Light ion recoil detector

Overall design

The detector for light (target-like) particles is a substantial part of the R3B setup. It allows registration of recoils in coincidence with the heavy fragments, neutrons and the γ-particles. Thus gives a unique possibility to study elastic, inelastic and quasi-free scattering, knockout and breakup reactions. Recoil particle detector provides a precise tracking, vertex determination, energy and multiplicity measurement with high efficiency and acceptance. Last two parameters are very important dealing with the radioactive beams. The general design of the light ion detector has been described in the R3B LoI [1].

A thick liquid hydrogen target (200 – 250 mg/cm^2) will be used to reach a reasonable luminosity for the radioactive beams. It allows almost background-free data taking. A using of the extended (3 – 4 cm long) requires a determination of the interaction vertex with the precision of 1-2 mm. This corresponds to an effective target thickness below 20 mg/cm^2, and permits a correction for an energy loss of the recoils in the target.

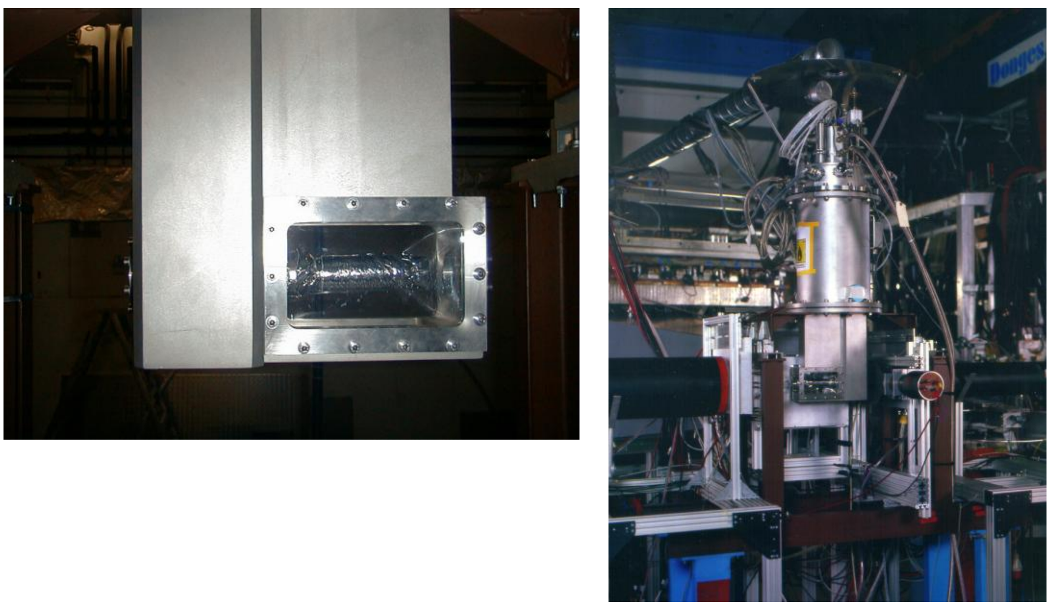

Figure 1.The photograph of the existing liquid hydrogen target.

We are going to use a modified version of the liquid hydrogen target that has been used for the elastic and quasi-free scattering experiments at GSI [2]. The vacuum chamber will be replaced by another one to fit into the gamma detector. The gamma detector will cover about ¾ of the total solid angle and has an opening in the backward hemisphere. This space free of the detectors will be used by the infrastructure of the liquid hydrogen target (tubes, et cetera) and the electronics of the tracker detectors.

Study of knockout reactions and a quasi-free scattering in inverse kinematics requires detecting of the recoils with energy in a range of 50 – 500 MeV. The typical angular range is in between 20° and 70° (assuming beam energy 700 MeV/u). The tracking system consists of two layers of position sensitive detectors. The general scheme of recoil system is shown at Fig. 2.

