BLM
update & overview

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(BLM System Lead)

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Outline

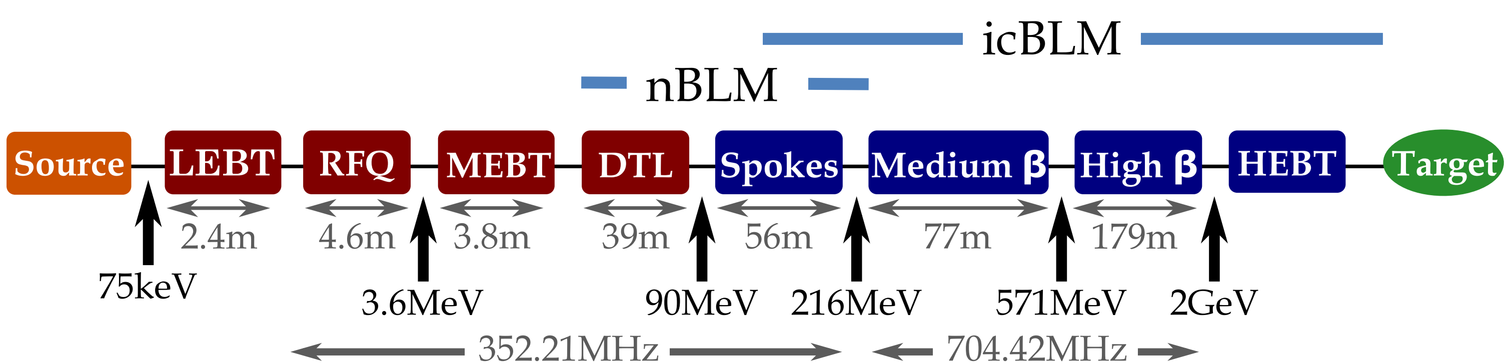
- ESS BLM:
  - Reminder
  - MC beam loss simulations
- nBLM
  - HW overview
  - FPGA functionality & neutron detection algo
- Other updates – not covered
  - Detector layout
  - Electronics layout
  - icBLM FPGA functionality

ESS BLM

Two BLM systems

- icBLM
  - Primary monitor in the high energy parts
  - Detector: ionization chambers (ICs)
- nBLM
  - Primary monitor in the low energy parts
  - Detector: neutron sensitive micromegas detectors

Linac section	Num. of devices: icBLM comment	icBLM count	nBLM comment	nBLM count
MEBT		/		2F+2S=4
DTL	1/tank	5×1=5	8/tank,2/end	5×(4F+4S)+1F+1S=42
Σ		5		23F+23S=46
Spoke	1/cryo,3/2q	13×4=52	1/2q, 1/cryo	13×(F+S)=26
MB	1/cryo,3/2q	21×4=84		1F+1S=2
HB	1/cryo,3/2q	9×4=36		1F+1S=2
MEBT	3/2q	16×3=48		/
A2T				
ramp	1/bend,3/2q	6×3+2×1=20		1F+1S=2
to target	3/2q, 3/4rast.	3×3+2×3=15		2F+2S=4
dump	1/mag.	6		/
Σ		261		18F+18S=36
ΣΣ		266		41F+41S=82
ΣΣΣ				348



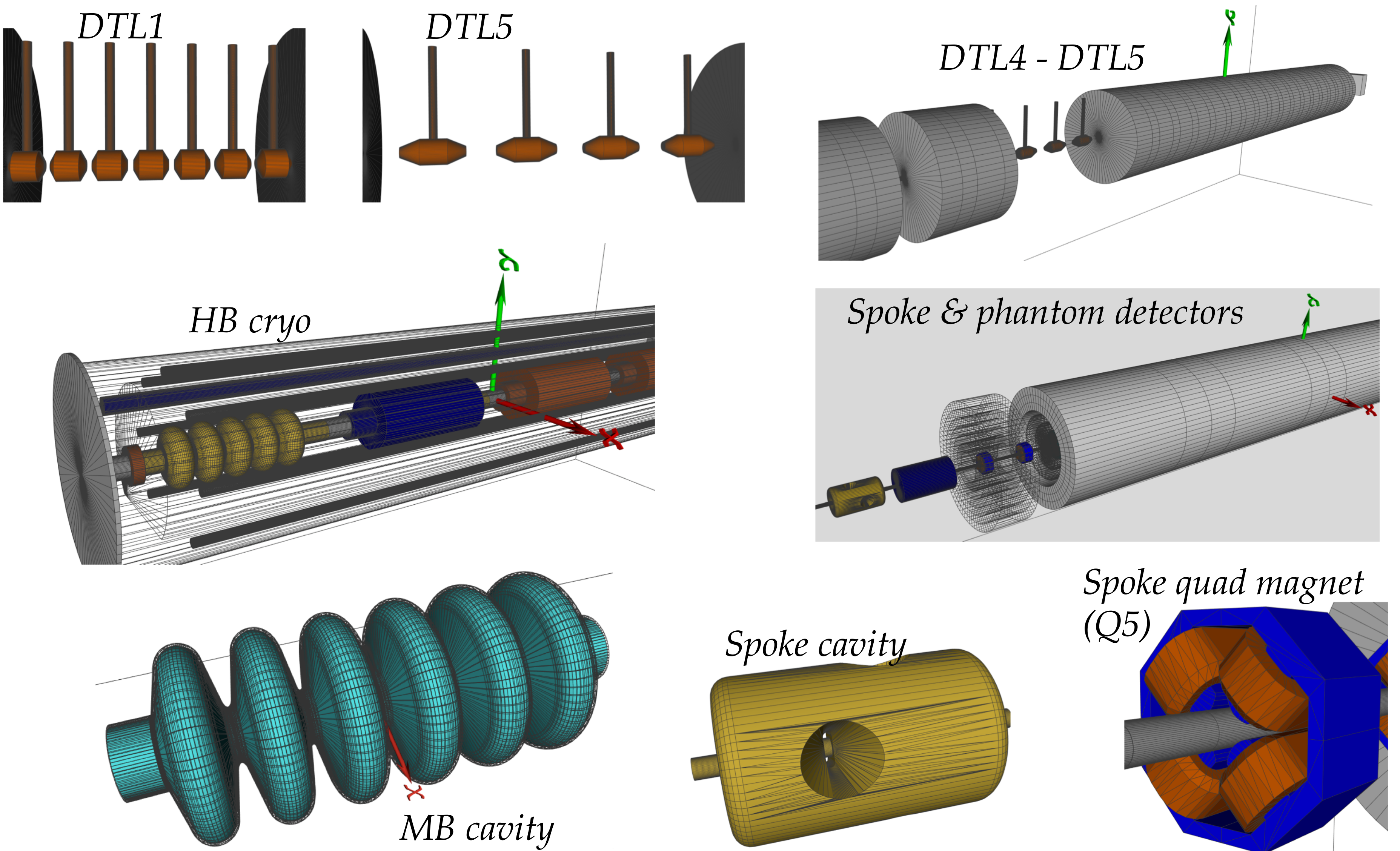
ESS BLM: beam loss simulations

- **MC simulations for tracking of lost protons needed to determine**
  - Detector locations, system response time and dynamic range
  - Expected particle fields, signals
  - Initial MPS threshold settings at the startup and later adjustments
  - Anticipated response of the system during fault studies - to verify and calibrate the system response

- **Required inputs**
  - Ideally
    - Expected loss maps during normal operation
    - A list of accidental beam loss scenarios with loss maps
    - Elements to be protected, damage levels
  - Large number of possible accidental scenarios: simplifications/assumptions needed

- **Simulation tool**
  - Geant4 simulation framework developed by the ESS neutron detector group
  - Geant4 based ESS linac geometry created (current version: DTL - HEBT)

ESS BLM: MC simulations - linac geo



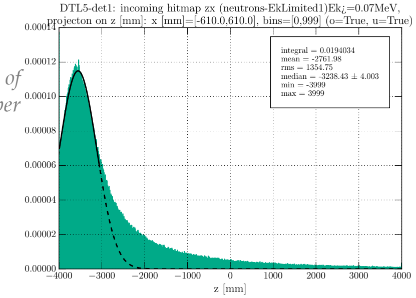
ESS BLM: MC simulations

EUROPEAN SPALLATION SOURCE

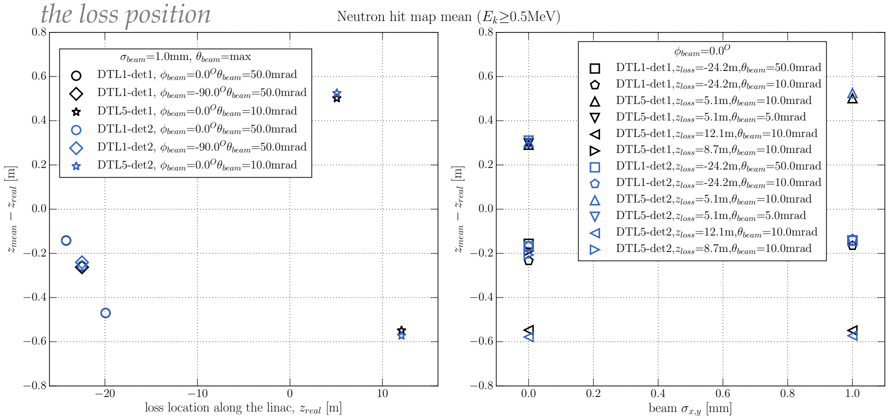
Past studies

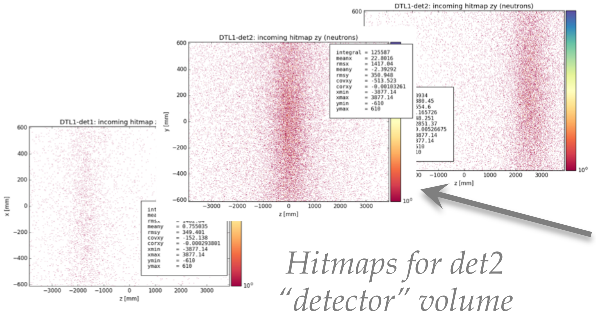
- Focused on DTL
- Tanks surrounded with “phantom detectors”
- Loss scenarios:
  - Accidental losses: scanned over various configurations of energy, beam size, hit angles and position along the DTL
  - Uniform loss, 1W/m loss
  - Nominal operation
- Studied:
  - Expected particle fields (type, energy, fluxes along the beam line)
  - Correlation between the loss location (center) and peak position in neutron hitmaps
  - Spread (RMS) of neutron hitmaps
  - Threshold energy to discriminate fast/slow neutrons
- Tasks:
  - Support nBLM detector design, results used
    - As inputs to MC simulations to optimize detector design
    - For signal estimations
  - nBLM detector layout

Sim2-9: loc. loss at the beginning of the DTL5 (histogram normalized per number of primaries):
hitmap mean=-2.76m
Gauss fit mean = -3.56m
Peak visible ~3.5m

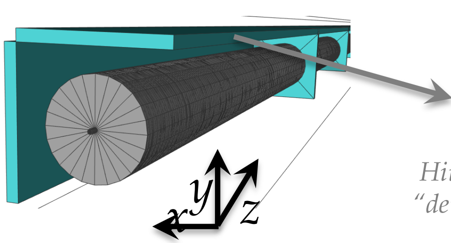


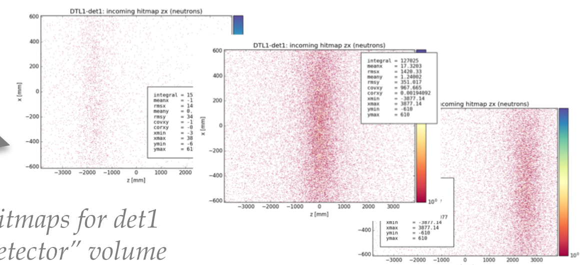
Neutron hitmaps with E_k>0.5 MeV cut: difference between the hitmap mean and the loss position





Hitmaps for det2 “detector” volume





Hitmaps for det1 “detector” volume

ESS BLM: MC simulations

Current focus

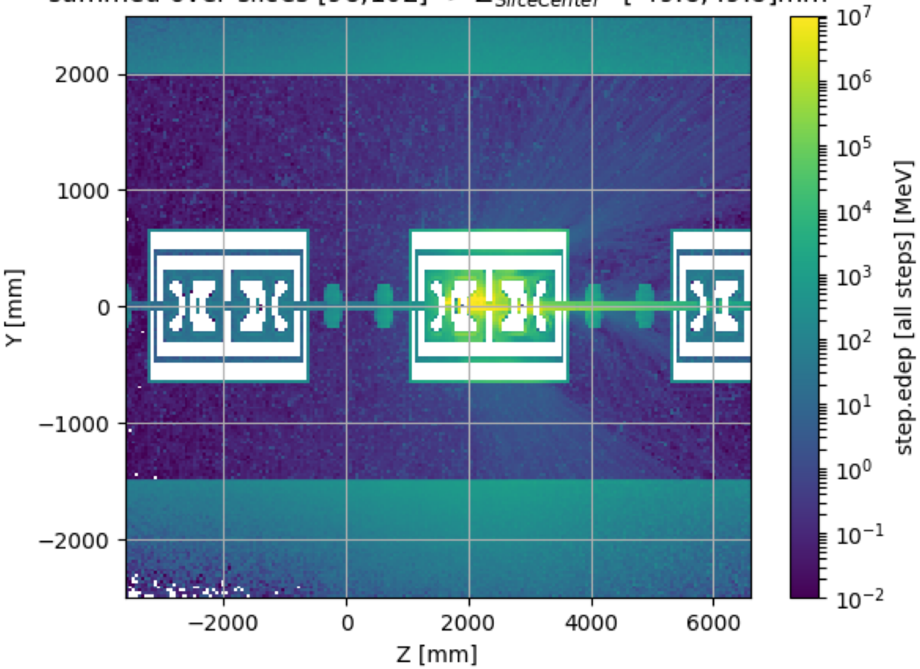
- Cold linac
- Loss scenarios:
  - Scanned over various for various configurations of energy, beam size, hit angles and position along the cryo modules or quads
  - Uniform loss, 1W/m loss
  - Nominal operation
- Tasks:
  - Expected particle fields (type, energy, fluxes along the beam line)
  - Estimate signals/rates
  - Correlation between loss location and peak in distributions (hitmaps, Edep) & spread
  - Starting point for further studies
    - Determination of loss location (loss pattern) from the measurements (ANNs?)
    - MPS Thresholds

ESS BLM: MC simulations

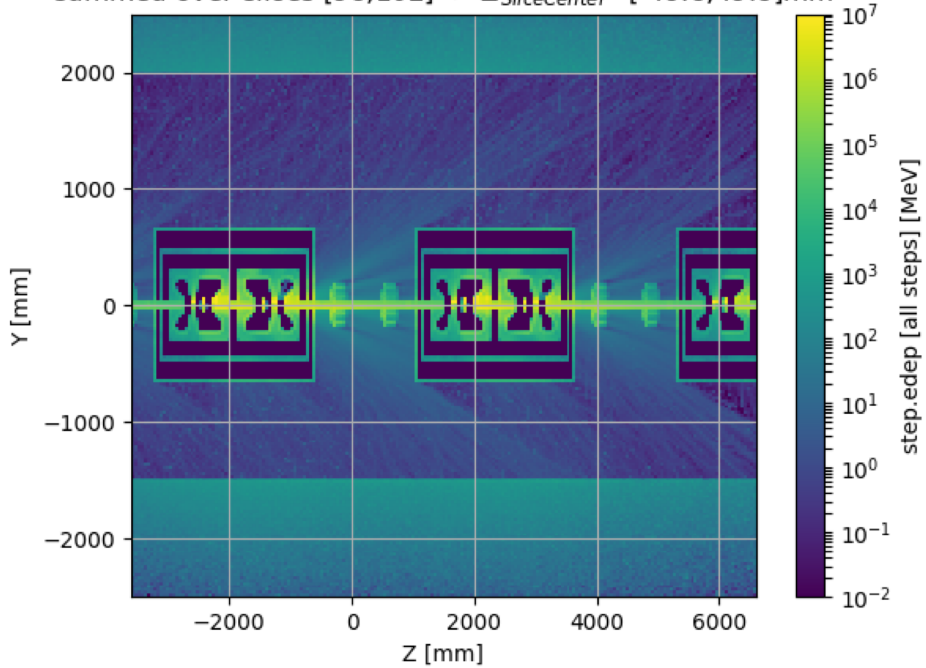
Example: energy deposition summed over 4 center slices along x

