New concept for beam loss monitoring: fast neutron detection with Micromegas

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2nd ATTRACT TWD
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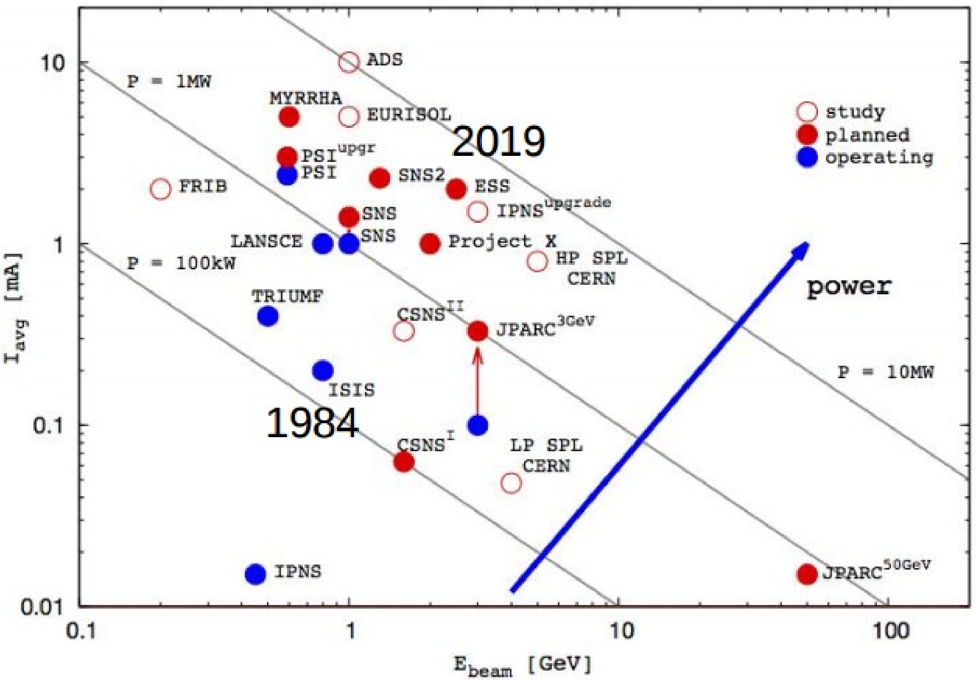
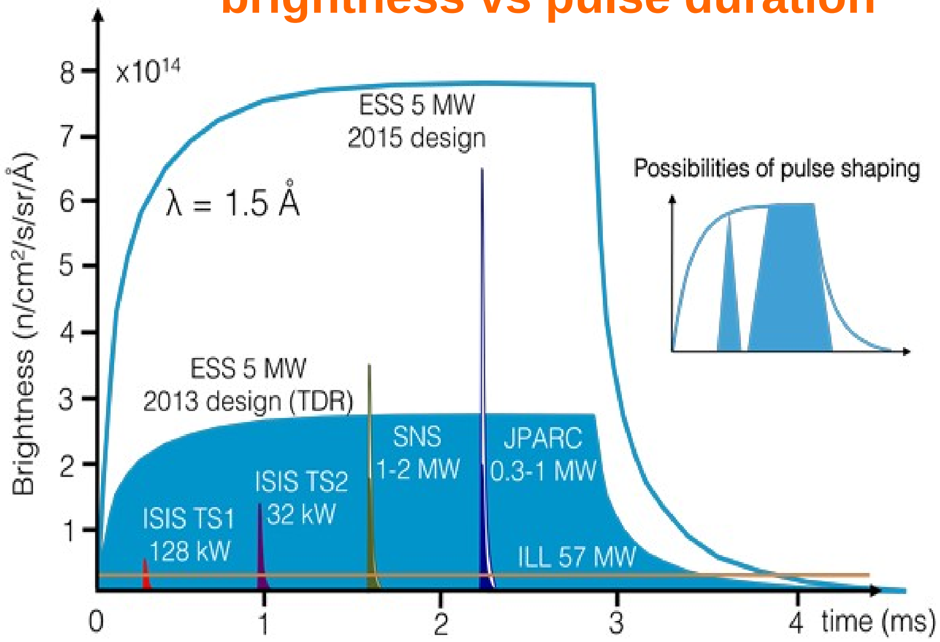
Why new BLM?

The hadron Intensity frontier



M. Lindroos, European Strategy in Particle Physics, Krakow, Sept. 2012

Neutron sources brightness vs pulse duration



European Spallation Source, https://europeanspallationsource.se/unique-capabilities-ess

- New **high intensity high power beam** hadron accelerator facilities under construction, as
  LIPAc (125 mA cw D+) or ESS (62.5 mA, 4% dc H+)
- Any lost can imply damage
- Machine operability
  - More down time due to cool-down before repairing.
  - Aging of materials due to stray radiation
  - Aging of the main magnets due to radiation in the high-losses zones

Why new BLM?

Challenges

- RF cavities emit γ-rays → a problem to ionization chambers used as BLMs
- In high intense but low energy regions of accelerator charged particles and γ's do not even exit the accelerator vessel
- At some cases, continuous monitoring of small losses is needed

Why new BLM?

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Proposal:

Neutron BLM (**nBLM**), Micromegas (MMs) equipped with combination of appropriate neutron convertors and moderators

