A man with glasses and a grey sweater is seen from the side, writing on a green chalkboard. The board contains several mathematical expressions related to quantum field theory or nuclear physics. The main text is overlaid on the image.

Hadron in nucleus
summary in 10+ min?

Ryugo S. Hayano
The University of Tokyo

YITP 31 Oct - 2 Nov

Excellent talks, many by young participants

In-medium Hadrons -- A Theoretical Overview --

T. Hatsuda (RIKEN)

5 % = baryons 27 % = dark matter 68 % = dark energy	$m_q \approx 3 \text{ MeV}$ $m_N \approx 1000 \text{ MeV}$	$m_0 = 0$ $m_q \approx 3 \text{ MeV}$
Cosmological constant Einstein (1917)	"Chiral" condensate Nambu (1960)	"Higgs" condensate Englert-Brout, Higgs (1964)

Condensates ↔ Elementary excitations

Introduction: NS observations

1/16

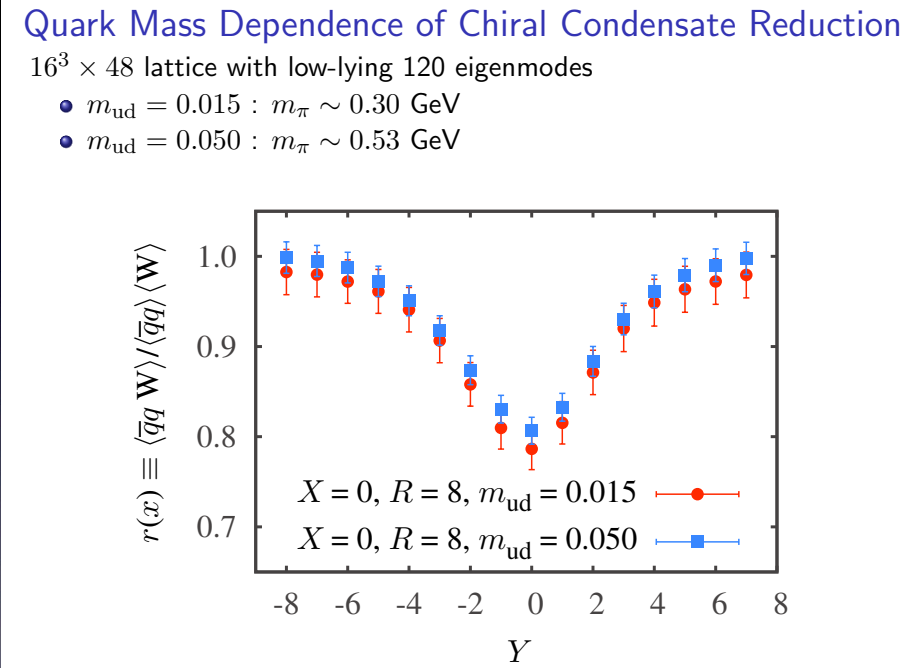
NS observations

Mass
(1.97 ± 0.04) M_⊙ Demorest et al. (2010)
(2.01 ± 0.04) M_⊙ Antoniadis et al. (2013)

Cooling
Cooling of CAS-A Heinke et al. (2010)

EOS
Relation to stiffness of EOS and the existence of the exotic components ?

Superfluid / Superconducting phase
Relation to nucleon and quark superfluidity inside NSs ?

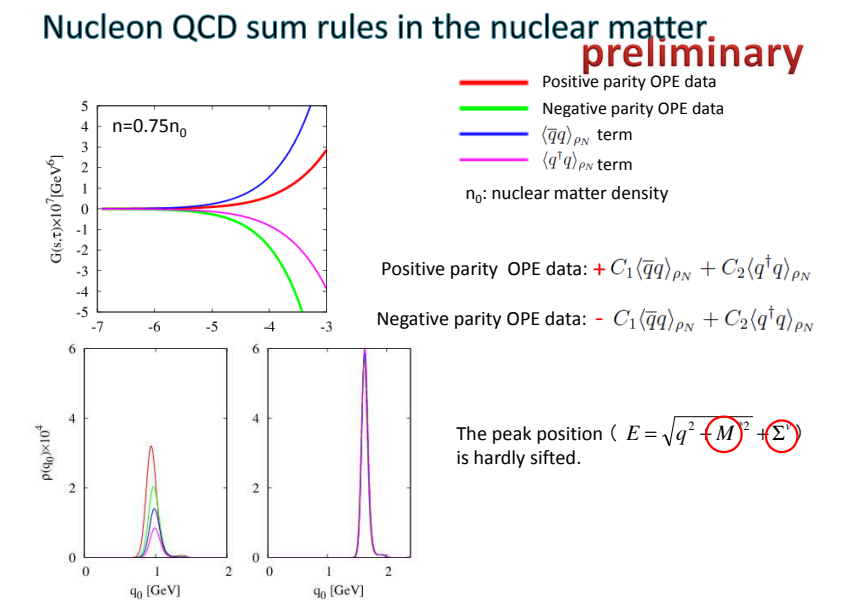


Topological models and soliton

Structure

- What is a nucleon and, in particular, its core?
- At large number of colors it still has the mesonic content

October 31, 2013 Talk @ YITP, Kyoto 2013



Medium effect of Λ hyperon

Modification of magnetic moment in medium

$B(M1) = (2J_{up} + 1)^{-1} |\langle \Psi_{low} || \mu || \Psi_{up} \rangle|^2$
 $= (2J_{up} + 1)^{-1} |\langle \Psi_{A1} \Psi_c || \mu || \Psi_{A1} \Psi_c \rangle|^2$
 $\mu = g_c J_c + g_\Lambda J_\Lambda = g_c J + (g_\Lambda - g_c) J_\Lambda$
 $\Gamma = BR / \tau = \frac{16\pi}{9} \frac{E_\gamma^3}{E_\gamma^3} B(M1)$ (If Br M1 = 100%, $\tau = 1/\Gamma_{M1}$)

g_c : g-factor of core nuclei
 g_Λ : g-factor of Λ

E_γ and lifetime (τ) can be measured by γ -ray spectroscopy using Ge detectors of a few keV resolution

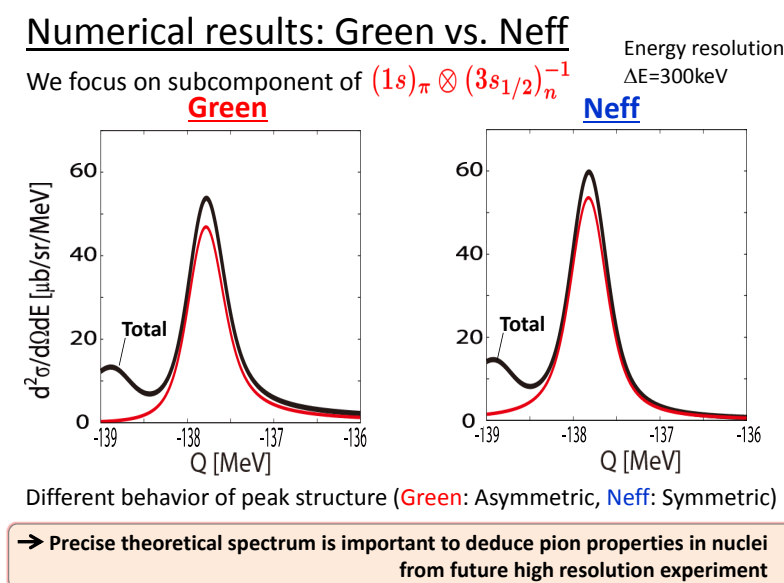
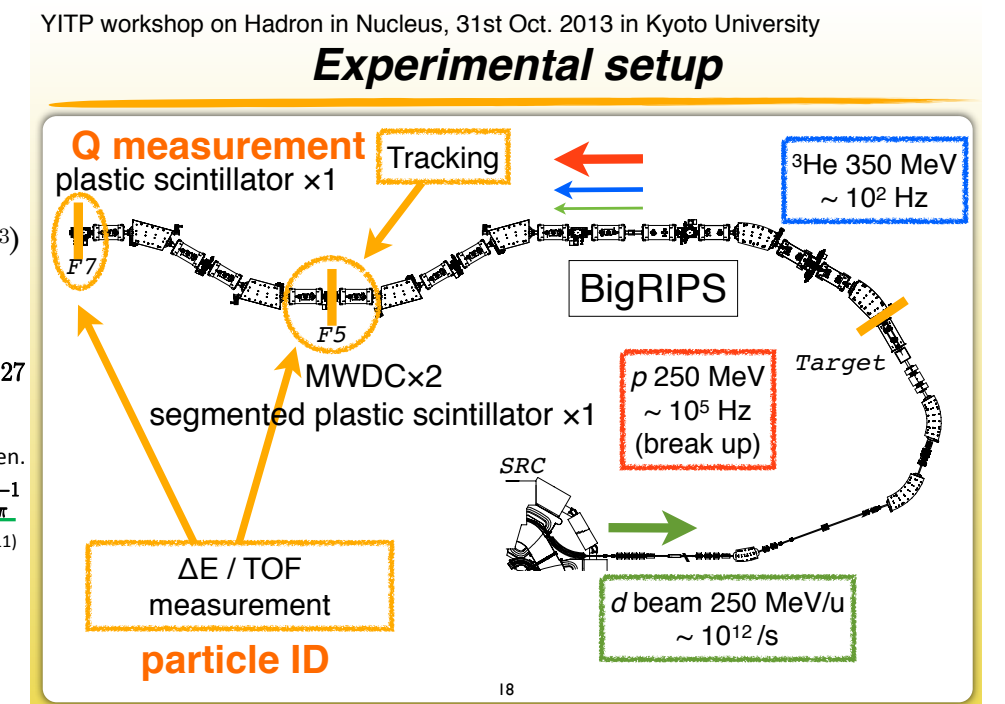
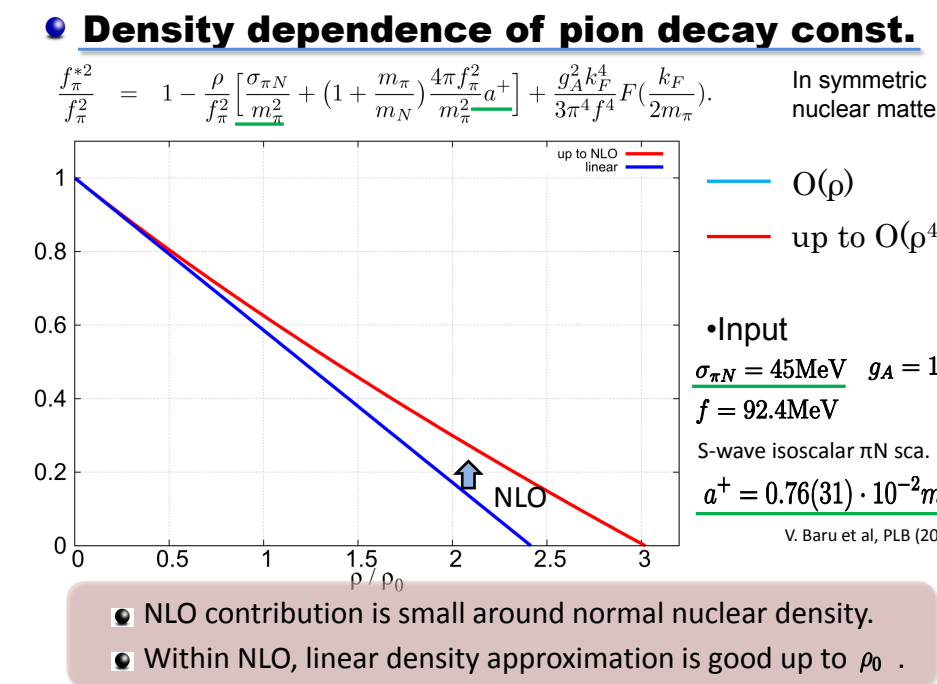
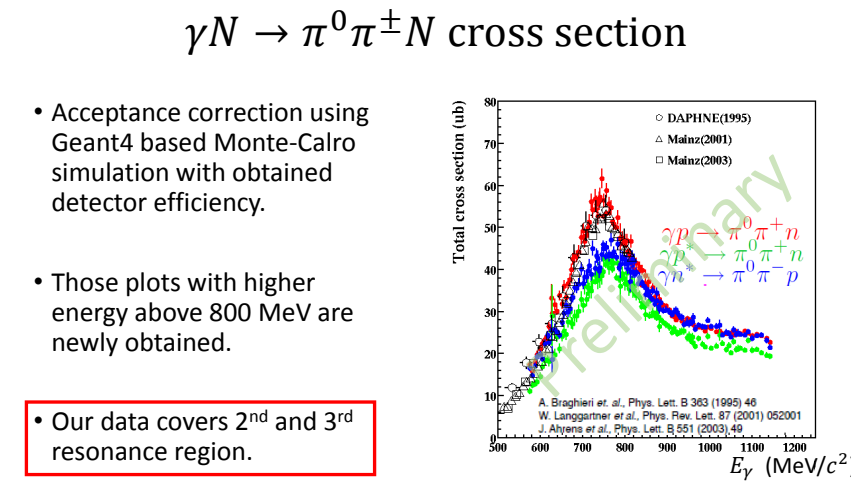
Main motivation of J-PARC E13

It's Halloween, today. My talk is:

In-medium Tomozawa-Weinberg Relation with nuclear correlation effects

Ryoichi Seki
California State University, Northridge

Hadrons in Nucleus, YITP 10/3/2013

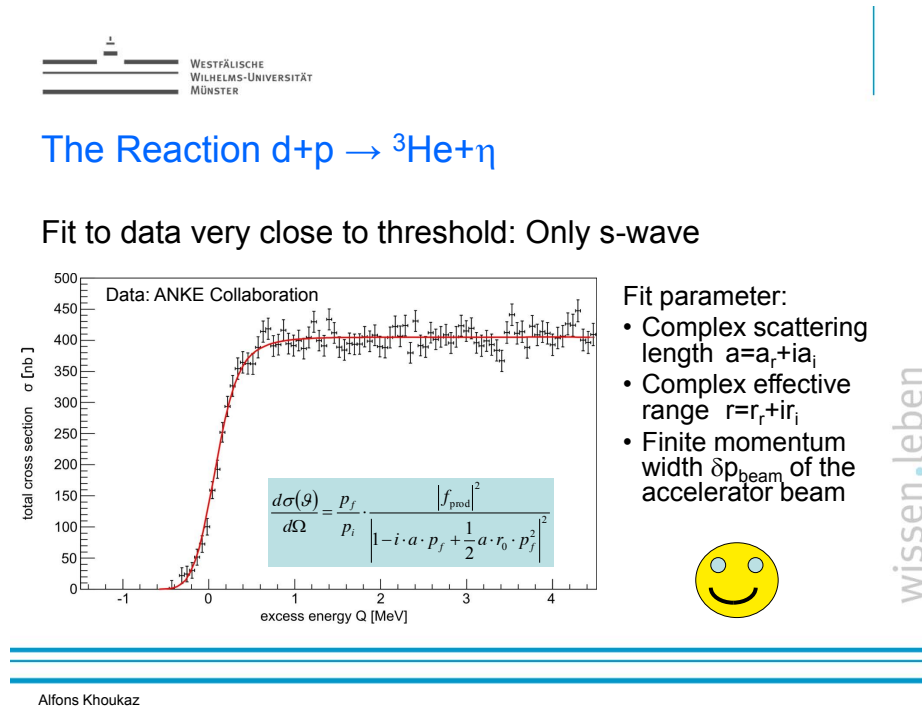
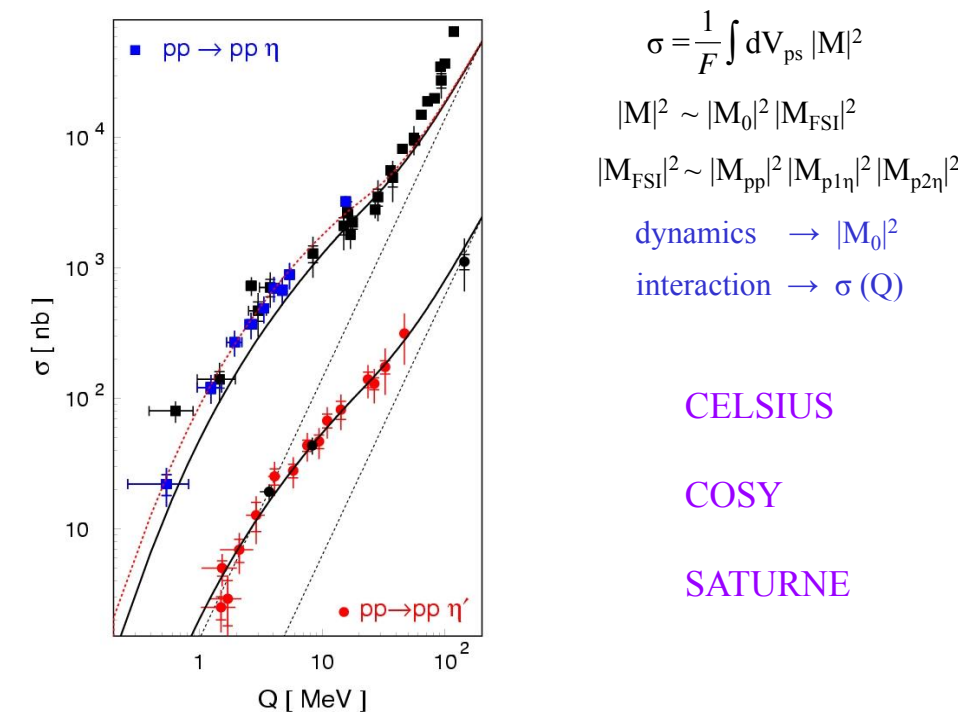


