Recent results from J-PARC
for E10 and E27

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   Sakaguchi's sides
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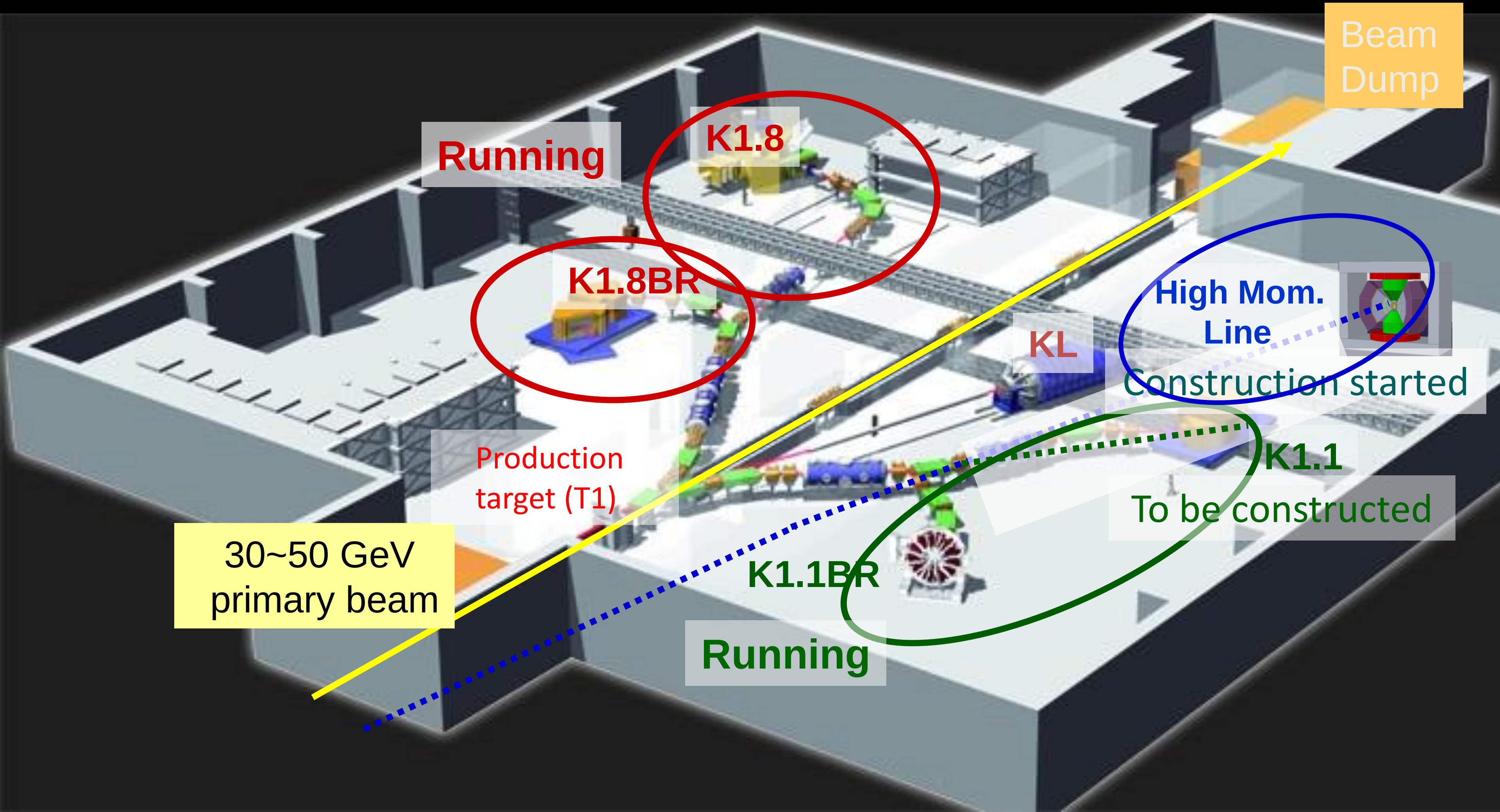
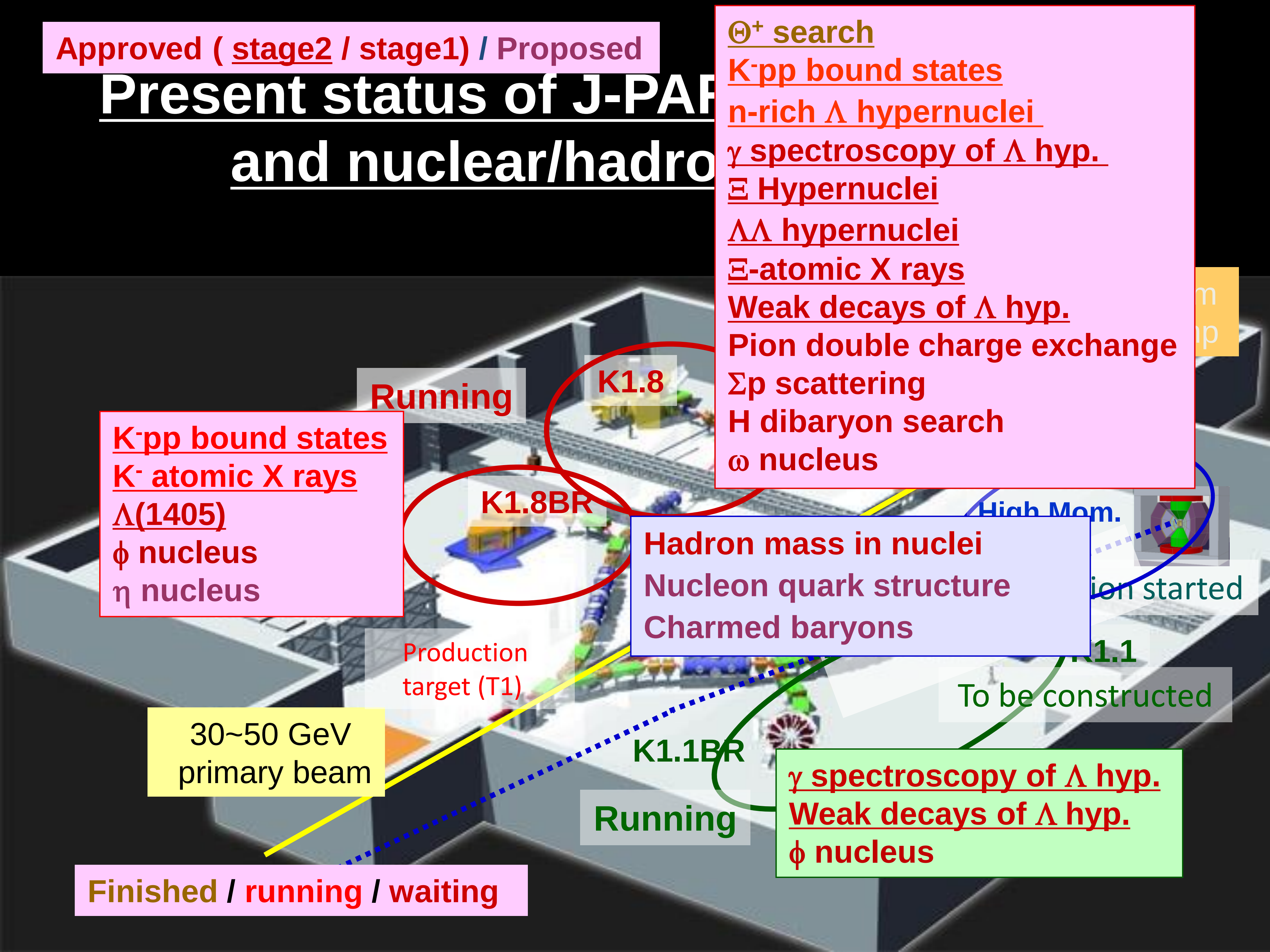
4. Future Plan of Hadron Hall

Present status of J-PARC Hadron Hall and nuclear/hadron physics





Approved (stage2 / stage1) / Proposed
Present status of J-PAR
and nuclear/hadro
Θ+ search
K-pp bound states
n-rich Λ hypernuclei
γ spectroscopy of Λ hyp.
Ξ Hypernuclei
ΛΛ hypernuclei
Ξ-atomic X rays
Weak decays of Λ hyp.
Pion double charge exchange
Σp scattering
H dibaryon search
ω nucleus
Running
K1.8
K-pp bound states
K- atomic X rays
Λ(1405)
φ nucleus
η nucleus
K1.8BR
High Mom.
Hadron mass in nuclei
Nucleon quark structure
Charmed baryons
ion started
K1.1
To be constructed
Production
target (T1)
30~50 GeV
primary beam
K1.1BR
Running
γ spectroscopy of Λ hyp.
Weak decays of Λ hyp.
φ nucleus
Finished / running / waiting

Status of hadron/nuclear experiments (stage2)

E19 (Pentaquark): Finished. Not observed and gave a stringent limit for hadronic production process. Published in PRL.

E10 (Neutron-rich Λ hyp.): 1st phase finished. ${}^{6}_{\Lambda}H$ not observed, published in PLB. *Tamura*

Tamura

E27 (K-pp by (π^+,K$^+$)): A part of data taken and analysis almost finished.

E15 (K-pp by (K-,n)): Running. A half of the phase 1 data taken and under analysis. *Inoue*

E13 (γ spectroscopy of Λ hyp.): Commissioning for phase 1 finished/waiting.

Ukai,…

E31 (Λ(1405)) : Ready for commissioning/waiting.

Yoshida

E07, E03 ($\Lambda\Lambda$ hypernuclei, Ξ atomic X-rays): Under preparation/waiting.

E17, E18 (K atomic X-rays, weak decay of Λ hyp.): Under preparation/waiting.

E05, E42: (Ξ hypernuclei, H dibaryon): Under spectrometer construction.

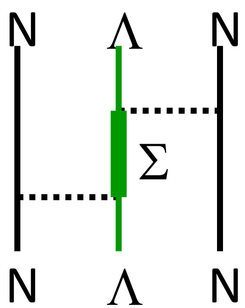
E10 experiment on neutron-rich hypernuclei

Atsushi Sakaguchi (Osaka University)
for the **J-PARC E10** Collaboration

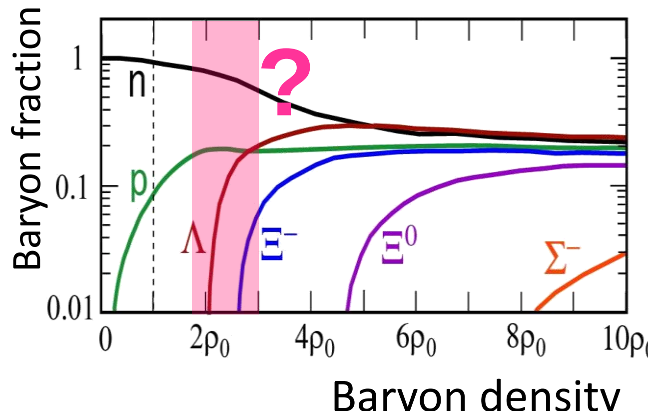
(talk is based on Phys. Lett. B729 (2014) 39)

Interest of neutron-rich Λ hypernuclei

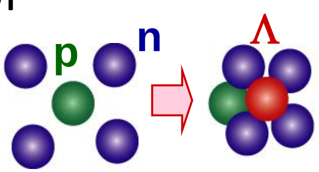
- **ΛN interaction as the first step to baryon-baryon interactions**
  - Properties of ΛN interaction have been clarified from hypernuclear structures via $(\pi^+,K^+)/(K^-,\pi^-)$ reactions and γ spectroscopy
  - But ΛN interaction is modified in nuclei due to ΛN-ΣN mixing process, giving a large effect of ΛNN 3-body force



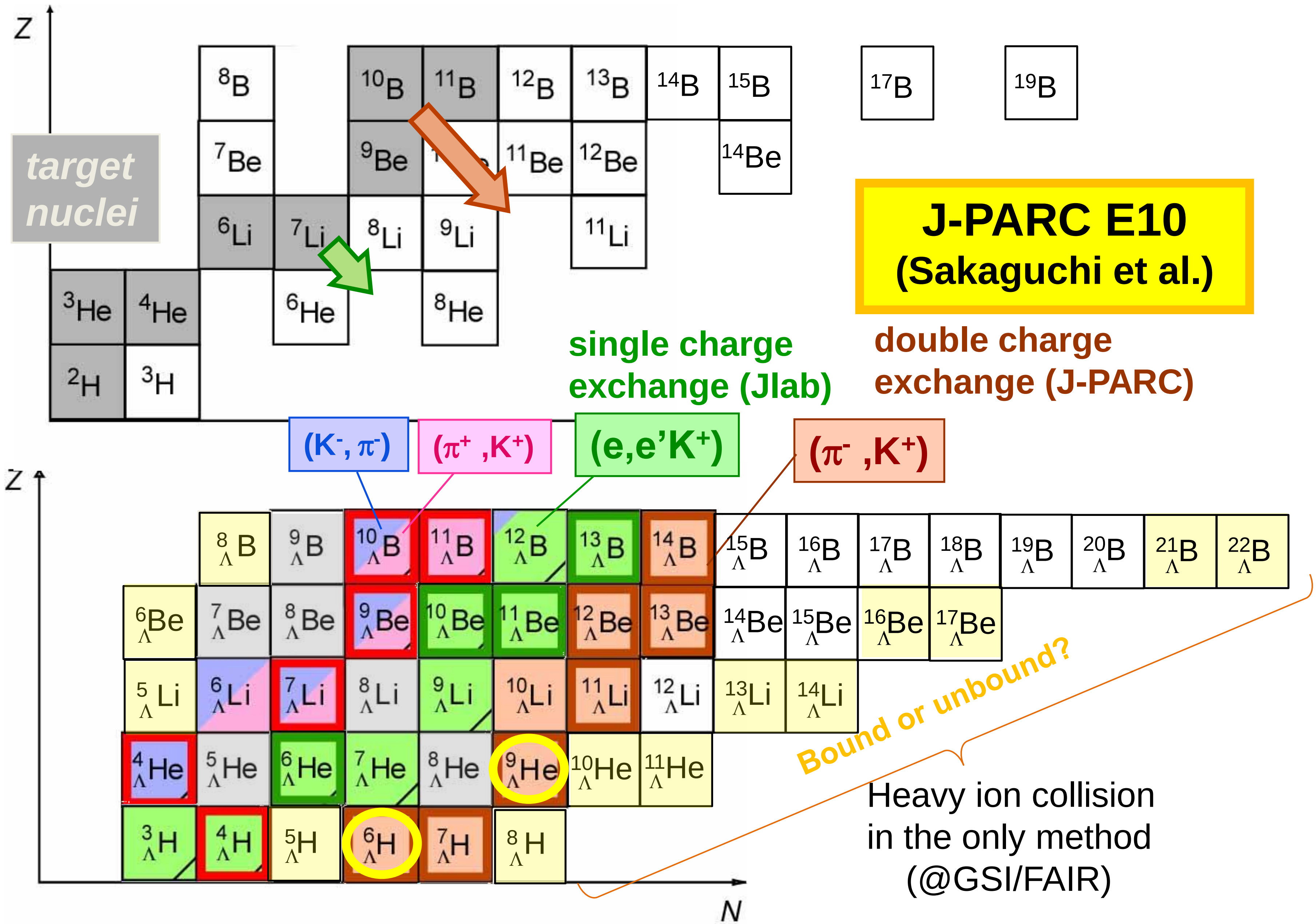
- **Understanding possible hyperon mixing in neutron stars**
  - Interaction of Λ in neutron-rich matter can be "simulated" by neutron-rich hypernuclei



