BEAM LOSS MONITORS DEPENDABILITY

Internal review

Basic Concepts

System fault events

- BLM are designed to prevent the Magnet Destruction (MaDe) due to an high loss (~ 30 downtime days). Preferably the quenches too (~ 5-10 downtime hour).
- BLM should avoid False Dumps (FaDu) (~ 3-5 downtime hours).
- Use of Safety Integrity Level (SIL), IEC 61508.

Sil Approach 1/4

Event likelihood (both)

Category	Description	Indicative frequency level (per year)
Frequent	Events which are very likely to occur	> 1
Probable	Events that are likely to occur	10^{-1} - 1
Occasional	Events which are possible and expected to occur	10^{-2} – 10^{-1}
Remote	Events which are possible but not expected to occur	10^{-3} – 10^{-2}
Improbable	Events which are unlikely to occur	10^{-4} – 10^{-3}
Negligible / Not credible	Events which are extremely unlikely to occur	< 10^{-4}

100 destructive losses/year

Sil Approach 2/4

Consequences

Category	Injury to personnel		Damage to equipment	
	Criteria	N. fatalities (indicative)	CHF Loss	Downtime
Catastrophic	Events capable of resulting in one or more fatalities	≥1	> $5*10^7$	> 6 months
Major	Events capable of resulting in very serious injuries	0.1 (or 1 over 10 accidents)	10^6 – $5*10^7$	20 days to 6 months
Severe	Events which may lead to serious injuries	0.01 (or 1 over 100 accidents)	10^5 – 10^6	3 to 20 days
Minor	Events which may lead to minor injuries	0.001 (or 1 over 1000 accidents)	0 – 10^5	< 3 days

MaDe

FaDu

Sil Approach 3/4

SILs

MaDe FaDu

Event Likelihood	Consequence			
	Catastrophic	Major	Severe	Minor
Frequent	**SIL 4**	**SIL 3**	**SIL 3**	**SIL 2**
Probable	**SIL 3**	**SIL 3**	**SIL 3**	**SIL 2**
Occasional	**SIL 3**	**SIL 3**	**SIL 2**	**SIL 1**
Remote	**SIL 3**	**SIL 2**	**SIL 2**	**SIL 1**
Improbable	**SIL 3**	**SIL 2**	**SIL 1**	**SIL 1**
Negligible / Not Credible	**SIL 2**	**SIL 1**	**SIL 1**	**SIL 1**

Sil Approach 4/4

Failure probability

Low demand mode of Operation (<1 year)

SIL	Average probability of failure to perform its design function on demand ($FPPD_{ave}$)
4	$10^{-5} < Pr < 10^{-4}$
3	$10^{-4} < Pr < 10^{-3}$
2	$10^{-3} < Pr < 10^{-2}$
1	$10^{-2} < Pr < 10^{-1}$

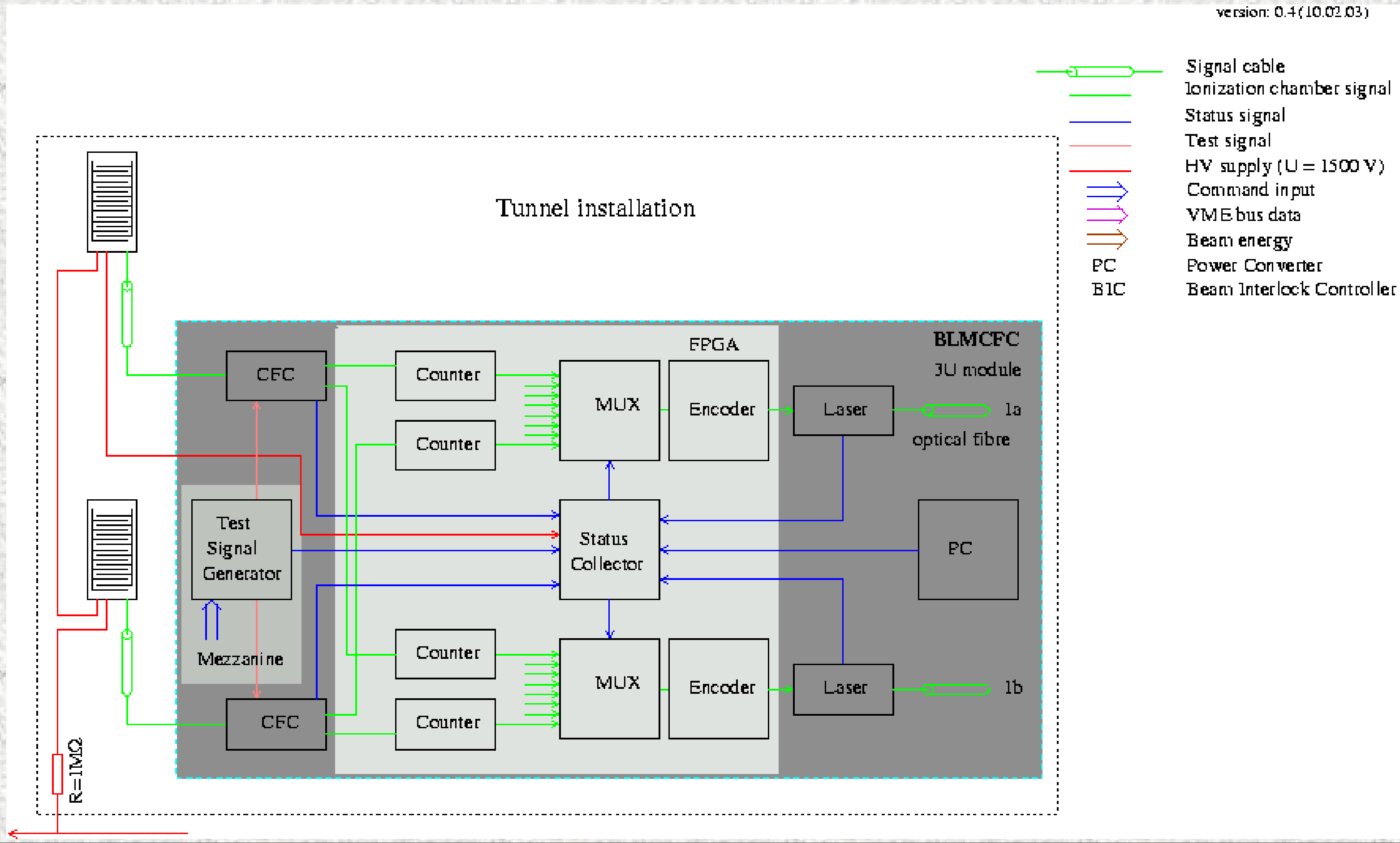
High demand / continuous mode of operation

SIL	Probability of a dangerous failure per hour
4	$10^{-9} < Pr < 10^{-8}$
3	$10^{-8} < Pr < 10^{-7}$
2	$10^{-7} < Pr < 10^{-6}$
1	$10^{-6} < Pr < 10^{-5}$

