AIDA
Advanced European Infrastructures for Detectors at Accelerators

Deliverable Report

Experience at LHC and definition of test programme

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AIDA

Advanced European Infrastructures for Detectors at Accelerators
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DELIVERABLE REPORT

EXPERIENCE AT LHC AND DEFINITION OF TEST PROGRAMME

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Abstract:

This work package aims to create a common database of materials and components for the upgrade of the LHC detectors. In order to understand the needs of the detector community a review of the current status of the LHC, CMS and ATLAS upgrades is reported. This summary will serve as a basis for a detailed test plan to be written.

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Delivery Slip

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1. EXECUTIVE SUMMARY

The plans for upgrading ATLAS and CMS have been reviewed and summarised. Radiation tests are advanced for some detector elements such as silicon detectors. Other elements, such as glues necessary to make a practical detector structure, are less well characterised and are expected to form part of a radiation test plan. A detailed radiation test plan will be prepared following further consultation with the community.

A web-accessible database will be made available to the community which will provide references to existing test data and to tests carried out as part of AIDA or related programmes.

2. INTRODUCTION

The construction of detectors for particle physics places demanding and conflicting requirements on designers. This task aims to provide a repository of information that is easily available to the worldwide community engaged in detector construction for the LHC upgrade projects. We also recognise that many other projects have similar requirements, and hope that a shared database will be useful for those communities. Within the LHC community more radiation-hard materials are required for magnet construction for example, and projects such as the European Spallation Source ESS are also interested in such information.

Typically suppliers of electronic components and materials do not consider particle physics as an application and so they do not provide data on the suitability of their products for this particular use. Testing materials and components for suitability in radiation environments is time consuming and costly and so sharing of information is desirable from an economic viewpoint.

This report reviews the status of the LHC detector upgrade plans and progress on qualifying components for these upgrades. Detector systems close to the interaction points receive the highest radiation dose and so in general it is these systems that will require upgrading soonest. This provides opportunities to introduce more up-to-date technology since the technology in CMS and ATLAS is now relatively old. For example the Transition Radiation Tracker (TRT) uses wire chambers which will be superseded by silicon detectors as part of the ATLAS inner tracker upgrade. The Insertable B-Layer (IBL) is another example, where a new layer of detectors will be inserted in the 2013 shutdown to give redundancy for the innermost detectors and as an opportunity to test more modern detectors in a hot environment.

Radiation damage in silicon detector systems manifests itself as an increase in leakage current, a change in the full depletion voltage and finally a decrease in charge collection efficiency and signal to noise ratio. The dose received to date (2011) is sufficient to be measured by an online dose monitoring system [1] and has already altered the leakage current and the depletion voltage of the LHC silicon detectors[2].

3. LHC MACHINE PLANS

Since the plans for experiment upgrades depend on the LHC machine schedule it is useful to review current plans for the LHC machine itself. Note that these plans are subject to change.

Currently the LHC is operating below the nominal energy and luminosity. Significant work is needed to enhance the magnet interconnects and quench protection system and to retrain magnets before the “design” or “nominal” magnet current, and hence nominal beam energy, can be delivered to the experiments.

3.1. PHASE 1

The Phase 1 LHC upgrade is currently planned in two parts, Long Shutdown 1 and Long Shutdown 2. LS1 plans to take the machine to a luminosity of 1e34 $cm^{-2}s^{-1}$ over the period 2013-14. During this period superconducting splices in the LHC machine magnets will be modified and the quench protection system will be completed, to enable stable beams at the design energy and nominal luminosity.

Long Shutdown 2, planned for 2018 intends to increase luminosity to 2e34$cm^{-2}s^{-1}$ with an upgrade of the injector and collimation. Figure 1 summarises the plans.