- 220MeV protons,
- Beam center hits inside a Spk cryo: on 1st insertion in 1st Spoke cavity
- Theta=1mrad

Pencil beam



3x3mm² (gaussian) beam



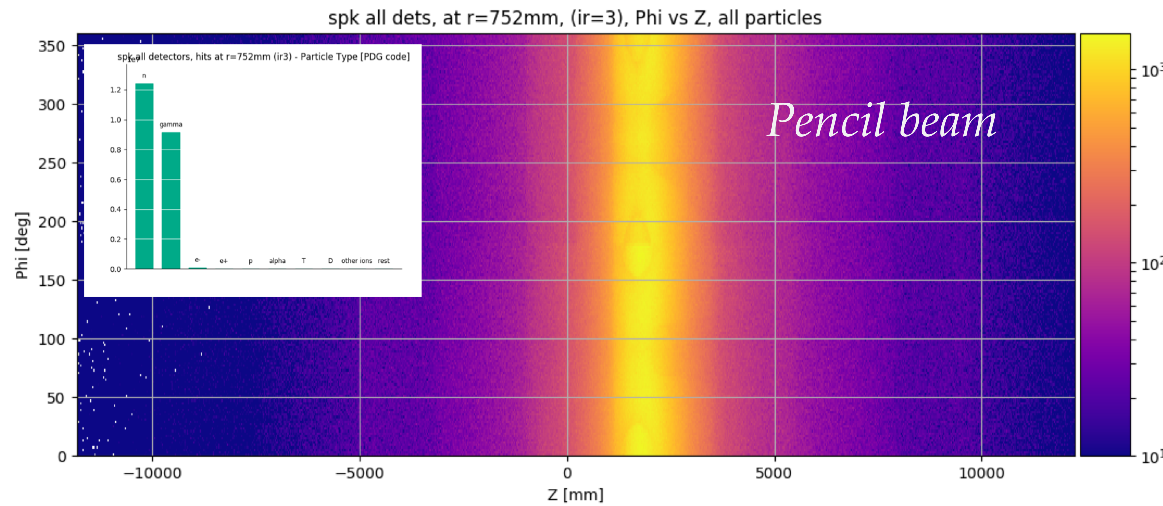
ESS BLM: MC simulations

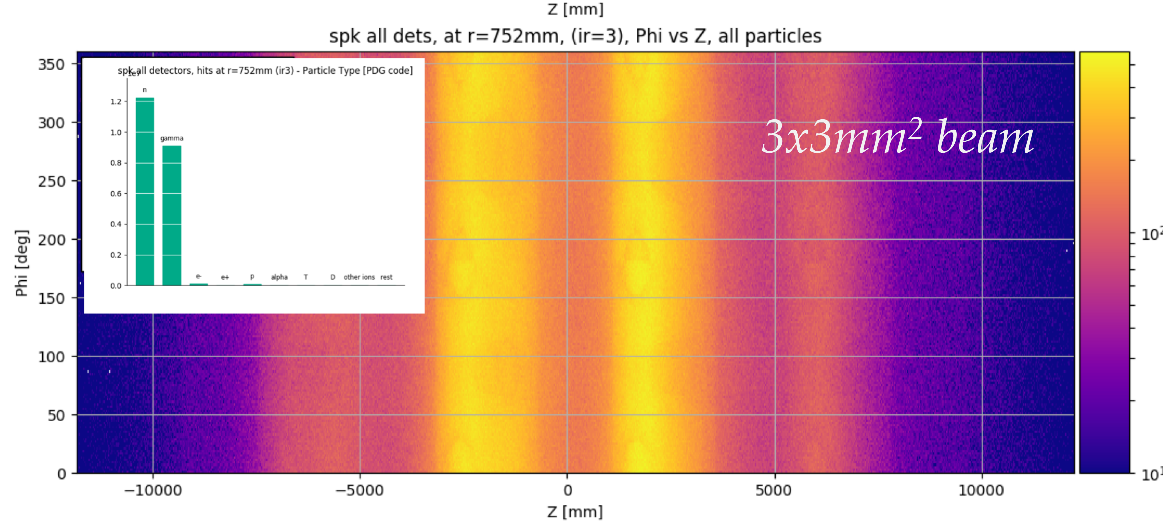
Example:

- 220MeV protons
- Hit center inside Spk cryo at 1st insertion in 1st Spk cavity (z=1650mm)
- Theta=1mrad

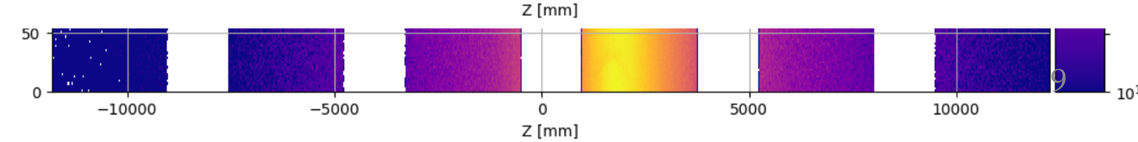
Plots:

- Phi vs Z for particles at r=752mm from the beam axis
- Particle types (n, gamma, e-,…)





Cryo module positions



nBLM

nBLM: collaboration

CEA DEDIP (BD IK)

- Detector and FEE design & production
- Gas system and mechanical support design & fabrication/procurement
- Procurement of part of DAQ HW (digitizers, HV, LV, short cables)

CEA DIS (ICS IK)

- Monitoring and control SW

LUT DMCS (ICS IK)

- FPGA FW design and implementation

ESS BD

- System architecture, for example
  - Detector and electronics layout
  - Mechanical support integration
  - Gas lines 3d model
  - Development of specifications and requirements
    - Spec. relevant for detector design
    - Def. of FW and SW functionality
      - Def. of data processing (FPGA algos)
      - Definition of monitoring variables and algos
  - Beam loss simulations: MC simulation of lost protons
- Installation
- System commissioning
- Coordination & project management

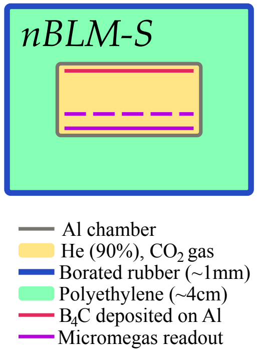
ESS ICS

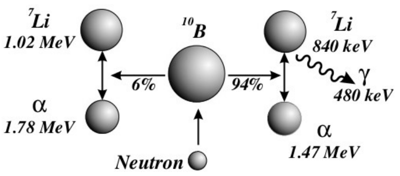
- FW and SW support and integration

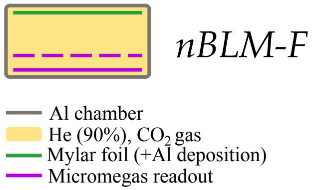
nBLM: overview

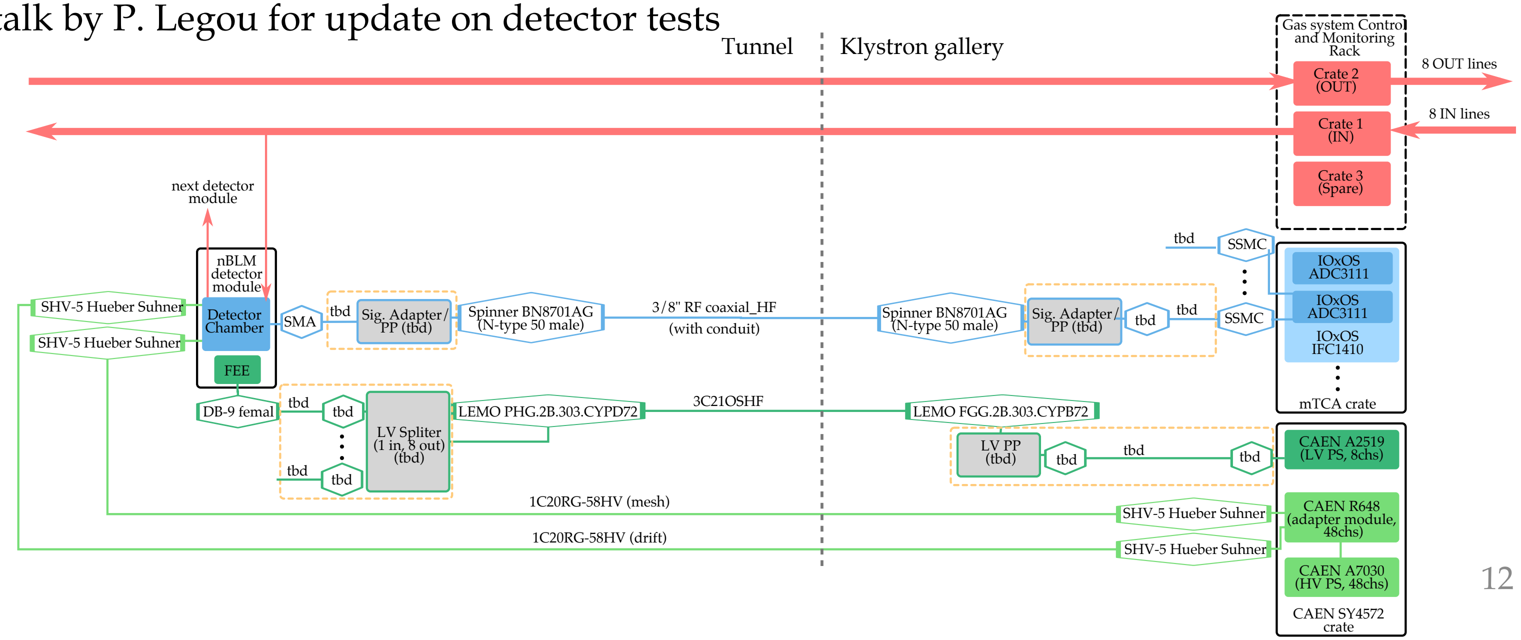
Detectors

- Micromegas detectors (CEA), designed to be:
  - Sensitive to fast neutrons – suppression of thermal neutrons (no correlation with beam loss)
  - Insensitive to low energy photons (X- and γ-rays) – to suppress the RF induced photon background
- 2 types
  - "Fast" – nBLM-F: to detect fast losses
  - "Slow" – nBLM-S: aimed to monitor slow losses
- See talk by P. Legou for update on detector tests



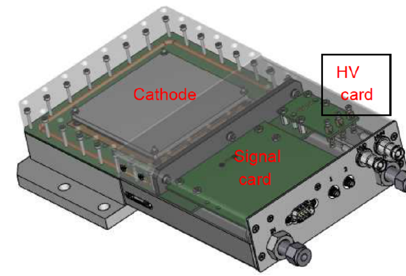




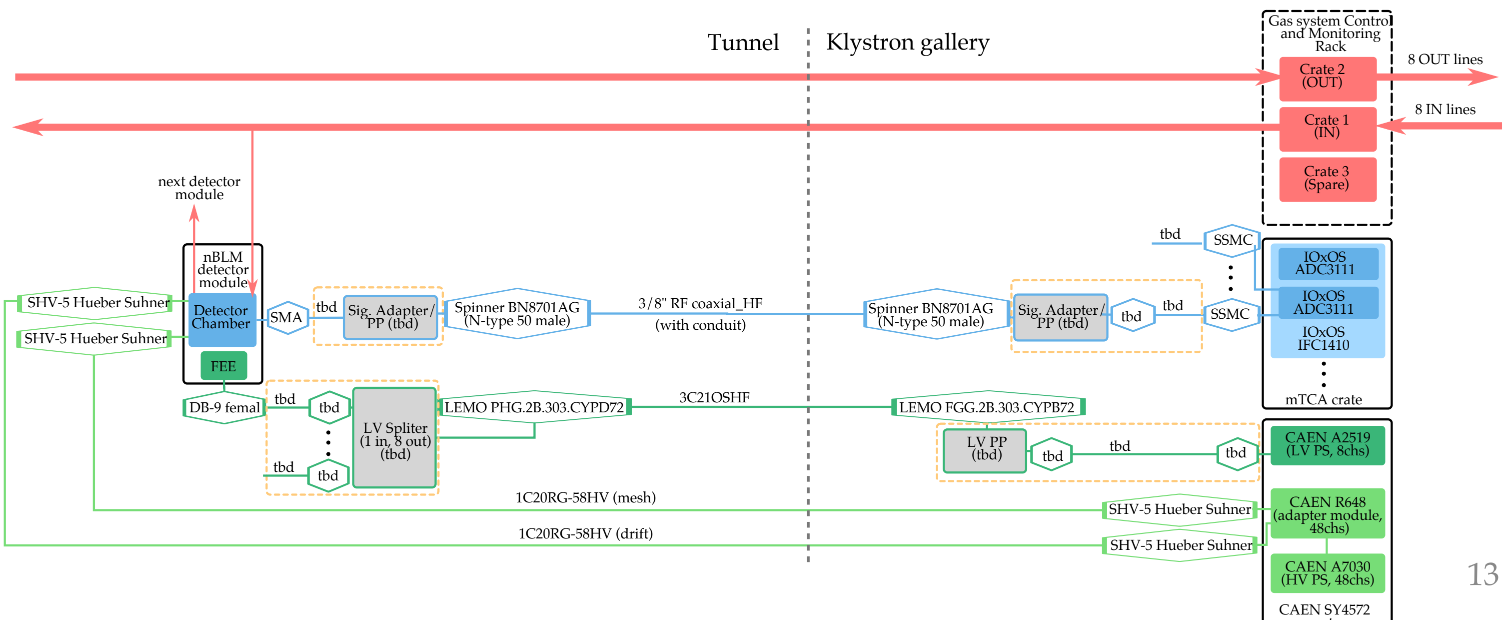


nBLM: overview

- **FEE:**
  - Custom made mezzanine card with FAMMAS preamps (CEA)
  - Housed in a detector module together with the detector chamber and HV mezzanine card

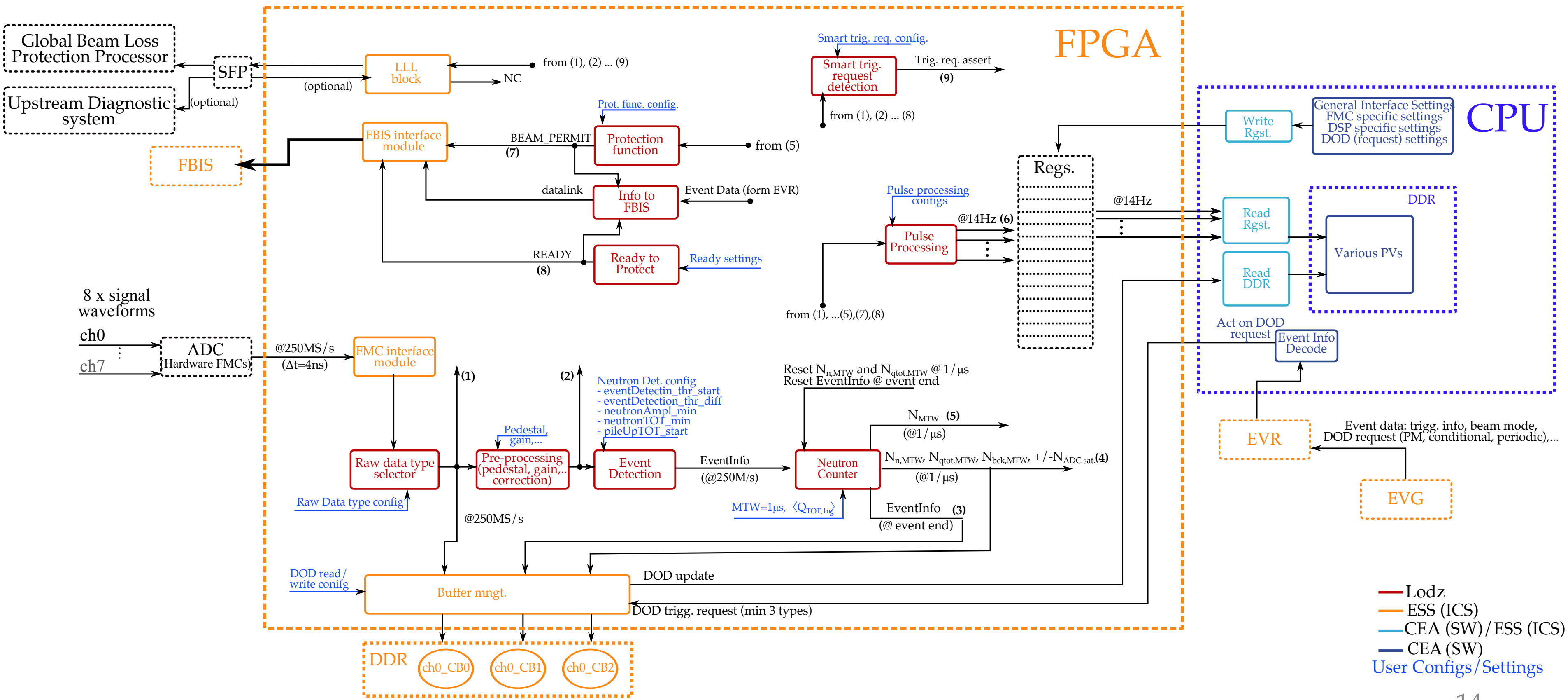


- **BEE**
  - IOxOS IFC1410
  - ADC3111 FMC digitizer (250MS/s, DC coupled).



