# Experimental studies on medium modification of vector mesons

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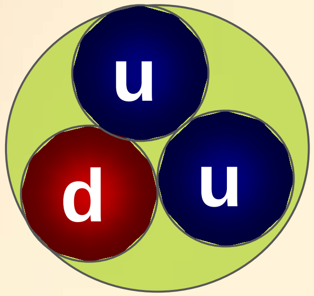
J-PARC hadron physics, 2014/2/11

# Contents

# Hadron Mass

***QCD Vaccum***




hadrons ***~GeV/c²***

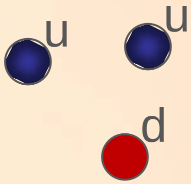
constituent quarks ***~300MeV/c²***

***Spontaneous Breaking of***

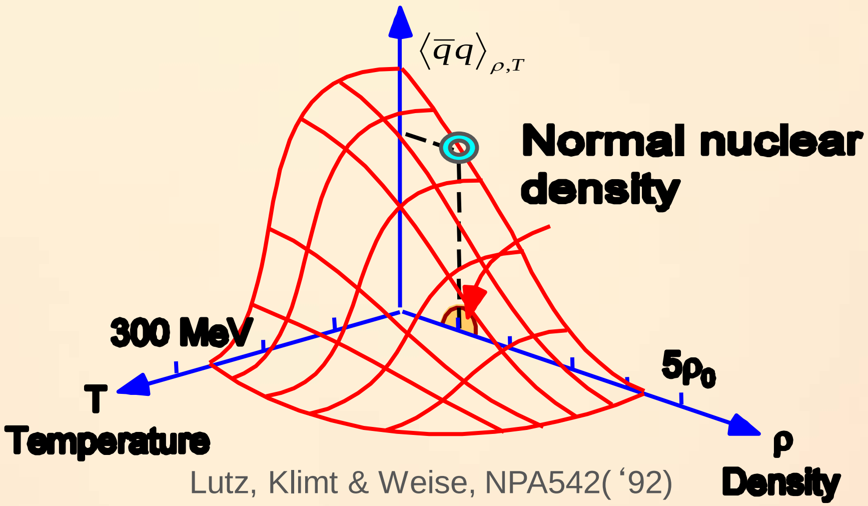
***Chiral Symmetry***

***Restoration***

***Hot/Dense Matter***

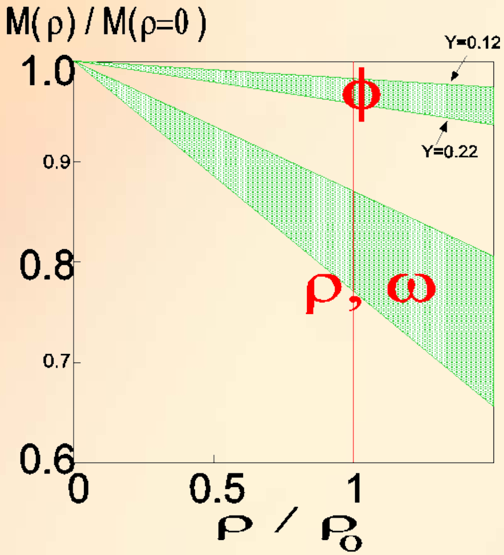



current quarks ***~MeV/c²***

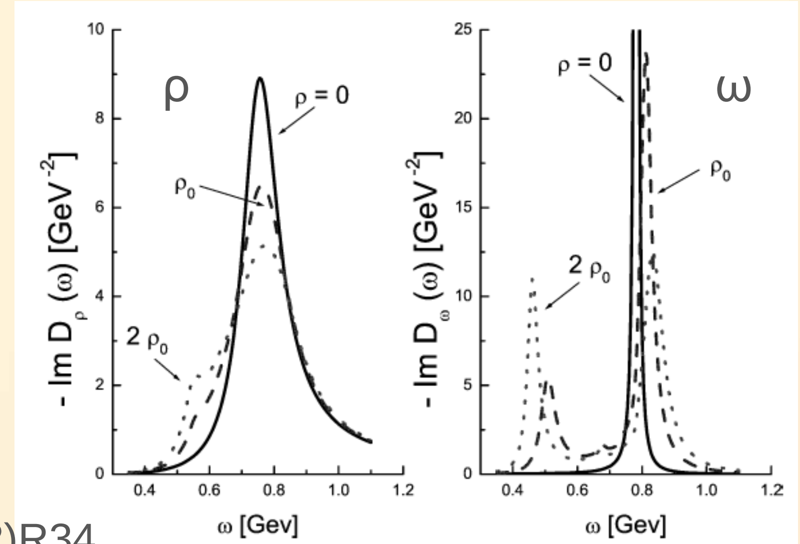



Lutz, Klimt & Weise, NPA542( '92)

# Density dependence of Mass

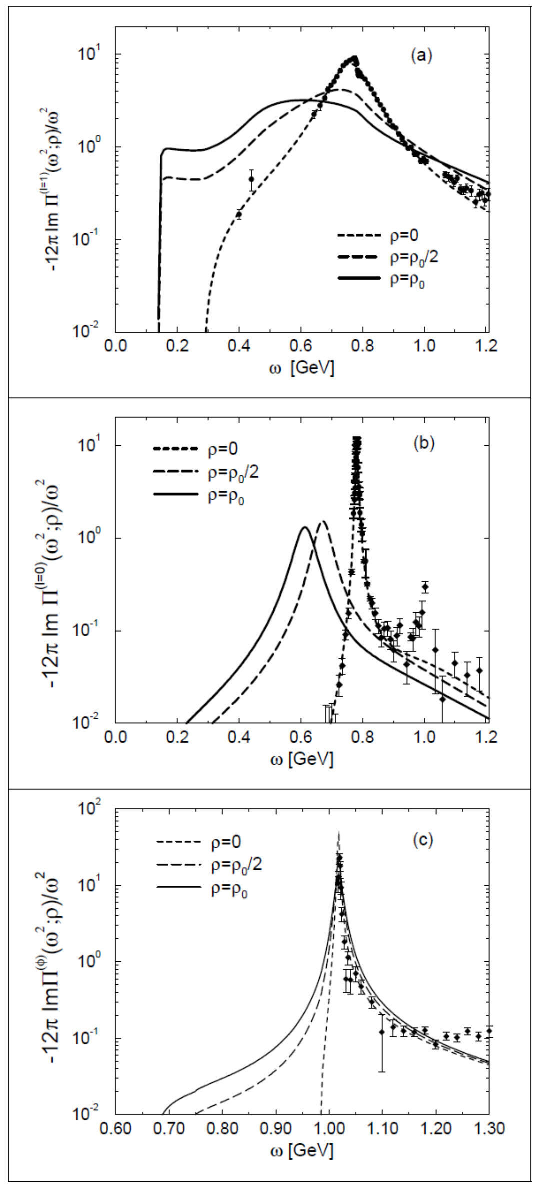


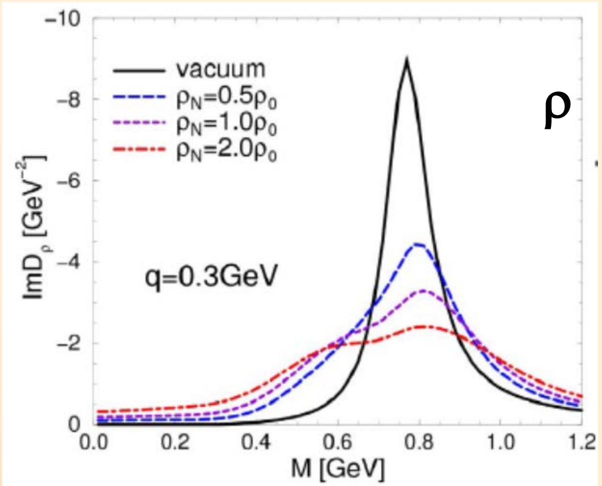

Hatsuda & Lee, PRC46('92)R34
base on QCDSR



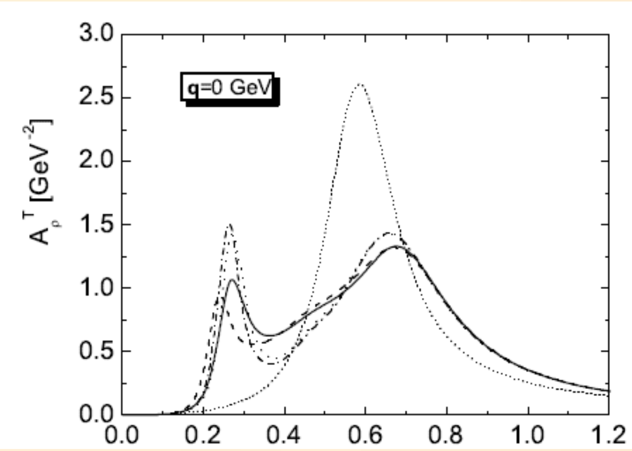

Lutz&Friman, NPA706('02)

Klingl,Kaiser&Weise, NPA624('97)



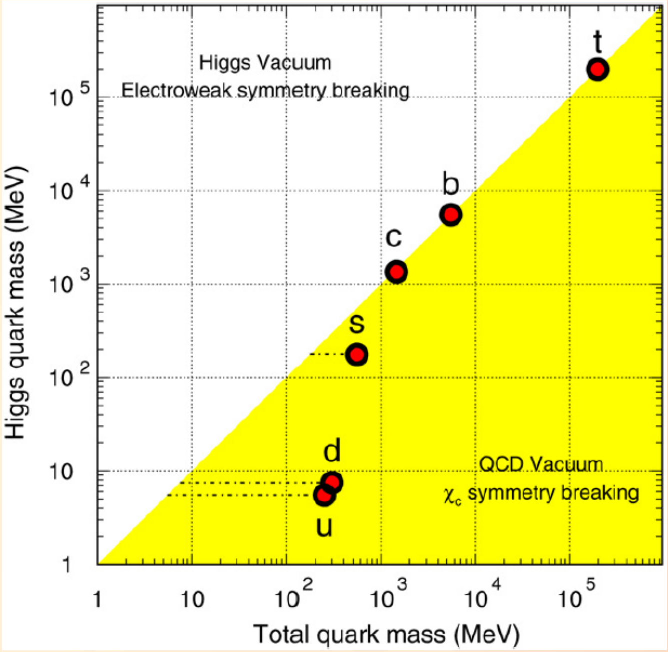




Rapp & Wambach, ANP25 ('00)




