Proposal for experiment submitted to GSI , PAC committee

Spokesperson: I. Tanihata
Co-spokesperson : R. Kanungo

Density distribution of ^{58,72}Ni and ^{72}Ge from proton elastic scattering

R. Kanungo, S. Kishi[1], T.Murakami[1], T. Ohnishi, A. Ozawa, H. Sakaguchi[1], T. Suda, H. Takeda[1], I. Tanihata, S. Terashima[1], M. Uchida[1], Y. Yasuda[1], K. Iida, A. Kohama, K. Oyamatsu[2]

RIKEN, 2-1, Hirosawa, Wako-shi Saitama 351-0198, Japan
[1]Graduate School of Physics, Kyoto University, Kyoto 606-8502, Japan
[2] Dept. of Media Production and Theories, Aichi Shukutoku University, Nagakute, Nagakute-cho, Aichi-gun, Aichi 480-1197, Japan

L. Chulkov, P. Egelhof , H. Geissel, O. Kiselev, G. Münzenberg, H. Simon, K. Summerer , H. Weick, and T. Yamaguchi,

GSI, Darmstadt, 6421 Germany

TU Darmstadt (to be confirmed)

Nasser Kalantar-Nayestanaki, M.N. Harakeh, Ad van den Berg and Heinrich Woertche

KVI, Gröningen

Motivation:

The study of nuclear density distributions is one of the fundamental interest in nuclear physics as it provides the basic understanding on its structure. This is particularly important for nuclei far from stability which show interesting deviations from usual systematics of stable nuclei. Furthermore, study of the isotopic dependence of the charge and matter density of nuclei is also extremely important from astrophysical view point since it serves as a guidance for the determination of equation of state (EOS) for asymmetric nuclear matter [1].

Protons have long been the simplest hadronic probes to be used for matter density distribution. This proposal aims to measure the density of neutron rich Ni isotopes ^{72}Ni in inverse kinematics using a proton target. For studying systematic isotopic trends the scattering from ^{58}Ni (stable nucleus) will also be performed using the same method. To study the isobaric trend similar measurement with primary beam of ^{72}Ge will be performed. The determination of the density distribution needs to be model independent to make an unambiguous prediction on the unknown structure of exotic nuclei. This requires proper energy selections which guides us to choose 400*A* MeV as best suited for the present purpose since all available methods of analysis can be applied at this energy. Furthermore, for extension of this study to more neutron rich Ni isotopes we look forward to the future facility RI Beam factory, RIKEN, Japan. In this facility the available energy range would be around 400*A* MeV. Moreover studies in the GSI future facility are aimed at the ESR which is also suitable in this energy range.

The choice of the required energy and the desired secondary beam intensity makes GSI the best suited laboratory at present to perform this experiment.

The experiment will be performed in inverse kinematics with a secondary beam of ^{72}Ni, produced by FRS, being incident on a hydrogen target placed at the final achromatic focus(F4) of the FRS. To deduce the root mean square radius (rms) and the surface density distribution, we need an angular coverage of the protons from 70^o to 85^o in the laboratory frame. This is expected to extend the proton detection covering the third diffractive minima (Fig.1,5). The elastic scattering angular distribution is intended to be measured in this angular range with an expected excitation energy resolution of 500 KeV (sigma).

It would be certainly interesting to perform similar study using ^{74}Ni and also ^{68,70}Ni (through ESR as they have isomeric states which is hard to separate at FRS) in future. The present beam intensity available from the SIS is a limitation for some of these studies. If upgradation of intensity by an order of magnitude can be achieved for ^{86}Kr or if ^{76}Ge with 10^{10} or 10^{11} / spill is available it maybe possible to study of these Ni isotopes. We would strongly urge this development of primary beam as it would help in enriching our study.

Density distribution :

The matter density in the shoulder and surface regions can be deduced with fairly good accuracy from the measured elastic scattering angular distribution with the help of different theoretical tools [2] . Such derivations for stable nuclei have successfully employed the relativistic impulse approximation (RIA) [3]. A prediction of the cross section of $^{58-70}$Ni with this model is shown in Fig.1.

