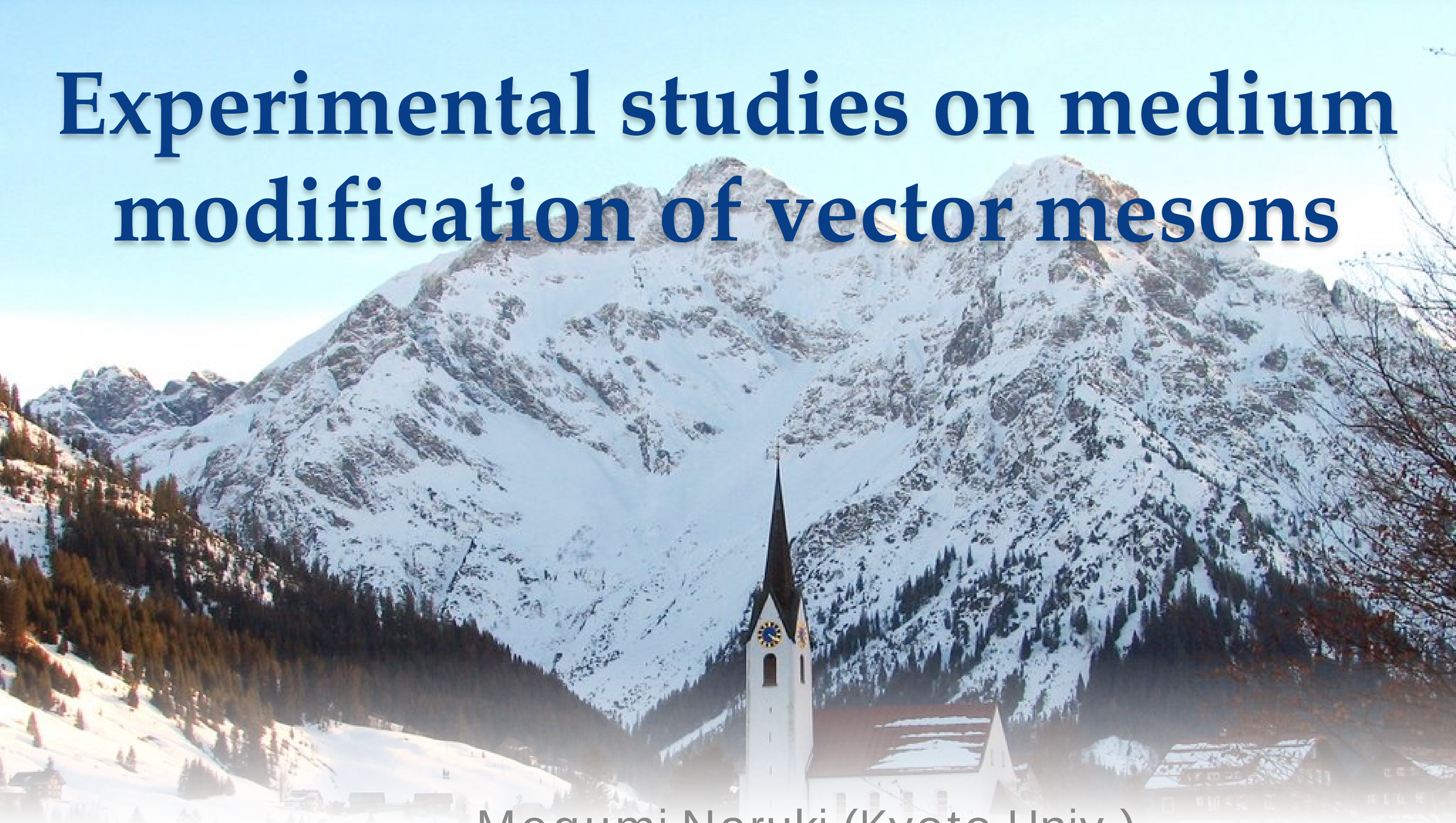
Experimental studies on medium modification of vector mesons

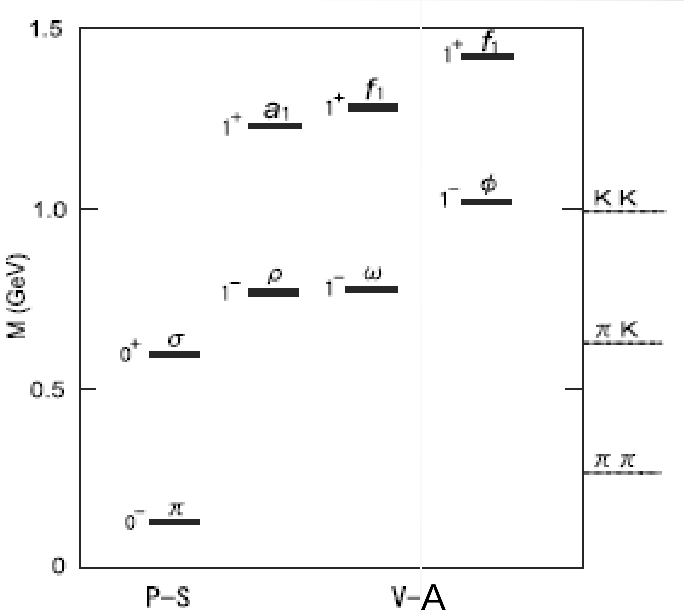


Megumi Naruki (Kyoto Univ.)

- Introduction
- dilepton measurement so far
- near future project at J-PARC

Hadron Mass

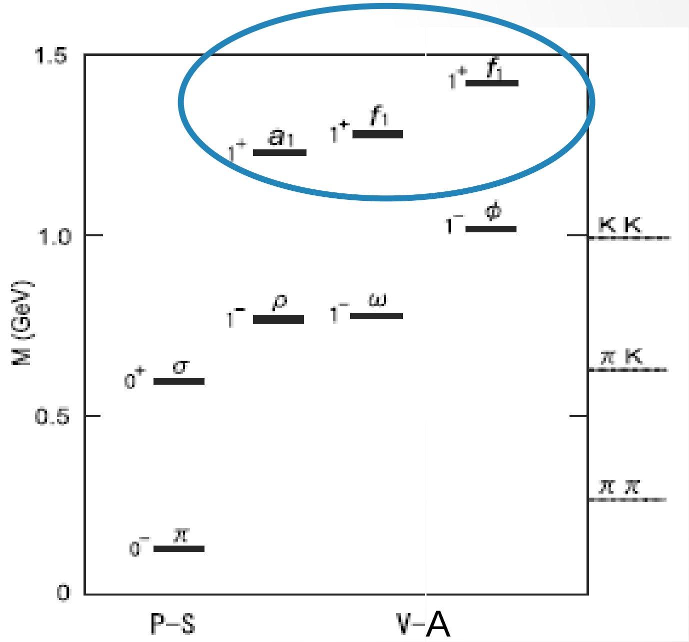
- spontaneous chiral symmetry breaking
  - o mechanism to generate hadron mass: really visible in universe. ~98% of protons' mass.
  - o experimental fact : parity doublet patterns
- origin of order parameter not a priori given
  - o quark condensate : $\langle \bar{q}q \rangle$ <-> $f_\pi m_\pi$
  - o four-quark condenste, strong gluonic interaction



Experimental Approach

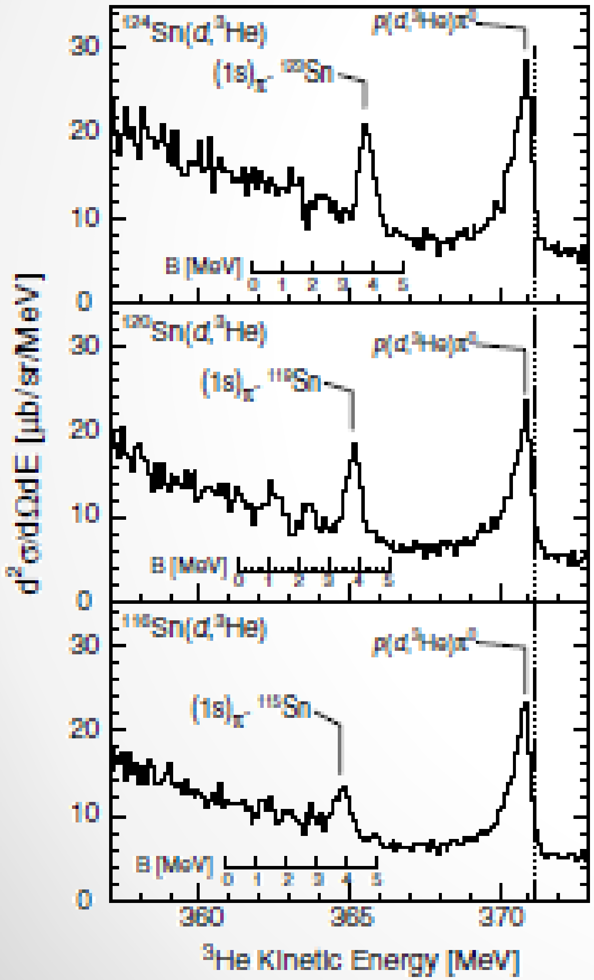
- bound system
  - pionic atom
    - – S236 experiment @ GSI
- nuclear mass number dependence
  - width modification
- dilepton measurement
  - mass of vector meson in hot/dense matter

hadronic decay, board width..



pionic atom spectroscopy

K. Suzuki et al., PRL 92(2004) 072302



S236 experiment @ GSI

π bound state is observed in Sn(d, ^{3}He) pion transfer reaction.

Reduction of the pion decay constant $f^*_\pi(\rho)^2/f_\pi^2 \approx 0.64$ *at the normal* nuclear matter density ($\rho = \rho_0$)

← W-T relation : $b_1/b_1(\rho_e) \approx f_\pi(\rho_e)^2/f_\pi^2$

from the p-nucleus scattering data, this can be connected to quark condensate in the medium.

$$\frac{\langle\bar{q}q\rangle^*}{\langle\bar{q}q\rangle} \cong \left(\frac{b_1}{b_1^*}\right)^{\frac{1}{2}}\left(1-\gamma\frac{\rho}{\rho_0}\right)$$

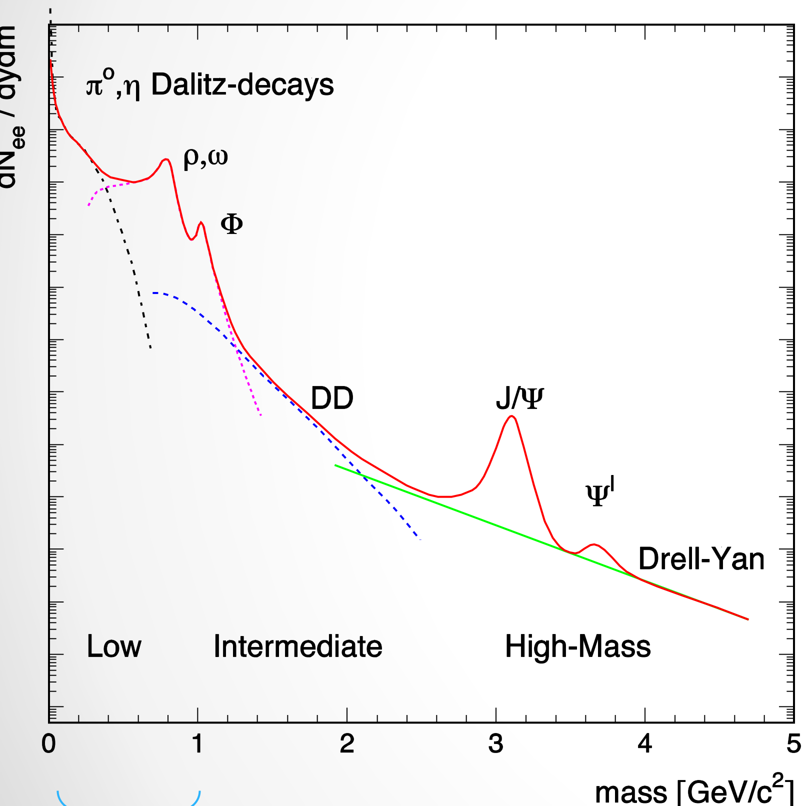
D. Jido et al., PLB670 (2008) 109

37% decrease of $\langle\bar{q}q\rangle$ at ρ_0

→ chiral symmetry restoration?

Dilepton Measurement

directly access to the properties of vector mesons



light quarks u, d — strange — charm

Low Mass Range $M_{ee} < 1.1$ GeV/c^2

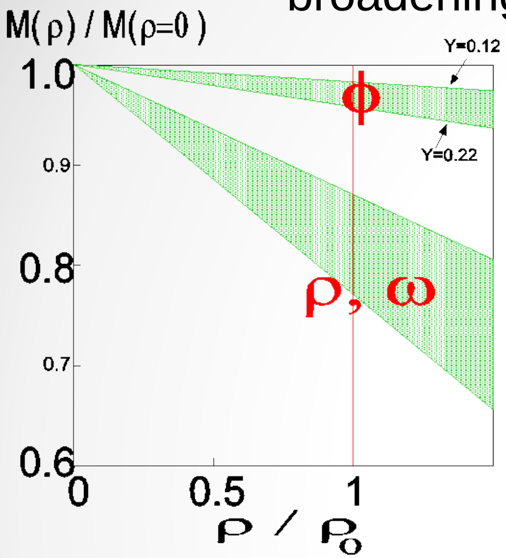
in-medium modification of vector mesons
possible connection to CSB

	Width	$c\tau$	ρ,ω vs ϕ
ρ	149.2 MeV	1.3 fm	large effect overlap
ω	8.44 MeV	24 fm	
ϕ	4.26 MeV	47 fm	single peak

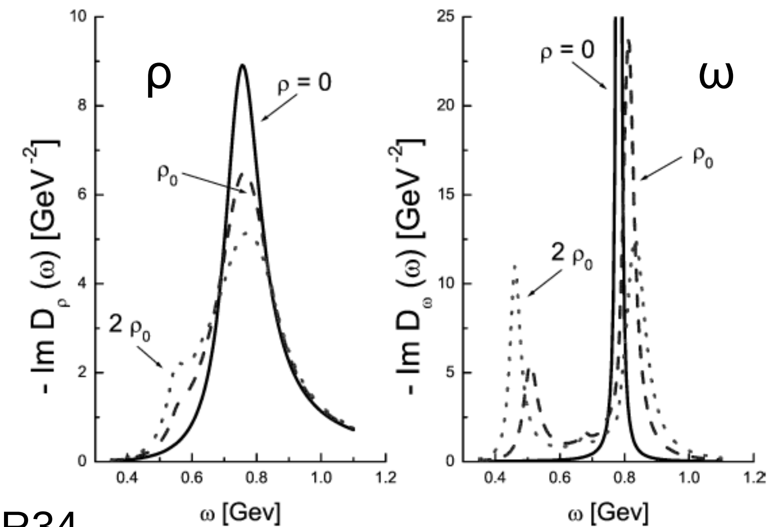
Density dependence of Mass

broadening, shift, low-mass peak :ρN*N

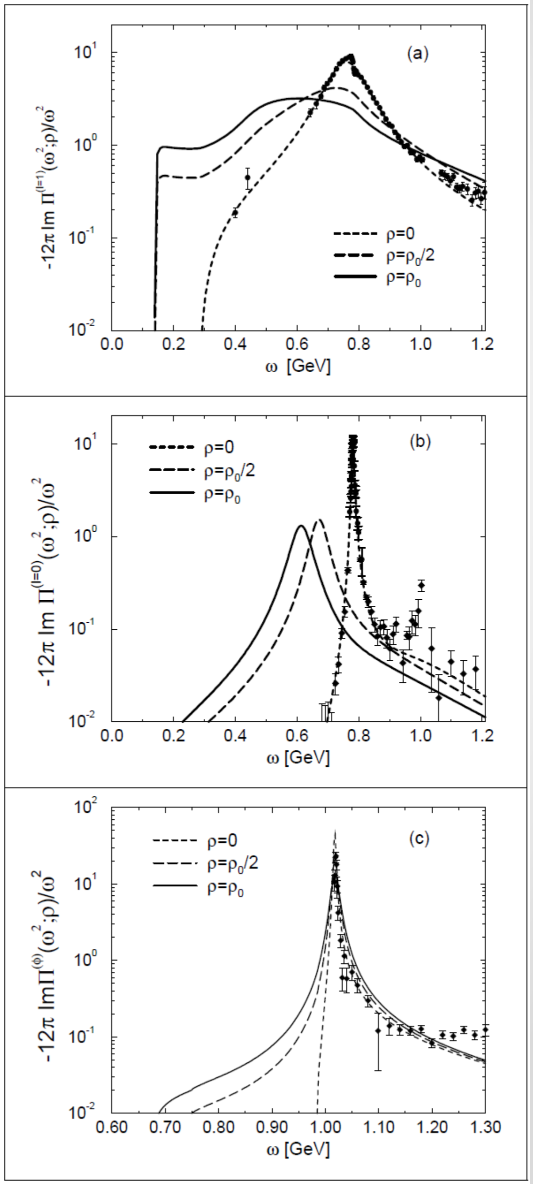
Klingl,Kaiser&Weise, NPA624('97)