Fast neutron high efficiency, low for thermal, blind for γ's and X-rays

Two objectives:
monitoring and safety

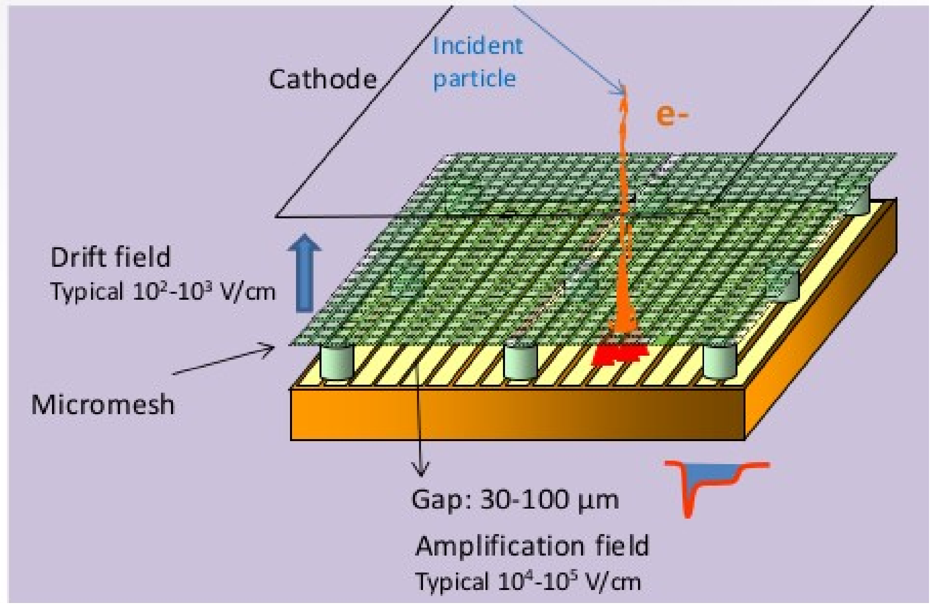
Signature of beam loss:
fast neutrons

Requirements

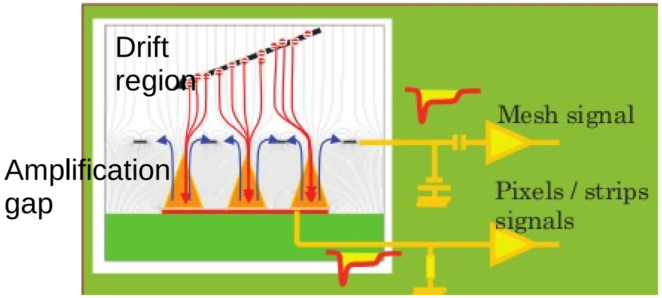
- ✔ Blind to gammas and X-rays from cavity emissions
- ✔ Blind to thermal or slow neutrons: loss their emission location
- ✔ Sensitive enough to monitor small losses
- ✔ Sensitive and **fast** enough to react on "catastrophic event"
- ✔ Appropriate for high rates, radiation hardness

Micromegas in a nutshell

MicroMesh Gaseous Structures (**Micromegas**) as a kind of MPGD
- ➢ Two-region gaseous detector separated by a Micromesh
- ➢ Micromesh suspended over an anode plane by insulator pillars.



- ✔ Simple and robust, used since long time in nTOF, COMPASS or CAST
- ✔ High gains (10^3 -10^4)
- ✔ Granularity, homogeneity, large areas, curved
- ✔ High fluxes greater than 10^8 c/cm²/s
- ✔ Spatial resolution <11 µm
- ✔ Time resolution <50 picoseconds (see talk by T. Papaevangelou)
- ✔ Resistive bulk technologies, reduce spark effects → reduce dead time → BLM

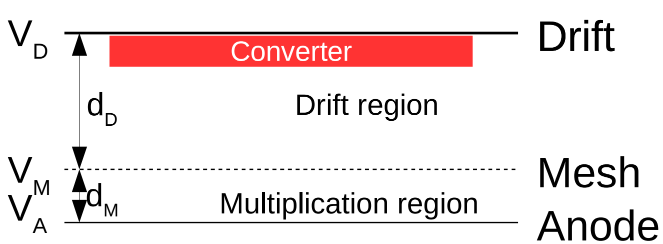


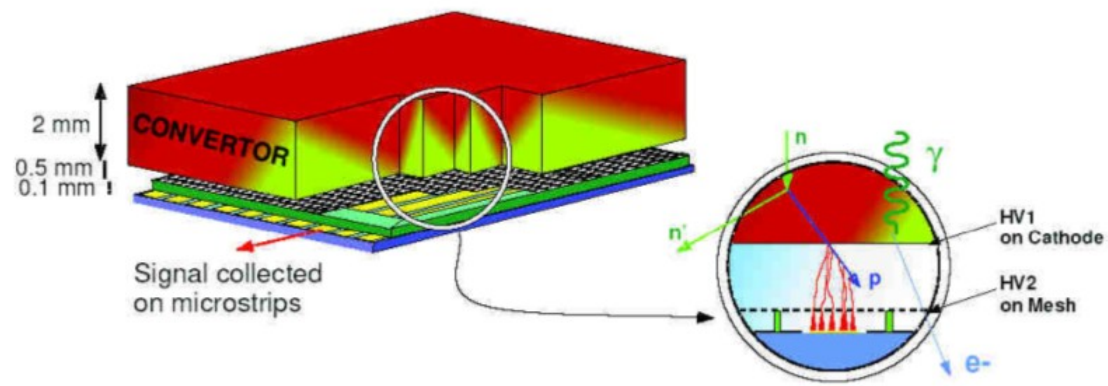
Neutron detection with Micromegas

Neutron detection → neutron-to-charge converter

Solid converter: thin layers deposited on the drift or mesh electrode (^{10}B, $^{10}B_4C$, ^{6}Li, ^{6}LiF, U, actinides...)