Alternatively, Kohama et al, [4] have done a numerical simulation model independently by using pseudo data to see how the obtained density distributions deteriorate as the statistics of data become low. This is based on the Glauber model using a density distribution expanded in terms of basis functions. Although the simulation has been done for 1*A* GeV, the density-data relation should be similar for our energy choice. Figure 2(a) shows that one could deduce rms radius with an accuracy of ±0.05 fm from such analysis. More importantly it can be noted that the shoulder of the density distribution (i.e. the peak in the probability distribution (Fig2b)) can be deduced with very good accuracy.

Besides these, there exists a well developed microscopic model by K.Amos [5], for explaining nucleon-nucleus scattering. Using these several theoretical tools we aim to derive model independently the density distribution of the Ni isotopes.

Equation of state of asymmetric nuclear matter :

It is now pertinent to look at the information required to deduce the EOS for asymmetric nuclear matter. Fig.3a shows the EOS calculated by two arbitrary different models (Skyrme Hartree Fock (SHF) and Relativistic Mean Field (RMF) [6]. It is seen that the two models predict quite different EOS for neutron rich matter. Thus a guidance is required as to which of the models is closer to reality.

Fig. 3b shows the central and shoulder density predicted by these two arbitrary different models SHF and RMF for Ni isotopes. It can be seen that around ^{68}Ni an accuracy of 7% in density distribution shoulder would allow us to distinguish between the different models which will give a guidance as to which model is appropriate for discussing EOS. From the Glauber model analysis (Fig.2b) and also from analysis by RIA this region can be predicted with an accuracy of around 2-3%.

Fig. 3c shows the accuracy in rms radius needed as a function of the neutron number for Ni isotopes to distinguish between the models SHF and RMF . It is seen that for the region around ^{72}Ni, this accuracy is 0.04fm while it can be 0.06fm when one goes to ^{78}Ni. In the analyses procedure following Ref.[4] one can see that the rms radius for ^{58}Ni with an intensity of 10^3 counts per sec can be obtained with an accuracy of 0.01fm while as statistics becomes worse this accuracy worsens and for ^{78}Ni which is expected in RIBF, RIKEN with an intensity of 10 per sec one can get an accuracy of 0.05fm.

Thus, it is expected that the measurement of elastic scattering angular distribution for neutron rich Ni isotopes would not only help us to derive density distribution of neutron rich nuclei with fairly good accuracy, but it would also provide valuable information constraining the EOS of asymmetric nuclear matter.

Description of setup:

A schematic view of the setup is shown in Fig.4. The secondary beam tracked by two wire chambers (TPC1 and TPC2) interacts with a solid hydrogen target (T) (inclined at 45 deg) located at the final achromatic focus F4 of FRS. The development of the windowless thin solid H_2 target is a challenging job and is now in progress at RIKEN. A solid hydrogen target of 5mm thickness is already available and a 3mm one is under construction. As an alternative polythelene (CH_2) target may also be used.

The scattered protons are detected using the recoil detetector assembly labeled as RPD. This detector system consists of two identical sections, which are arranged in a cylindrical geometry for the azimuthal coverage of scattered protons. The target (T) is at the center of the system. Each section is 50cm long vacuum chamber terminated by aramid foil windows and is estimated to have a solid angle ~ 12 msr/deg.. Outside the window a drift chamber followed by a plastic scintillator and a thick NaI(Tl) forms the total detection system. While the drift chamber provides the angle of the scattered protons the plastic scintillator and the NaI(Tl) serves the purpose of energy loss (ΔE) and total energy (E) measurement of the protons. Additionally the Time-of-flight (TOF) between the scintillator SF4 and Sp1 also provides the proton energy which maybe used for certain angular range. The present system will be covering scattering angles from 70^o to 85^o in the laboratory frame.