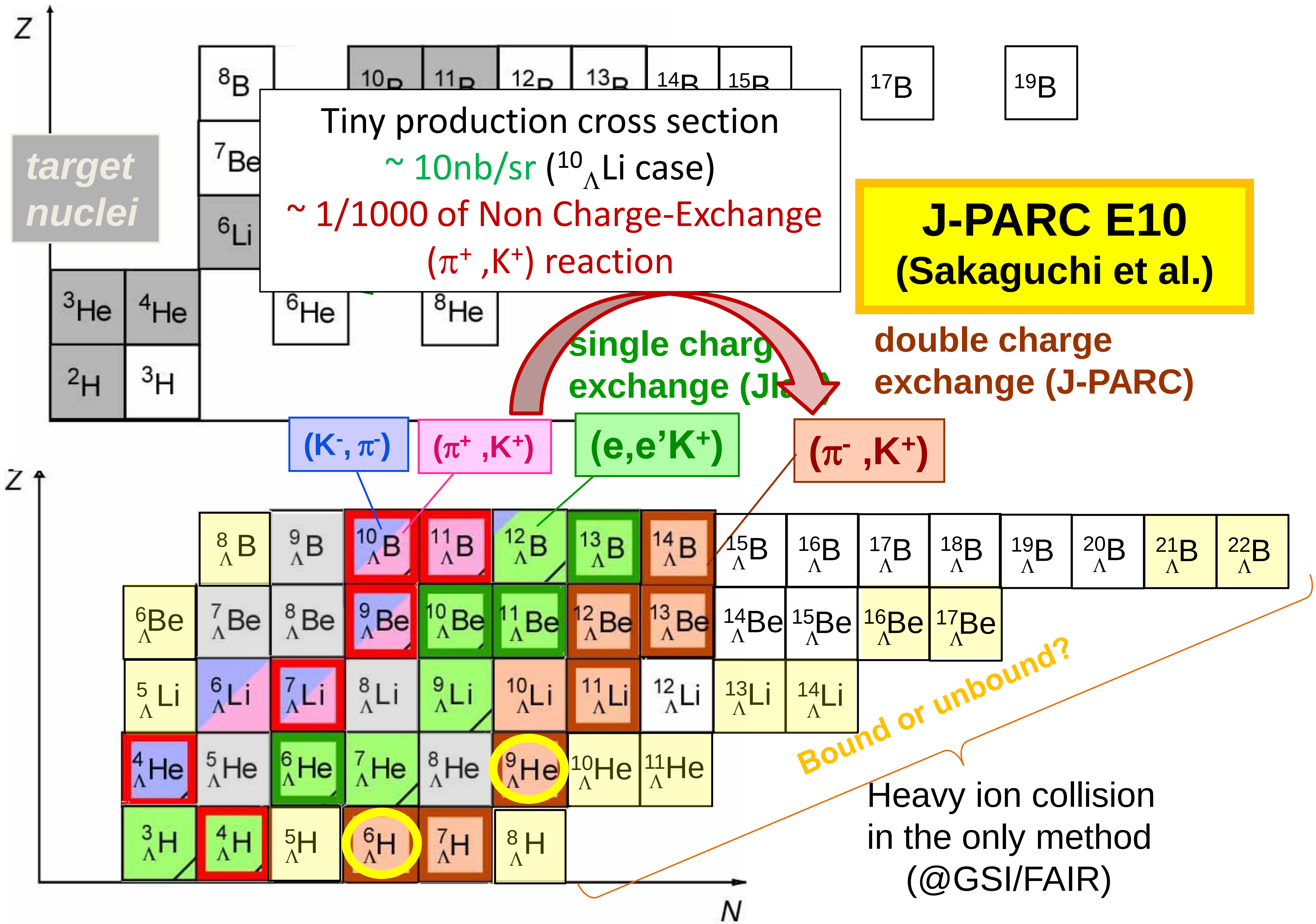
- **Extending the hypernuclear chart**
  - "glue-like role" : Λ in 0s orbit stabilizes the host nucleus
  - Exotic structures of neutron-rich nuclei can be studied from nuclear response by a Λ = "impurity effect" (structure change of the host nucleus by a Λ)



How to extend S=-1 nuclear chart?



How to extend S=-1 nuclear chart?



(π^-,K^+) Reaction

- Convert p p -> Λ n

  2 step: π^- p -> n π^0, π^0 p -> Λ K^+ or π^- p -> Λ K^0, K^0 p -> n K^+

  1 step: π^- p -> Σ^- K^+, Σ^- p <-> Λ n

P.K. Saha et al. PRL 94 (2005) 052501

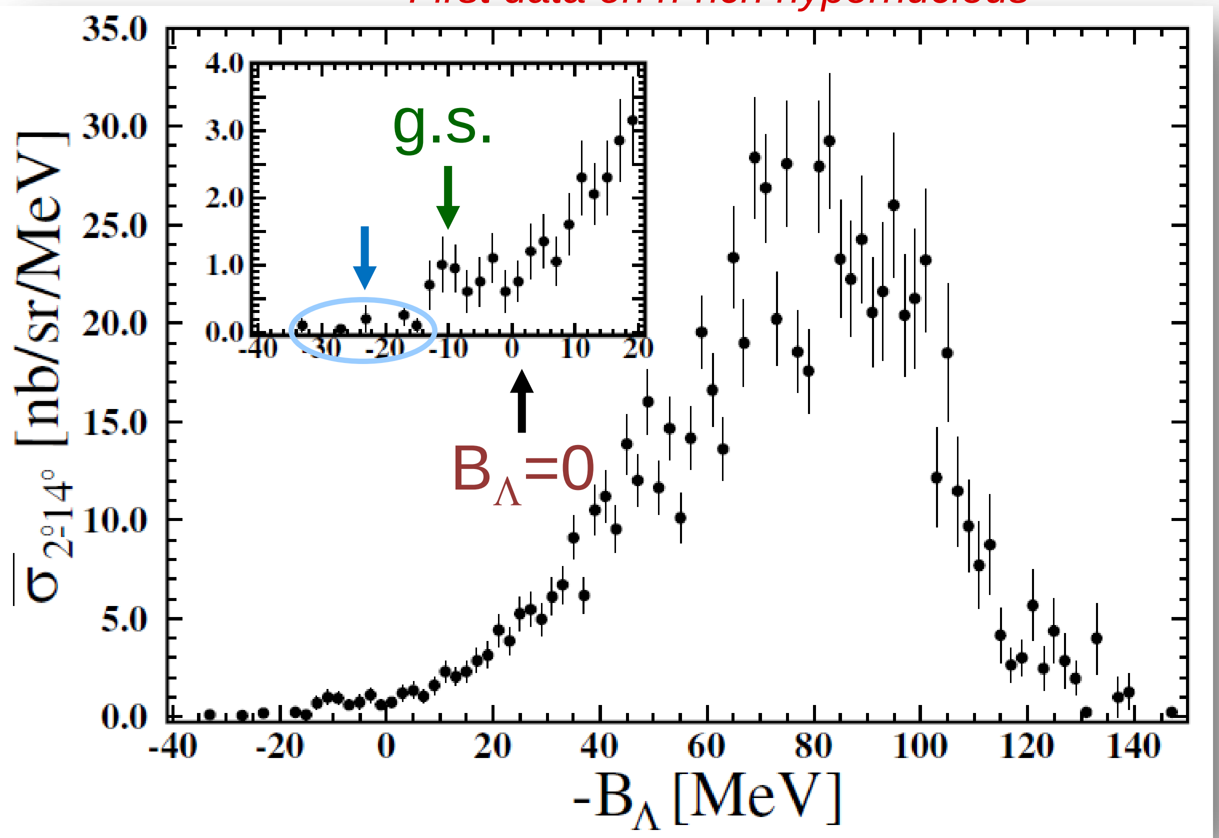
First data on n-rich hypernucleus

- KEK-PS E521
  - ^{10}B (π^-,K^+)$^{10}{}_{\Lambda}Li$
  - Clean, no BG

47 events in bound region

dσ/dΩ ~ 10 nb/sr

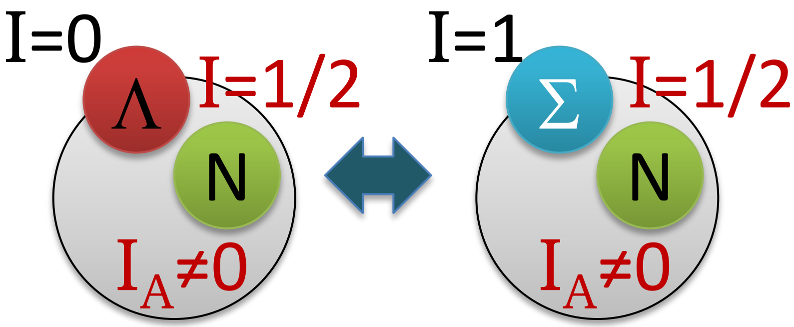
(1/1000 of NCX)



J-PARC E10 is designed based on E521 result

ΛN-ΣN Mixing and n-rich Λ Hypernuclei

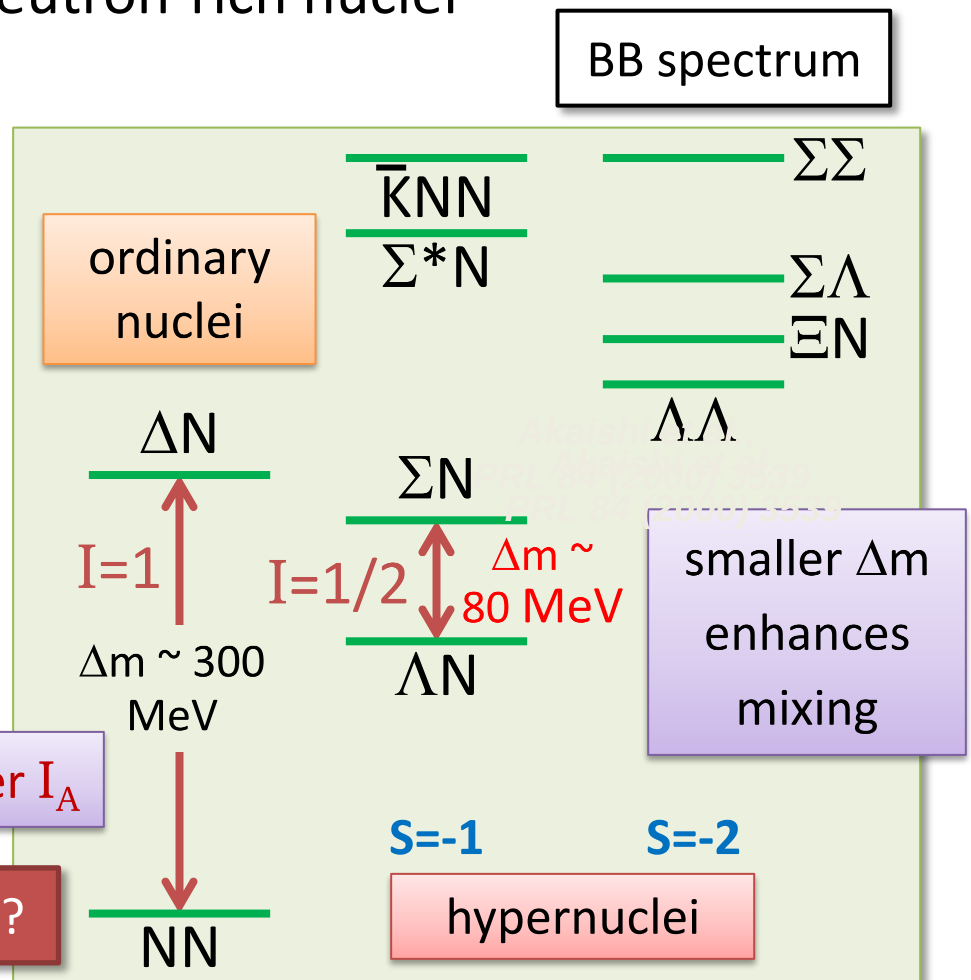
- Strong mixing of ΛN and ΣN pairs
  B.F. Gibson et al. PR C6 (1972) 741
- Coherent effect in proton/neutron-rich nuclei
  Akaishi et al. PRL 84 (2000) 3539



overall conservation of isospin is required
nucleus is a buffer of isospin

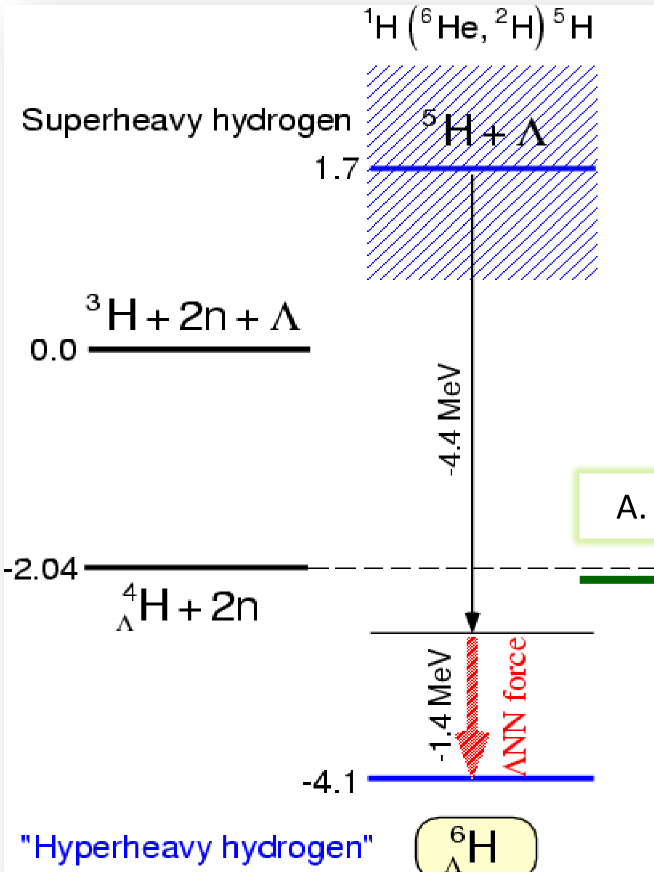
larger mixing in host nucleus with larger I_A

How large mixing in n-rich hypernuclei?



$\Lambda\Sigma$ Mixing in n-rich hypernucleus $^{6}_{\Lambda}H$

- Possible observation of mixing effect in $^{6}_{\Lambda}H$ structure



Y. Akaishi and T. Yamazaki, Frascati Phys. Ser. XVI (1999) 59

Prediction of Akaishi and Yamazaki

Normal ΛN interaction ("glue" effect)

B_{Λ} ~ 4.4 MeV

Coherent ΛN-ΣN mixing

B_{Λ} ~ 4.4 + 1.4 MeV

A. Gal and D.J. Millener, Phys. Lett. B 725 (2013) 445

Prediction of Gal and Millener

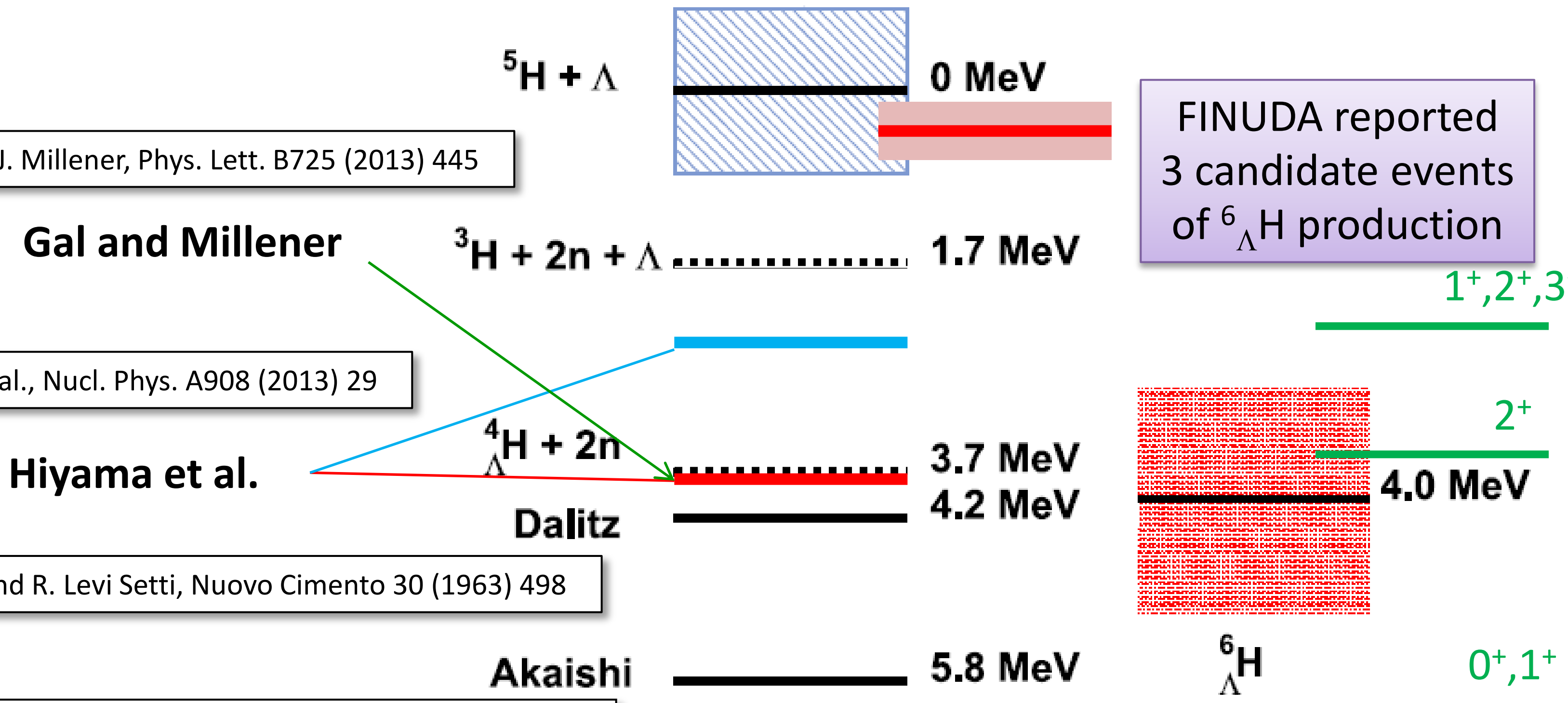
Coherent ΛN-ΣN mixing

$\Delta B_{\Lambda N\text{-}\Sigma N}$ ~ 0.1 MeV

Structure of $^{6}_{\Lambda}H$ should be investigated experimentally

Structure of $^{6}_{\Lambda}$H hypernucleus

– FINUDA reported 3 candidate events of $^{6}_{\Lambda}$H production
– Sensitive to ΛN interaction and also properties of ^{5}H



A. Gal and D.J. Millener, Phys. Lett. B725 (2013) 445

E. Hiyama et al., Nucl. Phys. A908 (2013) 29

R. H. Dalitz and R. Levi Setti, Nuovo Cimento 30 (1963) 498

Y. Akaishi and T. Yamazaki, Frascati Phys. Ser. XVI (1999) 59

M. Agnello et al., FINUDA Collaboration, PRL 108 (2012) 042501
M. Agnello et al., FINUDA Collaboration, NPA 881 (2012) 269

FINUDA data have ambiguities. Complementary measurement is awaited.

