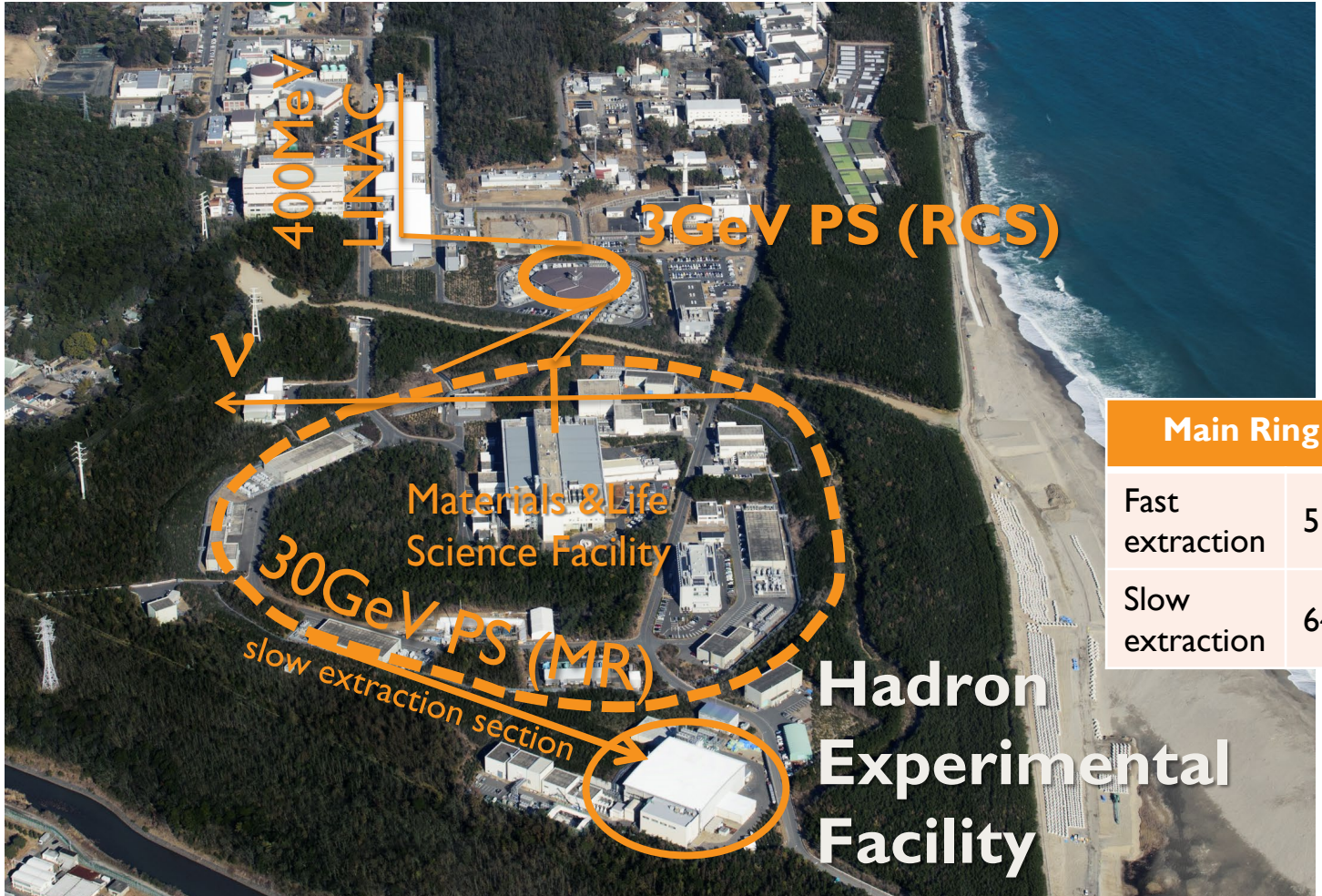
Hadron Physics at J-PARC

M. Naruki (Kyoto Univ.)

Contents

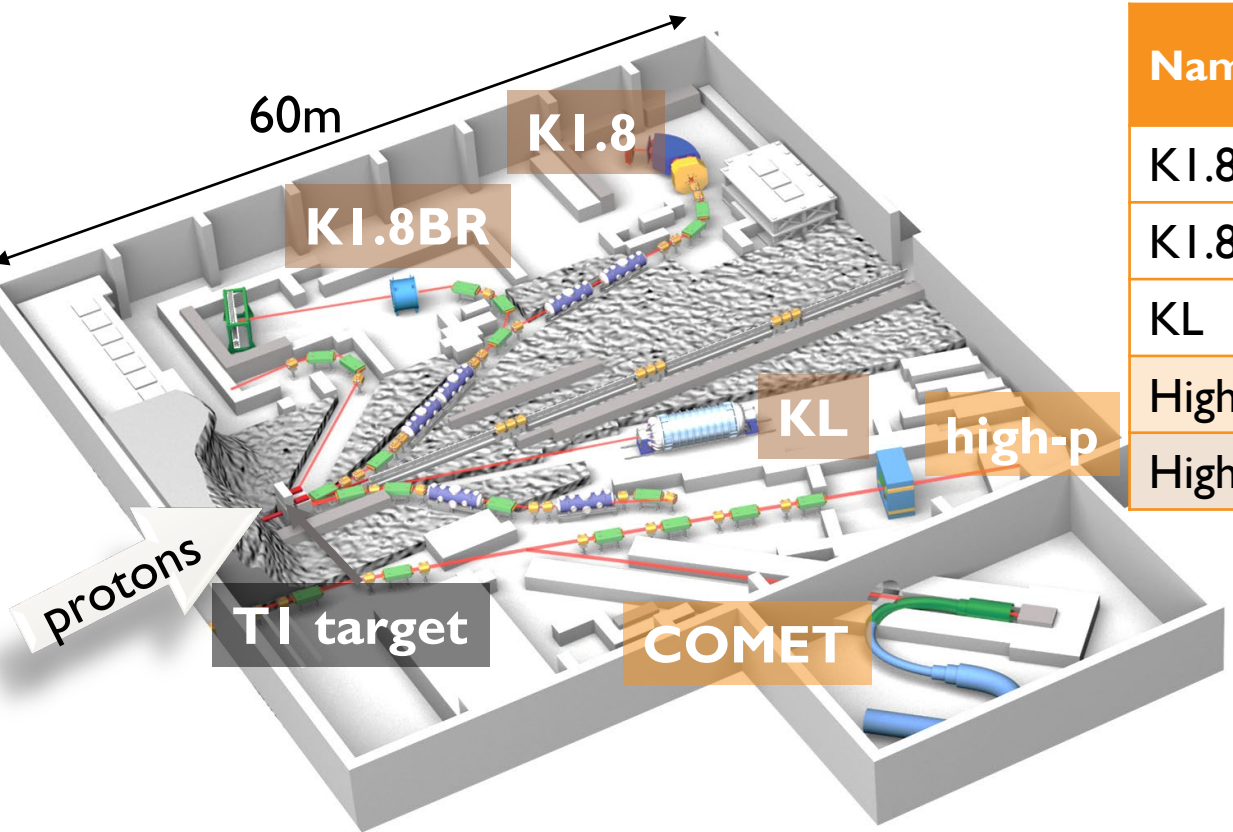
J-PARC bird's-eye view

Tokai, Ibaraki



Main Ring (MR)	
Fast extraction	510kW
Slow extraction	64.5kW

Hadron Experimental Facility

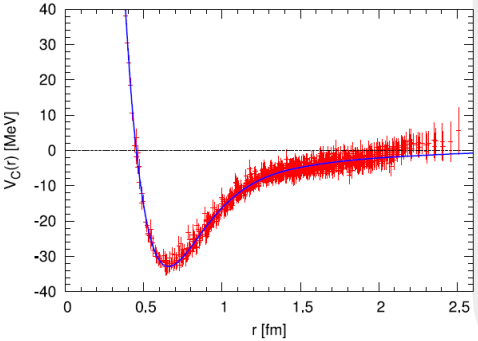


Name	Particles	P_{max} (GeV/c)	Intensity (/spill)
K1.8	π, K	2.0	10^6 K^-
K1.8BR	π, K	1.1	10^6 K^-
KL	K^0		
High-p	**proton**	**31**	10^{10} p
High-p2	**π/K**	**20**	10^6 K^-