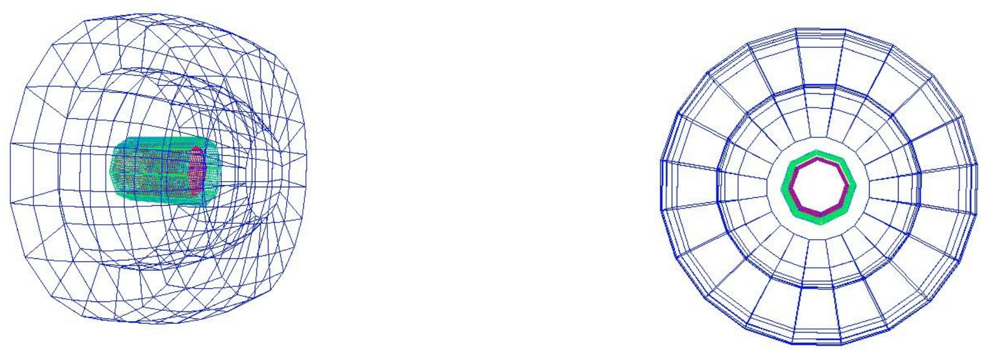

Figure 2. General scheme of the recoil detector. The red cylinder represents the first layer and the green cylinder – second layer of the tracker. γ-detector is show in blue.

Detection of the recoils

The main requirements are high resolutions for momentum and energy of the recoiling target-like nuclei. Some initial simulations have already been carried out that show the feasibility of the system. Extended simulation studies of the performance of the suggested detector scheme should be performed taking into account the size of each individual sensor and mechanical structure. The simulation package is based on the general purpose transport tool Geant4 [3]. It can trace particles through various materials; generate other particles according to the interaction cross sections and the decay probabilities, as well as calculate their energy loss and time-of-flight. The analysis of the simulated events is done using the histogramming tool ROOT [4]. The recoil particles are generated using external event generators. The main results of the simulations carried out so far have been obtained for the most demanding type of reaction – inelastic scattering.

The aim of the simulation is to find the conditions which optimize the detection system in terms of its tracking capability and detection with good energy resolution and particle identification. In particular the focus will be on the following points:

- Distance from the target to the first tracking layer, distance between the layers, thickness of the 1st layer, strip pitch, thickness of the 2nd layer, strip pitch
- Thickness, material and configuration of the vacuum chamber wall
- Thickness and material of the calorimeter
- Energy resolution of all detectors

The most important parameters of the detector system are resolutions on excitation energy and on centre-of-mass scattering angle. These values have been calculated for basic detector geometry:

- first layer of Si detectors – 2.5 cm away from the target, thickness is 100 μm, pitch size is 100 μm, energy resolution is 50 keV (FWHM);
- second layer – 5 cm away from the target, thickness is 300 μm, pitch size is 100 μm, energy resolution is 50 keV (FWHM);
- calorimeter – CsI crystals, thickness is 20 cm, energy resolution is 1% (FWHM);
- a wall of the vacuum chamber is 50 μm of stainless steel.

All coordinates and energy losses are folded with the resolutions. The coordinate determination is based on the strip size like in real microstrip detectors. The energy resolutions are based on known test results. The resolution on excitation energy ΔE* (σ) versus proton recoil energy E_p for the case of inelastic scattering of ^{12}C(p,p') with E = 400 MeV/nucleon is shown on the right panel of Fig. 4. The resolution on the centre-of-mass angle Δθ (σ) versus E_p for the same reaction is shown in the left panel of Fig. 4, resolution on the angle in laboratory system Δθ (σ) versus E_p for the same reaction – in Fig. 5.

