Simulazione Gemc dei raggi cosmici e analisi dei fasci secondari per l'esperimento nuBDX-mini

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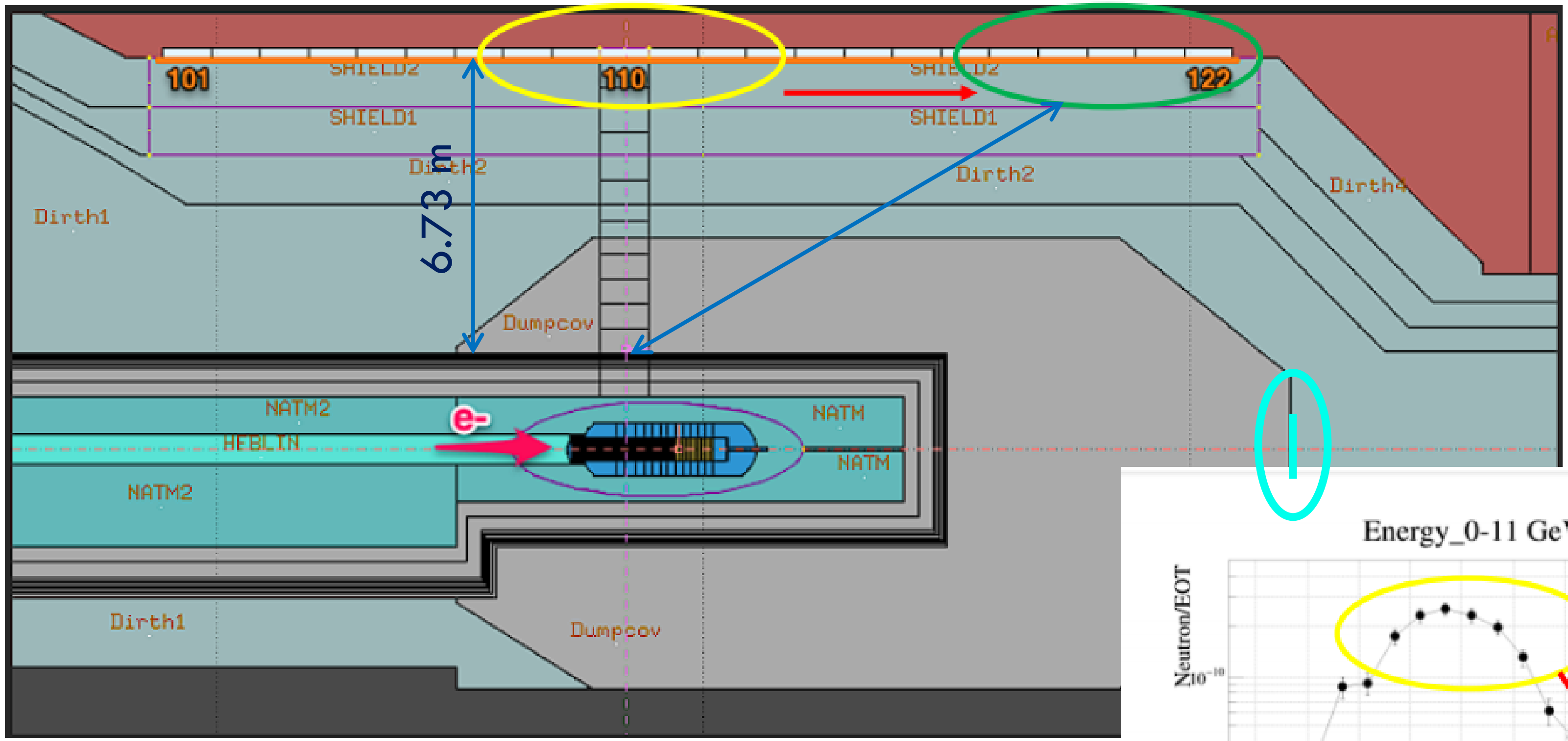
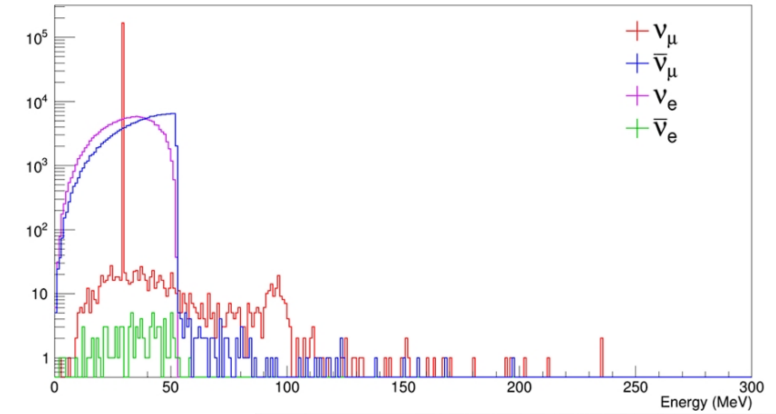
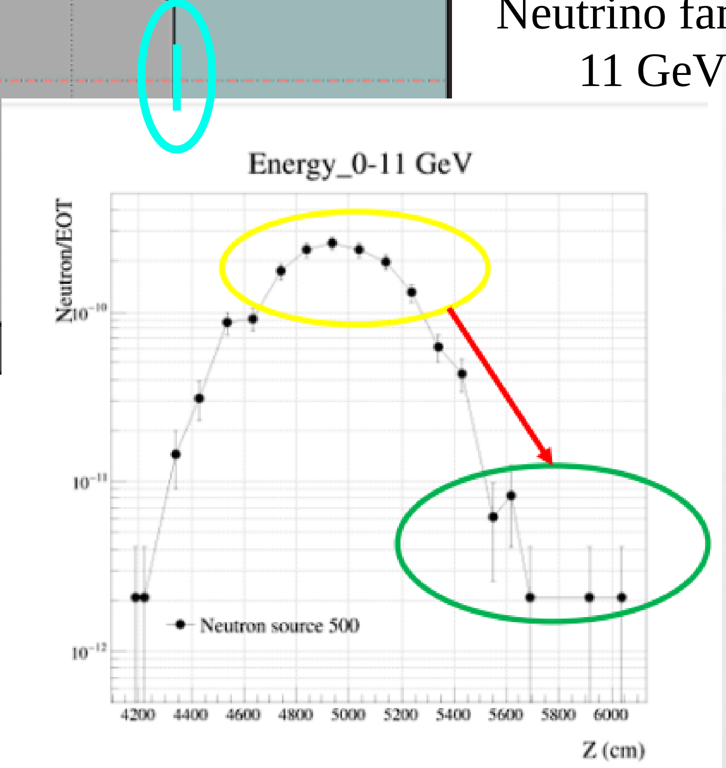
DETECTOR POSITION





Neutrino family spectrum produced by 11 GeV electron beam at JLab



Relocate the detector to reduce the neutron background

-> 2 order of magnitude less n-yield

-> only a factor of 2 reduction for ν

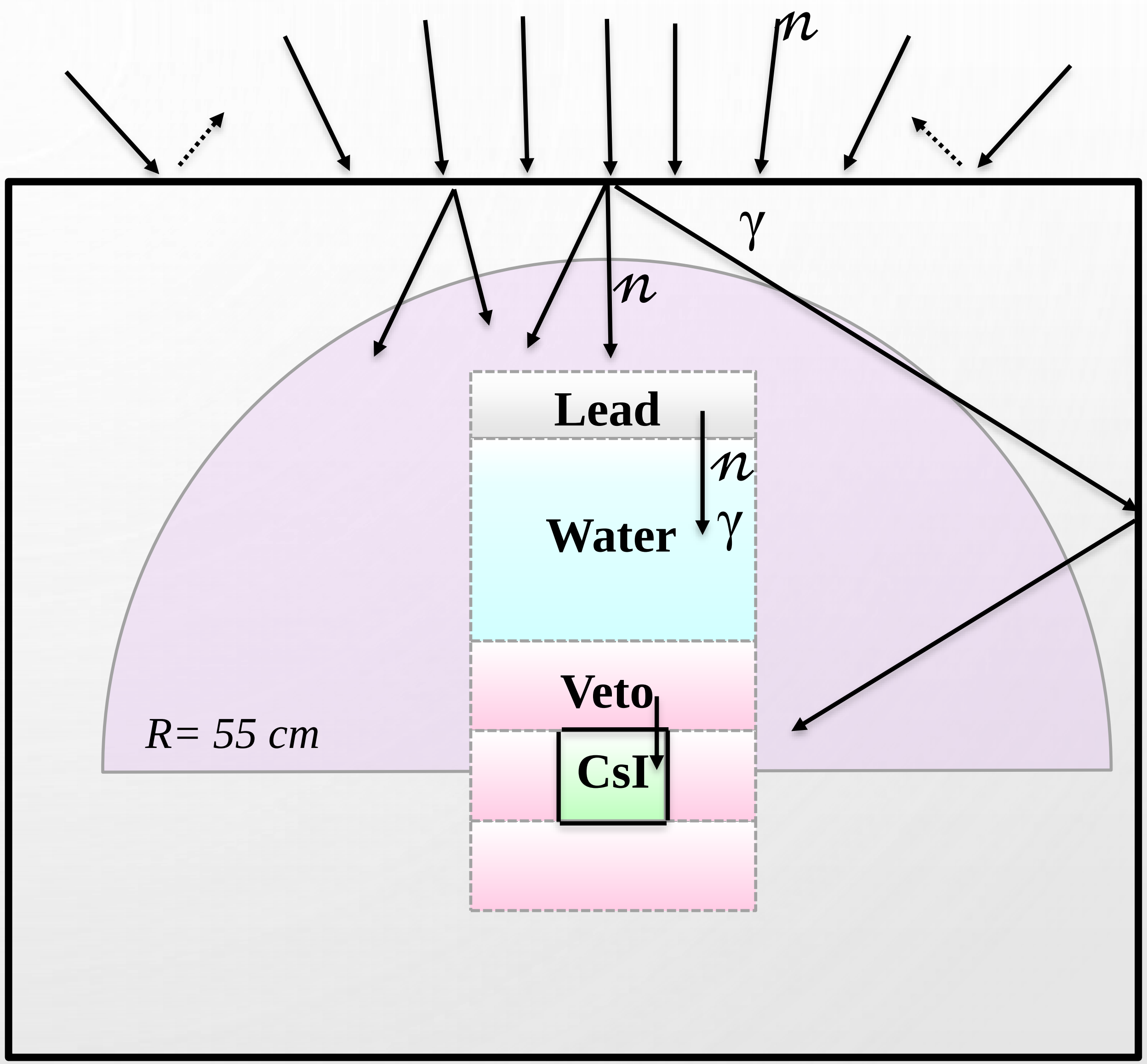
$\nu = \ 10^{18}\ vs. 5 \cdot 10^{17}$

COSMIC RAYS' BACKGROUND

Energy range	$^{neutrons}/_{cm^2 s}$	$^{neutrons}/_{m^2 day}$	*neutrons generated*
1 meV-1 eV	$2 \cdot 10^{-3}$	$1{,}64 \cdot 10^{6}$	$2 \cdot 10^{6}$
1 eV- 1keV	$1{,}43 \cdot 10^{-2}$	$1{,}17 \cdot 10^{7}$	$2 \cdot 10^{7}$
1keV-1MeV	$1{,}43 \cdot 10^{-2}$	$1{,}17 \cdot 10^{7}$	$2 \cdot 10^{7}$
1-2 MeV	$1{,}43 \cdot 10^{-3}$	$1{,}18 \cdot 10^{6}$	$2 \cdot 10^{6}$
2MeV- 100MeV	$3{,}06 \cdot 10^{-3}$	$2{,}51 \cdot 10^{6}$	$3 \cdot 10^{6}$
100-1000MeV	$1{,}54 \cdot 10^{-3}$	$1{,}27 \cdot 10^{6}$	$2 \cdot 10^{6}$
1GeV-10GeV	$7{,}8 \cdot 10^{-5}$	$6{,}4 \cdot 10^{4}$	$7 \cdot 10^{4}$
Total	$3{,}67 \cdot 10^{-2}$	$3{,}01 \cdot 10^{7}$	$5 \cdot 10^{7}$

