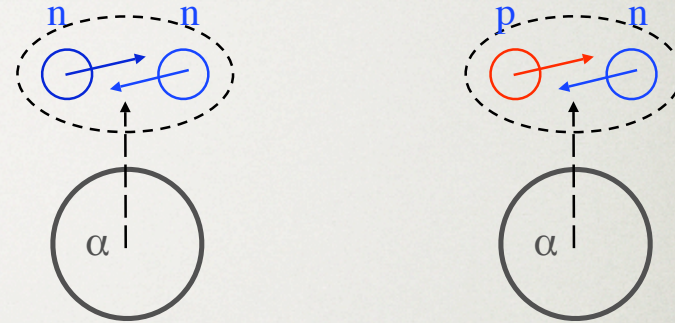
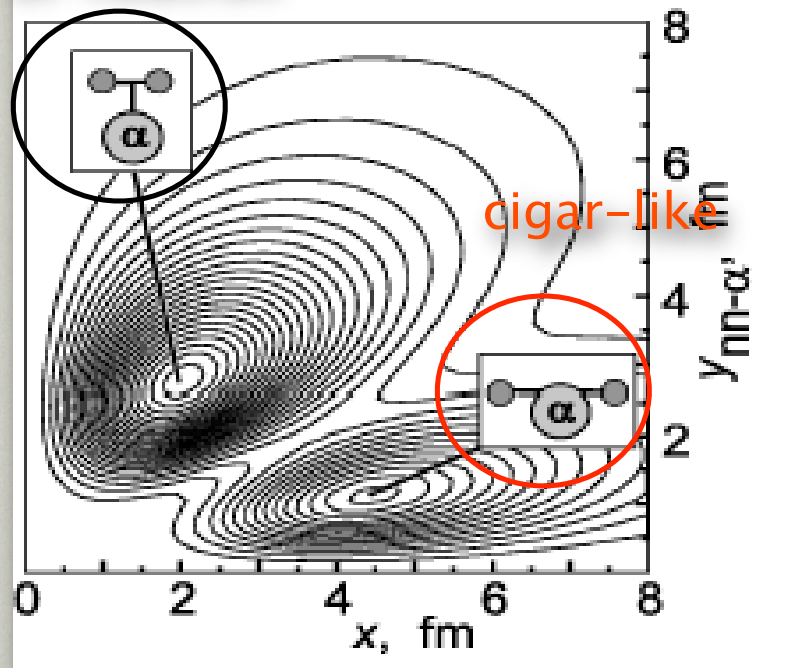


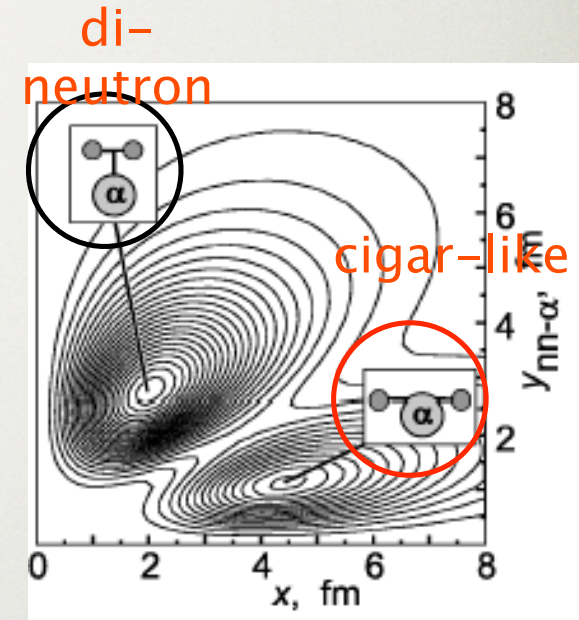
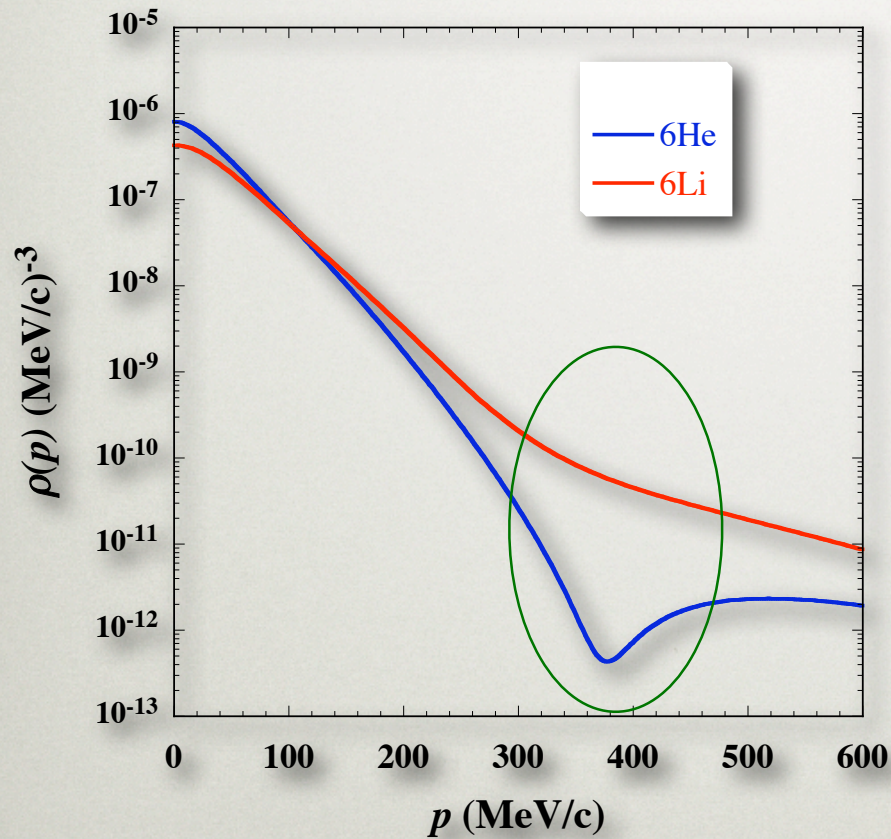
核子交換反応で探る ${}^6\text{He}$ 核内2中性子の空間分布

di-neutron



- ${}^6\text{He}, {}^6\text{Li}$ 核内2核子系
- ${}^6\text{Li} : \alpha + p + n'$
- ${}^6\text{He} : \alpha + n + n'$
- 核内2核子系の波動関数
- 相対運動量分布
- ${}^6\text{He}$ 核内2中性子系の空間分布に関する情報

