nBLM system overview

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ESS
(BLM System Lead)

nBLM CDR3, CEA, France, 12/02/2019

Outline

- ESS BLM
  - Reminder
  - L4 requirements
- nBLM
  - Teams involved
  - Interfaces
  - Components overview
  - Project timeline
  - FW/SW development plan
  - Procurement plan
- nBLM CDR3
  - Charge

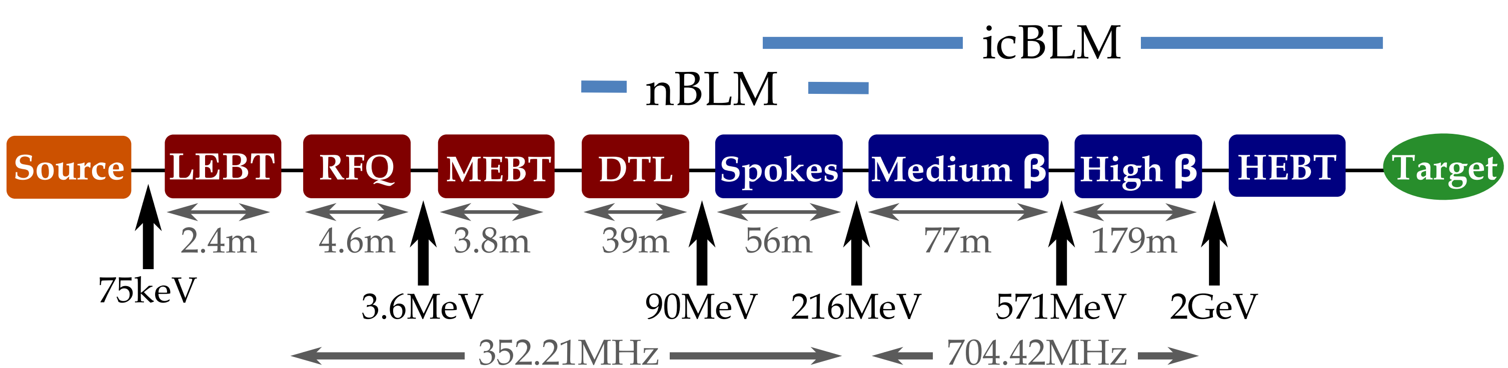
ESS BLM

EUROPEAN SPALLATION SOURCE

Two BLM systems

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



BLM L4 requirements

#	Type	Name	Description
1	Beam loss	XXX beam loss measurement	The beam loss shall be measured in the XXX section.
2	Beam loss	XXX beam loss measurement sensitivity	A beam current loss of 10 mW/m shall be detected.
3	General	XXX PBI damaging beam detection mitigation	Beam conditions that are potentially damaging to machine components shall be detected by the instrumentation and reported fast enough so that the conditions can be mitigated before damage occurs.
4	General	XXX PBI peak current range	Proton beam instrumentation in the XXX section shall function over a peak beam current range of 3 mA to 65 mA.
5	General	XXX PBI pulse length range.	Proton beam instrumentation in the XXX section shall function over a proton beam pulse length range of 5 μs to 2.980 ms.
6	General	XXX PBI pulse-by pulse measurement update rate	Unless specifically stated, all instrumentation shall be able to perform the measurements and report the relevant PV data at a repetition rate of 14 Hz.

Table 1: L4 PBI requirements [2] relevant for the BLM system. The 'XXX' refers to specific linac section and runs over all section from including MEBT on.

Coverage

Sensitivity, lower limit

Upper limit, response time, MP thresholds

System functioning for all beam modes

nBLM: teams involved

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: teams involved

CEA DEDIP (BD IK)

- T. Papaevangelou (local coordinator)
- L. Segui (detector)
- P. Legou (FEE, cabels, connectors)
- S. Aune (gas system)
- D. Desforge (mechanical support)
- C. Lahonde-Hmdoun (QA, verification plan)

CEA DIS (ICS IK)

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

LUT DMCS (ICS IK)

- W. Cichalewski (local coordinator)
- 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

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

nBLM interfaces

Interfaces

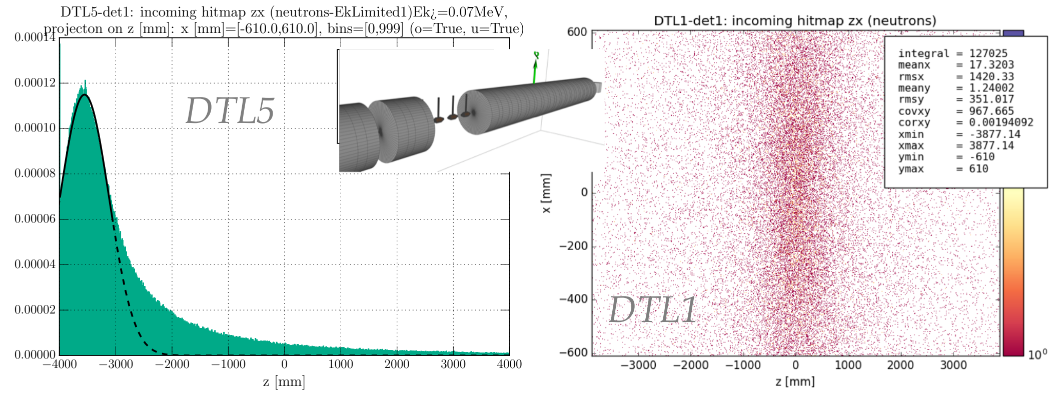
- Site Infrastructure
  - Lang haul cables
  - Gas system (long pipe connections)
  - Holes for mech. support (DTL rails, MEBT feet)
- Vacuum
  - Detector supports in LWUs
- Cryo
  - Detector mounting (Spoke cryo)
- With Machine Protection System (MPS)
  - FBIS (Fast Beam Interlock System)

nBLM: components overview

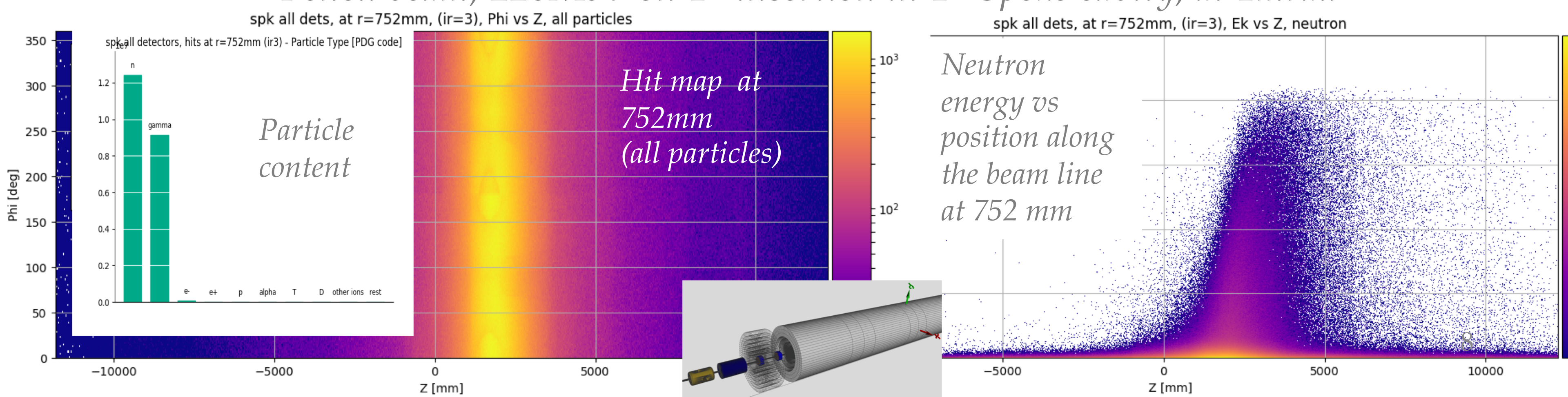
Detectors

- Micromegas detectors (CEA), designed specifically for ESS; idea:
  - 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