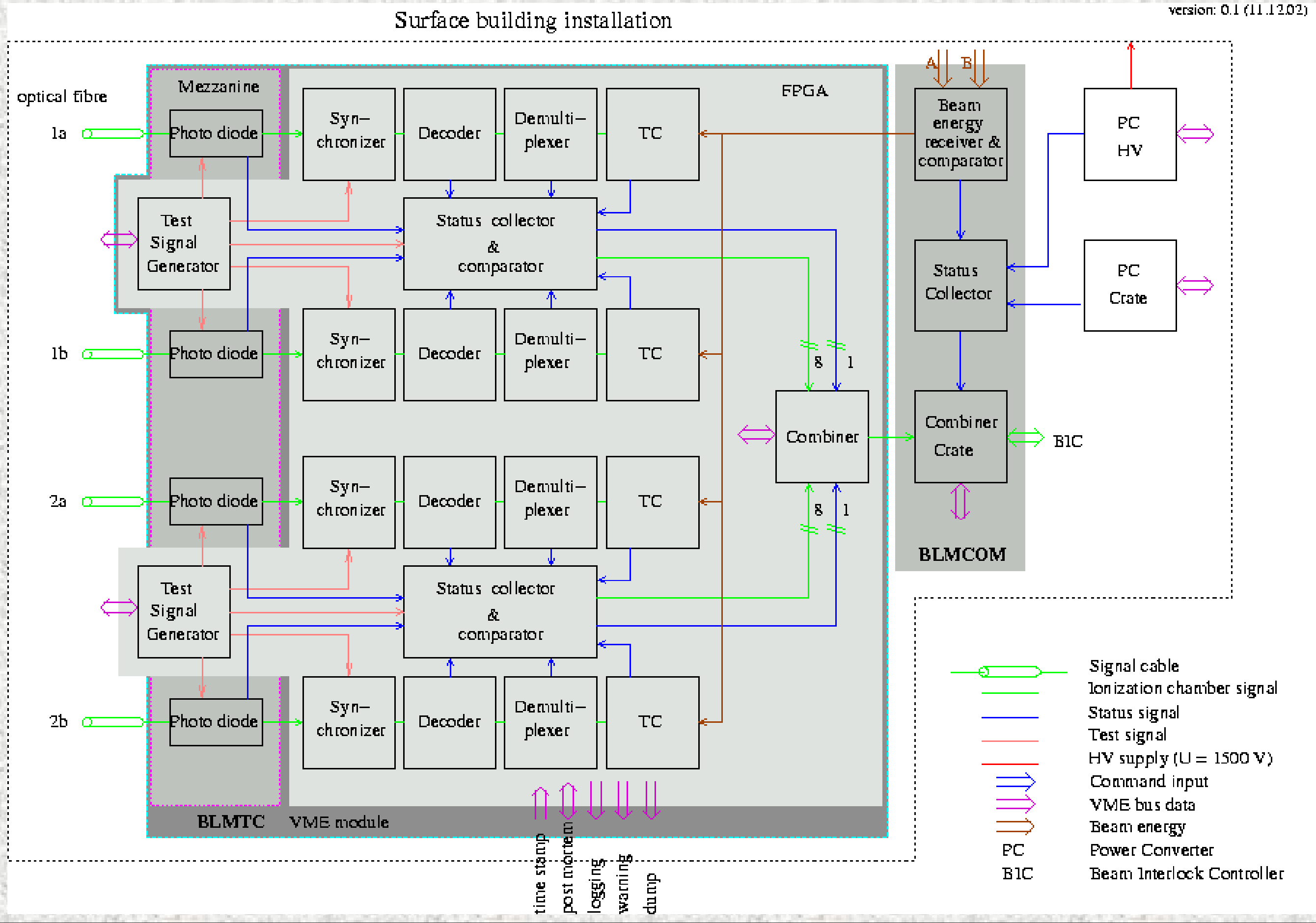
MaDe

FaDu

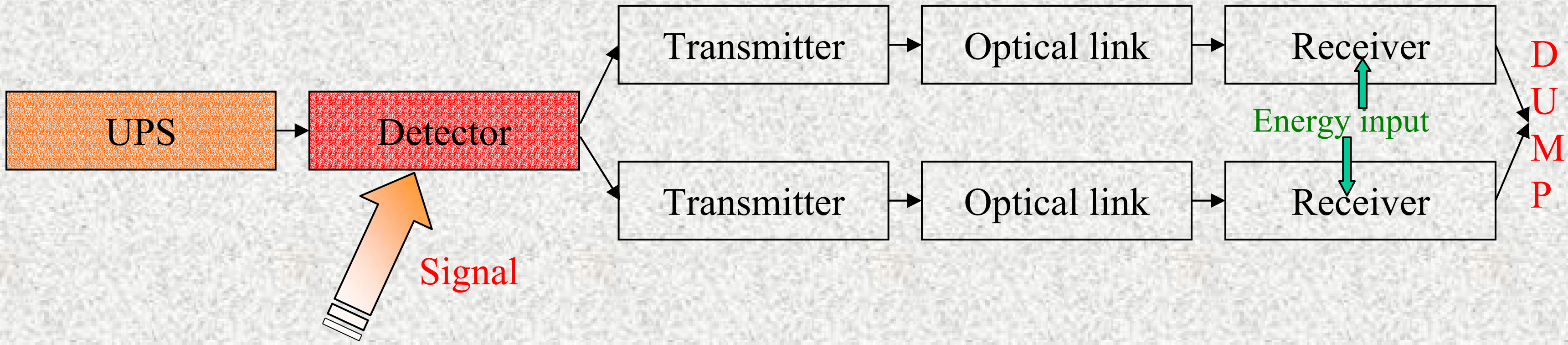
Front-end Electronic



Back-end Electronic



Our Layout

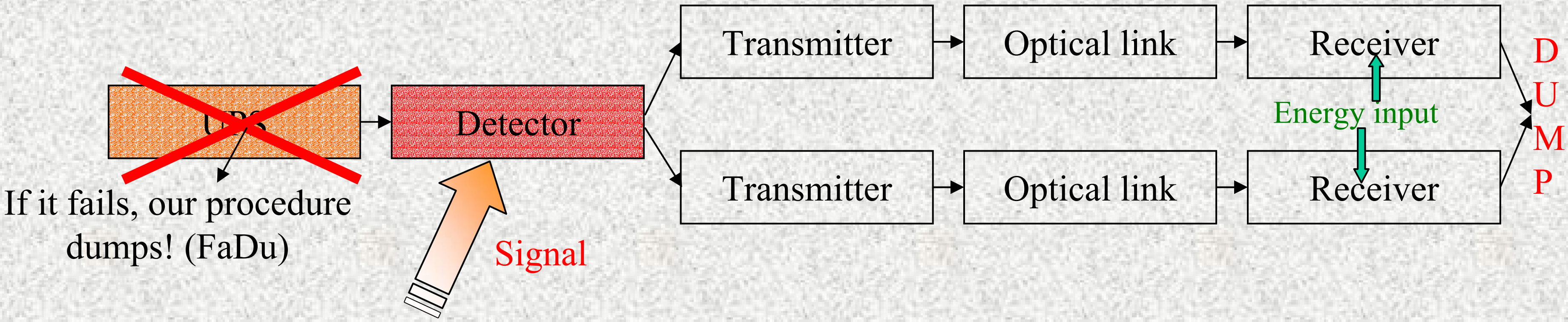


ELEMENT	λ [1/h]	inspection [h]
Ionization Chamber + 400m cable	2.58E-08	20
Amplifier (CFC)	2.78E-08	20
Photodiode	3.18E-08	continuous
JFET (CFC)	8.60E-08	20
2 Optical connectors	2.00E-07	continuous
Optical fiber	2.00E-07	continuous
FPGA RX	6.99E-07	continuous
UPS	1.00E-06	continuous
FPGA TX	2.02E-06	continuous
Laser	8.46E-06	continuous

Amplifier (CFC) → Continuous with bias current

JFET (CFC) → Continuous with bias current

MaDe



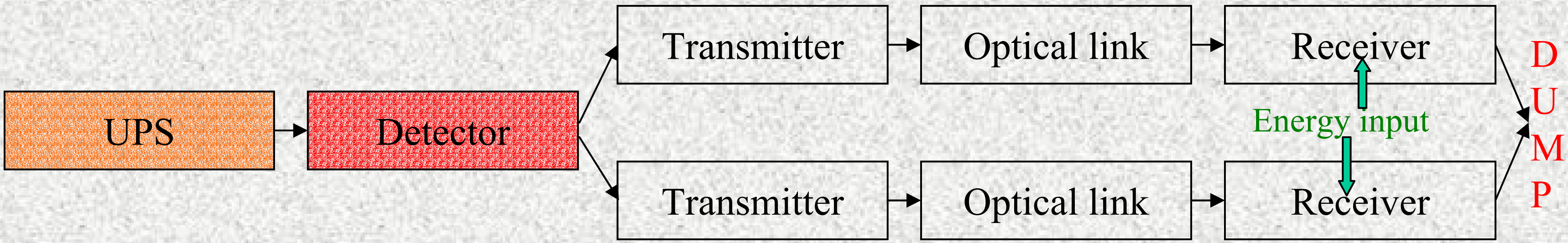
$$P_{MaDi} \sim P_S + Q_{BLM} + P_{en-} + Q_{DUMP}$$

- P_{MaDi}: **Probability to have a Magnet Disruption**
- P_S: **Probability not to detect the dangerous loss**
- Q_{BLM}: **Unavailability of the BLM system**
- P_{en-}: **Probability to underestimate the beam energy**
- Q_{DUMP}: **Unavailability of the DUMP system**

$< 10^{-7}$ /h

Threshold levels (FaDu) — **$4.96\ 10^{-7}$/h** — **?** — **?**

FaDu



$$W_{FaDu} \sim (W_{THR} + W_{BLM} + W_{en+}) * 3200$$

- W_{FaDu}: **Frequency of False Dump**
- W_{THR}: **Frequency of false dump signal**
- W_{BLM}: **Frequency of failure of BLM system+UPS**
- W_{en+}: **Frequency of overestimation of the beam energy**
- 3200: **Number of channels**