${}^6\text{Li}$, ${}^6\text{He}$ 核内2核子系の相対運動量分布



運動量分布から2中性子の配位の
違いが出せないか？

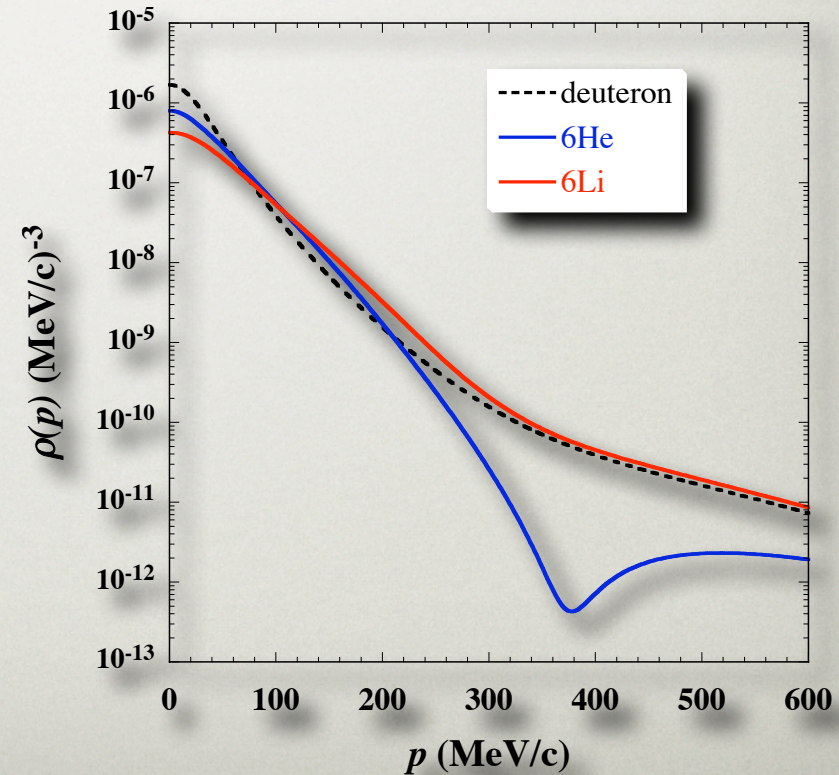
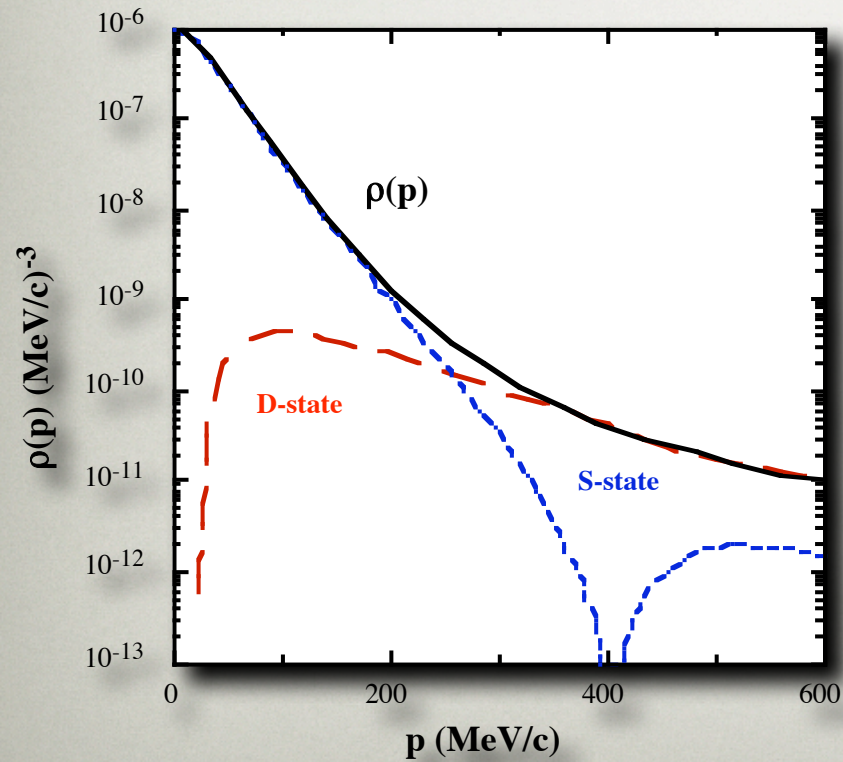
Di-neutron : at large p region
Cigar-like : at lower p region

${}^6\text{Li}$ 核内2核子系の相対運動量分布

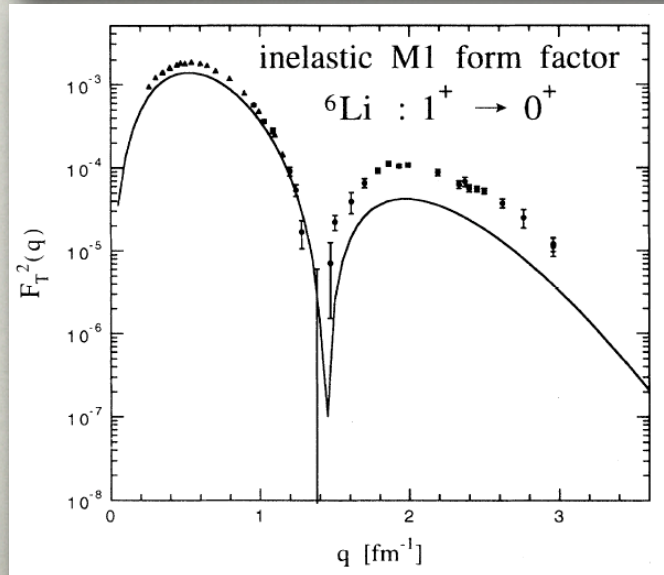
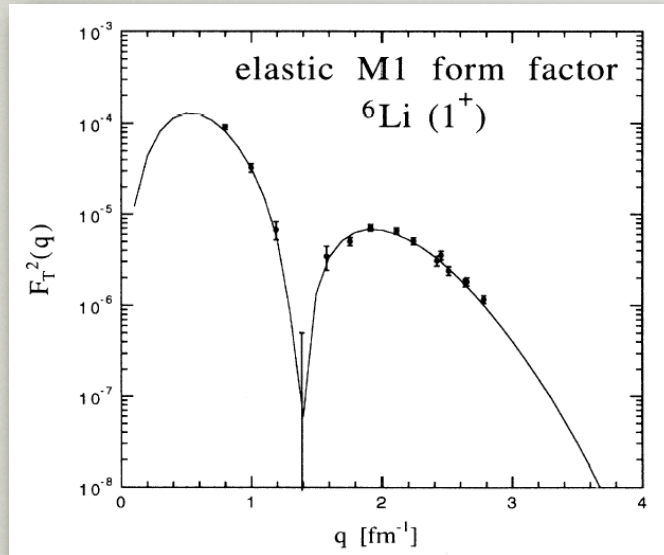
重陽子内の核子運動量密度分布

中心力、テンソル力起源の
S、D波成分
 $T=0, S=1, J=1$ ($L=0, 2$)
 ${}^{13}\text{S}_1 + {}^{13}\text{D}_1$

${}^6\text{Li}$ (1^+)
 $\alpha + \text{'pn'}$ クラスタ構造
 'pn' 系 $\sim {}^{13}\text{S}_1 + {}^{13}\text{D}_1$

