Studies of forward proton trajectories in vicinity of IP2 for the HL-LHC optics

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EMMI workshop Forward Physics in ALICE 3
19-Oct-2023

Work of P.P. was partially supported by Polish National Science Centre (project no. UMO-2019/34/E/ST2/00393).
Participation in workshop was financed by the ExtreMe Matter Institute EMMI of the GSI Helmholtz Centre for Heavy Ion Research.

Introduction

- In the last few years both ATLAS and CMS (CT-PPS) did feasibility studies for having Roman pots around IP1 and IP5:
  - CMS proceeds with design of Roman pots for LHC Run 4,
  - conditions foreseen for IP1 (see this and this publication) were judged by ATLAS Collaboration as not good enough to proceed towards detector construction.
- Feasibility studies for Roman pots in vicinity of IP8 (LHCb) were done (publication).
- **Based on the above work, feasibility studies for Roman Pots near IP2 were done**:
  - HL-LHC optics version 1.5, $\sqrt{s} = 14\,TeV$, $\beta^* = 10$ m,
  - beams colliding head-on (on_sep2 $= 0$), crossing angle of 270 μrad (on_x2 $= 270$; on_a2=0),
  - note: some discrepancy with the "official settings" optics public webpage.

Comment on HL-LHC Energy

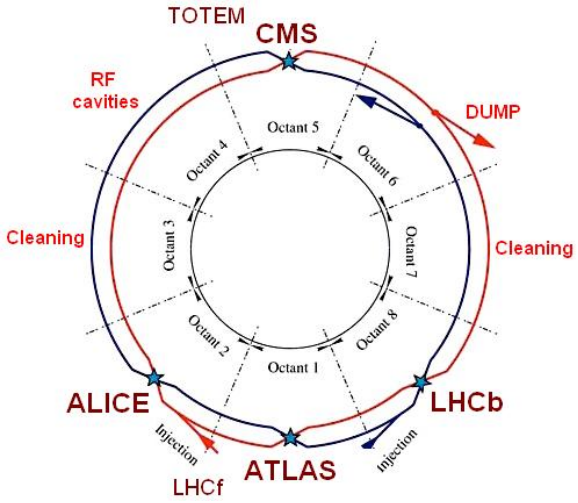
Date	:	**8th December 2021**
To	:	F. Gianotti, Director-General J. Mnich, Director for Research and Computing R. Bello, Director for Finance and Human Resources Members of the HL-LHC Executive Committee Members of the ATS-MB
CC	:	R. Billen, HL-LHC WPLs
From	:	M. Lamont
Subject	:	**Updated memorandum for ultimate energy exploitation of the LHC**
Reference	:	EDMS 1848761 v.2

Following the recommendation of the European Strategy update in 2013 that 'Europe's top priority is the exploitation of the full potential of the LHC', CERN evaluated the possibility of increasing the LHC beam energy towards the 'ultimate' value of 7.5 TeV, corresponding to a maximum dipole field of 9 T. All magnet circuits of the LHC have been designed with a 10% margin with respect to the powering at nominal beam energy of 7 TeV. By using these margins, one could hope to operate the LHC, from a magnet circuit point of view, at a beam energy of 7.5 TeV.

- Left: fragment (first paragraph) of memorandum circulated by CERN Directorate.
- 15 TeV might be possible, but feasibility studies from machine side are needed.
- In my calculations 14 TeV will be used.

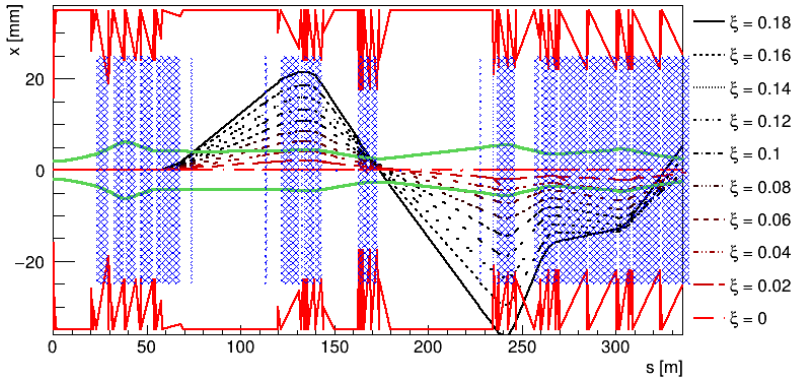
Coordinate System and LHC Ring Layout

- Coordinate system:
  - x points towards LHC ring (positive x "inside ring"),
  - y points upwards,
  - s is long the beam.
- In ALICE (as in LHCb) protons after interaction point are directed to the beampipe inner to the ring:
  - in region where beams are separated (from $\sim$BRAN) there is a very confined on the negative x (in between the beampipes) $\rightarrow$ challenging design of detectors to fit services,
  - on the other hand, there is quite some space at positive x (still constraint in order to not block the passage).