DCX: Double Charge-eXchange
NCX: Non Charge-eXchnage

Studies of n-rich hypernuclei by DCX

- Experiments by the (stopped-K$^-$,π^+) reaction
  - **FINUDA**: M. Agnello et al. PRL 108 (2012) 042501
  - reported 3 candidate events of $^{6}_{\Lambda}$H production
  - measured production and decay to reduce background

$$^{6}Li(\text{stopped–}K^-,\pi^+)^{6}_{\Lambda}H \qquad ^{6}_{\Lambda}H \rightarrow {}^{6}He + \pi^-$$

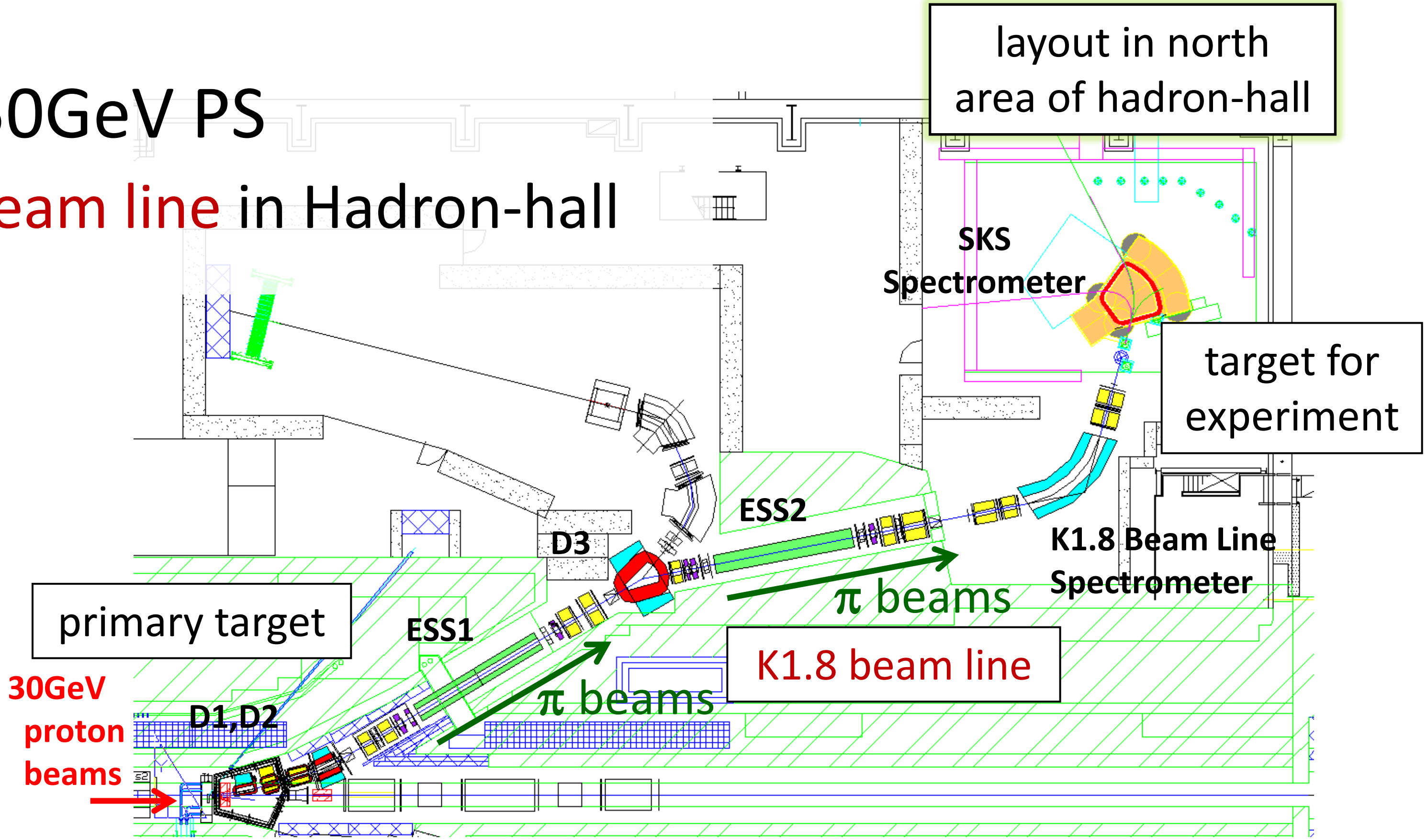
$$BR(DCX, {}^{6}_{\Lambda}H) / BR(NCX) \approx 2\times10^{-3} / event$$

- Experiment by the (π^-,K$^+$) reaction
  - **KEK E521**: P.K. Saha et al. PRL 94 (2005) 052501
  - successfully produced $^{10}_{\Lambda}$Li $\quad ^{10}B(\pi^-,K^+)^{10}_{\Lambda}Li$
  - background free, only production was measured

$$\frac{d\sigma}{d\Omega}(DCX, {}^{10}_{\Lambda}Li) \approx 10nb/sr \quad \frac{d\sigma}{d\Omega}(DCX) \Big/ \frac{d\sigma}{d\Omega}(NCX) \approx 10^{-3}$$

Design of E10 Experiment

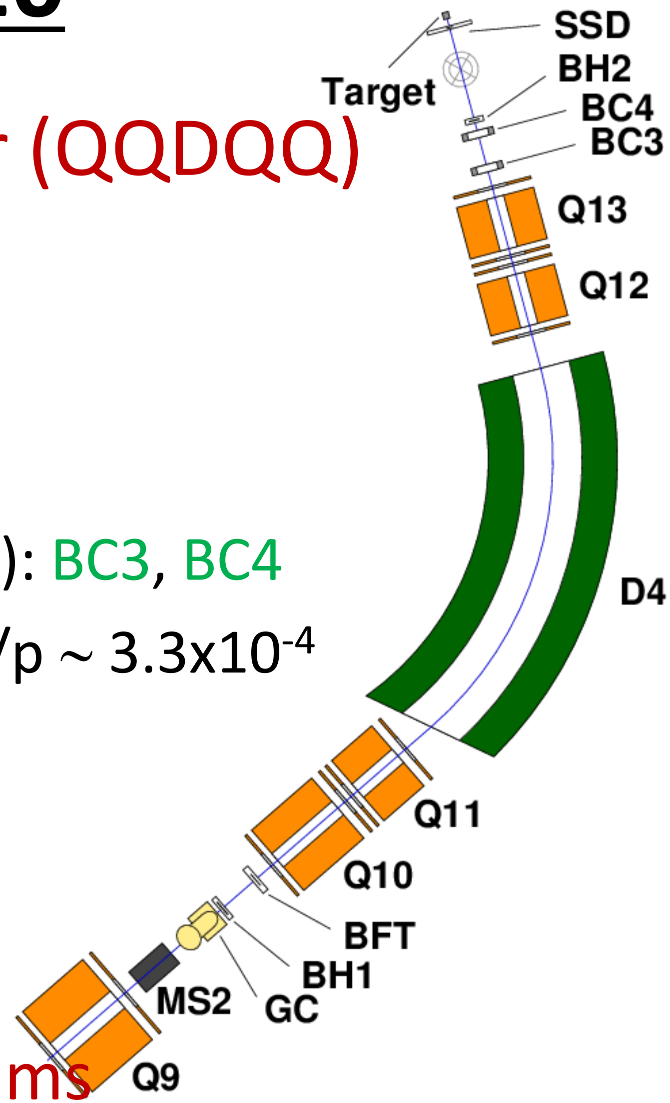
- J-PARC 50GeV PS
  - K1.8 beam line in Hadron-hall



- Method
  - Missing mass spectroscopy for the ^{6}Li(π^{-},K^{+})X reaction
    - K1.8 beam line spectrometer: π^{-} beams at 1.2 GeV/c
    - SKS spectrometer: produced K^{+} around 0.9 GeV/c

Setup of E10

- K1.8 beam line spectrometer (QQDQQ)
  - 1.2 GeV/c pion beams
  - Tracking of beam pions
    - Scintillating fiber tracker: BFT
    - Drift chambers (3mm wire pitch): BC3, BC4
    - 3rd order transfer matrix → dp/p ~ 3.3×10^{-4}
  - Trigger counters
    - Timing hodoscopes: BH1, BH2
- Key issue in E10 experiment
  - Handling of high rate pion beams
    - Typical beam rate: 12M - 14M/spill



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er (QQDQQ)

