LAYOUT STUDIES FOR FIXED-TARGET EXPERIMENTS IN ALICE BASED ON CRYSTAL-ASSISTED LHC BEAM HALO SPLITTING

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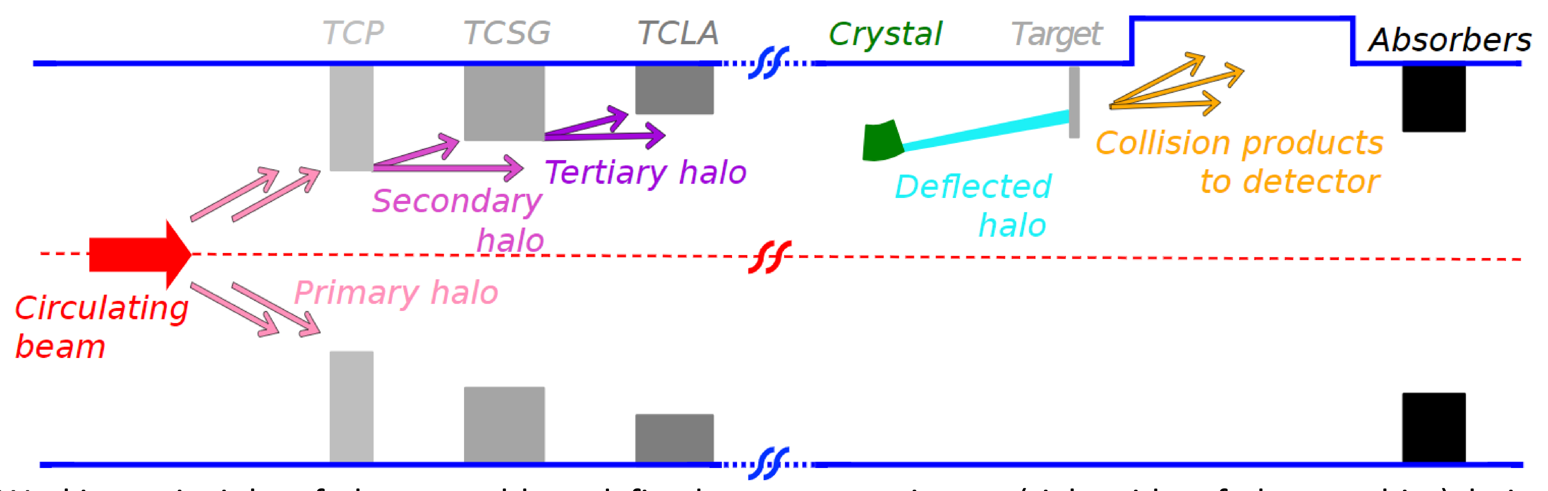
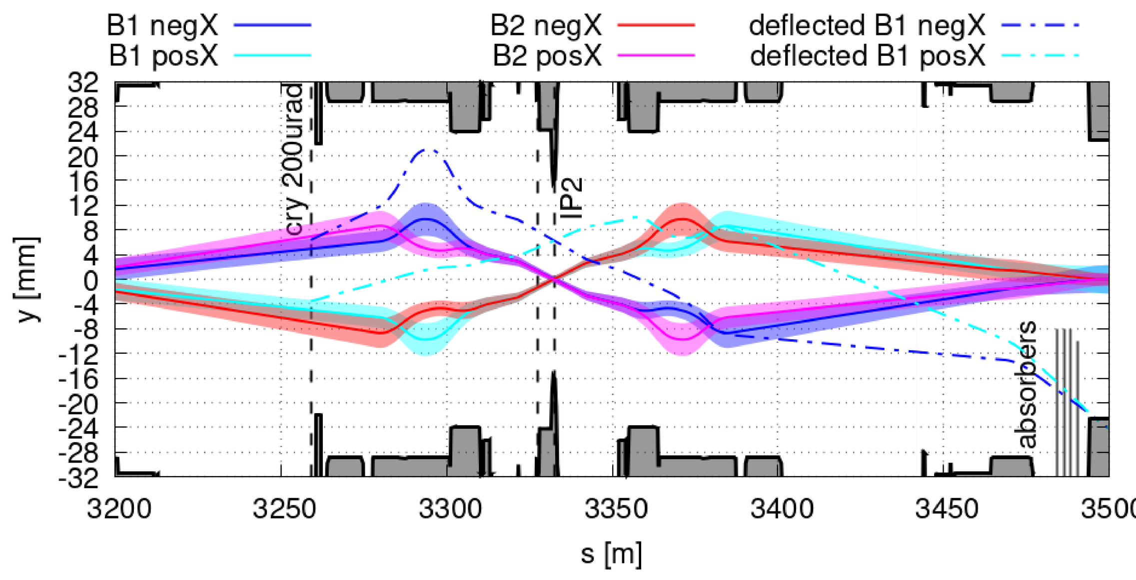
The Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) is the world's largest and most powerful particle accelerator colliding beams of protons and lead ions at energies up to 7 TeV and 2.76 TeV, respectively. ALICE is one of the detector experiments optimised for heavy-ion 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.

