J-PARC Program

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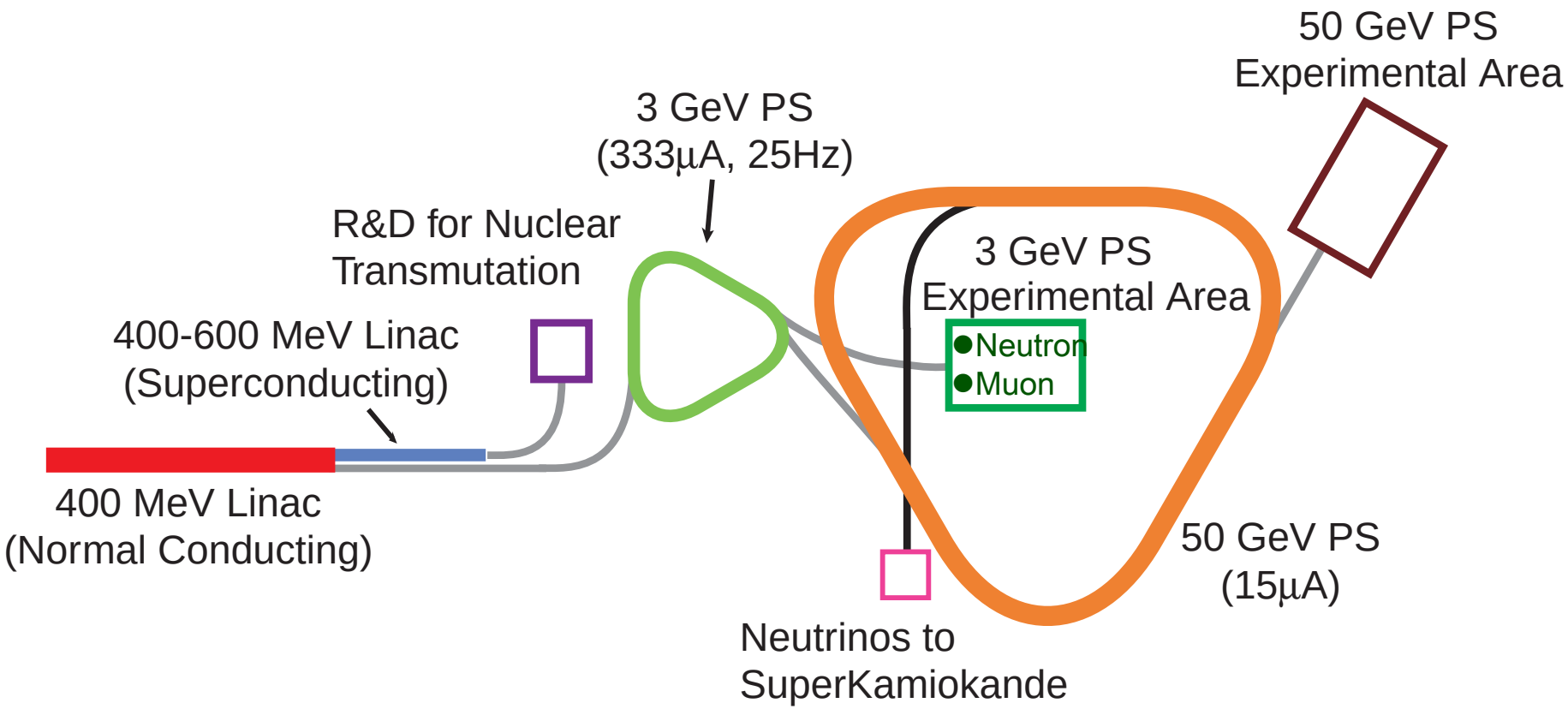
Workshop on Physics at an Upgraded Fermilab Proton Driver

- Overview of J-PARC
- Particle physics program
- Nuclear physics program
- Program of other sciences

Project overview

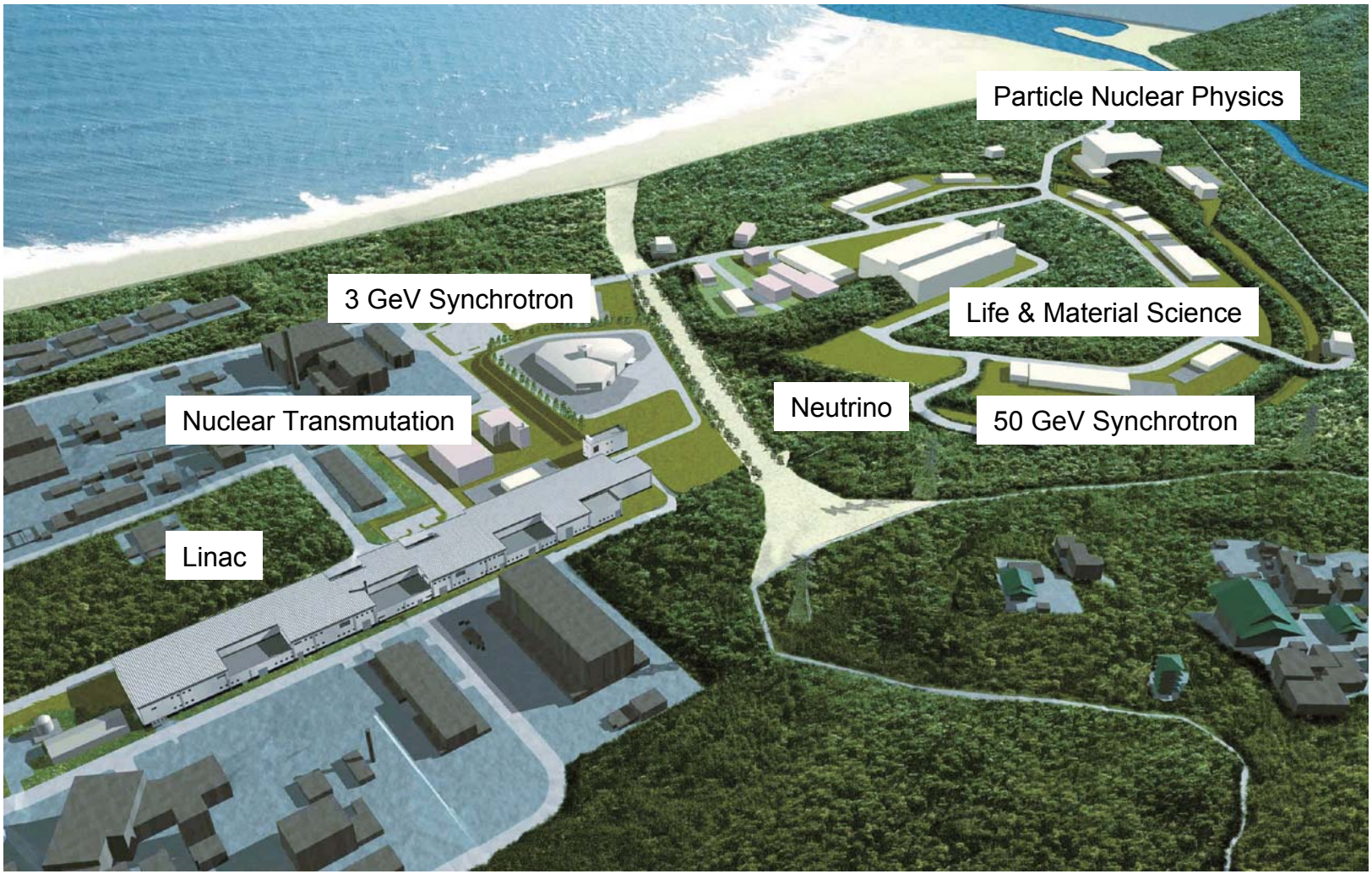
- J-PARC is a high-intensity proton accelerator complex in Japan now under construction consisting of:
  1. 600 MeV linac
  2. 3 GeV rapid cycling synchrotron
  3. 50 GeV main synchrotron
  4. Experimental facilities
- Joint project of High Energy Accelerator Research Organization (KEK) and Japan Atomic Energy Research Institute (JAERI)
- Construction started in 2001 at the JAERI Tokai site and completion will be in 2007.
- A variety of sciences ranging from particle physics to materials and life sciences will be carried out.

Configuration of the accelerators

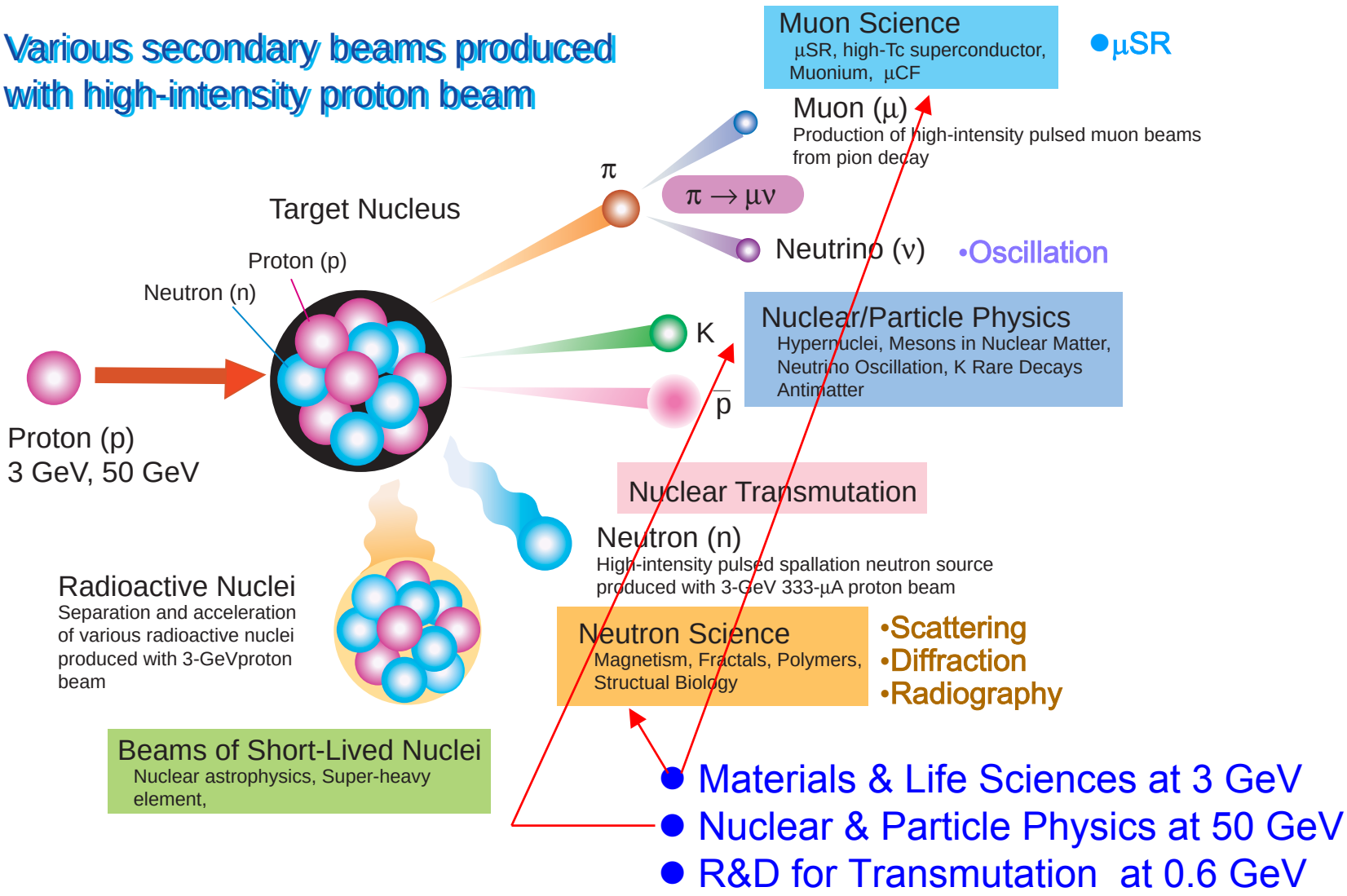


Bird's-eye view of J-PARC

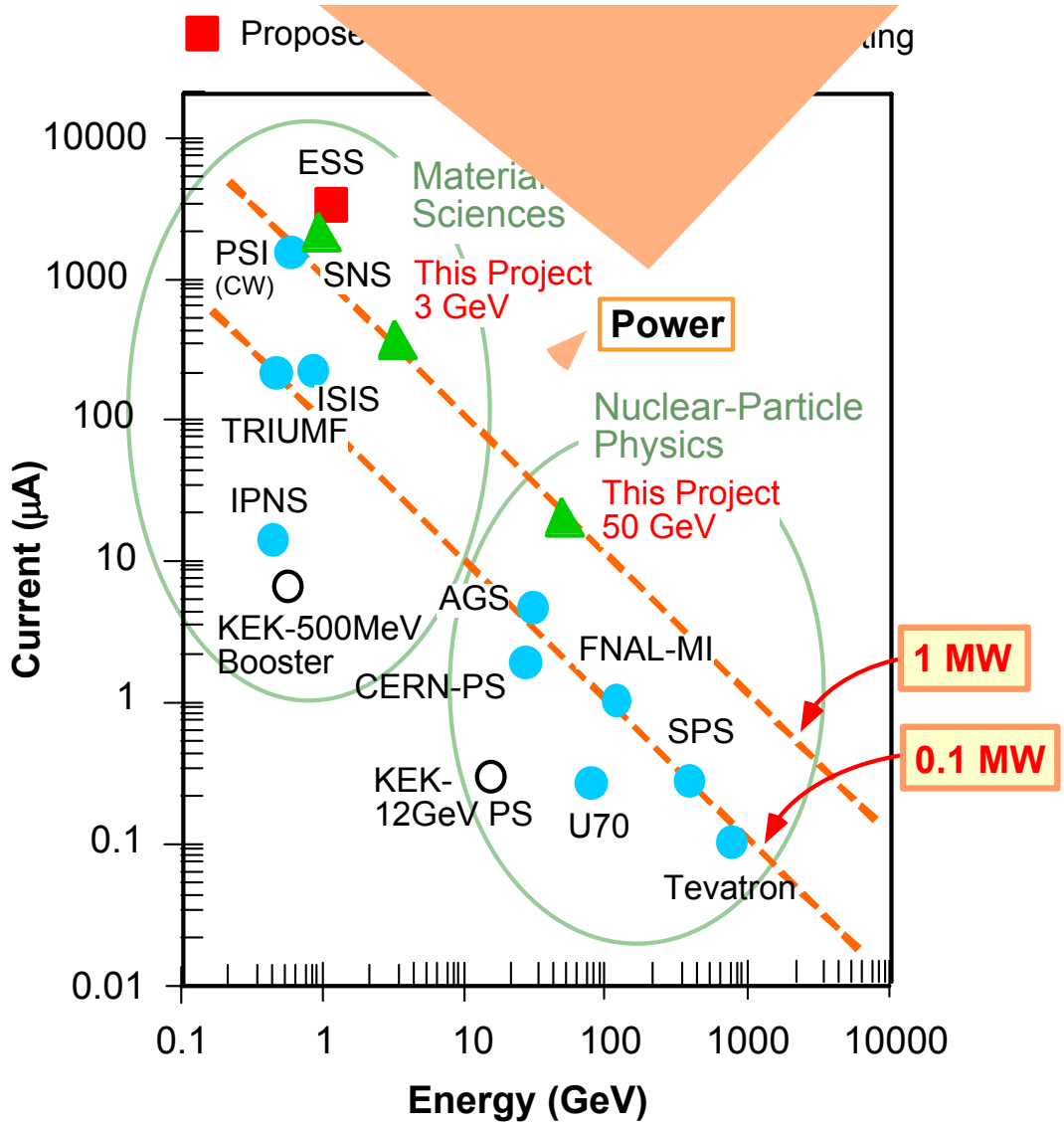
- Japan Atomic Energy Research Institute (JAERI) Tokai Site



