Proton flux monitor(s) for the UA9 Experiment

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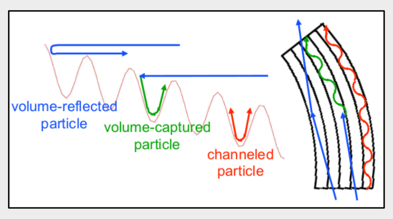
Abstract

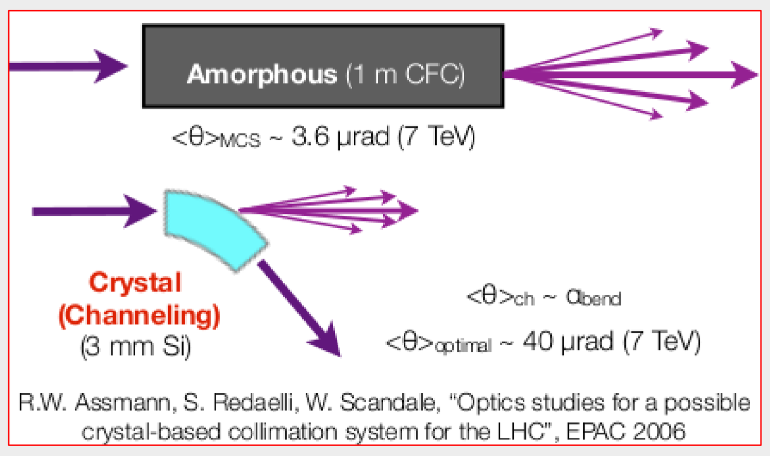
- The use of bent crystals for beam-manipulation or cleaning of the beam halo in particle accelerators is currently investigated by the UA9 collaboration at CERN.
- Investigation of the channeling process close to a circulating beam requires detectors which could be located inside the vacuum pipe itself.
- The CpFM – Cherenkov detector for proton Flux Measurements – is a calibrated detector fitting these requirements, with the aim of counting the mean number of deflected protons or ions. A first concept of the CpFM has been developped at LAL and was installed in the Super Proton Synchrotron (SPS) at CERN.
- We present results obtained with the CpFM in operation, focused on main performances for different purposes, as well as its limitations and possible improvements.

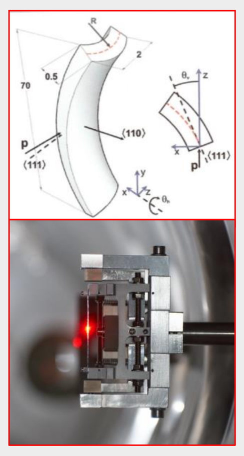
The UA9 Experiment and the CpFM

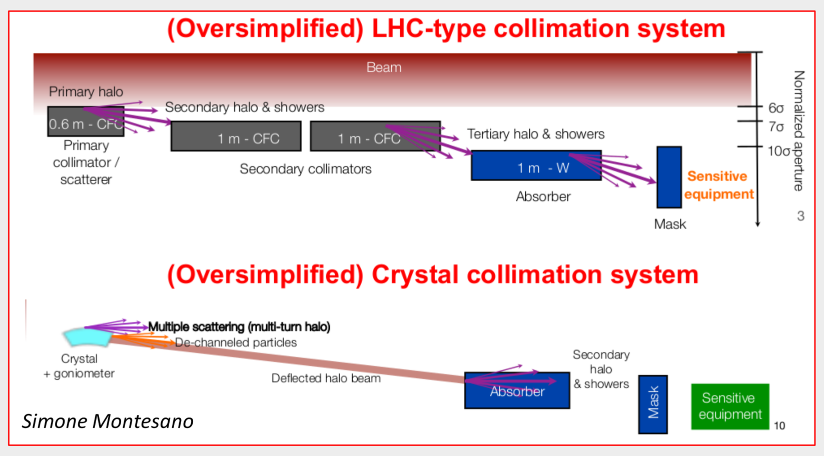
• The UA9 Experiment



- ✓ Charged particles traversing a crystal can undergo coherent interaction with the atomic lattice. This interaction depends on the impinging angle, and can reduce cross section for nuclear and / or Coulomb interactions.
- ✓ This "channeling" process of positive charged particles is possible for straight and moderately bent crystals.
- ✓ **Bent crystals can be used as small deflectors. The UA9 Experiment investigates how they can be used to steer particle beams.** 3 installations (since 2014): SPS North Area (H8), SPS & LHC.

