核内中間子分光実験

RIKEN Nishina Center,   Kenta Itahashi

NiSHiNA CENTER

核内中間子分光実験

LIGHT UNFLAVORED ($S = C = B = 0$)

	$I^G(J^{PC})$		$I^G(J^{PC})$
• $\pi^\pm$	$1^-(0^-)$	• $\pi_2(1670)$	$1^-(2^{-+})$
• π^0	$1^-(0^{-+})$	• $\phi(1680)$	$0^-(1^{--})$
• η	$0^+(0^{-+})$	• $\rho_3(1690)$	$1^+(3^{--})$
• $f_0(600)$	$0^+(0^{++})$	• $\rho(1700)$	$1^+(1^{--})$
• $\rho(770)$	$1^+(1^{--})$	$a_2(1700)$	$1^-(2^{++})$
• $\omega(782)$	$0^-(1^{--})$	• $f_0(1710)$	$0^+(0^{++})$
• $\eta'(958)$	$0^+(0^{-+})$	$\eta(1760)$	$0^+(0^{-+})$
• $f_0(980)$	$0^+(0^{++})$	• $\pi(1800)$	$1^-(0^{-+})$
• $a_0(980)$	$1^-(0^{++})$	$f_2(1810)$	$0^+(2^{++})$
• $\phi(1020)$	$0^-(1^{--})$	$X(1835)$	$?^?(?^{-+})$
• $h_1(1170)$	$0^-(1^{+-})$	• $\phi_3(1850)$	$0^-(3^{--})$
• $b_1(1235)$	$1^+(1^{+-})$	$\eta_2(1870)$	$0^+(2^{-+})$
• $a_1(1260)$	$1^-(1^{++})$	• $\pi_2(1880)$	$1^-(2^{-+})$
• $f_2(1270)$	$0^+(2^{++})$	$\rho(1900)$	$1^+(1^{--})$
• $f_1(1285)$	$0^+(1^{++})$	$f_2(1910)$	$0^+(2^{++})$
• $\eta(1295)$	$0^+(0^{-+})$	• $f_2(1950)$	$0^+(2^{++})$
• $\pi(1300)$	$1^-(0^{-+})$	$\rho_3(1990)$	$1^+(3^{--})$
• $a_2(1320)$	$1^-(2^{++})$	• $f_2(2010)$	$0^+(2^{++})$
• $f_0(1370)$	$0^+(0^{++})$	$f_0(2020)$	$0^+(0^{++})$
$h_1(1380)$	$?^-(1^{+-})$	• $a_4(2040)$	$1^-(4^{++})$
• $\pi_1(1400)$	$1^-(1^{-+})$	• $f_4(2050)$	$0^+(4^{++})$
• $\eta(1405)$	$0^+(0^{-+})$	$\pi_2(2100)$	$1^-(2^{-+})$
• $f_1(1420)$	$0^+(1^{++})$	$f_0(2100)$	$0^+(0^{++})$
• $\omega(1420)$	$0^-(1^{--})$	$f_2(2150)$	$0^+(2^{++})$
$f_2(1430)$	$0^+(2^{++})$	$\rho(2150)$	$1^+(1^{--})$
• $a_0(1450)$	$1^-(0^{++})$	$\phi(2170)$	$0^-(1^{--})$
• $\rho(1450)$	$1^+(1^{--})$	$f_0(2200)$	$0^+(0^{++})$
• $\eta(1475)$	$0^+(0^{-+})$	$f_J(2220)$	$0^+(2^{++}$ or $4^{++})$
• $f_0(1500)$	$0^+(0^{++})$	$\eta(2225)$	$0^+(0^{-+})$
$f_1(1510)$	$0^+(1^{++})$	$\rho_3(2250)$	$1^+(3^{--})$
• $f_2'(1525)$	$0^+(2^{++})$	• $f_2(2300)$	$0^+(2^{++})$
$f_2(1565)$	$0^+(2^{++})$	$f_4(2300)$	$0^+(4^{++})$
$\rho(1570)$	$1^+(1^{--})$	$f_0(2330)$	$0^+(0^{++})$
$h_1(1595)$	$0^-(1^{+-})$	• $f_2(2340)$	$0^+(2^{++})$
• $\pi_1(1600)$	$1^-(1^{-+})$	$\rho_5(2350)$	$1^+(5^{--})$
$a_1(1640)$	$1^-(1^{++})$	$a_6(2450)$	$1^-(6^{++})$
$f_2(1640)$	$0^+(2^{++})$	$f_6(2510)$	$0^+(6^{++})$
• $\eta_2(1645)$	$0^+(2^{-+})$	**OTHER LIGHT**	
• $\omega(1650)$	$0^-(1^{--})$	Further States	
• $\omega_3(1670)$	$0^-(3^{--})$		

STRANGE ($S = \pm1$, $C = B = 0$)

	$I(J^P)$
• $K^\pm$	$1/2(0^-)$
• K^0	$1/2(0^-)$
• K^0_S	$1/2(0^-)$
• K^0_L	$1/2(0^-)$
$K^*_0(800)$	$1/2(0^+)$
• $K^*(892)$	$1/2(1^-)$
• $K_1(1270)$	$1/2(1^+)$
• $K_1(1400)$	$1/2(1^+)$
• $K^*(1410)$	$1/2(1^-)$
• $K^*_0(1430)$	$1/2(0^+)$
• $K^*_2(1430)$	$1/2(2^+)$
$K(1460)$	$1/2(0^-)$
$K_2(1580)$	$1/2(2^-)$
$K(1630)$	$1/2(?^?)$
$K_1(1650)$	$1/2(1^+)$
• $K^*(1680)$	$1/2(1^-)$
• $K_2(1770)$	$1/2(2^-)$
• $K^*_3(1780)$	$1/2(3^-)$
• $K_2(1820)$	$1/2(2^-)$
$K(1830)$	$1/2(0^-)$
$K^*_0(1950)$	$1/2(0^+)$
$K^*_2(1980)$	$1/2(2^+)$
• $K^*_4(2045)$	$1/2(4^+)$
$K_2(2250)$	$1/2(2^-)$
$K_3(2320)$	$1/2(3^+)$
$K^*_5(2380)$	$1/2(5^-)$
$K_4(2500)$	$1/2(4^-)$
$K(3100)$	$?^?(?^{??})$

CHARMED ($C = \pm1$)

• $D^\pm$	$1/2(0^-)$
• D^0	$1/2(0^-)$
• $D^*(2007)^0$	$1/2(1^-)$
• $D^*(2010)^\pm$	$1/2(1^-)$
$D^*_0(2400)^0$	$1/2(0^+)$
$D^*_0(2400)^\pm$	$1/2(0^+)$
• $D_1(2420)^0$	$1/2(1^+)$
$D_1(2420)^\pm$	$1/2(?^?)$
$D_1(2430)^0$	$1/2(1^+)$
• $D^*_2(2460)^0$	$1/2(2^+)$
• $D^*_2(2460)^\pm$	$1/2(2^+)$
$D^*(2640)^\pm$	$1/2(?^?)$

CHARMED, STRANGE ($C = S = \pm1$)

	$I(J^P)$
• $D_s^\pm$	$0(0^-)$
• $D_s^{*\pm}$	$0(?^?)$
• $D^*_{s0}(2317)^\pm$	$0(0^+)$
• $D_{s1}(2460)^\pm$	$0(1^+)$
• $D_{s1}(2536)^\pm$	$0(1^+)$
• $D_{s2}(2573)^\pm$	$0(?^?)$
$D_{s1}(2700)^\pm$	$0(1^-)$

BOTTOM ($B = \pm1$)

• $B^\pm$	$1/2(0^-)$
• B^0	$1/2(0^-)$
• $B^\pm/B^0$ ADMIXTURE	
• $B^\pm/B^0/B^0_s/b$-baryon ADMIXTURE	
V_{cb} and V_{ub} CKM Matrix Elements	
• B^*	$1/2(1^-)$
$B^*_J(5732)$	$?(?^?)$
• $B_1(5721)^0$	$1/2(1^+)$
• $B^*_2(5747)^0$	$1/2(2^+)$

BOTTOM, STRANGE ($B = \pm1$, $S = \mp1$)

• B^0_s	$0(0^-)$
• B^*_s	$0(1^-)$
• $B_{s1}(5830)^0$	$1/2(1^+)$
• $B^*_{s2}(5840)^0$	$1/2(2^+)$
$B^*_{sJ}(5850)$	$?(?^?)$

BOTTOM, CHARMED ($B = C = \pm1$)

• $B^\pm_c$	$0(0^-)$

$c\bar{c}$

	$I^G(J^{PC})$
• $\eta_c(1S)$	$0^+(0^{-+})$
• $J/\psi(1S)$	$0^-(1^{--})$
• $\chi_{c0}(1P)$	$0^+(0^{++})$
• $\chi_{c1}(1P)$	$0^+(1^{++})$
• $h_c(1P)$	$?^?(1^{+-})$
• $\chi_{c2}(1P)$	$0^+(2^{++})$
• $\eta_c(2S)$	$0^+(0^{-+})$
• $\psi(2S)$	$0^-(1^{--})$
• $\psi(3770)$	$0^-(1^{--})$
• $X(3872)$	$0^?(?^{?+})$
$\chi_{c2}(2P)$	$0^+(2^{++})$
$X(3940)$	$?^?(?^{??})$
$X(3945)$	$?^?(?^{??})$
• $\psi(4040)$	$0^-(1^{--})$
• $\psi(4160)$	$0^-(1^{--})$
• $X(4260)$	$?^?(1^{--})$
$X(4360)$	$?^?(1^{--})$
• $\psi(4415)$	$0^-(1^{--})$

$b\bar{b}$

$\eta_b(1S)$	$0^+(0^{-+})$
• $\Upsilon(1S)$	$0^-(1^{--})$
• $\chi_{b0}(1P)$	$0^+(0^{++})$
• $\chi_{b1}(1P)$	$0^+(1^{++})$
• $\chi_{b2}(1P)$	$0^+(2^{++})$
• $\Upsilon(2S)$	$0^-(1^{--})$
$\Upsilon(1D)$	$0^-(2^{--})$
• $\chi_{b0}(2P)$	$0^+(0^{++})$
• $\chi_{b1}(2P)$	$0^+(1^{++})$
• $\chi_{b2}(2P)$	$0^+(2^{++})$
• $\Upsilon(3S)$	$0^-(1^{--})$
• $\Upsilon(4S)$	$0^-(1^{--})$
• $\Upsilon(10860)$	$0^-(1^{--})$
• $\Upsilon(11020)$	$0^-(1^{--})$

NON-$q\bar{q}$ CANDIDATES

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LIGHT UNFLAVORED ($S=C=B=0$)	$I^G(J^{PC})$		$I^G(J^{PC})$	STRANGE ($S=\pm1, C=B=0$)	$I(J^P)$	CHARMED, STRANGE ($C=S=\pm1$)	$I(J^P)$	$c\bar{c}$	$I^G(J^{PC})$
• $\pi^\pm$	$1^-(0^-)$	• $\pi_2(1670)$	$1^-(2^{-+})$	• $K^\pm$	$1/2(0^-)$	• $D_s^\pm$	$0(0^-)$	• $\eta_c(1S)$	$0^+(0^{-+})$
• π^0	$1^-(0^{-+})$	• $\phi(1680)$	$0^-(1^{--})$	• K^0	$1/2(0^-)$	• $D_s^{*\pm}$	$0(?^?)$	• $J/\psi(1S)$	$0^-(1^{--})$
• η	$0^+(0^{-+})$	• $\rho_3(1690)$	$1^+(3^{--})$	• K_S^0	$1/2(0^-)$	• $D_{s0}^*(2317)^\pm$	$0(0^+)$	• $\chi_{c0}(1P)$	$0^+(0^{++})$
• $f_0(600)$	$0^+(0^{++})$	• $\rho(1700)$	$1^+(1^{--})$	• K_L^0	$1/2(0^-)$	• $D_{s1}(2460)^\pm$	$0(1^+)$	• $\chi_{c1}(1P)$	$0^+(1^{++})$
• $\rho(770)$	$1^+(1^{--})$	$a_2(1700)$	$1^-(2^{++})$	$K_0^*(800)$	$1/2(0^+)$	• $D_{s1}(2536)^\pm$	$0(1^+)$	• $h_c(1P)$	$?^?(1^{+-})$
• $\omega(782)$	$0^-(1^{--})$	• $f_0(1710)$	$0^+(0^{++})$	• $K^*(892)$	$1/2(1^-)$	• $D_{s2}(2573)^\pm$	$0(?^?)$	• $\chi_{c2}(1P)$	$0^+(2^{++})$
• $\eta'(958)$	$0^+(0^{-+})$	$\eta(1760)$	$0^+(0^{-+})$	• $K_1(1270)$	$1/2(1^+)$	$D_{s1}(2700)^\pm$	$0(1^-)$	• $\eta_c(2S)$	$0^+(0^{-+})$
• $f_0(980)$	$0^+(0^{++})$	• $\pi(1800)$	$1^-(0^{-+})$	• $K_1(1400)$	$1/2(1^+)$			• $\psi(2S)$	$0^-(1^{--})$
• $a_0(980)$	$1^-(0^{++})$	$f_2(1810)$	$0^+(2^{++})$	• $K^*(1410)$	$1/2(1^-)$	BOTTOM		• $\psi(3770)$	$0^-(1^{--})$
								• $X(3872)$	$0^?(?^{?+})$

S — σ: CB, TAPS, CHAOS
PS — π: PSI, GSI
K: E471,549,570
η: COSY, CB
V — ρ, ω, Φ: TAGX, E325, CLAS, TAPS

$\rho(1570)$	$1^+(1^{--})$	$f_0(2330)$	$0^+(0^{++})$	• D^0	$1/2(0^-)$			• $\Upsilon(11020)$	$0^-(1^{--})$
$h_1(1595)$	$0^-(1^{+-})$	• $f_2(2340)$	$0^+(2^{++})$	• $D^*(2007)^0$	$1/2(1^-)$			NON-$q\bar{q}$ CANDIDATES	
• $\pi_1(1600)$	$1^-(1^{-+})$	$\rho_5(2350)$	$1^+(5^{--})$	• $D^*(2010)^\pm$	$1/2(1^-)$			NON-$q\bar{q}$ CANDI-DATES	
$a_1(1640)$	$1^-(1^{++})$	$a_6(2450)$	$1^-(6^{++})$	$D_0^*(2400)^0$	$1/2(0^+)$				
$f_2(1640)$	$0^+(2^{++})$	$f_6(2510)$	$0^+(6^{++})$	$D_0^*(2400)^\pm$	$1/2(0^+)$				
• $\eta_2(1645)$	$0^+(2^{-+})$	OTHER LIGHT		• $D_1(2420)^0$	$1/2(1^+)$				
• $\omega(1650)$	$0^-(1^{--})$	Further States		$D_1(2420)^\pm$	$1/2(?^?)$				
• $\omega_3(1670)$	$0^-(3^{--})$			$D_1(2430)^0$	$1/2(1^+)$				
				• $D_2^*(2460)^0$	$1/2(2^+)$				
				• $D_2^*(2460)^\pm$	$1/2(2^+)$				
				$D^*(2640)^\pm$	$1/2(?^?)$				

Hadron properties in the nuclear medium.
Ryugo S. Hayano, Tetsuo Hatsuda (Tokyo U.) . Dec 2008. 40pp.
Submitted to Rev.Mod.Phys.
e-Print: arXiv:0812.1702 [nucl-ex]

2007 野海研究会「J-PARC ハドロン実験施設のビームライン整備拡充に向けて」

Chiral Restoration of Hadrons in Nuclear Medium

電子対測定実験(E16)と高運動量ビームライン	理研	四日市悟
J-PARCにおけるΦ中間子原子核探索実験	理研	大西宏明
$\pi^-p \rightarrow \omega n$反応を用いたω束縛系と質量の同時測定実験の提案	東京大理	小沢恭一郎
Rough Idea ofK^++A→K^*+X Experiments	東北大理	金田雅司
In Medium N*(1535) Spectroscopy	理研	板橋健太
K1.1での実験計画	理研	應田治彦

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LIGHT UNFLAVORED ($S=C=B=0$)	$I^G(J^{PC})$		$I^G(J^{PC})$	STRANGE ($S=\pm1, C=B=0$)	$I(J^P)$	CHARMED, STRANGE ($C=S=\pm1$)	$I(J^P)$	$c\bar{c}$	$I^G(J^{PC})$
• $\pi^\pm$	$1^-(0^-)$	• $\pi_2(1670)$	$1^-(2^{-+})$	• $K^\pm$	$1/2(0^-)$	• $D_s^\pm$	$0(0^-)$	• $\eta_c(1S)$	$0^+(0^{-+})$
• π^0	$1^-(0^{-+})$	• $\phi(1680)$	$0^-(1^{--})$	• K^0	$1/2(0^-)$	• $D_s^{*\pm}$	$0(?^?)$	• $J/\psi(1S)$	$0^-(1^{--})$
• η	$0^+(0^{-+})$	• $\rho_3(1690)$	$1^+(3^{--})$	• K_S^0	$1/2(0^-)$	• $D_{s0}^*(2317)^\pm$	$0(0^+)$	• $\chi_{c0}(1P)$	$0^+(0^{++})$
• $f_0(600)$	$0^+(0^{++})$	• $\rho(1700)$	$1^+(1^{--})$	• K_L^0	$1/2(0^-)$	• $D_{s1}(2460)^\pm$	$0(1^+)$	• $\chi_{c1}(1P)$	$0^+(1^{++})$
• $\rho(770)$	$1^+(1^{--})$	$a_2(1700)$	$1^-(2^{++})$	$K_0^*(800)$	$1/2(0^+)$	• $D_{s1}(2536)^\pm$	$0(1^+)$	• $h_c(1P)$	$?^?(1^{+-})$
• $\omega(782)$	$0^-(1^{--})$	• $f_0(1710)$	$0^+(0^{++})$	• $K^*(892)$	$1/2(1^-)$	• $D_{s2}(2573)^\pm$	$0(?^?)$	• $\chi_{c2}(1P)$	$0^+(2^{++})$
• $\eta'(958)$	$0^+(0^{-+})$	$\eta(1760)$	$0^+(0^{-+})$	• $K_1(1270)$	$1/2(1^+)$	$D_{s1}(2700)^\pm$	$0(1^-)$	• $\eta_c(2S)$	$0^+(0^{-+})$
• $f_0(980)$	$0^+(0^{++})$	• $\pi(1800)$	$1^-(0^{-+})$	• $K_1(1400)$	$1/2(1^+)$	BOTTOM		• $\psi(2S)$	$0^-(1^{--})$
• $a_0(980)$	$1^-(0^{++})$	$f_2(1810)$	$0^+(2^{++})$	• $K^*(1410)$	$1/2(1^-)$			• $\psi(3770)$	$0^-(1^{--})$
								• $X(3872)$	$0^?(?^{?+})$

S — σ: CB, TAPS, CHAOS

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$\rho(1570)$	$1^+(1^{--})$	$f_0(2330)$	$0^+(0^{++})$	• D^0	$1/2(0^-)$			• $\Upsilon(11020)$	$0^-(1^{--})$
$h_1(1595)$	$0^-(1^{+-})$	• $f_2(2340)$	$0^+(2^{++})$	• $D^*(2007)^0$	$1/2(1^-)$			NON-$q\bar{q}$ CANDIDATES	
• $\pi_1(1600)$	$1^-(1^{-+})$	$\rho_5(2350)$	$1^+(5^{--})$	• $D^*(2010)^\pm$	$1/2(1^-)$			NON-$q\bar{q}$ CANDI-DATES	
$a_1(1640)$	$1^-(1^{++})$	$a_6(2450)$	$1^-(6^{++})$	$D_0^*(2400)^0$	$1/2(0^+)$				
$f_2(1640)$	$0^+(2^{++})$	$f_6(2510)$	$0^+(6^{++})$	$D_0^*(2400)^\pm$	$1/2(0^+)$				
• $\eta_2(1645)$	$0^+(2^{-+})$	OTHER LIGHT		• $D_1(2420)^0$	$1/2(1^+)$				
• $\omega(1650)$	$0^-(1^{--})$	Further States		$D_1(2420)^\pm$	$1/2(?^?)$				
• $\omega_3(1670)$	$0^-(3^{--})$			$D_1(2430)^0$	$1/2(1^+)$				
				• $D_2^*(2460)^0$	$1/2(2^+)$				
				• $D_2^*(2460)^\pm$	$1/2(2^+)$				
				$D^*(2640)^\pm$	$1/2(?^?)$				

動機

・中間子—原子核相互作用

・カイラル対称性の破れに伴うハドロン質量獲得のシナリオを裏付ける

Hadron properties in the nuclear medium.
Ryugo S. Hayano, Tetsuo Hatsuda (Tokyo U.) . Dec 2008. 40pp.
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π-nucleus 相互作用

Strong interaction optical potential

$U_{opt} = V_{s\text{-wave}} + V_{p\text{-wave}}$

scattering experiment

$V_{s\text{-wave}} = b_0\,\rho(r) + b_1\Delta\rho(r) + B_0\rho^2(r)$

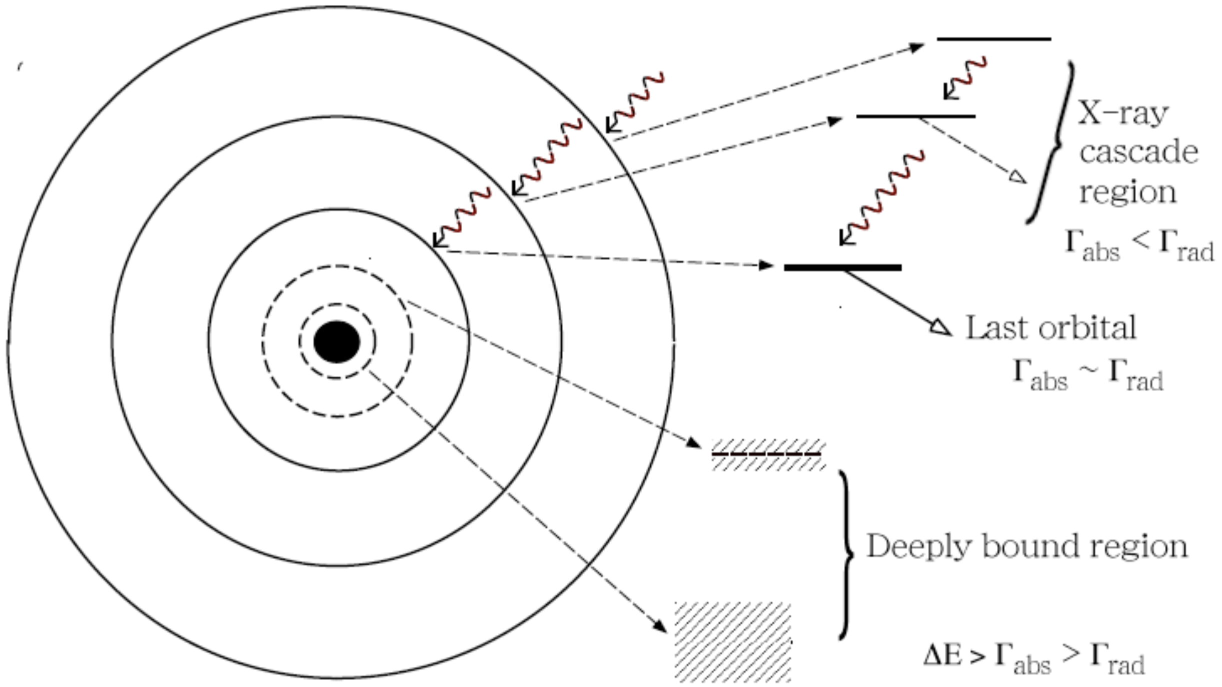
$\rho(r)=\rho_n(r)+\rho_p(r)$ =nuclear density

$\Delta\rho(r)=\rho_n(r)-\rho_p(r)$

b_0 isoscalar part parameter

b_1 isovector part parameter

X線測定



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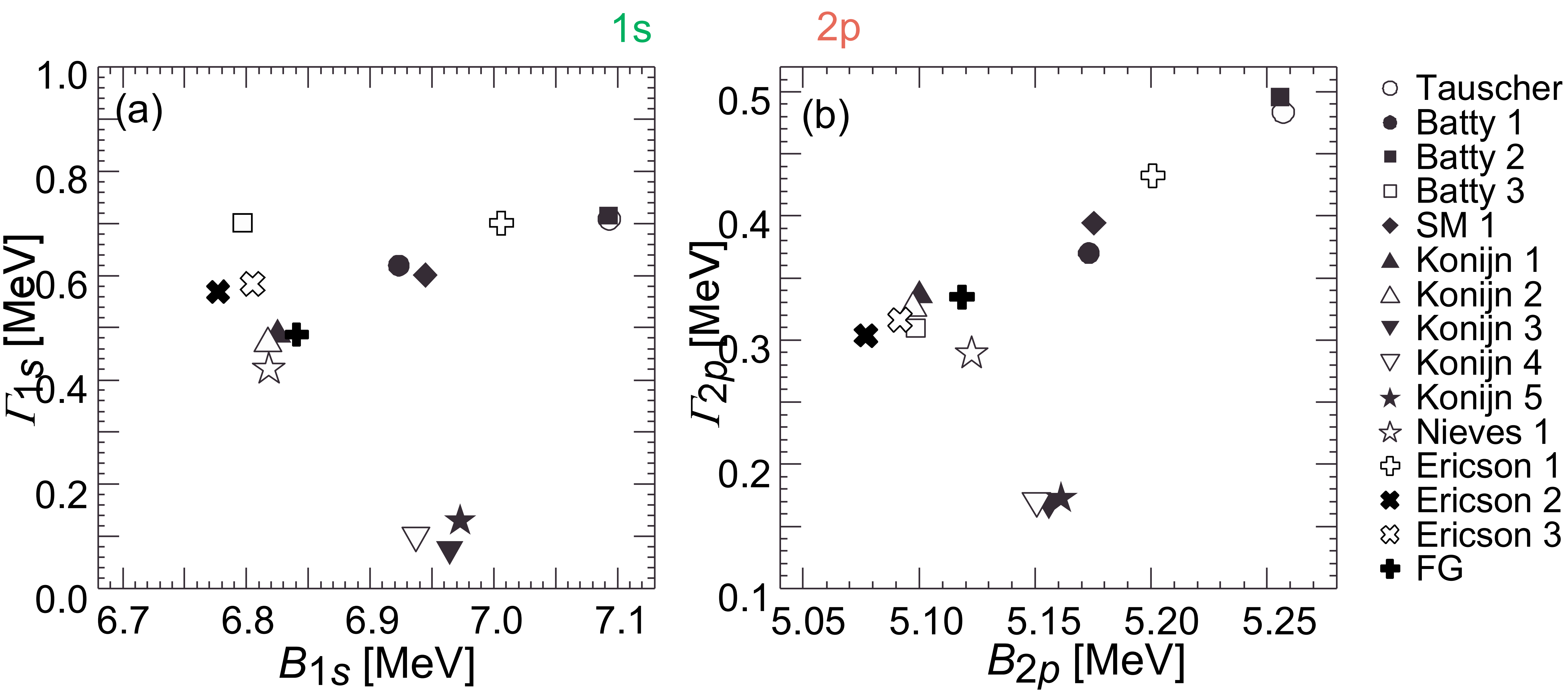
π鉛の理論計算

