Meson Properties at Finite Density from Meson Nucleus Systems

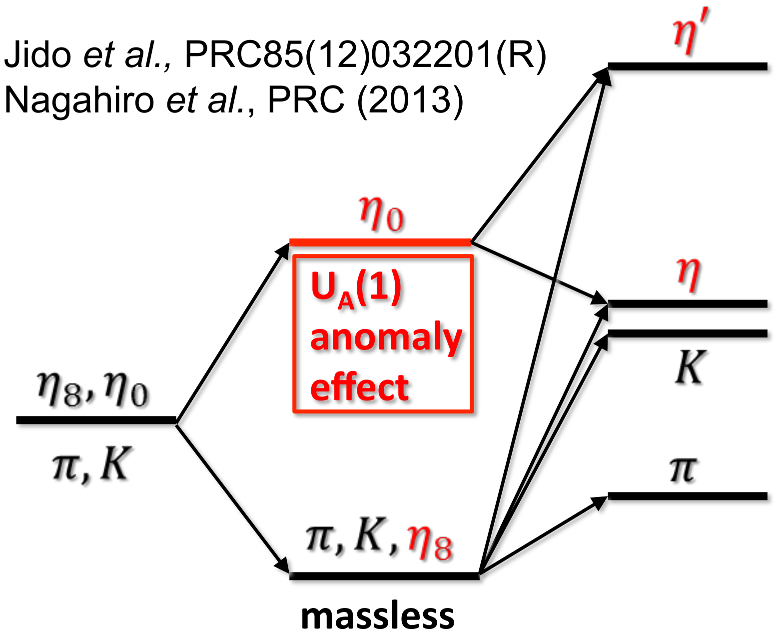
Satoru Hirenzaki (Nara Womens University, Japan)

4 March 2016 Progress on J-PARC hadron physics in 2016
@Ibaraki Quantum Beam Research Center

Meson mass spectrum and Symmetry Breaking Pattern (PS)

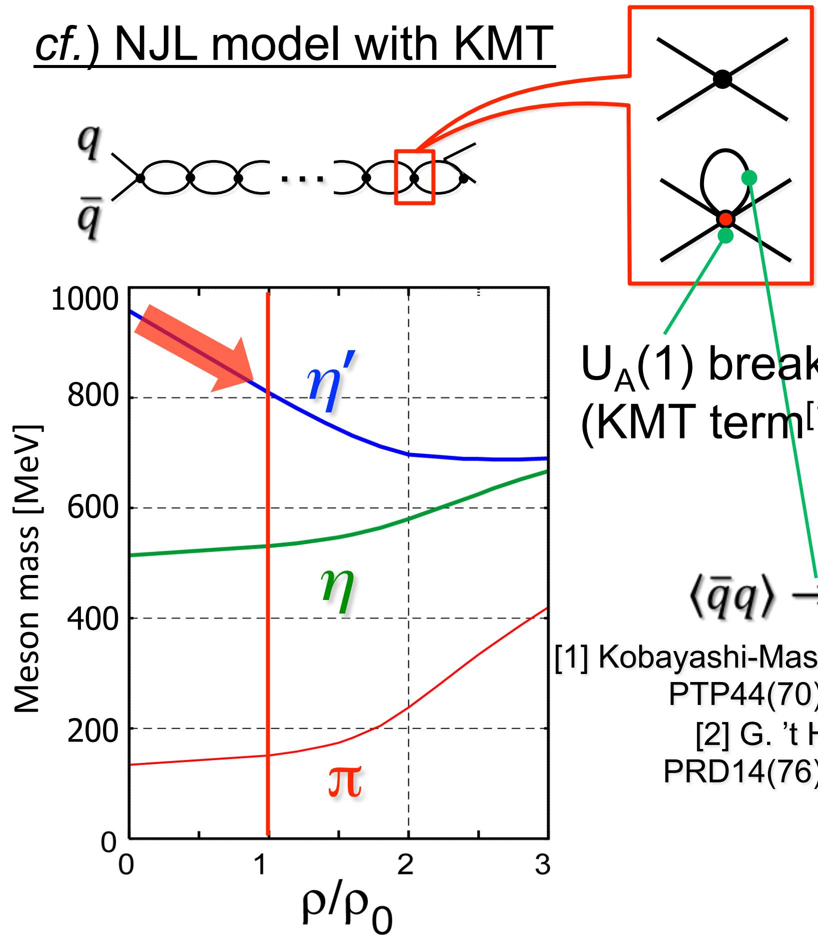
schematic view of the mass of π, K, η & η'

Jido *et al.*, PRC85(12)032201(R)
Nagahiro *et al.*, PRC (2013)



$m_q, m_s = 0$	$m_q, m_s = 0$	$m_q, m_s \neq 0$
$\langle \bar{q}q \rangle = 0$	$\langle \bar{q}q \rangle \neq 0$	$\langle \bar{q}q \rangle \neq 0$
ChS manifest	dynamically broken	dyn. & explicitly broken

cf.) NJL model with KMT



$U_A(1)$ breaking (KMT term[1,2])

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

[1] Kobayashi-Maskawa PTP44(70)1422
[2] G. 't Hooft, PRD14(76)3432

$\Delta m \sim -150$ MeV @ ρ_0

Costa *et al.*,PLB560(03)171,
Nagahiro-Takizawa-Hirenzaki, PRC74(06)045203

Meson in Nucleus (recent topics)

- Deeply Bound Pionic Atoms

  exp.@RIBF/RIKEN

- Kaonic Atoms, Kaonic Nuclei

  high-precision exp. plan (atom) JPARC E62

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- Vector Mesons at finite desnity

  ϕ, ω mass shift, width
- η mesic nucleus

  couple to $N^*(1535)$, J-PARC, COSY exp. d+d

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  couple to $N^*(1535)$, J-PARC, COSY exp. d+d
- $\eta'(958)$ mesic nucleus

  $U_A(1)$ anomaly effect @ finite density, Exp.
- ……….

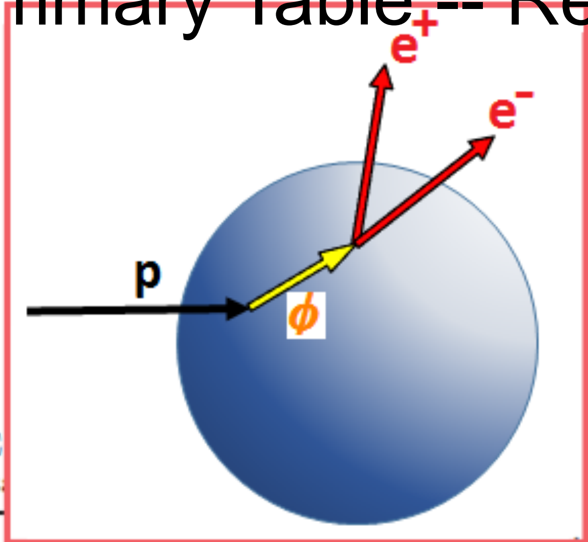
Vector mesons in nucleus

= Transparency ratio and Invariant mass =

with
S. Tokunaga (Nara Women's Univ.)

J. Yamagata-Sekihara
(Oshima National College
of Maritime Technology)
H. Nagahiro (Nara Women's Univ.)

Summary Table -- Results by independent groups



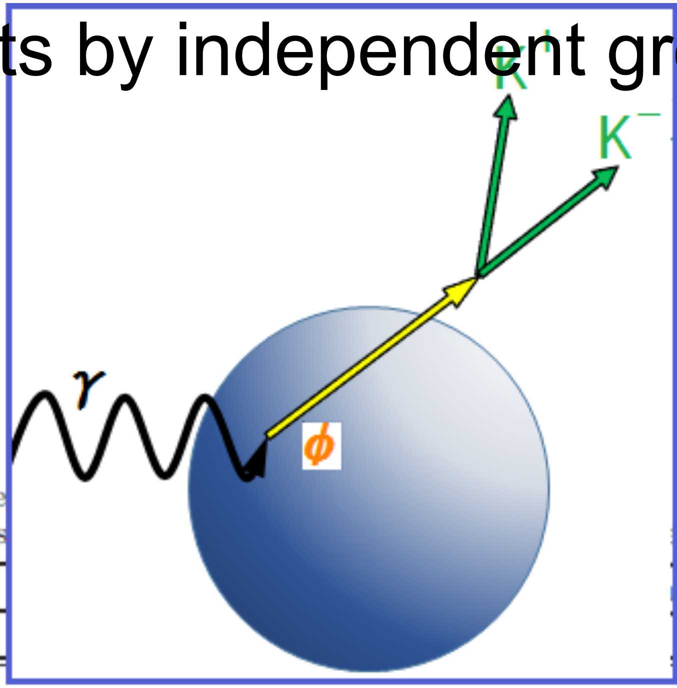


TABLE ... s on the ... ϕ mesons produced with element... eriments ... pared by Metag (2008a)

... mass ... ation

	E325 @ KEK	CLAS g7 @ Jlab			LEPS @ SPring-8
Reaction	pA 12 GeV	γA 0.6 – 3.8 GeV			γA 1.5 – 2.5 GeV
Momentum	$p > 0.5$ GeV/c	$p > 0.8$ GeVc	$p < 0.5$ GeV/c	$0.4 < p < 1.7$ GeV/c	$1.1 < p < 2.2$ GeV/c
ϕ	$\Delta m(\rho_0)/m = -3.4\%$ $\Gamma_\phi(\rho_0) \approx 15\mathrm{MeV}/c^2$	– –	– –	– –	$\sigma_{\phi N} = 35\mathrm{mb}$ $\to \Gamma_\phi(\rho_0) \approx 80$ MeV/c^2

† This may change as a result of the ongoing reanalysis (Metag, 2008b).

-Ryugo S. Hayano and Tetsuo Hatsuda: Hadron propaties in the nuclear medium

Rev. Mod. Phys. 82 (2010) 2949-2990

Mass shift: 3.4%

$$\Gamma_\phi(\rho_0) \approx 15\,[\mathrm{MeV}/c^2]$$

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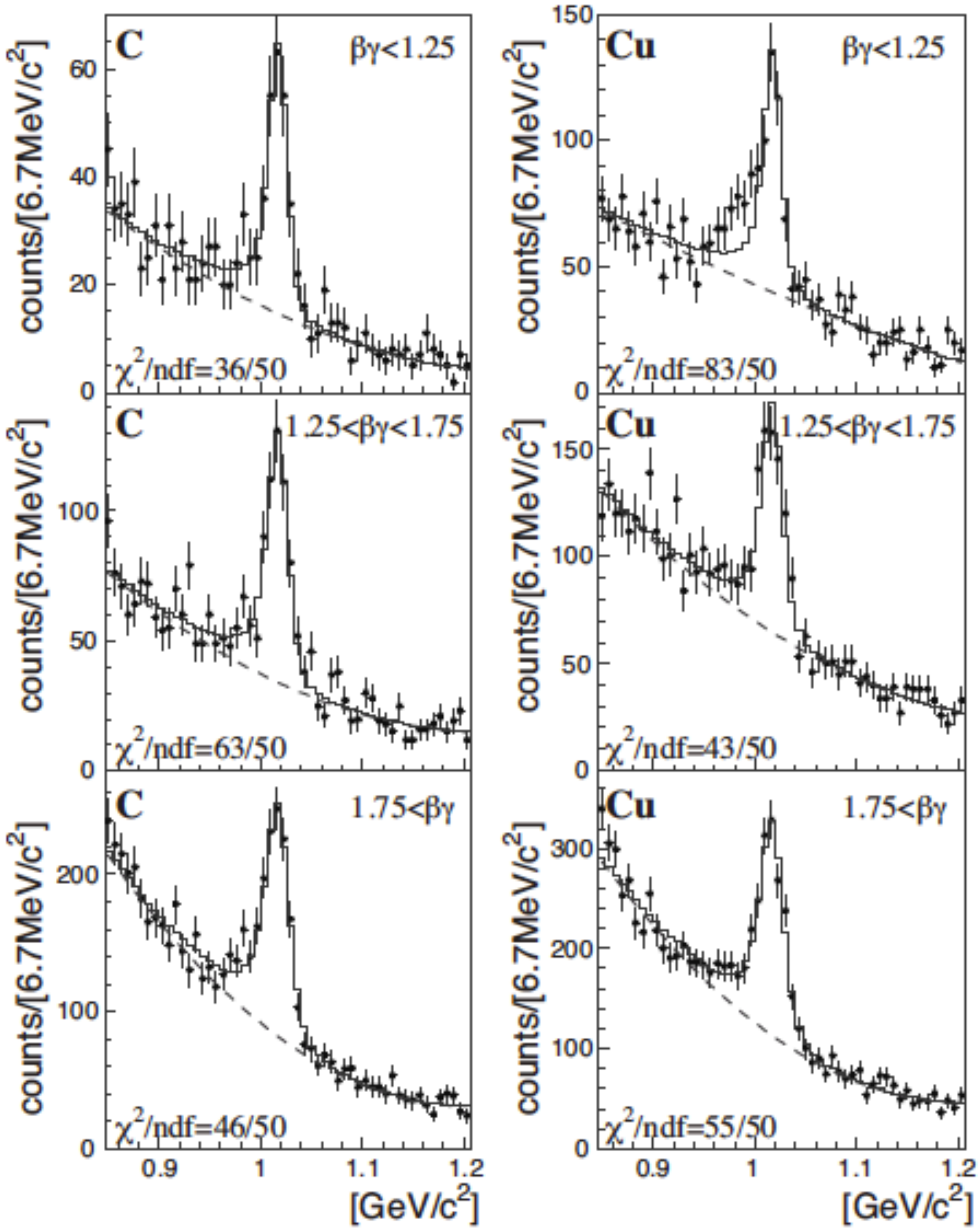
Muto, R., *et al.* (KEK-PS E325 Collaboration), 2007, Phys. Rev. Lett. **98**, 042501.

ϕ meson



- Isolated peak structure
- Long life time (selection of slow particle)

FIG. 55. Obtained e^+e^- distributions with the fit results. The target and $\beta\gamma$ region are shown in each panel. The points with error bars represent the data. The solid lines represent the fit results with an expected $\phi \to e^+e^-$ shape and a quadratic background. The dashed lines represent the background (Muto *et al.*, 2007).

We consider ϕ here.

- DATA by KEK E325, LEPS/SPring8, JPARC E16

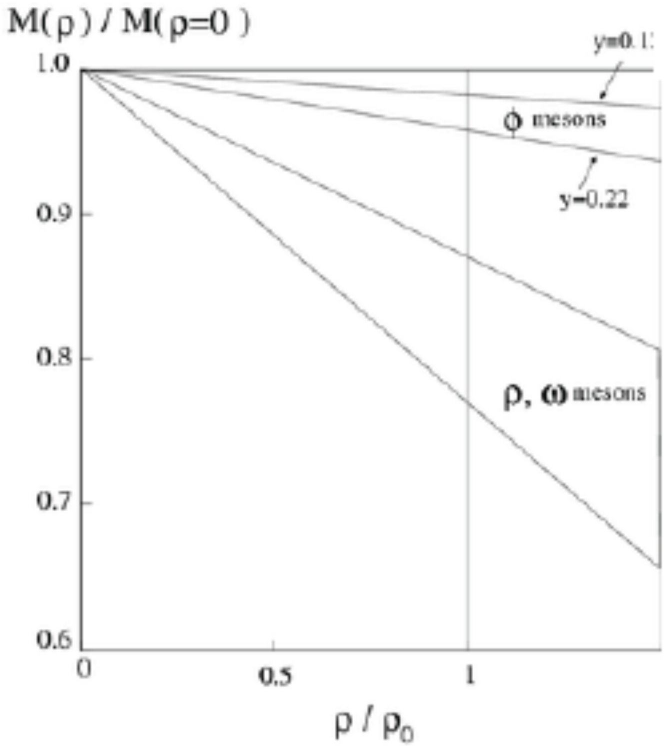
  R. Muto et al., Phys. Rev. Lett. 98 (2007) 042501

  T. Ishikawa et al., Phys. Lett. B 608 (2005) 215-222

  T. Sawada, Doctor Thesis, Osaka University (2013)

- Thoretical works from Hatsuda and Lee, importance and sensitivity to S quark condensate.

T. Hatsuda and S.H. Lee, Phys. Rev. C **46**, R34 (1992).



Vector meson masses mainly drop due to changes of the quark condensates.

The most important condensates are:

$\langle \bar{q}q\bar{q}q \rangle_\rho$ for $\rho,\ \omega$

$m_s \langle \bar{s}s \rangle_\rho$ for ϕ

Motivation / Interests

* Determine the <N|sbar s|N> from in-medium ϕ

* Importance of <N|sbar s|N>

  = How much is the strangeness component in nucleon
  (important for hadron structure studies.)

  = <N|sbar s|N> basic quantity for nuclear matter,
  which relate to various phenomena
  (KN sigma term => kaon condensattion in neutron star,
  etc)

* Now, we like to have
'Stable (consistent) interpretation of data'

* Then, we may safely deduce the condensate from the observed in-medium phi properties.

* Mass shift is not mandatory.   If, it is zero, it's important to confirm how accurately 0.

➔ Recent theoretical works.