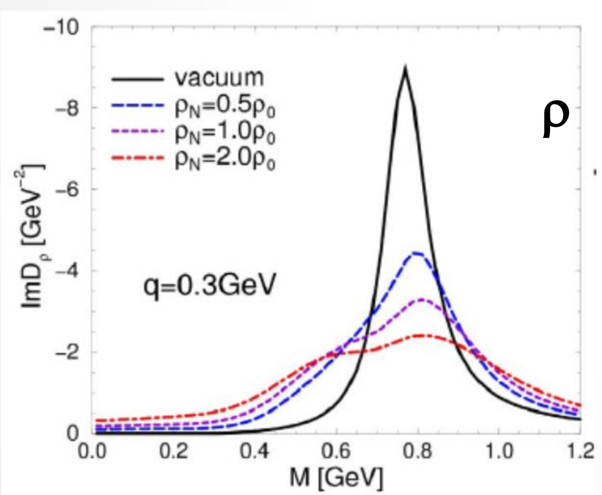


Hatsuda & Lee, PRC46('92)R34
base on QCDSR

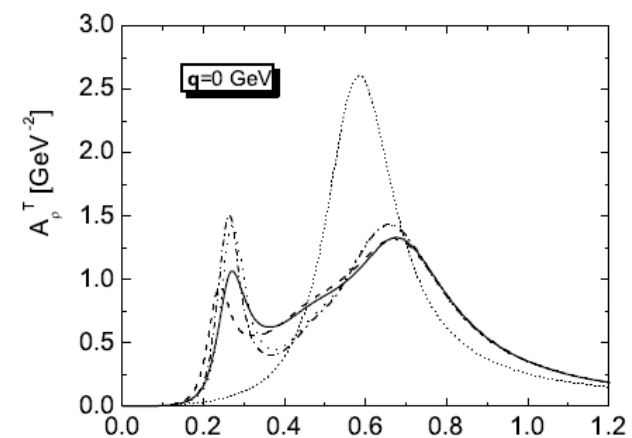


Lutz&Friman, NPA706('02)





Rapp & Wambach, ANP25 ('00)

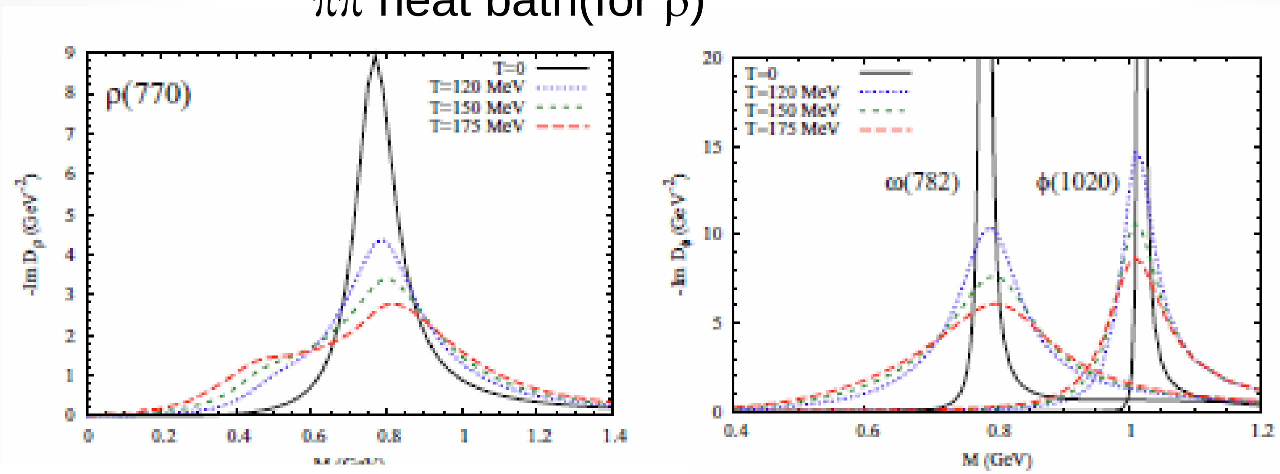


M. Post et al, NPA741('04)

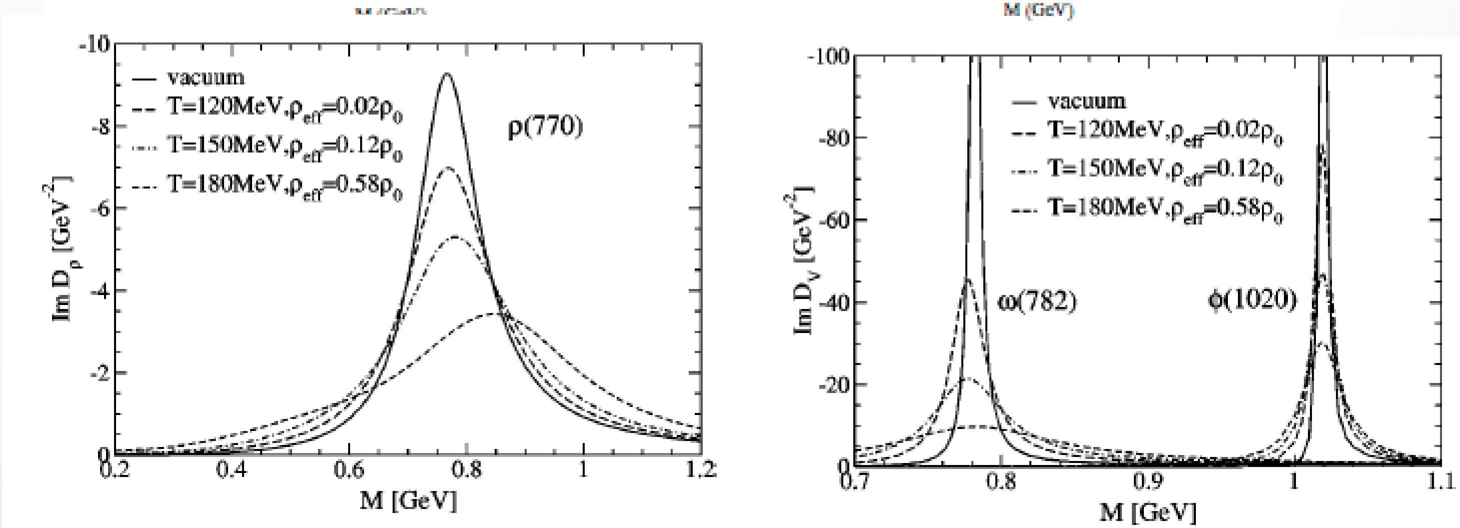
Temperature dependence

many-body theory: π-clouds w/ πBN,πBB
+ anti-baryon
ππ heat bath(for ρ)

SPS



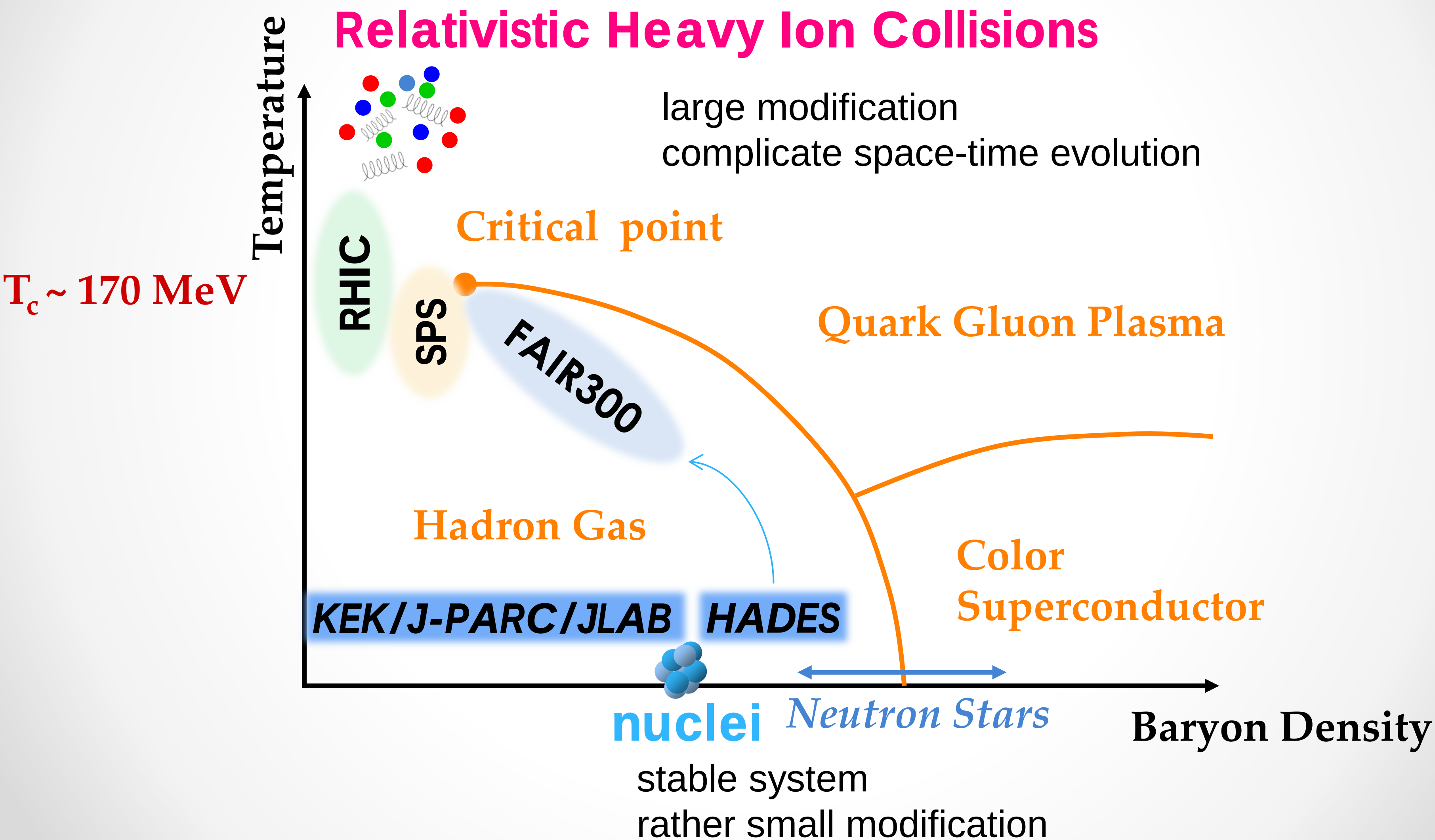
RHIC



melting at high temperature

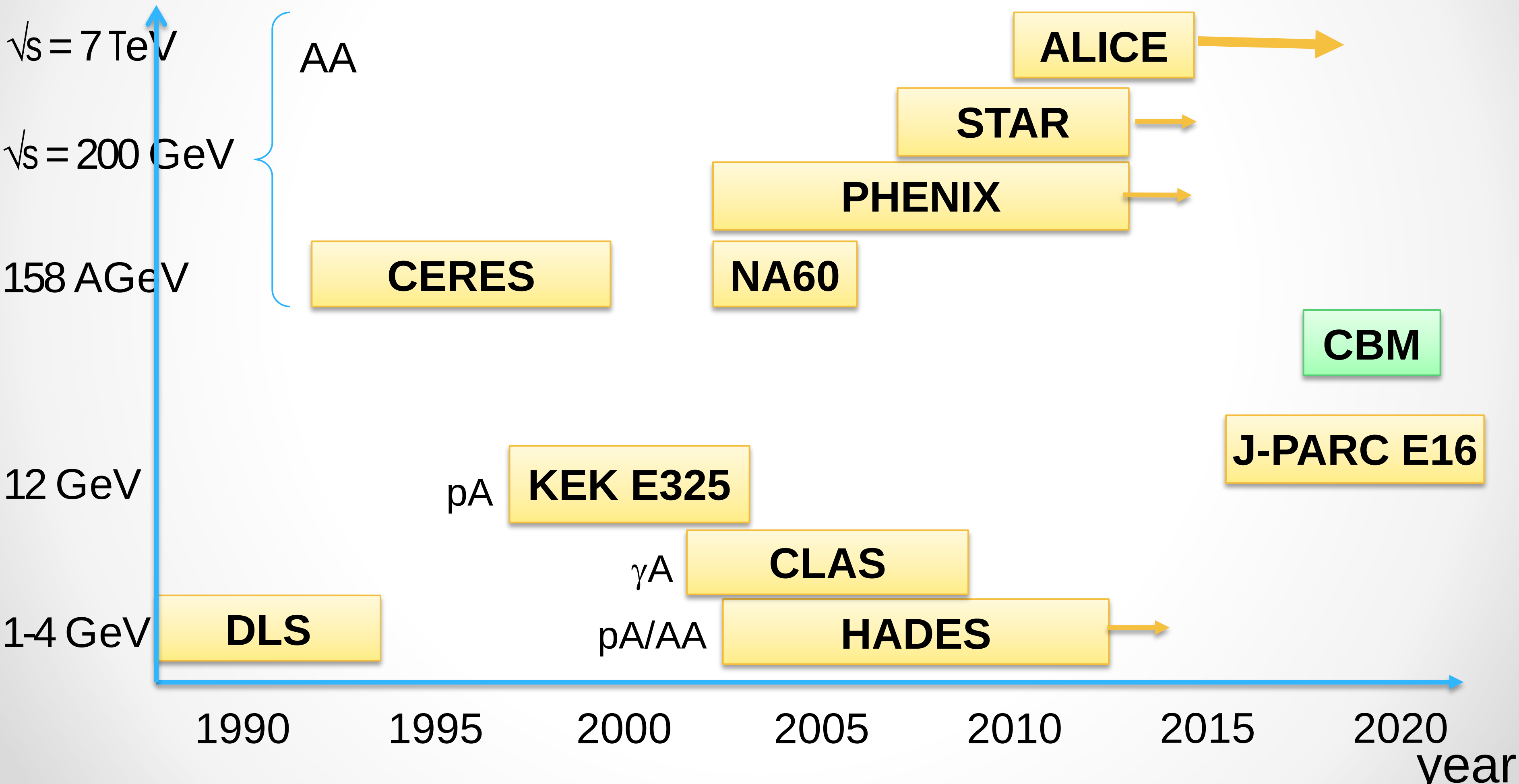
van Hees & Rapp NPA806(2008)