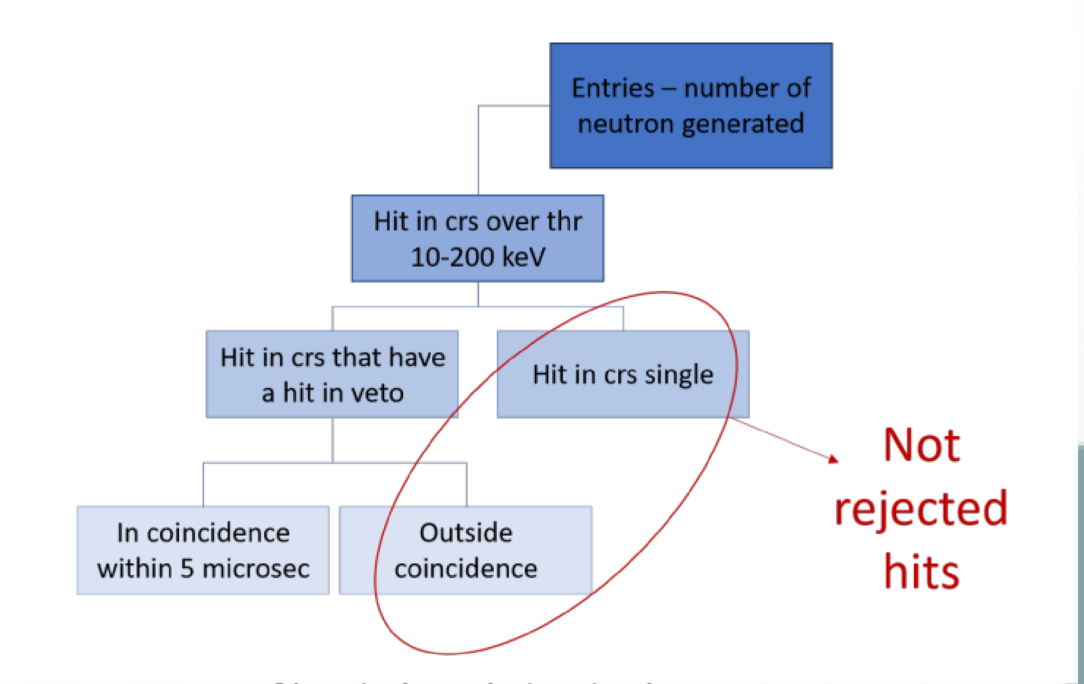
Calculate hits from cosmic neutrons not distinguishable from neutrinos.
Conditions: E_{dep}= 10-200 keV
Coincidence between veto and crystal less than 5 µs

Tasks:
Reduce the number of nonremovable hits
Minimize the thickness of layers (with preference to active shielding)



Cosmic neutrons

Range	Nentries	hit in veto	hit in crs	Rate hit/s in veto	Rate hit/s in crs
1 meV-1 eV	2,29E+06	113.766	36.127	1,319	0,419
1 eV- 1keV	1,62E+07	3.162.925	299.127	36,910	3,491
1keV-1MeV	1,64E+07	1.938.145	267.347	22,405	3,091
1-2 MeV	1,64E+06	81.183	25.640	0,942	0,297
2MeV- 100MeV	3,51E+06	158.664	54.121	1,834	0,626
100-1000MeV	1,77E+06	73.666	26.327	0,853	0,305
1GeV-10GeV	8,95E+04	4.560	1.461	0,053	0,017
	4E+07	**5.532.909**	**710.150**	**64,3**	**8,2**



$$\text{RATE} = \frac{Nentries\ detected}{Nentries\ generated} \cdot flux \cdot surface$$

Cosmic muons

Range	Nentries	hit in veto	hit in crs	Rate hit/s in veto	Rate hit/s in crs
200MeV-2Gev	9,02E+06	4.103	1.628	0,05	0,02
2GeV-10GeV	8,31E+06	339.599	132.446	3,93	1,53
10-100 GeV	2,88E+06	116.159	45314	1,34	0,52
100-500 GeV	6,08E+05	2.379	905	0,003	0,001
	2,08E+07	4,62E+05	1,80E+05	5,21	2,03

Surface of the sphere = 13’273,2 cm²

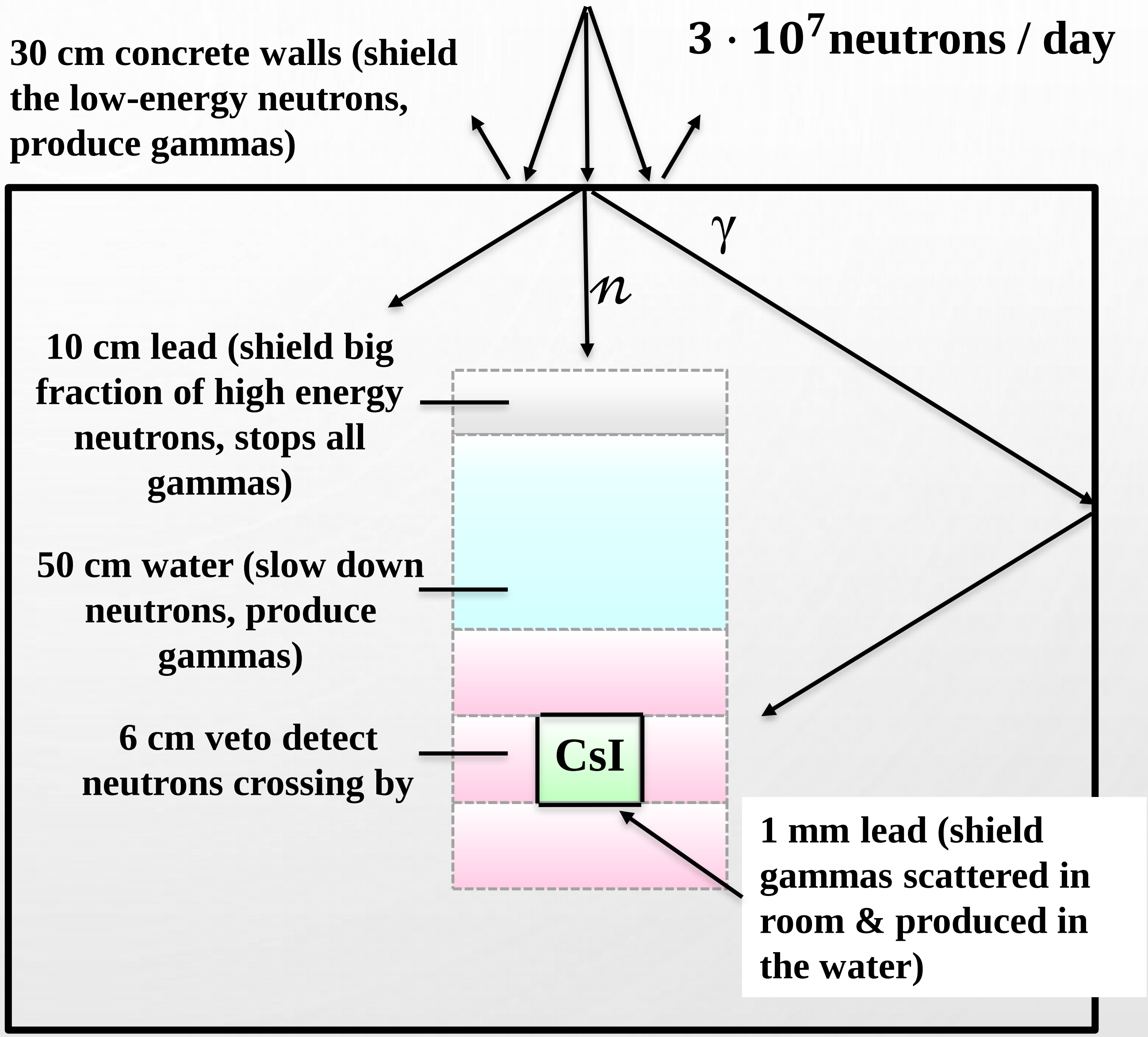
SHIELDING DESIGN

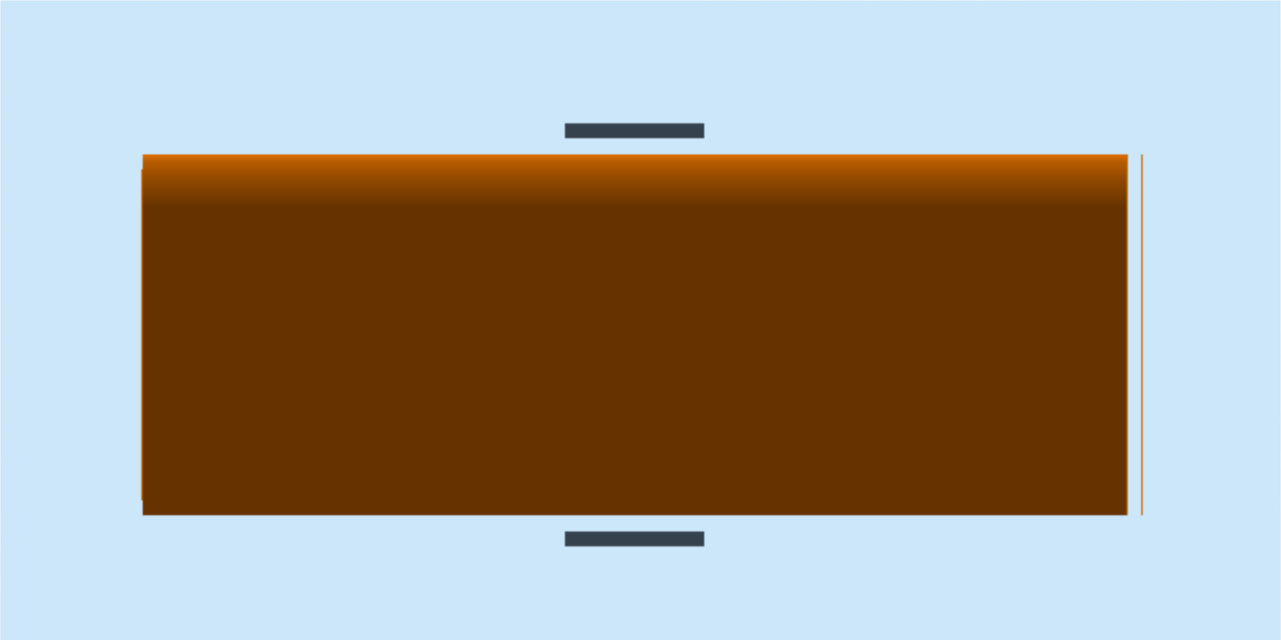
thr 1 MeV	Neutron single hit in crystal	Gamma single hit in crystal	Neutrons outside 5 µs coincidence	Gammas outside 5 µs coincidence	**hits not removable expected in a day**
1cm Pb	1832	37	420	89	**1510**
1cm Al	1816	38	401	92	**1493**
10cmLead 50cmWater	832	166	165	98	**804**
50cmWater 10cmLead	1042	364	30	41	**708**

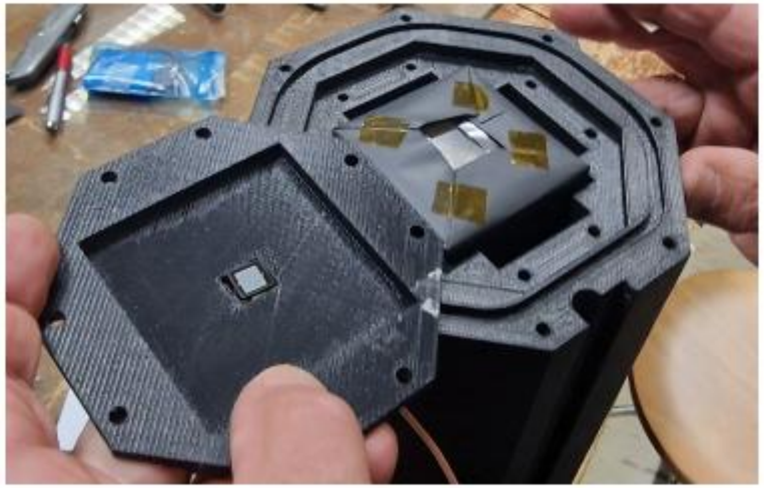
1 cm of lead (aluminium etc.) around crystal shields almost all gammas but increase neutron number.

