Roman Pots @ High-Luminosity LHC

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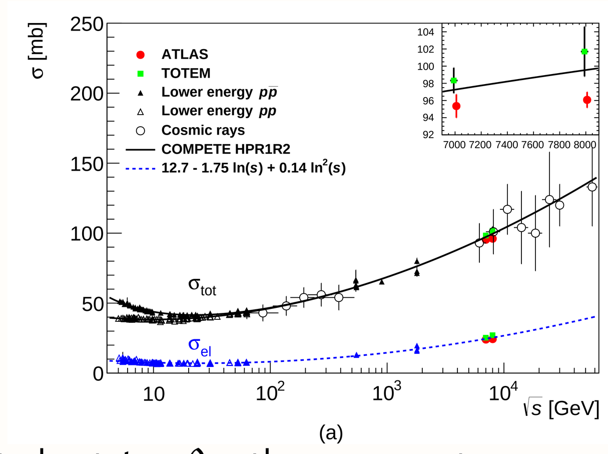
Physics with forward protons

Elastic scattering

Elastic scattering ($pp \to pp$) is the most frequent diffractive process in hadron–hadron collisions. The optical theorem relates the elastic scattering amplitude, f, at $t = 0$ to the total cross section:

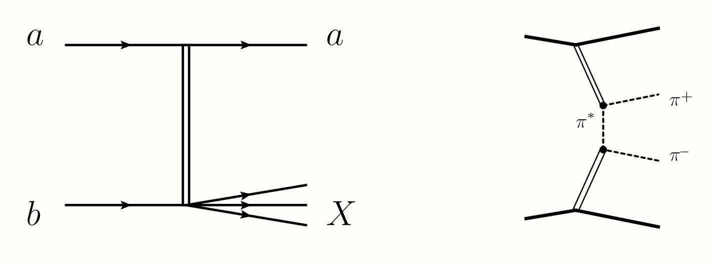
$$\sigma_{tot} = 4\pi \, \mathrm{Im} f(t = 0).$$



Measurements require dedicated high-β^* LHC optics (90 m). Even larger β^* allows accessing the Coulomb-nuclear interference region providing thus sensitivity to the ratio of the real to imaginary part of amplitude at $t = 0$ – the ρ parameter.

Single diffractive dissociation and central diffraction

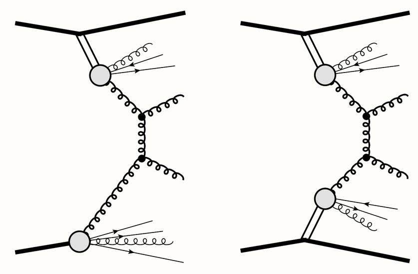
Single diffractive dissociation (also known as *single diffraction*) is a process in which one leading forward proton is produced. Single diffraction constitutes about 20% of the total proton-proton cross section. It is a process important in consideration of the QCD backgrounds at the LHC and also in physics of cosmic air showers.



Central diffraction (also known as *double pomeron exchange*) is a process with two forward protons. A particularly interesting class of central diffraction are exclusive processes, where all centrally-produced particles are detected. An example is the process of pion pair production $pp \to p\pi^+\pi^-p$, which can be used for studies of low-mass resonances, including searches for glueballs.

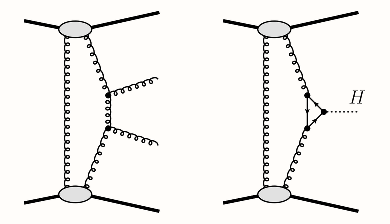
Hard diffraction

Diffractive processes are predominantly soft. However, in a fraction of them a hard scale is present which justifies the use of perturbative language for their description and allows defining and measuremnt of diffractive parton distributions and studying their QCD evolution. Since, in hadron–hadron collisions the QCD factorisation is broken by underlying soft events that destroy the rapidity gaps then a concept of the rapidity gap survival probability is introduced.



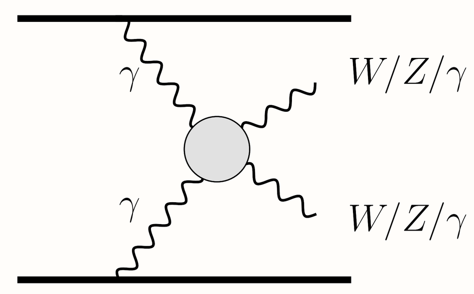
Hard exclusive diffraction

Hard exclusive events are interesting for several reasons. Contrary to non-exclusive hard diffraction, they can be described within QCD purely in terms of multi-gluon exchange without the need of introducing diffractive parton distributions. The measurements of all final-state particles and the energy-momentum conservation provide a powerfull background suppression. In addition, the quantum numbers of the centrally-produced states are limited to 0^{++} or 2^{++}.