In-medium \bar{K} & η mesons

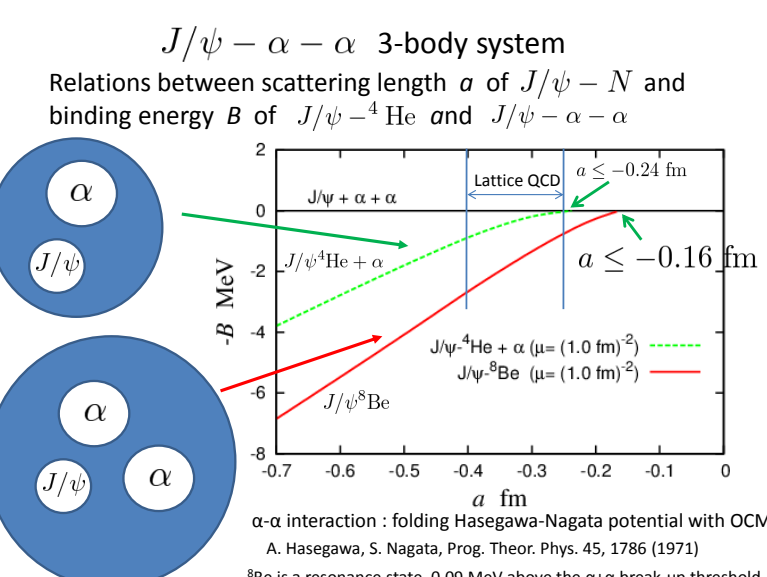
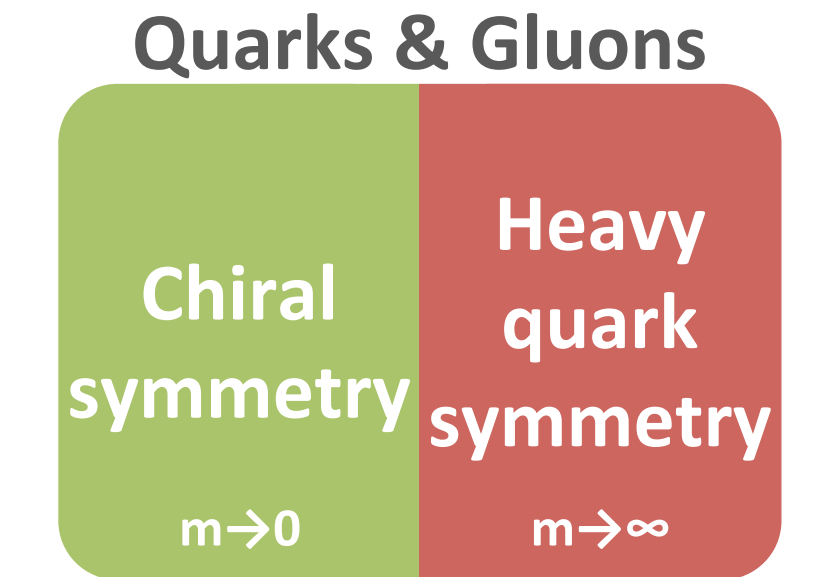
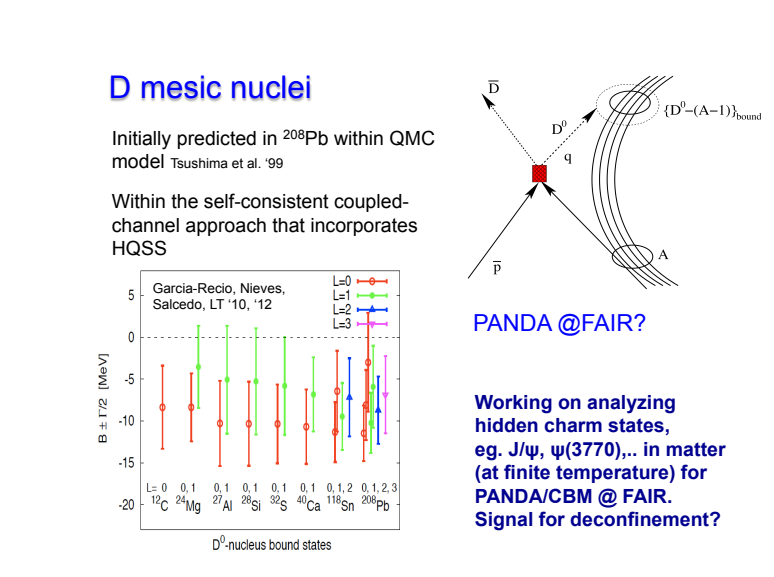
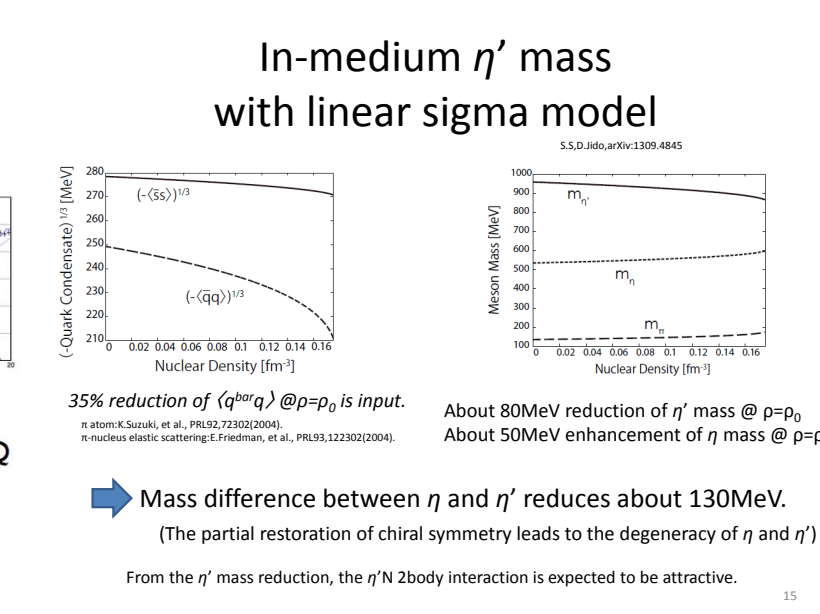
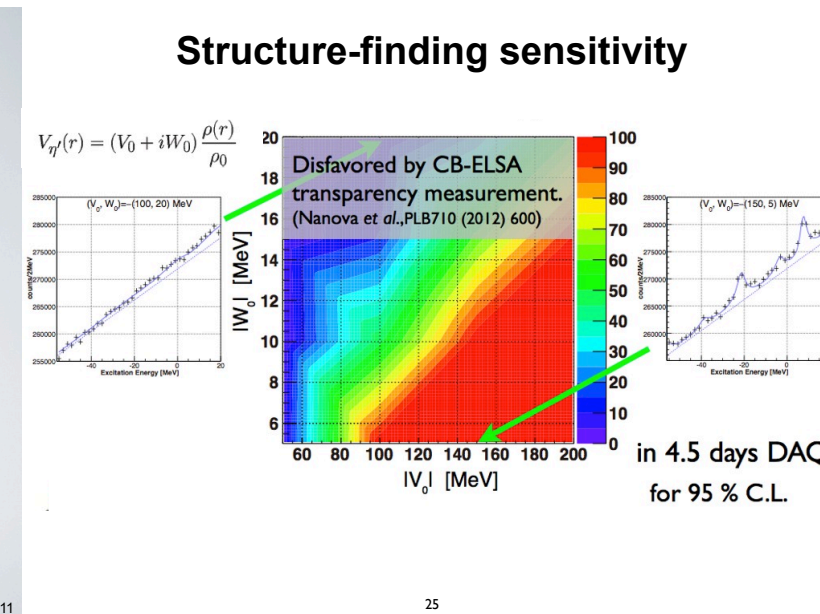
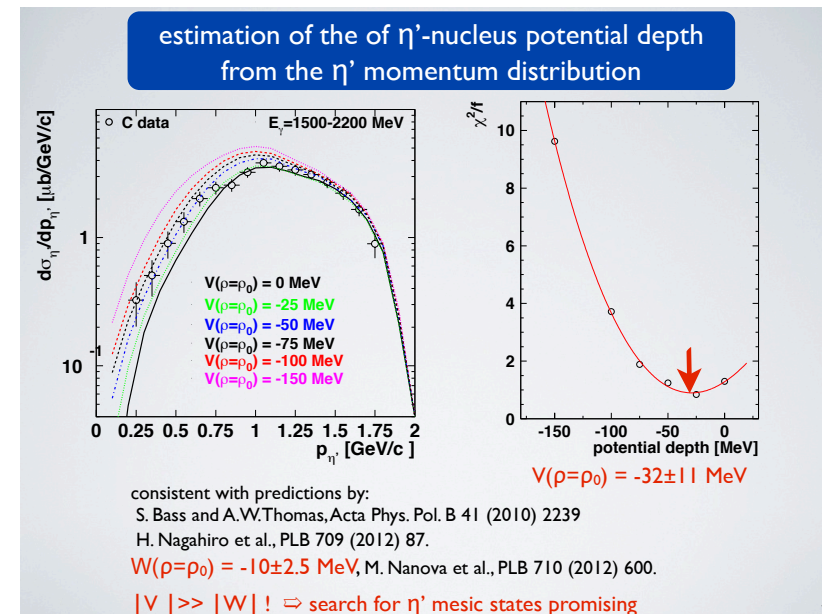
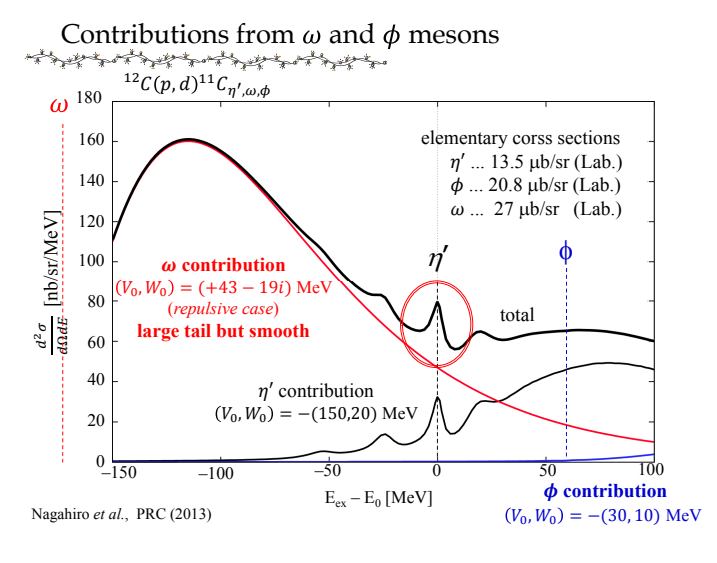
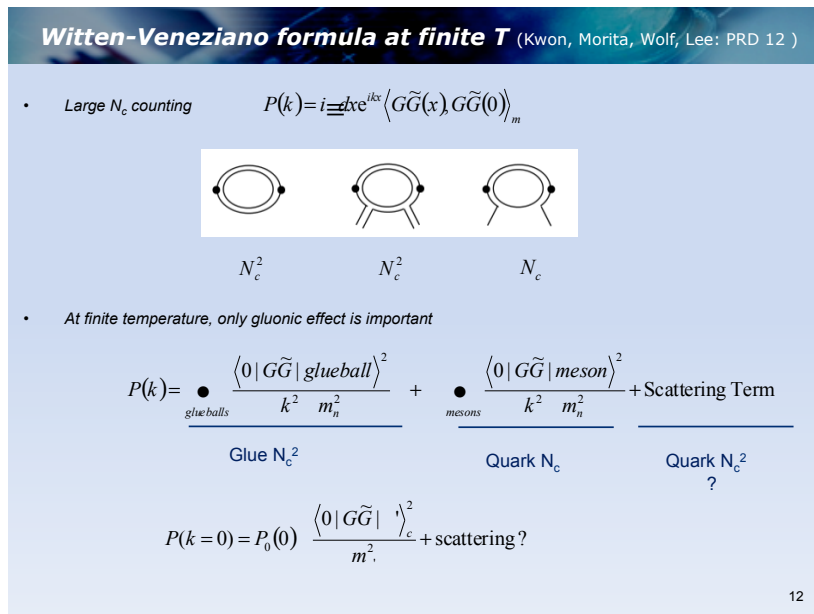
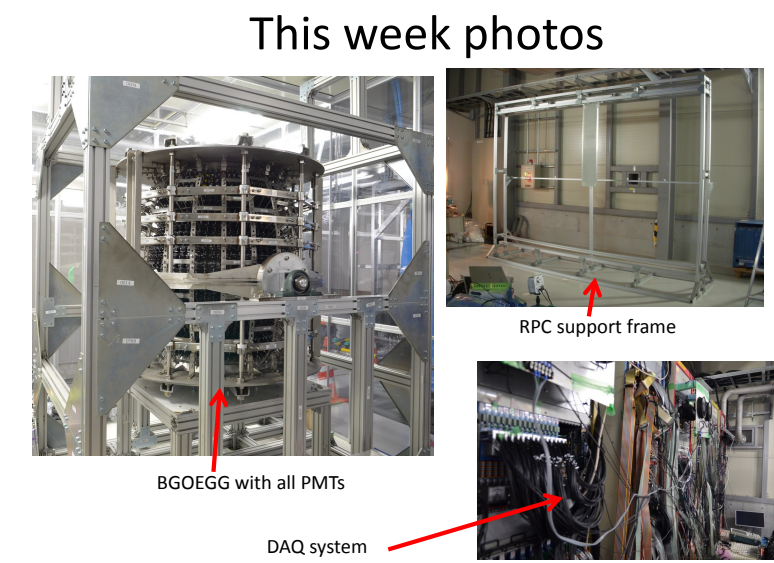
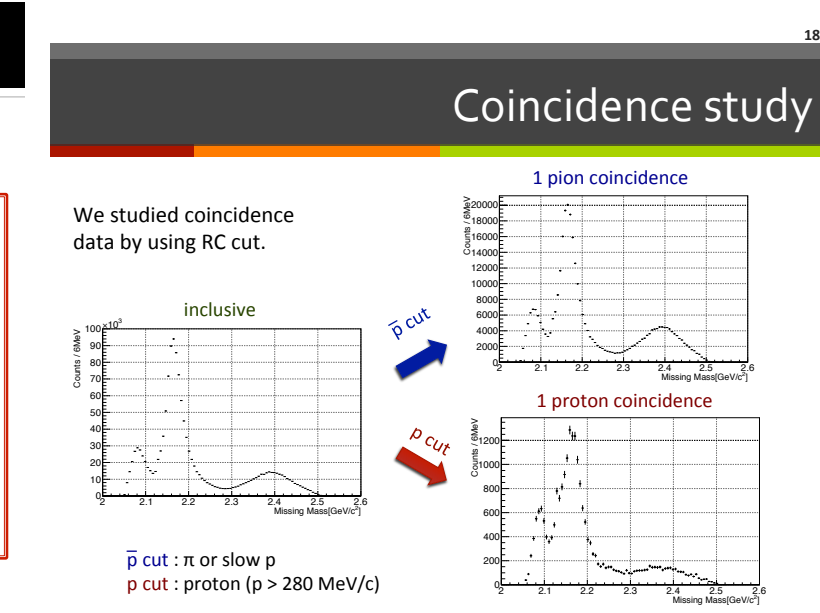
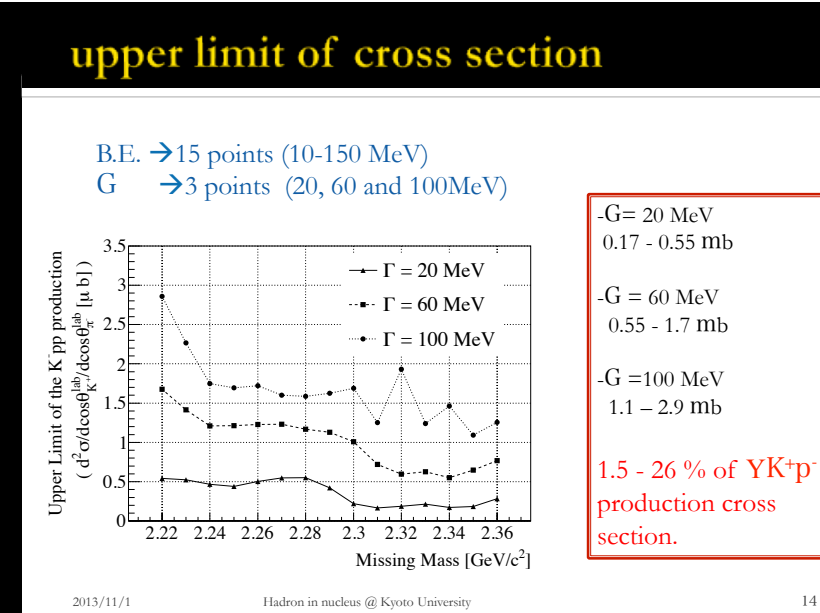
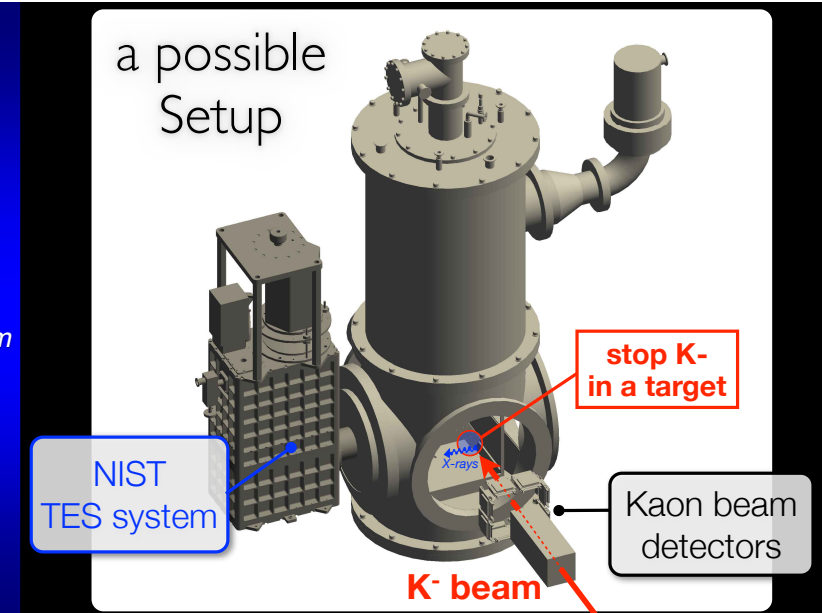
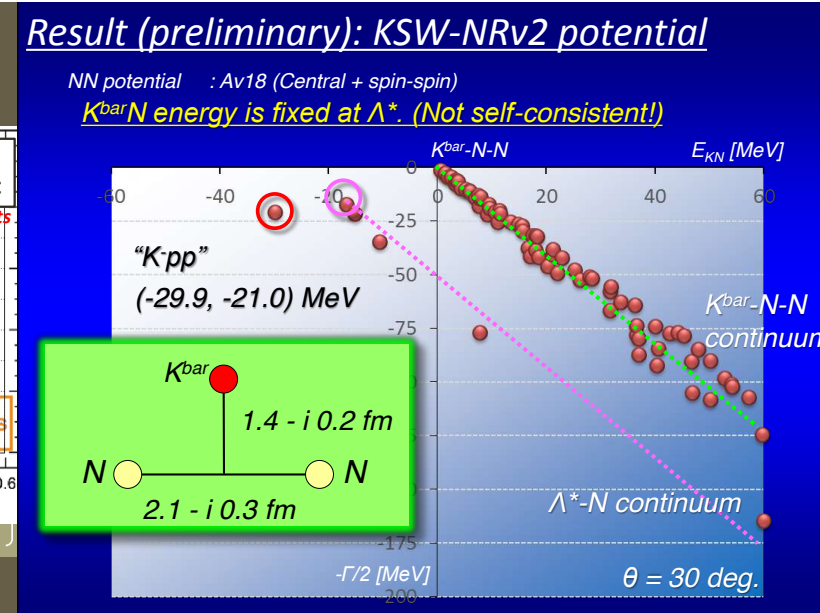
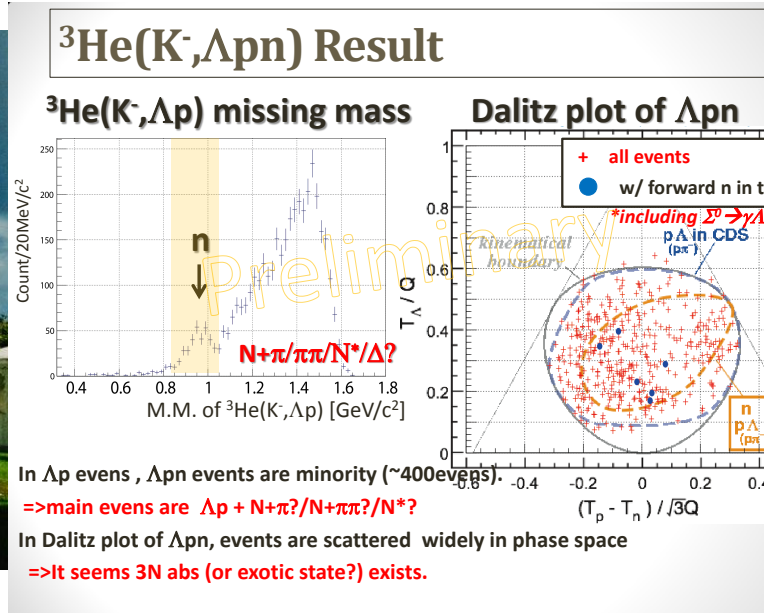
Mesic Nuclei, JU Krakow, Sept. 2013
Hadrons in Nuclei, YITP Kyoto, Oct. 2013

