nBLM System Status

L. Segui for the nBLM CEA group

3rd ESS Beam Diagnostics Forum

26/04/2017

OUTLINE

I. Introduction
II. Prototypes
III. Detector & FEE
IV. Gas system & Integration
V. DAQ & Control System
VI. MonteCarlo studies of response to ESS scenarios
VII. Conclusions and Outlook

INTRODUCTION

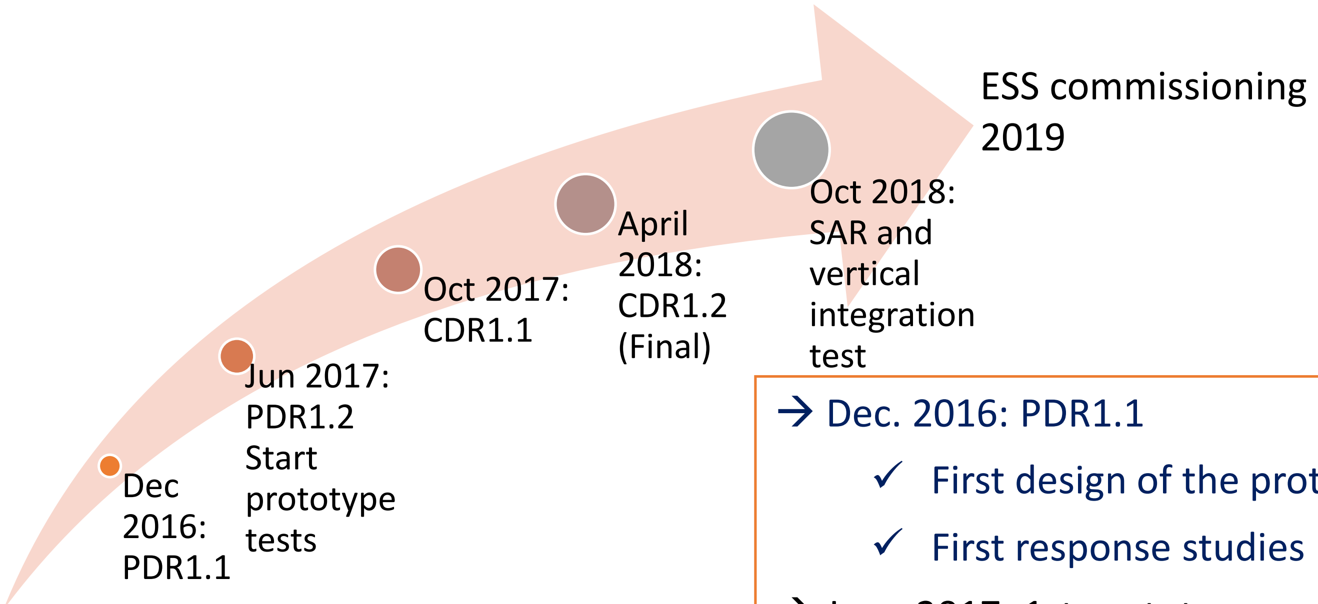
nBLM → neutron Beam Loss Monitoring system based on the detection of fast neutrons with Micromegas detectors. + low sensitivity to gammas and X-Rays.

- Objective: Protection + monitoring normal operation
  - ✓ To maintain accelerator activation at a low level (loss << 1 W/m)
  - ✓ For fine beam tuning purpose, particularly for high beam intensity
  - ✓ Machine Protection

- Project to deliver and commission 42 modules by **April 2019**
- To be installed mainly in the DTL region: E_{proton} 3.6 – 90 MeV
  - Some will be tested also at higher energies

- Why new BLM?
  - Complementary to the other ESS BLM systems
  - At low beam energy (E_{proton}>3 MeV), only neutrons and photons can escape beam pipe
  - Photons :
    - X-rays and γ's are highly produced by the RFQ as well as superconductive cavities
    - Impossible to distinguish contributions coming from beam than RF…
  - Neutrons :
    - Thermal neutrons: no loss locations
    - Fast neutrons: good for beam loss representation

INTRODUCTION: Schedule



→ Dec. 2016: PDR1.1

- ✓ First design of the prototype
- ✓ First response studies

→ June 2017: 1st prototype

From June 2017 – April 2018

nBLM tests at different radiation facilities

- ➢ SEDI: long term stability, efficiency, electronics
- ➢ LICORNE: neutron efficiency
- ➢ LINAC4: response under “close to real” conditions
- ➢ Birmingham MC40 irradiation facility: loss products detection, ageing

→ Oct 2018: Final prototype design

→ System delivered to ESS Nov. 2018

→ ESS hand over: April 2019

PROTOTYPES

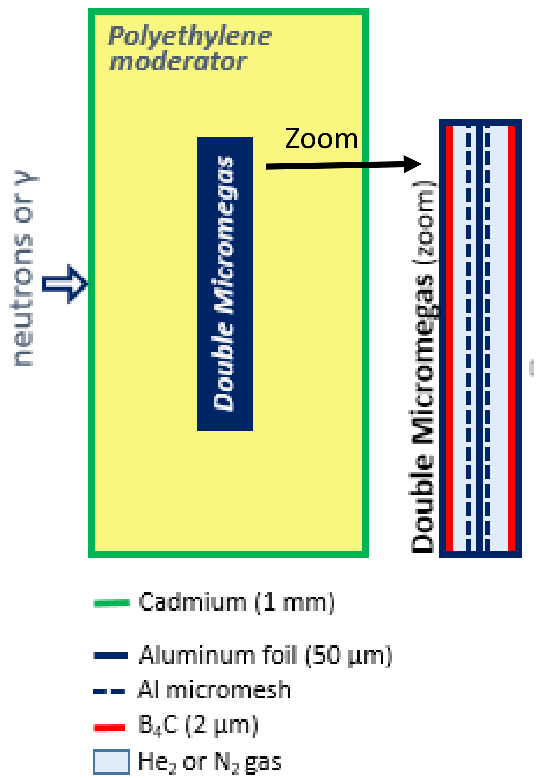
➢ Each nBLM module consist on two types of detectors: slow and fast

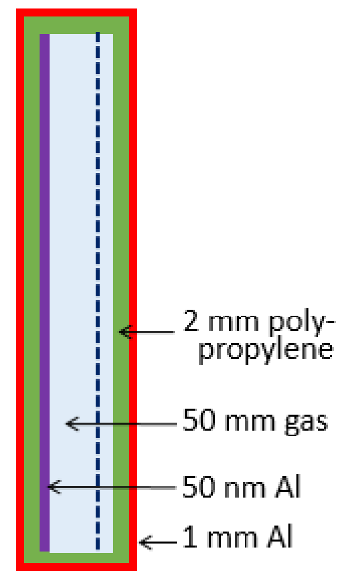
SLOW

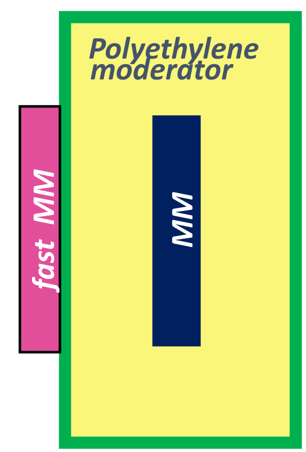
- ❑ (n, α) ^{10}B reaction
- ❑ Detection of fast neutrons after moderation in polyethylene (~4cm)
- ❑ More efficient, 4π, but slower response

FAST

- ❑ Recoil protons produced by neutrons in polypropylene
- ❑ High flux high energy n's (>0.1 MeV)
- ❑ Faster response







Assembled

PROTOTYPES

- Each nBLM module consist on two types of detectors: slow and fast

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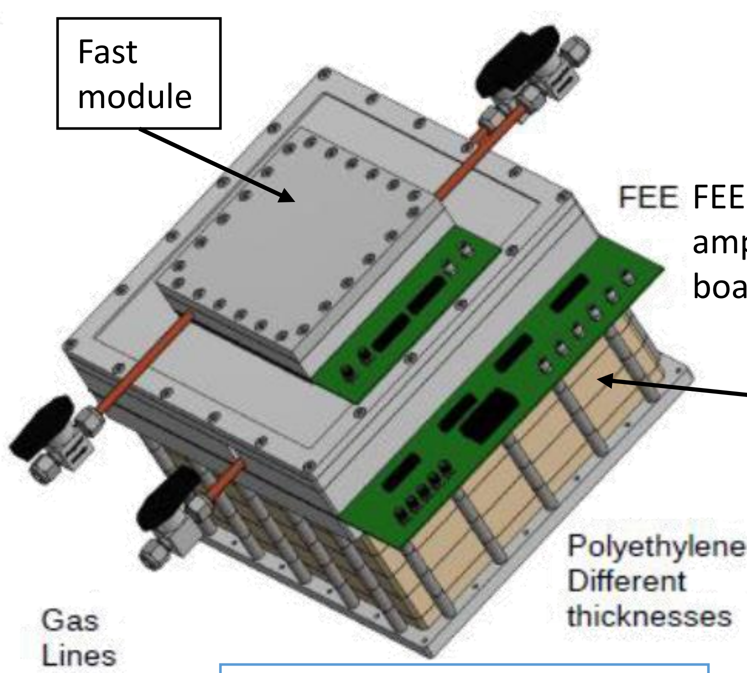
Fast module



FEE electronics: amplifier on board

Slow module:
- MMs chamber surrounded by moderator
- Size ~30x30x30 cm^3

- All dimensions easily modified in prototypes (drift, boron convertor, moderator, etc)

Design by D. Desforges

PROTOTYPES

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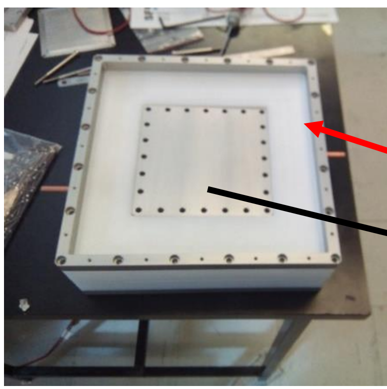
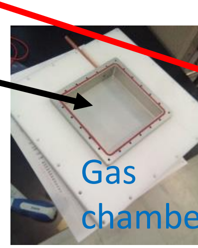
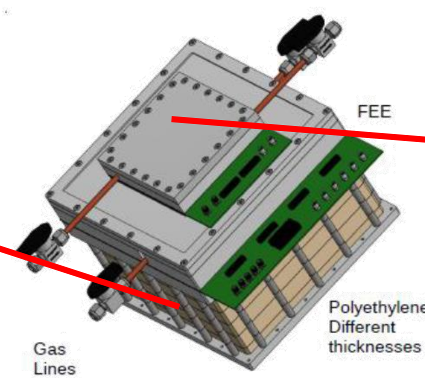
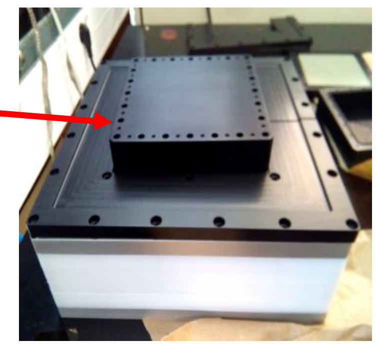




