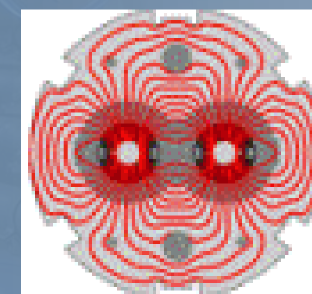
Lessons Learnt from Beam Commissioning and Early Beam Operation of the Beam Loss Monitors (incl. outlook to 5 TeV)



Preconditions for operating at 5 TeV in 2010

Session 1 - 25th January 2010

E.B. Holzer BE/BI
for the BLM team

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Outline

- Introduction
- Operational Experience
  - Noise and Offset
  - Dependability (Reliability, Availability and Safety)
  - Accuracy of Thresholds
  - Known Limitations
- Threshold Levels Compared to Dynamic Range
- Extrapolation to Higher Intensities
  - Beam Cleaning
  - Injection Losses
- Summary

Introduction

Introduction

- Up to now very satisfying performance
- Machine protection functionalities are being **phased in**, in order not to compromise the availability during commissioning
  - Beam loss thresholds: from masked to unmasked in stages (end of 2009: running with most channels unmasked)
  - Acquisition system self tests – failure aborts beam – operational during 2009 run (see talk Ch. Zamantzas Evian 2010)
  - Sequencer driven regular system tests – failure or non-execution within 24 hours inhibits beam injection – to become operational before 2010 run

Introduction

- The important step for the BLM system is to go to unsafe beams (10^{12} p at 450 GeV, see Jörg's talk). This will happen in 2010!
- → to reach full protection level we need (mostly not covered in this talk):
  - Technological tasks (see talk Ch. Zamantzas Evian 2010)
  - Validate threshold settings (document for MPP approval in preparation)
  - MPS tests (EDMS 896394)
  - Apply all procedures for changes (EDMS 1027851)

Operational Experience

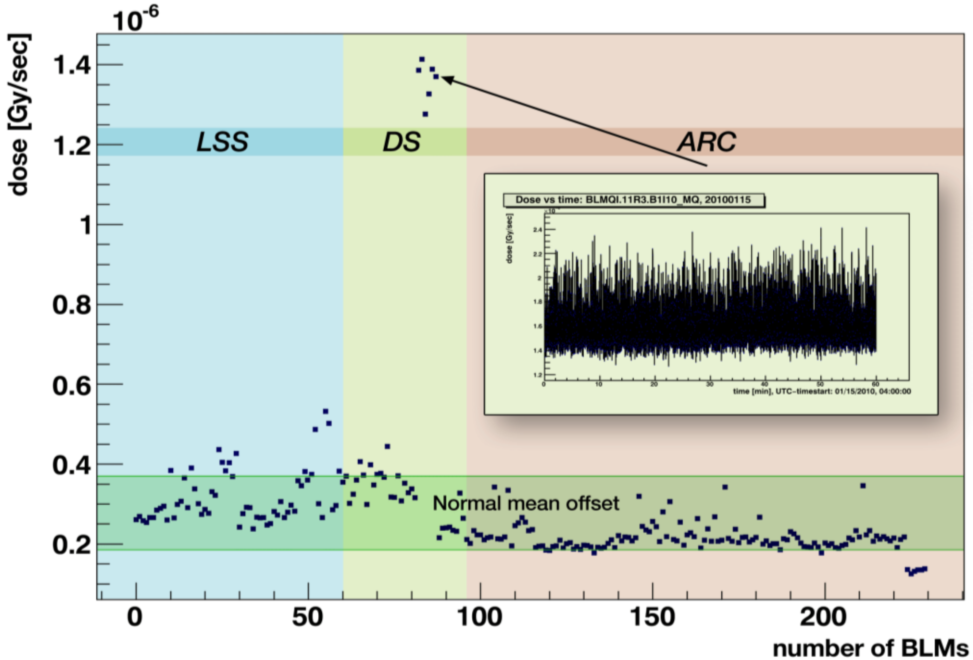
- Noise and Offset
- Dependability (Reliability, Availability and Safety)
- Accuracy of Threshold
- Known Limitations

Noise and Offset

- Important for availability (false dumps)
- Onset of problem detected early by about daily checks on offset and noise for each channel, cause can be identified (cable noise, card problem, ...)
- Cables had been exchanged (up to 800 m), noise reduction: **factor 2**
- Next shut-down: install single pair shielded cables, noise reduction: > **factor 5**
- Development of kGy radiation hard ASIC readout (PhD Giuseppe Venturini, ≈4 years): avoid long cables

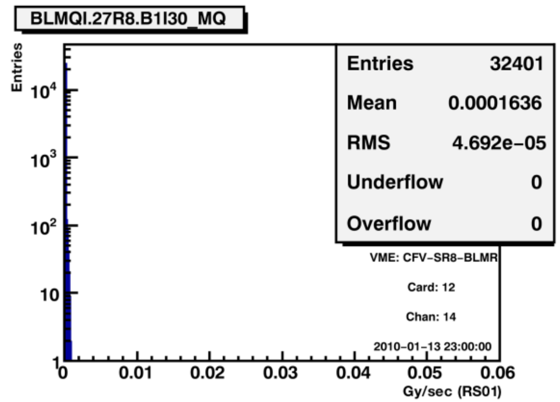
Example mean offset level right of IP3

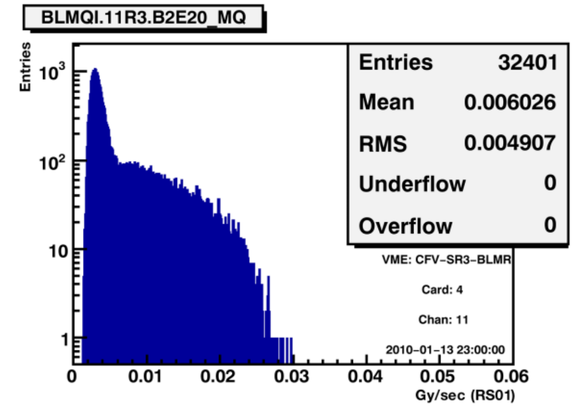
- Some bad channels in the DS have been repaired
- Long cables in LSS and DS lead to higher fluctuations



Noise and Offset

Noise single channel frequency distribution over 9 hours, low noise - short cable (left), high noise - long cable (right)

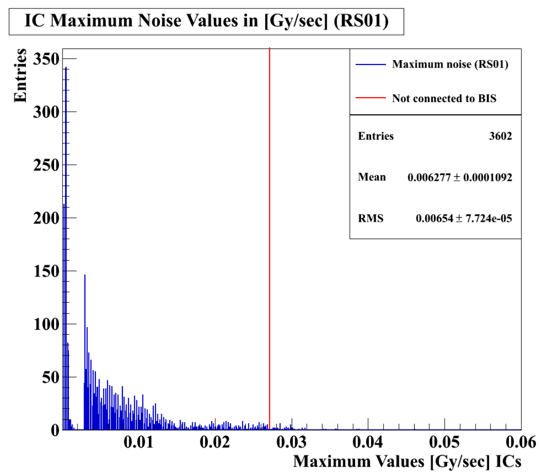


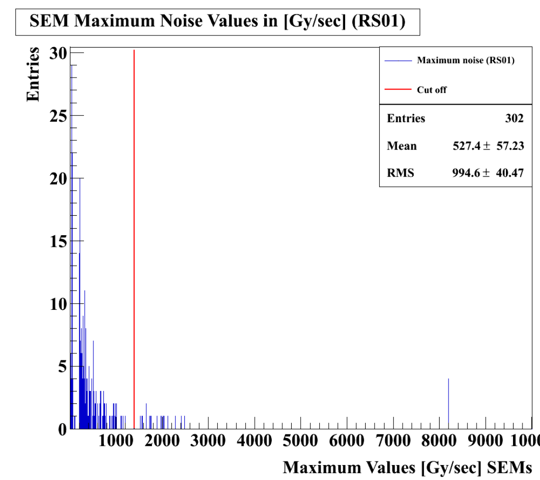


Max. noise frequency distribution, Ionization Chambers (IC) - left, Secondary Emission Monitors (SEM) - right

SEMs have a higher percentage of high noise

Max. noise above red line → channel will be repaired





≈3600 IC

≈300 SEM

A SEM is always installed next to an IC, it is less sensitive by factor of 70.000