nBLM FW functionality

- nBLM block diagram: FPGA based data processing, connection to SW
- See talk by G. Jablonski regarding implementation

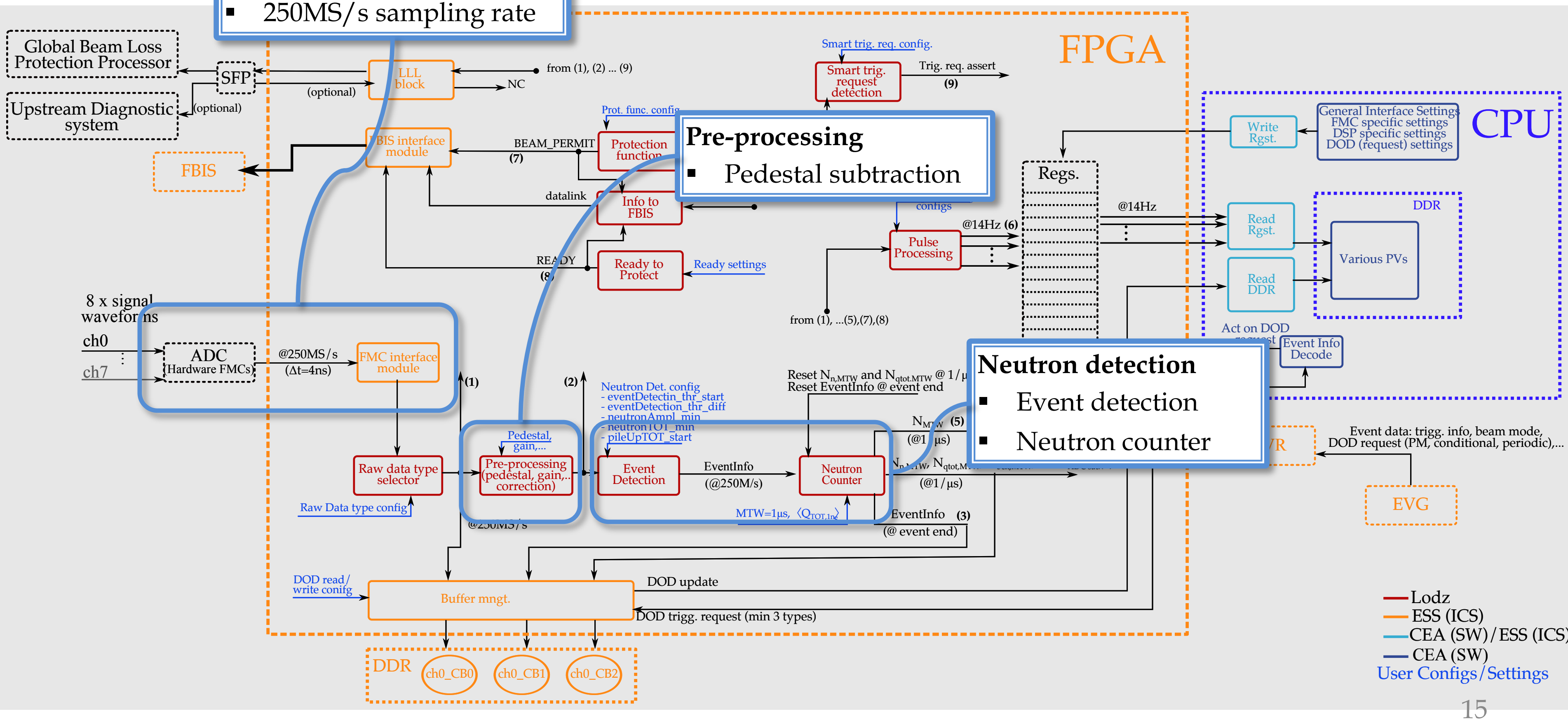


nBLM FW functionality

Raw data:
- 250MS/s sampling rate

Pre-processing
- Pedestal subtraction

Neutron detection
- Event detection
- Neutron counter



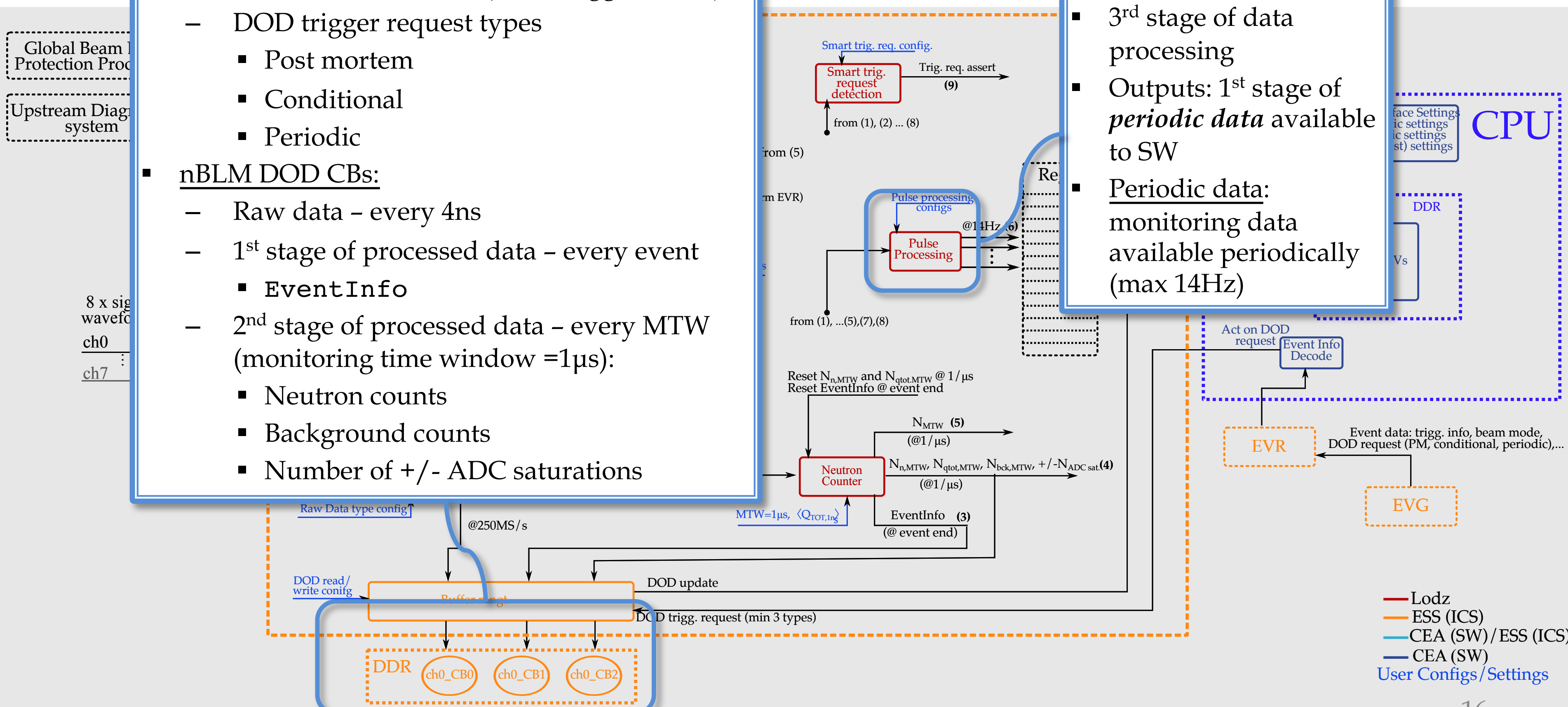
nBLM FW functionality

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

- DOD data:
  - available on demand (DOD trigger assert)
  - DOD trigger request types
    - Post mortem
    - Conditional
    - Periodic
- nBLM DOD CBs:
  - Raw data – every 4ns
  - 1st stage of processed data – every event
    - `EventInfo`
  - 2nd stage of processed data – every MTW (monitoring time window =1μs):
    - Neutron counts
    - Background counts
    - Number of +/- ADC saturations

Pulse processing

- 3rd stage of data processing
- Outputs: 1st stage of *periodic data* available to SW
- Periodic data: monitoring data available periodically (max 14Hz)



nBLM FW functionality

Low Latency Link block

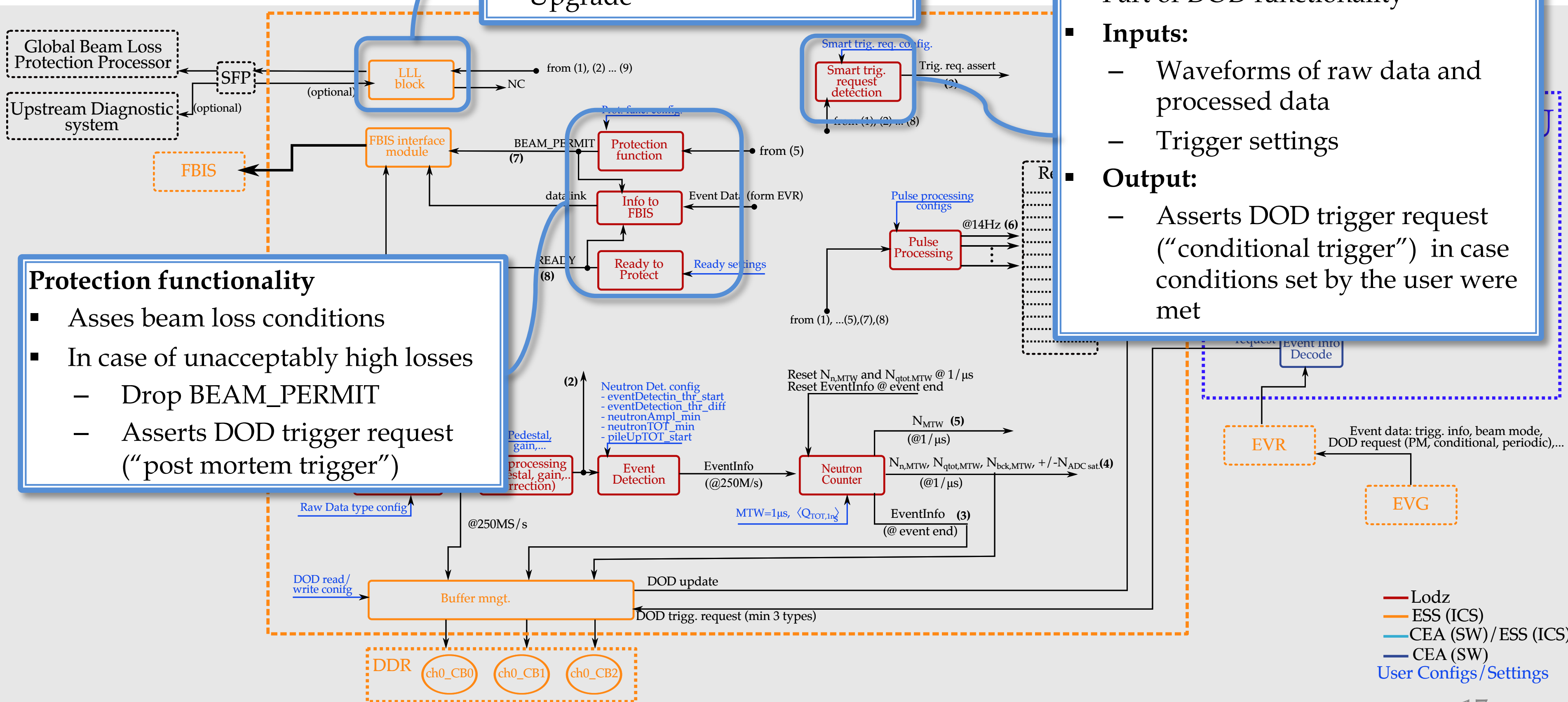
- To combine information coming from different systems of parts of a system
- Upgrade

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")



nBLM: signal

nBLM mode of operation:

- The system is operating in two modes, transition is automatic on the FW level.
- **Counting mode**: individual neutron signals are counted
- **Current mode:** the rate of incoming neutrons is too high to able to distinguish between 2 individual neutron signals
  - Events pile up
  - Number of neutrons estimated through charge.

Typical neutron signal

- The characteristics depend on detector properties/settings (drift length, applied voltage/gain) - settings not finalized.
- Typical numbers:
  - 30-50ns rise time
  - 100-200ns signal length
  - Amplitude:
    - nBLM-S: ~ constant (~100mV)
    - nBLM-F: continuous (maximum value 500mV - ADC saturation)
- **Note**: the nBLM signals are negative.

nBLM: neutron detection algo

What do the neutron detection related blocks provide?

- **Number of neutrons** reported after every MTW - N_{MTW}
  - Is calculated as a sum of a pair of numbers, representing the counts inside MTW calculated by the two different methods.
  - At the end of each MTW:
    - N_{MTW} is stored in the CB2 and
    - N_{MTW} is reset at the end of every MTW.
  - Additional data stored in CB2:
    - Number of pos. ADC saturations
    - Number of neg. ADC saturations
    - Background counts
- **`EventInfo`** for each "interesting event"
  - The structure contains information about the event (Q, TOT, rise time, time stamp,…)
  - The structure is stored in the circular buffer CB1 and
  - Reset at the end of each "interesting event".

