NP08, 5-7 March, 2008 in Mito

Hypernuclear Spectroscopy with a High-Resolution Beam Line

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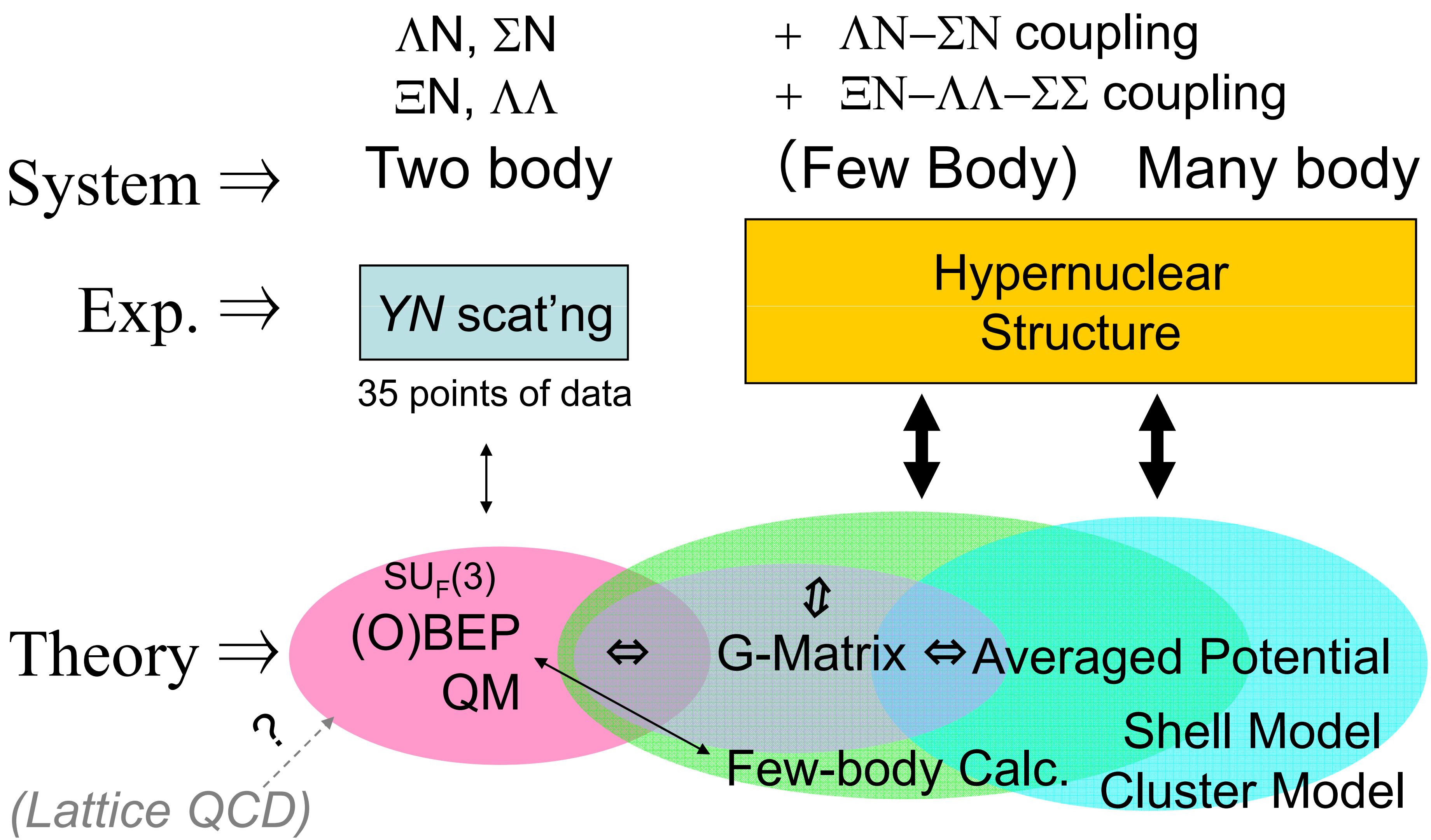
Mito Plaza Hotel

Precision Hypernuclear Spectroscopic Data
reveal *the Baryon-Baryon Interactions*
in collaboration with Precision Theoretical Calculations



BB Interaction through Hypernuclear Spectroscopy

- *In Λ hypernuclear system, the frameworks work very well, demonstrating that:*
  - *Single-Particle Structure: $B_\Lambda \rightarrow U_\Lambda$ G-matrix concept: Good*
  - *Spin-Spin, Spin-Orbit splitting: ΛN spin-dependent force*

→ BB Potential Models, reproducing Λ Single-Particle Potential

TABLE XIX: Values of U_Λ at normal density and partial wave contributions for ESC04a-d and NSC97e/f obtained from the G-matrix calculations with the QTQ intermediate spectra. All entries are in MeV.

	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Λ
ESC04a	–13.7	–20.5	0.6	0.2	0.5	–4.5	–1.0	–38.5
ESC04b	–13.3	–22.6	0.5	–0.0	0.6	–4.3	–1.1	–40.2
ESC04c	–13.9	–28.5	2.9	0.0	1.3	–6.5	–1.3	–46.0
ESC04d	–13.6	–26.6	3.2	–0.2	0.9	–6.4	–1.4	–44.1
NSC97e	–12.7	–25.5	2.1	0.5	3.2	–1.3	–1.2	–34.8
NSC97f	–14.3	–22.4	2.4	0.5	4.0	–0.7	–1.2	–31.8

Th. A. Rijken and Y. Yamamoto, Phys.Rev.C73: 044008,2006

BB Potential Models and Σ Single-Particle Potential

- U_{Σ}'s are to be repulsive. (E438 exp.)
  → To be improved in ESC07
- U_{Ξ}'s will be examined in J-PARC (E05, ...)

TABLE XXII: Values of U_{Σ} at normal density and partial wave contributions for ESC04a-d and NSC97f (in MeV).

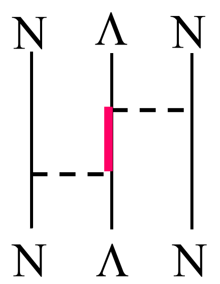
	T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_{Σ}
ESC04a	1/2	11.6	–26.9	2.4	2.7	–6.4	–2.0	–0.8	
	3/2	–11.3	2.6	–6.8	–2.3	5.9	–5.1	–0.2	–36.5
ESC04b	1/2	9.6	–25.3	1.8	1.6	–5.4	–2.1	–0.7	
	3/2	–9.6	9.9	–5.5	–1.9	5.4	–4.6	–0.2	–27.1
ESC04c	1/2	6.4	–20.6	2.4	2.9	–6.7	–1.6	–0.9	
	3/2	–10.7	6.9	–8.8	–2.6	6.0	–5.8	–0.2	–33.2
ESC04d	1/2	6.5	–21.0	2.6	2.4	–6.7	–1.7	–0.9	
	3/2	–10.1	14.0	–8.5	–2.6	5.9	–5.7	–0.2	–26.0
NSC97f	1/2	14.9	–8.3	2.1	2.5	–4.6	0.5	–0.5	
	3/2	–12.4	–4.1	–4.1	–2.1	6.0	–2.8	–0.1	–12.9

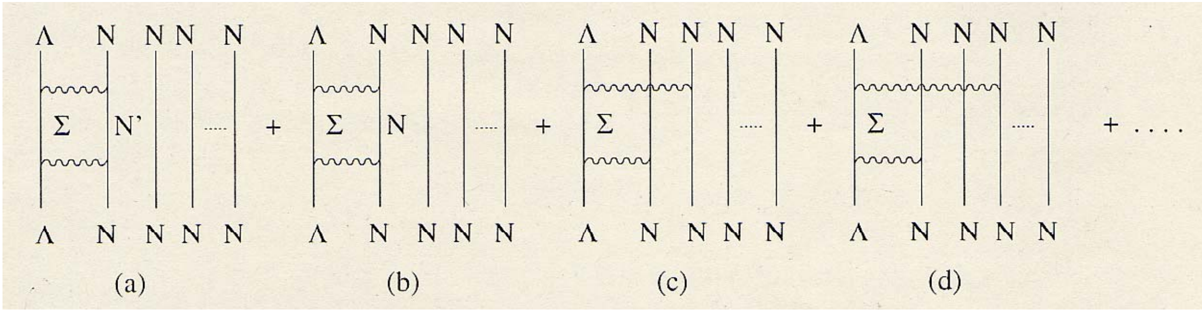
Th. A. Rijken and Y. Yamamoto, Phys.Rev.C73: 044008,2006

BB Interaction through Hypernuclear Spectroscopy

➢ In J-PARC, What would be investigated else?