Neutron hit maps for Pencil beam, at 1mrad in DTL



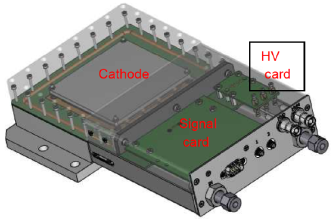
Pencil beam, 220MeV on 1st insertion in 1st Spoke cavity, at 1mrad



nBLM: components overview

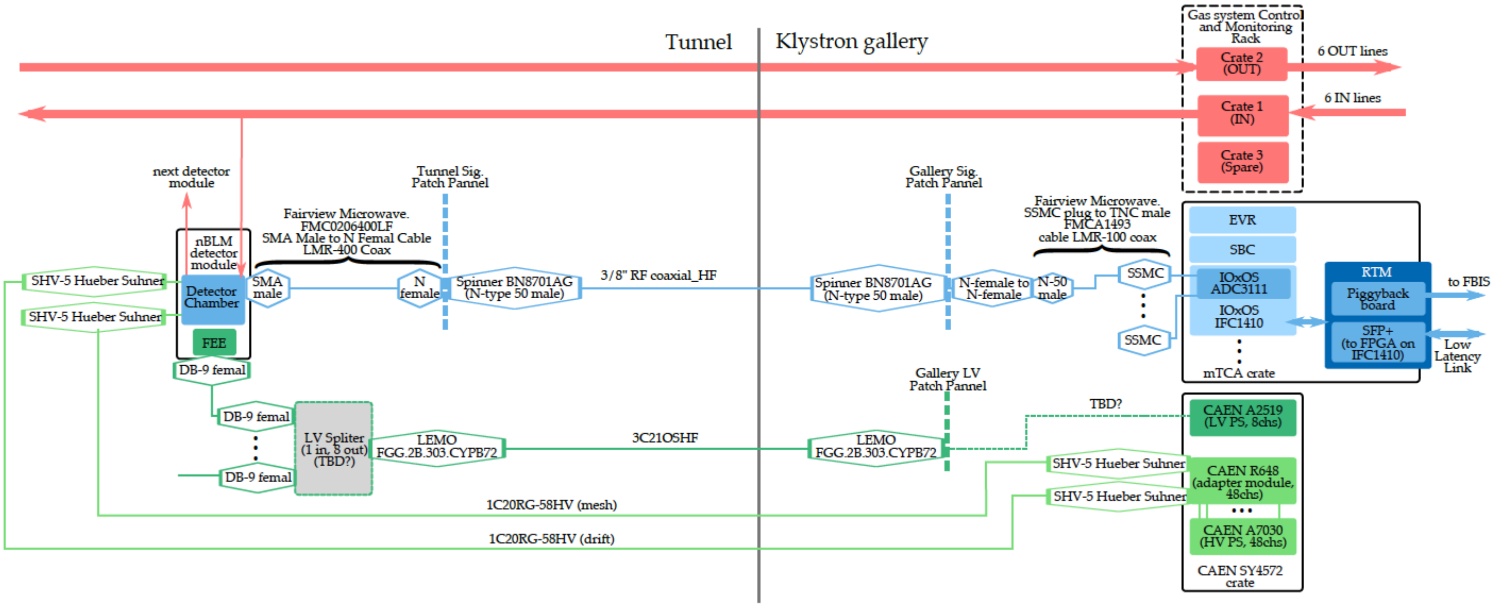
FEE:

- 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 (ESS standard platform)
- IOxOS ADC3111 FMC digitizer (250MS/s, DC coupled, 8 channels).



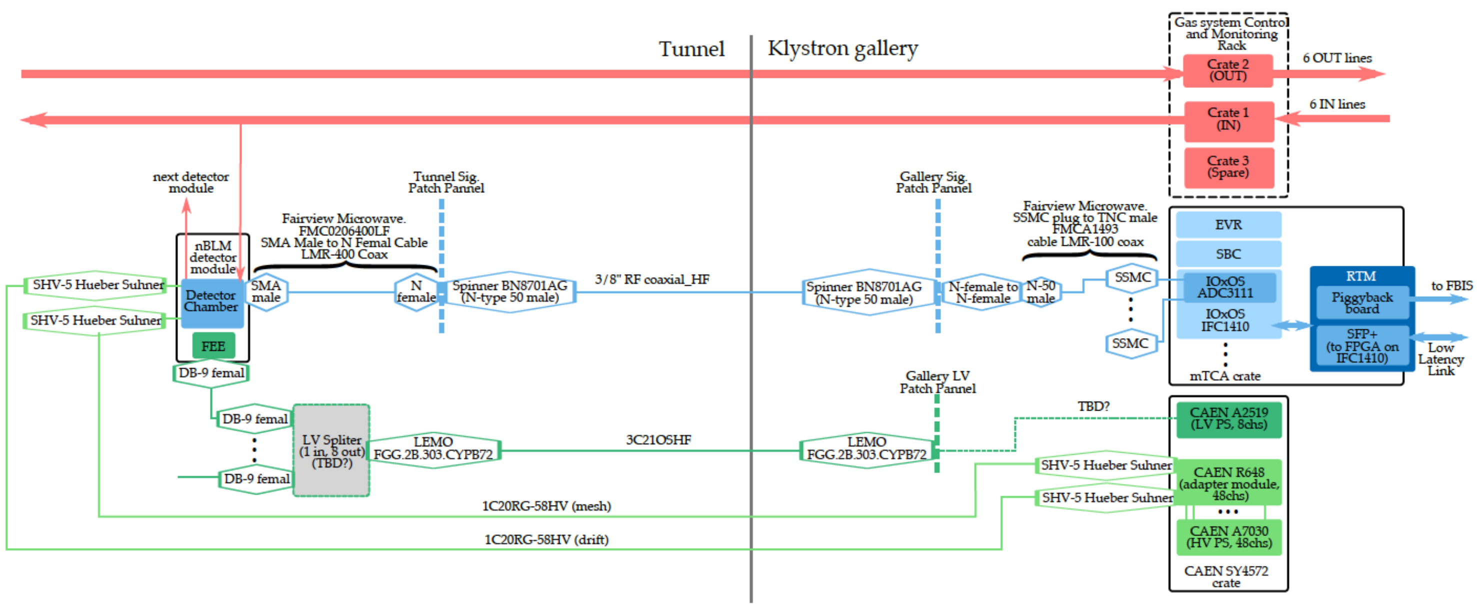
nBLM: components overview

BEE

- FBIS interface
  - Piggyback board on RTM, part of ICS standard platform (both still under development)
  - Temporary solution for test purposes: IOxOS DIO3118 FMC
- Low Latency Link connection
  - SFP+ on RTM to IFC1410 FPGA
  - Temporary solution: existing RTM from IOxOS

BEE - alternative

- Struck SIS8300-KU
- Digitiser: SIS8900 RTM
  - 125MS/s
  - +/-1V, 16 bit
  - DC coupled



nBLM project: time line

EUROPEAN SPALLATION SOURCE

Jul. 2016: Kick-off IK with CEA Dedip

Dec. 2016: PDR1
- Detector simulations

Jul. 2017:
- PDR2: updates from PDR1 on det. development
- ICS standard platform selected for BEE
- Start of prototype tests