Avraham Gal
Racah Institute of Physics, Hebrew University, Jerusalem

- $\bar{K}N - \pi Y$ chiral dynamics and its consequences
- \bar{K} nuclear few-body systems
- \bar{K} -nucleus potentials from K^- atoms
A.Gal in HYP2012 Proc., NPA 914 (2013) 270
- Quest for η nuclear quasibound states
E.Friedman, A.Gal, J.Mareš, PLB 725 (2013) 334



Excellent talks, many by young participants



- ### Outline
- Introduction
 - Heavy Quark Spin Symmetry
 - π exchange potential between heavy meson and nucleon.
 - Results of $\bar{D}^{(*)}NN$ and $B^{(*)}NN$
 - Results of $P^{(*)}NN$ in $m_Q \rightarrow \infty$
 - Summary
-
- 3-body system

Theory

Decay Constants

The decay constants are evaluated using the relation[15],

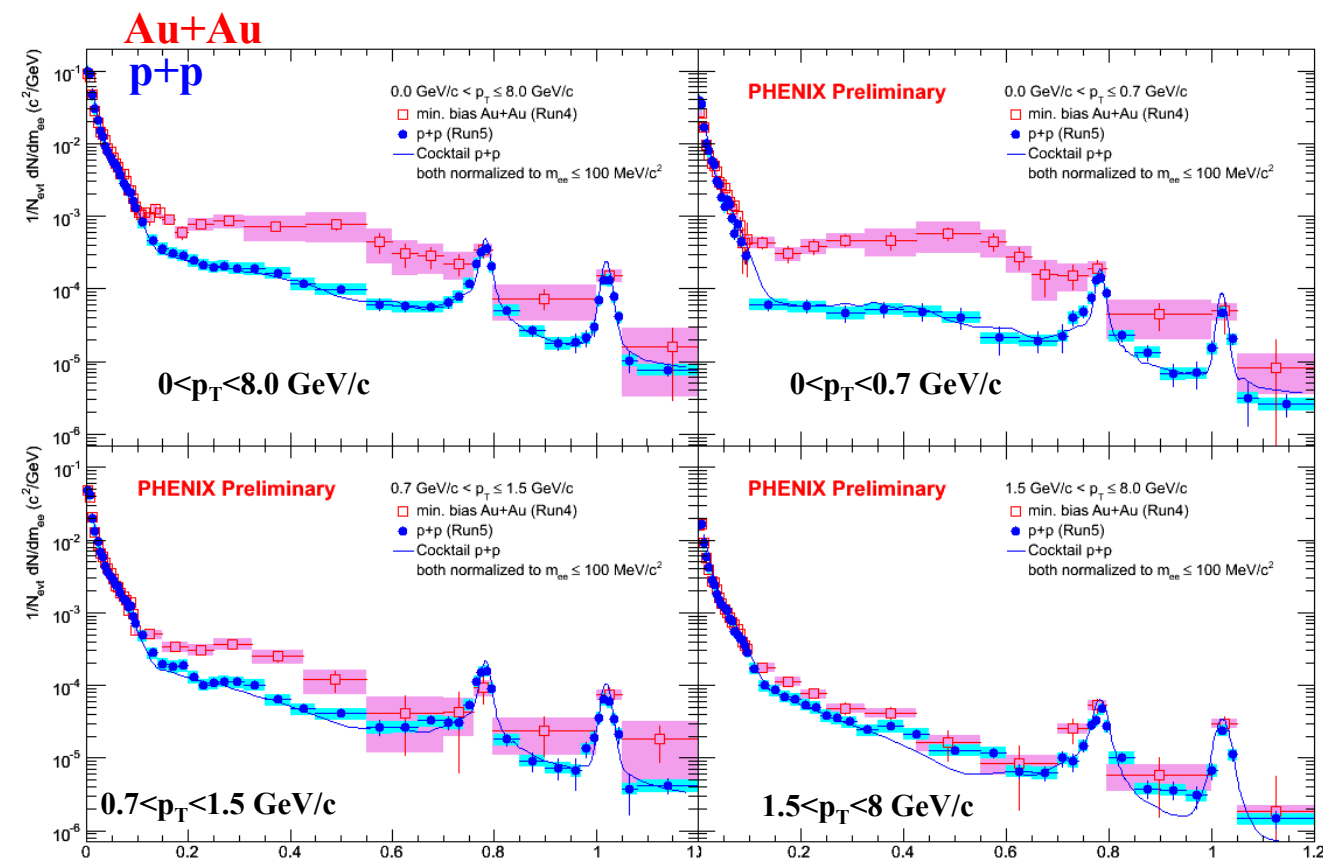
$$f_{\bar{D}^*}^2 = \frac{12 |\langle \psi_{P/V}(0) \rangle|^2}{M_{P/V}} \bar{C}^2(\alpha_S) \quad (8)$$

Where $\bar{C}(\alpha_S)$ is the QCD correction factor given by[16]

$$\bar{C}^2(\alpha_S) = 1 - \frac{\alpha_S}{\pi} \left[2 - \frac{m_Q - m_{\bar{Q}}}{m_Q + m_{\bar{Q}}} \ln \frac{m_Q}{m_{\bar{Q}}} \right] \quad (9)$$

Excellent talks, many by young participants

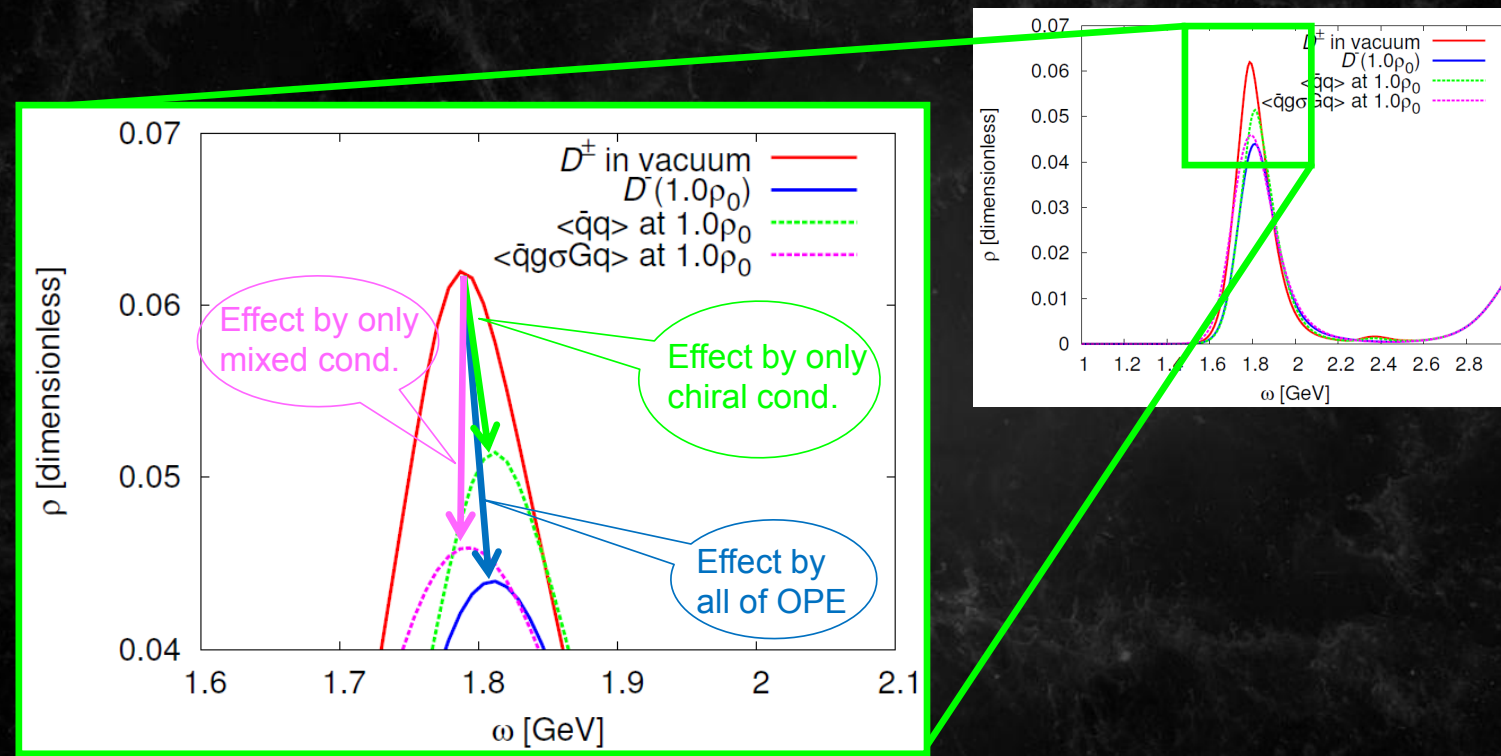
Low Mass Enhancement in Low- p_T



Low mass excess in Au-Au concentrated at low p_T

2013/11/02 YITP workshop on "Hadron in Nucleus" at YITP, Kyoto University, Oct. 31 - Nov. 2, 2013

Contribution of vacuum condensates



⇒ Most dominant contribution of mass shift to higher energy is D-dependence of chiral condensate

2/Nov/2013

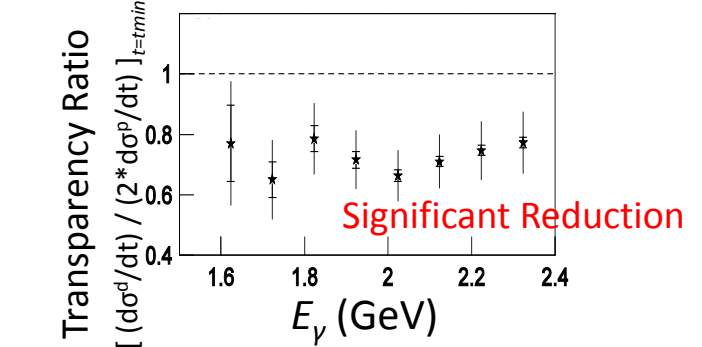
Hadron in Nucleus at YITP

18

Related(?) Topic

ϕ photo-production from the **deuteron target**
W.C. Chang et al. Phys.Lett., B684:6-10, 2010.

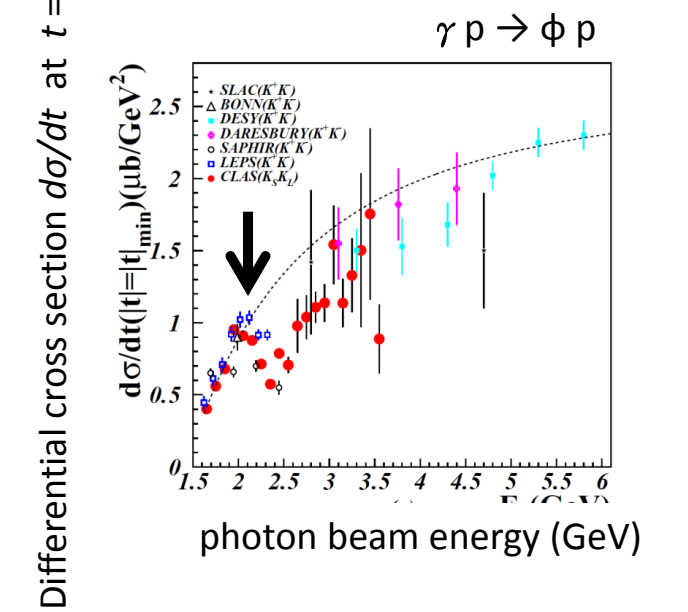
Transparency ratio at forward angles:



the nuclear medium effect is minimal since the deuteron is composed of a loosely bound proton and neutron

some effect other than nuclear density at forward angles?

ϕ photo-production on **proton target**
arXiv:1308.1363 [hep-ex]



21

CB@MAMI

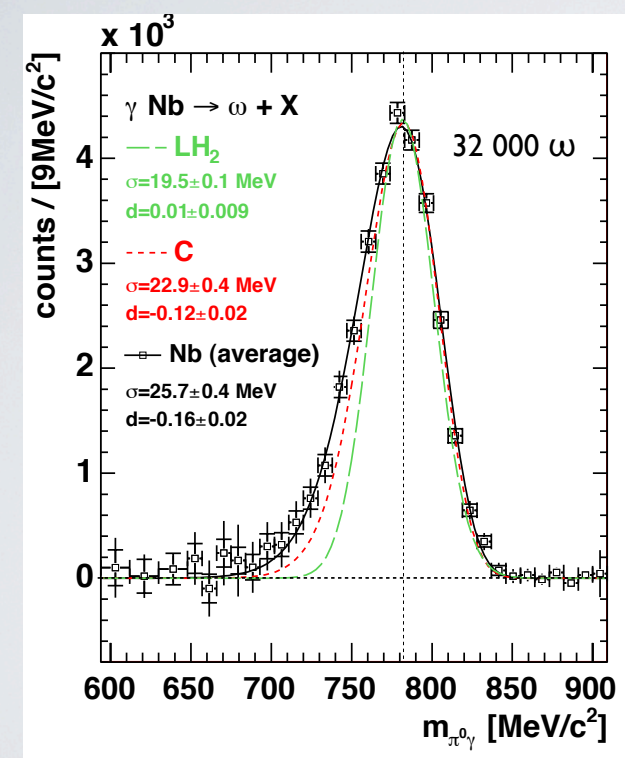
$E_\gamma = 0.9 - 1.3$ GeV

$\omega \rightarrow \pi^0 \gamma$ lineshape analysis

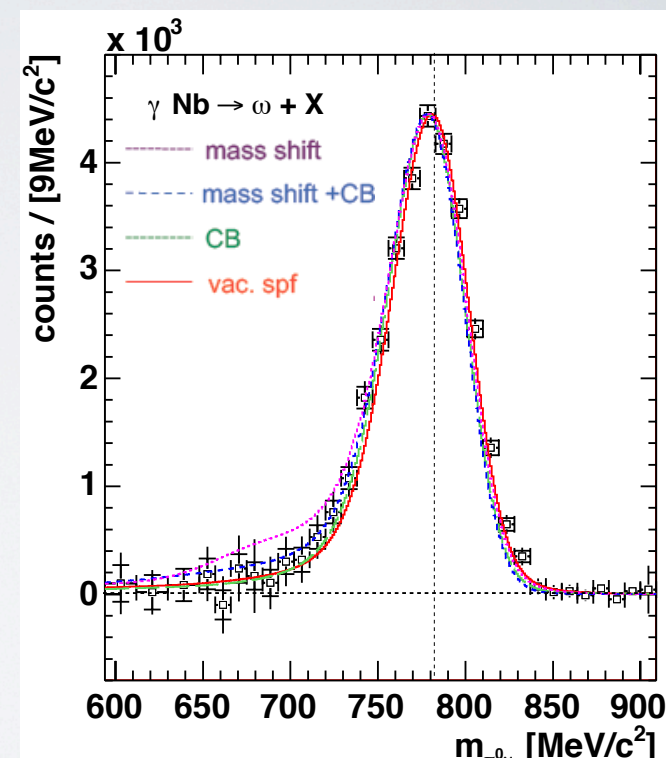
M.Thiel et al., Eur. Phys. J. A49 (2013) 132

comparison with reference measurement on LH₂

comparison with GiBUU calculations for different in-medium scenarios (J.Weil, U. Mosel)



no significant structure in spectral function; signal on Nb,C slightly broader than on LH₂



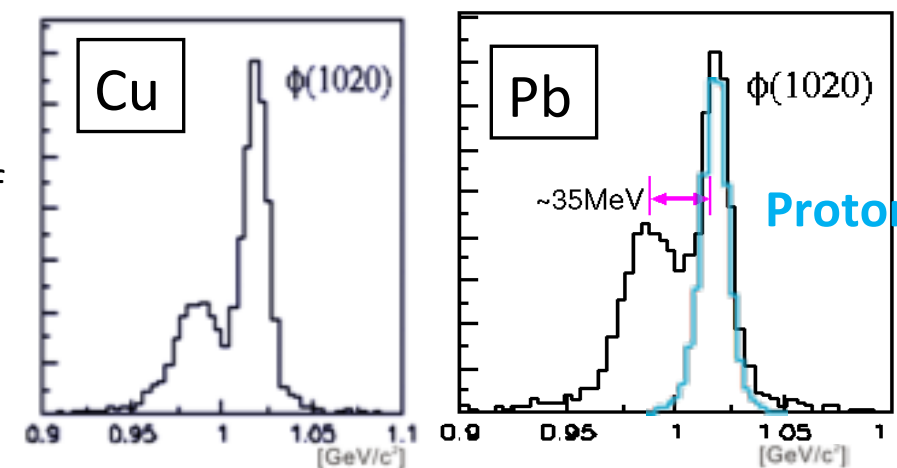
data consistent with collisional broadening; mass shift scenario less likely

20

Nov. 2, 2013

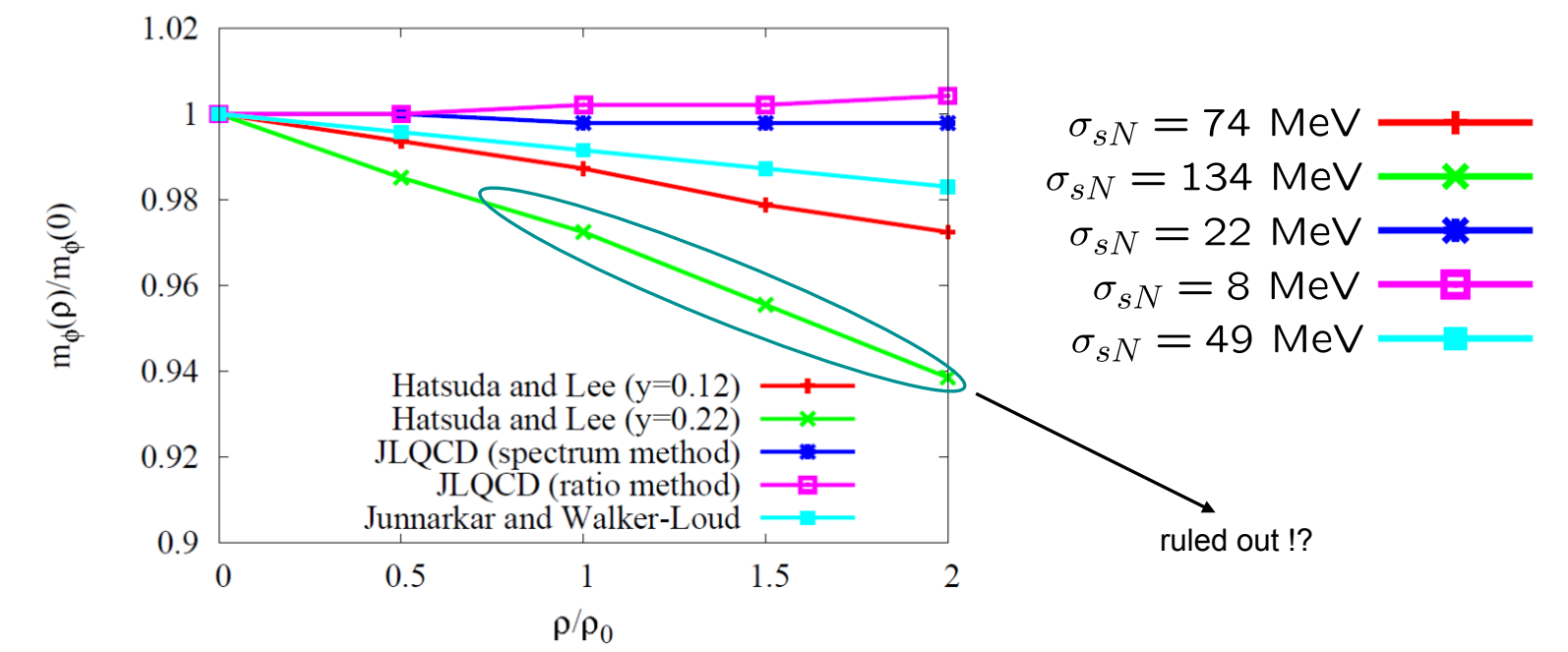
The double-peak structure of f_0 expected at J-PARC E16

- Mass modification of f_0
 - The mass shift is 3.4% at E325 if the excess is interpreted as the shift of the peak position
- Double-peak structure on invariant mass distribution
 - Observe f_0 decayed inside and outside the nucleus
 - In addition to the mass dist. obtained w/ proton target (CH₂), we can **understand the mass distribution of f_0**



E16 expectation (bg < 0.5 & s = 5 MeV)

ϕ meson at finite density



→ The ϕ meson mass shift strongly depends on the strange sigma term.