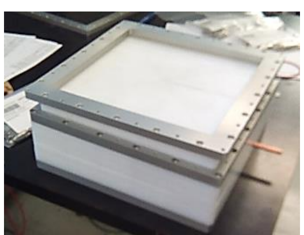
Gas chamber



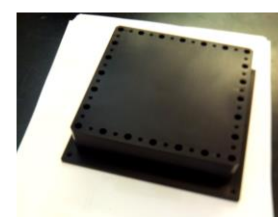


Different thickness of polyethylene can be added

Fast module integrated in the slow



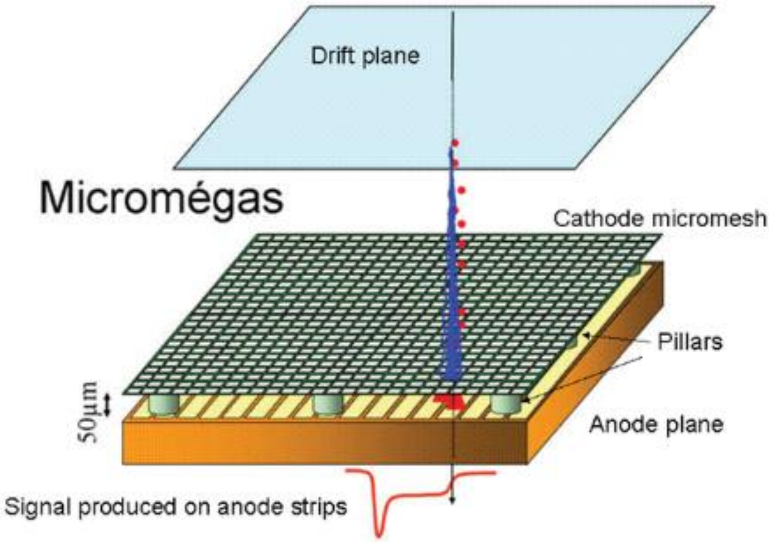
Detector size
~30x30x30cm3
~3kg
Easy to transport



Both can be tested separated

Detector & FEE

- Bulk Micromegas
- Single anode vs 4 pads
- First two prototypes manufactured at CERN
- Rest and production will be manufactured at the “Labo Bulk” at SEDI/CEA-Saclay



- Micromegas: Multi-Pattern Gaseous Detector, invented in 1995 at CEA Saclay[1]
- Parallel plate detector with a strengthened thin mesh dividing the gas volume in 2 parts:

Drift region (1 to 10 mm) → E ≈ 100 V/mm

Amplification region (30 to 100 µm) → E ≈ 10^5 V/mm

[1] Y. Giomataris, P. Rebourgeard, J.P. Robert and G. Charpak, “Micromegas: A high-granularity position sensitive gaseous detector for high particle-flux environments”, Nuc. Instrum. Meth. A 376 (1996) 29.

Detector & FEE

- Bulk Micromegas
    - Single anode vs 4 pads
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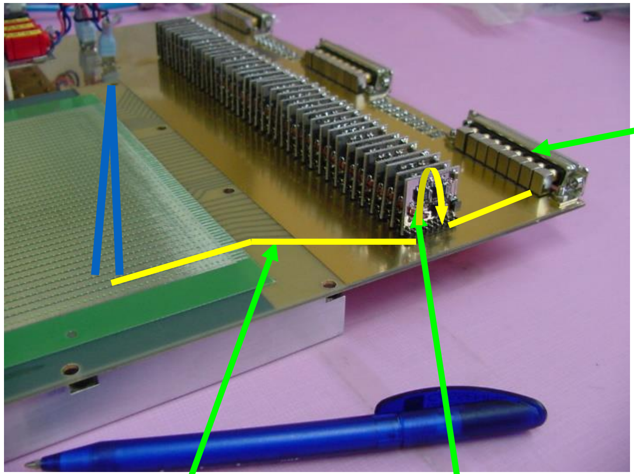
Very similar design for the nBLM



Coaxial connectors for analog signals

SMA Connectors for :
- Signals
- Low voltage

Reading strips

Preamplifiers

The 4-layers PCB, Strips, spacers and the mesh are sticked on the PCB by a single process.

Detector & FEE

- Bulk Micromegas
- Single anode vs 4 pads
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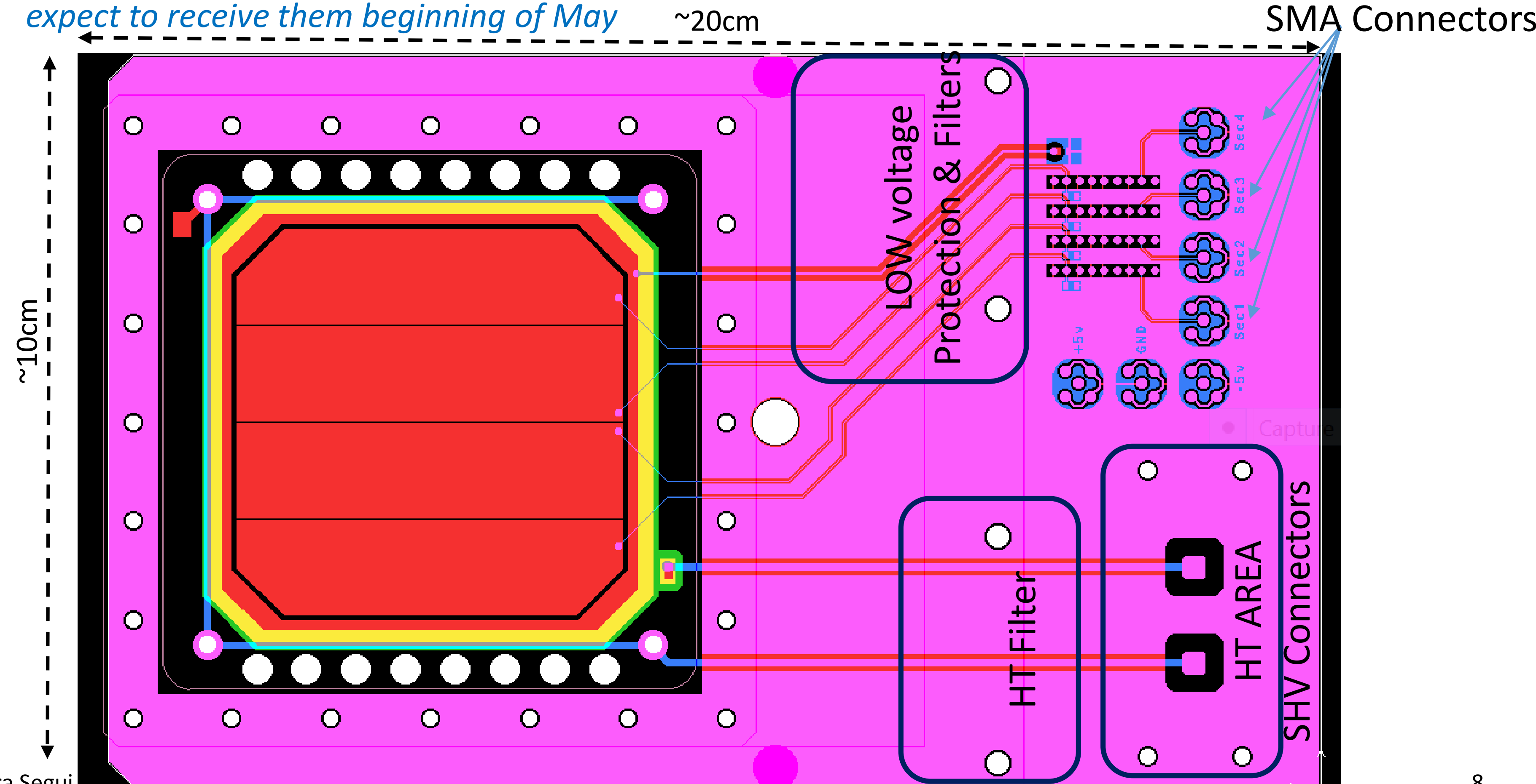
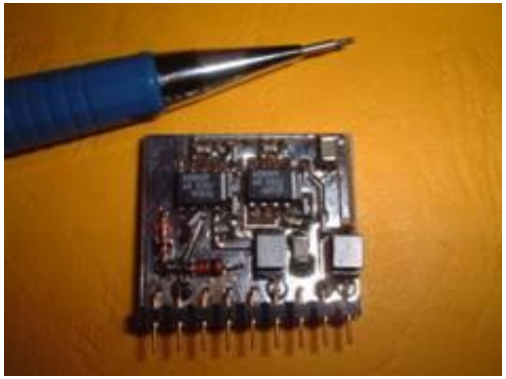
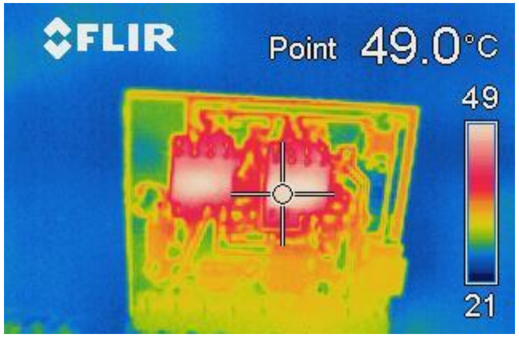
PCB Design:
expect to receive them beginning of May



