Formation of slow Heavy Mesons in Nuclei

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Based on collaborations and discussions with
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K. Itahashi, H. Fujioka, H. Ohnishi, K. Ozawa

1. Introduction and motivation

- Meson in Nucleus
  light ~ heavy

- Interests of Heavy Mesons
  (Φ, η', charm, bottom, ...)

- Difficulties in Production Process
  ... How to make it?

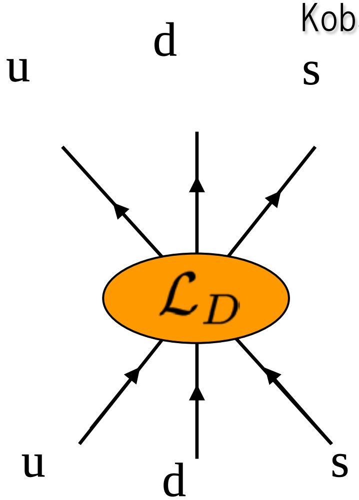
η' meson in Nuclei : H.Nagahiro, M.Takizawa, S.H

- **Nambu-Jona-Lasinio model** with the **KMT interaction**

$$\mathcal{L} = \bar{q}(i\,\partial\!\!\!/ - m)q + \frac{g_s}{2}\sum_{a=0}^{8}\left[(\bar{q}\lambda_a q)^2 + (i\bar{q}\lambda_a\gamma_5 q)^2\right]$$
$$+ g_D\left[\det \bar{q}_i(1-\gamma_5)q_j + h.c.\right]$$

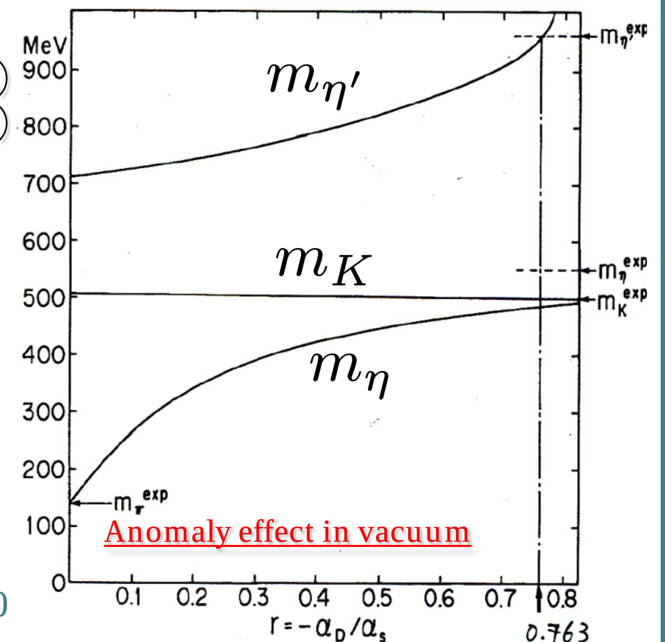
explicit breaking the $U_A(1)$ sym.

Kobayashi, Maskawa Prog. Theor. Phys. 44, 1422 (70)
G.'t Hooft, Phys. Rev. D14, 3432 (76)



One can reproduce the heavy η' mass

Kunihiro, Hatsuda, PLB206(88)385, Fig. 3



Anomaly effect in vacuum

ϕ meson in Nuclei

With
J. Yamagata-Sekihara (YITP, Kyoto Univ.)
D. Cabrera (Complutense Univ., Madrid)
M. J. Vicente Vacas (IFIC, Valencia Univ.)

- ϕN interaction …… s quark component
  - OZI rule violation
  - $\langle N|\bar{s}s|N\rangle$
  - Chiral symmetry restoration by $\bar{s}s$
- Strong coupling to $\bar{K}K$ …. Relate to Kaon in nuclei
- (asymmetric) medium effects from Π_K and Π_K

Mesons with c, b

- Meson Mass Spectroscopy by Dynamical effect vs current mass
- Different Response in Nuclear Medium?

