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JLab WS

Recent Achievements at J-PARC and Future Prospects of Hypernuclear Studies

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1. Present status of hypernuclear physics at J-PARC
2. ΛN-ΣN interaction and Λ in neutron matter
   2.1 hypernuclear γ-ray data for p-shell
   2.2 Charge Symmetry Breaking in ΛN -- New A=4 data --
   2.3 Neutron-rich hypernuclei
3. Toward double strangeness systems
4. Hadron Hall Extension Plan
5. Summary

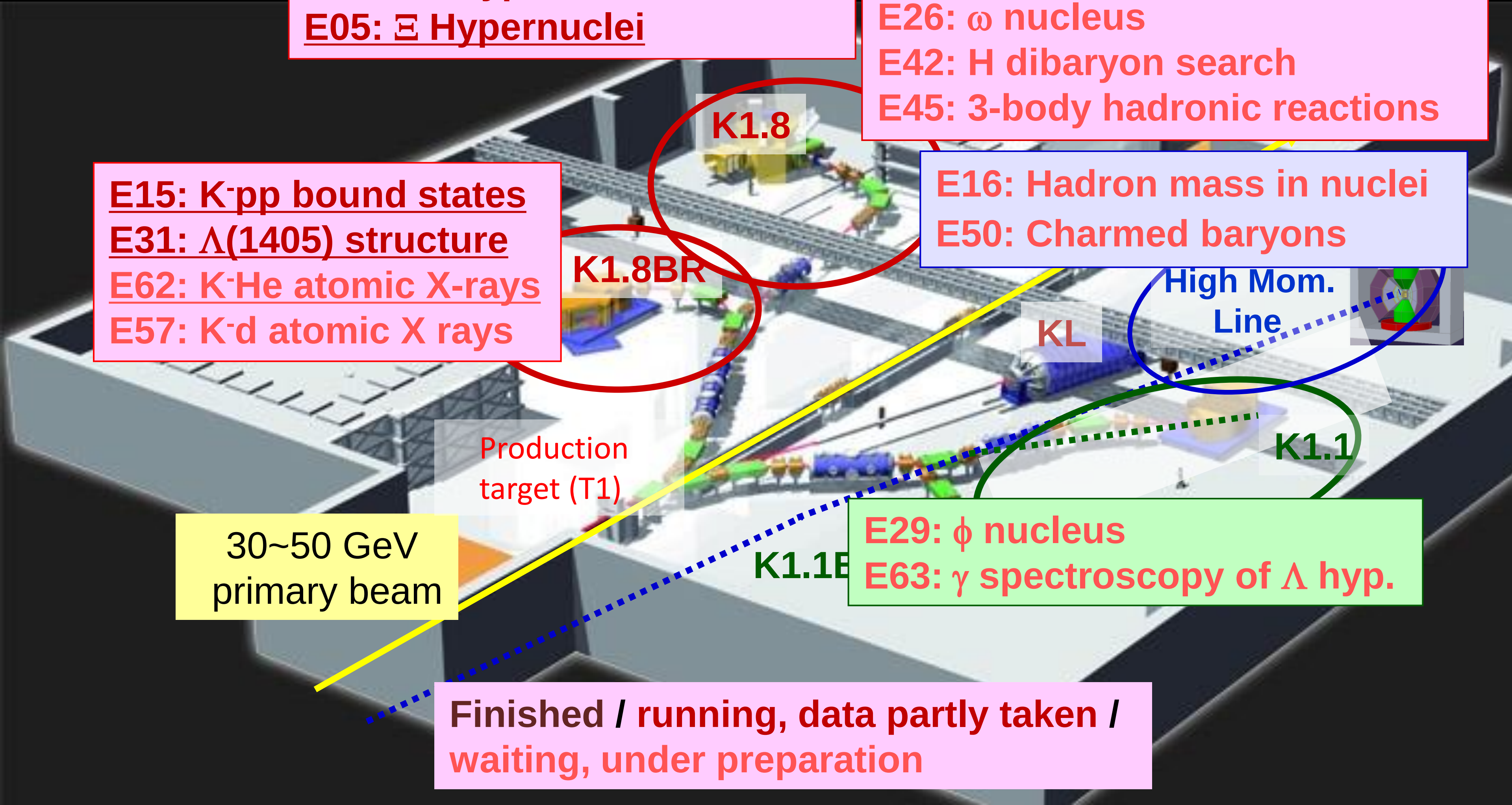
1. Present status of Hypernuclear physics at J-PARC

Approved experiments (stage2 / stage1)

Prese

E19: Θ^+ search
E10: n-rich Λ hypernuclei
E27: K^-pp bound states
E13: γ spectroscopy of Λ hyp.
E07: ΛΛ hypernuclei
E05: Ξ Hypernuclei

E03: Ξ-atomic X rays
E18: Weak decays of Λ hyp.
E40: Σp scattering
E08: Pion double charge exch.
E22: Weak decays of A=4 Λ hyp.
E26: ω nucleus
E42: H dibaryon search
E45: 3-body hadronic reactions



E15: K^-pp bound states
E31: Λ(1405) structure
E62: K^-He atomic X-rays
E57: K^-d atomic X rays

E16: Hadron mass in nuclei
E50: Charmed baryons

E29: ϕ nucleus
E63: γ spectroscopy of Λ hyp.

Finished / running, data partly taken / waiting, under preparation

Approved experiments (stage2 / stage1)

Prese

E19: Θ^+ search
E10: n-rich Λ hypernuclei
E27: K^-pp bound states
E13: γ spectroscopy of Λ hyp.
E07: $\Lambda\Lambda$ hypernuclei
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s in nuclei
med baryons

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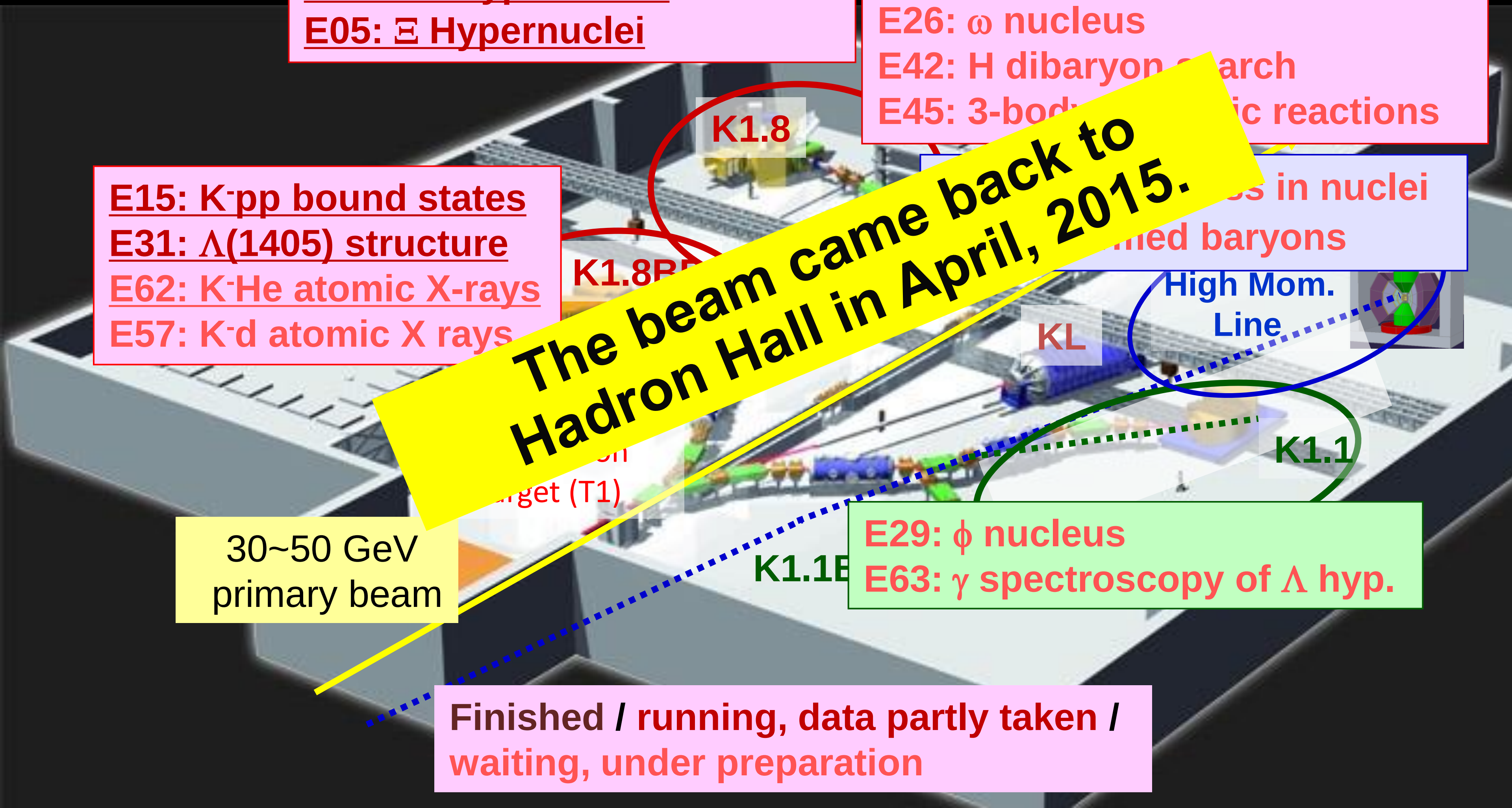


The beam came back to Hadron Hall in April, 2015.

30~50 GeV primary beam

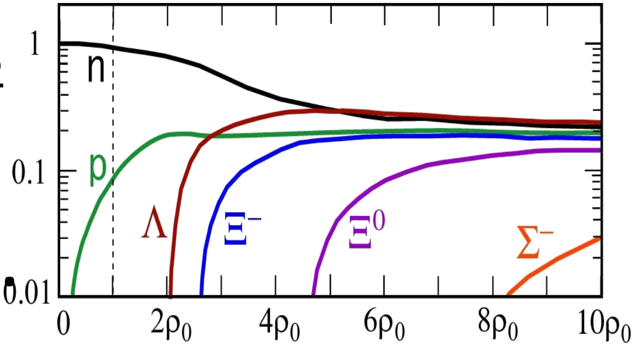
E29: ϕ nucleus
E63: γ spectroscopy of Λ hyp.

Finished / running, data partly taken / waiting, under preparation

Recent data

Under preparation/Planned

Experiments for neutron stars



1. ΛN interaction in neutron matter

(1) ΛNN 3-body force = ρ and T dep. of ΛN int.

Precise B_Λ for various (asymmetric) Λ hypernuclei

$^{12}_{\Lambda}$B, $^{16}_{\Lambda}$N, $^{28}_{\Lambda}$Al, $^{52}_{\Lambda}$V **JLab E01-011/ E05-115** **JLab E94-107** $^{40}_{\Lambda}$K, $^{48}_{\Lambda}$K, …., $^{208}_{\Lambda}$Tl **JLab 15-008** **J-PARC HIHR**

ΛN scattering exp. to determine 2-body force and to extract 3-body force effects from hypernuclear data **J-PARC K1.1**

(2) ΛN-ΣN coupling/ Λn force

J-PARC E10

Light neutron-rich hypernuclei $^{6}_{\Lambda}$H **DAΦNE FINUDA** $^{9}_{\Lambda}$He,… **J-PARC E10/ HIHR**

Charge Symmetry Breaking $^{4}_{\Lambda}$H, $^{4}_{\Lambda}$He, $^{7}_{\Lambda}$He, $^{10}_{\Lambda}$Be

Mainz A1 **J-PARC E13** **JLab E01-011/ E05-115** **J-PARC E63**

2. S=-2 interactions

ΛΛ hypernuclei, **J-PARC E07** Ξ hypernuclei, **J-PARC E05** Ξ-atomic X-rays **J-PARC E03/E07**

3. ΣN interaction (in particular, $\Sigma^-n = \Sigma^+p$)

$\Sigma^\pm p$ scattering experiment **J-PARC E40**

4. K^{bar} interaction in nuclear matter

K^-pp search **DAΦNE FINUDA** **J-PARC E27** **J-PARC E15**

2. ΛN-ΣN interaction and Λ in neutron matter

2.1 p-shell hypernuclear data

2.2 Charge Symmetry Breaking in ΛN

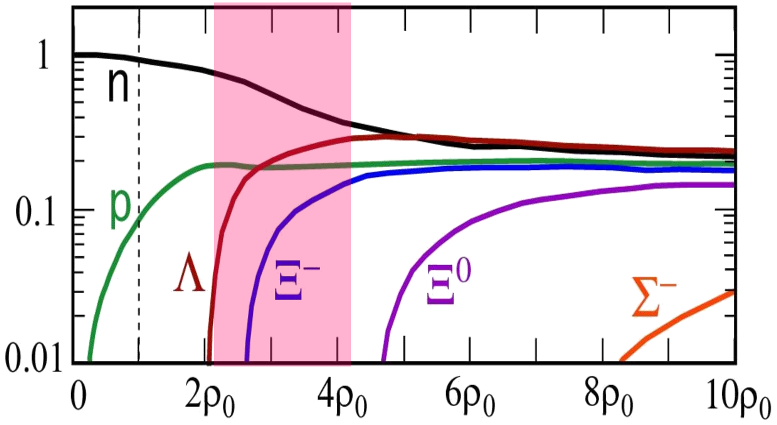
-- New A=4 data –

2.3 Neutron-rich hypernuclei

ΛN Interaction in neutron(-rich) matter

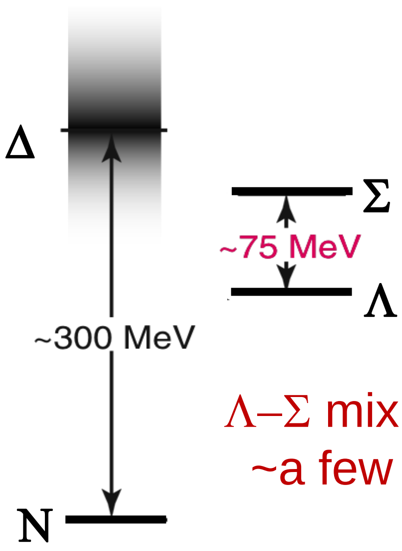
Hypernuclear data: U_Λ = - 30 MeV

= Λ in symmetric matter, at ρ_0



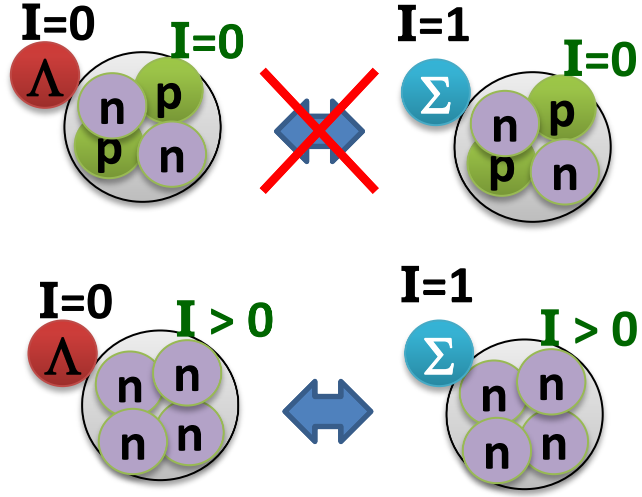
Λ has no isospin, but

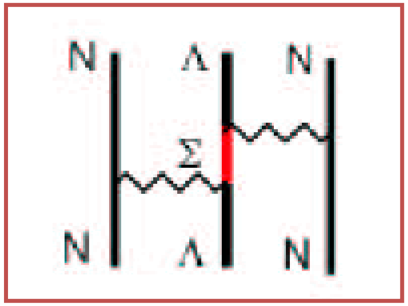
ΛN int. in neutron matter is different due to strong ΛN-ΣN int.