PHYSICAL REVIEW D 90, 094002 (2014)

Constraining the strangeness content of the nucleon by measuring the ϕ meson mass shift in nuclear matter

Philipp Gubler[1,*] and Keisuke Ohtani[2,†]

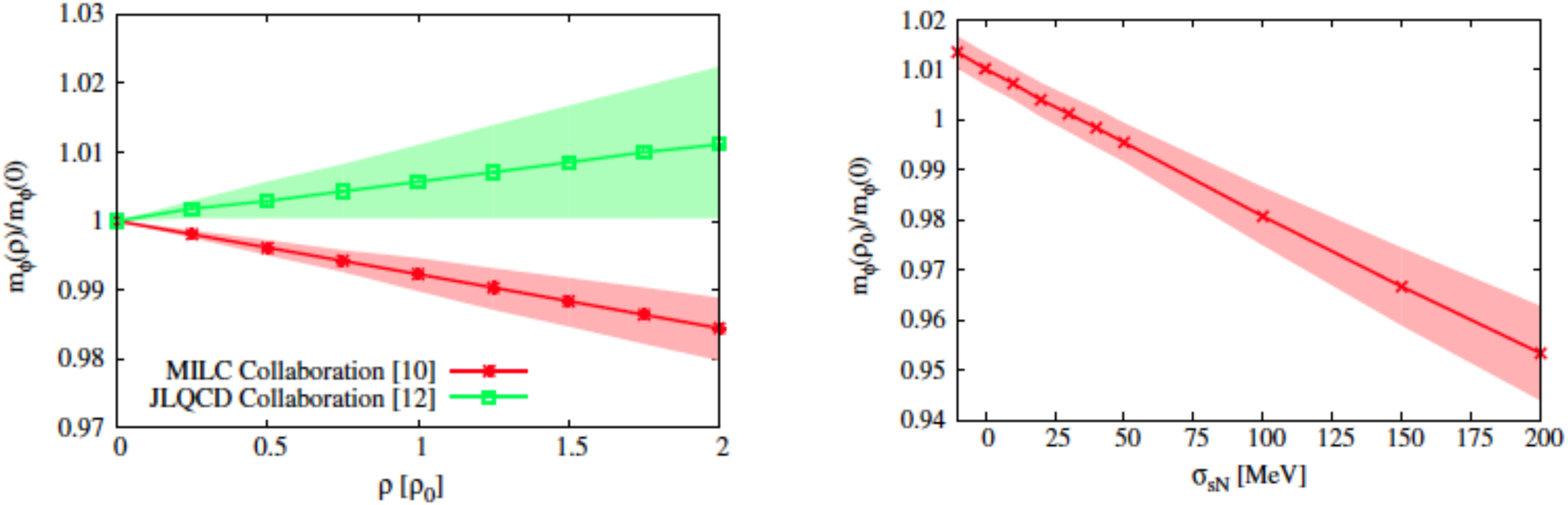
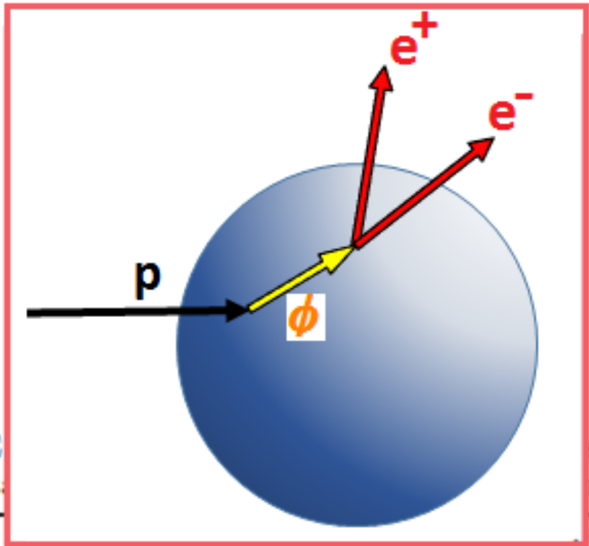
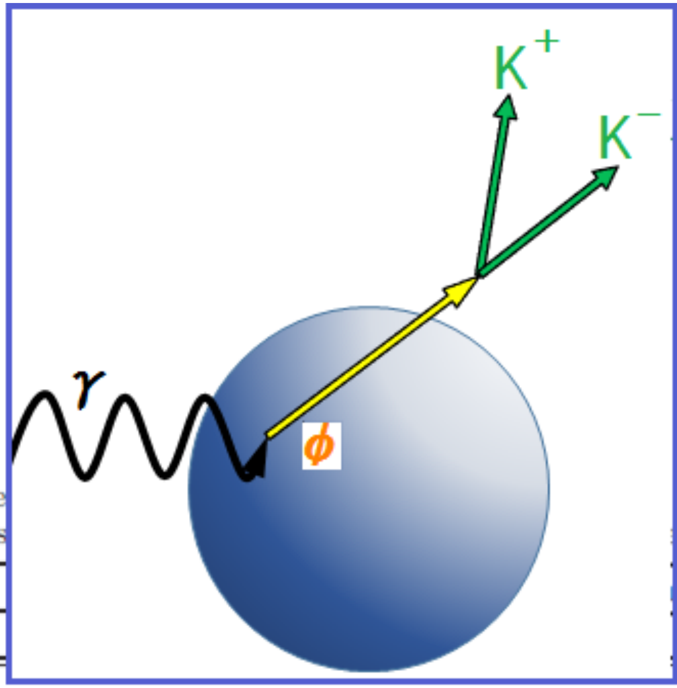


FIG. 4 (color online). (Upper plot): Peak position of ϕ meson as a function of the density ρ, for value ranges of the strange sigma term σ_{sN}, obtained from the MILC [10] and JLQCD [12] lattice QCD collaborations. The σ_{sN} values are 61 ± 9 MeV for MILC and 8 ± 21 MeV for JLQCD. (Lower plot): Peak positions of the ϕ meson at nuclear matter density ρ_0 as a function of $\sigma_{Ns} = m_s \langle N|\bar{s}s|N\rangle$. For both plots, the peak positions are given relative to the ϕ mass in vacuum.





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	$\Gamma_\phi(\rho_0) \approx 15$MeV/$c^2$	–	–	–	$\to \Gamma_\phi(\rho_0) \approx 80$ MeV/c^2

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First step

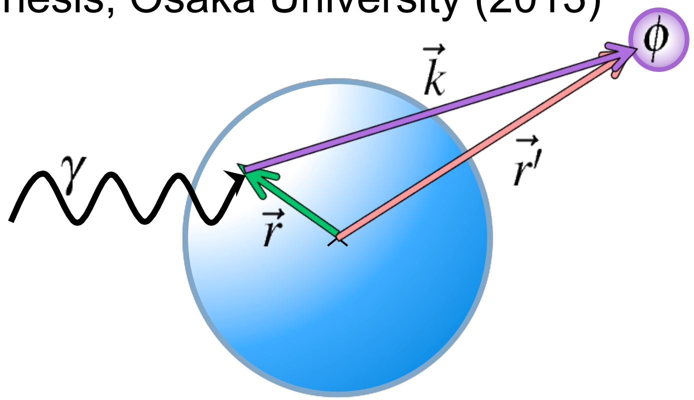
∗ Describe ‘Transparency ratio (LEPS/SPring8)’ and ‘Invariant Mass (KEK E325)’ in an unified manner.

∗ Find the consistent interpretation of the observables. And deepen the understanding between observables and meson properties.

(∗ Possible suggestions to future experiments ?)

Formula of the transparency ratio

-T. Ishikawa et al., Phys. Lett. B 608 (2005) 215-222
-T. Sawada, Doctor Thesis, Osaka University (2013)



Transparency ratio T_A

$$T_A = \frac{1}{A}\int d^3 r N_{in} S_i(\vec{r})\rho(\vec{r})S_f(\vec{r})$$

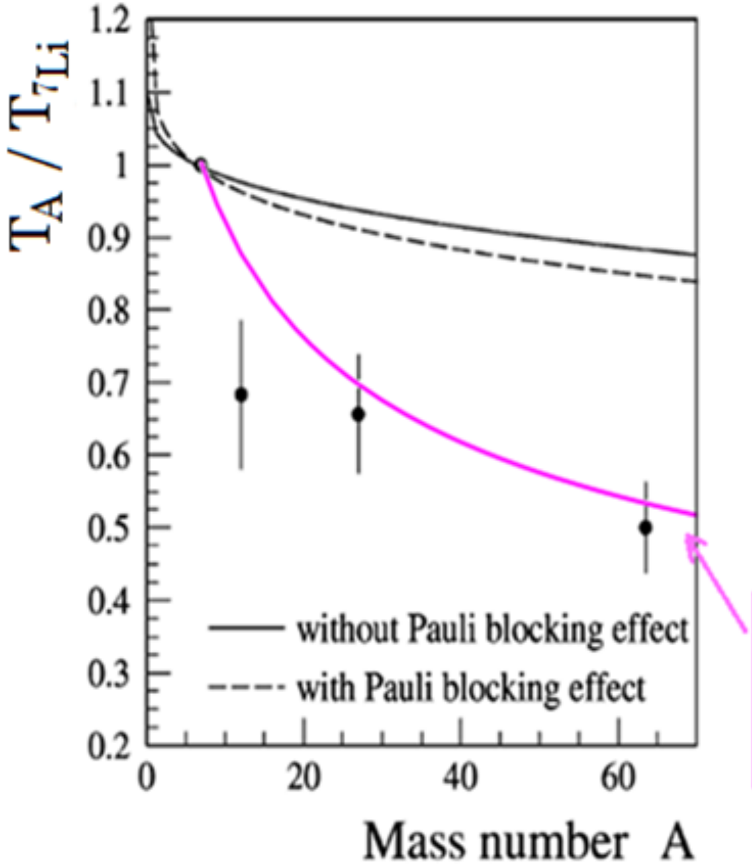
A : mass number N_{in} : incident photon number

$$S_i(\vec{r}) = \exp\left[-\sigma_{\gamma N}\int_{-\infty}^{z} dz'\rho(\vec{b}, z')\right]$$: Flux loss of the incident photon

$$S_f(\vec{r}) = \exp\left[-\sigma_{\phi N}\int_{0}^{\infty} dl\rho(|\vec{r}'|)\right]$$: Flux loss of phi

$$\vec{r}' = \vec{r} + l\frac{\vec{k}}{|\vec{k}|}$$: path of the phi

$\vec{k}$: phi momentum



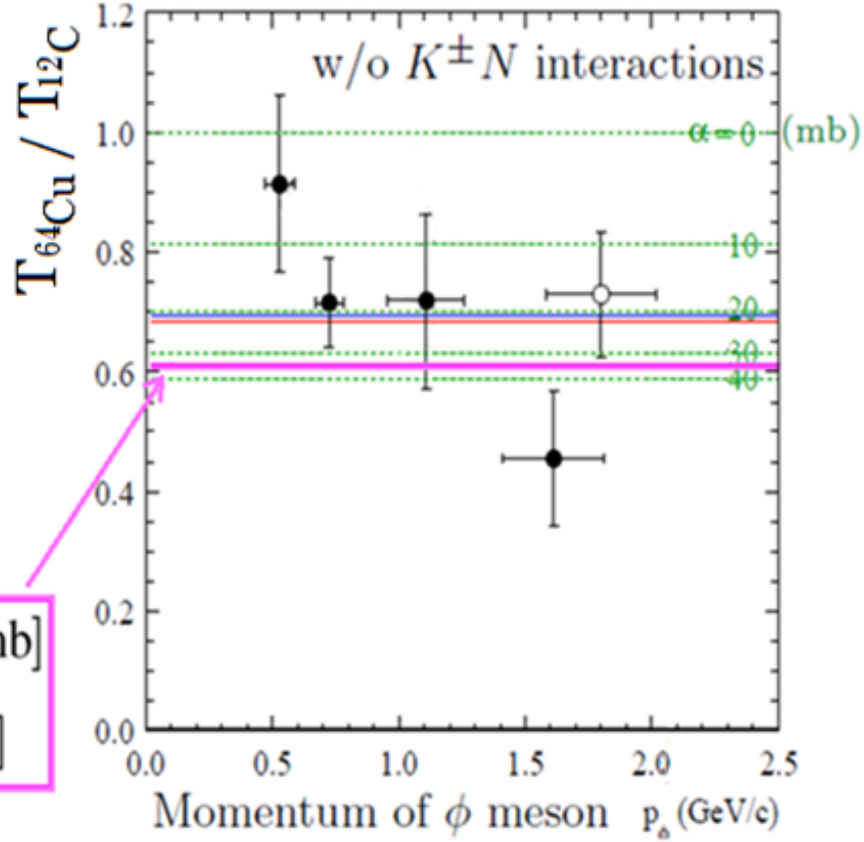
T. Ishikawa et al., PLB 608 (2005) 215-222

Calculated Results

input

$$\sigma_{\gamma N} = 0.14\,[\mathrm{mb}]$$

$$\sigma_{\phi N} = 35\,[\mathrm{mb}]$$



T. Sawada, Doctor Thesis, Osaka Univ. (2013)

Formula for Invariant Mass

- Unified treatment with Transparency

  → Calcualte Invariant mass dist. by the same model parameters as the Transparency

Decay phi number N_ϕ^{decay}

$$N_\phi^{\mathrm{decay}} = N_\phi(z_0) - N_\phi(z)$$

$$\underline{\underline{N_\phi(z_0)}} = N_{in} \exp\left[-\sigma_{iN}\int_{-\infty}^{z_0} dz' \rho(\vec{b}, z')\right]\rho(\vec{b}, z_0)$$: Produced phi at (b, z0)

$$N_\phi(z) = \underline{\underline{N_\phi(z_0)}} \exp\left[-\sigma_{\phi N}\int_{z_0}^{z} dz' \rho(\vec{b}, z')\right] \underline{\exp\left[-\frac{1}{\gamma v}(z - z_0)\sum_i (B.R.)_i \Gamma\right]}$$: Number of phi at (b, z)

