J-PARC

Japan Proton Accelerator Research Complex

J-PARC Hadron Hall Extension Project

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on behalf of HEF-ex TF

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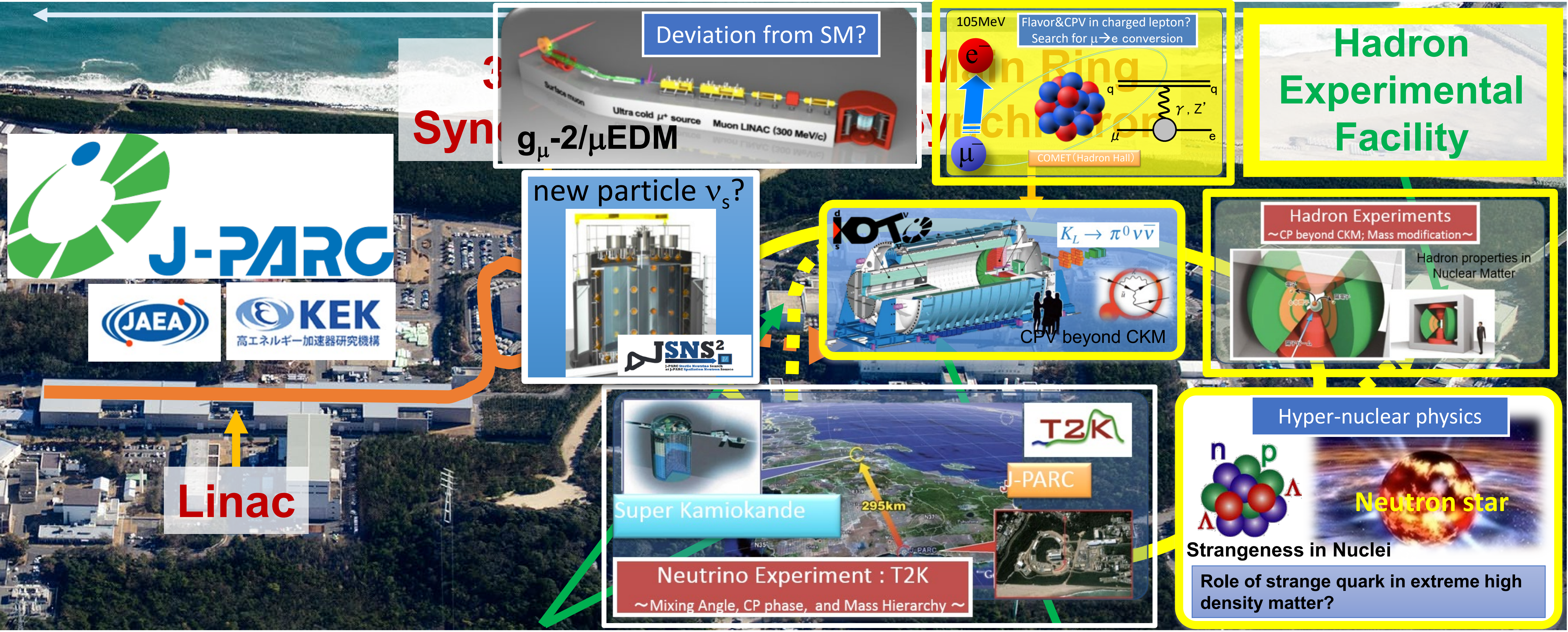
Hadron in Nucleus 2025 (HIN25), 2–4 Apri., 2025, Kyoto

Particle and Nuclear Physics @ J-PARC



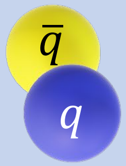
Neutrino Experimental Facility

Material and Life Science Experimental Facility

Origin & Evolution of Matter

Matter-Antimatter Symmetry

matter dominated universe



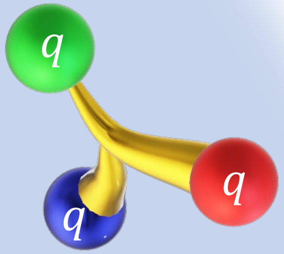
Flavor Physics

CP violation
weak interaction
→ new physics

Kaon rare decays
μ→e conversion

Origin of Matter Creation

formation of hadrons from quarks



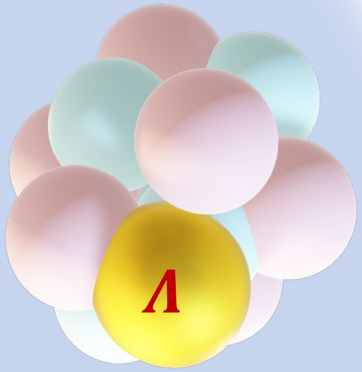
Hadron Physics

quark interactions
hadron mass-generation mechanism

Hadron spectroscopy
Meson in nuclei

Matter in Extreme Conditions

dense matter in neutron stars



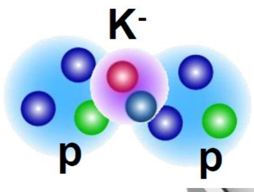
Strangeness Nuclear Physics

hadron interactions
hadronic many-body systems

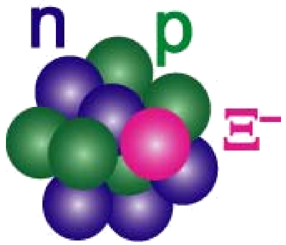
Hyperon-Nucleon scattering
Hypernuclear spectroscopy

Present Hadron Experimental Facility (HEF)

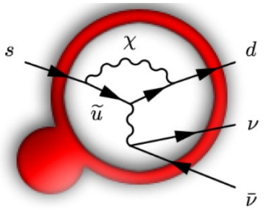
- < 1.1 GeV/c
- ~ 5x10^5 K$^-$/spill
- **Kaon in nuclei**

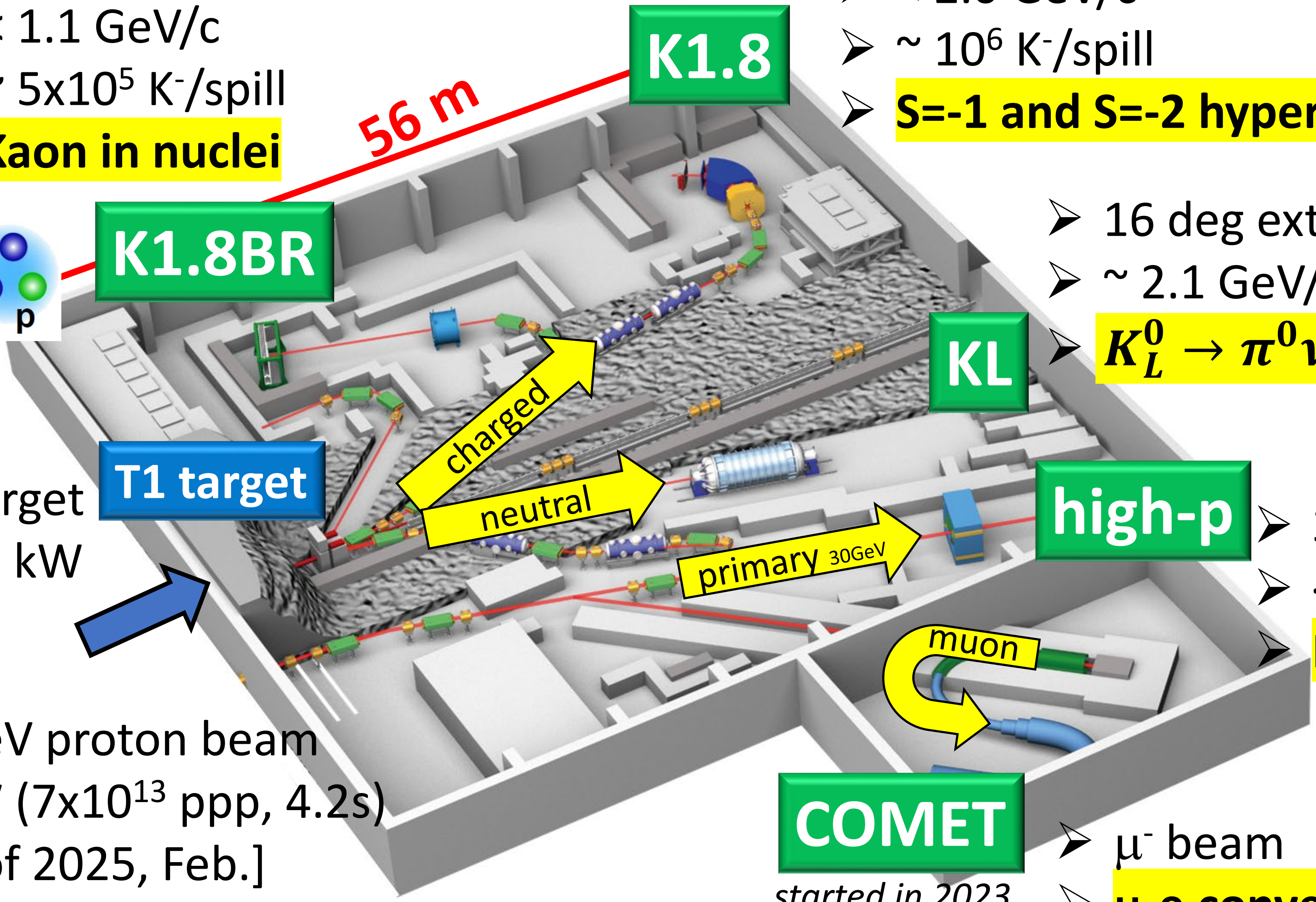


- < 2.0 GeV/c
- ~ 10^6 K$^-$/spill
- **S=-1 and S=-2 hypernuclei**



- 16 deg extraction
- ~ 2.1 GeV/c ~ 10^7 K^0_L/spill
- $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$

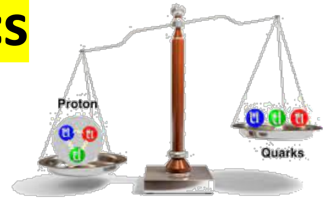




- Au Target
- < 115 kW

launched in 2020

- 30 GeV proton ~ 10^{10}
- < 31 GeV/c unsepa. π ~ 10^7
- **Hadron physics**



- 30 GeV proton beam
- 84kW (7x10^{13} ppp, 4.2s)
  [as of 2025, Feb.]

started in 2023

- μ$^-$ beam
- **μ-e conversion**

Achievements in research at the Hadron Experimental Facility

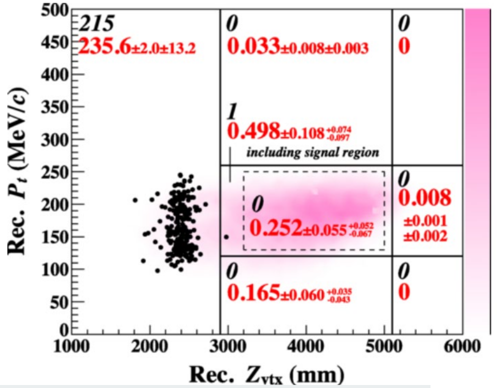
Flavor Physics

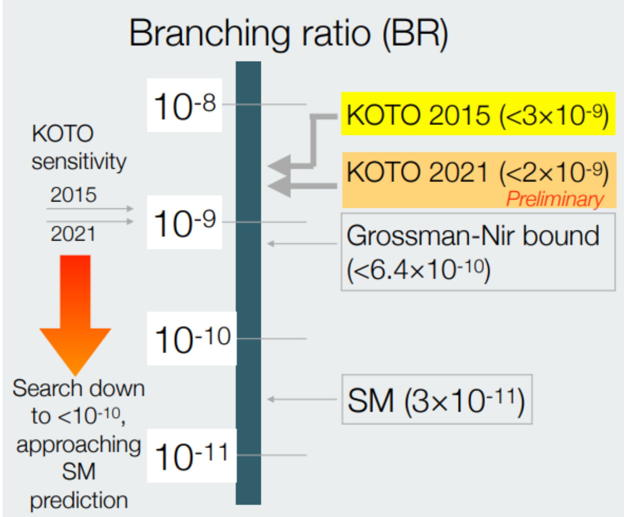
$K_L^0 \to \pi^0 \nu \bar{\nu}$ search @ KOTO

