THE SE-CpFM DETECTOR FOR THE CRYSTAL-ASSISTED EXTRACTION AT CERN-SPS

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Abstract

The UA9 experiment at CERN-SPS investigates the manipulation of high energy hadron beams using bent silicon crystals since 2009. Monitoring and characterization of channeled beams in the high energy accelerators environment ideally requires in-vacuum and radiation hard detectors. For this purpose the Cherenkov detector for proton Flux Measurement (CpFM) was designed and developed. It features a fused silica bar in the beam pipe vacuum which intercepts charged particles and generates Cherenkov light. In this contribution the SE-CpFM (Slow Extraction CpFM) detector is described in detail. It has been installed in early 2016 in the TT20 extraction line of SPS to study the feasibility of the crystal-assisted extraction from the SPS. Before the installation the detector has been fully characterized in 2015, during the UA9 data taking in the H8-SPS extraction line with 180 GeV pions. The single particle detection efficiency and the photoelectron yield per proton have been estimated and are shown in this contribution.

INTRODUCTION

Presently the SPS accelerator provides the beam for Fixed Target physics in the North Area (NA) using a slow resonant process and through electrostatic septa (ZSs). The main problematic issue of the resonant slow extraction process regards the small fraction of the beam that is unavoidably lost on the ZS wires. These losses produce both limitation to the delivered beam intensity and a strong activation of the SPS. Bent crystal technology applied in different configurations [1] offers promising solutions for the losses issue in the SPS LSS2 extraction region.

The UA9 experiment [2–7] and the CERN Accelerator Beam Transfer group are working together to demonstrate the feasibility of a crystal-assisted slow extraction toward the NA of the SPS. As a first step, a "proof of principle" experimental campaign started in 2016 during dedicated Machine Development (MD) sessions of the SPS and it is still ongoing. In this frame the installation of the SE-CpFM was needed to detect and measure the crystal-assisted extracted beam flux directly in the TT20 extraction line (Fig.1).

THE CHERENKOV DETECTOR FOR PROTON FLUX MEASUREMENTS

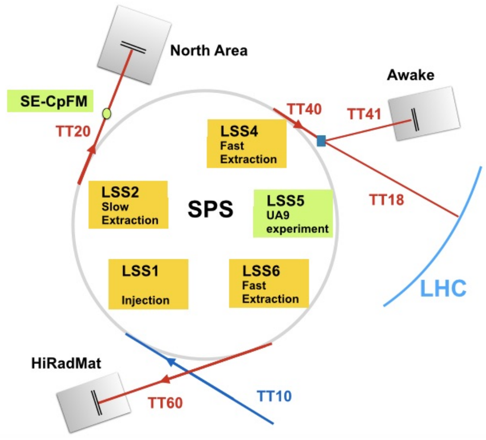

Figure 1: Conceptual sketch of the injection and extraction lines of the SPS.

A "proof of principle" experiment basically consists of a very low intensity and bunched extraction from the SPS to the TT20 extraction line. The halo of a low intensity LHC-type bunch ($\sim 1.6 \times 10^{10}$) is extracted at each turn (every 23 μsec) from the circulating beam by a bent crystal located in the UA9 experimental area in LSS5 [8] and then reaches, with the right phase advance, the ZS through a closed orbit bump [9]. The flux of protons expected on the detector in TT20 ranges from 1 up to about 200 protons per turn (from 10^5 up to 10^7 p/s). Such a low flux doesn't allow to use the standard SPS instrumentation like for example BCTs (Beam Current Transformer [10]). During its collimation tests, the UA9 experiment uses to deal with a proton flux of the same order and since 2014 a Cherenkov detector (CpFM, **C**herenkov detector for **p**roton **F**lux **M**easurement) has been installed in LSS5 to measure the proton flux extracted by crystals [11, 12]. Therefore to design the SE-CpFM (**S**low **E**xtraction-CpFM) we started from the CpFM concept using the experience collected by UA9.

SE-CpFM Requirements & Layout

The SE-CpFM detector has been devised as an ultra-fast and high resolution proton flux monitor. It has to provide the measurement of the extracted beam directly inside the beam pipe vacuum of the TT20 line, discriminating the signals coming from different proton bunches in case of multibunch beam in the SPS, with a 25 ns bunch spacing. The sensitive part of the detector is located in the beam pipe vacuum in order not to deteriorate the resolution of the flux measurement, avoiding the interaction of the protons with the vacuum-air interface. All the design choices are explained in details in [11, 12]. They were lead by the need to get very high performances matching at the same time the

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environmental specifications, especially concerning vacuum and the high radiation field. A conceptual sketch of the SE-CpFM is shown in Fig. 2. The sensitive element consists in a synthetic quartz bar ($5 \times 10 \times 300\,mm^3$, 5 mm in the beam direction) acting both as Cherenkov radiator and light guide. When a relativistic charge particle crosses the bar it produces Cherenkov light that is transported by internal reflection to the other end of the bar. To transmit the light signal outside the beam pipe a standard quartz viewport has been used. The light is collected by a R7378A Hamamatsu PMT directly and mechanically coupled to the viewport. The PMT signal is carried upstairs by a low attenuation cable and readout by an ultra fast analog memory [13]. The bar can gradually approach the extracted beam through a movable bellow on which the viewport is mounted. To maximize the light yield of the detector we decide not to install the 4 m quartz fiber bundle used to bring the light signal 1 m away from the pipe in the case of the LSS5-CpFM. The bundle was indeed responsible for a strong reduction of the light yield per proton. Instead we kept the same bar and viewport geometry (inclined at 47°) of the LSS5-CpFM to speed up the production of the tank hosting the detector and to have the possibility to easily add the bundle in case the PMT got damaged by radiation too fast.

