September 22, 2011
Erice School

J-PARC Project and Its Science

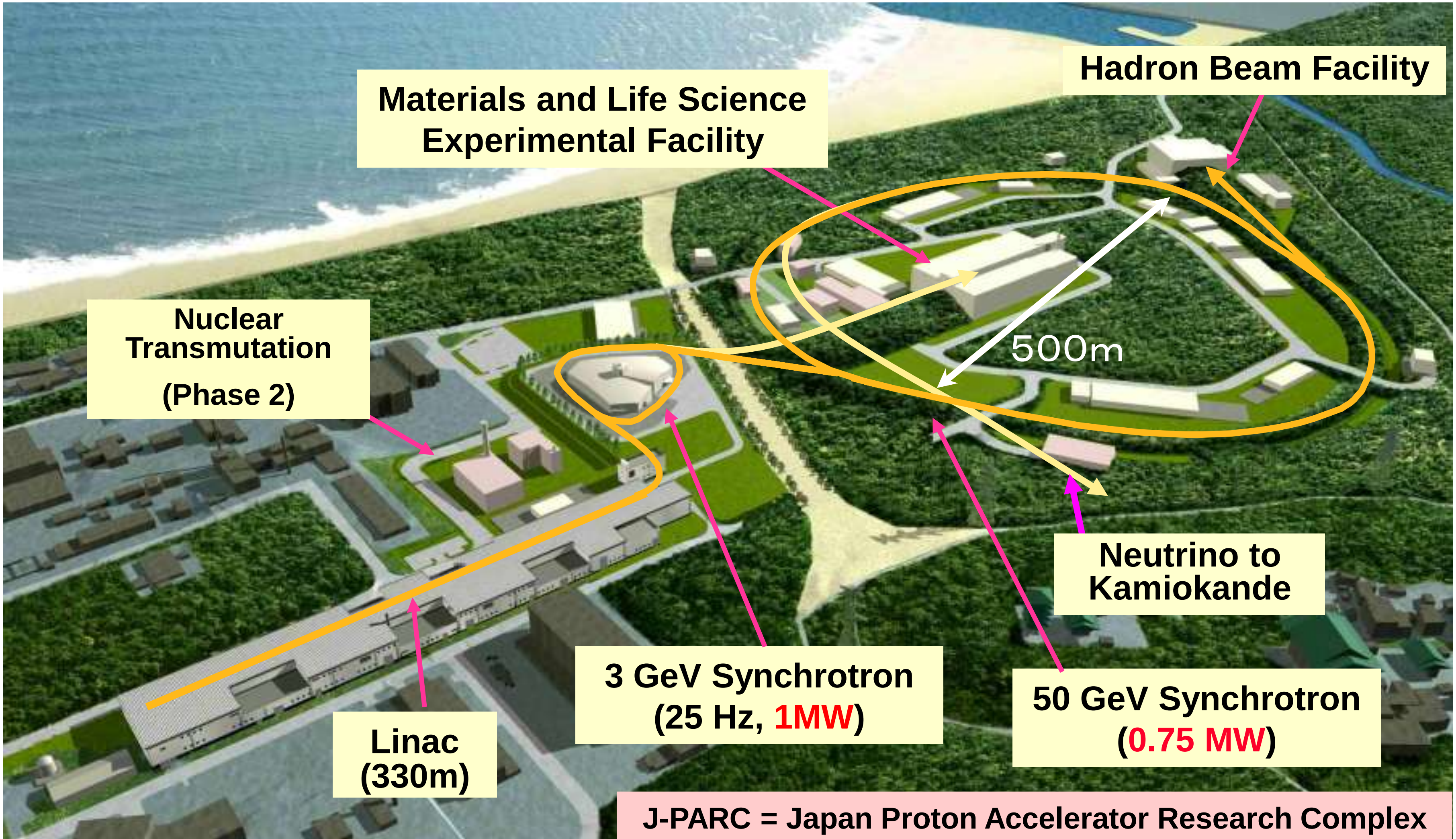
Shoji Nagamiya

J-PARC Center

Japan Atomic Energy Agency (JAEA)
High Energy Accelerator Research Organization (KEK)

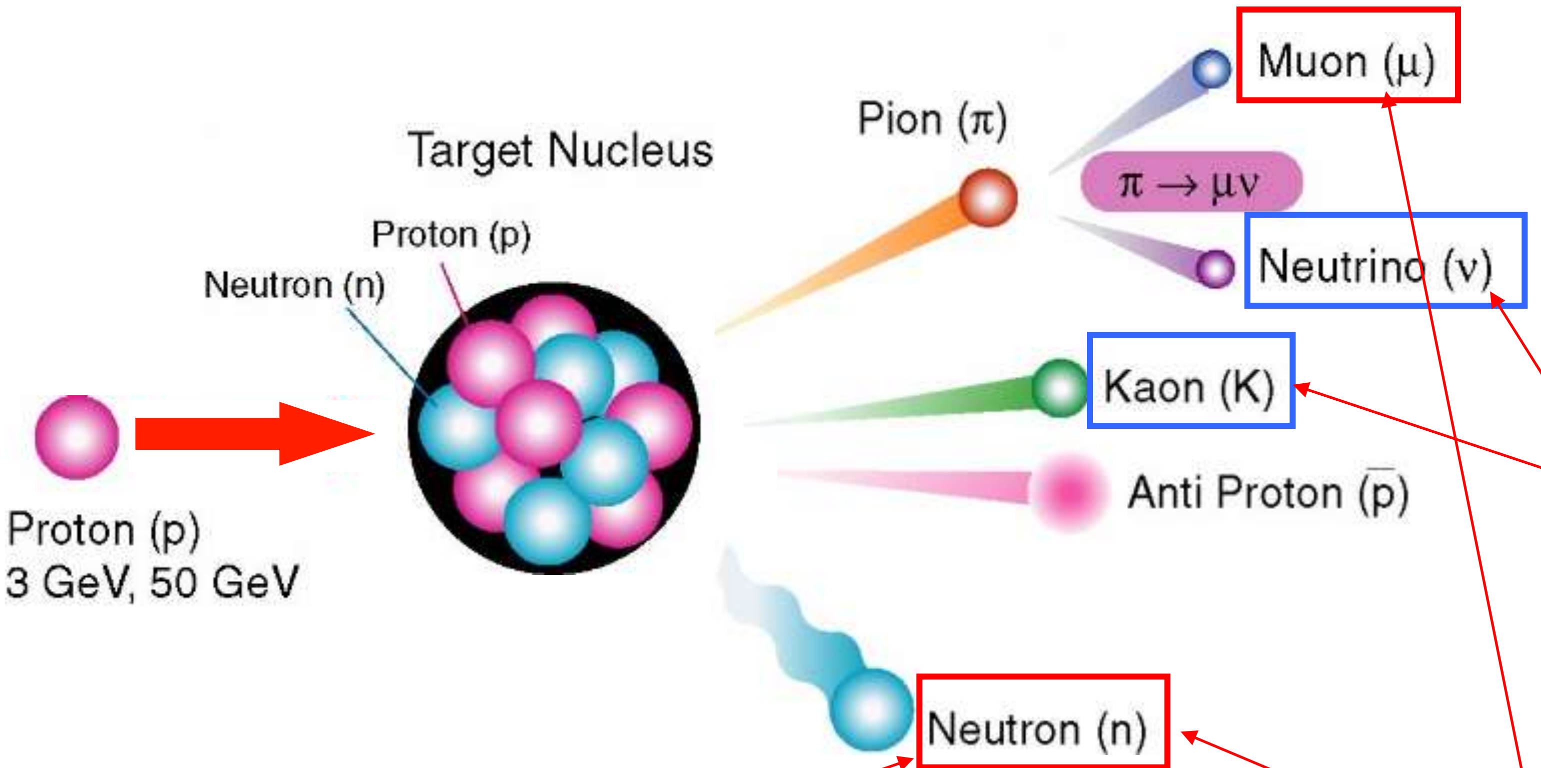
J-PARC

J-PARC Facility



Joint Project between KEK and JAEA

Goals at J-PARC

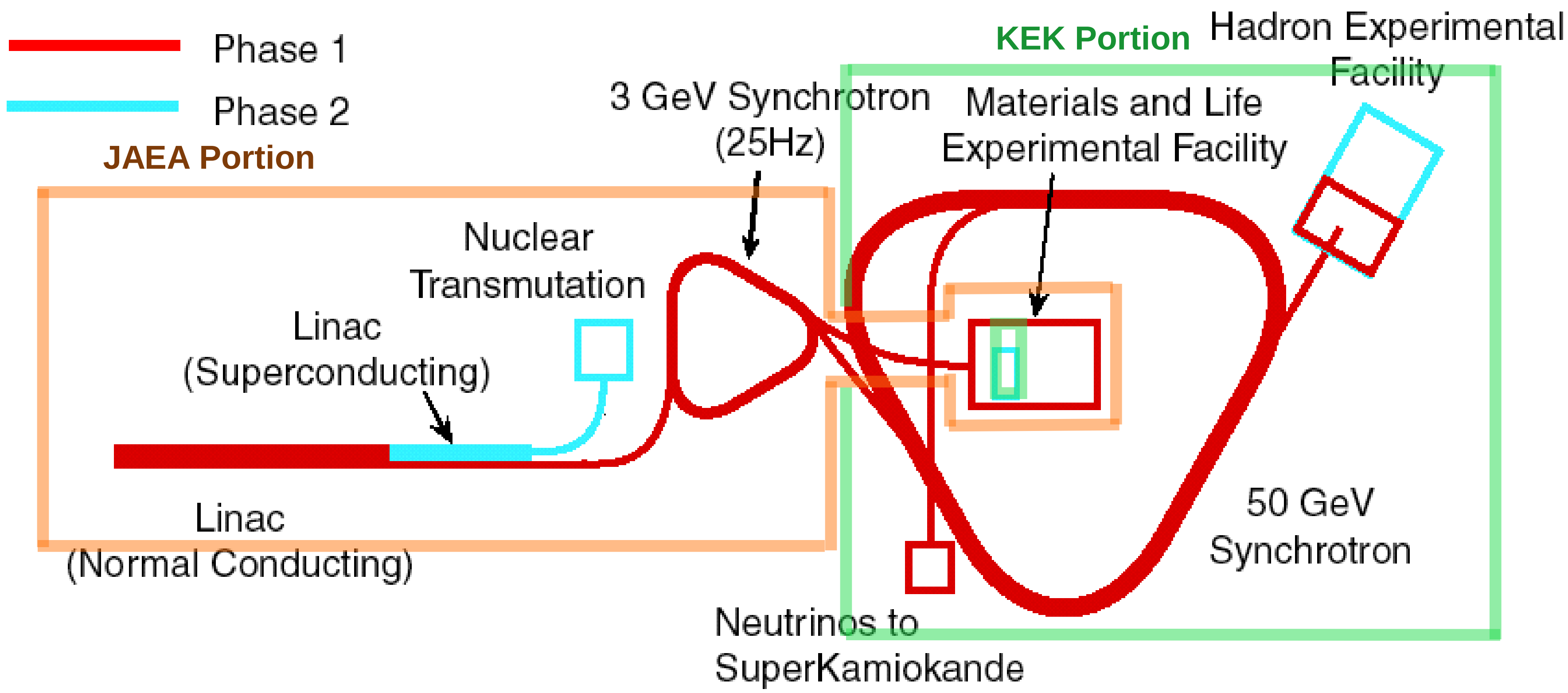


Need to have high-power proton beams

→ MW-class proton accelerator
(current frontier is about 0.1 MW)

Materials & Life Sciences at 3 GeV
Nuclear & Particle Physics at 50 GeV
R&D toward Transmutation at 0.6 GeV

Phase 1 and Phase 2

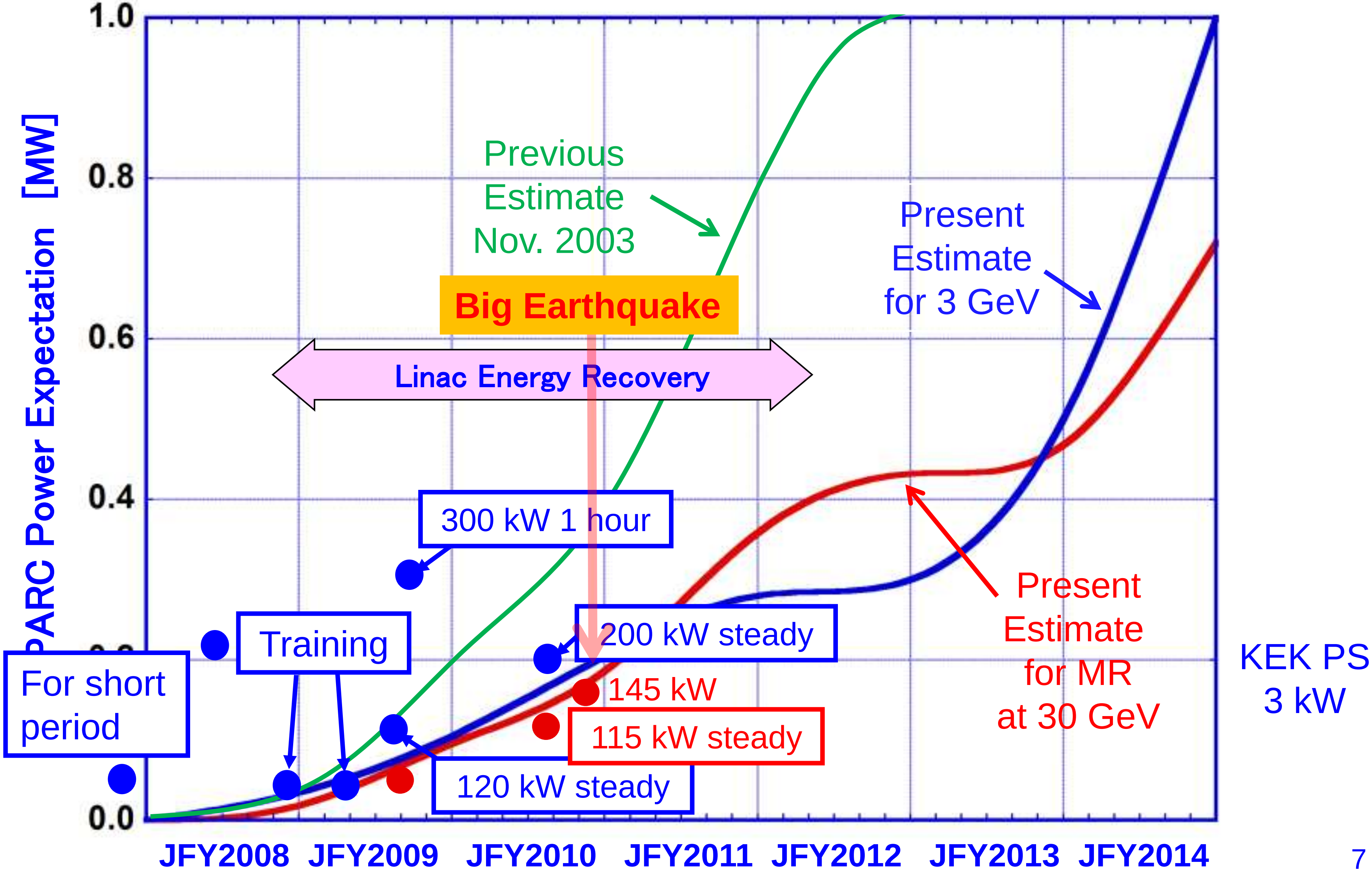


- Phase 1 + Phase 2 = 1,890 Oku Yen (= $1.89 billions if $1 = 100 Yen).
- Phase 1 = 1,527 Oku Yen (= $1.5 billions) for 8 years.
- JAEA: 860 Oku Yen (56%), KEK: 667 Oku Yen (44%).

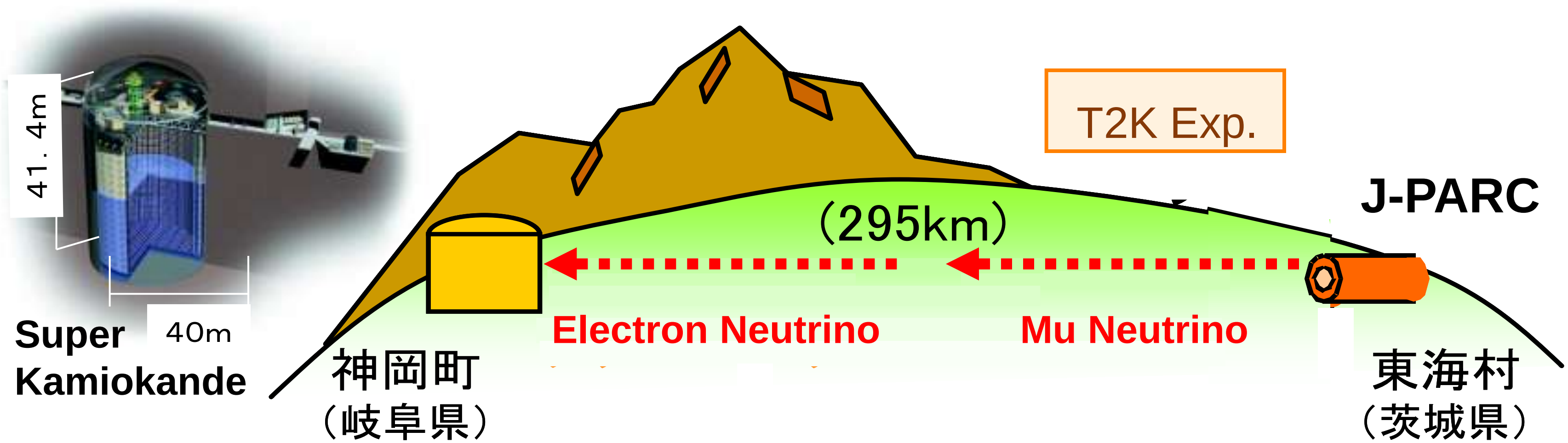
J-PARC

Status (before the Earthquake)

Power Capability



Neutrino Oscillation (T2K) Experiment



100 times sensitivity as compared with K2K

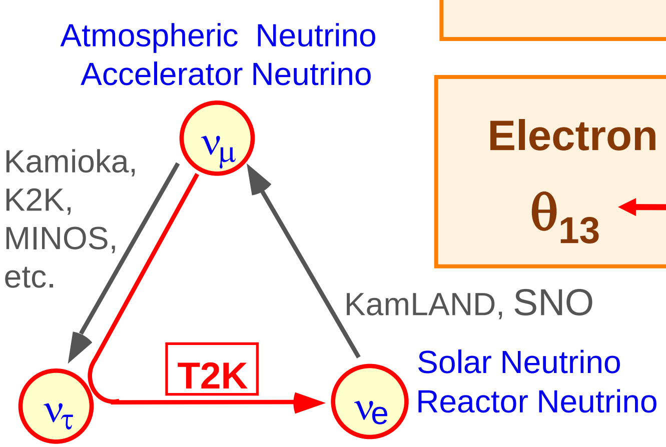
For example

100 neutrinos ← 150 neutrinos

Disappearance of neutrinos ↔ Finite Mass

Electron neutrinos ← Mu neutrinos

θ_{13} ↔ Mixing between the 1st and 3rd generation



CP violation experiment later by increasing intensity

Competition with Double Chooz, FNAL, etc.