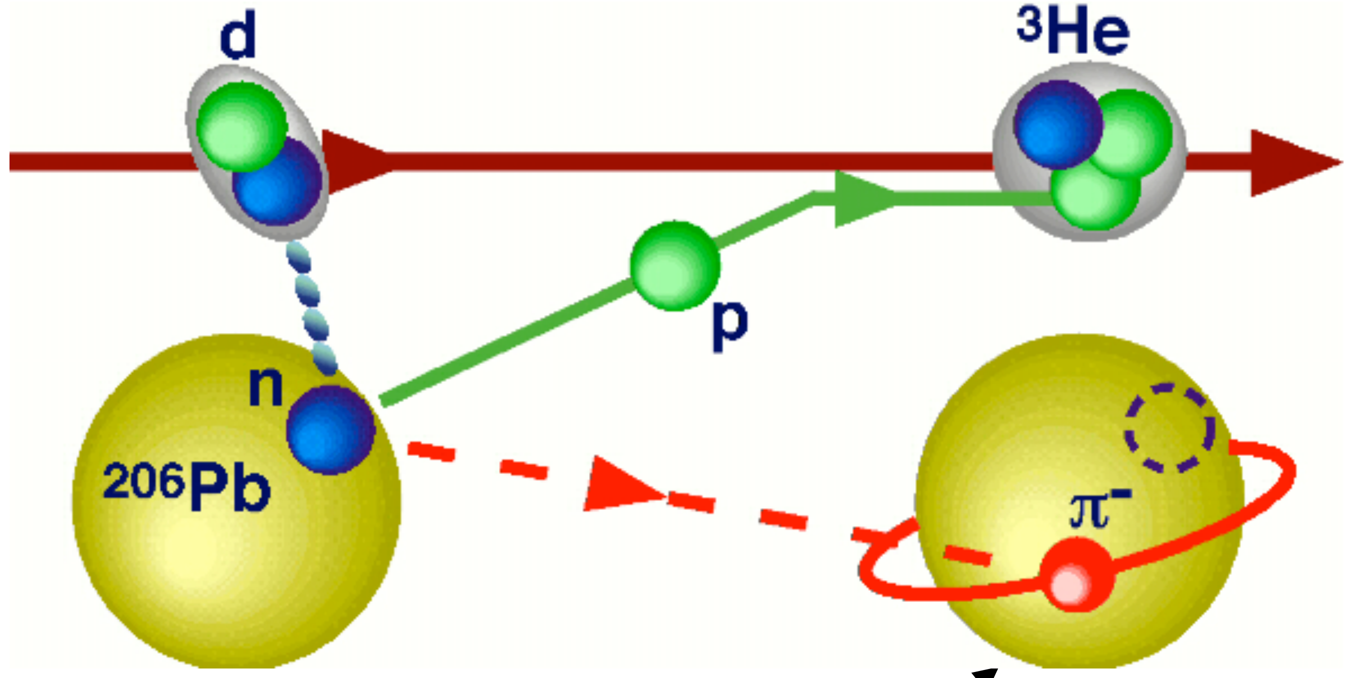

1s
2p
(a)
(b)
1.0
0.8
0.6
0.4
0.2
0.0
6.7
6.8
6.9
7.0
7.1
Γ_{1s} [MeV]
B_{1s} [MeV]
0.5
0.4
0.3
0.2
0.1
5.05
5.10
5.15
5.20
5.25
Γ_{2p} [MeV]
B_{2p} [MeV]
Tauscher
Batty 1
Batty 2
Batty 3
SM 1
Konijn 1
Konijn 2
Konijn 3
Konijn 4
Konijn 5
Nieves 1
Ericson 1
Ericson 2
Ericson 3
FG

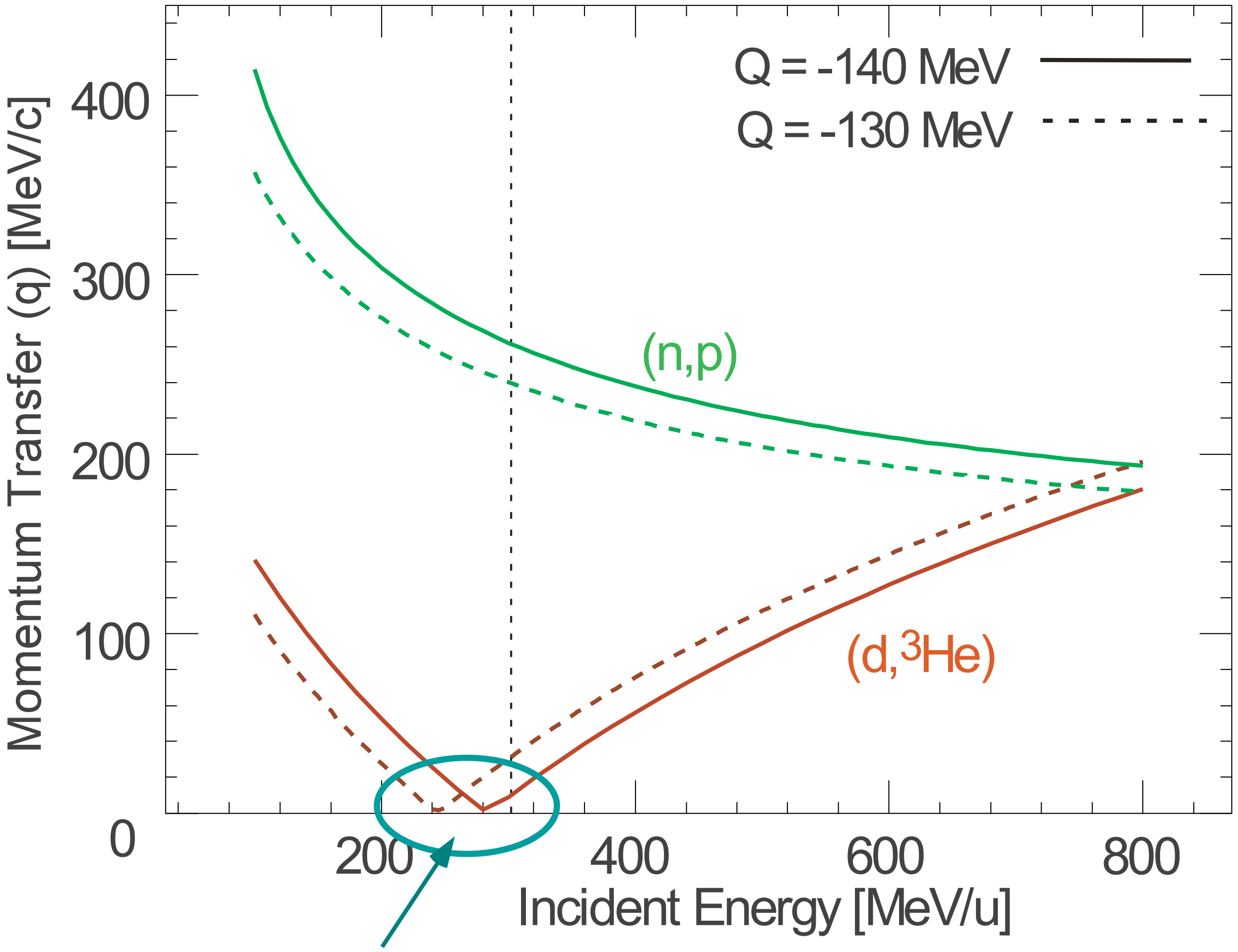
Experimental Principle

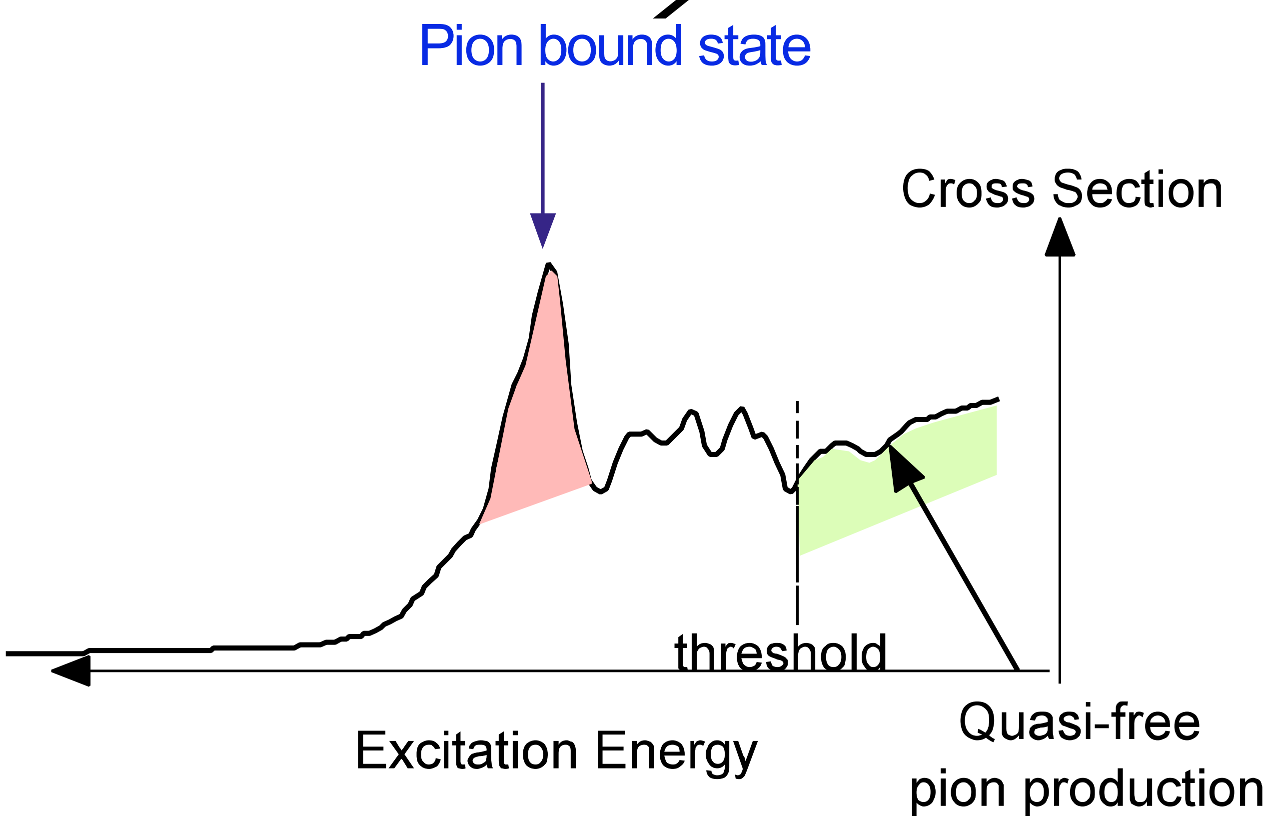
new method to populate deep π

Nuclear reaction to directly
Populate pionic bound states.

A(n,p)A+π⁻ reaction







Quasi-substitutional (Δl~0) reaction
Small momentum transfer(q)

(d,³He) reaction

T_d=250~300 MeV/u

H. Toki and T.Yamazaki

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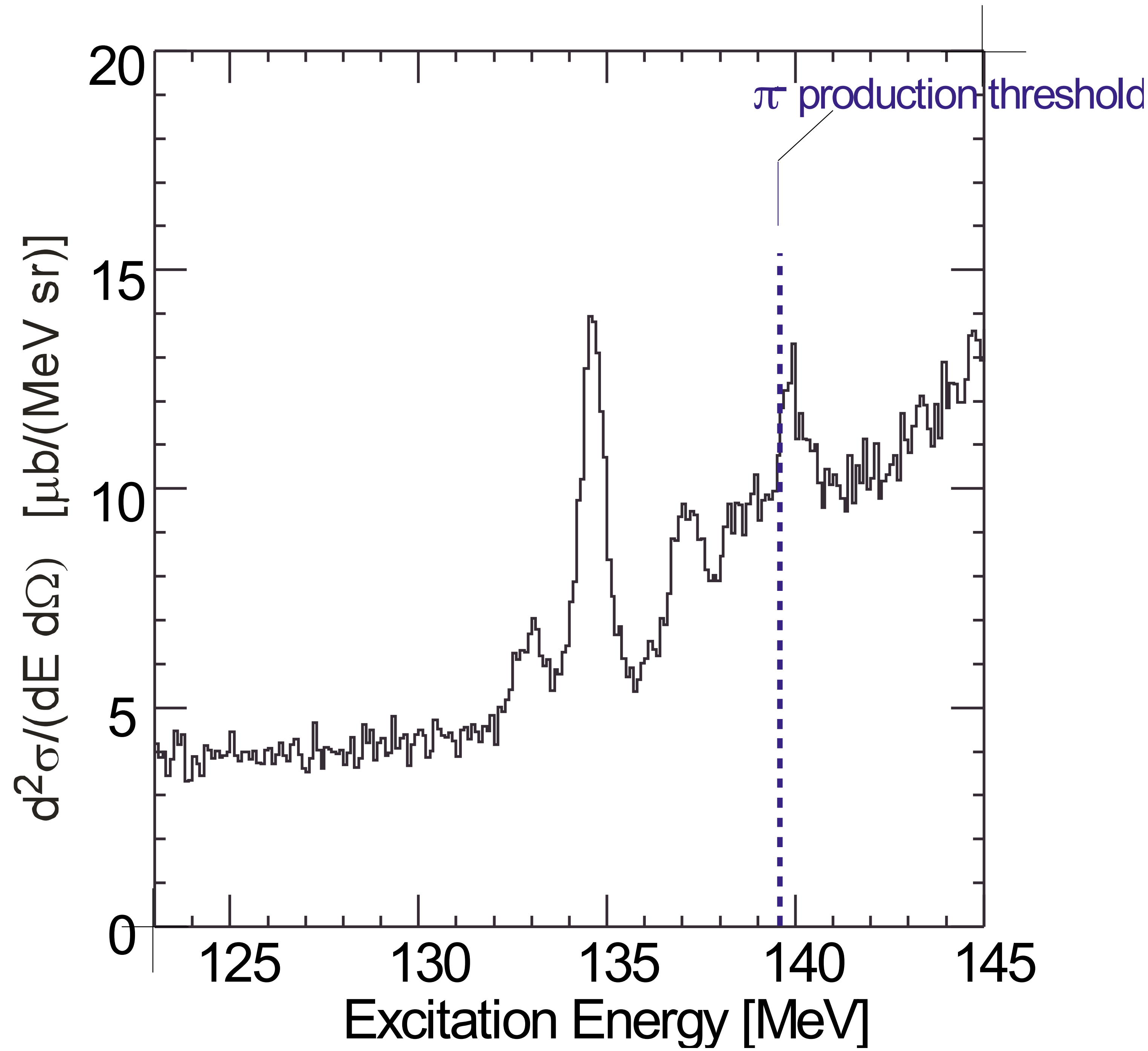
Pionic lead atom

Measured Excitation Spectrum of $^{206}Pb(d,^{3}He)$



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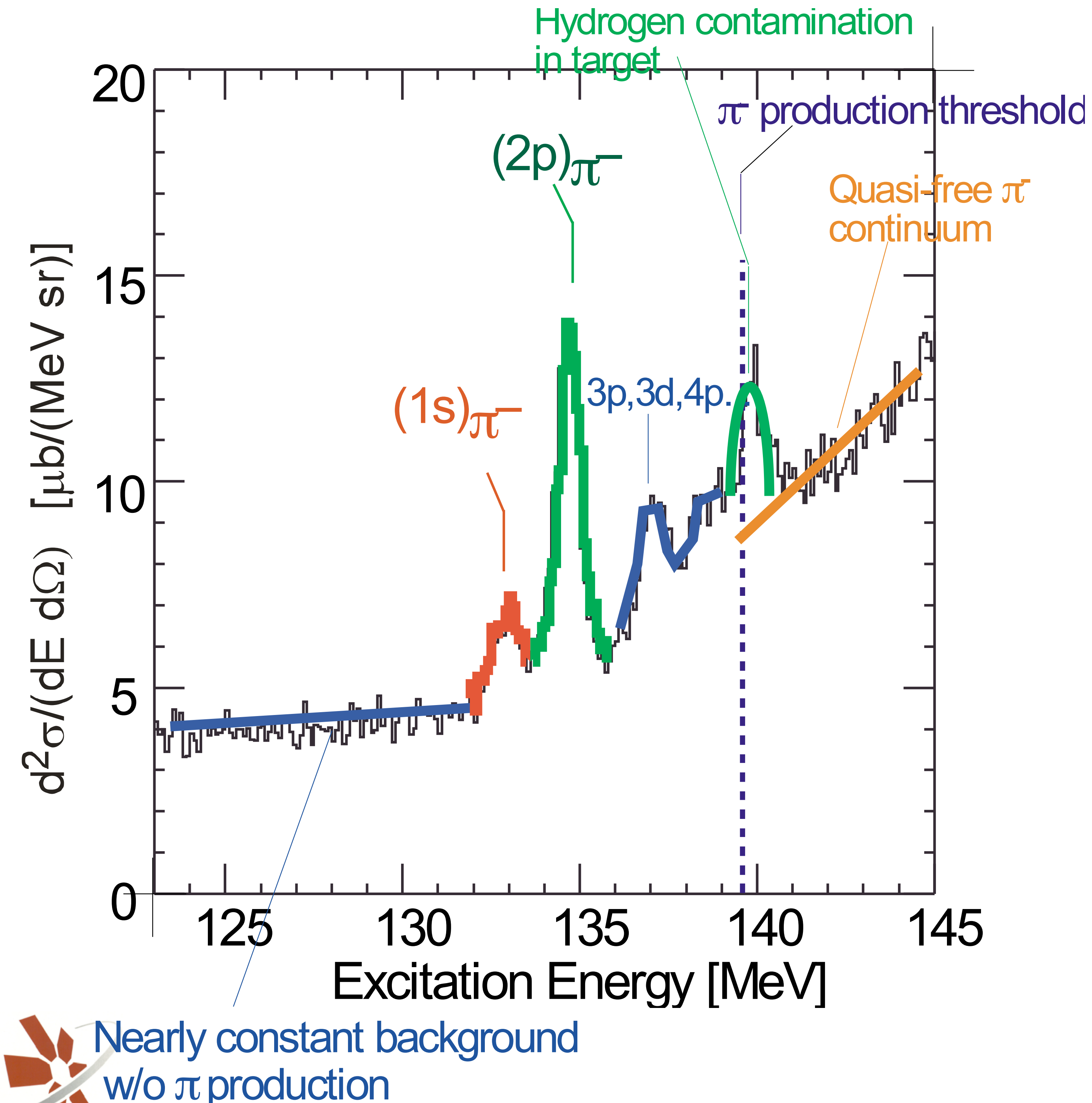
Pionic lead atom

Measured Excitation Spectrum of $^{206}Pb(d,^{3}He)$



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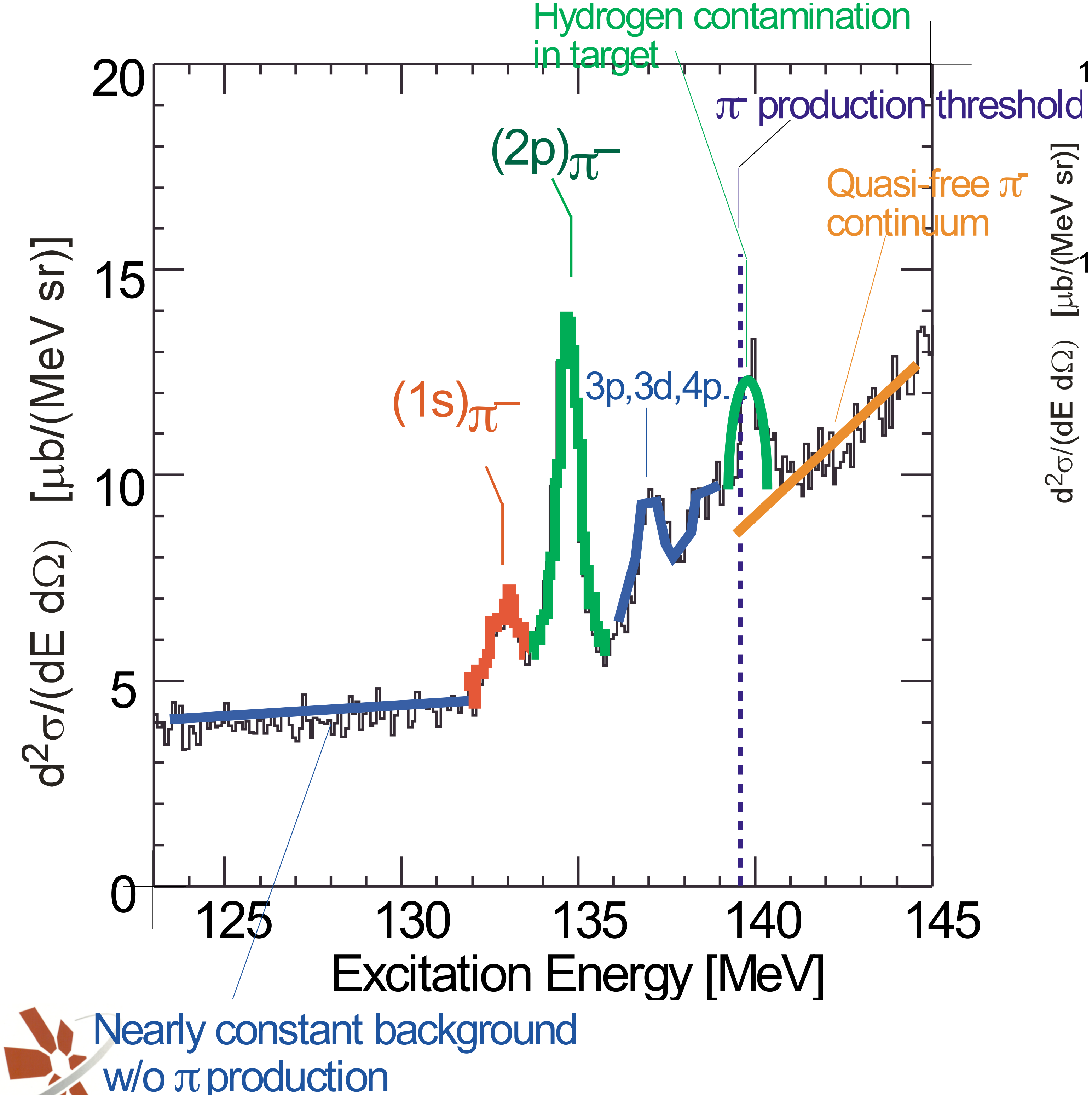
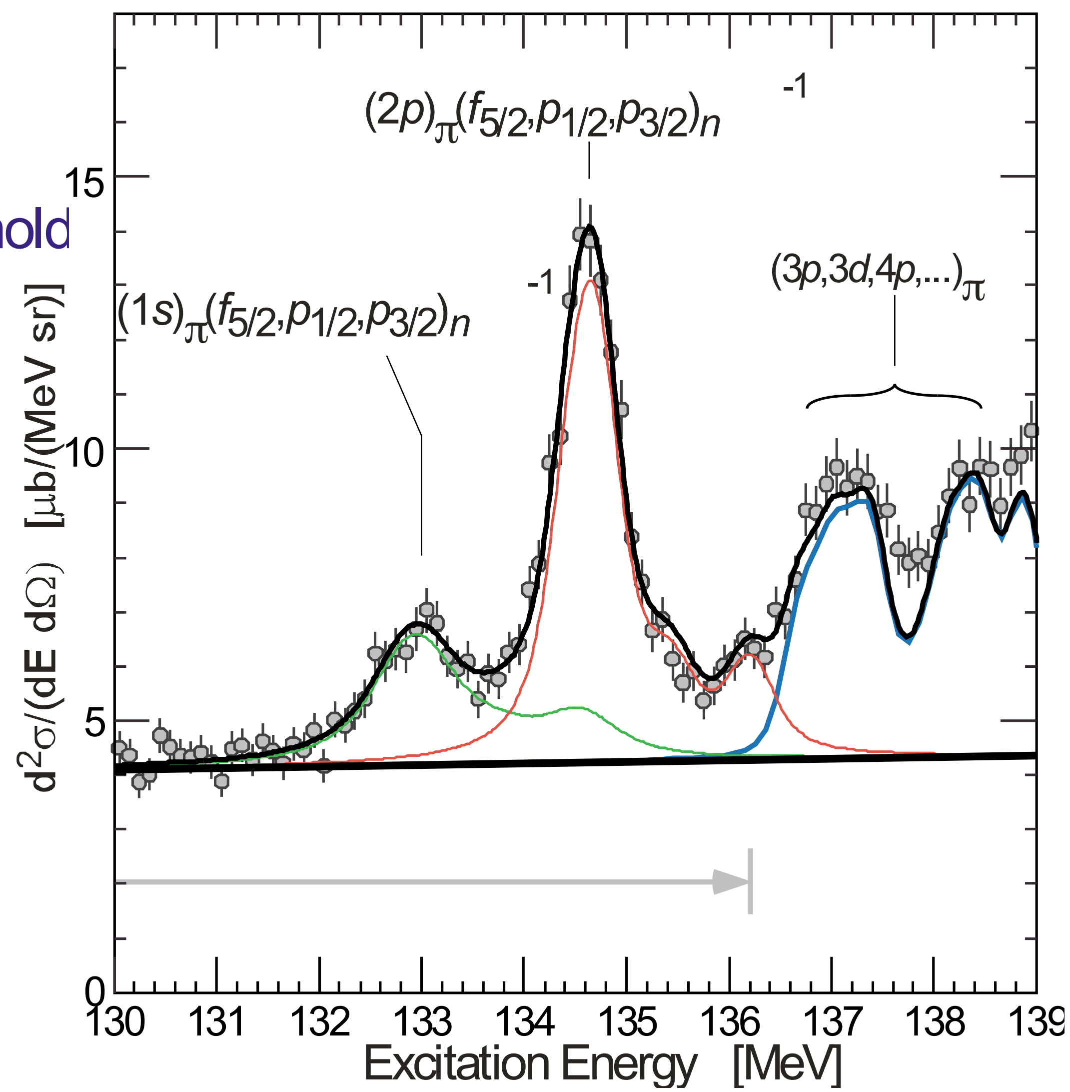
Pionic lead atom

