Off-beam neutron background at NEAR: Status and plans

J. Lerendegui-Marco, M. Bacak, Z. Eleme, N. Patronis, C. Domingo-Pardo et al.

n_TOF Collaboration Meeting, Edinburgh, 13-14 Dec 2022

Outline

- **Review Motivation:** Cyclic activation station for (n,g) measurements at NEAR

- Summary simulations of the off-beam neutron background:
  - Initial situation
  - Improving the n-background conditions

- Experimental campaign with CR-39:
  - First experiment, and results vs simulations

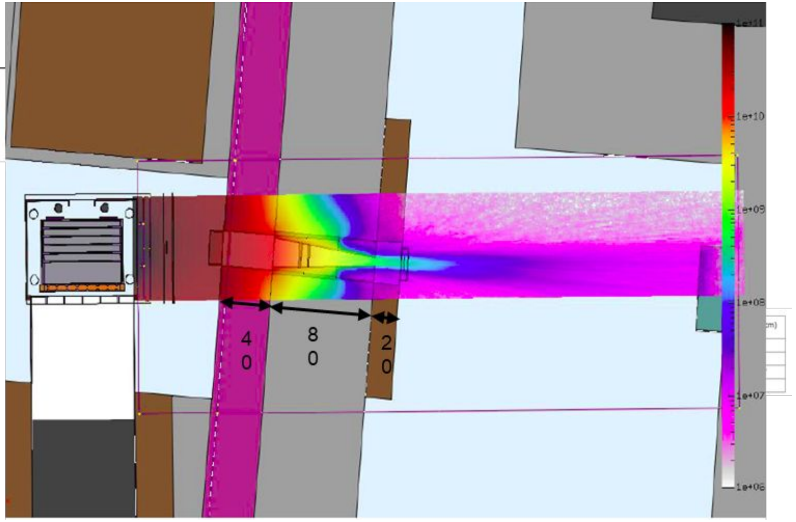
- Next steps:
  - Improving the knowledge with simulations and measurements (CR39)
  - Development & plans for campaign with active detectors

- Summary and outlook

Motivation: Cyclic activation station

Up to now: Activations via days-long irradiation + transport to HPGe @ GEAR:

- E. Stamati et al.,CERN-INTC-2022-008; INTC-P-623 (2022): benchmark with long-lived (n,g) products
- Not able to measure activation with short lived (**seconds, minutes**) (n,g) reaction products



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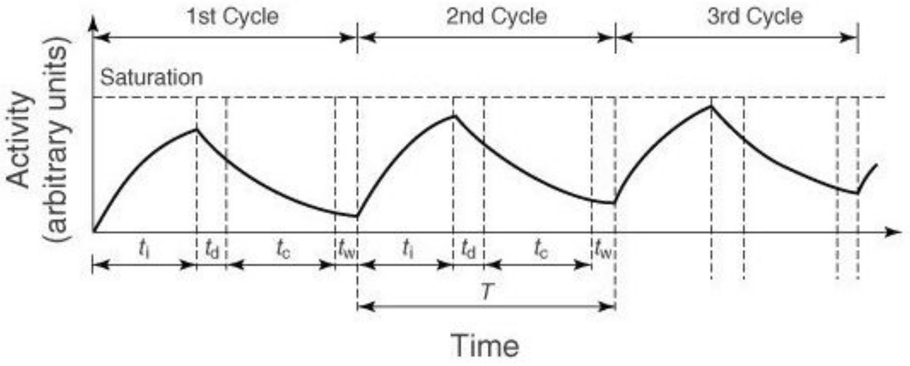
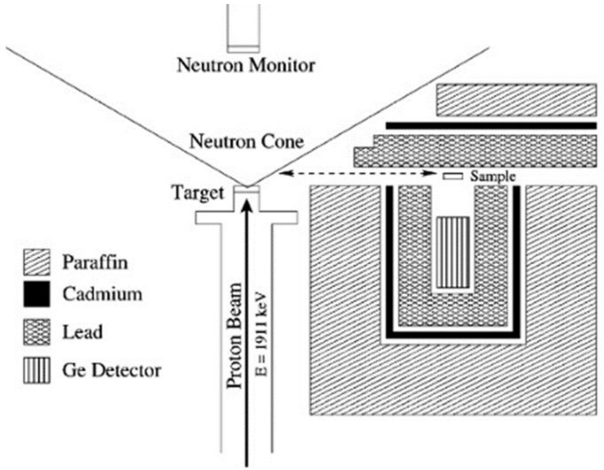
CYCLING: CYCLIc activation station for (N,G) measurements at NEAR





Setup at FZK 3.75MV Van de Graaff

Motivation: Cyclic activation station

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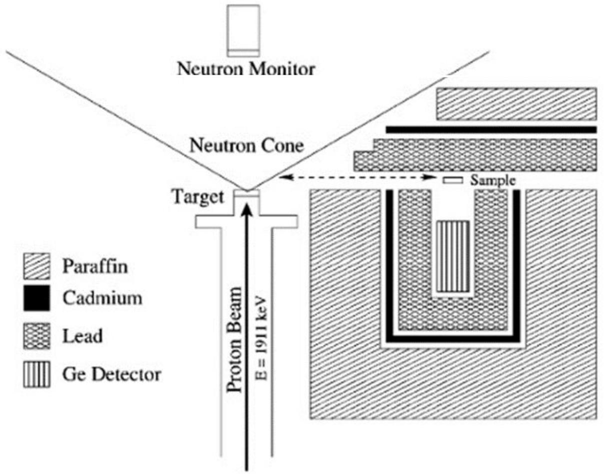
CYCLING: CYCLIc activation station for (N,G) measurements at NEAR

Rabbit systems may be an alternative / complementary solution!

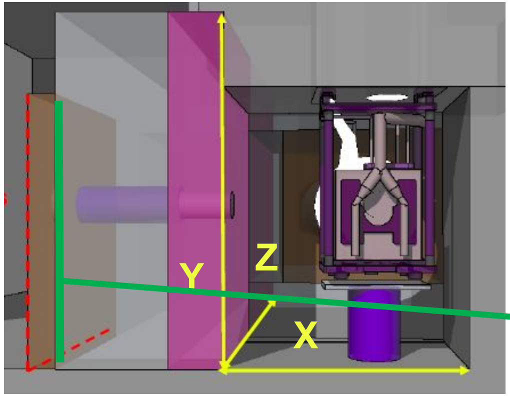


Setup at FZK 3.75MV Van de Graaff

Requisites

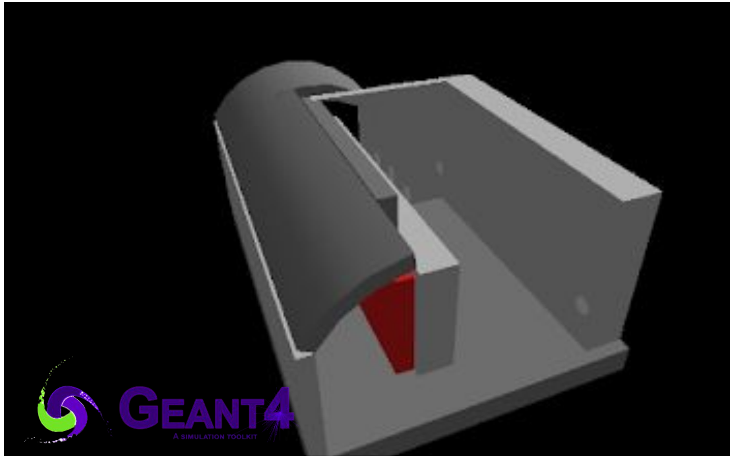
- Beam period: Rep. rate of n_TOF (max 0.8 Hz) is well suited for short lived (seconds)
- Operate a high resolution g-ray detector (ideally HPGe) in **the harsh radiation environment in the NEAR bunker**

