Fermilab

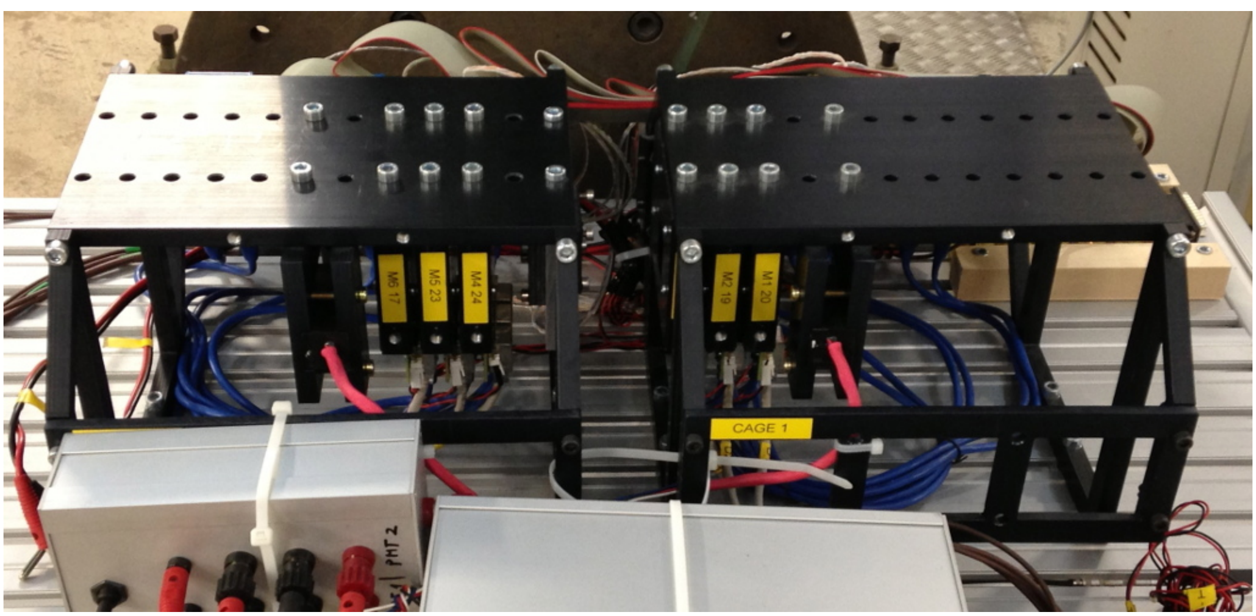
Directorate

TECHNICAL SCOPE OF WORK
FOR THE 2014 FERMILAB TEST BEAM FACILITY PROGRAM

T-1056

ATLAS DBM Module Qualification

June 18, 2014



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INTRODUCTION

This is a technical scope of work (TSW) between the Fermi National Accelerator Laboratory (Fermilab) and the experimenters of Jozef Stefan Institute, CERN, and University of Toronto who have committed to participate in beam tests to be carried out during the 2014 Fermilab Test Beam Facility program.

The TSW is intended primarily for the purpose of recording expectations for budget estimates and work allocations for Fermilab, the funding agencies and the participating institutions. It reflects an arrangement that currently is satisfactory to the parties; however, it is recognized and anticipated that changing circumstances of the evolving research program will necessitate revisions. The parties agree to modify this scope of work to reflect such required adjustments. Actual contractual obligations will be set forth in separate documents.

This TSW fulfills Article 1 (facilities and scope of work) of the User Agreements signed (or still to be signed) by an authorized representative of each institution collaborating on this experiment.

Description of Detector and Tests:

Luminosity monitors, beam monitors and tracking detectors of the experiments at the Large Hadron Collider and their upgrades must be able to operate in radiation environments several orders of magnitude harsher than those of any current detector. ATLAS has observed that as the environment becomes harsher detectors not segmented, either spatially or in time, have difficulty handling the separation of signal from background. To remedy this problem, present tracking detectors close to the interaction region are based on highly segmented silicon sensor technology. Chemical Vapour Deposition (CVD) diamond has a number of properties that make it an attractive alternative for high energy physics detector applications. Its large band-gap (5.5 eV) and large displacement energy (42 eV/atom) make it a material that is inherently radiation tolerant with very low leakage currents and high thermal conductivity. CVD diamond is being investigated by the RD42 Collaboration for use very close to LHC interaction regions, where the most extreme radiation conditions are found. This document builds on that work and proposes a highly spatially segmented diamond based luminosity monitor to complement the time segmented ATLAS Beam Conditions Monitor (BCM) so that when Minimum Bias Trigger Scintillators (MTBS) and LUCID (LUminosity measurement using a Cherenkov Integrating Detector) have difficulty functioning the ATLAS luminosity measurement is not compromised.

The Physics Mission

ATLAS has already shown that it can measure the luminosity in LHC collisions with a precision of better than 5%. Measuring the luminosity at this scale opens up the possibility of making a number of measurements that had not originally been anticipated in the LHC physics studies. One such measurement is the indirect determination the top mass from a precision measurement of the top quark production cross-section[1]. The relative top mass (m_t) dependence of the top pair production cross section (σ_t) is given by $\delta m_t/m_t = 0.21\delta\sigma_t/\sigma_t$. A measurement of the top pair cross section with a total precision (including theory) of 5% will therefore lead to an indirect determination of the top mass with a 1% precision or 1.5GeV. This would provide an

[1] LHC Lumi Days Workshop, http://indico.cern.ch/conferenceDisplay.py?confId=109784, see in particular the contribution by Michelangelo Mangano.

independent determination of the top mass with roughly the same precision but different systematics than the reconstruction of the top mass from its decay products. It is expected within a few years the theoretical uncertainty in the top pair production cross section will be reduced to 3-5%. ATLAS is working to reduce the experimental systematics to the 1% level. A luminosity measurement at the 3% level would mean the luminosity uncertainty would be negligible in a 1% indirect measurement of the top mass.

The W and Z production cross sections are hard processes at the LHC with intrinsic theoretical precision of around 2%. Given the expected large amount of data in the next few years, very soon the systematics of these measurements will be dominated by the luminosity measurement. This in some sense sets a natural 2% benchmark goal for future luminosity measurements at the LHC. Note that below a 5% measurement of luminosity one may begin extracting new information on the proton parton distribution function (PDF). The improved determination of PDFs will hopefully lead to reduced systematics of several other precision measurements. For instance, a precision determination of the scattering cross-section at different LHC energies constrains elastic and diffractive scattering processes that may be crucial to understanding production mechanisms for new high-p_t physics (i.e. diffractive production of the Higgs). These measurements rely on the ability to measure the luminosity at the 3% level. A complete discussion of the physics motivation for high precision luminosity measurements can be found in [1].

Diamond Development within ATLAS

Within ATLAS, diamond tracking sensors are being developed as an official ATLAS Upgrade R&D project[2] for diamond pixel sensors by University of Bonn, CERN, University of Göttingen, Ljubljana, Ohio State University and the University of Toronto. The original aim of this upgrade project was to industrialize diamond production and build ATLAS pixel modules of the current detector, i.e. with a sensor of ~2cm x 6cm bump-bonded to 16 FE-I3 chips. This goal was successfully achieved in an industrialization process with IZM[3] in Berlin mastering all the steps from bare sensor metallization to bump bonding (Fig. 1).

Fig. 1: Diamond sensor bump-bonded to 16 FE-I3 chips (left) and the completed ATLAS diamond pixel module under test (right).