Measured Excitation Spectrum of $^{206}Pb(d,^{3}He)$





Fitting $\chi^2 \sim 95.2/N_{DF}=132$

B(1s) = 6.768 +- 0.061 MeV

Γ(1s) = 0.778 +- 0.160 MeV

B(2p) = 5.110 +- 0.045 MeV

Γ(2p) = 0.371 +- 0.060 MeV

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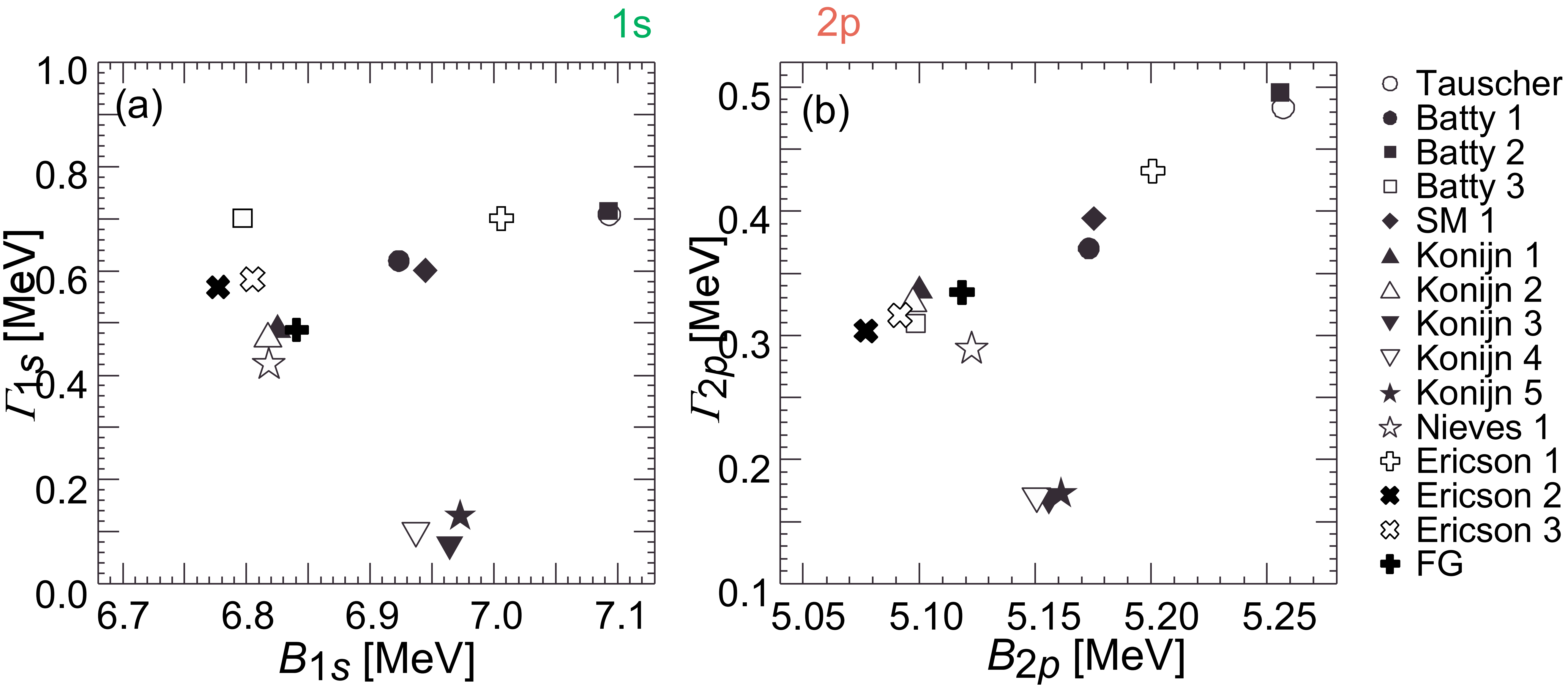
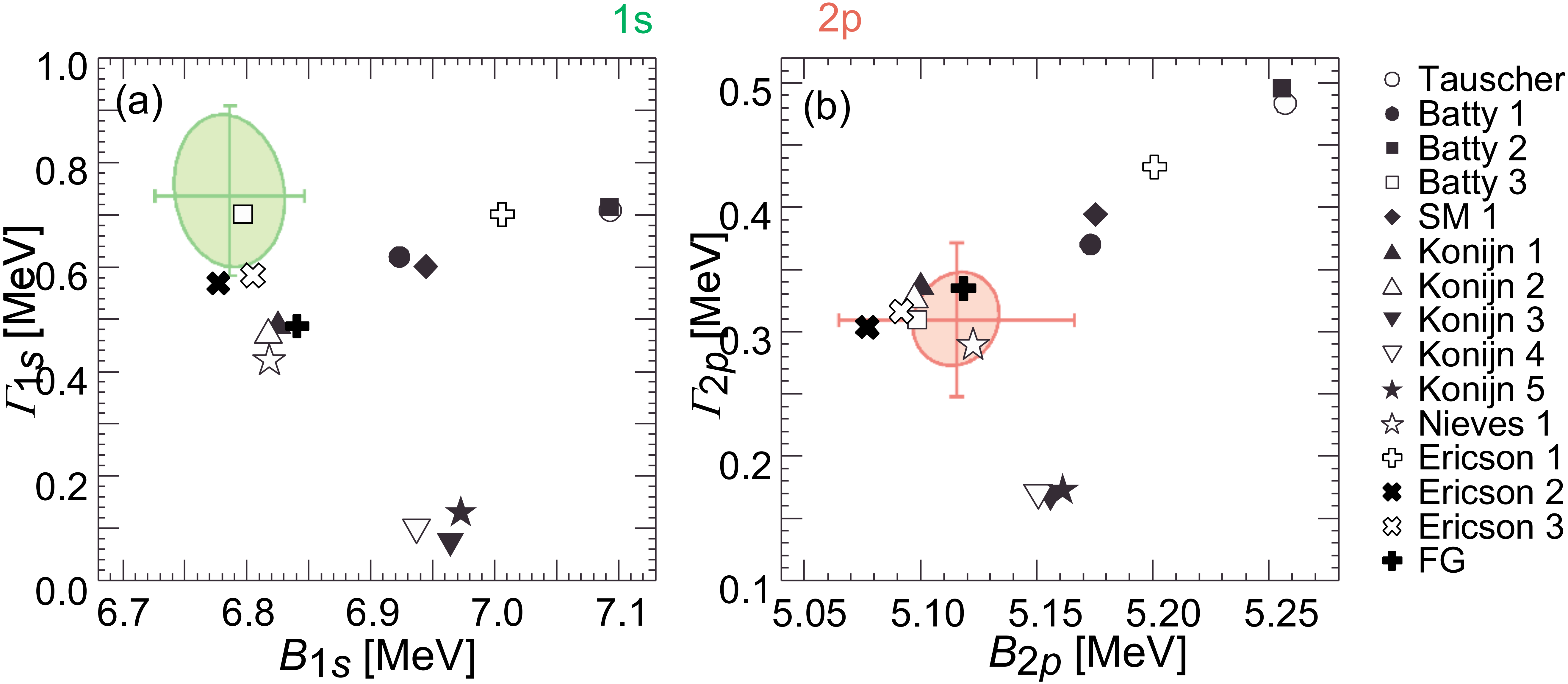
Comparison between theoretical prediction and experimental result



Comparison between theoretical prediction and experimental result



π-nucleus 相互作用

Strong interaction optical potential

$U_{opt} = V_{s\text{-wave}} + V_{p\text{-wave}}$

scattering experiment

$V_{s\text{-wave}} = b_0\ \rho(r) + b_1 \Delta\rho(r) + B_0 \rho^2(r)$

$\rho(r)=\rho_n(r)+\rho_p(r)$ =nuclear density

$\Delta\rho(r)=\rho_n(r)-\rho_p(r)$

b_0 isoscalar part parameter

b_1 isovector part parameter

Isovector part measurement

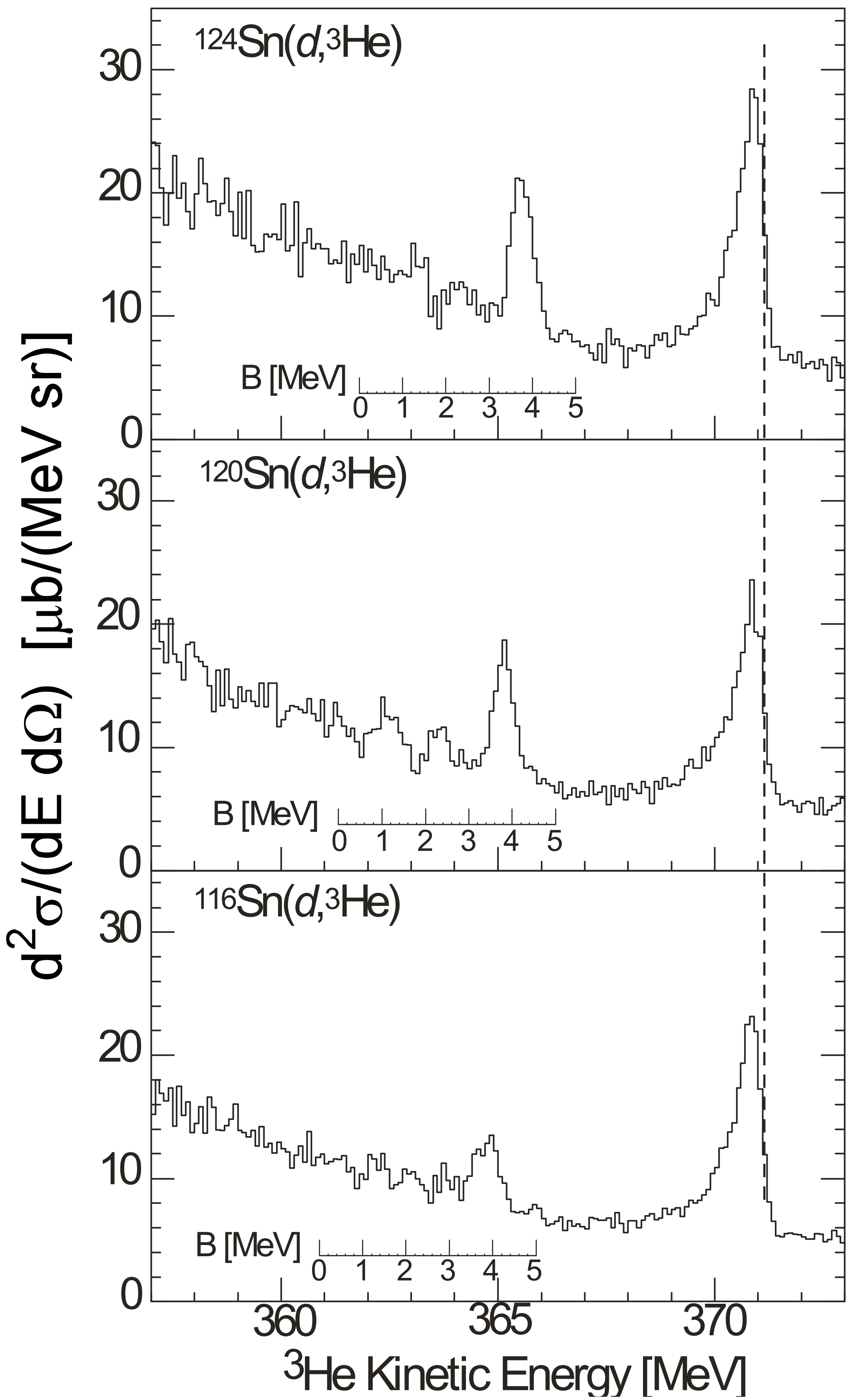
Target:

15 mg/cm^2 Sn 116, 120, 124
with thin polyethylen layer attached.

Beam:

T_d = 250 MeV/u

to enhance $(1s)_\pi \times (s_{1/2})_n$



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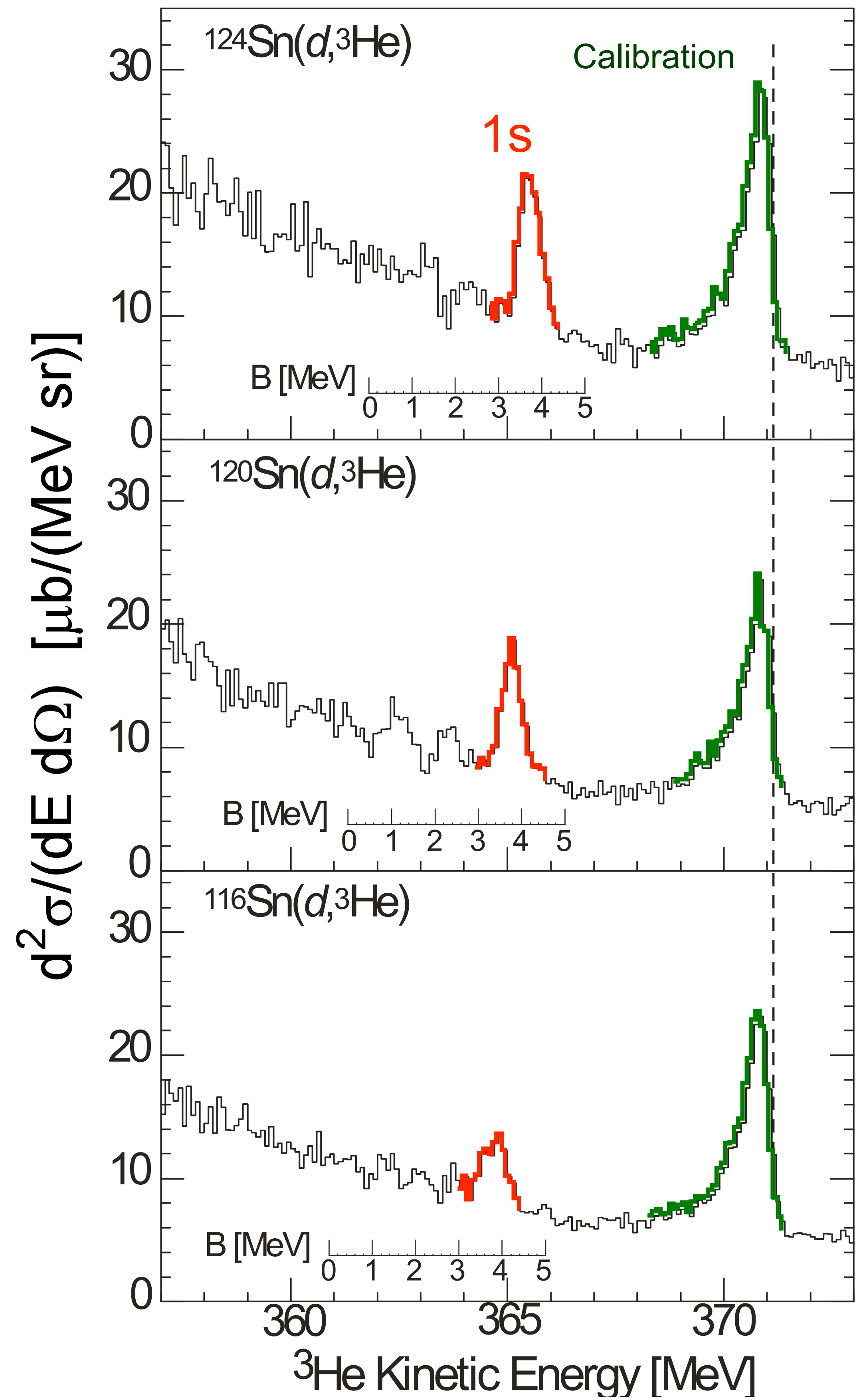
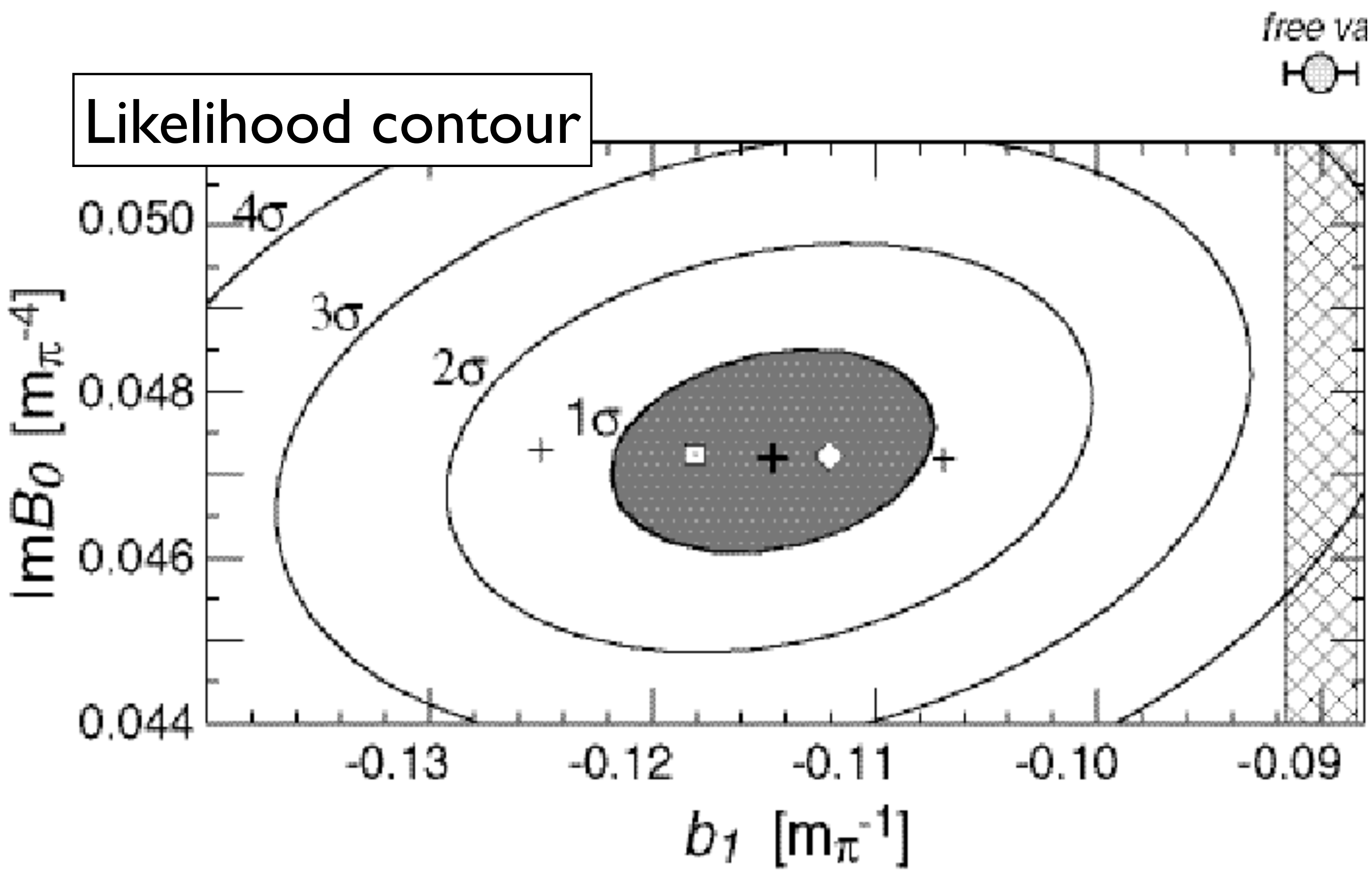
T_d = 250 MeV/u
to enhance $(1s)_\pi \times (s_{1/2})_n$

$$BE(^{115}Sn) = 3906 \pm 21(stat) \pm 12(sys)\ \text{keV}$$
$$BE(^{119}Sn) = 3820 \pm 13(stat) \pm 12(sys)\ \text{keV}$$
$$BE(^{124}Sn) = 3744 \pm 13(stat) \pm 12(sys)\ \text{keV}$$
$$\Gamma(^{115}Sn) = 441 \pm 68(stat) \pm 54(sys)\ \text{keV}$$
$$\Gamma(^{119}Sn) = 326 \pm 47(stat) \pm 65(sys)\ \text{keV}$$
$$\Gamma(^{124}Sn) = 341 \pm 36(stat) \pm 63(sys)\ \text{keV}$$



Present situation

Likelihood contour



Suzuki et al. PRL92 (04)072302

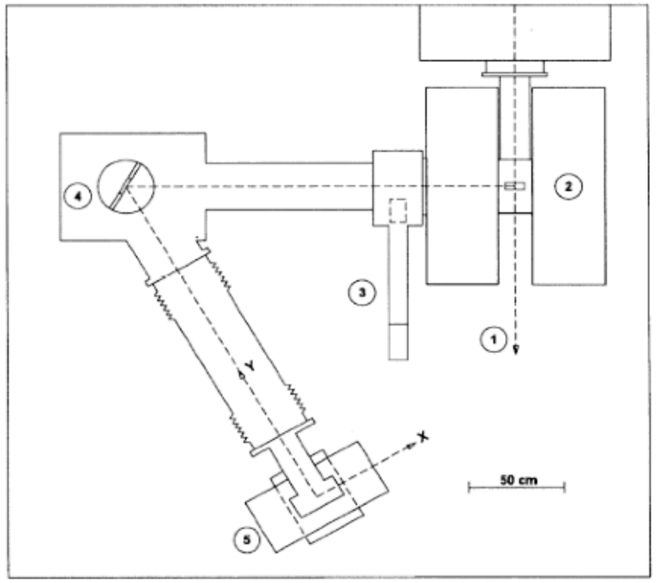


FIG. 1. Schematic layout: (1) beam direction, (2) cyclotron trap with target cell, (3) movable argon source for the stability monitoring, (4) turntable with crystal assembly, and (5) XY table with CCD x-ray detectors.

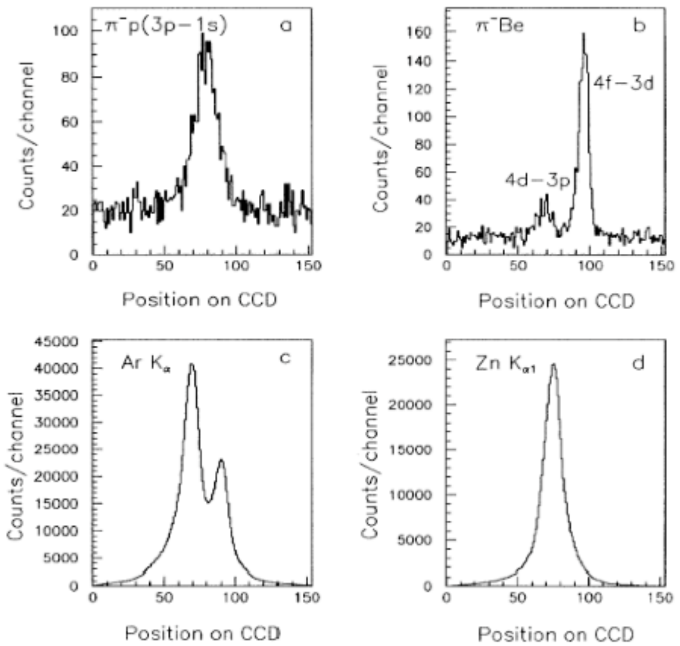
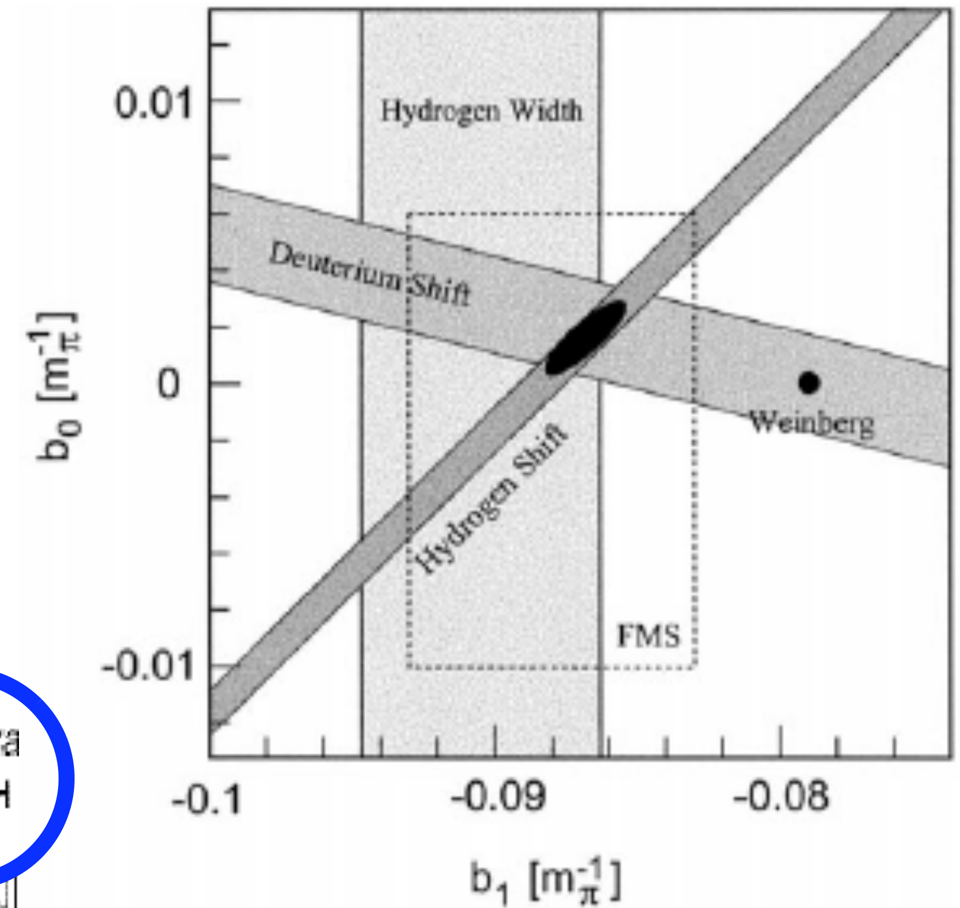
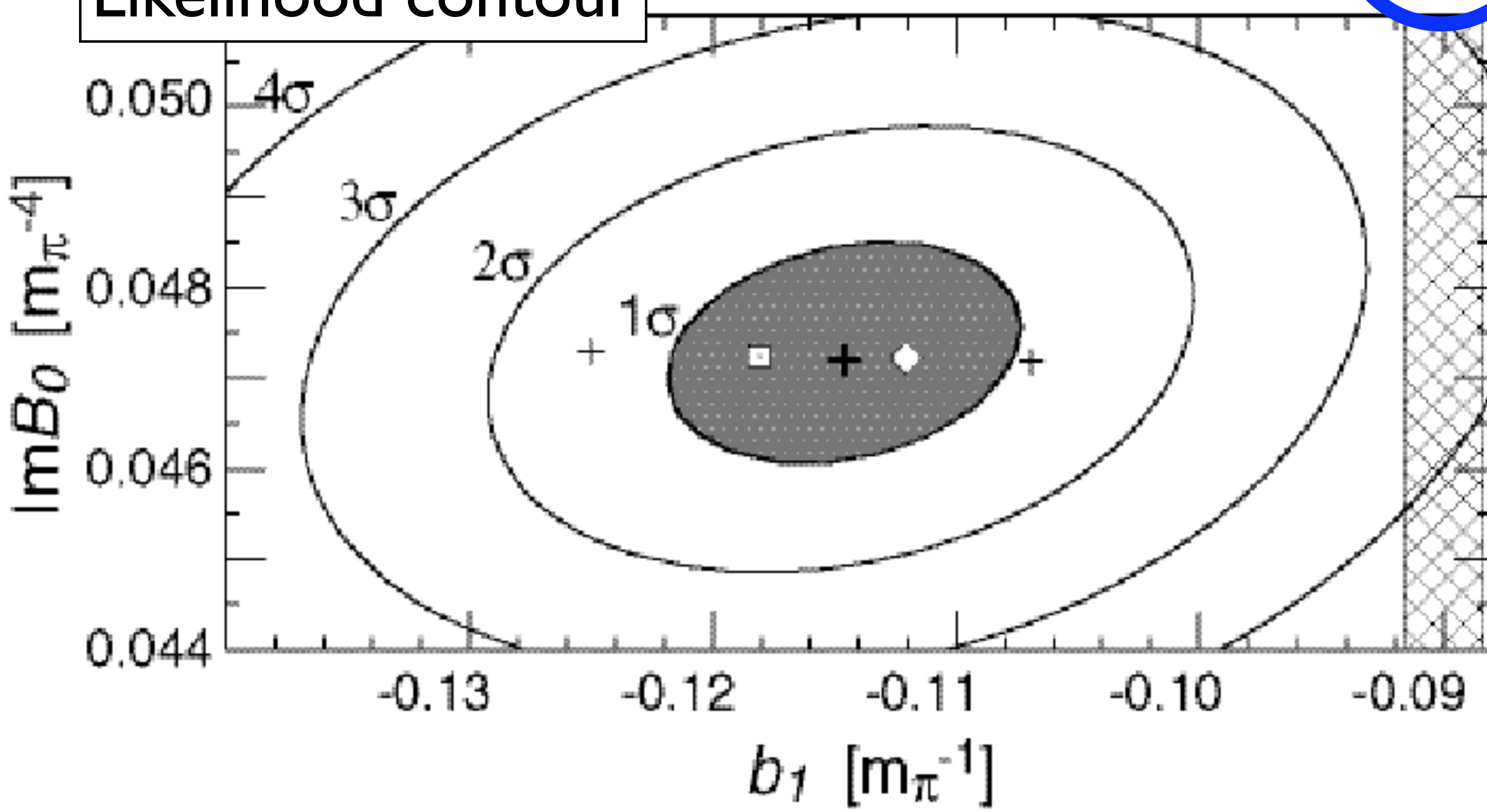


FIG. 2. Measured x-ray lines: (a) Pionic hydrogen line. (b) With the pionic beryllium line, the instrumental resolution function was measured. (c) The electronic argon $K\alpha$ line was used as a wavelength standard. (d) The energy calibration was cross checked with the zinc $K\alpha_1$ line, measured in third order.