Experimental conditions at n_TOF NEAR

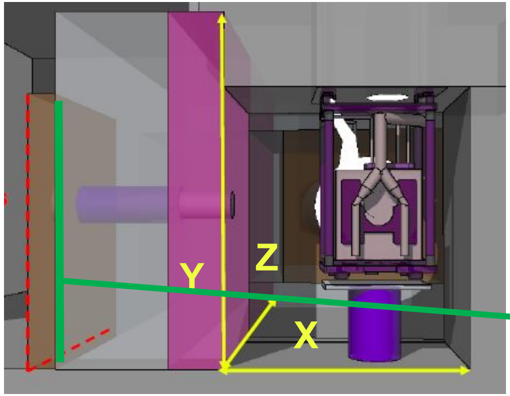


1.- **MC study** for first feasibility study & optimize the background conditions

Input: FLUKA simulations 100x100 cm scorer (interface marble-concrete)
2nd step Simulation: Carried out with Geant4 10.7.p02 + Physics List with **G4NeutronHP** for the high accuracy transport of neutrons below 20 MeV



Experimental conditions at n_TOF NEAR



1.- MC study for first feasibility study & optimize the background conditions

2.- Experimental campaign: neutron & g-ray detectors (LoI submitted INTC June)

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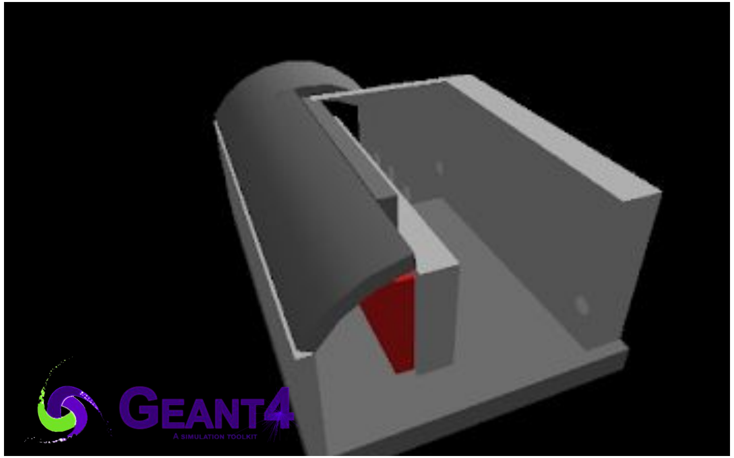

Measurement of the radiation background at the n_TOF NEAR facility to study the feasibility of cyclic activation experiments

May 4, 2022

J. Lerendegui-Marco[1], M. Bacak[2], V. Alcayne[3], D. Cano-Ott[3], A. Casanovas[4], G. Cortés[4], C. Domingo-Pardo[1], C. Guerrero[5], C. Massimi[6,7], E. Mendoza[3], A. Mengoni[8], A. Musumarra[6], N. Patronis[9], A. Tarifeno-Saldivia[1], and the n_TOF Collaboration[10]

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- **Summary simulations of the off-beam neutron background:**
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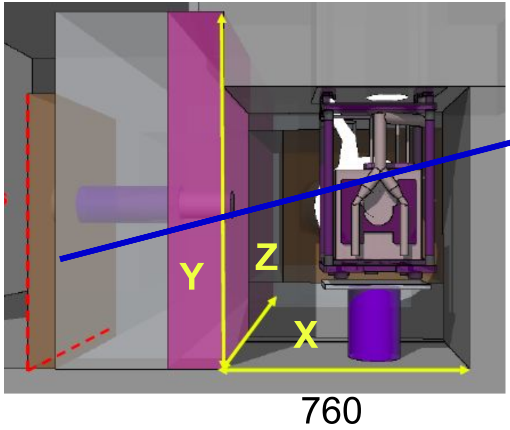
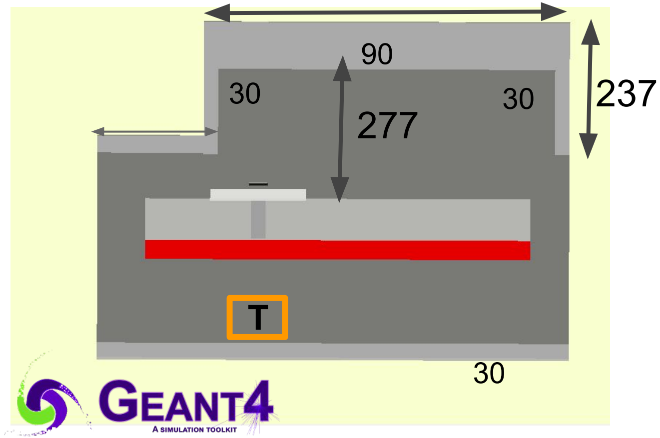
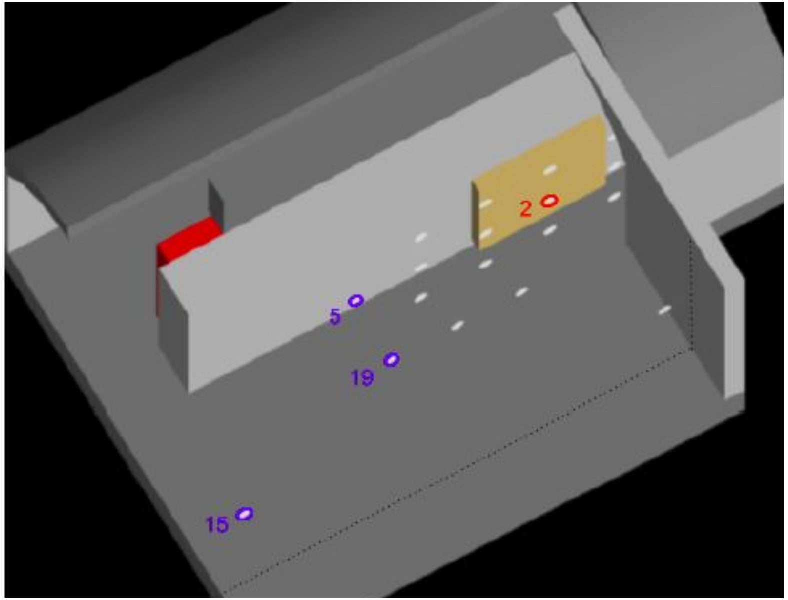
Geant4 simulations of the background



Input: Latest FLUKA simulations provided by Matteo

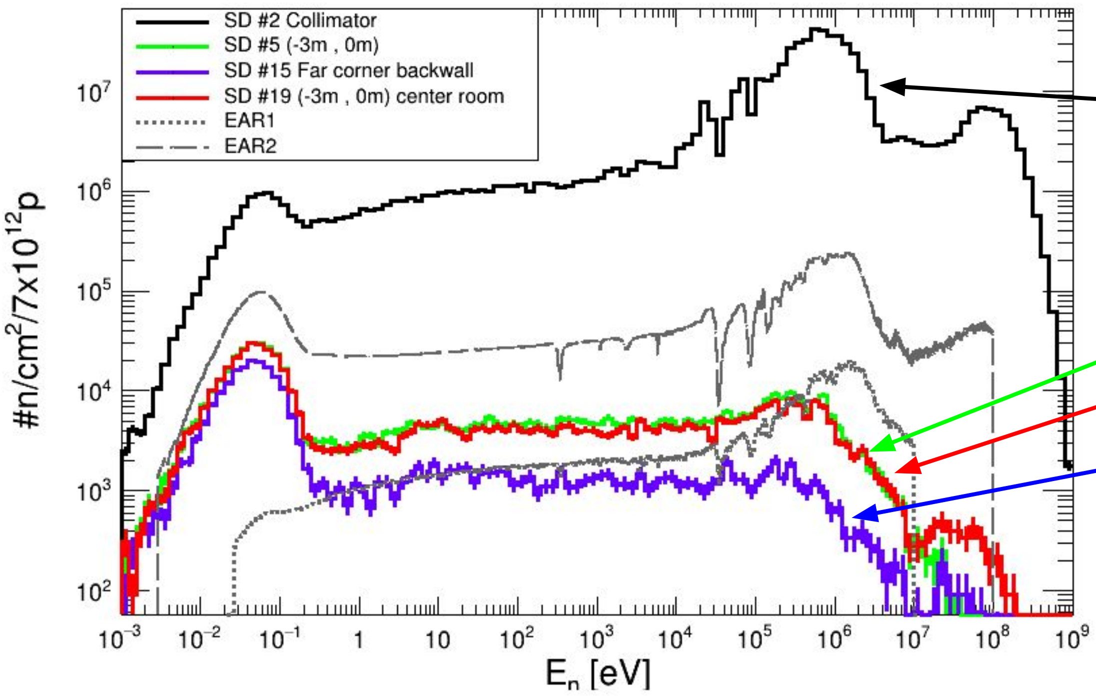
1 m radius scoring between concrete and the marble