$$< \mathbf{10^{-6}}/h \longrightarrow < \mathbf{3*10^{-10}}\ /h$$

? **$1.24\ 10^{-6}$/h** **?**

Risk Matrix 1/2

- Foreseen failure rate:
  - MaDi: 4.96 10-7/h * 4000 h/y * 100 = 0.2/y

    Probable

  Beam hours: 200 d*20 h/d

  Dangerous losses per years

  - FaDu: 1.24 10-6/h * 4000 h/y * 3200= 16/y

    Frequent

  Number of channels

Risk Matrix 2/2

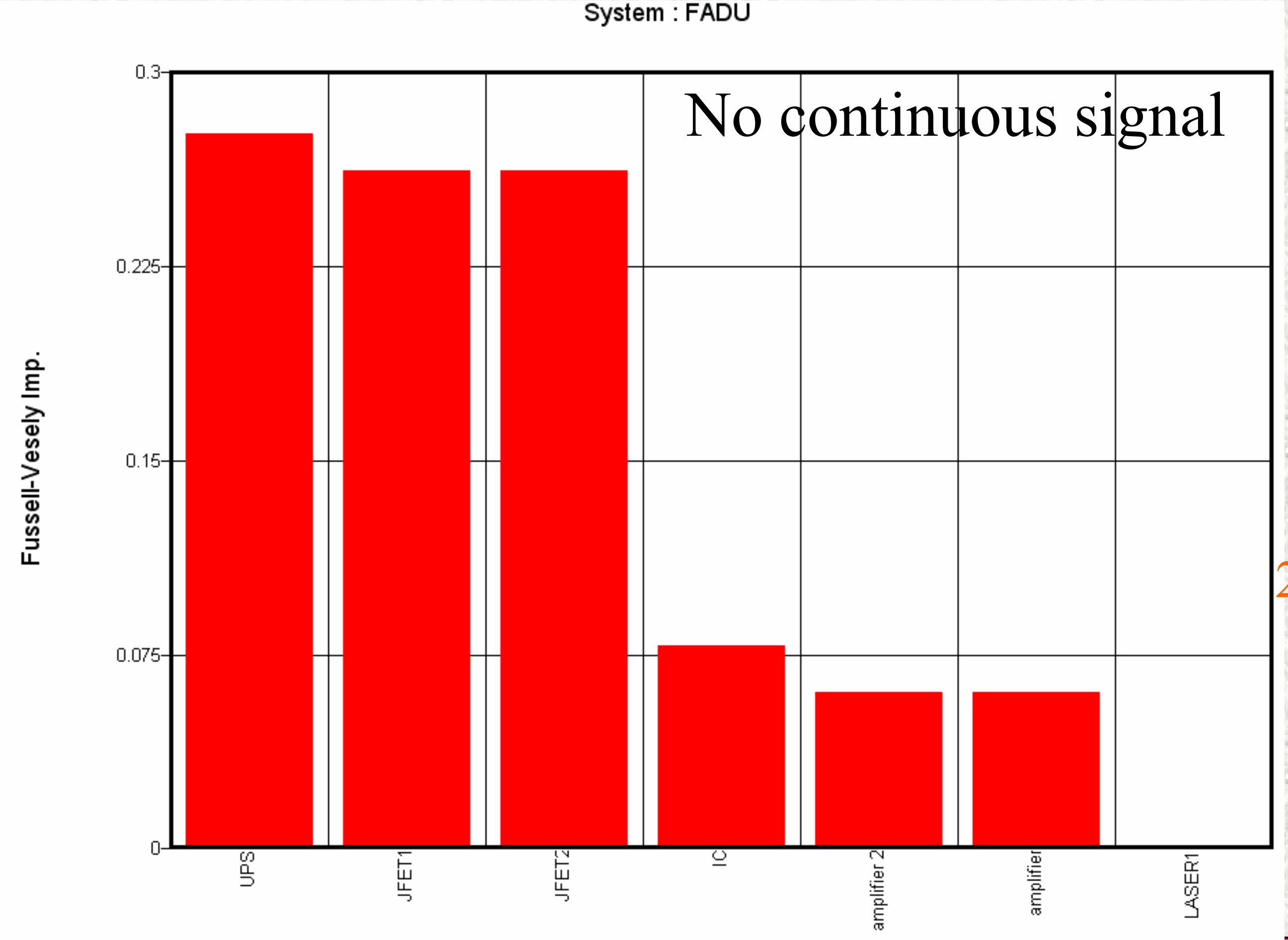
MaDe (Major) — FaDu (Minor)

Frequency	Consequence			
	Catastrophic	Major	Severe	Minor
Frequent	I	I	I	II
Probable	I	I	II	III
Occasional	I	II	III	III
Remote	II	II	III	IV
Improbable	II	III	IV	IV
Negligible / Not Credible	III	IV	IV	IV

We are beyond the border !!

I. Intolerable.
II. Tolerable if risk reduction is impracticable or if costs are disproportionate.
III. Tolerable if risk reduction cost exceeds improvement.
IV. Acceptable.

Event occurrence 1/2



FaDu frequency:

1.24E-6/h*4000h/y*3200= 16 FaDu/y

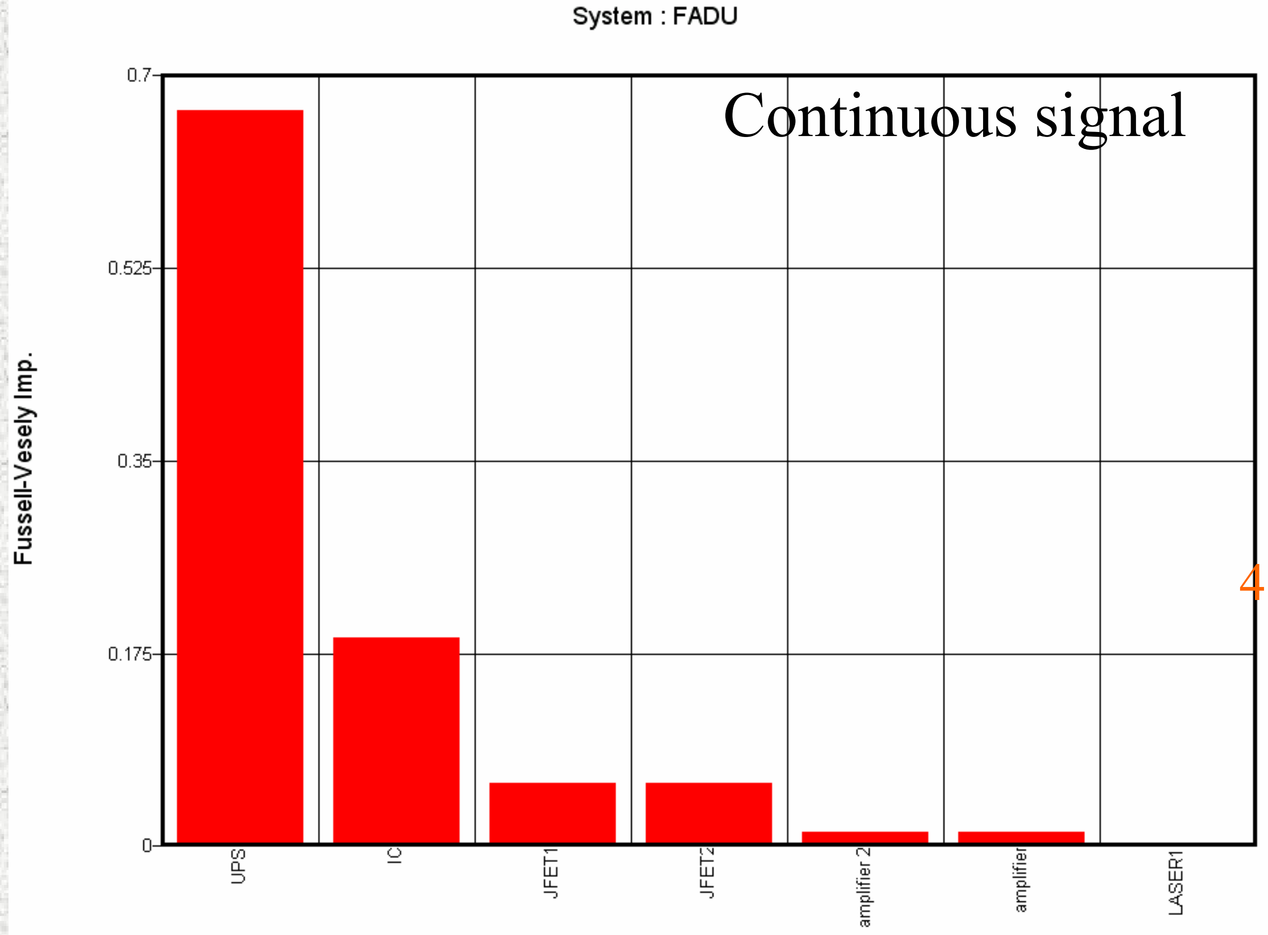
MaDe risk:

2.6E-6/h*4000h/y*100danger/y

~ 1 Magnet/y

Not acceptable!!

Event occurrence 2/2



FaDu frequency:

1.24E-6/h*4000h/y*3200= 16 FaDu/y

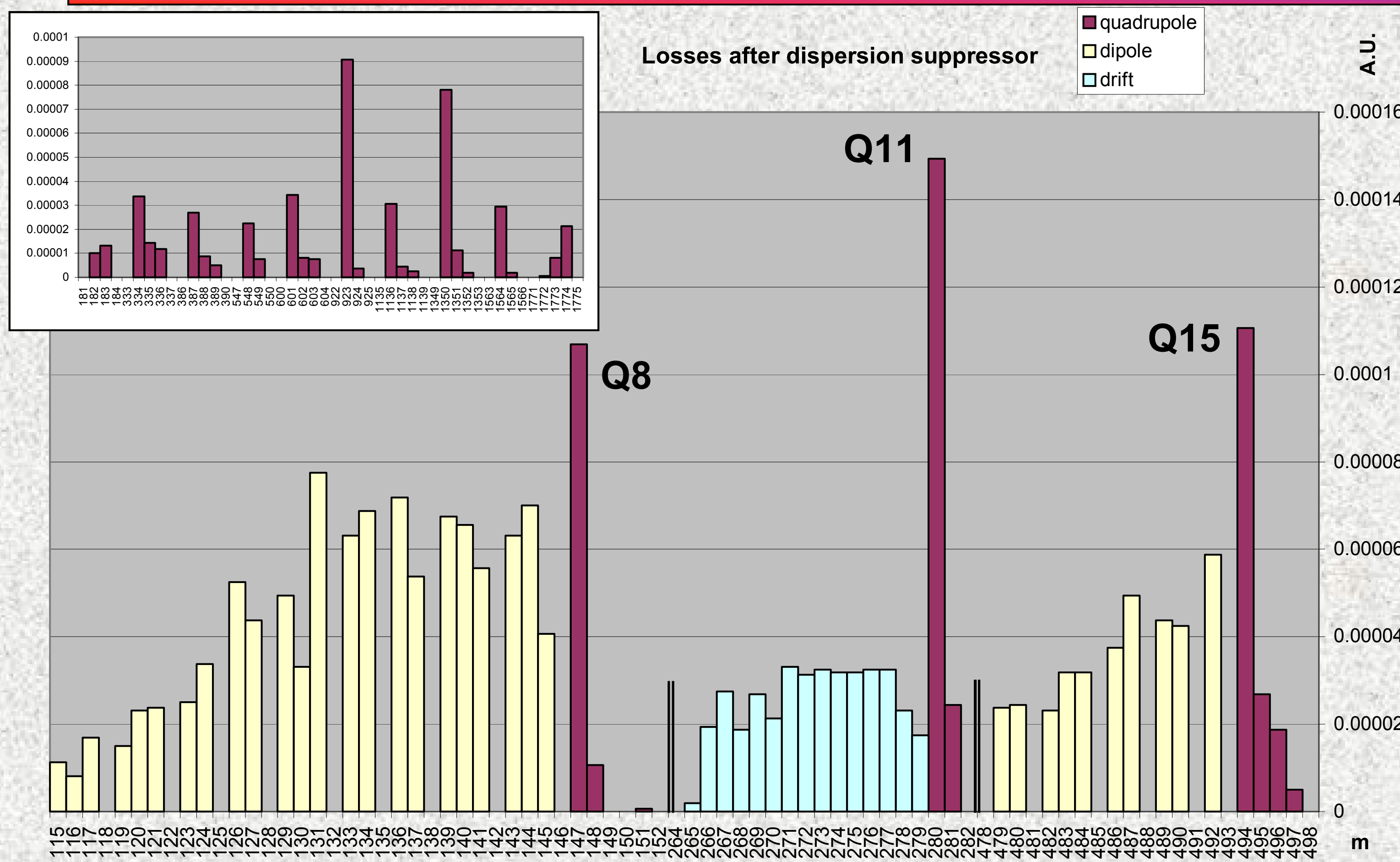
MaDe risk:

4.96E-7/h*4000h/y*100danger/y

~0.2 Magnet/y

Better...

Simulations



Possibilities:

1. Multiple losses: great reduction of MaDe.
2. Losses fingerprint: better definition of the position.

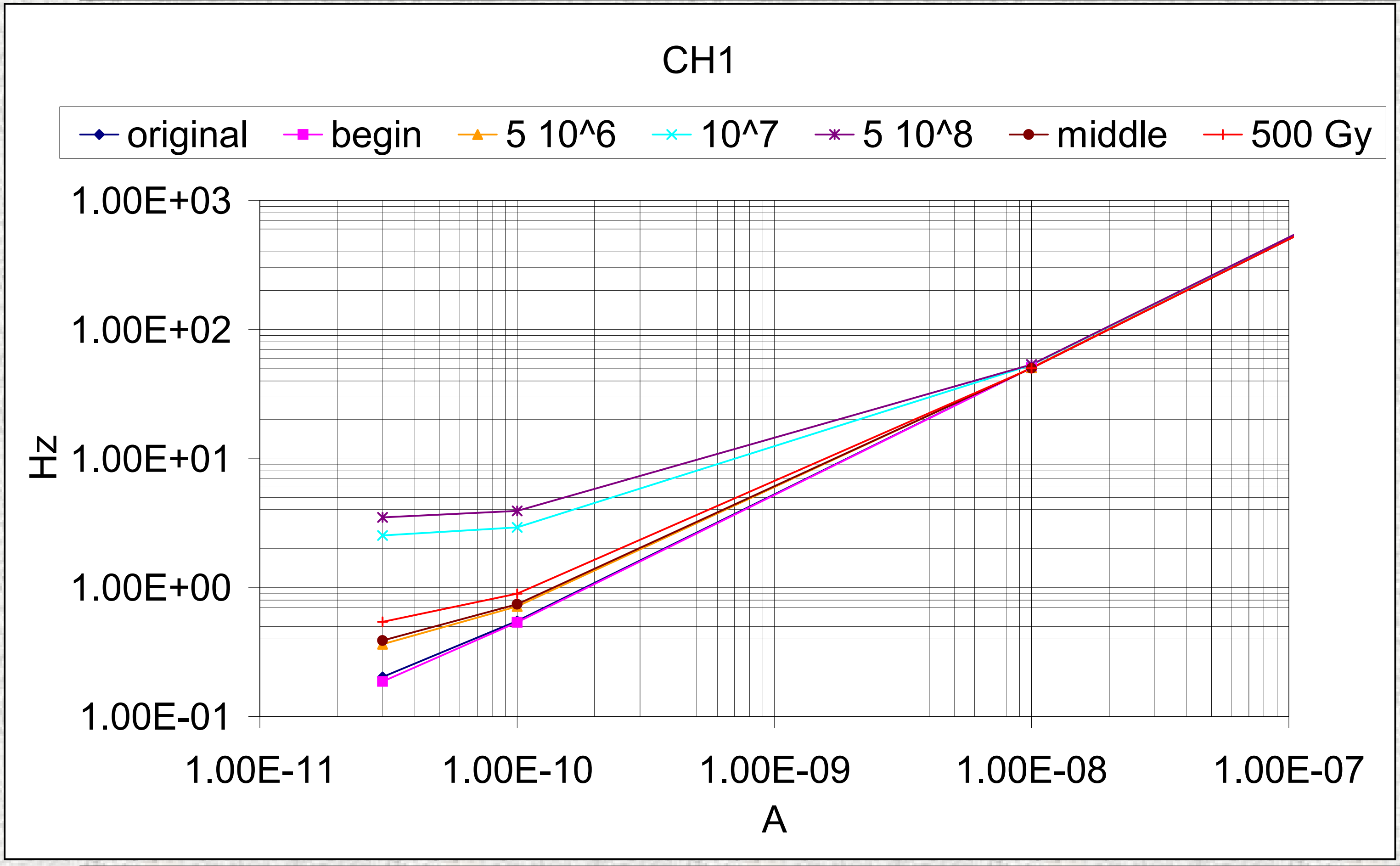
Partial conclusions

- We are on the border but:
  1. Probable multi-detection per loss (further simulations).
  2. Possible improving with continuous IC detection.
  3. Improving with better electronic components.

Irradiated Components

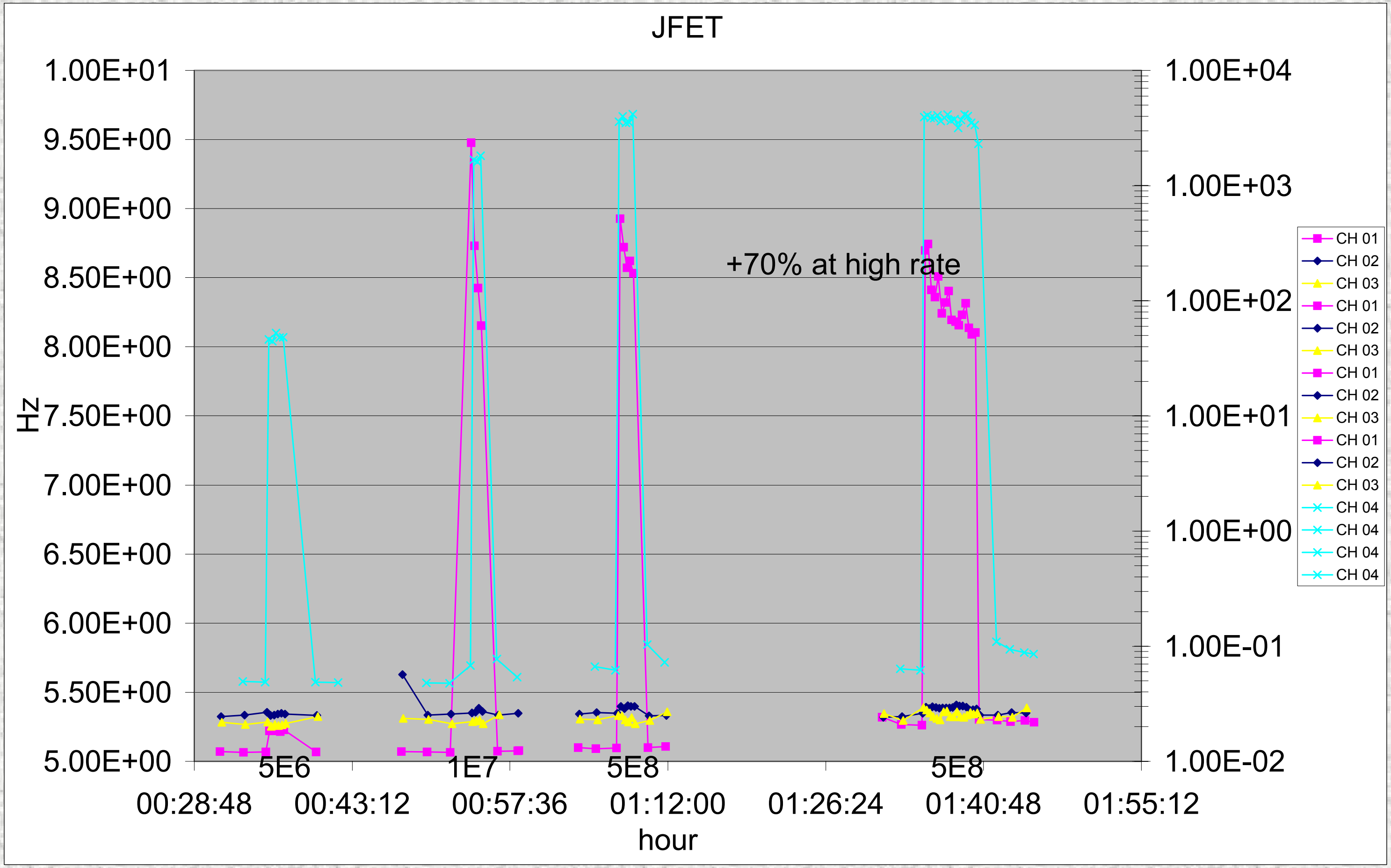
Component	Supplier	Name	Integral dose (effects after irradiation)	Single event (5E8 p/s/cm^2)
CFC JFET	TEMIC	J176	70 pA after 500 Gy (→ calibration)	+700 pA (dark current)
CFC Amplifier	BURR-BROWN	OPA627	No	-800 pA (current into the component)
CFC threshold comparator	PHILIPS	NE521	No	~+100 pA (threshold value is lower)
CFC monostable	PHILIPS	74HCT123	No	Small
Monodirectional Transceiver	ITEC	TRX03-SX5SC	1oo2 lasers dies at 500 Gy. PDs worsen at 300 Gy, break at 500 Gy.	Photodiodes lose ~ 18 dB of sensitivity
Monodirectional Transceiver	PHOTON TEC	PT7311-31-1	No laser breaks up to 1000 Gy. PDs worsen at 300 Gy, breaks at 430 Gy.	Photodiodes lose ~ 18 dB of sensitivity
Bidirectional Transceiver	ITEC	WBR 03-3SX5SC	Lasers die at 400 Gy. Photodiodes don't break up to 500 Gy	Photodiodes lose ~ 18 dB of sensitivity
Bidirectional Transceiver	PHOTON TEC	PT8X52-31-1	No laser break up to 700 Gy. Photodiodes break at 700 Gy.	Photodiodes lose ~ 18 dB of sensitivity

