

Beam Conditions and Radiation Monitoring Concerns of the Experiments

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Radiation Monitoring: Objectives

- Experiments designed to operate for 10 years of LHC running

- Equipment failure due to radiation damage is not expected.

- Exceptions:** Components overlooked in our radiation hardness qualification program

- Note: Strict QA for stuff close to beam; more relaxed further out

- Radiation Monitoring Concerns

- Understand the radiation field in the experimental cavern

- Understand bkgds that could compromise physics performance of expt

- Identify any potential shield holes

- Bench mark the radiation field simulations, including activation predictions

- Assessment of the long term functionality of detector components as function of machine operation and machine related backgrounds

- What are our SEU rates:

- How often will we need to reset and resynchronize different systems?

- Susceptibility to COTS components?

Radiation levels - Example: LHCb

MARS '97(IHEP): LHC-B absorbed dose levels map

Radiation levels in detectors and cavern simulated with Fluka and Mars (crosschecked)

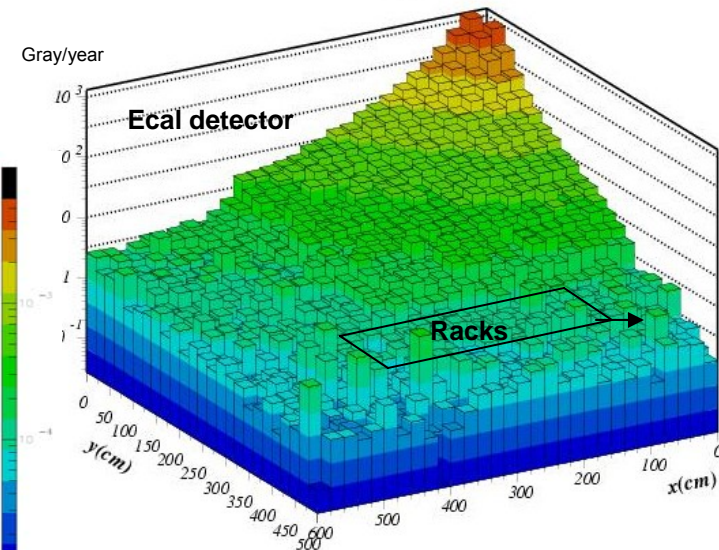
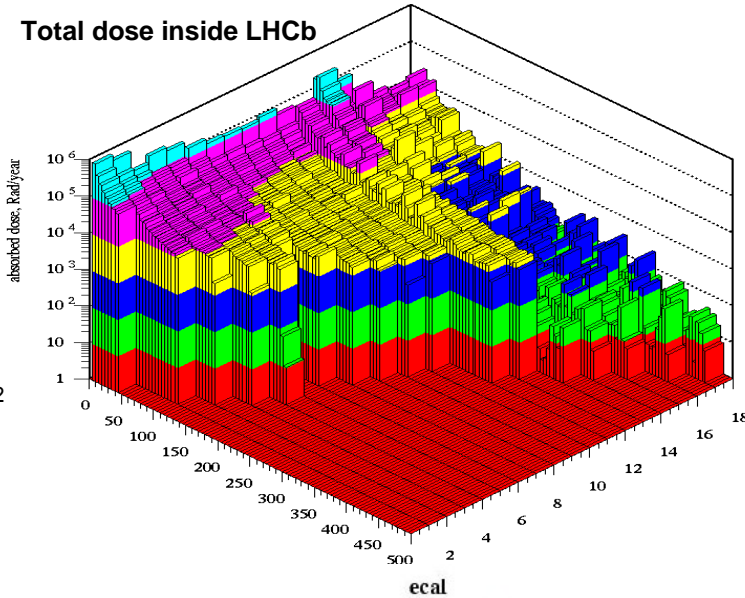
Simulation safety factor: 2 (rather low)

- Total Ionizing Dose,
- 1Mev neutrons
- Hadrons above 20MeV (SEU, SEL, SEB)

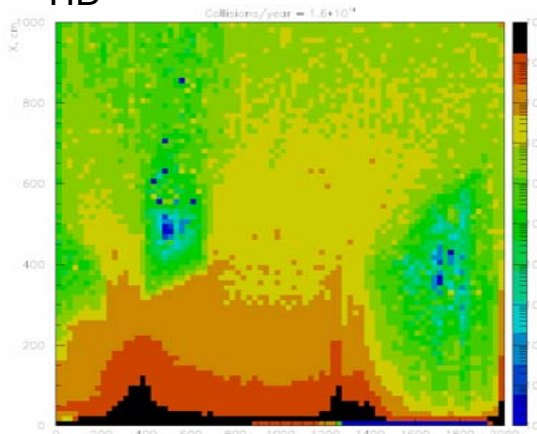
Clearly defined radiation hardness requirements for 10 years operation for all locations with electronics

web page: <http://lhcb-background.web.cern.ch/lhcb-background/Radiation/SUMtable2.htm>

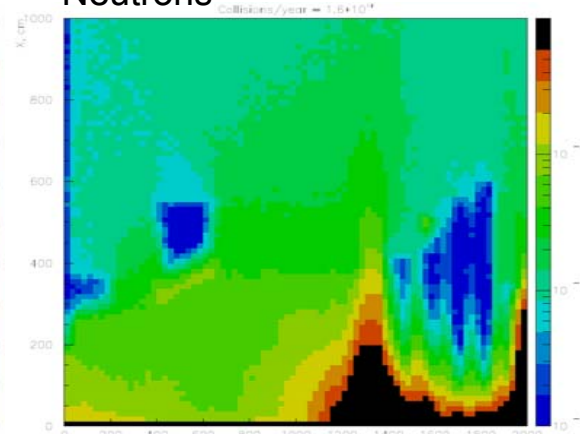
Location	TID/rad	Neu/cm ²	Hadrons/cm ²
Velo & Pileup	10M	10 ¹⁴	10 ¹⁴
IT & Muon	1M	10 ¹³	10 ¹³
RICH1 front-end.	25k	3*10 ¹²	3*10 ¹¹
Muon crates	10k	10 ¹²	5*10 ¹⁰
Cal crates	4k	10 ¹²	3*10 ¹⁰
Bunker	1k	10 ¹²	3*10 ¹⁰
Balcony	650	3*10 ¹¹	6*10 ⁹