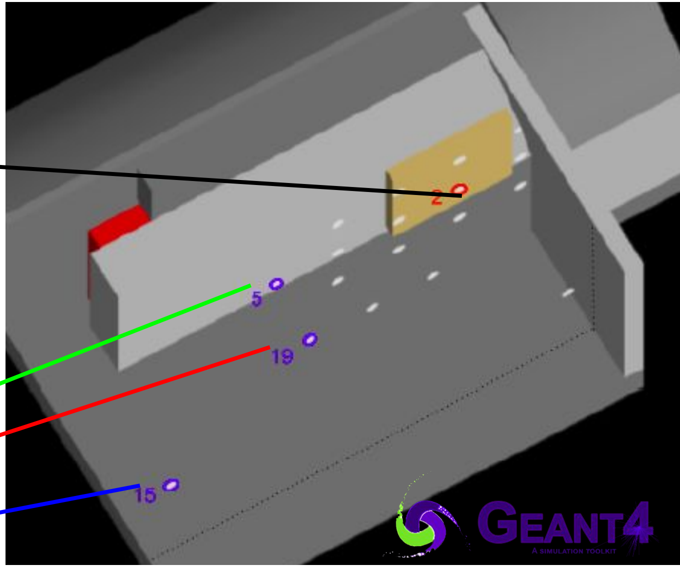




Results: **in-beam flux (2)** and the **off-beam positions with the minimum neutron flux (5, 15, 19)**

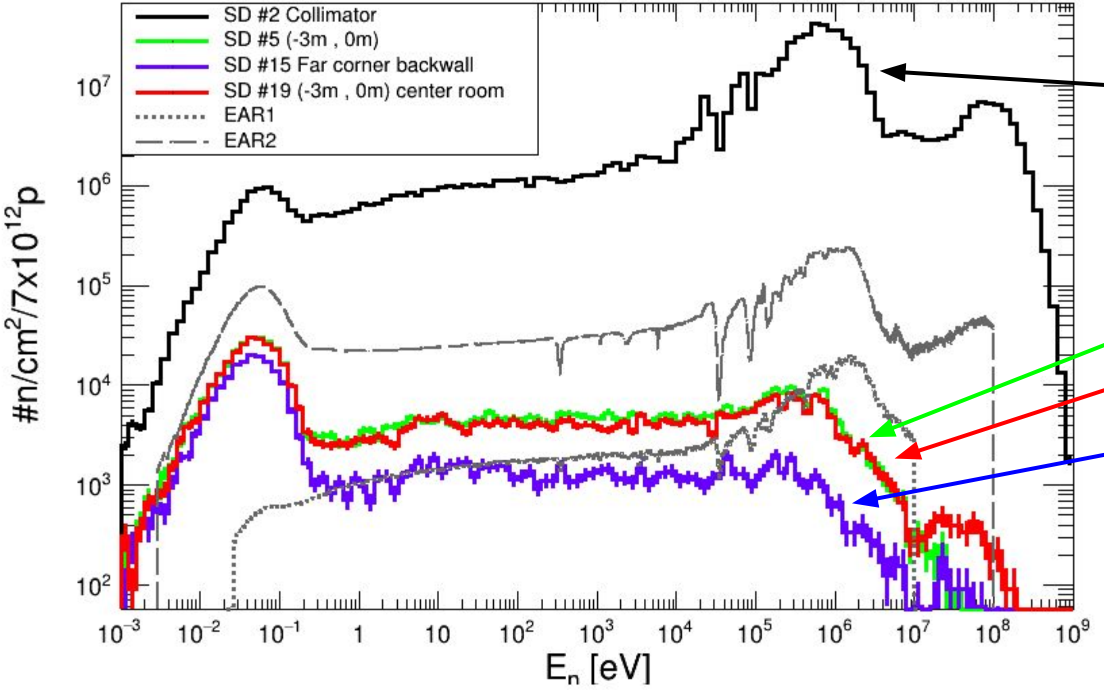
Simulations n-background @ NEAR

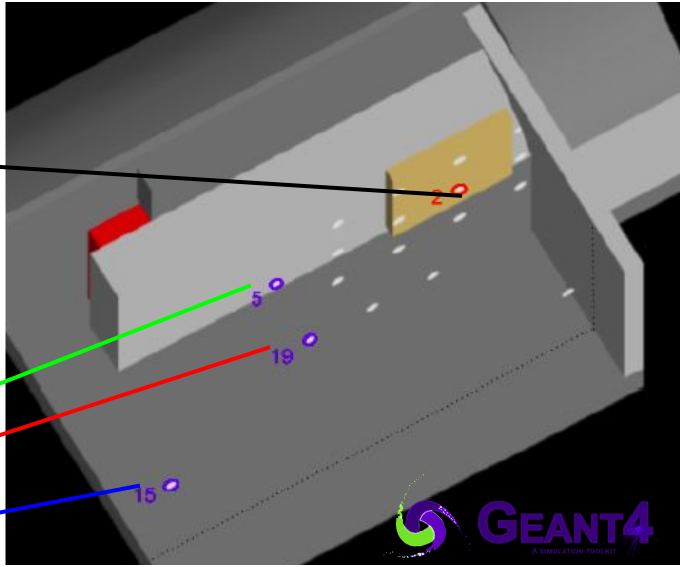




Initial situation: Minimum off-beam flux (SD 5,15,19) is similar to that of EAR1 (in-beam) or in-between EAR1 and EAR2

Simulations n-background @ NEAR





Initial situation: Minimum off-beam flux (SD 5,15,19) is similar to that of EAR1 (in-beam) or in-between EAR1 and EAR2

Can we reduce the neutron fluence far from the beam?

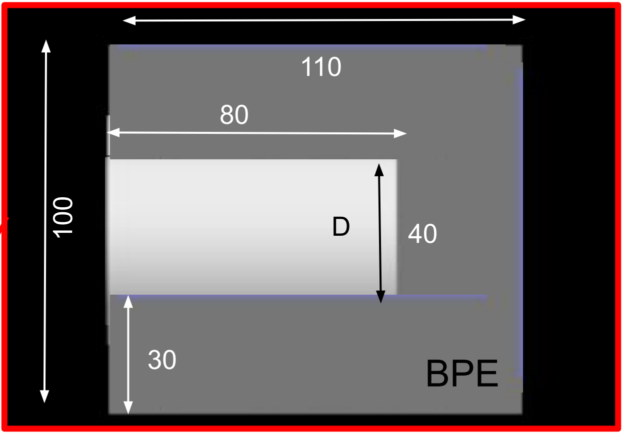
Improving the n-background?

