CEA - Saclay

A New Beam Loss Monitor Concept Based on Fast Neutrons Detection and Very Low Photon Sensitivity

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Overview

Why new BLM?

Micromegas in few words

nBLM simulations

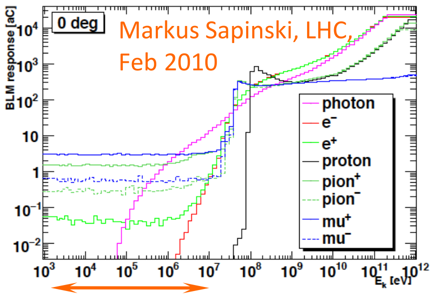
Summary

Why new BLM?

high beam intensity hadron accelerator facilities like LIPAc (125 mA cw D^+),
ESS (62.5 mA 4% dc H^+)…

- ➢ Beam Dynamics Physicists[1,2] tuning recommendations
  - Minimize the beam losses (safety, maintenance hands-on…)
    - → Emittance will growth: "halo matching"
  - Note that is unlike classical beam for which emittance is minimized: "emittance matching"

- ➢ Measure the Beam Losses quite accurately → important
  - Beam loss locations
  - Low beam energy
    - Neutrons and γ's as primary and/or secondary
    - Low rates since close to the reaction thresholds
    - background: electron emissions emitted from RFQ or superconductive cavities where huge surface electric field are applied → X-rays and γ's
  - High beam energy
    - All particles, including charged ones
    - Higher signal (IC regime)



[1] Nicolas Chauvin, " Beam dynamics Challenges in IFMIF ", HB2016, TUAM2Y01.

[2] P.A.P. Nghiem et al., " The IFMIF-EVEDA challenges in beam dynamics and their treatment ", Nucl. Instrum. Meth. Phys. Res. A 654, 63–71.

nBLM

Focus on Low Energy → neutrons and γ's

- Requirements
  - 1- avoid γ and X-rays contributions from cavity emissions
  - 2- directionality → good correlation beam loss location / detection
  - 3- reasonable efficiency
  - 4- good time response for Safety

1- Avoid γ contributions from cavity emissions

→ BLM **blind** to X-rays and γ's

2- Directionality or good correlation beam loss location / detection

→ thermal neutrons: they may be thermalized by rebounds on concrete accelerator wall, on beam line structures… losing their location emission: **thermal neutron should be avoided**

→ fast neutrons: directly detected from loss location, **high sensitivity**

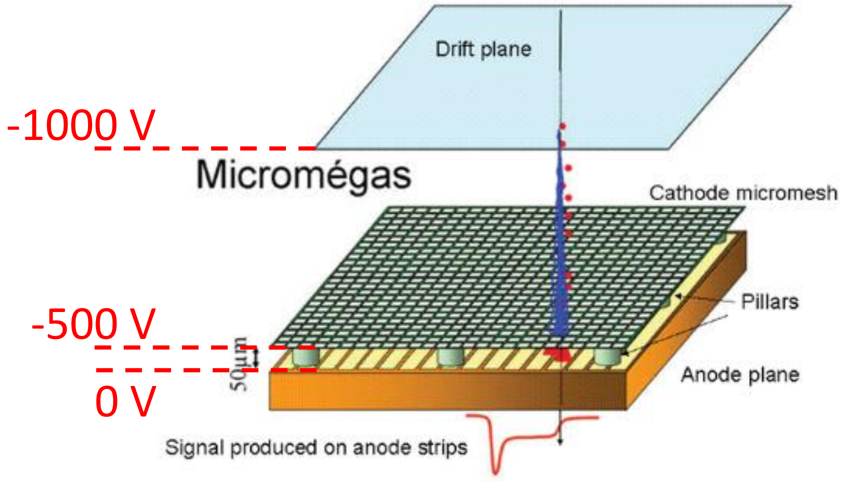
3, 4- Reasonable efficiency and good time response for Safety

→ selecting detector structures

neutron BLM (nBLM), based on Micromegas detectors

- fast neutron high efficiency, but low for thermal
- Blind to X-rays and γ's

Micromegas working principle



- 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 ≈ 10000 V/mm
- Grounded read-out: conductive strips connected to FEE
- Pillars are used to reinforce the response uniformity

Lot of improvements, evolutions can be done on Micromegas and by changing their parameters (gaps, gas, electric potential, read-out…). It can achieved:

