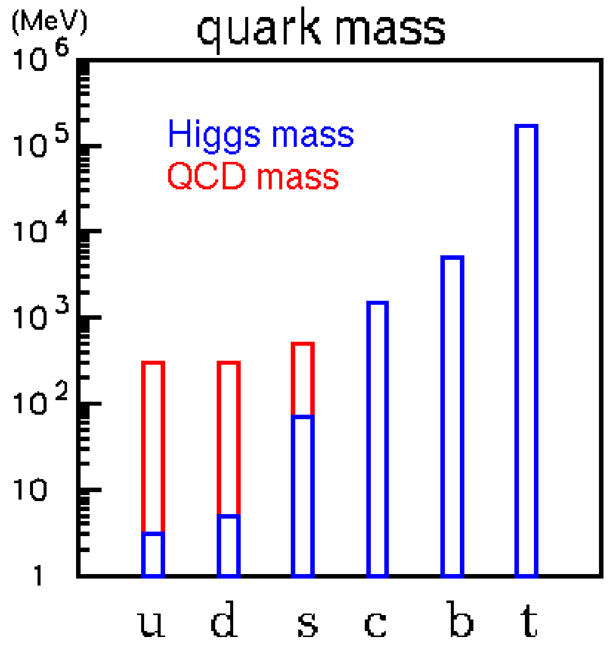
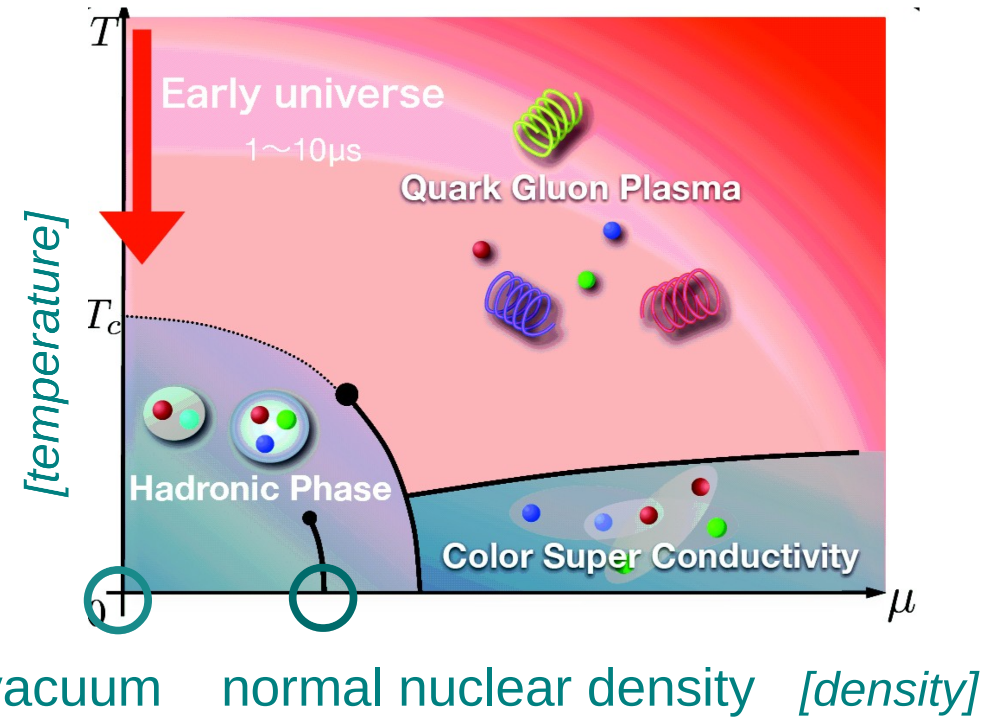
研究会
原子核媒質中のハドロン研究＝魅力と課題＝
＠東海

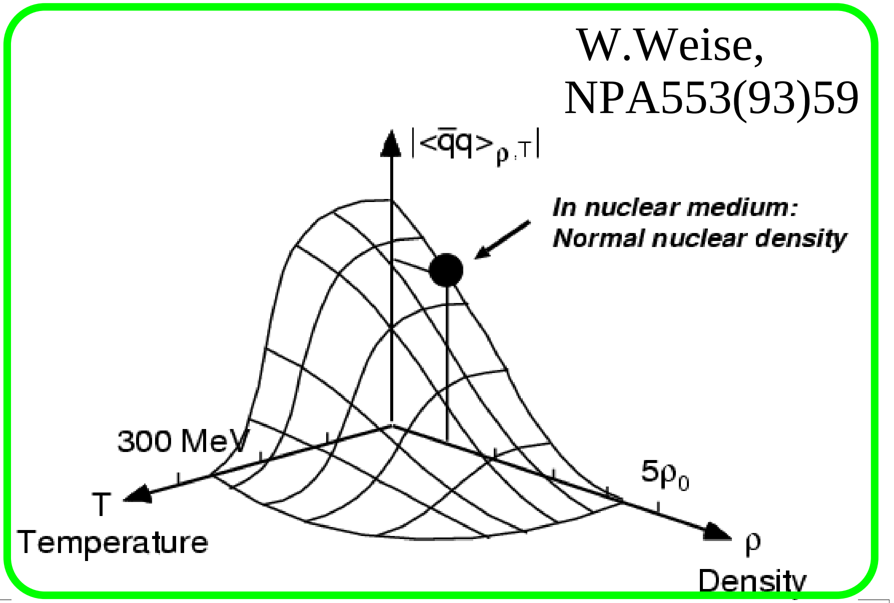
- dilepton mass spectra in the world
- J-PARC E16

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 (mass , width) modification is also expected

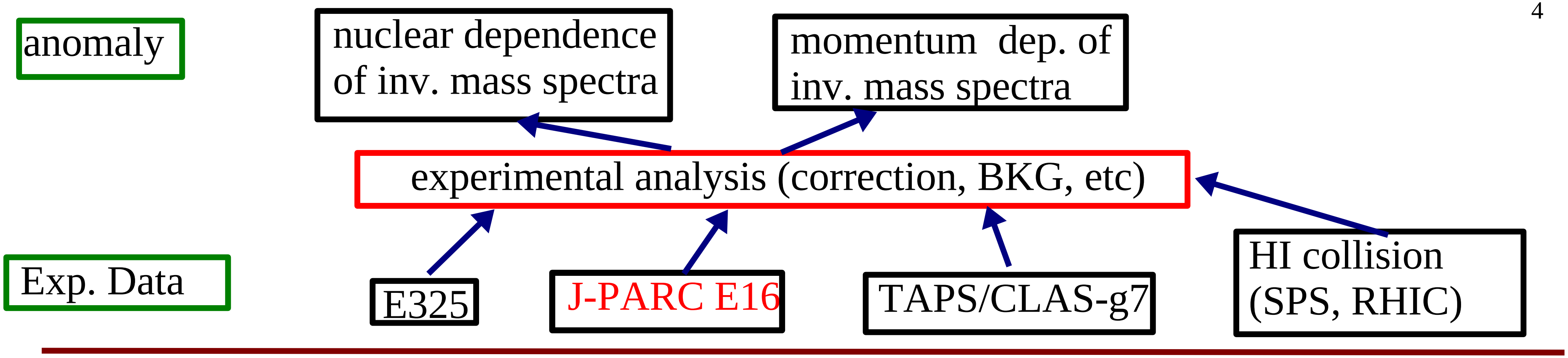


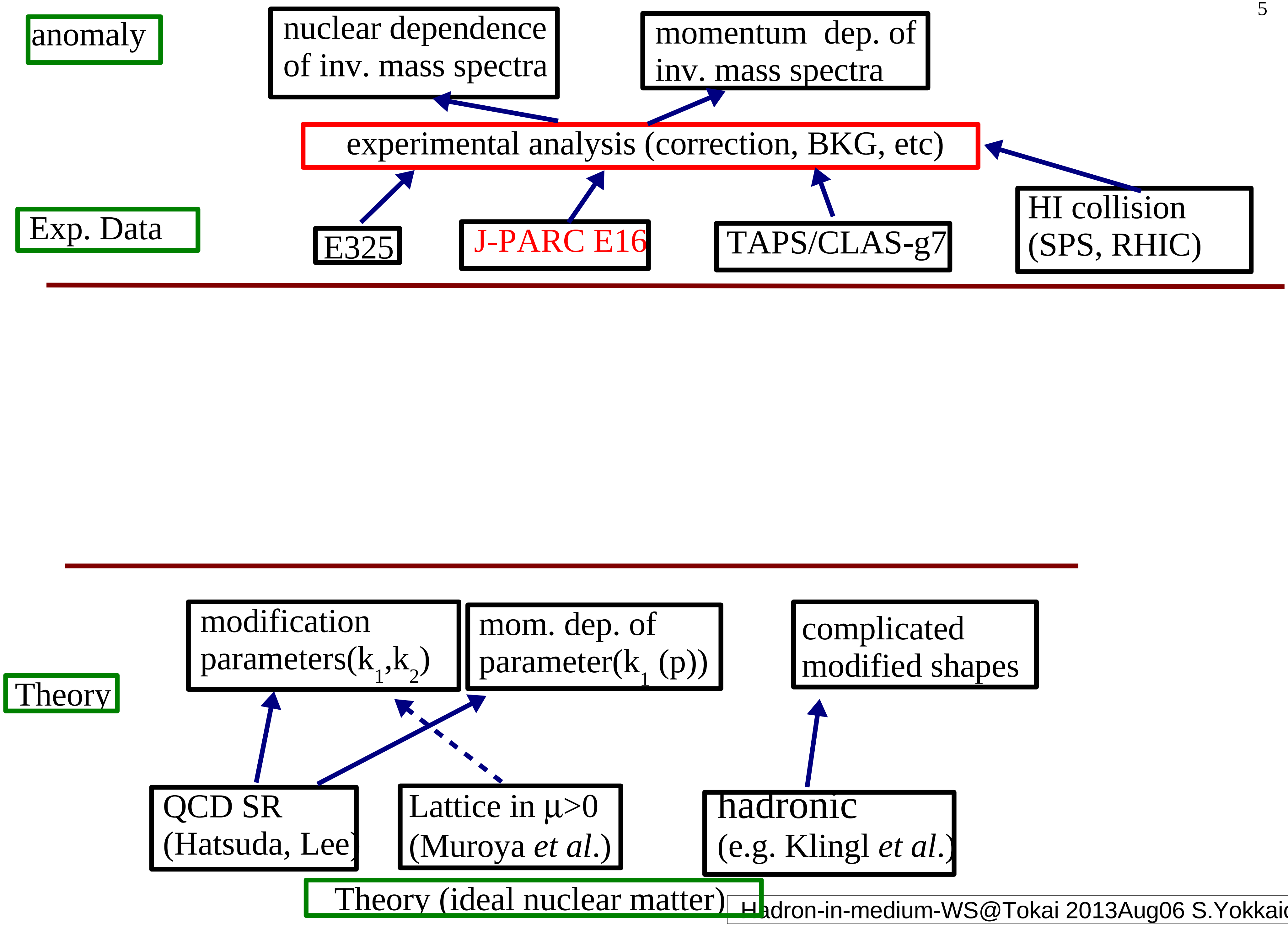




Summary

- （歴史的に）QGP の証拠としてのカイラル対称性の回復による中間子質量の変化が探索されてきた。
- 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 中間子の質量スペクトルの変化は存在した。
  - 形に　medium size 依存性 (pp,pA,AA, velocity) がある。
- 変化の原因は？　：　解釈の哲学
  - hadronic な計算だけでも変形する。
  - ”dropping VS broadening … chiral symmetry VS hadronic ?”
    - 単純化しすぎ。
    - QCD からの予測と hadronic な予測は本来矛盾してはいけない
  - QCD の low energy における数少ない予測の検証の機会
- 解釈の方法論
  - 中間子も媒質も " 動いて " いる : 系の時間空間発展、FSI 、質量変化の運動量依存
  - 少ない統計、dataset では何をやっても合ってしまう : 結論の有意性
  - ρ–ω interference, etc.


anomaly
nuclear dependence of inv. mass spectra
momentum dep. of inv. mass spectra
experimental analysis (correction, BKG, etc)
Exp. Data
E325
J-PARC E16
TAPS/CLAS-g7
HI collision (SPS, RHIC)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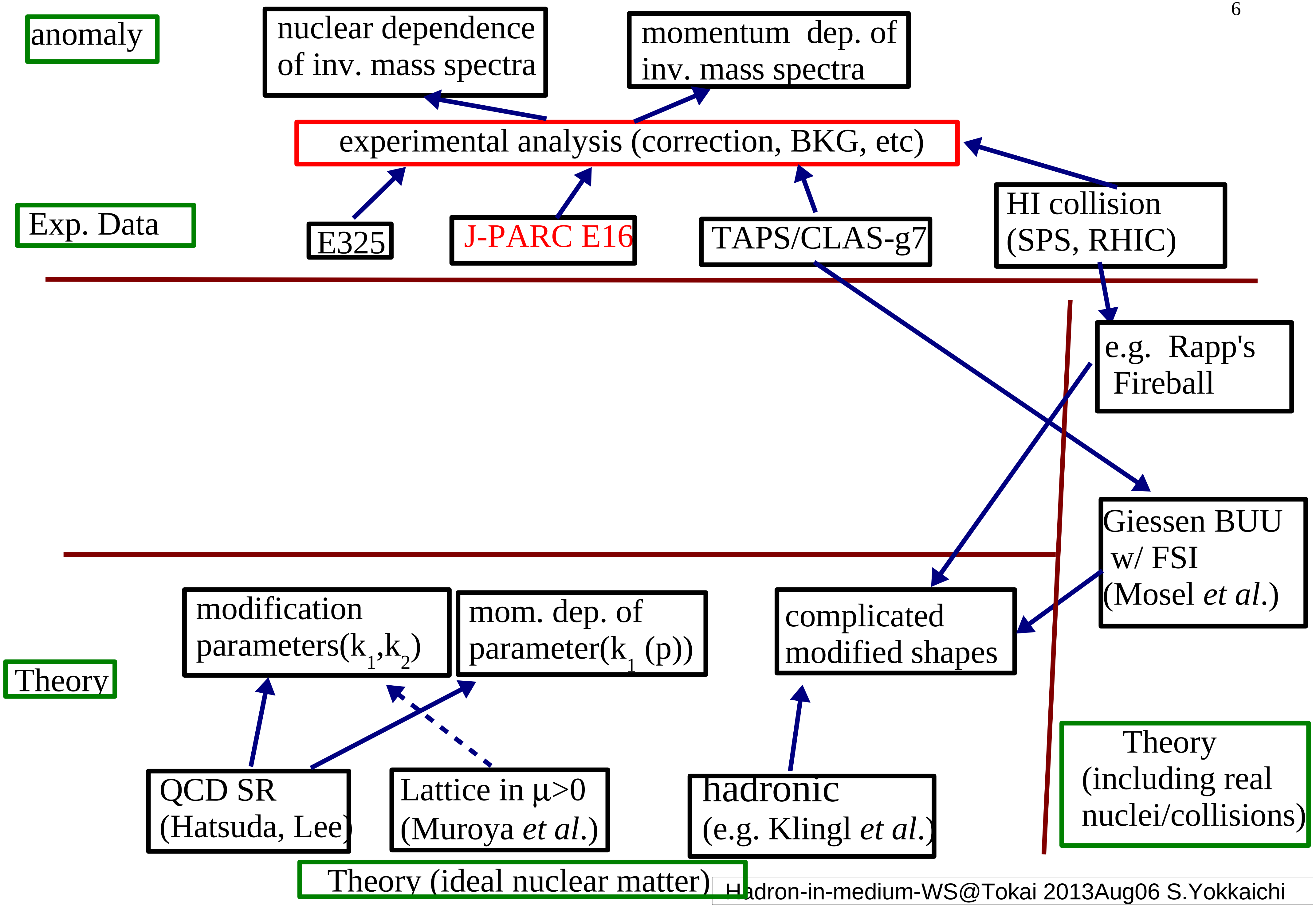
Theory
modification parameters(k1,k2)
mom. dep. of parameter(k1 (p))
complicated modified shapes
QCD SR (Hatsuda, Lee)
Lattice in μ>0 (Muroya et al.)
hadronic (e.g. Klingl et al.)
Theory (ideal nuclear matter)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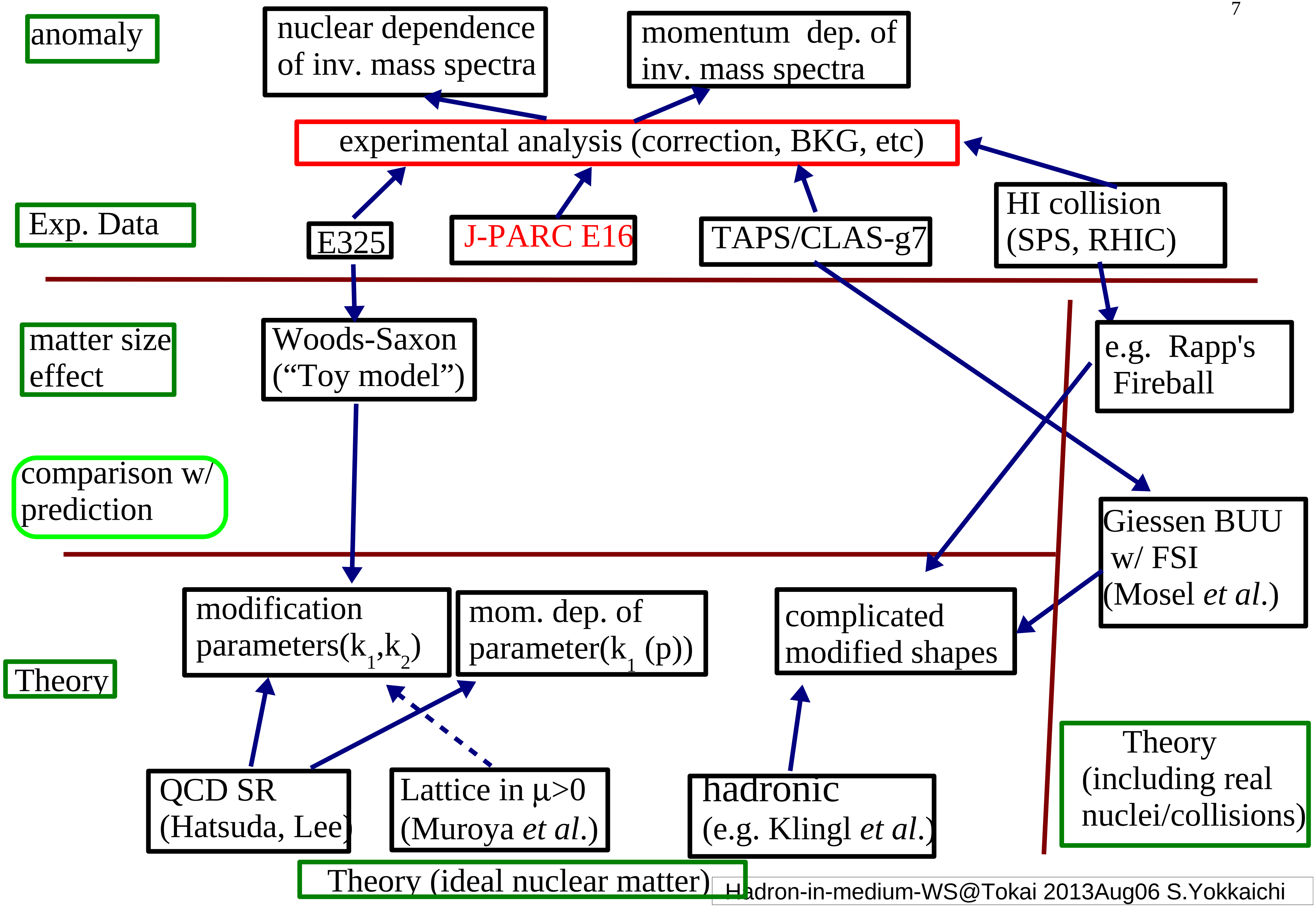
Theory (including real nuclei/collisions)
Theory (ideal nuclear matter)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matter size effect
Woods-Saxon (“Toy model”)
e.g. Rapp's Fireball
comparison w/ prediction
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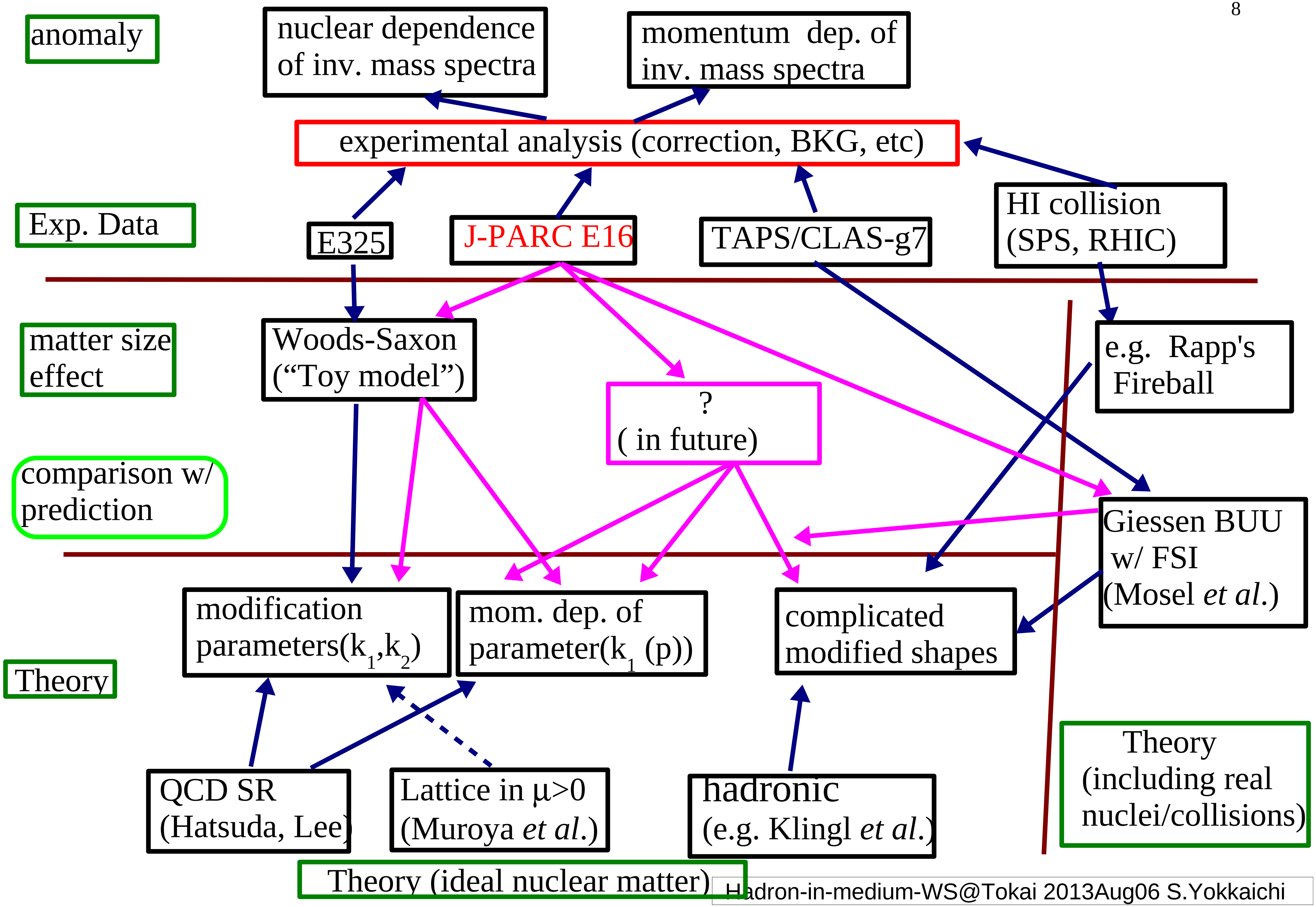
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matter size effect
Woods-Saxon (“Toy model”)
?
(in future)
e.g. Rapp's Fireball
comparison w/ prediction
Giessen BUU w/ FSI (Mosel et al.)
modification parameters(k1,k2)
mom. dep. of parameter(k1 (p))
complicated modified shapes
Theory
QCD SR (Hatsuda, Lee)
Lattice in μ>0 (Muroya et al.)
hadronic (e.g. Klingl et al.)
Theory (including real nuclei/collisions)
Theory (ideal nuclear matter)

Summary

- 次の一手
  - 実験　(@J-PARC)
    - 質量変化の系統的(物質サイズ・運動量)測定: E16　*30 GeV p+A*
    - 中間子束縛核 (E26, E29) からの中間子崩壊　*~2GeV/c π+A, pbar+A*
      - 中間子も系もきれい 崩壊点の密度もわかる
      - ee channel をみるには数が足りなそう
      - bound してなくても　遅い中間子がたくさんいるのでは。
    - 密度依存性:高密度@重イオン衝突？　*A+A ?*
  - 理論:　質量分布の実験データと QCD の予言を結ぶには?
    - 現象論　：　解析上の”バックグラウンド”
      - 系の時間空間発展、原子核サイズ効果，FSI　：
        - BUU?　'dropping' を手でいれていいのか?
      - in-medium mixing などの 不変質量分布への影響
    - QCD ： “ 無限核物質中に静止した中間子”ではないので。
      - 運動量依存性
      - 有限サイズ物質で結論はかわらないのか。

