icBLM system: data processing

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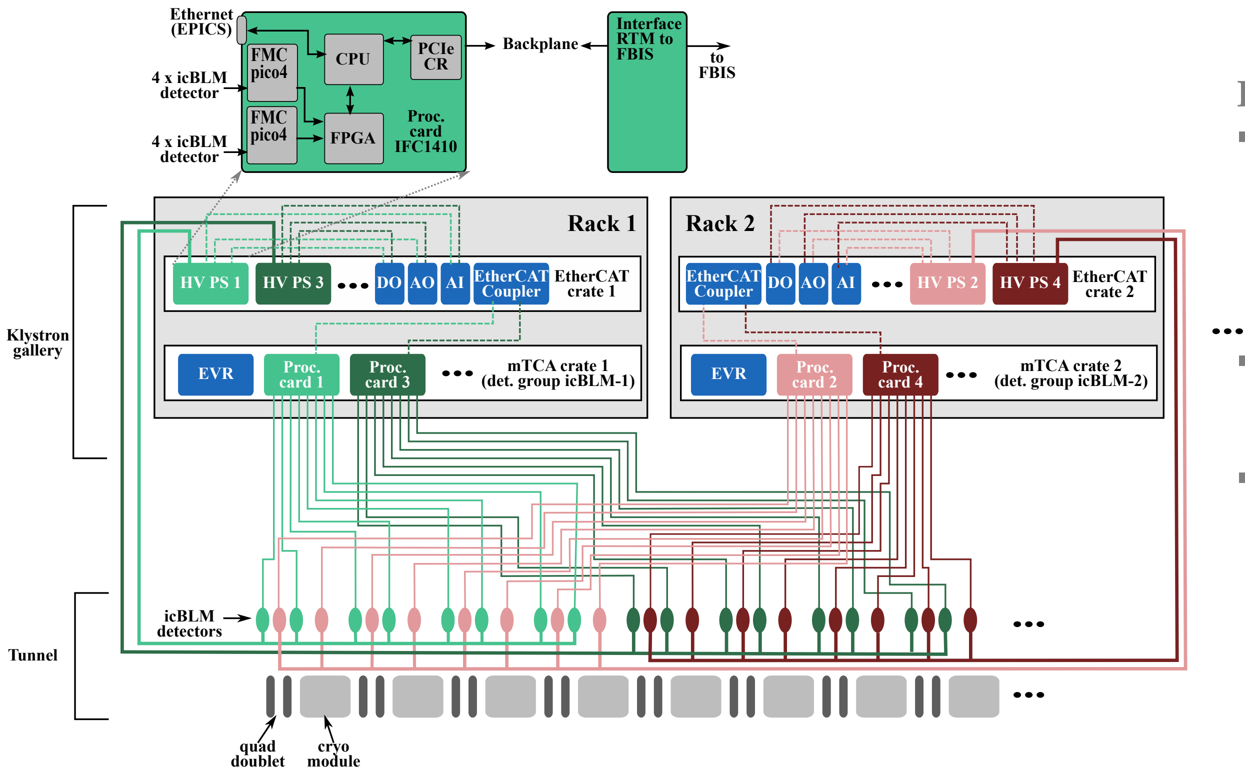
Outline

- icBLM
  - Remainder
  - Background issue
- FW functionality (block diagram)
  - Background subtraction
  - Protection algo

icBLM: components

Detectors

- Parallel plate gas Ionisation Chambers (ICs) developed for the LHC BLM.
- Beam loss information based on ionisation current measurement of secondaries - **current mode**



BEE

- IOxOS IFC1410
- Pico4, FMC digitizer (CAENels)
  - Modified COTS
  - 1MS/s, 20-bit ADC, 300kHz bandwidth
  - Dynamic range:
    - 0 – 500µA,
    - 0 – 10mA

HV PS

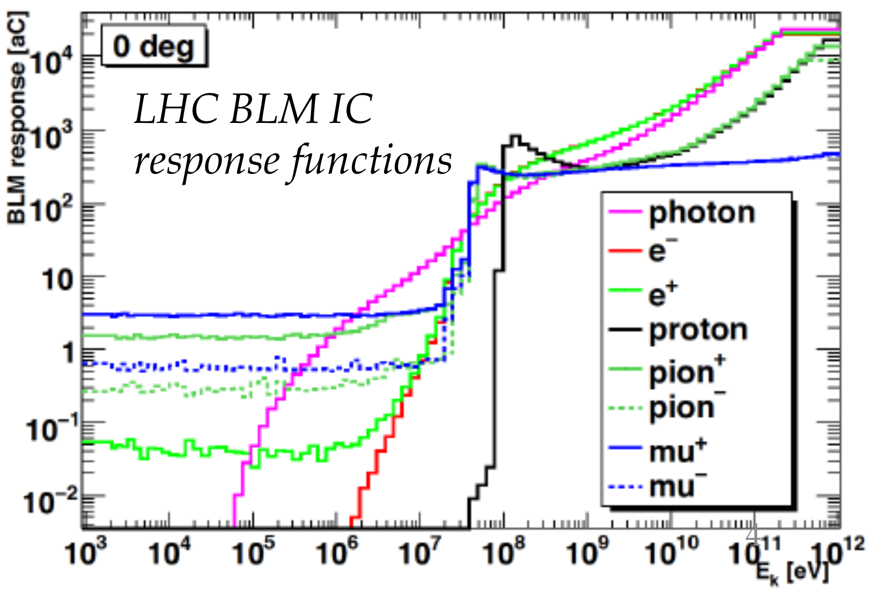
- Provides:
  - Power the ICs (1.5kV) – several ICs are daisy changed and connected to one HV ch
  - Modulation voltage for system HEALTH check.
- HV module (1ch):
  - ISEG DPr 40 305 24 5_CAB High Precision HV-PS
- Ethercat crate with
  - ethercat coupler,
  - DIO (for PS config.) and
  - Analogue module (to modulate)
  - with real time kernel on the CPU.

icBLM: Background

- Photon background due to the RF cavities
  - Bckg. mainly due to el. field Emission from cavity walls, resulting in bremsstrahlung photons created on cavity/beam pipe material.
  - Levels are difficult to predict numerically – depend on the quality of cavities, operation conditions and time.
  - Energy spectra estimation photons with energies up to tens of MeV in the high energy parts expected.

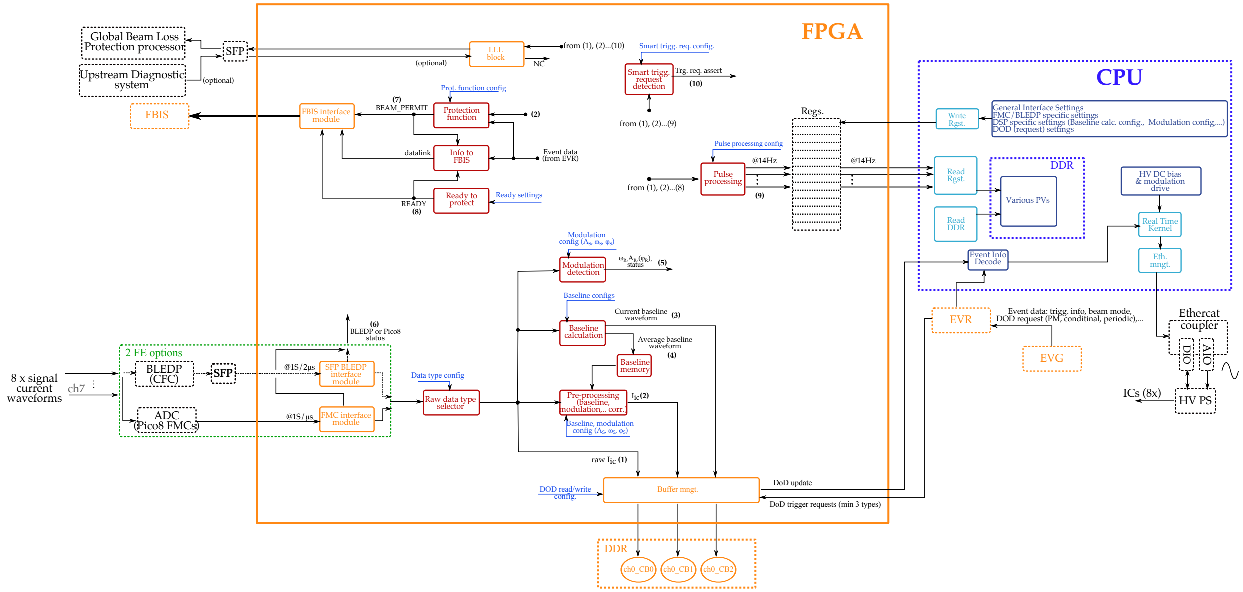
- Ionisation chambers
  - “cut off” at transversal photon and electron incidence ~2MeV (~30MeV for p and n)