Recently, this group has focused on the bid of diamond as the sensor material for the ATLAS Insertable B-Layer (IBL) project[4]. In this context resources for 20 single FE-I4 chip modules with diamond detectors were produced. The modules were produced as part of the sensor qualification programme. The 2011 Chamonix LHC meeting and the resulting delay of the LHC shutdown prompted ATLAS to fast-track the IBL, bringing its installation forward from 2015 to

[2] ATU-RD-MN-0012, EDMS ID: 903424.

[3] Fraunhofer Gesellschaft, Institut für Zuverlässigkeit und Mikrointegration, High Density Interconnect & Wafer Level Packaging, Gustav-Meyer-Allee 25, D-13355 Berlin, Germany.

[4] ATLAS Insertable B-Layer Technical Design Report, CERN-LHCC-2010-013; ATLAS-TDR-019.

2014. The resulting schedule requires 448 sensors be available for module loading by October 2011, followed by an additional 448 sensors by the middle of 2012, to ensure that all IBL staves are complete by the end of 2012. For diamond, this shortened delivery schedule was not possible, since the existing production capability would have to be quickly and greatly enhanced to deliver the sensors necessary in one and a half years (Jun 2012) that were to be available in the original schedule of three years.

However, the existence of IBL diamond qualification modules and the excellent performance of the FE-I4[5] from the first engineering run lead us to propose a new highly segmented forward luminosity monitor just outside the IBL tracking volume based on diamond pixel detectors with FE-I4 electronics. The primary aims of this device are luminosity measurement and beam monitoring, providing online bunch-by-bunch relative luminosity and beam spot information. This new detector is named the Diamond Beam Monitor or DBM.

The DBM Motivation and Architecture

As already seen in 2011, the much higher number of interactions per crossing, which will become routine as the LHC moves towards its design luminosity, will challenge the existing ATLAS luminosity detectors (LUCID, MBTS, etc.)[6]. The principal challenge lies in the fact that these detectors have limited segmentation and are already showing signs of saturation. Once the charged particle multiplicity reaches the point where all segments of these detectors have a high probability of having a hit in every bunch crossing their luminosity sensitivity quickly vanishes. This is already happening to the MBTS counters that were removed in the 2011 year-end shutdown and LUCID cannot be far behind. The BCM sensors, despite their tiny acceptance, will start to show signs of saturation as the luminosity approaches $1\text{x}10^{34}$. The DBM proposed here has three orders of magnitude higher segmentation than the MBTS and will be positioned at comparable η. As a result the DBM should never saturate.

In addition to measuring bunch-by-bunch luminosity, the DBM will complement the existing BCM, providing three orders of magnitude higher spatial segmentation (relative to the single BCM pads) at the expense of lower (25 ns vs 2 ns) time resolution. However, these two systems will complement one another in the characterisation of the beam backgrounds. The BCM will still use its exquisite timing resolution to localise beam background sources up (or down) stream of ATLAS, while the DBM will provide additional spatial information about the source(s) of background. In addition, it is expected the DBM will be able to identify isolated tracks over a limited range of phi in the η range from 3.0 to 3.5. It may even be possible to use these tracks to study the FCAL response for single pions. The tracking resolution of the DBM is presently being studied.

To accomplish these goals, the proposed DBM architecture is four 3-layer telescopes on each side of the interaction point with each layer consisting of one FE-I4 module, namely 20mm x 16.8mm active area. Figure 2 shows the layout of the FE-I4 chip, with the active area and the control bond pads at the bottom. The first and last layers of the telescope are offset so that particles from both the ATLAS interaction point and beam halo background can be tracked. To

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5 Marlon Barbero et al. »Submission of the first full scale prototype chip for upgraded ATLAS pixel detector at LHC, FE-I4A«, Nucl. Instr. and Meth. A(2011), in press, doi:10.1016/j.nima.2010.11.131 .

6 For a good recent summary see the ATLAS weekly presentation on luminosity by Vincent Hedberg: https://indico.cern.ch/conferenceDisplay.py?confId=106716.

be able to build the DBM in the accelerated new Service Quarter Panel (SQP) schedule, it must rely heavily on the building blocks developed for the IBL, adapting only those that are impossible to incorporate without changes.

Basic Considerations

The DBM will be positioned between the first and second cruciforms of the Beam Pipe Support Structure (BPSS). To monitor the interaction point the DBM sensors will face the interaction, requiring at least 20mm in the radial extent, preferably as close as possible to the beam axis. For beam spot determination it is advantageous to maintain resolution along the beam axis, positioning the sensors as close to the interaction point as makes sense.

With single-chip modules having an active sensor dimension of 20mm x 16.8mm, adequate space is available inside in the BPSS of the pixel detector. The structure was initially covered with Service Quarter Panels, hosting the services of the pixel detector, and buried in the heart of the ATLAS experiment. However, the BPSS was brought to the surface in 2013, and the SQP's exchanged. This opened a window to install the DBM, but also fixed the installation time to October 2013. When the new SQPs were closed, access to proposed DBM was lost.

Fig. 2: The FE-I4 chip floorplan, showing the 336 active rows (on 50 μm pitch) by 80 columns (on 250 μm pitch) giving an active area of 16.8mm x 20 mm with an overall chip/module dimension of 18 mm x 21 mm.

The ATLAS diamond community already has a detector installed on the BPSS – the ATLAS Beam Conditions Monitor (BCM), which sits on the middle of three circular plates (cruciforms) linking the structural rods (longerons) of the BPSS (Fig. 3). An almost ideal location for DBM is therefore the inner cruciform, about 900 mm from the ATLAS interaction point. Striving for a symmetric arrangement, 4 - 8 or even up to 12 3-module telescopes per side were considered.

The DBM modules are fully-fledged pixel tracking devices. Although one will, at least initially, infer the luminosity by hit counting, being able to distinguish tracks from collisions from halo particles, for background estimation, argues for a tracking arrangement. Residing in a homogeneous solenoidal field of 2 T, even at angles < 0.1 there is enough field to bend high-p_t tracks. This argues for an arrangement in telescopes of three tracking planes (minimum) to allow for track reconstruction. The spacing between planes is not tightly constrained. However the combination of projectivity (with an angle of < 0.1) combined with acceptance for parallel tracks (from beam halo particles) suggests an overall spacing of 10 cm (5 cm between planes) giving 100% acceptance for tracks from the IP and 75% acceptance for halo (over the 2cm high diamond modules). Preliminary Monte Carlo simulations of minimum bias collisions and machine-induced background have confirmed these choices.

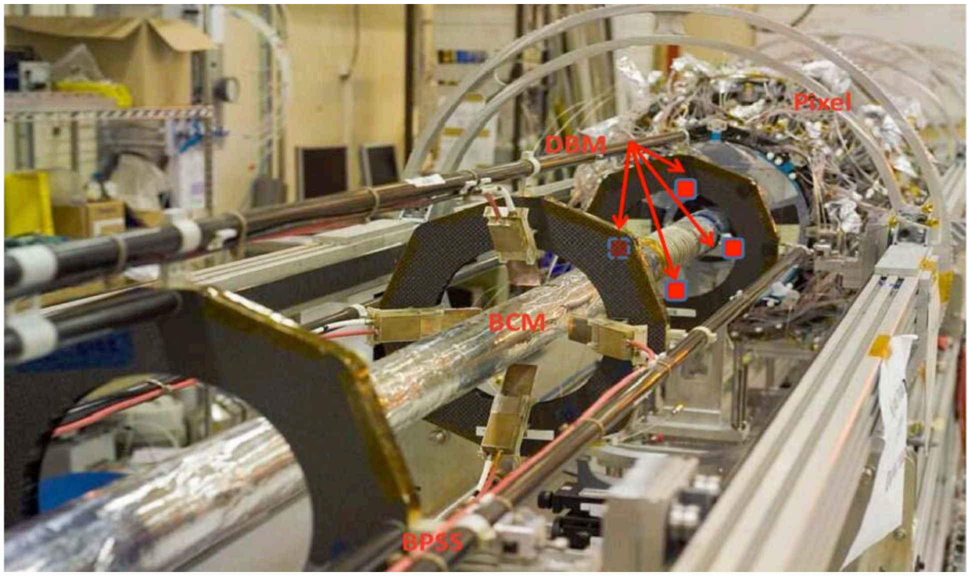


Fig. 3: The Beam Pipe Support Structure of the ATLAS pixel detector before coverage with Service Quarter Panels. The longerons and cruciforms are exposed, the middle cruciform hosting four BCM modules. The locations on the inner cruciform for four DBM modules are indicated.