N_{in} : Num of Incident particles

$(B.R.)_i$: Branching Ratio of phi in vacuum, $\sum_i (B.R.)_i = 1$

An Example

ϕ Production at origin

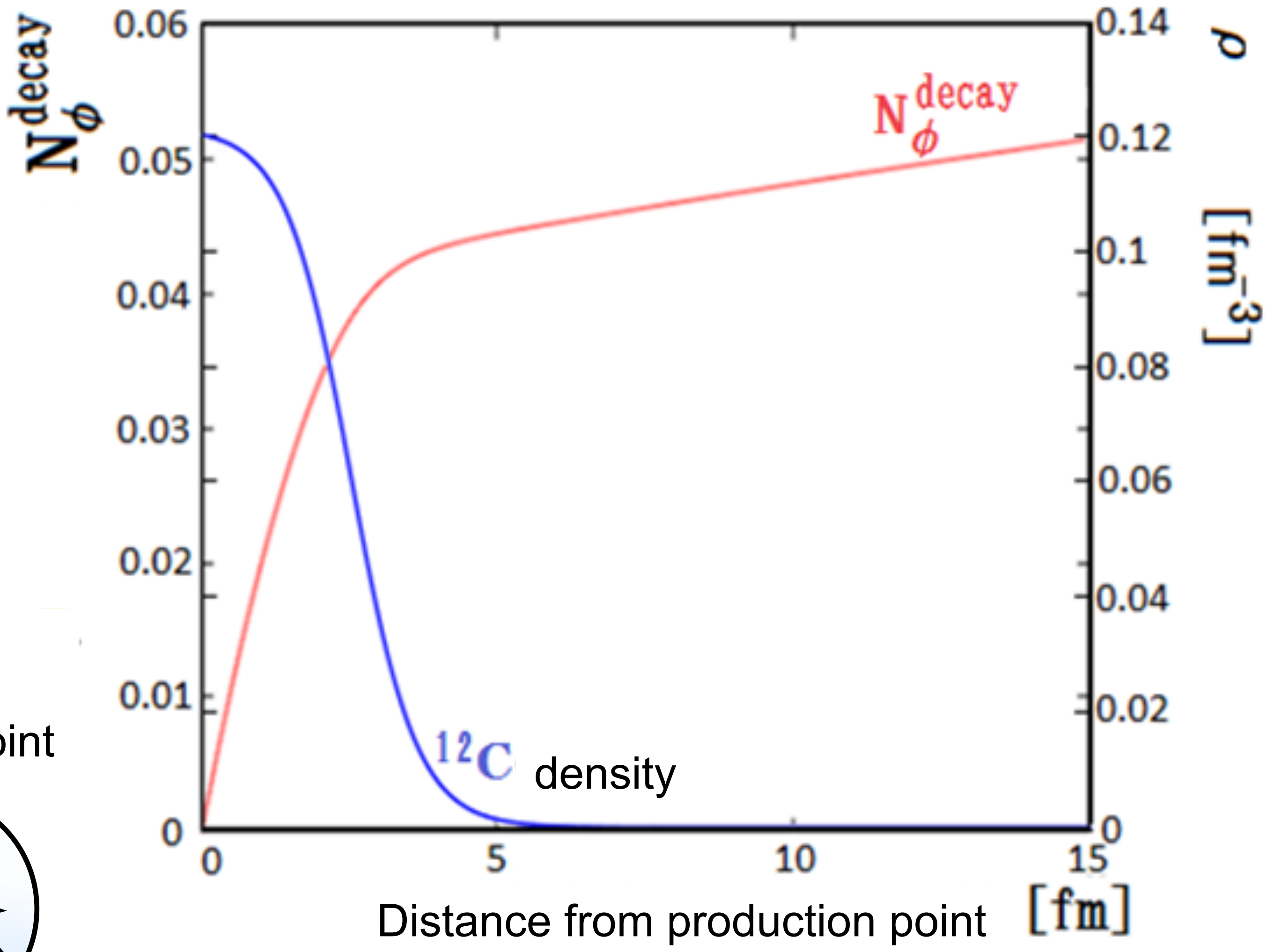
target : ^{12}C

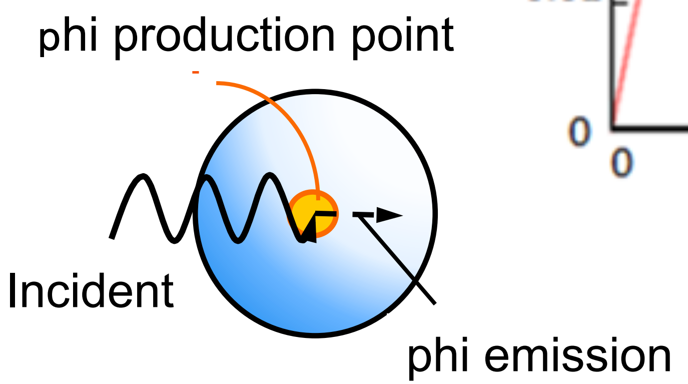
$$N_{in} = 1$$

$$\sigma_{iN} = 10\,[\mathrm{mb}]$$

$$\sigma_{\phi N} = 20\,[\mathrm{mb}]$$

$$\beta\gamma = 1.25$$



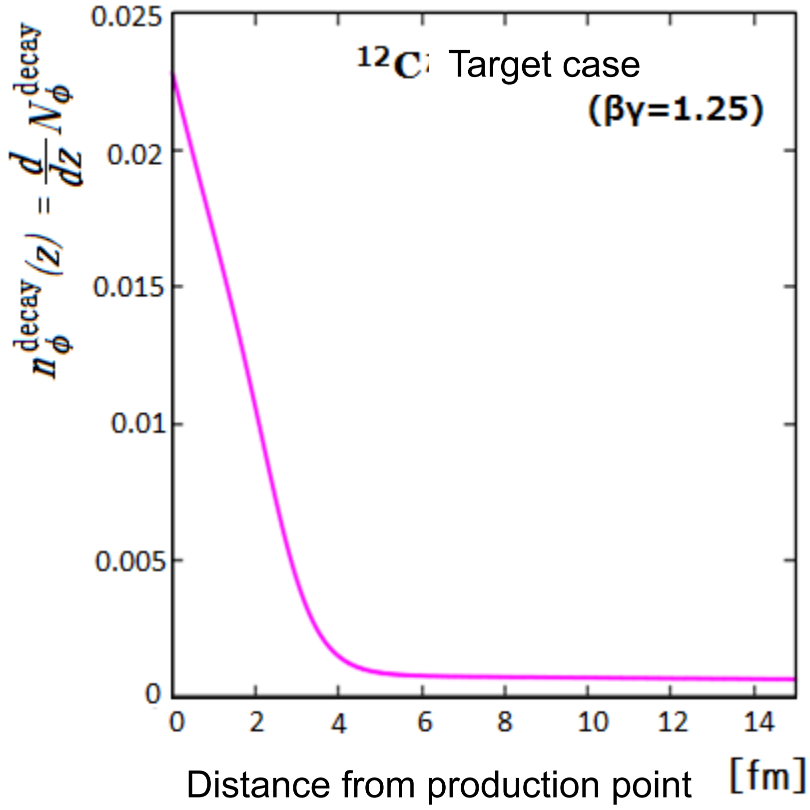


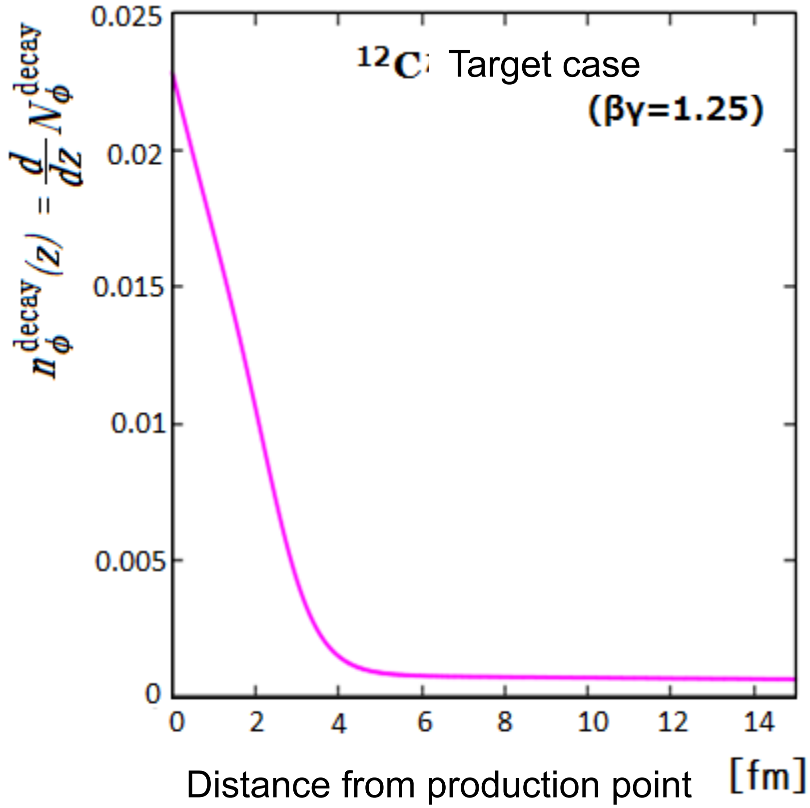
Phi meson decay number per unit length $n_\phi^{\text{decay}}(z)$

$$n_\phi^{\text{decay}}(z) = \frac{d}{dz} N_\phi^{\text{decay}} = n_{\phi N} + n_{e^+e^-} + n_{K^+K^-} + \cdots$$

Phi meson decay number to e+e- channel $n_{e^+e^-}(z)$

$$n_{e^+e^-}(z) = \frac{1}{\gamma v} \Gamma_{e^+e^-} \times N_\phi(z)$$


$n_\phi^{\rm decay}(z) = \frac{d}{dz}N_\phi^{\rm decay}$
^{12}C: Target case
(βγ=1.25)
0.025
0.02
0.015
0.01
0.005
0
0
2
4
6
8
10
12
14
Distance from production point [fm]



^{12}C Target case
(βγ=1.25)
$n_\phi^{decay}(z) = \frac{d}{dz} N_\phi^{decay}$
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0.015
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0.005
0
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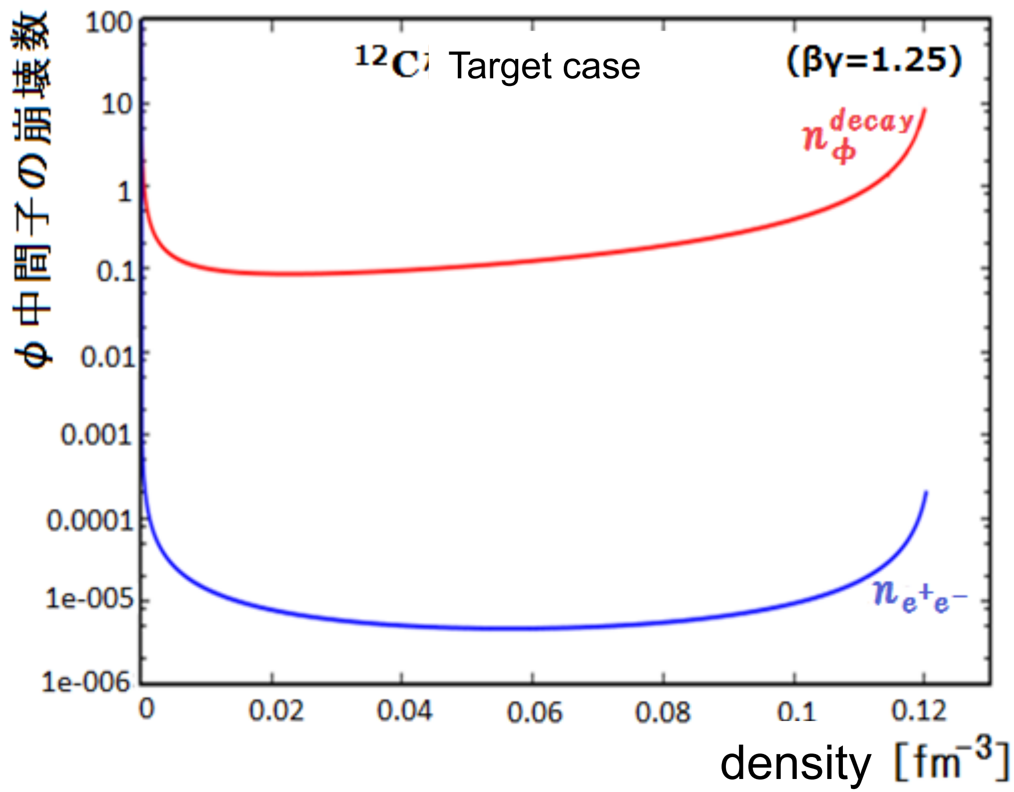
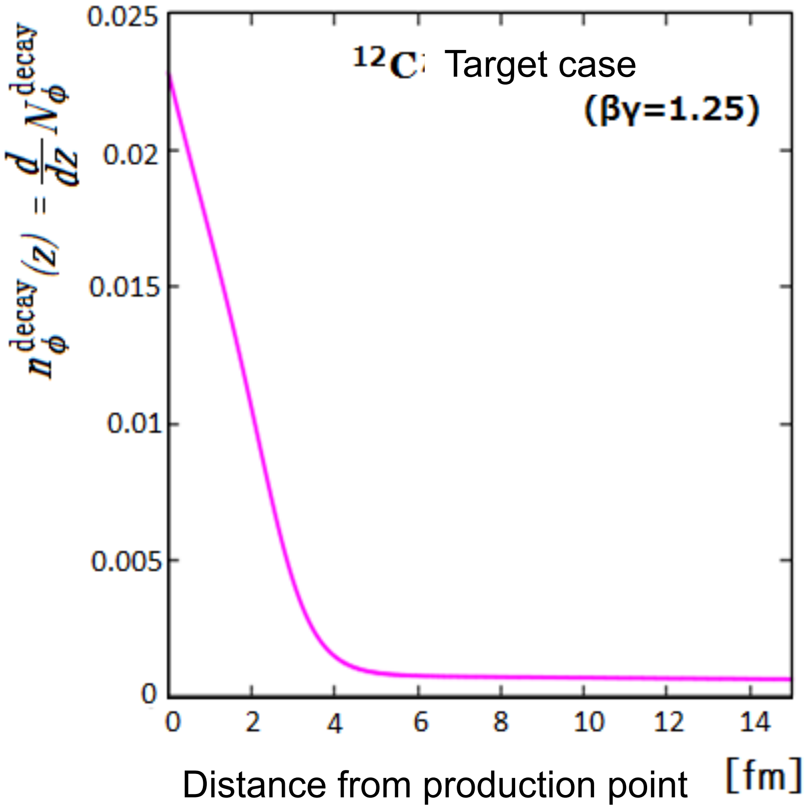
Distance from production point [fm]



^{12}C Target case
(βγ=1.25)
φ中間子の崩壊数
n_ϕ^{decay}
$n_{e^+e^-}$
100
10
1
0.1
0.01
0.001
0.0001
1e-005
1e-006
0
0.02
0.04
0.06
0.08
0.1
0.12
density [fm^{-3}]



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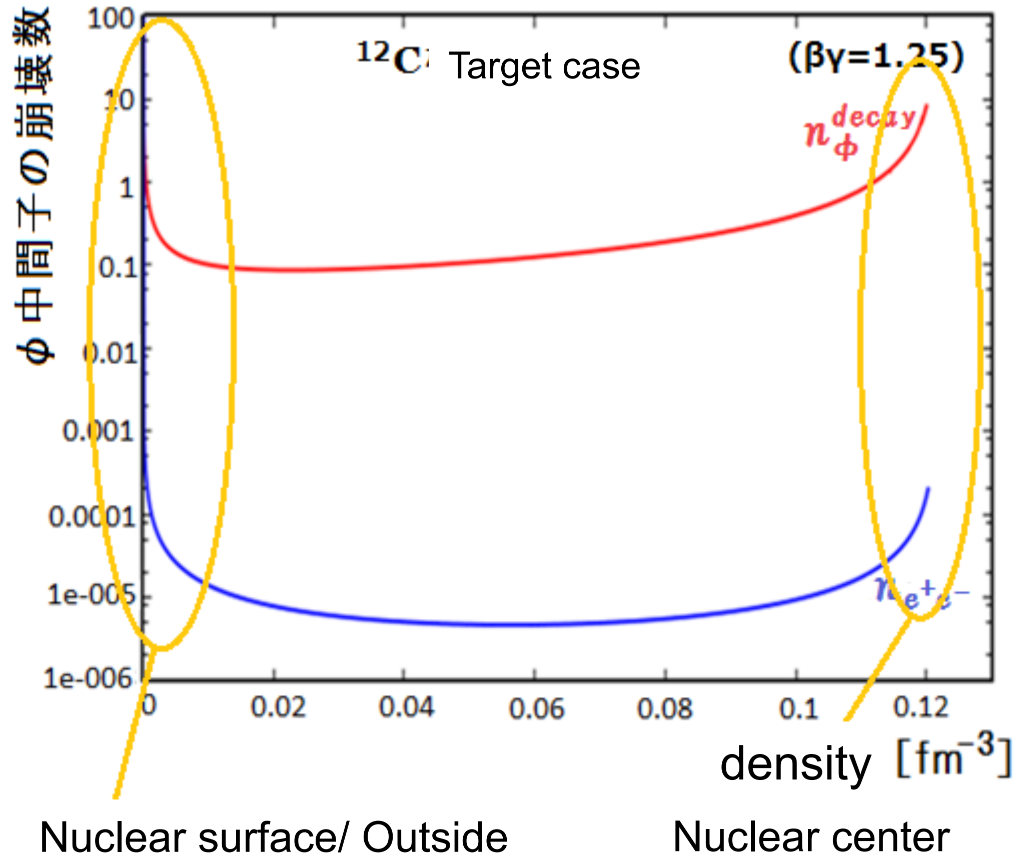
0.025
0.02
0.015
0.01
0.005
0
0 2 4 6 8 10 12 14
Distance from production point [fm]



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(βγ=1.25)
ϕ 中間子の崩壊数
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0.0001
1e-005
1e-006
n_ϕ^{decay}
$n_{e^+e^-}$
0 0.02 0.04 0.06 0.08 0.1 0.12
density [fm^{-3}]
Nuclear surface/ Outside
Nuclear center

Phi meson decay number per unit length $n_\phi^{\text{decay}}(z)$

$$n_\phi^{\text{decay}}(z) = \frac{d}{dz} N_\phi^{\text{decay}} = n_{\phi N} + n_{e^+e^-} + n_{K^+K^-} + \cdots$$

Phi meson decay number to e+e- channel $n_{e^+e^-}(z)$

$$n_{e^+e^-}(z) = \frac{1}{\gamma v} \Gamma_{e^+e^-} \times N_\phi(z)$$

Invariant mass distribution seen in e+e- decay channel $S_{e^+e^-}(m)$

$$S_{e^+e^-}(m) = \int d^3 r_0 \int_{z_0}^{\infty} dz\, n_{e^+e^-}(z) \frac{\Gamma_\phi}{2\pi} \frac{1}{\left(m - m_\phi(1 - c\rho(r)/\rho_0)\right)^2 + \Gamma_\phi^2/4}$$

$r_0 = (\vec{b}, z_0)$ phi production point

$\Gamma_\phi = \Gamma_\phi^{\text{free}} + \Gamma_\phi(\rho)$, $\Gamma_\phi^{\text{free}}$ Full width in vacuum m_ϕ : phi mass in vacuum

C : Parameter for mass shift

Numerical Results – Invariant Mass of e+e- pair

- Input data

γ-distortion:

$$\sigma_{iN} = 0.14[\mathrm{mb}]$$

proton-distortion:

$$\sigma_{iN} = \frac{1}{2}\{(\sigma_{\mathrm{pp}}^{\mathrm{tot}} - \sigma_{\mathrm{pp}}^{\mathrm{ela}}) + (\sigma_{\mathrm{pn}}^{\mathrm{tot}} - \sigma_{\mathrm{pn}}^{\mathrm{ela}})\}$$

$$= 29.52\,[\mathrm{mb}]$$

TABLE IV Compilation of experimental results on the in-medium mass and width of the ρ, ω and ϕ mesons produced with elementary reactions, measured in different experiments. This is based on and updating the table prepared by Metag (2008a)

	Invariant mass				Attenuation
	E325 @ KEK	CLAS g7 @ Jlab	CBELSA/TAPS		LEPS @ SPring-8
Reaction	pA 12 GeV	γA 0.6 – 3.8 GeV	γA 0.7 – 2.5 GeV		γA 1.5 – 2.5 GeV
Momentum	$p > 0.5$ GeV/c	$p > 0.8$ GeVc	$p < 0.5$ GeV/c	$0.4 < p < 1.7$ GeV/c	$1.1 < p < 2.2$ GeV/c
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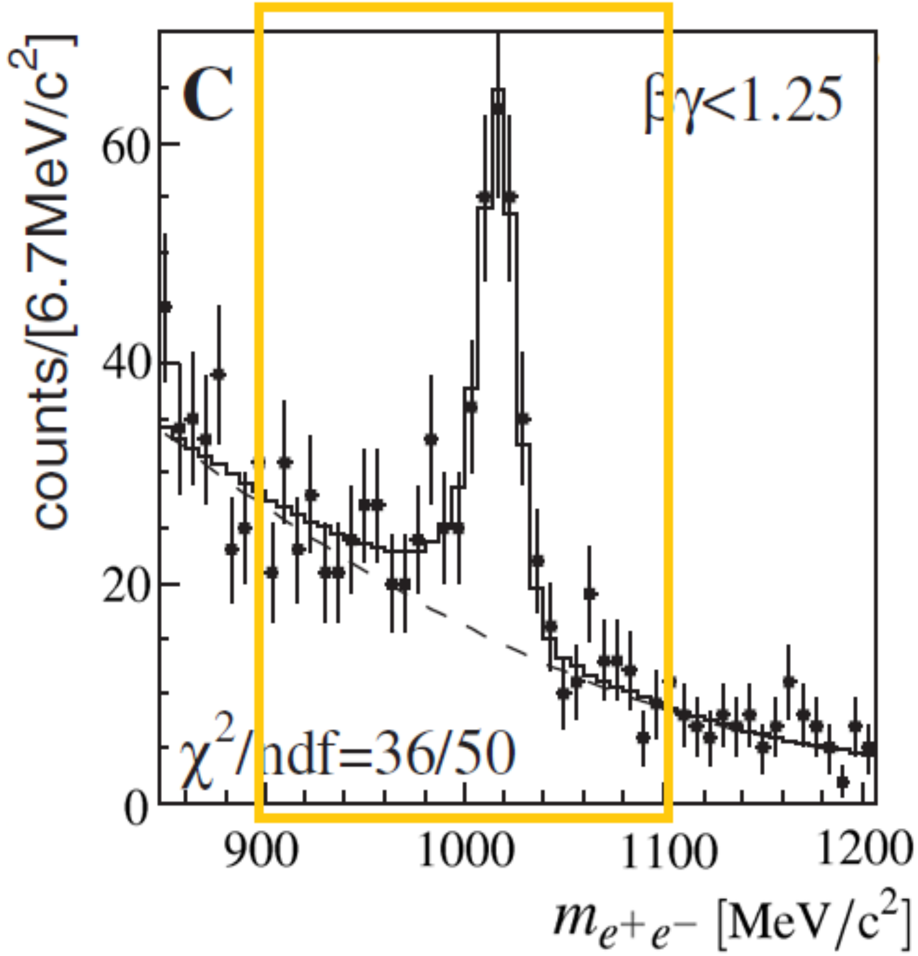
Rev. Mod. Phys. 82 (2010) 2949-2990

