BEAM LOSS MONITORS DEPENDABILITY

STATE OF ART

Basic Concepts

System fault events

- BLM are designed to prevent the Magnet Disruption (MaDi) due to an high loss (~30 downtime days).
- BLM should avoid false dumps (FaDu) (~6 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}

MaDi: 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

MaDi

FaDu

Sil Approach 3/4

SILs

Event Likelihood	MaDi	Consequence		FaDu
	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	$10^{-2} < Pr < 10^{-1}$

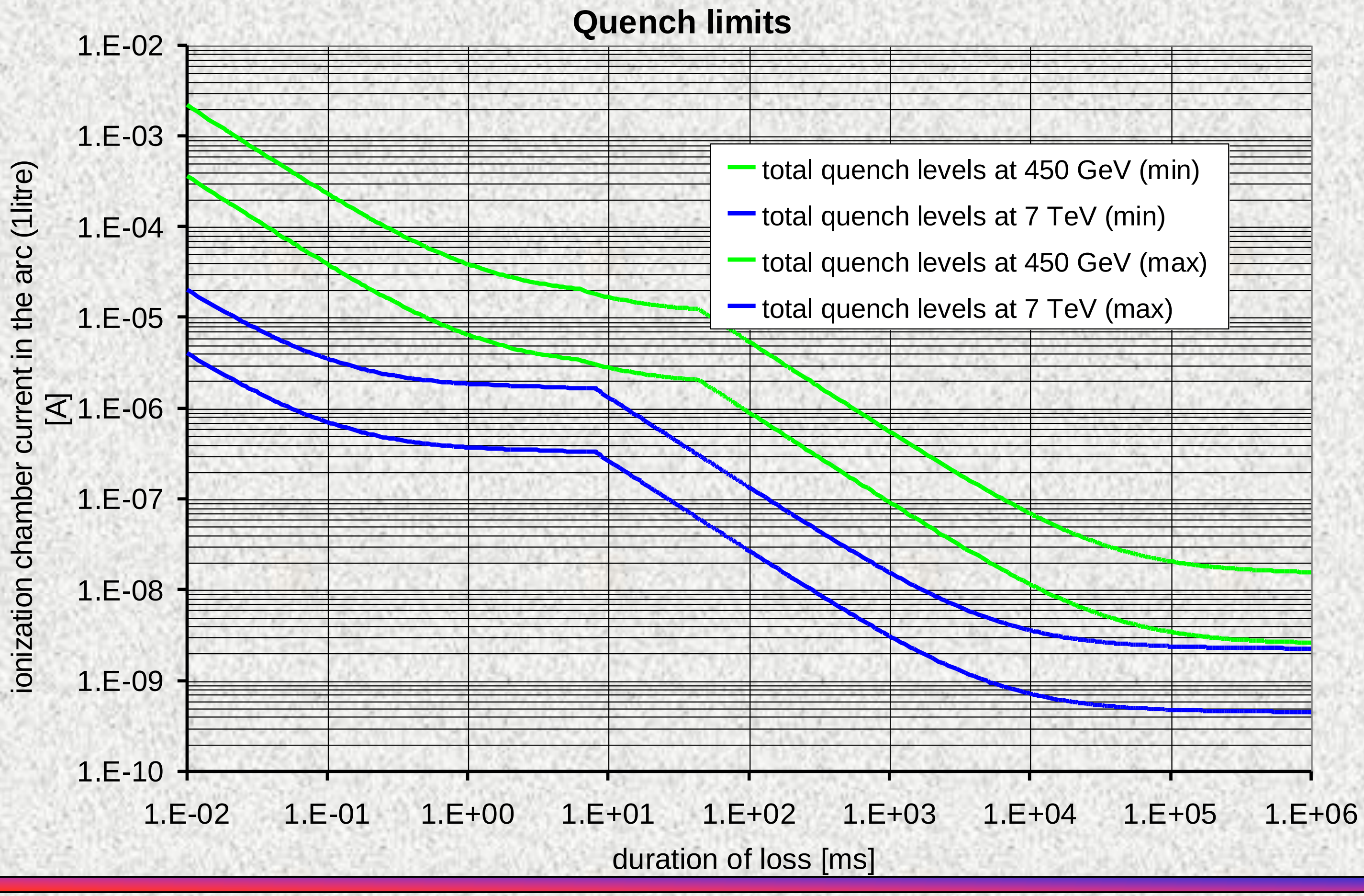
High demand / continuous mode of operation

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	$10^{-6} < Pr < 10^{-5}$

Our Scenario

- ~180 BLMs for collimators.
- ~3000 BLMs for magnets.
- Scan every 40 μs.
- Check every 1 ms.
- Signal with 8 order of magnitude.

