EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – ACCELERATORS AND TECHNOLOGY SECTOR

CERN-ATS-2010-150

UA9 Instrumentation and Detectors in the CERN-SPS

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The UA9 experiment was installed in the CERN-SPS in March '09 in view of investigating crystal assisted collimation in coasting mode. Inside a vacuum vessel, two 2 mm long silicon crystals, bent by about 150 microradians are mounted on accurate goniometers, and a small 10mm long tungsten target is used to compare the effect of crystals with that of a standard scatterer. A moveable 60 cm long block of tungsten is located downstream at about 90 degrees phase advance to intercept the deflected beam. Scintillators, gas GEMs and beam loss monitors measure nuclear loss rates induced by the interaction of the halo beam in the crystal itself. A Roman pot is installed in the path of the deflected particles in between the crystal and the collimator, equipped with a Medipix detector to reconstruct the transverse spot of the impinging beam. Finally UA9 takes advantage of an LHC-collimator prototype installed close to the Roman pot to help in setting the beam conditions and to reveal in a destructive manner the deflected beam shape. This paper describes in details the hardware installed, and the procedures developed to set-up and detect the channeling conditions.

Presented at: IPAC10, Kyoto, Japan, 30 April 2010

Geneva, Switzerland,
14 June 2010

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INTRODUCTION

UA9 is an approved CERN experiment that aims at demonstrating the feasibility of collimating intense beams of hadrons using bent crystals. UA9 explicitly addresses the problem of crystal collimation in the LHC (for both protons and Pb ions), as a possible alternative to the baseline solution of collimating the beam halo with amorphous materials. This solution may provide advantages, like for instance the reduced activation of primary collimators, reduction of off-momentum particles produced by single diffractive collisions that are re-captured by the machine and lost in the arcs, relaxation of tolerances for the majority of the secondary collimators. It also involves technical challenges to be solved, already discussed in [1], and still to be addressed in details. UA9 has fixed as first priority the demonstration of high channelling efficiency, measured as number of particles channelled by the crystal vs. the number of particles impinging on the crystal. In order to do that, UA9 had a very dense experimental program in both the North Area experimental lines of the SPS, to measure the single pass channelling efficiency of silicon crystals, and the probability of nuclear interaction of protons in the crystal at different orientations [2]. In addition, six periods of two or three eight-hour shifts have been used in the SPS to assess the efficiency of multipass channelling on a coasting beam. This paper focuses on the layout of the UA9 equipment installed in the SPS ring and provides detailed information about the different beam instrumentation and detectors, as well as about the procedures to detect the channelling condition and measure the collimation efficiency.

THE UA9 LAYOUT

The UA9 experiment is installed in the Long Straight Section 5 of the SPS, and consists of several mechanical assemblies for both crystal holders and detectors. UA9 has installed in March 2009 a first vacuum vessel ("TEC 51795" in Fig. 1), equipped with two silicon crystals, one produced by PNPI, in general called "crystal 2" and one produced by the Ferrara section of INFN, called "crystal 1". The crystals are mounted on two precision goniometer produced in the nineties for the RD22 experiment, that was aiming at demonstrating the possibility to use crystal for smooth extraction of protons form the SPS. The two goniometers were not in use since the end of RD22 and have been completely refurbished before installation. They were tested to provide accuracy close to the microradians, even if subject to a small hysteresis on repeated cycles. Unfortunately, due to the obsolescence of some mechanical parts, both failed during operation and though allowing the positioning of the crystal, they do not ensure now a full repeatability of the positioning within the required accuracy of a few microradians. Several ideas are now pursued by the UA9 partners to substitute them with goniometers of new generation.

In the same vessel we mounted a tungsten scatterer to make direct measurements of the difference in efficiency between crystals and amorphous materials. The scatterer will be used to better understand the effect of obstacles in the ring and to compare the experimental results with simulations performed with both tracking codes and energy deposition codes. A full model of the crystal, including electromagnetic interaction and nuclear interactions is under development in collaboration among the different institutes participating to UA9.

