Forward Tags for New Physics

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Abstract

Traditionally the forward region in fixed target experiments, is a solid angle around the beam direction where experimenters' life is difficult (particularly at high energy) due to large fluxes of energetic particles produced at small angles. Luckily, since Rutherford scattering experiments, the interesting region appears to be at large angles, where beam particles tend to recoil after probing the target's interior constituents, measuring their size and structure.
At colliders, the forward regions are two, around the two colliding beams, and correspond to the solid angles just around (and inside) the beam pipes along the directions of the two beams exiting the region of interaction, usually totally surrounded by hermetic detectors covering most of the solid angle, around 90^{o} (η = 0) with respect to the beam's directions. The parameter η (pseudorapidity) is currently used in collider physics to represent the scattering angle wrt the beams' axis, with (η = 0) at 90^{o} and ($\eta = \infty$) at 0^{o}; the forward regions therefore correspond to large-η values. At colliders these regions are even more difficult to handle than at fixed target. With the increasing luminosity achieved for LHC and ever more planned for HL-LHC only very specific detectors would be sufficiently radiation hard to survive for significant periods of time in these regions, and their space, time and energy (for calorimeters) resolutions should be optimal. The solid angles, not covered by central large detectors, are usually relatively small and therefore the necessary detectors will not be massive and not too expensive [1]. We do not review here the many subject that may profit from forward measurements at colliders, but just give few hints of interesting subjects that we intend to survey in a more complete paper. An initial remark, which however is basic as justification for these studies, is that in considering physics beyond the Standard Model (BSM) the role of the forward regions may become fundamental, as we are now addressing production of new states that may be produced everywhere in the η–ϕ phase space. This aspect has been explicitly made clear in the impressive physics survey of the proposal for the Forward Physics Facility at the High-Luminosity LHC [2]. Here we consider few experimental instruments that may be installed at many different locations of LHC; for sake of concreteness we focus ion forward regions at LHC around the IP5 intersection where CMS is located, with which we are more familiar, but other locations would be possible is preferable. We give few examples of a general experimental method consisting in tagging specific processes through particles or jets that act as "spectators", giving signatures for event selection and in certain cases, providing kinematical constraints to the associated production processes.

1. Introduction

''Yesterday's discovery is today's calibration…
…and tomorrow's background!
(Richard Feynman and Val Telegdi)

The Higgs discovery (July 4, 2012) came principally via gluon-gluon fusion, but the so called Vector Boson Fusion (VBF) is another mechanism for Higgs production (Fig.1), which is considered particularly interesting for studying processes where the Higgs decay to BSM particles, in particular dark matter particles, in a mechanism that is called “Higgs Portal”.

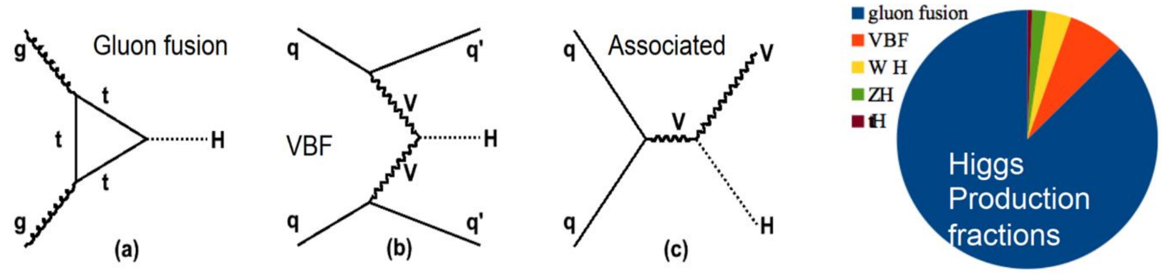


Fig 1: Higgs production processes, and relative fractions; gluon fusion is dominating, but VBF Is expected to provide better tagging and kinematical constraints.