Proton Trajectories

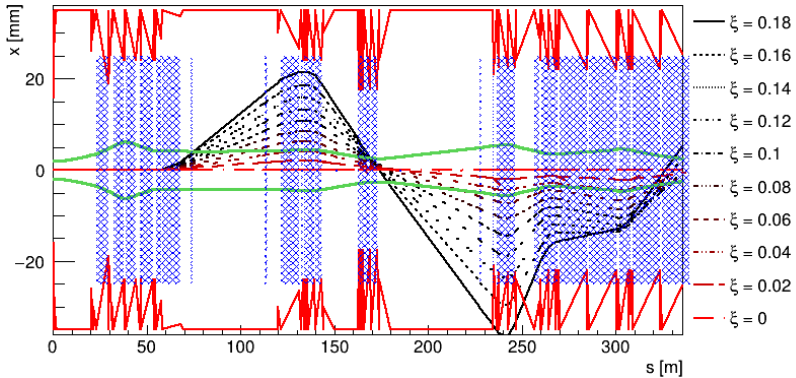
- Proton relative energy loss is defined as: $\xi = 1 - E_{proton}/E_{beam}$.
- IP2 is present at $(s, x) = (0, 0)$ where s is distance from IP2 along the beam pipe and $+x$ point towards the LHC ring.



- LHC magnets are marked as blue areas, red line represent their aperture.
- Continuous red line along $x = 0$ is a nominal trajectory (note: coordinate system includes 97 mm shift at around 110 m), dashed/dotted red/black lines are trajectories of protons which lost energy (note: higher losses translate to larger divergence from the beam).
- Green line indicates 15σ beam envelope.

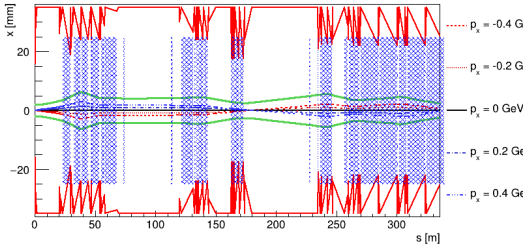
Proton Trajectories – Initial Thought on Detector Location

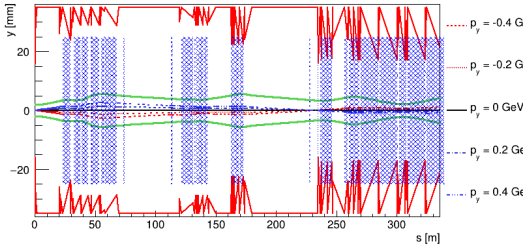
- In locations between ∼75 and ∼160 m diffractive protons are going inside the ring.
- After ∼175 m proton trajectories are at negative $x \rightarrow$ detectors to be placed in between beampipes.

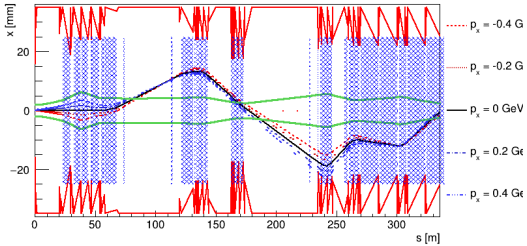


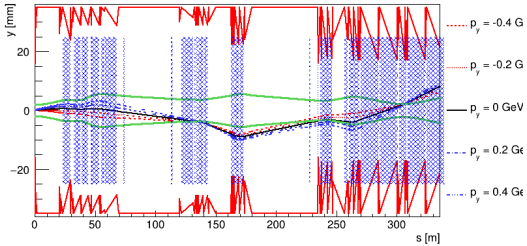
- There is one collimator impacting trajectories between ∼75 and ∼230 m: TCLIA.4R2 located at 3953.85 m (74.24 m from IP2) $\rightarrow$ impact of its closure to 15σ can be imgained by looking at the green line.
- From a first glance, the best Roman pot position is at ∼150 m from IP2:
  - already 2 separated beampipes,
  - highest divergence.