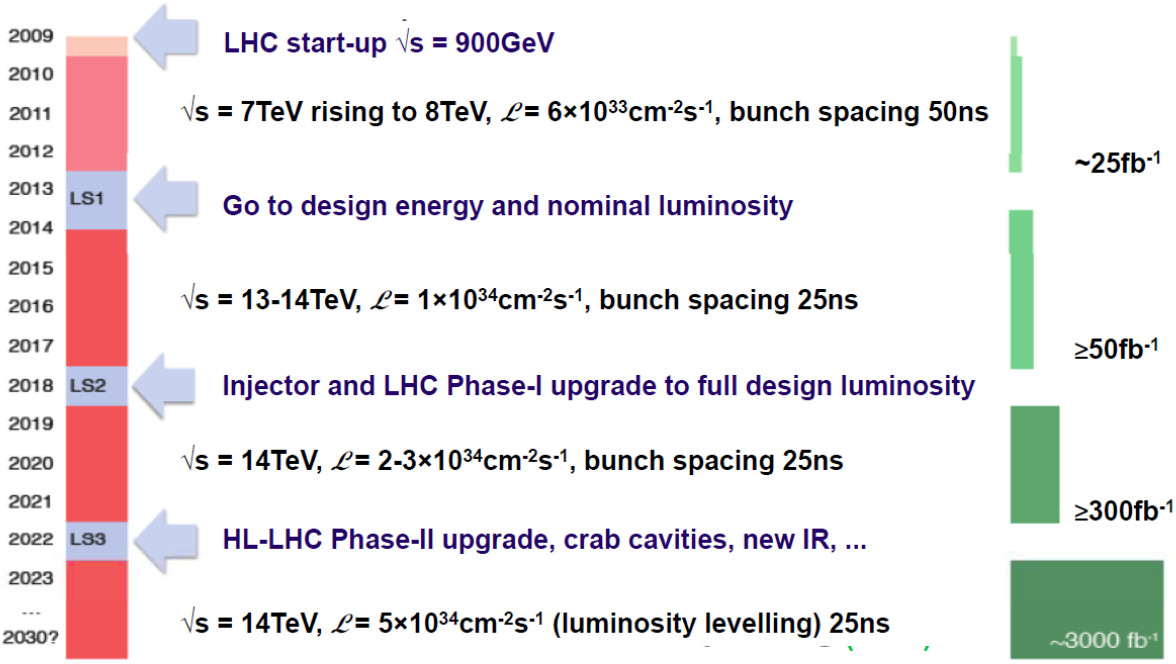

Fig. 1 LHC schedule[3].

3.2. PHASE 2

The Phase 2 “High Luminosity” upgrade in 2022, following Long Shutdown 3, intends to increase luminosity by a factor of ten. The details of this upgrade will develop as it is 11 years away at the time of writing. Schemes including crab cavities and high-field and large aperture inner triplet quadrupoles equipped with Nb3Sn super-conducting cables are being considered [4] [5]. The effects of a factor ten increase in luminosity on detectors are expected to be significant. By this time any systems that are life-limited due to radiation damage will have received their design dose. Even safety factors as large as a factor 10 (on the “nominal LHC”

design) will be nullified by the luminosity upgrade, and so detector groups are planning the upgrades required to cope with the upgrade.
Beyond Phase 2 a High Energy LHC scheme is under development, requiring still higher field magnets.

4. COMMON ISSUES FOR DETECTOR UPGRADES

4.1. MOTIVATION

A detector upgrade is most likely to be motivated by degradation in the detector performance rather than changes in mechanical properties. For silicon detectors such as those in closest proximity to the IP, an integrated luminosity of 700fb^{-1} is the limit for radiation damage[6]. Material degradation to cope with increased dose due to material damage or activation issues; and detector electronics to cope with higher data rates. Sometimes the two changes occur in one component, for example pixel detectors. Beam pipes themselves can be affected, can affect the performance of other systems because of interaction of the beampipe material with particles. So for example stainless steel materials are replaced with beryllium to reduce radiation background.

A detector upgrade is also an opportunity to use new materials and reduce the material budget in radiation lengths used in the inner tracker which degrades the calorimeter performance for electron and photon energy measurement.

From a detector design perspective the HL upgrade presents challenges because this is a factor 10 greater than the detectors were designed for. Issues such as pile-up and random triggering of detectors become more of an issue. From a materials perspective, absorbed doses will also be higher and safety factors built into designs will probably be exceeded if no changes were made. The high luminosity also leads to high background radiation in experiment caverns, and so detectors far away from the interaction point, that were designed to cope only with a low dose, may be expected to be affected.

4.2. PREDICTION AND MEASUREMENT OF RADIATION DOSE

Issues of radiation doses, shielding and background have been estimated and the damage mechanisms on the inner detector systems comprehensively reviewed[7] .

Detector systems have purpose-built systems for measuring the radiation dose received. Excellent agreement between simulated and received dose have been reported[1].This gives confidence to the models used for predicting radiation levels in upgrade scenarios. As of the end of 2011 a dose of 450Gy and 8x10^{11} 1MeV n-eq fluence had been recorded, with an integrated luminosity of 3.4fb^{-1}.

Since the characteristics of silicon detectors change due to radiation, opportunistic measurements can be made. For example the ATLAS pixel detectors use the leakage current in the high voltage delivery system to measure integrated luminosity and reasonable agreement has been found between expected and actual leakage current in operation[8] .

Radiation levels predicted for the ATLAS upgrade are listed in Table 1 below[9]. In general levels increase by an order of magnitude owing to an order of magnitude increase in luminosity.