Λ–Σ mixing
~a few %

-> Large Λ-Σ mixing in hypernuclei





Akaishi et al. PRL 84 (2000) 3539

Coherent effect in n-rich matter

-> Attractive ΛNN force

Explains A=3,4,5 hypernuclei

At short range (large ρ), Λnn strongly repulsive?

How to experimentally study?

- Precise B_Λ and level energy data for asymmetric (neutron-rich) Λ hypernuclei

(e,e'K$^+$)@JLab (π$^-$, K$^+$)@J-PARC

- B_Λ for s- and p-shell hypernuclei: $^{4}_{\Lambda}$H, $^{6}_{\Lambda}$H; $^{7}_{\Lambda}$He, $^{9}_{\Lambda}$He; $^{9}_{\Lambda}$Li, $^{10}_{\Lambda}$Li; …
- γ-rays for s- and p-shell (K$^-$, π$^-$) @J-PARC

(e,e'K$^+$)@JLab (K$^-$, π$^-$) @J-PARC ?

- Charge Symmetry Breaking: $^{4}_{\Lambda}$H / $^{4}_{\Lambda}$He, $^{7}_{\Lambda}$He / $^{7}_{\Lambda}$Li*, $^{10}_{\Lambda}$Be / $^{10}_{\Lambda}$B, $^{12}_{\Lambda}$B / $^{12}_{\Lambda}$C
  -> ΣN-ΛN interaction
- B_Λ for medium/heavy asymmetric Λ hypernuclei: $^{40}_{\Lambda}$K / $^{48}_{\Lambda}$K, …$^{208}_{\Lambda}$Tl; ($^{40}_{\Lambda}$Ca $^{48}_{\Lambda}$Ca, …$^{208}_{\Lambda}$Pb)
  -> T, ρ dependence of ΛN int. (e,e'K$^+$)@JLab (π$^+$, K$^+$)@J-PARC ?
  (ΛNN force)

- ΣN->ΛN scattering experiments @J-PARC

2. ΛN-ΣN interaction and Λ in neutron matter

2.1 p-shell hypernuclear data

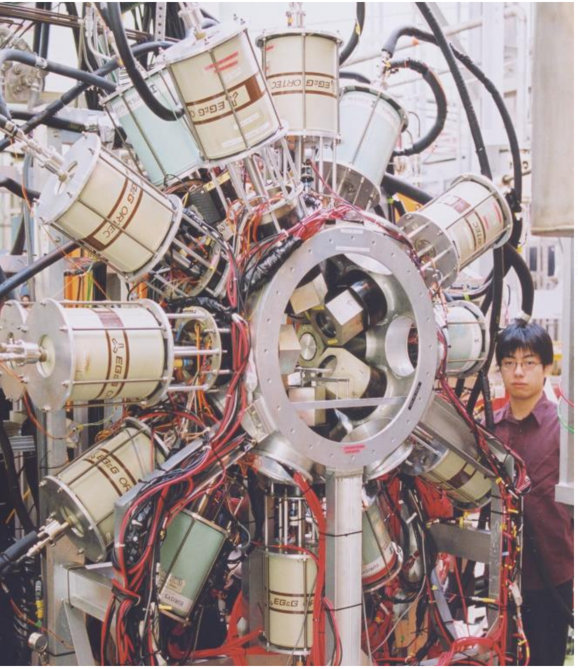
2.2 Charge Symmetry Breaking in ΛN

-- New A=4 data –

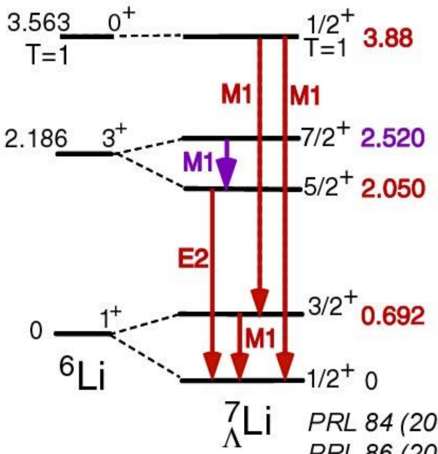
2.3 Neutron-rich hypernuclei

Hyperball 1998~

Hypernuclear γ-ray data (2014)

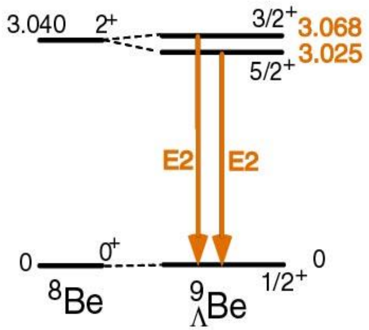


^{7}Li (π^+,$K^+\gamma$) KEK E419



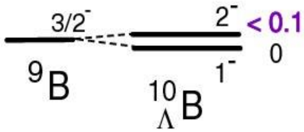
PRL 84 (2000) 5963
PRL 86 (2001) 1982
PLB 579 (2004) 258
PRC 73 (2006) 012501

^{9}Be (K^-,$\pi^-\gamma$) BNL E930('98)



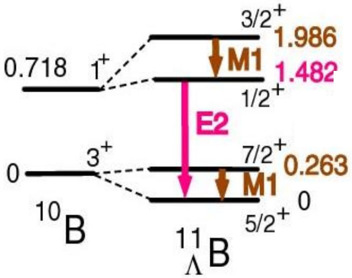
PRL 88 (2002) 082501
NPA 754 (2005) 58c

^{10}B (K^-,$\pi^-\gamma$) BNL E930('01)



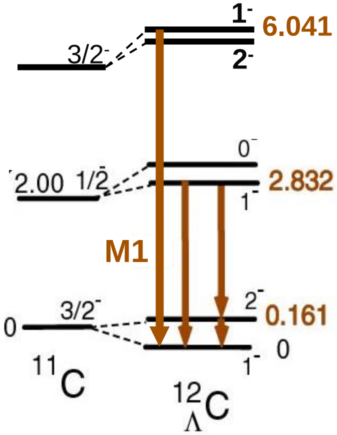
NPA 754 (2005) 58c

^{11}B (π^+,$K^+\gamma$) KEK E518



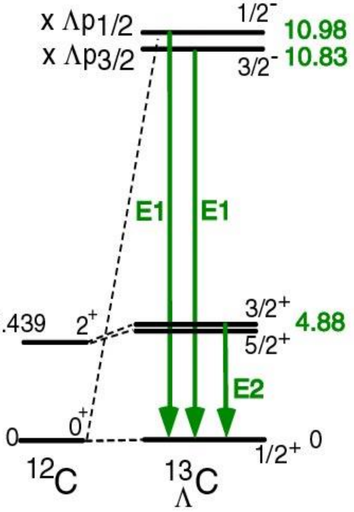
NPA 754 (2005) 58c

^{12}C (π^+,$K^+\gamma$) KEK E566



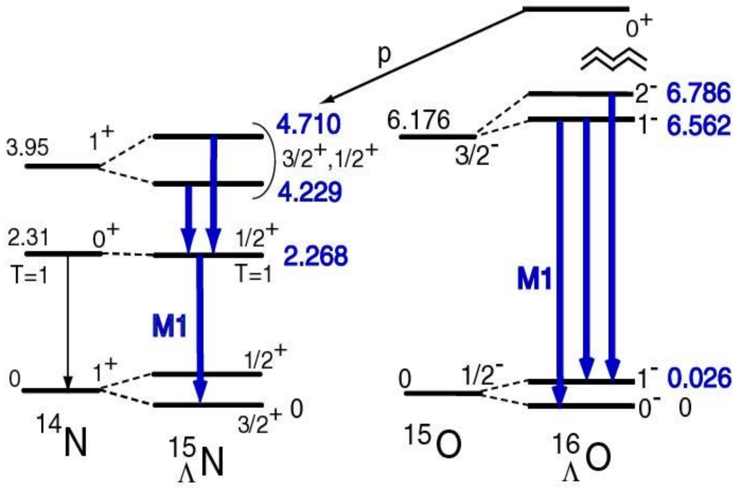
EPJ A33 (2007) 243
PTEP 2015 (2015) 8, 081D01

^{13}C (K^-,$\pi^-\gamma$) BNL E929 (NaI)



PRL 86 (2001) 4255
PRC 65 (2002) 034607

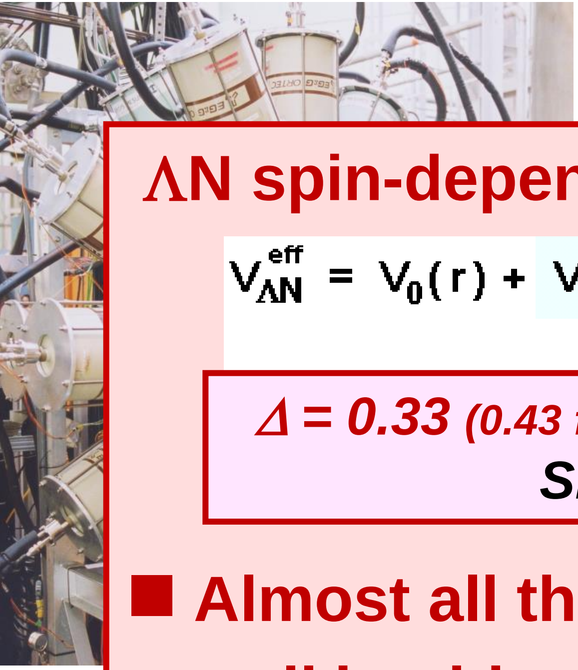
^{16}O (K^-,$\pi^-\gamma$) BNL E930('01)



PRC 77 (2008) 054315

PRL 93 (2004) 232501
EPJ A33 (2007) 247

Hyperball 1998~



Hypernuclear γ-ray data (2014)

ΛN spin-dependent interaction strengths determined

$$V_{\Lambda N}^{\mathrm{eff}} = V_0(r) + \underbrace{V_\sigma(r)\, \vec{s}_\Lambda \vec{s}_N}_{\Delta} + \underbrace{V_\Lambda(r)\, \vec{l}_{\Lambda N} \vec{s}_\Lambda}_{S_\Lambda} + \underbrace{V_N(r)\, \vec{l}_{\Lambda N} \vec{s}_N}_{S_N} + \underbrace{V_T(r)\, S_{12}}_{T}$$

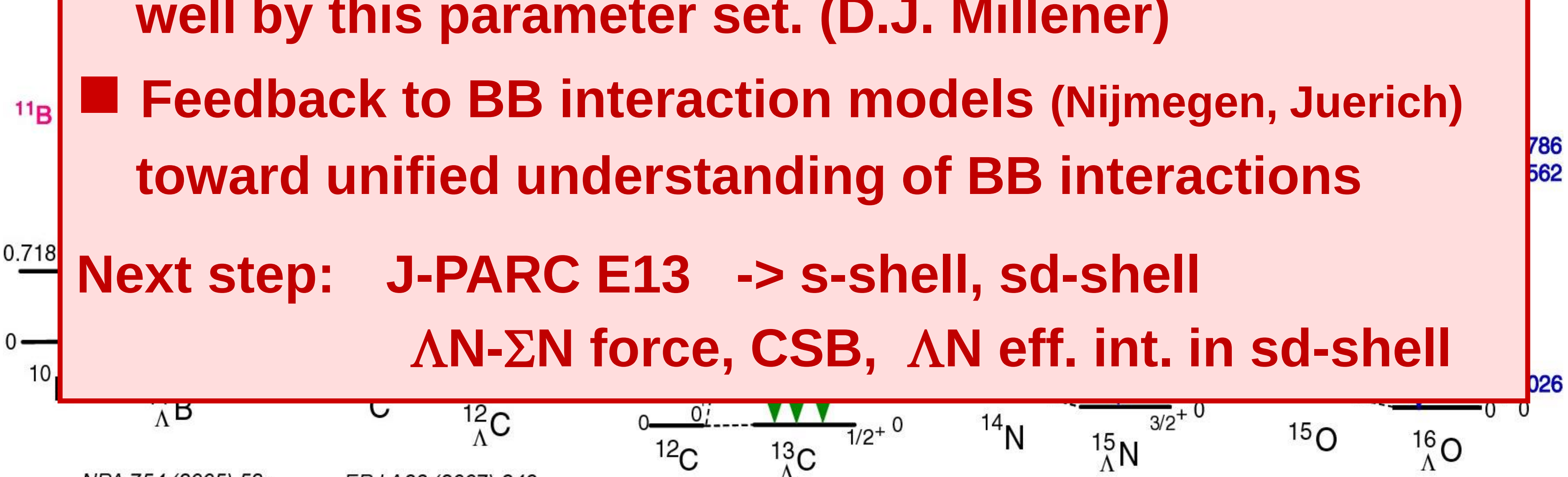
Δ = 0.33 (0.43 for A=7), S_Λ = -0.01, S_N = -0.4, T = 0.03 [MeV]

Smaller than NN forces by 1/10~1/50

- **Almost all these p-shell levels are reproduced quite well by this parameter set. (D.J. Millener)**
- **Feedback to BB interaction models (Nijmegen, Juerich) toward unified understanding of BB interactions**

Next step: J-PARC E13 -> s-shell, sd-shell

ΛN-ΣN force, CSB, ΛN eff. int. in sd-shell



NPA 754 (2005) 58c

EPJ A33 (2007) 243
PTEP 2015 (2015) 8, 081D01

PRL 86 (2001) 4255
PRC 65 (2002) 034607

PRC 77 (2008) 054315

PRL 93 (2004) 232501
EPJ A33 (2007) 247

D.J. Millener, NPA 881 (2012) 298

Millener's parameter set

A=7,9 $\Delta = 0.430, \quad S_\Lambda = -0.015, \quad S_N = -0.390, \quad T = 0.030.$ **MeV**

A=10~16 $\Delta = 0.330, \quad S_\Lambda = -0.015, \quad S_N = -0.350, \quad T = 0.0239.$ **MeV**

doublet spacing

Calculated from G-matrix using ΛN–ΣN force in "D2"

			contribution of each term (keV)					(keV)	
	J^π_u	J^π_l	$\Lambda\Sigma$	Δ	S_Λ	S_N	T	ΔE^{th}	ΔE^{exp}
$^{7}_{\Lambda}$Li	$3/2^+$	$1/2^+$	72 +10%	628	−1	−4	−9	693	692
$^{7}_{\Lambda}$Li	$7/2^+$	$5/2^+$	74	557	−32	−8	−71	494	471
$^{9}_{\Lambda}$Be	$3/2^+$	$5/2^+$	−8	−14	37	0	28	44	43
$^{11}_{\Lambda}$B	$7/2^+$	$5/2^+$	56	339	−37	−10	−80	267	264
$^{11}_{\Lambda}$B	$3/2^+$	$1/2^+$	61	424	−3	−44	−10	475	505
$^{12}_{\Lambda}$C	2^-	1^-	61 +40%	175	−12	−13	−42	153	161
$^{15}_{\Lambda}$N	$3/2^+_2$	$1/2^+_2$	65	451	−2	−16	−10	507	481
$^{16}_{\Lambda}$O	1^-	0^-	−33 -143%	−123	−20	1	188	23	26
$^{16}_{\Lambda}$O	2^-	1^-_2	92 +37%	207	−21	1	−41	248	224

Agreement looks almost perfect when the $\Lambda\Sigma$ coupling effect included.