In addition, a quartz Cherencov detector, provided by PNPI, is mounted in between the two crystals. The idea behind is to quantify the number of particles impinging on crystal 2 to have a direct measurement of the collimation efficiency. A second identical crystal is mounted in vacuum ~40 meters downstream, in front of the tungsten dump for the channelled beam ("TACW.51988" in Fig. 1). The collimation efficiency would therefore be calculated as ratio between the rates of nuclear interactions in the two crystals. Unfortunately the high number of particles interacting with the quartz even at low intensity (a few 10^9 protons in a single bunch) saturates the crystals and

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accurate calibrations need to be performed to provide a realistic measurement. This process has been done with difficulty due to the limited beam time available and is still on-going. Very useful information has come however from the two crystals, in particular from the one mounted on the TACW which provides evidence of the fact that the crystal is in channelling mode. When channelling we see a steady increase in the rate of counts in the Cherencov.

In the proximity of the vessel TEC.51795 we mounted scintillators (provided by the University of Roma La Sapienza), to count the rate of nuclear interactions in the crystals and the scatterer, and GEM detectors, provided by INFN Frascati, with the same function.

About 45 meters downstream we installed a roman pot with a MEDIPIX pixel detector to image the channelled beam and give a measurement of the number of particles captured by channelling. The detector can be masked using the graphite jaws of an LHC collimator prototype already installed upstream for different purposes, and that is now actively used as a tool to cut portions of the SPS beams, to measure the beam size at that position and fix the aperture to 3σ or 6σ as requested by the experimental conditions. More scintillators are installed downstream in the dispersive region to measure losses that could come from off-momentum particles generated in the interaction of the beam with the crystals. Another dump (TAL.52196) has been installed at about 90 degrees phase advance to capture the remaining off momentum particles that could be generated by the interactions, still in conjunction with scintillators and a quartz detector to do quantitative measurements of the number of particles involved.

Finally, during the short technical stop of 2010, an additional vessel (TECS.51793) with a special design of goniometer conceived and built by IHEP, has been installed upstream the first vessel and should provide the possibility to more precisely and reliably position crystals in the SPS beam, increasing the efficiency of use of the beam time by UA9. Two more crystals, again provided by PNPI and INFN Ferrara, and already calibrated and tested in the North Area beam lines, have been installed in this vessel.

Finally, some settings have been carried out using the LHC BLMs that were installed in the area for test with the LHC prototype collimator. The SPS BLM system is on the contrary not suitable for the intensities and the beam conditions that we have used. An upgrade of the system to the LHC standards is under discussion for operation purposes, but not yet approved. In the context, we will test in 2010 the possibility to use CVD diamond detectors for detecting single or multi particles diffracted in the area.

OPERATIONAL PROCEDURES

A consistent part of the beam time in 2009 has been devoted to set up stable beam conditions for proper measurements. Most of the conditions requested could successfully be set by the SPS operation team, with exception of the slow diffusive regime, due to the difficulty to generate white noise on the beam trajectory with the magnetic bumper.

During the different runs, we have operated with different number of bunches in the machine, starting with a single bunch of 2×10^{10} protons up to 16 bunches for high intensity runs. Once stable beam was provided by the machine, we always proceed in the following way:

1) Measurement of beam position and emittance, and set-up of the two LHC collimator jaws to limit the aperture of the SPS to the desired value (typically 6σ), and cut with the beam halo beyond this aperture.
2) Then we move in one at the time all the relevant objects until we see on the different detectors (cerencov, scintillators, BLMs, GEMs), an increase in the interaction rate. That fixes the 6σ line for each element.
3) For each element we then determine its position during the experiment (e.g. crystal 6σ, Medipix 7.5σ, TAC 8σ).
4) The LHC collimator is then retracted and each element positioned at its nominal position.
5) At this point we start the angular scan, by moving slowly and continuously the selected crystal angle, and plotting at the same time the nuclear interaction with the different detectors [2-4].
6) Depending on the phenomenon to be studied, we then decide at which angle we work (on the minimum, or in volume reflection regime). This is where the reproducibility of the goniometers becomes critical, and it is our weak point at present, that we hope to overcome with the new IHEP goniometer.

It is worth mentioning that the simple procedure described above is very delicate to realise, since it assumes a perfectly stable machine, very efficient Graphical user interface and a powerful middleware to bring in a single environment data coming from both the machine control system and the experimental devices, that have conceptually different low level control electronics. A big effort has been done during the year 2009 by the different partners to improve this process. The success of the experiment, whose results as described in other papers in this conference [3, 4], was only possible by the combined use of the redundant instrumentation described above. The experimental determination of the channelling condition is not easy, as witnessed by the difficulty encountered also in the experiments in RHIC and Fermilab, and the analysis of the combined measurements from different detectors has been essential to use efficiently the available beam time.