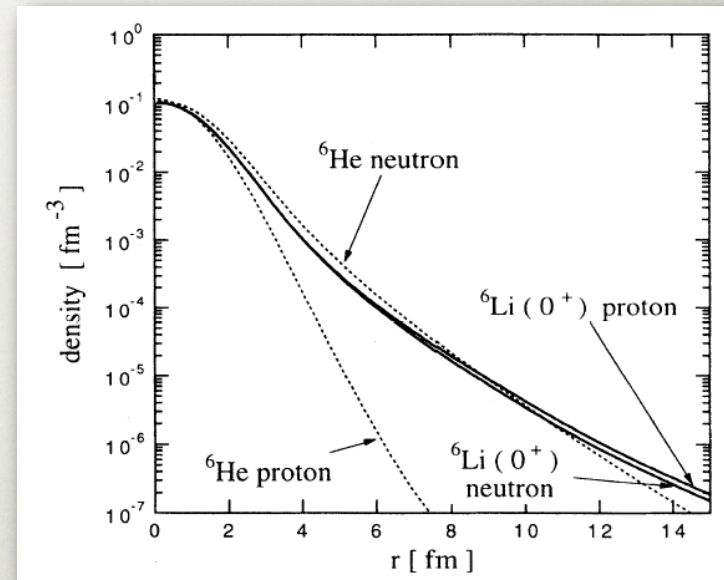


6Li FORM FACTOR



${}^6\text{Li}(0^+)$ 3.56 MeV

isobaric analogue

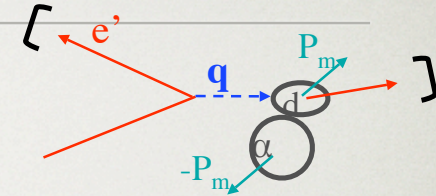


${}^6\text{Li}$ 核中の”重陽子”形状についての実験

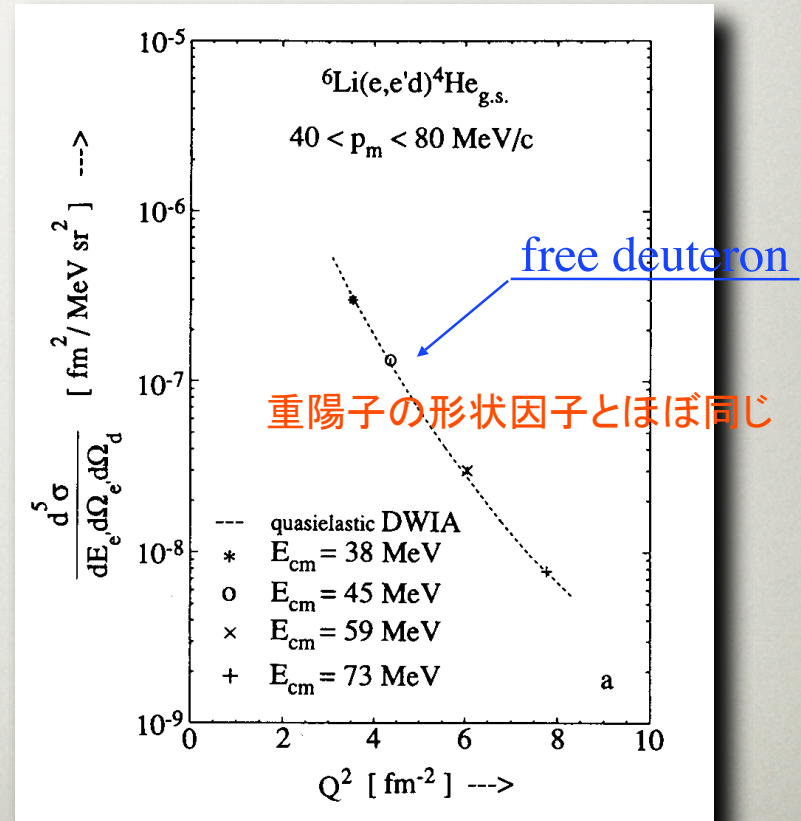
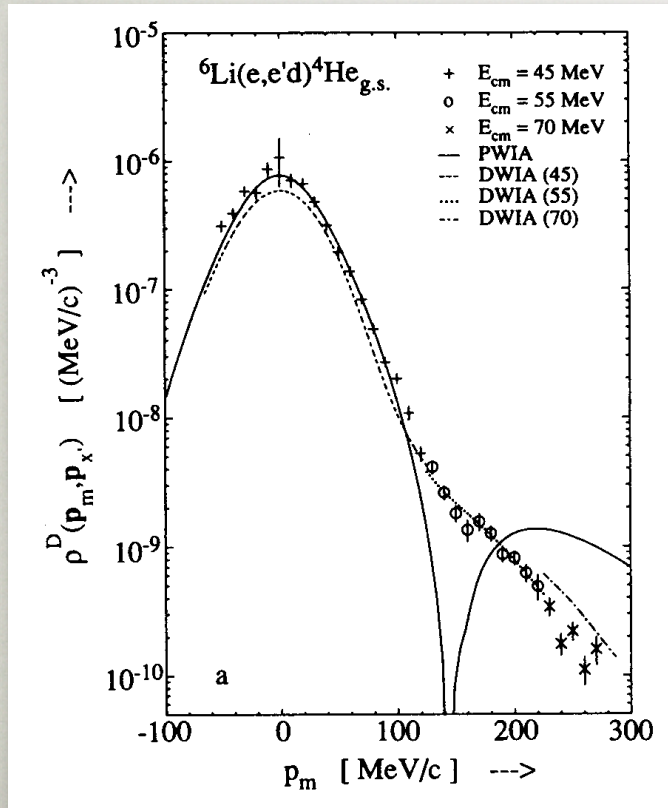
${}^6\text{Li}$ 核内の”重陽子”の運動量分布、”形状因子”

- 準弾性散乱運動学での ${}^6\text{Li}(e, e' d)\alpha$

- ・ 運動量分布 : 核内 d の運動量分布
- ・ 形状因子 : ${}^6\text{Li}$ 核内”重陽子”の大きさ



$$\frac{d^6\sigma}{dp_e dp_d} = K \sigma_{ed}(q) |\phi(p_m)|^2$$



p+' d' , p+' nn' 反応の、幾何学

p+' d' -> p+d



${}^{13}S_1$

${}^{13}S_1$

J=1

J=1

T=0

T=0

Spin

$$\frac{\vec{1}}{2} + \vec{1} \rightarrow \frac{\vec{1}}{2}, \frac{\vec{3}}{2} \rightarrow \frac{\vec{1}}{2} + \vec{1}$$

Isospin

$$\frac{\vec{1}}{2} + 0 \rightarrow \frac{\vec{1}}{2} \rightarrow \frac{\vec{1}}{2} + 0$$

p+' nn' -> n+d



${}^{31}S_0$

${}^{13}S_1$

J=0

J=1

T=1

T=0

Spin

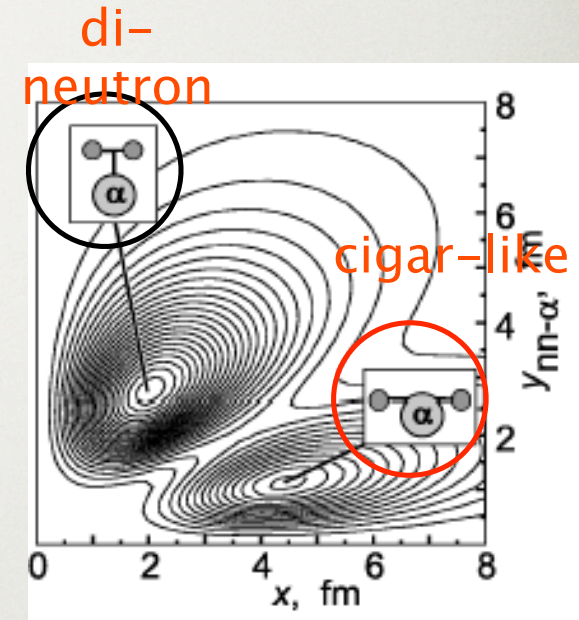
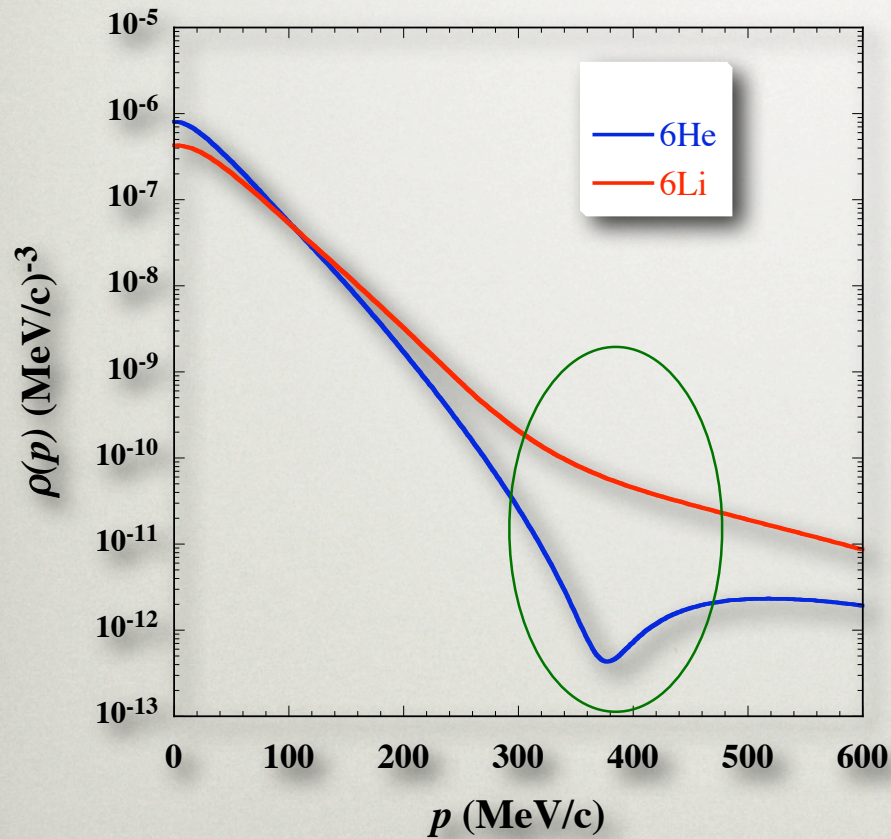
$$\frac{\vec{1}}{2} + 0 \rightarrow \frac{\vec{1}}{2} \rightarrow \frac{\vec{1}}{2} + \vec{1}$$

Isospin

$$\frac{\vec{1}}{2} + \vec{1} \rightarrow \frac{\vec{1}}{2}, \frac{\vec{3}}{2} \rightarrow \frac{\vec{1}}{2} + 0$$

$$\frac{\sigma_{ONE}(p+{}^6He)}{\sigma_{ONE}(p+{}^6Li)} = \frac{S_{{}^6Li(d\alpha)}}{S_{{}^6He(di-neutron)}} \frac{[\rho_{nn}(p)]^2}{[\rho_{pn}(p)]^2}$$