Arranging modules in triple-plane telescopes limits in practical terms the number of telescopes to four per side, yielding a total of 24 modules. The rest of this document is based on this number, although, if time and resources were available, the detector is completely scalable to double or even triple the number of telescopes of this baseline.

The installation radius of the sensor is the critical parameter to the DBM's performance in luminosity measurements. The number of minimum bias particles in proton collisions in an area A at perpendicular impact scales as A/r^2, where r is the distance from the beam axis. The sensors should therefore be placed as close to the beam pipe as they can. A possible arrangement is shown in Fig. 4 where the radial envelope starts at r=46 mm, a stay-clear of 5 mm would put the inner edge of the sensor at 55 mm – allowing some room for a support frame around the sensitive area of the detector. The resulting minimum pseudo-rapidity is η=3.18 well below the tracking coverage of η<2.5, but nicely in the FCAL acceptance offering the possibility of identifying a sample of isolated charged particles for calibration purposes – though this is not the main physics aim of the DBM. The maximum η would then be at 3.48 for an η coverage of 0.3. The telescopes would then subtend an angle of 0.26 in $\Delta\phi$ giving about a factor of 5.4 larger acceptance than a single module of the current BCM, by virtue of their larger size.

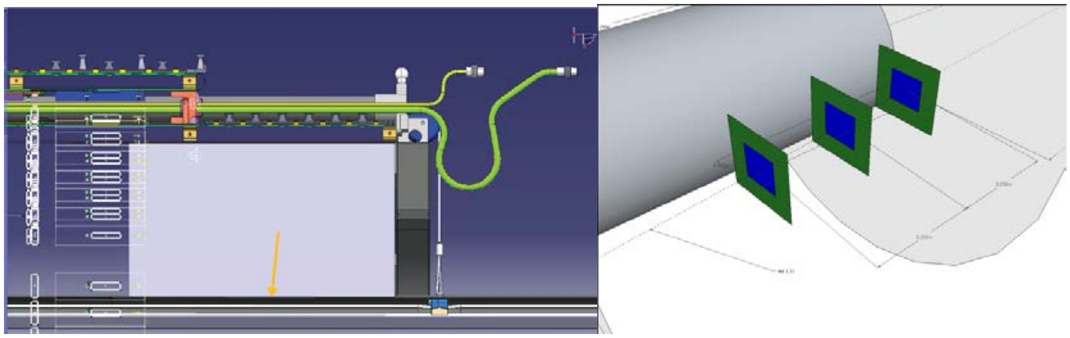


Fig. 4: DBM envelope in the BPSS (left) and 3-D sketch of positioning of three planes of a DBM telescope (right).

Detector Performance Specifications

In the table below is listed the detector parameters necessary to realize the DBM goals described above. All of these parameters can be met with material in hand or presently available:

Property	Specifications
Sensor size	21mm x 18mm (active area 20mm x 16.8mm)
Sensor Thickness	500 microns
Minimum charge collection distance	200 microns
Minimum average charge	7200 electrons
Minimum collection distance/ charge after $2x10^{15}$ cm^{-2}	100 microns/3600 electrons
Minimum signal/threshold after 2x1(cm^{-2}	3
Maximum operating voltage	1000 V
Maximum total leakage current (@1000 V)	100 nA

THE BUILDING BLOCKS OF THE DBM

This section describes the building blocks of the DBM, the modules. To install 24 modules, 30 good modules were constructed. Assuming 25% losses during production, the goal was to make 40 diamond sensors.

Sensors

40 sensors had to be procured. The sensitive area of the chip is 20mm x 16.8mm. To guarantee an adequate stand-off from the cutting edge, the sensors were ordered as 21mm x 18mm. To maximize the collected charge the sensors will be operated at a voltage of 800-1000 V. The sensor thickness has been chosen to balance the material budget and initial charge with the charge available after 5 years of operation. In the latest delivery from DDL, the charge collection distance (CCD) of sensors 750 µm thick was 300 µm. Polishing these further, down to a thickness of 500 µm, should yield a CCD >200 µm. Further, after a fluence of $2x10^{15}$

degradation is expected of less than 50%, to a CCD of 110 μm, yielding an average signal of 4000 electrons that should still be highly efficient given the thresholds in the FE-I4 chip.

The volume of procurement will depend on the yield. Recent experience with a batch of twenty 500 μm thick diamonds for the BCM, subject to the same 1000 V specification, showed that about 50 % of diamonds fulfilled the requirement. The experiment will arrange with the diamond suppliers to sample a selection of 80 sensors, selecting the 40 that have suitable HV performance. The rejected sensors are fully adequate for other applications, and the characterisation of the rejected sensors adds value to the manufacturer (who can sell them to other customers whose radiation and HV specs are not as stringent as ours).

It would be prudent to spread the purchase of diamond sensors over more than one manufacturer. The effort has been made to balance the order between two manufacturers - E6 and II-VI.

Read-out ASIC's

The DBM employs FE-I4 ASIC front-end chips. Preliminary results exhibit a very favourable operating threshold of <1000 e. The built-in time walk compensation should allow the electronics to be efficient down to this threshold, preserving high efficiency operation after irradiation towards the end of DBM lifetime. The chip features 26880 individual readout cells with a pitch of 50μm x 250μm. 50 tested chips were needed for the DBM, allowing for a 25 % loss in assembly.

Sensor metallization and bump bonding

IZM has mastered all of the steps of metallization and bump-bonding from bare diamond sensors to flip-chip assembly on several 6cm x 2cm old-style ATLAS FE-I3 pixel modules and the first four IBL diamond pixel modules. The metallization pattern follows the FE-I4 layout, and metallization is the IZM derivative of the Ohio State University (OSU) /RD42 prescription. Bump-bonding on 50 μm pitch with Ag-Sb bumps has been already demonstrated on diamond on sizes of the FE-I3 ASIC, and more than thirty FE-I4 assemblies have been flip-chipped up to today, showing excellent noise and threshold performance in the tests. Position resolution studies from testbeams in DESY in 2013 are underway.

Flexible hybrid

Out of two module hybrid solutions under development for the IBL, the solution that features a connector for testing purposes that is cut off when loading an IBL module onto its stave, was chosen. For the DBM, the connector was kept, easing the connection to services. Being outside the tracking acceptance, and shadowed by significant additional material in the SQP, this addition to the material budget should be acceptable. The DBM flexible hybrid was developed by the Bonn group in collaboration with the Genoa group and modified by CERN.

Mechanical mount

This mechanical mount had been designed and fabricated specifically for the DBM. It provides support for integrating 3 DBM modules into a telescope and to attach it rigidly to the cruciform. The preferred material would be carbon fibre. Nevertheless, PEEK as an extremely radiation tolerant material has been chosen as it is dimensionally stable enough for use this application. As 8 of the mounts were needed, 10 were produced by the Toronto group, coordinated with the IBL engineers. The design of a prototype telescope mounting system is shown in figure 5.