JFET integral dose



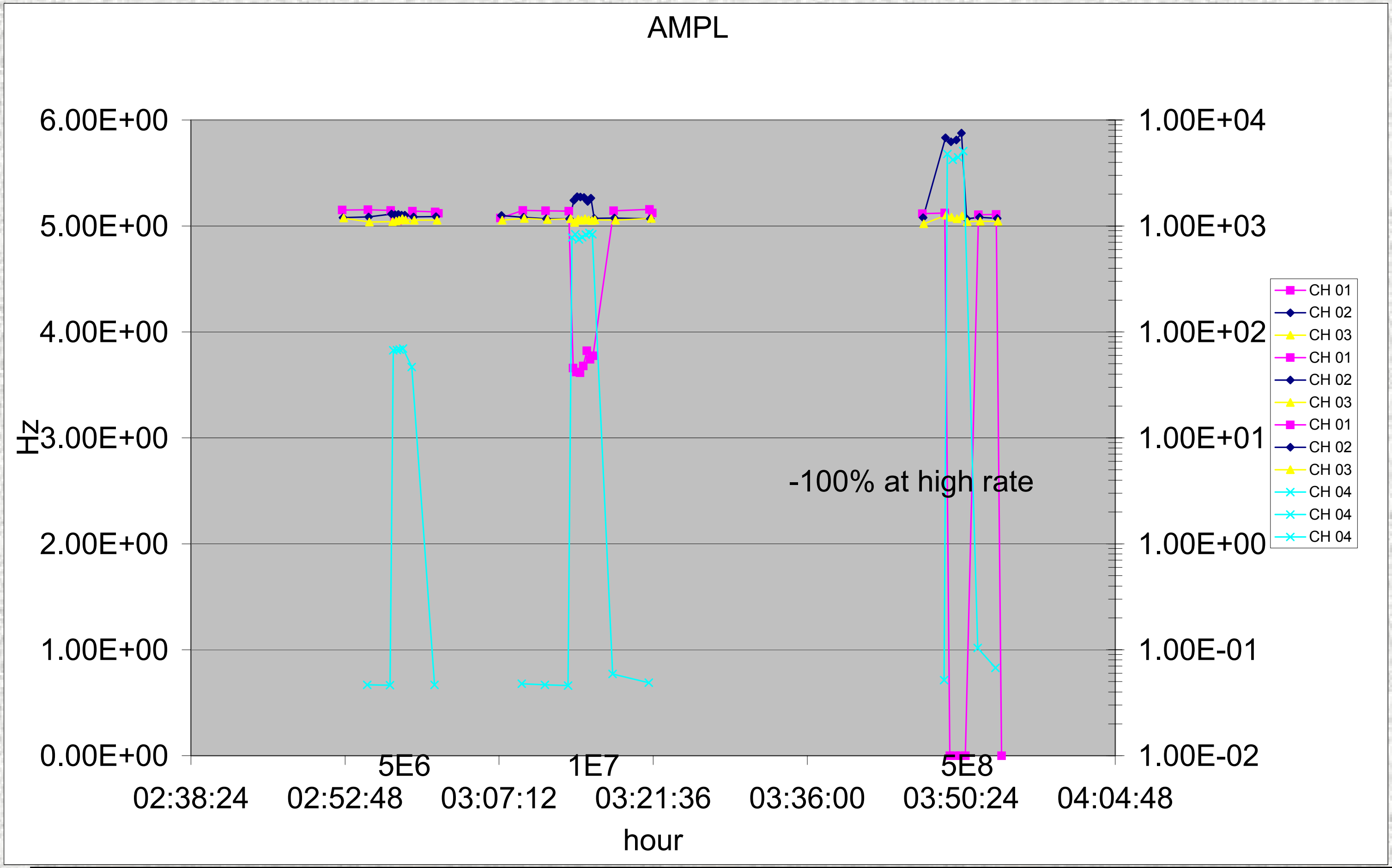
Increasing of (low) signal for irradiation and integral dose.

JFET Single event



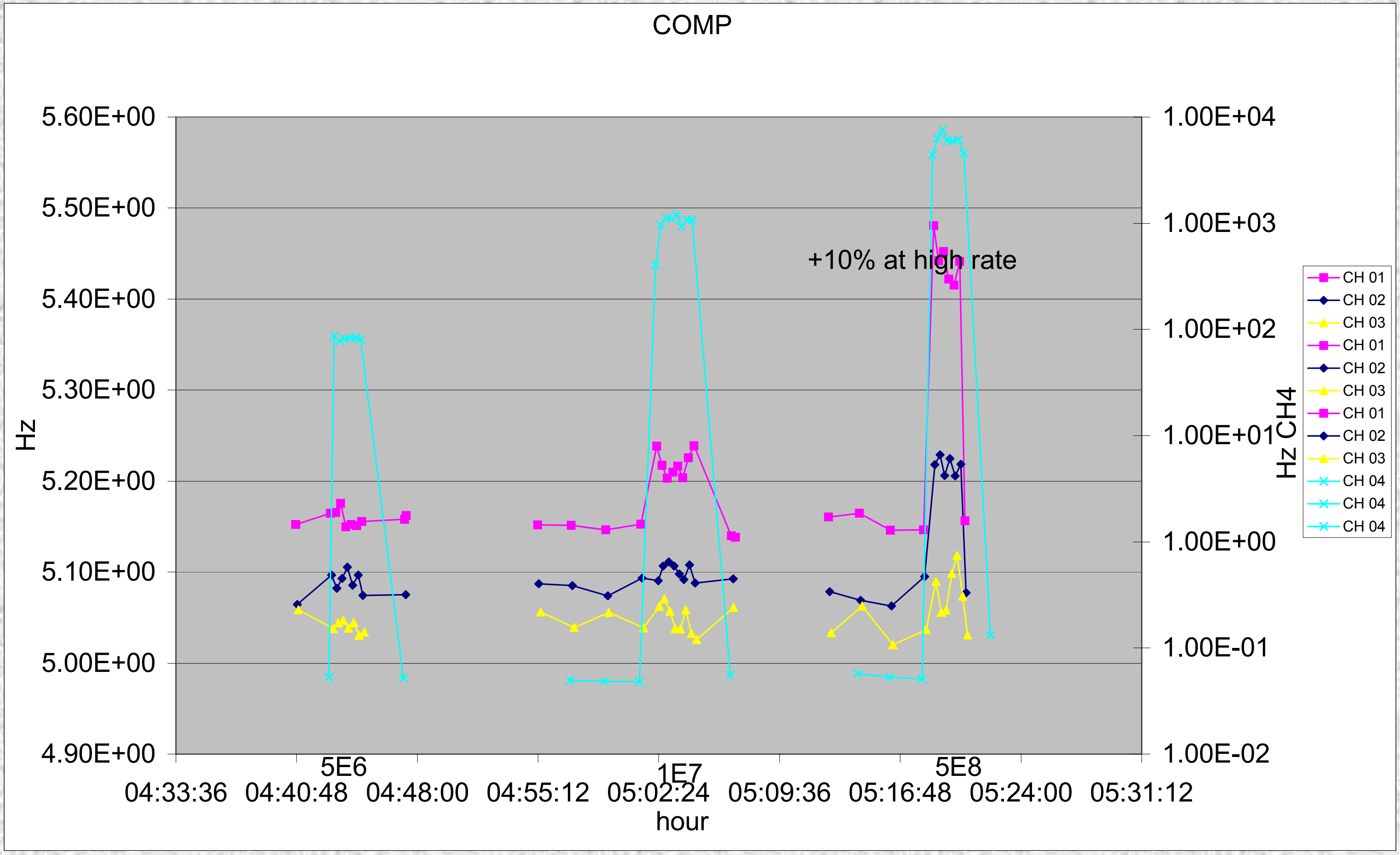
Increasing of signal above 1E7 $p/cm^2/s$