→ **Approaching the SM sensitivity for CP violation**

KOTO 2021

Single Event Sensitivity = 9×10^{-10}



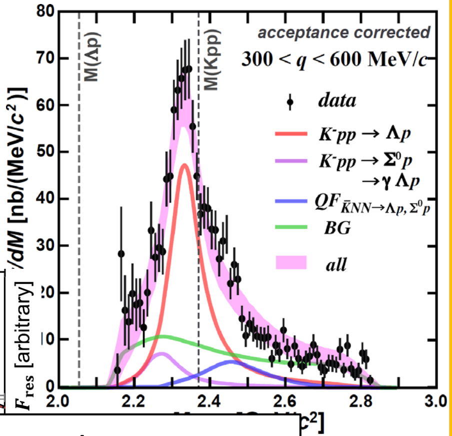


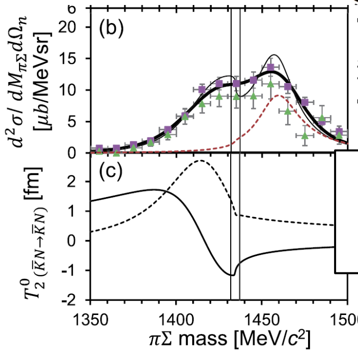
Hadron Physics

Observation of an exotic hadron bound system including K^- meson

→ **Established a new direction to understand meson-baryon int.**

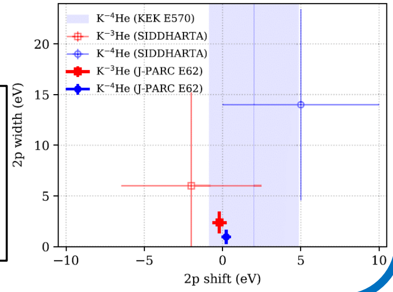
Kaonic nuclear state, "K-pp"





Pole position of $\Lambda(1405)$

Ultra-precise measurement of kaonic atoms

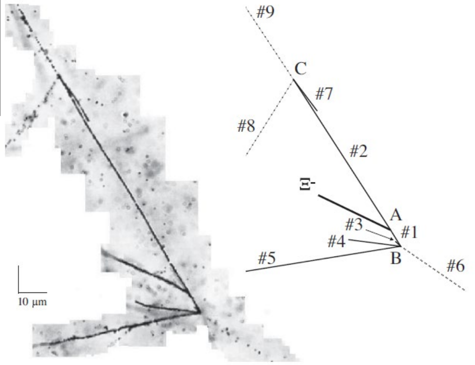


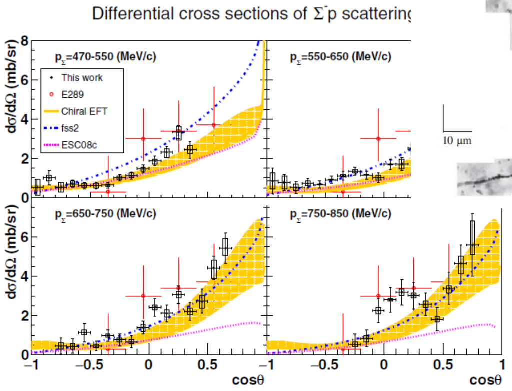
Strangeness Nuclear Physics

A lot of progress in hypernuclear research

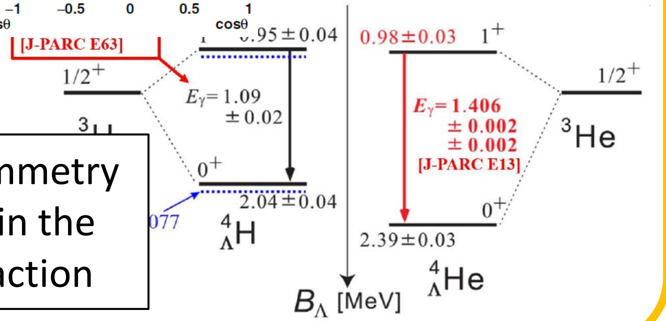
→ **Clarified attractive S=−2 ΞN interaction and deepened S=−1 ΛN, ΣN interactions**

Observation of Ξ hypernuclei





First precise ΣN scattering



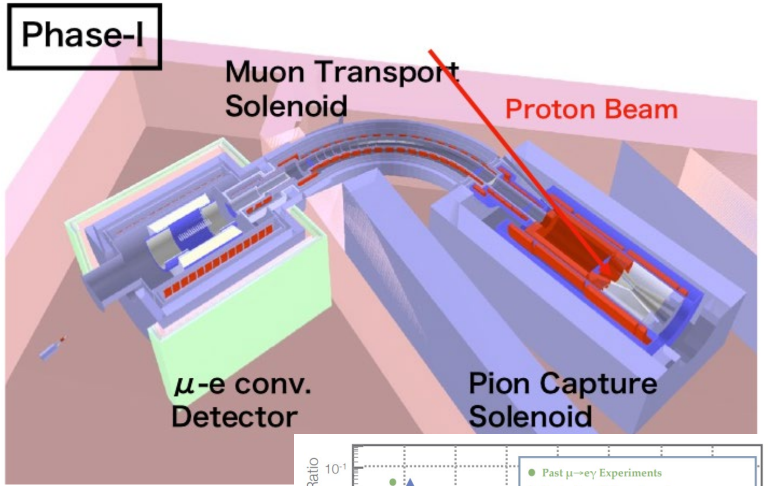
Charge-symmetry breaking in the ΛN interaction

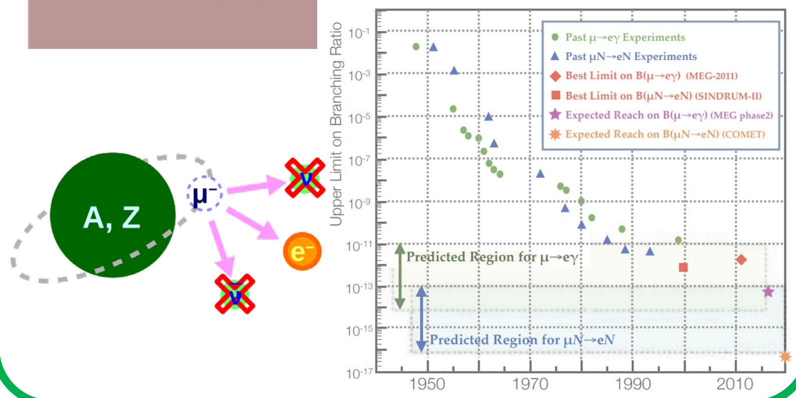
Further research directions at the Hadron Experimental Facility

Flavor Physics

Search for μ→e conversion @ COMET (2023~)

→ **Search for charged lepton flavor violation**

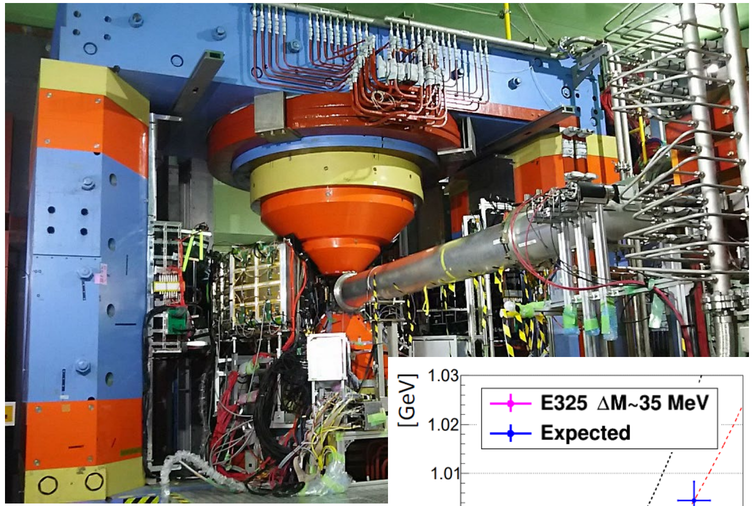


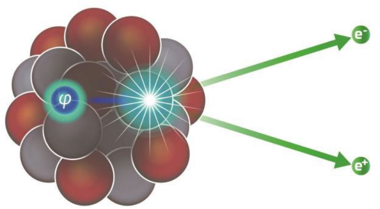


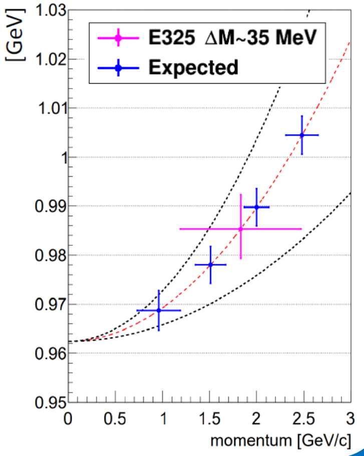
Hadron Physics

Measurement of spectral modification of ϕ meson in nuclei (2020~)

→ **Attack mass-generation mechanism of hadrons**



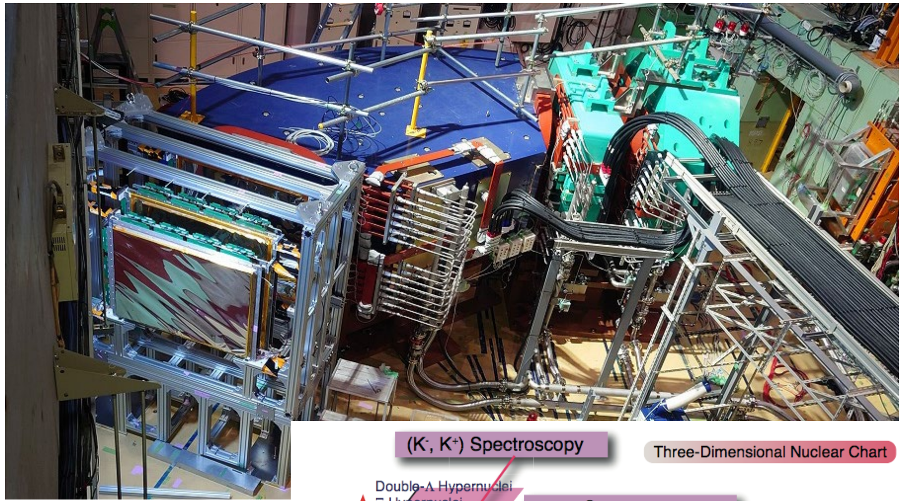


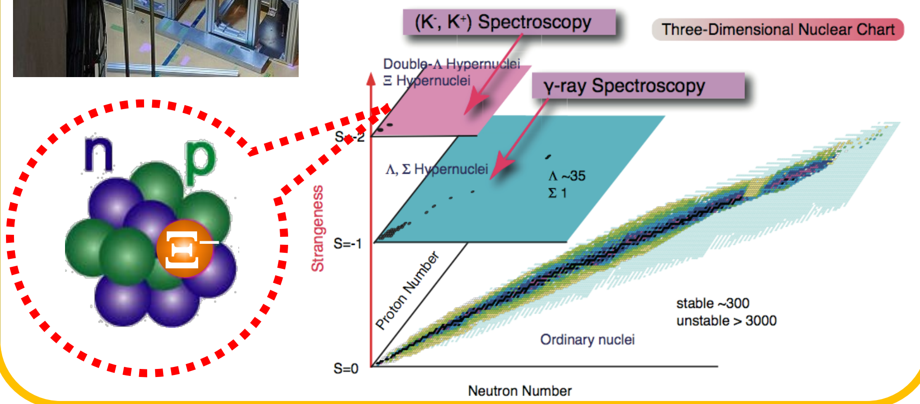


Strangeness Nuclear Physics

High-resolution spectroscopic study of S=–2 Ξ-hypernuclei (2023~)