2. How to make Heavy Mesons in Nucleus?

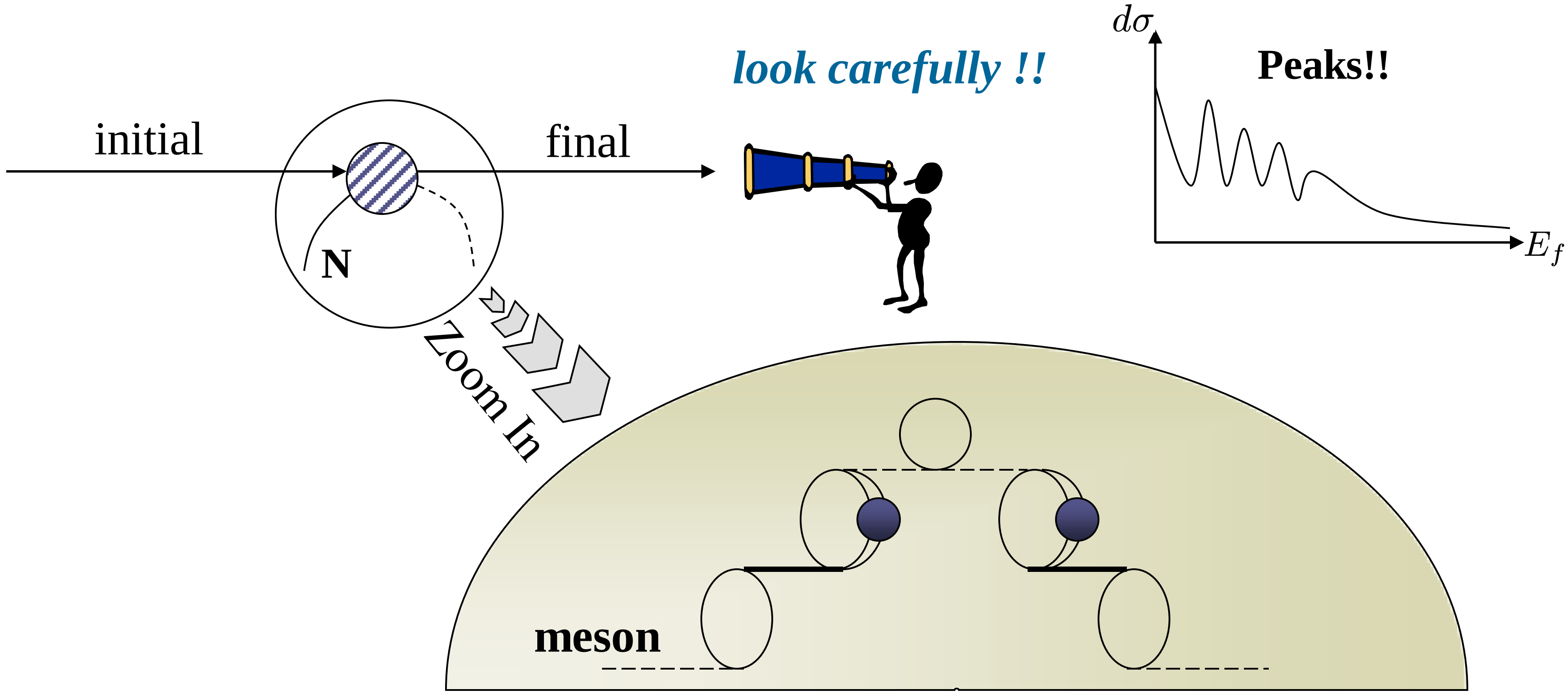
1. Missing Mass Spectroscopy

2. Invariant Mass method

3. Combined Method

-> Φ production as an example

MISSING MASS SPECTROSCOPY



In-Medium Dispersion Relation

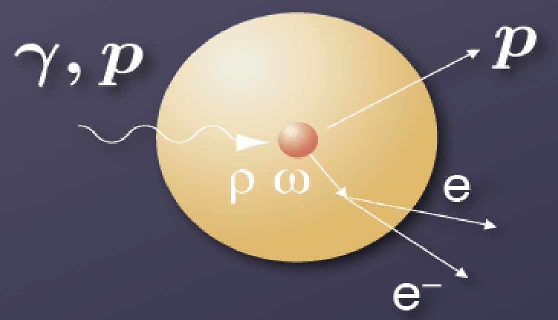
Medium Effects

$$[-\nabla^2 + m^2 + \Pi(\rho(r), \omega)]\phi = \omega^2 \phi$$

Vector Mesons in Nuclei

By Hayano@INPC07

M_{e+e-}



KEK E325 p+A → V + X
J-LAB g7 γ+A → V + X

$$m_{\rho,\omega} = \sqrt{(p_{e+} + p_{e-})^2}$$

- small FSI
- rare decay
- fast ω, φ decay outside

	BR(e^+e^-)	cτ
ρ (770)	4.7×10^{-5}	1.3 fm
ω (782)	7.2×10^{-5}	23 fm
φ (1020)	3×10^{-4}	44 fm

