The superthin fixed target for the LHCb experiment in Run4

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On behalf of LHCb. This is a proposal by LHCb members for a possible future project and it's being reviewed by LHCb FITPAN. However, it is not a LHCb approved project.

Introduction

Fixed target studies at the LHC energies (√ S_{NN} about 70-120 GeV) are considered as a powerful tool for exploring the QCD phase diagram in a weakly known domain of densities and temperatures with variety of possible peculiarities in the EOS in entrance and exit channels in high energy heavy ions collisions. Implementing a gas-filled cell set-up, SMOG2, with a unique feature of data taking in the collider and fixed-target mode, simultaneously, the LHCb Collaboration plans to contribute significantly here during Run3 [1].

- Run 3 conditions:

Novel centre-of-mass energy, √s = 14 TeV for p-p collisions

Instantaneous luminosity, 5×Linst = 2×10^{33} cm^{-2} s^{-1}

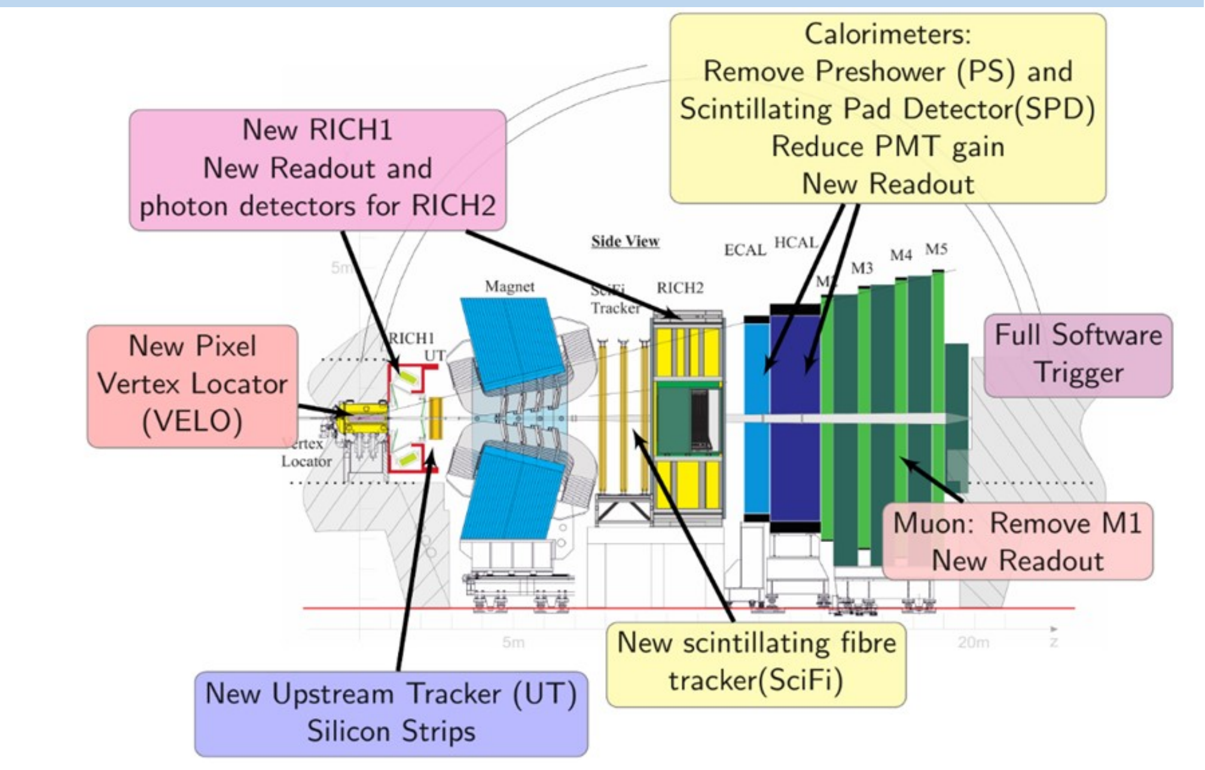
Step-up of radiation levels, etc.