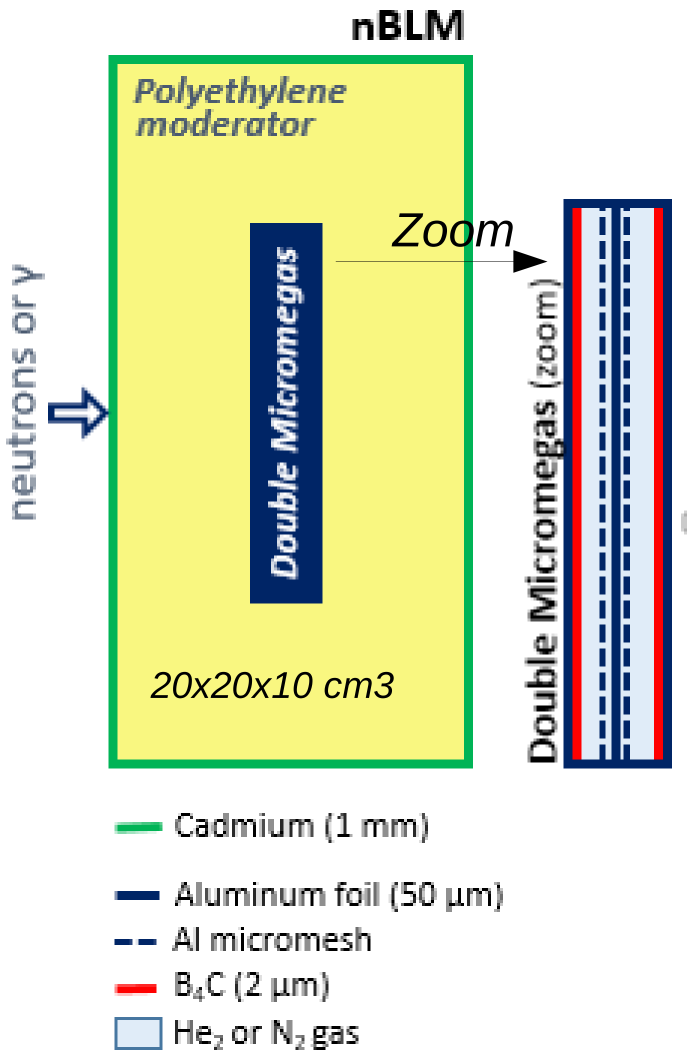
- ✔ Sample availability & handling
- ✔ Efficiency estimation
- ✗ Limitation on sample thickness from fragment range
  → limited efficiency
- ✗ Not easy to record all fragments





nBLM module

Sensitivity to fast neutron fluxes ~ few n·cm^{-2}·s^{-1}



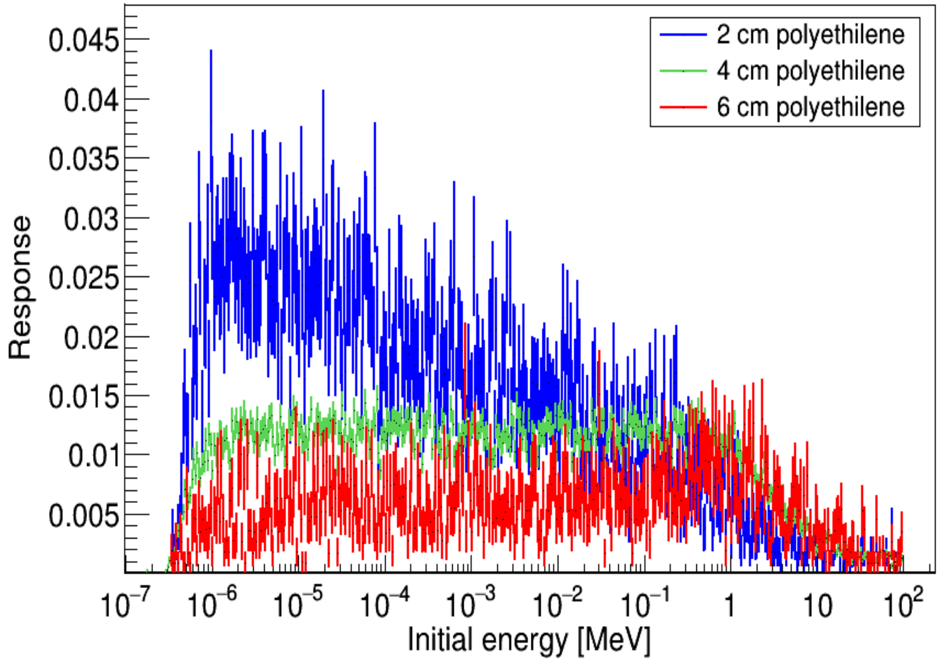
Proposed geometry

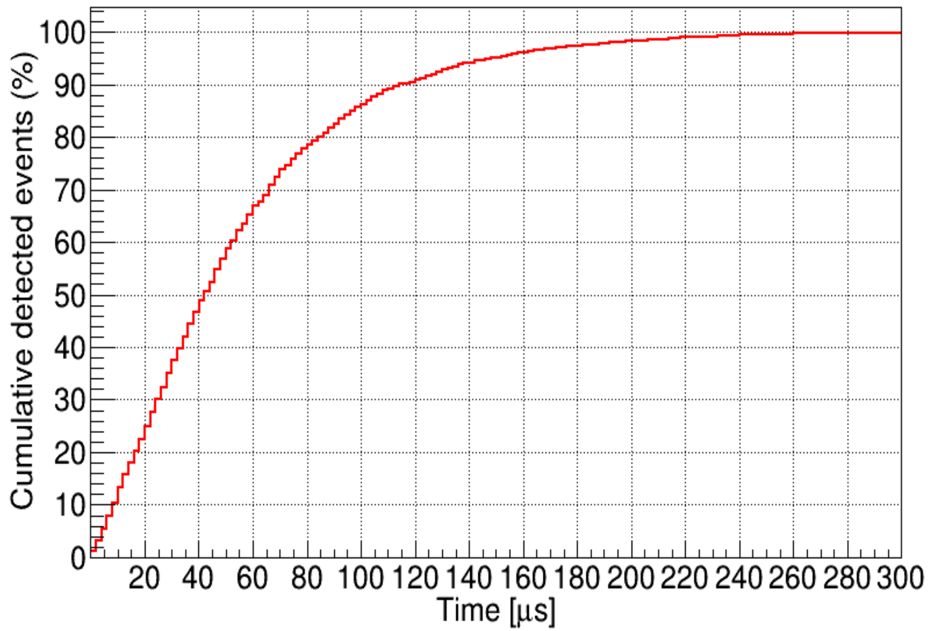
- Cadmium layer
  → to absorb the incident thermal neutrons
- Polyethylene
  → to thermalize the incident fast-neutrons
- B4C layer
  → Increase neutron detection efficiency(~1µm)
- Double Micromegas: back to back
  ~5mm drift → optimize for dynamic range
- Gas: He2 (or N2, Ne…) + quencher: CO2, methane, …
  →He is better for photon discrimination
  - Leak-tightness more difficult
- Front-end electronics integrated
- Possibility of segmentation → multi channel output
  ✔ Higher rate