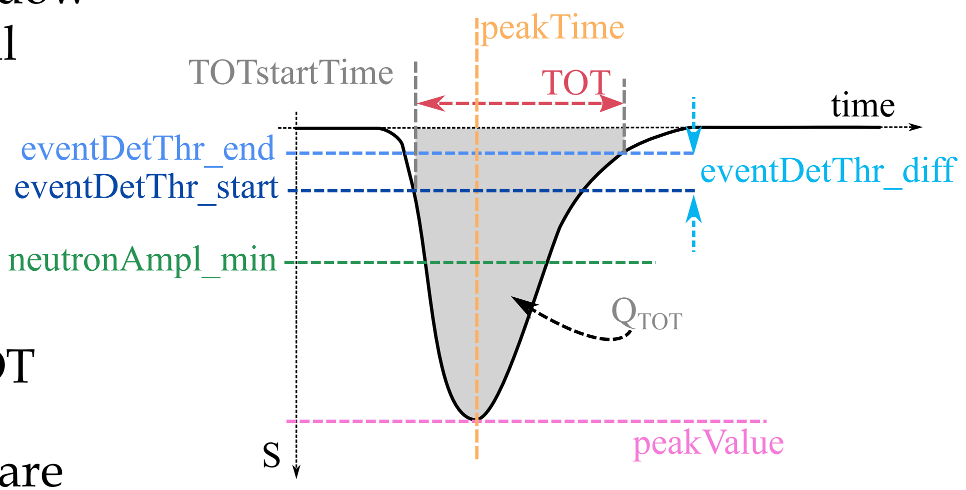
MTW (Monitoring Time Window):

- *Time window in which the neutron counts are measured/reported*
- *Currently set to 1us (250 samples).*

nBLM: neutron detection algo

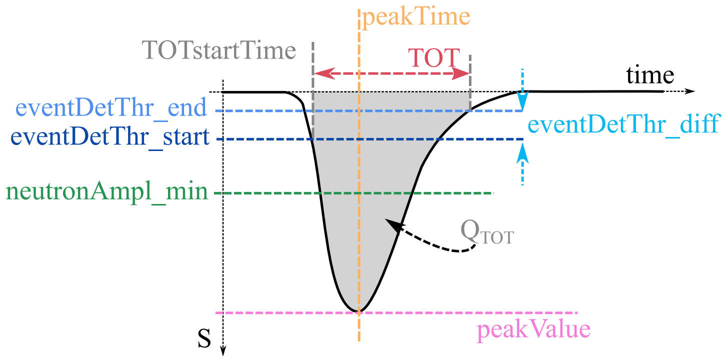
`EventInfo` structure

- `TOT` – event Time Over Threshold
- `Q_TOT` – charge inside the TOT window
- `peakValue` – amplitude (min signal inside TOT window)
- `TOTstartTime`
- `peakTime`
- `peakValid` – true if condition on amplitude for single neutron is met
- `TOTvalid` – true if condition on TOT for single neutron is met
- `pileUp` – true if pile up conditions are met
- `MTWindx` – index of the MTW where event started
- `isTruncated` – true if event 1. part of a split signal
- `isPart2` - true if event 2. part of a split signal



nBLM: neutron detection algo

Basic idea (by T. Papaevangelou):



- Detect **“interesting events”**
  - Identify **single neutrons**
    - *TOT within a certain range*
    - *Amplitude below a certain limit*
  - Identify **pile-up** events
    - *Amplitude below the same limit as for single neutron*
    - *TOT above the upper limit for single neutron*
- Use either of 2 methods for neutron counting for each neutron event:
  - <u>Single neutron counting method</u>
    - for single neutron events: count events
  - <u>Charge method</u>:
    - for pile-up events: calculate counts from charge

nBLM data processing (by ESS):

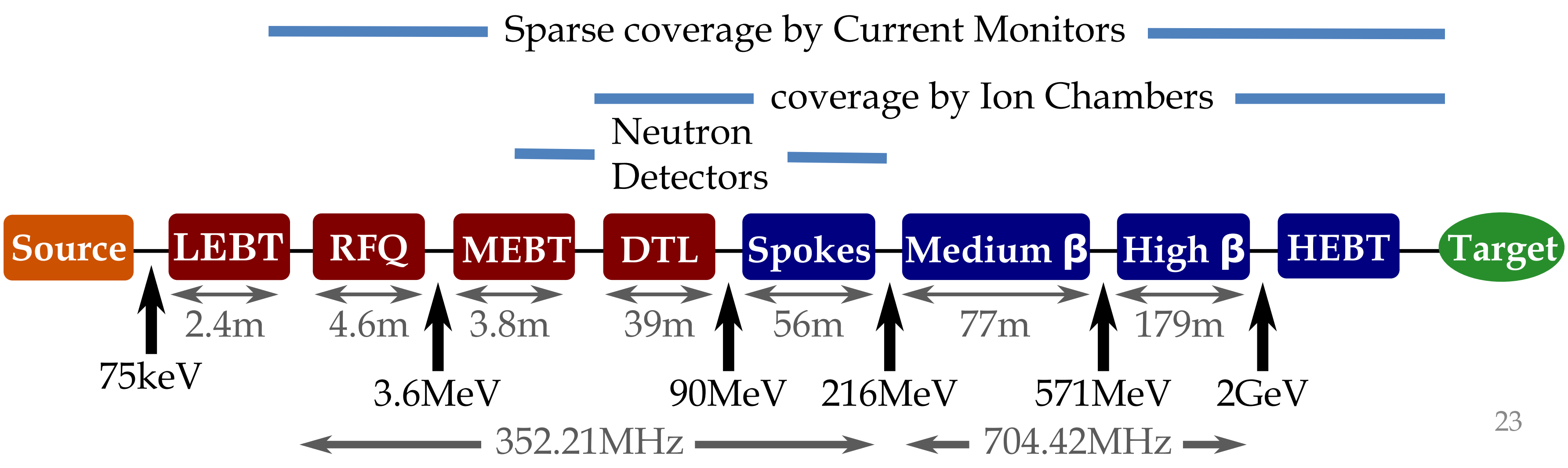
- Basic idea applied to real time processing and MTW framing of counts/events.
- <u>Requirement:</u> algo must provide information (neutron counts) without unnecessary delays.
- Both nBLM-F and –S have the same neutron algo running (different settings)

Back up material

ESS Beam Loss diagnostic tools

(from T. Shea)

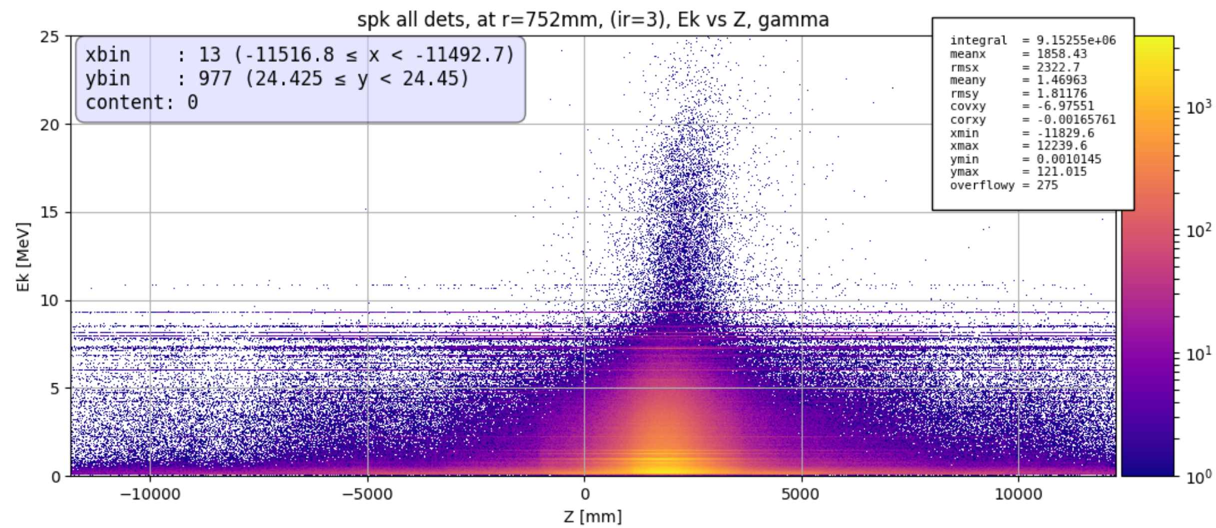
- **Total beam loss**, microsecond measurement latency required for protection
  - BCM, icBLM (saturation, nBLM (current mode) ➔ Interlock; Threshold/derivative term for fast protection
- **> 1.6 milliamp lost for up to 200 µs**
  - BCM, icBLM, nBLM -> Interlock; Damage model for protection
- ~ **µC 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

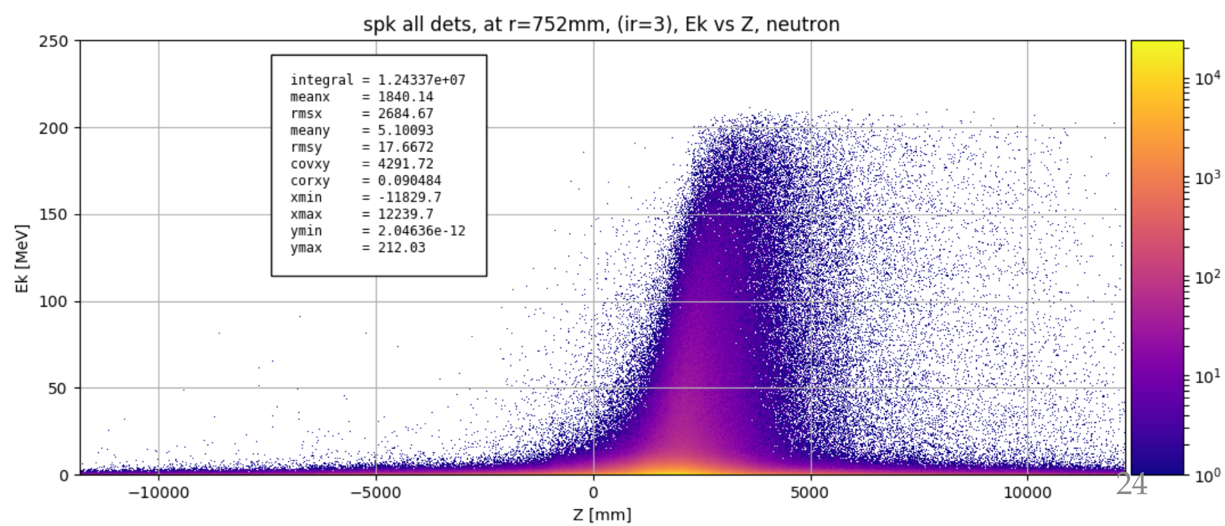


ESS BLM: MC simulations

Example:
- 220MeV protons
- Hit at: 1st insertion in Spk cavity
- Theta=1mrad
- Pencil beam

Plots: hits at r=752mm from beam axis
- Neutron and photon energy along the beam line





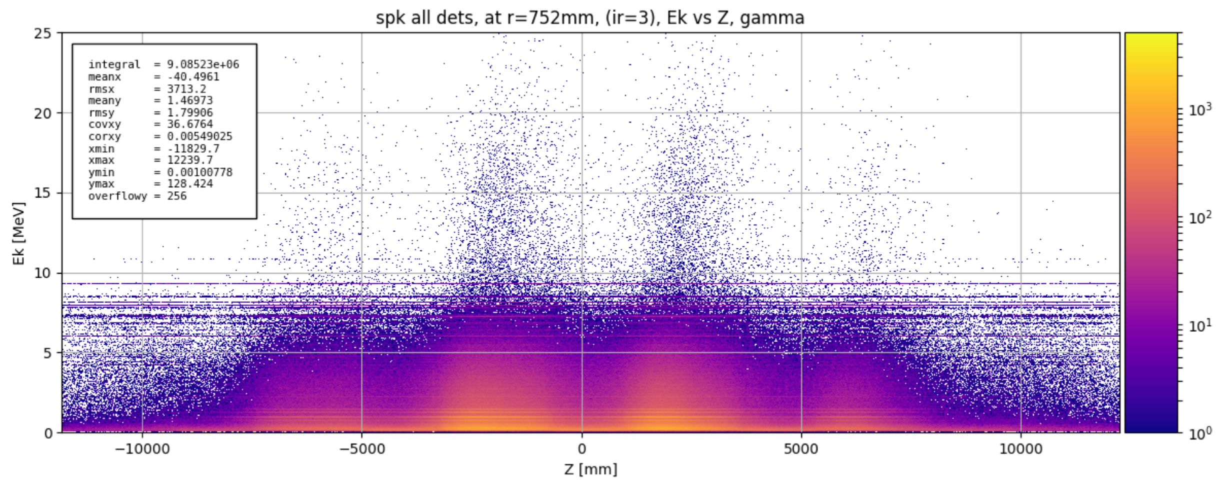
ESS BLM: MC simulations

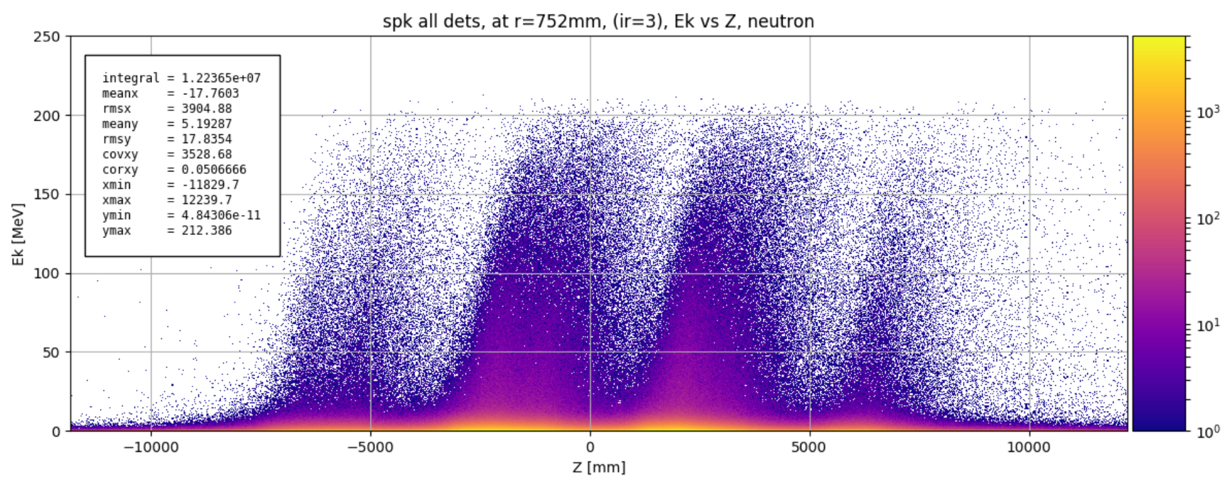
Example:

- 220MeV protons
- Hit at: 1st insertion in 1st Spk cavity
- Theta=1mrad
- 3x3mm^2 beam

<u>Plots:</u> hits at r=752mm from beam axis

- Neutron and photon energy along the beam line





ESS BLM: detector layout (MEBT-MB)

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nBLM-F vs. nBLM-S

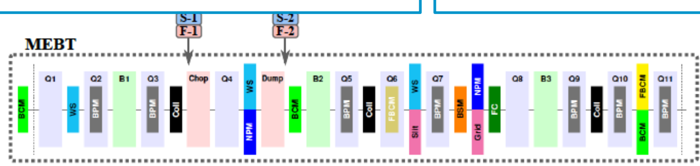
- Majority of the linac: F and S placed separately in an alternating fashion
- At certain locations: a pair of F & S device

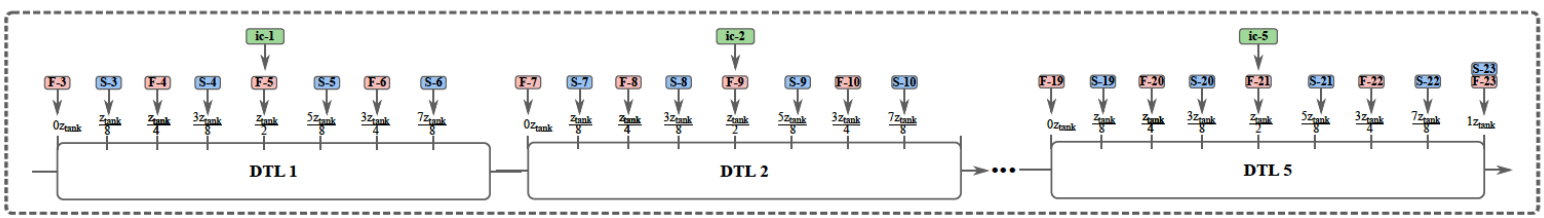
Normal conducting linac (NCL):