M. Post et al, NPA741('04)

# Dilepton Measurement



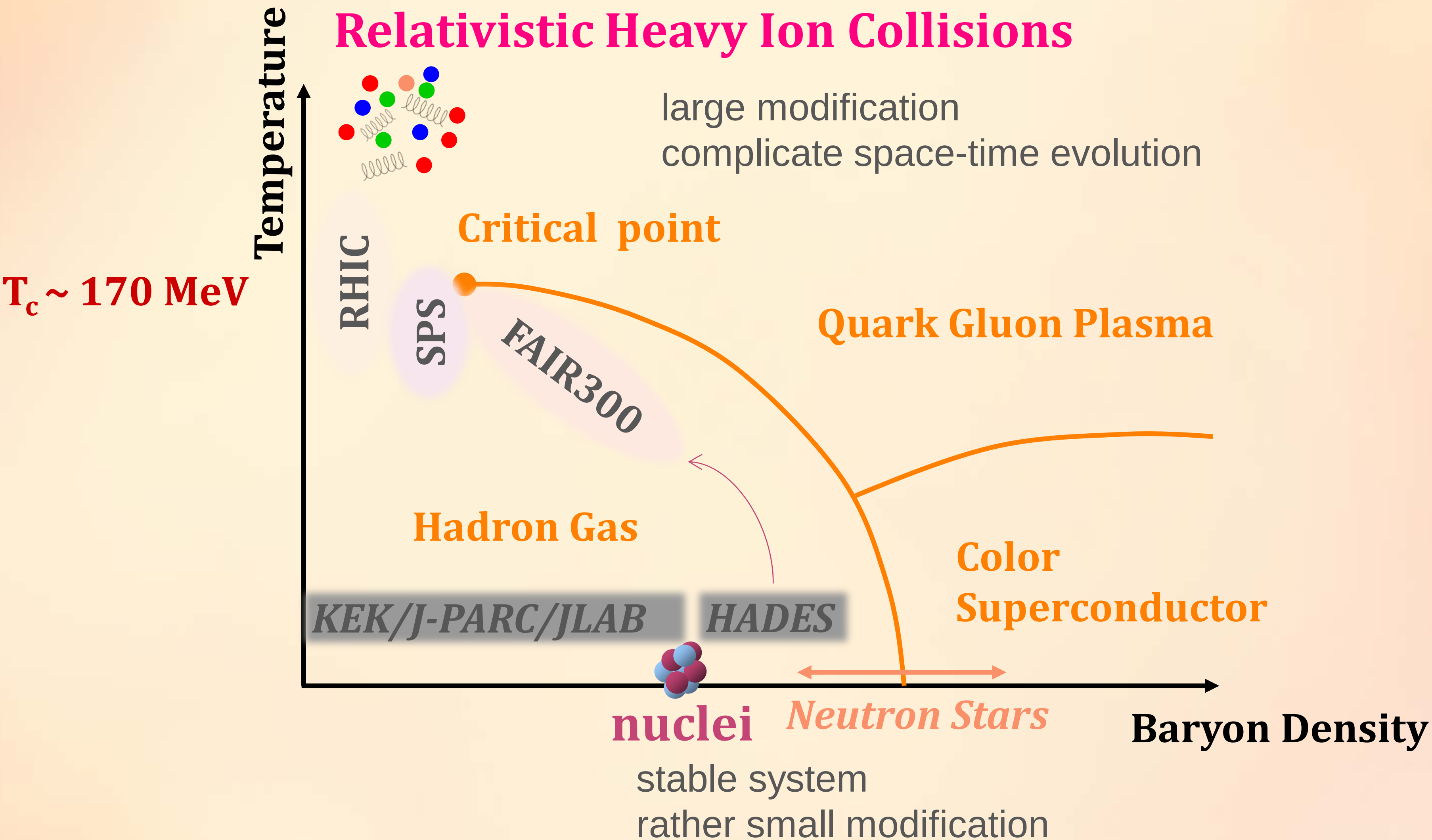

directly access to the properties of vector mesons

region of interest: < 1 GeV/$c^2$

in-medium modification of vector mesons possible connection to CSB

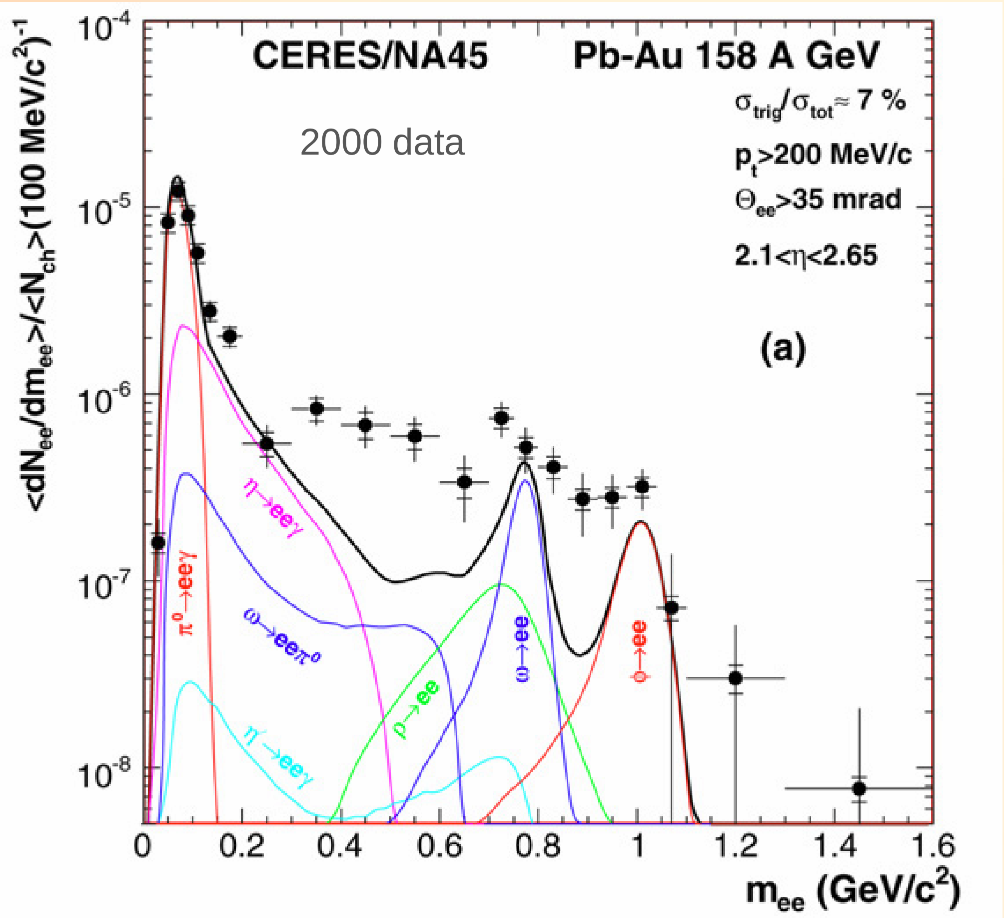
| | Mass | Width | $c\tau$ | $\rho,\omega$ vs $\phi$ |
|---|---|---|---|---|
| $\rho$ | 770MeV | 149.2 MeV | 1.3 fm | large effect overlap |
| $\omega$ | 782MeV | 8.44 MeV | 24 fm | |
| $\phi$ | 1020MeV | 4.26 MeV | 47 fm | single peak |

# HIC vs. cold nuclear matter

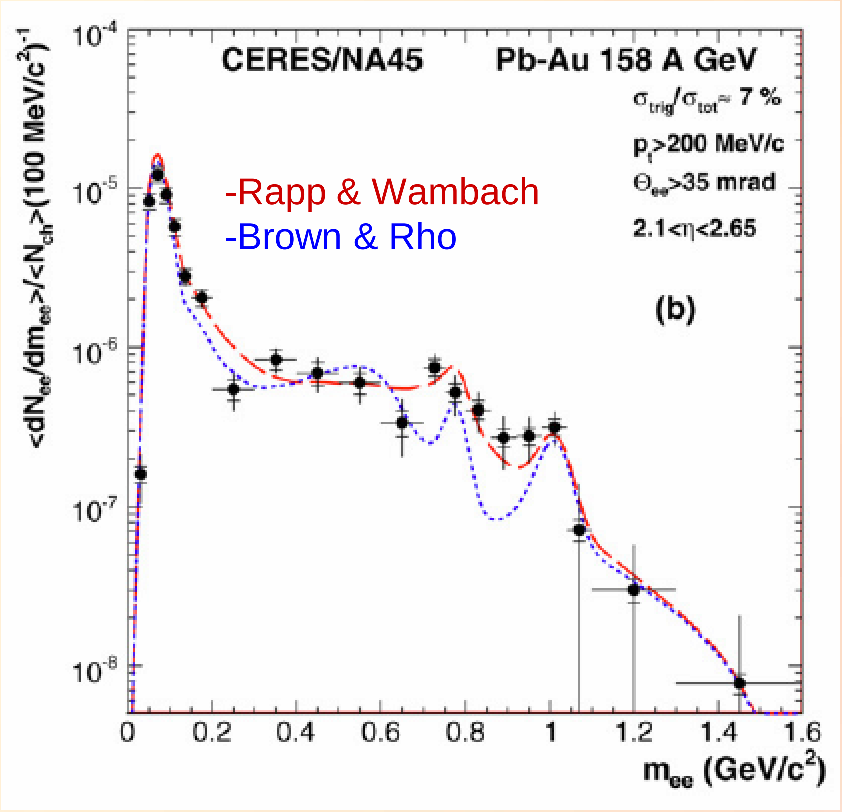


# CERES @ SPS

e+e− pair measurement in central Pb–Au collisions at 158A GeV/c

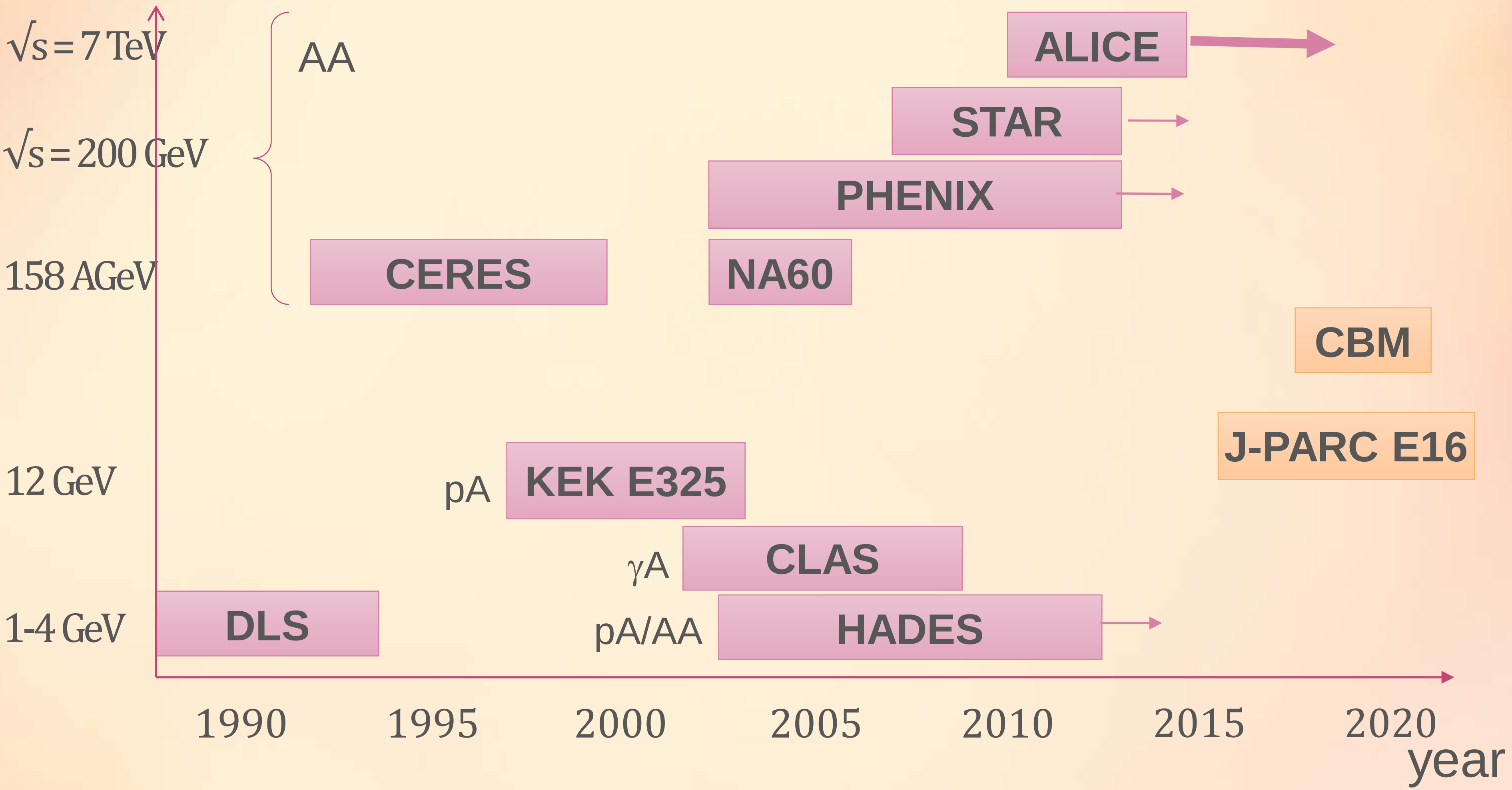



Phys. Lett. B666 (2008) 425




both scenarios are possible
within the systematic uncertainty

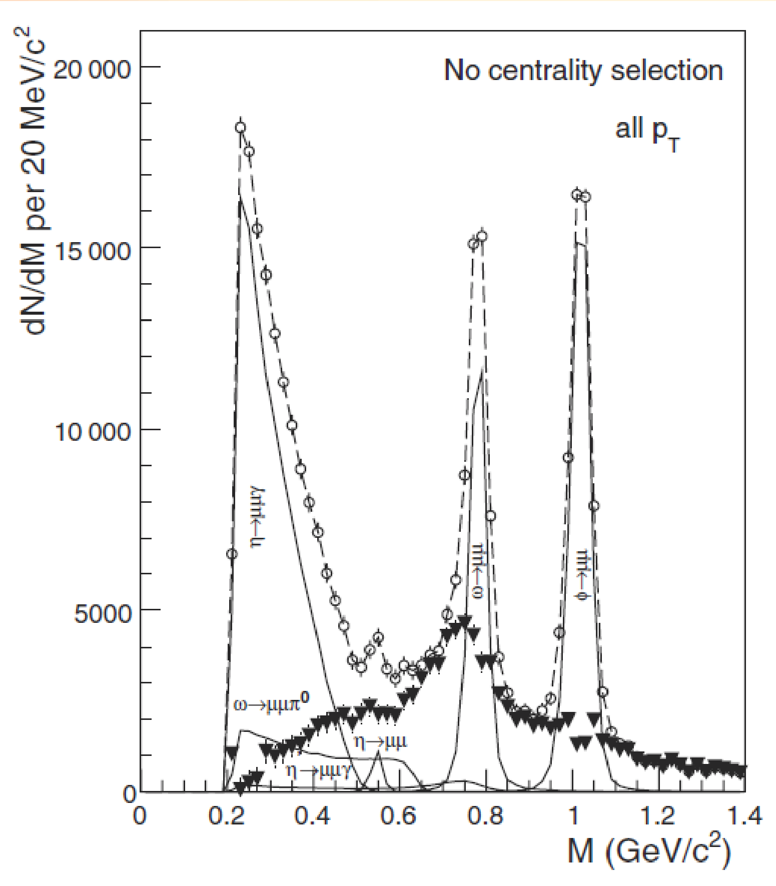
# Dilepton Measurements
## History vs. Energy scale

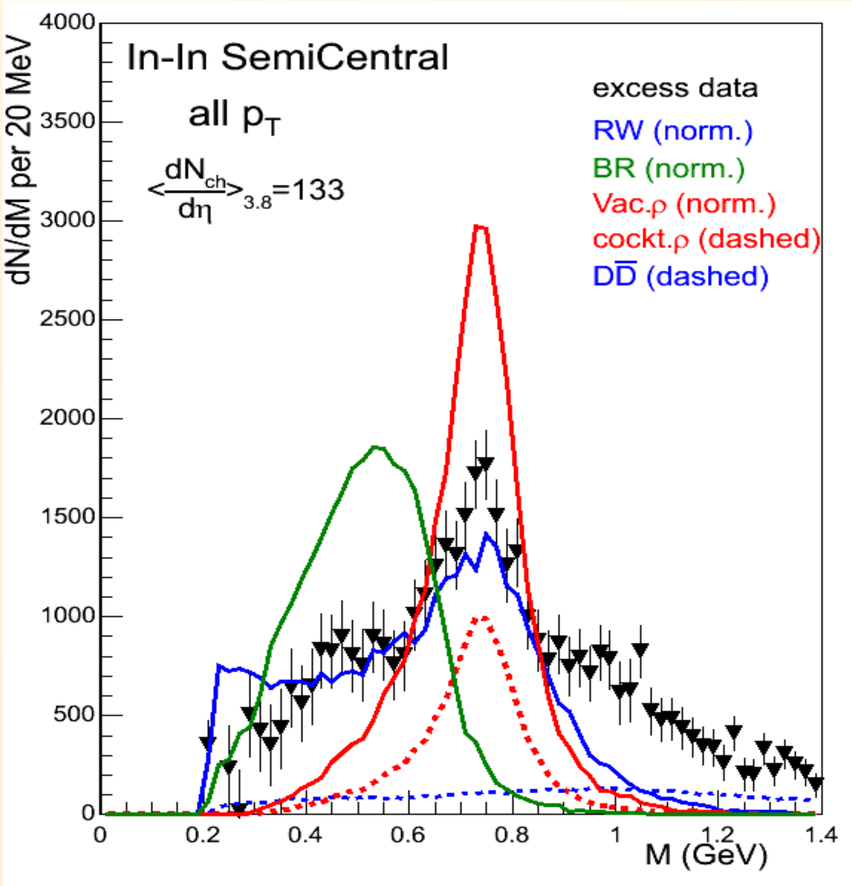


# NA60 @ SPS

**invariant mass of μ+μ− in In-In at 158 AGeV($\sqrt{s_{NN}}$=19.6 GeV)**

PRL 96, 162302 (2006)