→ *This geometry was simulated using **FLUKA** and **GEANT 4** codes to check the compliance with the requirements, on-going optimization of structure/dimensions and materials. (Georgios Tsiledakis, Laura Segui)*

Proof of concept: nBLM studies with MC simulations

Response to neutrons
Neutrons between 0.1 eV – 100 MeV





- Optimize geometry for dynamic range
- Efficiency of few %

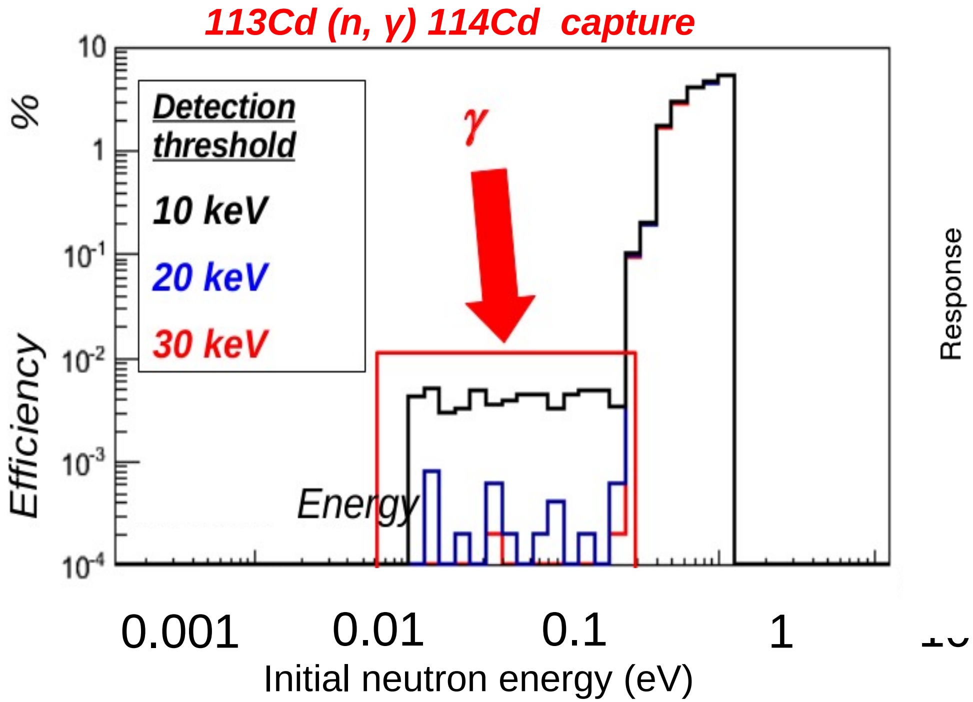
- Time response
  - 10% < 10 μs
  - 95% after 150μs
  - Depends on energy
  - May not be fast enough

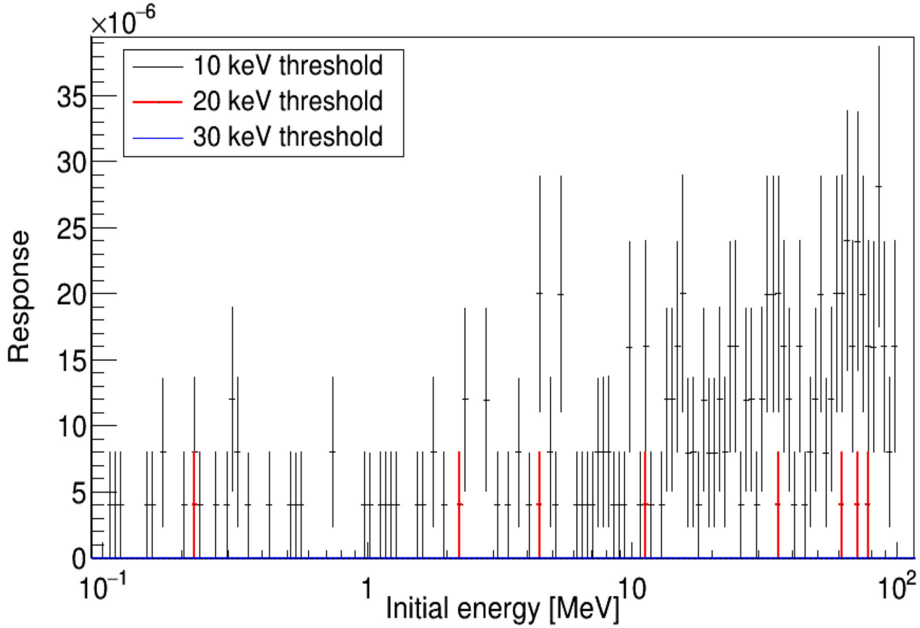
Proof of concept: nBLM studies with MC simulations

Background rejection

Response to external "thermal" neutrons
0.01 < Eneutron (eV) < 1

Response to X-rays and γ
0.01 < Ephoton (MeV) < 100





Efficiency with respect to detection thresholds:

10 keV → ε ~ 0.007 %

30 keV → ε ~ 0 → blind

Efficiency with respect to detection thresholds:

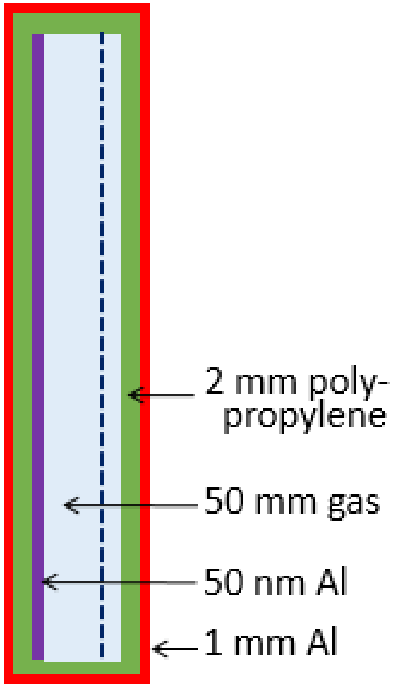
10 keV → ε = 0.005 %

30 keV → ε < $2x10^{-6}$ % → blind

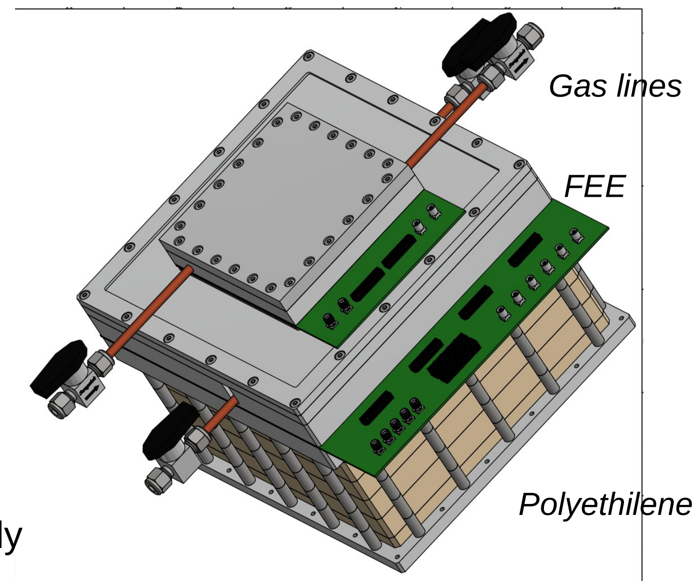
Adding a faster module

Detection of recoil protons produced by neutrons in polypropylene

High flux high energy n's, from the front



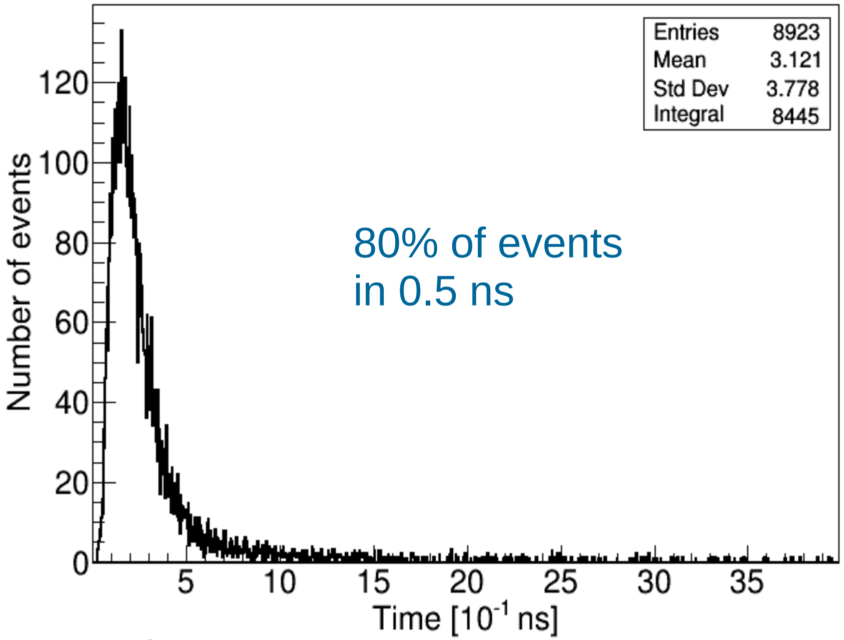
- Polypropylene: (n,p) reaction, ~2mm
  → quiet insensitive to thermal n's
- Thin Al (50 nm) coating on polypropylene
  → to polarize the MMs, insure high transparency to recoil protons.
- Gas same as slow detector
  → Drift: 0.5 – 8 mm (under optimization
- One single side MMs



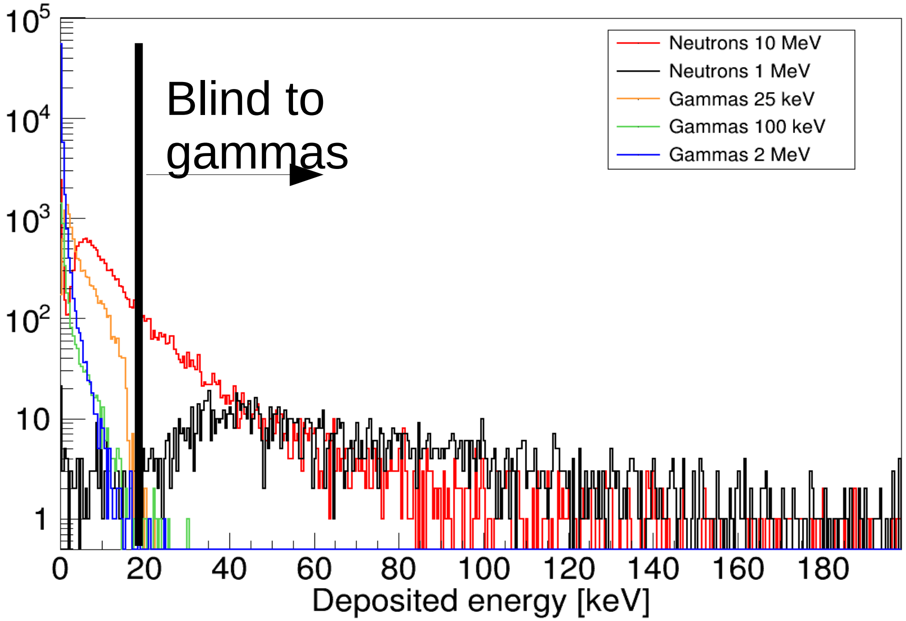
- First design for prototypes by D. Desforges
  - As flexible as possible to test
  - different options experimentally

Adding a faster module: MonteCarlo results

Efficiency (10 keV energy cut)
ε = 3.5% for 10 MeV
ε = 0.35% for 1 MeV



Time response to neutrons
0.1 < Eneutron (MeV) < 100



Very good photon/neutron discrimination
With an energy cut >20 keV
→ detector blind to gammas