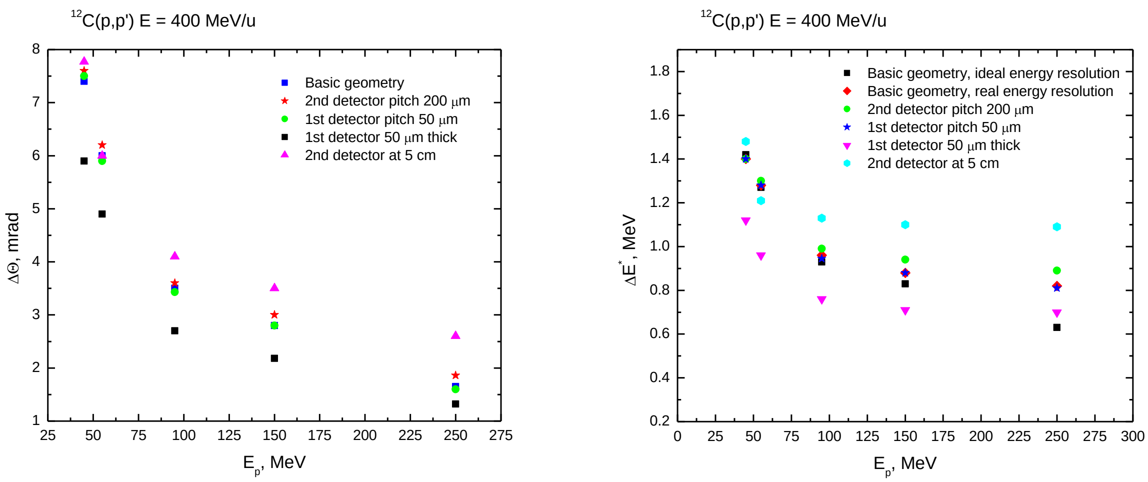

Figure 4. Right panel: excitation energy resolution versus the proton recoil energy E_p for the case of inelastic scattering of $^{12}C(p,p')$ with E = 400 MeV/nucleon. Left panel: resolution on the centre-of-mass angle $\Delta\theta\,(\sigma)$ versus E_p for the same reaction.

The results of the simulations for the higher energy (700 – 1000 MeV) and heavier ions show very similar performance. The first conclusions are the following:

- ✓ The first layer should be placed close to the target. It improves the precision of the vertex determination and reduces a size (and the cost) of the system. For the time being we consider the first layer 2.5 cm away from the middle of the target made of 50 μm thick detectors. 100 μm thick detectors introduce larger multiple scattering so might be used in case the lowest energy of the recoiling protons is about 100 MeV. The individual detectors are arranged to form a barrel with a length of 13 cm, surrounding a target.

- ✓ The second layer, made from 300 μm thick sensors, can be positioned at a distance of 5 cm from the middle of the target. The detectors will be fixed on 17 cm long ladders with the electronics on one side to reduce the dead zones.

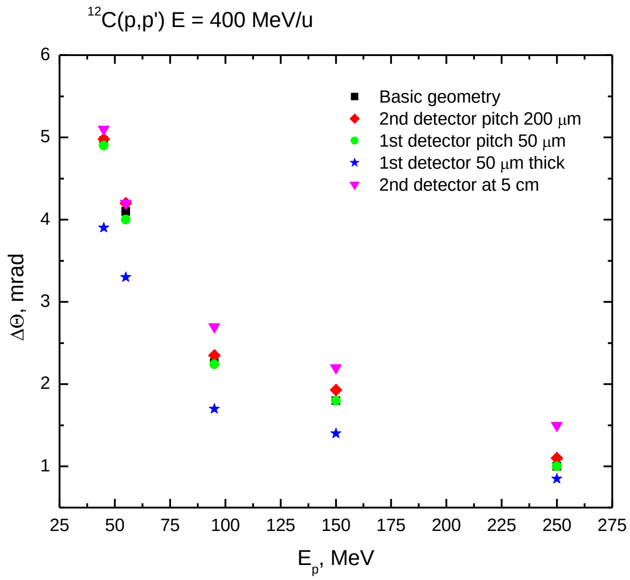

Figure 5. Resolution on the angle $\Delta\theta$ (σ) in laboratory system versus E_p for the case of inelastic scattering of $^{12}C(p,p')$ with E = 400 MeV/nucleon.

Figure 6. Example of the arrangement of the double-sided Si detectors on a ladder (part of the tracker system of AMS experiment).