ΔM = 23 MeV at the φ

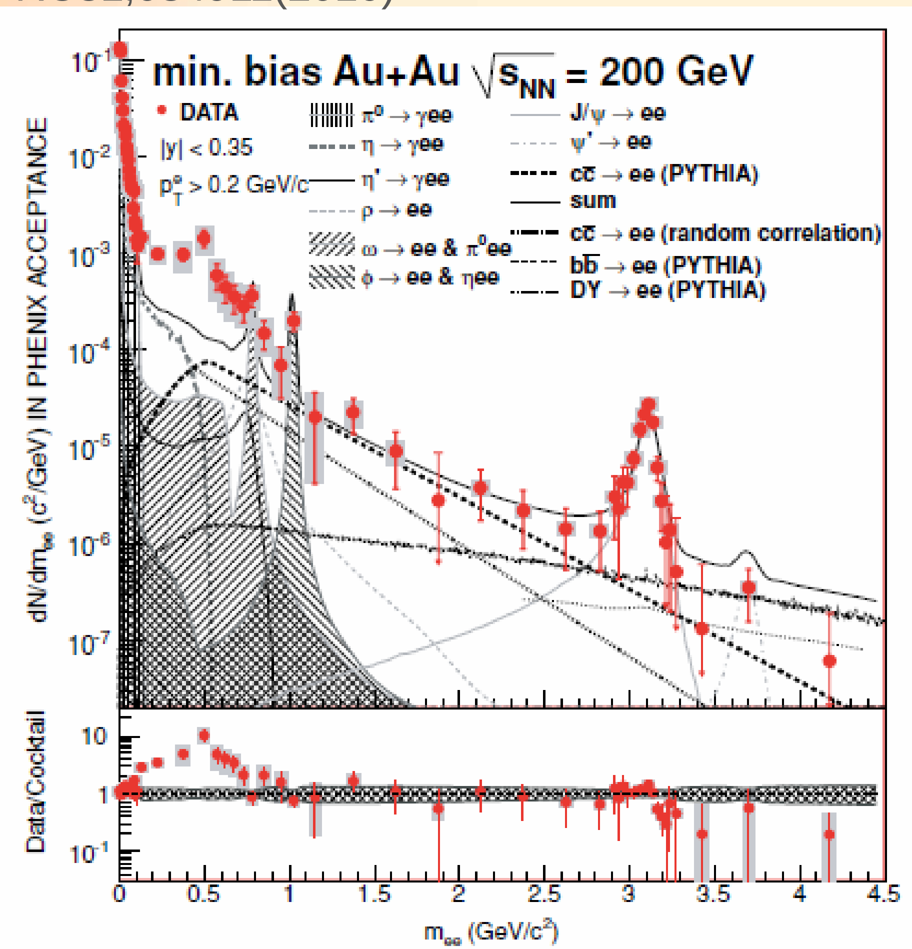
ρ spectrum is reproduced with broadening of ρ (Rapp & Wambach)

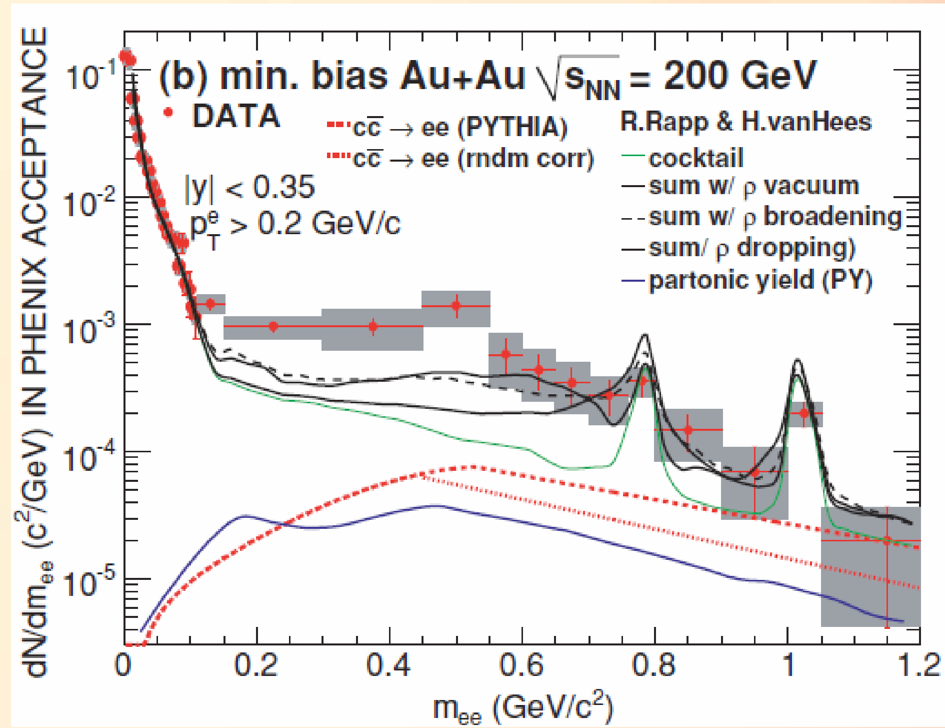
space-time evolution: thermal fireball model

# PHENIX @ RHIC

## invariant mass of e+e- at $\sqrt{s_{NN}}$=200 GeV

PRC81,034911(2010)

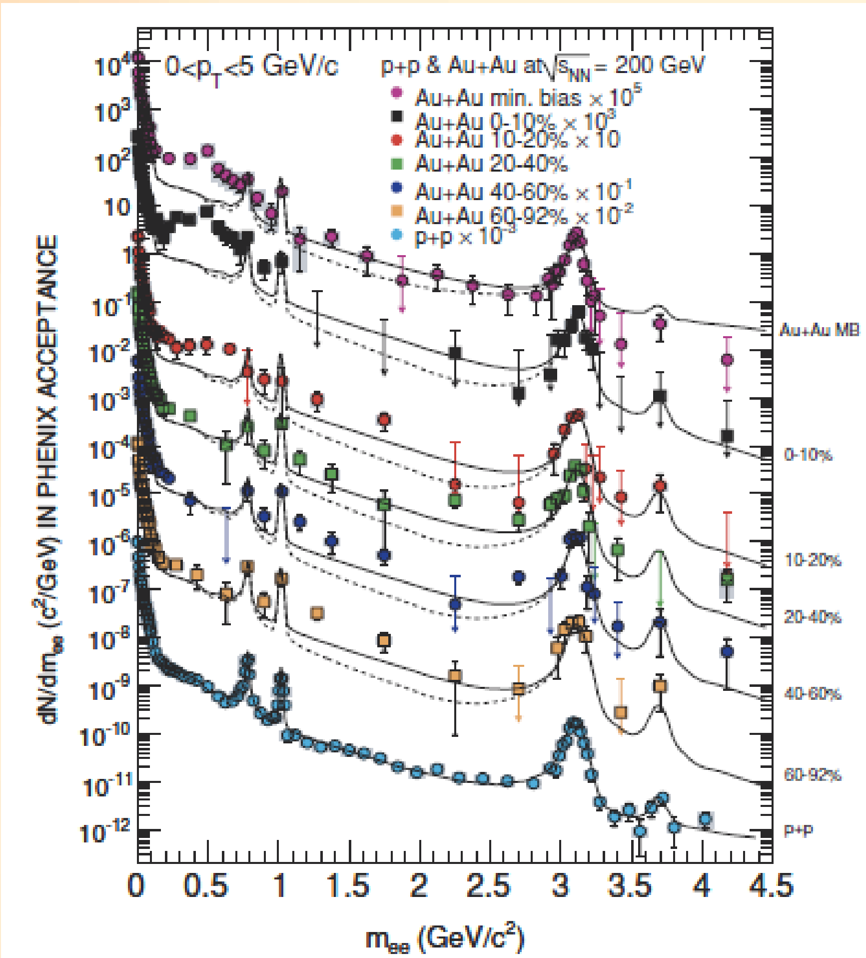


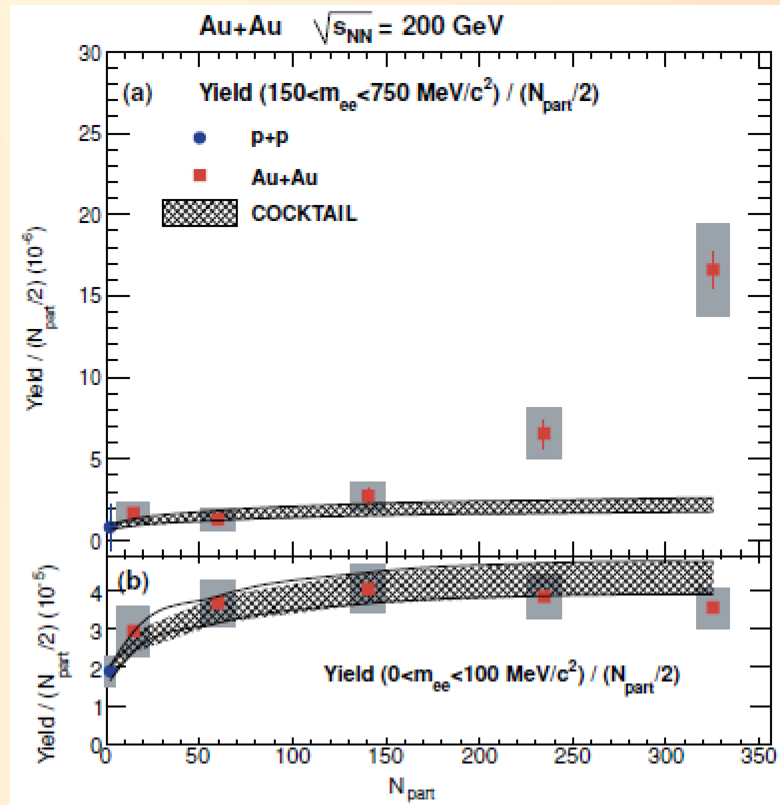




All models and groups that successfully described the SPS data fail in describing the PHENIX results

strong enhancement in 150 <$m_{ee}$<750 MeV:
4.7 ± 0.4(stat.) ± 1.5(syst.) ± 0.9(model)

# PHENIX Au+Au: Centrality dependence

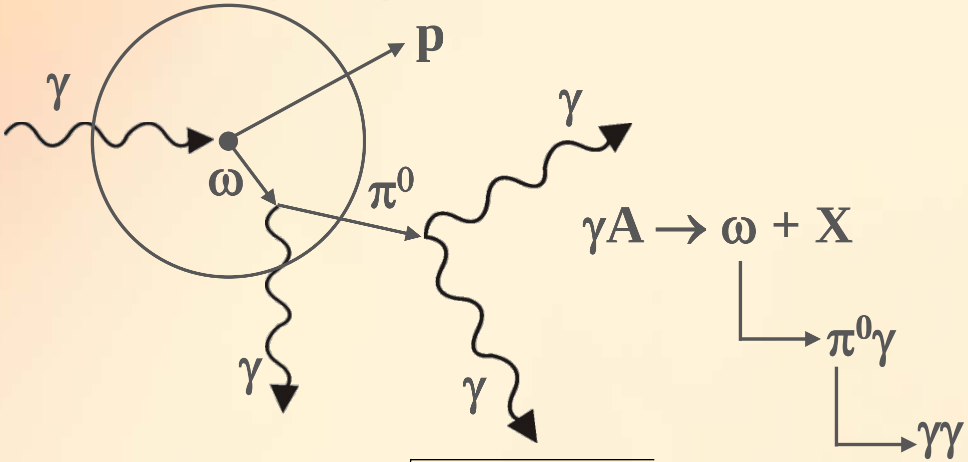


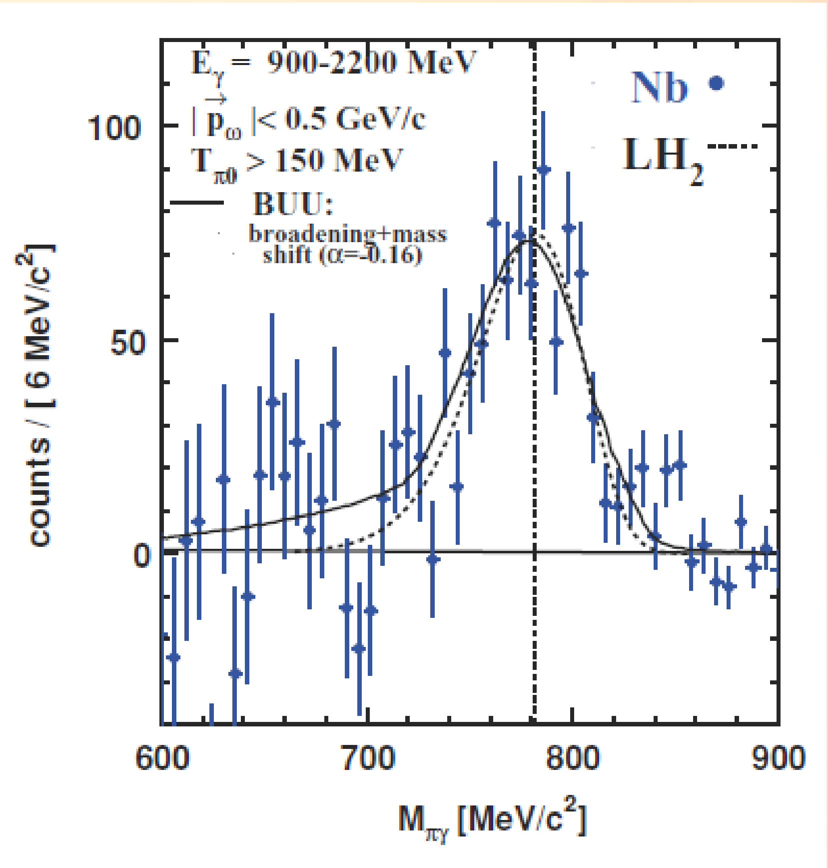

Strong centrality dependence in the Low-Mass Region.