HIC vs. cold nuclear matter



Dilepton Measurements

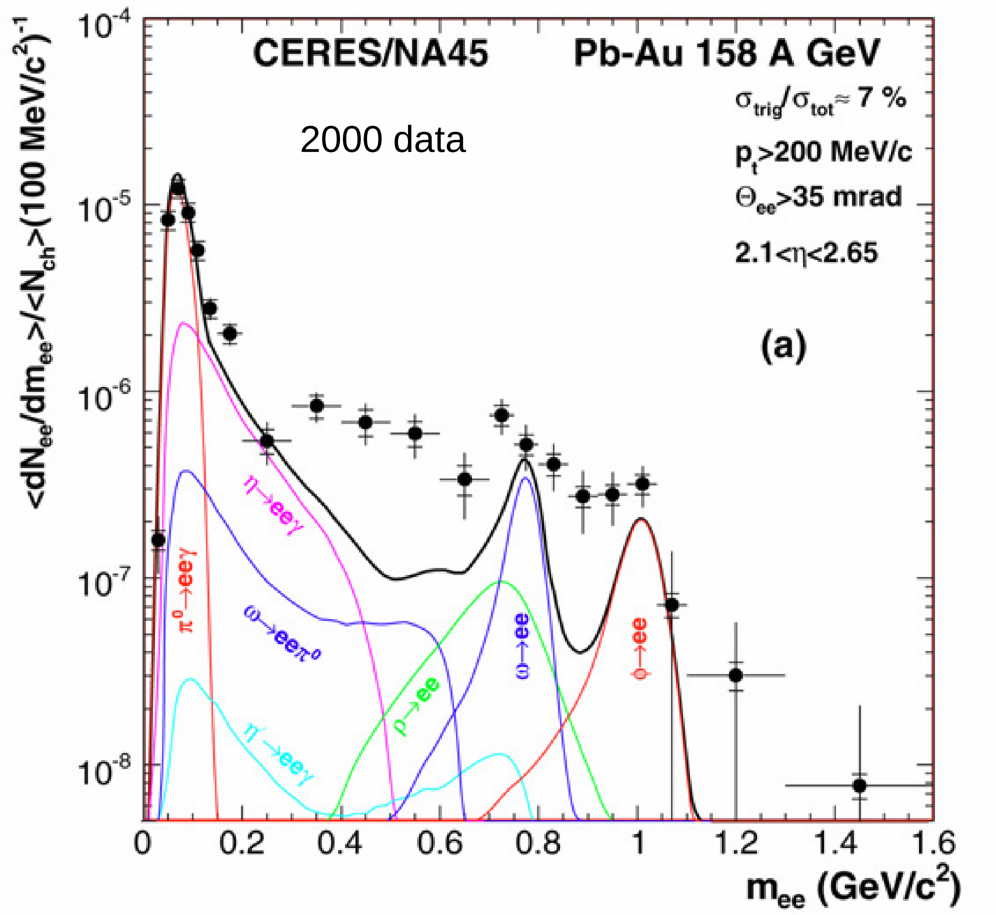
History vs. Energy scale



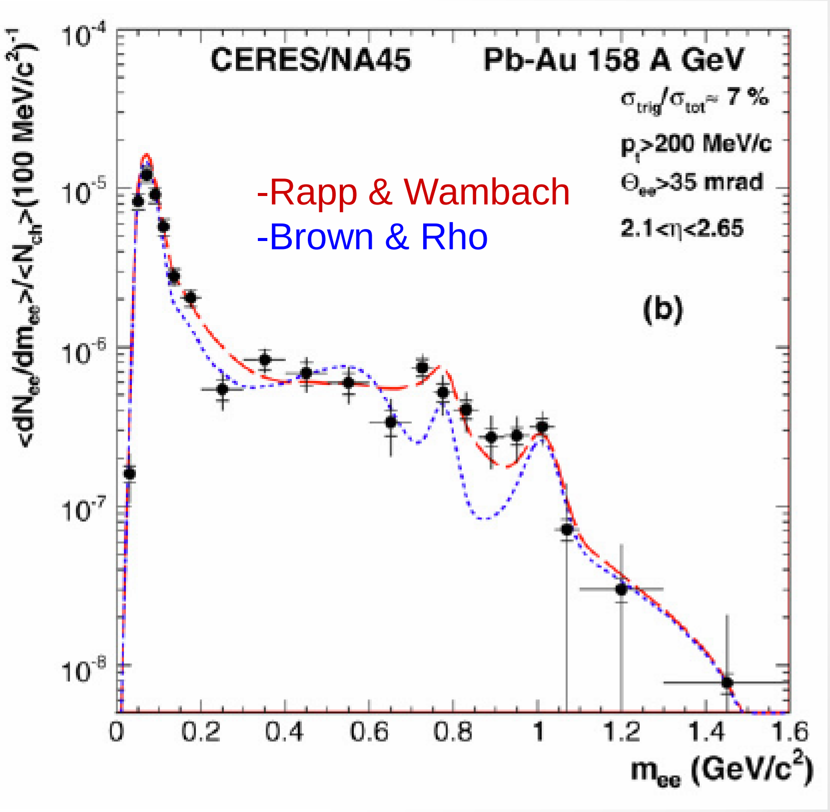
Experimental results at high temperature

CERES @ SPS

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



Phys. Lett. B666 (2008) 425

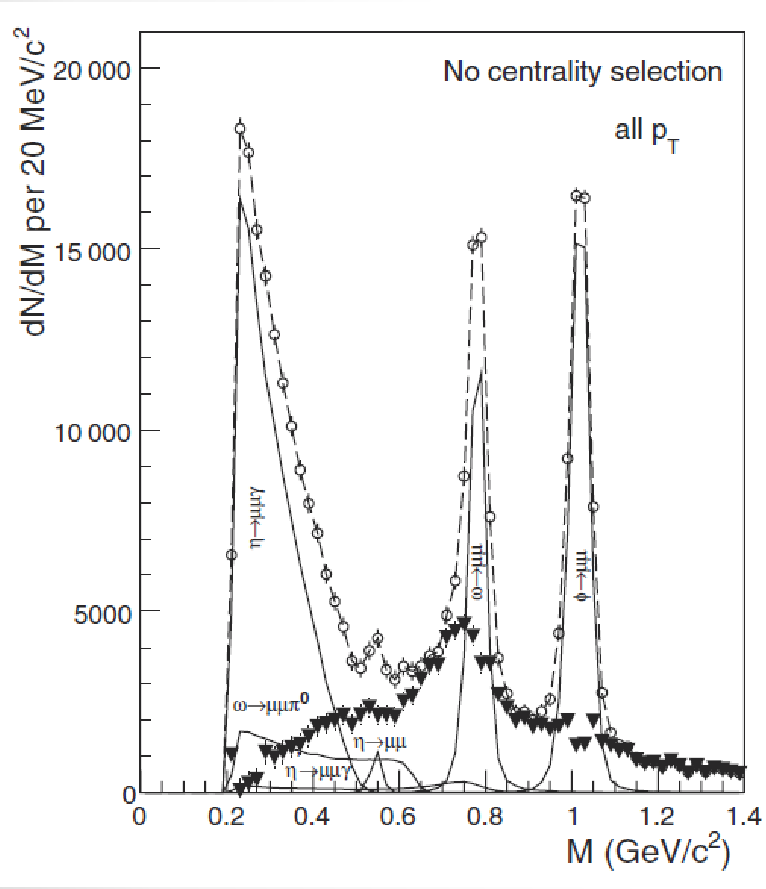


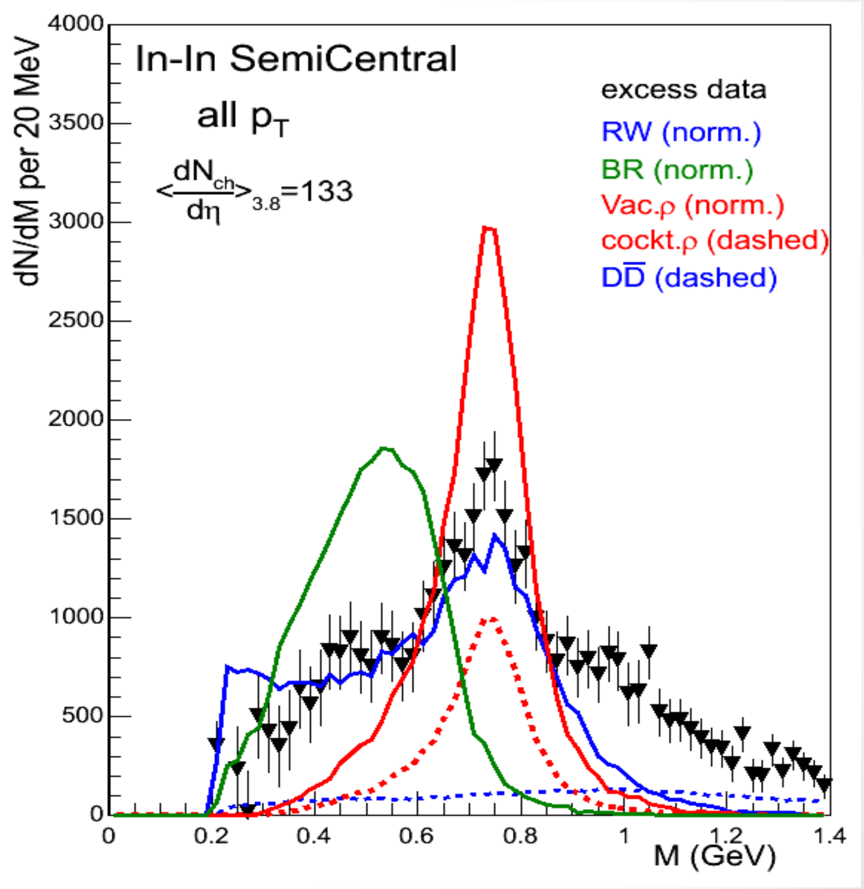
both scenarios are possible
within the systematic uncertainty

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

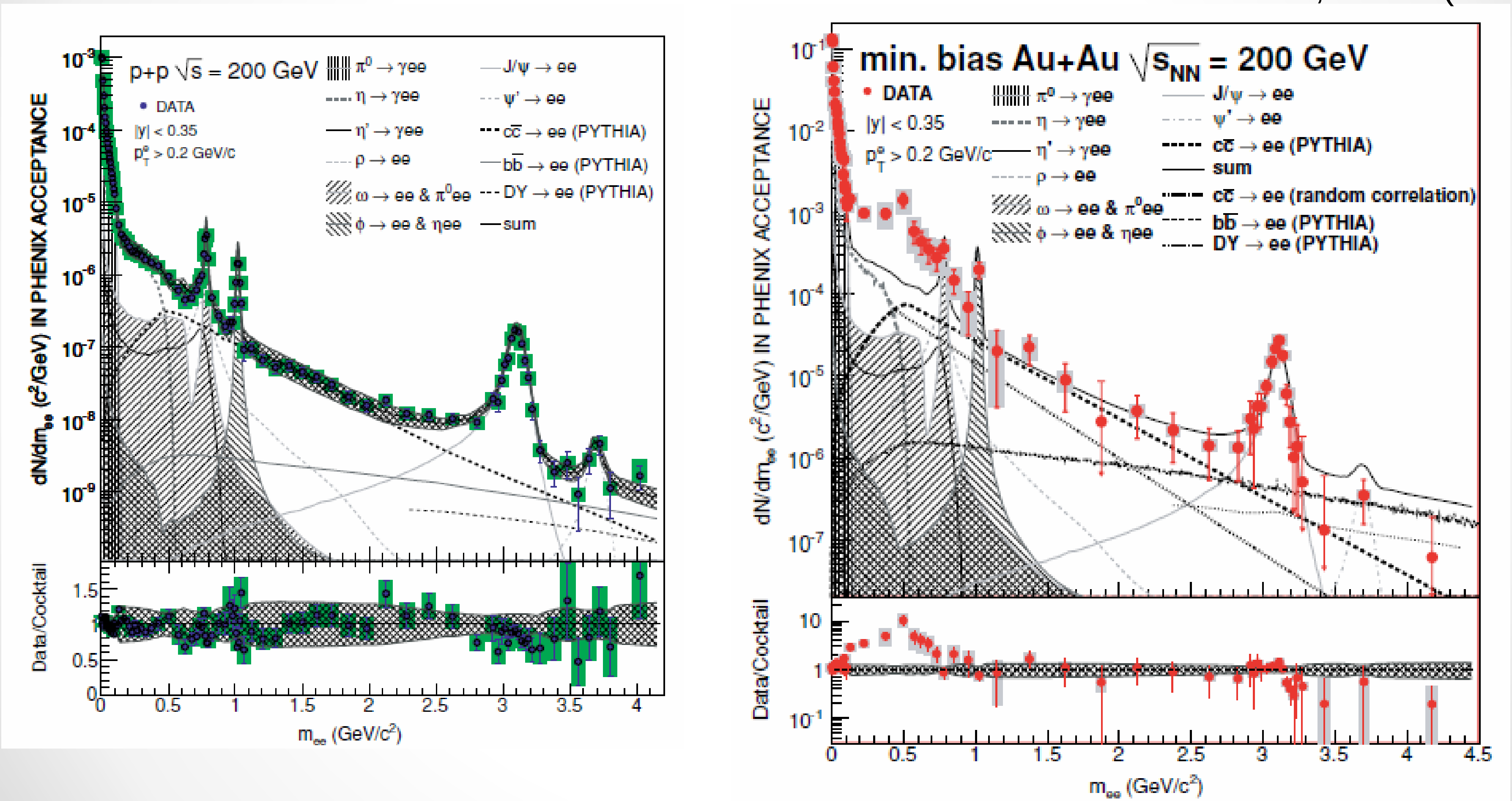
ρ spectrum is reproduced with broadening of ρ (Rapp & Wambach)

space-time evolution: thermal fireball model

PHENIX @ RHIC

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

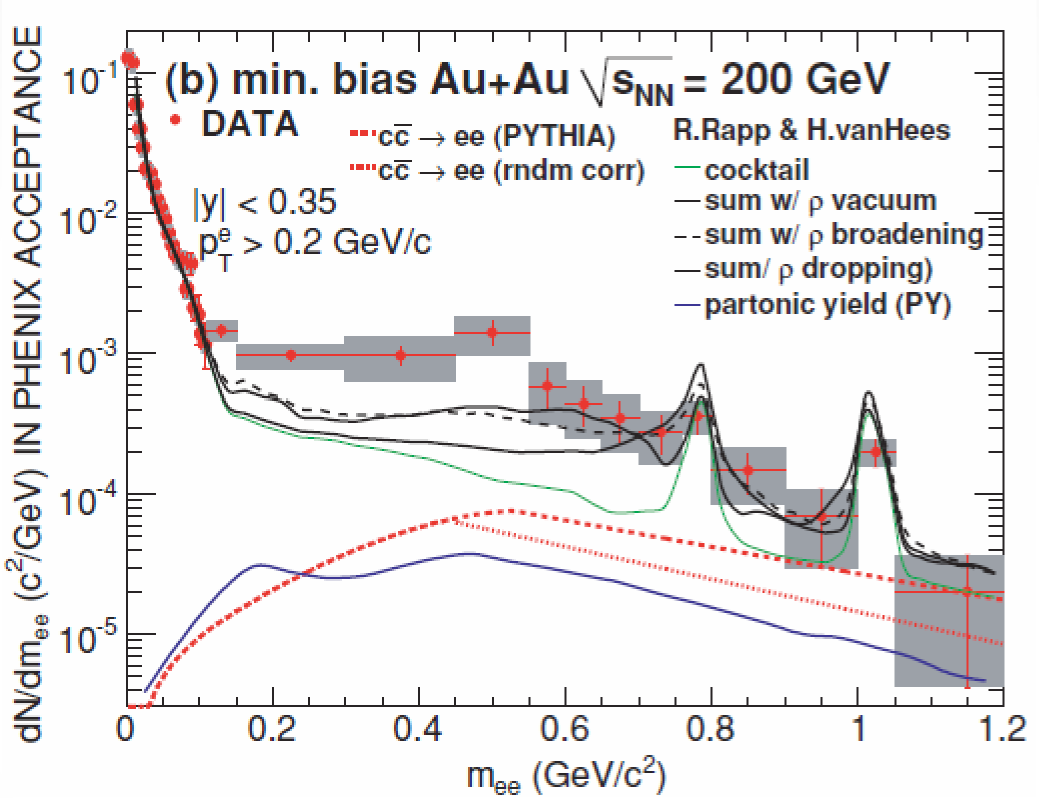
PRC81,034911(2010)



strong enhancement in 150 <m_{ee}<750 MeV:

4.7 ± 0.4(stat.) ± 1.5(syst.) ± 0.9(model)