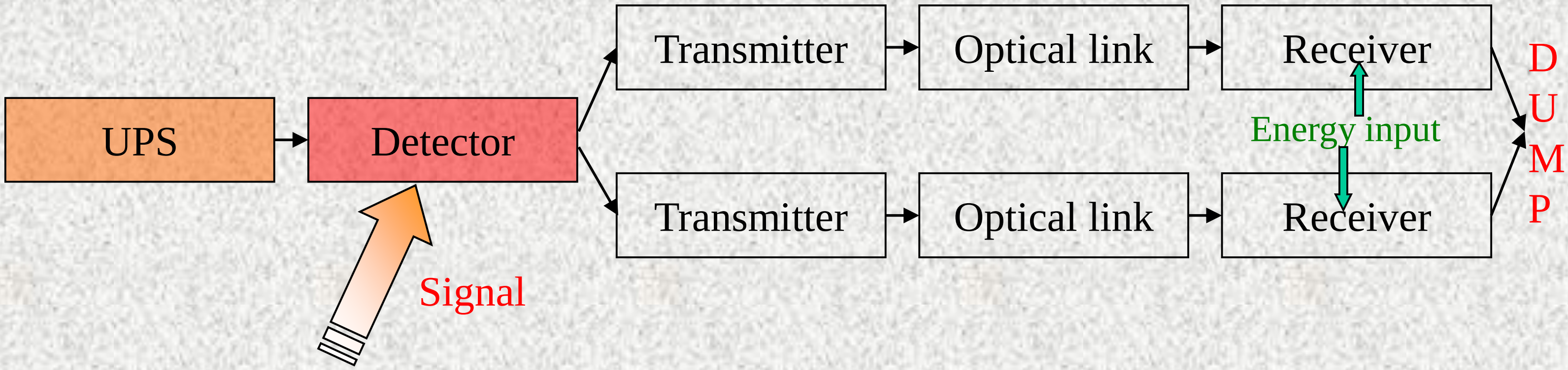
Threshold Levels



Our Selection

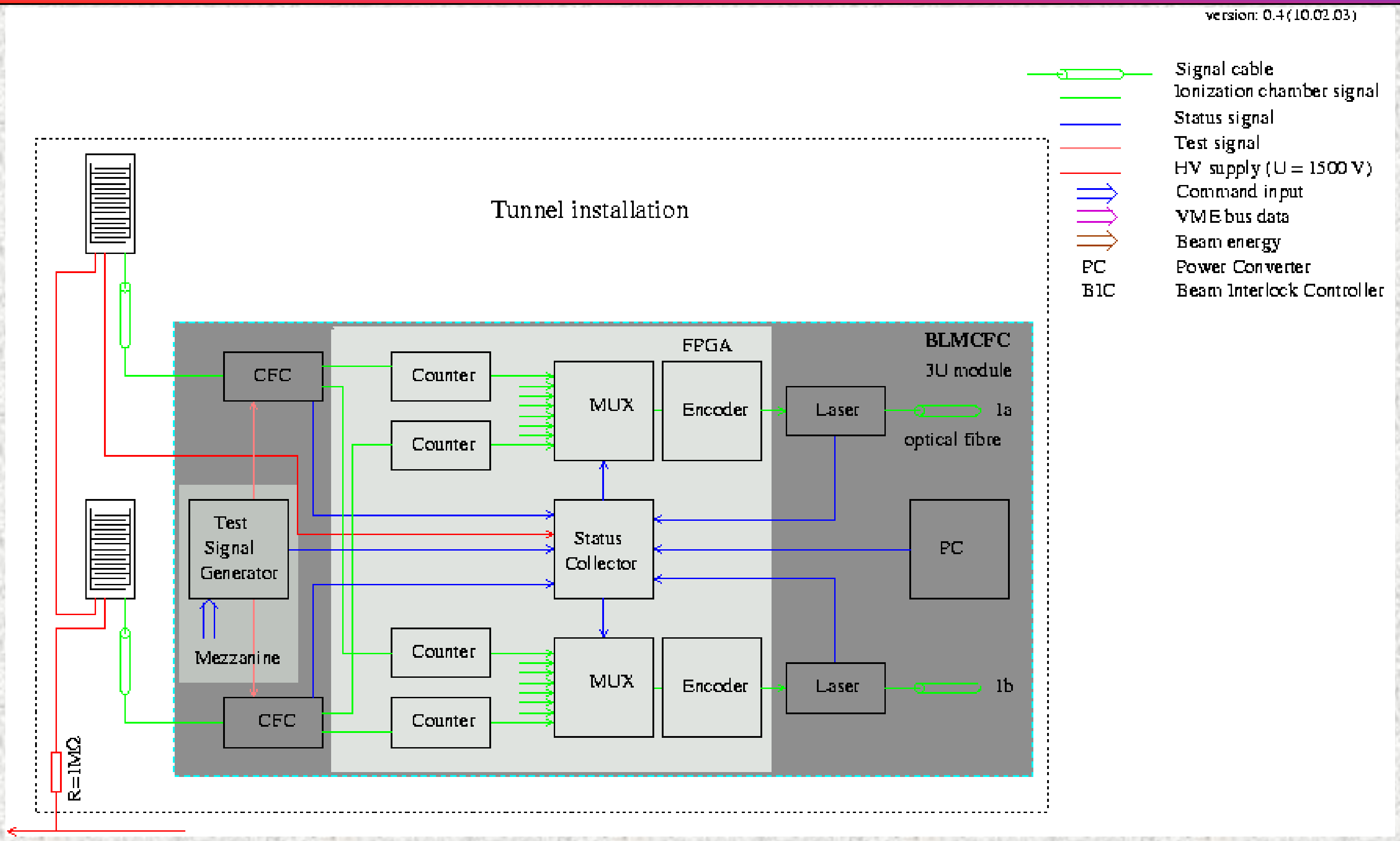
- Ionization chambers: reliable (no fails with 200 chamber during 20 years in SPS), wide range.
- Current to Frequent Converter (CFC), from 10^{-2} to $5\ 10^{6}$ Hz.
- Two optical lines: bandwidth, reliability.
- Use FPGAs: reliability, flexibility, cheap.