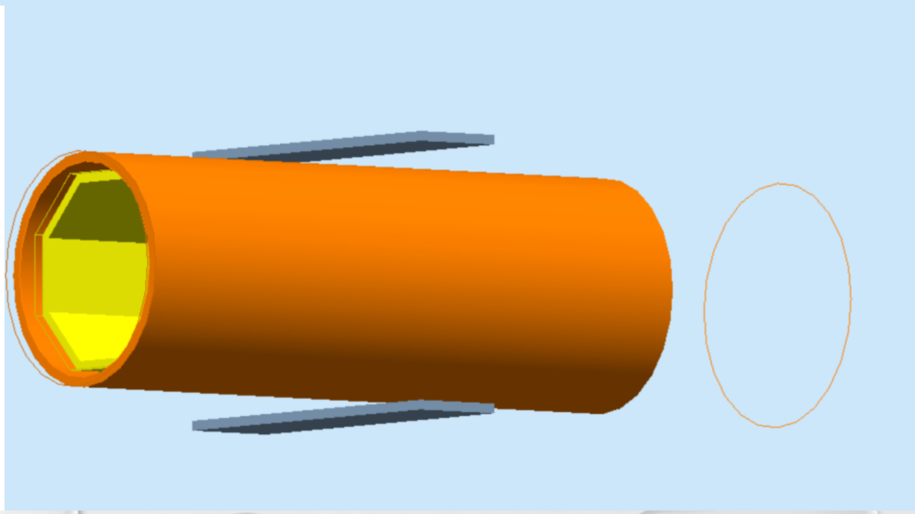
Composition	Total hits not removable in a day
6cm Veto 50 cm water 10 cm lead	1722
6cm Veto 50 cm water 5 cm lead	1832
1mm lead, 6cm Veto, 5cm lead 50cm water	936
1 mm lead 6cm Veto 55 cm lead	490

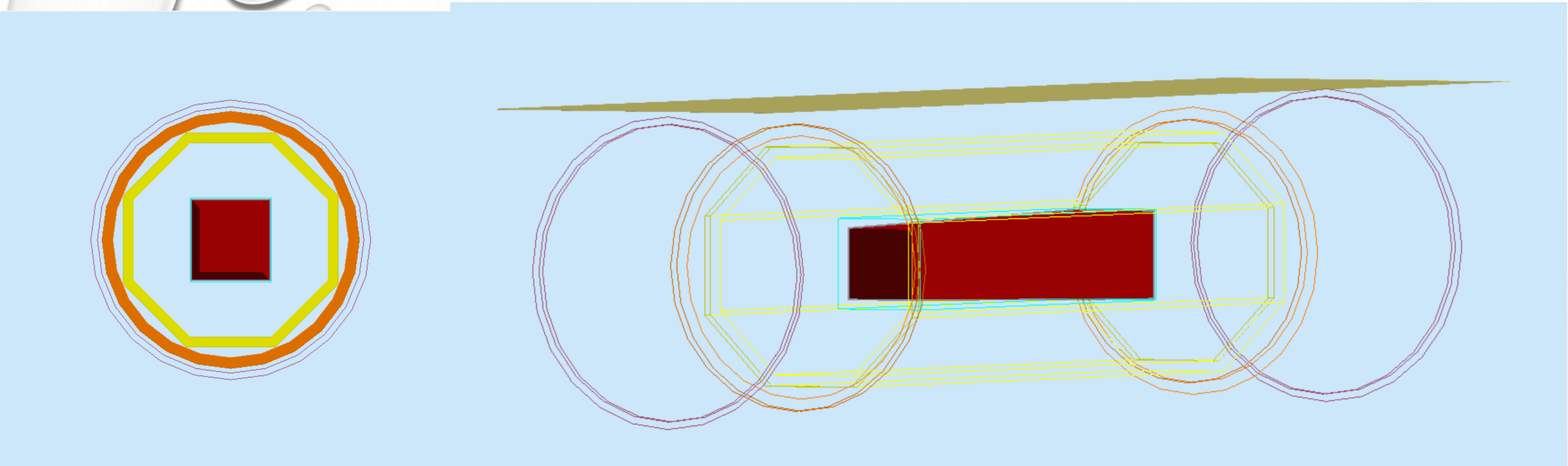
1 mm of lead around crystal works well for shielding gammas and not producing neutrons.
The minimum of not removable hits for now is 490 / day