$\Sigma\Lambda$ coupling force by Millener (Akaishi's D2, central force only)

➔ Why agreement is so good? Constraint to the $\Lambda\Sigma$ coupling force?

2. ΛN-ΣN interaction and Λ in neutron matter

2.1 p-shell hypernuclear data

2.2 Charge Symmetry Breaking in ΛN

-- New A=4 data –

2.3 Neutron-rich hypernuclei

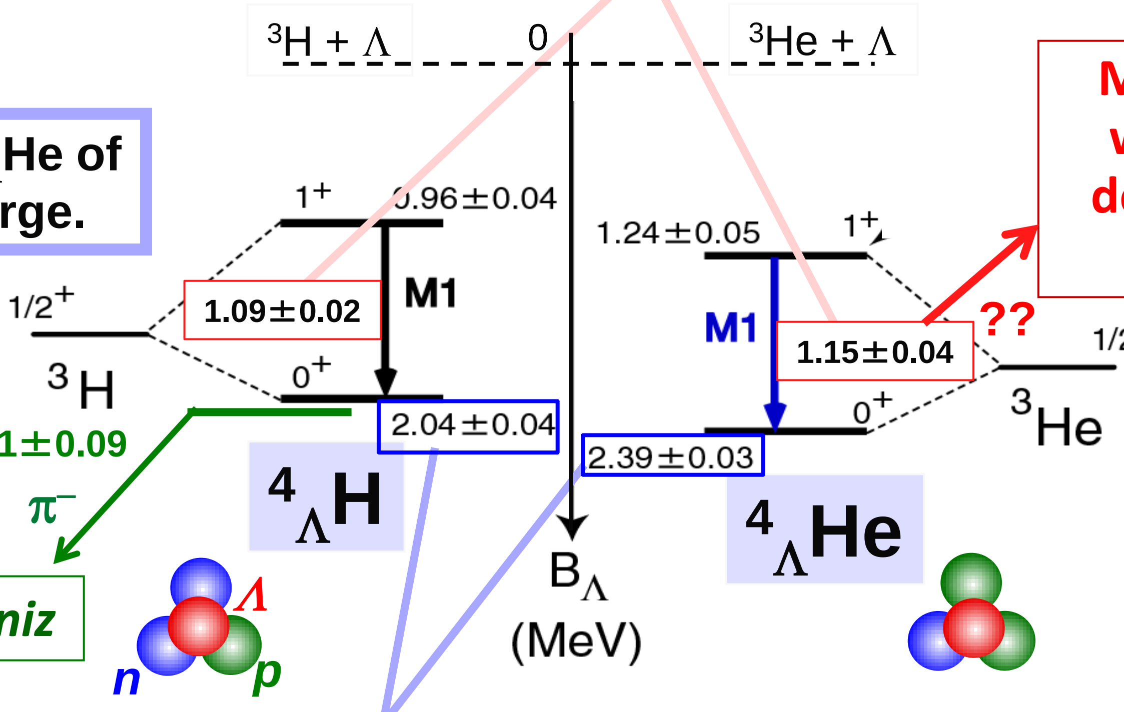
Charge Symmetry Breaking puzzle in hypernuclei

^{3}H / ^{3}He binding energy difference due to strong int.
~60 keV

B_Λ diff. in $^4_\Lambda$H / $^4_\Lambda$He of **350 keV** is too large.

Old NaI data

Bedjidian et al.
PLB 62 (1976) 467
PLB 83 (1979) 252



Measure with Ge detectors
=> E13

Measured at Maniz

A. Esser et al.,
PRL 114 (2015) 12501

Old emulsion data — *no systematic errors given*

M. Juric et al. NPB 52 (1973) 1

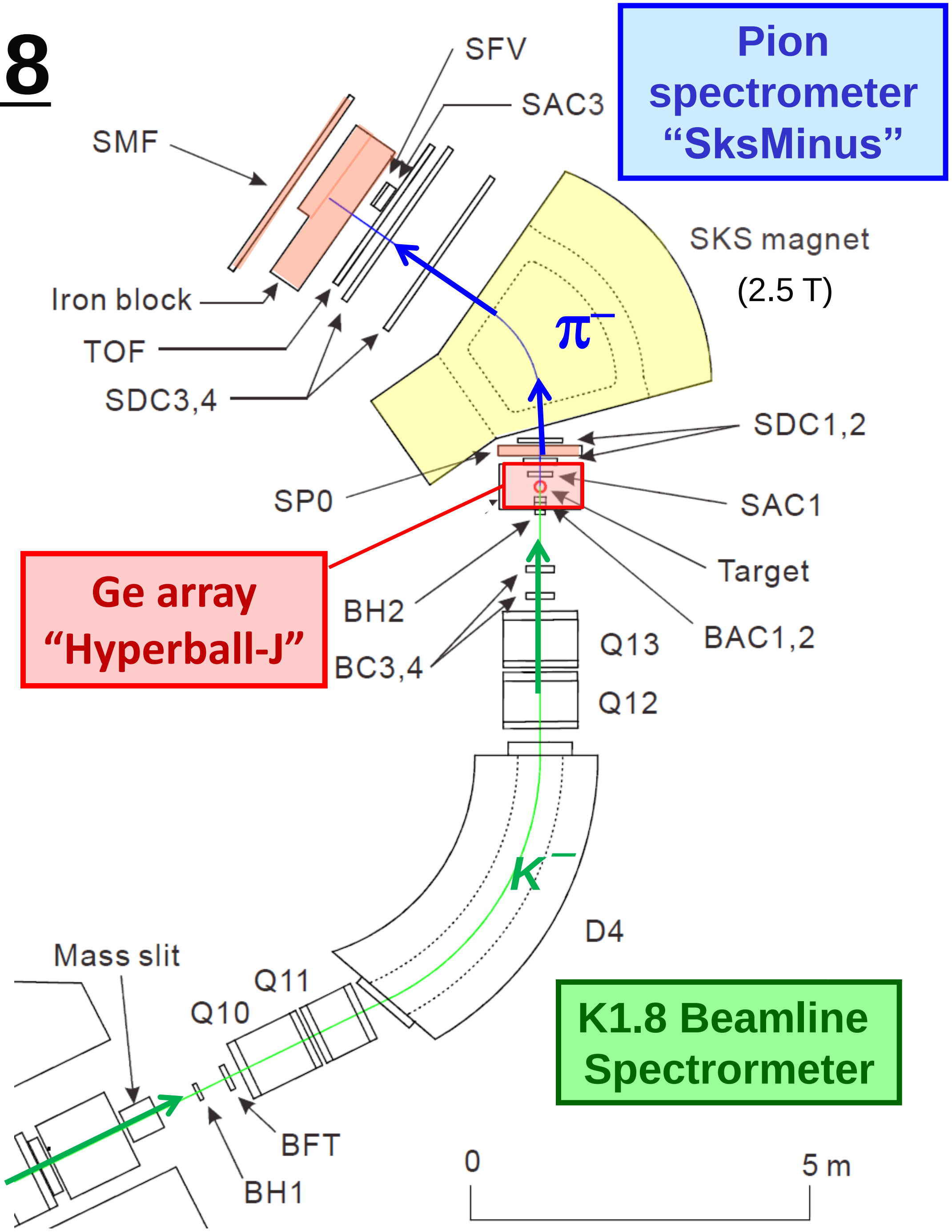
4-body exact calc's with Λ–Σ mixing using Nijmegen BB interaction models failed
=> Long standing puzzle

Experimental confirmation of CSB is necessary

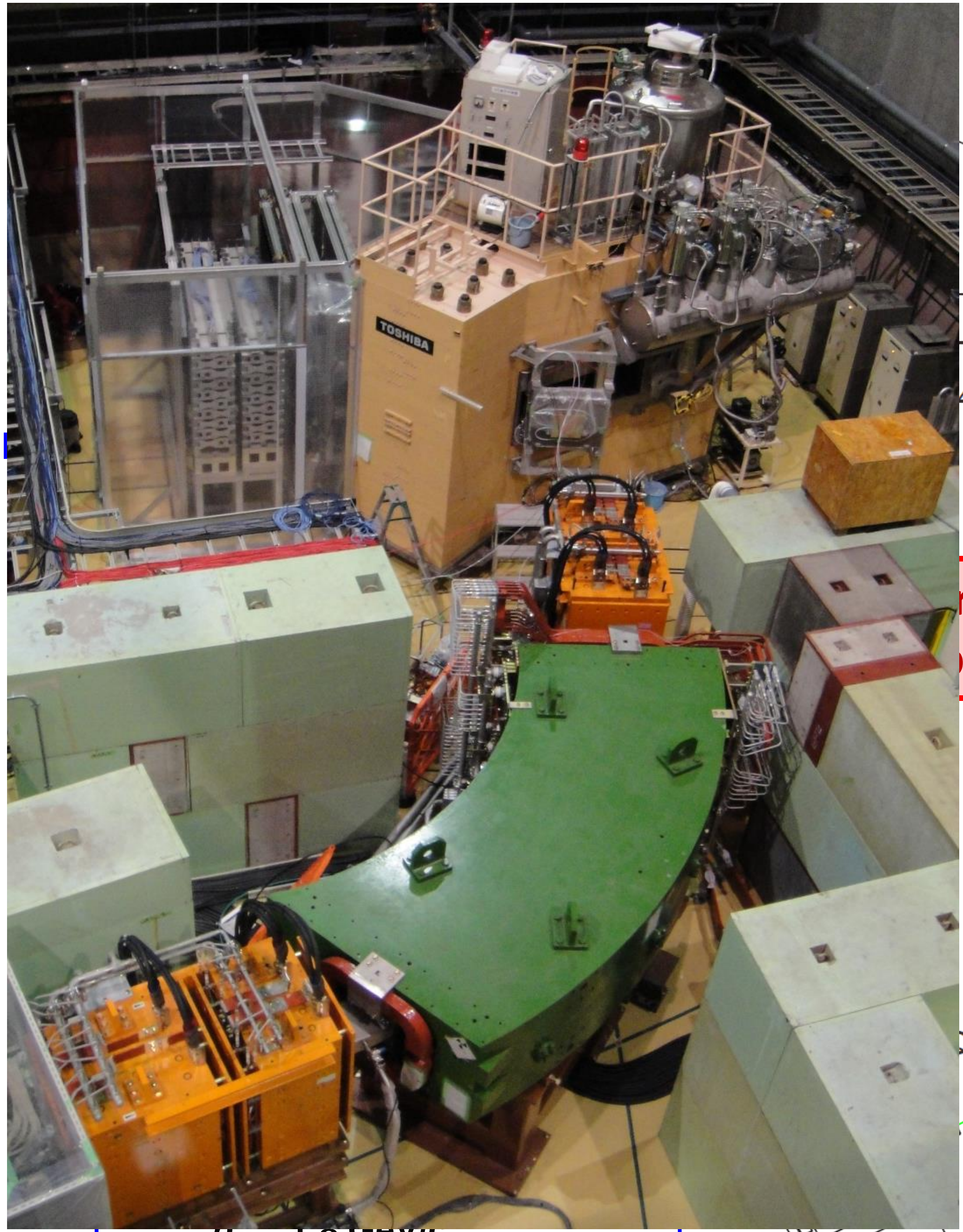
E13 setup at K1.8

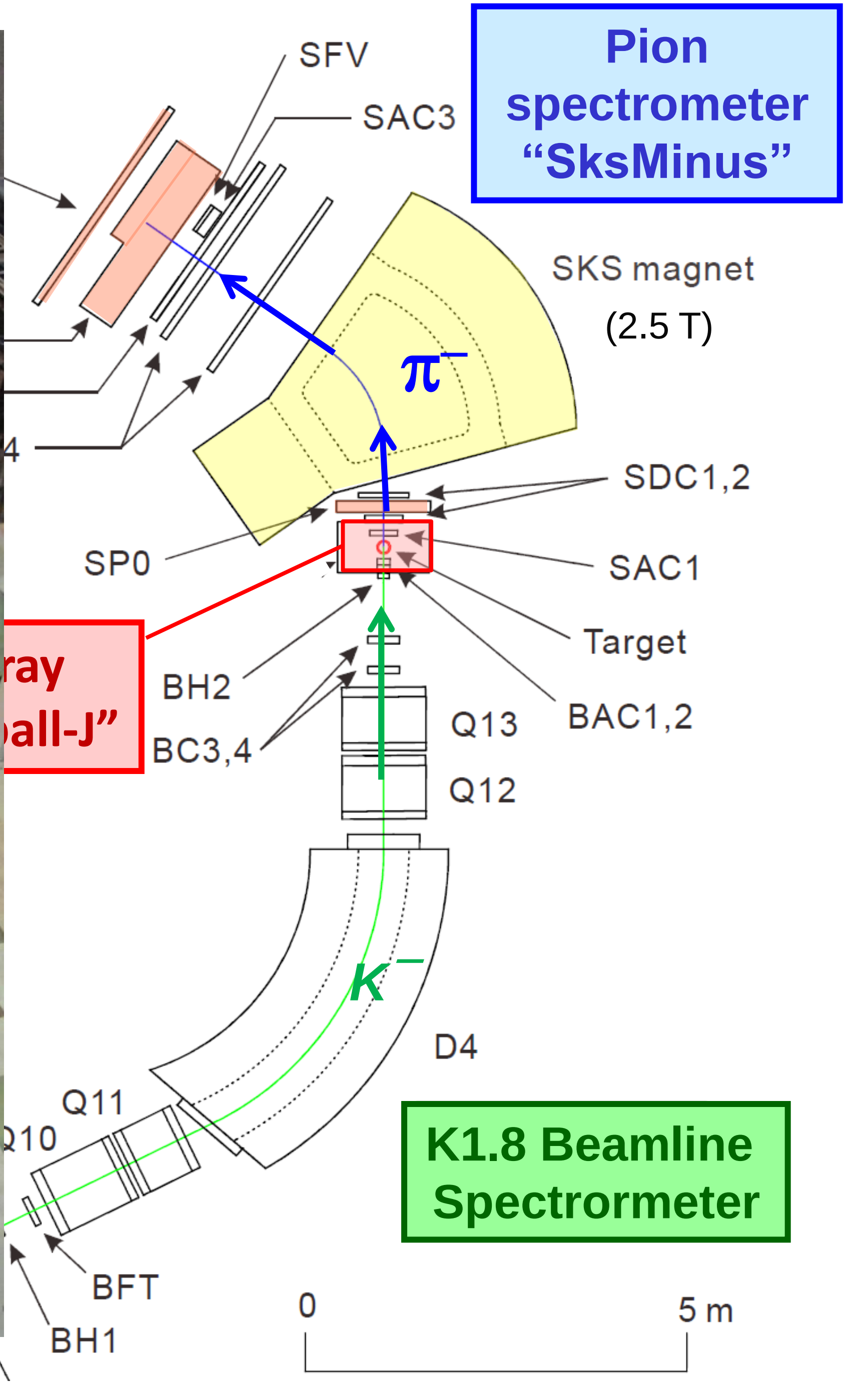
$$
{}^{A}Z\,(K^{-},\pi^{-})\,{}^{A}_{\Lambda}Z^{*} \rightarrow {}^{A}_{\Lambda}Z+\gamma
$$