→ **Provide accurate and systematic information on ΞN, ΛΛ interactions**



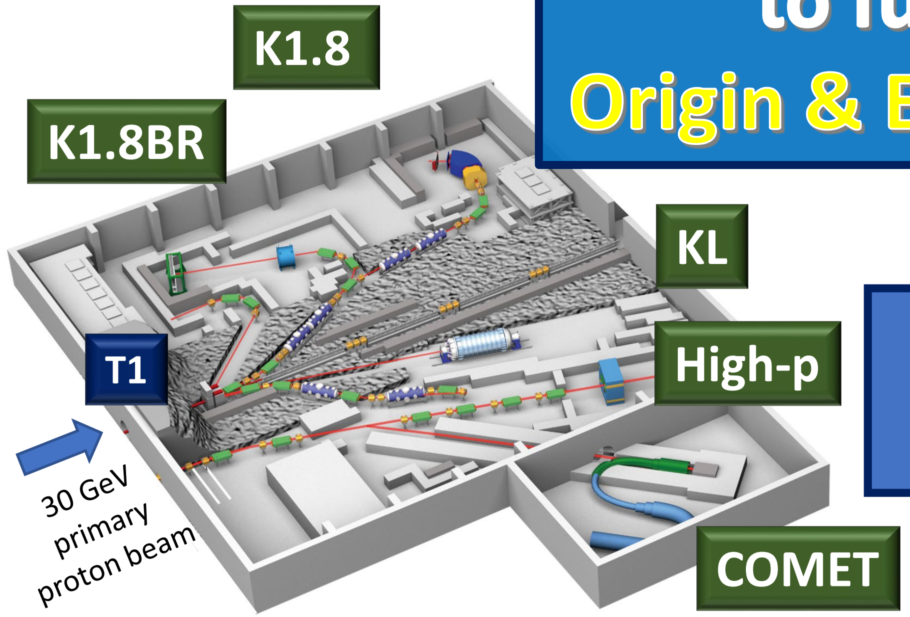


Hadron Experimental Facility eXtension (HEF-ex) Project

Hadron Experimental Facility extension (HEF-ex) Project

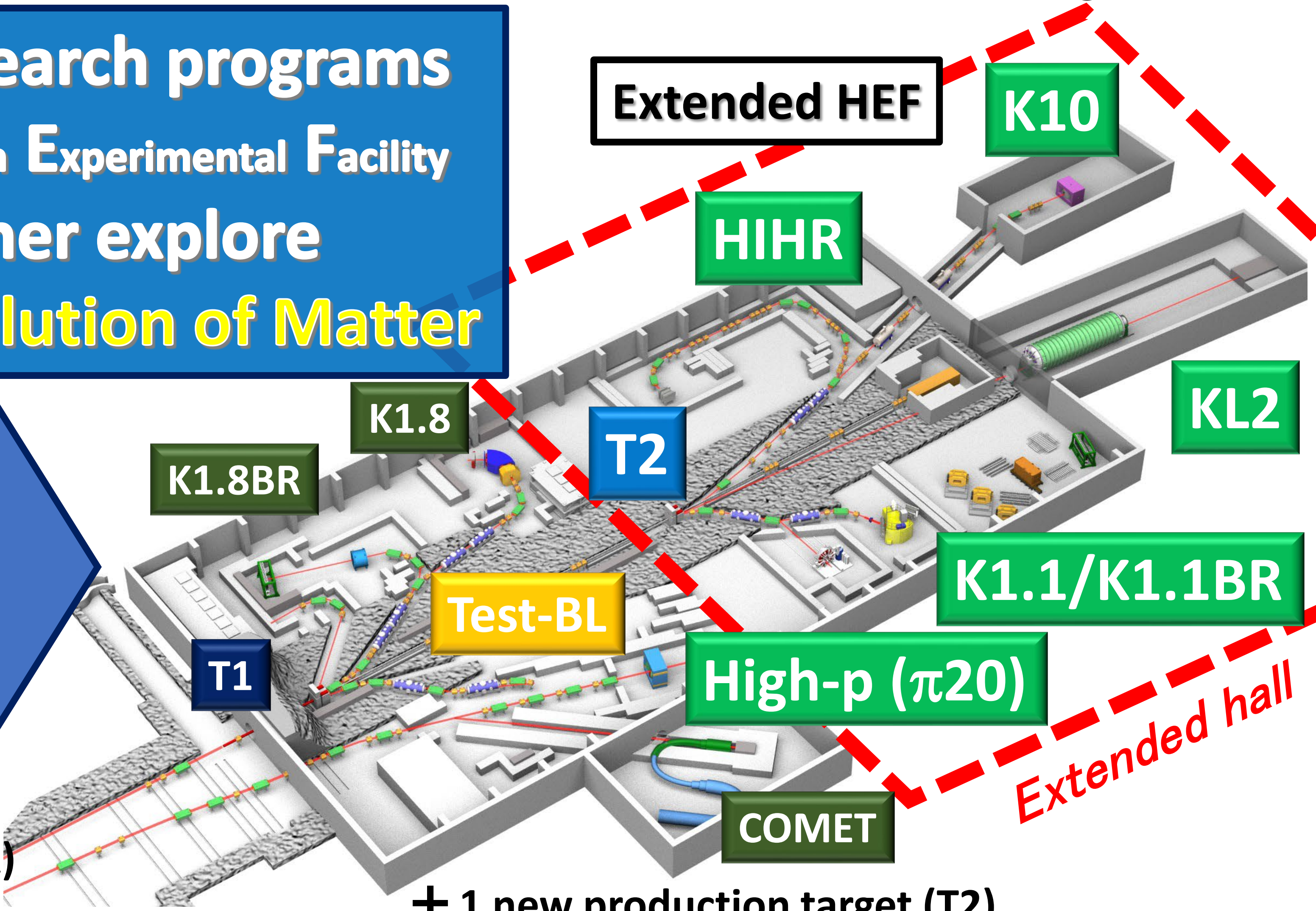
expand research programs at the Hadron Experimental Facility to further explore Origin & Evolution of Matter

Present HEF (2009～)



1 production target (T1)
1 secondary-charged beamline (K1.8/K1.8BR)
1 neutral beamline (KL)
1 primary beamline (High-p)
1 muon beamline (COMET)

Extended HEF



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

Expanded Research Programs

at the Extended Facility

Extract density dependent ΛN interaction

HIHR **Ultra-high-resolution Λ hypernuclei spectroscopy**
- intense dispersion matched π beam

K1.1 **Systematic ΛN scattering measurement**
- intense polarized Λ beam

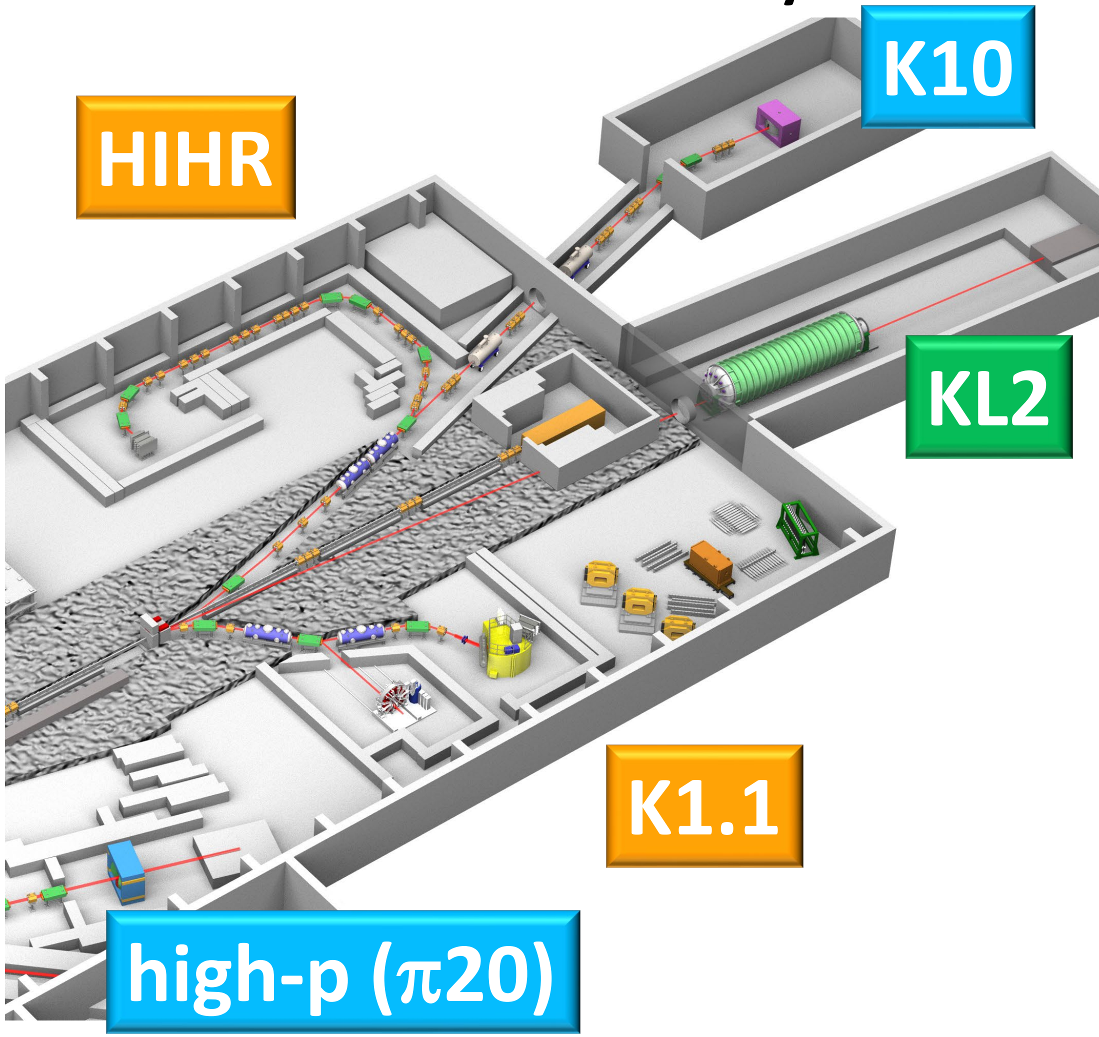
Investigate diquarks in baryons

high-p (π20) **High-resolution charm baryon spectroscopy**
- intense high-momentum π beam

K10 **High-resolution multi-strange baryon spectroscopy**
- intense high-momentum separated K beam

Search for new physics beyond the SM

KL2 **Most sensitive $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ measurement**
- intense neutral K beam



