3rd March 2023

Hypernuclear Physics Workshop 2023 @ F324/325 @ JLab

THE UNIVERSITY OF TOKYO

Strangeness nuclear physics in the world and significance of research project at JLab

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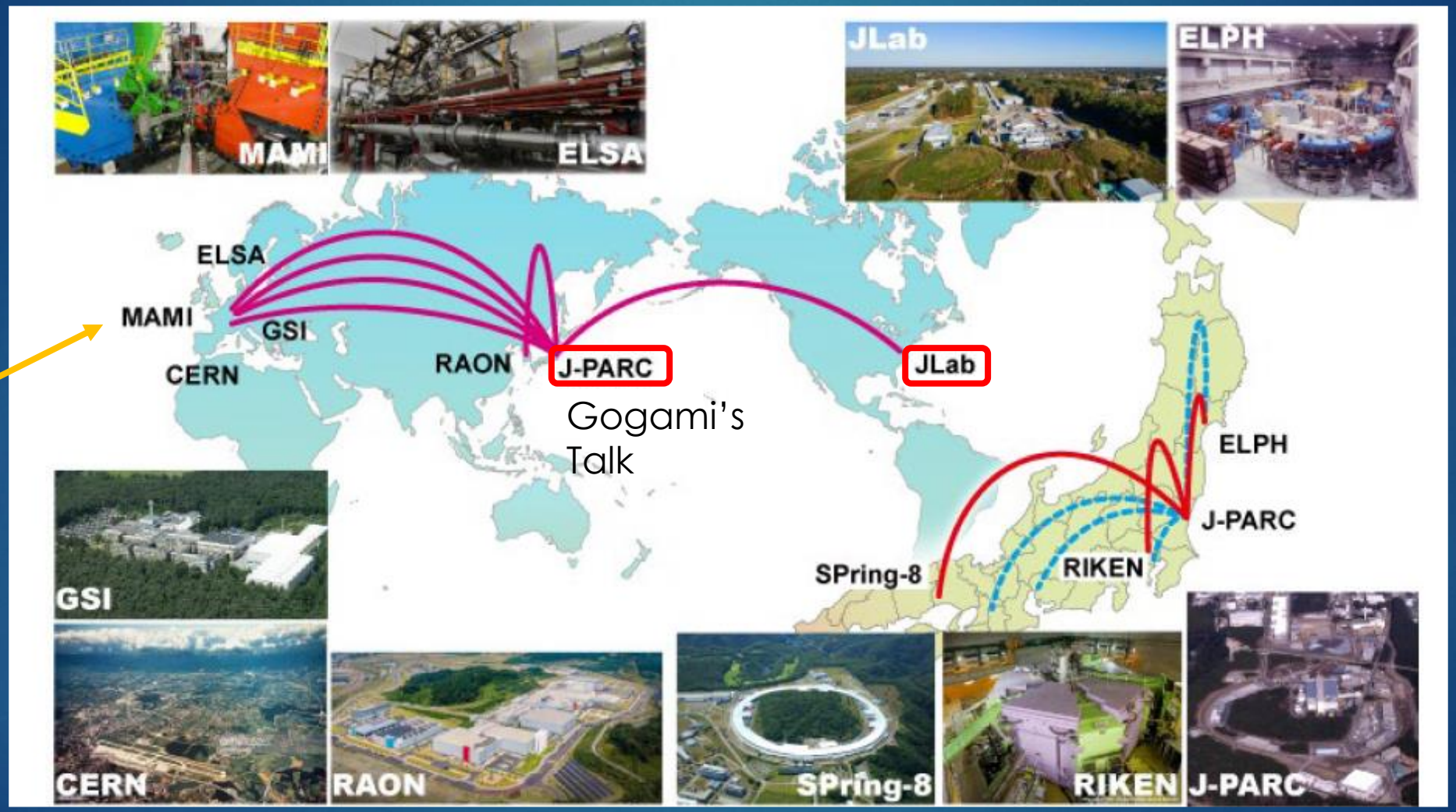
THE UNIVERSITY OF TOKYO

Why we meet in-person (+zoom) now at JLab?

It is time to back to normal after COVID-19 pandemic.

- International collaboration should keep activities by in-person discussion though zoom is quite useful tool.
- New projects on strangeness/hadron physics are in progress. Especially J-PARC Hadron Experimental Hall Extension Project.
- We decided to redesign the 1st phase of the hypernuclear experiments for Hall-C.

Key players in the hadron physics

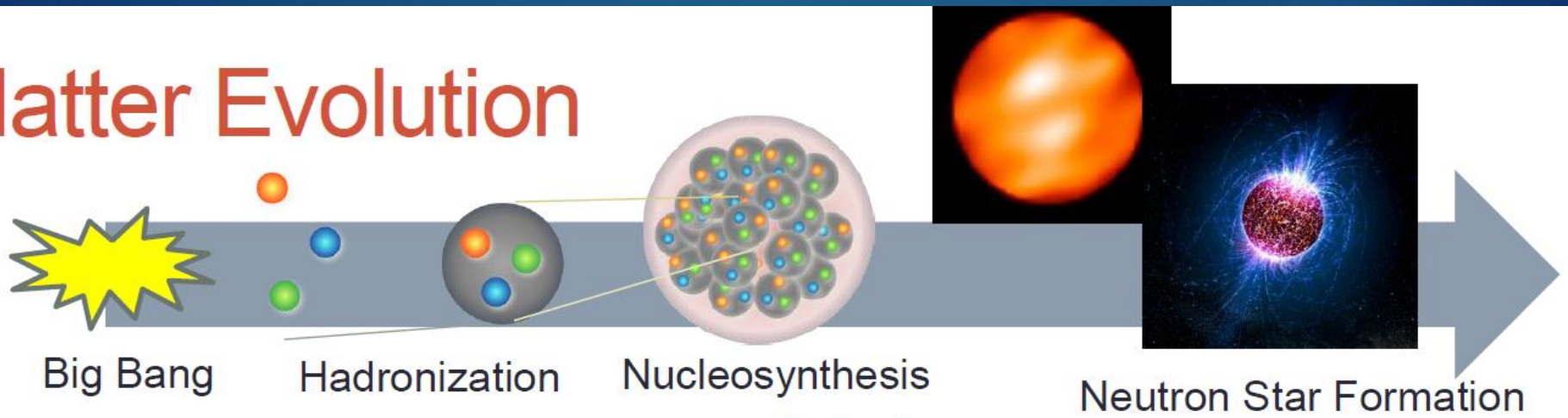


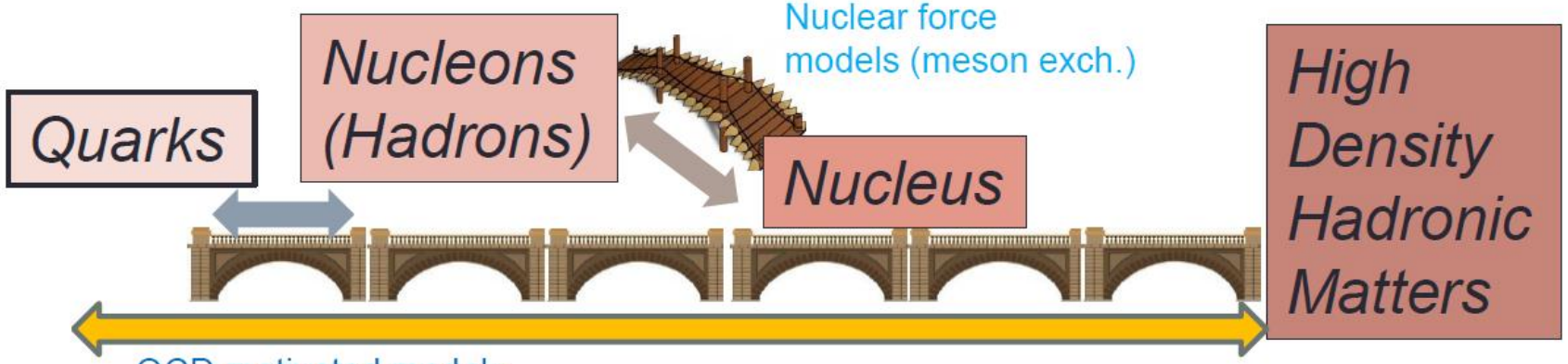
Nagao's talk

Gogami's Talk

From the proposal of International Leading Research,
International platform for the next generation research with young scientists in nuclear and hadron physics (2023)

Matter Evolution





Properties of various forms of matter → *Understand Matter Evolution in Universe*