13

YITP workshop on Hadron in Nucleus @ Kyoto

π, K, η, η'
vector mesons

N, Λ

K^-, p, p

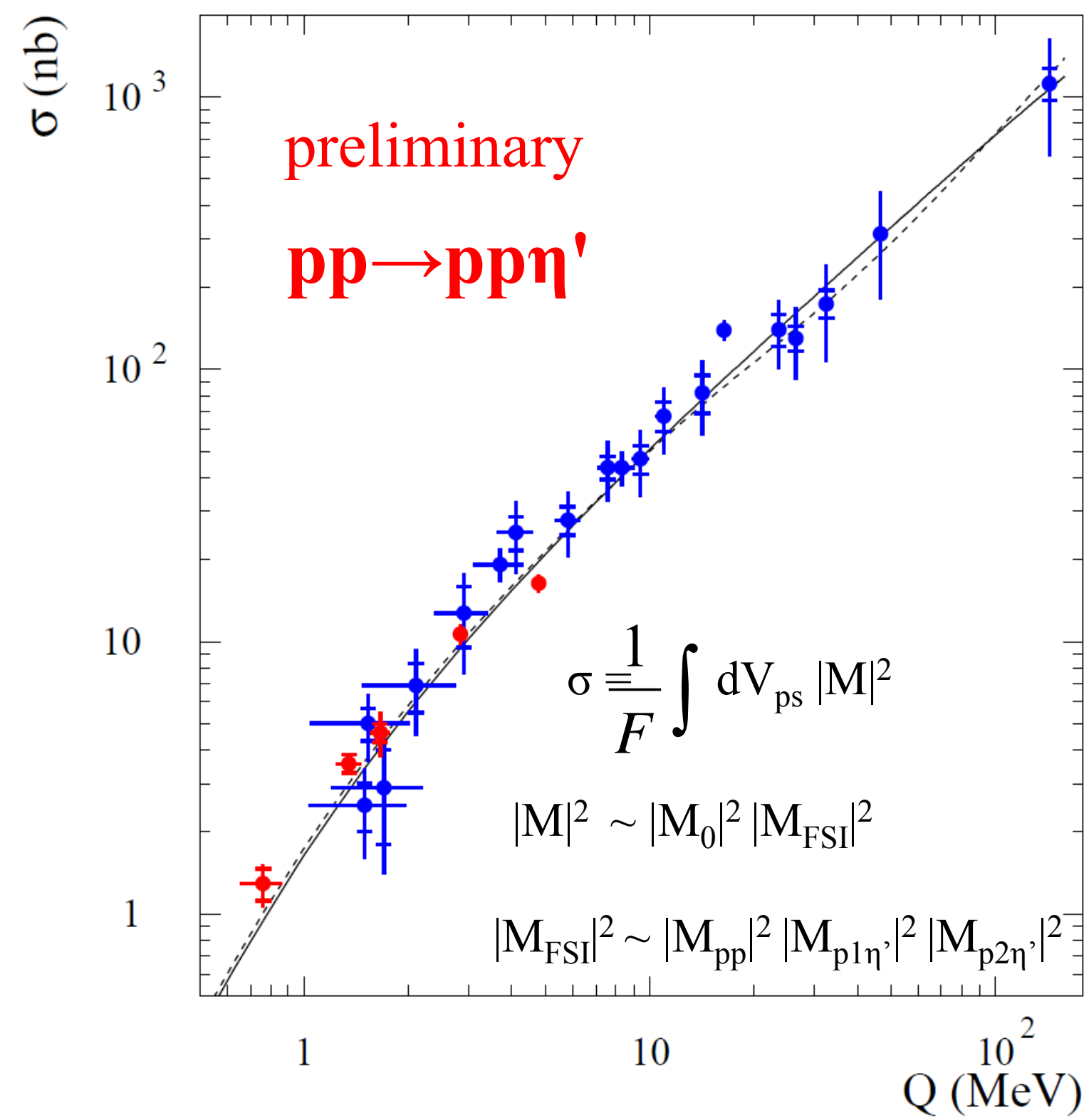
c, b, \dots

H, E, H, I

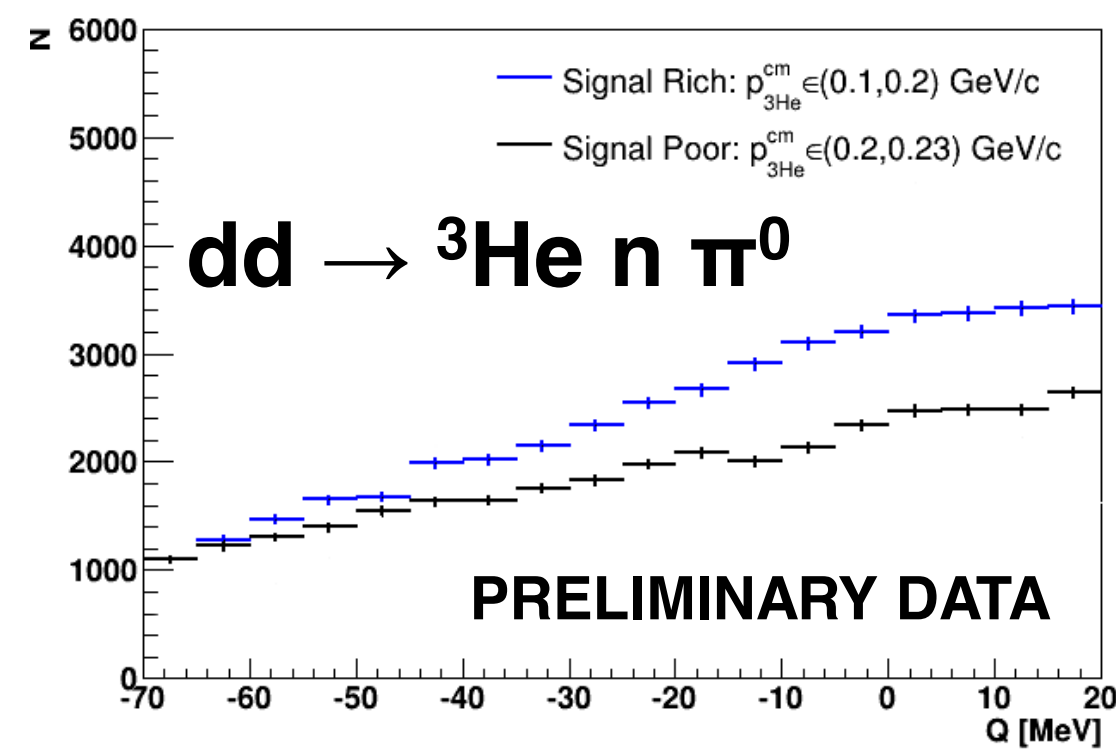
neutron star

new data

η & η'



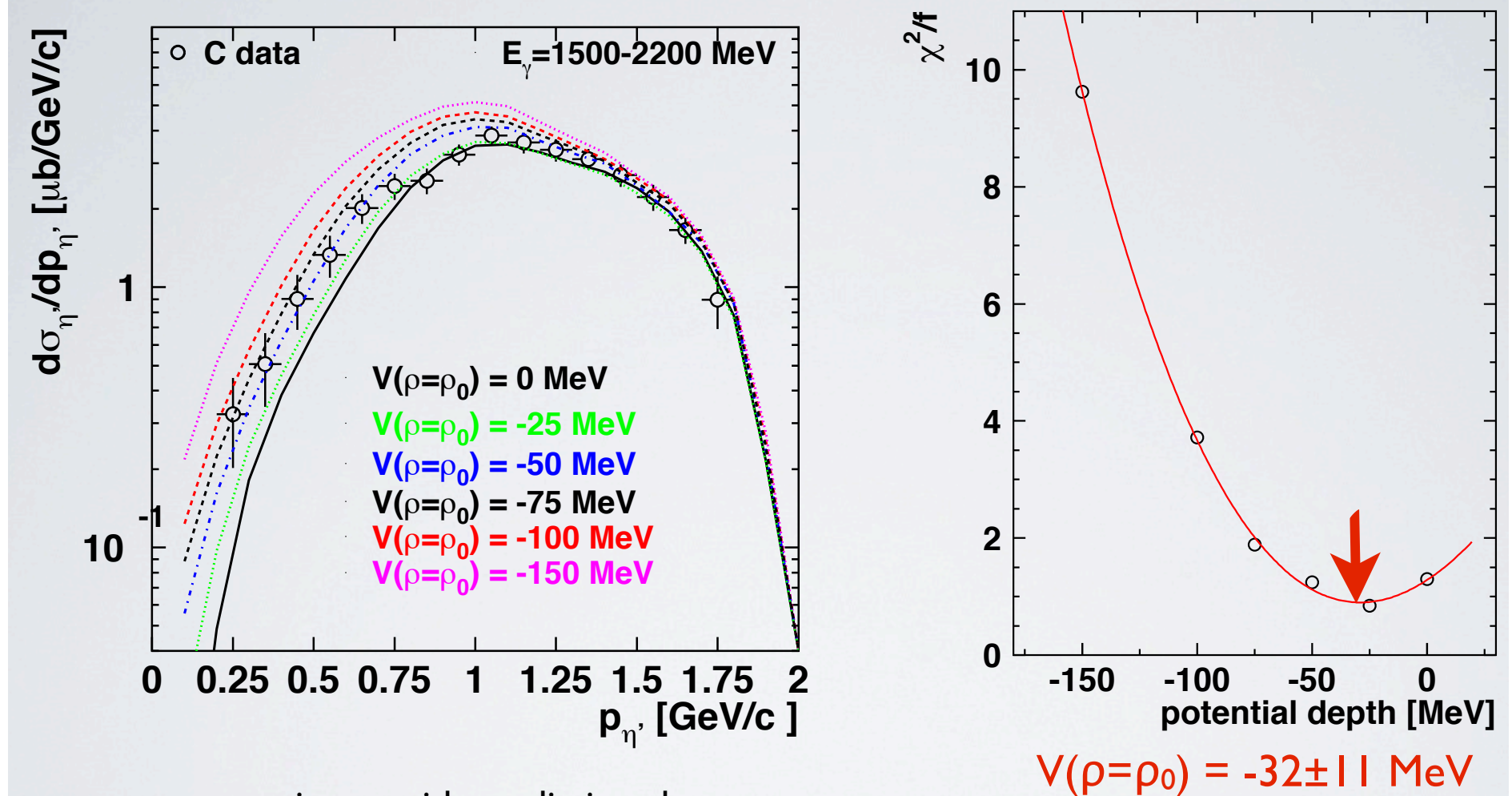
SOLID LINE (CFS) DASHED LINE
 $|\text{Re}_a| = 0.3 +0.1 -0.2$ [fm] $|\text{Re}_a| = 0.2 +0.2$ [fm]
 $\text{Im}_a = -0.1 + -0.1$ [fm] $\text{Im}_a = -0.0 + -0.1$ [fm]



Moskal

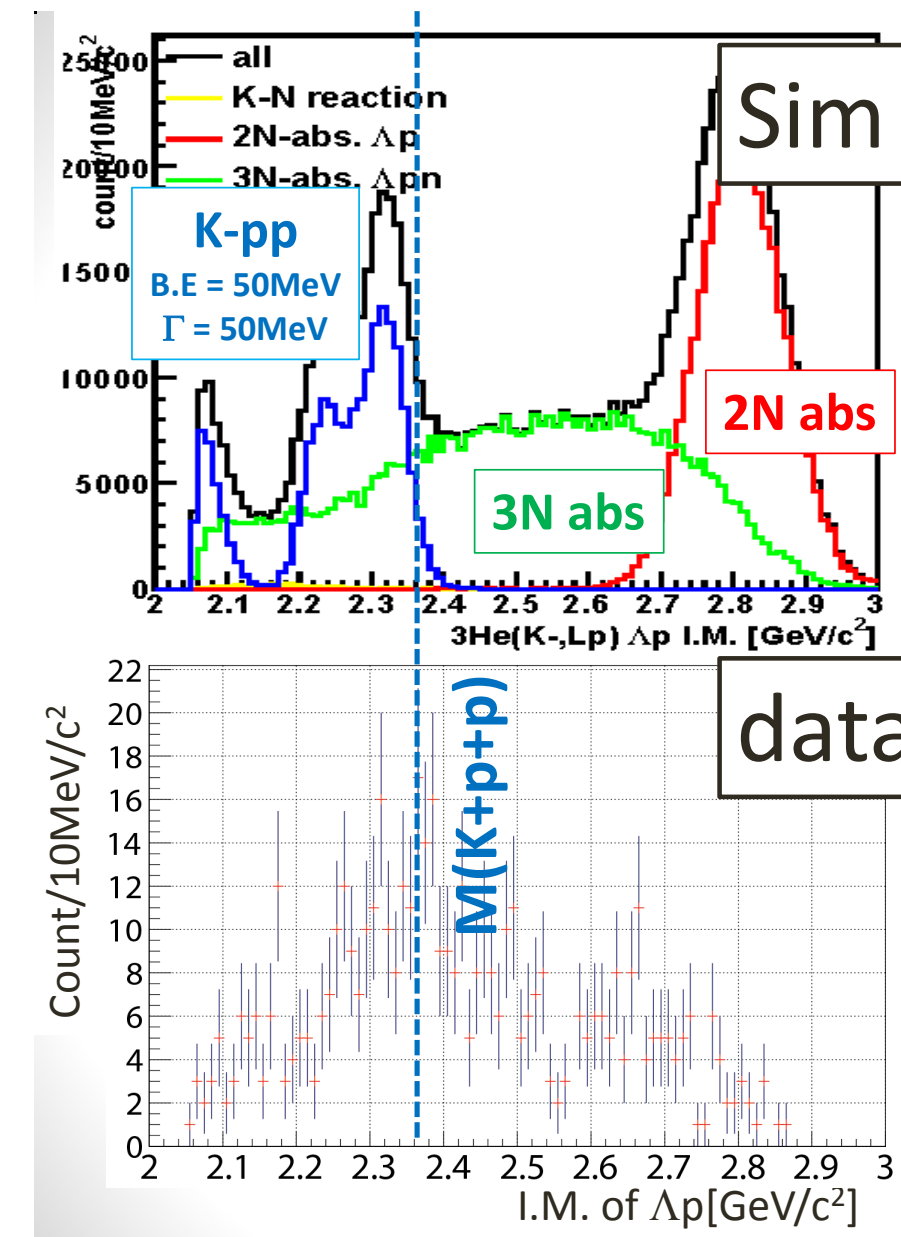
η - ${}^4\text{He}$

estimation of the of η' -nucleus potential depth from the η' momentum distribution



Nanova

K-pp



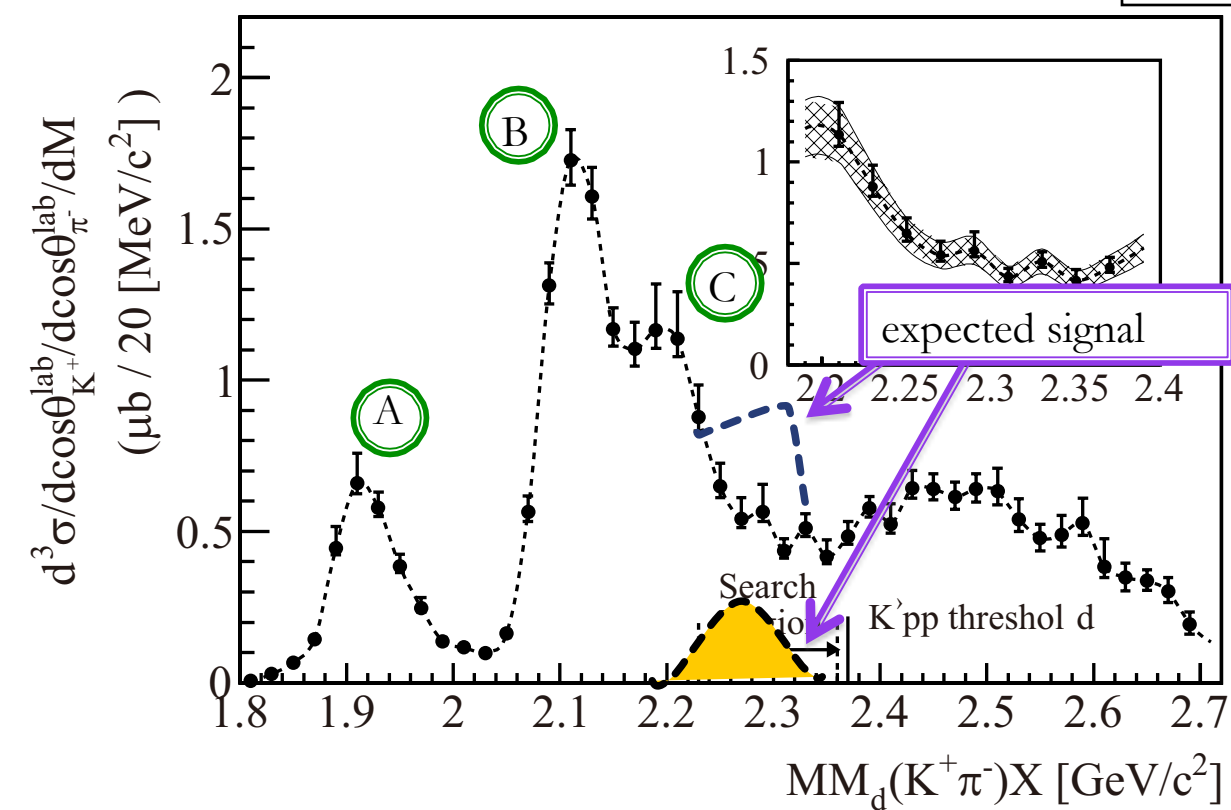
Sada
 $^3\text{He}(K^-,n)$ at J-PARC

From MC, 2Nabs makes peak in high energy region
 => real data spectrum don't have the peak in high energy region.
 It seems 3N abs (or exotic state?) is dominant.

(24)

missing mass spectrum

Tokiyasu
 $d(\gamma, K^+p)$ at LEPS



cut condition

- $\cos\theta_{K^+}^{\text{lab}} > 0.95$
- $\cos\theta_{p^-}^{\text{lab}} > 0.95$
- $0.25 < p_{K^+} < 2.5$
- $0.25 < p_{p^-} < 0.6$

- A:
 $g_n \rightarrow S^- K^+$
 $S^- \rightarrow n p^-$
- B:
 $g_p \rightarrow L K^+ p^-$
- C:
 $g_{p/n} \rightarrow S^{-/0} K^+ p^-$

B + C : ~11 mb

Peak structure was searched in 2.22 - 2.36 GeV/c².