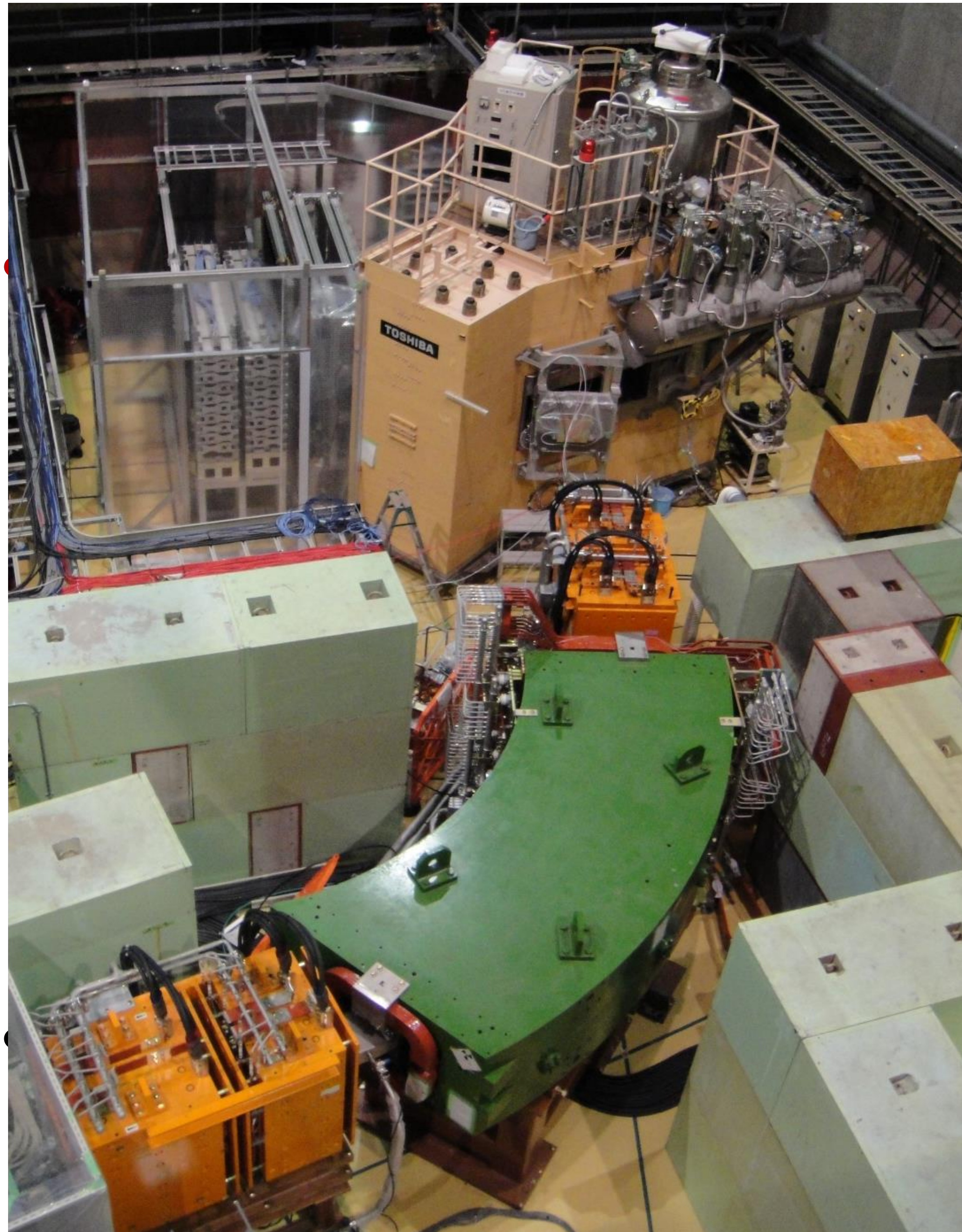
ch): BC3, BC4

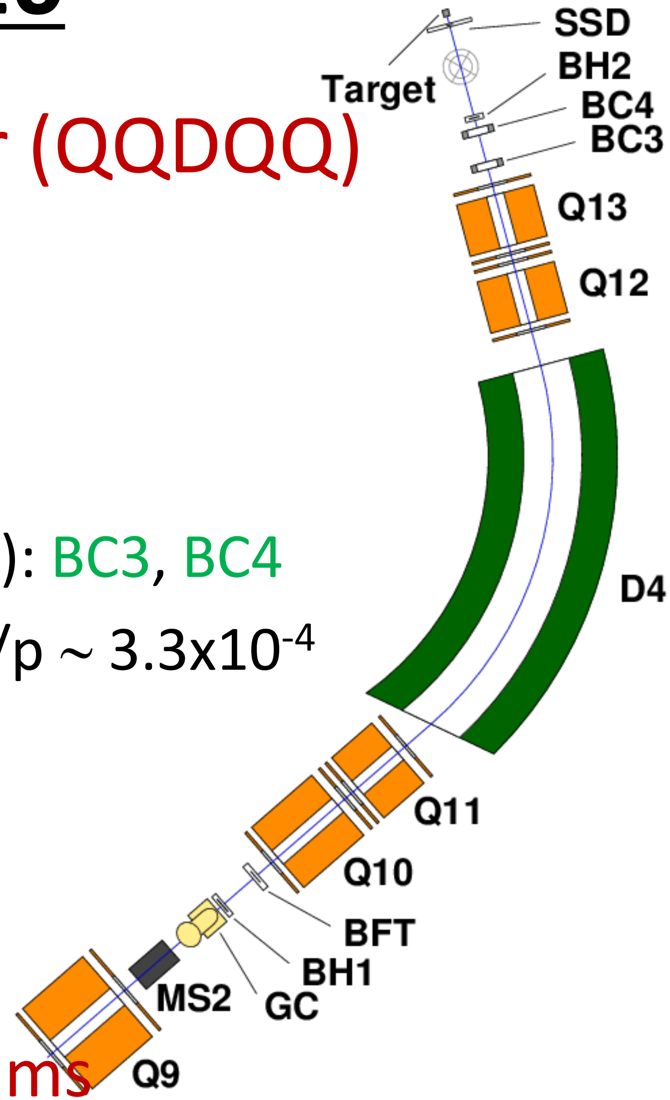
p/p ~ 3.3x10^{-4}

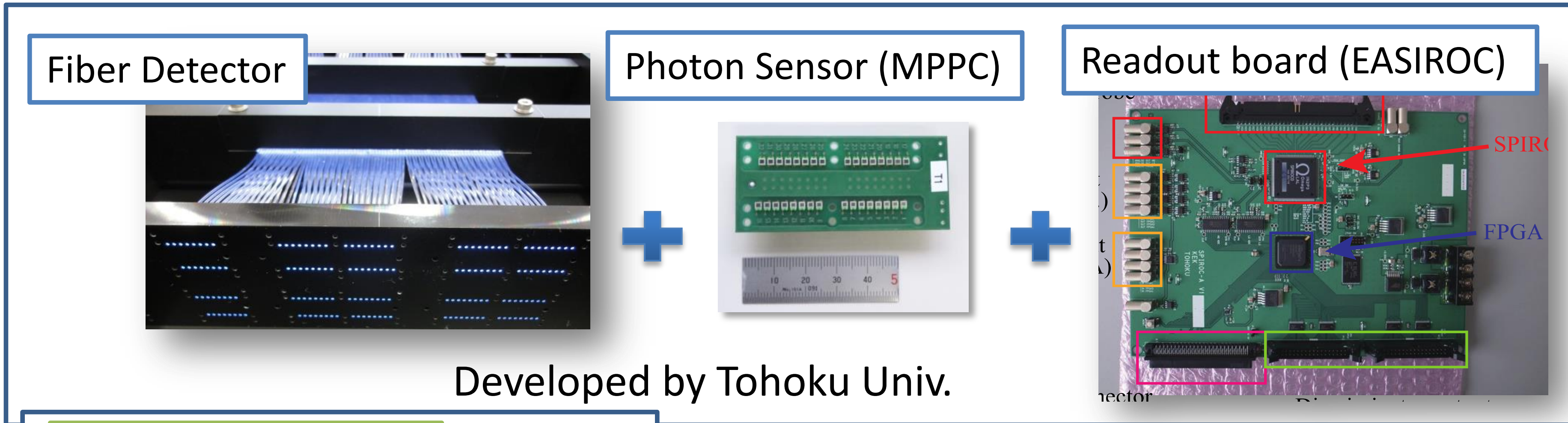
t

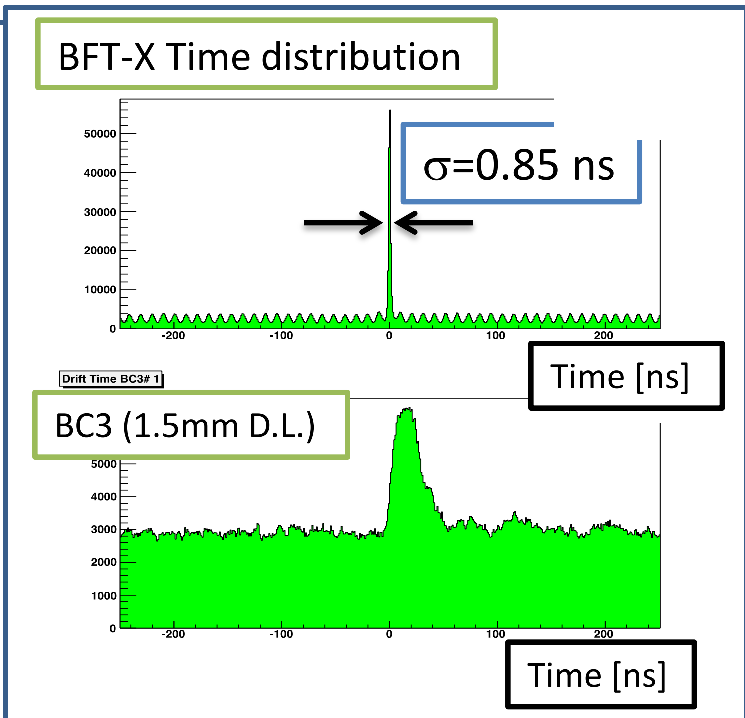
eams

- Typical beam rate: 12M - 14M/spill









pions

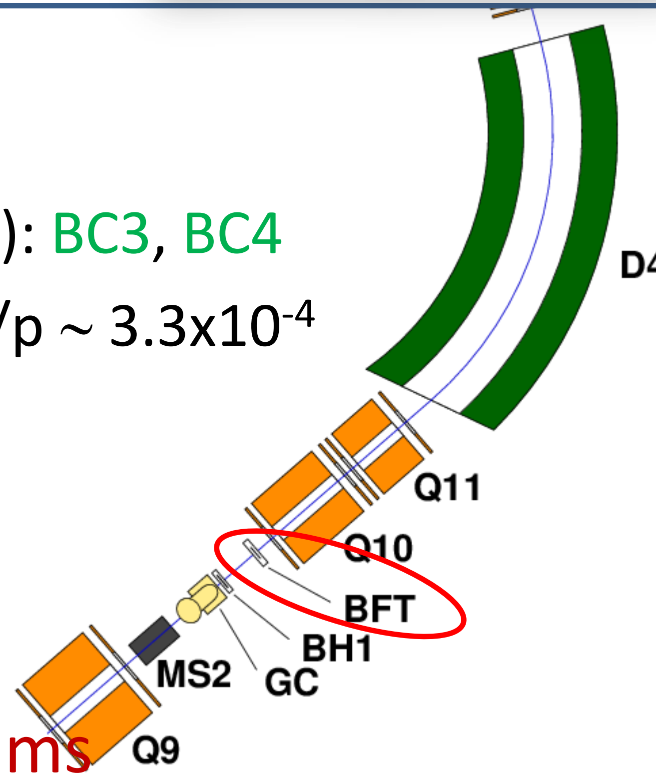
tracker: BFT

mm wire pitch): BC3, BC4

r matrix → dp/p ~ 3.3×10^{-4}

es: BH1, BH2

xperiment

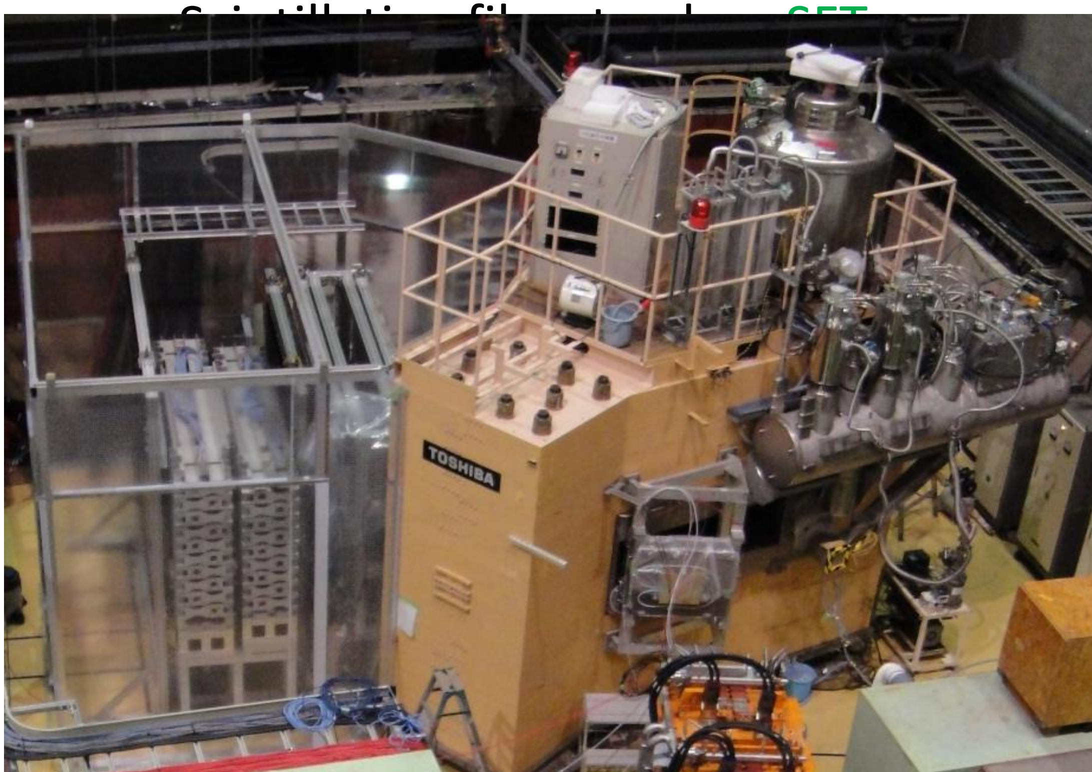


– Handling of high rate pion beams

- Typical beam rate: 12M - 14M/spill

Setup of E10

- SKS spectrometer
  - 0.9 GeV/c produced K^+
  - Tracking of scattered particles



OF

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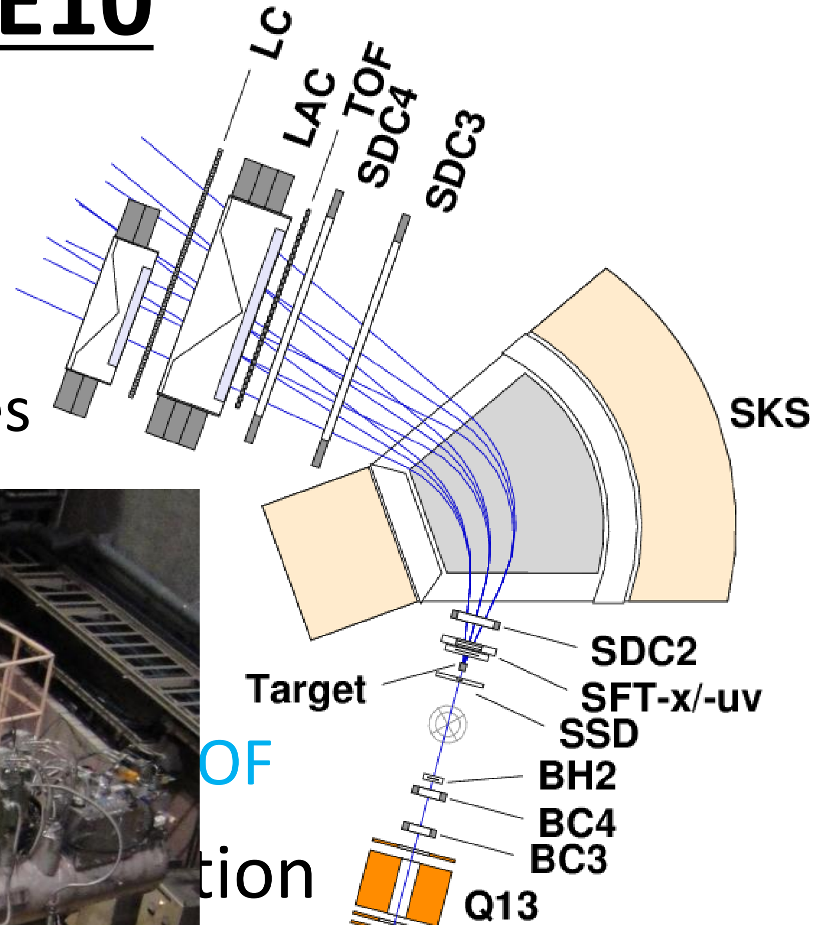
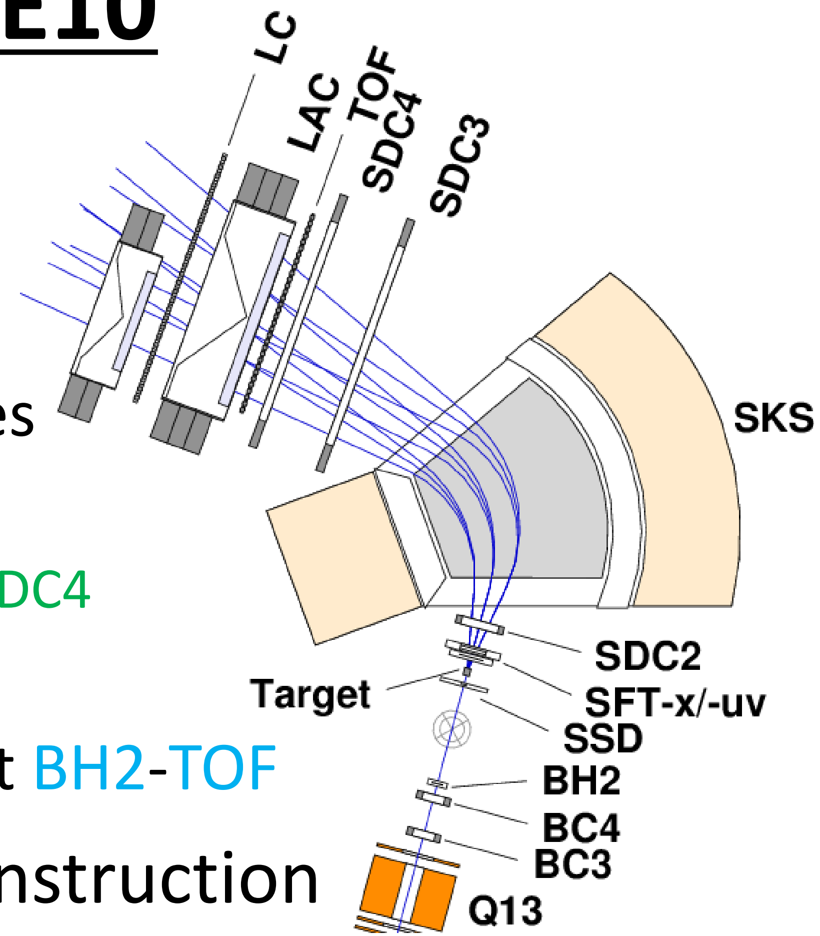
for calibrations



Setup of E10

- SKS spectrometer
  - 0.9 GeV/c produced K^+
  - Tracking of scattered particles
    - Scintillating fiber tracker: SFT
    - Drift chambers: SDC2, SDC3, SDC4
    - $dp/p \sim 10^{-3}$, $d\Omega \sim 100$ msr
  - K^+ PID made by time-of-flight BH2-TOF
- (π^-,K^+) reaction vertex reconstruction
  - Silicon strip detector: SSD in front of the target
- Targets ($\sim$3.5 g/cm^2)
  - ^{6}Li for production runs, C and $(CH_2)_n$ for calibrations

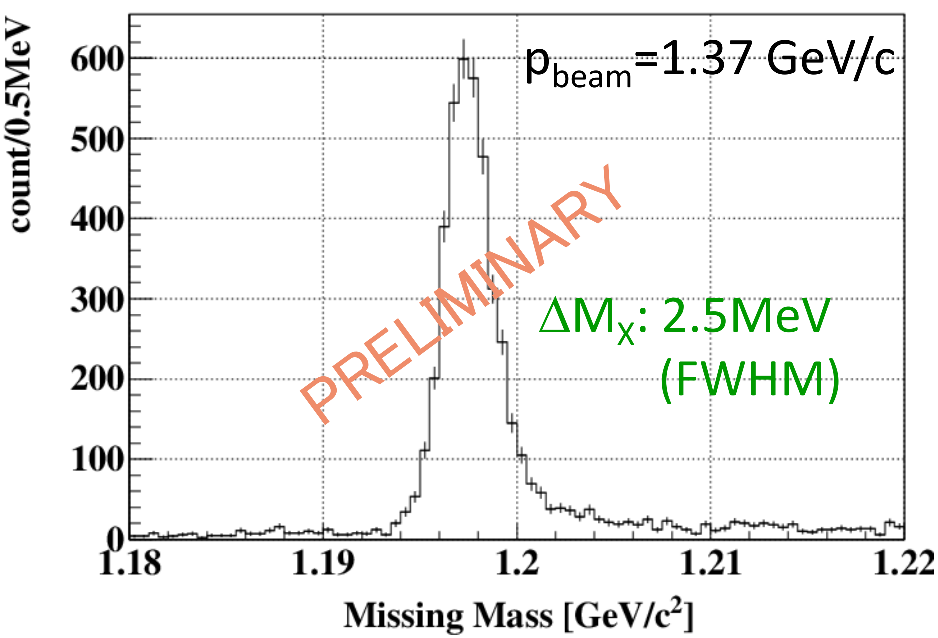


Calibration runs with Σ^- and Σ^+

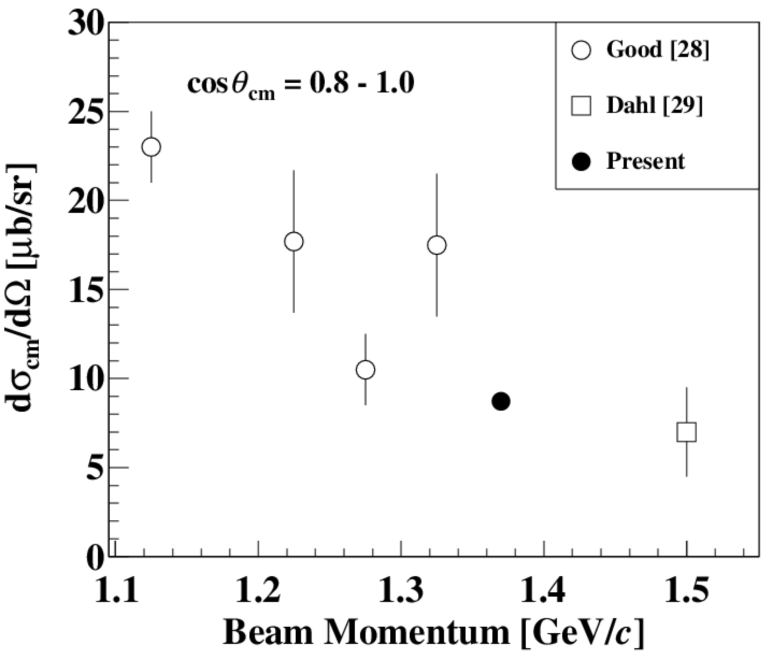
- Momentum calibrations of beam π^- and scattered K^+
  - Momentum adjusted: Σ^- and Σ^+ come to known mass
  - Cross section was compared with existing data