The example of this ladder is shown in Fig. 6. The maximum active area of the first layer is about 200 cm^2, of the second one – 500 cm^2; in real situation it will be smaller due to the infrastructure of the target and a mechanical arrangement of the individual sensors. The exact geometry and the crystal type that will form the calorimeter (served at the same time as a γ-detector), will depend on the results of the detailed simulations. In general, the described above scheme should fulfill the requirements.

One of the solutions for the first layer of the tracker can be double-sided Si detectors but such detectors are normally thicker – 200 μm or more. This solution requires some R&D and prototyping to prove a possibility of having much thinner sensors. The advantage of this solution is moderate amount of readout channels (40000 or less) and experience gained by several high-energy experiments [5, 6, 7].

Another prominent solution is based on Monolithic Active Pixel Sensor (MAPS) technology [8]. These detectors can have a thickness down to 30 - 50 μm and the single point resolution of 5 μm with the efficiency of 99%. The maximum active size is at the moment ~3 cm^2. The example of the detectors made on the 6” wafer is shown in Fig. 7.

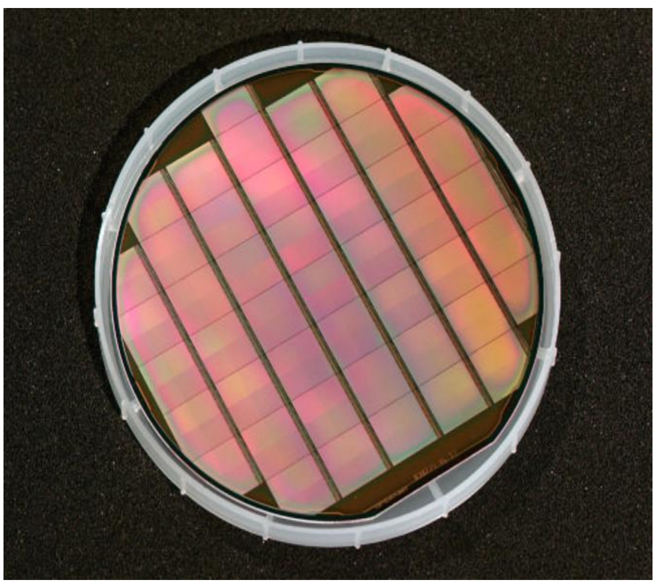

Figure 7. Prototypes of the MAPS detectors on 6” Si wafer.

An attractive feature of MAPS is that they allow fabricating Systems-on-Chips by integrating signal processing micro-circuits (amplification, pedestal subtraction, digitization, and discrimination) on the detector substrate. The resulting chip may be thinned down to few tens of microns. There is an extensive R&D going on in with the aim to use MAPS as the vertex detector in CBM experiment [9] and in other future experiments in nuclear and high energy physics.

One more solution for the first layer is the Image Sensor with in-situ Storage (ISIS) pixel detector that developed for the future linear collider [10]. It based on the CCD technology and the existing prototypes have already size of 10 cm^2 (Fig. 8). The arrangement of sensors mounted on a ladder also fits the geometry of the first layer. The position resolution of ISIS can be in the same order as MAPS (~5 μm) and there is no problem to make lager pixel size. This detector can also be 30 μm thick [10]. The drawback of MAPS or ISIS detectors is, of cause, a large amount of pixels (~ 2□10^6) that requires a special readout scheme. Most probably, the energy loss measurement will be impossible using so thin sensors. In this case the total energy will be measured by the second layer of the tracker and the calorimeter and corrected for the missing energy in the first layer. Simulations show that the errors, introduced due to that, are very small.

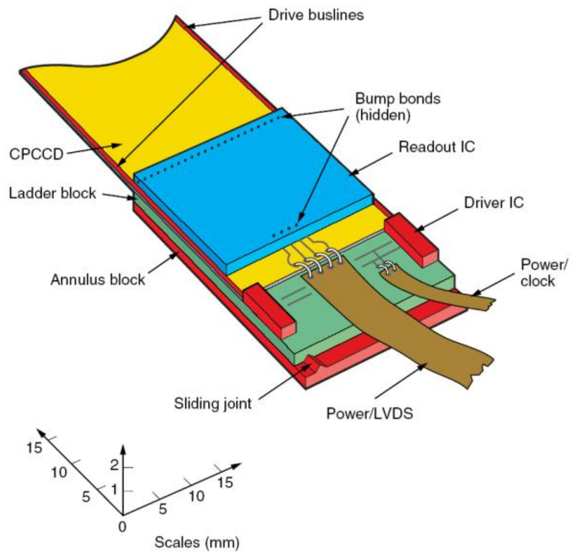

Figure 8. Prototype of the ISIS detector on the ladder.