Amplifier Single Event



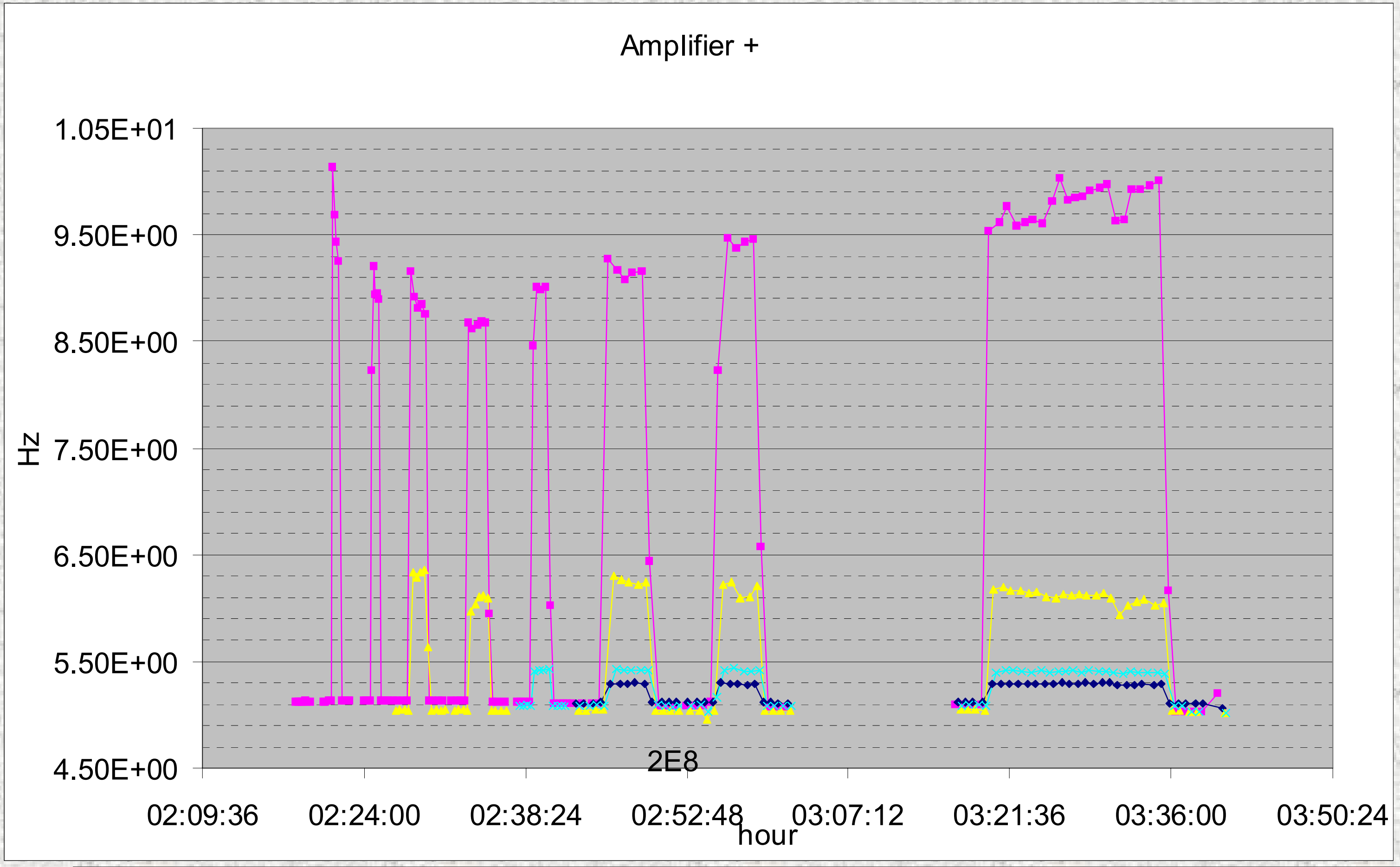
Decreasing of signal above 1E7 $p/cm^2/s$

Comparator Single Event



Little increasing of signal above 1E7 $p/cm^2/s$

AMPL+JFETs



General irradiation of Amplifier and JFET brings to signal increasing.

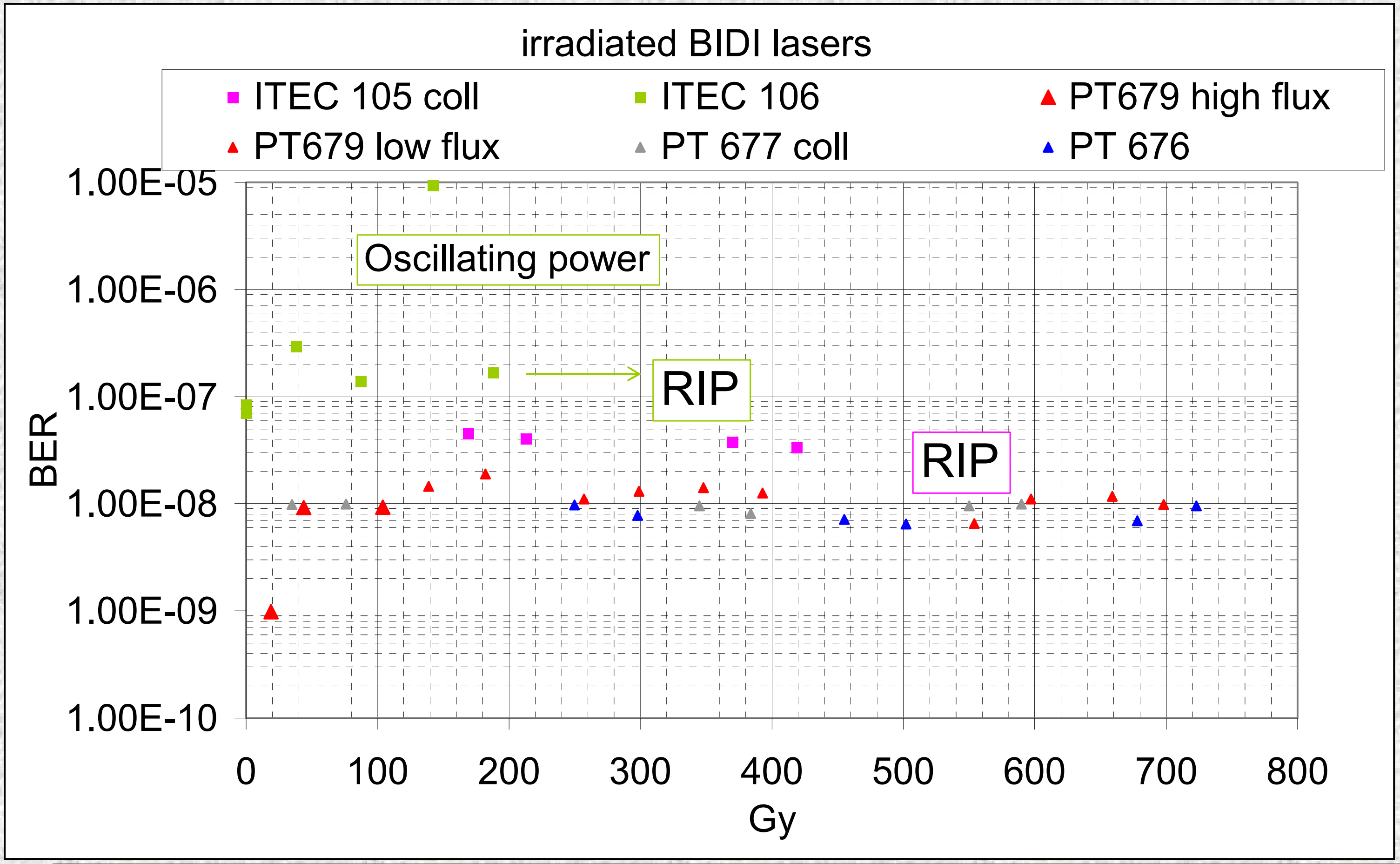
Single Event Effect

Energy	Steady state loss [p/m/s]	Geometrical factor	Loss FWHM [m]	MIP/p/cm^2	MIP/s/cm^2 on the CFC	quench limits current	Gy/y	weights	range (at dump limit)
450 GeV	7.00E+08	1.00E-01	3	3.00E-03	6.30E+05	60 nA	5.59E+02	0.3	max Gy/y
				5.00E-04	1.05E+05	10 nA	9.32E+01	0.3	7.26E+01
7 TeV	7.00E+06	1.00E-01	3	4.00E-02	8.40E+04	8 nA	7.46E+01	0.7	min Gy/y
				8.00E-03	1.68E+04	1.6 nA	1.49E+01	0.7	1.27E+01

For steady state loss we should not see single event effects: fluence on CFC too low.

