Design and performance of coronagraph for beam halo measurements in LHC

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ABSTRACT

The CERN Large Hadron Collider is equipped with two Beam Synchrotron Radiation systems (BSR), one per beam. These systems are used to monitor the transverse distribution of the beam, its longitudinal distribution and the abort gap population. During the 2015-2016 winter shut-down period, one of the two BSR systems was equipped with a prototype beam halo monitor, based on the Lyot coronagraph, classically used in astrophysics telescopes to observe the sun's corona. The system design, as well as part of the optics, was taken from the coronagraph used in the KEK Photon Factory, adapted in order to satisfy the LHC BSR source constraints.
This project is in the framework of the HL-LHC project, for which there is the requirement to monitor the beam halo at the level of 10^{-6} of the core intensity. This first prototype has been designed as a demonstrator system aimed at resolving a halo-core contrast in the 10^{-3} to 10^{-4} range.
After illustrating the design of the LHC coronagraph and its technical implementation, this contribution presents the result of the first tests with beam and the planned system upgrades for 2017.

LHC CORONAGRAPH

Optics :

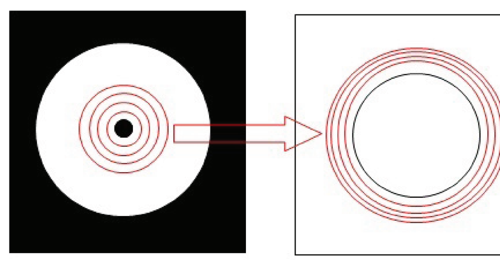
- ❑ Objective lens: plano-convex f=2000mm
- ❑ Field lens: apochromat f=800mm
- ❑ Relay lens: apochromat f=500mm
- ❑ Eyepiece f=18mm
- ❑ Motorized rectangular objective lens aperture
- ❑ Motorized rectangular Lyot stop
- ❑ Mask: 12 opaque disks from 100 to 650um

Total Magnification : ~1.5

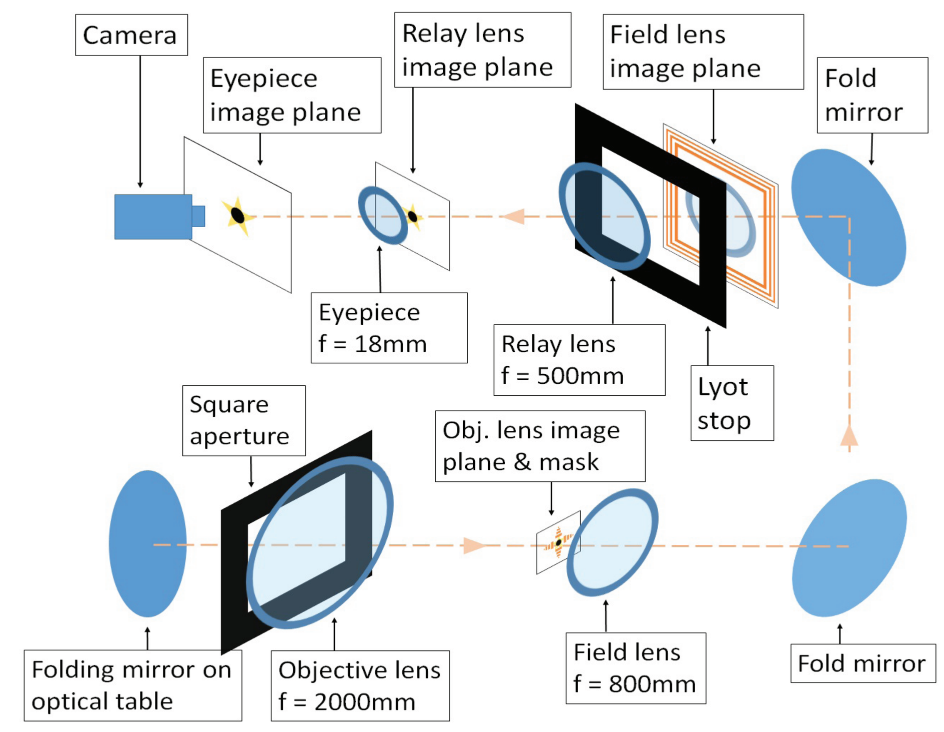
Limitations (analysis & simulations) :