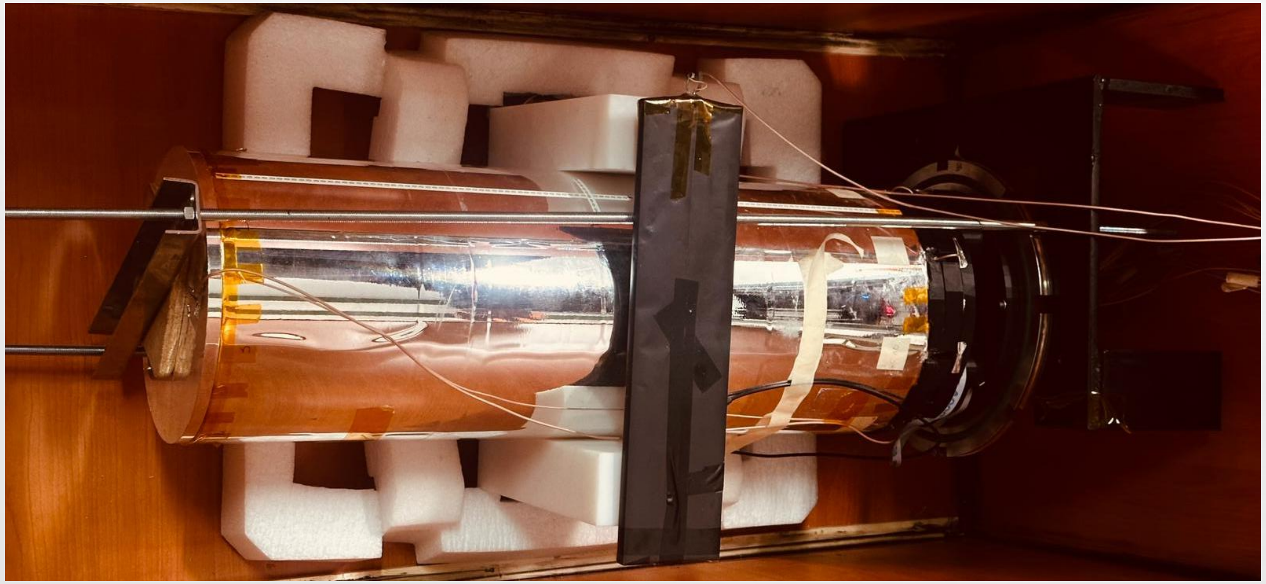


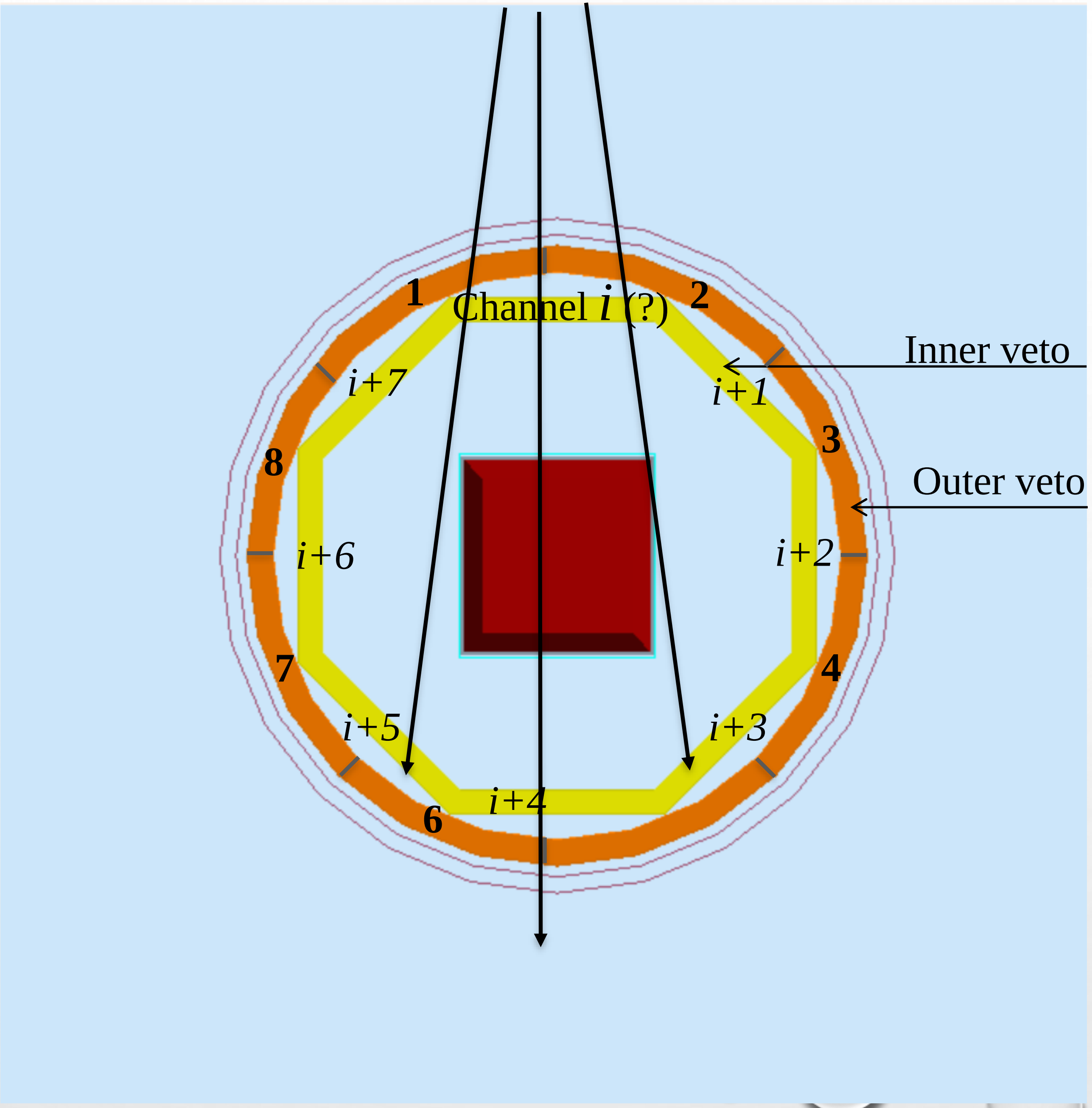






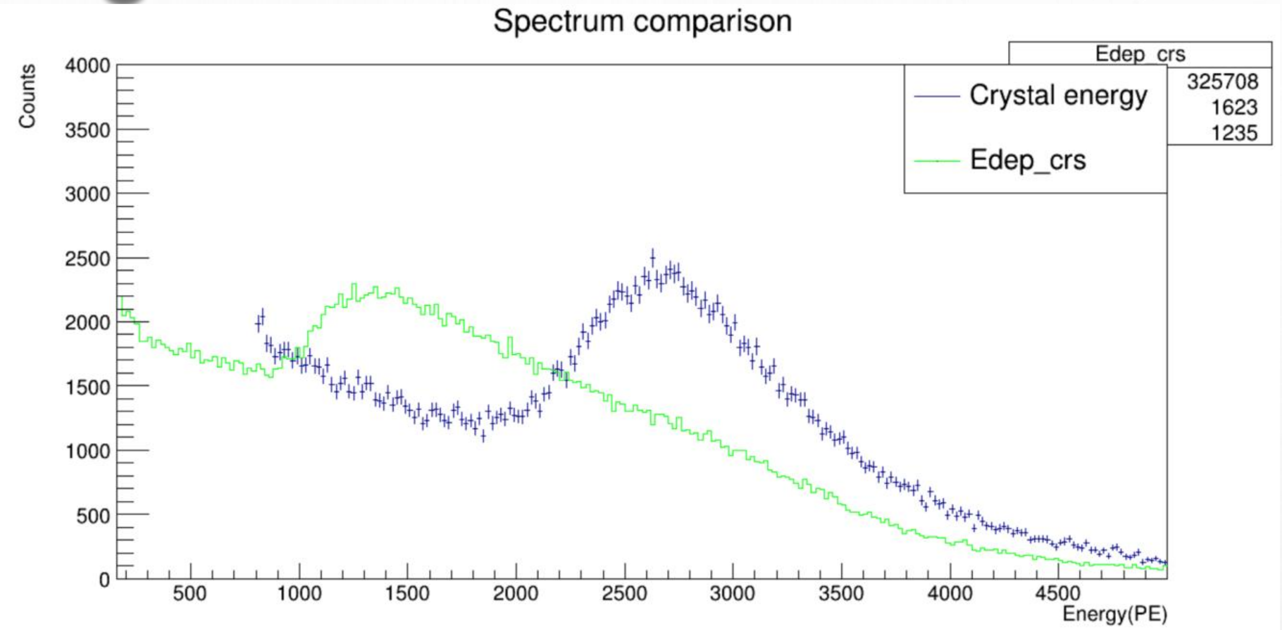


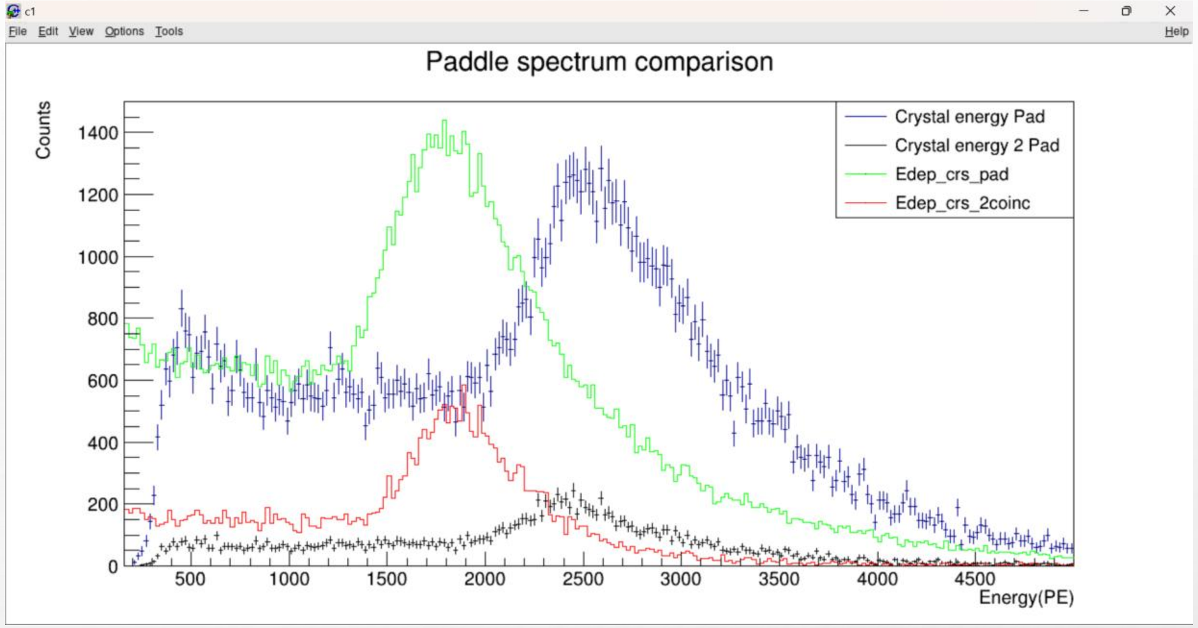




Channel i (?)
i+1
i+2
i+3
i+4
i+5
i+6
i+7
1
2
3
4
6
7
8
Inner veto
Outer veto

EXPERIMENTAL AND SIMULATION DATA COMPARISON





Crystal spectsum

Crystal spectrum comparison in coincidence with paddles

Green – simulations: crystal ∩ one paddle
Blue – experimental data: crystal ∩ one paddle
Red – simulations: crystal ∩ both paddles
Black – experimental crystal ∩ both paddles

PARAMETERS CHECK

Lpos =0, muon beam 5GeV

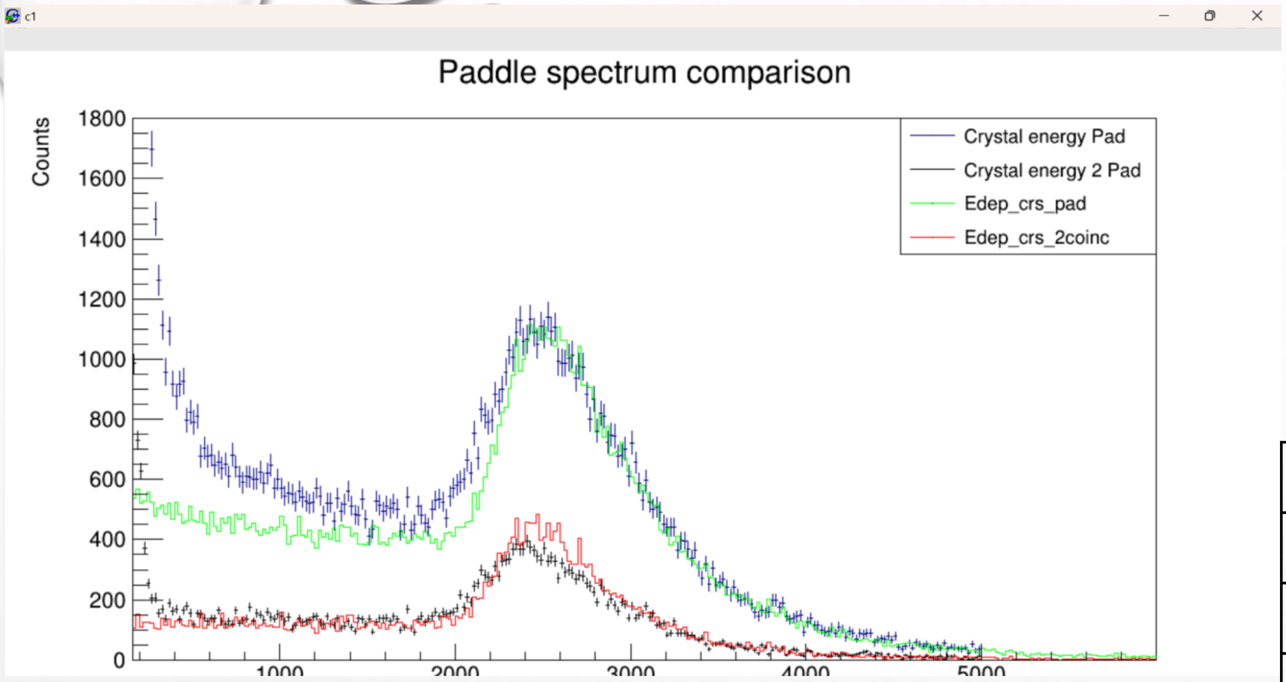
att_length_crs	*360 mm*
light_yield_crs	*60’000 γ/MeV*
sensor_qe_crs	*0,5*
optical_coupling	*0,9*
sensor_surface_crs	$36\ mm^2$
redout_surface_crs	$57x60\ mm^2 = 3420\ mm^2$
light_coll_crs	$36/3420 = 0{,}0105$

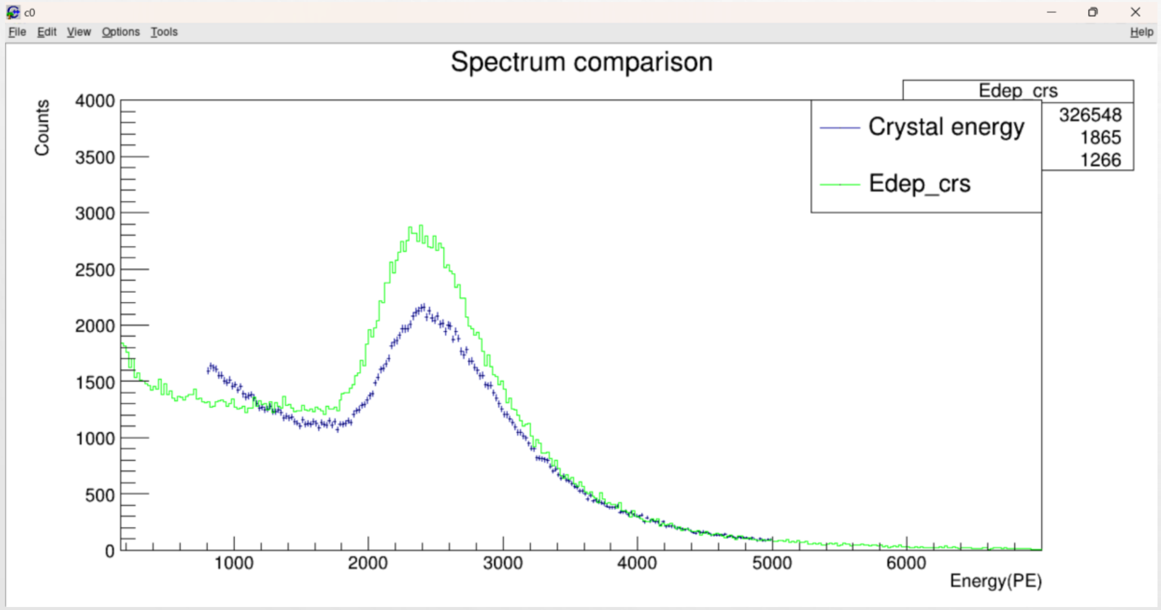
```
Lpos -0.647195
Lpos -0.473417
Lpos -0.0494865
Lpos -0.0495319
Lpos 0.0717297
Lpos -0.0230983
Lpos 0.0409739
 peR_crs 3271.93
 etotR_crs 11.5124
 Etot_noB_crs 35.7655
 length_crs 317
 att_length_crs 360
 light_yield_crs 60000
 sensor_qe_crs 0.5
 optical_coupling 0.9
 light_coll_crs 0.0105263
 Etot_noB_crs 35.7655
```

$$peR_{crs} = etotR_{crs} \cdot light_{yield_{crs}} \cdot sensor_{qe_{crs}} \cdot optical_{coupling} \cdot light_{coll_{crs}}$$

$$= \frac{\Sigma Edep_{B_{crs}}}{2} \cdot e^{-\frac{\frac{length_{crs}}{2} - Lpos[s]}{att_{length_{crs}}}} \cdot 284{,}21 = totEdep_{B_{crs}} \cdot e^{-\frac{length_{crs}}{2att_{length_{crs}}}} \cdot e^{\frac{Lpos[s]}{att_{length_{crs}}}} \cdot 142{,}1$$

$$= totEdep_{B_{crs}} \cdot e^{\frac{Lpos[s]}{att_{length_{crs}}}} \cdot 0{,}64 \cdot 142{,}1 = [Lpos[s] = 0] = 91{,}5 \cdot totEdep_{B_{crs}} = 3272$$