Vector meson measurements in the world

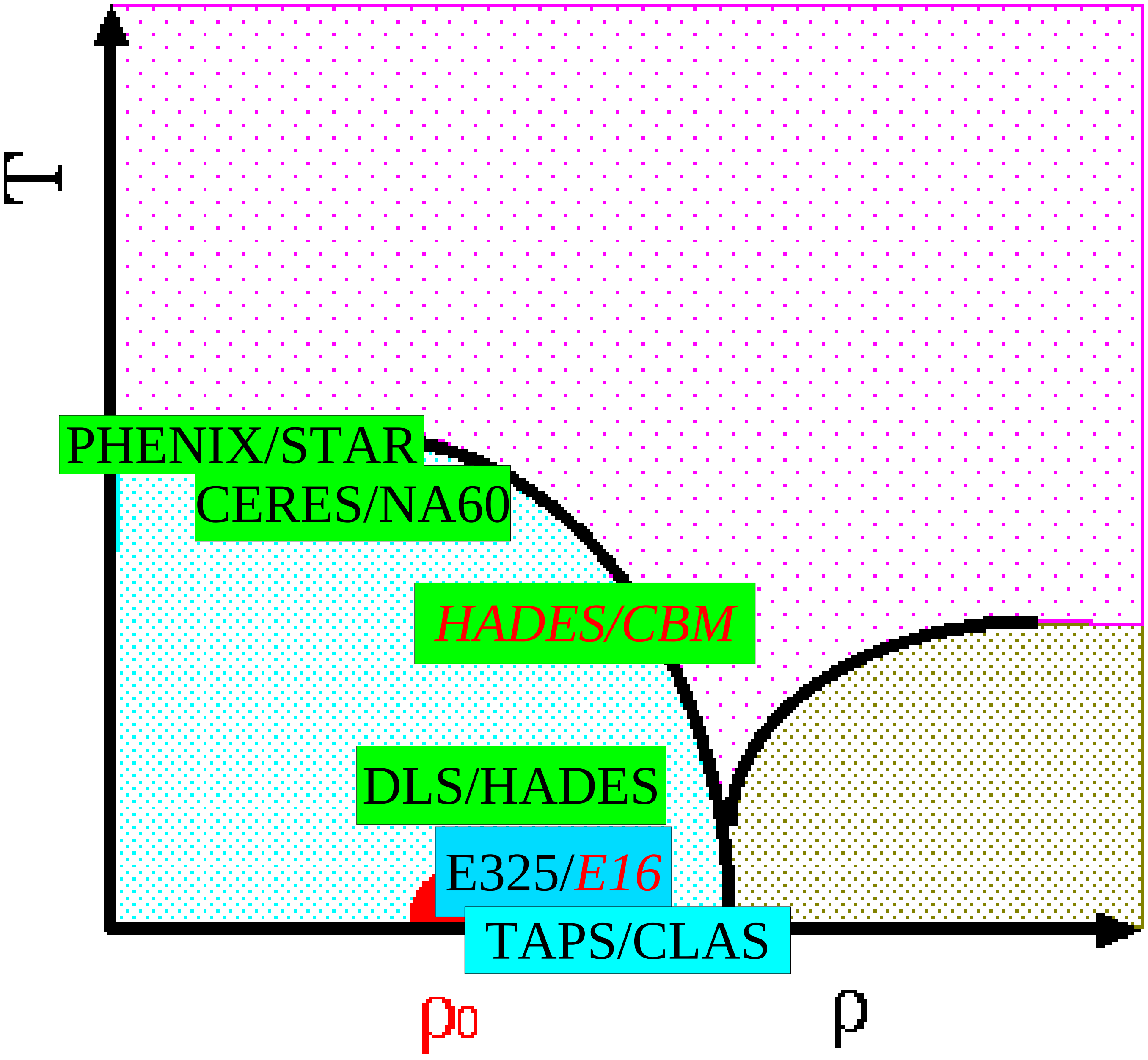
dilepton measurement

- 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
- STAR (ππ, KK, ee) p+p/Au+Au
- HADES (*) (ee) 1-4 GeV p+A/ 1-2GeV A+A
- CLAS-g7 (*) (ee) 1~2 GeV γ+A
- *J-PARC E16* (ee) 30/50GeV p+A
- *HADES/FAIR* (ee) 2~8GeV A+A
- *CBM/FAIR* (ee) 20~30GeV A+A

- TAGX (ππ) ~1 GeV γ+A
- LEPS (KK) 1.5~2.4 GeV γ+A
- CBELSA/TAPS(*) ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb
- ANKE (KK) 2.83 GeV p+A

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

Dilepton spectrum measurements in the world



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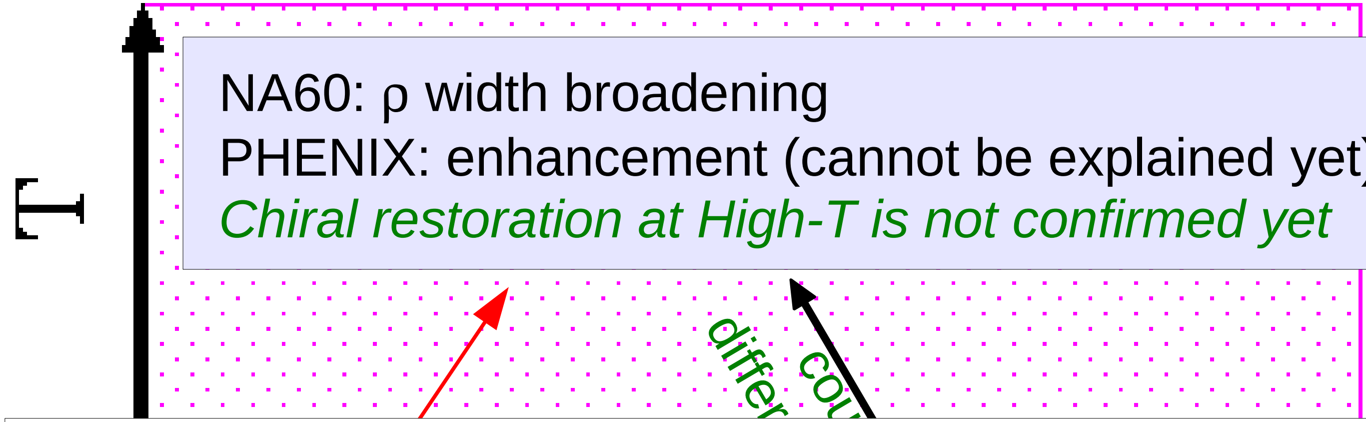
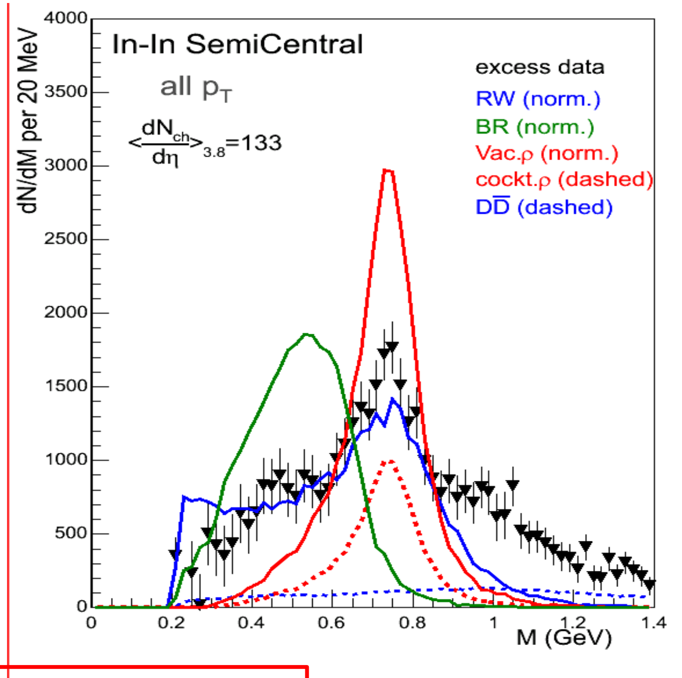
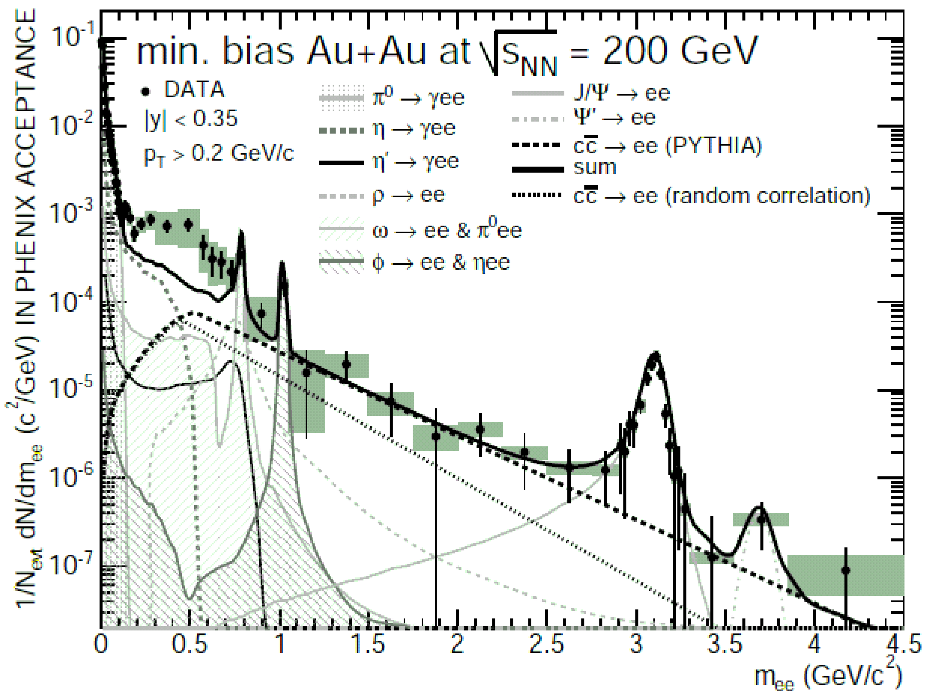


NA60: ρ width broadening
PHENIX: enhancement (cannot be explained yet)
Chiral restoration at High-T is not confirmed yet



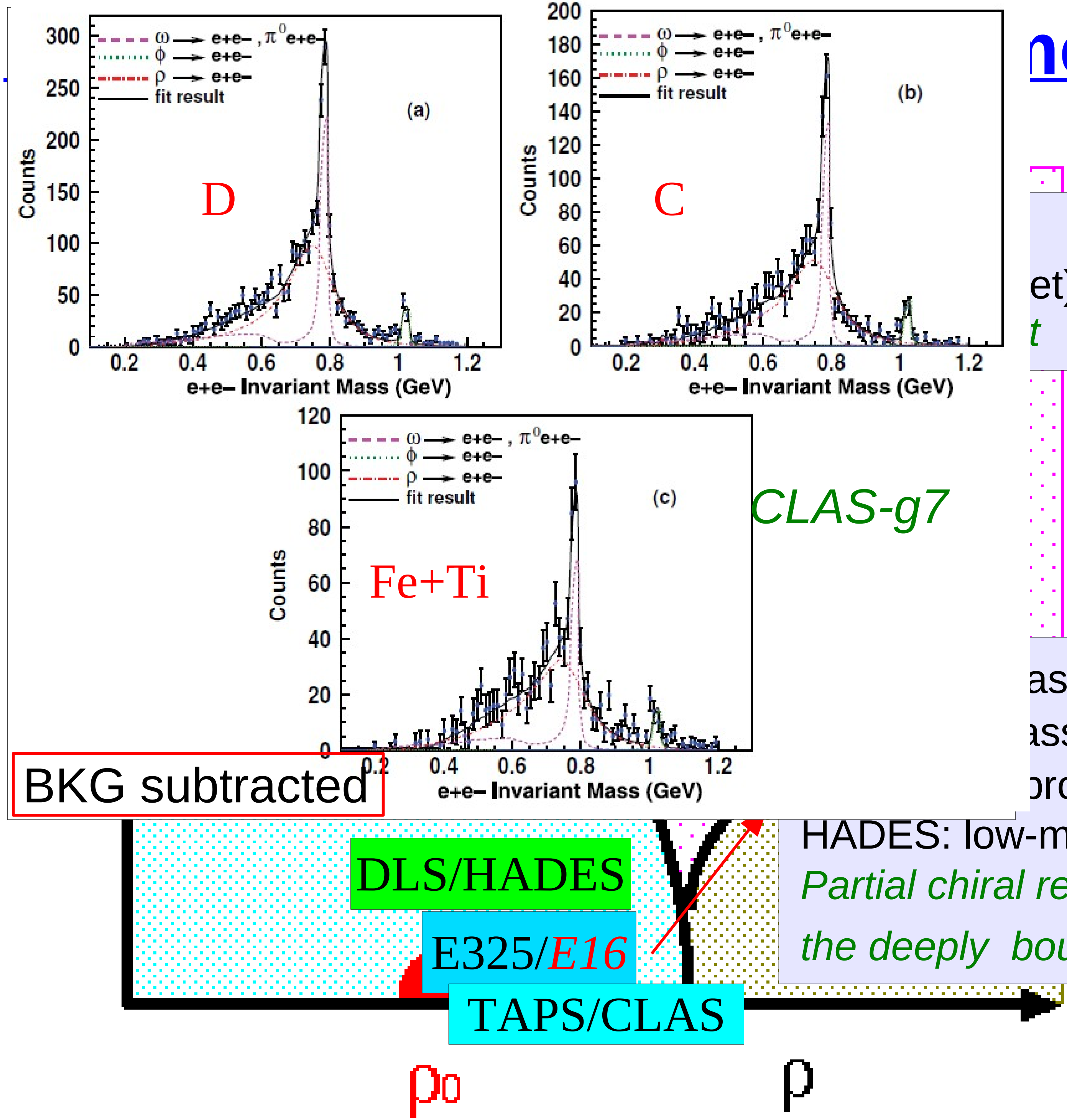
BKG subtracted

NA60



PHENIX

nents in the world



et)

t

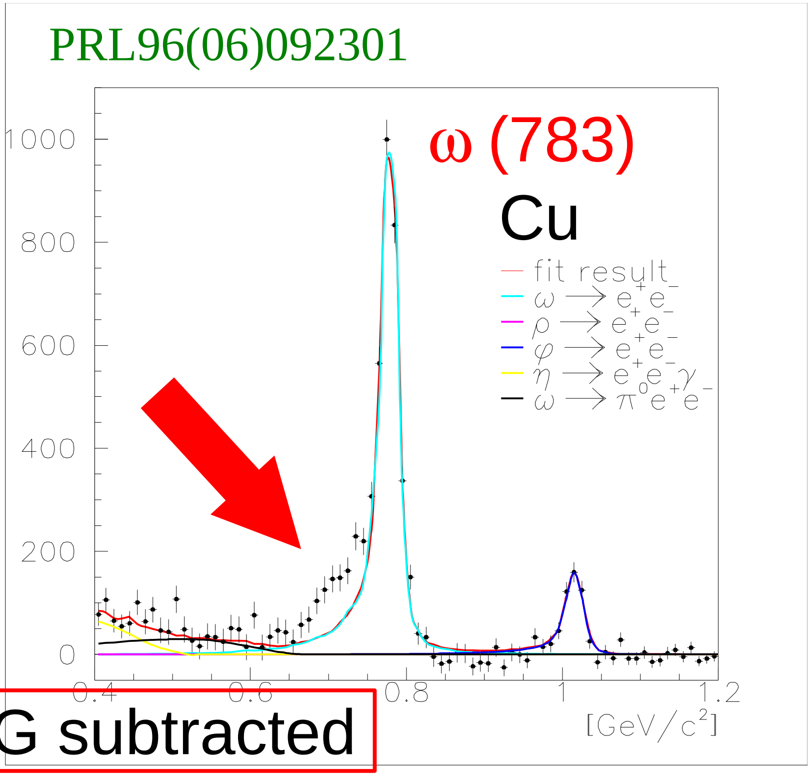
ass dropping

ass dropping and broadening

broadening

HADES: low-mass enhancement

Partial chiral restoration at ρ_0 is measured w/ the deeply bound pionic atom



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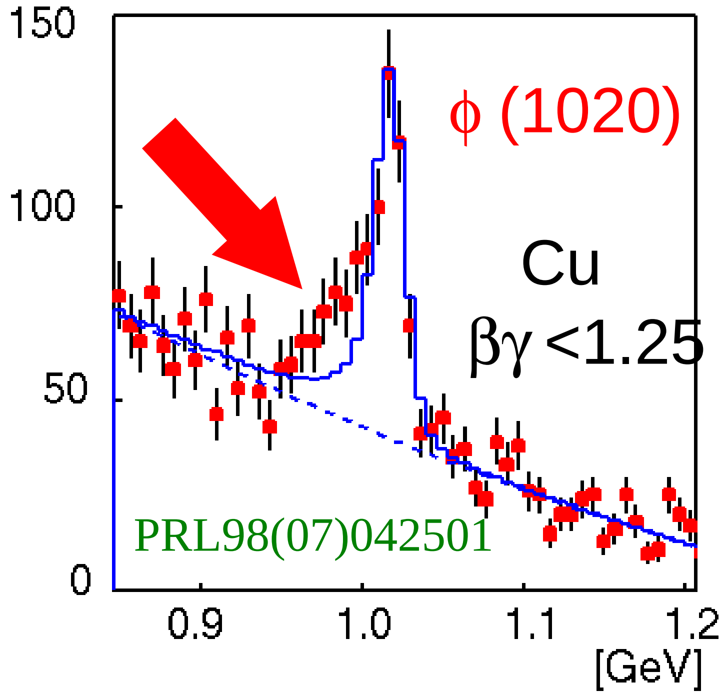
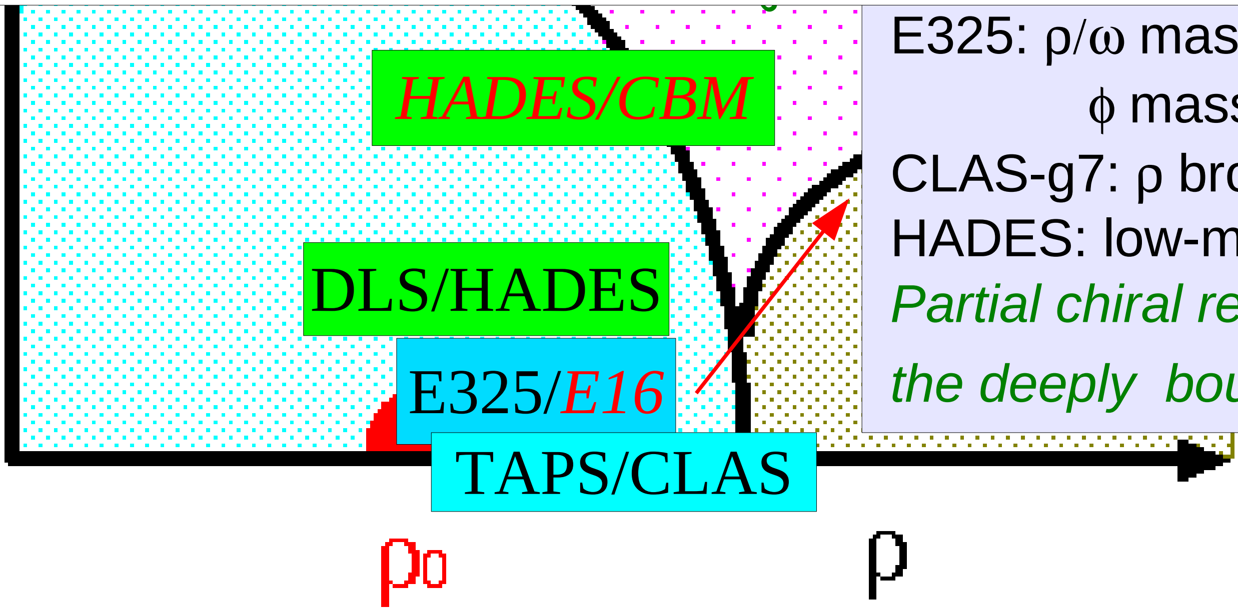
E325





E325: ρ/ω mass dropping

ϕ mass dropping and broadening

CLAS-g7: ρ broadening

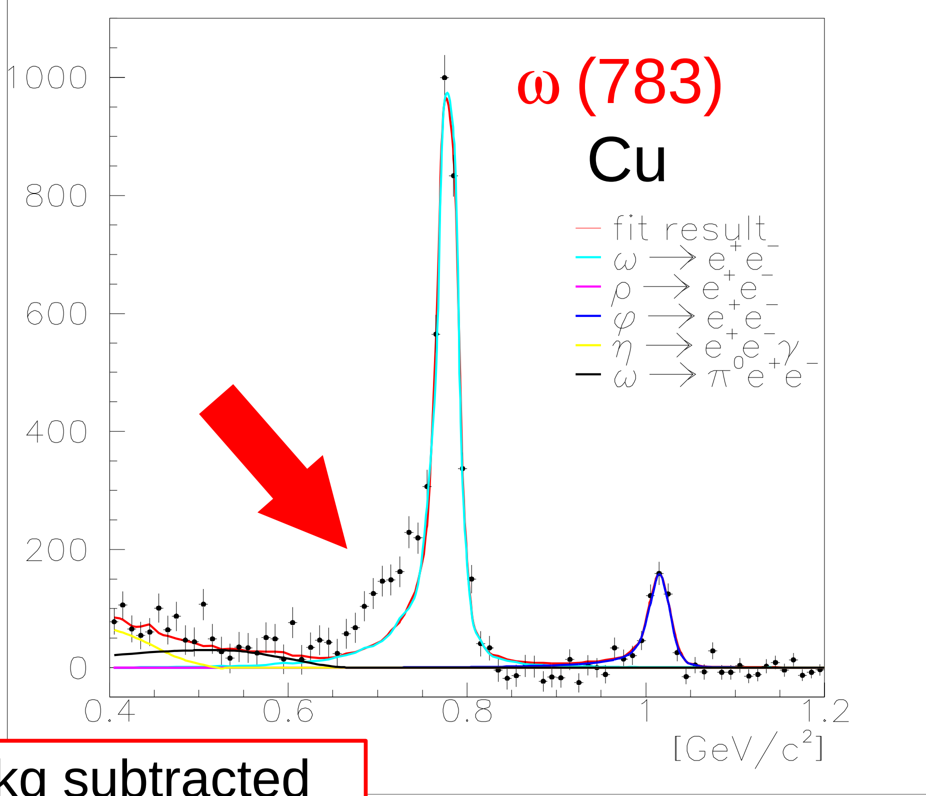
HADES: low-mass enhancement

Partial chiral restoration at ρ_0 is measured w/ the deeply bound pionic atom

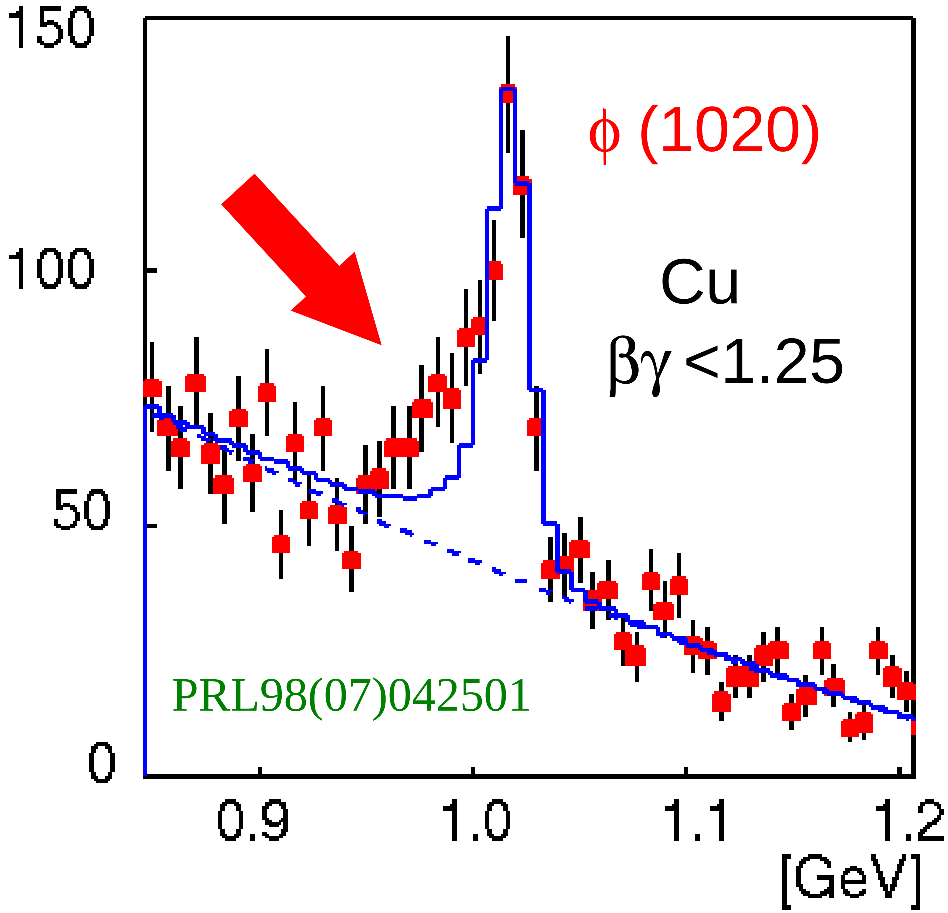
KEK-PS E325

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

PRL96(06)092301



bkg subtracted



PRL98(07)042501

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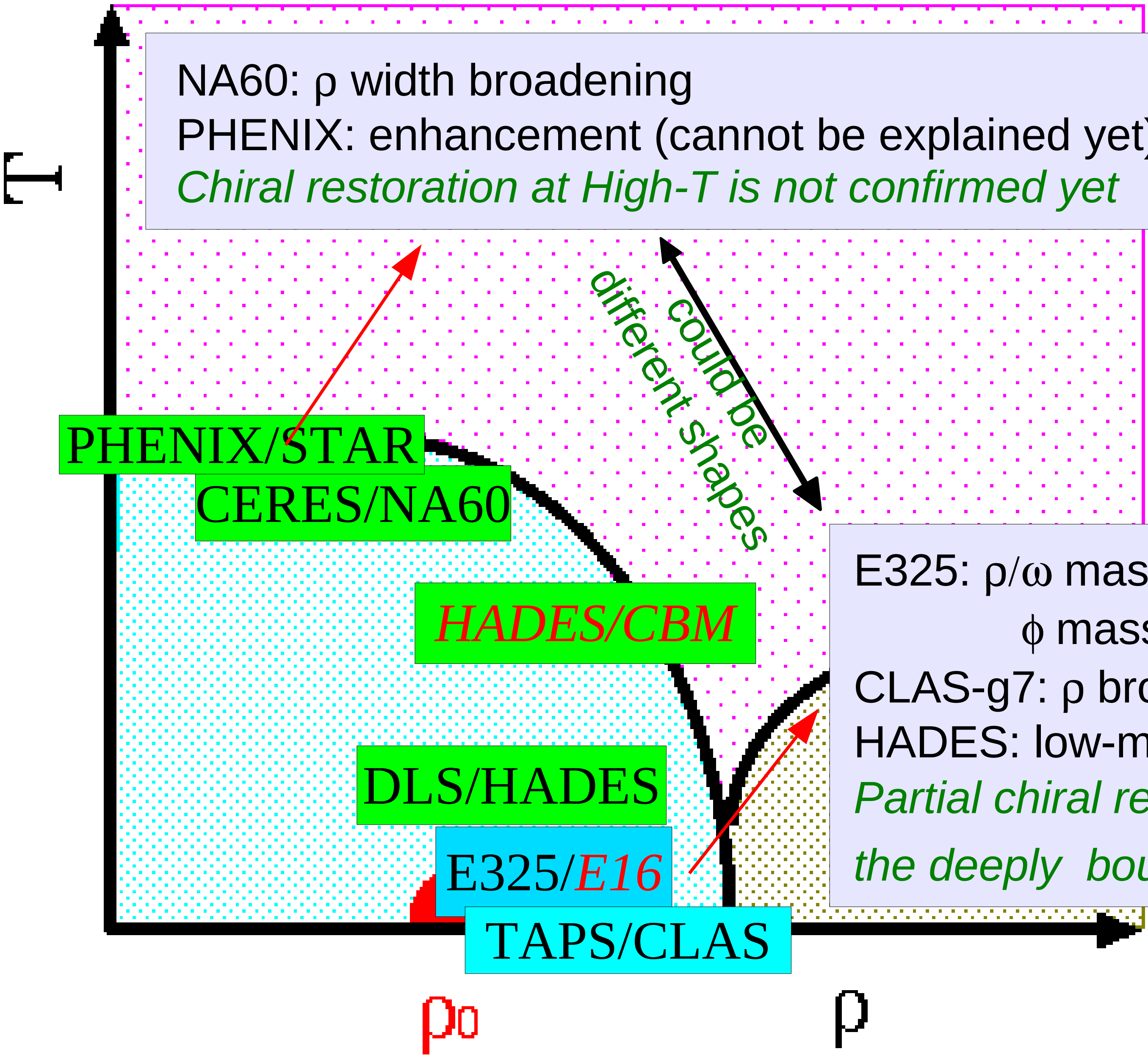

E325: ρ/ω mass dropping
ϕ mass dropping and broadening
CLAS-g7: ρ broadening
HADES: low-mass enhancement
Partial chiral restoration at ρ_0 is measured w/ the deeply bound pionic atom

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

Dilepton spectrum measurements in the world

Mosel, Leupold, Metag (arXiv:1006.5822)

experiment	momentum acceptance	ρ	ω	ϕ
KEK-E325 pA 12 GeV	$p > 0.6$ GeV/c	$\frac{\Delta m}{m} = -9\%$ $\Delta\Gamma \approx 0$	$\frac{\Delta m}{m} = -9\%$ $\Delta\Gamma \approx 0$	$\frac{\Delta m}{m} = -3.4\%$ $\frac{\Gamma_\phi(\rho_0)}{\Gamma_\phi} = 3.6$
CLAS γA 0.6-3.8 GeV	$p > 0.8$ GeV/c	$\Delta m \approx 0$ $\Delta\Gamma \approx 70$ MeV $(\rho \approx \rho_0/2)$		
CBELSA /TAPS γA 0.9-2.2 GeV	$p > 0$ MeV/c		$\Delta m \approx 0$ $p_\omega < 0.5$ GeV/c $\Delta\Gamma(\rho_0) \approx 130$ MeV $\langle p_\omega \rangle = 1.1$ GeV/c	
SPring8 γA 1.5-2.4 GeV	$p > 1.0$ GeV/c			$\Delta\Gamma(\rho_0) \approx 70$ MeV $\langle p_\phi \rangle = 1.8$ GeV/c
CERES Pb+Au 158 AGeV	$p_t > 0$ GeV/c	broadening favored over mass shift		
NA60 In+In 158 AGeV	$p_t > 0$ GeV/c	$\Delta m \approx 0$ strong broadening		

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not from the spectra
but CS from the A-dep.