5 hours at 13M/spill

$p(\pi^-,K^+)\Sigma^-$



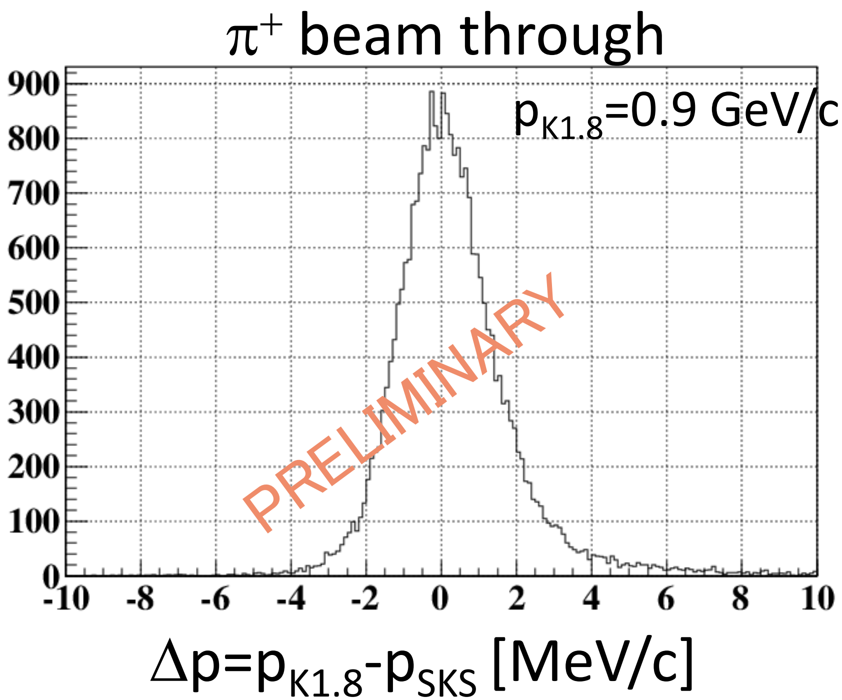
$p(\pi^-,K^+)\Sigma^-$



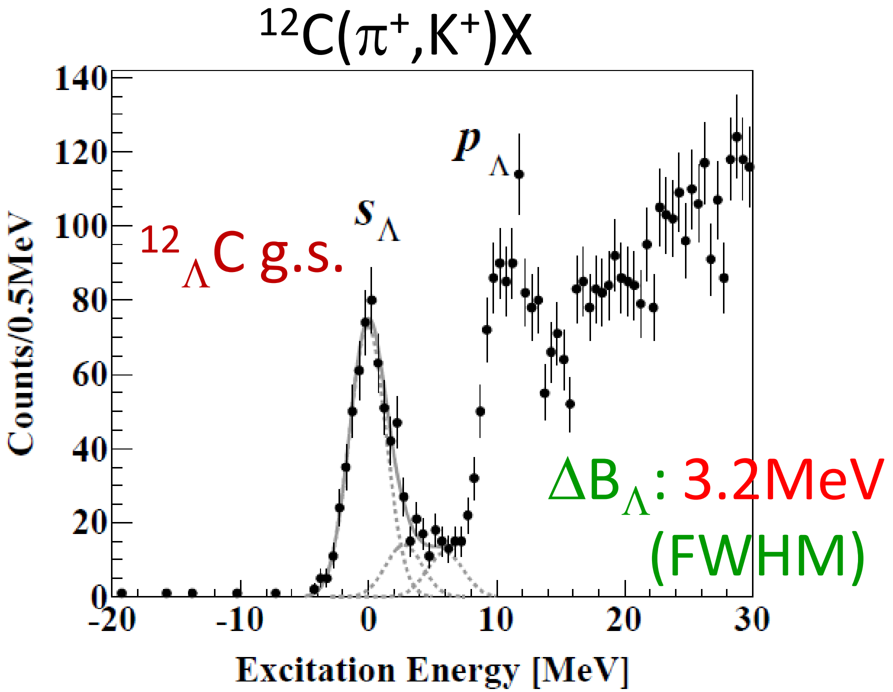
Systematic error and resolution

- Beam through runs at 0.8, 0.9, 1.0 and 1.2 GeV/c
  - Systematic error of the beam momentum was 1.34 MeV/c
- Missing mass resolution was estimated from $^{12}{}_{\Lambda}C$

1 hour (8 settings)



13+6 hours at 4.1M/spill



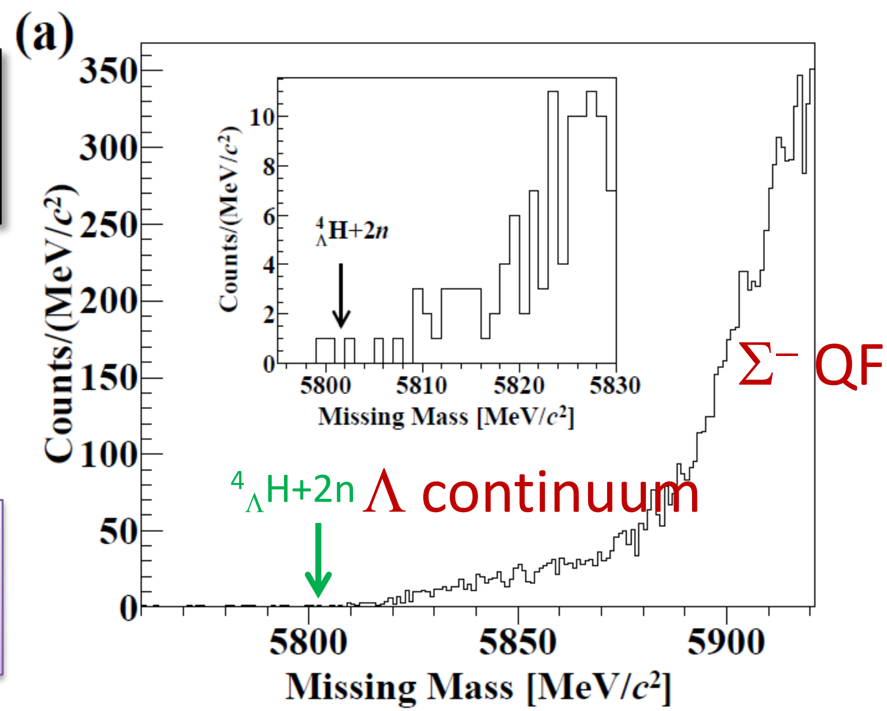
Results of production runs

- Missing-mass spectrum of the $^{6}Li(\pi^{-},K^{+})X$ reaction
  - Systematic error of missing-mass 1.26 MeV/c^2
  - Tentative angle cut 2-14 degrees is applied
    - Same as KEK-E521 and SKS acceptance is well known

$^{6}Li(\pi^{-},K^{+})X$
θ_{LAB}=2-14 deg.

No clear peak of $^{6}_{\Lambda}H$ production

Yield was extremely smaller than we expected



Results of production runs

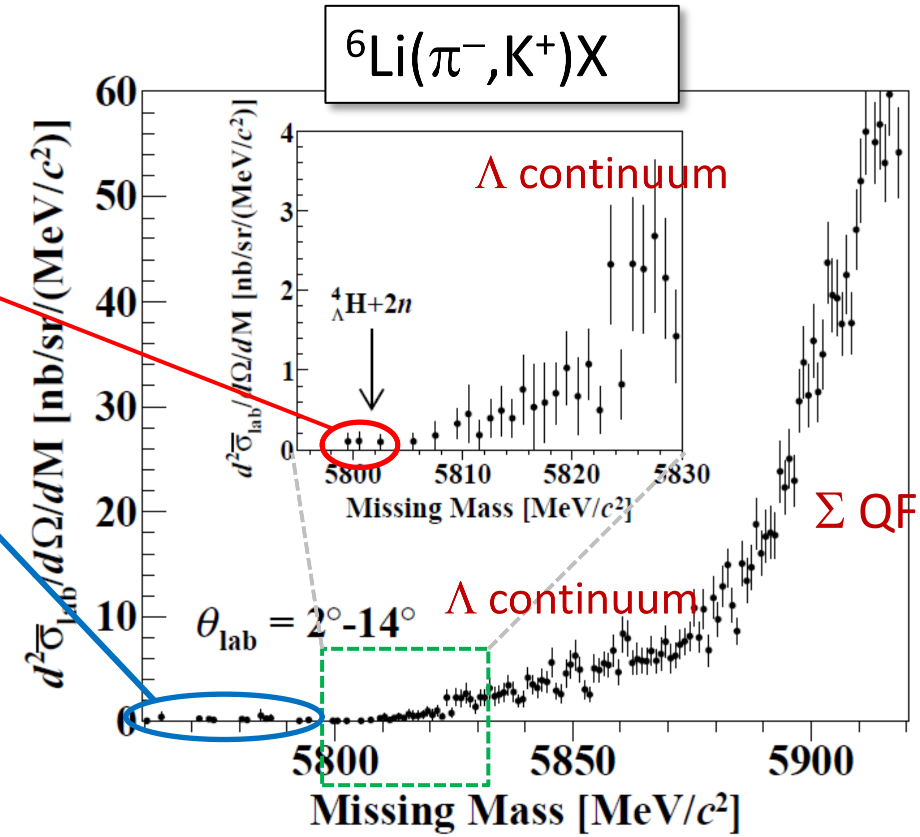
- Estimation of cross section upper-limit

3 events around $^{4}_{\Lambda}$H+2n threshold

Background due to miss-PID
0.39±0.05 event/(MeV/c^2)

Expected number of background is ~2 events

1 event ~ 0.18 nb/sr



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

E10 Summary

- Phase-1 beamtime of J-PARC E10 experiment
  - Run at high beam intensity as proposed: 10M-12M/spill
  - 1.4 T pion beams on target (about 50% of proposal)
- All calibration runs were done ($\Sigma^{\pm}$ and ${}^{12}_{\Lambda}C$)
  - Systematic error of missing-mass scale is 1.26 MeV/c^2
  - Missing-mass resolution is 3.2 MeV/c^2 (FWHM)
- Analysis of ${}^{6}_{\Lambda}H$ production data was done
  - No clear peak was observed in the threshold region
  - Cross section upper-limit is 1.2 nb/sr (90% C.L.)
  - Studies are still in progress to improve the sensitivity

E27 experiment
Search for light kaonic nuclei "K^-pp" via the $d(\pi^+, K^+)$ reaction at J-PARC.

Yudai Ichikawa
Kyoto University / JAEA
2014/2/15
SNP school 2014

Introduction

- $\bar{K}N$ interaction
  - Known to be strongly attractive from K^-p atomic X-ray shift and low energy K^- p scattering data
  - $\Lambda(1405)$ can be interpreted as a K^-p bound state
- K^-pp bound state KNN(Total charge; +1, I=1/2)
  - The simplest kaonic nucleus
  - Theoretical prediction of B.E. and Γ depend on the KN interaction and theoretical framework.
- $\bar{K}N$ interaction in matter
  - Clarify possible existence of K^- condensation in neutron stars

Calculated K^-pp binding energies B and widths Γ (in MeV). *A. Gal / Nuclear Physics A 914 (2013) 270–279*

	Chiral, energy dependent			Non-chiral, static calculations			
	var. [7]	var. [8]	Fad. [9]	var. [10]	Fad [11]	Fad [12]	var. [13]
B	16	17–23	9–16	48	50–70	60–95	40–80
Γ	41	40–70	34–46	61	90–110	45–80	40–85

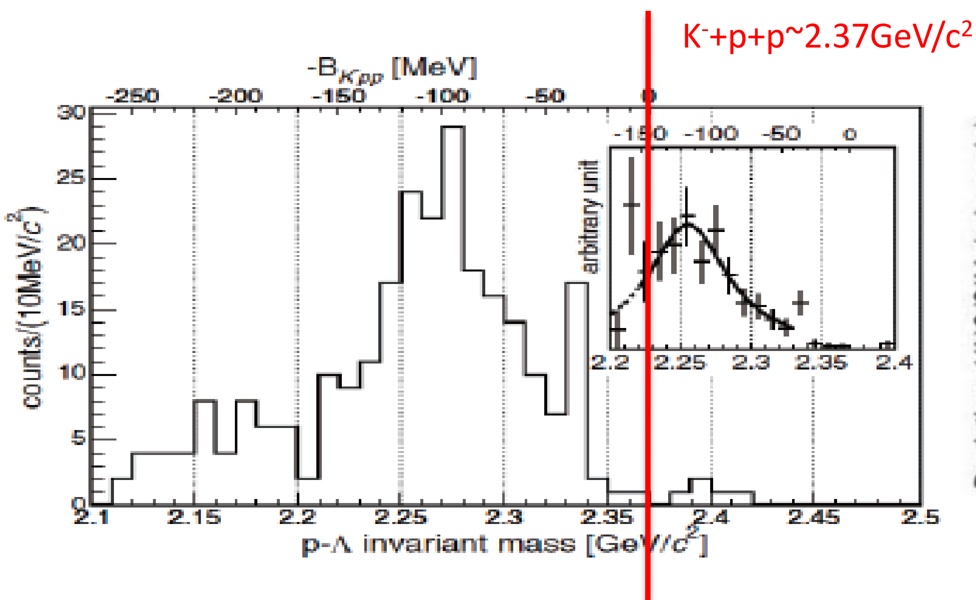
[7] N. Barnea, A. Gal, E.Z. Liverts, Phys. Lett. B 712 (2012) 132.
[8] A. Doté, T. Hyodo, W. Weise, Nucl. Phys. A 804 (2008) 197; A. Doté, T. Hyodo, W. Weise, Phys. Rev. C 79 (2009) 014003.
[9] Y. Ikeda, H. Kamano, T. Sato, Prog. Theor. Phys. 124 (2010) 533.
[10] T. Yamazaki, Y. Akaishi, Phys. Lett. B 535 (2002) 70.
[11] N.V. Shevchenko, A. Gal, J. Mareš, Phys. Rev. Lett. 98 (2007) 082301; N.V. Shevchenko, A. Gal, J. Mareš, J. Revai, Phys. Rev. C 76 (2007) 044004.
[12] Y. Ikeda, T. Sato, Phys. Rev. C 76 (2007) 035203; Y. Ikeda, T. Sato, Phys. Rev. C 79 (2009) 035201.
[13] S. Wycech, A.M. Green, Phys. Rev. C 79 (2009) 014001.

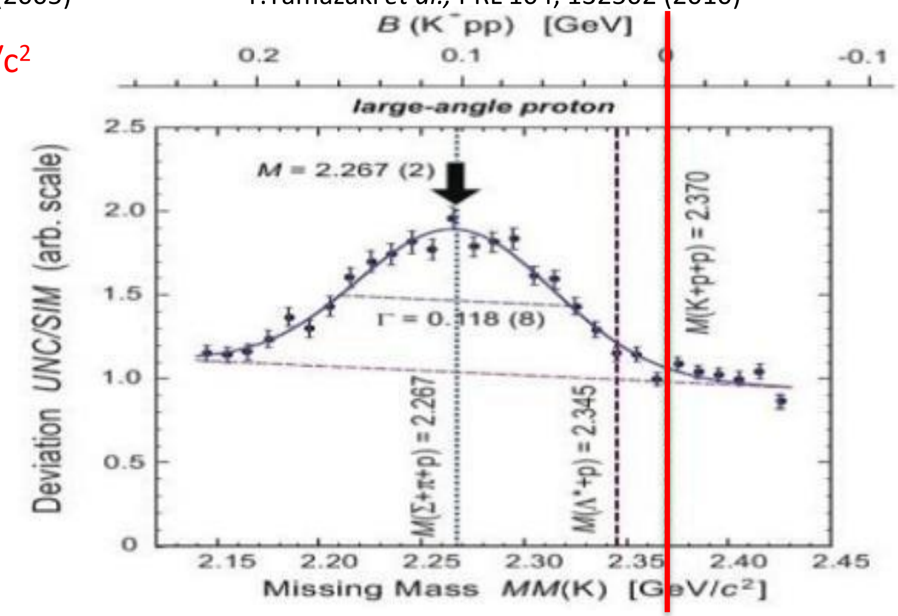
Previous experiments for K^-pp

	FINUDA	DISTO
reaction	Stopped K^- absorption on $^{6,7}Li + ^{12}C$	p + p @ Tp=2.85GeV
method	Invariant mass of back-to-back Λp pairs	$p+p \rightarrow X+K^+$ (missing mass) $X \rightarrow \Lambda + p$ (invariant mass)
B.E	$115^{+6}_{-5}(stat)^{+3}_{-4}(syst)$ MeV	105 ± 5 MeV
Width	$67^{+14}_{-11}(stat)^{+2}_{-3}(syst)$ MeV	118 ± 8 MeV

M.Agnello *et al.*, PRL 94, 212303 (2005)

T.Yamazaki *et al.*, PRL 104, 132502 (2010)





J-PARC E27 experiment

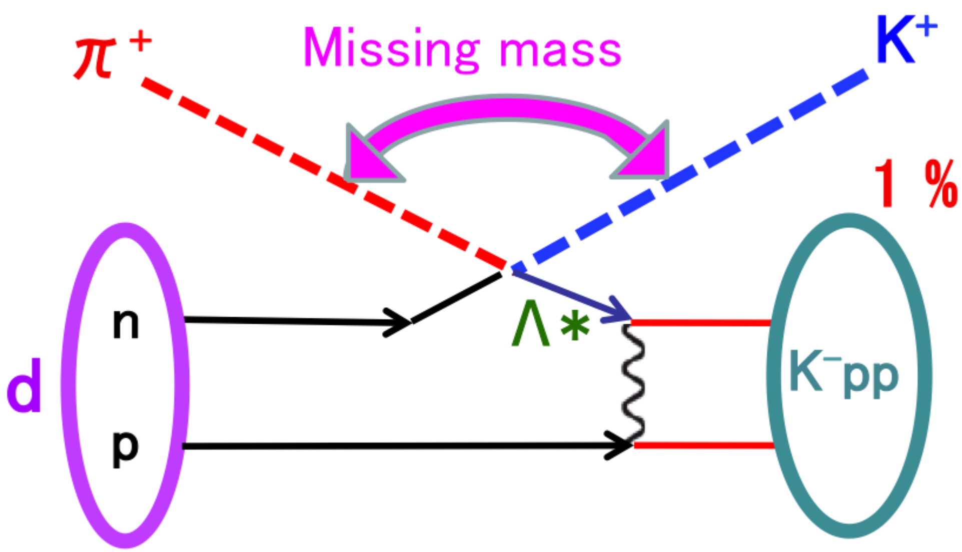
d(π^+, K^+)X reaction (P_π = 1.7GeV/c)

K^-pp is produced via a Λ(1405) doorway.