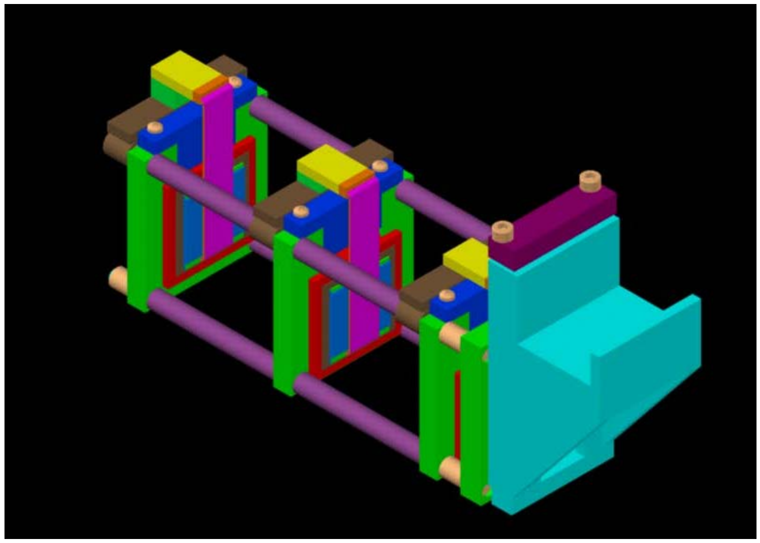


Fig. 5 A prototype 3-module telescope support structure for the DBM.

Services

Services for the DBM must exit the nSQP, and then merge with the rest of IBL services at the Inner detector end plate. The list of services for a DBM telescope (shown in figure 6) for three diamond modules, includes:

- TP 36AWG Cu (clock&command)
- 2 TP 36AWG Cu (high voltage)
- 1 TP 36AWG Cu (detector and environment control)
- 3 TP 28AWG Cu-clad Al (data)
- 8 21AWG Cu-clad Al (low voltage)

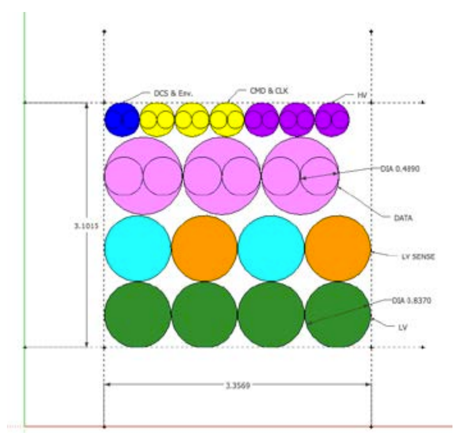


Fig. 6 Packaging of services for a DBM telescope

Note that the services exclude cooling. The sensor operation does not require cooling, and the chip, dissipating around 2 W, is known to operate horizontally on a PCB with convective cooling only. In the DBM the chips are almost vertical, which eases the convective flow. Furthermore, the telescope package is open in-between planes. The mount has been designed to optimize convective flow but also provide cold-plate cooling surfaces nearby to ensure that the DBM is thermally neutral relative to the nSQP/Pixel environment.

Data transmission, power and HV supply, detector & environmental control

Figure 7 shows a preliminary concept for the first patch panel (PP0) that gathers the data from all four telescopes on one side of the DBM. This panel also receives clock/command signals and distributes the low and high voltages necessary to operate the DBM devices. Beyond this patch panel the cable groupings and connectors duplicate the IBL services allowing the remainder of the readout to be an exact copy. In this regard the DBM modules represent two additional half-staves in the 14-stave IBL system allowing us to profit from the IBL spare pool and DAQ architecture.

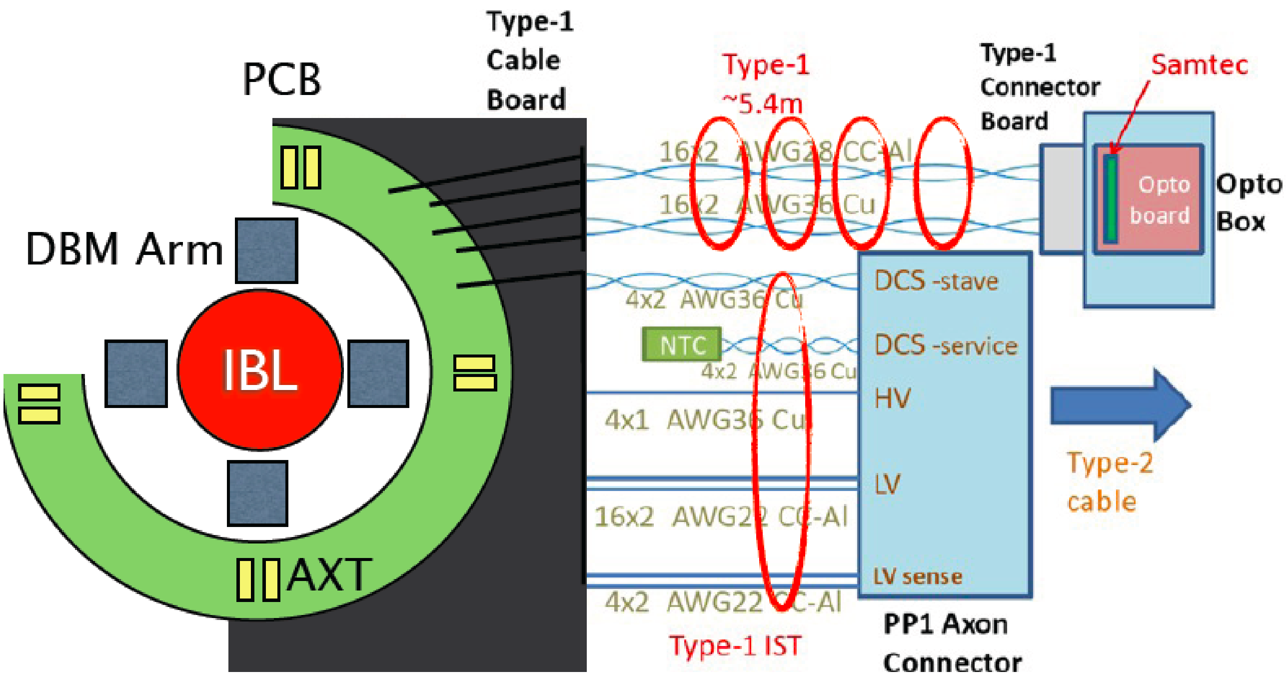


Fig. 7 Layout of the services for one DBM arm . Beyond the right-hand side of this figure the service bundles are identical to a half-stave of the IBL allowing us to service and readout the DBM as two-additional IBL half staves.

Data acquisition

Due to the specific aim of the DBM, DAQ firmware functionality beyond that of the IBL is being explored. Although the DBM uses the same read-out drivers (ROD) as the IBL, the DBM system may have two output branches. One is DBM-specific and is triggered by an unbiased, pseudo-random signal, uniformly sampling all the 3564 LHC bunches (BCID). The ROD will need to contain four counters per DBM module per BCID to record the number of misses, single hits etc. for each un-biased trigger occurrence. Bunch-by-bunch relative luminosity can be deduced from the contents of these counters. The exact content of the counters and eventual grouping of correlated planes of all (or part of) telescopes remain to be determined from simulation, and will depend on the instantaneous luminosity regime. Each module contains 26880 individual pixels, so saturation with charged tracks should never be encountered at any luminosity. In the same data stream, events with one or more hits in each of the three telescope planes are tagged and written to a DBM-specific data stream. These data will be used to reconstruct tracks. The share of multiple track events strongly depends on the number of pp interactions per crossing (μ), so the data transferred to the DBM stream has to be adaptive, selecting multiple track events for μ >~1. The tracks, in turn, can be used to reconstruct the luminous region at the ATLAS IP. For BCIDs, where tracks are too scarce to pin down the beam spot, algorithms used in medical imaging for limited angle tomography should render it possible to still map out the interaction region. The Ohio State and Bonn groups are developing this algorithm together with the Jozef Stefan Institute.

