Plastic scintillator fiber detectors for heavy ion trajectory reconstruction for the Super-FRS at FAIR

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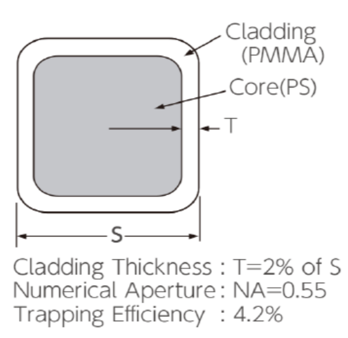
Motivation

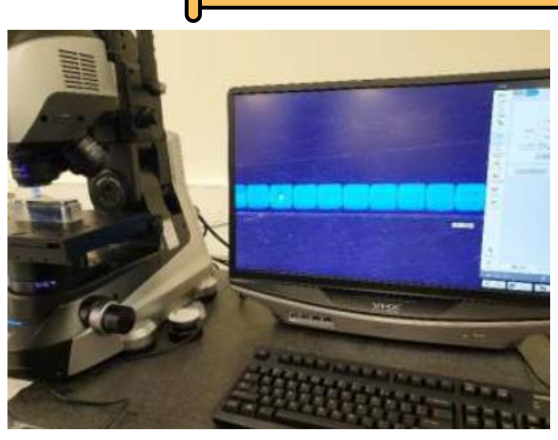
At the FAIR facility, currently under construction at GSI (Darmstadt), a 1.5 AGeV uranium beam with intensities up to intensity 2.5×10^{11} ^{238}U/spill will impinge on a graphite target at the entrance of the Superconducting Fragment Separator (Super-FRS) for the production of a wide range of rare isotopes by projectile fission and fragmentation. The next generation in-flight magnetic separator Super-FRS [1] operated up to a magnetic rigidity of 20 Tm with a large angular acceptance ($\Delta\theta = \pm40$ mrad, $\Delta\phi = \pm20$mrad) and momentum acceptance ($\Delta p/p = \pm2.5\%$) requires a new generation of tracking detectors with a position resolution of 0.2 mm (σ_x) over large detector areas of about 300 cm^2.

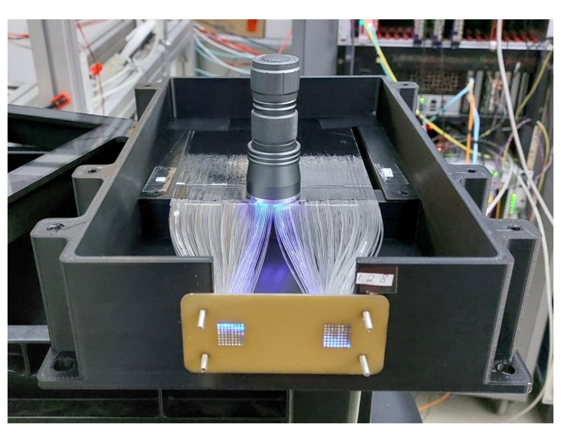
Scintillating Fibers

SCSF-78 scintillation fibers manufactured by Kuraray have a square cross section of S = 0.2 mm thickness with a polystylene (PS) core and polymethylmethacrylate (PMMA) cladding. They are characterised by blue light emission with a peak at 450 nm, a decay time of 2.8 ns and a long attenuation length of more than 4.0 m [2].