- ✓ Ξ-nuclear system (S=-2): E03, E05, E07, ...
- ✓ Σ-nuclear system: Repulsive U_Σ (KEK-PS E438)
  YN(YA) scattering?→Miwa's Talk (Tamura's LOI, 2007)
  Coulomb Assisted Hybrid Bound State? or a few-body system?
- ✓ Neutron-Rich Λ hypernuclear system:
  - ΛΣ mixing effect in medium: Many-Body Force
    ΛN-ΣN coherent coupling effect in I≫0 Nucle





...may affect:

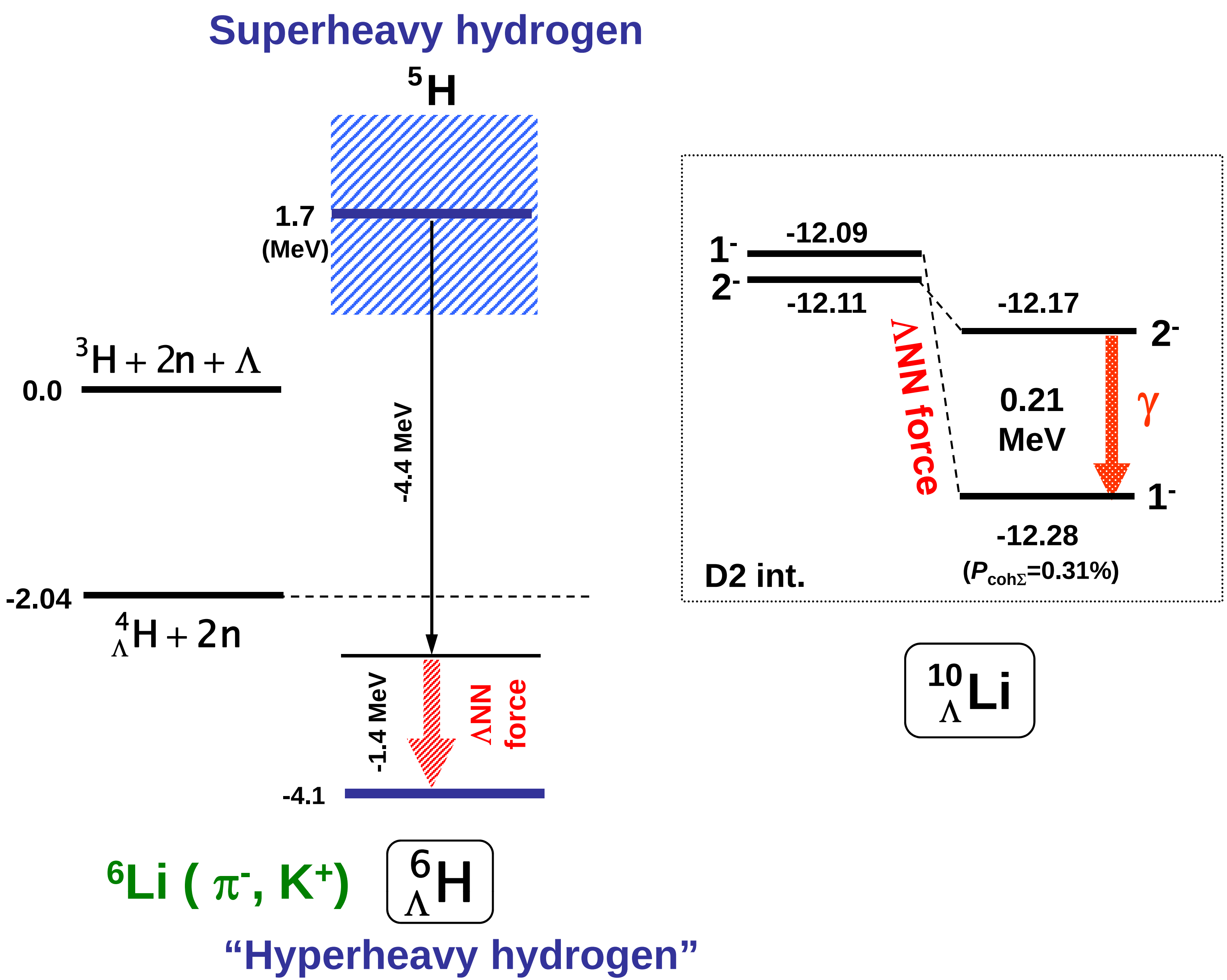
Λ Binding Energy: B_Λ

production mechanism of n-rich Λ hypernuclei

- ✓ High Dense Nuclear Matter: *i.e.* Neutron Star Core
  - ΛΣ coupling effect
  - density dependent of U_Λ

...may affect the EoS of NS

ΛΣ Coherent Coupling Effect　　Y. Akaishi et al.



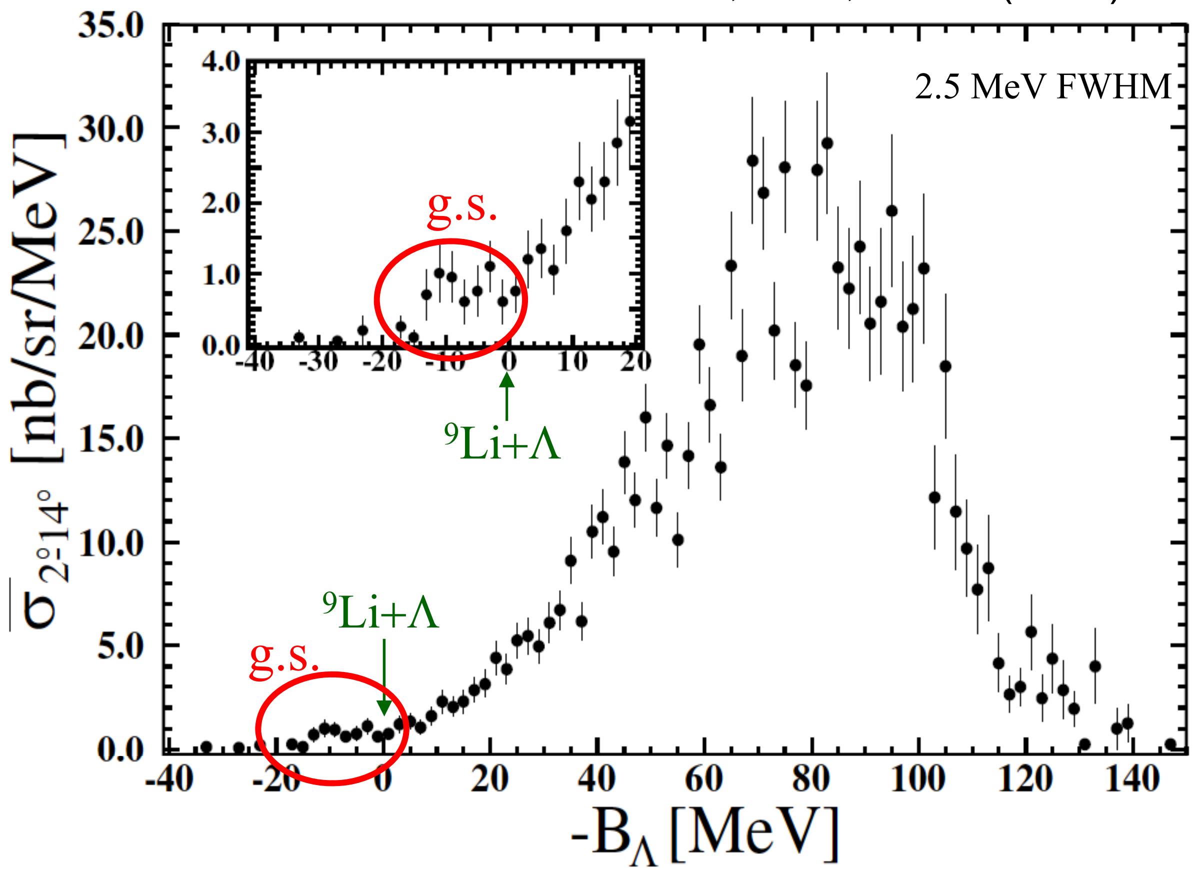
First Observation of n-rich $^{10}_{\Lambda}$Li via the (π^-,K^+) reaction at KEK-PS

$d\sigma/d\Omega$ = 11.3$\pm$1.9 nb/sr at 1.2 GeV/c

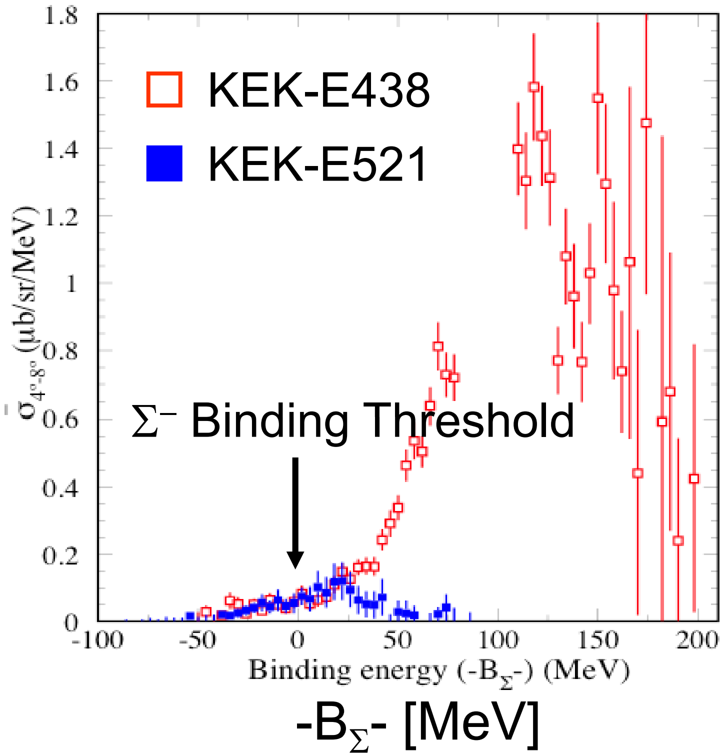
as small as ~1/1000 of (π^+,K^+)

→ the Λ state produces via Σ component through $\Lambda\Sigma$ coupling ?