TID

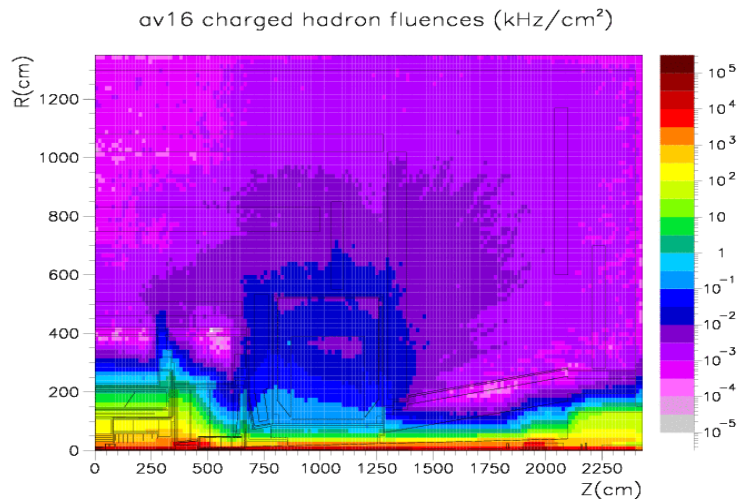
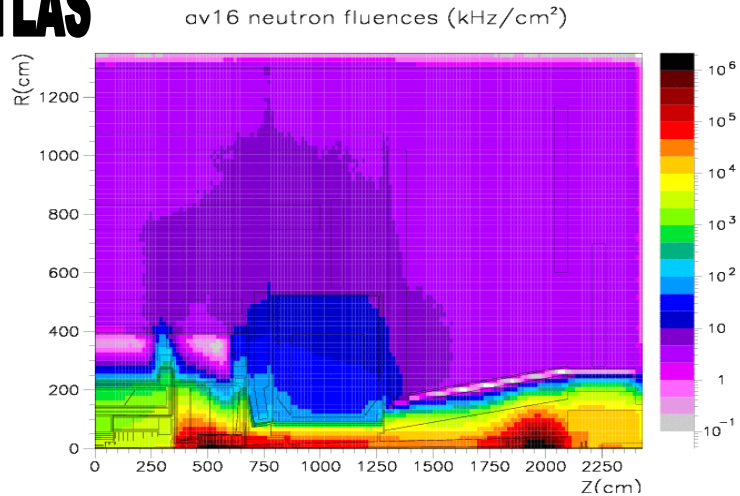


Neutrons

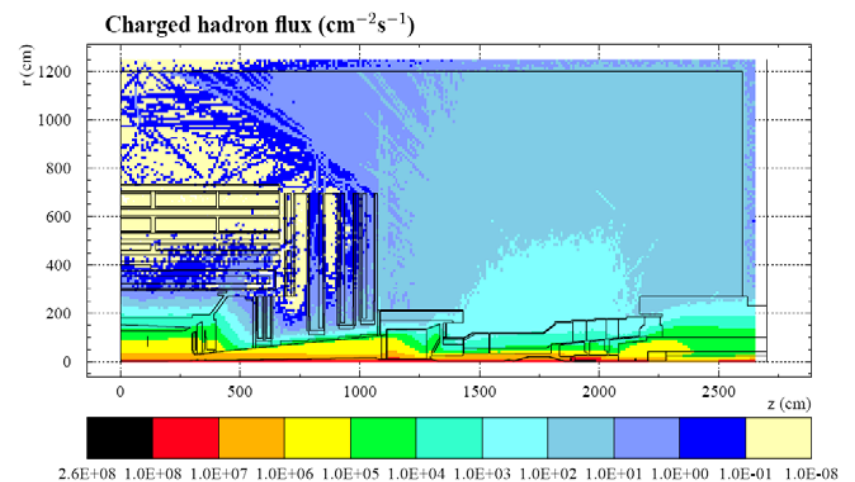
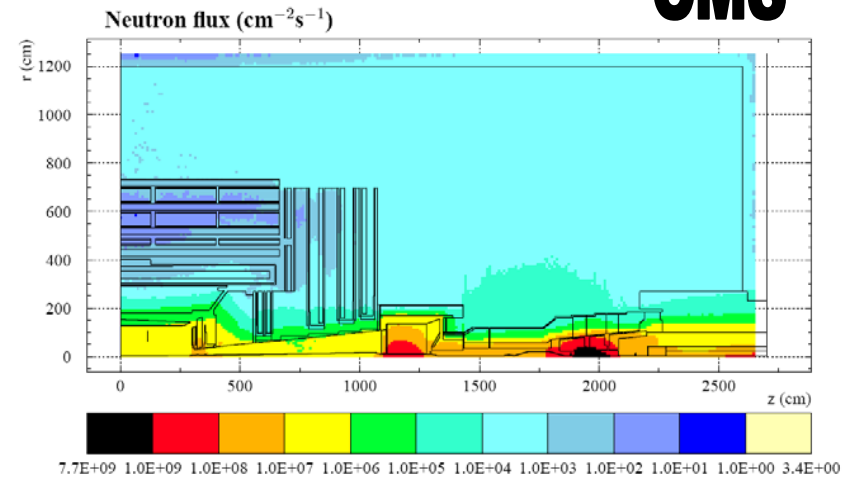


More Radiation Levels

ATLAS

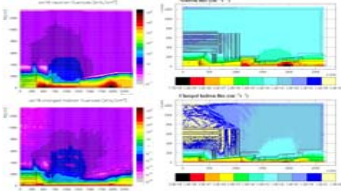


CMS



ATLAS and CMS: Radiation levels in the experimental caverns < 1 Gy/year
Radiation Levels at cavern wall = radiation level in ARC under Cryostat

Understanding the Radiation Field



We have designed our experiments, their services and the shielding on the basis of detailed simulations