Dec. 2017: CDR1
- Planned focus: electronics design
- Additional topics: detector layout, electronics layout, gas system design
- Progress on electronics delayed due to availability of BEE HW (ICS standard platform) – available in Nov. 2017
- Review on BEE postponed to the final CDR – planned for June 2018

April 2018:
- Start of the FW development (ICS IK)
- Start expected in January

Jul. 2018: CDR2 (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

~August 2018:
- Gas system design finalized

Sept. 2018:
- 1st bitstream for SW development available

Nov. 2018: planned CDR3
- Expected Prototype with basic FW and SW and possibility for external triggering
- Postponed again (chs/AMC, no SW, stability & planform maturity issues)

Dec. 2018
Start of development of SW part of DAQ

Jan. 2019
- Most of Electronics HW components selection finalized (cables, connectors, PPs, FBIS interface,…)

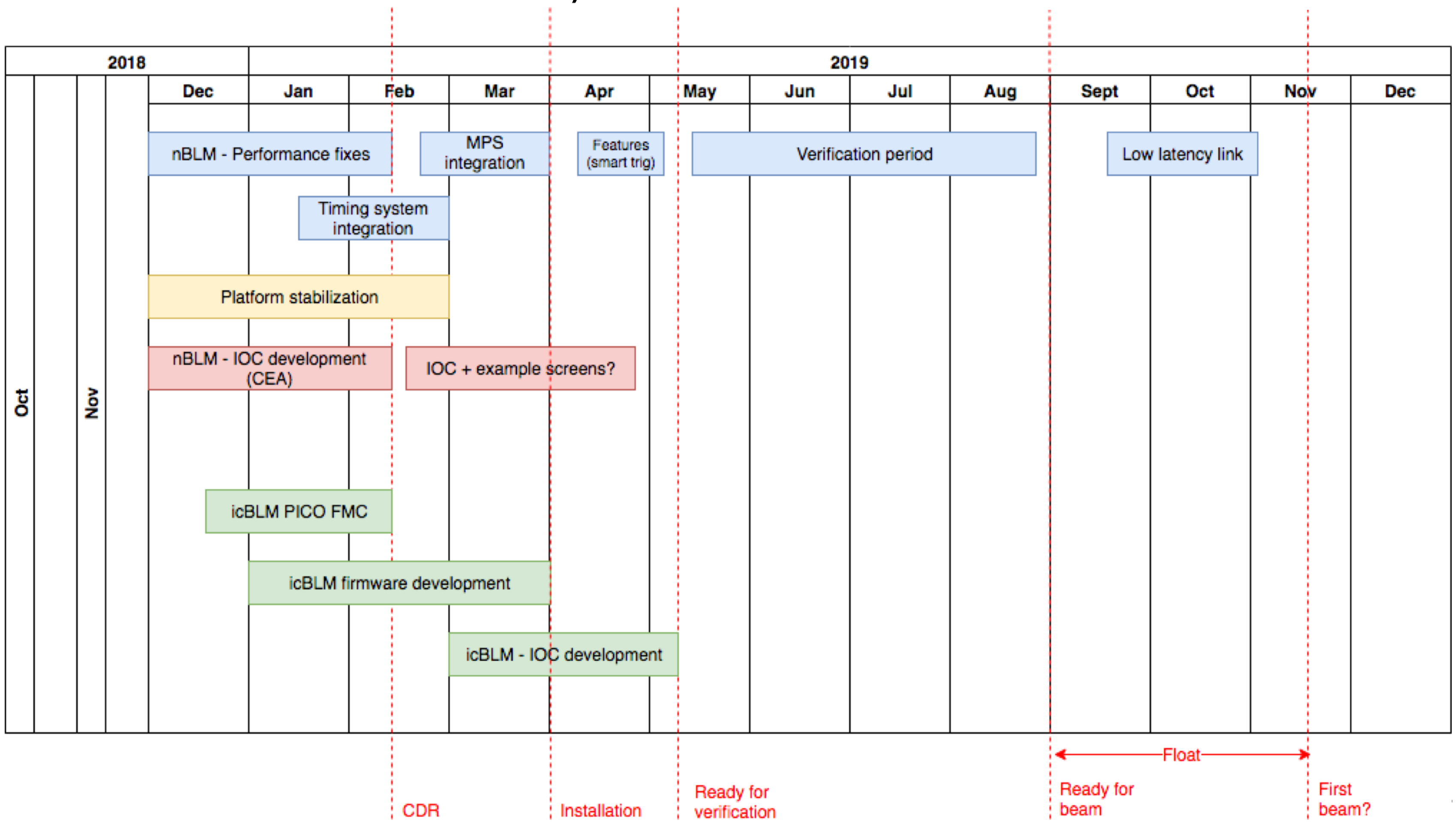
Now (12/02/2019): CDR3 - final
- Main focus: (BEE) electronics
- Expected
  - prototype with basic FW and SW functionality and option for external triggering
  - Limitations clear
  - Stable platform