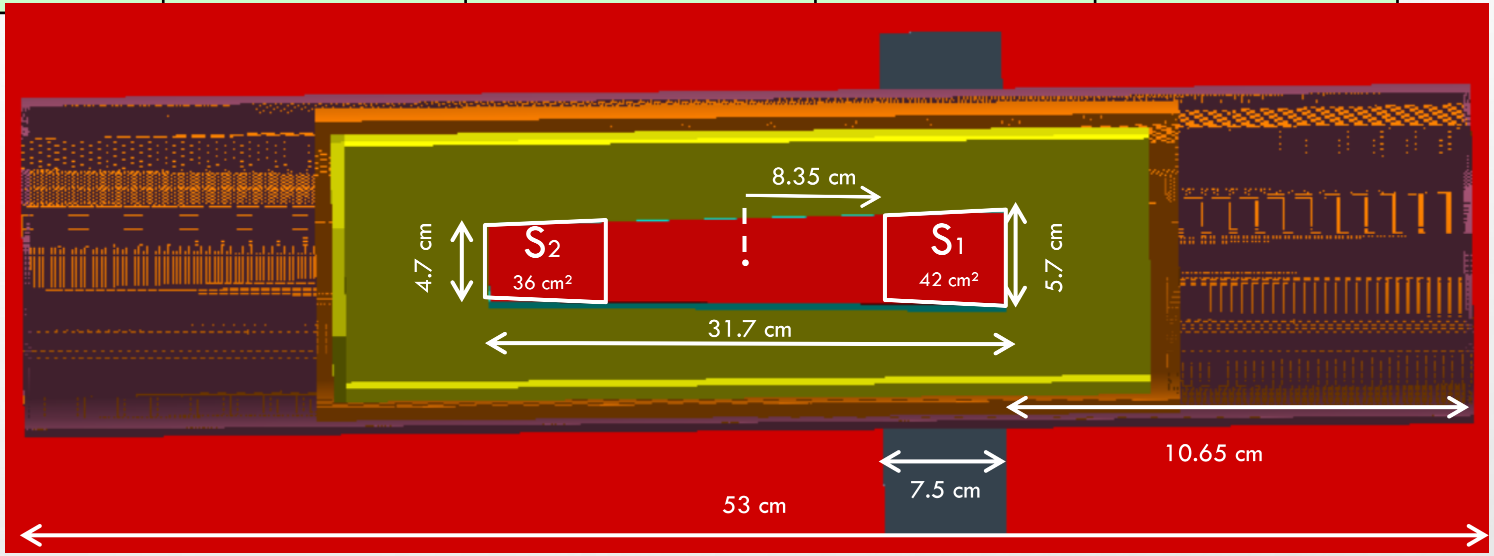
att_length_crs	*2000 cm*
light_yield_crs	*45’000 γ/MeV*
sensor_qe_crs	*0,49*
optical_coupling	*0,75*
ref	*0,1*

Green – simulations: crystal ∩ one paddle
Blue – experimental data: crystal ∩ one paddle
Red – simulations: crystal ∩ both paddles
Black – experimental crystal ∩ both paddles

30% of intensity reduce is caused by presence of a hill close to department

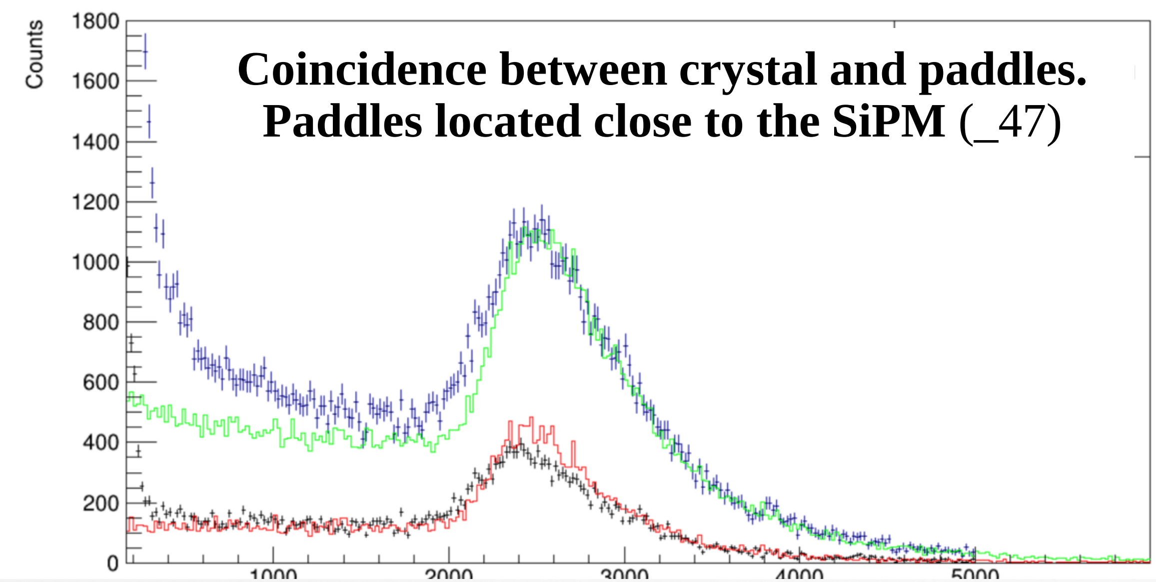
	Events	*Rate, events/s*	*Events (thr 800)*	*Rate, events/s*	
Edep crystal	*324’732 (?)*	*225*	*223’091/222’953*	*155*	
Big face 1 paddle	*112’793*	*78*	*80’297*	*56*	
Small face 1 paddle	*100’211*	*70*	*67’934*	*47*	
Big face 2 paddles	*33’755*	*23*	*25’774*	*18*	
Small face 2 paddles	*29’268*	*20*	*20’873*	*14*	

Proportion Big face / Small face (theoretical value = 1,16)		
	Without thr	Thr 800 pe
1 paddle	1,15	1,18
2 paddles	1,12	1,23

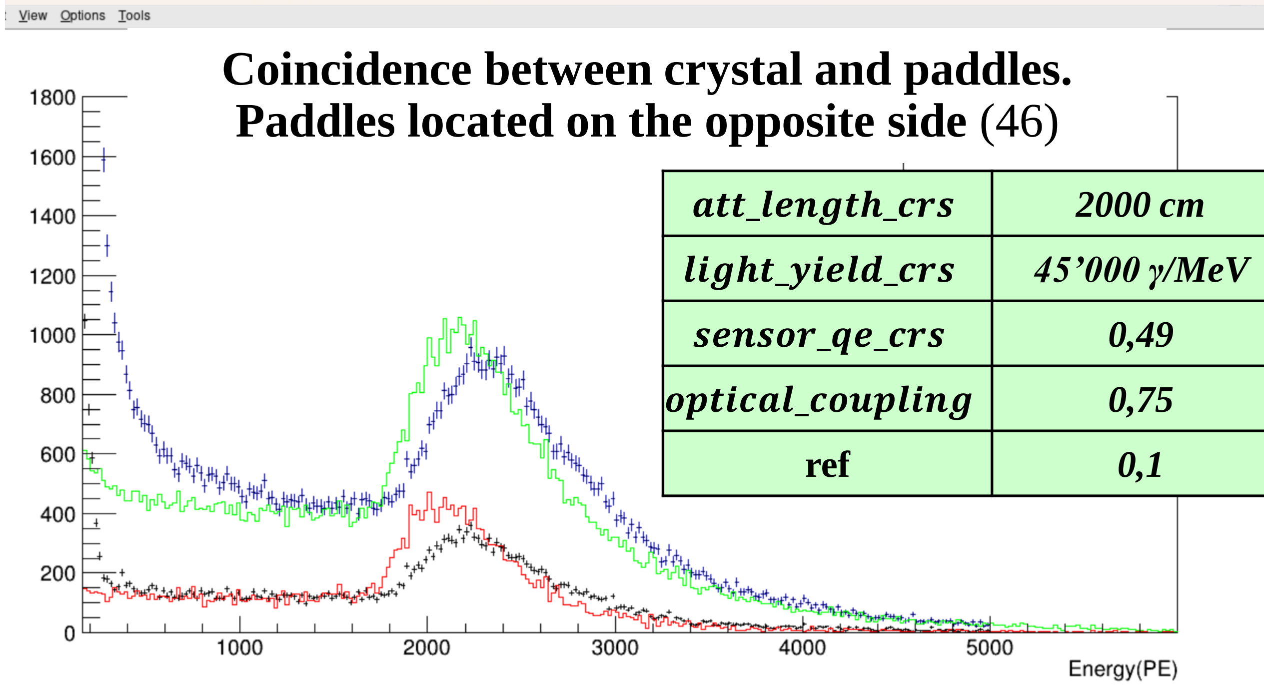


Simulation parameters which correspond to experimental results

Coincidence between crystal and paddles. Paddles located close to the SiPM (_47)

