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IR2 Aperture Measurements at 4.0 TeV

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Summary

The aperture of the IR2 triplets was measured to determine if there is enough margin for $\beta^* = 0.8$ m operation in heavy ion runs. Squeezed proton beams with $\beta^* = 0.8$ m were used with special bumps in addition to the nominal crossing and separation bumps, in order to determine the vertical and horizontal aperture in the triplet magnets. This note describes the strategy for the aperture measurements and the analysis of the collected data.

Contents

1 Introduction

The goal of the machine study was the measurement of the IR2 aperture limitation, expected to occur at the triplet magnets, to have experimental information whether a running scenario with $\beta^* = 0.8\,\mathrm{m}$ is feasible in p-Pb and p-p runs.

The collimators in IR3 and IR7 were kept at the same tight settings [1] used during the proton run to reach $\beta^* = 0.6\,\mathrm{m}$ in IR1/IR5. IR2 was operated at $\beta^* = 3\,\mathrm{m}$ during the proton run. The feasibility of squeezing down further to $\beta^* = 0.8\,\mathrm{m}$ called for an experimental assessment of the available aperture in IR2.

The aperture was measured for both beams in both transverse directions. In vertical direction, the lower limit for the left triplet was measured using Beam 1 and the upper limit of the right triplet using Beam 2. In addition to the standard on-momentum measurements, the vertical aperture measurement in B2 was also performed off-momentum for both signs, $\frac{\Delta p}{p} = -2.33 \cdot 10^{-4}$ and $\frac{\Delta p}{p} = 2.17 \cdot 10^{-4}$.

The MD was carried out in the p-Pb running period, on 17 January 2013 between 6:00 pm and 12:00 pm (LHC Fill Number 3466).

2 Strategy

2.1 Beam conditions

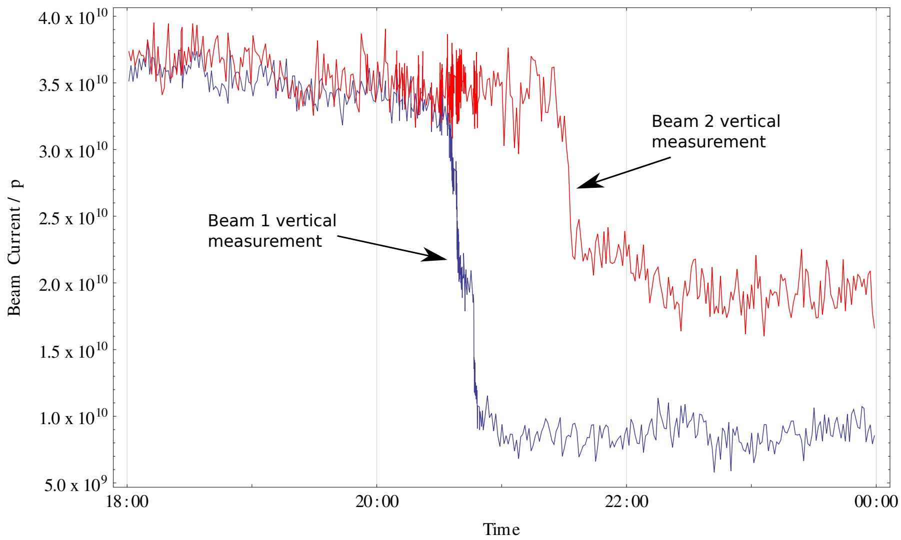

Figure 1: Intensity evolution over the MD. The Beam losses during the vertical scans for Beam 1 and Beam 2 are clearly visible.

The squeezed proton beams with $\beta^* = 0.8\,\mathrm{m}$ at $4.0\,\mathrm{TeV}$ were taken over from the previous MD on loss maps. The nominal IR2 crossing and separation scheme was applied with the ALICE spectrometer magnet switched on. The polarities of the regular crossing bumps were such that the crossing angle from the external corrector magnets was $+145\,\mu\mathrm{rad}$ and the internal crossing bump was $+120\,\mu\mathrm{rad}$ for B1. The intensity evolution is shown for both beams together in Figure 1. The intensity losses during the vertical aperture measurements are clearly visible.