Front-end electronics for nBLM → Design by Philippe Legou

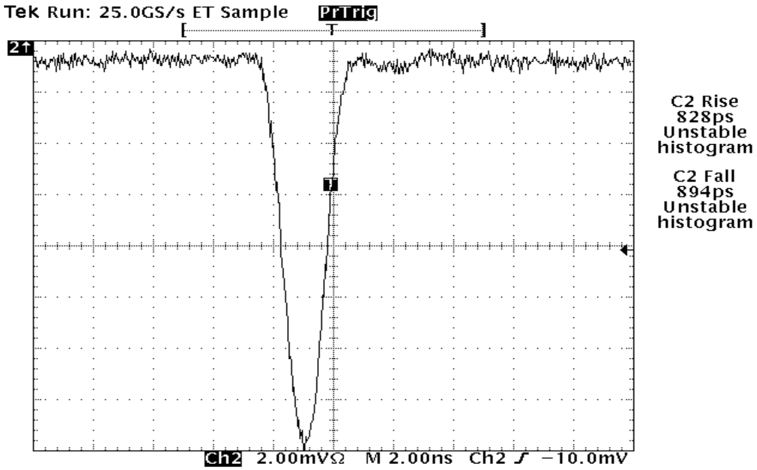
FAMMAS front-end module (Fast Amplifier Module for Micromegas ApplicationS)





In few figures …

- *Power supply : + 5V -5V*
- *Consumption ≃ 50 mW*
- *Input: positive or negative*
- *Noise: 600 μV rms*
- *Rise time : < 1ns*
- *weight : 4g*
- *Size: 22 x 20 x 5 mm*
- *Reliability*



Cables for :

- Signals (SMA)
- Low voltage (SMA)
- High Voltage (SHV) (2xdetector)

\+ patch pannels at both ends

42 modules → 84 detectors → min ~250 cables

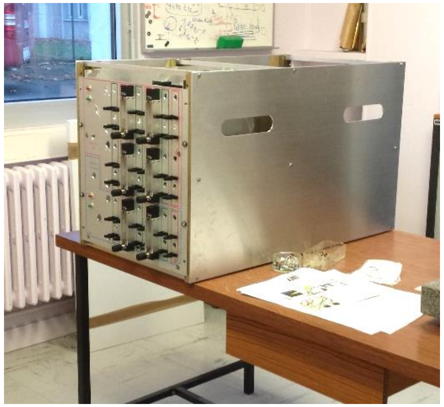
Lenght between racks and DTLs ~50m

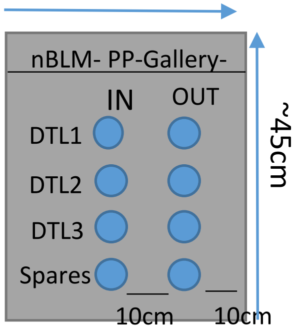
Gas System

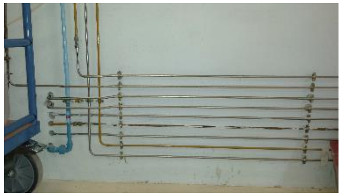
- Gas: He + 10% CO_2
- Flow: ~ 5 l/h, in recirculation
- P ~ 1 atm
- Volume/detector ~ 0.25 l
- Leak tight and low outgassing
- Gas bottle storage: 6-12 rack premix
  - ~200 bar/bottle, 50 l →
  - 2 IN/2 OUT lines (1 in use, 1 spare)
  - Outside gallery
- From gas bottle to gas rack to patch panel to tunnel
  - Distribute in 5 lines → one per DTL, in parallel
    - 5 IN/5 OUT Lines going to tunnel (+ spares)
  - Electrovalve in/out in Klystron gallery
    - Isolate system
  - Flowmeter in/out in Klystron gallery
    - Leak monitoring
- Gas in serial for detectors in DTL

Bottle rack

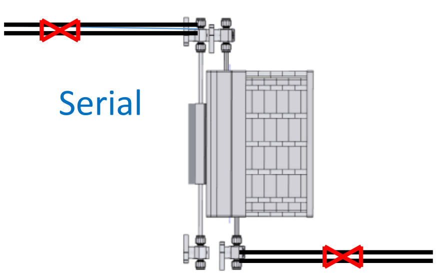
Gas controller

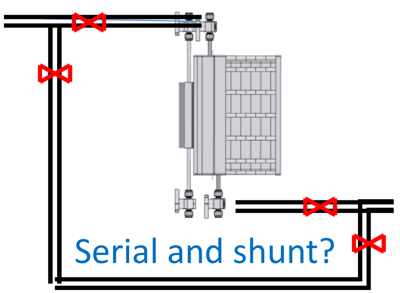






Designed by Stephan Aune





Gas System

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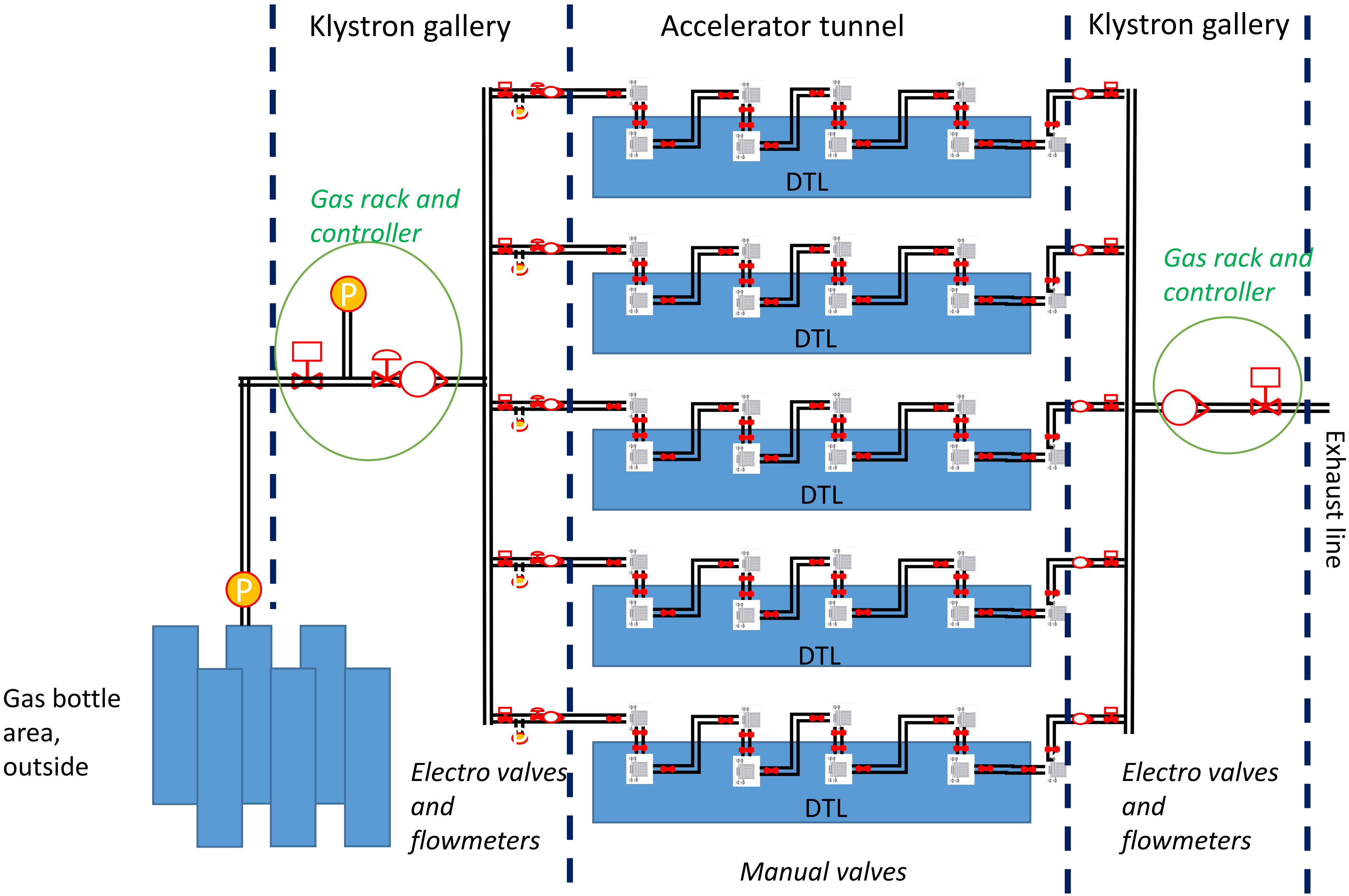
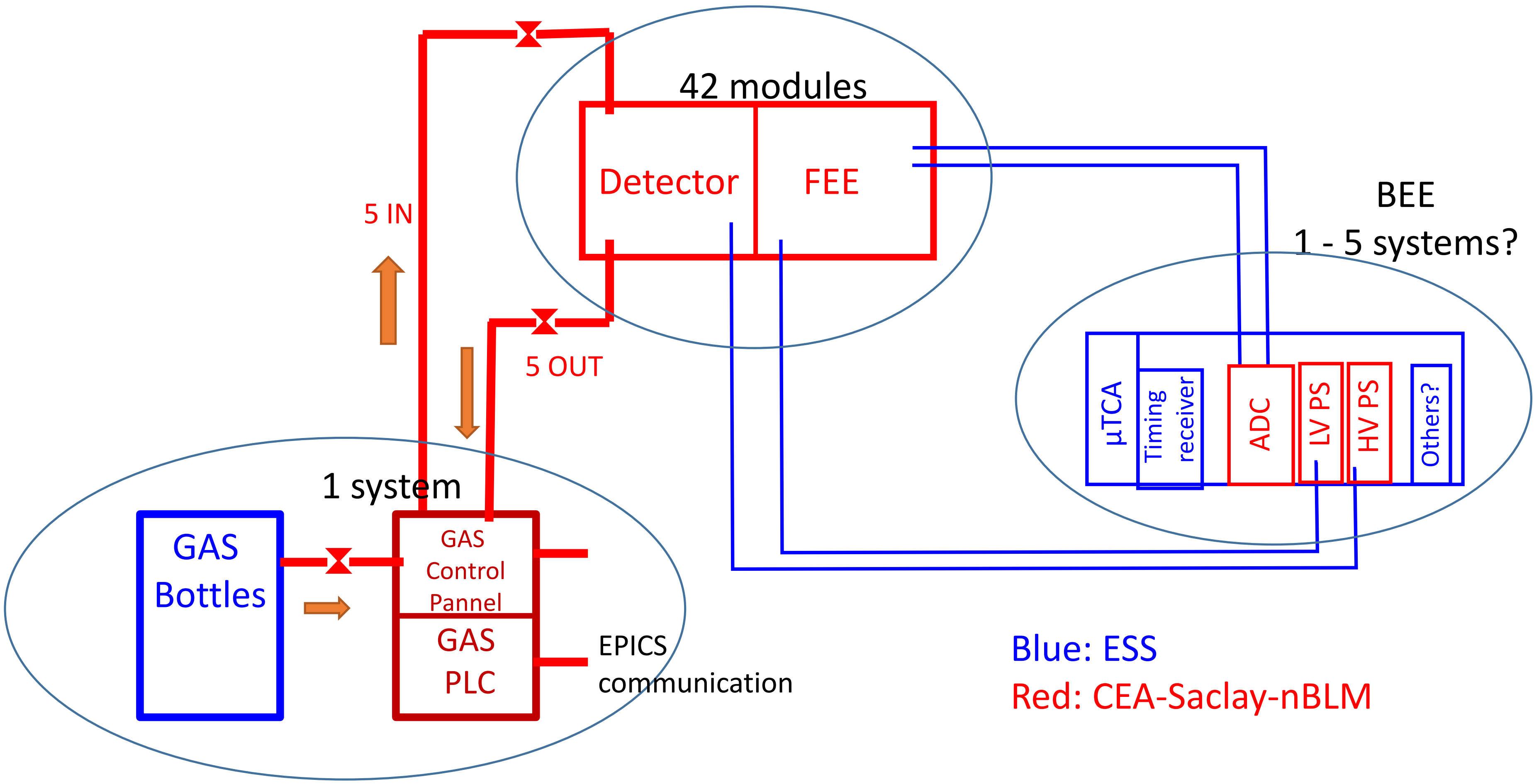


