Simulation studies towards a full scale experiment

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Picture by M. Volpi

Goal

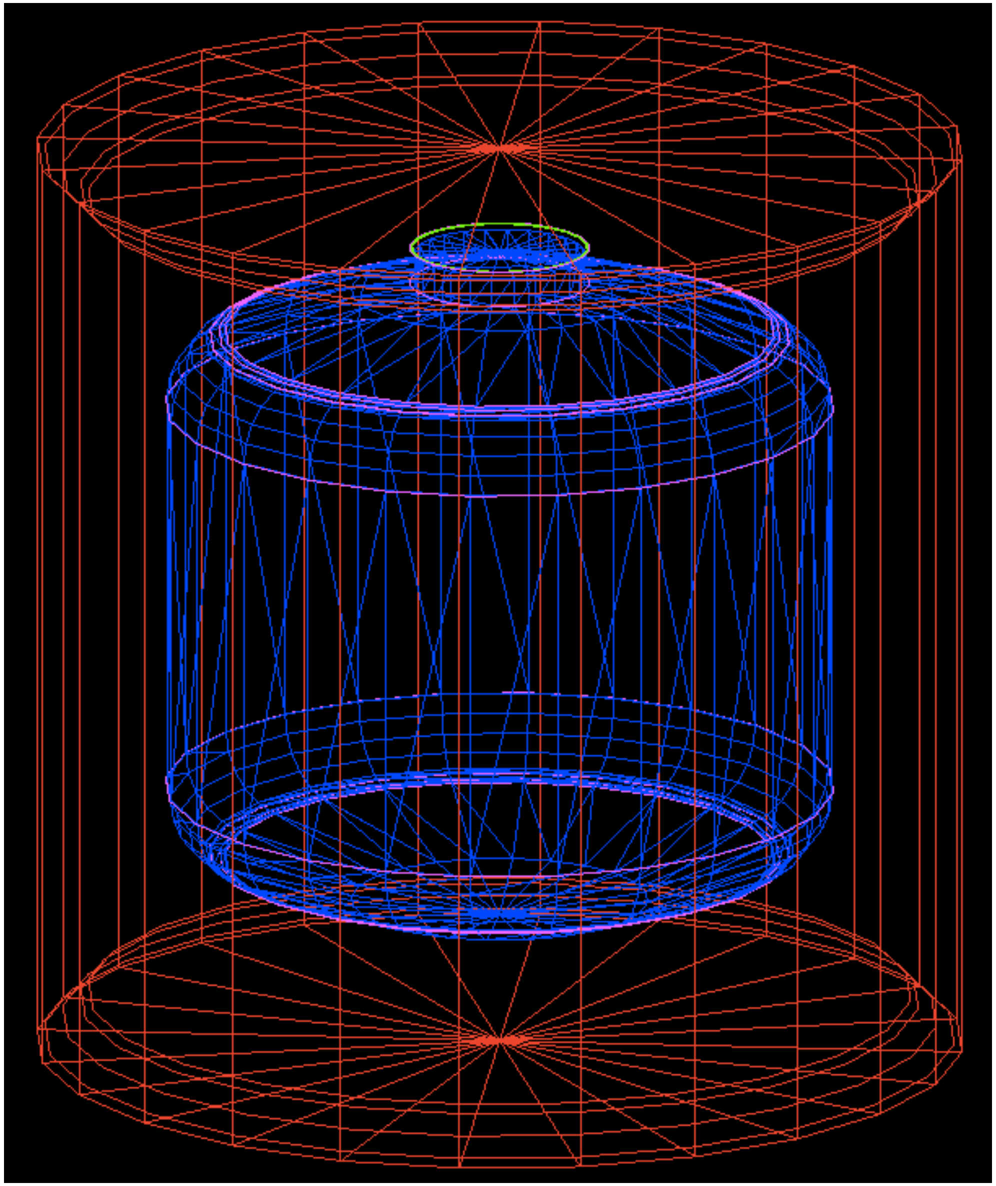
Investigate the reduction of the background resulting from the choice of

- Passive shielding
- Liquid scintillator system
- Crystal insertion system

Work towards solution which minimize the background in dark matter measurement mode

In this presentation only external background from radiogenic neutrons and gammas are considered

