# The status of the German spallation source project (SNQ).

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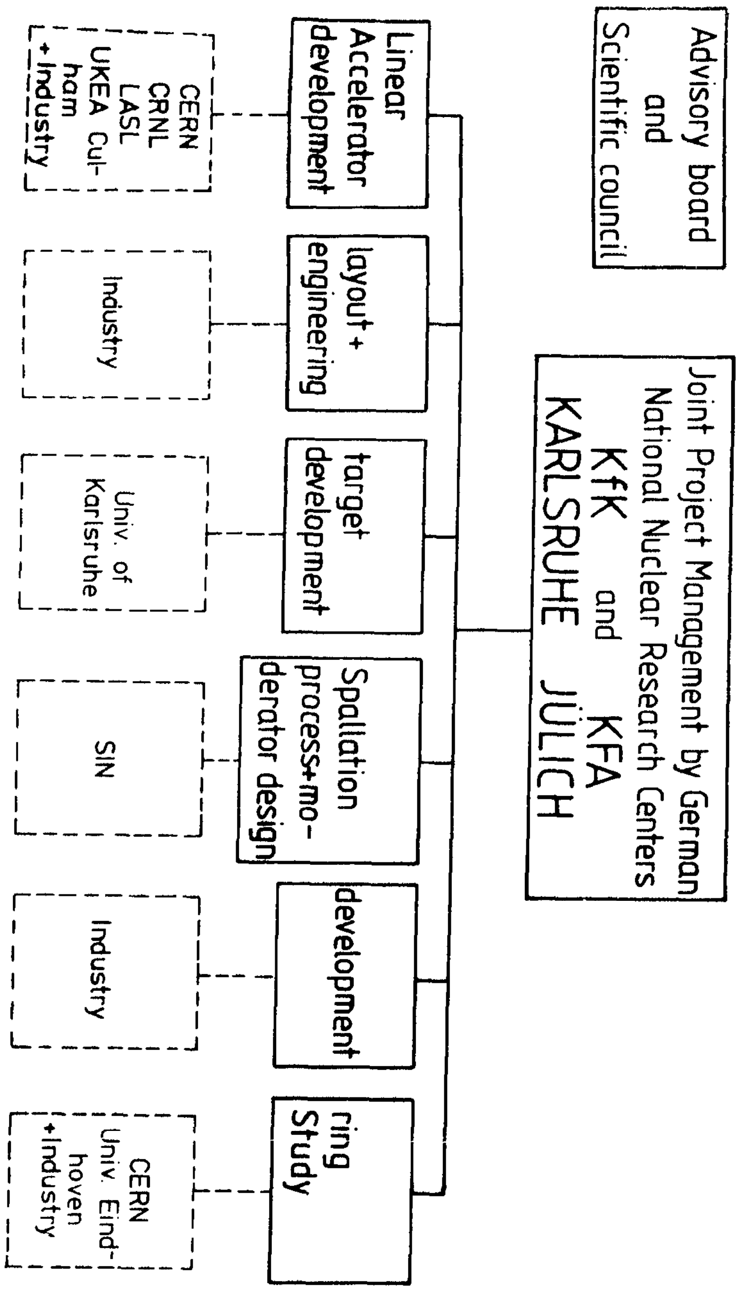
## 1. Progress since ICANS-III

In 1977, the German minister for research and technology (BMFT) appointed a panel of scientists to study future developments for research with neutrons. In 1979, the panel recommended a detailed investigation on the feasibility of a spallation neutron source. This recommendation was based on the fact, that one of the research reactors presently in operation in Germany, the FR-2 in Karlsruhe, is planned to be shut-down in 1981, and that with one exception also all other research reactors in Germany are more than 20 years old. Germany is a partner with the tri-national high flux reactor in Grenoble, France, but the average admission rate for experiments with this neutron source is below 50% already now. There are more than 30 very active research groups in Germany using neutron beams. Thus we need a sufficient potential for neutron research with national installations.

