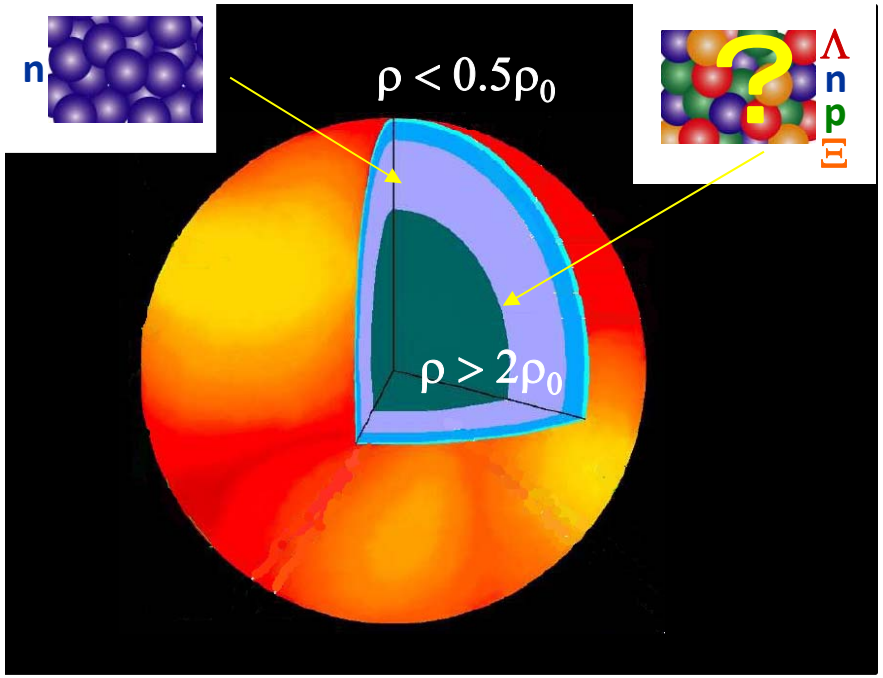
「多重ストレンジネスのバリオン間相互作用」（計画研究A01）
Baryon-Baryon Interaction with Multi-Strangeness

A01班代表

高橋俊行（KEK素核研）

1. Introduction
   1-1 Neutron-star and Strangeness
   1-2 Known information on S=-2
2. Research Project (Experiments)
   2-1 Emulsion Experiment (J-PARC E07)
   2-2 Ξ-hypernuclear Spectroscopy (J-PARC E05)
   2-3 Search for H dibaryon with Hyperon Spectrometer (J-PARC E42)
   2-4 Schedule
3. Summary

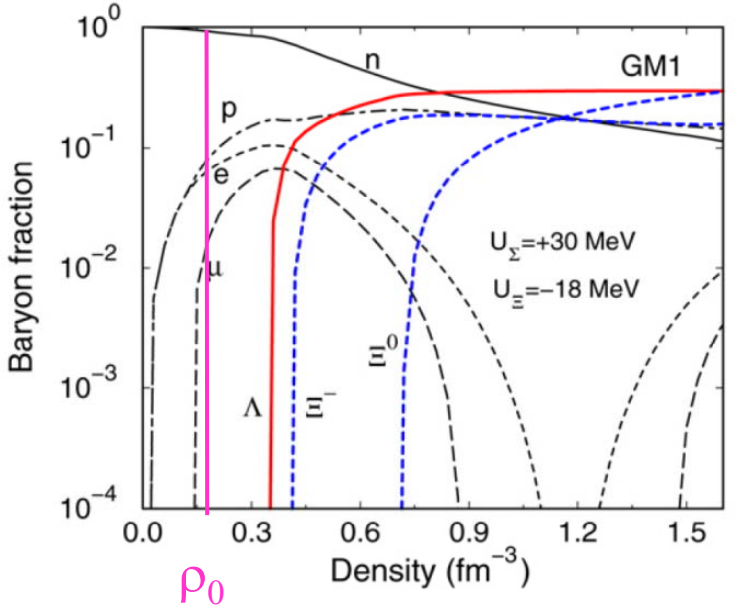
Strangeness in the Neutron Star



Hyperon Matter
should be appeared at high density

EOS should support $2M_{\odot}$

J.Schaffner-Bielich, NPA804(2008)309



$$\mu_Y = m_Y + \frac{k_F^2}{2m_Y} + U_Y(k_F)$$

to be experimentally determined

Hyperon Potential & Interactions

Λ:

U_Λ = –30 MeV in normal (N~Z) matter at ρ_0

U_Λ ? in neutron-rich matter

Σ (Σ^+, Σ^0, Σ^-) :

ΣN int. is repulsive but how much?

Group-A02 (S=–1)

Ξ (Ξ^0 , Ξ^-) : Ξ nucleus is not well established

U_Ξ = –14 MeV ? ($^{12}_{\Xi}$Be) to be established

B_Ξ = –2.6 MeV ? (Ξ^-+^{14}N–>twin Λ-nucleus)

$\Lambda\Lambda$ interaction:

$\Delta B_{\Lambda\Lambda}$ = 0.67 ± 0.17 MeV from *NAGARA* event

systematic data (A-dependence)

Group-A01 (S=–2)

YY:

Ω^-N:

S=-2 Baryon-Baryon Interaction

Strong attraction in the flavor singlet channel

$$BB\ ^{(1)} = H = -\sqrt{\frac{1}{8}}\Lambda\Lambda + \sqrt{\frac{3}{8}}\Sigma\Sigma + \sqrt{\frac{4}{8}}\Xi N$$

No repulsive core

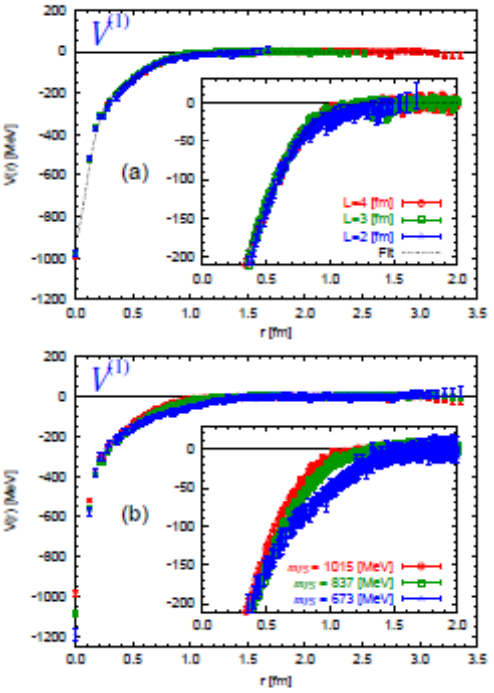
Recent L-QCD suggests the existence of bound or resonance *H* dibaryon