~ Mid 2019: installation - start

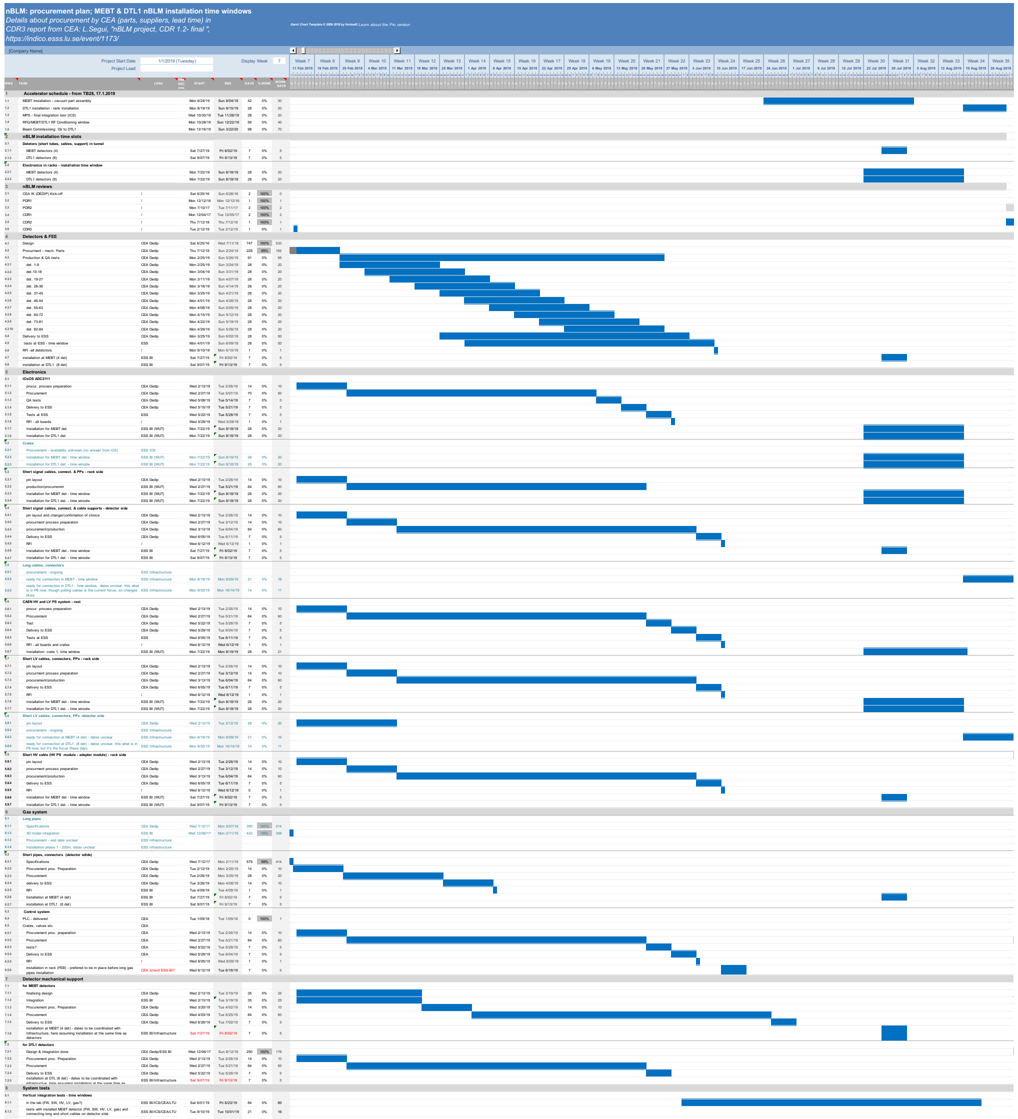
Winter 2019: system commission - start

nBLM FW/SW development plan

K. Rosengren, FW/SW development plan (See .xlsx file under the nBLM CDR3 material)



Procurement/production



See .xlsx file under the nBLM CDR3 material for detailed view (procurement plan, installation time windows for MEBT and DTL1 detectors, system tests, SW and FW development plan)

Procurement/production

- Detector production on time
- Other lead times: not longer then 12 weeks
- If all as planed, ready for installation in MEBT with minimum ~5 weeks contingency
- Potential risks for MEBT nBLMs:
  - Long gas pipes installation (Infrastructure) – dates unknown
  - MEBT detector support integration – lack of resources
  - Detector and support installation – dates to be coordinated with Infrastructure
  - Some cabling details TBD (fx. pin layouts, LV distribution box design and integration, short signal cables) – only LV distribution box integration higher risk due to lack of resources
  - Installation in racks during summer – resource problem?
  - Availability of crates (ICS) – unclear (but consider as low risk)
  - Long and part of short cables available for installation (Infrastructure) – dates unclear (but consider as low risk)

nBLM CDR3

- Supporting documentation available on top of the agenda since Monday, 5/2/2019: https://indico.esss.lu.se/event/1173/

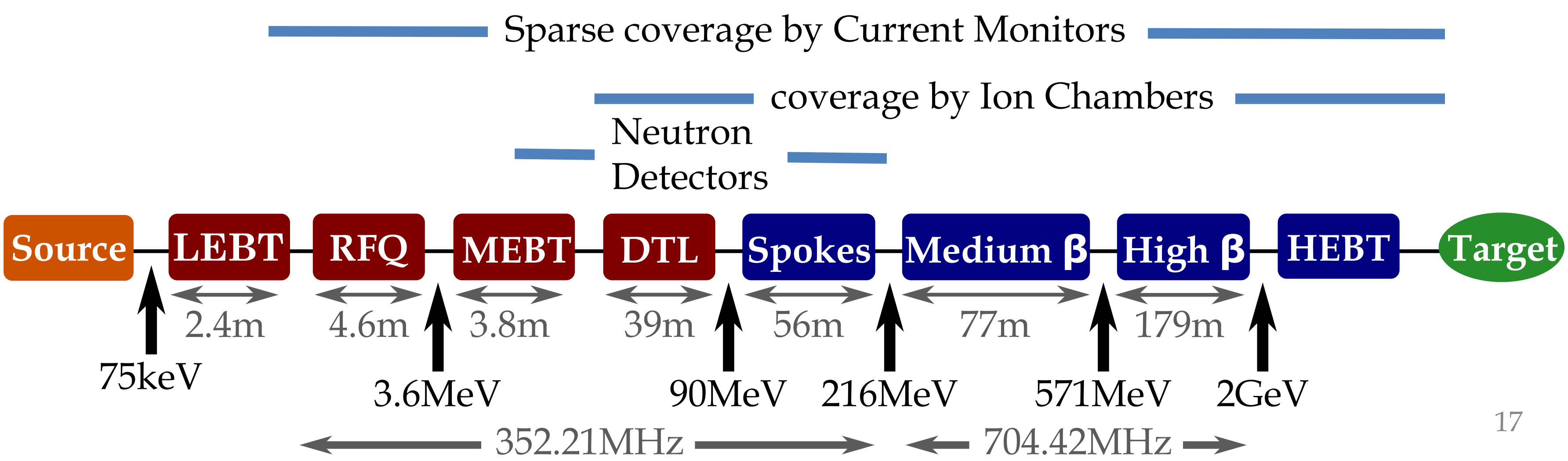
- nBLM CDR3 charge:
  - nBLM overall system.
  - Main focus: electronics, in particular BEE.

Back up material

EUROPEAN SPALLATION SOURCE

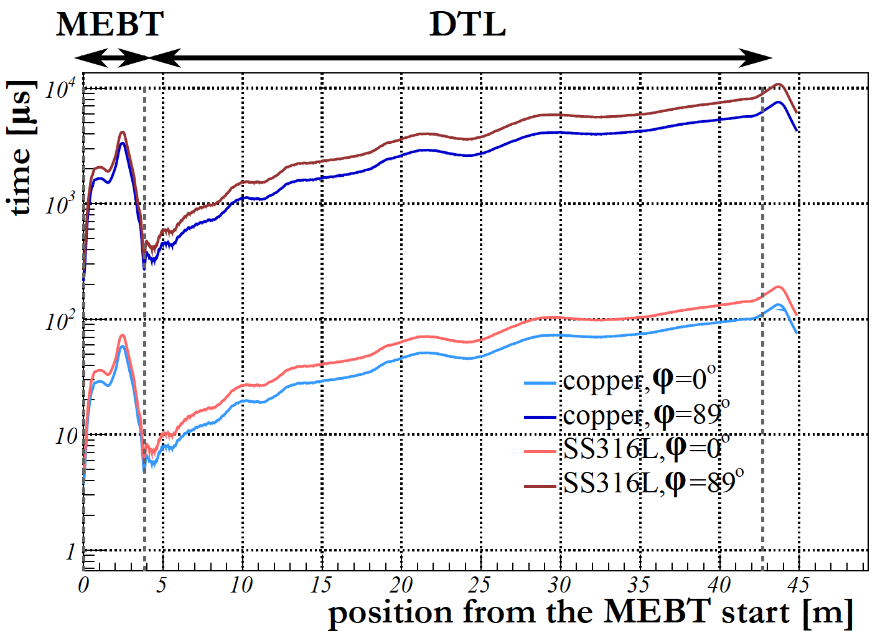
ESS Beam Loss diagnostic tools
(from T. Shea)

- **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: beam loss simulations

EUROPEAN SPALLATION SOURCE

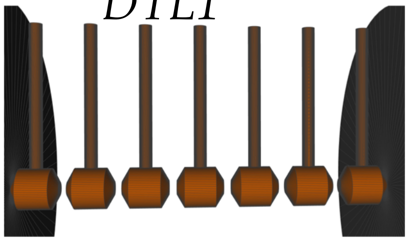
- **MC simulations for tracking of lost protons needed to determine**
  - Detector locations, system response time and dynamic range
  - Expected particle fields, signals
  - Initial MPS threshold settings at the startup and later adjustments
  - Anticipated response of the system during fault studies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