The drift chambers for recoil proton detection will have an active area of 462mm x462mm and is currently being designed. It is expected to certainly have a position resolution better than 200μm (sigma). Each NaI(Tl) will have a cross –section of 50mmx50mm and will be about 450mm long. Each section of RPD will have 6 sections if NaI(Tl). The resolution of this detector tested for low energy protons is 1% (FWHM). The plastic scintillators will also have a width of 50mm and a length of 45 cm. The resolution of plastic scintillator of 3mm thickness tested for 13MeV protons was 18ps (sigma). For safety in our estimate, we assume 30ps (sigma).
These dimensions have been designed for common use also at RIBF, RIKEN and thus the length of detectors are longer than necessary to cover 70-85 deg in GSI setup.

We have performed a Monte Carlo simulation of the setup with all detector resolutions and multiple scattering effects to estimate an expected excitation energy resolution of 500 KeV (sigma).

The energy of the incident secondary beam will be measured by Time-of-flight (TOF) between two plastic scintillators SF2 and SF4 placed at the second dispersive focus (F2) and final achromatic focus (F4) of the FRS respectively.

To help in minimizing background contribution, the elastically scattered projectile will be detected downstream of the target with the help of an ion chamber, plastic scintillator(SAT) and GSO (or NaI(Tl))crystal using the TOF-ΔE method for Z identification and TOF-E method for the mass identification. Background from non-target materials will be estimated from data without proton target.

Experimental conditions :

Beam :

Primary Beam :

Ion	Energy (*A* MeV)	Intensity/spill
^{86}Kr	600	10^{10} or higher
^{58}Ni	450	10^5

^{72}Ge	450	10^5

Secondary beam:

Ion	Energy (A MeV) (at target)	Intensity/spill At F4
^{72}Ni	400	150

A higher intensity primary beam will certainly help to make the measurement time shorter and also we can go to more neutron rich Ni isotopes.

Target :

Primary target :

Material	Thickness(g/cm^2)
Be	3.0

Secondary target :

Material	Thickness(cm)
Solid H_2	0.1 (0.00708 g/cm^2)

Wedge degrader at F2 :

Material	Central Thickness(g/cm^2)
Al	2.0

Estimation of count rate :

The estimated count rate for ^{72}Ni for a period of 20 days is shown in Fig.5. To successfully deduce the density distribution model independently with the desired accuracy as discussed above, one requires this level of statistics.

It must be stressed that the goal is to measure as neutron rich nucleus as possible. In this perspective we request strongly the primary beam intensity upgradation which will make it possible to measure ^{74}Ni. For the present we have not included ^{74}Ni in the estimation table below (as its intensity works out to be ~ 8/spill) but we are looking forward to an opportunity to measure it.