Hadron Physics at J-PARC

Quark degrees of freedom - Nuclear Force

NN potential from LQCD

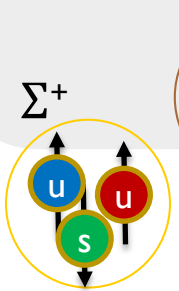


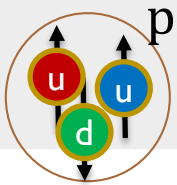
N. Ishii, S. Aoki and T. Hatsuda, PRL 99, 022001 (2007)

Hadron-Hadron

Interaction

YN scattering

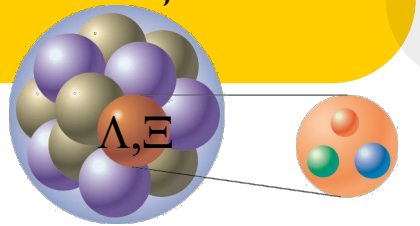




Hypernuclei

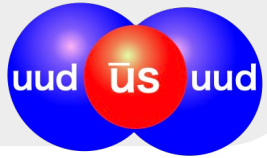
multi-strangeness hypernuclei

ΞN, ΛΛ



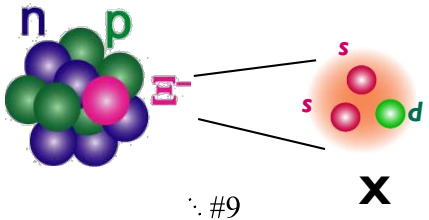
Few-body systems

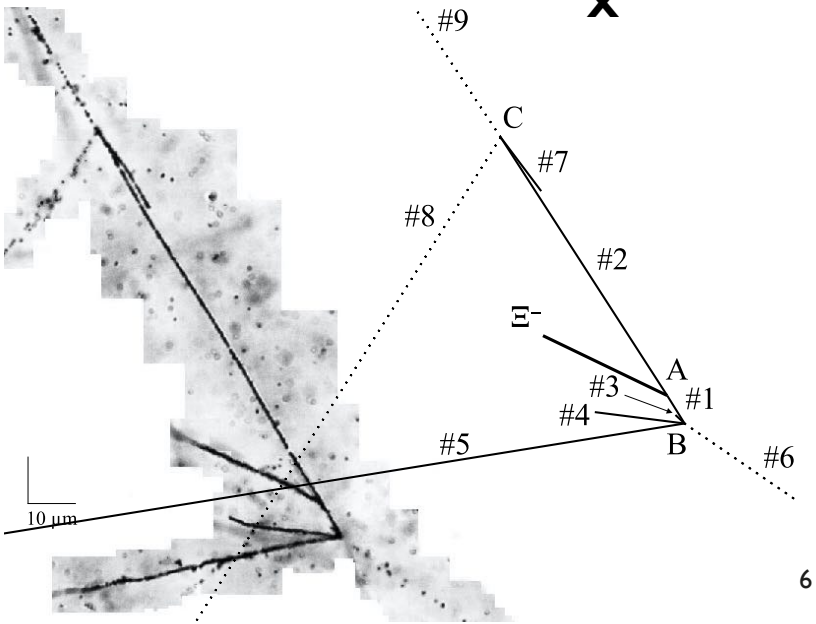
K-pp



Observation of Ξ- nucleus bound system (E07)

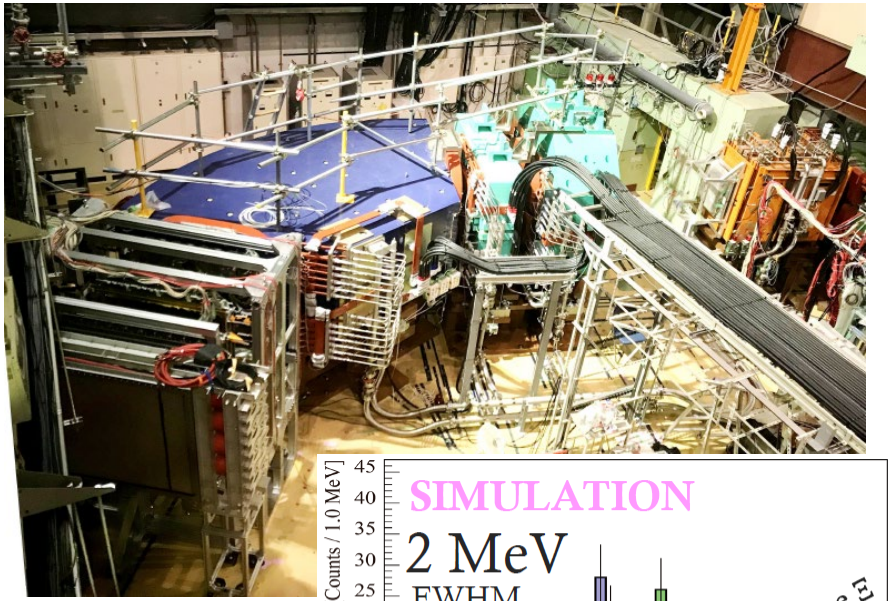
- emulsion & spectrometer experiment (hybrid)
- Ξ hypernucleus event (IBUKI event)
  - Uniquely identified decay mode
    - $\Xi^- + {}^{14}N \rightarrow {}^{10}_{\Lambda}Be + {}^{5}_{\Lambda}He$
  - For the first time Ξ-nucleus interaction is measured precisely
  - Binding energy B_{Ξ^-} = 1.27 ± 0.21 MeV
  - likely to be Coulomb-assisted 1p state
    - weak ΞN-ΛΛ coupling

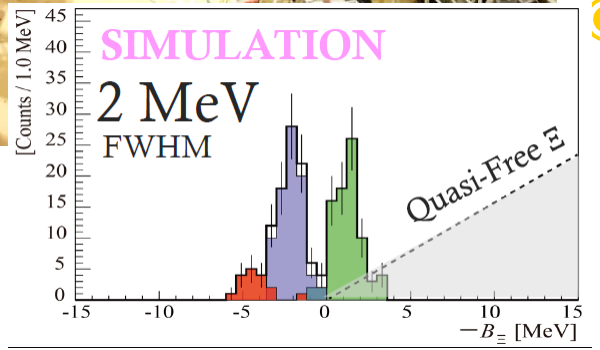




Hayakawa *et al.* PRL126, 062501 (2021)
Editor's suggestion, Cover page

Xi hypernucleus in future (E70)