Dependability

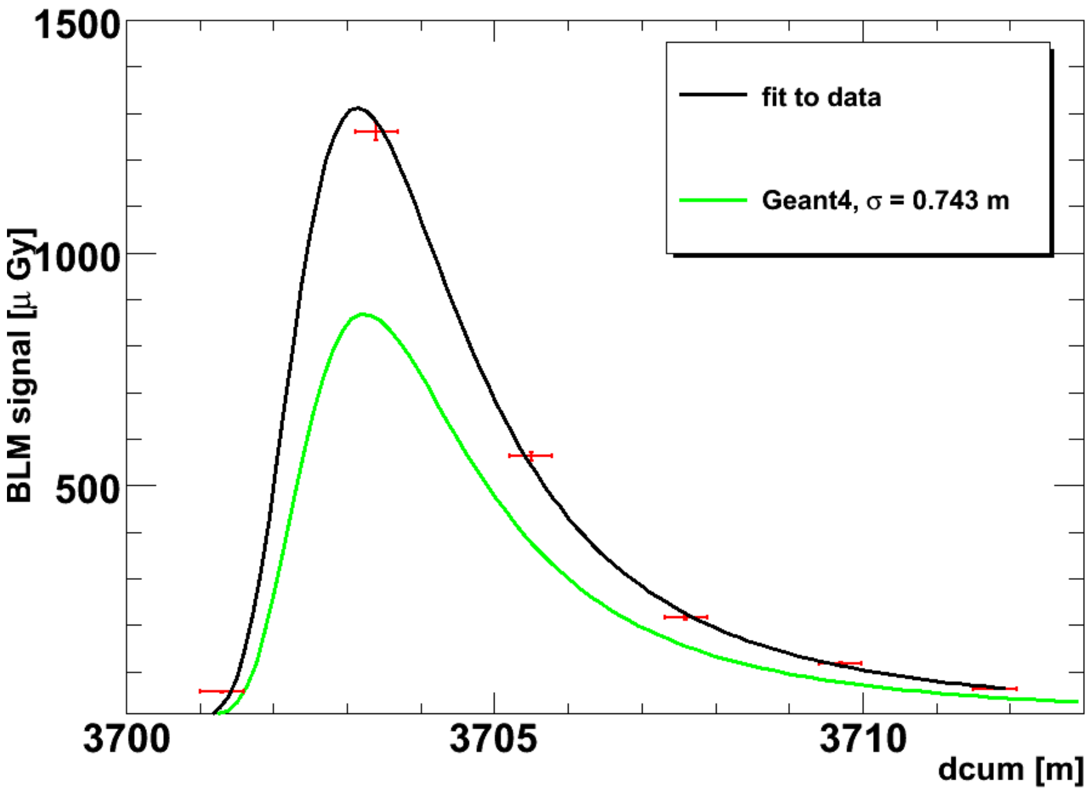
- Safety
  - No safety related issues detected (hardware, firmware, software, parameters).
- Availability, too early to give hardware failure and intervention rate. All hardware problems had been detected before the run. About one month of running: no newly developed problems.
  - 3 hardware problems giving false dumps
    - 2 previously detected, but not considered urgent (optical fiber, tunnel card)
    - 1 detected intermittently during the summer (mezzanine surface card)

Accuracy of Thresholds

- All quenches so far on MB (all injected beam). Most likely loss with circulation beam locations are the quadrupoles.
- 2 quenches in 2008 (injected beams): signals in BLMs could be reproduced by GEANT4 simulations to a factor of 1.5
  - → thresholds raised by ≈50%

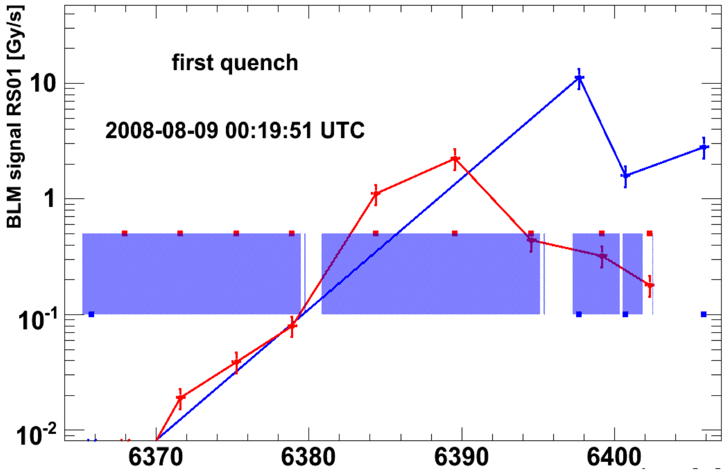
Analysis of second quench

LHC Project Note 422

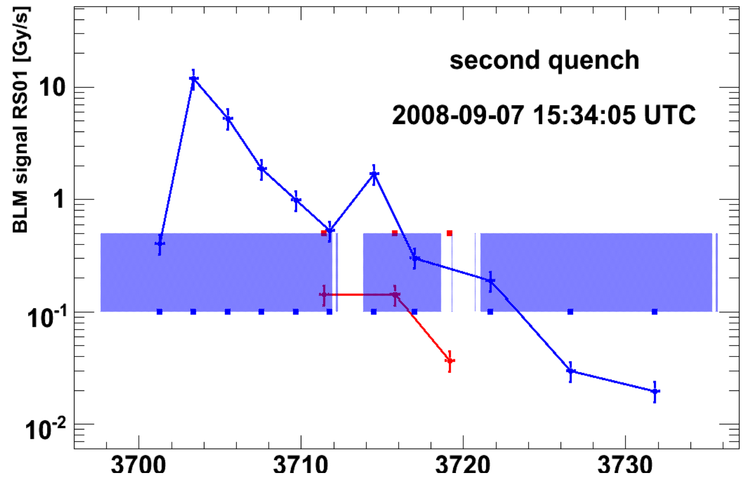


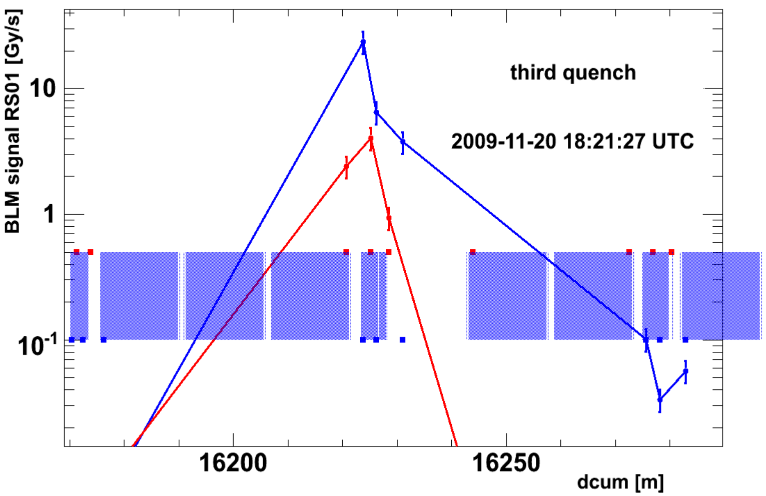
The Four Quenches

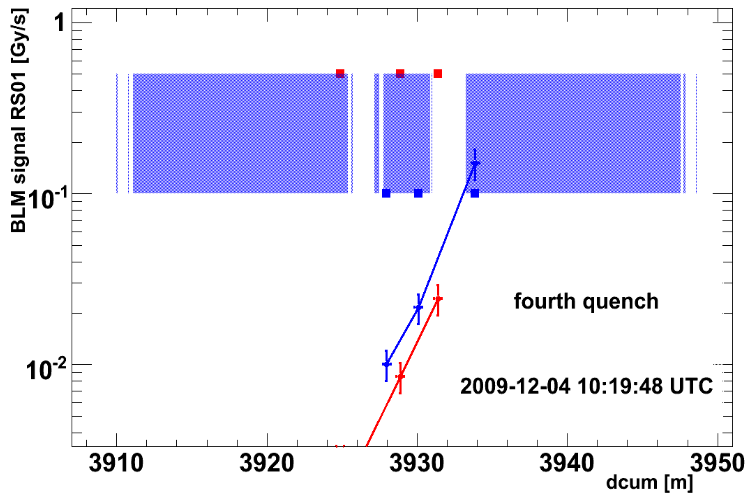
analyzed (opposite beam equipped)



analyzed







highest IC saturation

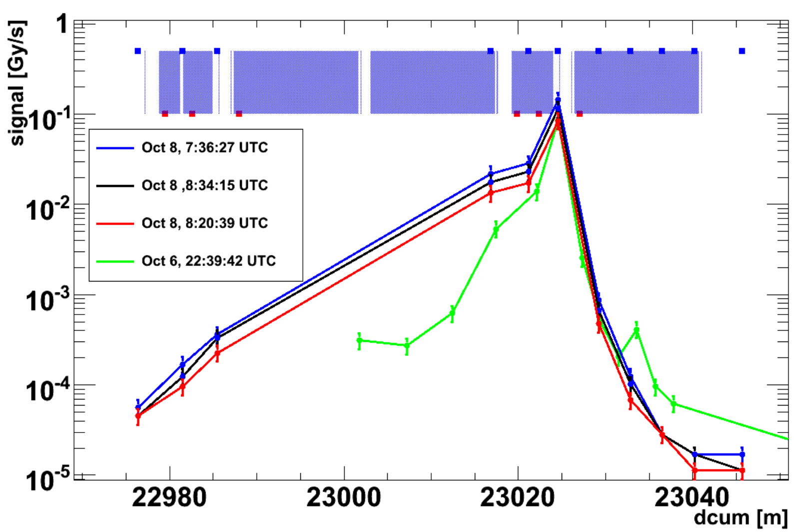
MB not equipped

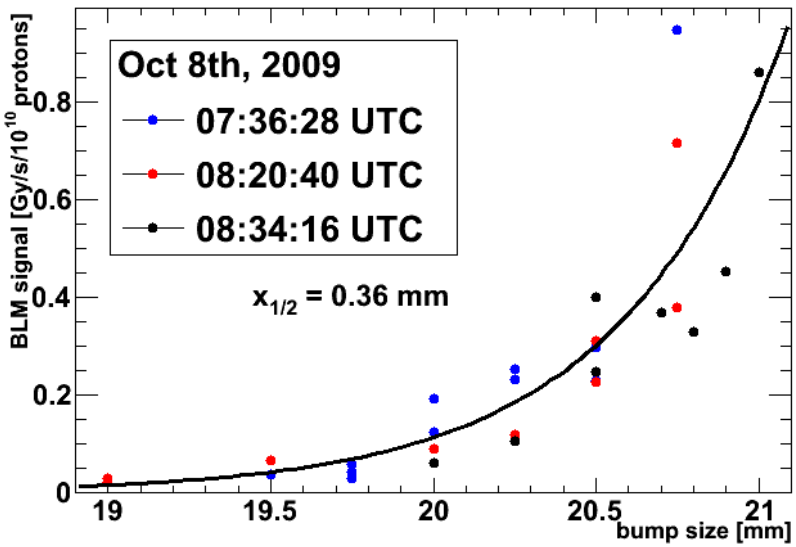
Accuracy of Thresholds

- → beam tests: provoke either a quench, or better, a 'recovering quench' on different magnets.
  - Injected beam – detect with special version of nQPS
  - Steady state (circulation beams) – detect with magnet temperature monitors
  - Propose these tests for very beginning of 2010 run