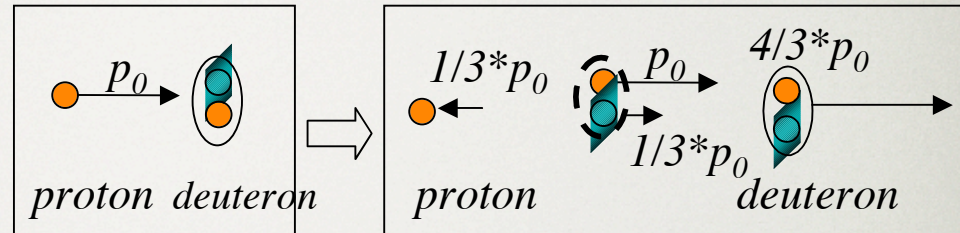
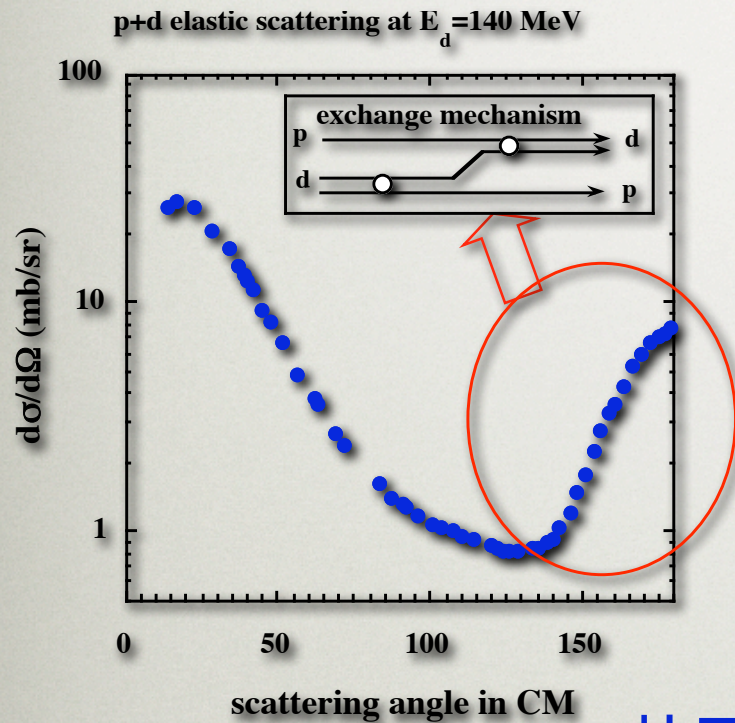
${}^6\text{Li}$, ${}^6\text{He}$ 核内2核子系の相対運動量分布



運動量分布から2中性子の配位の
違いが出せないか？

Di-neutron : at large p region
Cigar-like : at lower p region

p+d 後方弾性散乱 ⇨ 核内核子運動量分布



- 後方での弾性散乱は、
核子交換過程が主 (One Nucleon Exchange : ONE)

PWIA

$$\frac{d\sigma}{d\Omega} \propto \kappa \cdot [\rho(p)]^2 \quad p = \frac{1}{3} p_0$$

核子運動量密度



K. Sekiguchi et al.,
PRC 65,034003,2002

断面積は陽子・中性子間の相対運動量密度で決まる。

p+d 後方散乱 @ $E_p = 70 \text{ MeV}$

$$\theta_p = 150 - 180^\circ$$

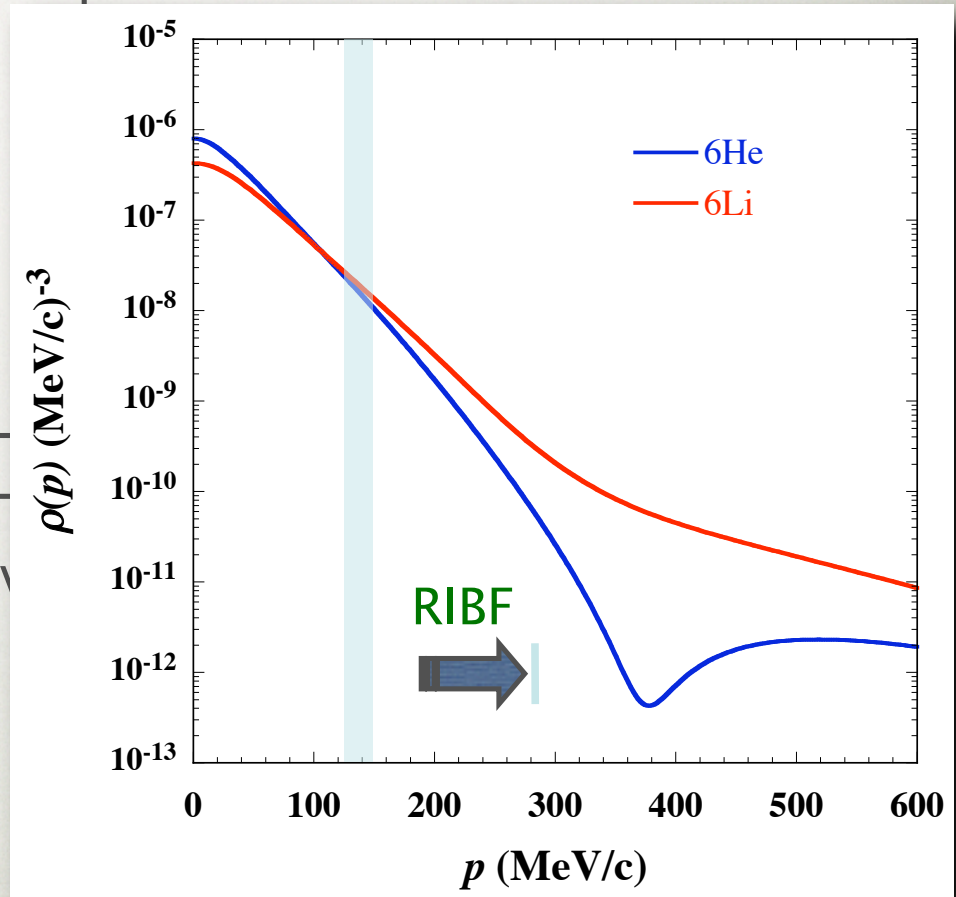
$p+d \rightarrow p+d$
後方では核子交換反応



p+'nn' 後方散乱 @ $E_p = 70 \text{ MeV}$

$$\theta_n = 150 - 180^\circ$$

$p+'nn' \rightarrow n+d$
核子交換反応



核子交換反応 (ONE) 過程断面積の比

$$\frac{\sigma_{\text{ONE}}(p+{}^1nn' \rightarrow nd)}{\sigma_{\text{ONE}}(p+{}^1pn' \rightarrow pd)} \propto \frac{[\rho_{nn}(p)]^2}{[\rho_{pn}(p)]^2}$$

$$\frac{\sigma_{\text{ONE}}(p+{}^1nn' \rightarrow nd)}{\sigma_{\text{ONE}}(p+{}^1pn' \rightarrow pd)} = \frac{|\langle \text{spin} \cdot \text{isospin} \rangle|^2 [\rho_{nn}(p)]^2}{|\langle \text{spin} \cdot \text{isospin} \rangle|^2 [\rho_{pn}(p)]^2}$$

${}^6\text{He}$ 核内 nn 系運動量密度

$$= \frac{|\langle nd | \hat{O} | p(nn) \rangle|^2 [\rho_{nn}(p)]^2}{|\langle pd | \hat{O} | pd \rangle|^2 [\rho_{pn}(p)]^2} = 0.4444 \frac{[\rho_{nn}(p)]^2}{[\rho_{pn}(p)]^2}$$

北大:菊地氏

${}^6\text{Li}$ 核内 pn 系運動量密度

pn,nn系の動径方向の波動関数が同じと仮定 (SpinIsospin CGのみ)