2. VBF, VBS and Higgs Portal processes

In VBF the quarks q’ produce jets that have characteristic features:

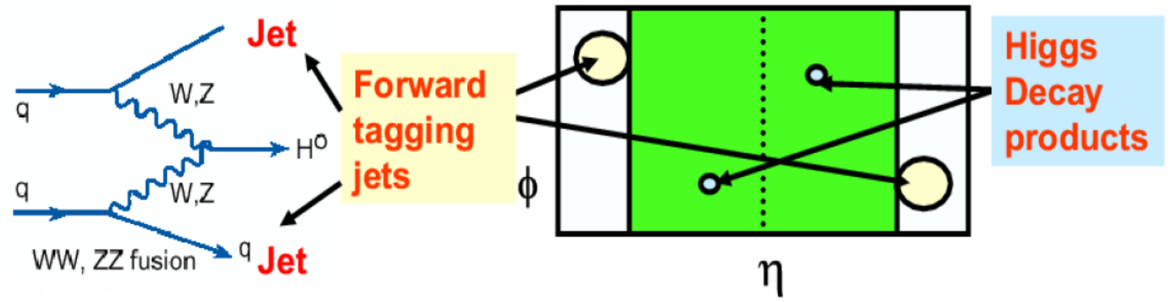


Fig 2: Higgs production through VBF process

The η-distribution of tagging jets is shown in Fig, 3.

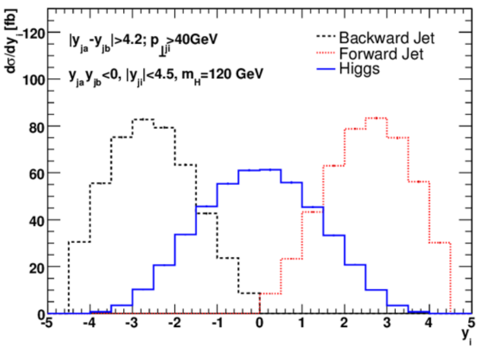


Fig 3: η-distribution of Higgs produced through VBF process and tagging jets.

2. Added modules to HF

We are proposing to implement the HF detectors with ad -hoc EM sections, to improve granularity, timing and EM shower resolution. With this improvement the HF calotimeters would be able not only of tagging Higgs VBF production, but also constrain the process in order to have the possibility of measuring Higgs “portal” events shown in Fig. 4, where the Higgs decay in BSM particle, f.i. dark matter.

3. Higgs Portal processes

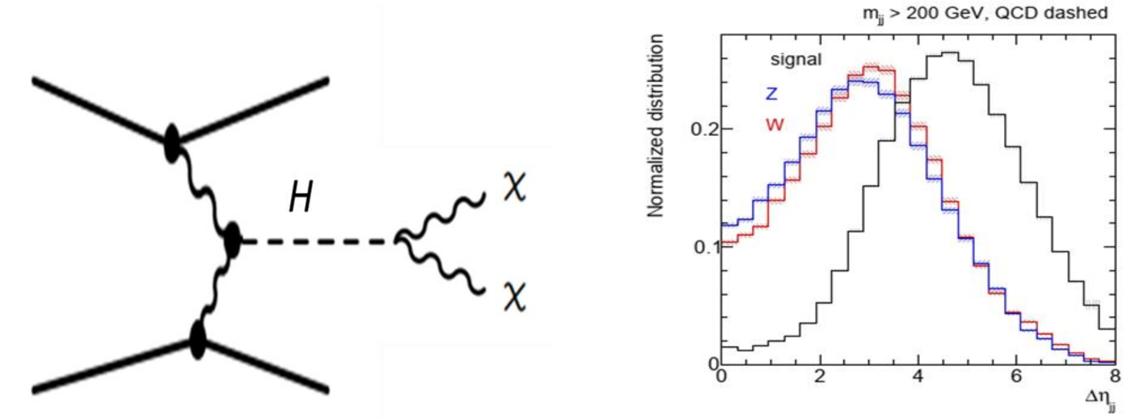


Fig. 4: Higgs portal event with VBF production; on the right the η-separation of the tagging jets, and the background contributions from Z or W productions.