Neutrino beamline

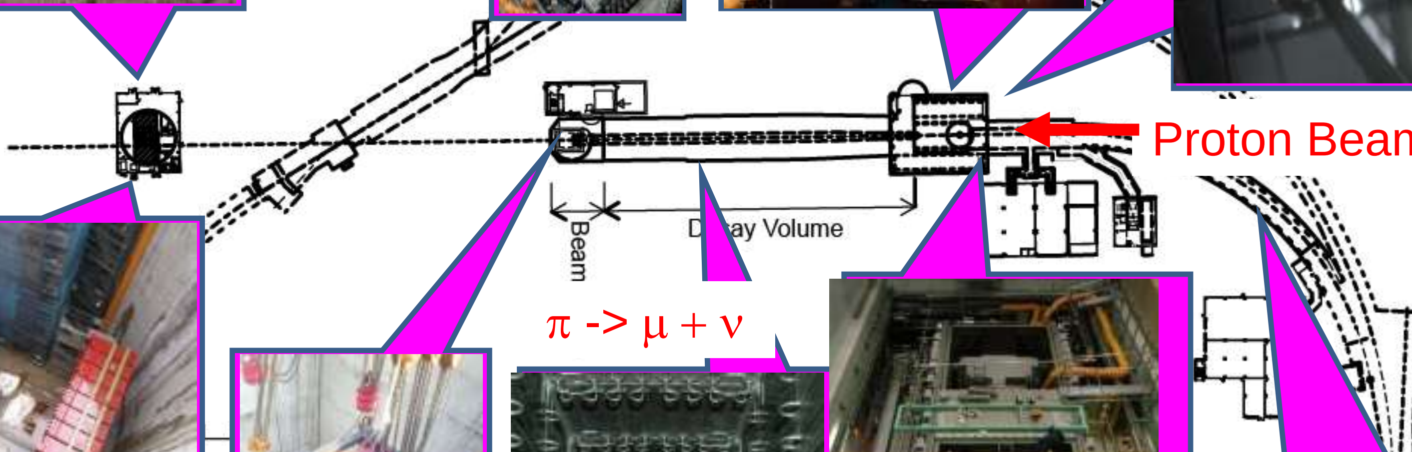
Neutrino monitor build.

Focusing

Electromagnetic horn

Production of π

Graphite target



Proton Beams

$\pi \rightarrow \mu + \nu$

UA1 magnet donated from CERN installed in Apr-Jun, 2008 on schedule

Confirmation of ν production

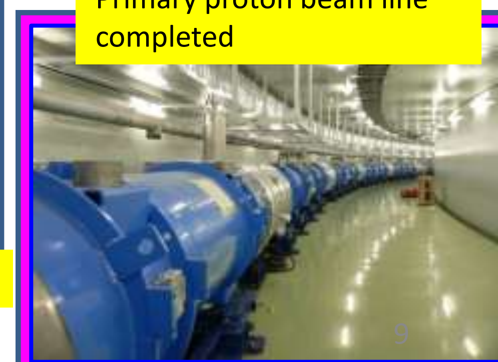
On-site detector

Beam dump completed

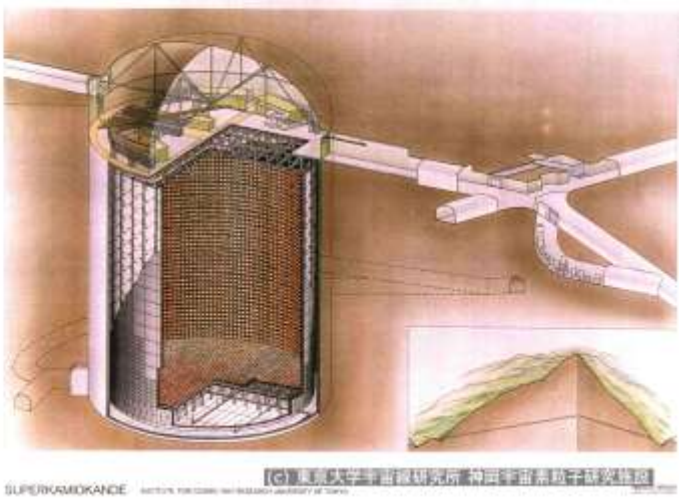
Decay volume completed

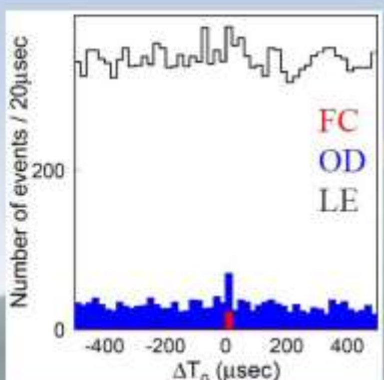
Target station completed

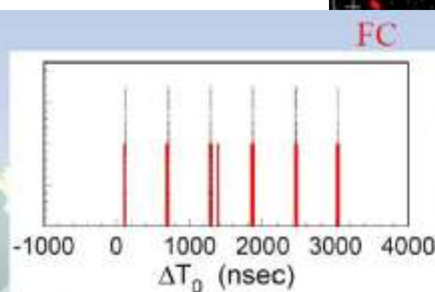
Primary proton beam line completed



Neutrino Detection at SuperK (Feb. 24, 2010)



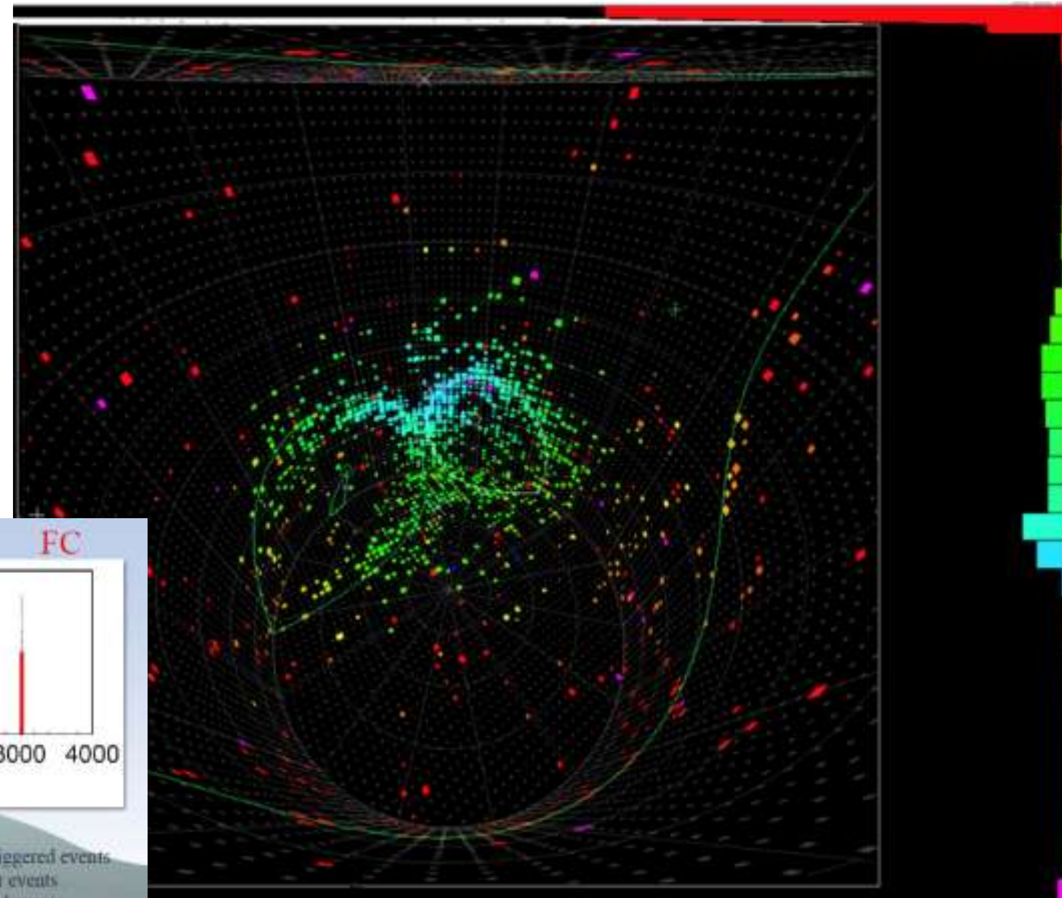




LE: Low energy triggered events
OD: Outer detector events
FC: Fully contained events

- Event time distribution clearly show beam structure
- Observed # of Fully contained events: 22 (by Mid. May)
- Expected non-beam BG: $<10^{-2}$evts

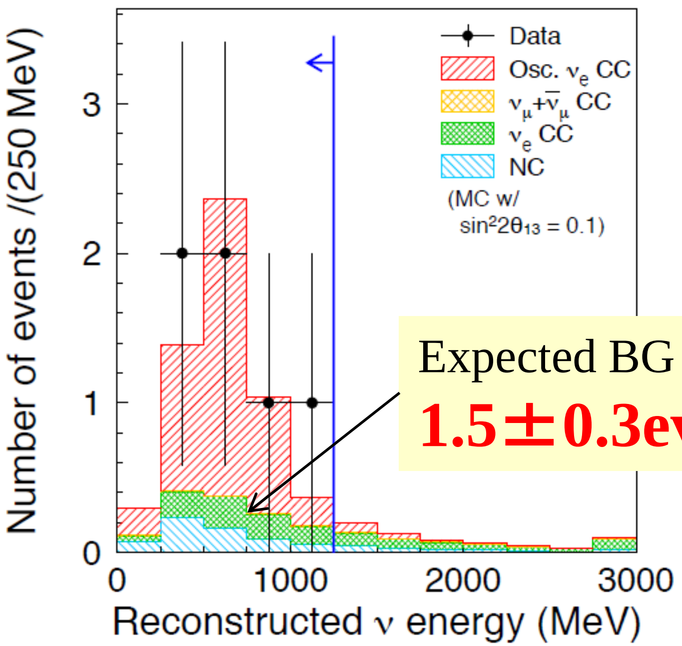
21

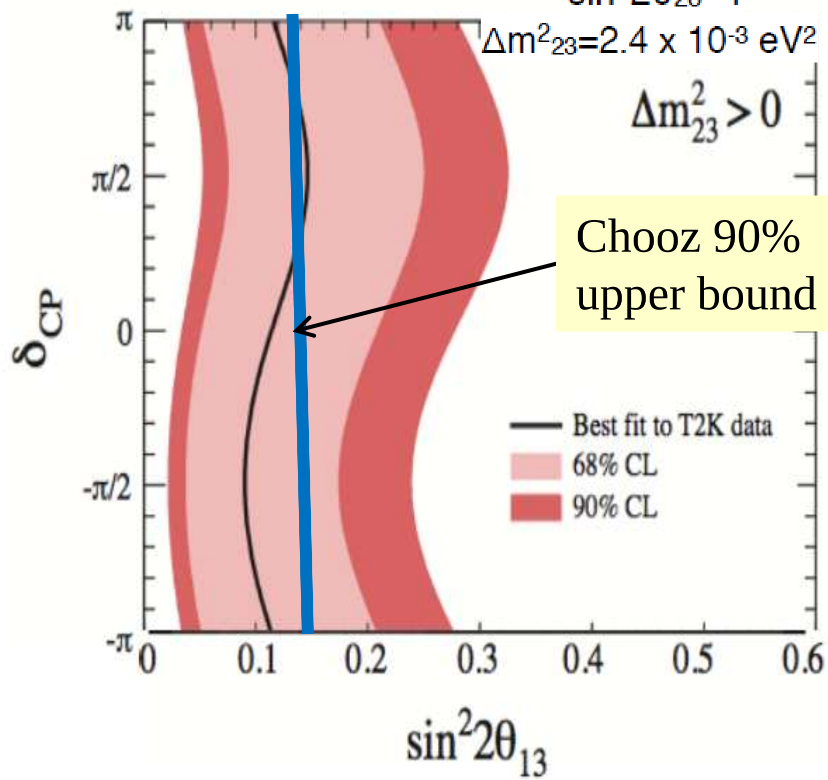


The first neutrino event detected at Super Kamiokande.

Indication of ν_e appearance (non-zero θ_{13})

6 ν_e candidates found!





- Prob. of 6 are all BG: **0.7% (2.5σ equiv)**

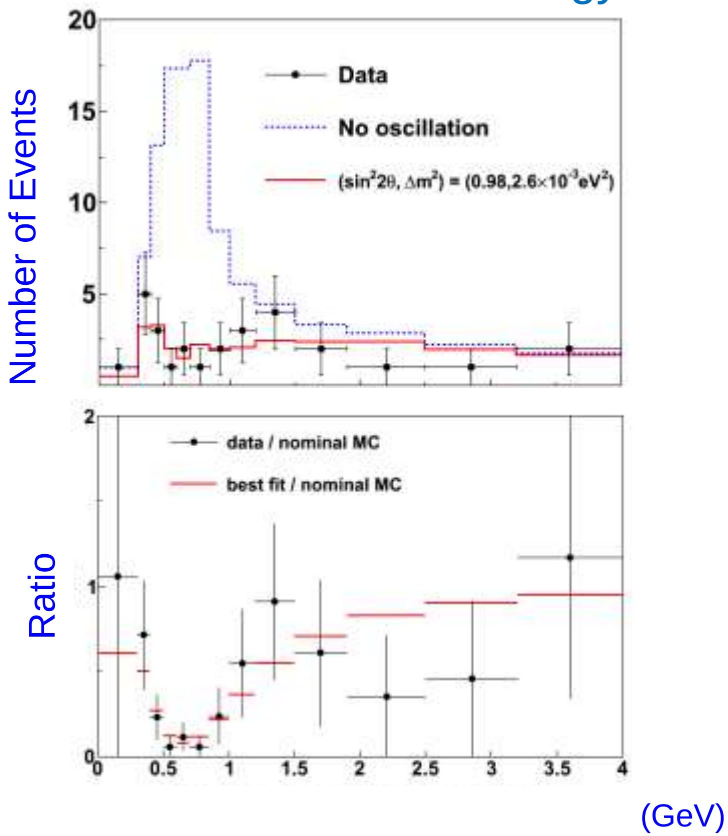
($\Delta m_{23}{}^2>0$)		($\Delta m_{23}{}^2<0$)
$0.03 < \sin^2 2\theta_{13} < 0.28$	**90%CL range**	$0.04 < \sin^2 2\theta_{13} < 0.34$
$\sin^2 2\theta_{13} = 0.11$	**Central value**	$\sin^2 2\theta_{13} = 0.14$

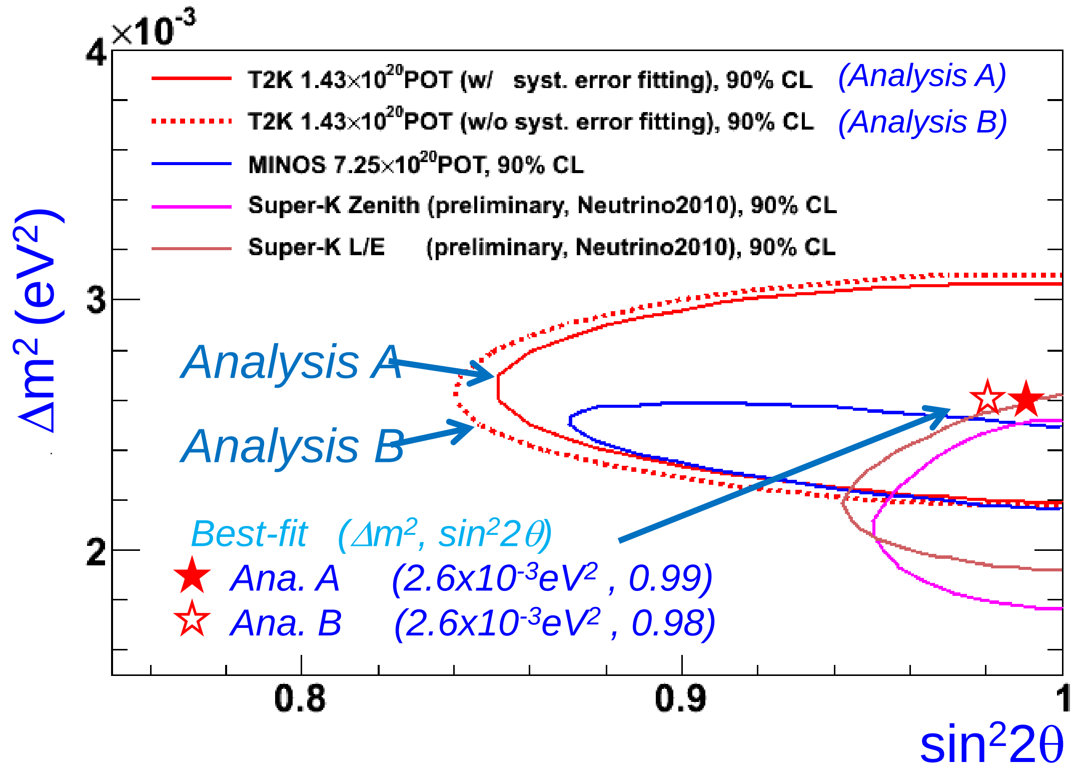
assuming $\Delta m^2_{23}=2.4 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{23}=1$, $\delta_{CP}=0$

Measurement of ν_μ disappearance (Δm_{23}^2, $\sin^2 2\theta_{23}$)

Single–μ ring events
- **104 events expected w/o osc**
- **31 events detected**

Reconstructed ν energy





90% C.L. allowed region

	Δm^2 (eV^2)	$\sin^2(2\theta)$
Analysis A	2.1 ~ 3.1 x 10^{-3}	> 0.85
Analysis B	2.1 ~ 3.2 x 10^{-3}	> 0.84

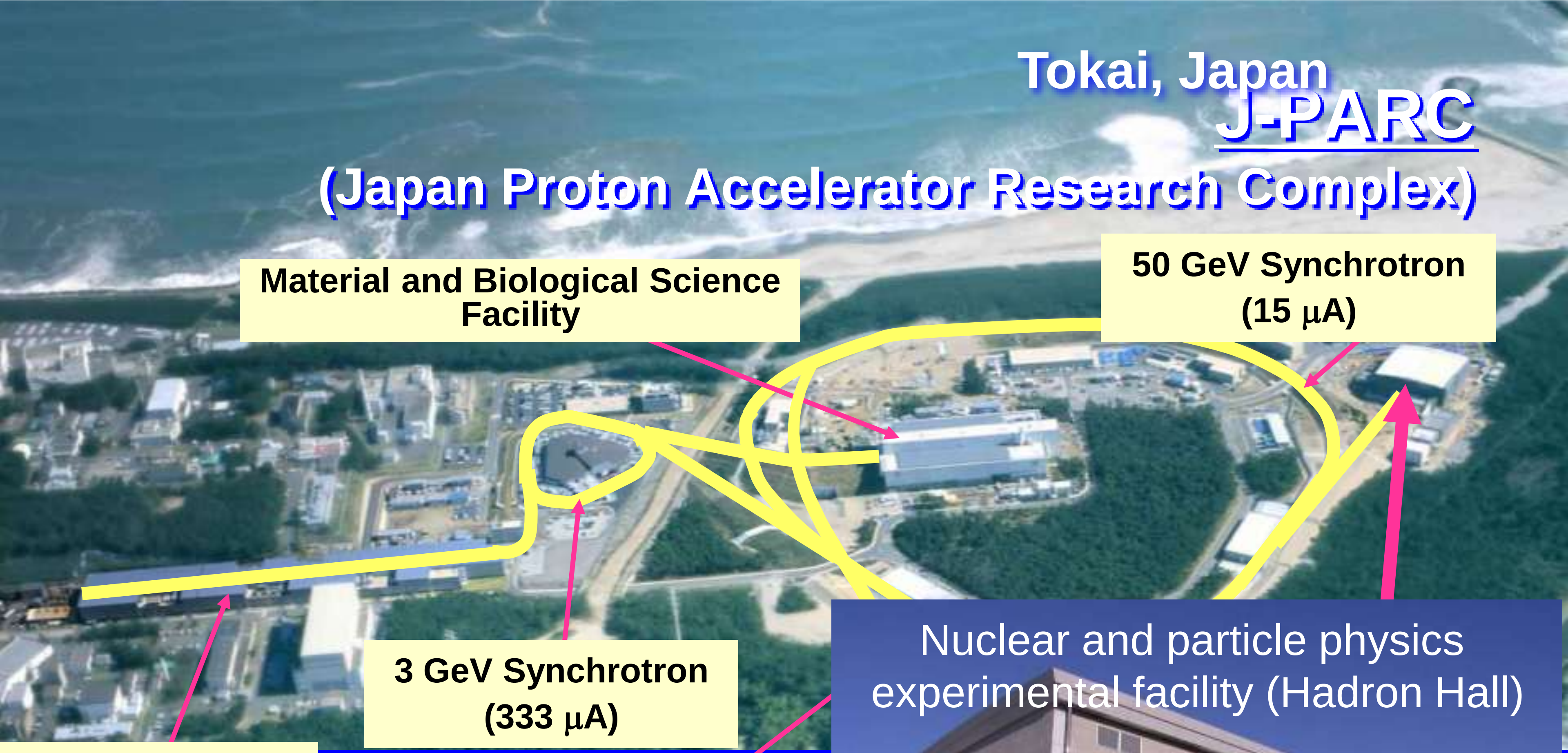
Clear disappearance and oscillation pattern observed!!