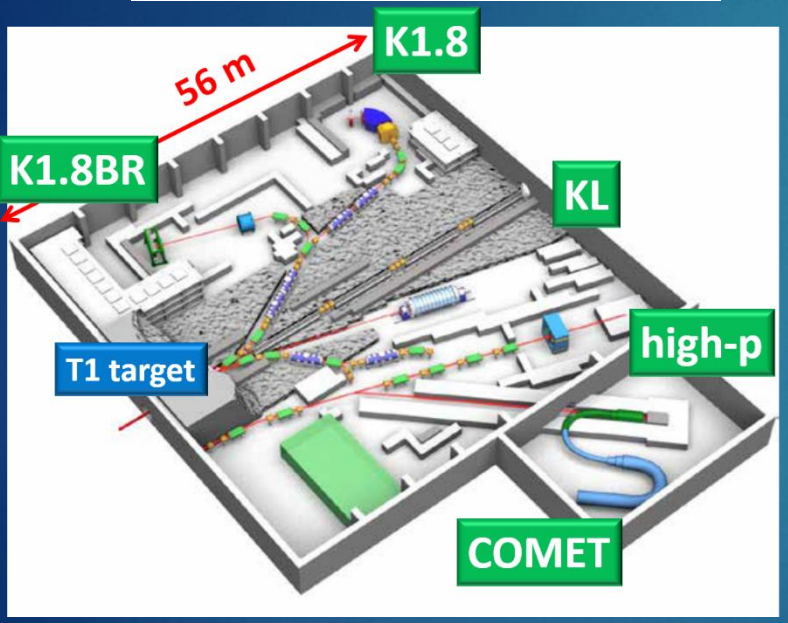
Three Research Topics at J-PARC

- Structure of hadrons
- Properties of high density hadronic matter
- Properties of hadrons in matter

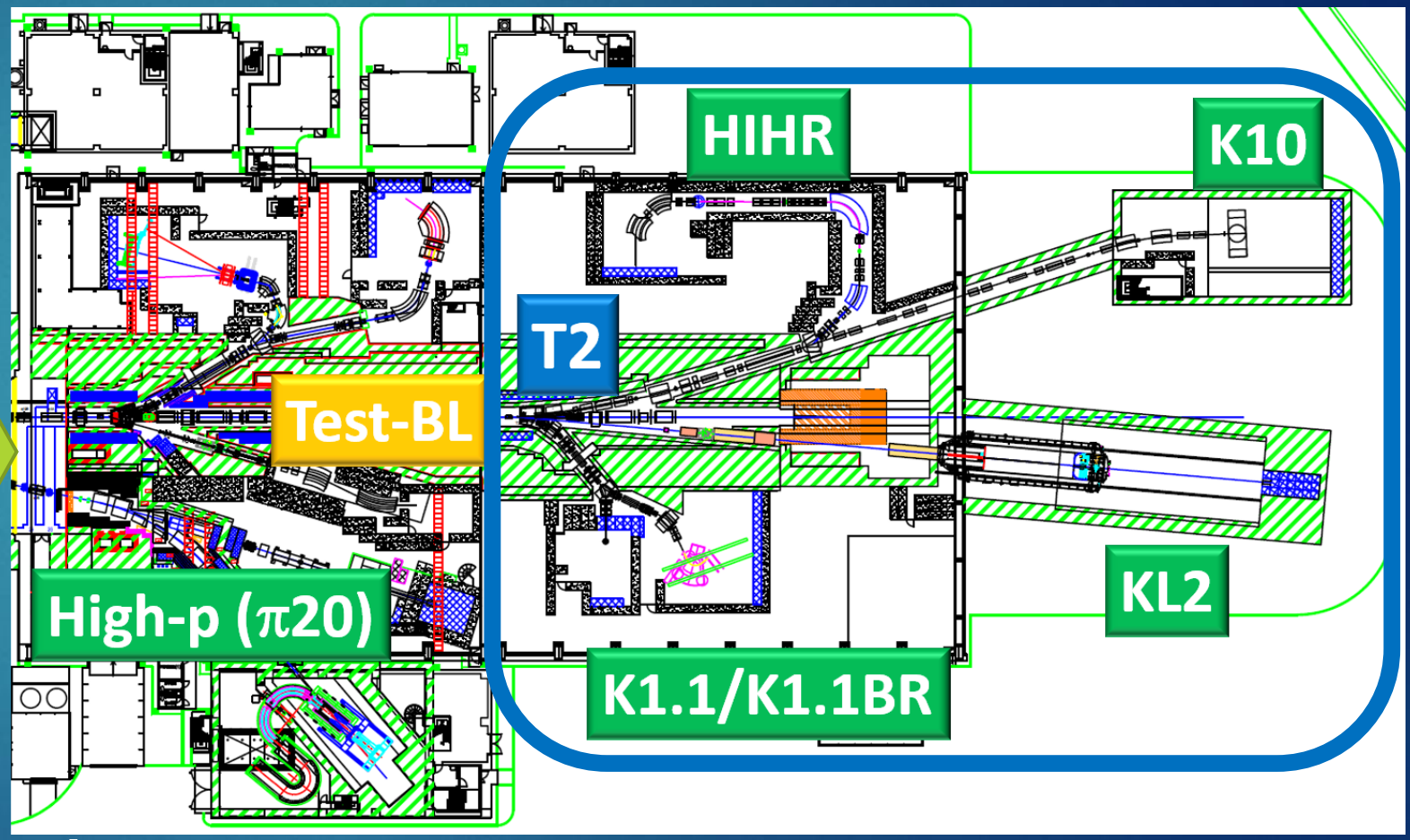
S.Sawada
KEK PIP
HEF-ex project

Hadron Experimental Facility EXtension (HEF-Ex) Project @J-PARC

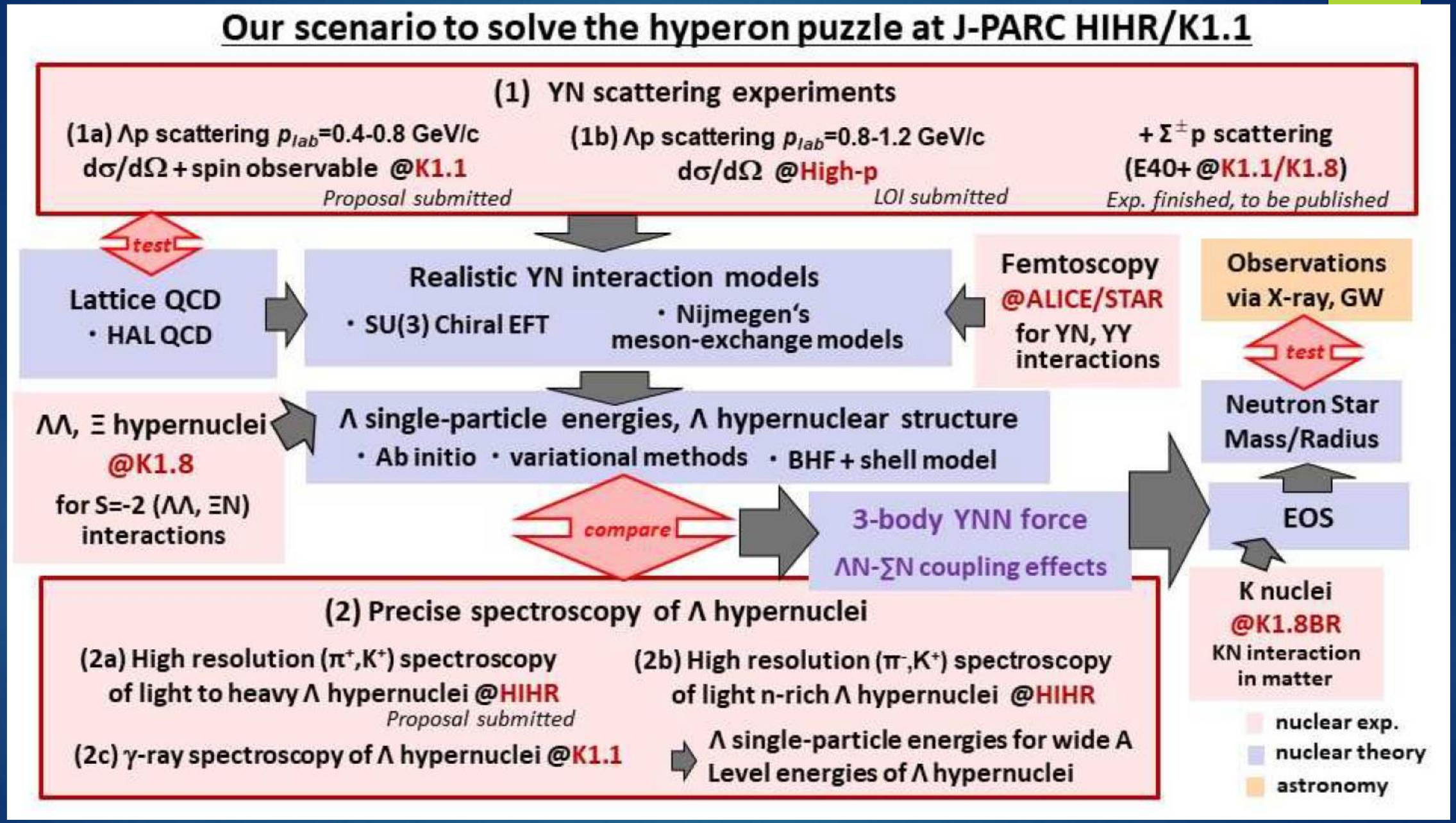
Present facility



1 production target (T1) +
2 charged beamlines (K1.8/1.8BR, High-p)
1 neutral beamline (KL)
1 muon beamline (COMET)



1 new production target (T2) +
4 new beamlines (HIHR, K1.1/K1.1BR, KL2, K10) +
2 modified beamlines (High-p (π20), Test-BL)