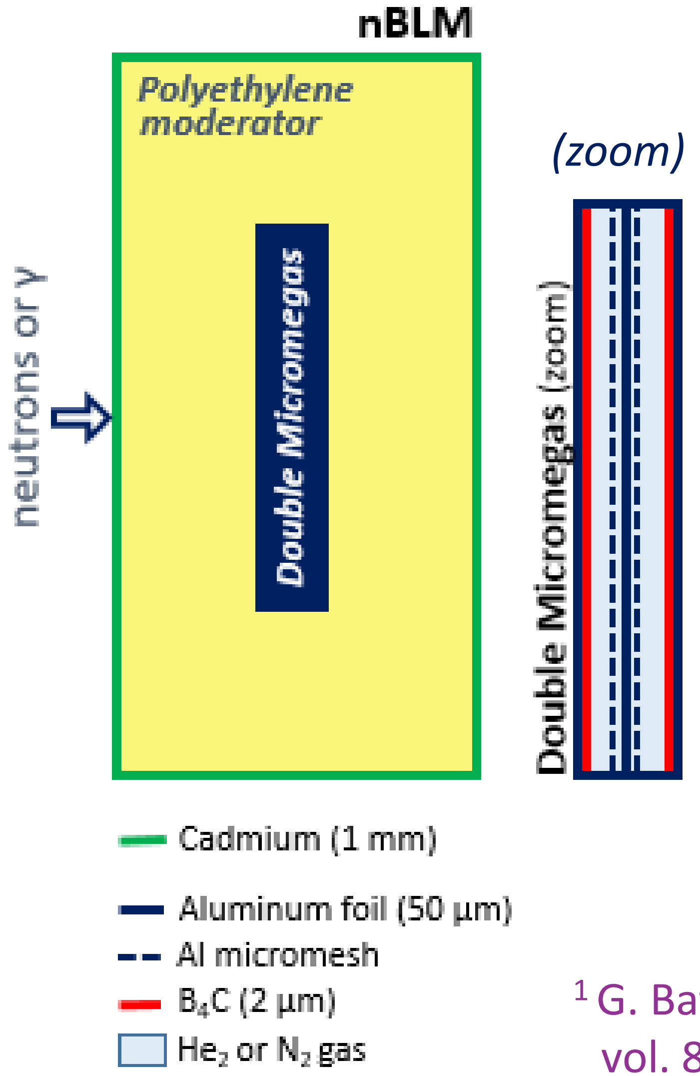
- high fluxes greater than 10^8 counts/cm^2/s
- spatial resolutions down to 50 µm
- time resolution down to 30 ps

Cylindrical shape are now working routinely,
large surface area (>1 m^2) can be covered
Resistive bulk technologies allow now to reduce drastically spark effects, decreasing dead time → BLM

[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.

nBLM simulations

nBLM geometry



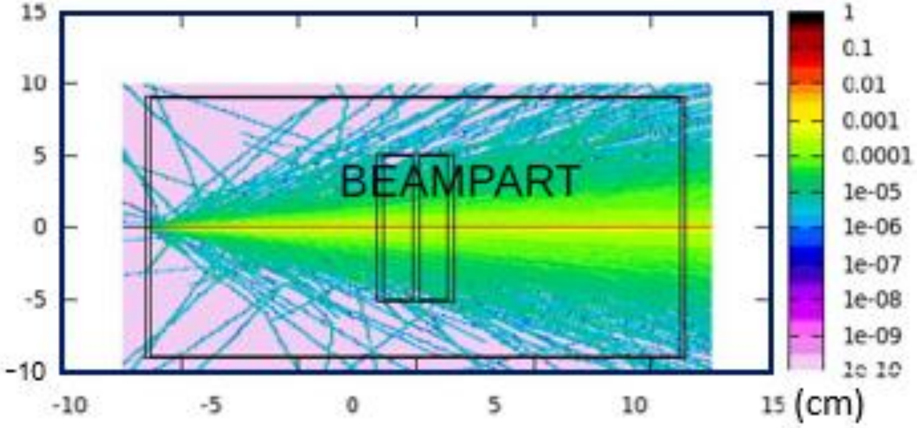
- Cadmium envelop
  - to absorb the incident thermal neutrons
- Polyethylene moderator
  - to thermalize the incident fast-neutrons → varying thickness allows to adjust the energy threshold
  - to absorb the remaining incident thermal neutrons
- Double Micromegas
  - to increase the neutron detection efficiency with B_4C thin films (~1.5 - 2 µm)
  - gas: He (≈ 1.1 bar) or N_2, Ne…
    - He is better for photon discrimination

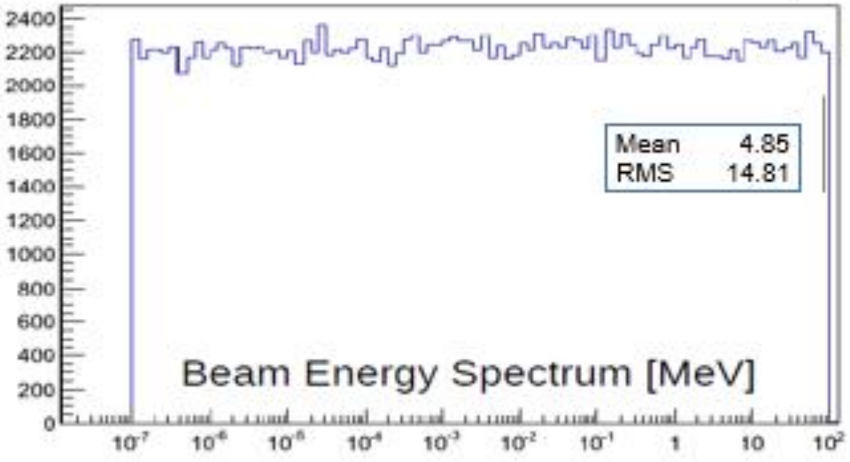
This geometry was simulated using FLUKA[1] and GEANT 4[2] codes to check the compliance with the requirements

[1] G. Battistoni et al., The FLUKA code: Description and Benchmarking, in Proc. AIP Conf. Proc. 03, vol. 896, 2007, pp.31. http://dx.doi.org/10.1063/1.2720459.

