Hadronic Physics through J-PARC

Shinya SAWADA

High Energy Accelerator Research Organization (KEK)

The 3rd Japan-Korea Workshop on Hadrons and Nuclei at Korea University, Seoul, Mar 2-3

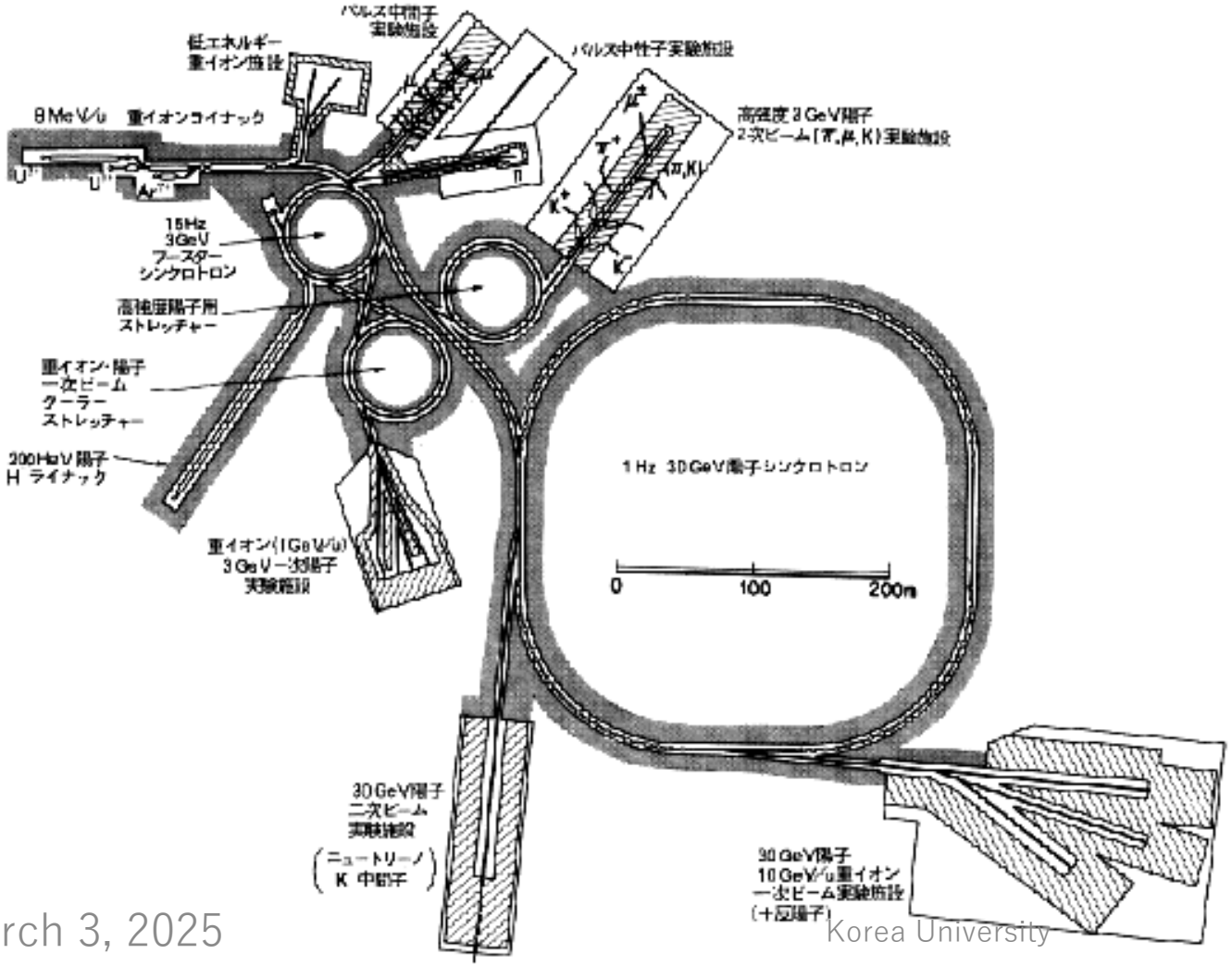
Contents

- J-PARC: Past and Present
  - Facility
  - Strangeness nuclear physics and hadronic physics
- EIC
  - Yellow Paper
- Hadron Extension
- Hadronic Physics for Future J-PARC
- Physics and Facility
- Summary

J-PARC

Past and Present

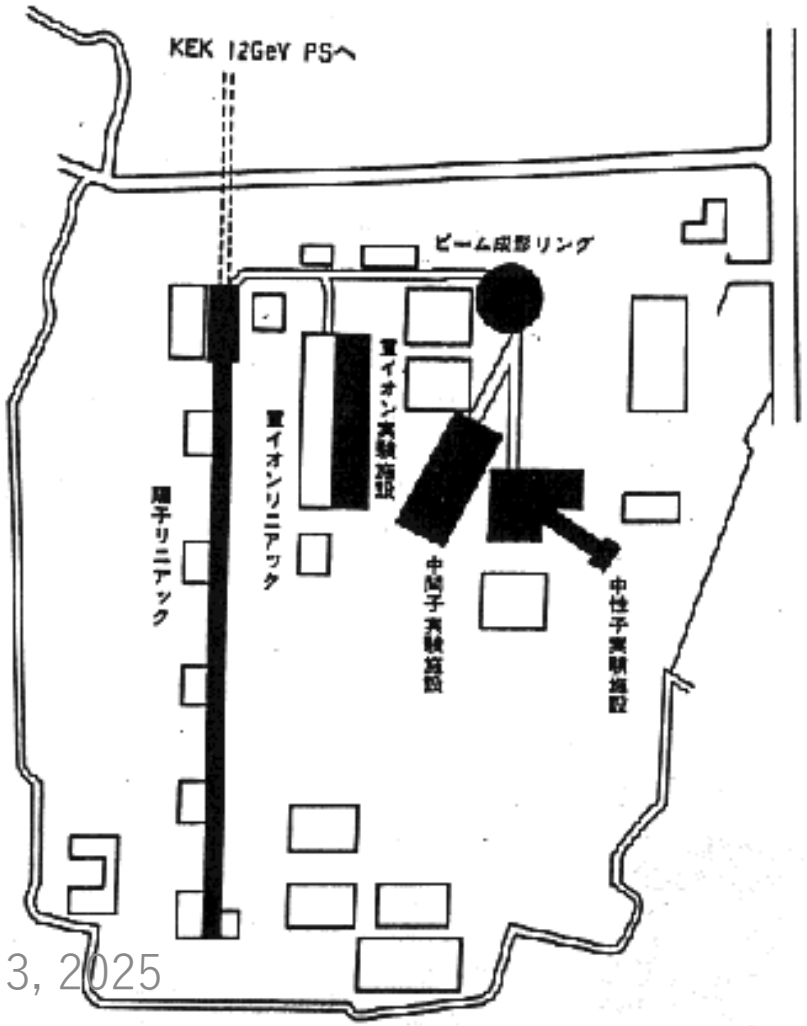
大ハドロン計画 Great Hadron Project
→大型ハドロン計画 Japan Hadron Facility (JHF)



大ハドロン計画
Great Hadron Project（1985年）
核物理コミュニティが提案
Proposed by Nuclear Physics Community of Japan

大強度陽子 High Intensity Protons
　3 GeV (100 mA) +
　30 GeV (30 mA)
重イオン Heavy Ions
　1 A GeV +
　10 A GeV

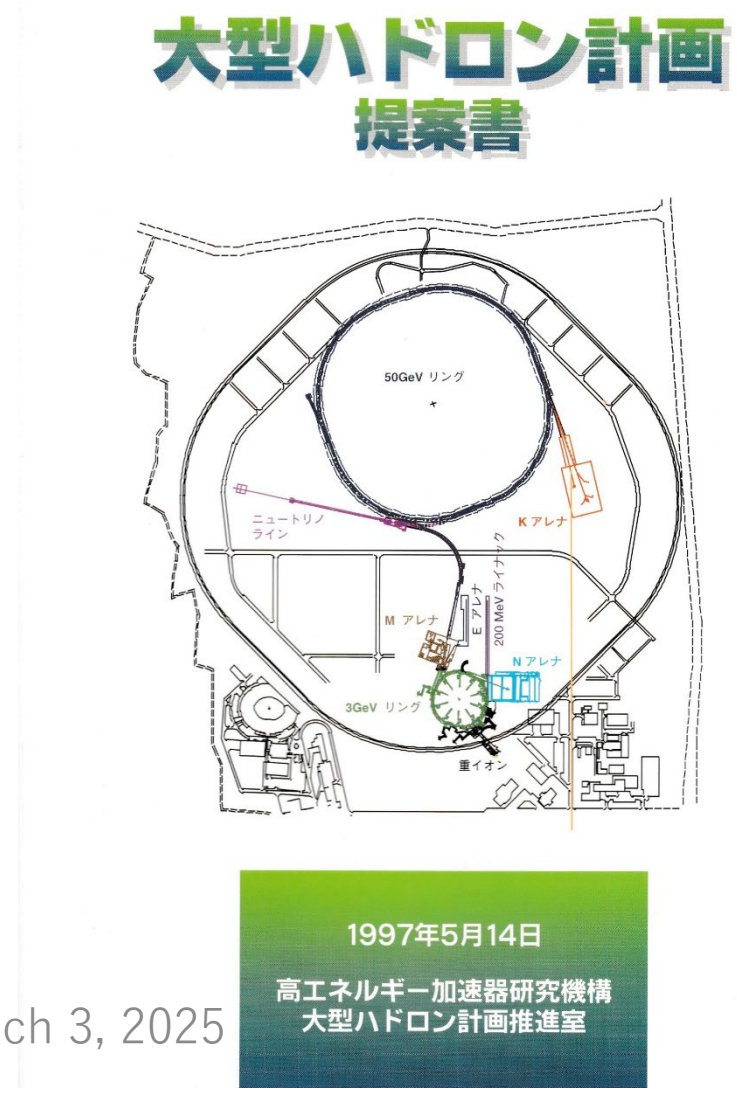
大ハドロン計画 Great Hadron Project
→大型ハドロン計画 Japan Hadron Facility (JHF)



大型ハドロン計画＃１(JHP)（1987）
Japan Hadron Project
東大原子核研究所による提案
Proposed by Institute for Nuclear Studies (INS), University of Tokyo
KEKの敷地を仮定
Assumed KEK’s campus

大強度1 GeV 陽子ビーム
High Intensity 1-GeV proton beam
（＞200　μA）

大ハドロン計画 Great Hadron Project
→大型ハドロン計画 Japan Hadron Facility (JHF)



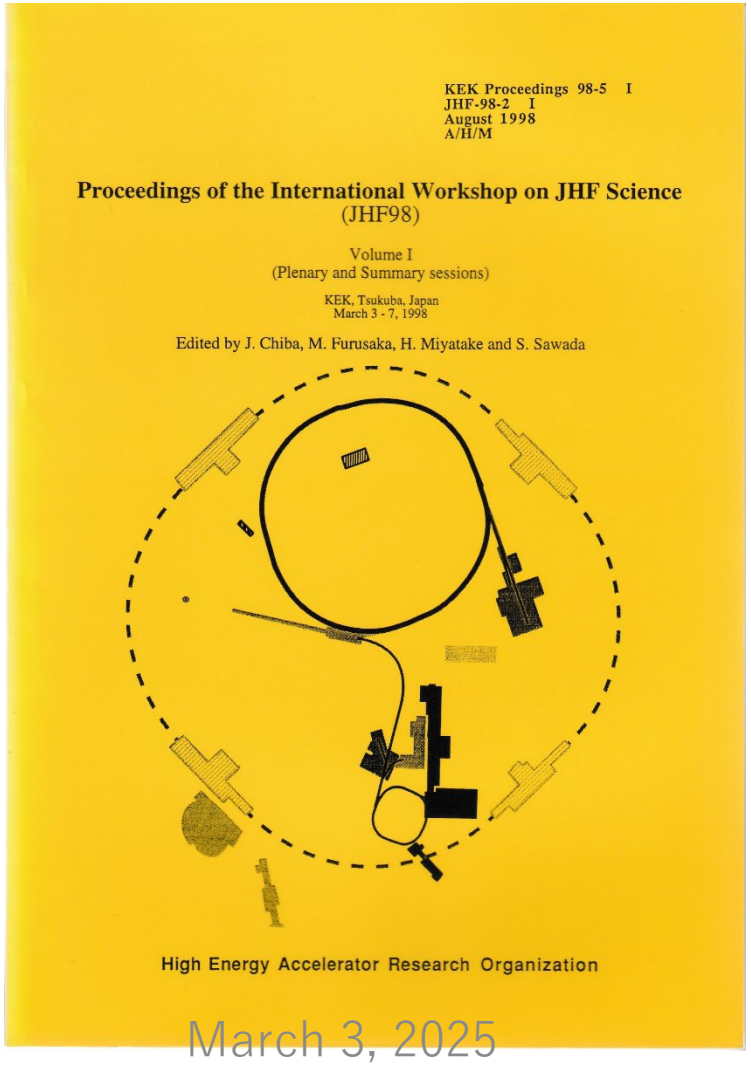
大型ハドロン計画＃2（JHF）（1997）
Japan Hadron Facility
1997年4月に東大核研と合併した新KEK（高エネルギー加速器研究機構）から提案
Proposed by KEK when the new KEK was established by merging the old KEK, INS (U. Tokyo), and Meson Physics Lab (U. Tokyo)

大強度陽子ビーム
High Intensity Proton Beams
3 GeV (200 μA) + 50 GeV (10 μA)
+ (重イオン Heavy Ions)

K-arena, M-arena, N-Arena, E-arena
ニュートリノは既存ビームラインを利用
Neutrino by existing neutrino beamline

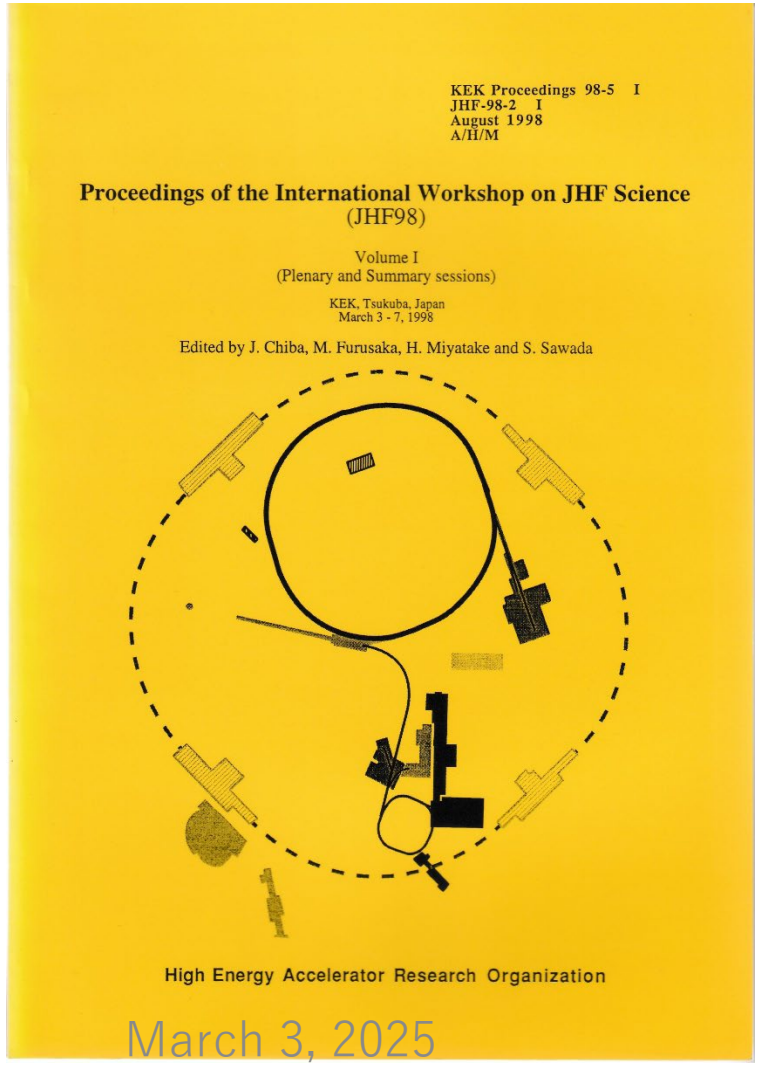
JHF98

International Workshop on JHF Science



JHF98

International Workshop on JHF Science



Contents

JHF98

International Workshop on JHF Science

Particle physics with K, μ, ν （Kuno、Littenberg）

Strangeness nuclear physics （Bassalleck）

Physics with primary beam (Chiba)