- Background correction in the data processing chain (on the FW level) foreseen.



icBLM: FW functionality

- icBLM block diagram:
    - FPGA based data processing, connection to SW
    - Here: short overview of the functionality
    - More details in icBLM CDR supporting material (I.D.Kittelmann, "*Requirements and technical specifications – ESS nBLM system*")
- Implementation details:
    - Talk by G. Jablonski
    - More in related report (part of icBLM CDR supporting material)



Processing & monitoring requirements

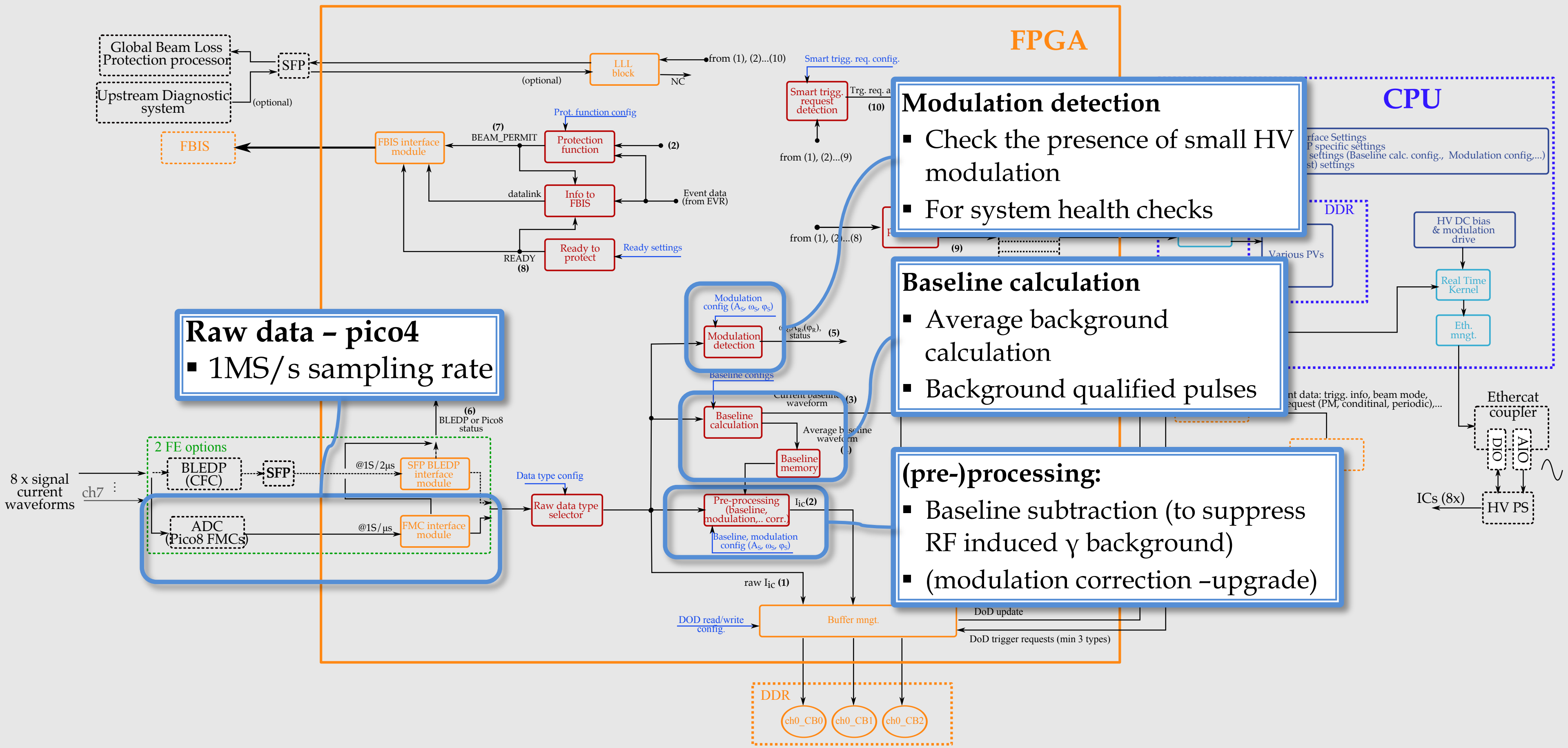
- System able to run stand alone independent of linac operation.
- Each AMC able to process up to 8 detector channels simultaneously.
- Signal samples at minimum 2MS/s
- All BLM systems follow the same approach where applicable.
- Monitoring data available either:
  – On demand – DoD data
  – Periodically (@max 14Hz) – periodic data

Processing & monitoring requirements

DoD data:

- Continuously buffered and accessible for retrieval without stopping the buffering.
- Min 3 consecutive pulse periods of raw data and 100 pulse periods of processed data available for retrieval on demand (pulse period = 1/(14 Hz)).
- Configurable post- and pre-trigger
- In case of raw data (processed data), the post and pre-trigger can be at minimum set to select from 2 (99) pulse periods before to 2 (99) pulse periods after the tagged pulse period – together minimum 3 (100) consecutive pulse periods per request.
- 3 different types of DoD trigger requests at min:
  - Post-mortem
  - Periodic (fx. 1/day)
  - Conditional (certain conditions reached in one of the systems)