The recommendation of the scientific panel was also based on the belief that, if feasible, a spallation neutron source would have a number of interesting advantages in comparison to a fission source, in particular the flexibility in time structure of the neutron flux. Hence the study was leveled for a spallation source which would yield a time-averaged thermal neutron flux comparable to the one of a high flux reactor, and for a time structure optimized to the needs of the scientific experiments.

Following the recommendation, the BMFT asked the two big German National Nuclear Research Laboratories to organize the project study (fig.1).

A reference-concept was fixed in March 1980 and the different tasks are considered by Karlsruhe and Jülich in collaboration with European research laboratories and industry.



Organigram of the snq project study

Computations as well as measurements which will be described in other papers at this conference have shown that with protons as primary particles and lead as target material a time-averaged thermal neutron flux of $7 \times 10^{14}$ cm$^{-2}$ sec$^{-1}$ requires a beam power of 5.5 MW in the target. As to the time structure a pulse repetition rate of 100 sec$^{-1}$ appears optimal for time of flight experiments. In view of these two numbers a linear accelerator had to be choosen for the primary particles. Thus the reference concept is based on a linac for protons (fig. 2), a lead target, and two moderators, a fast small volume ($H_2O$) and a large volume ($D_2O$) one. The primary pulse width was chosen as small as technically feasible: 0.5 msec. In order to render possible an injection of the beam into a compressor-ring the proton energy was chosen to be 1.1 GeV. Hence a mean current of 5 mA is required, with a peak current of 100 mA (the limit of what seems achievable with present technology).

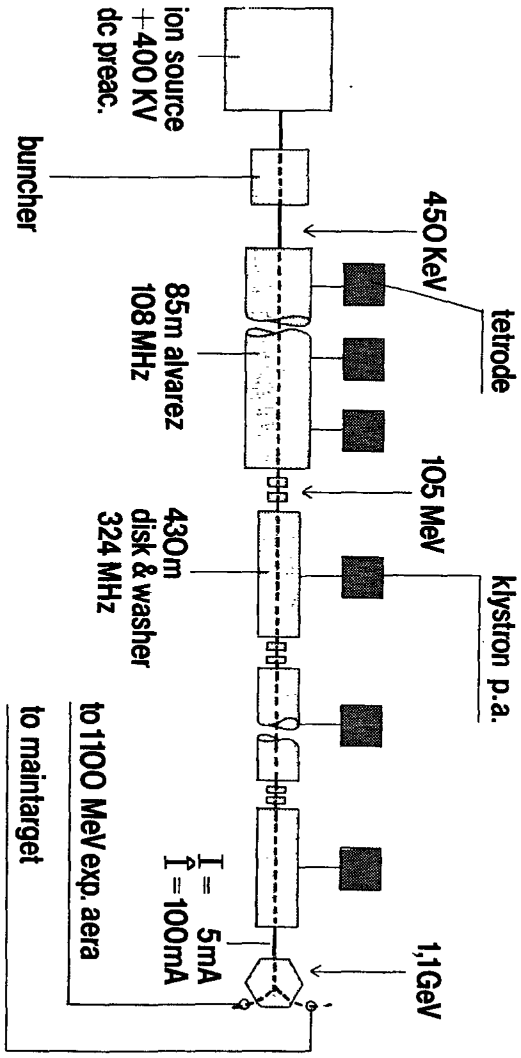
Future options for the machine include a compressor ring for protons (fig. 3) to compress the pulses from the linac by a factor of 65o, gaining a neutron peak flux for the higher thermal and epithermal energy ranges, and - using the protons directly - attracting other research fields.

## 2. Major goals of the SNQ study.

In fig. 4 you find a birds-eye-view on the presently considered main R&D goals. Detailed information will be provided in several contributions to ICANS-IV by Drs.