Comparison w/ Models

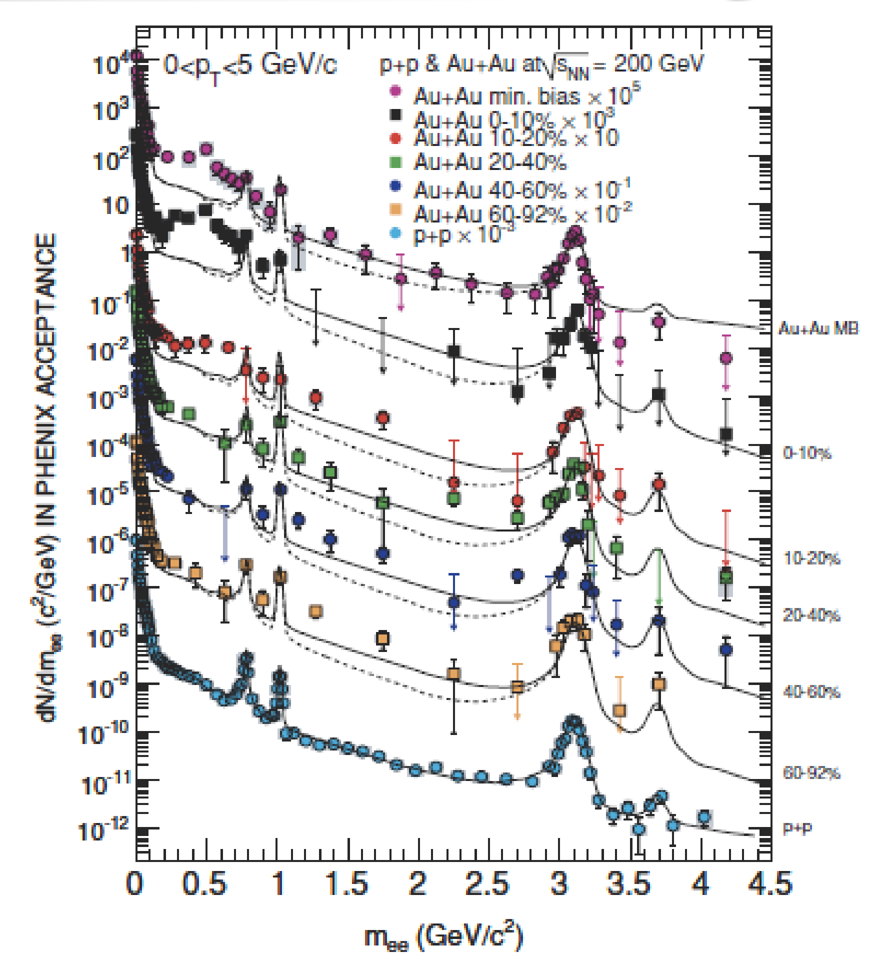


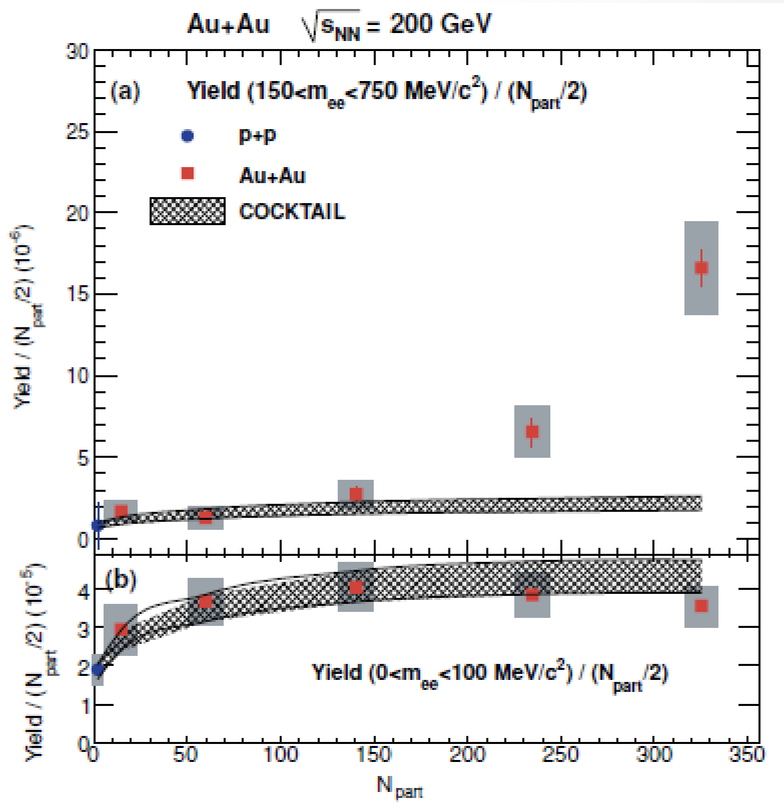
PRC81,034911(2010)

- thermal fireball model by Rapp & vanHees
- Hydro dynamical evolution model by Dusling & Zahed
- Transport model by Bratkovskaya & Cassing

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

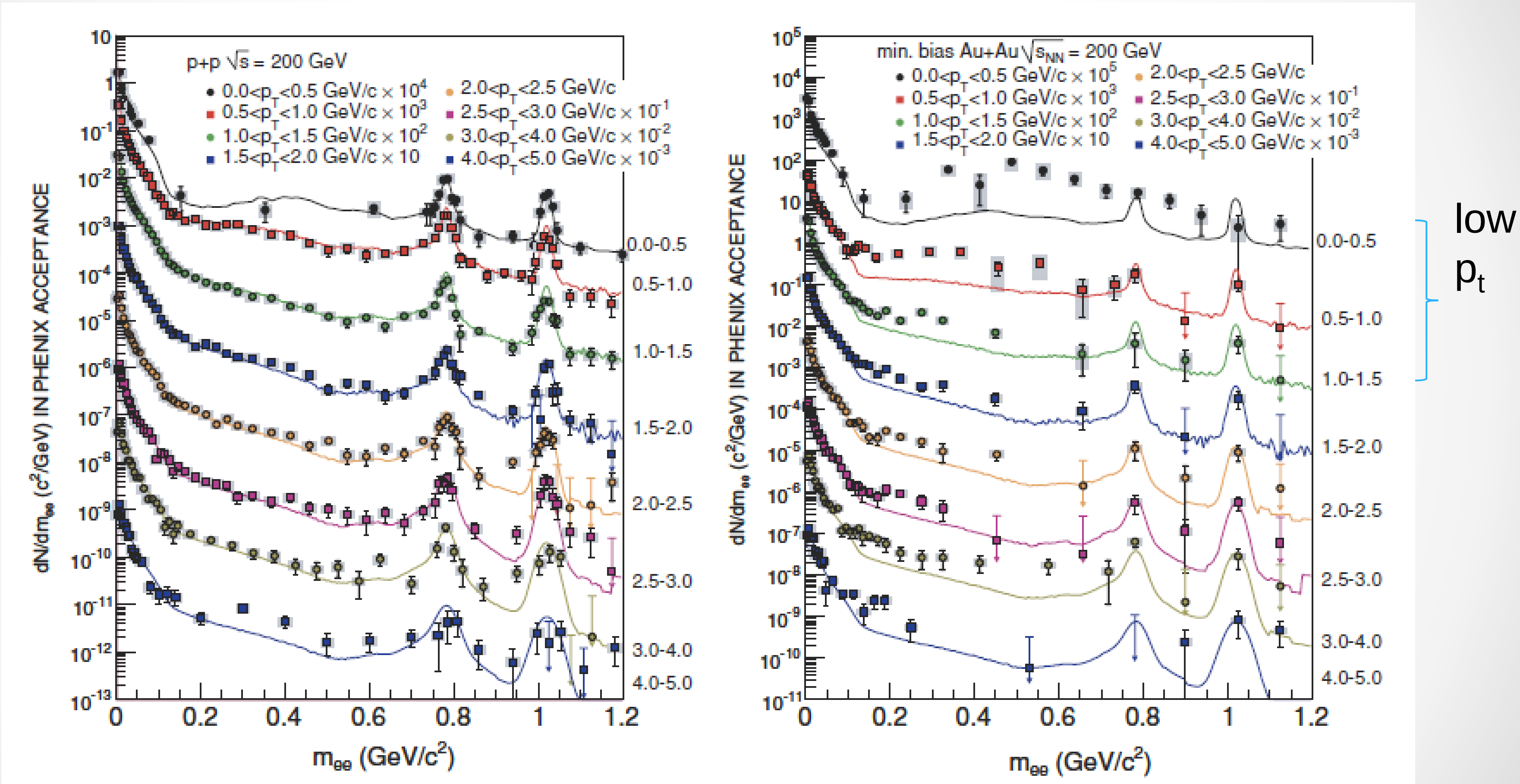
Centrality dependence





Strong centrality dependence in the Low-Mass Region.

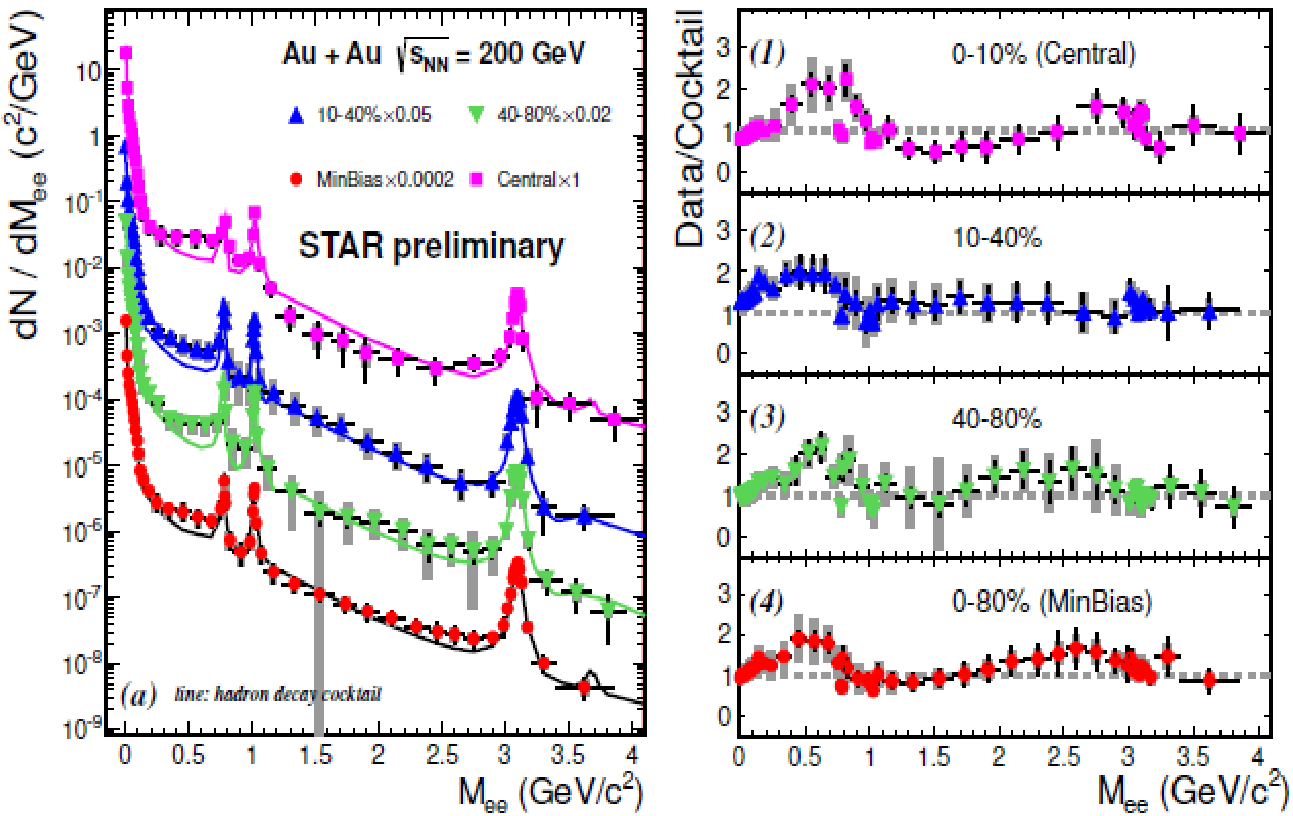
p_T dependence of low mass enhancement

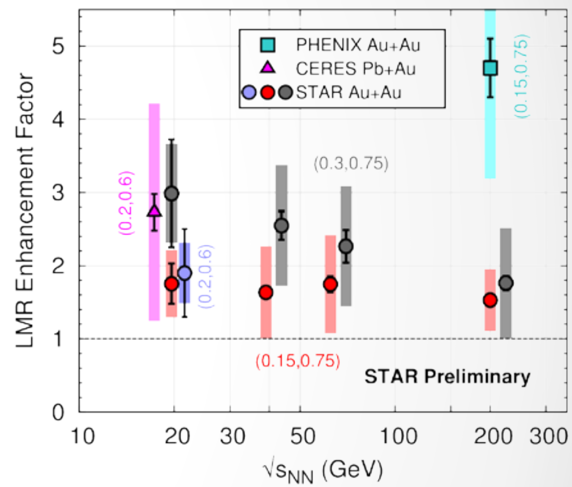


Low mass excess in Au-Au concentrated at low p_T

STAR in Au+Au collisions

F. Geurts *et al.*, J. Phys., **458** (2013) 012016



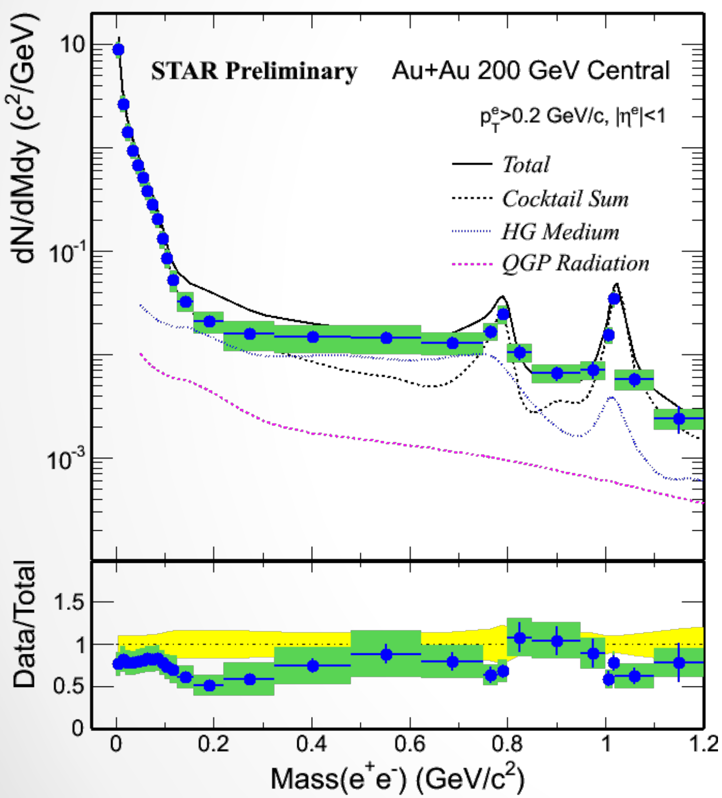


clear enhancement over the hadronic cocktail

weak centrality dependence

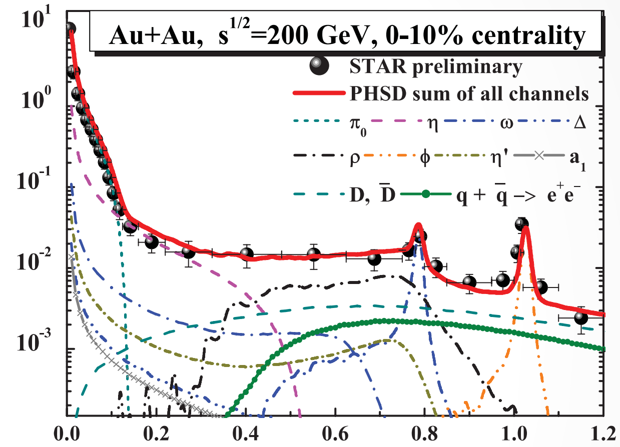
Comparison w/ Model

Thermal model by R. Rapp (priv. comm.) cf. PRC 63 (2001) 054907

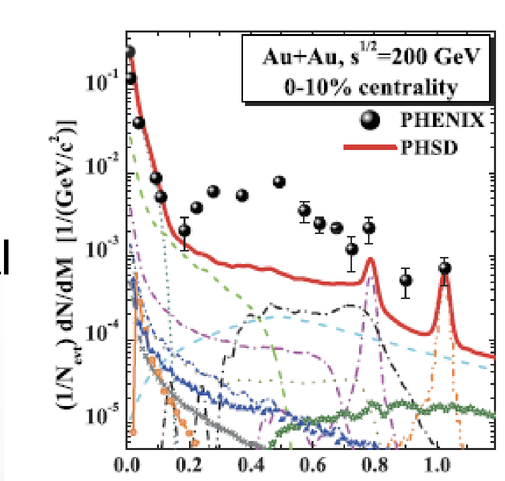


rough agreement in M_{ee} > 0.4GeV but overshoot in low-mass side

Transport model by Linnyk et al. PRC85, 024910(2012)

