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JHF Physics

ICFA-HB2002

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KEK, IPNS

Outline

- Overview of the project
- Particle physics
- Nuclear physics
- Materials/Life sciences and others
- Status and summary

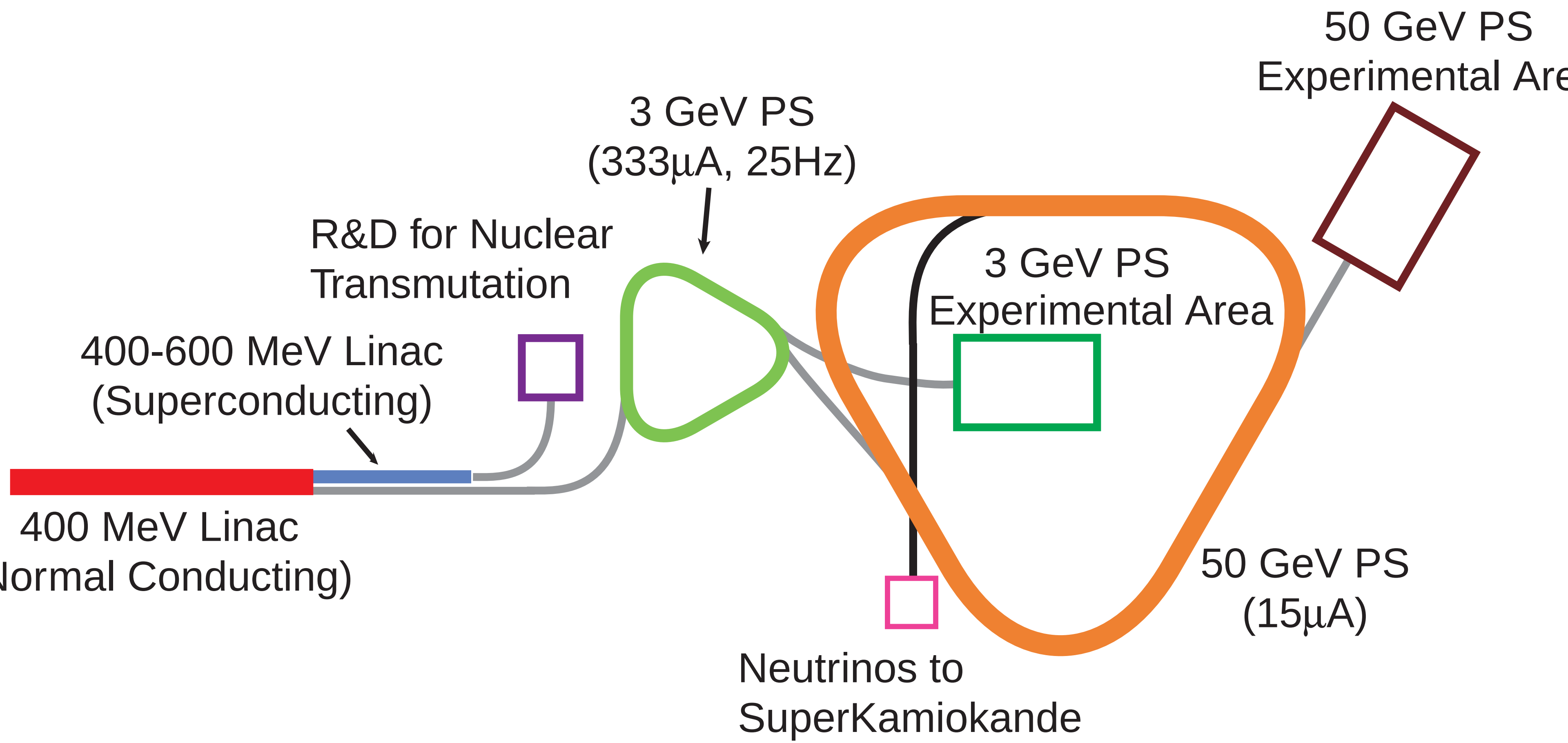
Project overview

- "JHF" is a high-intensity proton accelerator complex in Japan consisting of:
  1. 600 MeV linac
  2. 3 GeV rapid cycling synchrotron
  3. 50 GeV synchrotron
  4. Experimental facilities

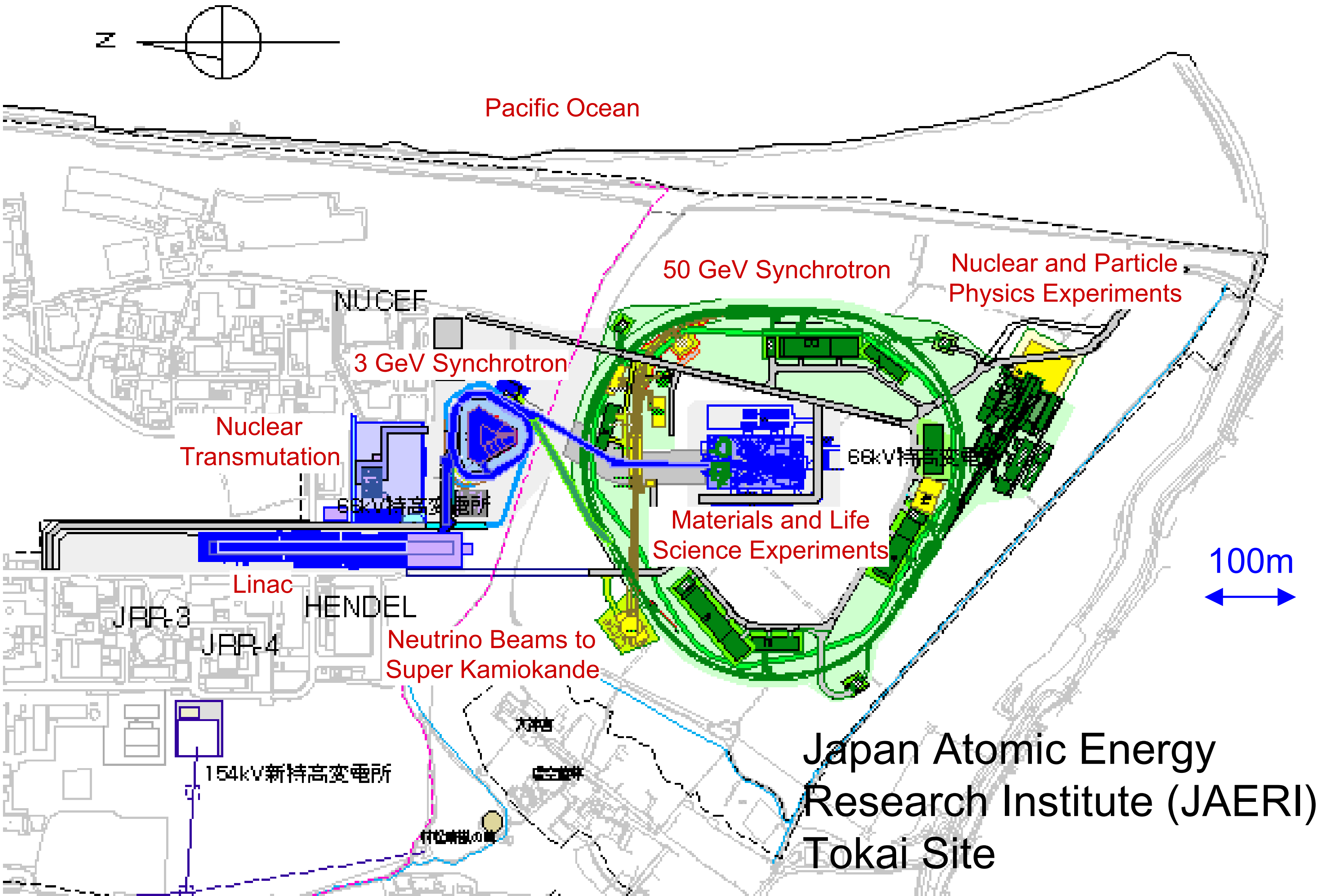
- Joint project of High Energy Accelerator Research Organization (KEK) and Japan Atomic Energy Research Institute (JAERI)

- Construction started in 2001 and the completion of Phase1 will be in FY2006.
- "JHF" is not the official name yet.

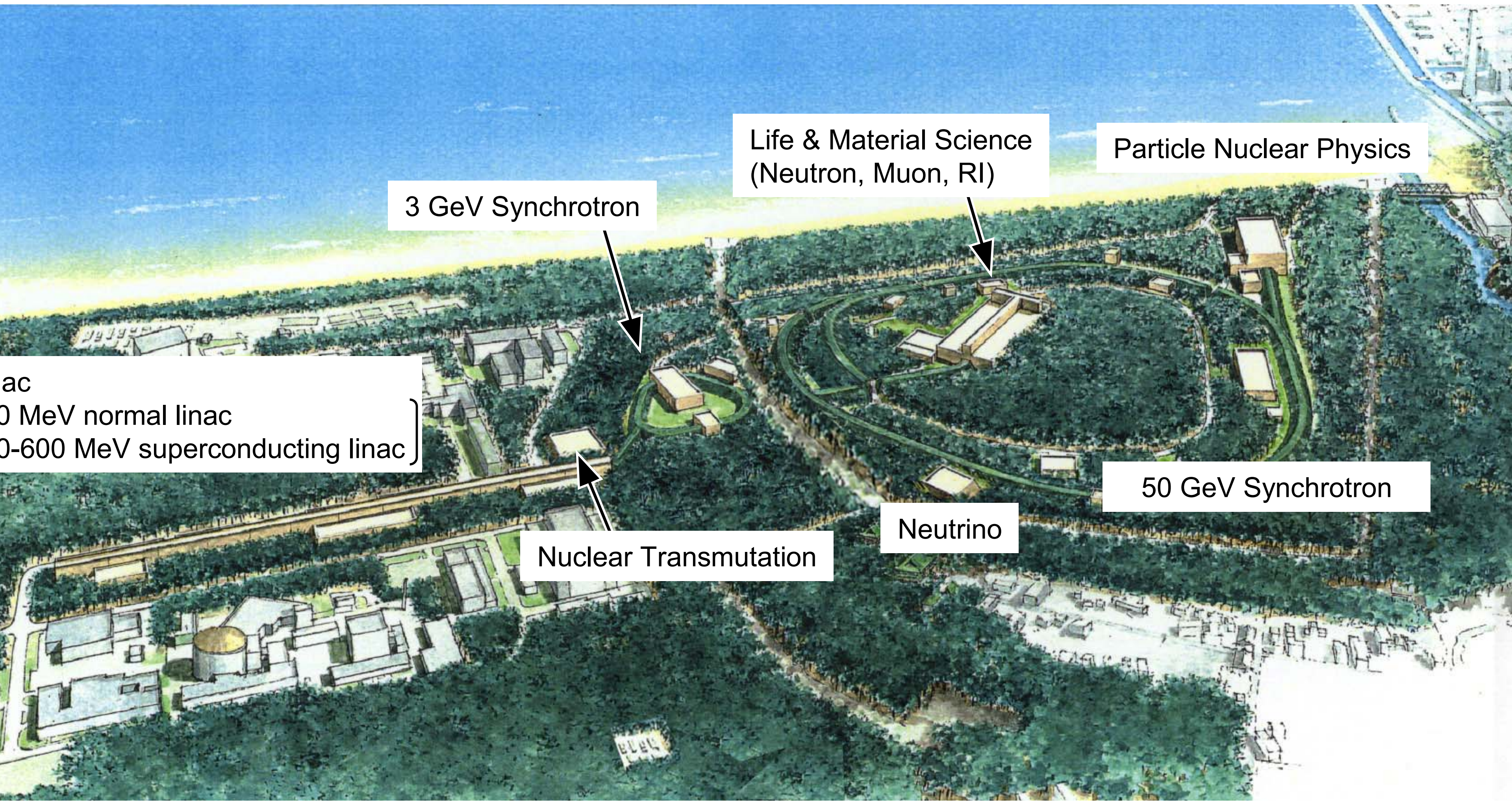
Configuration of the accelerator complex