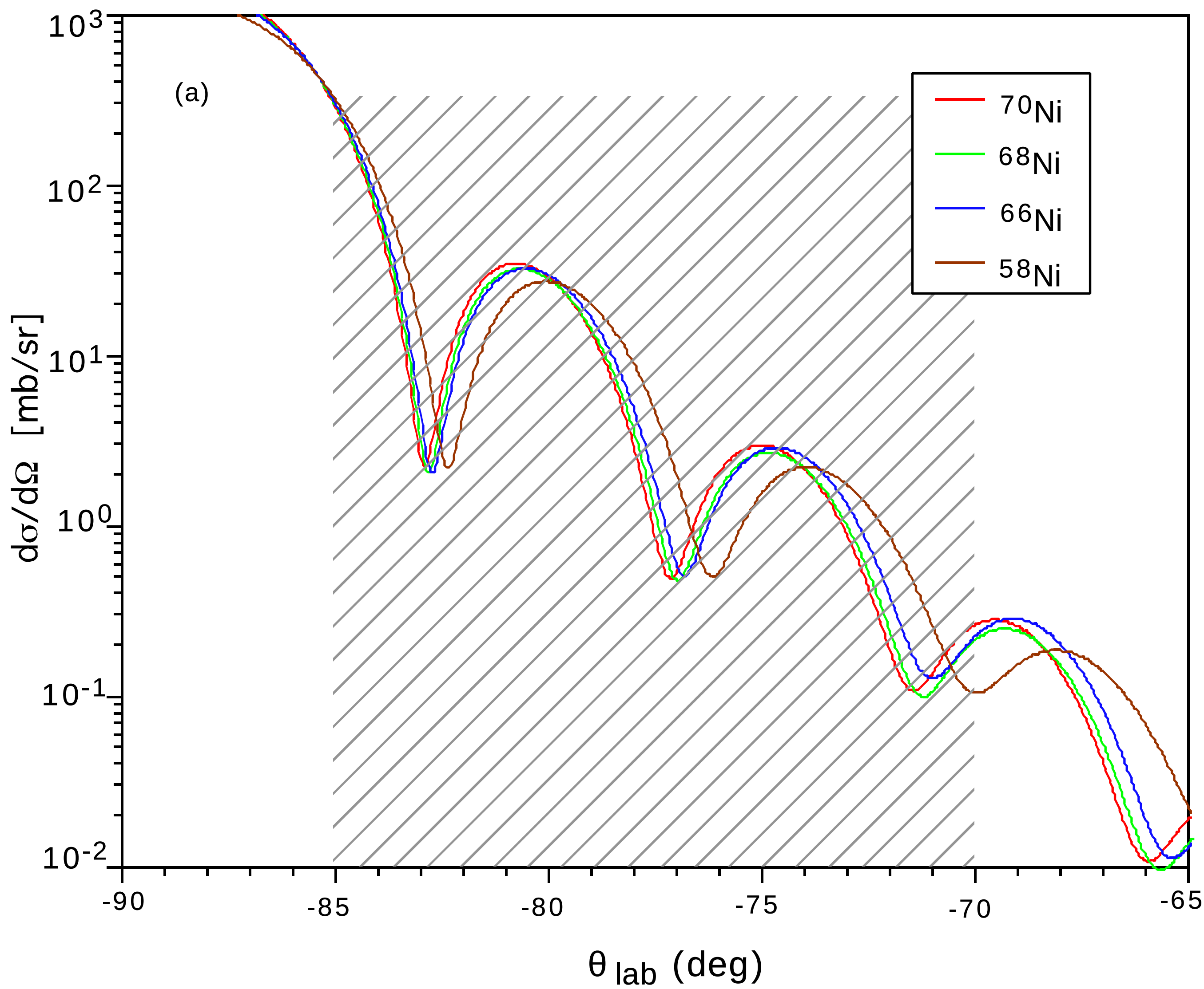
Beam time estimation :

Job	Time (days)
^{72}Ni, FRS tuning + electronics setup + calibration	3
^{72}Ni	
H_2 target in data	20
H_2 target out data	10
^{58}Ni	
FRS tuning	0.5
H_2 target in data	2.0
H_2 target out data	1.0
^{72}Ge	
FRS tuning	0.5
H_2 target in data	2.0
H_2 target out data	1.0
Total beam time	40 days

*** The time estimation for target out data is based on the consideration of estimating background mainly arising due to scattering from plastic scintillator before the target. The estimated thickness of plastic may be ~ 6 times that of the H_2 target, thus we can measure the background with the same accuracy as the real data with the estimated time.

It maybe mentioned that study of p-elastic scattering in the storage ring is an attractive option if enough luminosity is available. We are considering this option for future studies which is also a part of RIKEN-GSI future facility collaborative program and if the count rate and excitation energy resolution are found to be much better than separator experiments we will certainly opt for it.

References:
[1]. K. Iida and K. Oyamatsu, nucl-th/0204033
[2]. C.J. Batty et al, Adv. Nucl. Phys. 19 (1989) 1
[3]. H. Sakaguchi et al, Phys. Rev. C 57 (1998) 1749
[4]. A. Kohama et al, RIKEN-AF-NP-413 Nov. 2001;
A.Kohama, R.Seki, A.Arima, and S.Yamaji, RIKEN Review, 39, (2001) 155.
[5] K. Amos et al, Advances in Nuclear Physics, Vol.25, p.275,
Plenum Press, New York (2000)
[6] K. Oyamatsu et al, Nucl. Phys. A 634 (1998) 3