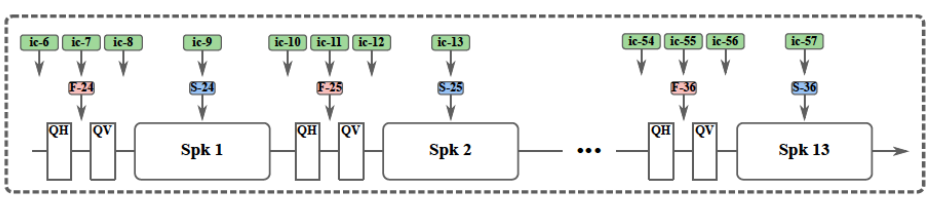
- **nBLM:**
  - MEBT: 4 devices (nBLM)
  - DTL: ~ 1 device / 1m
- **icBLM:**
  - DTL: 1device/tank

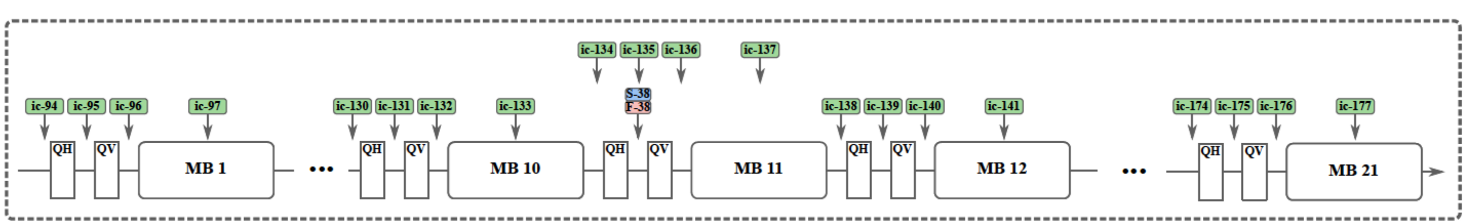
Superconducting linac (SCL):

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









ESS BLM: detector layout (HB – end)

nBLM-F vs. nBLM-S

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- At certain locations: a pair of F & S device

Normal conducting linac (NCL):

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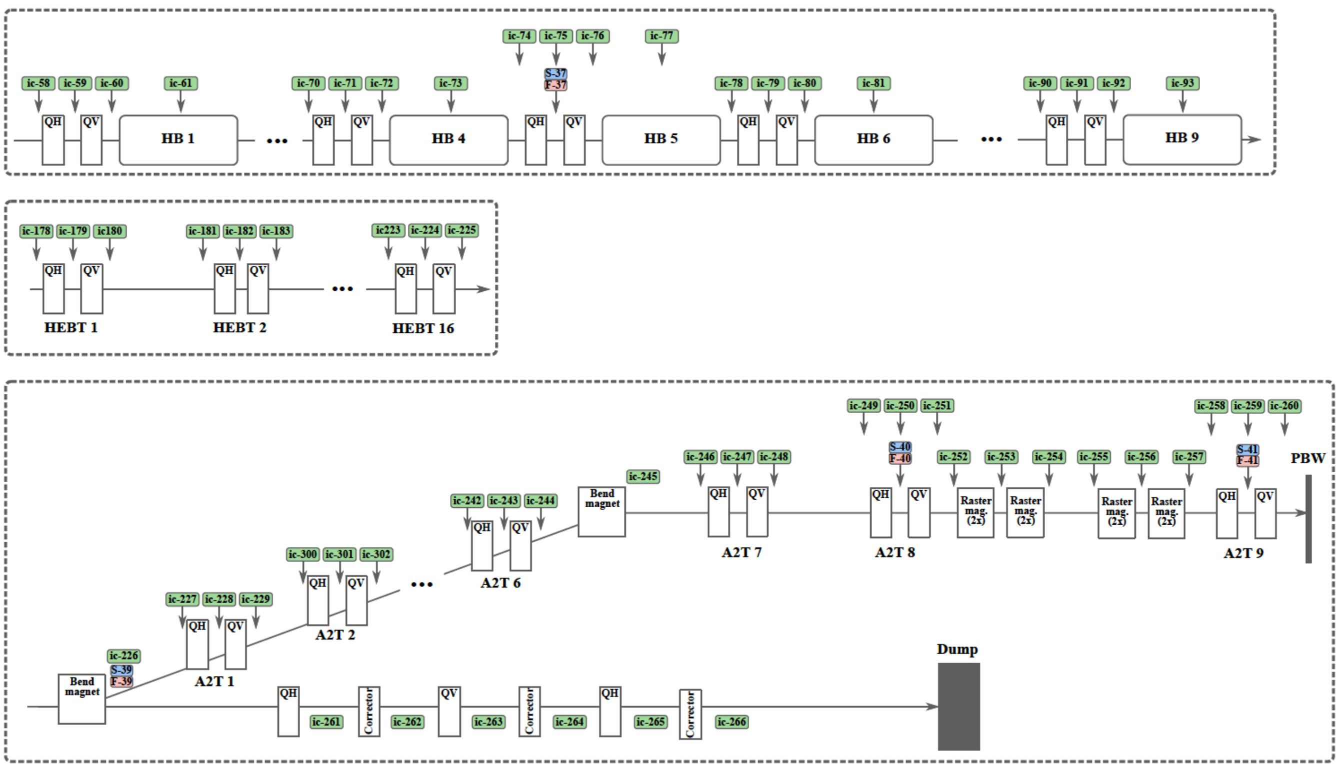
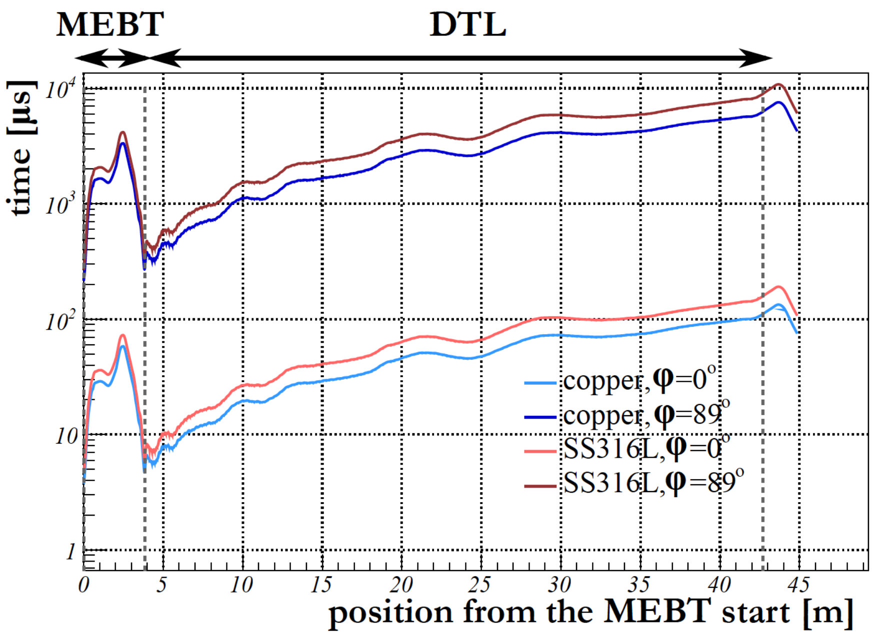


ESS BLM: Response time

- 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).



icBLM

icBLM: collaboration

LUT DMCS (ICS IK)

- FPGA FW design and implementation
- SW design and implementation

ESS BD

- System architecture, for example
  - Detectors & electronics
  - Detector and electronics layout
  - Mechanical support
  - Development of specifications and requirements
    - Spec. relevant for detector design
    - Def. of FW and SW functionality
      - Def. of data processing (FPGA algos)
      - Definition of monitoring variables and algos
  - Beam loss simulations: MC simulation of lost protons
- Installation
- System commissioning
- Coordination & project management

ESS ICS

- FW and SW support and integration

icBLM: collaboration

LUT DMCS (ICS IK)

- W. Cichalewski (proj. management)
- G. Jablonski (FW, SW)
- R. Kielbik (FW)
- W. Jalmuzna (FW)

ESS BD

- T. Shea (section leader, interim BLM system lead)
- I. Dolenc Kittelmann (BLM system lead)
- K. Rosengren (FW, DOD)
- H. Kocevar (SW)
- J. Norin (bookkeeping: det. & el. Layout, naming)
- S. Grishin (installation, gas system)
- C. Derrez (verification plan, QA, electronics)
- E. Bergman (cables, connectors, PPs)
- T. Grandsaert (mech. integration, mech. support)

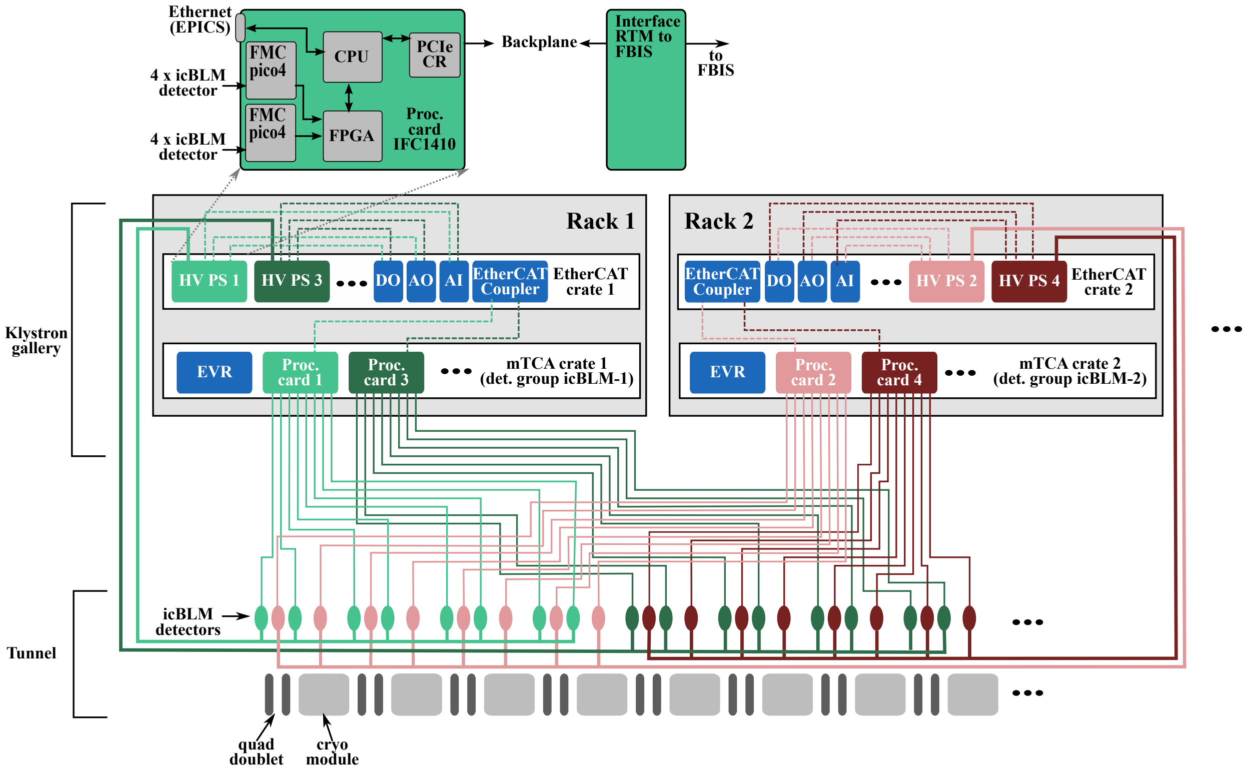
ESS ICS

- S. Farina
- F. dos Santos Alves
- (W. Fabianowski)

icBLM: overview

Detectors

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



BEE

- IOxOS IFC1410
- Pico 4 FMC digitizer (CAENels)
  - Modified COTS
  - 1MS/s, 20-bit ADC, 300kHz bandwidth
  - Dynamic range:
    - 0 – 500µA,
    - 0 – 10mA

HV PS

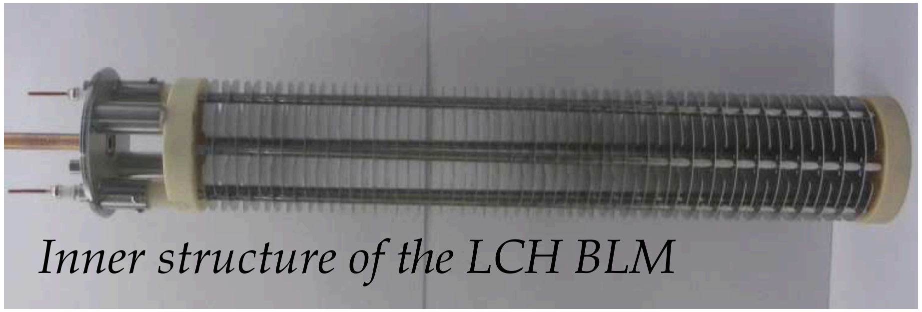
- Provides:
  - Power the ICs (1.5kV) – several ICs are daisy changed and connected to one HV ch
  - Modulation voltage for system HEALTH check.
- HV module (1ch):
  - ISEG DPr 40 305 24 5_CAB High Precision HV-PS
- Ethercat crate with
  - ethercat coupler,
  - DIO (for PS config.) and
  - Analogue module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

icBLM: detectors (1)

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 **ionisation current** 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



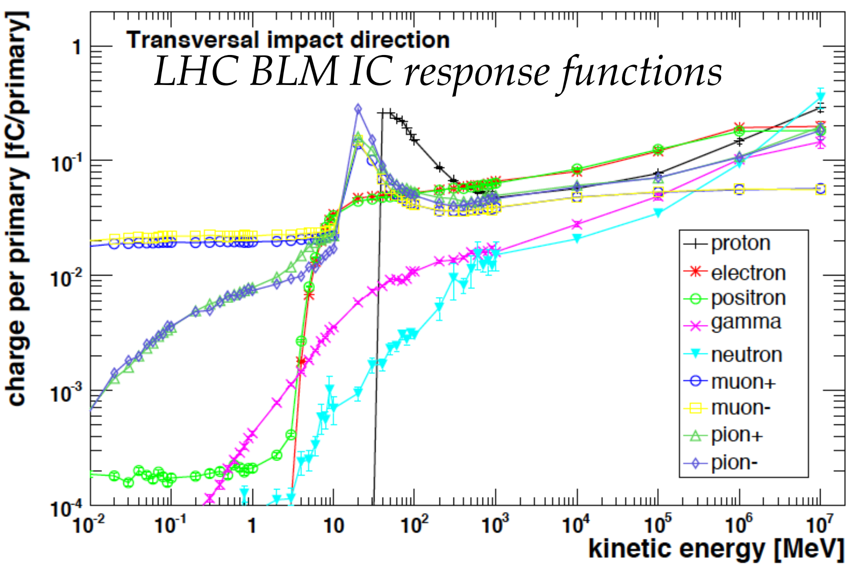
Inner structure of the LCH BLM

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

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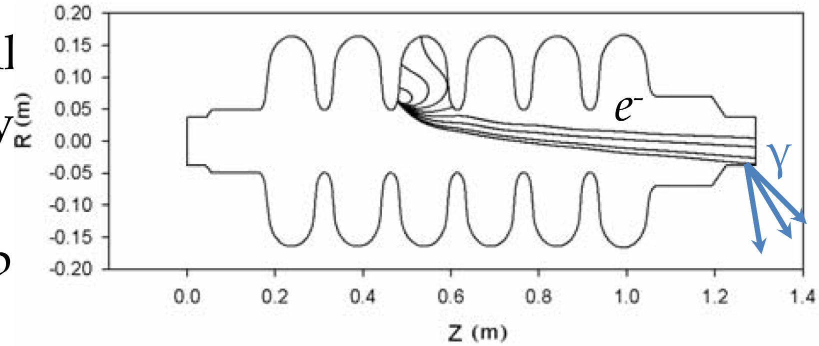
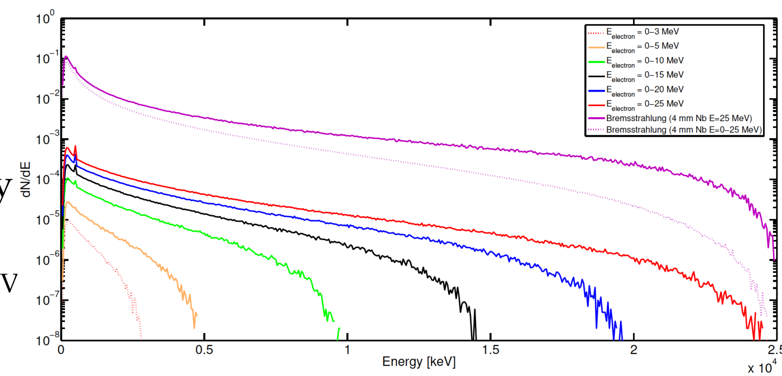
- Photon background due to the RF cavities mainl due to field emission from electrons from cavity walls, resulting in bremsstrahlung photons created in the field of nuclei of cavity/beam pip materials [3].



