Hector, a fast simulator of proton propagation through the LHC beamline

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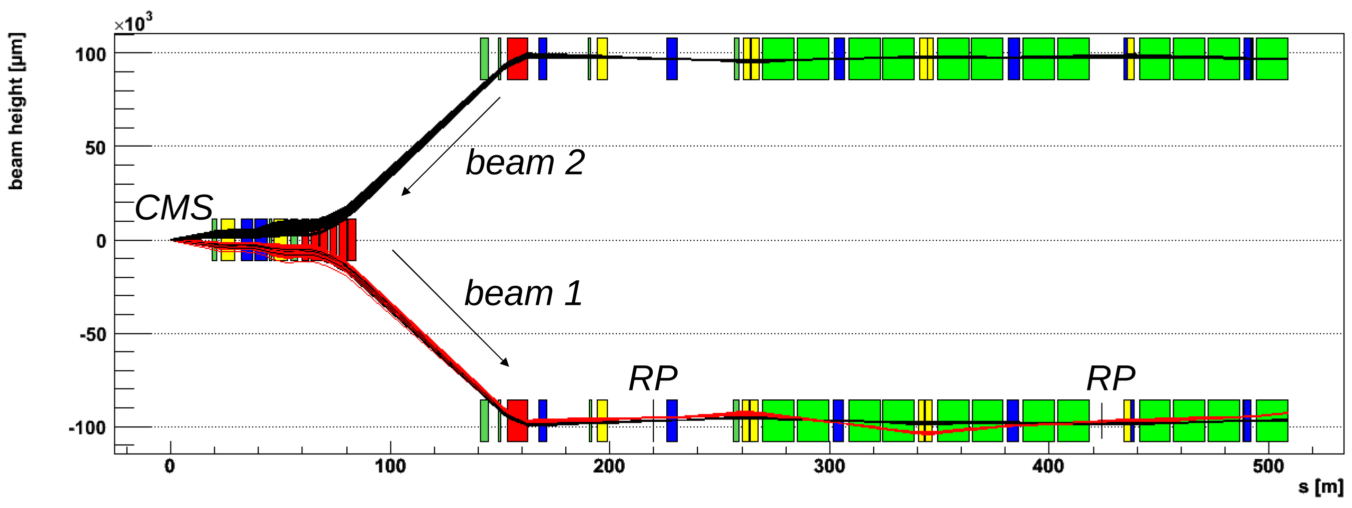
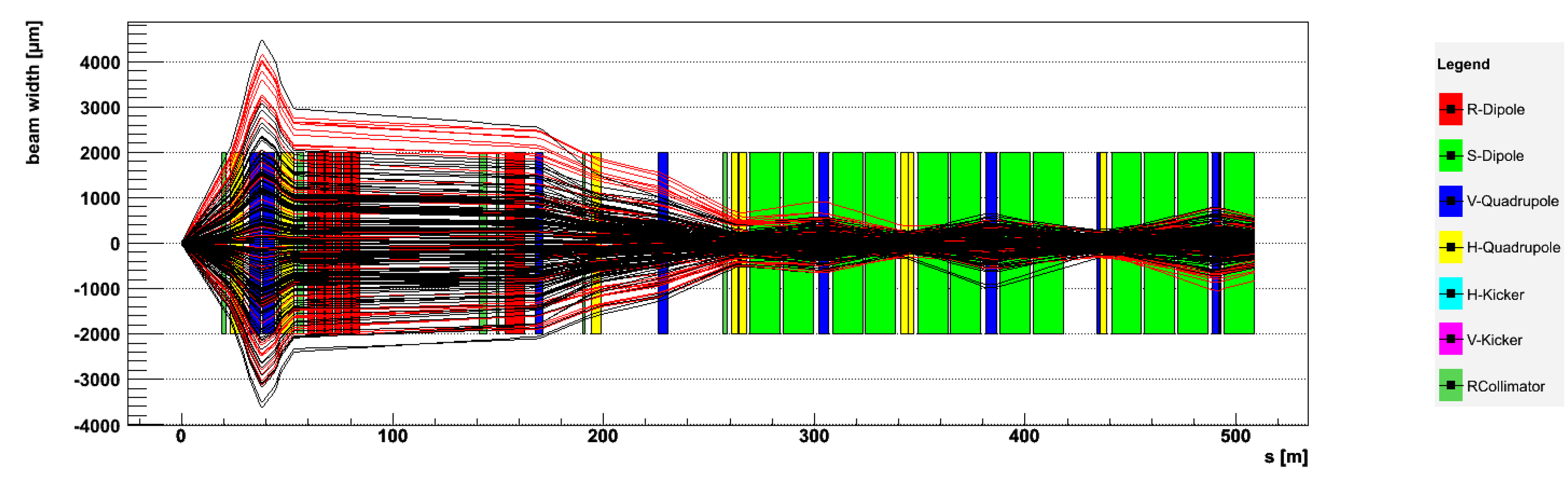
Motivation