The supplementary EM section in front of HF will be realized in rad-hard technology throughout. A series of successful tests are described in DN-2022-021, CMS note.

4. LLP Searches: FACET

More generally we are considering the possibility of performing a Long-Lived-Particle (LLP) [3] search around the LHC vacuum pipes at about 100m from the IP5 intersection (CMS) (Fig.5).
Fig. 5 describes FACET with a large beam pipe section (18m long, 50cm radius); as this special vacuum tank is not included in the LHC baseline plans, we are considering the possibility to perform the LLP search in presence of the standard pipes, using high speed selection method, with active vetoes and hodoscopes.
It is very interesting to consider how LLP lifetime intervals can be measured with these different forward detectors, HF and FACET; in Fig 6 some examples of detector coverage are given; a representation comparing all the detectors is being produced to compare with detailed studies shown in Fig. 7.

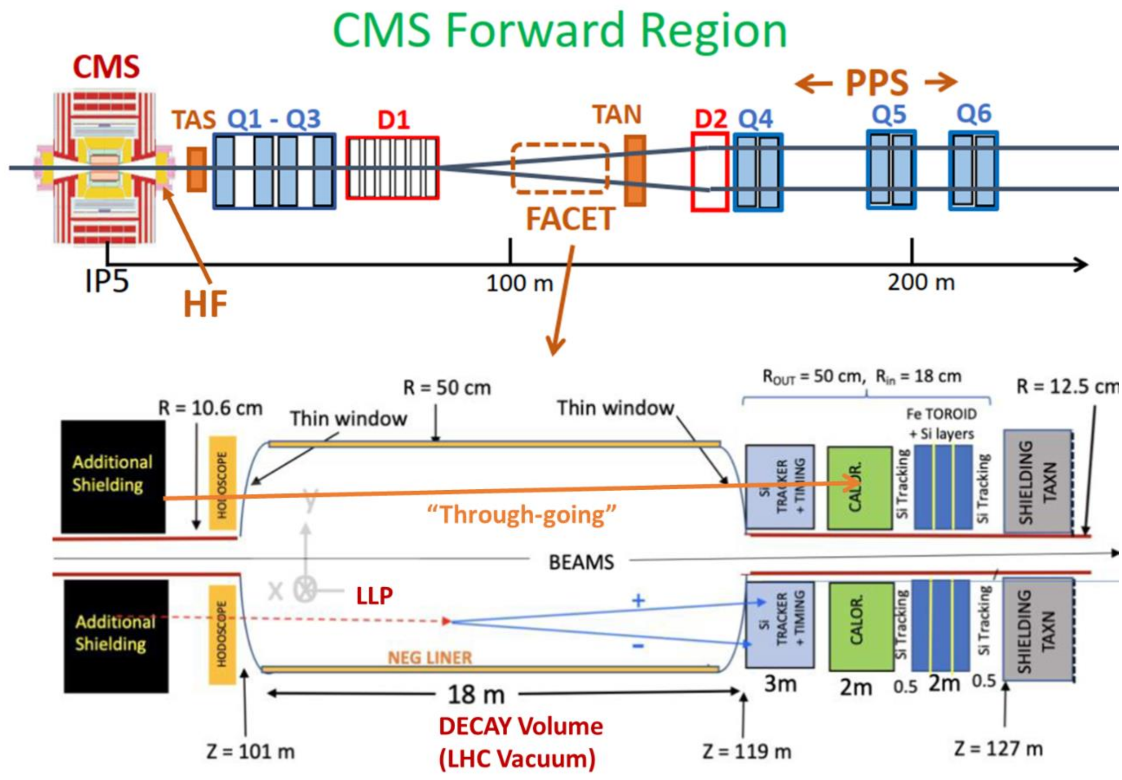
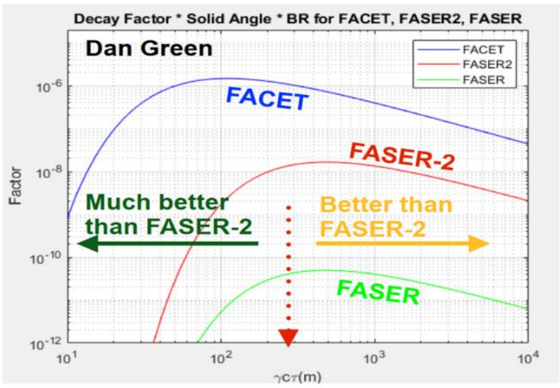