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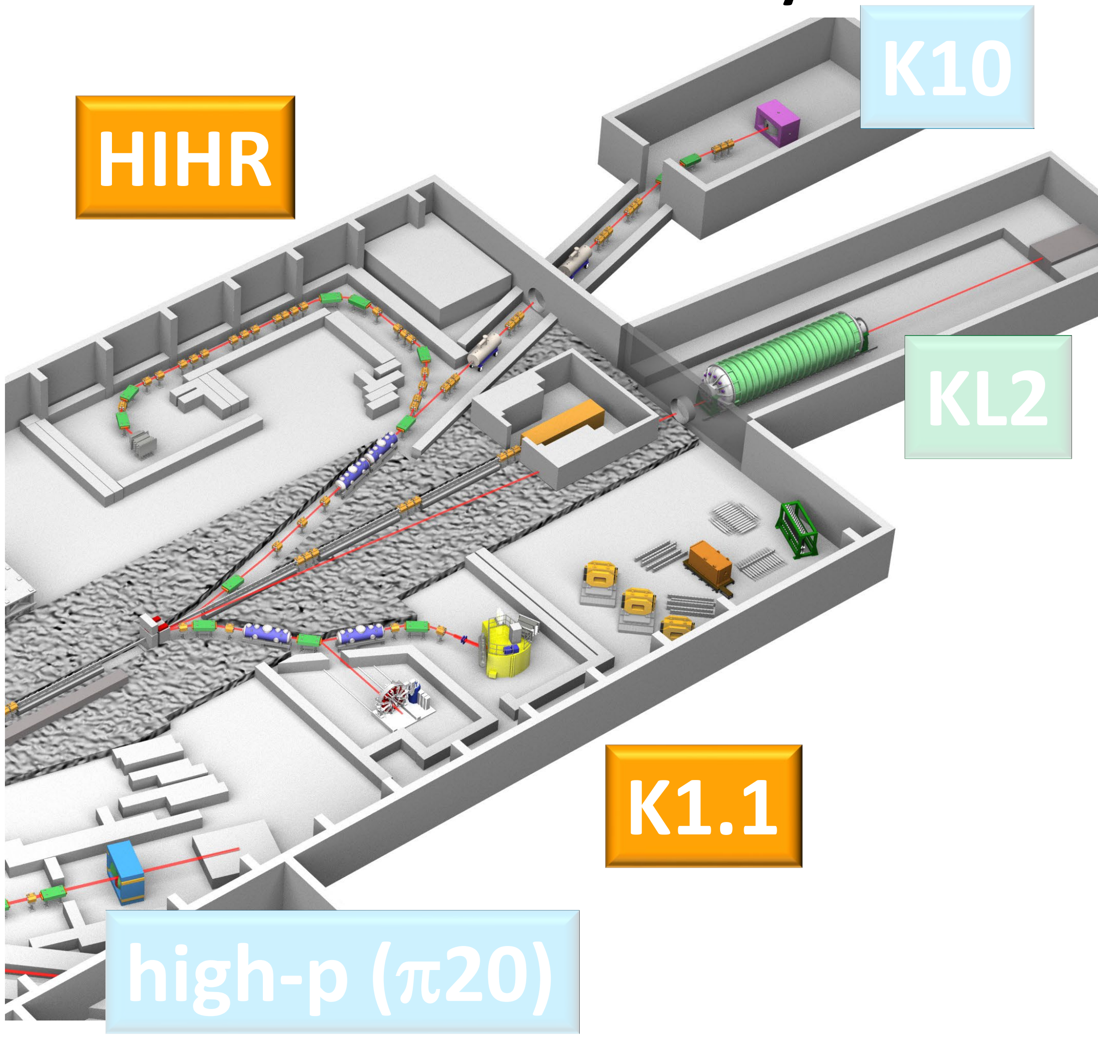
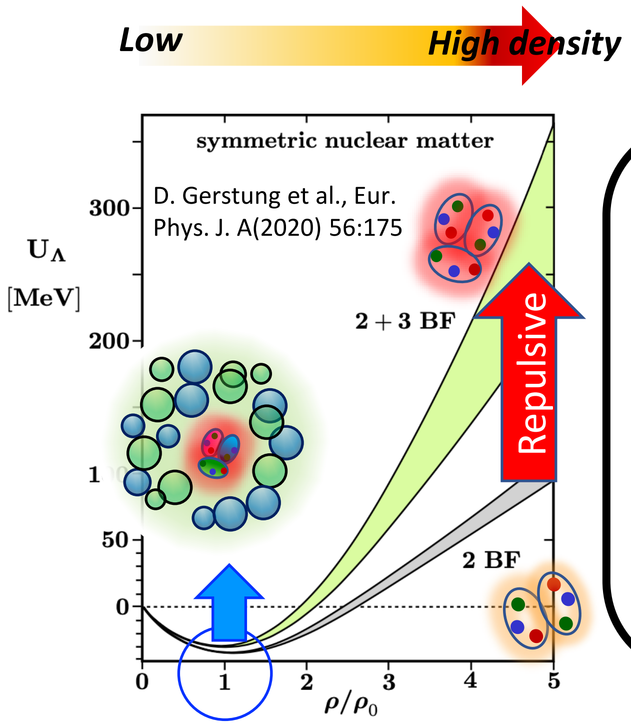


Strangeness Nuclear Physics: Hyperon in Dense Environment

Why can heavy neutron stars exist?

- **Hyperons (Λ, Ξ, ...) emerge in dense neutron star matter?**

ΛNN 3 Baryon Force is a key



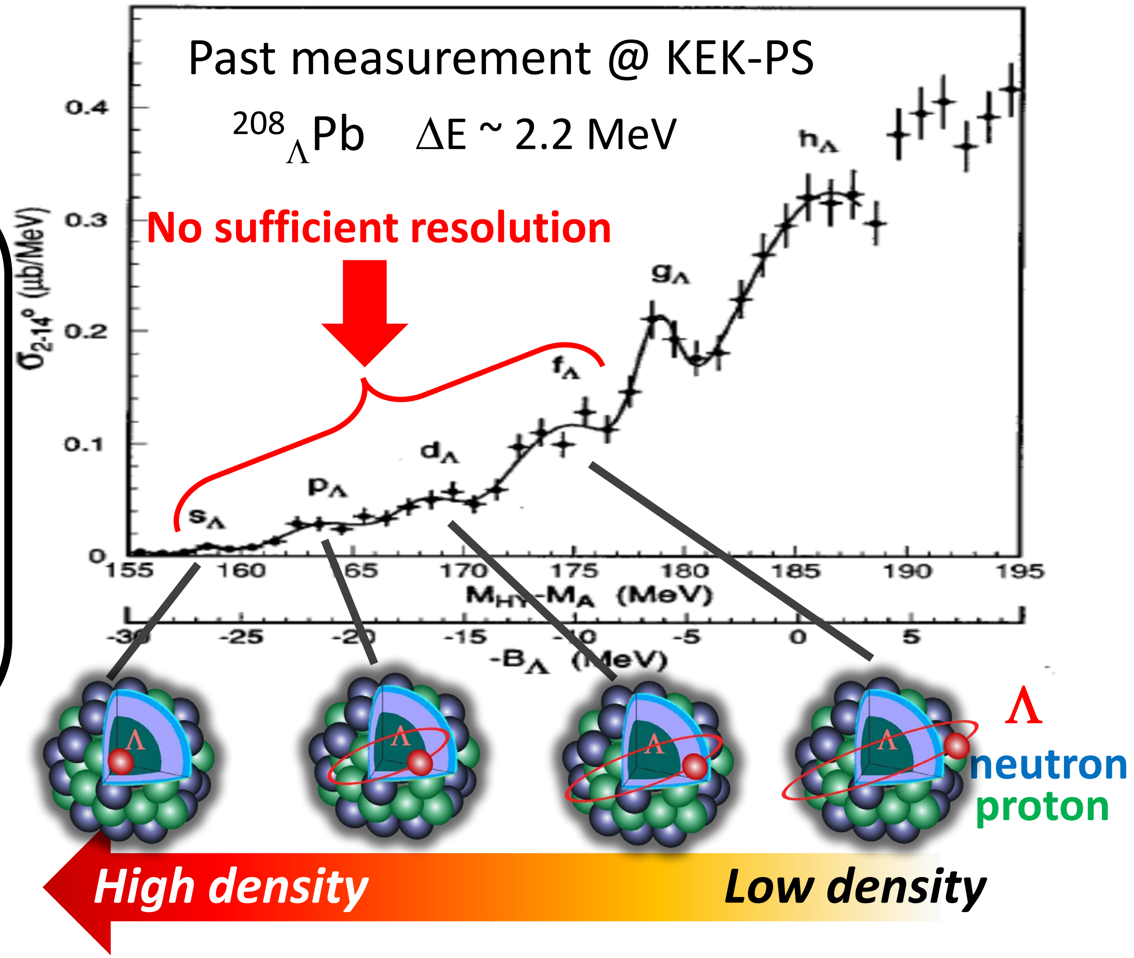
We need to determine
a tiny fraction of 3 Baryon Force effects

heavy Λ-hypernuclei :

Λ binding energies (B_Λ)

→ density dependent ΛN interaction

→ We need precise measurements



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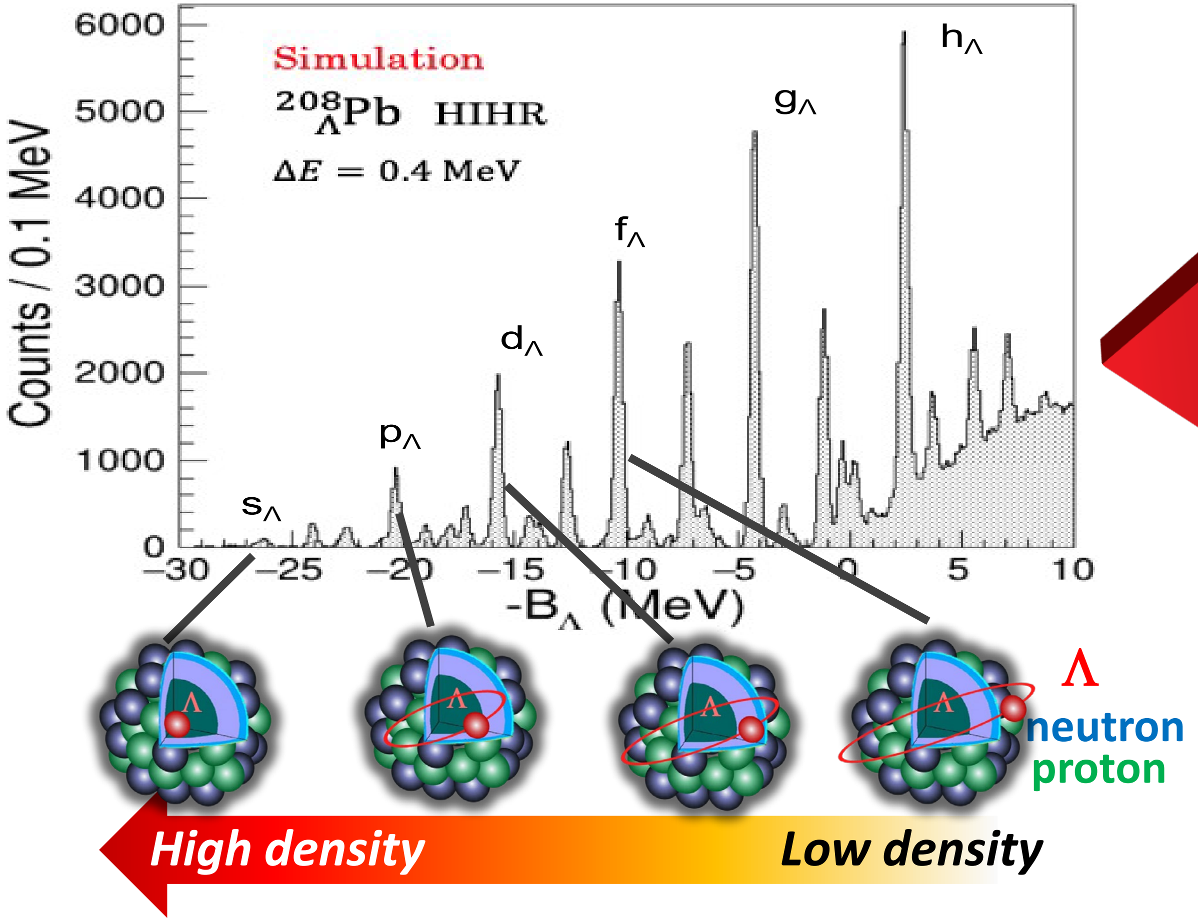
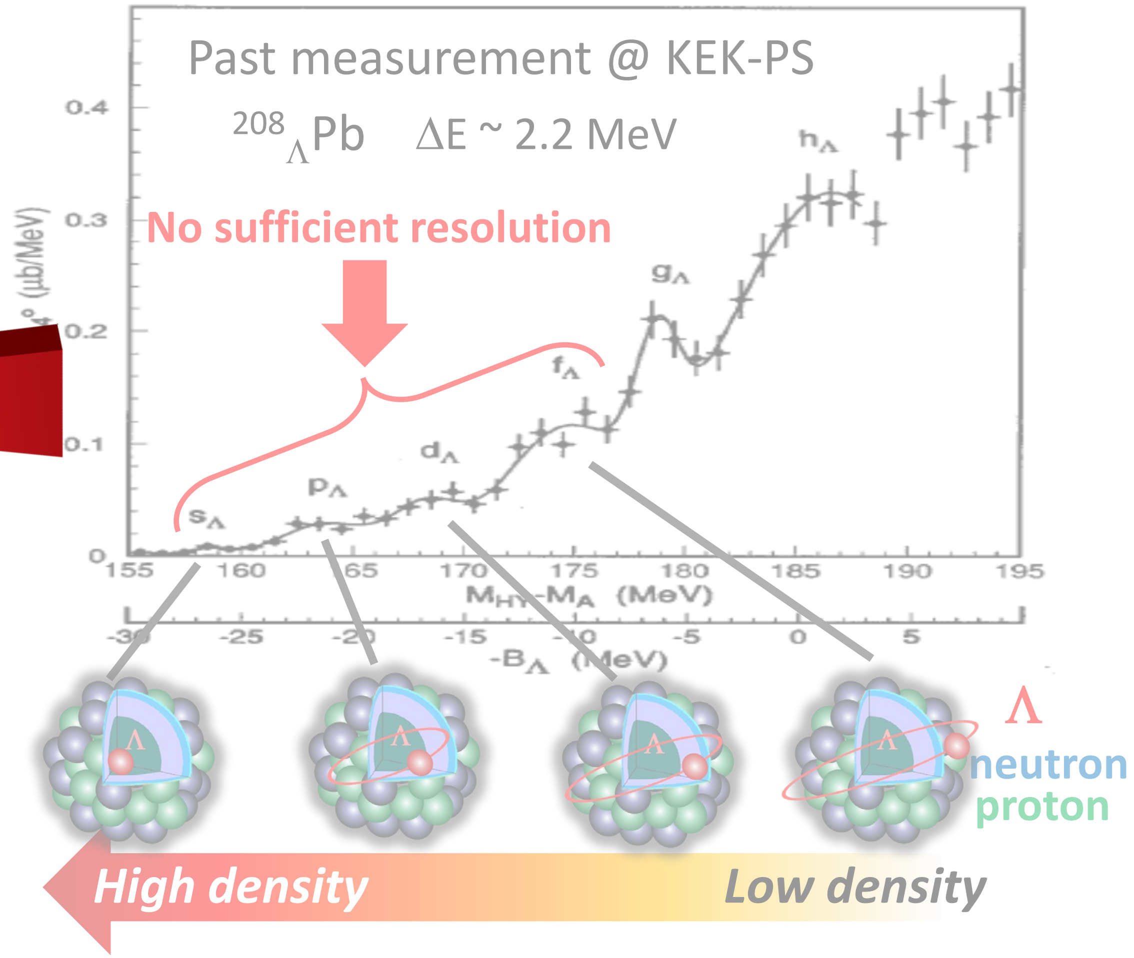
Need separation of each Λ orbital state