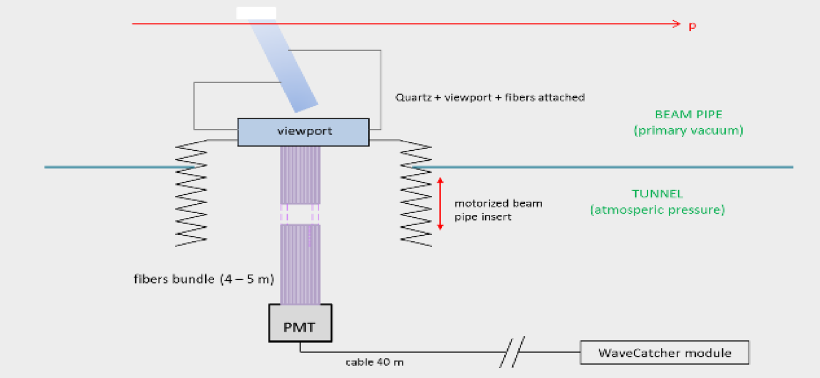




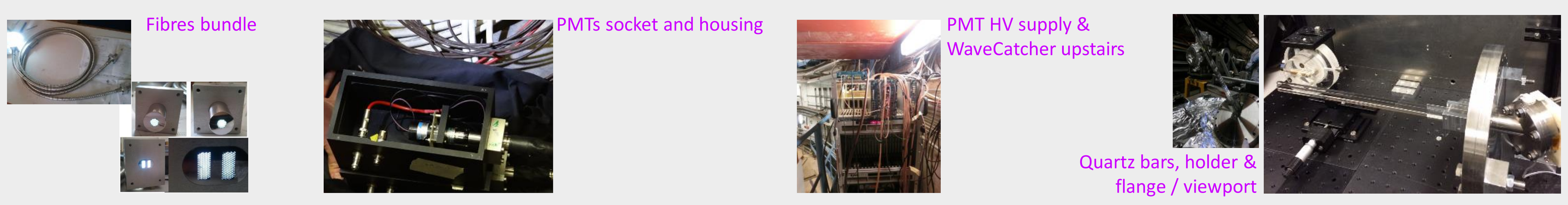


• The Cherenkov detector for Proton Flux Measurements (CpFM)

- ✓ **<u>C</u>herenkov detector for <u>p</u>roton <u>F</u>lux <u>M</u>easurement**, main contribution of LAL to UA9 Experiment.
- ✓ Aim of the CpFM: **count the number of deflected protons** with a precision of about 15% in the LHC environment (**<u>mean value over several bunches</u>, with expected values between 1 and 200 p/bunch**).

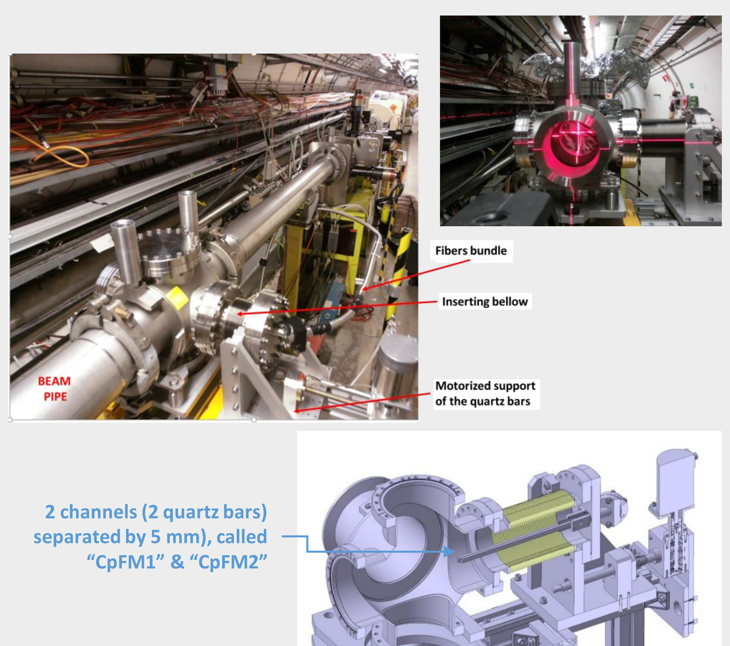


In vacuum, radiation hard detector:
- **Interception of the channeled beam by a quartz radiator** (retractable finger)
- **Emission and transmission along the bar of Cherenkov light**, **readout by a PMT** (Hamamatsu R7378, bialkali photocathode, synthetic silica window, glass base) placed 1 m from the beam pipe (light brought through a viewport and by silica fibers)
- PMT amplified **signal readout by a WaveCatcher module** (3,2 GHz digitizer), **integrated to the SPS acquisition system**; amplitude, charge and timing extracted
- 40 m cable between PMT and WaveCatcher (remotely controlled)