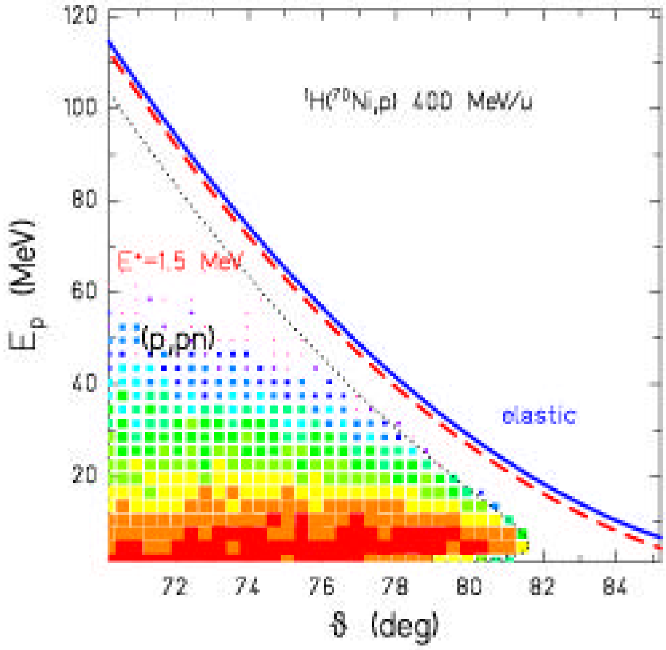
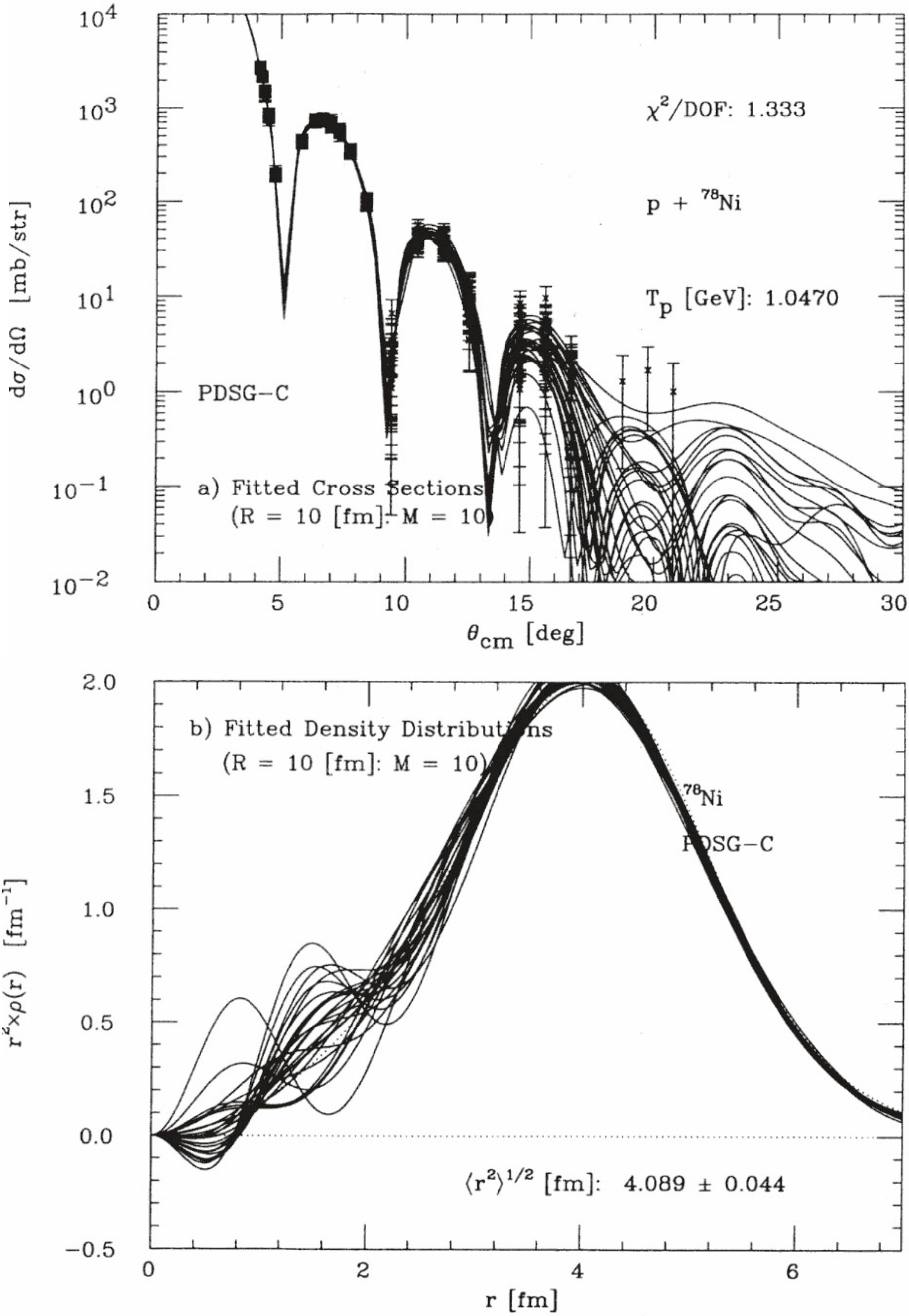