- **Tag production of hypernuclei**
- **Detect γ-rays from hypernuclei**



${}^{4}_{\Lambda}$He : liq.He target (2.5 g/cm^{2})
p_K = 1.5 GeV/c
${}^{19}_{\Lambda}$F : HF -> CF$_4$ target (20 g/cm^{2})
p_K = 1.8 GeV/c



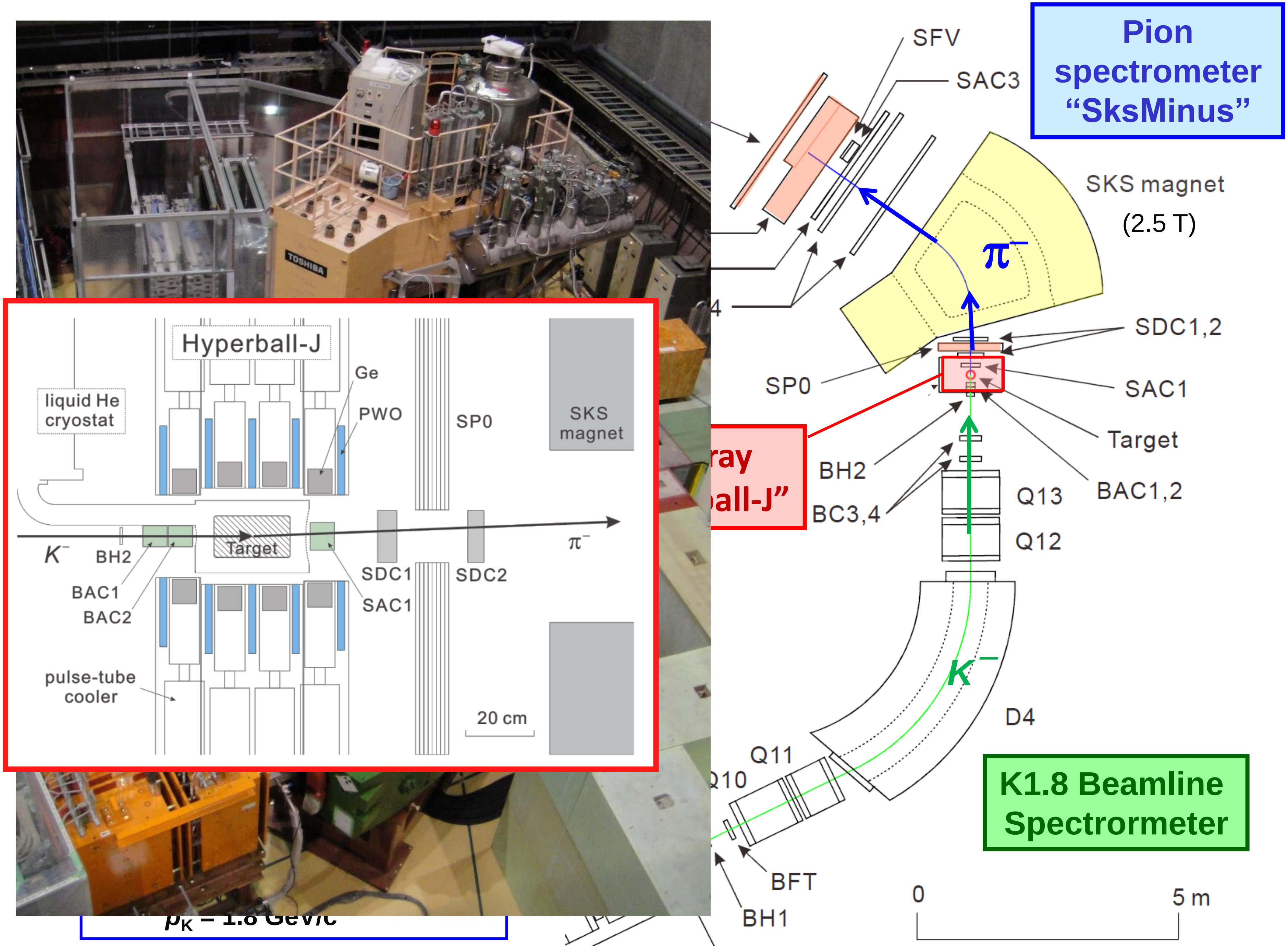


Pion spectrometer "SksMinus"

K1.8 Beamline Spectrormeter

ray
all-J"

p_K = 1.8 GeV/c



Pion spectrometer "SksMinus"

K1.8 Beamline Spectrormeter

p_K = 1.8 GeV/c

Hyperball-J

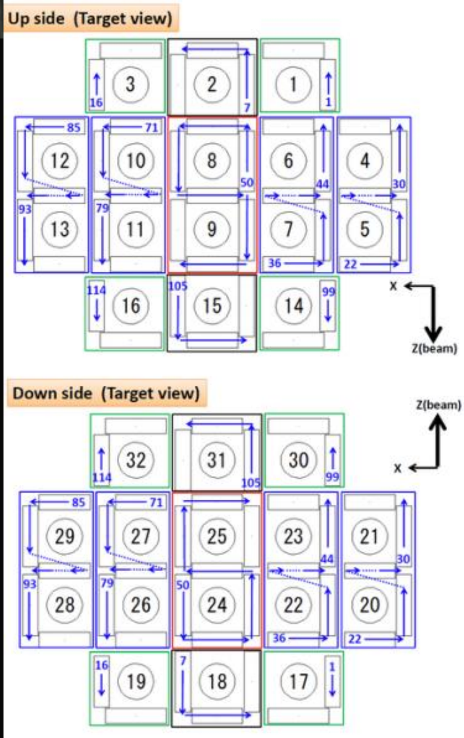
A newly developed Ge array for hypernuclei

Ge cooled down to ~70K
by a pulse-tube refrigerator
(c.f. 92K w/LN$_2$) to suppress
radiation damage

Fast background suppressor
made of PWO

ΔE= 3.1(1) keV at 1.33 MeV

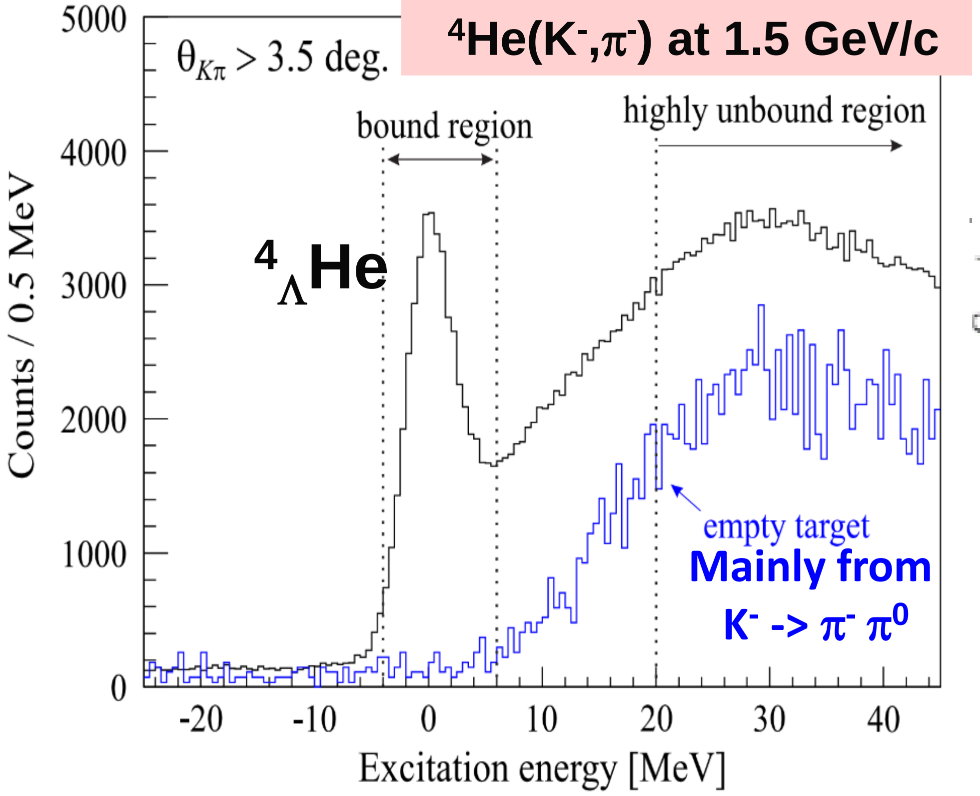
Eff. = 5.4% @1 MeV
with 28 Ge(re=60%)



E13: Spectroscopy of $^{4}_{\Lambda}$He

24kW / 5days’ data taking just after the beam resumption

Missing mass



^{4}He(K^{-},π^{-}) at 1.5 GeV/c

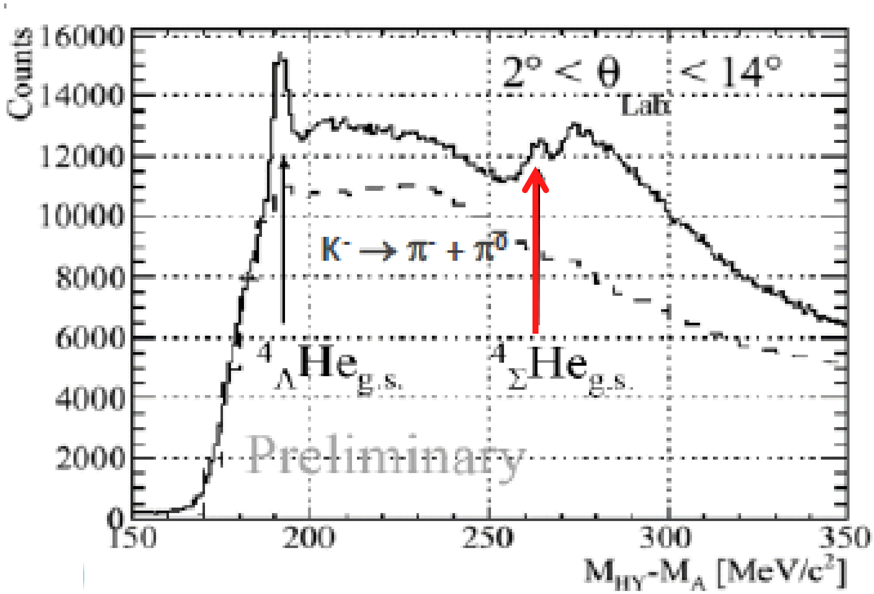
$^{4}_{\Lambda}$He

Mainly from

K^{-} -> π^{-} π^{0}

$^{4}_{\Lambda}$He(0^{+}) dominant + $^{4}_{\Lambda}$He(1^{+})
Peak width = resolution ~5.4 MeV (FWHM)

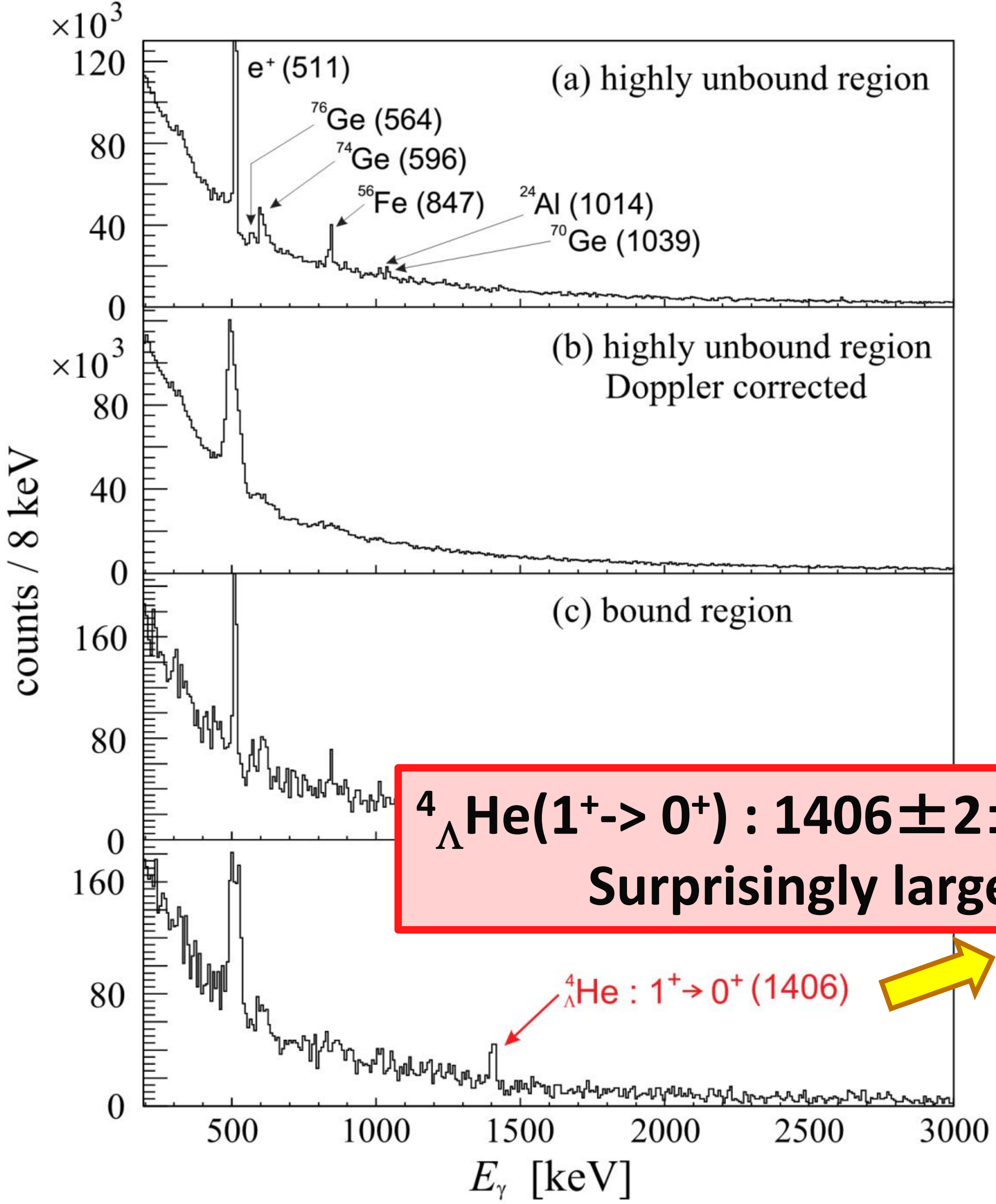
Black : with liq. He (physics run)
Blue : empty target
(w/o liq. He, w/target cell)



Nakagawa et al., HYP2015 proceeding.