More Proton Trajectories (Momentum Dependence)





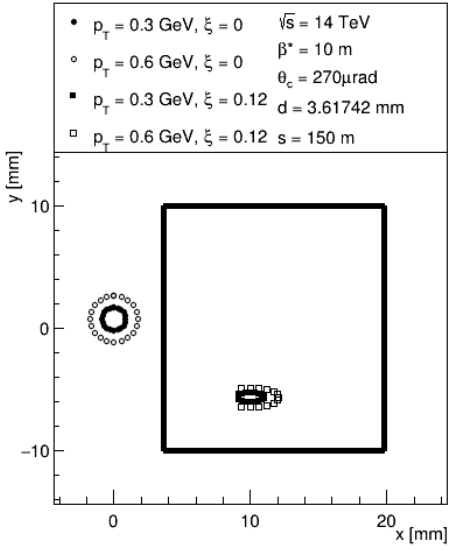




- Top: beam energy ($\xi = 0$), bottom: $E_{proton} = 6160$ GeV ($\xi = 0.12$).
- Note: "focal point" moves towards IP2.

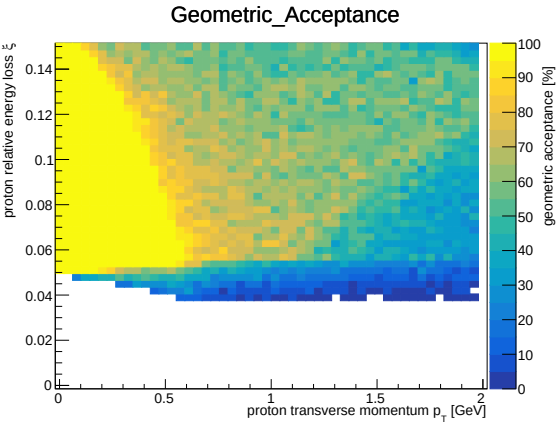
Proton Positions at 150 m

- On plot – proton positions at 150 m from IP2:
  - the solid rectangle marks the possible active area of proton detector,
  - the distance of the detector from the beam center was set to $15\sigma \approx 3.62$ mm.
  - The "TCLIA.4R2" collimator was closed to 15σ.
- As kinematics of scattered protons is correlated to kinematics of central system, it is important to understand proton position at the detector of various kinematics:
  - circles represent protons with $\xi = 0$ and non-zero p_T and squares ones with $\xi = 0.12$,
  - shift towards y values for $\xi = 0.12$ is due to crossing angle,
  - "missing points" for $\xi = 0.12$ are due to TCLIA.4R2.



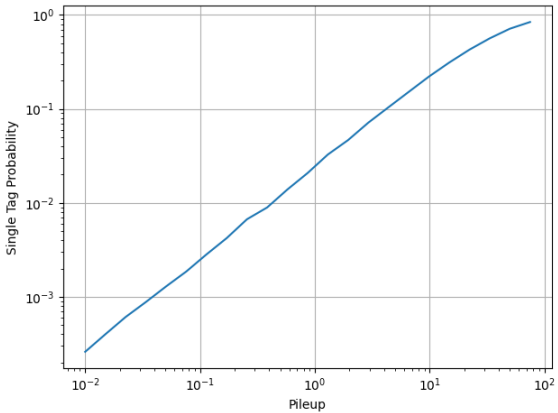
Geometric Acceptance for Detector at 150 m

- Geometric acceptance is defined as the ratio of protons with a given (ξ, p_T) that reached the detector to the total number of the scattered protons having given (ξ, p_T).
- The collimator "TCLIA.4R2" present at $\approx 75m$ from the IP2 is closed at 15σ and the possible limitations from aperture are considered..
- The distance of the detector from the beam center was set to $15\sigma \approx 3.62$ mm.
- This setting should give access to protons with $0.05 < \xi < 0.15$.



Pile-up Dependence

- Majority of events visible in the Roman Pots comes from min-bias protons.
- It is useful to see what would be the probability of having proton visible in the detector for a given value of pile-up.
- Min-bias events were generated by Pythia 8 and then transported to 150 m.
- Each proton was checked to be in the detector acceptance (assumed beam-detector distance: 3.6 mm).
- On plot: single tag probability as a function of pile-up.



Summary

- Studies of proton trajectories in vicinity of IP2 were done using HLLHC optics ver. 1.5.
- In locations between $\sim$75 and $\sim$160 m diffractive protons are going inside the ring.
- After $\sim$175 m proton trajectories are at negative x, for these locations detectors should be placed in between beampipes (may be difficult).

- For location at 150 m geometric acceptance lies in the range of 5% to 15% for diffractive protons.
- Single tag probability as a function of pile-up was checked for location at 150 m.

- In case a new optics version is developed, studies can be easily repeated.