- 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

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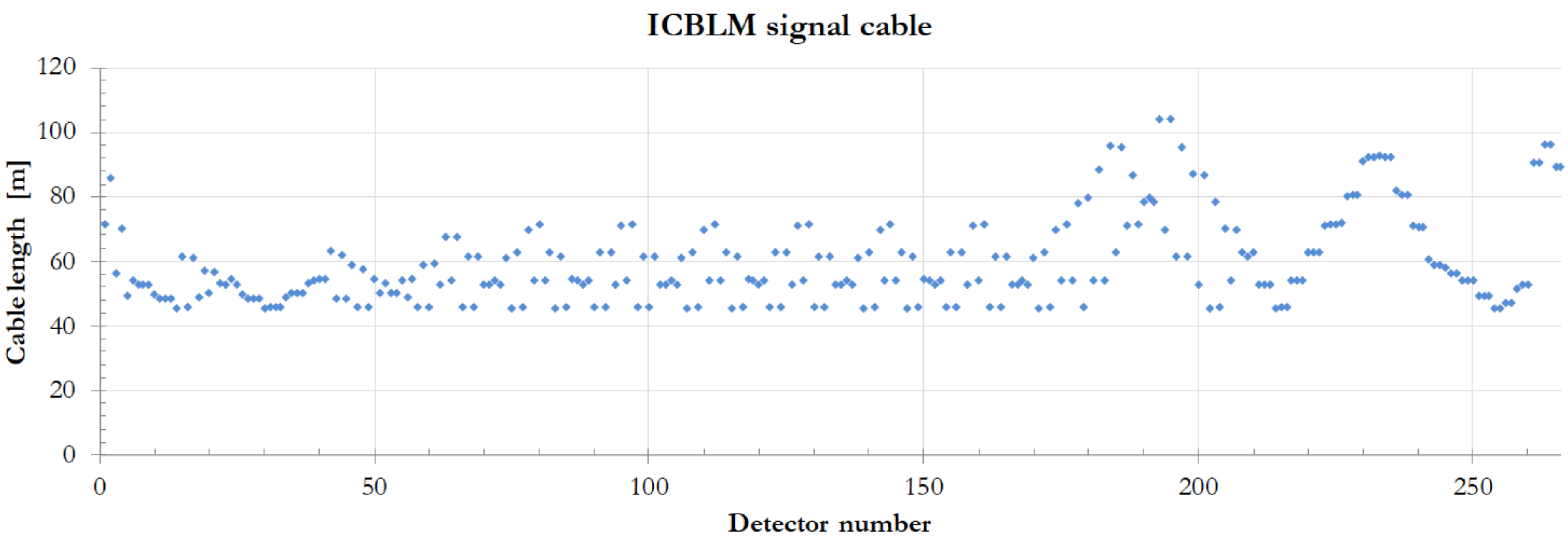
Estimated signal cable length

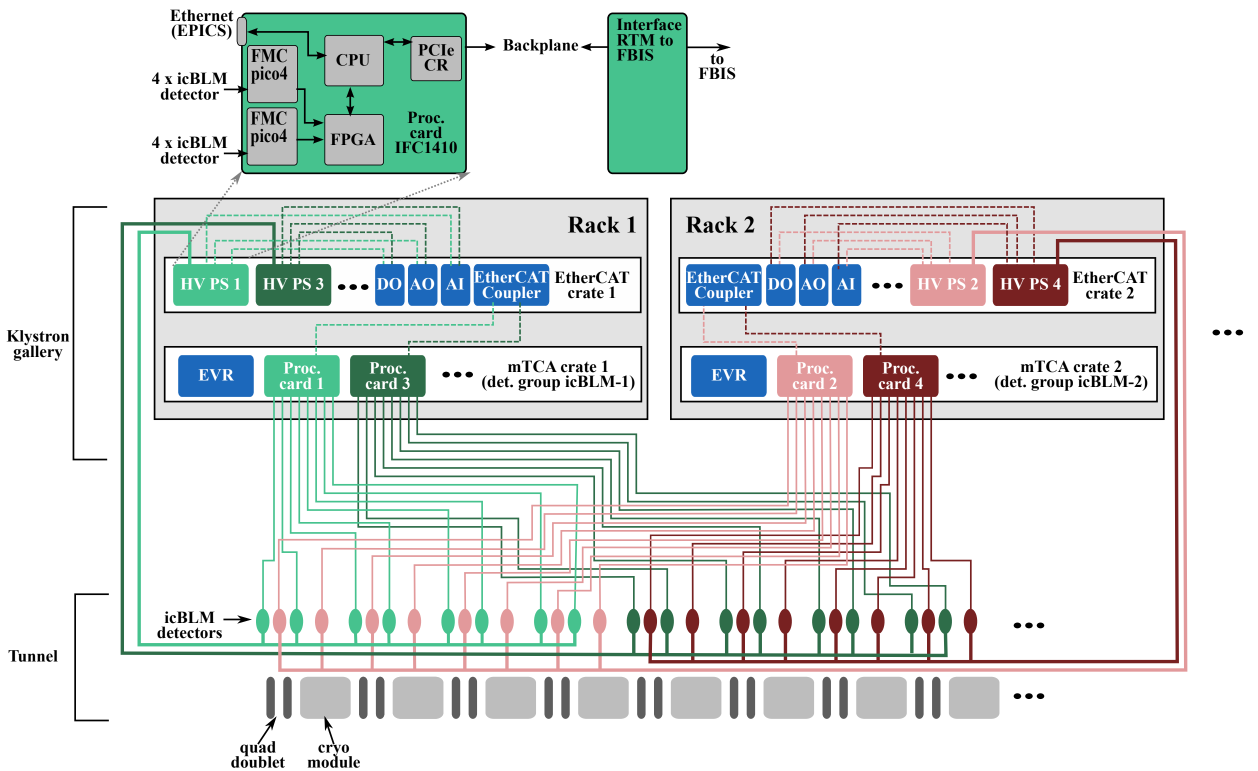
- Most detectors: 40 - 70m
- < 110m



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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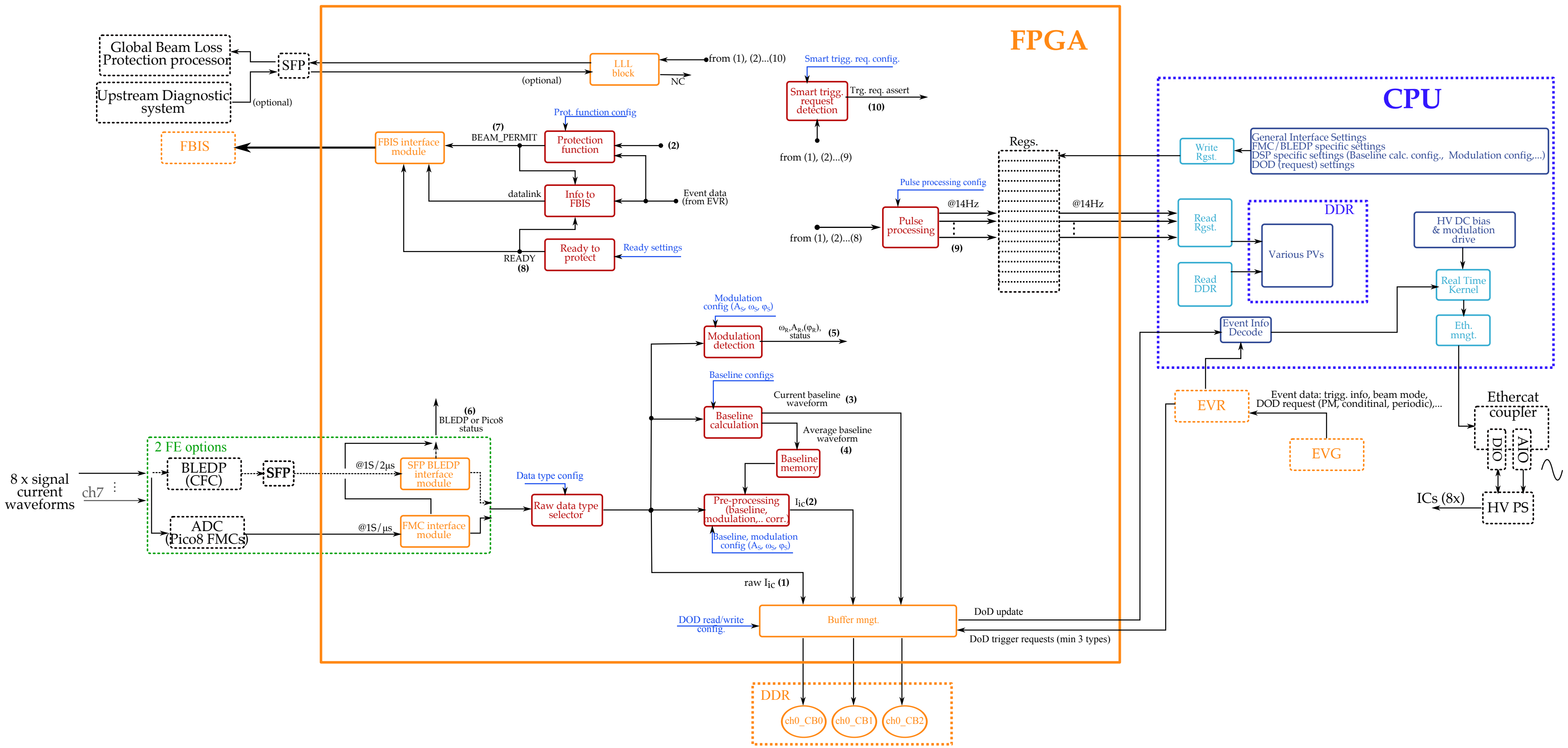
HV connections

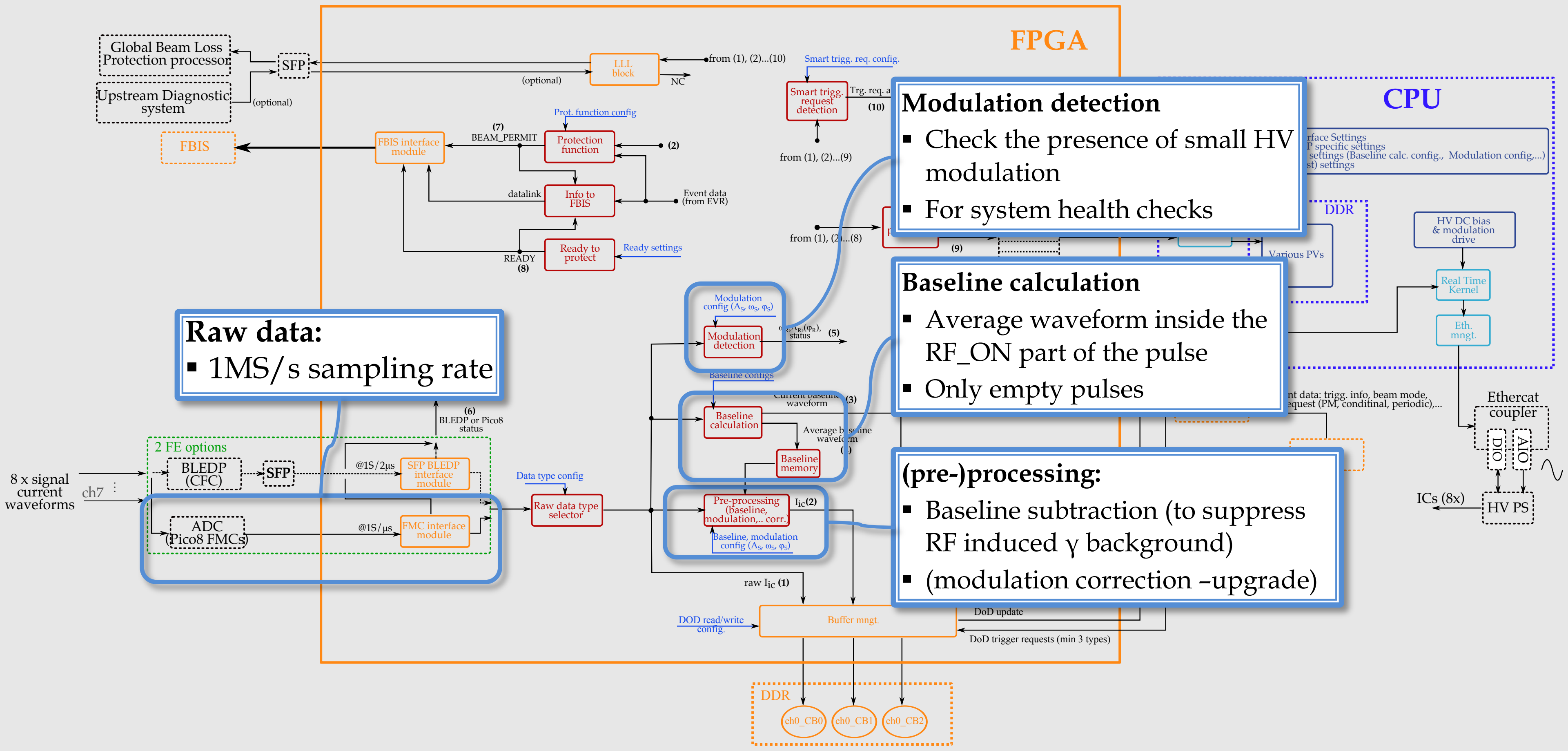
- Same separation scheme as for signal connections
- A set of odd/even detectors (5-7)
  - Connected a given AMC in Group1/Group2 rack X
  - Powered by a HV PS (HV ch) located in rack X