KEK-PS-E521 P. K. Saha, et al., PRL94(2005)052502

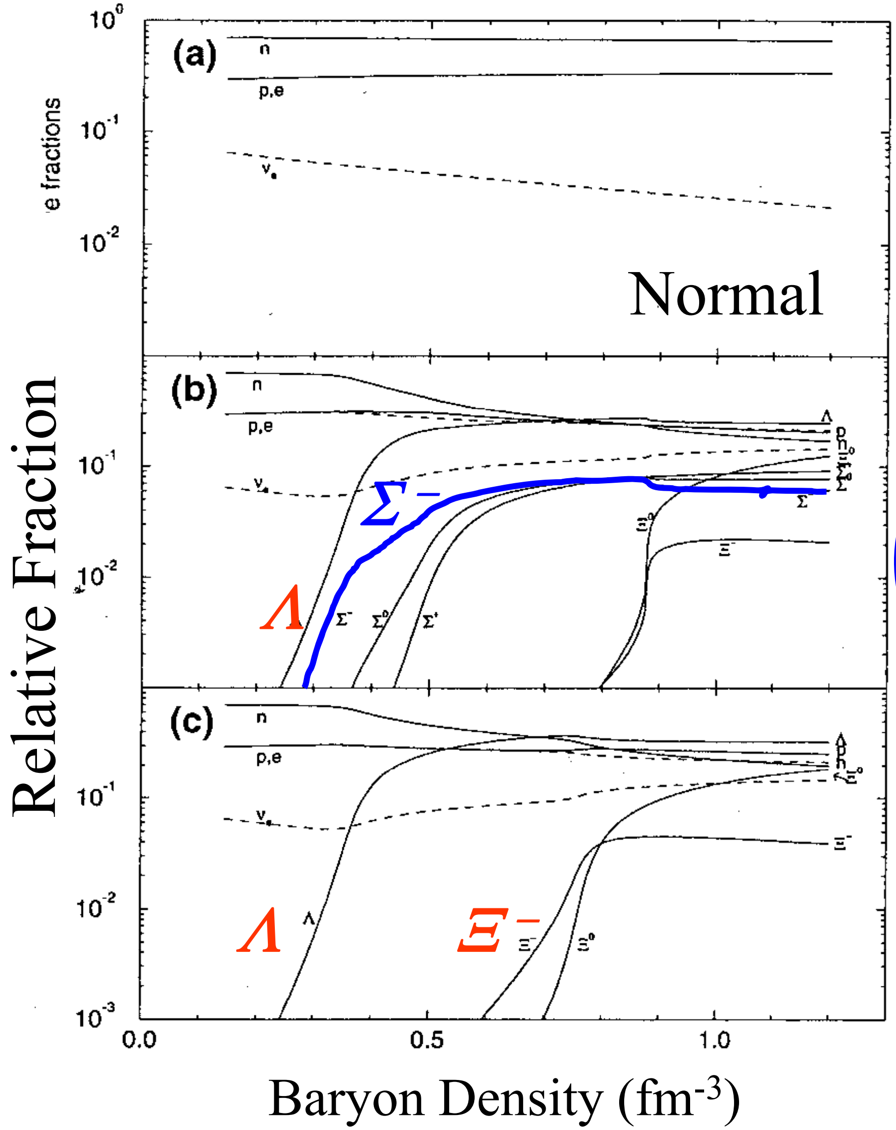


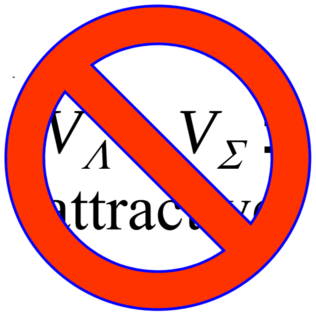
consistent w/
Absorptive
Imaginary Σ-Nucl. Potential



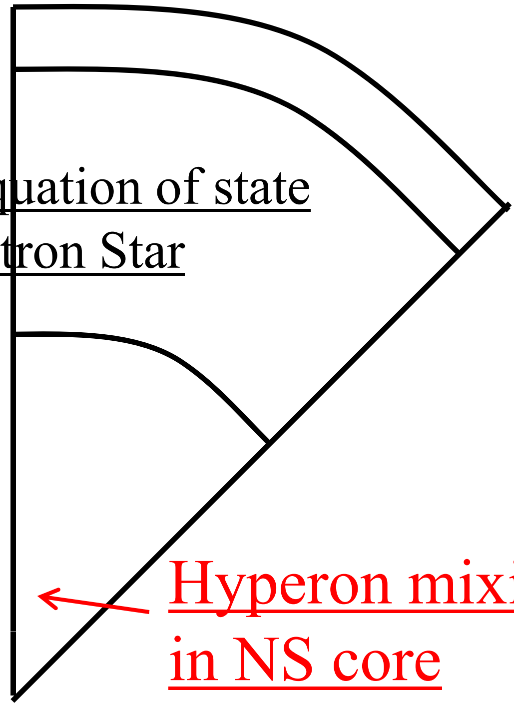
Impact of Hyperon-Nucleus Potentials on Hyperon Constituent in Neutron Star Cores

S. Balberg and A. Gal, NPA625(1997)435





The Equation of state of Neutron Star



Hyperon mixing in NS core makes the EoS soft.

V_Σ : repulsive

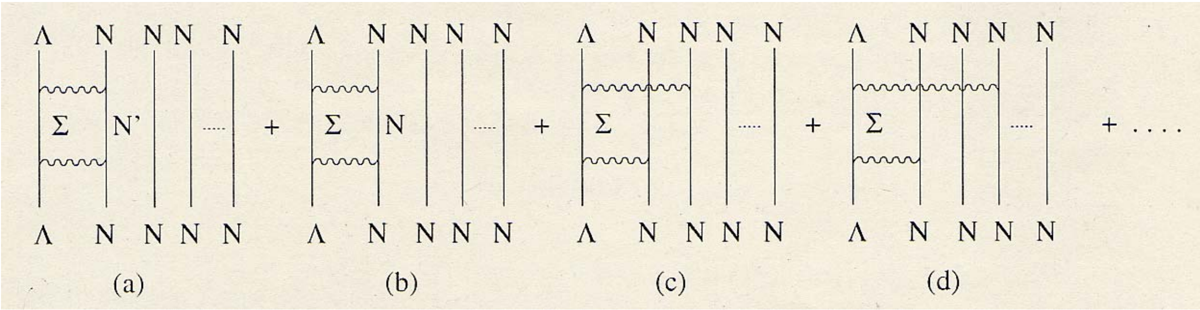
V_Ξ : attractive

M_{NS}<1.44$M_\odot$

if V_Ξ>0, Kaon Condensation?

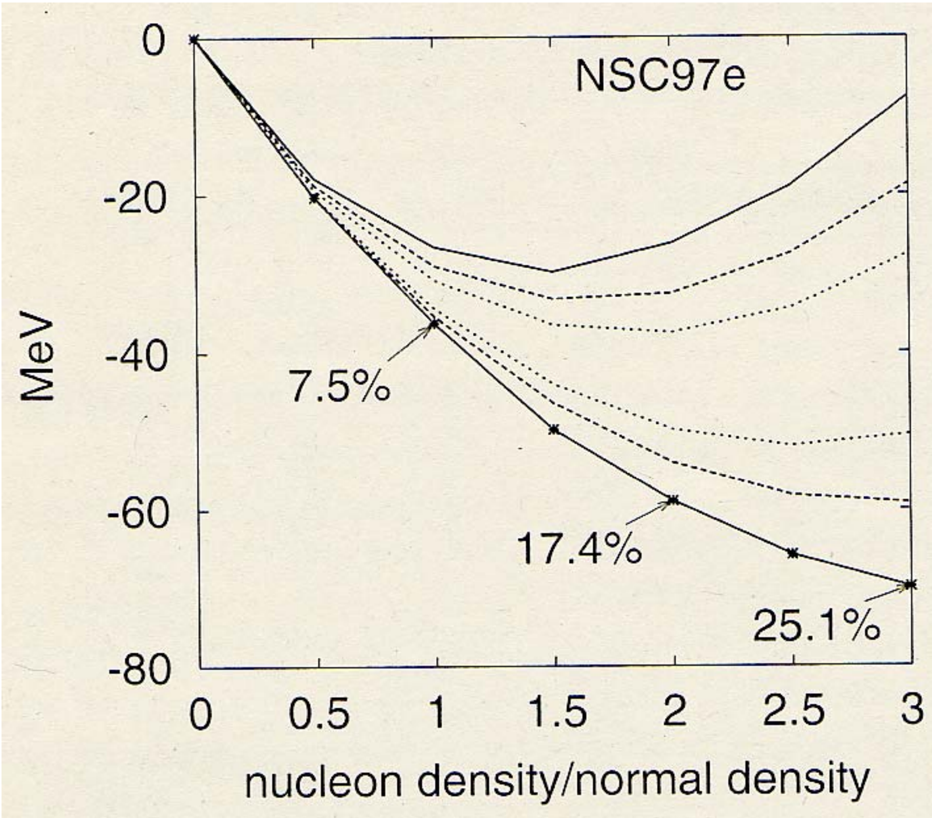
Role of the Λ N-ΣN coupling in Neutron Star Cores

