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# A time projection chamber for high accuracy and precision fission cross-section measurements

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ABSTRACT

The fission Time Projection Chamber (fissionTPC) is a compact (15 cm diameter) two-chamber MICROMEGAS TPC designed to make precision cross-section measurements of neutron-induced fission. The actinide targets are placed on the central cathode and irradiated with a neutron beam that passes axially through the TPC inducing fission in the target. The $4\pi$ acceptance for fission fragments and complete charged particle track reconstruction are powerful features of the fissionTPC which will be used to measure fission cross-sections and examine the associated systematic errors. This paper provides a detailed description of the design requirements, the design solutions, and the initial performance of the fissionTPC.



## 1. Introduction

Neutron-induced fission cross-sections of the major actinides ($^{235}$U, $^{238}$U, $^{239}$Pu) have been studied for many years [1–6]. Evaluations of the cross-sections are based on a large number of datasets and are thought to be very precise, better than 1% in some cases, but the individual underlying datasets have uncertainties of 3–5% in the fast neutron region (incident neutron energies from 100 keV to 14 MeV) and perhaps more significantly the individual experiments do not agree to within quoted experimental uncertainties [7]. The impact of cross-section uncertainty has been studied extensively in the context of applications such as reactors, weapons and nucleosynthesis calculations [8] and it was concluded that uncertainties of 1% or better are needed. In order to have confidence in the small uncertainties of the cross-section evaluations and to understand the reasons for the spread in the current datasets, it is essential to perform a measurement with comparable uncertainty to the evaluation and that is as uncorrelated as possible to the previous measurements. At the same time,

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the new experiment needs to be similar enough to previous experiments to explore the systematic errors of the previous experiments, and these sometimes competing needs have to be balanced. The majority of fission cross-section measurements have been conducted with fission chambers [9]: simple, robust, easy-to-model detectors that have served the nuclear physics field well. Although a list of possible error sources for the fission chamber experiments is well known [10], it appears that further reduction of uncertainties is unlikely with traditional fission chambers [7].

The NIFFTE (Neutron Induced Fission Fragment Tracking Experiment) collaboration has built a Time Projection Chamber (TPC) [11,12], the fissionTPC, to perform precision cross-section measurements of the major actinides with the goal of better than one percent uncertainty. The focus of the fissionTPC design is to study uncertainties of previous measurements, including three of the largest sources of error: alpha particle and fission fragment differentiation, the target and beam non-uniformity, and the cross-section uncertainty of the reference in ratio measurements (typically $^{235}$U). The unique experimental conditions also impact the design of the fissionTPC: the neutron beam passing through the detector, the high activity targets (of order MBq), and the large energy deposited by fission fragments.

The fissionTPC is a MICROMEGAS (MICRO MEsh Gaseous Structure) [13] TPC with 5952 hexagonal pads, 2 mm in pitch. A magnetic field is not required to control diffusion because of the short drift distance (54 mm). The argon–isobutane drift gas mixture is usually operated at 550 Torr where most particles of interest range out and stop in the active volume because of ionization energy loss. Measuring this energy loss provides the total energy of each particle. Fig. 1 shows a cutaway drawing of the fissionTPC. The 15 cm diameter pressure vessel is supported at the center by 12 plastic legs that provide electrical isolation. All of the analog and digital processing is contained in the volume between the vessel and the end of the legs, an annulus approximately 16 cm wide (in radius) by 11 cm thick. Air cooling of the electronics is accomplished with fan packs. Detector gas flows continuously through the fissionTPC via electrically isolated stainless steel tubes also supported by this structure.

## 2. Design requirements

Ideally, the fissionTPC design will provide the capability to quantify the known and suspected systematic errors in previous fission chamber measurements (Table 1) while maintaining the features that have been measured with low uncertainty in previous experiments (e.g. time of flight). To do this, the fissionTPC is designed to provide good 3D tracking of charged particles with near 100% efficiency, and specific ionization measurements for particle identification. This section describes the design requirements related to addressing sources of systematic uncertainty as well as requirements related to the unique operational environment at the LANSCE neutron source.

### 2.1. Particle identification

Perhaps the most significant contribution to the cross-section uncertainty is the error in differentiating a fission event from a spontaneous alpha decay. In a fission chamber particles are identified based on the energy deposited in the chamber gas. One problem with this method is that the observed energy difference is narrowed by energy loss of fission fragments in the target. This is a small effect for thin targets and for particles emitted perpendicular to the target surface. The energy loss for fragments emitted near-parallel to the target can be large enough that alpha particles and fission fragments are not distinguishable in a fission chamber; one has to rely on simulation to correct for this effect. In the case of $^{239}$Pu, the alpha decay rate is much larger than the neutron induced fission rate, increasing the possibility of misidentification.

Simulations indicate that measuring a nominal 20 ionization points along a typical track would be sufficient to identify the particles through differences in specific ionization, even when degenerate in energy. The protons and alpha particles exhibit a Bragg peak at the end of the ionization track, while fission fragments produce the largest ionization at the start of the track. This pronounced difference and the ability of the fissionTPC to measure the specific ionization is the key to particle identification. High-resolution tracking also allows one to study the effects of energy loss in the target (the source of particle identification difficulty) as a function of emission angle, and make fiducial cuts to remove detector volume (e.g. shallow angles) that cannot be corrected. Also important is sufficient dynamic range to measure the energy deposit of fission fragments and light recoil particles. Preliminary calculations and measurements indicate that the 12-bit resolution is sufficient.

### 2.2. Target and beam uniformity

A standard fission chamber does not have the ability to measure target uniformity. The uniformity is measured outside of the fission chamber by examining variation in alpha decay rates across the surface. The beam profile is measured with either neutron-sensitive film placed directly in the beam, or an external detector scanned through the beam. One challenge, and source of error, is the alignment of these different measurements. An experimental simplification frequently used is to either make the beam larger than the target or the target larger than the beam, and assume that the larger item is uniform. This has the convenient result that one does not need to know the uniformity of the smaller item and the edge effects are removed; however the assumption of uniformity is questionable at the few percent level. In addition, the beam profile likely changes as a function of energy, which further complicates the matter. To improve on previous experiments, the fissionTPC will autoradiograph the target continuously, in situ, by tracking alpha particles from spontaneous decay. The beam profile is measured by monitoring the recoiling ions from neutron scattering on the drift gas: argon, carbon and hydrogen. This allows one to measure both the target and beam uniformity with the same instrument at the same time and as a function of energy.

The pointing resolution required to accurately characterize this uncertainty can be estimated by considering the expected variations in both the beam and the target. Typical film exposures of a collimated spallation neutron beam show that the profile is smoothly varying and a resolution better than a few millimeters is sufficient. The target is expected to have thickness variations at nearly all length scales [14] and is highly dependent on the method of depositing the material [15]. It is possible that large amplitude variations of target thickness occur on an area scale smaller than the fissionTPC pointing resolution. If the amplitude of these variations is comparable to the range of fission fragments it could cause anomalies in the measurement. This effect cannot be corrected at all in a fission chamber. In a TPC with sub-micron resolution, the complication of small area, large thickness features vanishes because the range of the fission fragments in the target material is larger than a sub-micron feature. It is not practical to build a TPC with sub-micron pointing accuracy but fortunately this is not necessary. The expected pointing resolution from the fissionTPC is sufficient to split the target area into an ensemble of over a thousand patches that can each be analyzed and compared for consistency between the cross-section and mass