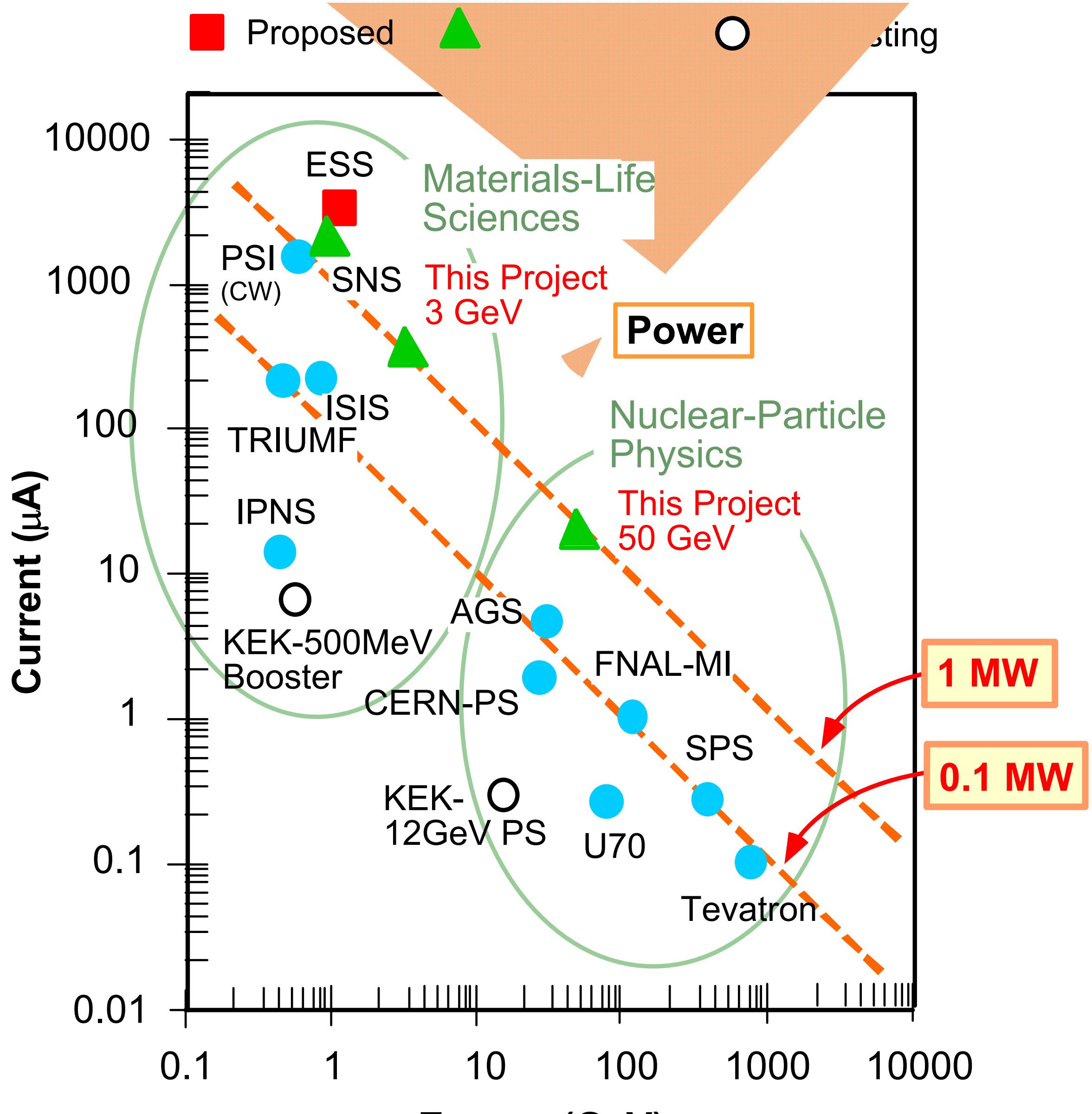
Plan view of the facility



Bird's-eye view of the project

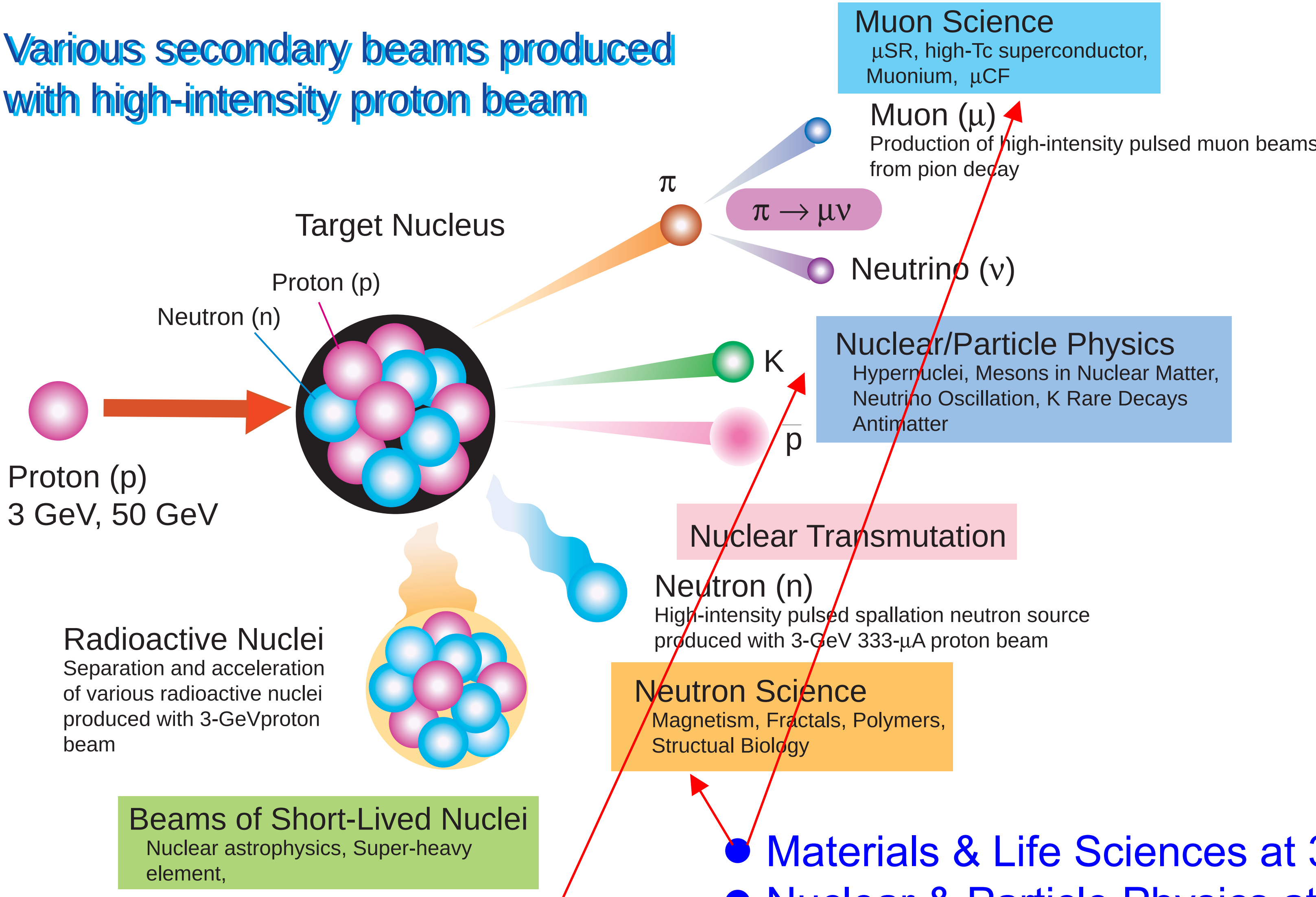


World's proton accelerators



Physics at JHF

Various secondary beams produced with high-intensity proton beam



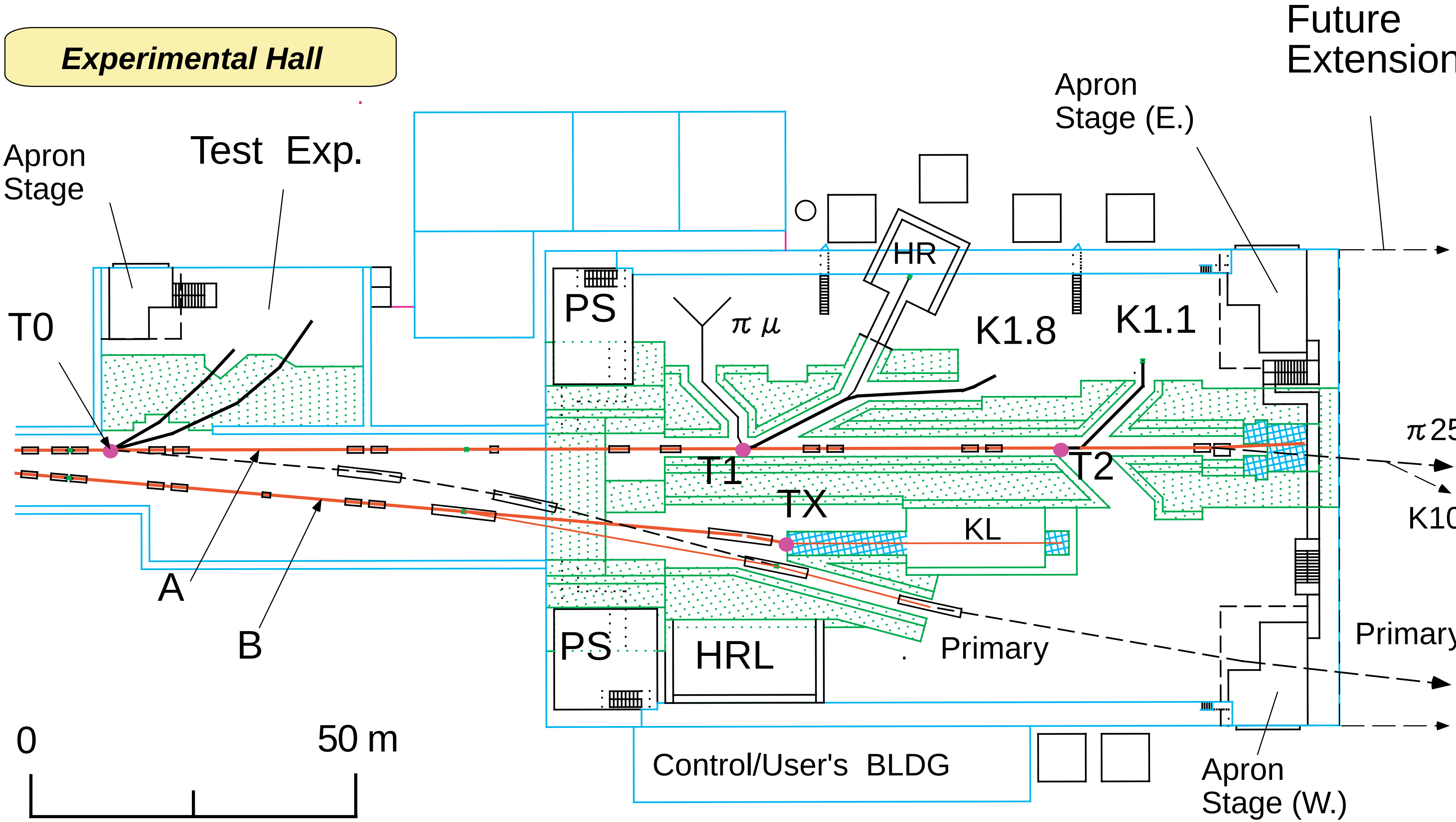
- Materials & Life Sciences at 3 GeV
- Nuclear & Particle Physics at 50 GeV
- R&D toward Transmutation at 0.6 G

50-GeV PS Physics

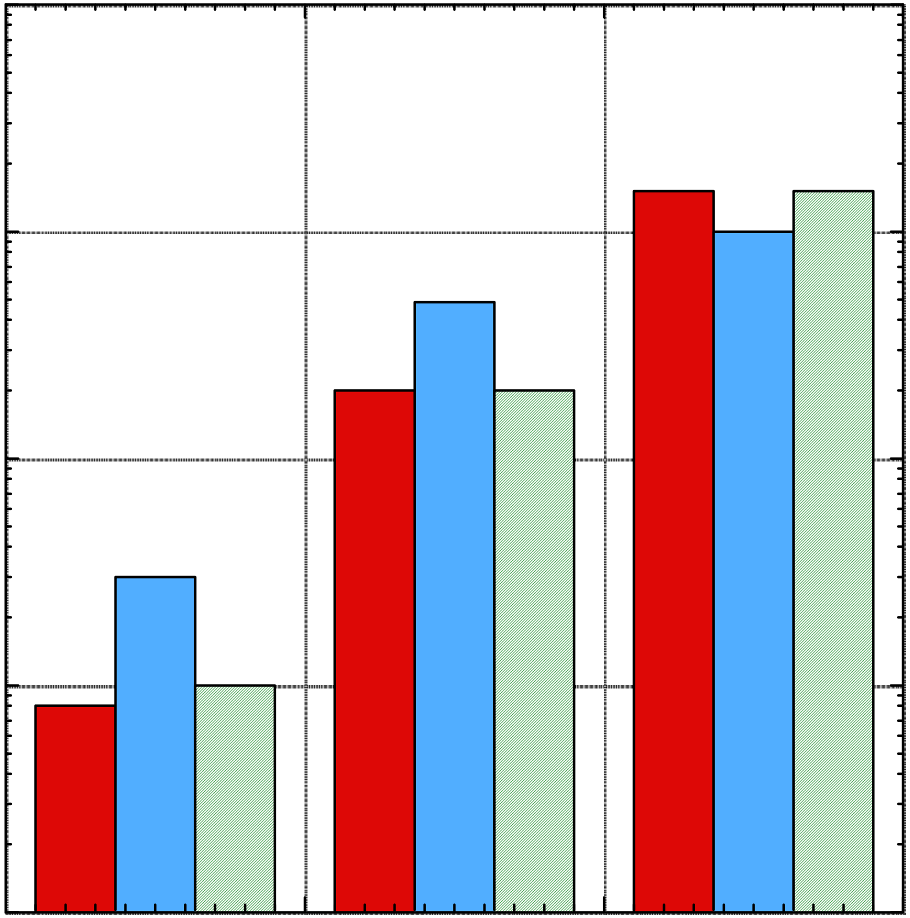
Physics at 50-GeV PS

- Nuclear & Particle physics with K, π, μ, ν, pbar, and other secondar beams
  - Hypernuclear Spectroscopy
  - Hyperon-nucleon scattering
  - Mesons in nuclear matter
  - Hadron spectroscopy
  - Kaon rare decays to measure CKM matrix elements
  - CP violation and other symmetry breaking
  - Flavor mixing and other topics beyond the Standard Model
  - Neutrino oscillation experiment using Super-Kamiokande
- Nuclear physics with primary beams
  - Physics with polarized proton beams
  - High-density matter with heavy-ion beams

Experimental hall



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)

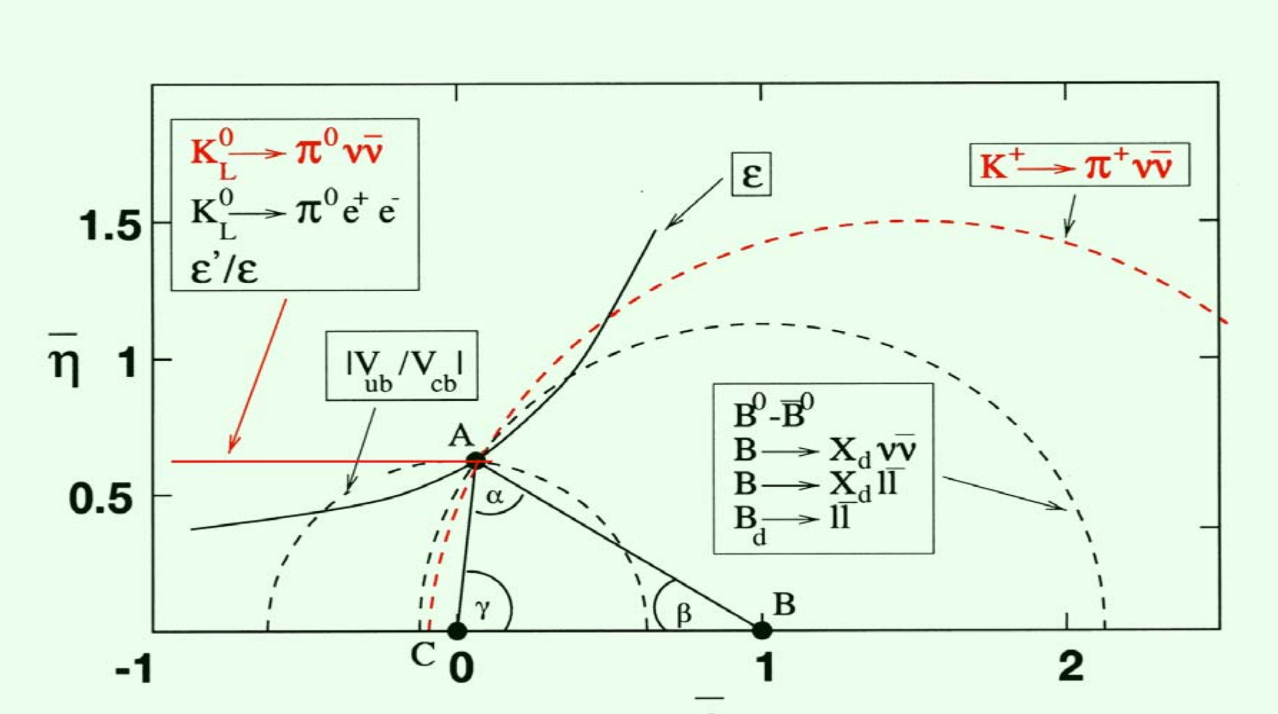
(K^-,π^-), S=-1

Particle Physics

Kaon decay physics

- High precision frontier using high-intensity beams
- Test of the Standard Model and search for new physics
- Complementary to *B* physics and to the energy frontier

CKM matrix determination and test of unitary triangle



- Usefullness of FCNC decays

$K^0_L \to \pi^0 \nu\bar{\nu}$

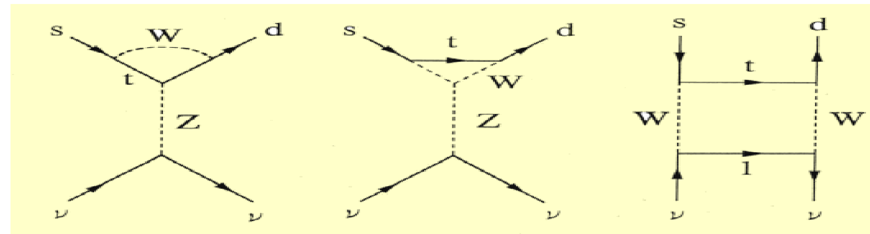
$K^+ \to \pi^+ \nu\bar{\nu}$

Symmetry violation

- CP violation
  - Violation in the Standard Model
  - Violation due to new physics
  - Baryogenesis in the universe
- T (time reversal invariance) violation
  - Complementary to CP violation
  - Test of CP violation models
- CPT violation
  - Test of locality and Lorentz invariance of quantum field theory

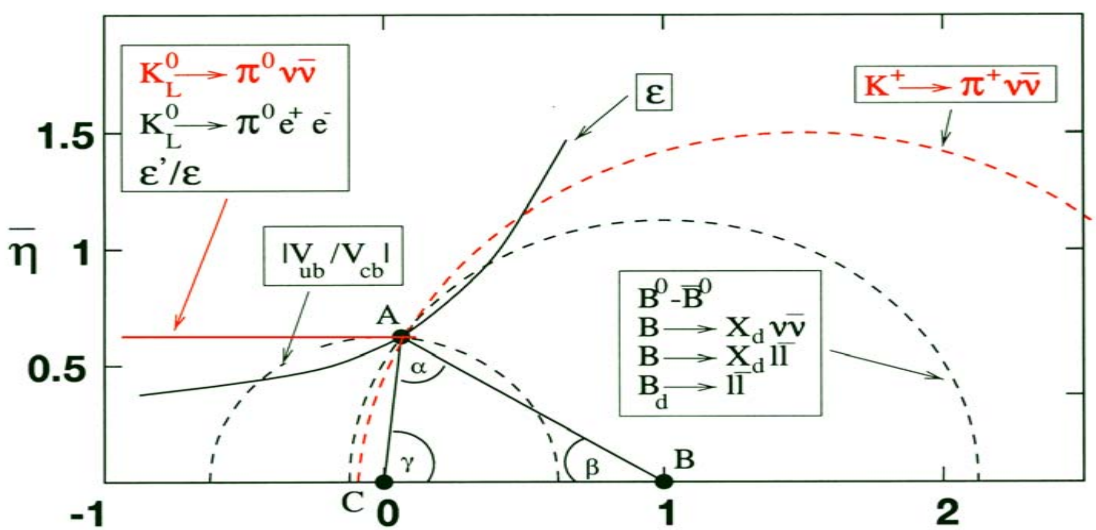
CP violation in $K_L \to \pi^0 \nu \bar{\nu}$