Hadron spectroscopy and physics with antiprotons and antinucleus （Bressani）

JHF98: K arena

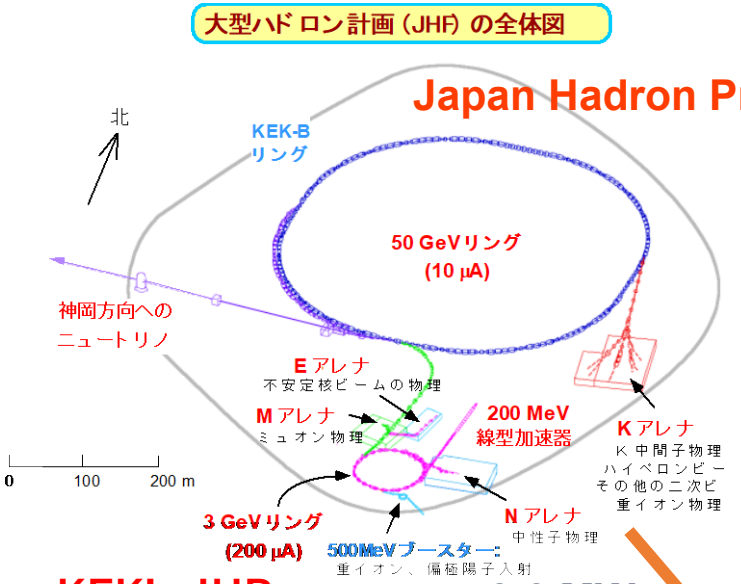
International Workshop on JHF Science

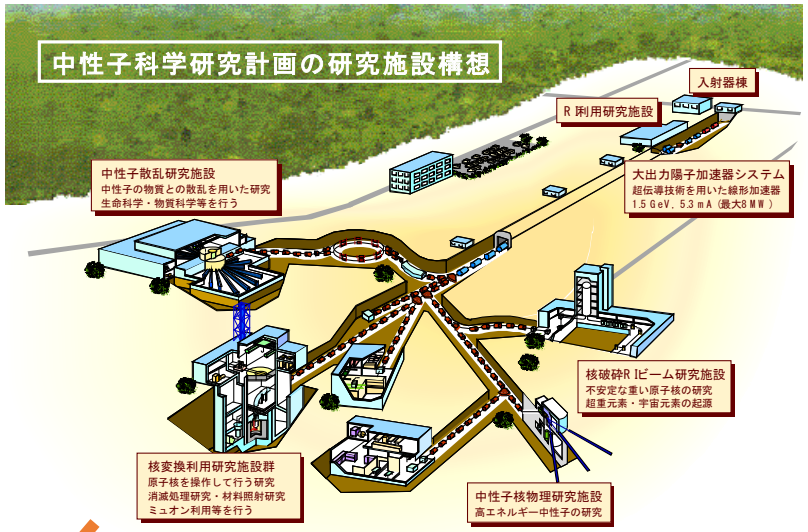
Parallel Sessions

K-Arena

1-a; Kaon and muon rare decays
1-b; Neutrino physics
1-c; Strangeness nuclear physics
1-d; Physics with primary beams
1-e; Hadron spectroscopy and physics with anti-proton and anti-nuclei

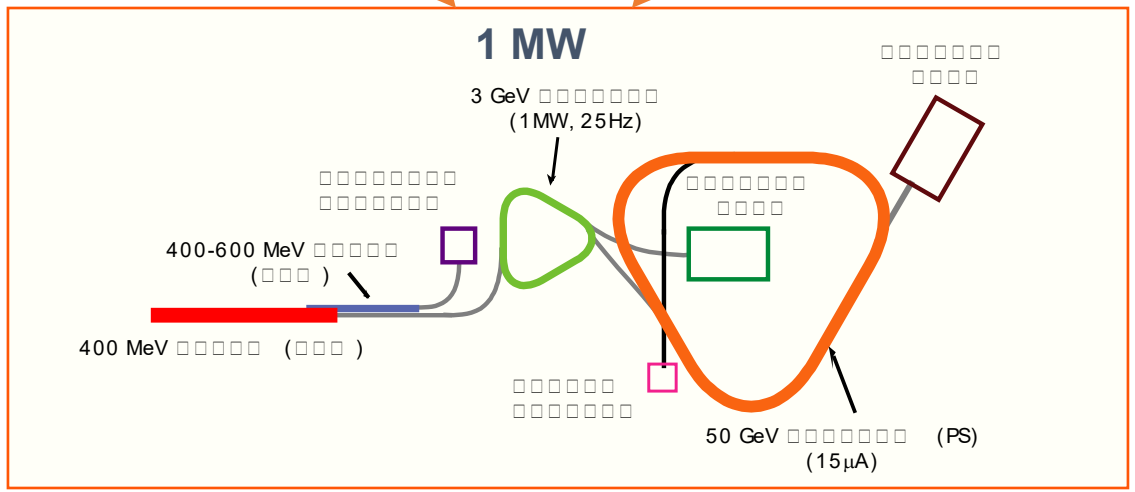
KEK-JAERI Joint Project (1998~)





KEK's JHP 0.6 MW

8 MW JAERI (current JAEA) 's Omega Project



Unified project

Funded from JFY2001

NP01

International Workshop on Nuclear and Particle Physics at 50-GeV, 10-12, Dec. 2001

****
**** Scientific Program (Plenary Sessions) ****
****

Dec. 10 (Mon)
8:00 - 9:00 = Registration =
9:00 - 9:10 H. Sugawara(KEK)*, Welcome Address
9:10 - 9:50 S. Nagamiya(KEK), Present status of the Joint Project
9:50 - 10:10 Y. Yamazaki(KEK), Accelerator Complex Design and Construction
10:10 - 10:30 = Coffee Break =
10:30 - 11:10 Y. Mori(KEK), 50-GeV Proton Synchrotron
11:10 - 11:50 T. Nagae(KEK), Strangeness Nuclear Physics experiments at 50-GeV PS
1:20 - 2:00 H.C. Bhang(Seoul)*, Study of the weak decay of hypernuclei with 50-GeV High Intensity Proton Accelerator
2:00 - 2:40 H. Spinka(ANL), Hadron Physics experiments at 50-GeV PS*
2:40 - 3:20 T. Numao(TRIUMF), Kaon rare decay experiments at 50-GeV PS
3:20 - 4:00 N. Sasao(Kyoto), Physics with high intensity muon beams
4:00 - 4:20 = Coffee Break =
4:20 - 5:00 T. Nakaya(Kyoto), Neutrino experiment at JHF
5:00 - 5:40 K. McFarland(Rochester), Neutrino oscillation experiments*
5:40 - 6:20 E. Widmann(Tokyo), Atomic Physics with Ultra-Slow Antiprotons
6:45 - 8:30 = Reception Party =

Dec.11 (Tue)
9:00 - 9:20 J. Imazato(KEK), Activities of Nuclear/Particle Physics Group
9:20 - 10:00 K. Tanaka(KEK), Present design of beam lines

10:00 - Parallel Working Session

Dec.12 (Wed) Working Group Reports
9:00 - 9:30 WG#1: M. Ieiri(KEK)/H.C. Bhang(Seoul)
9:30 - 10:00 WG#2: S. Sawada(KEK)/H. Spinka(ANL)/T. Nakano(RCNP)
10:00 - 10:30 = Coffee Break =
10:30 - 11:00 WG#3: Y. Kudenko(INR)/K.Yoshimura(KEK)
11:00 - 11:30 WG#4: A. Konaka(TRIUMF)/T. Kobayashi(KEK)

1:00 - 2:30 Discussions

*Parallel Working Session:
WG#1: Strangeness Nuclear Physics experiments,
WG#2: Nuclear/Hadron Physics experiments,
WG#3: Kaon/Muon Rare Decay experiments,
WG#4: Neutrino experiments.

The coordinators of each session are,
WG#1: M. Ieiri(KEK)/H.C. Bhang(Seoul),
WG#2: S. Sawada(KEK)/H. Spinka(ANL)/T. Nakano(RCNP),
WG#3: Y. Kudenko(INR)/K.Yoshimura(KEK),
WG#4: A. Konaka(TRIUMF)/T. Kobayashi(KEK).

NP01: Hadron Physics

International Workshop on Nuclear and Particle Physics at 50-GeV, 10-12, Dec. 2001

Summary of Nuclear/Hadron Physics Working Group

Shin'ya Sawada (KEK)

Subjects discussed

- Complementary future project at GSI (Kienle)
  - Multipurpose facility
  - Not officially approved yet. Some of the ideas can be realized at JHF.
- Research using (high momentum) p, p-bar, pi, K,...
  - Hadron physics is very well summarized by the plenary talk by Dr. Spinka.
    - Partonic content of nuclei
      - Dimuon measurement (Sawada)
    - Transition region between nucleon+meson and quark+gluon pictures
    - Baryon and meson spectroscopy
      - Possibility of pol. p-bar beam
      - Talks by Peaslee and Tsuru
        - » RF separator for K beams is now under development at IHEP (Protovino) which may be moved to JHF. JHF has much higher (orders) proton intensity.
  - Nuclear-matter-related physics
    - "Spectral function" (Asakawa)
      - Fruitful phase diagram.
    - Vector meson modification (Ozawa)

NP01: Hadron Physics

International Workshop on Nuclear and Particle Physics at 50-GeV, 10-12, Dec. 2001

Subjects Discussed (cntd.)

- Multifragmentation (Tanaka)
- Research using HI beams
  - Unique tool to study "relativistic hypernuclei" (Sakaguchi)
  - Important and unique tool to study nuclear matter with high baryon density (Sugitate)
    - Experimental setup for flow measurement was proposed. (Esumi)
- Research using polarized proton beams
  - Spin physics
    - Parity violation experiments (Arvieux)
  - Prof. Hatanaka suggested polarized beam might be able to be accelerated with "tune jump" method.
- Research using ultra-slow antiprotons (Widmann)
  - Not only atomic physics, but also fundamental physics.
  - They will transfer the antiproton decelerator to JHF after CERN experiments.

Dec 12, 2001 #2 Summary/S. Sawada@NP01 4

Strategy

- First of all, we should brush up the physics cases.
  - Uniqueness, relationship with experiments at other facilities, ...
  - Will make documentations in the coming year.
- For experiments using high momentum p, p-bar, pi, K, ...
  - Will start design work and R&D for the "multipurpose beam line". The key is the quality of the beam. Beam channel expert (Tanaka) think we will be able to have a design of a good quality beam line in half a year.
  - Consider possibility of the RF separators.
  - Detector R&D will be started, including hadron blind detectors etc. by the subgroups. This is related with the ongoing research programs (RHIC, LHC, etc.).
- For HI experiments:
  - We should not only brush up the physics cases, but also consider various realistic possibilities of HI acceleration.
  - Will ask project headquarters to consider construction of the HI injectors with these studies.

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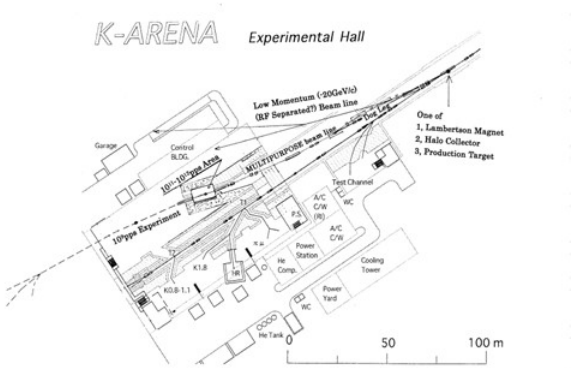
NP01: Hadron Physics

International Workshop on Nuclear and Particle Physics at 50-GeV, 10-12, Dec. 2001

Multipurpose Beam Line

- To accommodate various needs for beams from hadron physics experiments;
  - 50-GeV protons with ~10^{12} pps <= Str. Fn.
  - 50-GeV protons with ~10^{9} pps <= Vec. Meson
    - Very small beam size (~1mm2), stable, very small beam halo
  - 5~50-GeV variable energy protons with ~10^{9} pps <= Multifragmentation
  - 5~30-GeV variable energy secondary particles with ~10^{9} pps <= Multifragmentation & others
  - HI beams with 10^{10} ions per second



Strategy (cntd.)

- For polarized proton experiments:
  - Question on the needs of pol. proton beams at JHF is open, when we have pol. p beams at AGS/RHIC-Spin.
  - We should ask wide range of the physics communities.