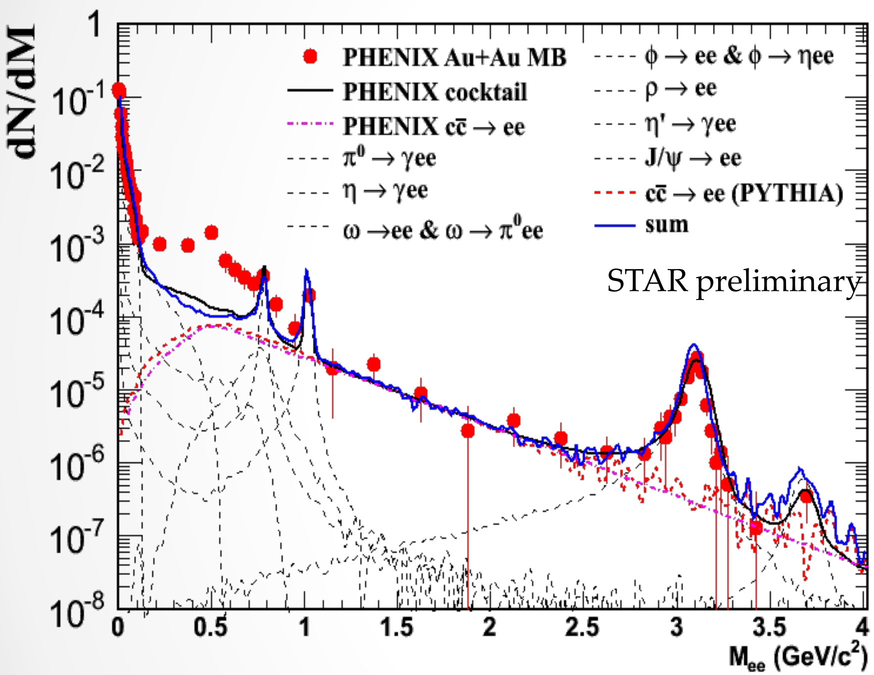


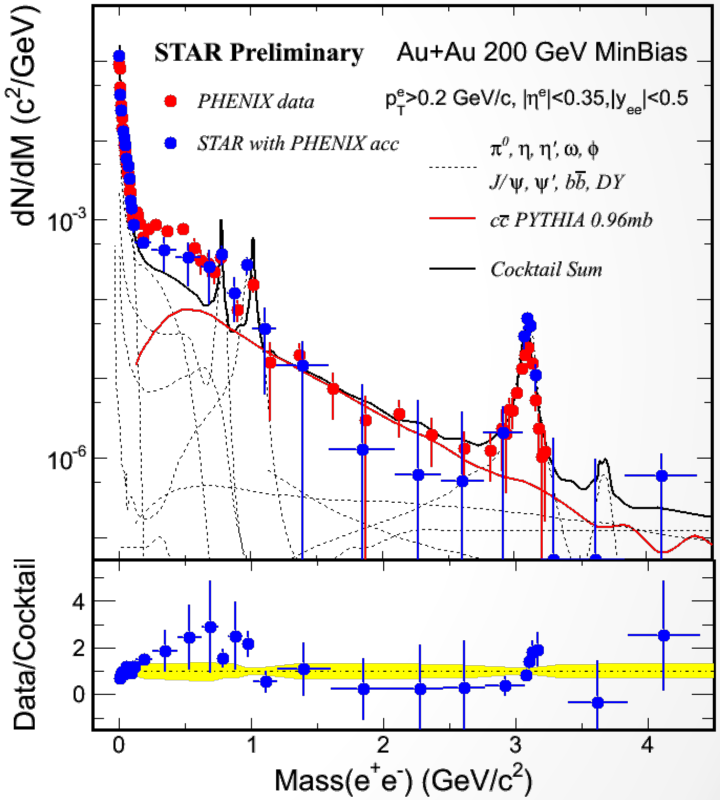
rough agreement with STAR central but not with PHENIX



STAR vs. PHENIX

F. Geurts, presentation at WWND2013





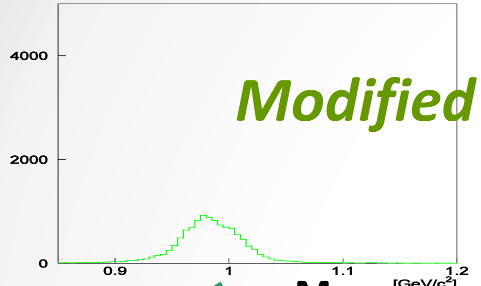
Scaled by all the yields from PHENIX result, STAR reproduces the PHENIX cocktail.

Experimental Results in cold nuclear matter

…

Signal on the spectrum

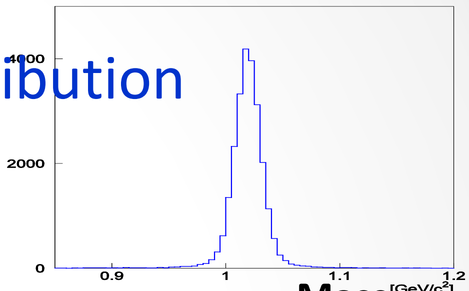
Decay inside Nucleus



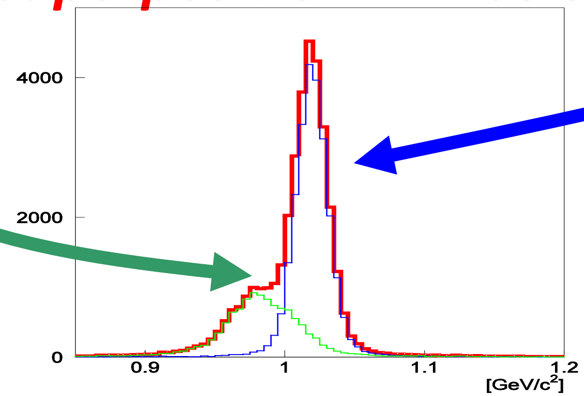
Modified Distribution

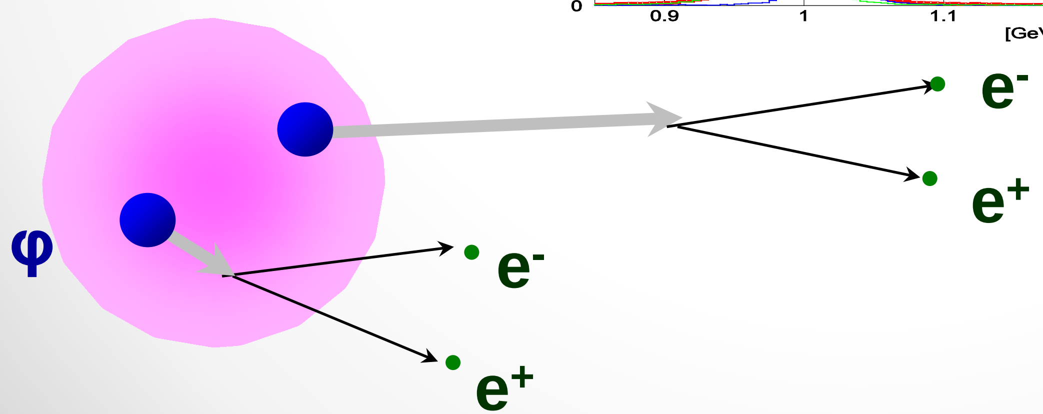
Decay in vacuum

Normal Distribution
(known)



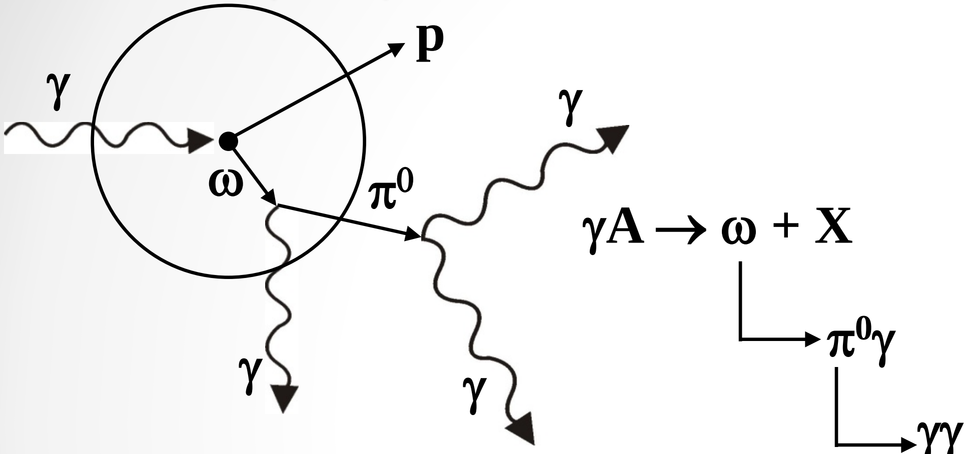
The superposition will be observed





CBELSA/TAPS experiment

$\omega \to \pi^0\gamma$ in γ+A



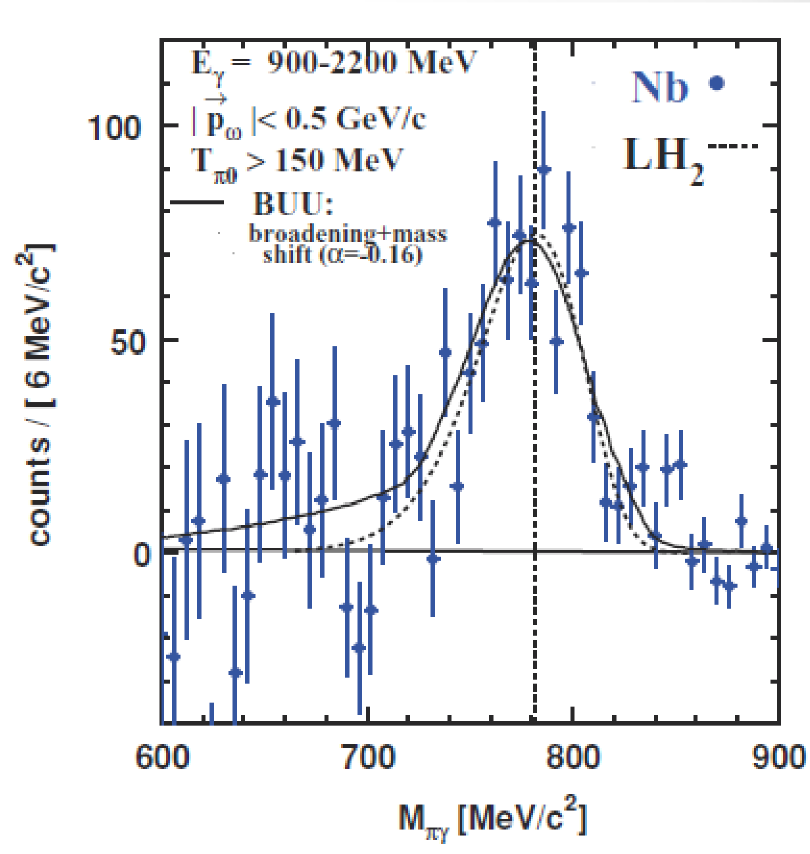
$$m_\omega = \sqrt{(p_\pi + p_\gamma)^2}$$

<u>**advantage:**</u>

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

<u>**disadvantage:**</u>

- **π^0-rescattering**

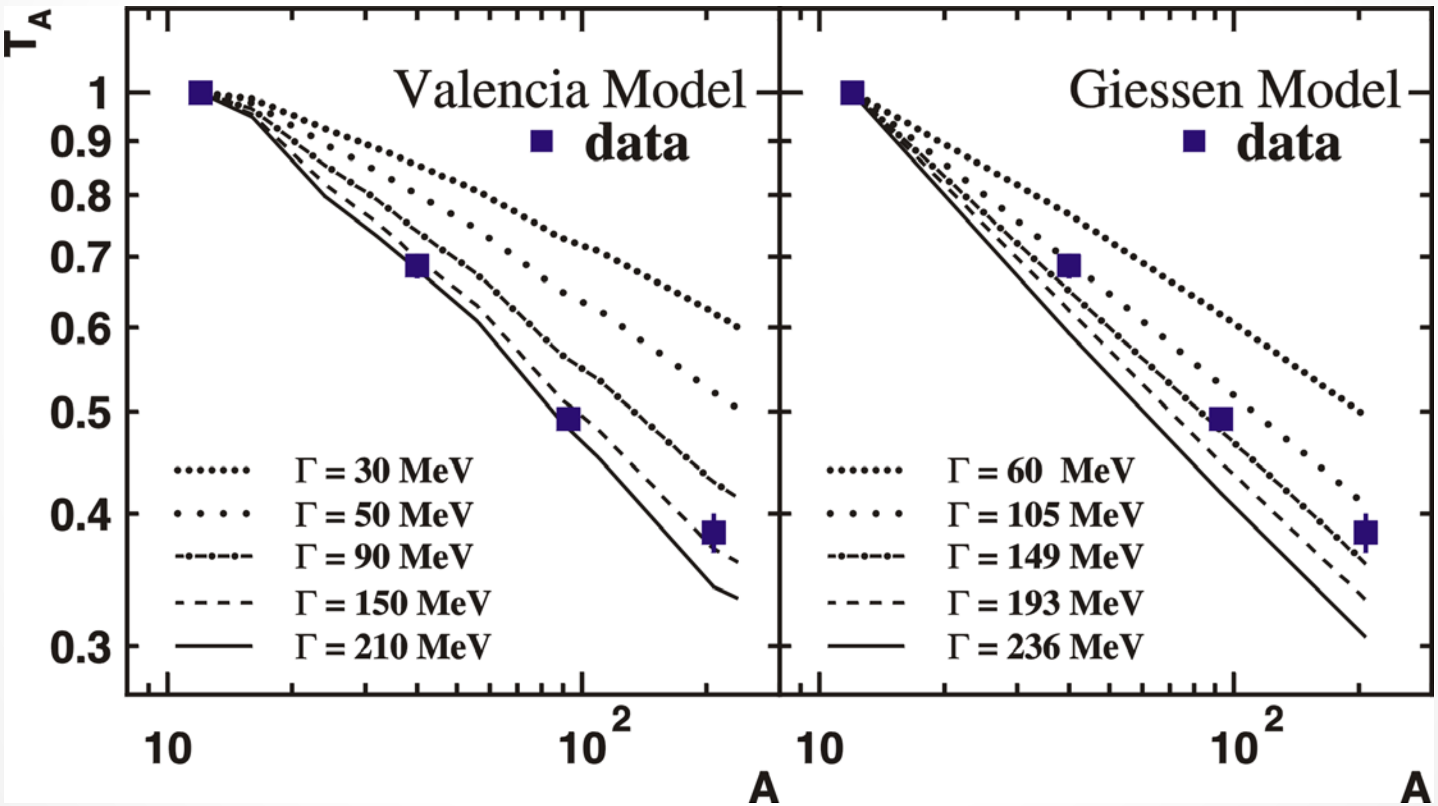


Nanova et al., PRC82(2010)035209

In-medium Width of ω

estimated from transparency ratio $T_A = \frac{\sigma_{\gamma A \to \omega X}}{A \cdot \sigma_{\gamma N \to \omega X}}$