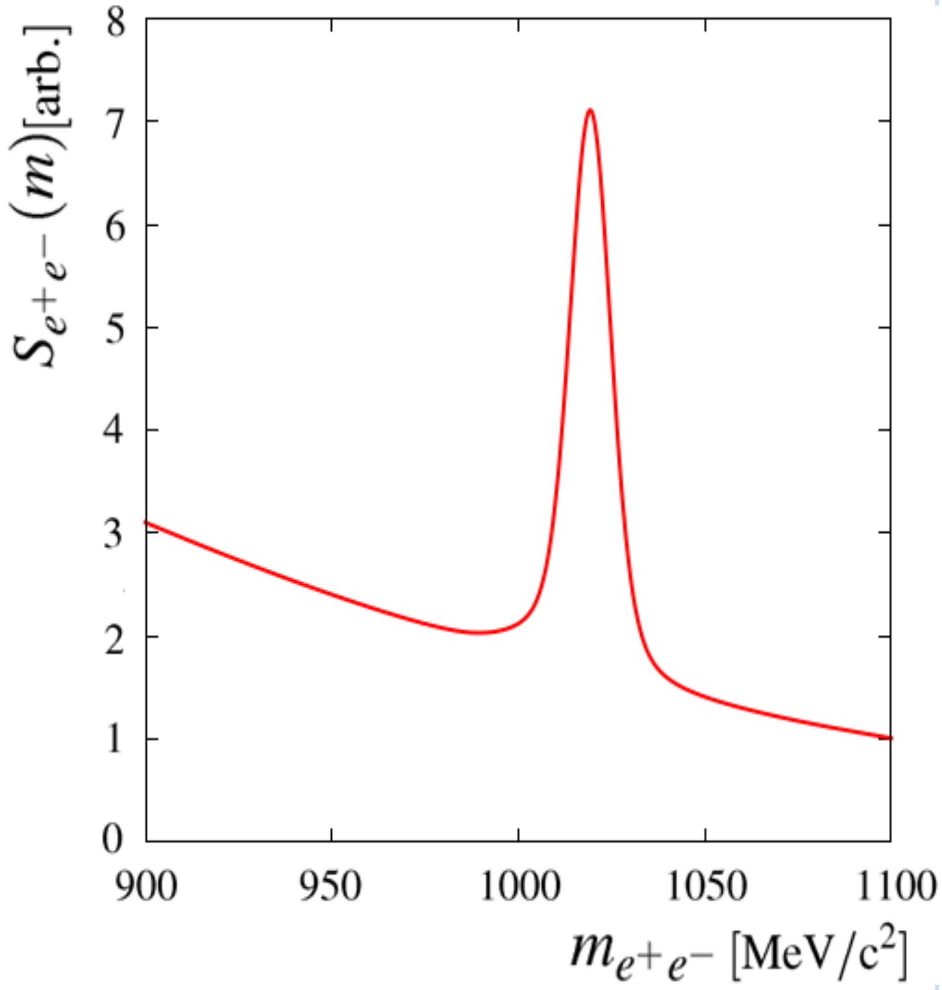
$$\Gamma_\phi(\rho_0) = \beta\rho_0\sigma_{\phi N}$$

$$\left(\begin{array}{l}\beta\gamma = 1.0 \\ \rho_0 = 0.17\,[\mathrm{fm}^{-3}]\end{array}\right. \rightarrow \boxed{\begin{array}{l}\sigma_{\phi N} \simeq 6.3\,[\mathrm{mb}] \\ c = 0.034\end{array}}$$

$$\boxed{\begin{array}{l}\sigma_{\phi N} = 35\,[\mathrm{mb}] \\ c = 0\end{array}}$$

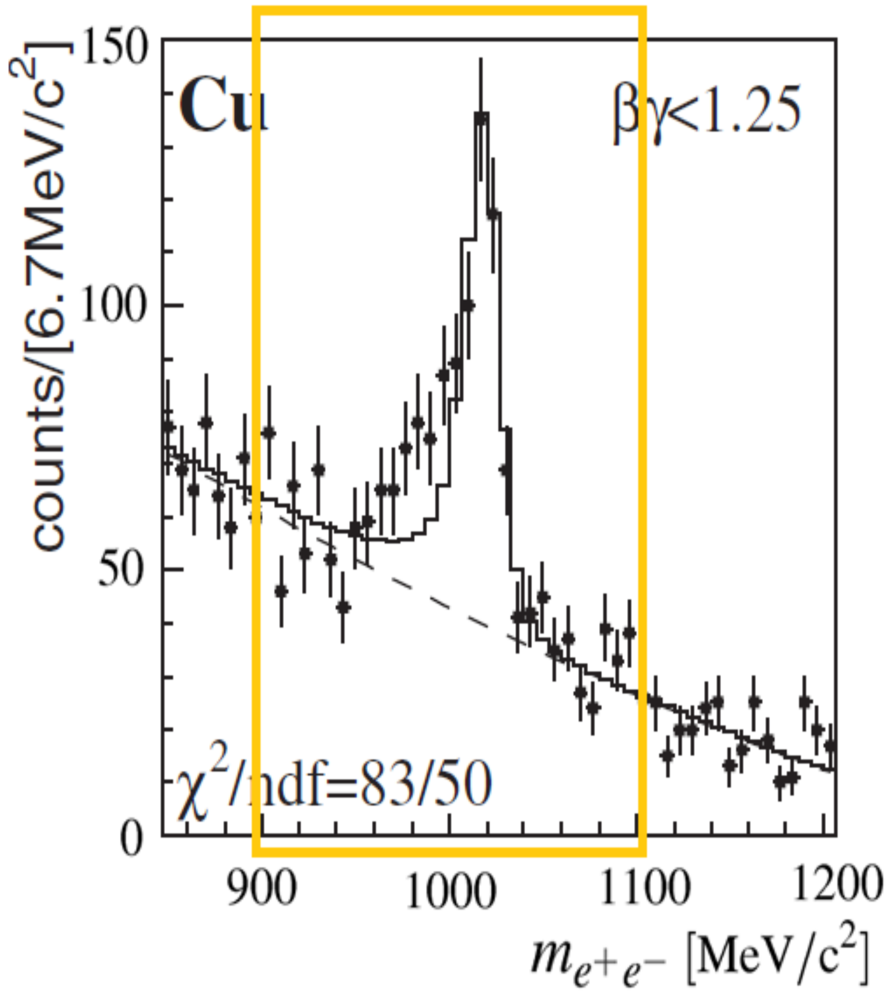
KEK-PS E325 exp, Target : $^{12}\mathrm{C}$, $\beta\gamma = 1.0$





-R. Muto, *et al.,* Phys. Rev. Lett. 98 (2007) 042501.

KEK-PS E325 exp, Target: ^{64}Cu , $\beta\gamma = 1.0$



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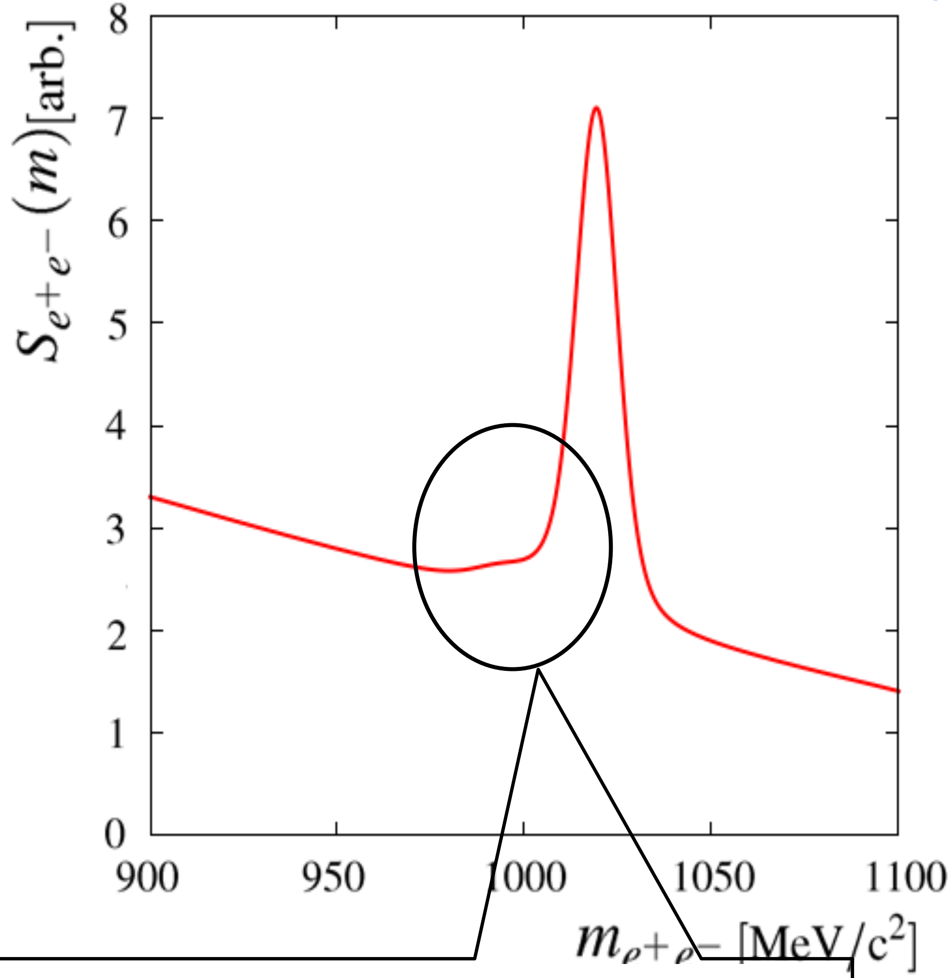
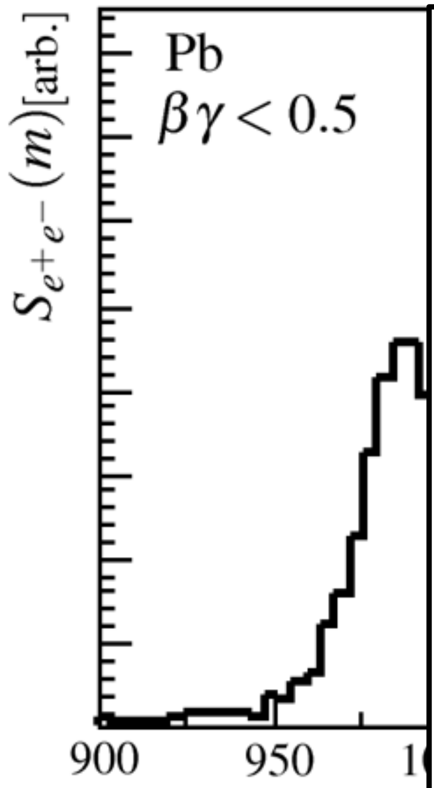
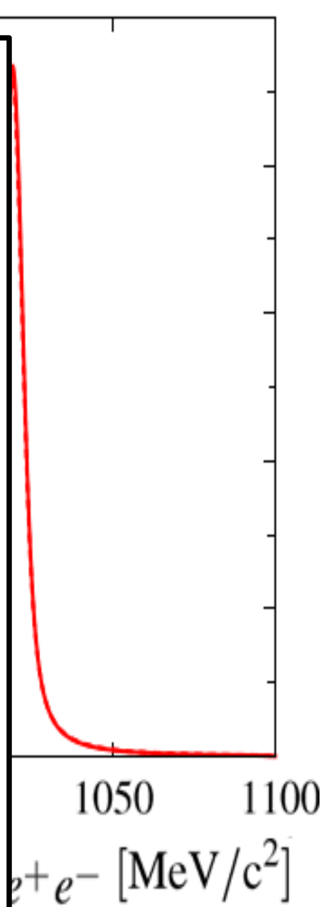
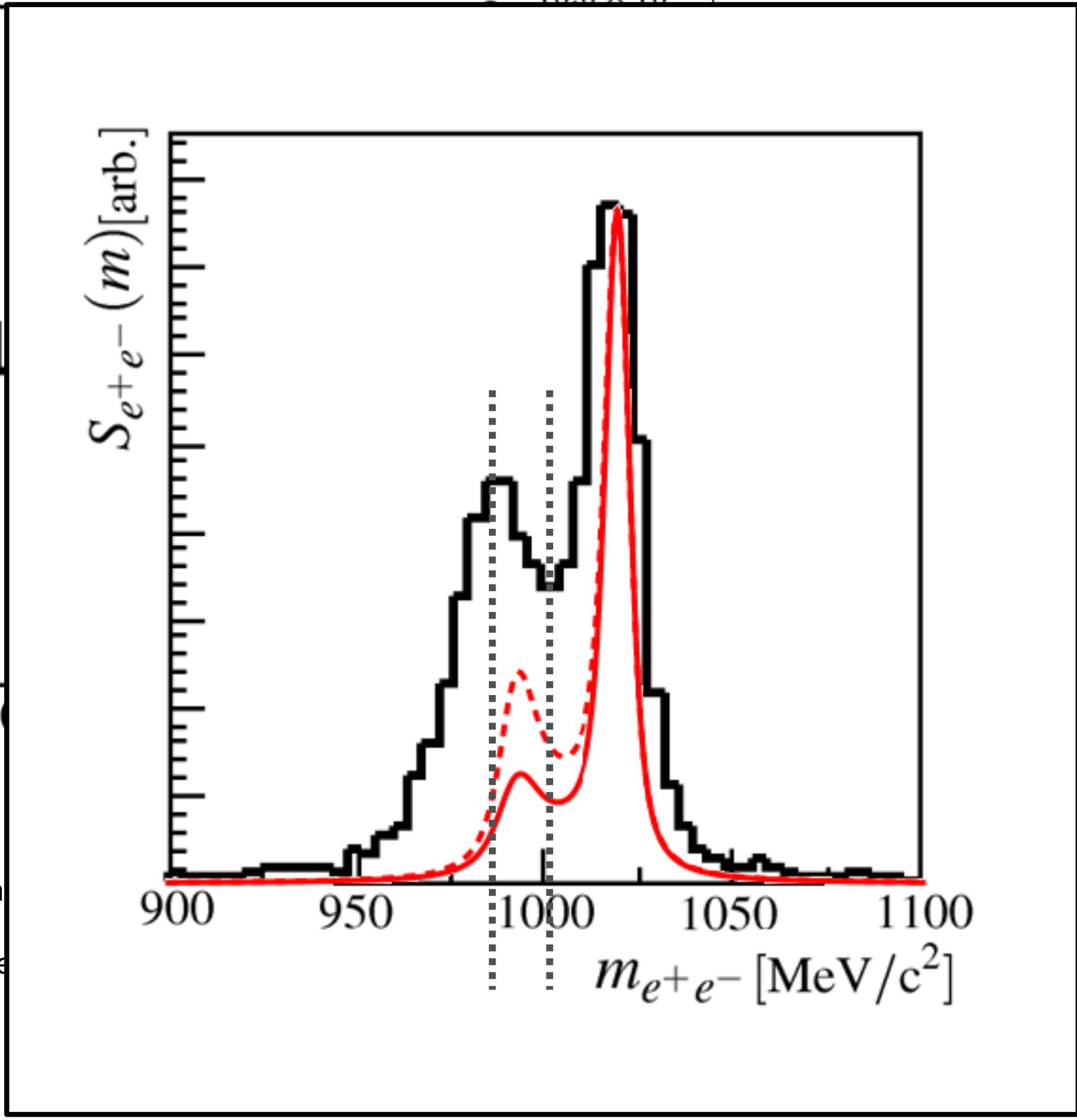


Some extra strength seen, from in-medium decay

J-PARC E16 exp, Target: ^{208}Pb (Simulation by Yokkaichi)







-S. Yokkaichi,
"Measurements of di-electron
J-PARC",
talk given at Hadrons in Nucle
2014.

E325 Results (2)

Production Cross sections

T.Tabaru et al., PRC74(2006)025201

nuclear dependence of CS : $\sigma(A)=\sigma_0 * A^{\alpha}$

$\alpha_{\omega} = 0.710 \pm 0.021(\text{stat.}) \pm 0.037(\text{syst.})$

$\alpha_{\phi} = 0.937 \pm 0.049(\text{stat.}) \pm 0.018(\text{syst.})$

Note:

α ~2/3 : production on the surface of nucleus

α ~1 : production in the whole nucleus

Summary for vector mesons

- In-medium vector (phi) meson -- interesting
  Data exist. But no consistent interpretation
- Unified description of ‘Transparency Ratio’ and ‘Invariant mass’ ??

One possibility

- All disappearance attributed to sigma_phiN => LEPS results,
- Some of them may be due to Re V (elastic) and/or 2step production
- Re V changes invariant mass and will be related to the observed mass shift.

Further

- Transparency by simulation (JAM?)
- realistic meson self-energy.