HAL: $SU(3)_f$ limit

30 - 40 MeV bound *H* from ($\Lambda\Lambda$-$\Sigma\Sigma$-ΞN)

NPQCD:

B^H_∞=16.6±2.1±4.6 MeV (m_π~ 389MeV)

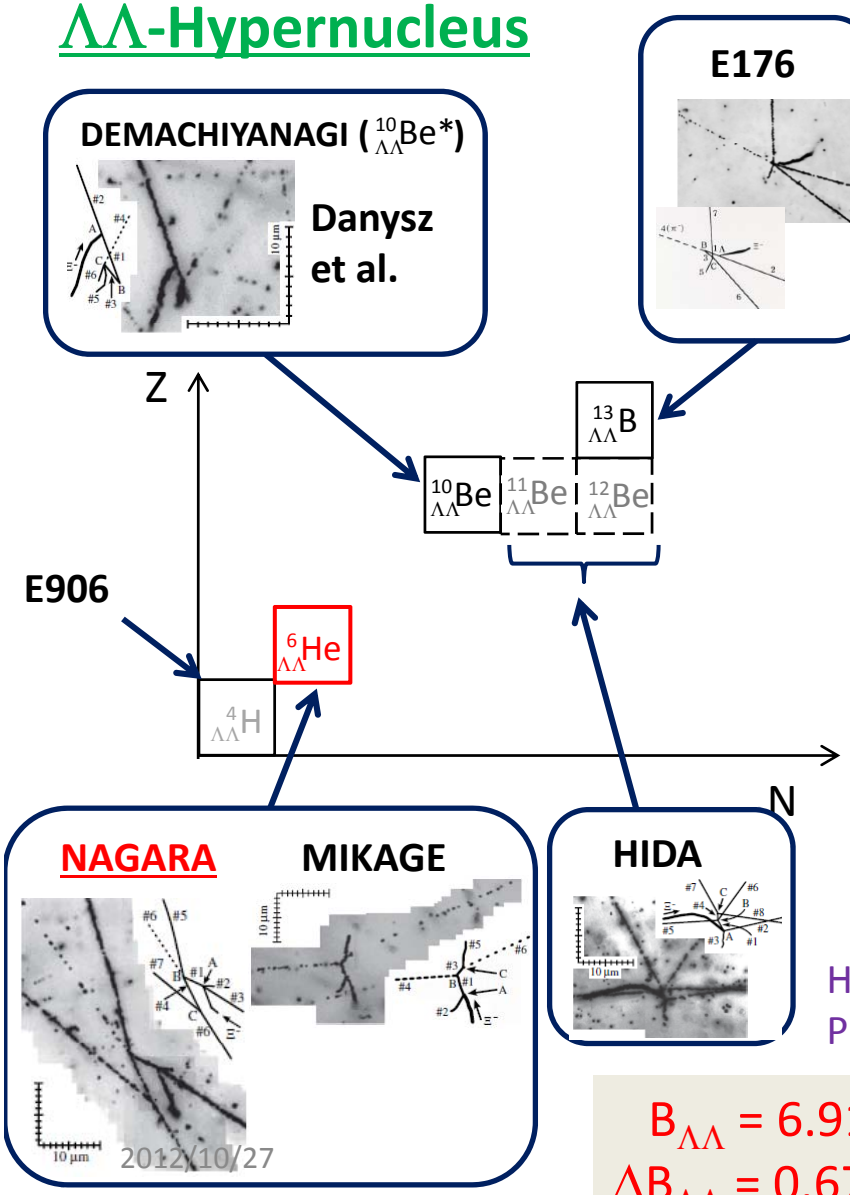


HAL
T.Inoue et al.
PRL106(2011)16002

Expermentally confirmation of the existance of *H*

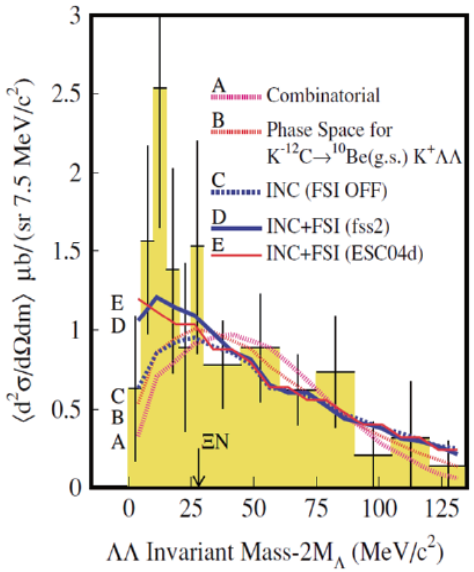
Information on S=−2 System, so far (1)

ΛΛ-Hypernucleus



H-particle , ΛΛ-invariant mass

KEK-E522



Resonance *H* ?

C.J.Yoon et al.
PRC75(2007)022201(R)

Y. Nara et. al, Nucl. Phys. A 614(1997)433.
A. Ohnishi, et al, Nucl. Phys. A670(2000)297c, A684(2001)595, A691(2001),242c;Few-Body Syst. Suppl. 12 (2000), 367

$m_H \geqq 2223.7$ MeV/c²
(7MeV window for bound *H*)

H.Takahashi et al.
PRL87 (2001) 212502

$B_{\Lambda\Lambda} = 6.91 \pm 0.16$ MeV
$\Delta B_{\Lambda\Lambda} = 0.67 \pm 0.17$ MeV

weakly attractive

Information on S=−2 System, so far (2)

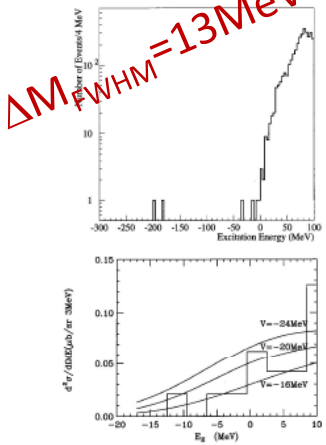
Ξ-Nucleus Missing mass spectroscopy of $^{12}C(K^-,K^+)^{12}_{\Xi}Be$