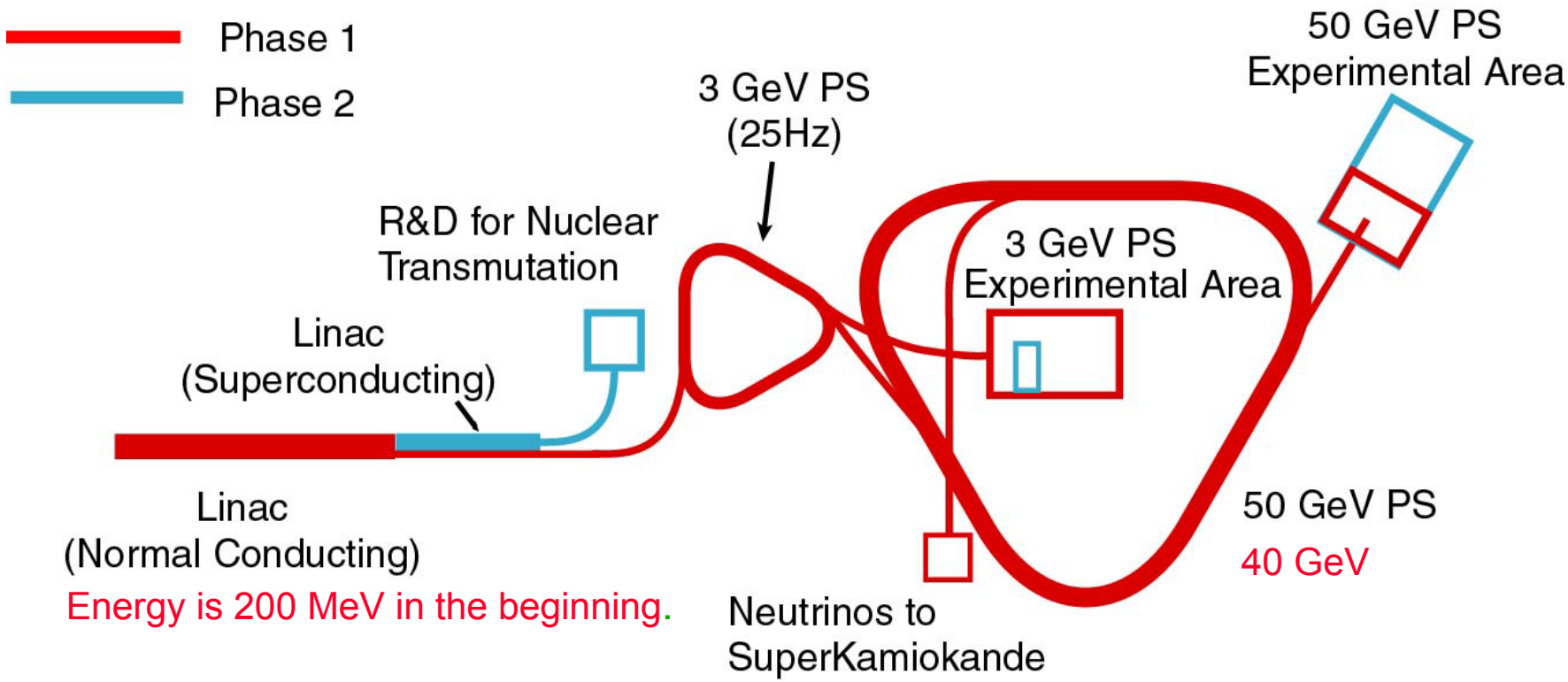
Physics at J-PARC



Proton accelerators in the world

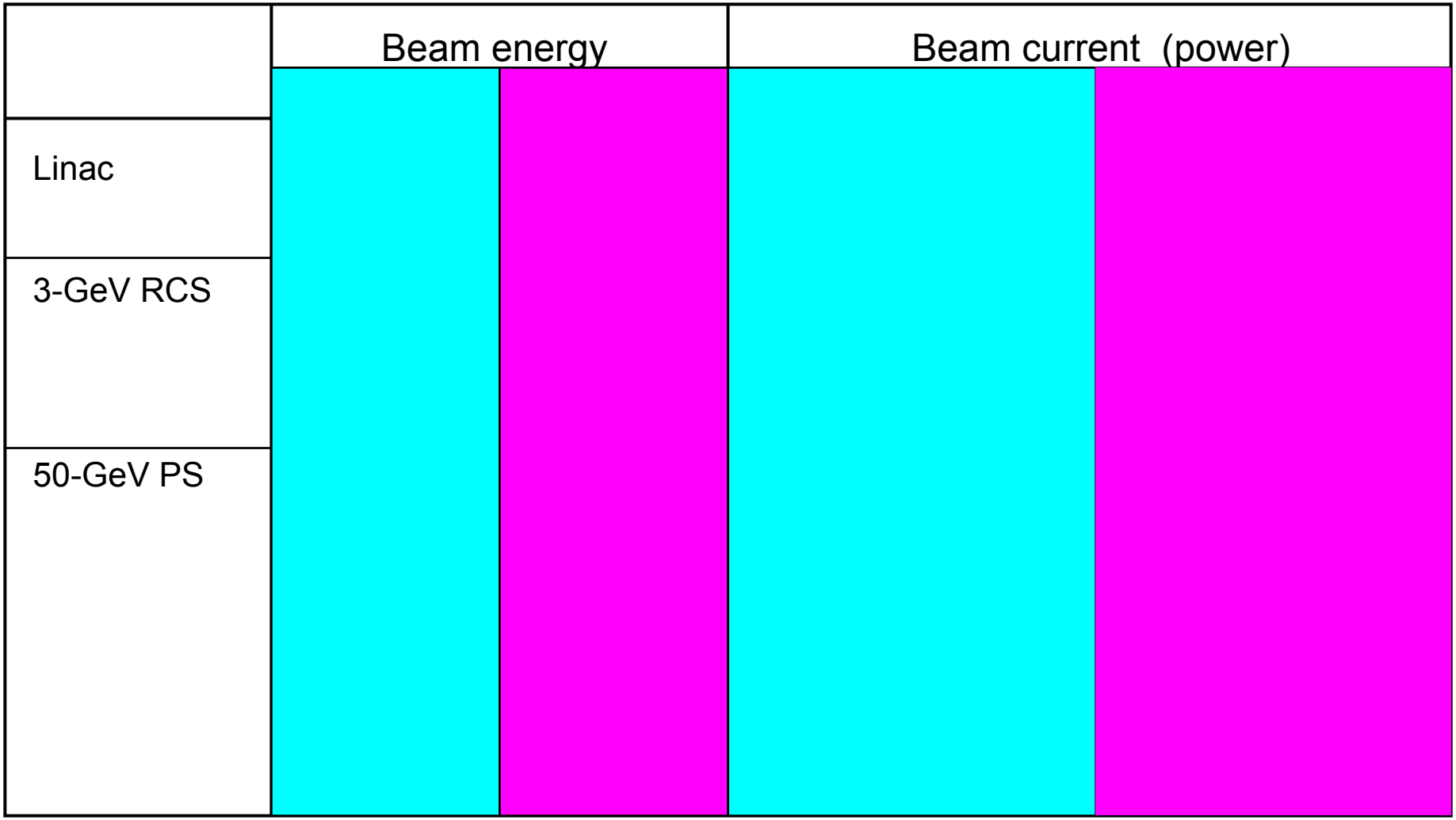


Phase 1 and Phase 2 (as of today)



- Phase 1 + Phase 2 = 189 billion Yen (= $1.89 billion if $1 = 100 Yen).
- Phase 1 = 151 billion Yen for 7 years.
- Construction budget does not include salaries.

Machine parameters (as of September 2004)

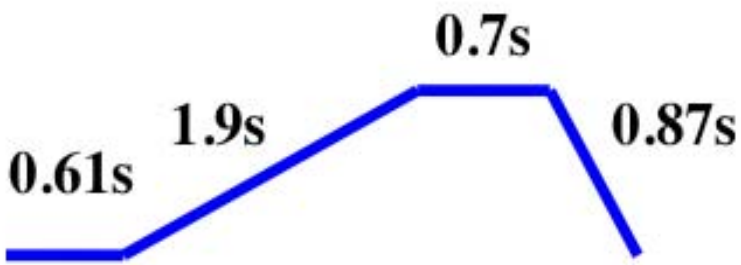


* The energy of slow extraction beam is 30 GeV. **Reds are after the linac energy upgrade. ***400 MeV to the 3-GeV RCS and 600 MeV to the ADS test facility. #*h*=9 has 8 bunches and *h*=18 has15 bunches.

50 GeV-PS acceleration pattern

181MeV Linac case
15batches/15bunches

30GeV slow extraction



total 4.08s

40GeV fast extraction

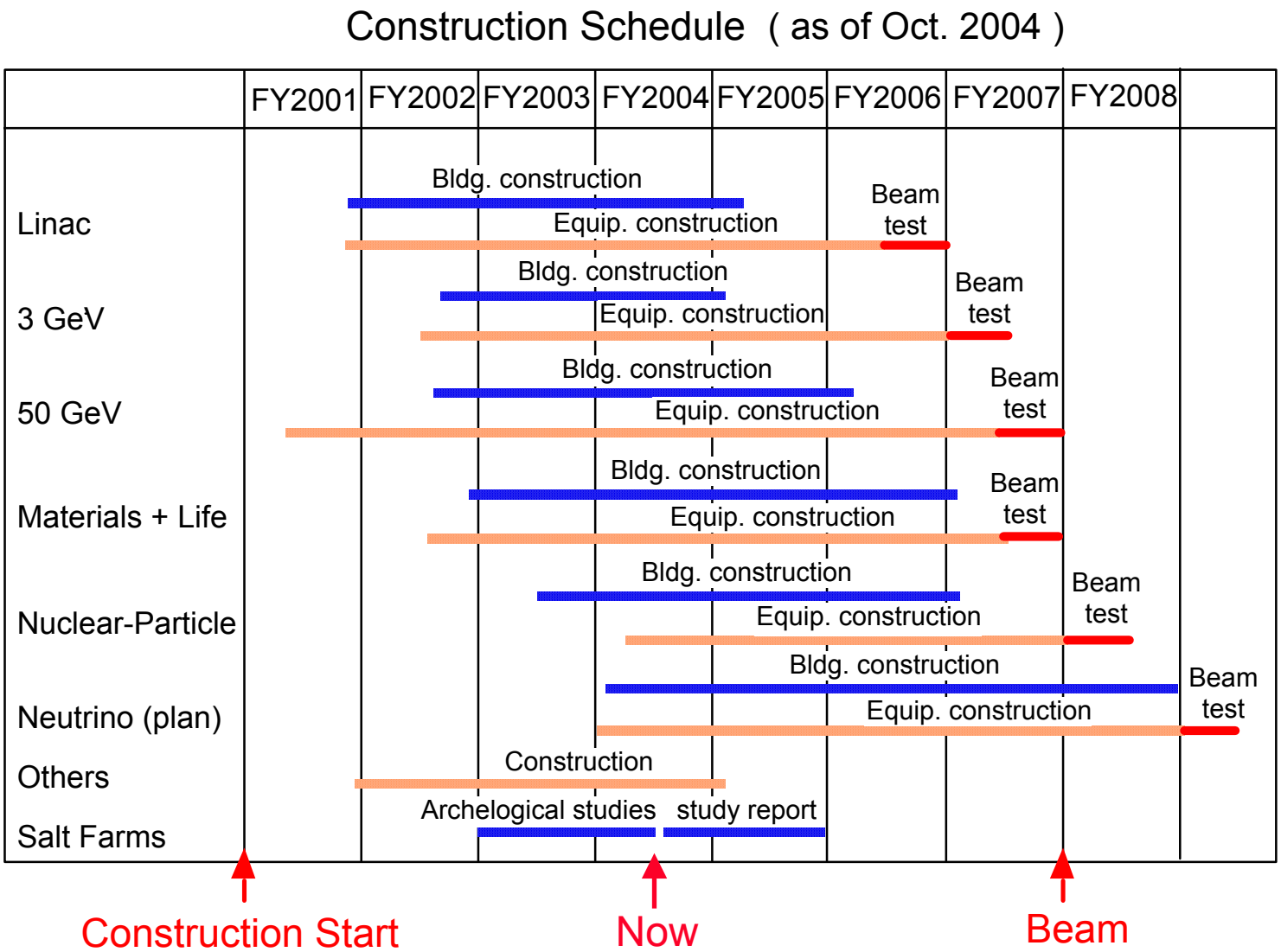
total 3.38s

beam current: f × 24μA
beam power: f × 0.73MW

beam current: f × 29μA
beam power: f × 1.17MW

- **f~0.6 if beam loss by long injection is small**
- **0.6 expected ratio of beam intensity per one bunch for 181MeV/400MeV cases**

Construction schedule




February, 2004

Physics program at 50 GeV PS

- Workshops
  - NP01: December 2001
  - NP02: October 2002
  - NP04: August 2004
    - Neutrino oscillation physics
    - Kaon decay physics
    - Strangeness nuclear physics
    - Hadron physics
    - Muon physics