Consistent with MINOS/SK results

Tokai, Japan

J-PARC

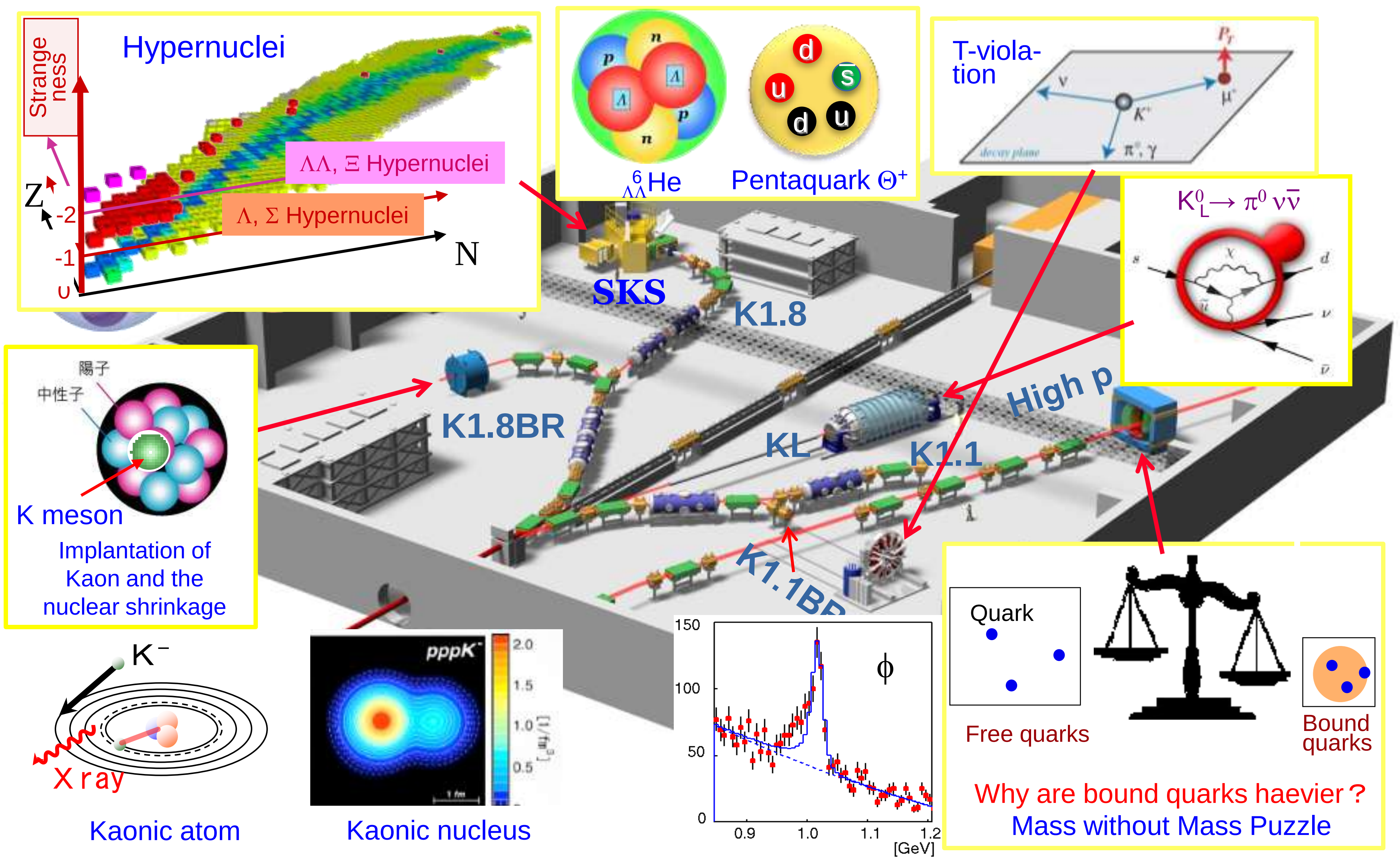
(Japan Proton Accelerator Research Complex)



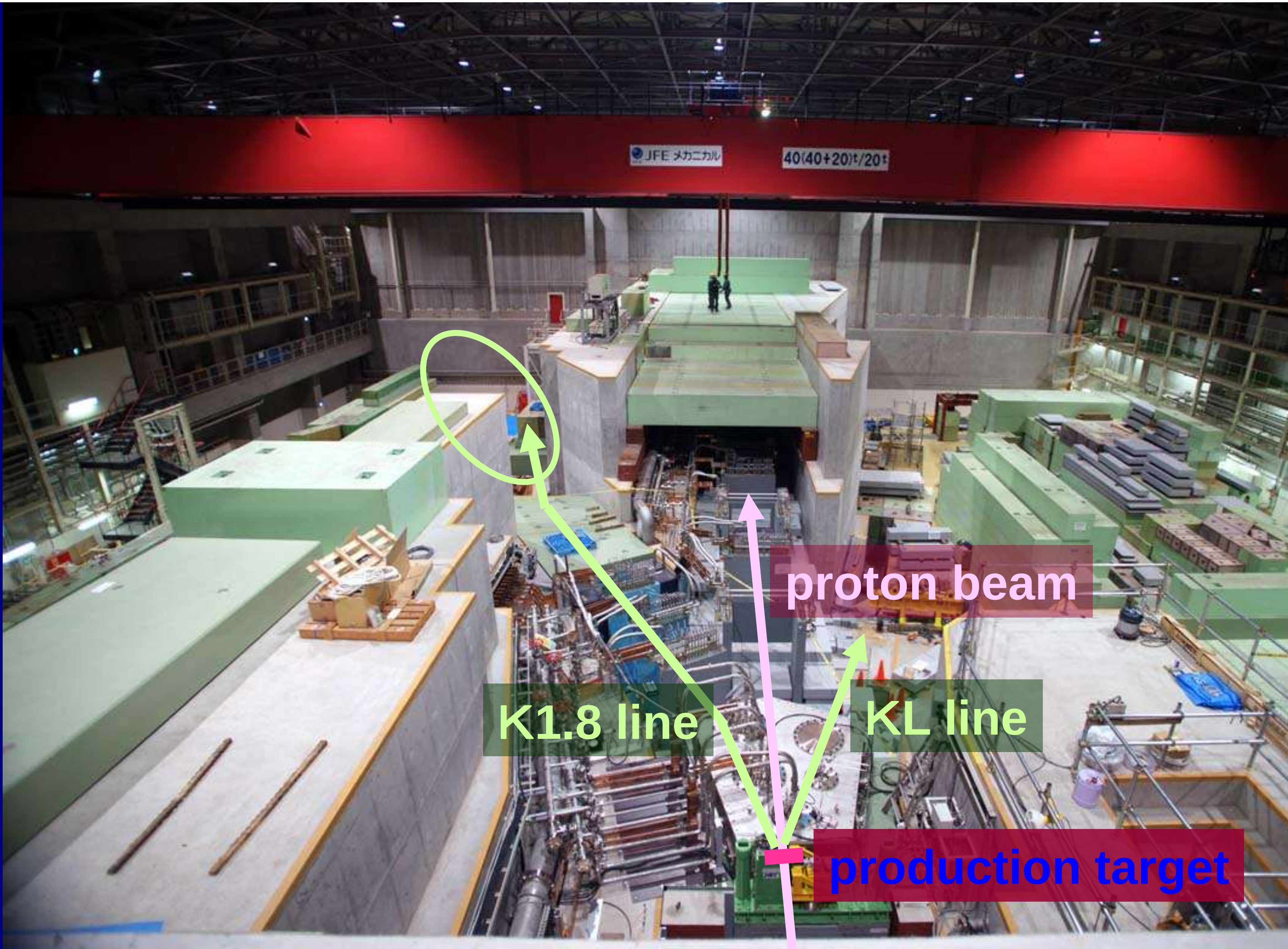
Meson ($K^{\pm}$, K^0_L, $\pi^{\pm}$) beams of world highest intensity (x10 of BNL-AGS, x100 of KEK-PS)

Launched in 2009, Beam intensity and quality being improved

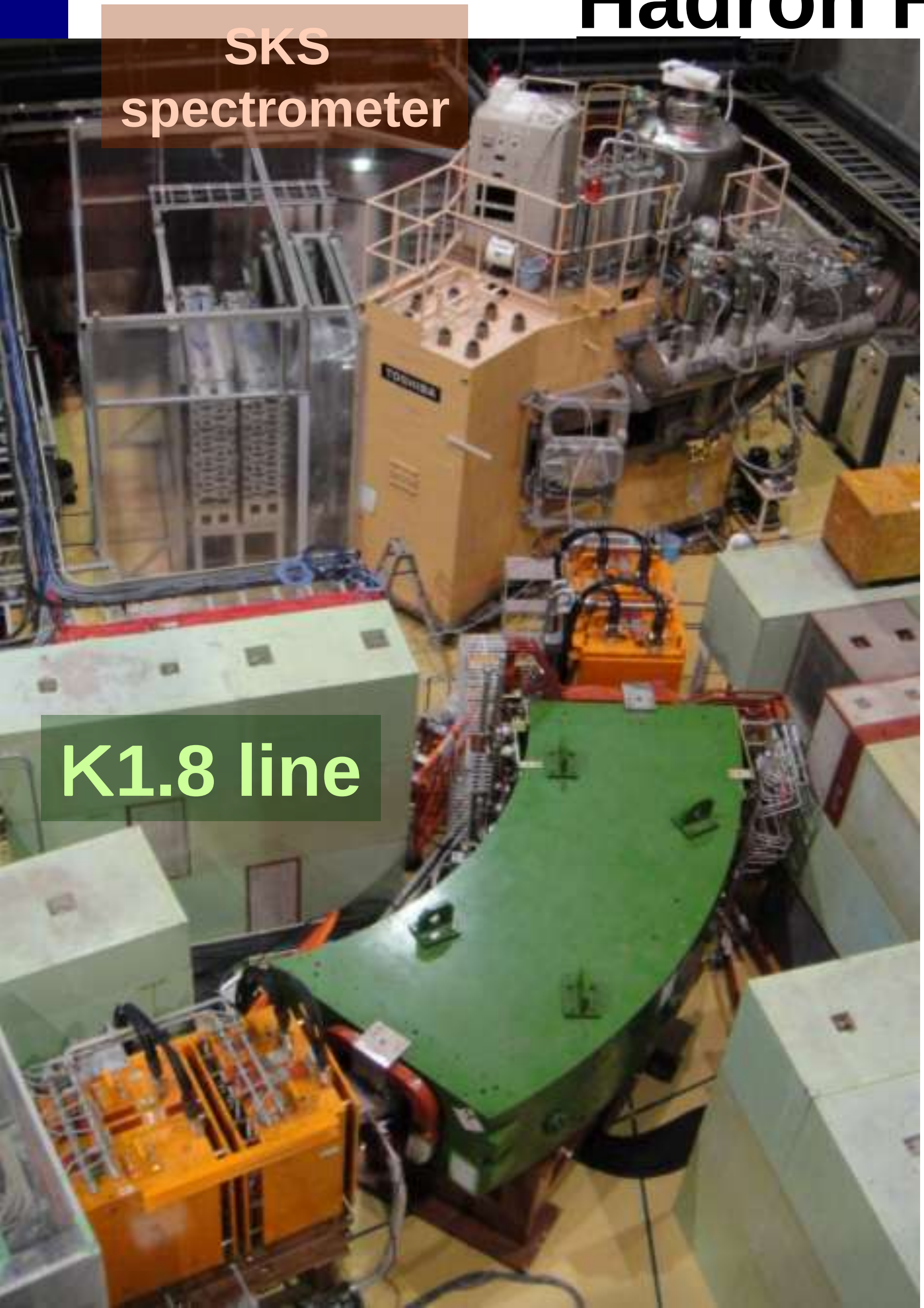
Nuclear & Hadron Physics at J-PARC

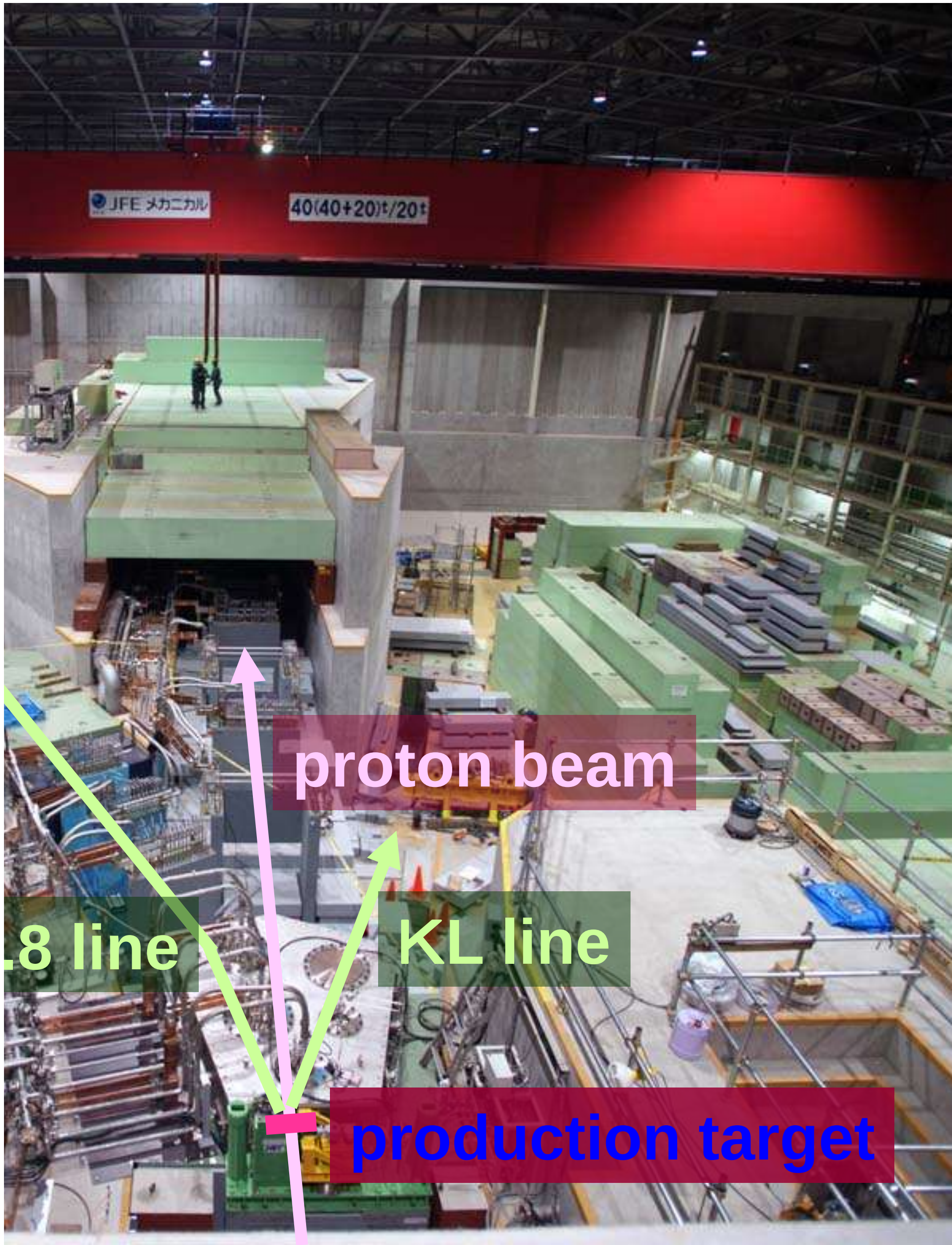


Hadron Hall as of 2008.10



Hadron Hall as of 2008.10



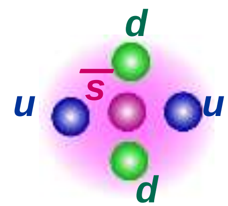


E03	K.Tanida	SNU	Measurement of X rays from X^- Atom	Stage 2			K1.8	preparation
E05	T.Nagae	Kyoto U	Spectroscopic Study of X-Hypernucleus, $^{12}{}_{X}Be$, via the $^{12}C(K^-, K^+)$ Reaction	Stage 2	Day1	1	K1.8	preparation
E06	J.Imazato	KEK	Measurement of T-violating Transverse Muon Polarization in $K^+ \to \pi^0 \mu^+ n$ Decays	Stage 1			K1.1BR	
E07	K.Imai, K.Nakazawa, H.Tamura	JAEA, Gifu U, Tohoku U	Systematic Study of Double Strangeness System with an Emulsion-counter Hybrid Method	Stage 2			K1.8	preparation
E08	A.Krutenkova	ITEP	Pion double charge exchange on oxygen at J-PARC	Stage 1			K1.8	
E10	A.Sakaguchi, T.Fukuda	Osaka U	Production of Nuetron-Rich Λ-Hypernuclei with the Double Charge-Exchange Reactions	Stage 2			K1.8	preparation
E11	T.Kobayashi	KEK	Tokai-to-Kamioka (T2K) Long Baseline Neutrino Oscillation Experimental Proposal	Stage 2			neutrino	data taking
E13	T.Tamura	Tohoku U	Gamma-ray spectroscopy of light hypernuclei	Stage 2	Day1	2	K1.8	preparation
E14	T.Yamanaka	Osaka U	Proposal for $K_L \to p^0$ n n-bar Experiment at J-PARC	Stage 2			KL	beamline tuning
E15	M.Iwasaki, T.Nagae	RIKEN, Kyoto U	A Search for deeply-bound kaonic nuclear states by in-flight 3He(K-, n) reaction	Stage 2	Day1		K1.8BR	preparation
E16	S.Yokkaichi	RIKEN	Electron pair spectrometer at the J-PARC 50-GeV PS to explore the chiral symmetry in QCD	Stage 1			high p	
E17	R.Hayano, H.Outa	U Tokyo, RIKEN	Precision spectroscopy of Kaonic ^3He 3d->2p X-rays	Stage 2	Day1		K1.8BR	beamline tuning
E18	H.Bhang, H.Outa, H.Park	SNU, RIKEN, KRISS	Coincidence Measurement of the Weak Decay of $^{12}{}_{L}C$ and the three-body weak interaction process	Stage 2			K1.8	preparation
E19	M.Naruki	KEK	High-resolution Search for Q^+ Pentaquark in $p^-p \to K^-X$ Reactions	Stage 2	Day1		K1.8	data taking
E21	Y.Kuno	Osaka U	An Experimental Search for Lepton Flavor Violating $\mu^- - e^-$ Conversion at Sensitivity of 10^{-16} with a Slow-Extracted Bunched Proton Beam	Stage 1			new beamline	