Physics studies :

The Large Hadron Collider at CERN will soon start colliding high-energy protons. Apart from the study of the parton interactions, as gluon-gluon or quark-anti-quark fusion, some very interesting physics can be driven by photon-proton (γp) and photon-photon (γγ) interactions. Thanks to high energy and luminosity of collisions at the LHC a significant rate of the events involving photon interactions is expected. These events are characterized by the protons scattered at very small angles. So, a detection of very forward protons would provide a clear signature of such interactions. Hence, the dedicated forward detectors integrated into the LHC beamline, called **roman pots**, would give access to





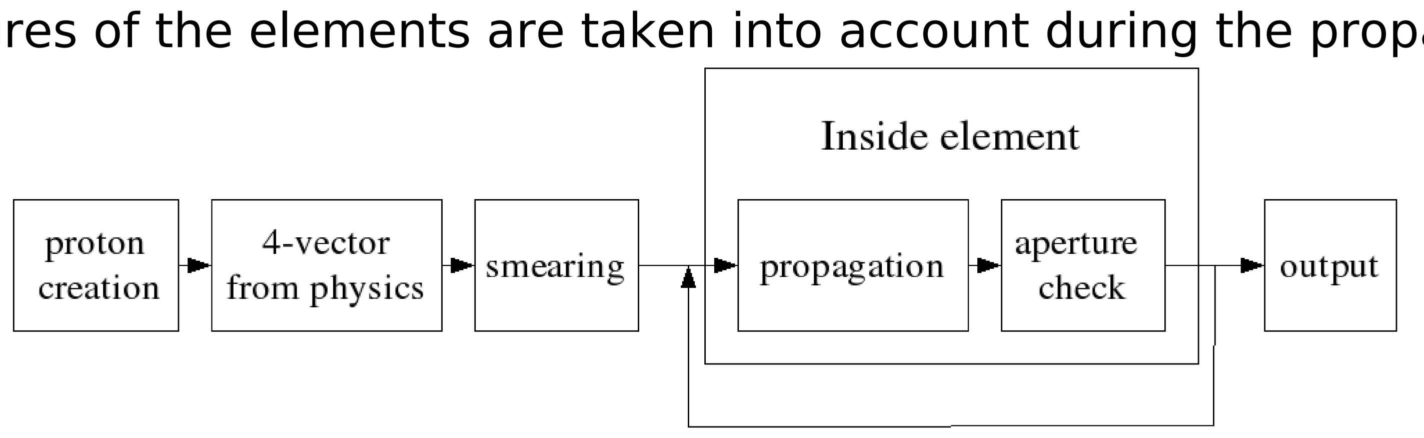
Top (left) and side (right) views of both beams of the LHC, next to the CMS interaction point – up to a few hundred of meters away. The proton trajectories (red and black) are superimposed on the layout of the beamline elements (dipoles and quadrupoles). A red trajectory corresponds to a proton which emitted a 200 GeV photon. Bending of the beamline, normally starting after first light green dipoles, has been suppressed to simplify the picture.

These photon interactions are experimentally cleaner than the partonic ones. Moreover, the roman pots provide some information that constrains better event kinematics. Therefore the development of new detectors and new simulation tools are needed. A Monte Carlo simulator called **Hector** has been developed in order to provide a realistic simulation of the propagation of forward-scattered protons, between the interaction point and the roman pots, some hundred meters away from the IP.