- ❑ Diffraction leakage: 3.7 10^{-4}
- ❑ Mie scattering : 10^{-4} to 10^{-5}

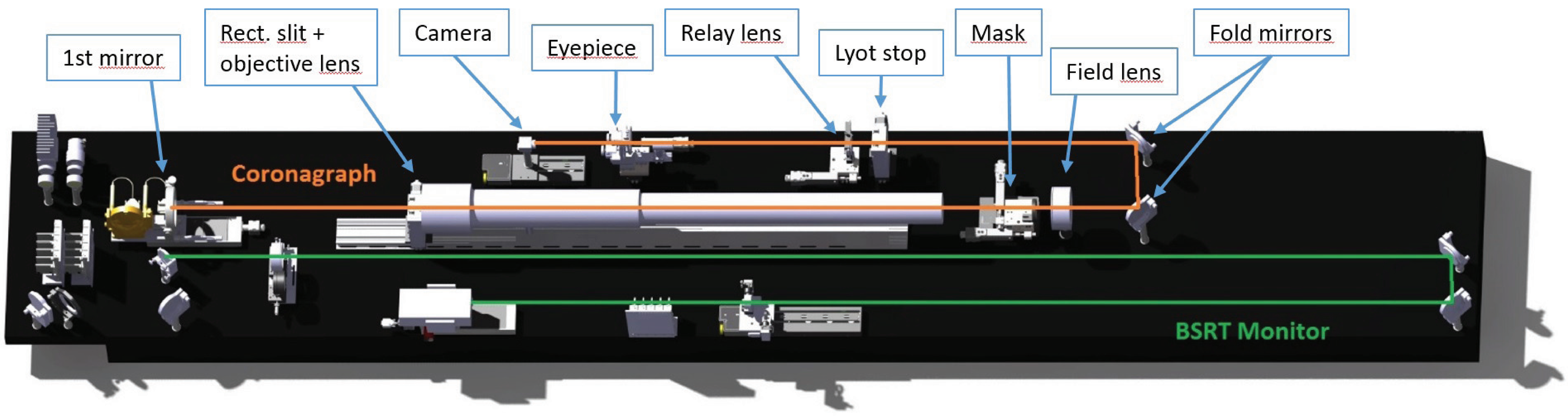
10^4 contrast expected



Diffraction pattern at mask and Lyot stop locations



LHC coronagraph layout



LAB TESTS

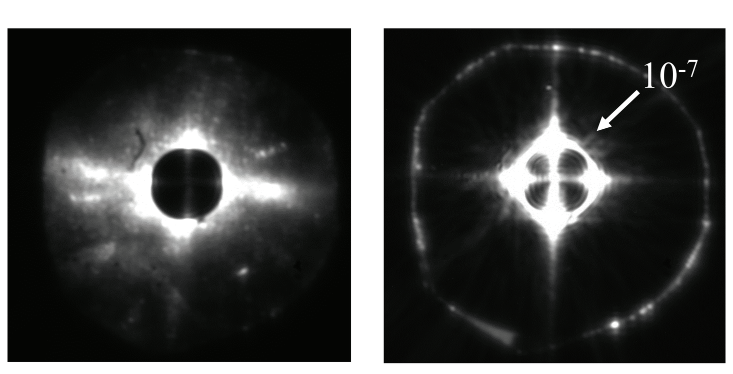
Setup :

- ❑ 27m drift line to mimic LHC conditions
- ❑ 200um illuminated pinhole
- ❑ Piece of transparent plastic to produce artificial halo

Steps :

1 : find objective lens image plane
2 : apply a mask
3 : set objective lens aperture (20x20mm)
4 : tune Lyot stop
5 : tune camera integration time

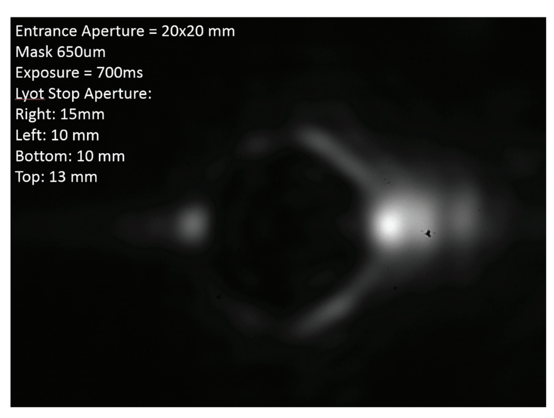
Results : 10^7 contrast observed



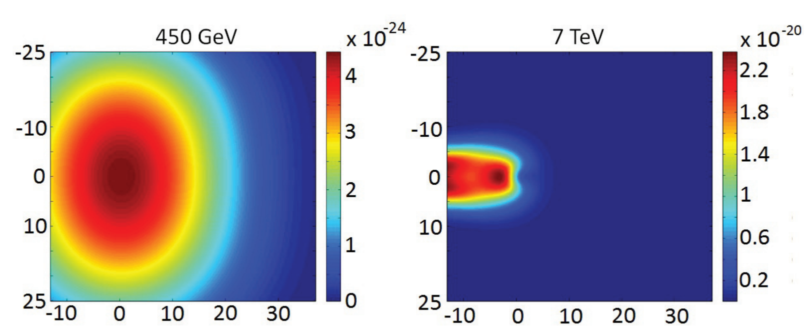
800mm mask, With artificial halo, 1s exposure

800mm mask, Without artificial halo, 10s exposure

BEAM TESTS @ 6.5TeV



LHC halo monitor acquisition



Synchrotron light power on extraction mirror

Diffraction quantification :

- ❑ 650um mask used → only diffraction visible because of LHC collimators aperture

Results :

- ❑ Parasitic light of 10^{-4} observed.
- ❑ Hypothesis: diffraction created by the edge of extraction mirror
- ❑ Solution: 2nd Lyot stop at mirror image plane created by field lens to block the diffraction from the mirror edge
- ❑ Next step: test @ 450GeV to verify hypothesis

CONCLUSION

Successful tests of the LHC beam halo monitor were conducted on a test stand and allowed the optical and mechanical design of the system to be validated.
The system was able to distinguish the halo from the core for a test lamp with a contrast of 10^7, well above the 10^4 contrast expected for this prototype with beam, for which the main limitation is expected to come from diffraction.
Tests of the real system performed with the LHC proton beam at 6.5TeV, showed a parasitic spot with an intensity of 10^{-4} with respect to the beam core, above the level of the halo expected to be observed.
A potential cause of this parasitic light is the diffraction of the synchrotron light on the edge of the in-vacuum mirror, which then effectively acts as a secondary light source.
A way to avoid the propagation of this light to the image plane would be to add a second adjustable Lyot stop at the image plane of the mirror created by the field lens.
Tests are foreseen to be carried out at injection energy, in order to verify this hypothesis, which would then allow mitigation measures to be put in place for further testing of the coronagraph for beam halo measurements in late 2016.

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