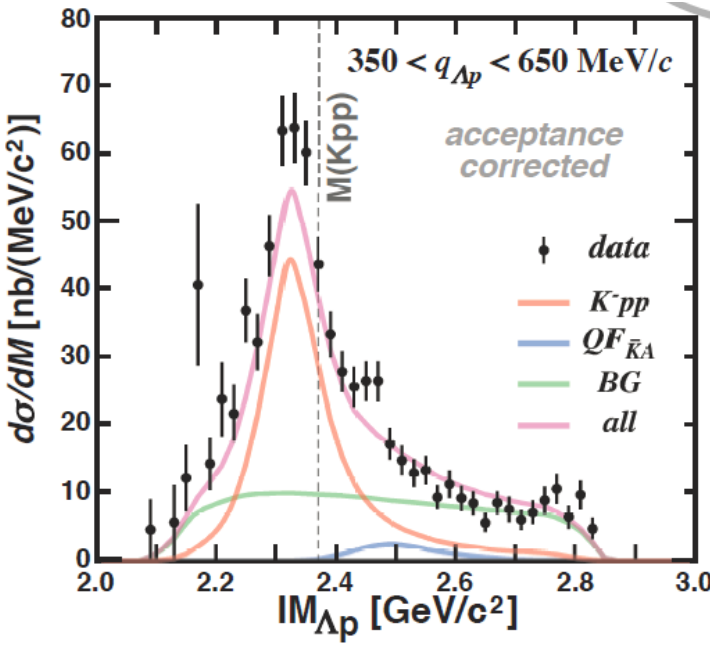




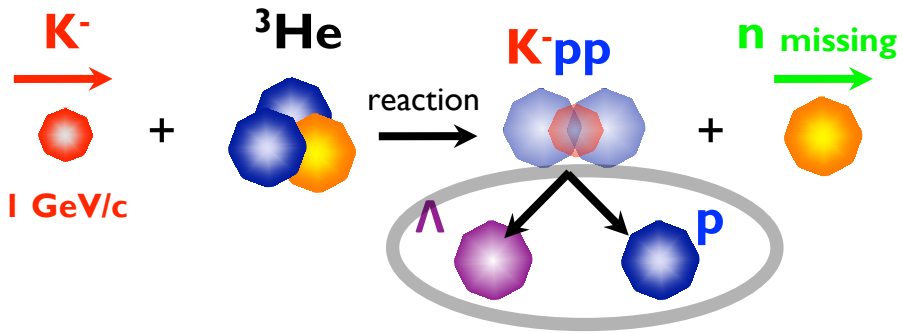
- $^{12}_{\Xi}$Be is produced in ^{12}C(K$^-$,K$^+$)
- Far better resolution of 2 MeV
  - cf. BNL E885 ΔM=14 MeV
- New spectrometer S-2S is now being constructed (~2022).
- Binding energy & width

Ξ- / double Λ hypernuclei will be studied for **hydrogen**
→H. Fujioka, Nuclear Strangeness, 9/9

Observation of K-pp bound state (E15)



Phys. Lett. B. 789, 620 (2019)

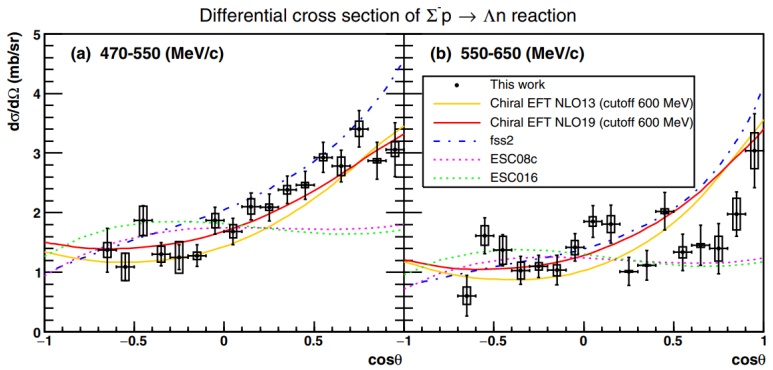


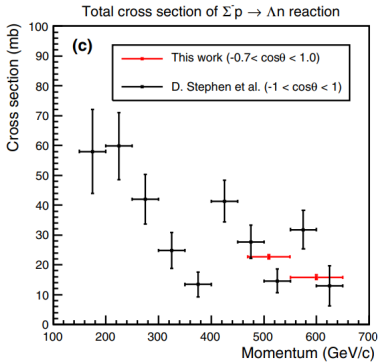
binding energy: ~ 50 MeV
decay width: ~ 110 MeV

T. Yamaga (E15) R. Maruyama (Kd reaction, E31)
9/9 "Nuclear Strangeness" session

Hyperon-Nucleon Scattering (E40)

- differential cross section of $\Sigma^- p \to \Lambda n$
- Σ produced in LH2(1.33 π^-,K^+)
- Secondary reaction is identified with spectrometer
  - cf. topological information w/ bubble chamber





- new-standard technique
- much better accuracy

K. Miwa et al. PRL128(2022)072501

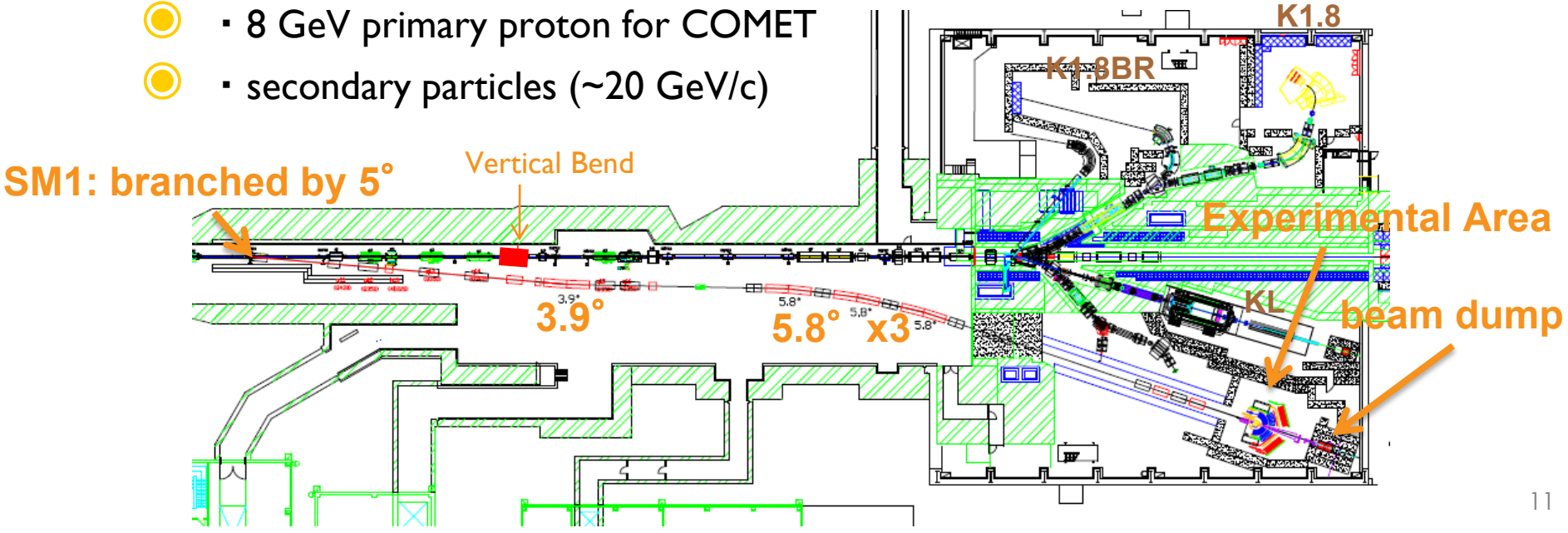
→9/9 morning, Nuclear Strangeness session

New beamline and activities

Ongoing experiment at newly constructed beamline

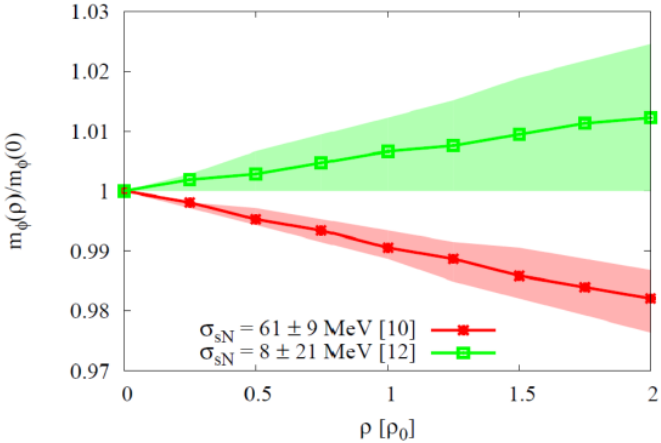
High-momentum beam line

- at SM1 protons branches off from the primary line
  - 30 GeV primary proton (10^{10}/s)
  - 8 GeV primary proton for COMET
  - secondary particles (~20 GeV/c)