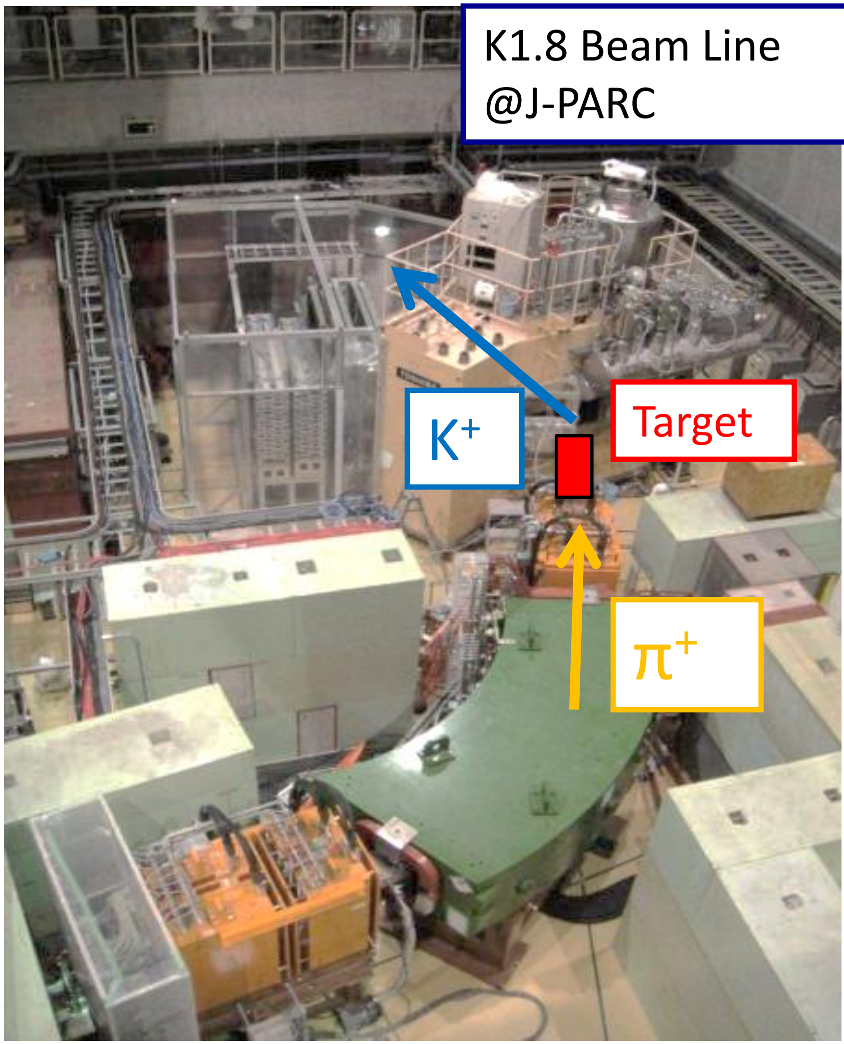
$\pi^+ + n \rightarrow \Lambda(1405) + K^+$

$\Lambda(1405) + p \rightarrow K^-pp$

(→quasi free Λ*)

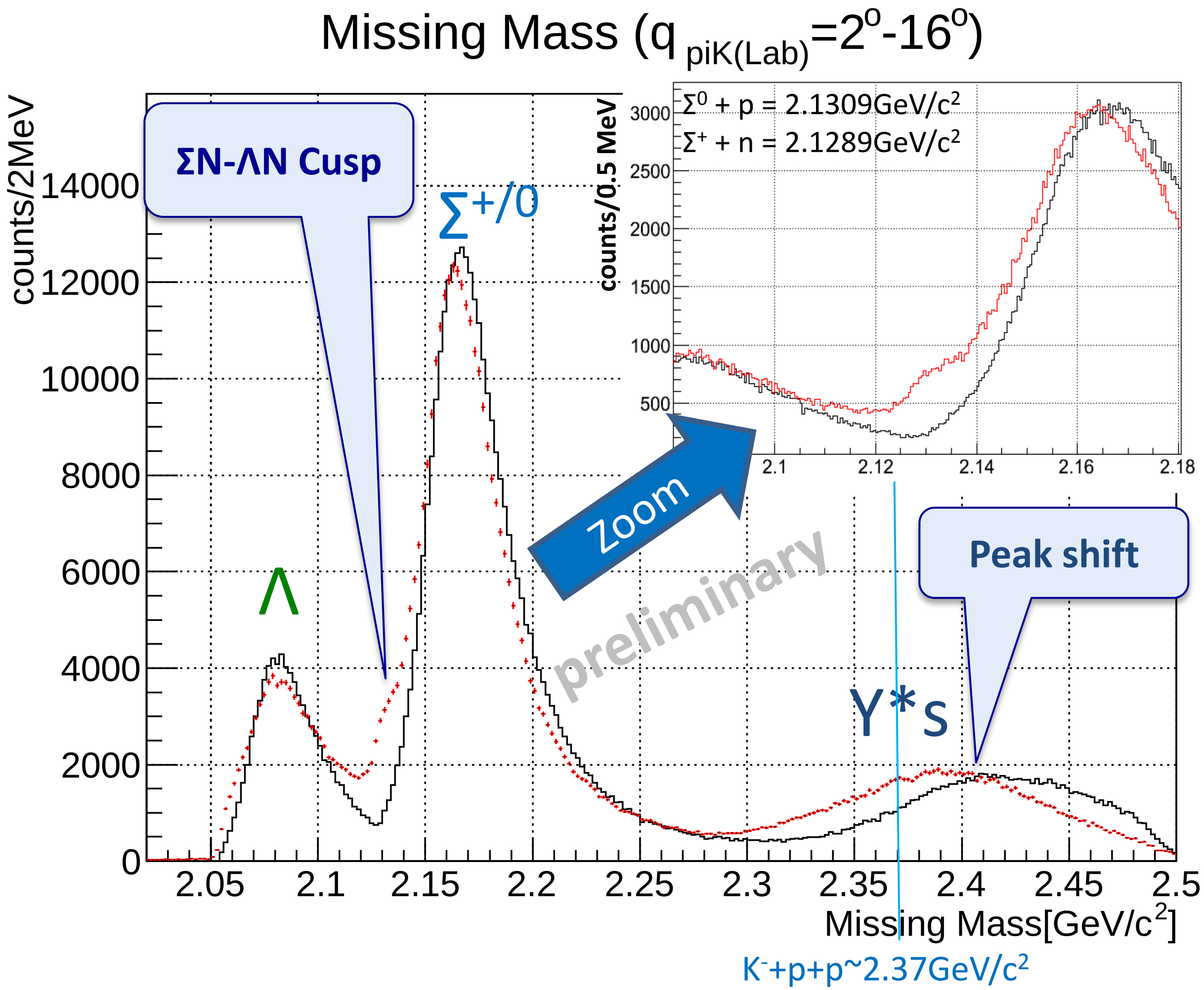


Y.Akaishi, T.Yamazaki, Phys. Rev. C 76 045201 (2007)



d(π^+, K^+)X inclusive spectrum

Black: Simulation for the B.G.
(quasi-free hyperon production)
Red: Data



Quasi-free B.G.

- Λ, Σ
- Y* : Σ (1385)$^{+/0}$,
  Λ (1405)
  Λπ, Σπ

There are a lot of B.G.
→It is difficult to identify the K^-pp bound state from inclusive spectrum.

→**Coincidence analysis to suppress these B.G.**

ΣN-ΛN Cusp

Excess is observed around 2.13 GeV/c^2.

Peak shift

Y* peak shift to lower mass side by ~ 30 MeV/c^2.

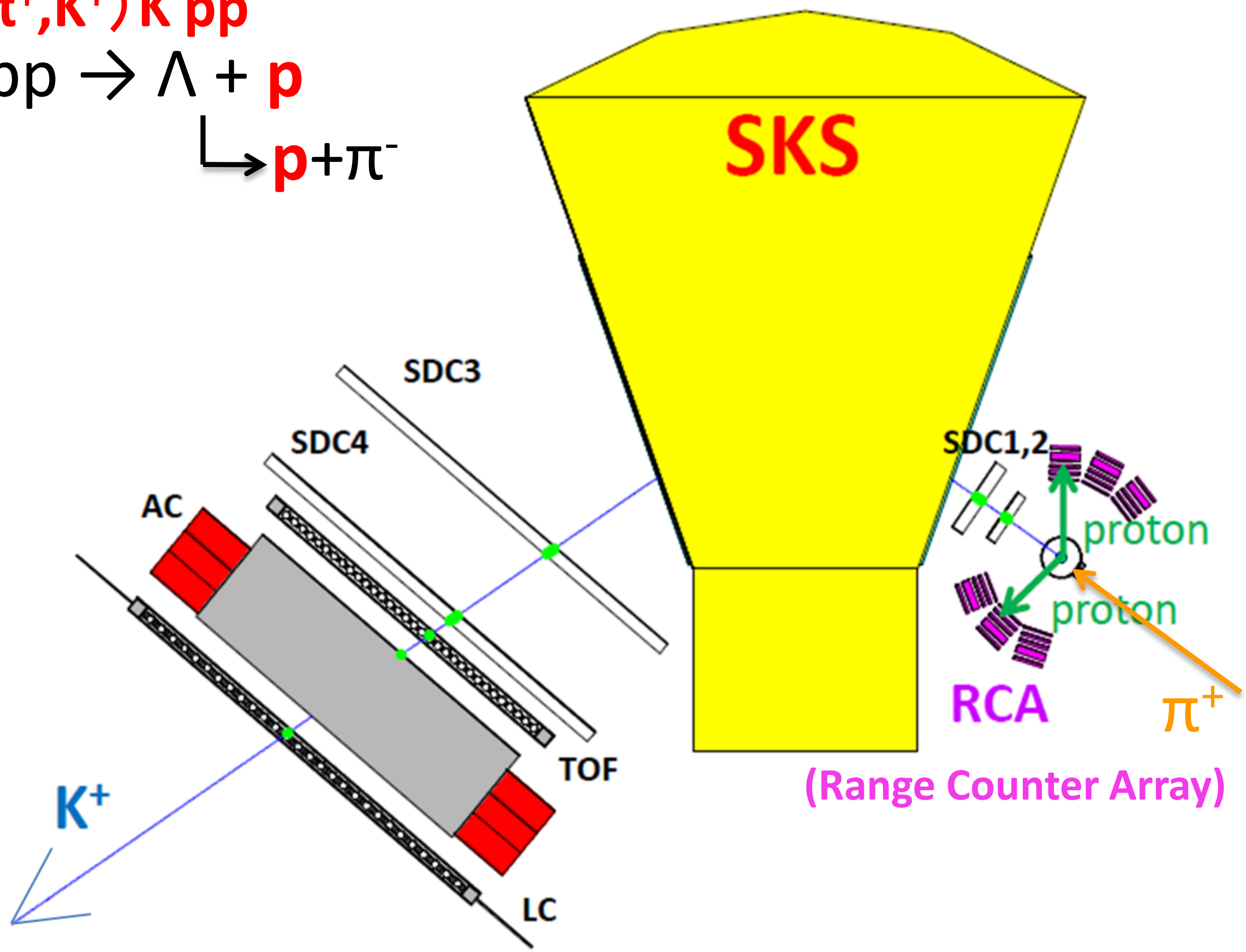
Range Couner Array for B.G. suppression

Coincidence measurement!!

$d(\pi^+,K^+)K^-pp$

$K^-pp \rightarrow \Lambda + \mathbf{p}$

$\quad \hookrightarrow \mathbf{p} + \pi^-$



RCA for B.G. suppression

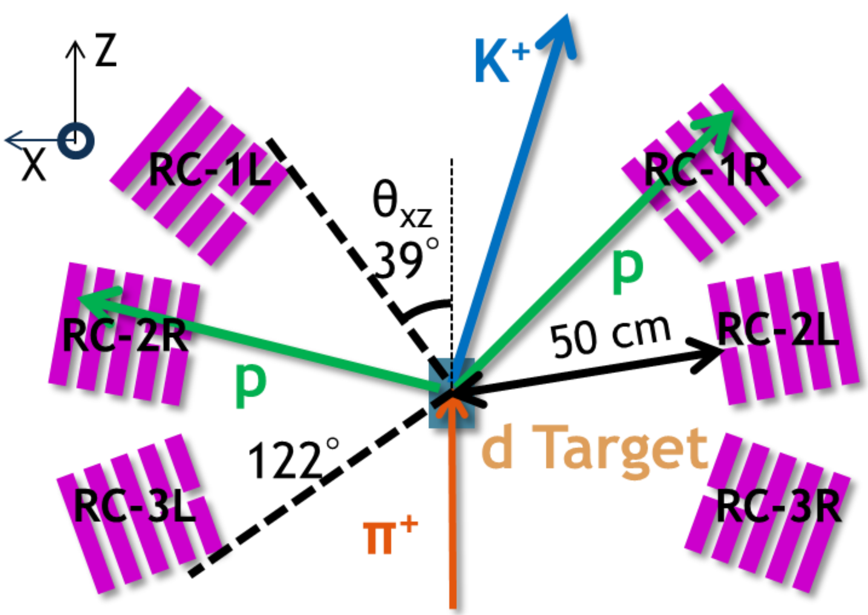
- 6units, 5 layers (1+2+2+5+2cm) of plastic scintillator.
- TOF: 50cm, θ_{xz}:39° –122° (L+R)

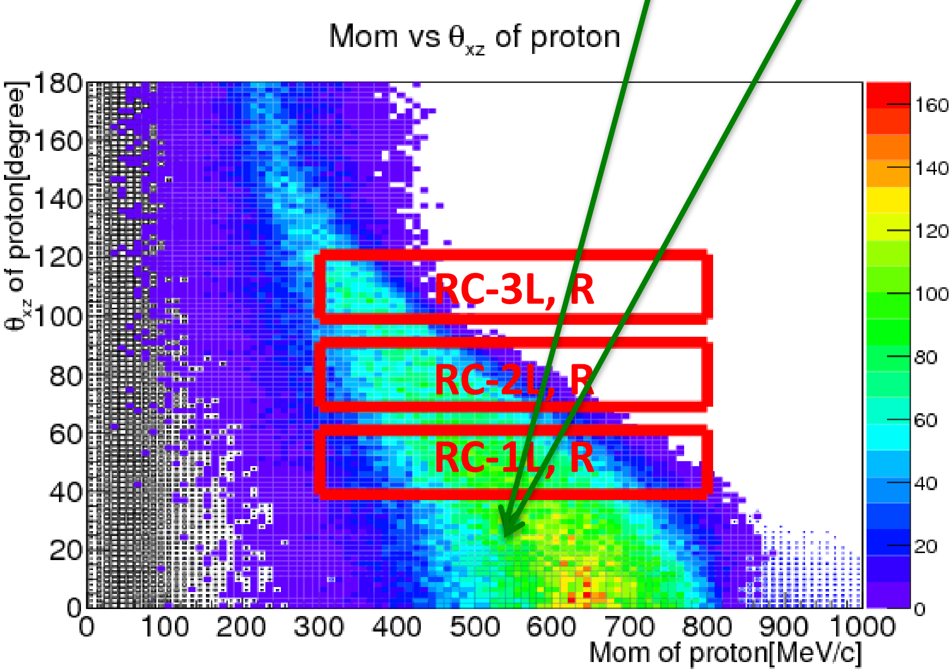
→We suppress the B.G. by tagging a proton at RC-2, 3.

→More strongly suppress by tagging two protons.

