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THE BEAM GAS VERTEX PROFILE MONITORING STATION FOR HL-LHC*

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Abstract

A new instrument is under development for the High Luminosity upgrade of the Large Hadron Collider at CERN (HL-LHC) to provide non-invasive transverse beam size measurements throughout the full acceleration cycle. The Beam Gas Vertex (BGV) monitor consists of a tank supplied with gas at very low pressure attached to the LHC beam pipe with a series of particle tracking stations located downstream outside vacuum. Inelastic collisions between the beam and the gas target produce secondary particles that are detected by the tracking stations. The beam size is measured from the spatial distribution of several thousand beam-gas interaction vertices, which are identified by means of reconstructed tracks. A demonstrator device, operated over several years, has proven the feasibility of the BGV concept and has motivated the development of a fully operational device for HL-LHC. The status of current design studies for the future instrument will be presented, with particular emphasis on potential tracking detector technologies, readout schemes, and expected performance.

INTRODUCTION

Since the birth of circular colliders, operators have been seeking a means of monitoring the stored beam emittance evolution throughout the full acceleration cycle: injection, ramp, flat top, squeeze, stable beams. Analysing the emittance growth evolution is the best way to optimize accelerator performance and in turn the experiments luminosity. The emittance is usually obtained from beam profile measurements performed at a fixed location in the ring. Most classic beam profile measurement techniques introduce a physical object in the beam path: secondary emission grids, imaging screens, wire scanners. These instruments often cannot be used with full physics beams since they would be damaged [1], or produce unacceptable levels of beam losses [2]. Non-invasive techniques have therefore been actively developed to allow beam profile measurements with almost no effect on the beam. Synchrotron radiation (SR) is the most common technique available at ultra-relativistic beam energies. It make use of dipole or undulator magnets to generate SR, which is then extracted through a view port and imaged to obtain the beam profile. In the case of the LHC, the beam synchrotron radiation telescope (BSRT) uses three different SR sources (undulator, dipole edge radiation and dipole radiation) to cover the energy range from injection (450 GeV) to flat top (6.5 TeV) [3]. This change in source during the energy ramp implies that the system is not capable of continuous beam size monitoring, but can only be used to provide measurements at injection and at top energy. The HL-LHC beam gas vertex monitoring station (HL-BGV hereafter) presented in this paper addresses this issue by proposing an elegant way to measure the beam profile continuously throughout the acceleration cycle.

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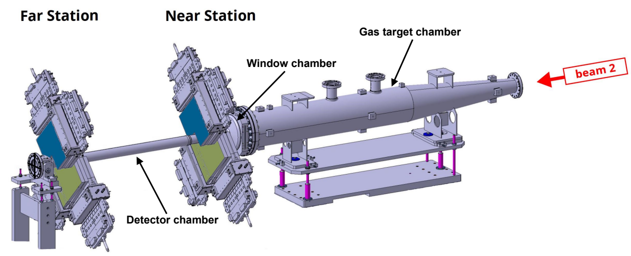

Figure 1: Sketch of the BGV demonstrator as installed in LHC point 4.

LEGACY FROM THE BGV DEMONSTRATOR

The BGV demonstrator shown in Fig. 1 is based on the LHCb VELO SciFi technology [4] and has been successfully measuring the LHC beam size in real time, publishing a beam size measurement after only a few seconds of integration [5]. While not planned to be an operational device, it has been run for testing purposes almost continuously during the last months of the 2018 LHC run. The demonstrator geometry did not allow precise vertexing and therefore the beam profile could not be imaged directly as first expected. The beam size was therefore obtained by means of a track correlation method as previously used in [6, 7]. Based on the experience with the BGV demonstrator, the HL-BGV aims to overcome this issue to provide a two dimensional transverse profile of the beam in real time.