Prototype

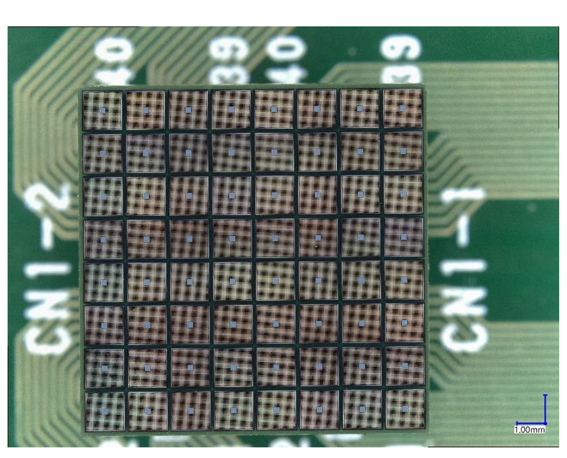




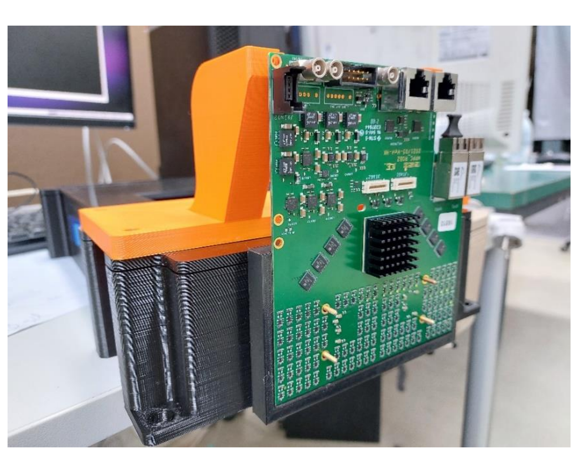
Left: optical inspection of the fibers ribbon with a microscope at the GSI Detector Laboratory [5].

Right: one layer detector consisting of 128 fibers with an active area of 25.6x100 mm^2 coupled to MPPC and read by the MPPC ROB [5].