→ No peak structure was observed!

1 pion tagging spectrum

$$R_\pi = (\text{Pion coincidence spectrum}) / (\text{Inclusive spectrum})$$

$$R_\pi \propto (\pi \text{ emission BR}) \times (\pi \text{ detection efficiency})$$

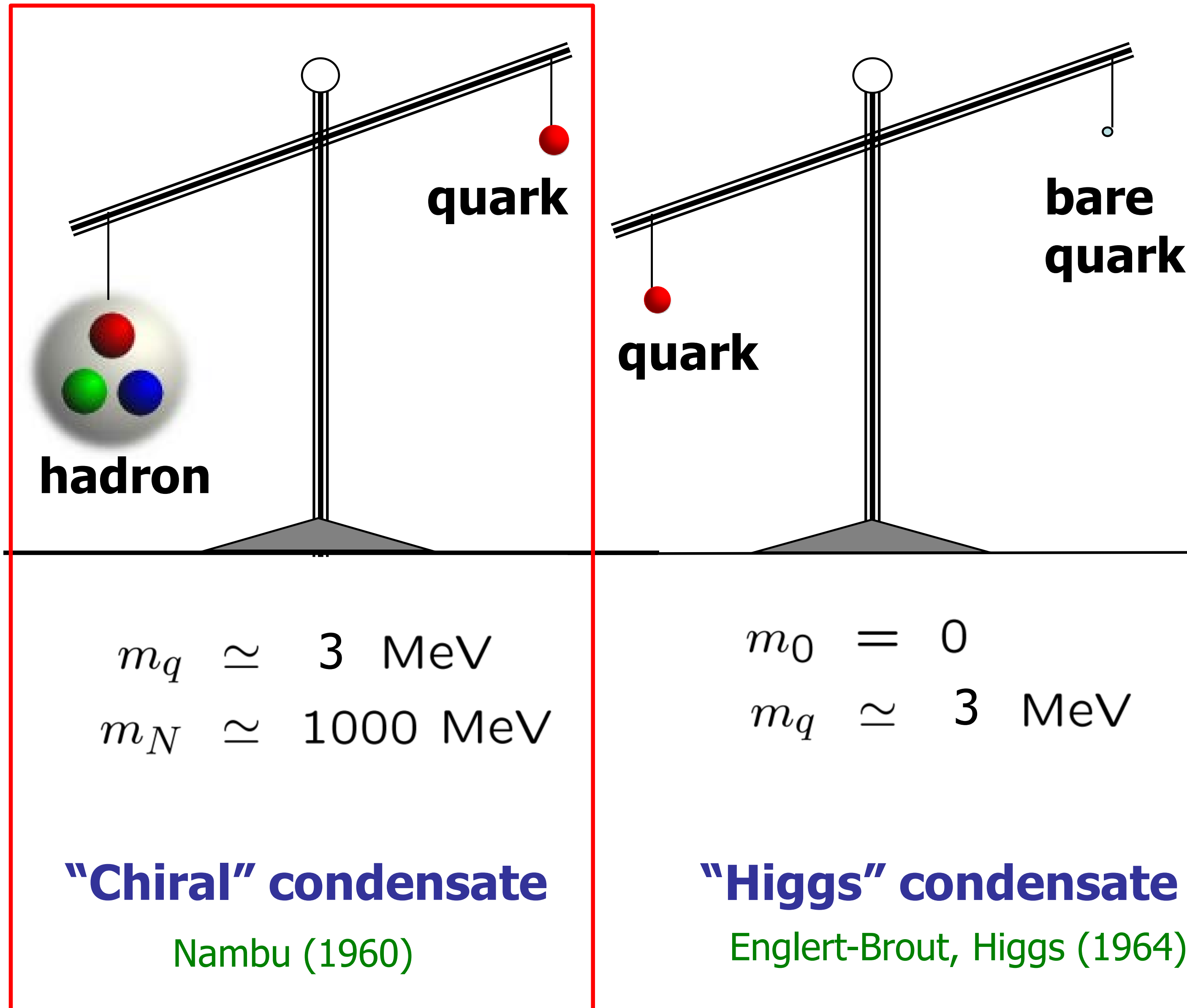
QFΛ and QFΣ emit 1 pion
 QFY* and πYN emit 2 pions

R_π reflects π emission probability, therefore the ratio in QFY* + πYN region is higher than those in the other regions.

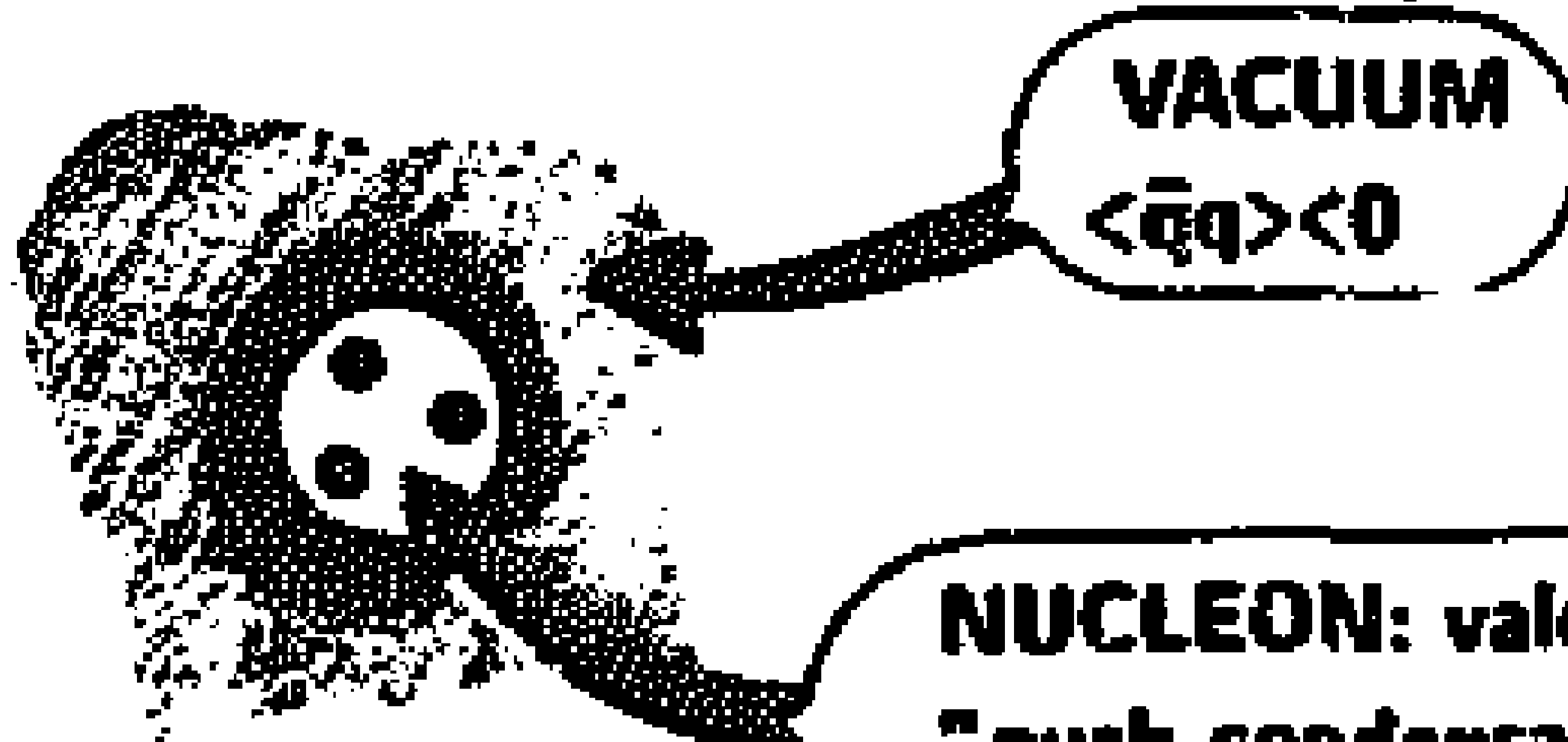
R_π is almost constant at each region.

?

Ekawa; $d(\pi^+, K^+)$ at J-PARC



$$\langle \bar{q}q \rangle_\rho = \langle \bar{q}q \rangle_0 + \langle N | \bar{q}q | N \rangle_\rho = \langle \bar{q}q \rangle_0 + \frac{\sigma_{\pi N}}{2m_q} \rho$$



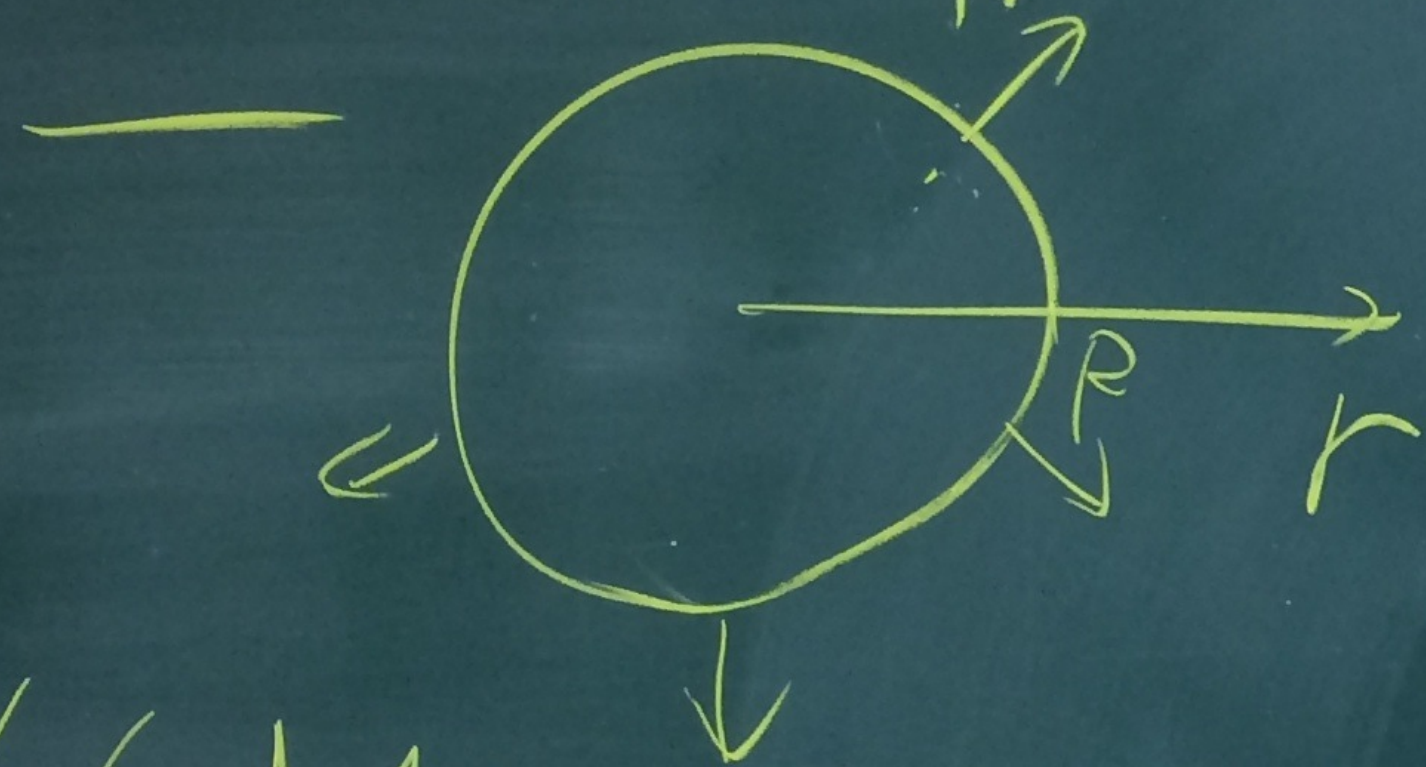
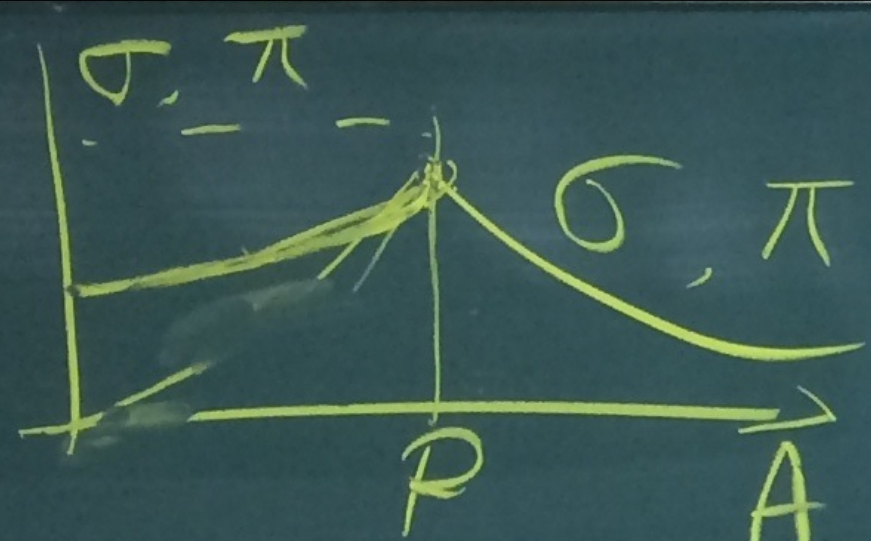
VACUUM

$\langle \bar{q}q \rangle < 0$

NUCLEON: valence quarks

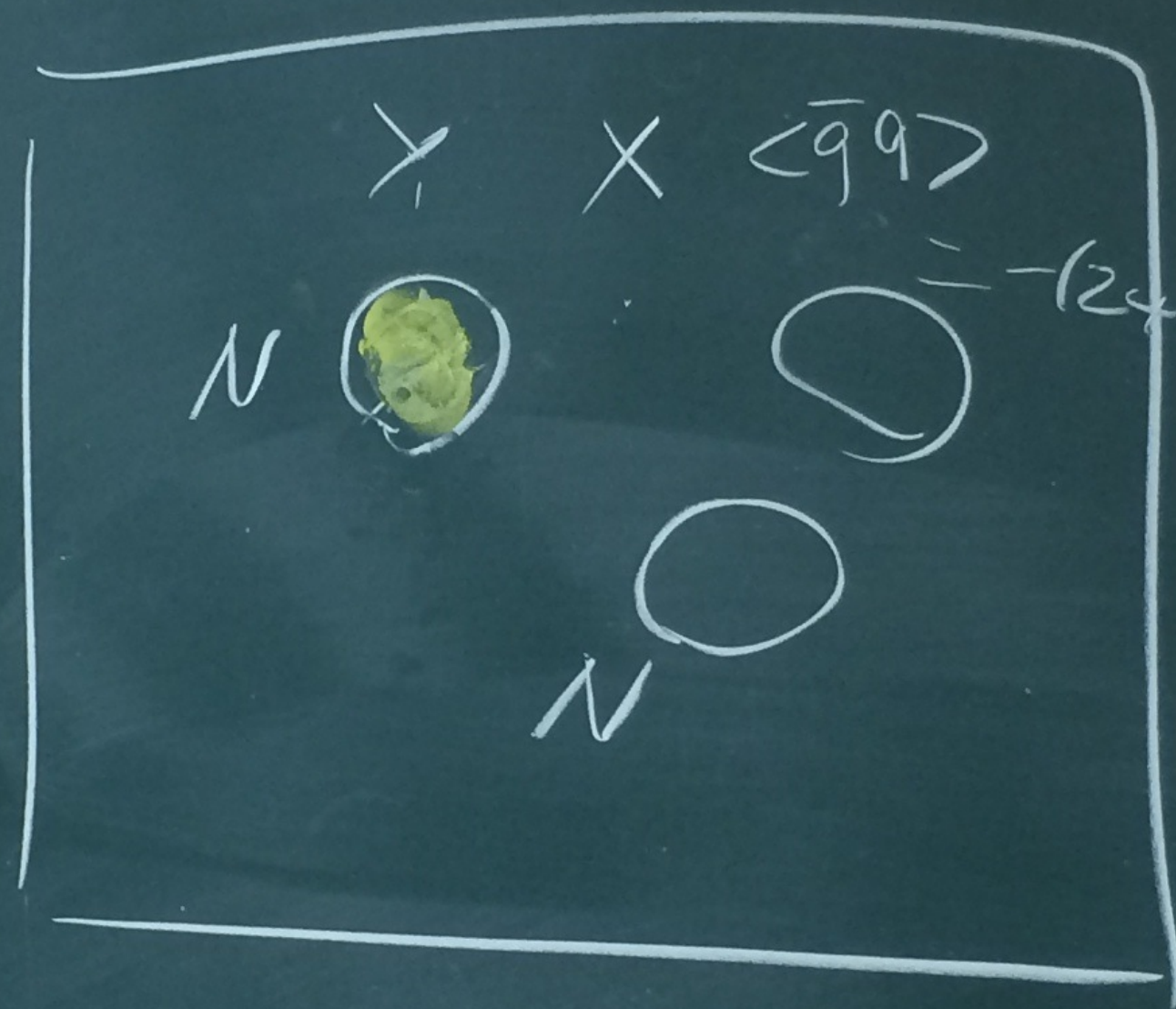
"push condensate aside"