$K^-pp \rightarrow \Lambda p$

$\rightarrow p\,\pi^-\,p$



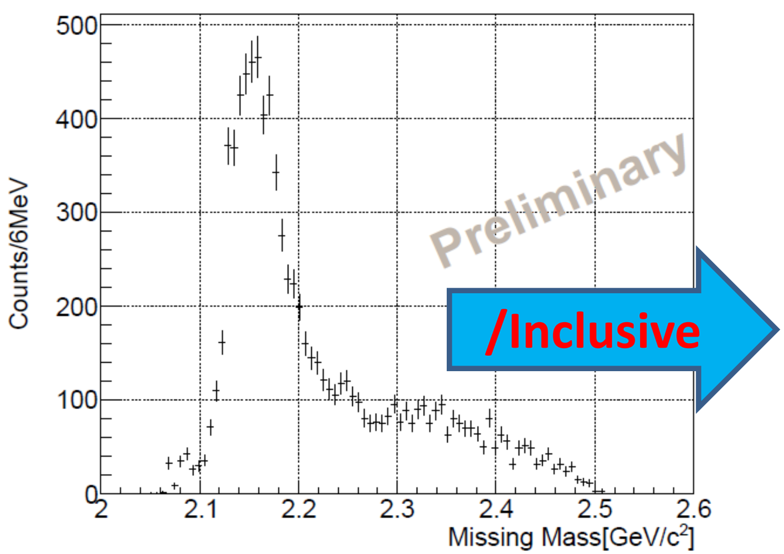


1 proton coincidence analysis

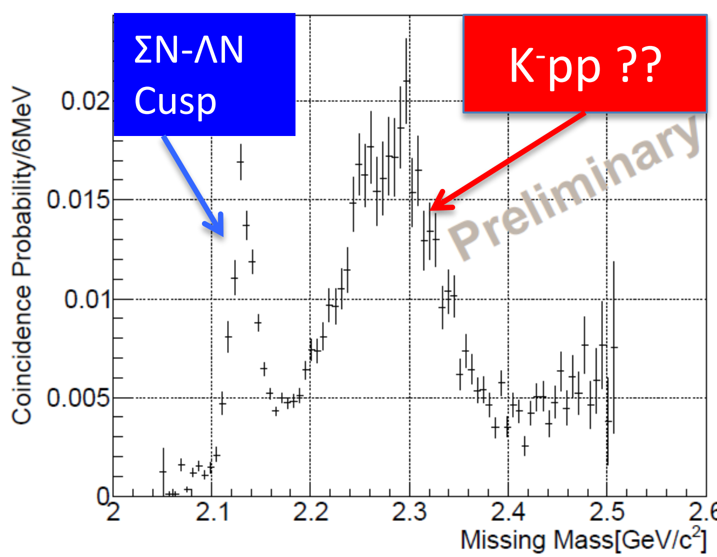
- RC-2L, R are almost free from QF backgrounds.
- Excess due to ΣN-ΛN cusp is clearly observed ~ 2.13GeV/c^2.
- Broad Enhancement is observed around 2.3 GeV/c^2.
  - There is a proton emitting source involving two nucleons (non quasi-free) in a high emission probability.
  - A possible explanation of the observed structure is K^-pp.

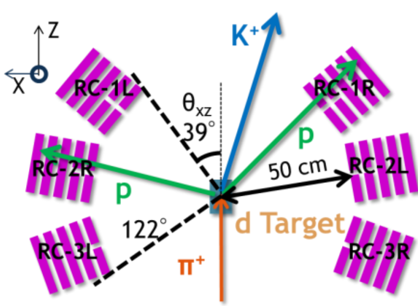
RC-2L, R

<1P coincidence spectrum>
1 p hit in the RC-2L, R is required.



<1P coincidence probability>
P coin spectrum / Inclusive





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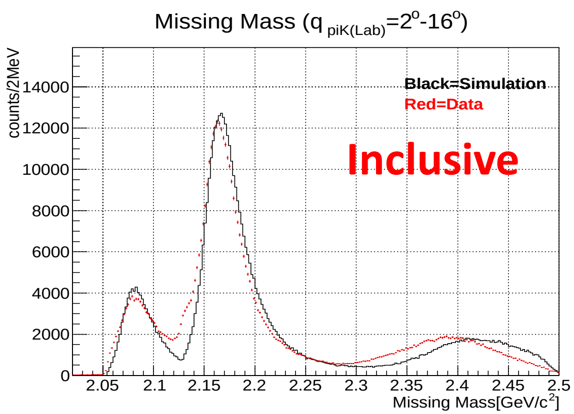
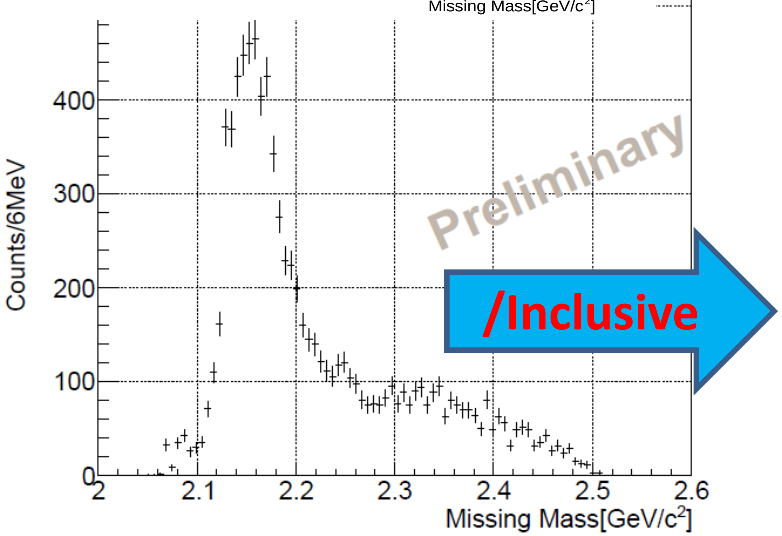
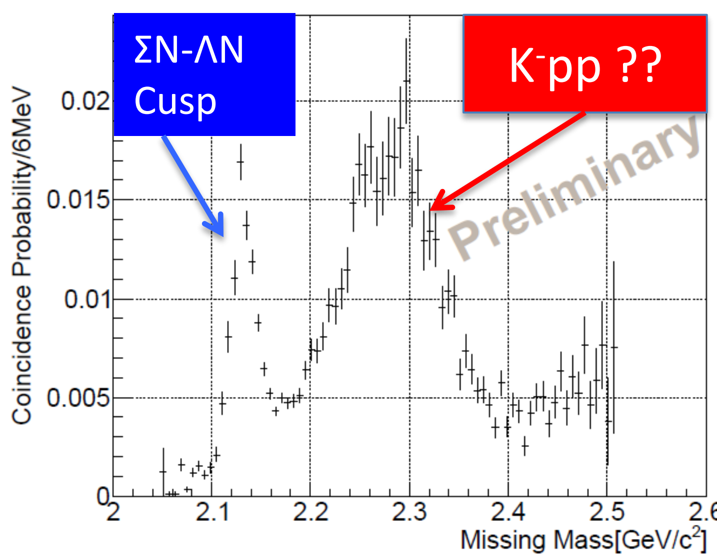


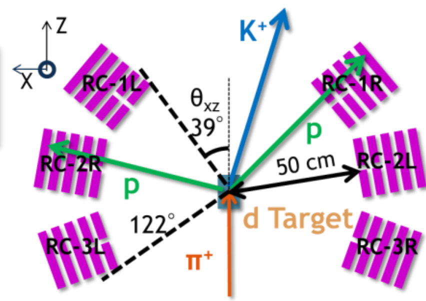
C-2L, R

d.

<1P coincidence probability>
P coin spectrum / Inclusive





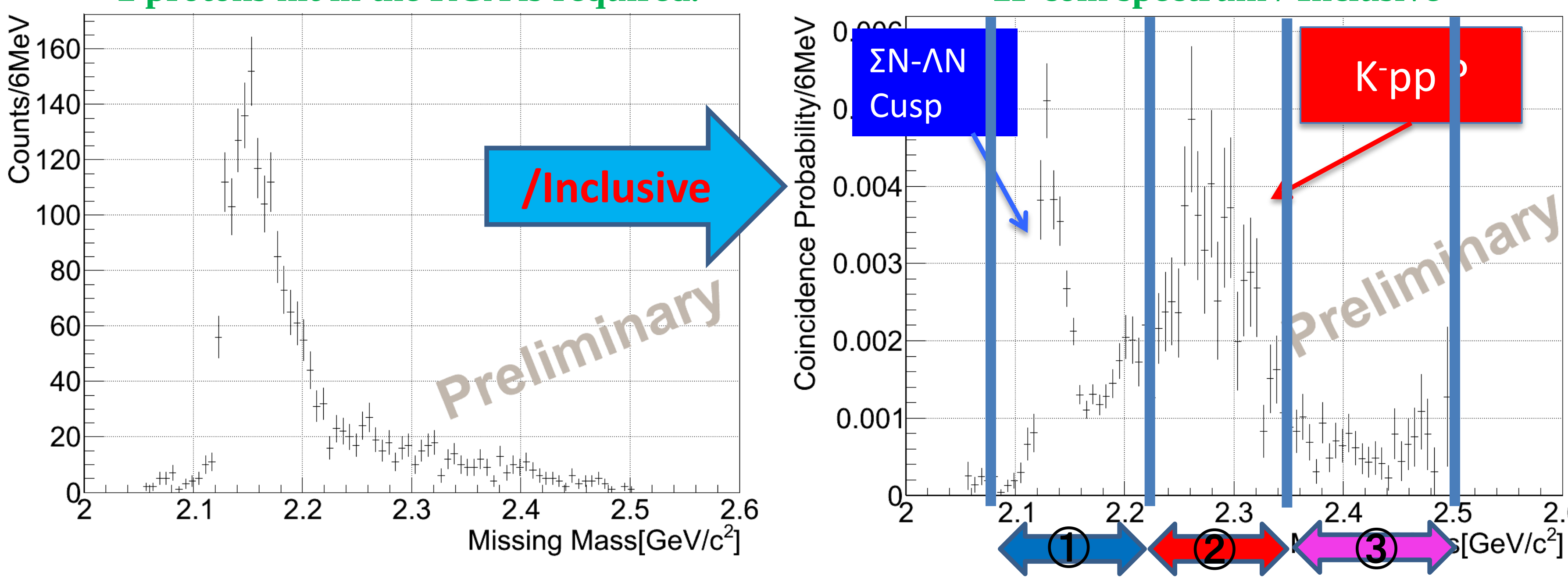


2-proton coincidence analysis

- The 2-proton coincidence spectra show the same tendency as the 1-proton coincidence spectrum.
- We set 3 regions in the missing mass spectrum.
  - ①MM<2.22GeV, ②2.22<MM<2.35GeV, ③MM>2.35GeV
    Cusp region, Enhance region, Y* region

<2P coincidence spectrum>
2 protons hit in the RCA is required.

<2P coincidence probability>
2P coin spectrum / Inclusive



The final state of X (2p coin events)

- Hyperon masses are reconstructed by 2p coin analysis.

  ・$d(\pi^+, K^+)X$; $X \rightarrow Y + p$, $Y \rightarrow \pi + p$ (+…)

  ※ $M_Y^2 = (E_\pi + M_d - E_K - E_p)^2 - (p_\pi - p_K - p_p)^2$

Black: **Data ,**

Red: **X->Λp,**

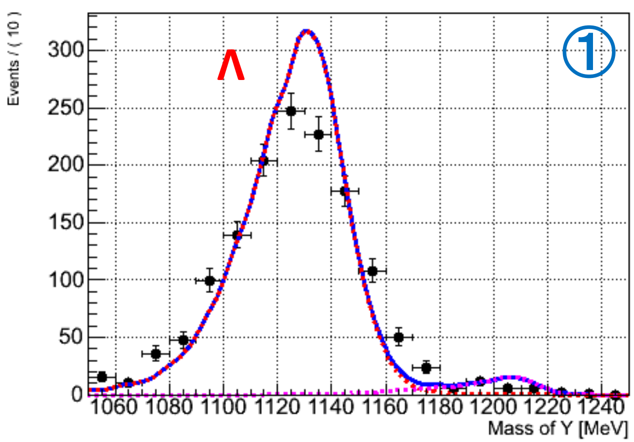
Pink: **X->Σ⁰p,**

Green: **X->Λπ⁰p,**

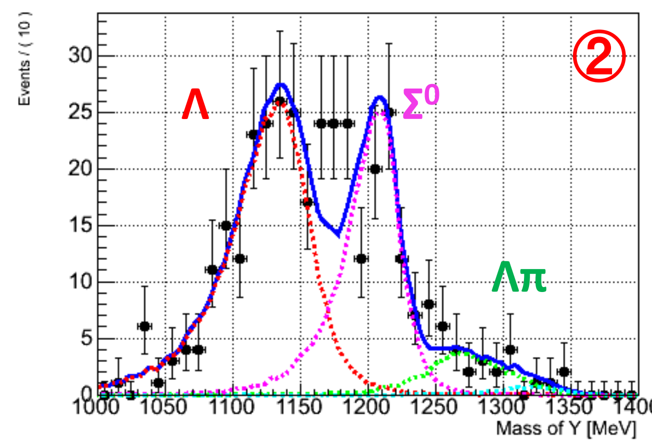
Sky: **X->Σπp,**

Blue: **Sum**

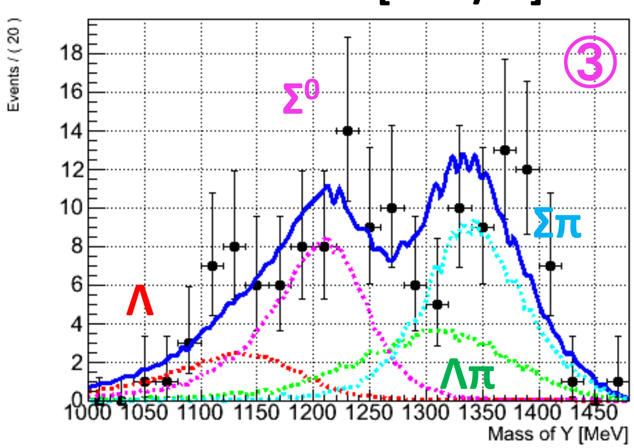
2.1<MM<2.22[GeV/c²]



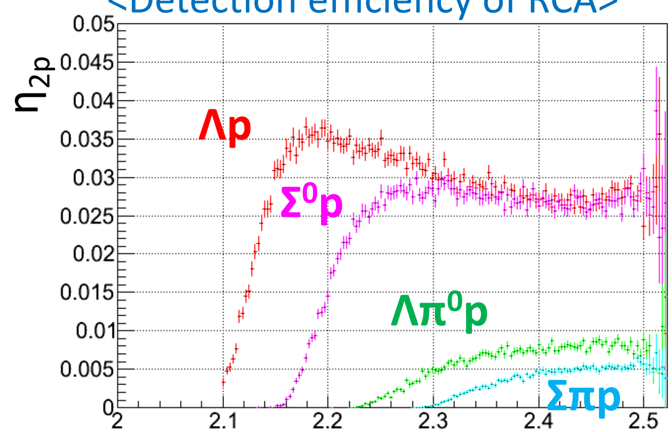
2.22<MM<2.35[GeV/c²]

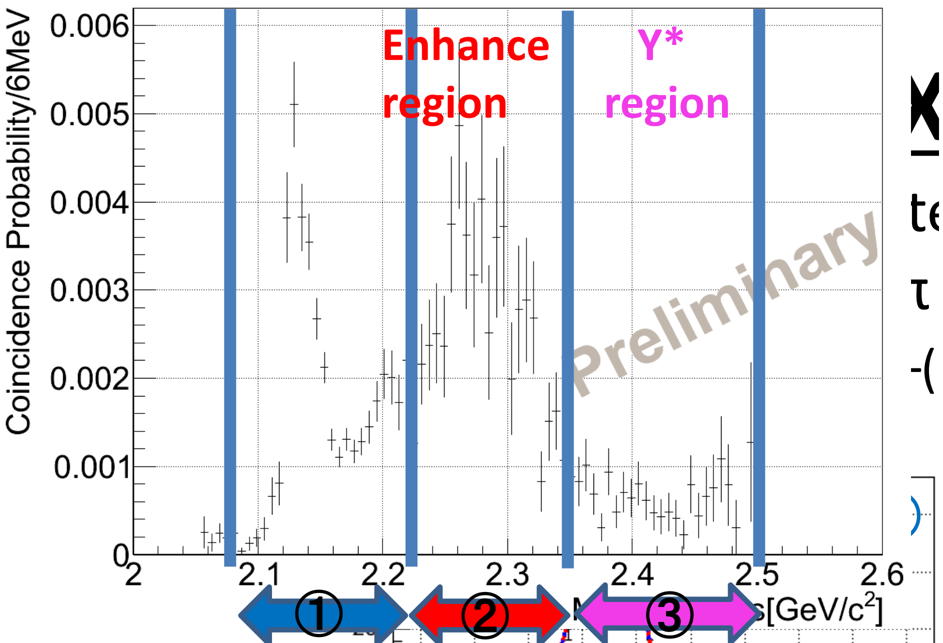


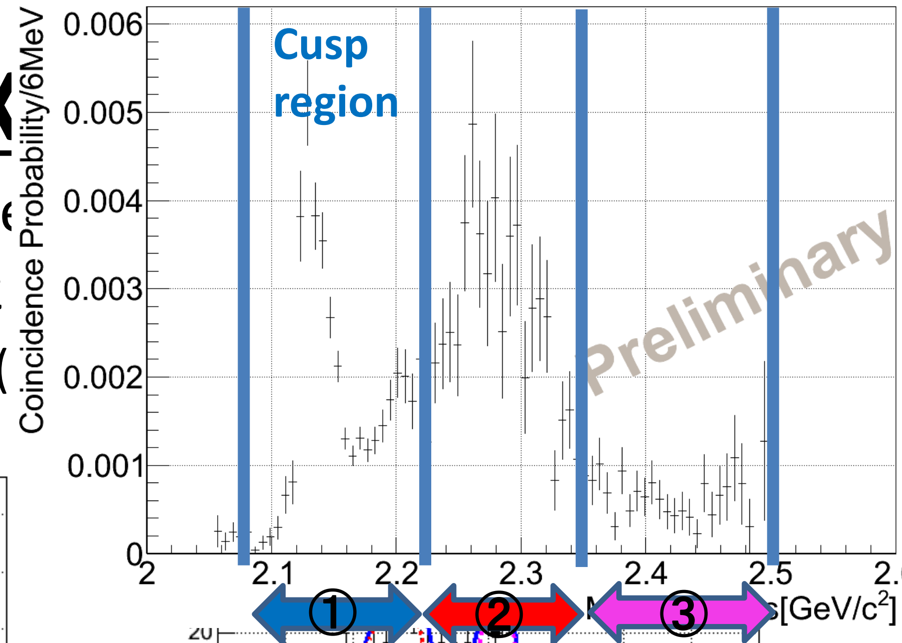
MM<2.35[GeV/c²]