S.Shinmura, K. S. Myint, T. Harada, and Y. Akaishi, J. Phys. G28(2002)L1



coherent Λ→Σ
w/o exciting N
(b)~(d)…
No effect in T=0

Single-particle Λ potential in neutron matter (*T*=∞)



p=0%
p=10%
p=20%

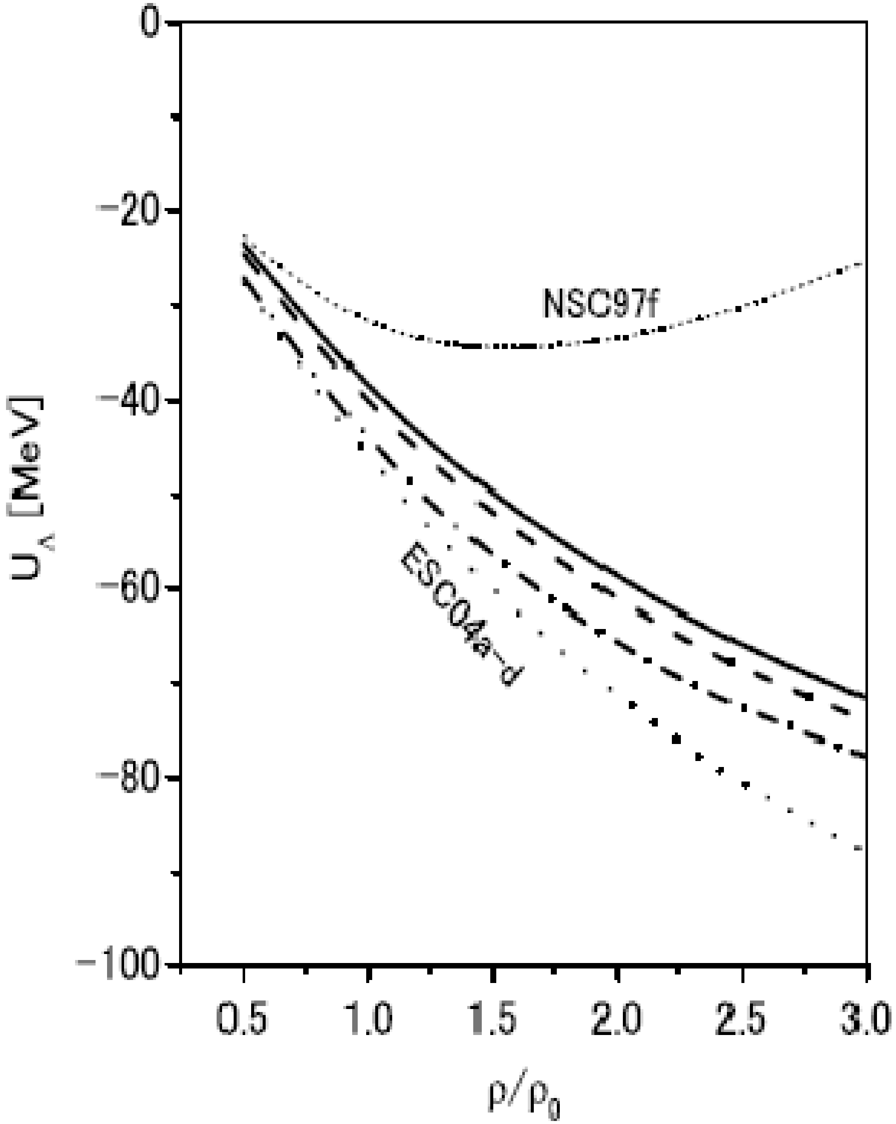
without coherent *ΛN-ΣN coupling*

p=20%
p=10%
p=0%

with coherent *ΛN-ΣN coupling*

P_{Σ^0} increases with ρ_N

Density Dependence of Λ-Single Particle Potential



Difference of
P-wave contribution

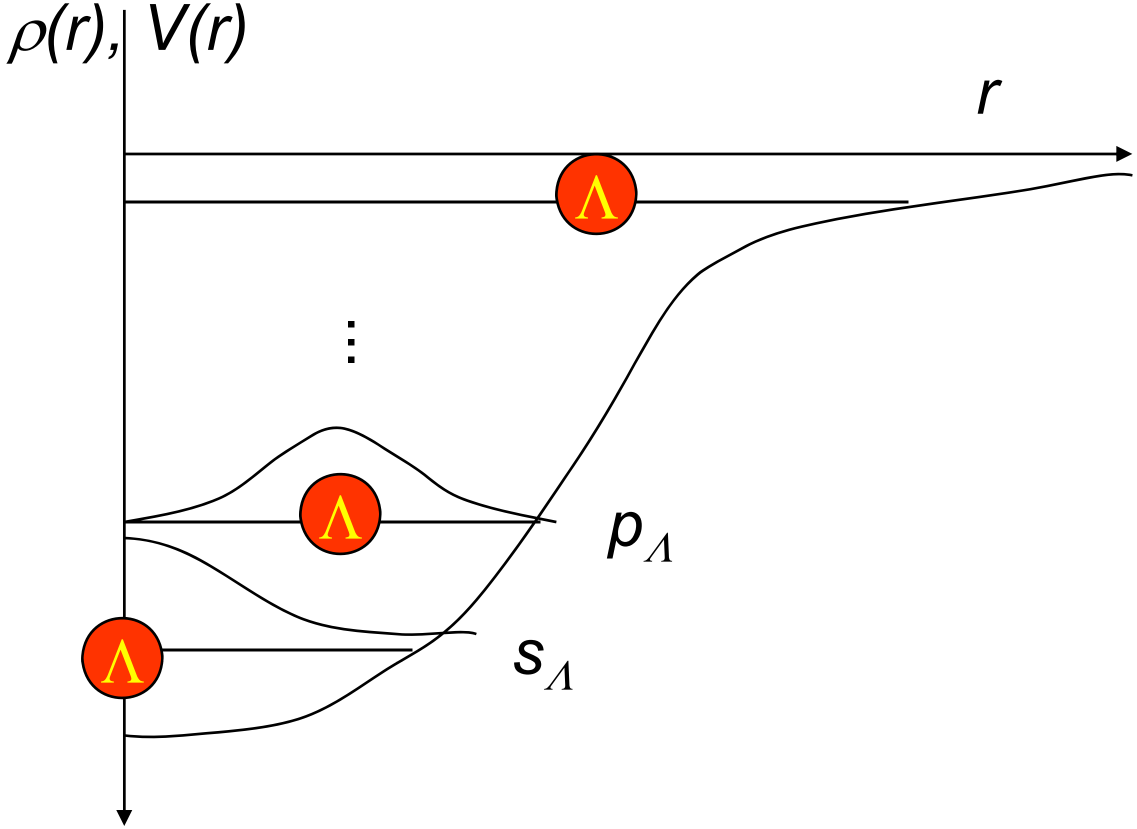
Th. A. Rijken and
Y. Yamamoto,
Phys.Rev.C73:044008,2006

FIG. 12: Calculated values of U_Λ as a function of ρ/ρ_0 for ESC04a (solid curve), ESC04b (dashed curve), ESC04c (dotted curve) and ESC04d (dot-dashed curve). The thin dashed curve is for NSC97f.

$U_\Lambda(\rho)$ is of interest to test YN potentials,
manner of which affects EoS of High Dense Matter, *i.e.* NS.

It would be nice if one can make a dense nuclear matter with a Λ being implanted...

Precise and systematic measurements of the Λ-single particle states in various hypernuclei may give information on $U_\Lambda(\rho)$.



In order to Explore
neutron-rich Λ with High Statistics and High Precision,

High Intensity, High Resolution Beam Line

is indispensable.