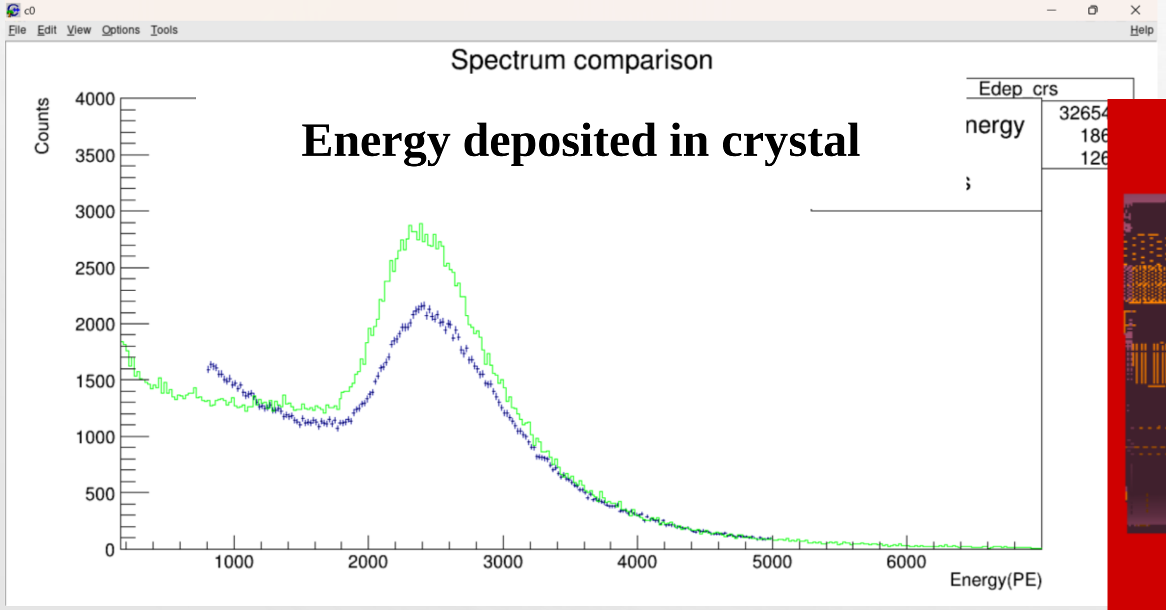


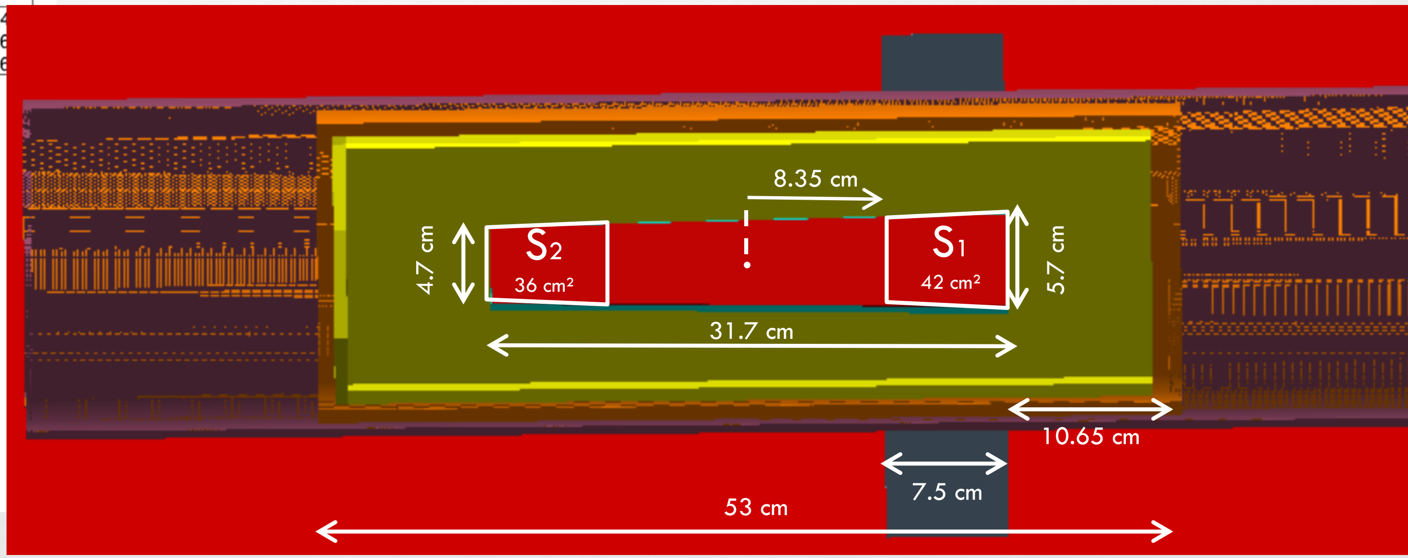
Coincidence between crystal and paddles. Paddles located on the opposite side (46)



att_length_crs	*2000 cm*
light_yield_crs	*45’000 γ/MeV*
sensor_qe_crs	*0,49*
optical_coupling	*0,75*
ref	*0,1*

Energy deposited in crystal





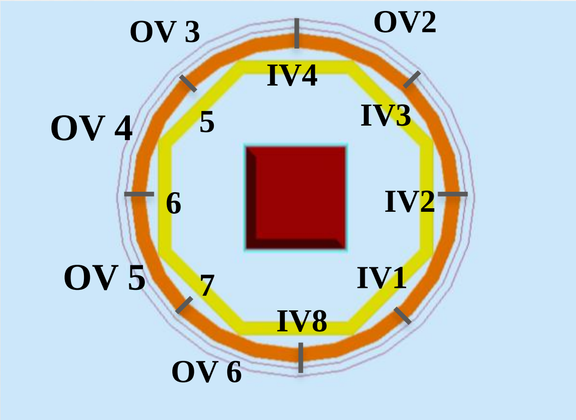
	Peak position, pe		Right shift, pe	%	Peak position, pe		Right shift, pe	**Peak shift, %**
	OV perpendicular	OV parallel			IV perpendicular	IV parallel		
crs	2403	2459	56	**2,3**	1191	1278	87	**6,8**
2	1108	1134	26	**2,3**	1068	1090	22	**2**
3	1526 / 2832	1535 / 2877	9 / 45	**0,6 / 1,6**	3400	3481	81	**2,3**
4	1539 / 2667	1577 / 2736	38 / 69	**2,4 / 2,5**	2808	2856	48	**1,7**
5	1726 / 3271	1791 / 3341	65 / 70	**3,6 / 2,1**	1321	1371	50	**3,6**
6	1944 / 3178	2011 / 3208	67 / 30	**3,3 / 0,94**	1072	1470		
7	826	858	32	**3,7**	1314 / 3140	1329 / 3186	15 / 46	**1,1 / 1,4**
8	1623 / 2864	1708 / 2958	85 / 94	**5 / 3,2**	1152 / 3147	1103 / 3229	82	**2,5**

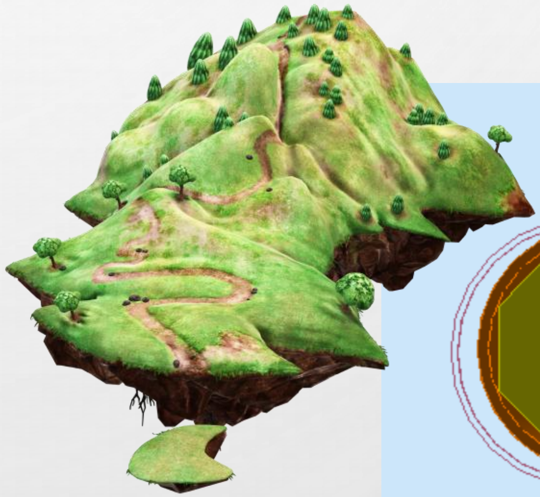
La rotazione porta a uno spostamento a destra di ≈ 2,6 ± 1,42 %

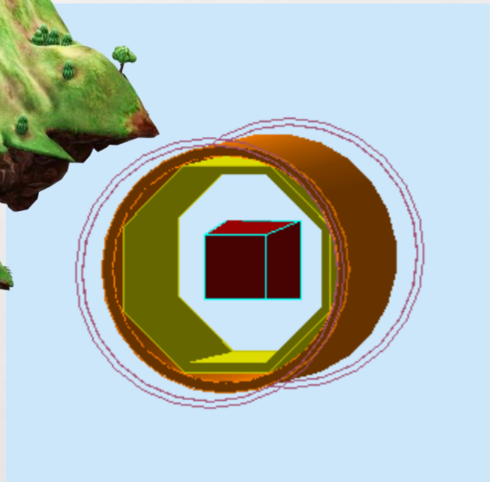
I cambiamenti più evidenti hanno i veti laterali

Perpendicular: paddle-long-day.root

Parallel: parallel-day_4.root

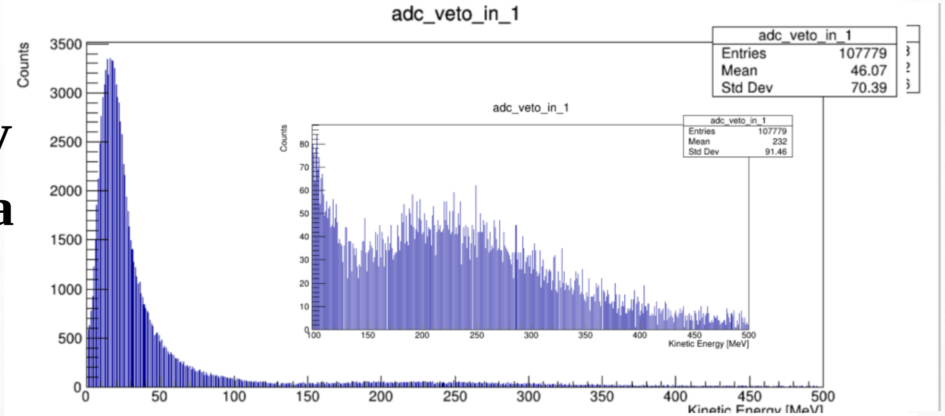


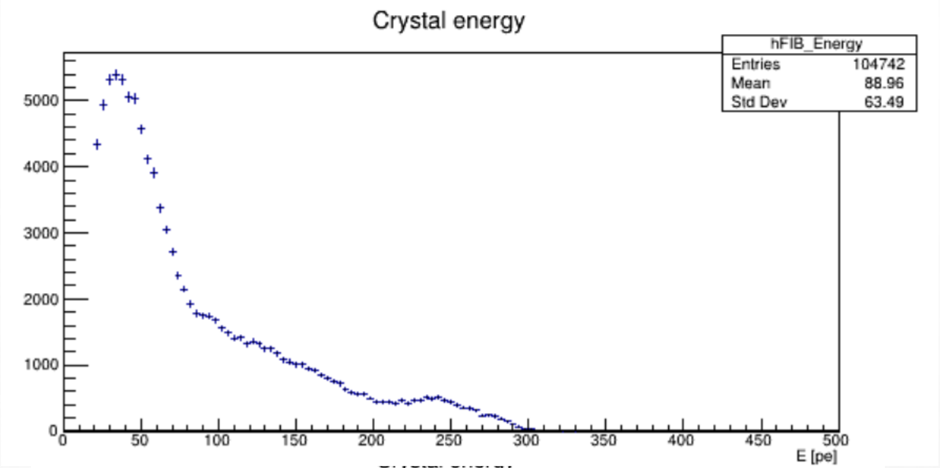


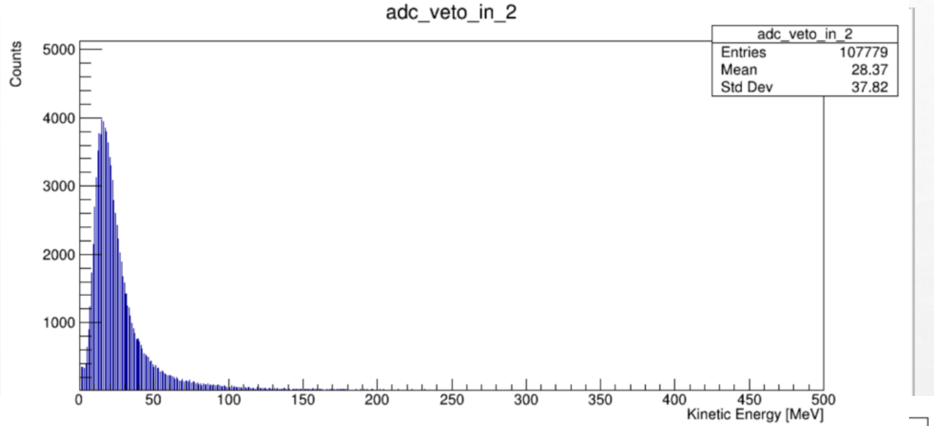


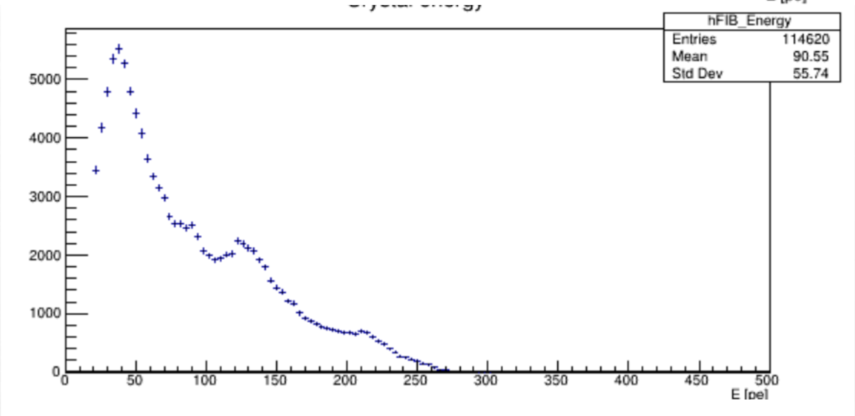
Simulations with mountain (energy from 0) & experimental data
Inner veto