Two-photon processes

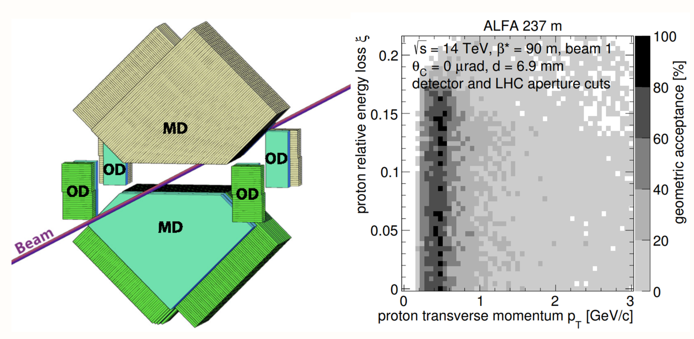
Two-photon processes are similar to hard exclusive diffraction, but they are mediated by electromagnetic interactions. Also here, exclusivity provides a high background reduction, which makes this process perfect for studies of multi-boson couplings: $\gamma\gamma\gamma\gamma$, $\gamma\gamma ZZ$, $\gamma\gamma WW$. Such measurements have great sensitivity to new physics processes demonstrating themselves in the electroweak sector.



Existing forward proton detectors – ATLAS example

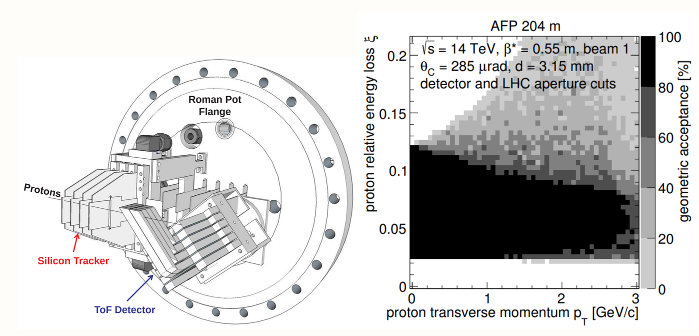
ALFA detectors (vertical RPs, high-β^*)

At nowadays LHC the Roman Pot detectors are used by the ATLAS, CMS and TOTEM Collaborations for precise measurement of the total and elastic cross-sections as well as to study soft, hard and central diffraction. The ATLAS associated detectors are located symmetrically w.r.t. the Interaction Point at the distances of about 240 m. The ALFA RPs approach the beam in the direction perpendicular to the accelerator ring. They are equipped with planes of the scintillating fibres to measure the elastically scattered protons. Such measurements can be performed during the dedicated runs with high-β^* optics.



AFP detectors (horizontal RPs, low-β^*)

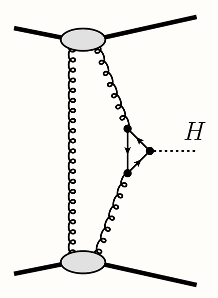
The AFP system consist of four Roman Pots, which approach the beam in the accelerator plane. All stations contain the silicon pixel detectors. Two outer ones are equipped with precise time-of-flight counters. The detectors take data routinely during the standard LHC runs (low-β^* running). Precise timing enables determination of the interaction vertex thus helping to reject the backgrounds due to the pile-up. Primary physics goal is to study diffraction and particularly the central exclusive production of large mass systems.



Possible physics cases for HL-LHC

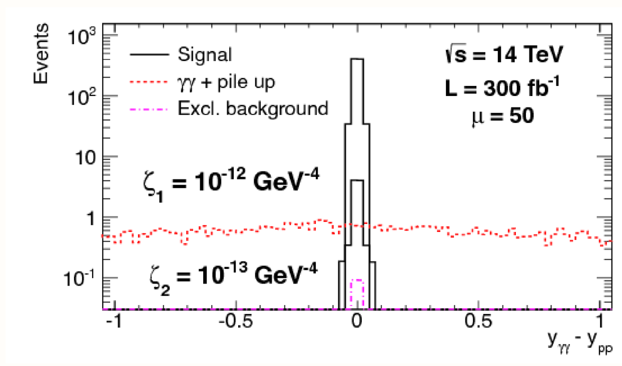
Exclusive Higgs

Measurements of the Higgs boson in the exclusive channel has several advantages over the standard methods. First, the quantum numbers are constrained to 0^{++} or 2^{++}. Second, the measurement in $b\bar{b}$ channel is possible (exclusive $b\bar{b}$ jets are suppressed). Taking into account that the production is purely due to gluon–gluon fusion, the process offers complementary constraints to couplings, in particular Hbb.



New physics searches

Two-photon processes offer a great opportunities to search for new physics. The suppression of background by exclusivity cuts leads to very clean signals, especially in $pp \to p\gamma\gamma p$ channel.