icBLM: FW functionality



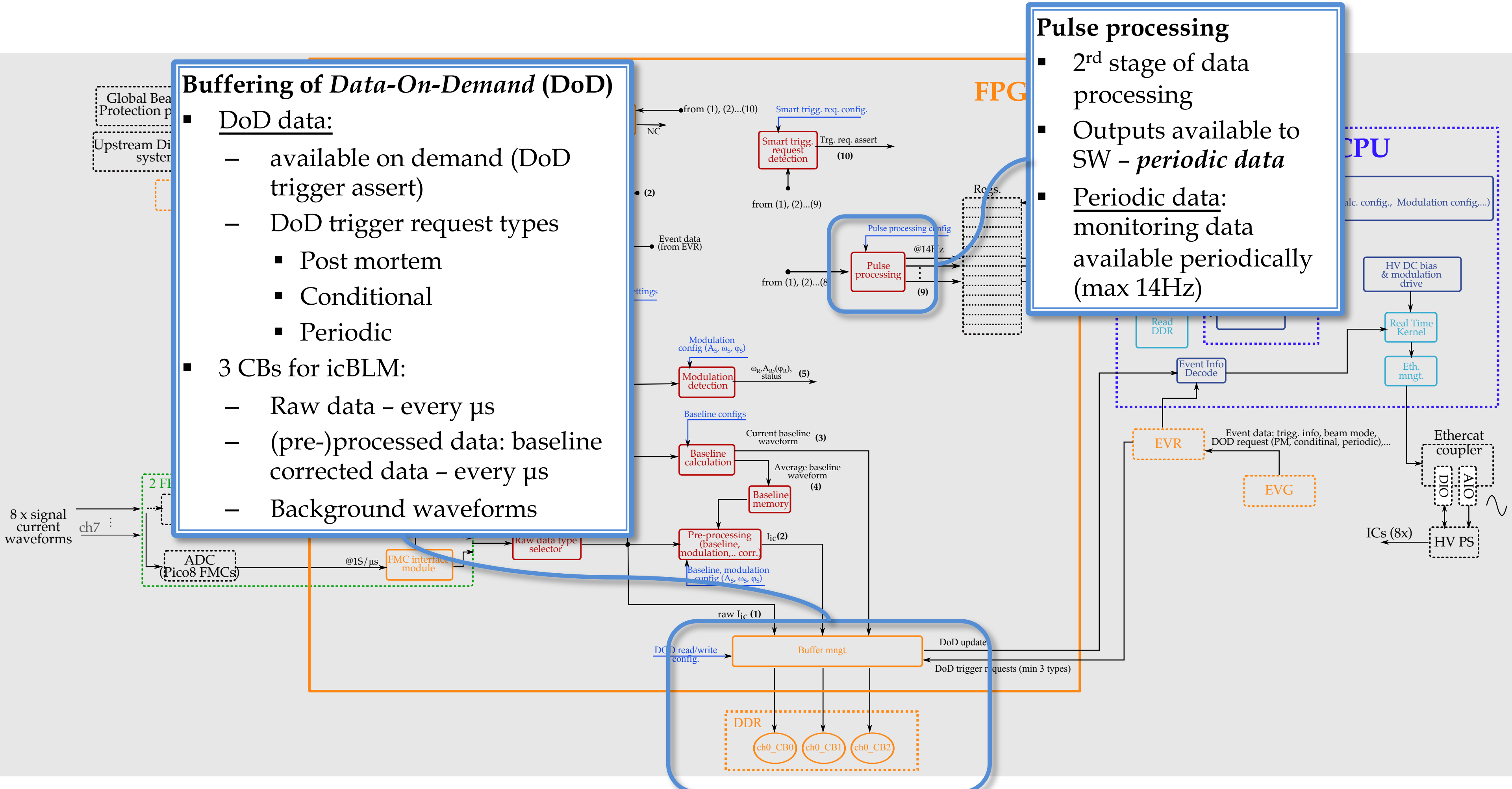
Raw data – pico4
- 1MS/s sampling rate

Modulation detection
- Check the presence of small HV modulation
- For system health checks

Baseline calculation
- Average background calculation
- Background qualified pulses

(pre-)processing:
- Baseline subtraction (to suppress RF induced γ background)
- (modulation correction –upgrade)

icBLM: FW functionality



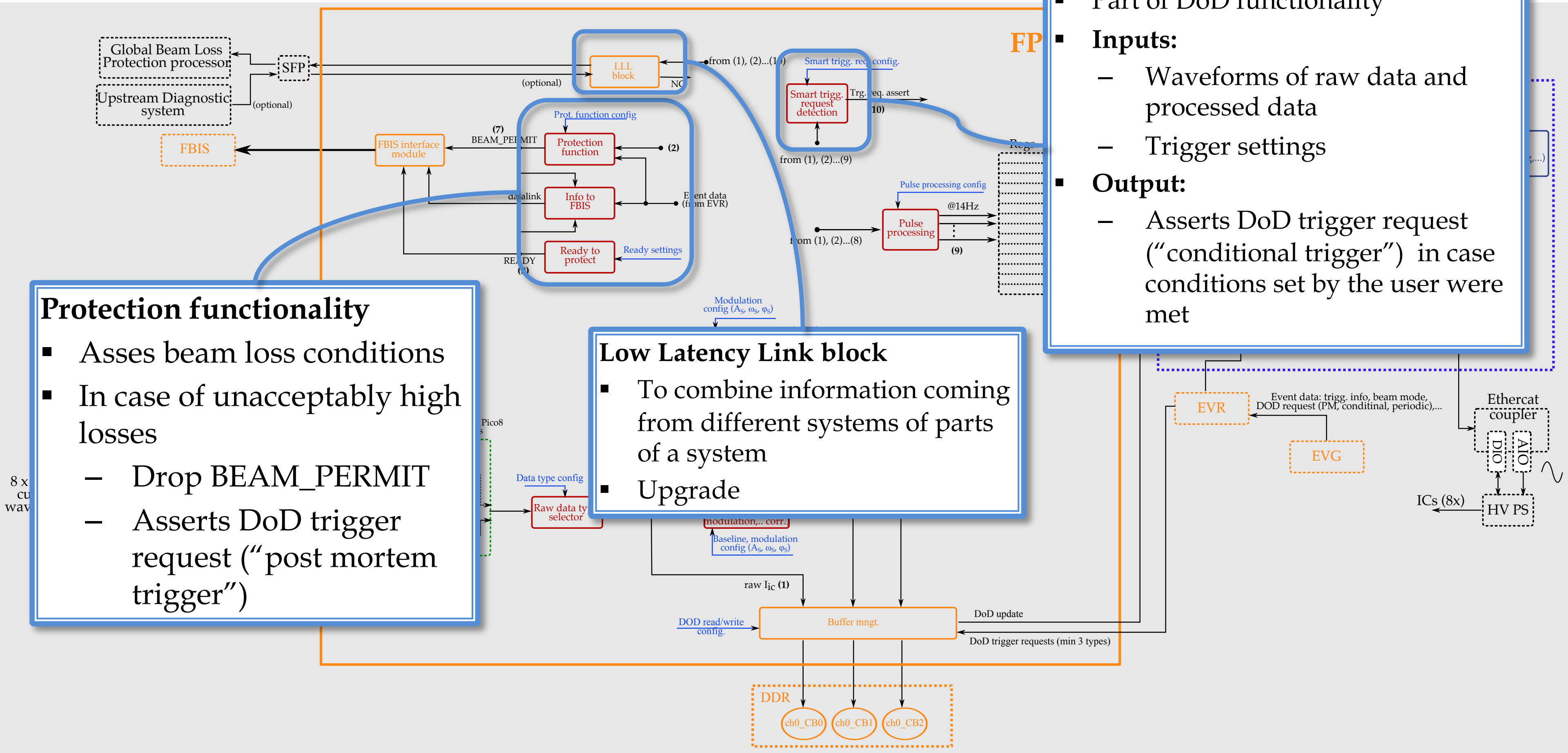
Buffering of *Data-On-Demand* (DoD)

- DoD data:
  - available on demand (DoD trigger assert)
  - DoD trigger request types
    - Post mortem
    - Conditional
    - Periodic
- 3 CBs for icBLM:
  - Raw data – every µs
  - (pre-)processed data: baseline corrected data – every µs
  - Background waveforms

Pulse processing

- 2rd stage of data processing
- Outputs available to SW – ***periodic data***
- Periodic data: monitoring data available periodically (max 14Hz)

icBLM: FW functionality



Smart trigger
- Part of DoD functionality
- **Inputs:**
  - Waveforms of raw data and processed data
  - Trigger settings
- **Output:**
  - Asserts DoD trigger request ("conditional trigger") in case conditions set by the user were met

Protection functionality
- Asses beam loss conditions
- In case of unacceptably high losses
  - Drop BEAM_PERMIT
  - Asserts DoD trigger request ("post mortem trigger")

Low Latency Link block
- To combine information coming from different systems of parts of a system
- Upgrade

Background subtraction

Empty pulses

- With RF but no beam
- Used for BCM (calibration) and icBLM (background subtraction)
- Present during linac operation (including normal), one per 5-20min