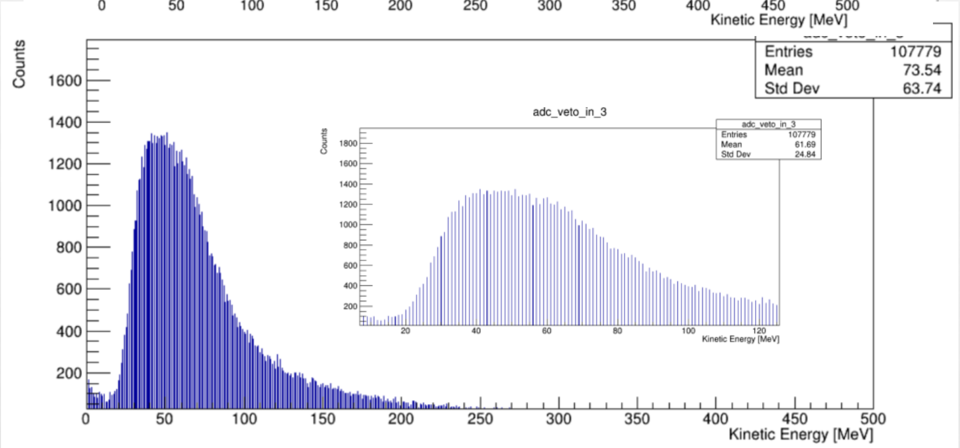
Threshold 12 pe
Energy range 0-500GeV
Rate 1,25 Hz (1,99 senza montagna) vs. 1,21 Hz

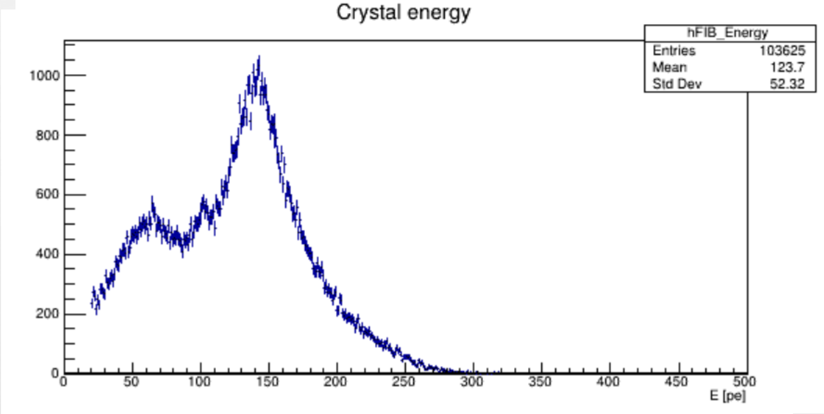


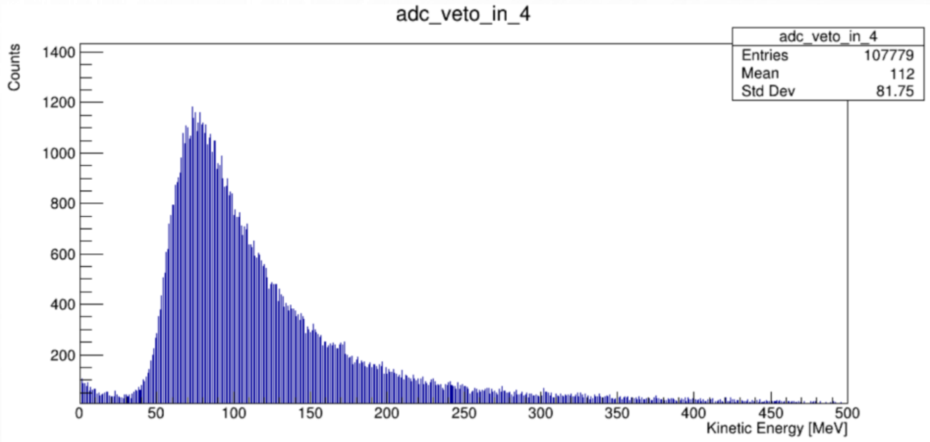


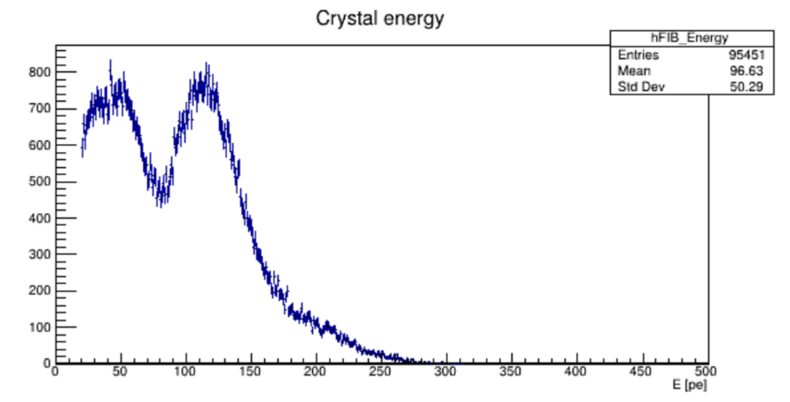


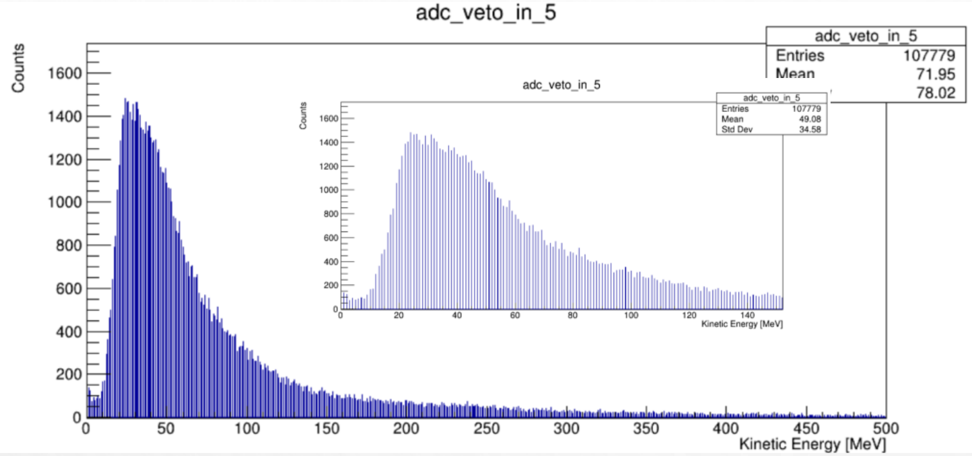


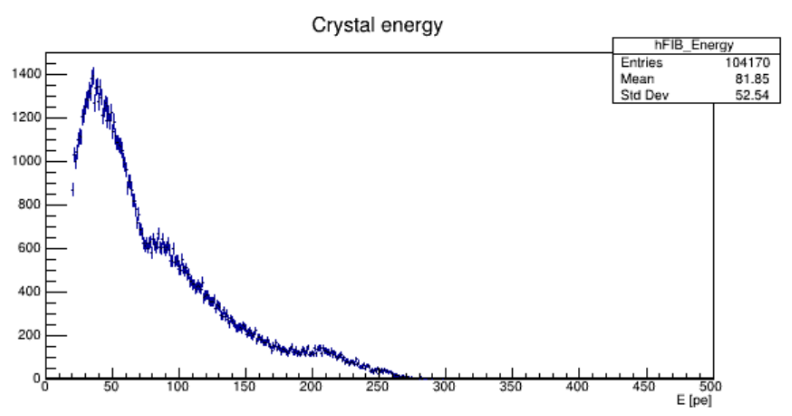


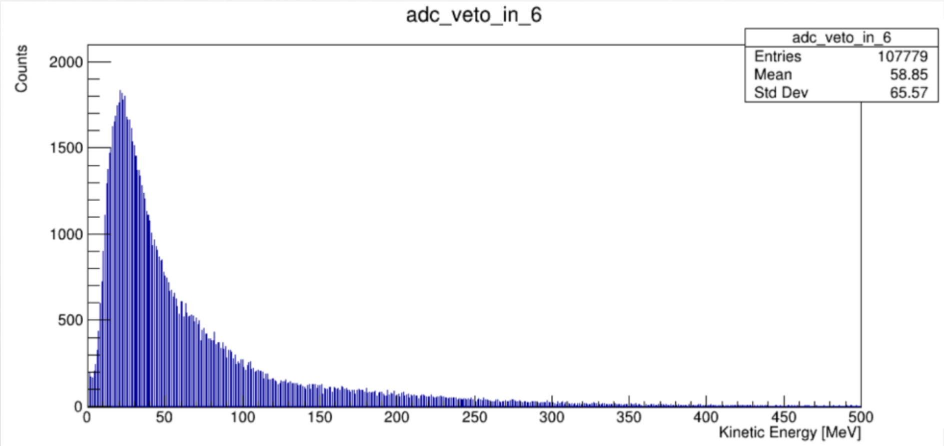


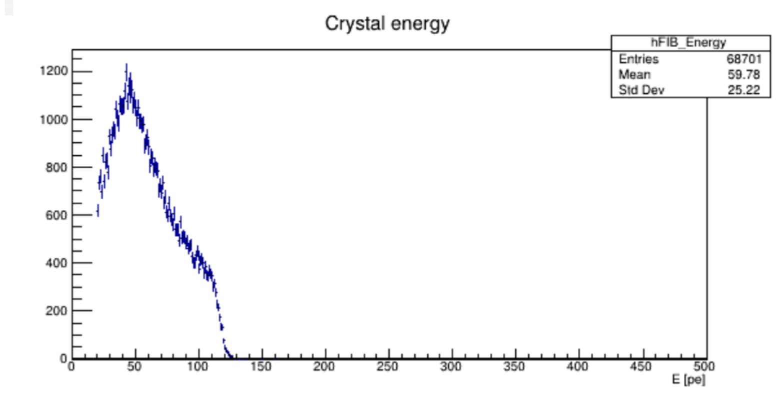

adc_veto_in_4
adc_veto_in_4
Entries 107779
Mean 112
Std Dev 81.75
Counts
Kinetic Energy [MeV]