THE HL-BGV GAS TARGET

In order to reach a beam gas inelastic collision rate of 200 Hz per bunch a gas target is required, created by injecting neon gas into a specially designed tank. Active pumping is present on both extremities of this vacuum vessel in or-

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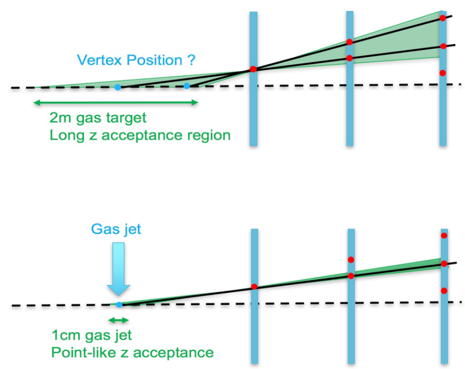

Figure 2: Acceptance sketch for a long gas target (top), and a gas jet target (bottom).

der to maintain normal LHC vacuum conditions outside the gas tank volume. The BGV demonstrator used a long gas tank volume of 1.8 m with an average neon pressure of 1×10^{-7} mbar. For the HL-BGV the potential benefits of confining the beam gas interactions to a 1 cm long gas jet target at 1.8×10^{-5} mbar, which maintains the same interaction rate, is currently under study [8].

Acceptance

The drastic reduction of the beam-gas collision region along the beam path will have a direct impact on the efficiency of correctly associating clusters with tracks, as illustrated in the sketch presented in Fig. 2. For the BGV demonstrator, using a long gas target volume, the fake track ratio has been calculated to reach 30 % using Monte Carlo simulation, something that could be greatly reduced using a thin gas target. Furthermore, a centimetre scale interaction region would lead to a reduction of the needed tracker geometrical acceptance and in turn a reduction of the required sensor surface area.

Tracking and Vertexing Resolution

As the beam-gas collision locations in the BGV demonstrator are distributed along the full gas target, many of these vertices sit in a region where the impact parameter resolution is poor and dominated by multiple scattering in the exit window and tracker layers (Fig. 3 right hand side of the plot). The optimum position for a 1 cm thick gas jet is a compromise between the impact parameter resolution of Fig. 3 and the acceptance as shown by the dotted line on Fig. 4. The potential gain from the additional constraints given by a thin gas jet target is tremendous, and it would certainly allow accurate vertexing, opening the path for real-time 2D profile reconstruction.

THE HL-BGV TRACKING STATION

One of the main bottlenecks of the BGV demonstrator was the lack of a third detector station. With only two sensor stations, performing beam-based alignment was a real challenge, reducing the overall tracking accuracy. This can

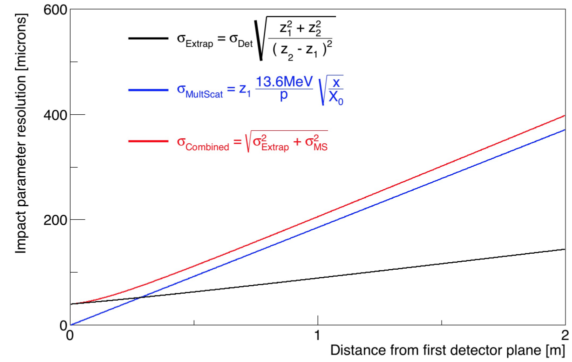

Figure 3: Impact parameter resolution with respect to beam gas collision distance from the first detector. In black the effect of the sensor spatial resolution, in blue the error due to multiple scattering, and in red the combined resolution.

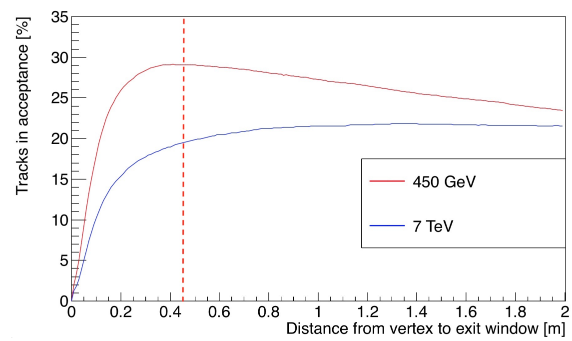

Figure 4: Percentage of tracks in the acceptance of the gas tank exit window with respect to beam gas collision distance from exit window. The dotted line corresponds to the optimum gas jet location.

be overcome on the HL-BGV by adding a third station to the tracker system.

Detector Technology

The main aspects for the selection of the tracking sensor technology are: the spatial resolution, the material budget and the overall cost. As observed in Fig. 3, multiple scattering of the secondary particles is the main contributor to the degradation of the vertexing resolution. Potential detector technologies offering ultra-low material budget (reducing multiple scattering) have therefore been compared in terms of their performance.