NP01: Strangeness Nuclear Physics

International Workshop on Nuclear and Particle Physics at 50-GeV, 10-12, Dec. 2001

Strangeness Nuclear Physics experiments at 50-GeV PS

Tomofumi Nagae

KEK

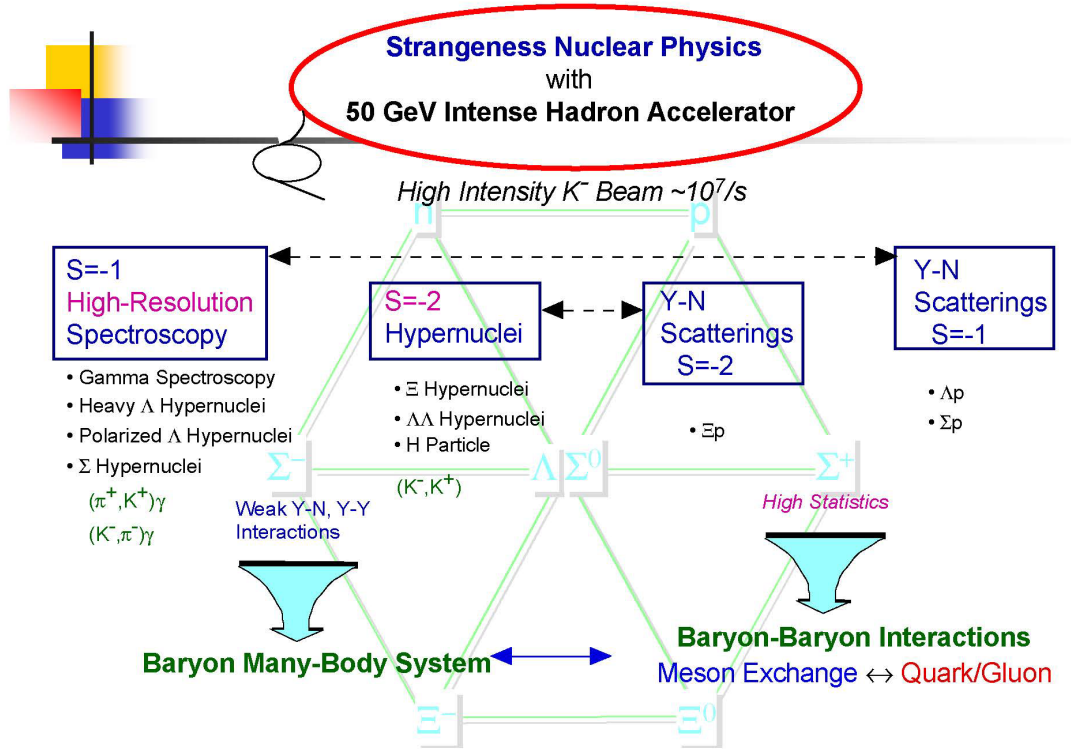
- LOI for the Experiments on Strangeness Nuclear Physics at the 50-GeV Proton Synchrotron, July, 2000.
  - K. Imai, T. Nagae, M. Ieiri, H. Noumi, T. Fukuda, H. Outa, K. Nakazawa, K. Yamamoto, T. Yoshida, O. Hashimoto, H. Tamura, T. Takahashi, Y. Fujii, T. Kishimoto, K. Tanida, B. Bassalleck
  - http://www-jhf.kek.jp/JHF_WWW/LOI/50GeVNP-LOI-v1.0.pdf or visit http://jkj.tokai.jaeri.go.jp/NuclPart/Science.html

NP01: Strangeness Nuclear Physics

International Workshop on Nuclear and Particle Physics at 50-GeV, 10-12, Dec. 2001

Contents of LOI

- Introduction
- Spectroscopic Study of S=-2 Systems
- Hyperon Proton Scattering
- Hypernuclear γ-ray spectroscopy
- High-Resolution Reaction Spectroscop of S=-1 Hypernuclei
- Study of Dense Nuclear Matter with Strangeness



NP01: Strangeness Nuclear Physics

International Workshop on Nuclear and Particle Physics at 50-GeV, 10-12, Dec. 2001

WG#1 Strangeness Nuclear Physics experiments by M. IEIRI & 25 participants

Letter of Intent (July 12, 2000) [http://jkj.tokai.jaeri.go.jp/NuclPart/Science.html]

- T. Nagae "Strangeness Nuclear Physics experiments at 50-GeV PS"
- T. Fukuda "Double-Lambda at BNL"
- K. Nakazawa "Next step on the coming hybrid experiment(AGS-E964) at JHF"
- M. Ieiri "Hyperon-proton scattering experiment"
- K. Tanida "Gamma-ray spectroscopy of hypernuclei"

- Y. Akaishi "Characteristic features of Strangeness Nuclear Systems"
- T. Yamazaki "Kbar-nucleus bound state spectroscopy"
- M. Iwasaki "Experimental search for Kbar-nucleus bound state"

- V. Kopeliovich "Multibaryons with Strangeness and Charm"
- E. Hiyama "Comments from the theoretical side"

- A. Sakaguchi "Feasibility of Production and Detection of Relativistic Hypernuclei "

- H. Noumi "Secondary beam lines"
- H. Hotchi "Possibility of moving the BNL-AGS D6 line to JHF"

•Discussion

Subjects	Beamline	Specials	Beamtime (days)	estimated counts	output
Spectroscopic Study of S=-2 Systems					
• Spectroscopy of Ξ Hypernuclei		upgraded SKS			
production of Ξ Hypernuclei	K1.8		20	~ 120 events/MeV/(^{208}Pb)	Ξ-N potential
production of ΛΛ Hypernuclei	K1.8		100	~ 60 events/peak	excited states of ΛΛ hypernuclei
• ΛΛ Hypernuclei by Sequential Pionic Decays	K1.8	CDS	not yet	-	g.s. mass of ΛΛ hypernuclei
• Double-Strangeness Nuclei by an Emulsion-Counter	K1.8	Emulsion	36	~ 10000 X stopping	B.E.
Hyperon Proton Scattering		Liq. H2 & CDS			
• Ξp→Ξp, ΛΛ	K1.8		100	2300, 550	direct input to BB strong interaction Models
• Asymmetry	K1.8		not yet	-	direct input to BB strong interaction Models
Hypernuclear γ-ray spectroscopy					
• Spectroscopy of Light and Heavy Hypernuclei		Hyperball			ΛN effective two-body interaction
$^{12}_{\Lambda}$C	K1.1		5	single ~10000, γγ ~100	
$^{12}_{\Lambda}$B	K1.1		30	single ~10000, γγ ~100	(CSB)
$^{208}_{\Lambda}$Pb	K1.8		5	~1000 /transitions	
• "Impurity N.P." - Nuclear Structure Change Induced by Λ					
$^{7}_{\Lambda}$He	K1.1		10	330 E2 γ-rays	Λ in neutron-skin
$^{20}_{\Lambda}$Ne	K1.1		a few	1000-10000 ?	spectroscpoy & effective ΛN spin-dependent int.
• B(M1) : g-Factor of Λ in Nuclear Matter; $^{12}_{\Lambda}$C	K1.1		17	~ 15000	size of baryon in nuclear matter
• Spectroscopy of ΛΛ Hypernuclei					
$^{4}_{\Lambda\Lambda}$H	K1.8		10	~ 3100, γγ ~110	ΛΛ spin-orbit force
$^{13}_{\Lambda\Lambda}$B	K1.8		10	~ 100	ΛΛ spin-orbit force
• Spectroscopy of neutron-rich Hypernuclei	?		not yet		
• Ξ⁻-atom X-ray	K1.8				Ξ⁻ nucleus interaction
High Resolution Reaction Spectroscopy of S=-1Hypernuclei		HRBL			
• Fine structure of Λ-single particle potential; $^{90}_{\Lambda}$Zr	K1.8		10	~ 1700 for g.s.	further decomposition of spin-orbit splitting
• Precision spectroscopy of light hypernuclei; $^{12}_{\Lambda}$C	K1.8		10	~ 1000	check of inter-shell mixed configuration
• Spectroscopy of neutron-halo Λ hypernuclei; $^{12}_{\Lambda}$Be	K1.8		10	~ 200	Λ-neutron interaction
• Spectroscopy of Σ hypernuclei; $^{208}_{\Sigma}$Hg	K1.8		10	~ 100	
Kbar-nucleus bound state spectroscopy	K1.1				hadron dynamics in cold dense matter
Hypernuclei production with Heavy Ion					Life time, decay, size

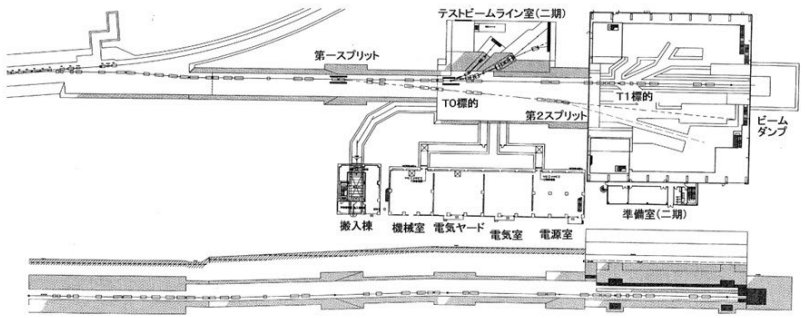
NP02

2nd International Workshop on Nuclear and Particle Physics at 50-GeV, 27-29, Sept. 2002

Summary of Nuclear/Hadron Physics Working Group

Hideto En'yo (RIKEN)
Shin'ya Sawada (KEK)

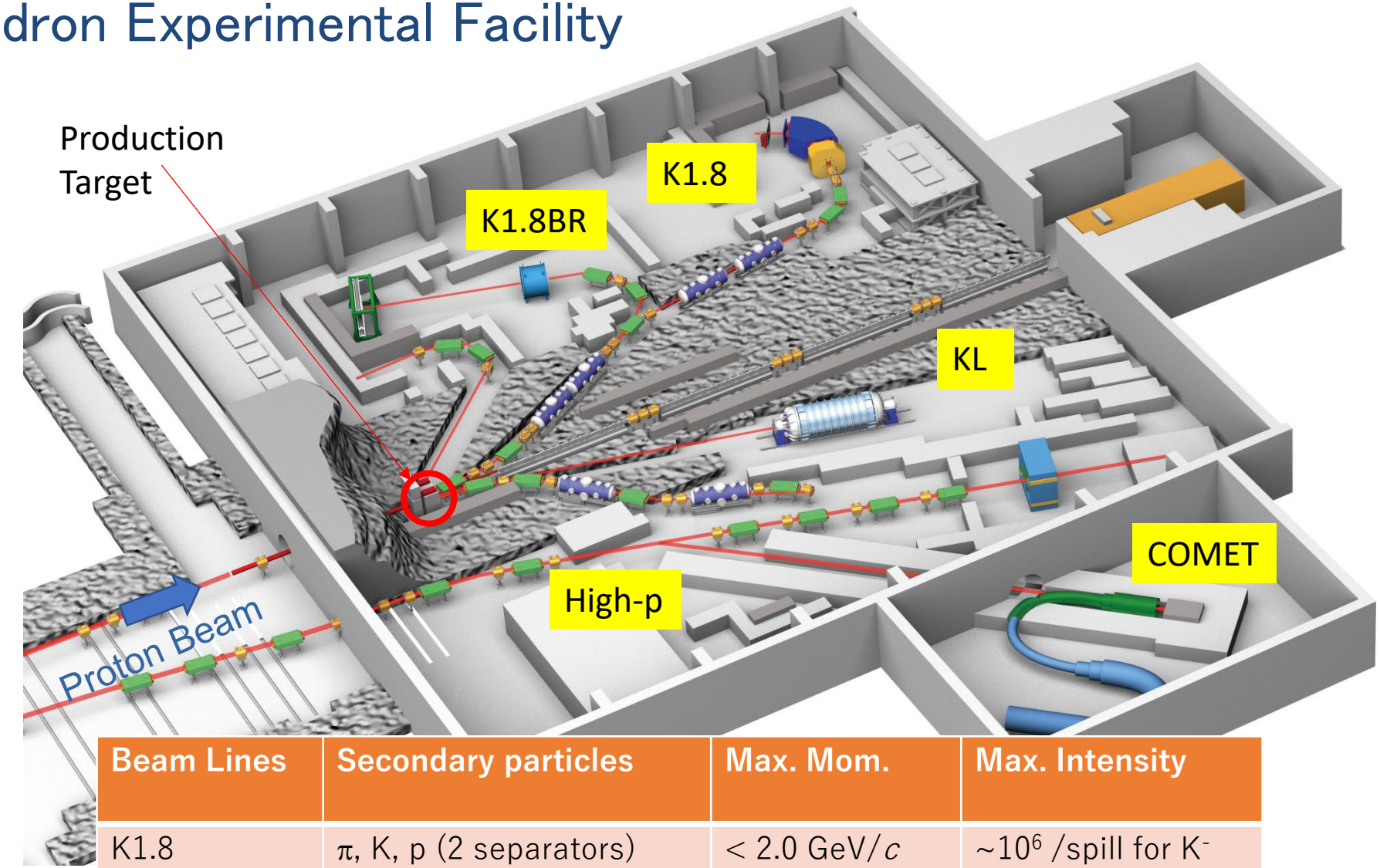
Concept for Multipurpose Beamline K.H.Tanaka



Summary of physics topics discussed at nuclear/hadron physics session

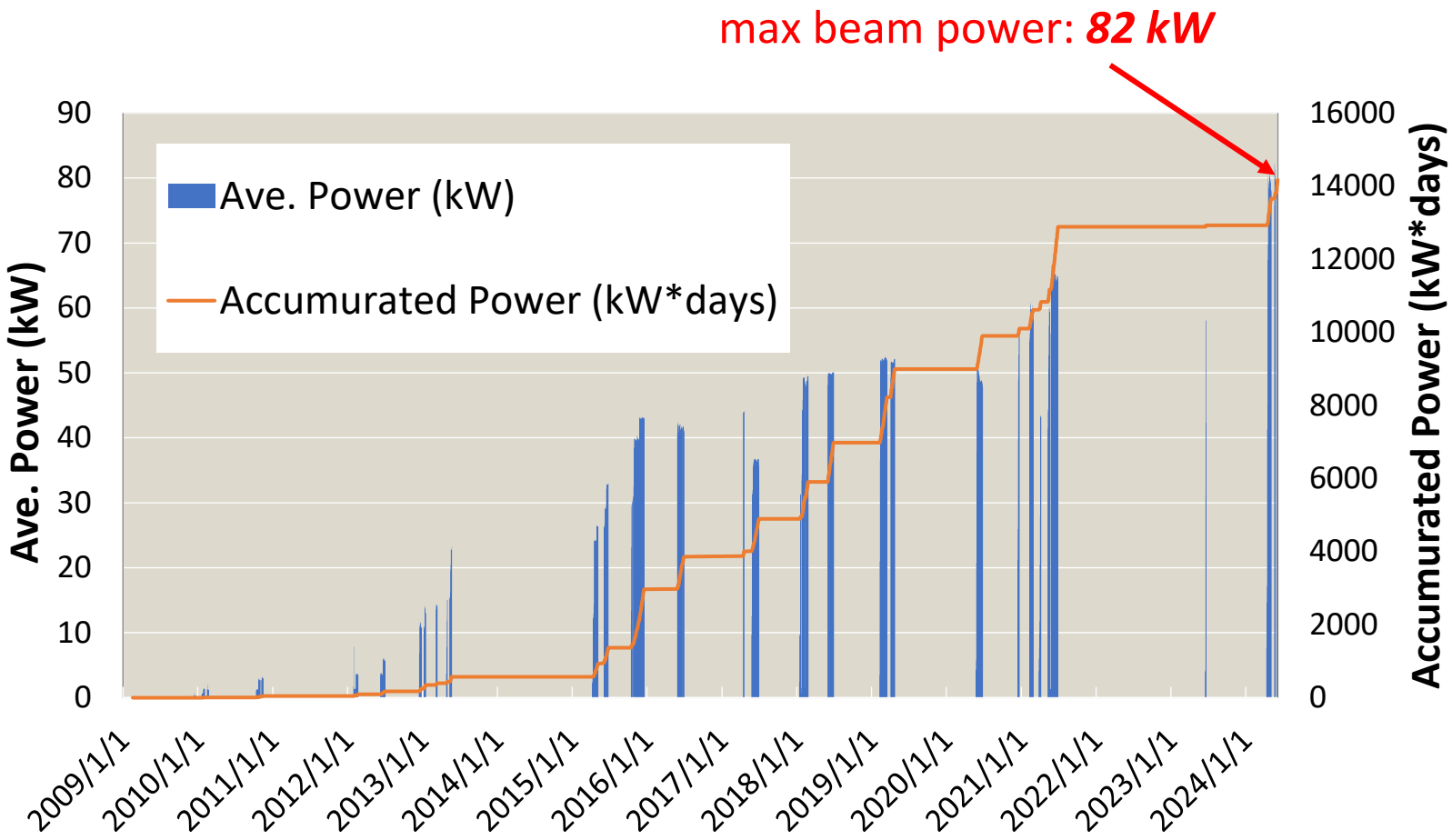
			beam			Apparatus	Comment
			low intensity	high intensity	future		
	Keynote talk	H. Spinka					
	Possibility of HI and pol-p acceleration	Y. Mori					
	Towards the construction of multi-purpose beam line	K.H. Tanaka					
Sturucture function	Future of structure functions of the nucleon and nuclei	T.-A. Shibata		primary p	pol. p		
	Sturucture function and related physics	N. Saito		primary p	pol. p		
	Muon pair measurements and physics	S. Sawada		primary p			
	The vertex spectrometer of the NA60 experiment	K. Banicz	primary p		HI	dimuon spectrometer	pixel telescope
Nuclear matter physics	Vector Meson Measurement at JHF to Explore the Chiral Symmetry of QCD	S. Yokkaichi	primary p, secondaries				
	Proposed spectrometer	K. Ozawa				dielectron spectrometer	HBD
	Comments and discussion	H. Hamagaki	primary p		HI	crystal ball	
	Experiments with HI beams*	S. Esumi			HI	multipurpose	
	The vertex spectrometer of the NA60 experiment	K. Banicz			HI	dimuon spectrometer + pixel tracking	
	Muon pair measurements and physics	S. Sawada		primary p		dimuon spectrometer	
	Multifragmentation in GeV-energy domain – now and future	T. Murakami	primary p, secondaries		HI	Bragg curve counter	
	Overview of Lattice QCD Calculations – Studies of New Aspects of QCD at JHF –	A. Nakamura					
	Diphoton emission from hot and dense matter near the critical end point	K. Fukushima					
Nuclear force	Very High P_t proton-proton elastic scattering at U-70 and possibly JHF	A.D. Krish/K. Yonehara	primary p	primary p			pol. p target
Meson hadron spectroscopy	Hadron physics with monochromatic KL beam: Z+ search	T. Nakano	1GeV/c pi			charged particle spectrometer + neutron	
	Has the PROMICE/WASA detector at CELSIUS seen the first true dibaryon?	T.J. Goldman					
	Separated K+ beam line and hadron spectroscopy	V. Obraztsov T. Tsuru		secondary K		beam line spectrometer	RF separator