In-medium Spectral Information on Vector Mesons - E16 -

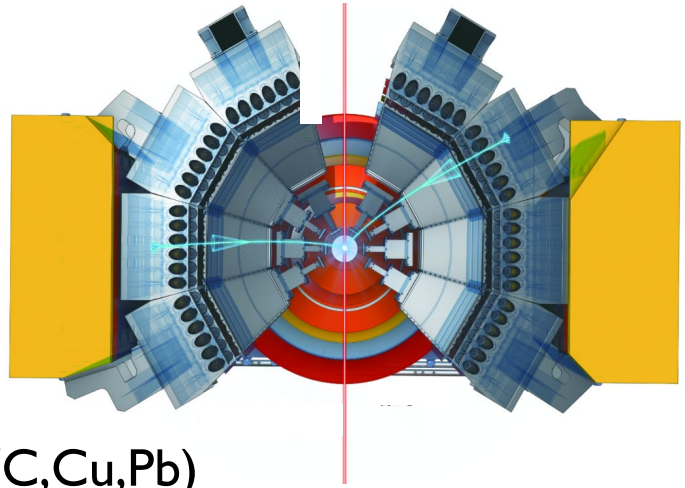
- Explore the world of light quarks
  - determine quark and gluon condensations
  - key symmetry – chiral symmetry
- Leptonic probe – di-lepton
  - clean signal from complicated hadronic system
- Next-generation experiment
  - catch up e+/e− pairs produced in 30 GeV p+A interactions
  - w/ J-PARC intense beam & state-of-the-art experimental techniques



P. Gubler and K. Ohtani, Phys. Rev. D 90, 094002 (2014).

Dilepton measurement at J-PARC

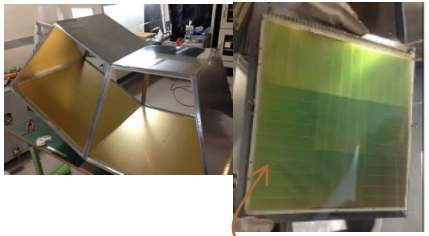
- 30GeV pA→φX→ee
- systematic studies
  - velocity/target dependences
  - High statistics
    - 10^{10} p/spill (2 seconds) x 0.1% targets (C,Cu,Pb)
    - high rate capability 100k channel
  - High mass resolution ΔM = 7 MeV



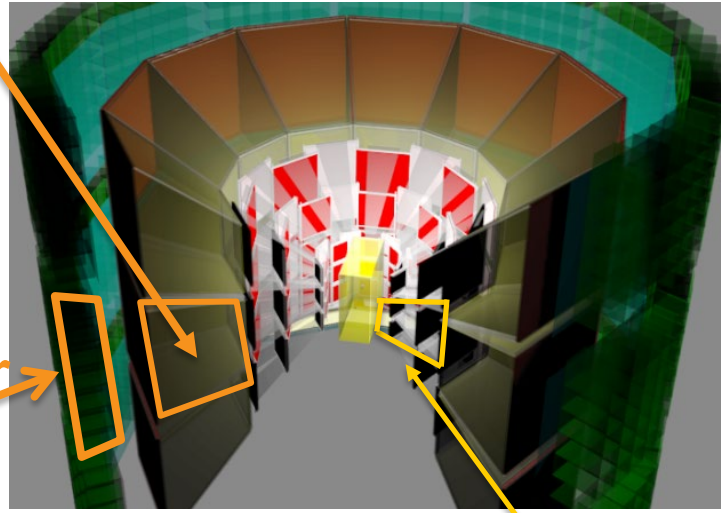
spectrometer

- Tracking devices
  - SSD
  - GEM Tracker (GTR)
- double-stage Electron ID counters
  - Hadron Blind Detector (HBD)
  - Lead-glass calorimeter (LG)

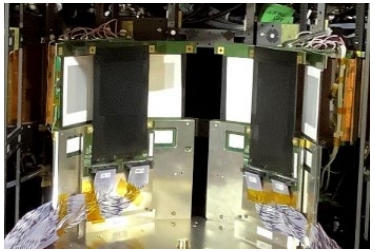
Hadron Blind Detector (HBD)



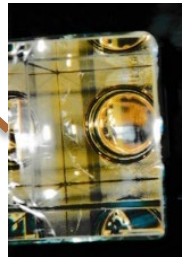
CsI evaporated GEM
(inside the gas chamber)



SSD



Lead-glass calorimeter

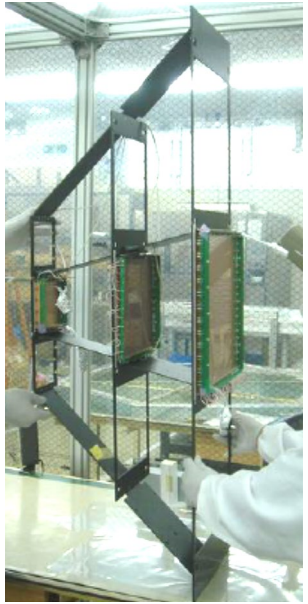


rejection power :
3x10-4

SF6W lead-glass

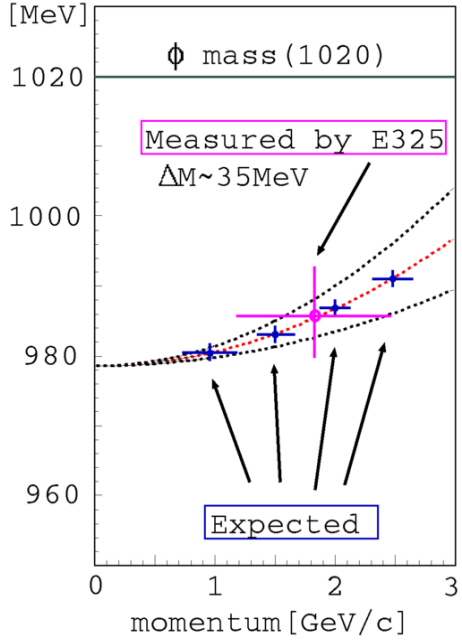
GEM Tracker

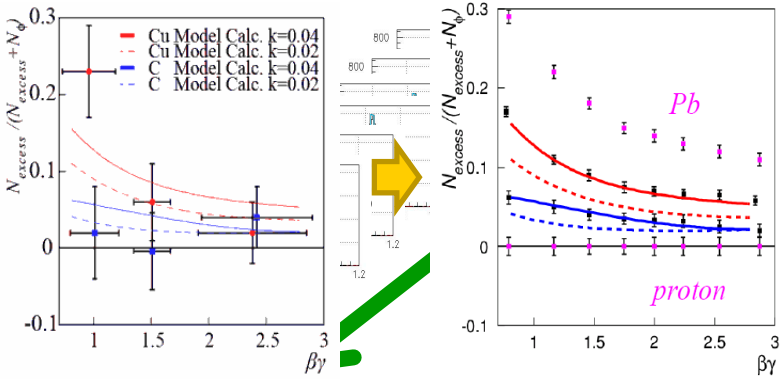
3 size of GEM
(10, 20 and 30 cm)