Byproduct:
Spectrum for $^{4}_{\Sigma}$He (p_K=1.5 GeV/c) was also successfully taken.

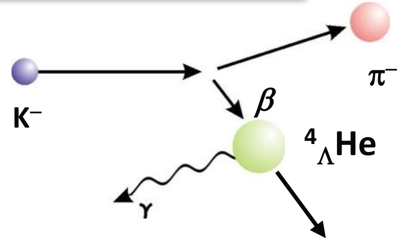
Mass-gated γ-ray spectrum



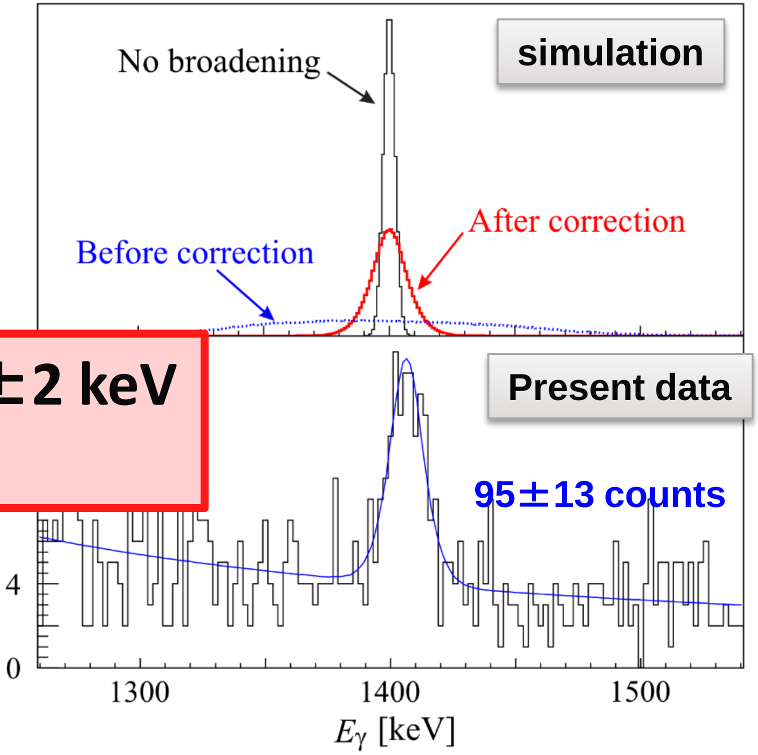
$^{4}{}_{\Lambda}$He(1⁺-> 0⁺) : 1406±2±2 keV

Surprisingly large

Doppler shift correction

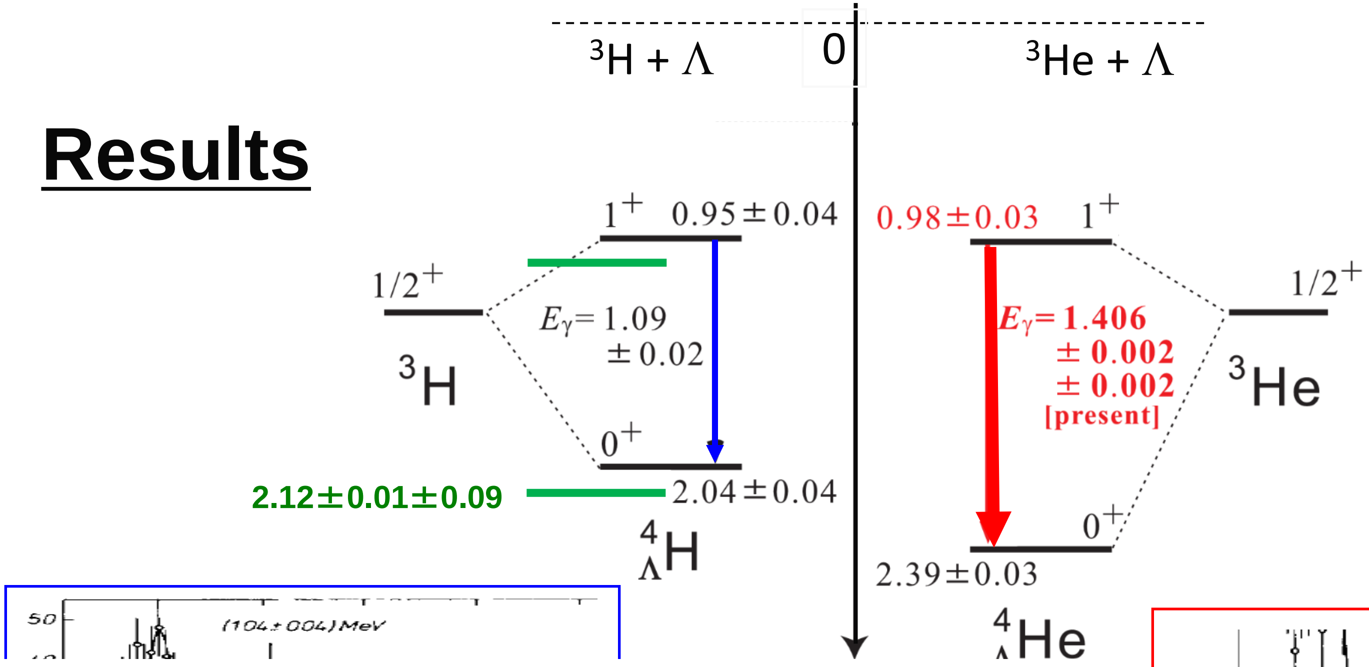


$$E_{corrected} = \frac{E_{measured}}{\gamma(1+\beta cos\theta_{\gamma})}$$



1⁺ cross section seems lower by 1/2-3

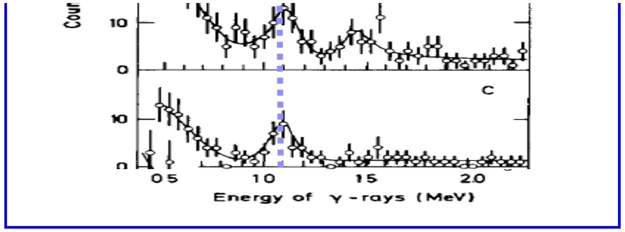
Results

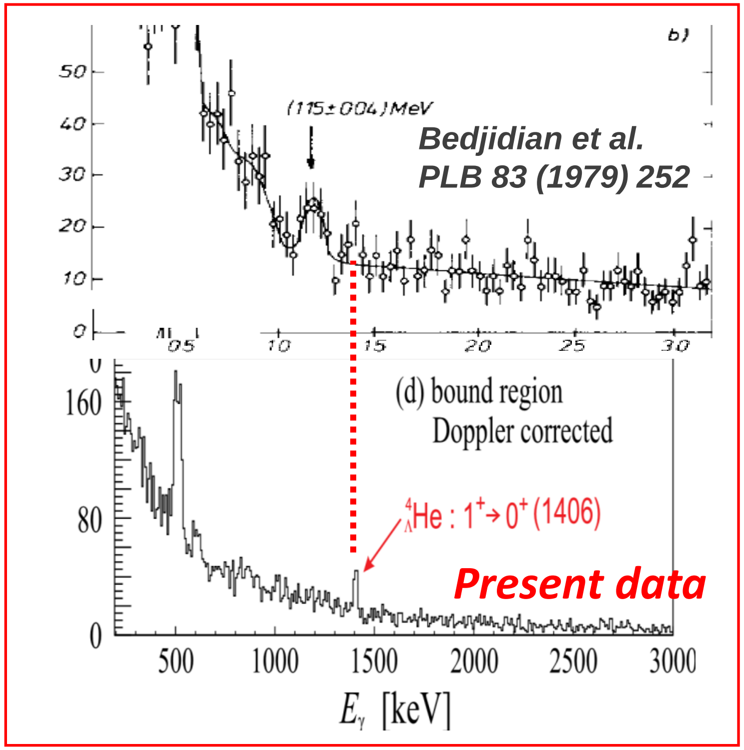


=> Existence of a large CSB effect confirmed only by γ-ray data

Combining with emulsion data,	$\Delta B_\Lambda(1^+)$: 0.03±0.05 MeV $\Delta B_\Lambda(0^+)$: 0.35±0.05 MeV

=> Large spin dependence in CSB found





Bedjidian et al. PLB 83 (1979) 252

Present data

PRL **115,** 222501 (2015) PHYSICAL REVIEW LETTERS week ending 27 NOVEMBER 2015

Observation of Spin-Dependent Charge Symmetry Breaking in ΛN Interaction: Gamma-Ray Spectroscopy of ${}^{4}_{\Lambda}$He

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(J-PARC E13 Collaboration)

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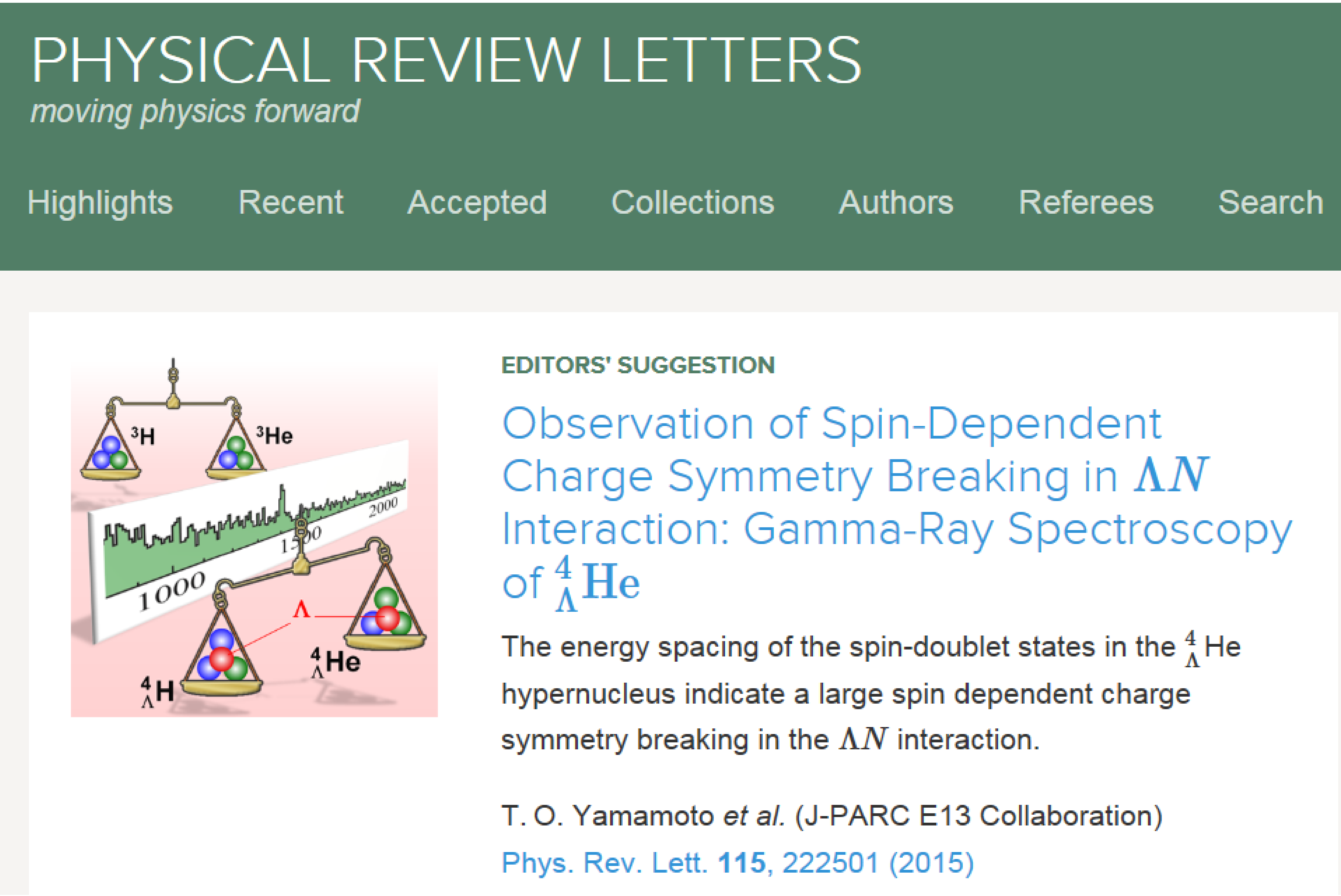
(Received 12 August 2015; published 24 November 2015)

The energy spacing between the spin-doublet bound state of ${}^{4}_{\Lambda}\mathrm{He}(1^+, 0^+)$ was determined to be $1406 \pm 2 \pm 2$ keV, by measuring γ rays for the $1^+ \rightarrow 0^+$ transition with a high efficiency germanium detector array in coincidence with the ${}^{4}\mathrm{He}(K^-, \pi^-){}^{4}_{\Lambda}\mathrm{He}$ reaction at J-PARC. In comparison to the corresponding energy spacing in the mirror hypernucleus ${}^{4}_{\Lambda}$H, the present result clearly indicates the existence of charge symmetry breaking (CSB) in ΛN interaction. By combining the energy spacings with the known ground-state binding energies, it is also found that the CSB effect is large in the 0^+ ground state but is vanishingly small in the 1^+ excited state, demonstrating that the ΛN CSB interaction has spin dependence.