2.2 Measurement technique

The measurement technique is described in detail in several notes [2, 3, 4]. Initially, the tertiary collimators (TCTs) are aligned to $8\,\sigma$ around the beam centre. The TCPs are positioned to $4\,\sigma$. Then, additional bumps from the external corrector magnets are superimposed to the regular ALICE crossing and separation bumps to deviate the beams from the regular orbit. Initially, the bump is applied repeatedly until the beam touches the TCTs, which can be detected by the beam loss monitors (BLMs). After this, the TCTs are symmetrically opened around the closed orbit in steps of $0.5\,\sigma$. The bump strength is then increased in two steps of $0.25\,\sigma$ each, until the beam touches the TCT again. This is repeated until the beam loss position moves from the TCTs to the triplet location after the TCT opening.

Before and during the measurement, the ADT was used to blow up the beam dimensions in order to ensure that the beam was filling the TCT collimator's gaps.

2.3 Bumps

Dedicated bumps with 32μrad crossing angle are used in addition to the nominal bumps. This angle at the IP corresponds to an orbit excursion at the triplet position of $1\,\sigma$, so the trim of the bump can directly be translated into the number of σ. During the TCT scan, the bump was thus increased in steps of 1/4 of the total strength. The standard 32 μrad crossing bump for both beams in both transverse directions is shown in Figure 2. The outer magnets which have been used to create the external bump are indicated as well.

2.4 Off-Momentum Measurements

Information of the available aperture with off-momentum beams is of interest, because the beams are moving slightly off momentum during p-Pb operation of the LHC [5]. In order to bring the beams off-momentum, the RF-frequency has been increased by 30 Hz, and reduced by 28 Hz, to allow measurements with $\Delta p/p = -2.33 \cdot 10^{-4}$ and $\Delta p/p = 2.17 \cdot 10^{-4}$, respectively. This is in the same order as the momentum offset which is required for p-Pb operation [5].