Implementation

Linear approximation using transfer matrices :

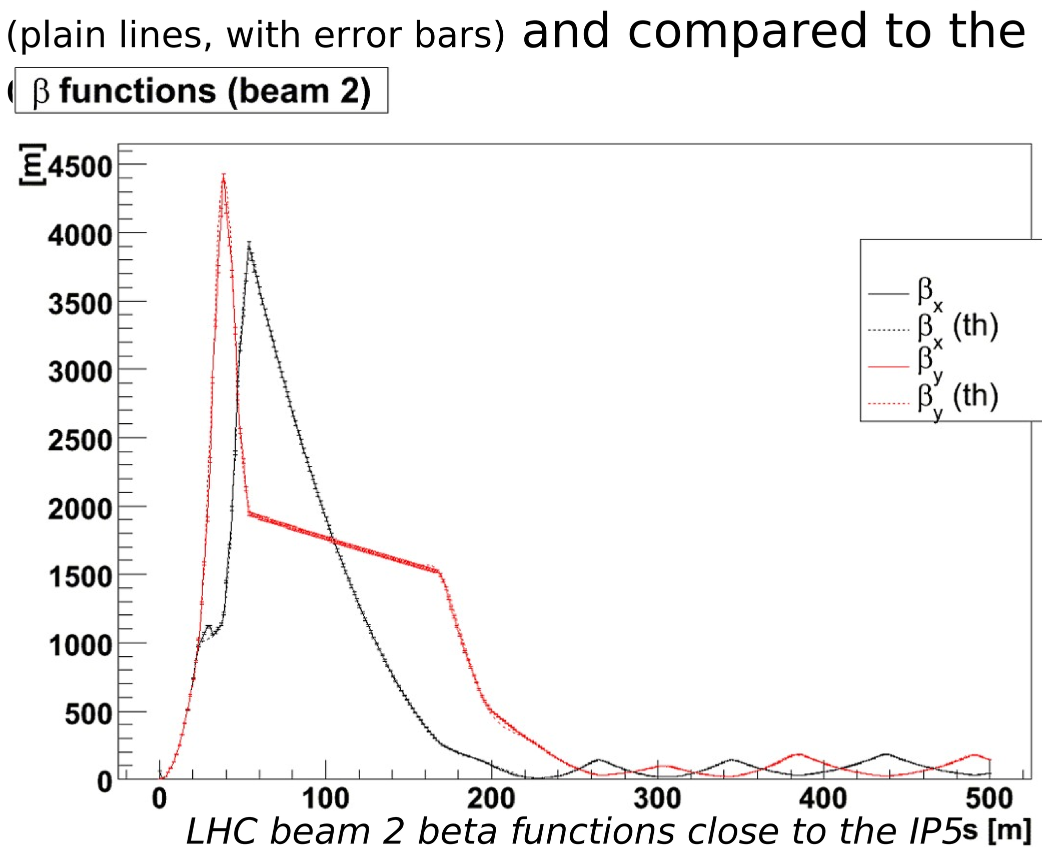
Each *optical* element of the beamline is represented by a transfer matrix acting on a proton phase space vector. The whole beamline is then reduced to a global transfer matrix describing the path of a single proton (no intrabeam interactions). Limited apertures of the elements are taken into account during the propagation of the protons.



$$\begin{pmatrix} x(s) \\ x'(s) \\ y(s) \\ y'(s) \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} \cos X & R\sin X & 0 & 0 & R(1-\cos X) \\ -(1/R)\sin X & \cos X & 0 & 0 & \sin X \\ 0 & 0 & 1 & s & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_0 \\ x'_0 \\ y_0 \\ y'_0 \\ \Delta p/p \end{pmatrix}$$