Response to **thermal neutrons (0.025 eV)**
1 keV minimum E deposit: ε = 0.13 %
10 keV energy cut $\varepsilon = 8.00\ 10^{-5}$ %
20 keV energy cut $\varepsilon < 2.00\ 10^{-5}$ %

Conclusions & Outlook

- Micromegas is a high performing MPGD, suitable for neutron measurements
  - Mature technology
  - Radiation hardness, aging properties
  - Very good gain, energy & time resolution, granularity...
  - Simplicity / low cost

- Micromegas can be coupled with appropriate neutron converters to detect high energy n's with adjustable sensitivity

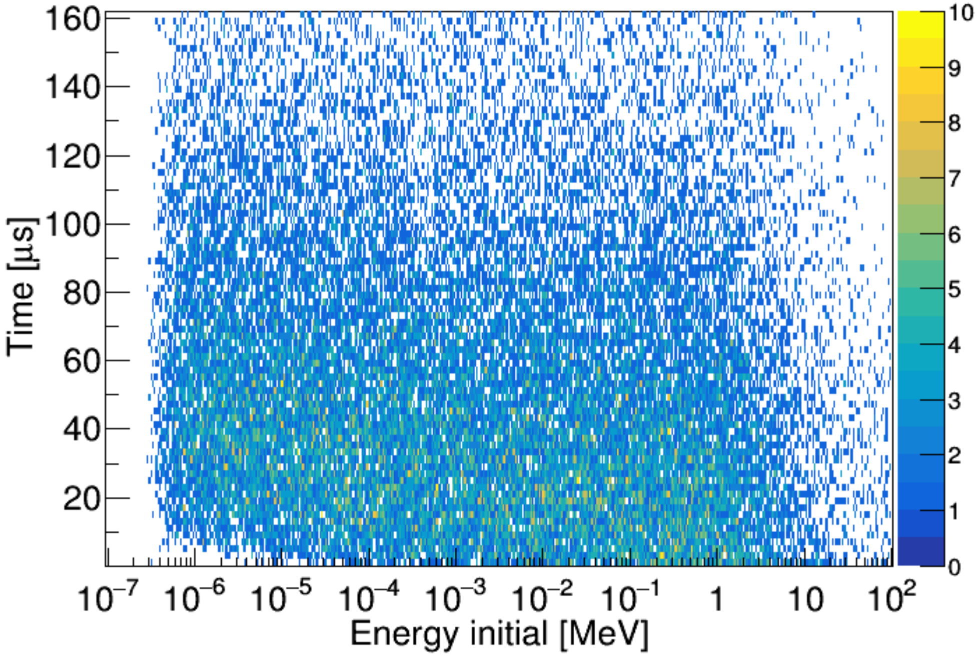
- The operation parameters can be adjusted to:
  - Increase neutron to gamma discrimination
  - Coop with very high or low particle fluxes
  - Extend the energy dynamic range

- In-kind contract with ESS to deliver 42 nBLM modules in 2.5 years
  - Design of detectors + FEE + BEE in collaboration with ESS
  - Design and MC simulations on-going
  - Test it at different facilities along next year

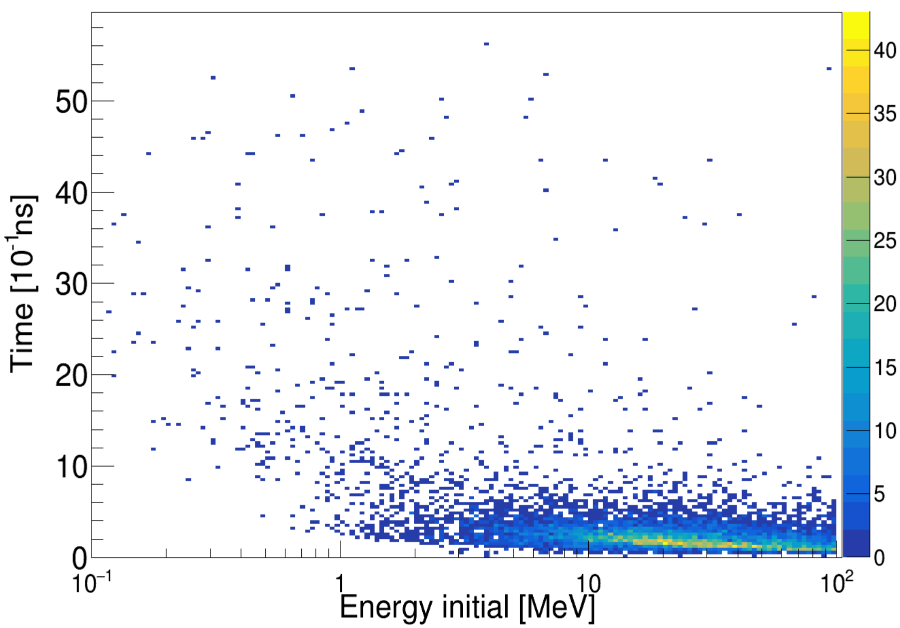
- A similar system is under discussion with SARAF or the CERN Linac