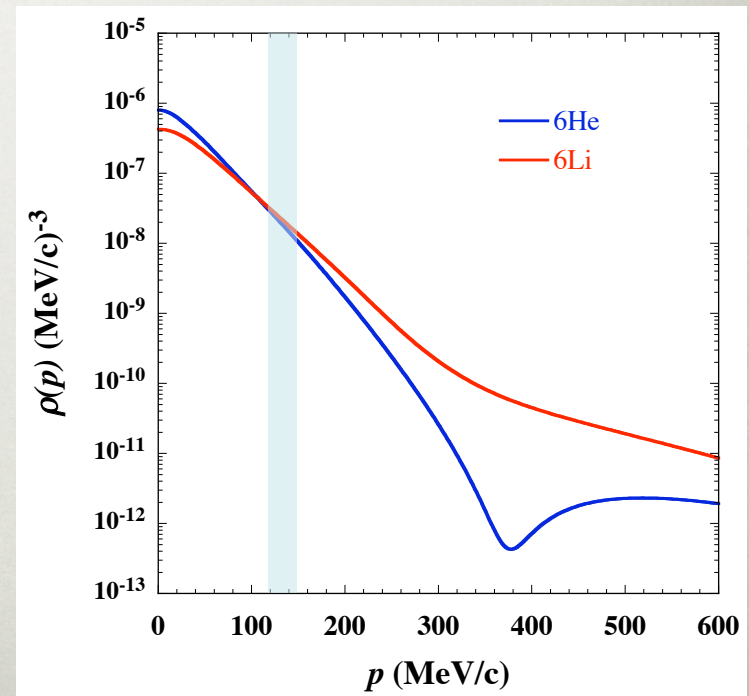
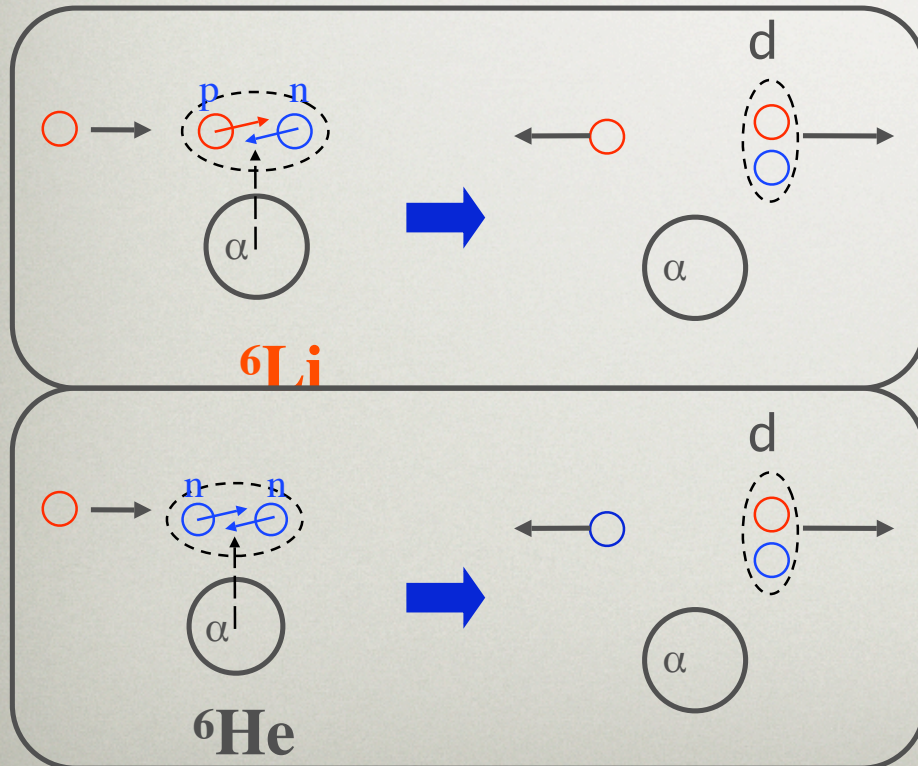
$$\frac{|\langle nd | \hat{O} | p(nn) \rangle|^2}{|\langle pd | \hat{O} | pd \rangle|^2} = 0.4444 \quad \hat{O} = V(\sigma_1 \cdot \sigma_2)(\tau_1 \cdot \tau_2)$$

実験の話の前に、今までの議論をまとめると

1. ${}^6\text{Li}$ 核内の”重陽子”は、自由な重陽子とほぼ同じ大きさ
⇒ 運動量密度分布もほぼ同じ

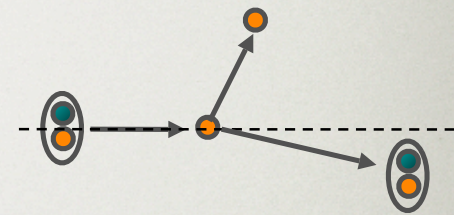
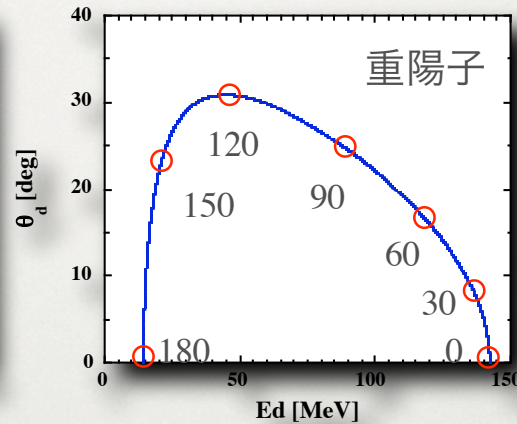
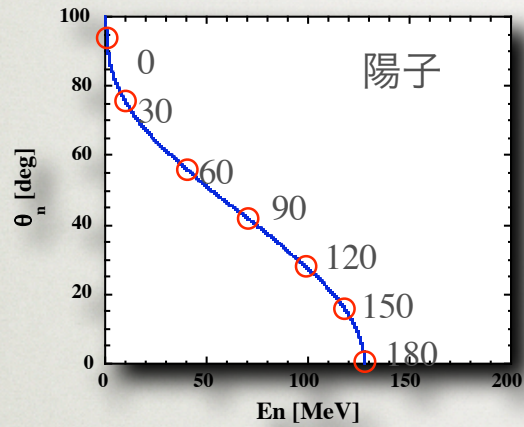
2. $E_p=70\text{MeV}$ での $p+d$ 後方弾性散乱 ($150 \leq \theta \leq 180^\circ$)
⇒ 相対運動量 120 - 150 MeV/cに対応

3. ${}^6\text{He}$ 核内の2中性子の相対運動量分布も同様

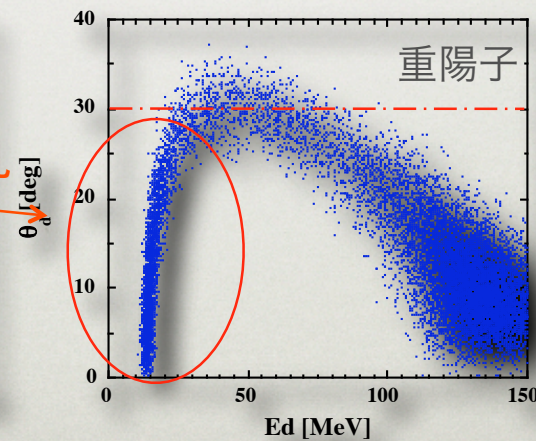
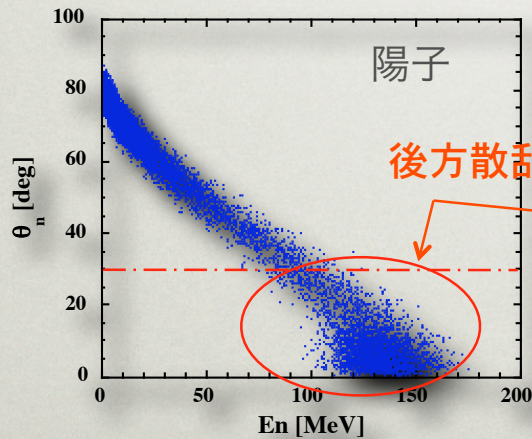


逆運動学での $d+p \rightarrow d+p$ 反応

$E_d = 70\text{MeV}/u$ での運動学



${}^6\text{Li}$ 核内の重陽子 ($d'+p \rightarrow d+p$)



後方散乱 ($\theta_{\text{CM}} \geq 130^\circ$)