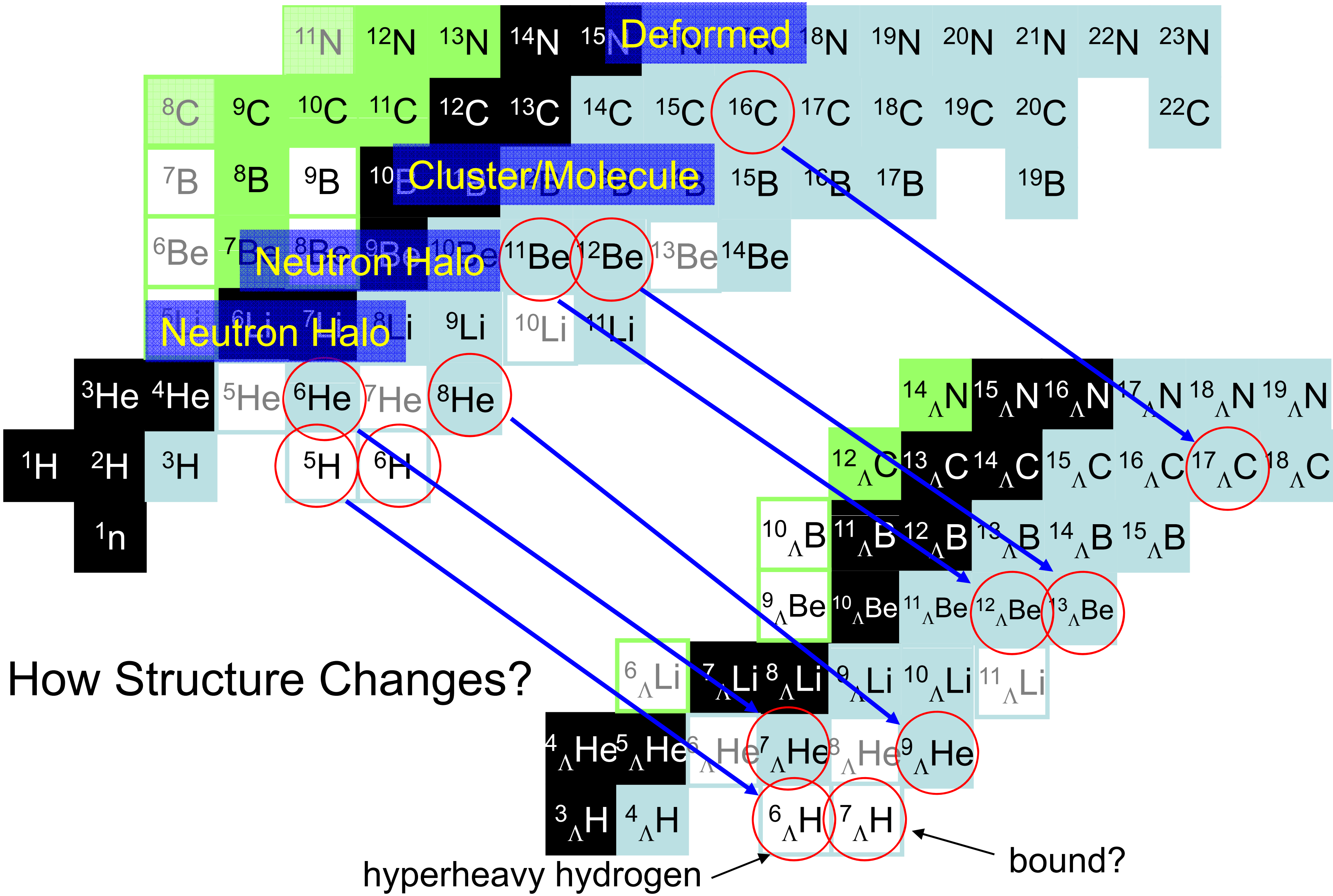
- Provide very intense pion beam of as high as 10^9 Hz
  to overcome a small cross section,
  to use a thin target for a high resolution.
- Dispersive beam at the exp. target and
- Momentum Matching of the Beam Line w/ the Spectrometer
- Realize a High Resolution of dp/p=1/10,000.

×100 higher Statistics
×10 higher resolution

Implication of Λ in Exotic Nuclei

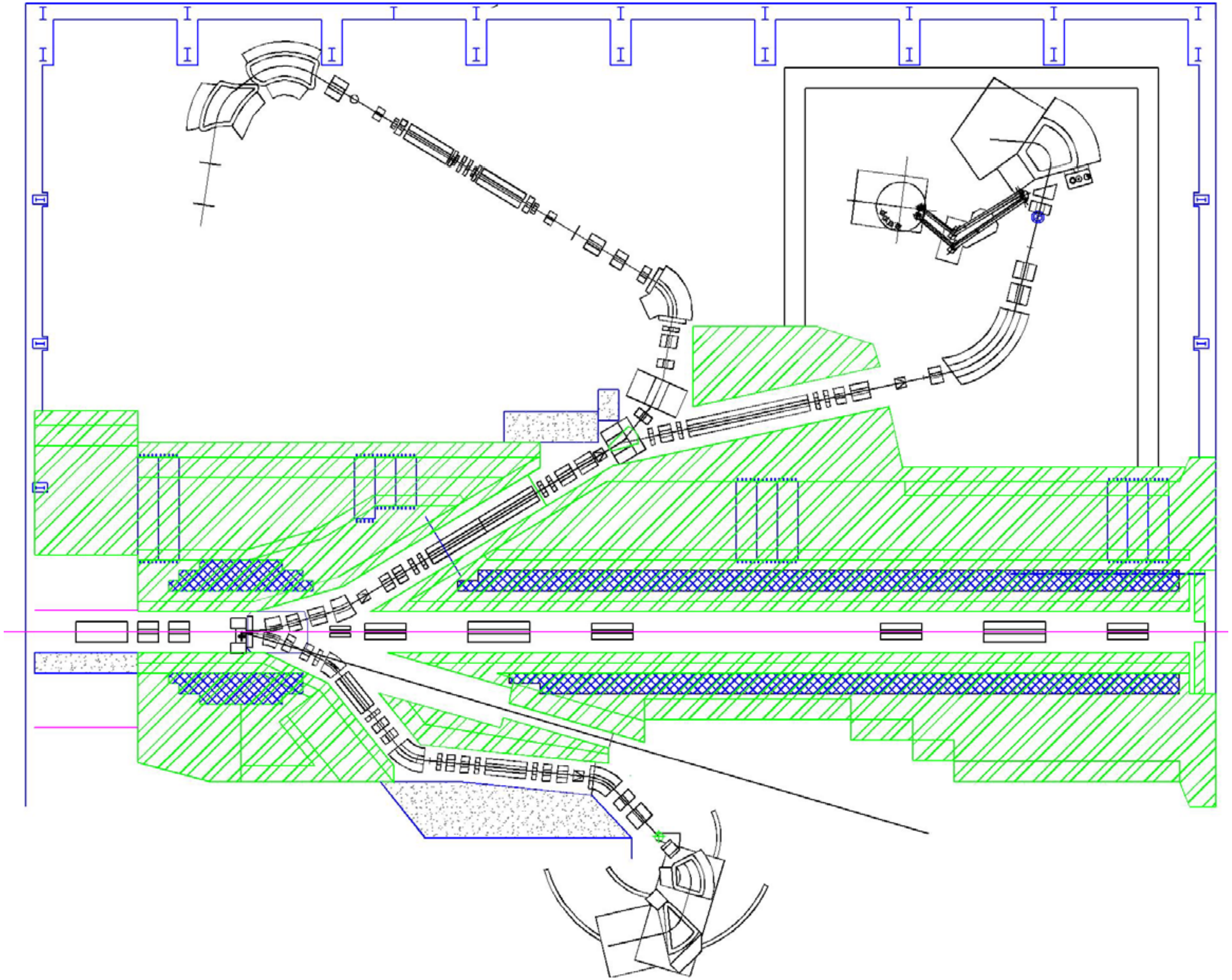
stable nucleus/core

β-,β+ unstable nucleus/core

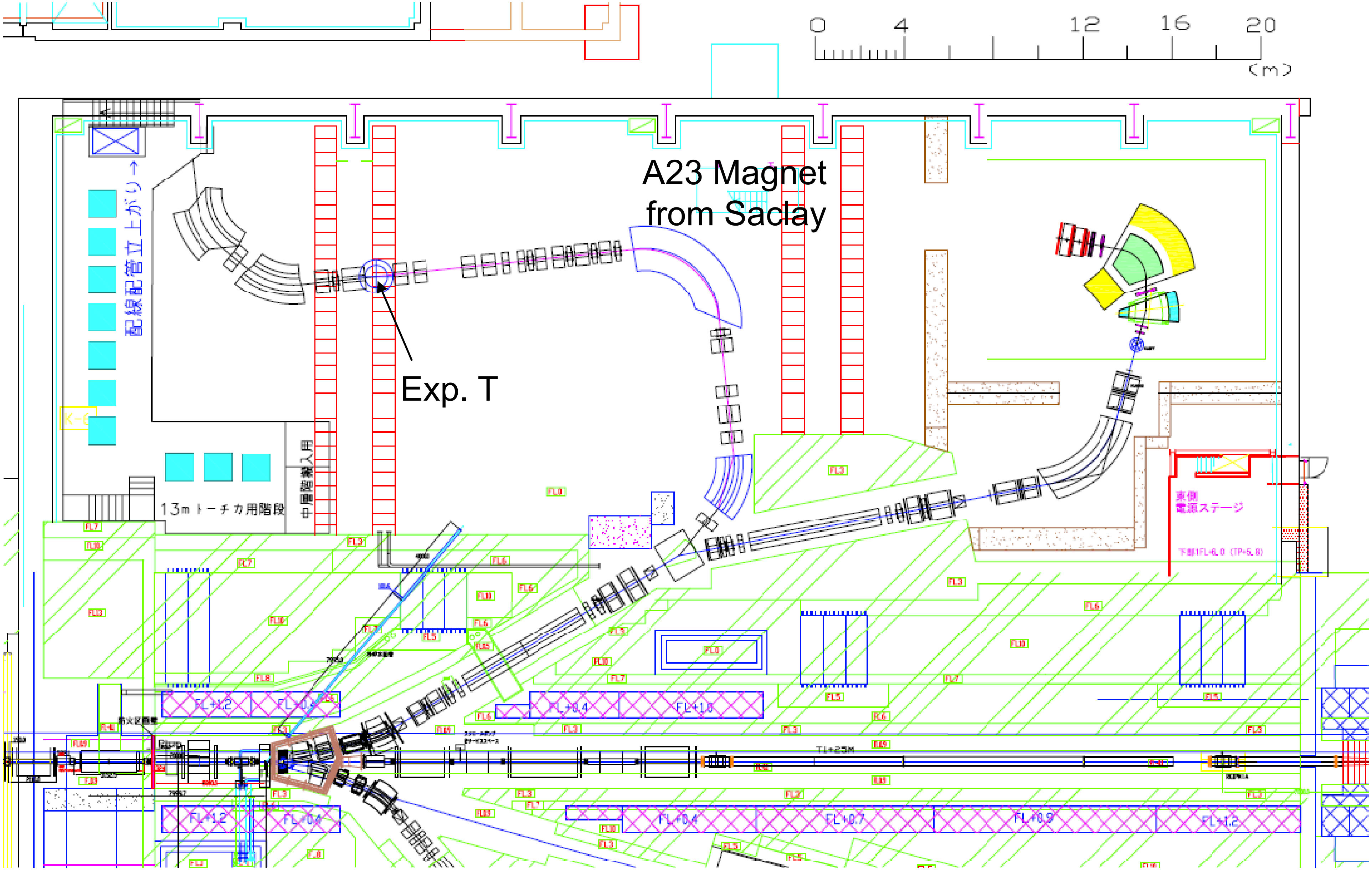


How Structure Changes?