HEF-ex White Paper, ArXiv2110.04462

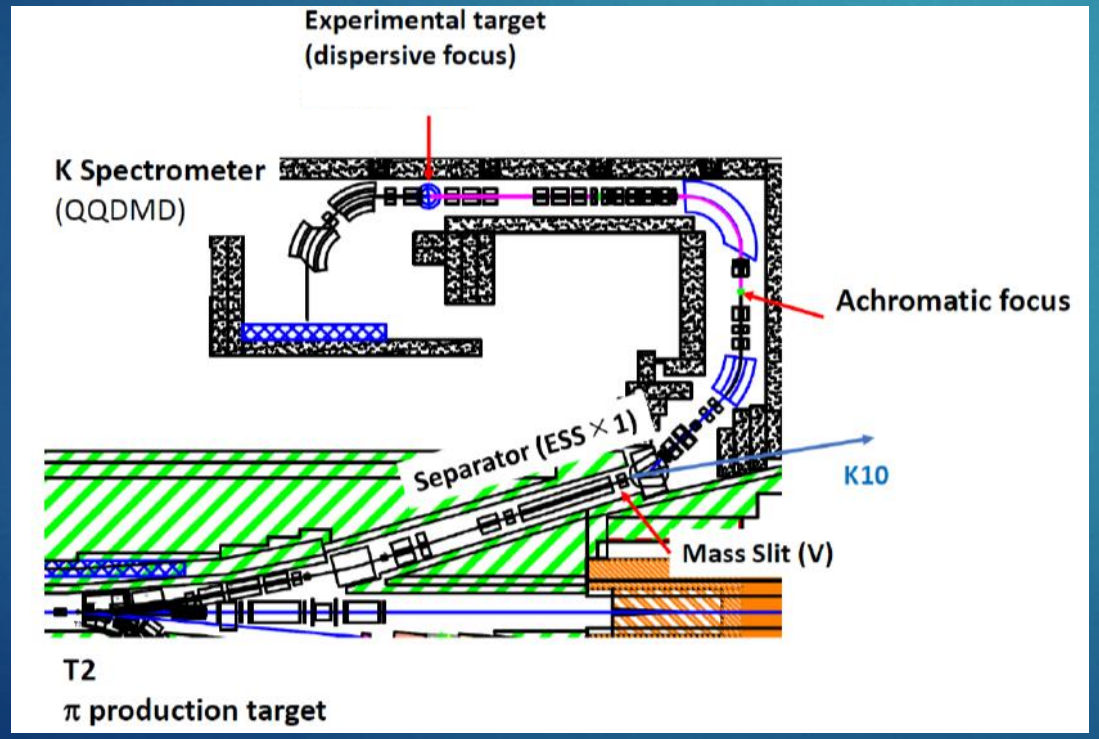
HIHR

Exist beamlines:
~10^6 pions/pulse, $\Delta p/p$ ~ 1/1000

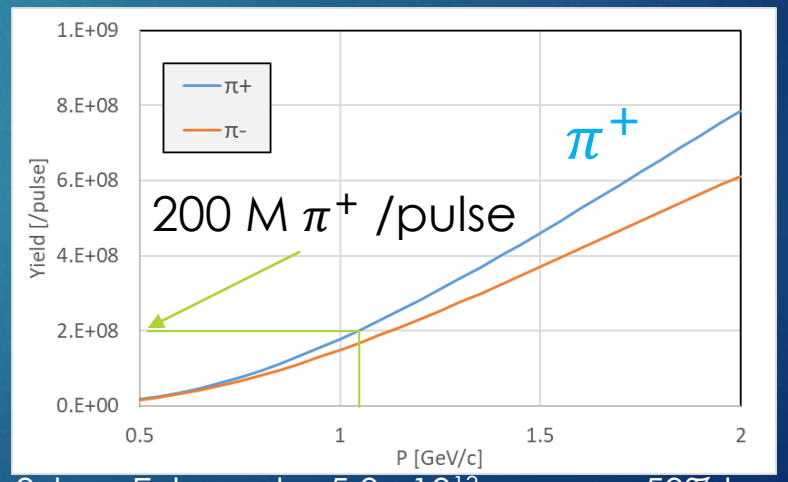
200 x 10^6 pions/pulse, $\Delta p/p$ ~ 1/10000

- High-Intensity High-Resolution Beamline for High Precision (π, K^+) Spectroscopy
  - Momentum dispersion matching

no beam tracking = **NO limit for π rate** from detectors



HR beamline (P_{max} = 2 GeV/c)
+ High Res. Kaon sectrometer

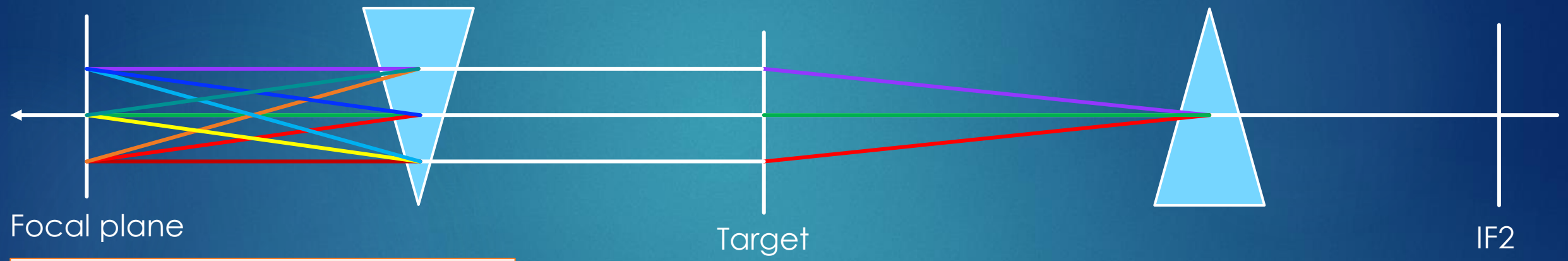


3deg. Ext. angle, 5.0×10^{13} ppp on 50% loss target (T2) 46kW, 5.2s (92kW on T1)
1.4msr%, (From T. Takahashi)

Momentum Dispersion Match

Scattered spectrometer | Reaction | Beam line

$$\begin{pmatrix} x_f \\ \theta_f \\ \delta_f \end{pmatrix} = \begin{pmatrix} s_{11} & s_{12} & s_{16} \\ s_{21} & s_{22} & s_{26} \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} T & 0 & 0 \\ 0 & \theta/\theta_1 + 1 & 0 \\ 0 & 0 & (K\theta + DQ)/\theta_0 + C \end{pmatrix} \begin{pmatrix} b_{11} & b_{12} & b_{16} \\ b_{21} & b_{22} & b_{26} \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_0 \\ \theta_0 \\ \delta_0 \end{pmatrix}$$



Momentum matching condition

$x_f = (s_{11}b_{11}T + s_{12}b_{26})x_0$ -------- total magnification → minimize

$+(s_{11}b_{12}T + s_{12}b_{22})\theta_0$ -------- point-to-point focus → 0

$+(s_{11}b_{16}T + s_{12}b_{26} + s_{16}C)\delta_0$ --- momentum matching → 0

$+(s_{1s} + s_{16}K)\theta$ -------- kinematical correction → 0

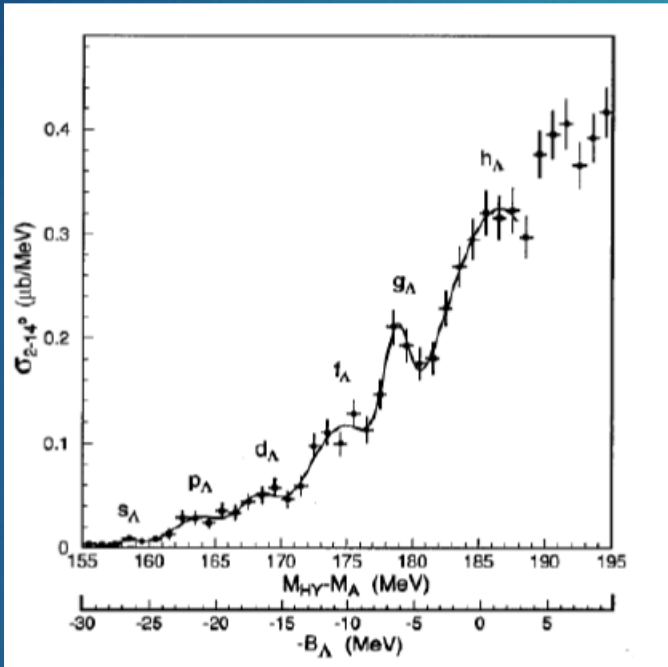
$+s_{16}DQ$ -------- a position shift by the excitation energy

$$\begin{aligned} \theta_1 &= b_{21}x_0 + b_{22}\theta_0 + b_{26}\delta_0, \\ K &= (\partial p_{scat}/\partial\theta)(1/p_{scat}), \\ C &= (\partial p_{scat}/\partial p_{beam})(p_{beam}/p_{scat}), \\ D &= (\partial p_{scat}/\partial Q)(1/p_{scat}). \end{aligned}$$

