The FP420 Project: The Challenge of Measuring Forward Protons at the LHC

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Abstract. FP420 is an R&D project to assess the feasibility of installing proton detectors at 420m from the ATLAS and/or CMS interaction point(s) at the LHC. They would function as new sub-detectors, allowing the measurement of the spatial position and arrival time of protons scattered at very low angles with fractional momentum loss between 0.2% and 2%. Forward proton tagging in this region is expected to open a new programme of electroweak, QCD and beyond-the-Standard-Model physics. The challenges of the project are presented, along with the solutions envisaged, notably for the replacement cryostat, the detectors, the moving mechanism to bring the detectors close to the beam, and the alignment.

1. Physics Motivation for FP420
In 2008, the LHC will begin colliding beams of 7-TeV protons. FP420 offers an extension to the LHC’s rich physics programme into the realm of far-forward diffractive physics[1, 2, 3]. A process of particular interest is Central Exclusive Production (CEP), shown diagrammatically in figure 1, where the outgoing protons remain intact and the central system “X” can be for example a Higgs Boson or other new particle; it is interesting to note that selection rules dictate that X is, to a good approximation, a 0^+ state[4, 5]. The outgoing protons lose a small fraction of their initial energy, and as a result they emerge slightly from the beam as it goes through the LHC optics. How far they come out of the beam depends upon how much energy they lost to making the centrally-produced particle, and can therefore be used to determine its mass; if the detectors are aligned sufficiently precisely with respect to the beam, a better mass resolution can be obtained using this technique than is possible using the central detector, and its potential for success is independent of how X decays. Forward-proton tagging can also significantly improve signal-to-background ratios, in some cases enough to become the discovery channel.

FP420 will be able to tag protons that have lost between about 15 and 100 GeV of energy, corresponding to central states with masses between about 30 and 200 GeV. It should be noted that if FP420 were to be combined with a similar detector at 220m from the interaction point, considerably higher-mass states could be detected.

2. Proposed Layout and the “Hamburg Beampipe”
At 420m from a main LHC interaction point, a cold section of the accelerator meets a warm section; in the baseline LHC design this
region is occupied by a “connection cryostat”. FP420 is proposing to replace this connection cryostat with a modified version which has the detector integrated into it, as shown schematically in figure 2. The beampipes are shown in dark blue; note that there is very little space between the beampipes, where FP420 must be mounted. This fact precludes the use of Roman Pots which has been the usual way to move far-forward detectors between operating and garage positions, but which are too large for the FP420 application.

![Schematic diagram of connection cryostat and Hamburg beampipe](image)

**Figure 2.** The proposed connection cryostat and a photo of a prototype “Hamburg beampipe”.

Due to this space restriction, FP420 plans to use a moving-beampipe technique which was developed at DESY[6, 7] and which has therefore been dubbed the “Hamburg beampipe”. The Hamburg beampipe is a section of beampipe which is larger in diameter than the LHC beampipe and which has a flattened area along one side; the FP420 detector stations and timing detectors will be mounted on this flattened area. This flat edge contains a very thin metal window (under the red arrow in the photo in figure 2) which allows the protons to pass out of the beampipe to the tracking detector with minimal scattering. The Hamburg pipe sections are connected to the LHC beampipe by bellows and will move through about 3cm, so that they can be kept a safe distance away from the beam during filling and tuning and moved close to the beam during collisions; the target distance of 5mm from the beam during data-taking corresponds to about 20 sigma of the beam envelope, safely outside the beam but close enough to maximise acceptance.