For this ROD branch the primary specification is the frequency at which DBM modules can be polled. The IBL ROD is built to cope with an ATLAS L1 trigger rate of 75 kHz, so this is the minimum DBM can count on. The data transfer out of the FE-I4 has a specification of 160 Mb/s, but has already been shown (on the testbench) to work at 320 Mb/s. Taking 100 bits as the event size from a single I4 DBM module it should, in principle, be possible to poll the modules at rates above 0.5 Mevent/s (at 160 Mb/s) or even in excess of 1 Mevent/s (at 320 Mb/s).

The second DAQ branch is an exact copy of the IBL concept. Upon receiving an ATLAS L1 trigger, DBM data are included in the IBL (or ATLAS-Pixel) event record providing additional information for ATLAS physics events. For this branch, as in any monitoring aspect, the DBM is treated as one of the IBL modules. It is hoped, that both branches will run in the same ROD, with the private DBM stream replacing the calibration stream foreseen for the IBL modules. The Ljubljana group is studying these options.

Off-line software

The full geometry description of DBM will be incorporated into the ATLAS ATHENA simulation and analysis software environment. The Toronto group has already generated a GEANT model (see Figure 8) and has done preliminary DBM acceptance and detector performance studies. Digitization models for the diamond pixels should be provided as soon, based on the summer 2013 test-beam data.

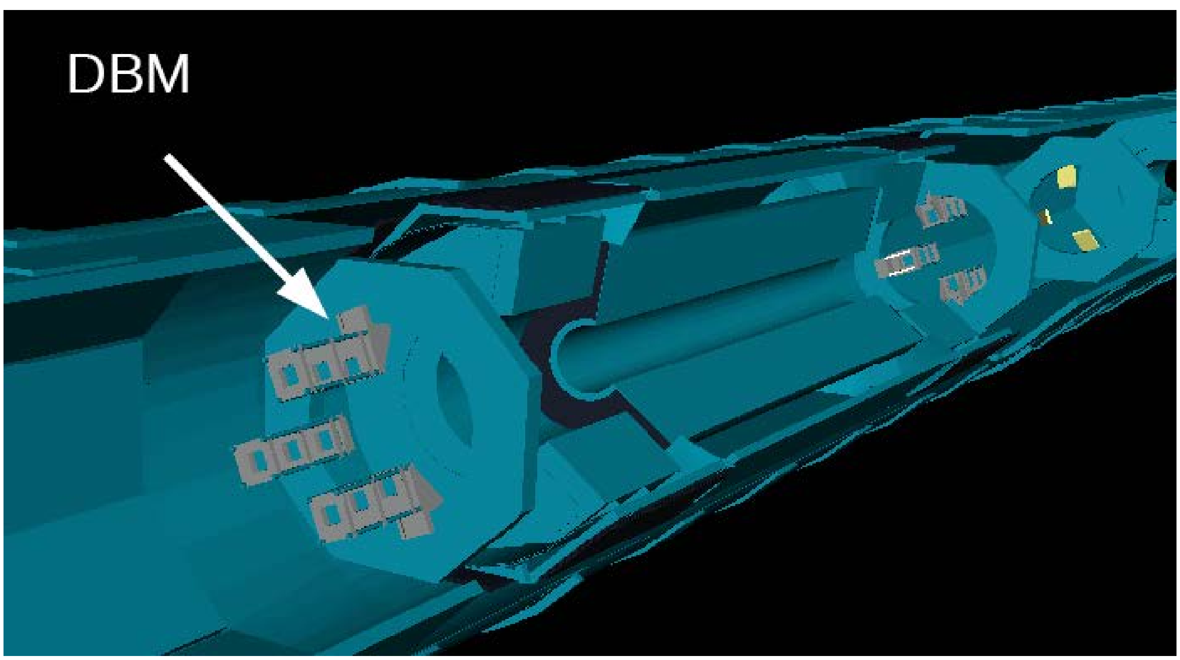


Fig. 8 The GEANT model of the DBM integrated with the existing ATLAS detector. One can see three of the four telescopes

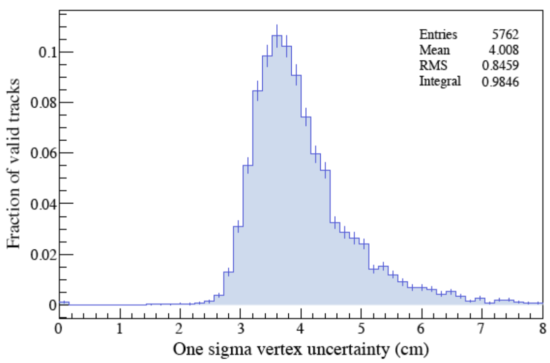
(one removed from each side as part of the 'quarter-cut' visualisation) on each side of the pixel detector.

DBM Anticipated Performance

For reliable figures on performance, Monte Carlo simulation of DBM in the ATHENA framework is a must. However back of the envelope estimates can be provided at this stage. The basic consideration is that while hits in the three modules of a telescope are correlated (and thus provide tracks), hits from different telescopes exhibit little correlation, and can be to first order treated as independent.

Pointing resolution

The first question, addressed with a standalone simulation, was the orientation of the FE-I4 pixels, which have an aspect ratio of 5. While traditional forward trackers privilege a precise measurement of the azimuthal coordinate (ie. segment ϕ with the fine pixel pitch) this is done to optimize the momentum resolution in a solenoidal magnetic field. With only a 10 cm lever arm (in z), a much smaller one in r, and no other tracking detector at these rapidities in ATLAS to extend this lever-arm, the DBM is not able to measure the curvature of charged tracks. Instead the experiment will rely on linear extrapolations back to the IP (or background sources up-stream of ATLAS) and thus will orient the pixels with the fine pitch segmenting r leading to an optimal θ or η resolution. Figure 9 shows the predict z impact parameter resolution for tracks produced in simulation proton collisions (over a range from momentum from below 0.5 GeV up to about 20 GeV). These two alternatives clearly indicate that radial segmentation is optimal.



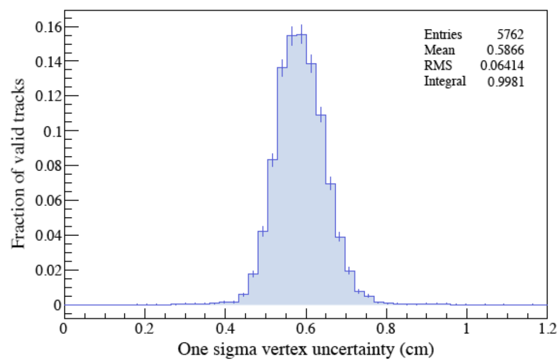


Fig. 9 The predicted extrapolation uncertainty (in *z*) for tracks produced in proton-proton collisions near the ATLAS IP. On the left the pixels are oriented with their fine pitch segmenting ϕ, optimal for momentum resolution permiting a helical extrapolation back to the IP, while on the right the pixel fine pitch segements *r*, optimal for a linear extrapolation, with no attempt made to measure the curvature of the tracks.