G.S. BAUER on the target station
J.E. VETTER on the linear accelerator and liquid metal target development
N. NUECKER on cold neutron sources
B. ALEFELD and N. NUECKER on instrument design to utilize the time structure of the flux.
H. STECHEMESSER, D. FILGES and W. LOHMANN on technical aspects and theoretical considerations.

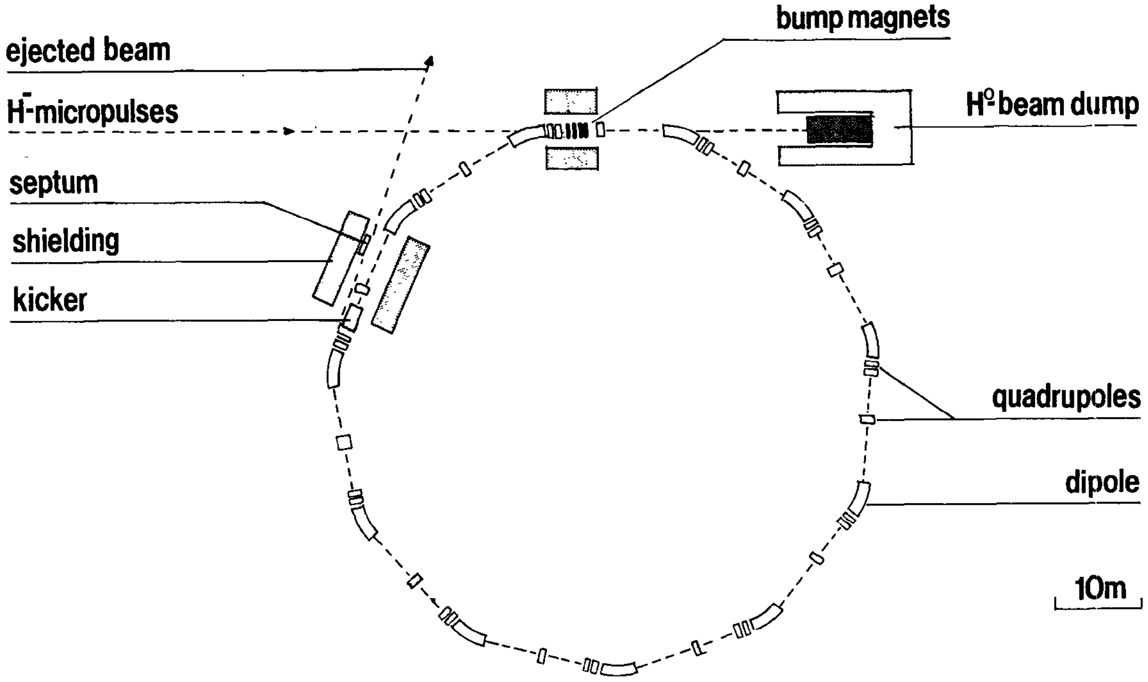
All authors are affiliated with one of the two national laboratories in Karlsruhe or Jülich.
I should only introduce into the different fields very briefly.



snq-linear accelerator, reference concept

| | |
|---|---|
| - better knowledge of the spallation process<br>- optimization of target-moderator arrangements<br>- minimization of background radiation | - experiments at SIN and CEN - Saclay (SATURNE)<br>- theoretical and experimental studies |
| - function test of rotating target (bearings+cooling)<br>- development of liquid-metal target | - prototype to be built<br>- modeling experiments underway |
| - injection into linear accelerator<br>- beam loss<br>- rf-generation | - analysis, experiments and prototype development in collaboration with CERN, LASL and Valvo |
| (option 3) compressor ring layout | -design and layout in co-operation with SIN, CERN, Scanditronix |

major r+d goals snq - study



schematic layout of compressor ring

## 2.1 General

In addition to the flexible time structure of the neutron production, the spallation process offers some further advantages compared to fission-production of neutrons:

- not a critical assembly;
- smaller $\gamma$-background;
- more neutrons per event and thus less heat produced per neutron.