State of the art: Intrinsic uncertainty of simulations (FLUKA, MARS) ~30%
Realistic uncertainty: up to 200% or 300%

- Difference between as simulated and as built detector
 - Issues of material composition and detector geometry
 - Integrity of shielding
- Machine related background
 - Machine halo from LSS, showers from limiting apertures near IP
 - Beam gas interactions
 - eg inelastic beam-gas losses
 - Quality of vacuum
 - eg Vacuum levels: 10^{11} -> 10^9 Torr => factor of 100 in radiation source term at IP

⇒ Use first year of running to validate simulations and measure particle flux and dose map in and around IPs

Radiation Monitoring Equipment

■ RADMON Units

Measures

- Dose, dose rate using RadFETs
- Hadron ($E > 20$ MeV) flux and fluence, SEU rate via SRAM
- 1 MeV equiv neutron fluence via pin diodes ($\alpha > 100$ keV fluence)

Maximum readout rate = 50Hz

Two versions

- **Standard** LHC model (T. Wijnands and C. Pignard).
 - Used around the ring, outside detector volume
- **Compact** version (ATLAS: G. Kramberger et al)
 - Used for monitoring inside the detector
 - Includes thermal neutron monitoring



Used for Online benchmark points for verification of simulations

■ Passive Dosimeters

CERN standard dosimeters

- TLDs, RPLs, Alanine
- Typically $O(100)$ units per experiment

Provide detailed radiation mapping after Pilot run



■ RAMSES Monitors: Provides cross check for long term dose and activation maps

Radiation Field mapping

Example: CDF radiation field from TLD measurements + model

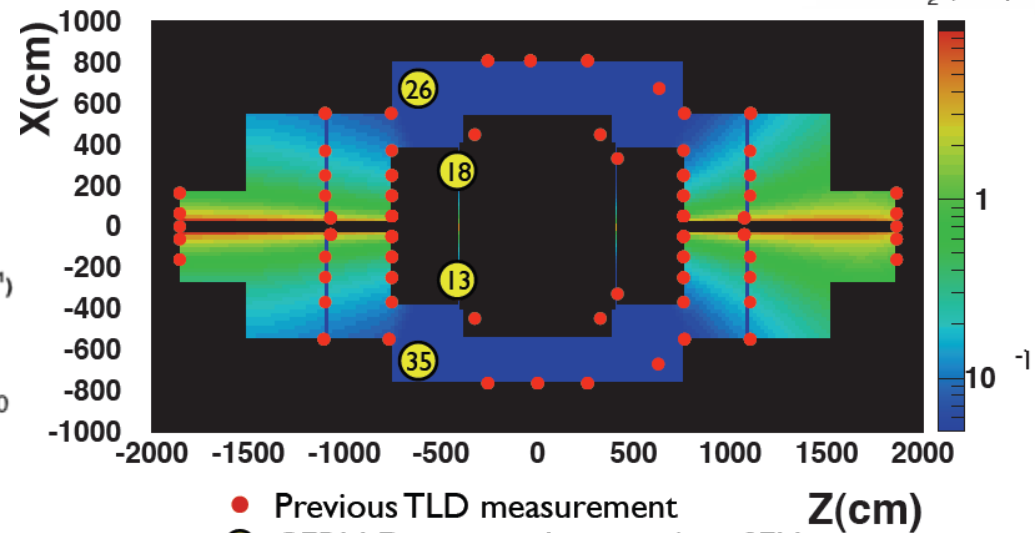
R. Tesarek, CDF

$$\text{Dose} = \frac{A}{r^\alpha}$$

$\alpha \sim 1.5$; $|z| < 100\text{cm}$

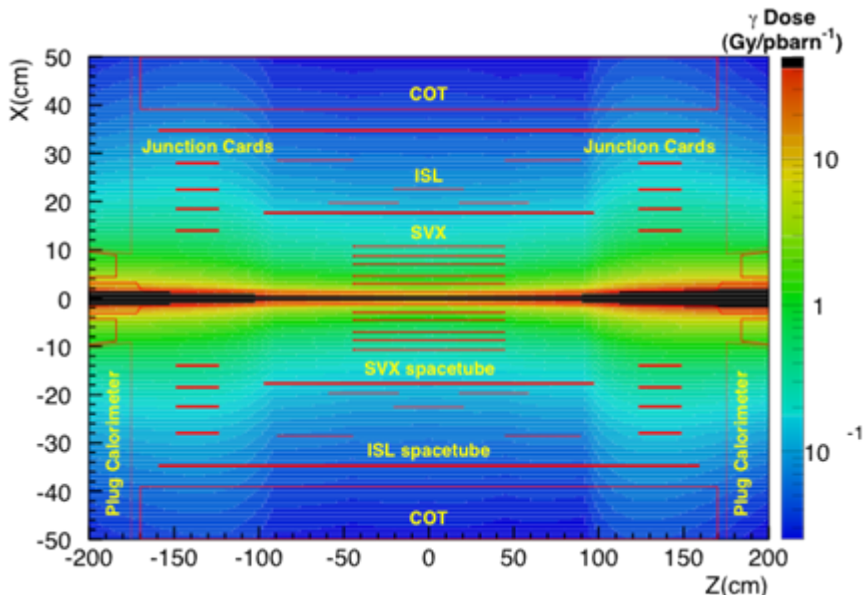
CDF Radiation Field (ionizing radiation)

Rdose₂ (rad/pb⁻¹)



Exposure Period: 27 April - 28 September 2005

Online RADMON used to understand SEU effects and correlate with beam operations
Example: Power supplies trips in CDF cavern from halo spray at injection



Beam Conditions Monitoring: Overview

- Steady state LHC running in good conditions will not create any problems

Damage scenarios for expts unlikely as machine protection and collimation system “absolutely robust”. **(primary + secondary + tertiary)**

- However:
 - Basic time scale of LHC = 1 turn (89us)
 - Basic time scale of the experiments = collision by collision
 - => Need for fast (sub-turn) monitoring within the experiments

- => Experiments must recognize and act on
 - Transient or anomalous beam conditions
 - Fast monitoring to identify potential damage situations for sub-detectors
 - Stable beam conditions in machine, but unhealthy localized machine related bkgds
 - LHC Beam Monitoring does not extend into the experimental regions

- **Questions:**
 - What are the Expts susceptible to?
 - What monitoring feedback should go to LHC operations?
 - Are there adverse beam conditions that only the Experiments can detect?
 - What beam loss scenarios have not been thought of?

