FEASIBILITY STUDY OF THE ALICE FIXED-TARGET EXPERIMENT WITH HL-LHC LEAD ION BEAMS BASED ON CRYSTAL-ASSISTED BEAM HALO SPLITTING

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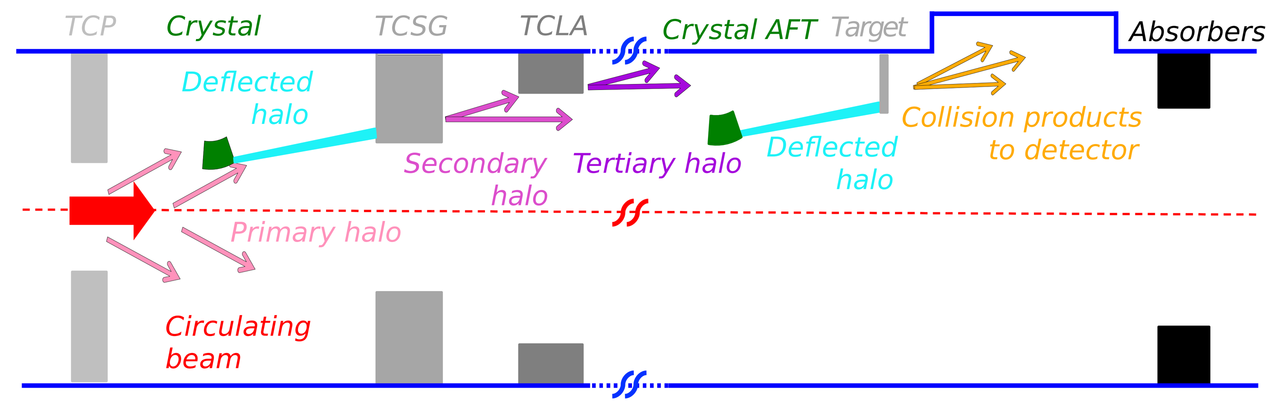
The Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) is the world's largest and most powerful particle accelerator colliding beams of protons and lead ions at energies up to 7 TeV and 2.76 TeV, respectively. ALICE is one of the detector experiments optimised for heavy-ion collisions. A fixed-target experiment in ALICE is considered to collide a portion of the beam halo, split using a bent crystal, with an internal target placed a few meters upstream of the detector. Fixed-target collisions offer many physics opportunities related to hadronic matter and the quark-gluon plasma to extend the research potential of the CERN accelerator complex. Production of physics events depends on the particle flux on the target. The machine layout for the fixed-target experiment is being developed to provide a flux of particles on a target high enough to exploit the full capabilities of the ALICE detector acquisition system. Steering the split beam is performer by exploiting the channeling process occurring inside a crystal, resulting in an effective trajectory deflection equivalent to the geometric bending angle of a crystal body.

ALICE-FT configuration in the LHC

The ALICE-FT setup was considered to be operated with High-Luminosity LHC (HL-LHC) beams. Collimating lead beams poses additional challenges due to the fragmentation of heavy ions within the collimators, which often results in significant leakage of particles with charge-to-mass ratios different from the main beam. Consequently, crystal collimation is employed as the baseline method for lead beams, incorporating bent crystals to act as primary collimators (TCPCs). This setup benefits from the substantial angular kick experienced by halo particles during the channeling process, directing them toward a downstream absorber.

Some parameters of the future HL-LHC lead beams important for the ALICE-FT experiment.

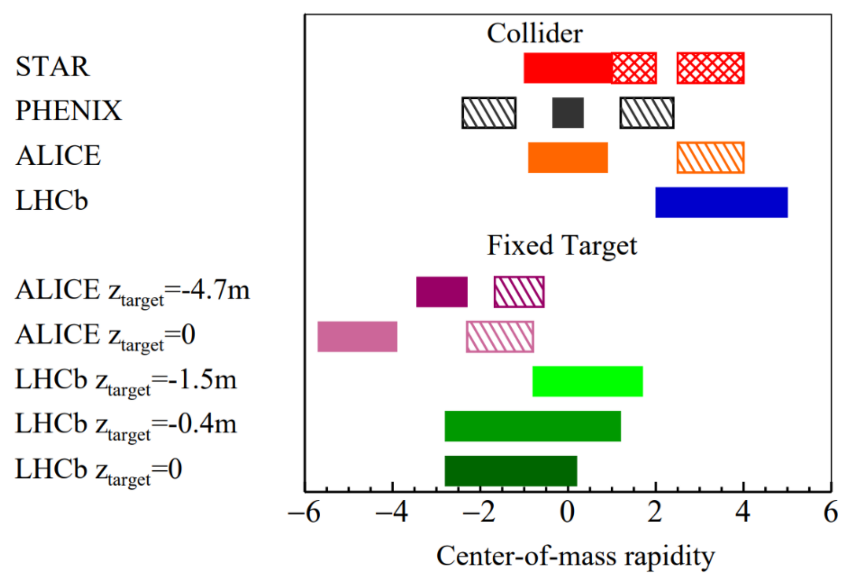
Beam energy in collision	E	7 TeV
Bunch population	N_b	$1.8 \cdot 10^8$
Number of bunches	n_b	1240
Beam current	I	33 mA
Stored beam energy		20.5 MJ
Transverse normalised emittance	ε_n	1.65 [μm]
β^* at IP2		0.5 m



