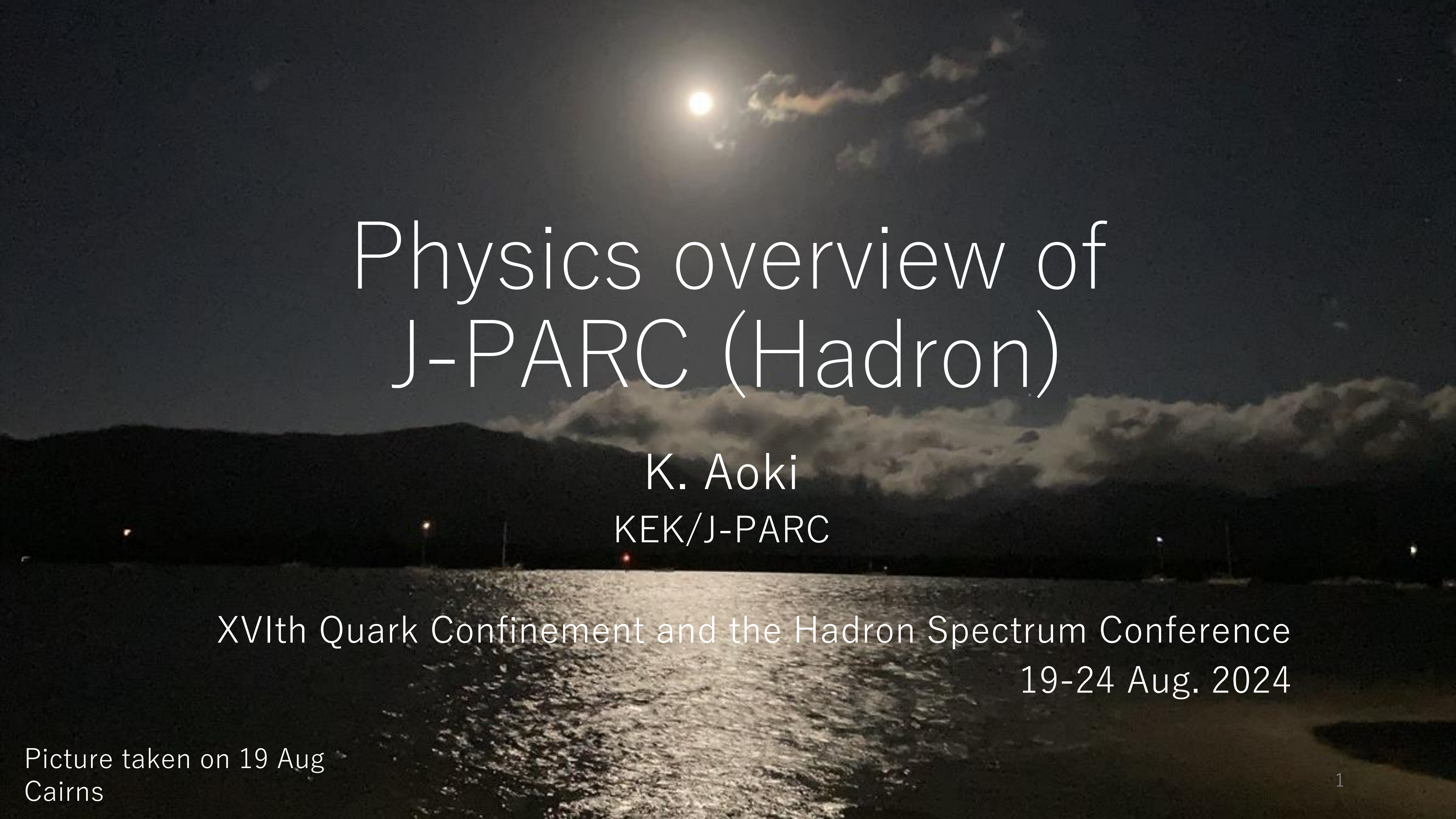


Physics overview of J-PARC (Hadron)

K. Aoki

KEK/J-PARC

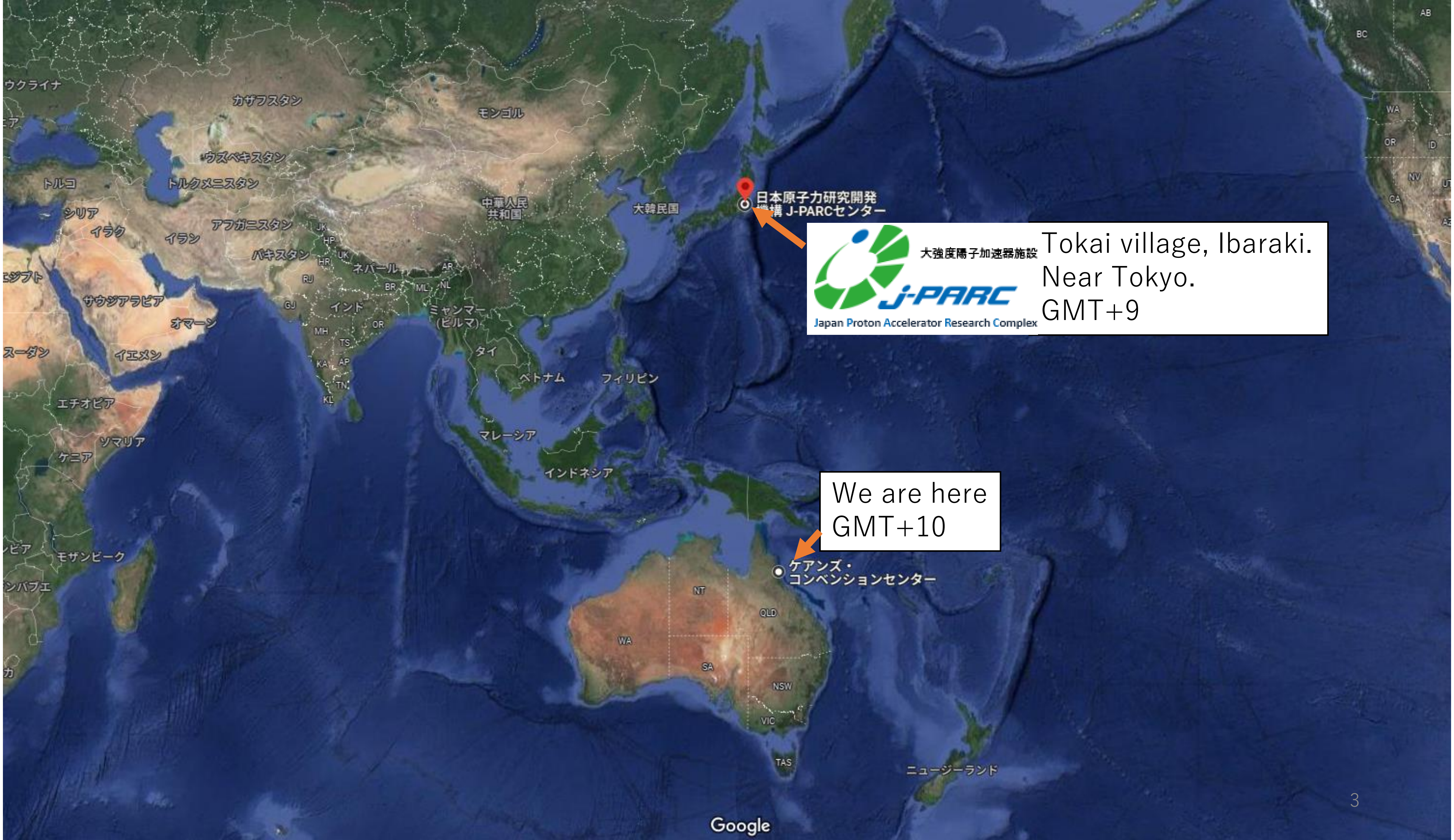
XVIth Quark Confinement and the Hadron Spectrum Conference

19-24 Aug. 2024

Picture taken on 19 Aug
Cairns

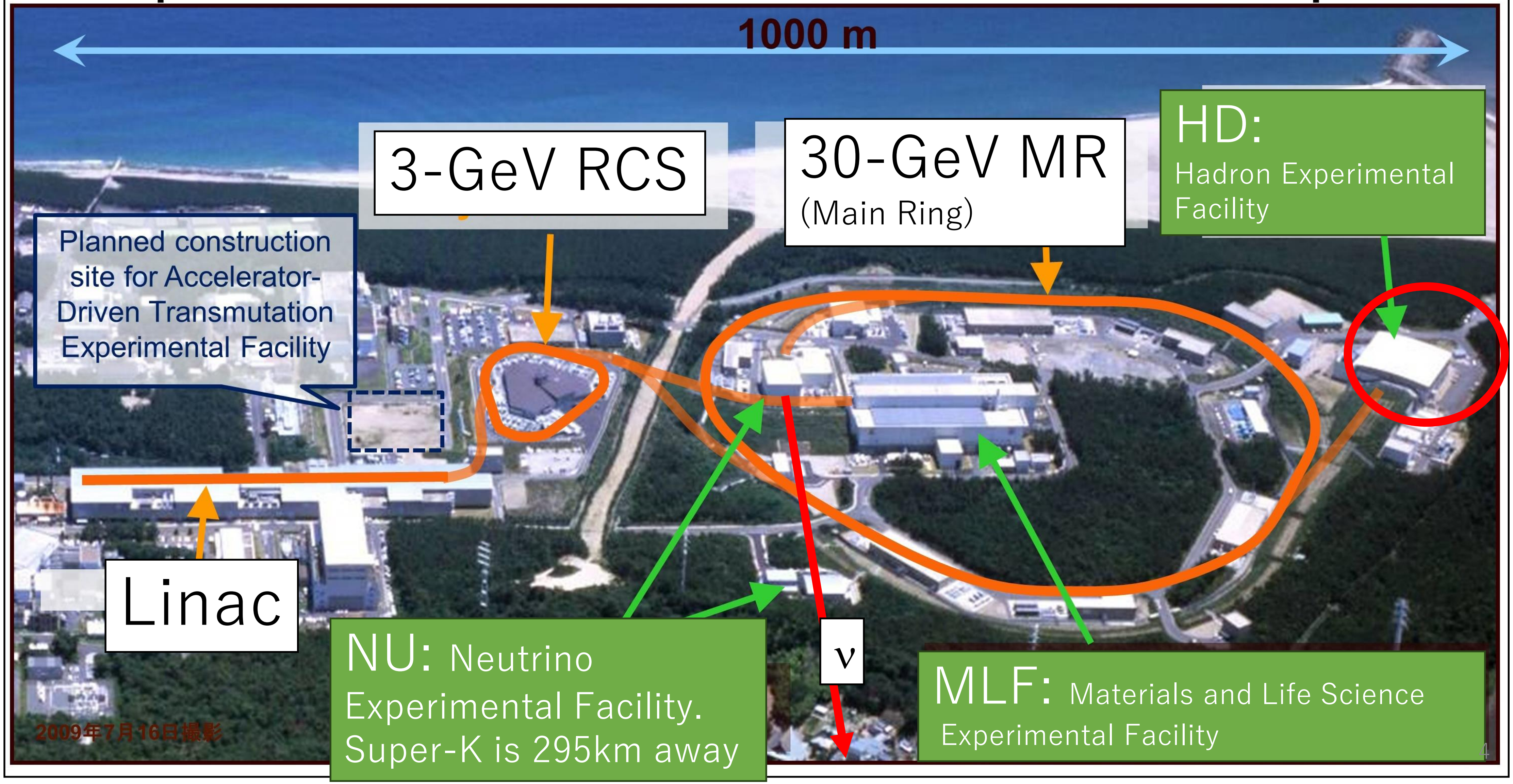
Contents

- J-PARC
- J-PARC HD (Hadron Experimental Facility) and beam lines
- Physics Motivation
- List of experiments already finished or in data-taking period
- Pick up some of experiments and discuss results and introduce some of on-going experiment.
- Future projects.


ウクライナ
カザフスタン
モンゴル
ウズベキスタン
トルコ
トルクメニスタン
シリア
イラク
イラン
アフガニスタン
パキスタン
中華人民共和国
大韓民国
日本原子力研究開発機構 J-PARCセンター
大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex
Tokai village, Ibaraki.
Near Tokyo.
GMT+9
エジプト
サウジアラビア
オマーン
インド
ネパール
ミャンマー(ビルマ)
タイ
ベトナム
フィリピン
スーダン
イエメン
エチオピア
ソマリア
ケニア
マレーシア
インドネシア
モザンビーク
We are here
GMT+10
ケアンズ・コンベンションセンター
NT
QLD
WA
SA
NSW
VIC
TAS
ニュージーランド
Google

Japan Atomic Energy Agency

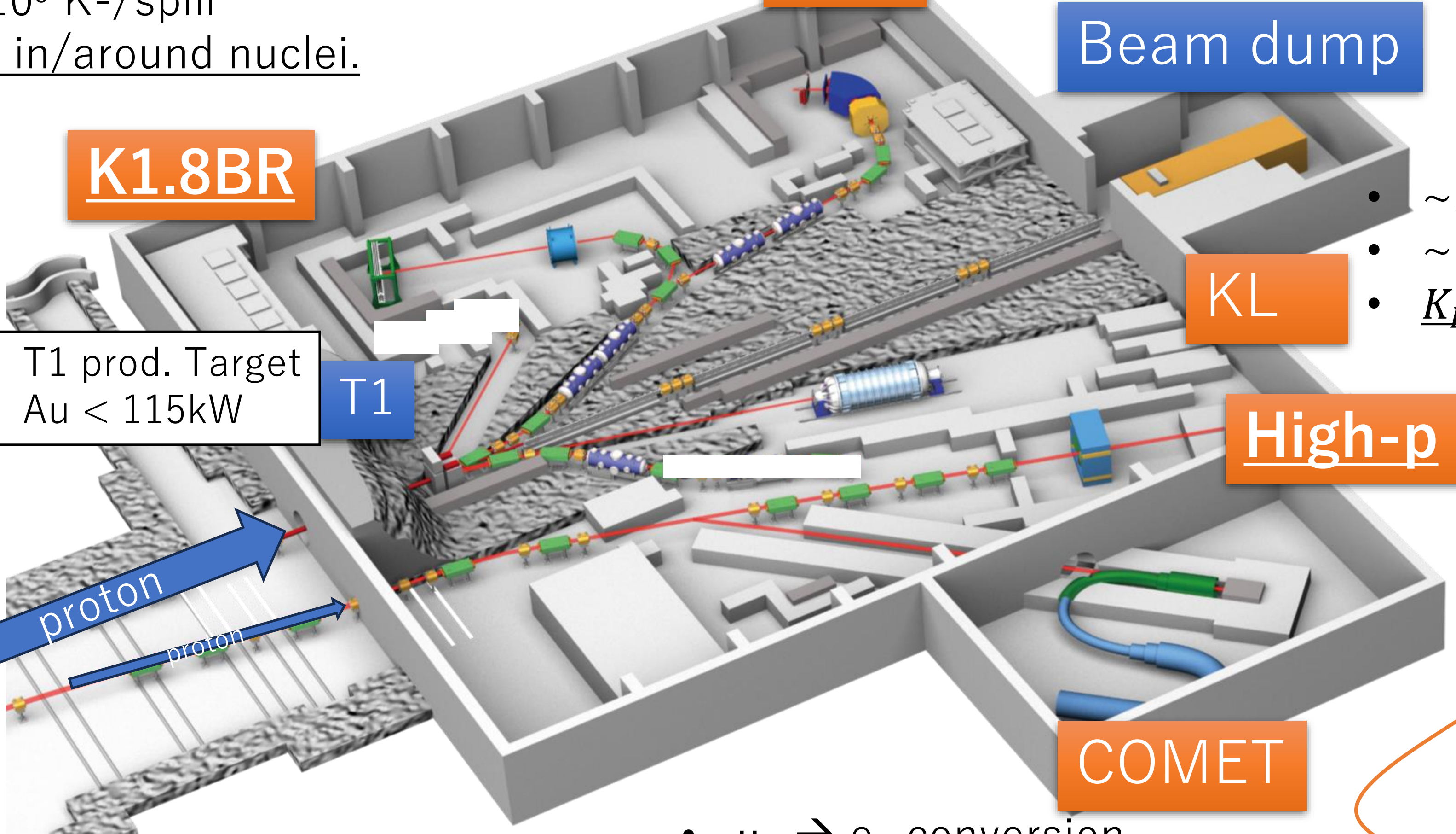
J-PARC
Japan Proton Accelerator Research Complex



Beam lines at J-PARC HD (Hadron Exp. Facility)

- < 2.0 GeV/c
- ~ 10^6 K-/spill
- S=-1, -2 Hypernuclei, YN scatt.

- < 1.1 GeV/c
- ~ 5×10^5 K-/spill
- Kaon in/around nuclei.



- ~2.1 GeV/c
- ~ 10^7 K_L/spill
- $K_L \rightarrow \pi^0 \nu \bar{\nu}$ rare decay.