Experimental methods:pros and cons

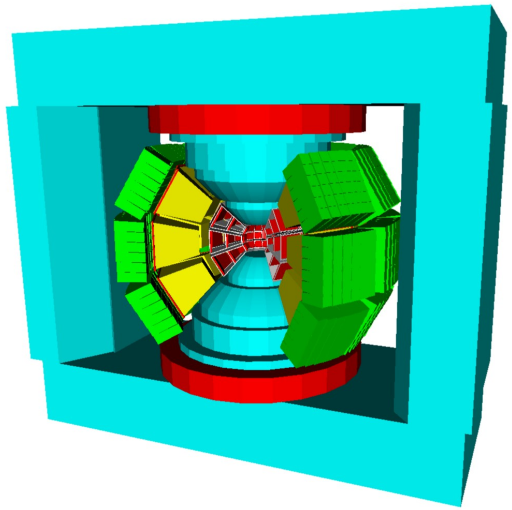
- leptonic decay VS hadronic decay
  - small FSI in the matter, but small branching ratio
- proton/photon induced VS heavy-ion collision
  - cold VS hot
  - static environment VS time evolution
  - S/N is better, production cross section is smaller
- ϕ VS ρ/ω
  - isolated and narrow, but production CS is smaller
- Why only KEK-PS E325 can observe the ϕ modification?
  - proton induced : better S/N than the HI collisions
  - large stat. using a high intensity beam : cope with the small CS
  - good spectrometer keeps the good mass resolution and works under the higher interaction rate

J-PARC E16 experiment

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

J-PARC E16 Collaboration

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



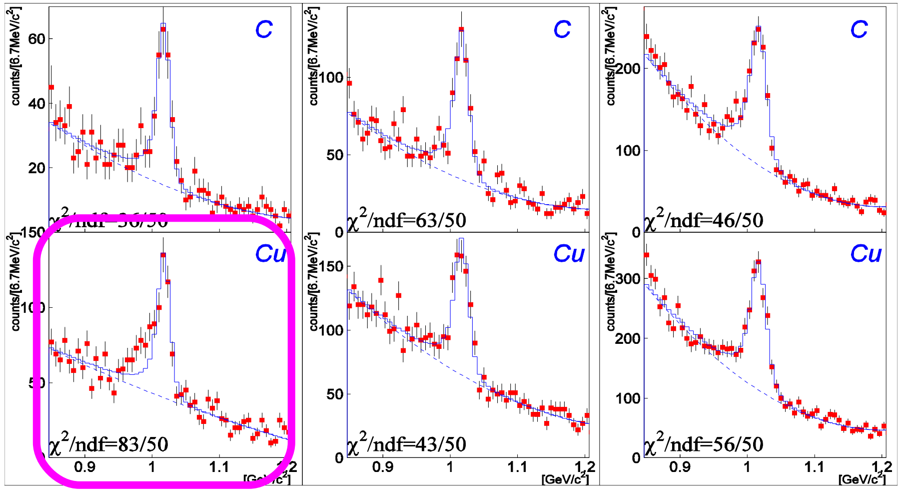
J-PARC E16 experiment

- Measure the vector-meson mass modification in nuclei systematically with the e^+e^- invariant mass spectrum

- A 30 GeV primary proton beam (10^{10}/spill) / 5 weeks of physics run to collect $\sim 10^5$ $\phi \rightarrow e^+e^-$ for each target

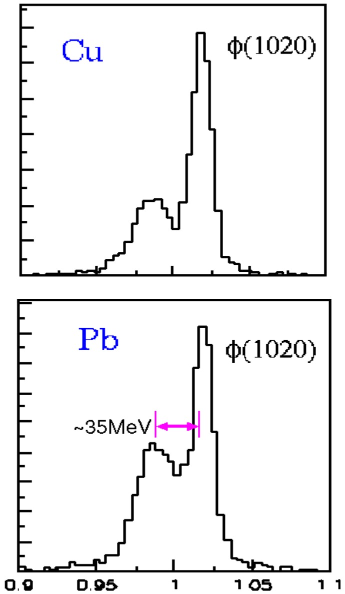
- confirm the E325 results, and provide new information as the matter size/momentum dependence of modification

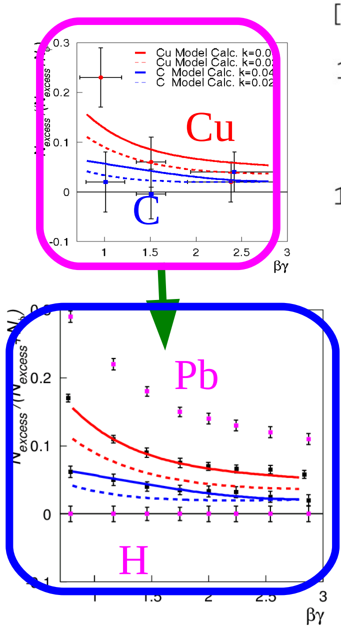
Precedent exp.(KEK-PS E325)

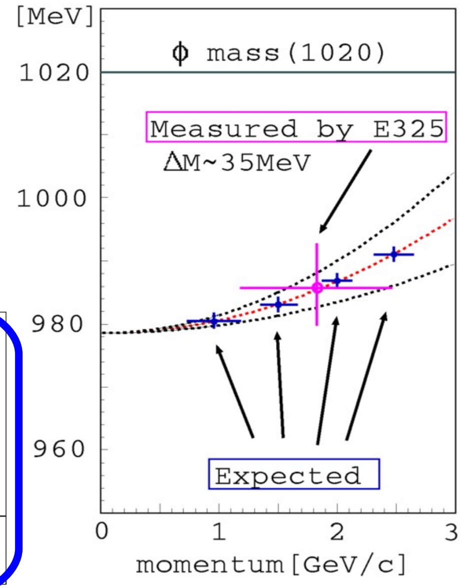


ϕ–mass is modified in large nuclei for slowly moving mesons... consistent with the prediction based on the QCD sum rule

Proposed exp. E16







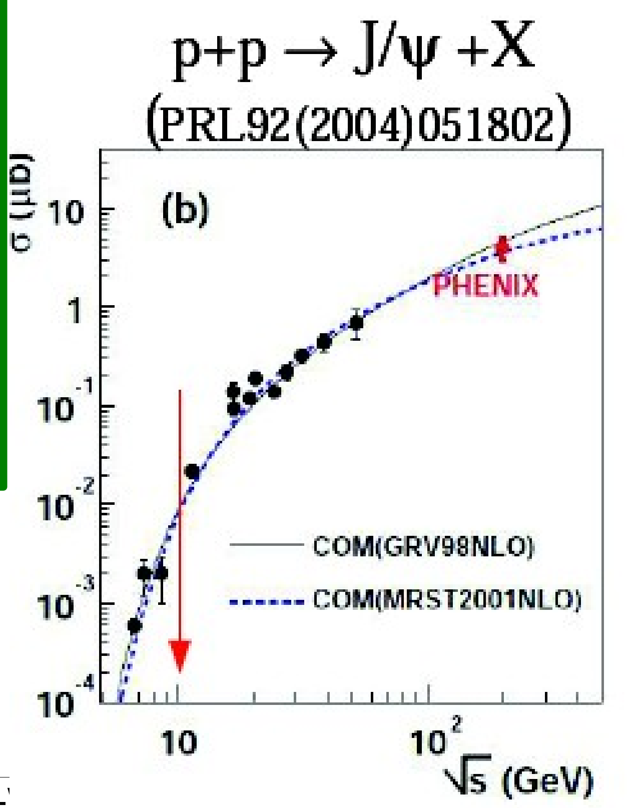
Nuclear matter size dependence & *Momentum dependence*

of mass modification are measured

charmonium yield @E16 (30 GeV)

- charmonium mass is governed by gluon condensate
  - small modification is expected for J/ψ
    - even narrow width (no in-medium decays)
  - width broadening (~10MeV) and mass dropping (~10-100MeV) for χ_c, ψ(2s)
- very rough estimation w/ the production CS ratio

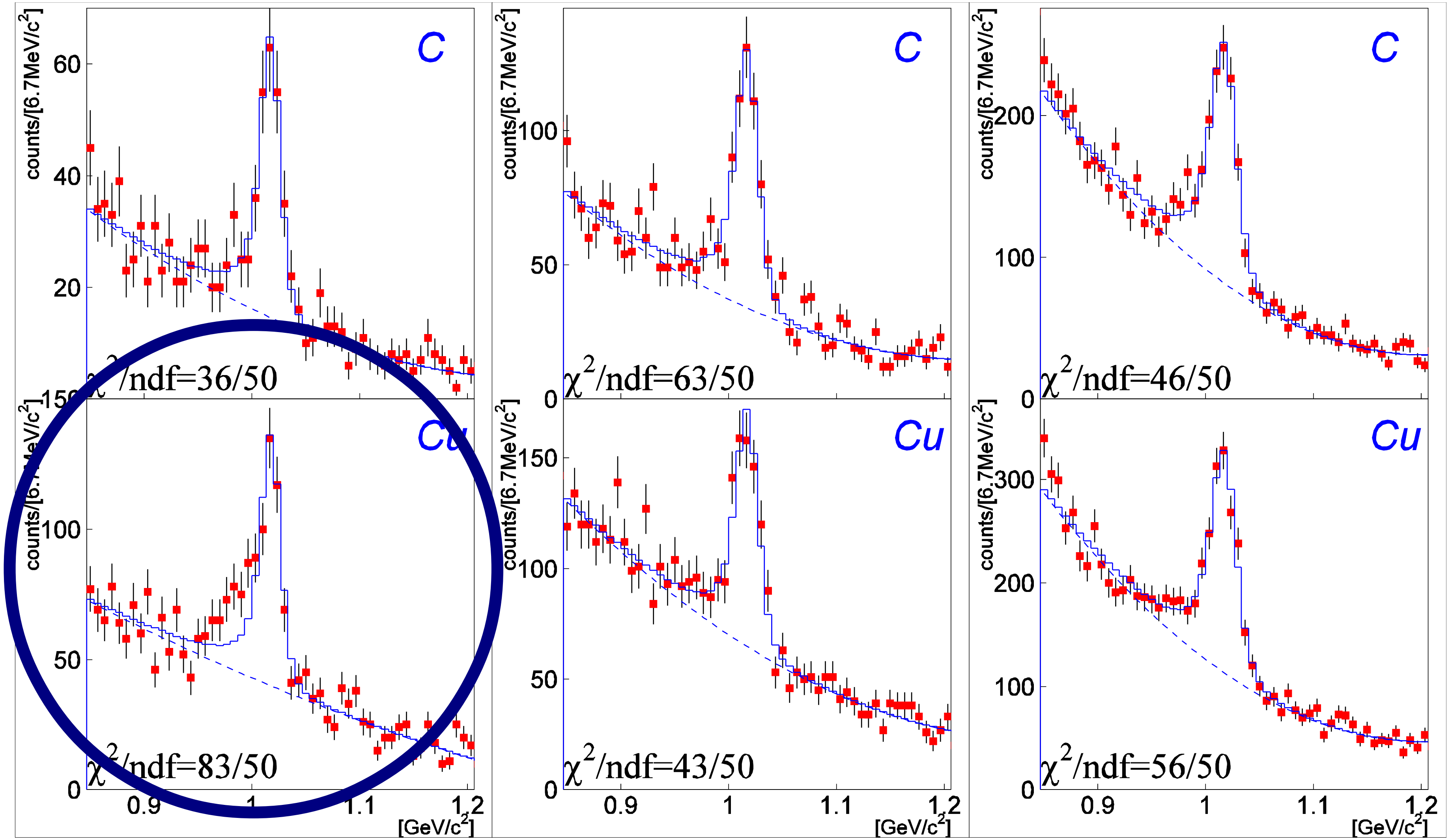
	ϕ 12GeV	ϕ 30GeV	J/ψ 30GeV	ratio	ψ (3686)
pp	70ub		2 nb		
pCu	1mb	3mb*1	0.1ub*2	1/30000	?
ee branch	0.03%		6%	200	0.7%
yield		100000	700	1/150	<70



- *1 : JAM & empirical formula, from 12GeV data
- *2 : nuclear dependence ~A , from pp
- 10^{10} ppp, 0.1% int. target

ee spectra of ϕ meson (divided by βγ)

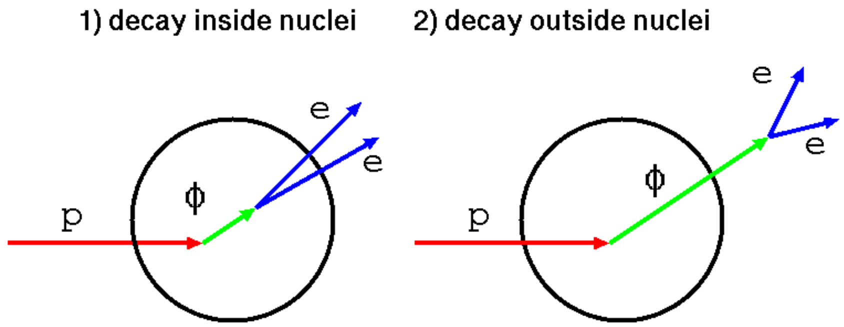
βγ<1.25 (Slow)	1.25<βγ<1.75	1.75<βγ (Fast)



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

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

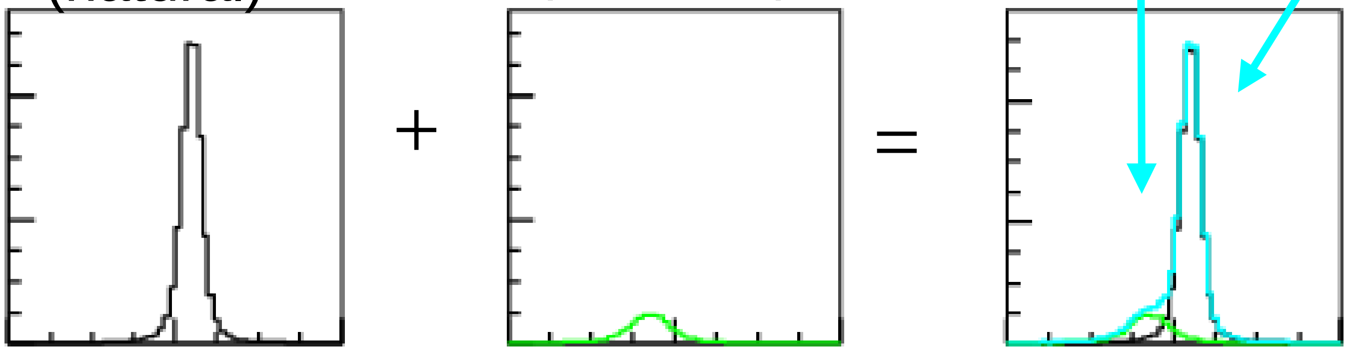


longer-life meson(ω & ϕ)cases : Schematic picture

outside decay (natural)

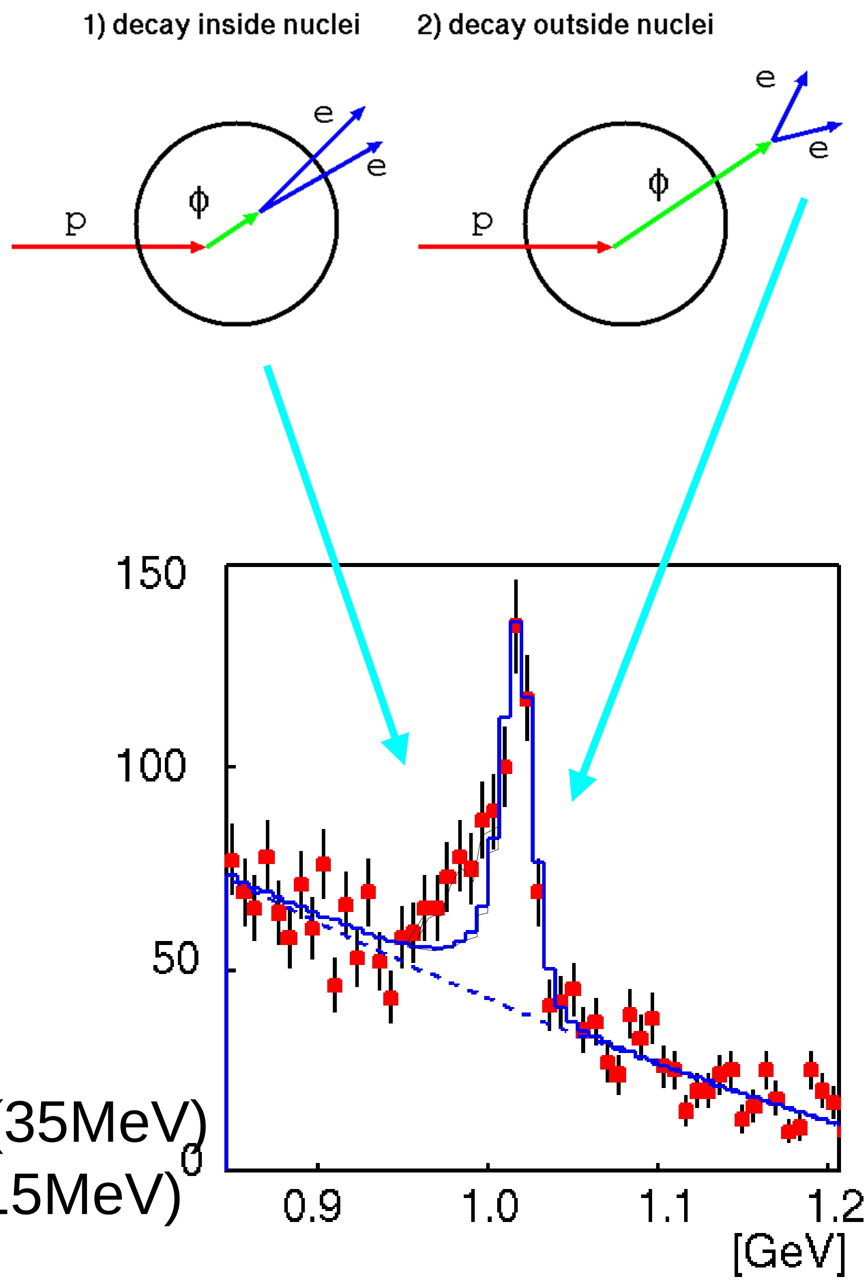
inside decay (modified)

expected to be observed



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)



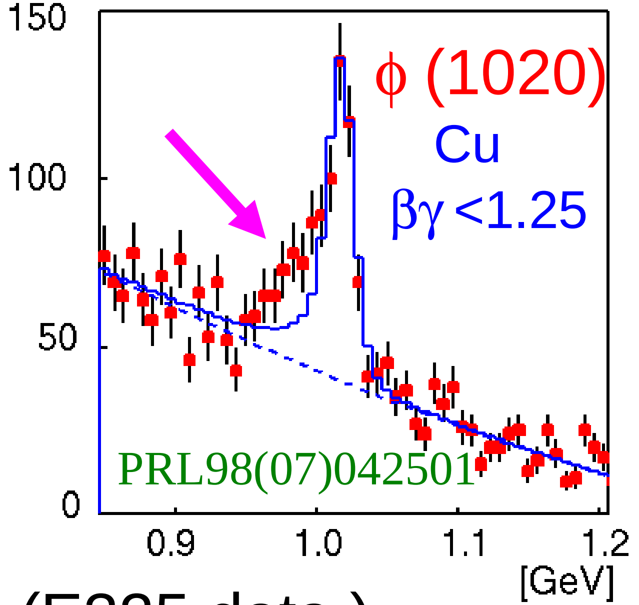
$$k_1 = 0.034^{+0.006}_{-0.007}$$

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

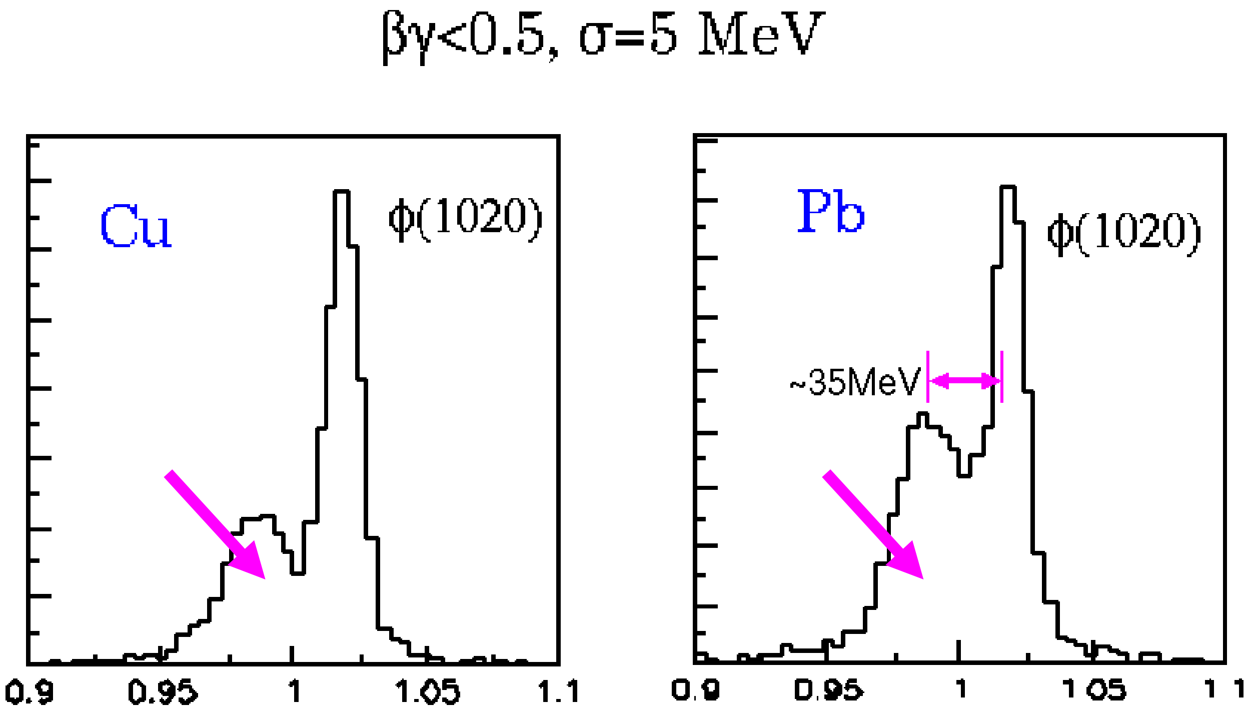
For φ, 3.4% mass reduction (35MeV)
3.6 times width broadening(15MeV)
at ρ_0

E16 : mass resolution requirement

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



(E325 data)



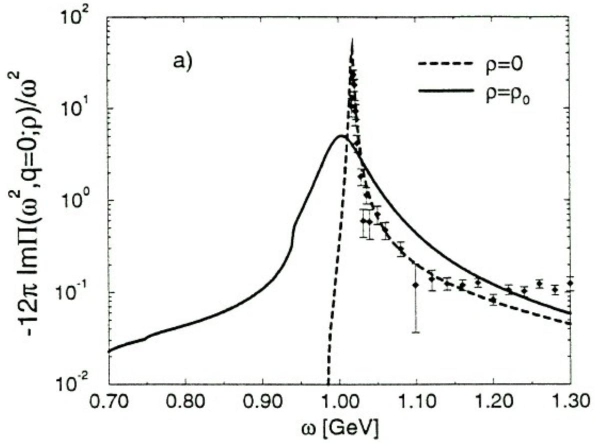
(model calc.)