Reduce the off-beam neutron fluence?
Evaluated the following elements

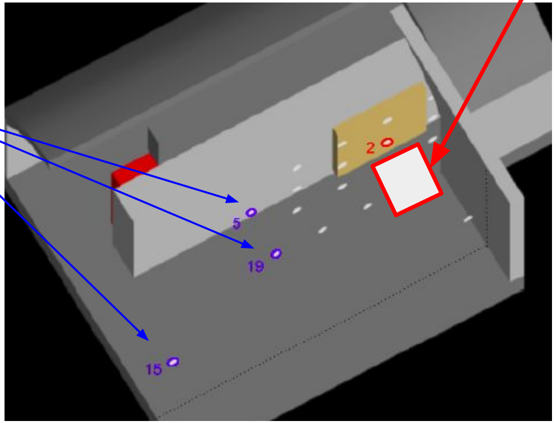
1) Neutron dump (B-PE)

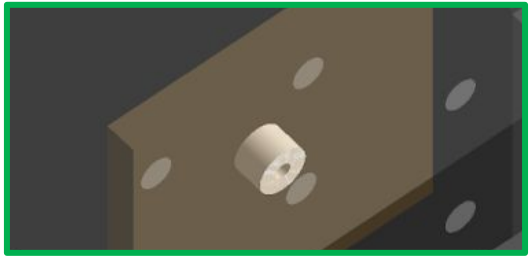
2.- Extra collimator in the hole of the marble wall (B-PE)

3.- n-absorbing shielding in the detectors (Cd or BPE)



Quantified for Scorers
#5, # 15 and #19
of minimum n-flux





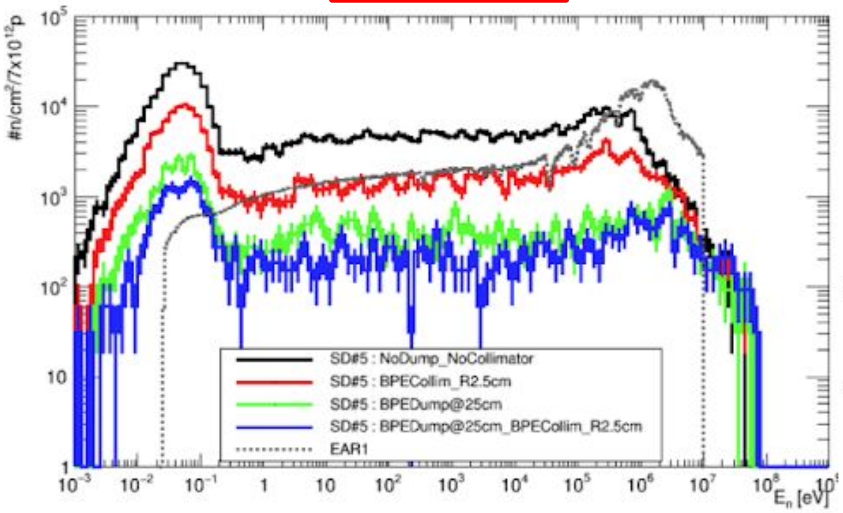
BPE, D=30mm x L=20 mm
Inner, R = 2.5 cm

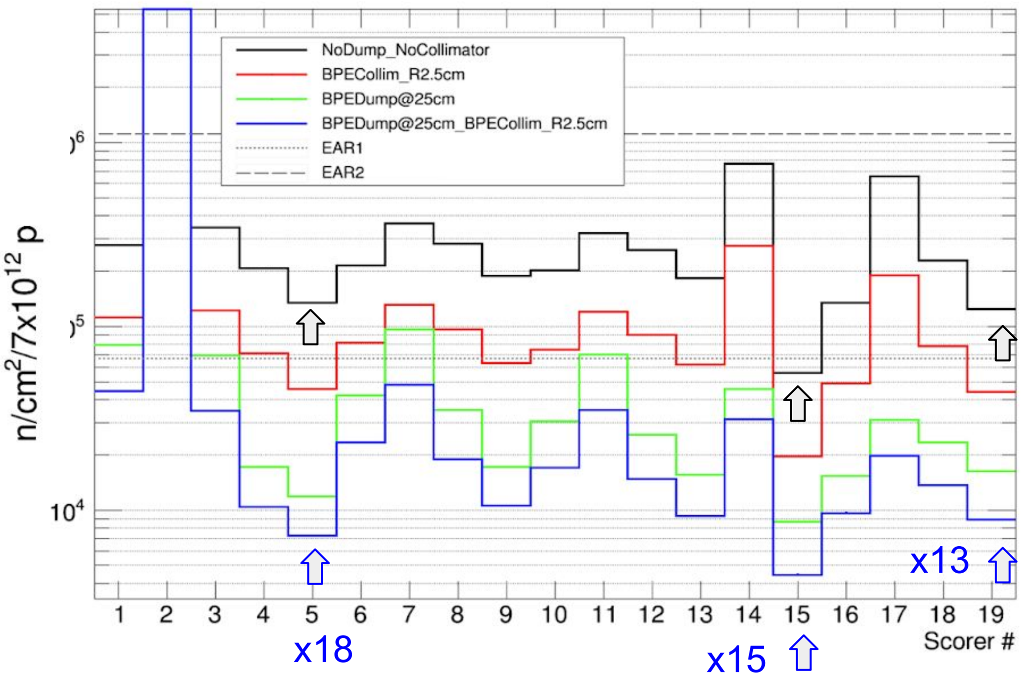
Improving the n-background: summary

1.- Neutron dump
(30 cm BPE, ~1m^3 total volume
@ 25 cm from marble)

SD #5 (-3m , 0m)

2.- Extra collimator
marble (20x30mm,
BPE, inner R=2.5cm)





Collimator + Dump works better than **only dump** and than **only collimator:**
Flux reduction in relevant positions → 15-20

Improving the n-background: summary

1.- Neutron dump
(30 cm BPE, ~1m^3 total volume
@ 25 cm from marble)