High precision (π^+,K^+) spectroscopy

^{12}C, ^{6,7}Li, ^{9}Be, ^{10,11}B, ^{28}Si, ^{40}Ca, ^{51}V, ^{89}Y, ^{139}La, ^{208}Pb

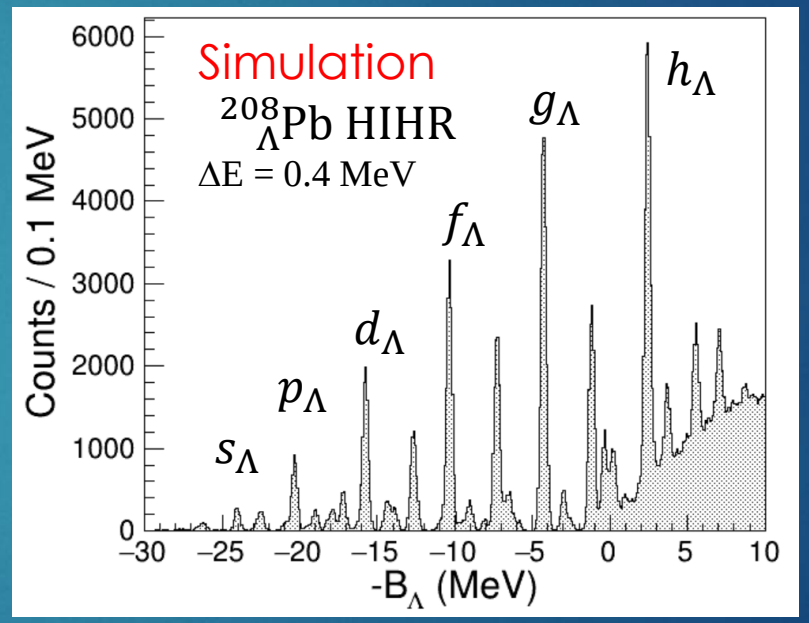
KEK-PS E369 with SKS



60 days × 3M π/spill @ KEK K6

ΔE~2.3 MeV(FWHM)

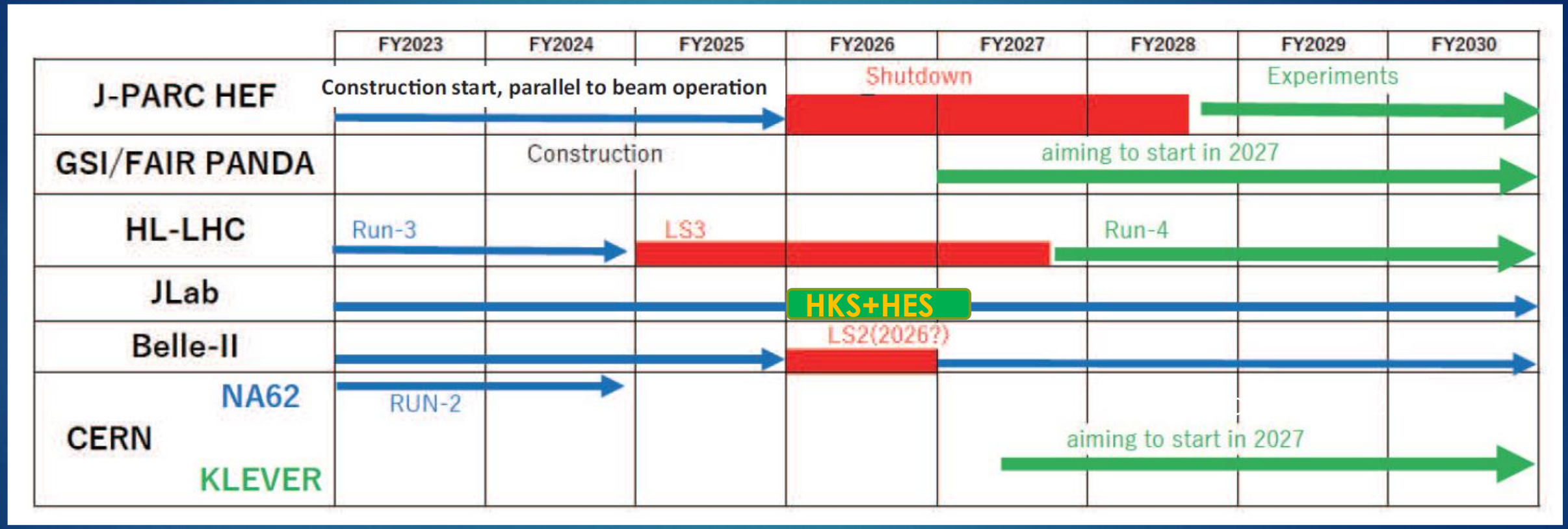
Expected at HIHR beamline



60 days × 200M π/spill @ HIHR

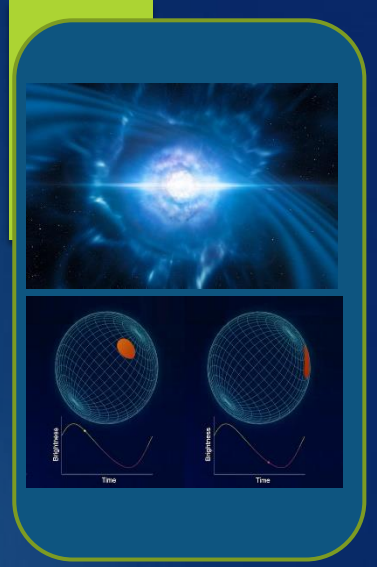
ΔE~**0.4 MeV(FWHM)**

Timelines of acc. facilities in the world



HEF-ex White Paper, ArXiv2110.04462

Current problems of Λ hypernuclei



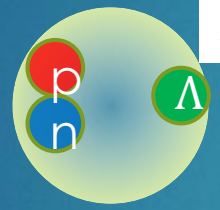
Recent astronomical observations

Hypertriton Puzzle

MAMI

JLab E12-19-002

Shallow bound
Short lifetime



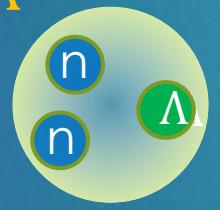
J-PARC

ELPH

$^{3}_{\Lambda}n$ Puzzle

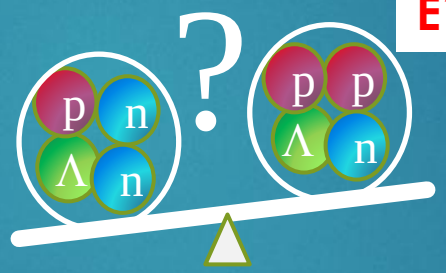
GSI

Bound?
Resonance?
Not Exist?



JLab E12-17-003

CSB of Λ Hypernuclei



JLab E12-15-008 E12-20-013

Hyperon Puzzle

Why massive NS exists?

$A=3$

10^{-15} m

$A\sim10^{57}$

10^{4} m

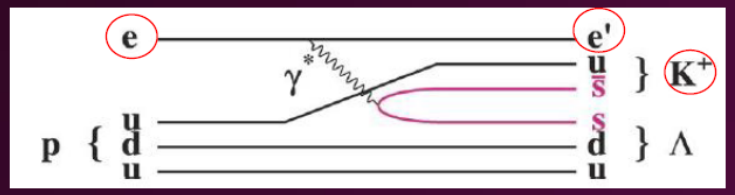
J-PARC HIHR

JLab is unique for HY study

High-quality beam + beamline + Established Spectrometers already exist

Only established reaction spectroscopic study for Λ hypernuclei

(e,e'K⁺) @ JLab

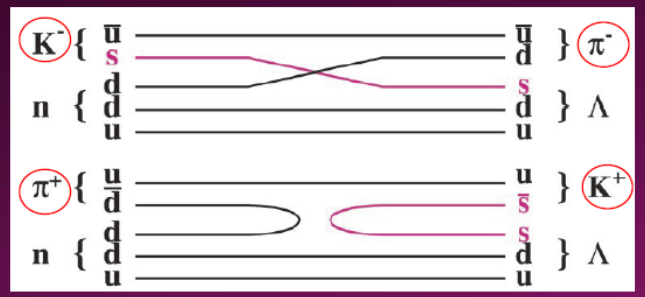


Excellent mass resolution
~ 0.5 MeV(FWHM)

Absolute energy calibration
p(e,e'K⁺) Λ, Σ^0

High Intensity
100 μA = 6×10^{14} /s

Thin target (isotopically enriched)
eg. ^{40,48}Ca, ^{3}H



(K⁻, π⁻)

Intensity limitation
< a few × 10^6 /s

1-2 MeV resolution
Normalized to $^{12}_{\Lambda}$C mass

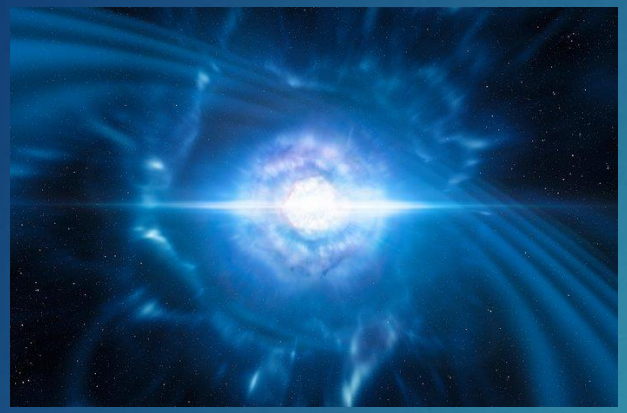
(π⁺, K⁺)