THANK YOU

Back-up



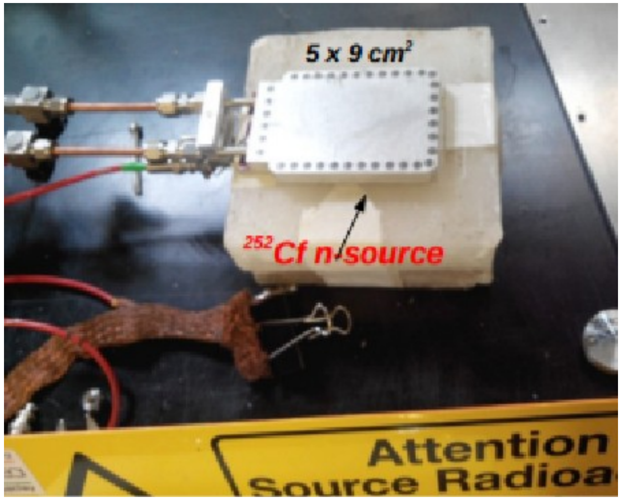
Slow detector
neutrons

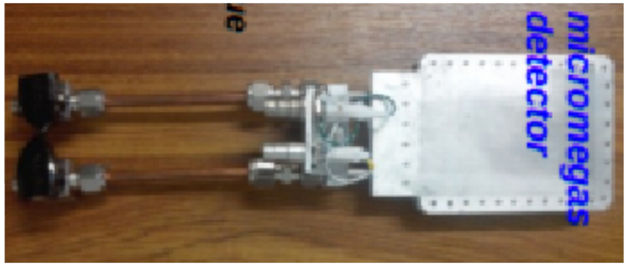


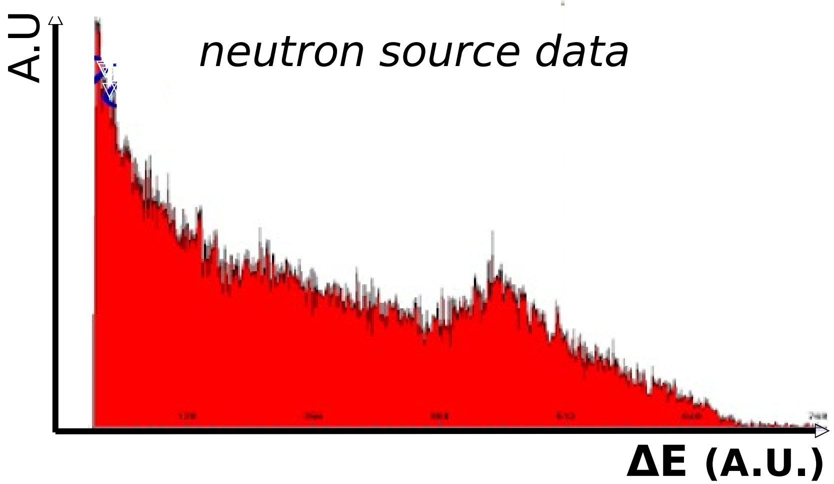
Fast detector
neutrons

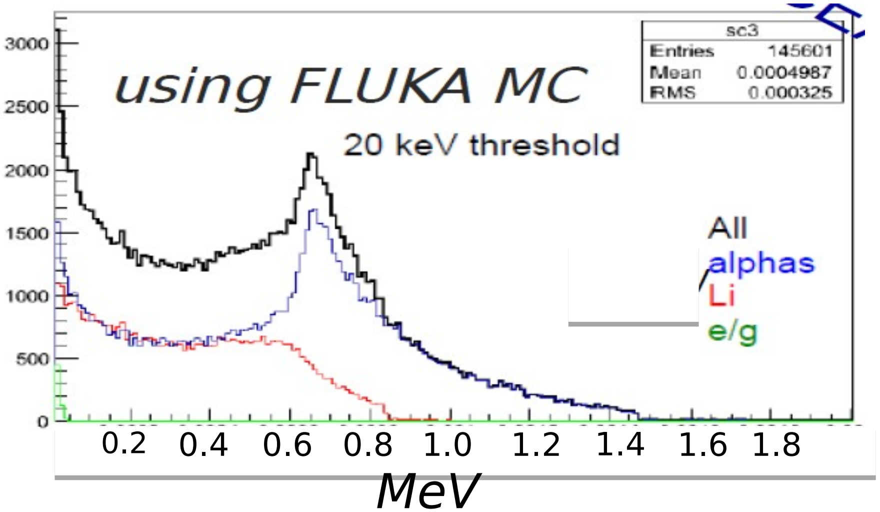
Experimental first results

- Experimental data using a MMs with one B_4C plate, top of a polyethilene box
- Data taken with a ^{252}Cf neutron source
- Good agreement between data and Fluka simulation
- Measured overall efficiency: 4.3 – 5%