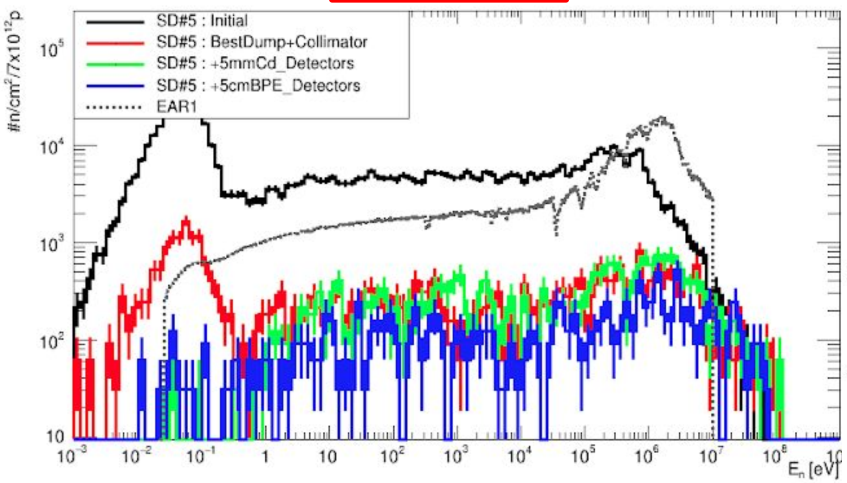
+

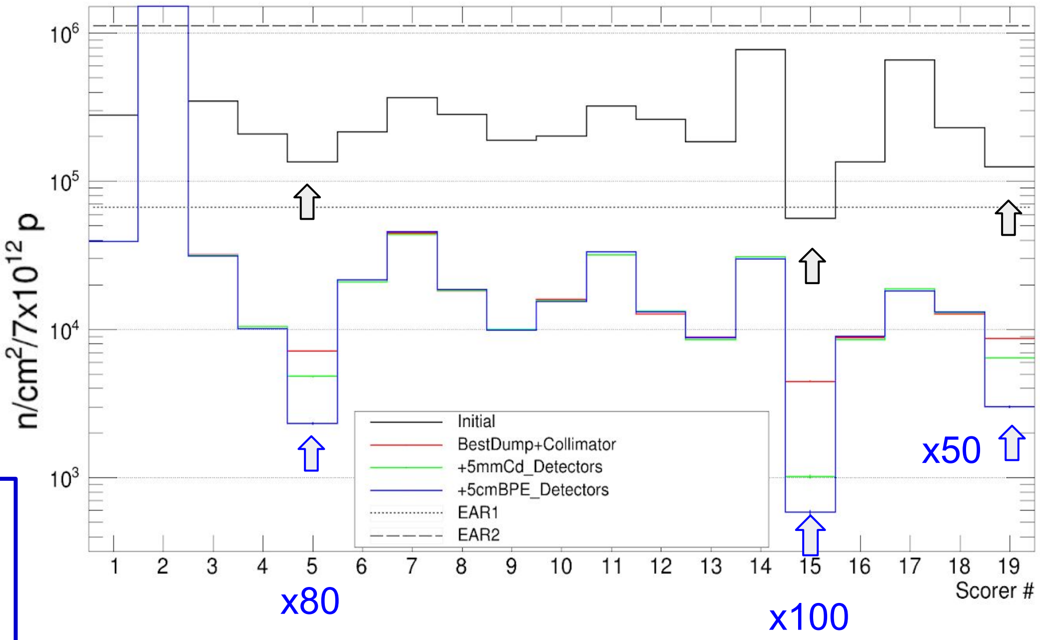
2.- Extra collimator
marble (20x30mm,
BPE, inner R=2.5cm)

+

3.- n-absorbing shielding
@ detectors (Cd or BPE)

SD #5 (-3m , 0m)





Neutron shielding @ detectors → Thermal peak removed.

Collimator + optimum dump + 5 cm BPE :

Flux reduced up to 2 orders of magnitude!!

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Proposed setup & plan

Characterization of the **neutron and γ-ray field in positions of interest** for the CYCLING station will be carried out with different **active** and **passive** detectors:

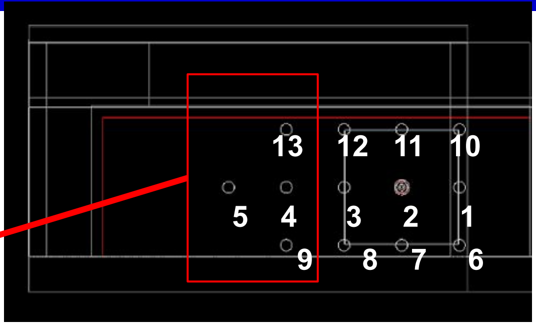
system	type	sensitivity: neutrons	sensitivity: γ-rays	comment
CR39	passive	thermal / fast	no	-
Diamond	active	thermal – fast	yes	n/γ discrimination
TARAT	active	fast	yes	n/γ discrimination and energy resolved
$LaBr_3$	active	no	yes	potential final detector
BC501	active	fast	yes	n/γ discrimination
^{3}He3	active	thermal – fast	no	-

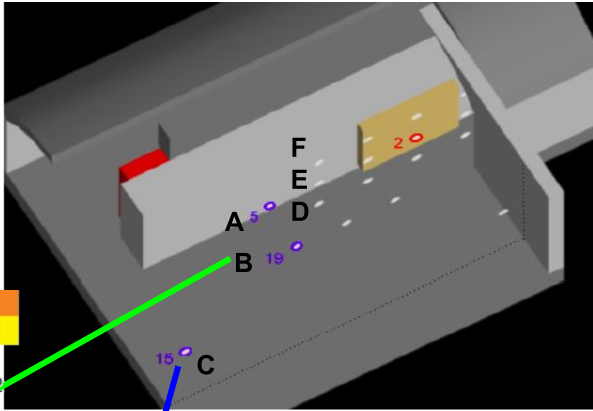
Experimental campaing

1) **2022: CR-39 passive dosimeters**
   - First comparison with the simulations → Are they realistic so far?

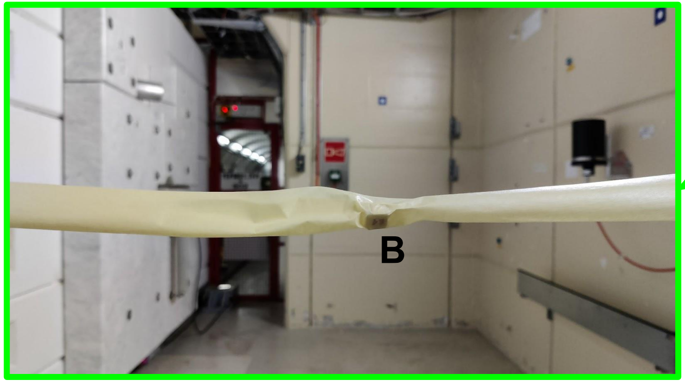
2) **2023: Active detectors**
   - Prior installation of equipment at NEAR
   - Background reduction components may be added