- T1 prod. Target
- Au < 115kW

- 30 GeV proton
- 10^{10} p/spill
- ϕ meson in nuclei

- <31 GeV/c
  10^7 π/spill
- Charmed Baryon spectroscopy

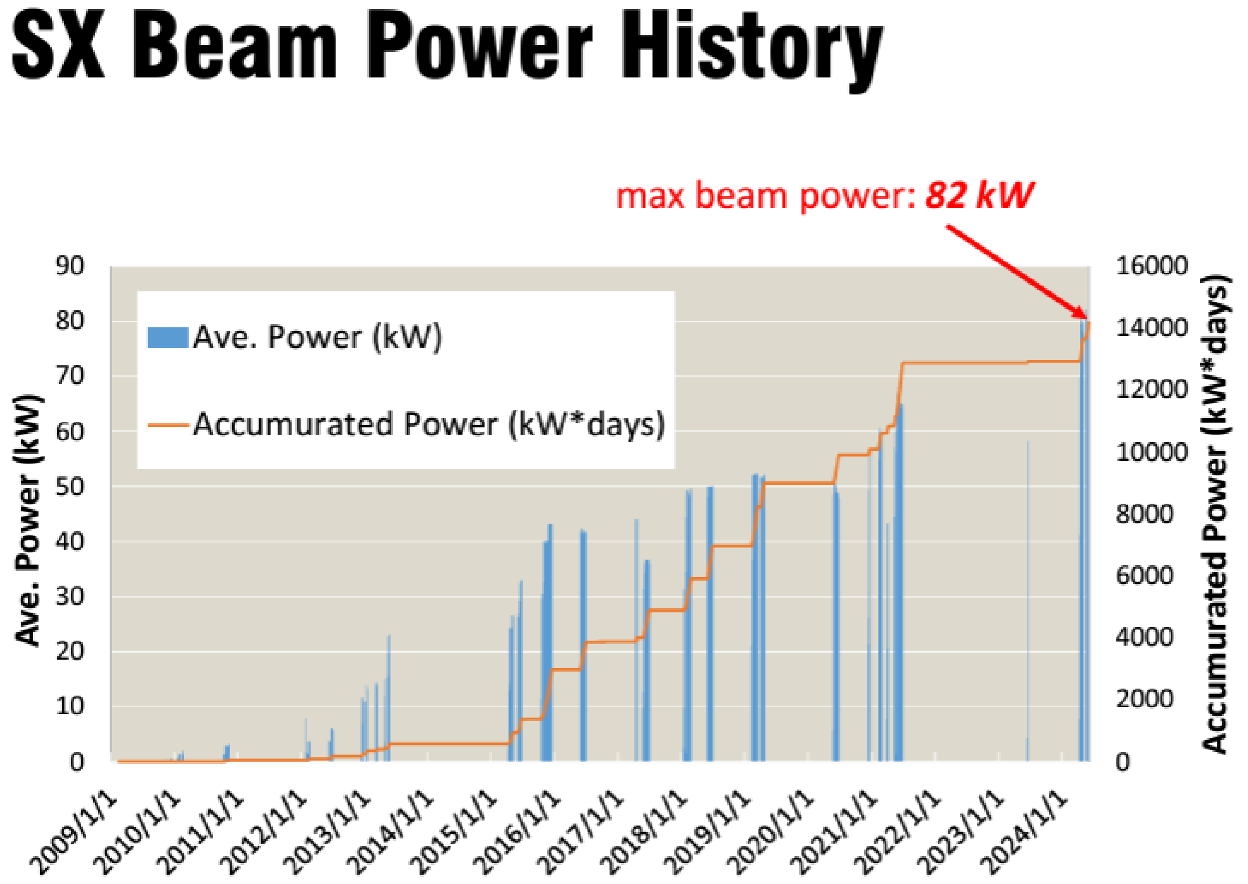
→K. Shirotori 22th Aug

- μ- → e- conversion

- 30GeV proton
- 82 kW, 7.2×10^{13}ppp as of 2024.

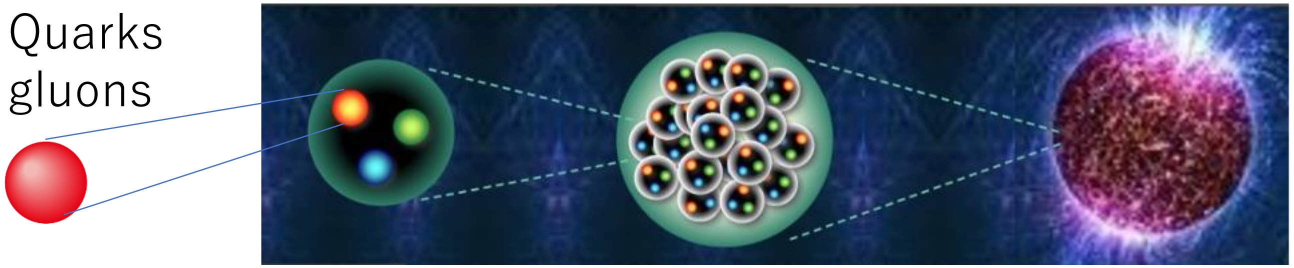
SX (Slow extraction) beam power

- Beam power gradually increased over the 15 years.
- Reached 82kW. 30GeV proton, 7.2E13/spill. Spill=4.24 sec.



Physics motivation in one slide:

Understand strongly interacting system from quark to neutron star.



- Quark → Hadron : How quarks and gluons form hadrons?
  - Quark Confinement. Spontaneous breaking of chiral symmetry.
  - Meson in nuclei→ **ϕ (high-p, E16)**, **K^{bar} (K1.8BR, E15)**
- Hadron → Nucleus → Neutron Star : Property of dense matter?
  - Precise Baryon-Baryon interaction incl. hyperons and Its density dependence
  - ΣN Scattering experiment **(K1.8, E40)**
  - S=-1, -2 hypernuclei and γ-ray spectroscopy. **(K1.8)**

Experiments completed or data-taking.

- K1.8 beam line:YN int. by S=-1, -2 hypernuclei and scatt.
  - Completed
    - E19: Search for Θ^+ pentaquark in π^- p → K^- X reactions
    - E27: Search for a nuclear K^{bar} bound state K^-pp in d(π^+,K^+)
    - E10 1st : Neutron rich Λ hypernuclei ($^{6}_{\Lambda}H$) search (S=-1)
    - E13: γ–ray spectroscopy of light hypernuclei $^{4}_{\Lambda}He$
    - E05: Spectroscopic study of Ξ^- hypernuclei, $^{12}_{\Xi}Be$, via ^{12}C (K^-,K^+) (S=-2)
      - Events in bound region. E70 is going to measure it with x4 resolution.
    - E07: Systematic study of double strangeness system with an emulsion-counter hybrid method.
      - Xi- hypernuclei (IBUKI 1st uniquely identified state, IRRAWADY)
    - E40: Cross sections of Σp scatterings.
    - E03 1st: Measurement of X rays from Ξ^- atom.
    - E42: Search for H-dibaryon with a Large Acceptance Hyperon Spectrometer
      - Blind analysis. Not opened yet.
  - Data taking
    - E70 : Proposal for the next E05 run with the S-2S spectrometer
    - E96 : X rays from Ξ^- C atom with an active fiber target system

Experiments completed or data-taking.

- K1.8BR beam line: $\bar{K}N$ interaction
  - Completed
    - E15: A search for deeply-bound kaonic states by in-flight 3He(K-,n)
    - E31: Spectroscopic study of hyperon resonance below KN threshold via d(K-,n)
    - E62: Precision Spectroscopy of kaonic atom X-rays with TES.
  - data taking
    - E73: ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$ mesonic weak decay lifetime meas with ${}^{3,4}He(K^{-},\pi^{0}){}^{3,4}_{\Lambda}H$.
- KL beam line: BSM
  - Data taking
    - E14: $K_L \rightarrow \pi^0 \nu \bar{\nu}$ experiment.
- High-p beam line: Meson in medium
  - Data taking (Commissioning.)
    - E16: Measurements of spectral change of vector mesons in nuclei

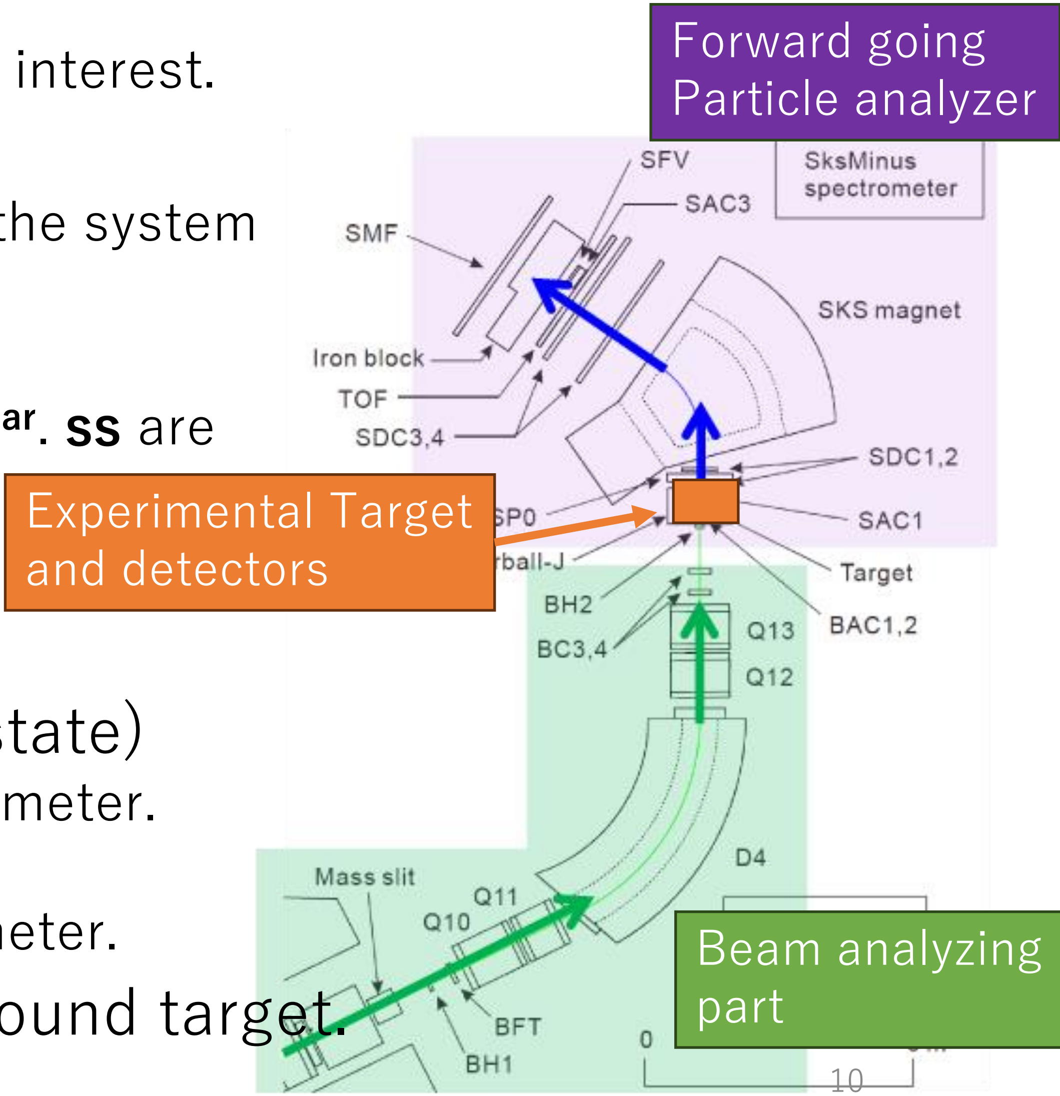
K1.8 beam line : S=-1,-2 hypernucleus, YN scattering experiment.

Hyperon, hypernuclei production scheme

- (beam , out-going particle)
- (K^-, π) -- S=-1 system
  - **s** in the beam and the **s** is put into the system of interest.
- (π, K^+) -- S=-1 system
  - **ss**^bar pair created. K^+ take away **s**^bar. **s** is put in the system of interest.
- (K^-, K^+) -- S=-2 system
  - **s** in the beam and **ss**^bar created. K^+ take away **s**^bar. **ss** are put into the system of interest.

K1.8 common concept

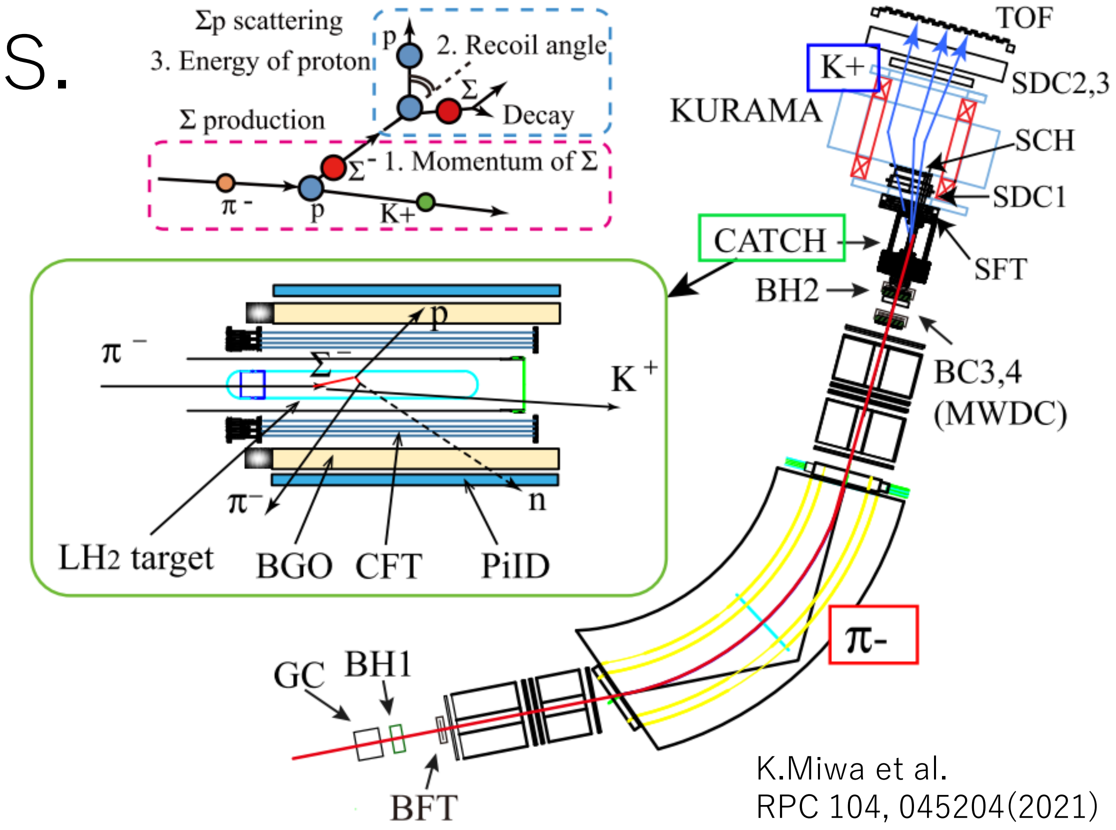
- Missing mass technique. (Initial state) ←→invariant Mass (Final state)
  - Incoming beam is analyzed by beam line spectrometer.
  - Experimental target. (Seed of hypernuclei)
  - Out-going particle analyzed by forward spectrometer.
- Experiment specific detectors are placed around target.
  - γ-ray detectors / nuclear emulsion etc..



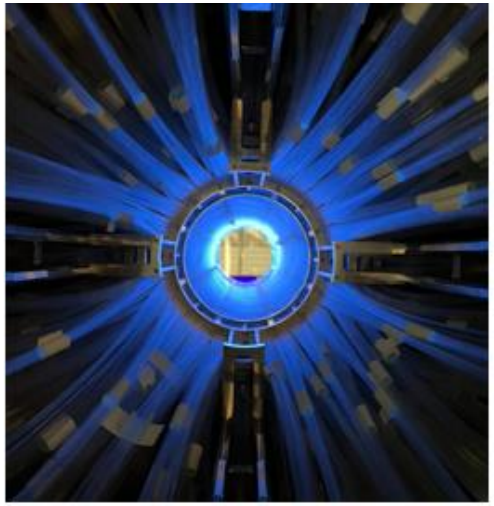
Taken from slide by M. Ukai at J-PARC Hadron 2024.

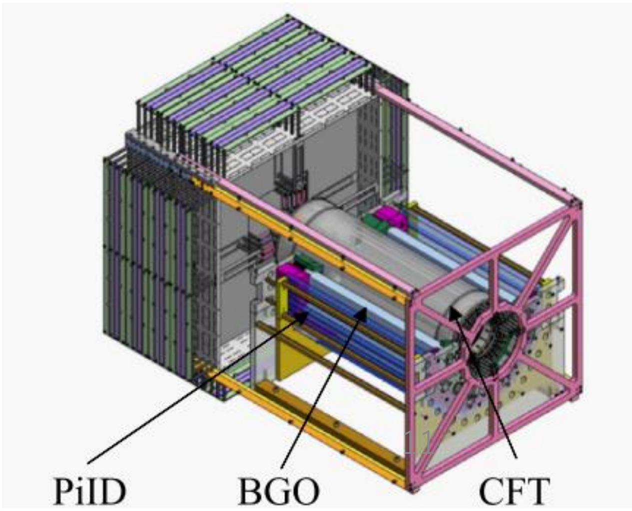
J-PARC E40 : Σp scatterings.

- $\Sigma^{\pm}$ "beam" produced in LH2 target
  - $p(\pi^-, K^+)$: $\pi^- p \to K^+ \Sigma^-$
  - $p(\pi^+, K^+)$: $\pi^+ p \to K^+ \Sigma^+$
    - beam line spectrometer ($\pi^{\pm}$)+ KURAMA spectrometer (K^+)
    - Missing mass ($\Sigma^{\pm}$)
- Σ p scattering
  - $\Sigma^- p \to \Sigma^- p$ 4500 events.
  - $\Sigma^+ p \to \Sigma^+ p$ 2400 events.
  - $\Sigma^- p \to \Lambda n$ 1000 events.
    - Detected by CATCH



K.Miwa et al.
RPC 104, 045204(2021)

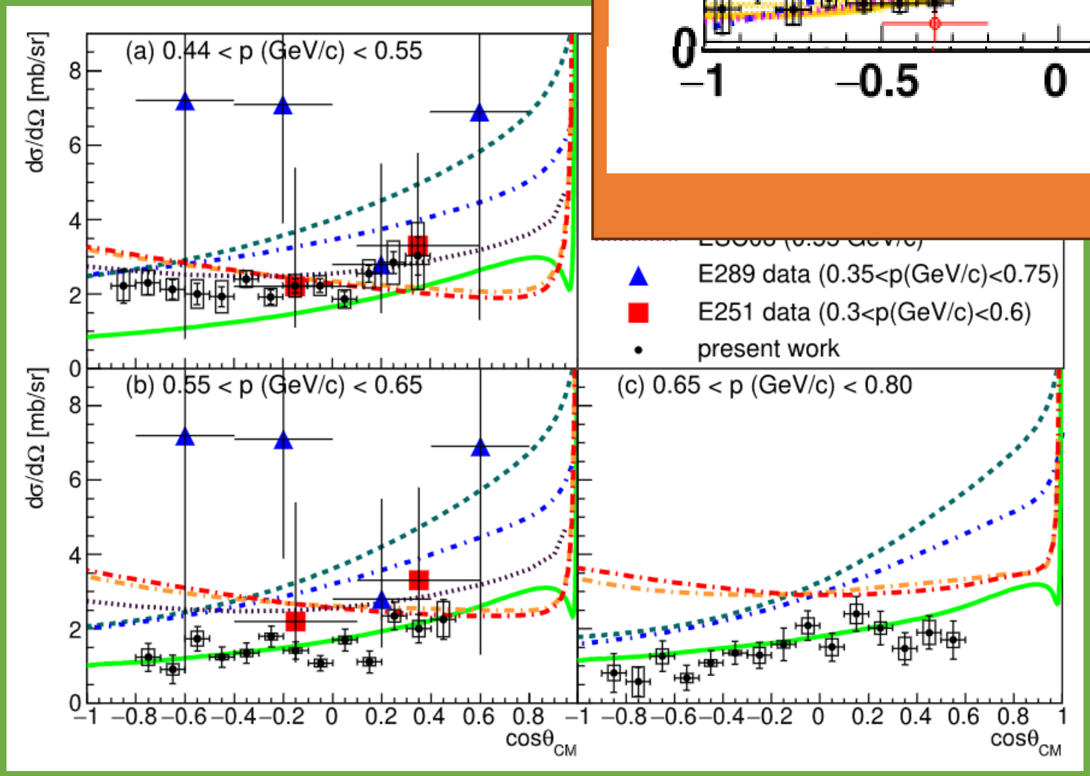




J-PARC E40 : Σp scatterings.