Direct CP Violating Process



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

Standard Model prediction ~3 x 10^{-11}



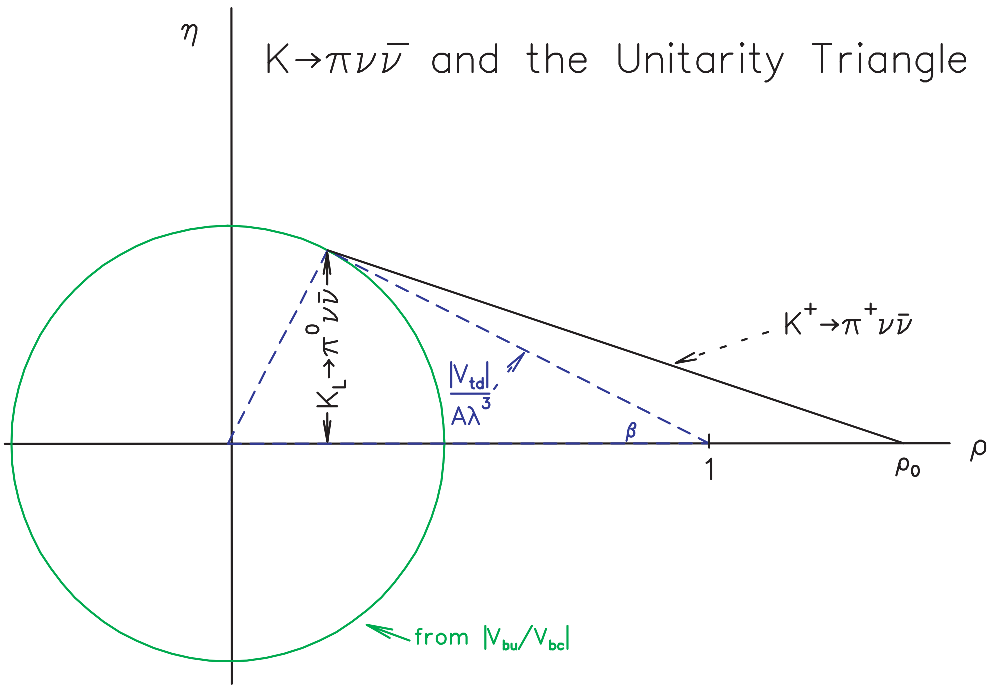
- E391a 10^{-9} - 10^{-10}
- JHF 10^{-12} (1000 ev.expected)

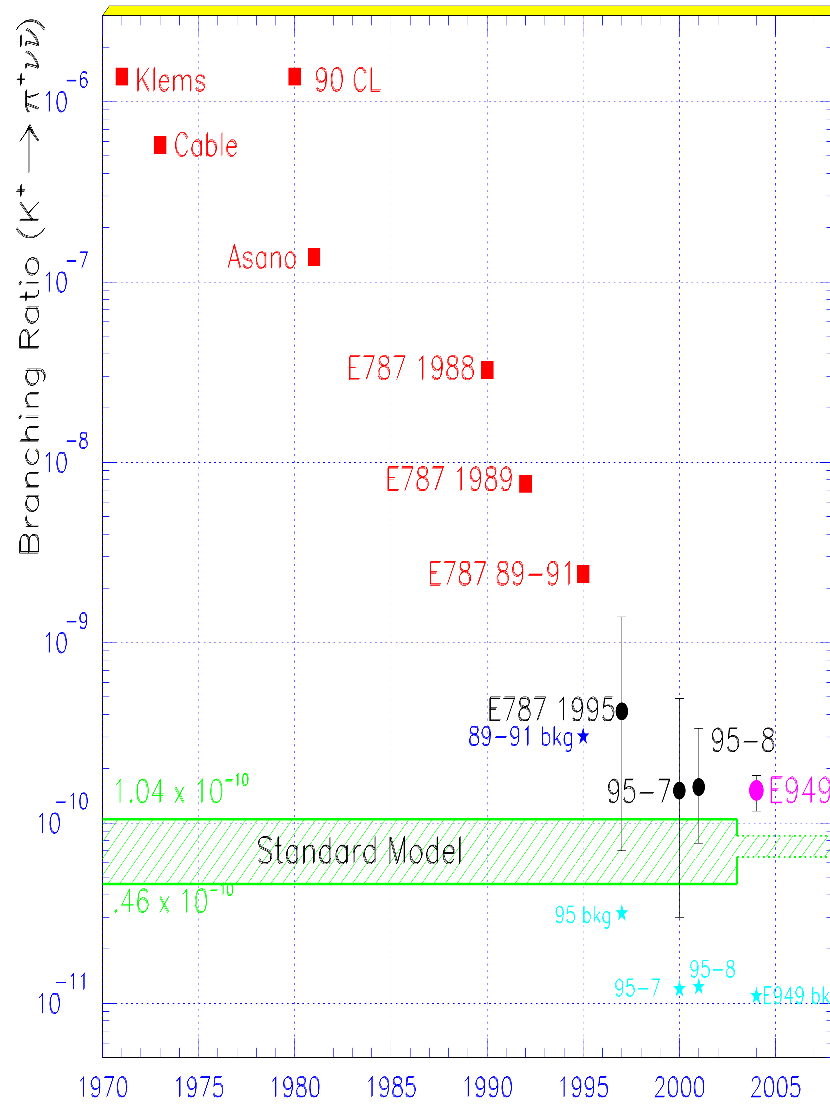
Determination of η
□□□□ 10% precisio

$K^+ \to \pi^+ \nu\bar{\nu}$ decay at JHF

$$\text{B.R.}(K^+ \to \pi^+ \nu\bar{\nu})$$

$$4.11 \times 10^{-11} \cdot A^4 \cdot X(x_t)^2 \cdot [\, (\rho_0 - \rho)^2 + \eta^2 \,]$$

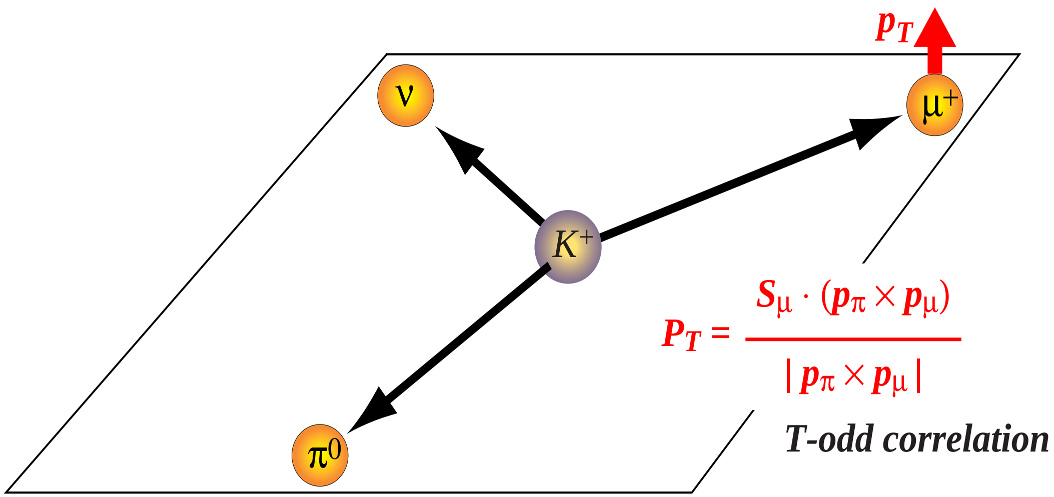




- Standard model prediction: $(0.75 \pm 0.29) \times 10^{-10}$
- Expected number of events at JHF :

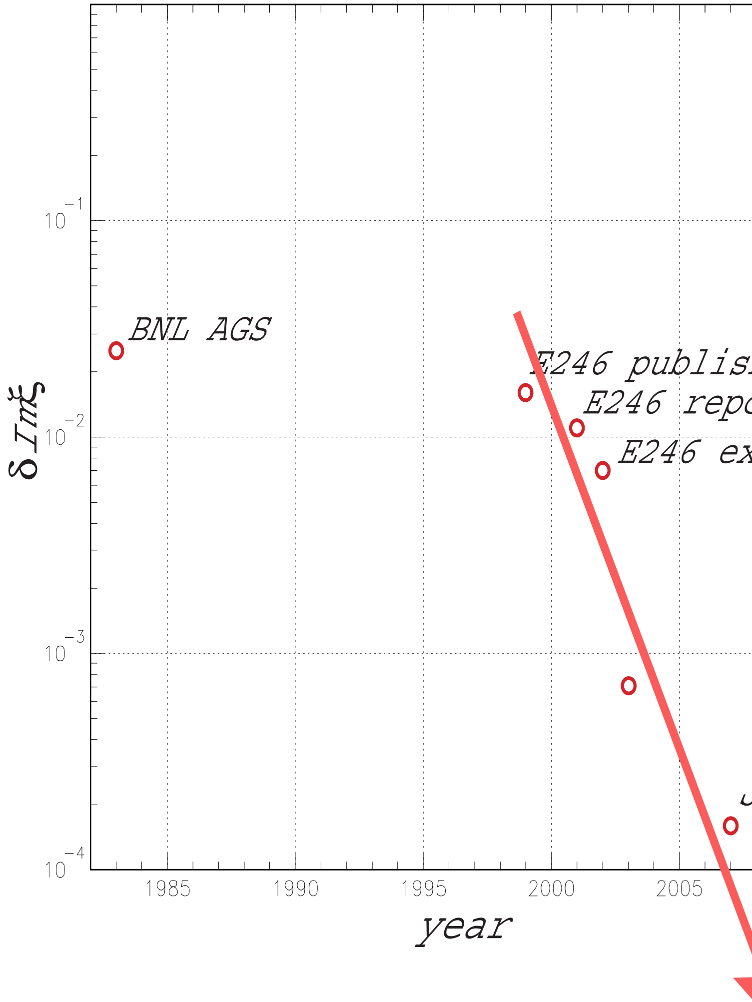
T violation in $K^+ \to \pi^0 \mu^+ \nu$ decay

- Muon transverse polarization



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

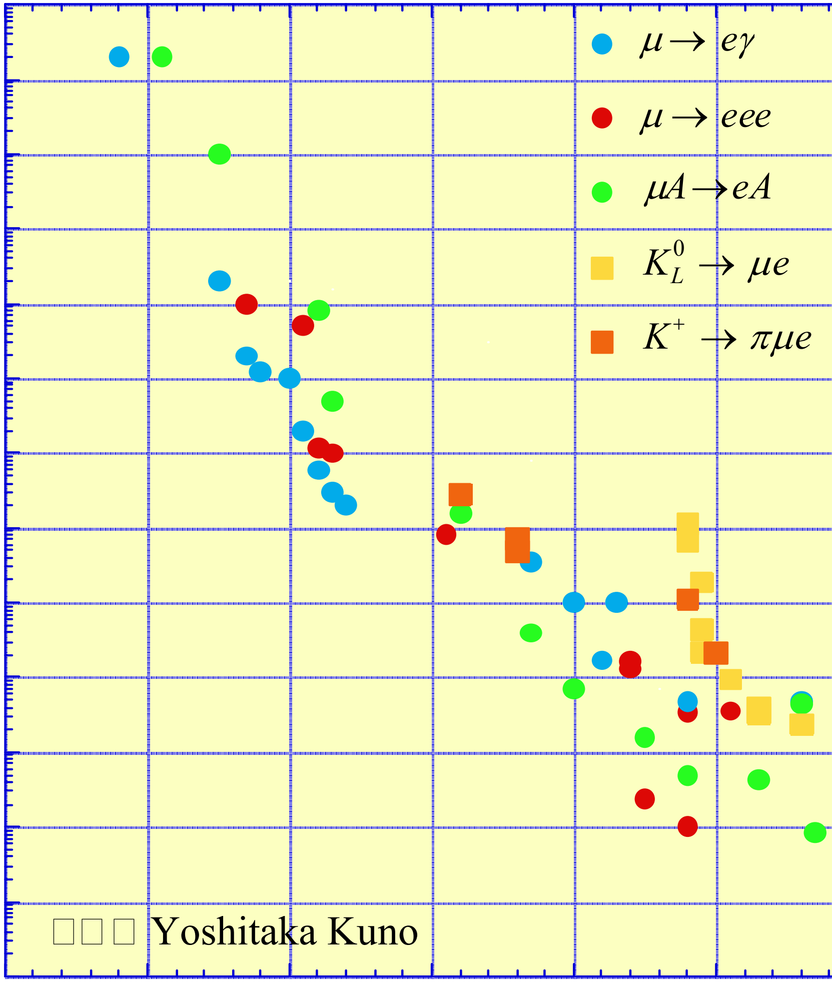
- Search for new physics beyond the SM
  - Multi-Higgs model
  - Leptoquark model
  - *R*-parity violating SUSY *etc.*



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

Muon physics

- Lepton flavor violation
  - μ→eγ
  - μ→3e
  - μ→e conversion
  - Mu-$\overline{\text{Mu}}$ conversion
  - $\mu^- - \mu^+$ conversion
- Precise measurements
  - Lifetime
  - Michel parameters

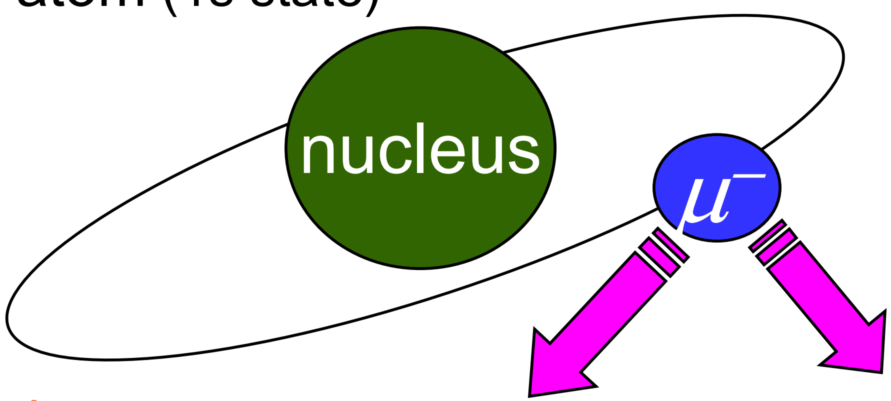


μ-e conversion

$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

Lepton flavors change by one un

- muonic atom (1s state)



nuclear muon capture

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

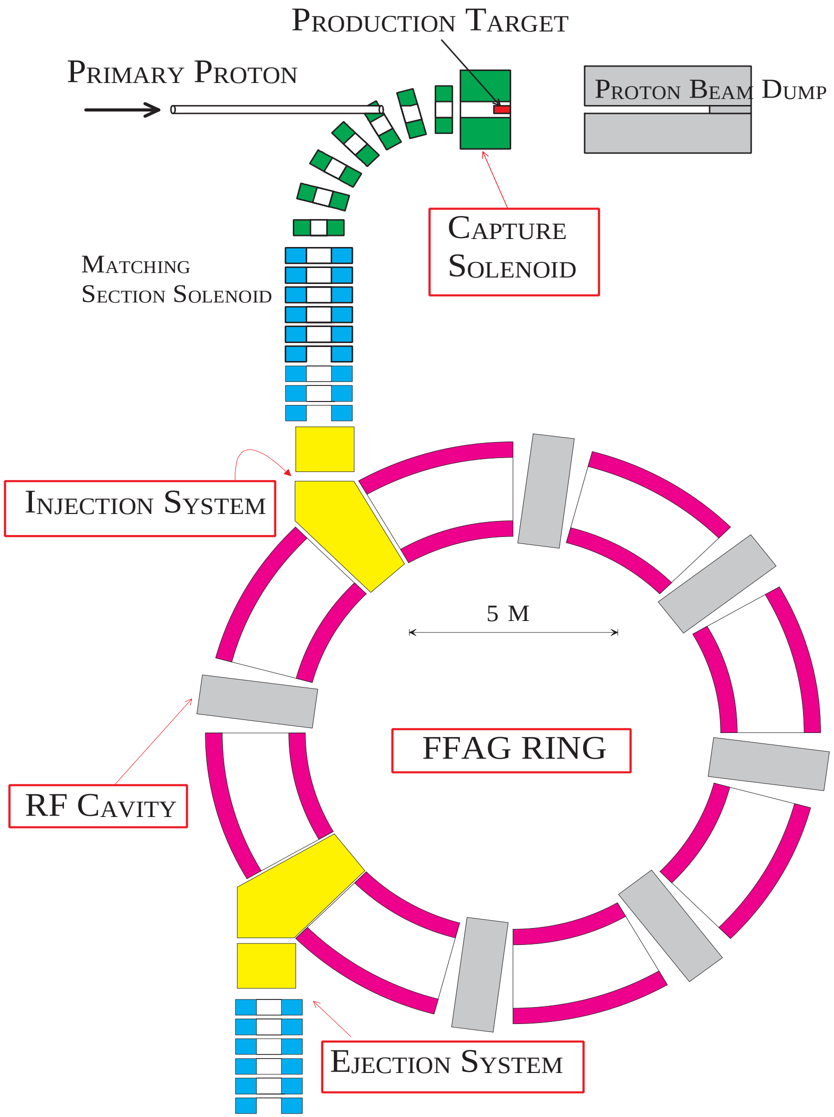
muon decay in orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