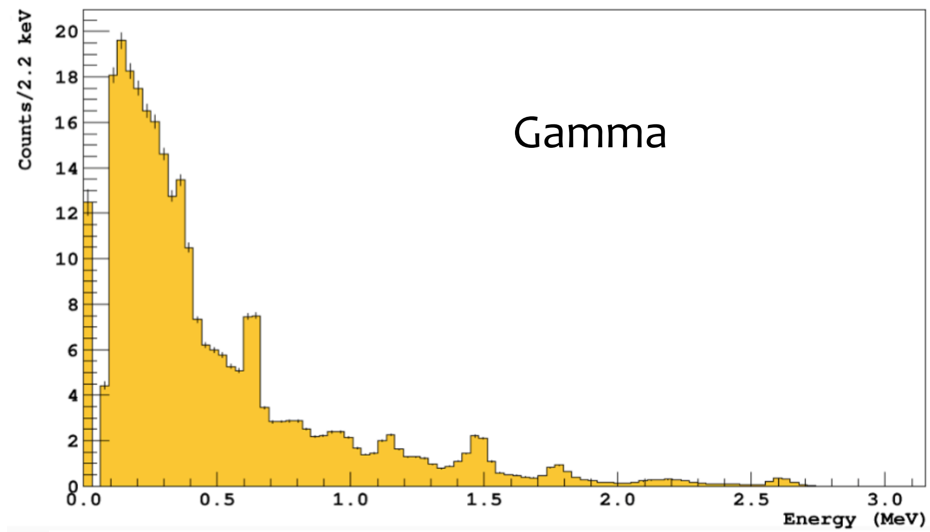
Passive Shielding

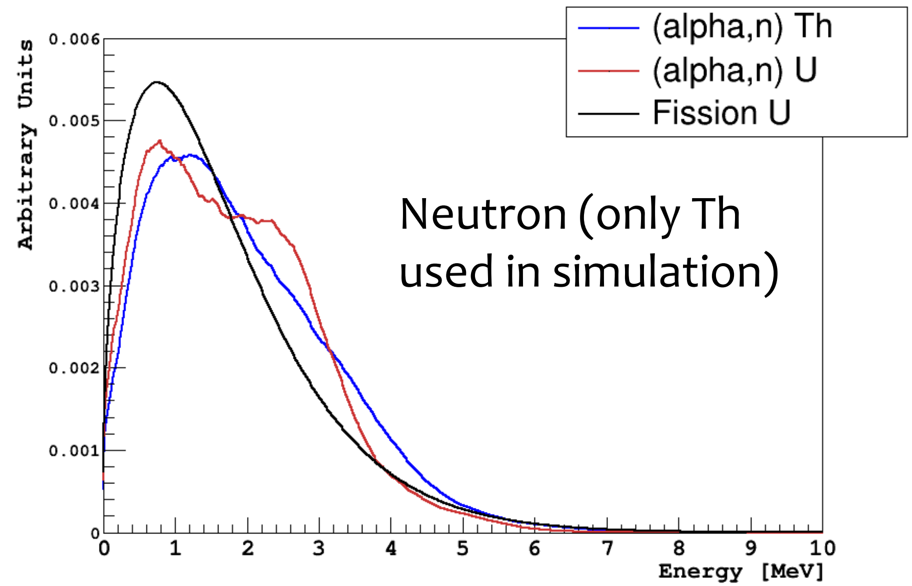


- Cylindrical shielding
- 4 layers alternating polyethylene (PE) and lead
- Several options considered
- Total thickness fixed: 10 cm of PE + 10 cm of Lead