- Major hard- & software novelties:

Triggerless readout system

Full software trigger with GPUs @30 MHz and CPUs@1MHz

Phase-I upgraded LHCb detector [1]



Solid target requirements

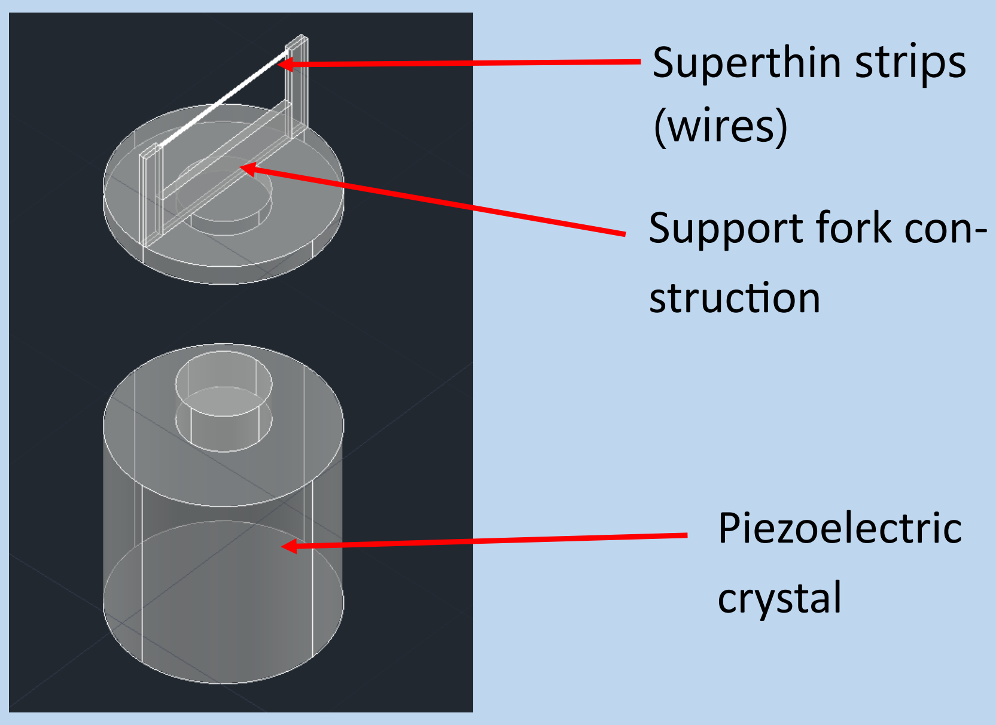
In addition to the basic requirements for the internal solid target related to the safe operation of the LHC, as well as the main experiments [2], the following demands are also being considered: achieving luminosity not exceeding the nominal value in collider mode with an acceptable target lifetime, a fast and precise target position control system, apparatus portability and compatibility with existing infrastructure or with minimal modifications to them etc.

The principal specs of the target: it should be lightweight (~10 g), thin (several μm), UHV compatible, precisely (~100 nm) positioned, quickly controlled (~1 ms) and dynamically adjustable, movable enough (~1-10 mm).

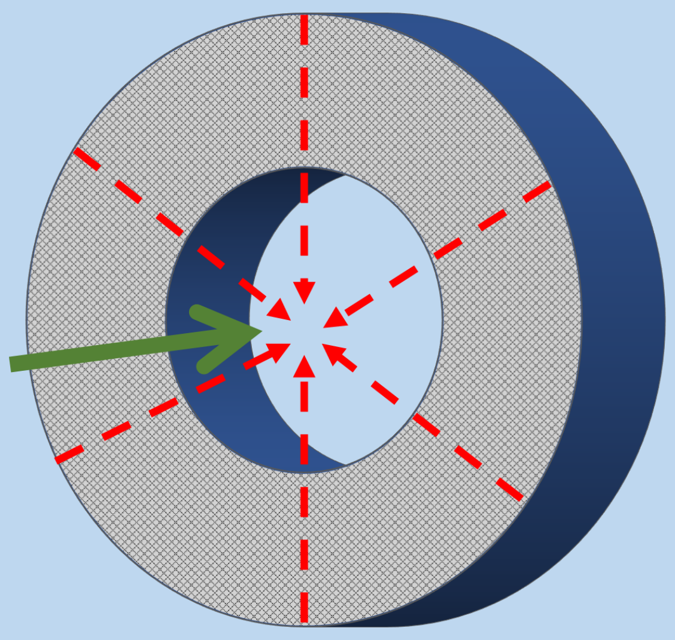
Superthin solid fixed target concept

In this presentation, we only consider a linear target design to be moved in/out of beam halo with a nanometer precision by a MEMS device. Such micro-electromechanical systems technology are widely used to create tiny integrated devices combining an electrical and mechanical components with abilities to sense, control and actuate on the microscale.[3]