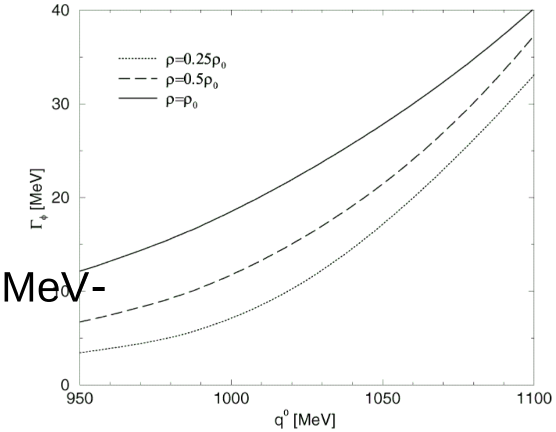
ϕ-mass modification at ρ_0

- (vacuum value : m(0)=1019.456MeV, $\Gamma(0)$= 4.26MeV)
  - **$m(\rho)/m(0) = 1 - k_1 (\rho/\rho_0)$, $\Gamma(\rho)/\Gamma(0) = 1 + k_2 (\rho/\rho_0)$**
- determined by E325 (PRL98(2007)042581)
  - Δm : –35 (28~41) MeV, Γ : 15 (10~23) MeV

$$k_1 = 0.034^{+0.006}_{-0.007}$$
$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$

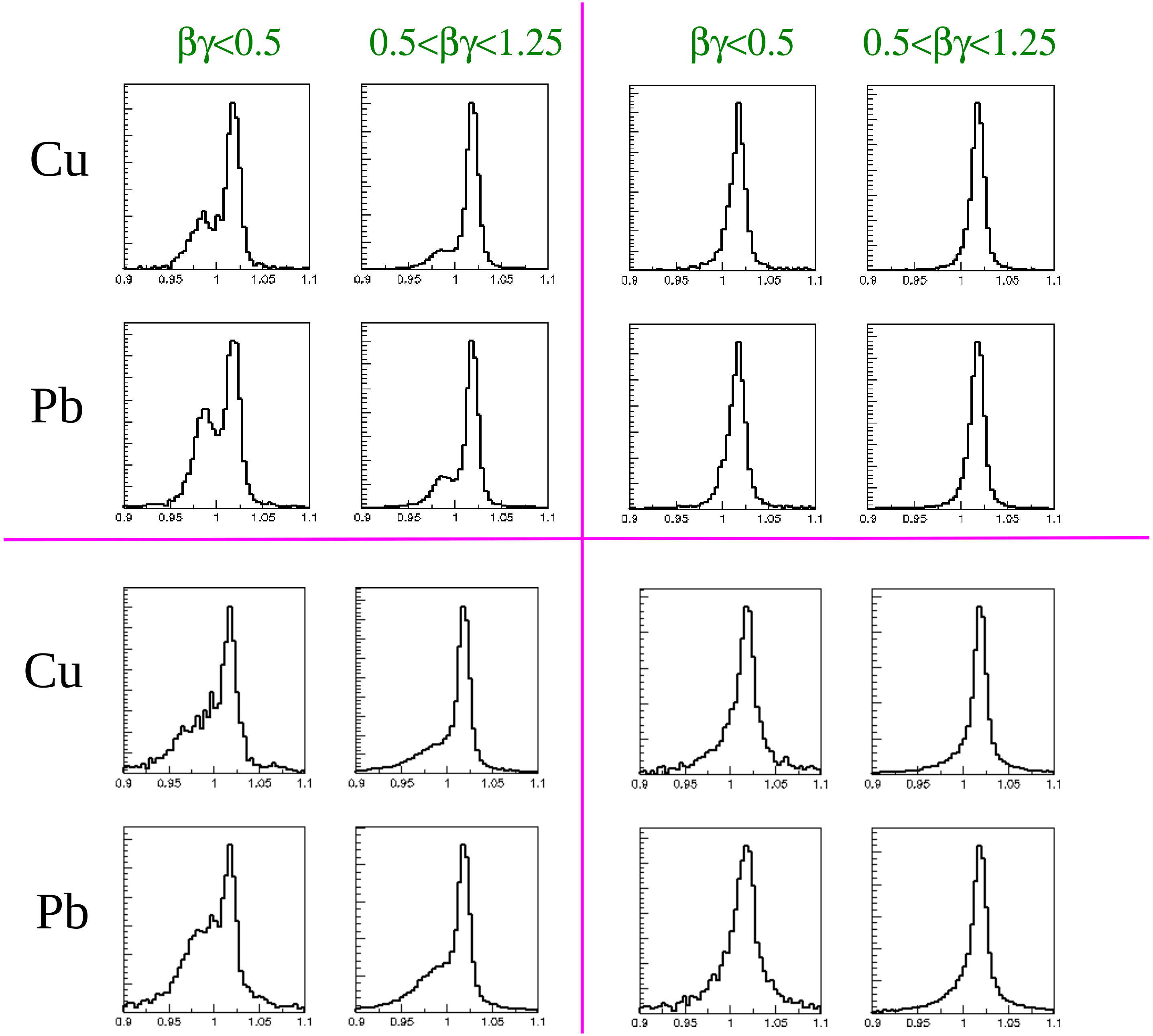
- Hatsuda, Lee [PRC46(1992)34)] *QCD sum rule*
  - Δm : –12~44 MeV (k=(0.15±0.05)y, y=0.12~0.22),
  - Γ : not estimated
- Klingl, Waas, Weise [PLB431(1998)254] *hadronic*
  - taking account of K-mass modification
  - Δm : < –10 MeV, Γ : ~45 MeV
- Oset , Ramos [NPA 679 (2001) 616] *hadronic*
  - different approach for K-mass
  - Δm : < –10 MeV, Γ : ~22 MeV for m=1020MeV, ~16MeV for m=985 MeV
- Cabrera and Vacas [PRC 67(2003)045203] OR01+ *hadronic*
  - Δm : – 8 MeV, Γ : ~30 MeV for m=1020MeV





expected shape w/ various parameters

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



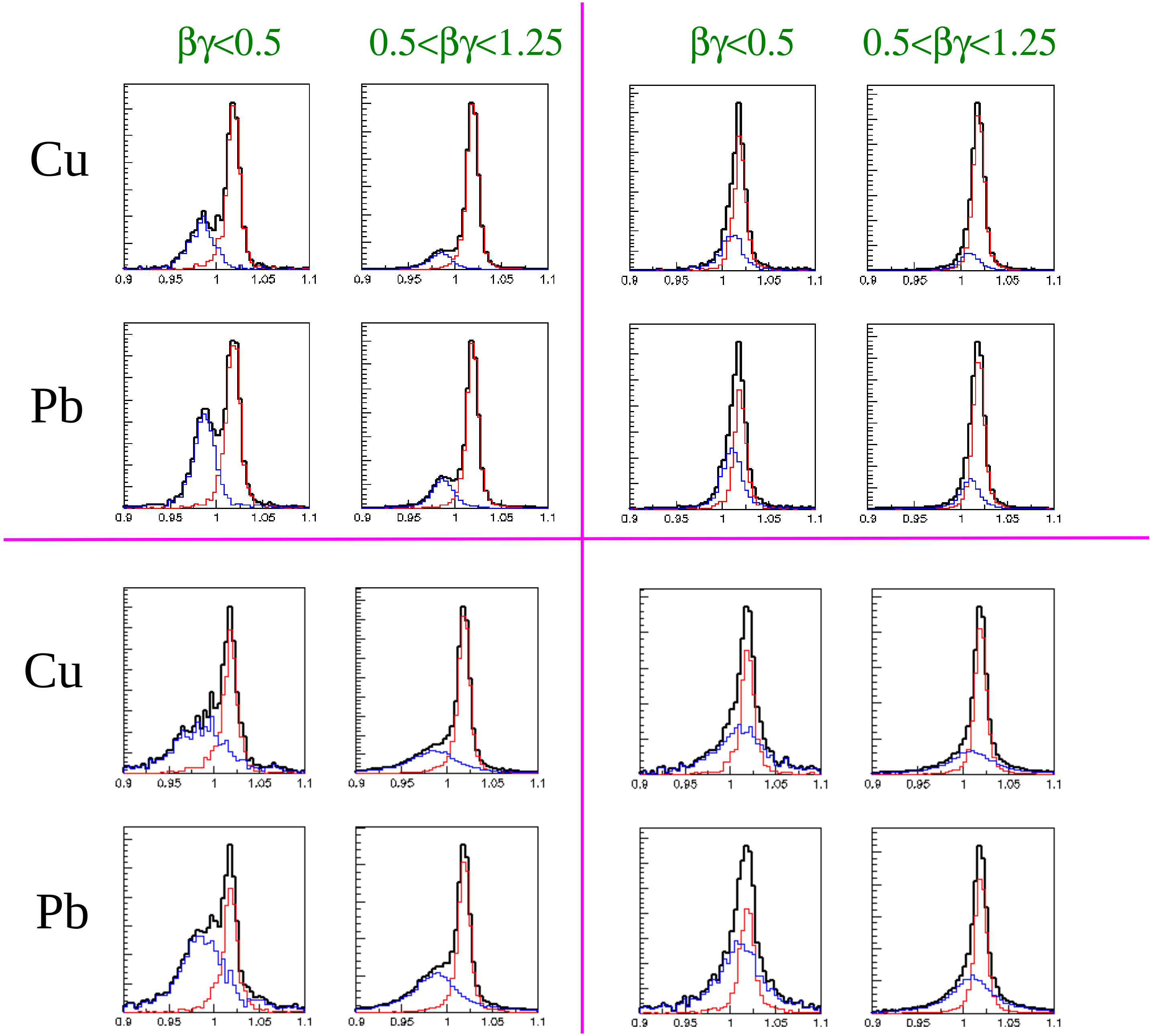
can distinguish

Δm = −35 or −10 MeV

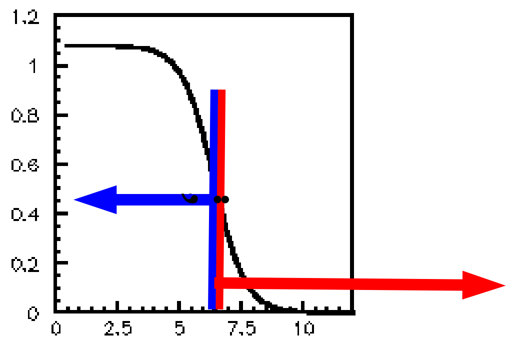
Γ = 15 or 50 MeV

expected shape w/ various parameters

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

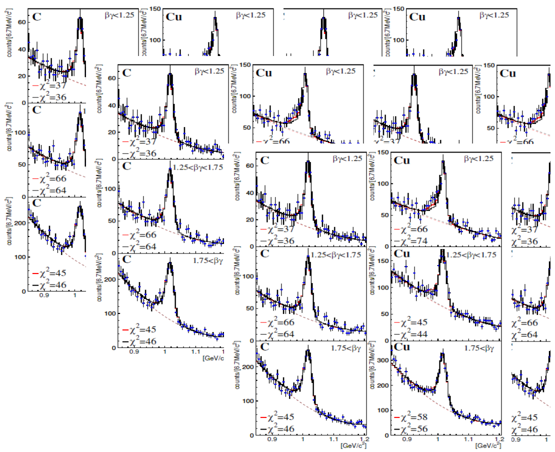


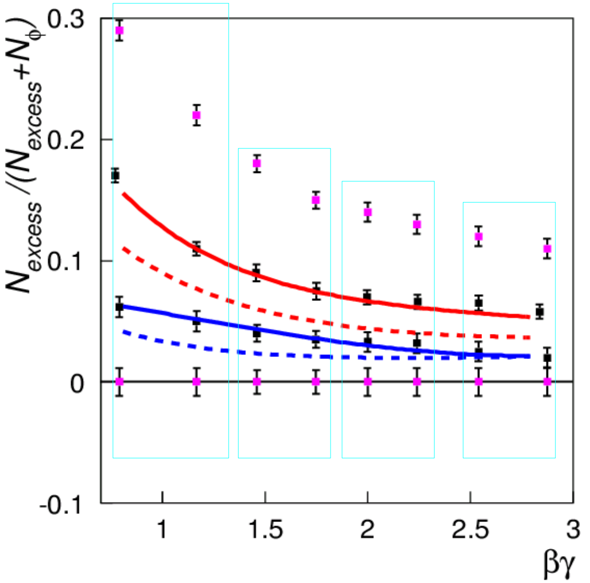
blue: decays inside the half-density radius of nuclei in the MC

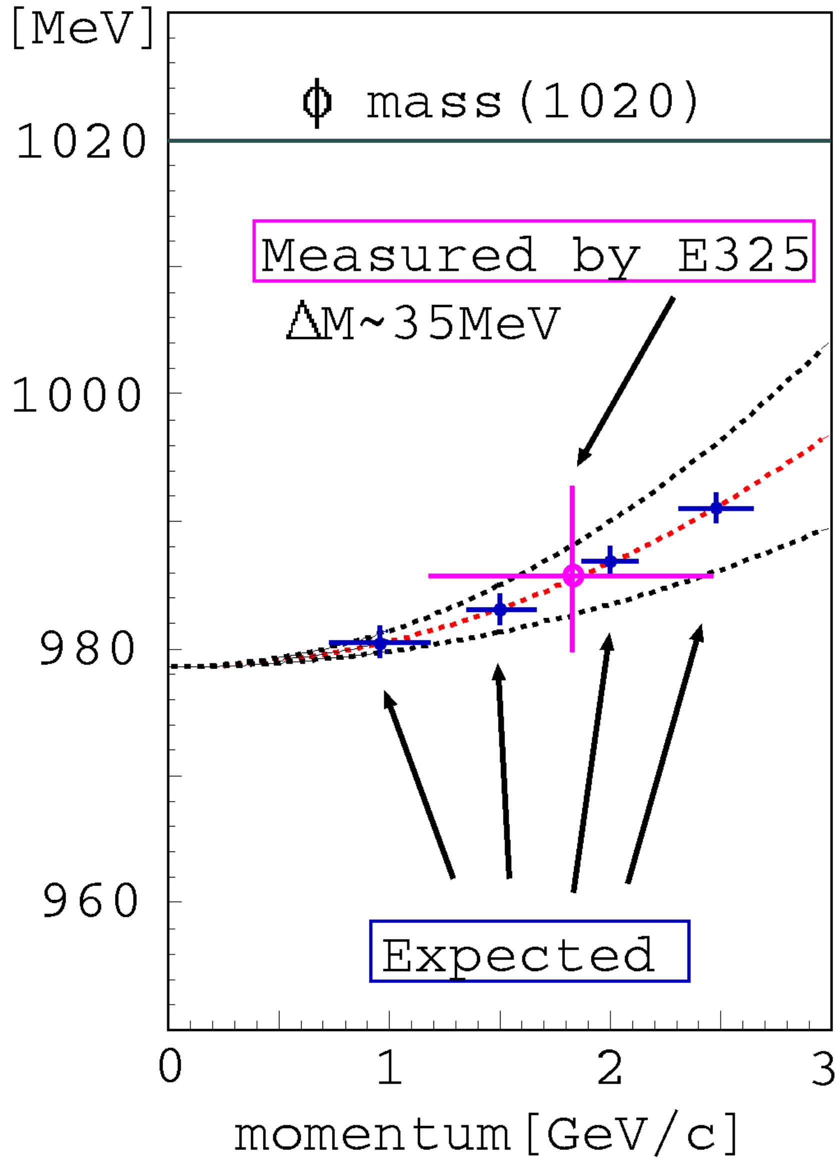


dispersion relation (mass VS momentum)

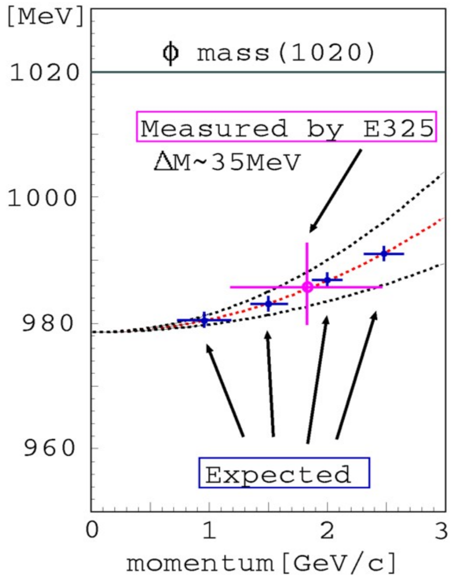
- prediction for ϕ by S.H.Lee(p<1GeV/c)
- current E325 analysis neglects the dispersion (limited by the statistics)
- fit with common shift parameter k_1(p), to all nuclear targets in each momentum bin





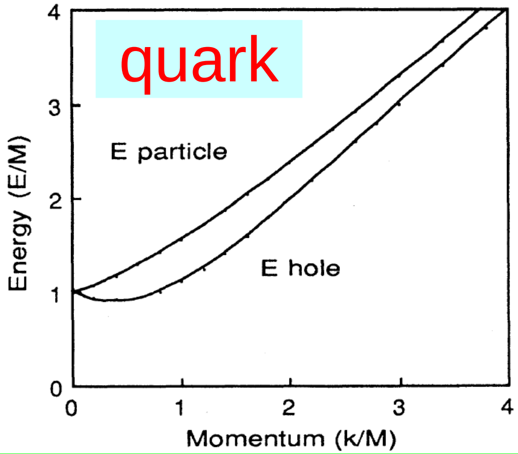


momentum dependence

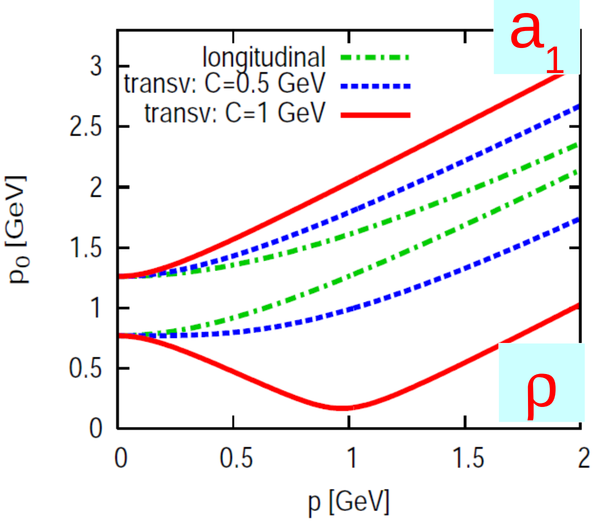


- From the view point of experimentalists
  - many predictions are for the mesons at rest (p=0)
    - extrapolation to p=0 if it is a simple dependence
- From the view point of theorists
  - dispersion relation of quasi particles are characteristic
  - other effects

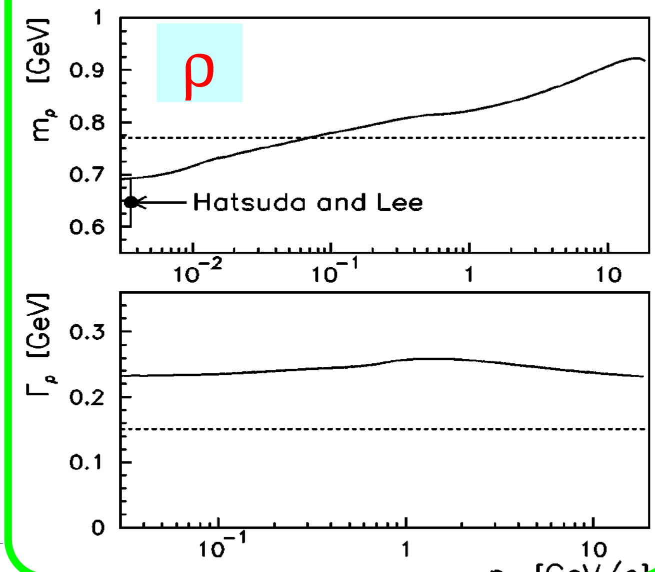
- Weldon
  (PRD40(89)2410)



- Harada & Sasaki
  (PRC80(09)054912)



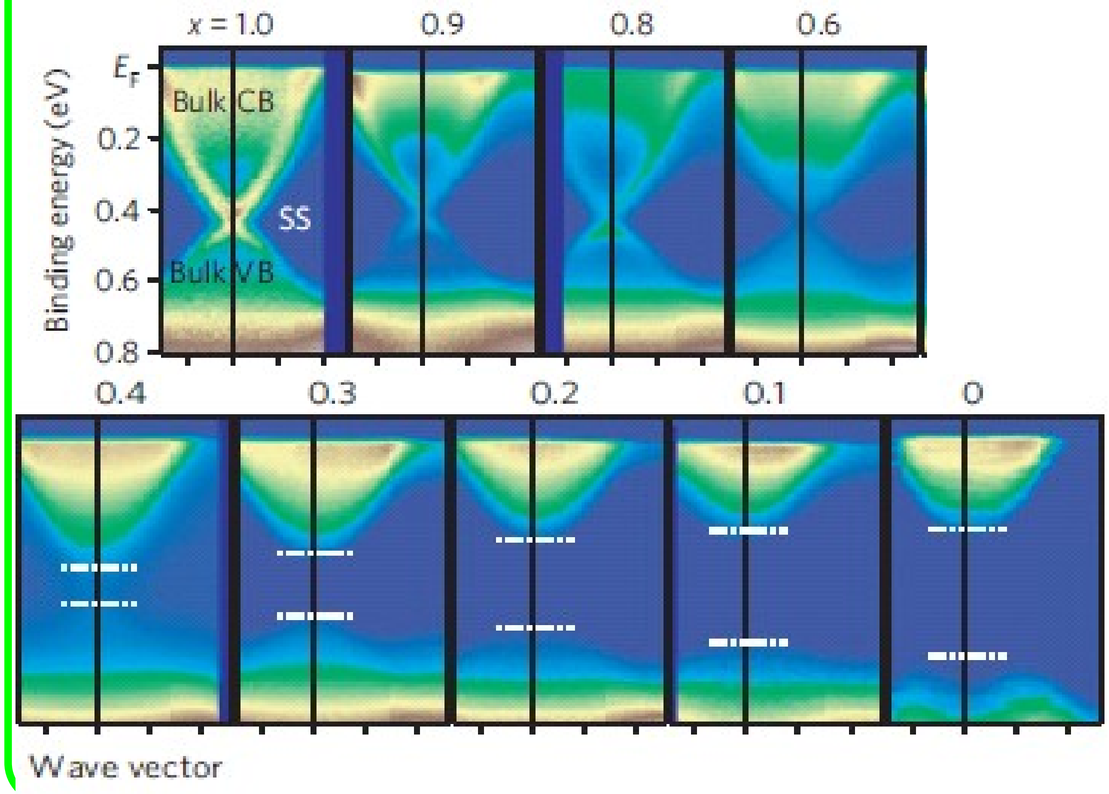
- Kondratyuk et al.
  (PRC58(98)1078)



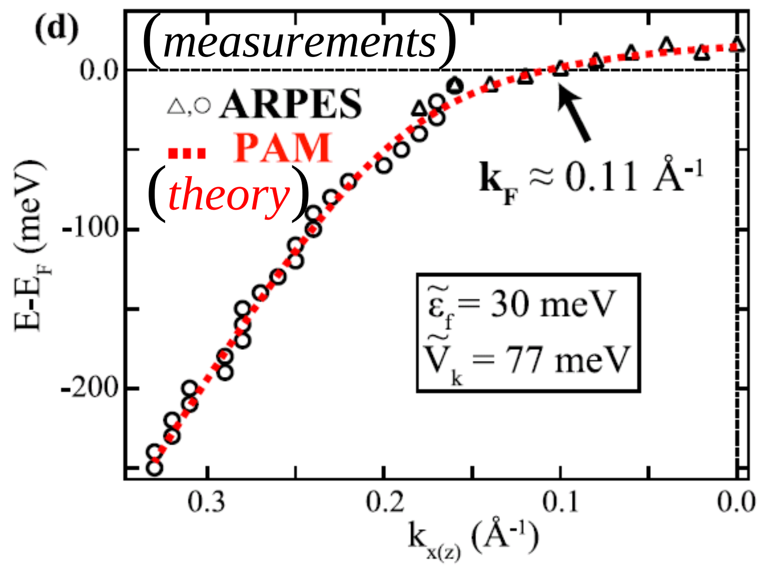
dispersion of quasi particle in condensed matter

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

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



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



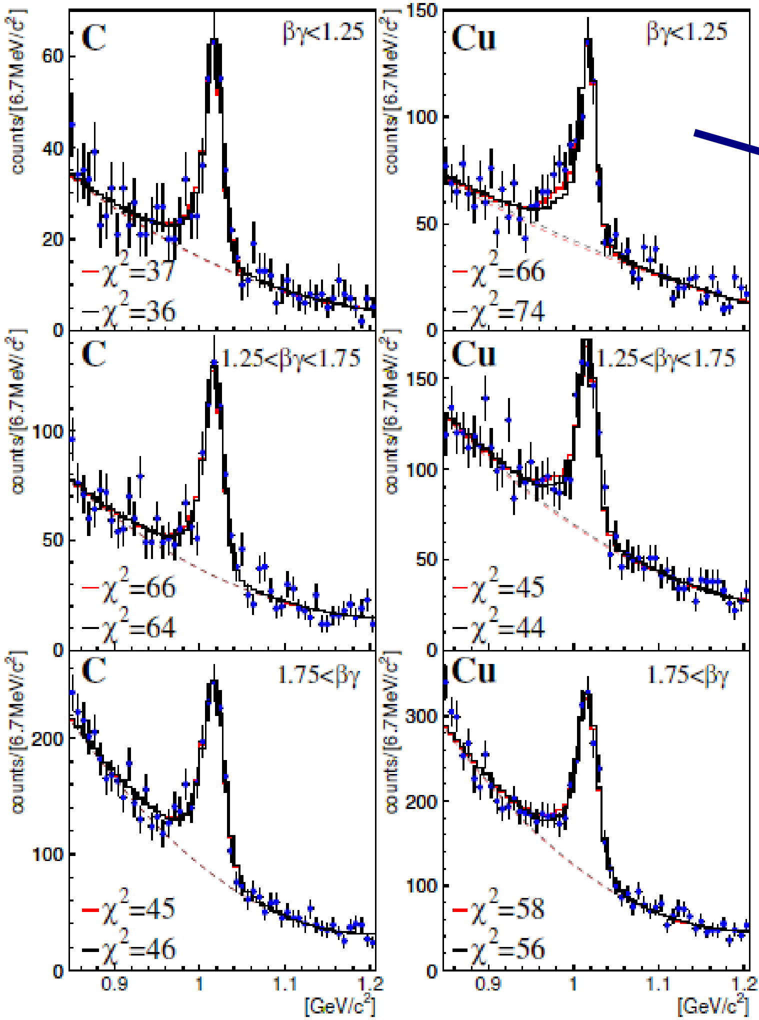
Impact of E16

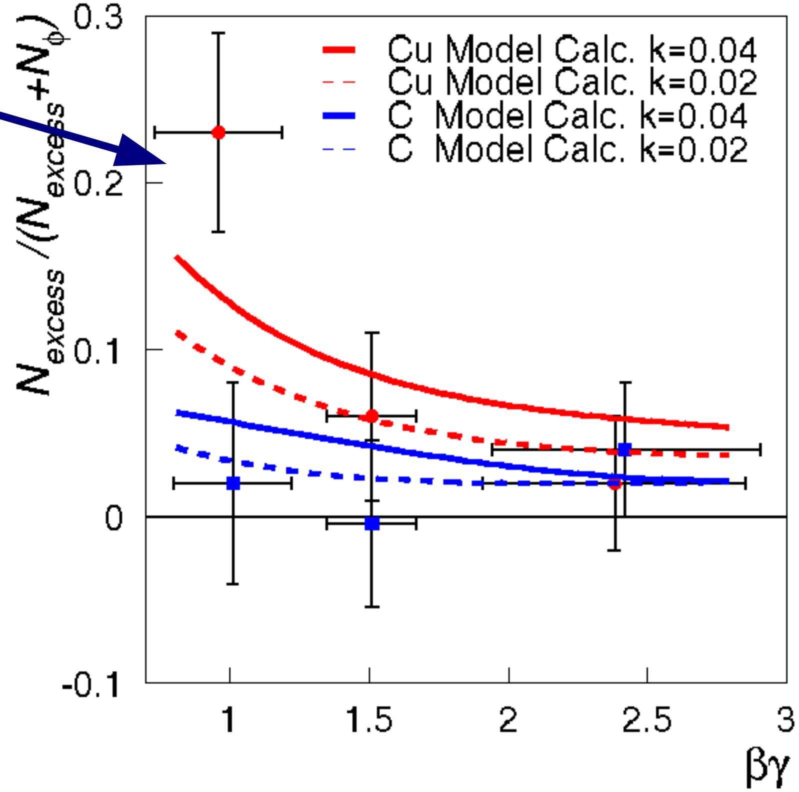
- hadron modification are observed in several experiments but interpretation is not converged : "mass dropping or broadening?"
  - theoretically the question is oversimplified : T- dependence, momentum dependence
  - analysis difficulties in ρ/ω in the dilepton decay channel
  - small statistics and small data sets
- pin down the phenomena for the vector meson in nuclei ($\rho=\rho_0$,T=0) using ϕ meson
  - confirm the E325 observation with improved resolution(x2) and statistics (x100)
  - matter-size dependence and momentum dependence will be examined systematically
    - first measurement of the dispersion relation of hadrons in nuclear matter
- establish a low energy phenomenon which can be predicted by means of QCD
  - mass generation due to the chiral symmetry breaking
- Further Step (future experiment)
  - slow ϕ at HIHR beam line with 10^9 π beam, $\mu\mu$ pair measurement, etc.
  - higher density state using medium-energy HI collisions
    - chiral phase transition in the high-density region