Hit and tracking efficiency

Single module efficiency for tracks resulting from minimum bias events (soft interactions) can be scaled from the efficiency of the BCM, as deduced from the van der Meer luminosity scan with 7 TeV proton collisions[7]. The efficiency for any of the four BCM modules read by one of the BCM ROD's to fire in a single 7 TeV pp interaction was quoted at 6.4 %. Both sensors are placed in the forward direction, BCM at η~4.2. Assuming a flat-rapidity distribution and taking into account the 10.8 times larger η - ϕ coverage of the DBM modules would mean that ~0.7 of a track should impact to the total of the eight telescopes for every proton interaction.

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[7] A. Gorišek et al., »Absolute calibration of the ATLAS BCM as a luminosity monitor by bunch-by-bunch analysis of van der Meer scan data«, ATL-COM-LUM-2011-005.

Luminosity determination

Assuming 0.7 tracks in the DBM system and, conservatively, 0.5 MHz polling rate, a quick estimate on luminosity precision can be made. The 350000 hits/s have to be spread over 3564 bunches, yielding ~100 hits/BCID/s for the BCID's that are filled. Thus 1 % statistical precision on relative luminosity can be achieved in about two minutes, a time scale comparable to the basic ATLAS luminosity block. The precision per lumi-block can be increased by sampling only a subset of (e.g. filled) bunches. Of course this estimate is based on one interaction per bunch crossing, whereas from 2013 onwards ATLAS is likely to only be running at $\mu > 20$ so the bunch-by-bunch relative luminosity should be easily measured with a statistical precision of less than 1 % in well under a minute.

If one were limited to multiple track events for luminous region determination, at $\mu=1$ there are still ~more than 15 % of events satisfying this criterion. Crudely estimating the telescope resolution in r-φ at √(2)x14 μm, multiplied by 10 at the vertex yields 200 um, so the centroid of the distribution in x and y can be determined to better than 10 μm per lumi-block. In z the data transfer in the private stream can handle the rate and provide sufficient processing power to unfold the resolution from the shallow angle of ~x20 magnification (from tracks emerging from the ATLAS IP at eta ~ 3.5) of the telescope resolution of ~100 μm to 10 mm must be verified. However, it should be adequate to provide a precise determination of the mean and width of the luminous region along the beam axis.

Radiation damage

The DBM sensors will sit in a radiation intense environment, however they actually sit at a larger radius than IBL modules. Scaling by $1/r^2$ turns the IBL fluence specification of 5×10^{15} n_{eq}/cm^2 into 2×10^{15} n_{eq}/cm^2. Assuming an equivalent fluence of pions, and taking the preliminary pion damage constant from RD42 still yields a CCD in excess of 100 μm, or 3600 e. This damage should not induce significant single MIP efficiency losses at FE-I4 thresholds up to 2000 e.

ANTICIPATED TESTS

In the Fermilab Testbeam Facility the DUTs will be tested using a reference detector to determine exact impact point of each MIP from the beam and to evaluate the resolution, the efficiency and other performance parameters at different running conditions for all detectors studied. In addition, tracking performance tests of multiple DUTs placed in series will be carried out.

I. PERSONNEL AND INSTITUTIONS:

Spokesperson: Andrej Gorisek, J. Stefan Institute

Fermilab Experiment Liaison Officer: Aria Soha

The group members at present are:

	Institution	Country	Collaborator	Rank/Position	Other Commitments
1.1	J. Stefan Institute	Slovenia	Andrej Gorisek	Senior Research Associate	ATLAS
			Marko Zavrtanik	Associate Professor	ATLAS, Piere Auger
			Grygorii Sokhranyi	Doctoral Student	ATLAS
1.2	University of Toronto	Canada	Garrin McGoldrick	Doctoral Student	ATLAS
1.3	CERN	Switzerland	Matevz Cerv	Doctoral Student	ATLAS

II. EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS:

2.1 LOCATION

2.1.1 The beam test(s) will take place in MT6.2B, as shown in Appendix I.
2.1.2 Assembly bench, desk for setting up computers, NIM crate, LV/HV supplies, with internet connection.

2.2 BEAM

2.2.1 BEAM TYPES AND INTENSITIES

Energy of beam: 120 GeV
Particles: protons
Intensity: 4k particles/ 4 sec spill
Beam spot size: 1x2cm^2

The optimal intensity for the experiment would be a 1 kHz rate inside the sensitive area of 1x2cm^2.

2.2.2 BEAM SHARING

The experimenters are willing to share the beam time with users with similar requirements.

The material budget inside the sensitive area is small. 9 layers of silicon readout chips (9x450um), 3 layers of diamond (3x500um), 2 layers of scintillator (2x1mm) – amounting to approximately 0.06X_0.
Outside 2x2cm^2 window there is a substantial amount of Aluminum frames.

2.2.3 RUNNING TIME

The experimenters will need frequent access (once per hour, sometimes for an extended period of up to 1 hour) to the Experiment during the setup period (about 1 day). Then access will be required only in the event of (typically infrequent) failures and changes of Detectors Under Test (DUT) – envisaged 4 times a day. It is expected to take data 24 hours a day.

See section 2.3.3 for total run time and long-term schedule.

2.3 EXPERIMENTAL CONDITIONS

2.3.1 AREA INFRASTRUCTURE

The experiment resides on a support table of ~1m x 0.7m. The weight of all the devices including the table is ~30kg (67 lbs.). In addition, there is a readout computer, NIM crate for logic, 2 LV power supplies, and 1 HV power supply that need to be placed close to the experiment.

The apparatus will sit on the 2B movable table to set the height of the experiment right for the beam.

FTBF will supply a cart for transporting the equipment to and from the experimental area. In addition, a desk or a rack for the electronics equipment is needed next to the setup.

No beam instrumentation is needed.

The Experiment does not use gas.

2.3.2 Electronics and Computing Needs

The experiment uses commercial electronics, such as LV, HV power supplies, NIM modules, NI PXI Express readout system.

See Appendix II for summary of PREP equipment pool needs.

The experimenters will bring a few computers (one to control the PXI Express readout system and another for remote system control). The network link between the beam enclosure and the electronics room is essential.

2.3.3 Description of Tests

6 independent samples will be characterized as DUTs. The samples will be used individually as well as in a telescope formation (3 planes in series). The samples will be operated at different working conditions, e.g. several front-end thresholds will be used:

- 2000e, 1500e, 1100e, possibly 1000e (if achievable - depends on the sample tested)

High voltage will be set to 1000V or to the maximum achievable. A lower reference voltage (e.g. 500V) will also be tested.

The DUTs will be tested at two different incidence angles, a nominal 10-degree angle and at perpendicular incidence.

There are 26880 pixels in each of the detectors. A 2.5M-event run is needed for average statistics of 100 per pixel. High statistics runs are also planned at optimal parameters selected (nominal incidence angle, high voltage and threshold).

Kartel telescope covers ~1/2 of the FE-I4 chip active surface area. As a result, two runs at different positions are needed for a full FEI4 coverage.

	Mon - Tue	Arrival, training course
Day 1	Wed	Obtain Operational Readiness Clearance, deploying equipment
Day 2	Thu	Setting up the experiment
Days 3 – 4	Fri - Sat	Commissioning the reference detector, triggering and readout
Days 5 – 9	Sun – Thu	Taking data with single DUTs
Days 10 – 12	Fri – Sun	Taking data with multiple DUTs – telescopes
Day 13	Mon	Additional day of data taking
Day 14	Tue	Disassembling the setup

2.4 Schedule

The experiment requests two weeks of beam time. One week (preferably the first one) could be in parasitic setting (secondary user) and will be used for setting up the experiment, triggering and readout and for understanding and learning the specifics of FTBF.