• Installation in SPS

- ✓ The CpFM was **calibrated in H8 line (CERN) and BTF (INFN Frascati) and installed on the SPS**, 58 m downstream the UA9 bent crystal.
- ✓ **The trigger of the WaveCatcher module is the revolution frequency (43 kHz) downscaled by 1000**. The 43 kHz frequency is too high for extracting data from the WaveCatcher (limit at 30 kHz). **<u>For CpFM, we are typically counting 1 bunch over 1000</u>.**
- ✓ 2 modes for acquisition: **counting** (using amplitude & charge measurements, **for estimating number of crossing particles**, at 43 Hz), and "**rates counters**" (self-triggered, when a given threshold is crossed, working at several hundreds of kHz).



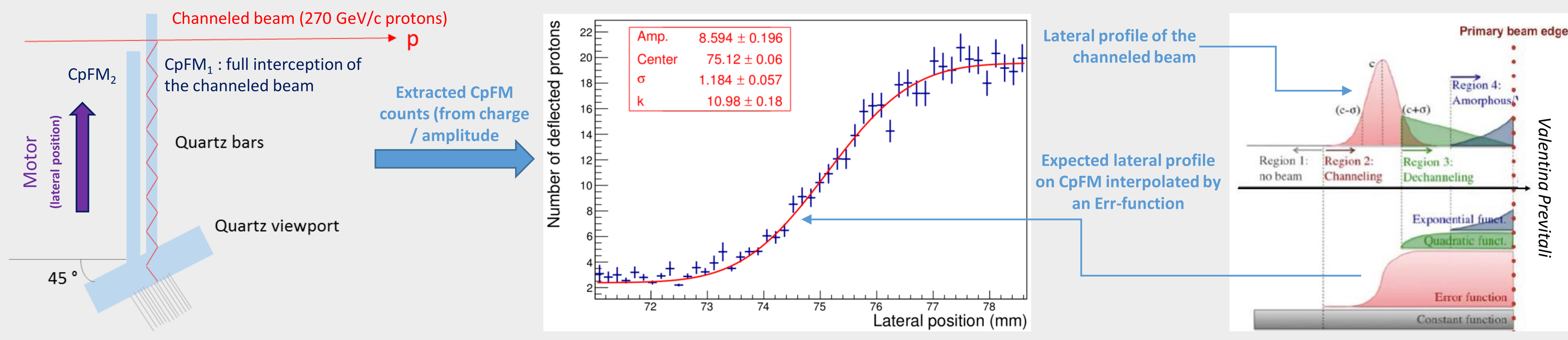
<u>See:</u> *V. Puill et al.* 2017, "The CpFM, an in-vacuum Cherenkov beam monitor for UA9 at SPS", JINST, Vol. 12

Conclusions

- ➢ **LAL successfully developed a proton flux monitor for the UA9 experiment, able to count and follow the number of channeled particles by bent crystals.**
- ➢ **This counter can be used for different purposes, taking advantage of its flexibility: intercepting the channeled beam and estimating the number of crossing protons (or ions, for low fluxes), giving a mean value over several bunches or an instantaneous estimation for a given bunch. It can also be used for estimating the angular spread of the channeled beam, or for finding the channeling angle of the crystal. Its results are also complementary and compatible with other UA9 instrumentation.**
- ➢ **The main limitations are the detection threshold, too high and giving sometimes an over estimation of the mean number of channeled particles, and the measurement frequency at 43 Hz, when the revolution frequency is 43 kHz.**
- ➢ **A new version of this detector is currently developed and tested, to ensure a better light collection (and a threshold well below 1 proton), as well as a faster acquisition system able to measure and count particles in each successive bunch.**