2. How to make Heavy Mesons in Nucleus?

- Missing Mass Spectroscopy

  - Overlap of Nuclear Excitation subcomponents
  - Energy Resolution for high energy emitted particles

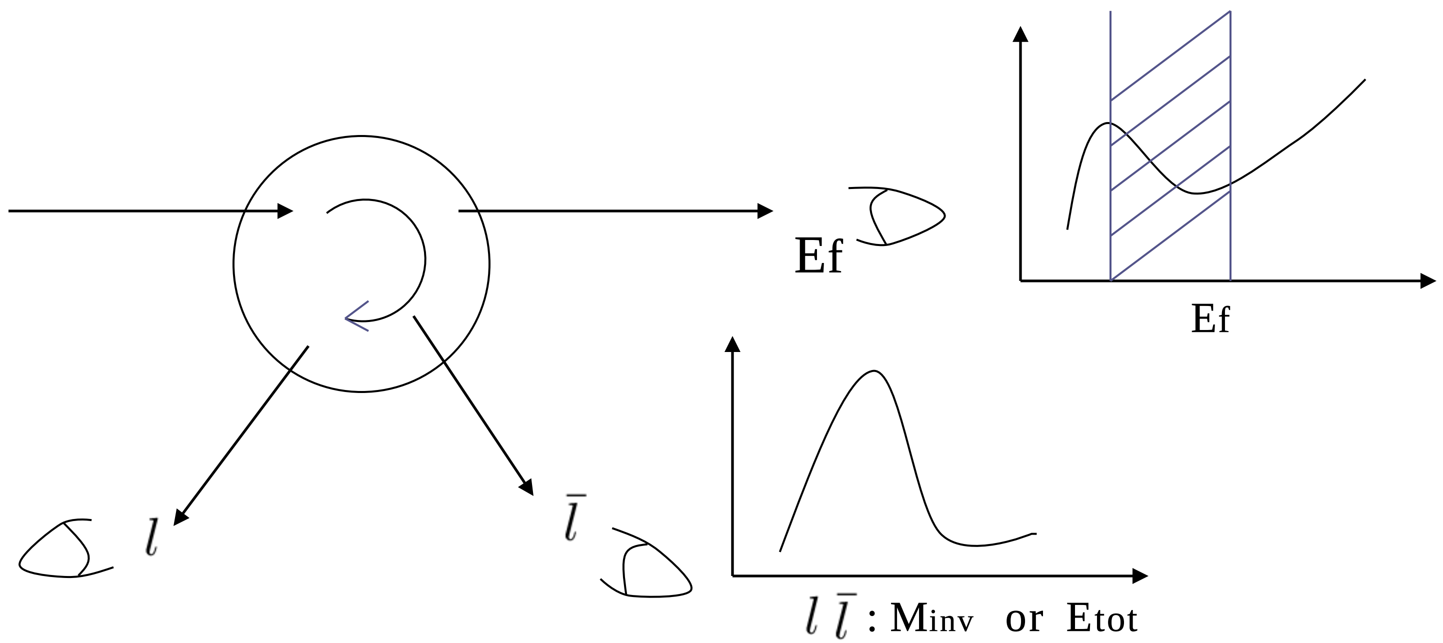
- Invariant Mass Method

  - Meson may decay outside (background)
  - Nucleus remains to be Nucleus?

Proposal at J-PARC（P16: Electron pair Spectrometer at the J-PARC 50-GeV PS to explore the chiral symmetry in QCD: *S. Yokkaichi (RIKEN, Japan)*）

Combined Method

- K; M. Iwasaki, J. Yamagata-Sekihara, ...
- ω; V. Metag, K. Ozawa, H. Nagahiro .....
- Φ; H. Ohnishi, ...