DOI: 10.1103/PhysRevLett.115.222501 PACS numbers: 21.80.+a, 13.75.Ev, 23.20.Lv, 25.80.Nv



PHYSICAL REVIEW LETTERS
moving physics forward

EDITORS' SUGGESTION

Observation of Spin-Dependent Charge Symmetry Breaking in ΛN Interaction: Gamma-Ray Spectroscopy of $^4_\Lambda\mathrm{He}$

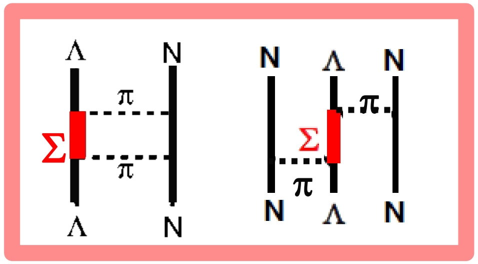
The energy spacing of the spin-doublet states in the $^4_\Lambda$He hypernucleus indicate a large spin dependent charge symmetry breaking in the ΛN interaction.

T. O. Yamamoto *et al.* (J-PARC E13 Collaboration)

Phys. Rev. Lett. **115**, 222501 (2015)

Press-released from Tohoku U., KEK, JAEA, J-PARC

CSB is sensitive to ΛN-ΣN force



Dalitz-Hippel
Bodmer, Gibson, Akaishi,..

Exp. $\Delta B_\Lambda(1^+)$: 0.03±0.05 MeV
$\Delta B_\Lambda(0^+)$: 0.35±0.05 MeV

Table 2 *A. Gal, PLB 744 (2015) 352*

Calculated CSB contributions to $\Delta B^4_\Lambda(0^+_{g.s.})$ and total values of $\Delta B^4_\Lambda(0^+_{g.s.})$ and $\Delta B^4_\Lambda(1^+_{exc})$, in keV, from several model calculations of the $A = 4$ hypernuclei. Recall that $\Delta B^{exp}_\Lambda(0^+_{g.s.}) = 350 \pm 60$ keV [3].

Σ^+/Σ^- mass difference **Λ/Σ^0 mixing**

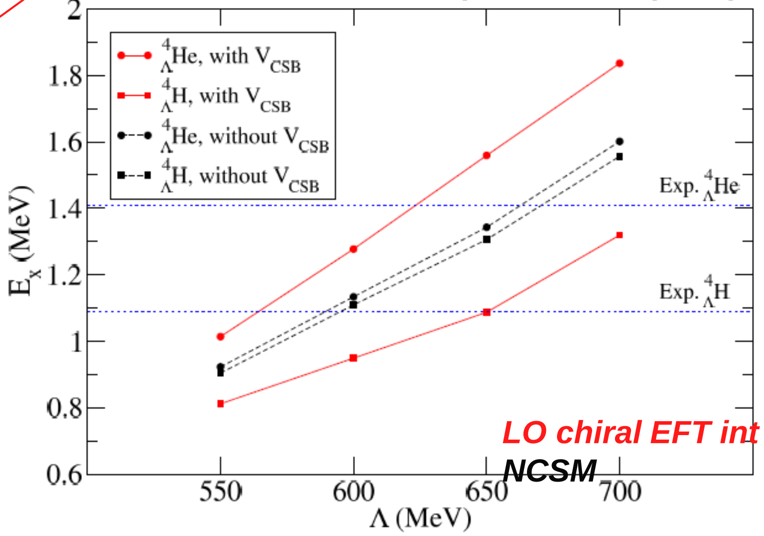
${}^4_\Lambda$He–${}^4_\Lambda$H model	P_Σ (%) $0^+_{g.s.}$	ΔT_{YN} $0^+_{g.s.}$	ΔV_C $0^+_{g.s.}$	ΔV_{YN} $0^+_{g.s.}$	ΔB^4_Λ $0^+_{g.s.}$	ΔB^4_Λ 1^+_{exc}
ΛNNN [9] *w/o Σ mixing*	–	–	−42	91	49	−61
NSC97$_e$ [10]	1.6	47	−16	44	75	−10
NSC97$_f$ [11]	1.8				100	−10
NLO chiral [12] *w/o CSB*	2.1	55	−9	–	46	
$(\Lambda\Sigma)_e$ [present]	0.72	39	−45	232	226	30
$(\Lambda\Sigma)_f$ [present]	0.92	49	−46	263	266	39

Gmatrix ΣN–ΛN : NSC but central only (Akaishi-Millener's D2)

NSC int. : ΣN–ΛN tensor dominated
=> cancel between ρ and π exch.
=> small CSB

LO chiral EFT int. : ΣN–ΛN central dominated
=> constructive between ρ and π exch.
=> large CSB

D. Gazda and A. Gal, accepted in PRL (2016)



LO chiral EFT int
NCSM

${}^A_\Lambda Z_>$–${}^A_\Lambda Z_<$ pairs	I, J^π	ΔB^{calc}_Λ (keV)	ΔB^{exp}_Λ [3] (keV)
${}^4_\Lambda$He–${}^4_\Lambda$H	$\frac{1}{2}, 0^+$	226	+350±60
${}^7_\Lambda$Be–${}^7_\Lambda$Li*	$1, \frac{1}{2}^+$	−17	−100±90
${}^8_\Lambda$Be–${}^8_\Lambda$Li	$\frac{1}{2}, 1^-$	+49	+40±60
${}^9_\Lambda$B–${}^9_\Lambda$Li	$1, \frac{3}{2}^+$	−54	−210±220
${}^{10}_\Lambda$B–${}^{10}_\Lambda$Be	$\frac{1}{2}, 1^-$	−136	−220±250

A. Gal, PLB 744 (2015) 352

CSB data for p-shell is also important -> (e,eK+)@JLab

2. ΛN-ΣN interaction and Λ in neutron matter

2.1 p-shell hypernuclear data

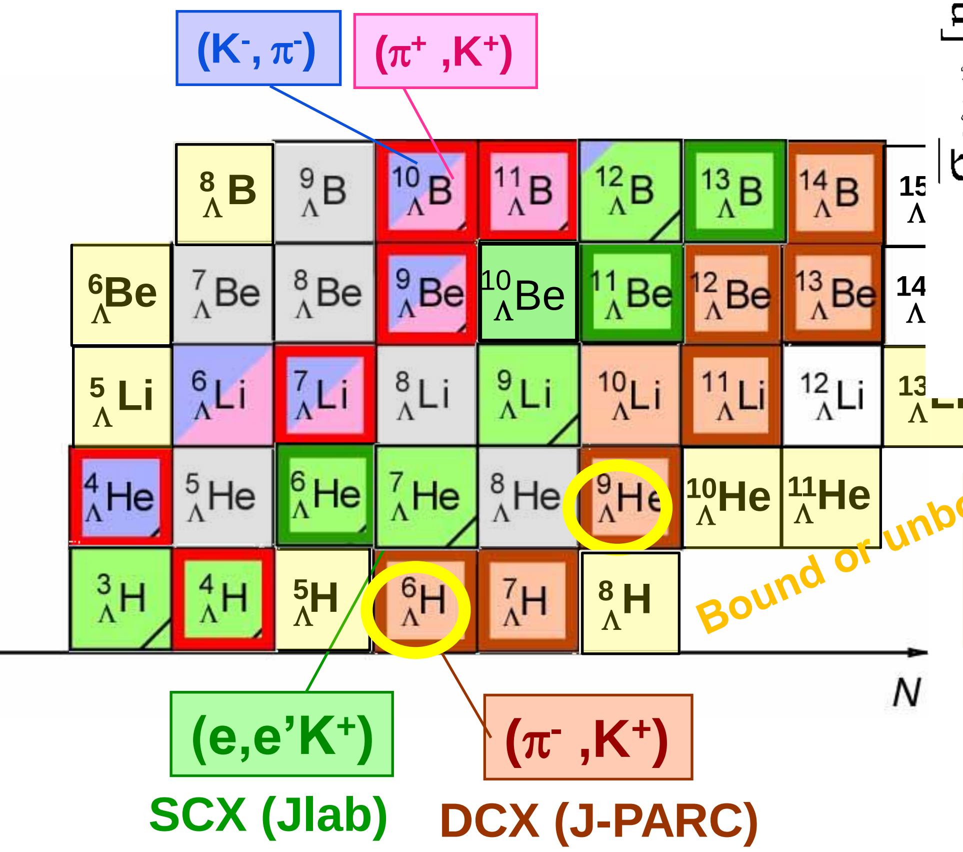
2.2 Charge Symmetry Breaking in ΛN
-- New A=4 data –

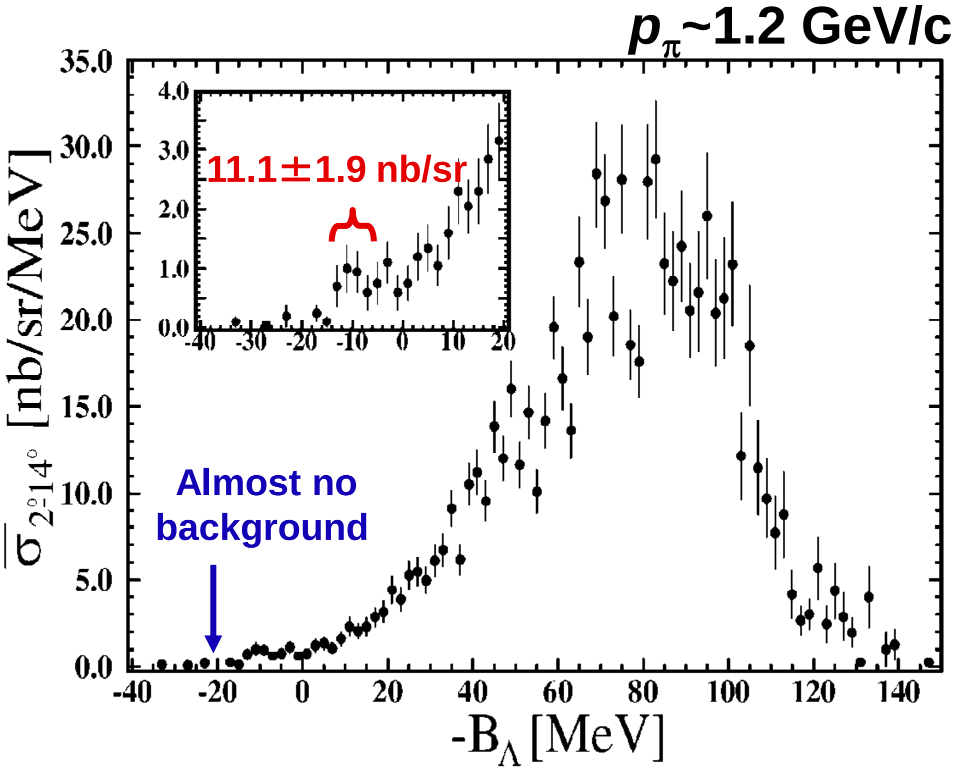
2.3 Neutron-rich hypernuclei

How to produce n-rich hypernuclei?

$^{10}B\ (\pi^-, K^+)\ ^{10}_{\Lambda}Li$

$\pi^- p\ p \to \Lambda\ n\ K^+$

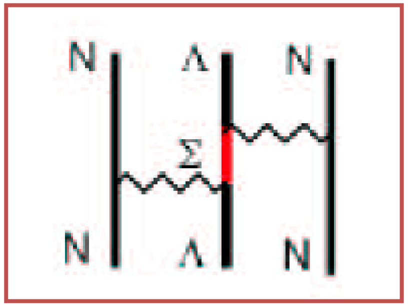




PRL 94 (2005) 052502

J-PARC E10
(Sakaguchi et al.)

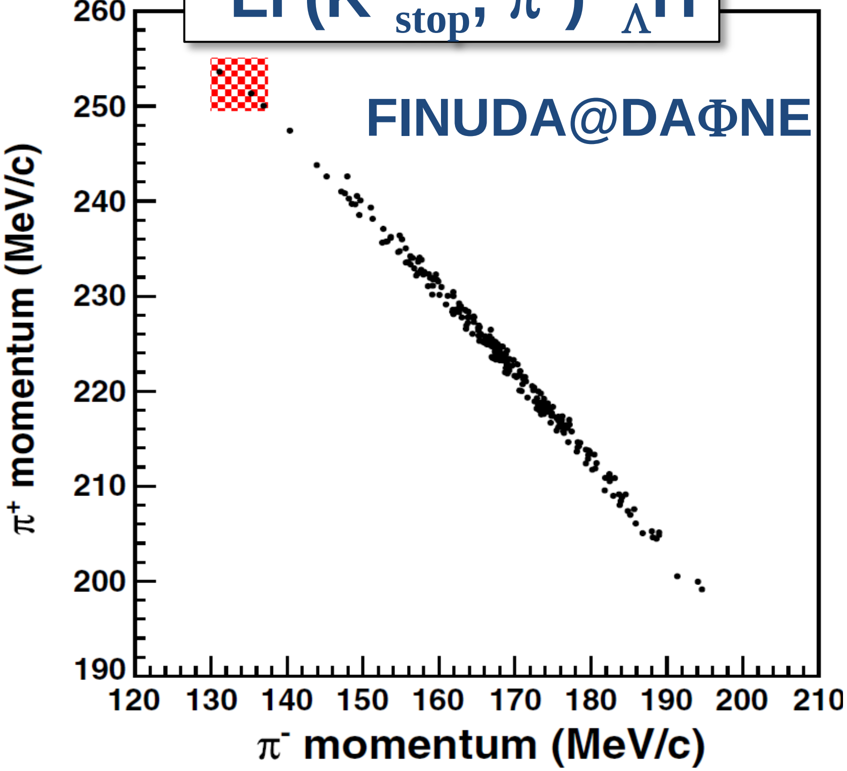
Deeper bound
by ΛNN force??