Safety of 'Recovering Quench' Test

- Similar to 2009 beam dump test with reduced threshold levels and beam bump.
- nQPS Voltage difference detection level to be set at 50 mV (factor 4 below the QPS and factor 2 below nQPS limit).
- Conditions of the bump are well understood and very reproducible – nQPS test will (most likely) not cause a magnet quench and should be perfectly safe for the machine.



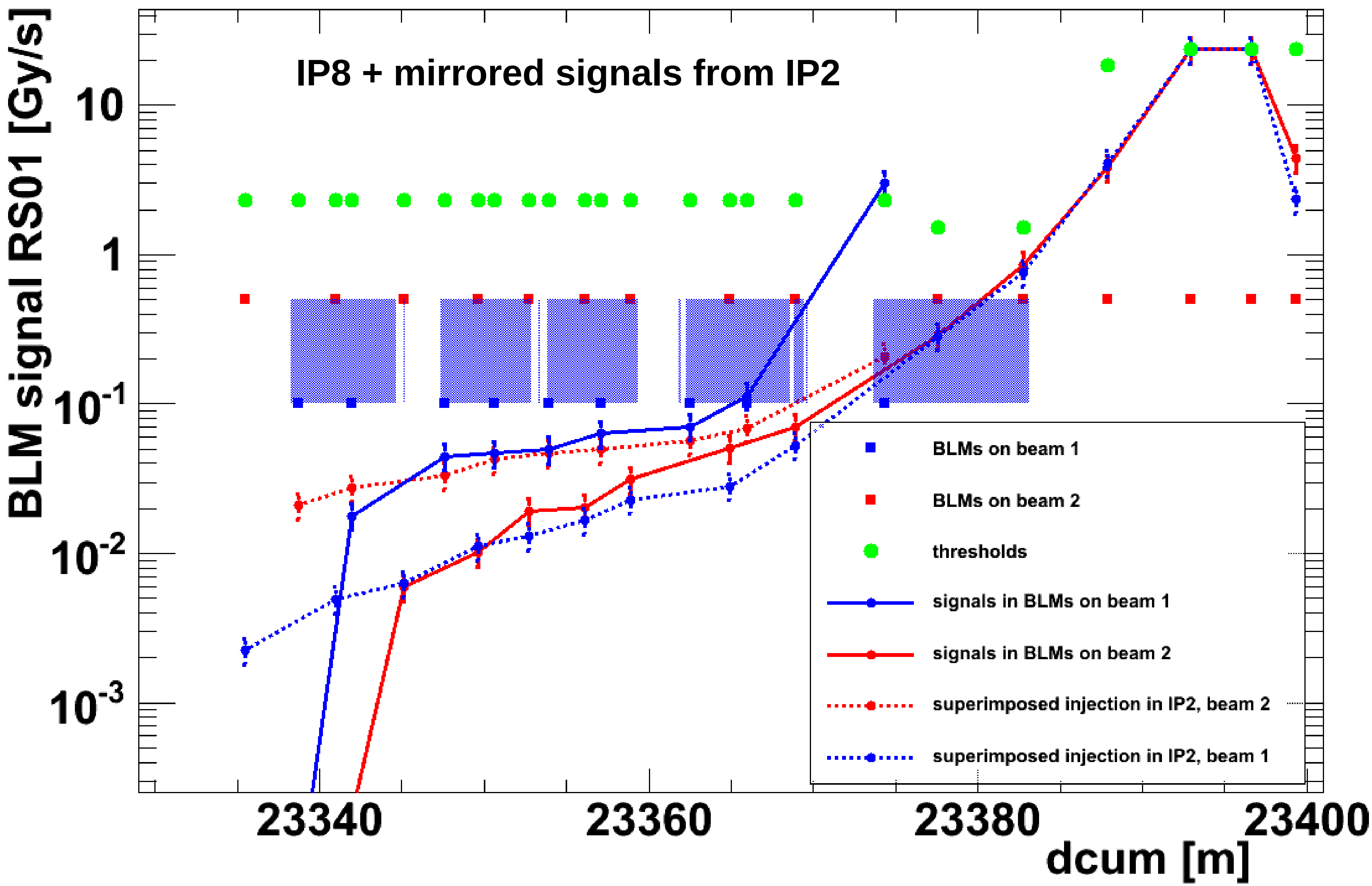


Position and detection reproducibility of 4 beam tests

Known Limitations

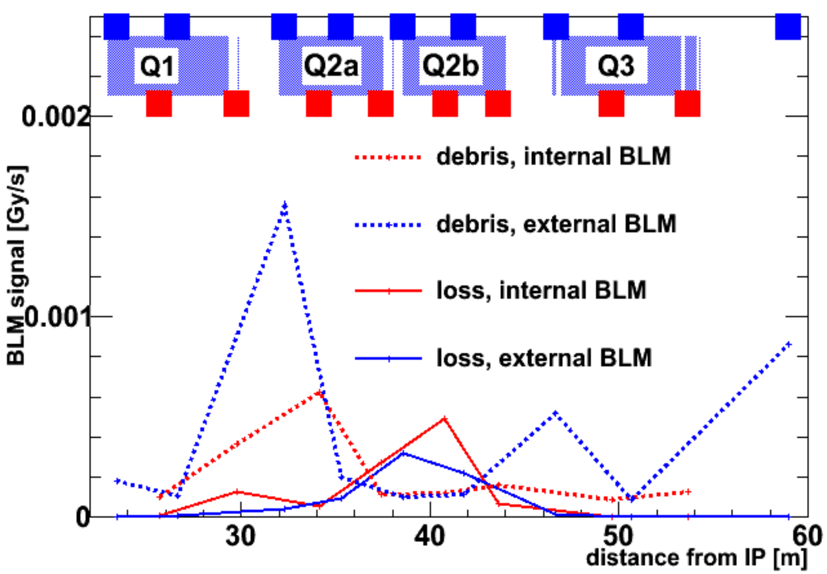
- **TDI at over-injection:** IC signal short integration times over electronic measurement limit – installation of capacitor
- **Triplet magnets at over-injection:** BLM over threshold. Measurements and beam tests suggest that radiation from TDI reaches monitors at triplet magnets from the outside (through the tunnel)
  - Long term solution: shielding
  - Short term solution: increasing the short integration time threshold or the monitor factor or installing an additional capacitor.

Triplet at Over-Injection

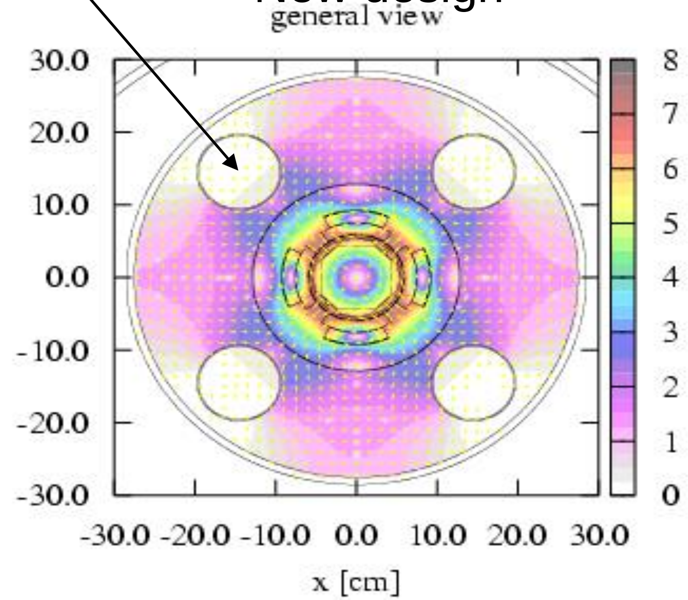


- **Triplet magnets at collision:** debris from interaction same magnitude signal as a critical loss
  - Long term solution: new monitors placed close to the coil of new triplet. *BLMs on Triplets preliminary studies*, Mariusz Sapinski et al., IR upgrade WG meeting 2009.02.12, EDMS 1049072
  - Short term: no problem up to luminosity of 10^{33} cm^{-2} s^{-1}