Hadron Experimental Facility



Beam Lines	Secondary particles	Max. Mom.	Max. Intensity
K1.8	π, K, p (2 separators)	< 2.0 GeV/c	~10^6 /spill for K^-
K1.8BR	π, K, p (1 separator)	< 1.1 GeV/c	~10^5 /spill for K^-
KL	Neutral Kaon	~ 2.1 GeV/c	~10^7 /spill

SX Beam Power History



K beam intensity

KEK-PS: K purity was for example ~25%.

KEK-PS Beamline	K / spill (4s)	Protons / spill (4s)	Note
K2	2×10^{4} K^-	2×10^{12}	1.67GeV/c, E522
	1×10^{4} K^-	3×10^{12}	1.0GeV/c, E549
K5	1.9×10^{5} K^+	2.2×10^{12}	0.66GeV/c, E470
	6×10^{3} K^-	1.5×10^{12}	stopped, E549
K6	1.3×10^{4} K^+	0.87×10^{12}	1.2GeV/c, E559

J-PARC K1.8 Beamline (with 51kW primary proton beam):

Beamline	K / spill (5.2s)	Protons / spill (5.2s)	Note
K1.8	3.3×10^{5} K^-	5.4×10^{13}	1.8GeV/c, E07 purity=82.5%
	7.0×10^{5} K^-	5.4×10^{13}	1.8GeV/c, purity=44%

Achievements in research at the Hadron Experimental Facility

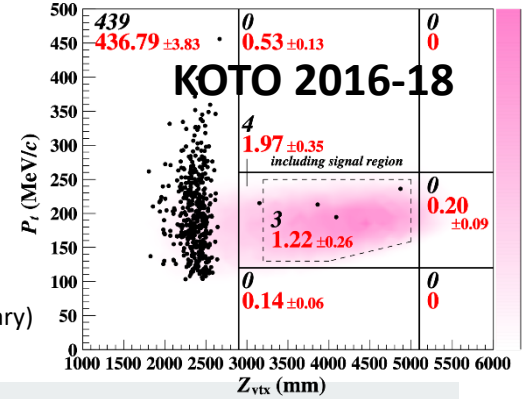
Flavor Physics

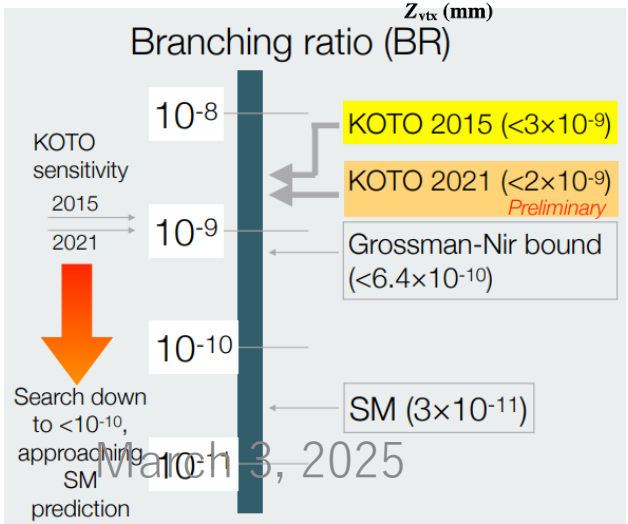
$K_L^0 \to \pi^0 \nu\bar{\nu}$ search @ KOTO

→ Approaching the SM sensitivity for CP violation

KOTO 2021

Single Event Sensitivity = 2×10^{-9} (Preliminary)



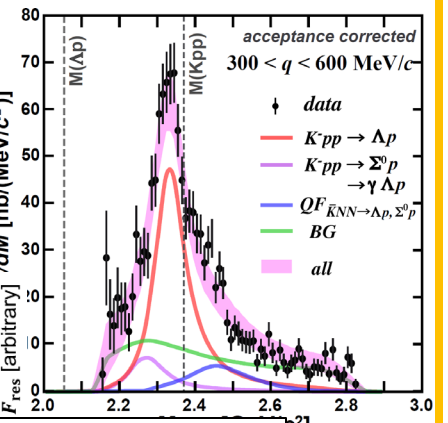


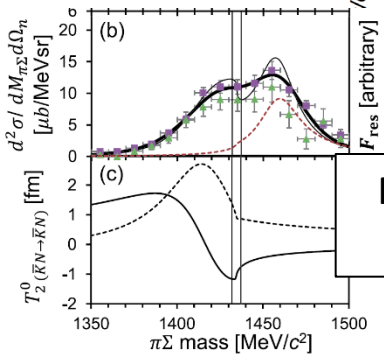
Hadron Physics

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

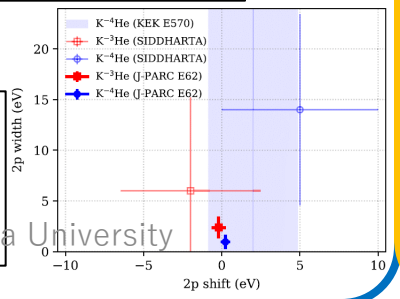
→ Established a new direction to understand meson-baryon int.

Kaonic nuclear state, "K-pp"





Pole position of Λ(1405)



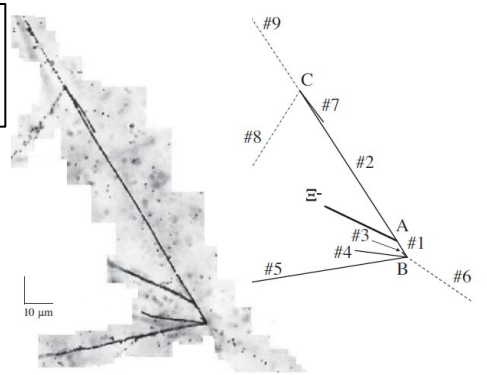
Ultra-precise measurement of kaonic atoms

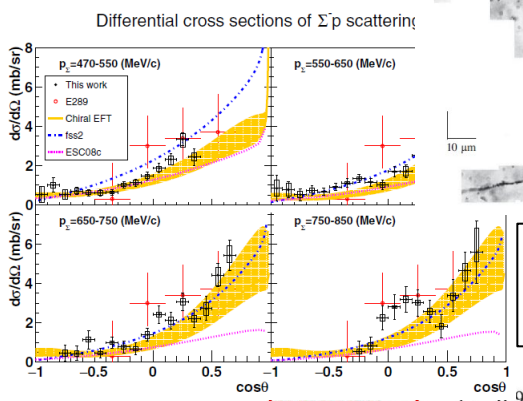
Strangeness Nuclear Physics

A lot of progress in hypernuclear research

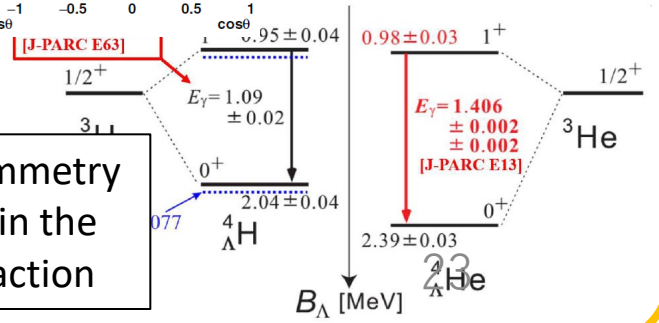
→ Clarified attractive S=–2 ΞN interaction and deepened S=–1 ΛN, ΣN interactions

Observation of Ξ hypernuclei





First precise ΣN scattering

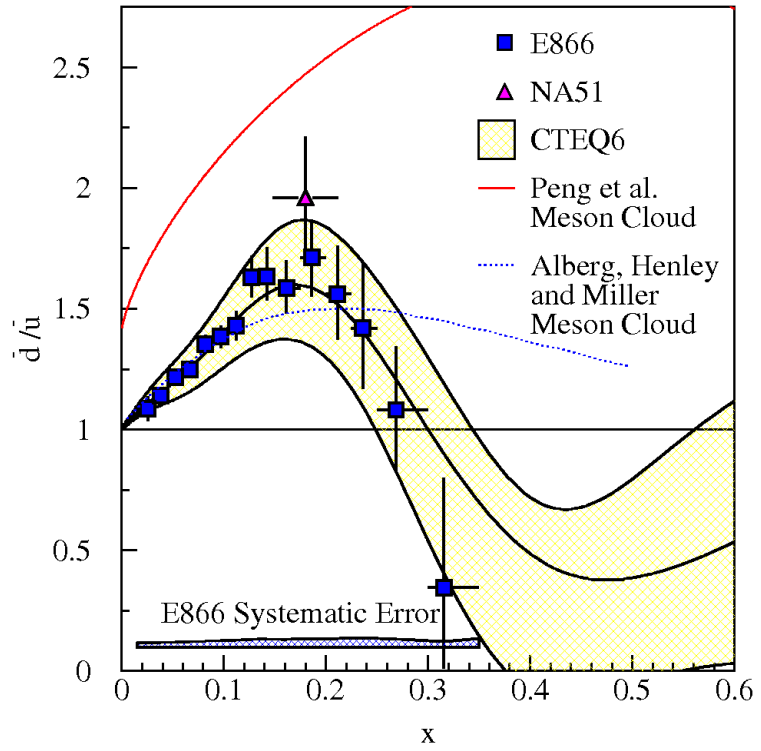


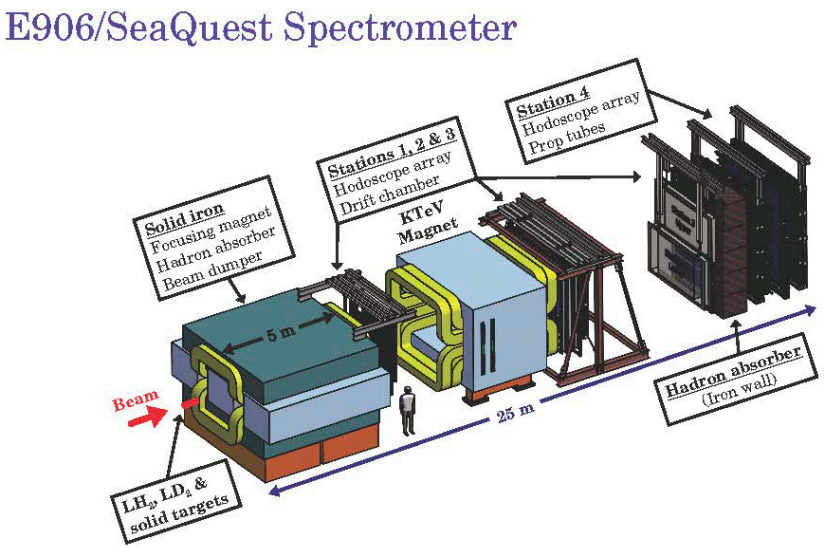
Charge-symmetry breaking in the ΛN interaction

- Strangeness Nuclear Physics
  - Though programs were shown somehow even almost around the beginning of J-PARC.
  - It is now 20 years then, many of them have been realized, or on the way to realization.
- Hadronic Physics
  - Various ideas were proposed around the beginning of J-PARC.
  - One of the first programs, the phi experiment (E16), is now being conducted, after 20 years.
    - “multipurpose beamline”（~10 oku-Yen）was not included in the first phase budget of J-PARC, but somehow realized. But this kind of “fortune” would not be a realistic currently.
  - There may be various possibilities of hadronic physics experiments, and we should make up an inclusive plan where many hadronic physicists can collaborate.