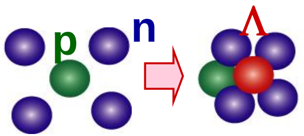
A neutron-rich hypernucleus, $^{6}_{\Lambda}$H

PRL 108 (2012) 042501

^{6}Li (K$^{-}_{stop}$, π^{+}) $^{6}_{\Lambda}$H



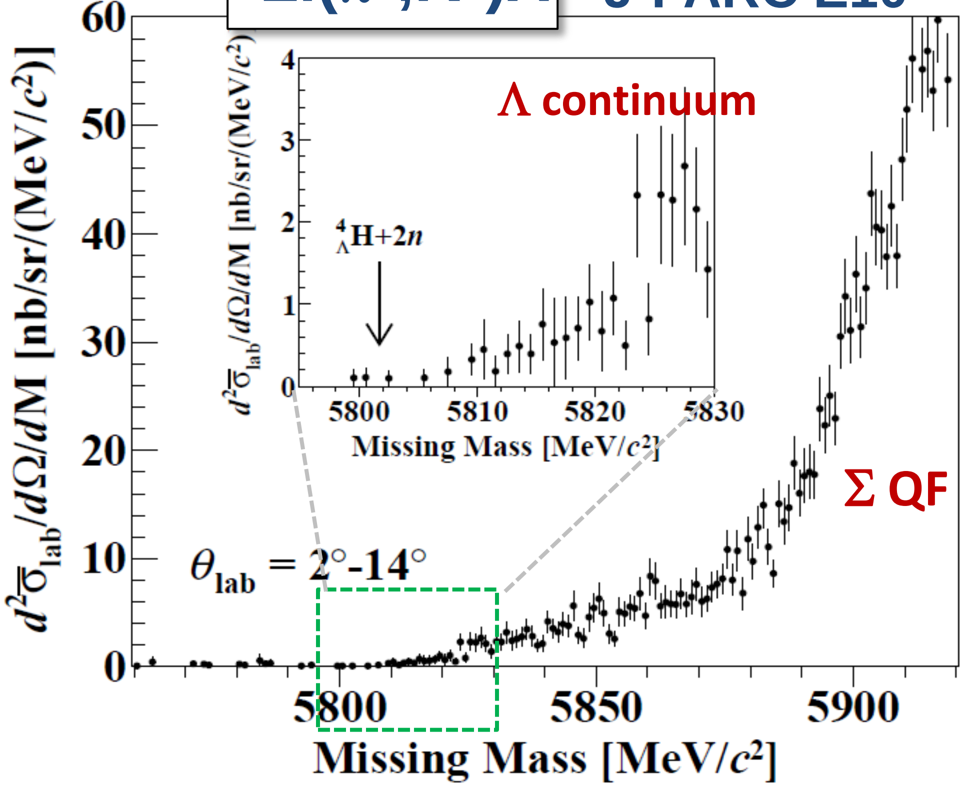
Three $^{6}_{\Lambda}$H events by ^{6}Li(K$^{-}_{stop}$,π^{+})



PLB 729 (2014) 39

^{6}Li(π^{-},K^{+})X

J-PARC E10



No $^{6}_{\Lambda}$H events observed.

$d\sigma_{2°\text{-}14°}/d\Omega$ < 1.2 nb/sr (90% CL)

More data for $^{6}_{\Lambda}$H and other n-rich hypernuclei necessary

J-PARC E10 next run: ^{9}Be(π^{-},K^{+}) $^{9}_{\Lambda}$He
In future, systematic studies at HIHR@Extended Hadron Hall

3. Toward double strangeness systems (E07 and E05)

“Kiso event”

fou

overall

m

K. Nakazawa et al.

PTEP

uniquel

$\Xi^- + {}^{14}$

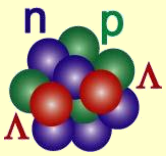
${}^{10}_{\Lambda}\text{Be}$ p

MeV

d state

eV)

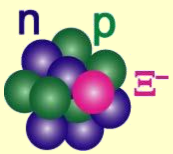
E07: More emulsion data for ΛΛ hypernuclei and Ξ atomic X-rays



-- Production run in June, 2016 and March, 2017

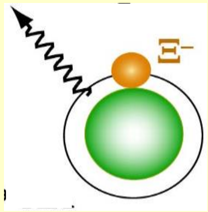
E05: Ξ hypernuclear spectroscopy by (K-,K+)

-- A pilot run done with SKS in Nov., 2015.
Main run with S2-S in 2018?



E03: Ξ atomic X-rays

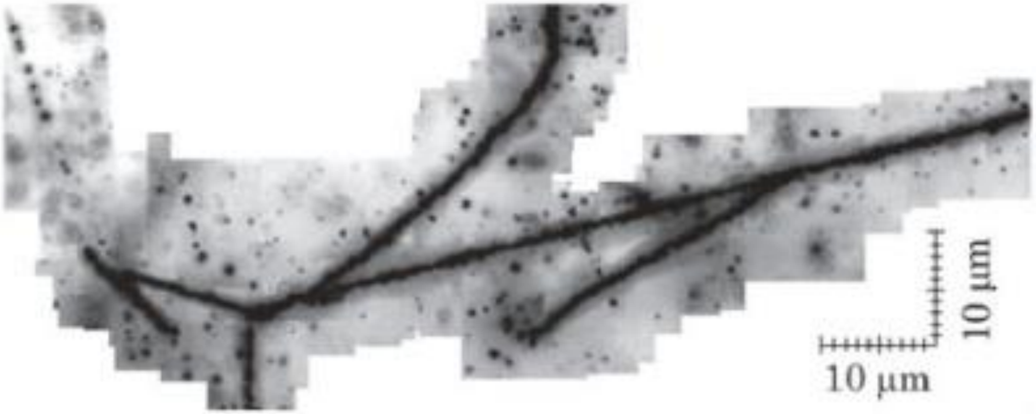
-- Run probably in 2017.



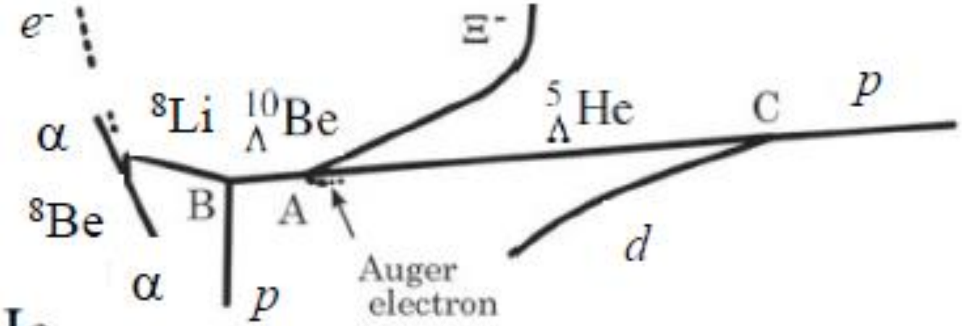
First evidence of a deeply bound Ξ state

But cannot extract ΞN force strength

“Kiso event” found by overall scanning method



K. Nakazawa et al.
PTEP 2015, 033D02



uniquely identified as

$$\Xi^- + {}^{14}\mathrm{N} \rightarrow {}^{10}_{\Lambda}\mathrm{Be} + {}^{5}_{\Lambda}\mathrm{He}$$

$$B_{\Xi^-} = 4.38 \pm 0.25\,\mathrm{MeV} \text{ —— } 1.11 \pm 0.25\,\mathrm{MeV}$$

$^{10}_{\Lambda}$Be production : in the ground state in the highest excited state

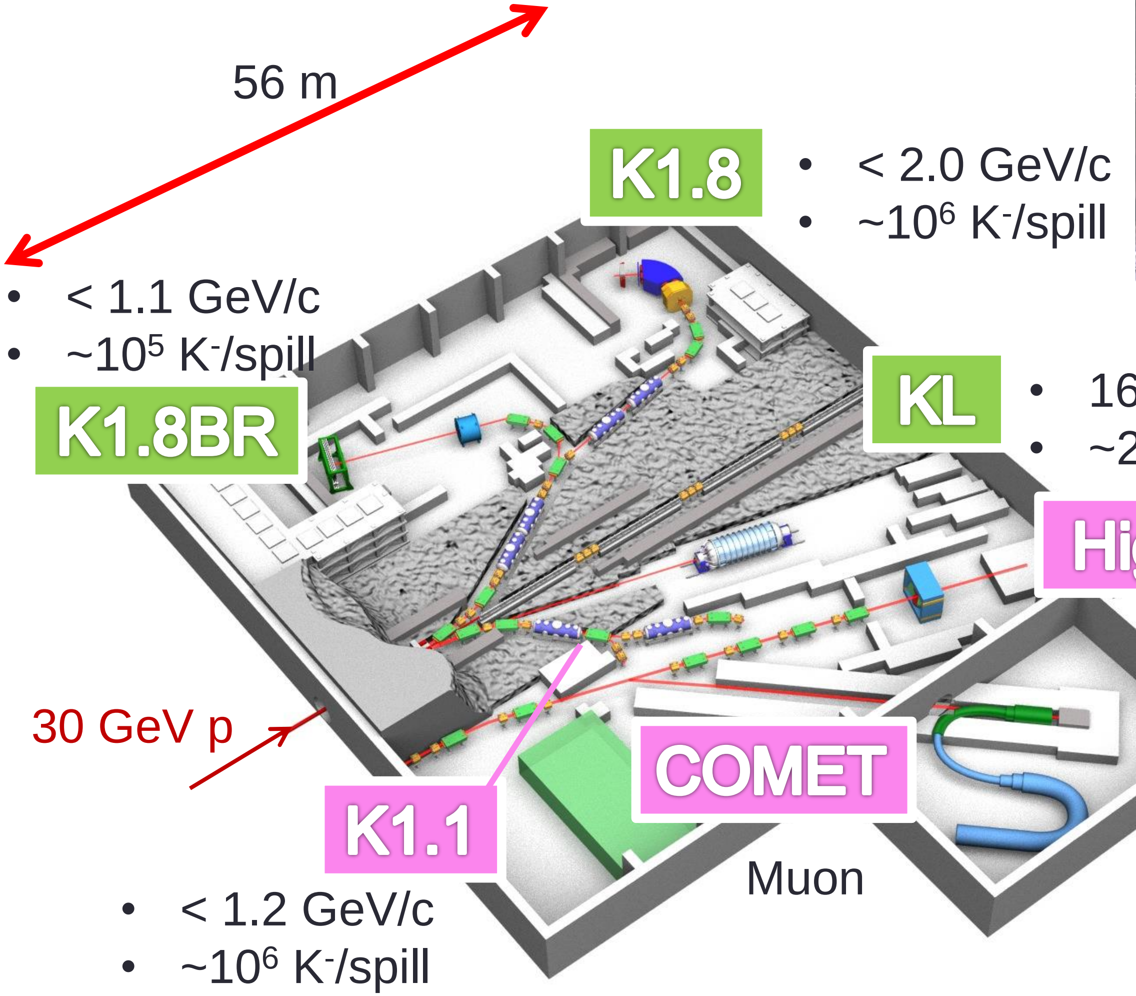
>> 3D atomic state of the Ξ^-–^{14}N system (0.17 MeV)

First evidence of a deeply bound Ξ state

But cannot extract ΞN force strength

4. Hadron Hall Extension Plan

Present Hadron Hall



56 m

K1.8

- < 2.0 GeV/c
- ~10^6 K^-/spill

- < 1.1 GeV/c
- ~10^5 K^-/spill

K1.8BR

KL

- 16 deg extraction
- ~2.1 GeV/c K^0

High-p

- 30 GeV proton
- <31 GeV/c unseparated 2ndary beams (mostly pions), ~10^7/spill

30 GeV p

COMET

Muon

K1.1

- < 1.2 GeV/c
- ~10^6 K^-/spill

Extended Hadron Hall (Plan)

Precise S=-1 systems

“Hypernuclear Microscope”

- 1
- x

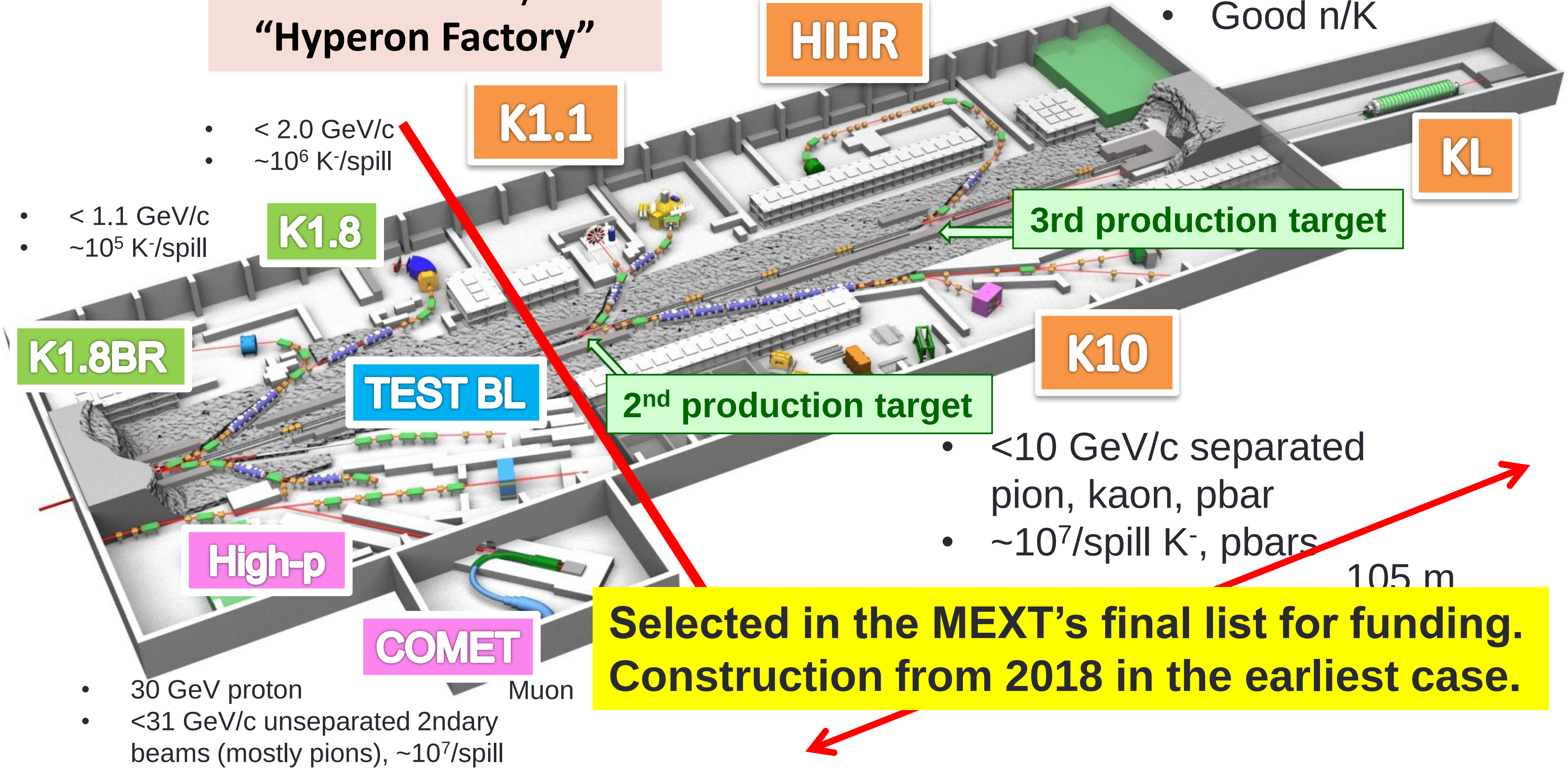
- 5 deg extraction
- ~5.2 GeV/c K^0
- Good n/K

Abundant S=-1 systems

“Hyperon Factory”

- < 2.0 GeV/c
- ~10^6 K^-/spill

- < 1.1 GeV/c
- ~10^5 K^-/spill



- <10 GeV/c separated pion, kaon, pbar
- ~10^7/spill K^-, pbars

- 30 GeV proton
- <31 GeV/c unseparated 2ndary beams (mostly pions), ~10^7/spill

Selected in the MEXT’s final list for funding. Construction from 2018 in the earliest case.