DAQ & Control System



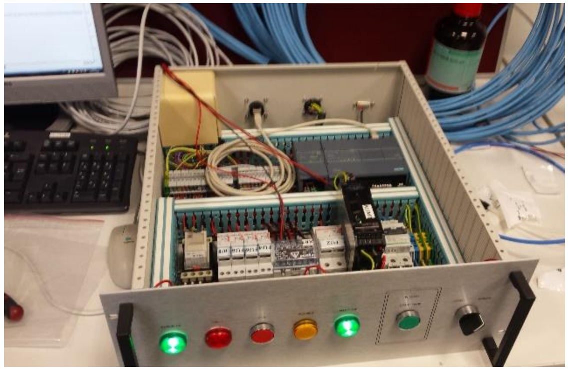
DAQ & Control System

Gas System

Françoise Gougnaud and her team

- PLC system
- Experience for other experiments
- Fit in rack
- Communication to EPICS

PLC system – gas controller



Control System

Françoise Gougnaud and Yannick Mariette and Victor Nadot

- In Nov.2016 test a µTCA crate sent to CEA
- Decision about ADC card and IFC made in April
  - ADC 3111 FMC Mezzanine Card, IOxOS: 8 channels, 250 Mps,
    - 2 controlled by a FPGA → can group detector per DTL, easier to do coincidences
  - IFC 1410
  - Start testing system in June → full system will be received in October
- Definition of interface between µTCA and Control System on-going

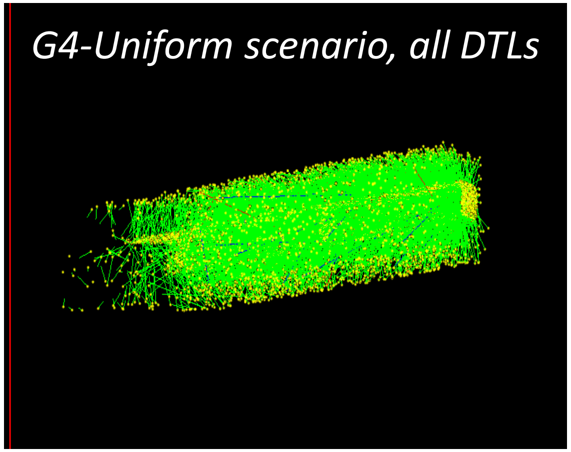
ADC 3111

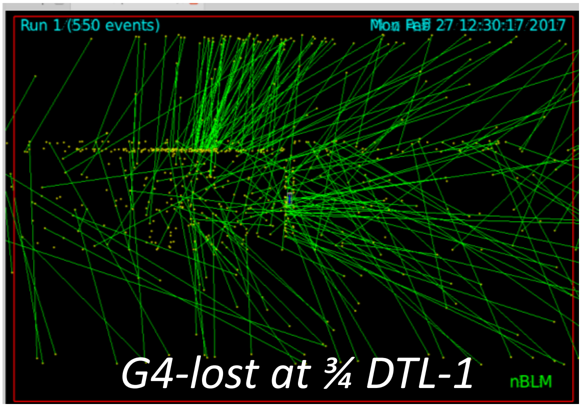
- For HV→ CAEN A-7030, 48 channels
- And mainstream SY-4527B crate
  - 16 boards per crate

Already supported by ICS

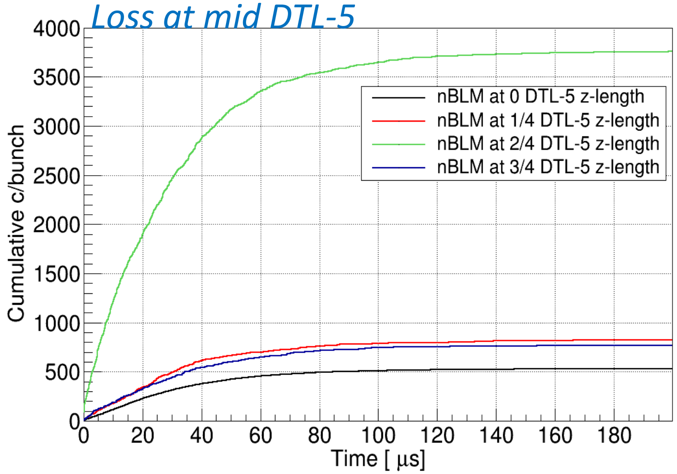
RESPONSE TO ESS SCENARIOS

- ESS scenarios received and integrated in the nBLM simulation framework based on Geant4
- Simulated accidental losses:
  - Known number of protons at fix energy in a point
  - Used also to scale to the case of 1% 1W/m in 14Hz
- nBLM placed at different locations around the DTLs
- Frequency in DTL shorter than the time response of the slow detector (100% events in ~180 µs)
  - Bunches will start overlapping in case of accidents
    - Calculate how many counts lost in 1st µs
  - For normal operation used a peak count rate