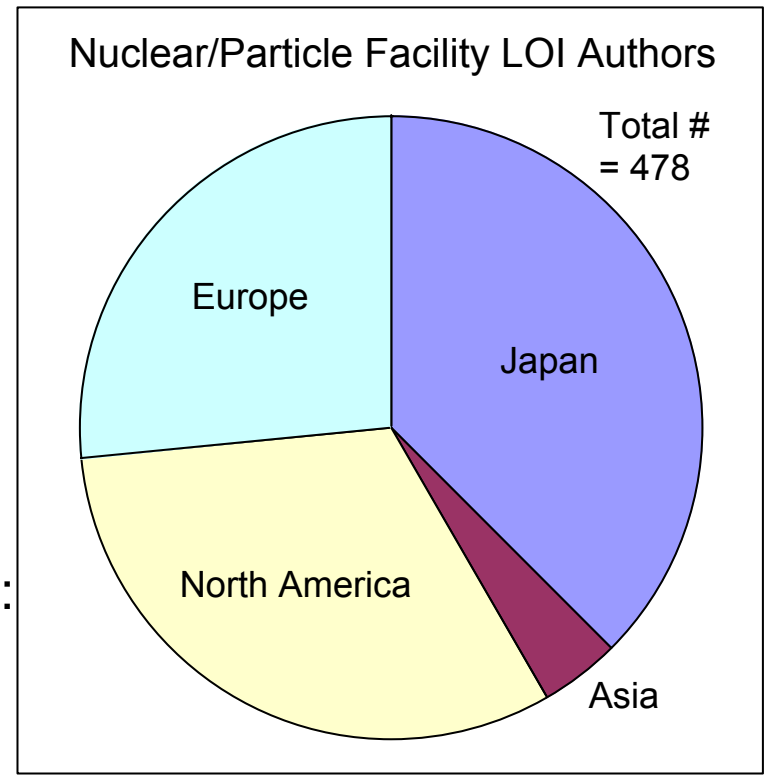
  http://www-ps.kek.jp/jhf-np/NP04/presentations/

- Letters of Intent

  http://www-ps.kek.jp/jhf-np/LOIlist/LOIlist.html

Letters of intent for 50 GeV

- Announce of LoI call : July 2002
- Thirty LoI's were submitted by early 2003
  - Strangeness nuclear physics 6
  - Nuclear/hadron physics 7
  - Kaon decay physics 4
  - Muon physics 3
  - Neutrino physics 1
  - Future facilities 9



- 478 physicists with 2/3 from outside Japan. Asian participation is still few.
- Committee meetings evaluated the LoI's:
  - March 22, 2003
  - June 26-28, 2003
- The real proposals:
  - Most likely, the call for the proposal will be made within this year.

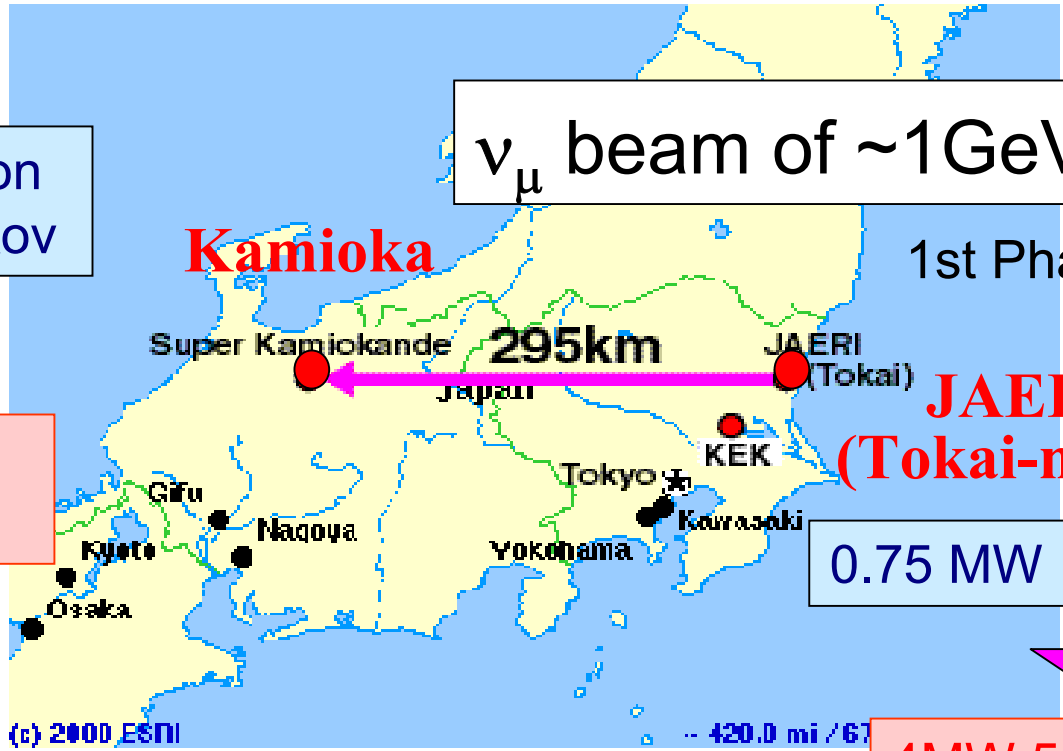
Particle physics program

- Long baseline neutrino oscillation
- Kaon decays
- Muon decays

T2K (Tokai-to-Kamioka) neutrino experiment

Super-K: 50 kton
Water Cherenkov

~Mt "Hyper Kamiokande"?



ν_μ beam of ~1GeV

1st Phase (x10^2 of K2K)

JAERI (Tokai-mura)

0.75 MW 50 GeV PS

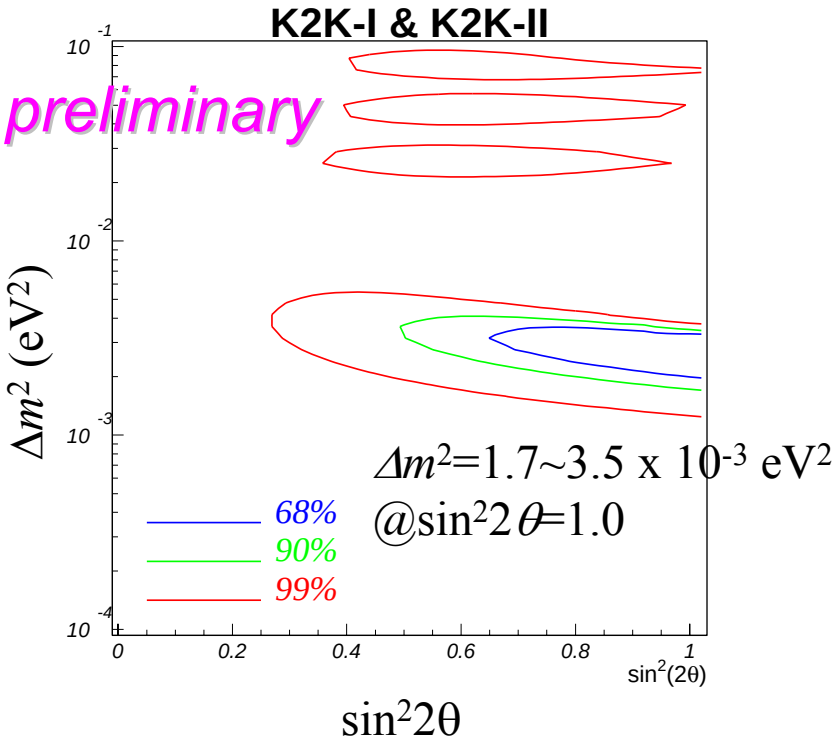
4MW 50GeV PS?

Physics motivations

- Discovery of $\nu_\mu \rightarrow \nu_e$ appearance
- Precise measurement of disappearance $\nu_\mu \rightarrow \nu_x$
- Discovery of CP violation (in the future)

□□□□□□□□□□□in ν_μ disappearance

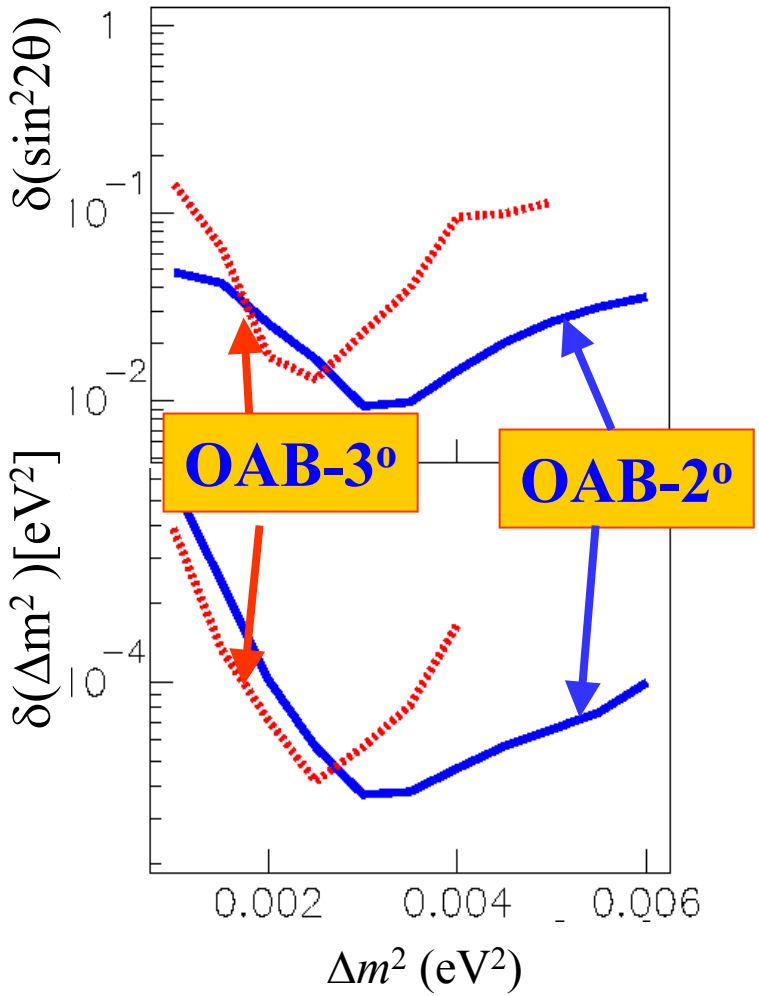
- Allowed region from K2K



- Sensitivity at J-PARC

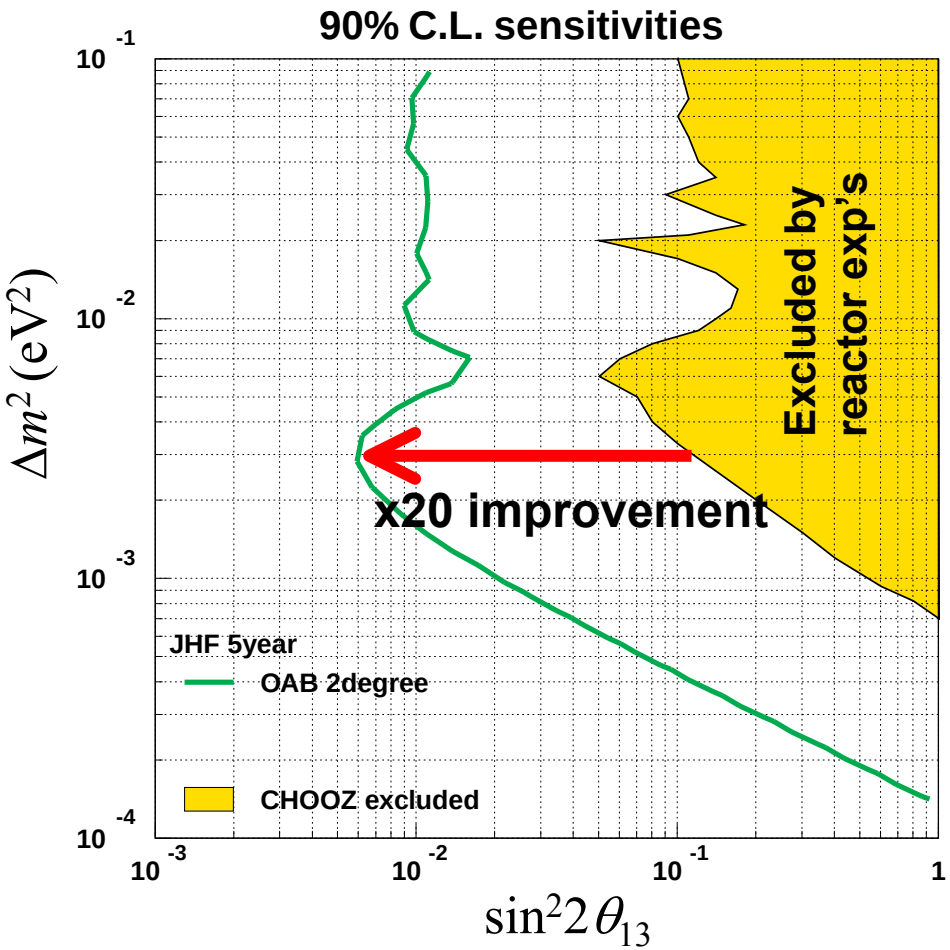
$\delta(\sin^2 2\theta) \sim 0.01$;
$\delta(\Delta m^2) \lesssim 1 \times 10^{-4}$ eV^2 ; in 5 years
(130 days/year)

T2K□□□□□□□



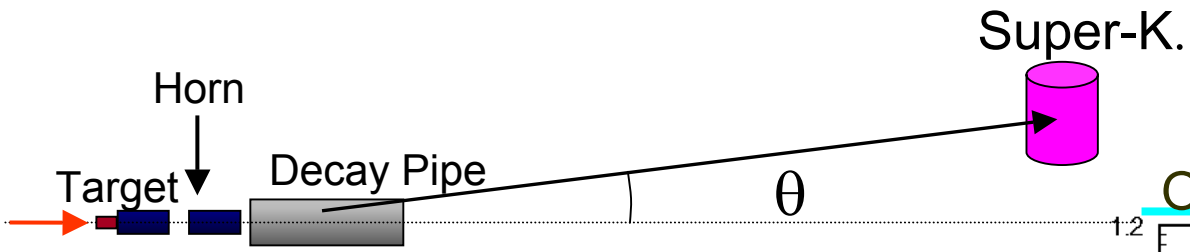
Sensitivity of $\nu_\mu \rightarrow \nu_e$ appearance

- 5 year run
  with off-axis angle 2°
- Discovery of $\nu_\mu \rightarrow \nu_e$
  with a sensitivity
  at $\Delta m^2 \sim 3\text{x}10^{-3}$ eV^2
  down to
  $\sin^2 2\theta_{13} \sim 0.006$
  (90% C.L.)
- Twenty times
  improvement over
  the past experiments