Likelihood contour



Pionic hydrogen and deuterium at PSI

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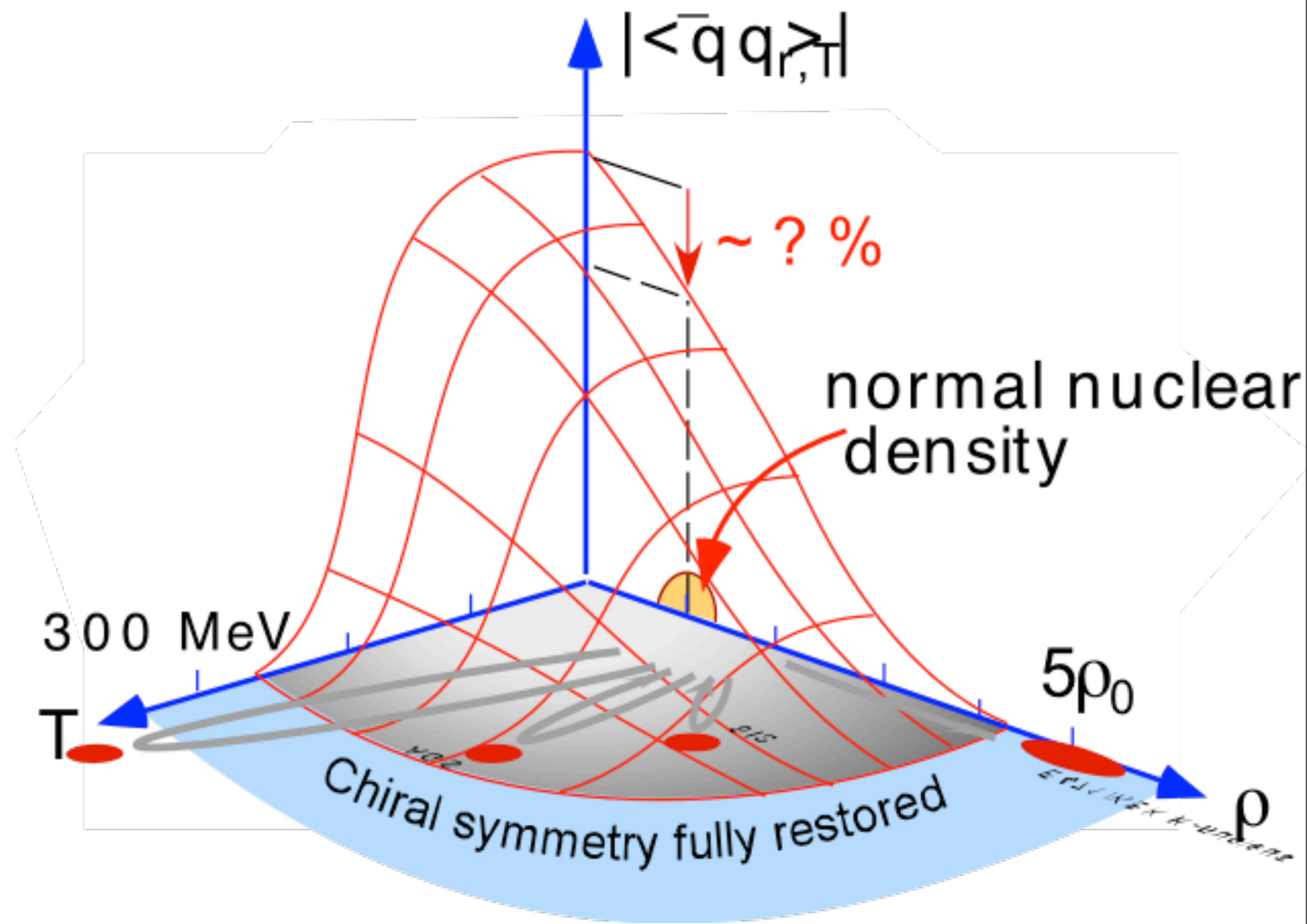
Isovector parameter b_1 and Chiral symmetry

$\langle \bar{q}q \rangle$: order parameter of chiral symmetry

Order parameter of Chiral symmetry $\langle \bar{q}q \rangle$



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Isovector parameter b_1 and Chiral symmetry

$\langle\bar{q}q\rangle$: order parameter of chiral symmetry

Tomozawa-Weinberg relation

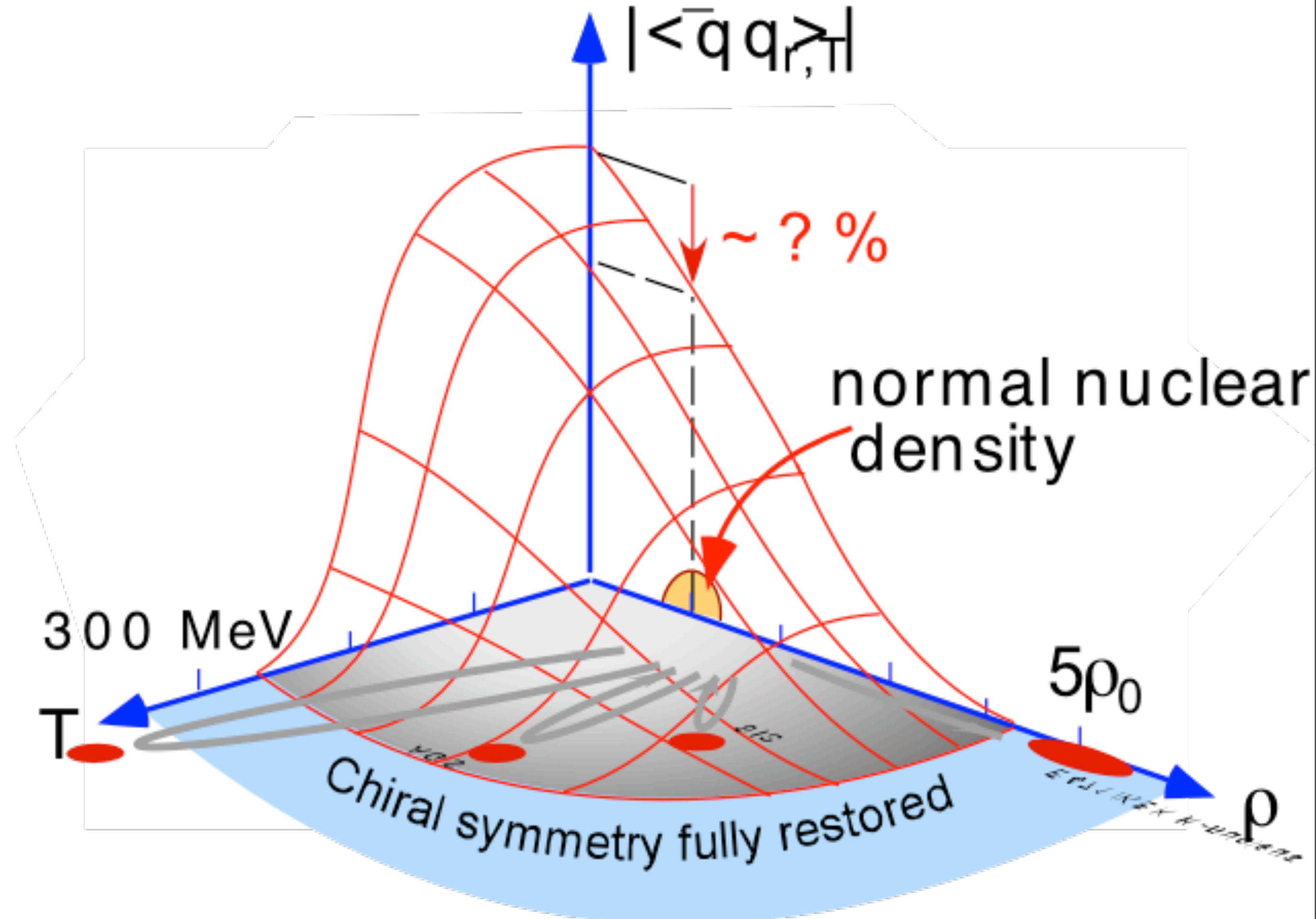
$$-4\pi(1+m_\pi/M)b_1 = m_\pi/2f_\pi^2$$

$$\frac{f_\pi^*(\rho)^2}{f_\pi^{\ 2}} = \frac{b_1^{free}}{b_1(\rho)}$$

Gell-mann-Oakes-Renner relation

$$m_\pi^{*\ 2} f_\pi^{*2} = -\frac{m_u+m_d}{2}\langle\bar{q}q\rangle_\rho$$

Order parameter of Chiral symmetry $\langle\bar{q}q\rangle$



$b_1^*/b_1 \Leftrightarrow \langle\bar{q}q\rangle$

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Density-dependent isovector term. We take the following form according to Weise [4]:

$$\text{DD:} \quad b_1(r)\Delta\rho(r) = \frac{b_1^{\text{free}}}{1-\alpha\rho(r)}\Delta\rho(r). \qquad (10)$$

Yamazaki and Hirenzaki , PLB557(03)20
[4] = Weise, Acta. Phys. Polon. B31 (00) 2715

$$R = b_1^{\text{free}}/b_1 = 0.78 \pm 0.05 \qquad (3)$$

$$\approx b_1^{\text{free}}/b_1^*(\rho_e) \approx f_\pi^*(\rho_e)^2/f_\pi^2 \approx 1 - \alpha\rho_e, \qquad (4)$$

where we used the fact [27,28] that the solution with a local-density-dependent parameter, $b_1^*(\rho) = b_1^{\text{free}}/[1 - \alpha\rho(r)]$, is equivalent to that using a corresponding constant parameter $b_1 = b_1^{\text{free}}/(1 - \alpha\rho_e)$ with an effective density $\rho_e \approx 0.6\rho_0$.

Suzuki et al. PRL92 (04)072302

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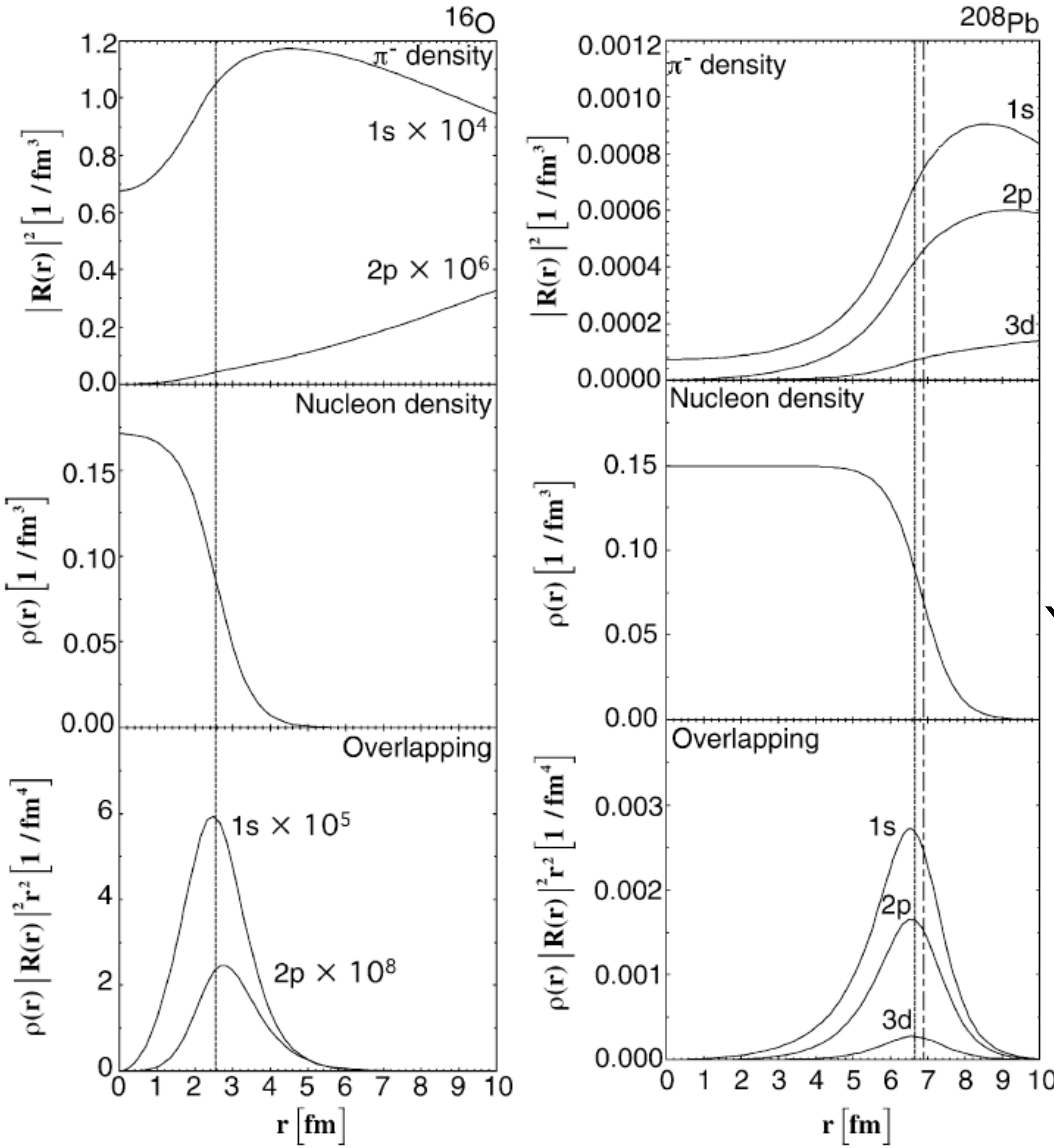

Yamazaki, Hirenzaki
PLB557(03)20

$0.6\rho_0$ 付近が
最大

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Isovector parameter b_1 and Chiral symmetry

$\langle\bar{q}q\rangle$: order parameter of chiral symmetry

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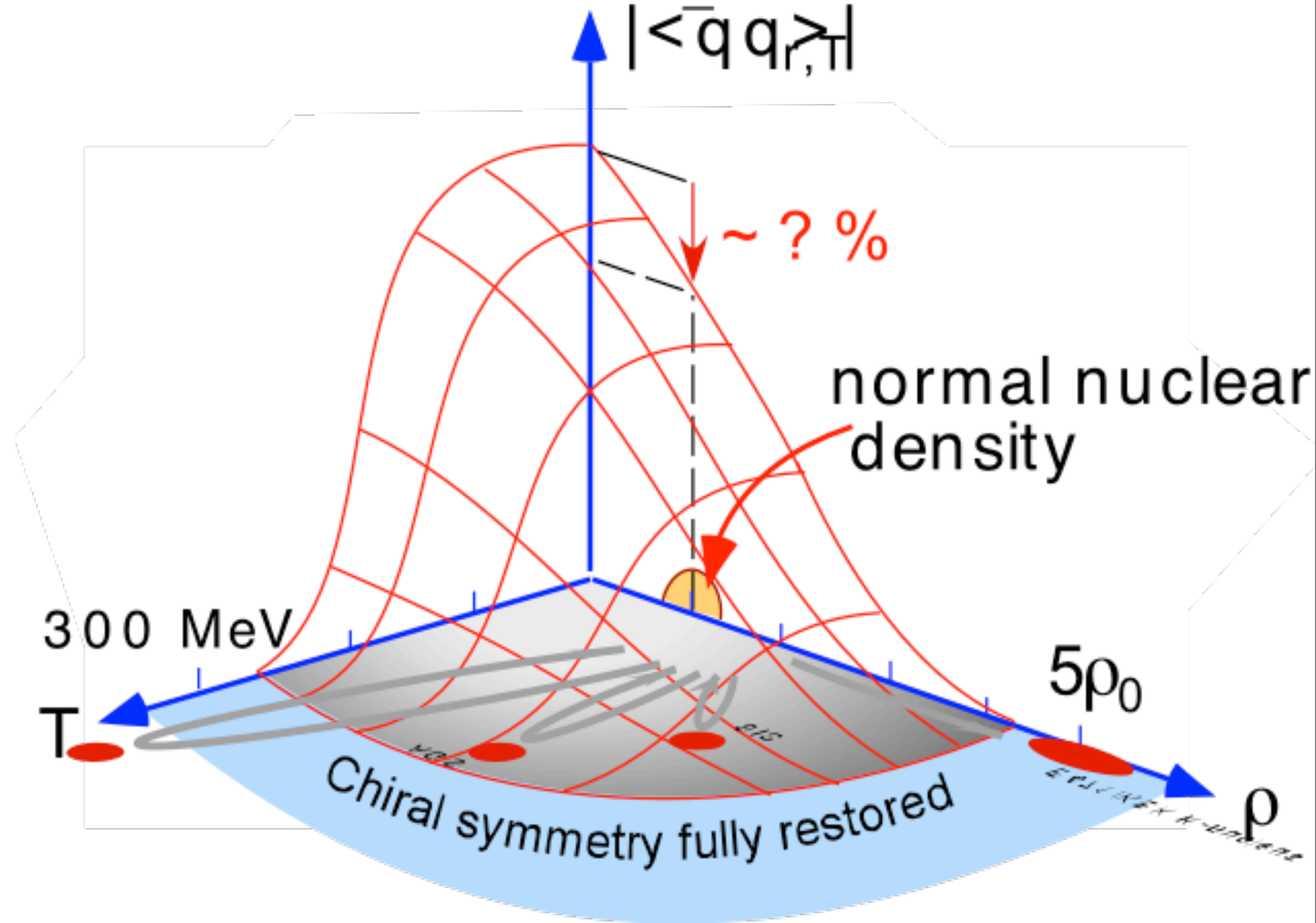

b_1^*/b_1 <=> $\langle\bar{q}q\rangle$

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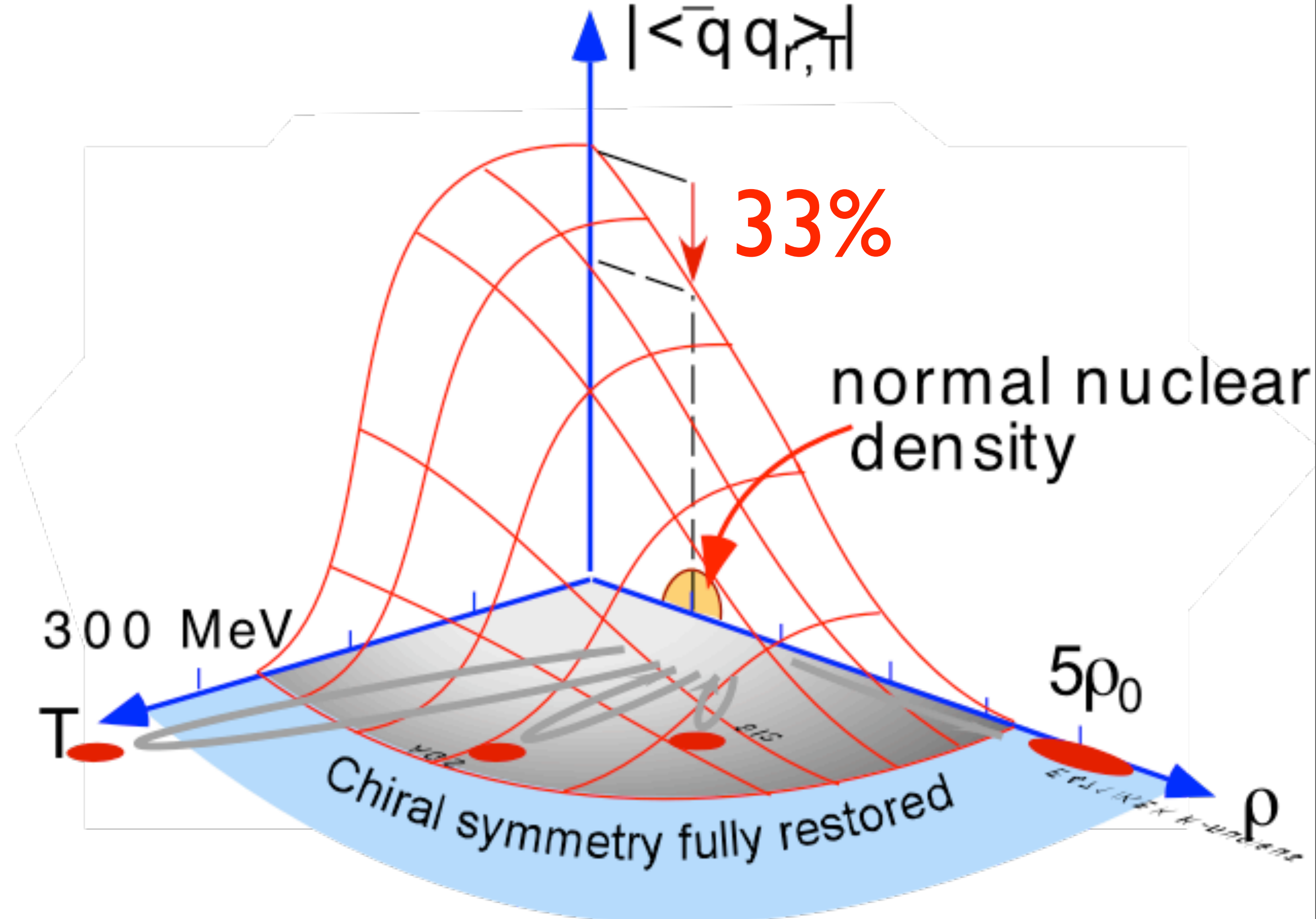

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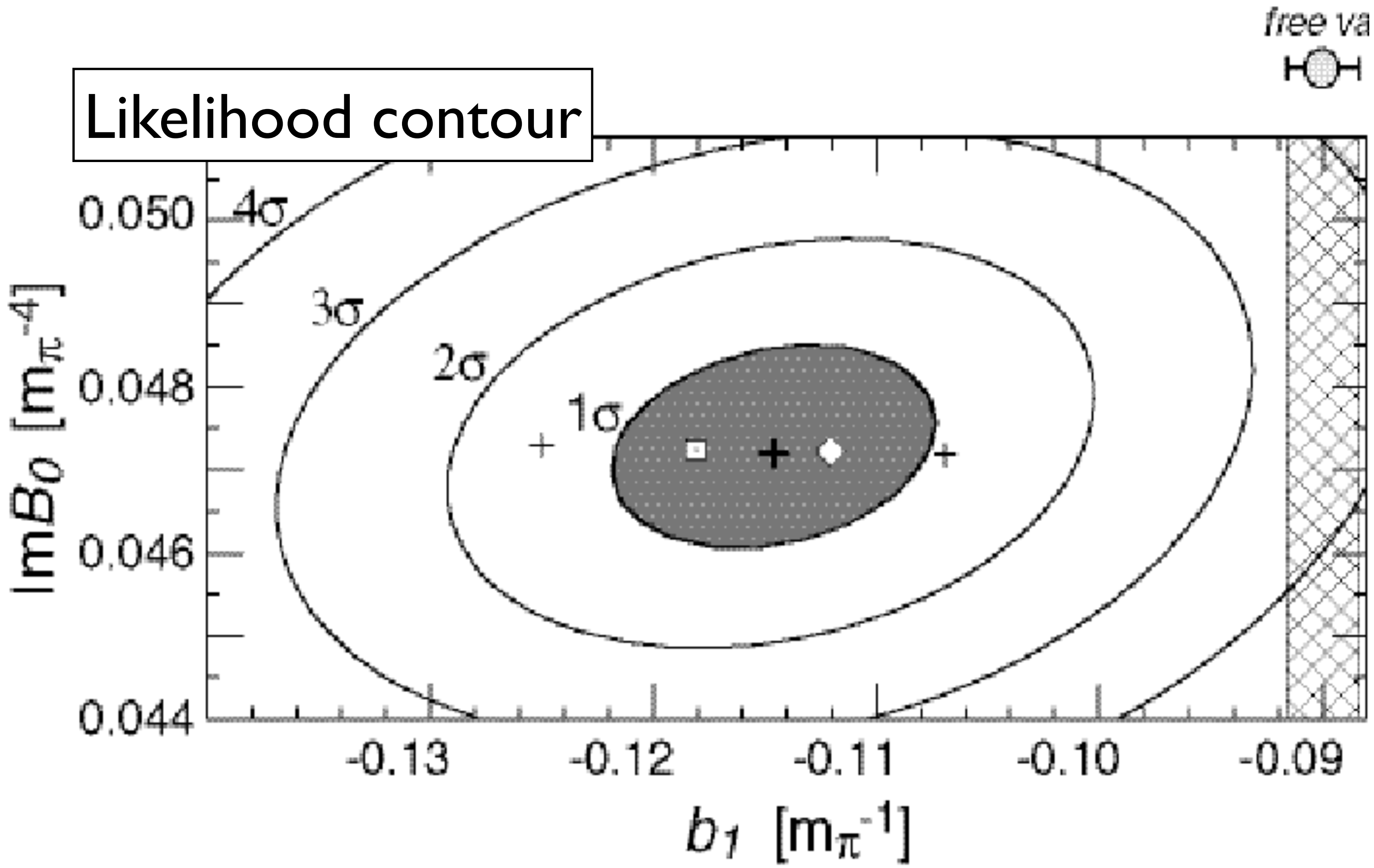
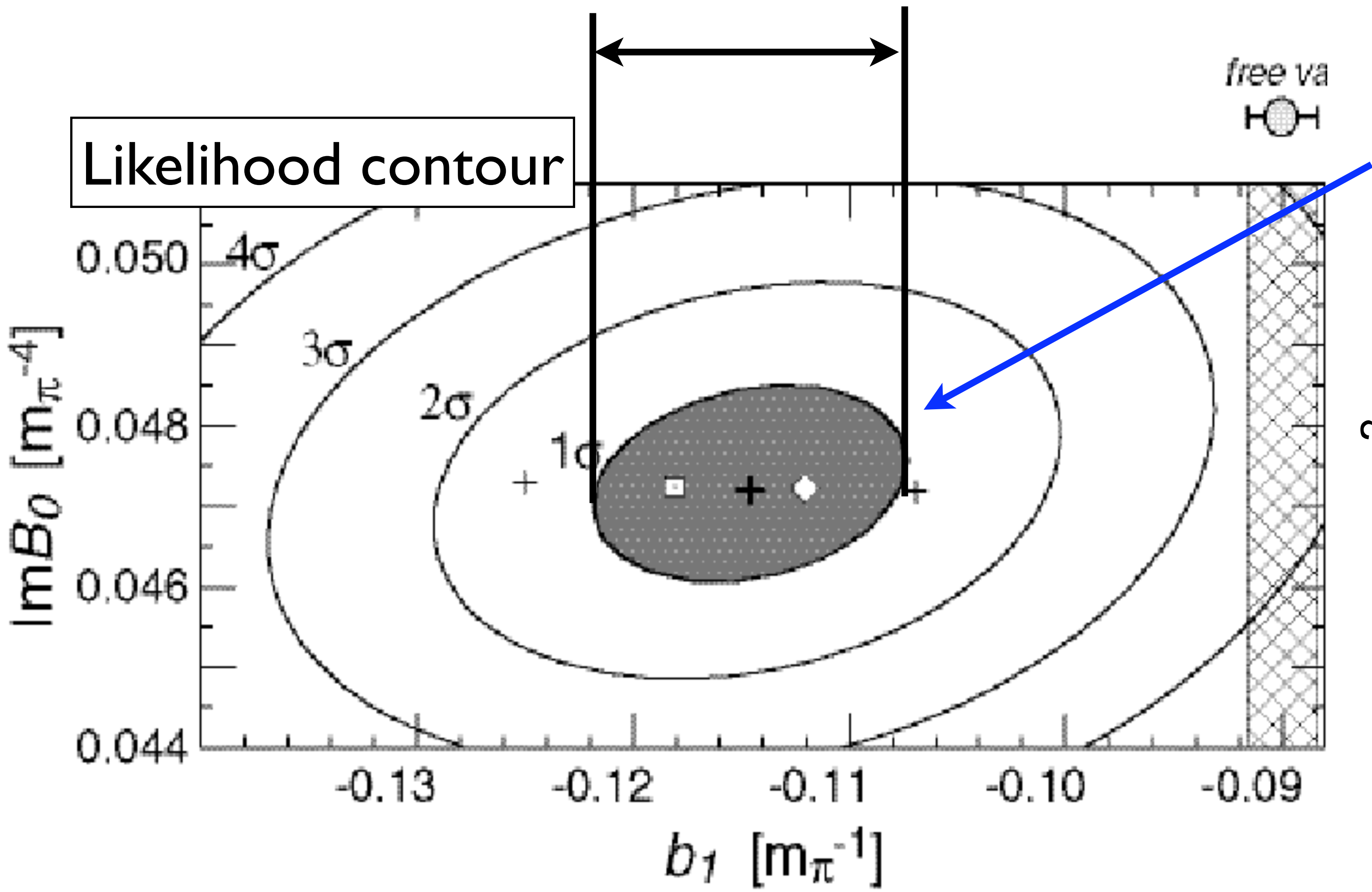
Suzuki et al. PRL92 (04)072302