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	

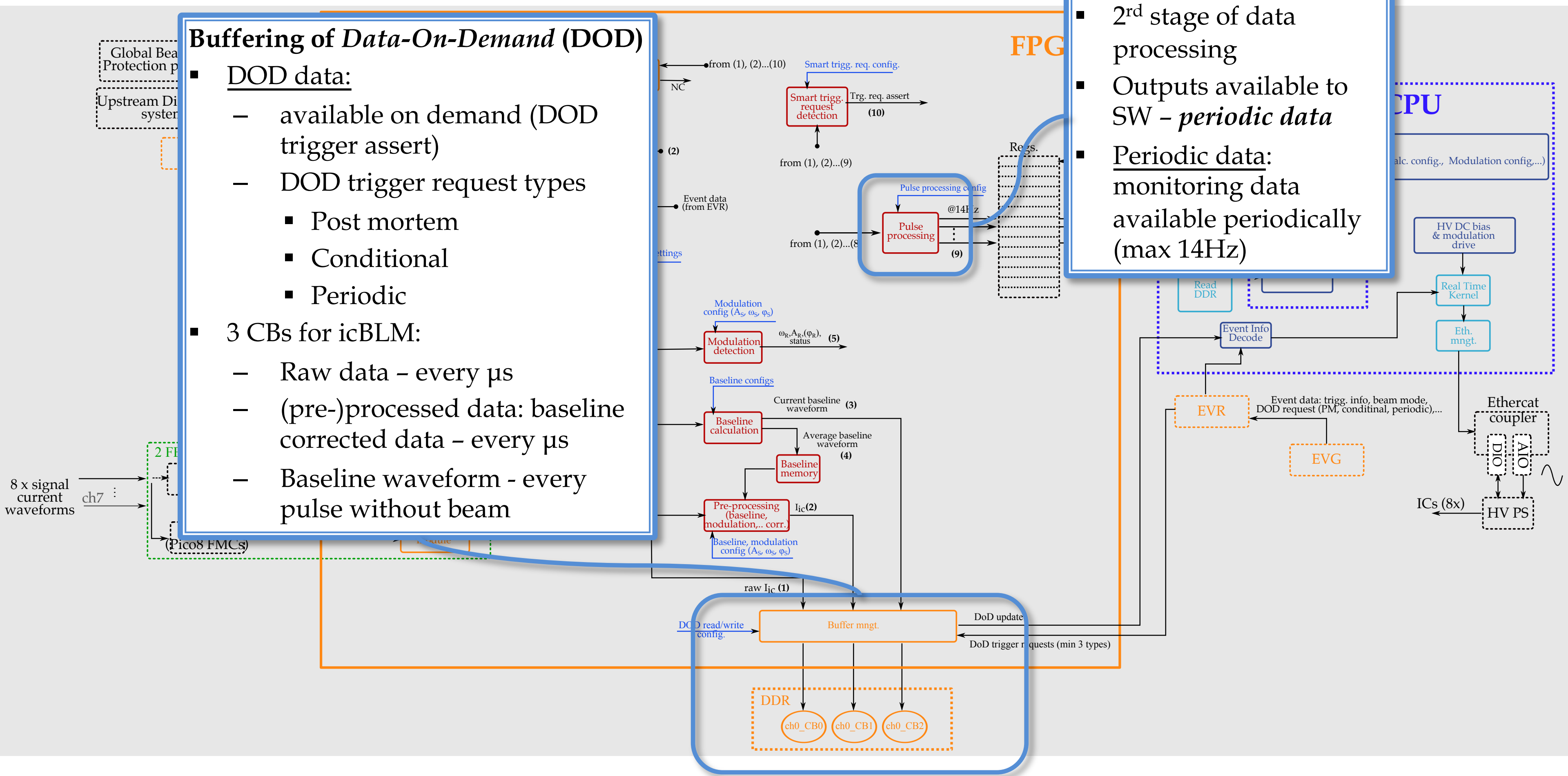
icBLM: FW functionality



icBLM: FW functionality



icBLM: FW functionality



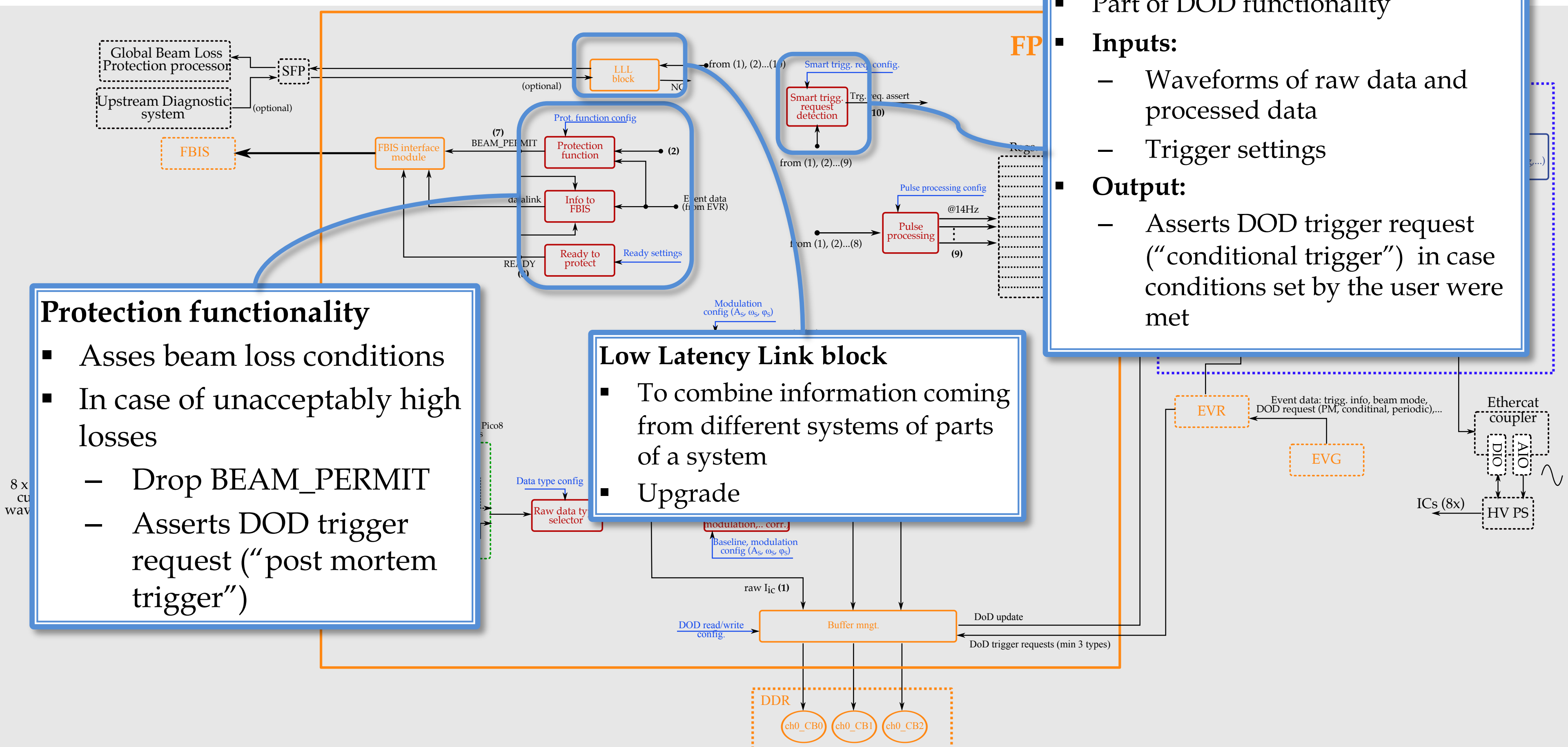
Buffering of *Data-On-Demand* (DOD)

- 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
  - Baseline waveform - every pulse without beam

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

nBLM

nBLM: collaboration

CEA DEDIP (BD IK)

- T. Papaevangelou (local coordinator)
- L. Segui (detector)
- P. Legou (FEE)
- S. Aune (gas system)
- D. Desforge (mechanical support)

CEA DIS (ICS IK)

- F. Gougnaud (local coordinator)
- Y. Mariette (EPICS)
- V. Nadot (EPICS)
- Q. Bertand (PLC)

LUT DMCS (ICS IK)

- W. Cichalewski (proj. management)
- G. Jablonski (FW, SW)
- R. Kielbik (FW)
- W. Jalmuzna (FW)

ESS BD

- T. Shea (BD section leader, interim system BLM lead)
- I. Dolenc Kittelmann (BLM system lead)
- K. Rosengren (FW, DOD)
- H. Kocevar (SW)
- J. Norin (bookkeeping: det. & el. Layout, naming
- S. Grishin (installation, gas system)
- C. Derrez (verification plan, QA)
- E. Bergman (cables, connectors, PPs)
- T. Grandsaert (mechanical integration)

ESS ICS

- S. Farina
- F. dos Santos Alves
- (W. Fabianowski)

nBLM project: time line

Jul. 2016: Kick-off

Dec. 2016: PDR1.1

Jul. 2017:
- PDR1.2
- Start of prototype tests

Dec. 2017: CDR1.1
- Planned focus: electronics design
- Progress on electronics delayed due to availability of BEE HW (ICS standard platform)
- Review on BEE postponed to the final CDR

April 2018:
- Start of the FW development

Jul. 2018: CDR1.2 (extra)
- Final detector module design (detector+FEE)
- Gas system control: rack architecture and components
- Additional review to start procurement
- Review on electronics postponed until Nov. 2018

Aug. 2018:
- Gas system design finalized

Nov. 2018:
- Start of the SW development

? 2019: CDR1.3 - final
- Prototype with basic FW and SW expected
- Postponed again due to maturity of the BEE

Mid 2019: installation - start

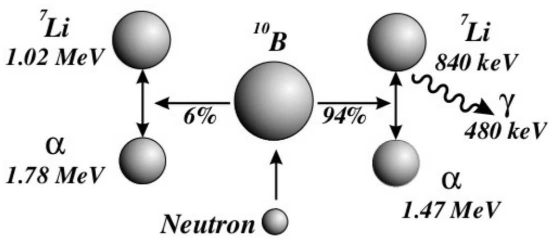
Autumn 2019: system commission - start

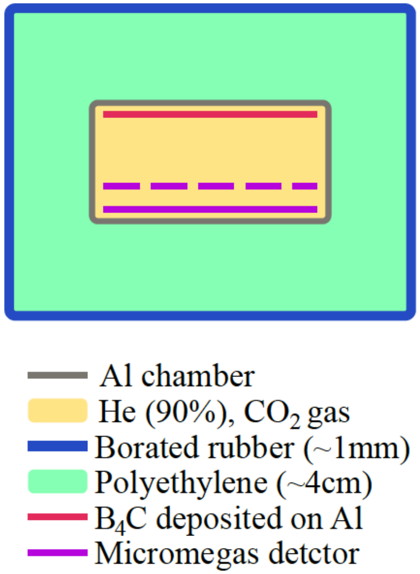
nBLM: Detectors (1)

nBLM detectors:

- 2 types,
- depending on location placed separately or back-to-back (detector unit)

- **1st module (slow losses): nBLM-S**
  - Capable of monitoring low fluxes (~few n $cm^{-2}s^{-1}$).
  - Response time: ~200µs (~10% events detected in 4µs).
  - Polyethylene (~4cm): moderator to thermalize the incoming fast n.
  - B_4C layer (deposited on the Al surrounding the gas chamber) to capture thermalized n – (n,α) ^{10}B reaction (α with fixed energy of 1.4MeV).
  - Borated rubber to eliminate background thermal *n*.
  - Efficiency: few 10^{-2} (1eV < E_n< few 10MeV)
  - Solid angle: 4π

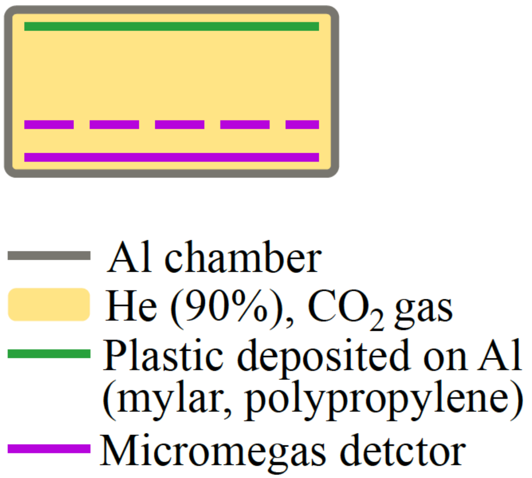




nBLM: Detectors (2)

nBLM detectors:

- **2^{nd} module (fast losses): nBLM-F**
  - appropriate for high fluxes of fast *n*, coming from the front (~few 0.01 *n* $cm^{-2}s^{-1}$).
  - Polypropylene (deposited on Al foil at the entrance window) for n conversion to *p* recoils (~ few mm) through *n* elastic scattering on H atoms (continuous distribution of recoiled *p* energies).
  - Cross-section threshold: E_n~0.5MeV.
  - Efficiency: 10-100 times lower than for nBLM-S (10^{-5}–10^{-3} for *En*= ~0.5MeV – 10MeV)
  - Solid angle: 2π
  - Response time: ~10ns



nBLM: Signals

- Typical neutron signal:
  - 30-50ns rise time
  - 100-200ns signal length
  - Amplitude
    - ~Constant for S
    - Continuous distribution for F

- nBLM originally planned to operate in **counting mode**

- MC simulations: up to GHz rates expected in case of complete loss.

	Rates	
	1% 1W/m	Complete beam loss (rate in 1st μs)
Slow	0.1 – 68 kHz	10MHz – 60 GHz
Fast	1 – 400 Hz	2-700 MHz

- Minimum response time for the system to drop the BEAM_PRMIT: ~5µs
- If counts are monitored in 1µs time window: pile-up when $\gtrsim$6 counts ("neutron events") $\Longrightarrow$ transition to **current mode.**
- The FPGA neutron detection algo. is foreseen to automatically transition to current mode (monitoring both TOT and Q).

nBLM electronics layout: signal

3 groups of detectors

- To limit the situations with larger parts of the system un-operational
- MEBT - Spoke: signal electronics for each group placed in separate racks
  - Group1: Odd pairs of S & F detectors
  - Group1: Even pairs of S & F detectors
- MB - A2T: Group3

nBLM electronics layout: signal

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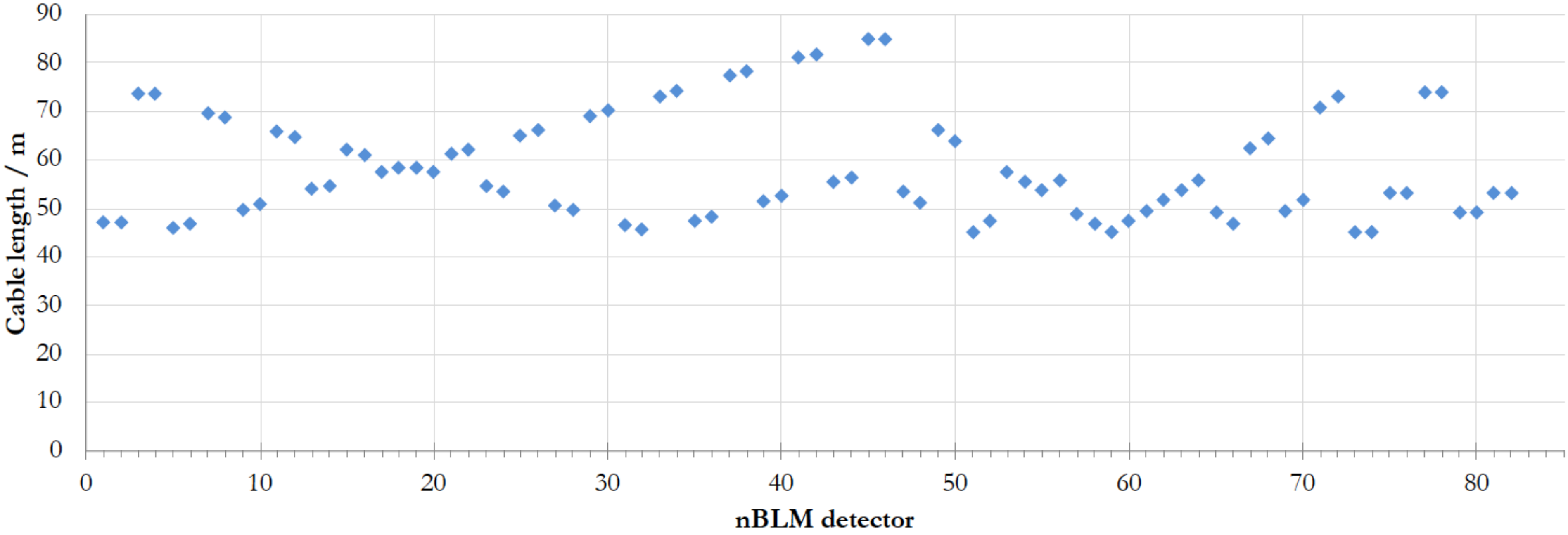
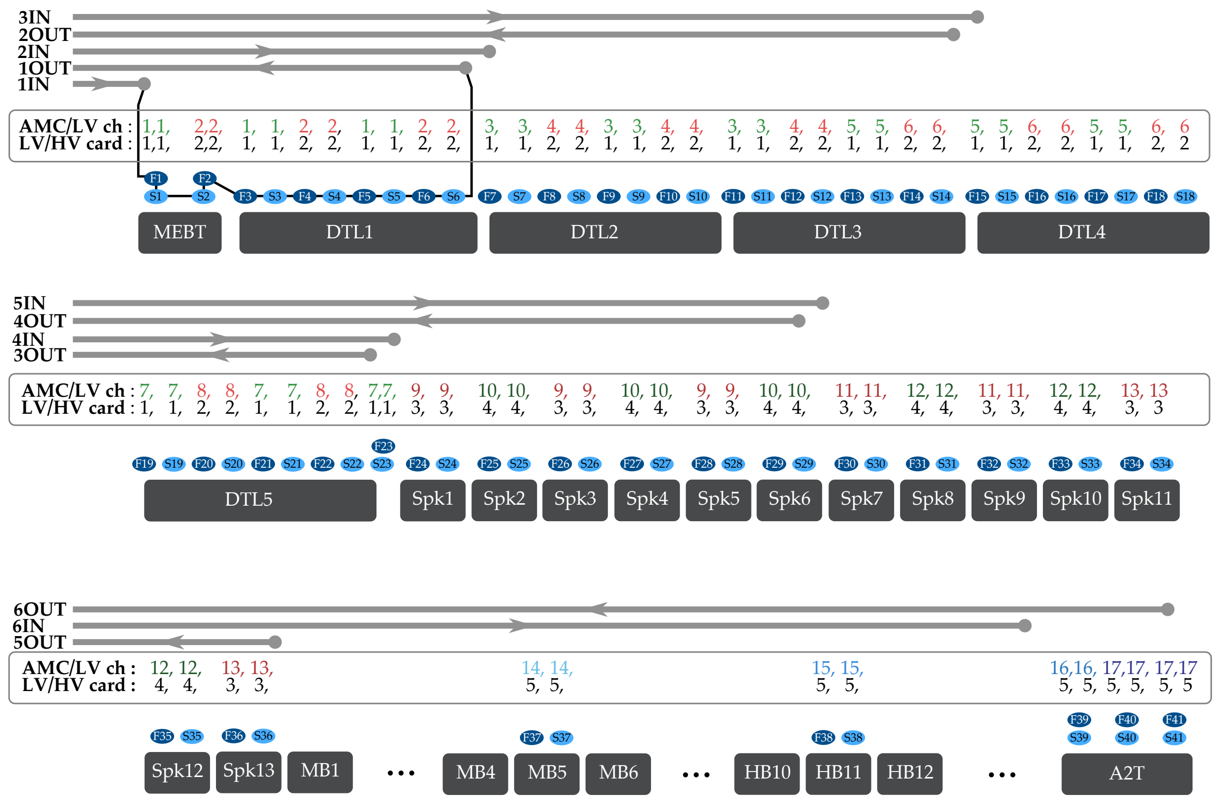
Estimated signal cable lengths 40 – 90m