# CBELSA/TAPS experiment

## $\omega \to \pi^0\gamma$ in $\gamma$+A




$$m_\omega = \sqrt{(p_\pi + p_\gamma)^2}$$




Nanova et al., PRC82(2010)035209

**advantage:**

- $\pi^0\gamma$ large branching ratio (8 %)
- no ρ-contribution ($\rho \to \pi^0\gamma : 7 \cdot 10^{-4}$)

**disadvantage:**

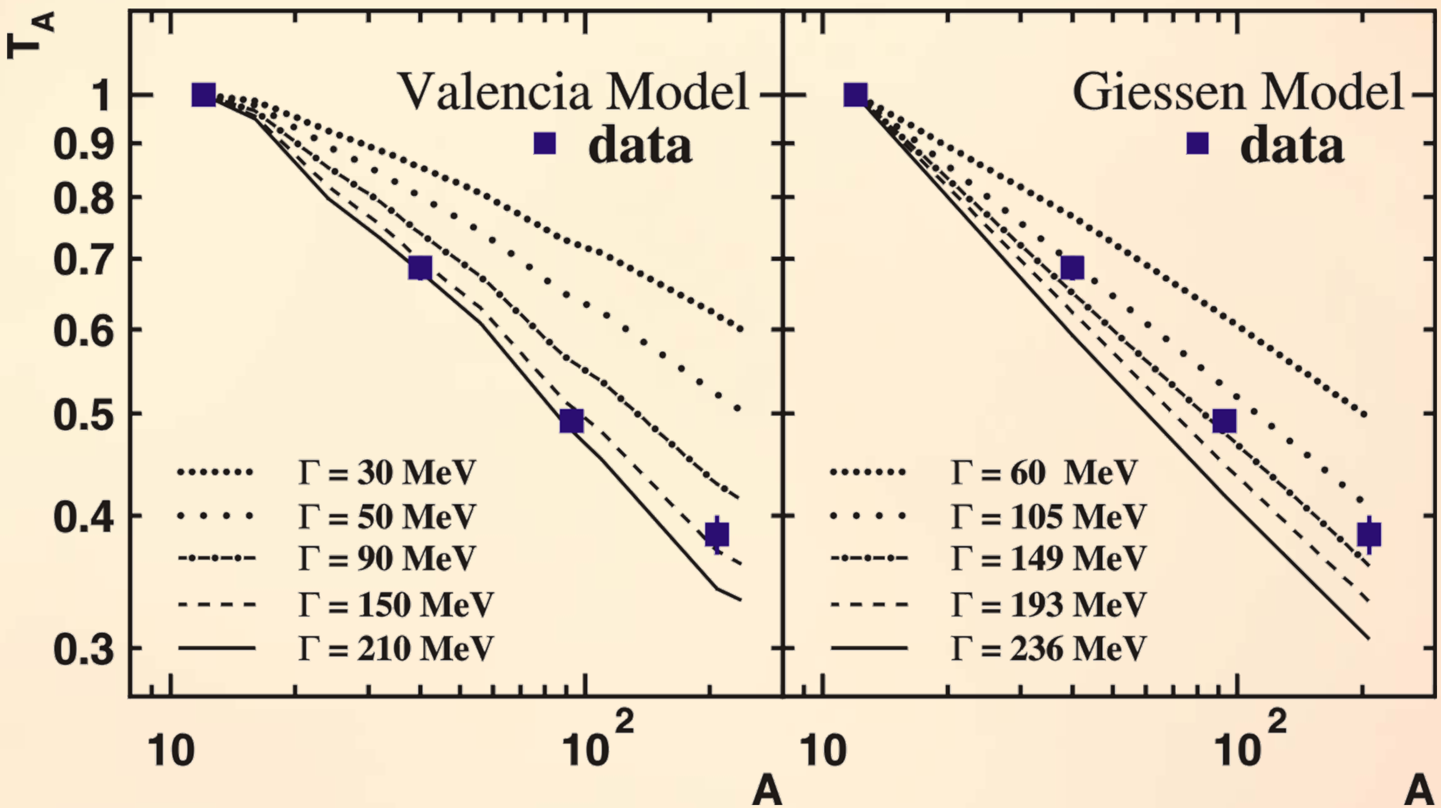
- $\pi^0$-rescattering

# In-medium Width of ω

estimated from transparency ratio

$$T_A = \frac{\sigma_{\gamma A \to \omega X}}{A \cdot \sigma_{\gamma N \to \omega X}}$$

PRL100,192302(2008)

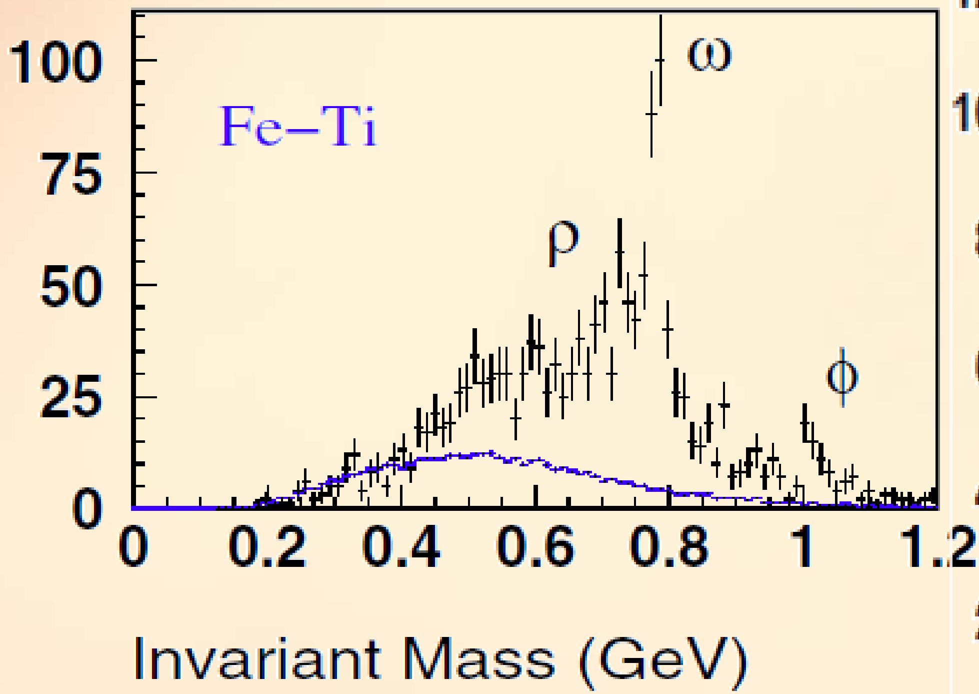


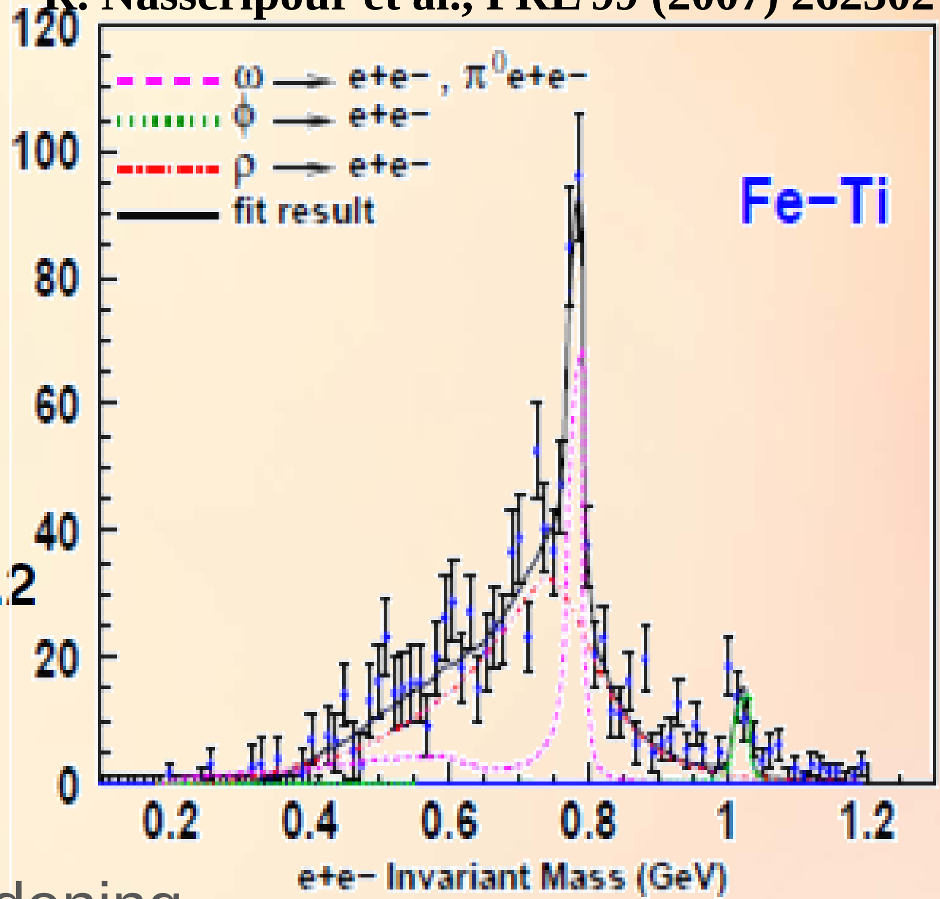

comparison to data $\Gamma(\rho_0, <|\vec{p}_\omega|> \approx 1.1$ GeV/c) ≈ 130-150 MeV

# CLAS g7a @ J-Lab

**Induce photons to Liquid deuterium, Carbon, Titanium and Iron targets, generate vector mesons, and detect e+e- decays with large acceptance spectrometer.**

R. Nasseripour et al., PRL 99 (2007) 262302



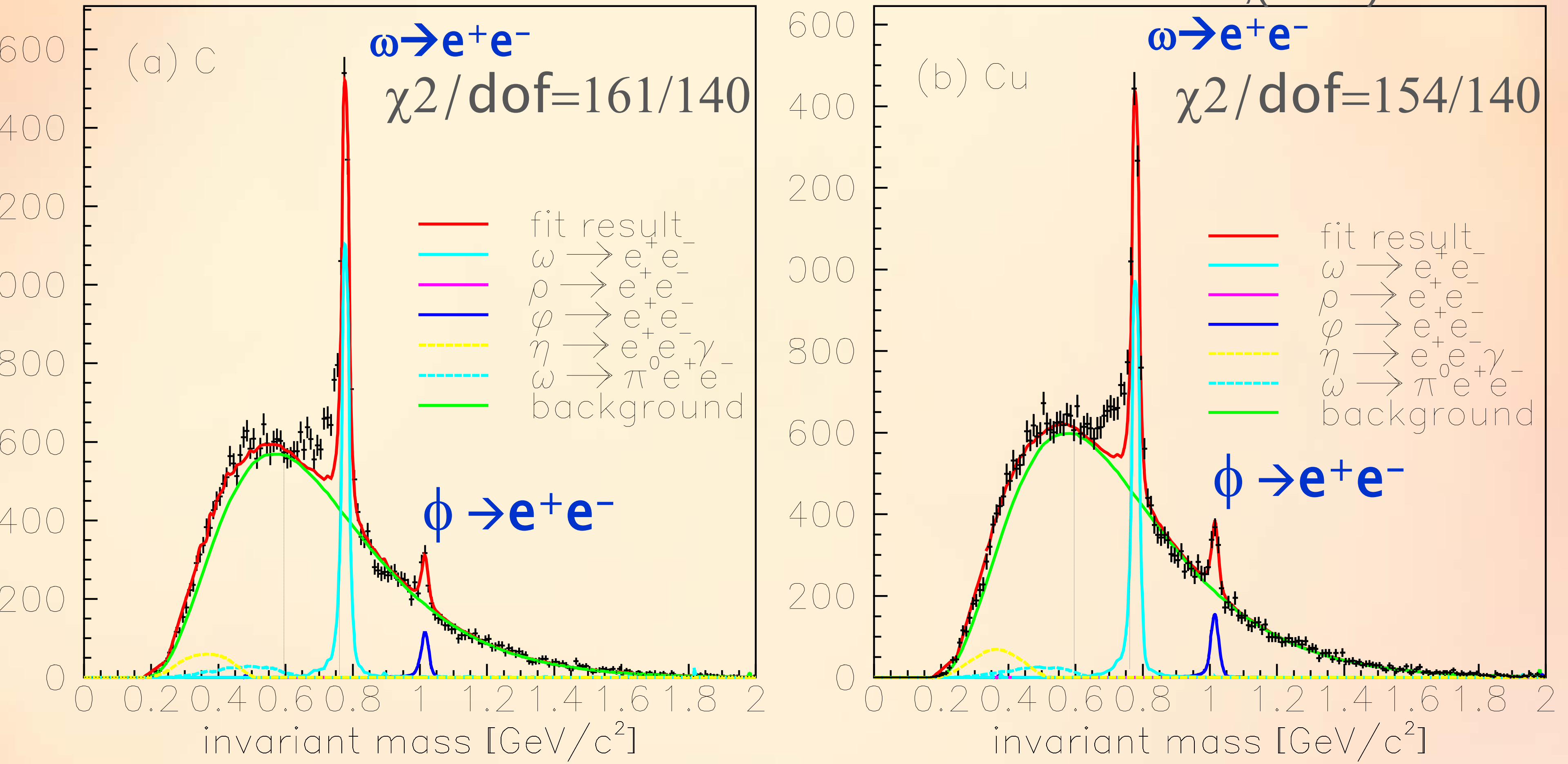

No peak shift of ρ
consistent with collisional broadening

**$m_\rho = m_0 (1 - \alpha\, \rho/\rho_0)$**
**for $\alpha = 0.02 \pm 0.02$**

# E325 @ KEK-PS

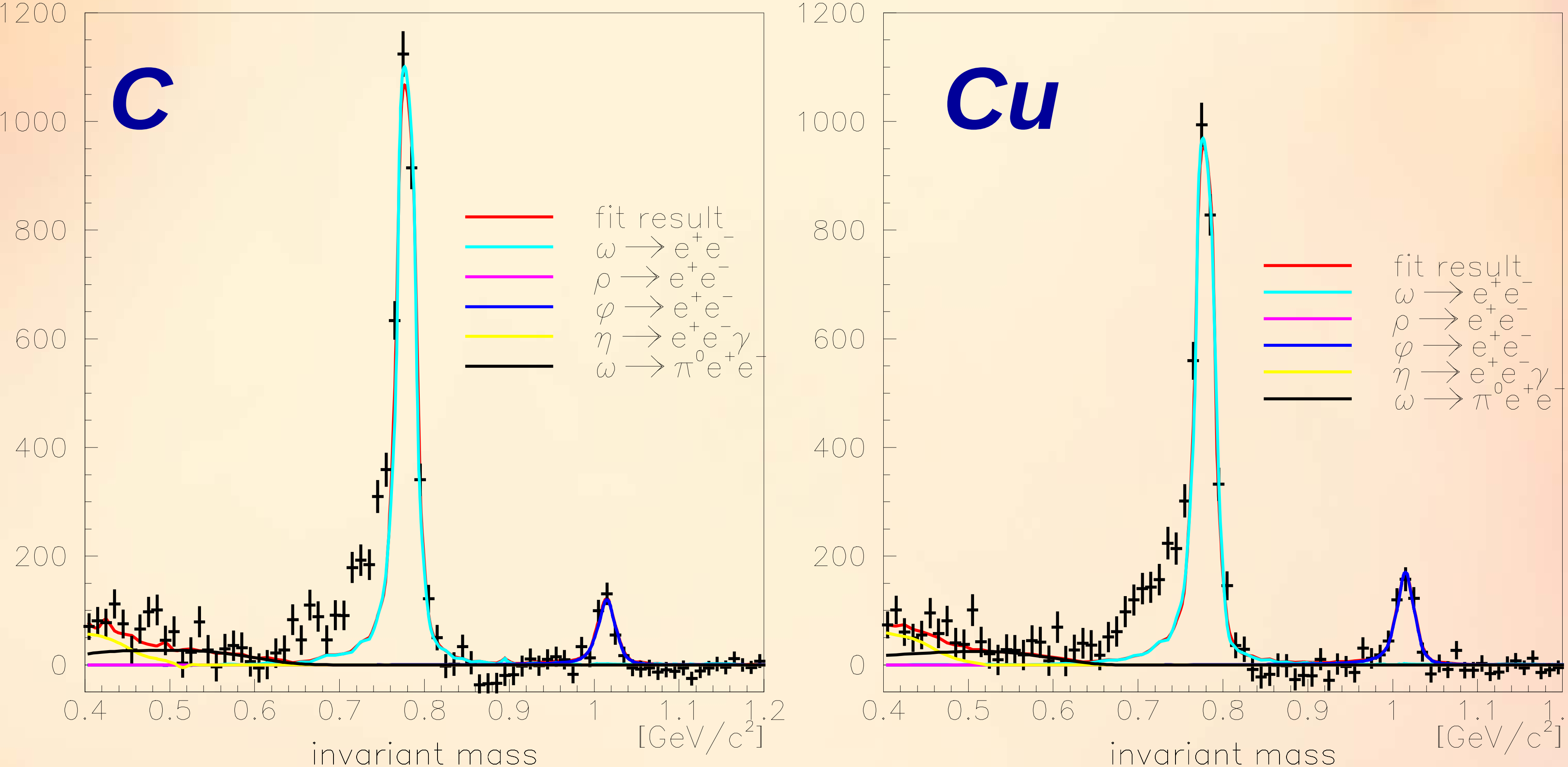
## Invariant Mass Spectrum of e+e− in 12GeV/c p+A

PRL**96**,(2006) 092301




the excess over the known hadronic sources on the low mass side of ω peak has been observed.