At this point in time only one beam run is foreseen.

III. Responsibilities by Institution – Non Fermilab

3.1 J. Stefan Institute, Ljubljana:

- Reference telescope hardware
- Mechanics
- Triggering
- Support

3.2 University of Toronto:

- Synchronized readout (DUT and reference) and offline analysis

3.3 CERN:

- DAQ of the reference telescope and DUT expertise.

IV. Responsibilities by Institution – Fermilab

4.1 Fermilab Accelerator Division:

4.1.1 Use of MTest beamline as outlined in Section II. [0.25 FTE/week]
4.1.2 Maintenance of all existing standard beam line elements (SWICs, loss monitors, etc) instrumentation, controls, clock distribution, and power supplies.
4.1.3 Scalers and beam counter readouts will be made available via ACNET in the MTest control room.
4.1.4 Reasonable access to the equipment in the MTest beamline.
4.1.5 Connection to ACNET console and remote logging should be made available.
4.1.6 The test beam energy and beam line elements will be under the control of the AD Operations Department Main Control Room (MCR). [0.25 FTE/week]
4.1.7 Position and focus of the beam on the experimental devices under test will be under control of MCR. Control of secondary devices that provide these functions may be delegated to the experimenters as long as it does not violate the Shielding Assessment or provide potential for significant equipment damage.
4.1.8 The integrated effect of running this and other SY120 beams will not reduce the neutrino flux by more than an amount set by the office of Program Planning, with the details of scheduling to be worked out between the experimenters and the Office of Program Planning.

4.2 Fermilab Particle Physics Division:

4.2.1 The test-beam efforts in this TSW will make use of the Fermilab Test Beam Facility. Requirements for the beam and user facilities are given in Section II. The Fermilab Particle Physics Division will be responsible for coordinating overall activities in the MTest beam-line, including use of the user beam-line controls, readout of the beam-line detectors, and FTBF computers. [6.5 FTE/week]
4.2.2 A cart or pallet jack for transporting the equipment around the experimental hall.
4.2.3 Conduct a NEPA review of the experiment.
4.2.4 Provide day-to-day ESH&Q support/oversight/review of work and documents as necessary.
4.2.5 Provide safety training as necessary, with assistance from the ESH&Q Section.
4.2.6 Update/create ITNA's for users on the experiment.
4.2.7 Initiate the ESH&Q Operational Readiness Clearance Review and any other required safety reviews.
4.2.8 Assistance setting up a private network between beam enclosure and electronics/control room. [0.2FTE]

4.3 Fermilab Scientific Computing Division

4.3.1 Internet access should be continuously available in the MTest control room.
4.3.2 See Appendix II for summary of PREP equipment pool needs.

4.4 Fermilab ESH&Q Section

4.4.1 Assistance with safety reviews.
4.4.2 Provide safety training, with assistance from PPD, as necessary for experimenters. [0.2 FTE]

V. Summary of Costs

Source of Funds [$K]	Materials & Services	Labor (person-weeks)
Accelerator Division	0	0.5
Particle Physics Division	0.0	6.7
Scientific Computing Division	0	0
ESH&Q Section	0	0.2
Totals Fermilab	$0.0K	7.2
Totals Non-Fermilab	[specify from Section III]	5

VI. General Considerations

6.1 The responsibilities of the Spokesperson and the procedures to be followed by experimenters are found in the Fermilab publication "Procedures for Researchers": (http://www.fnal.gov/directorate/PFX/PFX.pdf). The Spokesperson agrees to those responsibilities and to ensure that the experimenters all follow the described procedures.

6.2 To carry out the experiment a number of Environmental, Safety and Health (ESH&Q) reviews are necessary. This includes creating an Operational Readiness Clearance document in conjunction with the standing Particle Physics Division committee. The Spokesperson will follow those procedures in a timely manner, as well as any other requirements put forth by the Division's Safety Officer.

6.3 The Spokesperson will ensure at least one person is present at the Fermilab Test Beam Facility whenever beam is delivered and that this person is knowledgeable about the experiment's hazards.

6.4 All regulations concerning radioactive sources will be followed. No radioactive sources will be carried onto the site or moved without the approval of the Fermilab ESH&Q section.

6.5 All items in the Fermilab Policy on Computing will be followed by the experimenters. (http://computing.fnal.gov/cd/policy/cpolicy.pdf).

6.6 The Spokesperson will undertake to ensure that no PREP or computing equipment be transferred from the experiment to another use except with the approval of and through the mechanism provided by the Scientific Computing Division management. The Spokesperson also undertakes to ensure no modifications of PREP equipment take place without the knowledge and written consent of the Computing Sector management.

6.7 The experimenters will be responsible for maintaining both the electronics and the computing hardware supplied by them for the experiment. Fermilab will be responsible for repair and maintenance of the Fermilab-supplied electronics listed in Appendix II. Any items for which the experiment requests that Fermilab performs maintenance and repair should appear explicitly in this agreement.

At the completion of the experiment:

6.8 The Spokesperson is responsible for the return of all PREP equipment, computing equipment and non-PREP data acquisition electronics. If the return is not completed after a period of one year after the end of running the Spokesperson will be required to furnish, in writing, an explanation for any non-return.

6.9 The experimenters agree to remove their experimental equipment as the Laboratory requests them to. They agree to remove it expeditiously and in compliance with all ESH&Q requirements, including those related to transportation. All the expenses and personnel for the removal will be borne by the experimenters unless removal requires facilities and personnel not able to be supplied by them, such a rigging, crane operation, etc.

6.10 The experimenters will assist Fermilab with the disposition of any articles left in the offices they occupied.

6.11 An experimenter will be available to report on the test beam effort at a Fermilab All Experimenters' Meeting.

SIGNATURES:

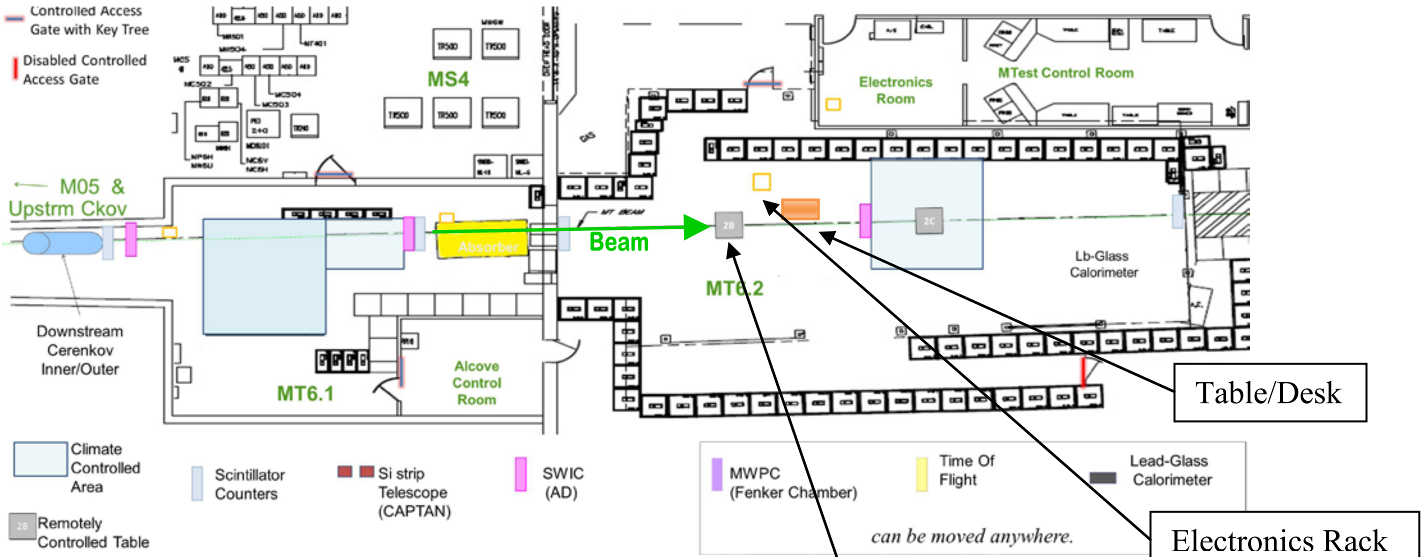
The spokesperson is the official contact and is responsible for forwarding all pertinent information to the rest of the group, arranging for their [training](), and [requesting ORC]() or any other necessary approvals for the experiment to run.
The spokesperson should also make sure the appropriate people (which might be everyone on the experiment) sign up for the [test beam emailing list]().