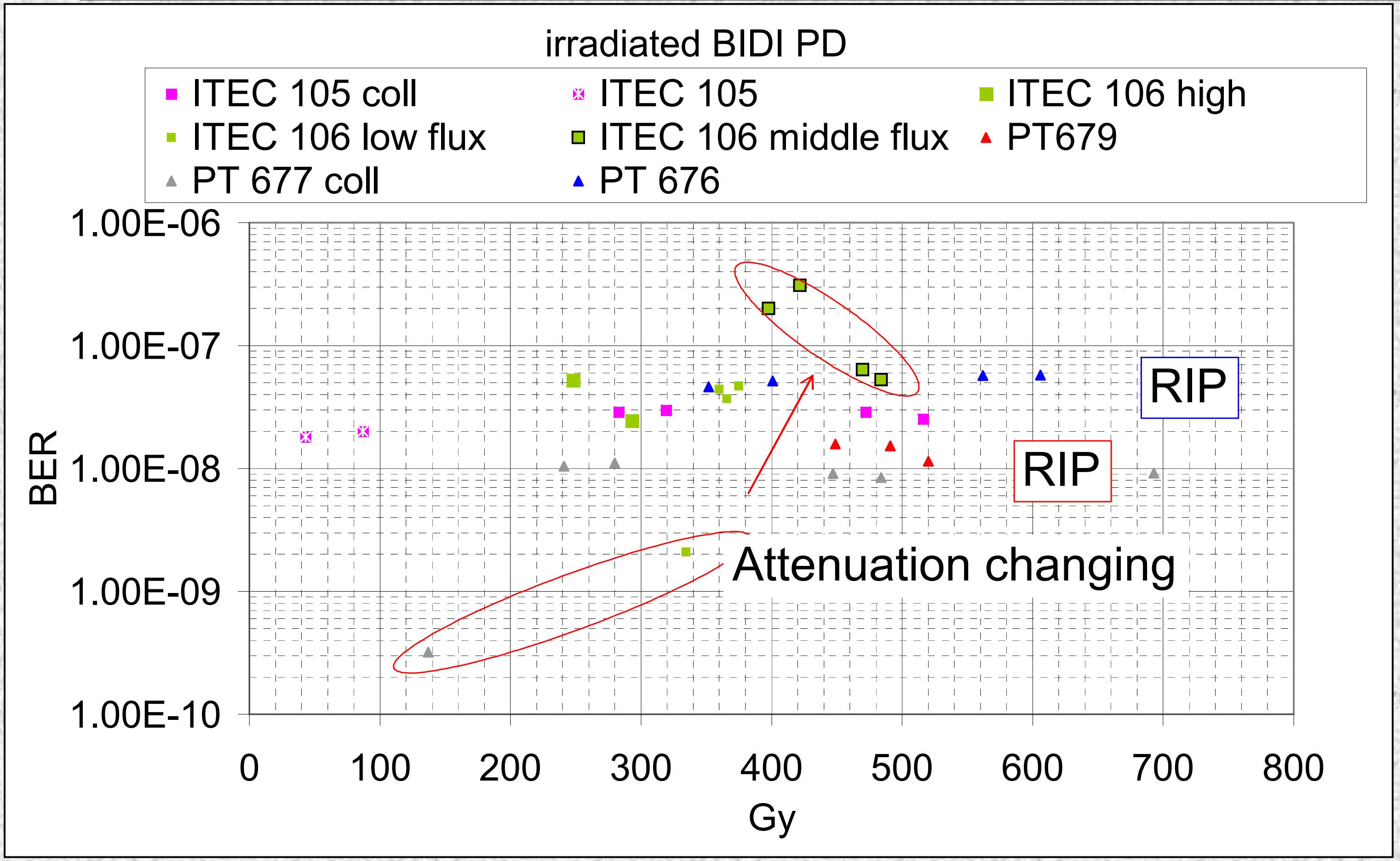
When we will have 5E6 MIP/s/cm^2 on CFC, we will have 1 nA of error current. At this fluence there are 476 nA coming from IC (corresponding to losses of 5.6E9 p/m/s @ 450 GeV, 4.2E8 p/m/s @ 7 Tev). Error of 1nA / 476nA = 0.2% at the dump limits: negligible error for the dump levels.

BIDI Lasers Irradiation



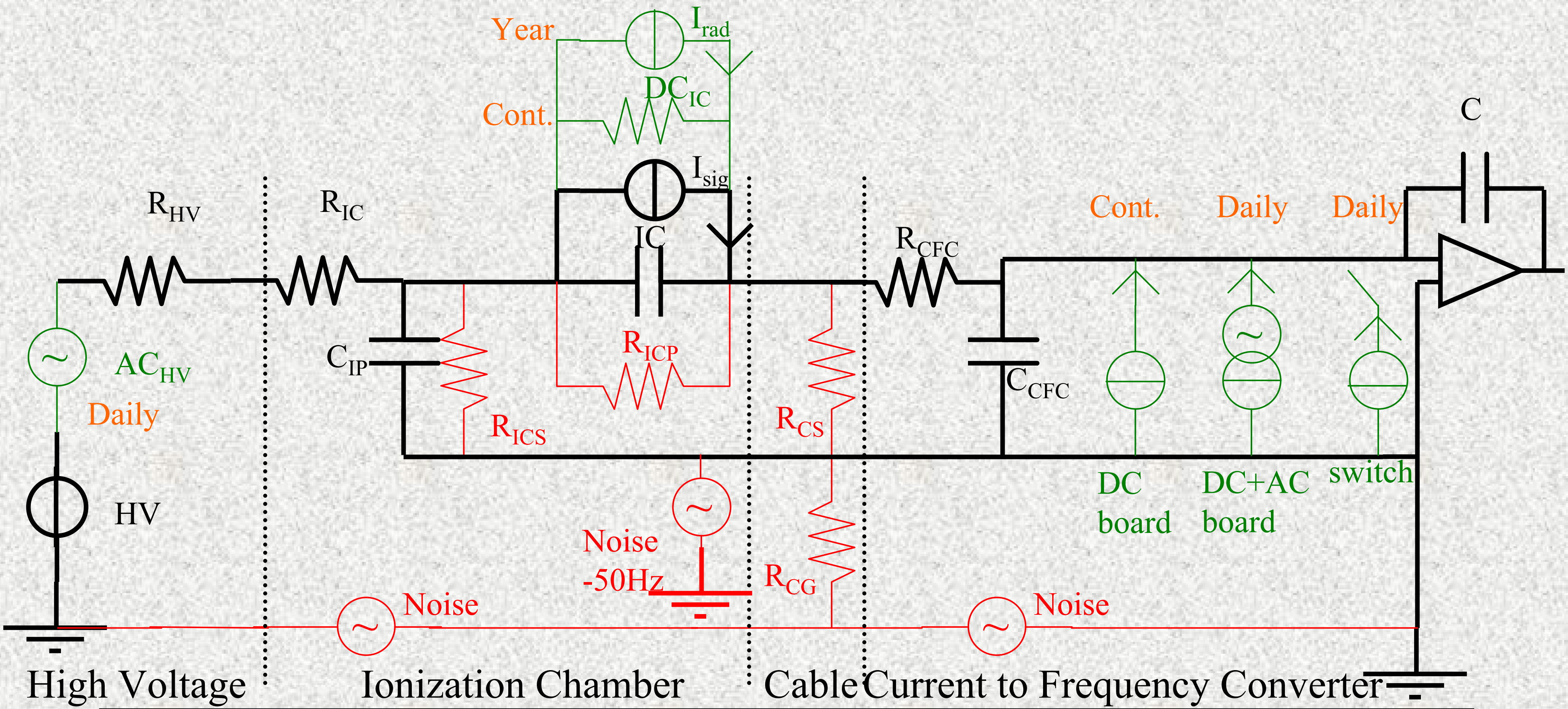
ITEC lasers had some problems during irradiation. Photontec ones no.

BIDI Photodiodes Irradiation



ITEC PD good up to 500 Gy. Photontec ones die around 700Gy.