# Background Subtracted

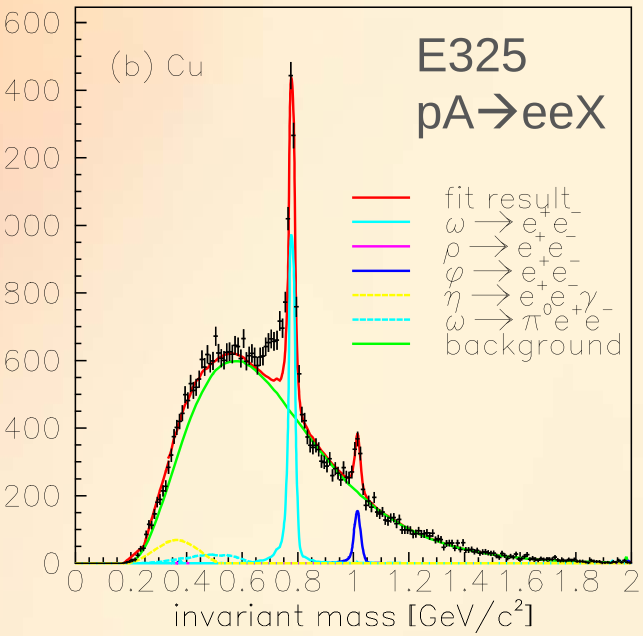


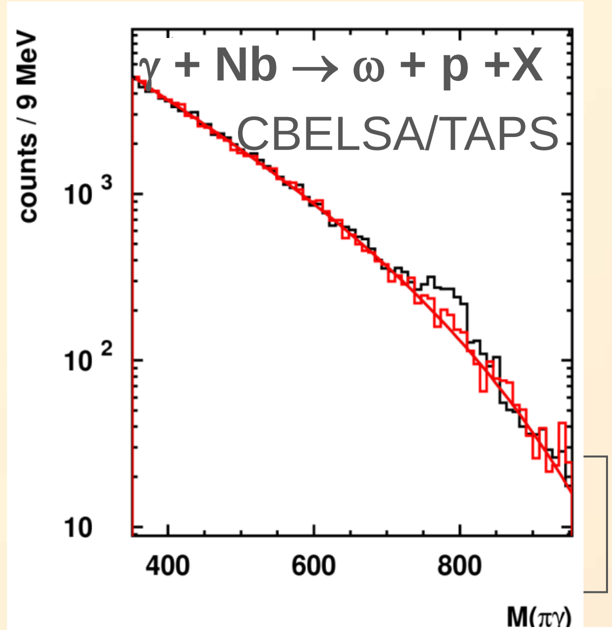

**ρ/ω ratio is consistent with zero. 95%C.L. allowed regions:**

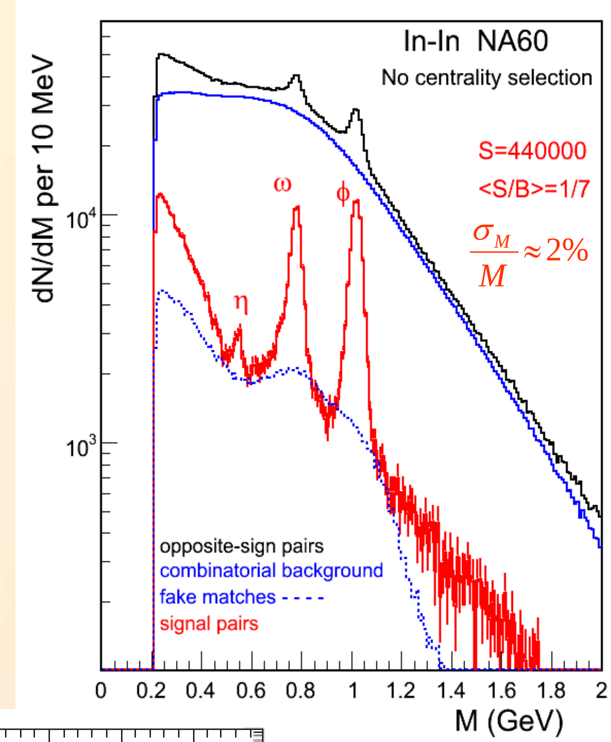
Nρ/Nω<0.04(stat.)+0.09(sys.) Nρ/Nω<0.10(stat.)+0.21(sys.)

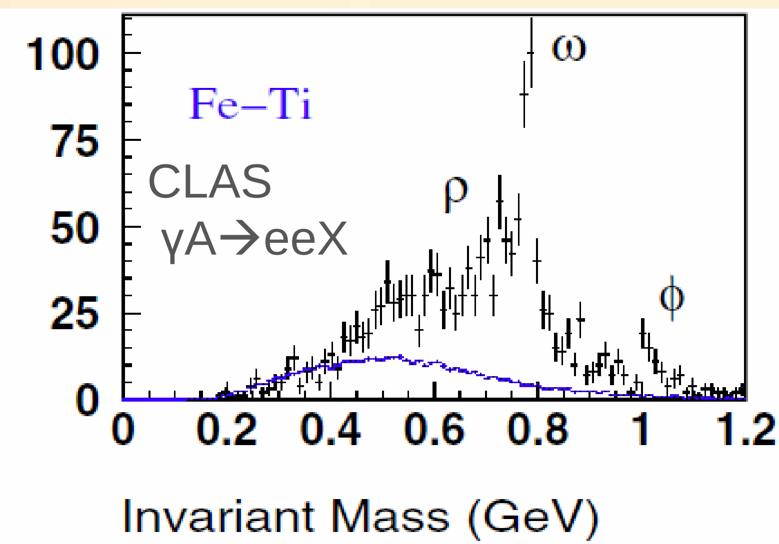
most of ρ decay in nucleus due to their short lifetime; τ ~ 1.3fm

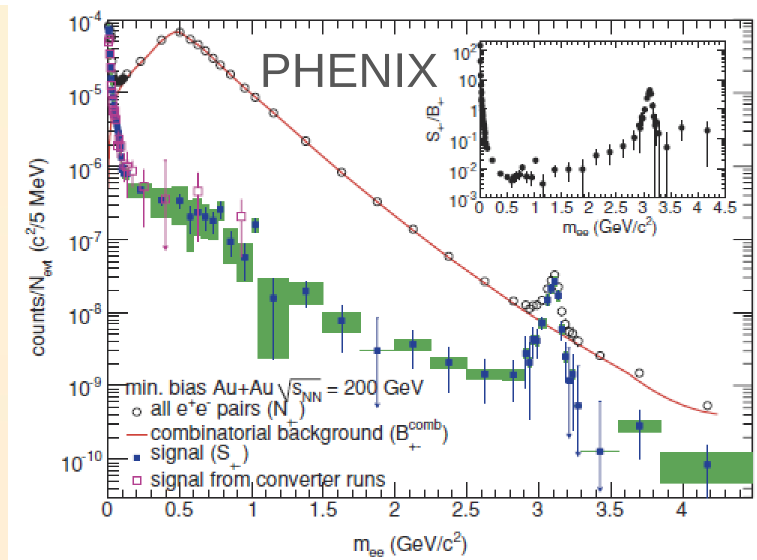
# S/B at a glance



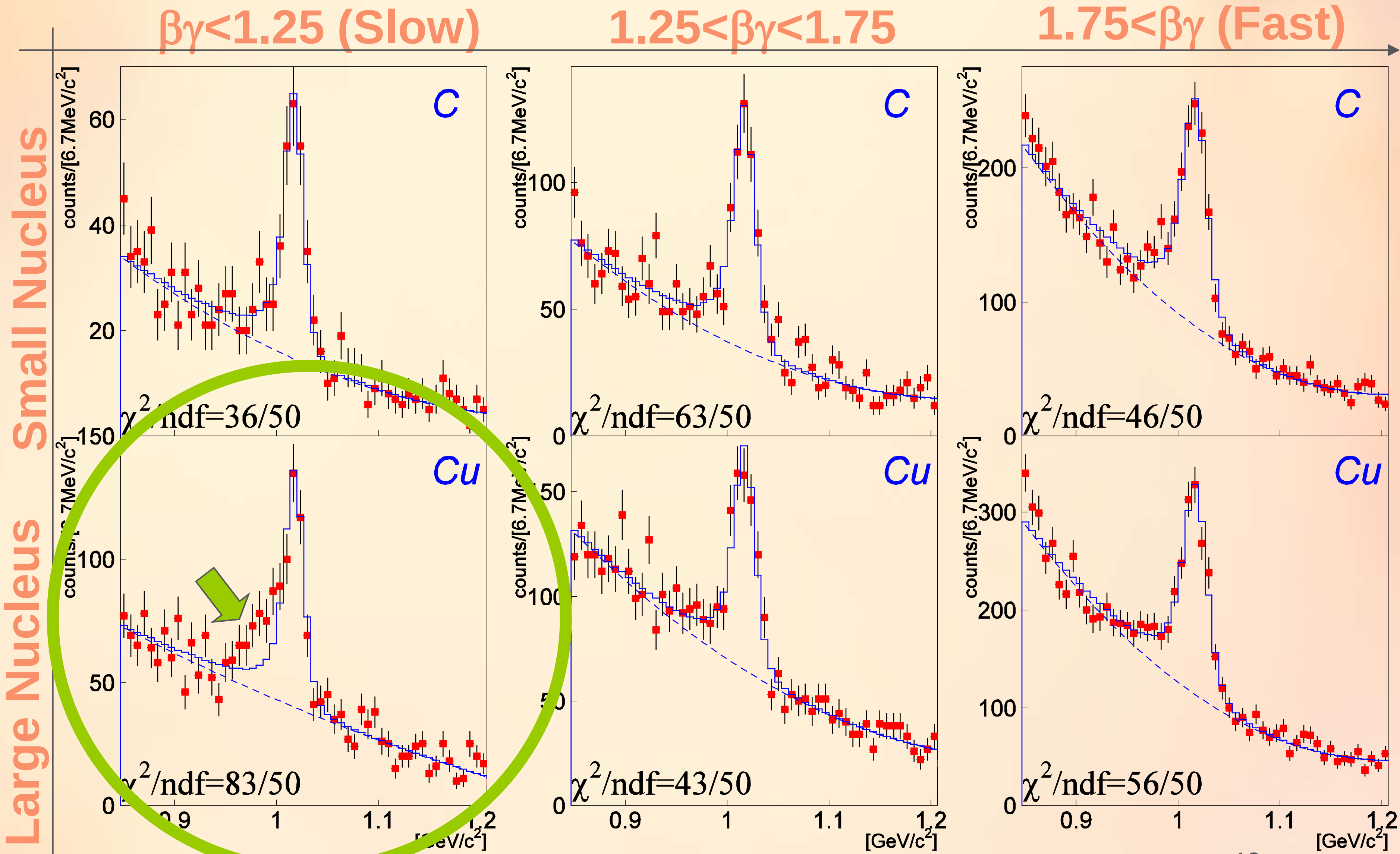



# Invariant mass spectra of φ→ $e^+e^-$




**Rejected at 99% confidence level**

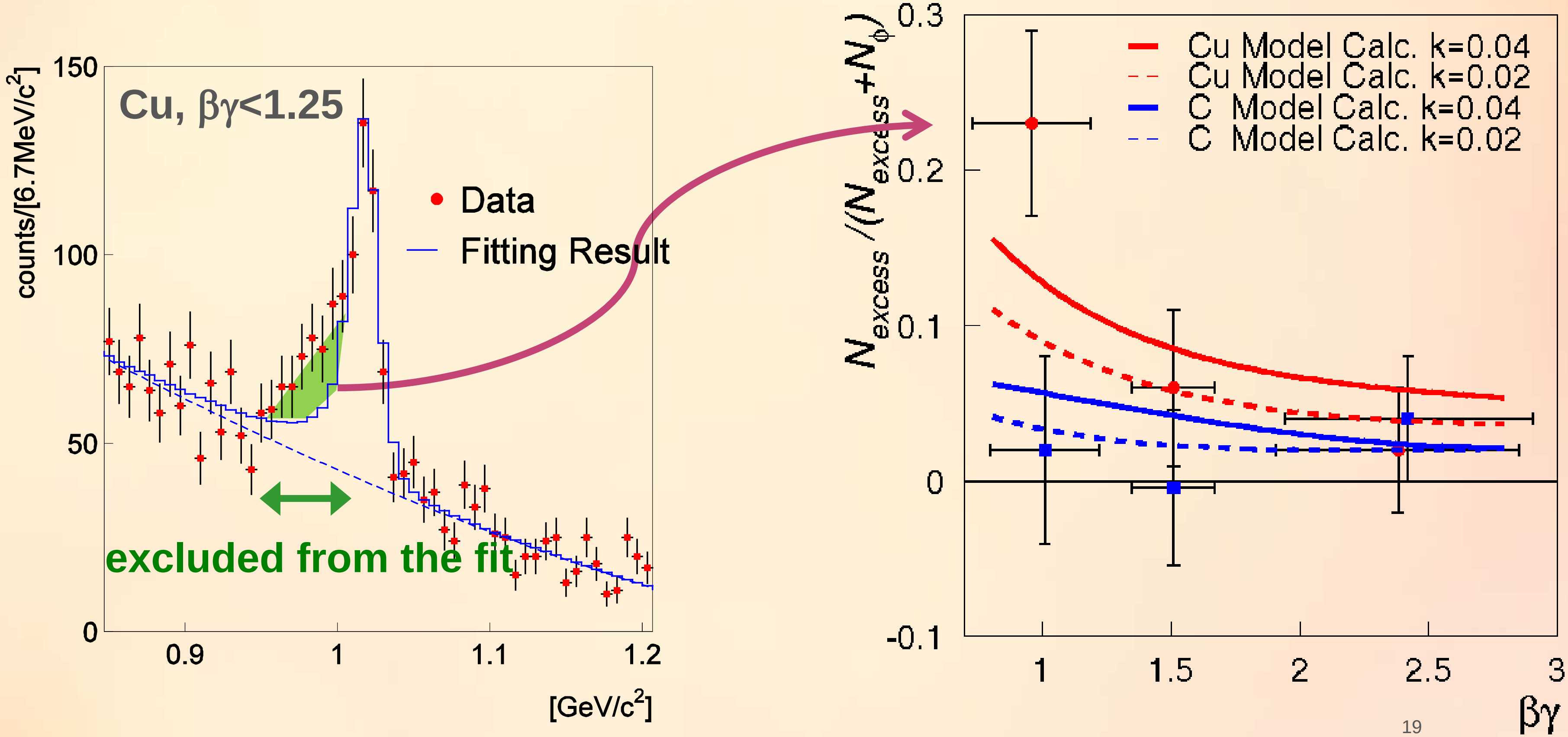


PRL 98(2007)042501

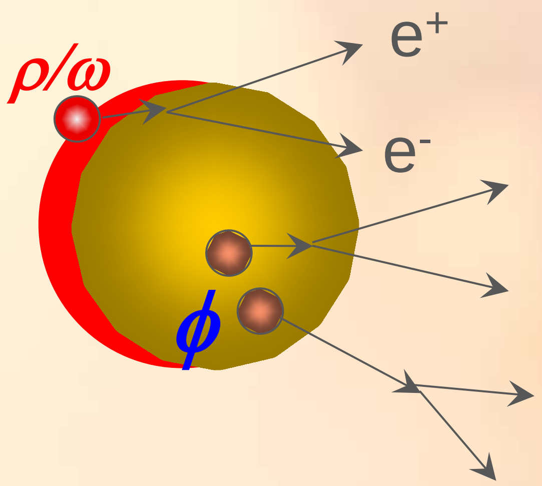
# Enhancement Factor

**The amount of the excess**

- number of excess in the region of 0.95~1.01 GeV/c$^2$→ $N_{excess}$
- normalized by the number of signal (ϕ+excess)