Metal Microstrip Detector –MMD-1024



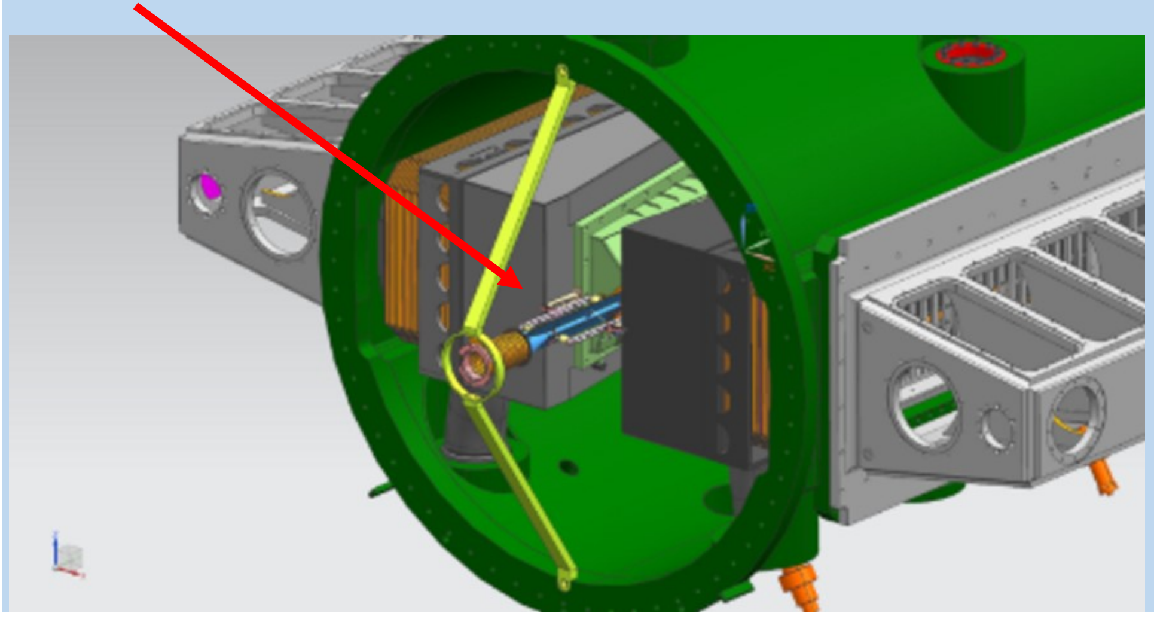
Sketch of MMD-based target placed on a piezoelectric MEMS linear motor.



Ring model of a multi-fixed-target device. The green line represents the direction of a beam, while the red lines represent the directions of linear movement of targets actuators.

It is proposed to use metal microstrip detectors developed in INR NAS of Ukraine as targets.

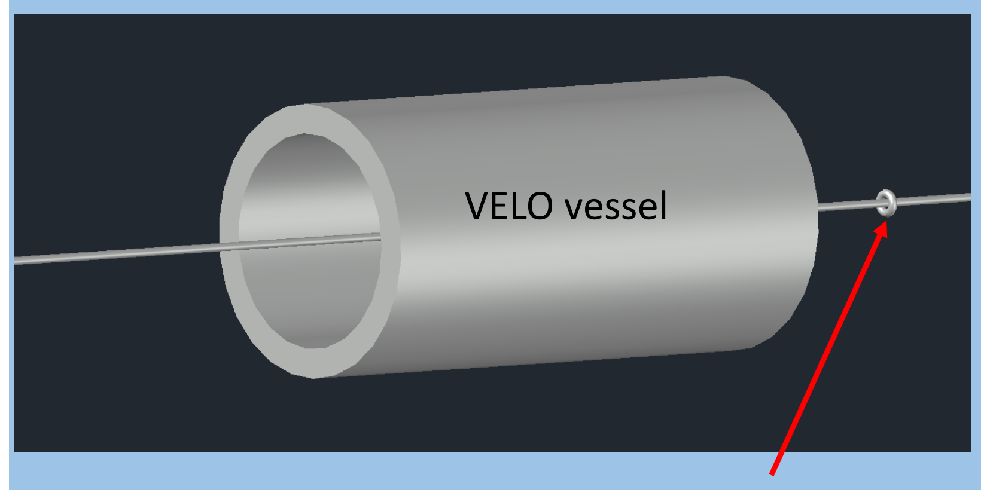
For the targets position steering, a combined scheme is suggested applying stepper motors with an accuracy of several micrometers and motors based on MEMS technology represented by piezoelectric crystals with nanometer accuracy. The installation of a compact multi-fixed-target set-up upstream of the VELO has been proposed. Targets, presented in the form of ultra-thin wires several micrometers thick and up to a centimeter long, are being dynamically maintained in the beam halo.



Region of the likely position of the solid target system in front of the VELO. The device can be considered as a structural element of the beam pipe or its extension in the VELO tank along with the SMOG2 storage cell. The Figure is taken from [1].