For protons as primary particles one has for $0.5 \leq E_p \leq 2.0$ GeV and mass-numbers A (target) $> 10$ a neutron yield

$$y = a\ (A+b) \cdot (E_p - E_s)$$

a,b depend on geometry and the kind of the target nuclei. A cylindrical target of 10 cm diameter and 60 cm length gives $a=0.1\ (\mathrm{GeV})^{-1}$ and $b=20$ for lead. So one has $y = 20$ (for uranium this amounts to 35) for a 1 GeV proton. The heat per neutron produced by a 1 GeV proton in lead is some 20 MeV.

Special drawbacks compared to a reactor are felt with the necessity to put continuously energy into the machine, and with the appearance of very high energy neutrons. About 5% of the neutrons generated are expected with energies above 100 MeV. They have to be filtered out by the time structure and, of course, by sufficient shielding.

## 2.2 Linear Accelerator

100 mA of peak beam current during macropulses of 500 µs duration have to be accelerated to an energy of 1100 MeV.

The main extrapolation from state of the art is the beam power of 5.5 MW. Beam loss and its consequences have been of primary concern for the linac design. As an example, the operation frequencies of the rf accelerator were chosen lower than usual, leaving large apertures for the beam, provisions for installation of remote handling is provided all along the accelerator, beam diagnostics will be installed at various locations and emittance control will be done at any suitable place along the accelerator.

These precautions aim at keeping the machine accessible for hands-on-maintenance after shut down. This imposes very stringent conditions on the long term beam spill which should not exceed a few watts/m length at highest energies (some $10^{-7}$ of total beam intensity per m!).
Besides beam loss, considerations of economy and reliability influenced the design parameters.

The reference accelerator consists of:

- Injection, i.e.: ion source, preacceleration, low energy beam transport and beam pulse forming devices
- Alvarez accelerator
- Disk and washer accelerator and high energy beam transport

A magnetic multipole ion source provides 250 mA of total beam current during the beam pulse of about 1 ms duration. After separation of the protons from molecular ions at 50 keV energy level,the beam is transversally shaped and preaccelerated to an energy of 450 keV. Formation of the macropulse and matching to the transverse and longitudinal acceptances of the following rf accelerator is done in the low energy beam transport. About 80% of the dc beam can be trapped into the acceleration process.

The Alvarez linac consists of 7 tanks, 12 m long each, fed by 1.7 MW tetrode power amplifiers operating at a frequency of 108 MHz. Most of the technology could be adopted from the GSI heavy ion accelerator (same duty cycle and frequency ), and from the CERN new linac (comparable space charge problems).

At 100 MeV transition to the disk and washer accelerator is made, because the drop of acceleration efficiency calls for another type of accelerating structure and a higher frequency.

57tanks, operating at 324 MHz, accelerate the beam with an energy gradient of 3 MeV/m, within Kilpatrick's limit of peak field strenghts. The overall length of the accelerator from injection to the high energy exit thus amounts to about 600 m. The accelerator structure is intersected by quadrupole focusing elements. Rf power is generated in 89 klystron amplifiers designed for 3.7 MW of saturated peak power, each. Development of a suitable klystron and fast control systems is underway in collaboration with industry.

Magnetic field strengths in all optical elements and vacuum conditions were chosen in view of an $H^-$ beam, replacing the protons, when the compressor ring shall be added to the accelerator.

Variable fractions of the beam pulses can be extracted into the 400 MeV and 1100 MeV areas for nuclear physics experiments, whereas most of the pulse will be transmitted to the neutron target.

### 2.4 Target

The target is designed as a rotating wheel of 2.5 m outer diameter (fig. 5). All target material is mounted on the circumference, the proton beam coming in at right angle to the axis of rotation. The target consists of 9000 individually Al-canned Pb-pins, cooled by water which enters and leaves through the shaft.