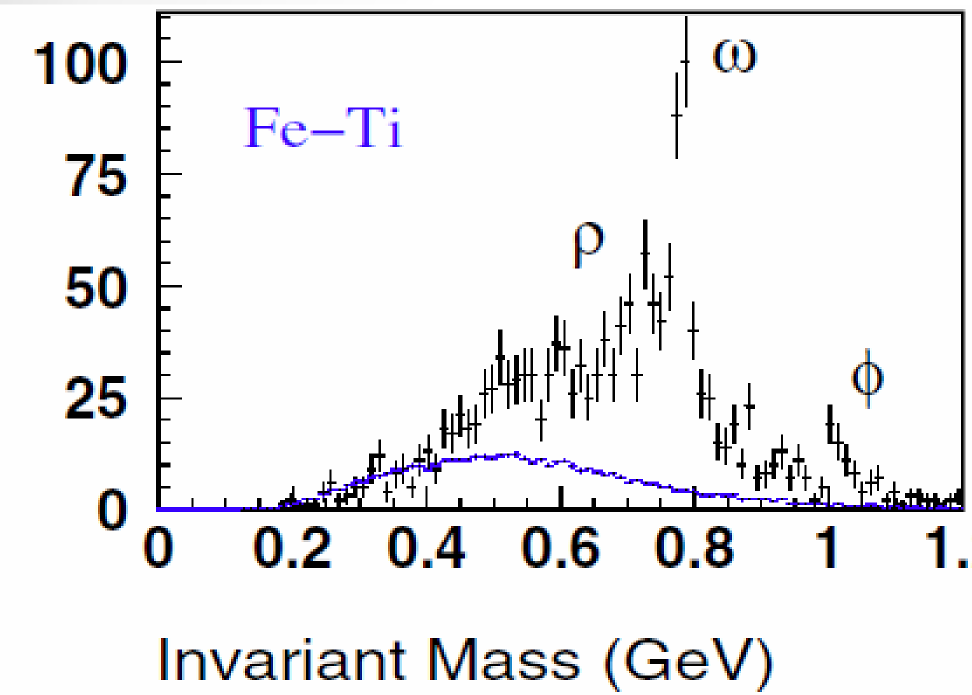
PRL100,192302(2008)



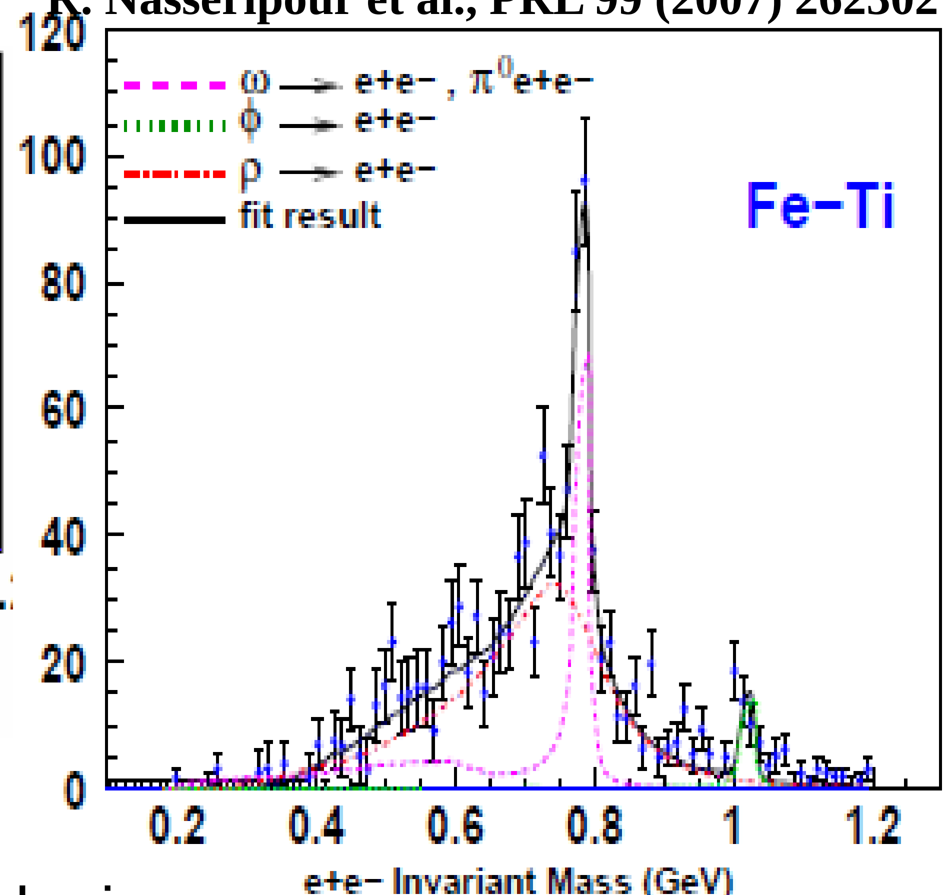
comparison to data $\Gamma(\rho_0, <|\vec{p}_\omega|> \approx 1.1$ GeV/c) ≈ 130-150 MeV

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



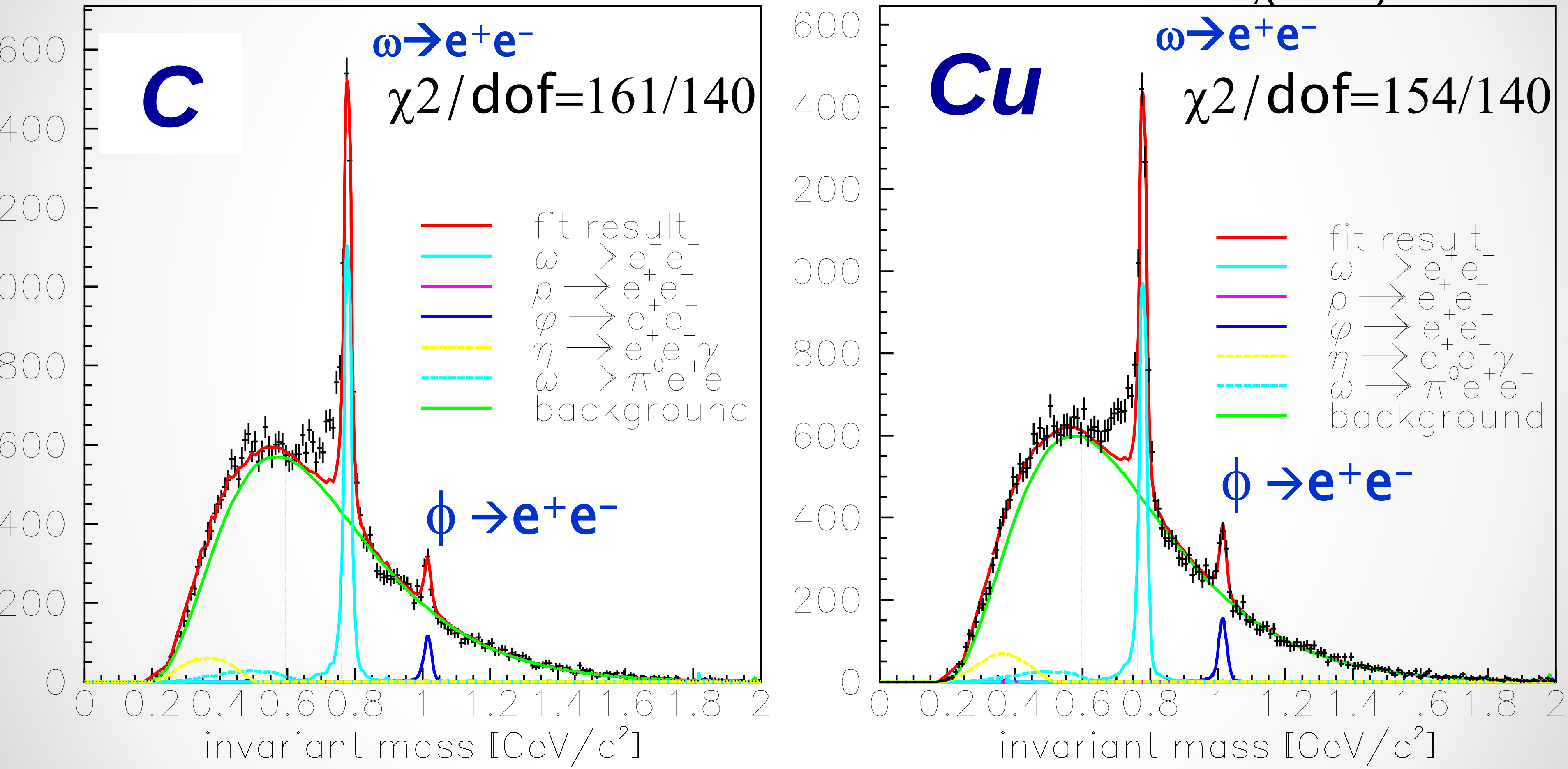
No peak shift of ρ
consistent with collisional broadening

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

E325 @ KEK-PS

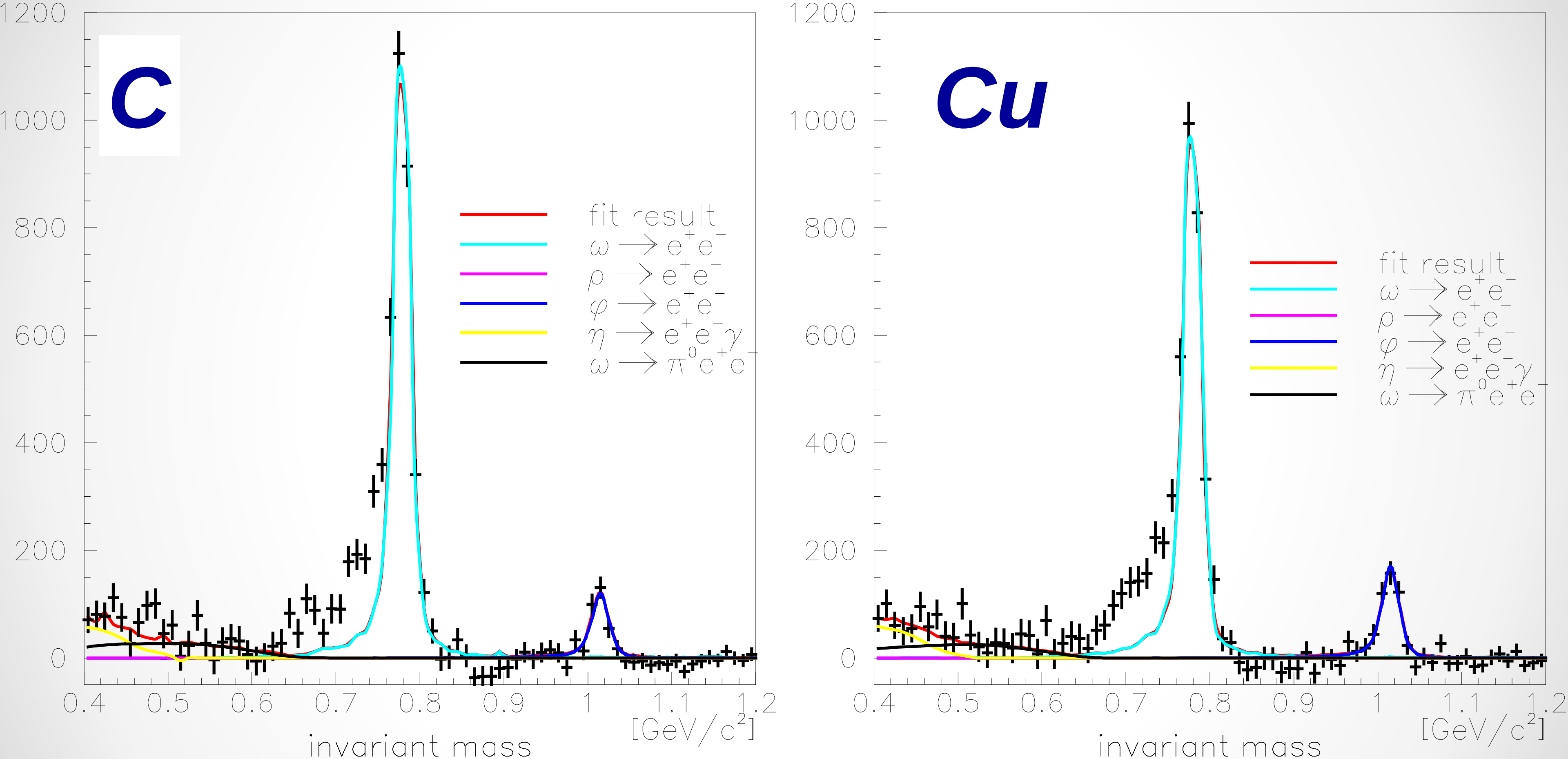
Invariant Mass Spectrum of e+e– in 12GeV/c p+A

PRL**96**,(2006) 092301



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

Background Subtracted



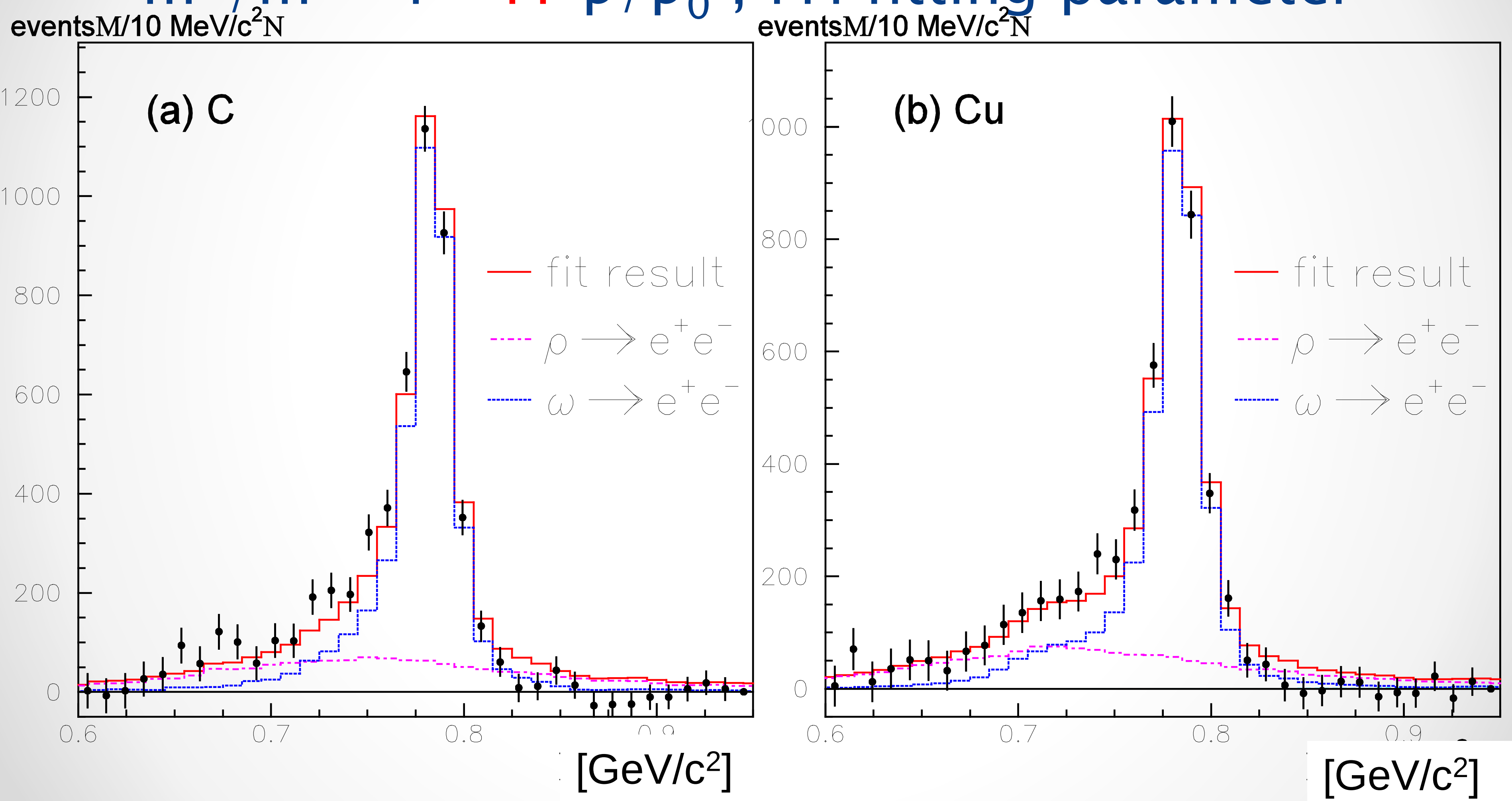
ρ/ω ratio is consistent with zero. 95%C.L. allowed regions:

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

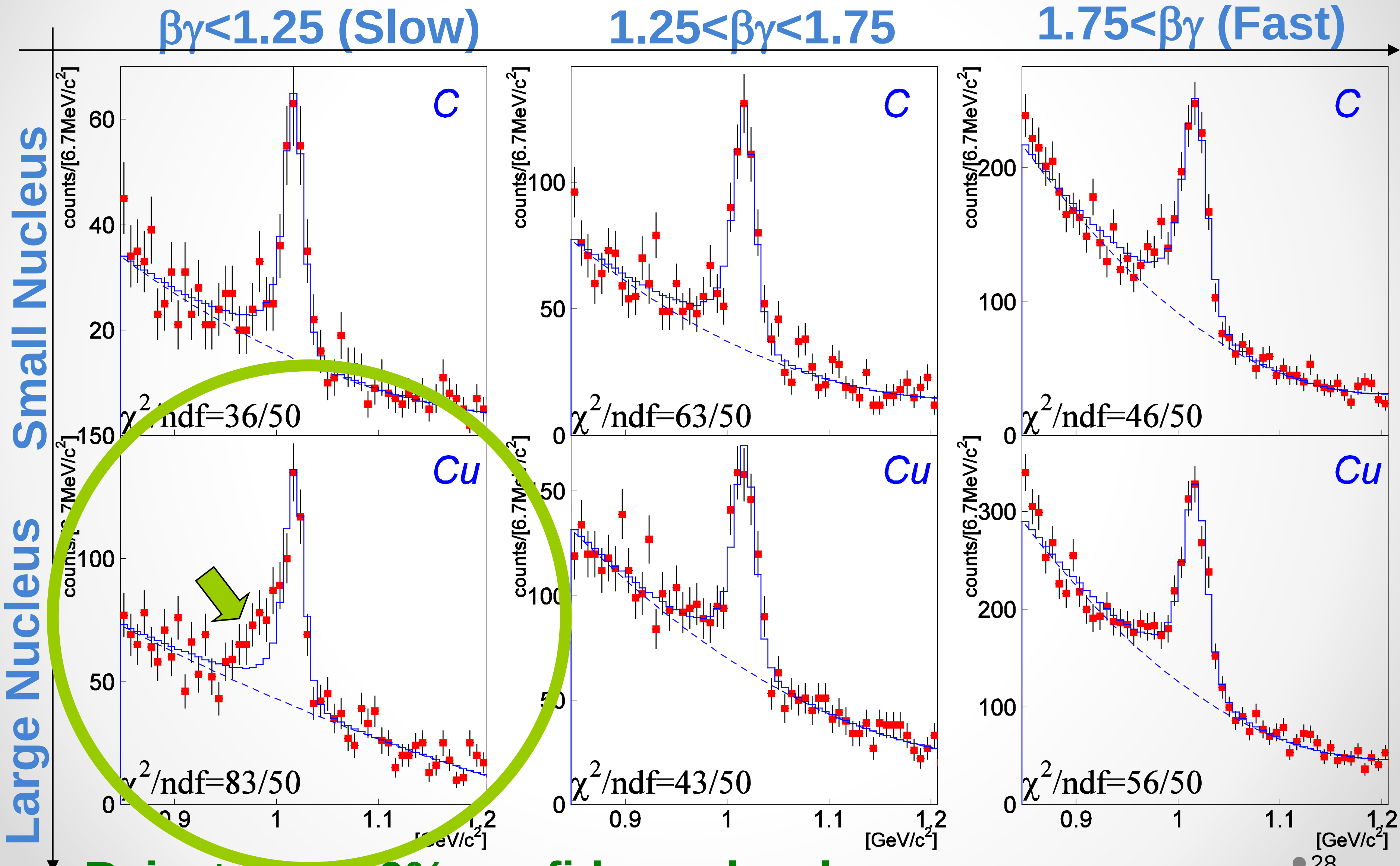
Comparison w/ Model

$m^*/m = 1 - f1\ \rho/\rho_0$, f1: fitting parameter



well reproduced with the 9% mass decrease at ρ_0.

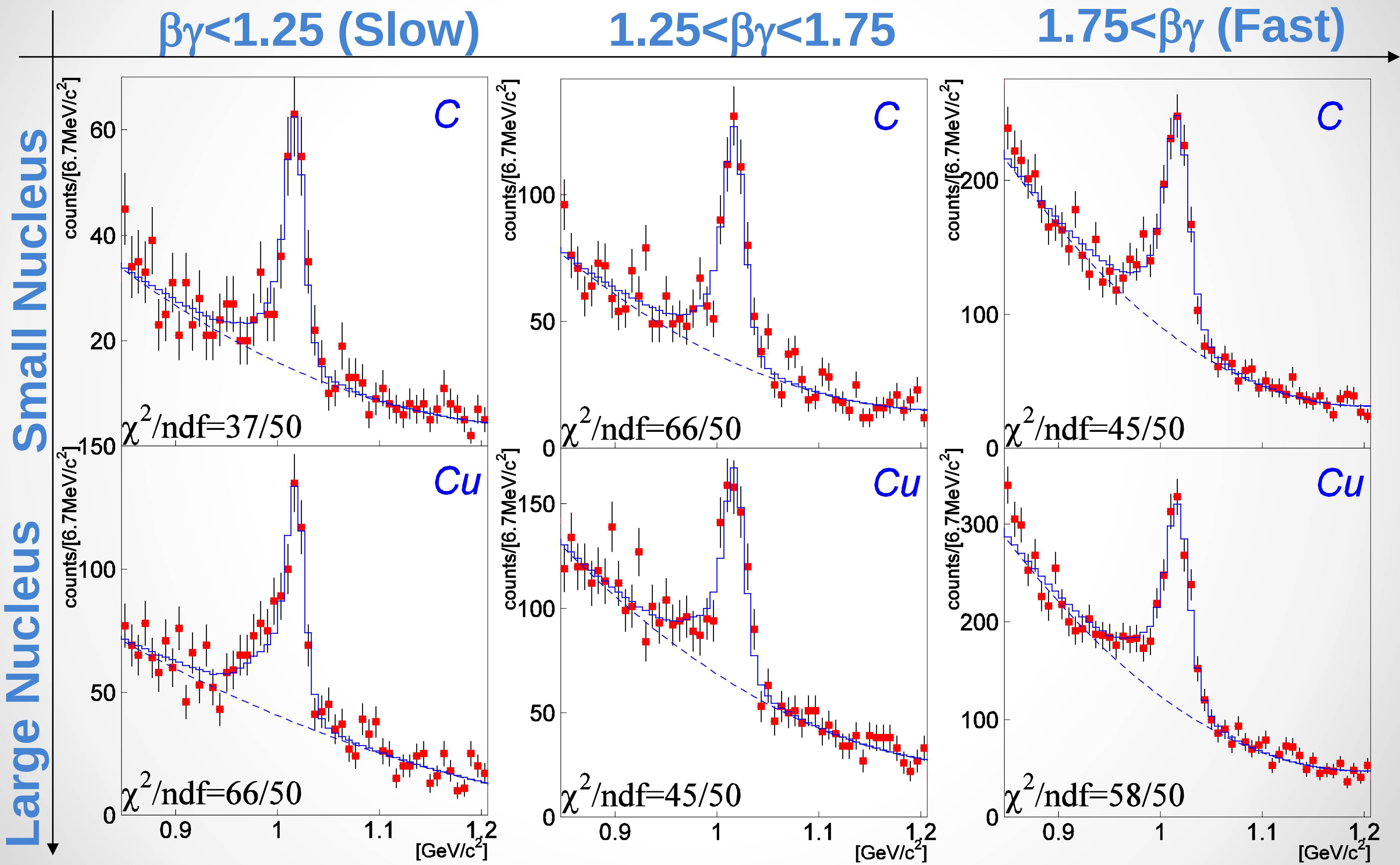
Invariant mass spectra of $\phi \rightarrow e^+e^-$



Rejected at 99% confidence level

PRL 98(2007)042501

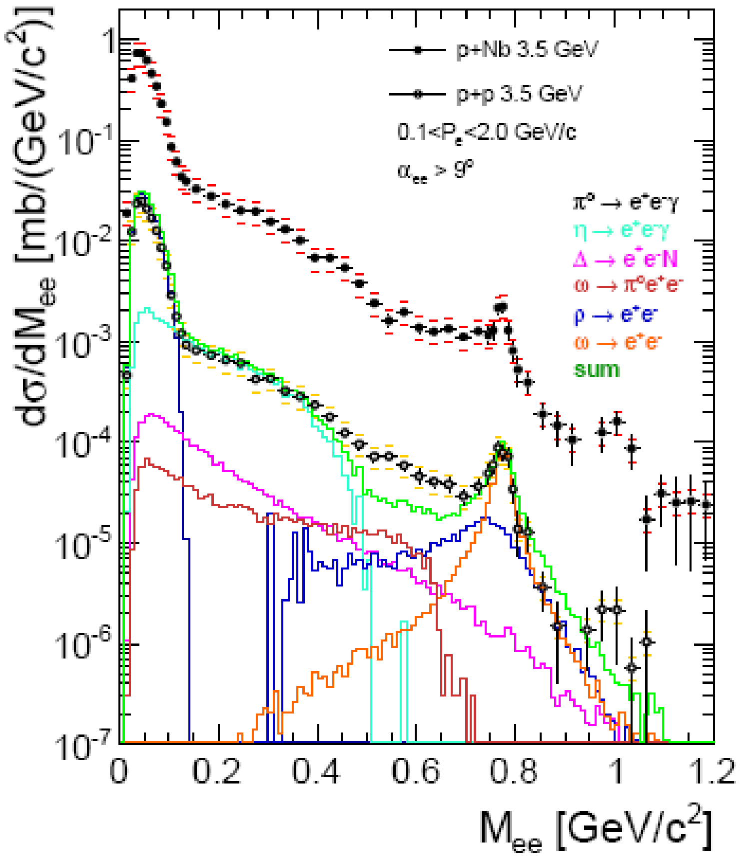
Comparison w/ Model Calc.



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

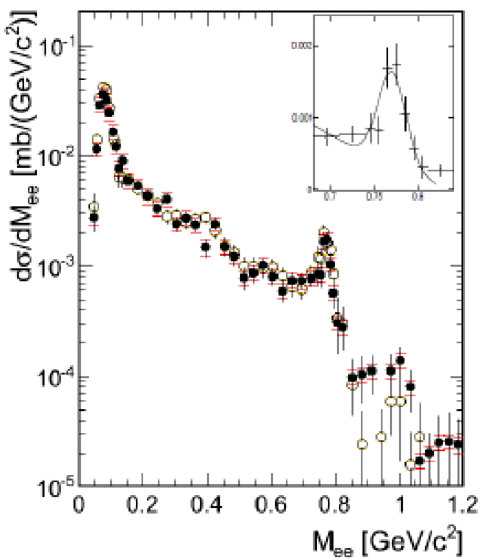
HADES @ GSI

PLB715(2012)304

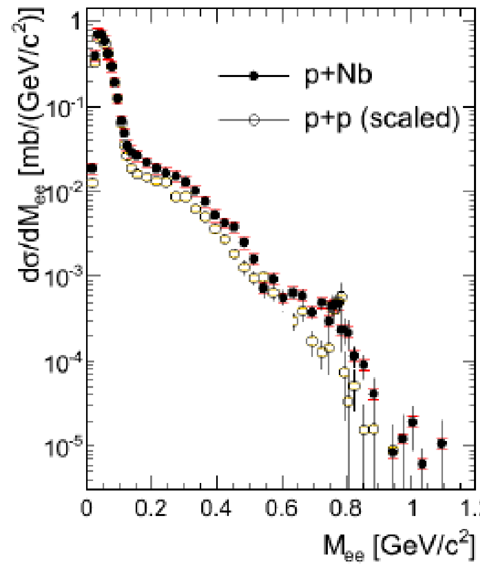


p + Nb at 3.5 GeV

p_{e+e-}>0.8 GeV/c



p_{e+e-}< 0.8 GeV/c



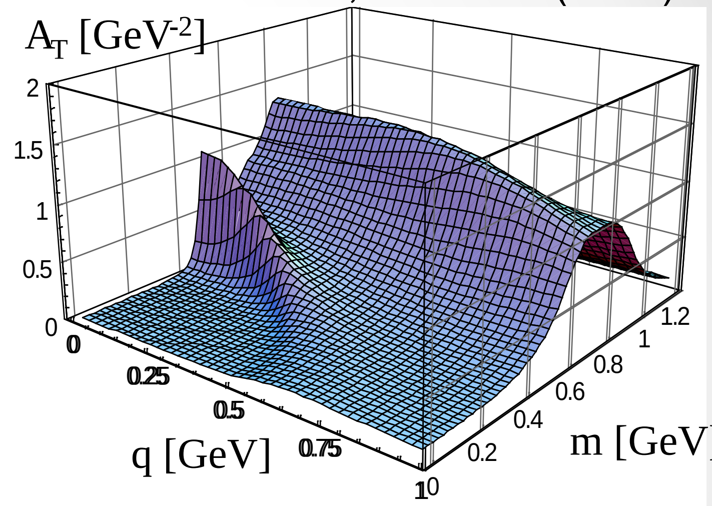
- large acceptance at small M_{e+e-} and p (<1 GeV/c) **(first measurement at low p !)**
- p+p data are cockail : based on known sources fixed to data π^0 /η/ ω/ ρ , Δ with constant eTFF

underestimeted e+e- yield below VM pole → higher resonances (Δ, N*)

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



- "shift" vs. 'broadening" is too naïve. The real effect might be a composition of shift, broadening, dip-like structure etc.
- The spectral modification will largely depend on momentum.