$\eta'(958)$ mesic nucleus

H.Nagahiro, S.Hirenzaki, Phys.Rev.Lett.94 (2005)232503
H.Nagahiro, M.Takizawa, S.Hirenzaki, Phys.Rev.C74 (2006)045203
D. Jido, H. Nagahiro, S. Hirenzaki, Phys.Rev.C 85, 032201 (R) (2012)
H. Nagahiro, S. Hirenzaki, E. Oset, A. Ramos, Phys. Lett. B 709 (2012) 87-92

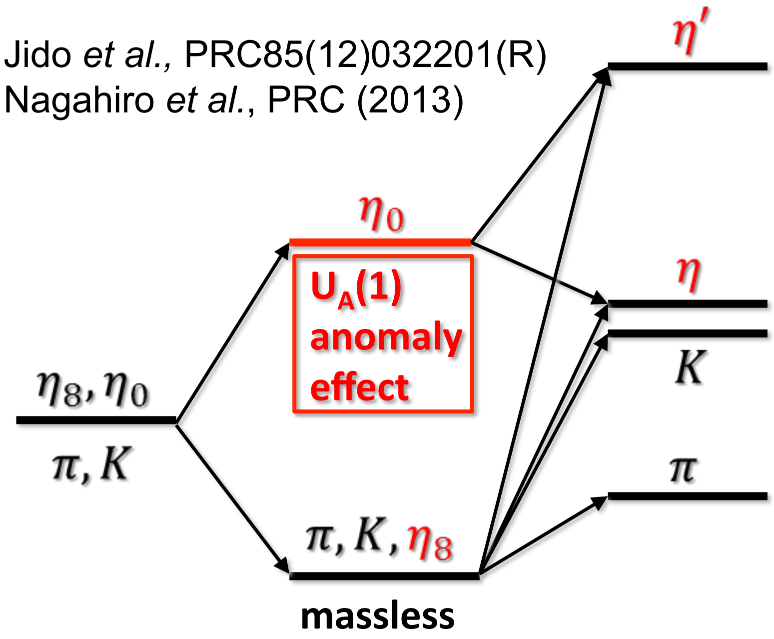
K. Itahashi, H. Fujioka, H. Geissel, R. S. Hayano, S Hirenzaki, S. Itoh, D. Jido, V. Metag, H. Nagahiro, M. Nanova, T. Nishi, K. Okochi, H. Outa, K. Suzuki, Y. K. Tanaka, H. Weick, Prog. Theor. Phys. 128 (2012) 601-613.

H. Nagahiro, D. Jido, H. Fujioka, K. Itahashi, S. Hirenzaki, Phys. Rev. C 87, 045201 (2013).
M. Miyatani, N. Ikeno, H. Nagahiro, S. Hirenzaki, Euro. Phys. J. A, submitted (2016).

Meson mass spectrum and Symmetry Breaking Pattern (PS)

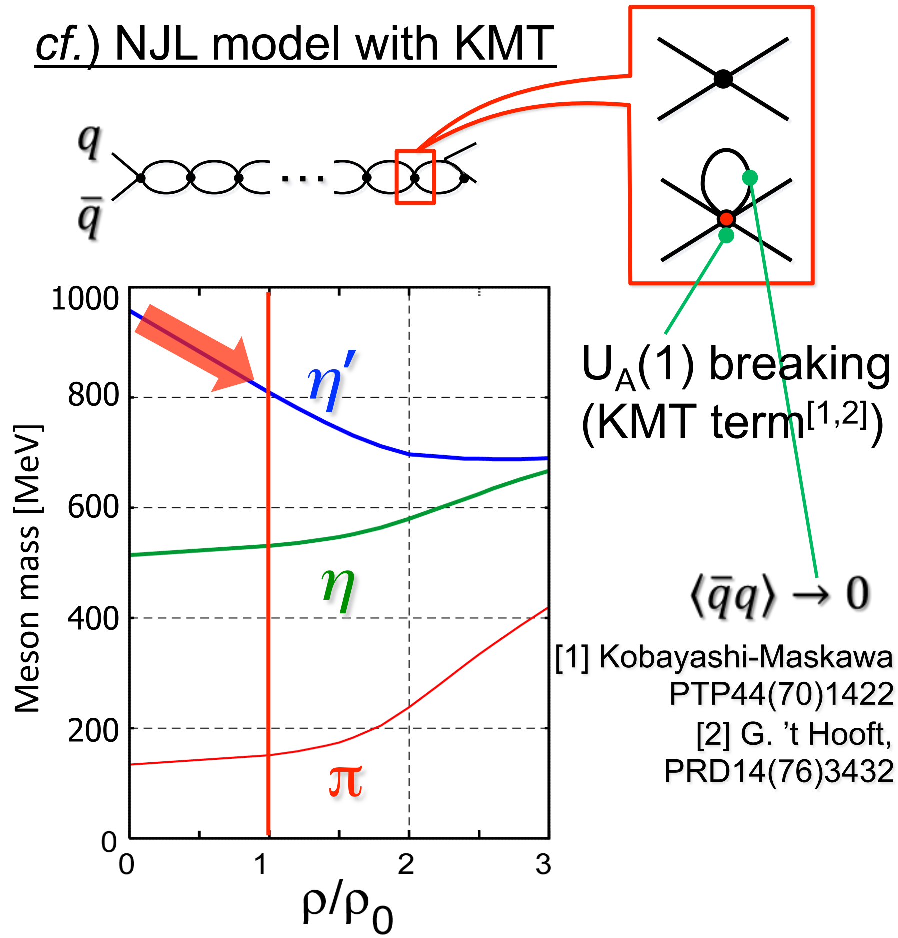
schematic view of the mass of π, K, η & η'

Jido *et al.*, PRC85(12)032201(R)
Nagahiro *et al.*, PRC (2013)



$m_q, m_s = 0$	$m_q, m_s = 0$	$m_q, m_s \neq 0$
$\langle \bar{q}q \rangle = 0$	$\langle \bar{q}q \rangle \neq 0$	$\langle \bar{q}q \rangle \neq 0$
ChS manifest	dynamically broken	dyn. & explicitly broken

cf.) NJL model with KMT



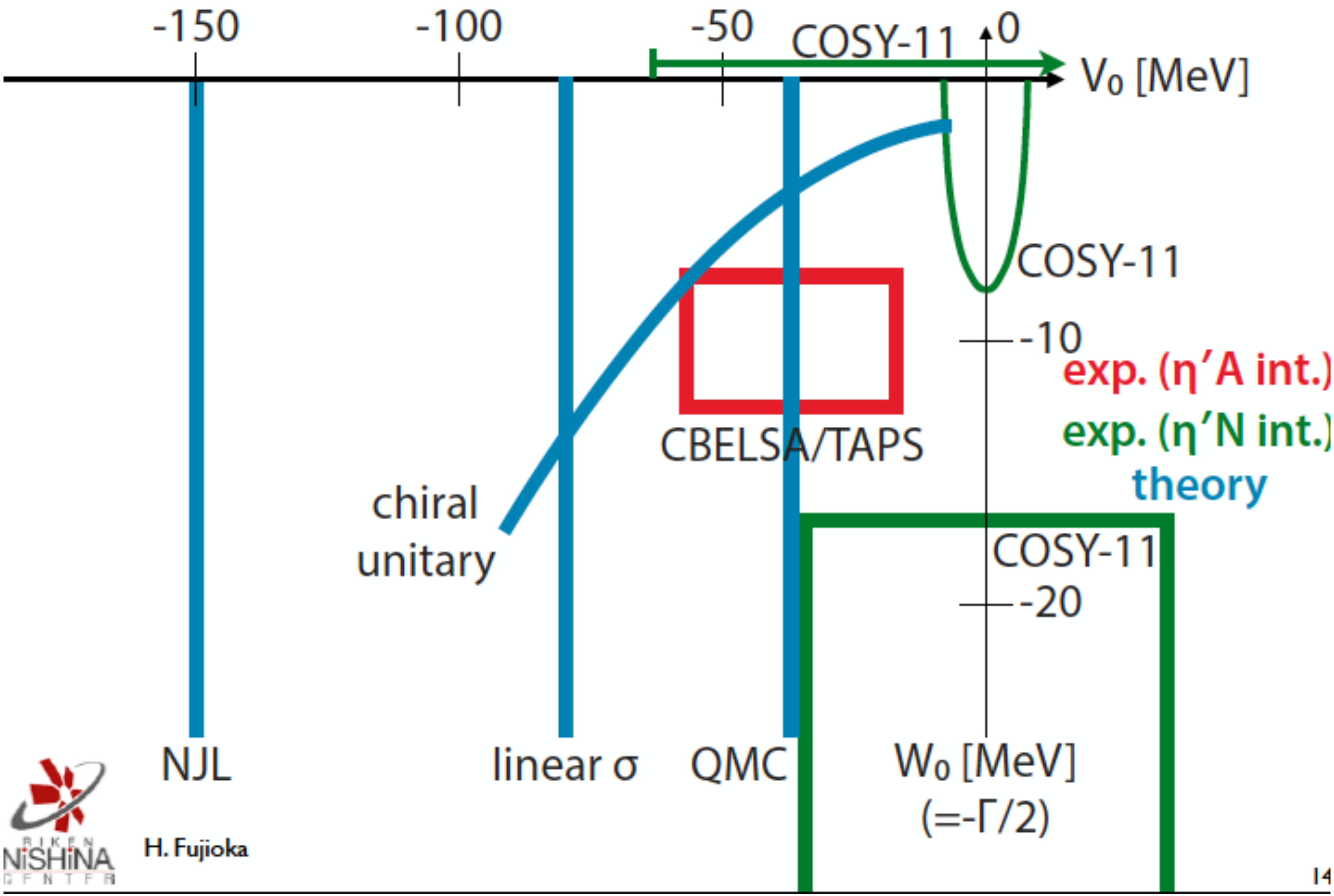
[1] Kobayashi-Maskawa PTP44(70)1422
[2] G. 't Hooft, PRD14(76)3432

$\Delta m \sim -150$ MeV @ ρ_0

Costa *et al.*,PLB560(03)171,
Nagahiro-Takizawa-Hirenzaki, PRC74(06)045203

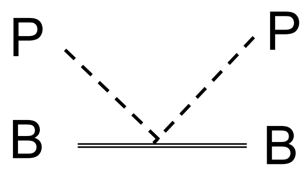
Slide by Fujioka

Summary of various report for eta(958)-N and eta(958)-Nucleus int.



Theoretical Model for eta(958)-N

Oset-Ramos, PLB704(11)334

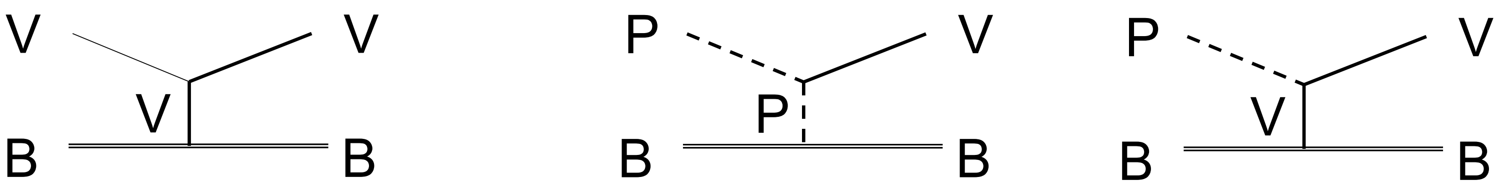


pseudoscalar-baryon (PB) : Weinberg-Tomozawa interaction

$\pi N, \eta N, K\Lambda, K\Sigma$ $+\boldsymbol{\eta' N}$ by the η -η' mixing

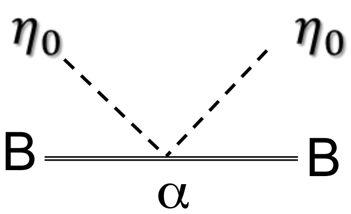
their result : $|a_{\eta' N}| = 0.01$ fm $\Leftrightarrow$ $|a_{\eta' N}| \sim 0.1 - 0.8$ fm [PLB'00]

vector-baryon channels : through PB-VB interaction



their result : $|a_{\eta' N}| = 0.03$ fm

coupling of the singlet component of pseudoscalar to baryons



$$\mathcal{L}_{\eta_0 B} \propto \eta_0^2 \langle \partial_\mu \bar{B} \gamma^\mu B - \bar{B} \gamma^\mu \partial_\mu B \rangle$$

α … free parameter

Borasoy , PRD61(00)014011
Kawarabayashi-Ohta, PTP66(81)1789

their result : $|a_{\eta' N}| = 0.1$ fm can be reproduced

Proposed formation reactions

Theoretical spectra predicted by

H. Nagahiro, M. Miyatani,

- (gamma,p)
- (p,d)
- Pion induced
- 2-nucleon transfer ((gamm,d), ….)

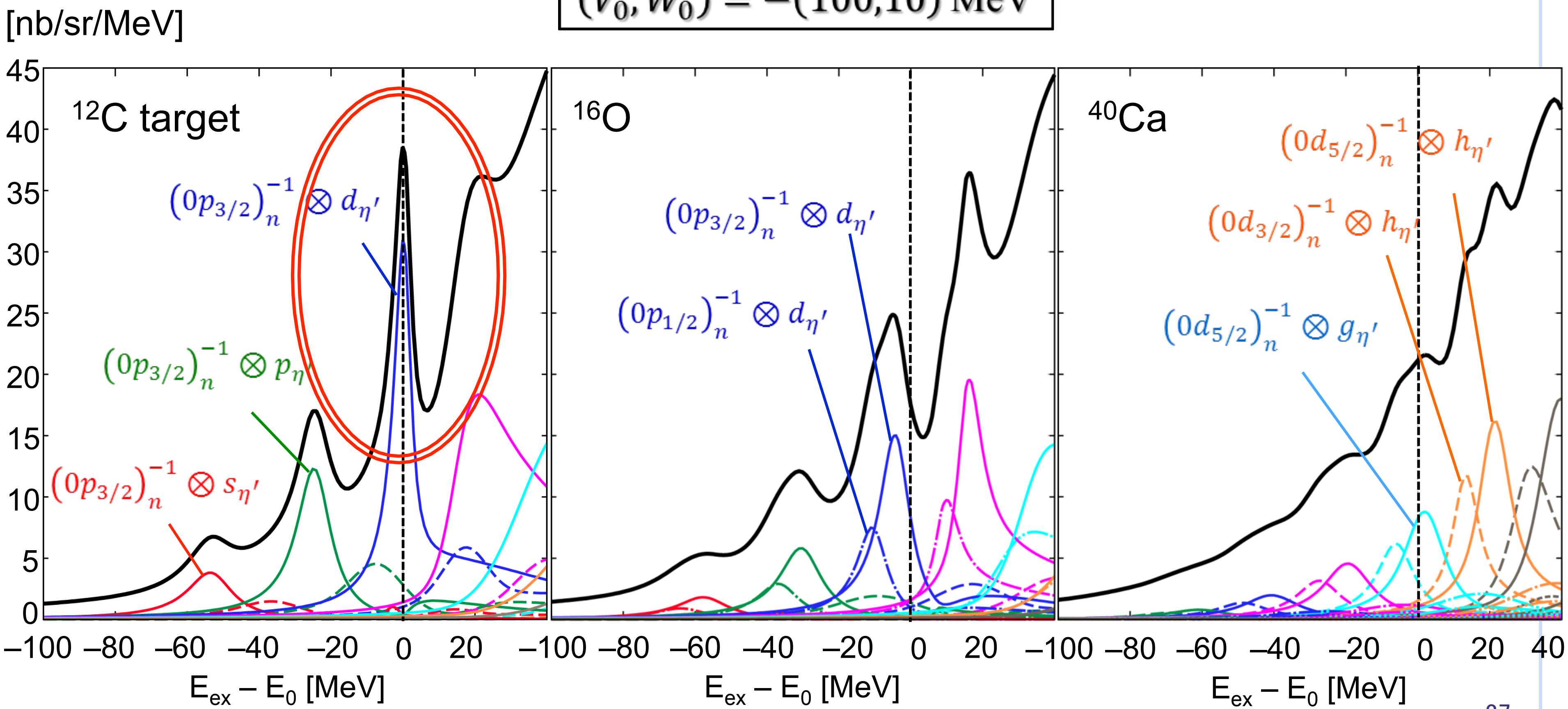
$^{12}C(p,d)^{11}C\ \eta'$: strong attraction $(V_0, W_0) = -(100,10)$ MeV

light nucleus ⟷ **heavy nucleus**

less (shallow) η' bound states
less hole-states
✓ simpler structure

many (deeper) η' bound states
many hole-states
✓ complex structure

$(V_0, W_0) = -(100,10)$ MeV



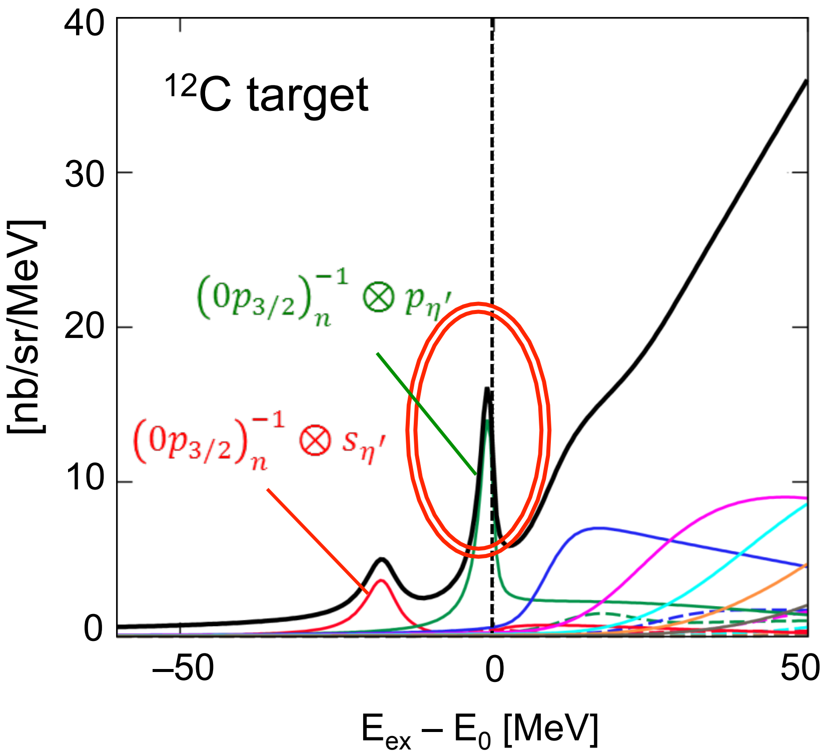
$^{12}C(p,d)^{11}C\ \eta'$: shallower case $(V_0, W_0) = -(50,5)$ MeV