# Model calculation w/ mass modification



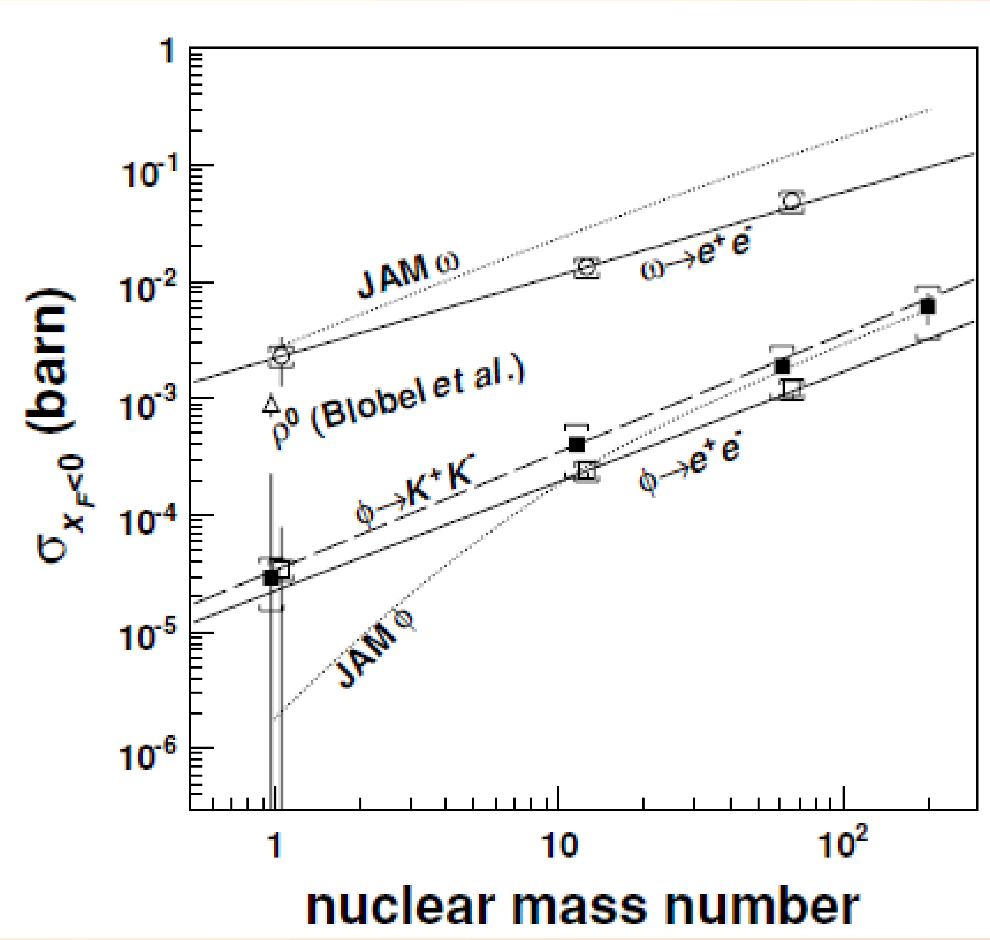

| | ρ/ω | ϕ |
|---|---|---|
| m(ρ)/m(0) | $1 - \mathbf{k_1}^{\rho/\omega} (\rho/\rho_0)$ | $1 - \mathbf{k_1}^{\phi} (\rho/\rho_0)$ |
| Γ(ρ)/Γ(0) | 1 | $1 + \mathbf{k_2} (\rho/\rho_0)$ |
| generation point | surface | uniform |
| $\alpha$ ($\sigma(A) \propto A^{\alpha}$) | 0.710±0.021 | 0.937±0.049 |
| density distribution | Woods-Saxon, radius: C:2.3fm/Cu:4.1fm | |

# nuclear mass number dependence

$$\sigma(A) = \sigma_0 A^{\alpha}$$

ω,ϕ production
in p+A(CH2,C,Cu)

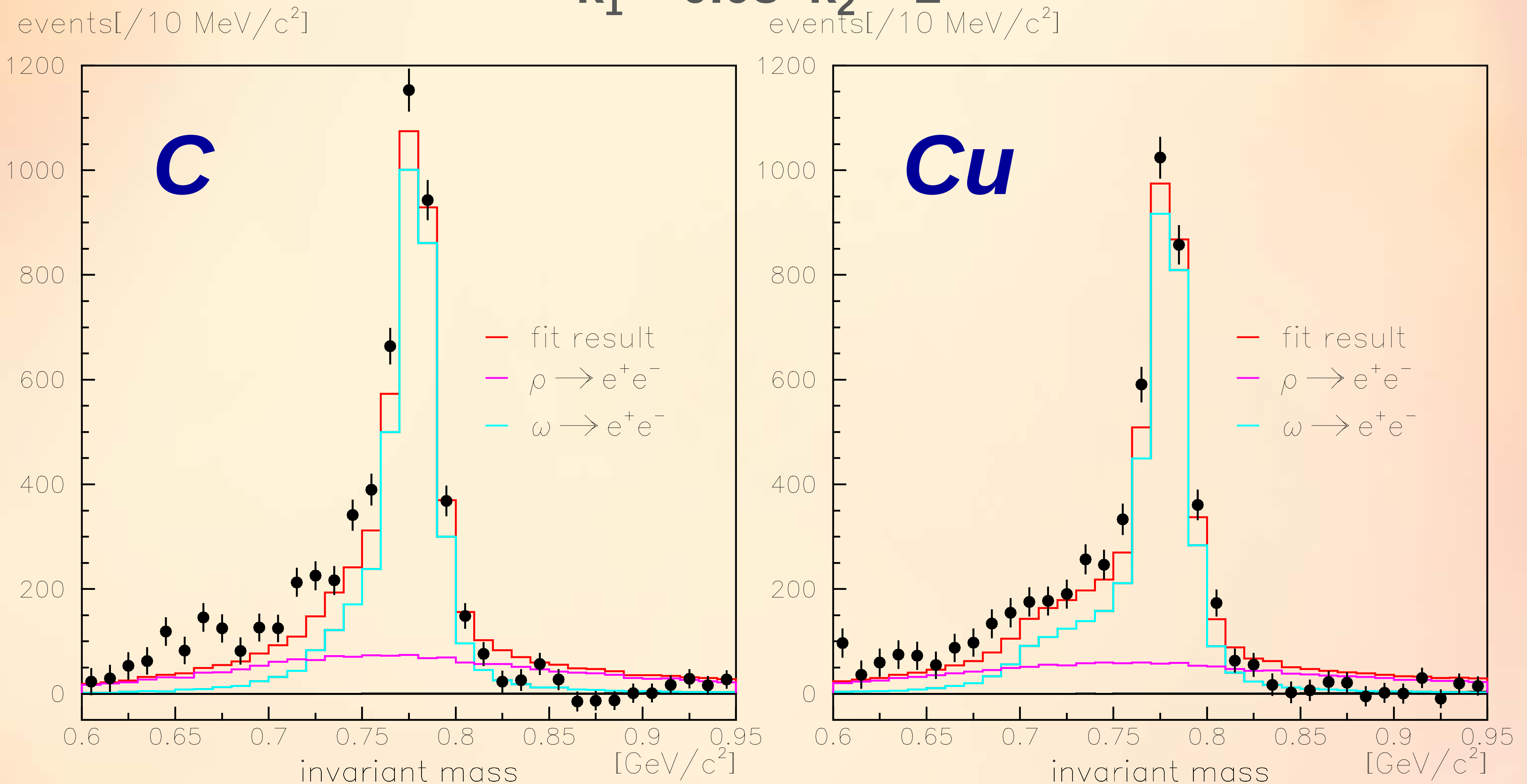
| | α |
|---|---|
| ω | 0.710 ±0.021 ±0.037 |
| ϕ | 0.937 ±0.049 ±0.018 |




T. Tabaru *et al*. Phys. Rev. C74 (2006) 025201

# Width Broadening

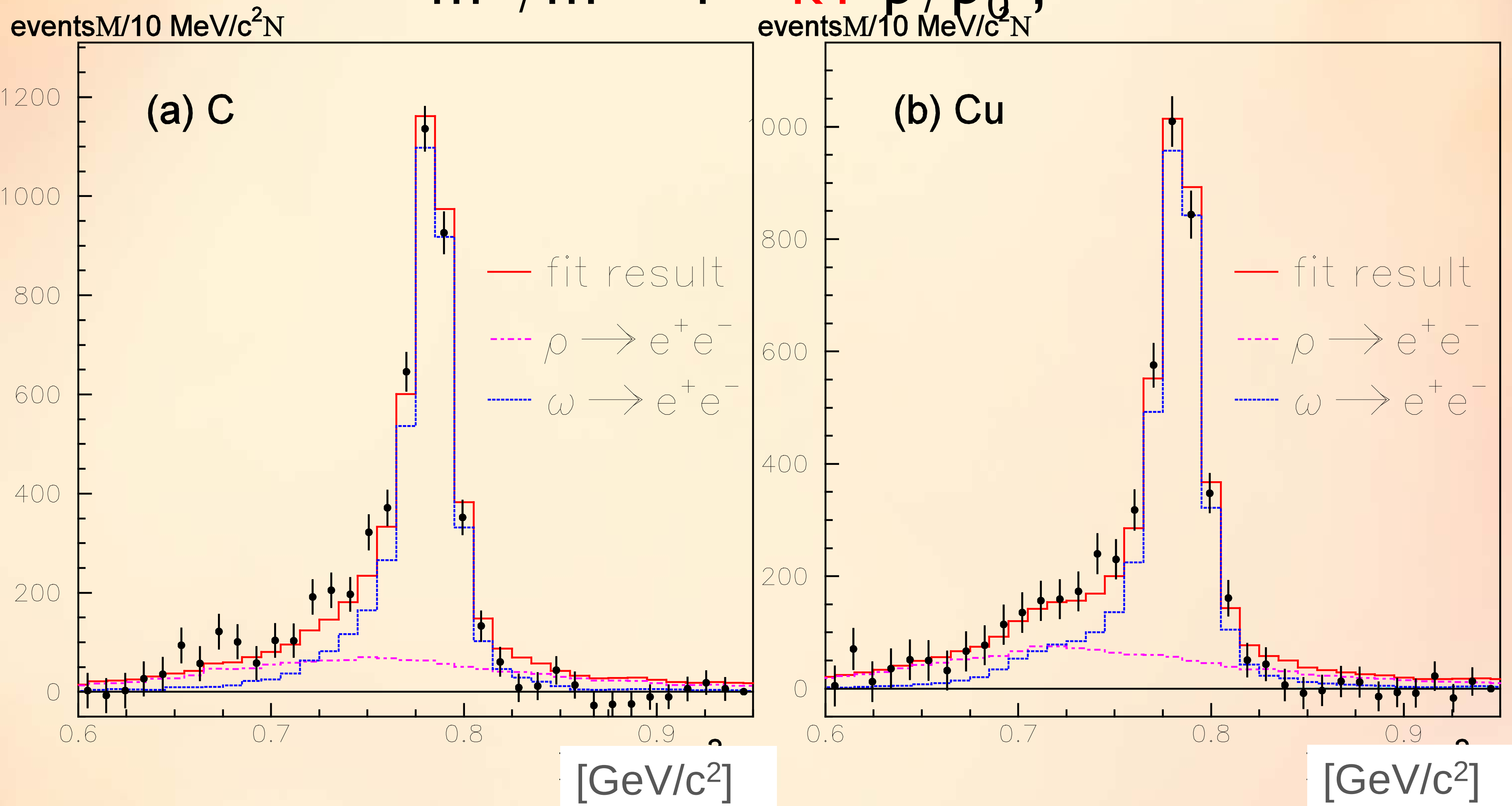
**$k_1$ = 0.08  $k_2$ = 1**




the best fit values are; $k_1$ = 9.2 ± 0.6%   $k_2$ <0.32(90%C.L.)