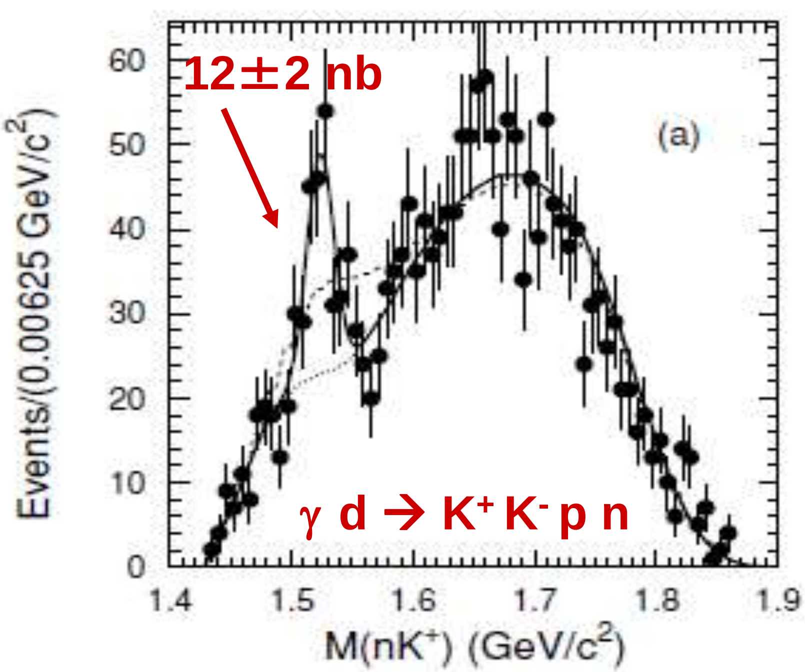
E22	S. Ajimura, A.Sakaguchi	Osaka U	Exclusive Study on the Lambda-N Weak Interaction in A=4 Lambda-Hypernuclei (Revised from Initial P10)	Stage 1			K1.8	
E26	K. Ozawa	KEK	Search for ω-meson nuclear bound states in the π^-+^{A}Z -> n+$^{(A-1)}$(Z-1) ω reaction, and for ω mass modification in the in-medium ω->$\pi^0\gamma$ decay.	Stage 1			K1.8	
E27	T. Nagae	Kyoto U	Search for a nuclear Kbar bound state K^-pp in the d(π^+,K^+) reaction	Stage 2			K1.8	preparation
P28	H. Fujioka	Kyoto U	Study of isospin dependence of kaon-nucleus interaction by in-flight 3He(K- ,n/p) reactions	approved as apart of E15			K1.8BR	
E29	H. Ohnishi	RKEN	Search for φ-meson nuclear bound states in the pbar + Z -> φ + φ(Z-1) reaction	Stage 1			K1.1	
E31	H. Noumi	RCNP, Osaka U	Spectroscopic study of hyperon resonances below KN threshold via the (K^- ,n) reaction on Deuteron	Stage 1			K1.8BR	
E40	K.Miwa	Tohoku U	Measurement of the cross sections of Σp scatterings	Stage 1			K1.8	
T25	S. Mihara	KEK	Extinction Measurement of J-PARC Proton Beam at K1.8BR	Test experiment			K1.1BR	data taking
T32	A. Rubba	ETH, Zurich	Towards a Long Baseline Neutrino and Nucleon Decay Experiment with a next-generation 100 kton Liquid Argon TPC detector at Okinoshima and an intensity upgraded J-PARC Neutrino beam	Test experiment			K1.1BR	data taking
P35	T. Kajita	ICRR, Tokyo	A test experiment to measure sub-GeV flux in the on-axis direction at the J-PARC neutrino beam	to be decided by E11 & Lab			neutrino	
T37	K. Inami	Nagoya U	Test of TOP counter for B-factory upgrade	Test experiment			K1.1BR	withdrawn
T38	T. Nanjo	Kyoto U	Proposal for Measuring Hadron Response at K1.1BR for KOTO Experiment	Test experiment			K1.1BR	completed
P39	K. Sakashita	KEK	A study of water Cherenkov detector for counting the number of neutrino at Near detector hall of J-PARC neutrino beam-line	to be decided by E11 & Lab			neutrino	

E19 (Naruki et al.)
Search for Pentaquark Θ^+ in $\pi^- p \rightarrow K^- X$ reaction

Physics Motivation



- positive evidences at low energy (LEPS, etc.)
- very narrow width ~ 1 MeV. Why?
- negative results at high energy

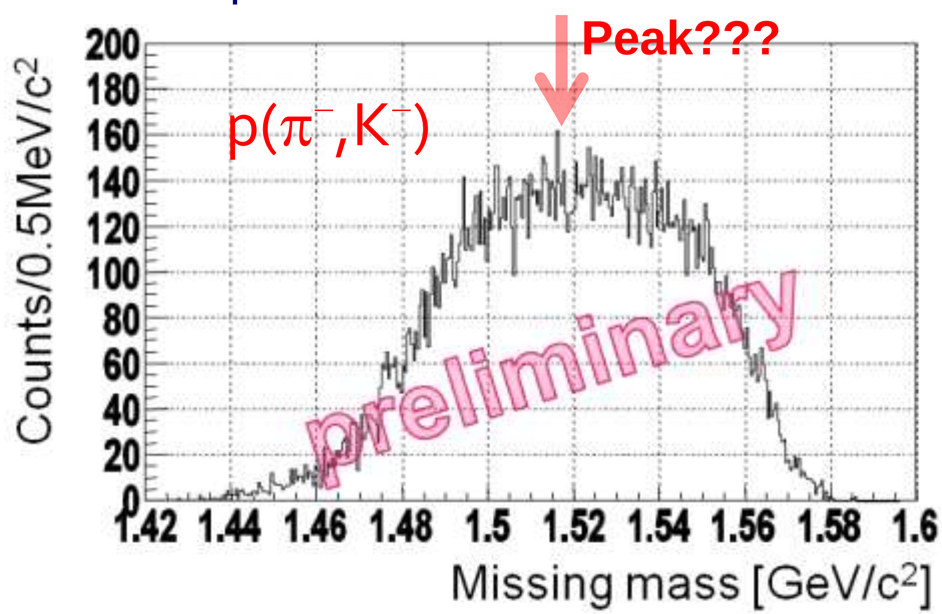


T. Nakano et al.,PRC79 (2009) 025210

J-PARC E19

- Hadronic “direct reaction”

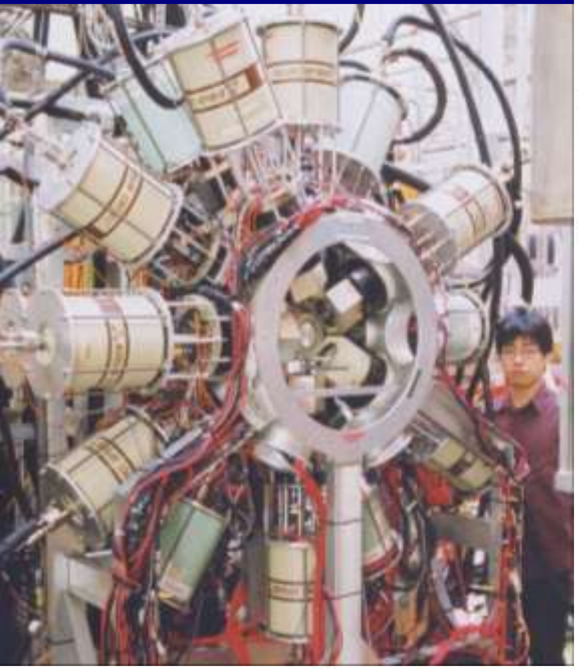
  $\pi^- + p \rightarrow K^- + X$
- Previous (π^-,K^-) missing mass spectrum shows a hint of 2.6σ.

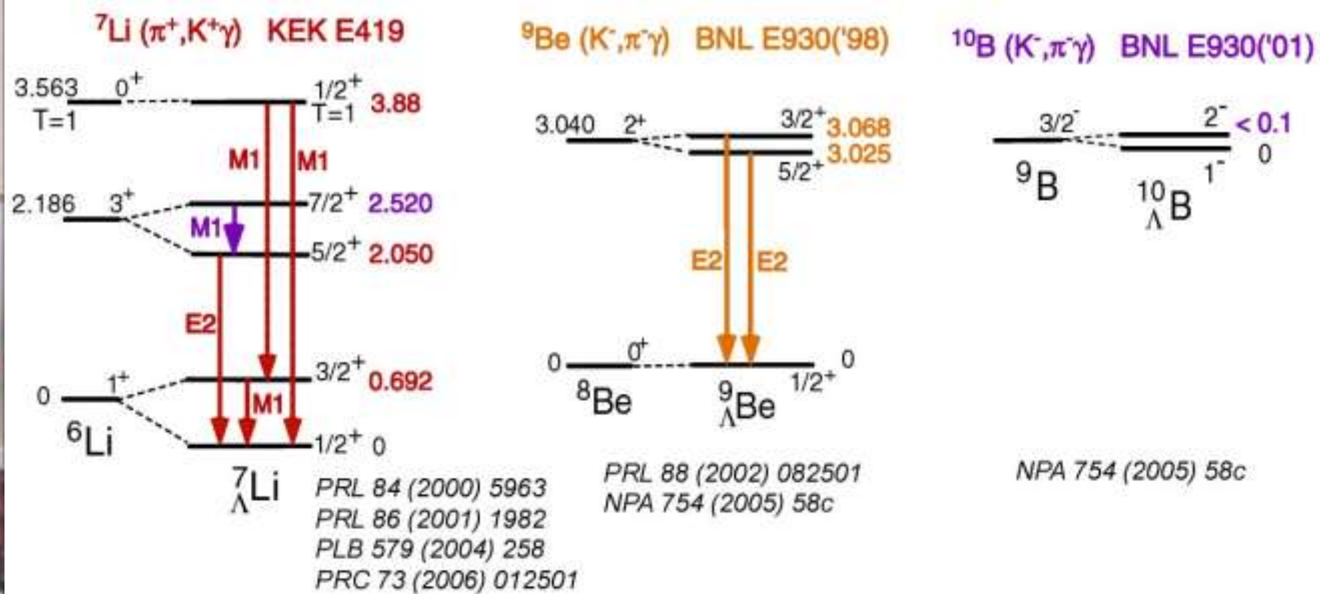


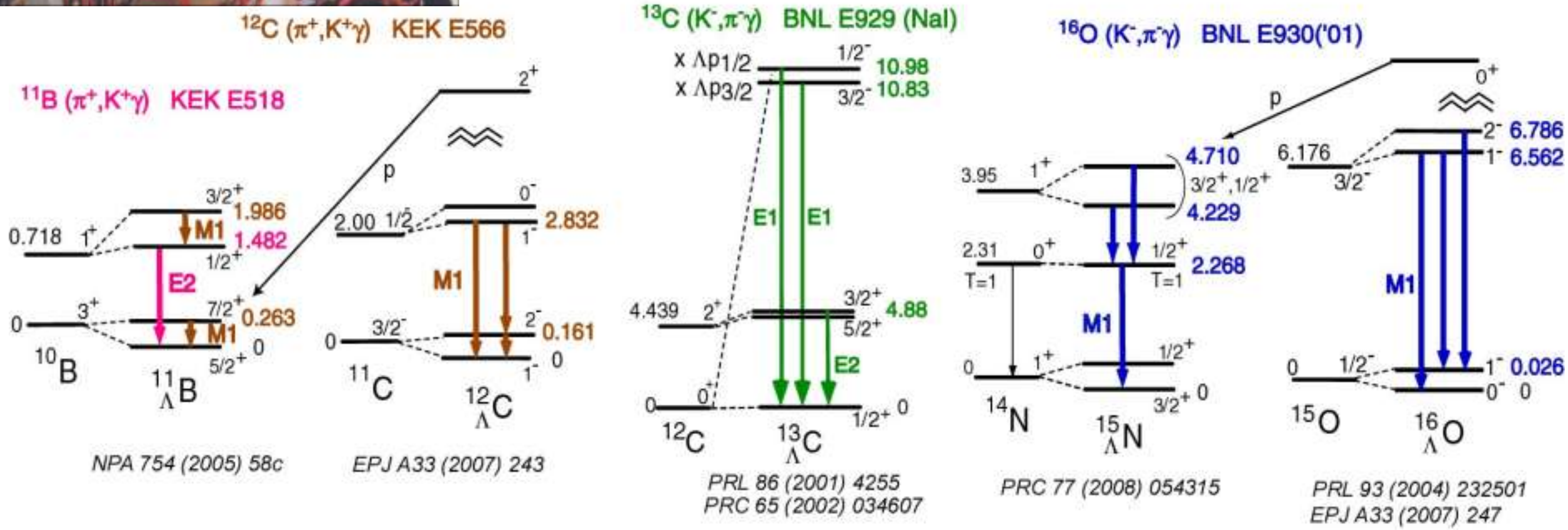
K^++n Experiment to produce directly Θ^+ must be done.

Hyperball

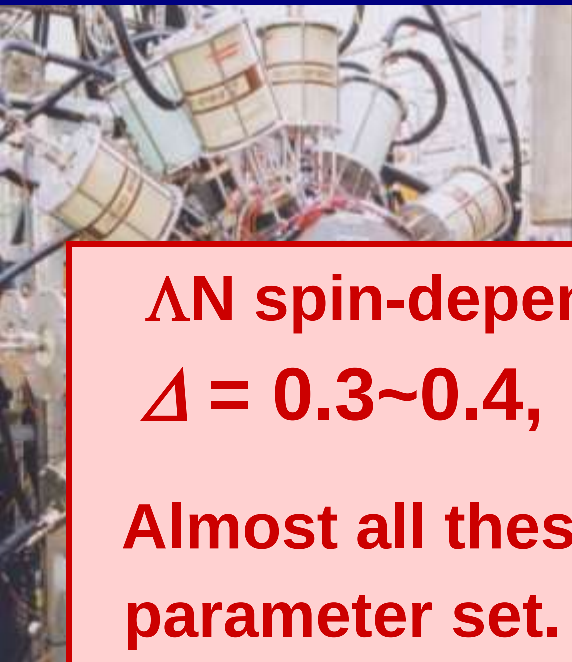
Hypernuclear γ-ray data



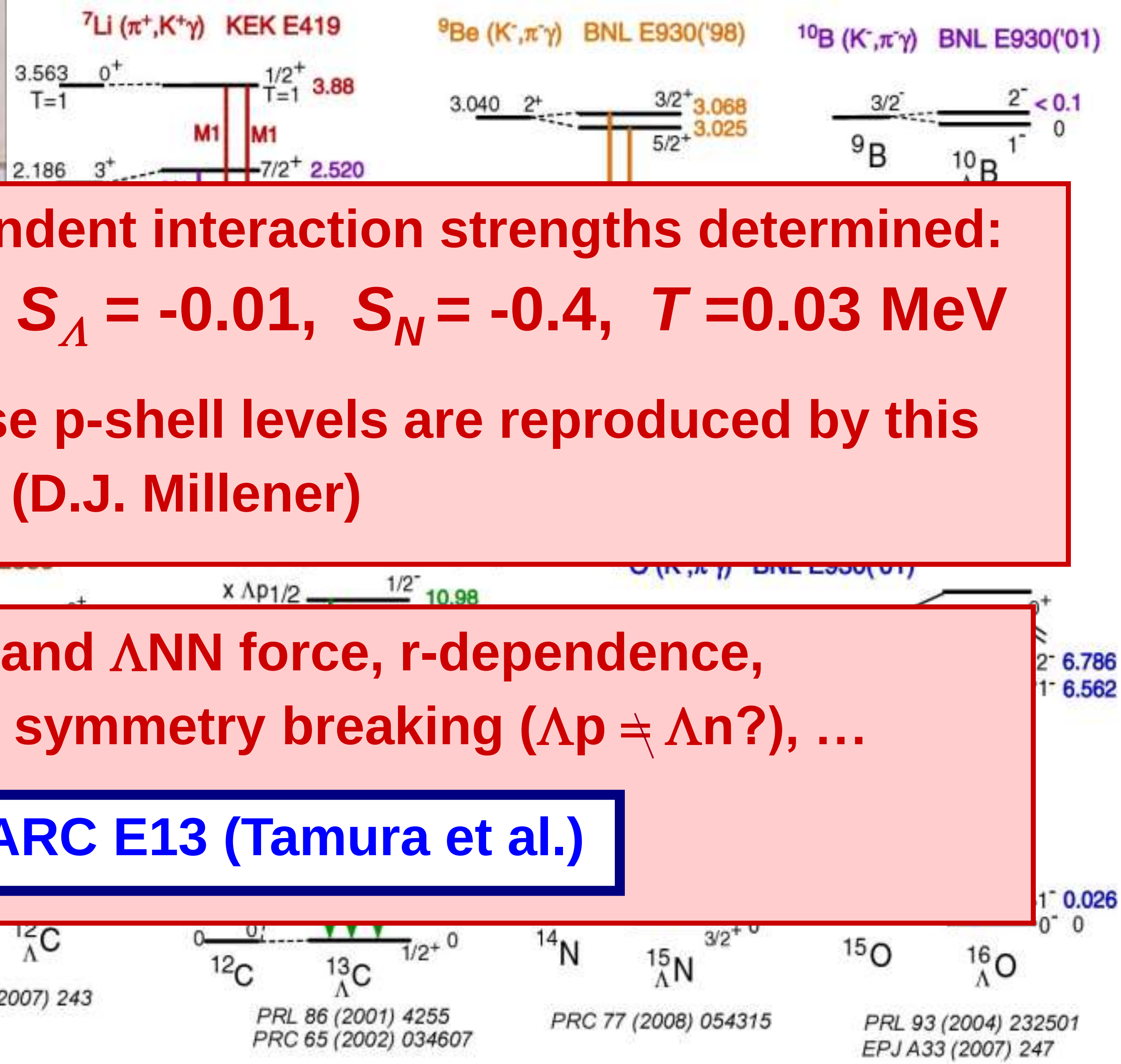




Hyperball



Hypernuclear γ-ray data



ΛN spin-dependent interaction strengths determined:

Δ = 0.3~0.4, S_Λ = -0.01, S_N = -0.4, T =0.03 MeV

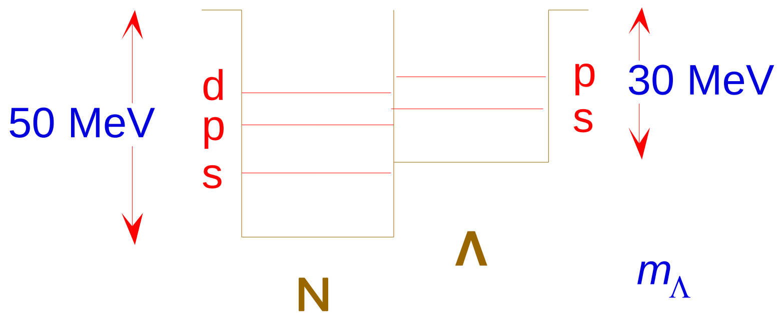
Almost all these p-shell levels are reproduced by this parameter set. (D.J. Millener)

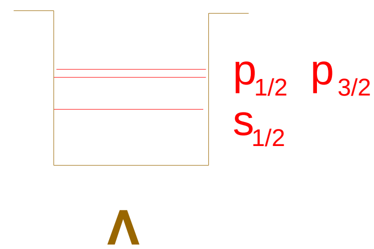
Further: ΛN-ΣN and ΛNN force, r-dependence, charge symmetry breaking (Λp ≒ Λn?), …

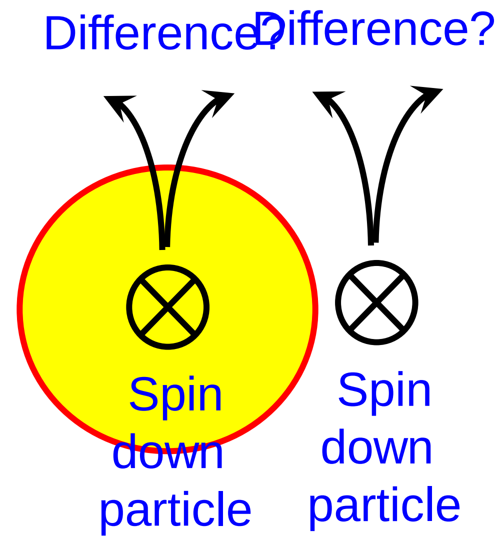
J-PARC E13 (Tamura et al.)