The speed of rotation is 0.5 rps. The temperature inside the target pin will stay below 120°C, the life-time is estimated to be more than 20 000 hours of operation at full power.

There are of course considerations to use as target material uranium instead of lead. The rotating wheel concept would permit a large variety of target materials. But there are some serious problems connected with such a choice, which might finally outweigh the advantage of the larger neutron production rate in uranium:

- more power at the target to be cooled off, or use of a smaller beam-current,
- pass a tighter legal approval scheme,

If materials other than lead were ruled out a different target concept also could be considered. Additional development work is done in parallel for a target of liquid Bi-Pb.[+)]

### 2.5 Moderators and reflectors

Since the SNQ-project aims to serve a broad range of different users (including irradiation with thermal or fast neutrons), the locations above and below the target-wheel may be used for 2 different moderators: a fast $H_2O$ moderator (with a Pb (or Be)-reflector) below the target for good pulse structure, and a $D_2O$ tank (for a large volume of high flux) above the target wheel. A cold source (probably $D_2$) will be inserted into the $D_2O$ tank, with neutron guides into a separate hall.

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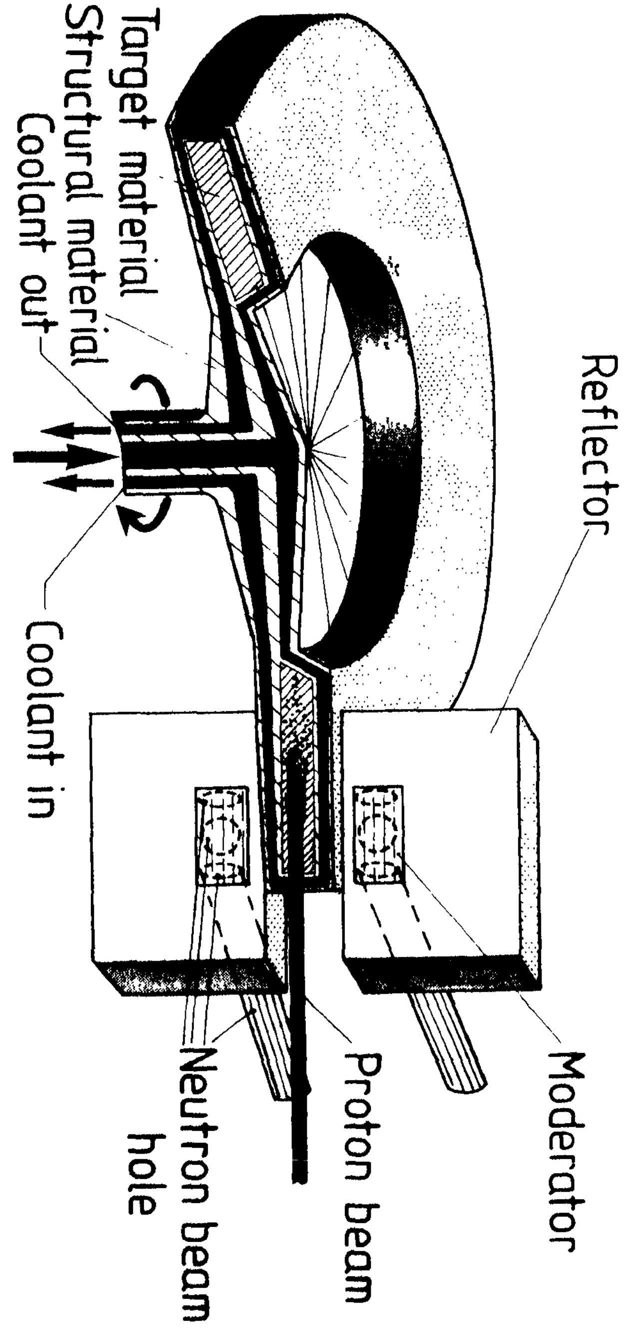
[+)] H.S.Hoffmann, P.E.Huber, M. Piesche, Liquid Metal Target Development for the German Neutron Source (SNQ), these proceedings



Rotating high power spallation target

## 2.6 Compressor Ring

If the proton pulses coming at 100 Hz in 0.5 ms bunches from the LINAC were stored in a circular orbit, one could empty this orbit, once completely filled by an accelator macropulse, at one stroke.