HIHR@J-PARC HD. Ex

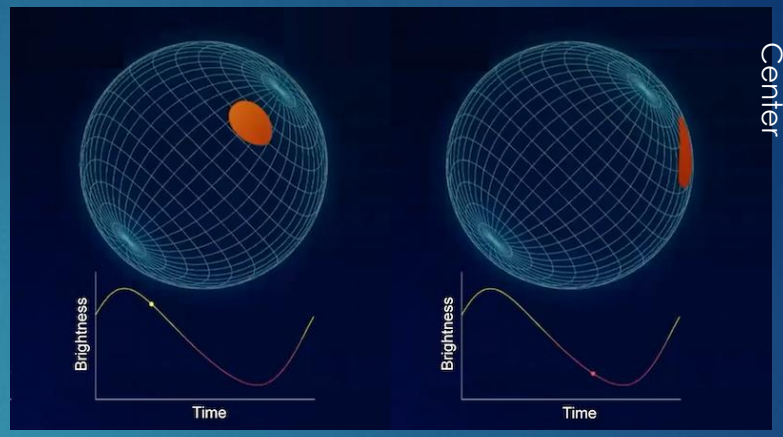
Excellent mass resolution
< 0.4 MeV
Thin target (isotopically enriched)
No limitation for beam intensity

$(e, e'K^+)$

New Astronomical Observations of Neutron Stars



Gravitation Wave from neutron star mergers
LIGO/Virgo PRL **119**, 161101 (2017)

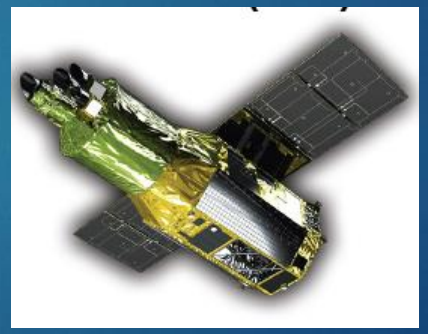


Goddard Space Flight Center

NICER : NS x-ray hot spot measurement
Physics 14, 64 (Apr. 29, 2021)

Great progresses
Macroscopic features of NS

Microscopic understanding
becomes more important!

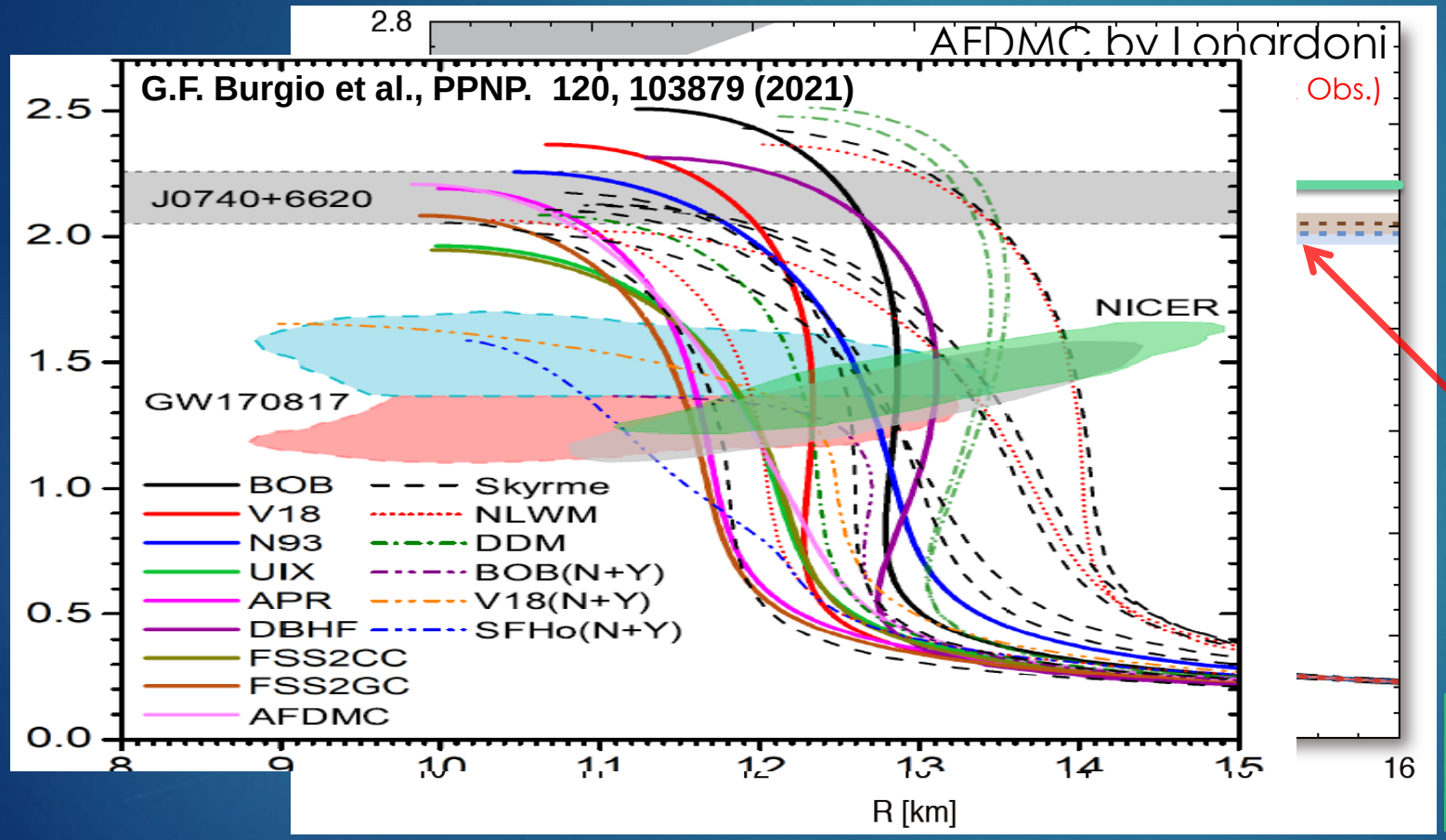


X-Ray Imaging and Spectroscopy Mission (XRISM) will launch in JFY 2023.

Hyperon Puzzle

Based on our knowledge on Baryonic Force:

Hyperon naturally appear at high density ($\rho=2\sim3\rho_0$)



Too Soft EOS

Contradict to observation

2 $M_\odot$ Neutron Stars

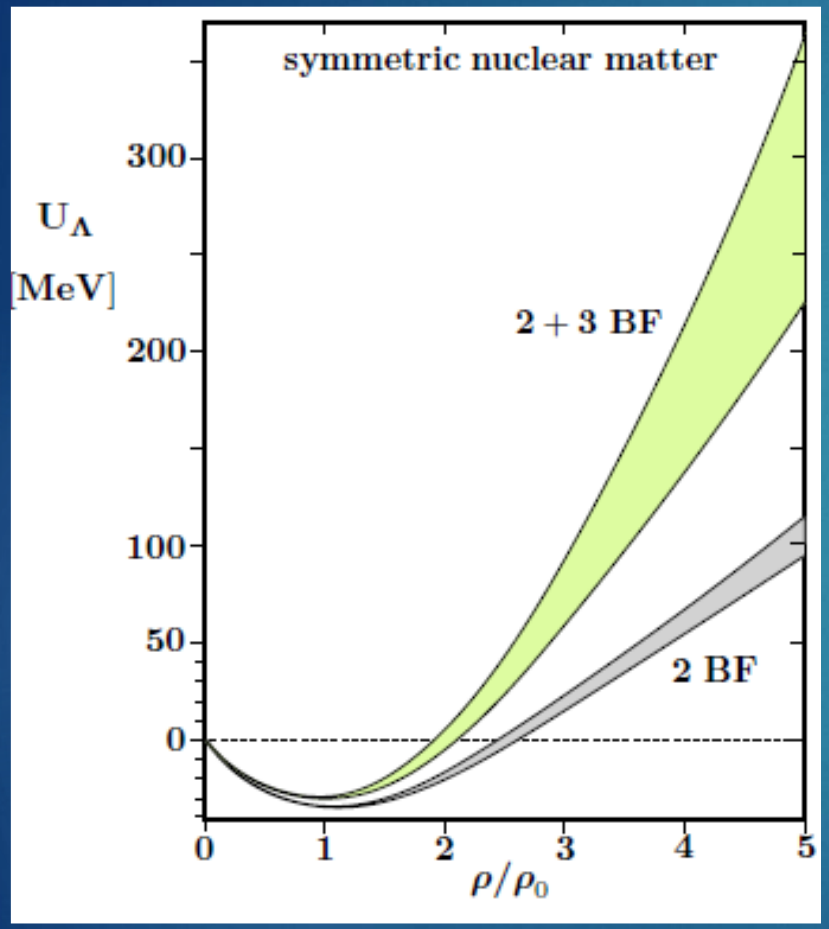
Additional Force to make EOS stiff

AFDMC by Lonardoni et al. PRL114 (2015) 092301, updated (2016)

ESC08c + 3B/4B RF : G-Matrix Calc. by Yamamoto et al., PRC 90 (2014) 045805.