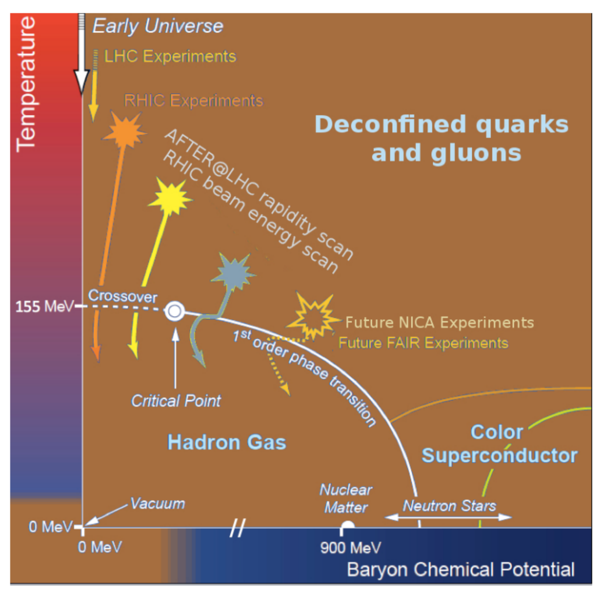
Working principle of the crystal-based fixed-target experiment (right side of the graphics) being embedded into the multi-stage collimation system (left side of the graphics). The crystal intercepts particles outscattered from the primary collimator and deflects them such that they impact the target. Products of these collisions are registered by the ALICE detector. Local absorbers, downstream of the ALICE detector, are added to intercept any particles originating from the crystal+target system that could be otherwise lost in the aperture of the machine. Graphics by D. Mirarchi.

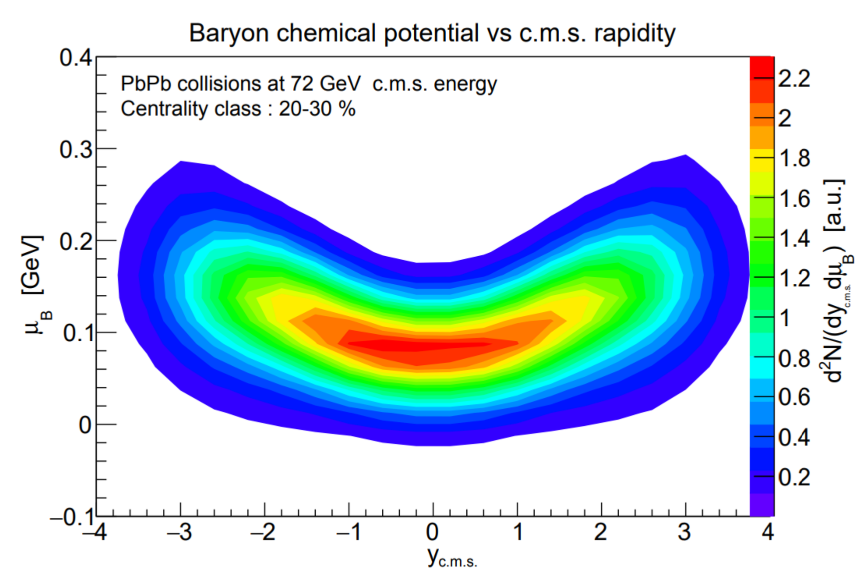
Research potential

Unique experimental geometry of fixed-target collisions at ALICE allows reaching far backward regions of rapidity, uncharted with head-on collisions and not accessible with other similar experiments, like LHCb (also in a potential fixed-target mode), PHENIX, STAR. This gives access to studying the structure of nucleons and nuclei at high momentum fraction x, which so far is not well known at both low and high scales of energy.



Some examples of the physics potential of the ALICE-FT experiment include phenomena such as the origin of the nuclear EMC effect in nuclei or a possible non-perturbative source of charm or beauty quarks in the proton carrying a significant fraction of its momentum. An experiment focused on high-x physics, where a single gluon carries the majority of the confined-system momentum, may also shed light on the still poorly understood confinement properties of the strong interaction, being one of the last open questions of the Standard Model.