- Improved statistics compared to old measurements.

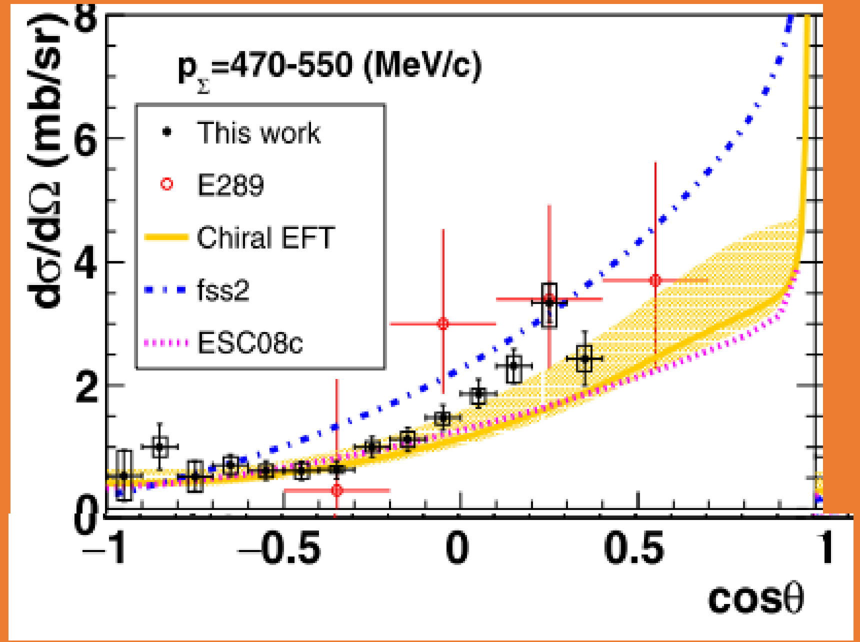
$\Sigma^+ p \rightarrow \Sigma^+ p$

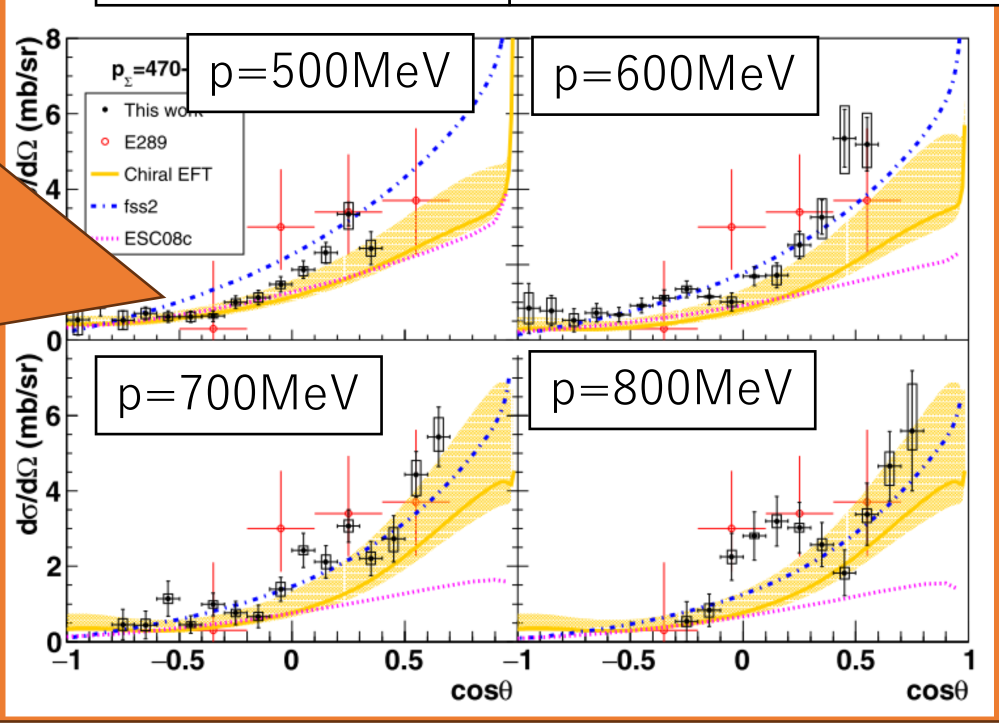


T.Nanamura et al. PTEP 2022 093D01

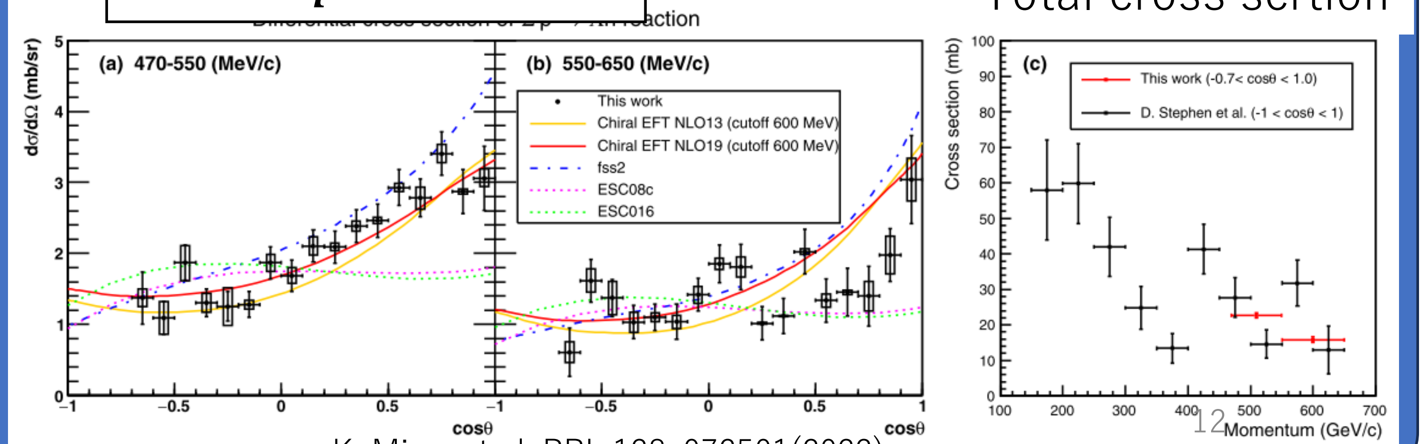
$\Sigma^- p \rightarrow \Sigma^- p$

K.Miwa et al.
RPC 104, 045204(2021)





$\Sigma^- p \rightarrow \Lambda n$

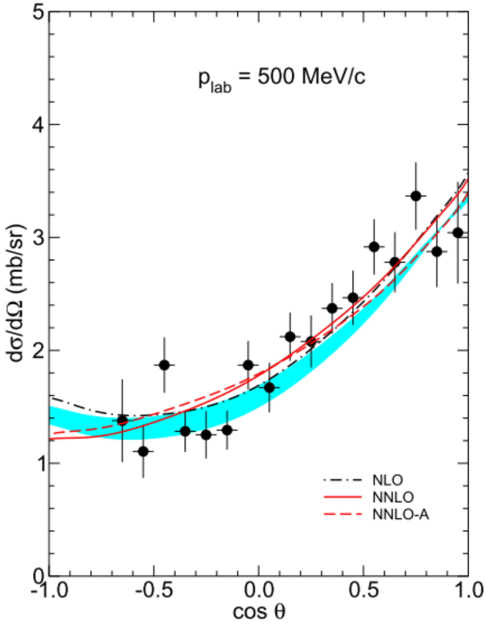


K. Miwa et al. PRL 128, 072501(2022)

J-PARC E40 : Σp scatterings.

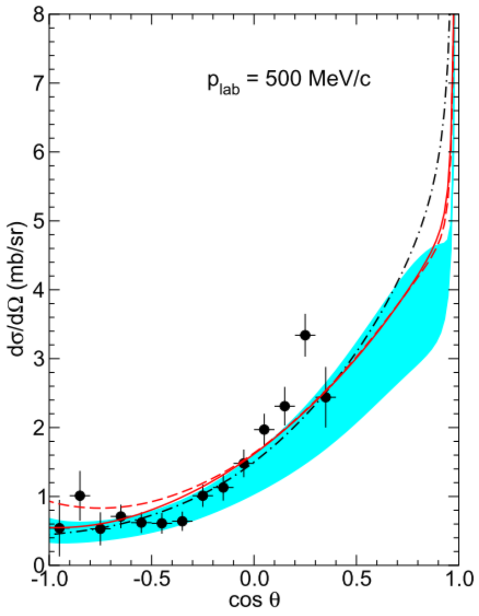
Cyan: NLO19 (w/o E40 data) ,
Solid: NNLO fit w/ E40 data.
Dashed NNLO-A: fine tuned to 500MeV/c data.

$\Sigma^- p \to \Lambda n$ I=1/2



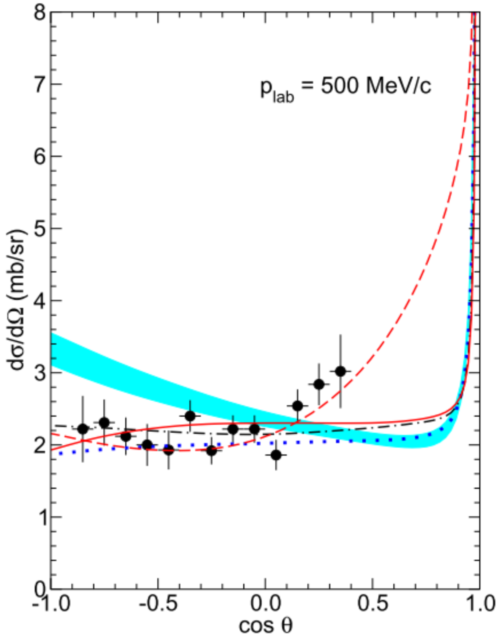
K. Miwa et al.
PRL 128, 072501(2022)

$\Sigma^- p \to \Sigma^- p$



K.Miwa et al.
RPC 104, 045204(2021)

$\Sigma^+ p \to \Sigma^+ p$ I=3/2



T.Nanamura et al.
PTEP 2022 093D01

1 and 3 refer to spin singlet and triplet
even/odd refer to OAM

BB channel (*I*)	^{1}even or ^{3}odd	^{3}even or ^{1}odd
$NN(I=0)$	—	(10^*)
$NN(I=1)$	(27)	—
$\Lambda N(I=\frac{1}{2})$	$\frac{1}{\sqrt{10}}[(8_s)+3(27)]$	$\frac{1}{\sqrt{2}}[-(8_a)+(10^*)]$
$\Sigma N(I=\frac{1}{2})$	$\frac{1}{\sqrt{10}}[3(8_s)-(27)]$	$\frac{1}{\sqrt{2}}[(8_a)+(10^*)]$
$\Sigma N(I=\frac{3}{2})$	(27)	(10)

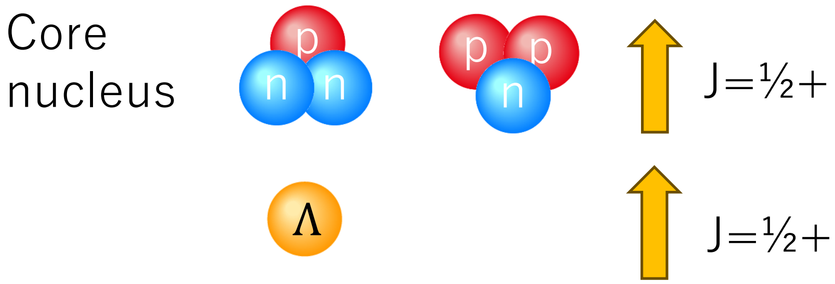
- E40 data has stimulated NNLO Chiral EFT.
  - Haidenbauer et al., Eur. Phys.J.A 59, 3 (2023)
    - No additional LEC (Low Energy Constant) at this level except for 3BF. 3BF LEC not considered.
    - Cyan: NLO19 (w/o E40 data) , Solid: NNLO fit w/ E40 data.
    - NLO19 successful reproduce a) and b) but not c). Fit w/ E40 improves.
    - c) Sensitive to 10-plet in SUf(3) which does not appear NN interaction.
  - Parameters not uniquely determined. Additional information needed. Polarized ΛN scattering experiment planned. → J-PARC E86

J-PARC E13

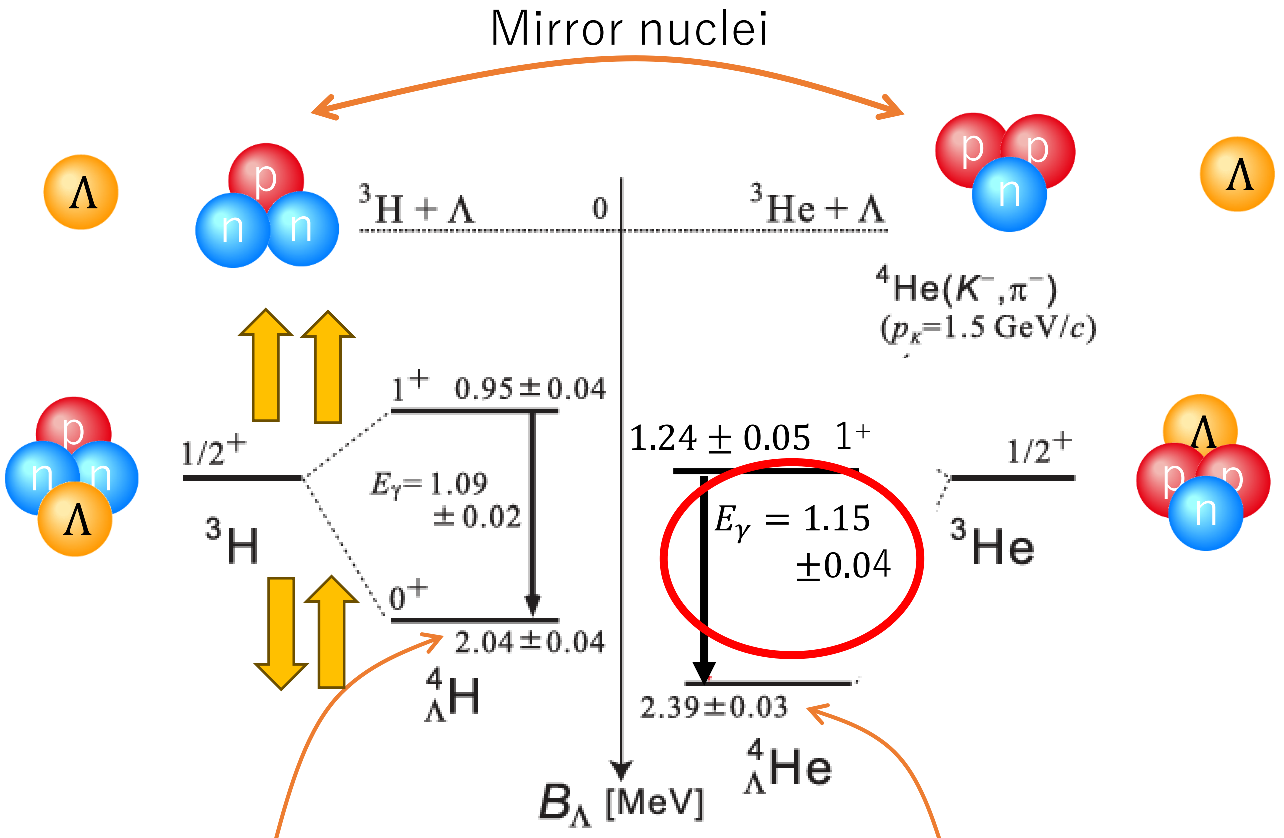
S=-1 hypernuclei γ-ray

Mirror nuclei ^{3}H vs ^{3}He (from Nuclear Wallet Cards)

- ΔM = 18 keV
- ΔB_{total} = 764 keV → 70keV after Coulomb corr.
  - $\rho - \omega$ mixing : Ann. Rev. N.P. Sci. 56,253(2006)



- Charge Symmetry Breaking (CSB) in g.s. of $^4{}_\Lambda$H and $^4{}_\Lambda$He
  - ~350keV
  - Not theoretically understood.
- Energy splitting due to spin-spin
  - previous γ-ray measured by NaI
  - $^3{}_\Lambda$He: Not reliable according to experts.
- $^3{}_\Lambda$He γ-ray measurement needs update. → J-PARC E13

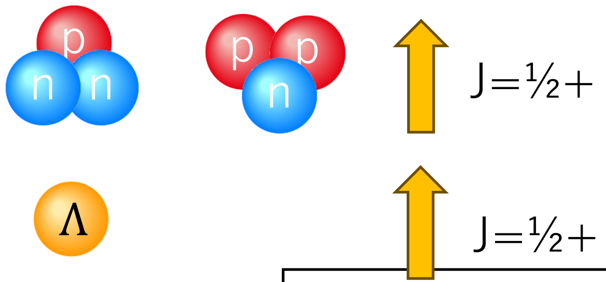


These g.s. energies deduced from old emulsion data.
Large energy difference 350 keV.
= Charge Symmetry Breaking (CSB)