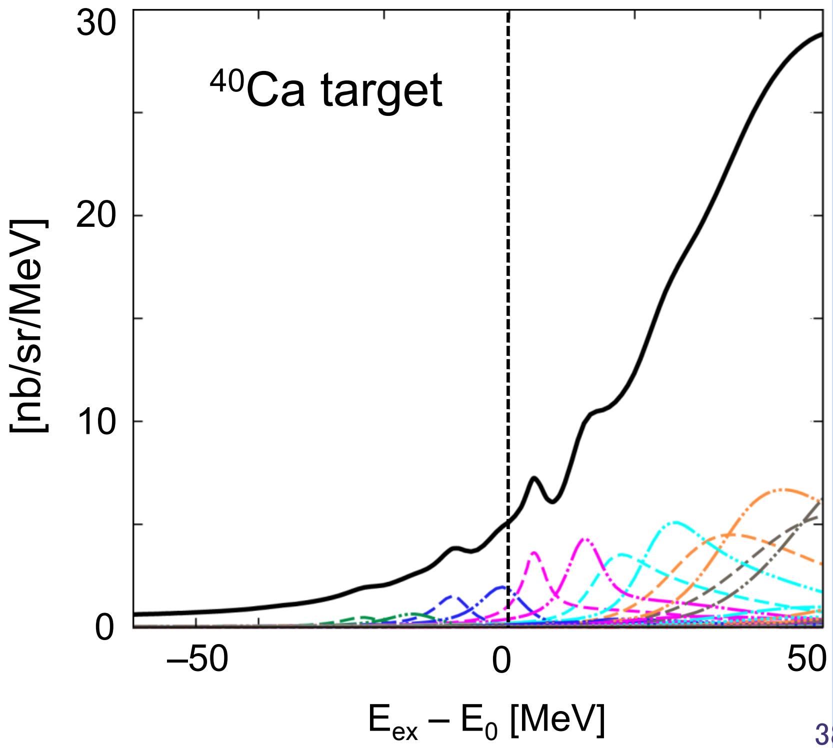
light nucleus ⟷ **heavy nucleus**

less (shallow) η' bound states
less hole-states
✓ simpler structure

many (deeper) η' bound states
many hole-states
✓ complex structure

Shallower case : $(V_0, W_0) = -(50,5)$ MeV





Experimental at GSI

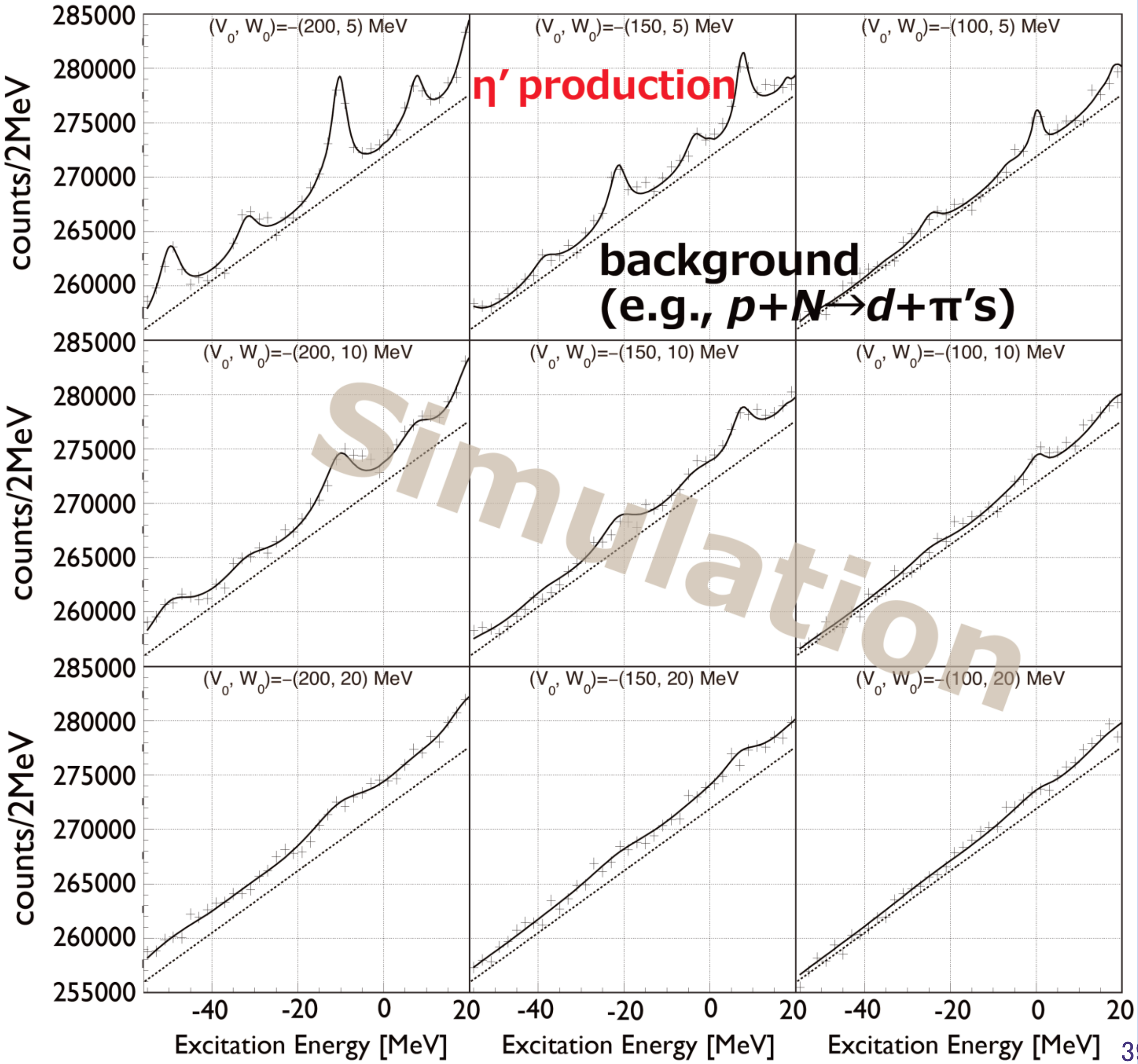
- 1st Step : Inclusive measurement of (*p,d*) reaction with FRS at GSI

Simulation of spectra

- $\eta' \times$ C formation and background processes

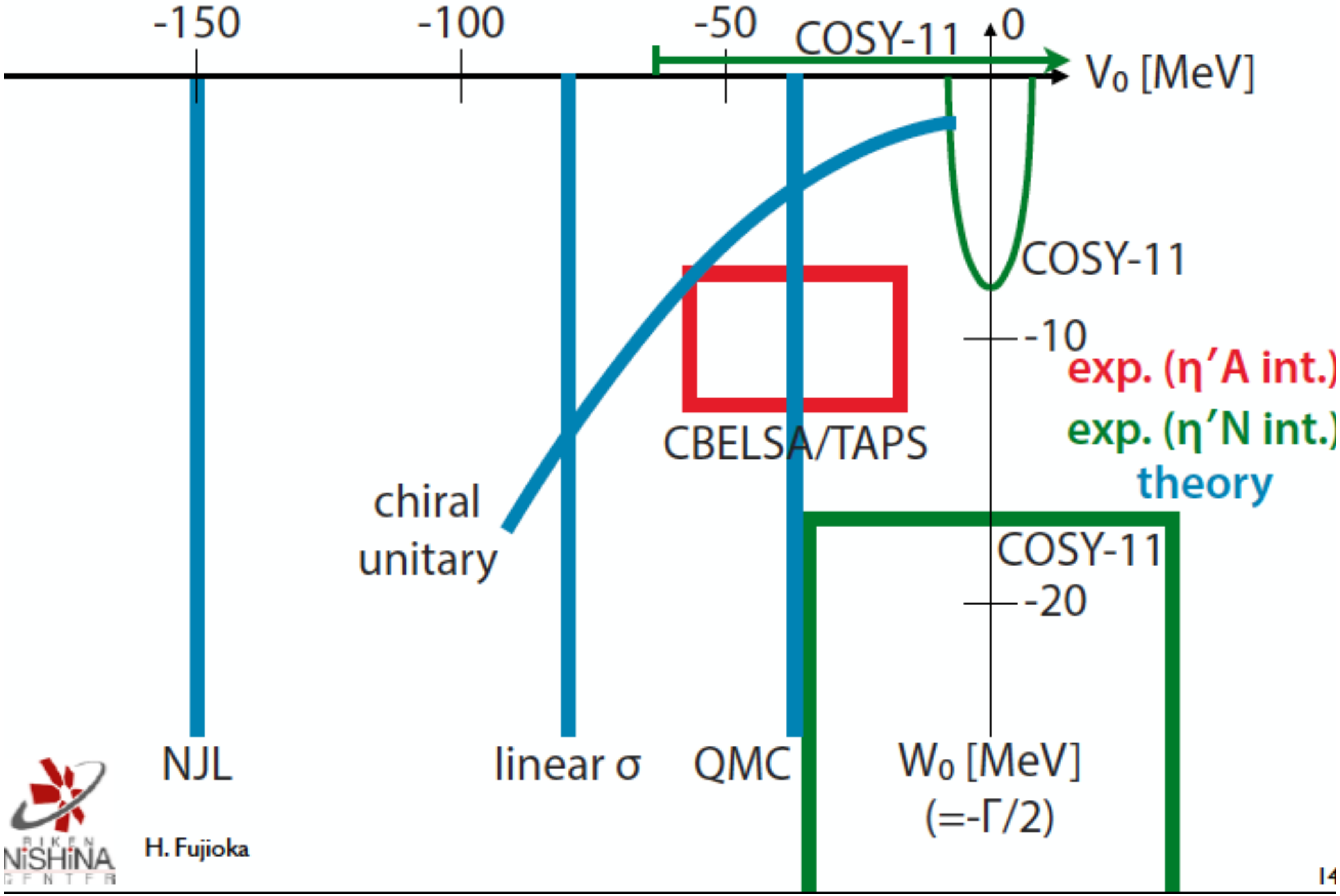
- 4.5 days DAQ assumed

By K. Itahashi, Y. Tanaka, H. Fujioka



Slide by Fujioka

Structure-finding Probability for First Step (GSI)



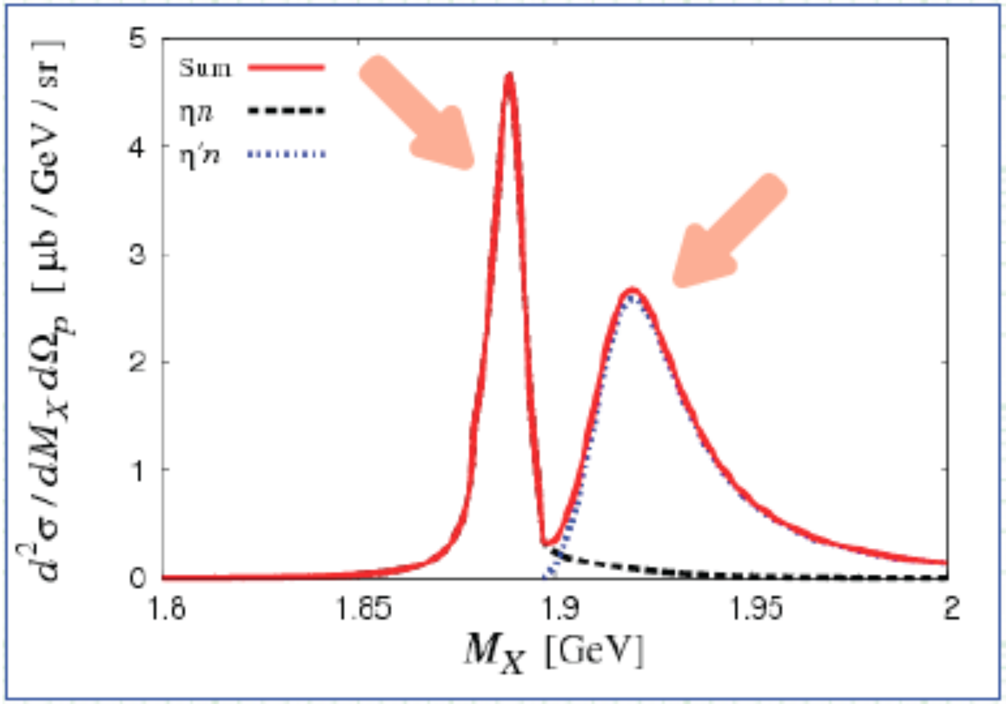
H. Fujioka

Slide by Sekihara@ Tokai Workshop Oct. 2015 (Sakai, Jido)

++ $\gamma\, d$ --> $p\, X$ ($X = \eta\, n, \eta'\, n$) reaction from the sum ++

- For observation of the signal of the $\eta'\, n$ bound state in real Exps., the signal should be comparable to the quasi-free η' contribution.

--> We plot sum of two differential cross sections for $\gamma\, d$ --> $p\, \eta'\, n$ and $\gamma\, d$ --> $p\, \eta'\, n$ reactions with $E_\gamma^{\rm lab} = 2.1$ GeV, $\theta p = 0^o$.



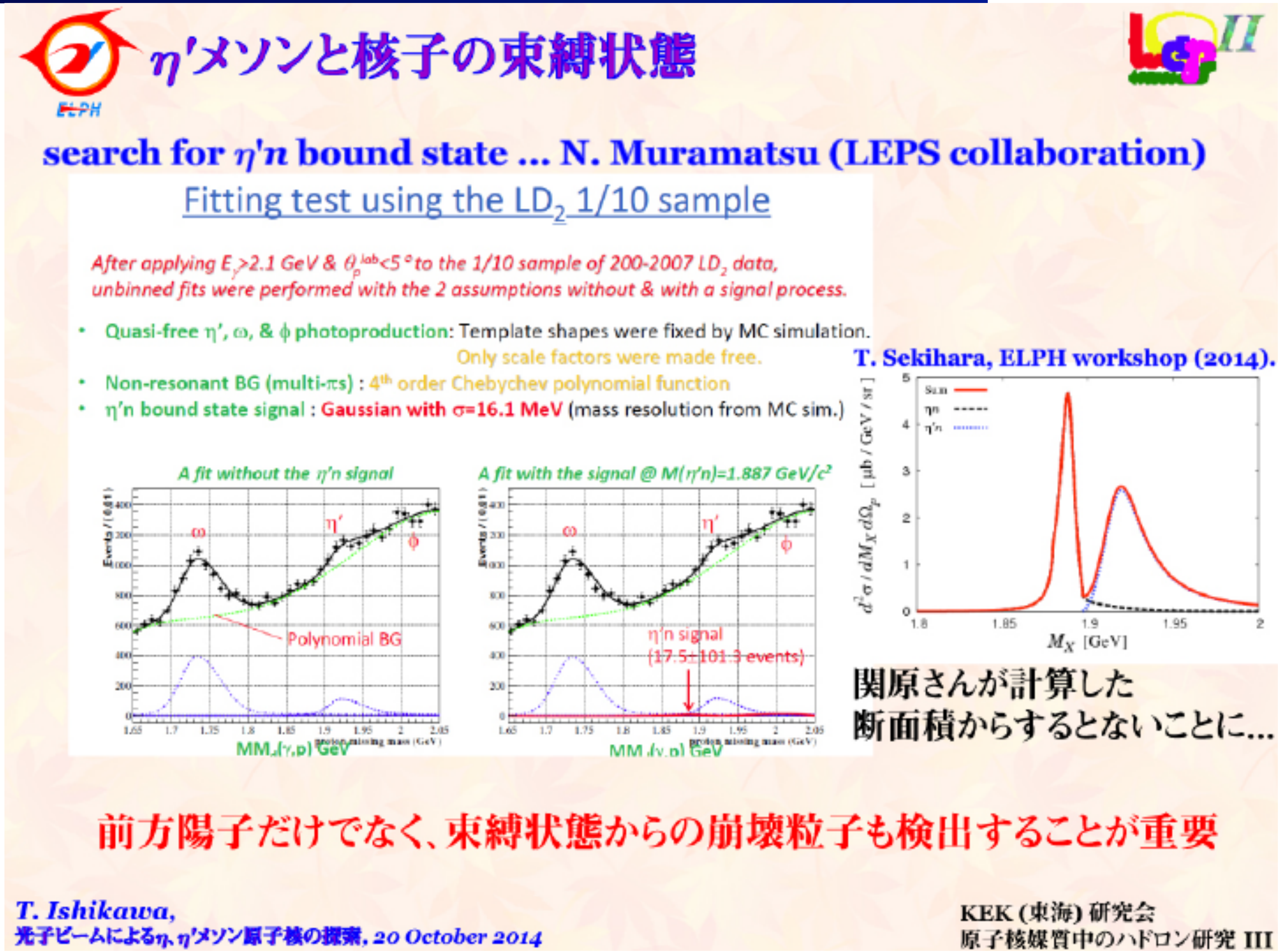
- We clearly find two peaks around the $\eta'\, n$ threshold.

--- The lower is the bound state signal, and the higher is the quasi-free η' part.

- Both the contributions are comparable with each other.

--> In our model we can observe the signal of the $\eta'\, n$ bound state.