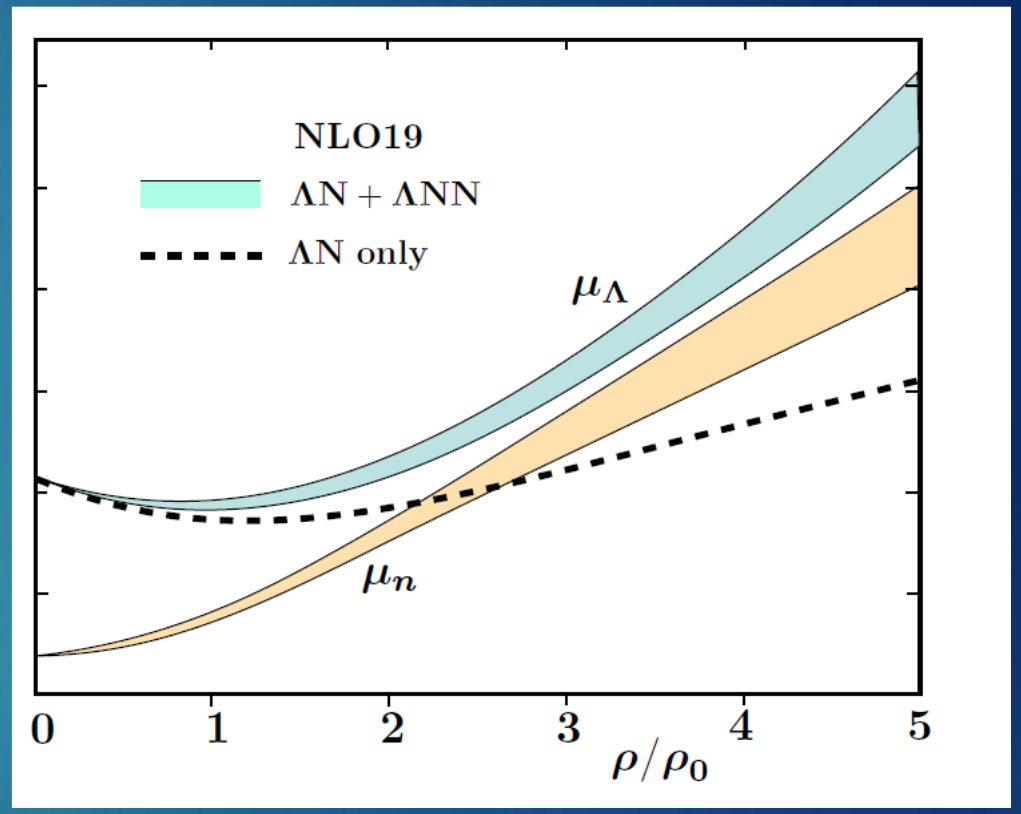
Variational Meth. + AV18+UIX by Togashi et al., PRC 93 (2016) 035808

3BF recovers stiffness



With 3BRF recover stiffness

With Hyperon too Soft

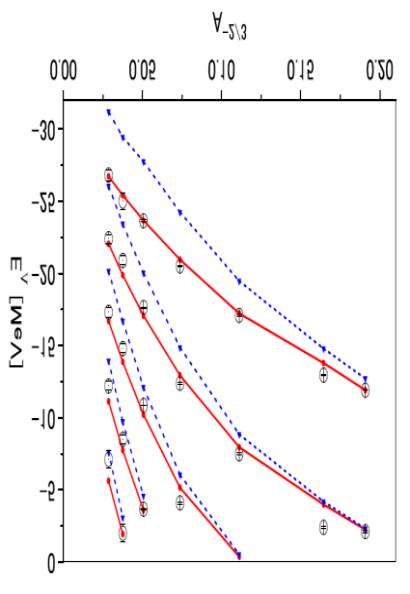


D.Gerstung et al., Eur. Phys. J. A (2020) 56:175; W. Weise EPJ Web. Of Conf. 271, 06003 (2022)

ChEFT(NLO: Saturation Decuplet)+Brueckner-Bethe-Goldstone eq.+ΛN-ΣN,ΛNN-ΣNN coupled channels

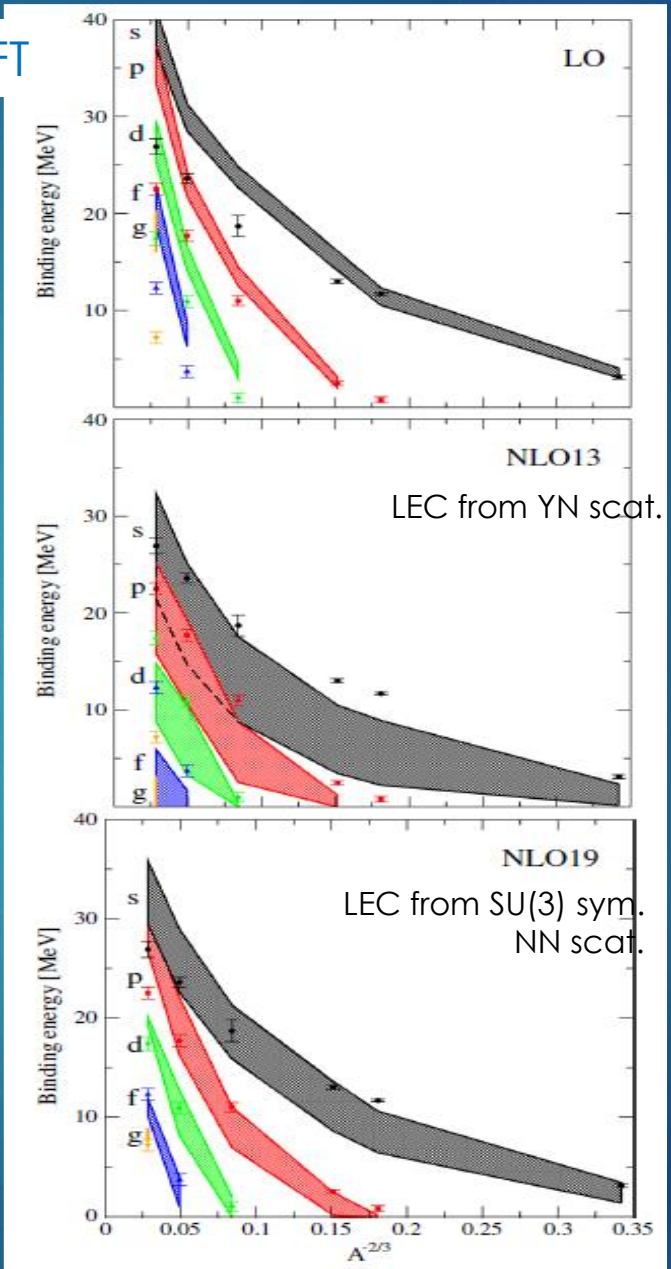
Λ Single Particle Energies of Λ Hypernuclei by Various Calculations

M.M. Nagels et al., PRC 99 (2019) 044003.

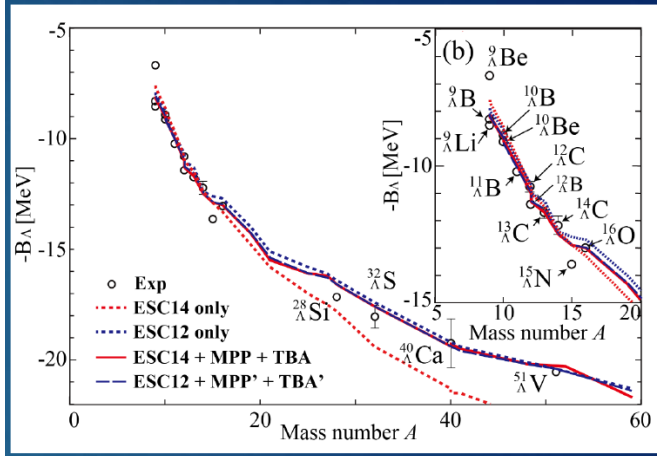


ESC16
ESC16+ (Inc. 3BF)
G-matrix

ChEFT

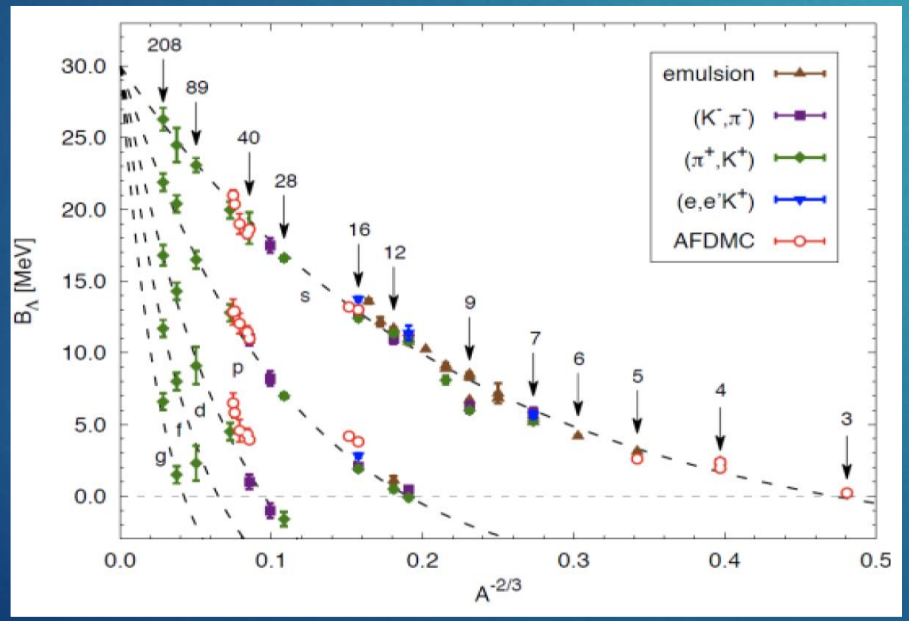


Hyper-AMD



M.Isaka et al., PRC94, 044310 (2016), PRC 95, 044308 (2017)