Beam losses and time constant

min ... hours

Very slow losses (lifetime 0.2 hours or more)

Cleaning system to maximize losses in cleaning sections

sec

Slow beam losses (several seconds – 0.2 hours)

Fast beam losses (5 ms – several seconds)

Very fast losses (some turns to some milliseconds)

At all times collimators should limit the aperture

– particles lost on collimators

Hardware surveillance and beam monitoring, detecting failure and extracting the beams into beam dump block

ms

Online Monitoring by Experiments

μ s

Ultra fast losses, mainly kicker magnets (single turn or less)

- **Single turn failures at injection**
- **Single turn failures at extraction**
- **Single turn failures with stored beams**

Passive protection with beam absorbers

Compliments LHC monitoring BLM, BPM etc

Concerns from around the ring

■ ALICE and LHCb

- Concern:** Problems at injection
 - No TAS but both have installed protective shielding
- LHCb VELO inner tracker at risk.
 - VELO motion control fails, driven into beam
 - Damage at injection: VELO kept open during injection
- Machine induced backgrounds from low β^* IPs
 - ie coming from IP1

■ CMS

- Concern:** CMS=limiting aperture between IP3 and IP7
- Concern:** Problems from the beam dump at Pt 6
 - Requires TCDQ and TCT to be in place

■ ATLAS

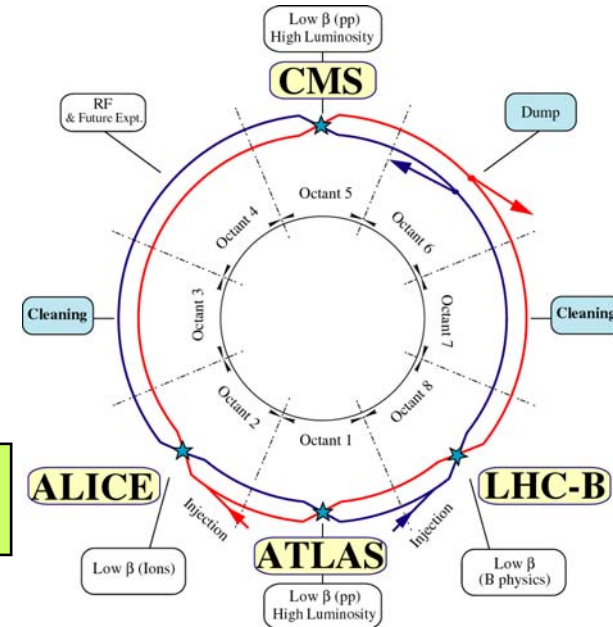
- No real issues due to location

■ Background Influence from other expts

- Pt1 and Pt5 conditions dominate and must be balanced.
- Fast BCM at both IPs for complimentary monitoring

■ Notes

- Cleaning = multi-turn process => expect some degree of transient bkgd



Must assess conditions even if losses on collimation system at acceptable level

Concerns in the Experiments

■ Beam-halo

- **Protection of Inner triplets** => experimental IPs should be screened
 - Halo muons: Old normal rate estimated at **below a few per $\text{cm}^{-2} \text{s}^{-1}$**
 - Showering of TCT or TAS into expt

- **Concern:** transient or extended showers from outside

- Induce voltage/current spikes that damage front end electronics ($0.25\mu\text{m}$ chips)
- Swamp of Level 1 trigger
- Risk of distortion of energy flow in event reconstruction

- **Worst case: Unsynchronized beam abort**

- 10^8 x normal flux at $z=2\text{m}$, $r=4\text{cm}$. **Simply must survive it.** (Especially CMS)
- ATLAS and CMS tracker units tested under unsynch beam abort conditions
Result: No damage (however statistic of tested modules is low)

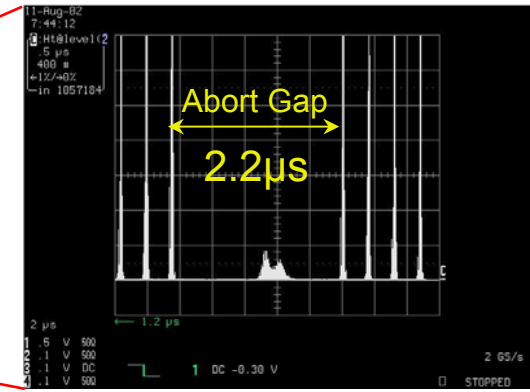
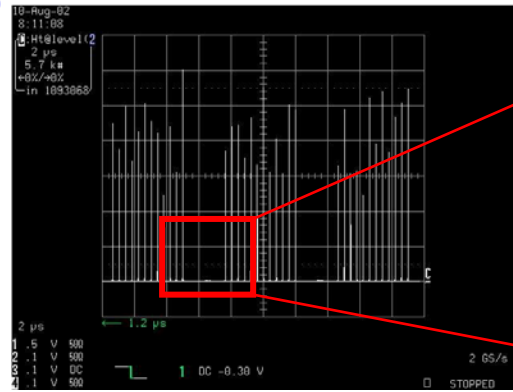
■ Satellite bunches

- Not obviously reconstructable in early running
- Can distort energy flow or give false missing E_T signature
- Fast BCM to complement LHC beam pickup and SPS monitoring of satellite bunch population