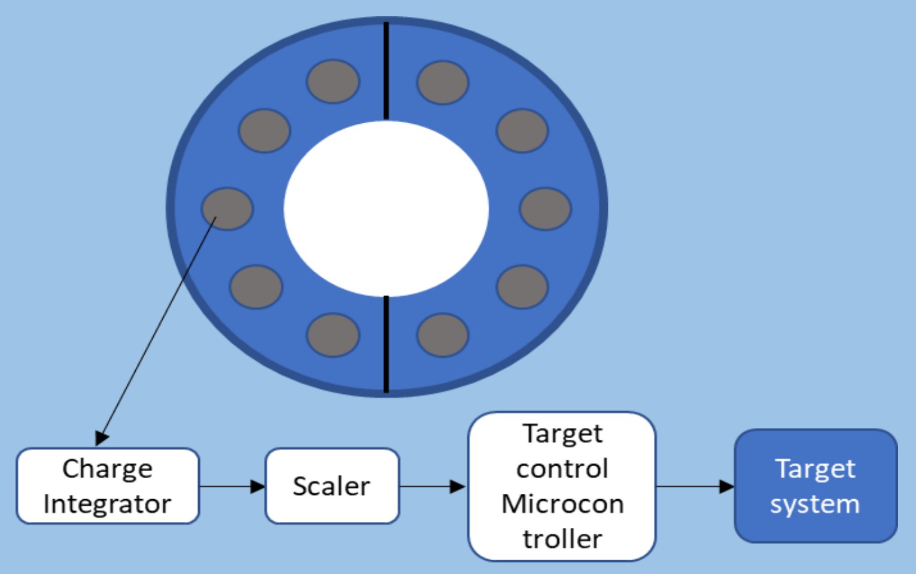
Target positioning control subsystem RMS-R4

Steering of the target will be provided by a specialized RMS-R4 system built upon the radiation hard technology of metal-foil detectors for stabilization of luminosity and safe operation of the internal fixed-target mode.



Proposed position of RMS-R4

Position RMS-R4 with respect to VELO vessel



Schematic view of RMS-R4 detectors together with their readout interfaced to the central target positioning control system

RMS-R4 is considered as a feedback system that controls the movements of the solid targets in the transverse direction relative to the beam line. Performing relative luminosity and machine induced background monitoring, the RMS-R4 is designed to prevent an accidental increase in radiation loads on the detector subsystems and superconducting LHC magnets. Functionally, the RMS-R4 signals, depending on their magnitude, can cause the gradual withdrawal of the target to a safe distance from the beam axis or give the command to instantly destroy the target.

Beam heating of the target

For super-thin solid-state targets, the problem of thermal heating is a challenge. Using the following thermodynamic formula, one can estimate in the simplest way the target temperature increase due to beam heating:

$$\Delta T = \frac{\overline{\Delta E} N_p N_b f_{rev} \Delta}{\rho S d C},$$

where ΔE - average energy losses resulting into the temperature rise of the target; Np - the number of protons (nuclei) in one bunch of the beam; Nb - the number of bunches in the beam; f_{rev} is the rotational frequency of LHC beams, c-1; Δ - the correction factor for the beam flux in the case of an ultrathin target; ρ - target density, g/cm3; S is the effective area of the target, cm2; d is the thickness of the target, cm;

When $N_p = 1.15\times10^8$ (protons), $N_b = 10^3$ (bunches), $f_{rev} = 11.245$ kHz, $\Delta = 2.83 \times 10{-}8$, ρ= 8.902 g/cm^3, S= 330 μm^2, d = 1 μm, C = 460 J/(kg K) we get ΔT ~ 1.5435 K/sec.

Therefore, based on the obtained calculation and assuming that the melting point of a Ni strip is 1726 K, we can conclude that the integrity of the target, located at a distance of 5σ (250 μm) from the center of the beam core, for about 20 min without cooling of the target.

CONCLUSIONS

The optimal characteristics of the fixed solid-state target mode are determined, which must satisfy the conditions of achieving the nominal value of instantaneous luminosity of the updated LHCb experiment of the order of 10^{33} cm^{-2} s^{-1} at an acceptable lifetime of the LHC beam. To run a fixed target mode with LHC beams focused to micrometer scale is a challenge that might be overcome with mechanical systems operating micro target with nanometer steps. Metal Microstrip target setup built in frames of MEMS technology presented above is a promising approach to its design. Beneficial features of solid state micro target include a large variety of nuclei to study, orders of magnitude better vertices localization, straight and forward tuning of the interaction rate, simple target replacement etc.

MEMS and stepper motors target control are carried out by the RMS-R4, that can force the target to move to a safe distance from the LHC beam or give the command to instantly destroy the target.

REFERENCES

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[3] - An Introduction to MEMS (Micro-electromechanical Systems), ISBN 1-84402-020-7, PRIME Faraday Partnership , January 2002

[4] - Sandia National Labs, SUMMiT *Technology, http://mems.sandia.gov.

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