Our Layout

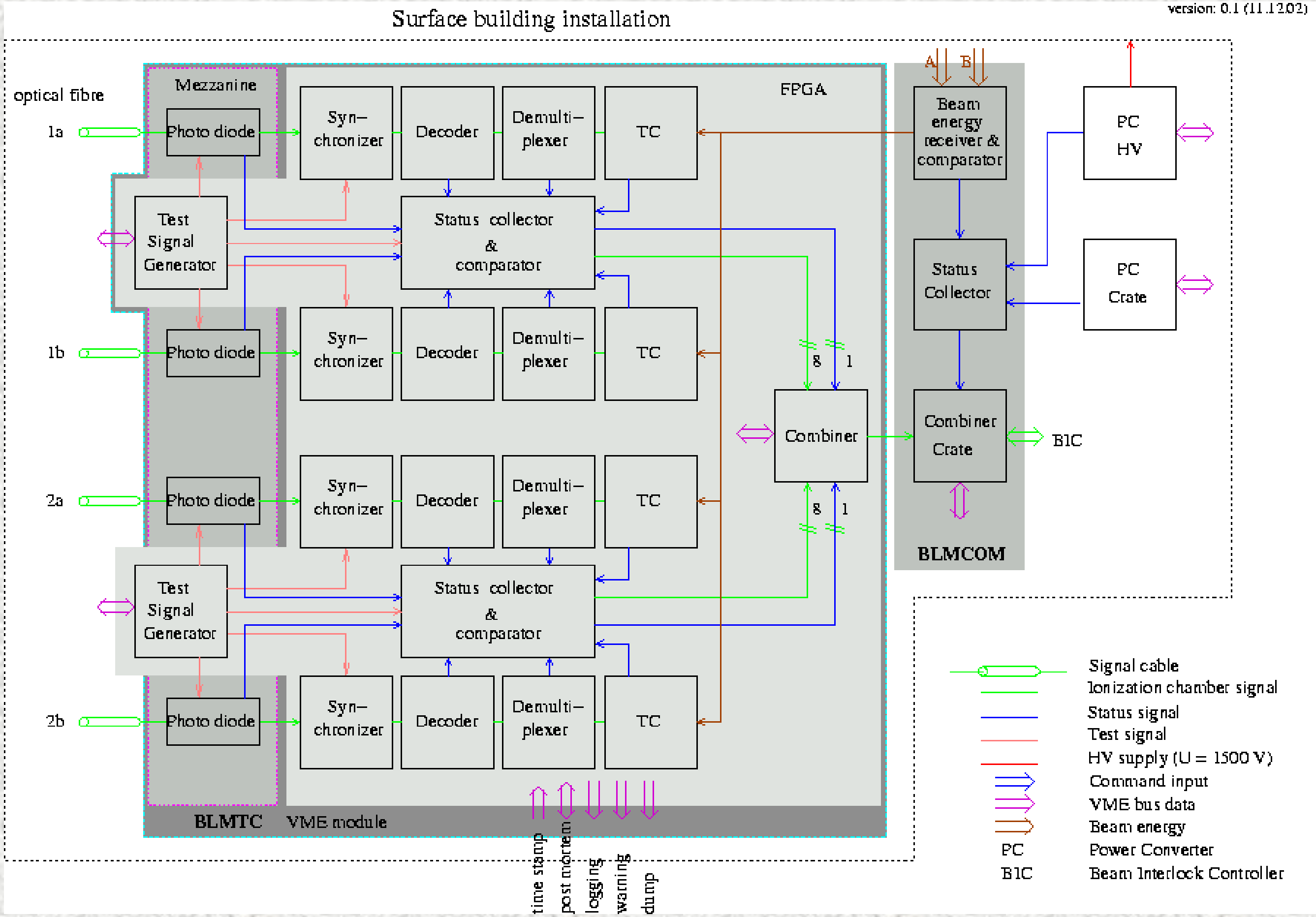


ELEMENT	λ [1/h]	inspection [h]
Ionization Chamber + 400m cable	2.58E-08	20
Amplifier (CFC)	2.78E-08	20
Photodiode	3.18E-08	2.78E-07
Switch (CFC)	8.70E-08	20
2 Optical connectors	2.00E-07	2.78E-07
Optical fiber	2.00E-07	2.78E-07
FPGA RX	6.99E-07	2.78E-07
UPS ??	1.00E-06	2.78E-07
FPGA TX	2.02E-06	2.78E-07
Laser	8.46E-06	2.78E-07