INPUTS

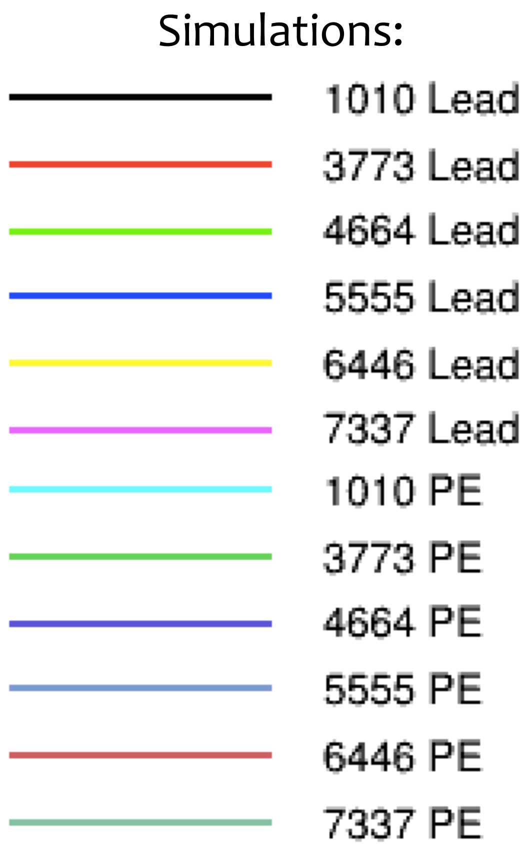
- Preliminary total fluxes at SUPL:
  - For photons
  - For neutrons
- Gamma energy distribution from the measurement at SUPL with a 6” NaI(Tl) detector
- Neutron energy from (alpha,n) interactions of Th in rock calculated with SOURCES (credit P. Mosteiro)
- (alpha,n) interactions and spontaneous fission of U also important but not yet included