Current set-up



New design



Losses at Injection

W. Bartmann Evian 2010

- TCDI set up:
  - losses in the ring already close to BLM interlock limit for pilot bunch…scraping in the SPS
  - Ratio of one pilot bunch to one nominal SPS batch: 6.4e3

TCDIs at..	BLM: threshold/losses B1/B2		
	5e9 (B1/B2)	1.6e10	Nominal
4.5 σ hor/vert	10/20		$1 \cdot 10^{3}/2 \cdot 10^{3}$
6.0 σ hor / 4.5 σ vert	30/60		$3 \cdot 10^{3}/6 \cdot 10^{3}$
6.0 σ hor / 4.5 σ vert + SPS scraping		$10^{3}/10^{5}$	$10^{-1}/10$

→ Superconducting machine demands a very clean injection

- Scrape tails in SPS
- Improve beam 1 to the quality of beam 2
- **Unfortunately we did not reproduce the above results → last chapter of this talk**

Known Limitations – Dynamic Range

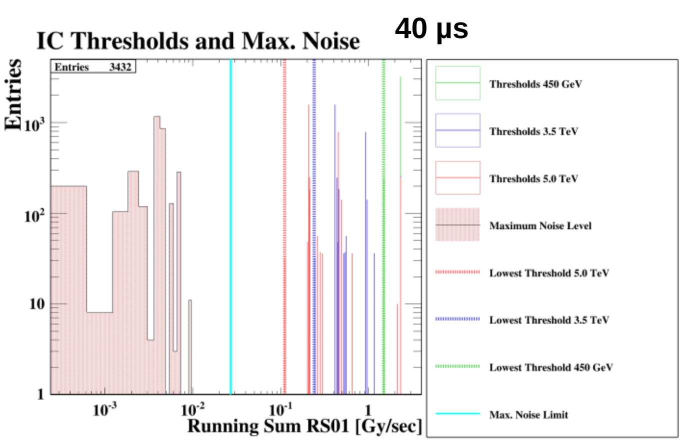
- SEM noise
  - Spurious signal: insulation problem - being corrected now
  - High noise (≈2000 Gy/s for short integration time)
    - Ambiguity for short losses in the gap between IC and SEM dynamic range
    - Thresholds cannot be set in SEM
- Partial activation of beam abort functionality was not foreseen in electronics (thresholds partially in SEM and partially in IC)
  - Installation of additional capacitors to spread the signal over longer time
  - Depending on requirement: new monitor type, small IC, 30 times less sensitive than IC (installation during 2010), ≈56 monitors.

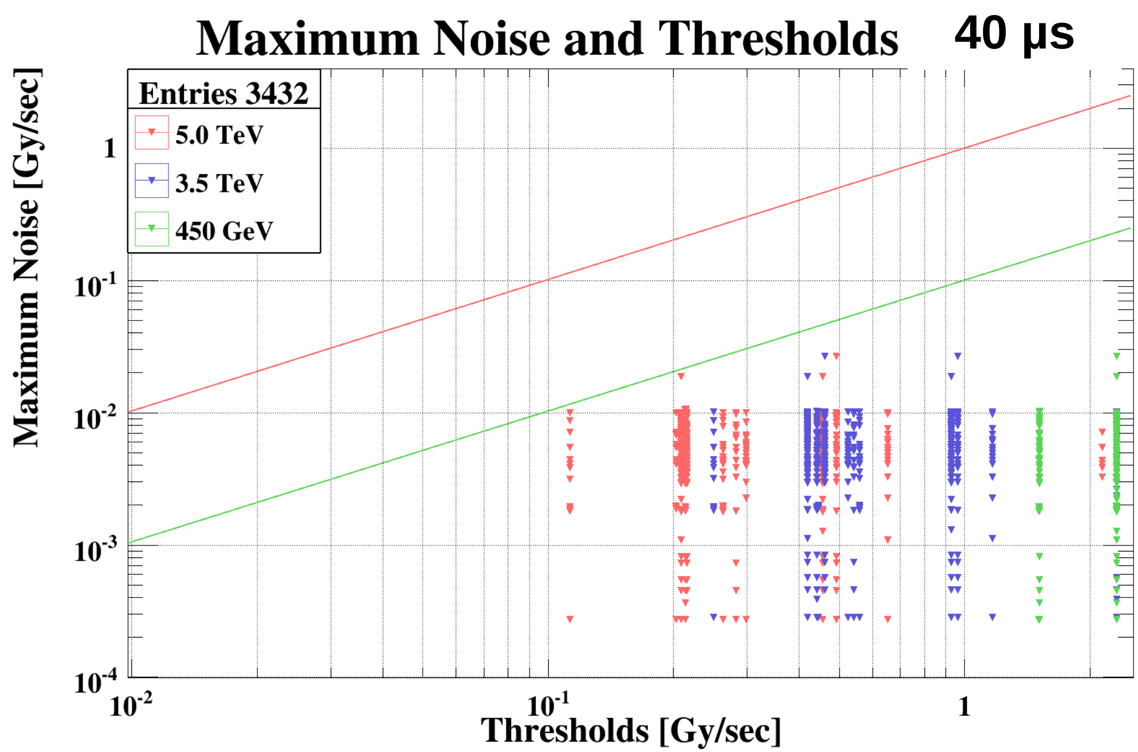
Threshold Levels Compared to Dynamic Range

Threshold levels compared to dynamic range

- ❑ Are the thresholds at higher energies still safely above the noise levels? → yes (analyzed IC 40 μs, 1.3 s and 84 s integration time window up to now)

Data set of 10 days: 18.12.2009 - 25.12.2009 and 08.01.2010 - 15.01.2010

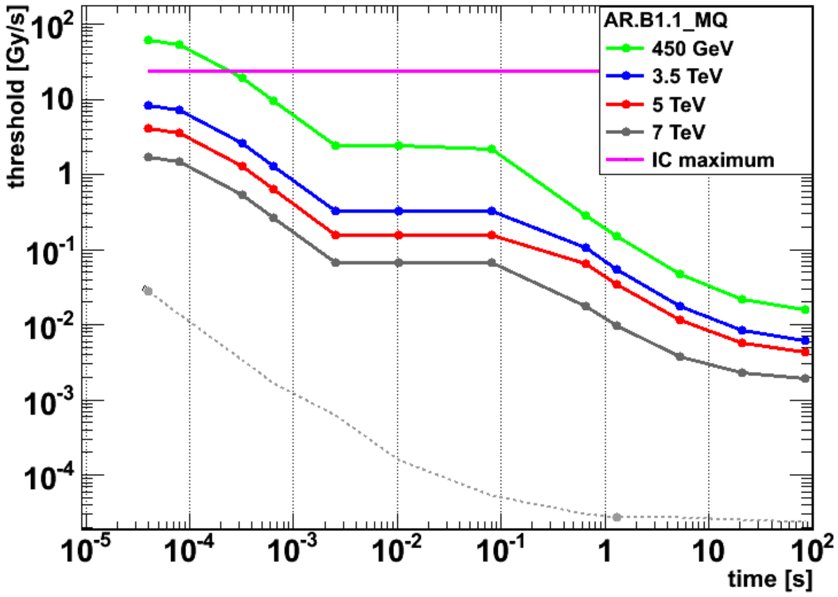


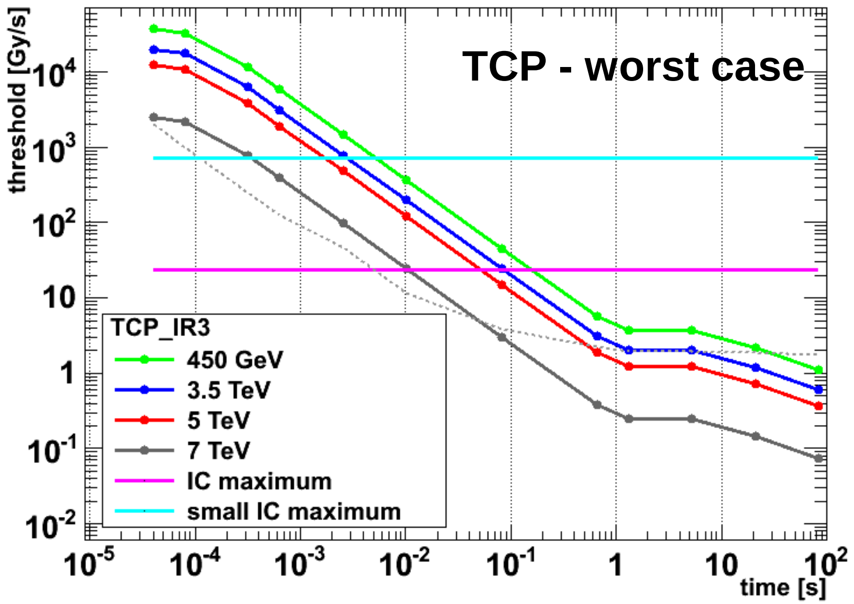


Threshold levels compared to dynamic range

Highest threshold cold magnets: OK (as defined in functional spec)

- Problem reduces with higher energies
- TCP: worst case
  TCSG and TCLI: 10 times lower thresholds
  → capacitor (up to factor 100)
- Similar for warm magnets
  → most locations should need no changes
- possible limitation? → see next slides