Hypernucleus

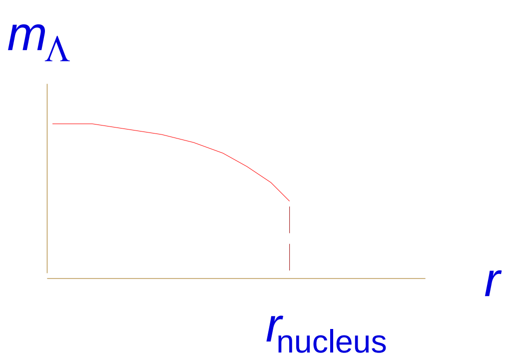
Shallow Potential | Small ($l \cdot s$) Force)

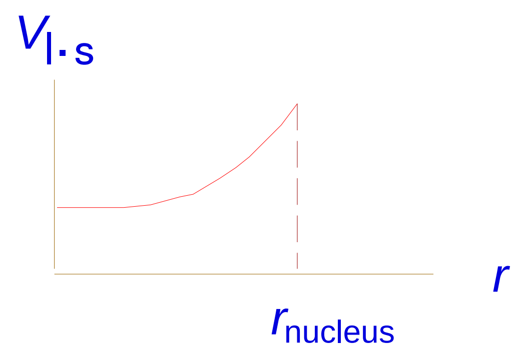






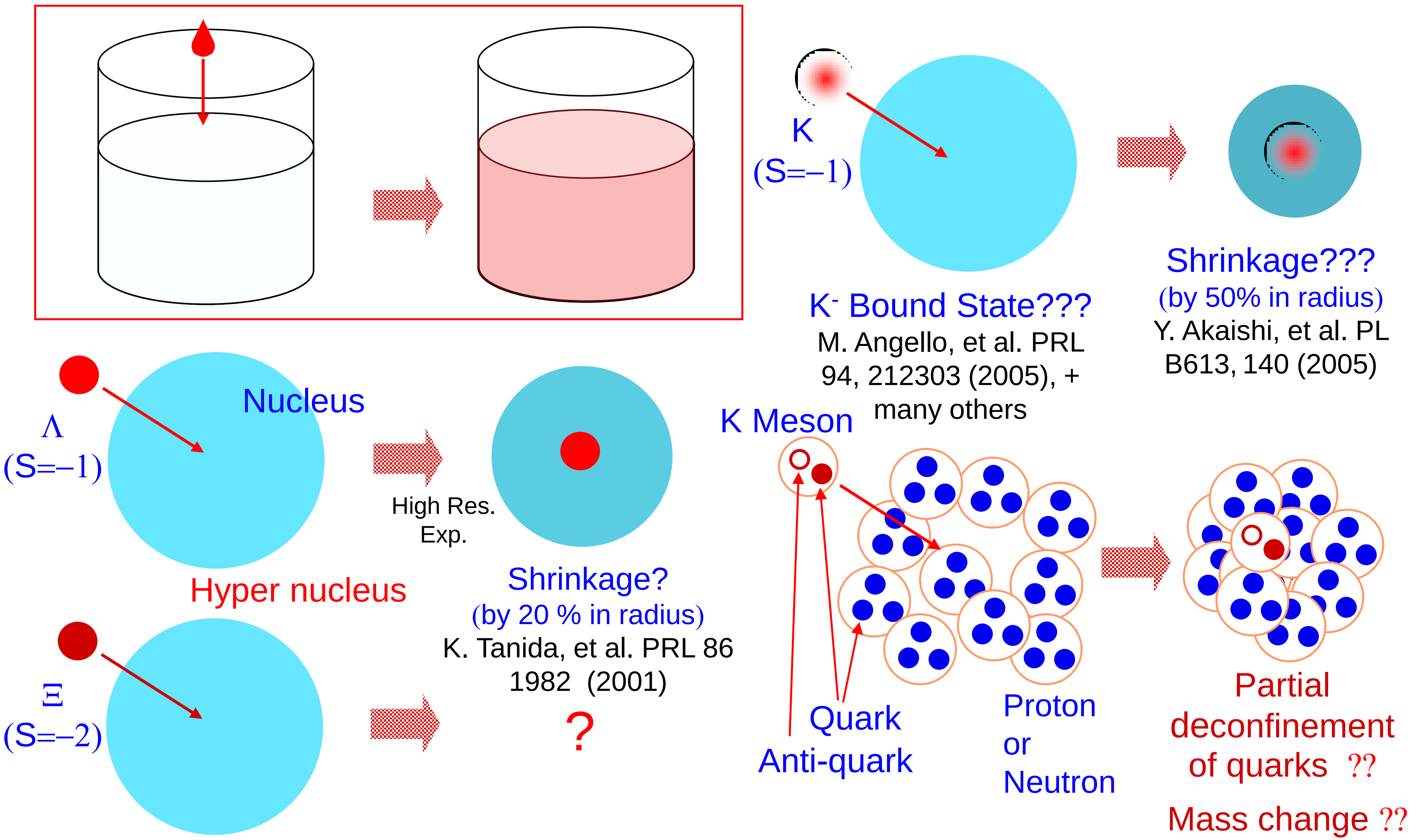
Deep potential + Heavier mass ? | $(l \cdot s)_{\text{surface}} > (l \cdot s)_{\text{interior}}$



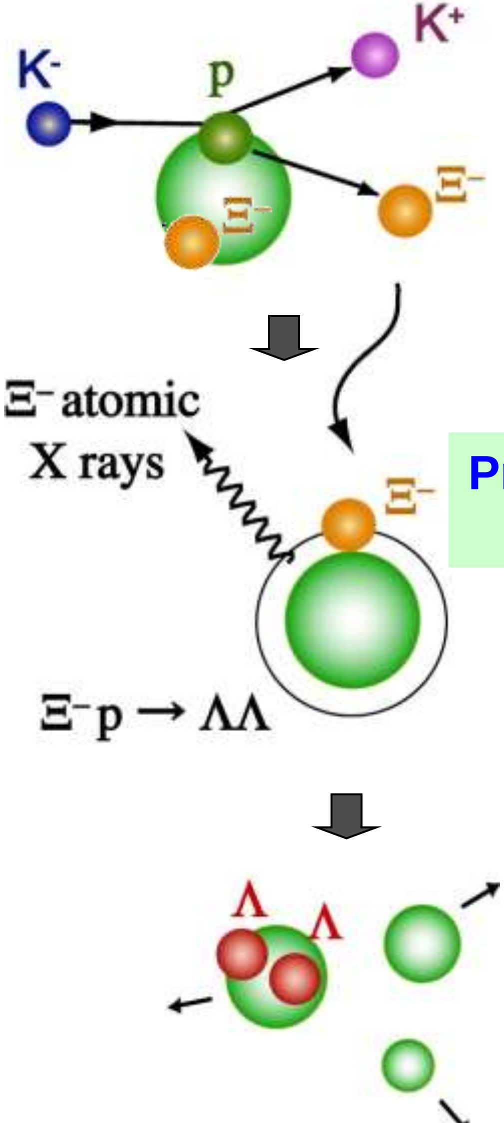


Analyze Hypernuclear Spectroscoy with $m_\Lambda(r)$, $V_{l \cdot s}(r)$ as two parameters!

Implantation of Hadron in the Nucleus



Studies on Double Strange Nuclear Systems



Spectroscopy of Ξ hypernuclei by (K^-,K^+) reaction

E05

Possible only at J-PARC

Ξ-N interaction

Λ-Λ interaction

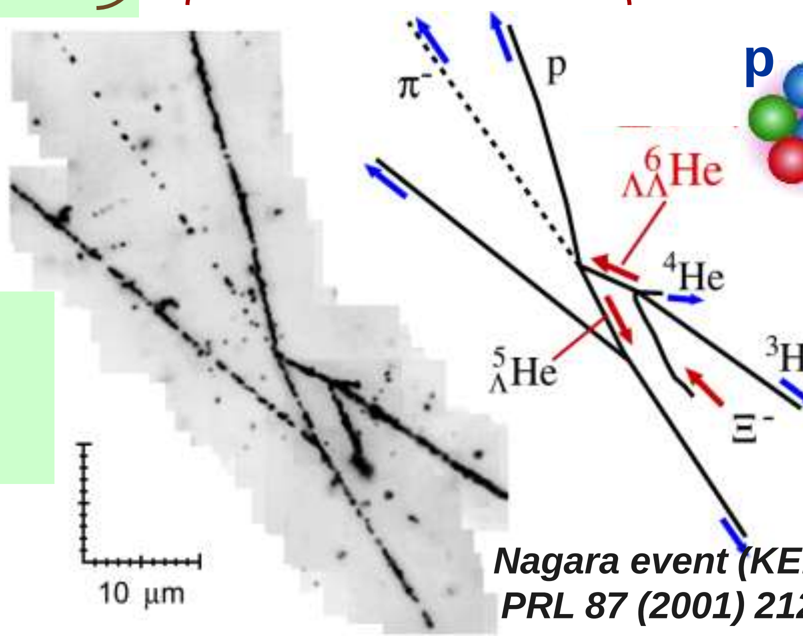
Essential to describe neutron star matter

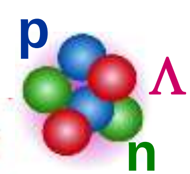
Precise measurement of Ξ^--atomic X-rays

E03 **E07**

Decays of ΛΛ hypernuclei in emulsion

E07



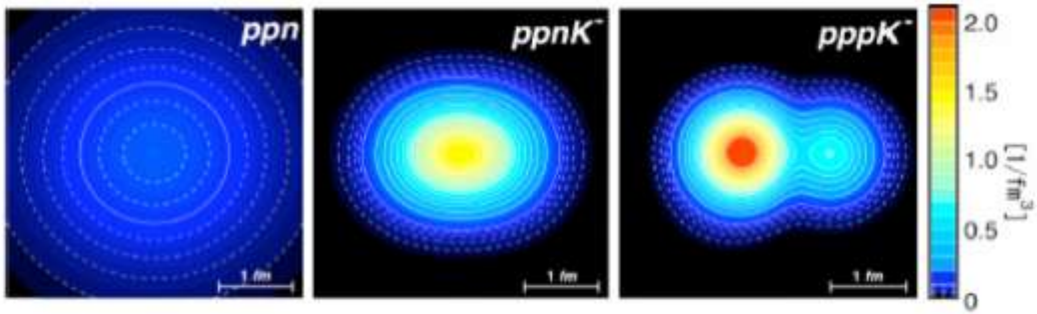


Nagara event (KEK E373)
PRL 87 (2001) 212502

A search for deeply bound kaonic nuclear states by in-flight ^{3}He(K$^-$,n) reaction

J-PARC E15 Experiment

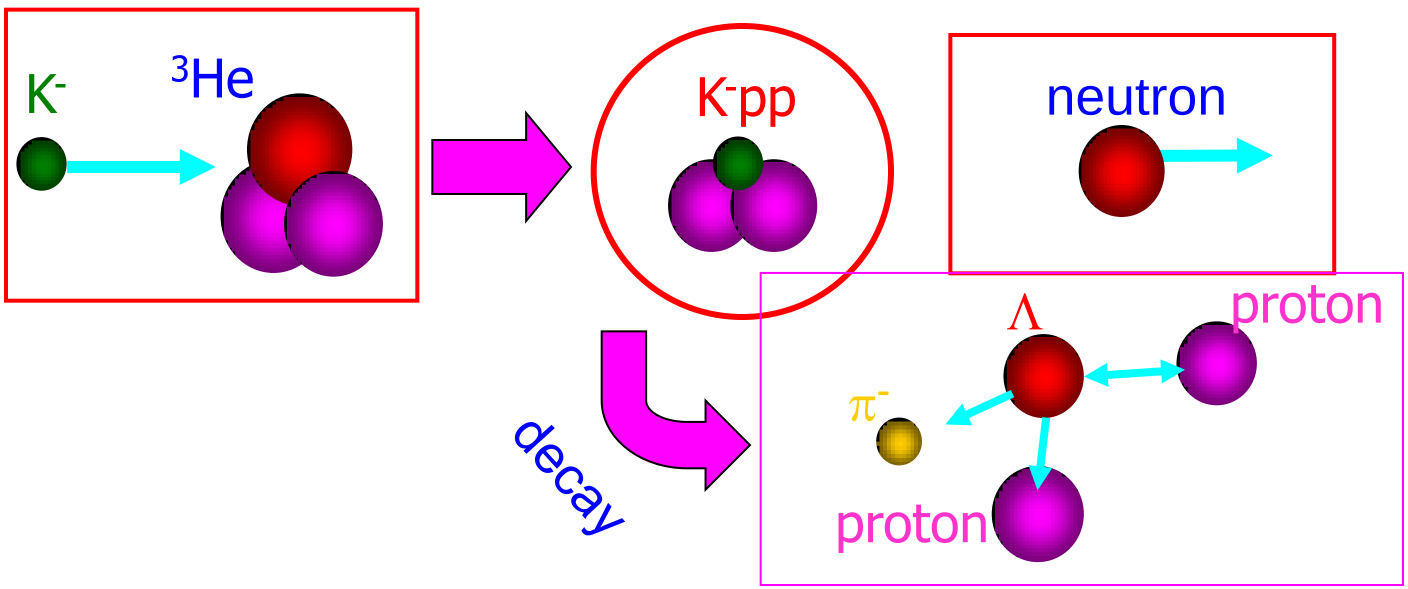
<u>prediction for nucleon density distribution by AMD</u>



A. Dote *et al.*, PRC70 (2004) 044313.

$\rho \sim 10\rho_0$:
extremely dense system

Does the deeply bound state really exist?