Experiment at Fermilab: SeaQuest

- A proposal to J-PARC, P05, has been realized at Fermilab with the 120-GeV Main Injector as “SeaQuest”





- Targets: LH_2, LD_2, C, Fe, W
- Focusing magnet (FMag) & Tracking magnet (KMag)
- Iron inside FMag, as hadron absorber & beam dump

- x ~ 0.3 程度の「大きな」xまで測定
- 大きなxで比が1以下となる？

$$\frac{\sigma^{pd}}{2\sigma^{pp}} = \frac{1}{2}\left[1+\frac{\sigma^{pn}}{\sigma^{pp}}\right] \approx \frac{1}{2}\left[1+\frac{\bar{u}_n(x_2)}{\bar{u}_p(x_2)}\right] \Rightarrow \frac{\sigma^{pd}}{2\sigma^{pp}} \approx \frac{1}{2}\left[1+\frac{\bar{d}(x_2)}{\bar{u}(x_2)}\right]$$

Experiment at Fermilab: SeaQuest

Nature 590, 561 (2021)

Article

The asymmetry of antimatter in the proton

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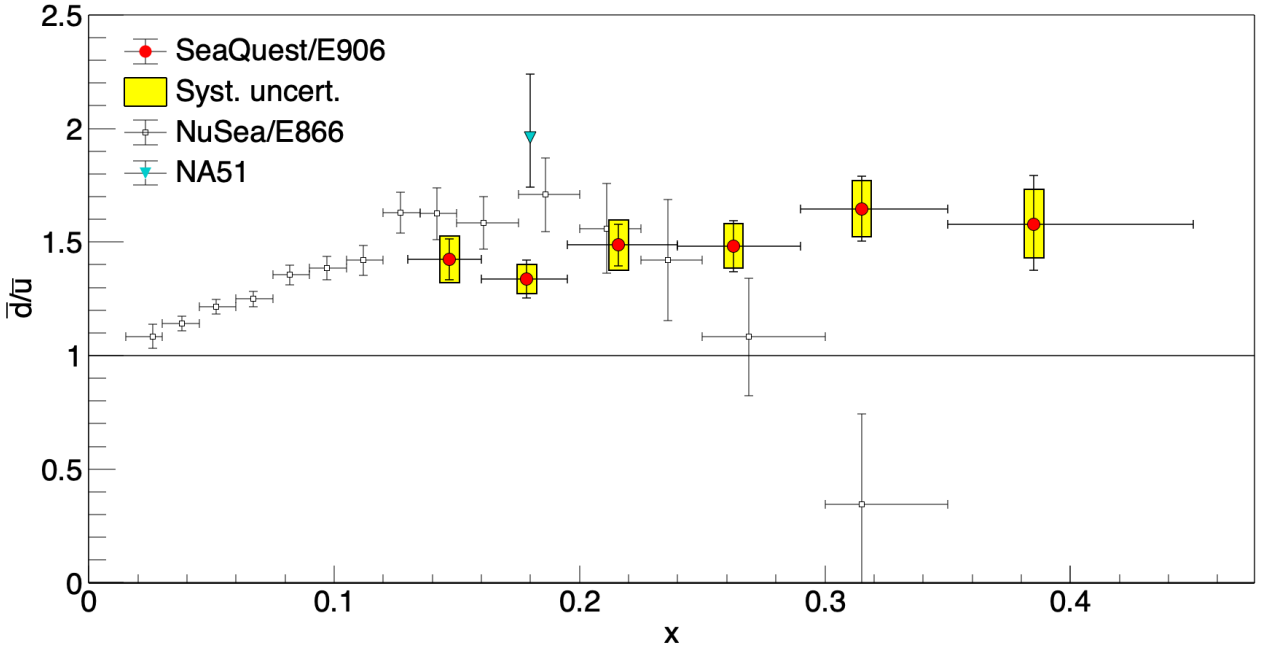
J. Dove[1], B. Kerns[1], R. E. McClellan[1,16], S. Miyasaka[2], D. H. Morton[3], K. Nagai[2,4], S. Prasad[1], F. Sanftl[2], M. B. C. Scott[3], A. S. Tadepalli[5,18], C. A. Aidala[3,6], J. Arrington[7,19], C. Ayuso[3,20], C. L. Barker[8], C. N. Brown[9], W. C. Chang[4], A. Chen[1,3,4], D. C. Christian[10], B. P. Dannowitz[1], M. Daugherity[8], M. Diefenthaler[1,16], L. El Fassi[5,11], D. F. Geesaman[7,21], R. Gilman[5], Y. Goto[12], L. Guo[6,22], R. Guo[13], T. J. Hague[8], R. J. Holt[7,23], D. Isenhower[8], E. R. Kinney[14], N. Kitts[8], A. Klein[6], D. W. Kleinjan[6], Y. Kudo[15], C. Leung[1], P.-J. Lin[14], K. Liu[6], M. X. Liu[6], W. Lorenzon[3], N. C. R. Makins[1], M. Mesquita de Medeiros[7], P. L. McGaughey[6], Y. Miyachi[15], I. Mooney[3,24], K. Nakahara[16,25], K. Nakano[2,12], S. Nara[15], J.-C. Peng[1], A. J. Puckett[6,26], B. J. Ramson[3,27], P. E. Reimer[7] ✉, J. G. Rubin[3,7], S. Sawada[17], T. Sawada[3,28], T.-A. Shibata[2,29], D. Su[4], M. Teo[1,30], B. G. Tice[7], R. S. Towell[8], S. Uemura[6,31], S. Watson[8], S. G. Wang[4,13,32], A. B. Wickes[6], J. Wu[10], Z. Xi[8] & Z. Ye[7]

PHYSICAL REVIEW C **108**, 035202 (2023)

Measurement of flavor asymmetry of the light-quark sea in the proton with Drell-Yan dimuon production in $p+p$ and $p+d$ collisions at 120 GeV

J. Dove,[1] B. Kerns,[1] C. Leung,[1] R. E. McClellan,[1,*] S. Miyasaka,[2] D. H. Morton,[3] K. Nagai,[2,4,5] S. Prasad,[1,6] F. Sanftl,[2] M. B. C. Scott,[3,6] A. S. Tadepalli,[7,†] C. A. Aidala,[3,5] J. Arrington,[6,‡] C. Ayuso,[3] C. T. Barker,[8] C. N. Brown,[9] T. H. Chang,[4] W. C. Chang,[4] A. Chen,[1,4,3] D. C. Christian,[9] B. P. Dannowitz,[1] M. Daugherity,[8] M. Diefenthaler,[1] L. El Fassi,[10,7] D. F. Geesaman,[6] R. Gilman,[7] Y. Goto,[11] L. Guo,[5,§] R. Guo,[12] T. J. Hague,[8,‡] R. J. Holt,[6,‖] D. Isenhower,[8] E. R. Kinney,[13] N. D. Kitts,[8] A. Klein,[5] D. W. Kleinjan,[5] Y. Kudo,[14] P.-J. Lin,[13,4] K. Liu,[5] M. X. Liu,[5] W. Lorenzon,[3] N. C. R. Makins,[1] M. Mesquita de Medeiros,[6] P. L. McGaughey,[5] Y. Miyachi,[14] I. Mooney,[3,¶] K. Nakahara,[15,**] K. Nakano,[16,2,11] S. Nara,[14] J. C. Peng,[1] A. J. Puckett,[5,††] B. J. Ramson,[3,9] P. E. Reimer,[6] J. G. Rubin,[3,6] S. Sawada,[17] T. Sawada,[3,‡‡] T.-A. Shibata,[2,11,§§] S. H. Shiu,[4] D. Su,[4] M. Teo,[1] B. G Tice,[6] R. S. Towell,[8] S. Uemura,[8,‖‖] T. S. Watson,[8] S. G. Wang,[4,12,¶¶] A. B. Wickes,[5] J. Wu,[9] Z. Xi,[8] and Z. Ye[6,a]
(FNAL E906/SeaQuest Collaboration)



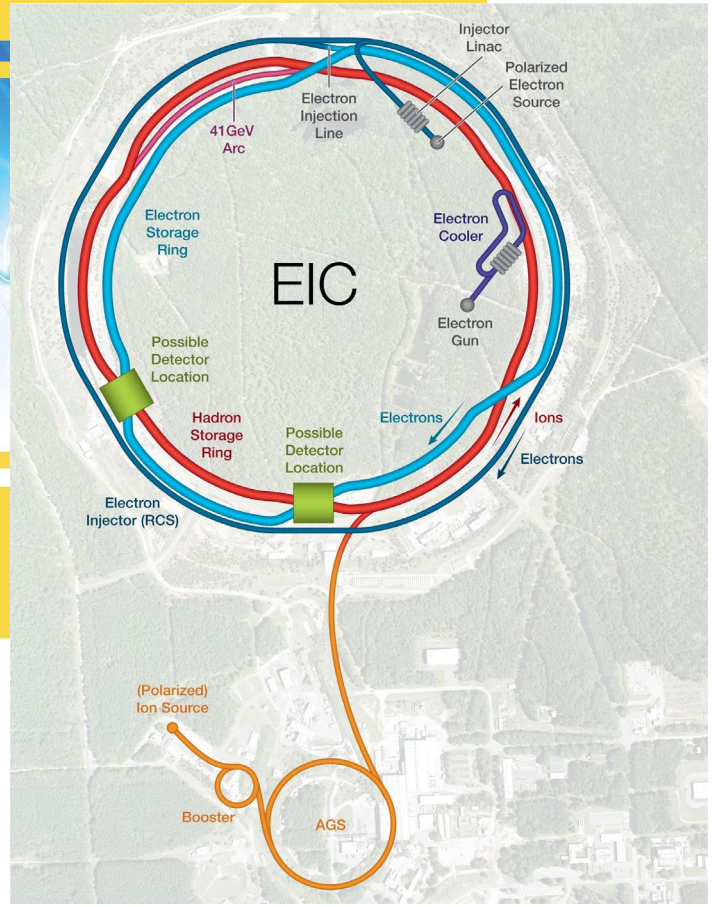
- The ratio of the Drell-Yan cross sections $(p+d)/2(p+p)$ at large x ($0.13 < x < 0.45$) was measured using the 120-GeV proton beam120 GeV and then the ratio of sea quarks $\bar{d}(x)/\bar{u}(x)$ was deduced.
- A previous experiment suggested this ratio might be smaller than 1, but the present experiment proved that the ratio is larger than 1 even at larger x values. This result is consistent with theories including the meson cloud model.

EIC

SCIENCE REQUIREMENTS AND DETECTOR CONCEPTS FOR THE ELECTRON-ION COLLIDER

EIC Yellow Report

計900ページ



- Physics of EIC
  - How nucleon spin emerged?
  - How nucleon mass emerged?
  - What emergent characteristics the high-density gluon system has?
- Status of the project
  - December, 2019: CD-0 (approval of scientific significance)
  - January, 2020: Brookhaven National Lab was selected as the site
  - 2025?: CD-3 (approval of beginning of construction), completion of construction and start of experiments are expected in 2032

- Highly polarized electron (~70%) and proton (~70%) beams
- Ion beams from electrons to heavy nuclei such as gold, lead, or uranium
- Variable e+p center-of-mass energies from 20-100 GeV, upgradable to 140 GeV
- High collision electron-nucleon luminosity 10^{33}-10^{34} $cm^{-2}s^{-1}$

As it takes some time to realize EIC, R&D and education at currently running facilities are important. Collaboration between EIC and J-PARC is essential.

Hadron Extension

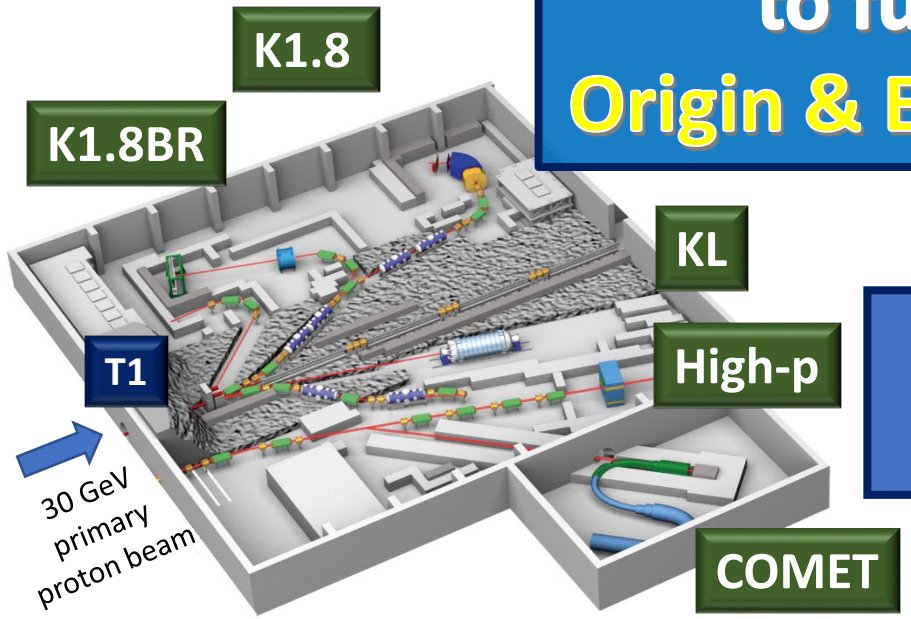
Many slides from Sakuma

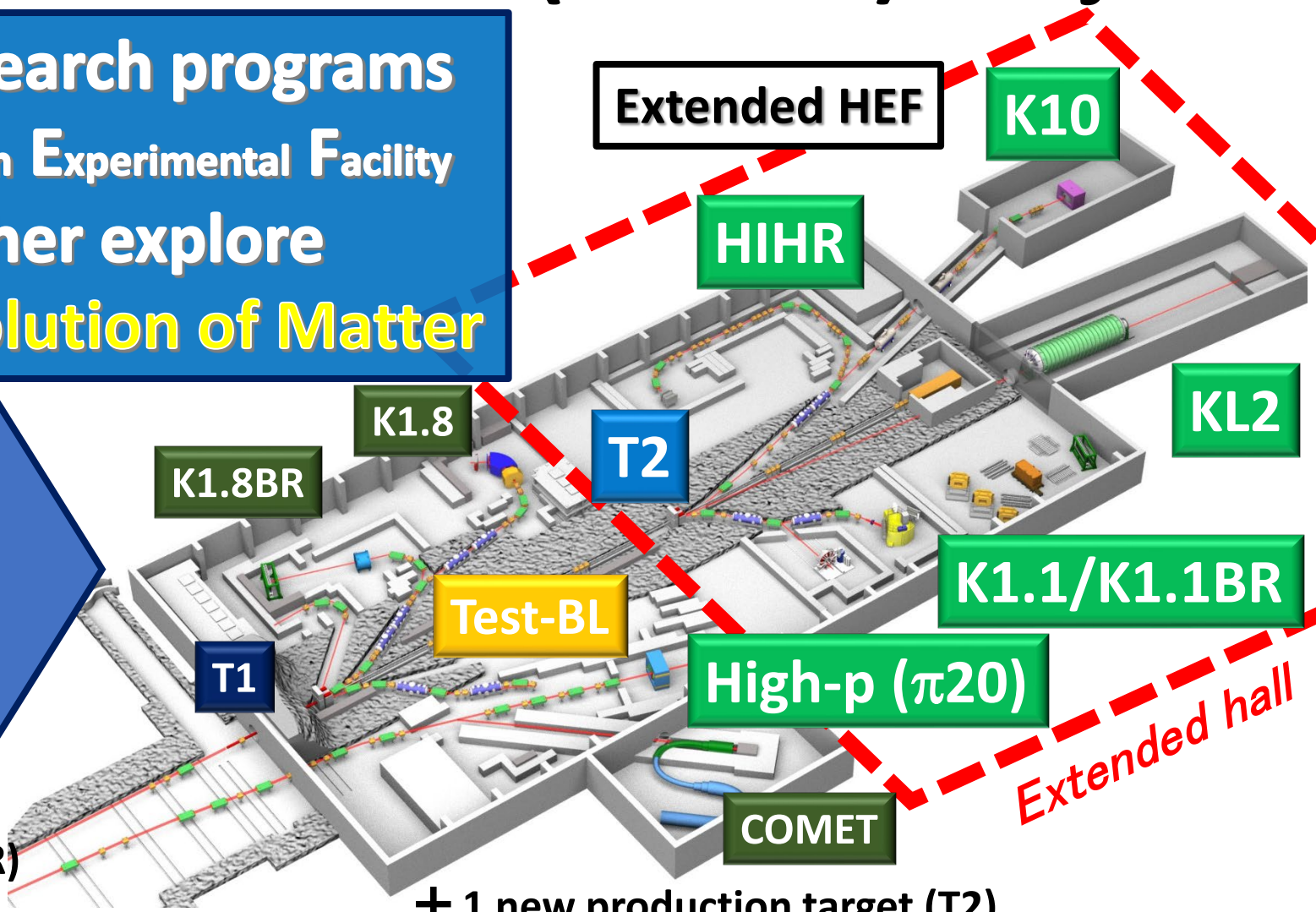
Hadron Experimental Facility eXtension (HEF-ex) Project