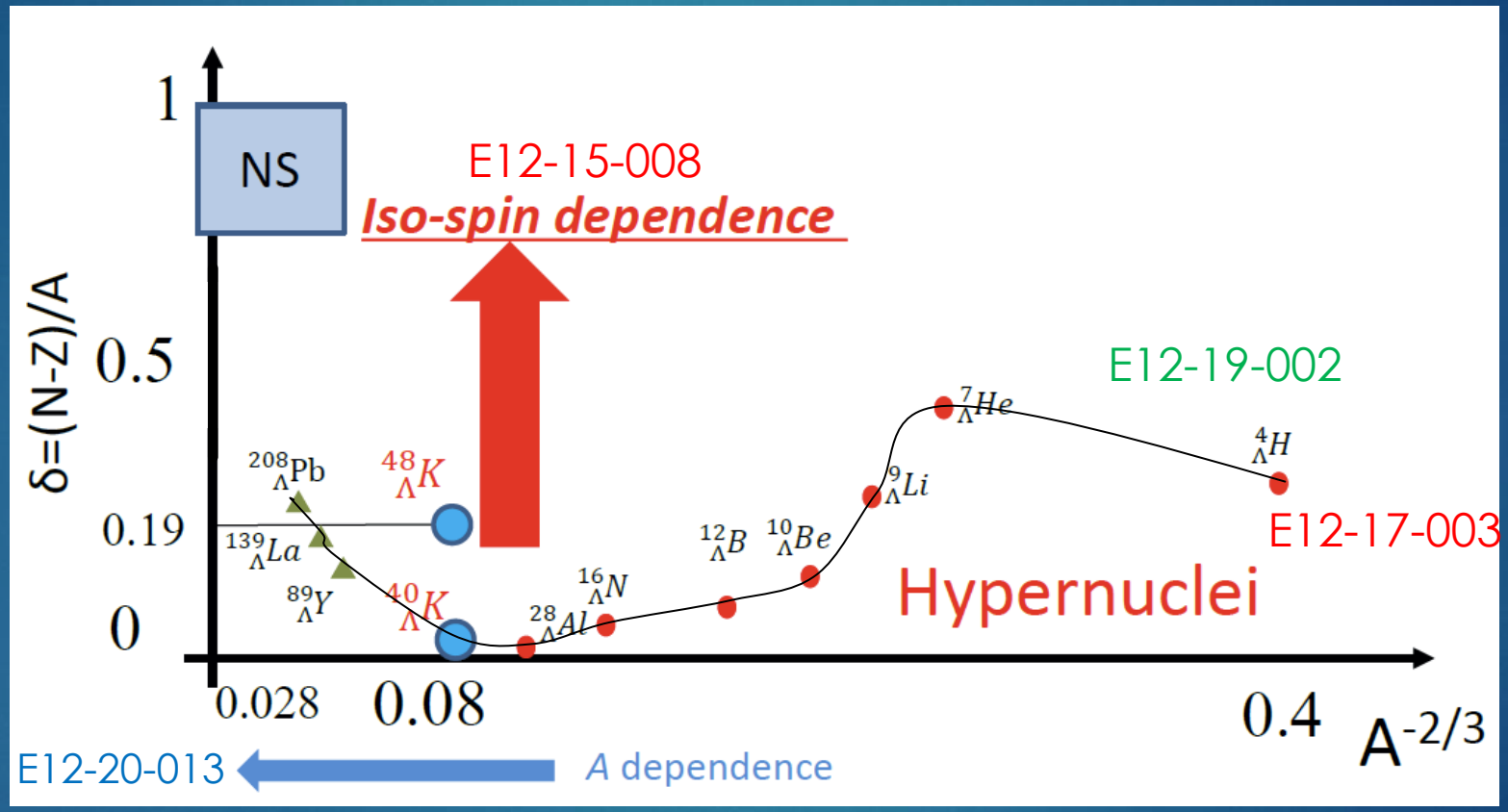
AFDMC



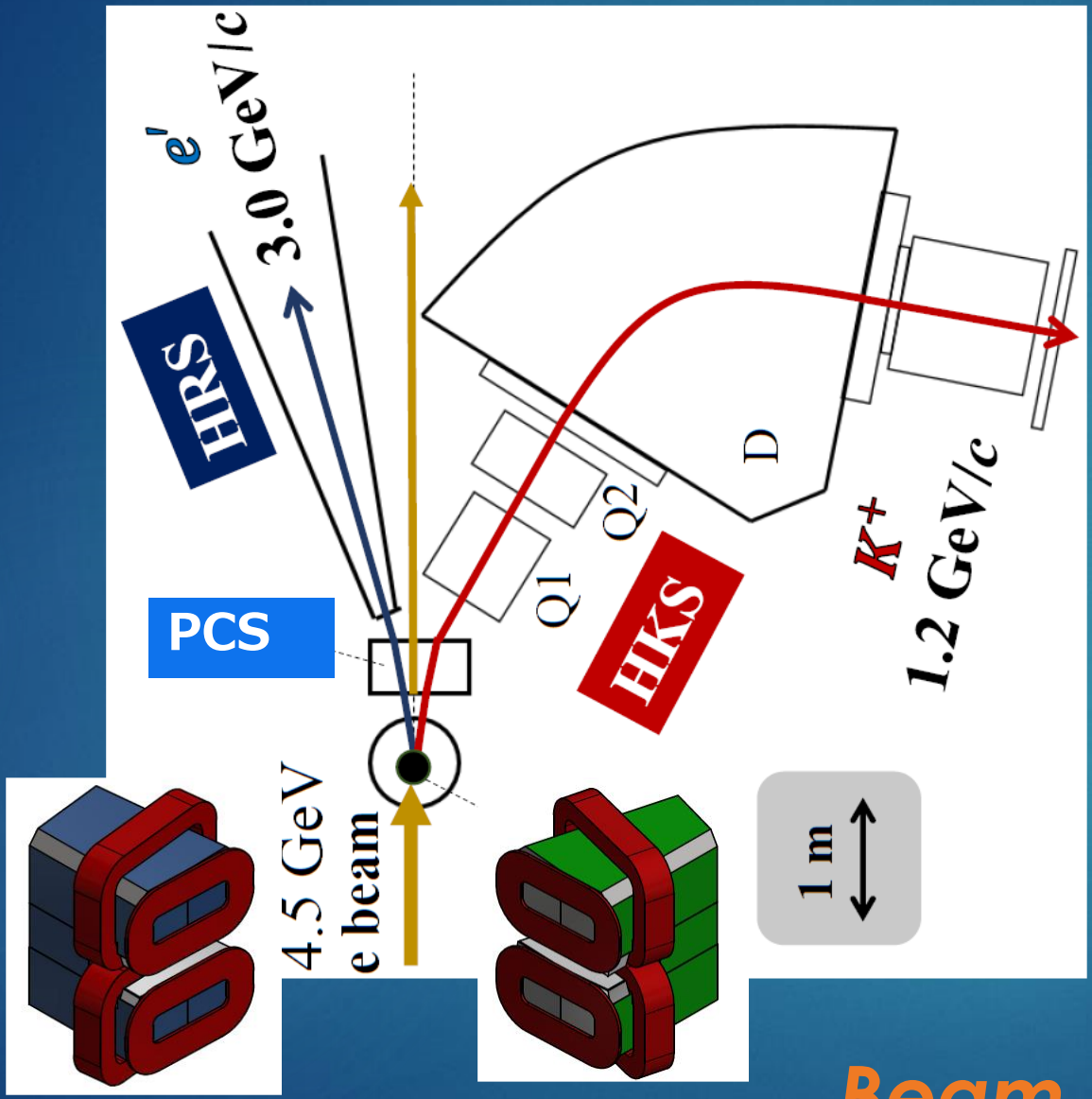
D.Lonardoni and F. Pederiva, arXiv:1711.07521.

J.Haidenbauer, I.Vidana, EPJA (2020) 56:55.