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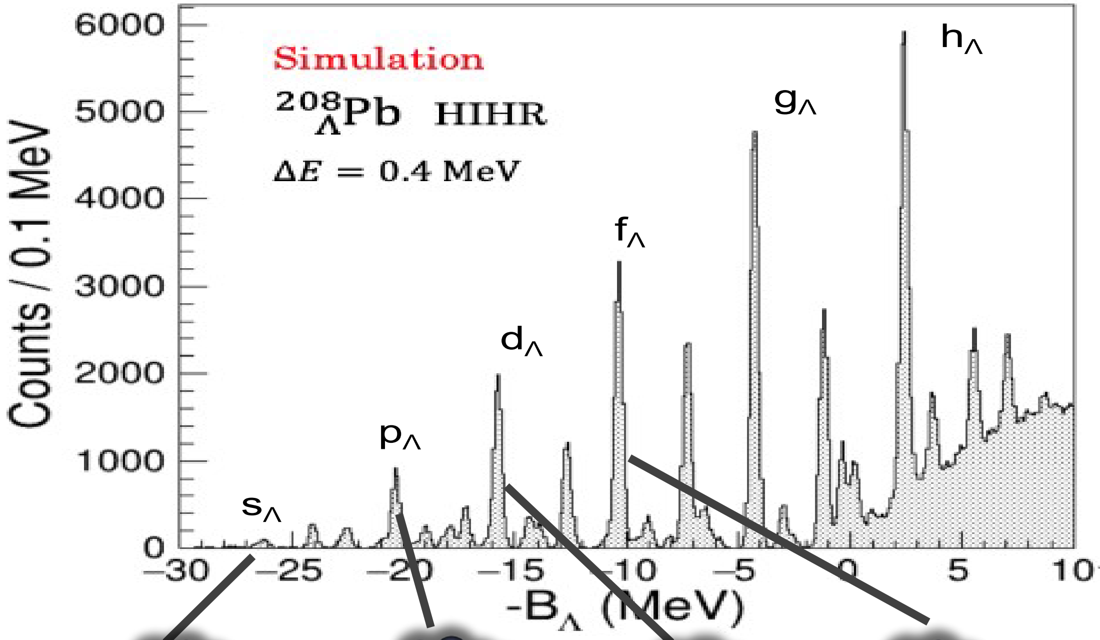
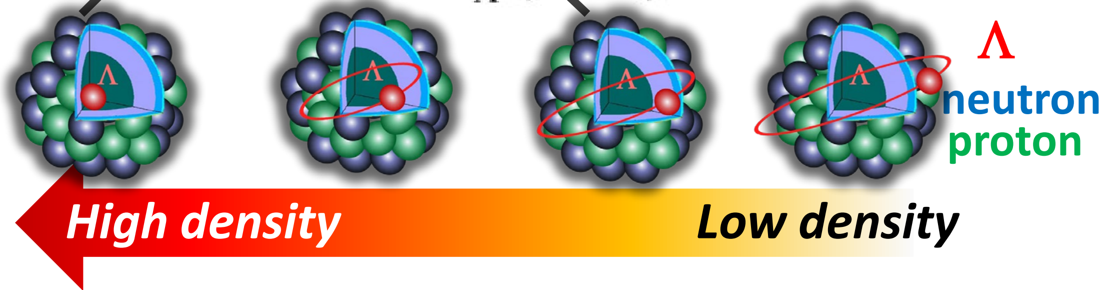
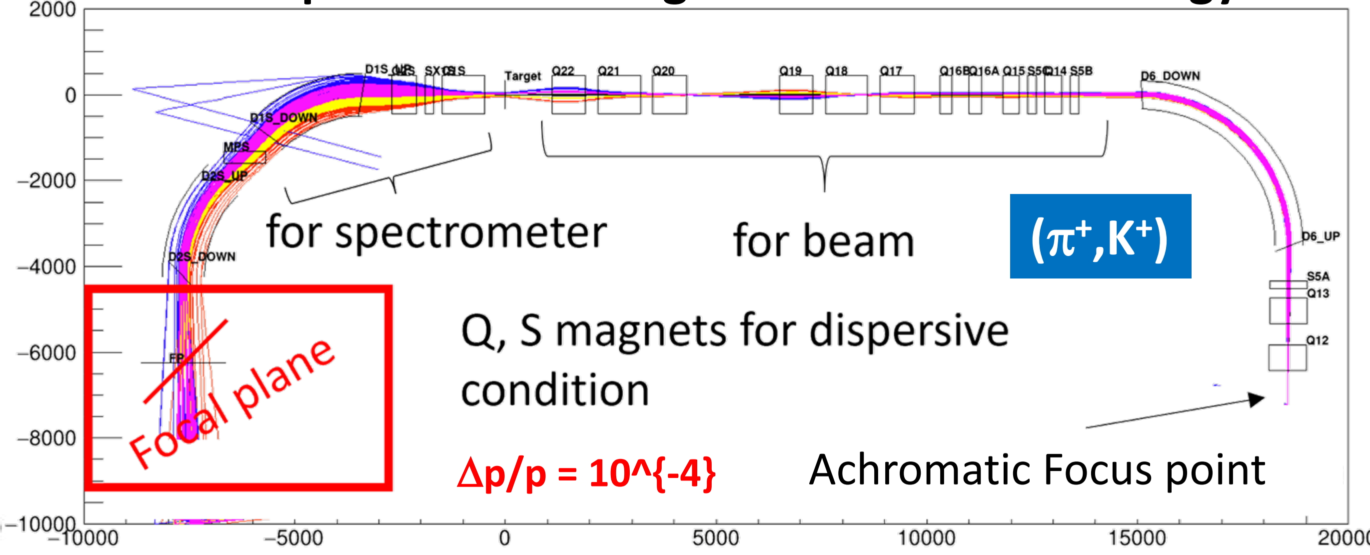
Ultra-high-resolution Λ-hyp. spectroscopy





HIHR beam line (High-Intensity High-Resolution)

First dispersion-matching beam line in GeV energy



- No need for beam tracking
- Intense π beam of > 10^8 /pulse

● **Break through the resolution limit:**

～2.2 MeV → **better than ～0.4 MeV** (FWHM)

Strangeness Nuclear Physics: Hyperon in Dense Environment

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➢ **Hyperons (Λ, Ξ, ...) emerge in dense neutron star matter?**

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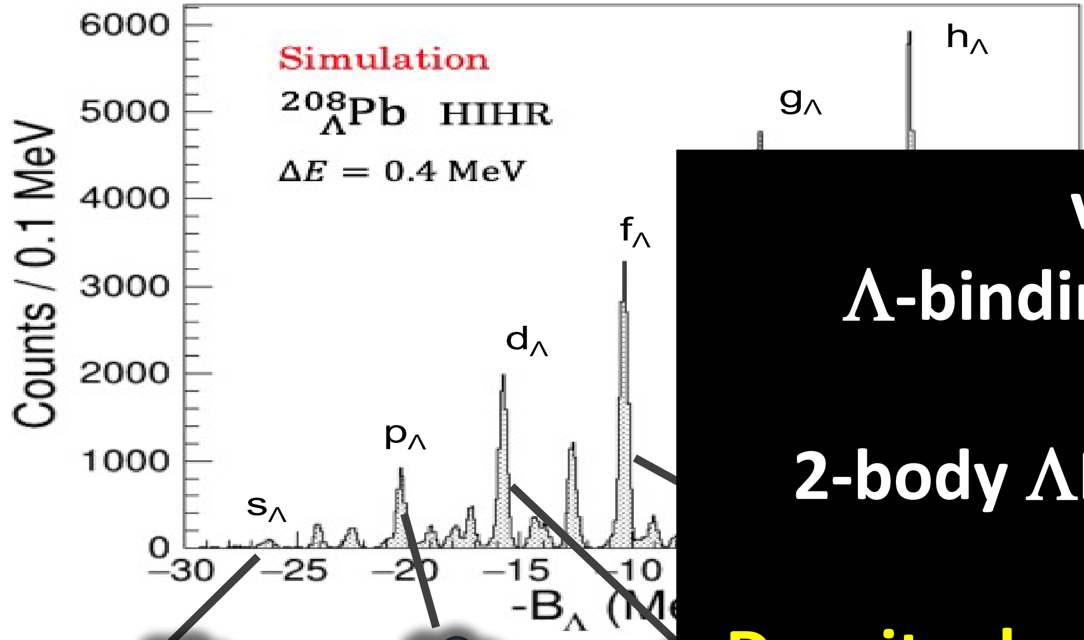