back up

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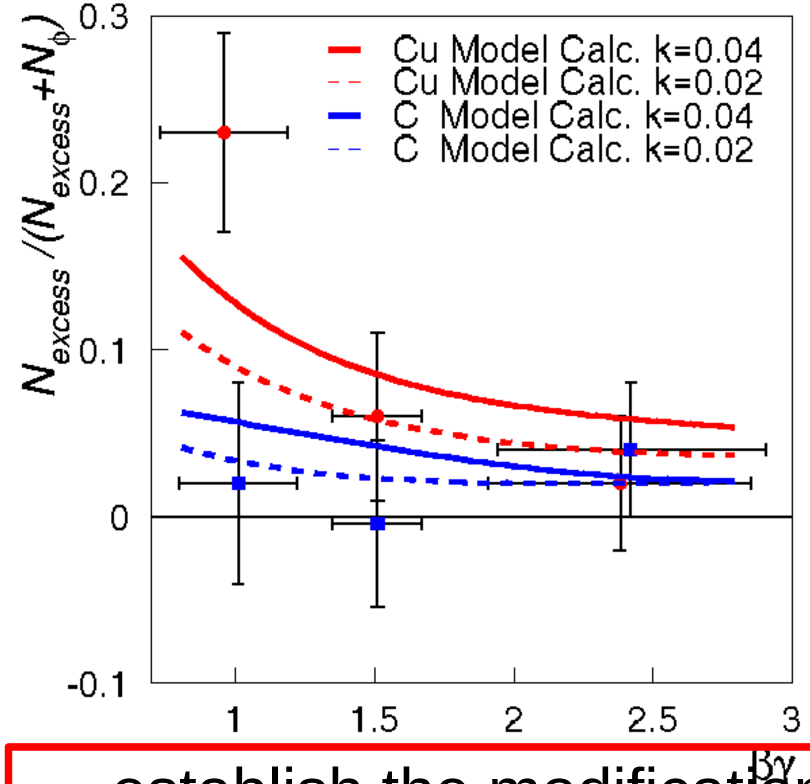
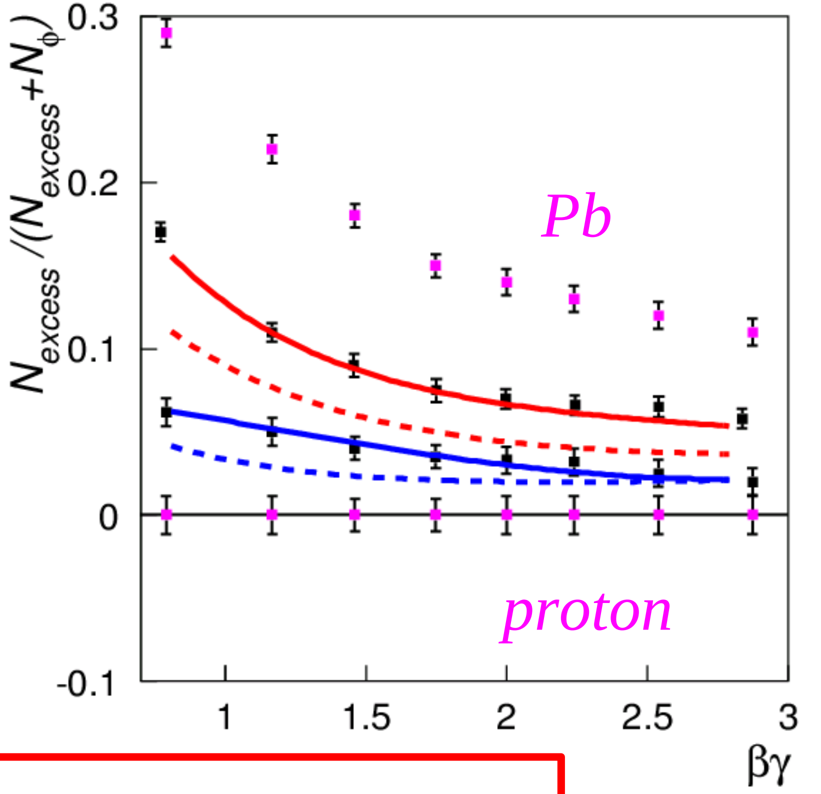
- systematic study : all the data should be explained the interpretation model



x 100 stat.



- establish the modification
-

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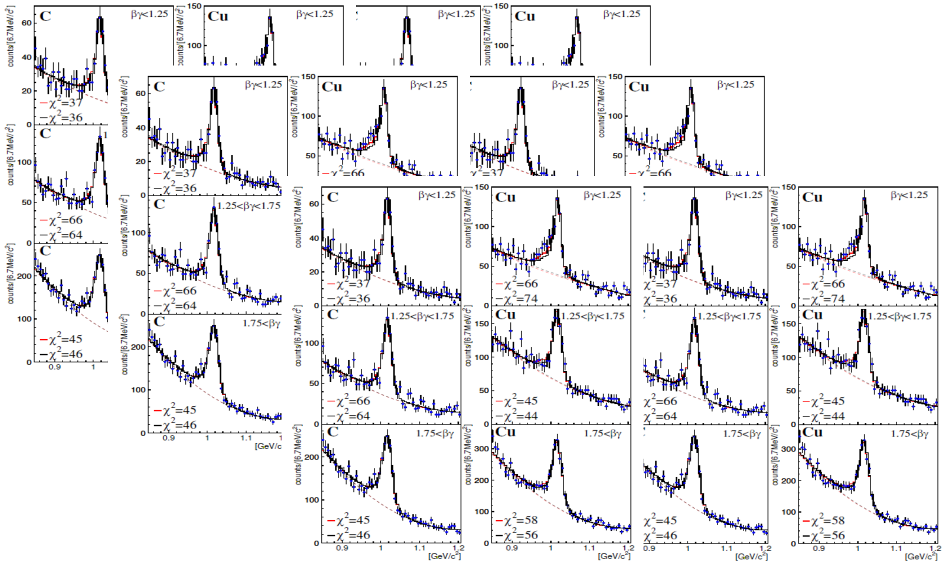
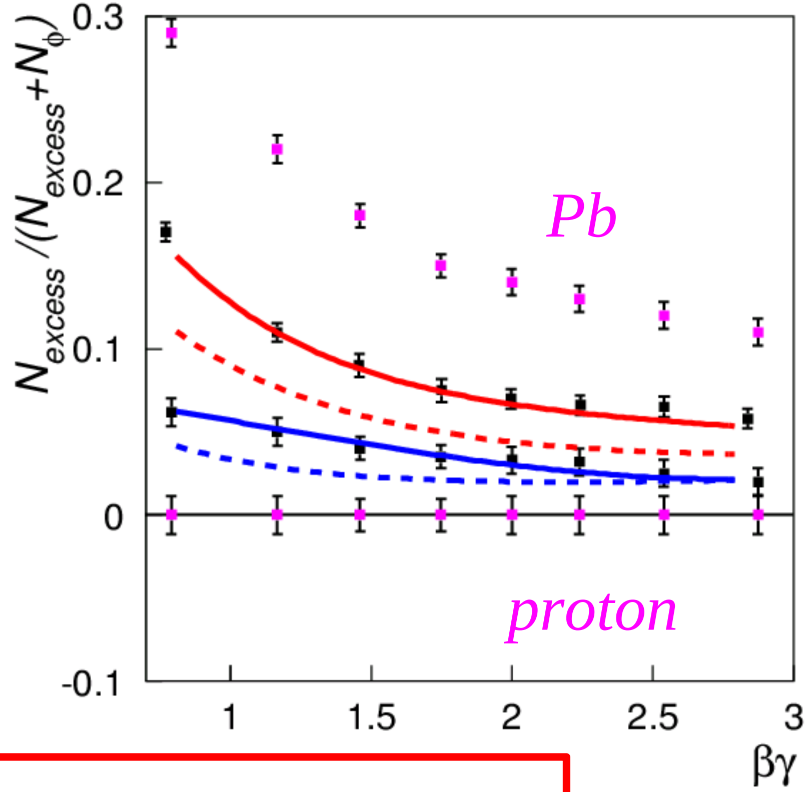
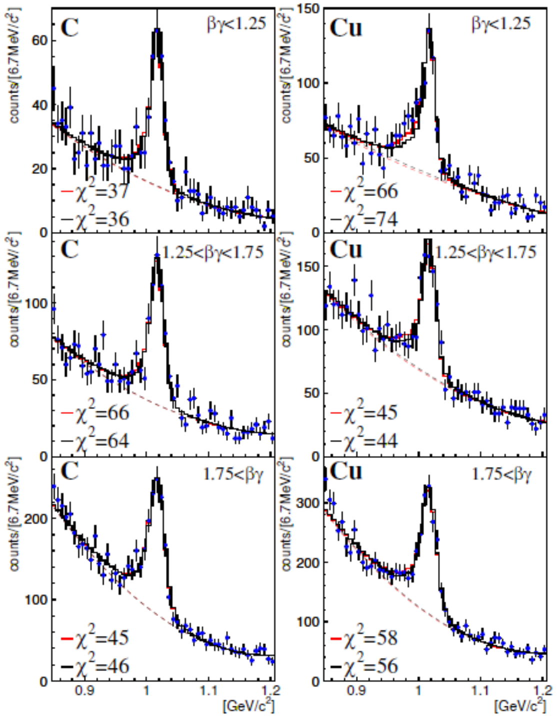


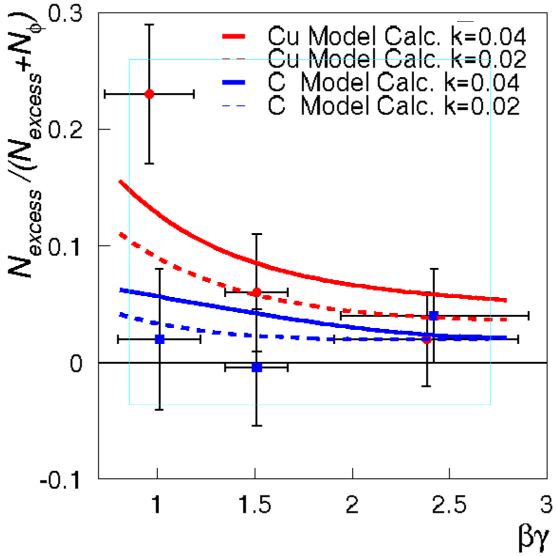


- establish the modification
- check the interpretation model with shape analysis for each histogram

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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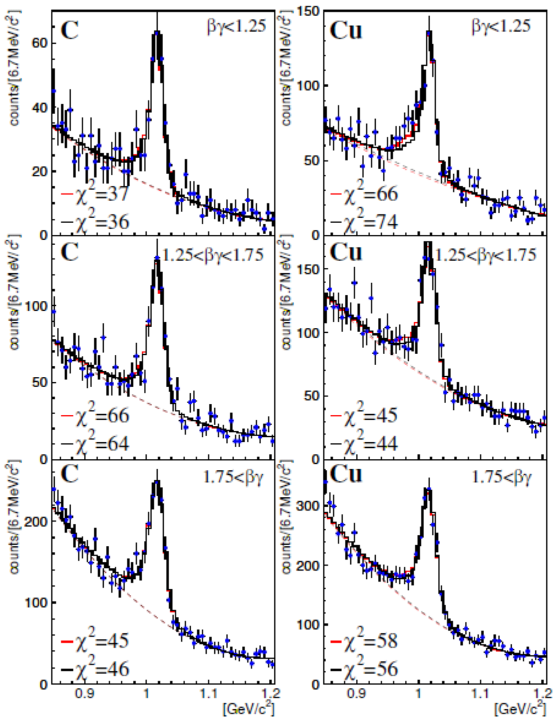

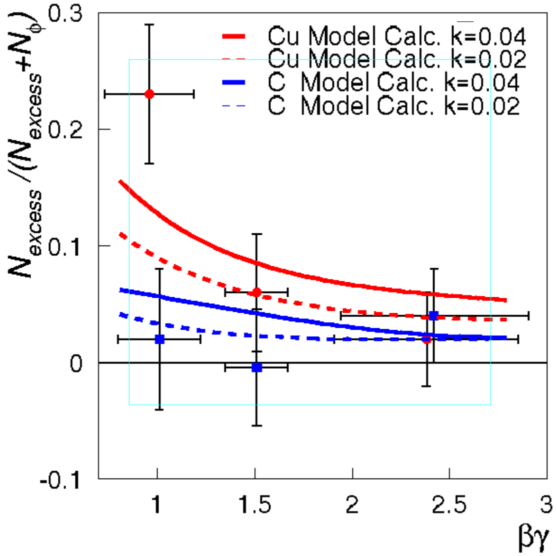

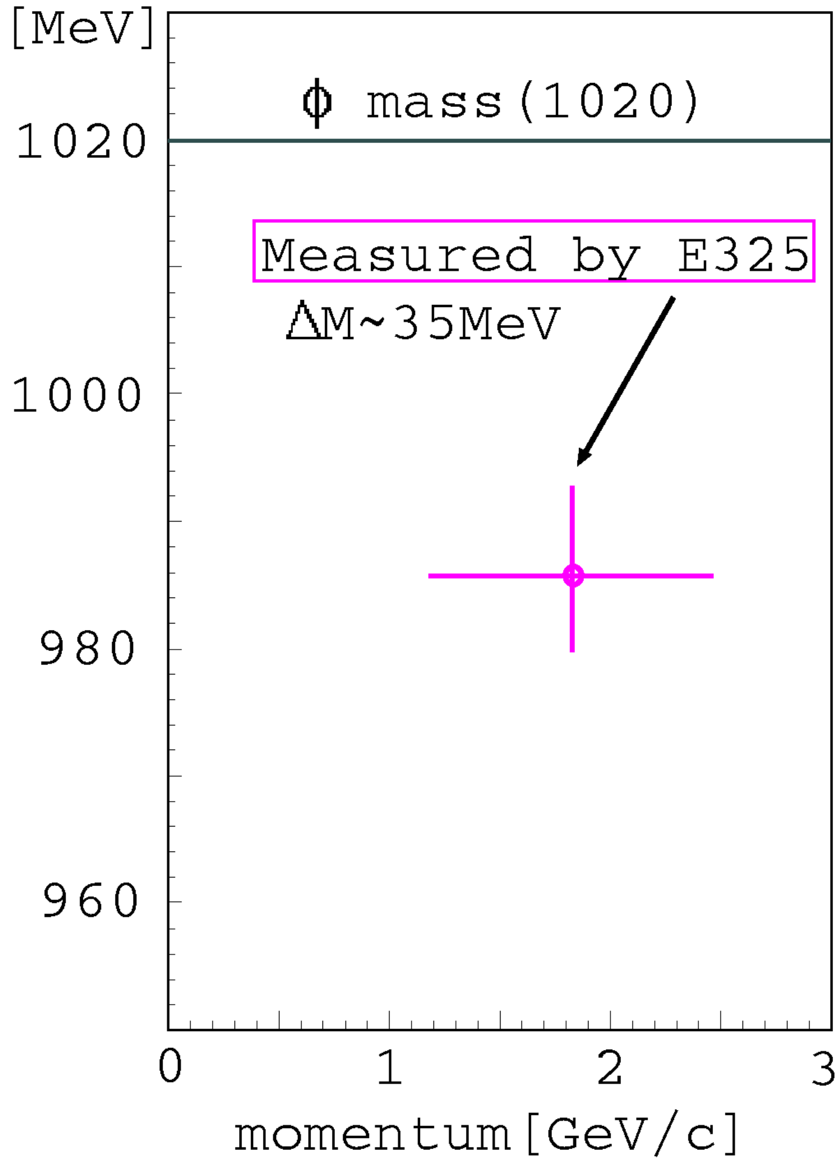

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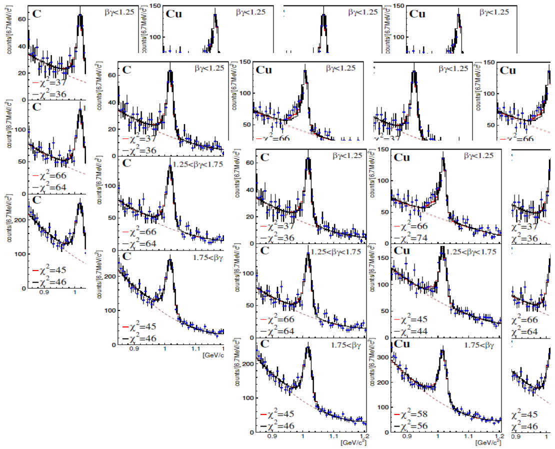
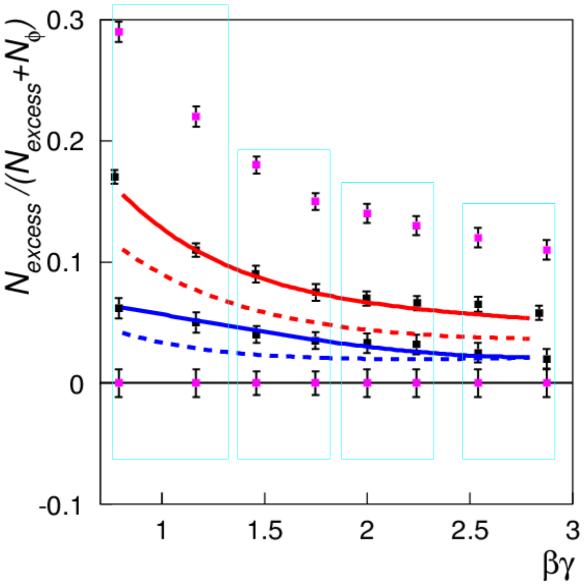
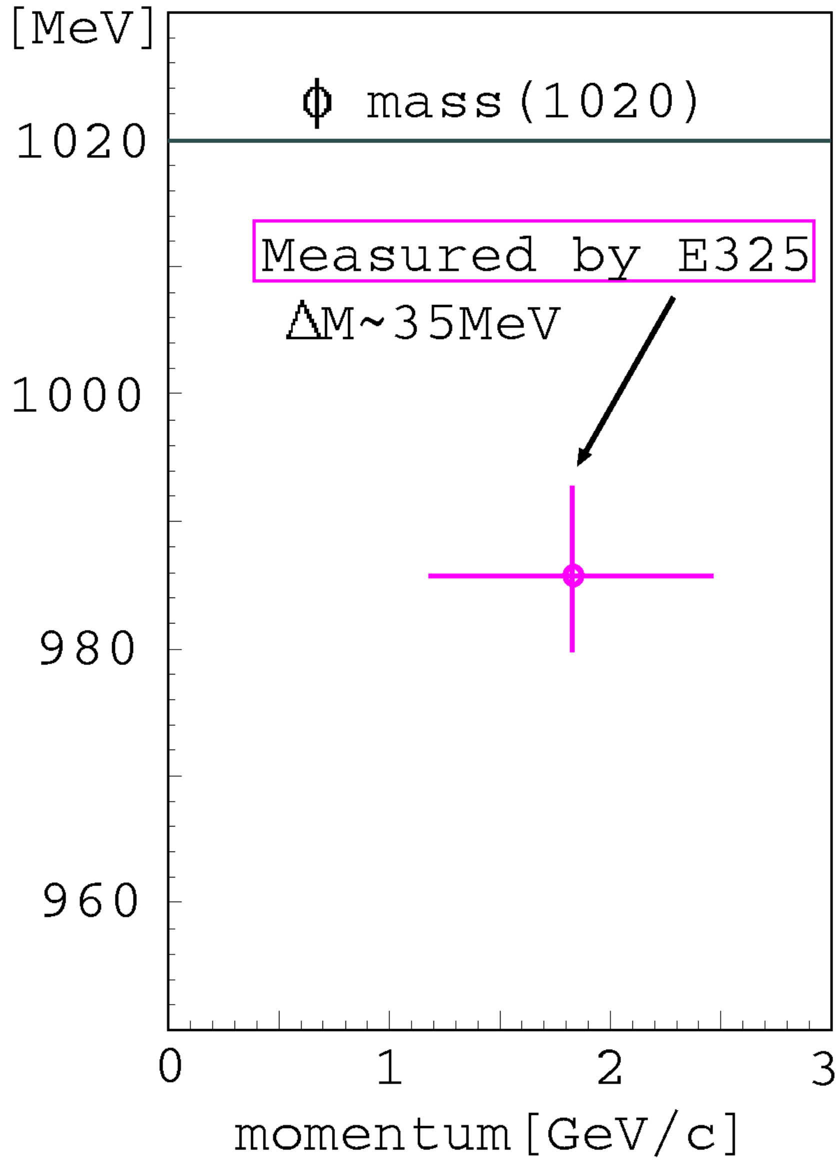
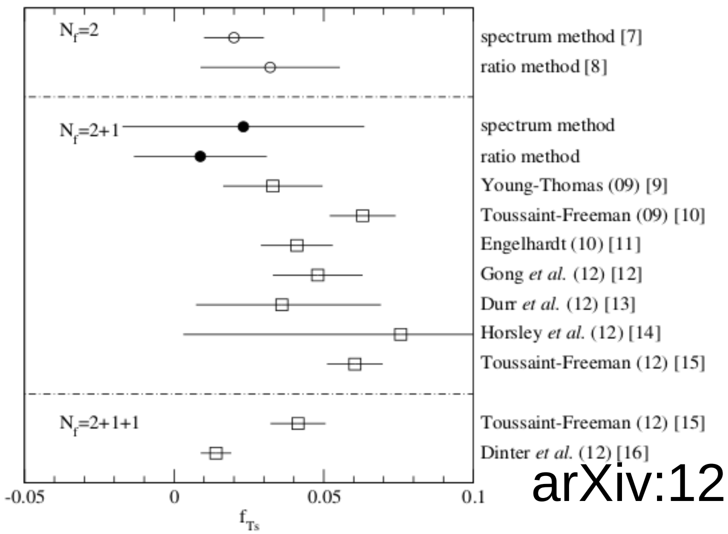






$\langle\bar{s}s\rangle$ & ϕ-meson mass

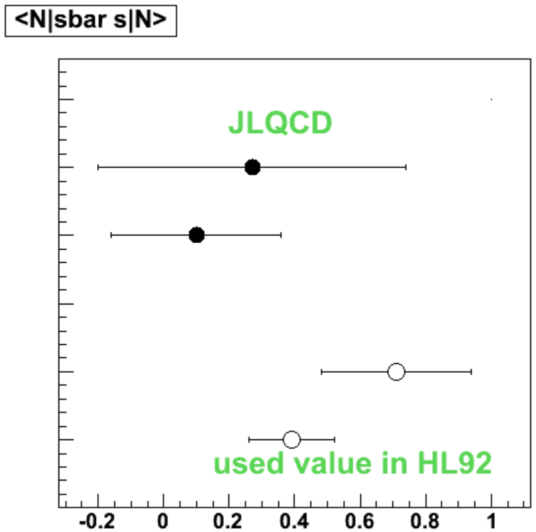
- $\langle\bar{s}s\rangle(\rho)$ ($\bar{s}s$ condensate in medium whose density is ρ) is relevant the ϕ mass in nuclear matter under the QCD sum rule analysis by Hatsuda & Lee (PRC46(92)R34 : HL92)
  - linear approx. : $\langle\bar{s}s\rangle(\rho)=\langle\bar{s}s\rangle$ (vacuum) + $\langle N|\bar{s}s|N\rangle \times \rho$
- $\langle N|\bar{s}s|N\rangle$ should be determined by experimental data
- Recently $\langle N|\bar{s}s|N\rangle$ (so called " strangeness content in nucleon") is calculated with Lattice QCD
  - found to be smaller than the assumed value in HL92, however, agree within the error : predicted value '2-4%' is not so affected



$f_{Ts} = m_s/m_N \langle N|\bar{s}s|N\rangle$

m_s=80MeV

arXiv:1208.4185



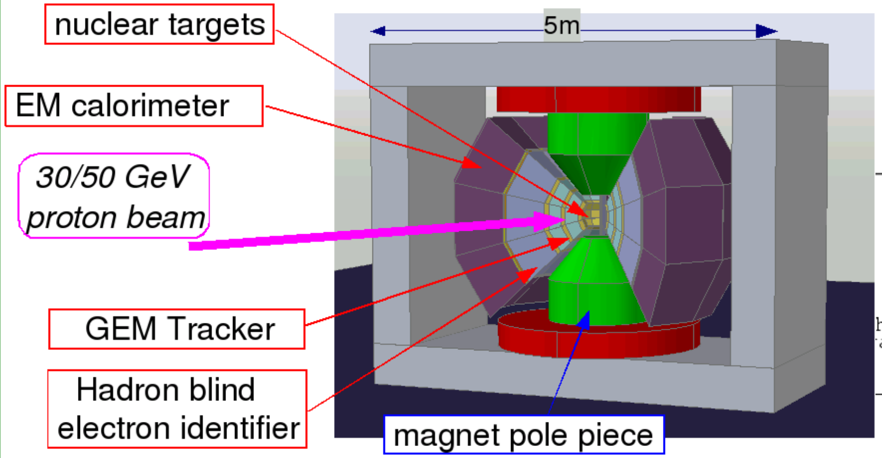
Hadron-in-medium

hi

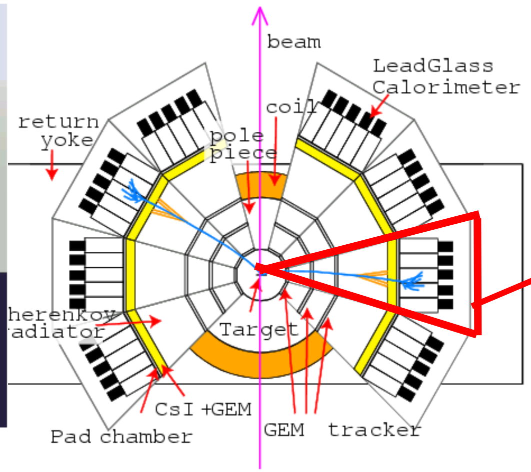
To collect high statistics

- For the statistics 100 times as large as E325, a new spectrometer and a primary beam in the High-p line are required.
  - To cover larger acceptance : x~ 5
  - Higher energy beam (12 → 30/50 GeV) : x ~2 of production
  - Higher intensity beam ($10^9 \rightarrow 10^{10}$ /spill (1sec)) : x 10 (→ 10MHz interaction on targets)
  - to cope with the high rate, new detectors (GEM Tracker & HBD) are required.