Table 1 Radiation levels predicted for the ATLAS upgrade

Current detector	**Upgraded detector (Phase II)**
Pixel (3 layers+ 2x3 discs) $5<R<12.3$ cm 10^{15} neq/cm^2	Pixel (4 layers + 2x6 discs) $3.7 < R < 20.9$ cm 2.2×10^{16} neq /cm^2
SCT (4 layers+2x9 discs) $30<R<51.4$cm 2×10^{14} neq/cm^2	Short Strip (2.4 cm): 3 layers $38 < R < 62$ cm 1.2×10^{15} neq /cm^2
TRT (drift tube system) barrel+2 endcaps $55<R<108$cm 3×10^{13} neq/cm^2	Long Strip (4.8 cm): 2 layers + 2x5 discs $74 < R < 100$ cm 5.6×10^{14} neq /cm^2

5. ATLAS UPGRADES

The ATLAS Inner detector will be adversely affected by radiation damage because it is closest to the interaction point. The complete inner detector will be replaced. Figure 2 [10] gives an overview of the inner detector.

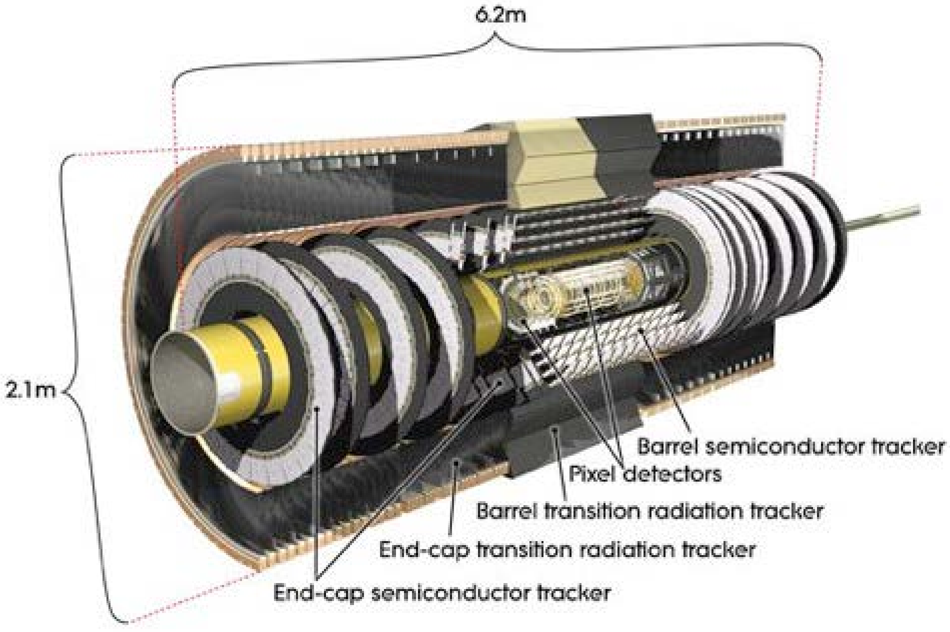

Table 2 gives an overview of the upgrades planned to the ATLAS detector [10].

Table 2

System	**Existing technology or material used**	**Proposed technology or materials**	**Advantages**	**Upgrade Phase** **LS1=Phase 0, 2013** **LS2=Phase 1, 2018** **LS3=Phase 2, 2022 or HL-LHC**	**Reference**	**Rad. test ref**
Beampipe	Beryllium (central part) Stainless steel (rest)	Aluminium Later all-Be	Reduction in background Reduction in activation	0	[11]	
Tracker detectors	Silicon	Thin silicon 3D Diamond p-type sensors	Replacement due to radiation damage and limitations due to high rates	IBL: 0 New pixel: 1 New tracker: 2	[11][3]	[12] [13] Hammamatsu sensors to 10e15 1MeV eg fluence PASSED
Tracker mechanical structure	Carbon-fibre with cyanate ester matrix	Carbon-fibre polymer composite		2		
Polymers and glues for fabrication of tracker	Epoxy	Epoxy, silicone	Rad-hardness. Thermal conductivity.	2		Schonbacher, Tavlet summary reports[14]
TRT	Drift tubes	Silicon Gridpixel proposal	Occupancy High Speed-suitable for level 1 trigger	2	[15] [16]	
Diamond beam monitor			Fast monitoring of beam in high rate environment		[6]	
Muon system		Increased neutron shielding	Reduce halo?	0 and 2		
		Muon small wheel update	Higher resolution, directionality	1	[3]	