J-PARC E13

S=-1 hypernuclei γ-ray

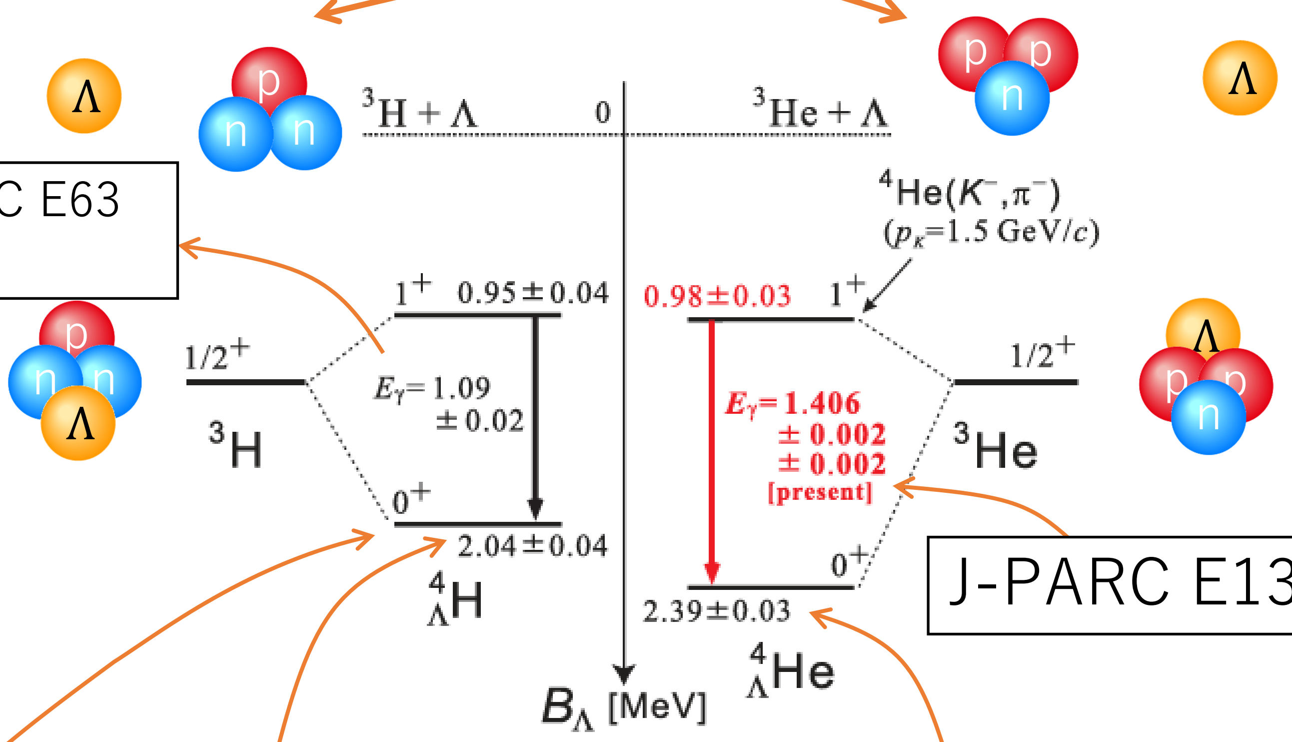
Mirror nuclei ^{3}H vs ^{3}He
- ΔM = 18 keV
- ΔB = 764 keV → 70keV after Coulomb corr.
  - $\rho - \omega$ mixing : Ann. Rev. N.P. Sci. 56,253(2006)



To be measured →J-PARC E63
→ H. Tamura 22th Aug.

Mirror nuclei

T.O. Yamamoto et al, PRL115, 222501 (2015)



J-PARC E13

- J-PARC E13 confirmed that that surely charge symmetry is broken. ΛN CSB interaction has spin-dependence.
- ΛN-ΣN coupling plays an important role in CSB.

These g.s. energy deduced from old emulsion data.

MAMI-C Measurement: $2.157 \pm 0.005 \pm 0.077$MeV
Nucl. Phys. A 954, 149 (2016)

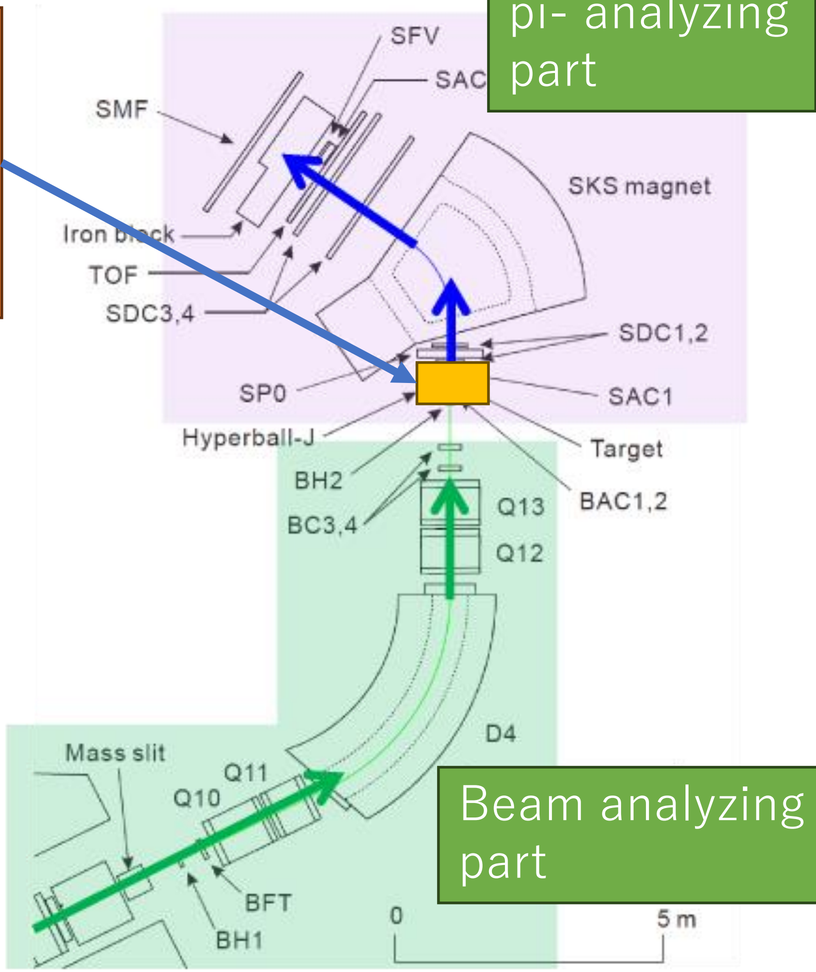
Update on g.s are expected from J-PARC E07
Emulsion automated-scan and Machine learning.

J-PARC E13
S=-1 hypernuclei γ-ray

- Reactions
  - ^{4}He(K$^-$, π^-) : K$^-$ +^{4}He → $^4_\Lambda$He(*) + π^-
- Detectors
  - K- beam (1.5GeV/c) and out-going π^- are analyzed.
  - Simultaneous γ-ray measurement by Hyperball-J
    - High resolution Ge instead of NaI used by previous measurement.

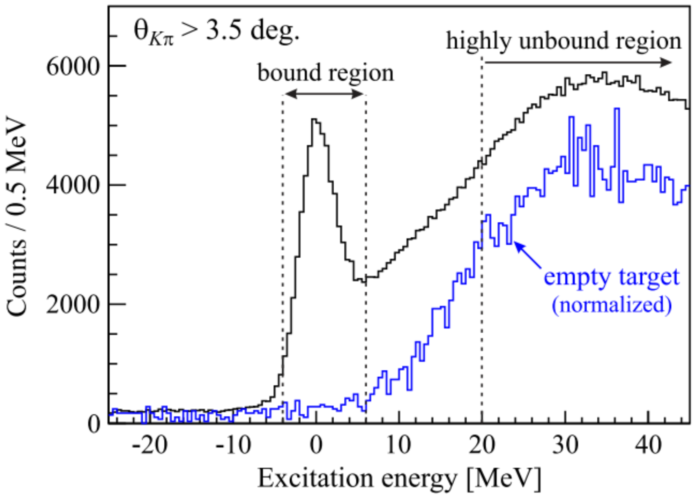
Liq. He target

Hyperball-J (Ge detector array)

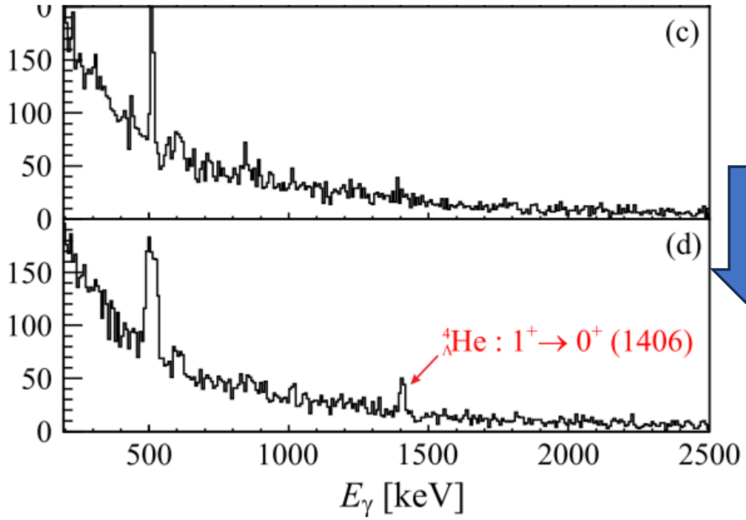


Taken from slide by M. Ukai At J-PARC Hadron 2024.

Missing mass, identify $^4_\Lambda$He



γ energy



Event-by-event Doppler correction

K- beam: 1.5 GeV/c, 2.3E10 K-,
K/pi ~ 2-3, 3E5/spill
Liq. He target (2.7g/cm2) 12cmϕ x 23cm

J-PARC E07

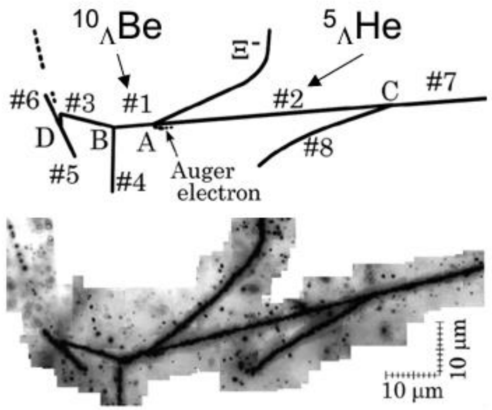
S=-2 hypernuclei by Hybrid emulsion method

Slide by
K. Miwa 2nd HEF-EX.

- Emulsions – literally photographic films that capture particle reactions.
- Hybrid – Ξ- productions were recorded by counters, later search for corresponding position in emulsion by microscope.

(KEK-E325)

KISO event



K. Nakazawa et al., PTEP. 2015, 033D02

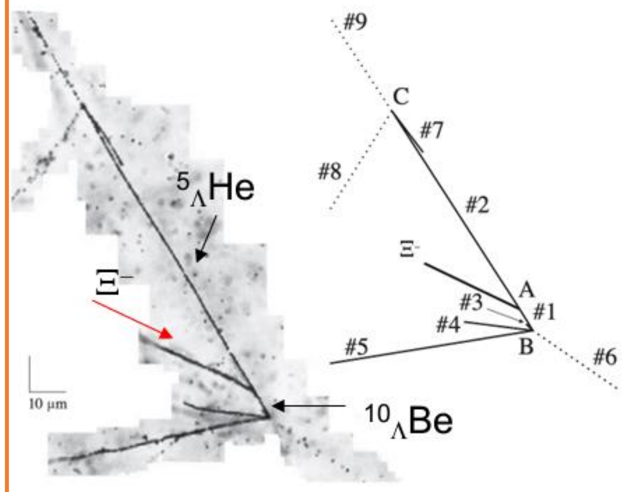
1st discovery of clear Ξ nuclear state

Two possibilities of B_{Ξ^-} depending on $^{10}_{\Lambda}$Be state

- B_{Ξ^-} ($^{10}_{\Lambda}Be_{g.s.}$) = 3.87 ± 0.21 MeV
- B_{Ξ^-} ($^{10}_{\Lambda}Be_{1st.\ Ex.}$) = 1.03 ± 0.18 MeV

(J-PARC E07)

IBUKI event



S. H. Hayakawa et al.,
Physical Review Letters, 126, 062501 (2021)

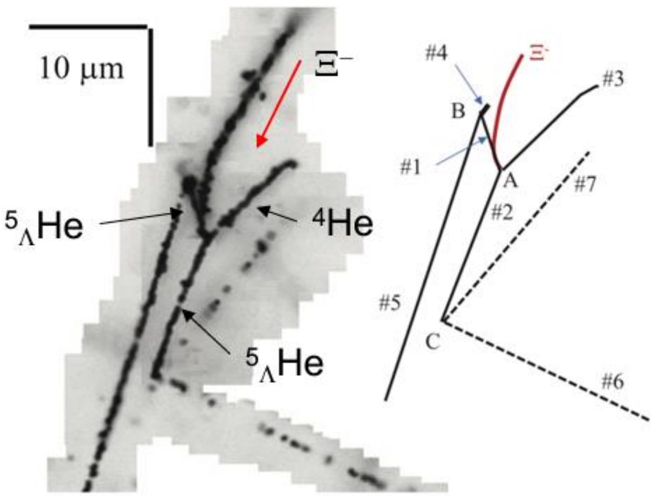
1st uniquely identified Ξ nuclear state

One reaction process satisfied kinematical consistency.

- B_{Ξ^-} = 1.27 ± 0.21 MeV

$\Xi^- + {}^{14}N \rightarrow {}^{5}_{\Lambda}He + {}^{5}_{\Lambda}He + {}^{4}He + n$

IRRAWADDY event



M. Yoshimoto et al., PTEP. 2021, 073D02

1st observation of nuclear s-sate of Ξ hypernucleus

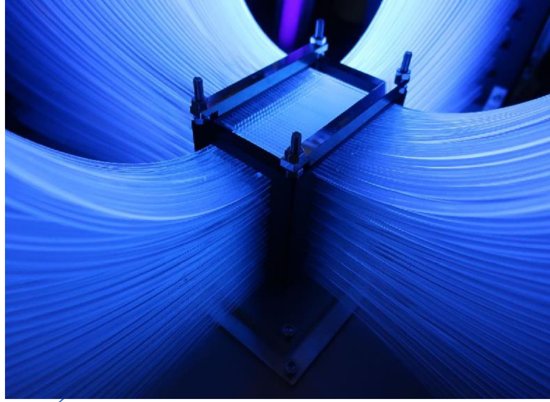
(This state maybe $^{14}C + \Xi^0$)
E.Friedman, A.Gal PLB837, 137640(2023)

- B_{Ξ^-} = 6.27 ± 0.27 MeV

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

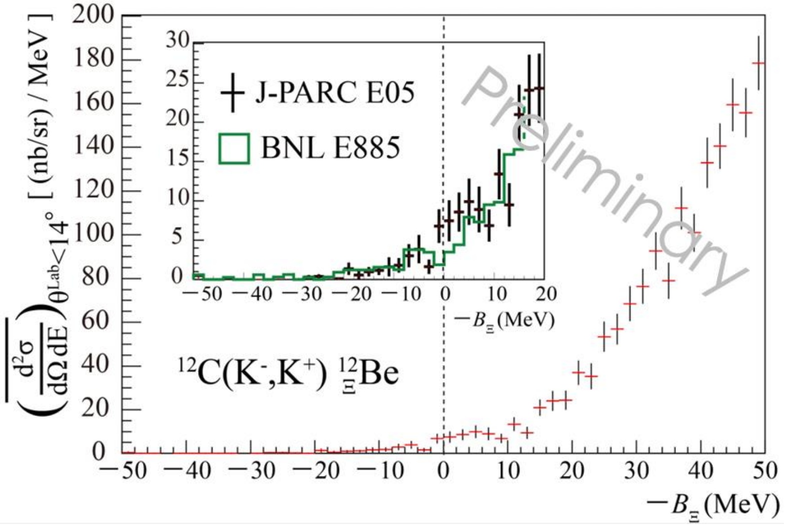
J-PARC E05(done) and E70(data taking)

AFT



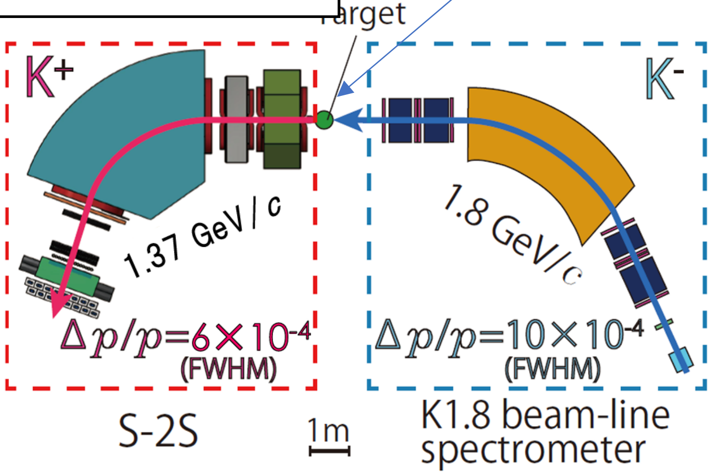
- $^{12}_{\Xi}$Be via ^{12}C(K^-, K^+) reaction.
- Ξ- nucleus search by
  - Missing mass.

J-PARC E05 results [submitted]
Events in bound region. Not clear.