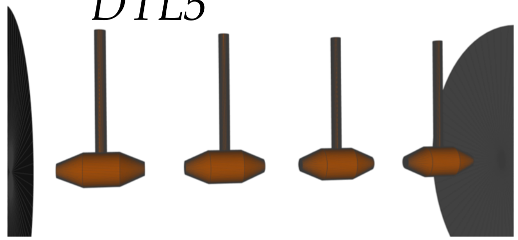
- **Simulation tool**
  - Geant4 simulation framework developed by the ESS neutron detector group
  - Geant4 based ESS linac geometry created (current version: DTL - HEBT)

ESS BLM: MC simulations - linac geo

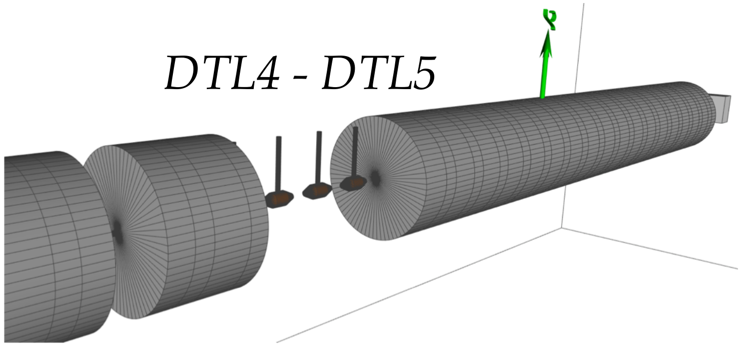
DTL1



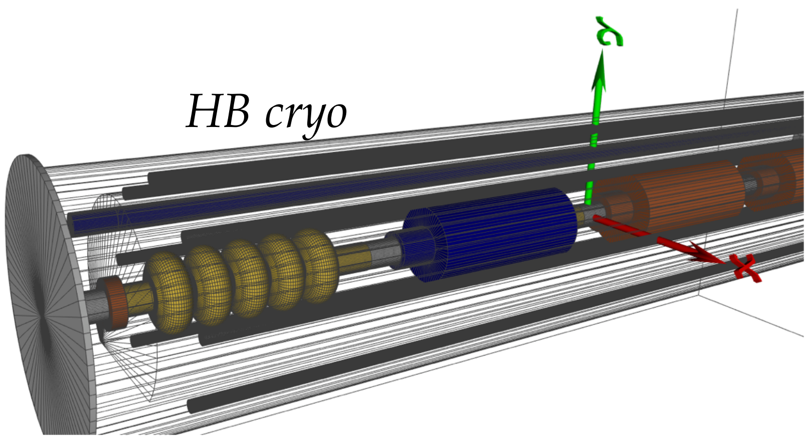
DTL5



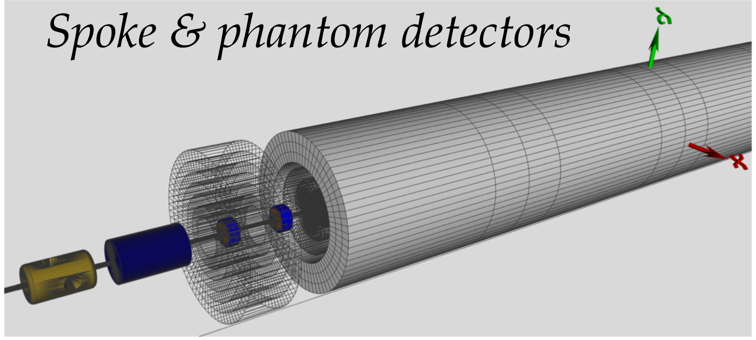
DTL4 - DTL5

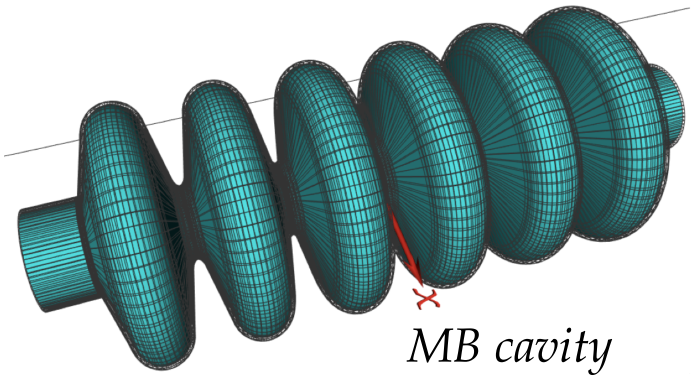


HB cryo



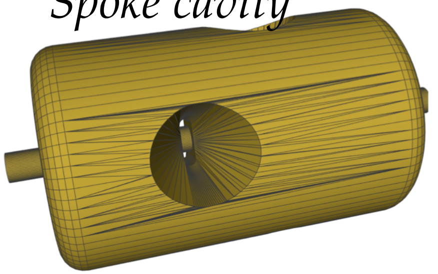
Spoke & phantom detectors



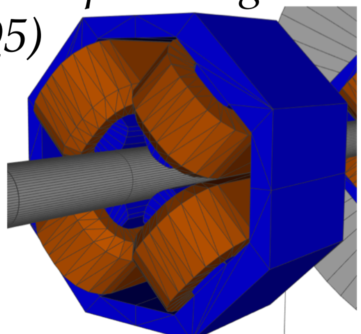


MB cavity

Spoke cavity



Spoke quad magnet (Q5)

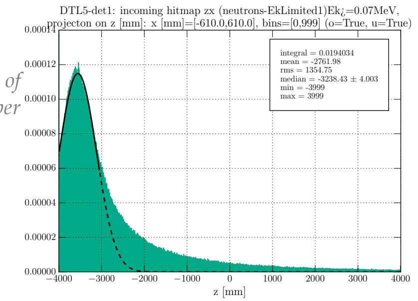


ESS BLM: MC simulations

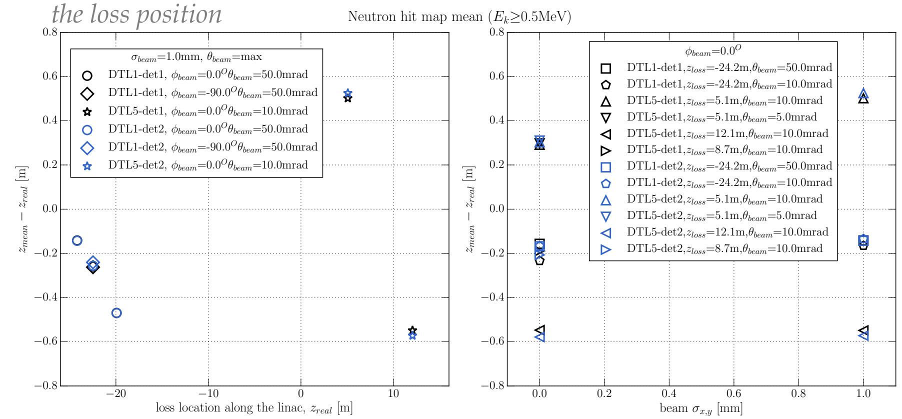
Past studies

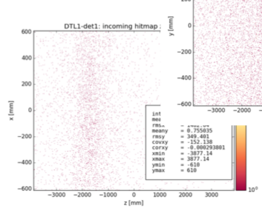
- Focused on DTL
- Tanks surrounded with “phantom detectors”
- Loss scenarios:
  - Accidental losses: scanned over various configurations of energy, beam size, hit angles and position along the DTL
  - Uniform loss, 1W/m loss
  - Nominal operation
- Studied:
  - Expected particle fields (type, energy, 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