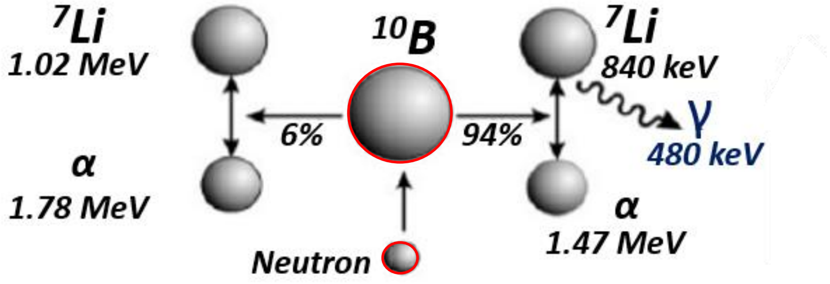
[2] GEANT Collaboration, S. Agostinelli et al., GEANT4-a sim-ulation toolkit, NIM A 509 (2003) 250.

Event simulation



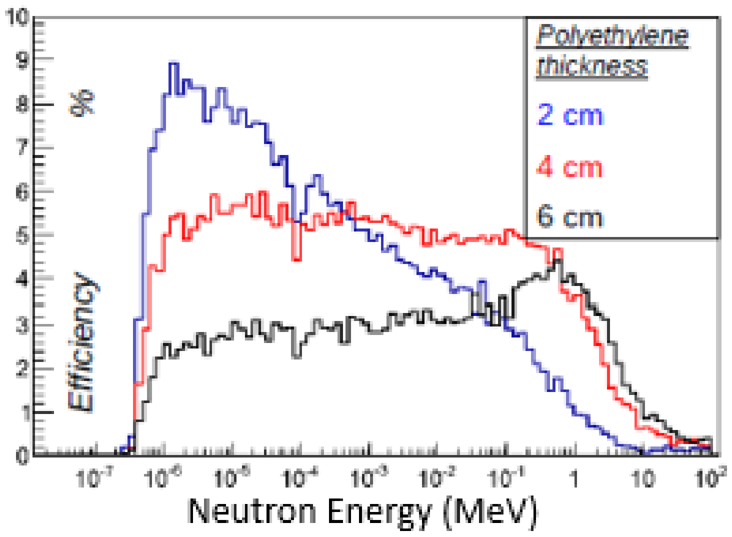


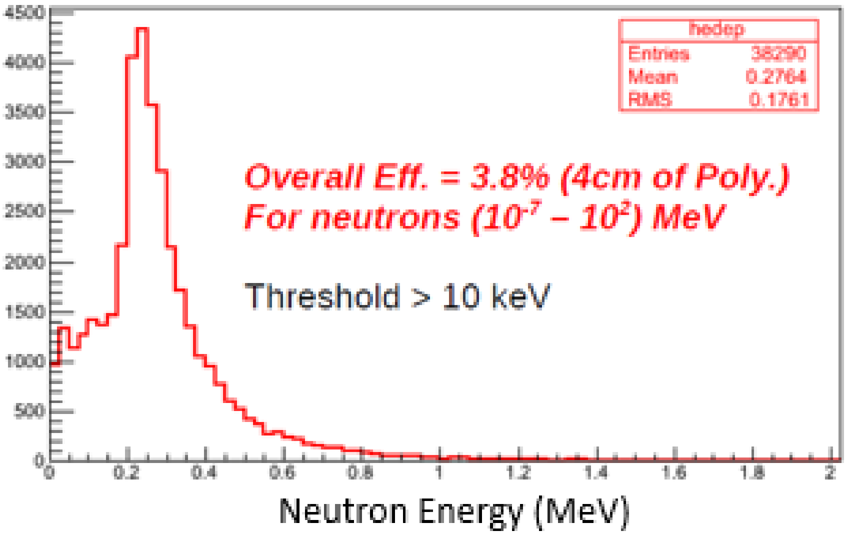
- Hypothesis for FLUKA & GEANT 4 codes
  - Neutrons: double exponential distribution for energy ranging from 0.1 eV to 100 MeV
  - Photons: double exponential distribution from 10 keV to 100 MeV
  - Withdrawing is done upstream and transversely to the nBLM entrance window in a volume filled with air
  - *angular divergence of 10 mrad for incident neutrons*
- Codes: calculate the energy deposition in the gas

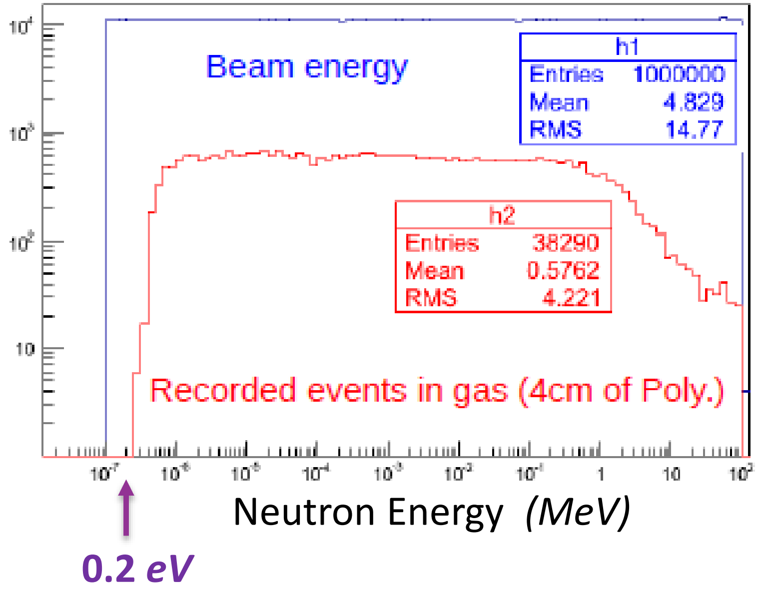


- Checked: results obtained with both codes are similar!