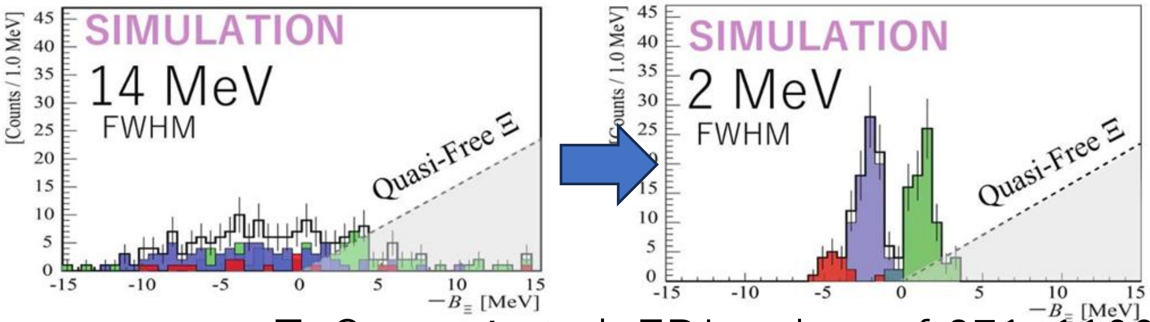
Resolution : 8 MeV (FWHM)

J-PARC E70: data taking.
+Spectrometer upgrade
+Active Fiber Target : Measure energy loss in target. Correction.



BNL E885 resolution

E70 resolution



T. Gogami et al, EPJ web conf 271, 11002

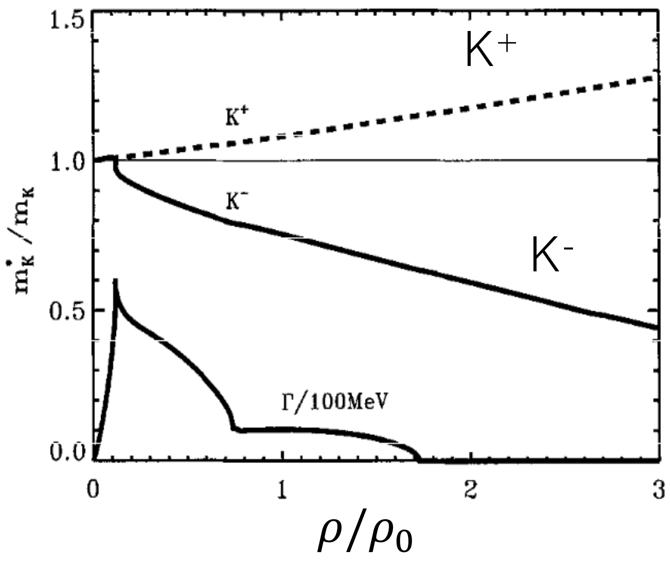
$(J^{\pi} = 1^-_1, 1^-_2 \text{ and } 1^-_3)$

K1.8BR : J-PARC E15 – $\bar{K}NN$ (“K⁻pp”)

A search for deeply-bound kaonic states by in-flight 3He(K⁻,n)

- $\bar{K}$: K^- and $\bar{K^0}$
- $\bar{K}N$ Strong attraction in I=0. $\Lambda(1405) = \bar{K}N$ molecule
- Larger Kaonic nucleus? $\bar{K}NN$, $\bar{K}NNN$ ⋯

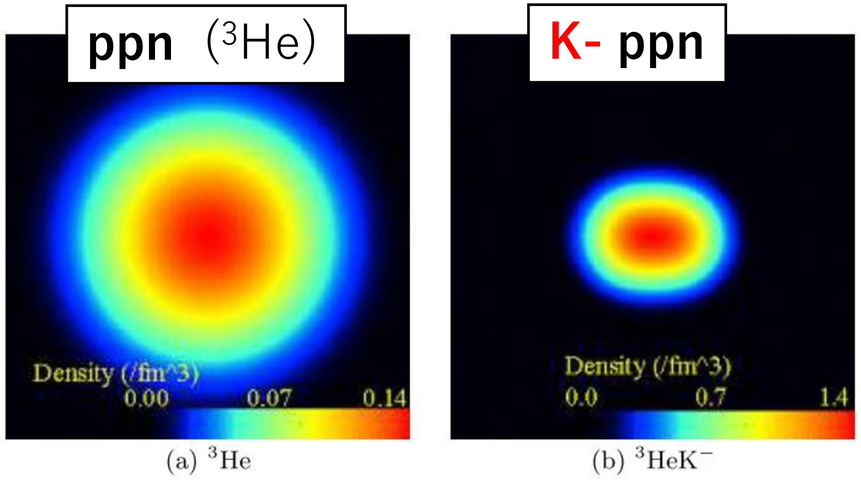
SU(3) χEFT that reproduce Λ(1405) as Bound-state of $K^{bar}N$, Suggests K- mass dropping in medium



K- mass reduction in medium?

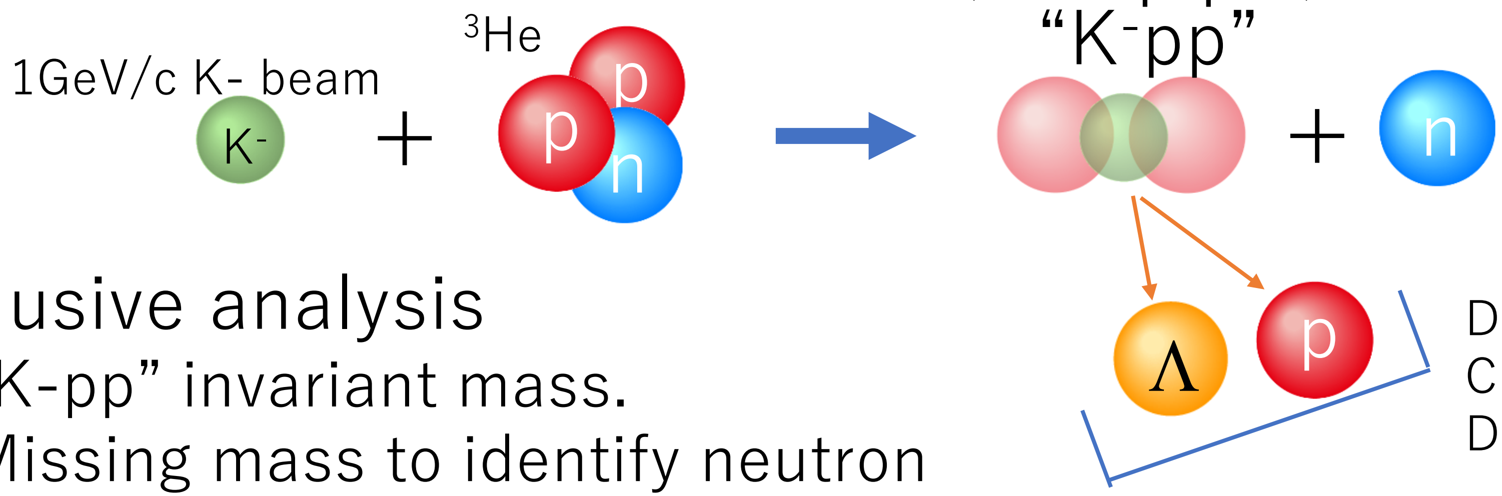
T. Waas, N. Kaiser, W. Weise Phys. Lett. B379, 34(1996)

Theoretical calculation suggests shrinkage of the system. Glue like role of K.
This early study may not be realistic, but interesting thing may happen.



A. Dote, et al. Phys. Lett. B590, 51(2004)

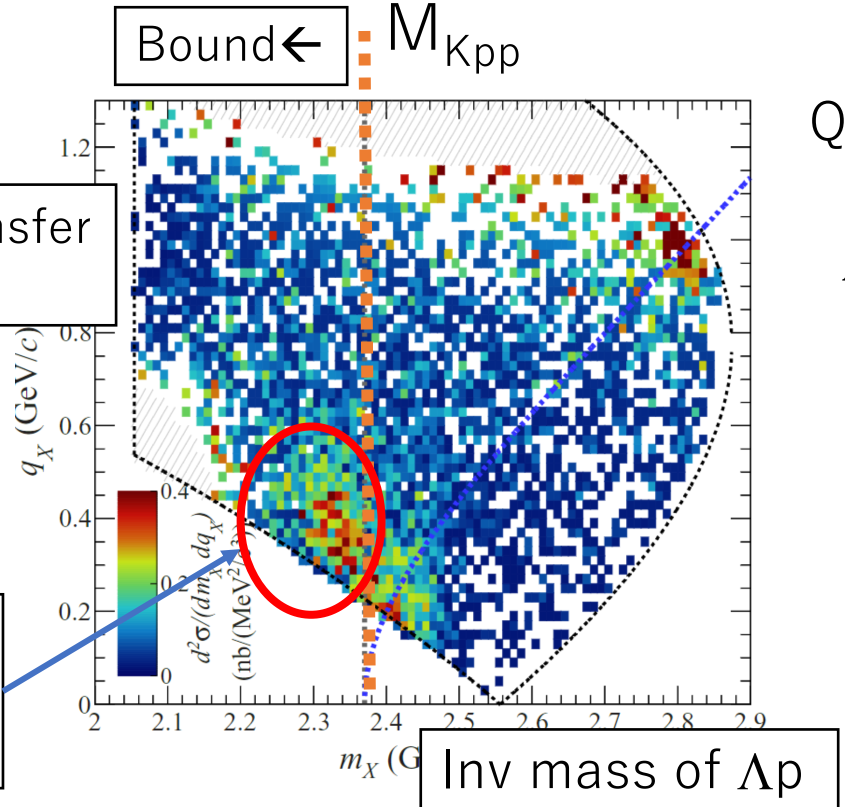
J-PARC E15 – $\bar{K}NN$ (“K-pp”)



Identified by missing mass

Detected with CDS (Cylindrical Detector System)

- Exclusive analysis
  - “K-pp” invariant mass.
  - Missing mass to identify neutron



Quasi-free process.

$$M = \sqrt{4m_N^2 + m_{\bar{K}}^2 + 4\mathrm{m_N}\sqrt{m_{\bar{K}}^2 + q_x^2}}$$

Momentum transfer = K^{bar} momentum

T. Yamaga et al, PRC102, 044002 (2020)

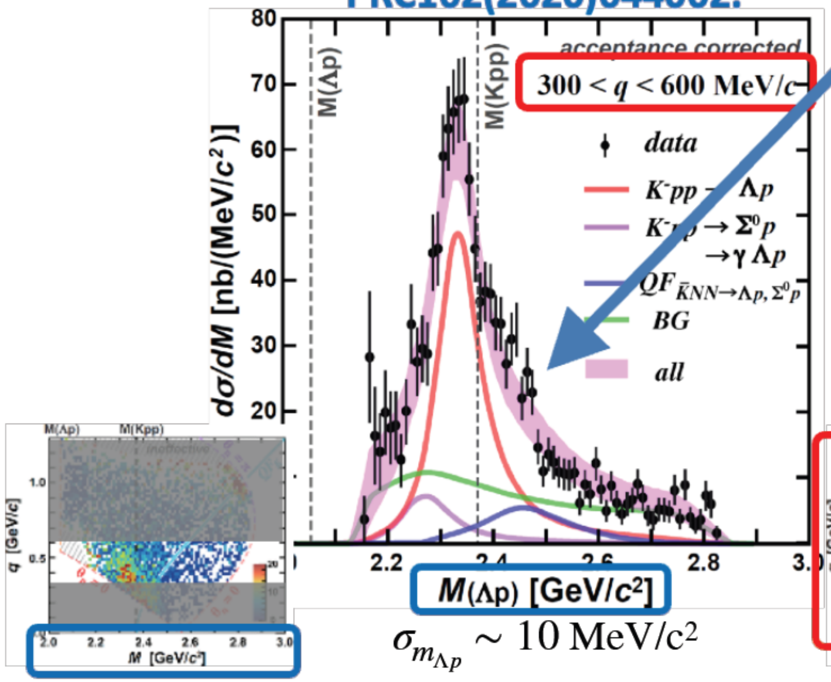
"$\bar{K}NN$" model fitting

0.3 < q_x <0.6 GeV/c: Signals are well separated from other process

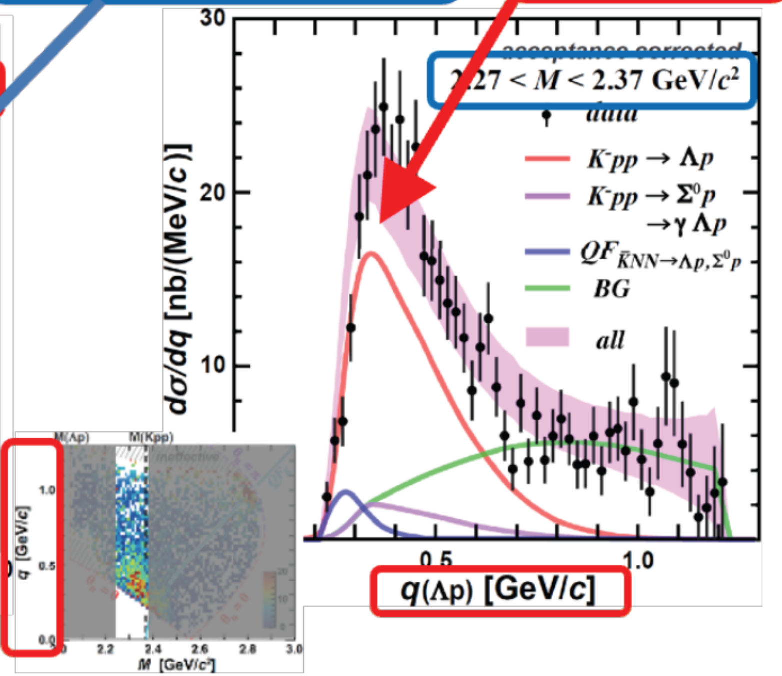
Fit with PWIA (phase space, Breit Wigner, form factor)

$$\sigma(M,q) \propto \rho(M,q) \times \frac{(\Gamma_{Kpp}/2)^2}{(M-M_{Kpp})^2+(\Gamma_{Kpp}/2)^2} \times exp\left(-\frac{q^2}{{Q_{Kpp}}^2}\right)$$

PRC102(2020)044002.



$\sigma_{m_{\Lambda p}} \sim 10$ MeV/c²



B_{Kpp} ~ 40 MeV, Γ_{Kpp} ~ 100 MeV
→ *large binding energy*

Q_{kpp} ~ 400 MeV (c.f. Q_{QF} ~ 200 MeV)

$$R = \frac{\hbar}{Q}\frac{(2m_N+m_{\bar{K}})}{2m_N} \sim 0.6 \text{ fm}$$

Indication of compact system.

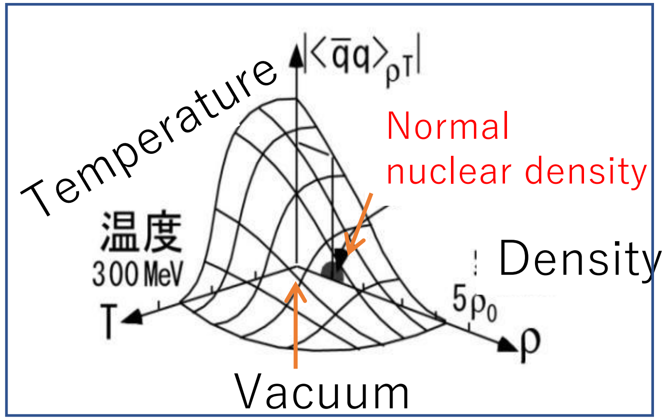
- Mesonic decay published
  - Yamaga et al. PRC110, 014002 (2024)
- Preliminary K^{bar}NNNresults obtained. Effort continued →J-PARC E80
- Upgrading detector.
  - x1.6 larger solid angle
  - x4 higher neutron detection eff.
  - Aim at data taking 2026.
- To study
  - K^{bar}NNN (J-PARC E80)
  - K^{bar}NN in detail.
    - Spin parity
    - Isospin partner K-pn
  - And more…

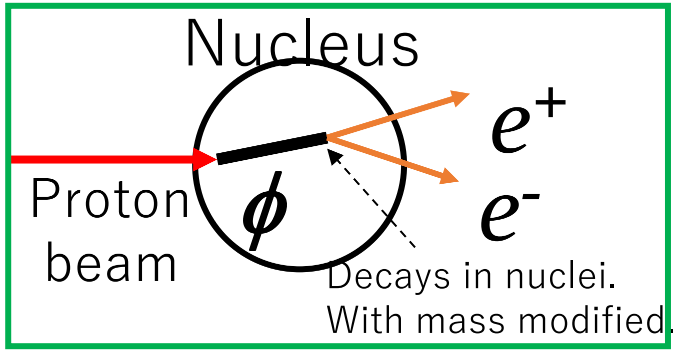
Slide by Hashimoto at J-PARC Hadron 2024.

High-p : J-PARC E16 [on-going] ϕ meson in nuclei

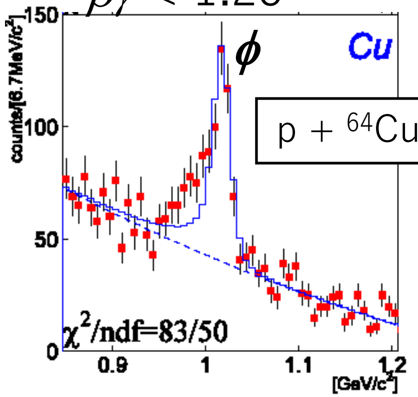
- Spontaneous breaking of chiral symmetry plays an important role in generating hadron mass.
- Chiral symmetry breaking $\langle \bar{q}q \rangle \neq 0$ depends on density.
- KEK E325
  - 12GeV **p + A → $\rho/\omega/\phi$ → e$^+$e$^-$**
  - Observed what can be interpreted as an in-medium spectral change of ϕ. 3.4% mass reduction at ρ_0 .
  - Chiral symmetry restored in nuclei?
- J-PARC E16 experiment:
  - 30GeV **p + A → $\rho/\omega/\phi$ → e$^+$e$^-$, (K$^+$K$^-$** E88)
  - Compared to E325, 6 times stat in 1st Run, Resolution 11→6 MeV
  - Spectrometer constructed for 1st physics run.
  - Commissioning run finished in June 2024.
  - 1st physics RUN in 2025.