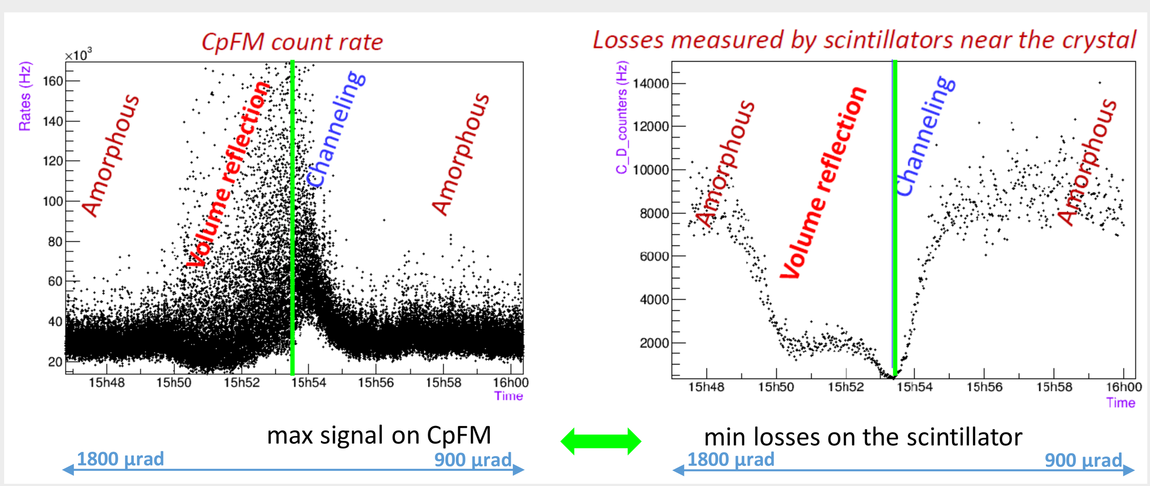
CpFM in operation

• Linear scan: full interception of channeled beam for counting



→ **CpFM 1 & 2 inserted in the channeled beam**: **number of crossing protons extracted from charge and / or amplitude measurements**, at 43 Hz (1 bunch over 1000). Mean value as a function of lateral position.
→ Interpolated by an **error function**: **mean number of channeled protons when the channeled beam is fully intercepted** (about 17 protons for the bent crystal configuration used for this test).
→ From Err-function: sigma of 1.18 ± 0.06 mm. **Angular spread of the channeled beam** derived: 12 ± 2 µrad in good agreement with the critical angle at 270 GeV.

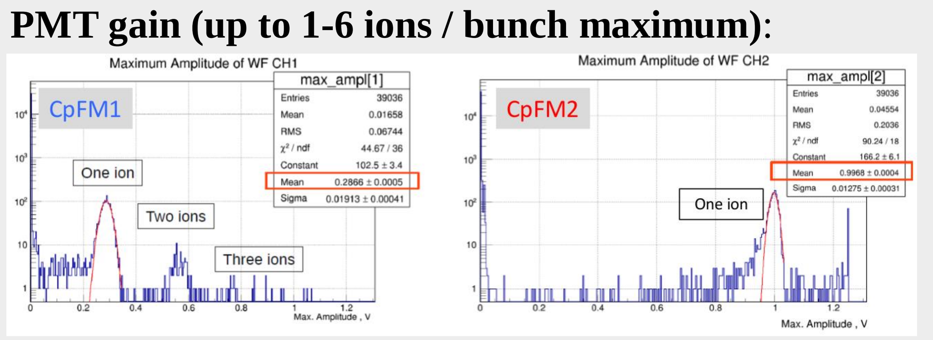
• Angular scan: find / check channeling angle of the bent crystal



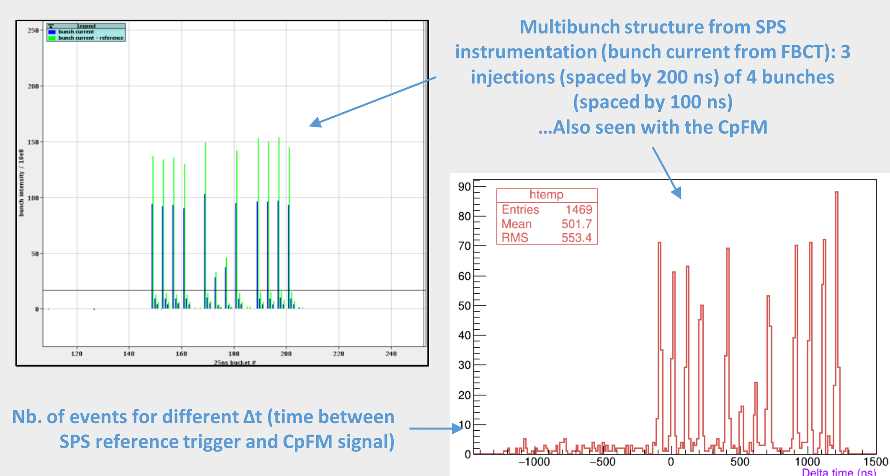
→ With **CpFM inserted** (able to intercept channeled beam), we move the **angular orientation of the UA9 bent crystal.**
→ Looking for the **best channeling angle** (**max. signal on CpFM**, and also min. losses on scintillators close to the crystal): found here at 1432 µrad, in good agreement on both detectors.
→ **Use rates counters** (number of deflected protons not measured): high stat.