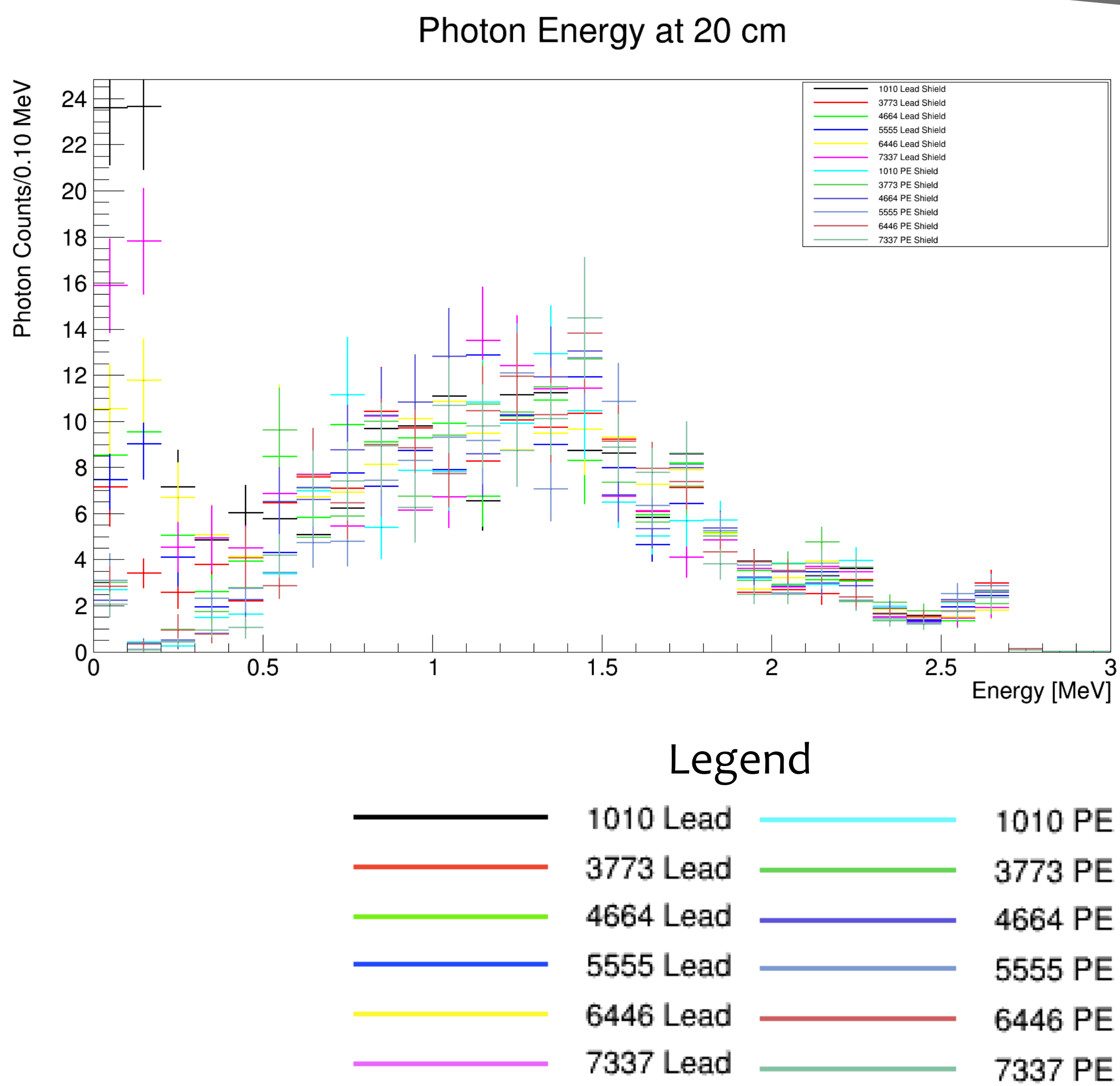


SHIELDING SIMULATION

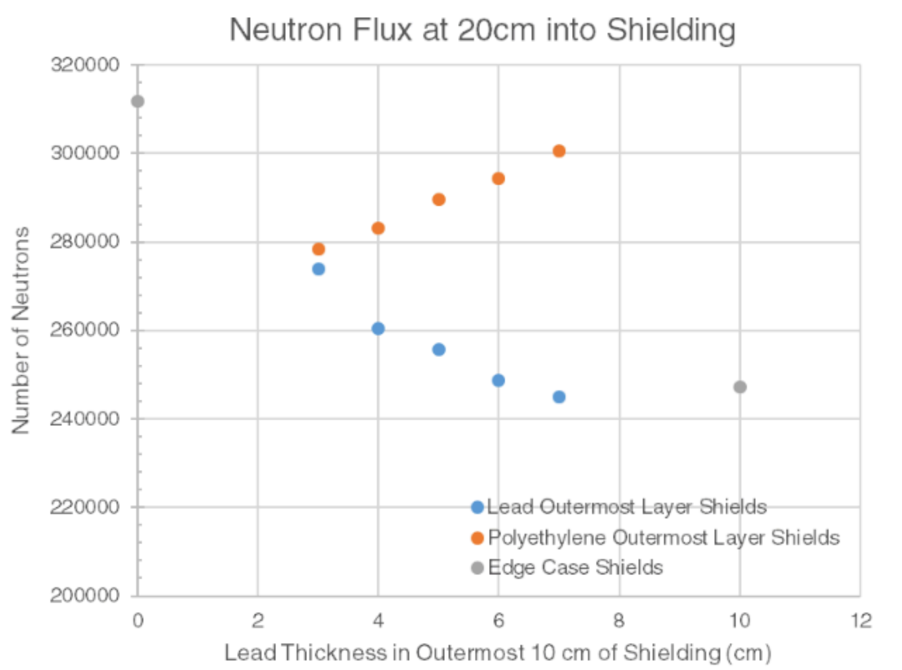
- Geant4 10.02.p03 simulation
- Generation of photons and neutrons from a spherical surface (r=2.2m) pointing to the center of the detector
- 1M events per simulation
- The shieldings are identified labelled “*x:10-x:10-x:x [material of outermost layer]*“, where *x= 3,4,5,6,7,10 cm* is the thickness of the outermost/innermost layer
- The flux of particles escaping the shieldings are recorded



- Survival probability ~1.5e-04 for Lead inside
- ~15% less rejection for PE inside
- Main difference for E<0.3 MeV