"Baseline calculation" block

- Calculates mean baseline WF of the RF induced photon background.
- WF length covers RF_ON period at minimum
- Configurables:
  - WF extent over RF_ON period
  - WF position relative to the RF_ON (account for different delays in detectors)
- Only background qualified pulses included (empty pulses) – identified as pulses with no BEAM_ON but RF_ON periods
- Upgrade: average calculation with forgetting factor

Pre-processing

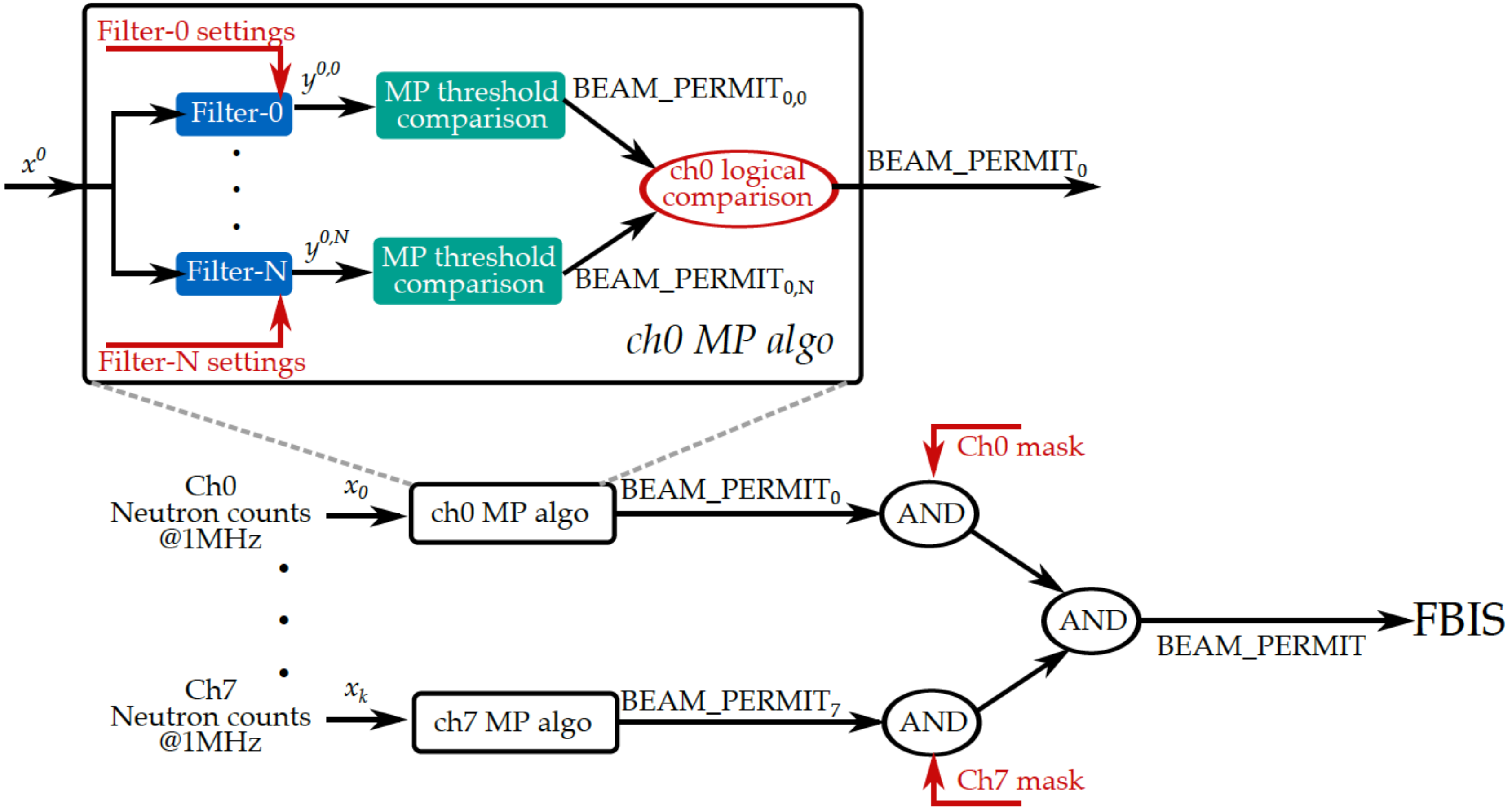
- Baseline WF subtracted for pulses with RF_ON period present

Startup:

- A sequence of empty pulses after RF settings fixed, to acquire initial statistics

Protection algorithm

1 BEAM_PERMIT per AMC propagated to FBIS



Protection algorithm

- To avoid spurious BEAM_PERMIT drops
  - Filtering measurements on each channel
  - Coincidences - upgrade (functioning LLL needed)

- Foreseen filter types
  - Relaxation filter (baseline)
  - Moving average (consistent with BCM)
  - Simple average (consistent with BCM)
  - X/Y algo

Protection algorithm

Relaxation filter

- 1st order IIR filter (with feedback)
- Output = weighted sum of old output y_{k-1} and new input value x_k

$$y_k = \lambda y_{k-1} + (1 - \lambda) x_k$$

- $\lambda \to 1$:
  - Forgets little
  - Comparable to moving average with large number of points

Protection algorithm

Moving average

- Calculate local average over the last time window t_{MA} (last n input points x_k)

$$y_k = \frac{1}{n} \sum_{l=0}^{n-1} x_{k-l}$$

- Increasing *n*: smoothing improved, delay between output and input increased.

Protection algorithm

Simple average

- Calculation carried out with a fresh set of values on each calculation restart.

X/Y algo

- Takes Y last number of inputs x_k
- If X out of them are above the MP threshold, $\text{BEAM\_PERMIT}_{c,X/Y}=1$
- Input *x:* neutron counts @ 1MHz
- Output *y:* $\text{BEAM\_PERMIT}_{c,X/Y}$

Protection algorithm

5 filter instances to be tested during commissioning:

- 2 time constants for moving average ($t_{MA,1}$~1us, $t_{MA,2}$~100us)
- Simple average over beam pulse (~3ms).
- Relaxation filter.
- X/Y algo.

Further developments

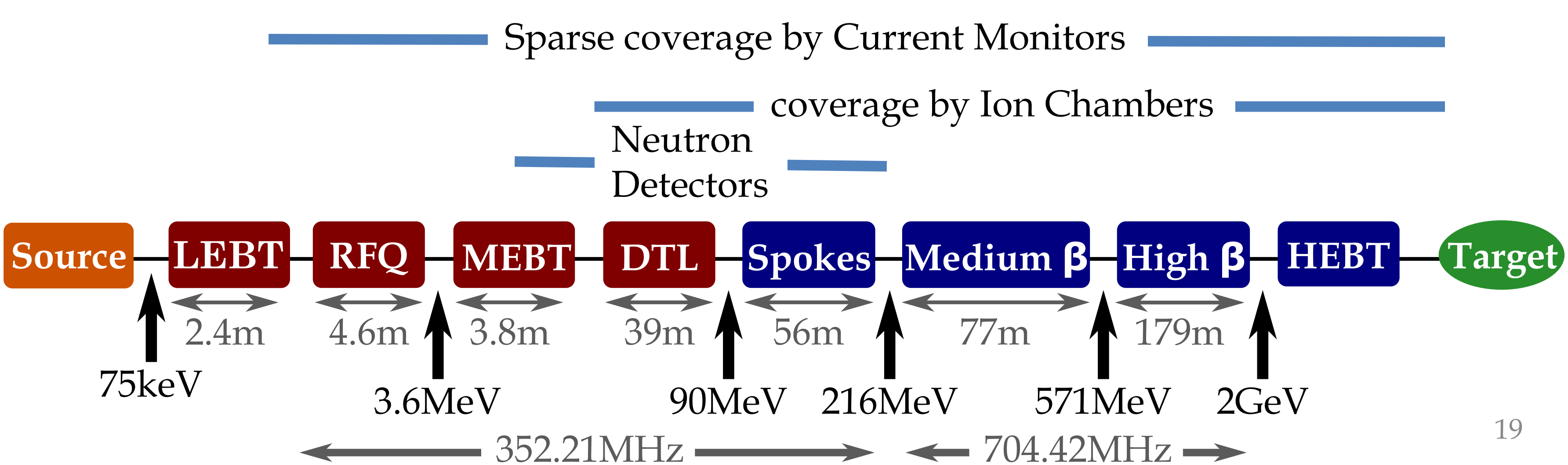
- Foreseen based on beam commission experience and simulations
- Plan to co-develop protection functions across the BI systems providing loss information