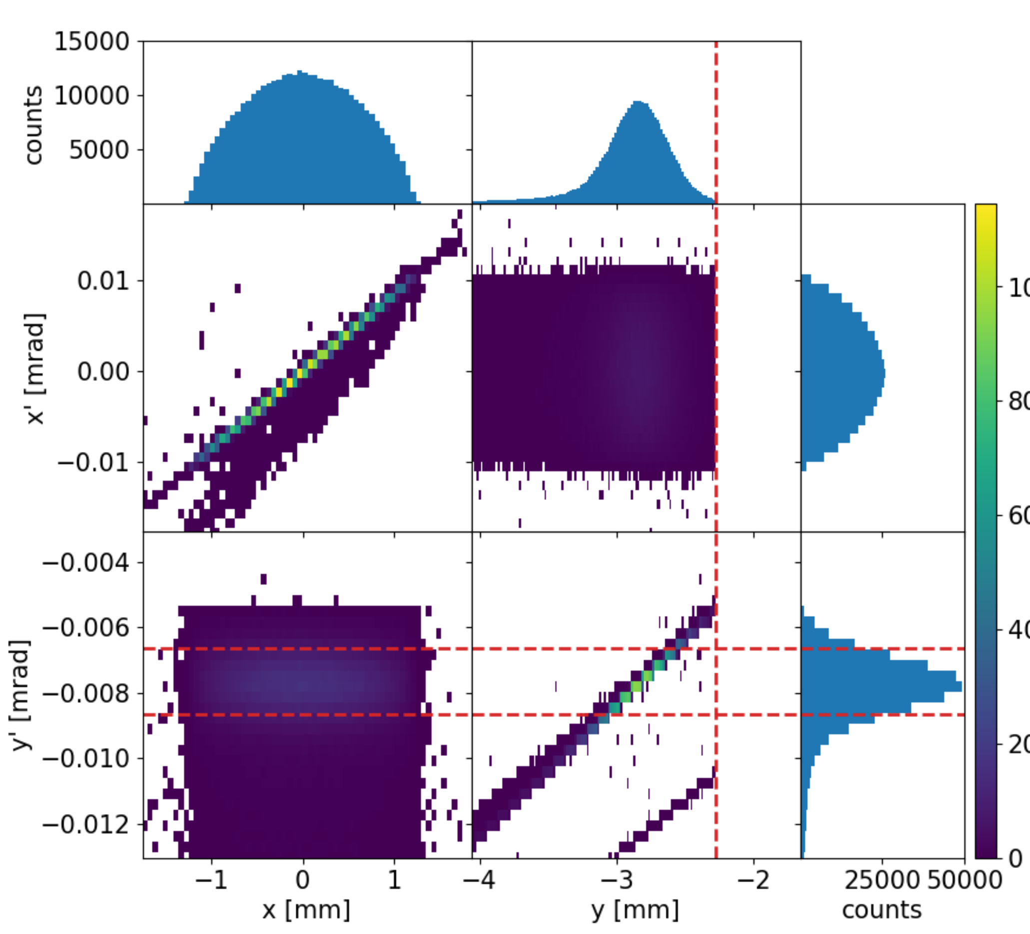




The heavy-ion programme of the ALICE-FT experiment is mainly focused on the production of the so-called quark-gluon plasma, a new state of matter where the quarks and gluons are deconfined, probing a different spectrum of the QCD phase diagram than existing and previous experiments. Moreover, with the expected dependence of the phase diagram quantities (temperature and baryonic potential) on the rapidity, a rapidity scan can be performed to study both the deconfined regime and the expected phase transition to the hadronic gas. In more general, with ultra-relativistic heavy-ion collisions at centre-of-mass energy of 72 GeV, it is possible to perform a 3D tomography of the quark-gluon plasma to explore new information on its properties in the longitudinal direction and its probes.

Feasibility evaluation

Distribution of beam particles at the location of a potential crystal installation with respect to the beam centre. x, y denote horizontal and vertical position, x', y' denote horizontal and vertical angle. Horizontal dashed lines indicate the angular acceptance of the crystal. The vertical dashed line indicates the minimum distance of the crystal edge from the beam centre such that collimation system hierarchy is not violated.



Tracking simulations were done to evaluate the performance of the ALICE-FT setup operated with lead ion beams in the SixTrack-FLUKA Coupling tool. The collimators hierarchy was set as in the table below and the primary beam halo was initialized at the entry of the TCTPCV with an impact parameter of 10 um and with the position-angle distributions defined by optical parameters at that location.

Coll. family	IR	Settings (σ)
TCPC/TCP/TSCG/TCLA	7	5.0/6.0/6.5/8.0
TCP/TSCG/TCLA	3	15.0/18.0/20.0
TCT	1/2/5/8	10.5/13.0/10.5/15.0
TCL	1/5	44.0
TCSP/TCDQ	6	10.3/7.4

1.31M of particles were injected into the simulation, 0.37M of particles hit the ALICE-FT crystal represented by a black absorber and 0.24M of particles fit its angular acceptance. Contribution from particles other than Pb-208 is negligible. The upper limit of vertical halo particles that enter the crystal collimation system and consequently can be channeled by the ALICE-FT crystal is estimated to roughly 18%, which is a very encouraging number. For the ALICE-FT proposal based on proton beams, the corresponding number is significantly smaller, about 0.4%.

The feasibility study based on particle tracking simulations indicates that the ALICE-FT not only can be adapted for the operation with lead ion beams, but also the ratio of particles that can be deflected towards the target, with re- spect to the total beam halo entering the crystal collimation system, is significantly higher than in case of protons beams, with an upper limit of about 18%. It sets a solid motivation for further feasibility studies covering the full ALICE-FT setup included into the simulation setup to investigate the expected flux of particles on target and cleaning efficiency of the collimation system in such a configuration. These results are expected to be obtained soon.

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