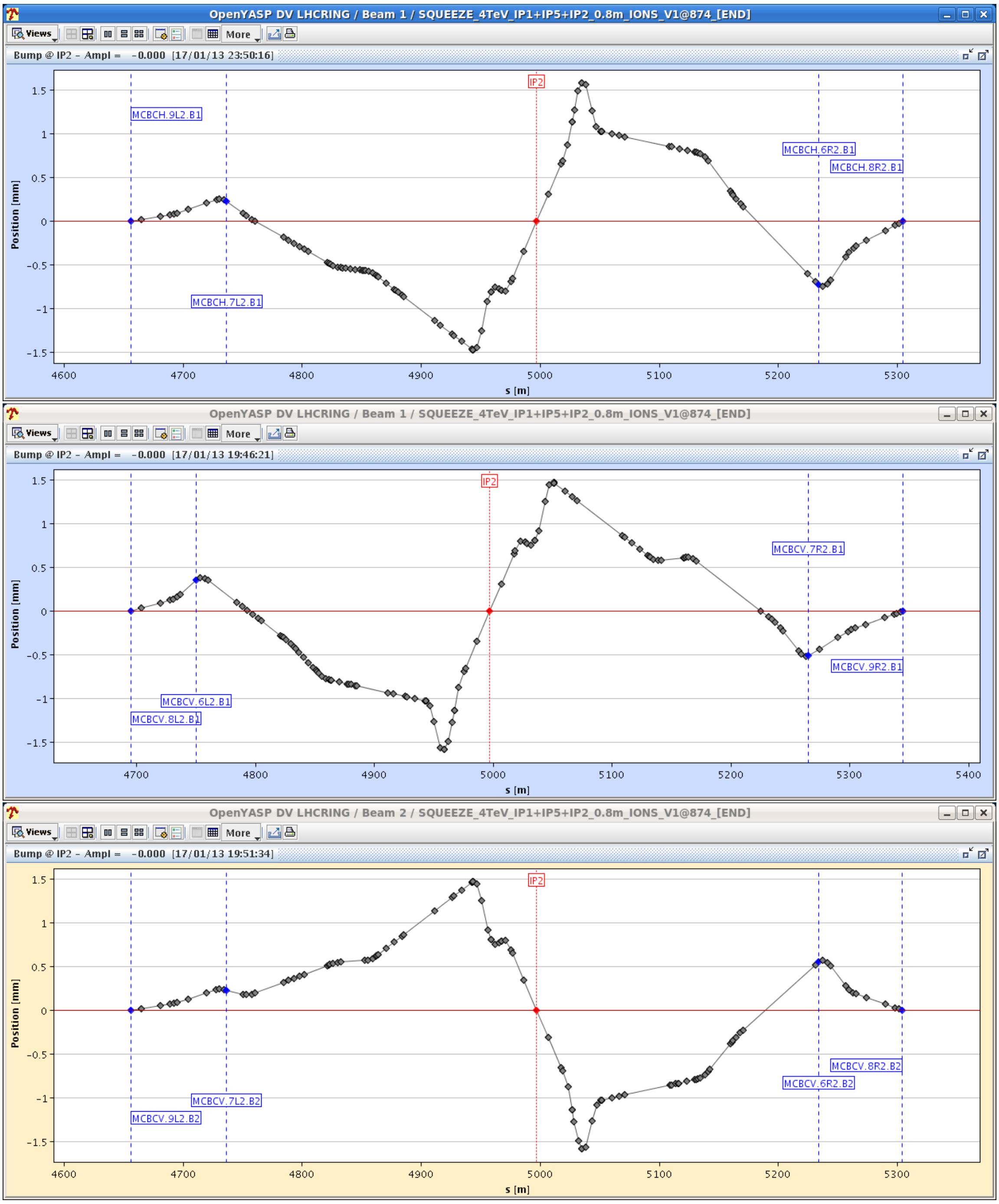

Figure 2: External bumps used for the aperture measurements

3 Measurement Results

Table 1: Beam-based collimator centres after the alignment at the beginning of the measurements with the nominal IR2 crossing and separation bumps.

Collimator	Beam-based centre [mm]
TCTH.4L2.B1	0.10
TCTVA.4L2.B1	-3.90
TCTVA.4R2.B2	-3.64
TCTH.4R2.B2	-0.71

The centres from the alignment of the TCTs are listed in Table 1. For the analysis of the data, the losses at the BLMs at the TCT and triplet location were recorded. The method of plotting the peak losses as a function of the TCT opening and using the intersection of the normalized losses in the TCT and the triplet [6] can not be used in this case because not enough data points are available. For the calculation of the TCT opening in terms of σ, the standard injection emittance of $\epsilon_N = 3.5\,\mu$m rad was used. The recorded normalized losses (normalized means in this case that the local losses were divided by the instantaneous intensity and the peak loss) and the corresponding TCT opening in function of time are given in Fig. 3. For the measurements in vertical direction, the triplet aperture corresponds to some TCT opening between the two openings where the peak losses were seen in the TCT and triplet respectively. Therefore, upper and lower limits can be given for the available aperture. The limits are summarized in Table 2. In order to save time, the horizontal TCTs were opened very quickly and the bump amplitude was increased step by step. The measurements in the horizontal plane were not pursued until the losses moved to the triplet, but stopped when a sufficient aperture for operation was achieved. A limit of $14\,\sigma$ was taken, therefore, the resulting lower limits for the available aperture correspond to the largest bump amplitudes which have been applied (see Table 2).

Table 2: Summary of the results of the aperture measurements.

Beam	Direction	$\Delta p/p$	Full TCT gap [σ]
B1	Vert.	0	$14.0 - 14.5$
B2	Vert.	0	$13.5 - 14.0$
B1	Hor.	0	> 14.0
B2	Hor.	0	> 14.5
B2	Vert.	$-2.33 \cdot 10^{-4}$	$13.0 - 13.5$
B2	Vert.	$+2.17 \cdot 10^{-4}$	$13.0 - 13.5$