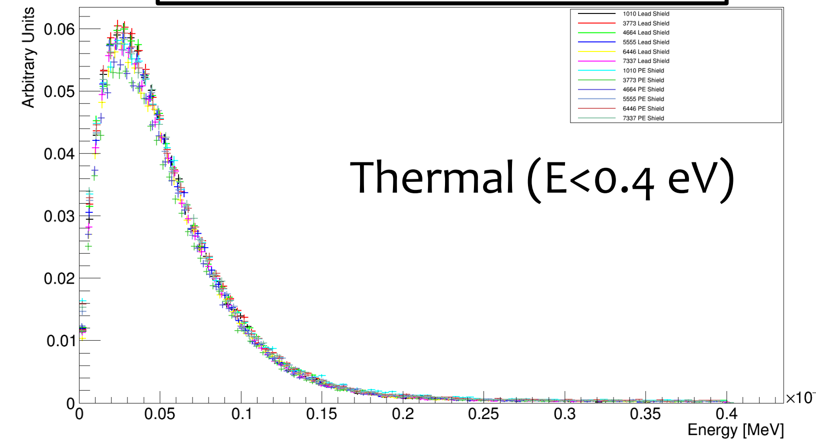


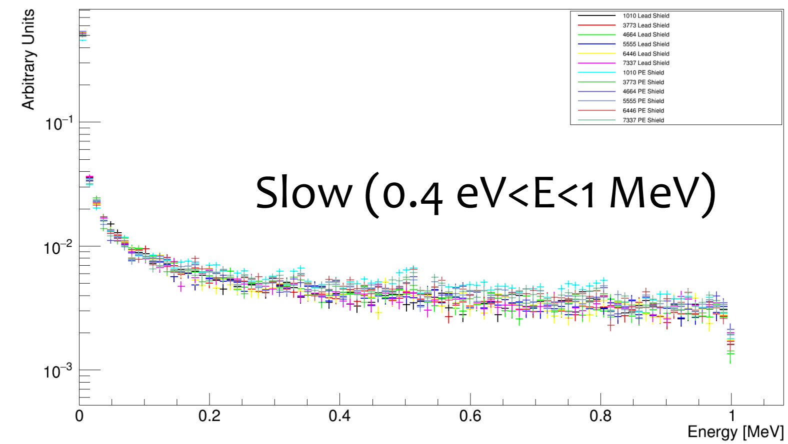
NEUTRONS AFTER SHIELDING

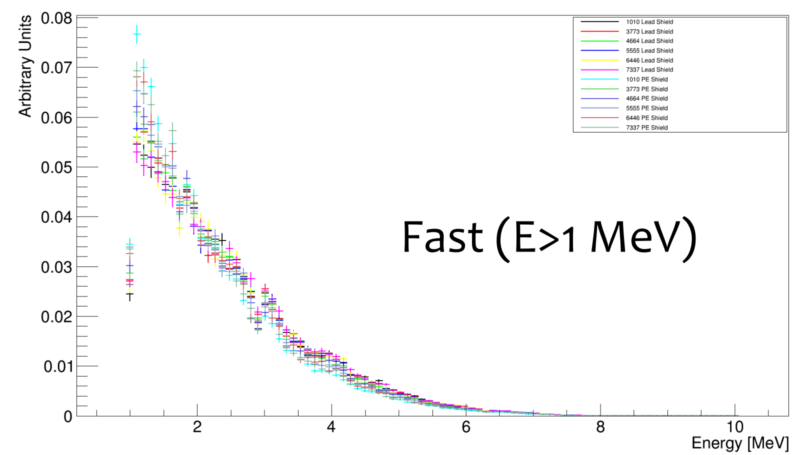


- Survival probability from 0.25 to 0.31
- The ticker the PE inside, the better
- Distribution of neutron energy similar for each configuration