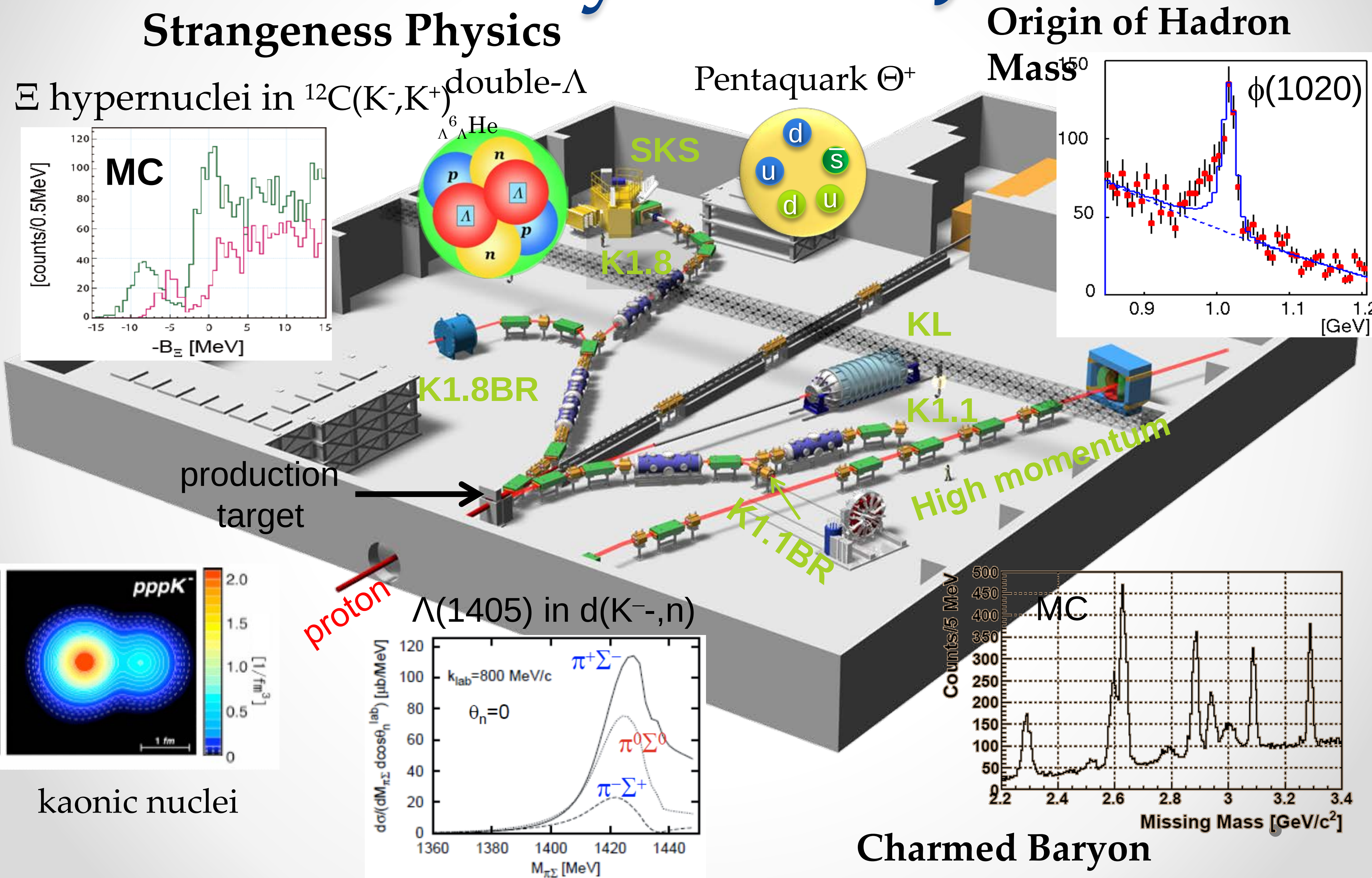
→ **precise measurement w/ high statistics & resolution**

- o systematic study: dispersion relation, system size dependence

J-PARC bird's-eye view

Tokai, Ibaraki, Japan

Hadron Physics at J-PARC



beam power

π K
30 days

now

3kW 10kW 25kW 270kW

K1.8

E19
Search for Pentaquark Θ^{+}

E05
Ξ-Hypernucleus (priority 1)

E10
neutron rich Λ-Hypernuclei

E07
Double Strangeness with Emulsion

E03
X rays from Ξ^{-} Atom

E27
Search for K-pp

E13
Gamma-ray spectroscopy of light hypernuclei (priority 2)

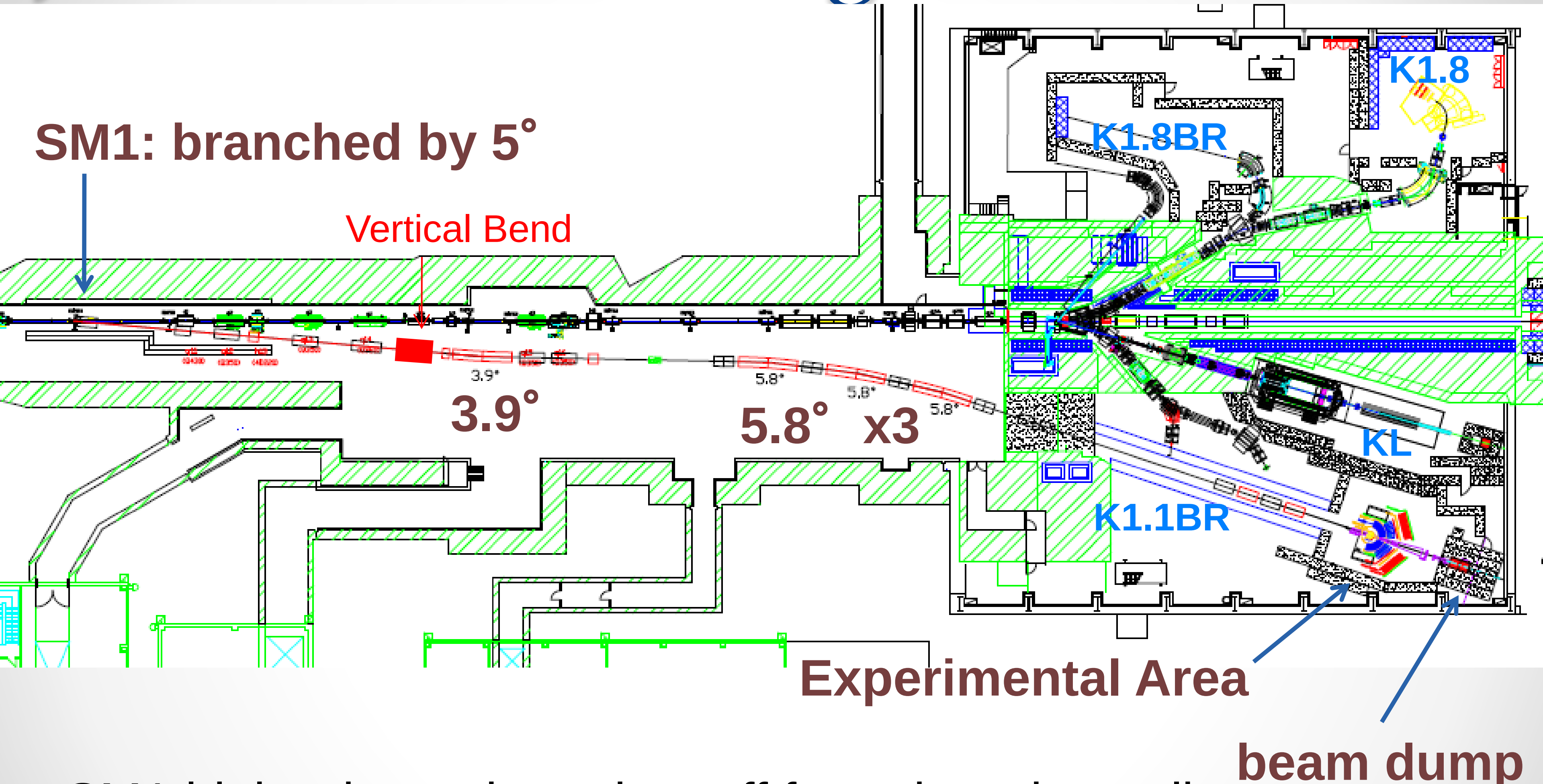
K1.8BR

E17
Kaonic 3He

E15
deeply bound kaonic nucleus

E31
spectral information of Λ(1405)

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**

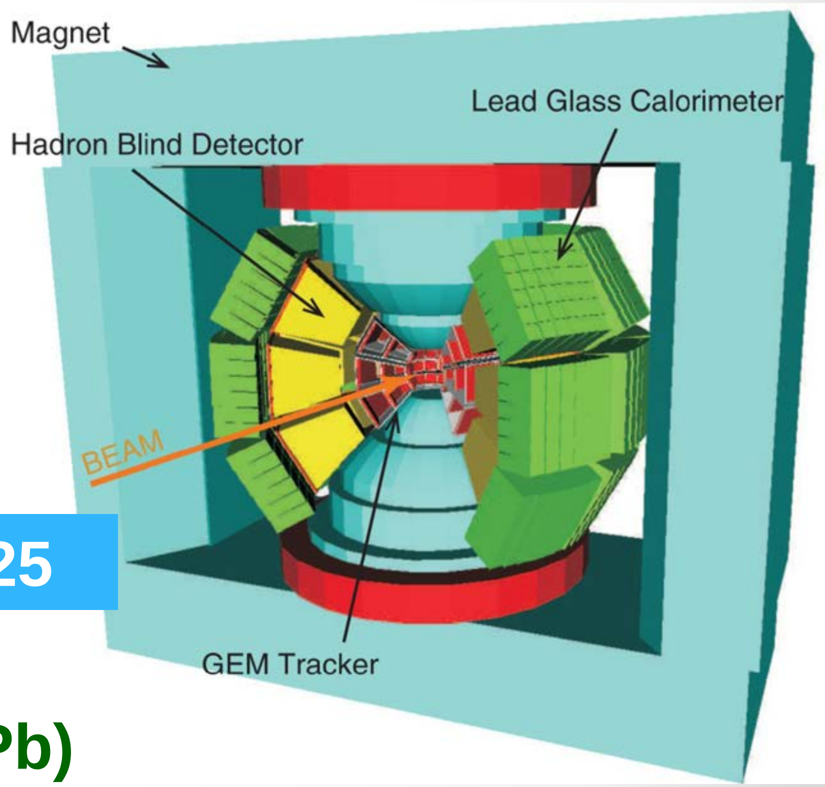
Large Acceptance (5 X E325)

Higher energy beam (12→ 30GeV)

x ~ 2 of production CS

100 times as large statistics as E325

E-ball @ high-p BL



velocity dependence

nuclear number dependence (p → Pb)

centrality dependence

→systematic study of mass modification

Detector R & D

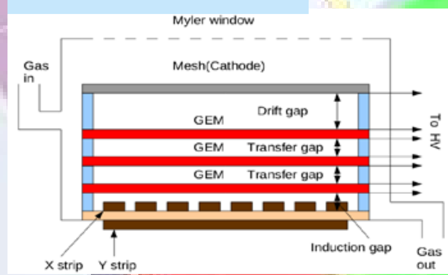
Particle tracking in a magnetic field and measure momentum.

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

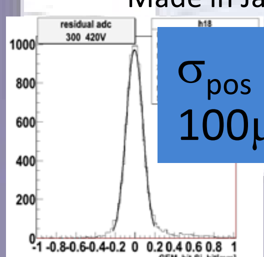
GEM foil (30cm x 30cm)

One GEM tracker



Beam test @ Tohoku ELPH

Made in Japan



σ_{pos} 100μm

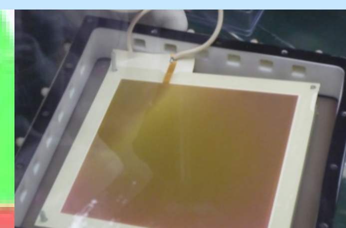
- Enough position resolution is achieved.
- Ready for mass production.

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**

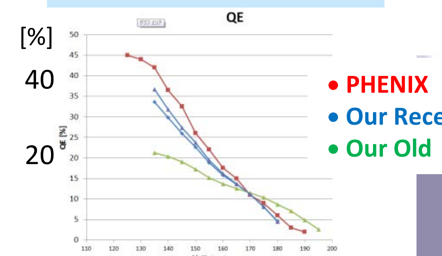
CsI is evaporated on the surface of the top GEM.
Photoelectrons are amplified using GEM (like Track

CSI evaporated GEM foil



GEM made in Japan
CsI is evaporated by ourselves.

Quantum Efficiency

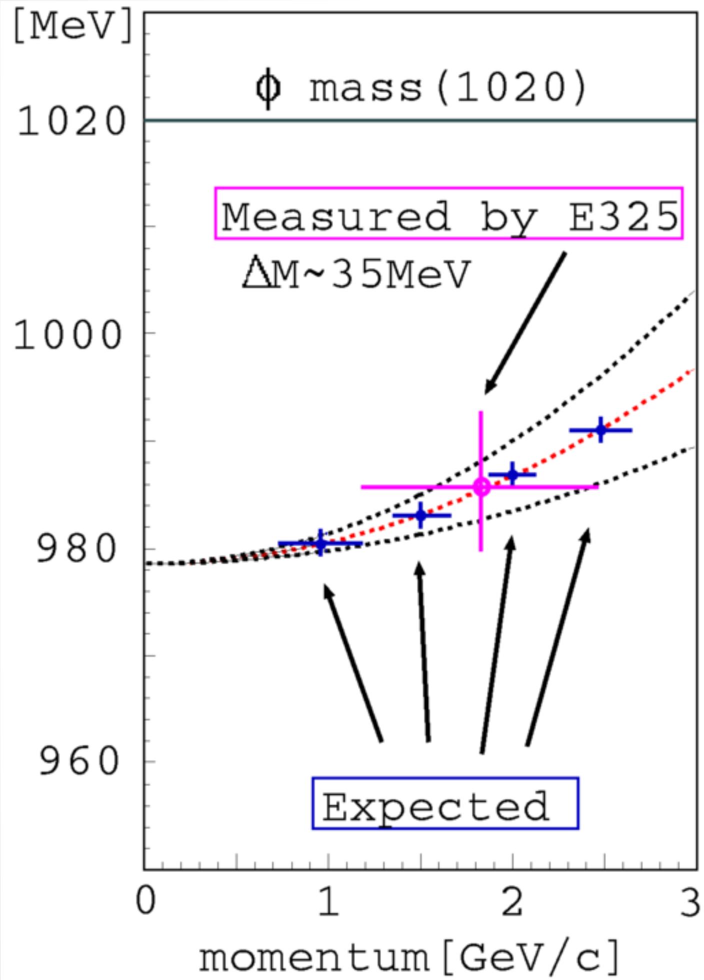


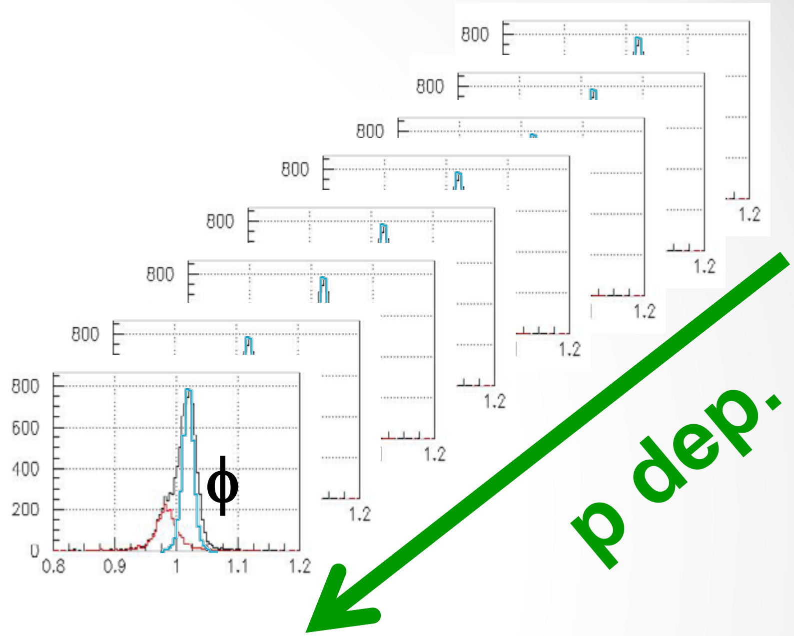
Enough Q.E. is achieved

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

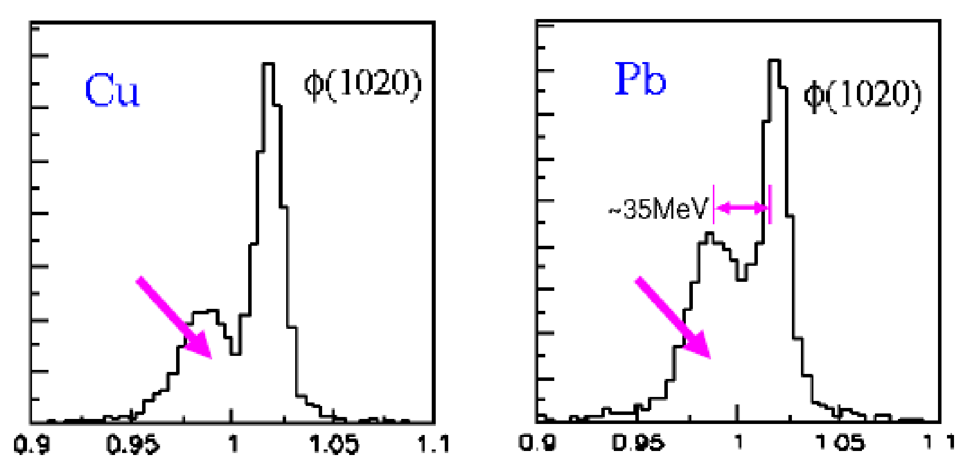
Expected Signal

momentum dependence of mass





βγ<0.5, σ=5 MeV



History & Schedule

- 2007 approval
- 2013 Jan.
  - beam line construction budget was approved.
- 2014
  - beam line construction
  - mass production
- 2015
  - spectrometer construction at the hadron hall
- 2016 Jan.
  - high-momentum beam line is completed.
  - first commissioning run

Thank you for your attention!