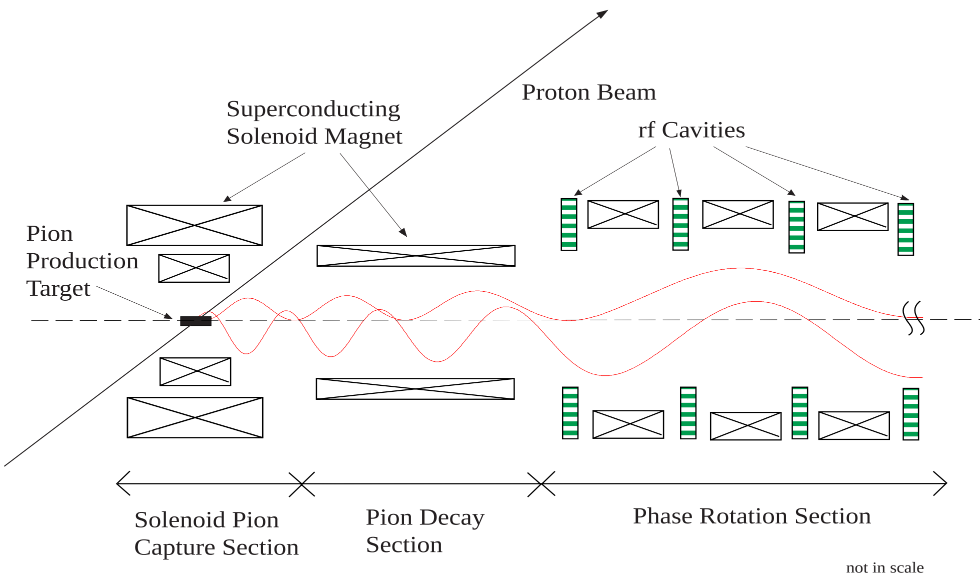
- neutrinoless muon nuclear capture (= $\mu\, e$ conversion)
- very high sensitivity to SUSY-GUT
- sensitivity at JHF will be 10^{-18} (10^{-16} at MECO)

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



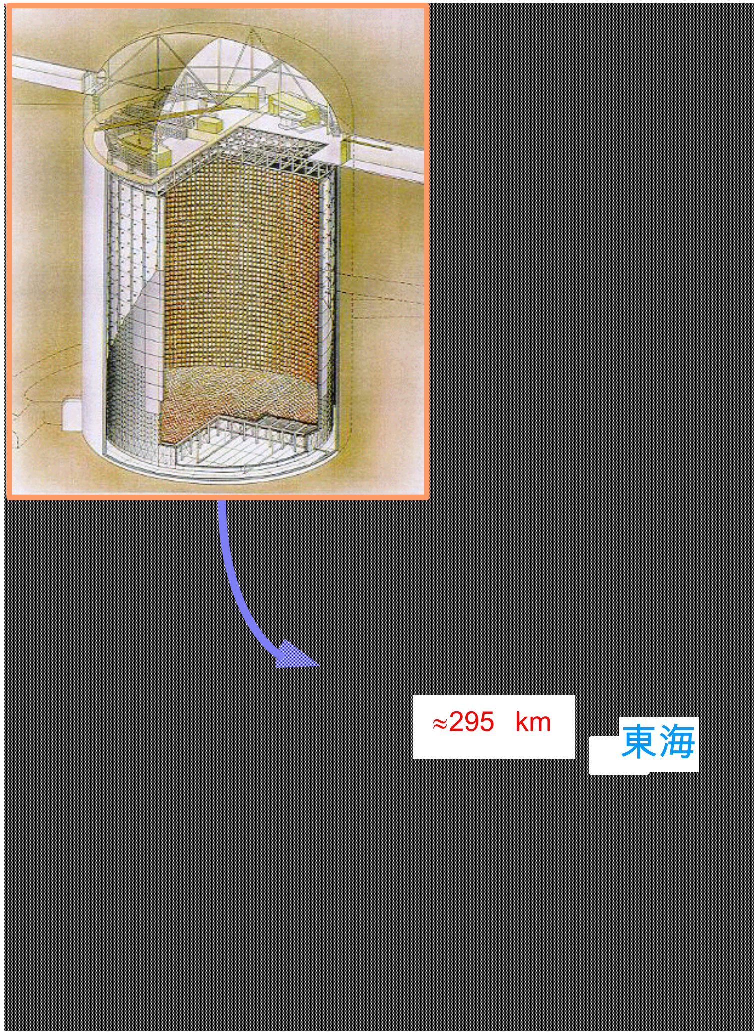
JHF-SuperKamiokande ν oscillation

Neutrino oscillation and neutrino mass (SuperK + K2K)

- SuperK's atmospheric ν experiment + recent SNO experiment showed finite mass for ν_{μ} and $\nu_{\square}$.
- K2K ν_{μ} disappearance experiment also suggests finite mass of ν_{μ}.

From measurement of m_{ν} to the lepton family mixing . Flux (ν_{μ}) at the 50 GeV PS ∼100 x Flux (ν_{μ}) at KEK 12 GeV PS

Future facility … towards CP violation



Neutrino oscillation

- Neutrino Mixing

$$|\nu_l\rangle = \Sigma U_{li} |\nu_i\rangle$$

ν_l: weak eigenstates ν_i :mass eigenstates
U : Maki-Nakagawa-Sakata Matrix

- Oscillation Probability

$$P_{l\to m} = \left|\langle \nu_m(t) | \nu_l(0)\rangle\right|^2 = \delta_{ml} - 2\sum_{i<j} \mathrm{Re}\left[\left(U_{mi}^* U_{li}\right)\cdot\left(U_{mj} U_{lj}^*\right)\cdot\left\{1 - \exp\left(-i\frac{\Delta m_{ij}^2}{2E}L\right)\right\}\right]$$

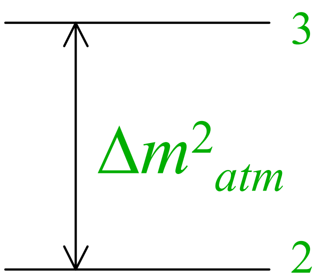
L =flight length, E =neutrino energy, $\Delta m_{ij}=m_i^2-m_j^2$

- ν_μ disappearance $P_{\mu\to x} \sim 1 - \sin^2 2\theta_{23} \cdot \sin^2(1.27 \Delta m^2_{atm} L/E_\nu)$
- ν_e appearance $P_{\mu\to e} \sim \underline{\sin^2\theta_{23} \cdot \sin^2 2\theta_{13}} \cdot \sin^2(1.27 \Delta m^2_{atm} L/E$

$\sin^2 2\theta_{\mu e}$

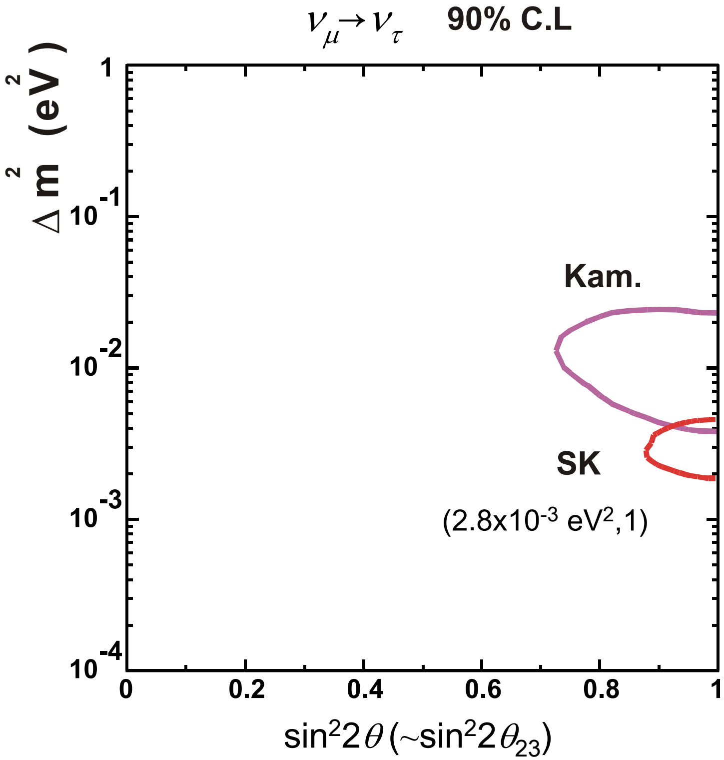
$P_{l\to m} \neq \delta_{ml} \Leftrightarrow \Delta m_{ij} \neq 0$,

Lepton Flavor Violation



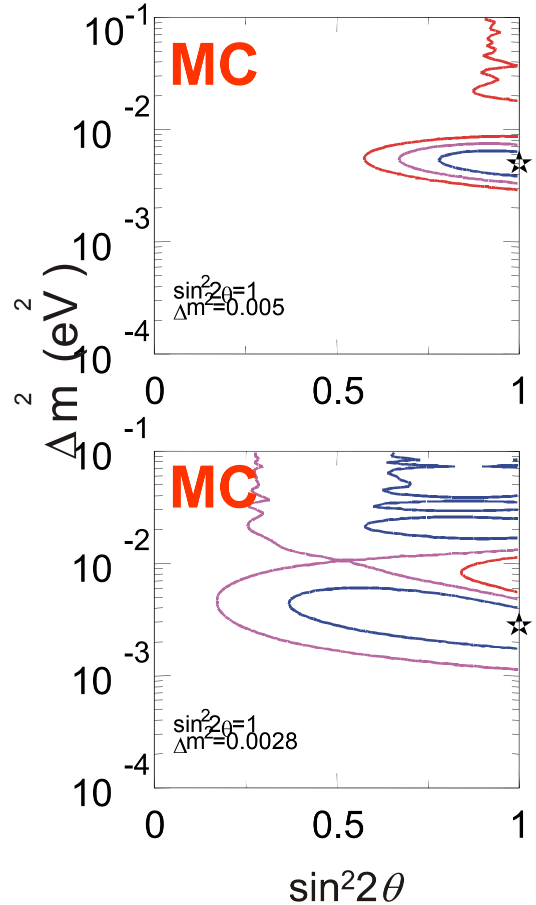
Limit on θ_{23} and Δm^2

- Allowed region from SK



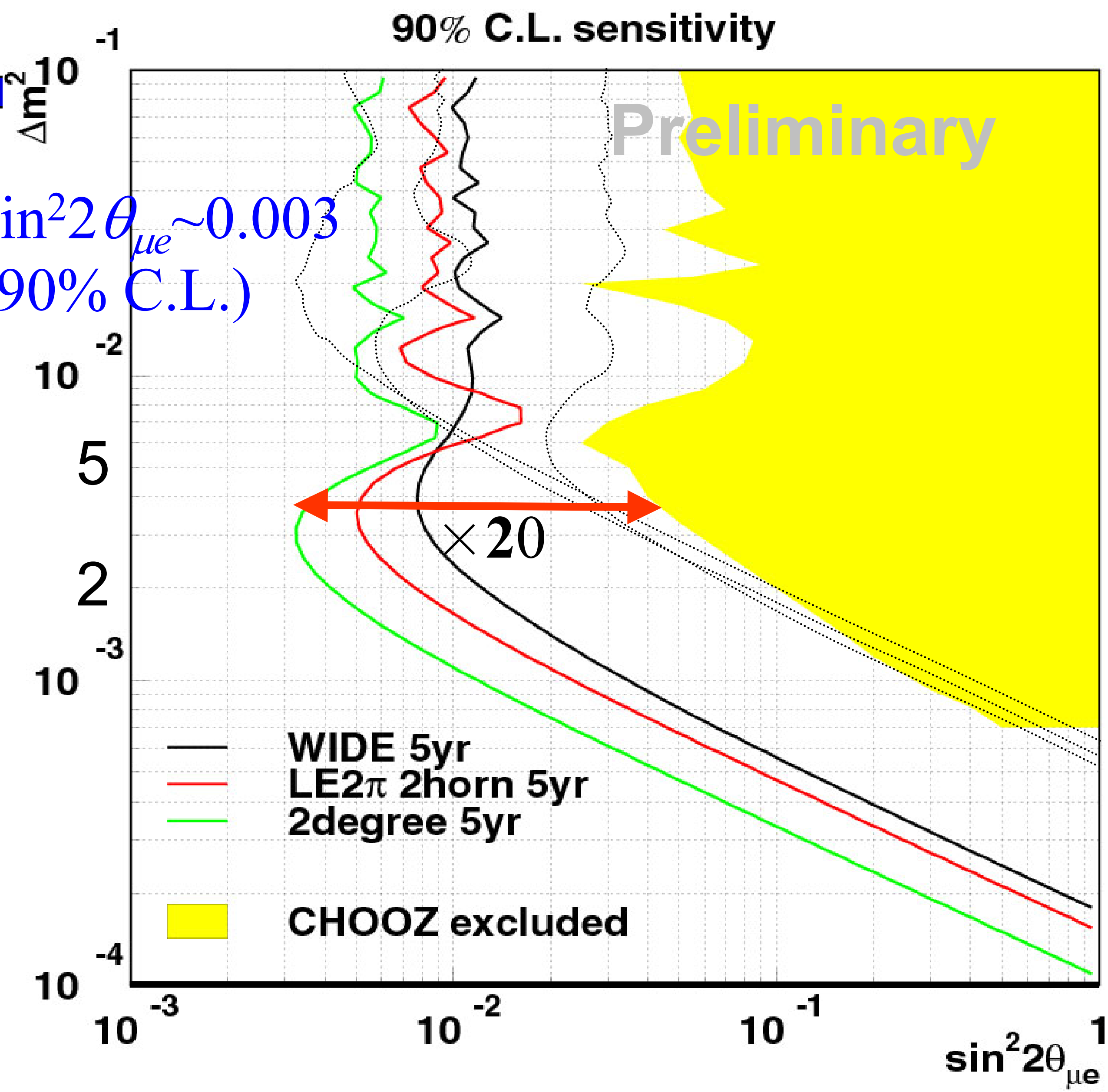
Δm^2=(1.6-3.6)x10^{-3} eV^2
$\sin^2 2\theta$ >0.89

- Expected allowed region from K2K (10^{20} POT)



- Sensitivity at JHF

$\delta(\sin^2 2\theta)\sim 0.01$; $\delta(\Delta m^2)\sim<1\times10^{-4}$; in 5 years appearance