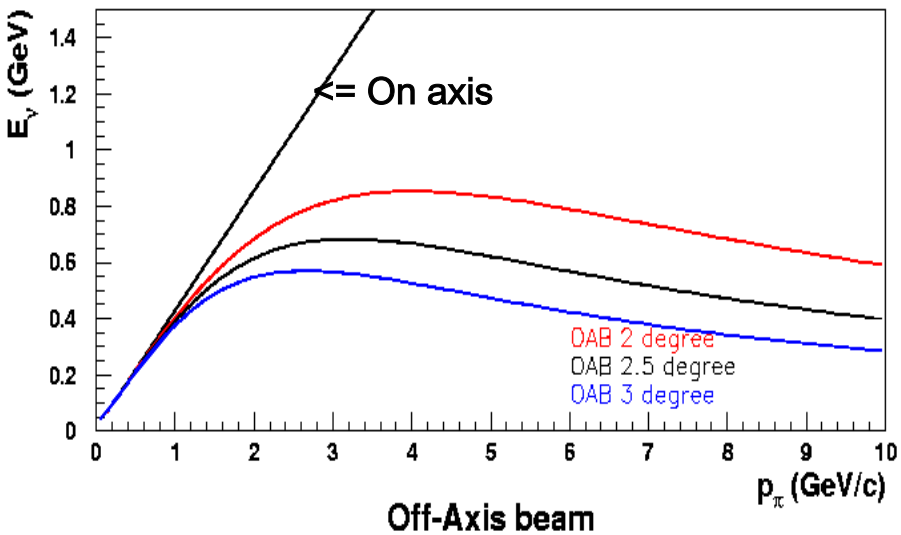
with δ=0, no matter, $\theta_{23} = \pi/4$

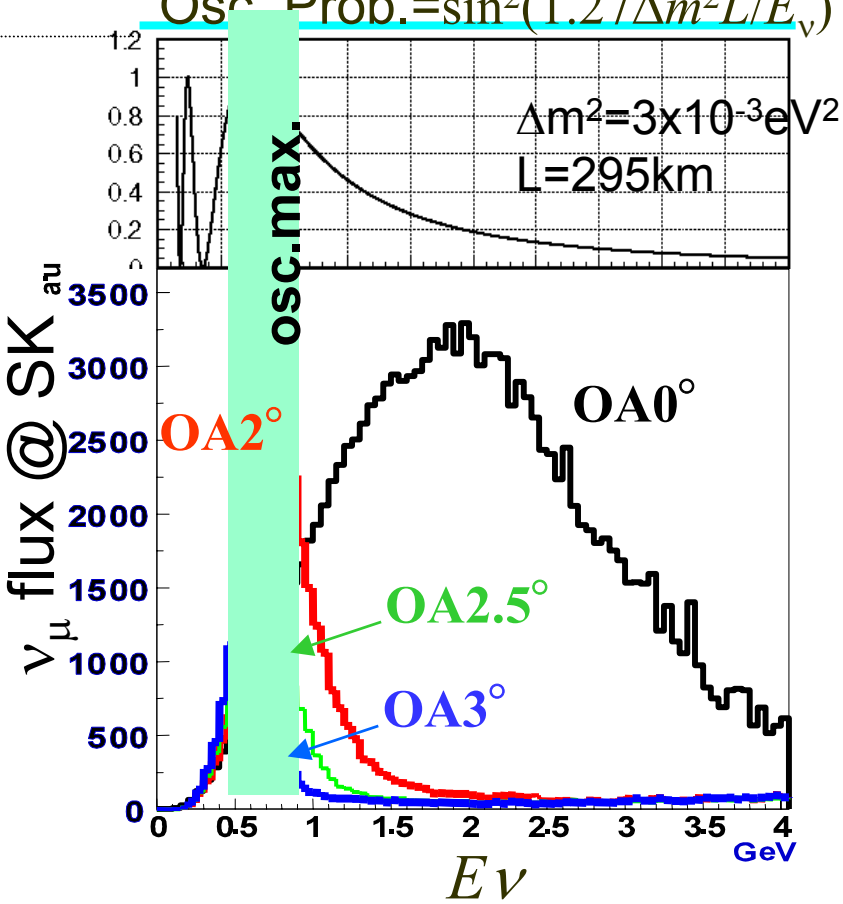
Off-axis beam



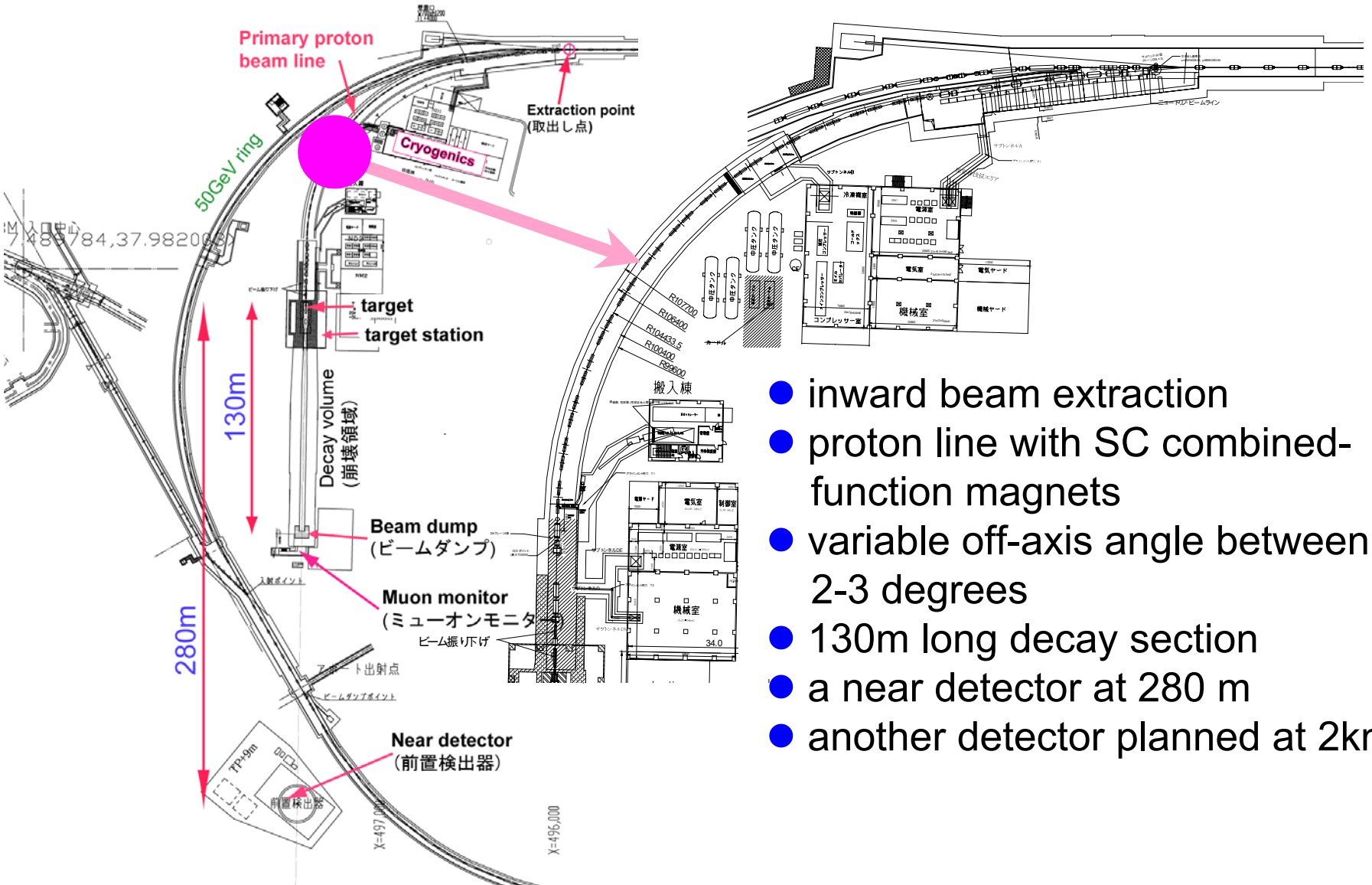
- WBB with an intentionally misaligned beam line from the detector axis

==> Quasi monocromatic beam with higher Intensity than NBB





Neutrino facility

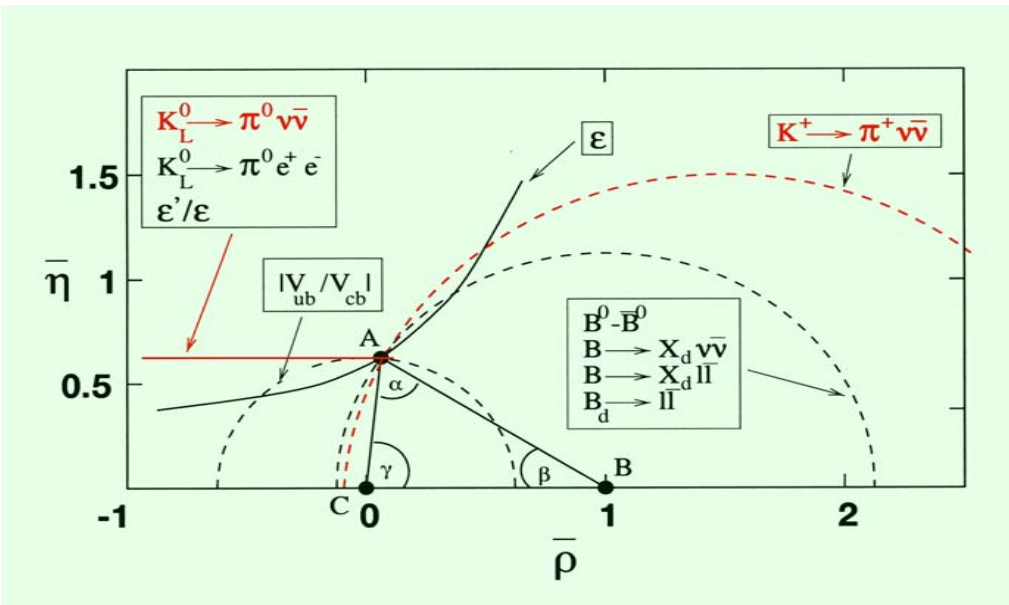


- inward beam extraction
- proton line with SC combined-function magnets
- variable off-axis angle between 2-3 degrees
- 130m long decay section
- a near detector at 280 m
- another detector planned at 2km

CP violation in $K_L \to \pi^0 \nu\bar{\nu}$

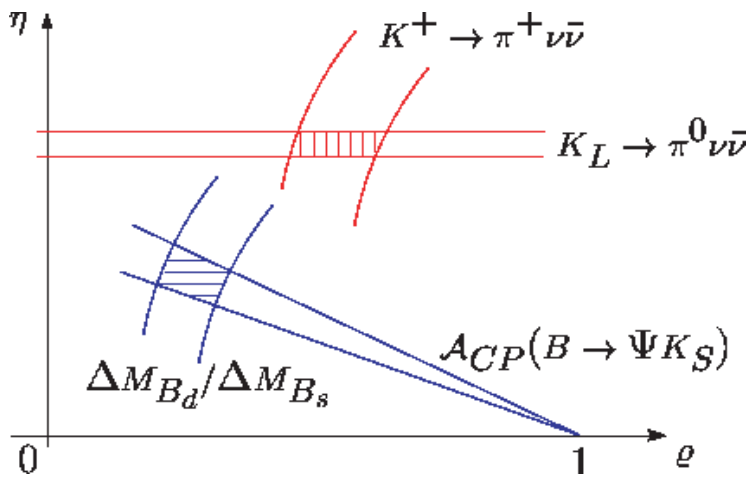
Most important rare decay channel in the J-PARC era

- Direct CP violation in FCNC process
- Clean measurement of Im(V_{td}) ~ η
- Clear test of the Standard Model
- Clue for new physics in comparison with *B* physics

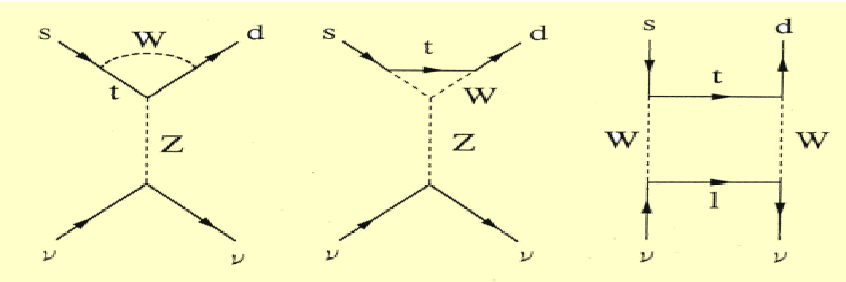


Unitarity relation

$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$



KEK E391a extension at J-PARC



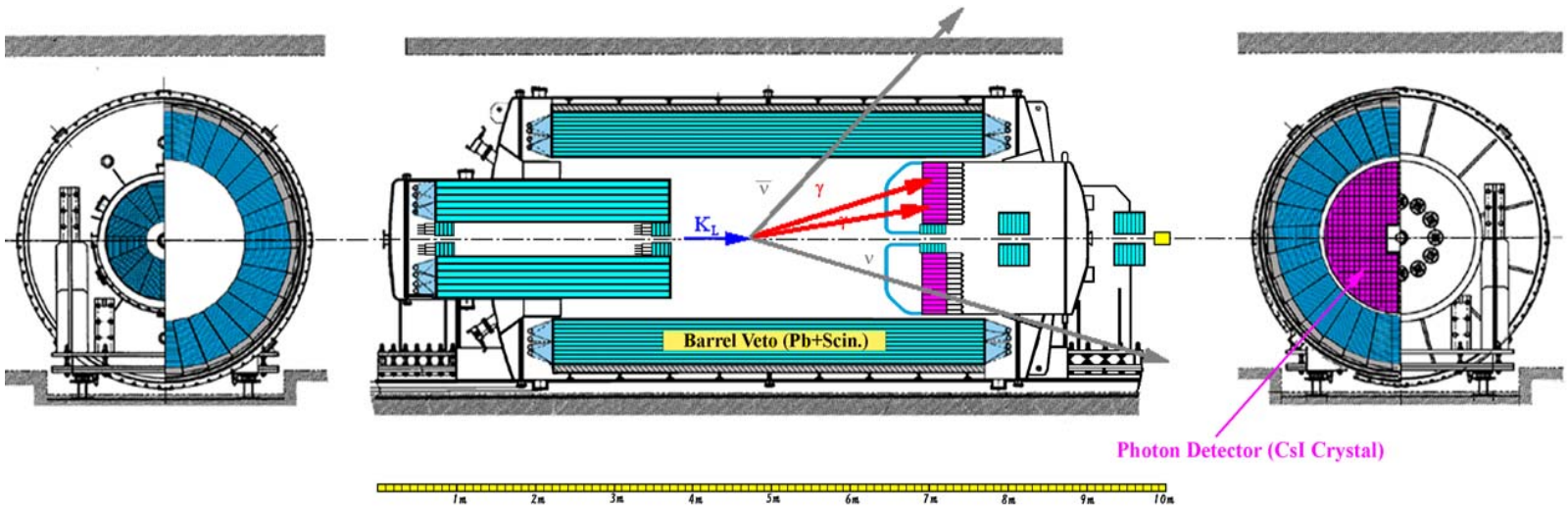
- Standard Model prediction

$$BR(K_L \to \pi^0 \nu \bar{\nu}) = 6\kappa_1 \cdot \mathrm{Im}(V_{td}V_{ts})^2 X^2(x_t) = 1.94 \cdot 10^{-10} \eta^2 A^4 X^2$$