nBLM efficiency to fast neutrons



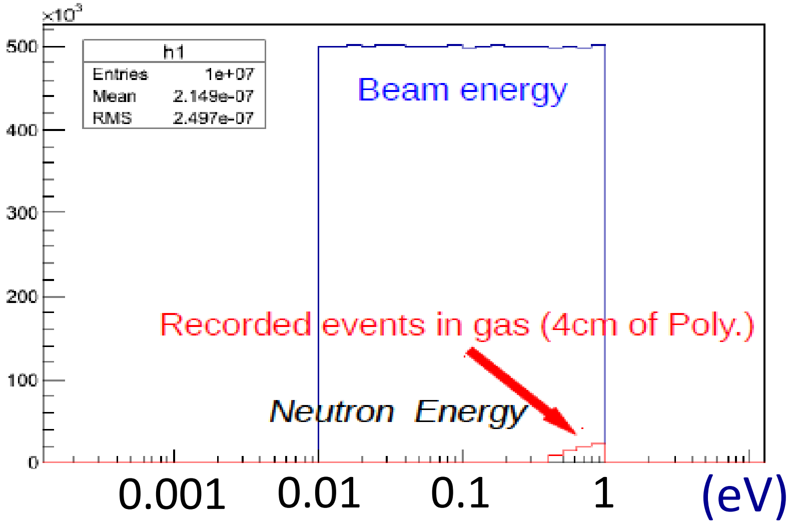


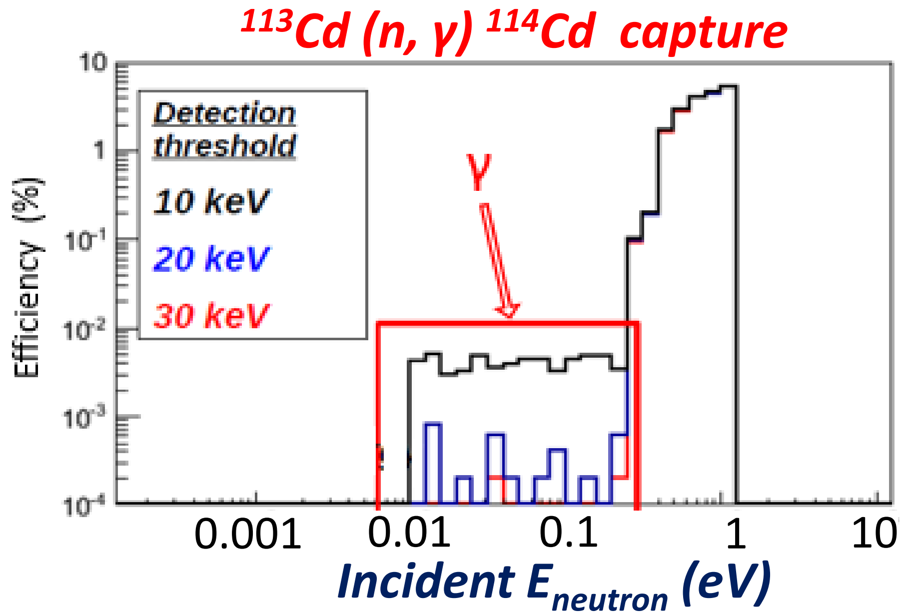


- Moderator thickness
  - 2, 4 and 6 cm
  - Threshold energy = 10 keV
  - Overall efficiency for 4 cm → 3.8%
  - Moderator thickness can be used to change slightly the neutron energy threshold as well as the shape
- Contribution of all neutrons under 0.2 eV is suppressed
  - Thermal neutrons are almost removed