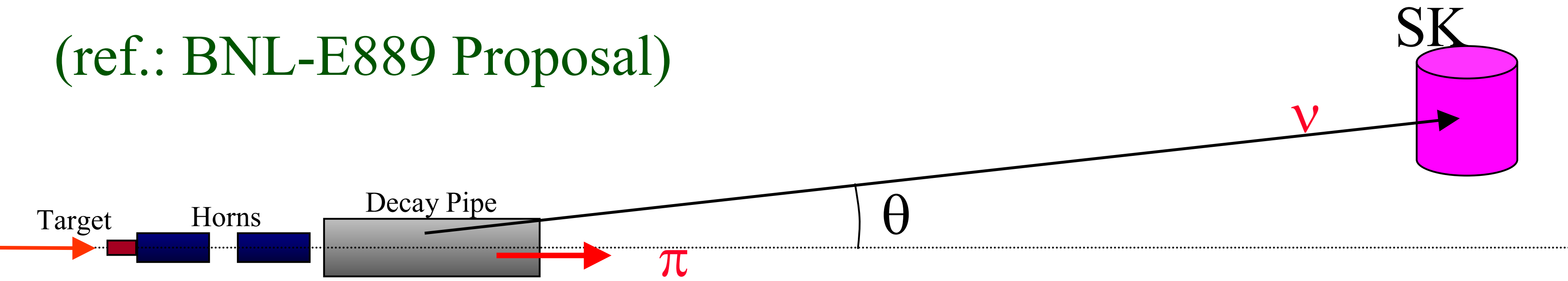


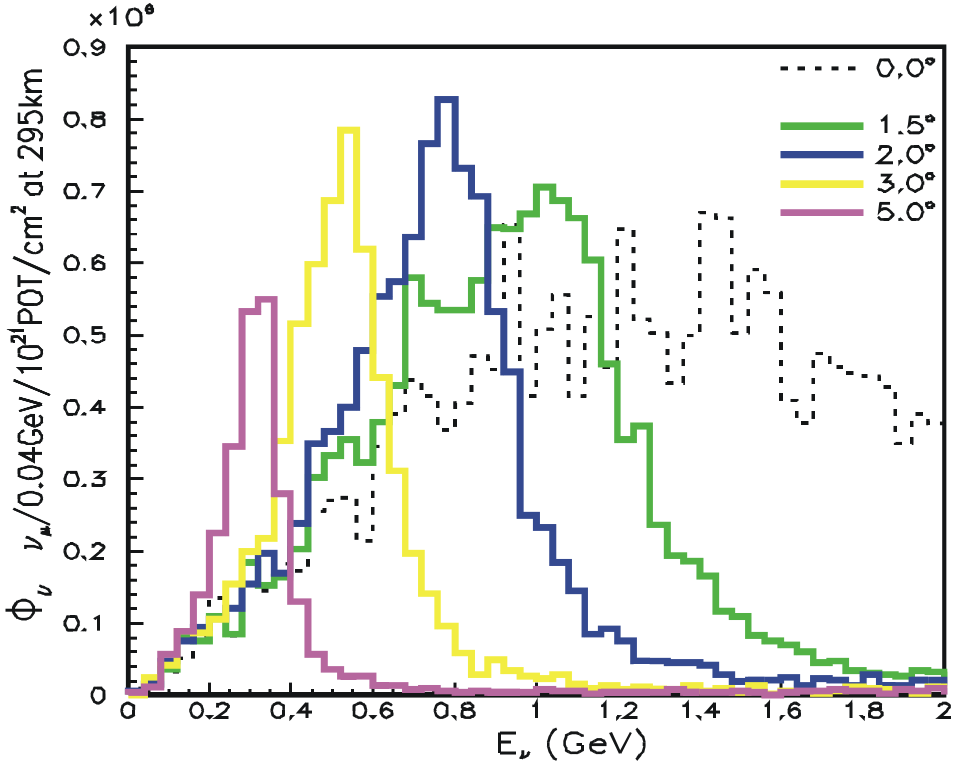
$\sin^2 2\theta_{\mu e}$~0.003 (90% C.L.)

Dashed lines: MINOS Ph2le, Ph2me, Ph2he from right (A.Para, hep-ph/0005012)

Off axis beam (a NBB option)

(ref.: BNL-E889 Proposal)





- intentionally misaligned beam line from detector axi
- quasi-monochromatic bear

Nuclear Physics

Strangeness nuclear physics

- S=-1
  - High-resolution γ spectroscopy of Λ-hypernuclei
    - $(K^-,\pi^-\gamma)$: HyperBall detector > 100 γ's/day
  - YN(S=-1) scattering: Λp, $\Sigma^{\pm}p$

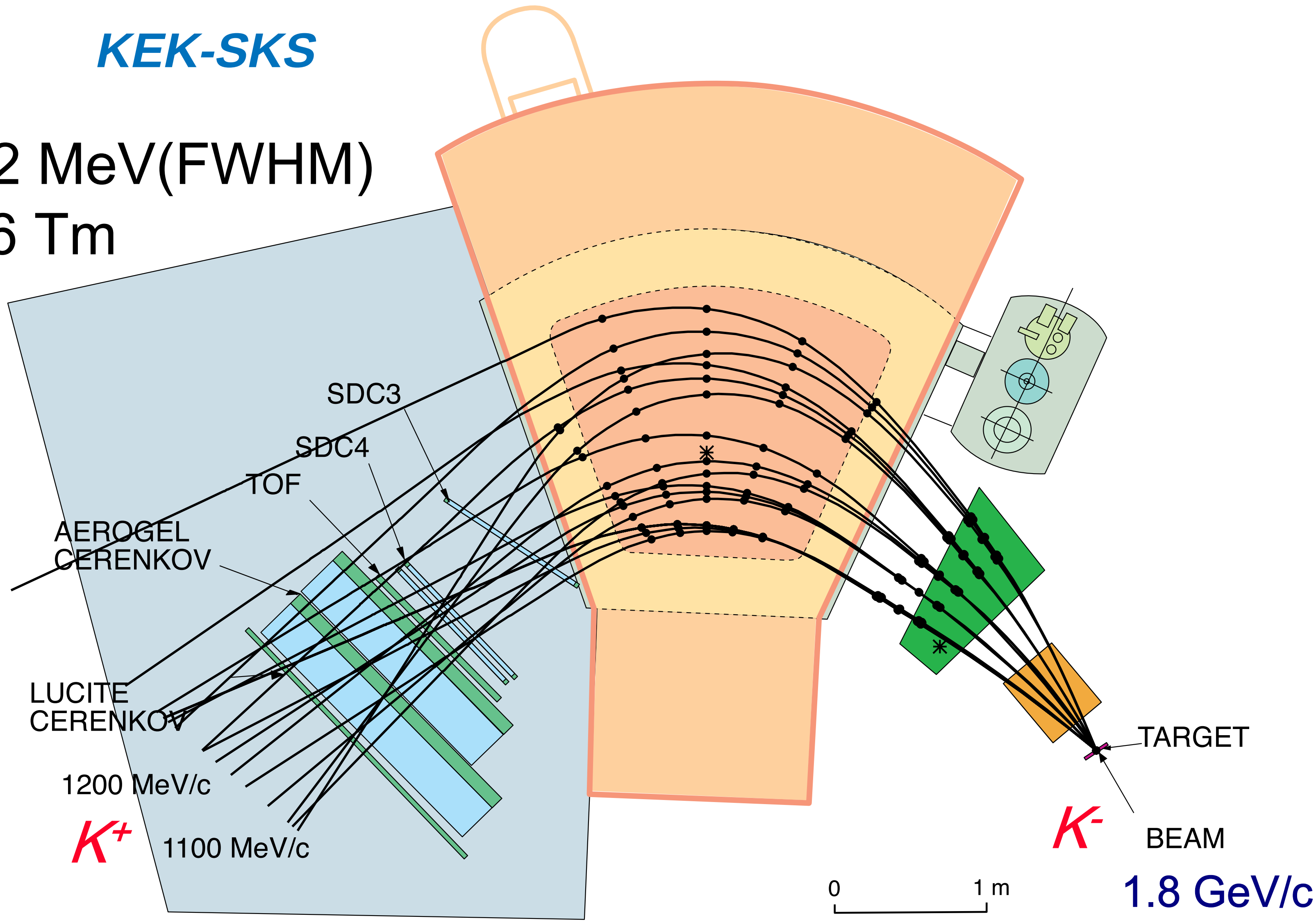
- S=-2
  - Spectroscopic studies of S=-2 systems
    - (K^-,K^+): Ξ-hypernuclei SKS 6 events /MeV/day
    - $(K^-,K^+)\pi\pi$: double-Λ hypernuclei (g.s) CDS
    - $(K^-,K^+)\gamma$: double-Λ hypernuclei(excited states) HyperBall
  - YN(S=-2) Scattering: $\Xi^- p$ CDS

(K^-,K^+) spectroscopy of Ξ-hypernuclei

KEK-SKS

ΔE~ 2 MeV(FWHM)

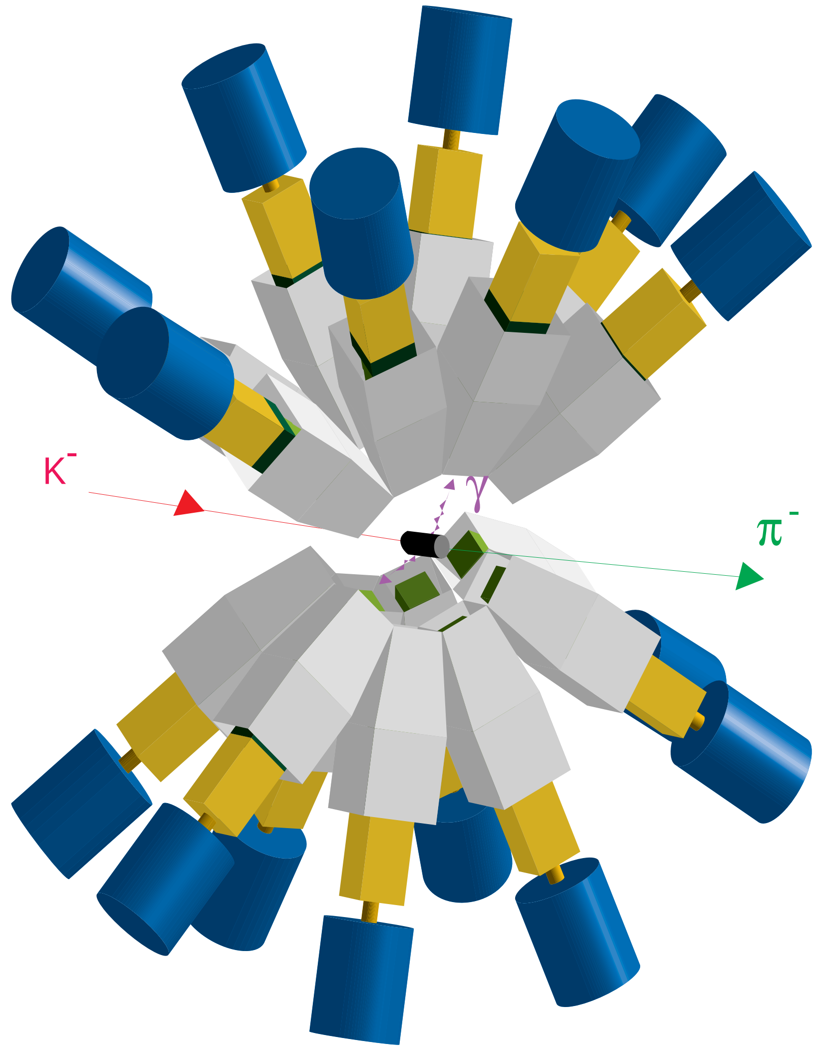
BL= 6 Tm



Ge-detector system: HyperBall

- 14 Ge detectors
- $\Delta\Omega$ = 40% of 4πsr
- Photopeak efficiency:
  = 12%(@1 MeV)

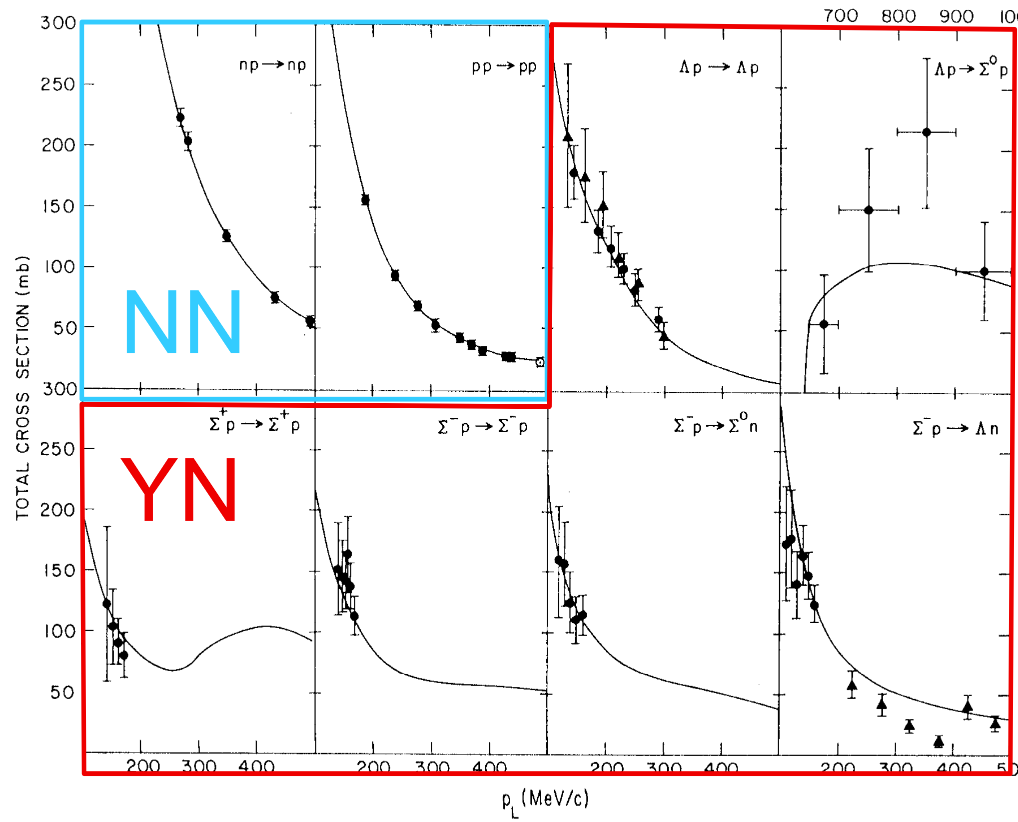
(a)



Hyperon-nucleon scattering

- Understanding of the flavor SU(3) baryon-baryon interaction
  - YN, YY < NN ? repulsive or attractive ?
  - Repulsive cores in YN/YY ? What is the origin ?
  - Spin-dependent forces in YN/YY.
  - Dibaryons ?

Λ+p, Σ⁺+p, Σ⁻+p and Ξ⁻+p scattering

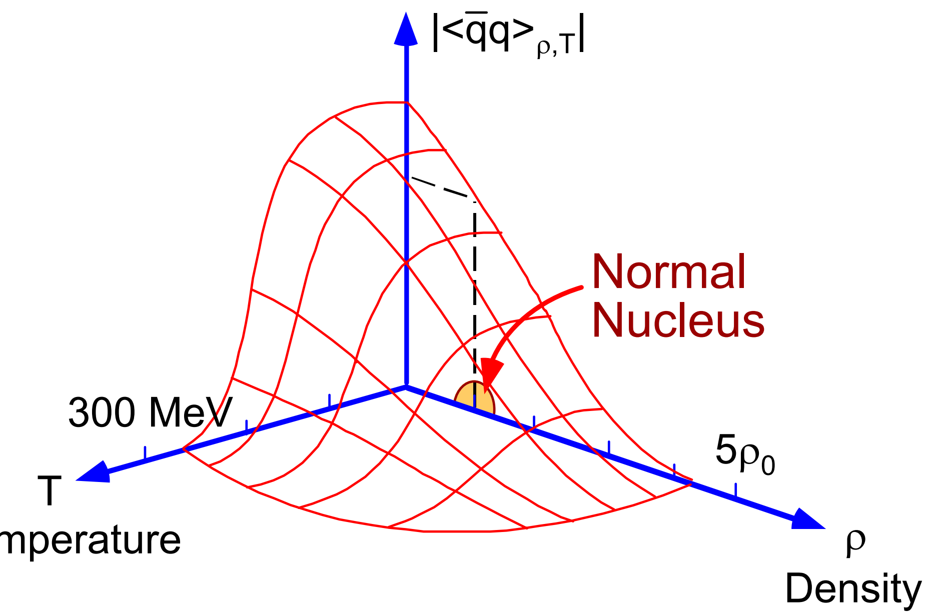


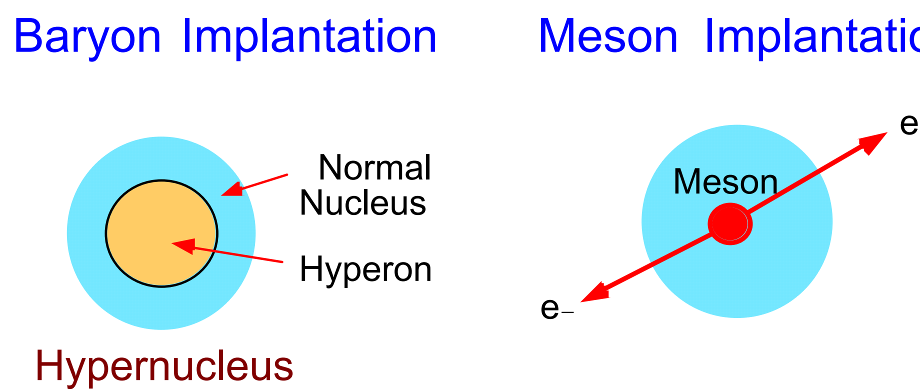
from Dover & Feshbach Ann.Phys.198(90)