SCALAR DENSITY $q > 0$



$$1.6 M_u = M_s$$

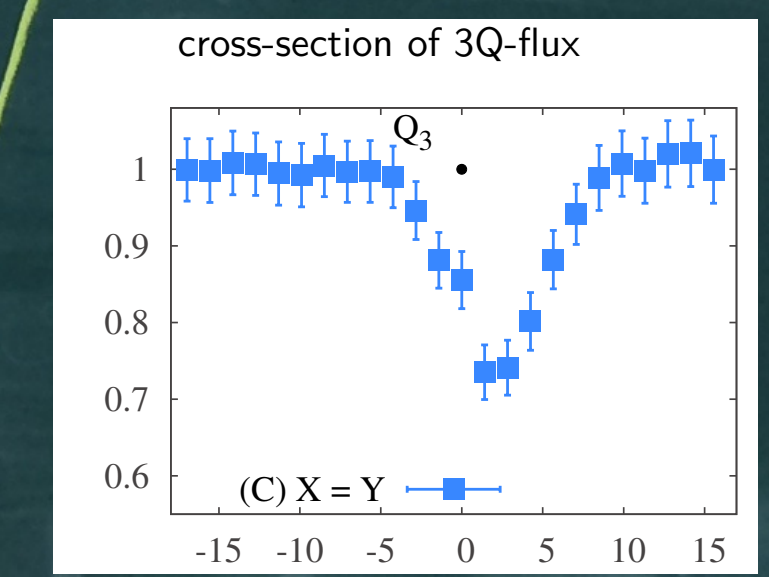
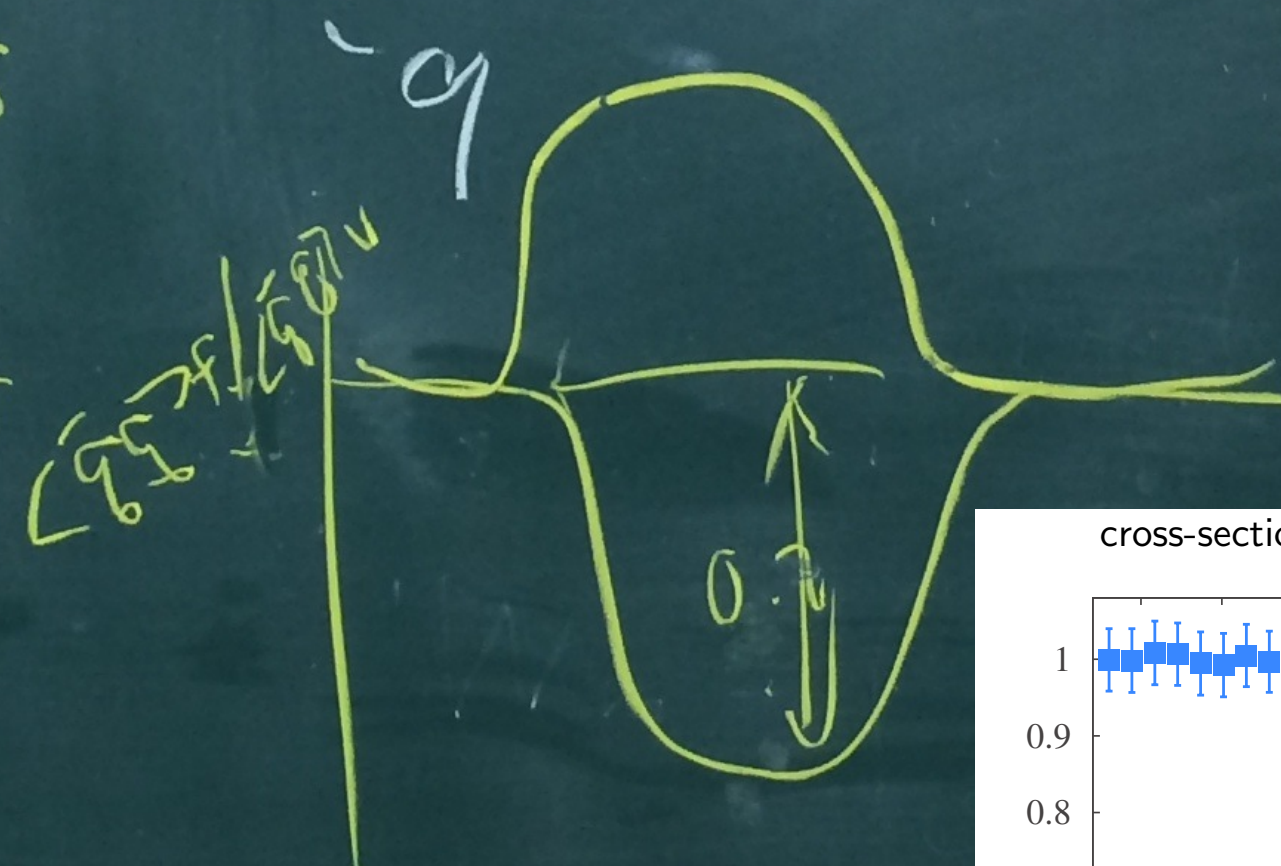
$$(20-30) \times M_u = M_s$$



$$\langle N | \bar{q}q | N \rangle$$

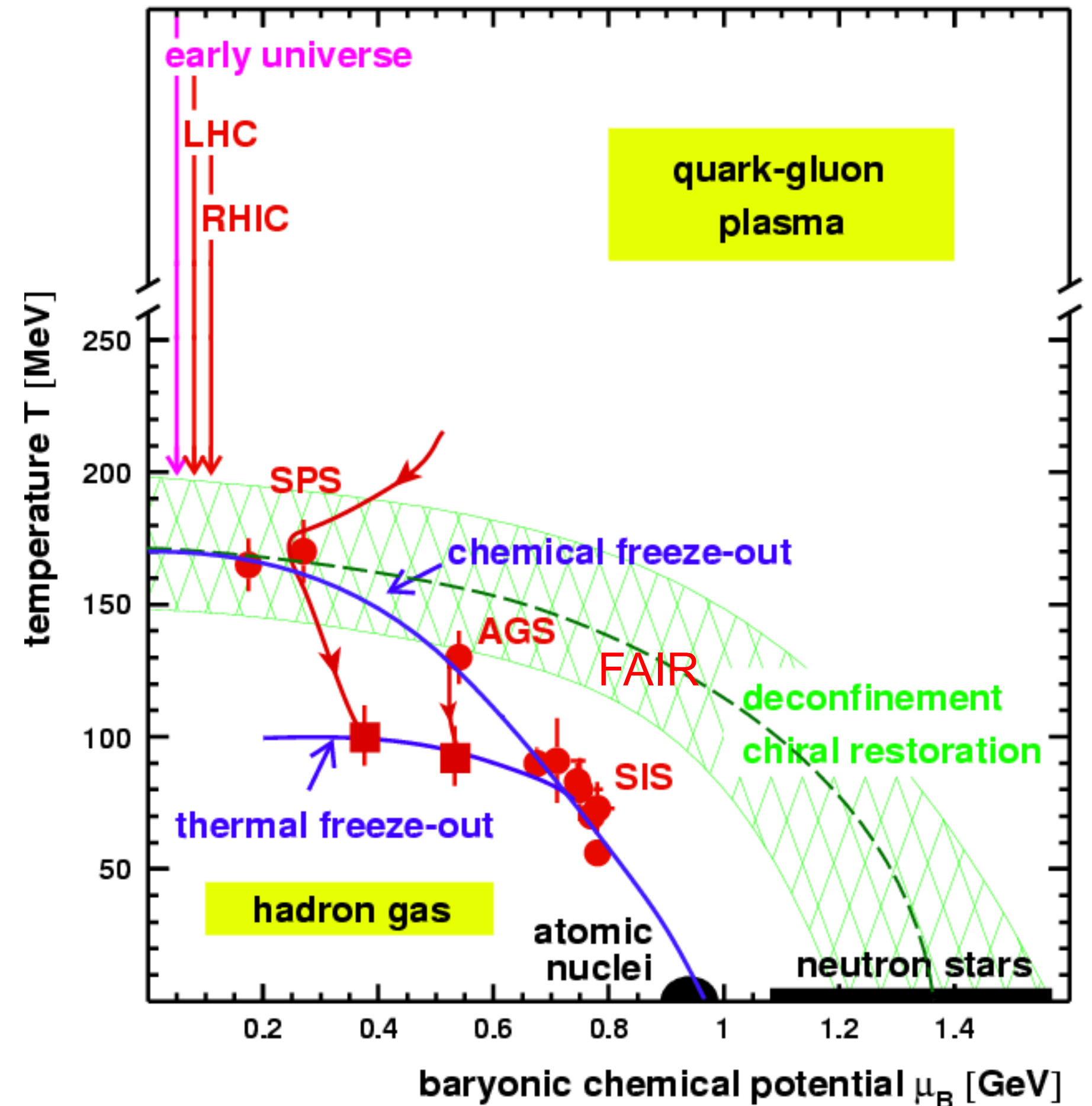
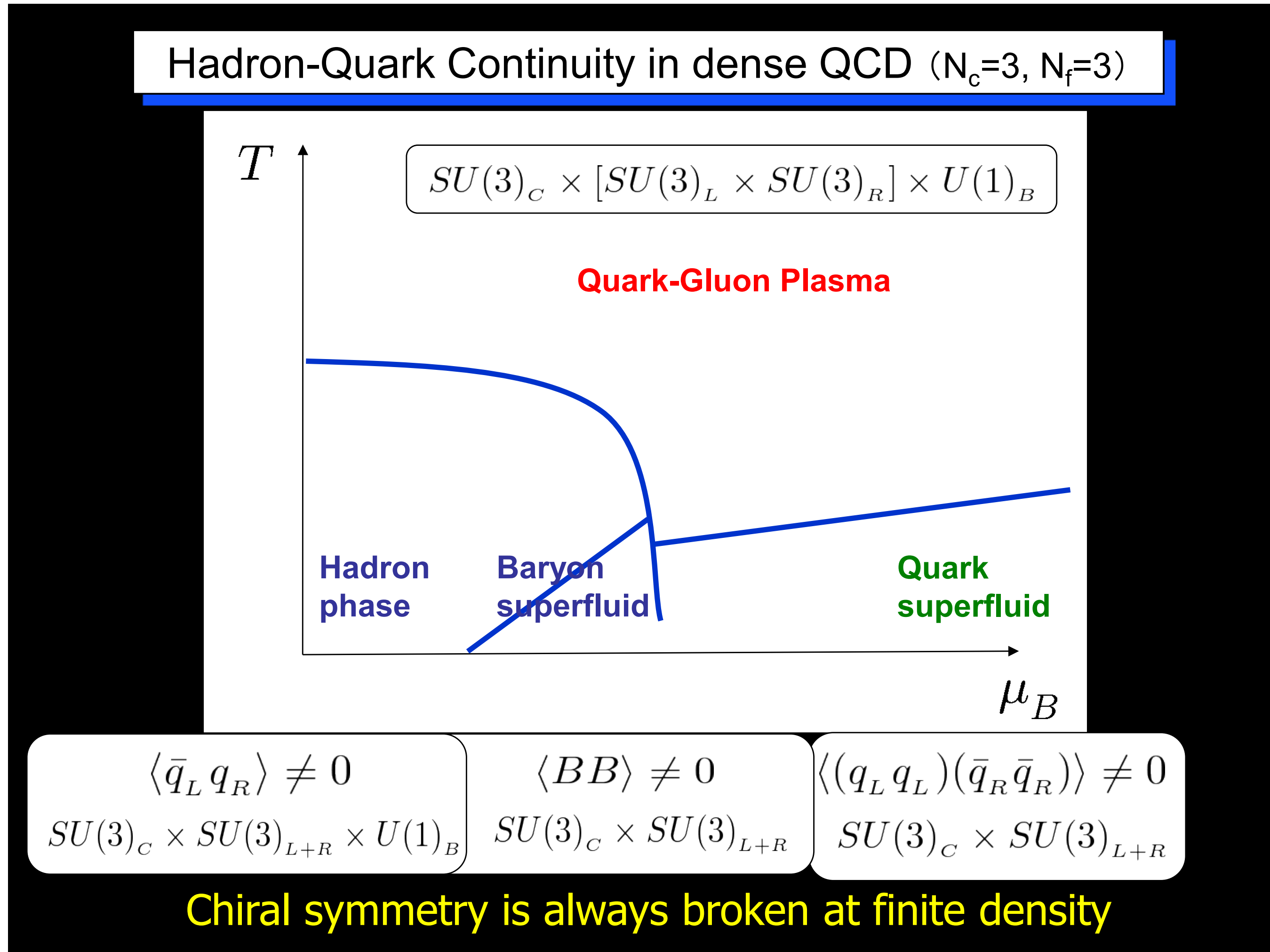
$$= \langle \bar{q}q \rangle - \frac{N}{V} \langle \bar{q}q \rangle$$

$$\langle N | \bar{q}q | N \rangle = \sum_{\tau} \tau N$$



$$\sum_{\tau} \tau N = -\hat{m} \langle N | \bar{u}u + \bar{d}d | N \rangle$$

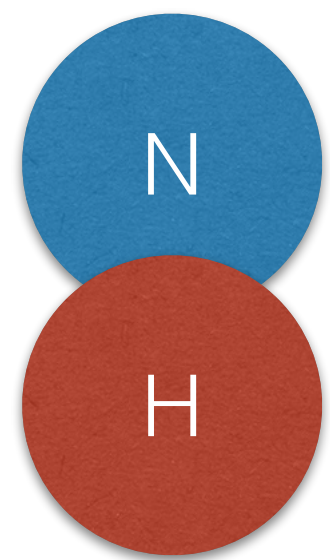
Experimentally-accessible region is rather limited
 Lattice is powerful, but is also limited for $\mu_B \sim 0$



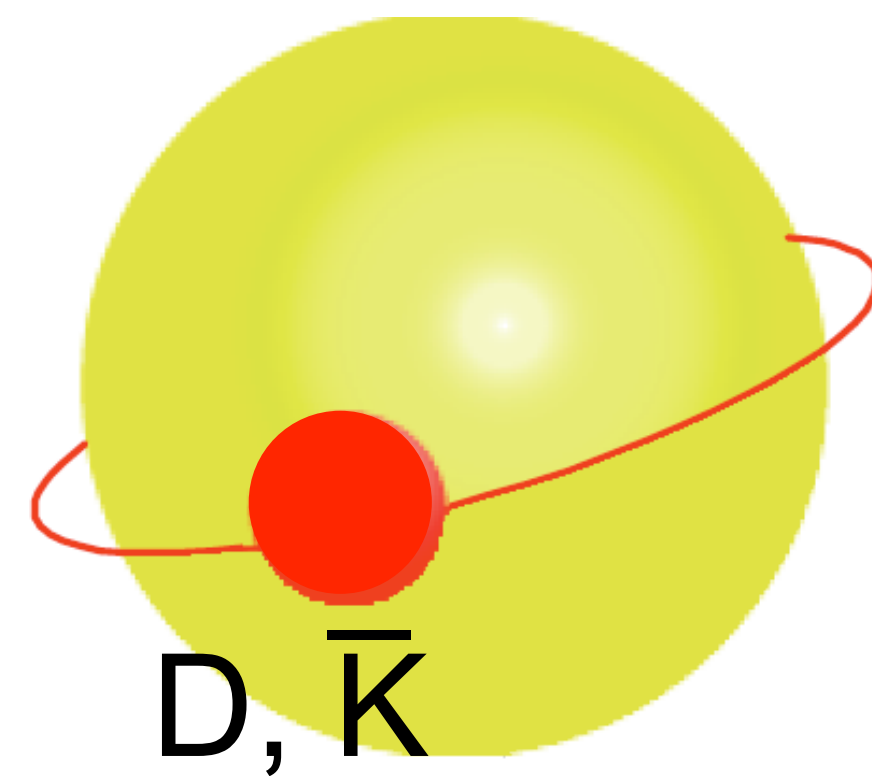
NuPECC report

HIN - Hadron in Nucleus

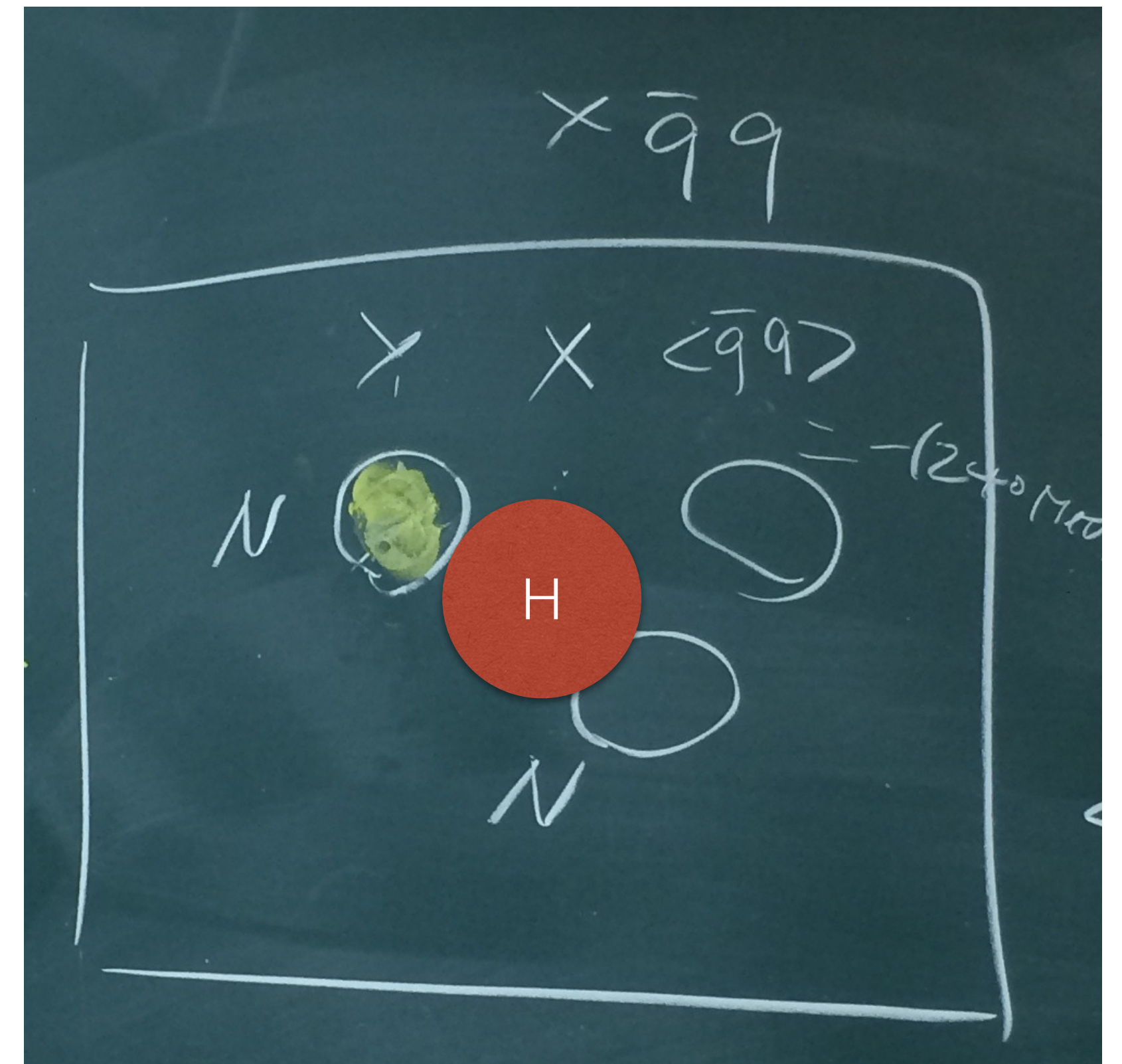
how does this “probe”
modify the environment?



hadron-nucleon
2-body
baseline
n.b. hypernuclei



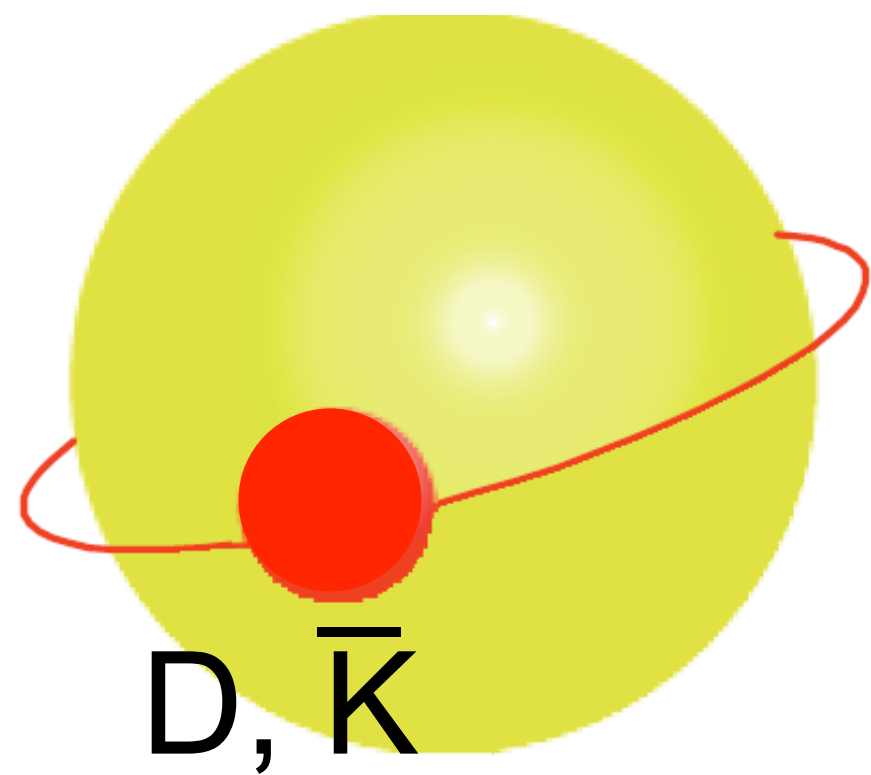
missing mass
invariant mass
transparency ratio
excitation energy
...



nuclear matter

HIN - Hadron in Nucleus

- π
pionic atom - assisted by Coulomb & recoilless mass shift ~ 0 , it is $f_\pi (f_t)$ which gets modified
- Λ
hypernuclei (in-medium μ_Λ)
- ω, Φ, \dots
 η, η', \dots
mass reduction + \sim recoilless ?
- charmed, $c\bar{c}$???



mass reduction?