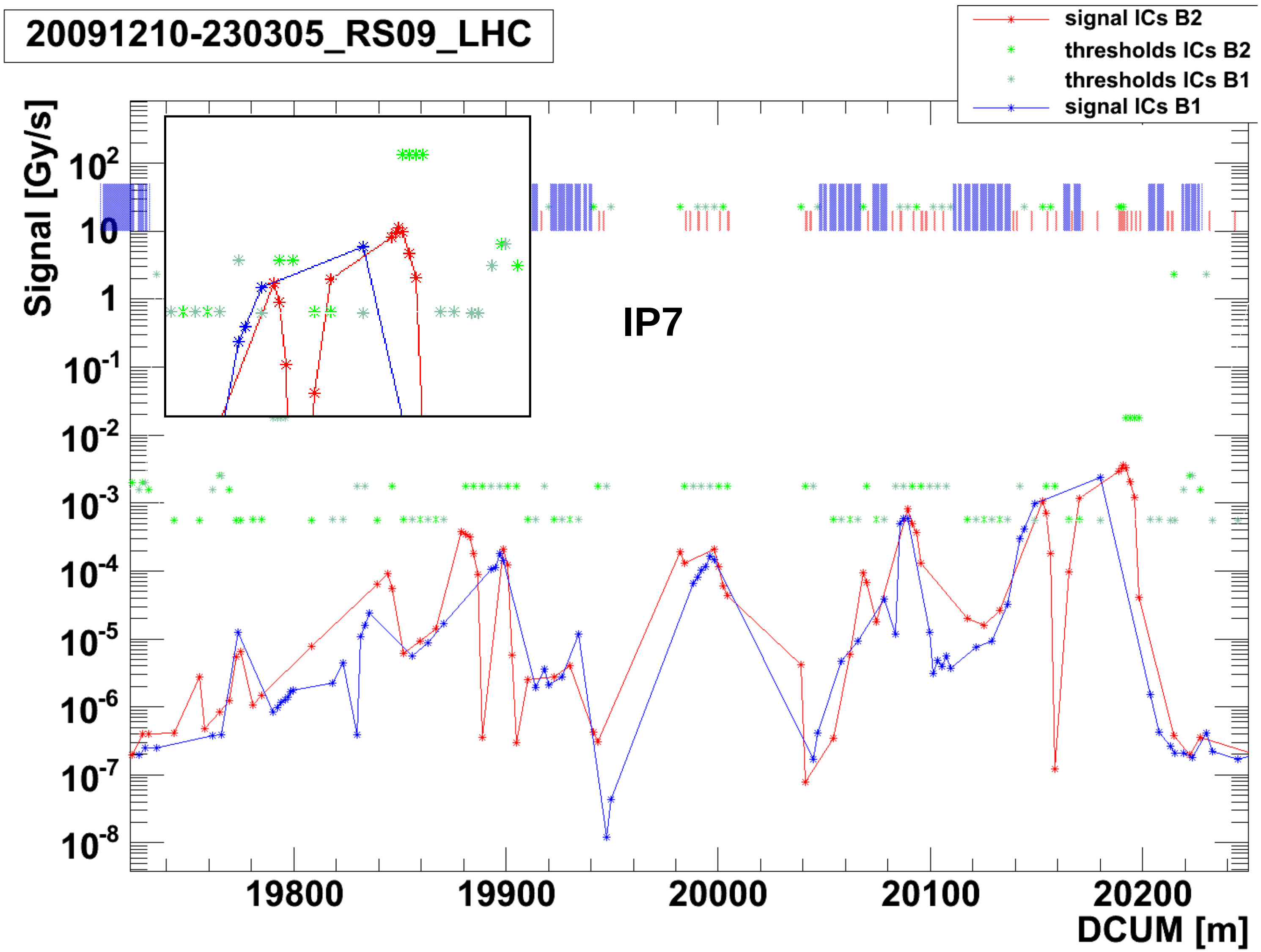
Extrapolation to Higher Intensities

- Beam Cleaning
- Injection Losses

Extrapolation to Higher Intensities

- Preliminary results
- Assuming intensity increases, all other conditions unchanged
- 6 data sets analyzed (same data sets as presented in Evian by Ch. Bracco and W. Bartmann)
- At what intensity do we reach the loss threshold? Which are the most-critical elements?
- Collimation cleaning 450 GeV (1.3 s loss data compared to 84 s thresholds), scaled to nominal intensity
  - B1 and B1 longitudinal cleaning
  - B1 vertical and B2 horizontal cleaning
- Injection (40 μs loss data compared to 40 μs thresholds)
  - B1 and B2, cleanest injections: SPS scraping, TCDI 6 σ hor. / 4.5 σ vert.

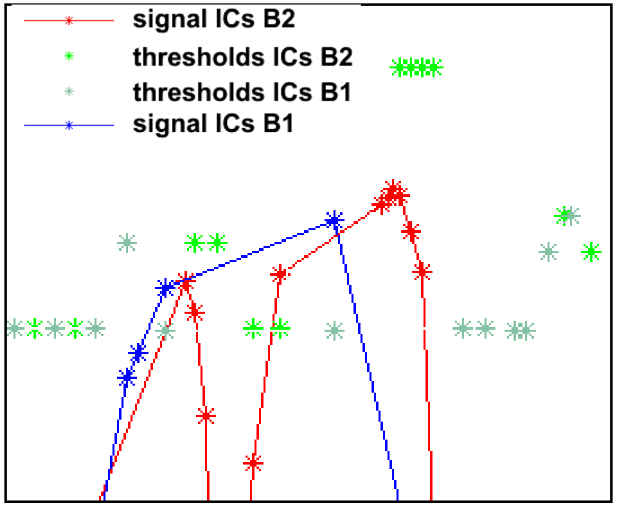
Cleaning - Beam 2 Horizontal



PRELIMINARY

Cleaning - Transversal

Most-Critical Elements **at nominal intensity 3E14**	***Beam lifetime at threshold [minutes]***
Beam 2 horizontal cleaning	
BLMEI.06R7.B1E10_**TCLA.B6R7.B1**	62 – 86
BLMEI.06R7.B1E10_**TCLA.A6R7.B1**	26 – 37
BLMQI.04**L6**.B2I10_**MQY**	18 – 24
Beam 1 vertical cleaning	
BLMEI.05R7.B2I10_TCSG.B5R7.B2	1 – 1.5



Beam 2 horizontal:

- TCLA losses seem to be caused by “crosstalk” particle showers from B2
- Most critical cold element in IP6
- No limits from BLM dynamic range (all long integration time thresholds are within the dynamic range of the BLM system)

PRELIMINARY

Cleaning - Longitudinal

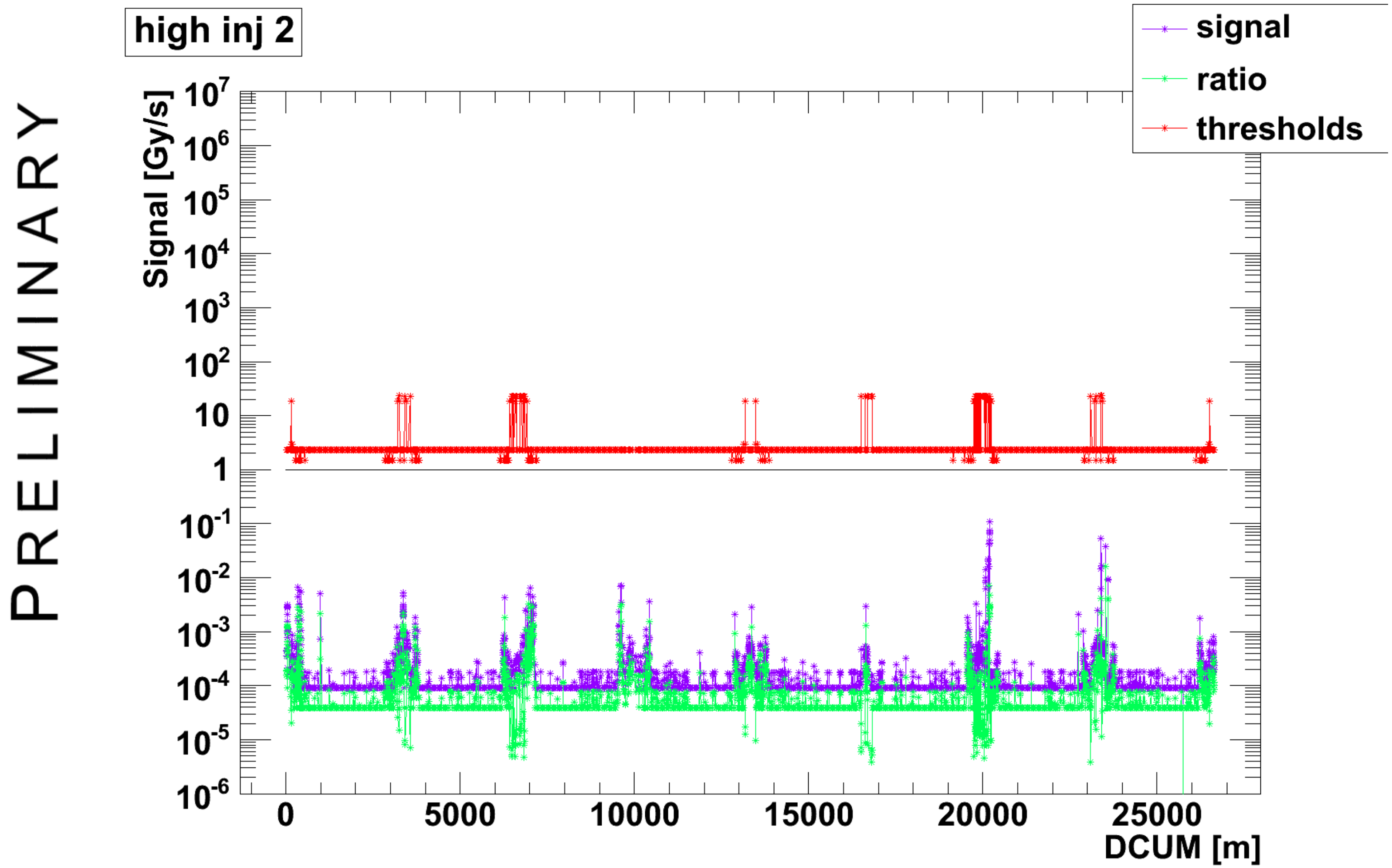
Most-Critical Elements **at nominal intensity 3E14**	***Beam lifetime at threshold [minutes]***
Beam 1 longitudinal cleaning	
BLMEI.05L3.B1I10**_TCSG.5L3.B1**	13 – 18
BLMEI.05R3.B1I10**_TCLA.A5R3.B1**	7 – 10
BLMEI.08R3.B1I23**_MBB**	7 – 10
Beam 2 longitudinal cleaning	
BLMEI.08R3.B2I30**_MBA**	22 – 31
BLMEI.05R3.B2E10**_TCSG.5R3.B2**	7 – 10
BLMEI.05L3.B2E10**_TCLA.A5L3.B2**	5 – 7