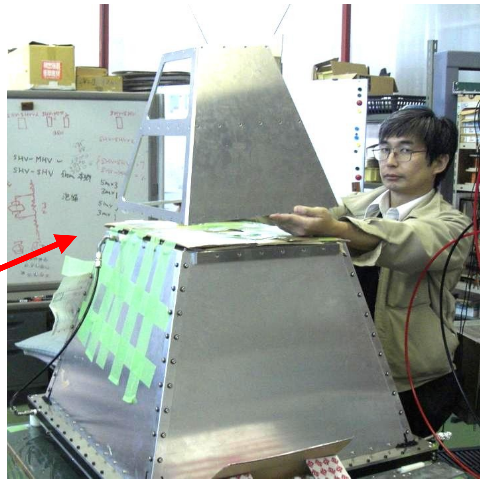
Proposed Spectrometer



Plan View

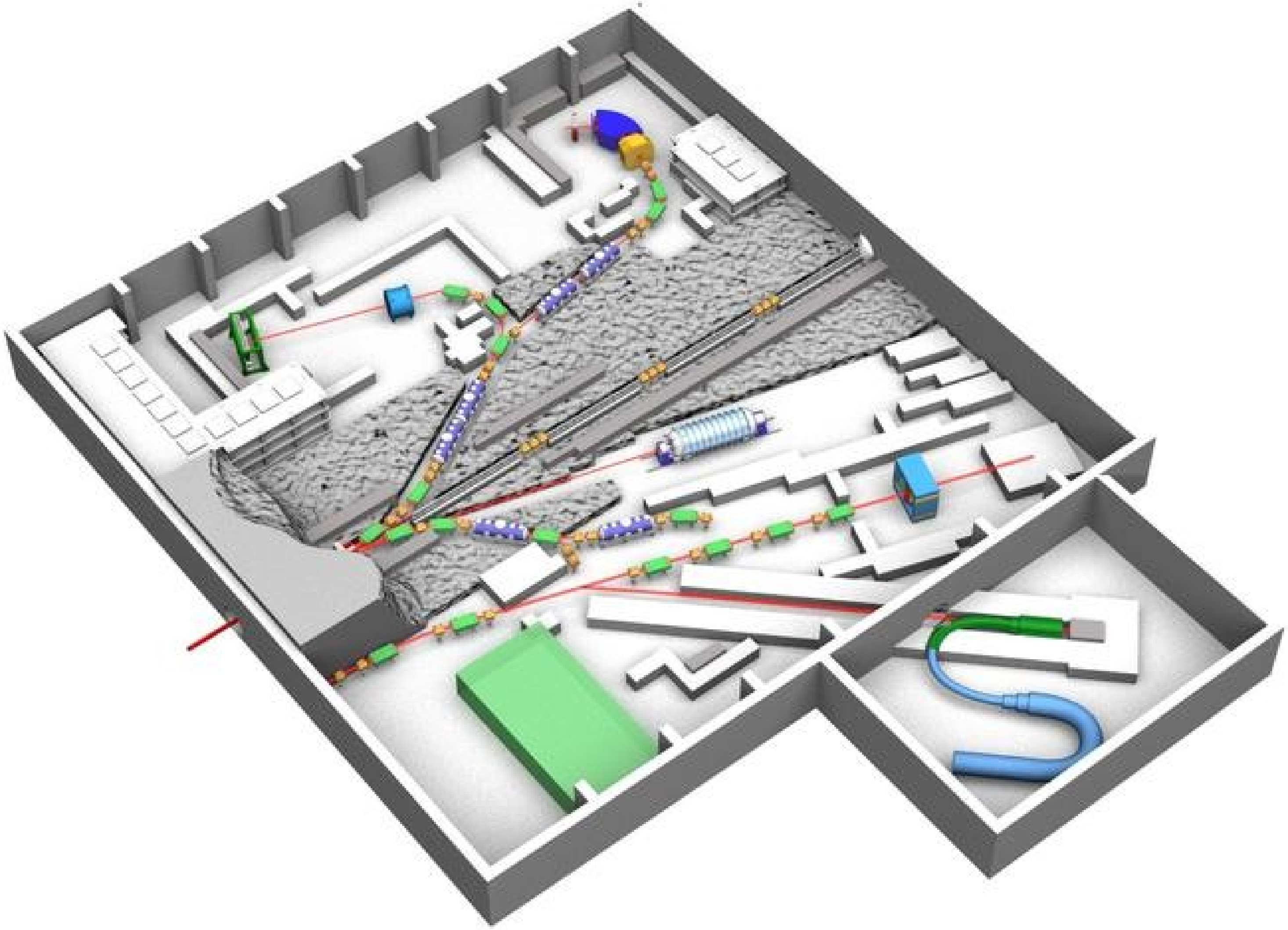


Prototype Module



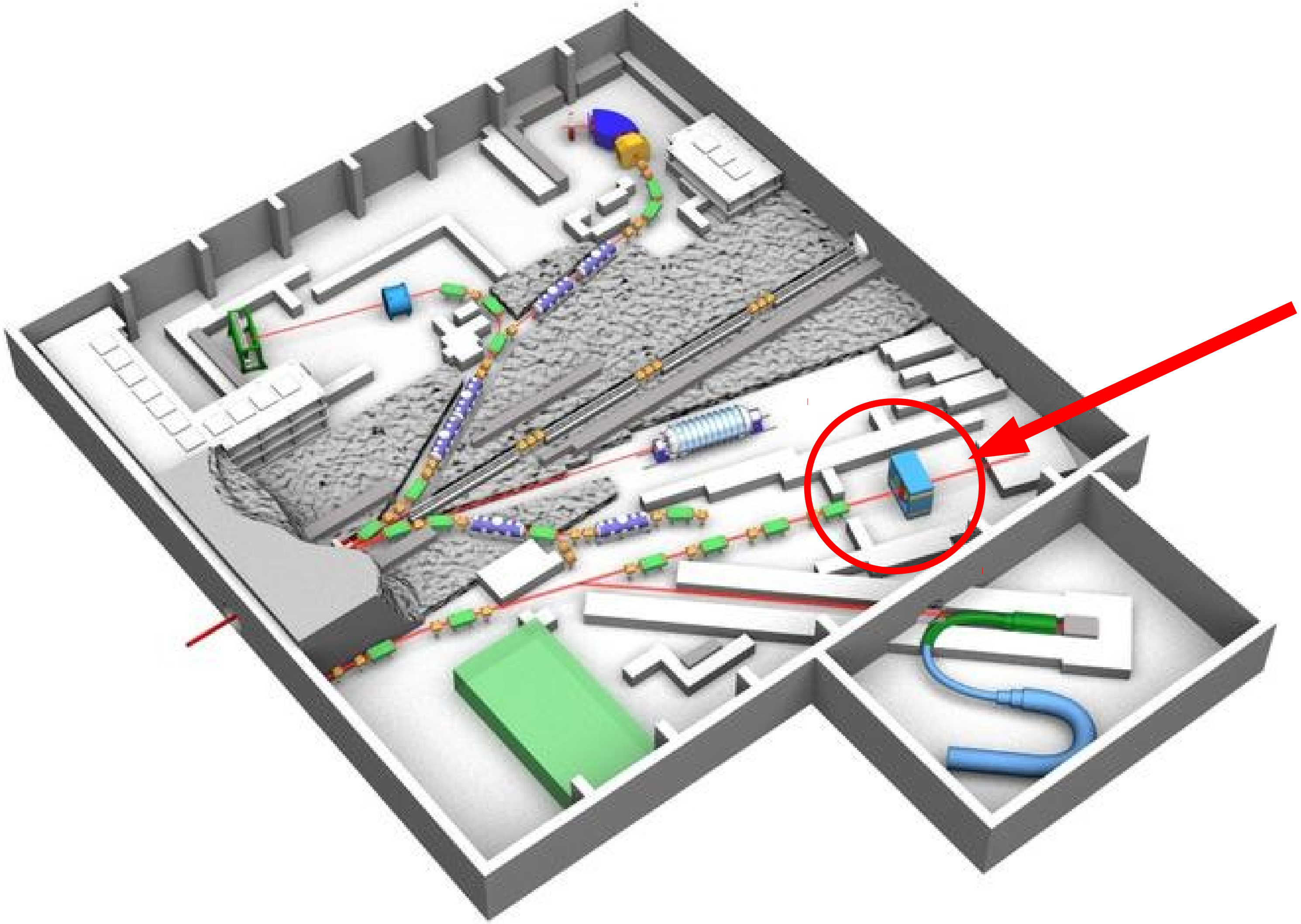
26 detector modules

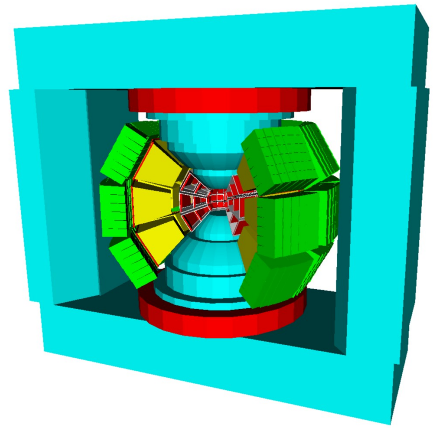
High-p line in the Hadron hall



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

High-p line in the Hadron hall





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

E16 Schedule

•2007: stage1 approval

•2008-2010 : development of prototype detectors w/ Grant-in-Aid(2007-8, 2009-13)

•JFY 2011-12 : additional parts of the spectrometer magnet , R/O circuit development

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

– 1st test type preamp for GT

  • tests @ J-PARC K1.1BR

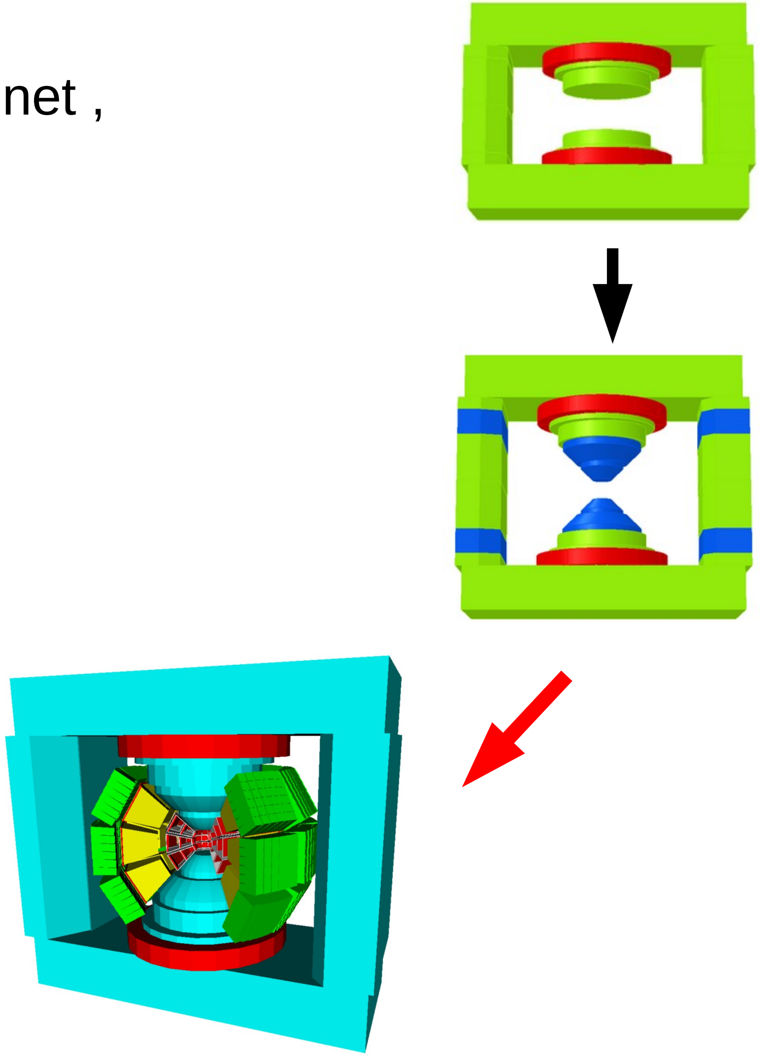
• JFY 2013 : start the production of the detectors/circuits

• JFY 2014/4Q : magnet reconstruction

  • start the detector install

•JFY 2015/4Q : ready for the first beam

– staged goal of the spectrometer construction (w/ 8 detector modules)



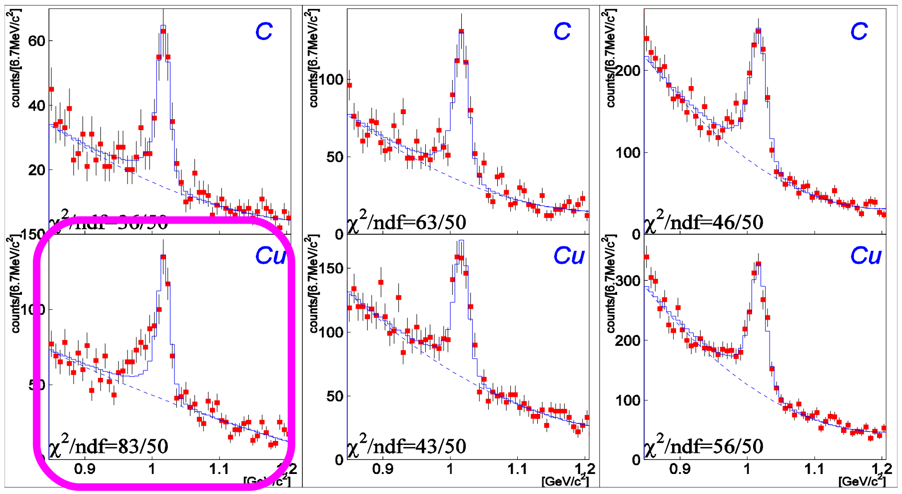
J-PARC E16 experiment

- Measure the vector-meson mass modification in nuclei systematically with the e^+e^- invariant mass spectrum

- A 30 GeV primary proton beam (10^{10}/spill) / 5 weeks of physics run to collect ~10^5 $\phi \rightarrow e^+e^-$ for each target

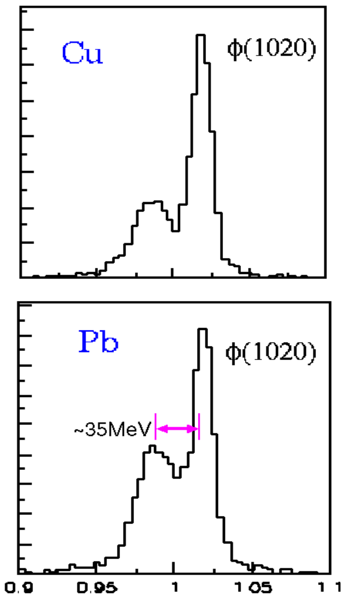
- confirm the E325 results, and provide new information as the matter size/momentum dependence of modification

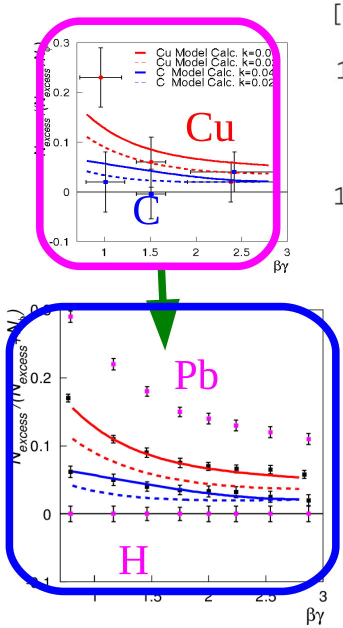
Precedent exp.(KEK-PS E325)

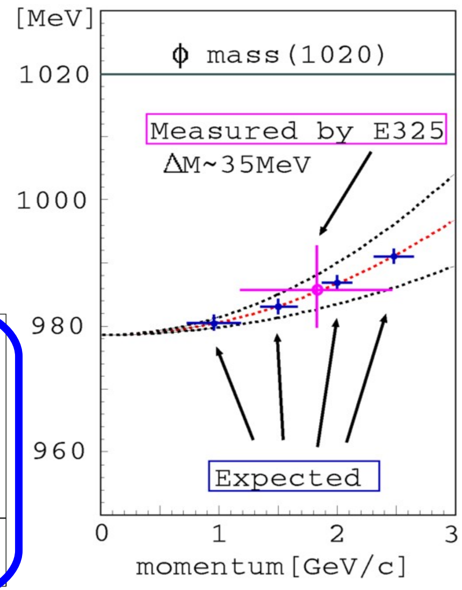


ϕ–mass is modified in large nuclei for slowly moving mesons... consistent with the prediction based on the QCD sum rule

Proposed exp. E16



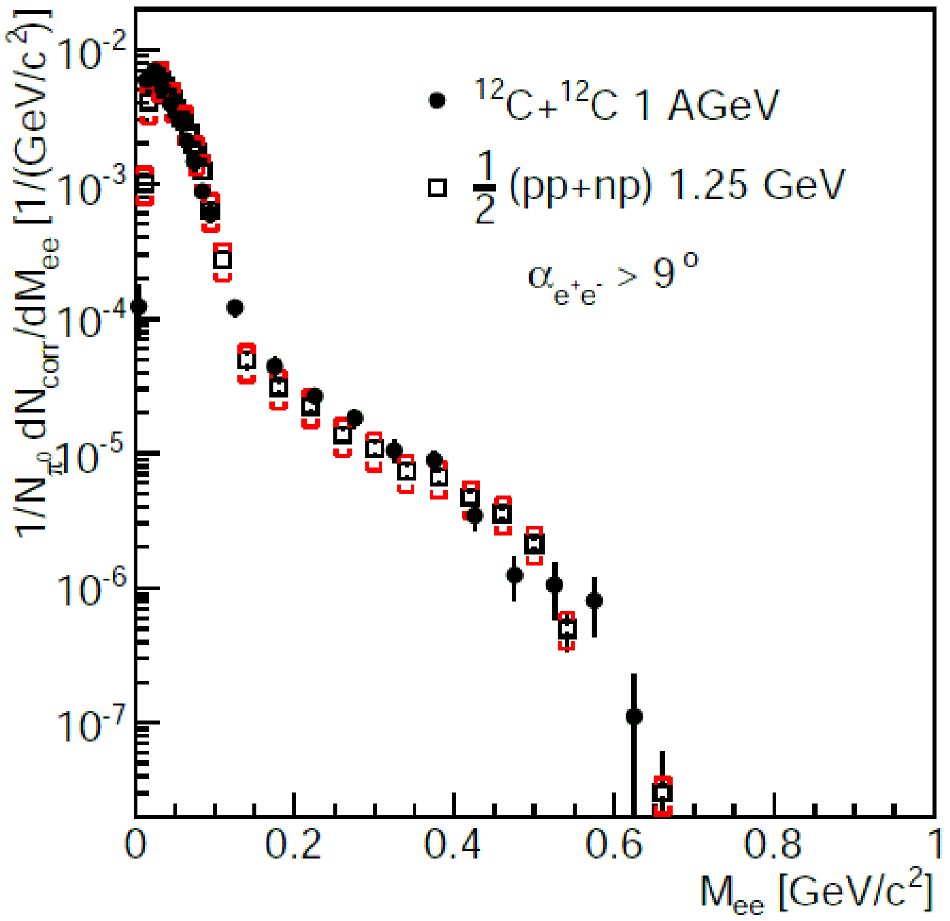


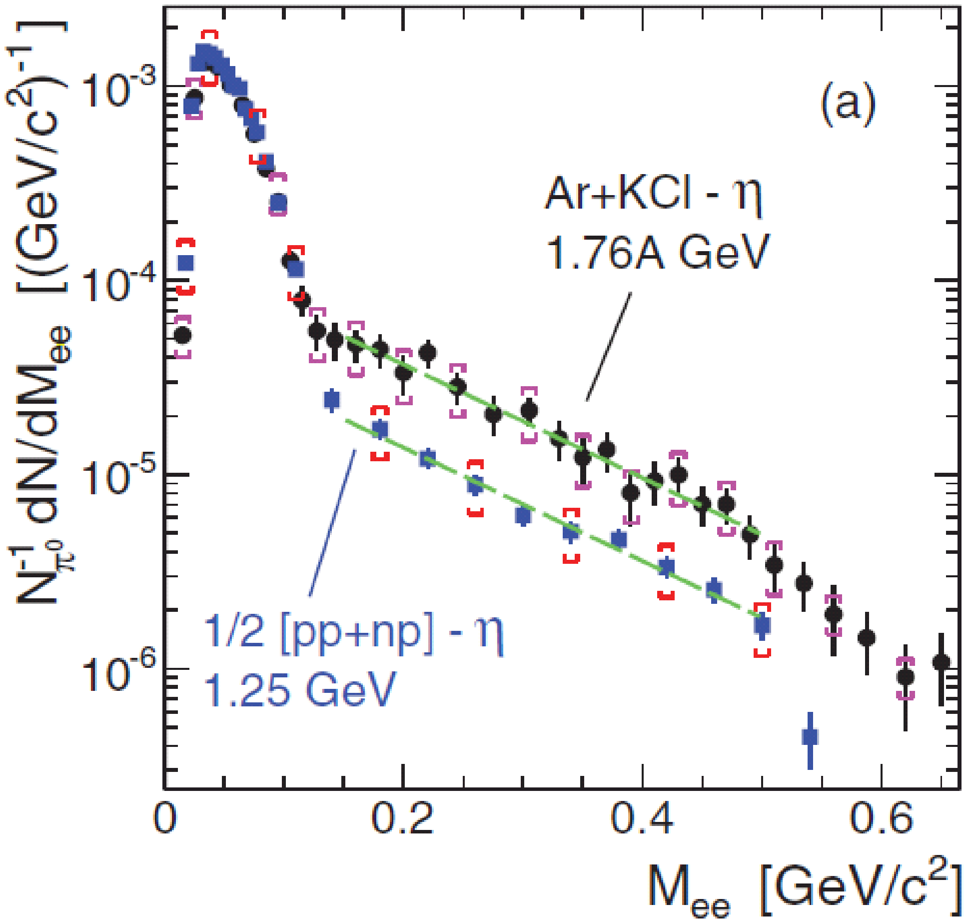


Nuclear matter size dependence & *Momentum dependence*
of mass modification are measured

HADES

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

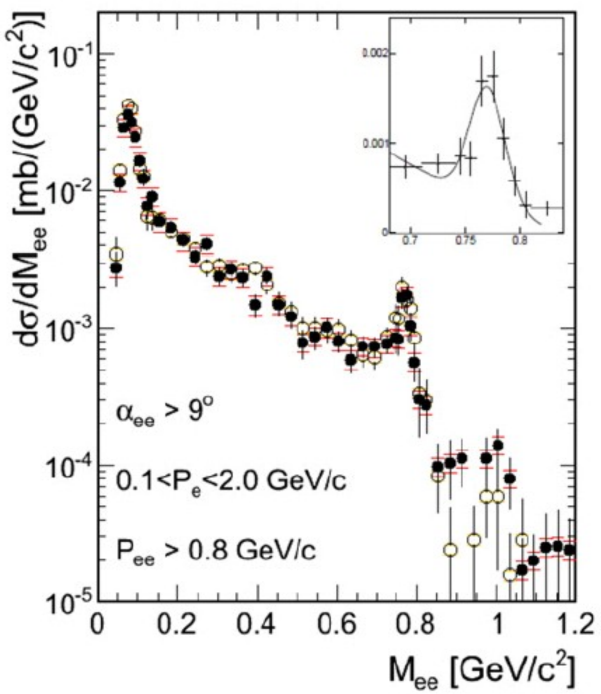




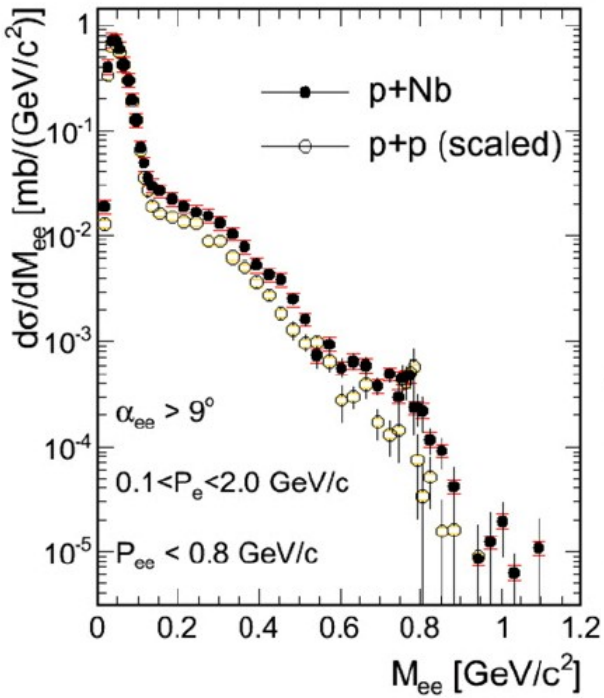
hi

HADES 3.5GeV/c pp and pNb

[PLB715(2012)304]

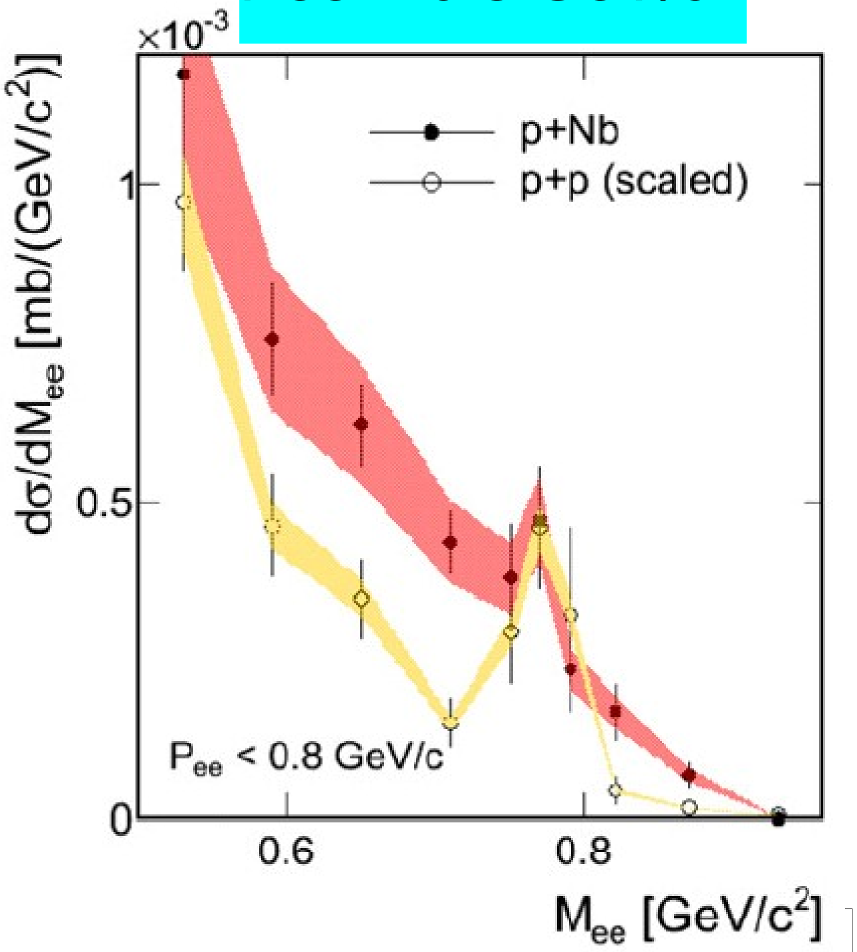


Fast :
Pee > 0.8 GeV/c



Slow:
Pee < 0.8 GeV/c

(zoomed)
Slow:
Pee < 0.8 GeV/c

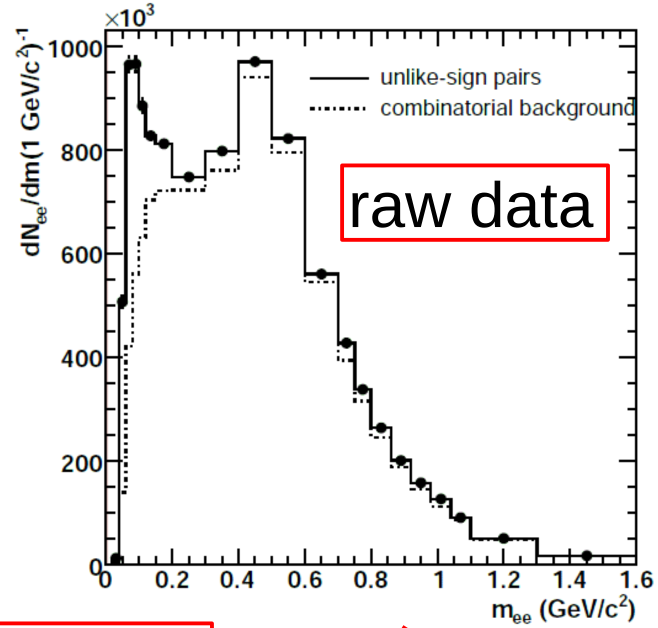


- Excess in the slow component in the p+Nb data
- ρ enhancement by secondary π & ω suppression?