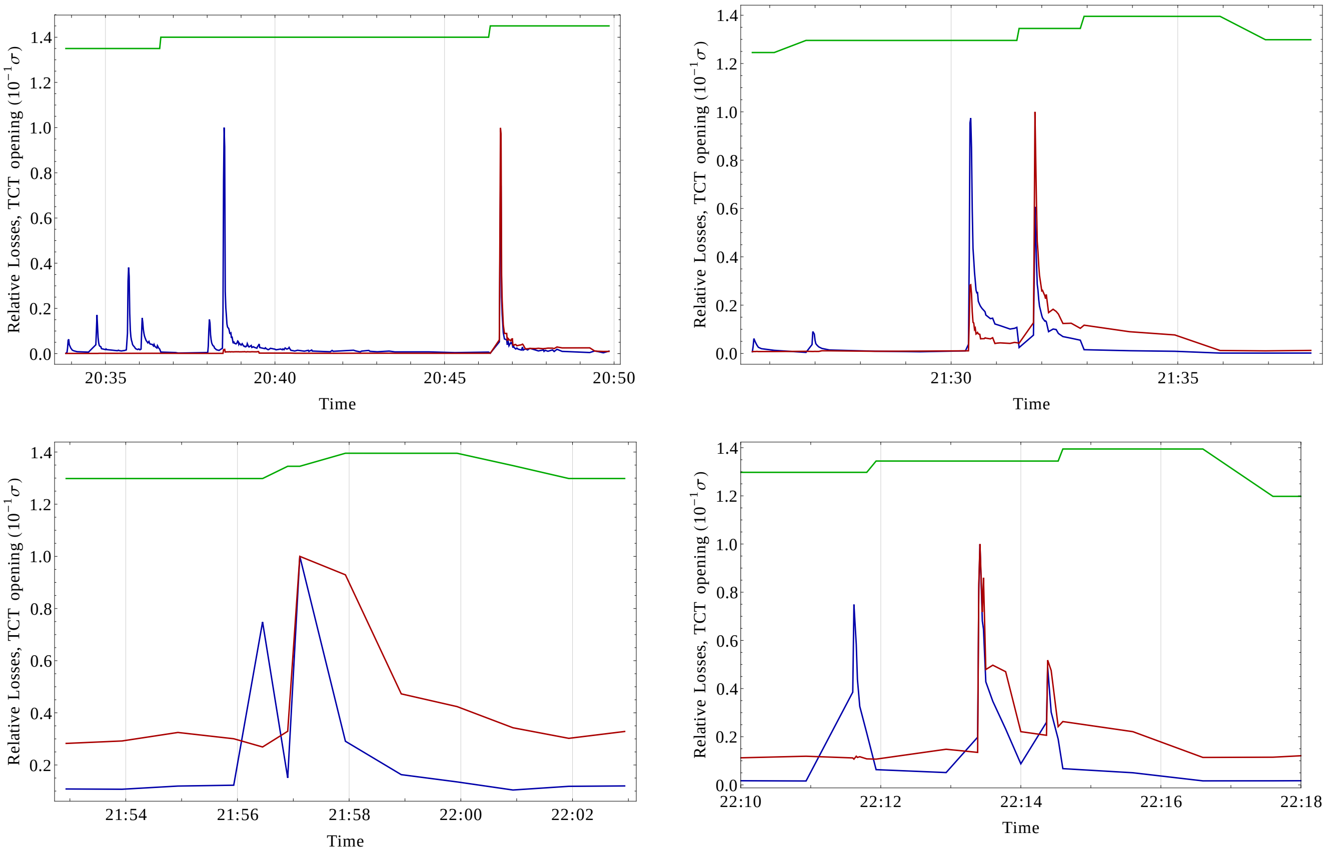

Figure 3: Normalized losses at the TCT (blue curves) and triplet (red curves) with the TCT opening in $10^{-1}\sigma$ (green curves) for the different measurements. Top left: B1 vertical, top right: B2 vertical, bottom left: B2 vertical with $\Delta p/p = -2.33 \cdot 10^{-4}$. Bottom right: B2 vertical with $\Delta p/p = 2.17 \cdot 10^{-4}$, the third peak is induced by an emittance blow up from the ADT.

4 Summary and Conclusions

The available aperture in the IR2 triplet region was examined for both transverse directions on both sides of the IP. As a result, lower and upper limits for the available aperture were obtained for the vertical crossing plane, while lower limits can be given for the horizontal crossing plane. The indicated values for both, off-momentum and on-momentum measurements, are sufficient for Pb operation at very low β^* (0.8m) and are well-above the limit of $11\,\sigma$ which was specified for the LHC [7].

Acknowledgements

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