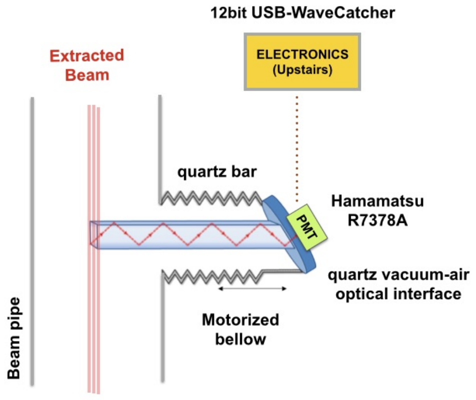

Figure 2: Conceptual sketch of the SE-CpFM.

THE SE-CPFM DETECTOR CHARACTERIZATION TEST

The whole SE-CpFM detector chain was assembled and characterized in May 2015 with a 180 GeV pion beam in the SPS-H8 extraction line, located in the SPS-North Area, during a beam test campaign of the UA9 experiment. The energy of the pions allows us to consider the results of the characterization test the same as in the case of a proton beam, being the production of Cherenkov light sensitive just to the β and to the charge of the particle. The pion beam intensity was $2-5\times10^5$ pions delivered in a 4.5 sec long spill; this means one proton delivered every 10 - 20 μs. The beam size at the SE-CpFM bar position was 2 mm in the horizontal axis and 10 mm in the vertical axis.

Test Layout

The setup layout is shown in Fig. 3. During the UA9 beam tests in H8 two experimental areas are available: Area 128 and, 50 m downstream, Area 138. The tank of the SE-CpFM was installed in Area 138 , aligned in the vertical axis (Y) with the center of the beam pipe. To align the detector with respect to the horizontal axis (X), the motorized bellow has been used. In order to perform the SE-CpFM efficiency measurement, a very light and efficient counter system was attached directly to the tank. The counter is a little bar of scintillator material sized in Y and Z ($10\,mm \times 5\,mm$) as the SE-CpFM bar, 30 mm long and readout by two silicon photomultipliers (SiPMs) on both sides. The counter was positioned to get the maximum overlapping surface with the detector bar. The signals were carried to the readout electronics (located upstairs) by 40 m long cables, a normal coaxial cable for the SipM signals and a low attenuation cable for the SE-CpFM PMT. The DAQ system was performed by the 8-channels USB-WC [13], operated at the sampling frequency of 3.2 GHz. To trigger all the system and therefore to open the 320 ns acquisition window of the USB-WC, the main trigger of the UA9 experiment has been used. This trigger is located in Area 128 and it consists of a $4\,cm\times4\,cm$ plastic scintillator coupled to a PMT.

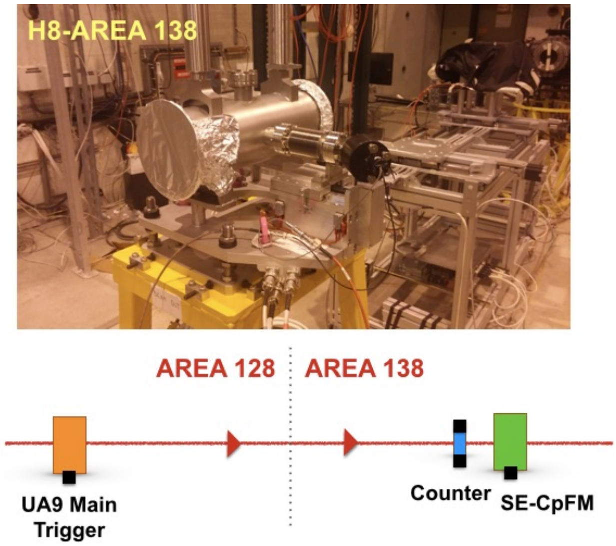

Figure 3: SE-CpFM characterization test layout.

Test Results

The main task of the characterization test was to measure two important operational factors: the SE-CpFM single proton efficiency and the single proton calibration factor, essential to count the number of extracted protons in TT20. The efficiency measurement was performed using both the little scintillator counter and the UA9 main trigger. The DAQ system was triggered by the UA9 upstream detector and the signal of the SE-CpFM, the two signals of the counter and the UA9 trigger signal were digitized by the USB-WC. Moreover the USB-WC is able to deliver for each event and for each channel the measurement of some signal parameters such as peak time, amplitude and charge. This USB-WC feature was used for the off-line signal analysis. The good events, namely the events corresponding to real pions, were selected off-line with several cuts on the signal of the SE-CpFM:

- Pedestal cut: to remove "empty" events, i.e. events in which there is just electronic noise or baseline oscillations.
- Time cut: stringent cut on the peak time calculated from the peak time of one SiPM signal (Leading edge time SE-CpFM signal - Leading edge time SiPM1).
- Counter cut: depending on the amplitude of both SiPM signals of the counter. Only SE-CpFM events were selected for which both signals of the SiPMs correspond to a real event.