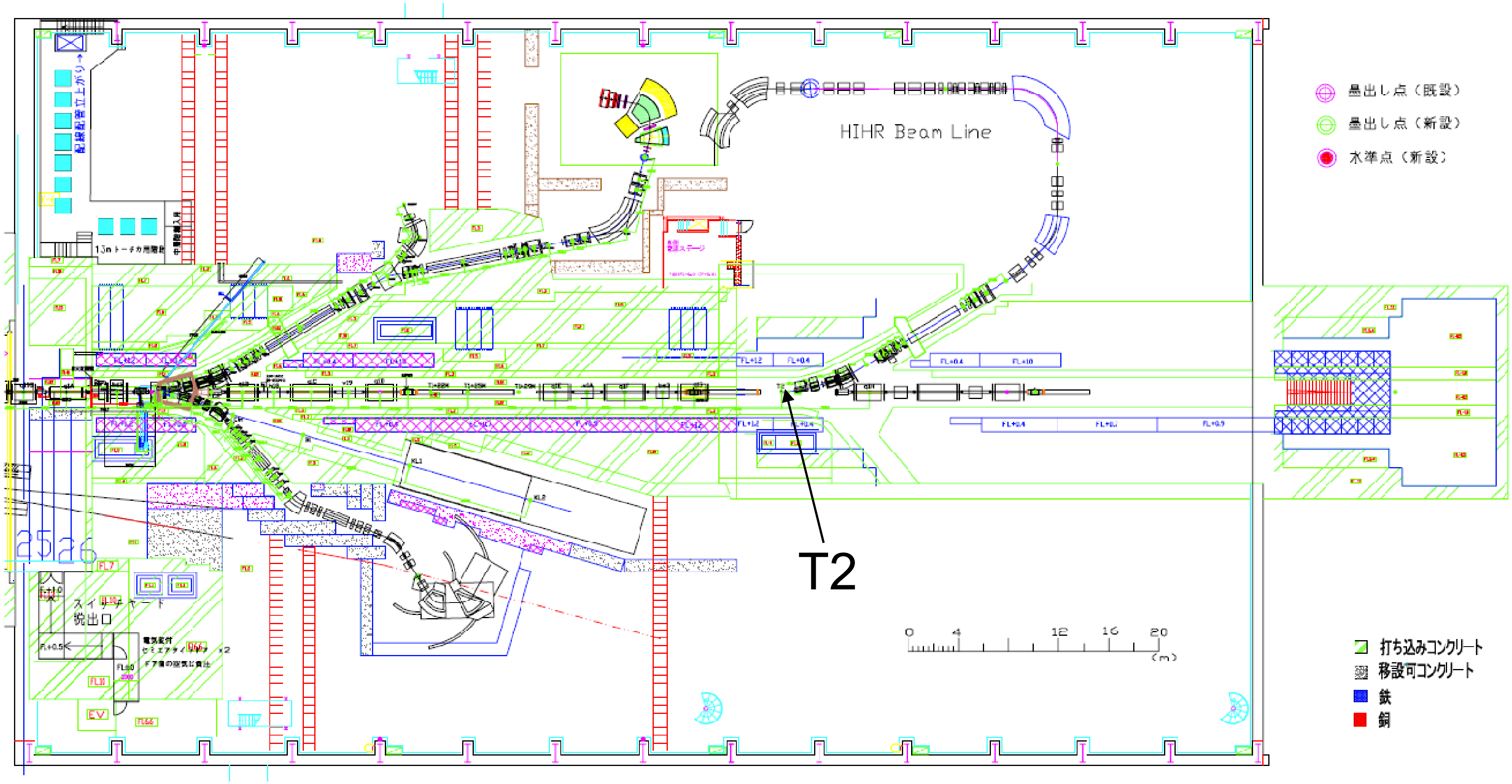
Layout Plan in NPFC(2002)



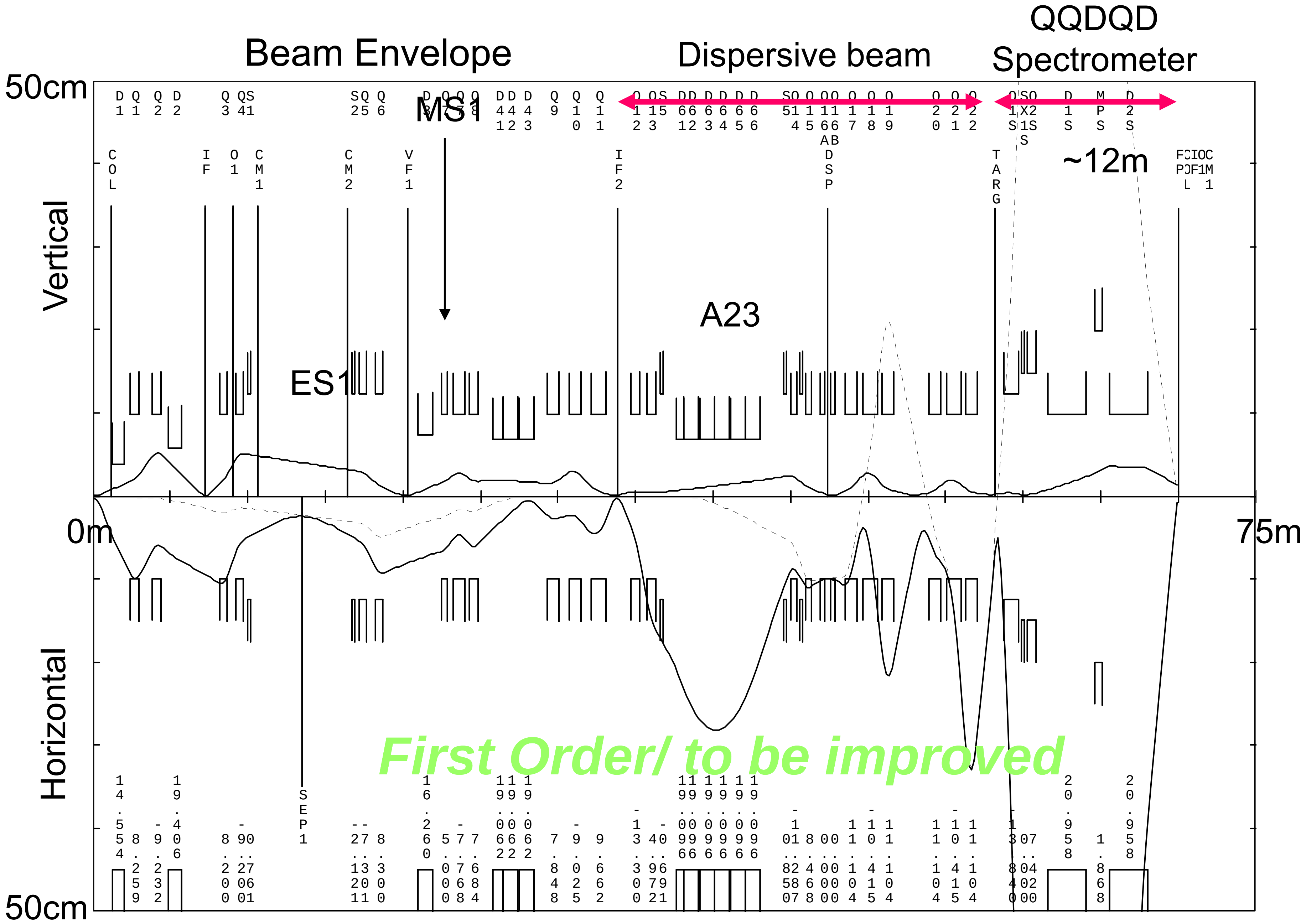
Layout Plan (under develop)