2-3 combined Method

➢Advantage

- Selection of low energy (even subthreshold)
  Meson by Ef window (Reject Meson decay in vacuum)
- Guarantee 'Nucleus' （by Energy Conservation）

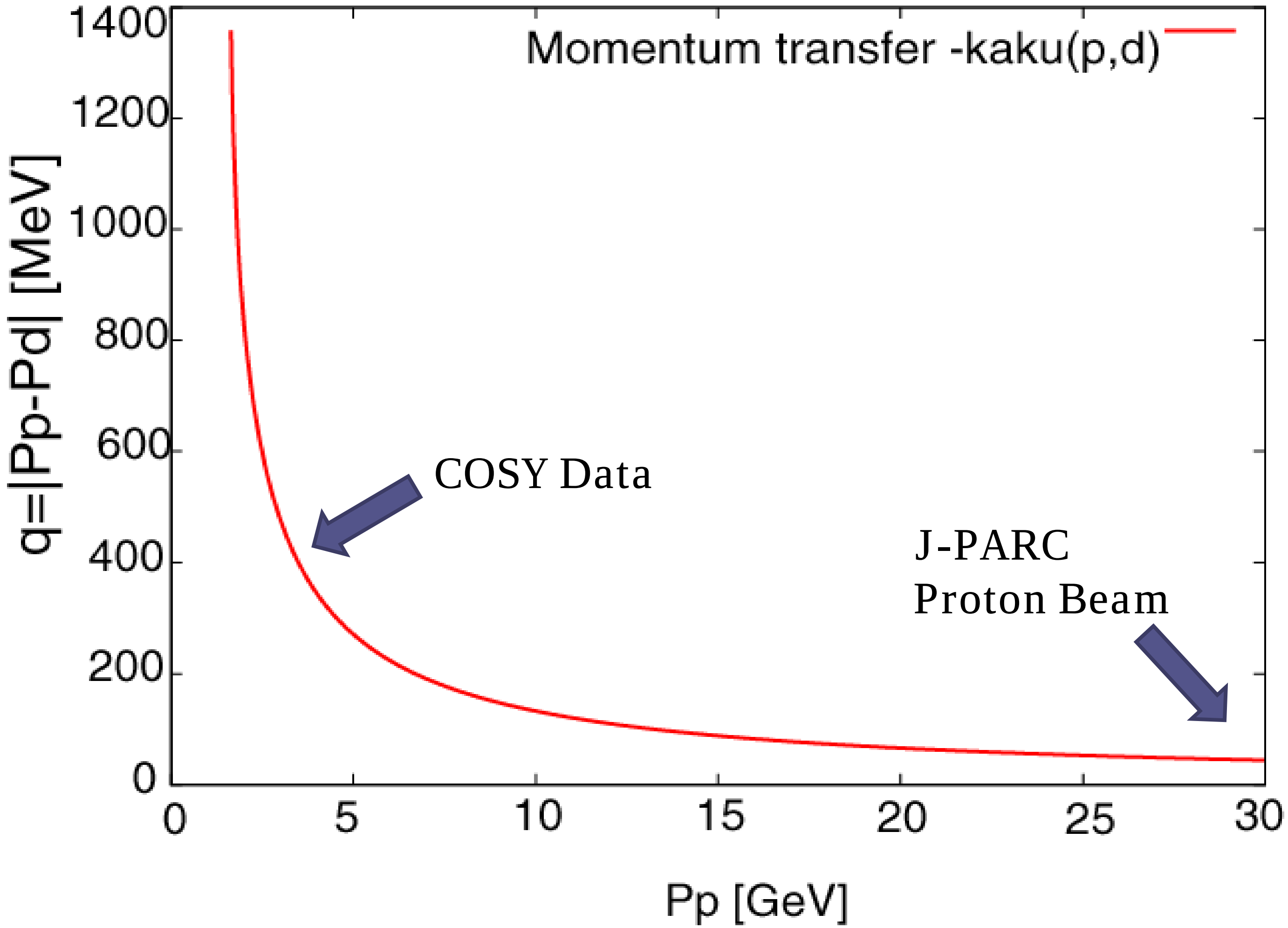
- Plot by $E_{tot} = E_l + E_{\bar{l}}$ to avoid nuclear excitation subcomponent

➢Disadvantage

- Reduction of Production rate
  (Inclusive -> exclusive)