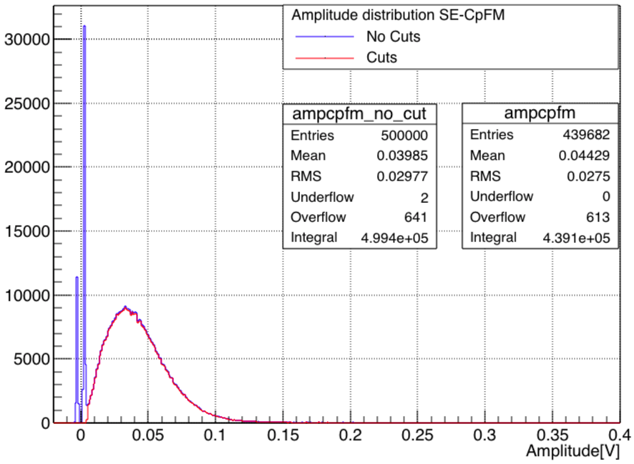

Figure 4: SE-CpFM single proton amplitude distribution with (red) and without (blue) applied cuts.

Figure 4 shows the SE-CpFM amplitude distribution with and without the applied cuts. The single proton efficiency is computed as the ratio between the number of pions measured by the CpFM (plot with cuts) and the number of pions selected by the counter. Considering a systematic error ($\pm 1\, mm$) on the vertical alignment of the SE-CpFM bar with respect to the little counter, the efficiency value has been estimated as:

$$\epsilon = 94 \pm 4.5\%$$

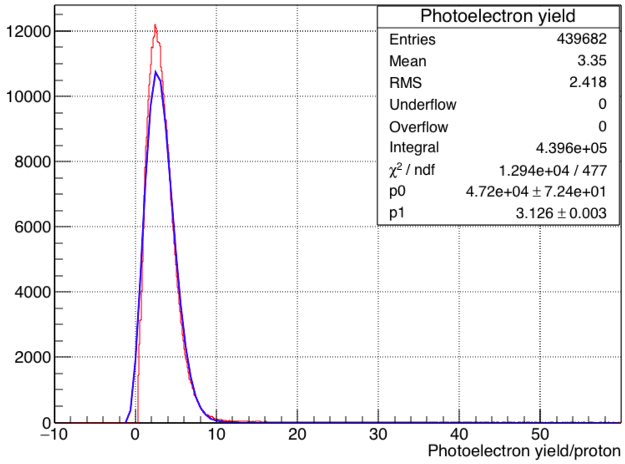

Figure 5: SE-CpFM Photoelectron yield per proton.

The photoelectron yield per single proton of the detector was obtained by the amplitude distribution, dividing by the amplitude of a single photoelectron event. The latter was extrapolated from a background measurement performed with the LSS5-CpFM PMT in SPS. The PMT of the LSS5 CpFM belongs to the same series of the SE-CpFM PMT but the gain can easily fluctuate from a PMT to another one of the same series. We evaluated that the effect of the PMT gain fluctuations on the photoelectron yield is of the order of 10%. The photoelectron yield distribution is shown in Fig. 5 together with the poissonian fit applied; the result is the estimation of the calibration factor of the detector:

$$ph.e\ yield = 3.1 \pm 0.3$$

CONCLUSION

A new concept of in-vacuum Cherenkov detector has been selected to perform the proton flux measurement in the first crystal-assisted slow extraction experiments at CERN-SPS. The SE-CpFM has been developed starting from the LSS5-CpFM detector, devoted to the same kind of measurements in the frame of the UA9 experiment, but with improved performances in term of efficiency and photoelectron yield. To characterize the whole detector chain, in May 2015 the detector has been tested with a 180 GeV pion beam, in the SPS-H8 line. The in-beam test campaign has shown a very good performance of the SE-CpFM. The efficiency was indeed evaluated to be $\epsilon = 94 \pm 4.5\%$ and the photoelectron yield per proton, mainly due to the bundle remotion, improved by a factor 5 with respect to the LSS5-CpFM detector changing from 0.63 (as masured in [14]) to 3.1 ph.e per proton.

The SE-CpFM was installed in the TT20 extraction line during the 2015 SPS winter shutdown and its commissioning is still ongoing. In October 2016, the detector has has been fundamental to prove the crystal-assisted proton extraction at the SPS (see Fig. 4 and 6 of [9]).

ACKNOWLEDGEMENT

The authors would like to thank the other members of the UA9 Collaboration, the CERN EN/STI, EN/EA, BE/OP, BE/RF, TE/VSC groups for the support during the design, the construction and the tests of the detector. This work has been partially supported by the ERC CoG CRYS- BEAM G.A. 615089.

ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-WEPCF04

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