Silicon Detectors In terms of spatial resolution, silicon strip or silicon pixels detectors are the obvious candidates [9]. State of the art dual-sided silicon strip device (DS-SSD) can be produced with 50 µm strip pitch for a 14.4 µm spatial resolution on a 300 µm silicon substrate by several commercial companies. The corresponding material budget for a DS-SSD sensor is 0.32% (in radiation lengths, x/X_0). Pixel sensors are overlaid with a readout-chip, which increases the material budget by factor of two but could provide better cluster separation. Silicon technology is nevertheless expen-

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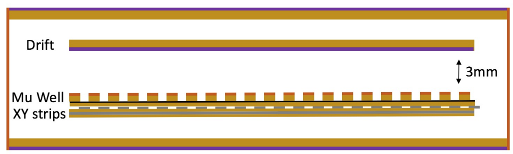
(a) Triple gas electron multiplier GEM



(b) The MicroWell gaseous detector.

Figure 5: Sketch of the two MPGD detector candidates.

sive, and necessitates the development of a highly integrated readout hybrid wire-bonded to the silicon sensor. This high level of complexity and the risk management associated with each step of a silicon tracker assembly also plays an important role in the overall tracker production cost.

Gaseous Detectors Multi-Pattern Gaseous Detectors (MPGD) can be implemented in a robust and cost effective way using industrial production techniques [10]. The physics of the particle detection process allows a spatial resolution in the 40 µm range using charge sharing with a 400 µm readout strip pitch. Recent advances in detector development within the RD51 collaboration framework at CERN have led to the possibility of building ultra-low material budget MPGD. Two attractive candidates have been identified: the gas electron multiplier (Fig. 5a)[11], and the micro-Rwell gas detector (Fig. 5b)[12]. Using 5 µm aluminum and 10 nm chromium instead of conventional 5 µm copper to produce the sensor elements, these detector modules can be built with an extremely low material budget of 0.184 %, and 0.153 % respectively. The amplification gain of the micro-Rwell is smaller than the one from the triple GEM structure, a tracking performance comparison will be done on a cosmic bench to select the best candidate.

READOUT ELECTRONICS AND ONLINE DATA PROCESSING

The tracker readout system must be able to record and process the secondary tracks from beam gas collisions at a high rate (>10kHz event rate) and process the data online to produce real-time beam size measurements. The requirements can be broken down into three main physical entities.

The Front-End Board

Also called the front-end hybrid, this is attached to the tracking sensor and hosts some dedicated Application Specific Integrated Circuits (ASIC)) able to withstand high radiation levels. These chips digitize the analogue charges generated in the tracking sensor on the passage of a particle. The actual choice of read-out chip depends on the sensor technology involved and its associated dynamic range. A candidate under test is the VMM3a [13] that has recently been developed for the ATLAS New Small Wheel in collaboration with the European Spallation Source (ESS). Additional radiation hard ASICs can then be employed to serialise the data of multiple readout ASICs for transmission over a high bandwidth optical fibre link.

The Back-End

Located in the service cavern, the back-end will consist of an FPGA based data concentrator. It will be used to assemble the hit information coming from each of the tracking planes into a full event (collection of hits belonging to the same 40 MHz LHC time stamp). Some low level processing – such as clustering - could also be performed in the FPGA to speed-up the processing time and reduce the bandwidth needed for subsequent data transfer. The back-end will also serve as the readout controller, distributing trigger and timing information in order to synchronise the acquisition over all front-end boards.

The CPU Farm

The CPU farm receives the events assembled by the back-end as data packets, distributed through a dedicated computing network, for online reconstruction. A push-pull mechanism similar to [14] can be used to manage the computing credits available in the CPU nodes and control the flow of data packets generated by the back-end. On each computing node, a series of processes can be run sequentially: event filtering, geometrical correction, detector calibration, pattern recognition, tracking, and finally vertex fitting. This processing will result in a set of track correlations and a reconstructed vertex position for each event. One specific computing node from the farm can be set aside to merge the data from all the processed events to build-up the beam profile measurement in real-time, continuously publishing the profiles obtained every few seconds.