Layout Plan in Extended HD-Hall



Momentum Matching Beam line and Spectrometer System



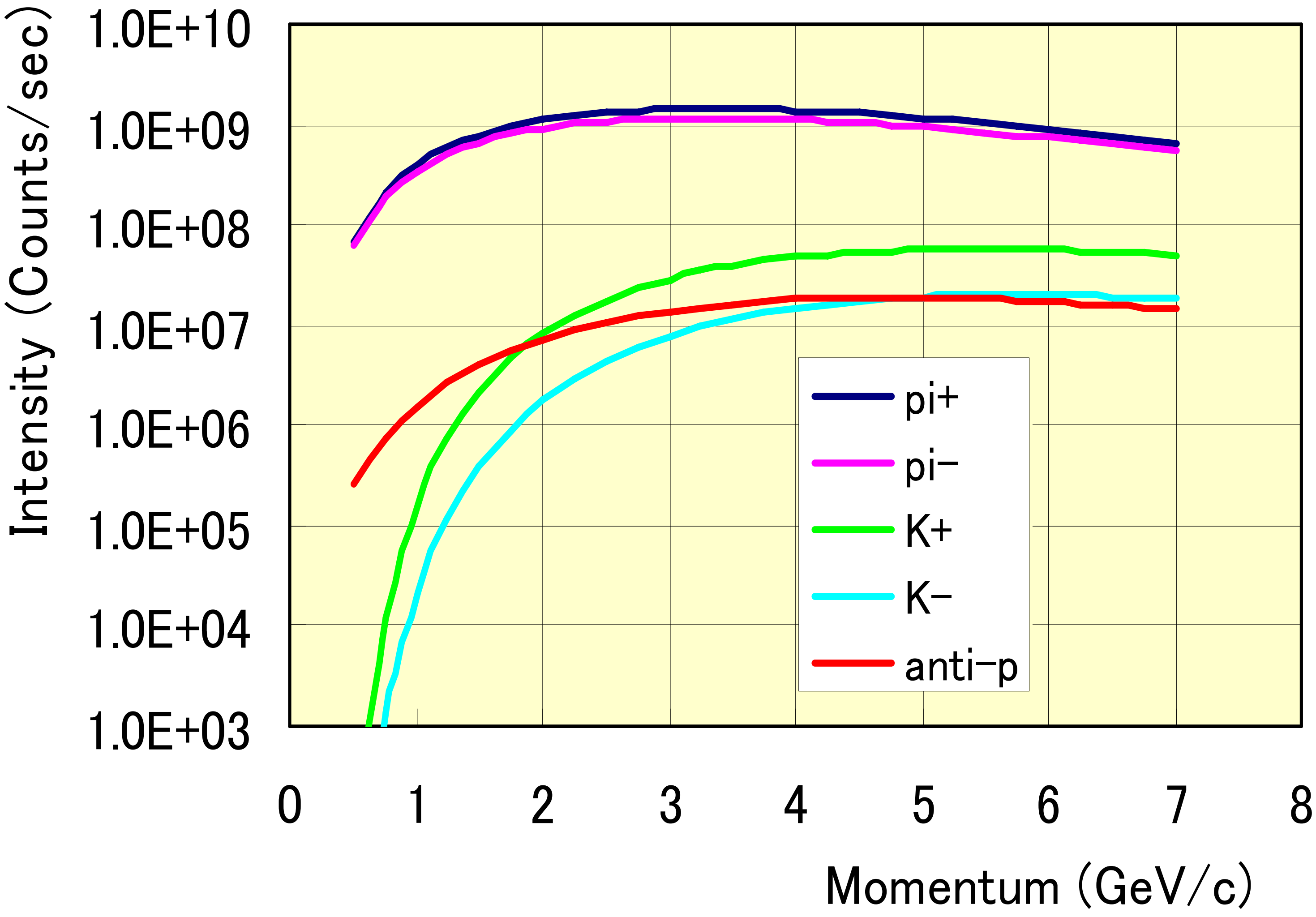
Specification (to be designed)

- Max. Beam Momentum: 2 GeV/c
  - Dispersion:b_{16}=-10m, x-magnification:b_{11}=1
  - Acceptance:~2msr*%
- Max. Scattered Momentum: 1.6 GeV/c
  - Dispersion:s_{16}=-10m, x-magnification:s_{11}=-1.2~-1.5
  - Solid Angle:~10 msr, Mom. Acc.:~+-10%

- (Almost) Full Momentum Matching Condition can be realized for
  - ①(π,K+) at p_π=1~1.2 GeV/c, dq~0.4~0.5 GeV/c
  - ②N(π,N)ϕ at p_π~2 GeV/c, dq~0.4~0.5 GeV/c
  - ③p(π^-,K^-)Θ^+ at p_π~2 GeV/c, dq~.1 GeV/c
- Intrinsic Energy Resolution at the matching condition (1st order):
  - ΔE~ 100 keV for ① and ③
  - ~ 200 keV for ② ,

  in the case of Δx=1 mm (expected rms beam size at T1).

Sanford Wang

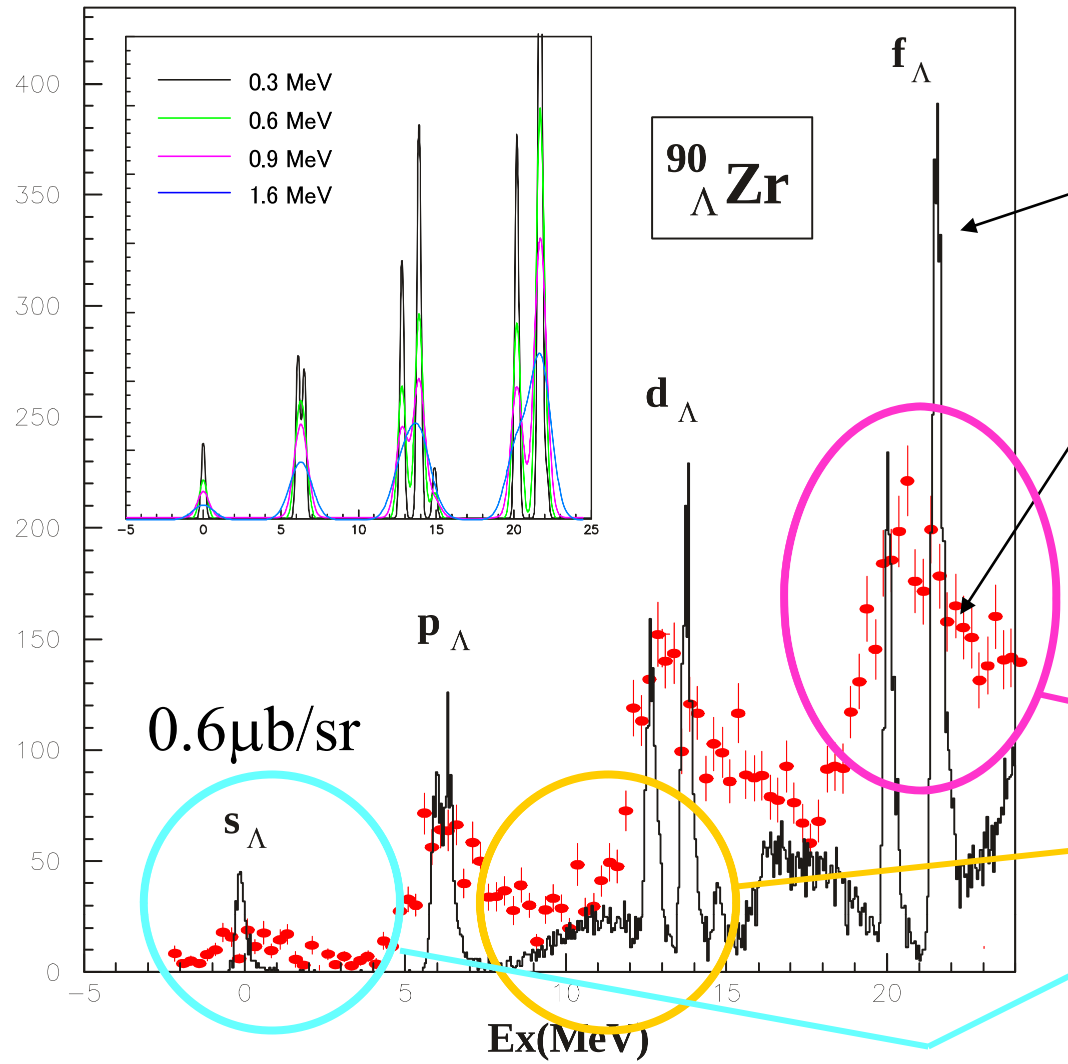


50GeV-15μA、Ni-54mm、BL-Length=50 m、Acceptance:2msr%

Demonstration

Superfine Structure of Medium Heavy Λ Hypernucleus

World of ΔE=0.2 MeV



Precise Measurement of Major Shell Intervals
→Density Dependent U_Λ?