Crystal-based beam splitting layout



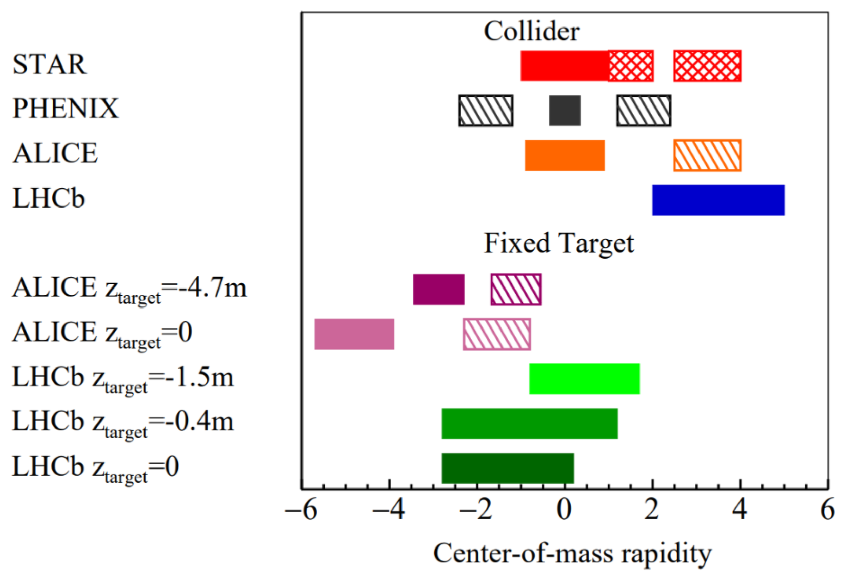
Working principle of the crystal-based fixed-target experiment (right side of the graphics) being embedded into the multi-stage collimation system (left side of the graphics). The crystal intercepts particles outscattered from the primary collimator and deflects them such that they impact the target. 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 lossed in the aperturę of the machine. Graphics by D. Mirarchi.



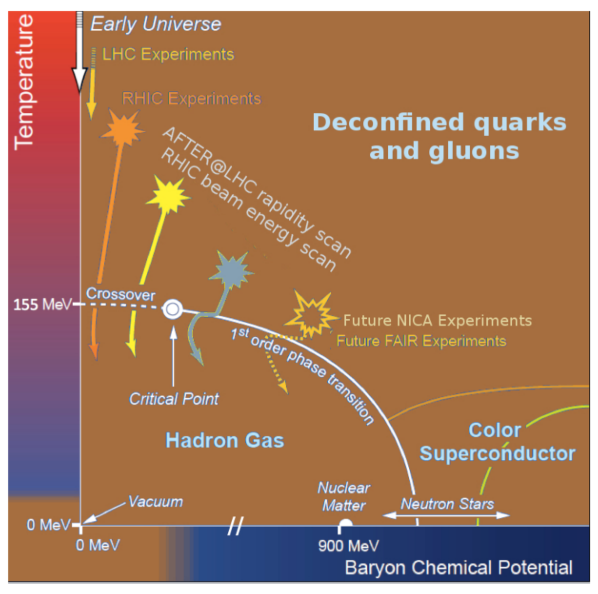
The proposed layout of the ALICE-FT experiment. Both beams (B1 and B2) with their envelopes (7.3 σ) are given with solid lines for both ALICE solenoid polarities (posX and negX). Deflected beams are given in dashed blue lines, crystal bending angle is 200 µrad. Machine aperture is given in solid black lines. Vertical dashed lines mark the locations of crystals, target and IP2, respectively. The location of absorbers is marked in the right bottom corner.