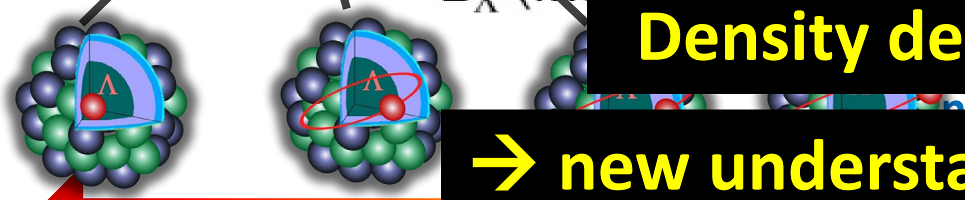

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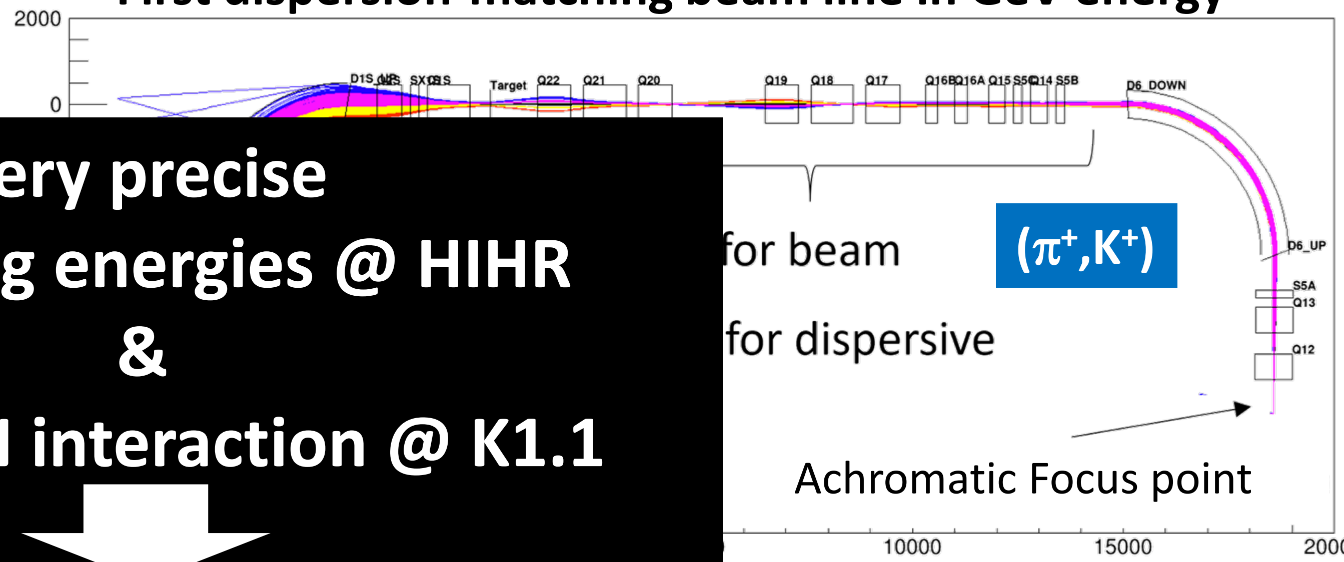

up to 2 GeV/c

very precise
Λ-binding energies @ HIHR
&
2-body ΛN interaction @ K1.1

Density dependent ΛN interaction

→ new understanding of neutron star matter

g

• Intense … beam of … /pulse

ion limit:

~2.2 MeV → better than ~0.4 MeV (FWHM)

Expanded Research Programs

at the Extended Facility

Extract density dependent ΛN interaction

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- intense dispersion matched π beam

K1.1 **Systematic ΛN scattering measurement**
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Investigate diquarks in baryons

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KL2 **Highest-sensitive $K_L^0 \to \pi^0 \nu \bar{\nu}$ measurement**
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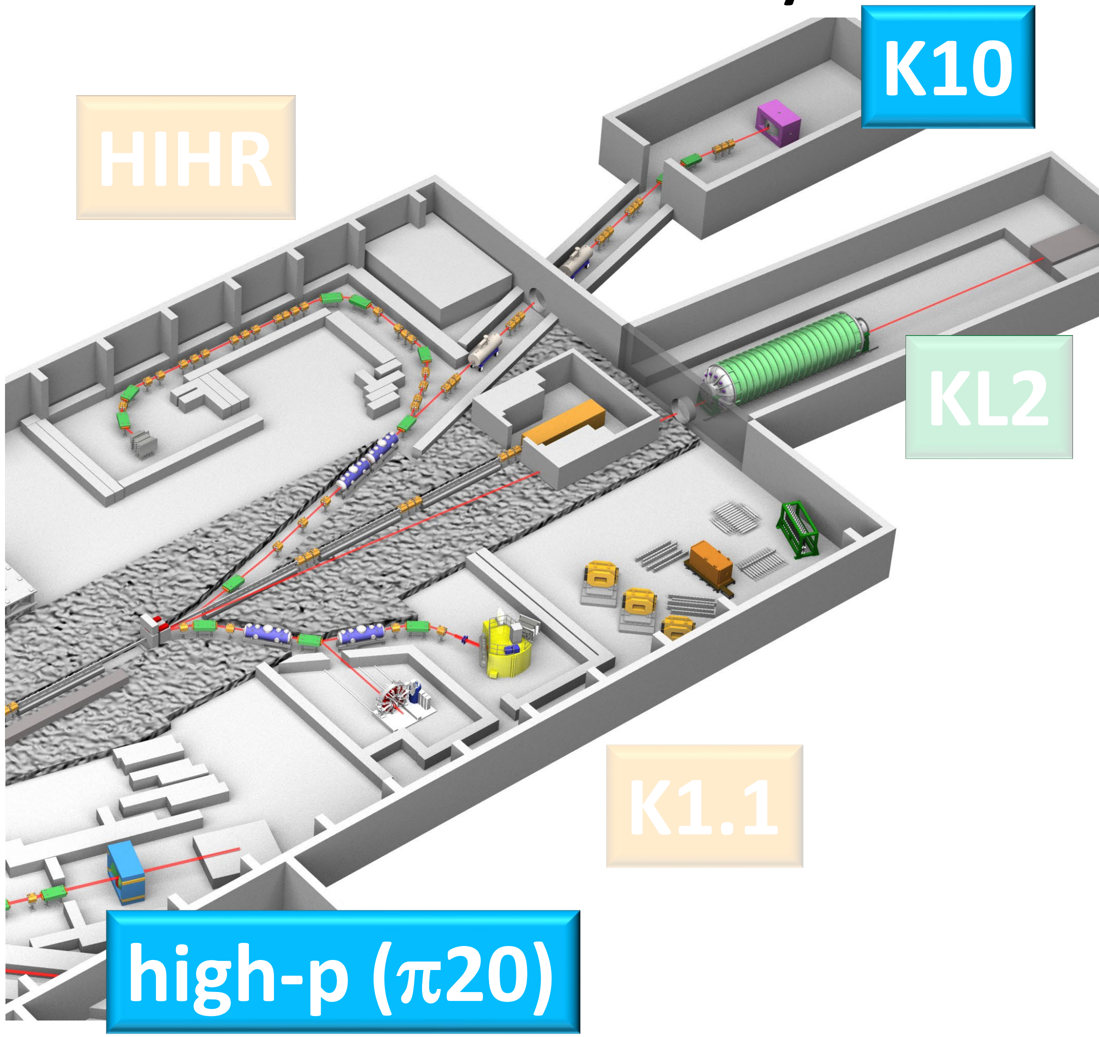


Behaver of non-perturbative QCD in low energy regime

Hadron Physics: Diquarks in Baryons

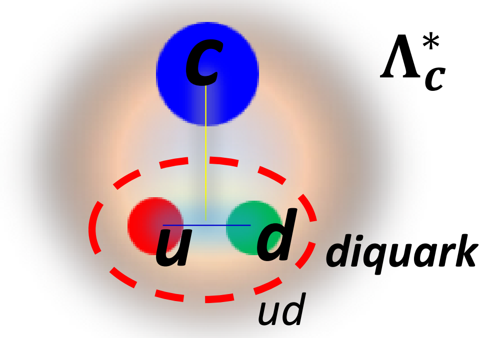
How quarks build hadrons?

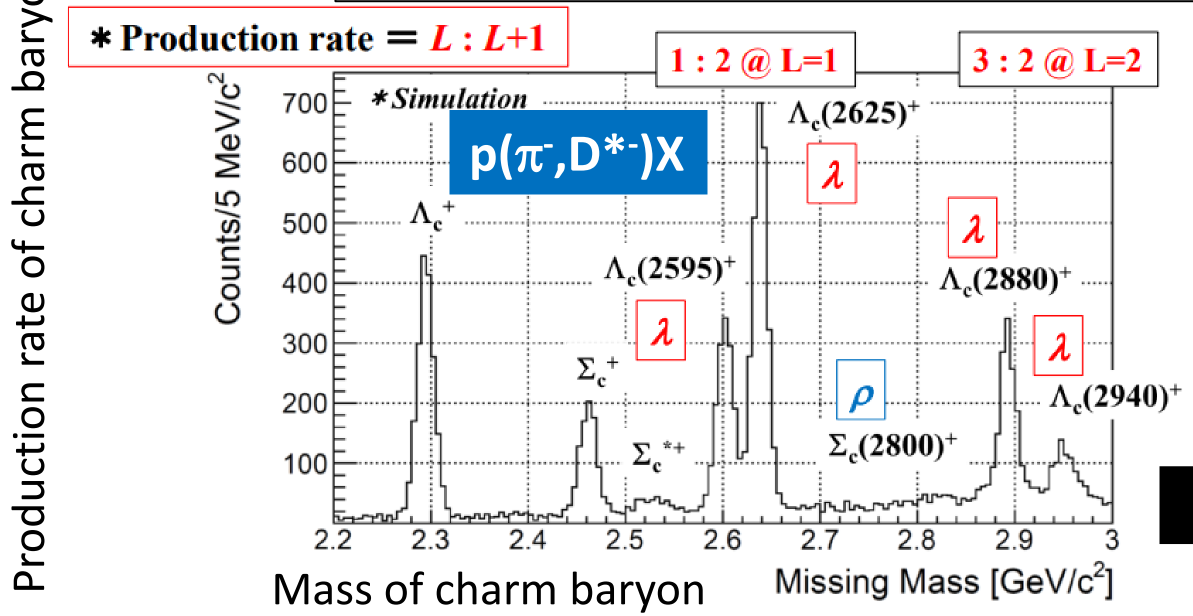
- Investigate **diquarks** in baryons **toward** understanding of **dense quark matter**

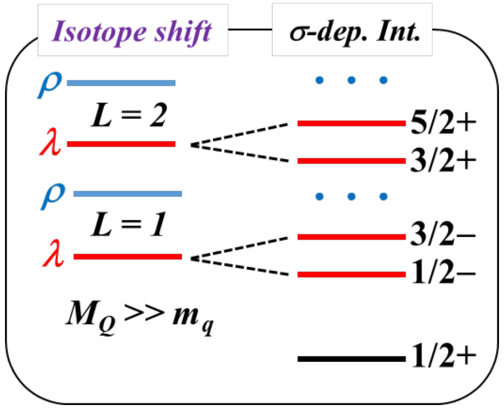
- **Charm Baryon Spectroscopy**
  using intense high-momentum π beam @ High-p (π20)

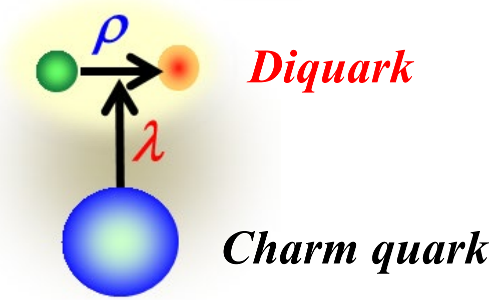
Establish a diquark (*ud*)

Λ_c^*: Disentangle "collective motion of *ud*" and "relative motion between *u* and *d*"