- Chiral order parameters; not unique : Dim.3 condensate, Dim.6 condensate, etc
- ~30% reduction in $\frac{\langle \bar{q}q \rangle}{\langle \bar{q}q \rangle_0}$; what does this mean for mass?

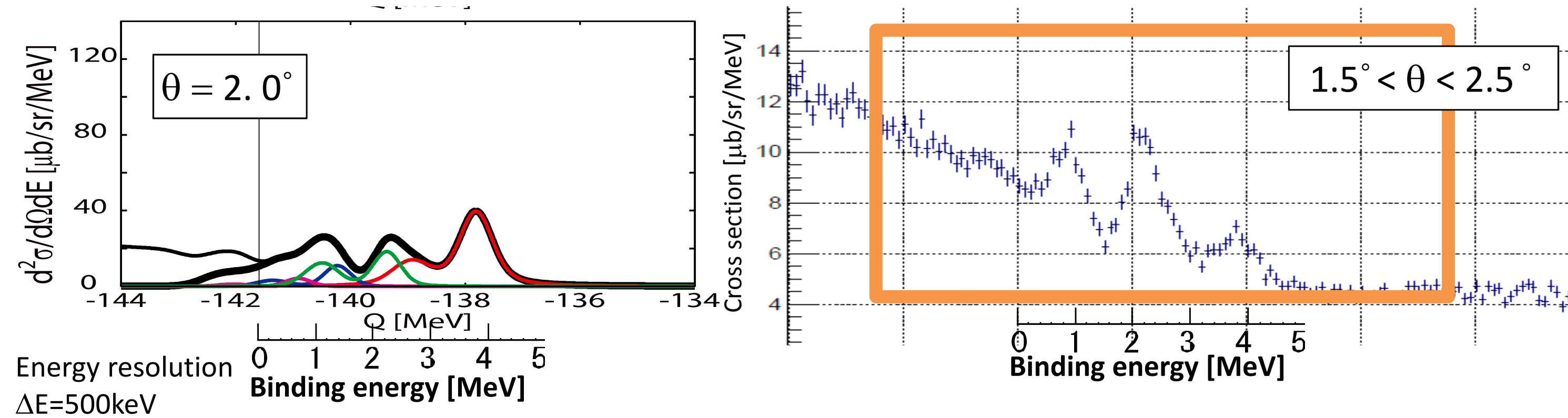
$$\underbrace{\frac{Q^2}{\pi} \int_0^\infty ds \frac{Im\Pi(s)}{s(s+Q^2)}}_{\text{hadronic side}} = \underbrace{-\frac{1}{8\pi^2} \left(1 + \frac{\alpha_s}{\pi}\right) \ln \frac{Q^2}{\Lambda^2}}_{\text{QCD side}} + \frac{m_q \langle \bar{q}q \rangle}{Q^4} + \frac{1}{24} \frac{\langle \frac{\alpha_s}{\pi} G^2 \rangle}{Q^4} - \frac{112}{81} \alpha_s \pi \frac{\langle \bar{q}q \rangle^2}{Q^6} + \dots$$

Metag

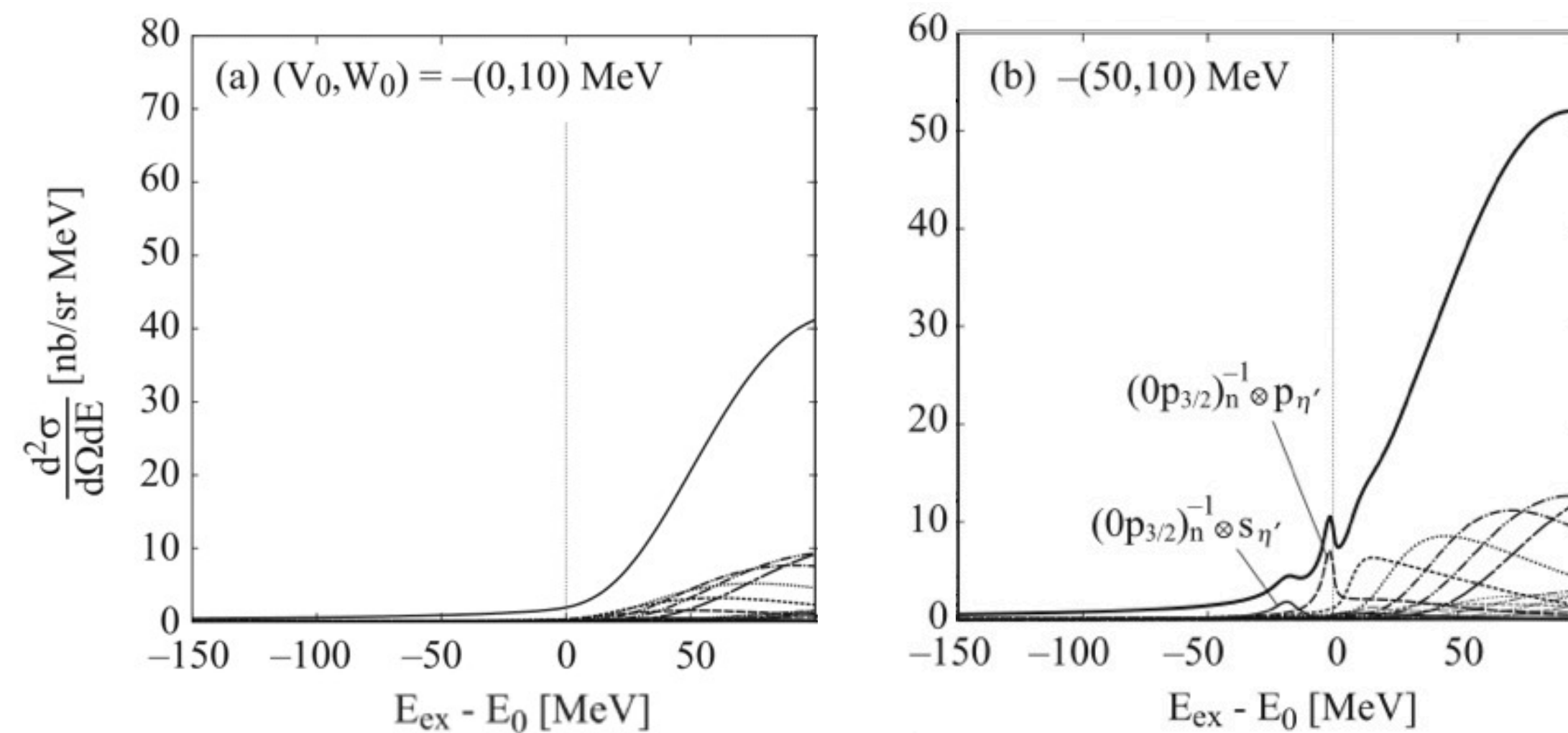
- Subthreshold behavior (energy dependence) of $f_{\eta N}, \dots$ is crucial
- imaginary part $W \ll$ real part V ?

How well do we understand QF?

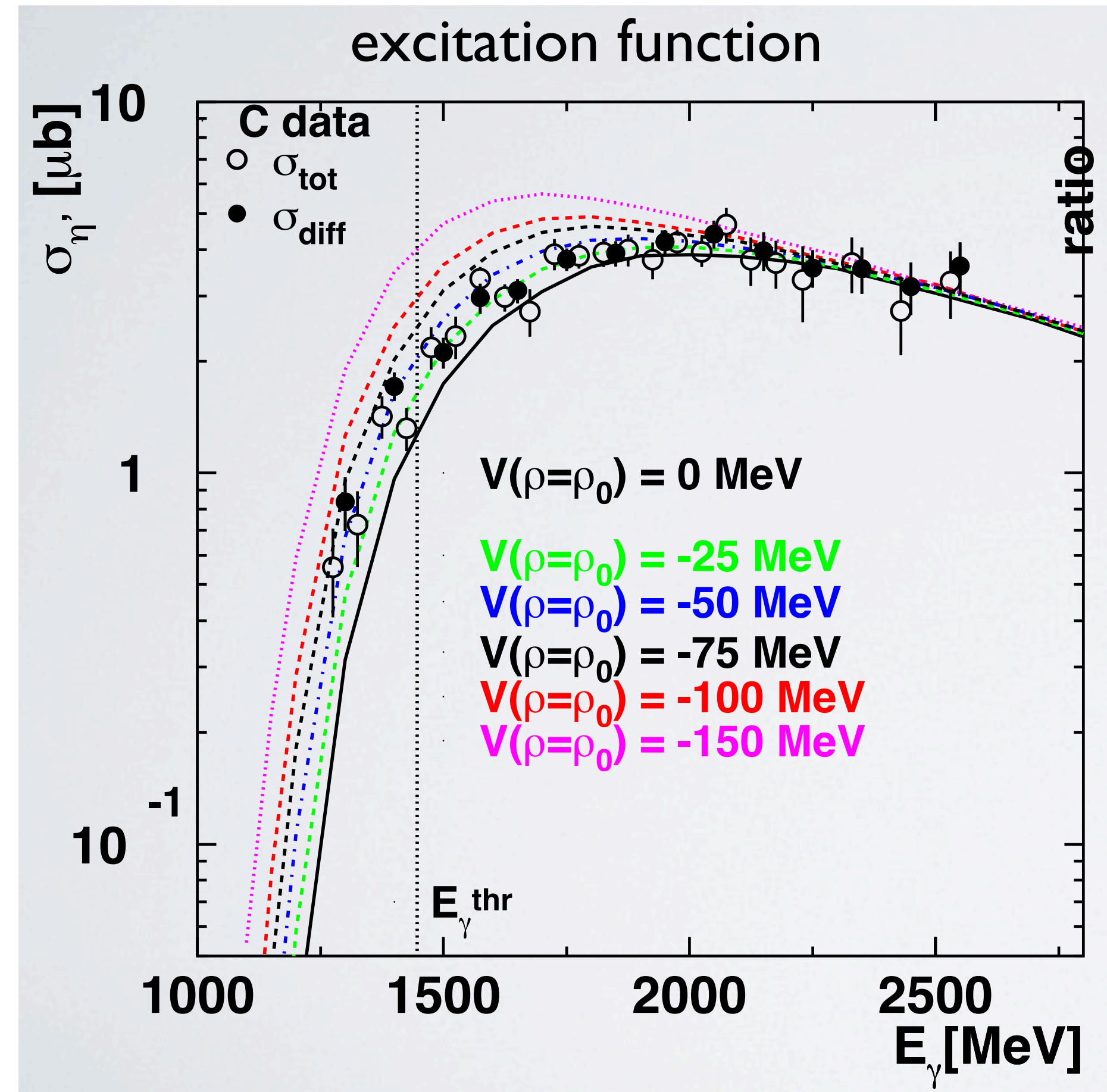
not easy even for pionic atoms



good understanding of QF, (and good energy resolution) essential for shallow V, large W



or the excitation function?



Nanova

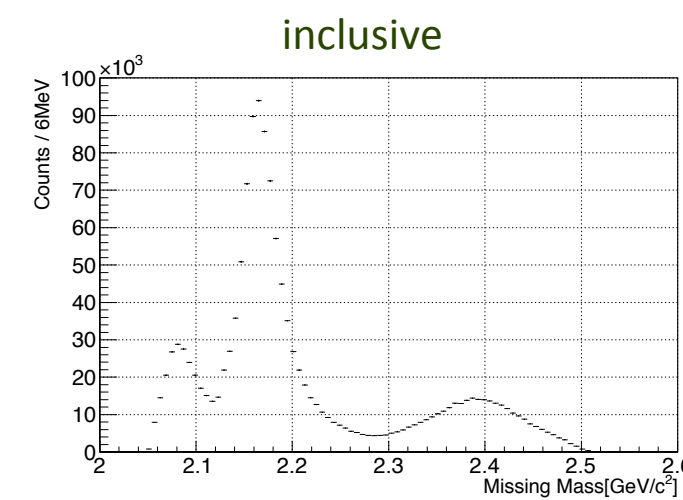
To tag, or not to tag, that is the question

Ekawa

Coincidence study

18

We studied coincidence data by using RC cut.

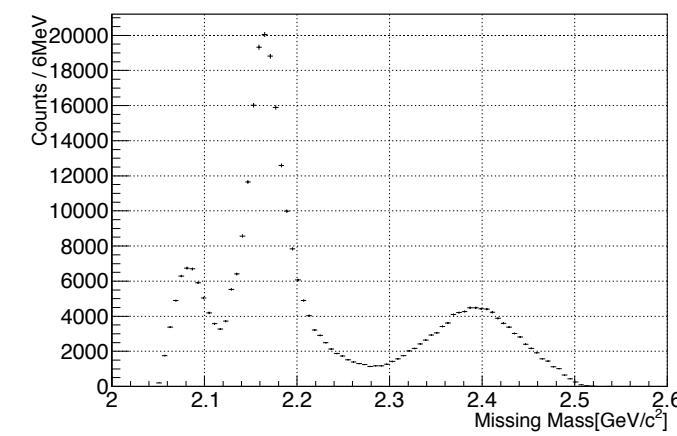


\bar{p} cut

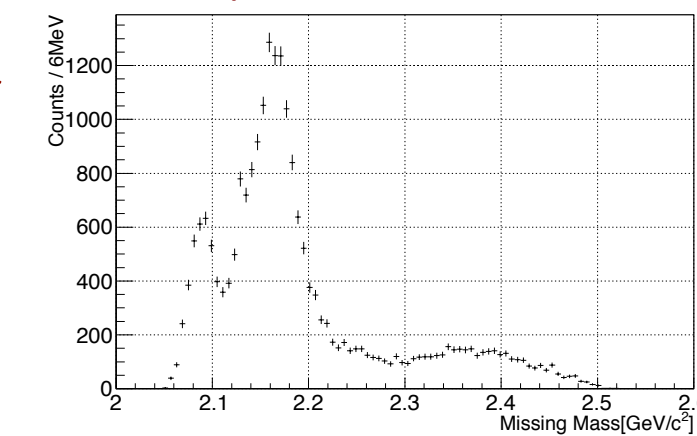
p cut

\bar{p} cut : π or slow p
p cut : proton ($p > 280$ MeV/c)

1 pion coincidence



1 proton coincidence



how to understand
(1-p tagged)/(inclusive)

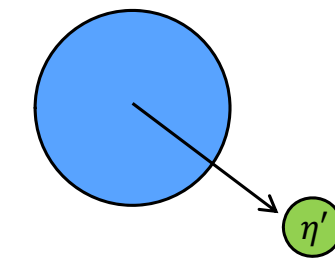
“2 proton tagging rate is very low”

decomposition into different final states

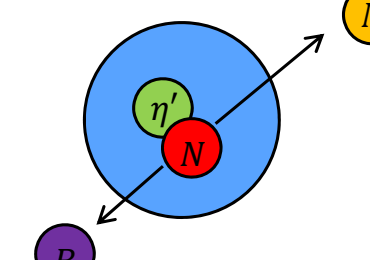
Based on the coupled-channel cal.

three final states

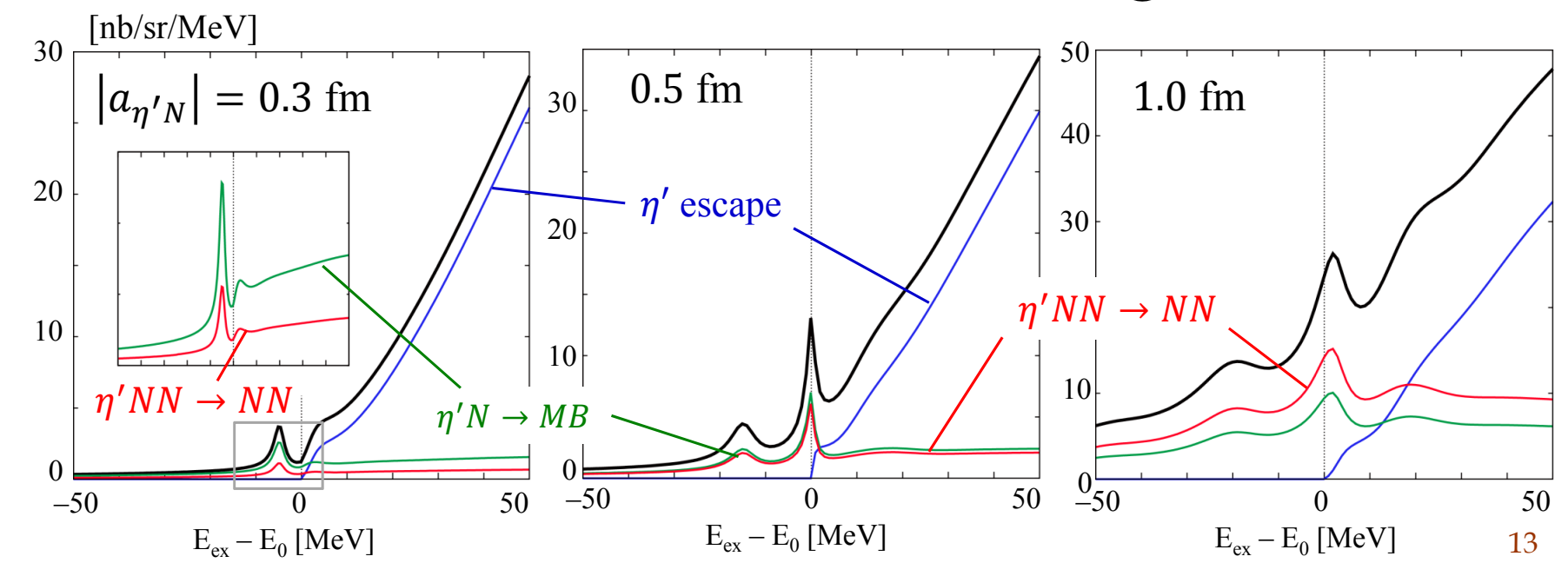
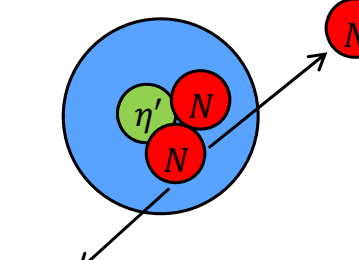
(a) η' escape