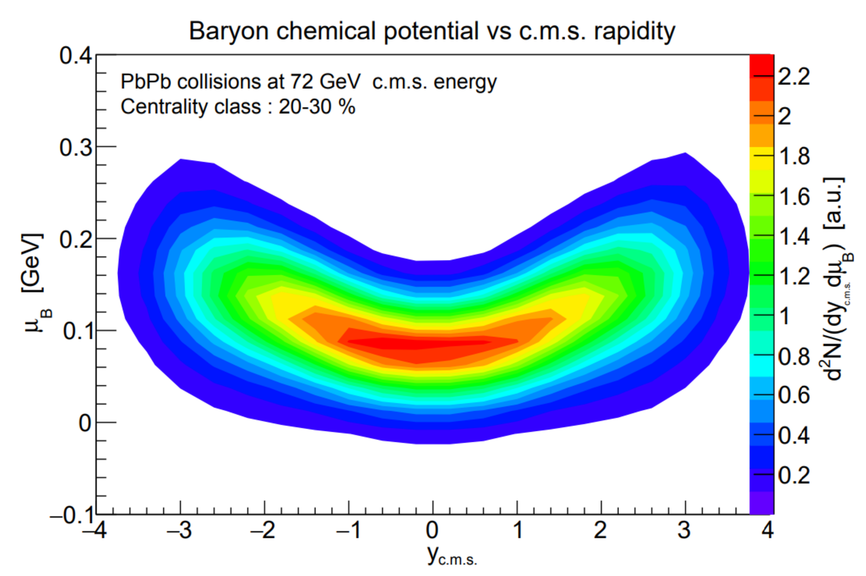
Research potential

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.



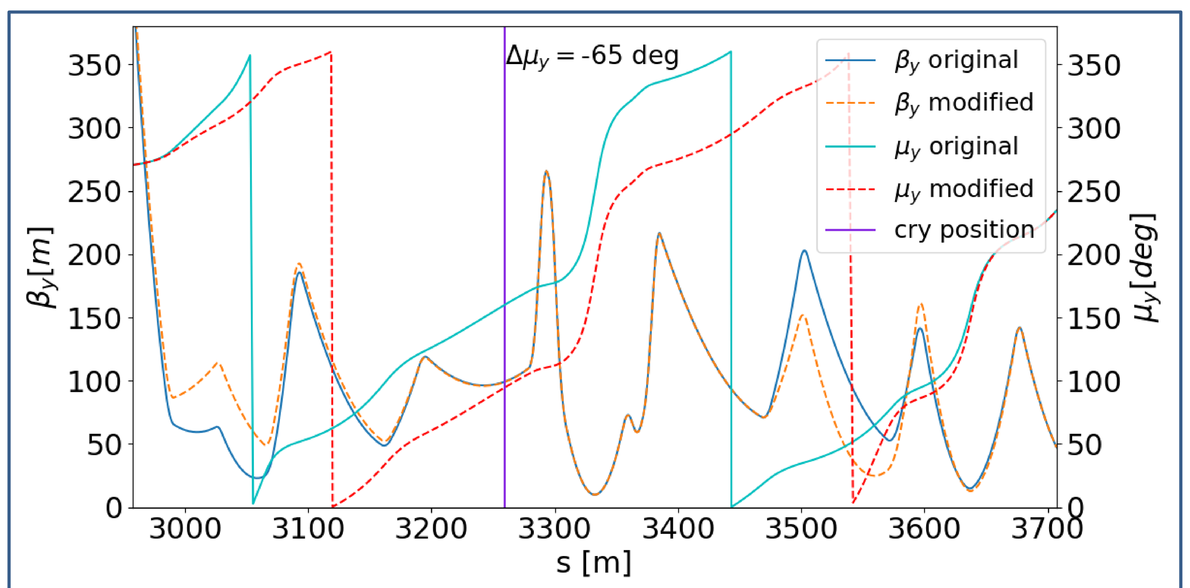
Some examples of the physics potential of the ALICE-FT experiment include phenomena such as the origin of the nuclear EMC effect in nuclei or a possible non-perturbative source of charm or beauty quarks in the proton carrying a significant fraction of its momentum. An experiment focused on high-x physics, 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.