$\theta_p \leq 30^\circ, E_p \geq 90 \text{ MeV}$

$\theta_d \leq 30^\circ, 20 \leq E_d \leq 40 \text{ MeV}$

${}^6\text{He}$ 核内のnn系 ($'nn'+p \rightarrow d+n$) も同様な運動学

逆運動学での実験

* 核内2核子系(pn, nn) と、陽子標的との”後方”弾性散乱

“pn” in ${}^6\text{Li}$

逆運動学

Lab系での運動学

運動学的特徴

$\theta_d \sim 30^\circ$ $E_d = 20\text{-}40 \text{ MeV}$
低エネルギー

$\theta_\alpha \sim 5^\circ$ $E_\alpha \sim 70 \text{ MeV}$
~ビーム速度

$\theta_p \sim 30^\circ$ $E_p \sim 140 \text{ MeV}$
ビームより高速

$E({}^6\text{Li}) \sim 70 \text{ MeV}/A$

“nn” in ${}^6\text{He}$

逆運動学

各 θ, E は、上に同じ

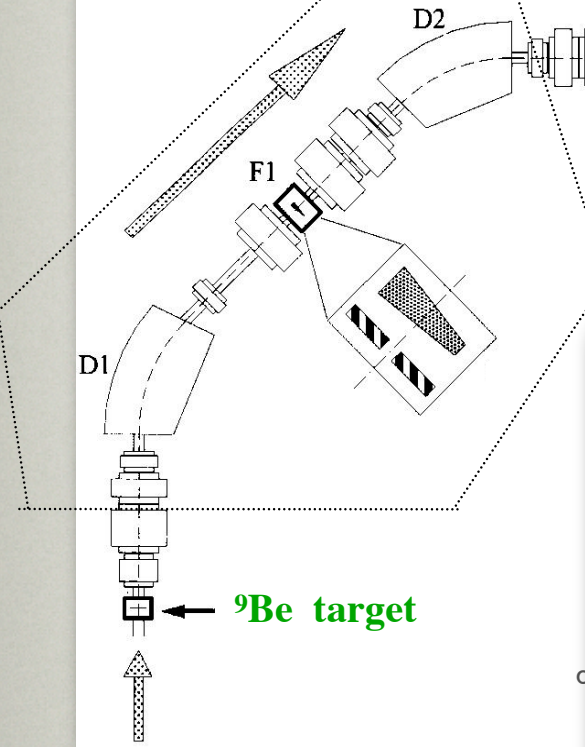
全く同じ実験セットアップで
 ${}^6\text{Li}$ と ${}^6\text{He}$ の比較を
Systematicエラー少なく
行える。

高速中性子

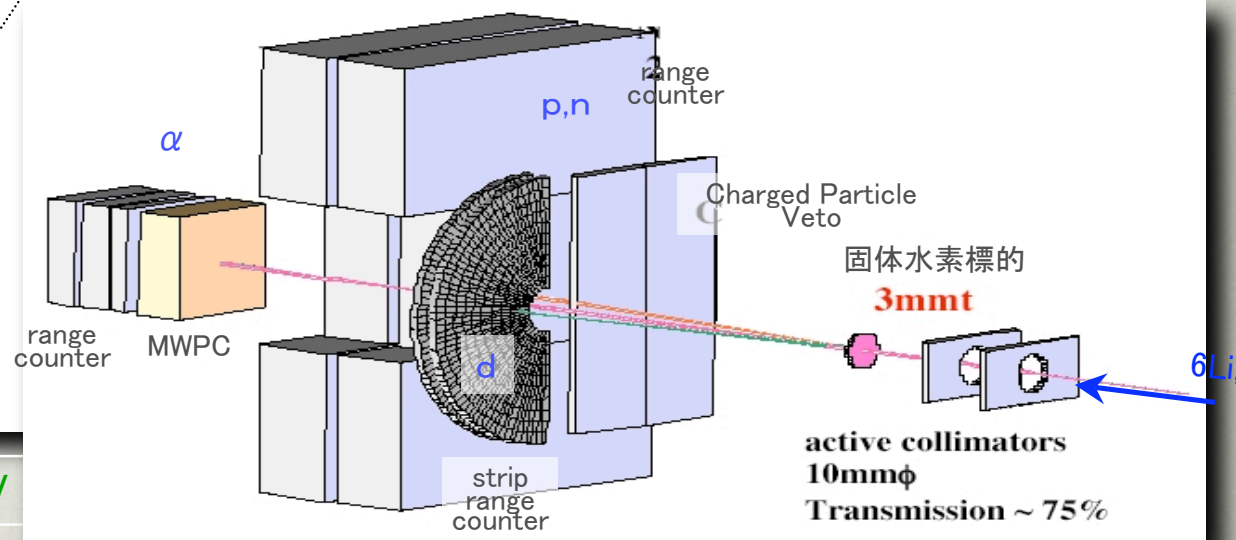
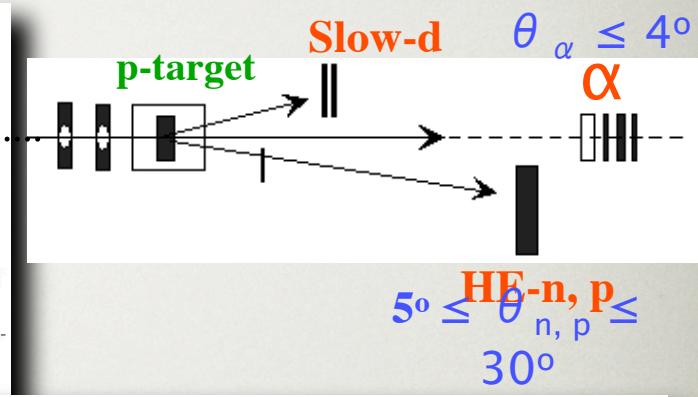
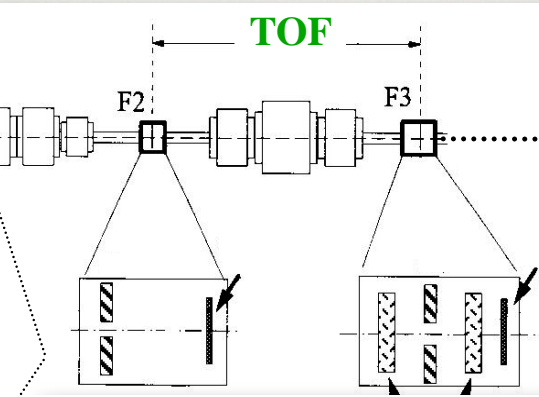
Experimental set-up @ RIPS