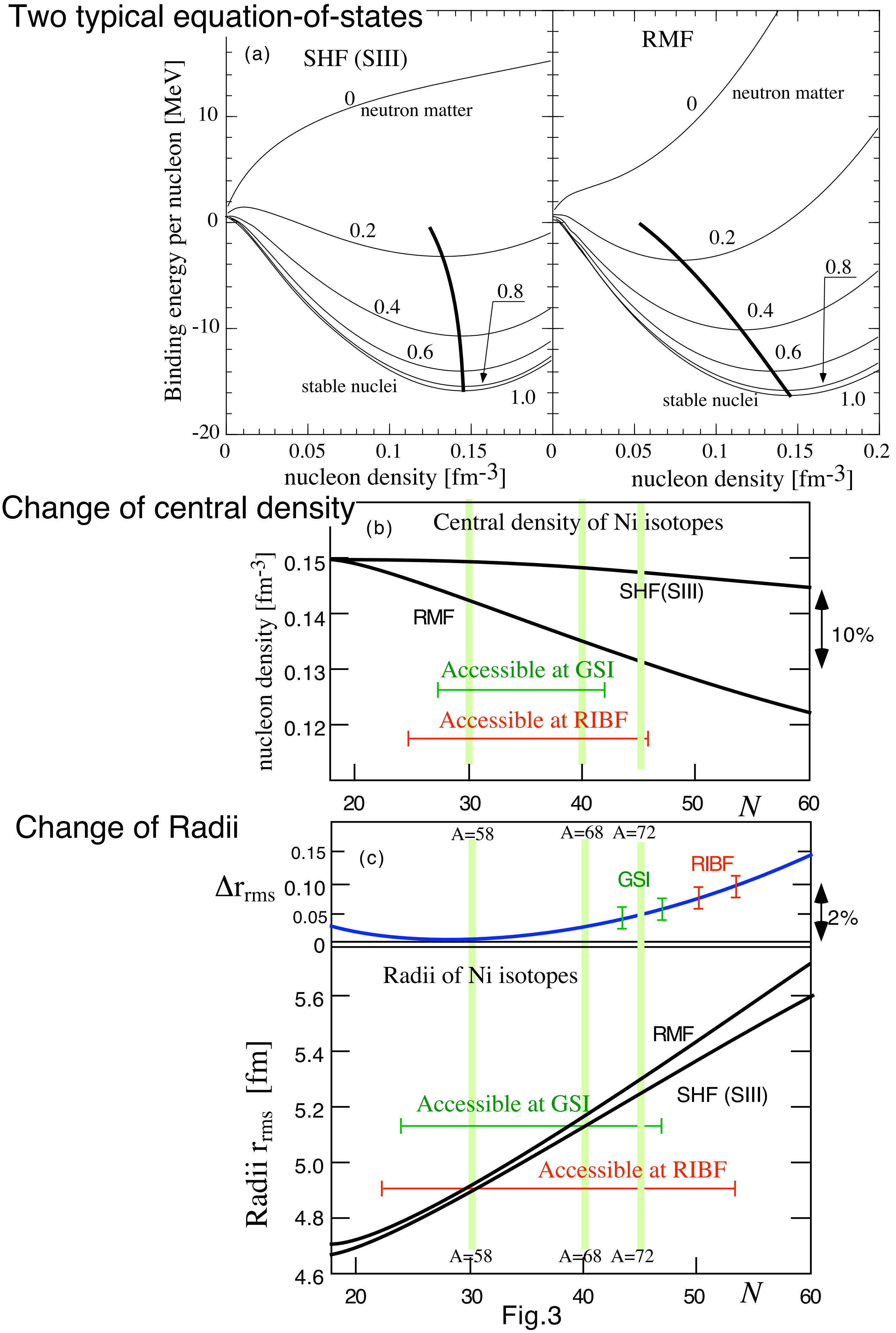
Fig.1

(a) ^{A}Ni+p calculated cross sections by RIA
(shaded area shows the region to be considered for measurement).
(b) An example of ^{70}Ni(p,p) kinematics.



χ²/DOF: 1.333
p + ⁷⁸Ni
T_p [GeV]: 1.0470
PDSG−C
a) Fitted Cross Sections
(R = 10 [fm]: M = 10)
dσ/dΩ [mb/str]
θ_cm [deg]
b) Fitted Density Distributions
(R = 10 [fm]: M = 10)
⁷⁸Ni
PDSG−C
⟨r²⟩^1/2 [fm]: 4.089 ± 0.044
r²×ρ(r) [fm⁻¹]
r [fm]

Fig.2



Two typical equation-of-states
(a) SHF (SIII)
RMF
Binding energy per nucleon [MeV]
neutron matter
stable nuclei
nucleon density [fm-3]
Change of central density
(b) Central density of Ni isotopes
nucleon density [fm-3]
SHF(SIII)
RMF
10%
Accessible at GSI
Accessible at RIBF
Change of Radii
(c)
Δr rms
GSI
RIBF
2%
A=58
A=68
A=72
Radii of Ni isotopes
Radii r rms [fm]
RMF
SHF (SIII)
Accessible at GSI
Accessible at RIBF
N