The second layer of the tracker can be made from double-sided Si detectors with a standard thickness of 300 μm. The amount of readout channels for this layer is 50000 – 100000. The collaboration has already purchased several detectors of this type equipped with readout which will act as the first prototypes of the second layer detectors. The detectors have a size of 32 cm^2 and readout pitch of 100 μm on the both sides of the sensors. The energy loss will be also measured. These prototypes will be used inside the existing LAND-ALADIN setup and will allow valuable experience to be gained.

Both layers of the tracker will operate inside a vacuum chamber with the radius about 25 cm. The mechanical support structure that will hold the detectors and the electronics should be designed. The relative positions of the sensors with respect to each other and the target must be measured with a precision of 50 μm or better so the alignment procedure should be foreseen.

The cost of the first layer of the tracker (based on DSSDs) is about 200 k€, the second layer – 250-500 k€ (depends on the choice of the readout pitch). We expect that the cost of the system using MAPS or ISIS will not be higher. Further simulations and tests of the prototypes will be performed with the aim to optimize a system and reduce a total cost.

Radiation hardness

The recoil detector will be used for the secondary particles appeared from the nuclear reactions in the target. Taking into account maximum rate of 10^8 - 10^9 radioactive ions/s and 1% interaction probability, we estimate the maximum flux of the recoils 10^6 - 10^7 particles/s per the whole detector system or 10^4 - 10^5 particles/s per cm^2. Assuming typical beam time of 2 months per year, the detector must stand a dose up to $5*10^{10}$ particles per cm^2 per year. This dose is anyway much smaller that the estimated doses for the Si detectors in vertex systems of LHC experiments - 10^{14} - 10^{15} charged particles per year [5, 6, 7].

Space requirements

The system will be very compact and fit into the inner part of the γ-detector – sphere with the inner diameter of 50 cm and outer – 100 cm. The support structures will allow using a liquid (hydrogen, helium) or solid targets. The additional space for the electronic racks in the order of 6-8 m^2 is necessarily.

Test experiments

Test experiments using proton and light ion beams are inevitably required in order to prove the simulations and make a decision on the best suitable detector technology. First test experiment is foreseen during 2005 and later on when every next prototype is ready. The energy of the protons should be in the range of 50 - 500 MeV. Test experiments using high rate accelerator facilities are foreseen to check the radiation hardness of each prototype.

Milestones

2005 - 2006	Simulations and optimization of the geometry, tests of prototypes
End of 2007	Decision on the detector concept
End of 2008	Preproduction prototypes, concept of installation and alignment
2009 - 2010	Mass production of the detectors and electronics, installation

References

1. R3B LoI, GSI, 2004.
2. F. Aksouh, PhD Thesis, Universitè de Paris XI, Orsay, France, 2002.
3. S. Agostinelli et al., Nucl. Instr. and Meth., A506 (2003) 250.
4. R. Brun and F. Rademakers, Nucl. Instr. and Meth., A389 (1997) 81.
5. CMS The tracker project, Technical Design Report, CERN/LHCC 98-6, TDR 5, 1998.

6. ATLAS Inner detector, Technical Design Report, TDR 5, 1997.
7. ALICE Technical Design Report of the Inner Tracking System (ITS), CERN/LHCC/99-12, ALICE TDR4, 1999.
8. M. Deveaux et al., Nucl. Instr. and Meth., A512 (2003) 71.
9. CBM LoI, GSI, 2004.
10. T. Goji Etoh et al., IEEE Trans ED (2003) 144.