"production rate" and "decay rate" will give us information about diquark

Behaver of non-perturbative QCD in low energy regime

Hadron Physics: Diquarks in Baryons

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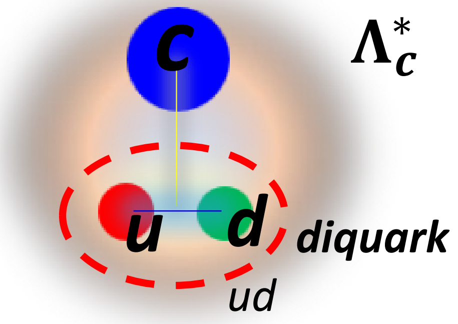


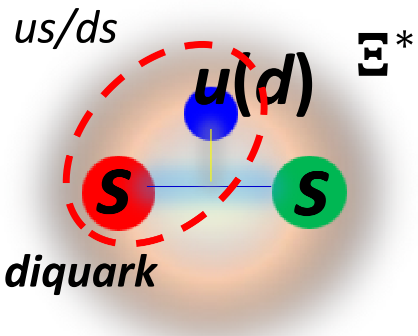
- **Multi-Strange Baryon Spectroscopy**
  using intense high-momentum K beam @ K10

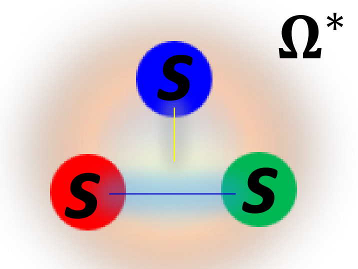
Diquarks in different systems

Ξ^*: *us/ds* diquark

Ω^*: the simplest *sss* system

→ diquark is expected to be suppressed





Systematic measurements will reveal the internal structure of baryons through the diquarks

Expanded Research Programs

at the Extended Facility

Extract density dependent ΛN interaction

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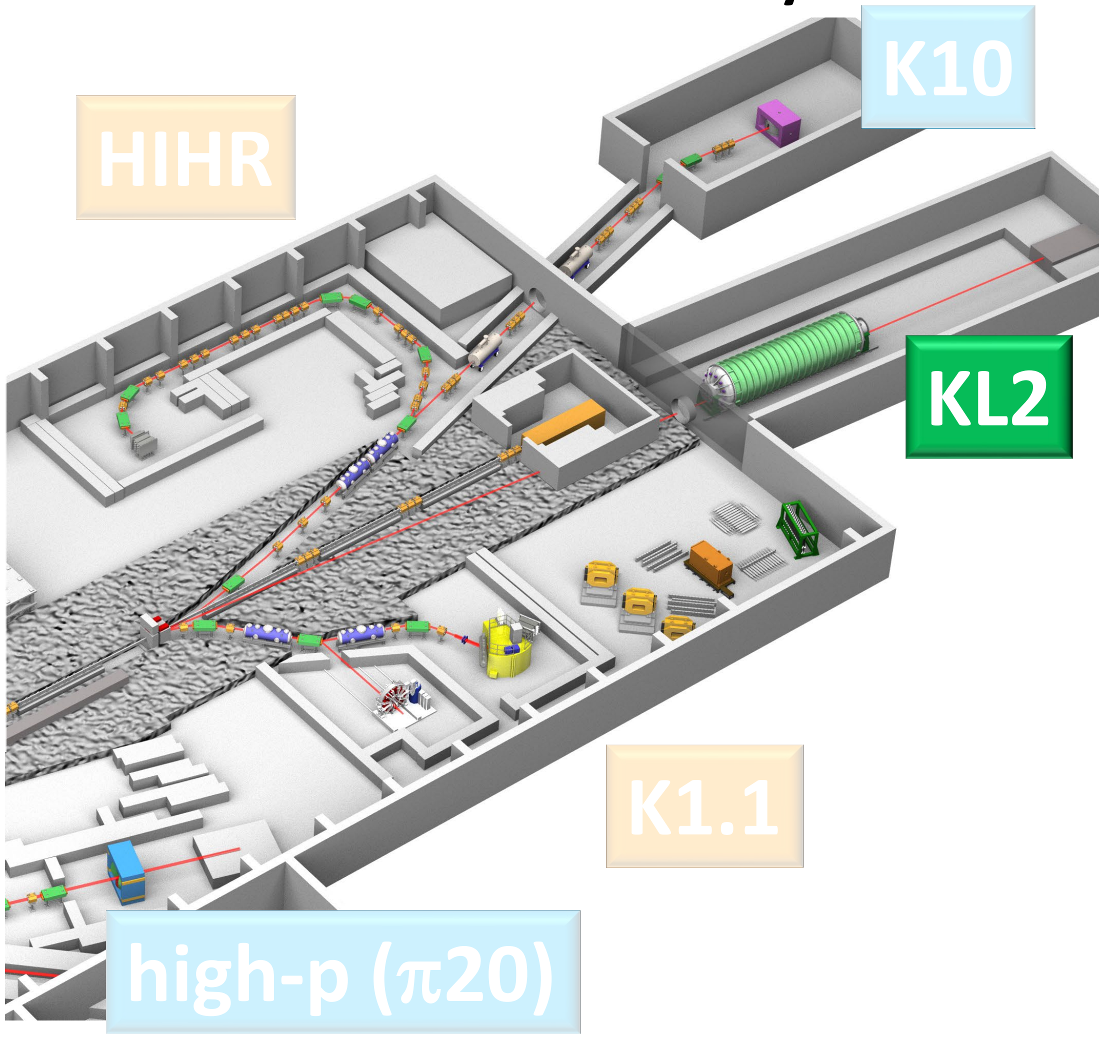


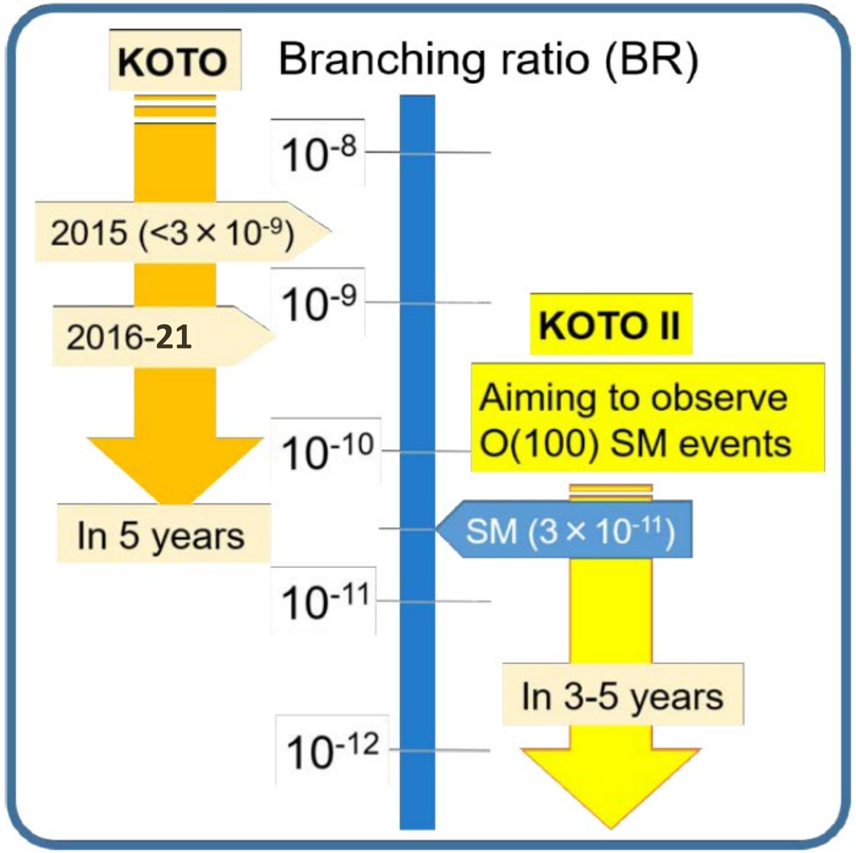
Flavor Physics: New Physics Search at KOTO Step-2

Is there new physics beyond the Standard Model?

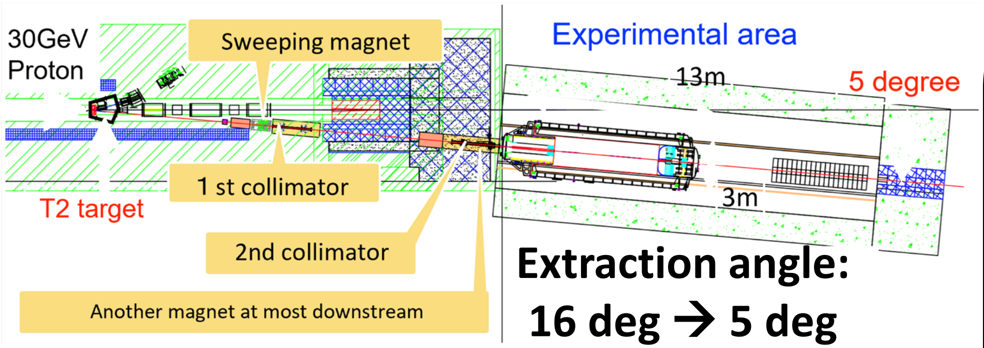
Rare kaon decay: $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$

One of the best probes for new physics searches

- Directly break CP symmetry
- Suppressed in the SM → Branching ratio ～ 3×10^{-11}
- Small theoretical uncertainties (～2%)

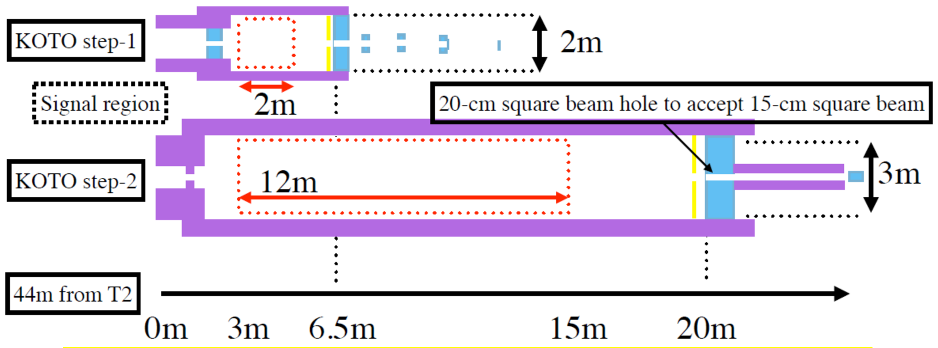


Sensitive to ~*O*(100) TeV physics



Extraction angle: 16 deg → 5 deg

Intense neutral kaon beam @KL2 (~x2.6)



Ultra-high sensitivity detector (~x70)

Step-2

New physics search with world's highest sensitivity more than 100 times

- Discover the $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ signal with 5σ
- Measure the branching ratio with 30% accuracy

Indicate new physics, if deviation form the SM > 40%

Status of the Extension Project

listed as a candidate for government funding:

- ➢ **MEXT Roadmap 2020** (2012, 2014)
- ➢ **Science Council of Japan Master Plan 2020** (2011, 2014, 2017)

The project was selected as **the top-priority project** to be budgeted in the KEK mid-term plan (FY2022-26) at KEK-PIP2022 (Project Implementation Plan)

KEK Inter-University Research Institute Corporation High Energy Accelerator Research Organization

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https://www.kek.jp/en/roadmap-en/

KEK Science Advisory Committee・KEK Roadmap・KEK-PIP

2022/06/24

KEK Science Advisory Committee

1.Report:The 4th Meeting of The KEK Science Advisory Committee (English, March 15, 2023)