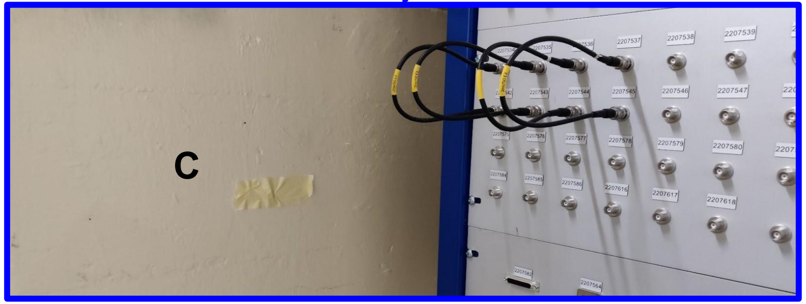
Exp. campaign with CR-39: Setup #1



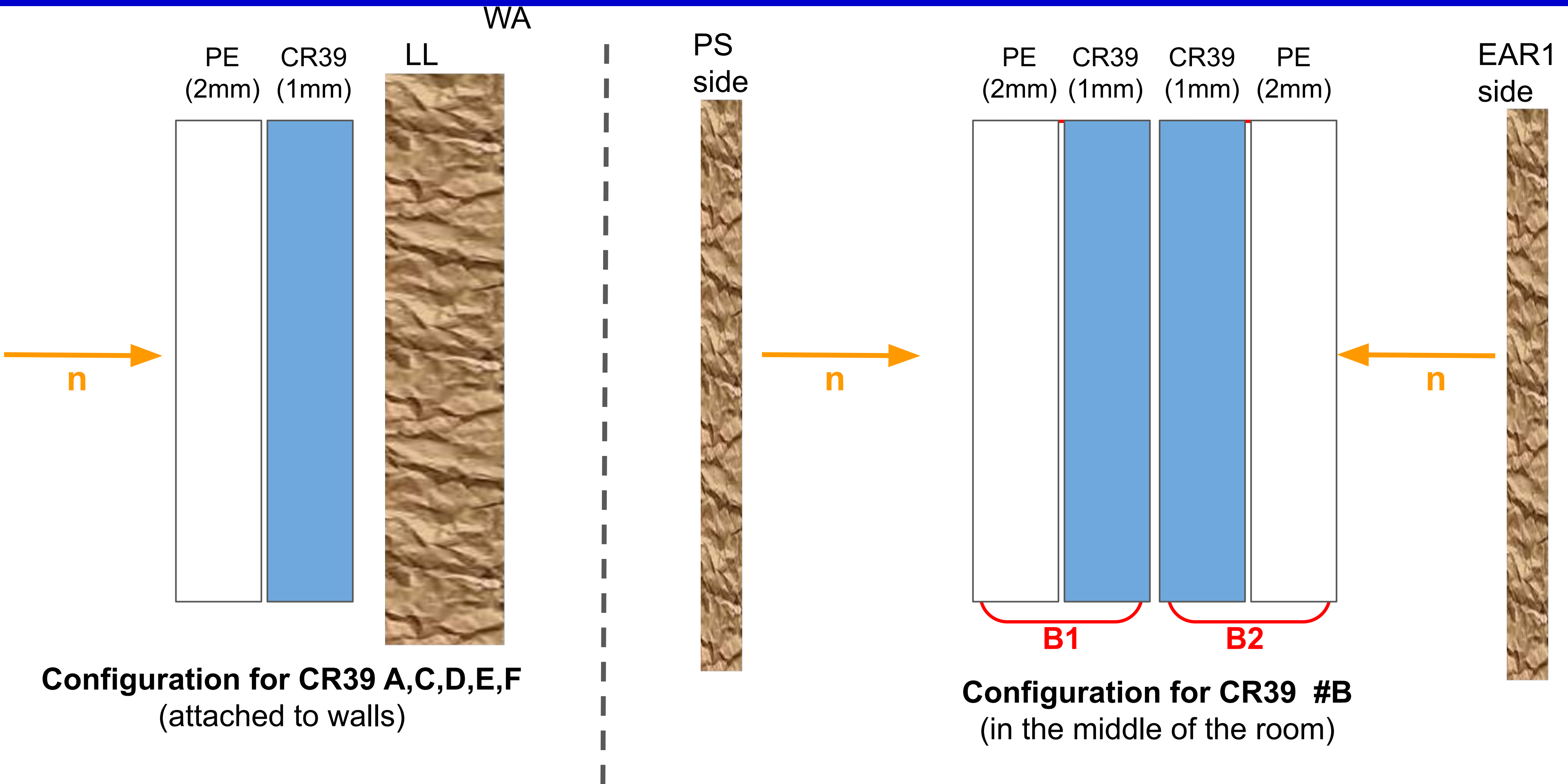


		DISTANCE FROM COLLIMATOR EXIT		
EXP. ID#	GEANT4 ID#	x (cm)	y (cm)	z (cm)
A	5	300	0	0
B	19	300	0	Z_bunker /2
C	15	X_bunker	0	Z_bunker
D	9	200	-1	0
E	4	200	0	0
F	13	200	1	0





Exp. campaign with CR-39: Setup #1

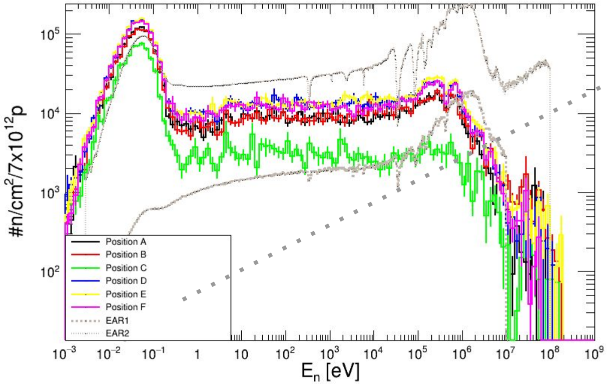


Configuration for CR39 A,C,D,E,F
(attached to walls)

Configuration for CR39 #B
(in the middle of the room)

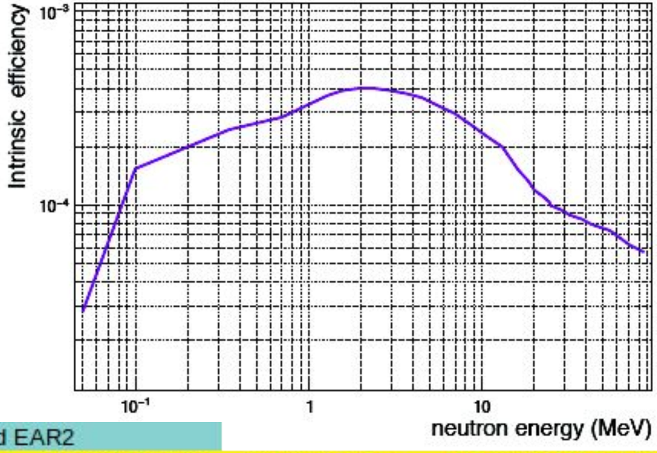
Simulations: Calculation No. Tracks

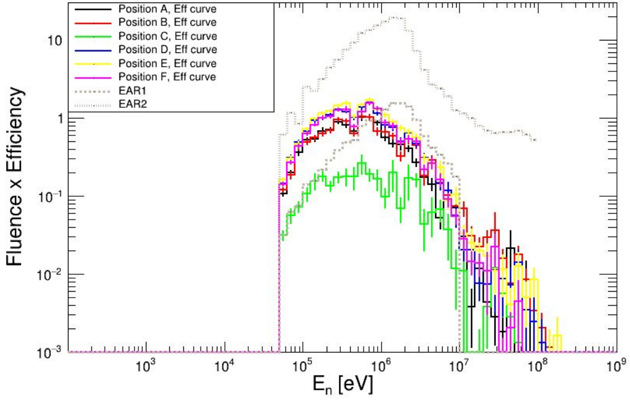
Fluence from G4 simulations



EXP. ID#	GEANT4 ID#
A	5
B	19
C	15
D	9
E	4
F	13

Efficiency curve (n-beam, N. Patronis)





RESULTS FLUENCE vs EAR1 and EAR2

Scorer/EAR	n/cm2/p(>50keV)	n/cm2/p_x_Eff	Tracks/cm2/p	Tracks/cm2(3.12e+16p)
EAR1	4.53E+04	13.63	1.022	4556
EAR2	6.61E+05	175.39	13.154	58631
A	5.29E+04	11.21	0.840	3746
B	5.63E+04	11.97	0.898	4002
C	1.32E+04	2.85	0.214	953
D	7.71E+04	16.51	1.238	5519
E	8.56E+04	18.61	1.396	6222
F	7.35E+04	15.87	1.190	5304

Opt. Field = 0.3 mm² / 4mm²

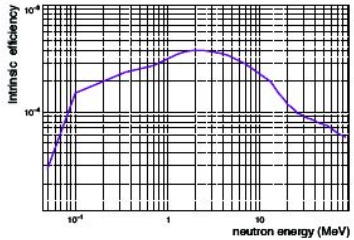
protons: 3.12E+16

CR-39 Exp. vs simulations? Validation EAR1/2

Validation: results using Evaluated Flux Ph3 + Eff. curve

EAR	Flux(>50 keV)	Flux x Eff	Tracks / pulse	Total Protons	Total tracks
EAR1	3.17E+05	95.40	7.2	9.37E+16	7183.12
EAR2	1.26E+07	3332.43	249.9	1.40E+16	37489.8

Calculated #tracks for EAR2/EAR1



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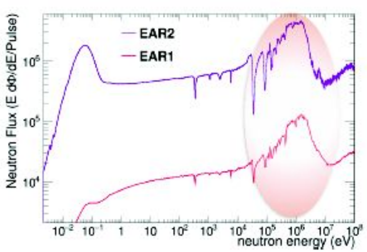
EPJA 53, p210, 2017: Marta, Massimo et al.



tracks/pulse = efficiency x neutrons/pulse x optical factor (field/step)

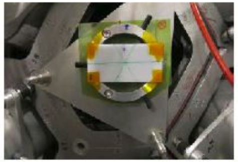
TRACKS/PULSE ("capture" collimator)	Experiment	Calculation (MC-Efficiency ✖ Evaluated FLUX)
EAR1	7	7
EAR2	170	238
Tracks Ratio (EAR2/ EAR1)	24	34