Present HEF (2009～)

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

Extended HEF





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)

＋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

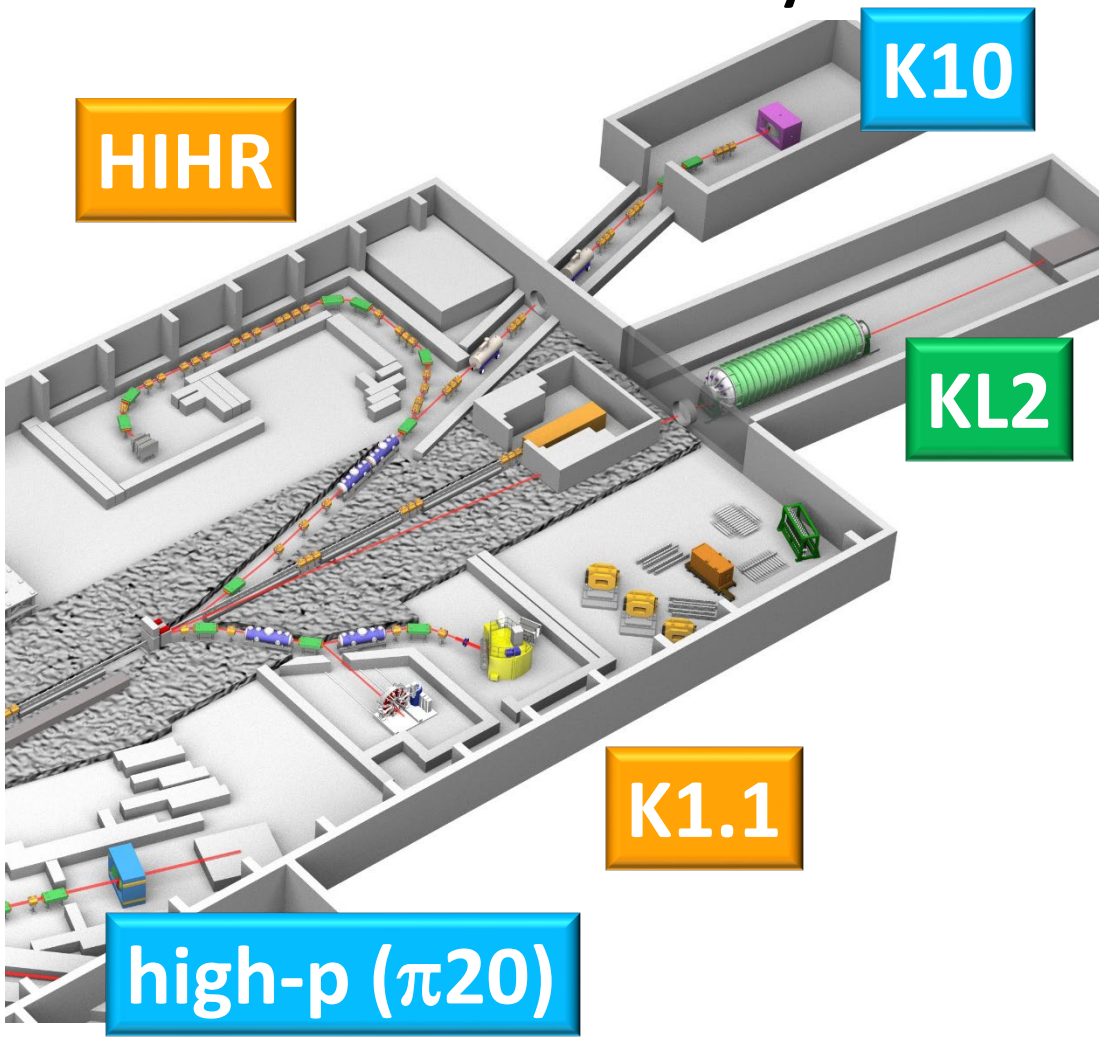
Investigate diquarks in baryons

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 $K_L^0 \to \pi^0 \nu\bar{\nu}$ measurement**
- intense neutral K beam



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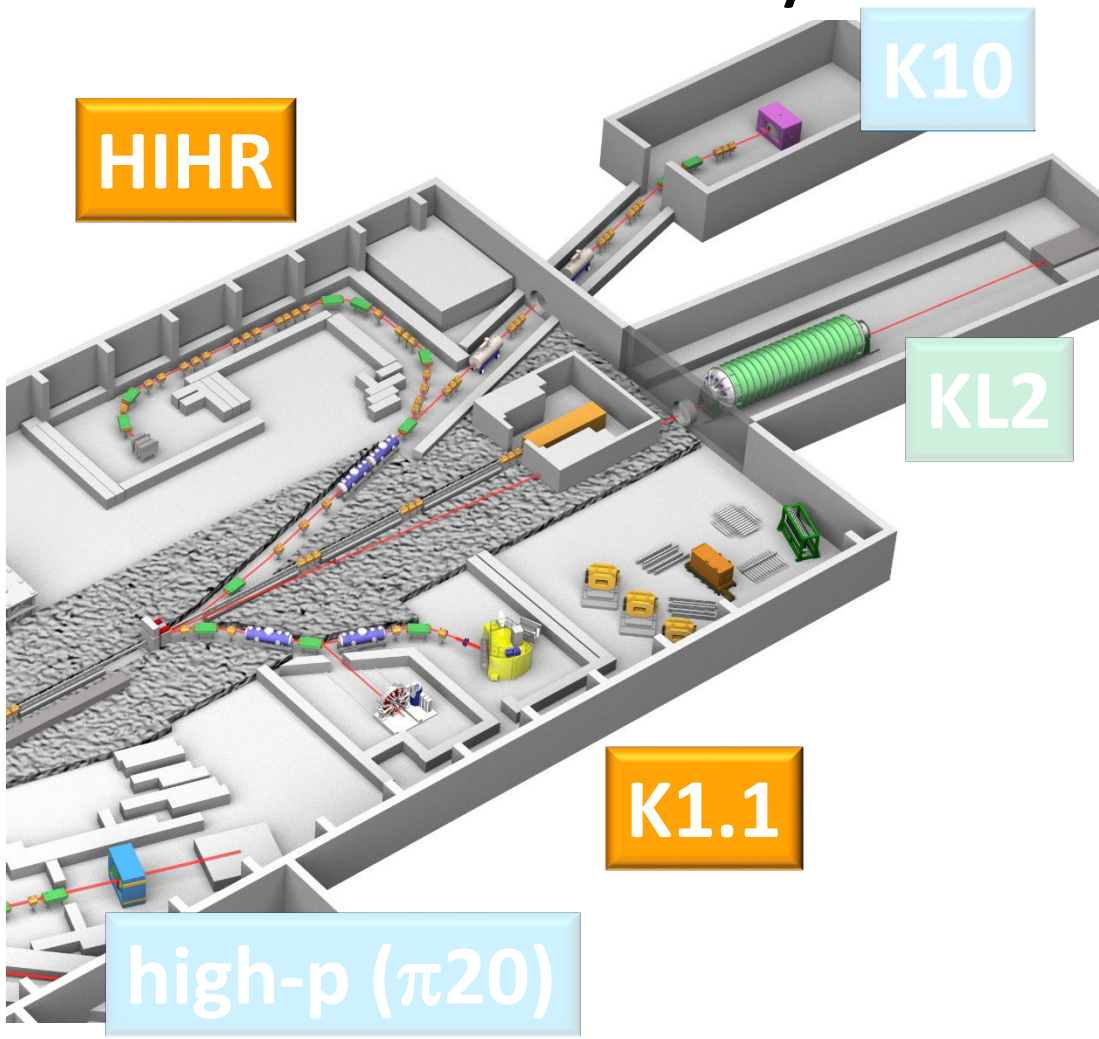
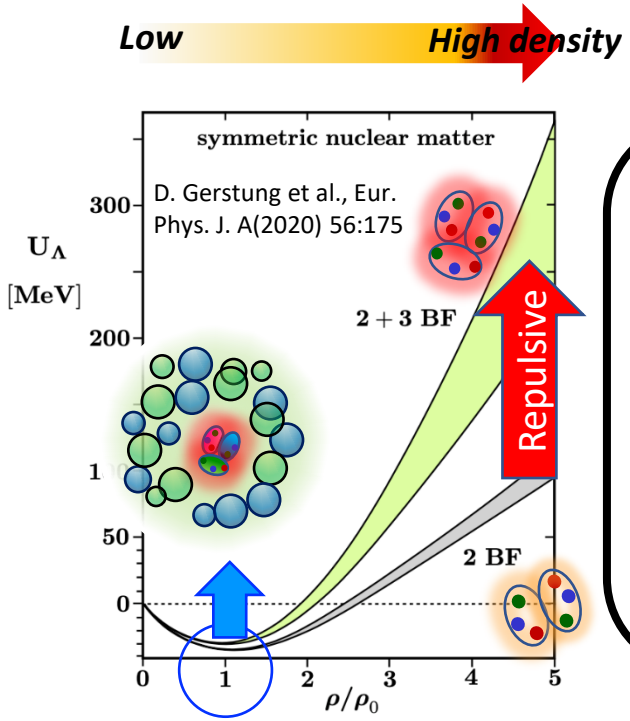


Strangeness Nuclear Physics: Hyperon in Dense Environment

Why can heavy neutron stars exist?

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

ΛNN 3 Baryon Force is a key

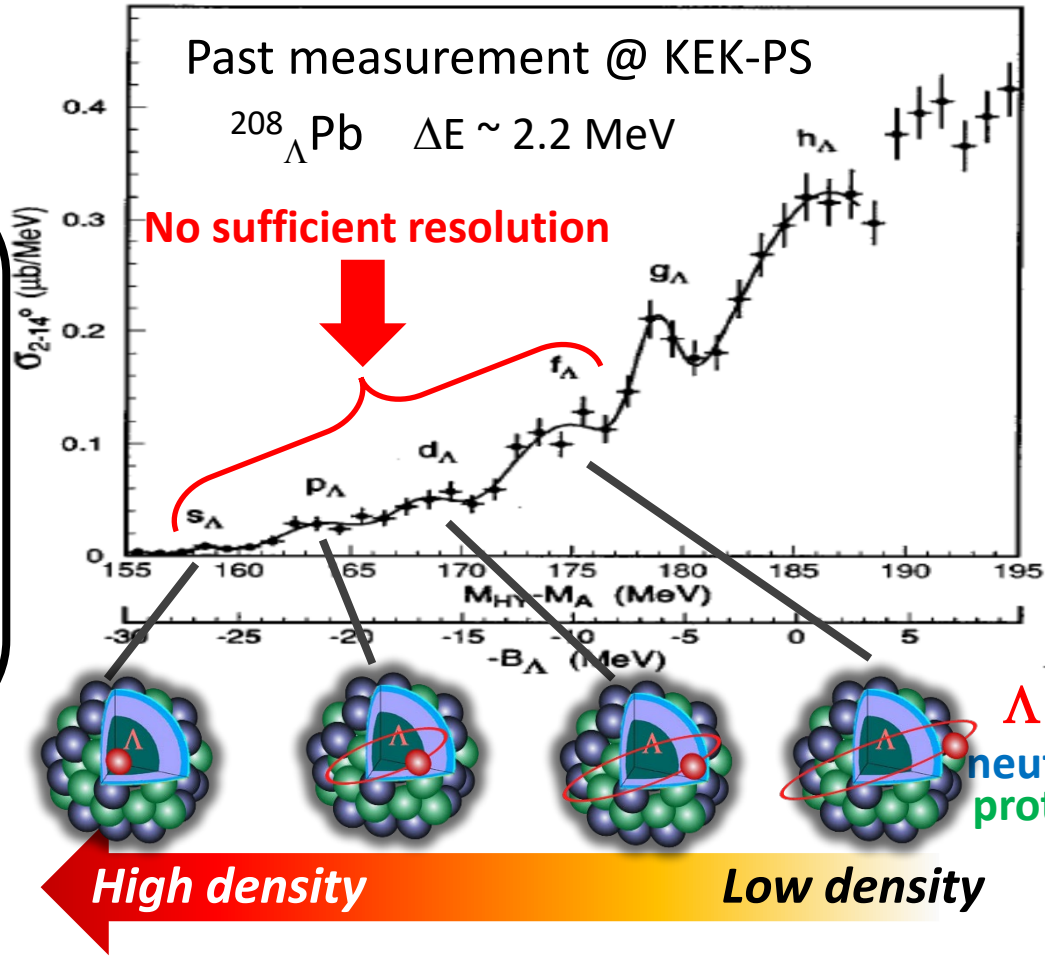


heavy Λ-hypernuclei :

Λ binding energies (B_Λ)