About KEK

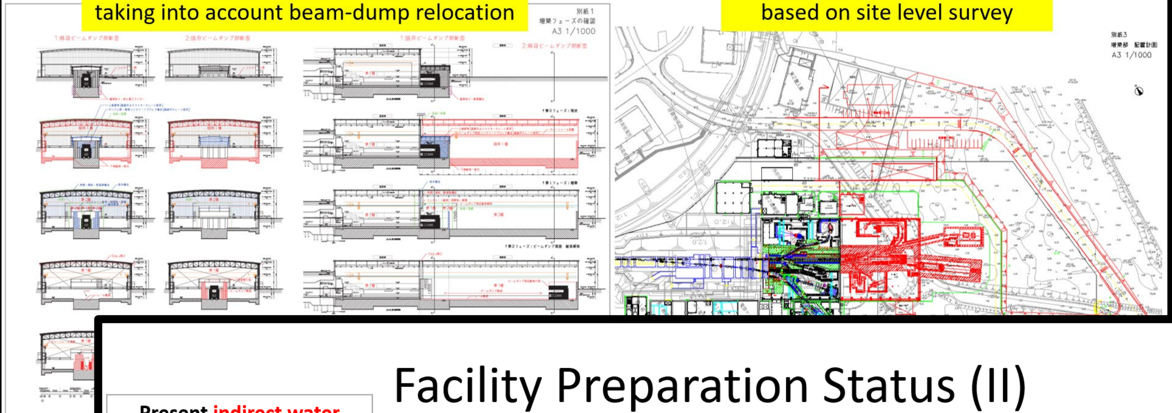
- What is KEK
- Mission
- Organization
- Corporatedevelopment

Facility Preparation Status (I)
Building and Civil Engineering Design

By Nikken Sekkei Ltd. (2018)

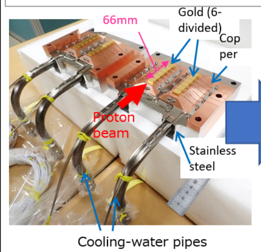
Building expansion plan taking into account beam-dump relocation

Realistic site development plan based on site level survey

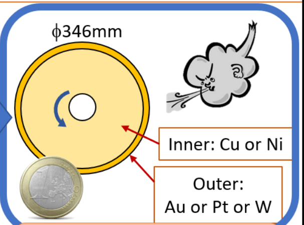


Facility Preparation Status (II)

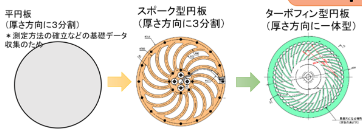
Present indirect water cooling fixed-target
→ max. 95kW (5.2s cycle)



Direct He-gas cooling rotating-target, under development

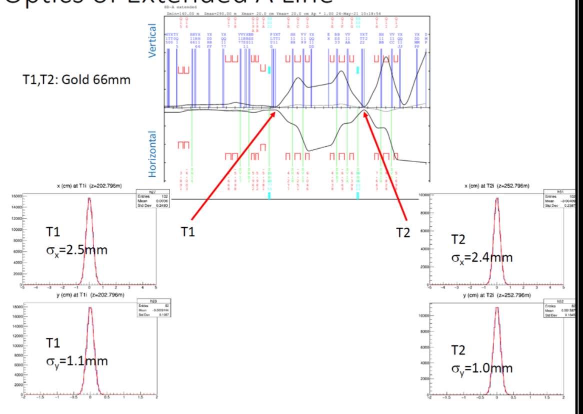


Toward max. >150kW primary beam



- demonstrate the proposed design in FY2021
- complete all necessary designs in FY2023

Optics of Extended A Line



Beam through both T1/T2 targets

Status of the Extension Project

top queue (carryover): **H-line and g-2/EDM**

PIP2016 (2016-21)		
1st	J-PARC upgrade for Hyper-K	DONE
2nd	HL-LHC/ATLAS	DONE
3rd	H-line and g-2/EDM	
4th	**HEF Extension**	

PIP2022 (2022-27)	
1st	**HEF Extension**
2nd	Contribution to HL-LHC
3rd	LiteBIRD
4th	Transmission Muon Microscope

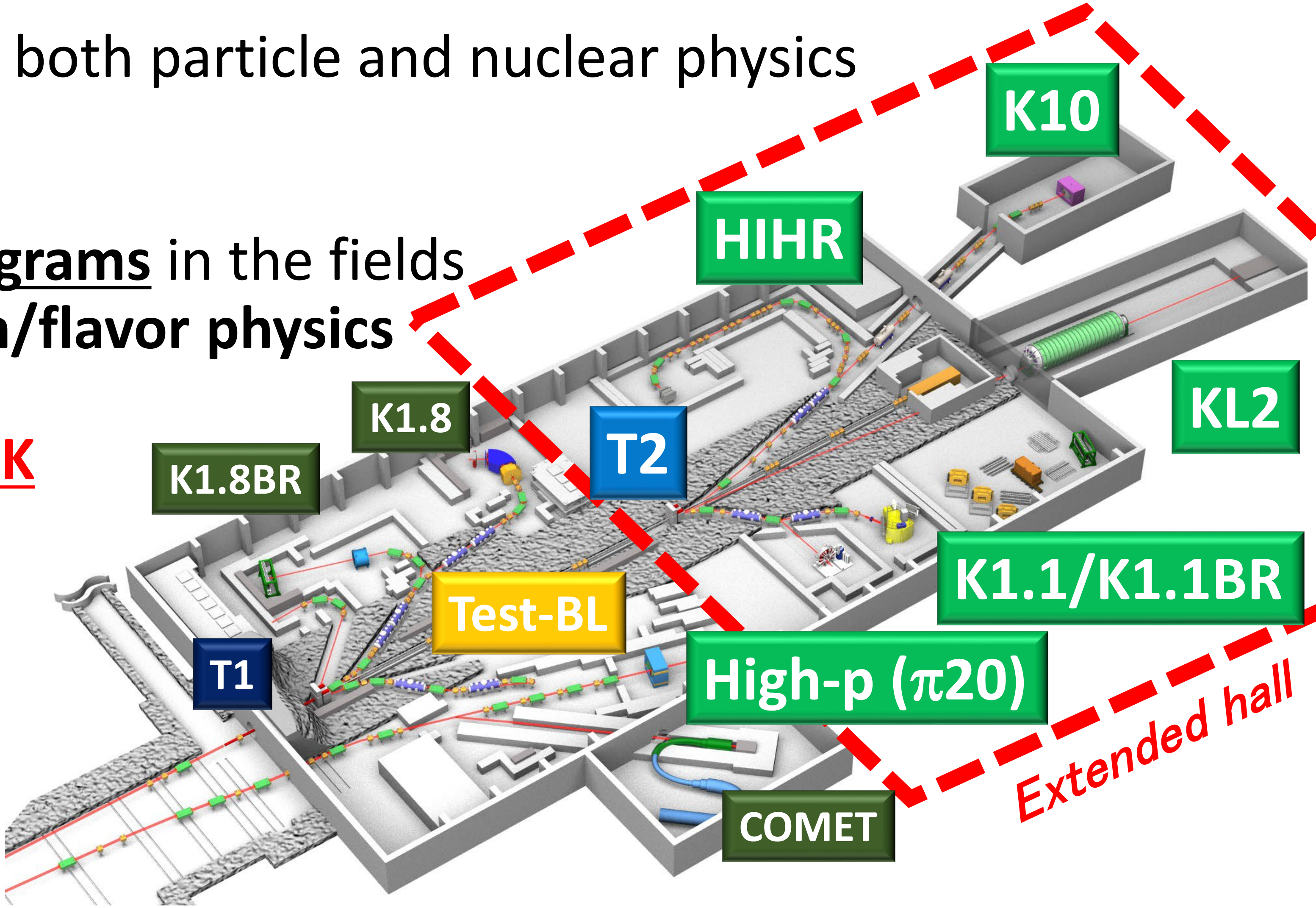
- g-2/EDM remains in the "queue" of budget requests
  - ➢ HEF-ex is considered as the next to g-2/EDM.
- Construction cost has been increased.
  - ➢ (150+15) Oku-yen at PIP2022 → (200+20) Oku-yen after COVID-19/Ukraine-War
- Cost reduction/optimization, staging plans with smaller steps, and seeking budgetary support from outside KEK are being discussed for early realization of the project.
  - ➢ We need community's help!

Summary of the Extension Project of the J-PARC Hadron Experimental Facility

- **<u>Unique research programs</u>** in both particle and nuclear physics at high-intensity frontier
- **<u>World's leading research programs</u>** in the fields of **strangeness-nuclear/hadron/flavor physics**
- **<u>Top-priority project in the KEK mid-term plan (FY2022-26)</u>** /

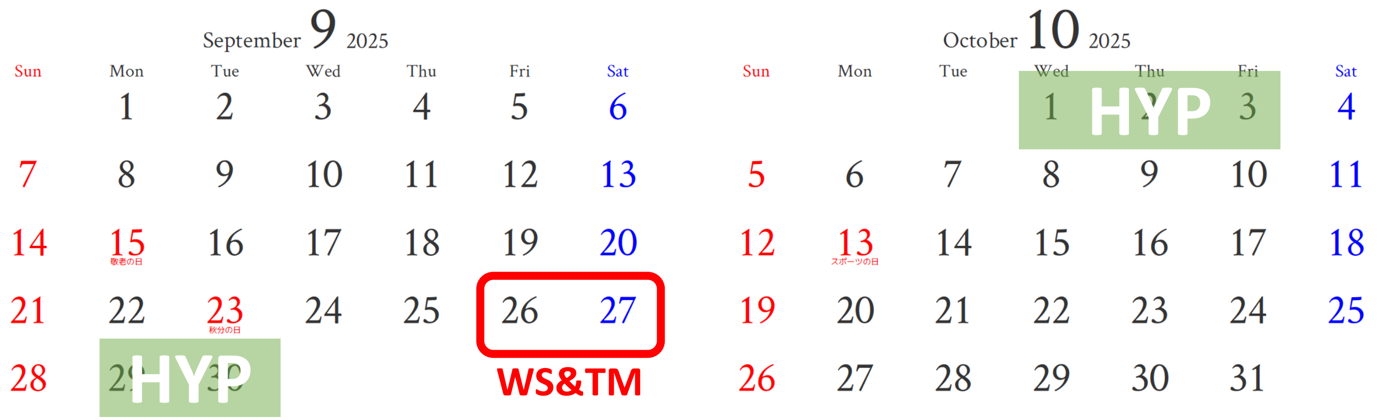
→ Project is now ready to start

Let's work together to make progress on the project!



"International workshop" and "town meeting" on the Extension Project for J-PARC Hadron Experimental Facility 2025 (HEF-ex WS/town-meeting 2025)

- A workshop with the 2nd Town Meeting is planned as a pre-WS of HYP2025
  - aiming to promote broader international discussions
- September 26-27 (2 days)
  - 1.5 days for WS, 0.5 days for TM
- Venue: RIKEN



Thank you for your attention!

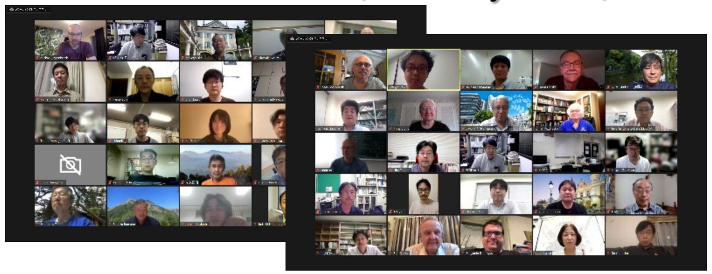
https://www.rcnp.osaka-u.ac.jp/~jparchua/en/hefextension.html


First-Beam WS at the J-PARC Hadron Experimental Hall
25-26 March 2009, IQBRC, Tokai


International WS on physics
at the extended hadron experimental facility of J-PARC
5-6 March 2016, KEK Tokai Campus


International WS on the project for
the extended hadron experimental facility of J-PARC
26-28 March 2018, KEK Tokai Campus

1st J-PARC HEF-ex WS, 7-9 July 2021, online



2nd J-PARC HEF-ex WS, Feb.16-18 2022, online


3rd J-PARC HEF-ex WS, Mar.14-16 2023, J-PARC


HEF-ex 2024, 19-21 February 2024, J-PARC