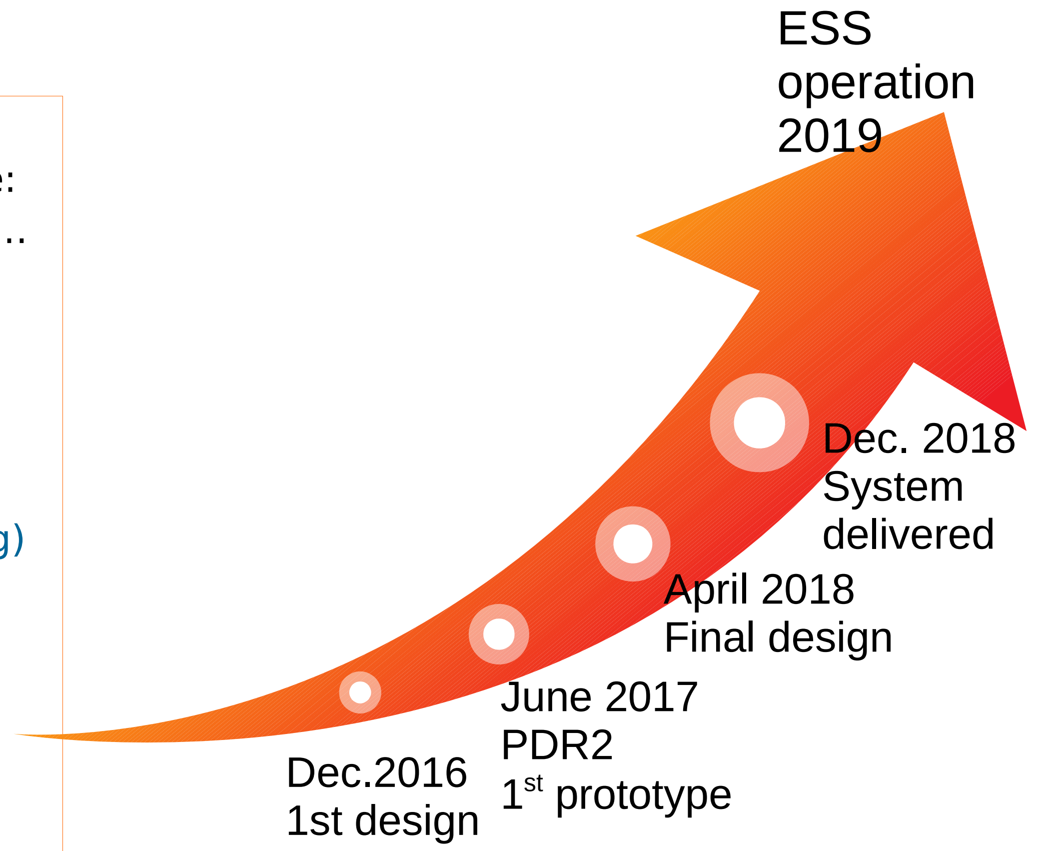
nBLM project for ESS

CEA/Saclay in-kind contract with ESS

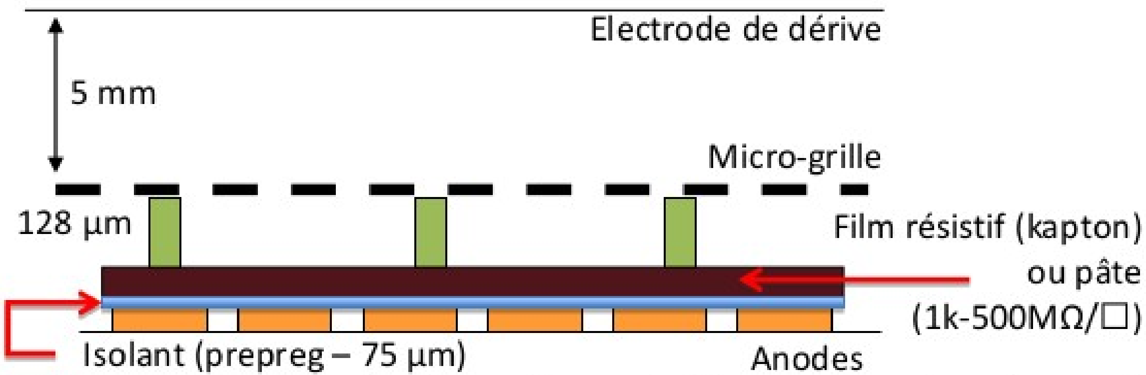
Expected time for optimization, design, construction, characterization, installation & commissioning of 42 modules: 2.5 year

- Dec. 2016 first design of the prototype
  - On going design and simulations to optimize:
    Drift, polyethylene thickness, convertor, …
- June 2017: 1st prototype
- June 2017 – April 2018
  Test the detector at:
  - LICORNE (fast neutrons)
  - COCASE (high activity ^{60}Co irradiator)
  - ORPHEE (high thermal neutron flux / aging)
  - SEDI laboratory (long term stability)

  Final prototype design
- System delivered to ESS Dec. 2018
- ESS hand over: begin of 2019



Micromegas with resistive strips



Protection against sparks
and/or
spread of the charge

M. Dixit et al., NIM A518 (2004), 721

Different technologies of resistive films developed @ CERN (R. de Oliveira)

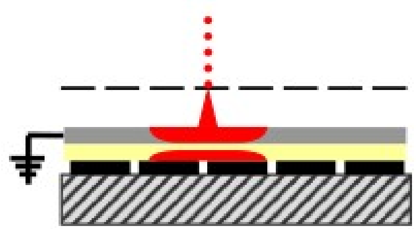
Characteristics:

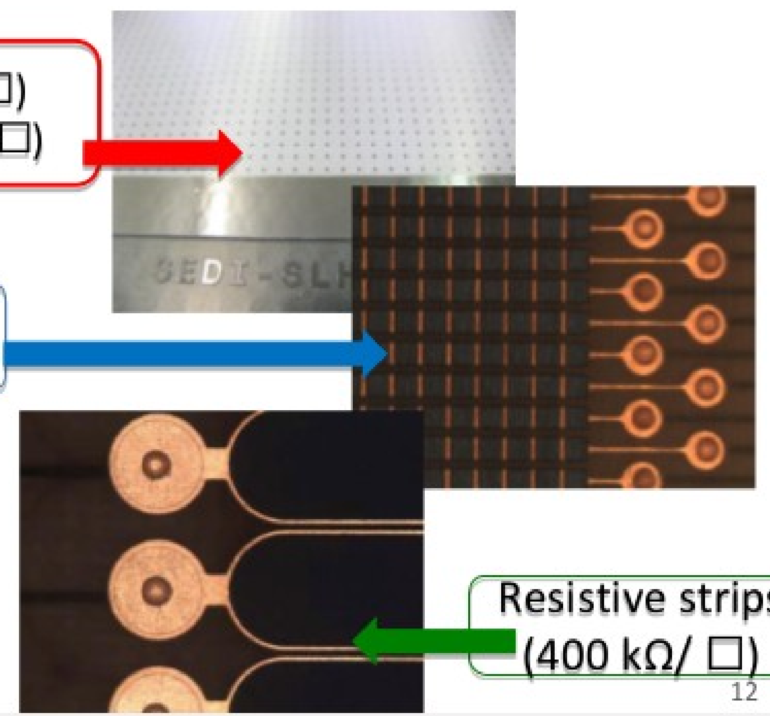
- Resistive strips connected to the ground
- Thin insulating layer between of the resistive and readout strips
- *AC coupling of signals*
- Sparks are neutralized through the resistive strips to the ground

Resistive kapton (2 MΩ/☐)
Resistive paste (250 MΩ/ ☐)

Resistive Pads
(a few tens of kΩ/☐)

Resistive strips
(400 kΩ/ ☐)





Why new BLM?

Challenges

- RF cavities emit γ-rays → may pose a problem to ionization chambers used as BLMs
- In the case of high intensity but low energy regions of an accelerator charged particles and γ's do not even exit the accelerator vessel
- At some cases, continuous monitoring of small losses is needed

→ Minimize and control any beam losses

- Location of lost is important to define BLM

"Low energy" region dominated by gamma and Xray emission from RF cavities

SNS commissioning

- Every 10s there is an energy RF pulse with no beam
- RF pulse subtracted
- Sensitive to fluctations