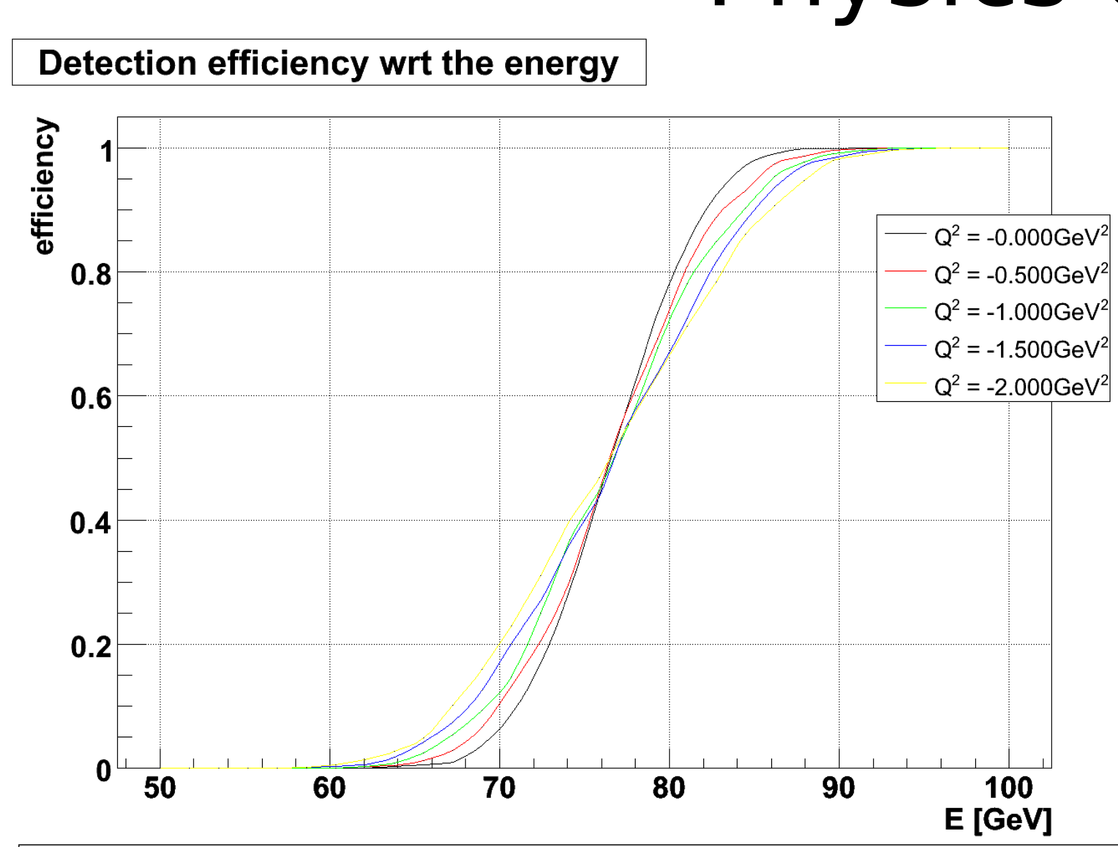
s : element length
x,y : proton transverse position
x',y' : proton momentum angle