- B2: most critical element is a cold dipole
- Losses localized: most-critical elements in IP3
- Most-critical TCSG and TCLA correspond for B1 and B2, MBs are next to each other
- No limits from BLM dynamic range (all long integration time thresholds are within the dynamic range of the BLM system)

PRELIMINARY

Injection with SPS scraping

- SPS scraping, TCDI 6 σ hor. / 4.5 σ vert., Beam 2, 2e10 p



Injection with SPS scraping

Most critical	*Beam 1*	*Number of injected protons at threshold*
16% of 38 most critical elements are cold magnets		
Collimator	BLMEI.06L7.B1E10_**TCP.A6L7.B1**	**1.5E+11**
Warm magnet	BLMEI.06L7.B1E10_**MBW.B6L7**	**5.5E+11**
Cold magnet	BLMQI.08L2.B1E30_**MQML**	**6.7E+11**
	Beam 2	
50% of 30 most critical elements are cold magnets		
Collimator	BLMEI.06R7.B2I10_**TCP.C6R7.B2**	**3.4E+12**
Cold magnet	BLMEI.04R8.B2E10_**MBXB**	**3.9E+12**
Warm magnet	BLMEI.06R8.B2E10_**MSIB**	**9.8E+12**

nominal: 3E13
2010: 4E12

PRELIMINARY

- Numerous elements (collimators, cold and warm magnets) yield similar limits for injected protons
- IC thresholds in warm elements limited by BLM dynamic range. But, losses at cold magnets about equally close to threshold (≈3 times below quench limit).
- → injection losses need to be reduced further, scraping in the SPS seems crucial
- → possible to increase thresholds on primary and secondary collimators and warm magnets (additional capacitors, small IC) but not on cold elements

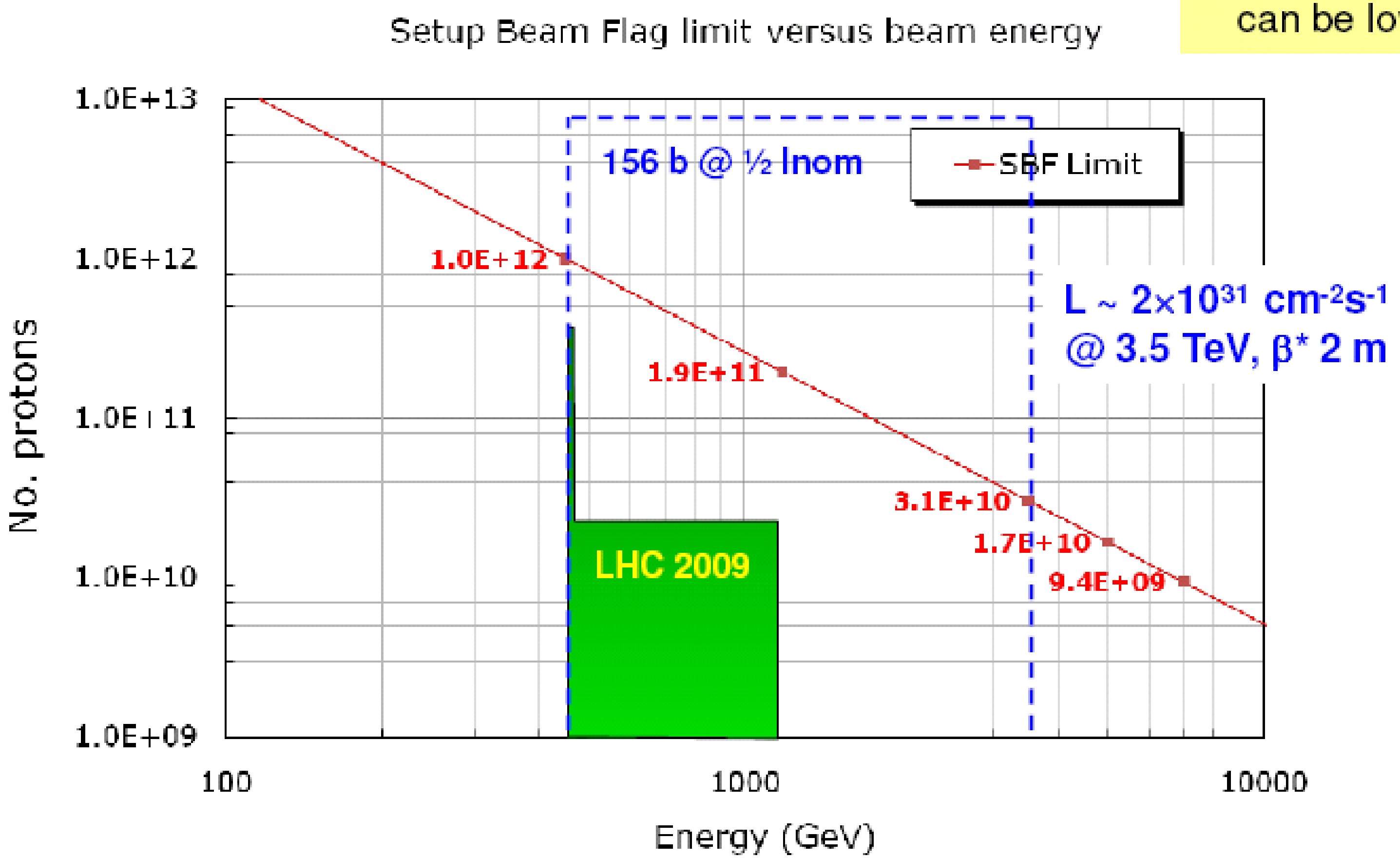
Summary

- Crucial to reach full protection level
  - Beam test to determine safe setting of threshold levels, full application of procedures
- Known BLM system limitations and upgrades look compatible with LHC schedule
  - Typically, warm elements should have higher thresholds
  - Certain locations **need** higher thresholds (add capacitor or install new small IC, choose different monitor location, install shielding, etc.)
- No additional limitation found for energies up to 5 TeV
- Collimation cleaning looks very promising
- Serious (2010!) **limitation** seen in **injection losses**
  - Various cold magnets are affected
  - Thresholds on warm elements could be increased (capacitor, small IC) but this will most likely not reduce the problem.

Some more slides

MP Footprint

For TCTs the limit can be lower !!



A pilot bunch is the only beam that can be used for commissioning (and for most MD) activities at ≥ 3.5 TeV !