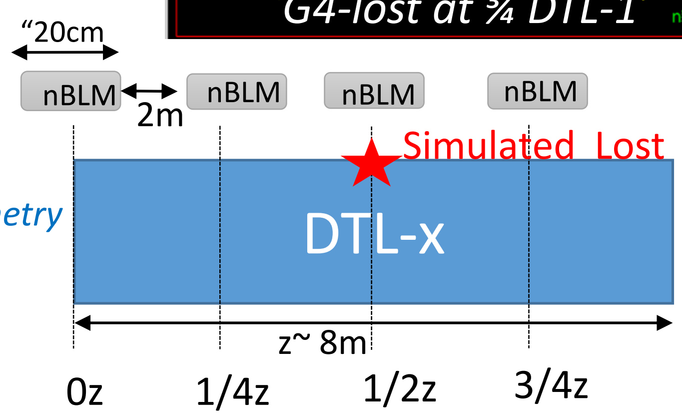




Loss at mid DTL-5

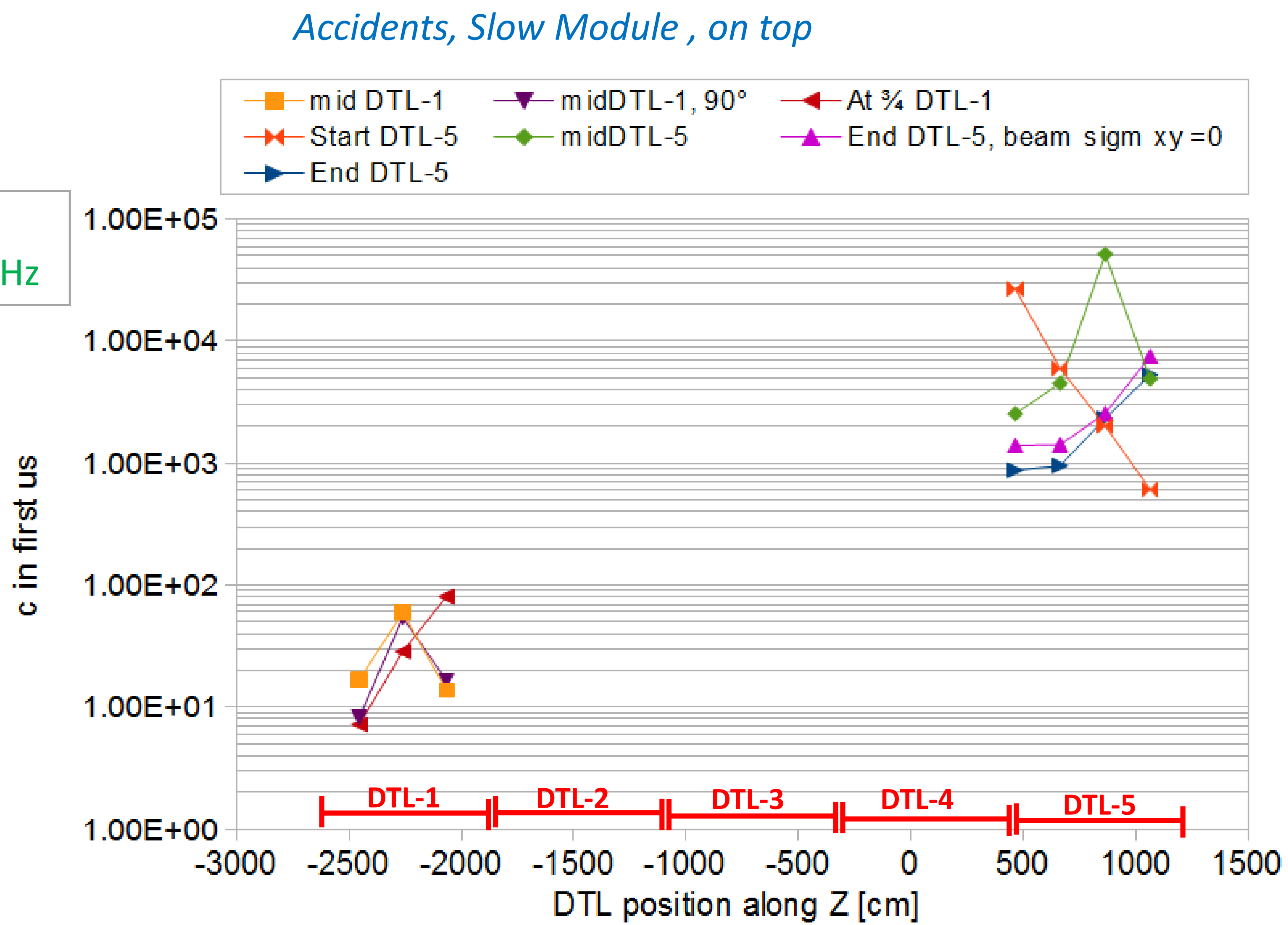


Sketch of the simulation geometry



RESPONSE TO ESS SCENARIOS

Rates of
10 MHz – 60GHz



RESPONSE TO ESS SCENARIOS

Accidents, Slow Module , on top

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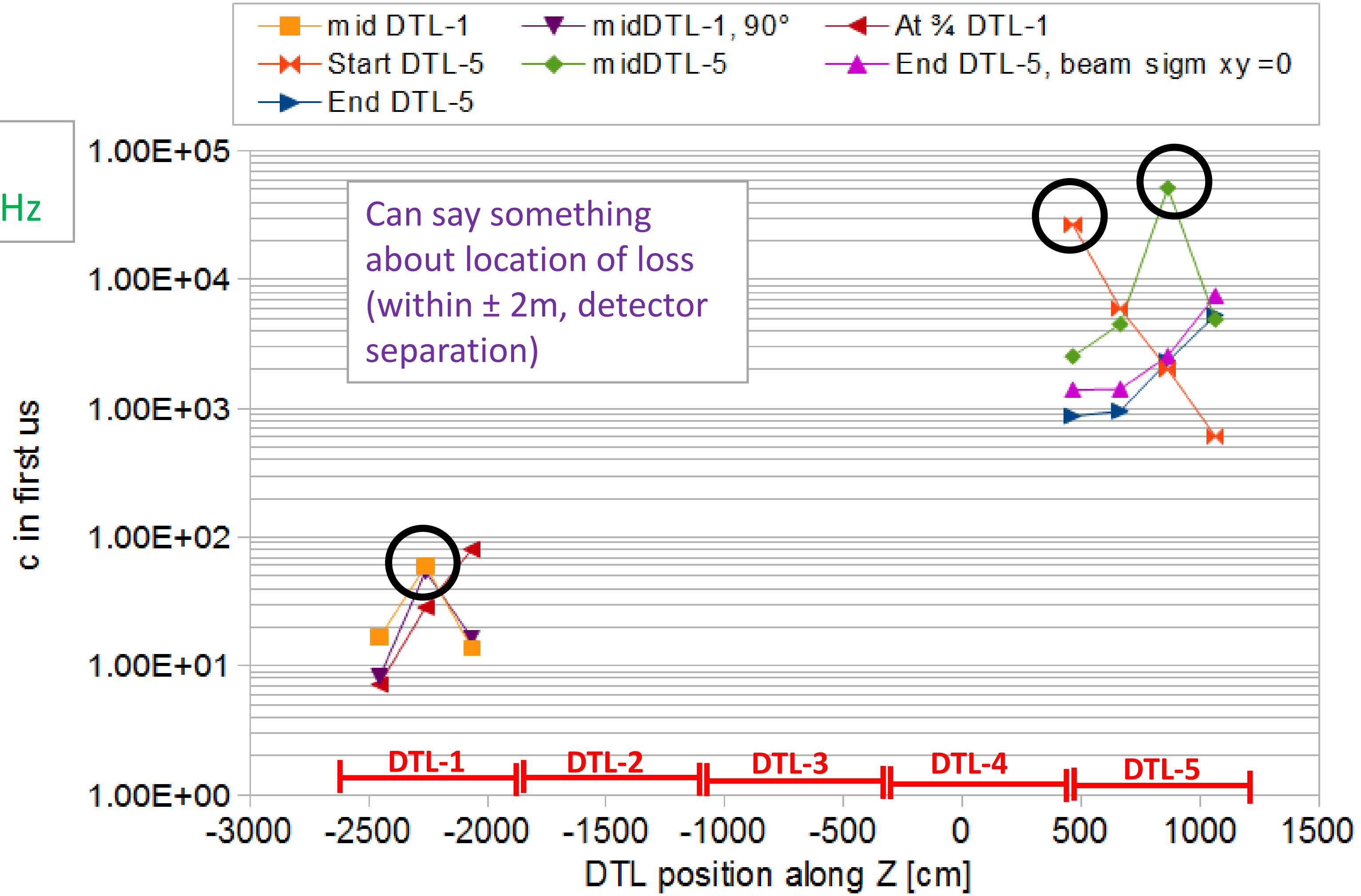
10 MHz – 60GHz