~3 x 10^{-11}

Determination of η
□□□□ 10% precision

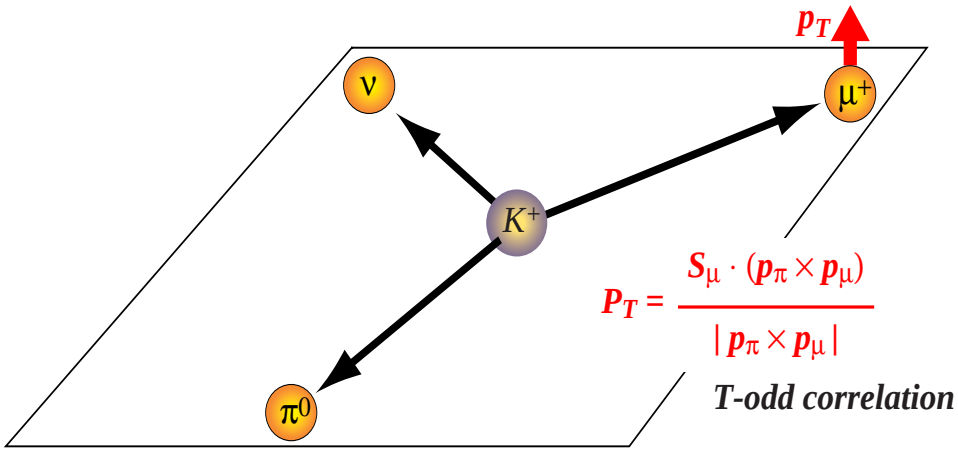
- Experiments
  - E391a :10^{-9} -10^{-10}
  - KOPIO :10^{-12} (50 events)
  - J-PARC : < 10^{-13} (1000 events)



1999

T violation in $K^+ \to \pi^0 \mu^+ \nu$ decay

- Muon transverse polarization P_T



$P_T^{spurious}$ *(Final State Interaction)* $\sim 10^{-6}$ *(Zhitnitskii, 1980)*

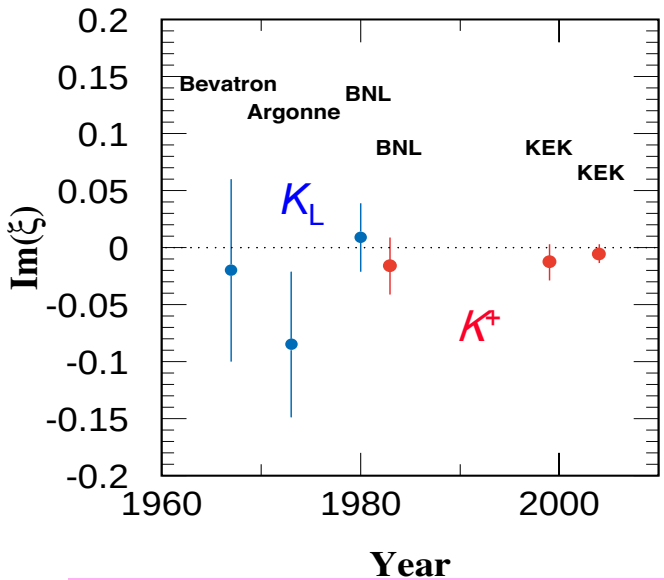
- Search for new physics beyond the SM
  - Multi-Higgs doublet model
  - Leptoquark model
  - *R*-parity violating SUSY *etc.*
- P_T in $K^+ \to \mu^+ \nu \gamma$ also measured.

KEK-E246

$P_T = -0.0017 \pm 0.0023(stat) \pm 0.0011(syst)$

$(|P_T| < 0.0050 : 90\%\ C.L.)$

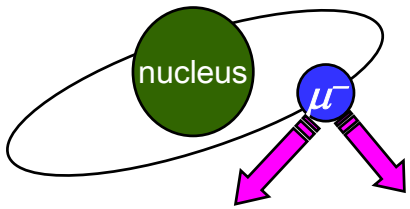
PRL 93 (2004) 131601



- $\delta P_T \sim 10^{-4}$ at J-PARC

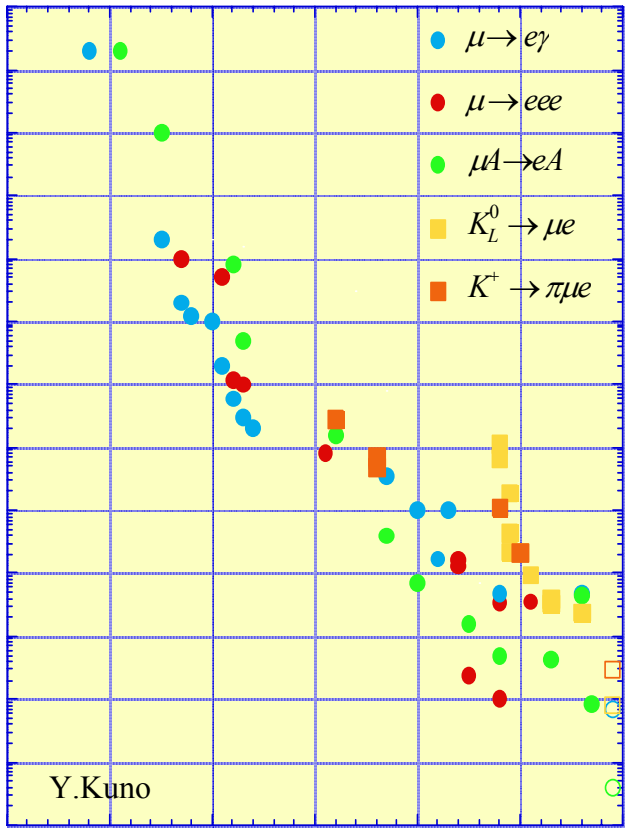
Muon physics

- Lepton flavor violation
  - μ→e conversion



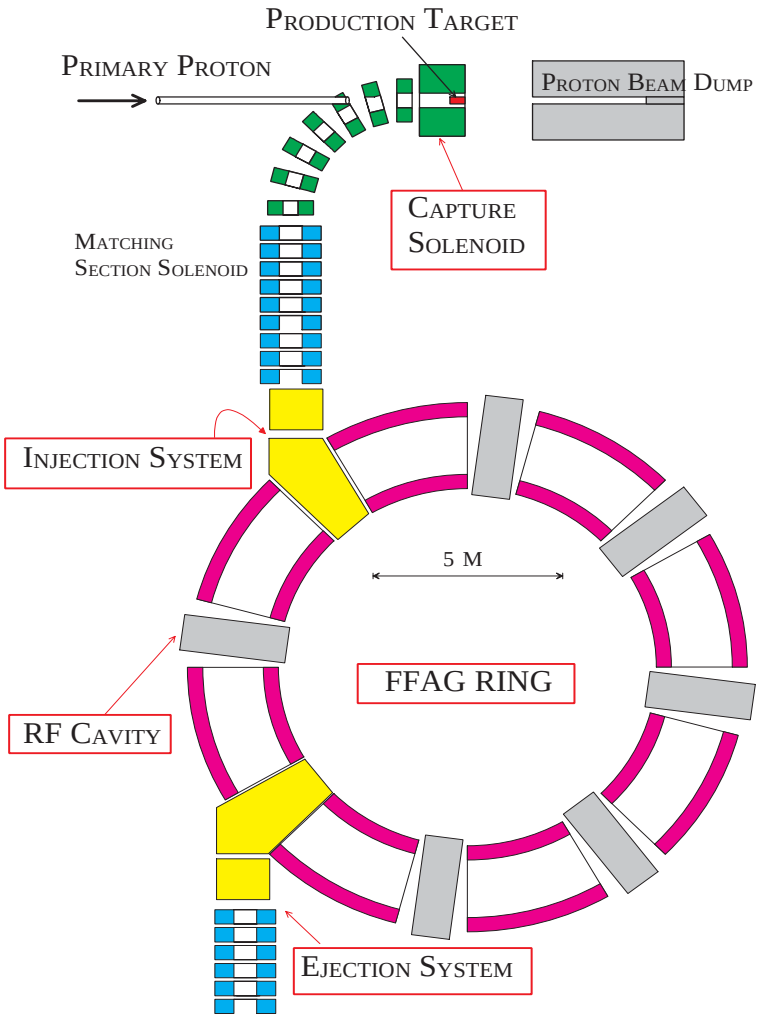
$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1) \qquad \mu^- \rightarrow e^- \nu\bar{\nu}$$

    10^{-18} at J-PARC
    sensitive to SUSY-GUT *etc.*
  - μ→eγ
  - μ→3e
  - Mu-$\bar{\text{M}}$u conversion
- Precise measurements
  - *g*-2, EDM
  - Michel parameters
- High intensity muon source
  - PRISM collaboration

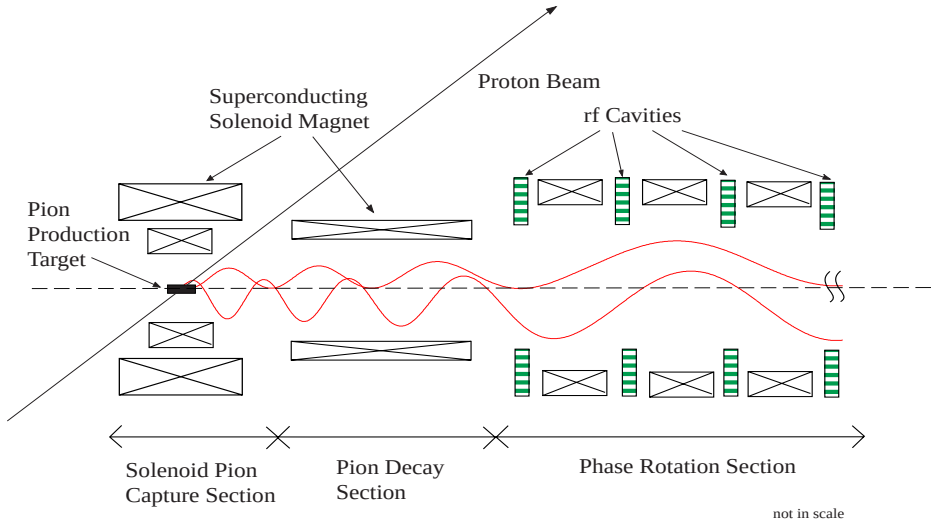


High intensity muon source

PRISM with FFAG



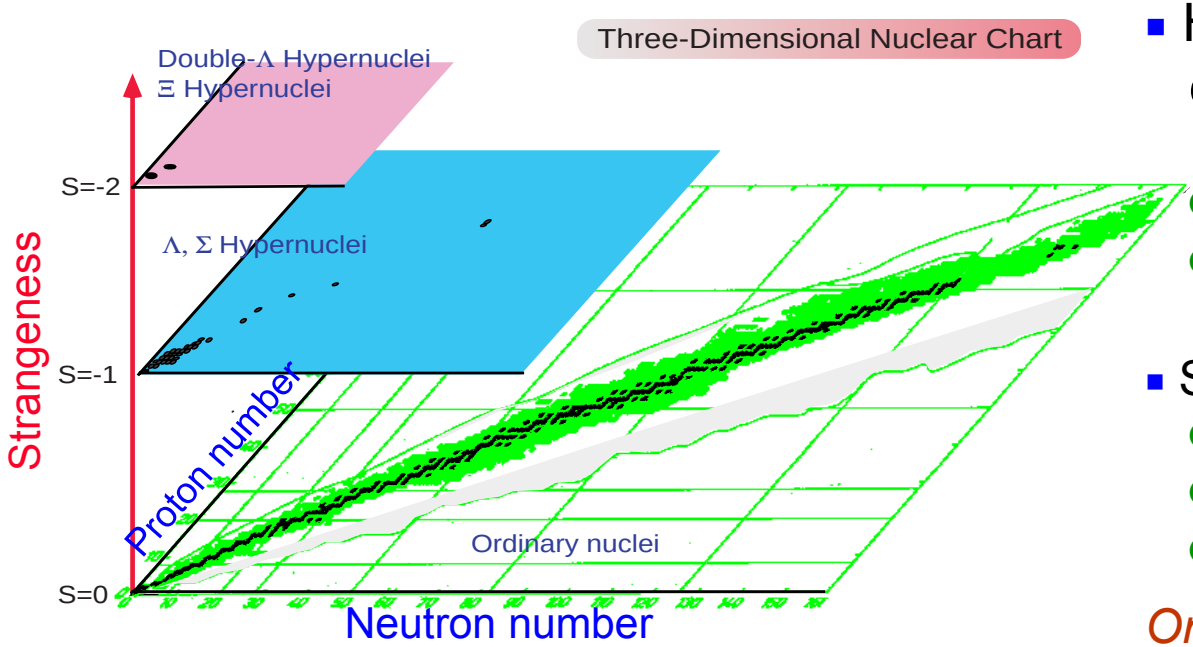
- Phase Rotated Intense Slow Muon
  - Pulsed proton beam
  - Pion capture by solenoid field
  - Pion decay section
  - Phase rotation section



Nuclear physics program

- Hyper-nuclear spectroscopy
- Hadrons in nuclear matter
- Hadron spectroscopy

Hyper-nuclear spectroscopy



- Hyperon imbedded in deep nuclear matter
  - *no Pauli blocking*
  - hyperon potential, property
  - YN interaction
- Spectroscopy with
  - reactions such as (π,*K*)
  - γ-transition
  - decays