Optics modification for an improved proton flux on target

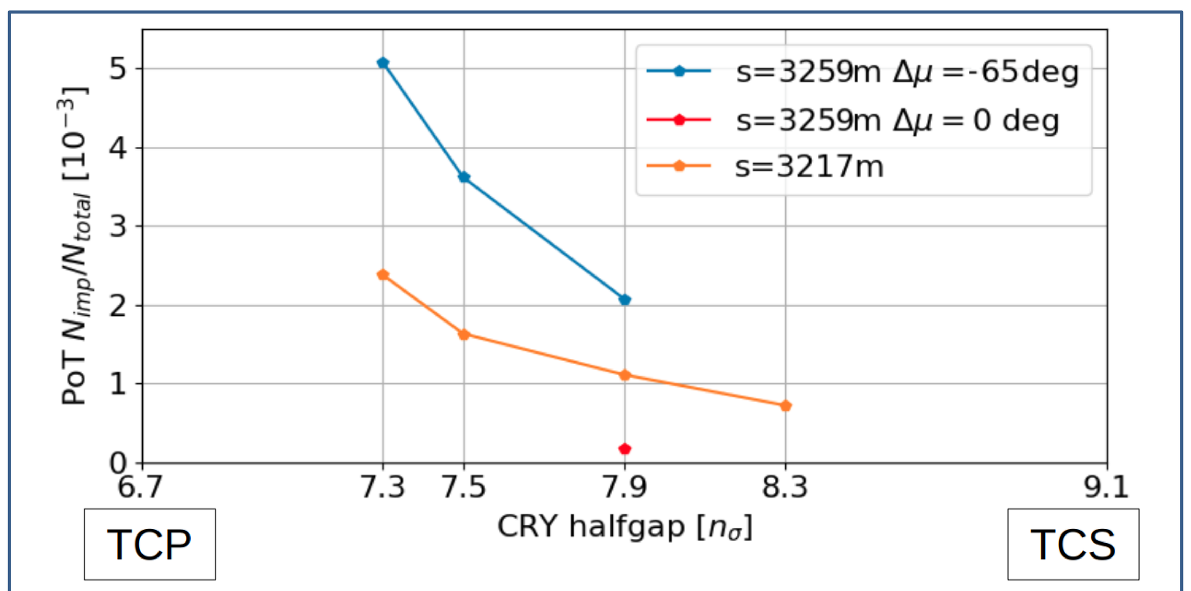


Vertical β function is locally modified to set an optimal betatron phase at the crystal. Optics at the interaction point (IP) stays unchanged. The betatron phase is brought to nominal downstream from the IP, such that this local optics modification does not affect the rest of the LHC.

Table: Normalised strengths of quadrupoles for nominal and modified optics. IR2 left and IR2 right stand for regions upstream and downstream from the IP2, respectively.

Quadrupole number	Quadrupole strength k_1 [10^{-3} m^{-2}] IR2 left nominal	IR2 left modified	IR2 right nominal	IR2 right modified
10	-6.39	-6.15	7.30	7.30
9	7.01	6.89	-6.60	-6.82
8	-5.41	-3.59	6.71	6.30
7	7.60	7.42	-6.36	-7.47
6	-4.91	-4.17	4.33	4.20
5	2.99	2.88	-3.63	-4.09
4	-2.80	-2.67	3.74	2.60

Expected proton flux on target	$7.6 \times 10^6 p/s$
Maximum flux that the ALICE acquisition system can accept	$10.0 \times 10^6 p/s$



Fraction of particles hitting the target over all particles impacting the collimation system. 3259m is a crystal location characterised with a good space availibility and 3217m is a previously considered location for a crystal. A clear increase of the system performance is observed.

The ALICE fixed-target programme is being developed to extend the research potential of the LHC and the ALICE experiment. The concept is based on steering onto a solid internal target a fraction of the proton beam halo split by means of a bent crystal, similar to crystals being developed for beam collimation at the LHC. Such a setup, installed in the proximity of the ALICE detector, would provide the most energetic proton beam ever in the fixed-target mode with centre-of-mass energy per nucleon-nucleon of 115 GeV. By using high-density targets, a high luminosity, in the order of an inverse femtobarn, can be achieved, allowing for an intensive study of rare processes, quark and gluon distributions at high momentum fraction (x), sea quark and heavy-quark content in the nucleon and nucleus and the quark-gluon plasma, including the QCD phase transition. Most of these phenomena are not accessible otherwise. This poster summarises our progress in designing the machine layout for the ALICE fixed-target programme. The proposed layout meets the requirements of safe operation in parallel to the main beam-beam collisions in the LHC and the required proton flux on target.

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