Back up material

ESS Beam Loss diagnostic tools

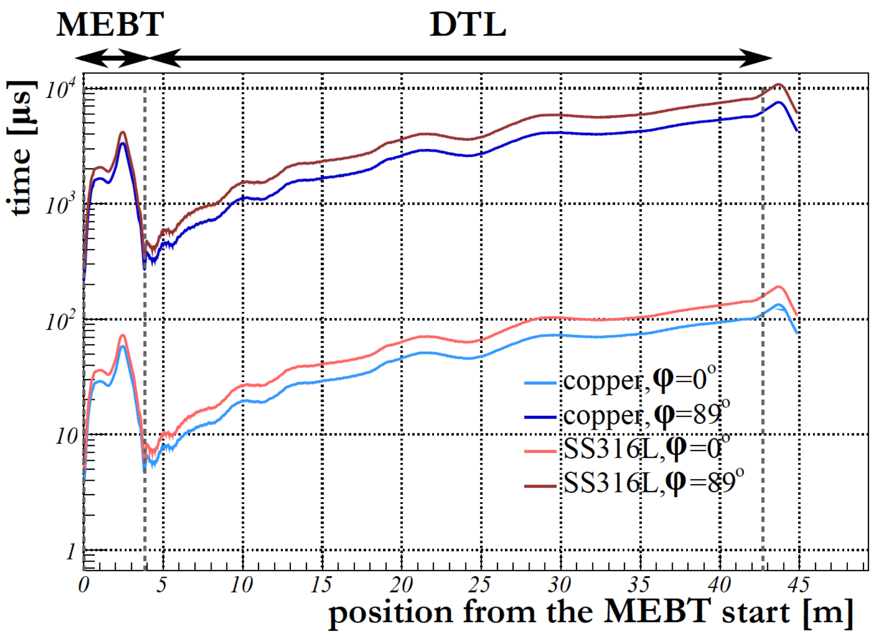
(from T. Shea)

- **Total beam loss**, microsecond measurement latency required for protection
  - BCM, icBLM (saturation, nBLM (current mode) ➔ Interlock; Threshold/derivative term for fast protection
- **> 1.6 milliamp lost for up to 200 µs**
  - BCM, icBLM, nBLM -> Interlock; Damage model for protection
- **~ µC lost over 200 µs to many seconds** (diffusion time)
  - icBLM, nBLM -> Interlock; Damage model for protection
- **~ "1 Watt/meter" radiation dose management**
  - icBLM, nBLM -> alarm based on dose/activation plan



ESS BLM: Response time

- Required response time set in the past:
  - NC linac (MEBT-DTL): ~5 μs.
  - SC linac: ~10 μs.
  - Numbers based on a simplified melting time calculations, where a block of material (copper or stainless steel) is hit by a beam of protons with a uniform profile under perpendicular incidence angle, no cooling considered [9].
- Numbers re-checked with a Gaussian beam and update beam parameters:
  - **NC linac:** calculated melting time values of 3-4μs imply even stronger demands on the response time (confirmed with a MC simulation as well).
  - **SC linac**: the 10μs requirement for response time fits well with the results of this calculations.
    However: other damage mechanisms ma mandate even shorter response time SCL (discussed further).



ESS BLM: detector layout (MEBT-MB)

EUROPEAN SPALLATION SOURCE

nBLM-F vs. nBLM-S

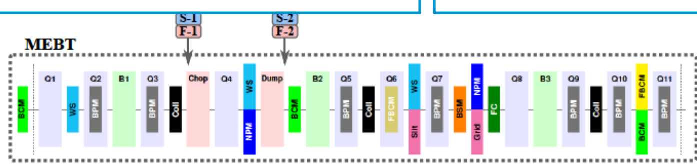
- Majority of the linac: F and S placed separately in an alternating fashion
- At certain locations: a pair of F & S device

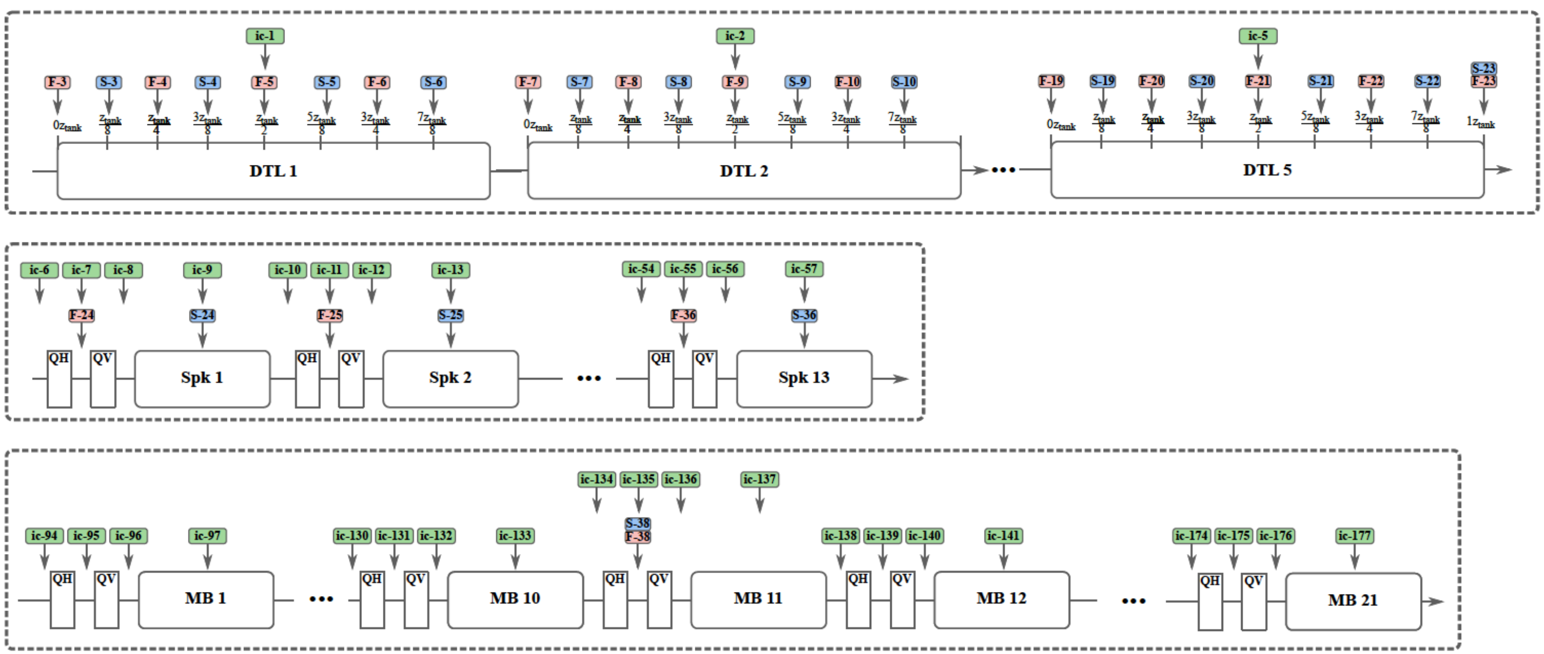
Normal conducting linac (NCL):