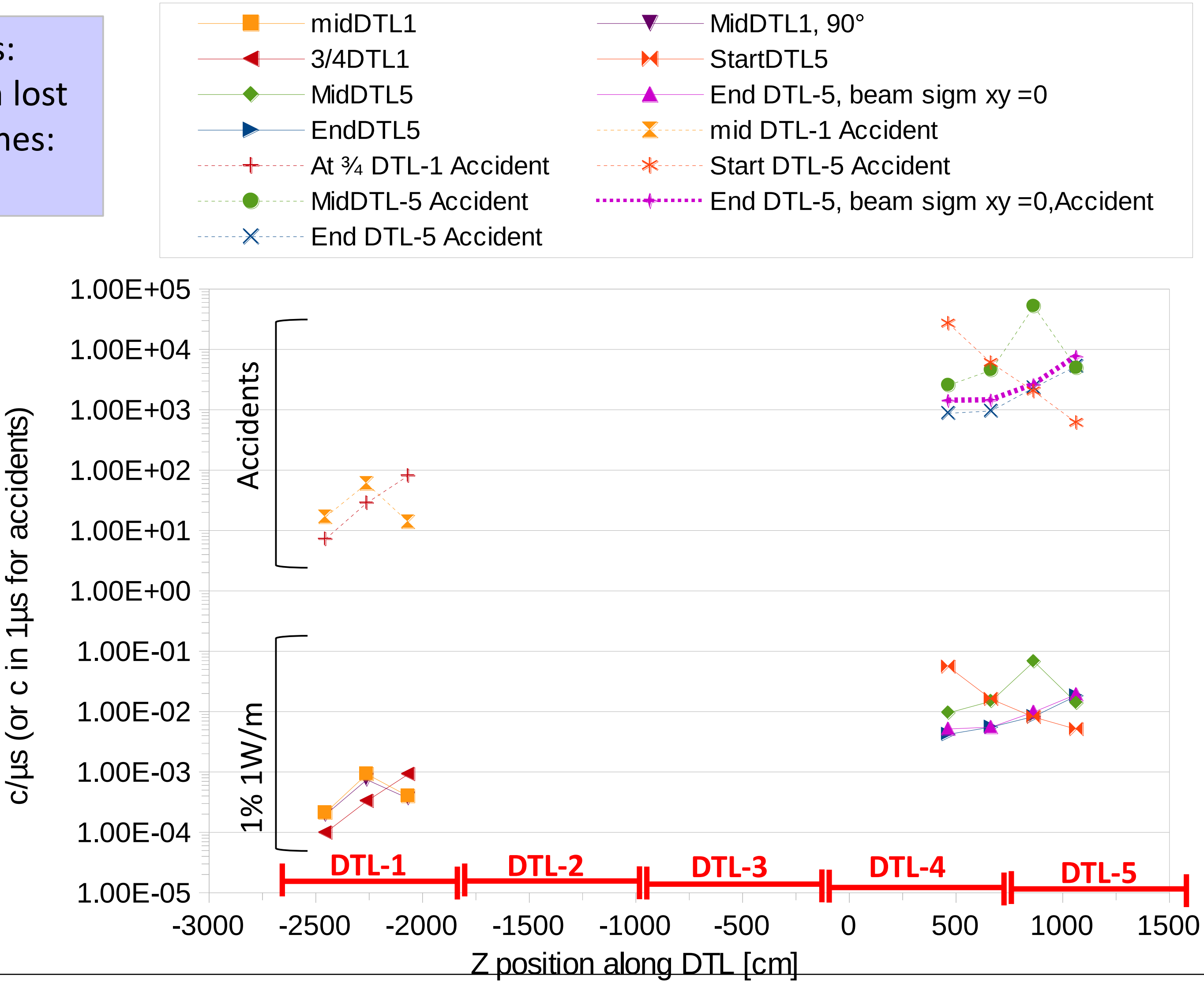
RESPONSE TO ESS SCENARIOS

Accidents vs 1% 1W/m, Slow Module , on top

Solid lines:
1% 1W/m lost
Dashed lines:
accidents

Accidents
10 MHz – 60GHz

1% 1W/m
0.1 kHz – 700 kHz



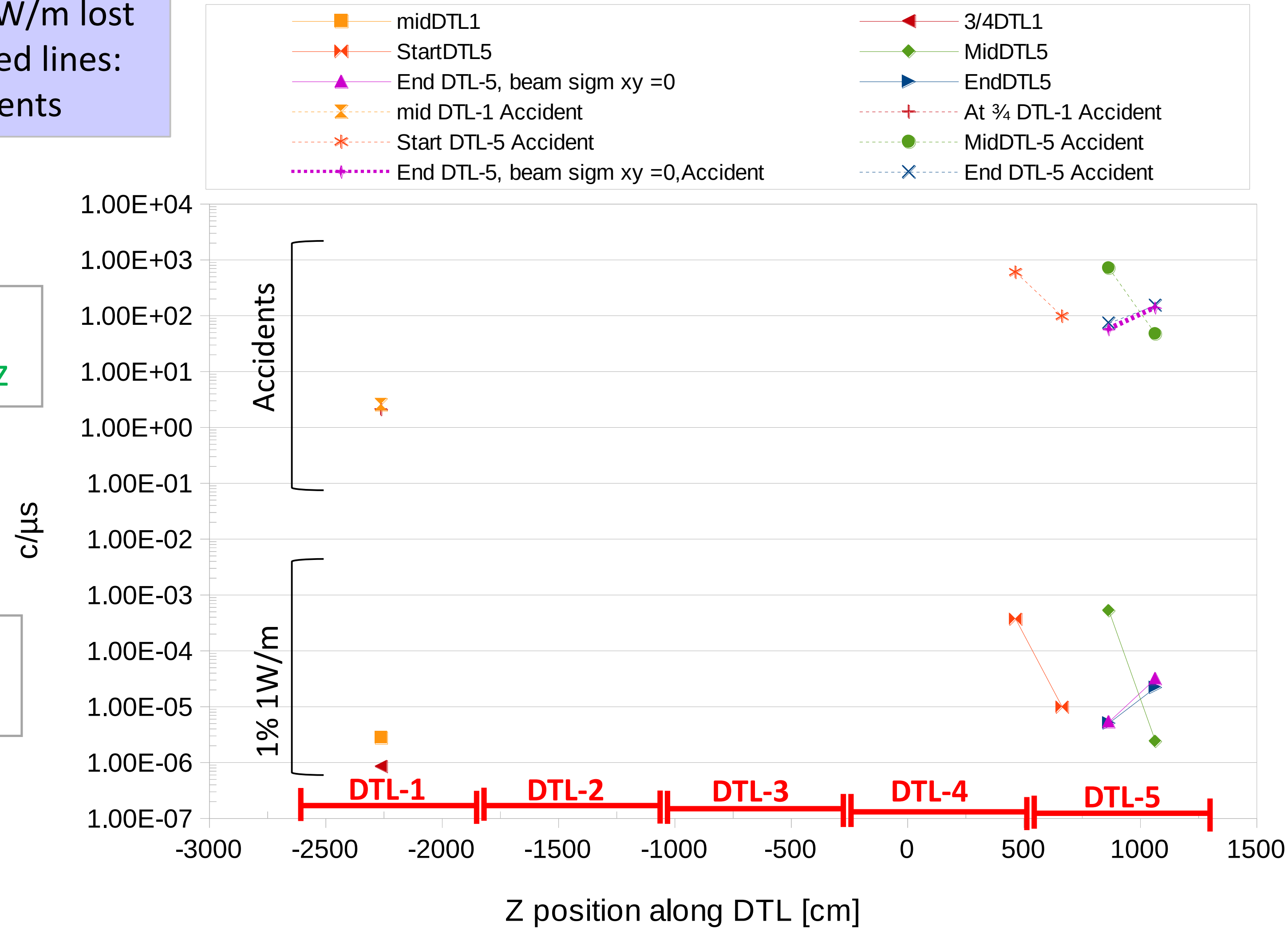
RESPONSE TO ESS SCENARIOS

Solid lines:
1% 1W/m lost
Dashed lines:
accidents

Accidents
2 MHz – 700 MHz

1% 1W/m
1 Hz – 400 Hz

Accidents vs 1% 1W/m, FAST Module , on top
Lower stats in some of the cases studied

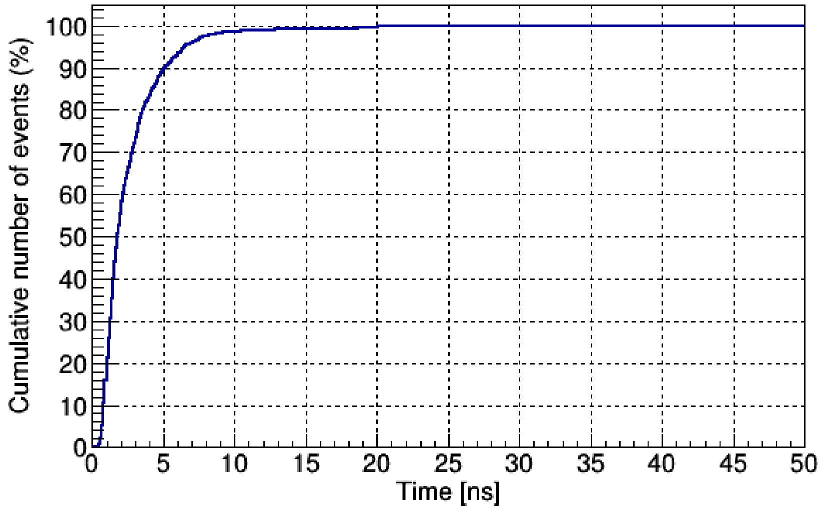


RESPONSE TO ESS SCENARIOS

Accidents detected in the fast module

→ Up to 80c/bunch → 50c in ~3ns

ESS input	nBLM detector	c/bunch	c/μs
sim2-0-DTL Mid DTL1	det3	0.060 ± 0.007	22.44 ± 2.54
sim2-1-DTL ¾ DTL1	det3	0.030 ± 0.005	10.65 ± 2.09
sim2-8-DTL Start DTL5	det1	52.70 ± 1.69	18569.94 ± 594.71
	det2	1.41 ± 0.28	495.20 ± 97.12
sim2-11-DTL End DTL5	det3	0.93 ± 0.16	326.50 ± 56.00
	det4	5.51 ± 0.39	1939.82 ± 136.49
sim2-12-DTL End DTL5	det3	0.88 ± 0.21	311.14 ± 73.34
	det4	3.83 ± 4.34	1348.27 ± 152.66
sim2-13-DTL Mid DTL5	det3	82.28 ± 2.01	285970.55 ± 707.65
	det4	0.38 ± 0.13	132.85 ± 46.97



Cumulative distribution events detected at middle of DTL-5

OUTLOOK

- Since last BI Forum
  - ✓ Finish MonteCarlo studies of geometry
  - ✓ Study response under ESS scenarios
  - ✓ Designed of first prototype
    - ✓ Received mechanics, Micromegas in a couple of weeks
  - ✓ First gas system design
  - ✓ Selection of Control System elements
  - ✓ Response range between few c/s in normal operation to few GHz in case of an accident (at high energy regions)

PDR1.1 (covers the first three items)

- In next month → start prototype tests
- Definition of cables specifications and gas pipes on-going
  - Discussed installation points and integration
- Defining interface between FPGA and Control system
- PDR1.2 in June

THANK YOU!

BACKUP

RESPONSE TO ESS SCENARIOS

The data from previous slide in table… Slow module

Losses in DTL-1

ESS input	nBLM	1% 1W/m c/ms (kHz)	Accidents c in the first μs (MHz)
Sim2-0 Mid DTL-1	det1	---	---
	det2	0.21 ± 0.01	16.70 ± 4.09
	det3	0.92 ± 0.01	59.81 ± 7.73
	det4	0.396 ± 0.003	13.82 ± 3.72
Sim2-1 @ ¾ DTL-1	det1	---	---
	det2	0.098 ± 0.004	7.20 ± 2.68
	det3	0.33 ± 0.01	28.60 ± 5.35
	det4	0.62 ± 0.01	80.76 ± 8.99
Sim2-3 Mid DTL-1 (-90°)	det1	---	---
	det2	0.195 ± 0.003	8.21 ± 2.87
	det3	0.74 ± 0.01	54.28 ± 7.37
	det4	0.364 ± 0.004	16.64 ± 4.08

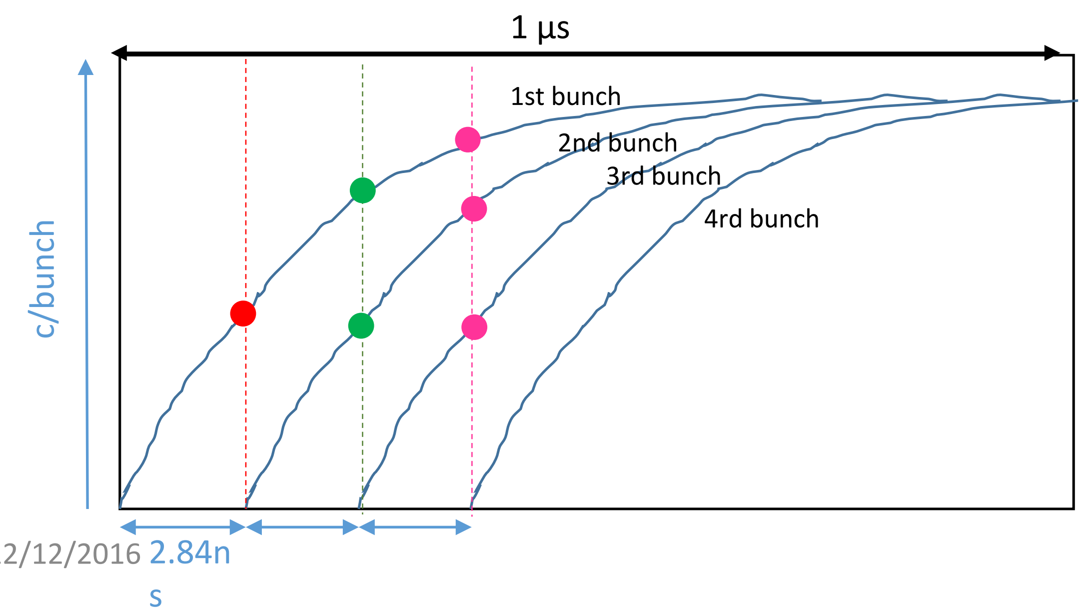
Losses in DTL-5

ESS input	nBLM	1% 1W/m c/ms (kHz)	Accidents c in the first μs (GHz)
Sim2-8 Start DTL5	det1	55.25 ± 0.34	26.83 ± 0.16
	det2	16.14 ± 0.19	0.59 ± 0.08
	det3	8.10 ± 0.13	0.20 ± 0.04
	det4	5.11 ± 0.10	0.06 ± 0.002
Sim2-11 End DTL-5	det1	5.17 ± 0.10	0.14 ± 0.04
	det2	5.53 ± 0.10	0.14 ± 0.04
	det3	9.87 ± 0.13	0.26 ± 0.05
	det4	19.34 ± 0.18	0.75 ± 0.09
Sim2-13 Mid DTL-5	det1	9.56 ± 0.13	0.25 ± 0.05
	det2	14.92 ± 0.50	0.45 ± 0.07
	det3	67.72 ± 0.77	51.79 ± 0.23
	det4	13.87 ± 0.35	0.49 ± 0.07

RESPONSE TO BI-ESS SCENARIOS → ACCIDENTAL LOSSES or SAFETY OBJECTIVE

Time Response and rate

- Time response is calculated as before
- In all cases we have few % of events below 1 µs
  - But we have more than one bunch in 1 µs
- In the DTL region ESS operates at 352 MHz → freq = 2.84 ns
  - In 1 µs → 353 bunches
- They will start overlapping in the nBLM, so after 2.84 ns events from the second bunch will start arriving