### 3. Tracking Detectors

The active portions of FP420 are likely to be constructed of 3D silicon[8], which is fast and radiation hard (a strong requirement for FP420 as radiation levels millimetres from the LHC beam are very intense) and can be made virtually “edgeless” (i.e. free of a dead region at the outer perimeter) by turning the edges into electrodes, thereby allowing the active region to be as close as possible to the beam. The baseline design uses 7mm-by-8mm sensors; the electrodes are ganged into 50\(\mu\) by 400\(\mu\) groups, to fit ATLAS pixel detector readout chips, which are bump-bonded onto the sensors. Four such sensors are arranged into a “superlayer”, with two of the four being placed very near to the beam but offset to one another; another sensor is placed at their outer edge i.e. further away from the beam, and the fourth in the farthest position. The four sensors together cover out to about 75mm from the beam centroid. Figure 3 shows drawings of a single superlayer and a detector station (which consists of 5 superlayers), and a photo of a prototype station.

### 4. Fast Timing Detectors

The main backgrounds in FP420 are expected to be from single-diffraction pileup events. Some of this background can be removed by kinematic cuts, for example by matching the mass measured by FP420 and that measured by the central detector. Almost all of what is left can
be rejected using fast timing detectors, provided these detectors have good enough resolution[9].
The technique employed is to measure the relative arrival time of the protons on the two sides
of the main detector (i.e. at ±420m); the z-position of the interaction point is simply
\[ z = \frac{c\Delta t}{2}. \]
This can then be compared with the measured vertex position from the central detector to veto
backgrounds.

FP420 is considering two different types of fast Cerenkov-type timing detectors: GASTOF
uses a gas-filled tube as the radiator and QUARTIC uses fused silica bars. GASTOF is very
low-mass and so can be placed in front of FP420 without causing too much multiple scattering;
QUARTIC is relatively massive and so can only be placed behind FP420.

5. Alignment
As discussed above, FP420 must measure proton-beam displacements as accurately as possible,
in order to precisely determine the mass of the centrally-produced state in the processes
of interest. The intrinsic energy spread of the LHC beam, when propagated through the machine
optics, corresponds to a 50µ position uncertainty at 420 meters; to avoid significant degradation
of this intrinsic uncertainty, FP420 must be aligned internally and relative to the beam to an
accuracy of at worst a few tens of microns.

While alignment can be done offline using tracks, it is planned to also build an independent
real-time alignment system into the detector, in part for redundancy but also as it will be
needed for safety while moving FP420 into its working position. Two options, both based on
Beam Position Monitors (BPMs) are being considered: a ‘local’ system consisting of a large-
aperture BPM mounted directly on the moving beampipe and related to the position of the
silicon detectors by knowledge of the mechanical structure of the assembly, and an ‘overall’
system (shown in figure 4) consisting of BPMs mounted on the (fixed) LHC beampipe at either
end of FP420, with their position and the moving silicon detectors’ positions referenced to
an alignment wire using a Wire Positioning Sensor (WPS) system (which uses a capacitive
measurement technique to measure the sensors’ position, along two perpendicular axes, relative
to a carbon-fibre alignment wire). Sources of uncertainty in such a system include the intrinsic
accuracies of the WPS system and the BPMs, and the mechanical tolerances involved in fixing
all the pieces together.

WPS systems have been shown to be very accurate, with individual sensor resolutions of
fractions of a micron[10]. BPMs have varying accuracy and resolution capabilities; the most
accurate ones tend to have very high impedances, making them unsuitable for use in a proton
accelerator. The button-style electrostatic BPMs intended for use in the LHC are not optimised
for accuracy at the level required by FP420, but it is believed likely that they could perform
well enough provided specialised readout electronics are designed; tests are underway to verify
this.
Figure 4. The proposed overall alignment system

The mechanical uncertainties on alignment precision are complicated by the fact that the detectors move with respect to the beam, although this can be handled with an LVDT or similar mechanical displacement-measurement device, provided an acceptably precise and radiation-hard version can be found or developed.

6. Schedule and Summary
FP420 is an international R&D collaboration between physicists from ATLAS, CMS and some other, non-affiliated groups; its conclusions will be submitted soon to the LHC experiments for consideration as an upgrade or extension to the existing detectors, to be installed in 2009 or 2010. If accepted, a Technical Design Report will be submitted shortly thereafter.

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