- **nBLM:**
  - MEBT: 4 devices (nBLM)
  - DTL: ~ 1 device / 1m
- **icBLM:**
  - DTL: 1device/tank

Superconducting linac (SCL):

- **nBLM**
  - Spoke: 1 device / 2m
  - Sparsely located in other parts of SCL
- **icBLM:**
  - 3/quad pairs
  - 1/cryo





ESS BLM: detector layout (HB – end)

EUROPEAN SPALLATION SOURCE

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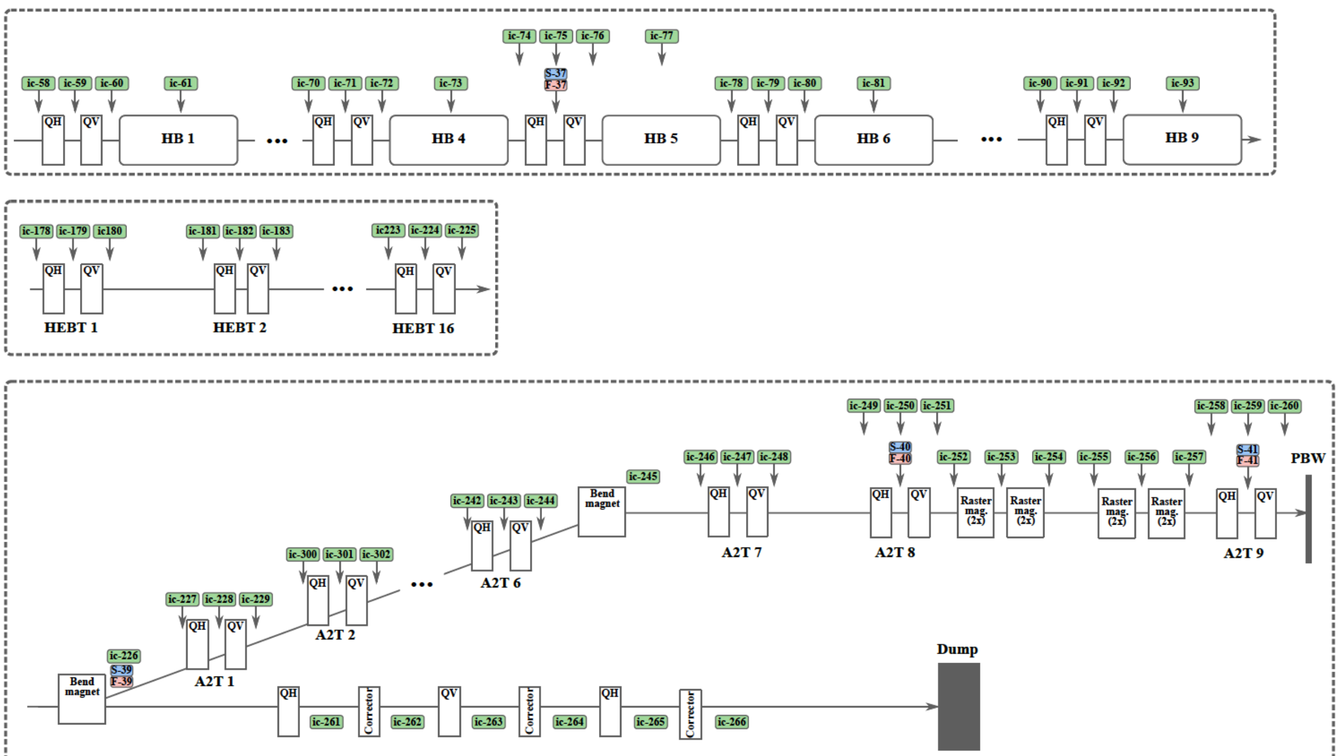


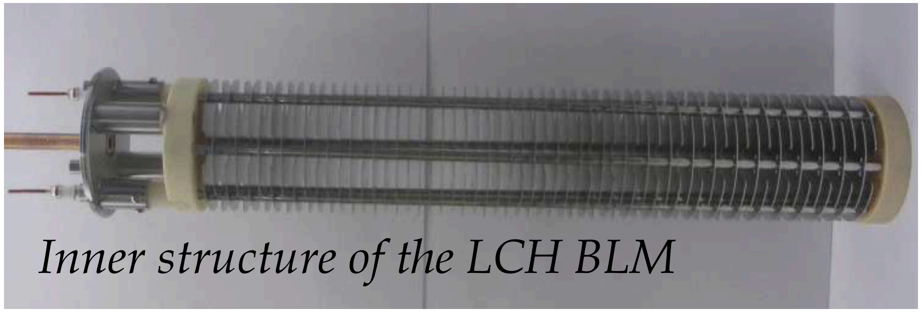
icBLM: detectors (1)

EUROPEAN SPALLATION SOURCE

icBLM

- Parallel plate gas Ionisation Chambers (Ics) developed for the LHC BLM system will be used
- Primary BLMs in SCL
- Beam loss information based on **<u>ionisation current</u>** measurement of secondaries.

Detector property property	Value
detector gas	N_2
pressure	1.1 bar
diameter	9 cm
length	50 cm
sensitive volume length	38 cm
num. of electrodes	61
electrode spacing	5.75 mm
electrode thickness	0.5 cm
electrode diamater	75 mm
bias	1.5 kV
max e^- drift time	300 ns
max ion drift time	83 μs
<energy> to create ion-e^- pair in N_2	35 eV
wall thickness:	
tube	2mm
bottom plate (facing el.box)	4mm
top plate	5mm



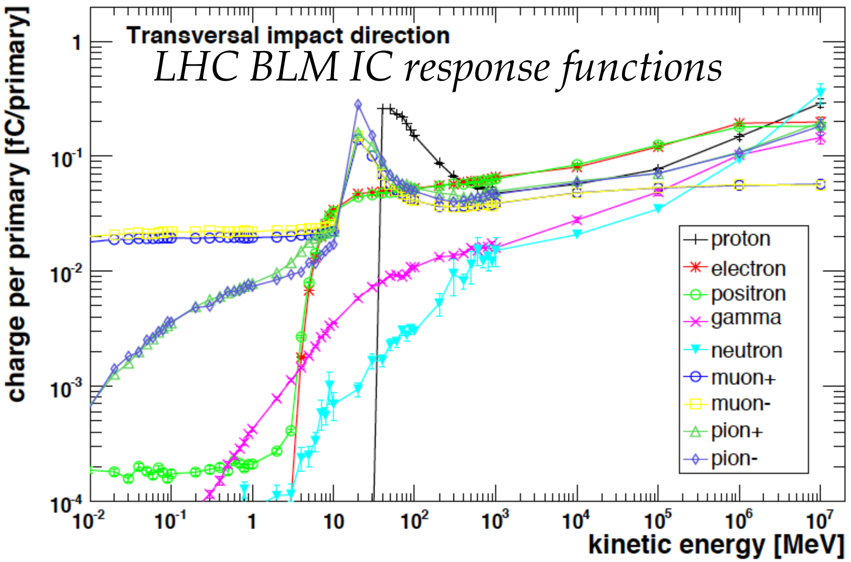
Inner structure of the LCH BLM

icBLM: detectors (2)

icBLM

- “cut off” at transversal photon and electron incidence ~2MeV (~30MeV for p and n) [1].