■ Filling of the abort gap

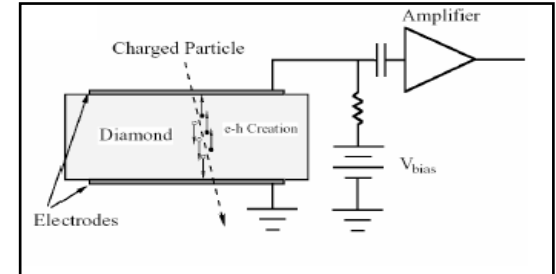
- localized or DC

Example
CDF monitoring of
Tevatron abort gap



Beam Conditions Monitoring: Observations

- ATLAS, ALICE, CMS, LHCb all to install Beam Conditions Monitors (BCM)
 - Mandate:
 - Protect experiment against damage from fast onset of adverse beam conditions
 - Specifically provide fast acting protection for the inner tracker and pixel detector systems against flux bursts and beam instabilities.
 - Technology:
 - Synthetic diamond sensor adopted as BCM units by the expts.
 - Measure ionizing radiation close to beam axis
 - Implementation differs between the experiments
 - Bunch by bunch readout with MIP sensitivity:
 - Diamond leakage current monitoring:
 - Timescale: $\sim 1\mu\text{s}$
 - Asynchronous readout of BCM units
 - Implications:
 - BCM to input directly into Beam Interlock Controller (BIC)
 - BCM thresholds have to be thoroughly commissioned



BCM systems must be in place on Day 1 (like the BLMs)

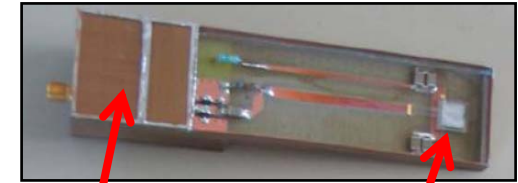
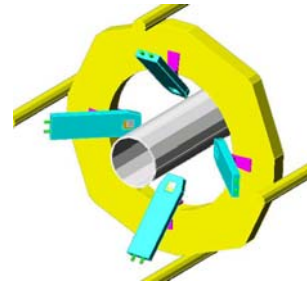
ATLAS Beam Conditions Monitor

■ Location

- Mounted on Pixel support structure at $z = \pm 183.8$ cm and $r = 5.5$ cm
- 4 stations/side

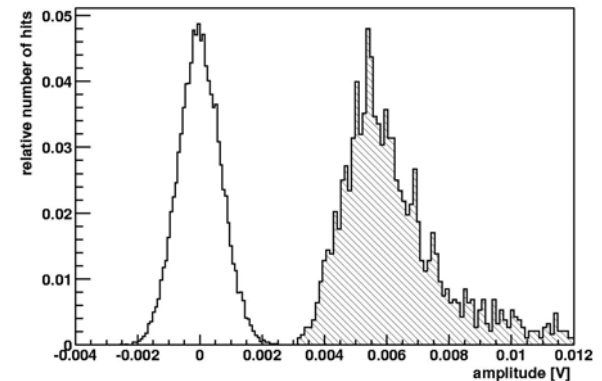
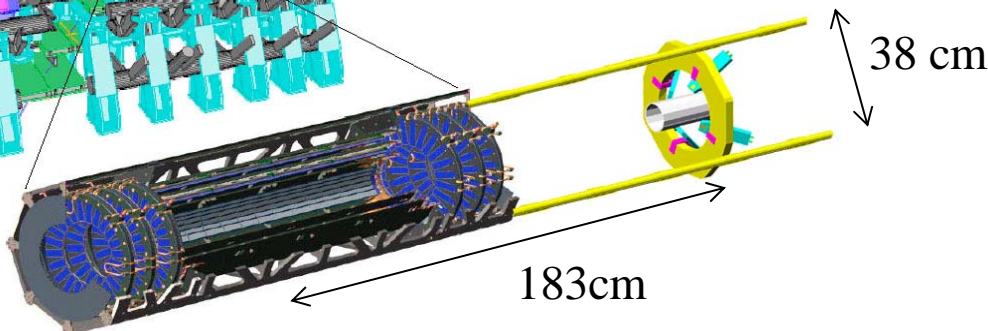
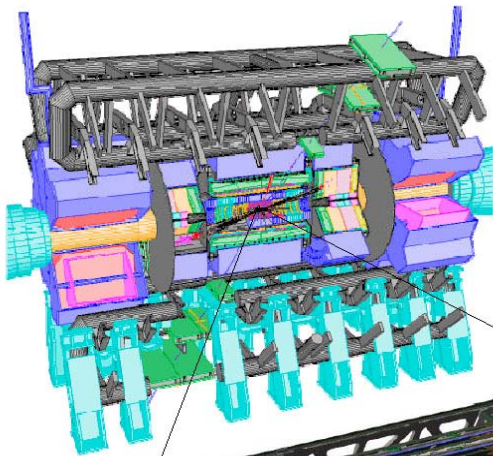
■ Each station:

- 1cm² Polycrystalline Diamond detector + Front-end analog readout



Front end analog electronics

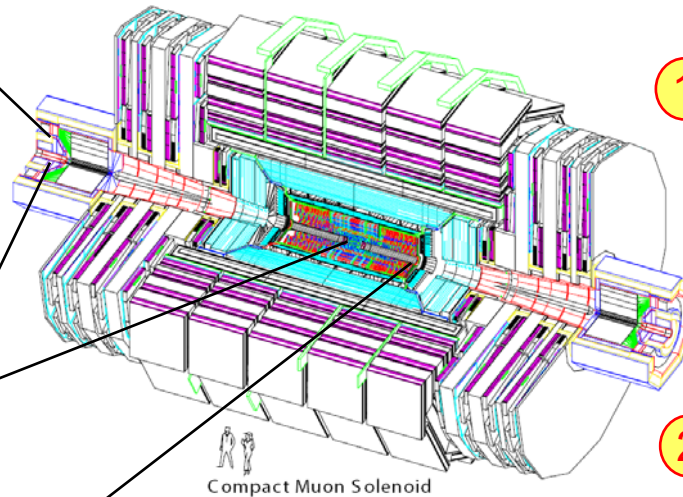
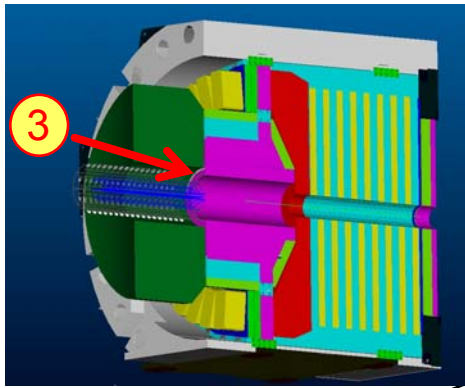
Diamond Sensor