nBLM electronics layout: HV, LV

- Same crate for LV and HV PS
- 2 HV lines per detector
- Each LV channel used to power several detector modules
- 2 crates along the linac
  - Separation in HV and LV connections between group 1 and 2 not possible down to the rack level
  - A set of detector modules
    - connected to an AMC/FMC has FEE powered by the same LV channel
    - with signal connected to the same rack has all HV cables connected to the same HV module



nBLM electronics layout

Rack	Detector count	AMC count	Crate count	Detectors per AMC	AMC tag	Spare cables per rack
FEB-050ROW	24	4	2	(6+6),(6+6)	(1,3),(5,7)	2
SPK-010ROW	22	4	2	(6+6),(6+4)	(2,4),(6,8)	2
SPK-030ROW	14	3	1	(6+4+4)	(9,11,13)	2
SPK-050ROW	12	2	1	(6+6)	(10,12)	2
MBL-050ROW	2	1	1	(2)	(14)	4
HBL-090ROW	2	1	1	(2)	(15)	4
HEBT-030ROW	2	1	1	(2)	(16)	1
A2T-010ROW	4	1	1	(4)	(17)	1
Sum	**82**	**17**	**10**			**18**

Table 3: Summary of the nBLM system signal connections. The column marked with "Detectors per AMC" indicates the number of detectors connected to a crate or AMC board. The parenthesis "()" and "+" sign are used to differentiate between the crates and AMCs respectively. The colours mark different detector groups as explained in the text and shown on figure

Rack	Det. count	Det. location	LV card count	LV card tag	Det. per LV card	Spare cables per rack
FEB-050ROW	74	MEBT–MB	1	LV1	6+6+6+6	2
			1	LV2	6+6+6+4	
			1	LV3	6+4+4	
			1	LV4	6+6+2	
SPK-010ROW	0	/	0	/	0	2
SPK-030ROW	0	/	0	/	0	2
SPK-050ROW	0	/	0	/	0	2
MBL-050ROW	0	/	0	/	0	4
HBL-090ROW	0	/	0	/	0	4
HEBT-030ROW	8	>MB	1	HV5	2+2+4	1
A2T-010ROW	0		0		0	1

Table 5: Summary of the nBLM LV connections. The column marked with "Det. per LV card" indicates the number of detectors connected to each LV card. The "+" sign is used to differentiate between the channels on a certain LV card. The colours mark different detector groups as discussed in the text and shown on figure 6

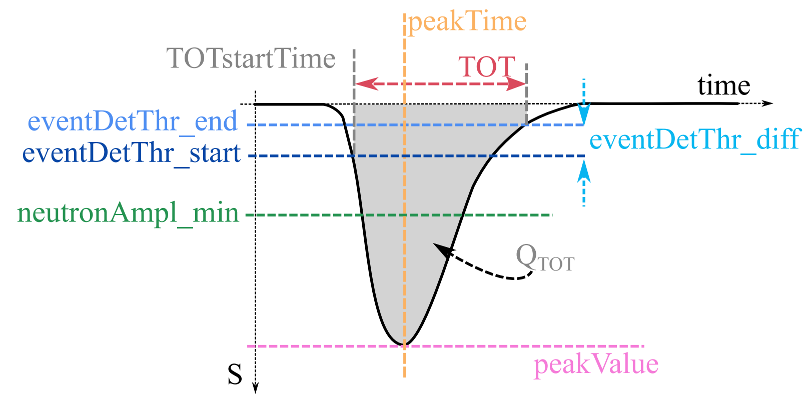
Rack	Det. count	Det. location	HV card count	HV card tag	Det. per HV card	Spare cables per rack
FEB-050ROW	74	MEBT–MB	1	HV1	24M+24D	2M+2D
			1	HV2	22M+22D	
			1	HV3	14M+14D	
			1	HV4	12M+12D+2M+2D	
SPK-010ROW	0	/	0	/	0	2M+2D
SPK-030ROW	0	/	0	/	0	2M+2D
SPK-050ROW	0	/	0	/	0	2M+2D
MBL-050ROW	0	/	0	/	0	4M+4D
HBL-090ROW	0	/	0	/	0	4M+4D
HEBT-030ROW	8	>MB	1	HV5	2M+2D+2M+2D +4M+4D	1M+1D
A2T-010ROW	0		0		0	1

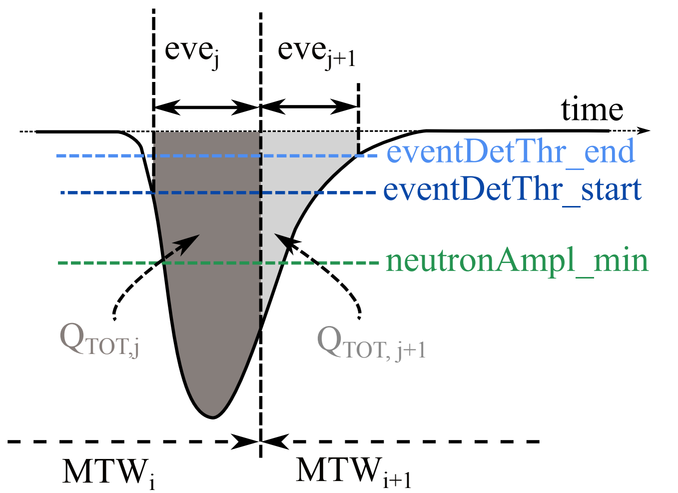
Table 4: Summary of the nBLM system HV connections. The column marked as "Det. per HV card" indicates the number of detectors powered by each HV card. Note that each a detector needs two HV connections, one for meash (M) and one for drift (D). The colours mark different detector groups as discussed in the text and shown on figure 6.

nBLM: neutron detection algo

"Interesting Event"

- Basic rule:
  - Starts when signal falls below start event threshold.
  - Ends when signal exceeds the end event threshold.
- Exceptions when signal extends over MTW edge
  - Split signal in 2 events if:
    - At the MTW edge the signal already qualifies as a single neutron.
    - Event too long (longer max TOT for a single neutron)
  - Otherwise end the event when signal exceeds end event threshold in the following MTW.

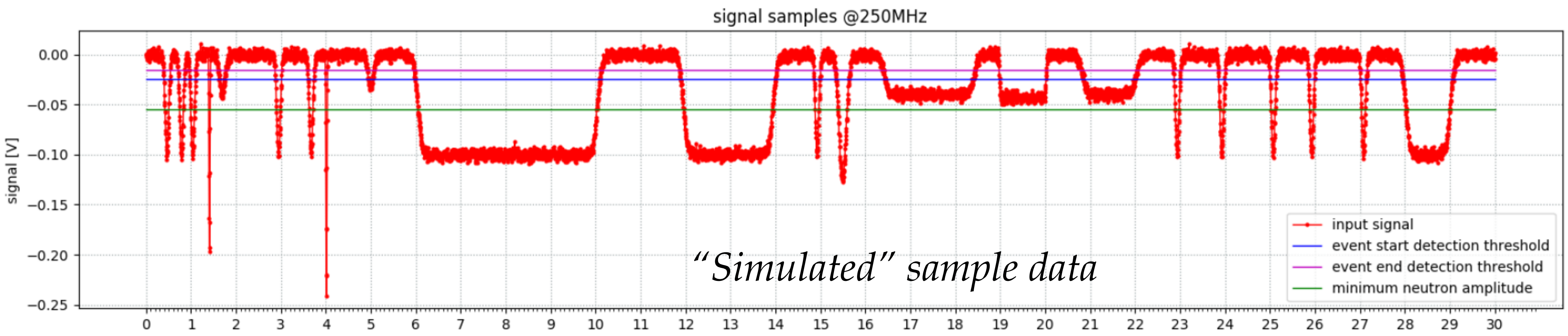




nBLM: neutron detection algo

"Interesting Event" types

- Single neutron
- Neutron pile up
- Background (gamma or other)
- Spike/noise, spark



nBLM: neutron detection algo

Neutron identification

- Single neutron
  - TOT: within limits
  - Amplitude: below the threshold
- Pile up neutrons
  - TOT larger than for single neutron
  - Amplitude: below the threshold

$$\mathtt{pileUpTOT\_start} > \mathtt{TOT}_j \geq \mathtt{neutronTOT\_min}$$

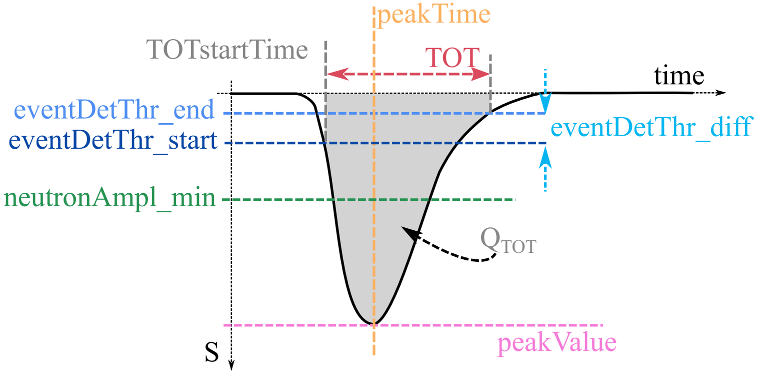
$$\mathtt{peakValue}_j \leq \mathtt{neutronAmpl\_min}$$

$$\mathtt{TOT}_j \geq \mathtt{pileUpTOT\_start}$$

$$\mathtt{peakValue}_j \leq \mathtt{neutronAmpl\_min}$$

Background identification

- Valuable for
  - Comparison with icBLM data and/or
  - Corsscheck that algo or detector settings are ok
- Initial version:
  - TOT above the limit for single neutron
  - Amplitude above single neutron limit



$$\mathtt{TOT}_j \geq \mathtt{neutronTOT\_min}$$

$$\mathtt{peakValue}_j > \mathtt{neutronAmpl\_min}$$

nBLM: neutron detection algo

EUROPEAN SPALLATION SOURCE

Neutron Counts per MTW:

$$N_{MTW,i} = N_{n;MTW,i} + N_{qtot;MTW,i} = \sum_{j=1}^{n_{eve;MTW,i}} (N_{n,j} + N_{qtot,j})$$

Number of single neutron events with i-th MTW
(**Single neutron counting method**)

Number of neutrons within i-th MTW calculated through **charge method**

- For pile up (or split) events:

$$N_{qtot,j} = \frac{\text{Q\_TOT}_j}{\langle \text{Q\_TOT}_{1n} \rangle}$$

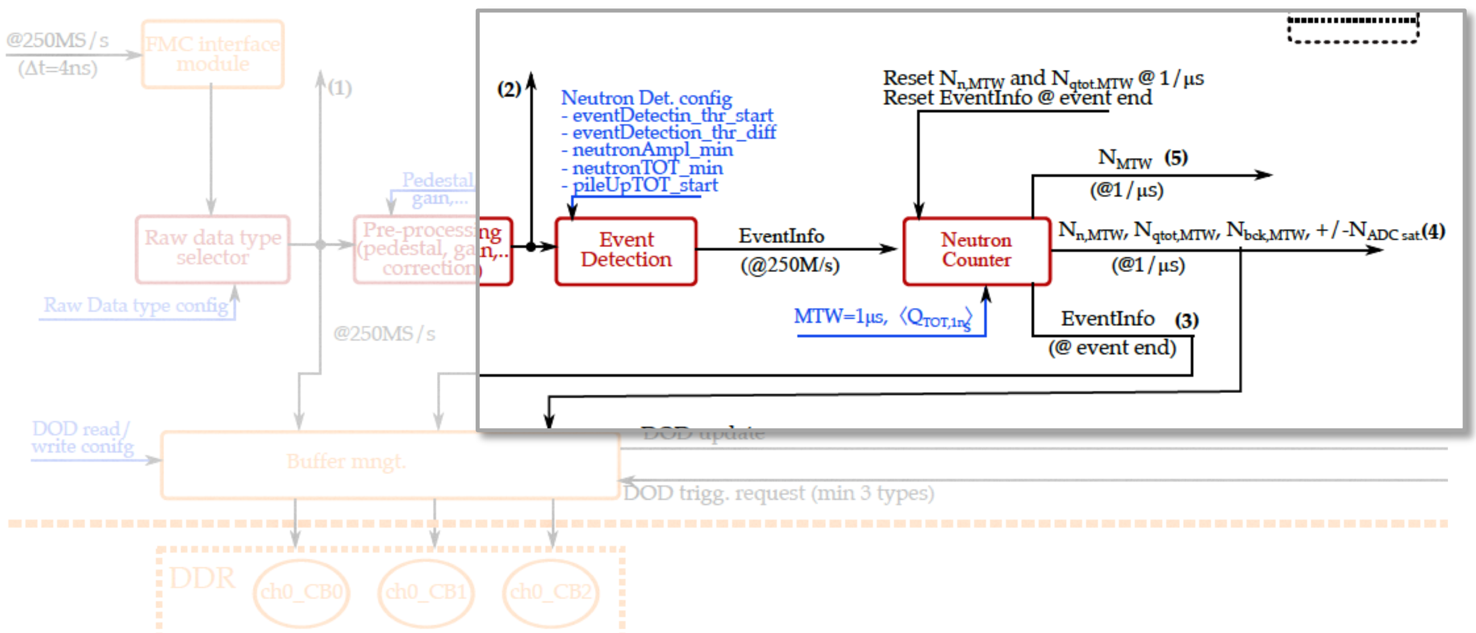
- Else:

$$N_{qtot,j} = 0$$

nBLM: neutron detection algo

Neutron detection related blocks

- "Event Detection"
  - Detects start of an "interesting event"
  - Updates `EvenInfo` every 4ns
- "Neutron counter"
  - Ends event and resets `EventInfo`
  - Sums and resets neutron counts at the end of each MTW



nBLM: neutron detection algo