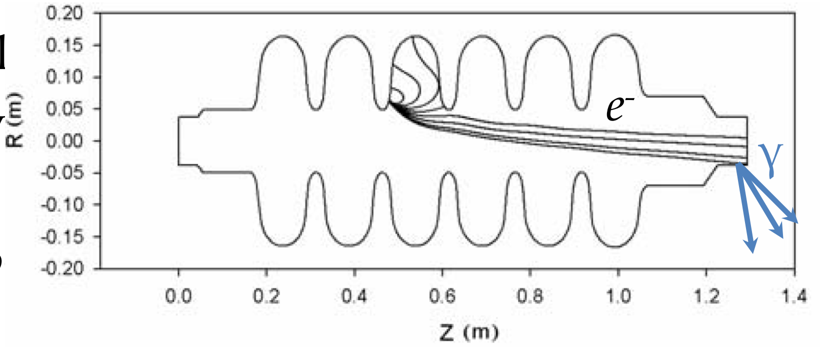
- Photon background due to the RF cavities
  - Bckg. mainly due to el. field Emission from cavity walls, resulting in bremsstrahlung photons created on cavity/beam pipe material [3].
  - Levels are difficult to predict numerically – depend on the quality of cavities, operation conditions and time.
  - Energy spectra estimation [4]: photons with energies up to tens of MeV in the high energy parts expected.



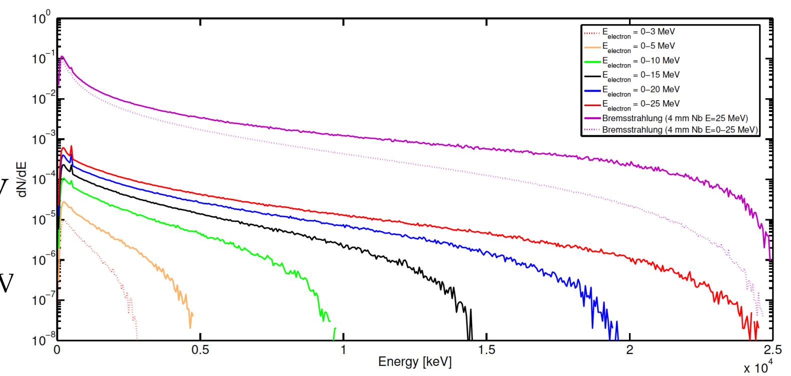
Background photons due to RF

EUROPEAN SPALLATION SOURCE

- Photon background due to the RF cavities mainl due to field emission from electrons from cavity walls, resulting in bremsstrahlung photons created in the field of nuclei of cavity/beam pip materials [3].



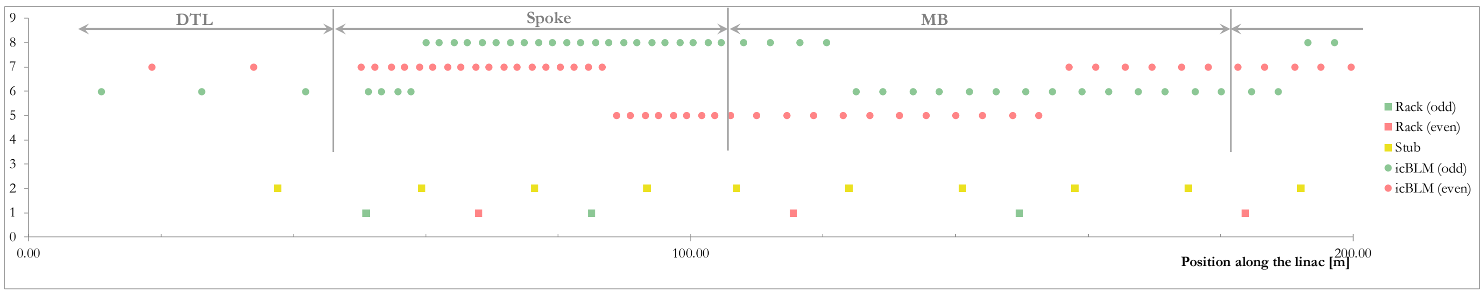
- Energy spectra estimations show that photons up to few tens of MeV can be expected [4]:
  - A MC code (FLUKA) was used for these estimations where a pencil electron beam is impacting a 4mm niobium foil.
  - Purple curves on the plot on the left show expected energy spectra for the photons produced at the exit of the foil:
    - Solid line – for the monochromatic beam of electrons with energy of 25MeV
    - Dotted line – for the beam of electrons with uniform energy distribution from 0 to 25MeV.
    - Spectra are normalized per number of primaries.
  - Note: maximum acc. Gradient expected at ESS ~25MeV/m, cavity size ~1m.

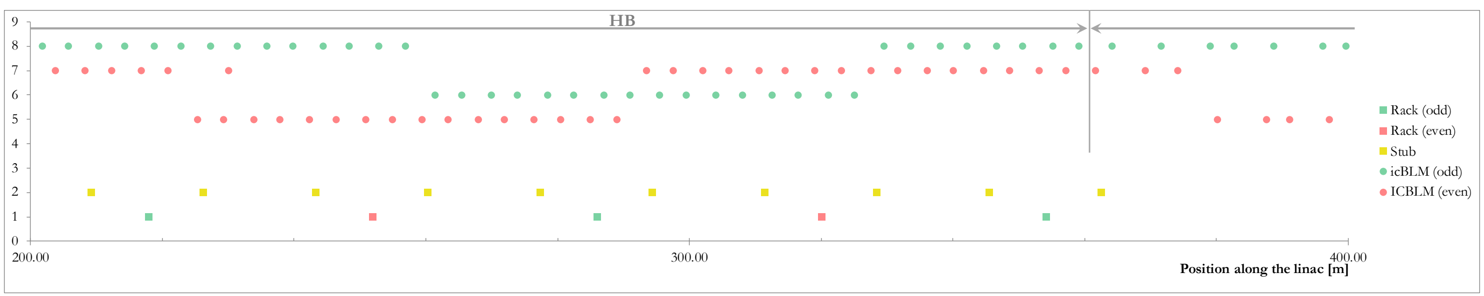


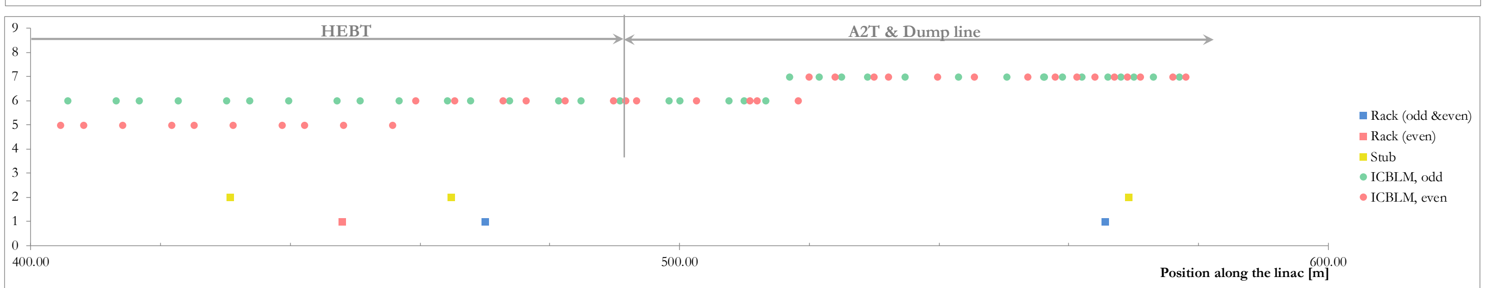
icBLM: electronics layout

2 groups of detectors

- To limit the situations with larger parts of the system un-operational
- Signal electronics for each group placed in separate racks
  - Group1: Odd detectors
  - Group2: Even detectors