$$5^\circ \leq \theta_d \leq 30^\circ$$

${}^6\text{He}$ (${}^6\text{Li}$) secondary beam at 70 A MeV

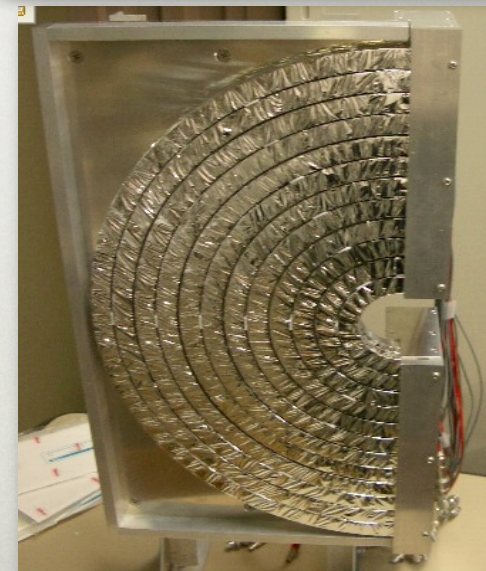
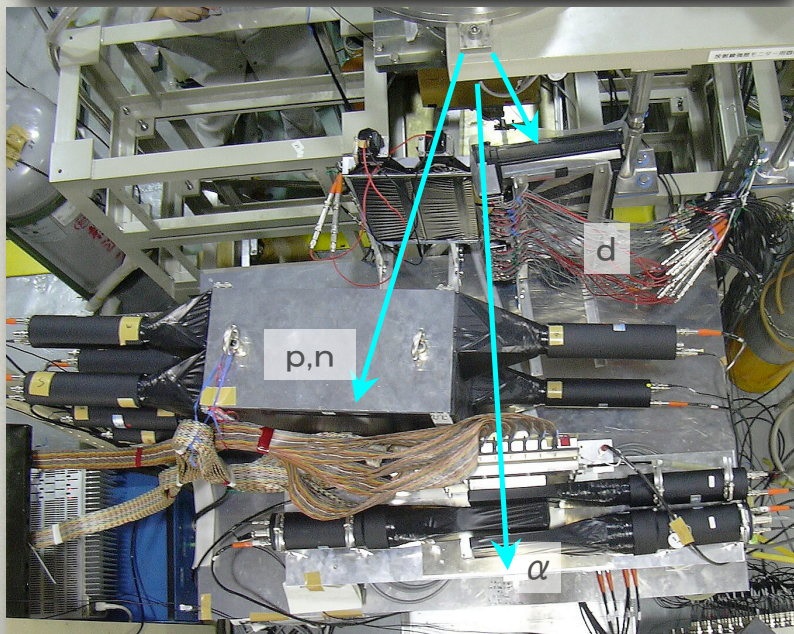
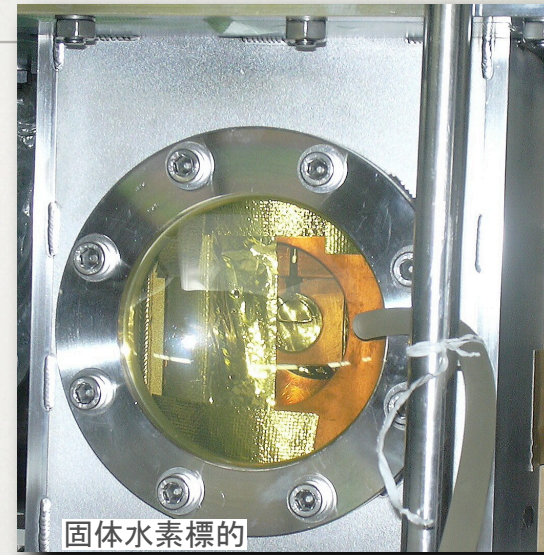
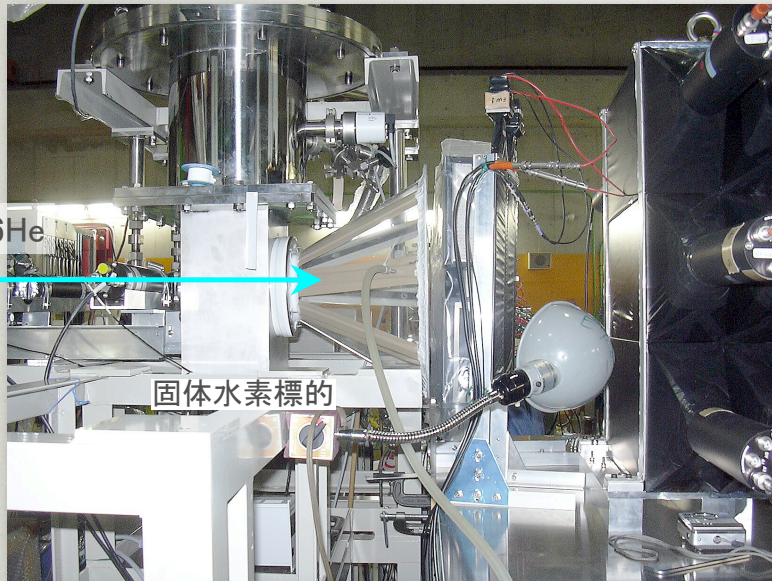


${}^{12}\text{C}$ Primary Beam at 92 A MeV



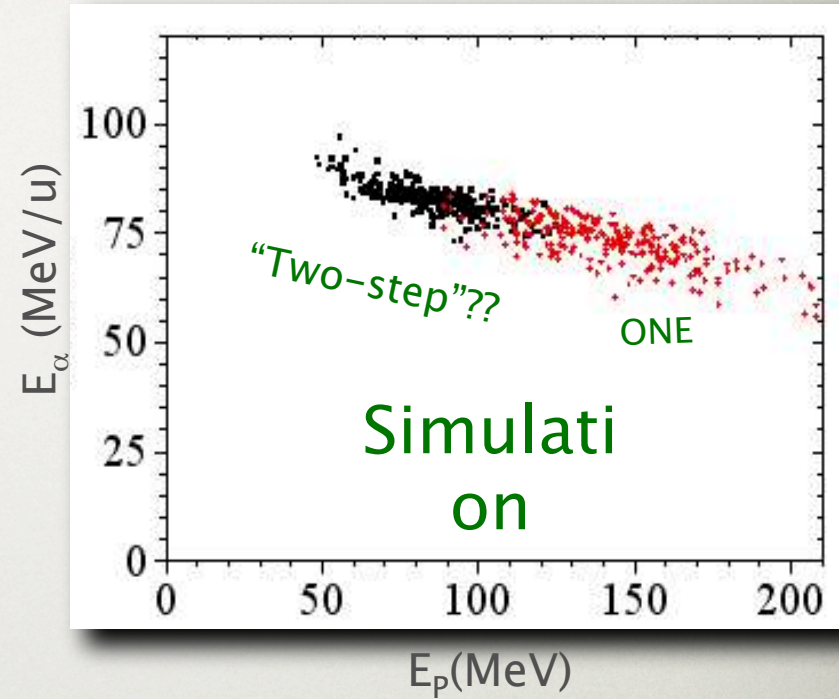
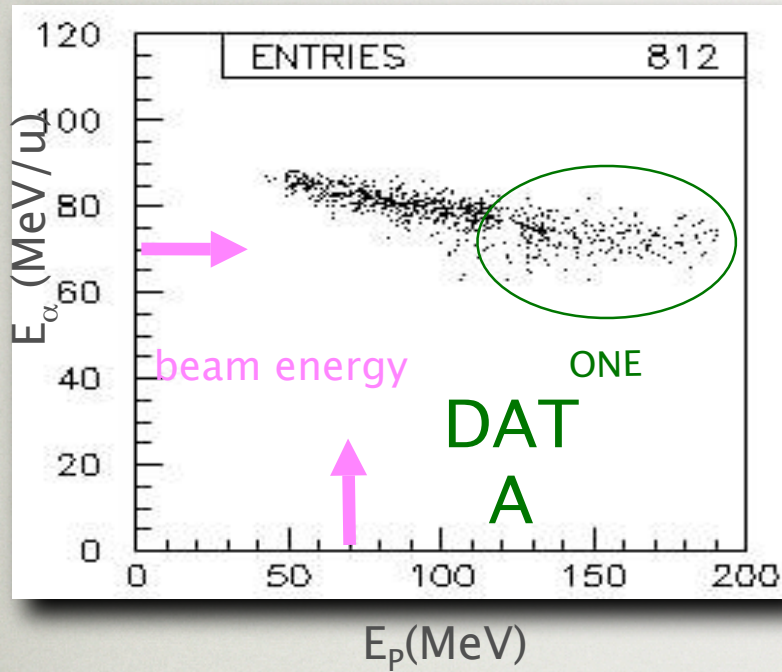
$$N({}^6\text{Li}), N({}^6\text{He}) \sim 10^5 / \text{s}$$