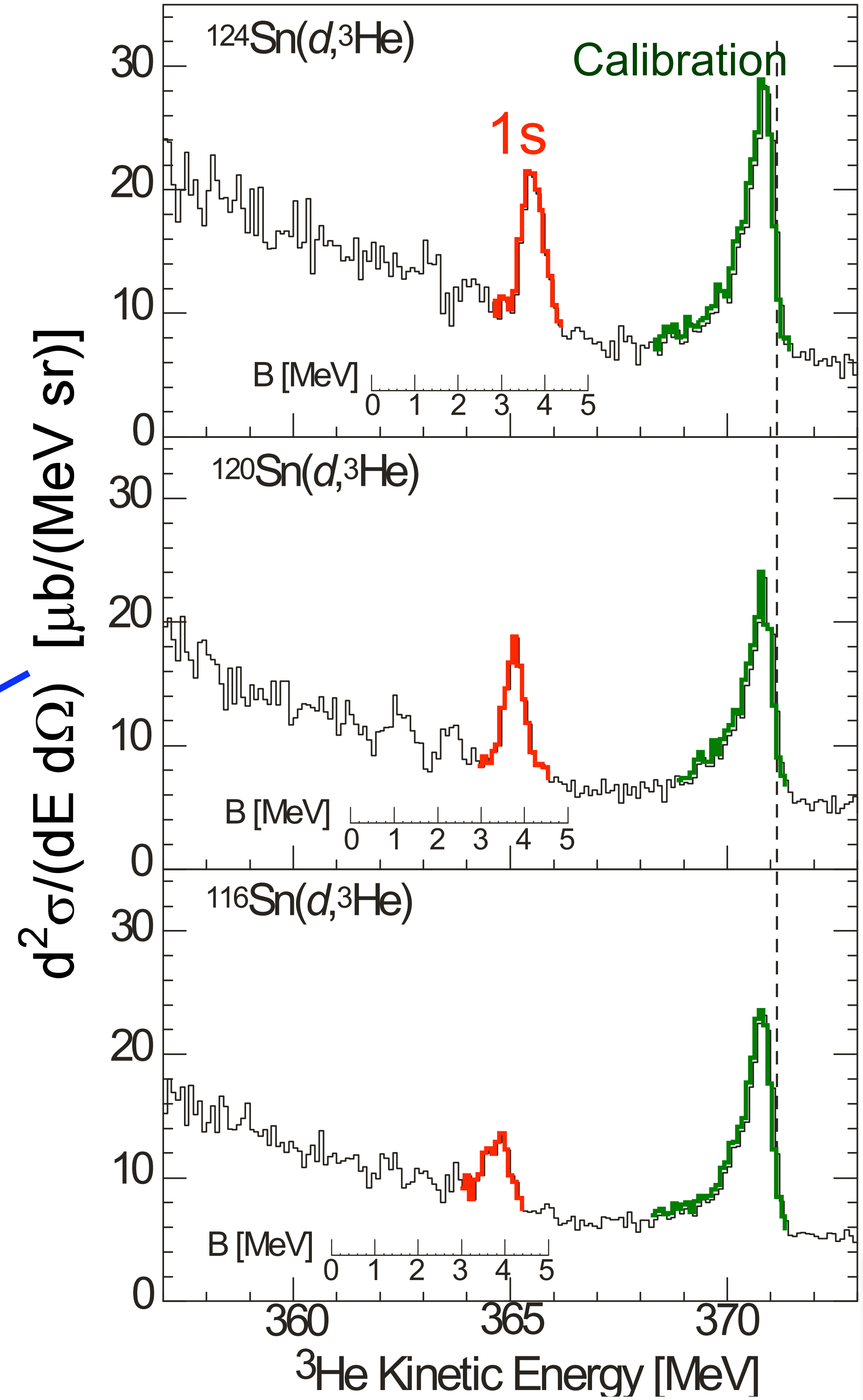
Present situation



Present situation

b_1^* has large error





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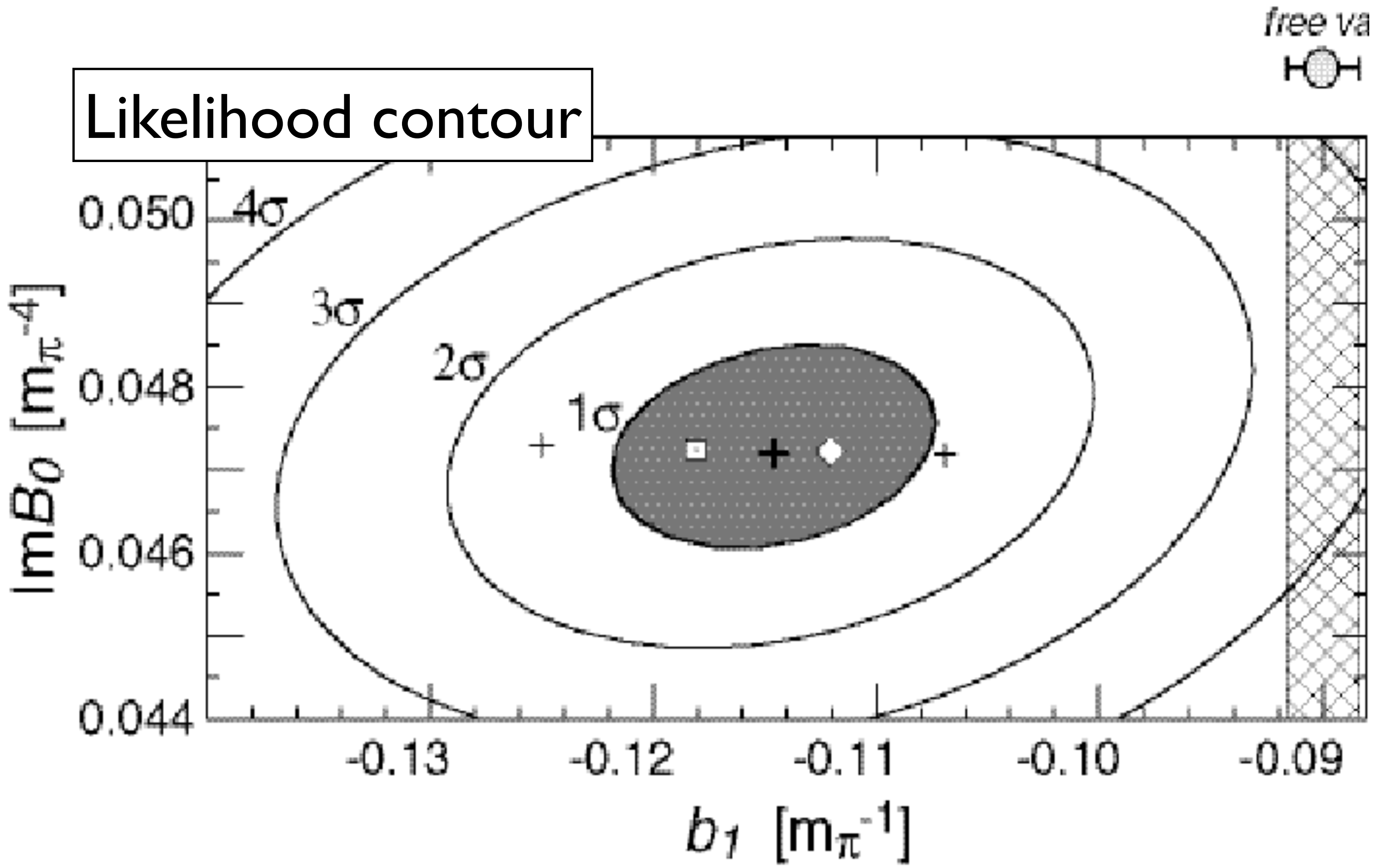
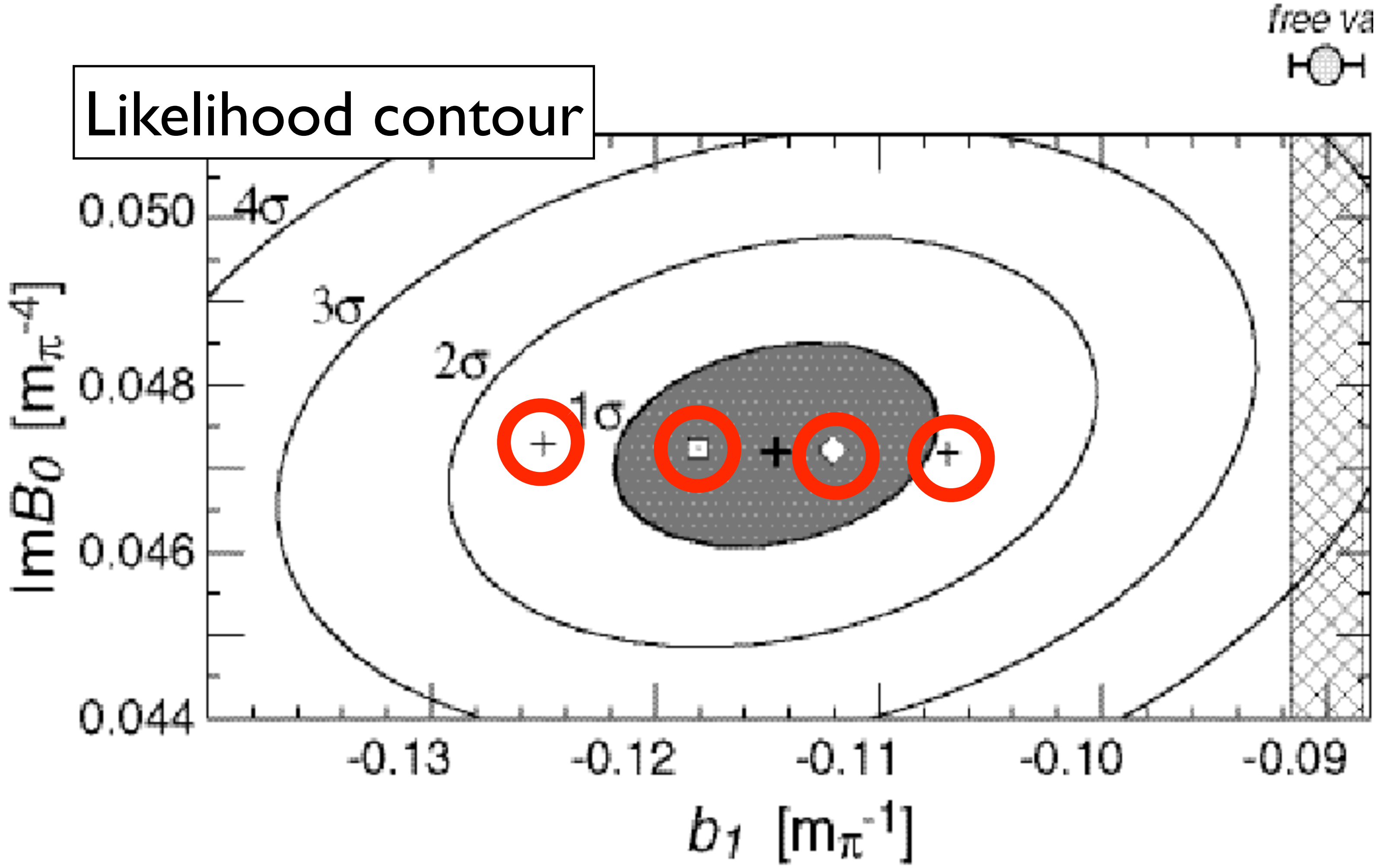


Present situation

Systematic errors due to
matter radii ambiguities of nuclei.



EXPERIMENTAL PROPOSAL FOR RI BEAM FACTORY

SPECTROSCOPY OF PIONIC ATOM IN ^{122}Sn(d, ^{3}He) NUCLEAR REACTION

(January 2008)

K. Itahashi[1], M. Iwasaki, H. Ohnishi, S. Okada, H. Outa, T. Suzuki, M. Wakasugi, T. Yamazaki, Y. Yano,
Nishina Center for Accelerator-Based Science, RIKEN, 2-1 Hirosawa, Wako, 351-0198 Saitama, Japan
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Gesellschaft für Schwerionenforschung mbH, D-64291 Darmstadt, Germany
R.S. Hayano, S. Itoh, N. Ono, H. Tatsuno,
Department of Physics, The University of Tokyo, 7-3-1 Hongo, Bunkyo, 113-0033 Tokyo, Japan
S. Hirenzaki, R. Kimura, J. Yamagata,
Department of Physics, Nara Women's University, Kita-Uoya Nishi-Machi, 630-8506 Nara, Japan
P. Kienle, K. Suzuki,
Stefan Meyer Institut für subatomare Physik, Boltzmangasse 3, 1090 Vienna, Austria
K. Lindberg, P.-E. Tegnér, I. Zartova,
Department of Physics, Stockholm University, AlbaNova University Centre, SE-10691 Stockholm, Sweden
and M. Sato
Department of Physics, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, 152-8551 Tokyo, Japan

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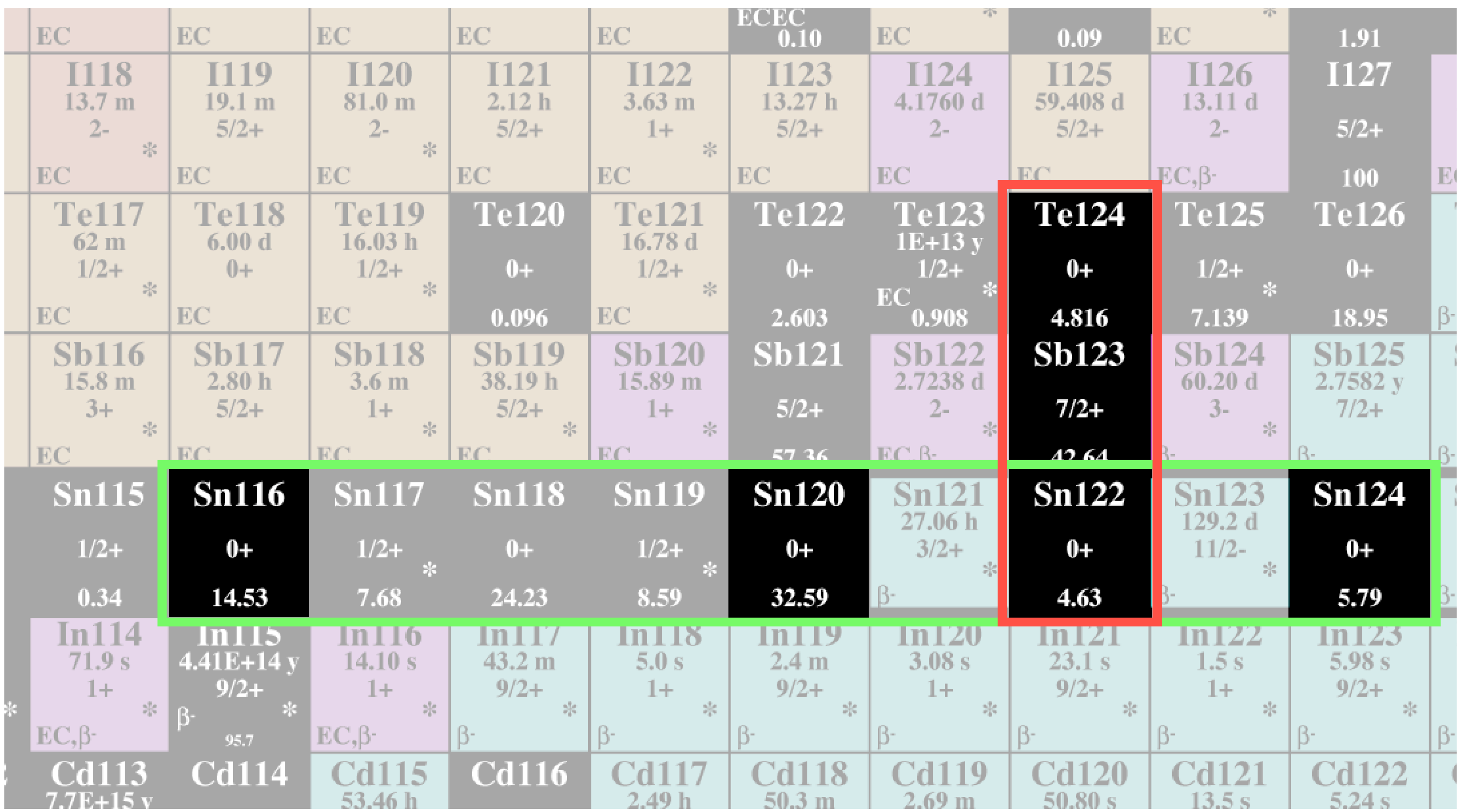
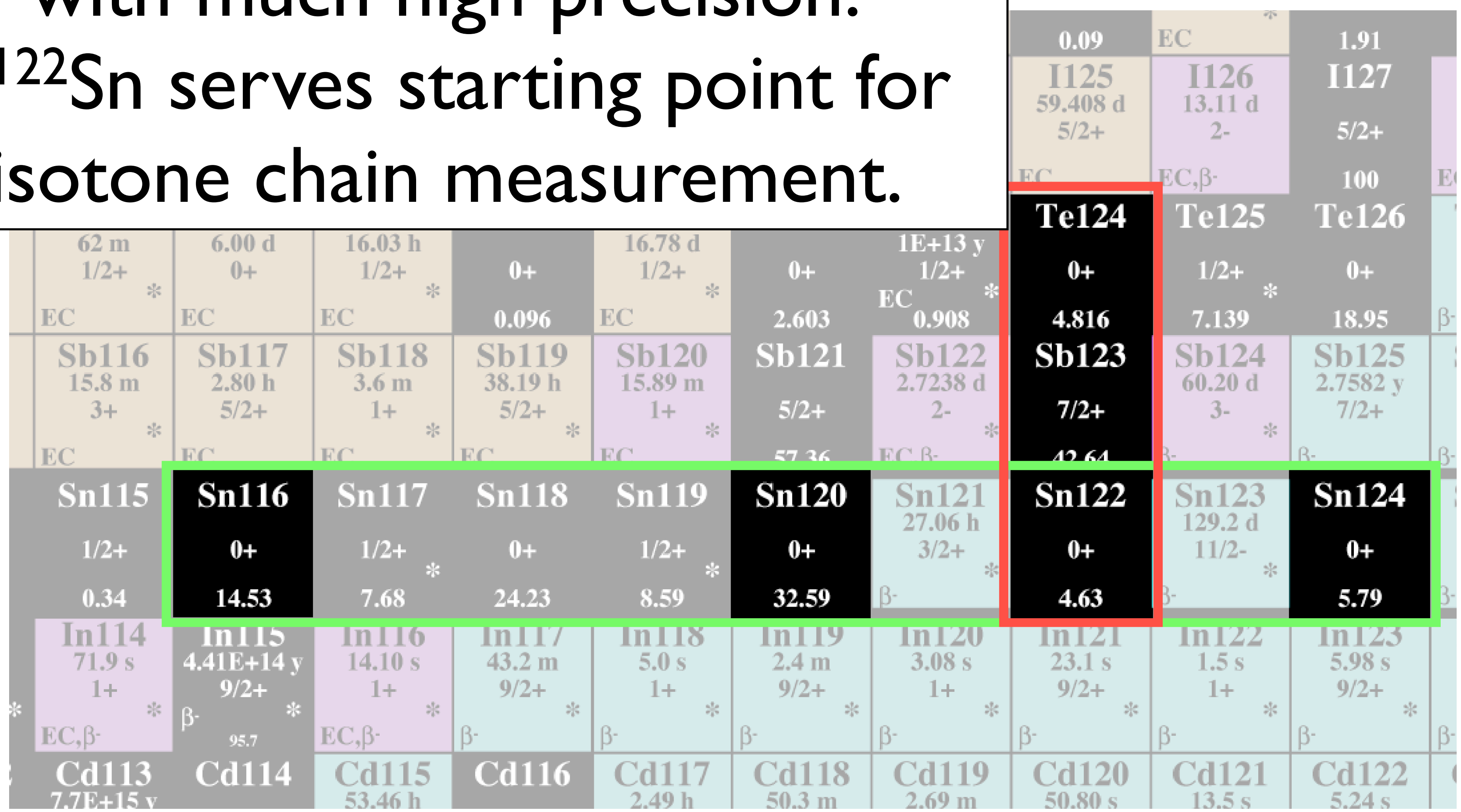
Important Features



Important Features

- First data for ^{122}Sn 1s and 2s
- Confirmation of prev. results with much high precision.
- ^{122}Sn serves starting point for isotone chain measurement.



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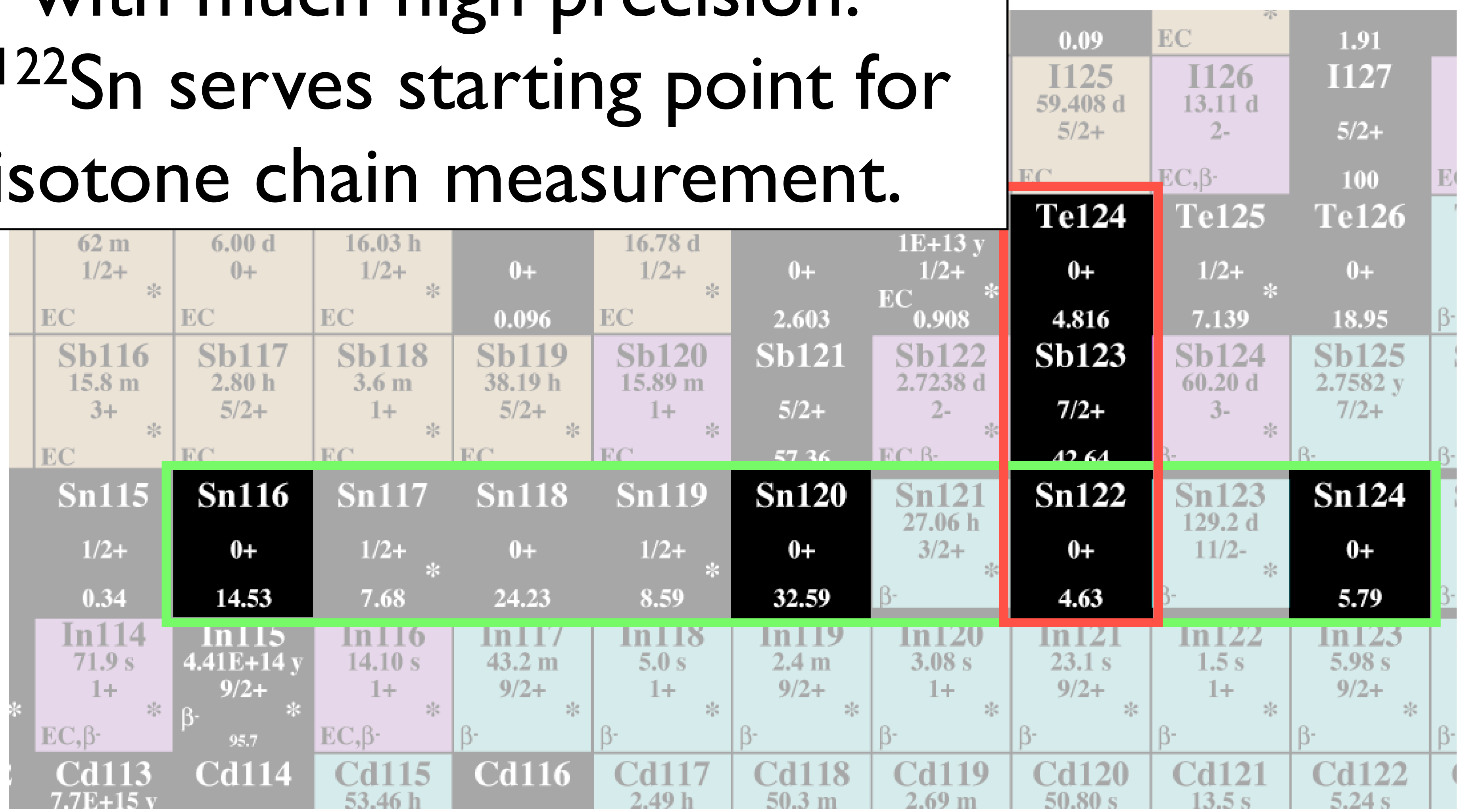
Merits of Isotone measurement
= small matter radii influence