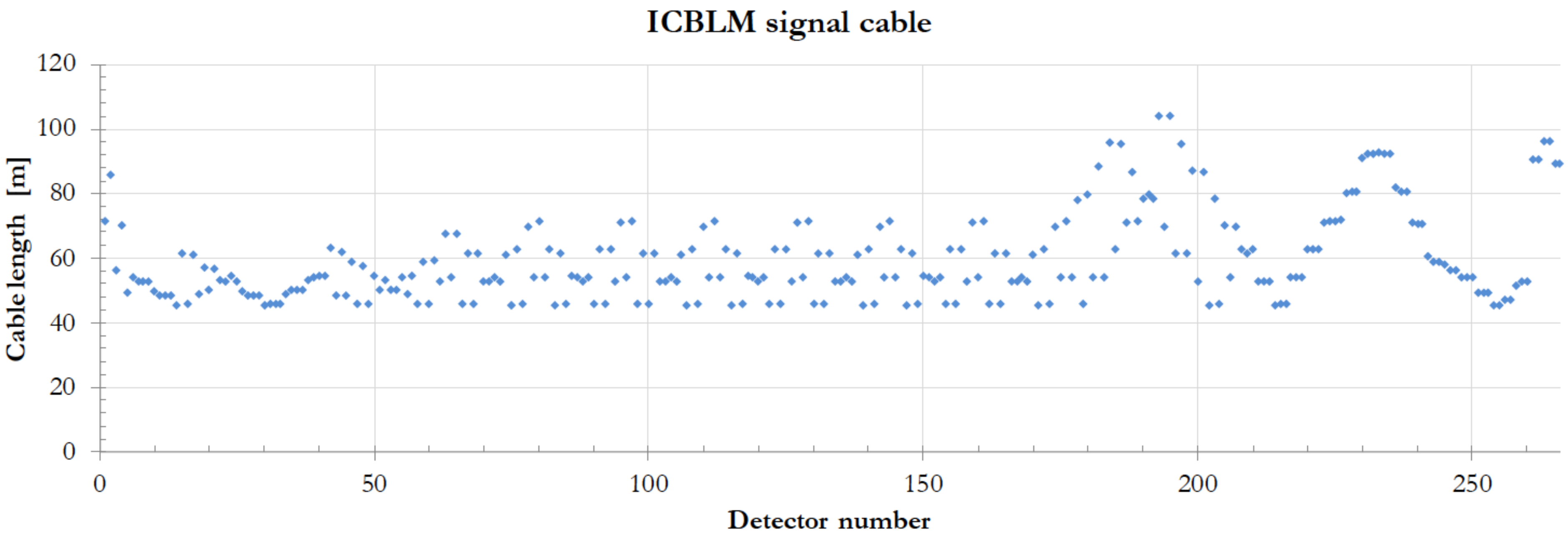




icBLM electronics layout

Estimated signal cable length

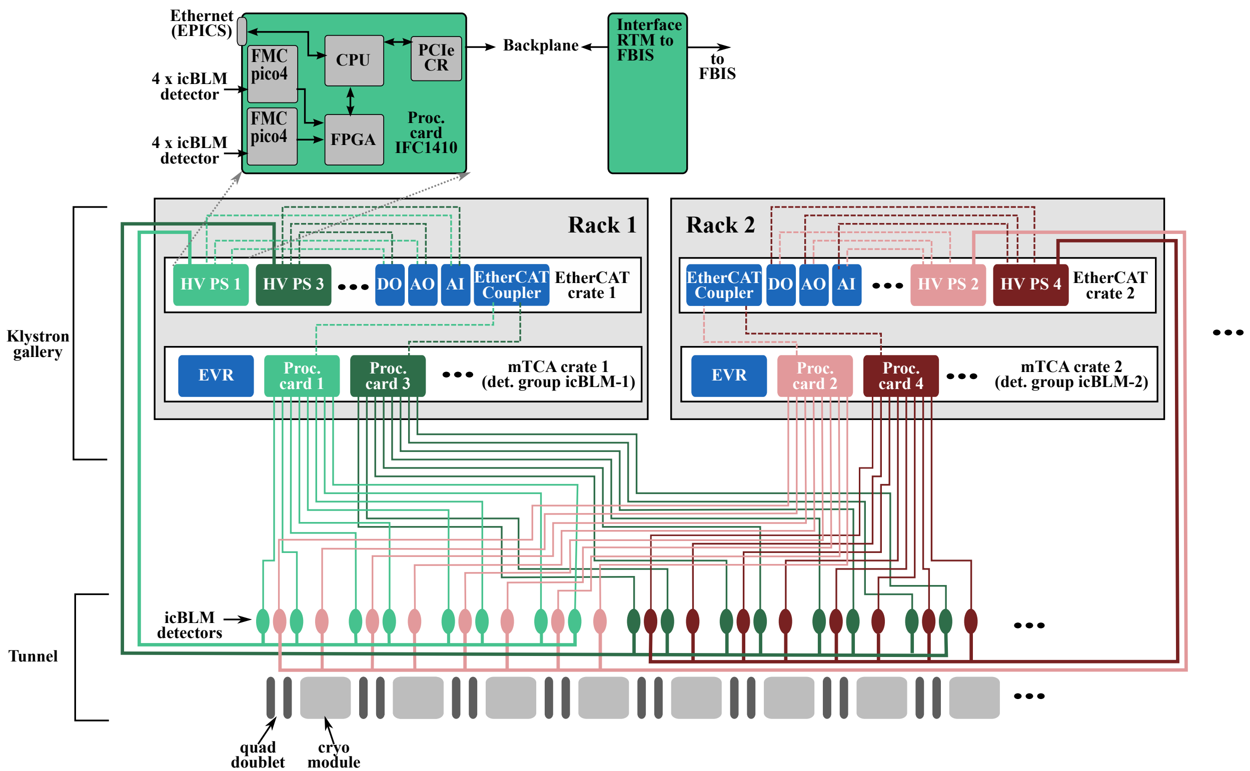
- Most detectors: 40 - 70m
- < 110m



icBLM electronics layout

HV connections

- Same separation scheme as for signal connections
- A set of odd/even detectors (5-7)
  - Connected a given AMC in Group1/Group2 rack X
  - Powered by a HV PS (HV ch) located in rack X



icBLM electronics layout

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Detector group	Rack	#Detectors	Det. group type	#Proc. cards	Detector distribution
ICBLM-01	SPK-010ROW	7	odd (green)	1	{7}
ICBLM-02	SPK-030ROW	20	even (red)	3	{7+7+6}
ICBLM-03	SPK-050ROW	26	odd (green)	4	{7+6},{7+6} (or {6+5+5+5+5+5})
ICBLM-04	MBL-020ROW	20	even (red)	3	{7+7+6}
ICBLM-05	MBL-050ROW	16	odd (green)	3	{6+5+5}
ICBLM-06	MBL-090ROW	16	even (red)	3	{6+5+5}
ICBLM-07	HBL-050ROW	16	odd (green)	3	{6+5+5}
ICBLM-08	HBL-090ROW	16	even (red)	3	{6+5+5}
ICBLM-09	HBL-120ROW	16	odd (green)	3	{6+5+5}
ICBLM-10	HBL-160ROW	19	even (red)	3	{7+6+6}
ICBLM-11	HBL-200ROW	15	odd (green)	3	{5+5+5}
ICBLM-12	HEBT-010ROW	14	even (red)	2	{7+7}
ICBLM-13	HEBT-030ROW	21	odd (green)	3	{7+7+7} (or {6+5+5+5})
ICBLM-14	HEBT-030ROW	12	even (red)	2	{6+6}
ICBLM-15	A2T-010ROW	16	odd (green)	3	{6+5+5}
ICBLM-16	A2T-010ROW	16	even (red)	3	{6+5+5}
Σ		266		45	

icBLM: signal

- Mode of operation
  – Current mode

- Signal range estimations (MC simulations)
  – 1% of 1W/m loss → ~800nA
  – 1% of the total beam loss during accidental loss scenario → few mA