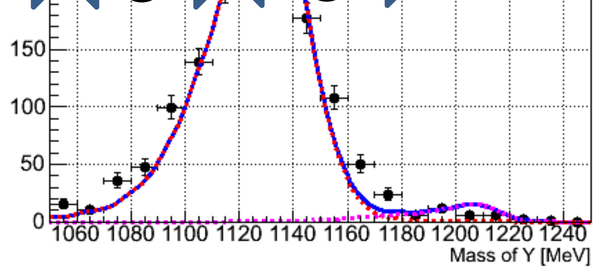


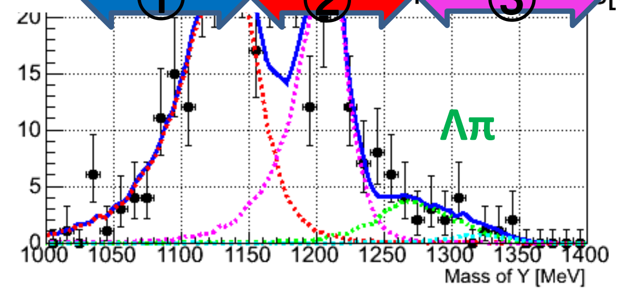
<Detection efficiency of RCA>











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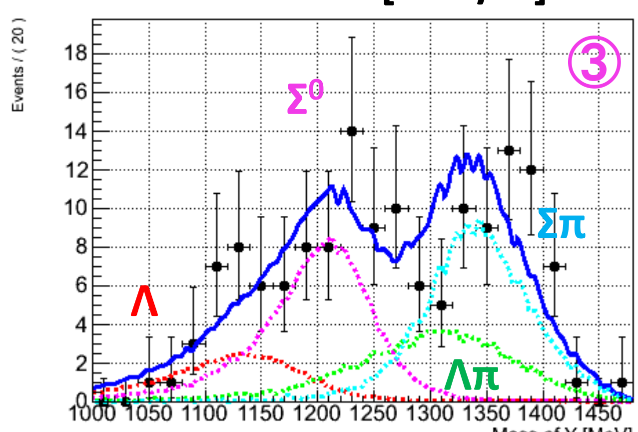

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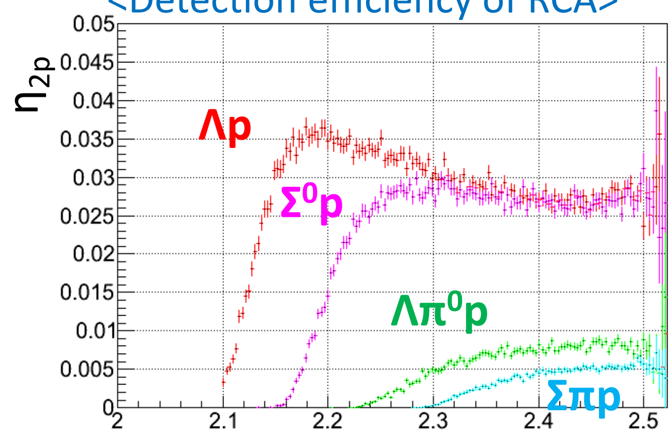


E27 Summary and Future

<Inclusive analysis>

- We have obtained d(π^+, K^+) at 1.7 GeV/c for the first time.
- In the Λ and Σ region, observed spectrum is almost reproduced by the simulation which is based on the quasi-free processes.
- ΣN-ΛN cusp structure and peak shift of Y* are observed.

<Coincidence analysis>

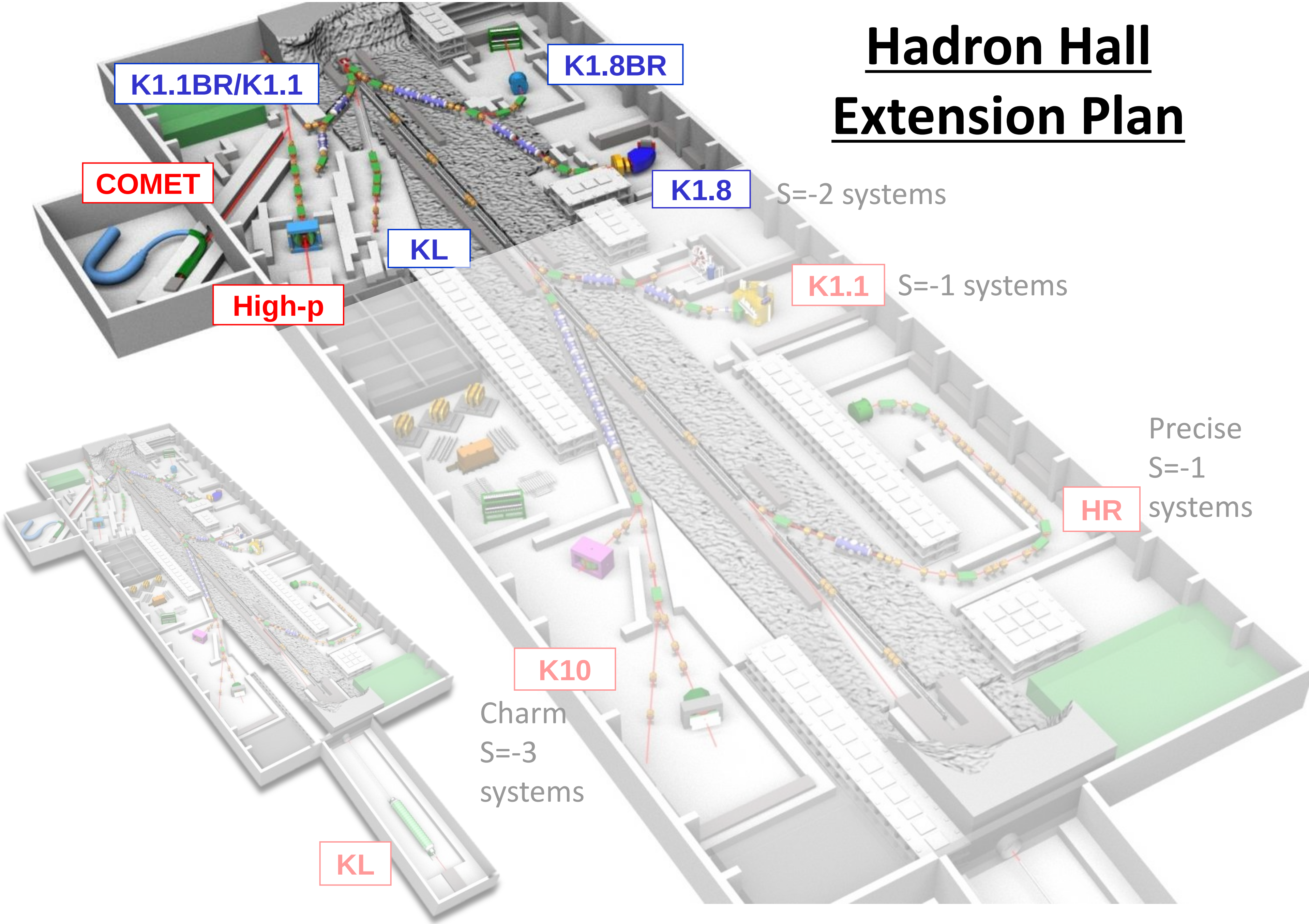
- In proton coincidence, the ΣN-ΛN cusp structure and an broad enhancement around 2.3 GeV/c^2 are clearly observed.
  → A possible explanation of the observed structure is K^-pp.
  → The detailed studies on detection efficiencies are in progress.
- Hyperon masses are reconstructed from 2 protons analysis .
  → The final states are determined.

<Future work>

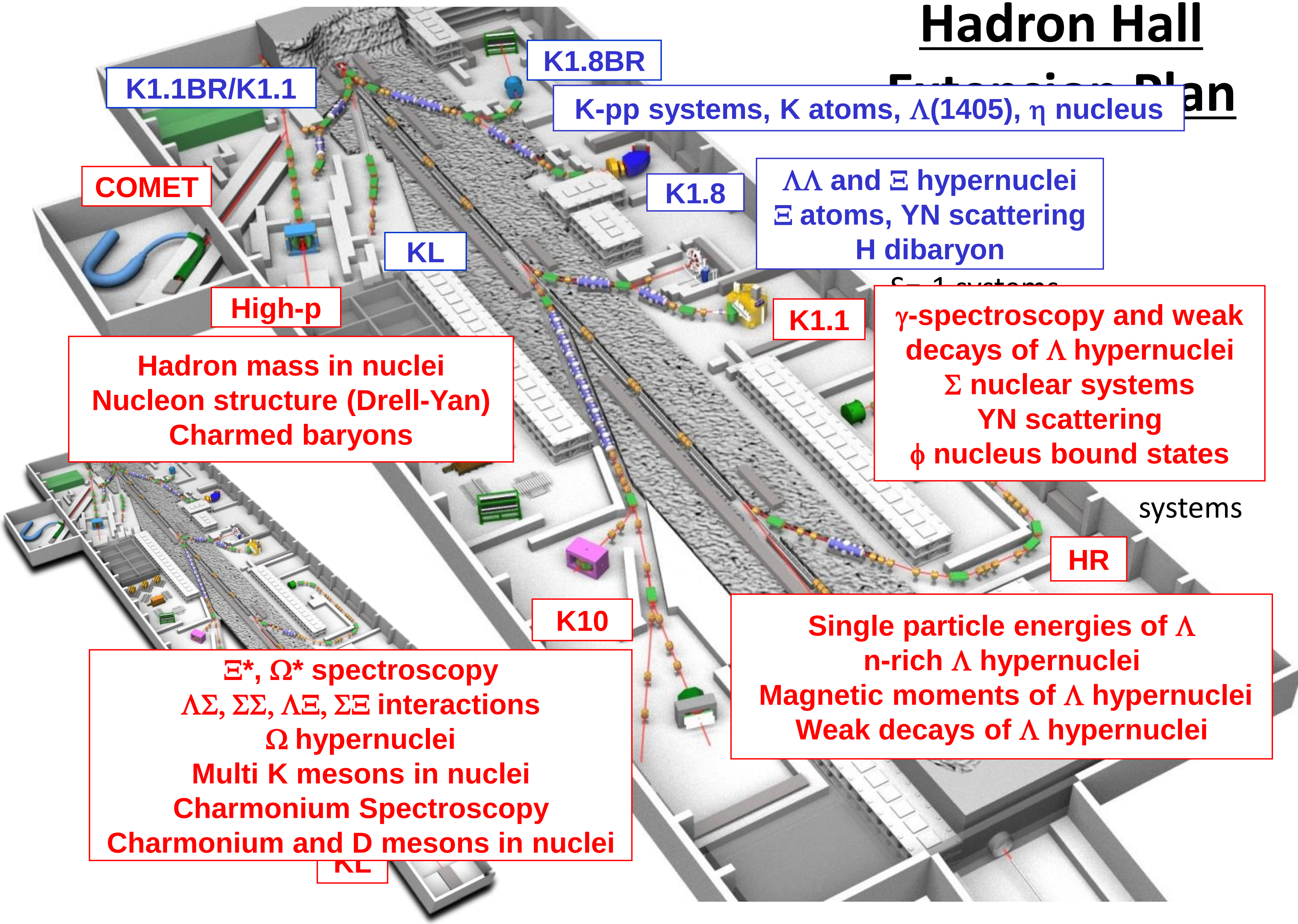
- Apply the acceptance correction for protons which detected by RCA.

A Future Plan of the Hadron Hall

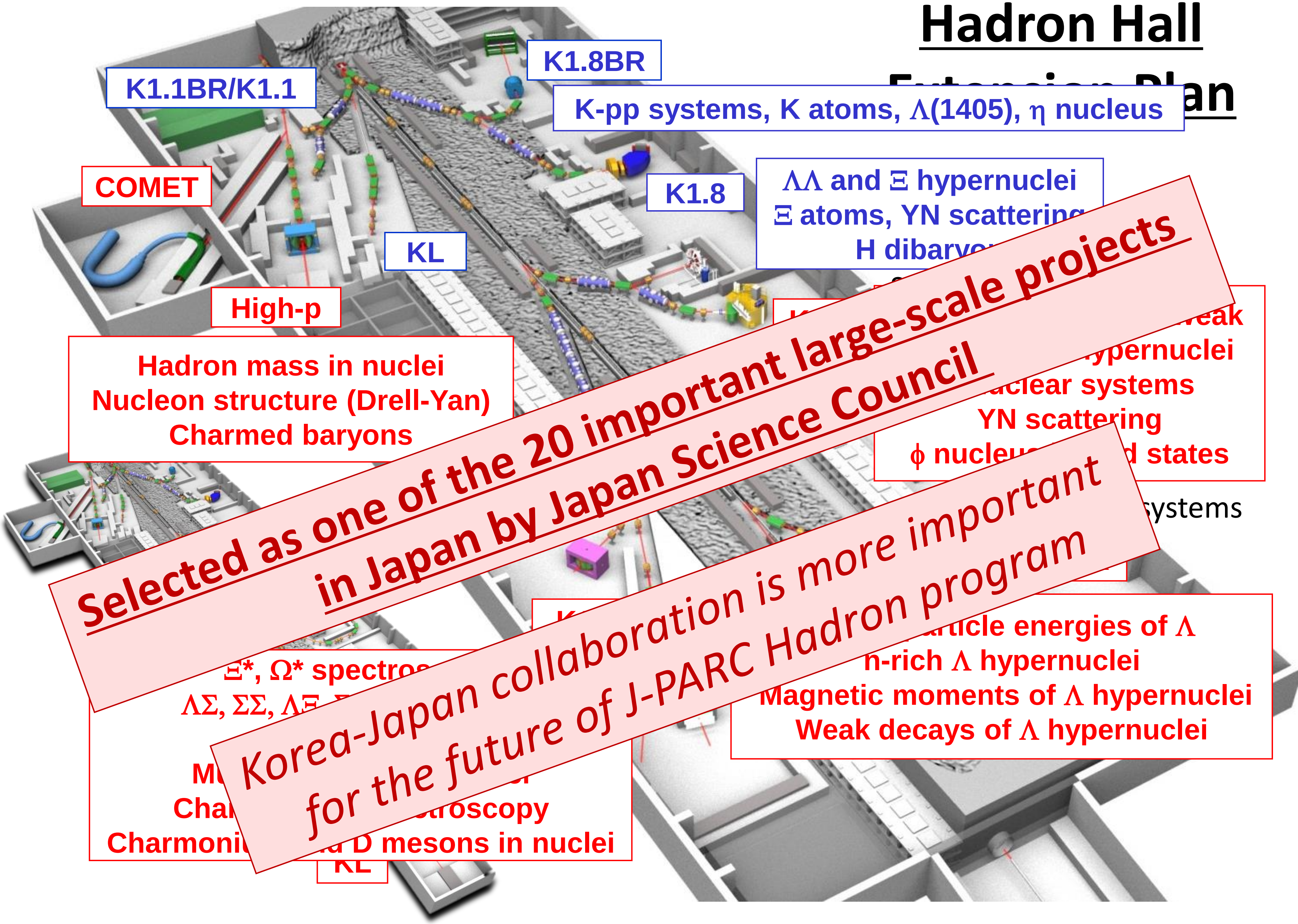
Hadron Hall Extension Plan



Hadron Hall Extension Plan



Hadron Hall



Selected as one of the 20 important large-scale projects in Japan by Japan Science Council

Korea-Japan collaboration is more important for the future of J-PARC Hadron program