(b) $\eta'N \rightarrow MB$



(c) $\eta'NN \rightarrow NN$

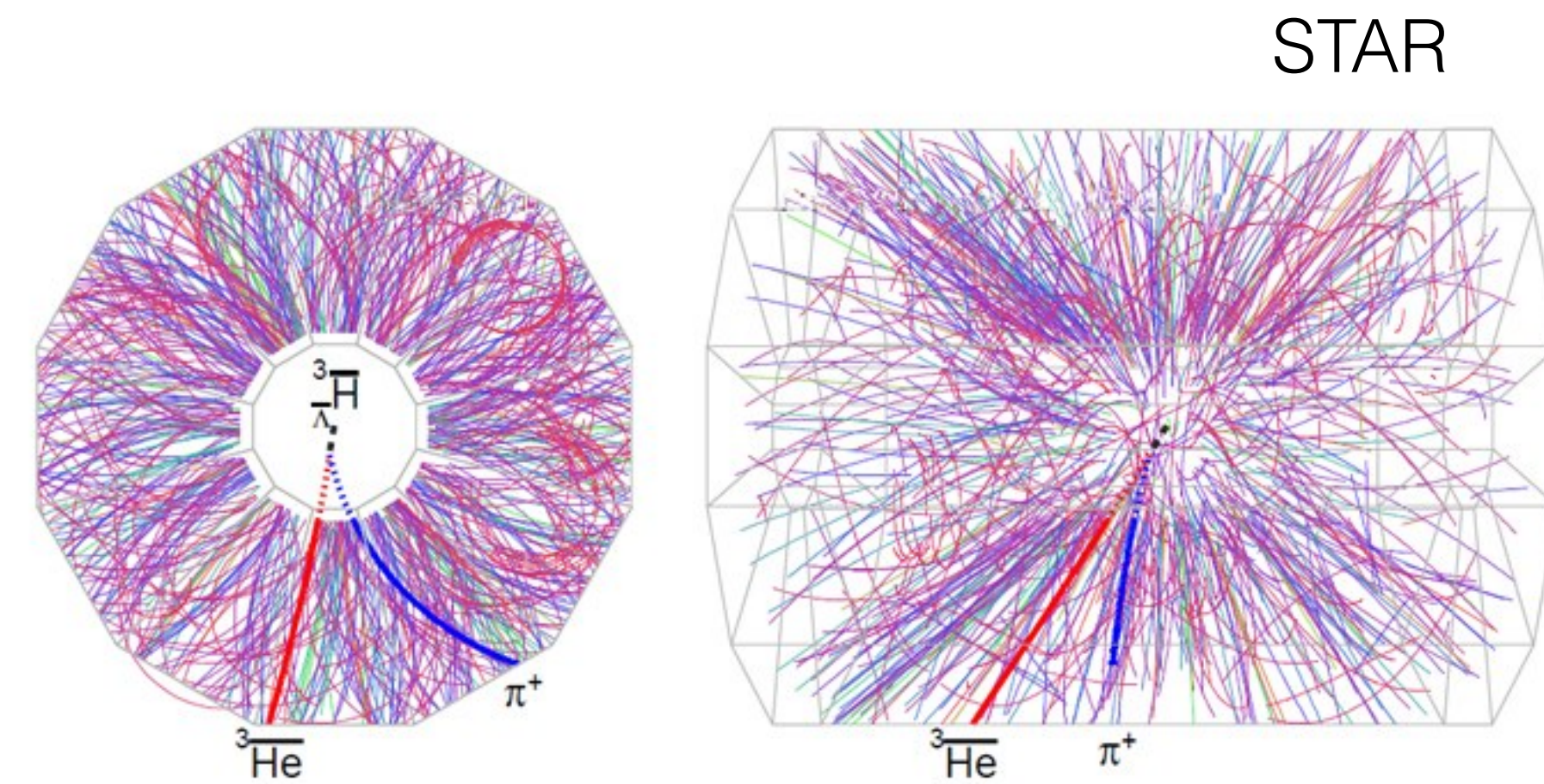


nagahiro

13

exotics in HEHI collisions

- exotics such as antihypertriton found in HEHI



- other exotics may have been formed, but not reconstructed - (Hamagaki, private comm.)
such as strange-strange-strange dibaryon

Ω -p

A final remark

Theorist's dreams are...

Wish list by an innocent theorist

- 1 Spectral difference between chiral partners
 π - σ , ρ - a_1 , ω - f_1 , etc

Determination of D=6 chiral condensates in the vacuum?
Tau-decay in nuclei ?

- 2 Individual properties of NG and "Higgs" bosons
 π , K , η (NG), σ (Higgs), η' (anomaly)

$\sigma \rightarrow 2\gamma$, $\eta \rightarrow 2\gamma$, $\eta' \rightarrow 2\gamma$

Mesic nuclei
Dipion

- 3 Individual properties of vector bosons
 ρ , ω , K^* and ϕ

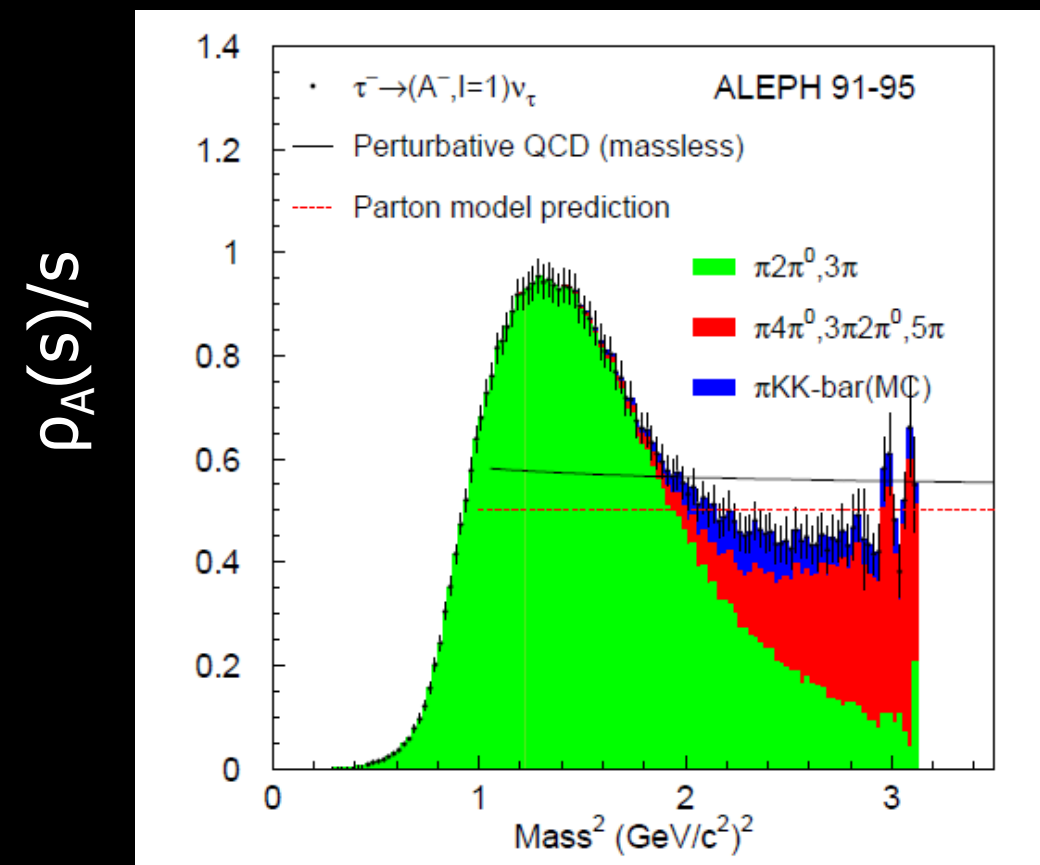
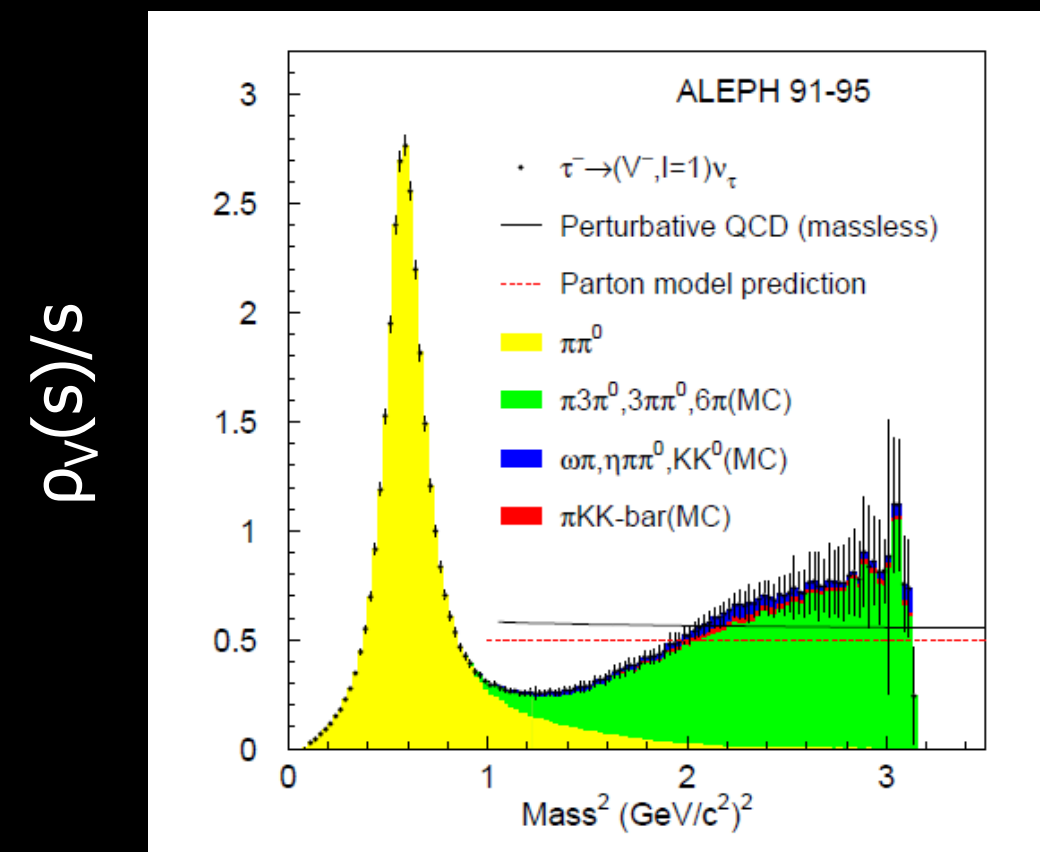
Precision/systematic studies
(dispersion relation, different targets, ...)

Dileptons
Hadronic decay

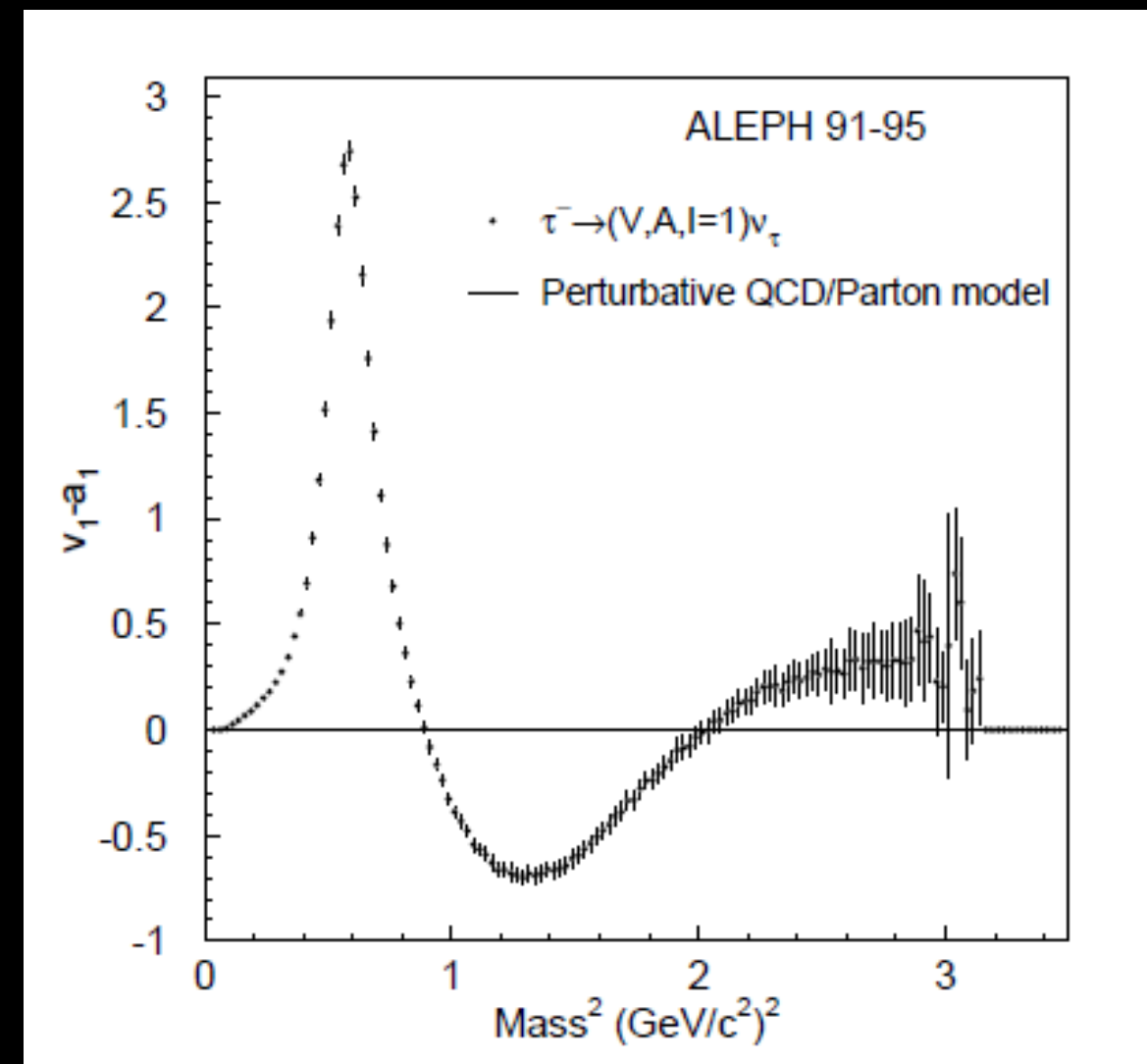
Experimentalist's nightmare

e.g., how to do this \downarrow in medium??

$\langle VV \rangle - \langle AA \rangle$ from τ -decays at LEP-1



$[\rho_V(s) - \rho_A(s)] / s$



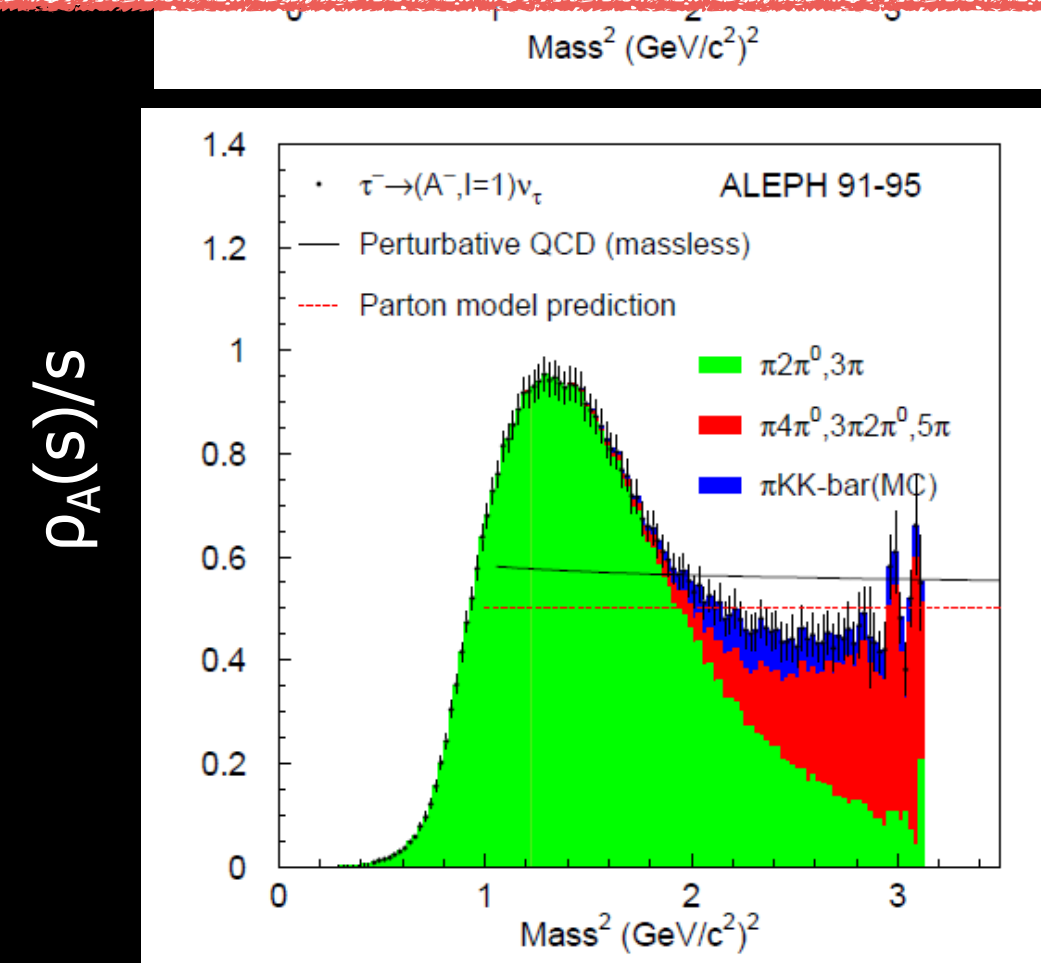
ALEPH Collaboration,
Phys. Rep. 421 (2005) 191

Experimentalist's nightmare

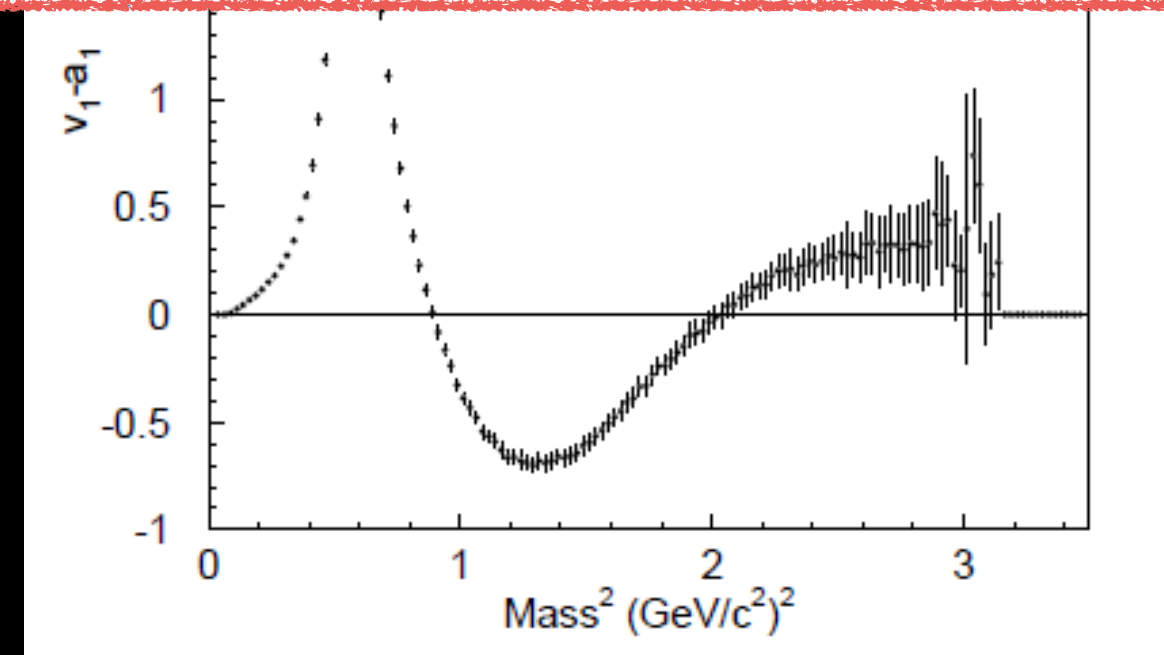
e.g., how to do this \downarrow in medium??

$\langle VV \rangle - \langle AA \rangle$ from τ -decays at LEP-1

Homework for
talented young people



$[\rho_V(s) - \rho_A(s)]$



hatsuda

Excellent program!!

Let us all thank the organizers