Consistent results within the accuracy of the method (~30% uncertainty)

Good agreement with N. Patronis, *EAR1 & EAR2 Beam Profile Using CR39 detectors*, Collab meeting Madrid, 2017

EAR1 "capture" collimator

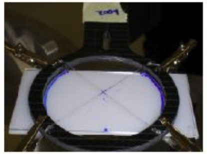
- Well centered beam (within 1 mm)
- FWHM (left to right): 15.5 mm
- FWHM (floor to ceiling): 17.2 mm
- Protons: $0.937 \cdot 10^{17}$
- # tracks (net area): $0.94 \cdot 10^{5}$



EAR2 "capture" collimator

Previous results

- Well centered beam (within 2-3 mm)
- FWHM (west to east): 23 mm
- FWHM (north to south): 21 mm
- Beam diameter at sample holder: ~40 mm
- Protons: $1.4 \cdot 10^{16}$
- # tracks: $3.4 \cdot 10^{5}$



Fair match with Exp. total tracks (Net A)
Tracks/bunch x No. bunches

CR39 Exp. vs simulations? Results NEAR

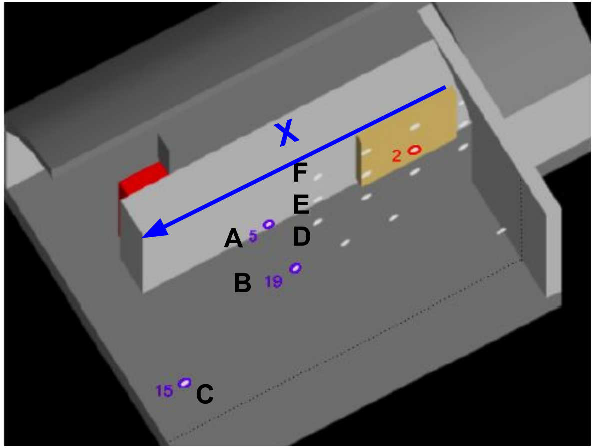
AVERAGE	CR-39 position	Experimental	Sim. Fluence	Sim. Flux	RATIO fluence
A	A	1760	150	80	11.742
B_1	B_1	1883	160	72	11.764
B_2	B_2	1980	160	72	12.367
C	C	2376	38	14	62.316
D	D	1596	221	134	7.228
E	E	1925	249	155	7.732
F	F	1629	212	128	7.680

Analysis CR39: Zina Eleme

Absolute numbers are at least a factor 7 wrong!

RATIO TO A	Experimental	Simulations
A	1.000	1.00
B_1	1.070	1.07
B_2	1.125	
C	1.350	0.25
D	0.907	1.47
E	1.094	1.66
F	0.926	1.42

RATIO TO E	Experimental	Simulations
A	0.914	0.60
B_1	0.979	0.64
B_2	1.029	
C	1.235	0.15
D	0.83	0.89
E	1.000	1.00
F	0.85	0.85



- Ratio **A/B, F/E & D/E** are **fairly good reproduced.**
- **Neutron fluence vs X** decreases in simulations but remains stable or increases experiment → **Indication: important sources of neutrons along the wall?**

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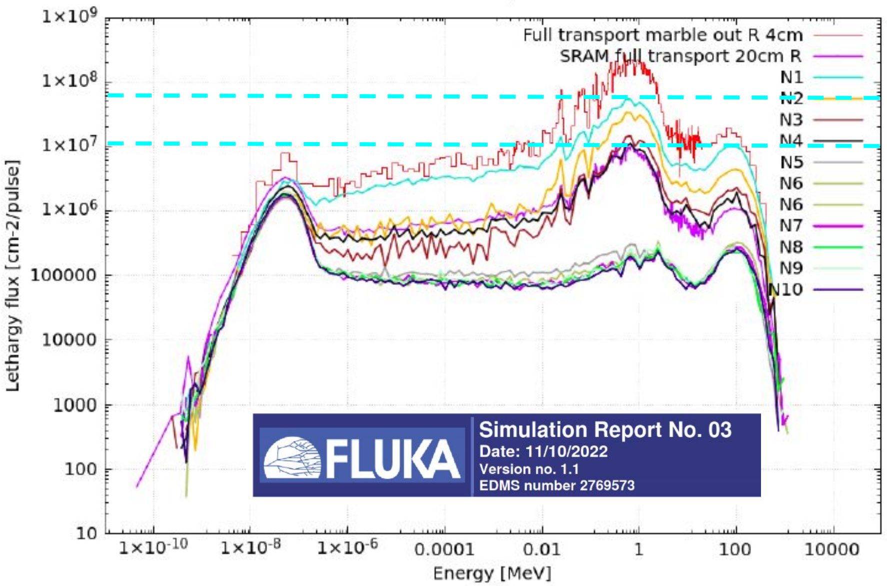
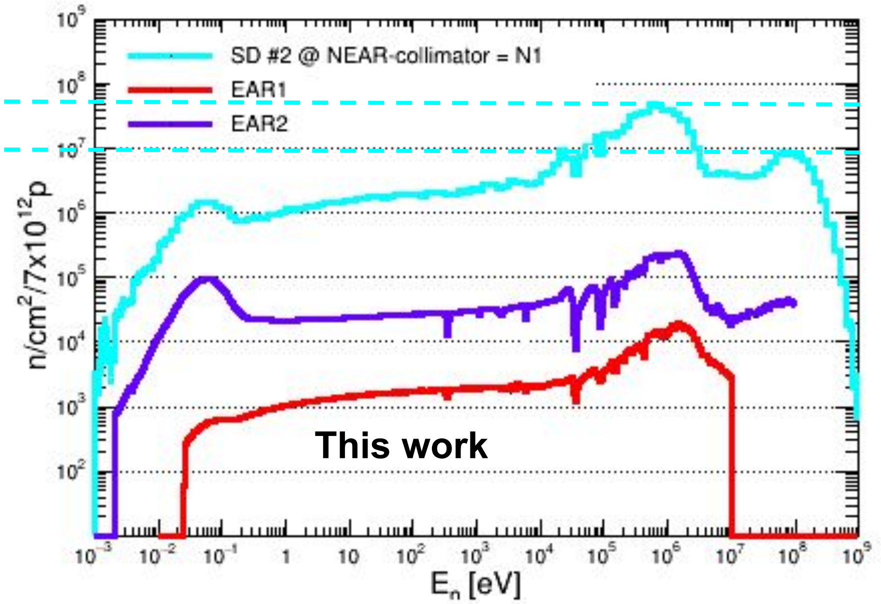
Next steps: Understanding the CR39 results

Checks up to now:

- Error in the simulation? (primaries, normalization, resampling, …) → **NO**
- Efficiency of the CR-39 →**Isotropic neutron field vs n-beam** does not change > 60-80% → **NO**
- Error in the calculation → No. tracks are consistent with NEAR fluences vs EAR1 /EAR2 → **NO**





- **Neutron flux at the exit of the marble agrees with the latest FLUKA results → No error in the simulations.**
- **Additional sources (whole shielding wall) are needed to reproduce the flux far from the collimator.**

Next steps: Understanding the CR39 results

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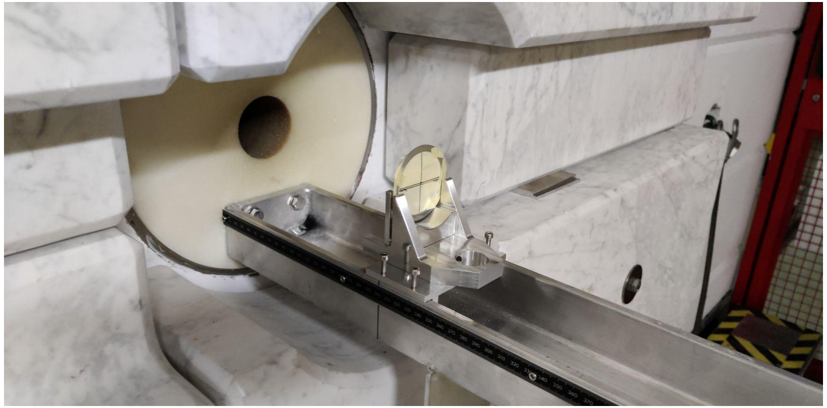
- Efficiency of the CR-39 →**Isotropic neutron field vs n-beam** does not change > 60-80% → **NO**
- Error in the calculation → No. tracks are consistent with NEAR fluences vs EAR1 /EAR2 → **NO**