Fig. 5: The forward region in the IP5 intersection (CMS) with indication of the position for the LLP search project FACET; this project is proposed as an independent appendage to CMS.



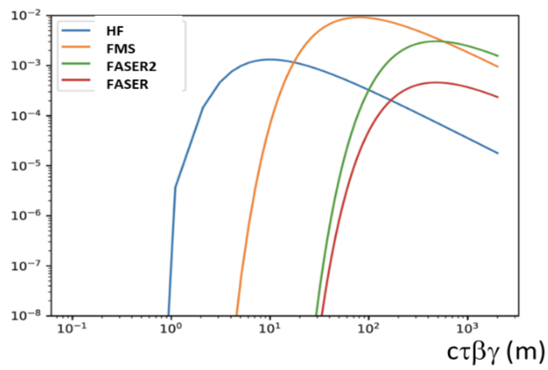


Fig.6 : Lifetime measurements' efficiencies for FACET (left) and HF (right) compared with other LLP search experiments.

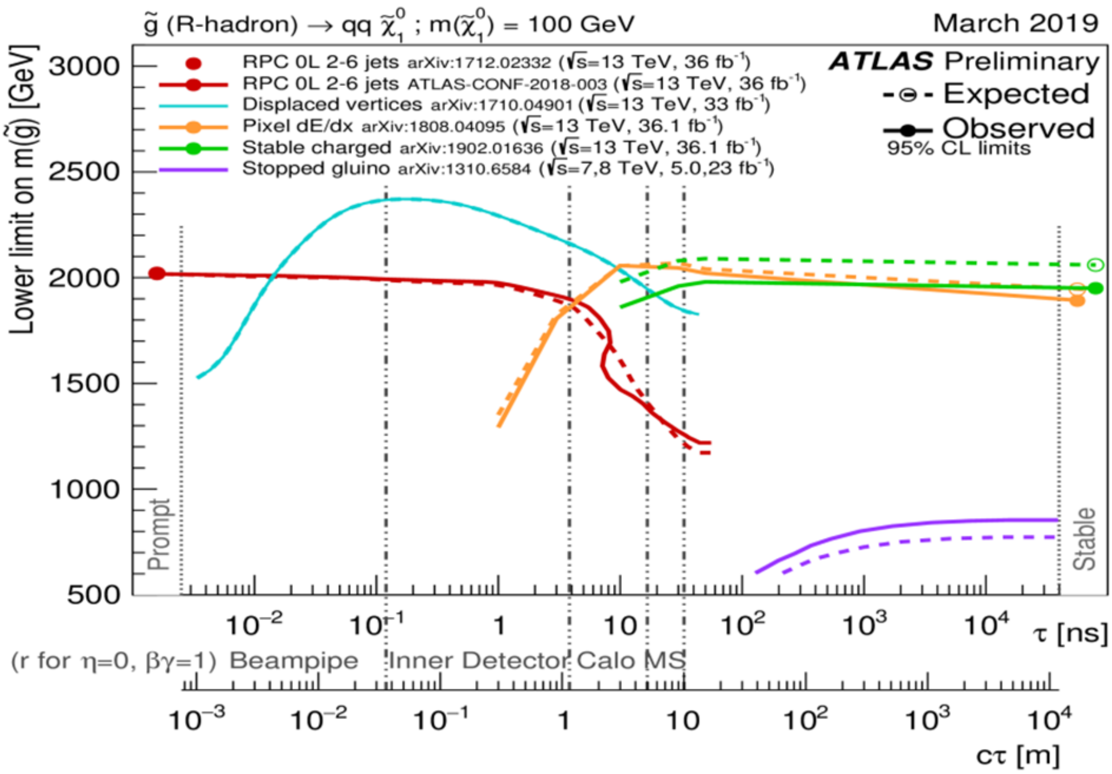


Fig.6 : Lifetimes measurements at ATLAS [3]