Only poor data until now

- Qualitative data improvements expected at J-PARC :
  - high resolution spectroscopy of Λ nuclei -> core excitation, decay width, *etc.*
  - γ–ray spectroscopy in Λ nuclei -> YN interaction, B(E2), B(M1), *etc.*
  - spectroscopy of S=-2 system with (K^-, K^+) reaction -> Ξ-nucleus *etc.*
  - deeply-bound kaonic nuclear states -> cold &dense nuclear matter

S=-2 nuclear systems

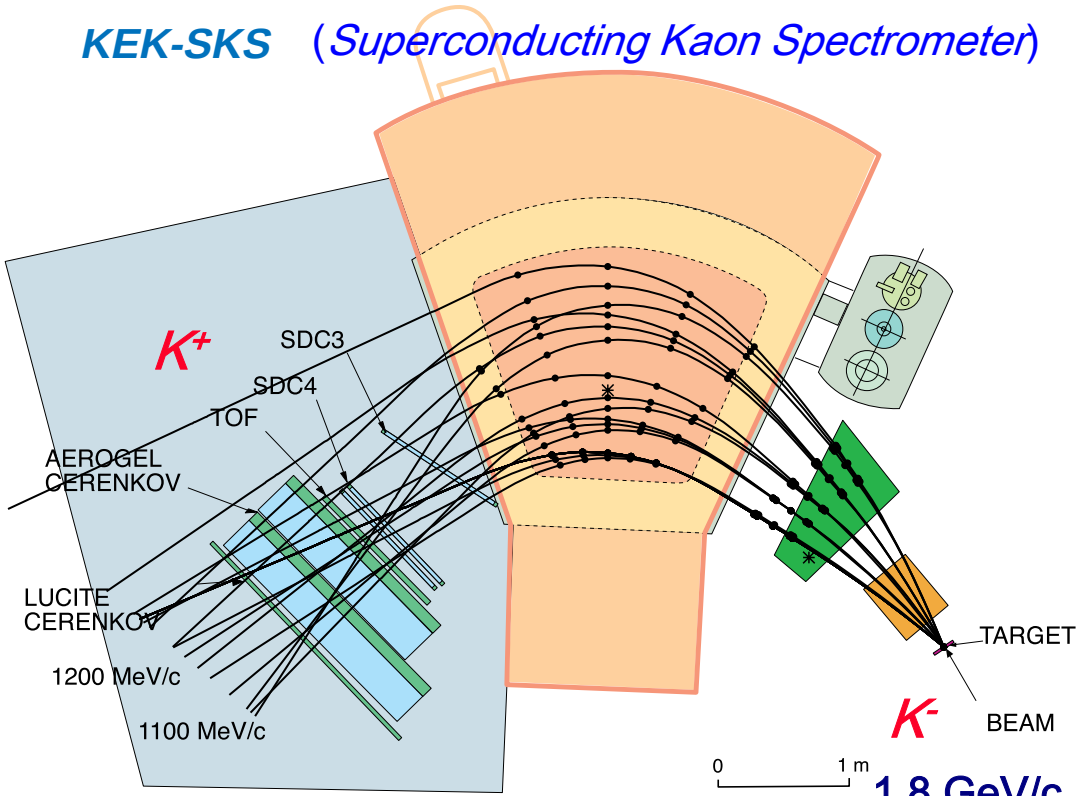
- Ξ hypernuclei and $\Lambda\Lambda$ double hypernuclei
  - $\Lambda\Lambda$ double hypernuclear spectroscopy :
    - only several events reported until now.
  - Ξ hypernuclear spectroscopy :
    - discovery of a Ξ hypernucleus expected.
  - mixed states of Ξ, $\Lambda\Lambda$ and *H* states ?

    K. Ikeda et al., Prog. Theor. Phys. 91 (1994) 747

- (K^-, K^+) reaction at 1.8 GeV/c needs high beam intensity
  - Small cross section
  - e.g. ^{208}Pb(K^-,K^+) with 2g/cm^2 thick target
    ~6 events/MeV/day
- Ξp (S=-2) scattering
  - YN interaction for S=-2
  - For S=-1 (Λ+*p*, Σ^++*p*, Σ^-+*p*) : data are also very poor.

Ξ spectroscopy with (K^-,K^+)

KEK-SKS (*Superconducting Kaon Spectrometer*)

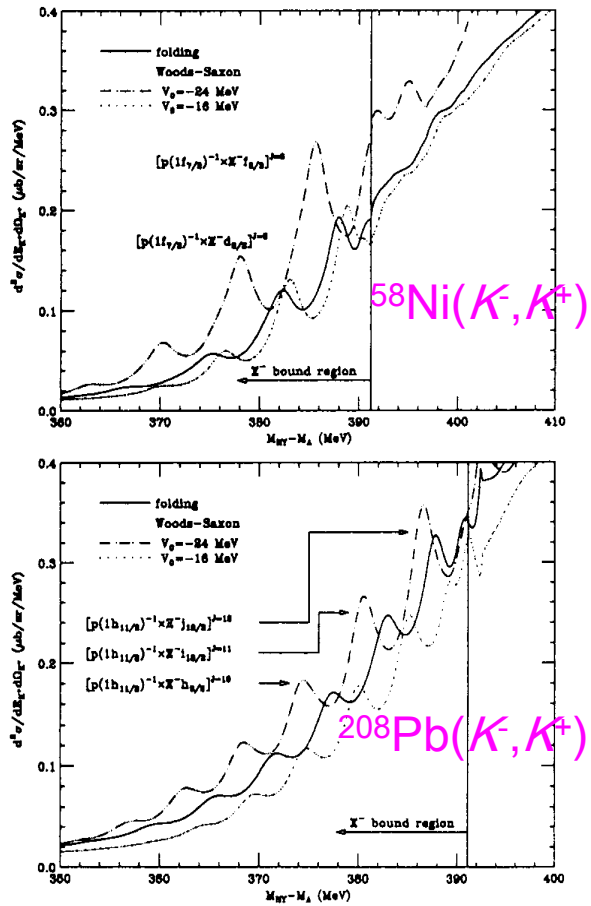


1.8 GeV/c

ΔE~ 2 MeV (FWHM)

BL= 6 Tm

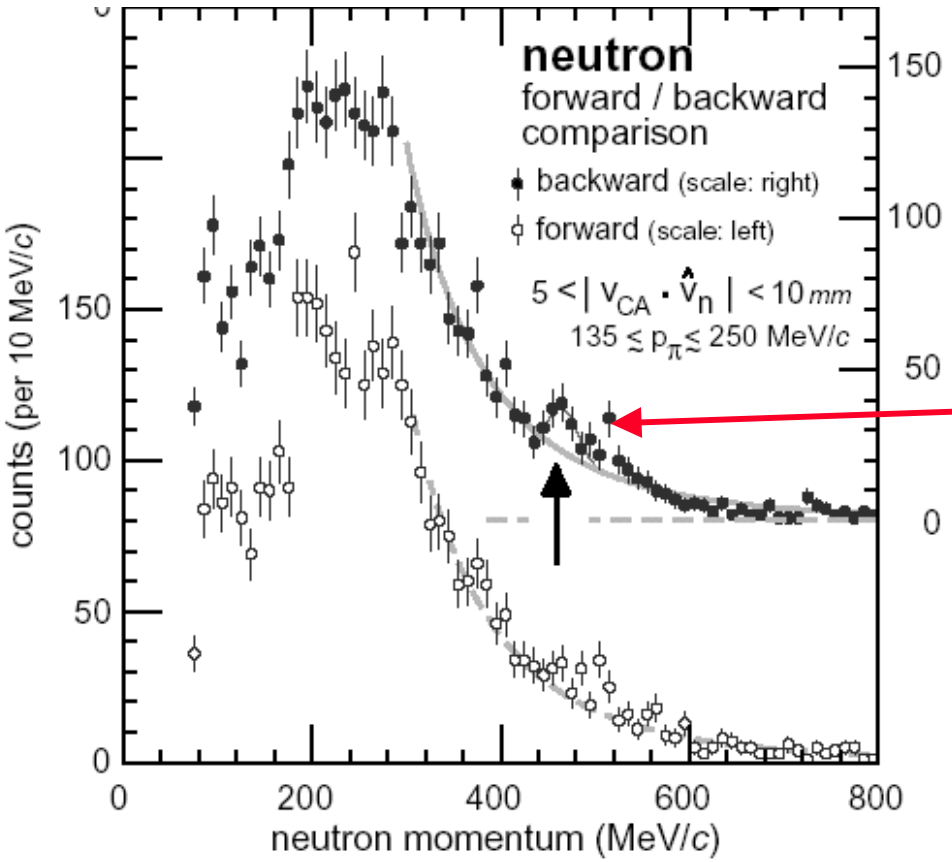
expectation



$M_{HY} - M_A$

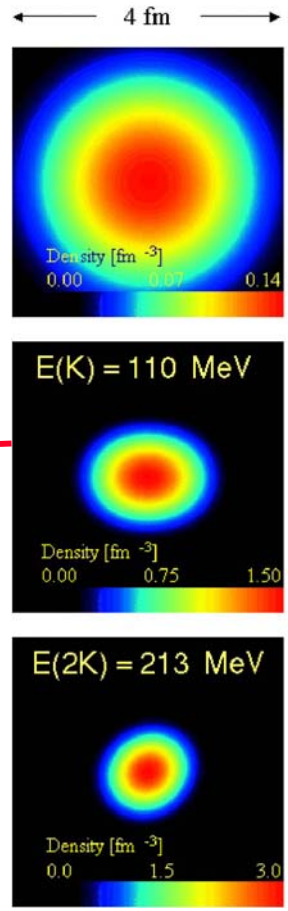
Strange meson implantation

$K^- + {}^4He \rightarrow$ "K^-ppn" + n @ KEK-PS



Experiment by M. Iwasaki, et al.

Theory by Y. Akaishi, et al.



normal ^3He

ppn
total B.E. = 6.0 MeV
central density = 0.14 fm^3
R_{rms} = 1.59 fm

$\rho_{center} = \sim \rho_0$

ppnK$^-$
total B.E. = 118 MeV
central density = 1.50 fm^3
R_{rms} = 0.72 fm

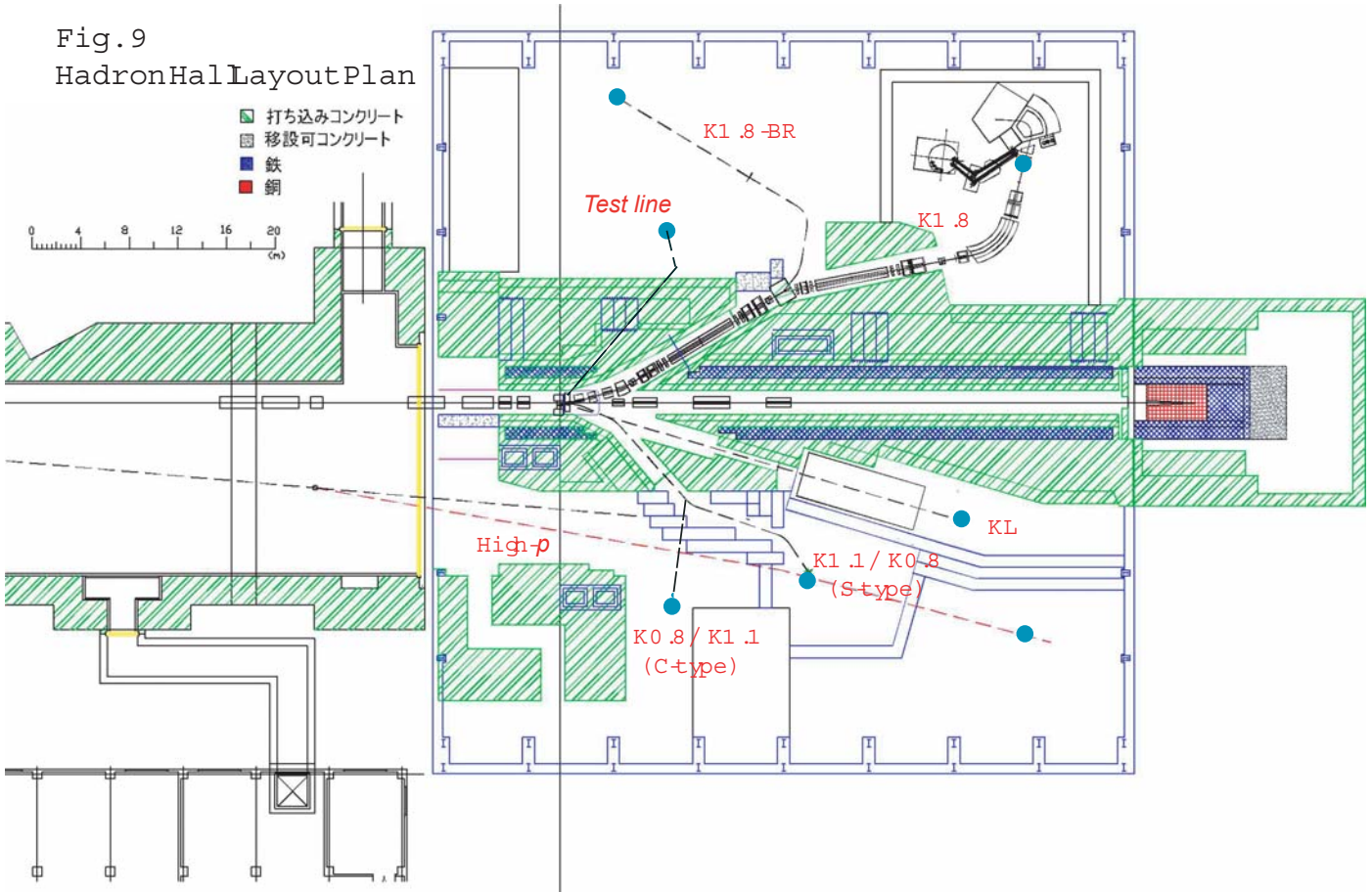
$\rho_{center} = \sim 10\ \rho_0$

ppnK$^-$K$^-$
total B.E. = 221 MeV
central density = 3.01 fm^3
R_{rms} = 0.69 fm

$\rho_{center} = \sim 20\ \rho_0$

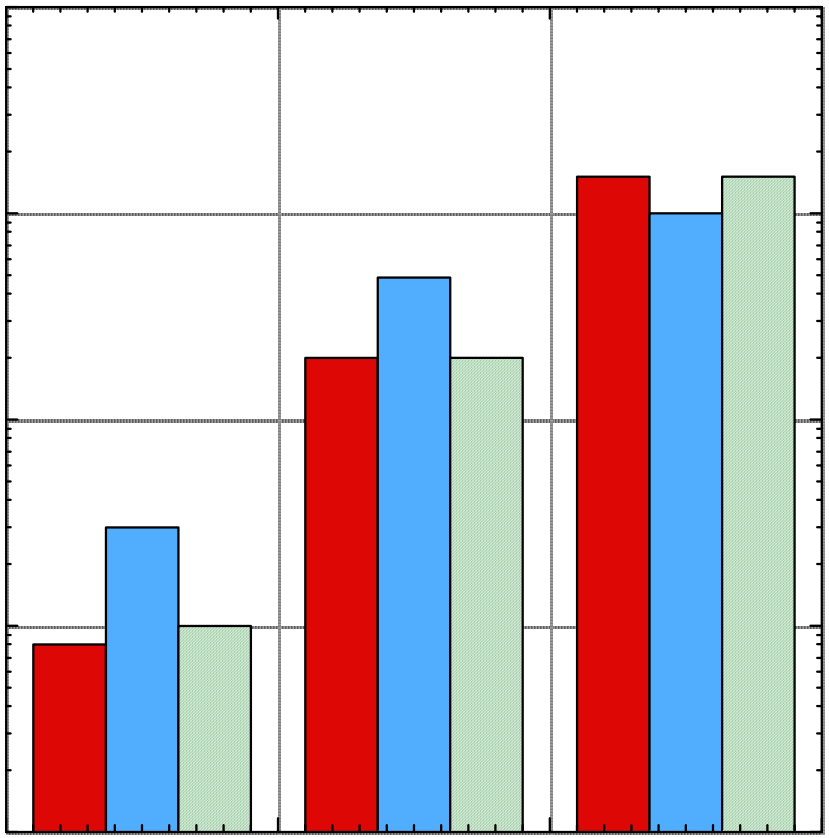
production of dense matter

Possible secondary lines in Phase 1



- Plan made by the beamline working group
- Presented to 3rd NPFC in Feb.2004

Expected secondary beam intensity



- K^-(1.8 GeV/c)