____ 6/18/ 2014
Dr. Andrej Gorisek, Experiment Spokesperson

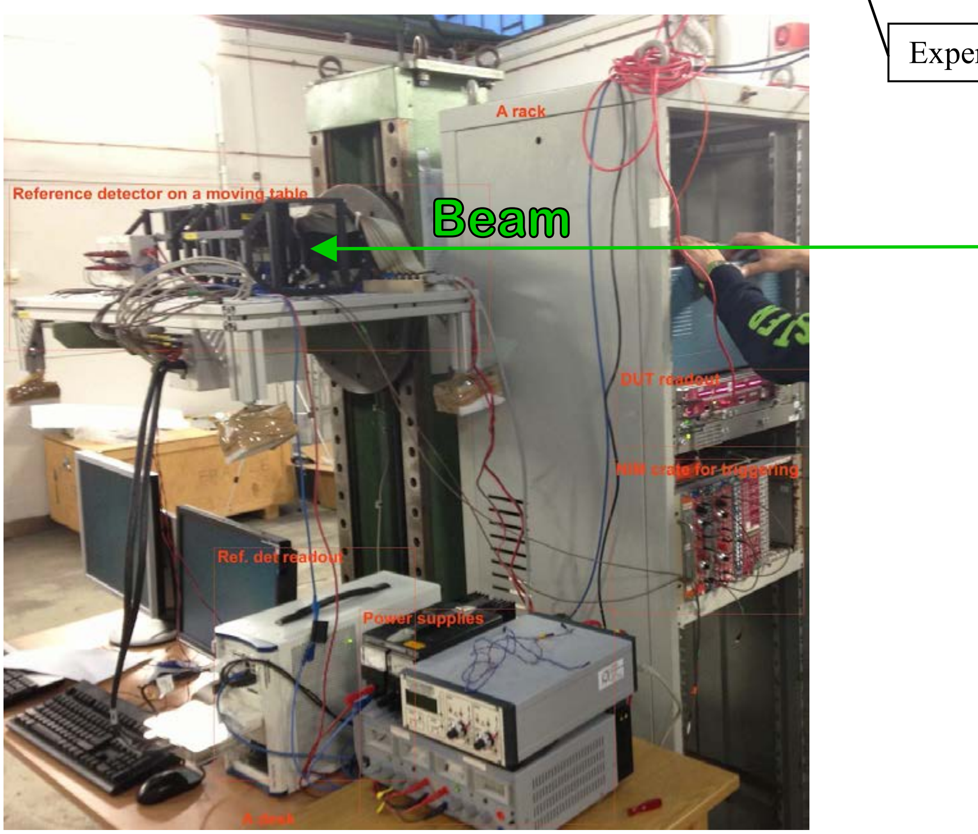
Appendix I: MT6 Area Layout

An optimal solution would be to use the 2B remote-controlled motion table in MT6.2 (the upstream one, outside the climate controlled area). The experimenters would make use of the 2B signal, HV, and Network patch panels.

MTest Areas



The photo below shows the positioning of the experiment in the test beam line in DESY, Germany.



APPENDIX II: EQUIPMENT NEEDS

Provided by experimenters:

1	NIM LVDS2ECL and ECL2LVDS level translator
1	reference detector (2 cages)
1	set of auxiliary data routing boxes
1	set of DUTs + PP0 routing board
1	RCE readout crate + HSIO + adapter card
1	NI PXI readout crate with data adapter and cables
1	PC with LPT port to configure Mimosa26
1	PC terminal

Equipment Pool and PPD items needed for Fermilab test beam, on the first day of setup.

PREP EQUIPMENT POOL:

Quantity	Description
	PHILLIPS: 726 — TRANSLATOR,LVL,TTL/NIM/ECL,150MHZ,NIM
	LRS: 364 — LOGIC,2CH,4-FOLD,MAJORITY,NIM
	LRS: 623B — DISCRIMINATOR,8CH,UPDATE,100MHZ,INHIBIT,NIM
	JOERGER: VS — SCALER,VISUAL,2CH,100MHZ
	2x 2CH LV laboratory supply with output of ~2A or more on each channel
	2CH HV power-supply (1000V @ 20 microA)
	NIM bin+PS (any brand that fits the above modules)

For the LV power-supply we need 4 channels that go up to 5V or more and have a maximum output of 2A or more (with settable max-current limits).
For HV power-supply we need 2 channels and our devices do not exceed few 10 microA. Again we would like to have a PS with settable I-limit. We normally use Iseg SHQ224 (http://www.iseg-hv.com/en/products/product-details/product/16/)

PPD FTBF:

Quantity	Description
1	Cart for moving equipment
1	Remotely Controlled Moving table
10	RG-58 signal cables (various lengths up to 2 m)

APPENDIX III: - HAZARD IDENTIFICATION CHECKLIST

Items for which there is anticipated need have been checked.
See ORC Guidelines for detailed descriptions of categories.

Flammable Gases or Liquids		**Other Gas Emissions**		**Hazardous Chemicals**		**Other Hazardous /Toxic Materials**
Type:		Type:			Cyanide plating materials	List hazardous/toxic materials planned for use in a beam line or experimental enclosure:
Flow rate:		Flow rate:			Hydrofluoric Acid	
Capacity:		Capacity:			Methane	
Radioactive Sources		**Target Materials**			photographic developers	
	Permanent Installation		Beryllium (Be)		PolyChlorinatedBiphenyls	
	Temporary Use		Lithium (Li)		Scintillation Oil	
Type:			Mercury (Hg)		TEA	
Strength:			Lead (Pb)		TMAE	
Lasers			Tungsten (W)		Other: Activated Water?	
	Permanent installation		Uranium (U)			
	Temporary installation		Other:	**Nuclear Materials**		
	Calibration	**Electrical Equipment**		Name:		
	Alignment		Cryo/Electrical devices	Weight:		
Type:			Capacitor Banks	**Mechanical Structures**		
Wattage:		X	High Voltage (50V)		Lifting Devices	
MFR Class:			Exposed Equipment over 50 V		Motion Controllers	
			Non-commercial/Non-PREP		Scaffolding/ Elevated Platforms	
			Modified Commercial/PREP		Other:	
Vacuum Vessels		**Pressure Vessels**		**Cryogenics**		
Inside Diameter:		Inside Diameter:			Beam line magnets	
Operating Pressure:		Operating Pressure:			Analysis magnets	
Window Material:		Window Material:			Target	
Window Thickness:		Window Thickness:			Bubble chamber	

The following people have read this TSW:

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