Need high quality data with high statisti

Hadrons in nuclear matter

- Methods of how to study the origin of hadron mass
  - Lattice QCD (theory)
  - Implantation of a hadron in nuclear matter (JHF)
  - Behavior of hadrons in hot and dense nuclear matter (RHIC)





$m_{u,\ d\text{-quark}}$ (5-10 MeV/c^2)

< (1/100) m_{proton} (1000 MeV/c^2)

T. Hatsuda and T. Kunihiro, Phys. Rev. Lett. **55** (1985) 158.
W. Weise, Nucl. Phys. **A443** (1993) 59c.

Materials and Life Sciences

- 3-GeV PS Physics -

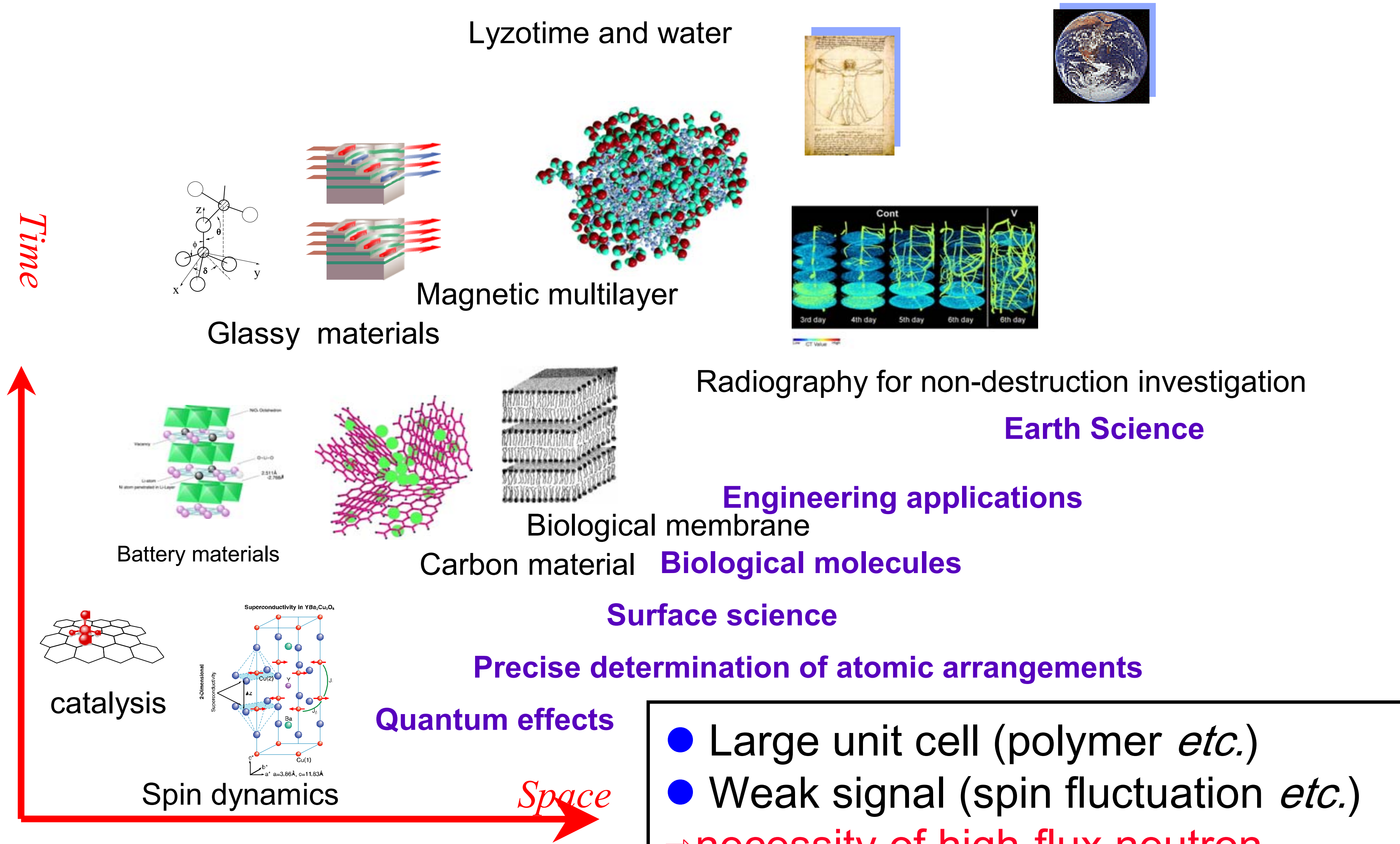
Neutron scattering

- Features of neutron scattering
  - Neutron wave length $\lambda \backsim a$: structure analysis by diffraction
    with energy $E_n \backsim E_{ex}$: with scattering function $S(q,\omega)$
  - Scattering from nuclei : sensitivity also to light elements
  - Neutron spin scattering : 1) study of magnetic structure
    2) application of pol. beam technique
  - Transparent beam : 1) study of bulk materials
    2) real-time/real-condition radiography
- Features of pulsed neutron with Time-of-flight method
  - High peak intensity
  - High (q, ω) resolution
  - Wide (q, ω) region
  - Ability to study dynamics and time dependent phenomena

Neutron science highlight

- Solid state physics: Observation of quantum effect
  (Understanding function and property of materials)
- Understanding precise atomic structure of materials
  (Indispensable base of materials science)
- Biomolecular science (Understanding life)
- Structure and dynamics of surface and interface
- Neutron imaging for industrial application and versatile researches
- High pressure and high temperature: Earth science

Neutron sciences in wide time-space range



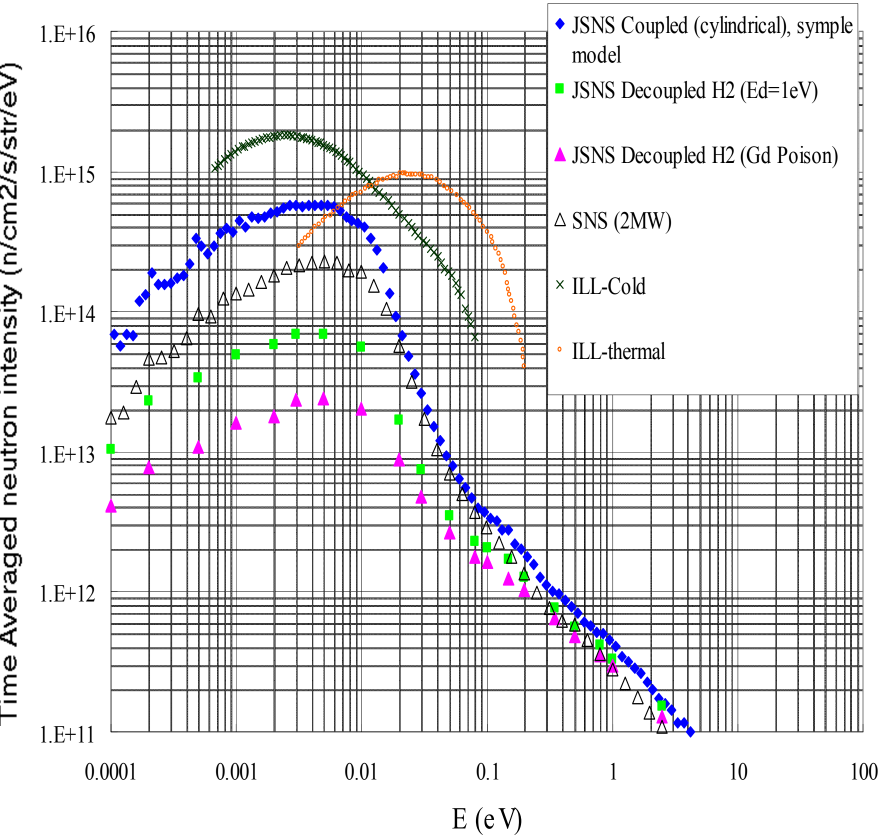
- Large unit cell (polymer *etc.*)
- Weak signal (spin fluctuation *etc.*)

⇨necessity of high-flux neutron

Comparison of flux

Time integrated intensity

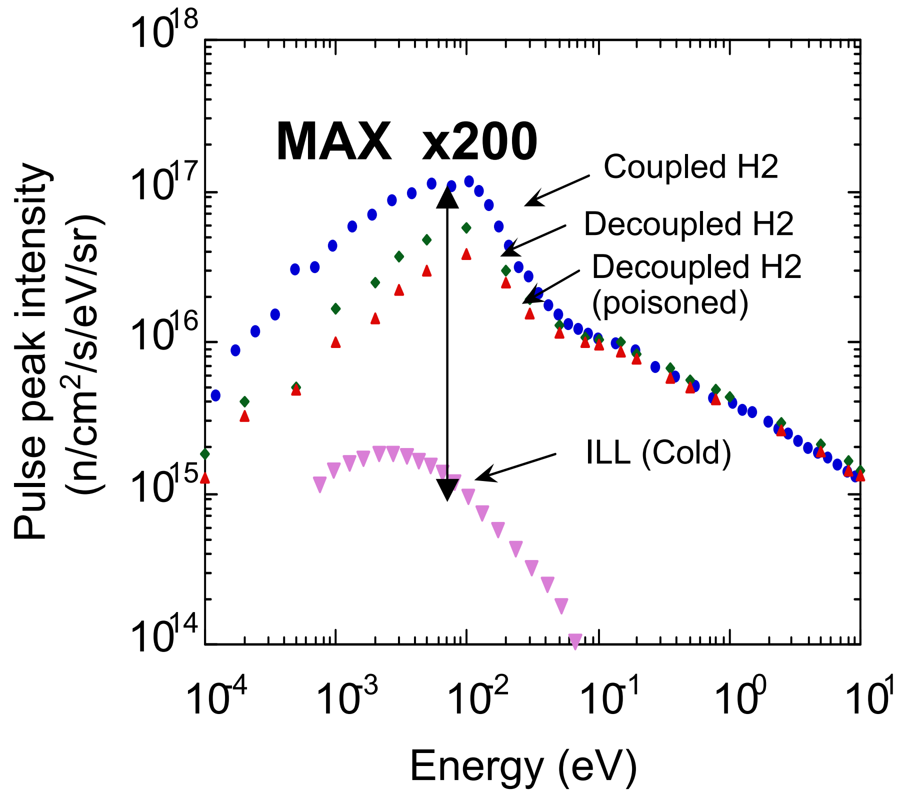
$\Phi^{JKJ}_{1MW} = 1/4 \ \Phi^{ILL}_{2nd}$



Time Integrated Intensity

Pulse Peak intensity

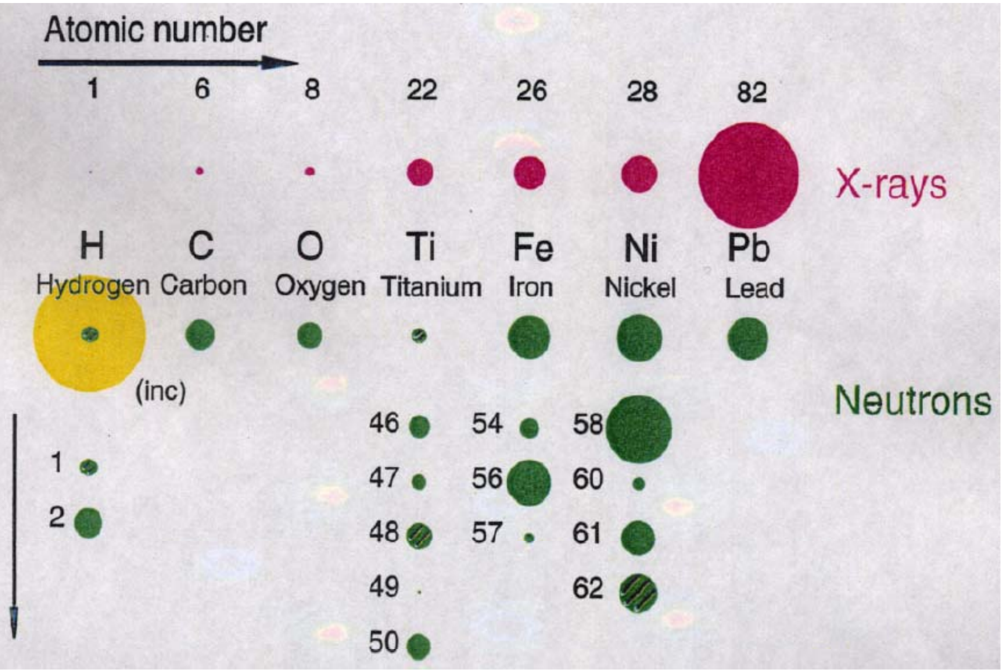
$\Phi^{JKJ}_{1MW} = \sim 200 \times \ \Phi^{ILL}_{2nd}$



Peak Intensity

Light elements

Z dependence of sensitivity compared with X ray



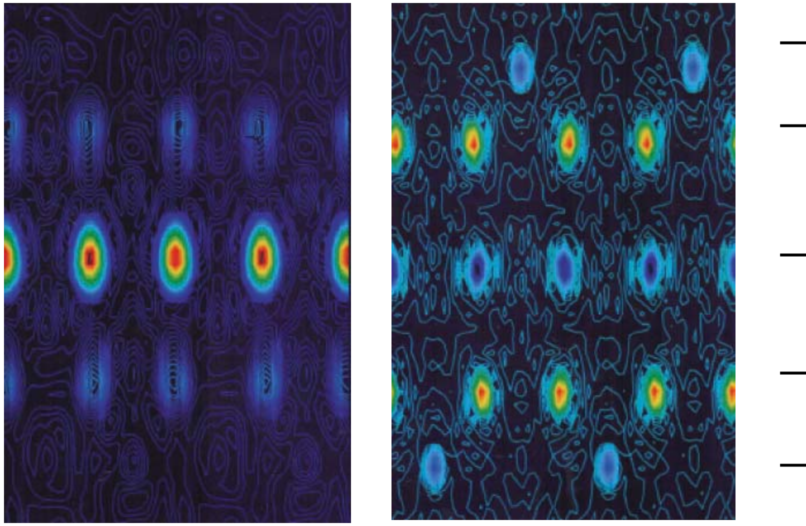
X-rays interact with electrons.

→ X-rays see high-Z atoms.

Neutrons interact with nuclei.

→ Neutrons see low-Z atoms.