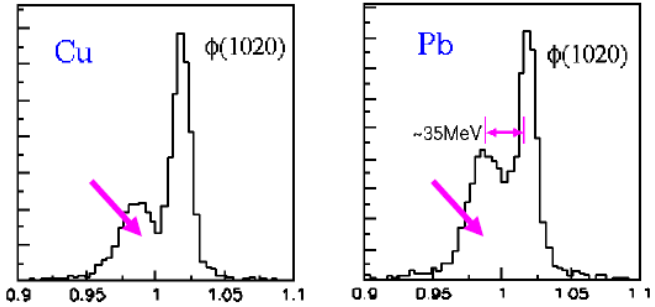
Expected Signal

momentum dependence of mass





βγ<0.5, σ=5 MeV



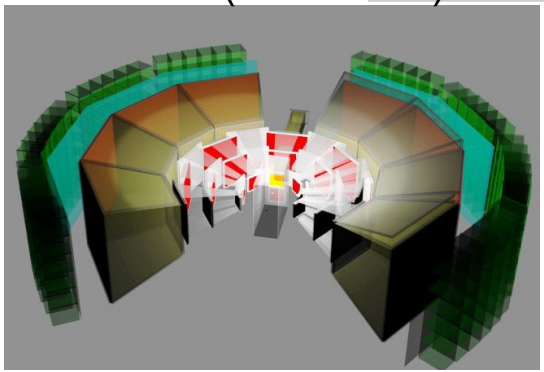
Schedule

- 2020-2021 RUN0 -- 320 hours, C/Cu targets
  - Beamline / Detector commissioning

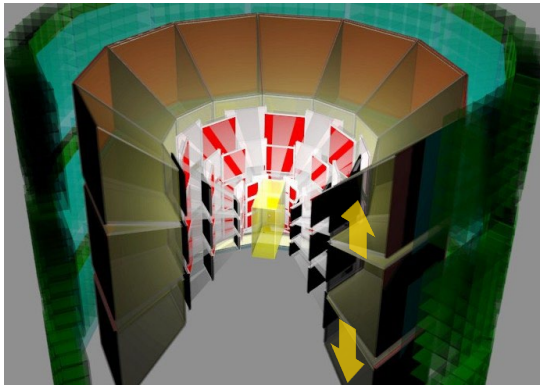
we are ready

- 2023 RUN1 -- 1280 hours, C/Cu targets
  - Physics run 15k of ϕ mesons
- 2025 RUN2 -- 2560 hours, C/Cu/Pb targets
  - nuclear size & velocity dependences
  - dispersion relation

RUN 1 (8 modules)



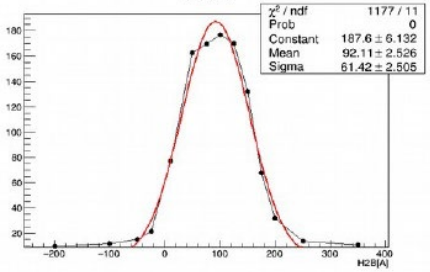
RUN 2 (26 modules)

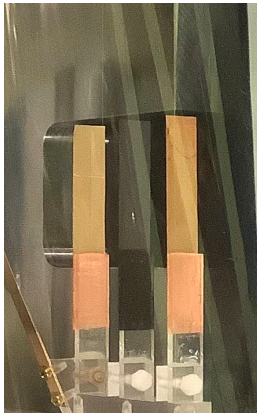


Current Status

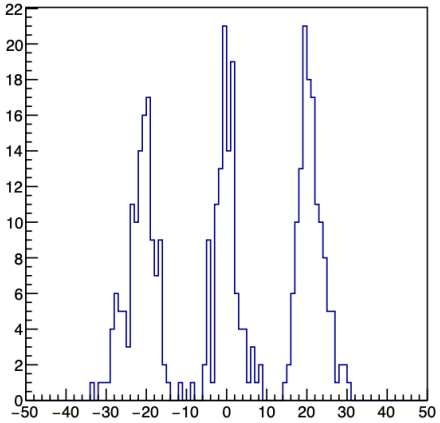
- quality of extracted primary beam
  - ✓ profile & global time structure
- detector performance
  - ✓ high-rate capability (10MHz interaction)
  - ✓ vertex reconstruction
  - ✓ electrons ID