Readout



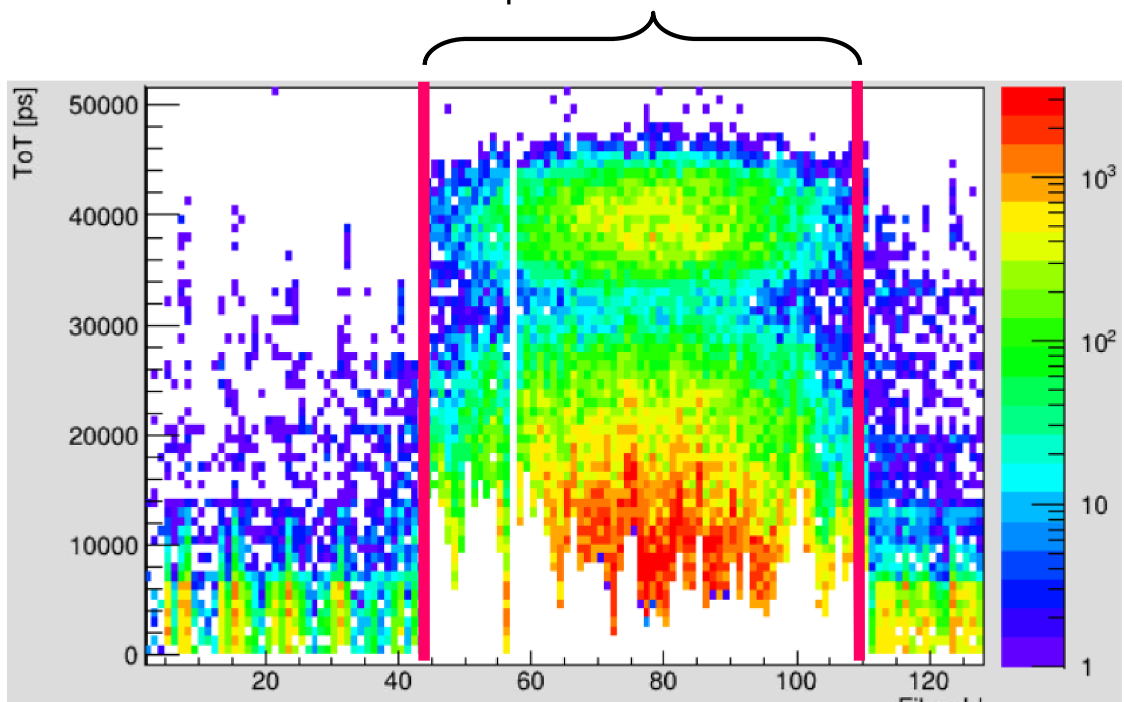
MPPC



MPPC ROB

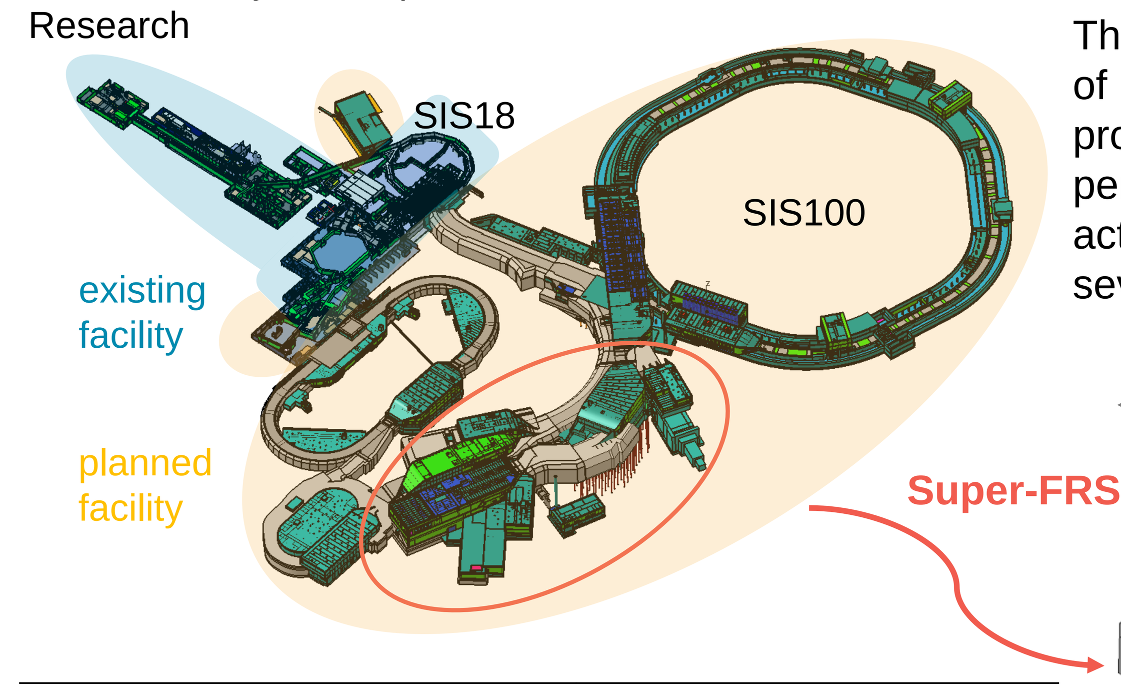
- MPPC (Multi-Pixel Photon Counter) 8 x 8 array S13361-1350AE-08 by Hamamatsu with breakdown voltage V_{BR} = 53 V [3].
- 128ch MPPC ROB (ReadOut Board) designed at GSI with multihit FPGA TDC able to provide time over treshold (ToT) measurement (σ= 200 ps).

Region with ToT calibration of ^{197}Au ions selected for position reconstruction

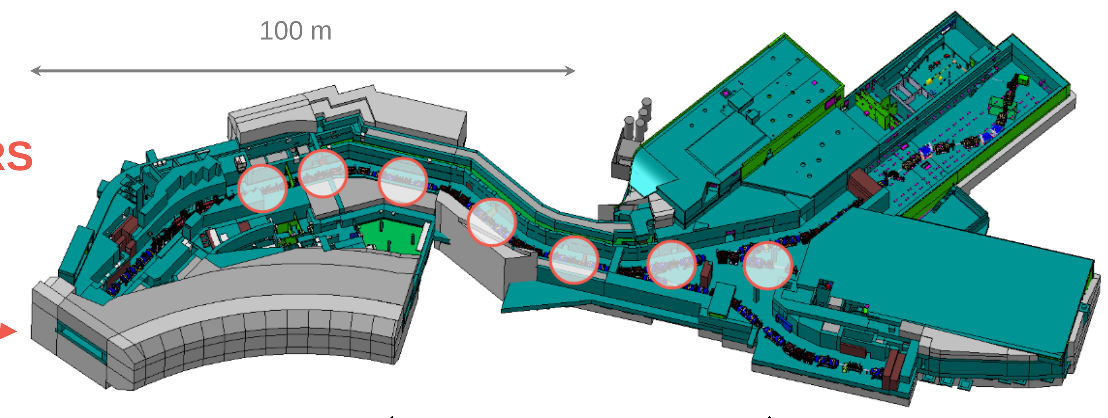


Super-FRS at FAIR

FAIR – Facility for Antiproton and Ion Research



The GSI is currently designing planar detectors consisting of scintillating fibers (SciFib) 0.2 mm thick. Each one provides the x and y positions of the ions via two perpendicularly arranged layers of fibers with a maximum active area of 570 cm^2. They are planned to be installed at seven locations in the Super-FRS tunnel at Q1-Q2 2026.