Inspection and Failure Circuits



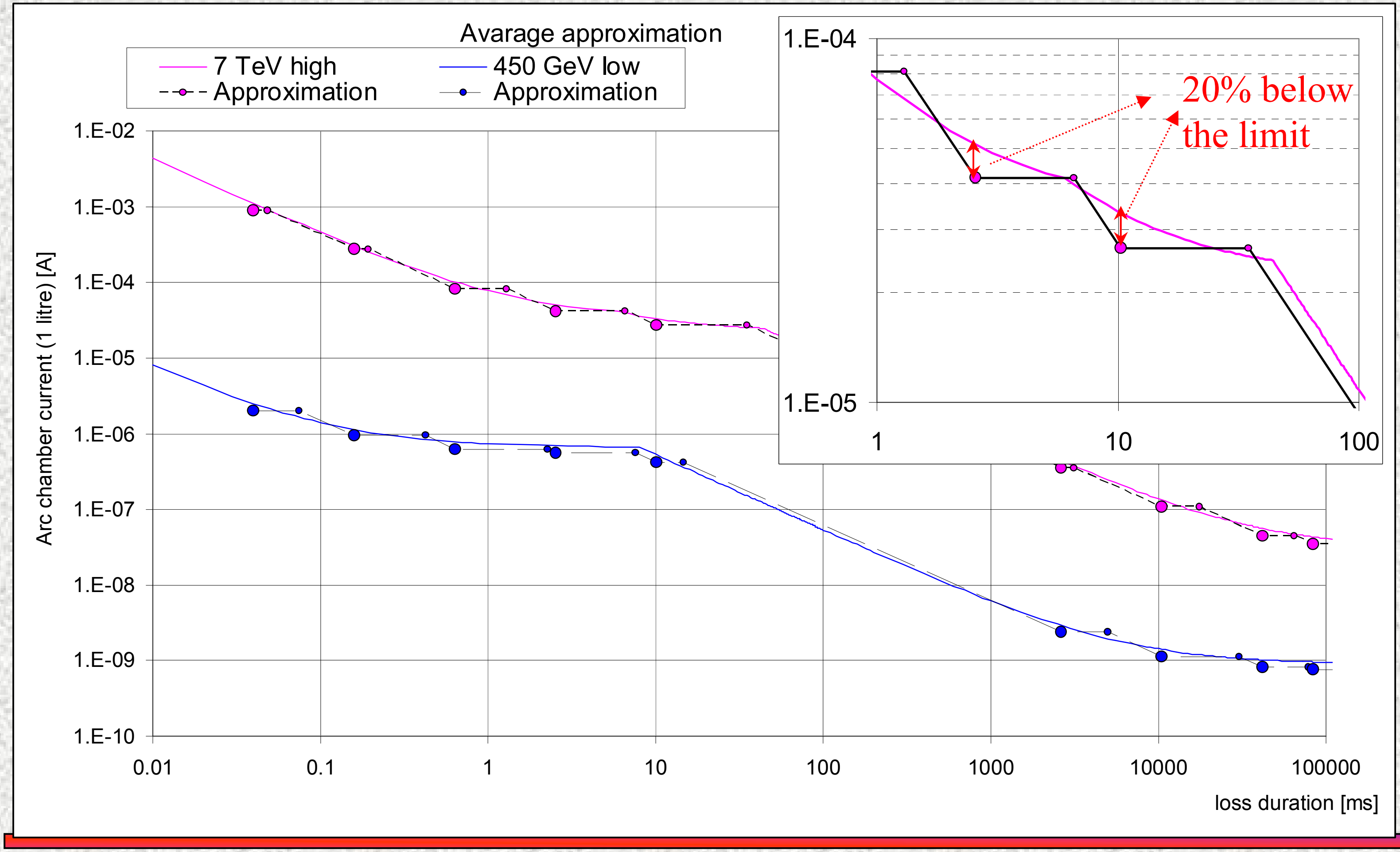
IC testing

	Detection time:	cont	cont	Fill	Fill	Fill	Year	Comments:
	Test:	DC-IC	DC-board	AC-board	SW-board	AC-HV	Rad-IC	
Ionisation chamber	Not connected	Cv				Ao, Sao	Cv	
	Wrongly connected						YES	
	R not nominal					Ao	Cv	
	C not nominal					Ao		
	Low R from chamber body to earth (Ricbg)					Ao, Sao	Scv	Noise level high, 50 Hz
	Low R from signal wire to earth (Rics)	Cv				Ao	Cv	
	Low R between plates (Ricp)	Cv	Cv	Ao, Bo	Cv	Ao	Cv	Current increase (choose optimal polarity)
HV	No HV	Cv					Cv	Check also with comparator at CFC
	HV not nominal	Cv					Cv	Check also with comparator at CFC
	Nominal gas mixture						Cv	
Cables:	Not connected	Cv				Ao, Sao	Cv	
	Wrongly connected						Cv	
	Low R from signal wire to earth (Rws)	Cv, Scv				Ao, Sao	Cv, Scv	General noise
	Low R from mass wire to earth (Rwg)	Scv				Sao	Scv	50 Hz noise
	Shielding connection broken	Scv				Sao	Scv	50 Hz noise
	Cross talk						Cv	

CFC testing

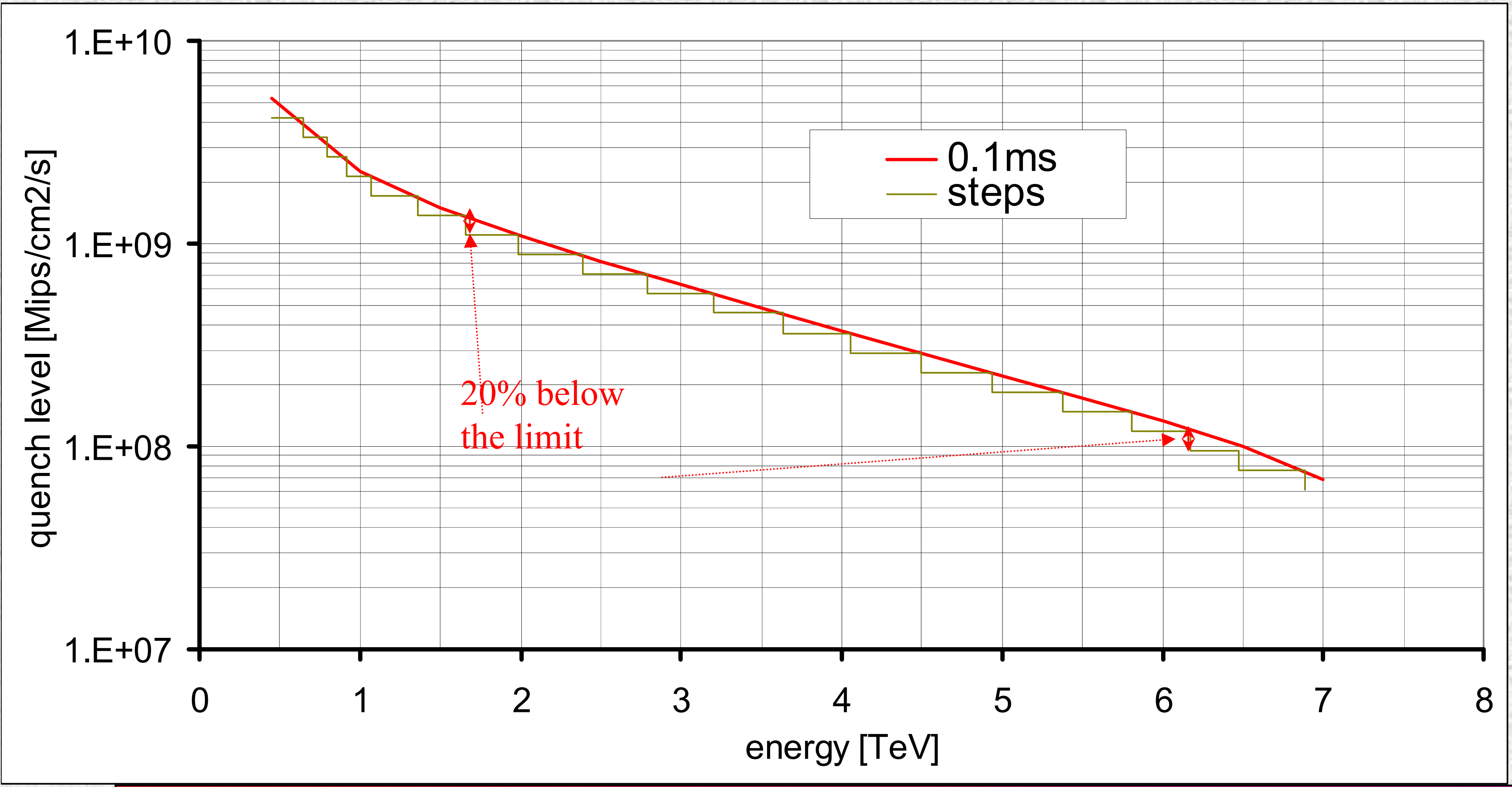
	Detection time:	cont	cont	Fill	Fill	Fill	Year	Comments:
	Test:	DC-IC	DC-board	AC-board	SW-board	AC-HV	Rad-IC	
Offset current changes	OPA 627 (amp)	Cv	Cv	Ao, Bo	Cv	Ao	Cv	
	Radiation	Cv	Cv	Ao, Bo	Cv	Ao	Cv	
	Humidity	Cv?	Cv?	Ao, Bo	Cv?	Ao	Cv	
	Temperature	Cv	Cv	Ao, Bo	Cv	Ao	Cv	
	J 167 (JFET)	Cv	Cv	Ao, Bo	Cv	Ao	Cv	
	Radiation	Cv	Cv	Ao, Bo	Cv	Ao	Cv	
	Humidity	Cv?	Cv?	Ao, Bo	Cv?	Ao	Cv	
	Temperature	Cv	Cv	Ao, Bo	Cv	Ao	Cv	
others	R1, R2, R3	Cv		Ao, Bo		Ao	Cv	
	C1, C2, C3			Ao, Bo		Ao	Cv	
	Supply voltage	Cv	Cv	Ao, Bo	Cv	Ao	Cv	Continuously checked
	Negative current	OK	OK	OK	OK	NO	OK	Needs a compensation
	Cross talk		Cv?	Ao, Bo?	Cv?		Cv	

Time Windows



9 time windows from 40 μs up to 100 s.

Energy Steps



32 Energy steps from 45 GeV to 7 TeV