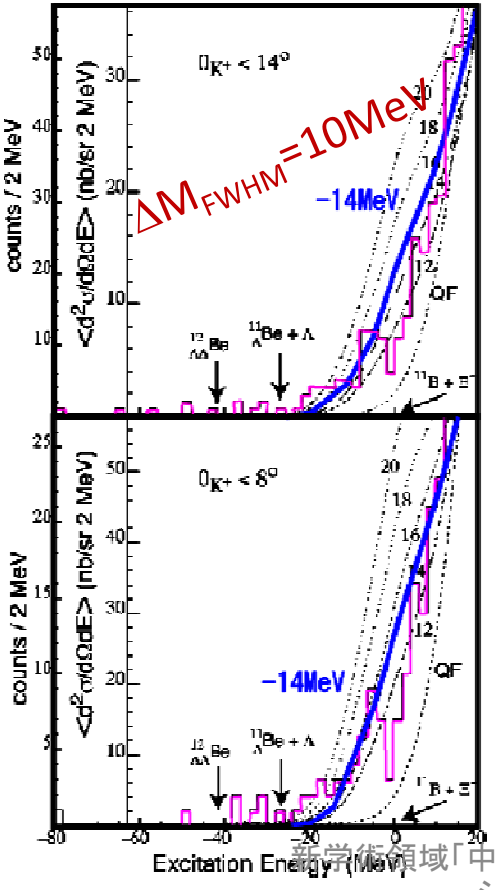
No clear peak was observed...,

Spectrum shape suggests attractive potential for Ξ.

KEK E224

T.Fukuda et. al,
PRC58(1998)1306





BNL AGS E885

U_{Ξ}=-14 MeV

P.Khaustov et. al,
PRC61(2000)054603

−20 < E < 0 MeV	89±14 nb/sr θ< 8° 42± 5 nb/sr θ<14°

Twin Λ hypernuclei from Ξ⁻ capture

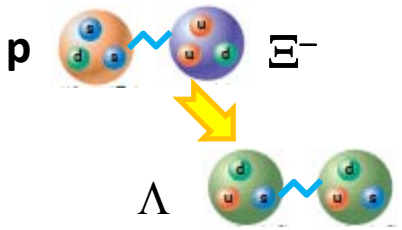
A.Ichikawa et. al, Phys.Lett.B500(2001)37

$\Xi^- + {}^{14}N \rightarrow {}^{5}_{\Lambda}He + {}^{5}_{\Lambda}He + {}^{4}He + n$