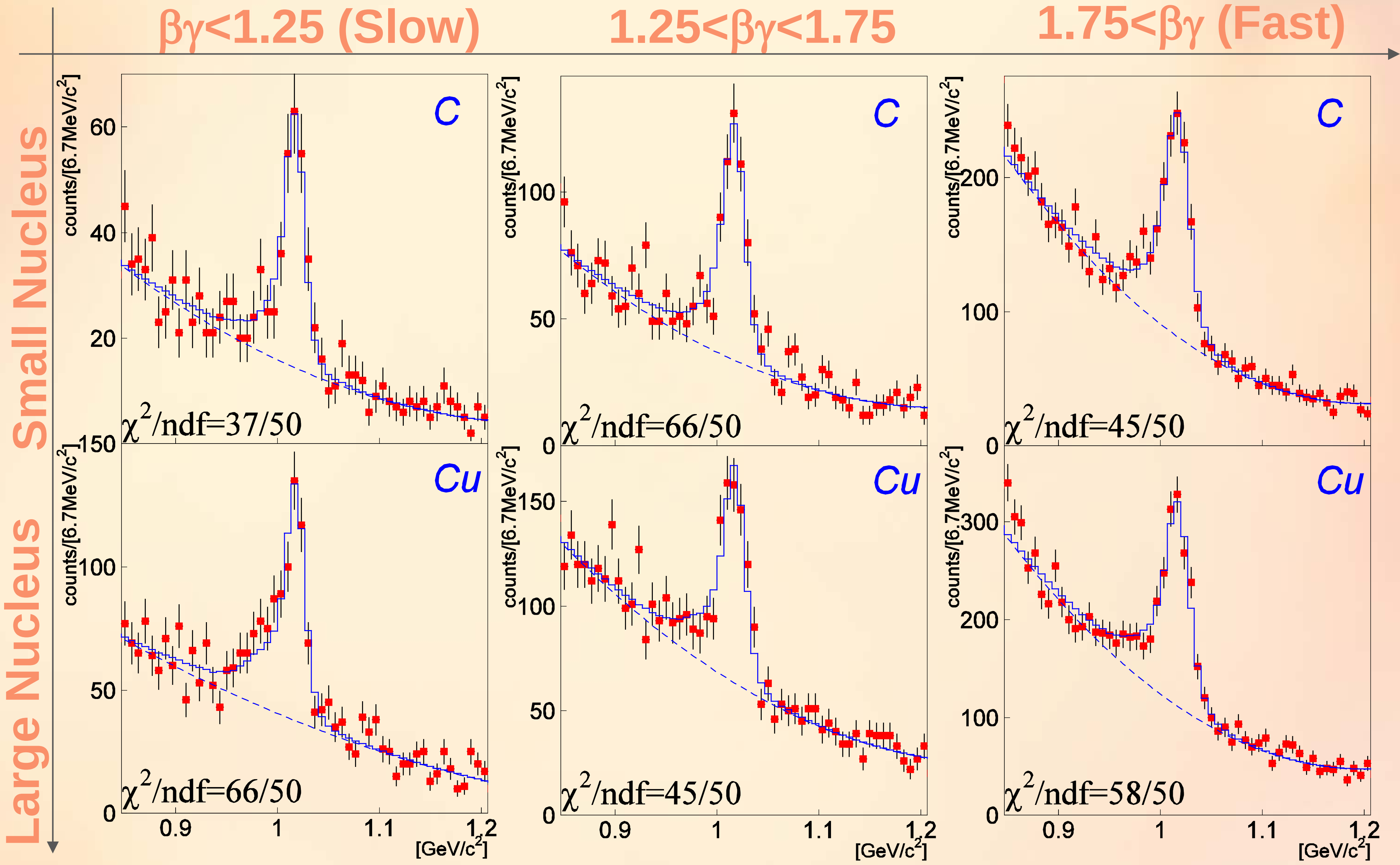
# Comparison w/ Model

$$m^*/m = 1 - k1\ \rho/\rho_0\ ,$$

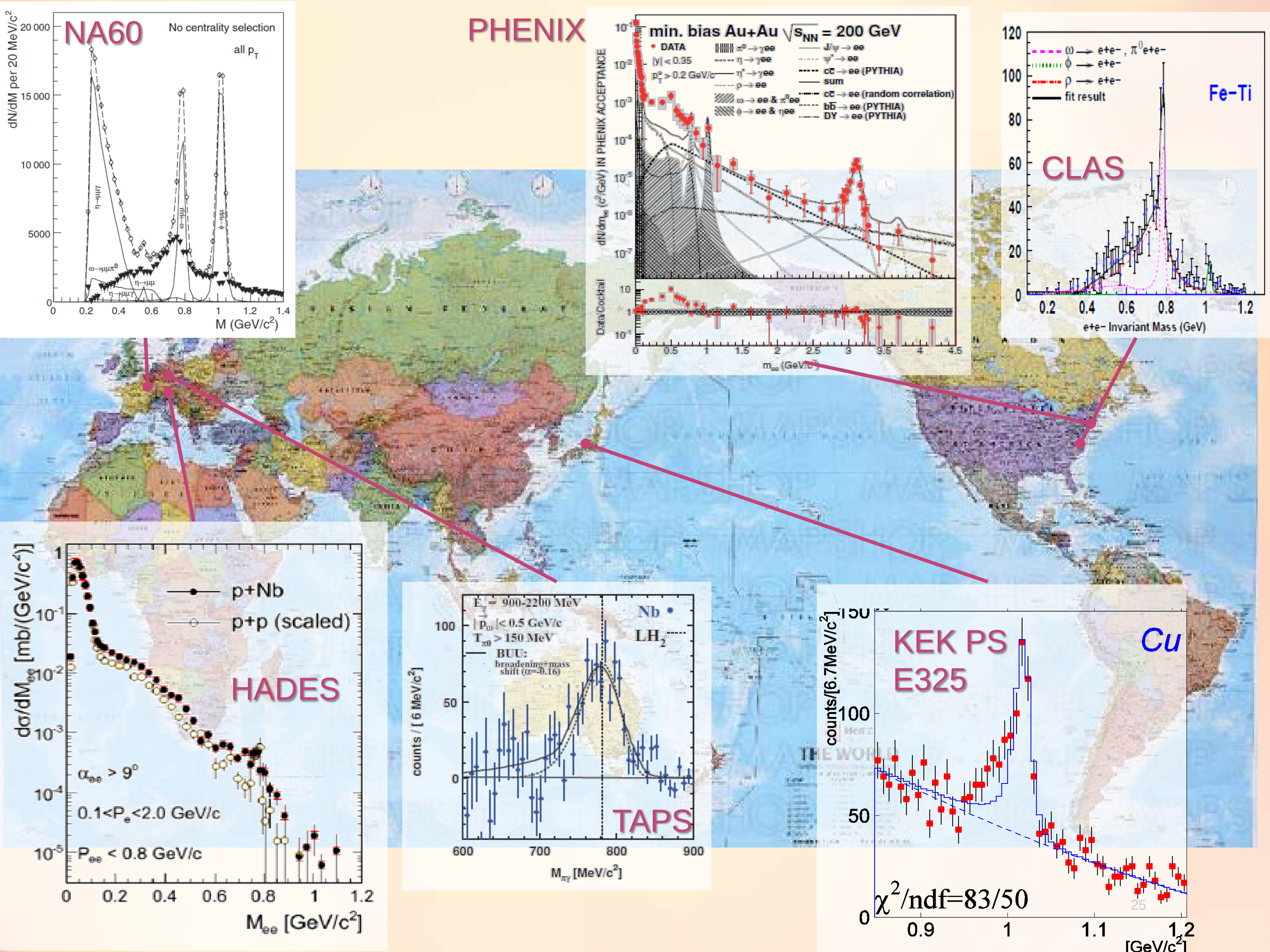



well reproduced with the 9% mass decrease at $\rho_0$.

# Comparison w/ Model Calc.




reproduced with $m^*/m = 1 - 3.4\%\ \rho/\rho_0$ & $\Gamma/\Gamma_0 = 1 + 2.6\rho/\rho_0$


NA60
No centrality selection
all $p_T$
dN/dM per 20 MeV/$c^2$
M (GeV/$c^2$)
PHENIX
min. bias Au+Au $\sqrt{s_{NN}}$ = 200 GeV
DATA
|y| < 0.35
$p_T^e$ > 0.2 GeV/c
J/ψ → ee
ψ' → ee
$c\bar{c}$ → ee (PYTHIA)
sum
$c\bar{c}$ → ee (random correlation)
$b\bar{b}$ → ee (PYTHIA)
DY → ee (PYTHIA)
$dN/dm_{ee}$ ($c^2$/GeV) IN PHENIX ACCEPTANCE
Data/Cocktail
$m_{ee}$ (GeV/$c^2$)
CLAS
Fe-Ti
ω → e+e−, $\pi^0$e+e−
φ → e+e−
ρ → e+e−
fit result
e+e− Invariant Mass (GeV)
HADES
p+Nb
p+p (scaled)
$d\sigma/dM_{ee}$ [mb/(GeV/$c^2$)]
$\alpha_{ee}$ > 9°
0.1<$P_e$<2.0 GeV/c
$P_{ee}$ < 0.8 GeV/c
$M_{ee}$ [GeV/$c^2$]
$E_\gamma$ = 900-2200 MeV
|$\vec{p}_\omega$|< 0.5 GeV/c
$T_{\pi 0}$ > 150 MeV
BUU:
broadening+mass shift (α=-0.16)
Nb
$LH_2$
counts / [ 6 MeV/$c^2$]
$M_{\pi\gamma}$ [MeV/$c^2$]
TAPS
KEK PS
E325
Cu
counts/[6.7MeV/$c^2$]
$\chi^2$/ndf=83/50
[GeV/$c^2$]

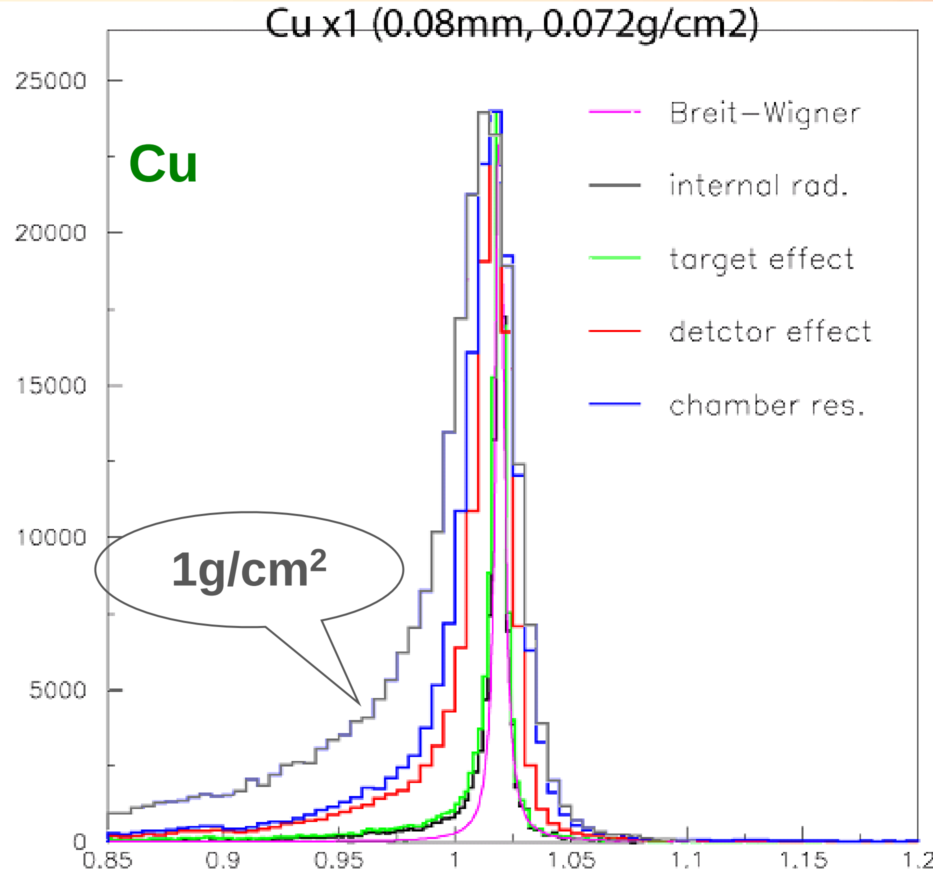
# Keys to Dilepton Measurement

- thin target (low material)
  - keep good S/N
  - suppress radiative tail
- good resolution
  - state spectral modification
- systematic study
  - crucial information to understand the physics behind

# Target

$$\sigma_V \propto A^{\alpha\approx 1}, Bremsh \propto Z^2, Background \propto Z^4$$

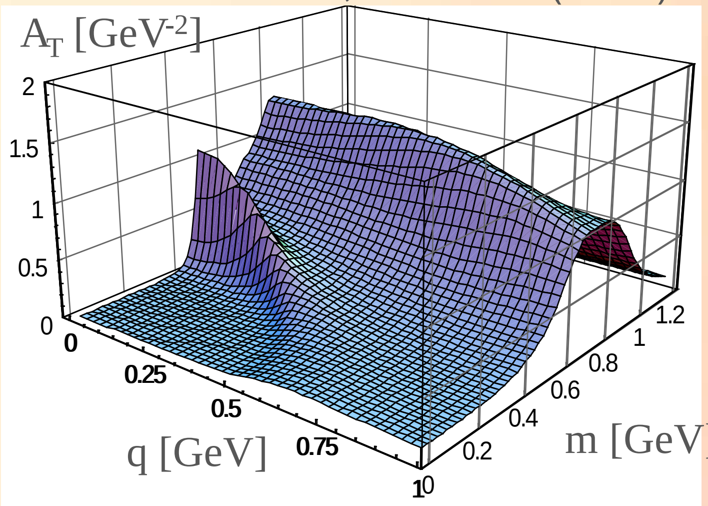
| | Target | | |
|---|---|---|---|
| | Matrl. | Beam Int. (pps) | Int. length |
| KEK E325 | Cu | 3x10[8] | 0.05% (0.07g/cm[2]) |
| CLAS | Fe-Ti | ~10[7]/s | 1g/cm[2] |
| TAPS | Nb | ~10[7]/s | 0.4% |
| HADES | Nb | 10[7]/s | ~2% |
| NA60 | In | 2.5×10[6] | 20% |



# Summary & Outlook

- ***Solid Statement***: spectral modification of vector meson have been observed in various  reactions at various energies.
- ***BUT*** there is no general consensus on the theoretical interpretations.