CONCLUSIONS AND OUTLOOK

UA9 has been assigned five new runs of two or three 8-hour shifts in 2010 starting in June, and will devote most of this time to improve the measurement of the collimation efficiency for both protons and lead ions. A constant effort in improving the software applications available on-line in the control room will be essential for the success. We are also looking forward to exchange the damaged goniometers with new ones in order to test conveniently the maximum number of crystals.

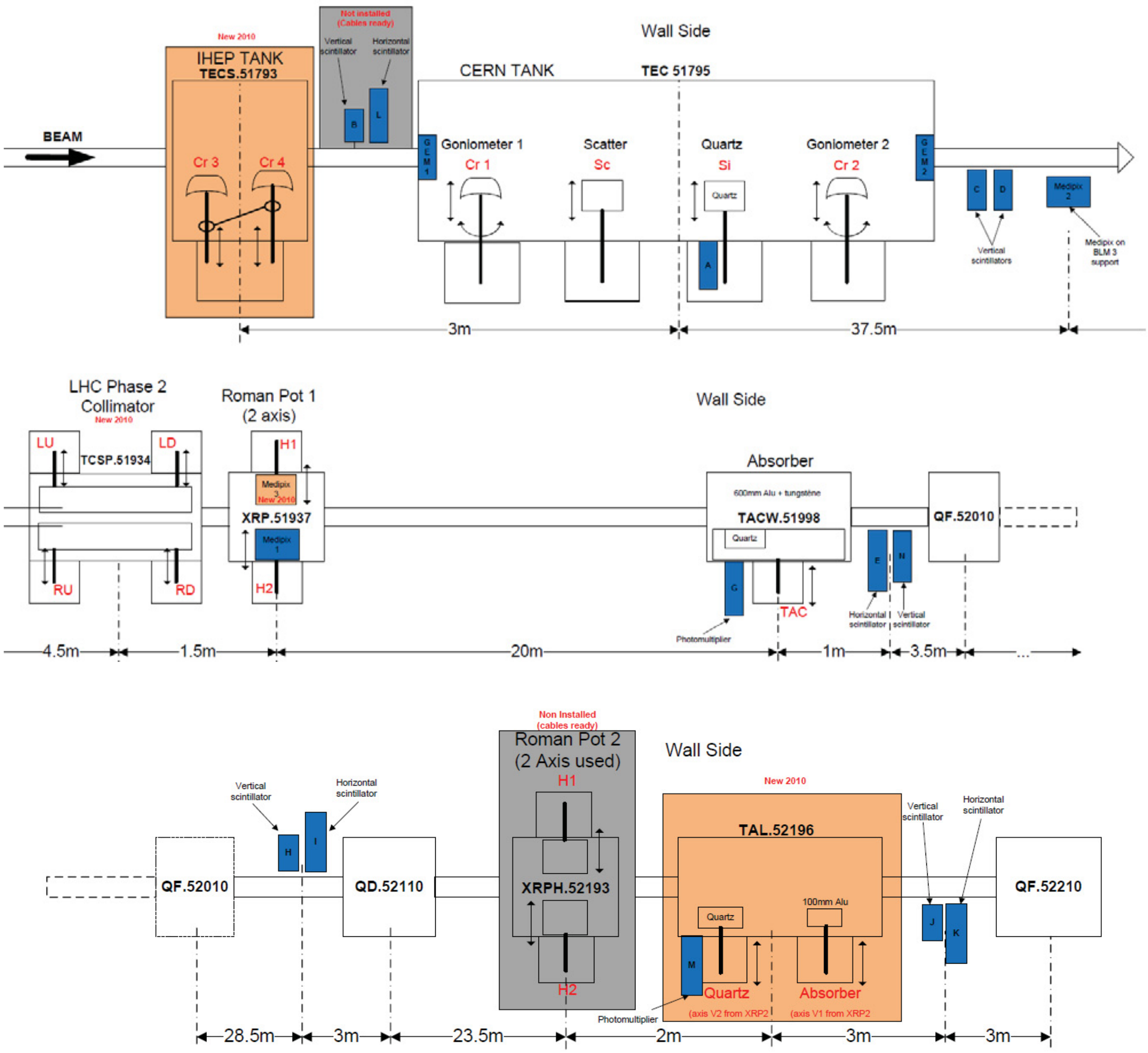

Figure 1: Layout of UA9 in the Long Straight Section 5 of the CERN-SPS.

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