Noise and Offset

Range [bits]	~ Range [Gy/s] 40µs	monitors in %	Nr. of monitors	
1-30	0 - 0.003	20.1	690	very good
30-100	0.003 - 0.01	71.2	2445	good
100-200	0.01 - 0.02	7.7	264	ok
200-300	0.02 - 0.03	0.7	23	candidates for problematic channels
> 300	> 0.03	0.0	0	critical noise
= 0	no data	0.3	10	no data

SEM Noise (302 monitors) 18.12 .2009-25.12.2009 RS01

Range [bits]	Range[Gy/s] 40µs	Monitors in %	Nr. of monitors
0.0-30.0	0.0-190.0	2.65	8
30.0-100.0	190.0-633.0	15.89	48
100.0-200.0	633.0-1265.0	52.32	158
200.0-300.0	1265.0-1898.0	12.25	37
>300.0	>1898.0	16.56	50
0	No data	0.3	1

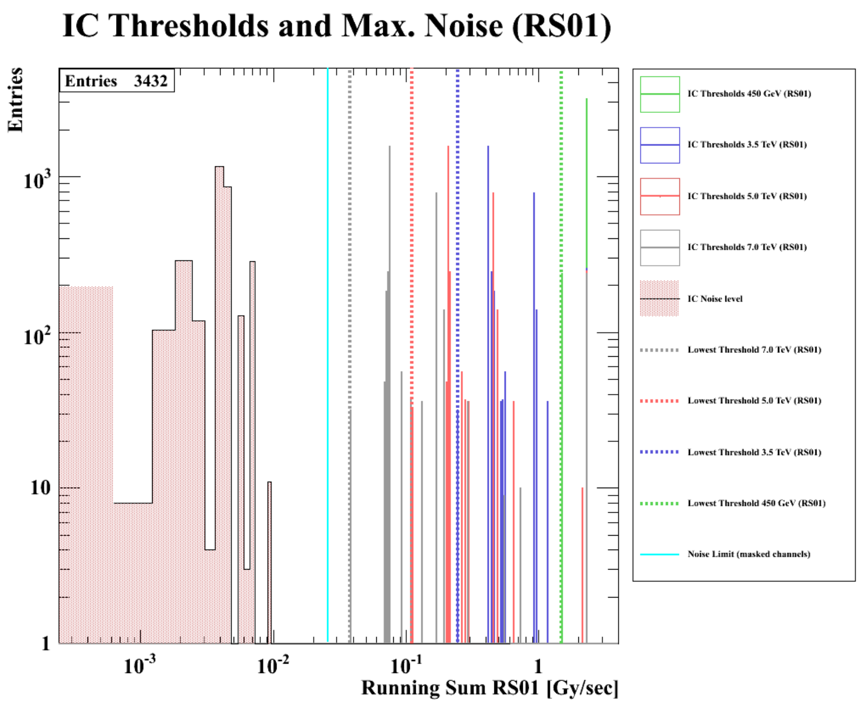
IC Offset (3592 monitors) 18.12.2009 (1hour) RS09

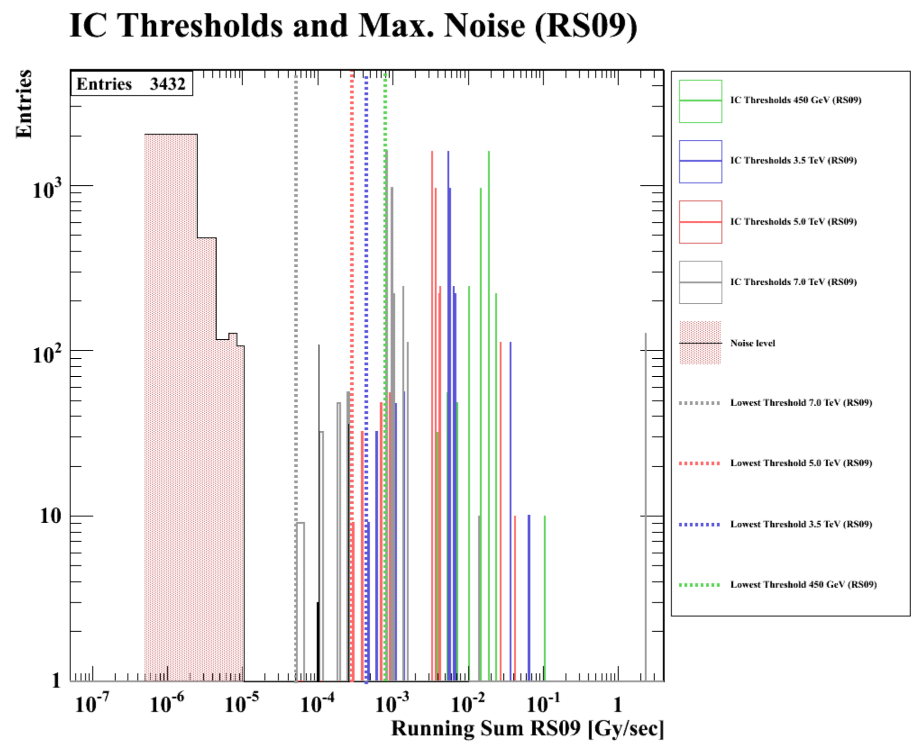
Range [bits/1310.72ms]	Range [Gy/s x10^{-7}] in 1310.72ms	Monitors in %	Nr. of monitors	Comment
6.0-53.0	0.19 -1.85	6.91	249	Too low
53.0-134.0	1.85-3.7	77.71	2799	Very good
134.0-201.0	3.7-5.56	6.83	246	good
201.0-537.0	5.56-14.8	3.28	118	Reset needed
537.0-1340.0	14.8-37.0	5	180	problematic
>1340.0	>37.0	0	0	serious card problem

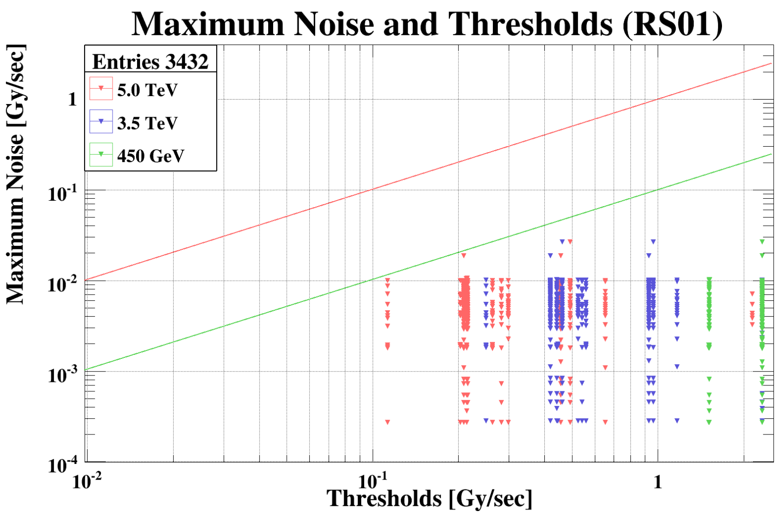
SEM Offset (302 monitors) 18.12.2009 (1hour) RS09

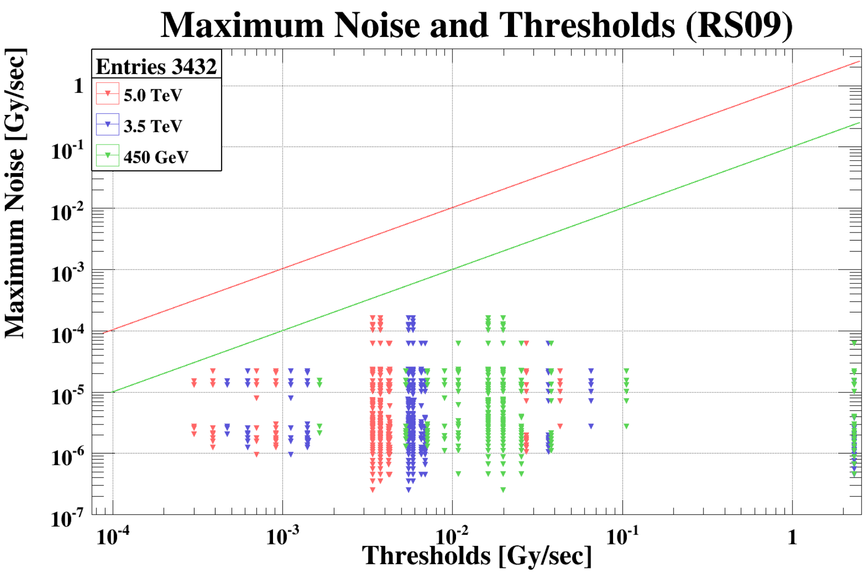
Range [bits/1310.72ms]	Range [Gy/s] in 1310.72ms	Monitors in %	Nr. of monitors	Comment
10.0-104.0	0-0.02	2	6	Too low
104.0-208.0	0.02-0.04	88	266	Very good
208.0-312.0	0.04-0.06	7.8	24	good
312.0-832.0	0.06-0.16	0	0	Reset needed
832.0-2080.0	0.16-0.4	1.1	3	problematic
>2080.0	>0.4	1.1	3	serious card problem

- Factor between noise level and lowest threshold:
- RS01: 450GeV: ≈150 3.5TeV: ≈25 5.0TeV: ≈11
- RS09: 450GeV: ≈81 3.5TeV: ≈37 5.0TeV: ≈20






Maximum Noise and Thresholds (RS01)
Entries 3432
5.0 TeV
3.5 TeV
450 GeV
Maximum Noise [Gy/sec]
Thresholds [Gy/sec]