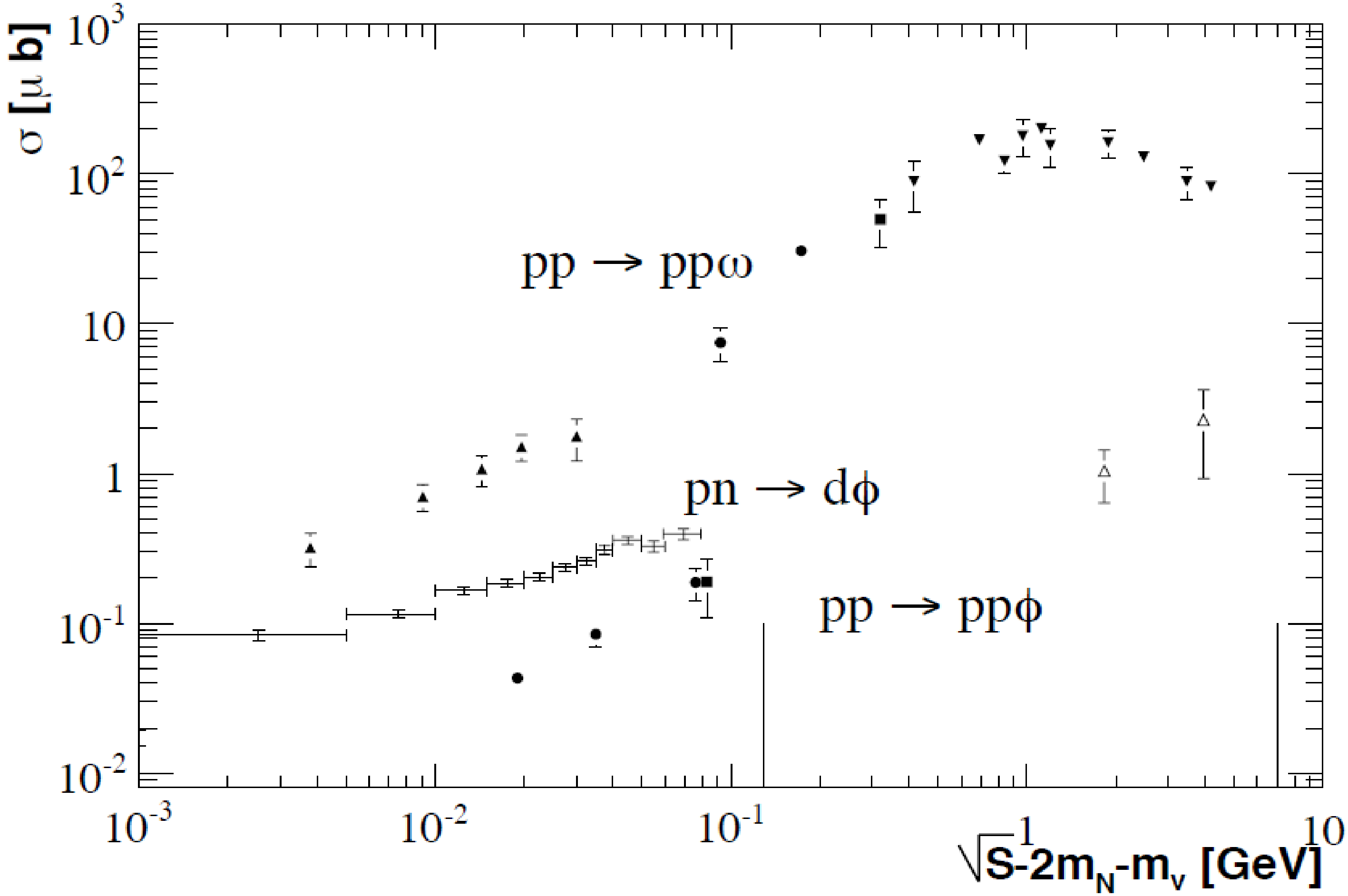
3. Example: Φ meson by proton beam (High Intensity@J-PARC)

- A(p,d) reaction



p+p→Meson production @2.65GeV (COSY-Julich)

Y. Maeda et. al,
(Center for proton beam therapy, Fukui prefectural Hospital)
PRC77(2008)015204, PRL96(2006)242301, PRL97(2006)142301



Elementary Process: pN->ΦX

Tp=2.65GeV (CM energy excess 18.5 MeV)@COSY-Julich

σ(pp->Φpp)=33 nb (PRC77(2008)015204,　PRL96(2006)242301)

σ(pn->Φd) =200 nb (PRL97(2006)142301(＊))

σ(pn->Φpn)=75 nb (No data, Estimation in ＊)

For p+A reaction,

σ(total) ~ 33+200+75 =308 nb

σ(pn->Φd) /σ(total) ~ 65%

No strong reduction due to select one channel.