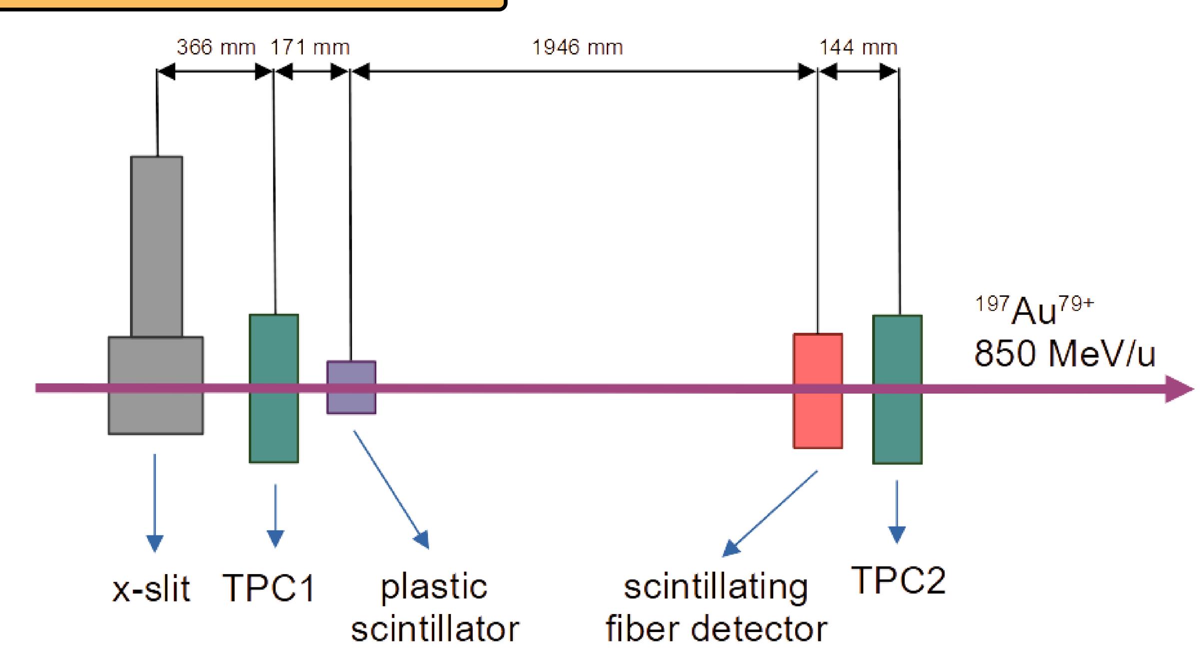
Magnetic rigidity	2 - 20 Tm
Emittance	$\varepsilon_x = \varepsilon_y$= 40 π mm mrad
Angular acceptance	σ = ± 40 mrad, ϕ = ± 20 mrad
Momentum acceptance	± 2.5 %
1st order resolution (σ_x=1mm, σ_y=2mm)	750 (1st stage), 1500 (2nd stage)

$$B\rho = B\rho_0\left(1 - \frac{x_{FHF1} - MxF_{MF2}}{D}\right) + \Delta B\rho$$

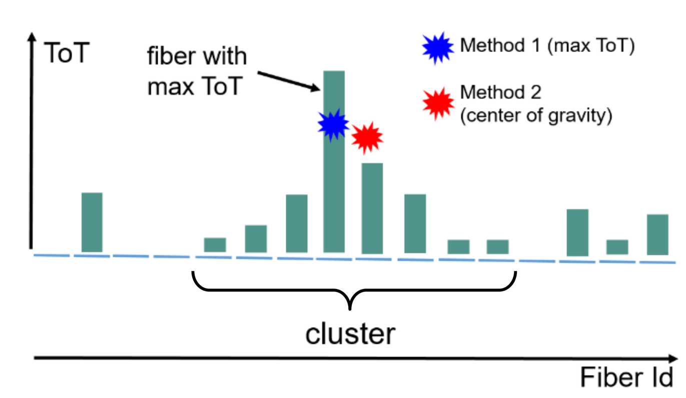
D~ 6 cm/% , Δx < 1mm → Δp/p ~ 10^{-4} momentum res. (1st order)

Experiment and results

Focal plane setup at the FRS [6] on June 2022: the prototype was placed between two reference TPC detectors [4]; a 1 mm thick plastic scintillator acted as a trigger; the x-slit in front were used to select the ^{197}Au^{79+} beam with energy E=850 MeV/n.