MIP signal distribution:
 $\text{SNR}_{\text{mp}} \sim 10:1$
Single MIP time response:
Rise-time: ~ 1.5 ns
Pulse width : ~ 3 ns

Can monitor on bunch-by-bunch basis

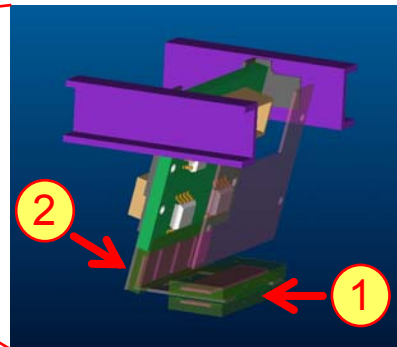
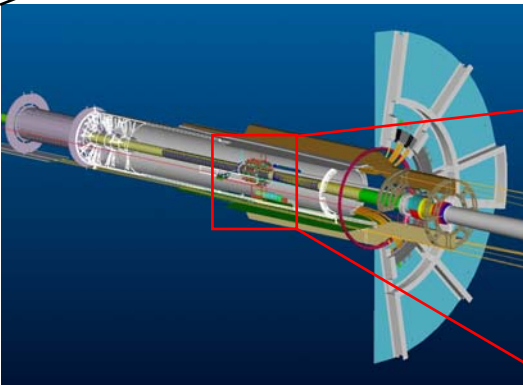
CMS Beam Conditions Monitor



CMS BCM Units

- ① **Leakage current monitor**
Location: $z=\pm 1.9\text{m}$, $r=4.5\text{cm}$
4 stations in θ
Sensor: 1cm^2 PCVD Diamond
Readout: 10kHz

- ② **Fast BCM unit**
Location: $z=\pm 1.9\text{m}$, $r=4.3\text{cm}$
4 stations in θ
Sensor: Single Crystal Diamond
Electronics: Analog+ optical
Readout: bunch by bunch



- ③ **Leakage current monitor**
Location: $z=\pm 14.4\text{m}$, $r=29\text{cm}$
8 stations in θ
Sensor: 1cm^2 PCVD Diamond
Readout: 10kHz
Sensors shielded from IP

2 Sensor Locations, 2 Monitoring Timescales

What BCM units are expected to do

- Measure flux at locations close to the beam axis

- ATLAS

- Beam monitoring on a bunch-by-bunch basis
- Detect first collision when they happen
 - Possible to implement fast OR for four stations on one side
- Discriminate collisions from bkgd by gated coincidences at $\Delta t=0$ (collisions) and $\Delta t=12\text{ns}$ (bkgd)

- CMS

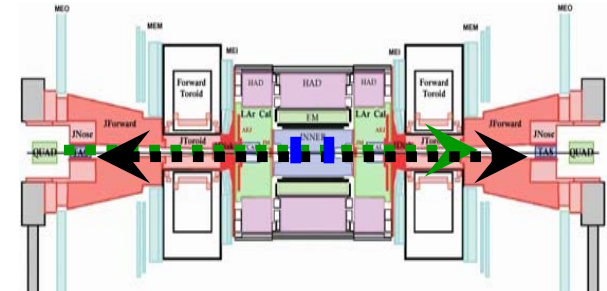
- Monitor diamond leakage current on $1\mu\text{s}$ time scale. Beam +Abort gap monitoring
- Fast monitoring on bunch by bunch basis
- Discriminate collisions from bkgd by sensors at $z=14\text{m}$ that are shielded from the IP

- Take warning/alarm/abort decisions on the sub-orbit to 1ms time scale

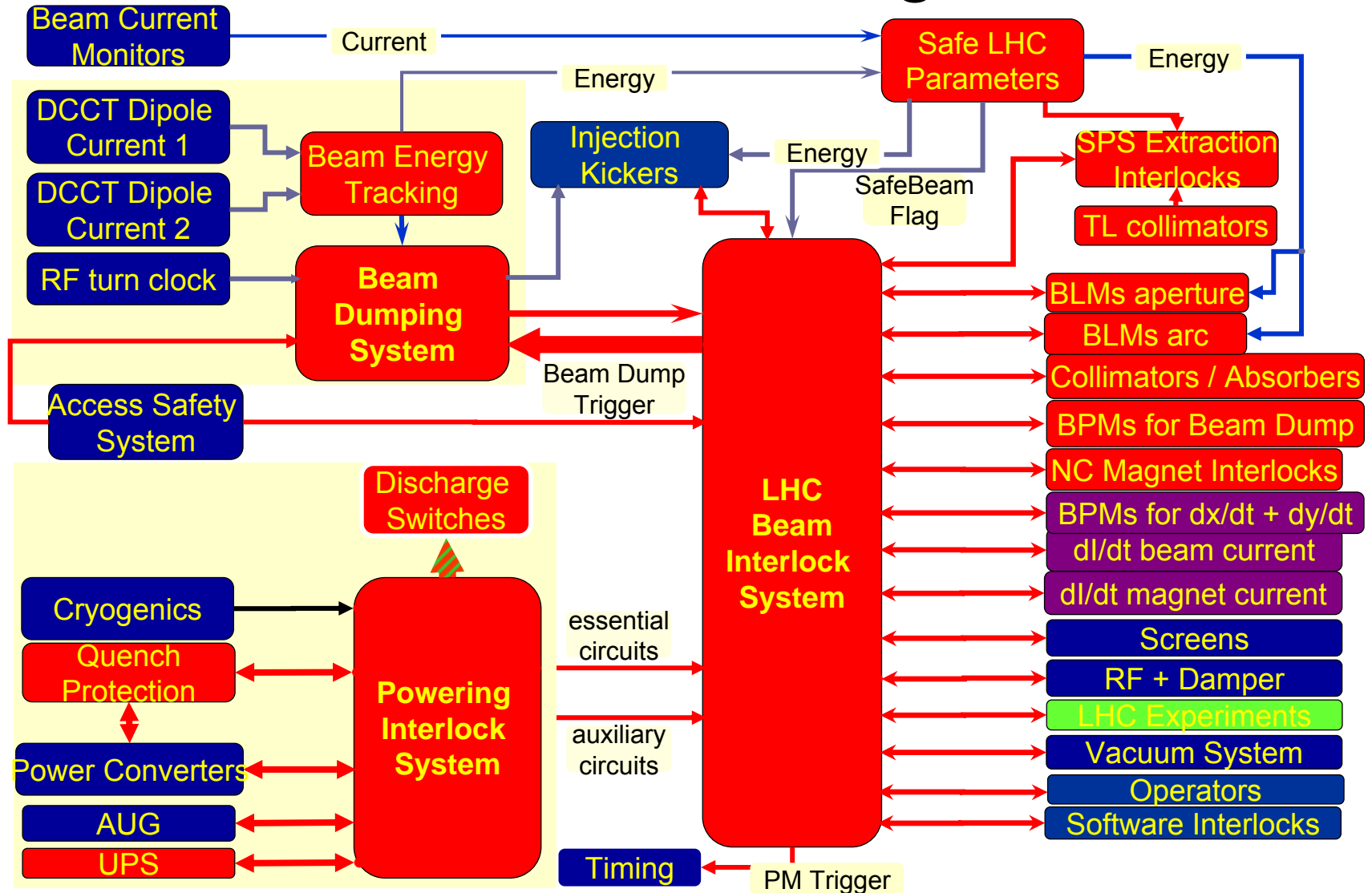
- Decision to abort beam based on multiple BCM readings