OUTLOOK

The key technologies for the HL-BGV have been well identified. The gas target re-design is underway. Low material budget gas sensor technology is being tested in collaboration with the gas detector group at CERN in order to evaluate the characteristics that are critical for the HL-BGV tracker. A full simulation and reconstruction framework is being adapted to the new tracker design, to optimise detector geometry and evaluate the expected performance. Studies are also ongoing to find the best instrument location based on the foreseen HL-LHC accelerator optics.

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REFERENCES

[1] E. Bravin, T. Lefèvre, and C. Vermare, "OTR studies for the high charge CTF3 beam," Jun. 2003, revised version number 1 submitted on 2003-07-01 15:38:48. https://cds.cern.ch/record/620199

[2] R. J. B. Goddard, "Interlocking of lhc btv screens," CERN-LHC, Geneva - Switzerand, Tech. Rep. LHC-BTV-ES-0001 rev 1.0, 2007.

[3] A. Fischer, "The lhc synchrotron-light telescope (bsrt) and abort-gap monitor (bsra), using dipole and undulator radiation, for both protons and ions," CERN-LHC, Geneva - Switzerand, Tech. Rep. LHC Performance Note-014, June 2009.

[4] P. Barbosa-Marinho *et al.*, "LHCb Tracker Upgrade Technical Design Report," CERN, Geneva, Switzerland, Tech. Rep. CERN-LHCC-2014-001, Feb. 2014. https://cds.cern.ch/record/1647400

[5] B. Würkner, "Measuring Beam size with the LHC Beam Gas Vertex Detector," in *Proc. of International Particle Accelerator Conference (IPAC'19), Melbourne, Australia, May 2019*, paper WEPGW084, this conference.

[6] R. Mankel, "Measurement of the transverse beam line width using impact parameter correlations," DESY, Hambourg, Germany, Tech. Rep. CMS-AN-2010/196, 2010.

[7] S. Donati and L. Ristori, "Measuring beam width and SVX impact parameter resolution," FERMILAB, Batavia, USA, Tech. Rep. CDF-Note-4189, 2003. http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=609

[8] R. Veness *et al.*, "Development of a Beam-Gas Curtain Profile Monitor for the High Luminosity Upgrade of the LHC," in *Proc. 7th International Beam Instrumentation Conference (IBIC'18), Shanghai, China, 9-13 September 2018*, ser. International Beam Instrumentation Conference, Geneva, Switzerland: JACoW Publishing, Nov. 2018, pp. 472–476. doi: doi:10.18429/JACoW-IBIC2018-WEPB16.

[9] A. Oblakowska-Mucha, "The LHCb vertex locator — performance and radiation damage," *Journal of Instrumentation*, vol. 9, no. 01, pp. C01065–C01065, Jan. 2014. doi: 10.1088/1748-0221/9/01/c01065.

[10] M. Titov and L. Ropelewski, "Micro-pattern gaseous detector technologies and RD51 Collaboration," *Mod. Phys. Lett.*, vol. A28, p. 1 340 022, 2013. doi: 10.1142/S0217732313400221.

[11] F. Sauli, "The gas electron multiplier (gem): Operating principles and applications," *NIM A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 805, pp. 2–24, 2016, Special Issue in memory of Glenn F. Knoll, issn: 0168-9002. doi: https://doi.org/10.1016/j.nima.2015.07.060.

[12] M. P. Lener *et al.*, "The micro-rwell: A compact, spark protected, single amplification-stage mpgd," *NIM A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 824, pp. 565–568, 2016, Frontier Detectors for Frontier Physics: Proceedings of the 13th Pisa Meeting on Advanced Detectors, issn: 0168-9002. doi: https://doi.org/10.1016/j.nima.2015.11.098.

[13] G. Iakovidis, "VMM3, an ASIC for Micropattern Detectors," CERN, Geneva, Tech. Rep. ATL-MUON-PROC-2018-003, Mar. 2018. http://cds.cern.ch/record/2309951

[14] R. Jacobsson, "Central fpga-based destination and load control in the lhcb mhz event readout," LHCb CERN, Geneva, Switzerland, Tech. Rep. LHCb-PUB-2011-023, 2011.