5. Very forward Detector: PPS

Going even further, the Precision Proton Spectrometer (PPS) is installed around 200m from IP5, and measures small-angle scattered protons, which have undergone a rather soft interaction at IP5, and continue without breaking and exchanging diffractive Pomerons of photons. These interactions , see Fig 7 give access to many states in the central CMS spectrometer.

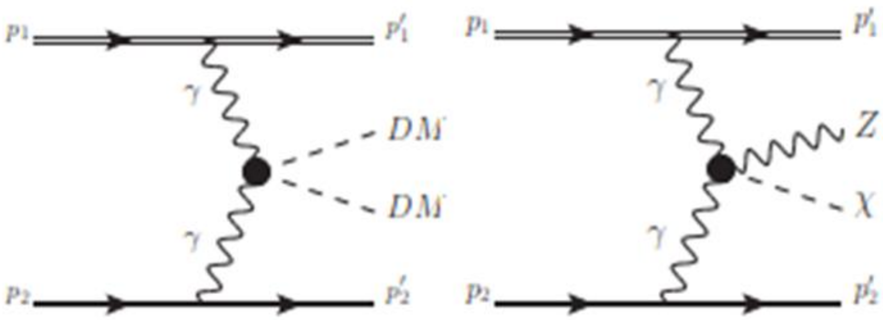


Fig 7: Processes that PPS propose to measure in HL-LHC

The new PPS project will try to continue using the equipment used during Run 3, also for HL-LHC; however the station at 420m is not foreseen initially. we are considering to propose a ToF system developed in collaboration with Istanbul University for the 420m station.

6. Summary

With the approaching of the HL-LHC phase of LHC, each experiment has proceeded to upgrade various parts of their detectors; however the forward regions have remained largely disattended, also because it becomes more and more difficult to equip them with detectors that survive in the harsh regime of HL-LHC. Indeed a large initiative for non-conventional relatively small scale experiments is being proposed: the Forward Physics Facility (FPF).
We believe that also this kind of endeavours, need connections with some large experiment, because it is not clear that forward only detectors might access to the complete event picture that can provided only by full acceptance experiments.
We intend to remain connected with CMS, continuing our participation to the HCAL subdetector, implementing HF calorimeters with simple but high performance EM sections.
Concerning the LLP program we would like to study the properties of delayed jets in HF and to build a simplified version of FACET at 100m from IP5, using the same technology proposed for the new EM section of HF.
If more resources become available for PPS and the HL-LHC program, it is our intention to contribute to the timing detectors for PPS and to the 420m station, if agreed by PPS and LHC.
We are already collaborating on HF and PPS with colleagues from Istanbul University; we are also in contact with Kansas University, and we are actively seeking with these collaborators funds to finance our projects.

References

[1] J. D. Bjorken, Forward Spectrometers at SSC; https://lss.fnal.gov/conf/C851111/p.363.pdf

[2] The Forward Physics Facility at the High-Luminosity LHC - Feng, Jonathan L. et al - arXiv:2203.05090UCI-TR-2022-01CERN-PBC-Notes-2022-001INT-PUB-22-006BONN-TH-2022-04FERMILAB-PUB-22-094-ND-SCD-T

[3] J. Boyd, Long Lived Particle Searches at the LHC;
https://conference.ippp.dur.ac.uk/event/934/contributions/4951/attachments/4059/4720/LLP-RAL-talk_11.11.20.pdf