NJL model
M. Lutz et al.
Nucl. Phys. A542,52(1992)





$\beta\gamma < 1.25$

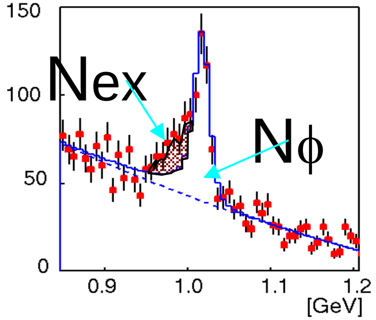


KEK-E325

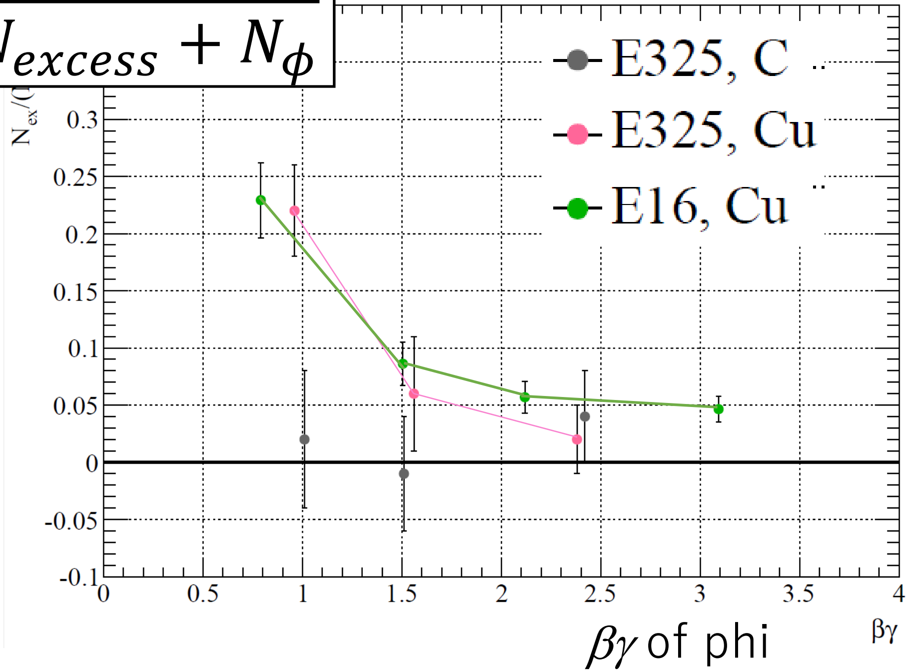
J-PARC E16

- 1st RUN expectation and beyond.

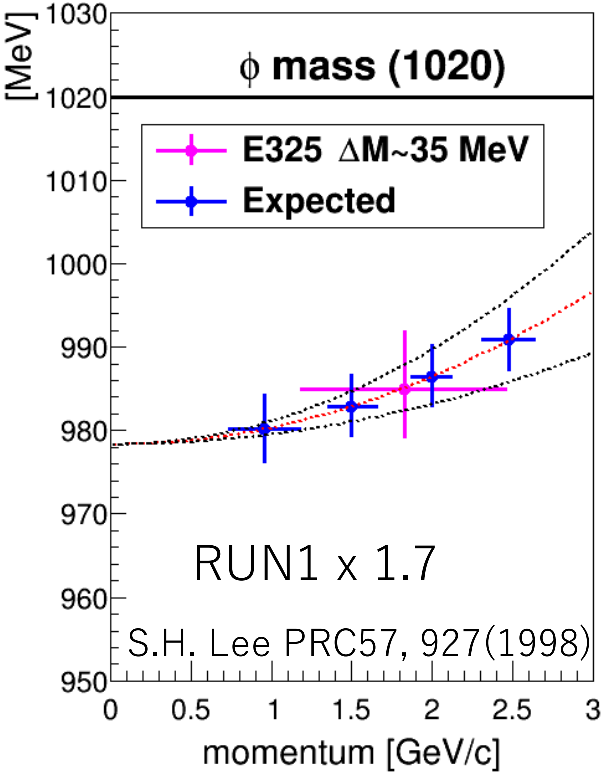
1st RUN expectation.
Clear tendency



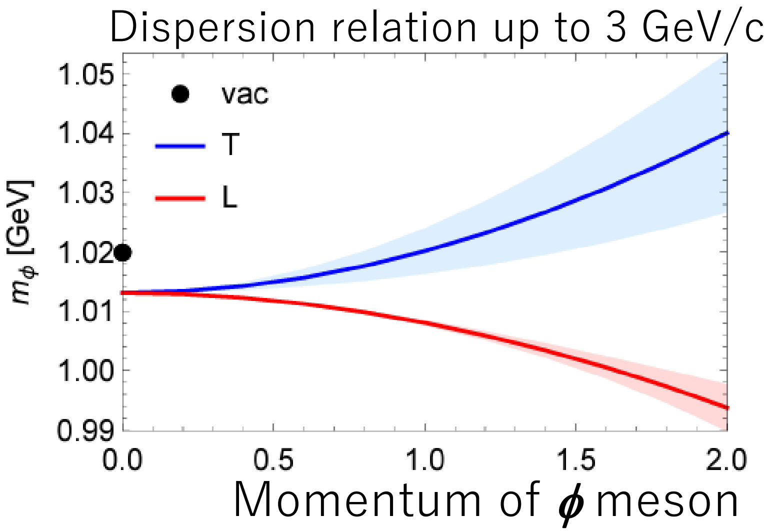
$$\frac{N_{excess}}{N_{excess} + N_{\phi}}$$



Dispersion relation can be obtained.



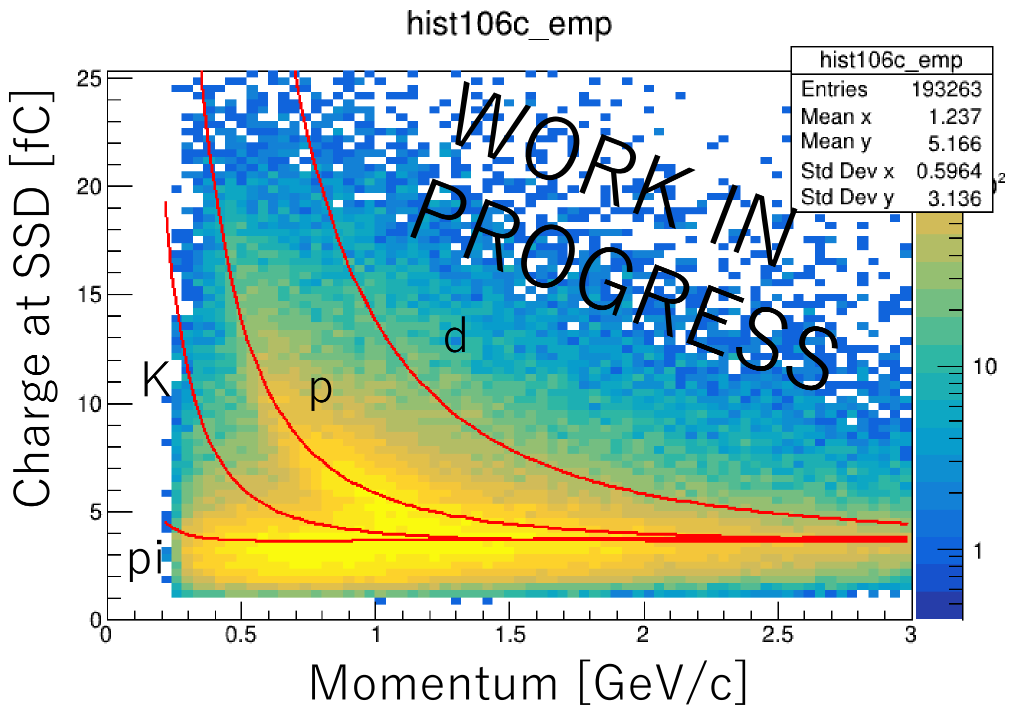
Polarization dependence can be accessed.

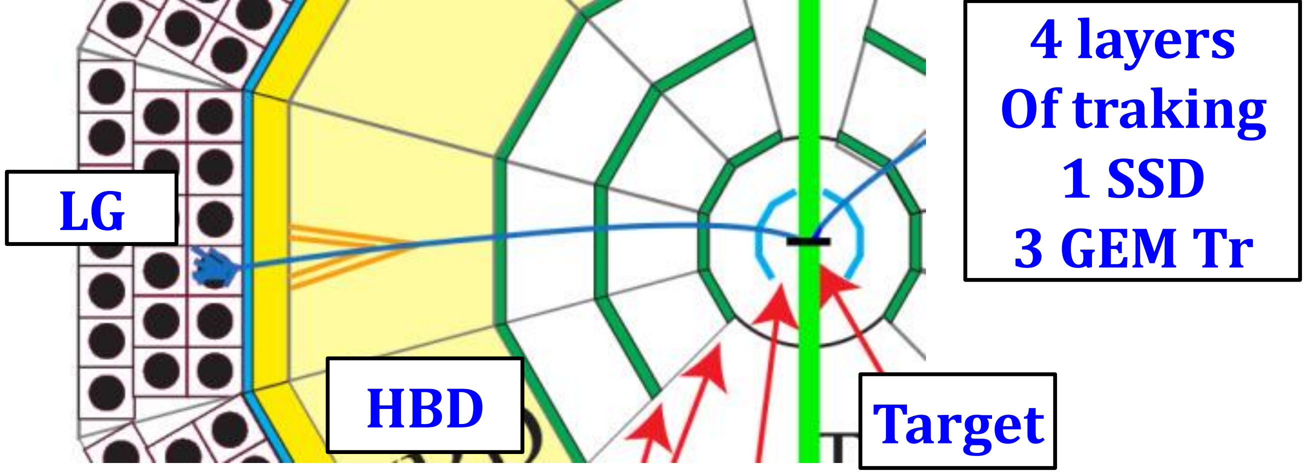


H.J. Kim, P.Gubler, PLB805, 135412 (2020)
I.W. Park et al, PRD 107, 074033 (2023)

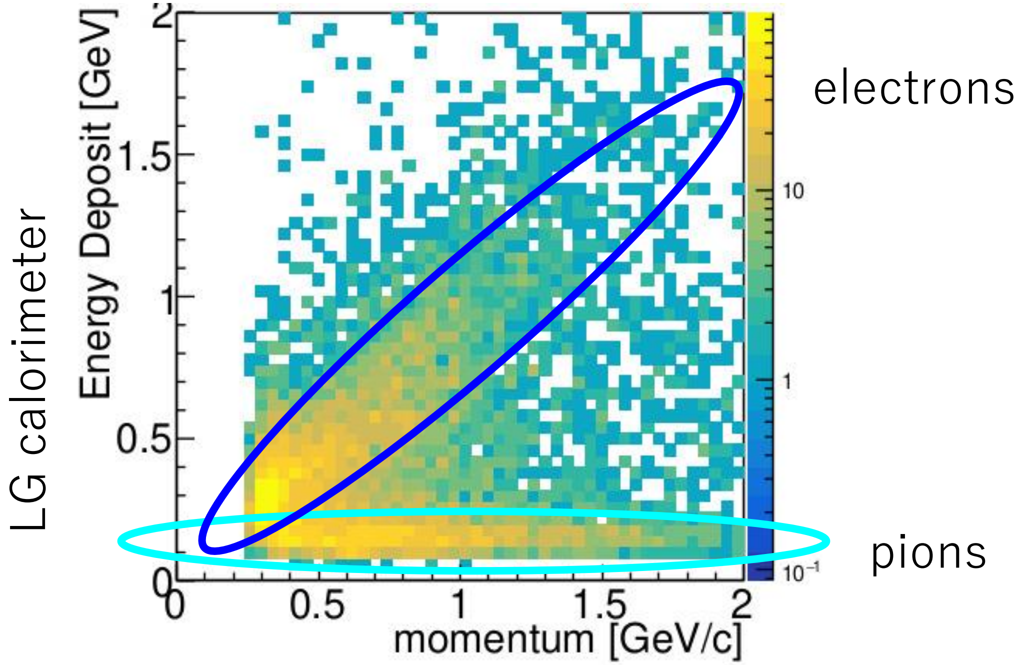
J-PARC E16 from commissioning run.

- Tracking: 1-layer of Silicon detector and 3-layers of GEM tracker.
- Silicon detector was developed in collaboration with GSI-CBM.
- Clear proton locus. SSD worked.



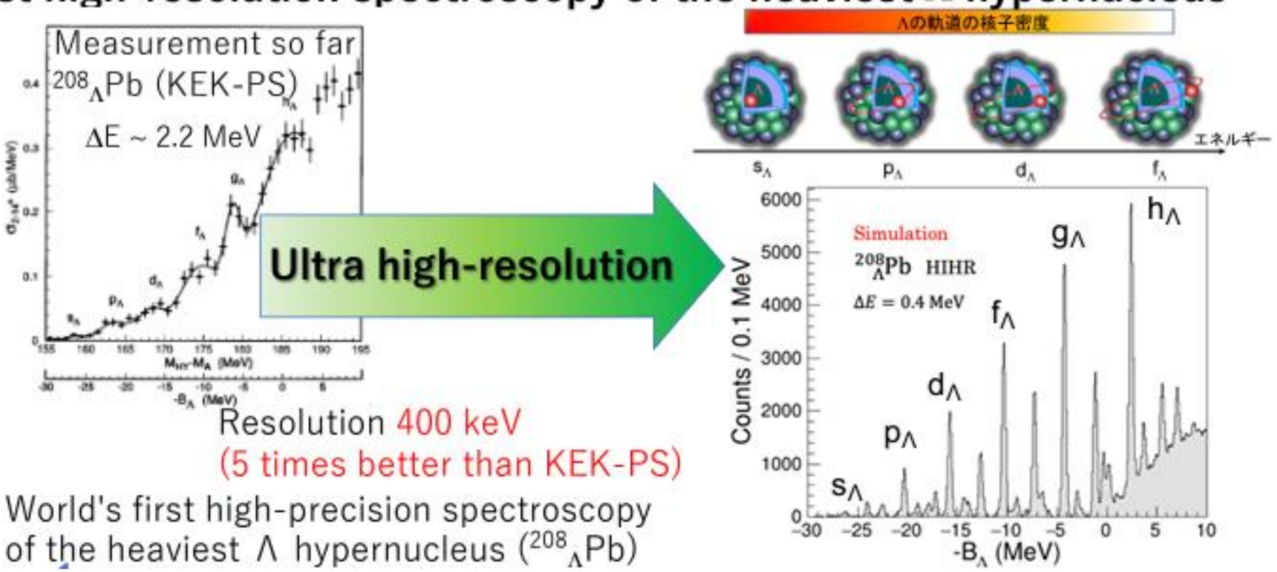


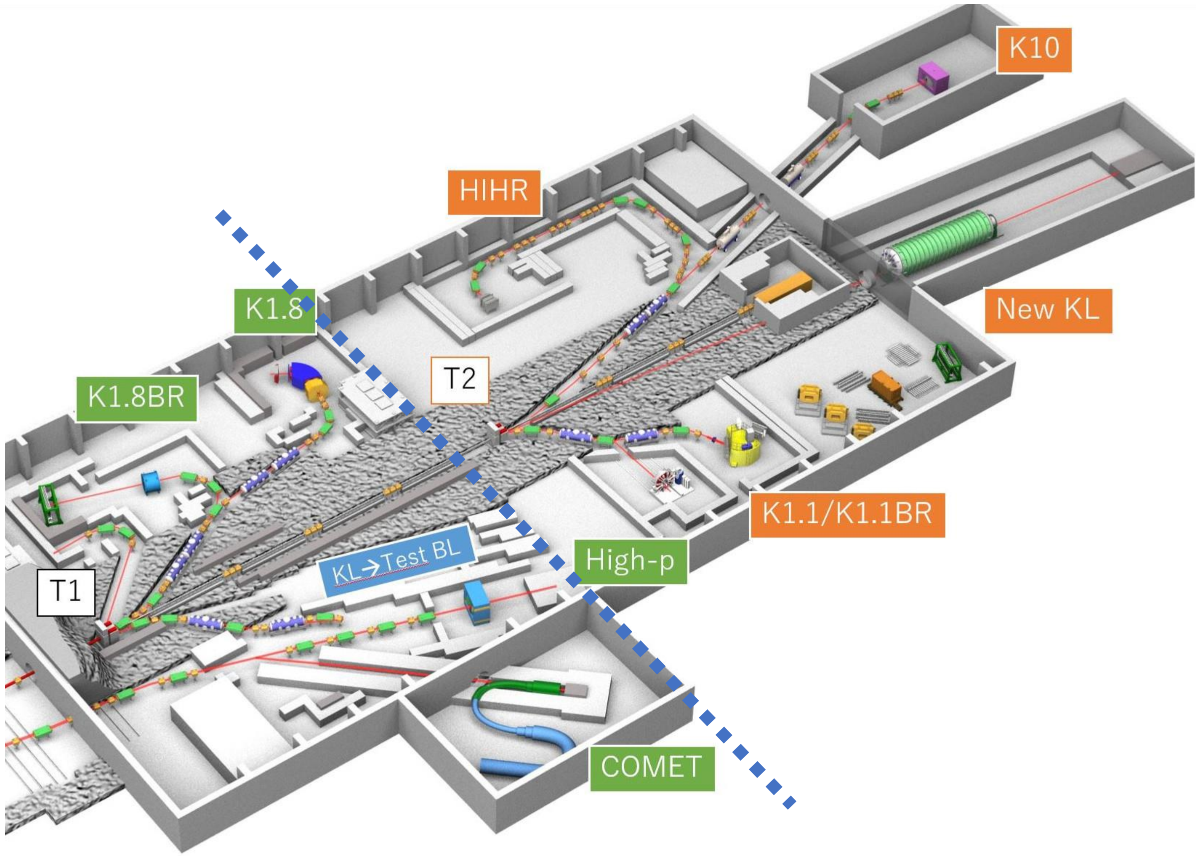
- Hadron Blind Detector (Cherenkov detector) to enhance electrons.
- Clear Momentum vs Energy (deposit on LG calorimeter) correlation of electron seen.