Further decomposition of the states

Yield Estimation

- ${}^{89}_{\Lambda}$Y-g.s. (0.6μb/sr), 1mm target

Production Rate (cps)

$= 10^9 * 0.635/89 * 6.022E23 * 0.6E{-}30 * \Delta\Omega * \varepsilon_{K^+} * \varepsilon_{all}$

$= 0.002$

$\Delta\Omega$ = 10 msr, ε_{K^+} = 0.1, ε_{all} = 0.8

→ 170 counts/day

→ 300 counts/10days

- ${}^{12}_{\Lambda}$Be (0.01μb/sr), 0.6g/cm2 target

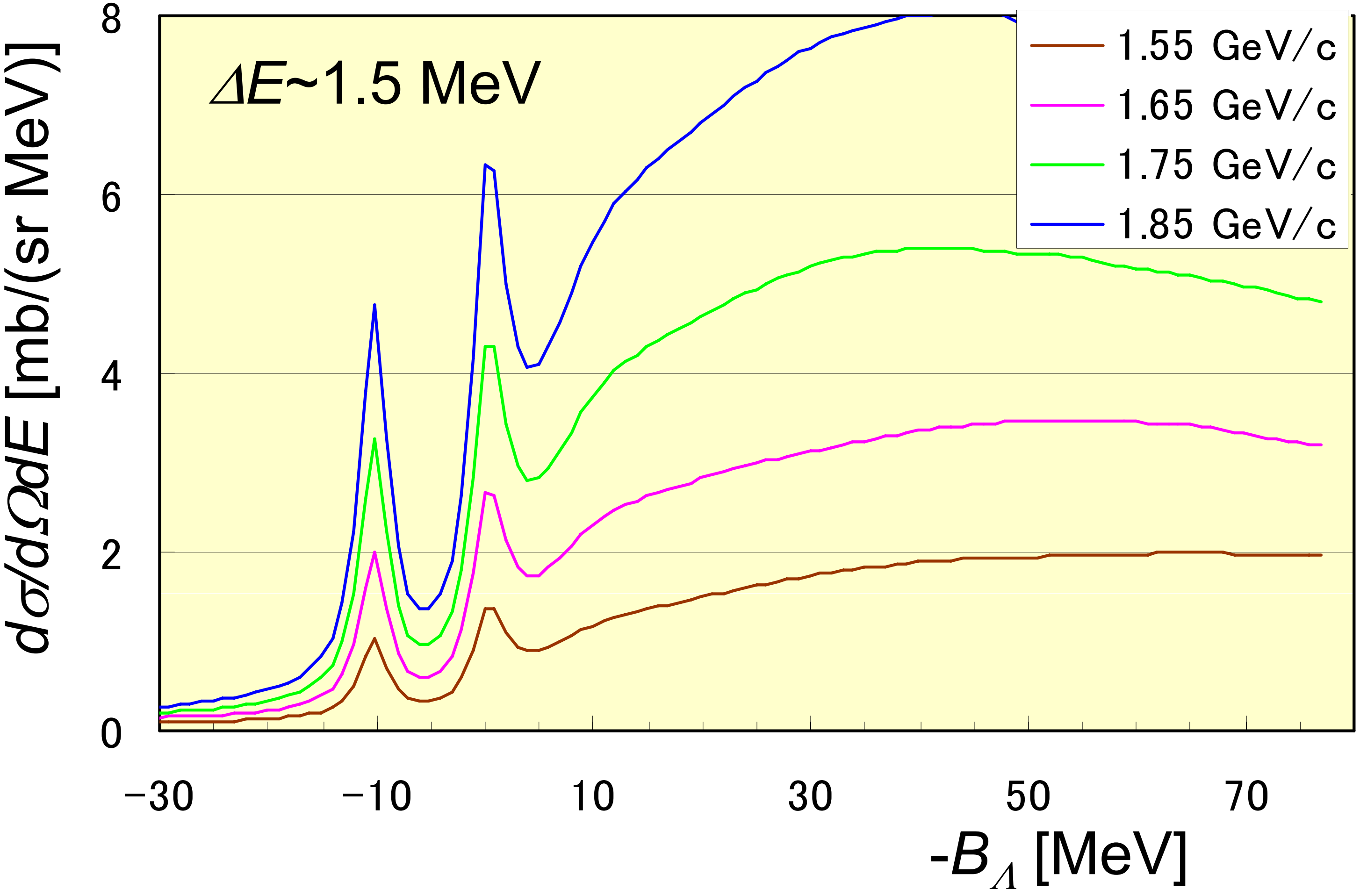
20 counts/day

Many Applications to High Precision Spectroscopy with High Intensity pion and pbar Beams

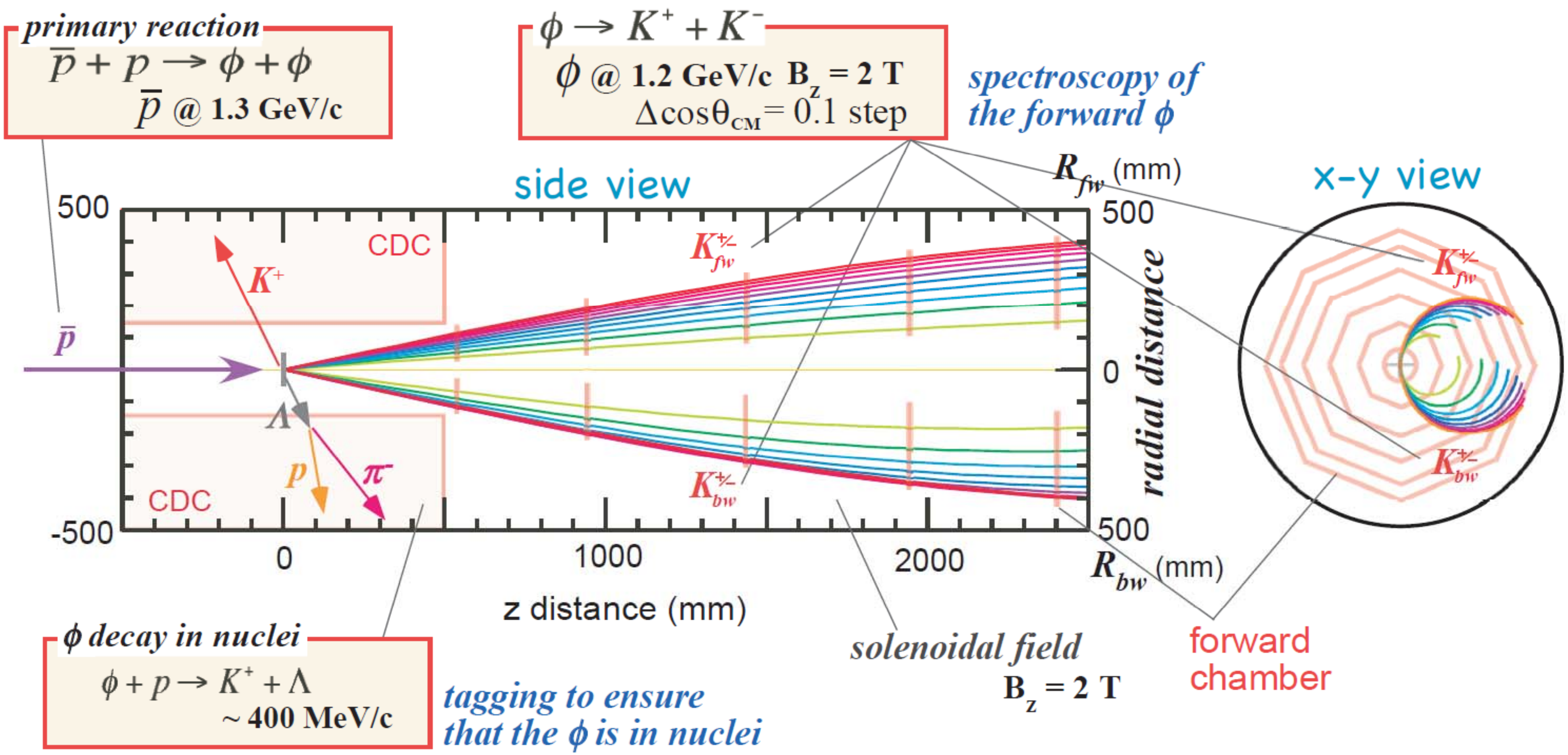
...No time to explain in detail.

- ✓ High Precision S=-1 Hypernuclear Spectroscopy
  - Neutron-rich Λ hypernuclei (→Sakaguchi)
    (π^-,K^+), (π^-,K^0) → (pbar,Λbar)
  - Λ Hypernuclear Weak Decay (→Ajimura for ${}^4_\Lambda$He, ${}^4_\Lambda$H)
    (π^+,K^+), (π^-,K^0) → (pbar,Λbar)
  - Σ-Nucelus System (CAHBS, Few-body→Tamura's LoI)
- ✓ Spectroscopic studies of ϕ, η-mesic nuclei
  - A(pbar,ϕ)$_\phi$D (→Ohnishi)
  - A(π,N)$_\eta$D (→Itahashi)
- ✓ Exotic Hadrons
  - Θ^+ (d$(K^+,p)\Theta^+$,p$(\pi^-,K^-)\Theta^+$) (→Tanida, Naruki)
    → d(pbar, K^-)Θ^+ may be available.
    BG free by Kaon Tagging!

(pbar,Λbar) on ^{12}C



HIHR Beam Line + Solenoidal Forward Spectrometer for neutral particles (ϕ,K^0,Λ)



SUMMARY

✓ High Precision Spectroscopy of Λ hypernuclei is necessary to establish YN interaction and Y-interaction in Nuclear Medium.

✓ High Intensity, High Resolution Beam Line is proposed as a powerful tool to explore a wide region of Λ hypernuclei, particularly n-rich Λ hypernuclei.

✓ Specification of HIHR BL:

- Momentum dispersion matched beam line and spectrometer system to achieve a resolution of as high as 1/10,000,
  Beam π of up to 2 GeV/c
  Scattered K+ of up to 1.6GeV/c
- Utilize very high intensity beam : 10^9 π/pulse (10^7 $\bar{p}$ /pulse)
  may open new paradigm in high resolution spectroscopy.
  It would bring a kind of break through in mass production of Λ hypernuclei