  (K^-,K^+), S=-2

- K^+(0.8 GeV/c)

  K^+ rare decay

- K^-(1.1 GeV/c)

  (K^-,π^-), S=-1

Program of other sciences

- Material and life science facility
  1. Spallation neutron source
  2. Muon source

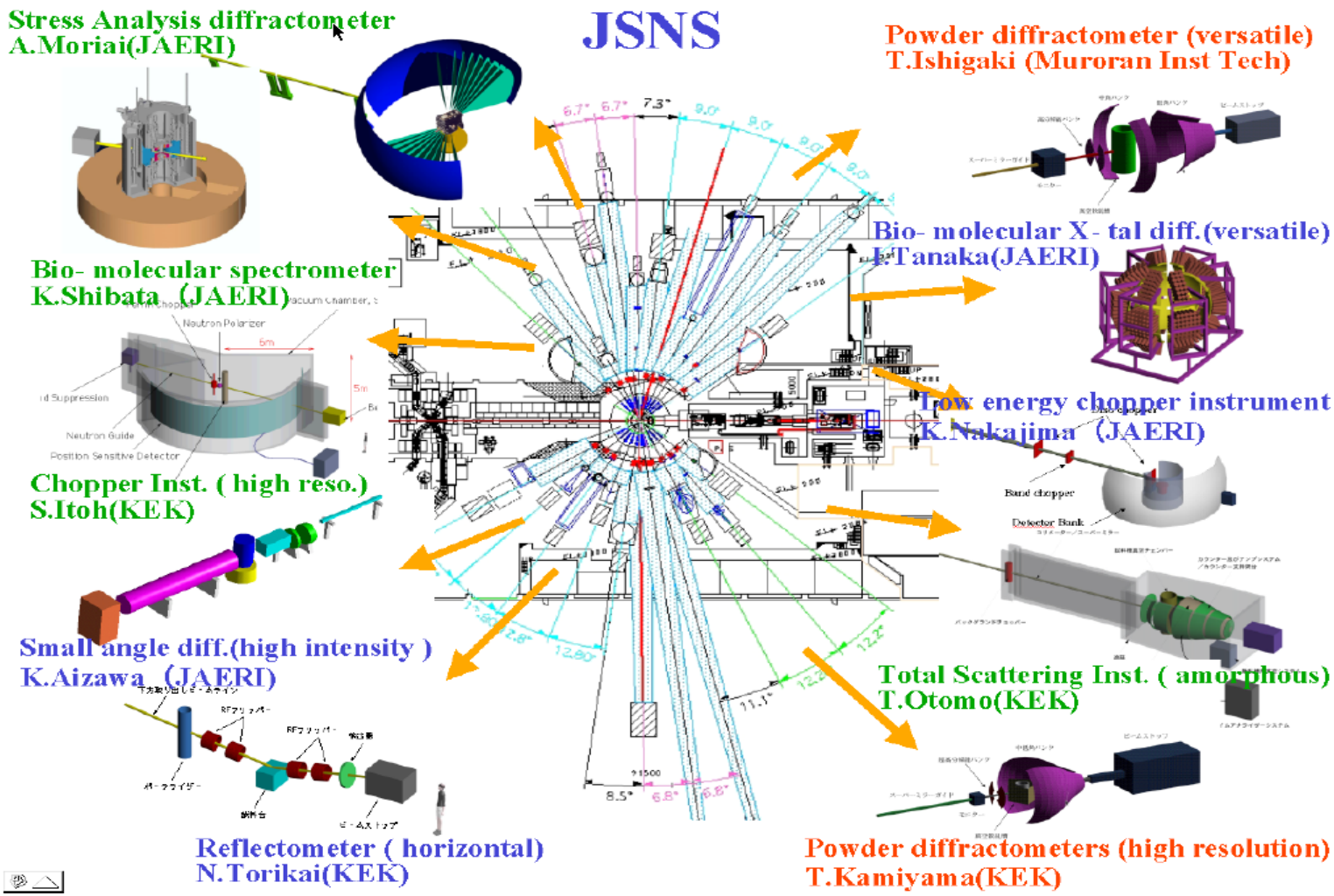
- Test facility for
  accelerator driven nuclear transmutation
  (Phase 2)

Neutron science program

- Solid state physics:
  e.g. Observation of quantum effects
- Materials structure sciences:
  Understanding precise atomic structure of materials
- Life science :
  Structure and dynamics of bio-molecule
- Surface and interface :
  Structure and dynamics
- Radiography:
  Industrial application and versatile researches
- Other industrial applications

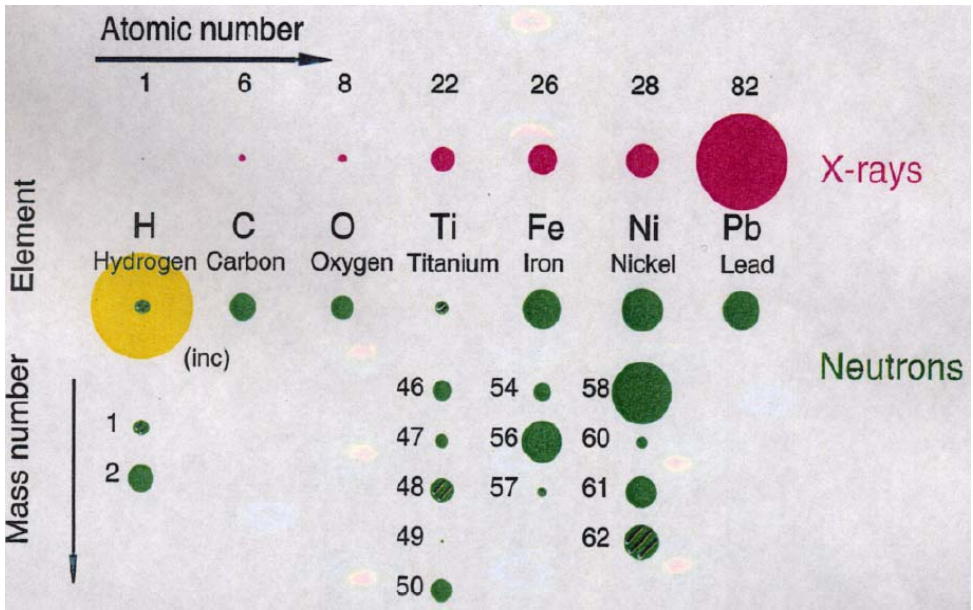
Material and life science facility

- More than 20 beamlines with diffractometers *etc.*



Light elements

Z dependence of sensitivity compared with X ray



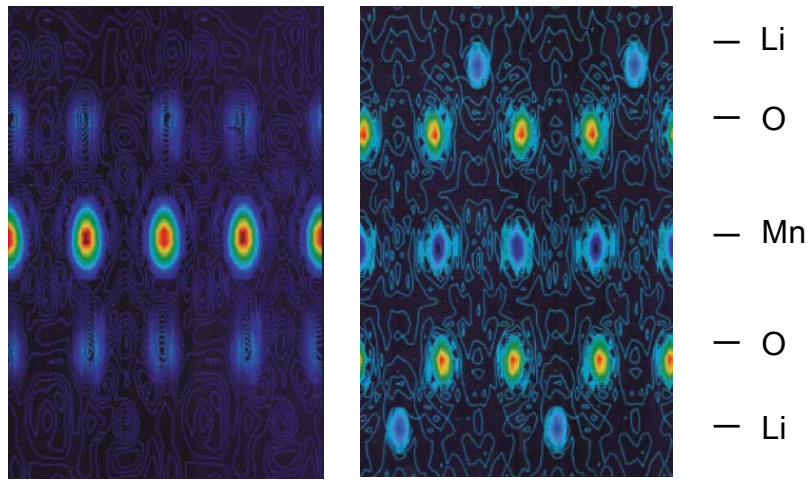
X-rays interact with electrons.

→ X-rays see high-Z atoms.

Neutrons interact with nuclei.

→ Neutrons see low-Z atoms, too.

An example: Behavior of Li in Li battery



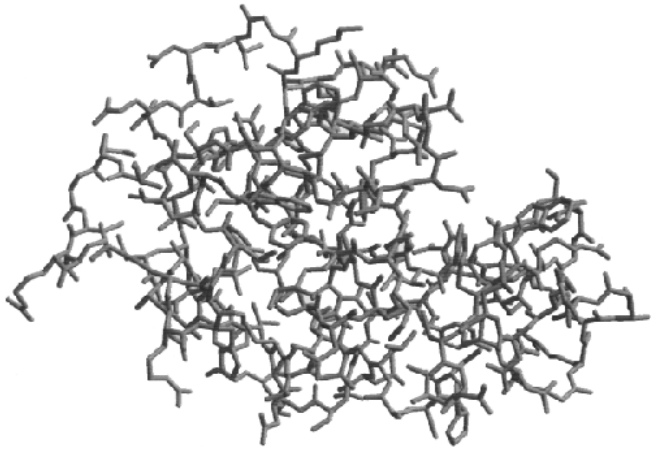
Material for Li-battery seen by

X rays (left) and

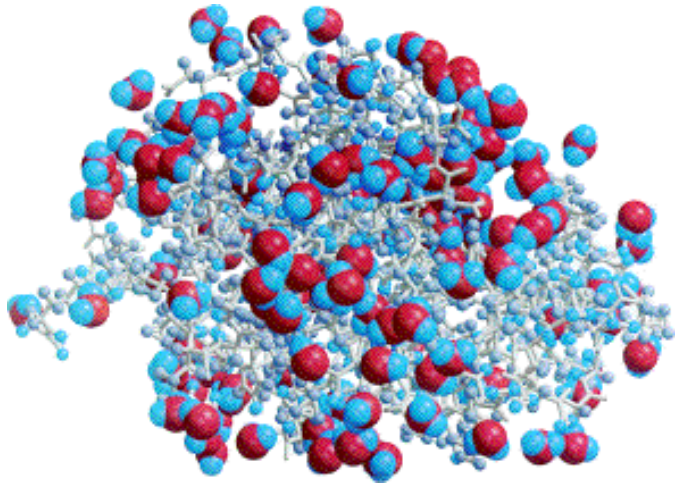
Neutrons (right)

Neutron diffraction from protein

Hen Egg-White Lysozyme



X-rays



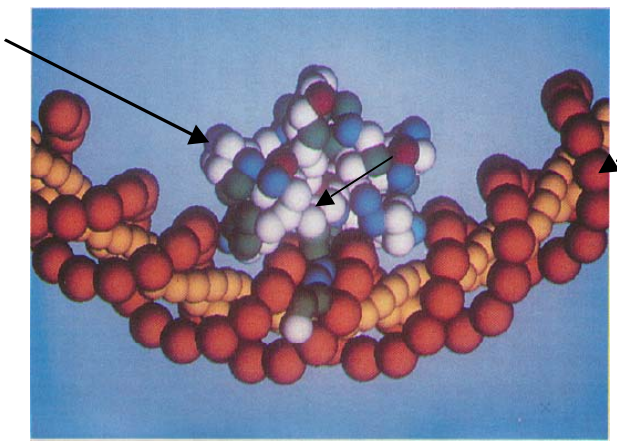
Neutrons

Water molecules observed with neutrons

- Hydrogen (H)
- Oxygen (O)