実験装置



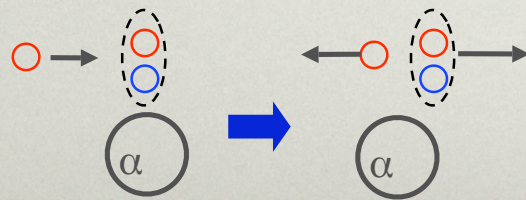
Identification for ONE events

後方散乱事象の運動学に矛盾しない事象

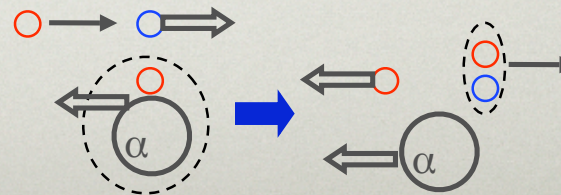


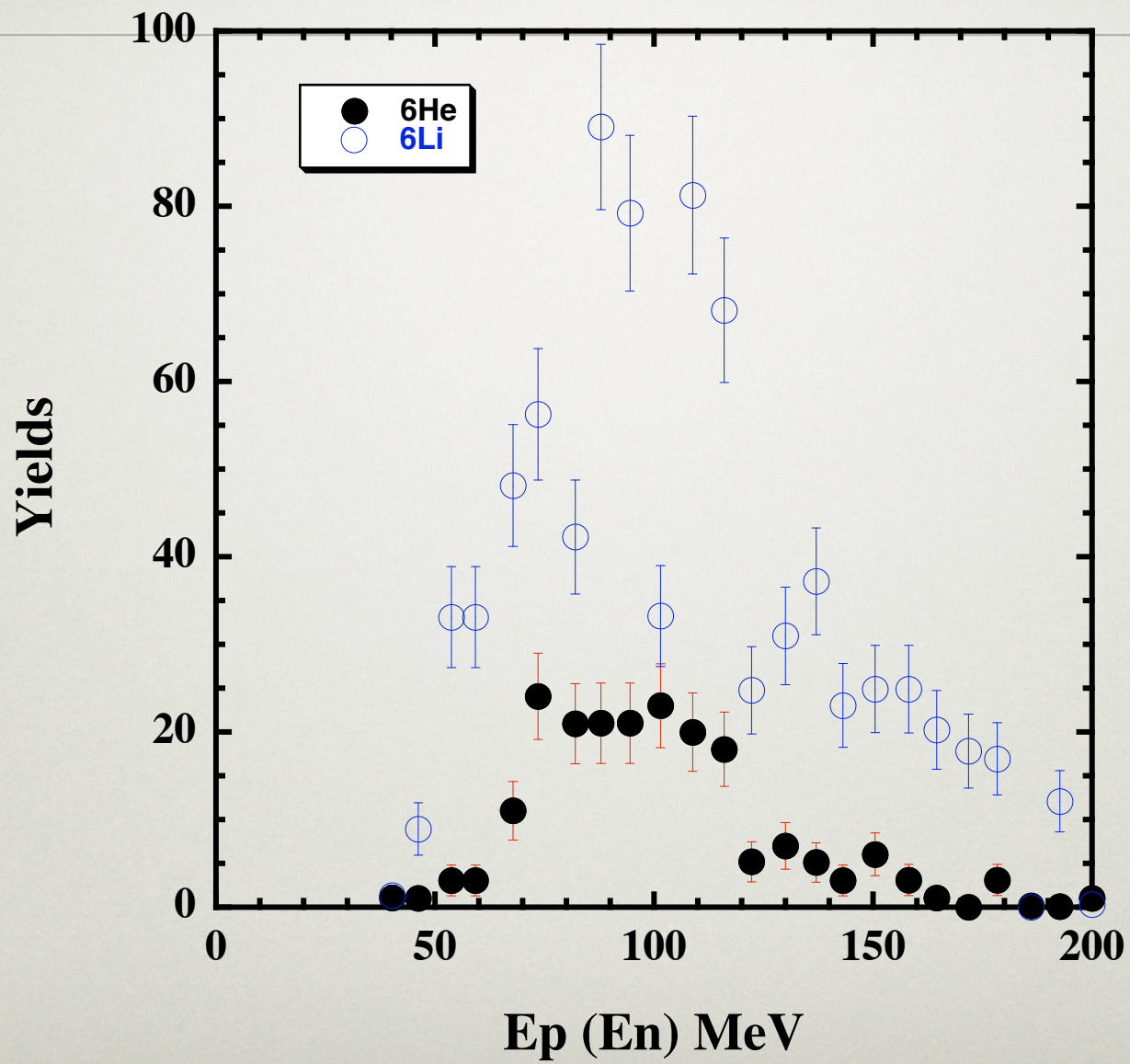
simulations

ONE



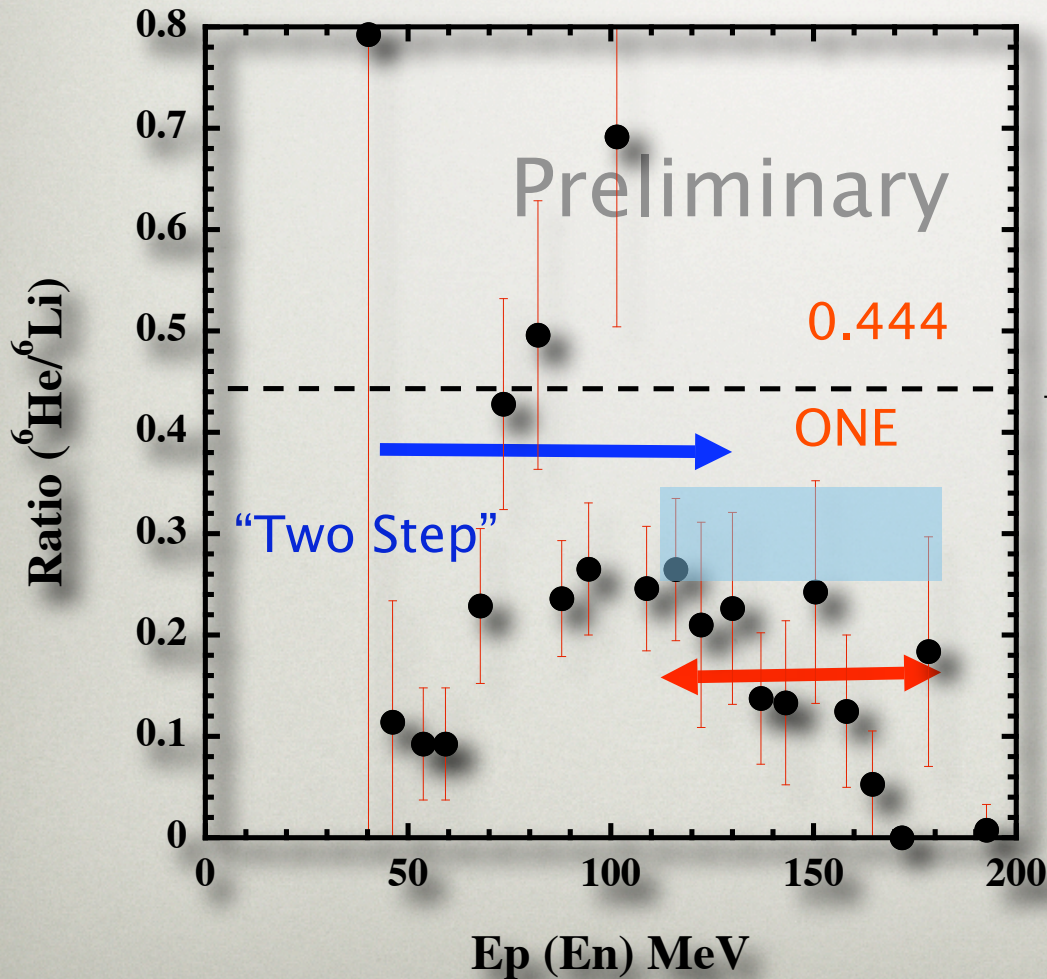
- 1) α does not have spectator-like momentum
- 2) back-scattered proton has lower energy





${}^6\text{He}/{}^6\text{Li}$ Ratio

$$\frac{\sigma_{\text{ONE}}(p+{}^6\text{He} \rightarrow nd)}{\sigma_{\text{ONE}}(p+{}^6\text{He} \rightarrow pd)} = 0.444 \frac{[\rho_{nn}(p)]^2}{[\rho_{pn}(p)]^2}$$



theory

$$\frac{\sigma_{\text{ONE}}(p+{}^6\text{He} \rightarrow nd)}{\sigma_{\text{ONE}}(p+{}^6\text{He} \rightarrow pd)} = 0.35 \sim 0.25$$

$$\left(\frac{\rho_{nn}(p)}{\rho_{pn}(p)} = 0.75 - 0.9 \right)$$

結論

- ・ ${}^6\text{He}$ 及び ${}^6\text{Li}$ 核内の2核子間の相対運動量密度に敏感な反応断面積
 - 後方散乱
 - $p + \text{''nn''} \rightarrow n + d$ for ${}^6\text{He}$
 - $p + \text{''d''} \rightarrow p + d$ for ${}^6\text{Li}$
 - $E_p = 70 \text{ MeV}$
- ・ “核子交換反応”の断面積
 - $\sigma({}^6\text{He})/\sigma({}^6\text{Li}) \sim 0.1-0.2$
- ・ 今後
 - データ解析継続角度分布(核子交換反応)
 - ${}^6\text{He}$ 内2中性子系
 - ・ 配位と運動量分布