Hadrc

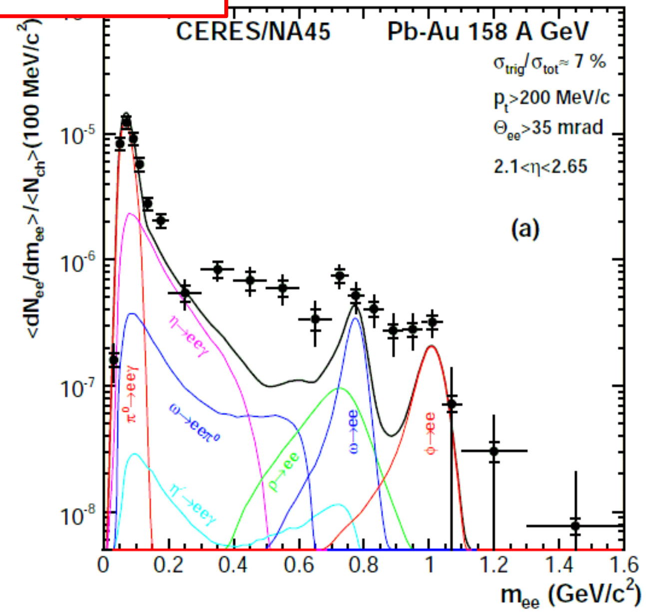
Vector meson measurements in Heavy Ion Collision

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

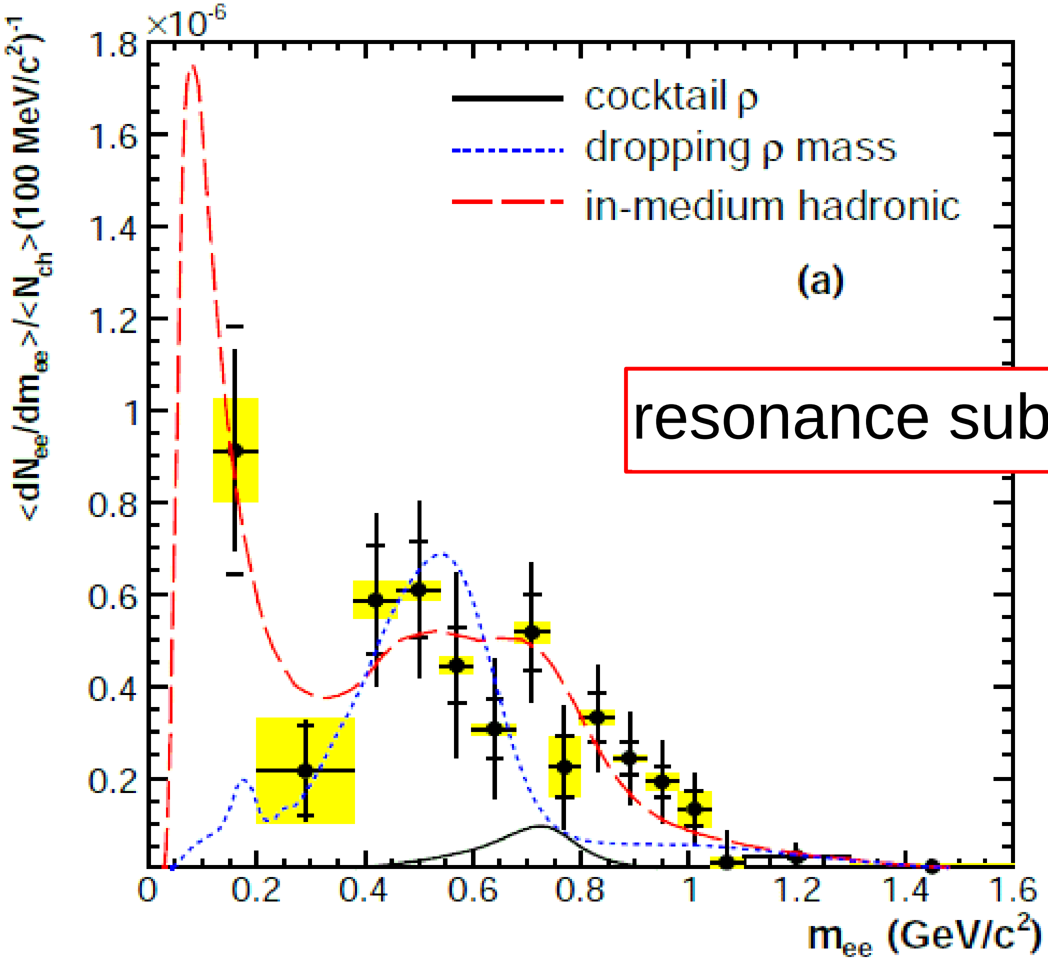


raw data

bkg subtracted



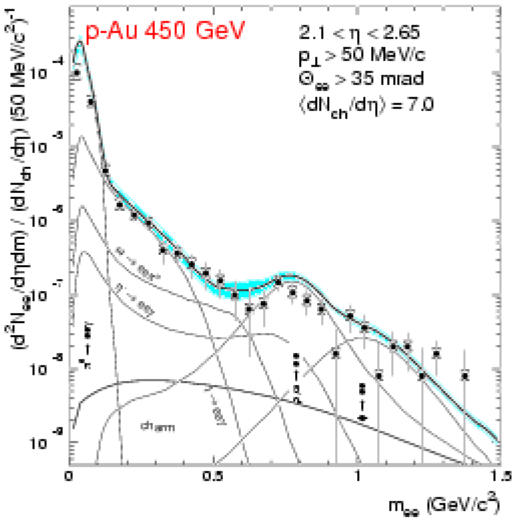
resonance subtracted

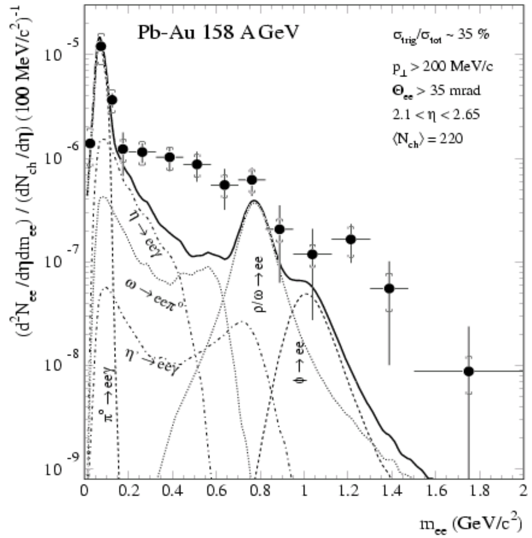


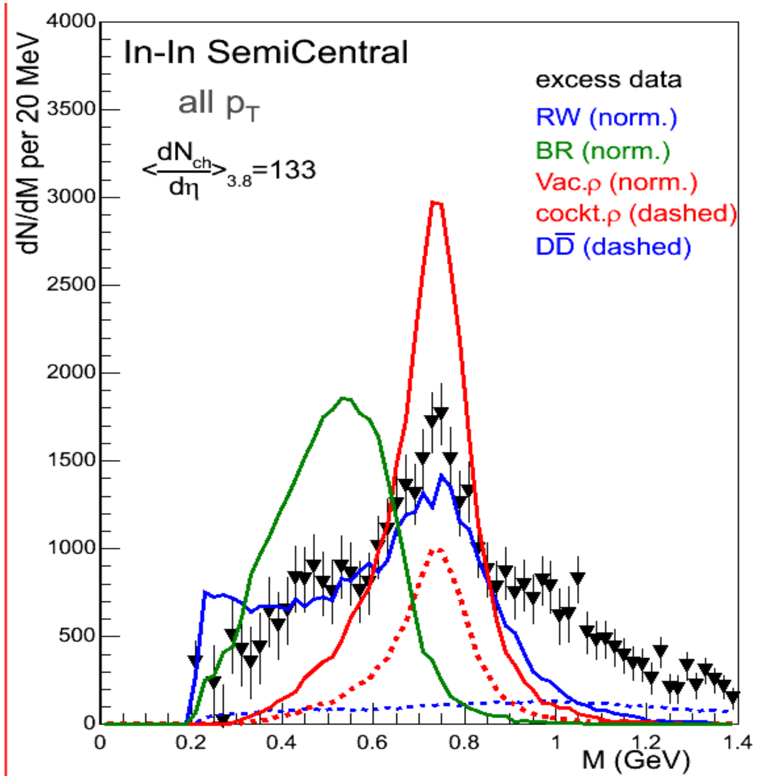
Vector meson measurements in HIC

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

bkg subtracted



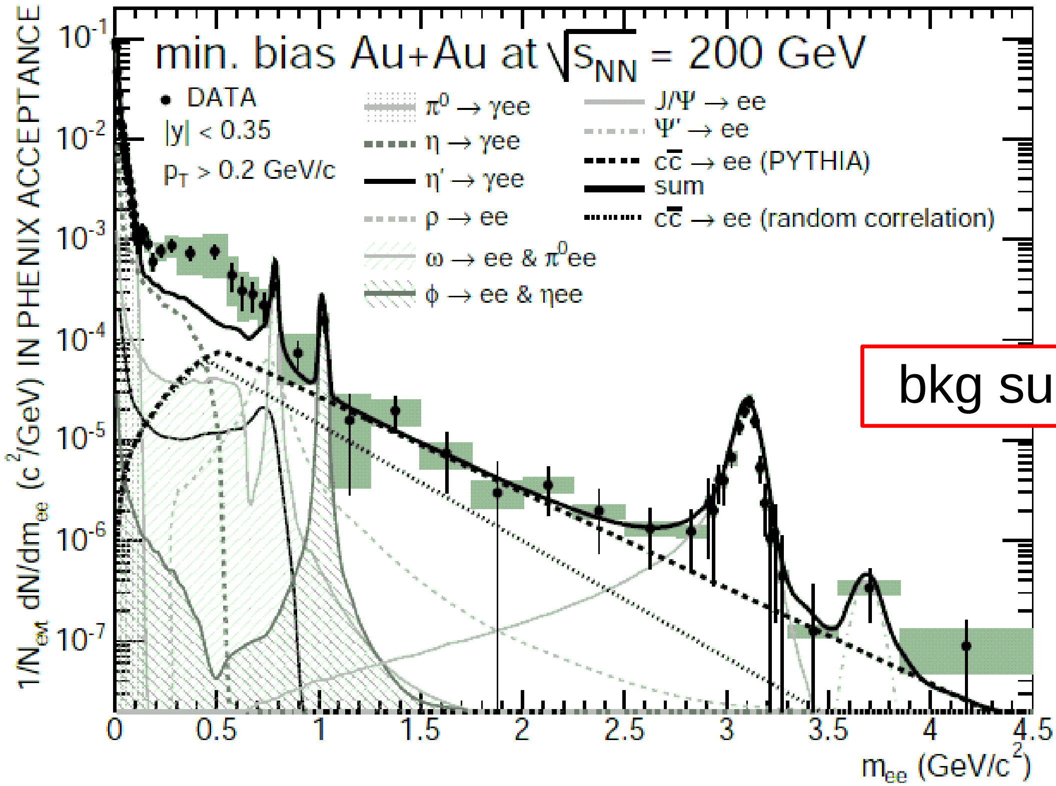




bkg & resonance subtracted

Vector meson measurements in Heavy Ion Collision

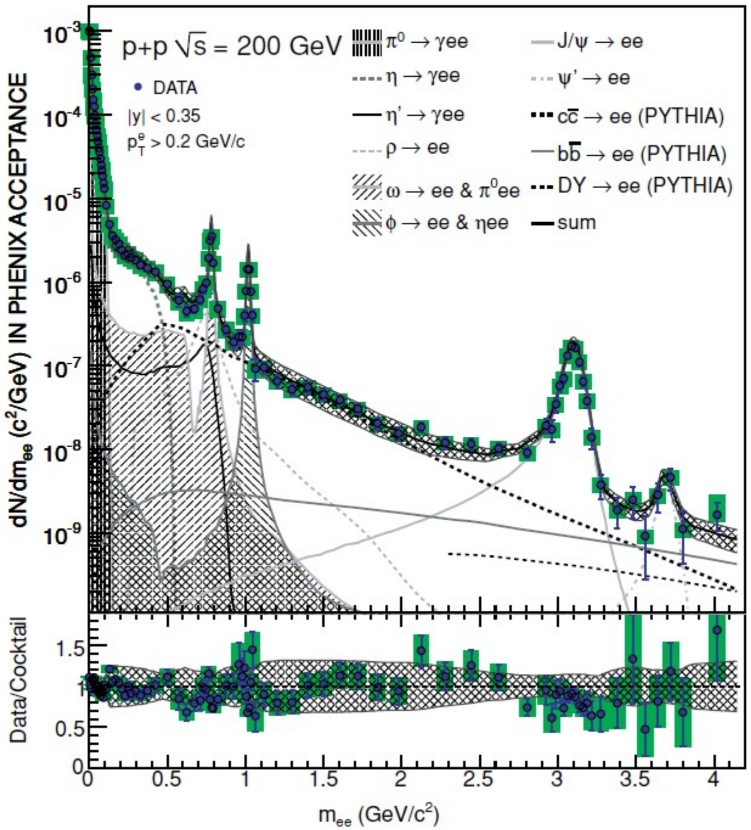
- PHENIX ：[arXiv:0706.3034v1,PRC81(2010) 034911]
  - 200GeV /u Au+Au → e^+e^-
  - enhancement below ω
  - cannot reproduced by any model at low pT
  - at high pT, thermal photons reproduce

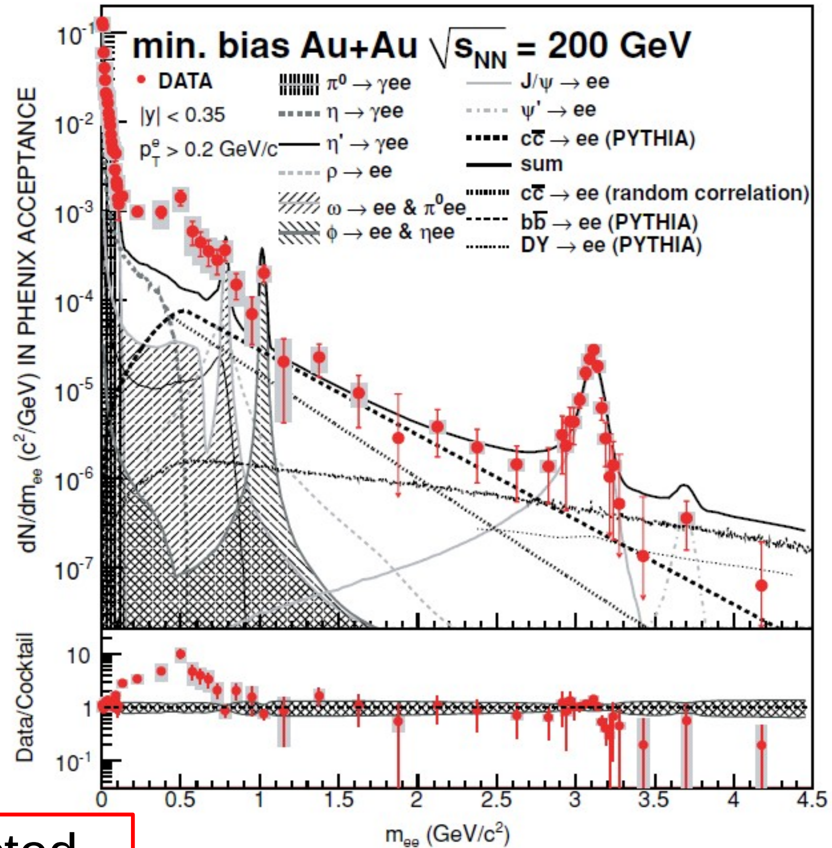


bkg subtracted

Vector meson measurements in Heavy Ion Collision

- PHENIX ： [arXiv:0706.3034v1,PRC81(2010) 034911]
  - 200GeV /u Au+Au → e^+e^-
  - enhancement below ω
  - cannot reproduced by any model at low pT(<1GeV/c)
  - at high pT, thermal photons reproduce

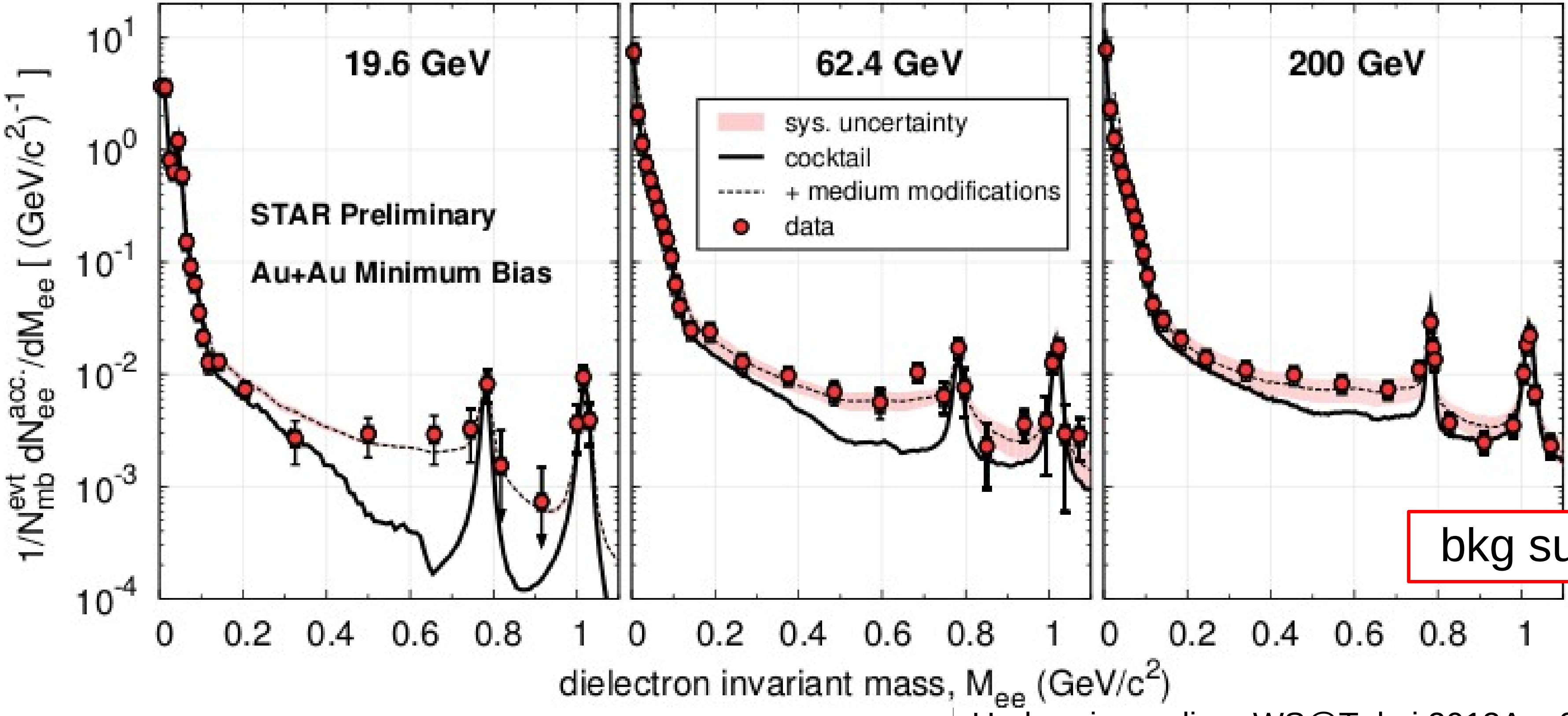




bkg subtracted

Vector meson measurements in Heavy Ion Collision

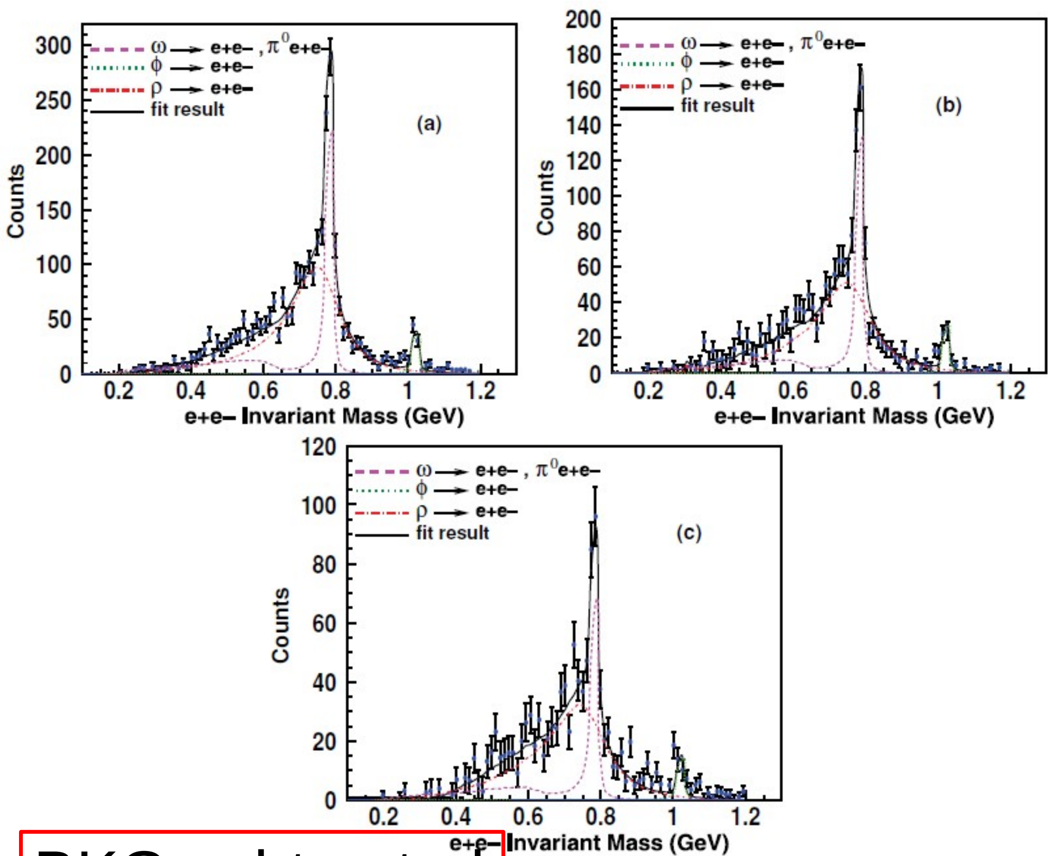
- STAR (preliminary): [arXiv:1305.5447v1,1208.3437,etc]
  - 200GeV /u (& 62.4, 39.0,19.6 GeV/u) Au+Au → e^+e^-
  - enhancement below ω
  - “discrepancy between the PHENIX data" ...acceptance?
  - some models (like for NA60) reproducethe data

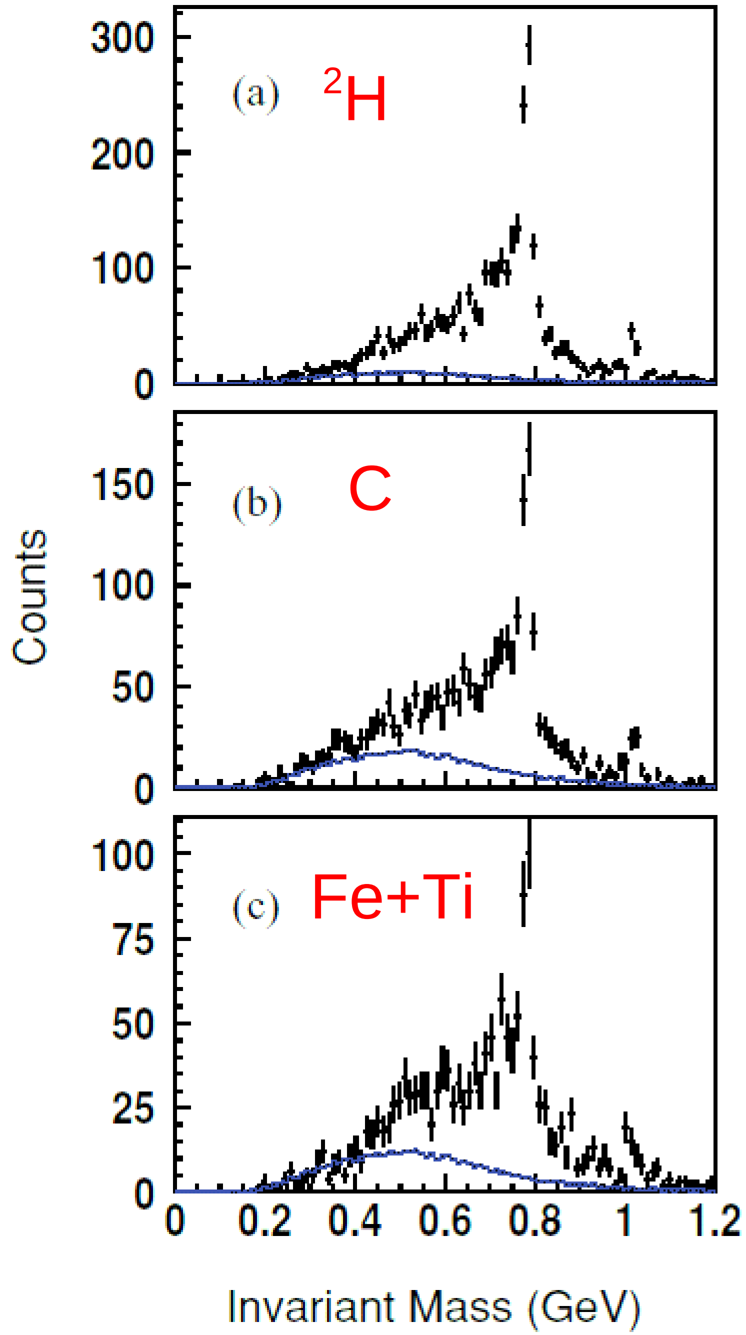


bkg subtracted

CLAS-G7(PRC78(2008)015201)