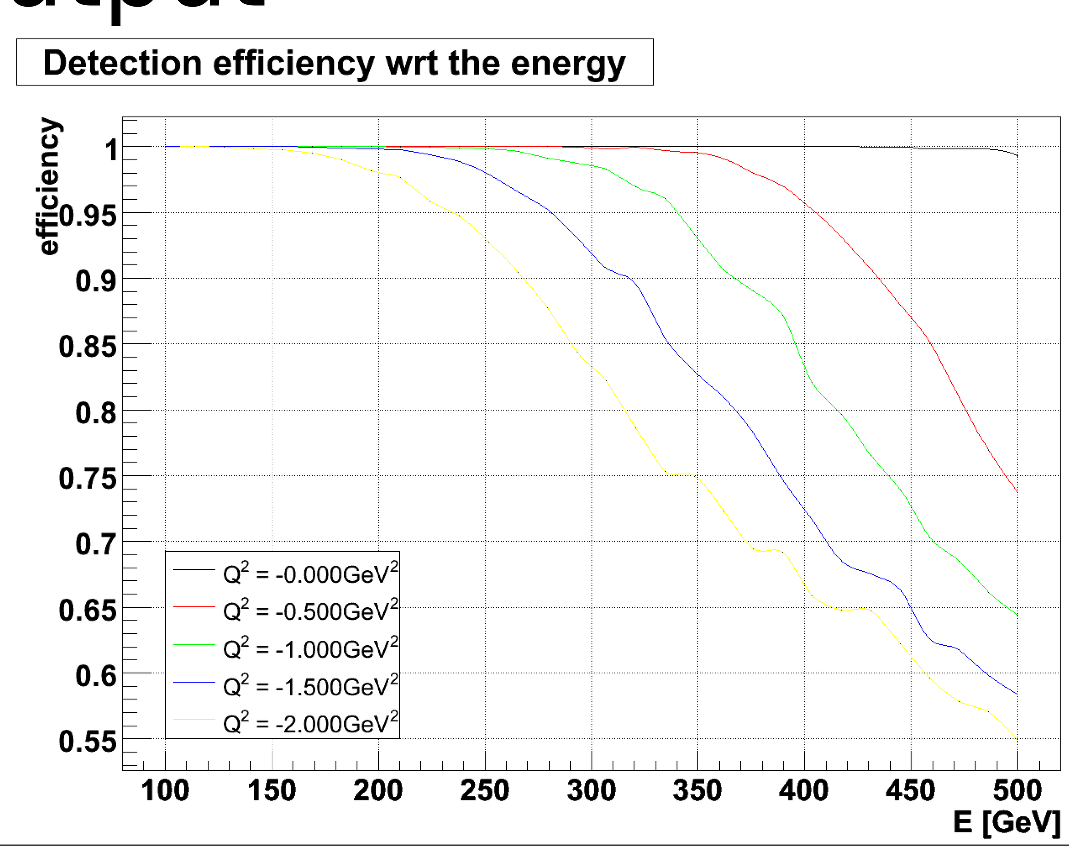
Hector performance is cross-checked by comparing to the output of a full (and very complex) LHC beamline simulation.The **beta functions**, roughly representing the transverse size of the beam can be computed (plain lines, with error bars) and compared to the



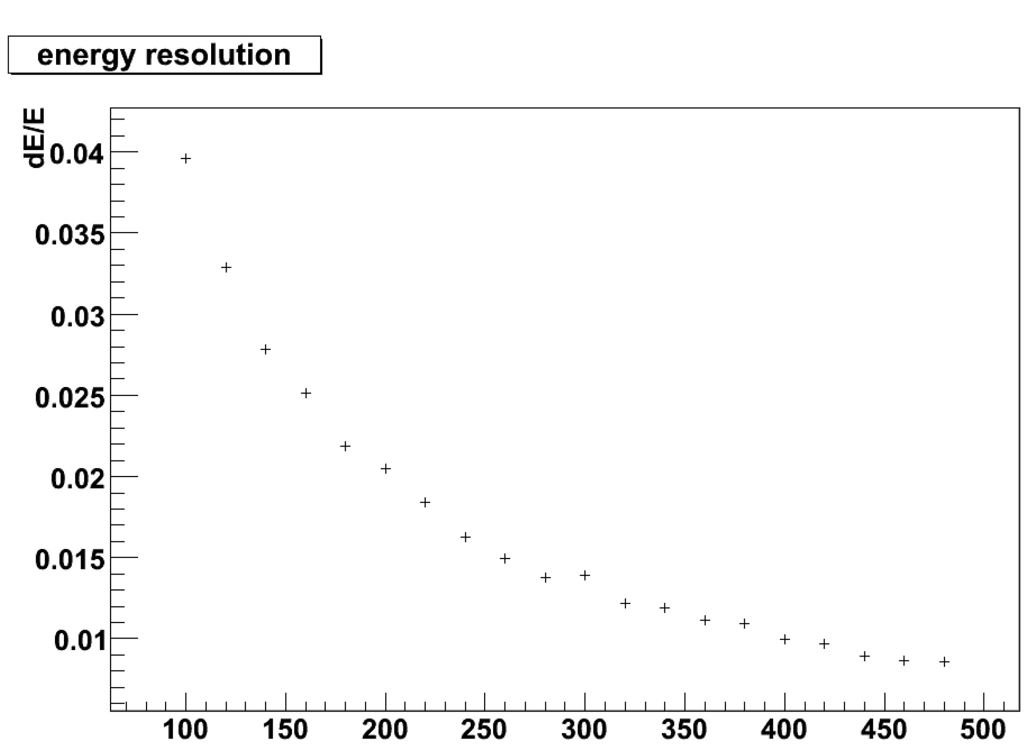
LHC beam 2 beta functions close to the IP5