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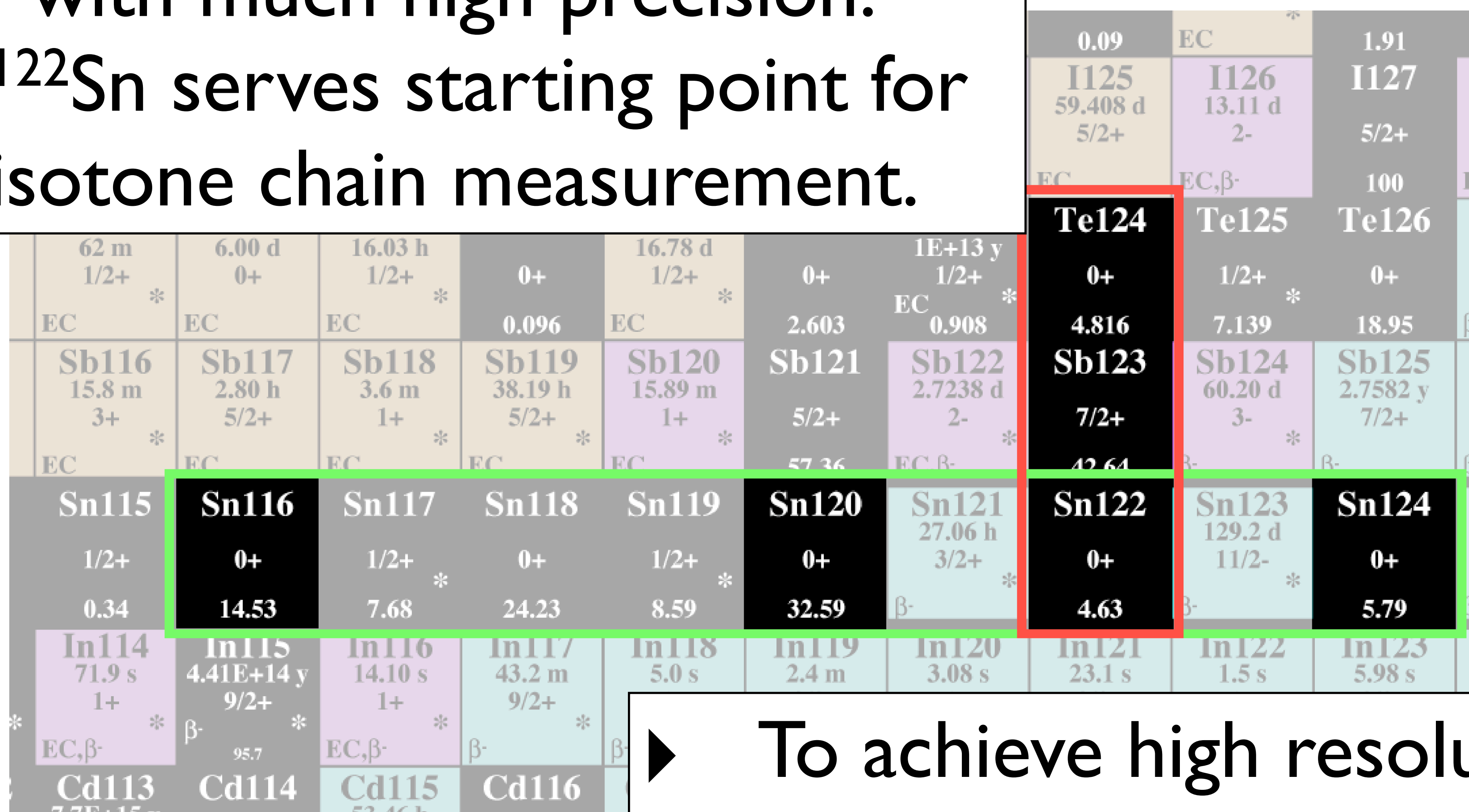
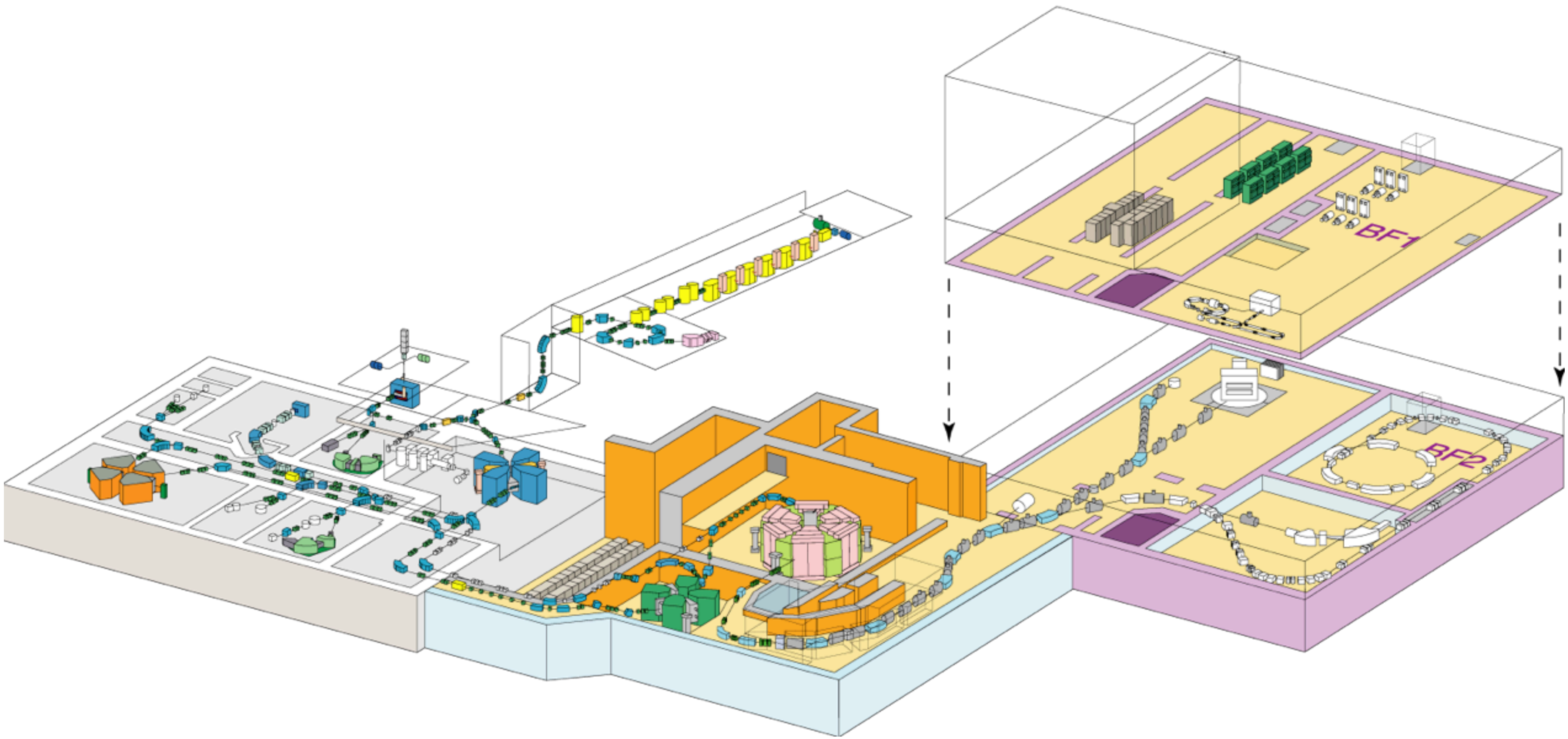


- To achieve high resolution is crucial.

RI Beam Factory



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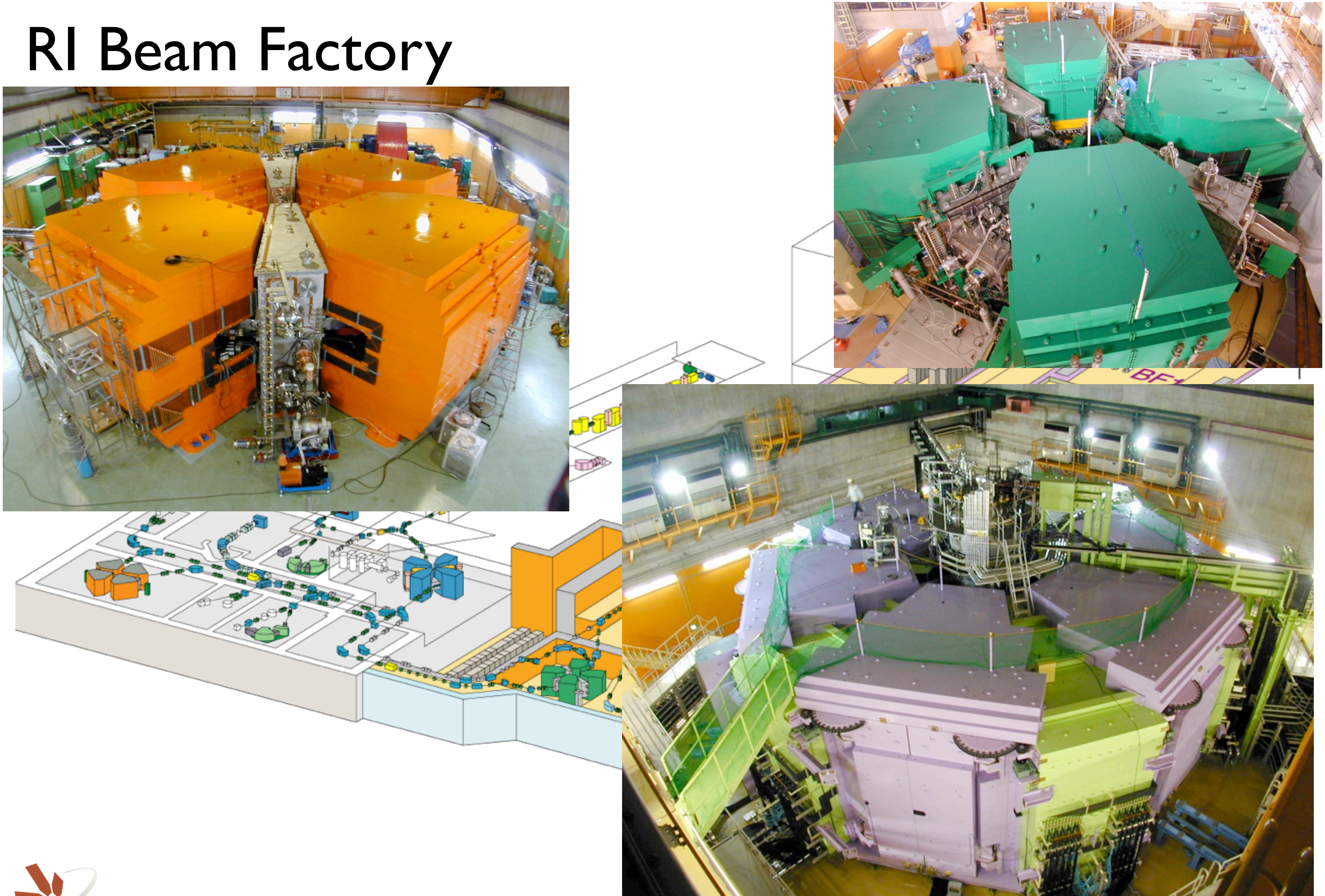
RI Beam Factory



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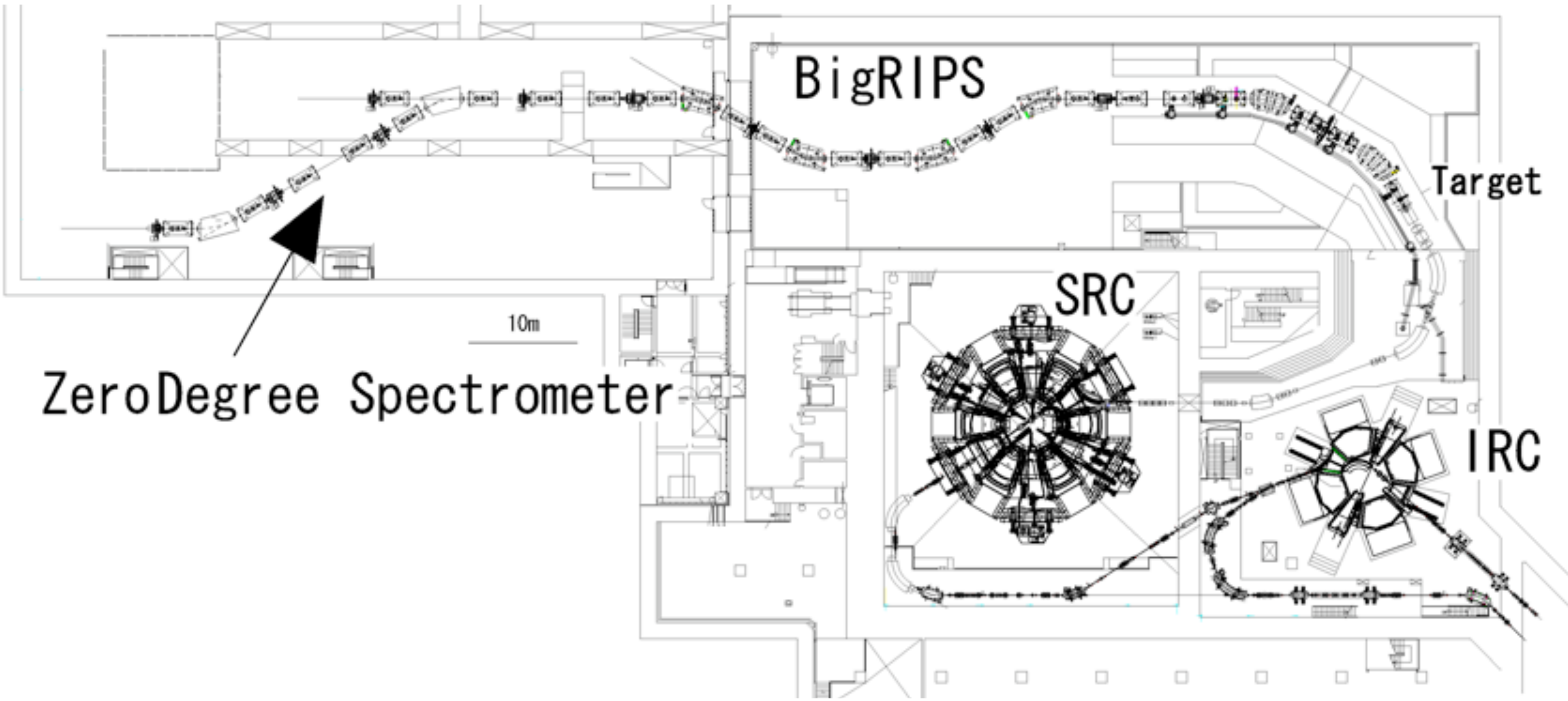
Pionic Atom Factory Project at the RIBF

（これまでの100倍のビーム強度）



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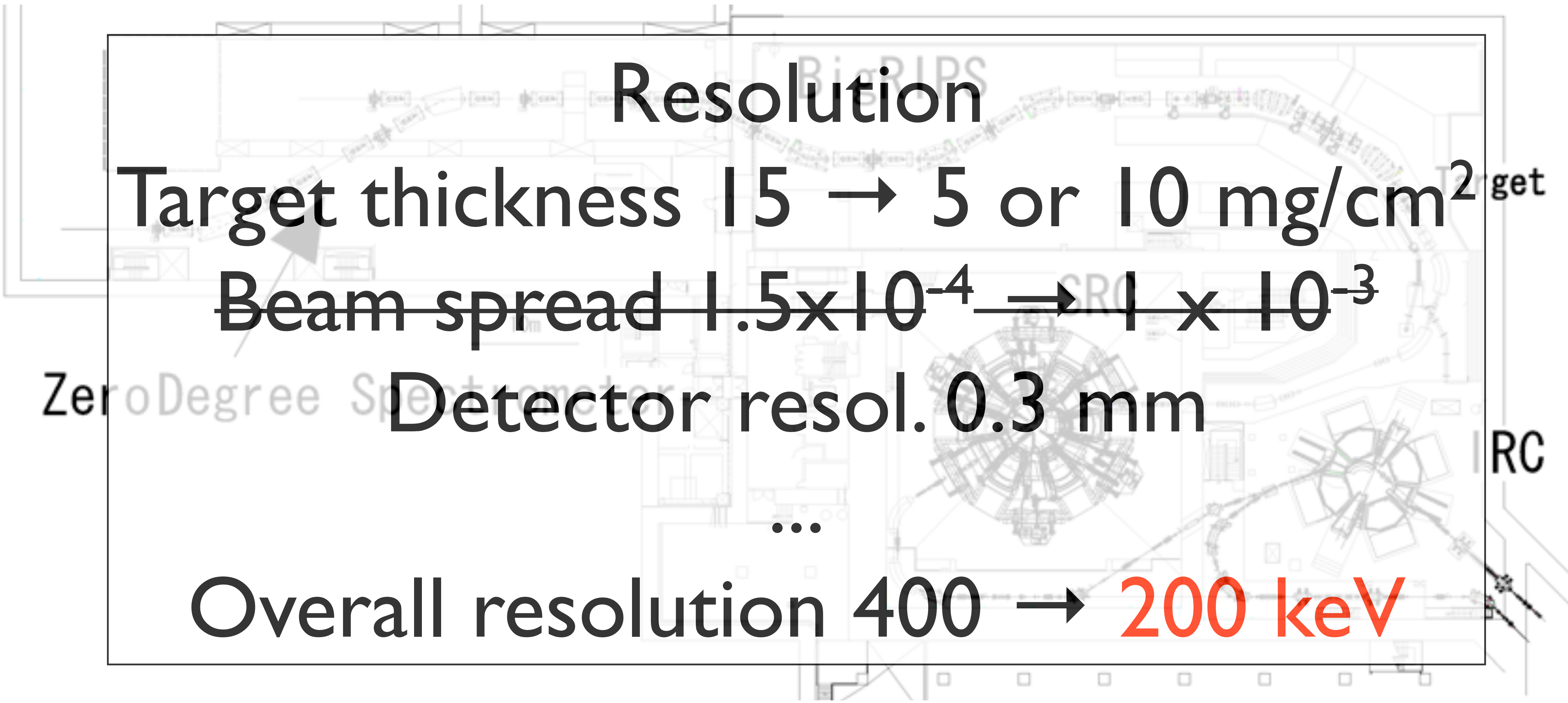

Resolution

Target thickness 15 → 5 or 10 mg/cm^2

~~Beam spread 1.5x10^{-4} → 1 x 10^{-3}~~

Detector resol. 0.3 mm

…

Overall resolution 400 → 200 keV

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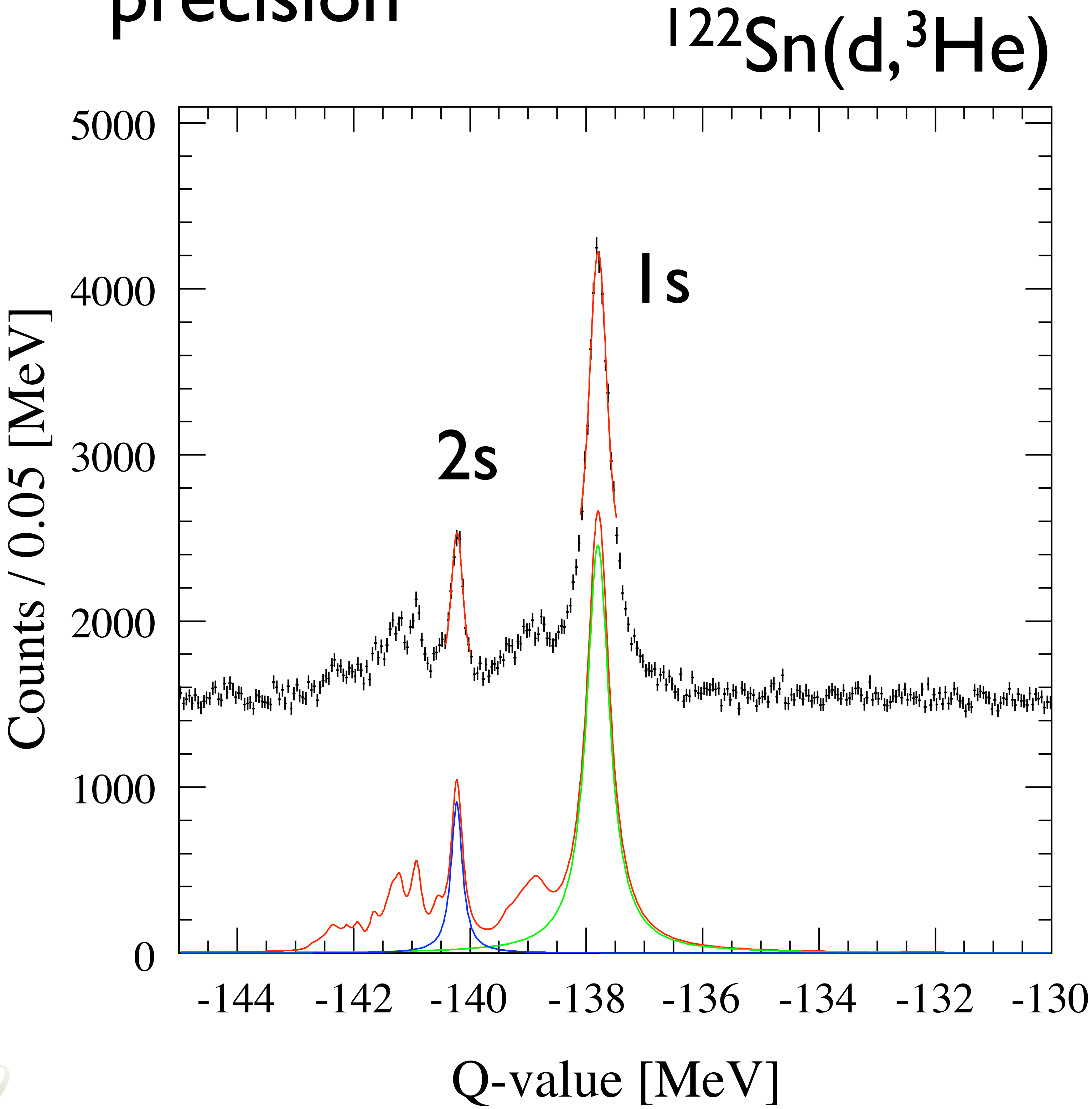
Expected spectrum and precision



Expected spectrum
(w/o q-free)

T_d = 500 MeV
Exp. Resol. (FWHM)
= 150 keV
(prev. 400 keV)

B.E. ± 9keV
(prev. 18~24 keV)

Based on Kimura's prediction

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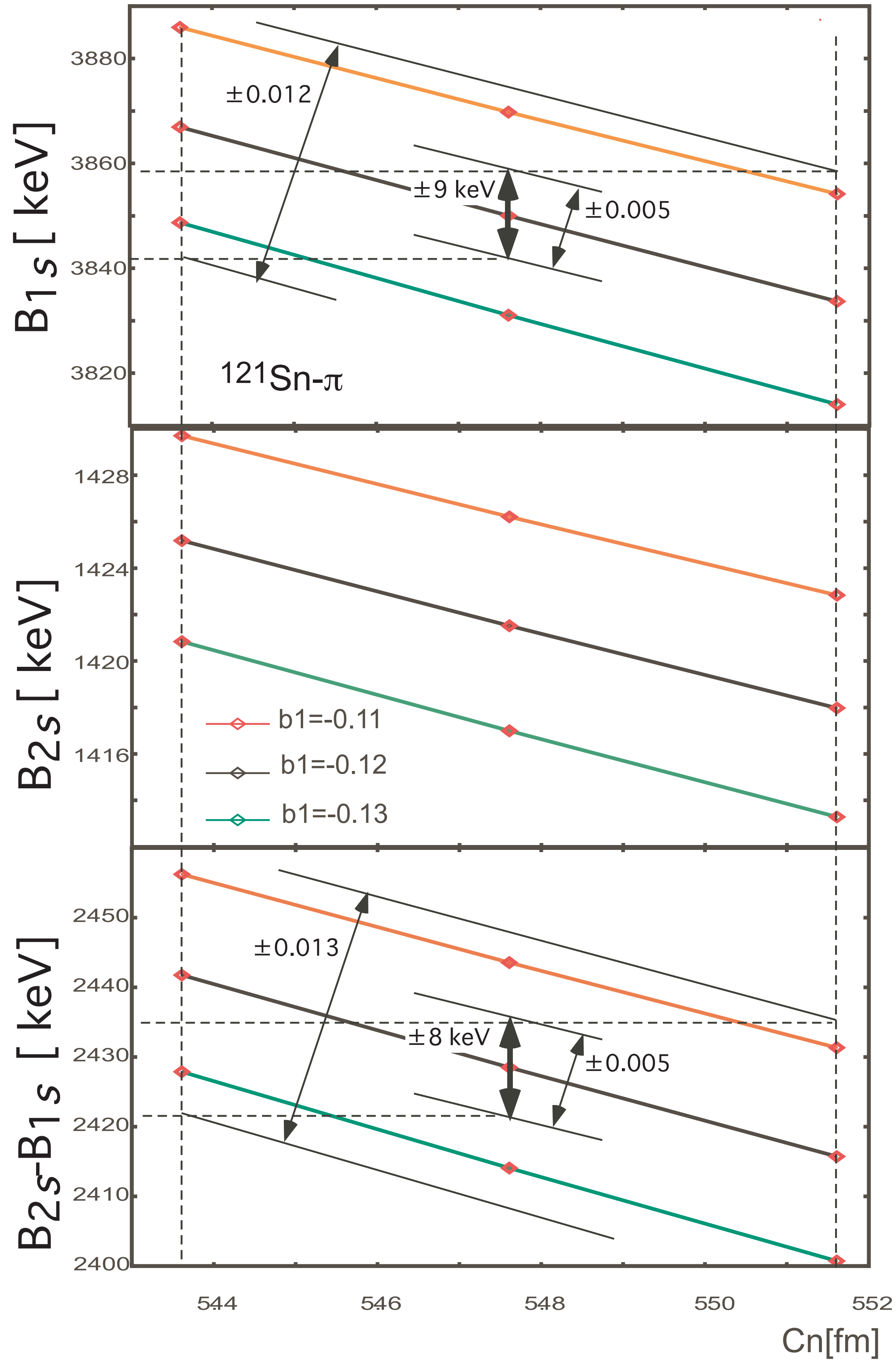
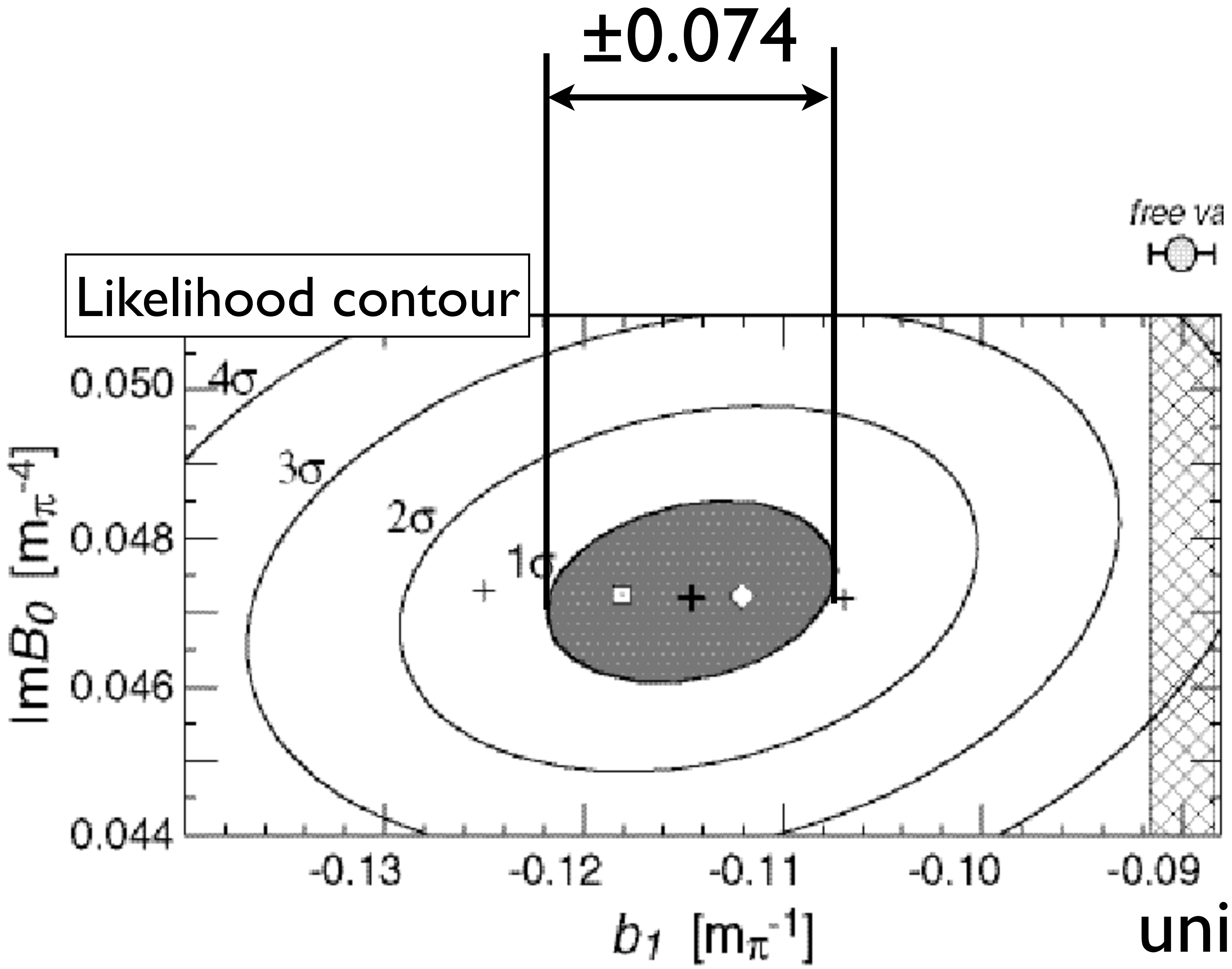