Formulation - Reaction

- **Green's Function Method**

O. Morimatsu, K. Yazaki NPA435 (85)727

O. Morimatsu, K. Yazaki NPA483 (88)493

$$\frac{d^2\sigma}{dE d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{K^- N \to N K^-} \sum_{\alpha} -\frac{1}{\pi} \mathrm{Im} \int d\vec{r} d\vec{r}' f_\alpha^*(\vec{r}') G(E;\vec{r}',\vec{r}) f_\alpha(\vec{r})$$

- $\left(\frac{d\sigma}{d\Omega}\right)_{K^- N \to N K^-}$: Elementary cross section (Exp. data)
- $G(E;\vec{r}',\vec{r})$: Green function for K interacting with the nucleus

  $$(H_{K^-} - E) G(E;\vec{r}',\vec{r}) = \delta^3(\vec{r} - \vec{r}')$$

- $f_\alpha(\vec{r}) = \chi_p^*(\vec{r}) \chi_K(\vec{r}) \langle \alpha | \psi_p(\vec{r}) | i \rangle$

*** Conversion Part**

$$\left(\frac{d^2\sigma}{dE d\Omega}\right)_{\rm con} = \frac{1}{\pi} \left(\frac{d\sigma}{d\Omega}\right)_{\bar{K}N \to \bar{K}N} S_{\rm con}(E)$$

$$S_{\rm con}(E) = -\tilde{f} G^+ \mathrm{Im} U \; G \; f$$

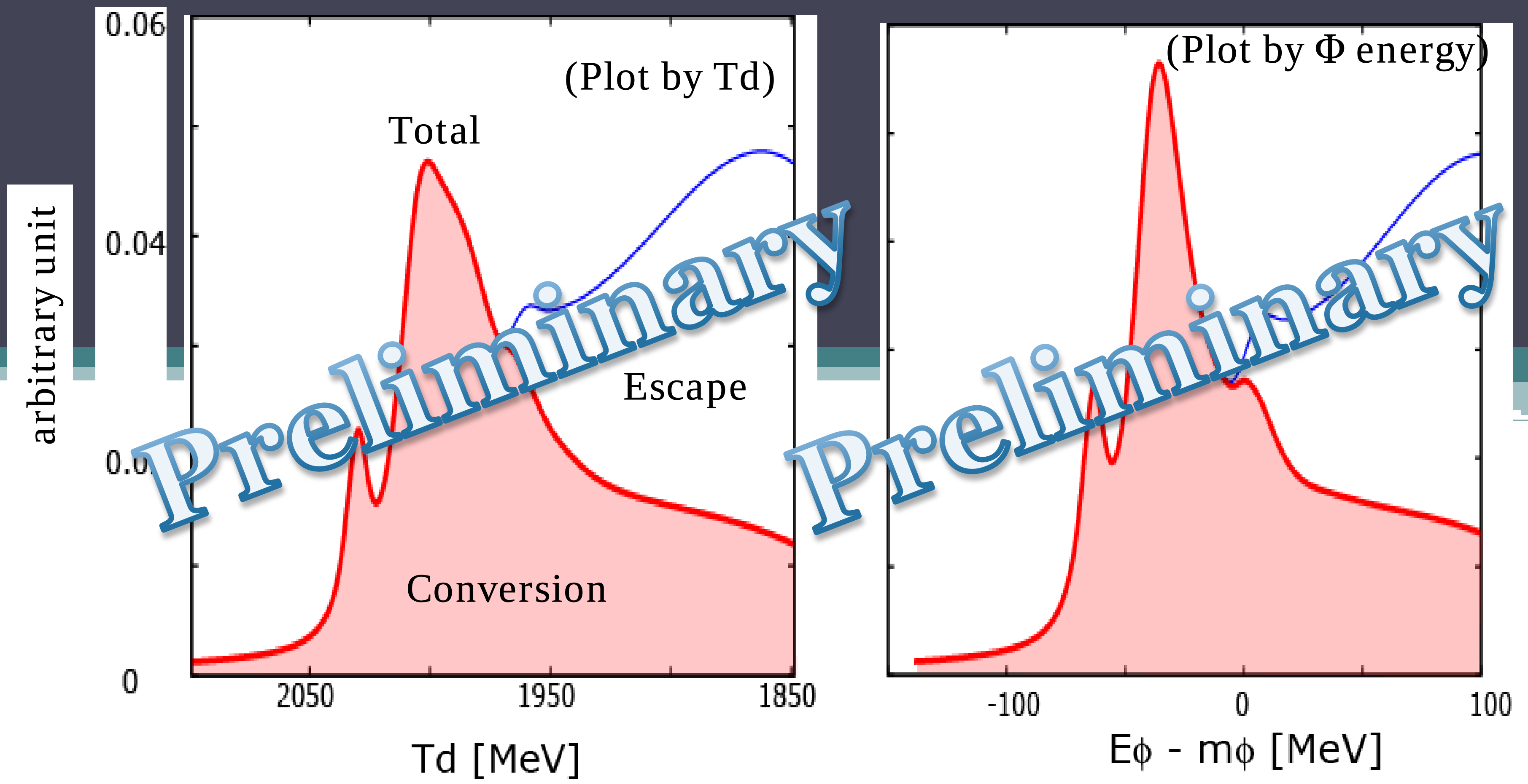
12C(p,d) reaction for Φ production in Green's function method