nBLM response to external "thermal" neutrons

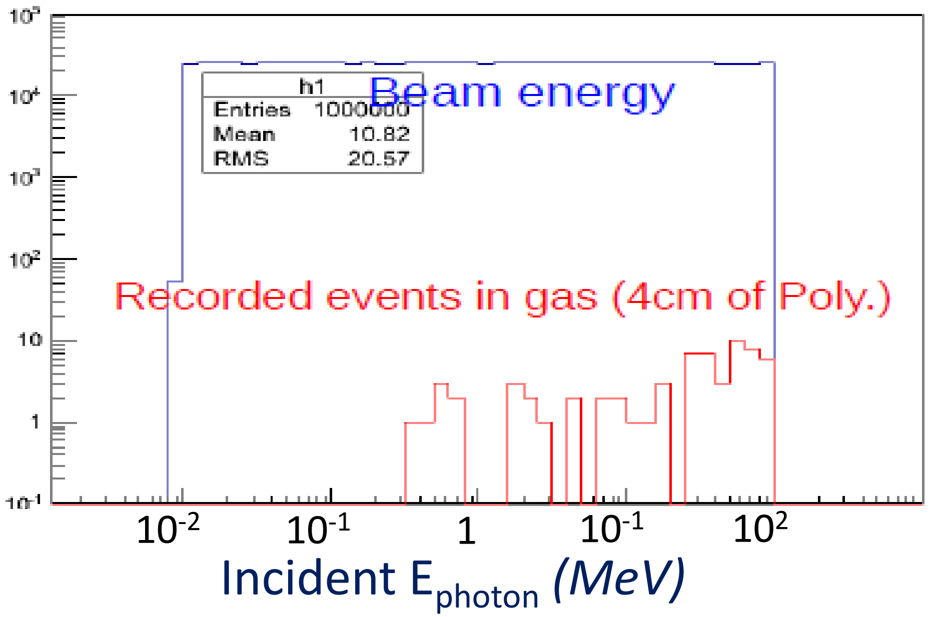
$0.01 < E_{neutron}\ (eV) < 1$

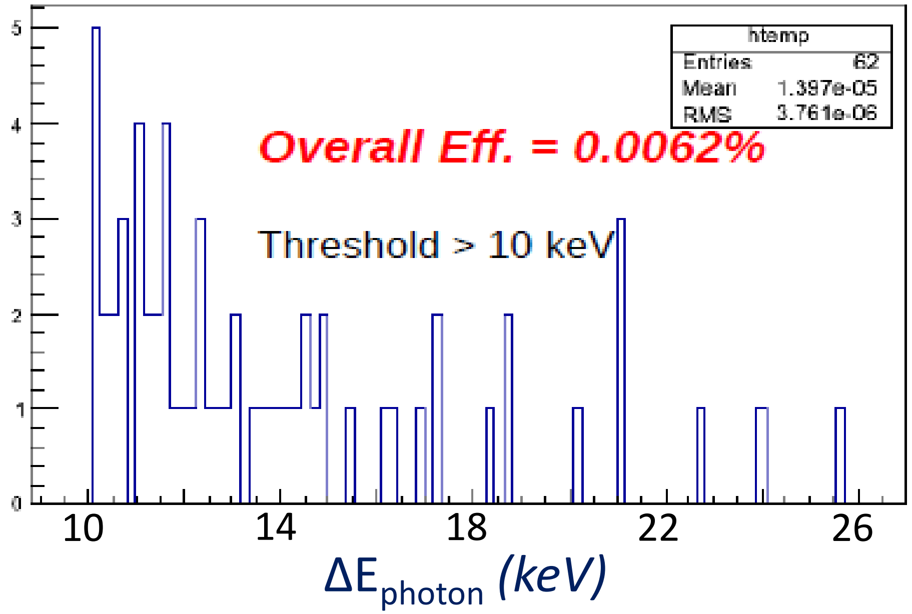




- Thermal neutrons with respect to detection thresholds:
  - 10 keV → Eff. < 0.007 %
  - 30 keV → nBLM is blind to external thermal neutrons
  - Background: γ contributions coming from ^{114}Cd and ^{10}B neutron are taken into account, but almost completely removed with low detection thresholds.