- Identify various beam conditions within the experimental region

- The onset of adverse conditions as indicated by flux increase in the monitoring
- The presence of machine induced bkgd
- Left/right asymmetry in machine bkgds
- Abort gap filling
- Satellite bunches



Interfaces: Fitting in



BCM Interface

- Inputs into beam abort via standard unmaskable BIC input

- Concerns

- Abort threshold Requires thorough commissioning
- Reliability Thresholds track LHC operational state
- Monitoring timescales Tunable for alarm sensitivity

- **Information to LHC operations**

- Real time and post mortem monitoring to CCC
- Use LHC standard protocols
- Expts now looking at how and what information is passed
 - Should be standardized

- Include optimization information on lumi, bkgds to get best performance**

- Example:

- CMS using DAQ based on BLM/BPM
 - Flexible user defined thresholds
 - Staggered buffer system provides post mortem record from bunch by bunch to ~100s
 - Uses LHC standard handling of beam status flags
 - Implementation of interfacing to BIC identical to that of BLM

Abort threshold Commissioning

- BCM interface to BIC => alarm/abort thresholds must be well understood
 - BCMs must be commissioned ASAP after first beam
 - NB: ATLAS Pixel detector installed for day 1;
CMS pixel detector installed after Pilot run

- Commissioning of thresholds
 - Pre-Commissioning
 - CMS to install BCM prototypes in CDF in March 06.
=> **validate BCM thresholds in CDF as function of CDF/Tevatron conditions**
 - Commissioning: ATLAS and CMS
 - Use single beam operation and Pilot run to set normal levels of BCM signals
 - Set alarm/abort thresholds only after in-situ calibration of “normal” operation
 - **Interface to BIC only after acceptable commissioning of BCM**
 - **Must define acceptable, as BCMs to protect trackers in commissioning/early running phase**
 - Commissioning of BCMs requires a full Expts-LHC operations partnership

- For all experiments
 - BCM units are to be operational and directly inputting into BIC whenever there is a possibility of beam in the machine. **(Includes Pilot Run)**
 - Commissioned BCM checked before ramping inner tracking detectors.

Online Monitoring Status

■ BCM

□ ATLAS:

- Front end modules ready, being assembled with diamonds. **Install: August 06**
- Proceeding with back-end electronics. A to D conversion uses TOT measurement

□ CMS

- Frontend well advanced. **Install: April 07.**
- Backend DAQ based on BLM structure, BIC interface, and postmortem analysis

□ ALICE and LHCb

- Just starting. Looking to model either ATLAS or CMS

■ RADMON

- **ATLAS** Strong design and implementation effort for compact RADMON units
- **ALICE** Installing compact RADMON units from ATLAS
- **CMS** Work directly with TS-LEA. Install std RADMON units around CMS
Consistent monitoring and readout of the LSS (including CMS hall)
- **LHCb** Std RADMON. **Commissioned Dec 2005.** Attention to Cryo at Pt8

■ Other Monitoring devices

- **Scintillator planes:** Primarily commissioning tool. ATLAS, CMS to install each side of IP
- **Relative luminosity monitors.** ATLAS, CMS study use of BCM related system (+ others)
- **The BLM system.** Experiments to interface to BLM data
- **The experiments themselves.** Use Inner tracker occupancy (once turned on)

Beam and Radiation Monitoring

What the experiments are doing

	ATLAS	ALICE	CMS	LHCb
BCM_Fast (Bunch by Bunch)	Y	Y	Y	Y
BCM_Slow (~1 μ s timescale)	N*	?	Y	?
RADMON_LHC Standard	N	N	Y	Y
RADMON_Compact (ATLAS)	Y	Y	N	Y
Relative luminosity monitoring	Y	?	Y	?
Thin aluminum foil dosimeters	N	?	N	Y
Scintillator panels for halo	Y	?	Y	?
Passives Dosimeters	Y	Y	Y	Y
RAMSES	Y	Y	Y	Y