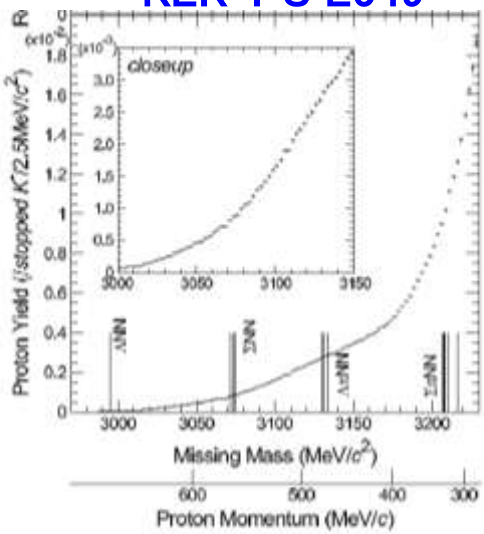


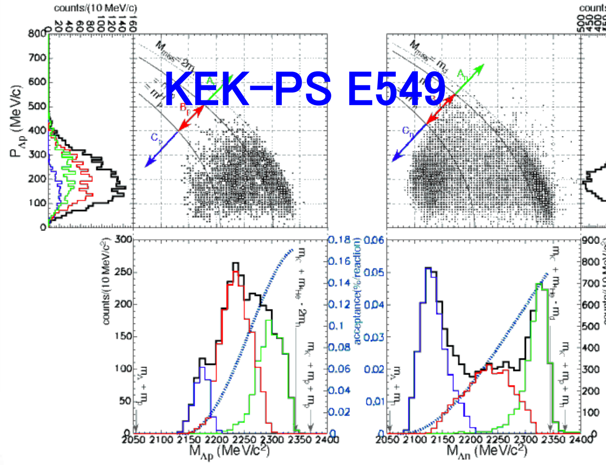
Missing mass spectroscopy via neutron

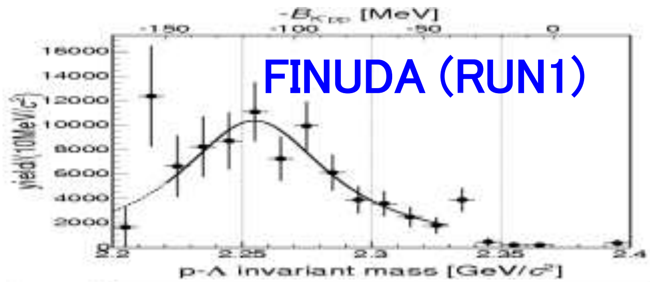
Invariant mass reconstruction

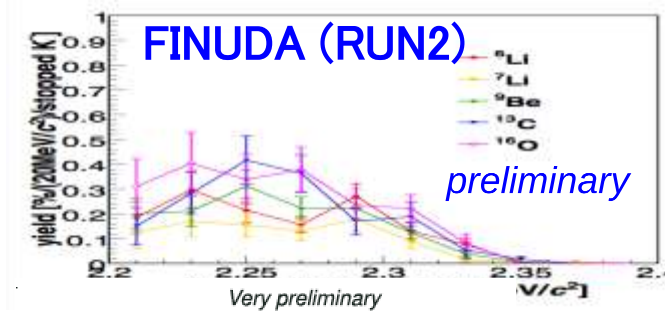
Recent Search for Kaonic Nuclei

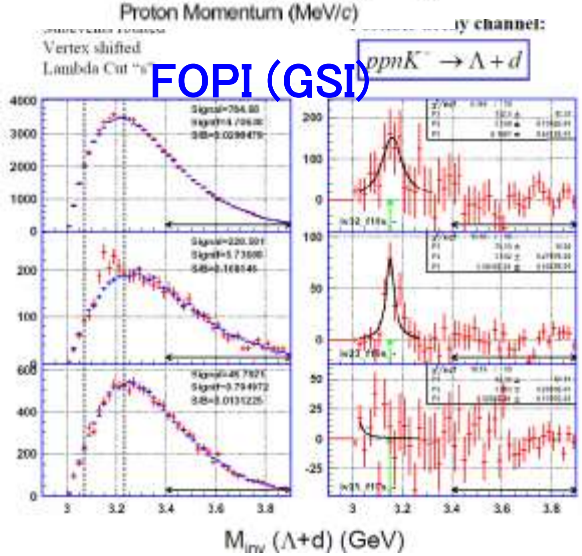
KEK-PS E549

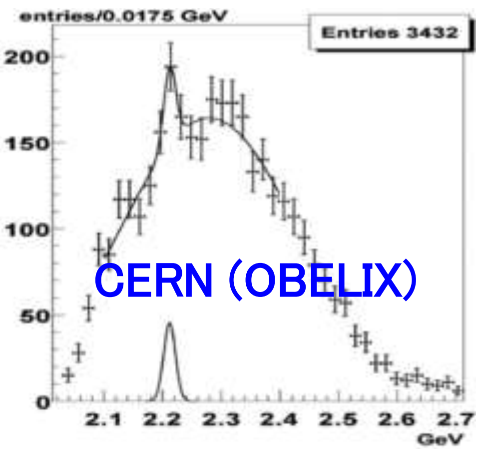




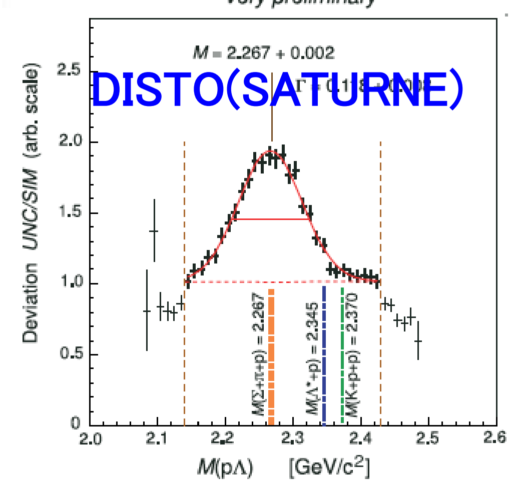




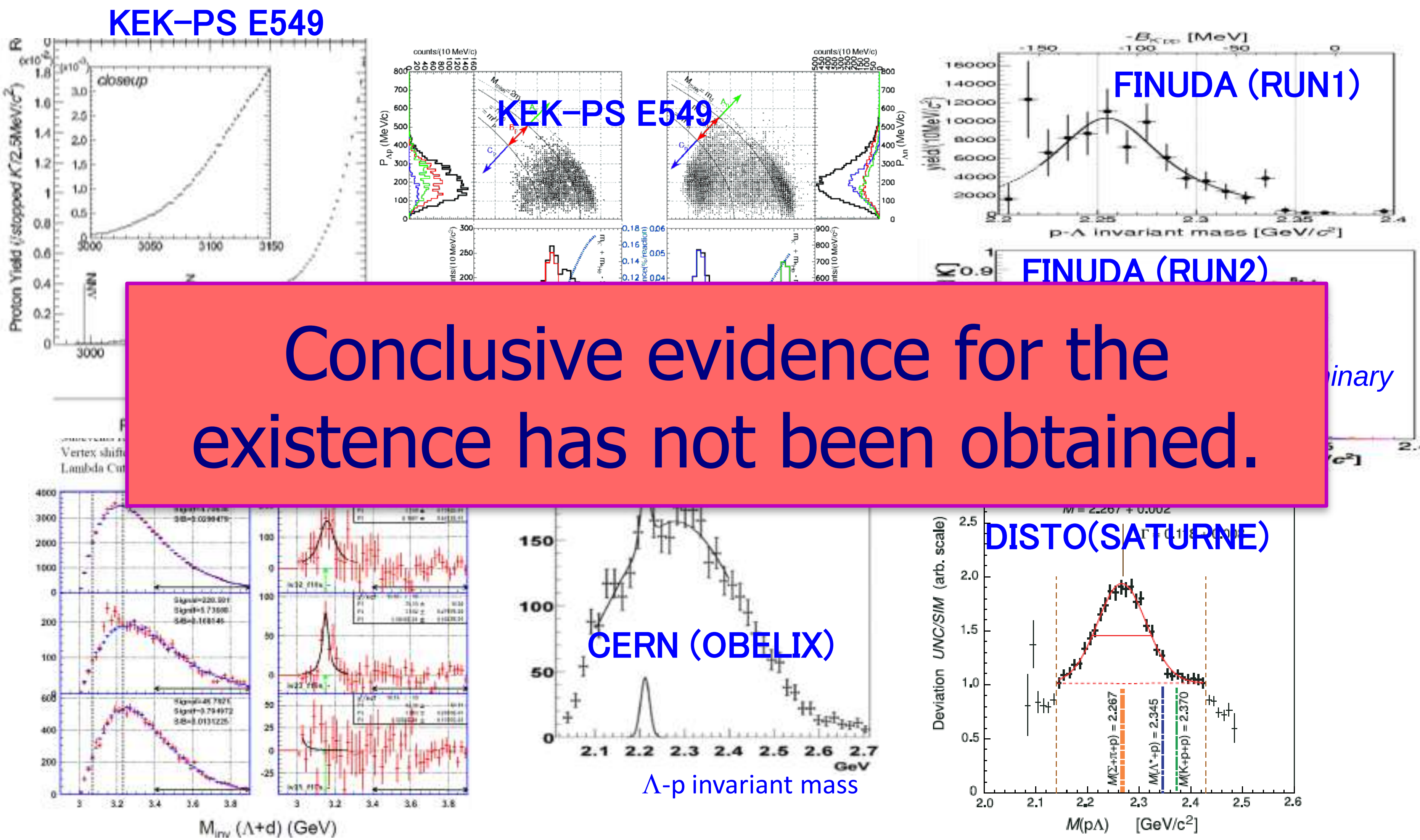




Λ-p invariant mass



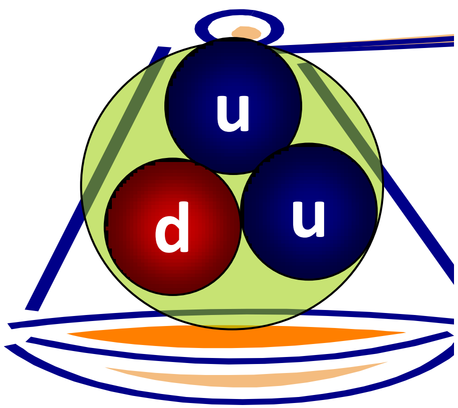
Recent Search for Kaonic Nuclei

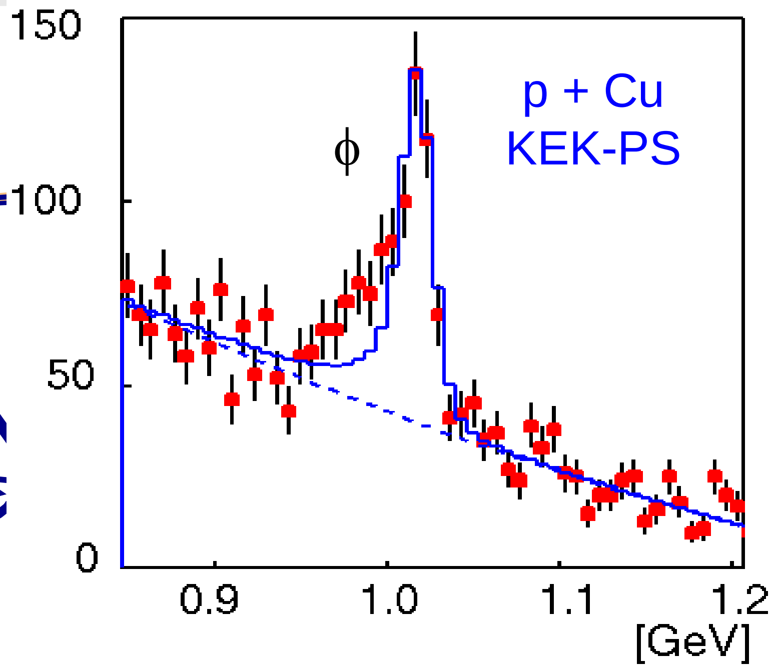


Conclusive evidence for the existence has not been obtained.

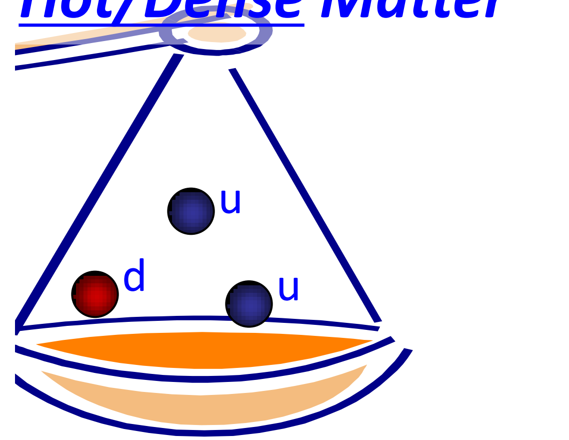
Origin of Hadron Mass - J-PARC E16 -

In Vacuum





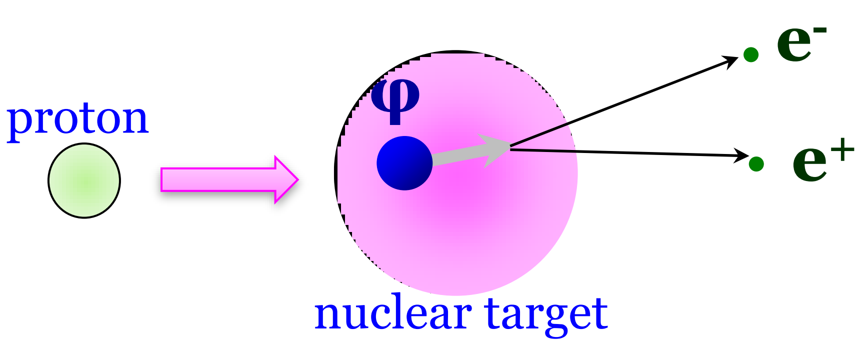
Hot/Dense Matter

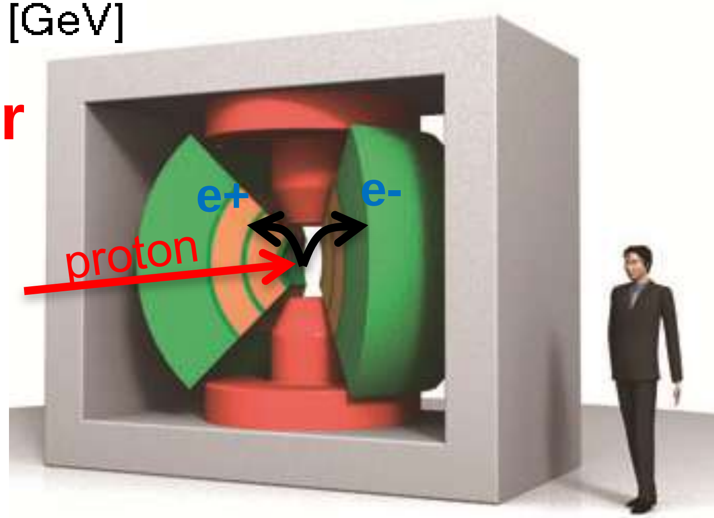


Hadrons ~ *1000 MeV/c²*
Constituent quarks ~ *300*

Current quarks ~ *5 MeV/c²*

→ vector meson mass in nuclear matter

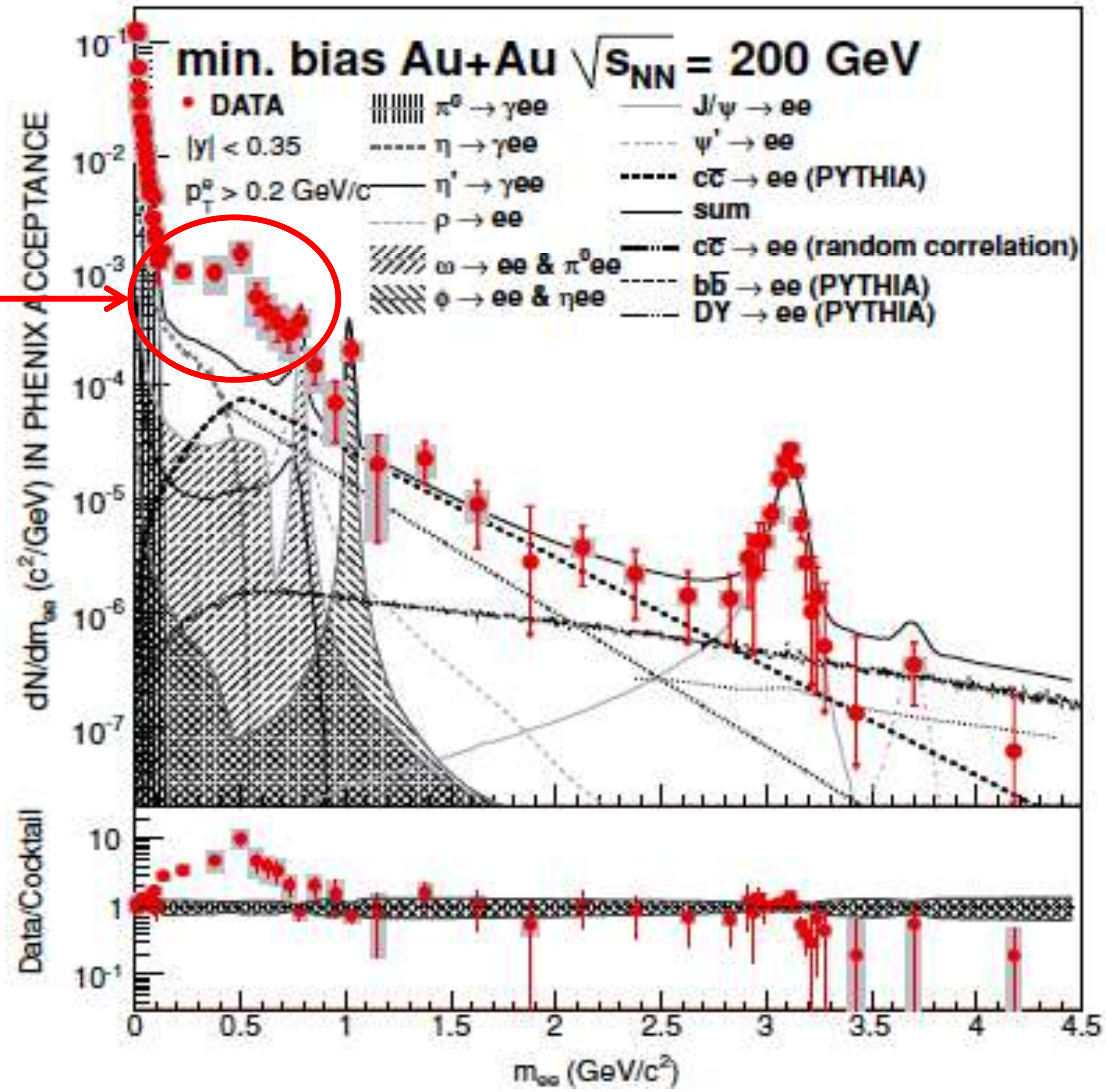




high momentum beamline + E16 Spectrometer

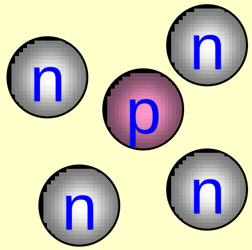
Electron Pair Production in PHENIX

Still a big Issue from CERN-SPS

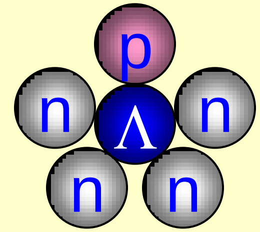


^{5}H

unbound
exotic nucleus



glue-like
role of
Λ-hyperon

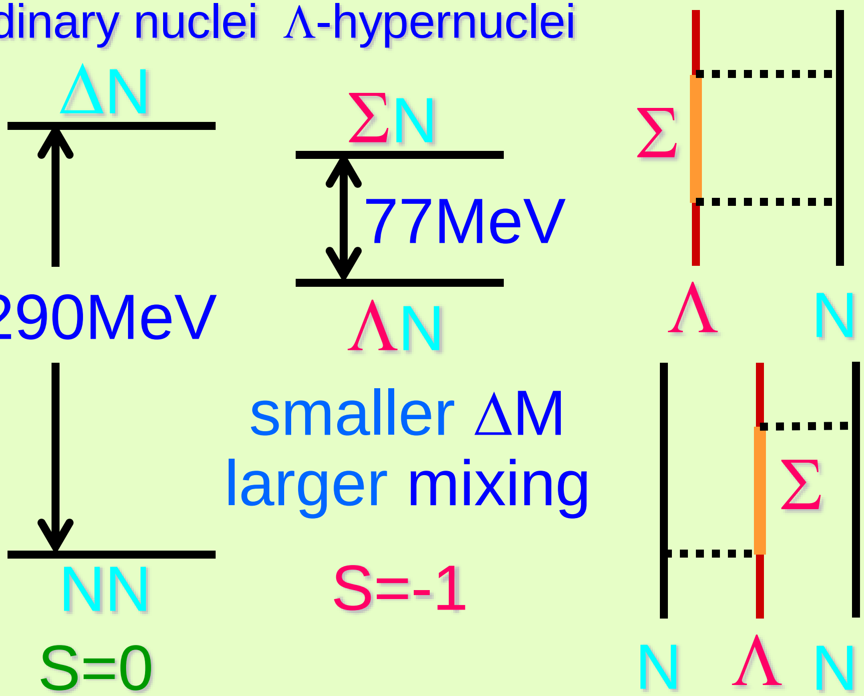


$^{6}_{\Lambda}H$

bound exotic
hypernucleus

insight into halo nuclear structure through hypernuclei

ordinary nuclei Λ-hypernuclei

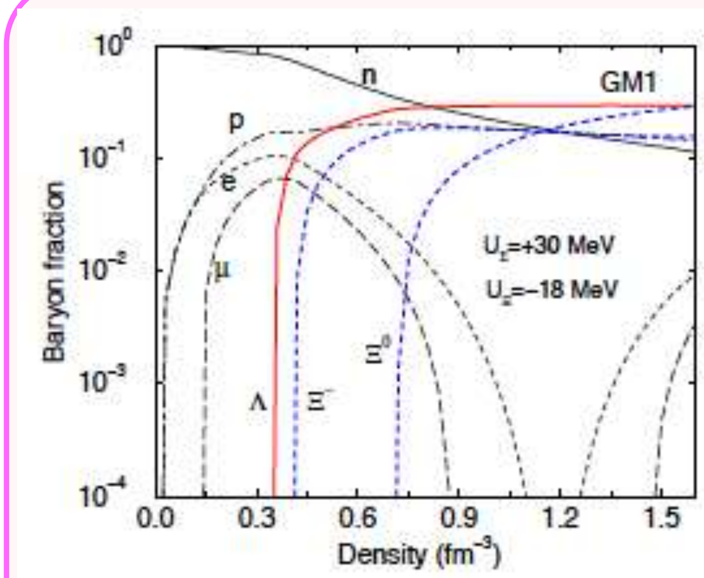


smaller ΔM
larger mixing

S=-1

S=0

contribution of Σ component and many body effect



J. Schaffner-Bielich, Nucl. Phys. A804 (2008) 309

n-rich hypernucleus is a doorway to n-star

Study of Neutron-Rich Hypernuclei
J-PARC/E10

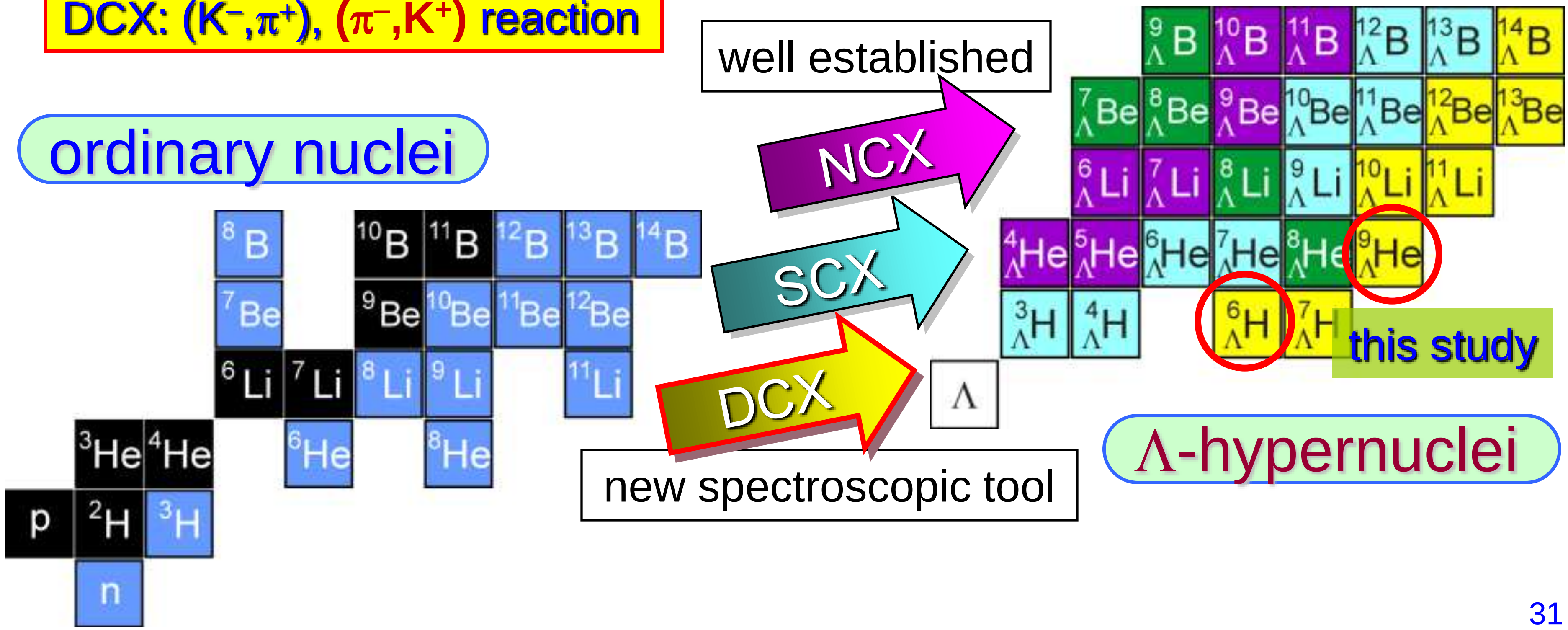
production of neutron-rich and exotic hypernuclei by the double charge-exchange (DCX) reaction