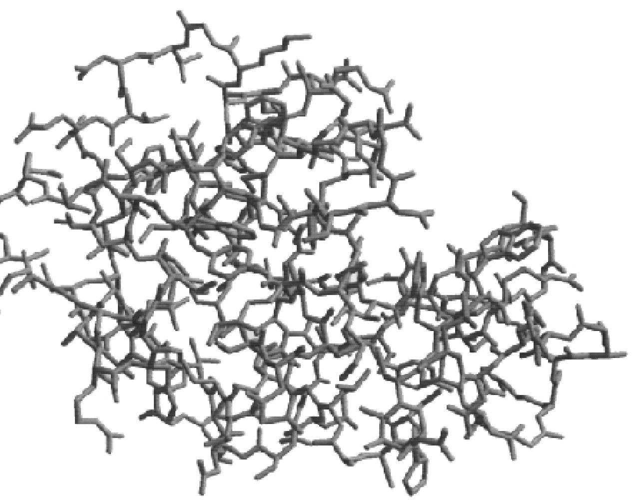
An example: Behavior of Li in Li battery



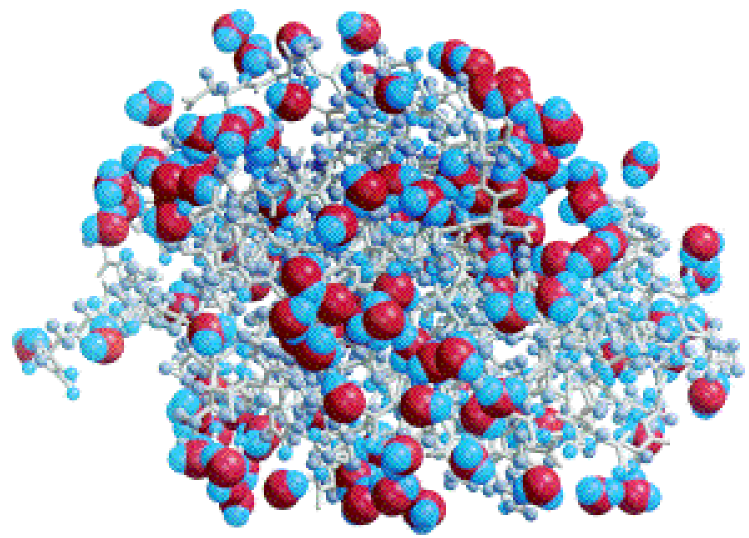
Material for Li-battery seen by X rays (left) and Neutrons (right)

Protein

Hen Egg-White Lysozyme



X-rays

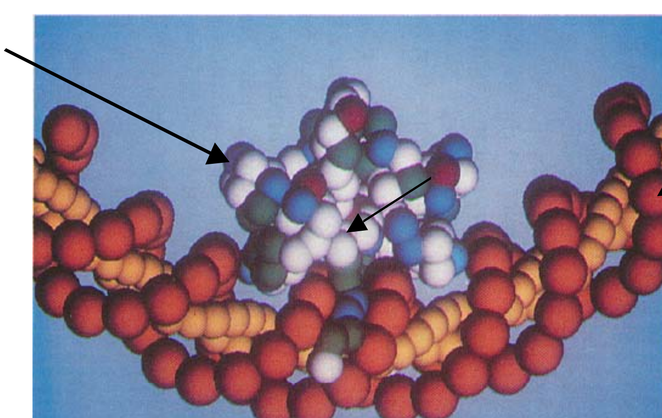


Neutrons

Water molecul
Observed with
neutrons

- Hydrogen (H)
- Oxygen (O)

Protein



DNA

A prot ein
molecule
moving alo

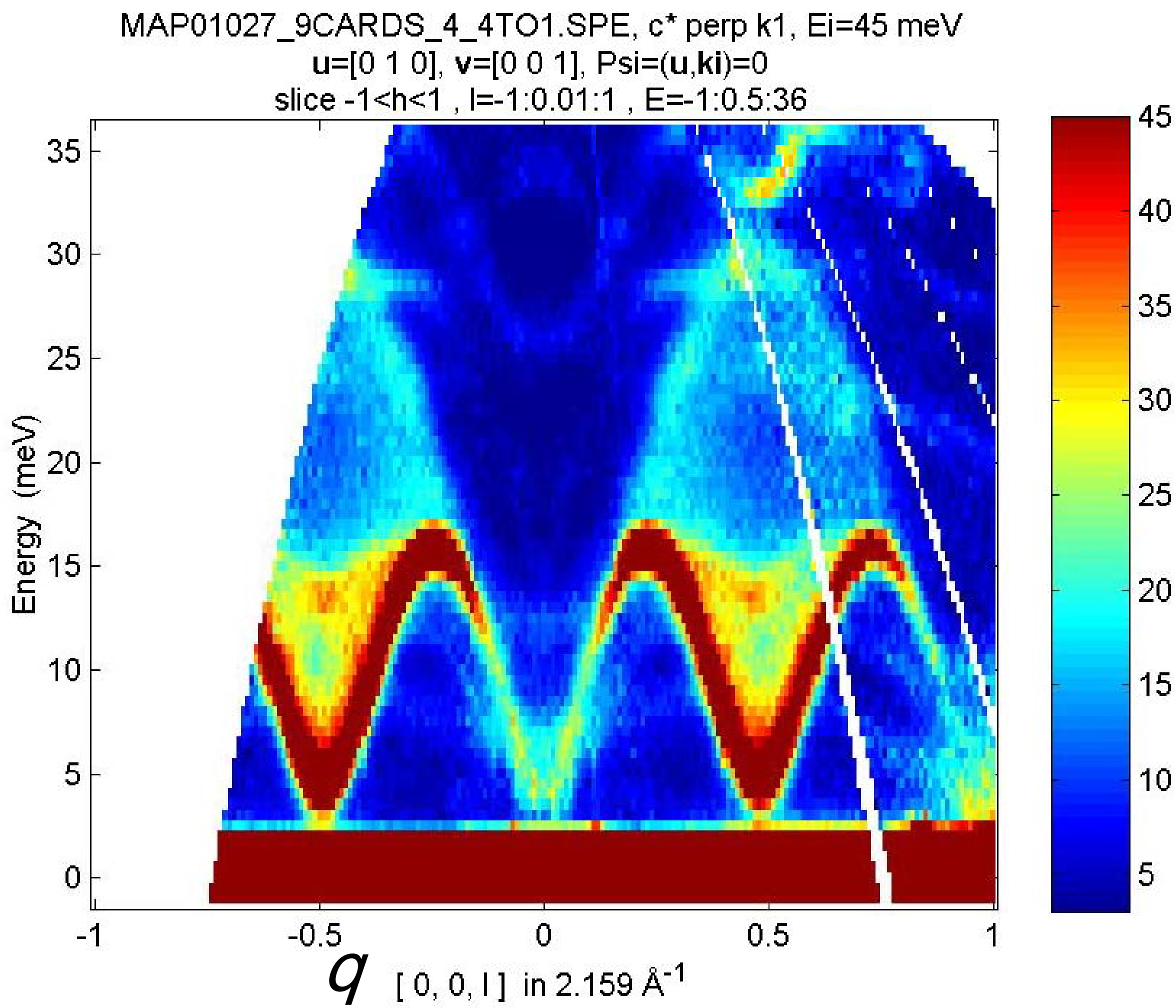
From structure to function

Quantum effect in spin excitation

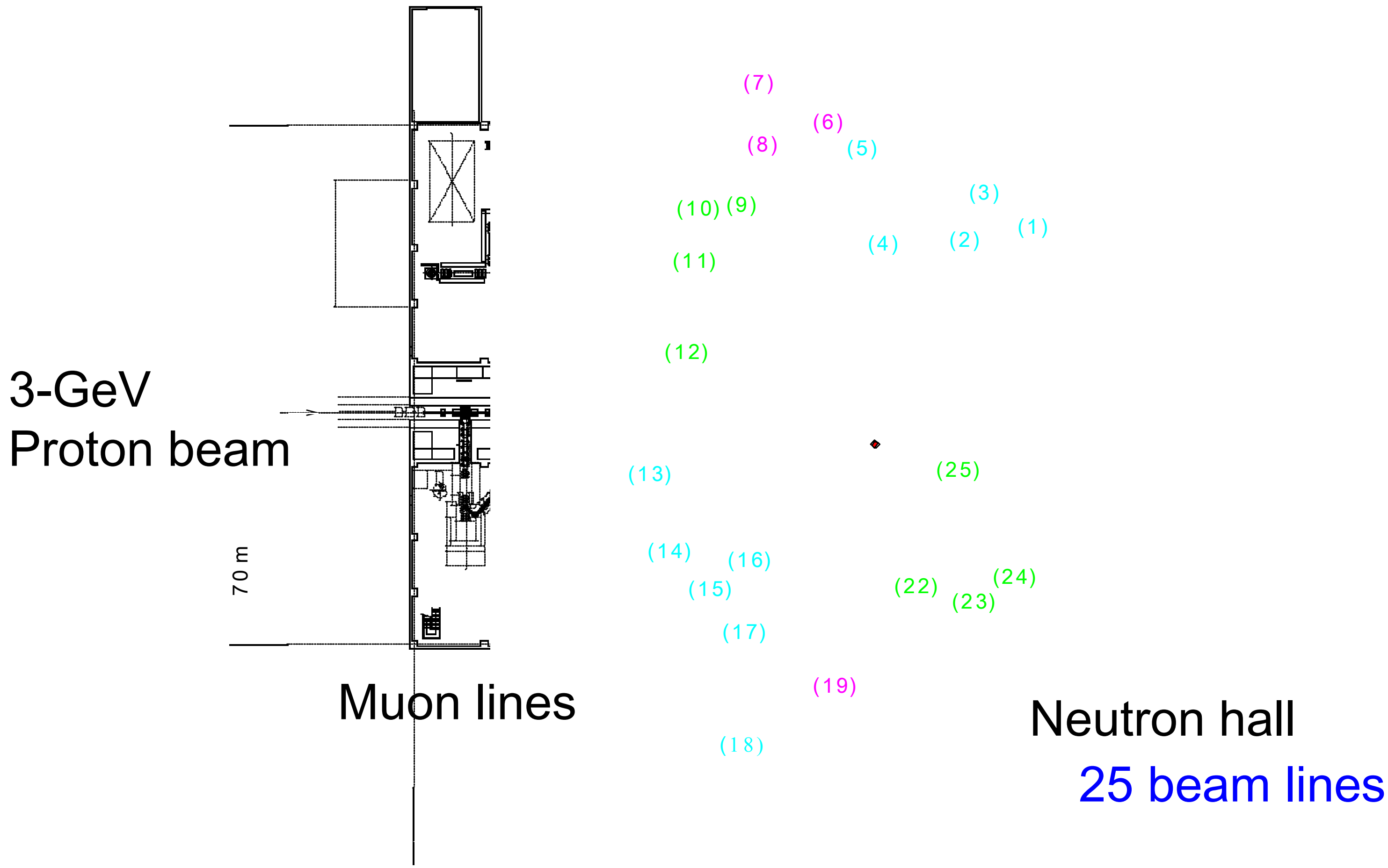
$CuGeO_3$

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

⇨ understanding of High T_c SC *etc.*



Materials/life science facility

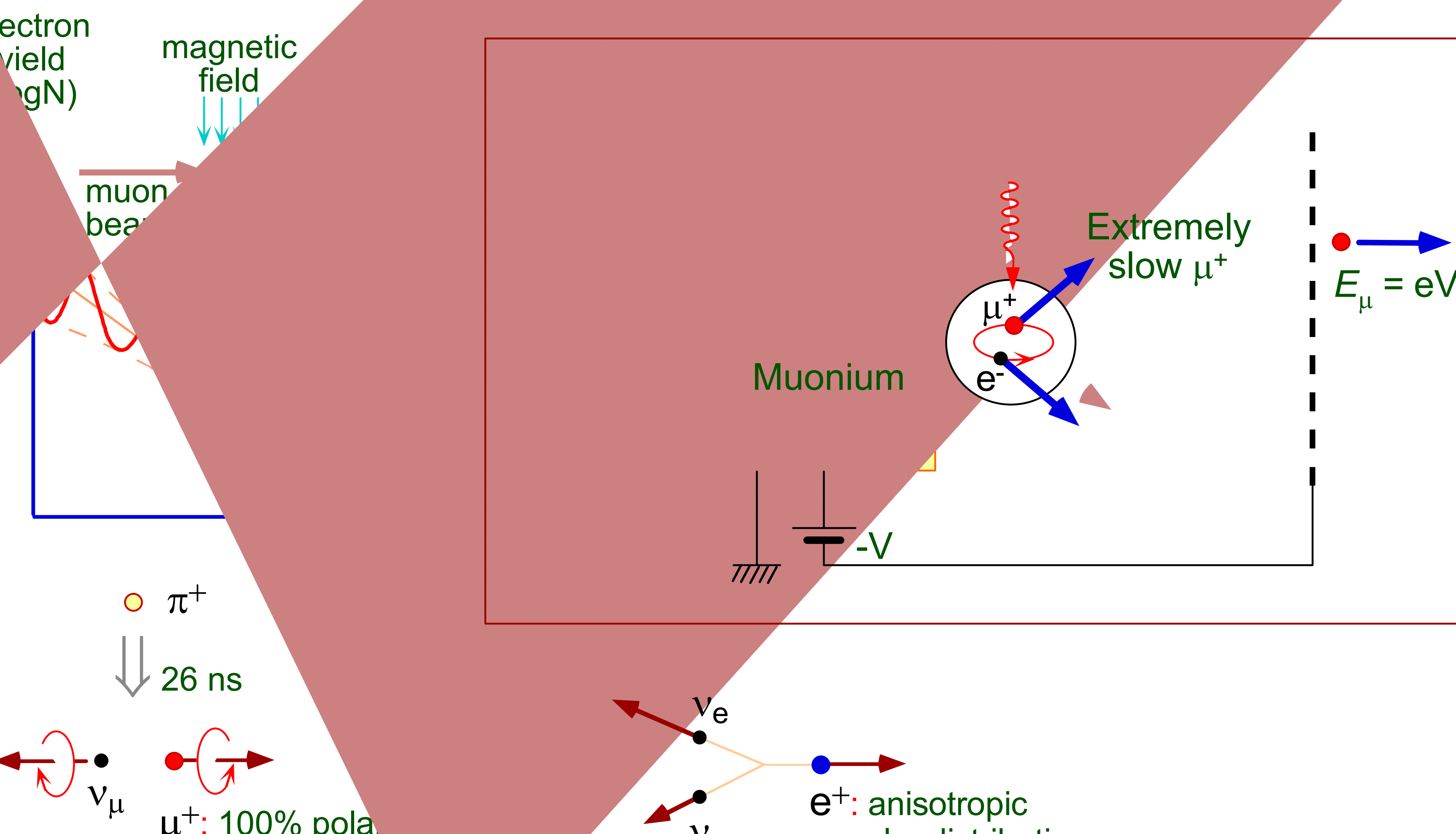


- High resolution chopper spectrometer
- Liquids total scattering diffractometer
- Inverted geometry spectrometer
- High resolution powder spectrometer
- Versatile single crystal diffractometer

μSR and ultra slow muon

μSR

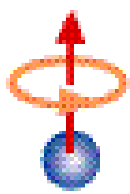
Muonium and Ultra Slow Muon



Muon science

Muon

Two charge states, +e and -e
Muon mass ≈ (1/10)×(proton mass)
200×(electron mass)
Finate magnetic moment