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



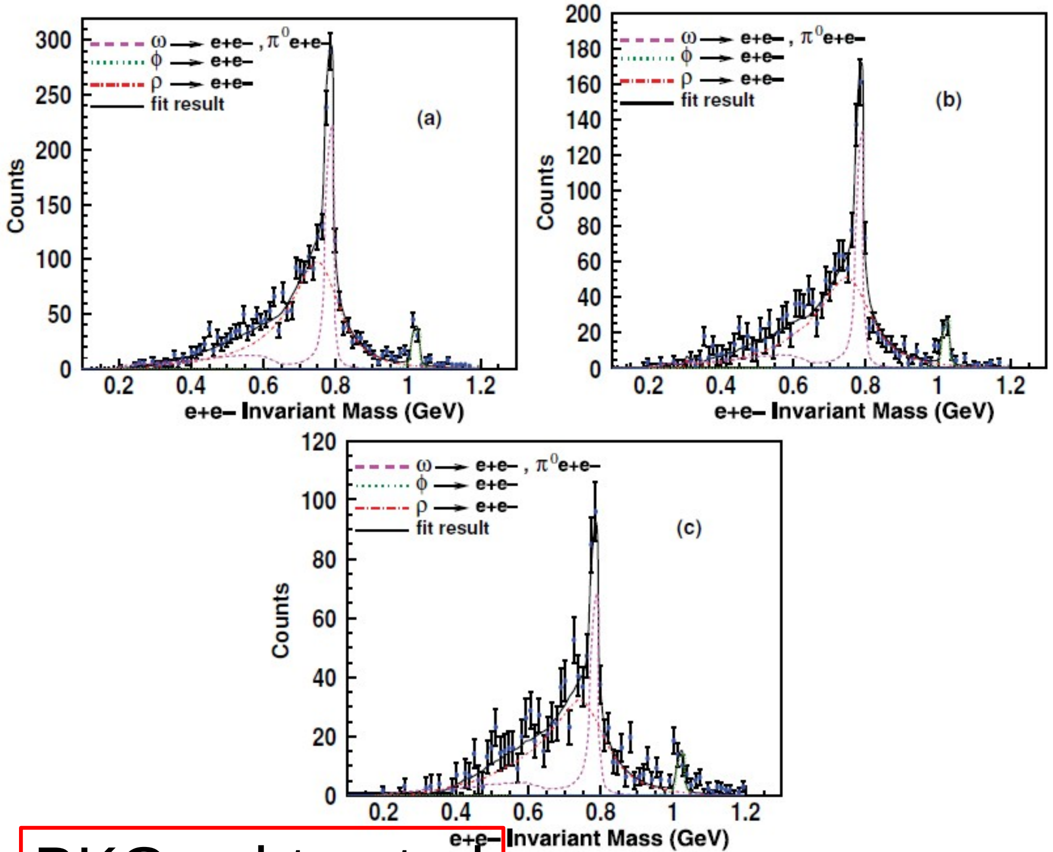


BKG subtracted

PRC78(2008)015201

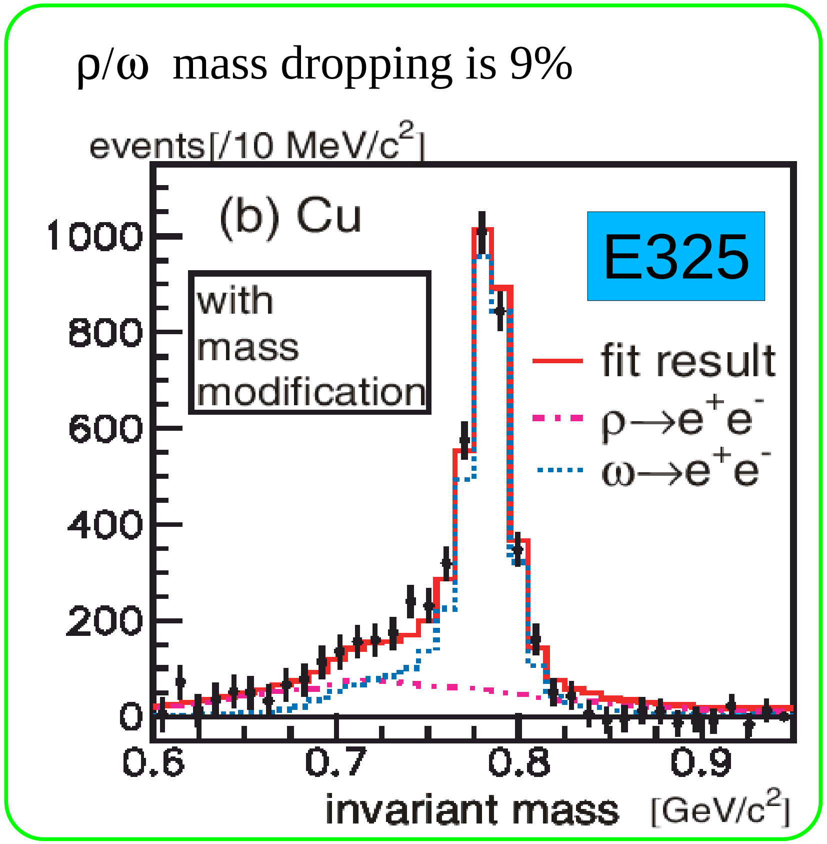
CLAS-G7(PRC78(2008)015201)

- γ+A → V → 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



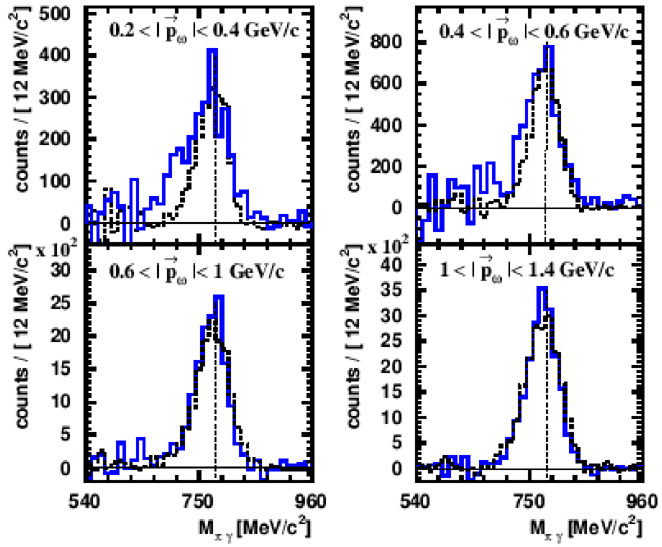
BKG subtracted

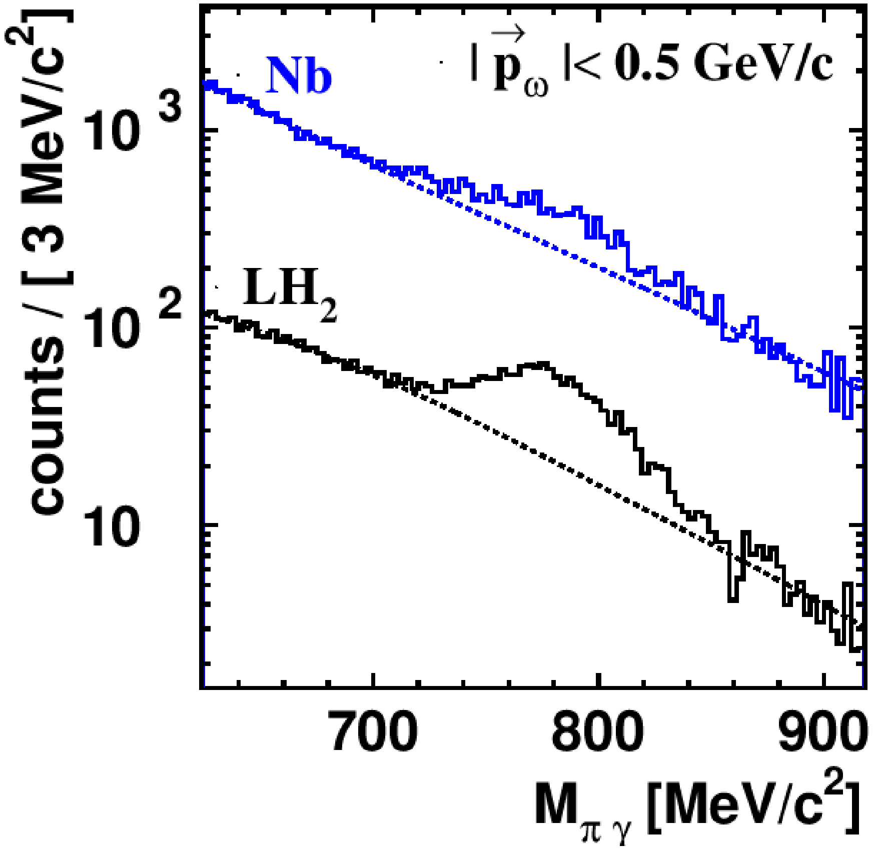
PRC78(2008)015201

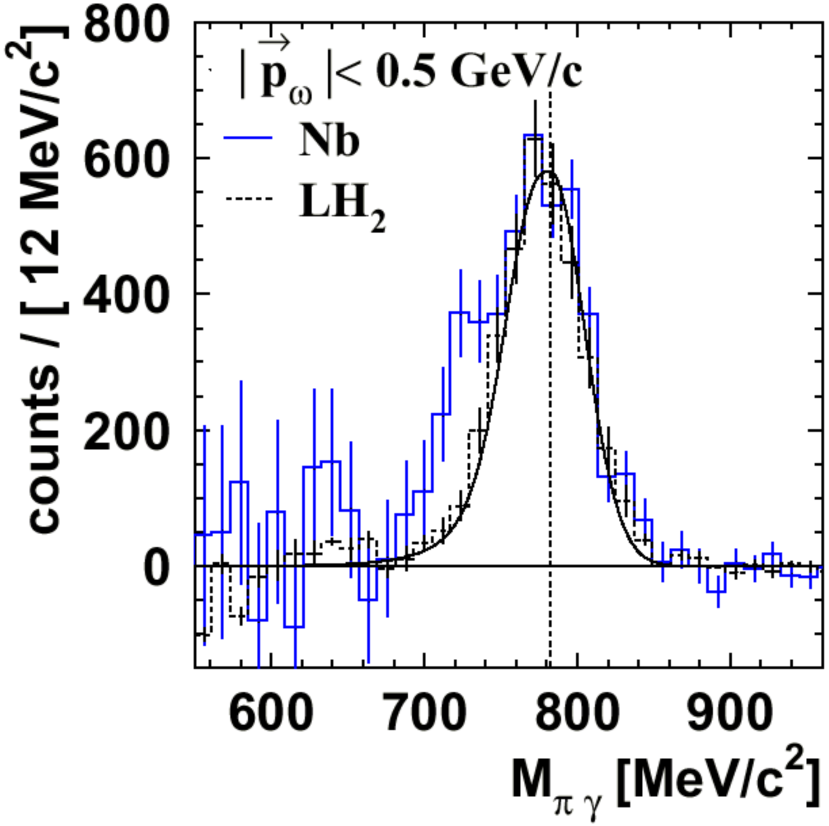


CBELSA/TAPS (PRL94(05)192303)

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



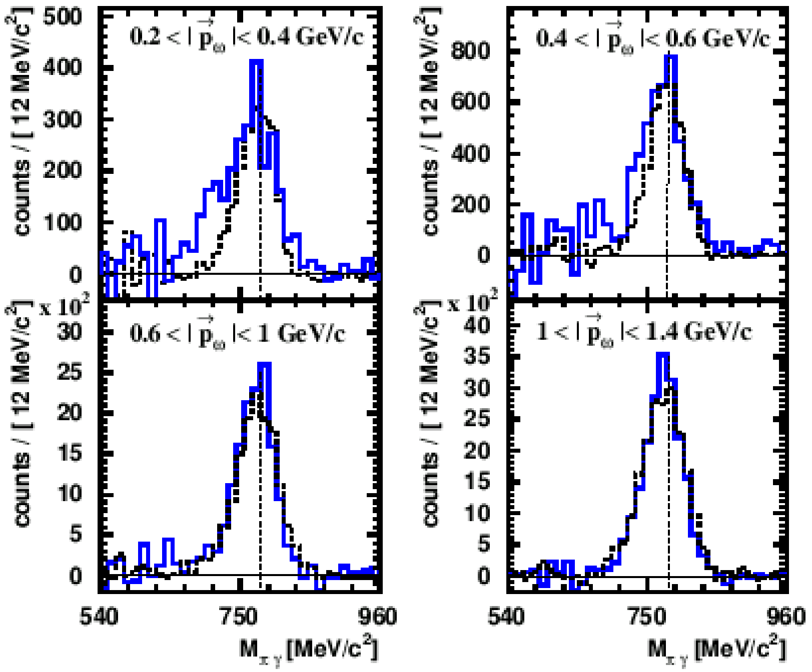


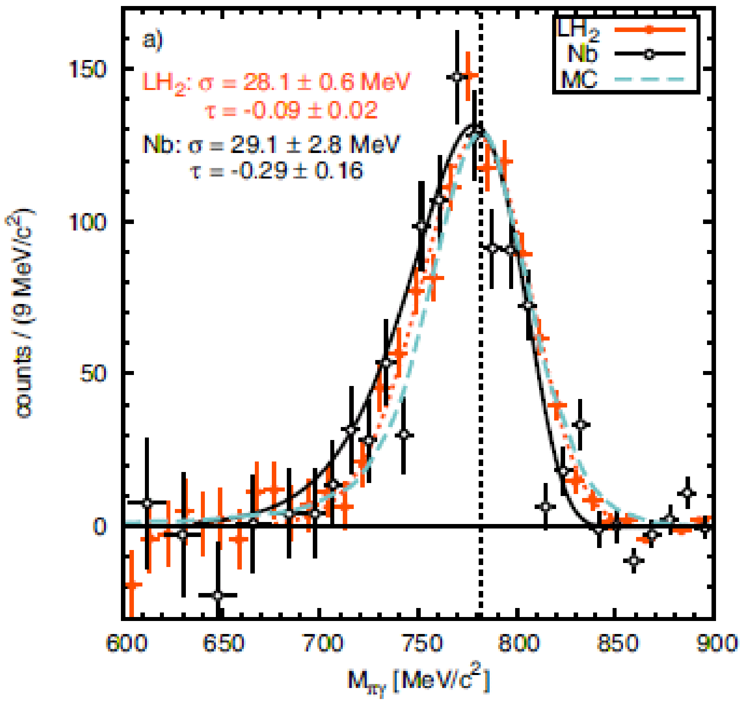


CBELSA/TAPS

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

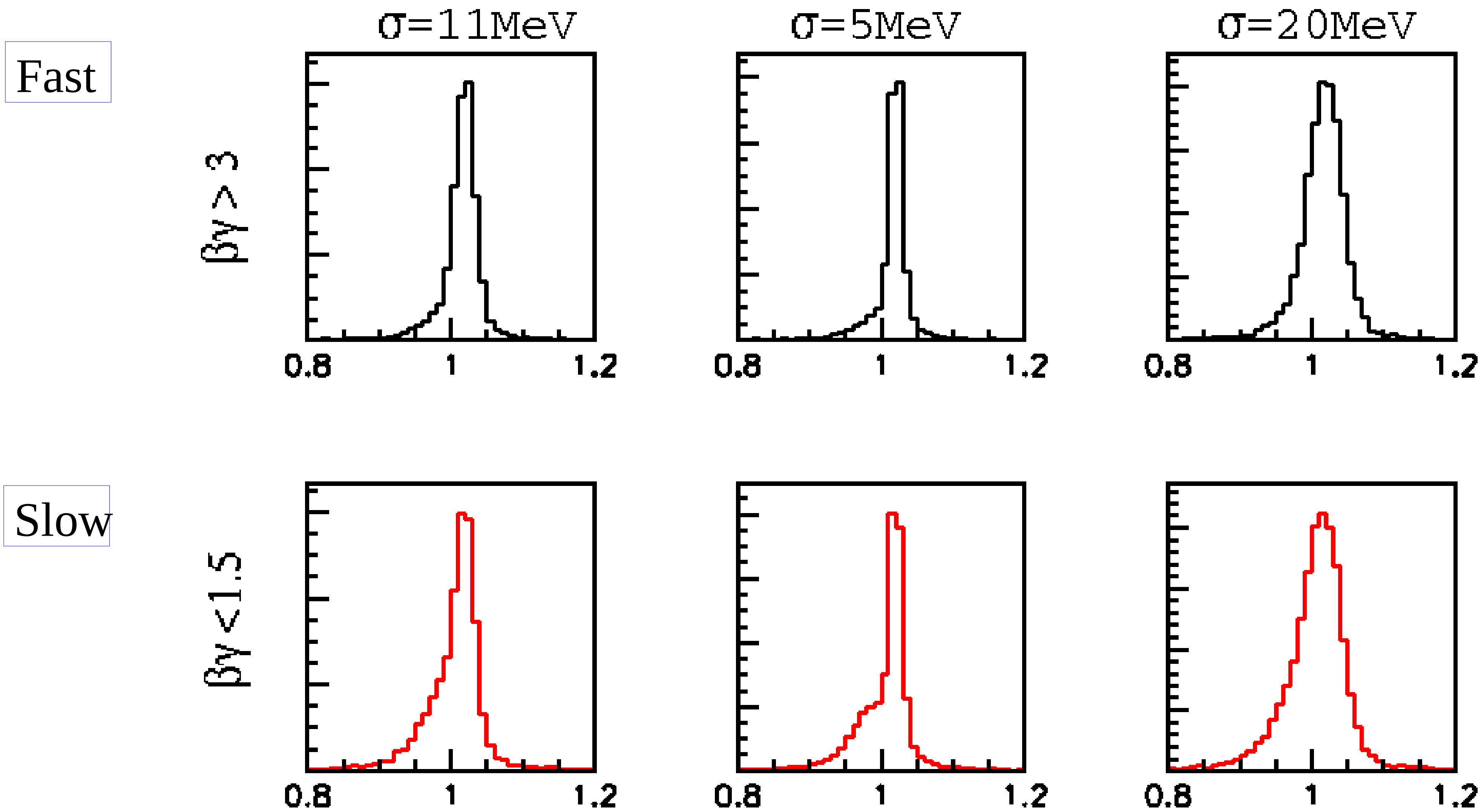
-
- excess is not reproduced significantly by the following experiment [EPJA47(11)16]





mass resolution requirement

- mass resolution should be kept less than ~10MeV



(model calc. for the Cu target, k_2=10)

target thickness optimization

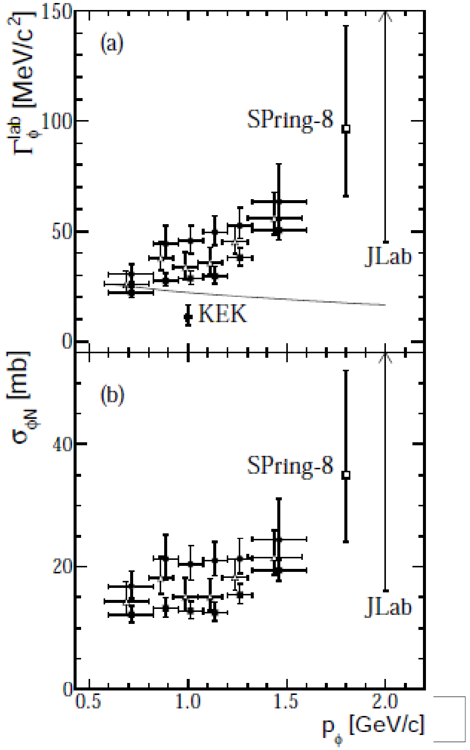
- γ-conversion in the target materials : trigger background
  - when 100 of π^0 are produced,
    - 1.2 ee pair from the Dalitz decay
    - [200 x target-X_0] ee pair from the $\pi^0 \rightarrow 2\gamma$ decay
  - Thus, comparable point is target-X_0 = 0.5%
- radiative tail (bremsstrahlung) for the electron tracks
  - Material budget is ~1% in the tracking detectors except the target.
-
- thin target is compensated using the higher intensity beam
  - interaction rate at the target can be conserved
  - beam halo is scaled to the intensity
    - halo rate is assumed as same as E325 : KEK-PS EP1B beamline
      - ~1-3k /mm^2 at 10cm from the beam axis for 1.6 x10^{10} protons

Note: shape and its nuclear matter size / momentum dependence

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

width broadening by absorption

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

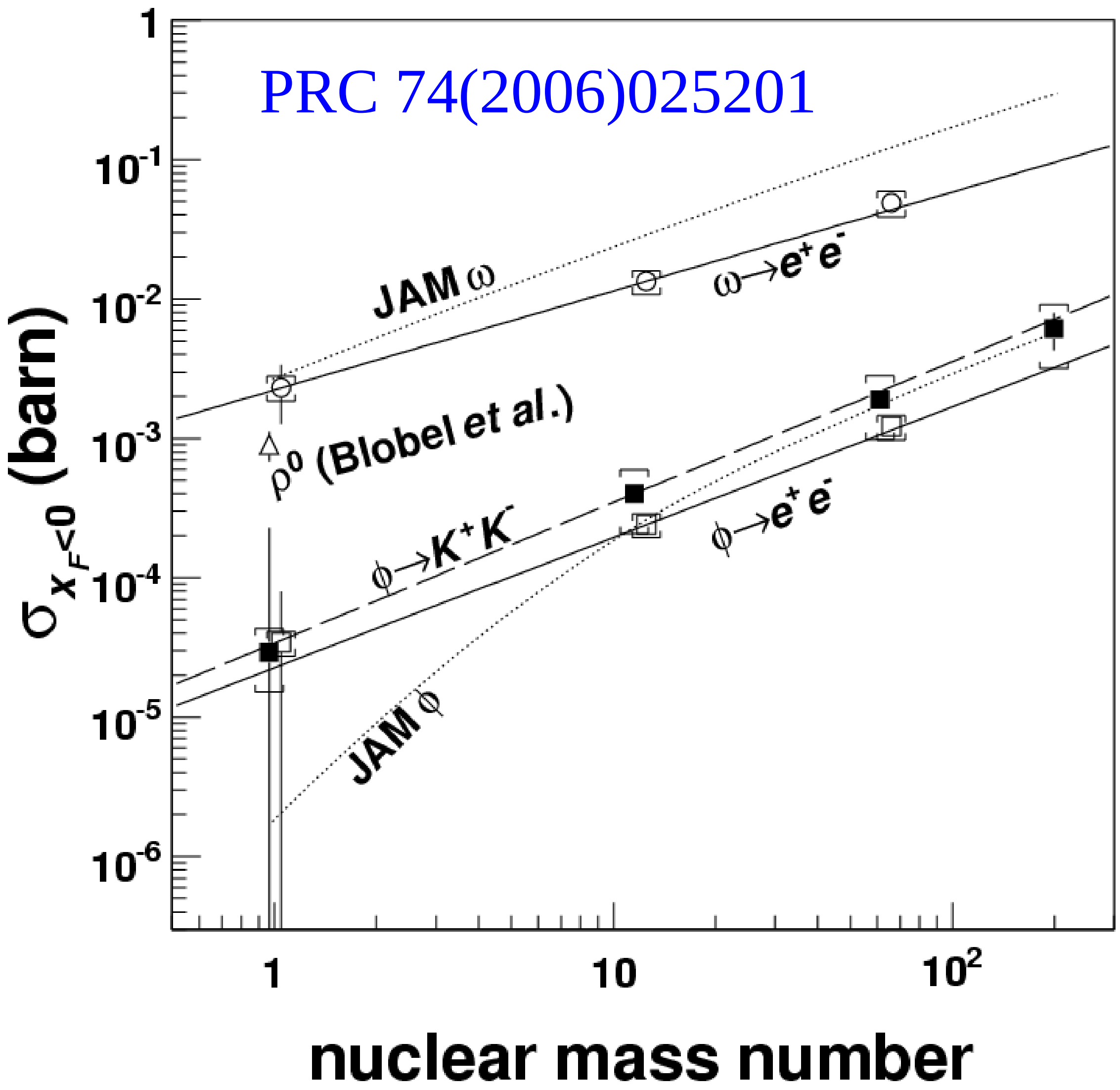


E325 A-dependence of the meson production cross sections

- values for the CM backward
- consistent w/ the former measurement for ρ meson by Blobel (PLB48(1974)73)
- Nuclear dependence α_ϕ = 0.937 corresponds to about $\sigma_{\phi N}$=3.7mb (cf. Sibirtsev et.al. EPJA 37(2008)287)

  additional Γ=12 MeV for 2 GeV/c ϕ (β=0.9) : consistent with Γ=15 MeV (i.e. k_2=2.6)
- Remark:

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



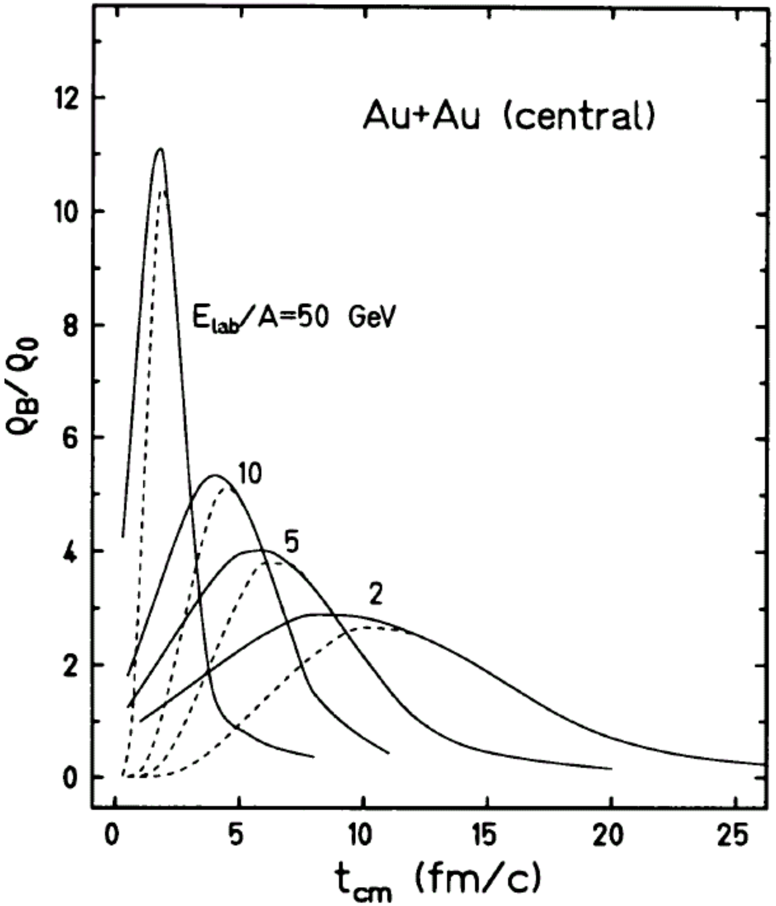
width broadening

- width broadening due to the nuclear interaction
  - absorption by nucleon : ϕ + N $\rightarrow$ X+Y
    - Γ_ϕ ($= \Gamma_{abs}$ (only in medium) + $\Gamma_{\phi\rightarrow KK} + \Gamma_{\phi\rightarrow ee}$ + ...) changes
      - additional 24MeV in near QGP (Smith and Haglin, PRC57(2001)1449)
  - Kaon mass modification : phase space changes
    - $\phi \rightarrow$ KK probability ($\Gamma_{\phi\rightarrow KK}$) changes
  - $\phi \rightarrow$ ee probability ($\Gamma_{\phi\rightarrow ee}$) could be modified through the wave function change
    - van Royen-Weisskopf formula $\Gamma_{V\rightarrow e^+e^-} = \frac{16\pi^2\alpha^2}{M^2}|\psi(x=0)|^2$
- fake width broadening in mass spectra
  - momentum dependence of mass : projection to invariant mass spectrum

density & chiral condensate in HIC

Which is suitable (interesting) energy for the search of anomaly,

between AGS and SPS?
[density]



(Friman et.al., EPJA 3(1998)165)

between SIS and AGS ?
[chiral condensate]

where $\langle \bar{q}q \rangle / \langle \bar{q}q \rangle_0$ is smaller than r