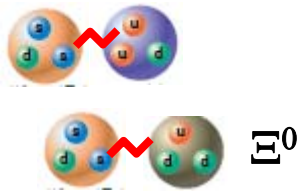
B_{Ξ}=−2.6±1.2 MeV

A01 多重ストレンジネスのバリオン間相互作用

ΞN→ΛΛ相互作用



ΞN相互作用

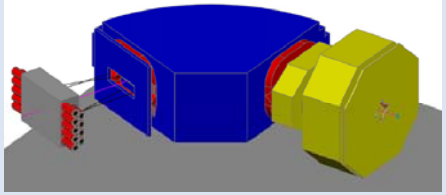


ΛΛ相互作用

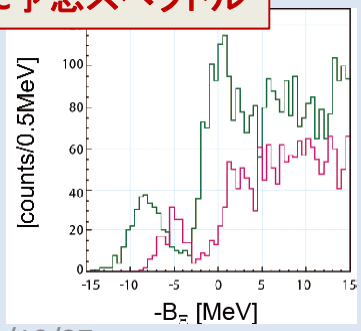
高密度核物質のEOSへ

ΞハイパーNuclear分光実験

S-2Sスペクトロメータ

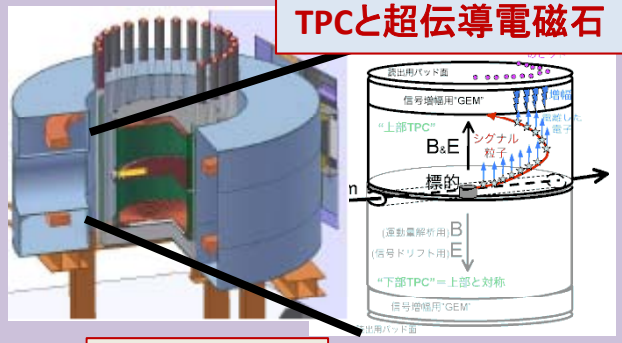


$^{12}_{\Xi}$C予想スペクトル

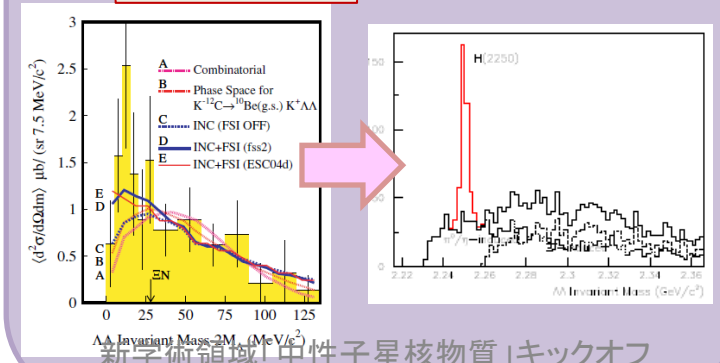


ハイペロン崩壊検出器によるΛΛ相関研究

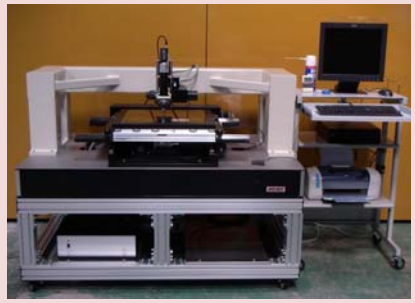
TPCと超伝導電磁石

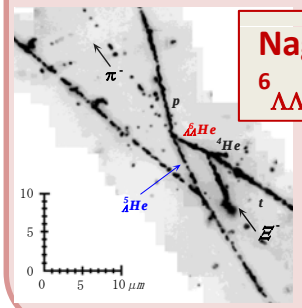


ΛΛ不変質量



エマルジョン実験＋画像自動解析システム

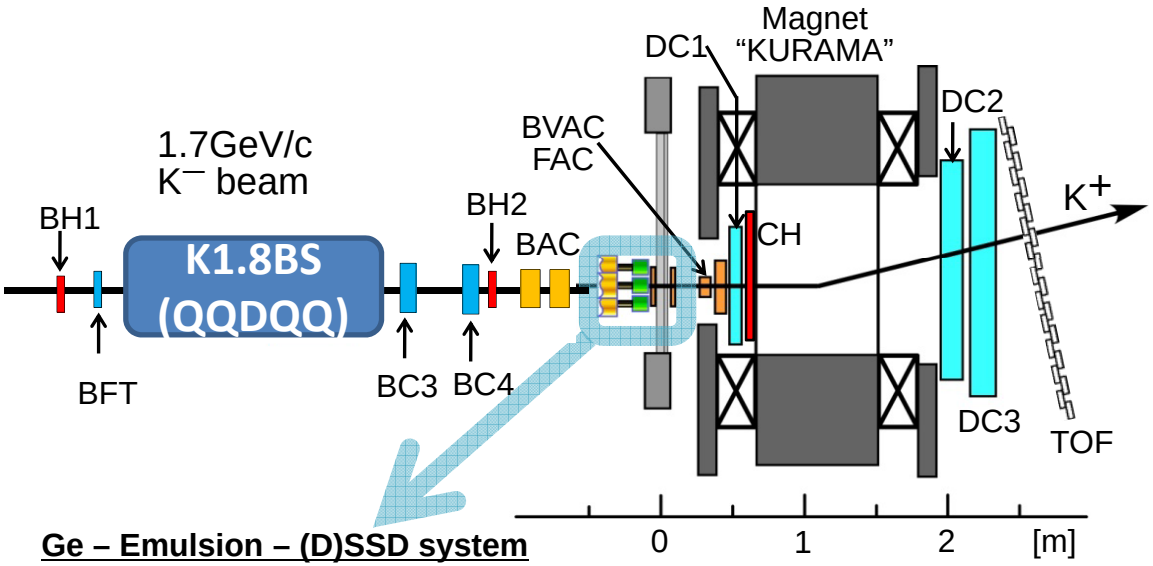




Nagara Event
$^{6}_{\Lambda\Lambda}$He

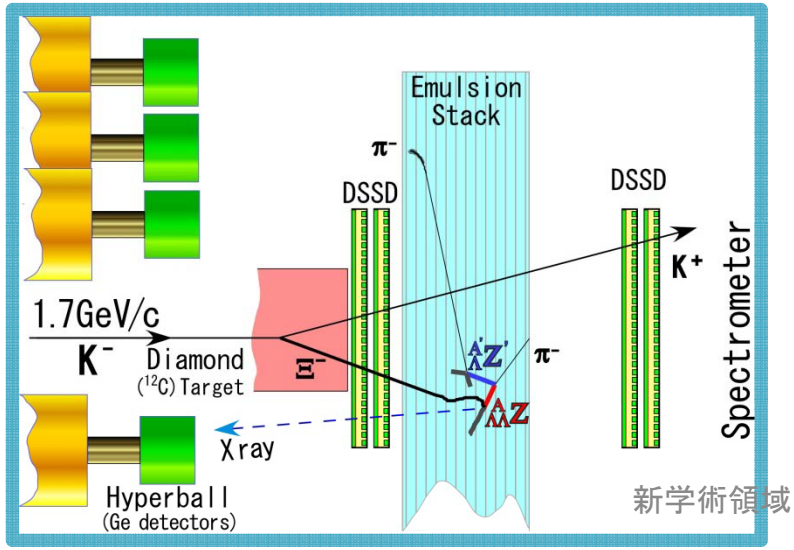
Study on S=−2 System by Emulsion-Counter Hybrid Method (J-PARC E07)

K.Nakazawa (Gifu), K.Imai(JAEA), H.Tamura(Tohoku)



Ge – Emulsion – (D)SSD system

double Λ hypernuclei
↓
ΛΛ interaction
w/ A-dependence

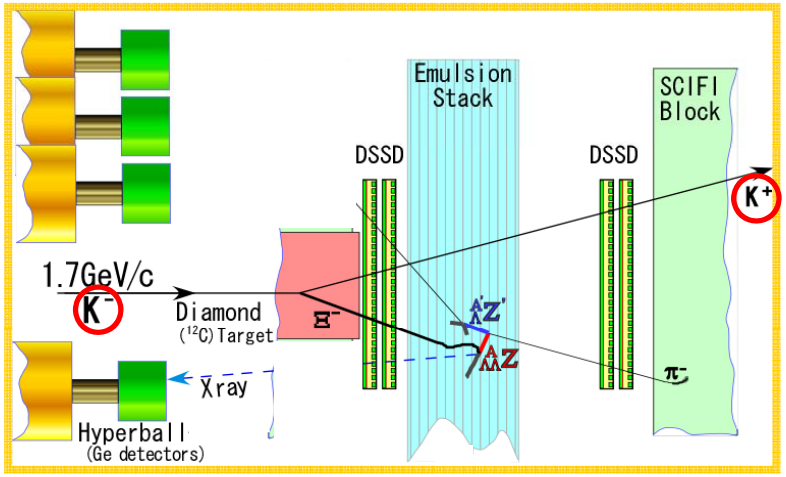


Improvement from E373

	Proposal	Present
1. K⁻ beam purity (K/π=1:1→3.5:1)	x3.5	??
2. Emulsion (2.1t 65MJPY)	x3	x2.4 106 stacks
3. KURAMA gap (50cm → 80cm)	x1 200msr	x1.6 ~350msr

Strategy of the E07@J-PARC

1-1.New Hybrid method



J-PARC

1. Pure K-beam
   (better 3.5 times than KEK-PS)
2. More emulsion volume (x 3)

10^3 (E373) ➔ 10^4 Ξ- stop events

1. X ray measurement from Ξ atom
   with Hyper-ball
   ➔ study of Ξ-N interaction
2. ~10^2 double hypernuclei

1-2.Overall scan

Fully automatic detection of
3 vtx. event
like "NAGARA event"

10 times statistics than that with the hybrid method

(1/0.3): acceptance & tracking
x
4 : ・'p'$(K^-, K^+)\Xi^-$ in the emulsion
・'n'$(K^-, K^0)\Xi^-$ reaction

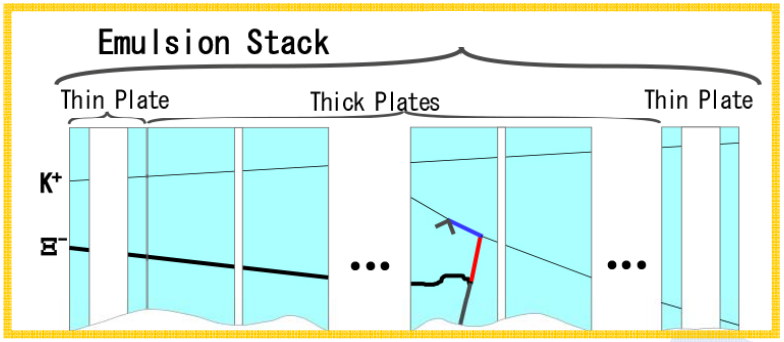
Measurement of the mass of
~10^3 double hypernuclei
with A<16