			and rate			
Diffractive detector			New detector 210m from IP			
Trigger		Level 1 and 2 upgrade	Higher granularity, speed	1	[3]	
Hadronic Endcap Calorimeter	Electronics and HV protection resistors designed for 1000fb-1	Add mini-FCAL or complete replacement if required	Due to overheating at high lumi		[6][3]	
Tile calorimeter electronics	Plastic scintillator, PMT, up to 2TeV (10 bit DAQ)	COTS. 12 bit DAQ. Survived radiation test (ANL APS, 300KRad)	Rad-hardness, improved trigger, reliability, resolution, reduce power consumption	2	[17]	
E-M liquid argon calorimeter electronics	ASICs (some now obsolete)	SiGe or CMOS front end. COTS ADC Rad-hard optical link	Rad-hardness. Update electronics.	2	[18]	

6. CMS UPGRADES

Table 3 gives an overview of the upgrades planned for CMS. Unless otherwise given, the information source is the CMS Upgrade TDR [19].

Table 3.

System	**Existing technology or material used**	**Proposed technology or materials**	**Advantages**	**Upgrade Phase** **LS1=Phase 0, 2013** **LS2=Phase 1, 2018** **LS3=Phase 2, 2022 or HL-LHC**	**Reference**
Pixel	BPIX and FPIX	4-layer barrel, 3-disk	Higher channel count. Redundancy. Trigger capability	1	[19] [20]
Pixel support		Ultra-lightweight, CO2 cooling, new readout chip, links and DC-DC convertors	Can cope with lumi above 1e34cm^{-2}s^{-1}		
Trigger and DAQ	VME	uTCA	Handle higher data rates and event sizes		
ECAL crystals	Lead Tungstate	Cerium Fluoride + heavy absorber sandwich calorimeter	far more radiation resistant	LS3	[19, 21]
ECAL crystals	Lead Tungstate	LYSo + heavy absorber sandwich calorimeter	slightly more radiation resistant	LS3	[19] [22] [23]
HCAL front end electronics	HPDs and PMTs	SiPM, thinner PMTs			
Muon detector	Cathode strip Chambers CSC (wire chambers) in end cap				
	Barrel muon	FPGA	BTIM early	0 (or	[19]

	drift tubes, DT (wire chambers) in barrel *BTIM hybrid issues*		failures	earlier?)	(data on FPGA proton irrad; ACTEL better than XILINX)
	Endcap RPC resistive plate chambers	RE4 (4th layer)	Improved trigger efficiency		
Back-end electronics in USC55	On-detector minicrates	Optical fibre links, relocate critical electronics (ROS/TSC)	Less hostile, more accessible environment	0	
Beam monitoring		Pixel luminosity telescope	new		
	Beam scintillation counters		Replacement due to radiation		
	BC1F diamond beam monitor		Replacement due to radiation	2	

7. DISCUSSION

It is planned to replace the detectors closest to the interaction points in both CMS and ATLAS. Parts of other systems further from the IP will also be upgraded in the light of experience, for example on-detector electronics.

A programme of irradiation and development of silicon detectors has been carried out over many years[24]. Hamamatsu sensors have been irradiated to 10^{15} cm^{-2} neq fluence for example [12][13]. Silicon detector components are however only one part of a tracker system. Polymers such as epoxy and cyanate esters are used in composite support structures as a matrix in “carbon fibre” or “CFRP” materials. Generally such materials start to degrade at around 1MGy dose[14], which is at or below the levels expected at the inner tracker upgrade. Other polymers are also proposed, for example thermally conductive epoxies such as Hysol 9396 with boron nitride, to bond cooling tubes into the ATLAS tracker stave structure [25]. Since these structures must be assembled close to ambient temperature, epoxy formulation choices are limited to those that tend to be less radiation hard compared to the skins, which can be manufactured in heated presses. These polymers can be expected to be the weak link in terms of radiation tolerance but are critical parts for successful operation of an upgraded detector system.

8. CONCLUSION

The plans for upgrading ATLAS and CMS have been reviewed and summarised. Radiation tests are advanced for some detector elements such as silicon detectors. Other elements, such as glues necessary to make a practical detector structure, are less well characterised and are expected to form part of a radiation test plan. A detailed radiation test plan will be prepared following further consultation with the community.

A web-accessible database will be made available to the community which will provide references to existing test data and to tests carried out as part of AIDA or related programmes. The design of this database is considered an important step and this work has started by drafting a specification. It is expected that the database will be hosted on mirrored servers at STFC-RAL to provide a robust service with access at any time. Read-only access would be possible for all, and write access for a restricted number of users to enter data. The working group has agreed a list of fields and made contacts within the community where irradiation work is already taking place.

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