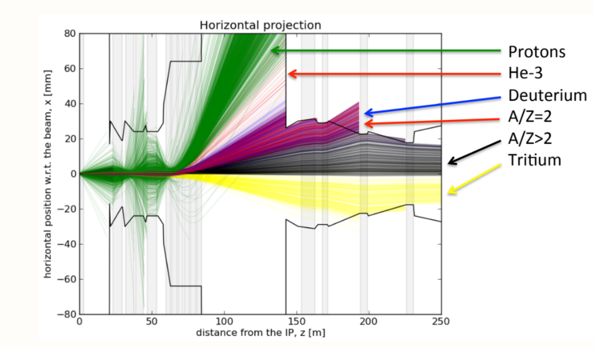


Diffraction

High pile-up environment of HL-LHC is likely to prevent measurement any non-exclusive diffraction processes. The high-β^* optics machine will probably not be possible. Therefore, the studies of soft, low-mass diffraction will not be feasible. However, it is always possible to decrease pile-up and study hard diffraction with low-β^* optics.

Centrality in HI physics

One of the most important concept in the heavy-ion physics is the centrality of the collision. Detectors in RPs offer a unique way of its determination – based not on measurement of participants, but on exclusive measurement of all spectators. The are scattered into the accelerator beam pipe as nuclear fragments and can be detected by a dedicated set of detectors. Moreover, he use of the such detectors to veto nucleus disintegration is a very important experimental tool aiding selection of two-photon physics processes in HI interactions.



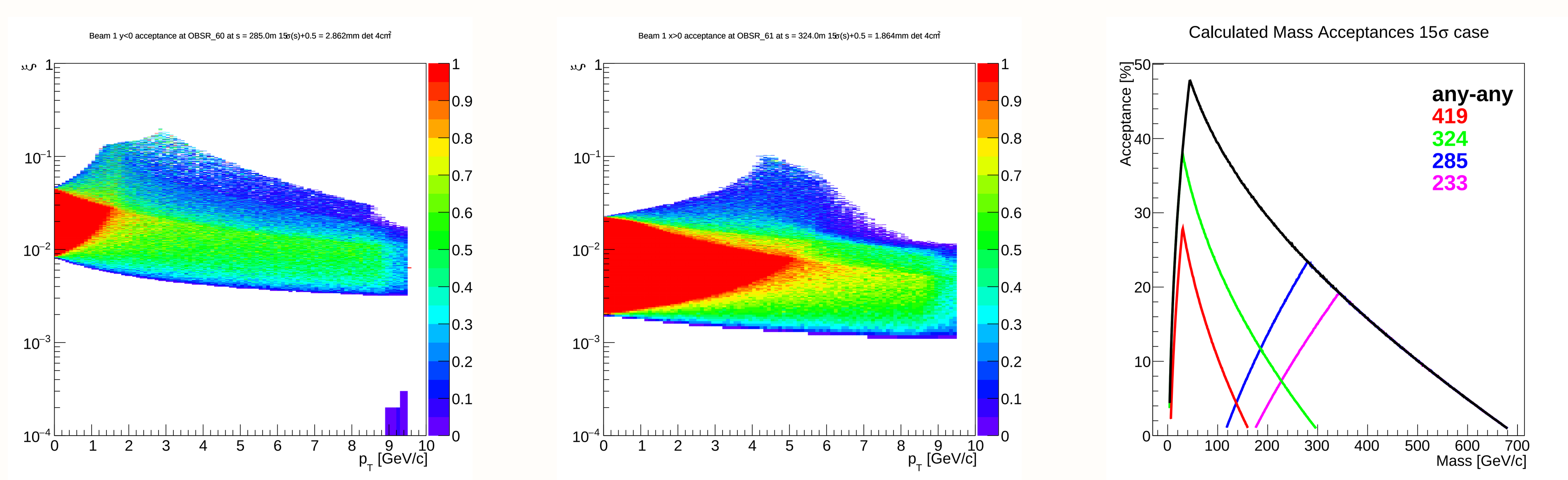
First feasibility studies with HL-LHC optics v. 1.3

Geometric acceptances of possible detectors

The first step to determine possibilities of forward proton registration is to study possible the detector locations. The present analysis concentrates on the determination of the acceptance of the hypothetical detectors of 2×2 cm^2 size located at the distance of $15\sigma + 500$ μm from the beam (σ – local beam width, 500 μm accounts for dead material).

The acceptance was studied as a function of the scattered proton relative energy loss (ξ) of and its transverse momentum (p_T). The left and centre plots show example results for two detectors located at 285 m and 324 m away from IP1 (ATLAS). The right figure presents the acceptance for the double proton tag as a function of M_X (centrally produced mass) using only detectors at a given position (colourful lines) and any–any combination (black line).

The results obtained in this study show that HL-LHC has a potential to observe exclusive Higgs and perform BSM searches with forward protons.



Acknowledgements

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