For Hybrid method

⇔ automatic tracking of Ξ- hyperons

10times (Statistics) ==> Fully automatic scan

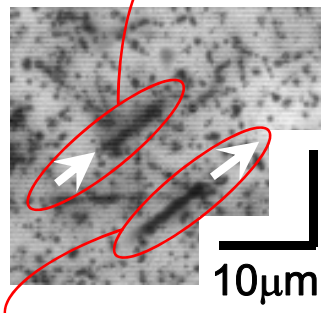
Precise position alignment in plate by plate tracking



(plate size : 35x35 cm^2)

E373 style

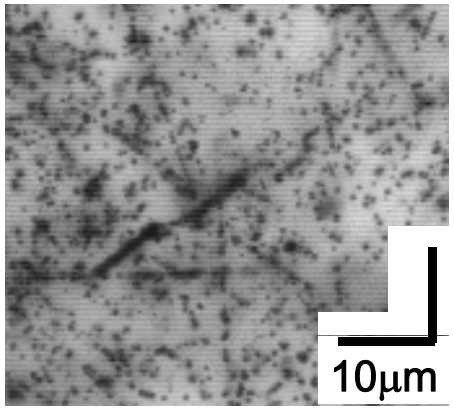
Track in upstream plate



in downstream plate

~20μm ==> human assistance is necessary

position alignment with beam pattern



Developed tracking method gives an accuracy of

1.2 μm ==> fully automatic available *!!*

For overall scanning

fast image capture

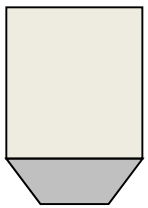
At present (Developed)

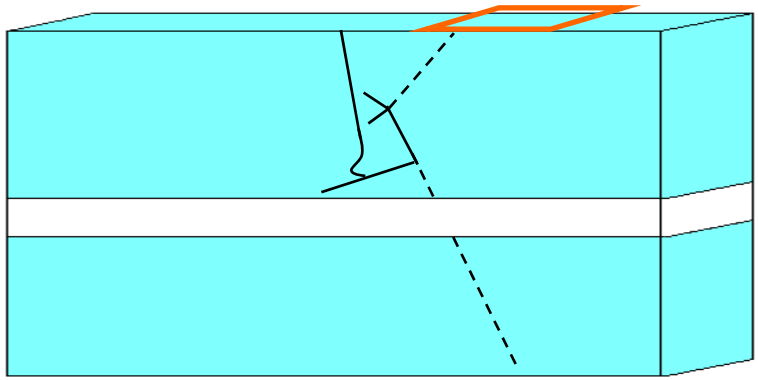
OS : Win2000 sp4
CPU : 3.0 GHz
1.57GB RAM

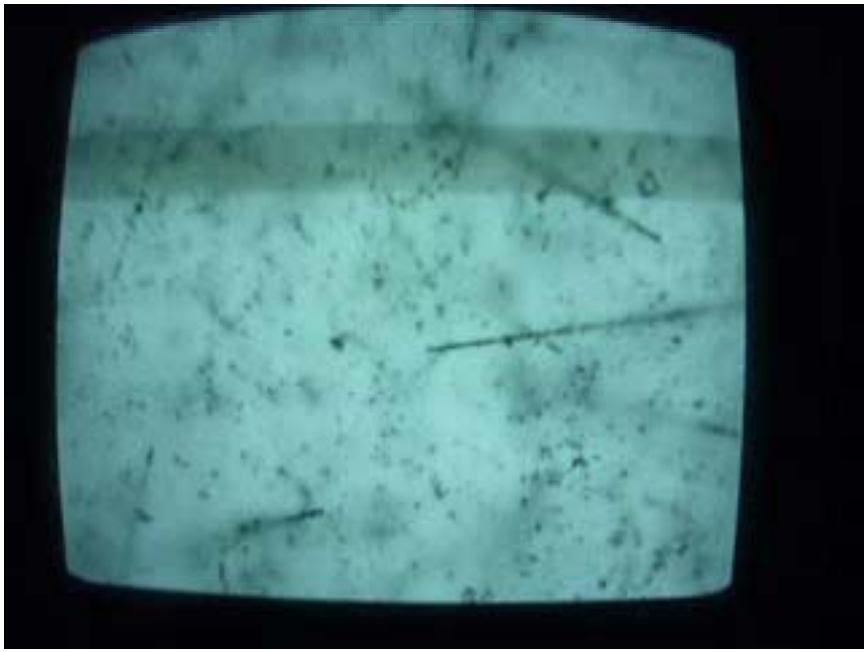
emulsion : 500μm
Objective lens : x50
area : 0.1x0.1mm^2
Camera : 100Hz (CCD)
# of image : ~100/cycle
Time : 3sec/cycle
[~ hard limit]

Developing

emulsion : 1000μm
Objective lens : x20
area : 0.8 x 0.3 mm^2
Camera : 800Hz (CMOS)
# of image : ~ 60/cycle
Time : 0.1 sec/cycle
×1000 faster !!







Scanning Device

Stage	present	change	Scan
Gifu			
#1, #2	30Hz	100Hz	Hybrid
#3	100Hz	100Hz	Overall
#4, #5	100Hz	800Hz	Overall
#6	---	---	Analysis
Kyoto			
(#7,8)	100Hz	100Hz	Hybrid
Toho/Korea		100Hz	Hybrid

upgrading by "this Kakenhi Budget"

plan to finish hybrid analysis by **1 year** from the irradiation

Image capture

8 hrs / 1 sheet (1000μm)
x 12 sheets
x 106 stacks
/ 2 devices
= 200-250 days

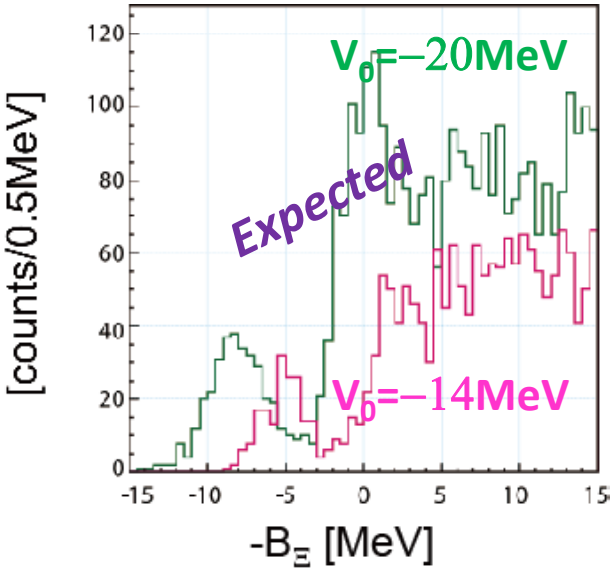
Analysis by Overall Method

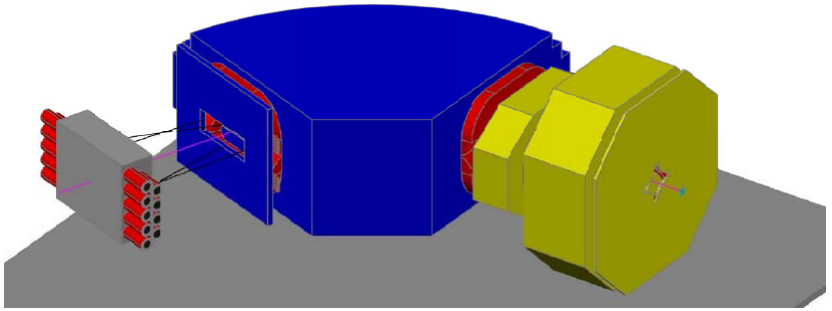
???