Physics output





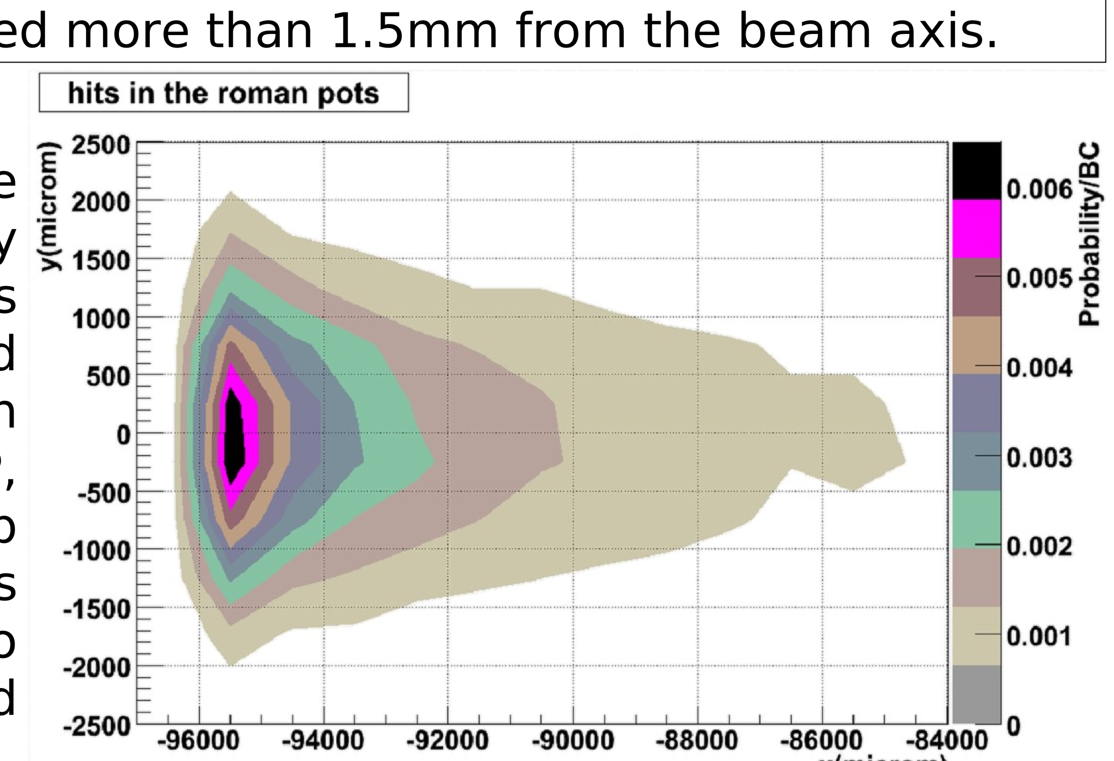
Computed efficiency of the proton detection in the roman pot, as a function of the emitted photon energy, for several small photon virtualities (Q^2). For photon energies ranging from 75 to 500GeV, the detection efficiency stays above 50%, for a roman pot installed 220m away from the IP and detecting protons deviated more than 1.5mm from the beam axis.



Photon energy resolution using roman pots

Resolution of the photon energy is better than 2% for $E_\gamma > 200$ GeV. As expected, strong kinematical constrains can be thus applied during the data analysis

A major concern for the roman pots is its heavily irradiated environment. This plot shows the expected number of hits in a roman pot, at 220m from the IP, resulting from inelastic pp interactions. Such events create also a background to the proper, photon-induced interactions.



(Nominal beam position: -97mm)

Hits distribution per bunch crossing in the roman pots area, due to inelastic pp->pX interactions. To obtain rates from this plot, one should multiply the hit probability by 40MHz.