Crystal energy
hFIB_Energy
Entries 95451
Mean 96.63
Std Dev 50.29
E [pe]


adc_veto_in_5
adc_veto_in_5
Entries 107779
Mean 71.95
78.02
Counts
Kinetic Energy [MeV]
adc_veto_in_5
Entries 107779
Mean 49.08
Std Dev 34.58
Counts
Kinetic Energy [MeV]


Crystal energy
hFIB_Energy
Entries 104170
Mean 81.85
Std Dev 52.54
E [pe]


adc_veto_in_6
adc_veto_in_6
Entries 107779
Mean 58.85
Std Dev 65.57
Counts
Kinetic Energy [MeV]


Crystal energy
hFIB_Energy
Entries 68701
Mean 59.78
Std Dev 25.22
E [pe]

GEMC DOCUMENTATION

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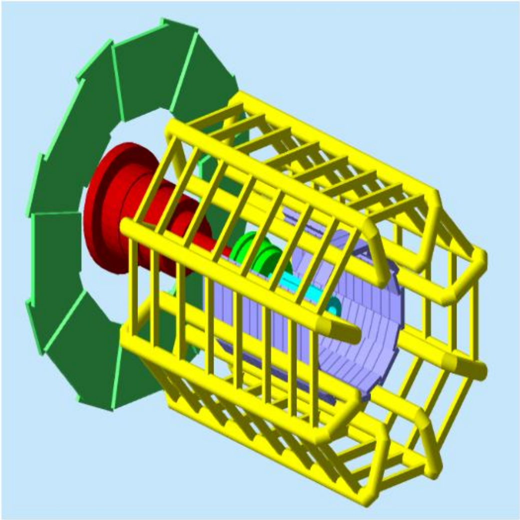
GEMC

Examples

build a scintillator array



check out some ATLAS cad solids

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- Geant4 Development Book
- Geant4 Bugzilla

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Internal Generator

A primary particle 4-momentum and vertex ranges can be set with the gcard directives:

```
<option name="BEAM_P"   value="proton, 4.0*GeV, 20.0*deg, 10*deg"/>
<option name="SPREAD_P" value="1*GeV, 10*deg, 180*deg"/>
<option name="BEAM_V"   value="(0, 0, -5)cm"/>
<option name="SPREAD_V" value="(0.1, 10)cm"/>
```

The above will generate a proton with:

- momentum between 3 and 5 GeV.
- θ between 10 and 30 degrees.
- ϕ between 0 and 360 degrees.
- vertex z between -10 and 0 cm.
- vertex radius between 0 and 0.1 cm.

Any gcard directive can be superseed by its corresponding command line. For example:

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GEMC

Installation

Refer to the celnstall page for the latest instructions on how to use gemc at Jefferson Lab, or through CVMFS, or by building it from source.

Using Docker

GEMC distributed using https://www.docker.com. You can download docker for free here.

Use a Docker Container The following docker containers are available:

jeffersonlab/gemc:gemc-dev-fedora36   jeffersonlab/gemc:gemc-dev–almalinux93   jeffersonlab/gemc:gemc-dev–ubuntu24

Use the following command to open a bash session on the container.

Batch mode:

```
docker run --platform linux/amd64 -it --rm -v ~/mywork:/usr/local/mywork jeffersonlab/gemc:gemc-dev-fedora36 bash
```

You need to use the option USE_GUI=0 to run gemc in batch mode.

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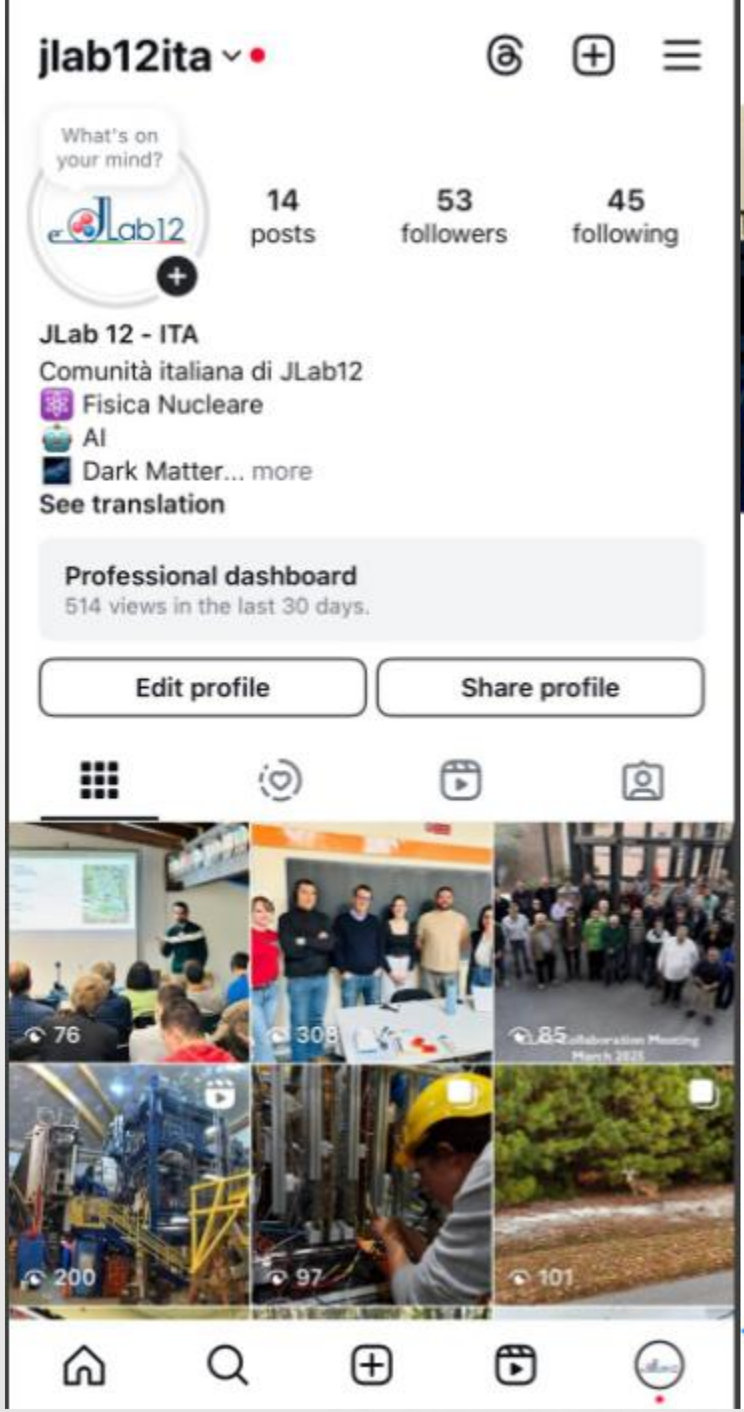
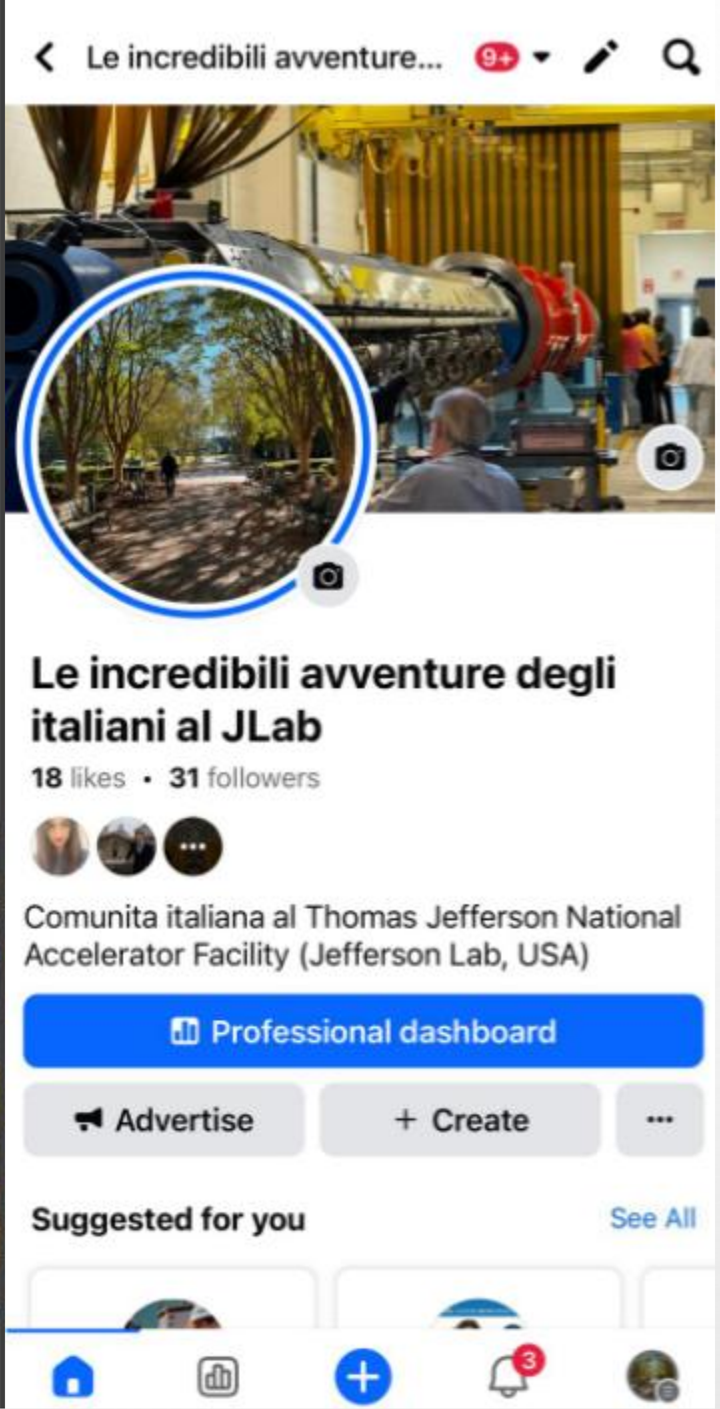
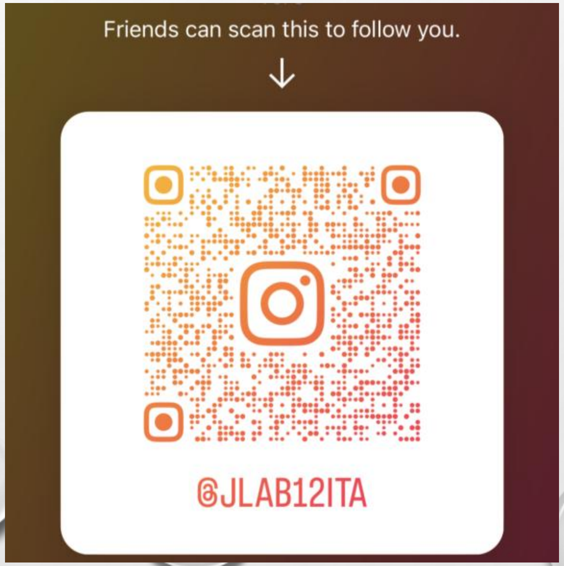
Go

Search within the gemc website.





https://photos.app.goo.gl/Edp4L1qweajL43xm8



THANK YOU!