beam profile

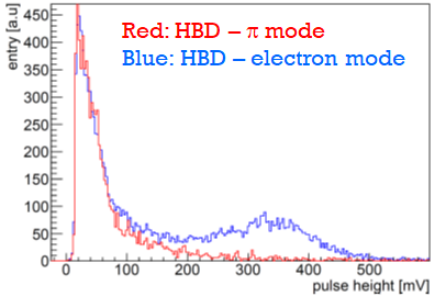




Vertex distribution

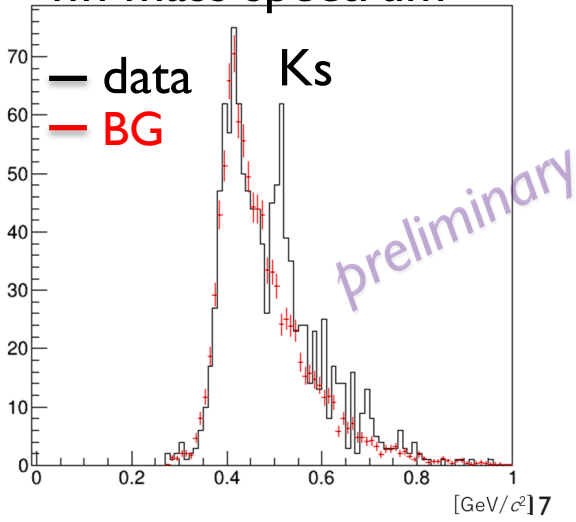


PID performance

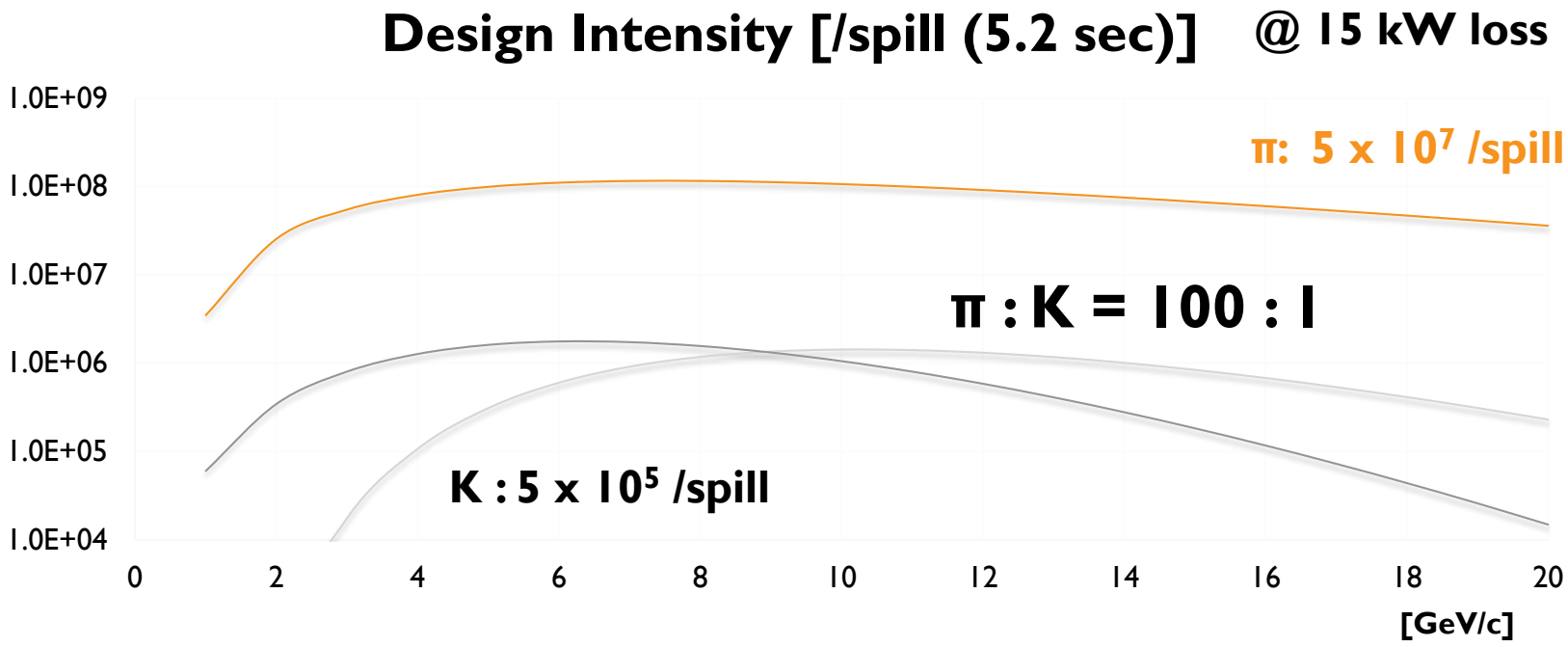


Pulse Hight Distribution of Lead Glass

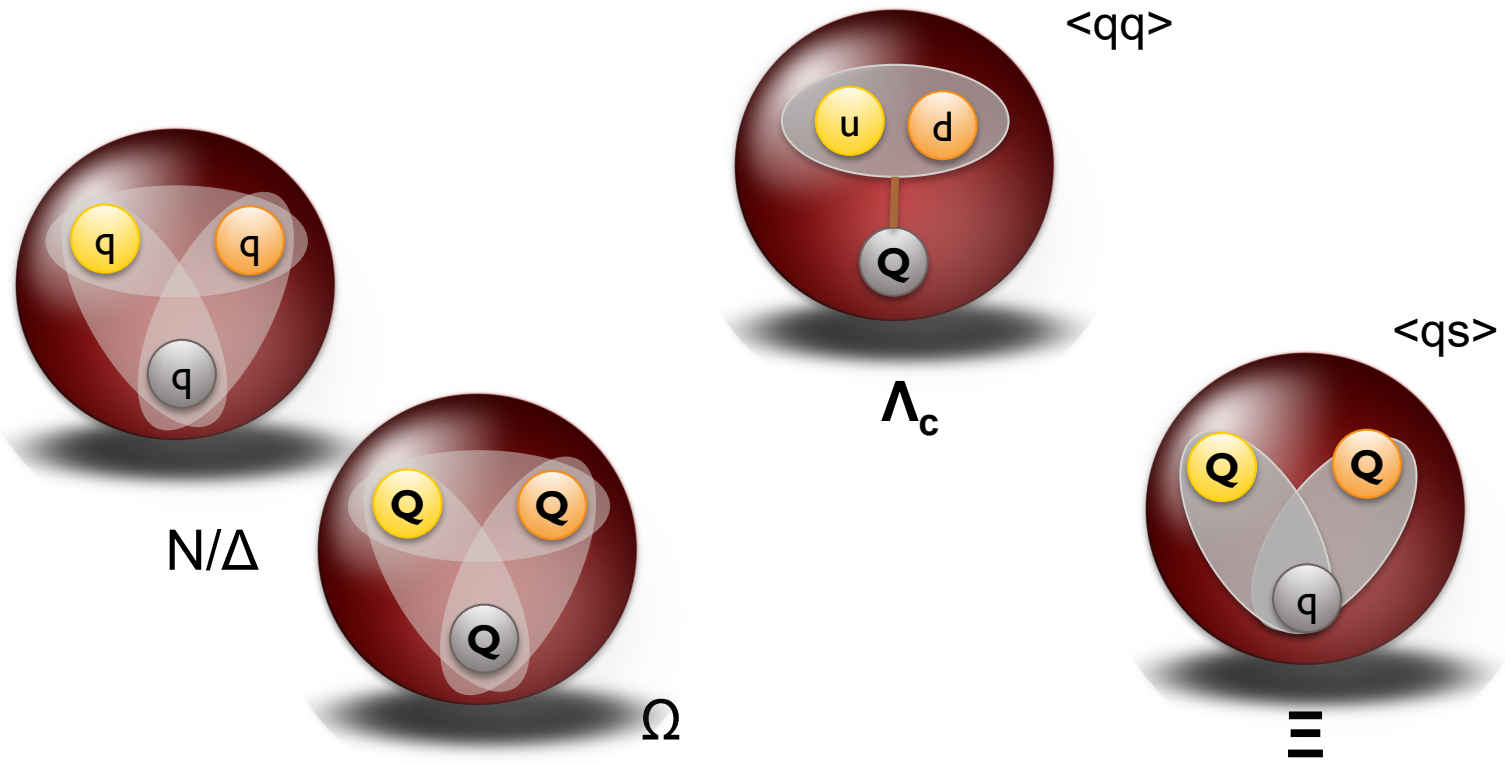
ππ mass spectrum



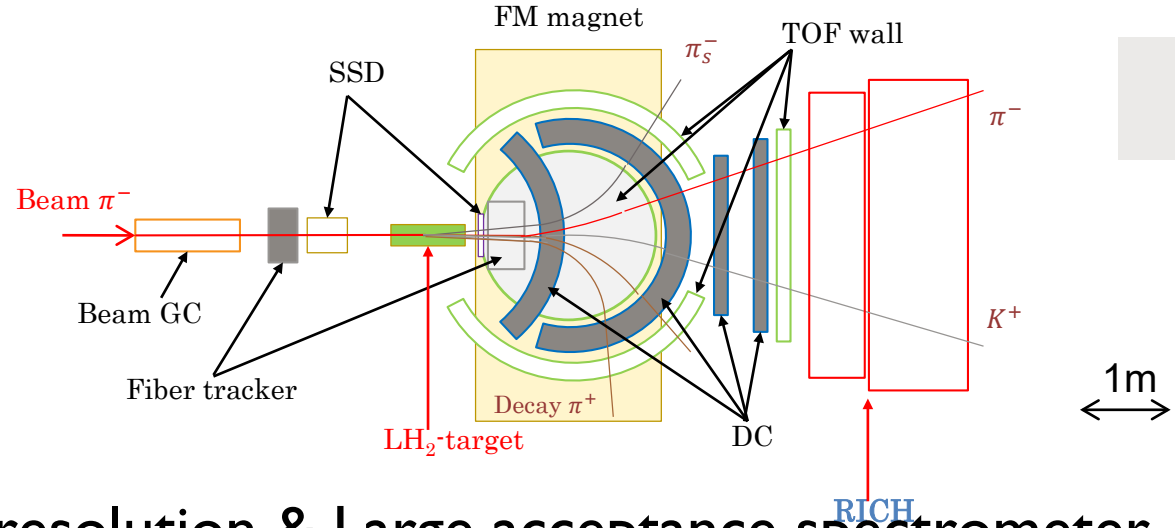
Beam Intensity at high-momentum secondary beamline