nBLM response to X-rays and γ
$0.01 < E_{photon}$ *(MeV)* < 100

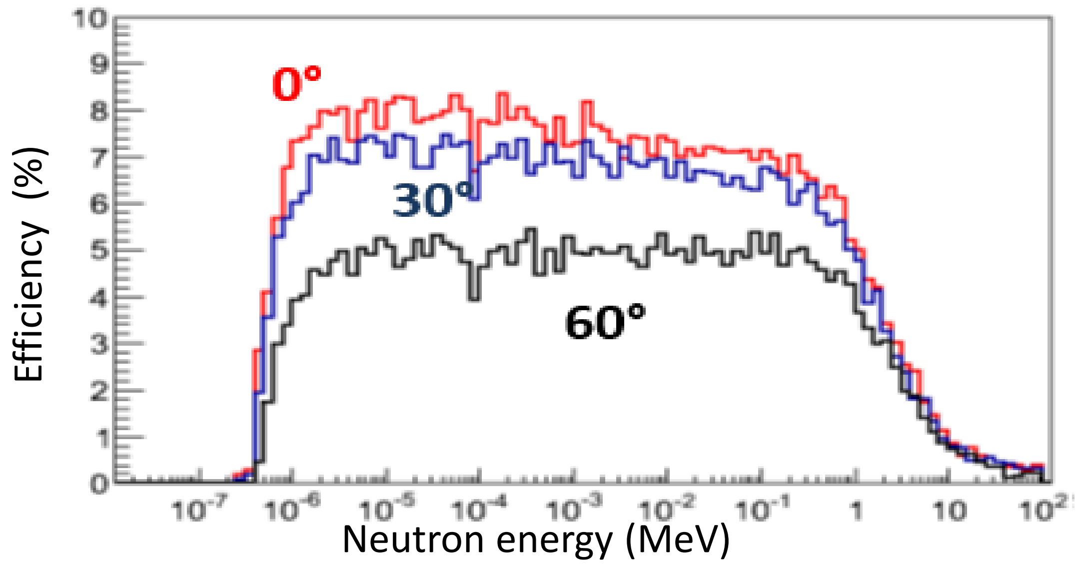


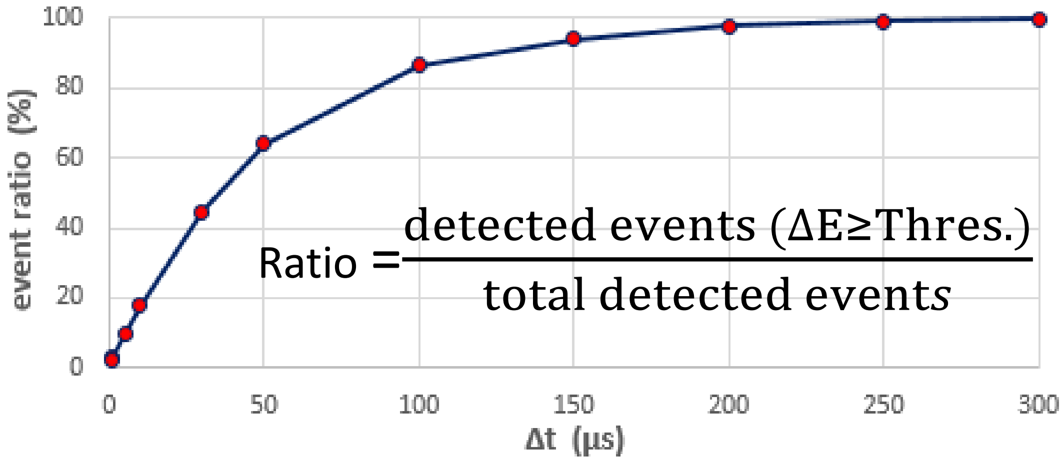


- Photons with respect to detection thresholds:
  - 10 keV → Eff. < 0.0062 %
  - 20 keV → nBLM almost blind to photons

  Note: Micromegas use small amount of material, explaining their transparency to photons (low RL)

angular and time responses of nBLM



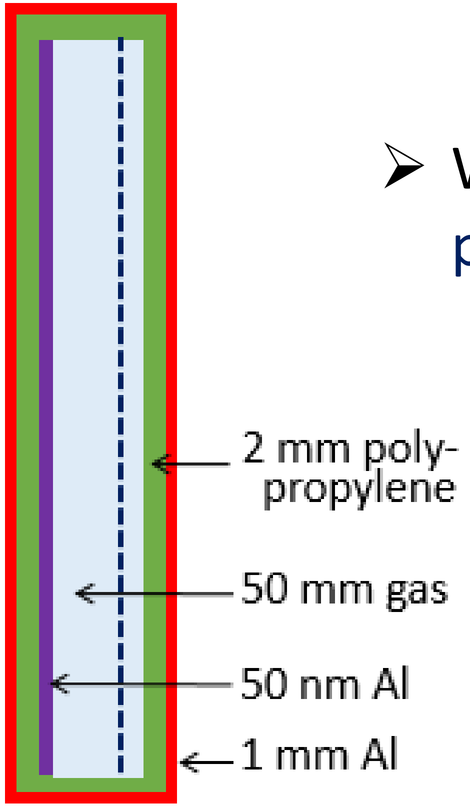


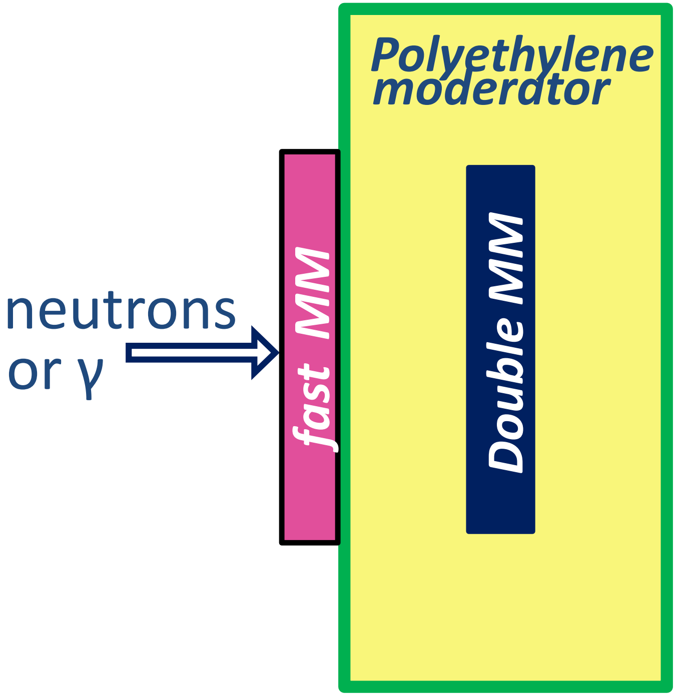
- nBLM angular response
  - quite low effect due to neutron slowing down inside moderator
  - this behavior let us expect a nBLM efficiency greater than the active surface of Micromegas
- nBLM time response
  - only 17% of events are detected during the 10 first µs, while they are all after 300 µs!
  - due to neutron moderation time
  - might be too slow for safety purposes

➔ Proposition to add a fast stage of BLM

Fast nBLM

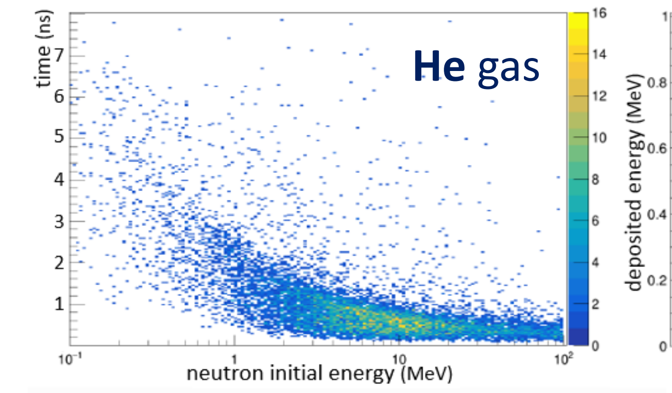
- Fast nBLM geometry
  - 1 mm Al + 2 mm polypropylene will be enough to be quite insensitive to thermal neutron
  - thin Al (50 nm) coating on polypropylene to polarize the Micromegas and to insure a high transparent to recoil protons.
- Working principle: detection of recoil protons produced in polypropylene