We can learn
halo nuclei property
ΛN-ΣN mixing
ΛNN 3-body force
EOS of n-star core

NCX: (K^-,π^-), (π^+,K^+) reaction

SCX: (K^-,π^0), (π^-,K^0) reaction

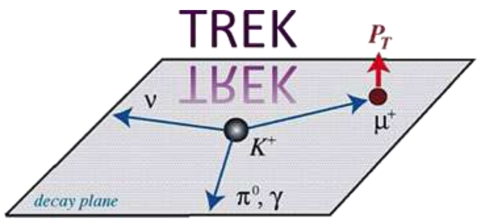
DCX: (K^-,π^+), (π^-,K^+) reaction



Particle Physics at Hadron Hall

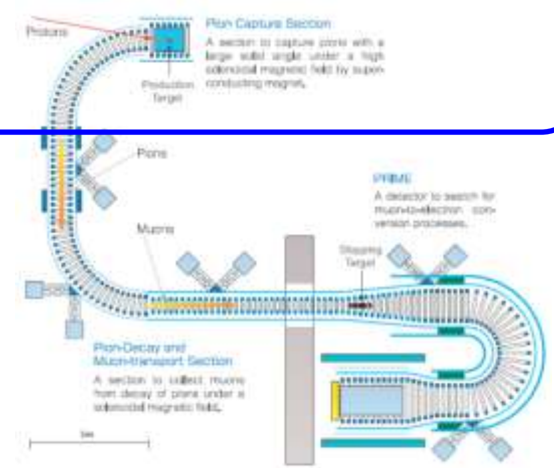
International Collaborations

- **KOTO**: **K0** at **To**kai
  approved



- **TREK**: **T**ime **R**eversal **E**xperiment with **K**aons
  scientific approved

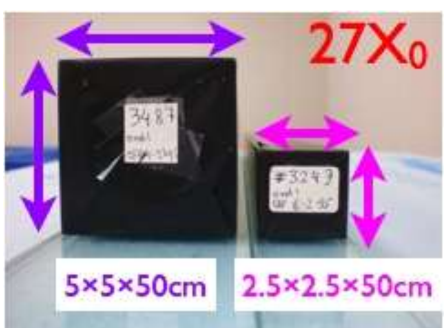
- **COMET**: **Co**herent **M**uon **E**lectron **T**ransition
  scientific approved



- new proposal on neutron EDM
- new proposal on muon g-2/EDM

Fermilab

KTeV
CsI calorimeter
dismantled by December 2008



stacking

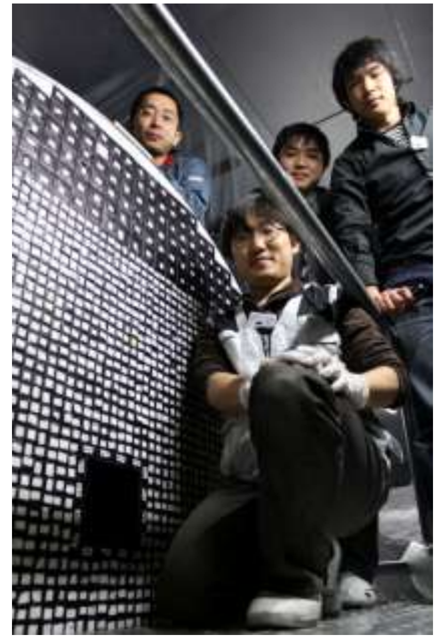
July 2010

October 2010:
engineering run
with 1800 crystals

completed

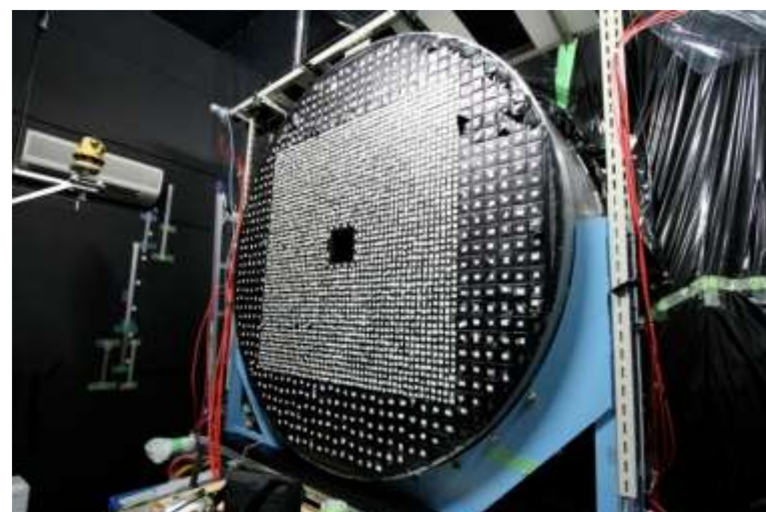
J-PARC

KOTO CsI calorimeter
with 2700 crystals



2011.Feb.08 16:30

May 2011
(after the earthquake)



Necessity for Hadron Hall extension

- Too small area ⇔ KEK-PS x2.4, BNL-AGS x4.1
- Only 4 beam lines ⇔ KEK-PS ~7 lines, BNL-AGS ~15 lines

-> Ineffective operation ("output per operation cost" is bad.)

Long waiting queue of approved experiments

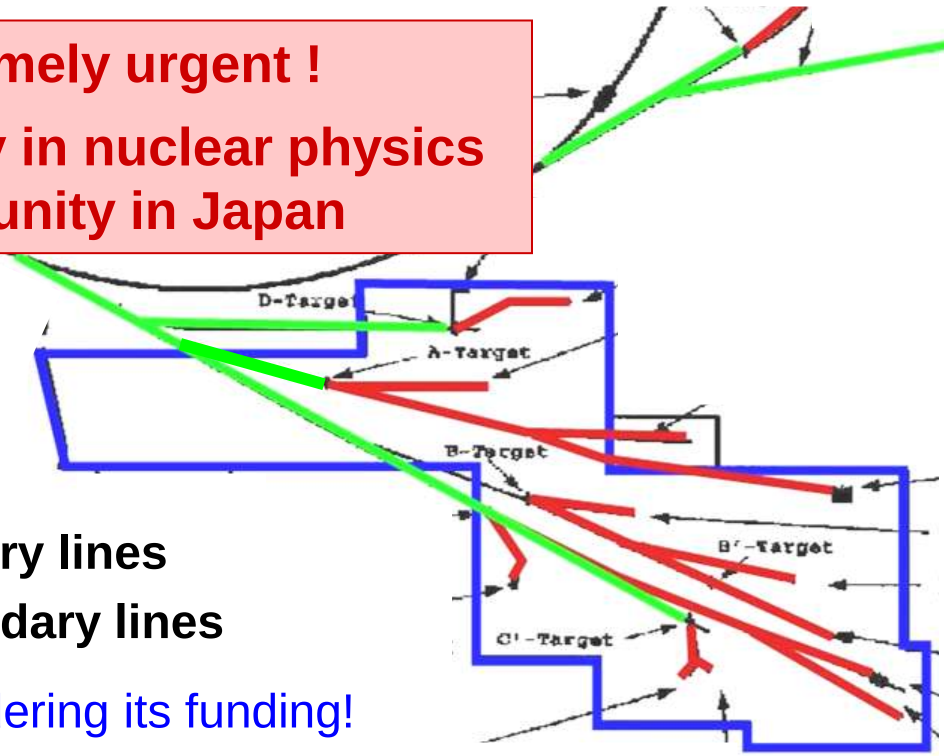
(At K1.8/K1.8BR lines, 6960 hours = more than 6 years)

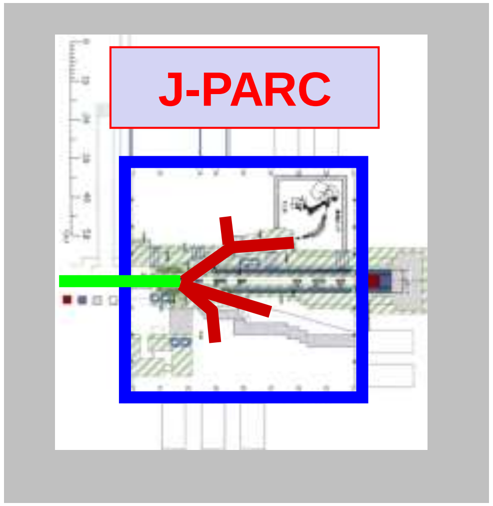
-> Discourage users in the world. Predominance will be lost.

Extremely urgent !

First priority in nuclear physics community in Japan

BNL-AGS



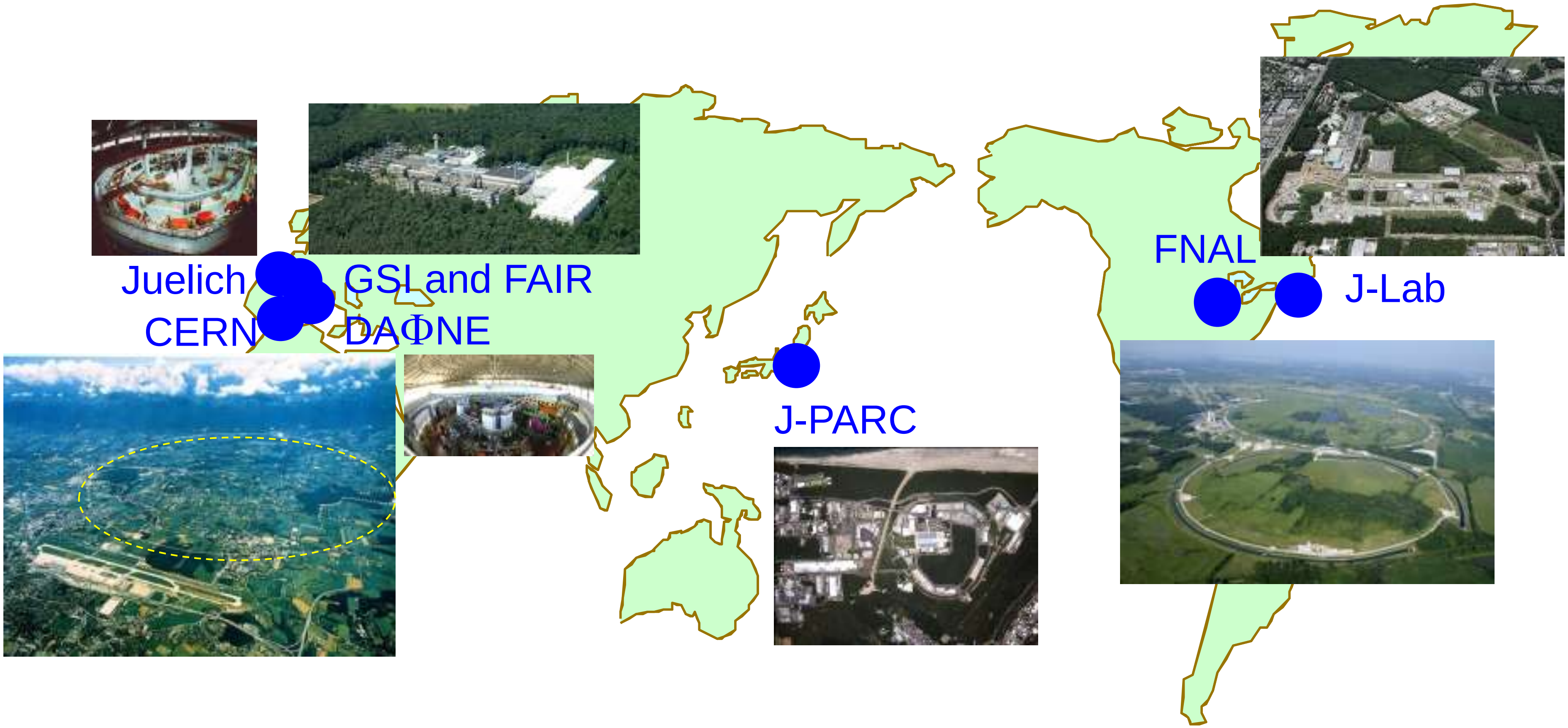


primary lines

secondary lines

RIKEN is considering its funding!

World Hadron Facilities



Summary Until March 11, 2011

- Highlights before March 11, 2011 (Earthquake)
  - Beam power has been steadily increasing: 200 kW for 3 GeV, 145 kW for Main Ring at 30 GeV.
  - 400kW long-run test completed. Goal is 1 MW.
  - Neutrino Facility: Started to take data at Super Kamiokande. 6 electron-neutrino candidate events were detected. Possibility of large θ_{13}. Encouragement to go to CP measurement.
  - Hadron Facility: About ready to run for many experiments. First data for penta-quark search were completed.
  - Materials and Life Facility: Neutron and muon beams already produced many fruitful data and the results are being published.
  - Need more and serious efforts towards “international usage” and toward creating “lively academic atmosphere”.
  - Also, need more effort toward “industrial usage” of J-PARC

Status (after the Earthquake)

LINAC-1

Outside of LINAC building
is heavily damaged.

We are getting water from an outside fire-hydrant, as original cooling water system has not yet been fixed.

LINAC-2

Many pipes for supplying cooling water were damaged.

Placing a temporal bridge for carrying in materials for repair.

LINAC-3

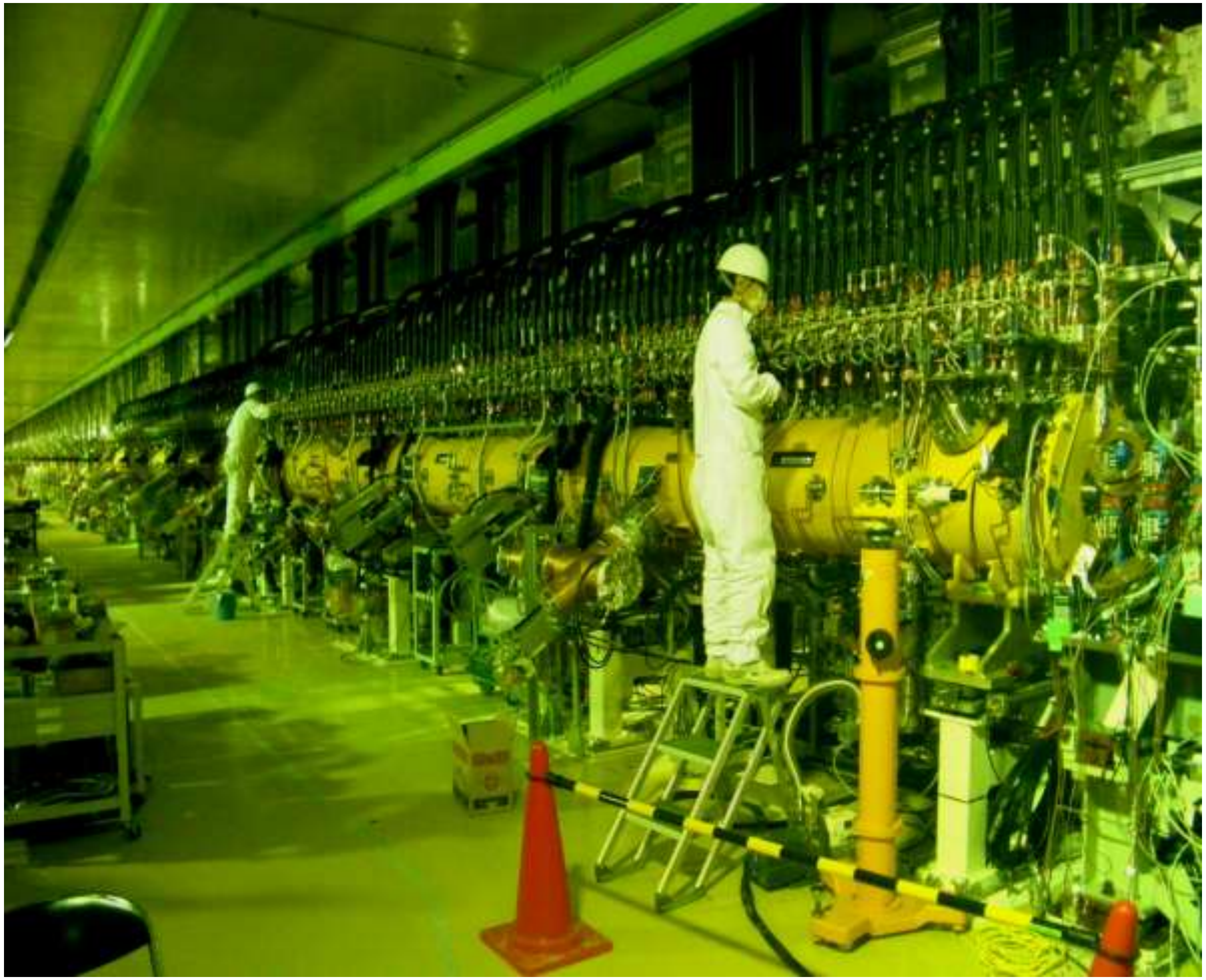
Inside of underground tunnel immediately after the Earthquake

Many piles reached to a basement rock minimized a direct damage to the tunnel. However, groundwater leaked into the tunnel and the water depth increased to 10 cm (100 tons) within two weeks after the earthquake.

Repairing water leaks in the tunnel is almost completed.

LINAC-4

・The floor level sagged 4 cm downward in the tunnel. Because accelerator cavities should be aligned within ±1 mm to each other along the beam line for the operation, they have been leveled and realigned where necessary.
・Restoration work on the cooling water system and power supply is going smoothly.



Realigned accelerator cavities of DTL and SDTL were tested for water-tightness.

3 GeV Synchrotron (RCS)-1

・There were severe damages on many facilities around the RCS building.
・The restoration work was started after repaved roads for carrying in materials and instruments for the work. The work is progressing smoothly.

The road was repaved.

The bent stage was repaired. Power has been supplied to the RCS building.

3 GeV Synchrotron (RCS)-2

- Many basements for the equipment were re-leveled.
- Replacing damaged water pipes and repairing many damaged parts.

Tilted condenser transformers were straightened.