SciFib detector prototype placed in front of TPC2 at FRS.



Au ions hitting the SciFib detector produce a large amount of light (E_{loss}≈300 MeV). Pulses are produced also by ions traversing the matter in front, contributing to the production of δ-rays. As a result, 8 strips fired on average for each single (trigger) event recorded, represented by a cluster.

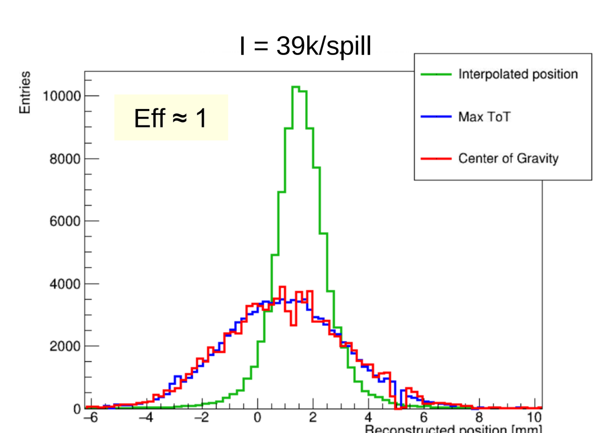
Spatial resolution can be defined as the standard deviation $\sigma_{\Delta x}$ of

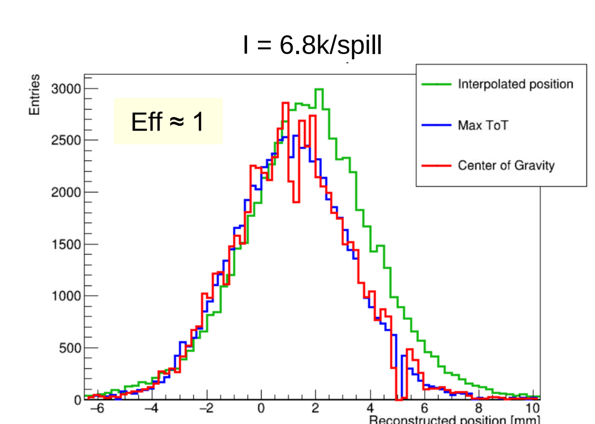
$$\Delta x = x_{interp} - x_{SciFib}$$

with x_{interp} the interpolated position obtained from the measurements at the two TPC detectors and x_{SciFib} the reconstructed position at the SciFib detector.

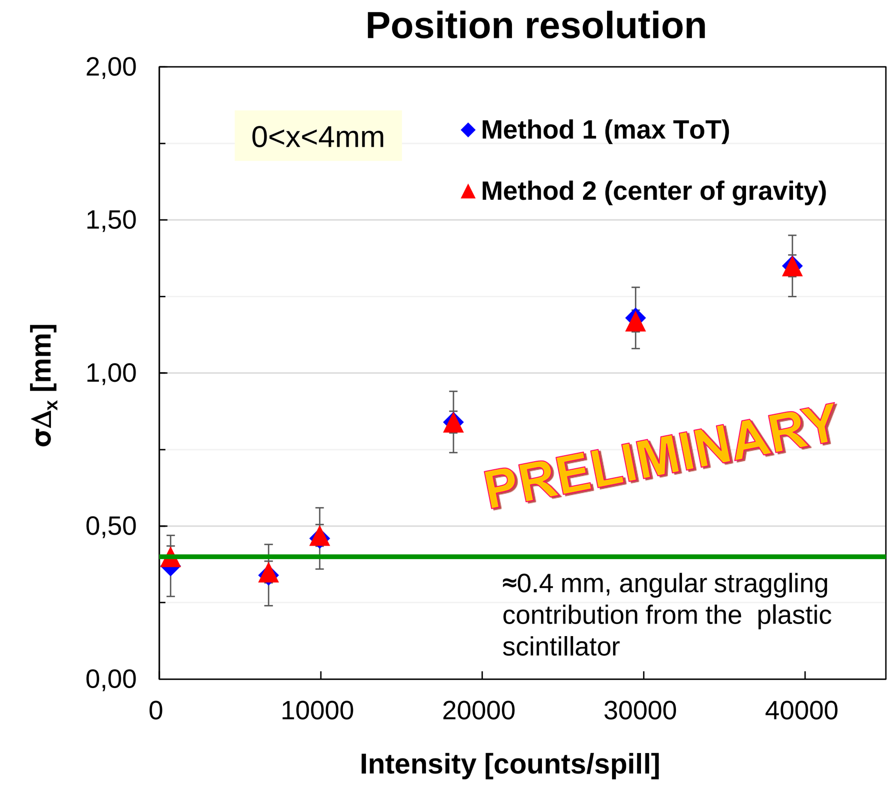
The x position of the ions was determined with two methods:

- Method 1 - by selecting the strip (ch) with the highest ToT
- Method 2 - by calculating the center of gravity.



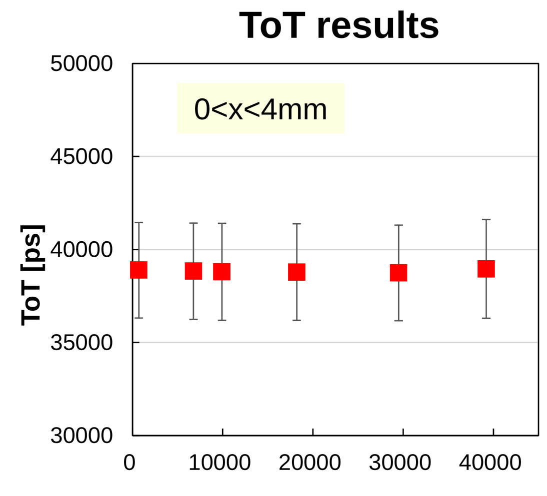


Position resolution



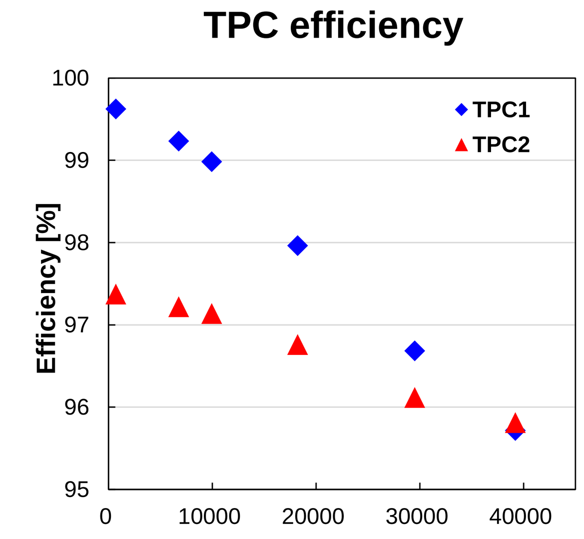
Up to a rate of 10k/spill, the position distribution at the SciFib detector is equivalent to the position distribution measured by the TPC detectors. This result indicates that the use of fiber detectors is suitable during the commissioning of the Super-FRS in Q3-Q4 2026 when the primary beam is steered at low intensity.

ToT results



At higher rates the position distribution at the SciFib prototype differs much from the one measured by the reference detectors. Further investigations are needed in order to understand under which conditions the fiber detector can be used also as a tracking detector of fragment beams produced at higher rates during the experiments at FAIR.

TPC efficiency



References:
[1] M. Winkler et al., The status of the Super-FRS in-flight facility at FAIR, Nucl. Instr. Meth. B 266 (2008) 4183
[2] Kuraray Co., Ltd. Datasheet, Plastic Scintillating Fibers
[3] Hamamatsu Photonics K.K. Datasheet, MPPC (Multi-Pixel Photon Couter) array S13552
[4] R. Janik et al., Time Projection Chambers with C-pads for heavy ion tracking, Nucl. Instr. Meth. A 640 (2011) 54-57
[5] S. Paschalis et al., Heavy-ion tracking detectors for the R3B setup, GR-2014-1-NUSTAR-KR-10, GSI Report 2014-1
[6] H. Geissel et al., Nucl. Instr. and Meth. B 70 (1992) 286