Spectroscopy of Ξ⁻-hypernucleus, $^{12}_{\Xi}$Be (J-PARC E05)

T.Nagae (Kyoto Univ.)

- First observation of Ξ-hypernucleus by the (K^-,K^+) missing mass with high-resolution and high-statistics.
- Ξ-Nucleus potential (inside nucleus) ↔ complimentary to Ξ-Atom
  - Potential depth → Ξ-N interaction
  - Width of state(s) → Ξ-N→ΛΛ interaction
  - EOS of high-density neutron-star matter





S-2S under construction by Grant-In-Aid for Specially Promoted Research(2011-2015 T.Nagae)

ΔΩ = ~50 msr

Δp/p = 0.05% → ΔM = 1.5MeV(FWHM)

Construction completed in 2014

Data-taking 2015?—

Search for *H*-Dibaryon with a Large Acceptance Hyperon Spectrometer (J-PARC E42)

J.K.Ahn (Pusan Univ.)

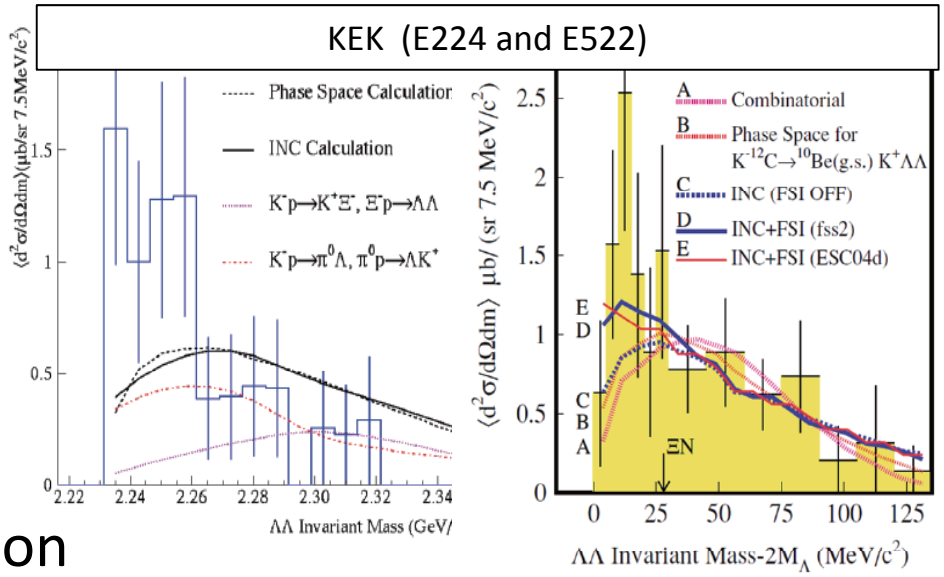
- Search for *H*-dibaryon via the A(K^-,K^+)*H*X

  H → ΛΛ , Λπ^-p, Σ^-p

  Λ → π^- p

  Σ^- → π^- n

- High statistics of >10k events (x 100)
- Good invariant mass resolution of ~1MeV/c^2 (x 1/10)



Based on:

INC(Intra Nuclear Cascade model): Y. Nara, A. Ohnishi, T. Harada, A. Engel, Nucl. Phys. A 614 (1997), 433.

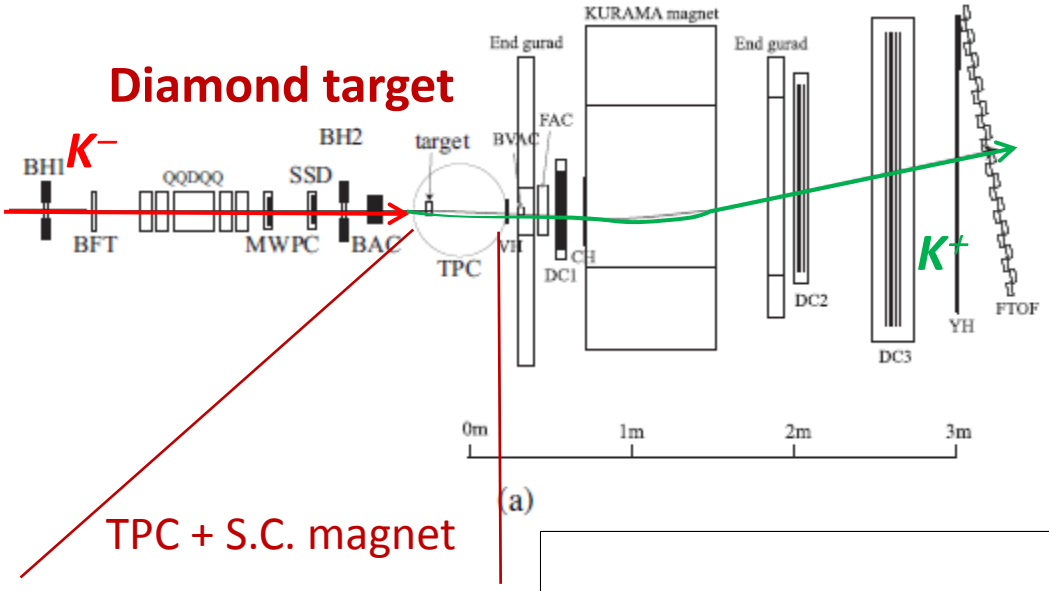
ΛΛ FSI and Evaporation effects: A. Ohnishi, Y. Hirata, Y. Nara, S. Shinmura, Y. Akaishi, Nucl. Phys. A670(2000),297c, A684(2001),595, A691(2001),242c; Few-Body Syst. Suppl. 12 (2000), 367.