→ density dependent ΛN interaction

→ We need precise measurements



We need to determine

a **tiny fraction of 3 Baryon Force effects**

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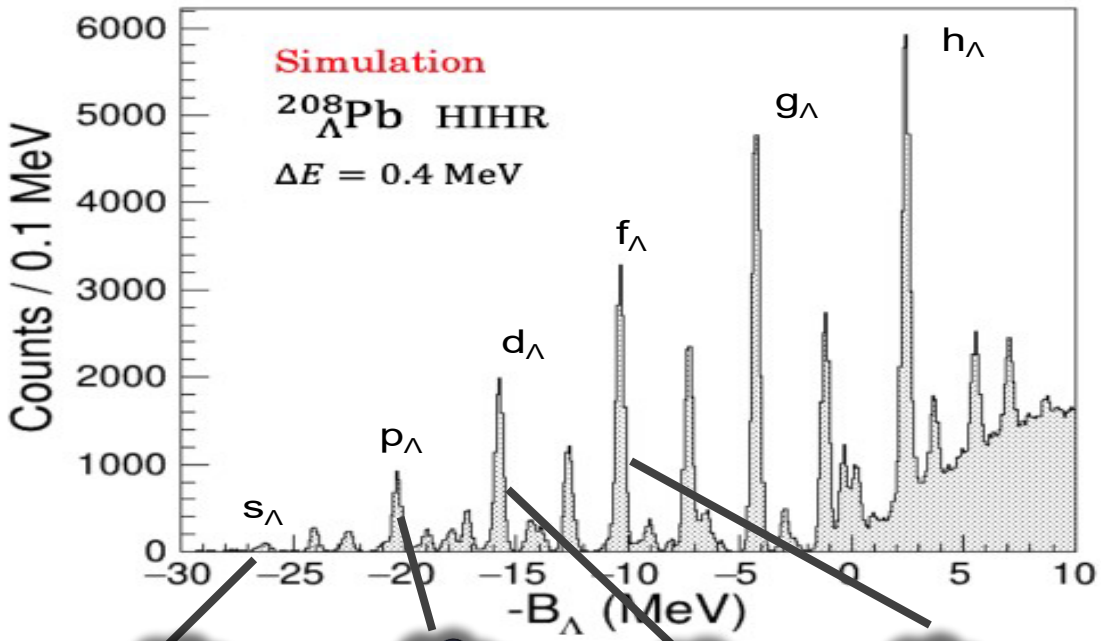
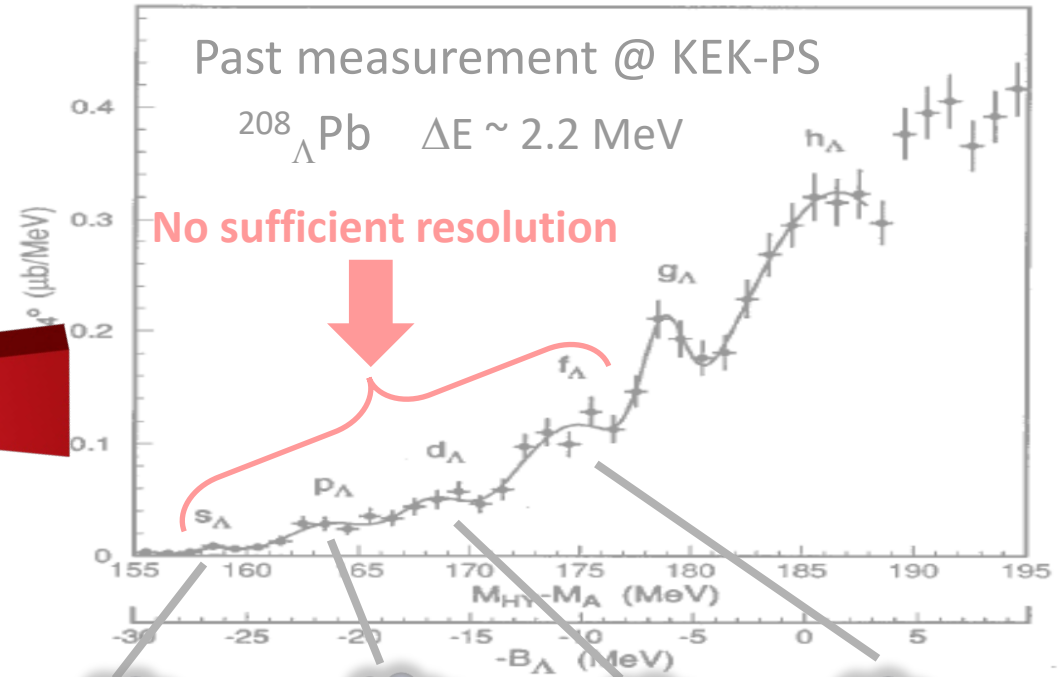
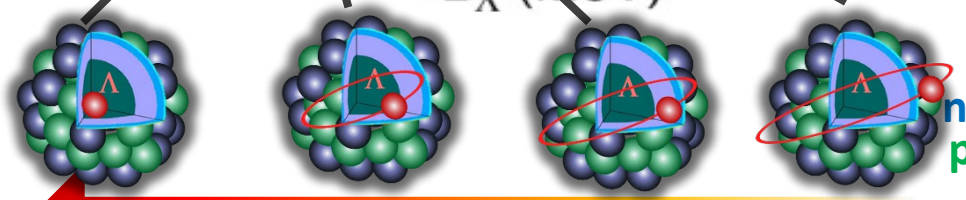
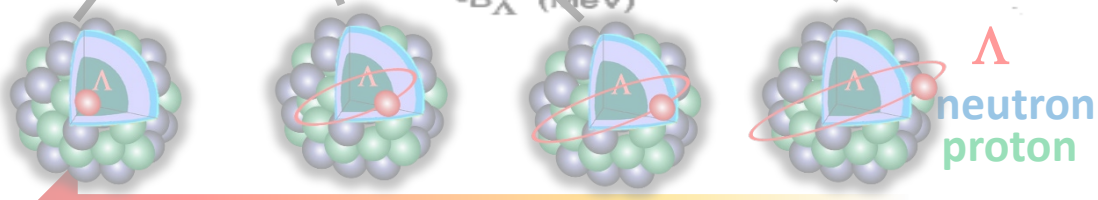
Need separation of each Λ orbital state









High density Low density

High density Low density

Strangeness Nuclear Physics: Hyperon in Dense Environment

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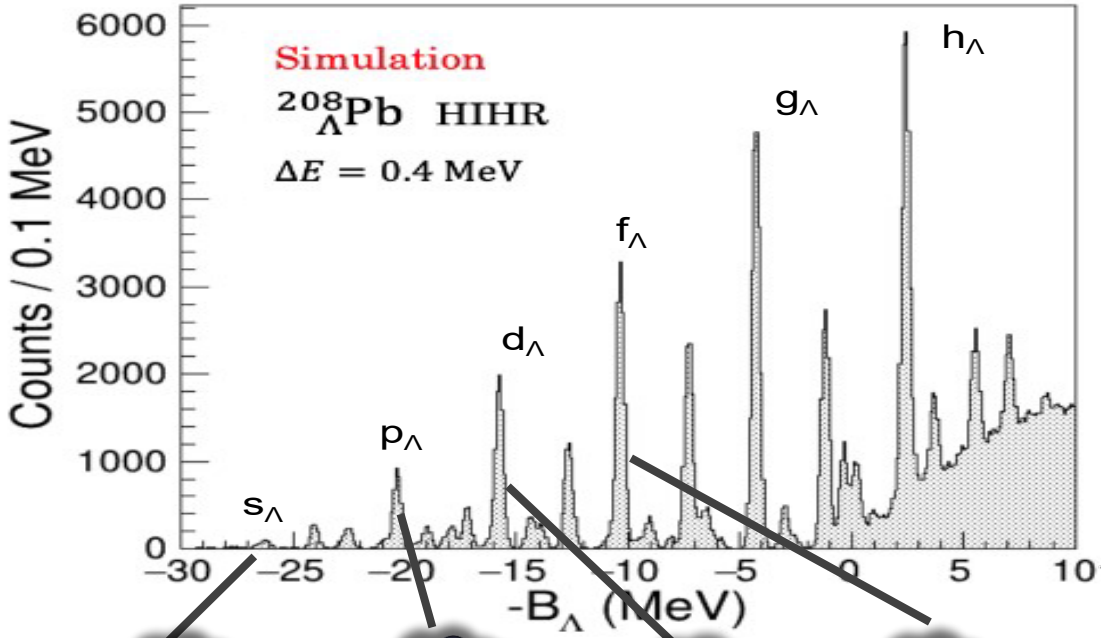
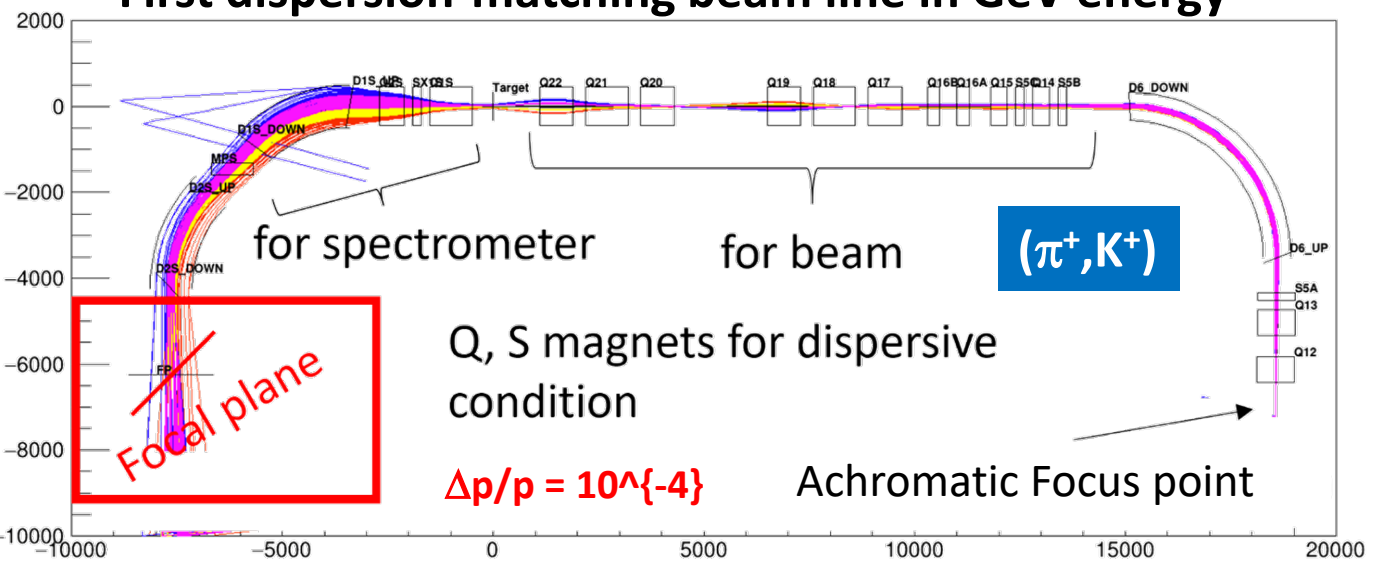
Ultra-high-resolution Λ-hyp. spectroscopy



HIHR beam line (High-Intensity High-Resolution)

First dispersion-matching beam line in GeV energy



up to 2 GeV/c

- 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)

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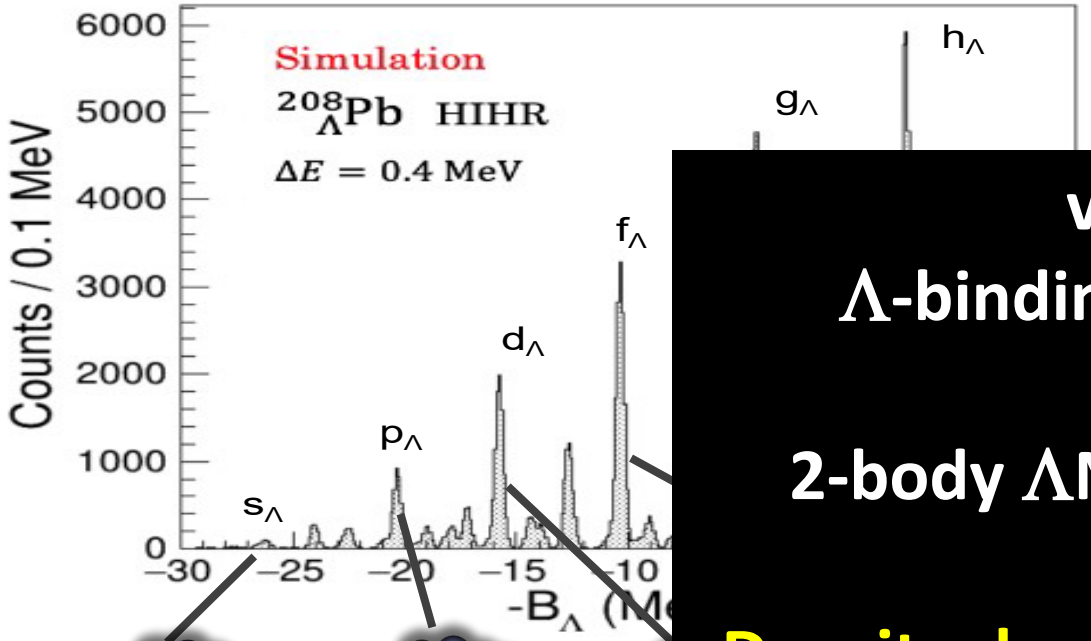
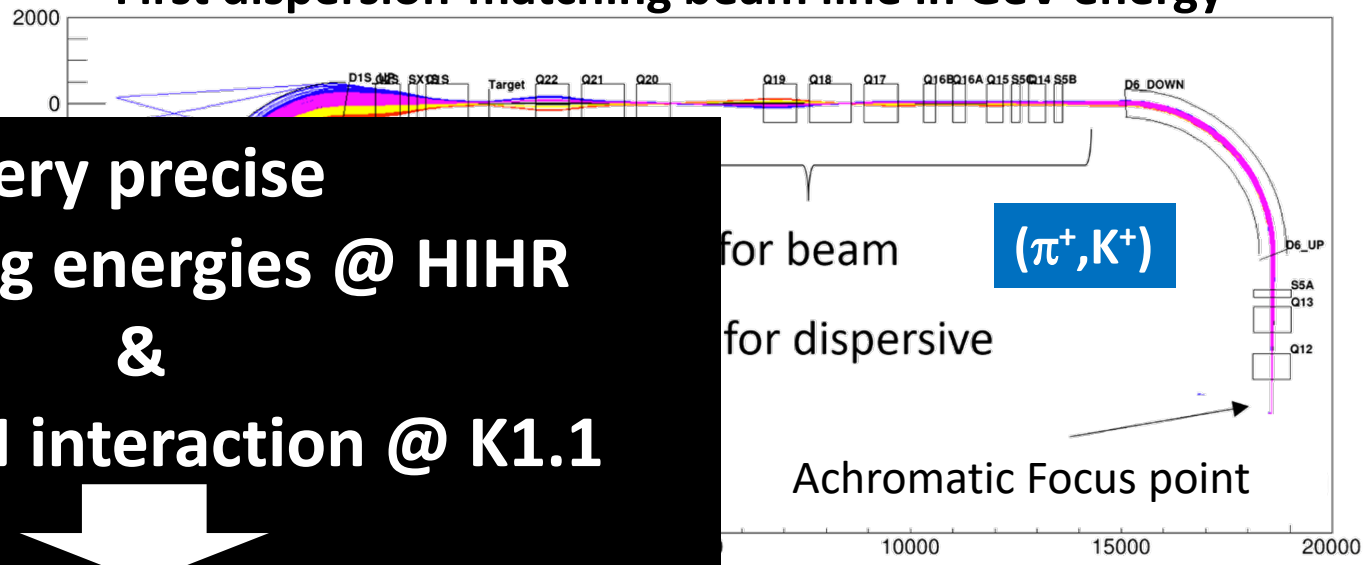


HIHR beam line (**H**igh-**I**ntensity **H**igh-**R**esolution)

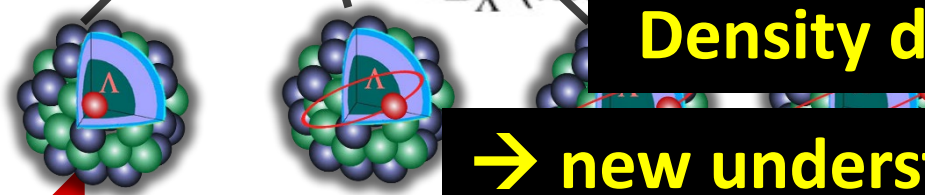
First dispersion-matching beam line in GeV energy