For $\phi$ = 65m one could fill eventually 80% of the orbits length with protons (about $2.7 \cdot 10^{14}$ protons). These protons then could be periodically extracted to give an intensity gain-factor of $\sim$ 650 by keeping just the same average current.

With such a device, neutron pulses with epithermal energies ($\lesssim$ eV-range) and a width of 10 $\mu$sec could be obtained, thus opening this energy range for experiments. (TOF: E=1 eV; $\Delta E/E = 10^{-2}$; $\Delta t = 10\mu$sec; flight-length $= \Delta t \cdot (E/\Delta E)\ (8E/m)^{1/2} = 30$m).

The conceptual design work for this device is done in collaboration with experts from Eindhoven, SIN, CERN, Scanditronix, the responsability given to H. WILLAX, from SIN. Several problems are to be solved:

- Injection (phase space problems)
- Space charge instabilities ($\sim v^{-2}\ (\frac{mo}{m})^3$ ).

## 3. Experiments under way in the course of a project verification.

As shown in Fig. 7 some crucial questions are tackled experimentally in collaboration with different laboratories:

Accelerator: CERN, LASL, VALVO
Target: Flux distribution in moderators (SIN)
Flux distribution for fast neutrons (SATURNE)
Spallation process: SIN, SATURNE.

## 4. Science connected with the use of SNQ.

Neutron experiments (physics, chemistry, biology) are the spear-head of the justification for such an expensive installation. Most types of experiments will be better off compared to the ILL-HFR. One could group the neutron scattering experiments into four classes:

(1) Experiments only using the mean flux (irradiation): gain factor 1

(2) Experiments using the mean flux, making profit from gating synchronously with the pulse to reduce background noise and higher order contamination (e.g. from a monochromator) estimated gain factor 2

(3) Thermal time-of-flight experiments, making full use of the peak flux gain factor 18 (without the compressor-ring)

(4) New types of experiments.

With the compressor-ring, another factor between 2 and 3 could be gained for time of flight measurements with thermal neutrons. The gain will be enormous for neutrons with energies above 0.1 meV. This gain, together with the fact that the pulse structure of the beam itself is appropriate for time of flight measurements with neutrons of such energies, renders the electron volt region accessible to neutron spectroscopy.

I will here not go into the details of solid state physics in this spectral range (electronic band structures via $\chi(Q,\omega)$, high excitation of local moments, high $\hbar\omega$, molecular excitations in solids or fluids, structural analysis of fluids and amorphous solids with high Q), but instead mention some physics based on $\mu^+$-particles, neutrinos, and direct use of the primary protons. $\mu^+$ as well as $\nu$ are produced by primary protons:

$$p + A \longrightarrow \pi^{\pm} + \ldots.$$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_\mu\ (\bar{\nu}_\mu\ ) \qquad \tau_\pi = 2.6 \cdot 10^{-8} \text{ sec}$$

$$\mu^{\pm} \rightarrow e^{\pm} + \nu_e + \bar{\nu}_\mu\ (\bar{\nu}_e + \nu_\mu\ ) \quad \tau_\mu = 2.2 \cdot 10^{-6} \text{ sec}$$

A suitable target may produce 99% of the neutrinos from stopped pions. The different life-times $\tau_\pi$ and $\tau_\mu$ are to be used in connection with the pulse-structure of the beam to separate pion or muon-decay events.