same area distributions

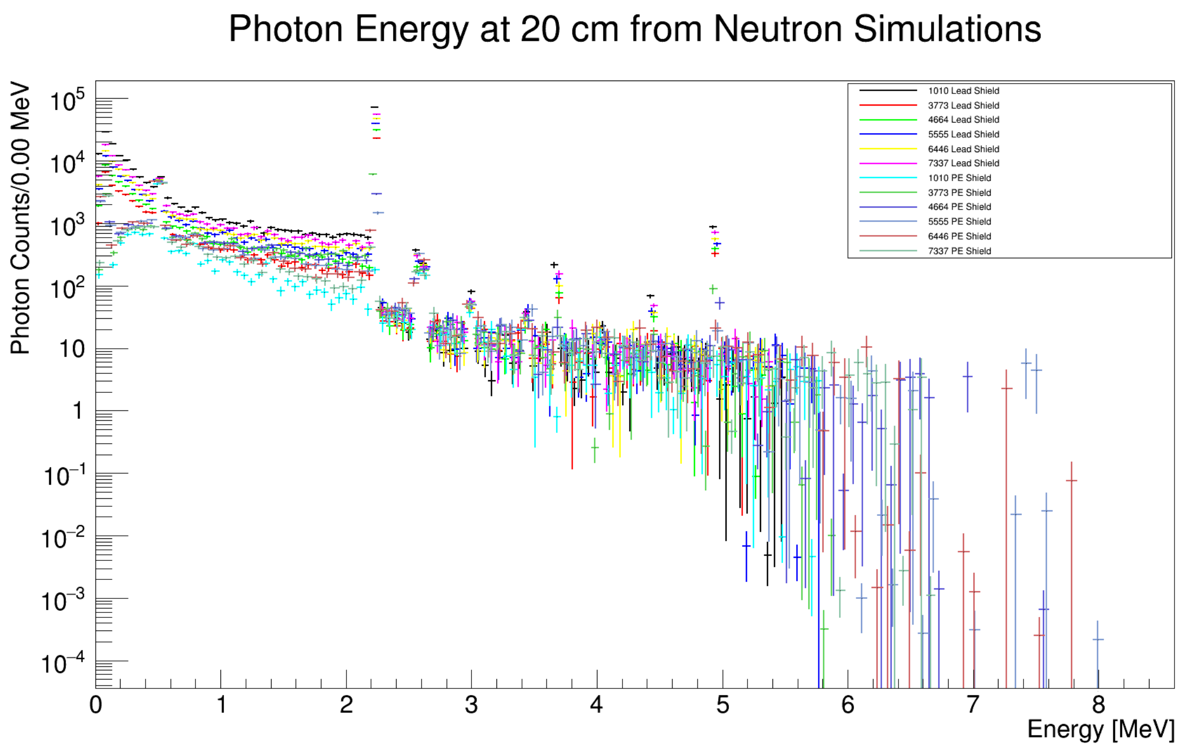


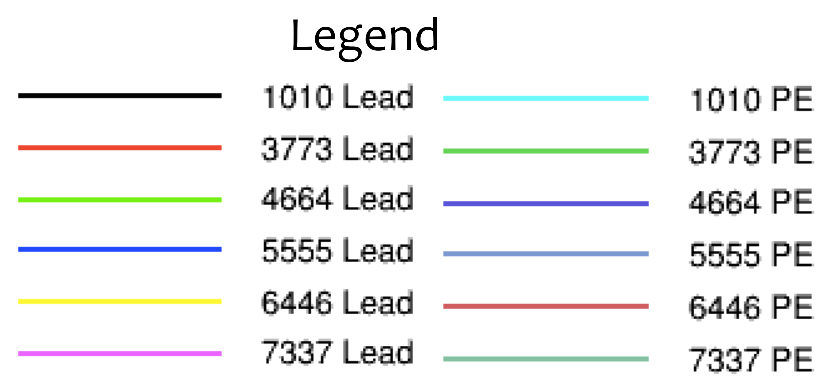




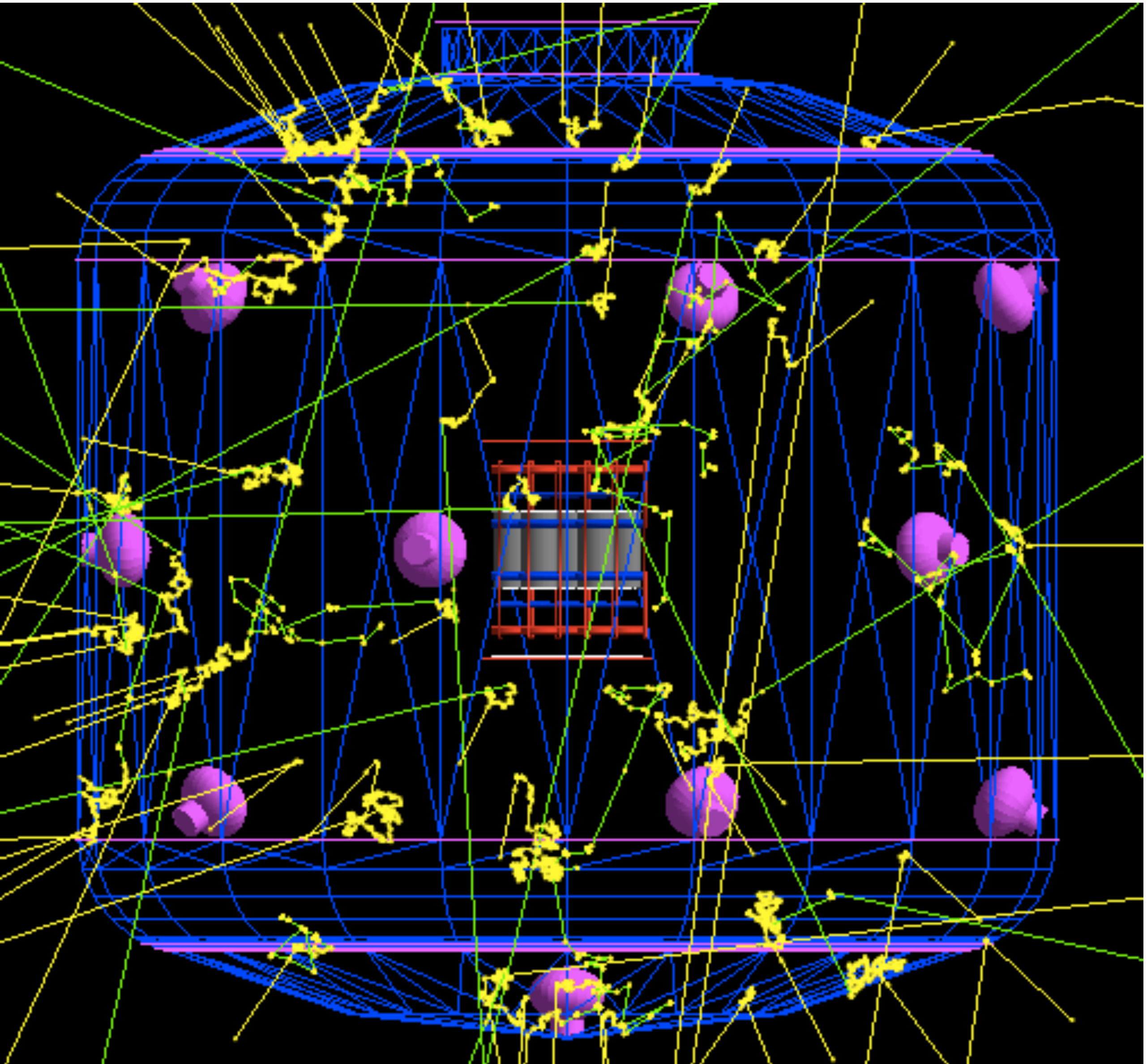
Photons generated in shielding

- Interactions of neutrons with the shielding (PE mainly) produce non-negligible amounts of photons