Slide by Ishikawa @ Tokai Workshop Oct. 2015



Recent Activities on Pionic Atoms

= N. Ikeno, J. Yamagata-Sekihara, H. Nagahiro

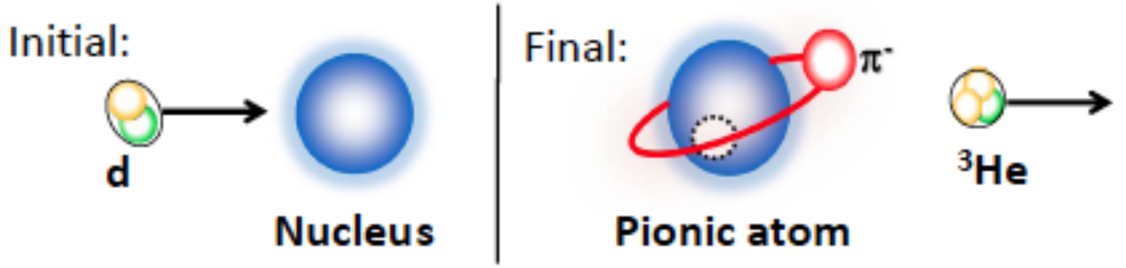
= GSI $\longrightarrow$ RIBF/RIKEN

* Higher Intensity→Syatematic study
* Finite angle observation
* Better resolution
* Unstable nuclei

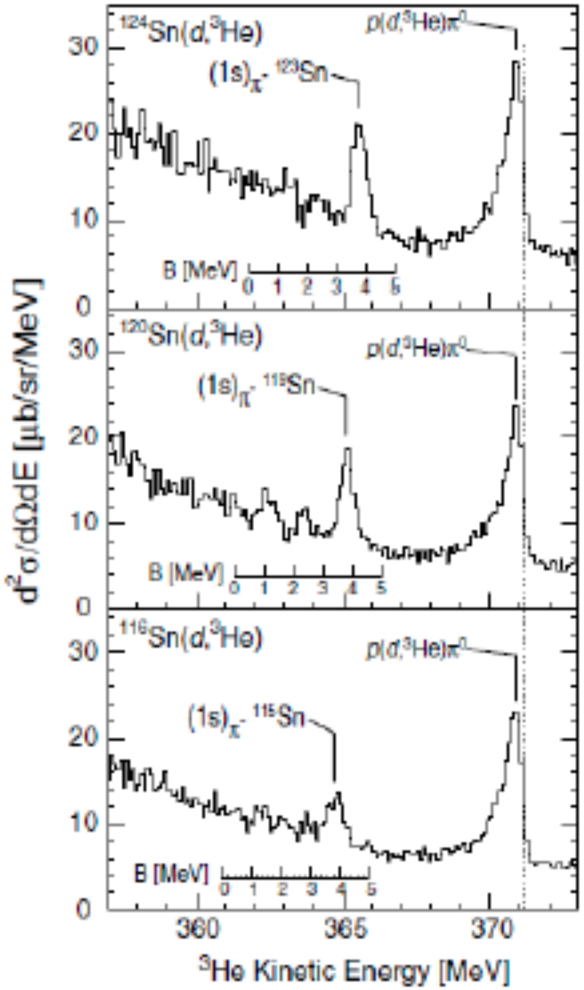
N. Ikeno , J. Yamagata-Sekihara, H. Nagahiro and S. Hirenzaki, PTEP(2013) 063D01
N. Ikeno, H. Nagahiro and S. Hirenzaki, EPJA47 (2011) 161
N. Ikeno, R. Kimura, J. Yamagata-Sekihara, H. Nagahiro, D. Jido, K. Itahashi, L. S. Geng and S. Hirenzaki, PTP126 (2011) 483

Introduction: Deeply bound pionic atom

- (d,^{3}He) reaction: Pionic 1s states in $^{115, 119, 123}$Sn



K. Suzuki *et al.*, PRL92(04)072302



- Pion-Nucleus optical potential

$$2\mu V^s_{\mathrm{opt}} = -4\pi[\varepsilon_1\{b_0\rho(r) + b_1\delta\rho(r)\} + \varepsilon_2 B_0\rho^2(r)]$$

- GOR relation + Tomozawa-Weinberg relation

$$\frac{\langle\bar{q}q\rangle_\rho}{\langle\bar{q}q\rangle_0} \simeq \frac{f_\pi^{*2}}{f_\pi^{2}} \simeq \frac{b_1^{\mathrm{free}}}{b_1^*(\rho)} = 0.78 \pm 0.05 \ @ \ \rho \simeq 0.6\rho_0$$

$$\sim 0.67 \ @ \ \rho = \rho_0$$

Theoretical basis

E.E. Kolomeitsev, N. Kaiser, W. Weise, PRL90(03)092501

D. Jido, T. Hatsuda, T. Kunihiro, PLB670(08)109

Useful system to study pion properties at finite density and partial restoration of chiral symmetry

What's next?

Interests

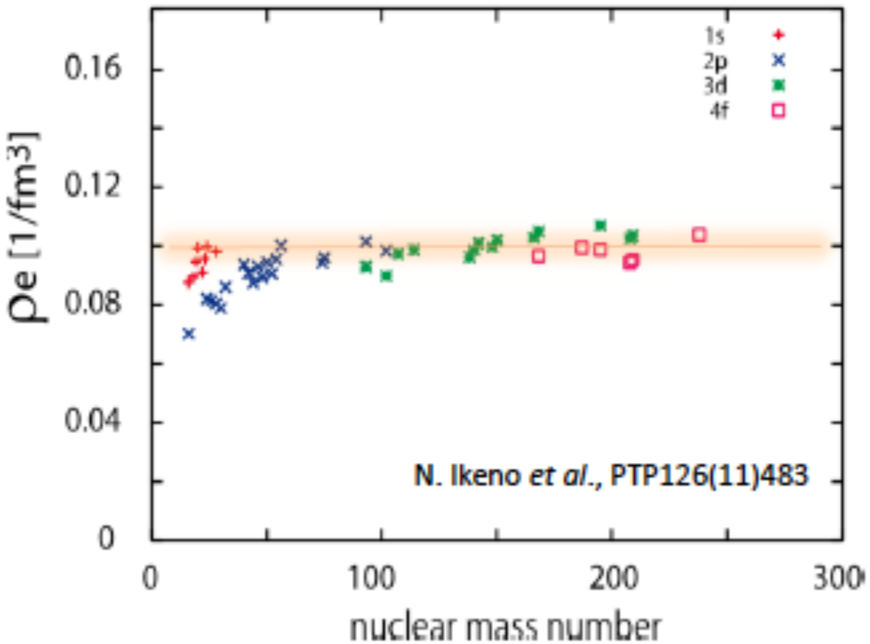
$\bar{q}q$ condensate: More accurate determination

Beyond the linear density approximation (Goda, Jido)

In asymmetric (n or p rich) nuclear matter

➔ Aspects of symmetry and pion properties in ``*various conditions (densities)*"

Difficulties for precise studies



Nuclear density probed by pionic atom

: Only limited at $\rho \simeq 0.6\rho_0$

- Strong correlation of parameters

  b_0 vs. $\mathrm{Re}B_0$

- $\frac{\langle\bar{q}q\rangle_\rho}{\langle\bar{q}q\rangle_0} \simeq \frac{f_\pi^{*2}}{f_\pi{}^2} \simeq \frac{b_1^{\mathrm{free}}}{b_1^*(\rho)} = 0.78 \pm 0.05 \ @ \ \rho \simeq 0.6\rho_0$

- Density probed by pionic atom is almost same for all states

- Linear density dependence of condensate up to normal nuclear density ??

➔

∗ To deduce more precise information,

Finite angle: several pionic states for one nucleus

Odd target: No residual interaction effects

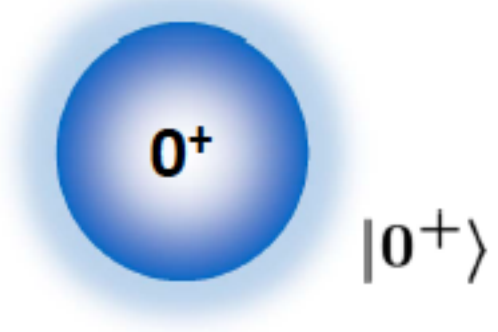
∗ Asymmetric nuclear matter

Odd neutron target case

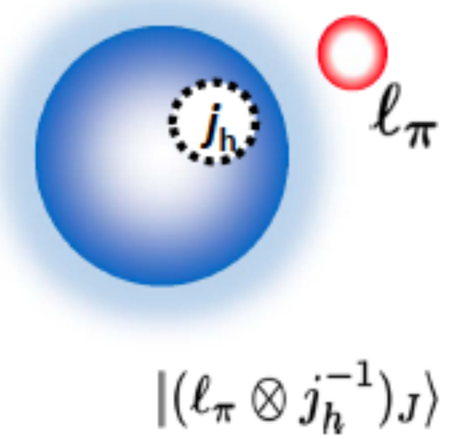
Acknowledgement
H. Nakada-san

Even target: ^{122}Sn (0^+)

Initial:

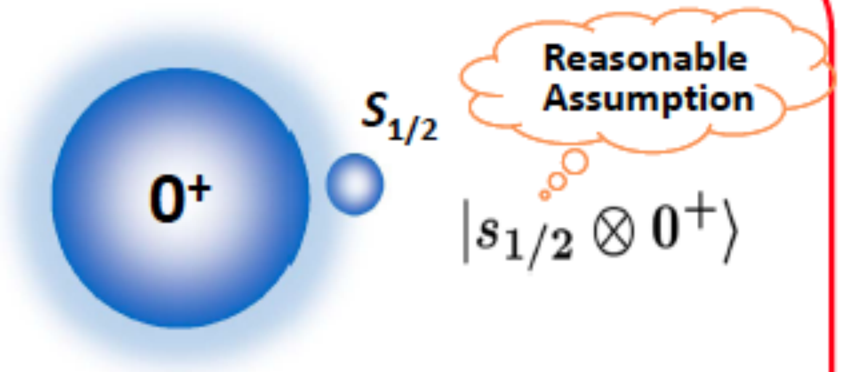


Final:



Odd target: $^{117,\,119}$Sn ($1/2^+$)

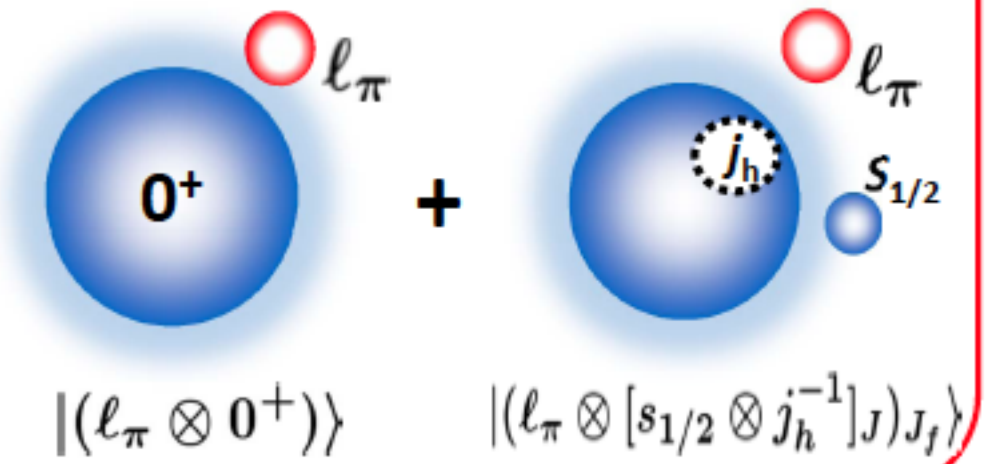
Initial:



Final:

(1) neutron pick-up from $s_{1/2}$ orbit

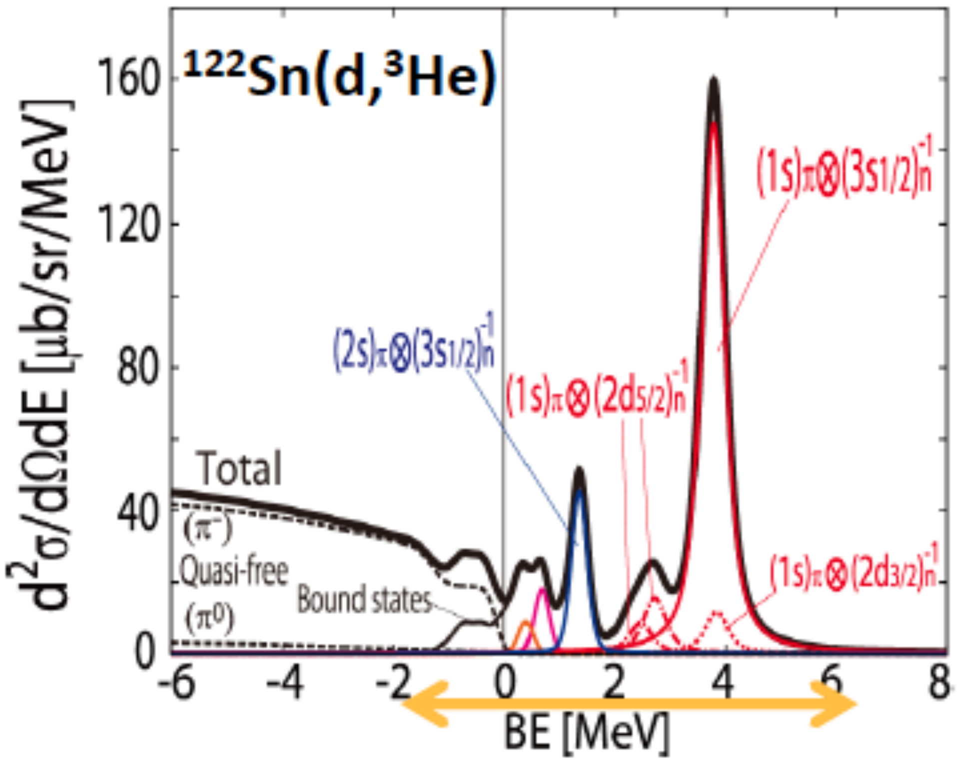
(2) neutron pick-up j_h orbit from other than $s_{1/2}$



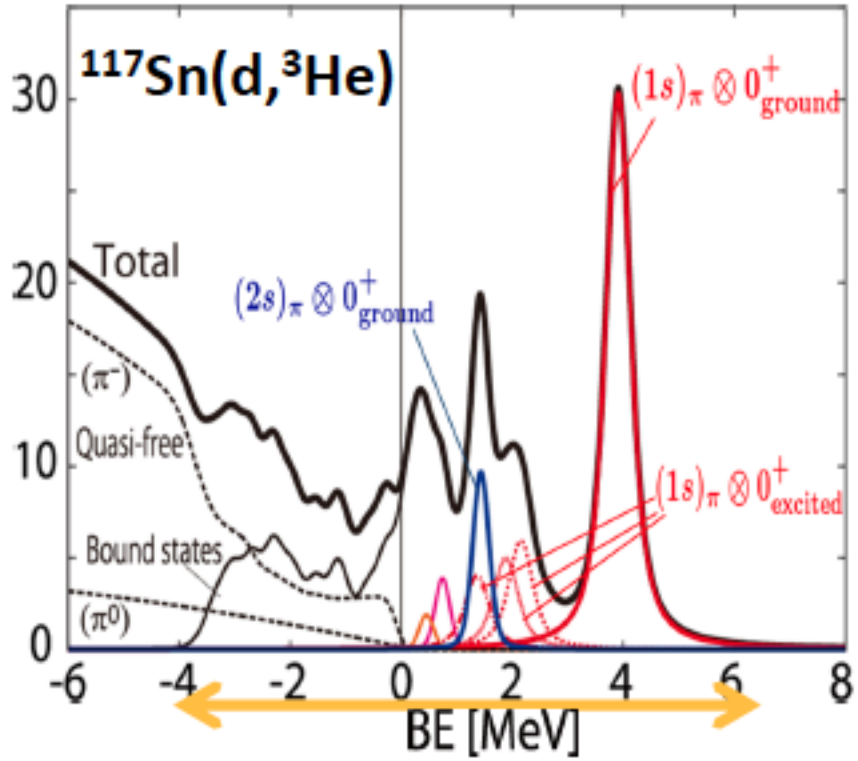
Numerical Results: Even vs. Odd target

0 degrees

Even target: ^{122}Sn (0^+)



Odd target: ^{117}Sn ($1/2^+$)



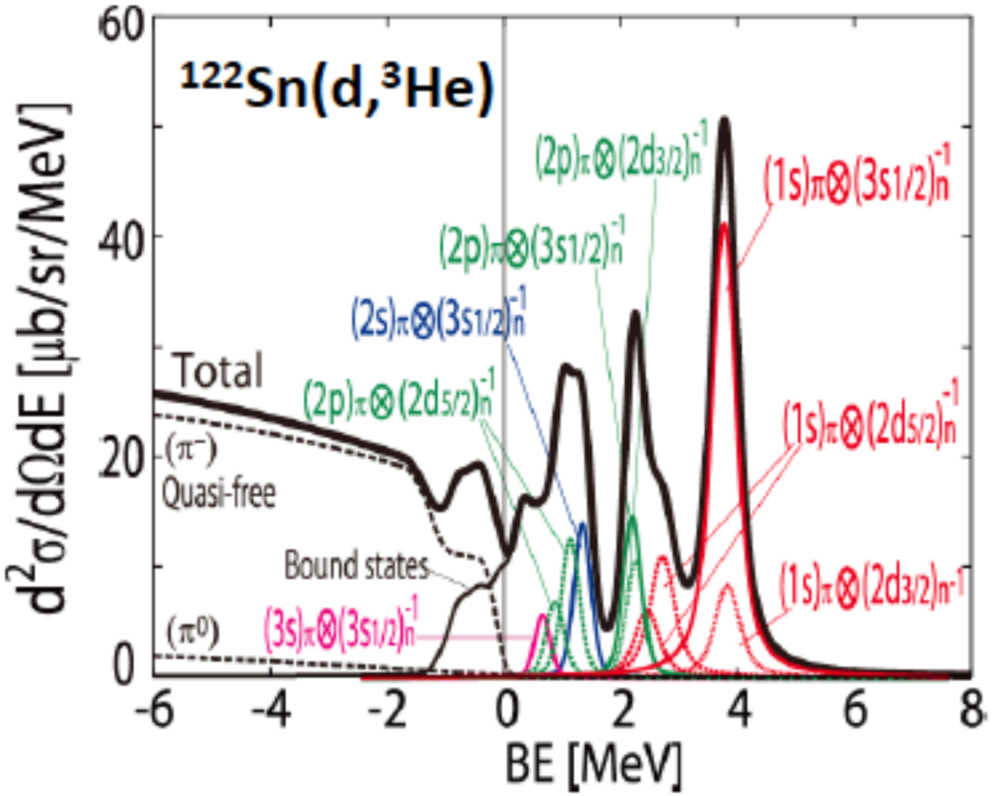
- Pionic 1s state formation with neutron s-hole state is large in both spectra.
- Bound pionic state formation spectra in ^{117}Sn(d,^{3}He) are spread over wider energy range.
- Absolute value of cross section in ^{117}Sn(d,^{3}He) is smaller.