From structure to function

Protein



DNA

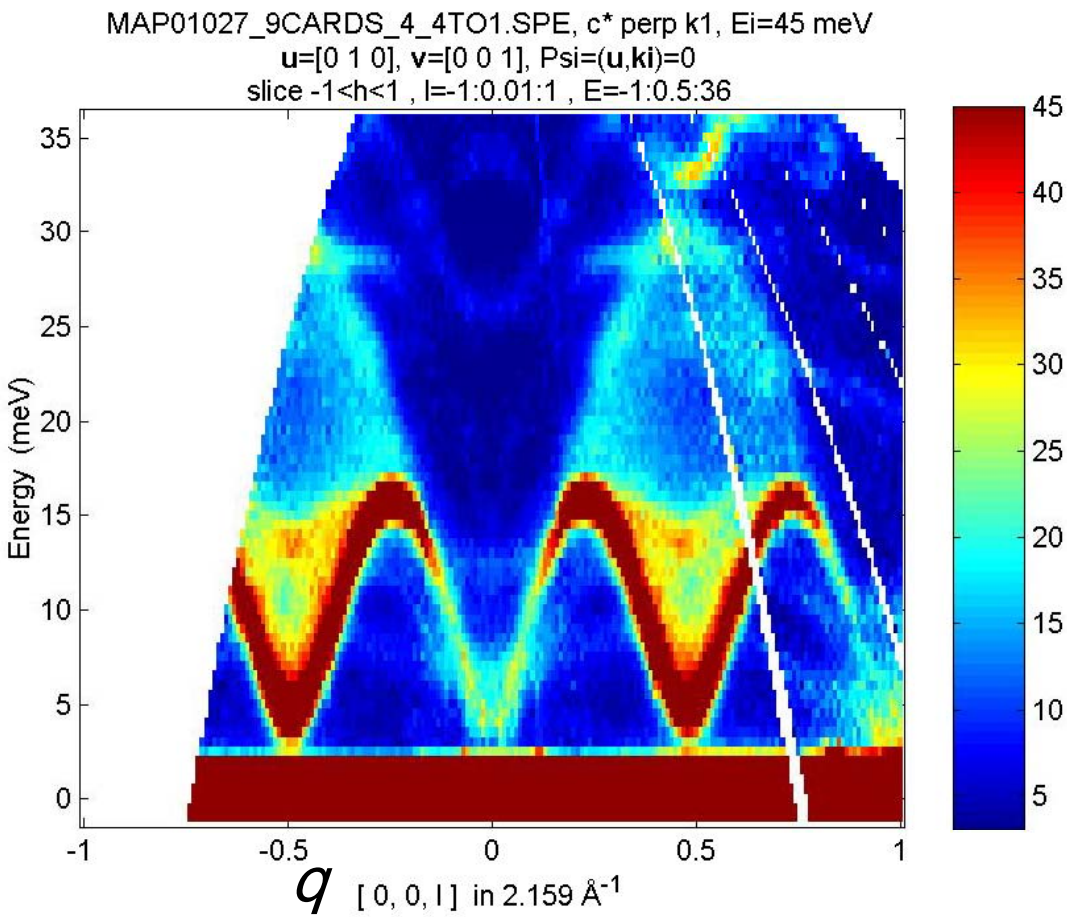
A protein molecule moving along the DNA chain

Quantum effect in spin excitation

$CuGeO_3$

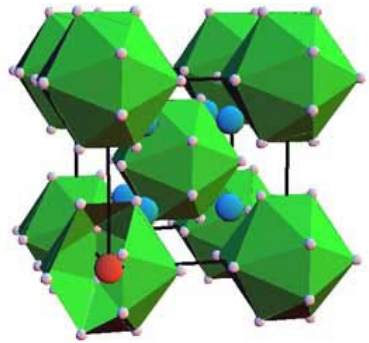
- Spin dynamics of low-dimension system
- Magnetic scattering
- Similar study of
  - lattice dymanics
  - electron dynamics
  - orbital dynamics

⇨ understanding of High T_c SC *etc.*



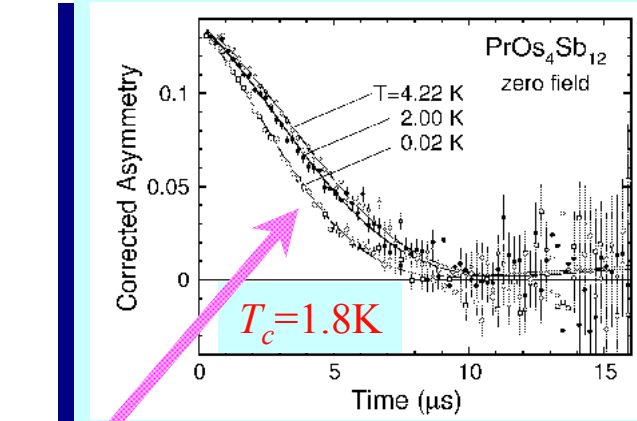
Magnetic Superconductivity

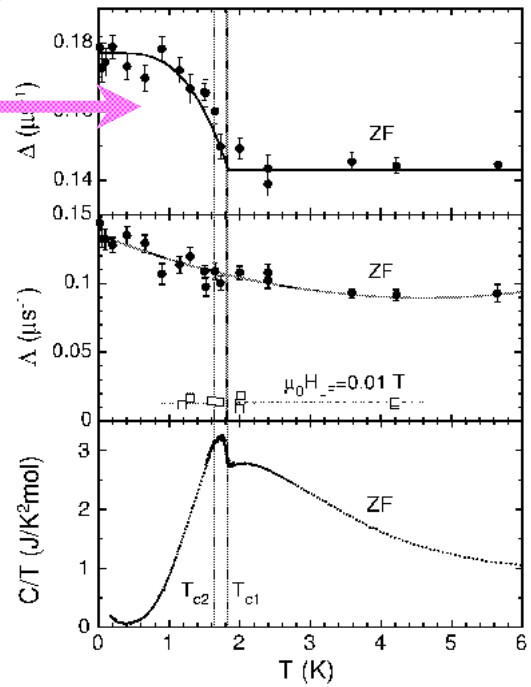
- Typical example of μSR



A new superconductor with the skutterudite structure, $\mathbf{PrOs_4Sb_{12}}$

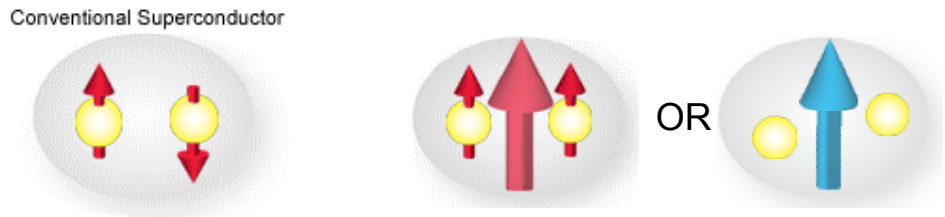
Weak magnetic field "associated with" super-conducting state below 1.8K has been observed by zero-field μSR.



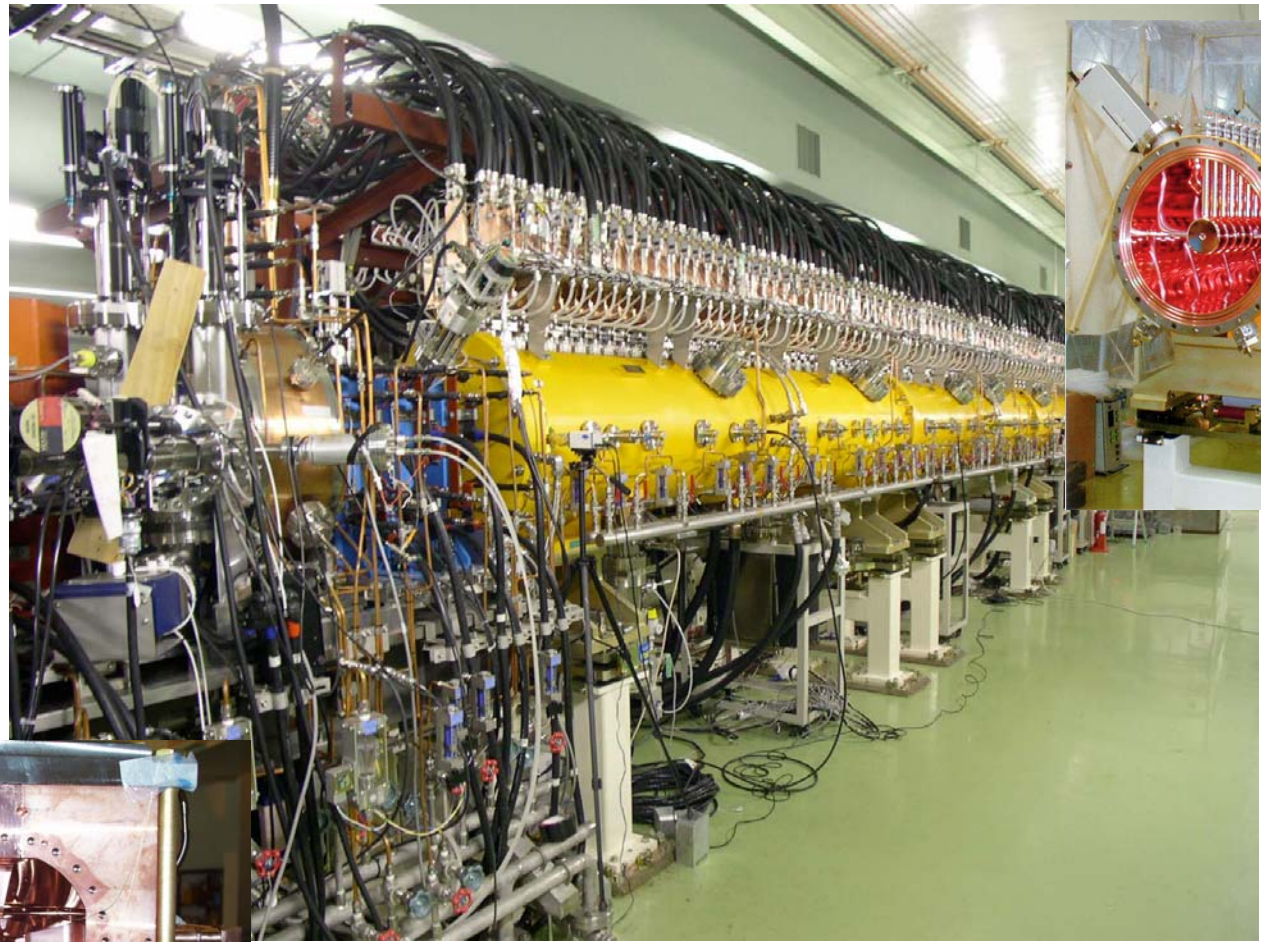


Conventional Cooper pair

…evidence for a new type of **"magnetic" Cooper pairing**↓

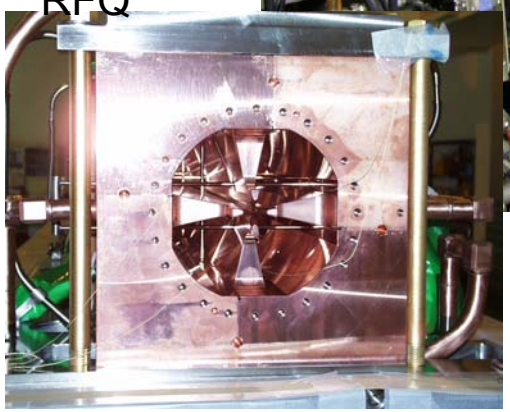


Linac construction status



Inside of drift tube linac

RFQ



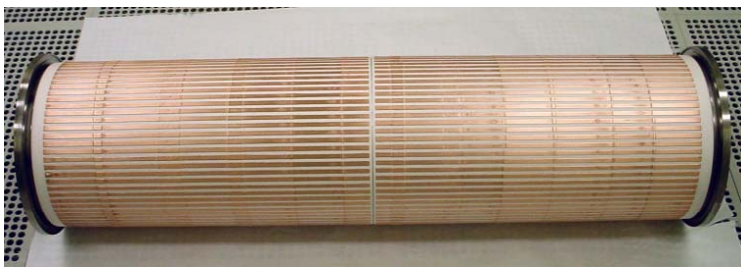
Beam test for chopper was also done.

On October 30, 2003,a successful acceleration of 6 mA at 20 MeV. On November 7, 30 mA was achieved.

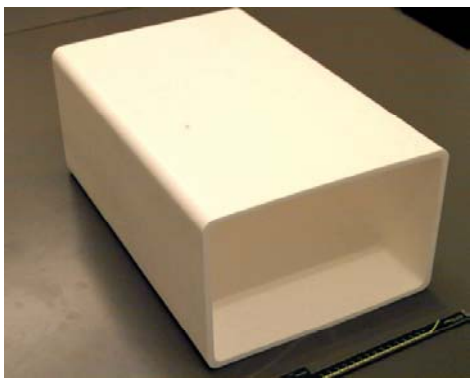
3 GeV vacuum pipe and 50 GeV RF cavity

For dipole magnet

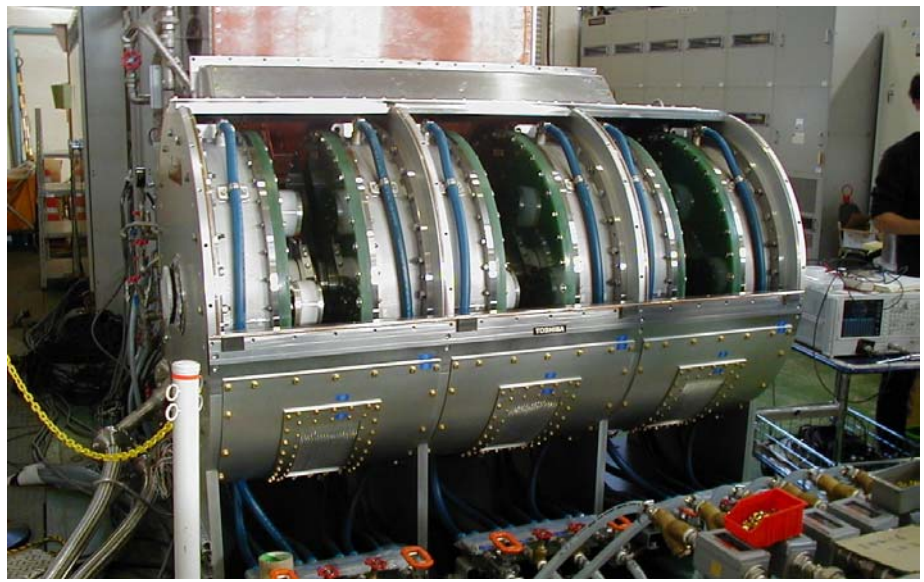
Ceramics vacuume beampipe for 3GeV RCS



For quadrupole magnet



Rectangular duct



RF cavity for 50 GeV with finemet

50 kV/m attained.

50 GeV PS magnets construction

Dipole magnets in mass-production

Quadrupole magnets

Summary

- J-PARC is a unique facility in which all kinds of frontier physics are carried out with the highest beam intensity.
  - 3 GeV PS : materials and life sciences
  - 50 GeV PS : particle and nuclear physics
  - 600 MeV Linac : basic studies of ADS
- Construction status :
  - Construction for both equipments and facilities: Almost on schedule.
  - The completion of the 50GeV experimental hall will be in 2007 and the first beams is expected in 2008.
  - Neutrino program from JFY2004 was approved caching up to other Phase 1 facilities. Completion is expected in 2008.
- J-PARC aims for an international research center.
  - Open to world-wide users.
  - International cooperation in facility construction.
- Issues at the moment
  - Recovery of linac energy, Organization, operation scheme (operation money *etc.*), ……