Kimura, Hirenzaki, Yamagata

Our first goals



units: m_π^{-1}

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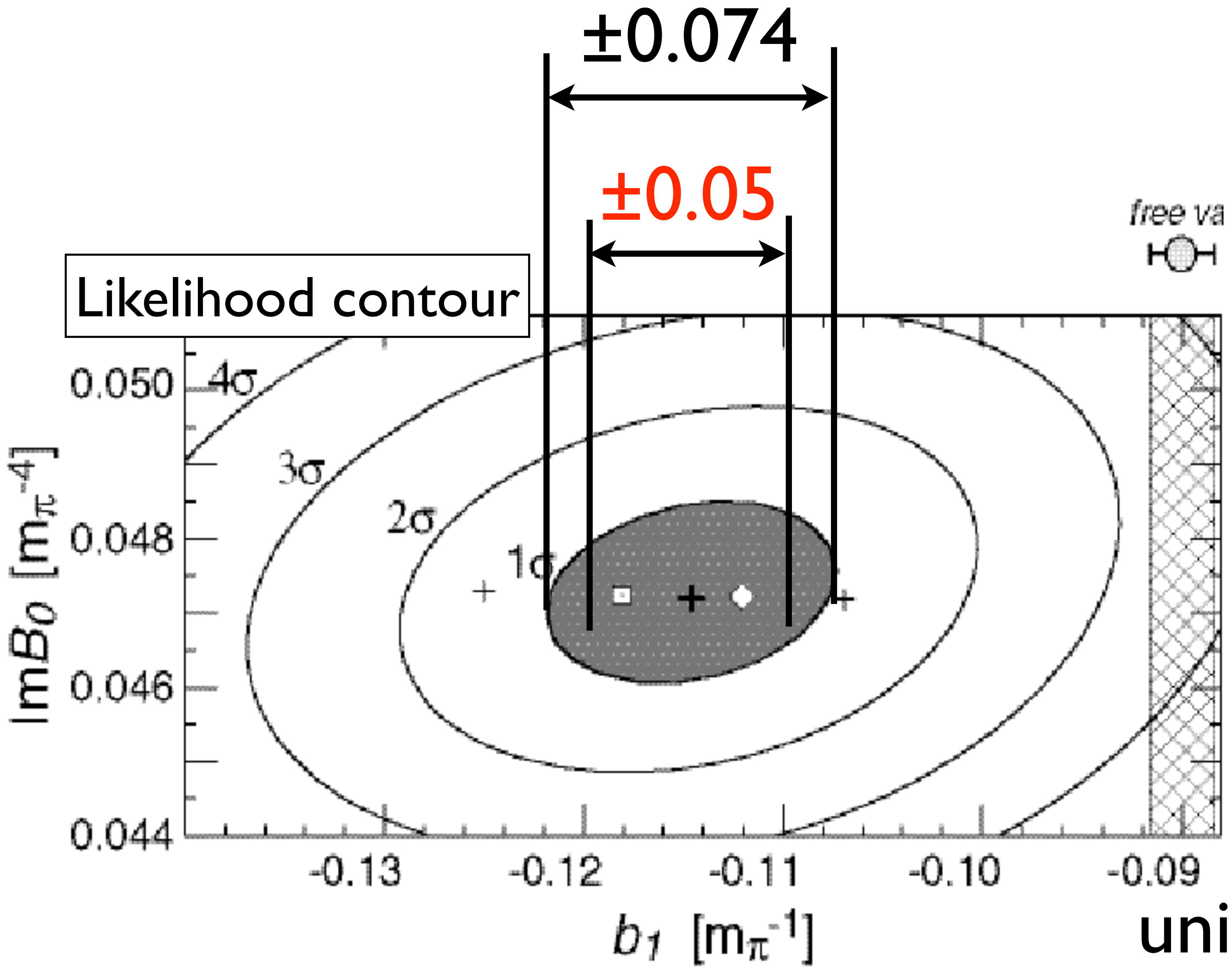
Our first goals



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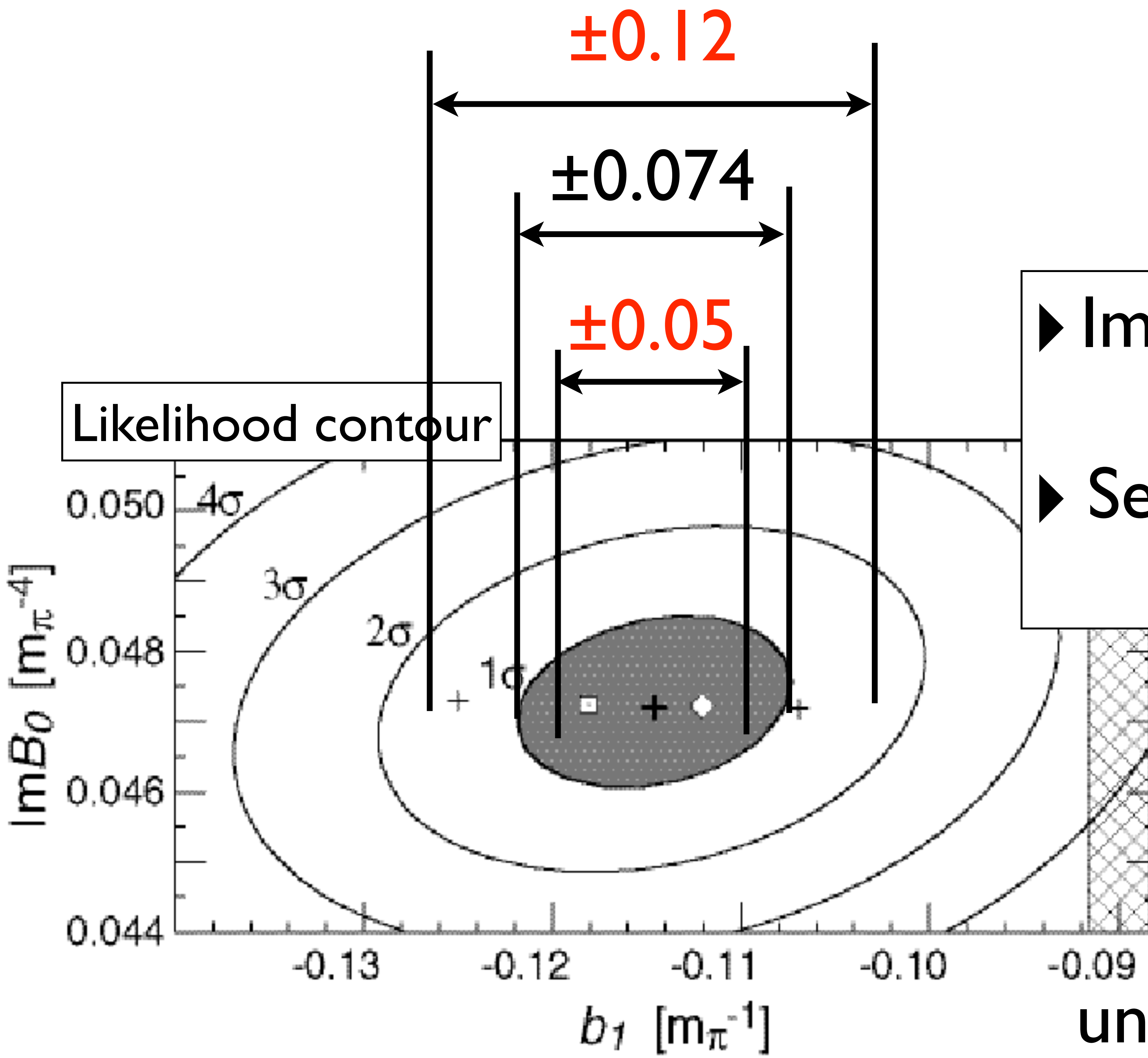
Our first goals



- Improve b_1 precision stat. ~ ±0.05
- Set systematic error syst. ~±0.12

units: m_π^{-1}

ただ、実験的には楽な事ばかりではない…

強度が 10 倍　○

運動量広がりが 10 倍　×

入射エネルギーの不定性が大きい　×

ビームのエミッタンスが大きい　×

…

泥臭い仕事が沢山

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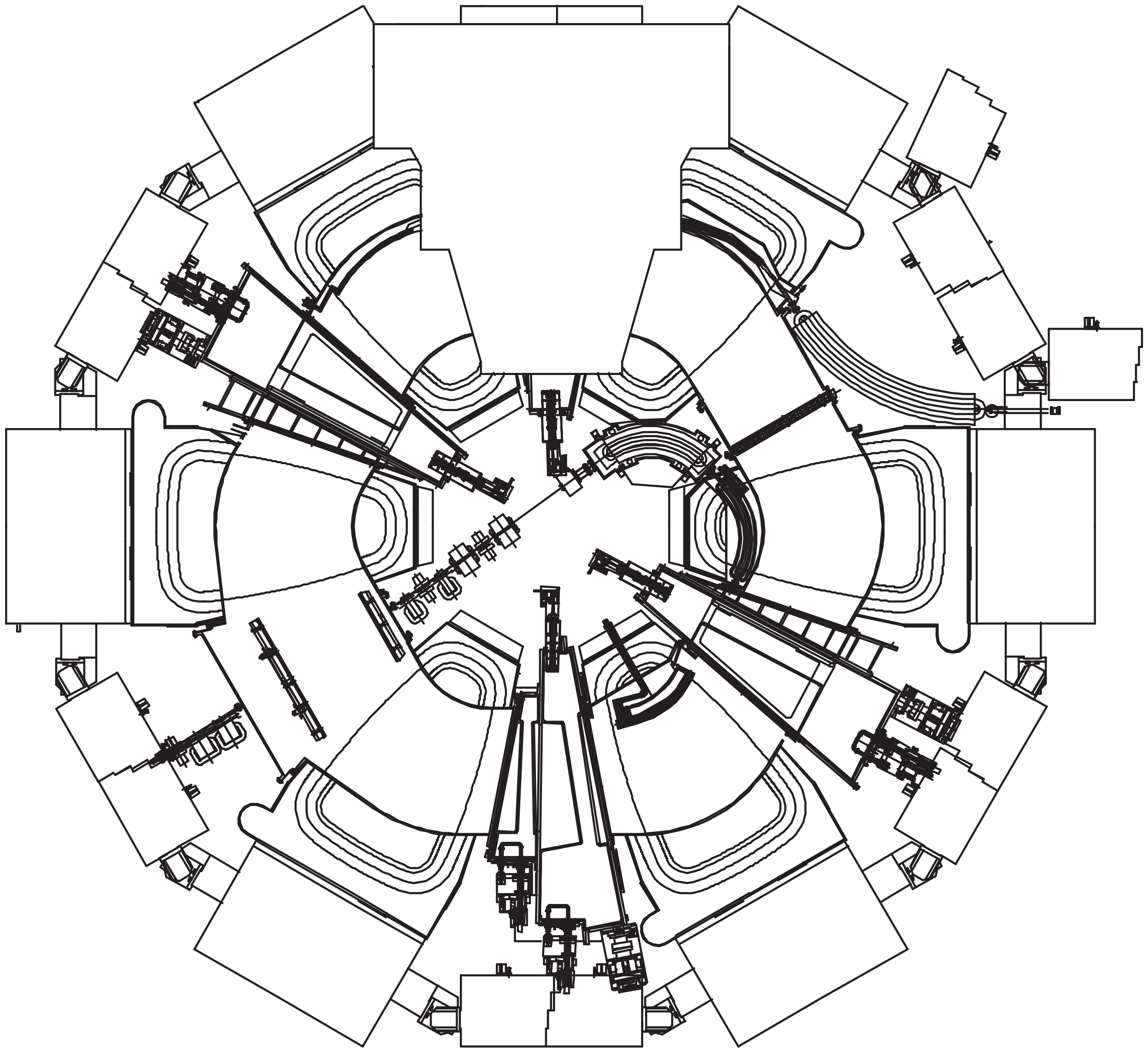
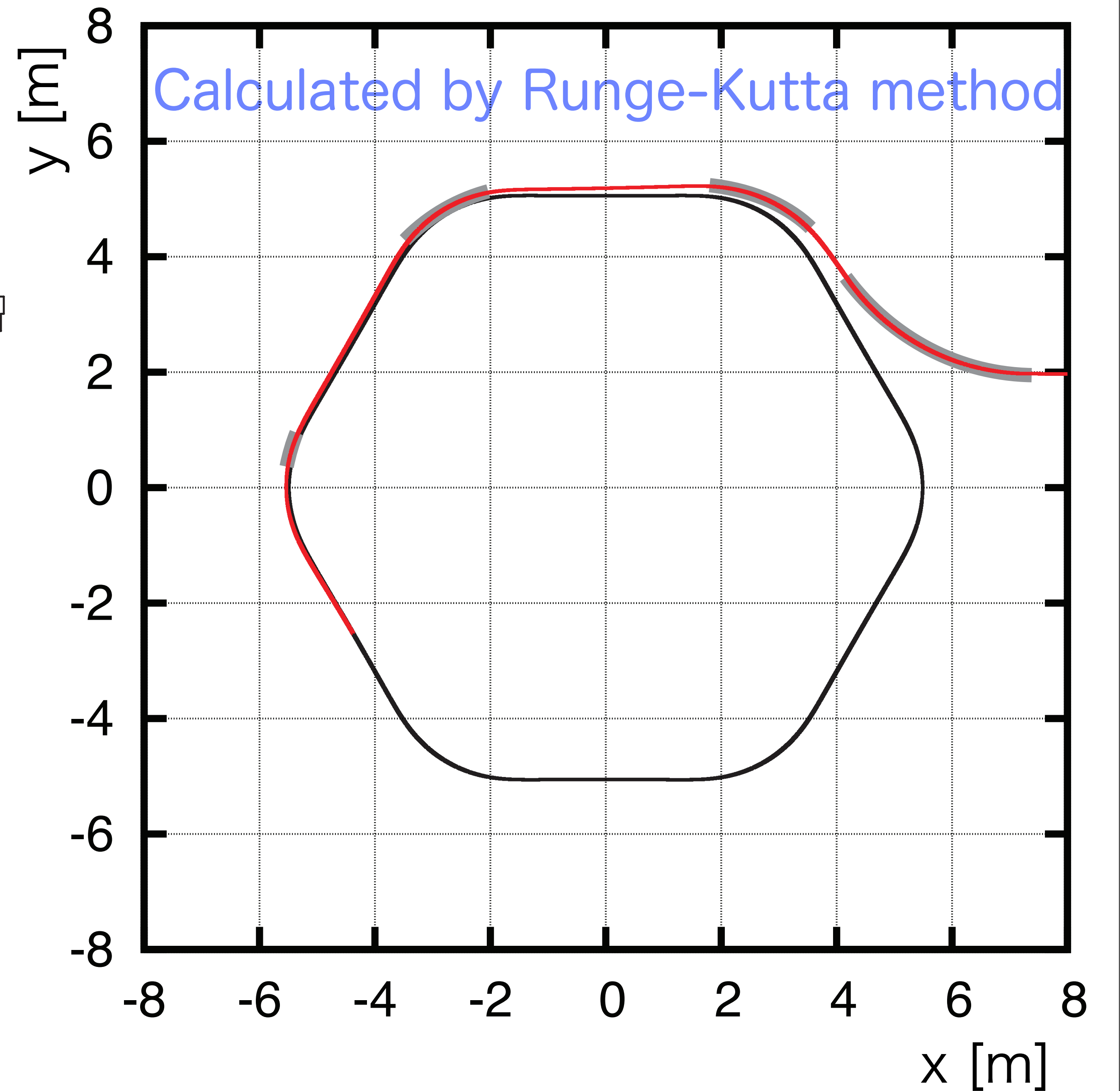
RIBF SRC





伊藤・福西

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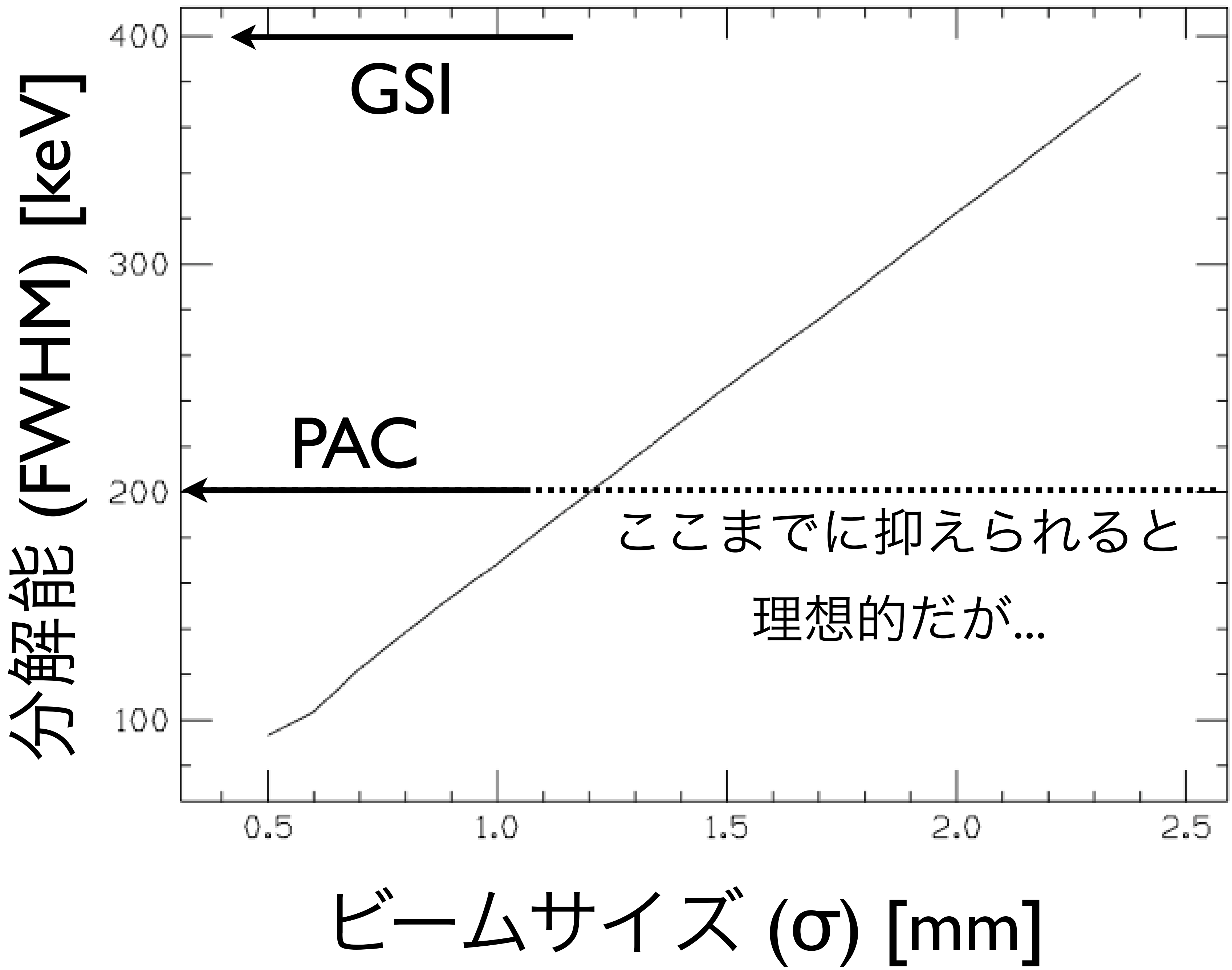
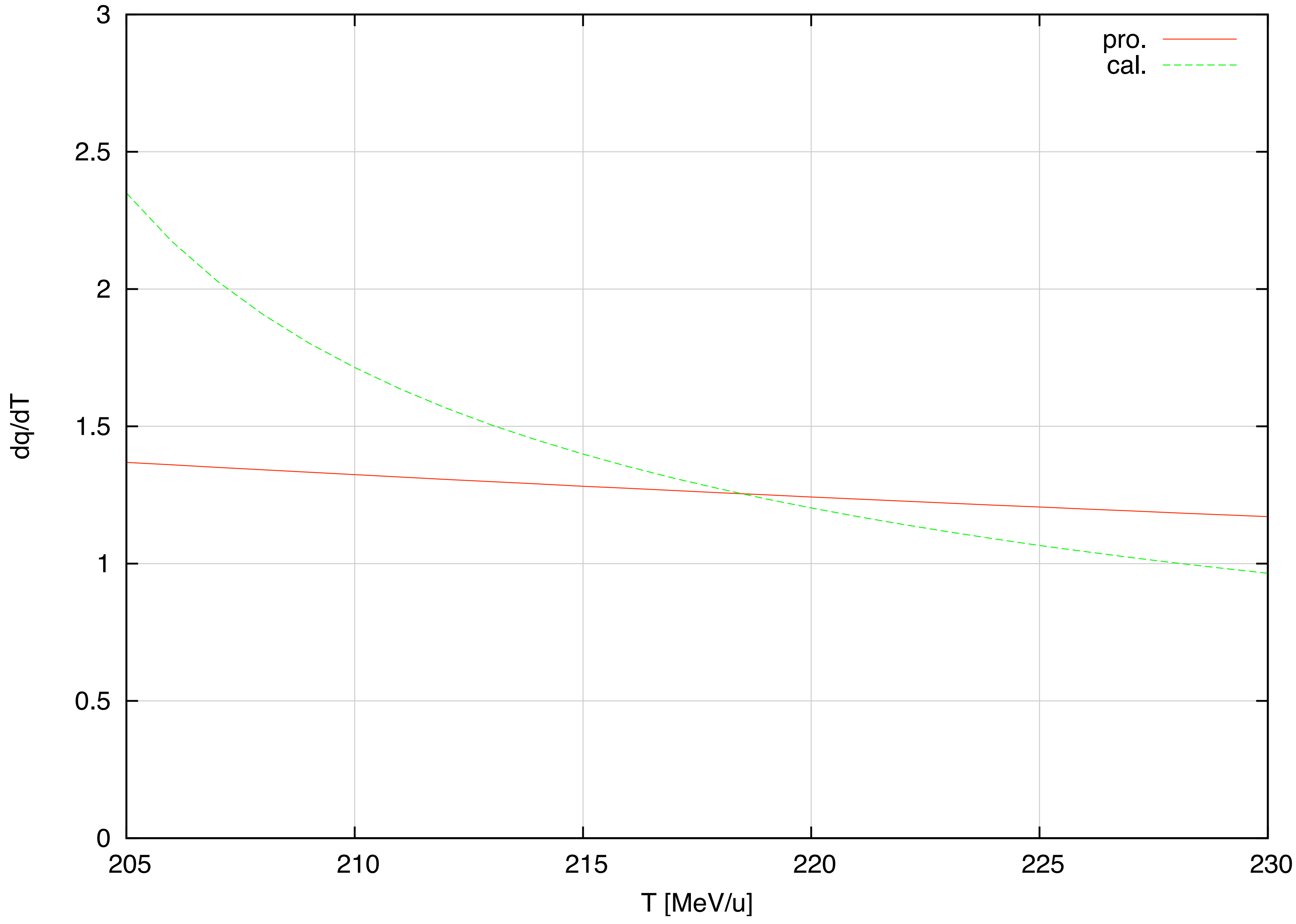
EBM での水平方向ビームサイズと分解能



入射エネルギーと較正誤差



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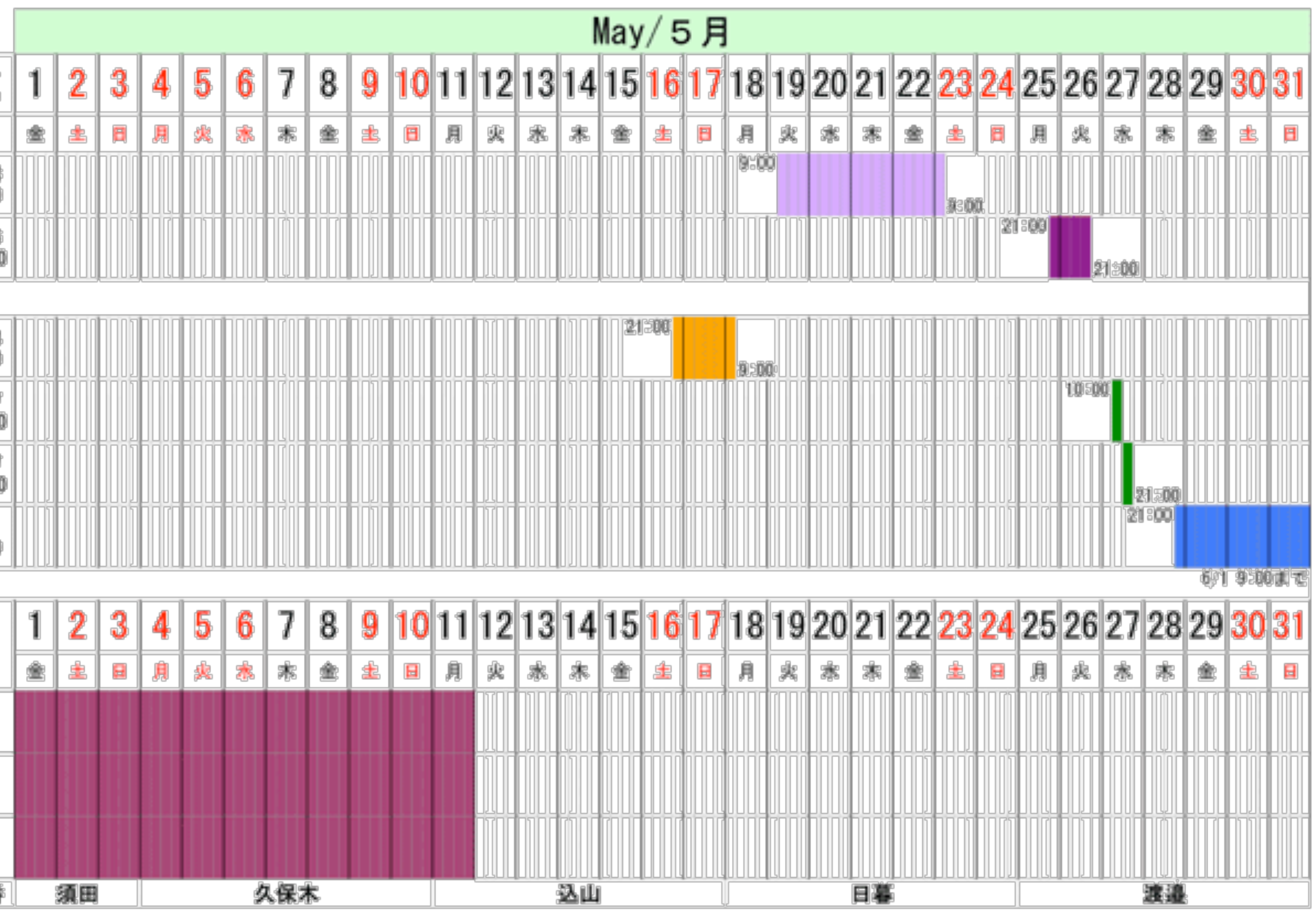
テスト実験(2009/5)