From Hypernuclei to NS



Original setup in Hall-A

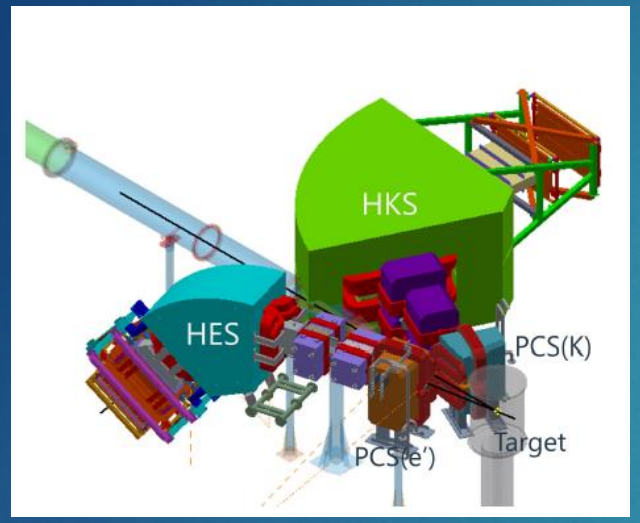


New Pair Charge Sep. Mag.
^{40,48}Ca, ^{208}Pb, Cryogenic-gas ^{3,4}He
with calibration targets

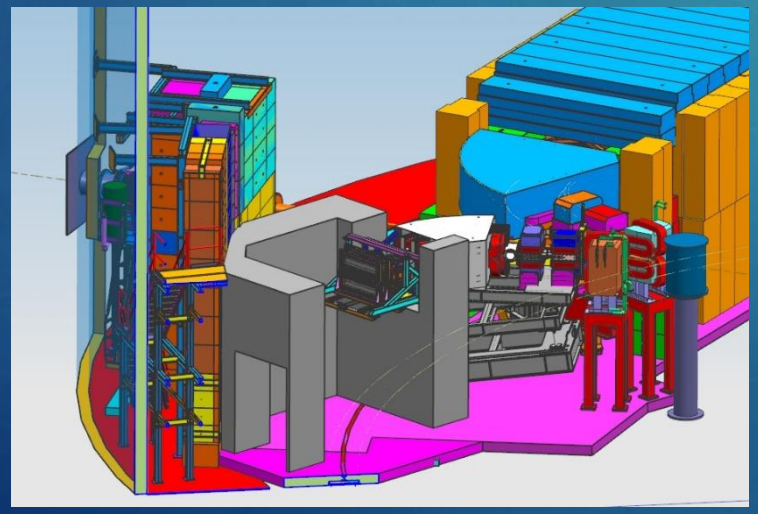
Beam availability issue in Hall-A

Move to Hall-C

V-HES option



H-HES option



Investigation of the strangeness baryon interaction by Λ hypernuclear spectroscopy

A pre-document for the experimental readiness review of E12-15-008, E12-19-002, and E12-20-013.

by

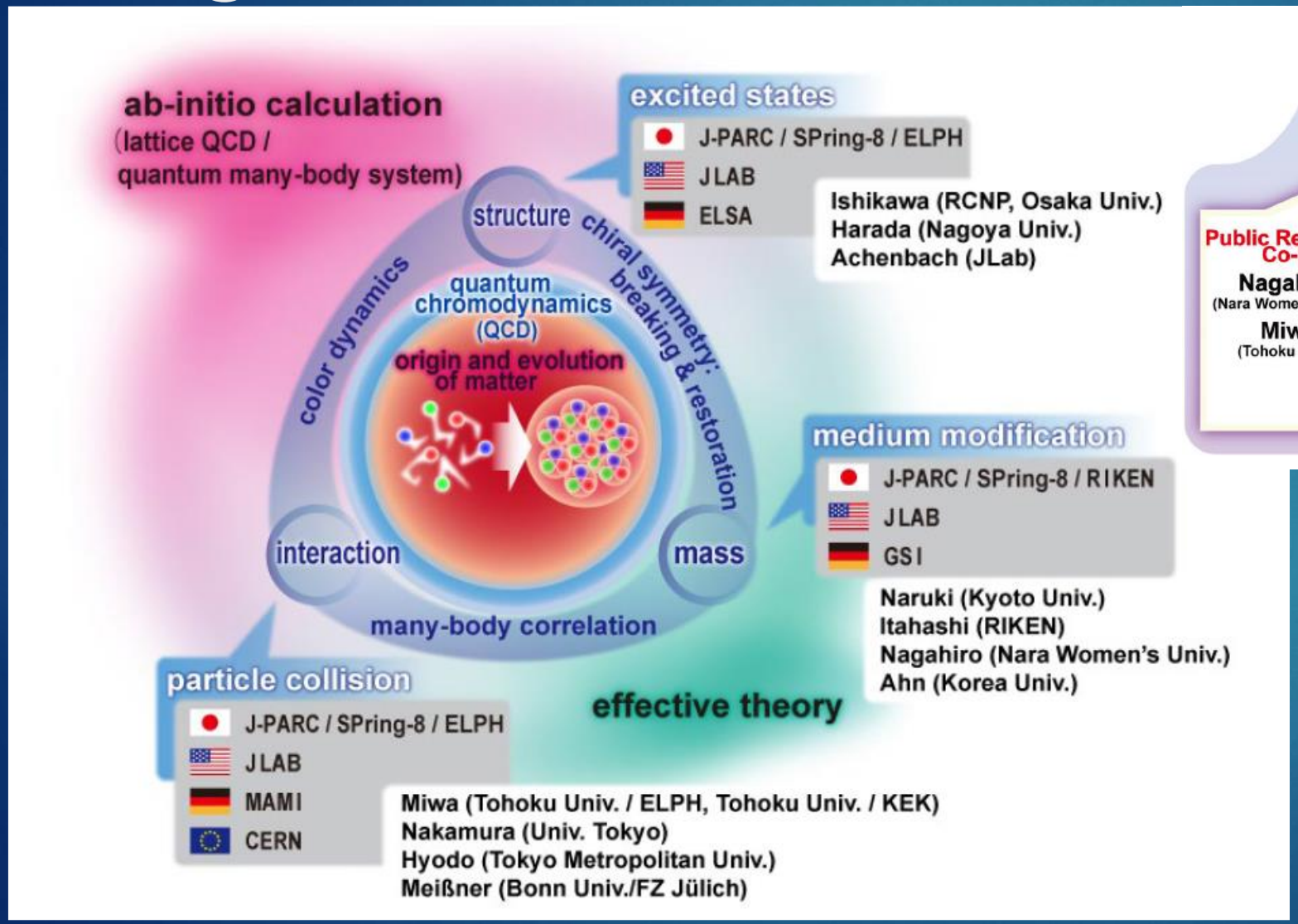
F. Garibaldi, T. Gogami, P. Markowitz, S. Nagao, S. N. Nakamura, J. Reinhold, L. Tang, G. M. Urciuoli

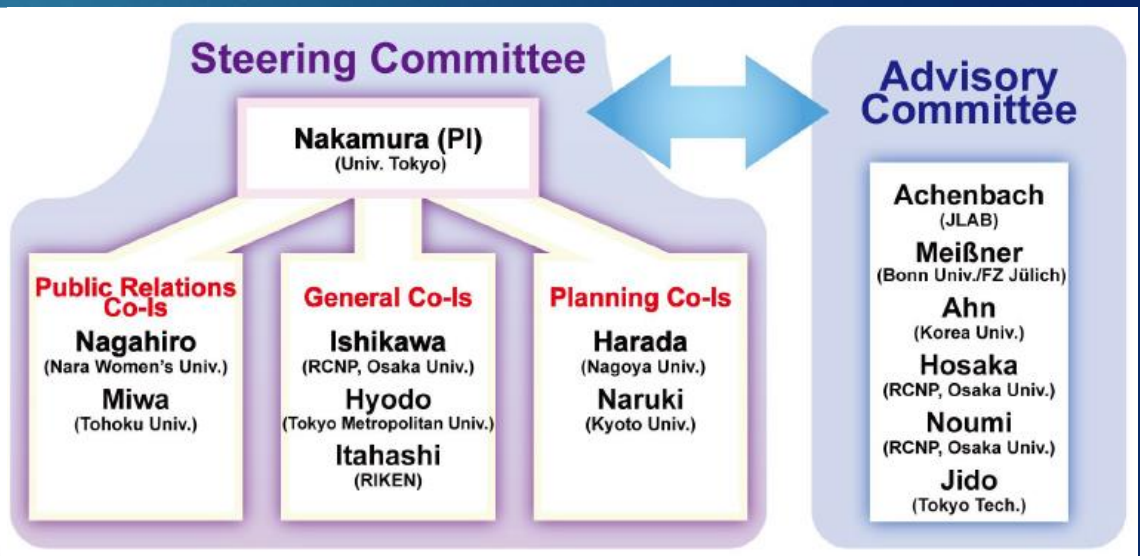
on behalf of JLab Hypernuclear Collaboration

This document is submitted to JLab for official request of supports by the JLab Hypernuclear Collaboration
November 13, 2022

⇒ **Ishige's talk**

A new proposal for elucidating the origin and evolution of matters





From the **proposal** of International Leading Research,
International platform for the next generation research with young scientists in nuclear and hadron physics (2023)

Summary

It is time to back to normal after COVID-19 pandemic.

Hypernuclear physics is now more important than previous.

We will have next hypernuclear experiments in Hall-C with the new HKS-HES-PCS configuration.