High-Intensity High-Resolution line (HIHR)

Solve the hyperon puzzle in neutron stars

High resolution (π,K^+) hypernuclear spectroscopy

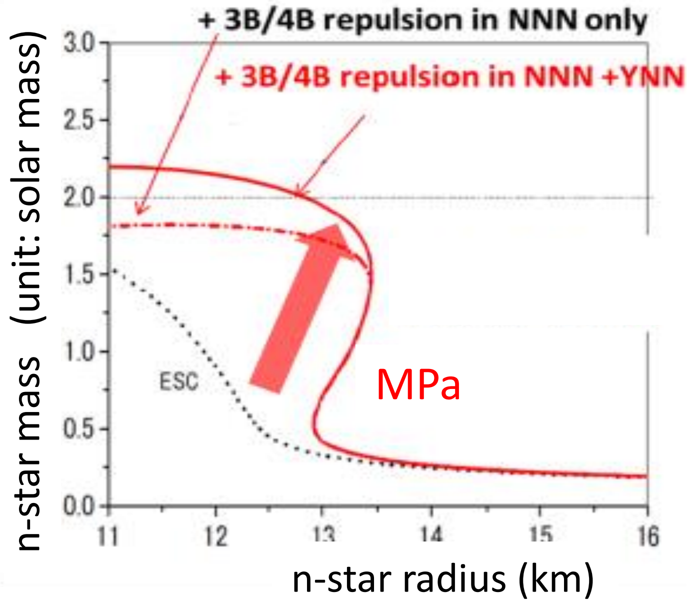
Precise B_Λ data for a wide range of Λ hypernuclei

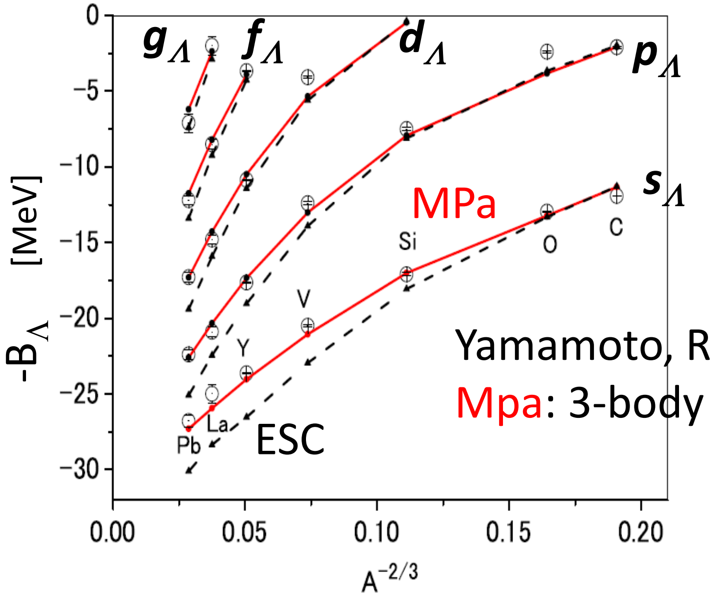
-> Density dependence of ΛN interaction (~ΛNN 3-body force）necessary to solve the “hyperon puzzle”

A few 100keV resolution is necessary

-> Momentum dispersion matching beam line and spectrometer

Very high intensity π beams can be utilized（～180Mpion/spill）

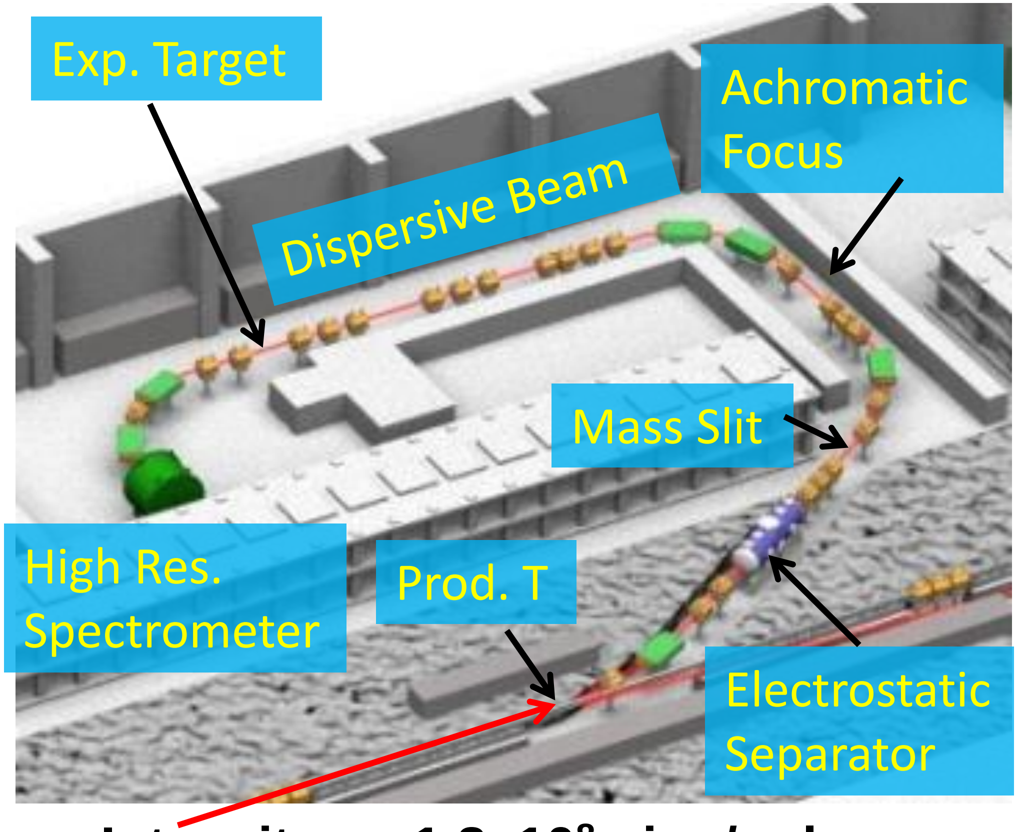


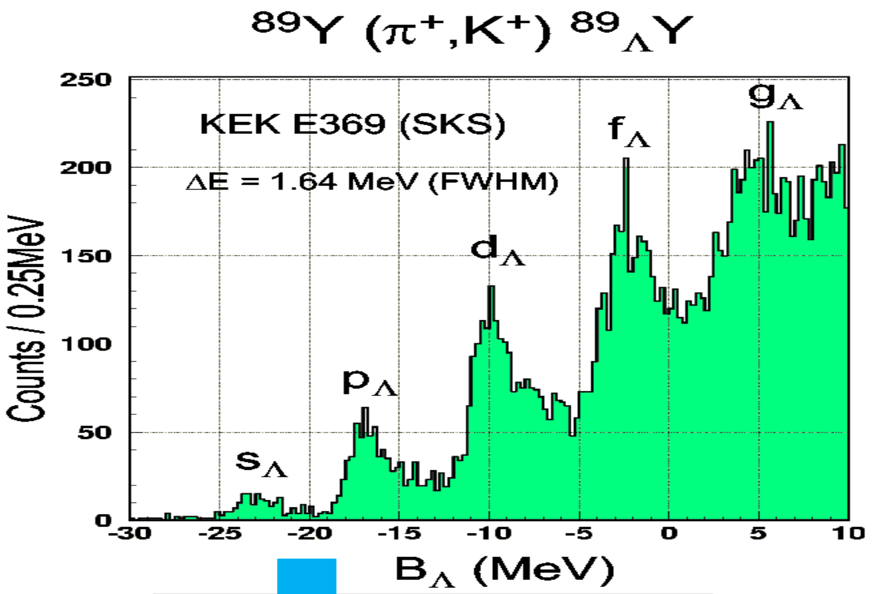


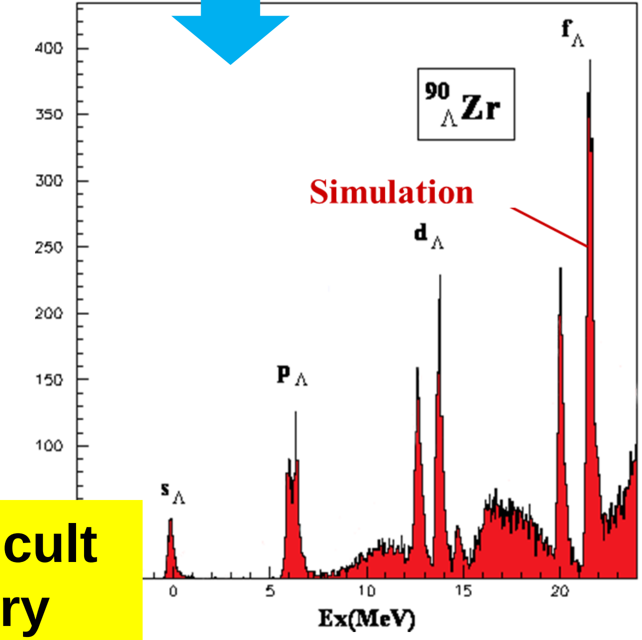
Yamamoto, Rijken

Mpa: 3-body repulsion

High-Intensity High-Resolution line (HIHR)







Intensity: ~ 1.8x10^8 pion/pulse

(1.2 GeV/c, 50 m, 1.4msr*%,
100kW, 6s spill, Pt 60mm)

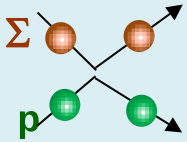
Δp/p ~ 1/10000 (Δm~200 keV)

Demerit: Absolute calibration for B_Λ is difficult
–> Precise (e,e'K+) data necessary

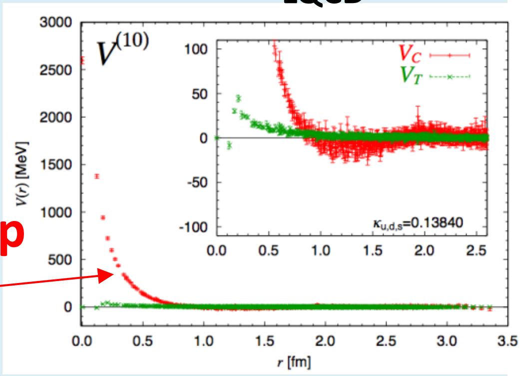
K1.1 beam line

Intense K beams for abundant production of S=-1 hyperons and kaons

Establish B-B interactions



LQCD



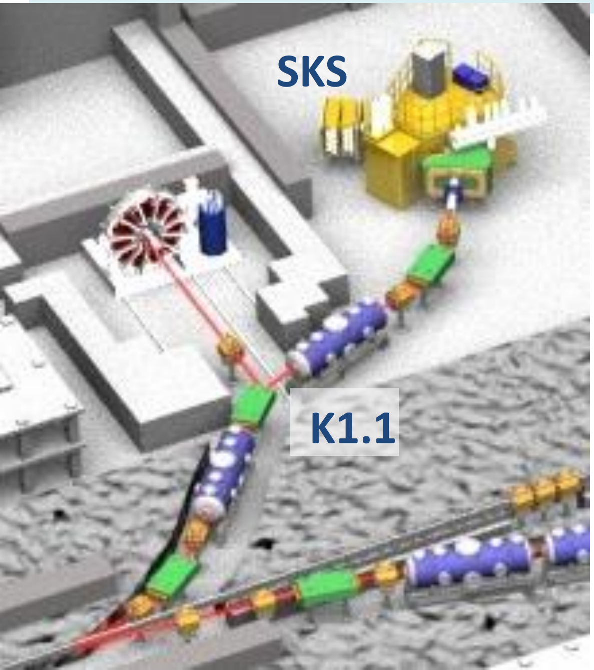
Σp, Λp scattering

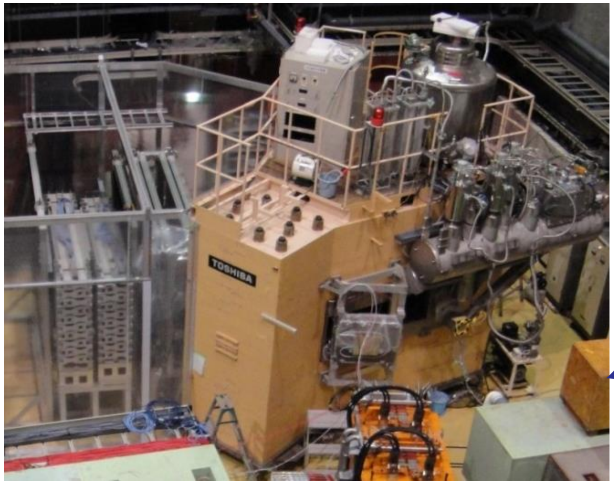
High statistical data of dσ/dΩ and spin observables with wide p

Quark Pauli effect in Σ^+p (S=1) channel

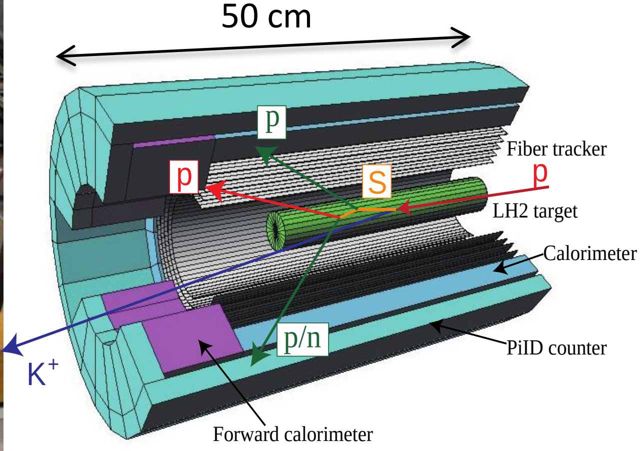
-> one of the origins of BB repulsive core

Precise 2-body data essential to extract many-body effects in hypernuclei





SKS



CATCH

5. Summary

- Beam came back to Hadron Hall in April, 2015.
- ΛN-ΣN interaction and Λ in neutron-rich matter
  - Observation of ${}^{4}_{\Lambda}$He(1^{+}->0^{+}) γ-ray and confirmed existence of a large CSB effect in ΛN interaction, giving good constraints to ΛN-ΣN force.
  - Both of the p-shell γ-ray data and the A=4 CSB data suggest a central-dominated ΛN-ΣN force.
  - More ${}^{6}_{\Lambda}$H data as well as other n-rich hypernuclear data are needed.
- Stronger beam power. S=-2 program has just started.
  - The emulsion exp. (E07) for ΛΛ hypernuclei and Ξ-atomic X-rays are will start production run soon.
  - Ξ-hypernuclear spectroscopy (E05) carried out a pilot run.
- Hadron Hall Extension is planned.
  - HIHR line for precise B_{Λ} for various Λ hypernuclei incl. n-rich ones.
  - K1.1 for ΛN, ΣN scattering experiments.