Beam Time schedule 2009年5月

2009/2/18

Proposal Number	Experiment Leader	Course	Particle	Energy (MeV/u)	Intensity	Time Frame (days)	start-time	end-time
AVF 単独								
NP0802 AVF46 -01	Wei-ping Liu	CRIB	^{10}B	8.5	500pnA	4	5/19 9:00	5/23 9:00
ML0702 AVF07 -07	篠原厚	E7b	^{12}C	7.3	1000pnA	1	5/25 21:00	5/26 21:00
AVF+RRC								
ML0707 RRC13 -03	久保山智司	E3A	Kr	70	1 pnA	1.5	5/16 21:00	5/18 9:00
IB0702 RRC01 -27	阿部知子	E5B	^{12}C	135	1 pnA	5hr	5/27 10:00	5/27 15:00
ML0702 RRC02 -25	泉雅子	E5B	^{12}C	135	1 pnA	6hr	5/27 15:00	5/27 21:00
NP0802 RRC49 -02	小沢顕	RIPS	^{18}O	100	100 pnA	3.5	5/28 21:00	6/1 9:00
RIBF								
NP0702 RIBF27 -02	板橋健太	BigRIPS	^{14}N	250	50 pnA	3	4/27	5/11
MS09 -01	小林俊雄	BigRIPS	^{14}N	>200	1 MHz	1	4/27	5/11
MS09 -02	上坂友洋	SHARAQ	^{14}N	250	10-250 pnA	7	4/27	5/11



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中間子束縛系研究の発展

π中間子原子

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中間子束縛系研究の発展

π中間子原子 → 系統的・高精度研究

カイラル対称性の破れ
＝質量の起源に迫る研究

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K中間子原子核

軽い中性子星
核密度より高い密度
（鈴木）

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π中間子原子 → η原子核

N*(1535) と関連して

バリオンのカイラル対称性

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RIBF

J-PARC

RIKEN Nishina Center, Kenta Itahashi

* Morimatsu, Yazaki NPA435(85)727
NPA483(88)493

by Green function method*

T_π = 820 MeV (p_π = 950 MeV/c) : θ = 0 deg.

recoilless at η threshold

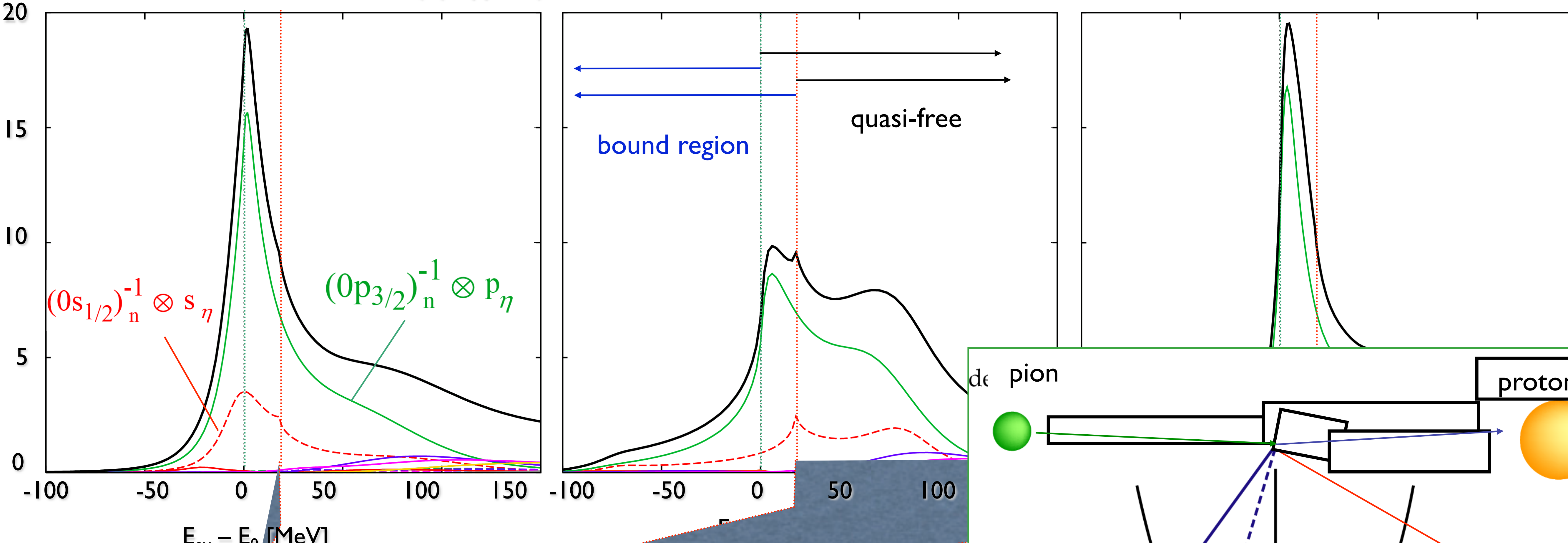
η production threshold

$\frac{d^2\sigma}{dEd\Omega}[\mu b/srMeV]$

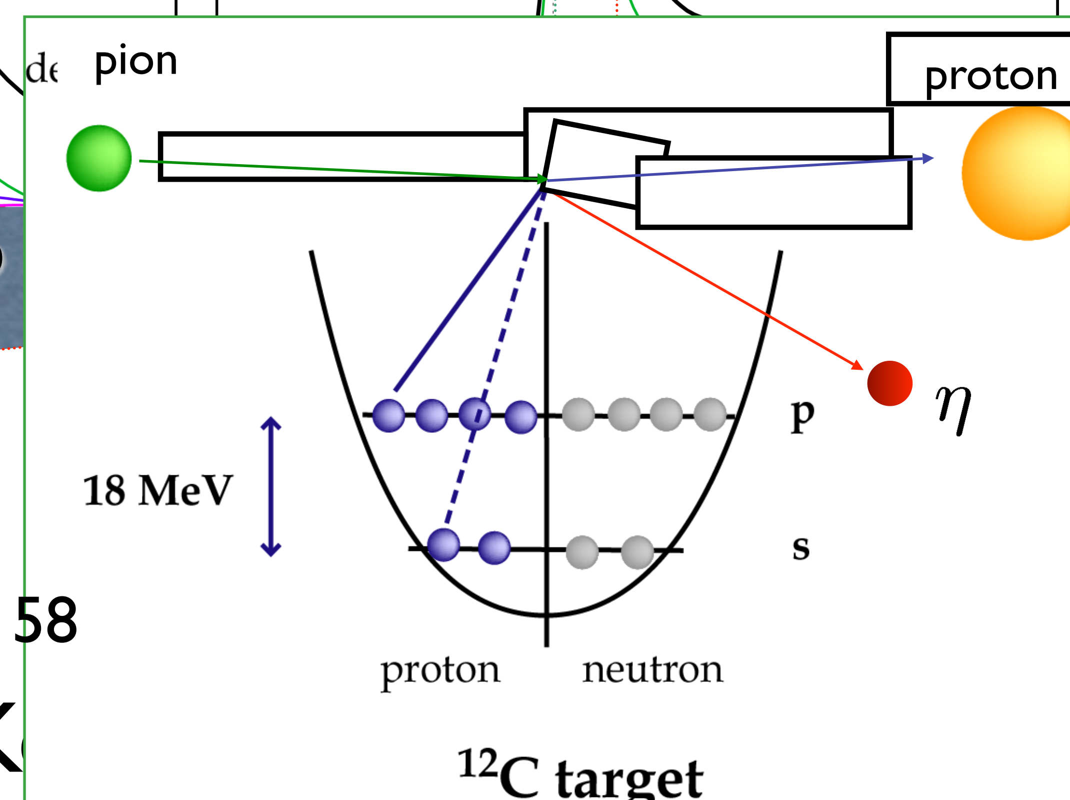
Chiral doublet model [C=0.0] (t-ρ approx.)

Chiral doublet model [C=0.2]

Chiral unitary model



η production threshold (s-state proton-hole)



Jido, Kolomeitsev, Nagahiro, Hirenzaki, NPA 811 (08)158

RIKEN Nishina Center, K

Letter of Intent for J-PARC

Spectroscopy of η mesic nuclei by (π^-, n) reaction at recoilless kinematics

K. Itahashi[a1], H. Fujioka[b2], S. Hirenzaki[c], D. Jido[d], and H. Nagahiro[e].

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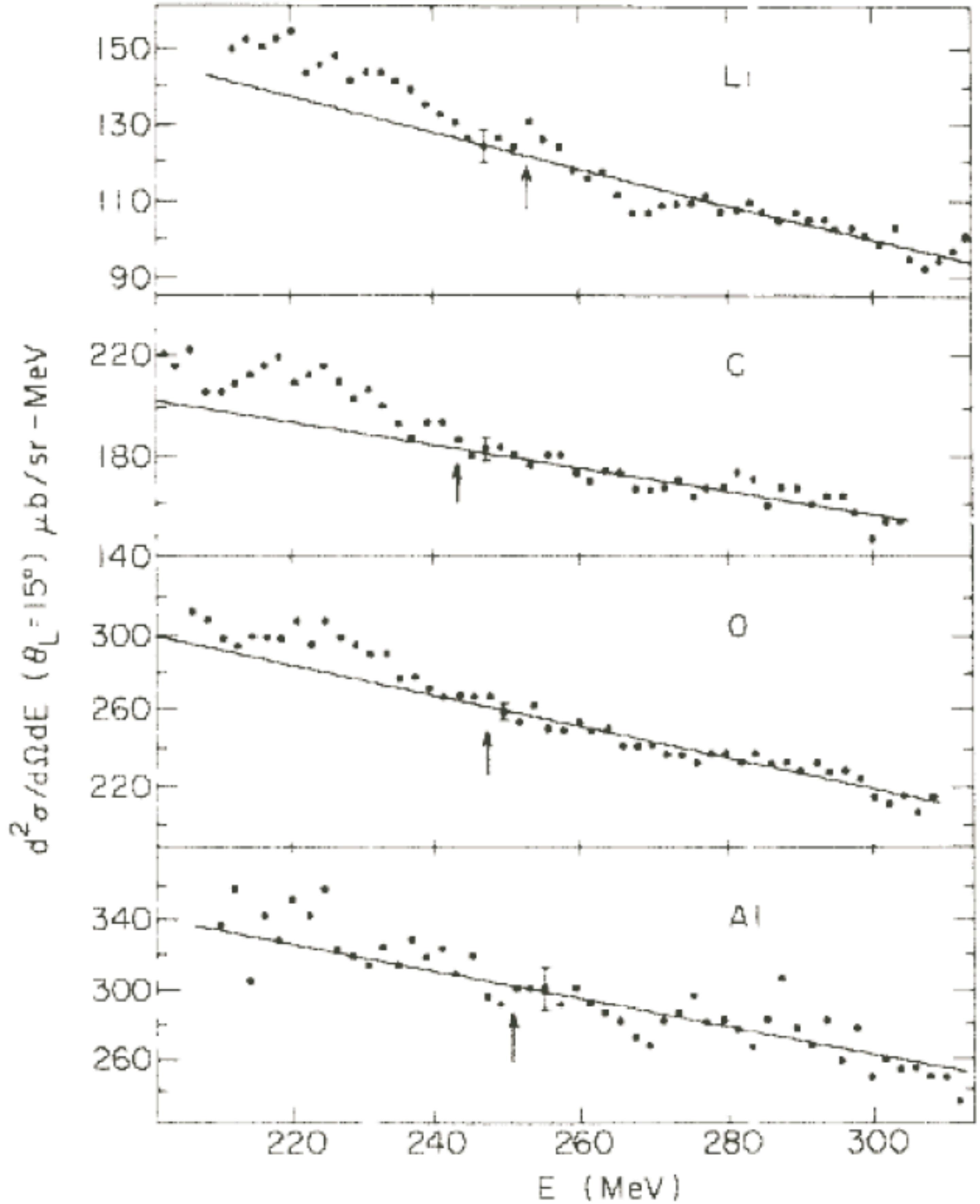
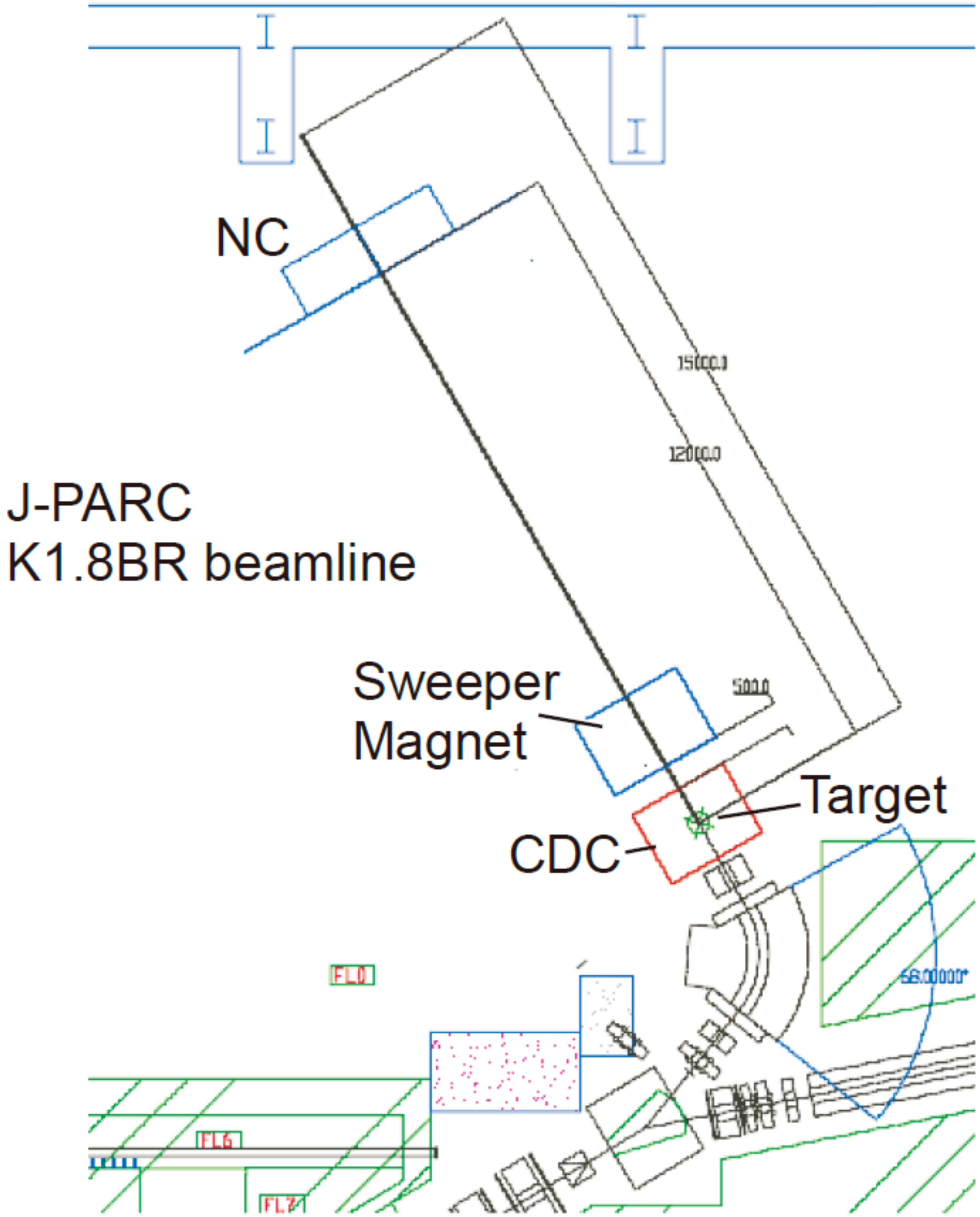
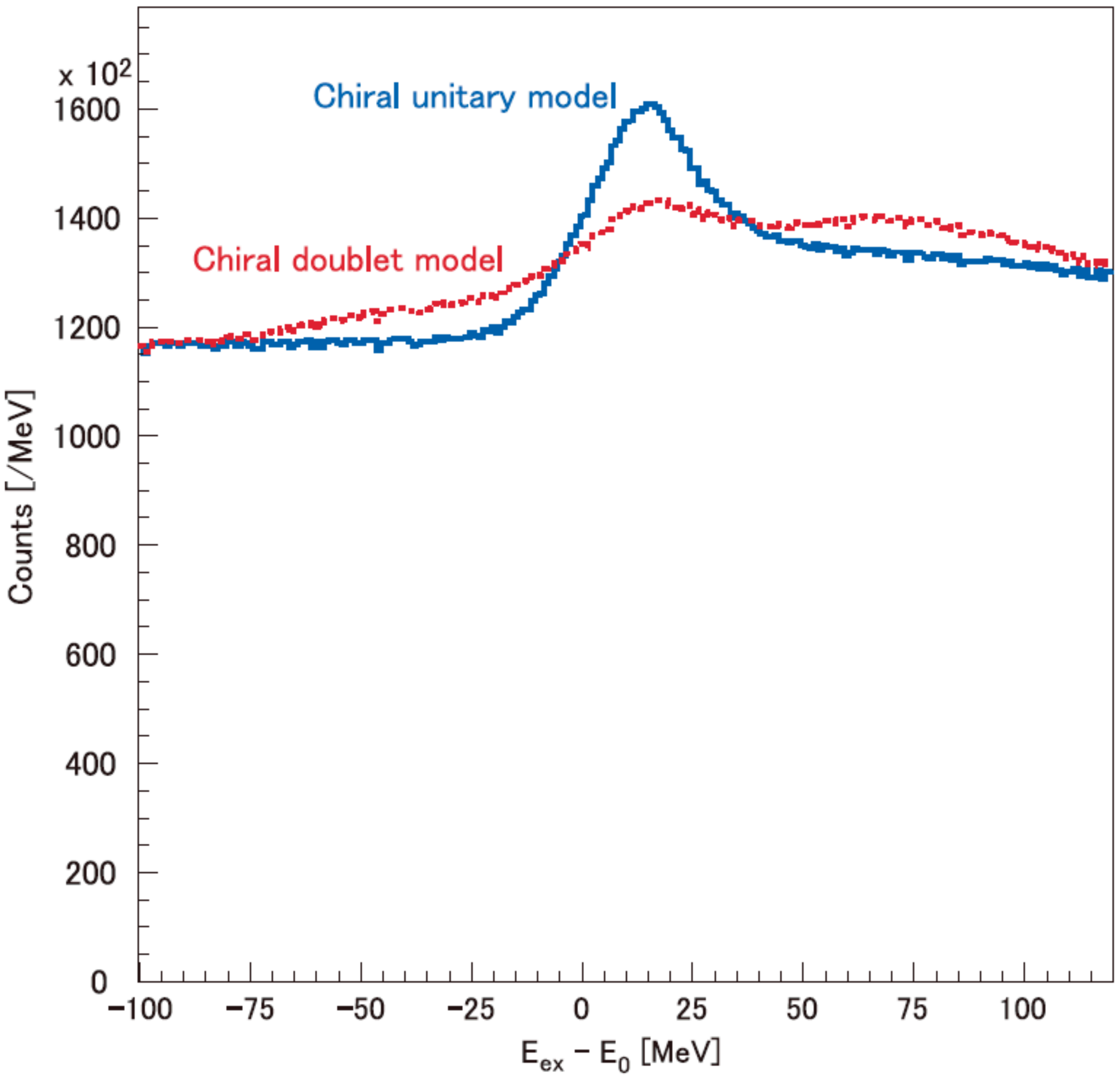
(π⁺,p) at 740 MeV/c



Chrien et al.
PRL60(88)2595

おそらく、decay mode と
タギングが鍵





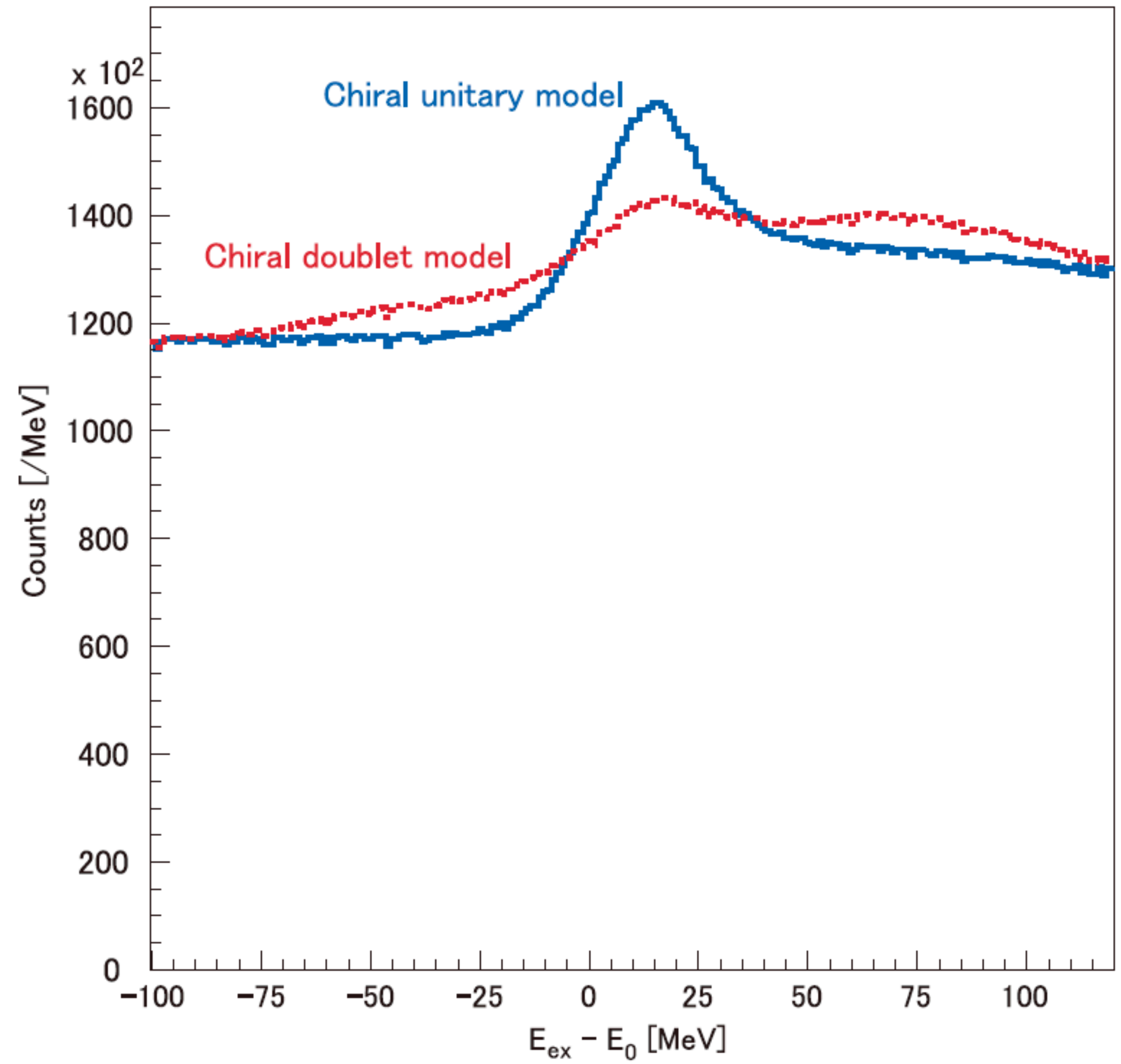
おそらく、decay mode と
タギングが鍵

free space なら

n* → p π⁻ q=400 MeV/c

in-medium なので

N*N → NN とかも？



議論とTodoと理論への要望(?)

η中間子原子核

- 崩壊モードをタグした時のBK評価
- (π^-,n) @ q = 0 と (π^+,p) @ q>0 の比較
- 出来たら、parasite で少しデータを取りたい...

π中間子原子

- $b_1(\rho)$ を決めるには何を計測すれば良い？
  = 束縛エネルギー以外の計測値の取り扱い
- π 二個入り？

中間子束縛系の研究

強い相互作用

カイラル対称性＝物質質量の起源

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カイラル対称性＝物質質量の起源

束縛状態＝量子力学的に決定＝不定性が小さい

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高精度の実験 ⟷ 高精度の理論

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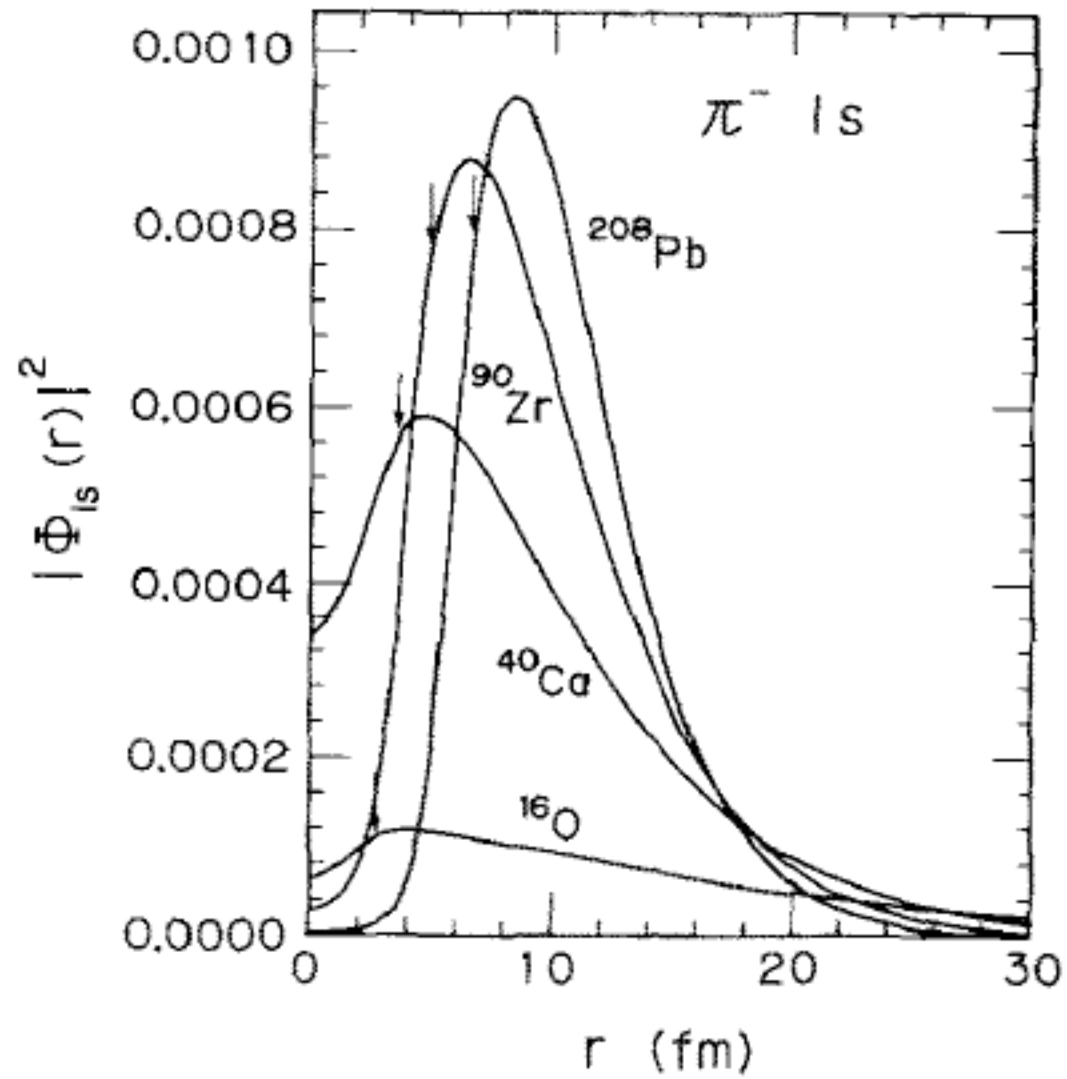

Toki et al., NPA501(89)653.