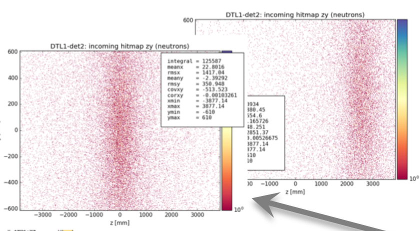
Sim2-9: loc. loss at the beginning of the DTL5 (histogram normalized per number of primaries):
hitmap mean=-2.76m
Gauss fit mean = -3.56m
Peak visible ~3.5m



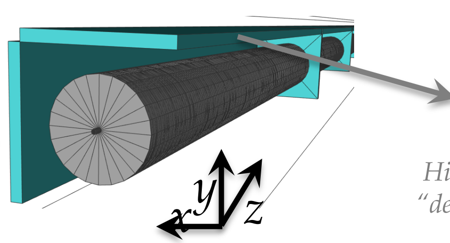
Neutron hitmaps with E_k>0.5 MeV cut: difference between the hitmap mean and the loss position

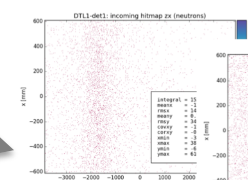


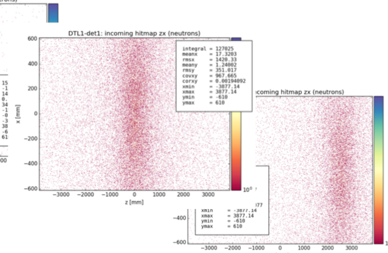




Hitmaps for det2 “detector” volume







Hitmaps for det1 “detector” volume

ESS BLM: MC simulations

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Current focus

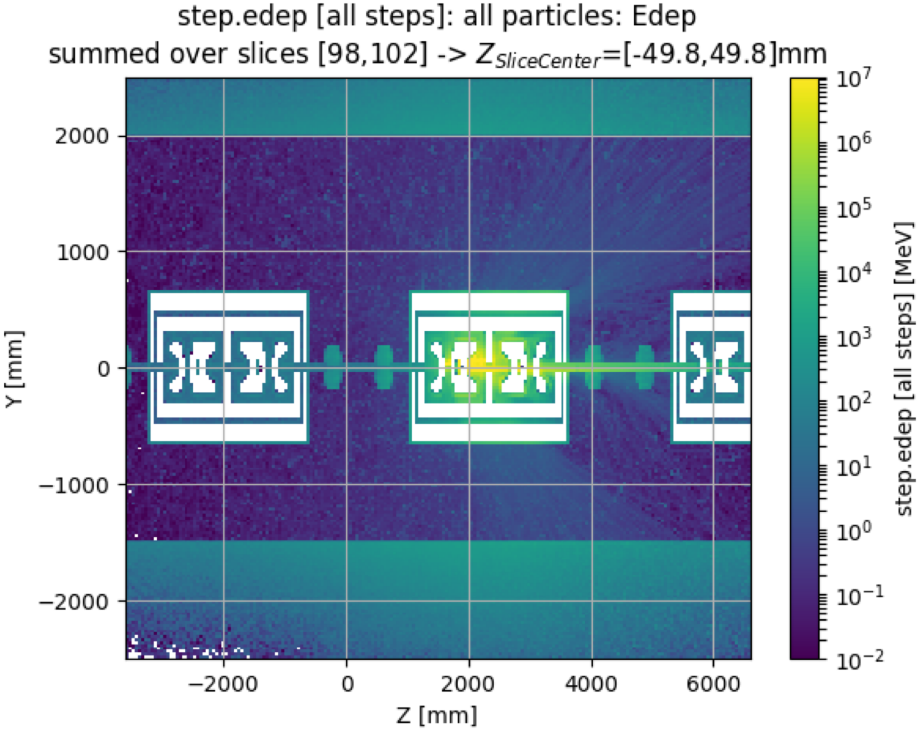
- Cold linac
- Loss scenarios:
  - Scanned over various for various configurations of energy, beam size, hit angles and position along the cryo modules or quads
  - Uniform loss, 1W/m loss
  - Nominal operation
- Tasks:
  - Expected particle fields (type, energy, fluxes along the beam line)
  - Estimate 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

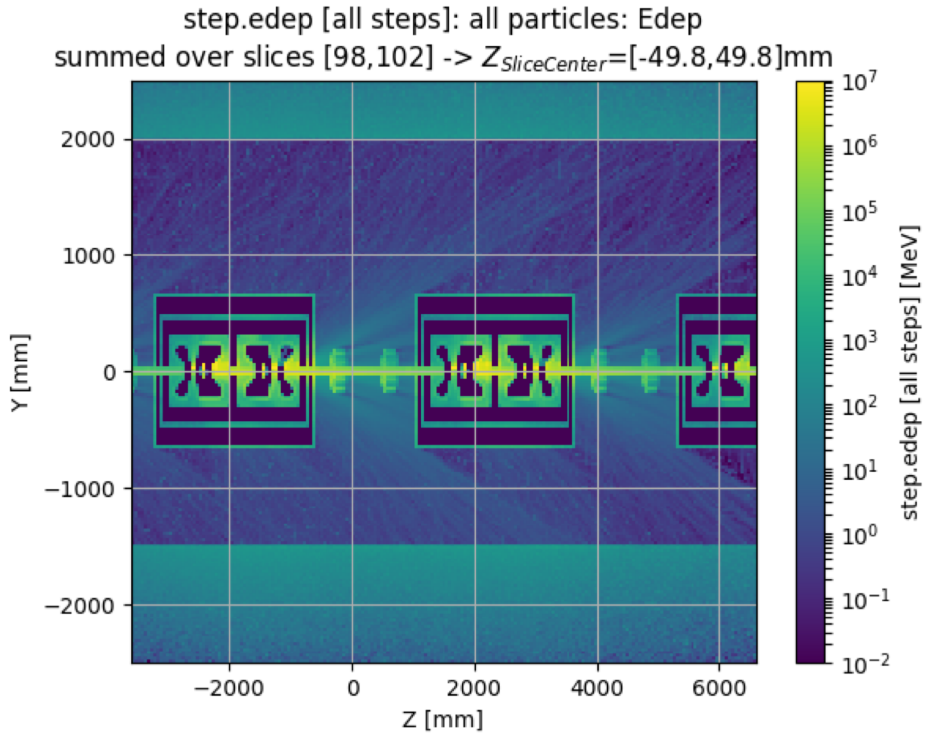
Example: energy deposition summed over 4 center slices along x