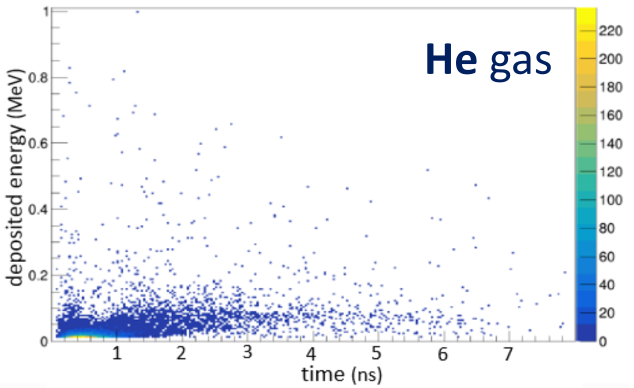


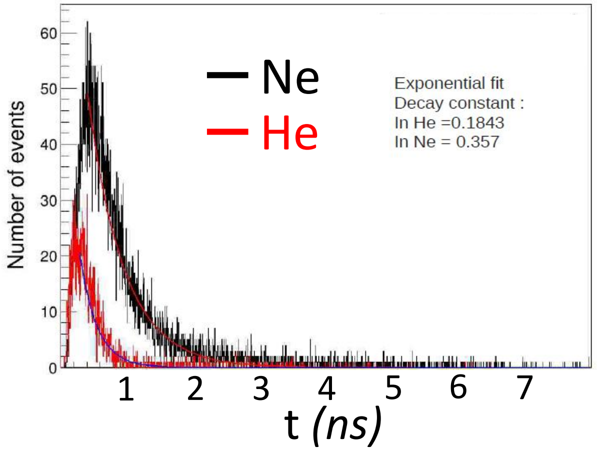


Time response of the fast nBLM

0.1 < $E_{neutron}$ *(MeV)* < 100



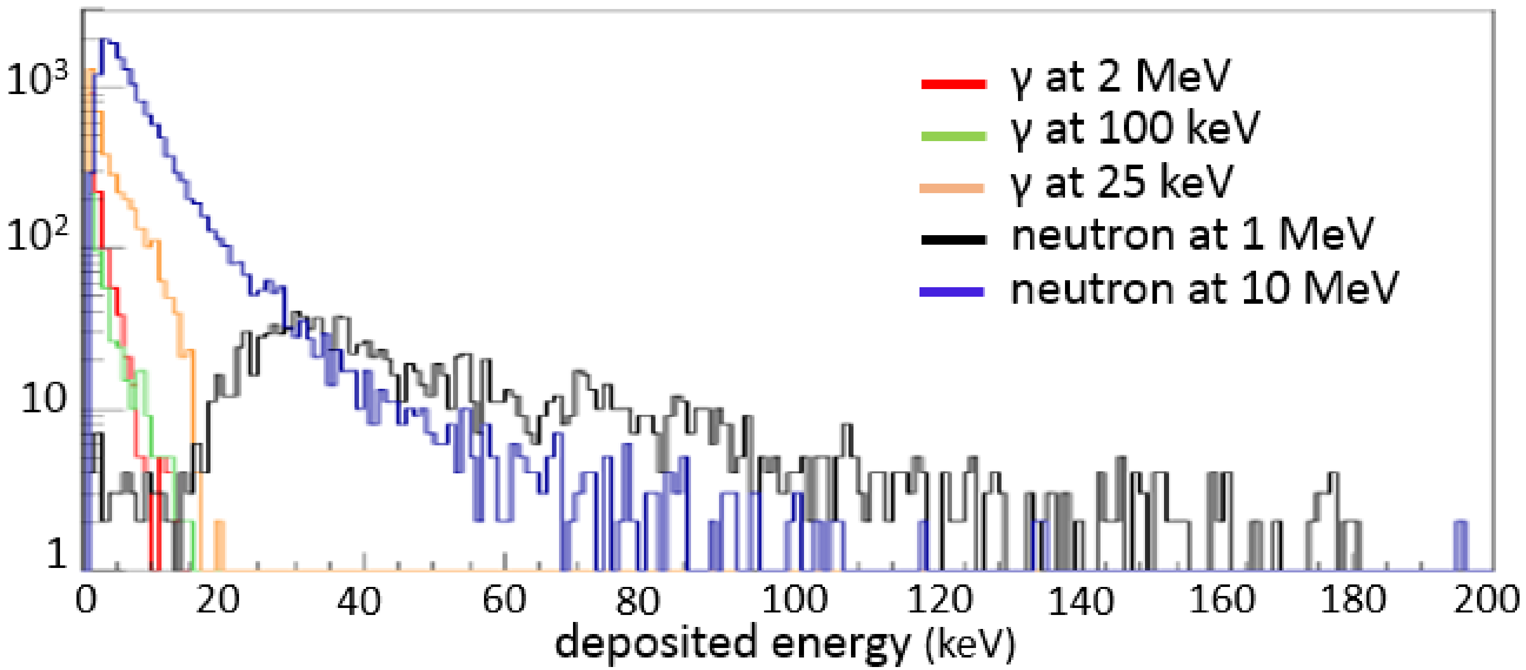




- Time response (Th=10 keV) < 8 ns
- Fast neutron (Th=10 keV) → low efficiency
  - for $E_{neut.}$ = 1 MeV → Eff. = 3 10^{-4}
  - for $E_{neut.}$ = 10 MeV → Eff. = 8 10^{-4}
- Thermal neutrons: E=0.025 eV
  - Thres. = 1 keV → Eff. = 6.6 10^{-5}
  - Thres. = 5 keV → Eff. = 5.8 10^{-6}
  - Thres. = 10 keV → Eff. < 5 10^{-7}