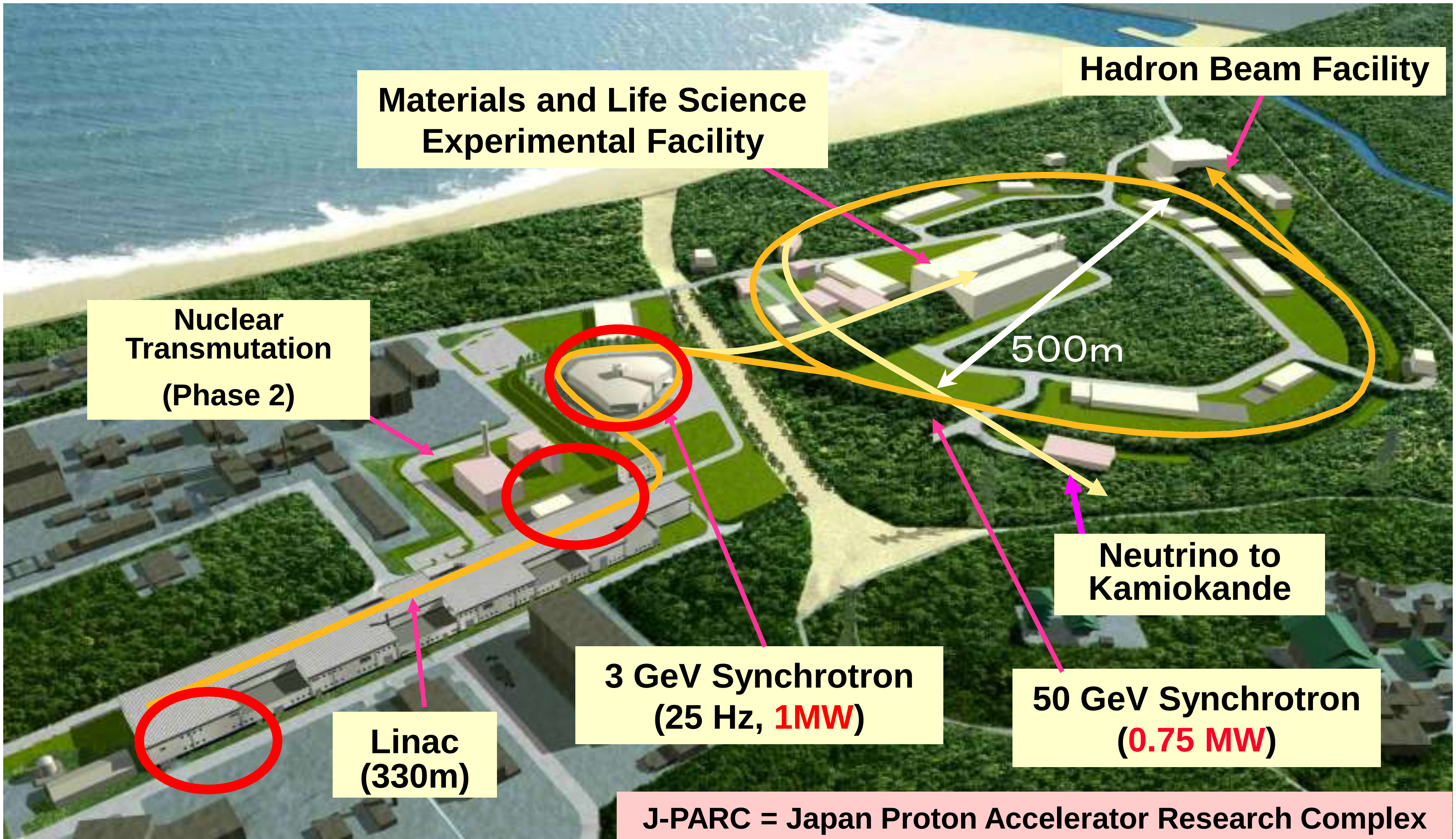
Water pipes were replaced, being ready for passing water.

Reinforced foundation for a cooling tower (right)
Refining work of pumps and motors (left)

3 GeV Synchrotron (RCS)-3

No obvious damages were observed.
(Photo taken on March 29).

J-PARC Facility



Joint Project between KEK and JAEA

50 GeV Synchrotron (MR)-1

- Repair of water leaks has been done. The facilities for electric power supply and cooling water supply have been restored as well.
- All electromagnets (~400) are being realigned at 5 magnets/day.
- Magnets moved more than 1 cm are realigned to change a stage position (Photos).

Jacking up an electromagnet to make a space between the magnet and the stage

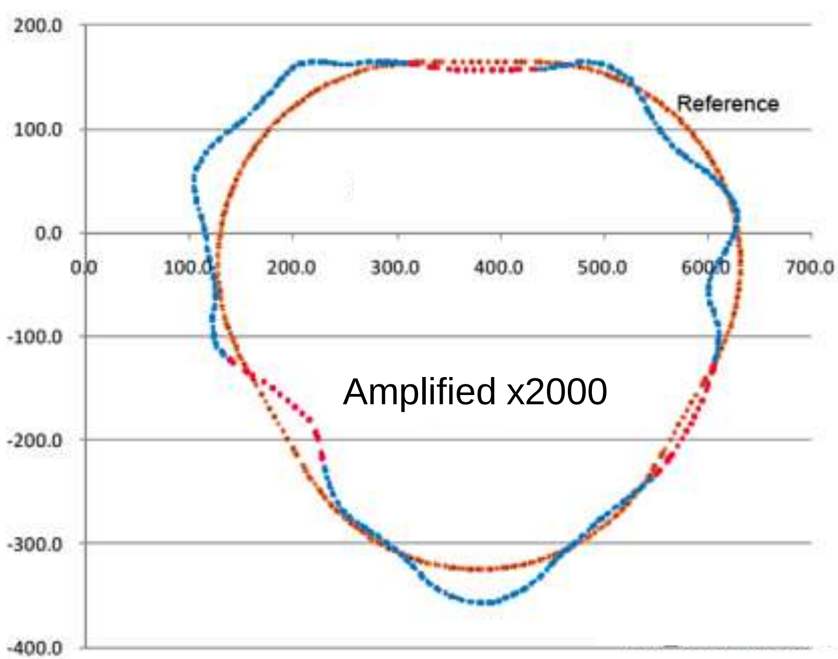
Hanging up the magnet

Pulling out the stage to put new longer height-adjust screws

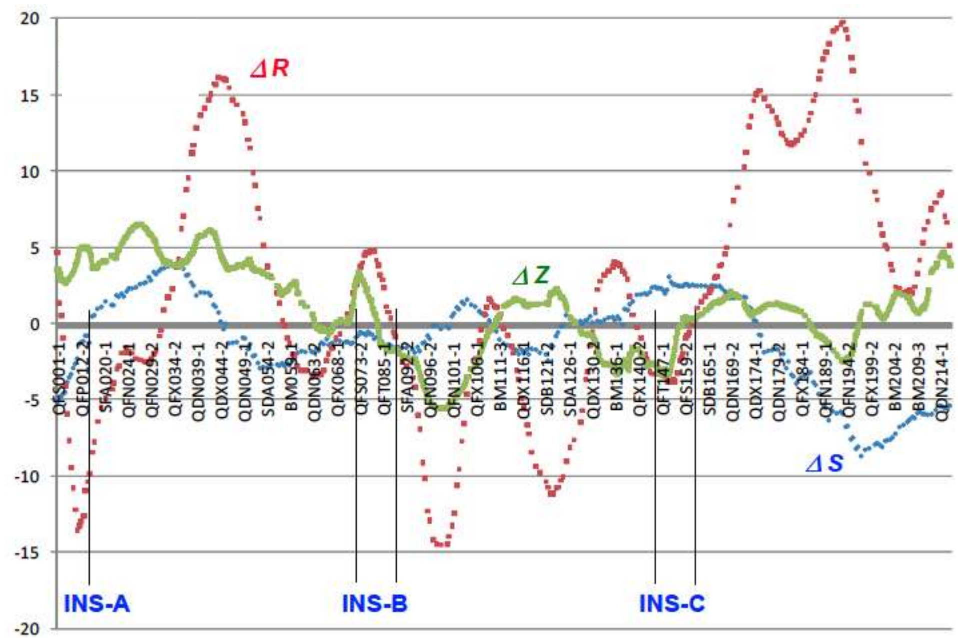
Sometimes we need to place an adapter to put a new longer anchor bolt.

50 GeV Synchrotron (MR)-2

- There were no serious damages on all MR equipment/instruments, such as electromagnets. It, however, appeared they misaligned in both vertical and horizontal directions.
- Some electromagnets that misaligned greatly are realigned with replacing a stage and/or an anchor part.
- Inspection of the high-frequency power amplifying system has been completed.



Red: Reference positions of electromagnets
Blue: Actual positions after the earthquake
(Please note the magnitude of displacement is amplified x2000.)



Electromagnet displacement in a vertical direction

50 GeV Synchrotron (MR)-3

・Not only restoration but also improvement/upgrade of the equipment/facility are conducted to increase beam intensity when the operation will be resumed.

Putting new hanging racks on ceiling for pipes for new cooling system to supply clear water

Materials & Life Science Experimental Facility (MLF)-1

Immediately after the Earthquake

The road was re-opened after filling depressions with pebbles.

A tilted He tank was removed to repair the foundation.

Inspection by the fire department

Materials & Life Science Experimental Facility (MLF)-2

Immediately after the Earthquake

An attached building to the west side of the main MLF building sank ~20 cm. The building is jacked up with 24 hydraulic lifters (blue). Created interspace will be filled with cement injected from holes of the floor.

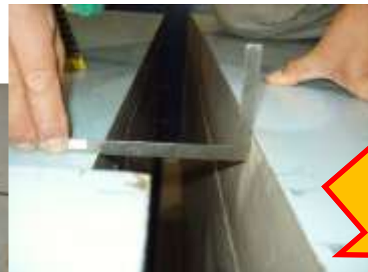
Immediately after the Earthquake

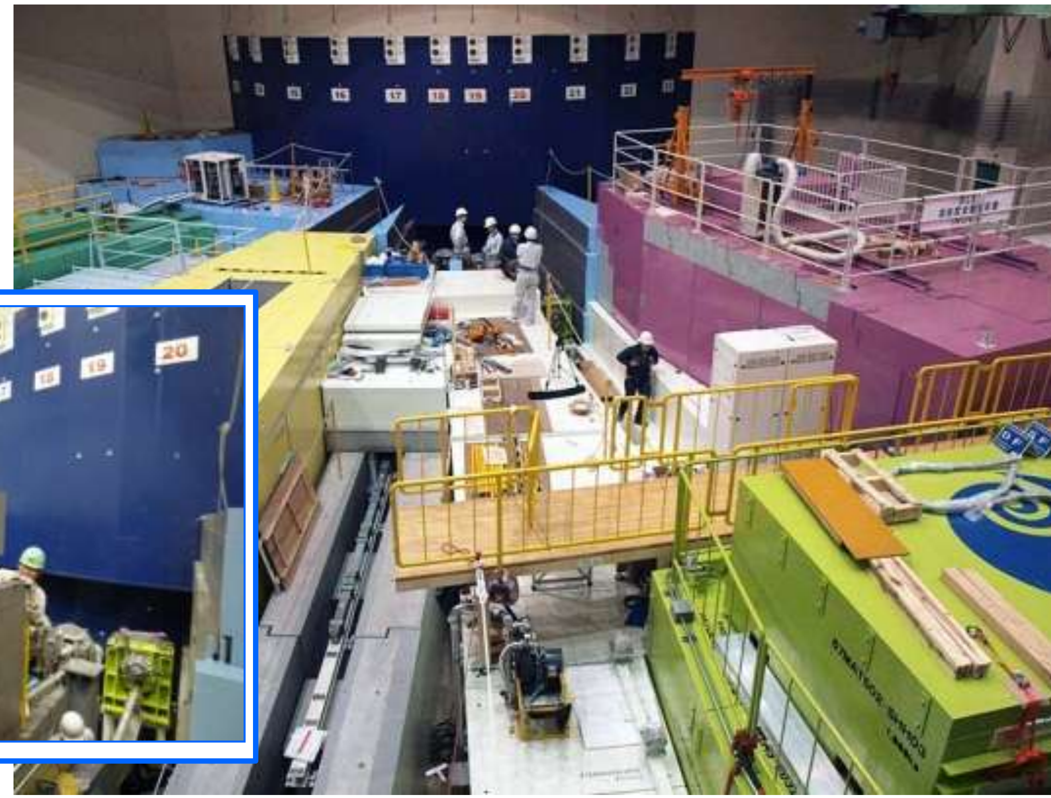
Putting new clay to maintain the level

Repairing cracks on the floor of 3NBT tunnel (left), and repairing a joint wall with removing concrete (right).

Materials & Life Science Experimental Facility (MLF)-3

Immediately after the Earthquake





Reassembling work of shielding blocks for neutron beams in the 2nd experimental hall (above). Inspection of the inside of the muon beam facility after removing shielding blocks (right). This area does not have any serious damage.

Neutrino Experimental Facility-1

Immediately after the Earthquake

AC device tilted toward a depression of a road. Many pipes were damaged

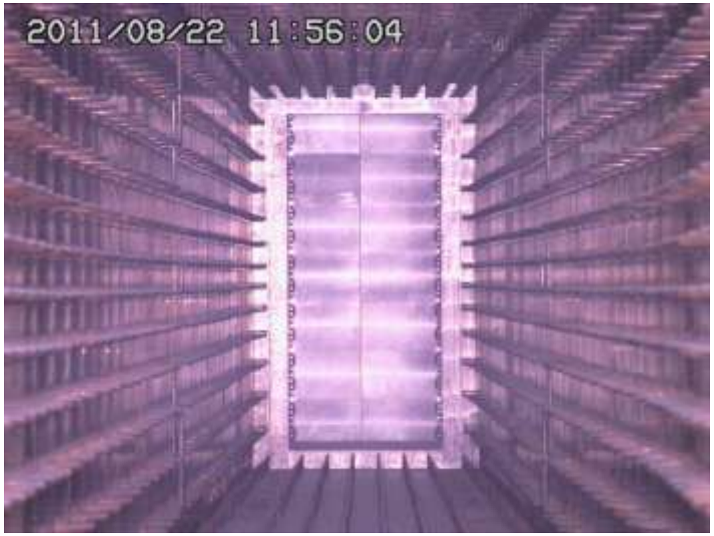
Repairing roads and plumbing have been completed.

Realignment work of electromagnets (above) and superconducting magnets (below) is progressing smoothly. We also try to improve cooling power.

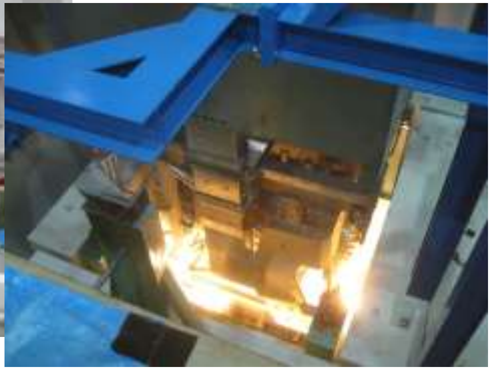
Neutrino Experimental Facility-2

・Inspection of highly radiated parts, such as a target station, is progressing smoothly.

・The soundness of all equipment and devices, including three horns, have been visually confirmed.



The soundness of Beam Dump and Decay Volume was visually confirmed. There were no water leaks.



The 3rd horn hung by a crane for inspection (left) and the 3rd horn in a shielding maintenance area.

Hadron Experimental Facility-1

Immediately after the Earthquake

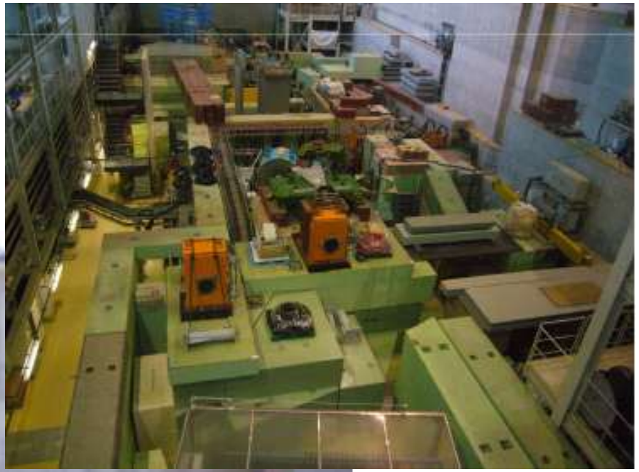
Repairing roads and plumbing have been completed.

Hadron Experimental Facility-2

Electromagnets in the switchyard need to be realigned. The work is progressing smoothly.

Hadron Experimental Facility-3

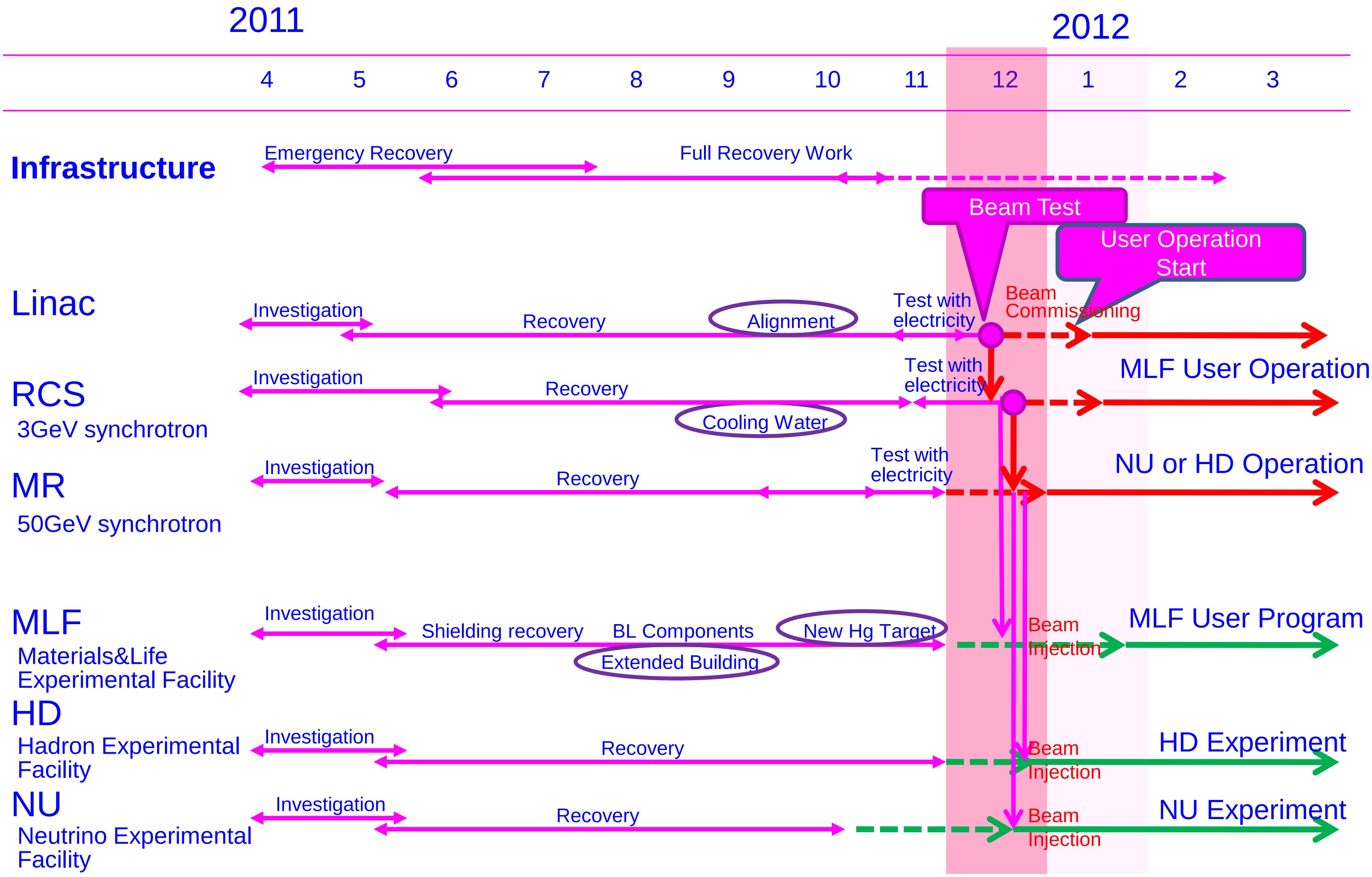
・After removing shields temporally, the soundness of all equipment and devices have been confirmed.
No realignments are required.



Inspection work in Hadron Hall

No damages in the device

J-PARC Recovery Schedule (@2011.5.20)



Summary of Damage

- No Tsunami Effect
  - We prepared up to 8 m Tsunami.
- Main Buildings were almost OK
  - Many underpins for major buildings.
- However, many utility buildings, roads, and added buildings had significant damage.
- When to recover ?
  - Aiming at recovering by the end of this year.
  - Expect to have 2 cycle (about 2 month) running this year.
- Operation of Next Fiscal Year
  - Full 9 cycle (200 day) operations for users.

Thank you!