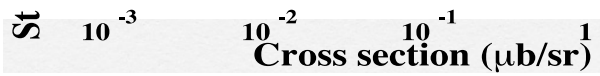
Proposal was approved as Stage-1 at the 15th PAC Meeting (2012 July 13-15)

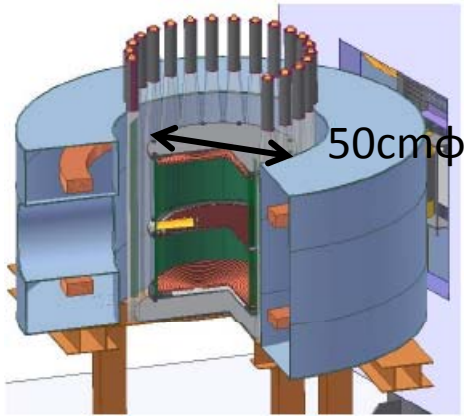
J-PARC E42

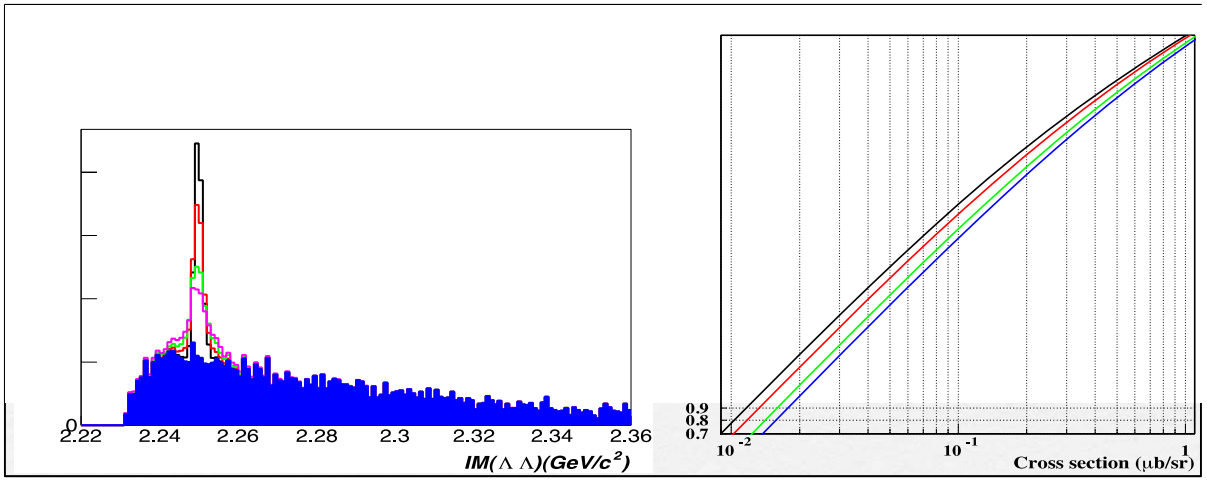
1x10^6 K$^-$ /spill beam
30 days

K1.8BL + KURAMA + **Hyperon Spectrometer**









Design of H.S. (TPC) is underway …

TPC+GEM:

Sensitive volume: 50cmϕ x 50cm

(1st prototype we have: 10cm角 × 20cm)

Pad size: 2.5 x 9 mm, 2.5 x 13 mm

GEM structure 50 x 50 x 100μm

Gas P10

DAQ:

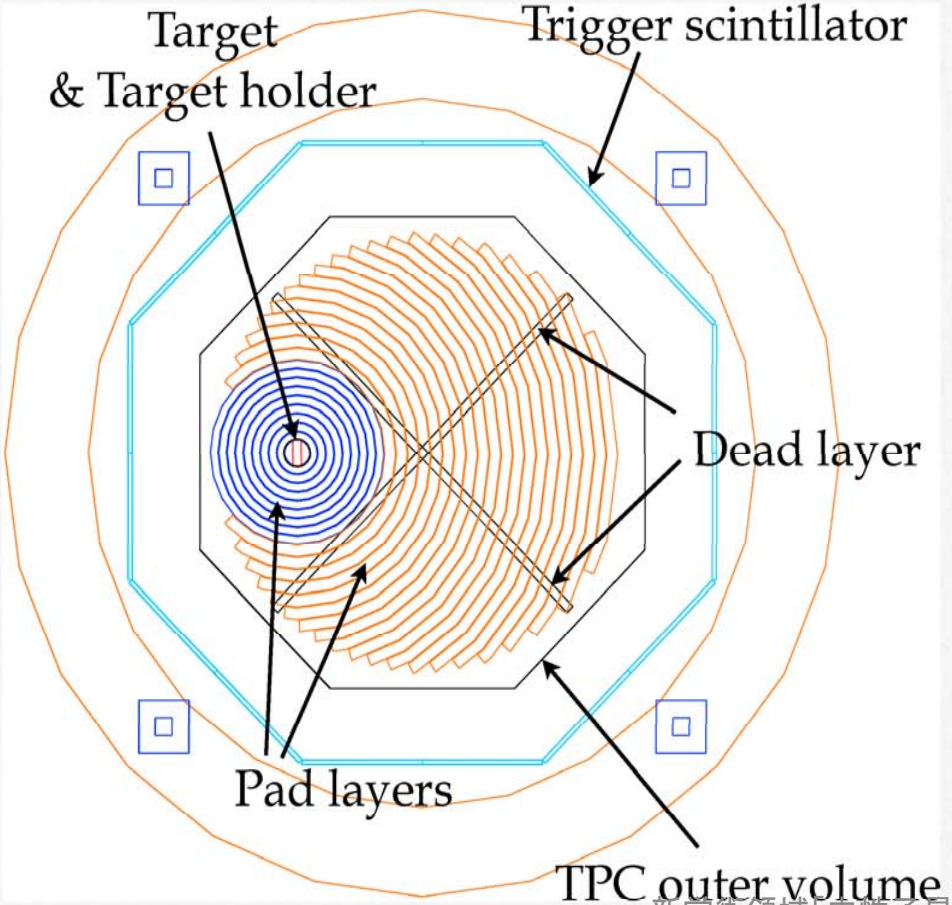
Readout electronics GET

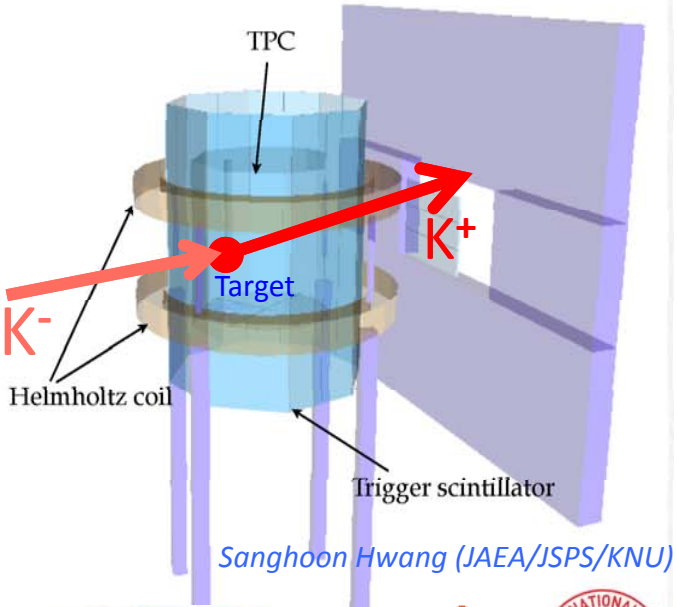
rate 1KHz

R&D Issue:

Laser calibration method

Field uniformity ExB

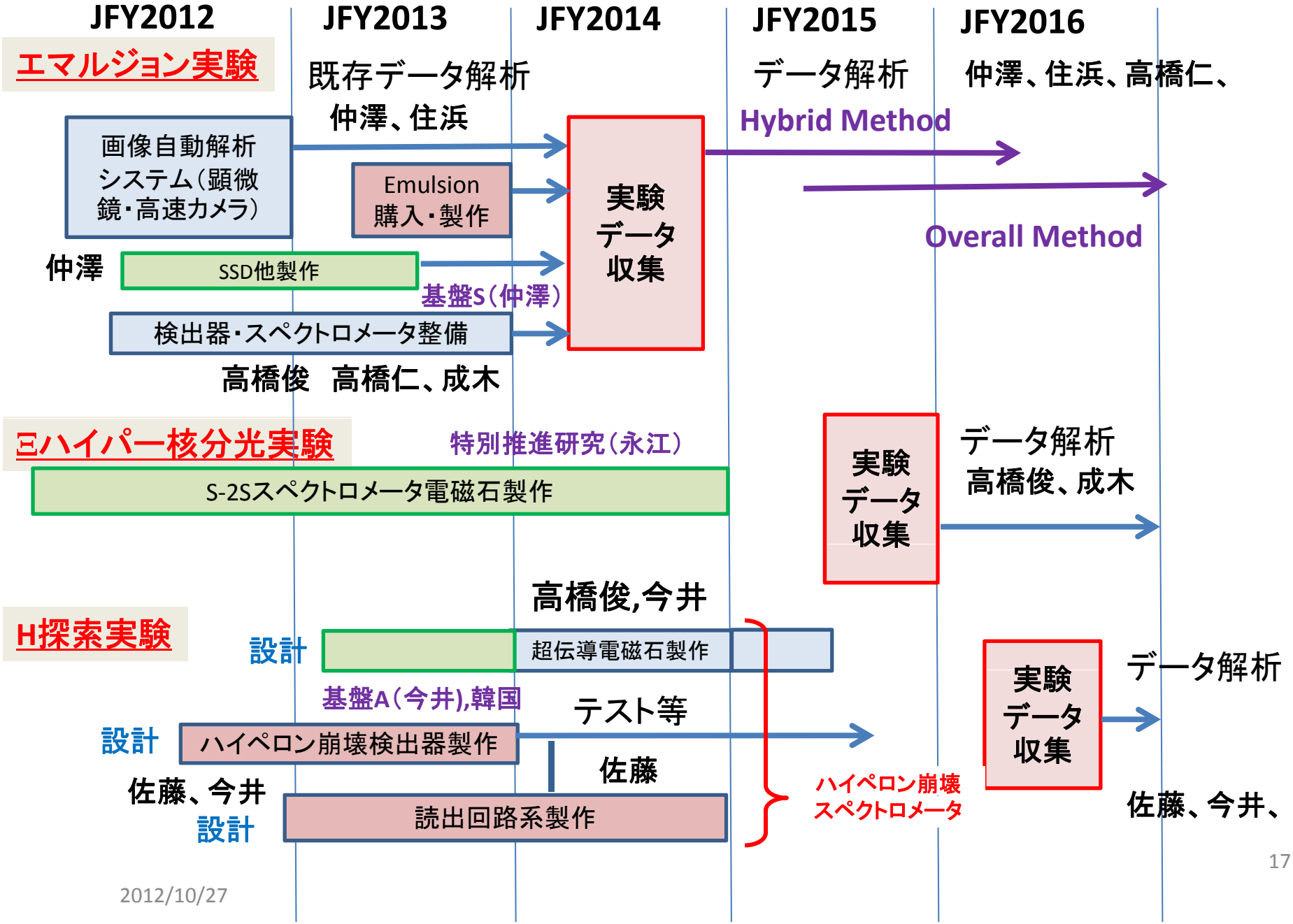




Sanghoon Hwang (JAEA/JSPS/KNU)

Active readout area's diameter : ~50cm

Schedule


JFY2012
JFY2013
JFY2014
JFY2015
JFY2016
エマルジョン実験
既存データ解析
仲澤、住浜
データ解析
仲澤、住浜、高橋仁、
Hybrid Method
画像自動解析システム（顕微鏡・高速カメラ）
Emulsion購入・製作
実験データ収集
Overall Method
仲澤
SSD他製作
基盤S（仲澤）
検出器・スペクトロメータ整備
高橋俊　高橋仁、成木
Ξハイパー核分光実験
特別推進研究（永江）
S-2Sスペクトロメータ電磁石製作
実験データ収集
データ解析
高橋俊、成木
高橋俊,今井
H探索実験
設計
超伝導電磁石製作
基盤A（今井),韓国
テスト等
設計
ハイペロン崩壊検出器製作
佐藤
実験データ収集
データ解析
佐藤、今井
設計
読出回路系製作
ハイペロン崩壊スペクトロメータ
佐藤、今井、

Summary

- Information on hyperon potential and B-B interaction with strangeness are very important to understand high-density nuclear matter and to construct the EOS.
  - S=–2 B.B interaction has unique feature

    no repulsive core in flavor-singlet channel → *H*-dibaryon
- Experiments to study S=–2 system and B-B interaction
  - Emulsion experiment to obtain 100 $\Lambda\Lambda$ hypernuclear events
  - Ξ-hypernuclear spectroscopy on $^{12}_{\Xi}$Be
  - Search for *H*-dibaryon both bound and resonance states

$\Lambda\Lambda$ interaction from nuclear dependence of $\Delta B_{\Lambda\Lambda}$, existance of *H* ?

Ξ potential and ΞN, ΞN→$\Lambda\Lambda$ interaction from Ξ-nucleus

研究組織（A01）

役割	氏名	所属	担当
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