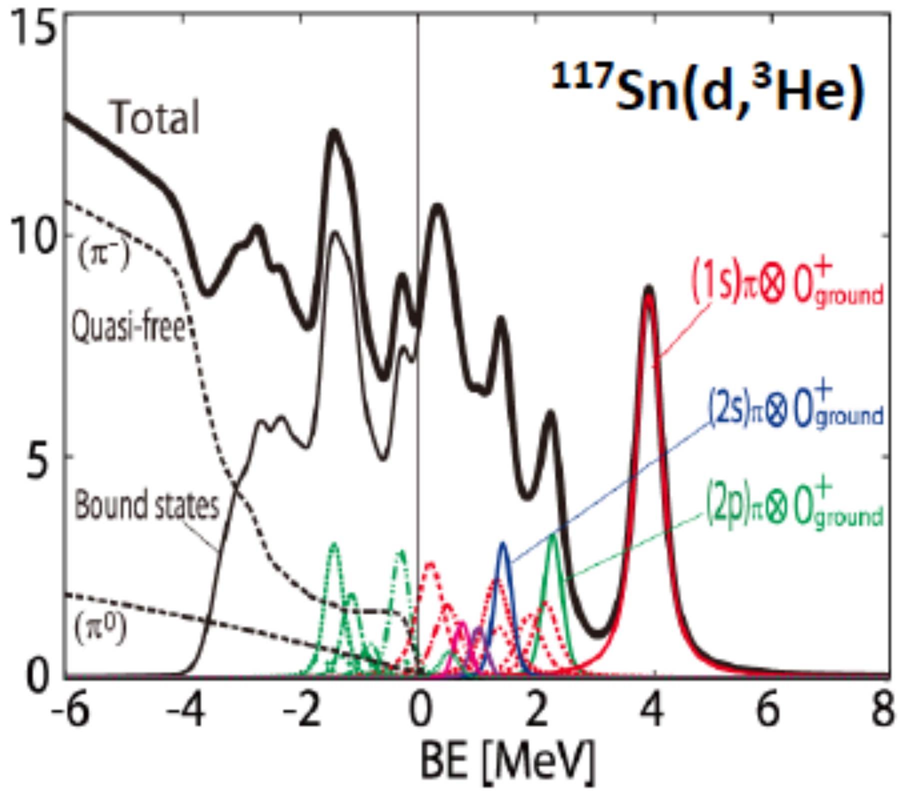
Numerical Results: Even vs. Odd target

2 degrees

Even target: ^{122}Sn (0$^+$)

Odd target: ^{117}Sn (1/2$^+$)





Even target:

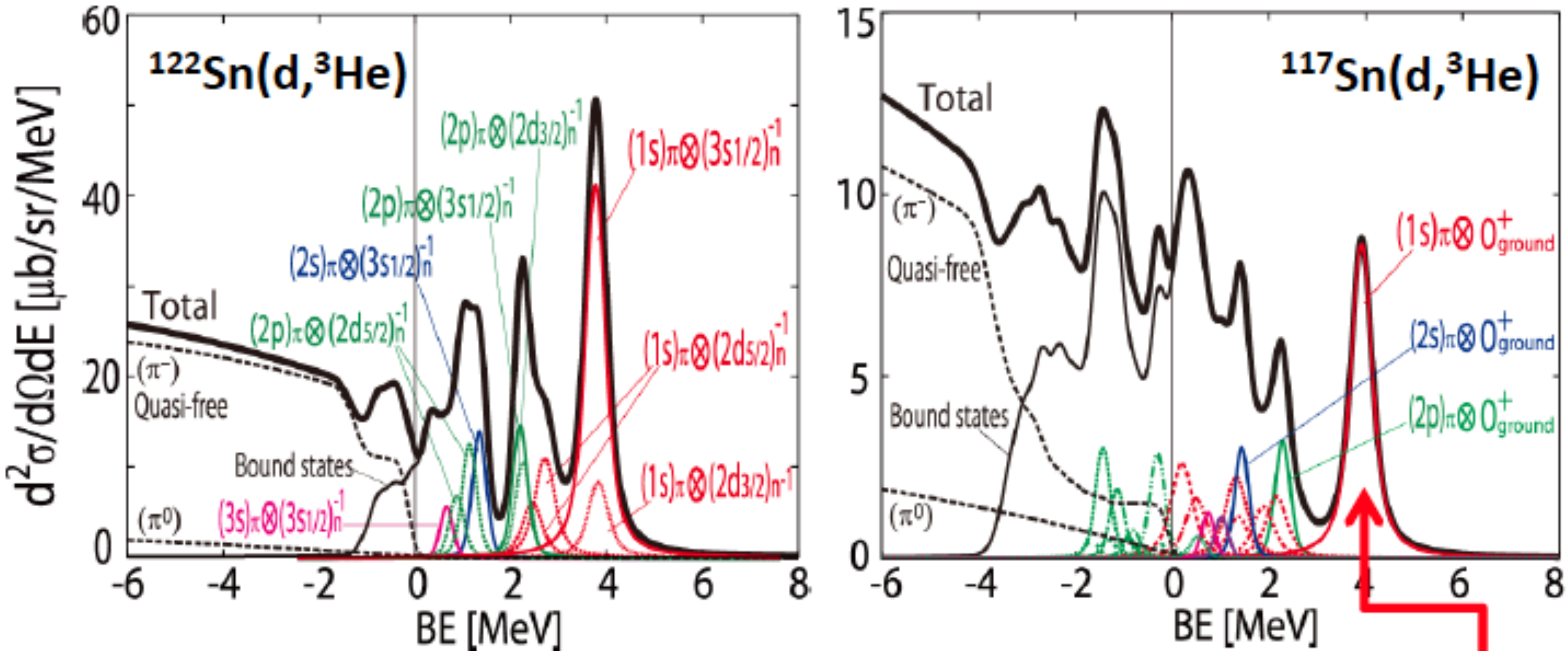
Simultaneous observation of several pionic 1*s*, 2*s* and 2*p* states at forward and finite angles

Numerical Results: Even vs. Odd target

2 degrees

Even target: ^{122}Sn (0^+)

Odd target: ^{117}Sn ($1/2^+$)



Odd target:

Isolated peak and single subcomponent (No residual interaction effect)

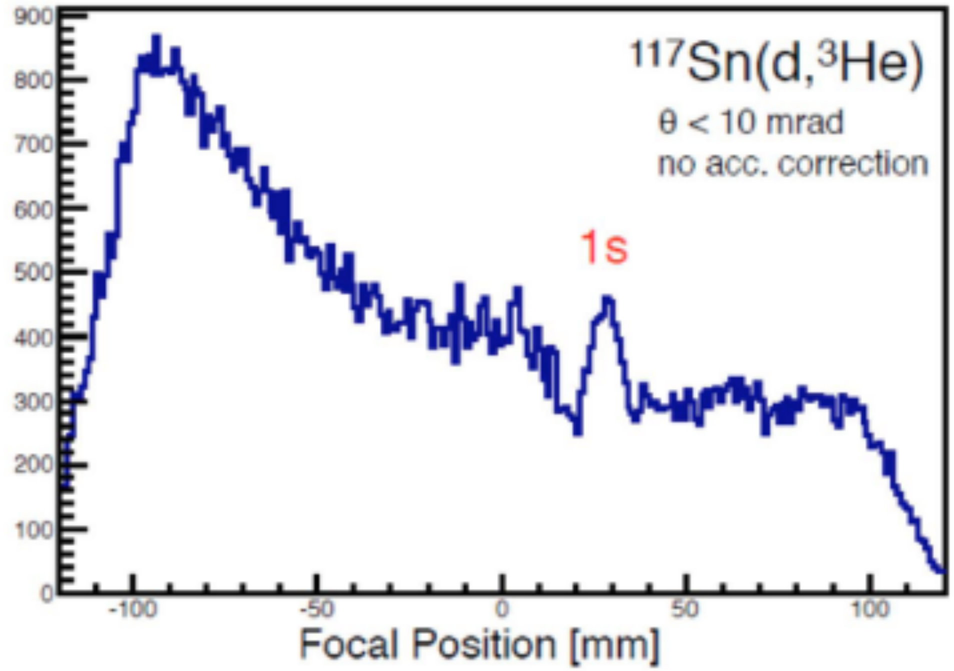
→ This pionic 1s state is preferable for extracting accurate information on pion properties

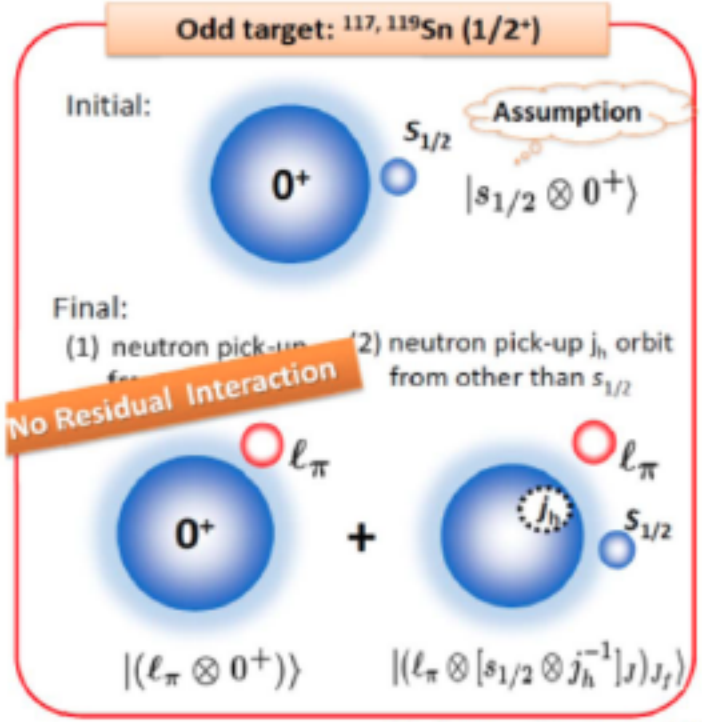
K. Itahashi's slide in EXA2014

Odd target ^{117}Sn

First observation with an even neutron number nucleus

New Data in 2014



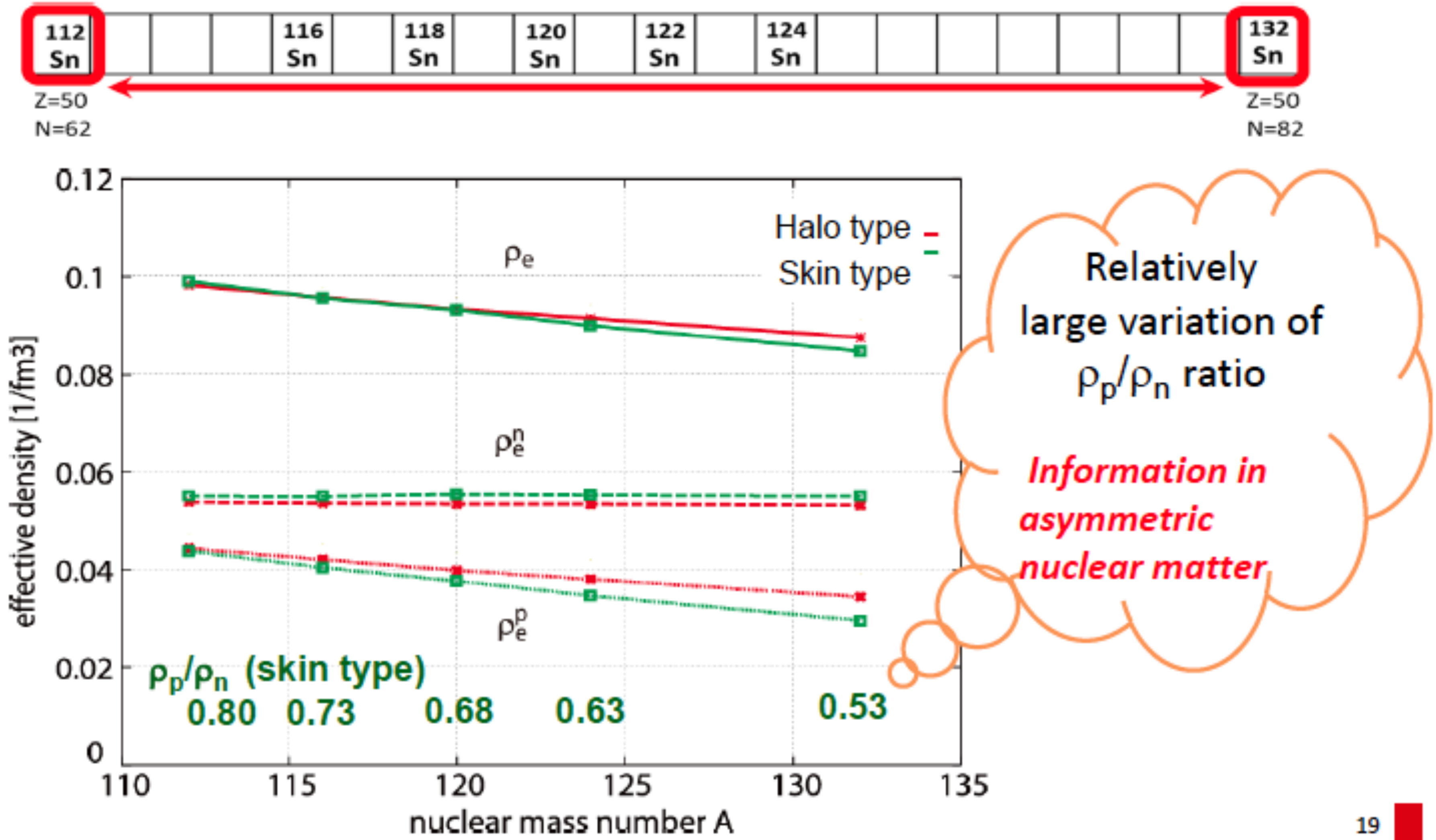


N. Ikeno (Hadron 2013)

First observation of pionic atom with even N
→ better separation in the neutron hole configurations.

Pionic atom in unstable nuclei

- Nuclear densities probed by pionic 1s states in $^{112\text{-}132}Sn$



Recent Activities on Kaonic Atoms

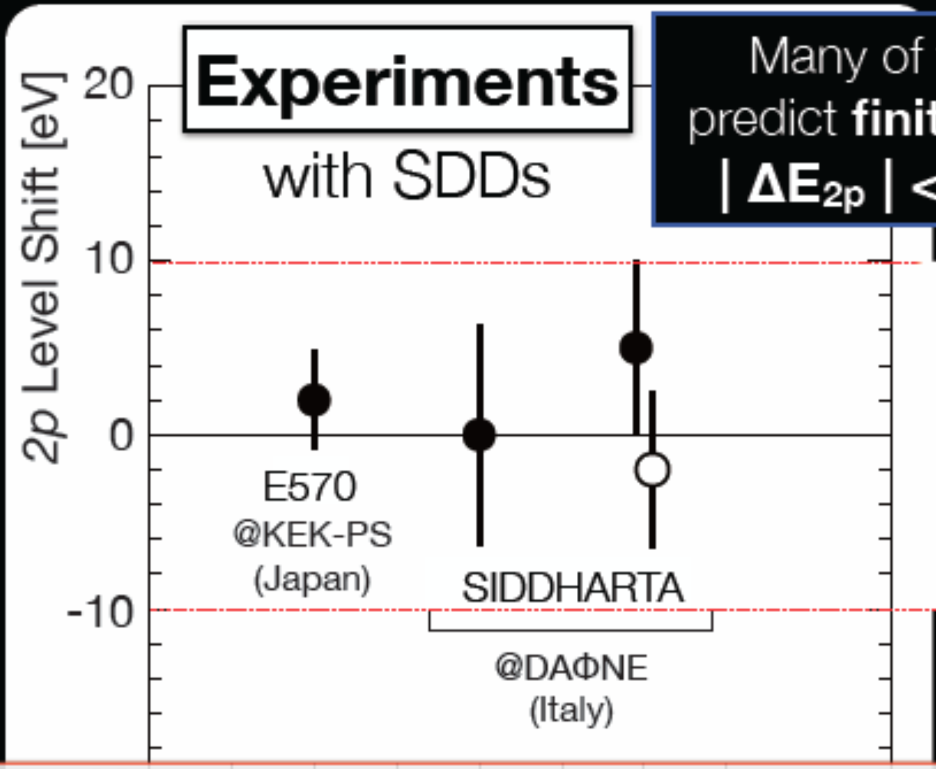
E17→E62: Kaonic helium atom X rays

= S. Okada,

= J. Yamagata-Sekihara, E. Hiyama

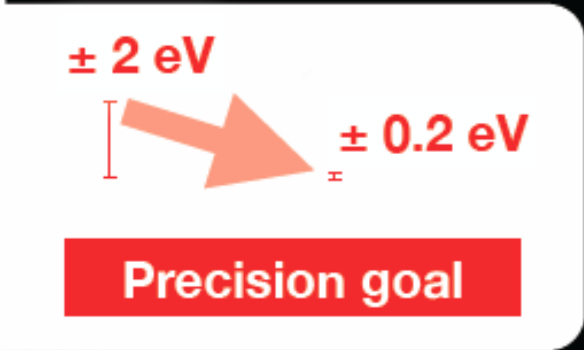
Precision goal : ± 2 eV → ± 0.2 eV

Shift



Many of theoretical calculations predict **finite values** of shift & width

$|\Delta E_{2p}|$ <~1 eV , Γ_{2p} >~ 1 eV



both for K-^{4}He - K-^{3}He

Breakthrough in energy resolution with TES microcalorimeters

Width Width measurement **for the first time**

Summary

- Meson property at finite density,
  Mesic atoms and Mesic nuclei

Some topics

Vector meson, phi, unified treatment

$\eta'(958)$: Anomaly effect at finite density

Pionic atom, systematic data at RIKEN

Kaonic atom, pricision frontier