Next steps: Second experimental campaign with CR39 (finished, not yet analyzed)

- CR 39s at the gap located at the end of the shielding → Important n-source?
- CR39s at collimator→ neutron beam → Check if reproduced by simulations (as EAR1 and EAR2)
- Response of the CR-39 without PE converter (neutrons & other particles) and with PE on either side



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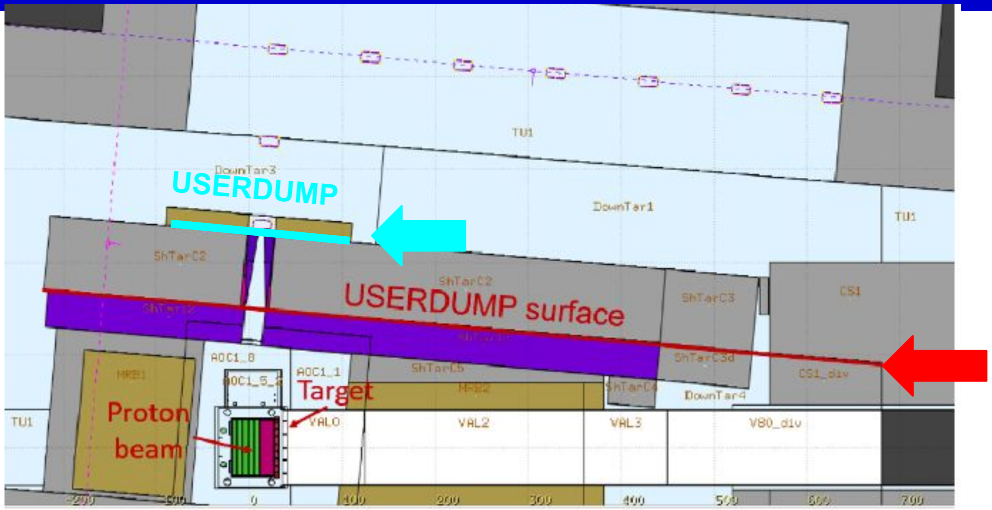
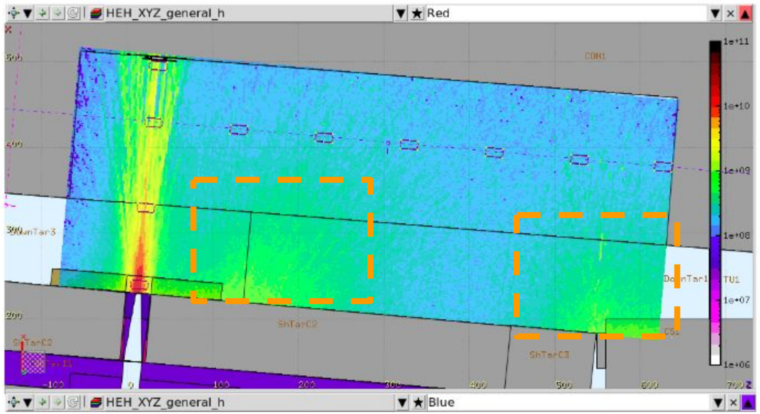


FLUKA
Date: 11/10/2022
Version no. 1.1
EDMS number 2769573



n emission not only from collimator + not homogenous →
→Consistent with the larger discrepancy
far from the collimator

HE neutrons:
Important sources not included up to now!
→ **Relevant for CR39 response!**

Next steps: More realistic FLUKA Input

- Improving the knowledge on the geometry
- New scoring plane (**USERDUMP surface**) to be used instead of the current (**USERDUMP**)
- Simulations already finished (**by Matteo, available since one week only**)

Outline

- Review Motivation: Cyclic activation station for (n,g) measurements at NEAR
- Summary simulations of the off-beam neutron background:
  - Initial situation
  - Improving the n-background conditions
- Experimental campaign with CR-39:
  - First experiment, and results vs simulations
- **Next steps:**
  - Improving the knowledge with simulations and measurements (CR39)
  - Development & plans for campaign with active detectors
- Summary and outlook

Technical requirements: Status

DACQs, signals & HV (Michi):

- Long **cables** available and tested for noise / losses ✓
- **DAQs:**
  a. Some detectors may have standalone DAQs ✓
  b. n_TOF DACQ with SPD:
     i. hardware is available (in pieces): need to assemble (**YETS**)
     ii. card swaps between the DACQs: to be done (**YETS**)
     iii. set up of the software to accept a 4th DACQ: to be done (**YETS**)
- **PS Trigger**: to be done (**YETS**)

Cables for tests @ e-Lab

Patch panel NEAR:
2x ~100 m connections

Technical requirements: Status

DACQs, signals & HV (Michi)

Access to NEAR: Discussed with RP

- Max. cool-down time after hours of beam : **4 hours**
- If only 2 min of beam → Cool-down time **reduced to 30 min**

Shielding elements 1st campaign with active detectors:

- Borated PE layers & Lead bricks (detector dependent)
- Extra Collimator in the marble hole → Possible to be prepared in the **YETS**
- Other possible shielding elements **under study**

Setups and planning: Status

Detector availability & requirements:

- **TARAT:** Detector at CERN, mobile CAEN digitizer. Contact: A. Musumarra.
- **Diamond**: In parallel with exp. campaign in-beam(M. Diakaki, M. Bacak), probably early next campaign Has its own DACQ. Contacts: E. Griessmeyer and C. Weiss.
- **He-3**: Discuss results of the simulations and CR39 doses to estimate the response. Contact: A. Tarifeño (IFIC)
- **Others**:
    a. Fast & small scintillators with n/g discrimination (EJ-200, EJ-301). Groups: CNA-Sevilla, CIEMAT,...
    b. Small $LaCl_3$, stilbene (Group: IFIC)

Dates & planning of the campaign:

- No final planning or final dates for any of the setups
- **MEETING WILL BE ORGANIZED SOON**

Summary & outlook

- **NEAR** + **Cyclic activation: (n,γ) via activation products with short half-lives (s, min)**

- NEAR : harsh radiation conditions, especially during beam-on periods. **Characterization of the background** is required → Feasibility to use active detectors.

- **Neutron background conditions expected at NEAR** were studied with MC simulations. The initial neutron off-beam fluence is **between EAR1 and EAR2 (in-beam).** With suitable combinations of a simple **BPE dump + extra collimator + n-absorbers** it could be **reduced up to a factor 100.**

- 1st **experimental campaign with CR39:**
    - Exp. Results vs simulations: Neutron background far from the collimator is underestimated in at least a factor ~6 →relevance of neutron sources along the shielding wall + gap at the end of the wall.
- **Next steps:**
    - 2nd experimental campaign: Also dosimeters in-beam + in the gap at the end of the shielding
    - Simulation input from FLUKA with Improved accuracy.
    - Preparation of the **first experimental campaign** with active detectors (LOI INTC June):
        - Ready or in YETS: long cables, n_TOF DACQ, Signal PS trigger
        - Short irradiations → access after 30 min
        - Simple shielding elements and background reduction elements (extra collimator) → YETS

THANK YOU FOR YOUR ATTENTION!