Fig.3

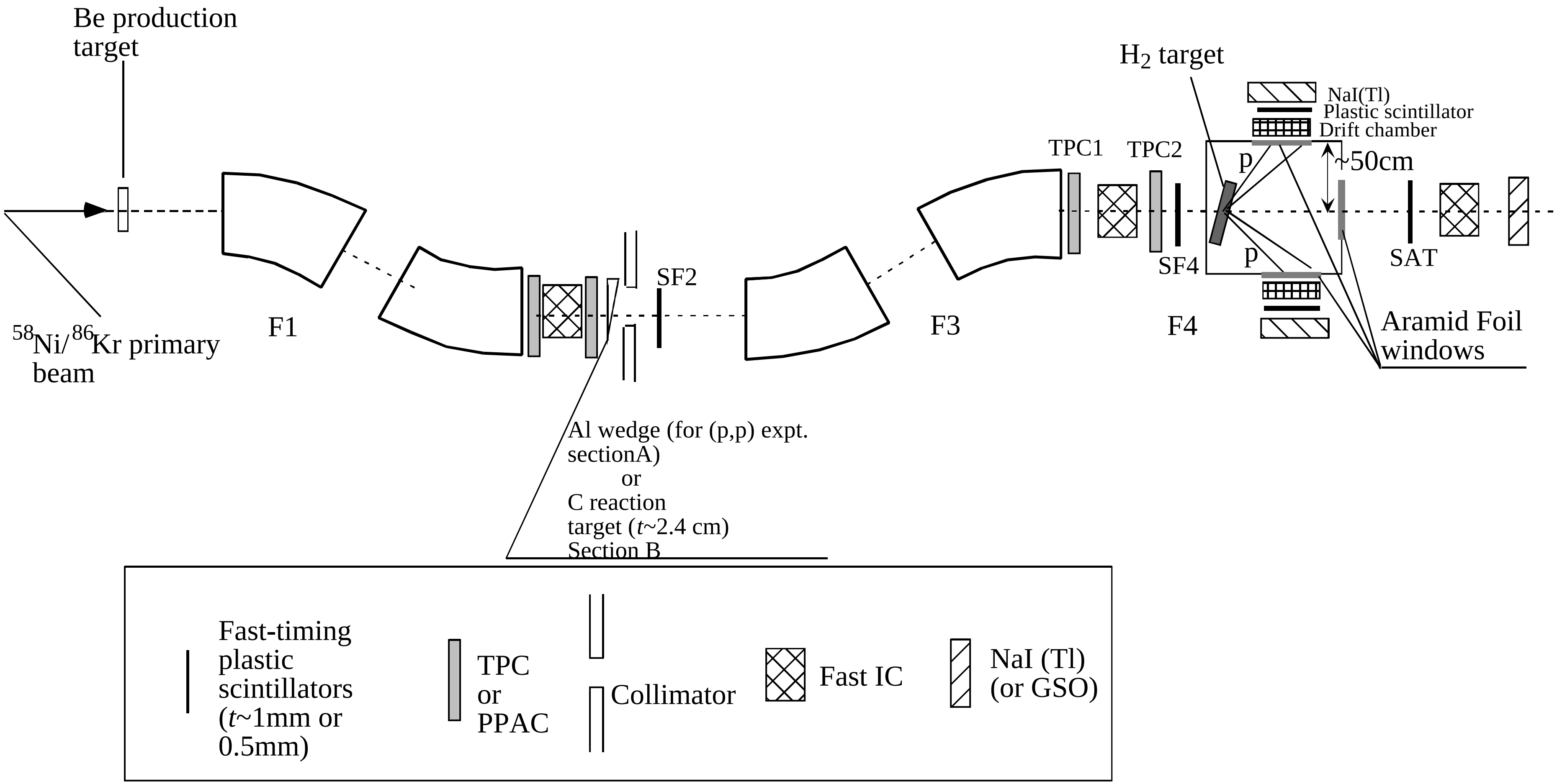
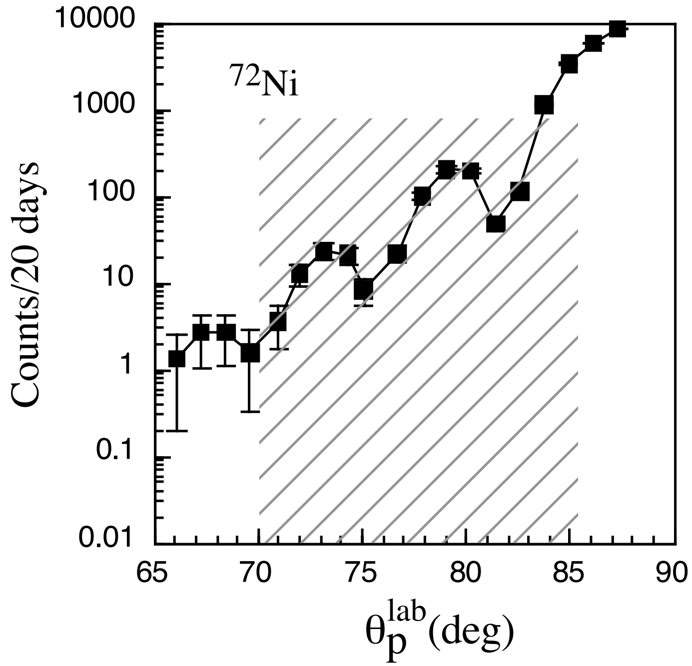


Fig. 4

Schematic view of experimental setup. For ^{68}Ni the setup shown at F4 will be placed downstream of ESR



Estimation of counts for ^{72}Ni(p,p) using the same cross section as for ^{58}Ni(p,p) measured at 400A MeV. For the heavier masses the difrractive minima will shift slightly to larger laboratory angles. The shaded region shows the angular range intended to be measured. *However, we are considering possibility of covering wider range if possible, thus we show estimation with a little extended angular range also.*

Fig.5