M. Post et al., NPA 741 (2004) 81

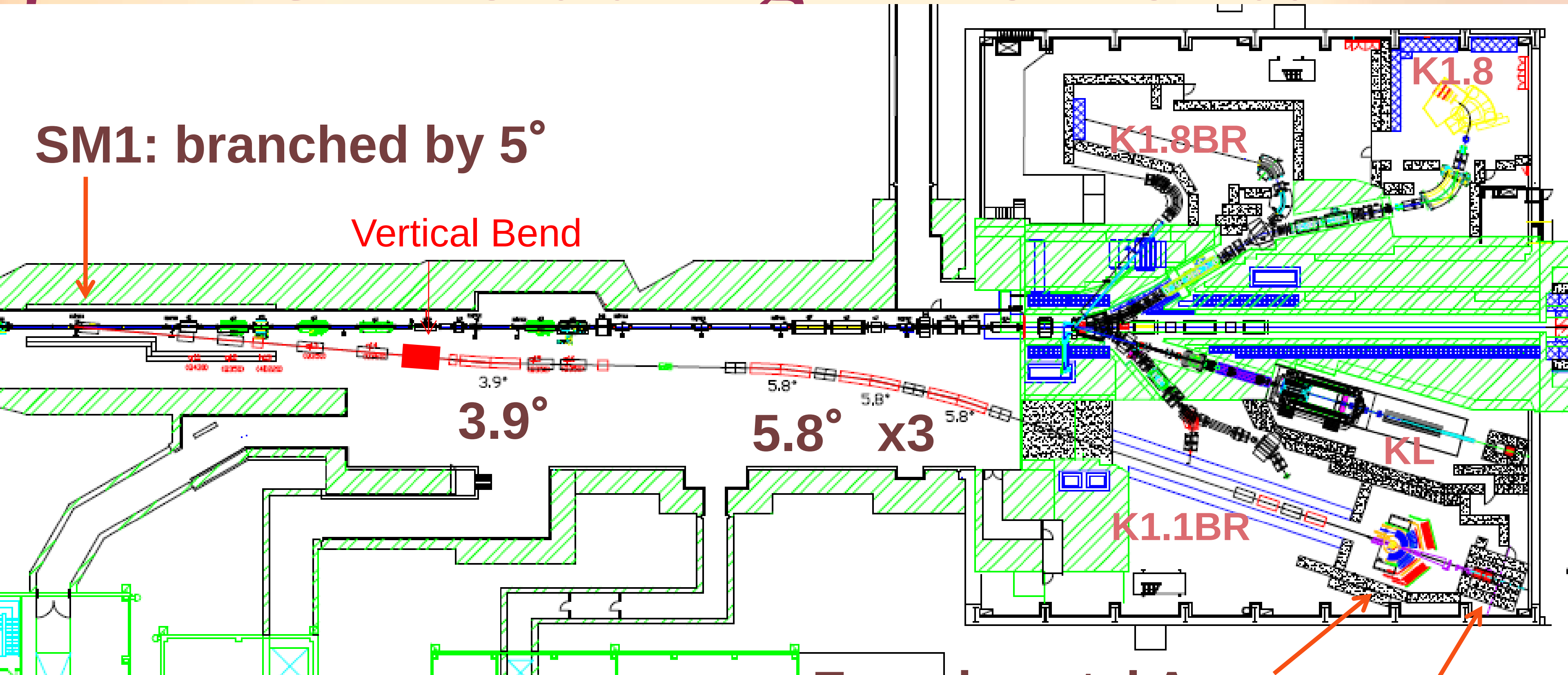



- The real effect might be a composition of shift, broadening and/or dip-like structure etc.
- The spectral modification will largely depend on momentum.

→ **precise measurement w/ high statistics & resolution**

  - systematic study: dispersion relation, system size dependence

# J-PARC E16 at High-momentum




at SM1 high-p beam branches off from the primary line

- 30 GeV primary proton ($10^{10}$/s, $10^{12}$/s)
- 8 GeV primary proton for COMET
- secondary particles (~20 GeV/c)

# Di-electron spectrometer to investigate medium mass modification of vector meson (J-PARC E16)

$10^7$ interaction (10 X E325)

$10^{10}$ protons/spill

with 0.1% interaction length target

→ **GEM Tracker**

**Large Acceptance (5 X E325)**

Higher energy beam (12→ 30GeV)

x ~ 2 of production CS

**100 times as large statistics as E325**

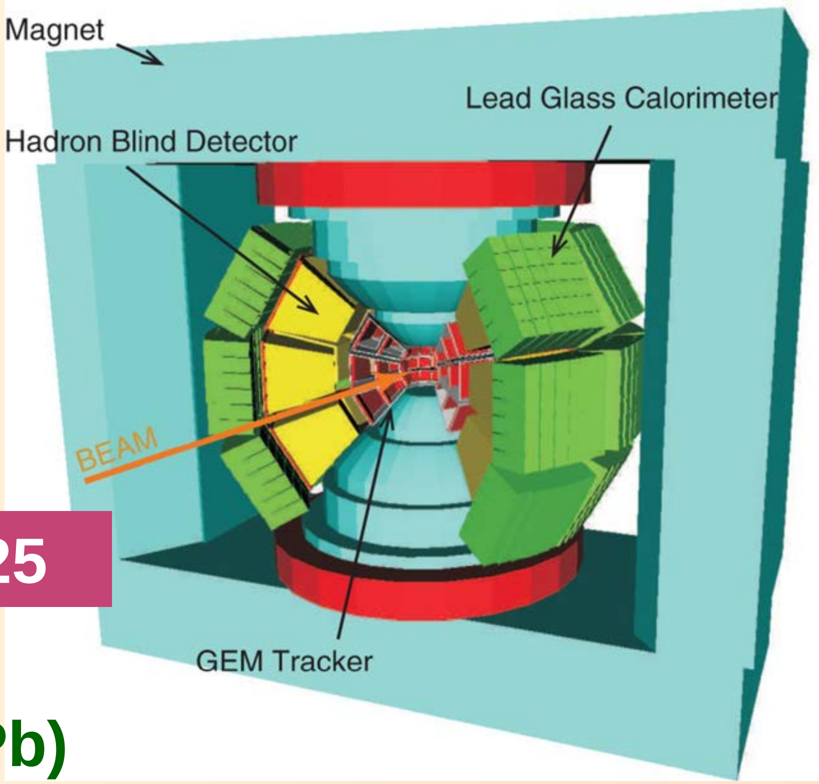
**velocity dependence**

**nuclear number dependence (p → Pb)**

**centrality dependence**

→systematic study of mass modification

**E-ball @ high-p BL**



# Detector R & D

Particle tracking in a magnetic field and measure momentum.

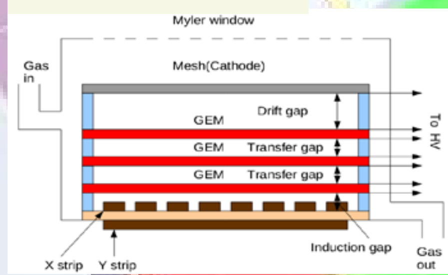
**Gas Electron Multiplier (GEM)**

- **High Rate Capability (up to 25kHz/mm$^2$)**
- **Can cover Large acceptance (No wire)**
- **Good resolution & Low material**

3 chambers of GEM Tracker @ r=20, 40, 60 cm

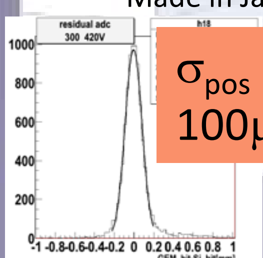
GEM foil (30cm x 30cm)

One GEM tracker




Beam test @ Tohoku ELPH

Made in Japan




$\sigma_{pos}$ 100$\mu$m

- Enough position resolution is achieved.
- Ready for mass production.

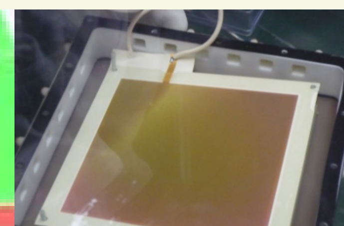
Electron identification in large acceptance

**Hadron Blind Detector (HBD)**

- **Mirror less gas cherenkov counter**
- **CsI photocathode (UV sensitive) +**
- **Gas Electron Multiplier (GEM)**
- **Follow PHENIX exp @ BNL**

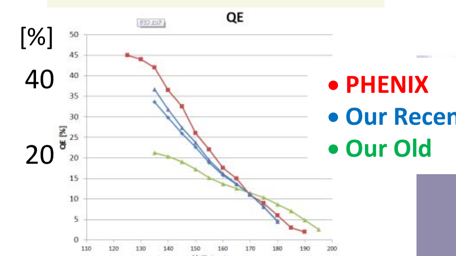
CsI is evaporated on the surface of the top GEM.
Photoelectrons are amplified using GEM (like Track

CSI evaporated GEM foil



GEM made in Japan
CsI is evaporated by ourselves.

Quantum Efficiency

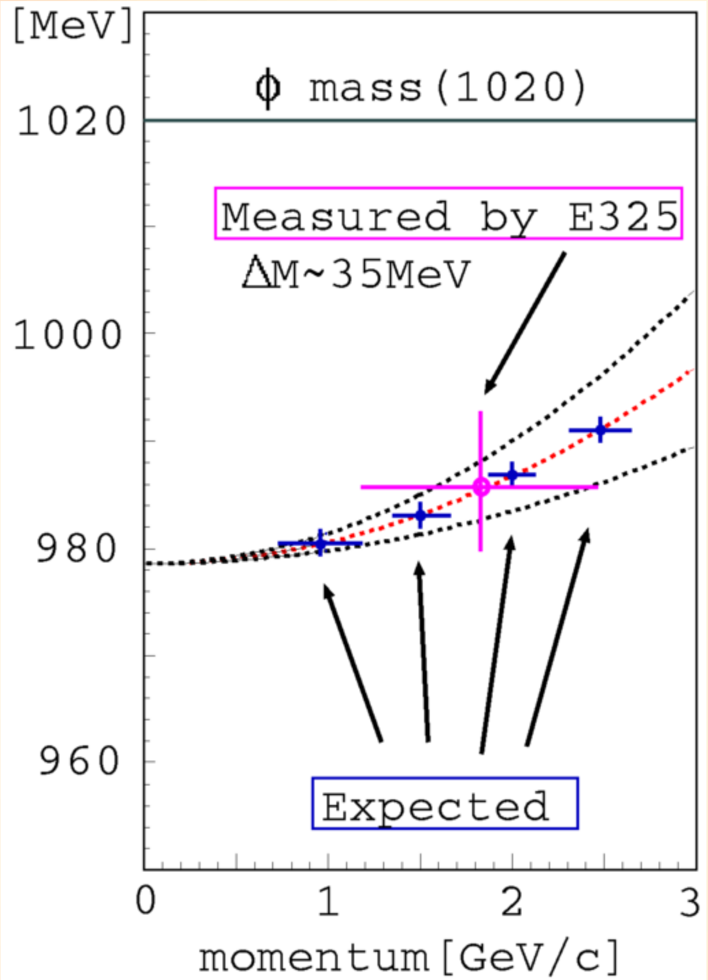


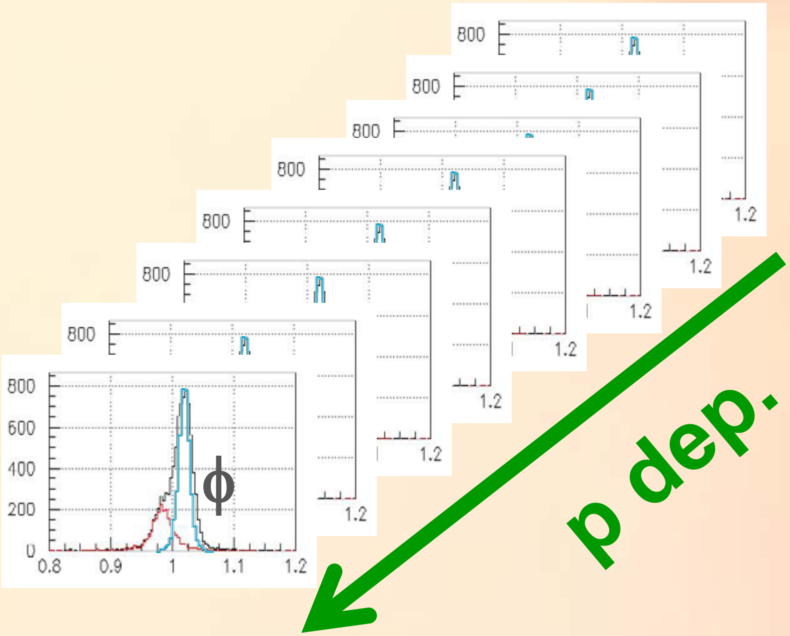

Enough Q.E. is achieved

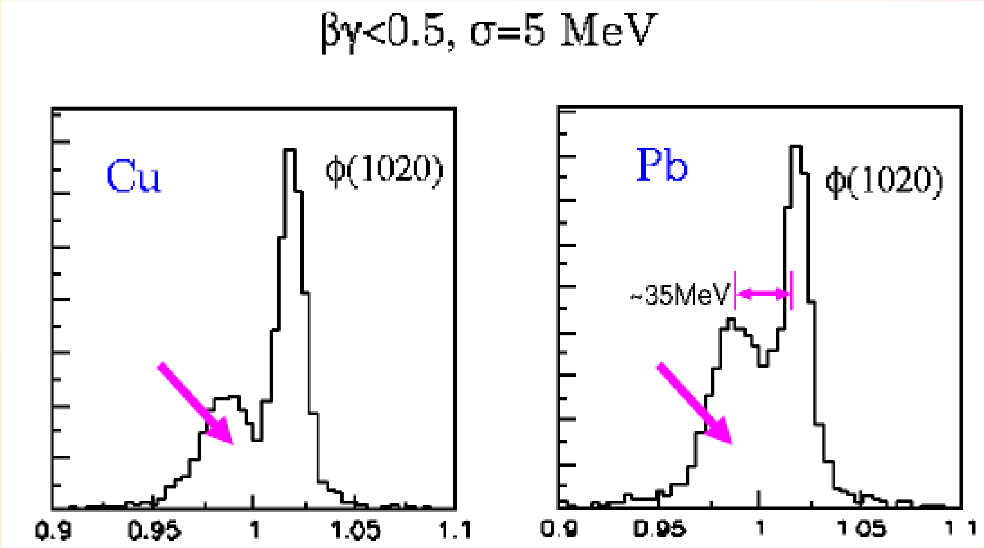
- pion rejection factor 100 with e-efficiency 70% achieved.
- Improvement of efficiency is on going.

# Expected Signal

momentum dependence of mass



# History & Schedule

- 2014
  - beam line construction
  - mass production
- 2015
  - spectrometer construction at the hadron hall
- 2016 Jan.
  - high-momentum beam line is completed.
  - first commissioning run


CSB
大岳1584.4m
赤倉岳1548m
井戸岳1550m
山頂駅
VI箒場平ルート
V八甲田温泉ルート
IV銅像ルート
前岳1251.7m
田茂萢岳1324m
II中央ルート
宮様ルート
spectrum in extreme condition
dilepton measurement
八甲田ロープウェー（101人乗り）
pionic atom
systematic studies
酸ケ湯ルート
酸ケ湯温泉
田茂萢沢
危険区域
寒水沢
危険区域
III城ケ倉ルート
八甲田ホテル
至十和田湖
城ケ倉温泉
ホテル城ケ倉
八甲田山ペアリフト
国見坂ゲレンデ
田茂萢ゲレンデ
至青森市内
国道103号
レストハウス八甲田
駐車場
山麓駅
駐車場
レンタル&スクール
山小舎
八甲田山荘
ヒュッテ寒水
寒水沢温泉
八甲田リゾートホテル
※コース・ルート以外の滑走は危険ですので、ご遠慮下さい。

# Thank you for your attention!