Strange&Charm Baryon Spectroscopy



Multi Purpose Spectrometer

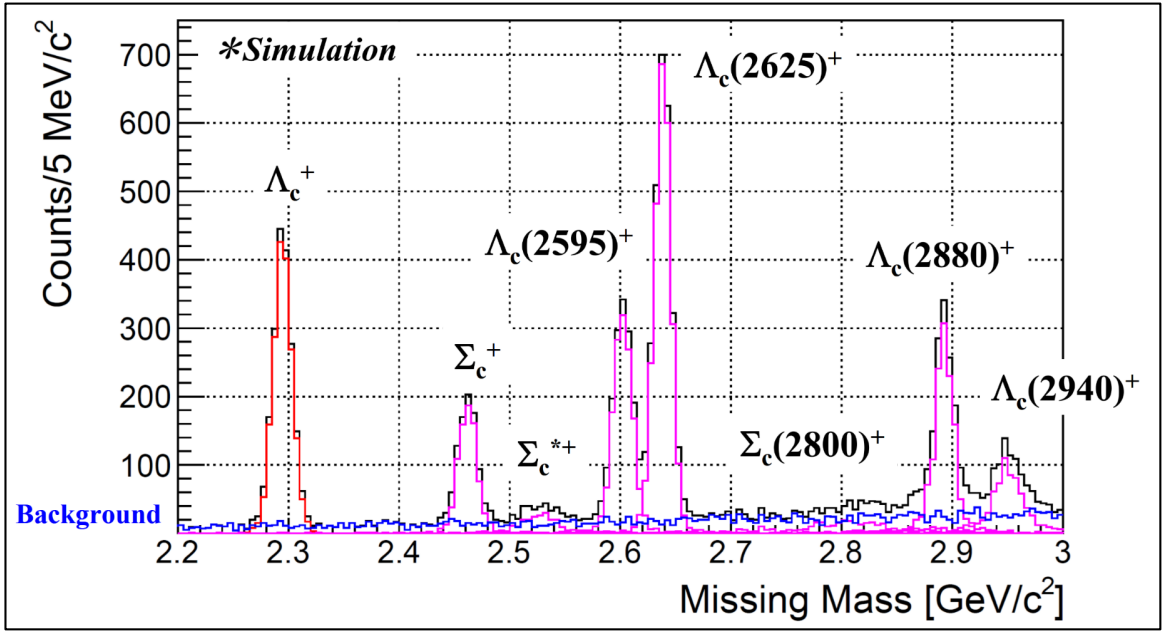


J-PARC E50 Spectrometer

High resolution & Large acceptance spectrometer

- Large acceptance (50% for K* / 60% for D*)
- Detector configuration for high-resolution (dp/p=0.2%)
  - Possible decay mode measurement: $Y_c^* \rightarrow Y_c + \pi$…
- Multi-particle detection in the high rate environment

Expected spectrum: σ(πp→D*-Yc) = 1 nb

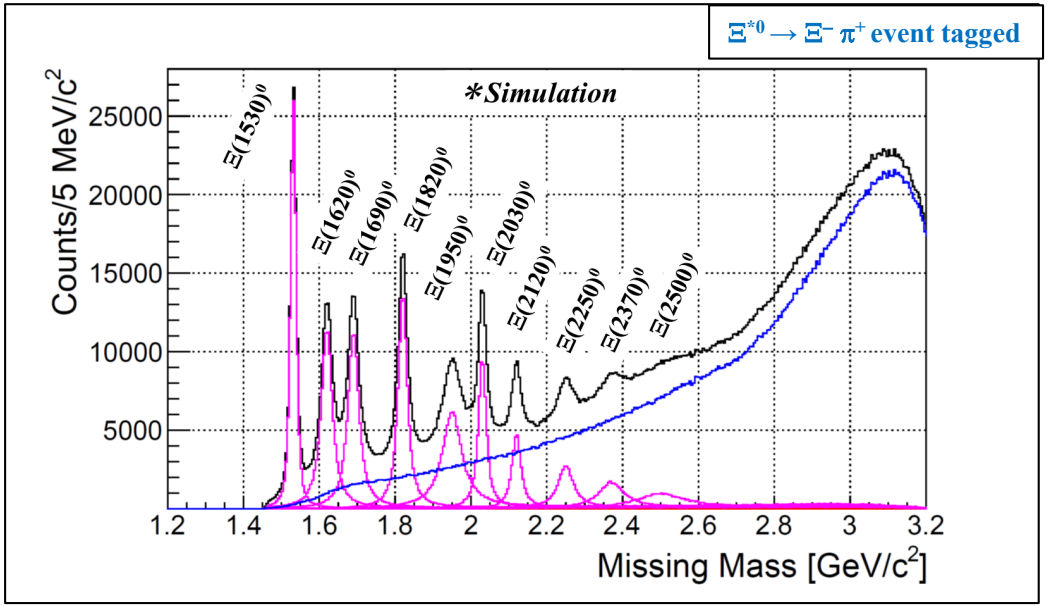


10M π beam + LH2

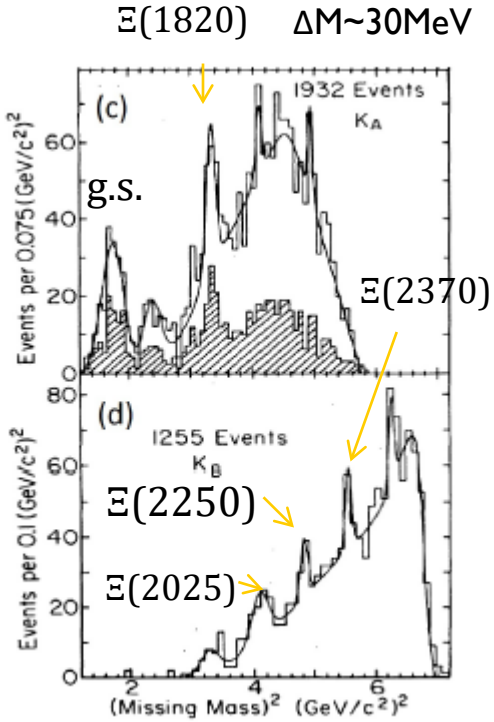
Y_c^{*+} yields: 2k events assuming $\sigma_{G.S.}$ = 1 nb in 100 days

- ΔM=8 MeV

Ξ* Expected spectrum



5GeV/c $K^-p \rightarrow K^+X$
Jenkins at al., PRL51('83)951

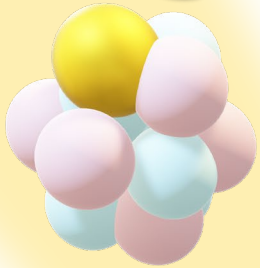


- Missing mass & decay measurements
  - cross section, mass and width with ΔM of 7 MeV
  - S/N ratio: 0.2-2.0 in 2.0-2.5 GeV/c^2 region