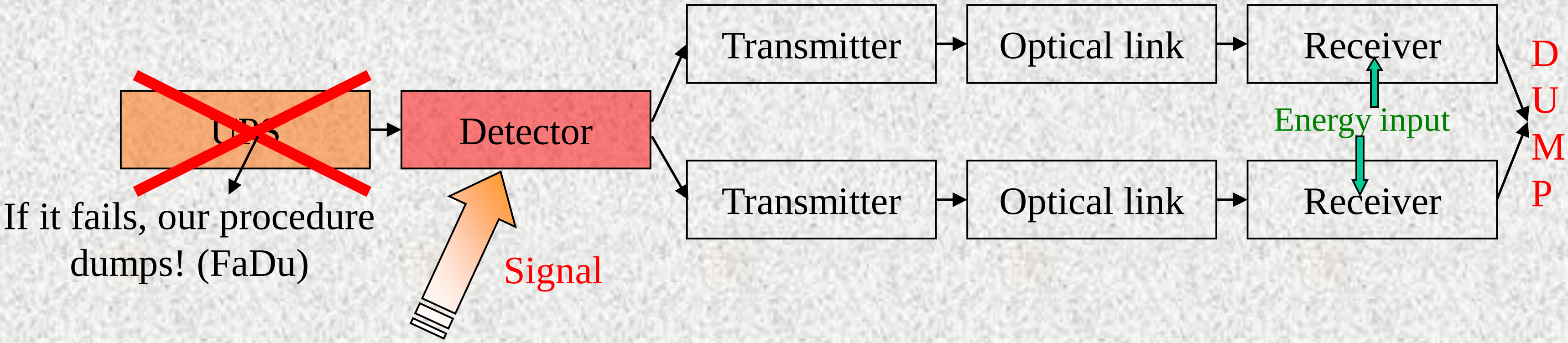
Front-end Electronic



Back-end Electronic



MaDi 1/2



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

Probability to have a Magnet Disruption

Probability not to detect the dangerous loss

Unavailability of the BLM system

Probability to underestimate the beam energy

Unavailability of the DUMP system

$< 10^{-7}$ /h

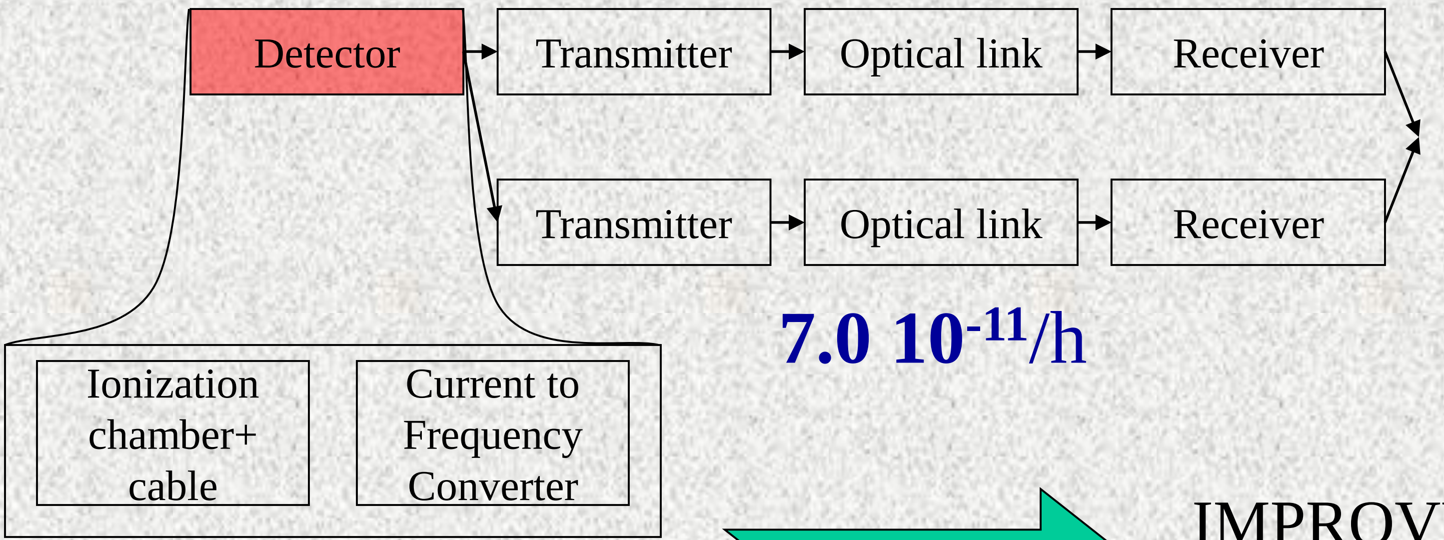
Threshold levels (FaDu)

$1.7\ 10^{-6}$/h

?

?

MaDi 2/2



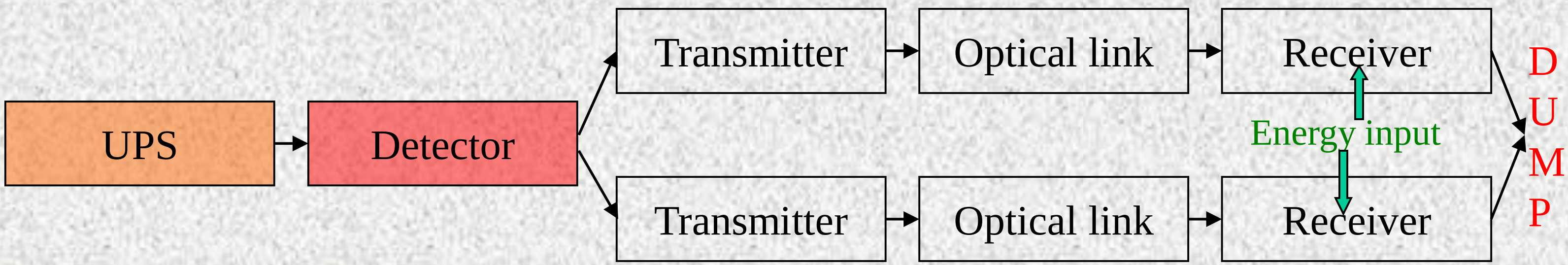
7.0 10^{-11}/h

< **2.8 10^{-7}**/h **1.4 10^{-6}**/h

$Q_{BLM} = 1.7\ 10^{-6}/h$

IMPROVE ELECTRONIC QUALITY + TESTING IC

FaDu



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

Probability to have a False Dump

Probability to have a false dump signal

Unavailability of the BLM system+UPS

Probability to overestimate the beam energy

Number of channels

$< 10^{-6}$/h → $< 3*10^{-10}$ /h

? $2.7\ 10^{-6}$/h **?**

Risk Matrix 1/2

- (Raw) Foreseen failure rate:
  - MaDi: 1.7 10-6/h * 4000 h/y * 100 = 0.7/y

    Probable

Beam hours: 200 d*20 h/d

Dangerous losses per years

  - FaDu: 2.7 10-6/h * 4000 h/y * 3200= 35/y

    Frequent

Number of channels

Risk Matrix 2/2

Frequency	**Consequence**	MaDi		FaDu
	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.

Actions

1. Improve the Current to Frequency Converter electronic quality.
2. Procedure to test the Ionization Chamber as frequent as possible.
3. Collect data about current unavailability of Beam Energy System and Beam Interlock Controller.
4. Estimation of the threshold levels failure rate for FaDu.

5. Multiple detections? If yes: coincidence (es: 2oo1000) in the Beam Interlock Controller?