### 4.1 Solid state physics by muons.

Fundamentally, one can use the charge or the magnetic moment of the muons for probing solid state behavior.
The Larmor frequency for muon-spin rotation (μSR) is : $\omega_L/H = 2\mu_\mu/\hbar =$ 85.5 KHz/Gauss. Since muons are emitted polarized parallel (or antiparallel) to the pion-momentum, one can measure the change in spin-direction by non-symmetric distribution of positrons after the muon decay.

#### 4.1.1 To probe internal magnetic fields (ferromagnetics, paramagnetic metals (Knight-shift), one could

either directly follow the $e^+$-intensity oscillations in a fixed detector after μSR. A spallation source with a "compressed" (accumulated) beam of small pulse width (e.g. $10^{-7}$sec) could lead to the detection of small $\omega_L$ ie. small H not accessible with only the muon-lifetime 2.2 μsec.

or choose an external field, so that $\omega_L$ equals the pulse-repetition frequency (100 Hz). Thus all muons would oscillate in phase, if not internal fields would cause deviations.
The precision of the measurements is directly proportional to the beam intensity (1o-1oo ppm Knight shift obtainable).

If the muons would show a fast diffusion in a random magnetic lattice, on the average there would be no effect on the muon spin. Traps for muons would then lead to a visible effect.
Again, short pulses from the accumulator would allow the detection of very small effects (e.g. relaxation rates during depolarization in a longitudinal external field).

#### 4.1.2 Channeling of $\pi^+$ or $\mu^+$.

There is a pronounced correlation between the decay-spectrum and the crystal axes. Perfect crystals show maximum intensity for thermalized $\mu^+$ or $\pi^+$ on interstitials along the "channels" in the lattice. Defects, especially holes trap the muons and reduce the intensity along close packed chains. High intensity is necessary. There is practically no noise for that measurements.

### 4.2 Neutrino-physics.

Pion-decay neutrinos come with 30 MeV, those from muon-decay with less than 53 MeV.
A neutrino flux of $\phi_\nu \sim 2.5 \cdot 10^9\ \mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$ in 5m distance from the target could be expected for an accumulated SNQ-p-beam. That would allow to reduce the lower limit for measurements of mass-differences between neutrinos $\Delta^2 := m_2{}^2 - m_1^2$, to $\geq 0.03\ (\mathrm{eV})^2$ [instead of $\Delta^2 > 1\ (\mathrm{eV})^2$ available now.]
Inelastic scattering of neutrinos at nuclei

$$\nu_\mu + (A,Z)\ [T,I] \rightarrow \nu_\mu + (A,Z)^+\ [T',I']$$

(T: isospin, I:spin)

e.g. $^7\mathrm{Li}\ (\nu,\nu')^7\ \mathrm{Li}^*$ or $^6\mathrm{Li}$, $^{12}\mathrm{C}$, $^{19}\mathrm{F}$ could be detected by the γ-particles emitted from $A^+$. Thus, nuclear physics with neutral-neutrino-currents could be performed, unique in the sense that neutrinos cannot change the nucleon-configuration in the target by either strong or electromagnetic interaction (as all other probes would do). Here you see the importance of the separation of neutrinos from pion and muon decays.
Using clean muon-neutrinos after pion-decay allows the determination of model free matrix-elements. (cf. T.W. Donnelly, R.D. Peccei, Neutral Current Effects in Nuclei, Physics Reports 50, 1, (1979)).

### 4.3 Nuclear physics with protons.

- (p,2p)-, (p,pn)-reaction for $300 \leq E_p \leq 500$ MeV
  (internal structure of the nucleus)
- few nucleon reactions for better understanding of internal dynamics of few-nucleon-systems
- (p,pα)-reactions for cluster-structure at the surface of nuclei.

We feel, that the goals in n-scattering physics as well as in nuclear and solid state physics as mentioned provide an interesting challenge to all of us to put this new type of instrument into being with all efforts possible, as soon as possible.