Maximum Noise and Thresholds (RS09)
Entries 3432
5.0 TeV
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450 GeV
Maximum Noise [Gy/sec]
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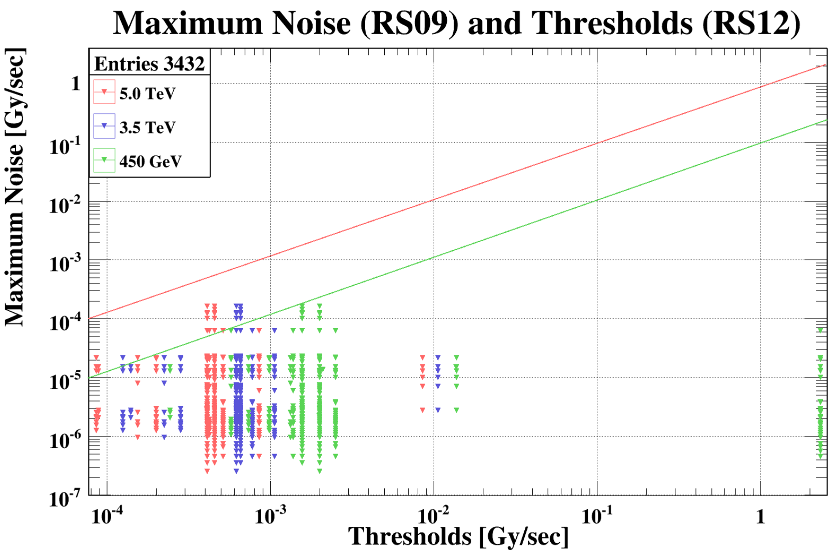
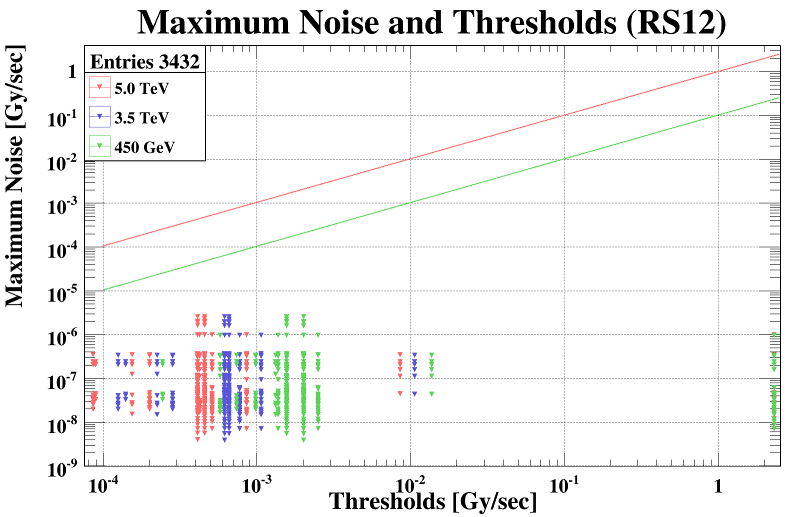
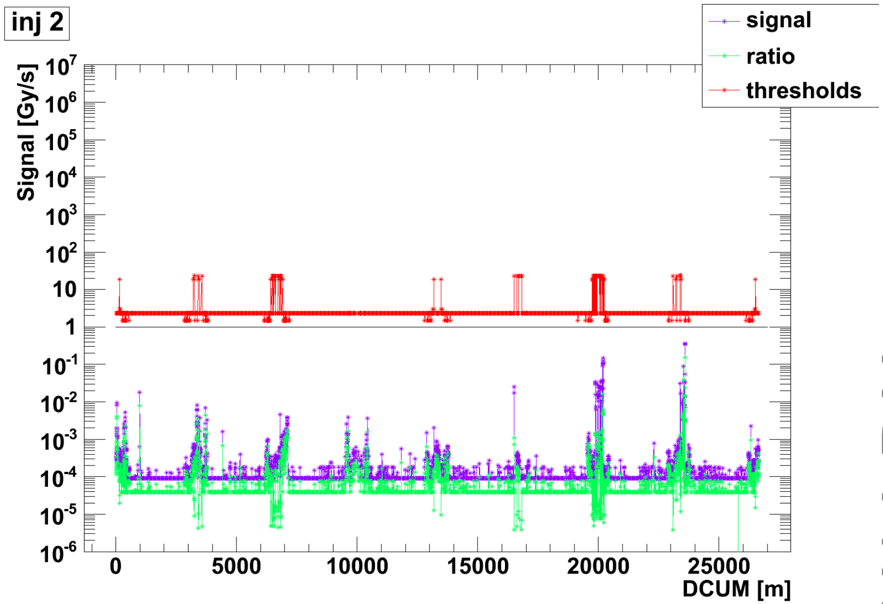
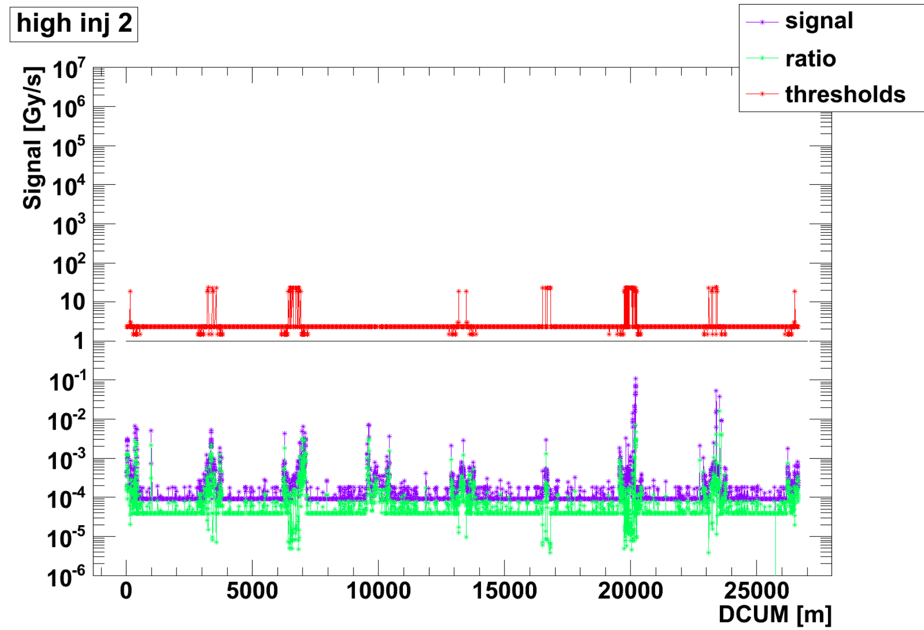
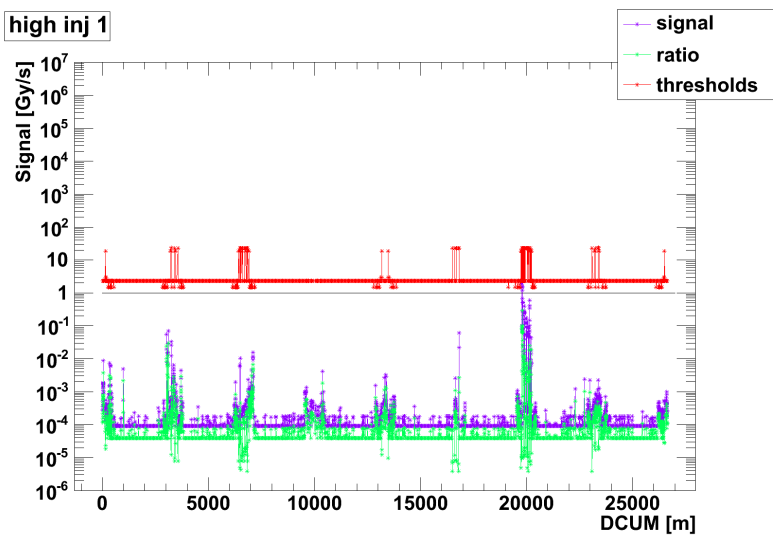

Maximum Noise (RS09) and Thresholds (RS12)
Entries 3432
5.0 TeV
3.5 TeV
450 GeV
Maximum Noise [Gy/sec]
Thresholds [Gy/sec]

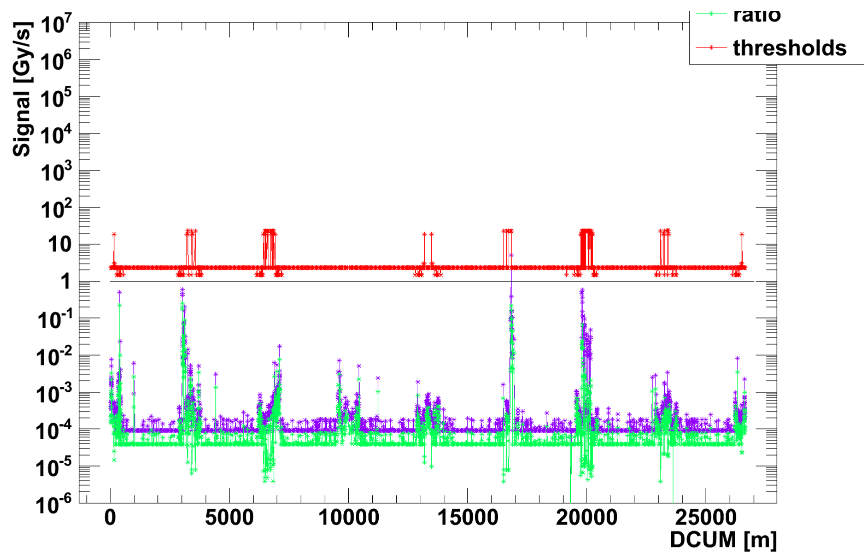

Maximum Noise and Thresholds (RS12)
Entries 3432
5.0 TeV
3.5 TeV
450 GeV
Maximum Noise [Gy/sec]
Thresholds [Gy/sec]





PRELIMINARY





- Beam 2 longitudinal (right)
- Beam 1 longitudinal (bottom right)
- Beam 2 horizontal (bottom left)