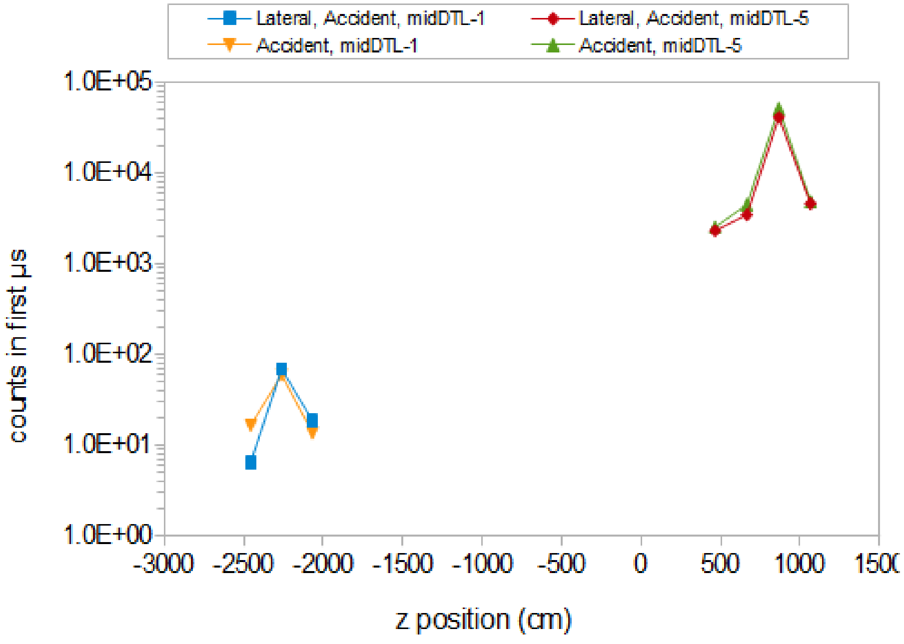


Strategy
- Histogram with the c/bunch in 1 µs with a binning of 2.84ns
- Add the previous bins together to make a new cumulative histogram
→ Last bin corresponds to neutrons detected in the first 1 µs

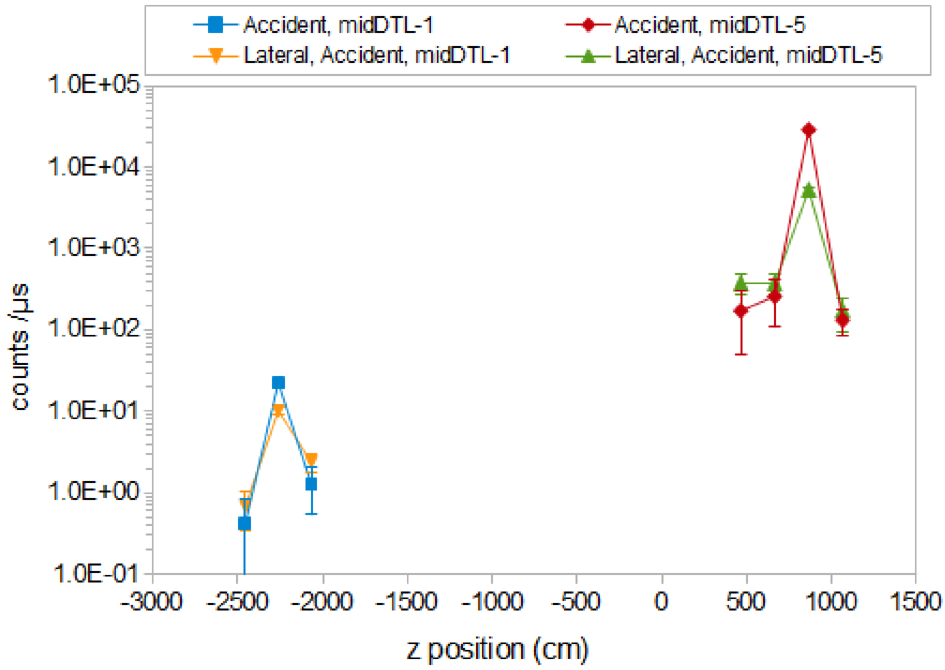
Placing the detectors on the lateral of accelerator

- Repeat scenarios accidents at mid DTL-1 and DTL-5 placing the detectors on the lateral
- Lower rate in the case of lateral detectors
    - Factor 0.5 to factor 2 or 6 at location of lost
    - Could be because **direction of lost**

"Slow" Modules



"Fast" Module



Placing the detectors between the tanks

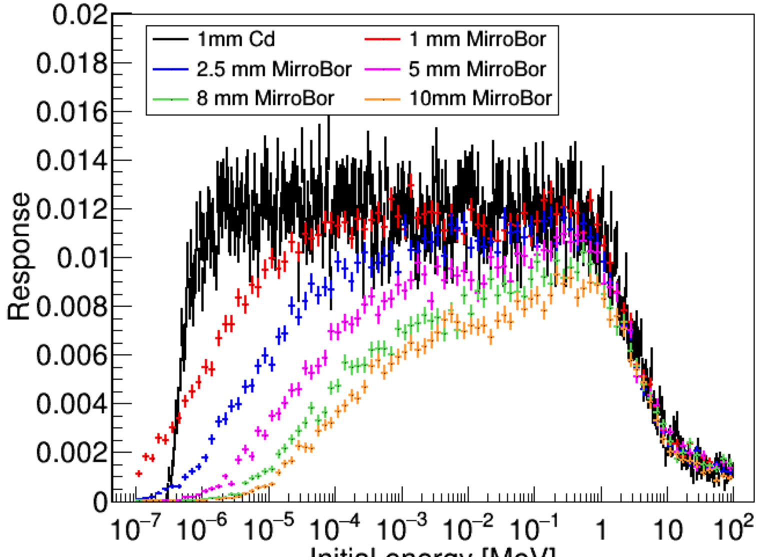
- Sensitivity if the detector close to the loss
  → 1MHz -- 5GHz
- Can also help to identify location of loss

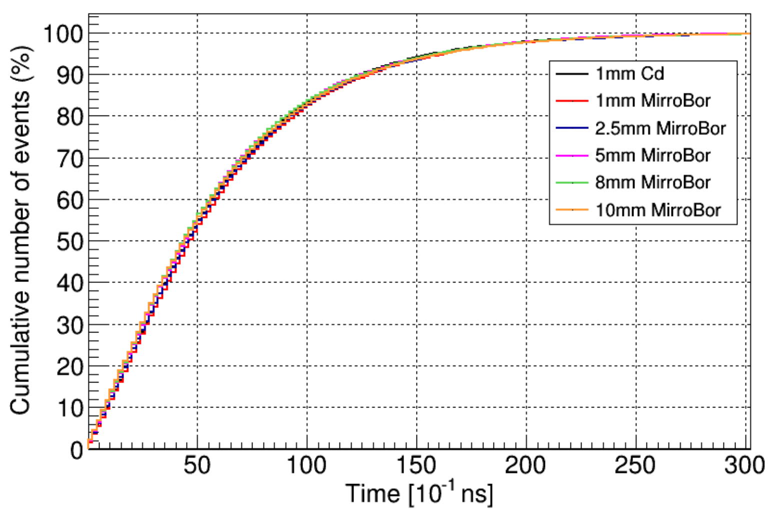
ESS input	nBLM detector between	Bunches simulated	Counts detected	c/bunch	c/µs (MHz)
sim2-0-DTL (mid DTL-1)	DTLs 1-2	4315.59	16 ± 4	0.004 ± 0.001	1.36 ± 0.34
	DTLs 2-3	4315.59	2 ± 1	Low stats	Low stats
sim2-1-DTL (¾ DTL-1)	DTLs 1-2	429.69	119 ± 11	0.28 ± 0.03	97.52 ± 8.94
	DTLs 2-3	429.69	2 ± 1	Low stats	Low stats
sim2-11-DTL (end DTL-5)	End of 5	9.17	22 ± 5	2.40 ± 0.51	845.07 ± 180.17
sim2-12-DTL (end DTL-5)	DTLs 4-5	10.19	2 ± 1	Low stats	Low stats
	End of 5	25.46	381 ± 20	14.96 ± 0.77	5268.63 ± 269.92

Using MirroBor (borated rubber) instead of Cd as absorber in the slow module

Geometry studies:

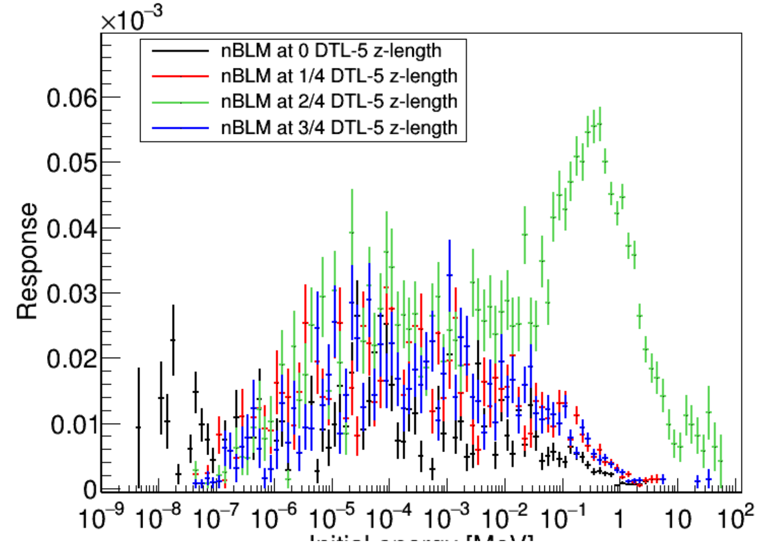
- Isolethargic flux, 0.1 eV – 100 MeV
- Different borated rubber thicknesses

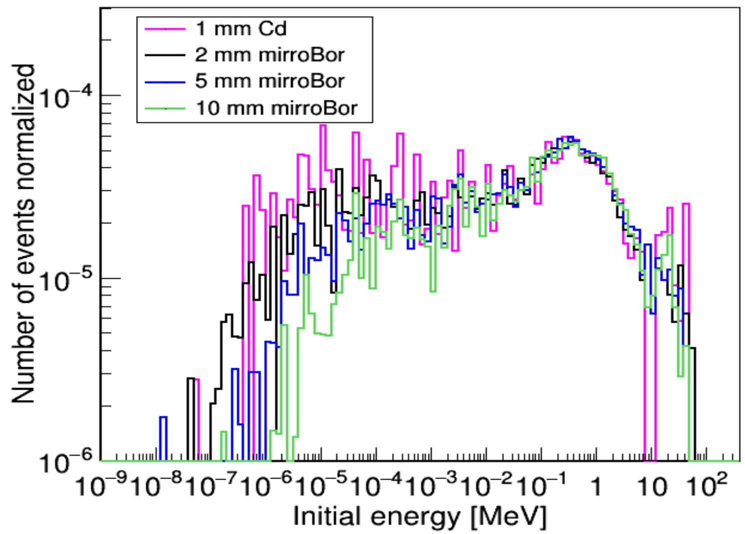




In ESS scenarios (loss midle DTL-5)