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

Density dependent ΛN interaction

→ new understanding of neutron star matter



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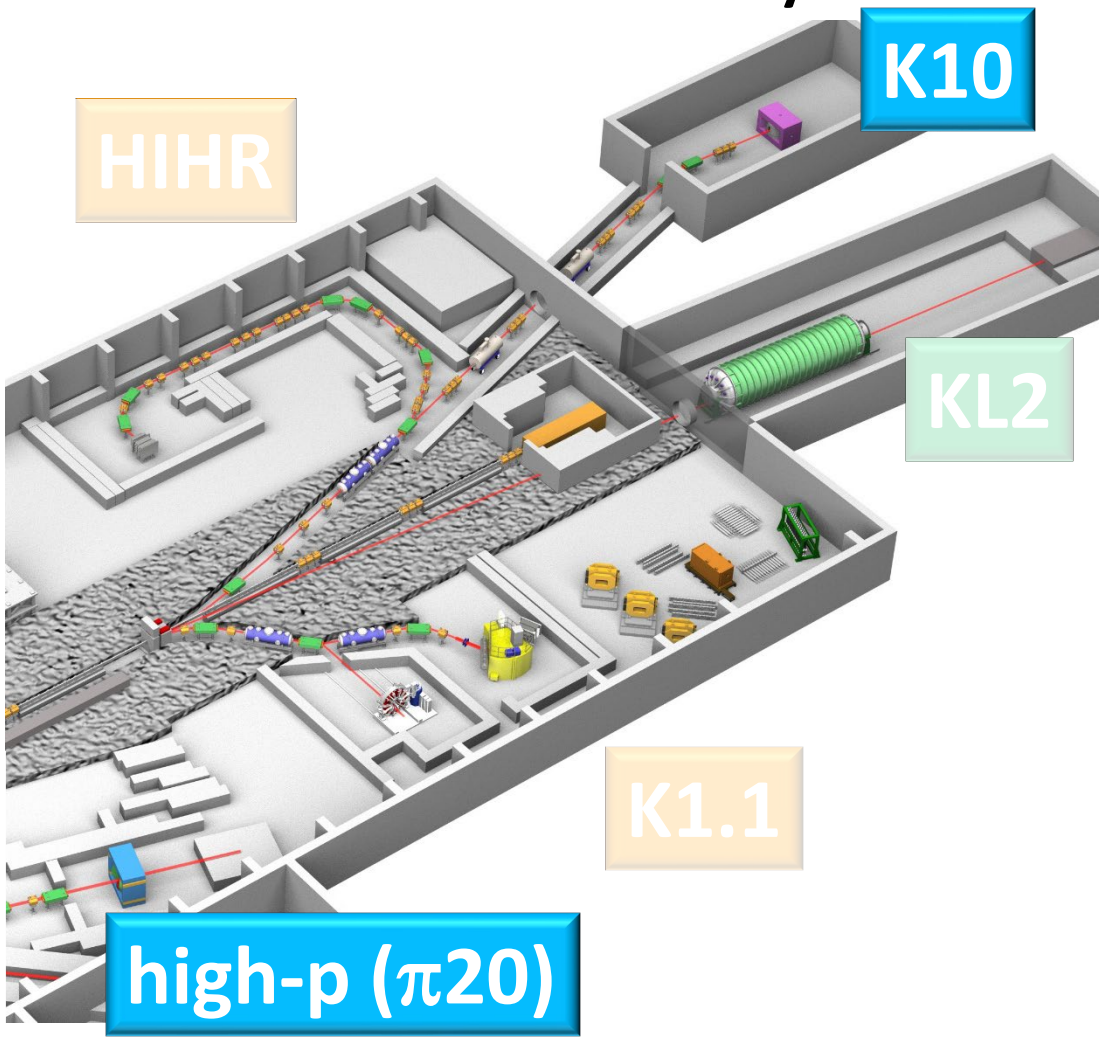


Hadron Physics: Diquarks in Baryons

How quarks build hadrons?

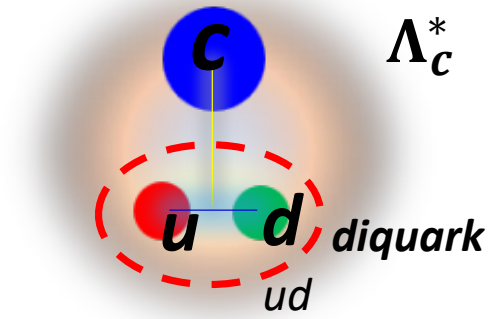
➢ Investigate **diquarks** in baryons **toward** understanding of **dense quark matter**

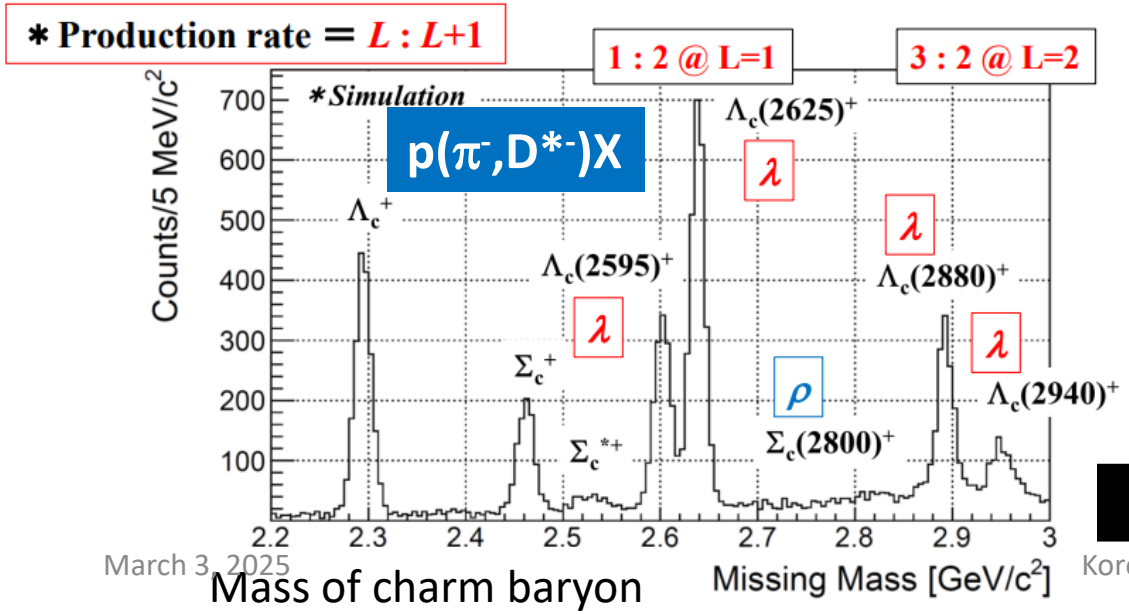
➢ Charm Baryon Spectroscopy

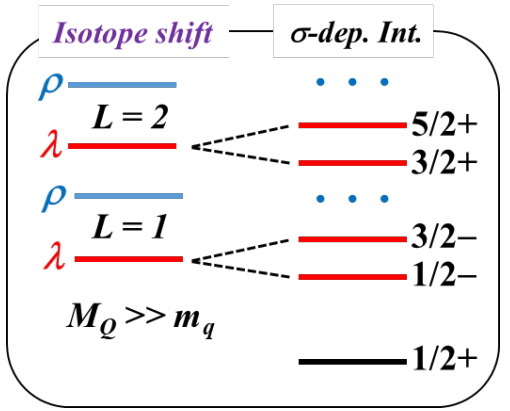
using intense high-momentum π beam @ High-p (π20)

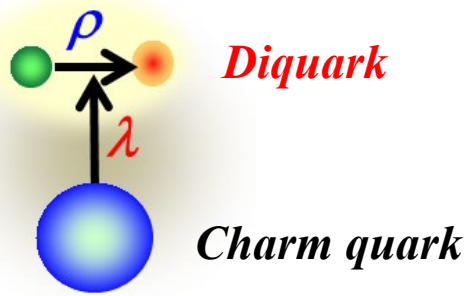
Establish a diquark (*ud*)

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

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using intense high-momentum π beam @ High-p (π20)

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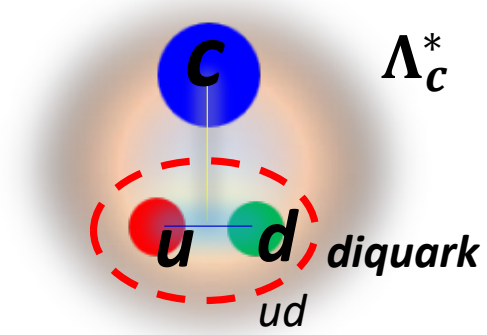


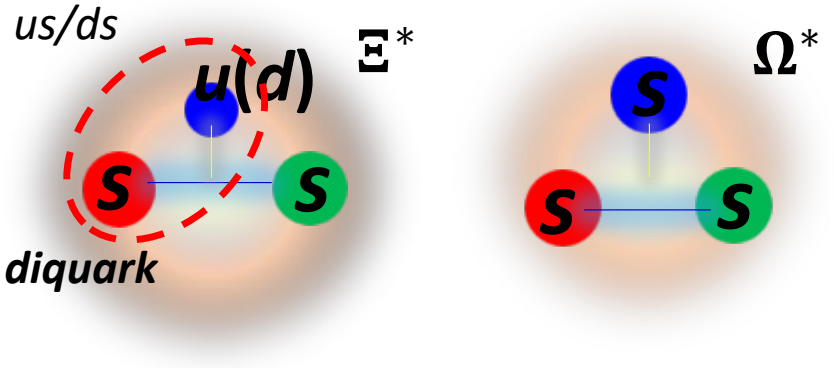
➢ **Multi-Strange Baryon Spectroscopy**

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

Efforts leaded by Hadron Hall Users' Association

- 3rd White Paper for Hadron Extension
  - https://arxiv.org/pdf/2110.04462
- Discussion on step-by-step realization
  - A town-hall meeting was held on February 20, 2025.
  - The next meeting will be September 26-27, as a post workshop of Hyp2025.

Hadronic Physics for the future J-PARC

What do we like to know from hadronic physics?

- How is the hadron mass generated?
  - It might be clear from theory, but how about experiment?
  - What should be measured?
  - We are conducting E16, the phi mass experiment. What is the next? How about other directions rather than getting more statistics?
  - Jlab/EIC are going to measure gravitational structure functions, which are connected to mass.
- What are the effective degrees of freedom for hadrons?
  - What can we draw physics beyond the E50 experiment?
- Parton structure of hadrons
  - J-PARC may do a good job especially large x regions, because of its “low” energy.
  - Structures related with strange quarks may be good at J-PARC.

Few words

We should do

- Continuous workshops and meetings
- Discussions not only on a single experiment, but also on a broad view of physics that will convince researchers of other fiellds

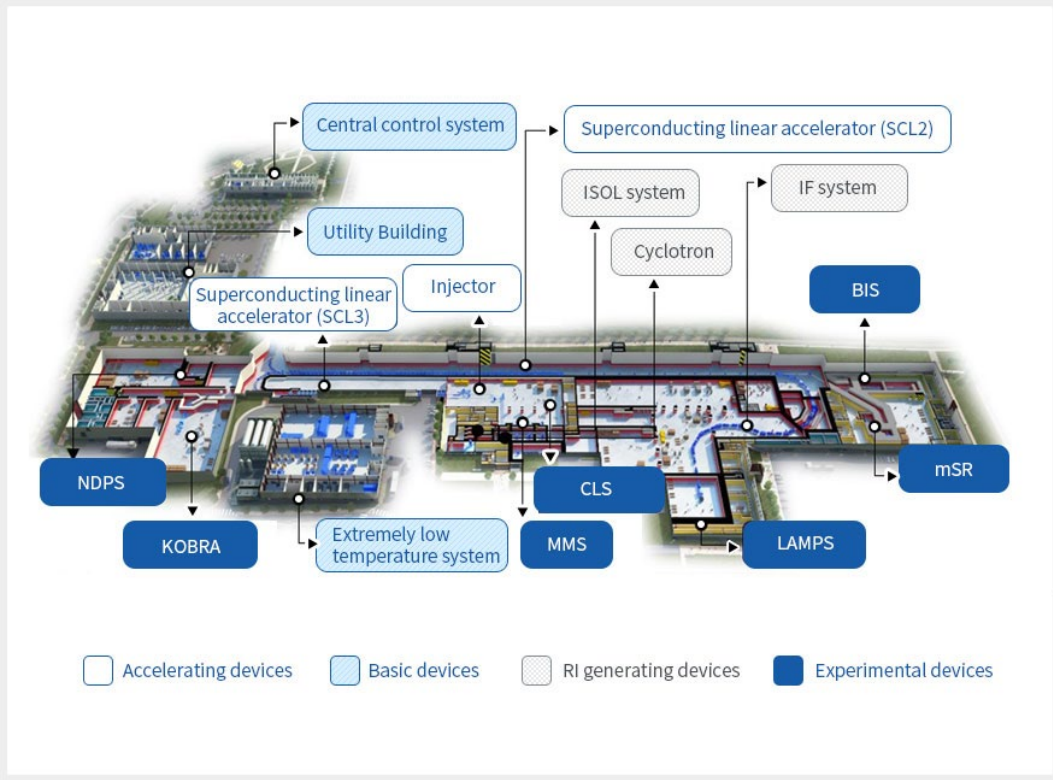
- How about a white paper on “Hadronic physics in Japan (Asia) ? at J-PARC?

- In Japan, the current funding situation is different from the one 10 years ago. Even KEK might not be able to bring big amount of money at once.
- Mixture of many large/mid-size fundings by collaborating universities/institutions would be realistic.
- For myself, the secondary beams at the high-momentum beamline would be one of the targets.

- What is the next direction of hadronic physics of RCNP?

Physics and Facility

- Facility is a part of the experiment.
  - Without particle beams, no one can conduct an experiment.
  - Quality of the beams defines the scope of the experiment in many cases.
- Physics is a key to develop facilities.
  - Facility equipment needs a lot of knowledge and development of physics. The situation is the same as detector development.



As a facility physicist

- Several ways of success
  - Be a super generalist who knows wide variety of things with much deep insight
    - Knowledge of detectors, analysis, accelerators, utilities such as cooling water and electricity,
  - Be a super expert who has the deepest knowledge
  - Be a super manager who prepares enough resources for the facility
  - These are sometimes exclusive, but sometimes somehow comprehensive
  - Be patient, as facility construction needs (a lot of) time
- Words to “pure” physicists
  - Physicists at facilities are a strong and indispensable collaborator to establish your physics

Words from Prof. Totsuka

- Prof. Yoji Totsuka, 1942 – 2008
  - neutrino physicist, worked with Prof. Koshiba
  - professor of U. Tokyo
  - KEK Director General 2003 – 2006

- “Experimentalists should do anything needed”
  - This means, in order to realize an experimental study, researchers have to work with not only “physics-related” matters, but also any other things needed. He said he went out drinking many times with local people around Kamioka, where a large-scale neutrino detector is located, to get locals involved.

Summary

- J-PARC
  - There were K, E, M, and N arenas at JHF.
  - The E arena went to the tandem accelerator at JAEA, and then RIKEN.
  - M and N arenas have been realized as MLF of J-PARC.
  - Among the originally proposed physics of the K-arena, neutrino physics and strangeness nuclear physics with low-momentum K/pi have been realized somehow.
  - Φ mass experiment with the primary beam is being realized.
- EIC
  - Big project
  - Japan will contribute with some amount of money.
    - Korea will also collaborate?
  - This is the major project of the next generation hadronic physics in the US.

Summary

- Extenstion of J-PARC Hadron Experimental Facility
  - 150~200 Oku Yen (100~150 M$) project
  - Recent funding situation may not allow funding approval for all the project at once.
  - “Staging” may be required.

- Secondary beams at the high-momentum beamline
  - Indispensable for E50
  - These beams will allow more physics.
    - Let’s show a thorough view with these beams.