* Slow time scale from summing over Fast BCM buffers. Not an independent measure

Summary

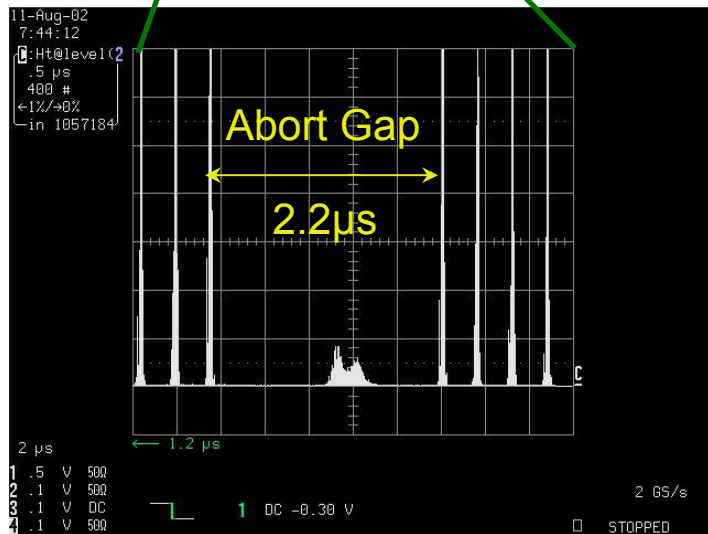
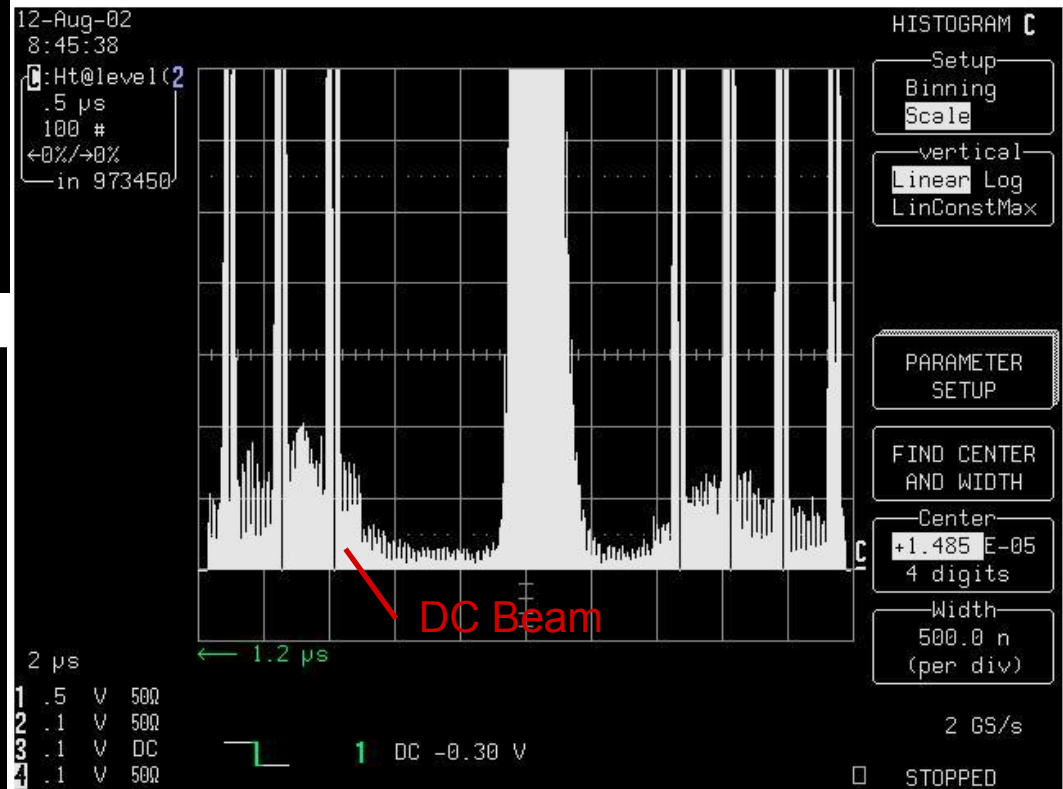
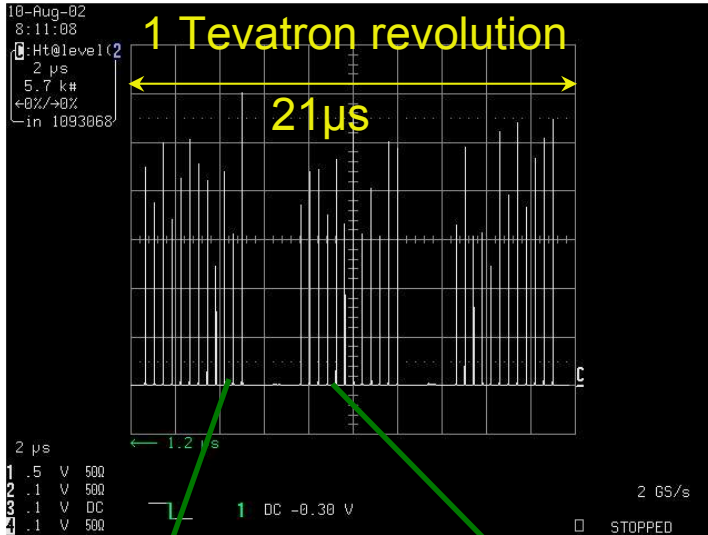
- All experiments designed for 10 years of running
 - ⇒ expecting no radiation damage problems in first years of running
 - But need to understand bkgds that could compromise physics performance of expts
- Online Radiation Monitoring based on RADMON units
- Concerns over transient or abnormal beam conditions
 - All expts to install fast monitoring (BCM) to protect inner tracker
 - BCM monitoring to compliment LHC beam instrumentation
- All BCMs based on the same technology
 - different implementations for different experiments
 - Hardware well advanced. Interface to LHC operations needs work
- Thorough commissioning of BCM thresholds essential for LHC operations confidence in BCM system
- In addition, all experiments developing additional radiation monitoring devices/methods (not discussed here)



Spare Stuff

Recording "Fast" Signals

Diagnose beam problems
Reduce risk of accident!



Fastest mechanism for multiturn proton losses: failure of D1 in IR1 and IR5 (pessimistic time constants, 7 TeV)