Future Prospects

Origin of Matter

Matter in Extreme conditions

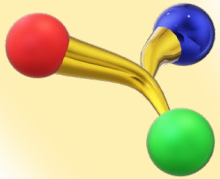


hyperon puzzle in neutron stars

flavor symmetry breaking
hadron interaction

Hypernuclei spectroscopy

Matter Evolution



fundamental structure of matter

chiral symmetry breaking
quark interaction

Hadron spectroscopy

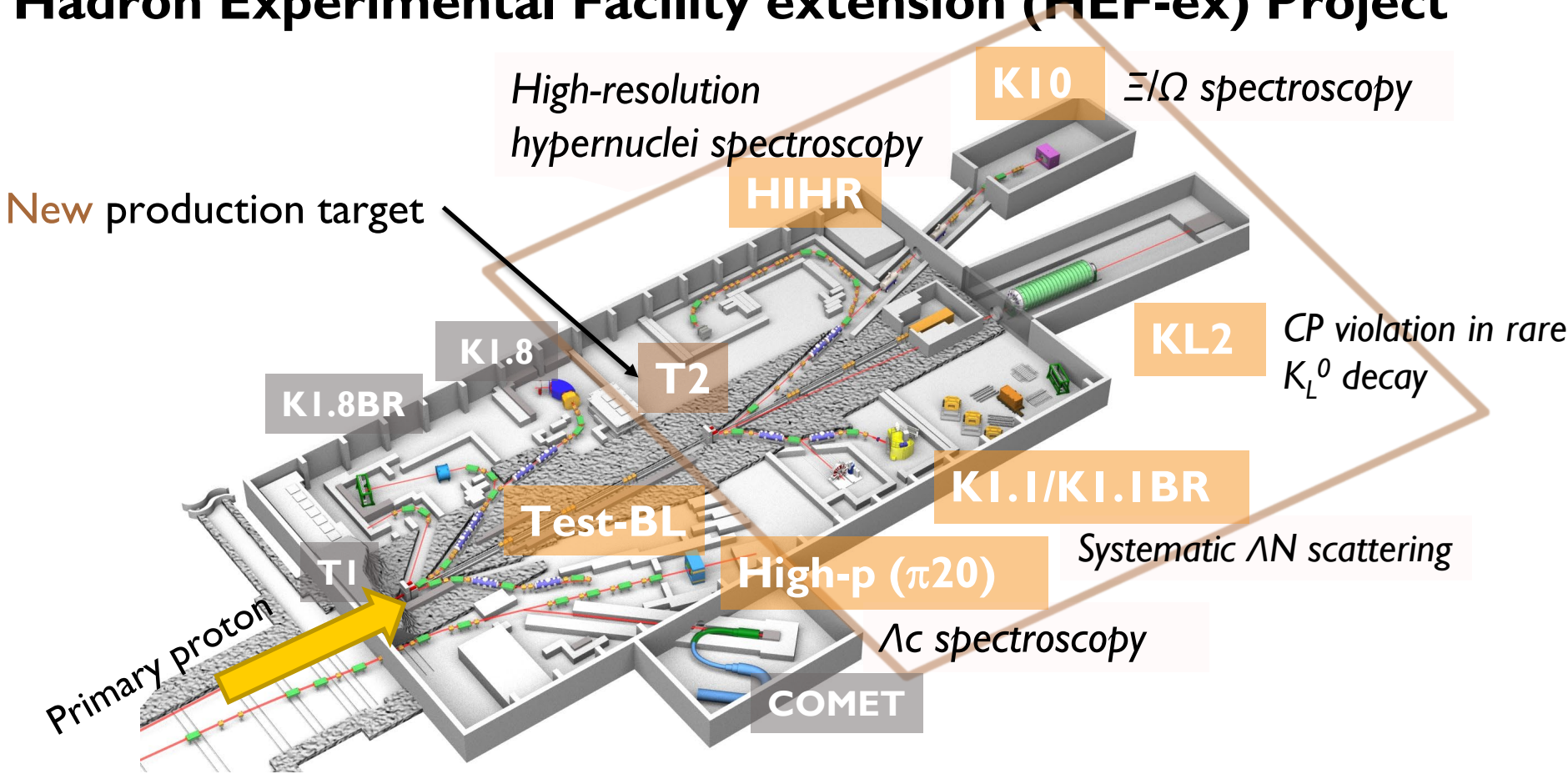
Birth of Matter

matter dominated universe

CP symmetry violation
weak interaction

Kaon rare decay

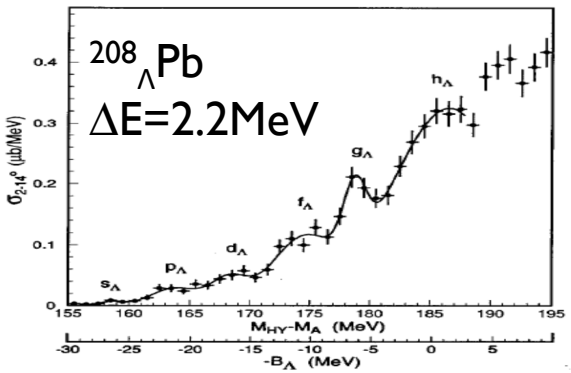
Hadron Experimental Facility extension (HEF-ex) Project



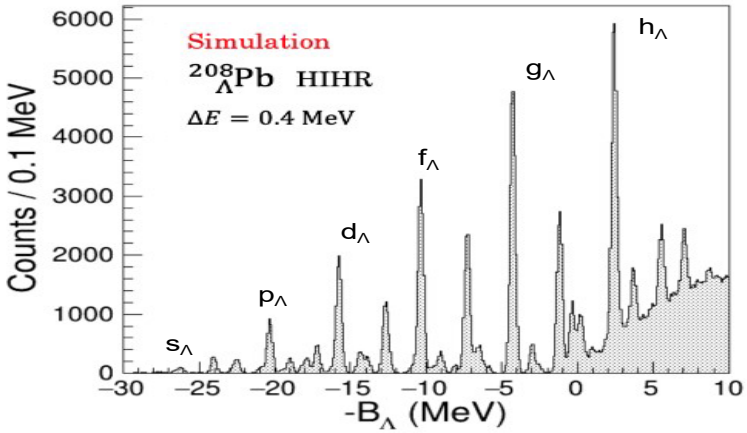
HIHR (High Intensity & High Resolution BL)

- Dispersion matching beamline at GeV-region
  - much better momentum resolution of $\Delta p/p=10^{-4}$ → ΔE=0.4MeV (FWHM)
  - precise measurement of Λ hypernuclei

KEK-PS

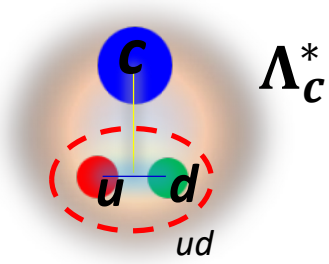


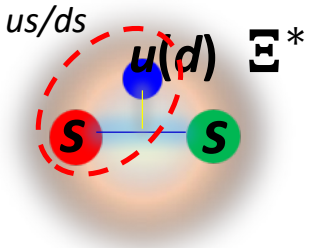
HIHR

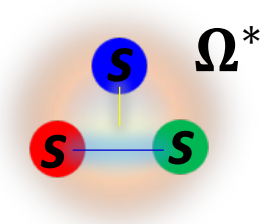


K10

- provides separated K/π beams up to 10 GeV/c
  - utilized with RF separators
- Baryon spectroscopies
  - $\Xi/\Omega/\Lambda_c$ baryons
- ΩN scattering
- ΞY / ΛΛΛ interactions

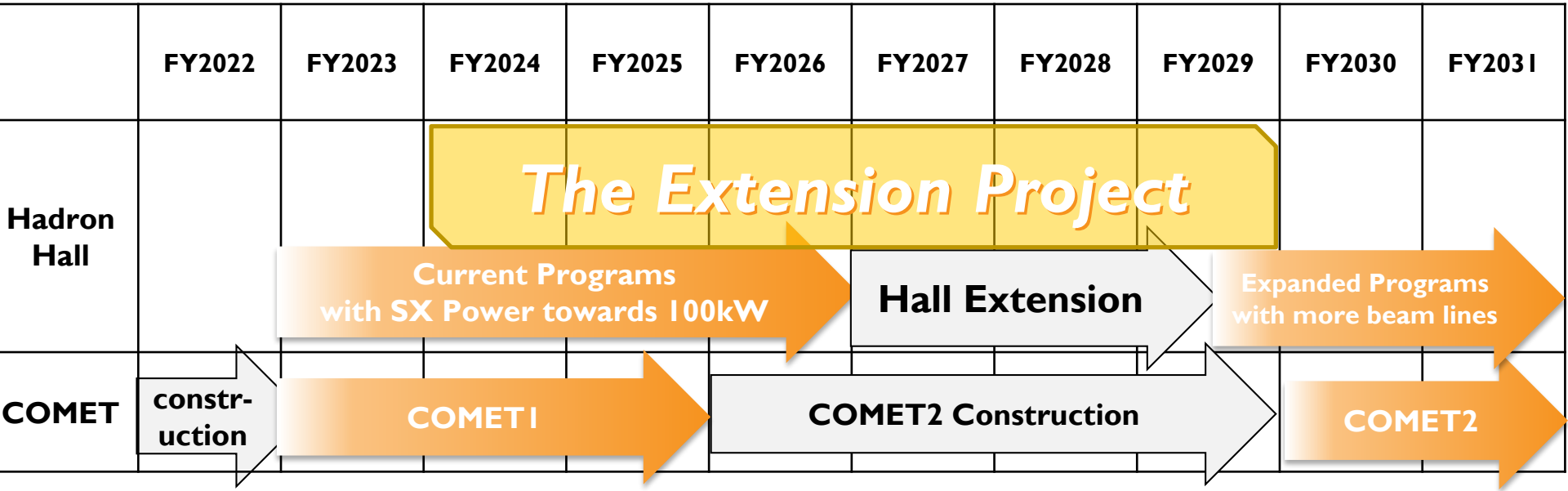






Schedule

- Listed as 1st priority in KEK Project Implementation Plan 2022



Summary

- J-PARC is a multi-purpose experimental facility for a wide range of physics.
- A bunch of results have been reported from J-PARC especially on strangeness physics.
- A new high-momentum beamline is now in operation. The dilepton measurement has been started successfully.
- Systematic $\Xi/\Lambda_c/\Omega$ baryon spectroscopies will be started soon.