Hadron Hall Extension

Elucidation of YN interaction in nuclear matter
First high-resolution spectroscopy of the heaviest Λ hypernucleus

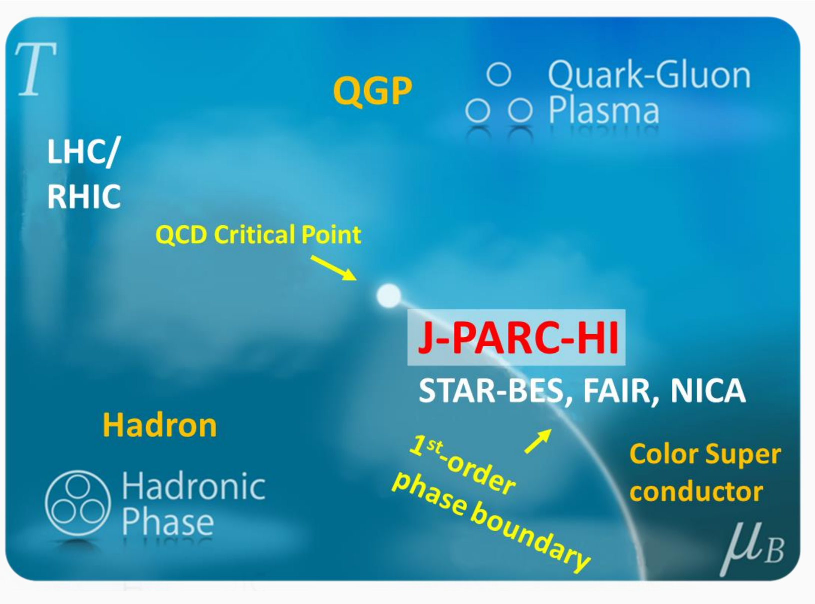




- Selected 1st priority in KEK PIP2022 (Project Implementation Plan)
- More beam lines with additional functionality
  - HIHR : High Intensity High Resolution beam by dispersion matching.
    - High precision systematic Λ hypernuclear spectroscopy up to Pb. Reveal 3BF.
  - K10 ΩΞ* spectroscopy, K1.1 polarized Λp scattering, New KL.

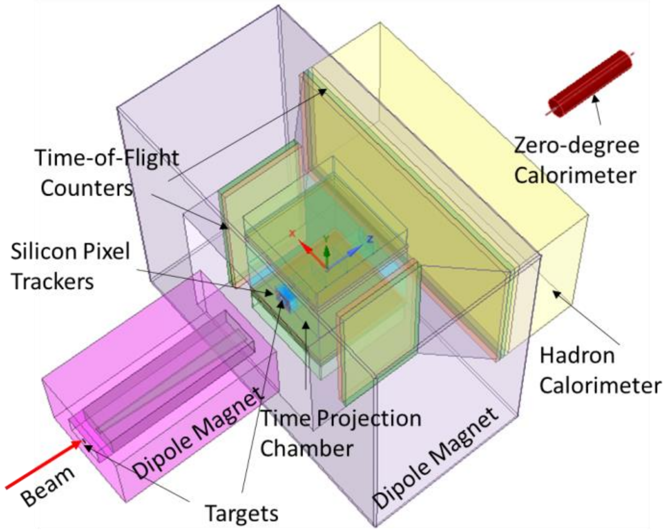
Future J-PARC Heavy Ion program

Explore the QCD phase diagram



EOS of Neutron Star
New state of the matter
  Quark Phase
  Color Super conductivity
Hadron physics in finite density

- Facility Upgrades Plan
  - New accelerator injector
  - New spectrometer
- Staging approach
  - Phase1:
    - Beam Intensity: 10^8 Hz for Au
    - Upgrade of the current E16 spectrometer
    - New LINAC and reuse of KEK-PS booster
  - Phase 2
    - Beam Intensity: 10^{11} Hz
    - New booster and new spectrometer



Schematic view of final spectrometer

Elab(Au)=1-12AGeV
$\sqrt{s_{NN}}$ =1.9-4.9GeV

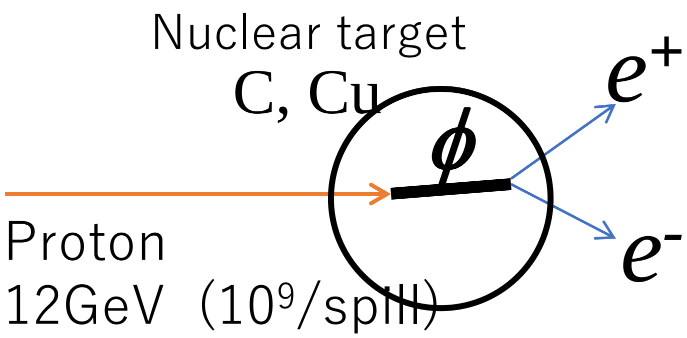
Summary

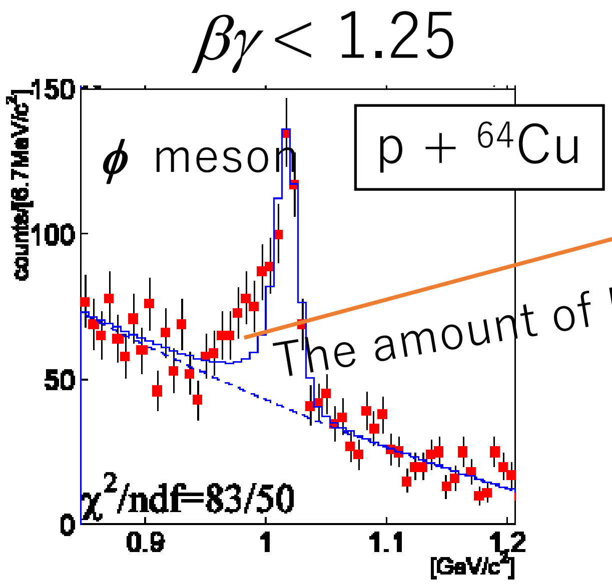
- J-PARC HD (Hadron) hosts many beam lines and various experimental programs conducted.
- Some of the experimental results and on-going efforts were introduced.
  - YN interaction by S=-1, -2 hypernuclear spectroscopy
  - YN interaction by YN scattering experiment.
  - Meson in nuclei, ϕ in A and $K^{bar}NN$ system and more.
- Future projects
  - Hadron Hall extension
  - J-PARC HI program

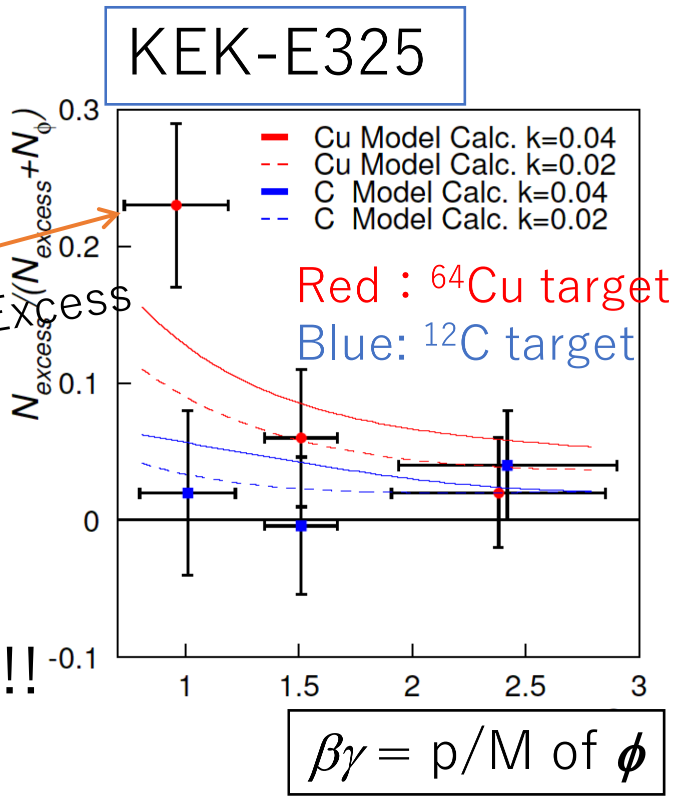
Backup slides

KEK-E325 results of ϕ meson

- The world's first results of ϕ modification.







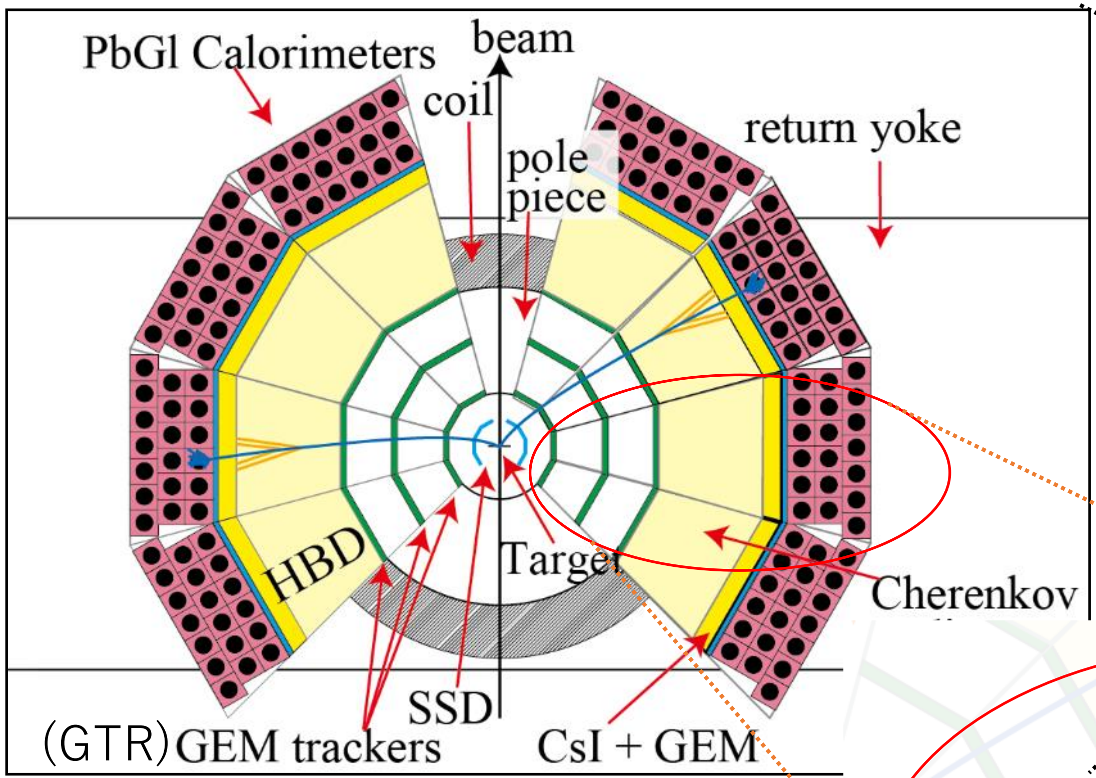
Assumption
In analysis

$$\frac{m(\rho)}{m(0)} = 1 - k_1\left(\frac{\rho}{\rho_0}\right)$$

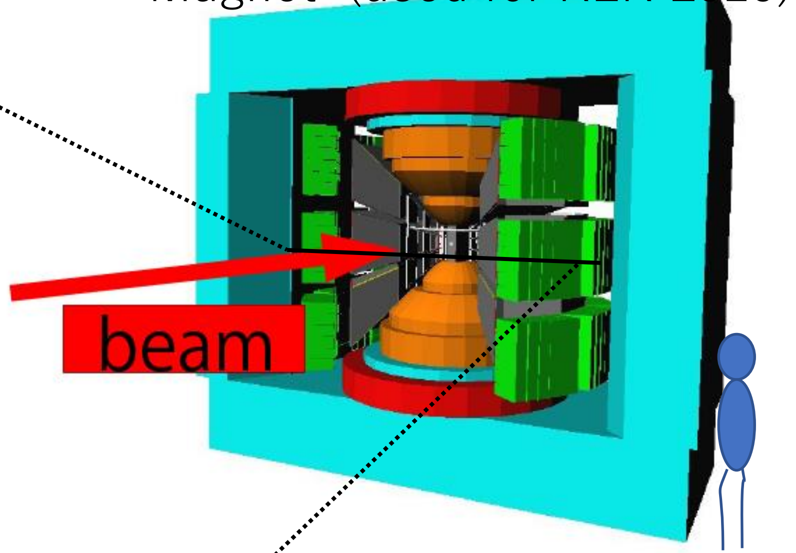
$$\frac{\Gamma(\rho)}{\Gamma(0)} = 1 + k_2\left(\frac{\rho}{\rho_0}\right)$$

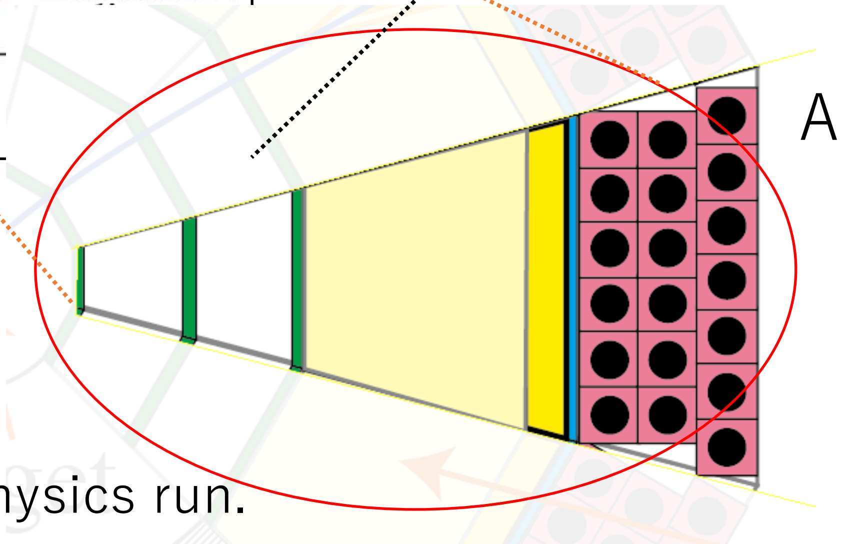
- Conclusion: Mass decreases in nuclei!!
  - Under the assumption of linear dependence of mass and width on density.
    - Mass: - 3.4 $^{+0.6}_{-0.7}$% ↓ At normal nuclear density
    - Width: x 3.6$^{+1.8}_{-1.2}$

The J-PARC E16 spectrometer



Magnet（used for KEK E325)





A module

X 26

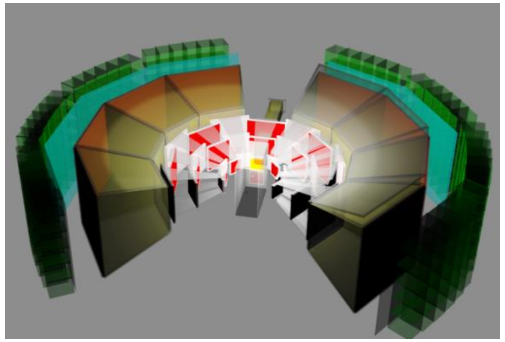
SSD : Tracking
GTR : Tracking
HBD : eID (Cherenkov)
LG : eID (Calorimeter)
26 modules in total. 8 for the 1st physics run.

Staging approach

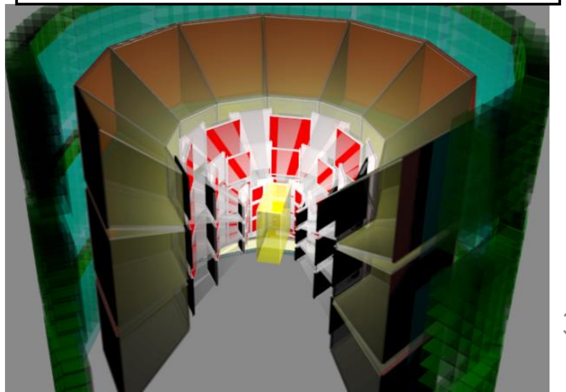
Executed!
PAC approved.