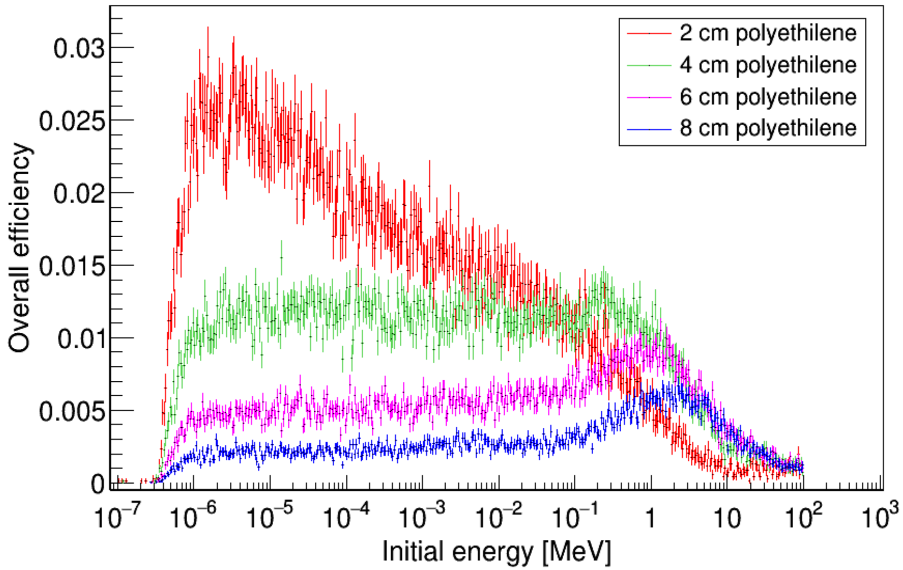
- And with different borated rubber thicknesses



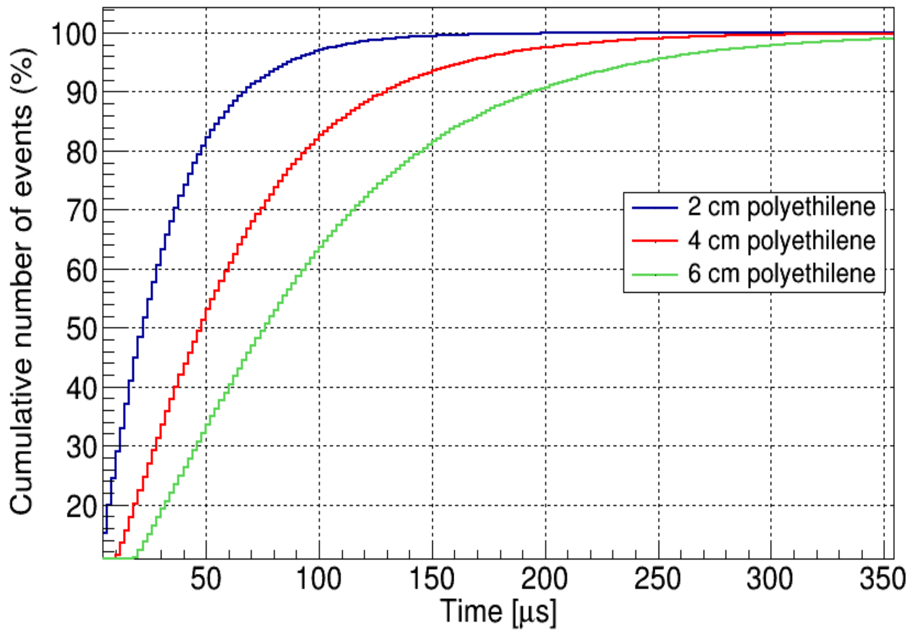


GEOMETRY DEFINITION THROUGH MC SIMULATIONS – RESULTS FIRST MODULE

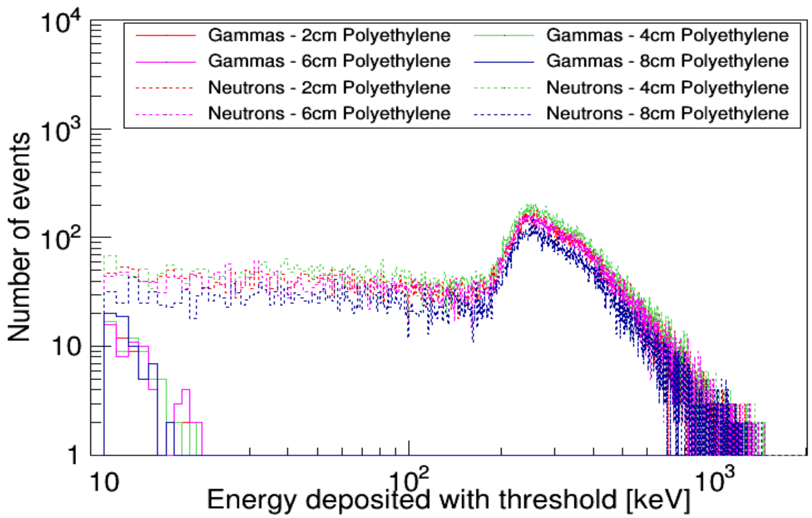
Neutron Efficiency



Time response



Gamma discrimination

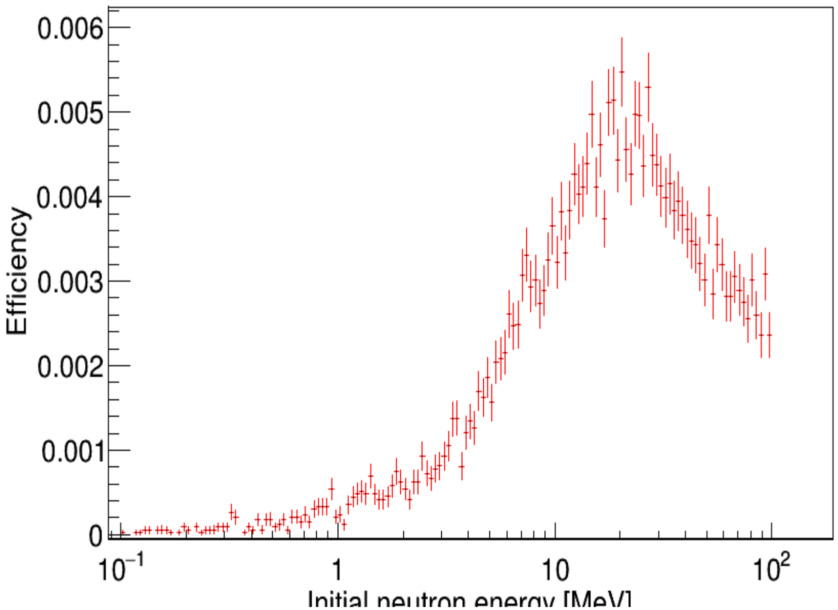


- Dependency with moderator thickness and initial n energy
  - ~5% below 1µs for 4cm polyethylene
    - 20% for 2cm
  - 100% in ~200µs
- Requirement by ESS 5 µs response where *3µs for detection and FEE*
- Gammas discriminated with 20-30 keV threshold

GEOMETRY DEFINITION THROUGH MC SIMULATIONS – RESULTS SECOND MODULE

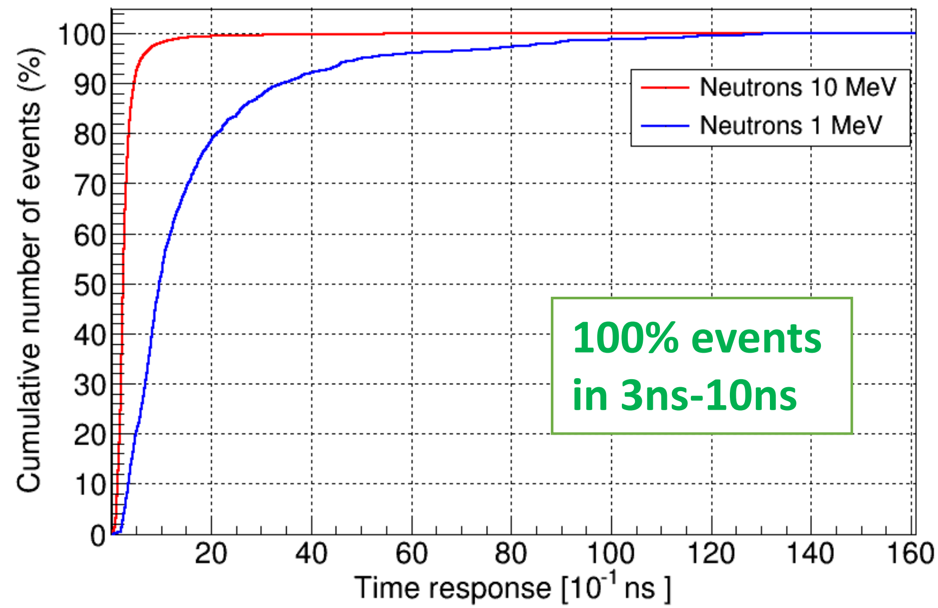
Neutron efficiency

Initial neutrons from 0.1eV to 100 MeV

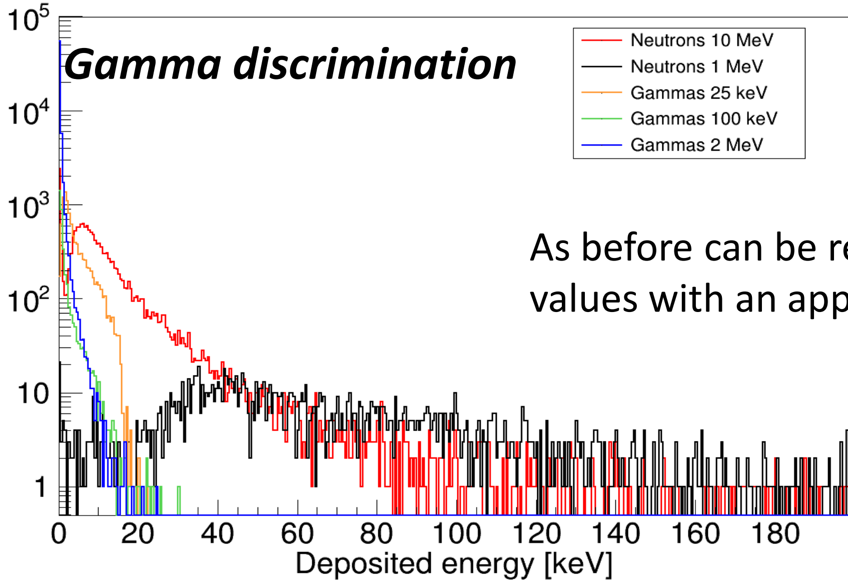


Time response:

just ToF, detector immediate response



Gamma discrimination



As before can be reduced to negligible values with an appropriate threshold