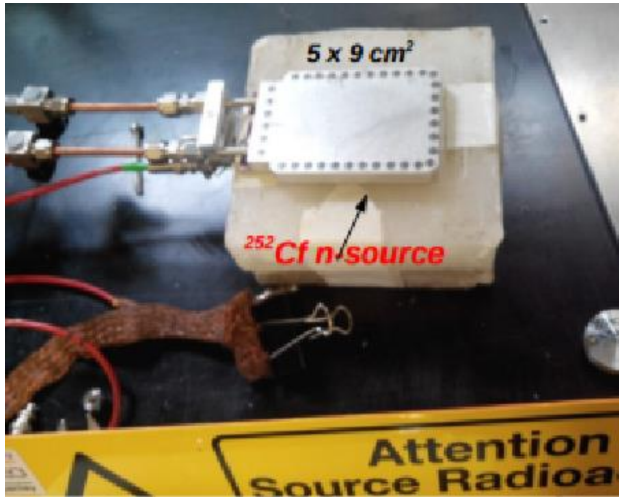
Note: this fast-BLM is just in case of very critical events → huge neutron emission!

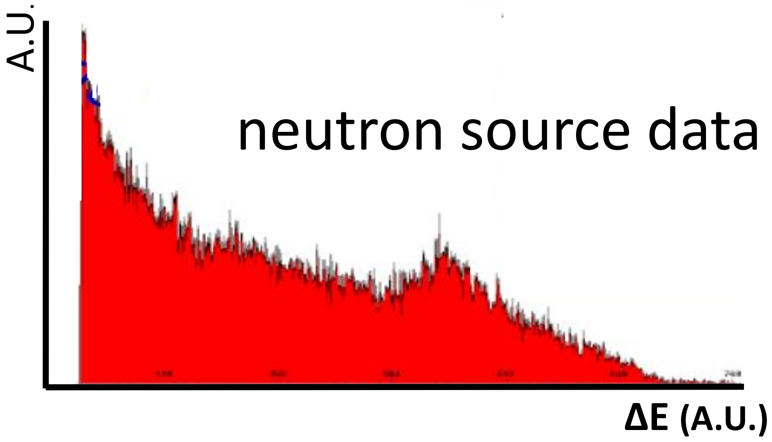
Energy response of the fast nBLM

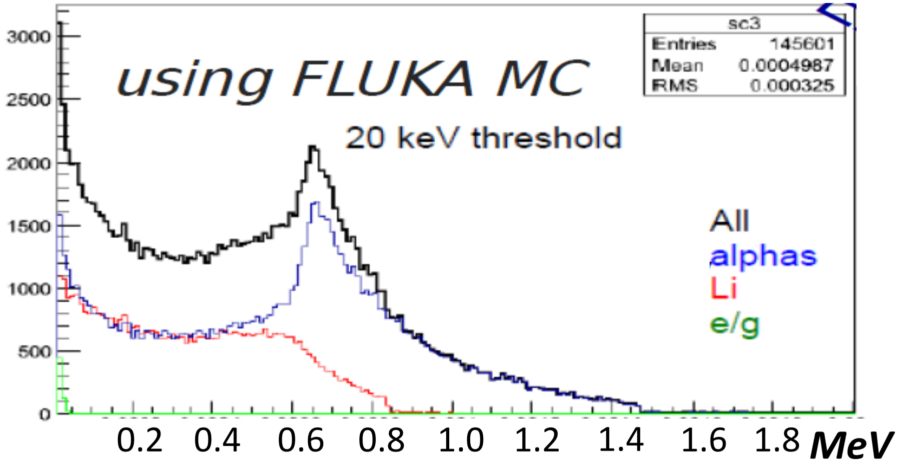


- Very good photon/neutrons discrimination
  - Threshold around 10 – 20 keV is enough to remove photon contributions

Experimental and simulation responses







- Experimental data using a Micromegas detector with one B_4C plate, placed on top of a polyethylene box with a ^{252}Cf neutron source
- Quite good agreement between ^{252}Cf source and FLUKA simulation code

Future

- Simulations are still in progress
- Prototype design will follow, as well as tests
  - neutrons
    - thermal: close to reactor
    - fast: facility like Licorne at Orsay (0.5 to 4 MeV)
  - γ's and X-rays
  - robustness, reliability, radiation hardness…
  - gas choice
  - fast and low noise FEE
  - sealed mode… already tested but need to be checked
- Foreseen to built 35 such nBLM stations for ESS, in the 3.6 to 90 MeV accelerator part
- Another nBLMs implementation is under study…

Conclusion / Summary

New kind of BLM based on Micromegas detector was simulated, exhibiting the following specifications

- good sensitivity to fast neutrons → overall efficiency ≈ 4%
- "blind" to thermal neutrons → directionality
- "blind" to X-rays and γ's → to avoid cavity photon emissions
- fast BLM component → t < 8 ns
- big neutron signal deposit (due to moderation) allows to count neutrons individually
- devoted to low energy part of beam line of high intensity accelerator facilities

Future: design prototypes and test them with real neutrons and photons before to proceed to nBLM production for ESS.

Thanks a lot for your attention

thanks to the organizers for the invitation

thanks to all my Saclay's colleagues, and also to I. Dolenc-Kittelmann & T. Shea from ESS for their fruitful discussions about BLM