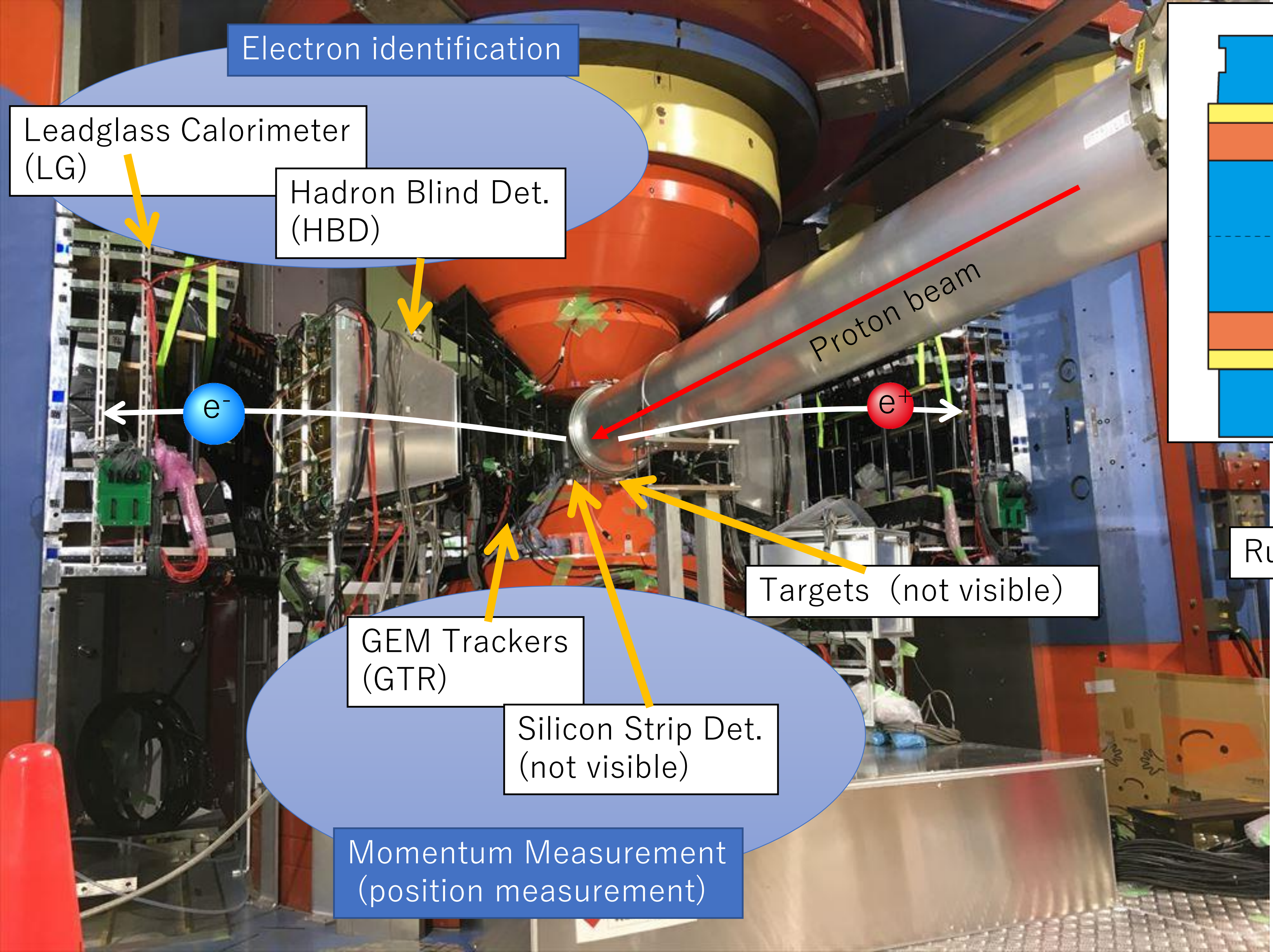
- **RUN 0a/b/c/d - 2020,2021,2023**– 413hrs.
  - **10 (SSD) + 8 (GTR) + 8 (HBD) + 8 (LG)** at last
    - Gradually increased acceptance and reached interm. Goal.
  - C+Cu targets
  - Beam / Detector commissioning
- **RUN 0e - 2024 (Apr.19-Jun.3) -- 206 hours.**
  - **8(SSD) + 10 (GTR) + 8 (HBD) + 8 (LG)**
  - Beam / Detector comm. + yield.
  - Upgraded Accelerator / DAQ. / Detectors.
- **RUN 1 2025(?)** -- 1280hrs (~53days)
  - **10 (SSD) + 10 (GTR) + 8 (HBD) + 8(LG)**
  - Physics data taking. ϕ: 15k for Cu.
  - Needs PAC approval based on comm. Runs.
- **RUN 2** -- 2560 hrs (~107 days)
  - **26 (SSD) + 26 (GTR) + 26 (HBD) + 26 (LG)**
  - + Pb/CH2 target
  - Needs additional budget.

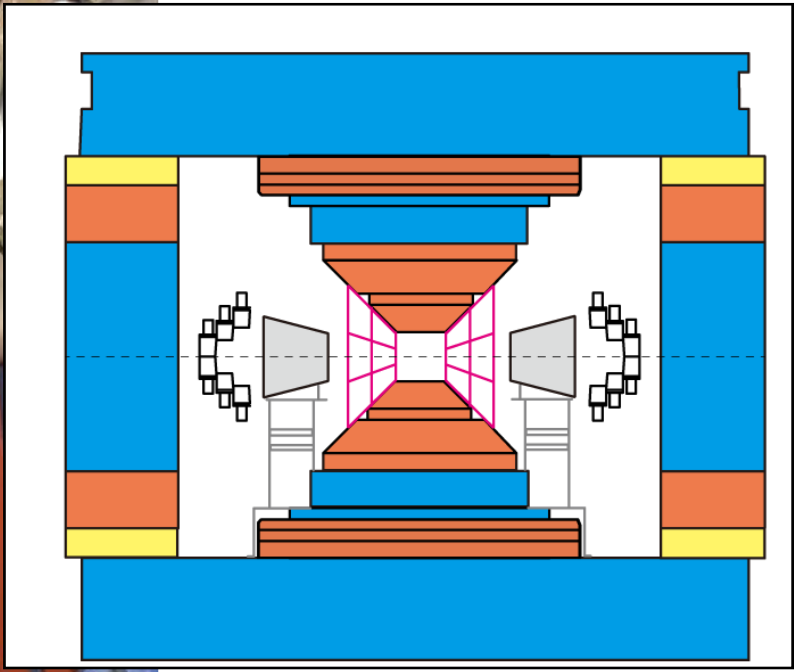
RUN 1 (8 modules)



RUN 2 (26 modules)



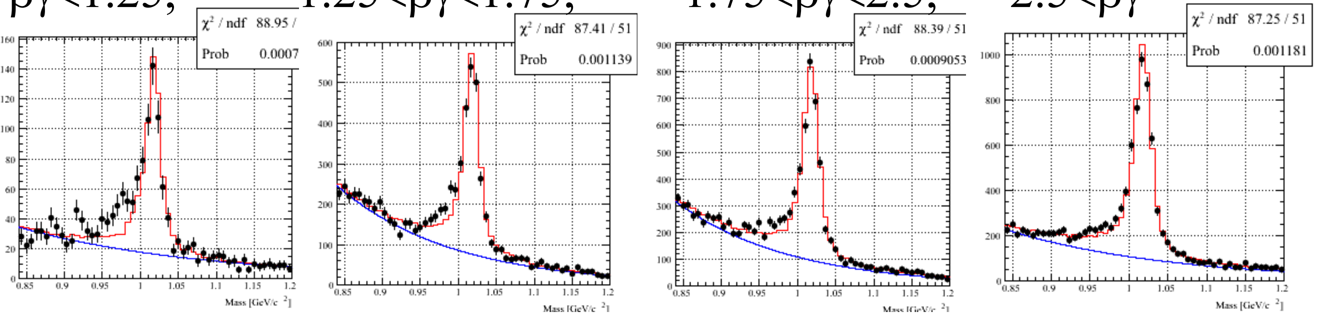




Run0b/c configuration(2021)

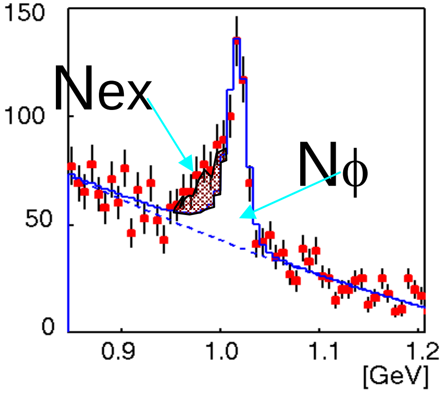
RUN1, Cu (INPUT:E325-BW)
Excess ratio vs $\beta\gamma$

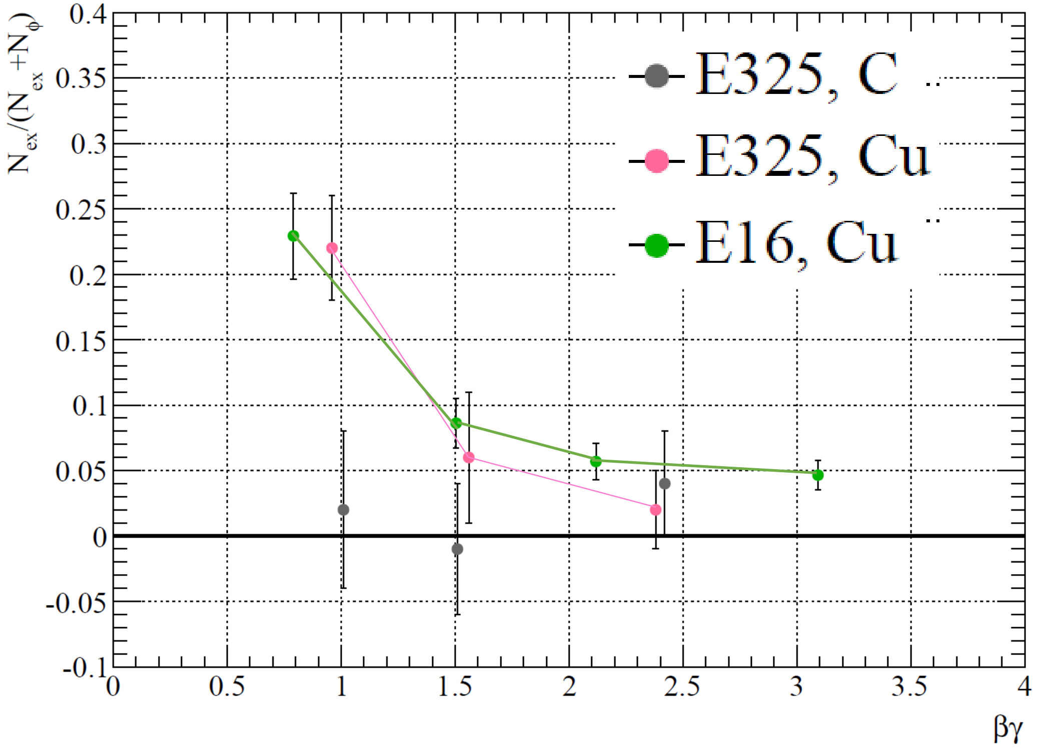
βγ<1.25, 1.25<βγ<1.75, 1.75<βγ<2.5, 2.5<βγ



(Fit fails when vacuum shapes are used.)

$$\frac{N_{excess}}{N_{excess} + N_{\phi}}$$





- ~15k ϕ for Cu target expected in RUN1
- All $\beta\gamma$ bins for Cu are significant in E16
- (cf) E325 only fastest $\beta\gamma$ bin is significant.

- Larger excess in lower $\beta\gamma$ bin.
- The tendency becomes clearer and more significant compared to E325.

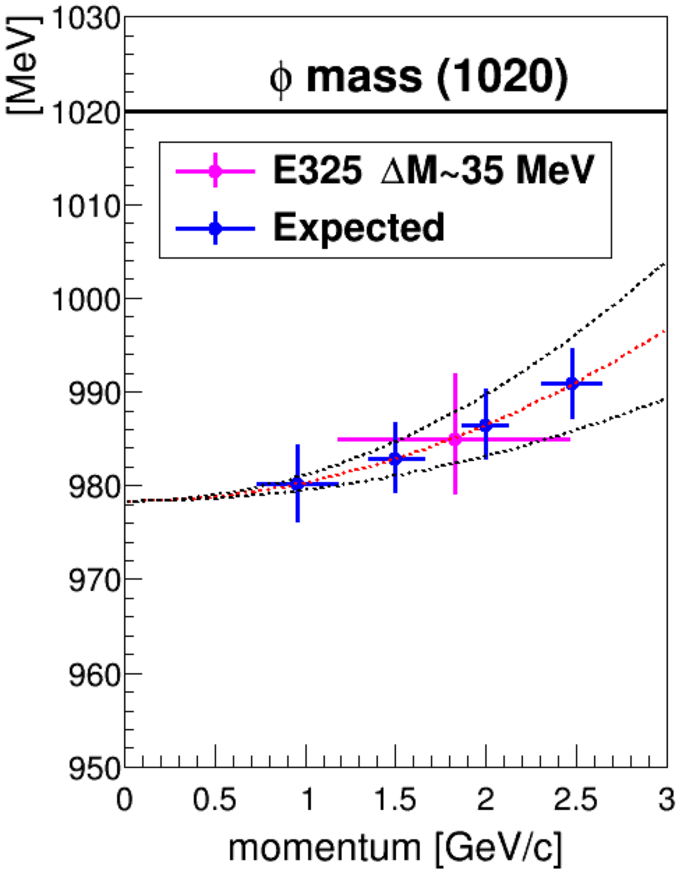
Momentum dependence (Dispersion relation)

H.Kim P. Gubler PLB805, 10 (2020)extends the validity of momentum range.
Show you on later slides.

- Momentum dependence of mass can be obtained for the first time.
- Expectation of RUN1 x 1.7 is shown.

- Dispersion relation itself is an important property of pseudo particles.
- We can extrapolate mass into 0 momentum, where most of the QCDSR calculation results apply.

- More discussion on later slides.

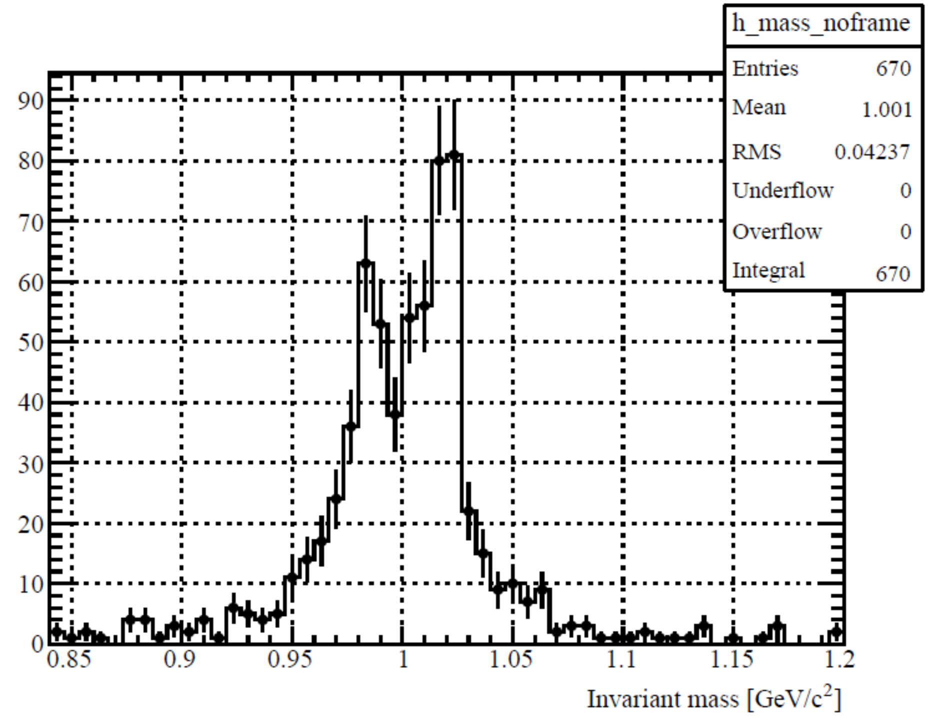


S.H. Lee PRC57, 927(1998)

Expected in RUN2

- RUN2 stat (320shifts)
- INPUT: E325-BW

- Pb target
- $\beta\gamma < 0.5$



BB interaction flavor SU(3)

- 8 x 8 =
  27 + (NN world.)
  10* + (NN world.)

  10 + (appears ΣN I=3/2)
  8s + (Pauli forbidden)
  8a +
  1
-

Table 2. SU(3) content of the different interaction channels with total strangeness S and isospin I. The upper half refers to the space-spin symmetric states $^3S_1$, $^1P_1$, ^3D, ..., and the lower half to the space-spin antisymmetric states $^1S_0$, ^3P, $^1D_2$, ...

S	I	Channels	SU(3)-irreps
		Space-spin symmetric	
0	0	NN	$\{10^*\}$
−1	1/2	ΛN, ΣN	$\{10^*\}$, $\{8\}_a$
	3/2	ΣN	$\{10\}$
−2	0	$N\Xi$	$\{8\}_a$
	1	$N\Xi$, $\Sigma\Sigma$	$\{10\}$, $\{10^*\}$, $\{8\}_a$
		$\Sigma\Lambda$	$\{10\}$, $\{10^*\}$
		Space-spin antisymmetric	
0	1	NN	$\{27\}$
−1	1/2	ΛN, ΣN	$\{27\}$, $\{8\}_s$
	3/2	ΣN	$\{27\}$
−2	0	$\Lambda\Lambda$, $N\Xi$, $\Sigma\Sigma$	$\{27\}$, $\{8\}_s$, $\{1\}$
	1	$N\Xi$, $\Sigma\Lambda$	$\{27\}$, $\{8\}_s$
	2	$\Sigma\Sigma$	$\{27\}$

Th. A. Rijken and H.J. Schulze
Eur. Phys. J. A52, 21 (2016)

BB interaction in flavor SU(3)

- 8 x 8 = 27 + 10 + 10* + 8s + 8a + 1

S	BB(I)	Symmetric	Anti-symmetric
0	$NN(I=0)$	----	$[10^*]$
	$NN(I=1)$	$[27]$	----
-1	ΛN	$\frac{1}{\sqrt{10}}([8s]+3[27])$	$\frac{1}{\sqrt{2}}(-[8a]+[10^*])$
	$\Sigma N(I=1/2)$	$\frac{1}{\sqrt{10}}(3[8s]-[27])$	$\frac{1}{\sqrt{2}}([8a]+[10^*])$
	$\Sigma N(I=3/2)$	$[27]$	$[10]$
-2	$\Lambda\Lambda$	$\frac{1}{\sqrt{5}}([8s]+\frac{9}{2\sqrt{30}}[27]+\frac{1}{2\sqrt{2}}[1])$	----
	$\Xi N(I=0)$	$\frac{1}{\sqrt{5}}([8s]-\frac{\sqrt{3}}{\sqrt{10}}[27]+\frac{1}{\sqrt{2}}[1])$	$[8a]$
	$\Xi N(I=1)$	$\frac{\sqrt{3}}{\sqrt{5}}[8s]+\frac{\sqrt{2}}{\sqrt{5}}[27]$	$\frac{1}{\sqrt{3}}(-[8a]+[10]+[10^*])$
	$\Sigma\Lambda$	$-\frac{\sqrt{2}}{\sqrt{5}}[8s]+\frac{\sqrt{3}}{\sqrt{5}}[27]$	$\frac{1}{\sqrt{2}}([10]-[10^*])$
	$\Sigma\Sigma(I=0)$	$\frac{\sqrt{3}}{\sqrt{5}}[8s]-\frac{1}{2\sqrt{10}}[27]-\frac{\sqrt{3}}{\sqrt{8}}[1]$	---
	$\Sigma\Sigma(I=1)$	---	$\frac{1}{\sqrt{6}}(2[8a]+[10]+[10^*])$
	$\Sigma\Sigma(I=2)$	$[27]$	---

Table based on PRC64, 054001 (2001)

Many theoretical calculation agrees with existence of K^{bar}NN, but results scattered.

AY: PRC65(2002)044005, PLB535(2002)70.
WG: PRC79(2009)014001.
BGL: PLB712(2012)132.
OHHMH: PRC95(2017)065202.
Kanada: EPJA57(2021)185.