*Total spectrum

*Conversion (Absorption) part spectrum

*Vopt(0,E=m_ϕ) ~ (-70 MeV, -10 MeV) case

（Spectra by J. Yamagata-Sekihara)



Estimation of Particle emission RATE from nucleus ex) electron-positron pair

1. Conversion part spectrum

   Rate ~ $\frac{\Gamma_{l\bar{l}}}{\Gamma_{tot}} = \frac{\Gamma_{l\bar{l}free}}{\Gamma_{N\phi} + \Gamma_{free}} = \frac{1.3keV}{24.3MeV} \sim 5.3 \times 10^{-5}$

(Strong Absorption width assumed to be 20 MeV)

(same situation as other invariant mass method like E325)

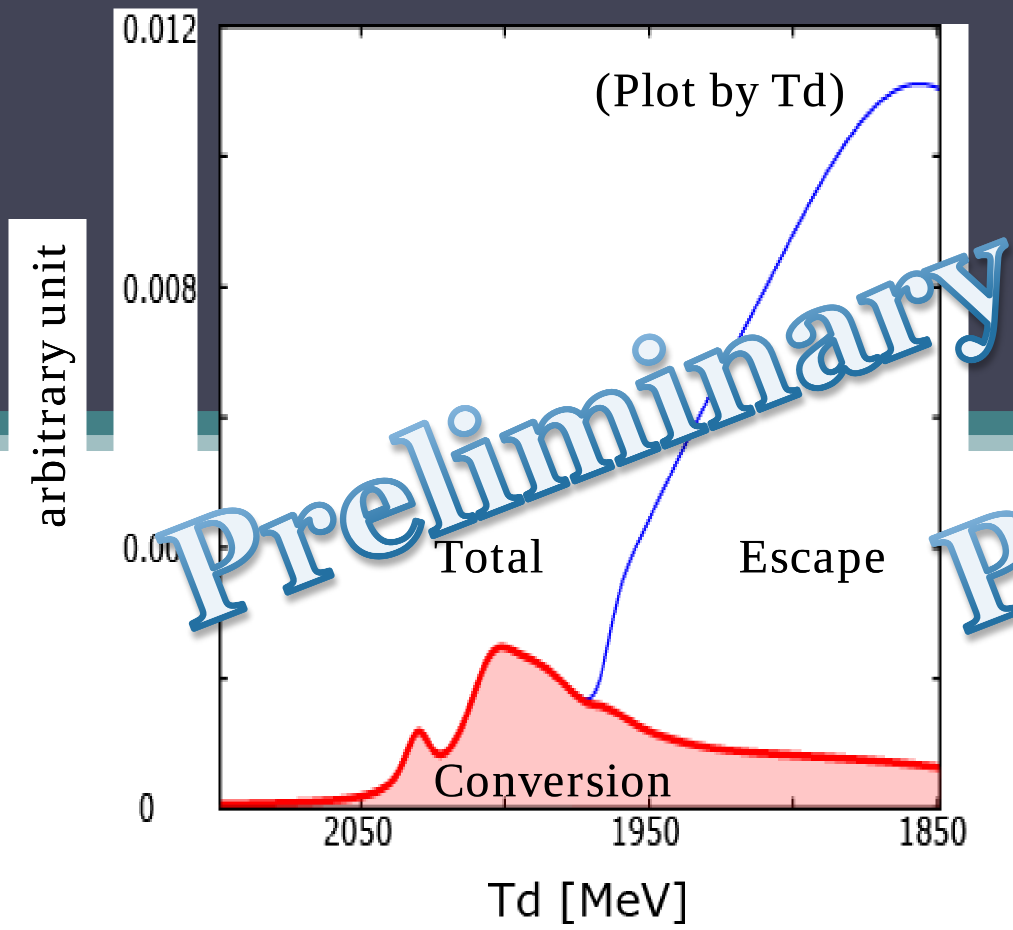
2. Escape part

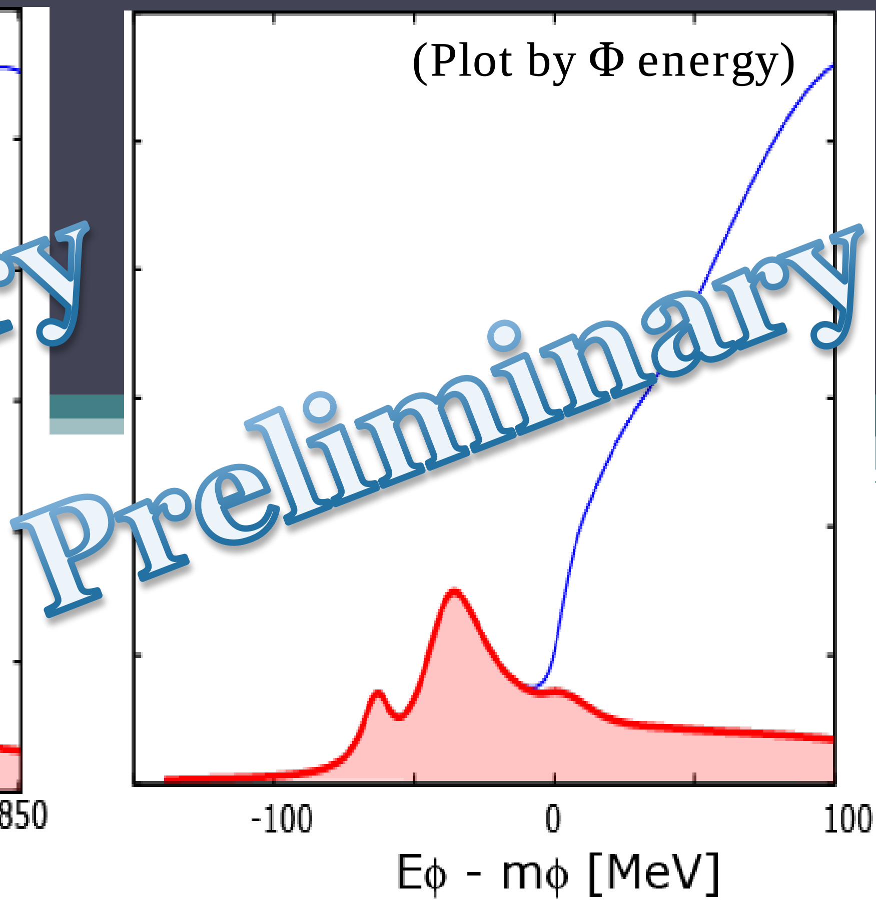
   Rate ~ same as Vacuum BR $\sim 3.0 \times 10^{-4}$

   (background part)

12C(p,d) reaction for Φ production in Green's function method
（Estimated particle emission RATEs are multiplied.)

（Spectra by J. Yamagata-Sekihara)





Summary

- Heavy meson in Nucleus
- Missing Mass + Invariant Mass (combined) method
- Conversion part (signal part)

  ….. Lepton decay vs strong absorption

  (same as other invariant Mass methods)
- Small production rate can be rescued by higher intensity ?

- Φ in nuclei by (p,d) reaction as an example
- If we select $E_\Phi < M_\Phi$ by emitted E_d, completely no background from $\Phi \to l\,\bar{l}$ in vacuum
- We can safely expect final 'Nucleus' by observing E_d.