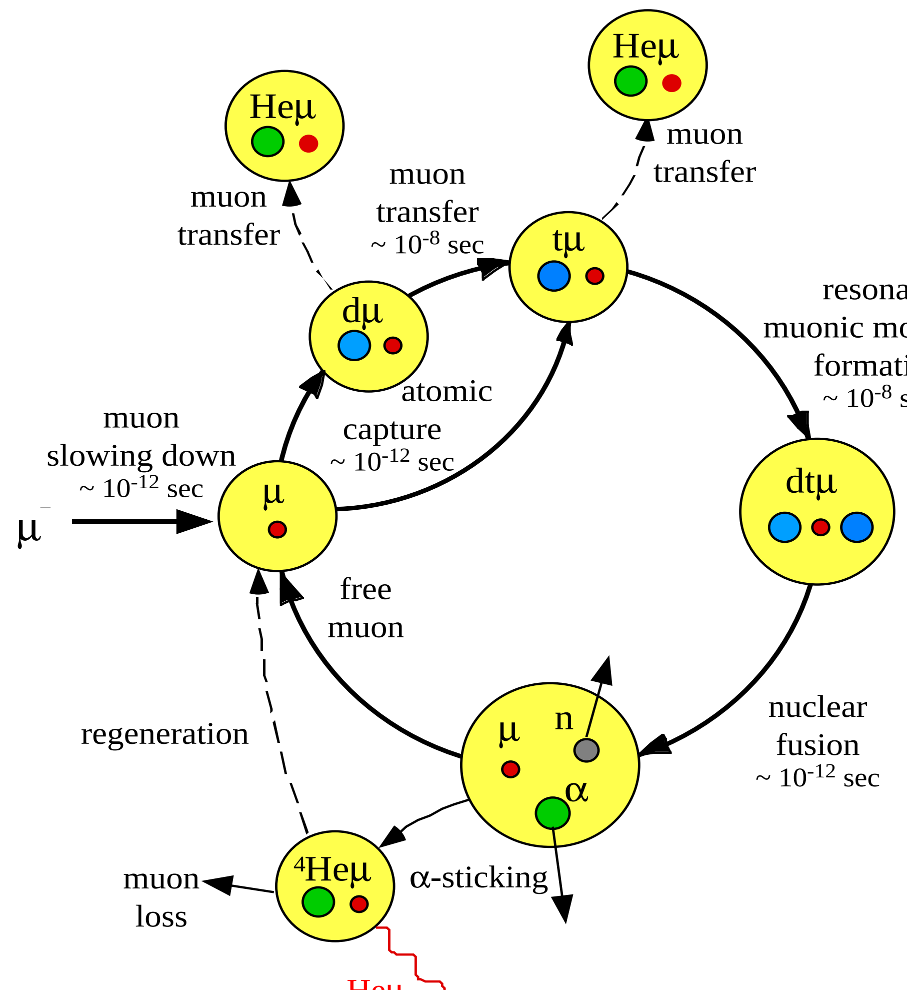
Muonic atom

Muonium

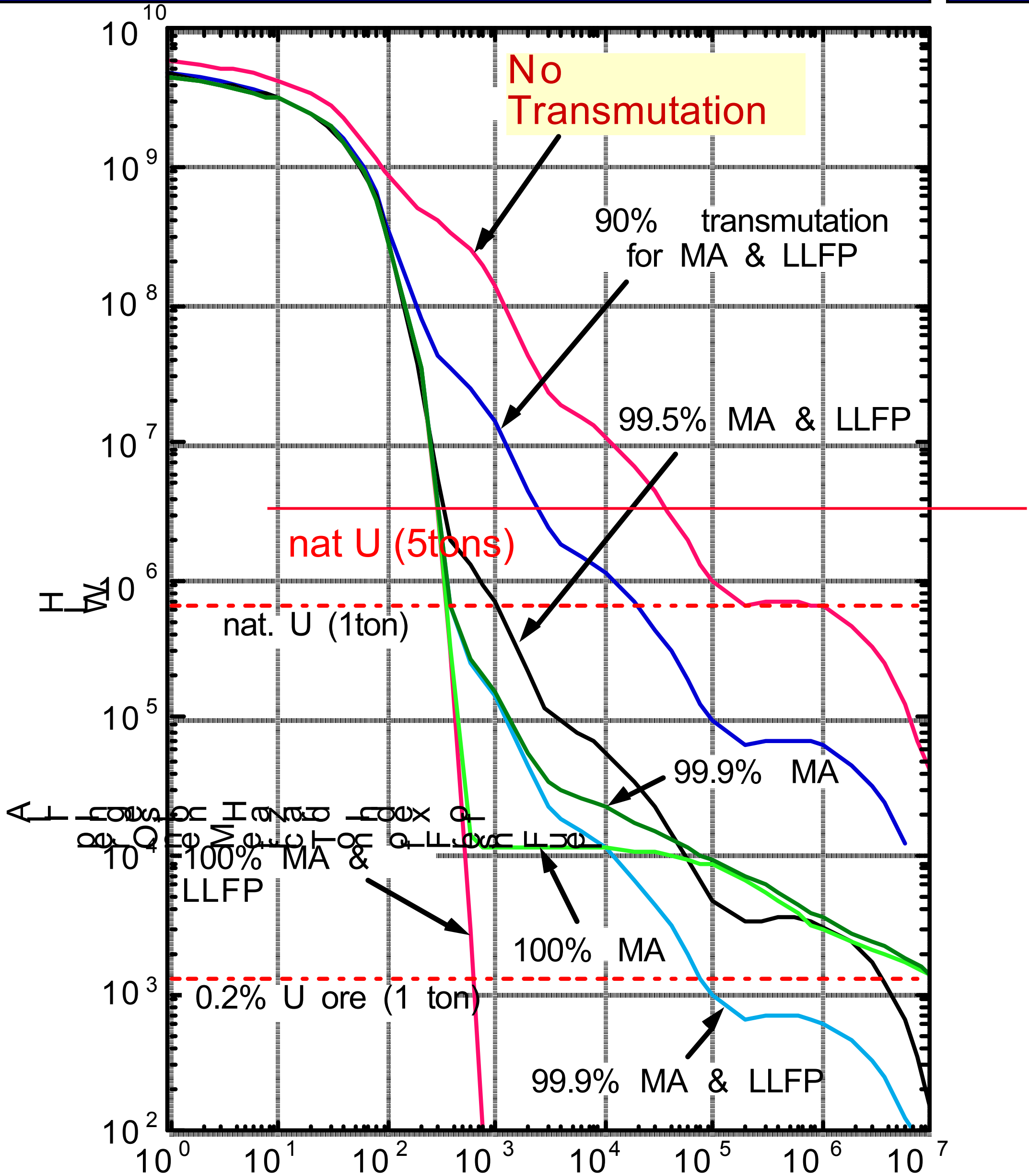
Radius is by 1/200 smaller than the normal atomic size.

Muon catalized fusion

Muon catalized fusion cycle in D_2-T_2 system



Necessity of nuclear transmutation

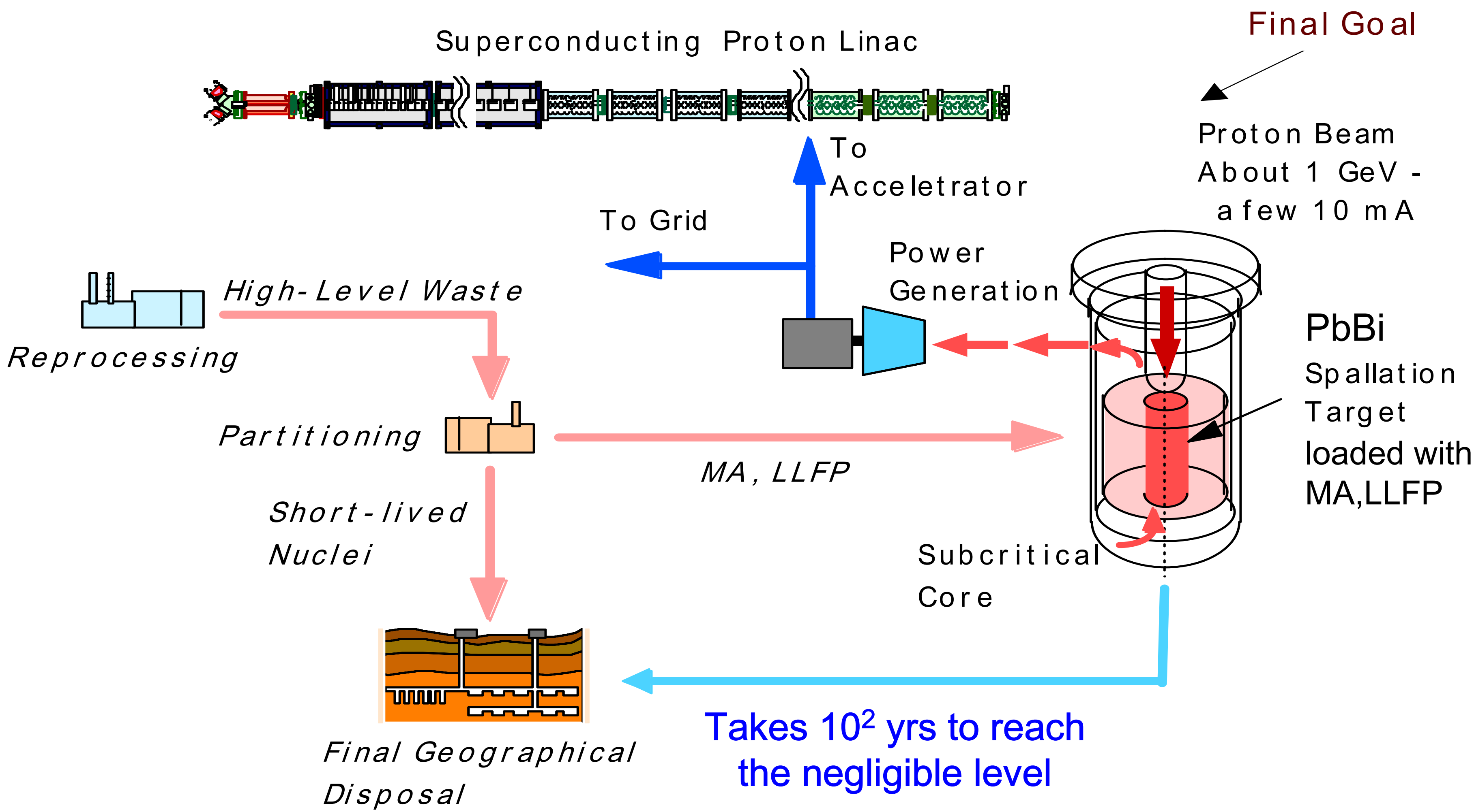


- 99.5% transmutation efficiency will reduce the radioactivity level to the natural uranium level within 500 years

- Technical feasibility is studied using 600 MeV beam at JHF

MA : Np, Am, Cm
LLFP : Tc-99, I-129

Accelerator-driven transmutation (ADS)

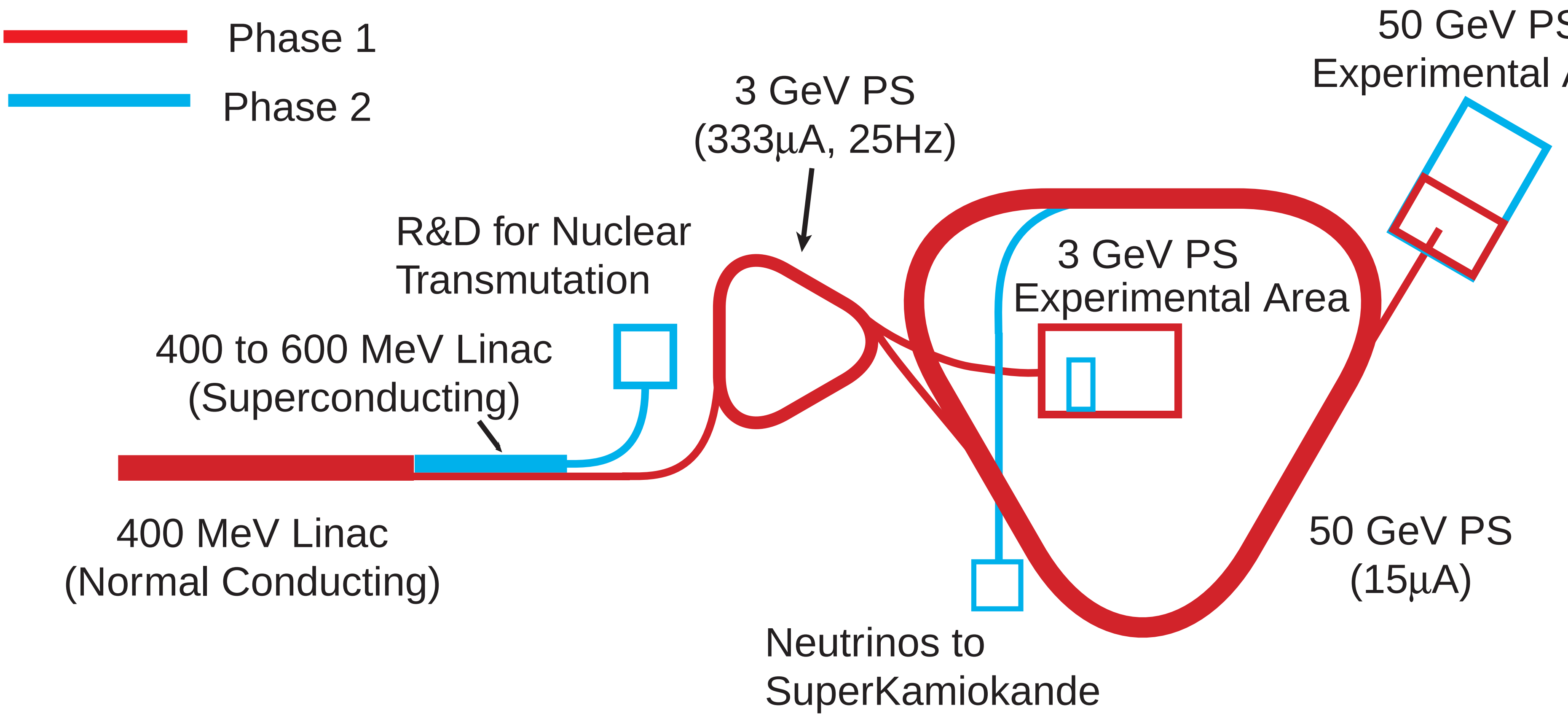


Nuclear transmutaion is an important issue for nuclear power stations. This project will explore the technical feasibility.

Status and Summary

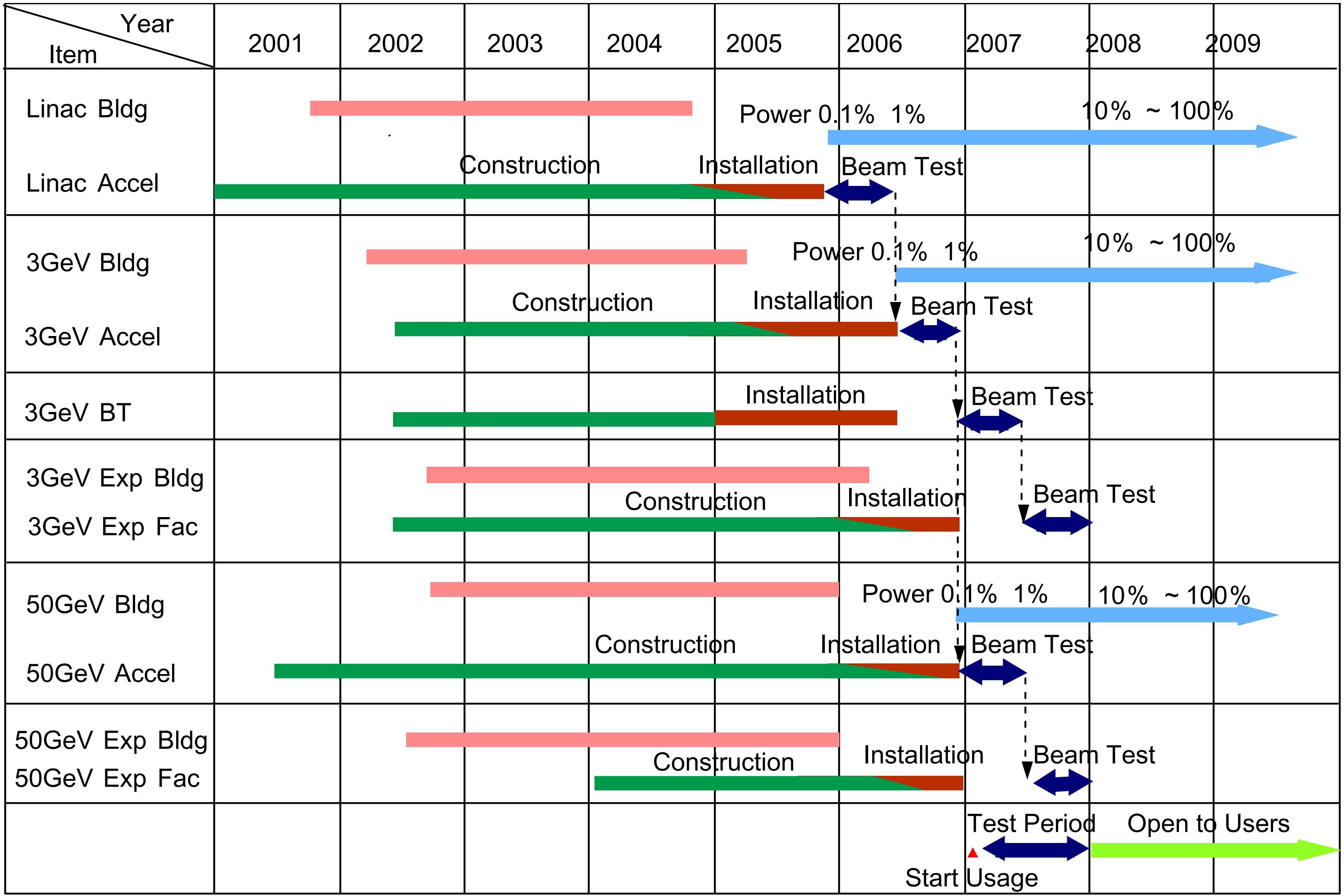
Budget status

- **Phase 1 : Completion in FY2006**



- **Phase 2 : Next budget**

Construction and commissioning



Summary

- ‘JHF’ will be a unique facility in which all kinds of physics are carried out with highest beam intensity.
  - 3 GeV PS : materials and life sciences
  - 50 GeV PS : particle and nuclear physics
  - 600 MeV Linac : basic studies of ADS
- Important elements for the “joint” project are;
  - KEK is strong for particle and nuclear physics
  - Both institutions are strong for neutron physics
  - JAERI is strong for nuclear transmutation
- ‘JHF’ aims for an international research center.
  - Open to world-wide users
  - International cooperation in facility construction