• Ions: (very) low flux, in multi-bunch configuration

→ Ions producing **much more Cherenkov light than protons** (ex. Pb ions: 6724 times more light, **following Z²**).
→ Given the dynamic range of the output signal (up to 2.5 V), corresponds to **very low flux, even at the lowest PMT gain (up to 1-6 ions / bunch maximum)**:

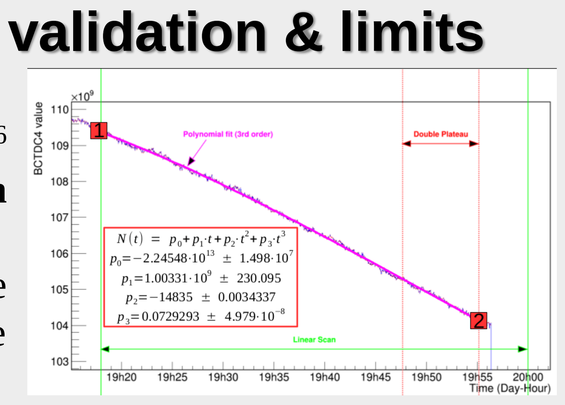


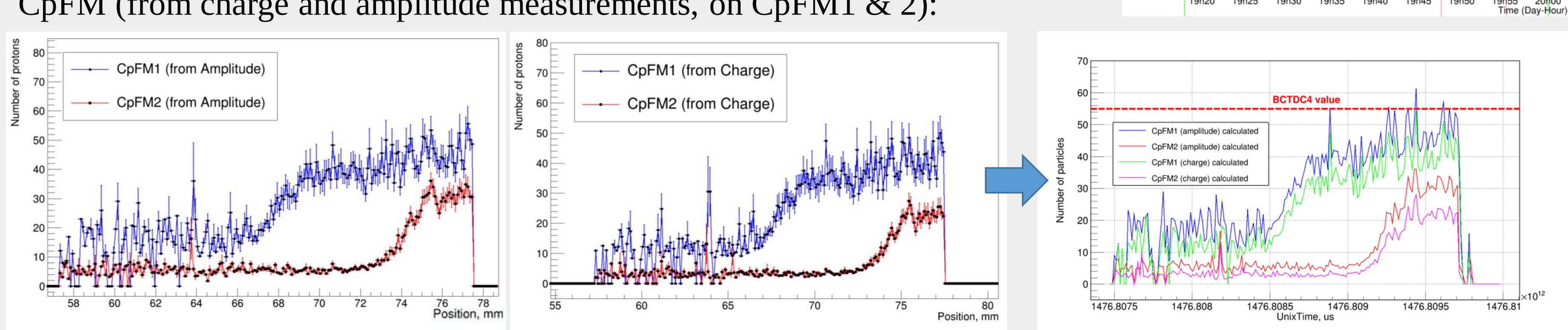
→ In multi-bunch configuration, we can follow the beam structure:



• Comparison with beam-line instrumentation: validation & limits

→ Stable conditions, **crystal in channeling and CpFM inserted (linear scan)**.
→ DC Beam Current Transformer (BCTDC): $2.35001 \cdot 10^6 \pm 0.19289 \cdot 10^6$ protons lost / second, corresponding to **54.6515 ± 0.4486 protons lost per turn** (single-bunch configuration, revolution frequency of 43 KHz).
→ Considering this value of about 55 protons as an absolute maximum possible for the number of channeled protons, we can compare results given by the CpFM (from charge and amplitude measurements, on CpFM1 & 2):





→ **Results compatible with BCTDC estimation**.
→ Mean values calculated can be different between CpFM1 & 2: due to **different detection threshold on both channels** (CpFM1 cannot detect less than 6 protons / bunch, as CpFM2 is limited at 2 protons / bunch). **We need a lower threshold, below 1 proton**.
→ Also, there is **huge fluctuations on the number of channeled particles** measured at 43 Hz: from some particles to several hundreds! **We are not measuring successive bunches**, only 1/1000. **We are loosing the history** of the channeling process.