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

Pencil beam



3x3mm² (gaussian) beam



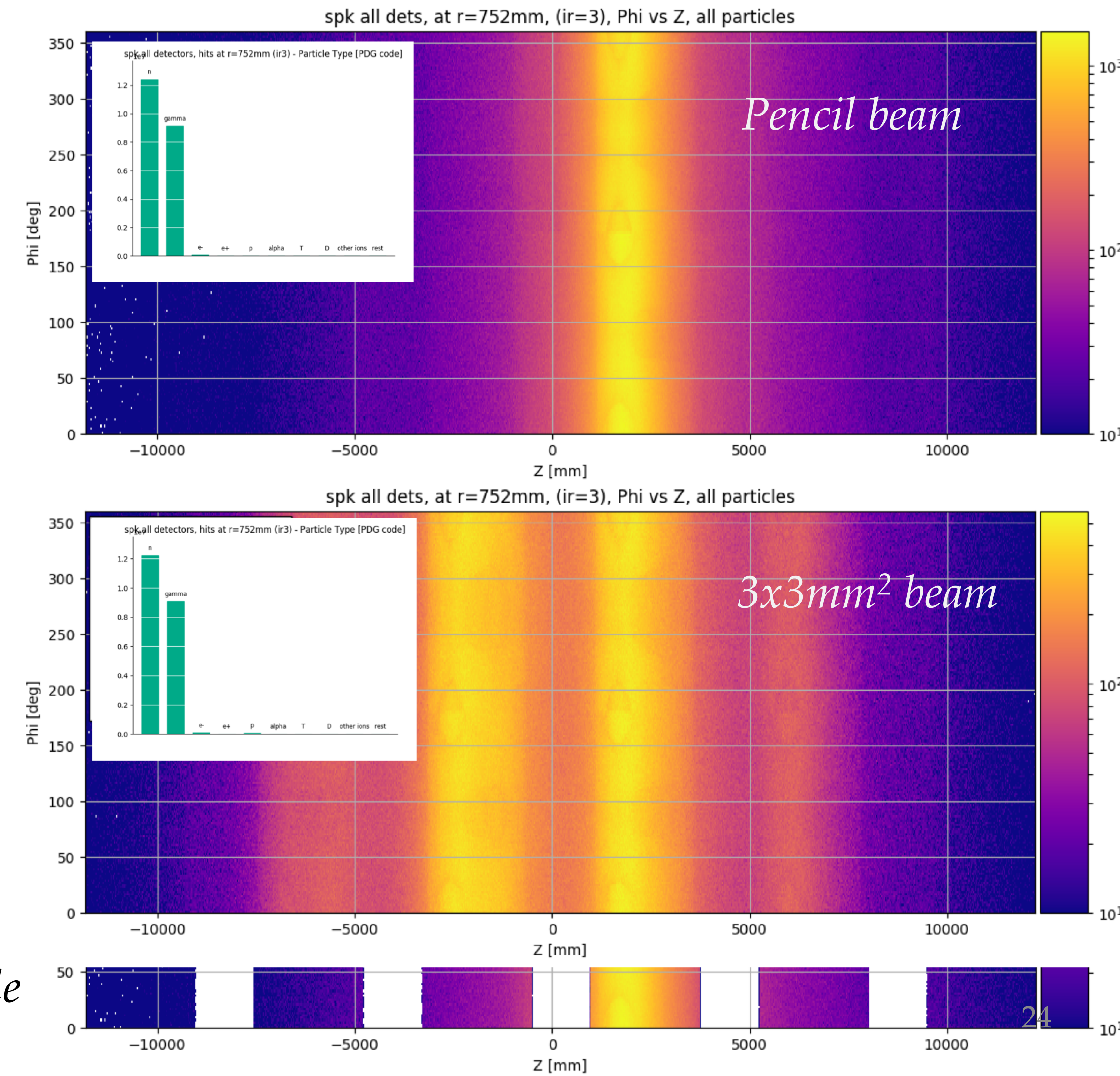
ESS BLM: MC simulations

Example:

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

<u>Plots:</u>

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



Cryo module positions

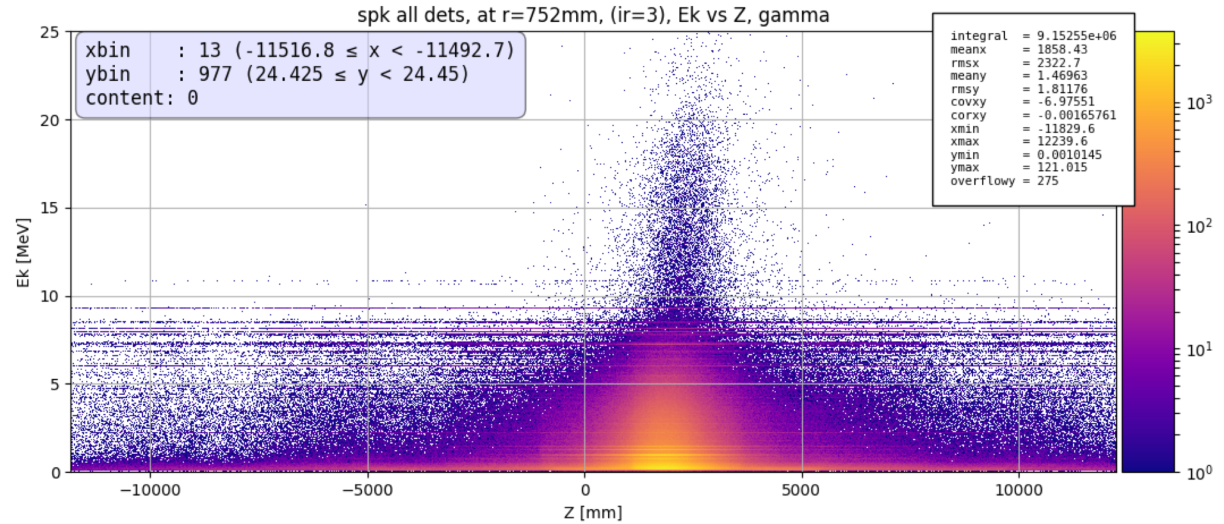
ESS BLM: MC simulations

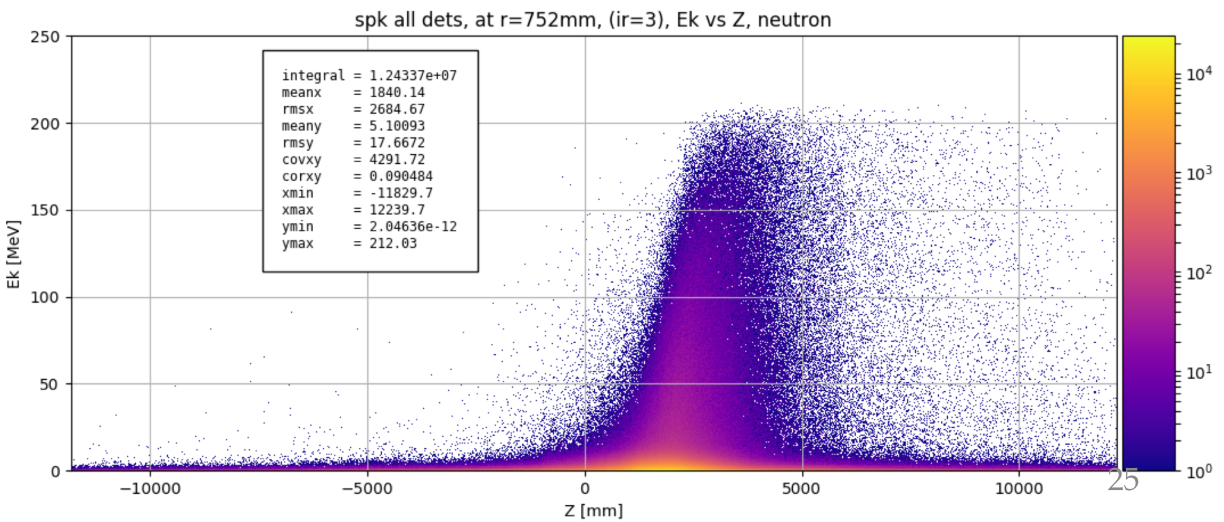
Example:

- 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





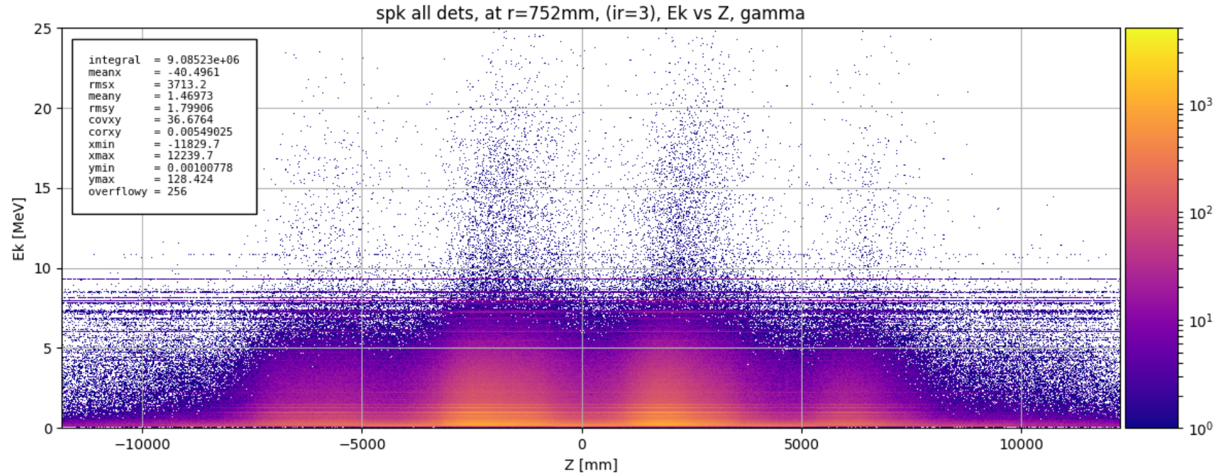
ESS BLM: MC simulations

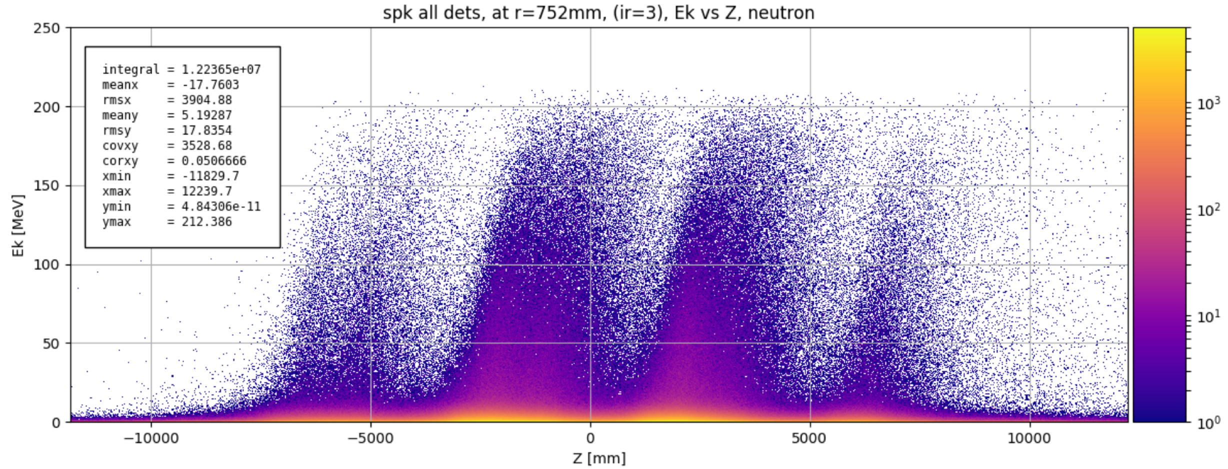
Example:

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

Plots: 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

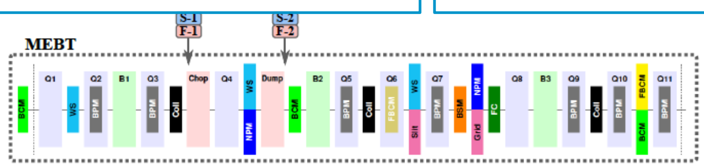
- Majority of the linac: F and S placed separately in an alternating fashion
- At certain locations: a pair of F & S device

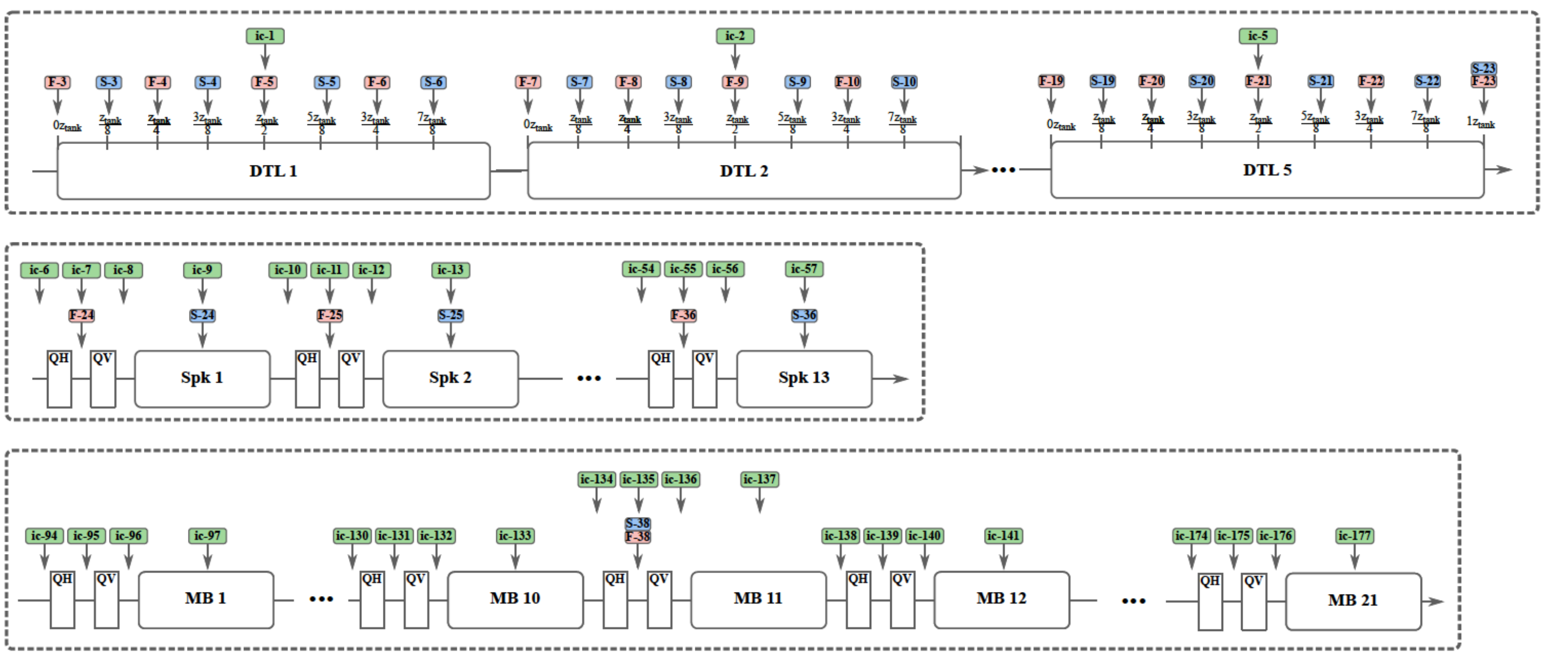
Normal conducting linac (NCL):

- **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

- 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