- The production probability 0.02-0.03 for Pb inside and 0.06-0.22 for PE inside
- Plenty of low energy photons and photons from neutron capture in H (2.2 MeV peak)

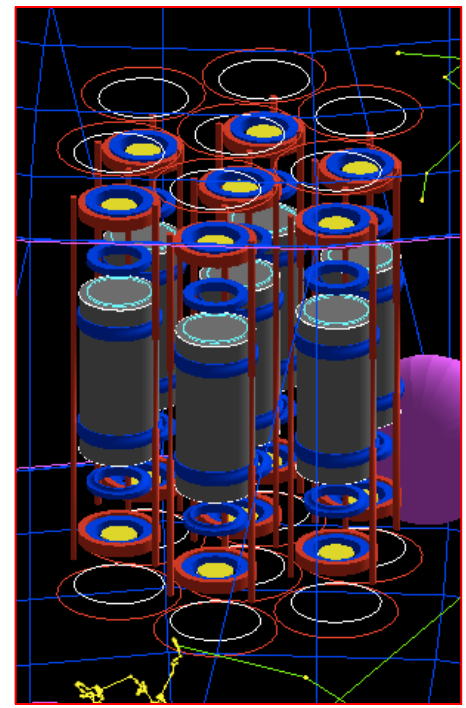




VESSEL



- 2.6 diameter x 2.6 height vessel
- 16 PMTs
- 7 crystals



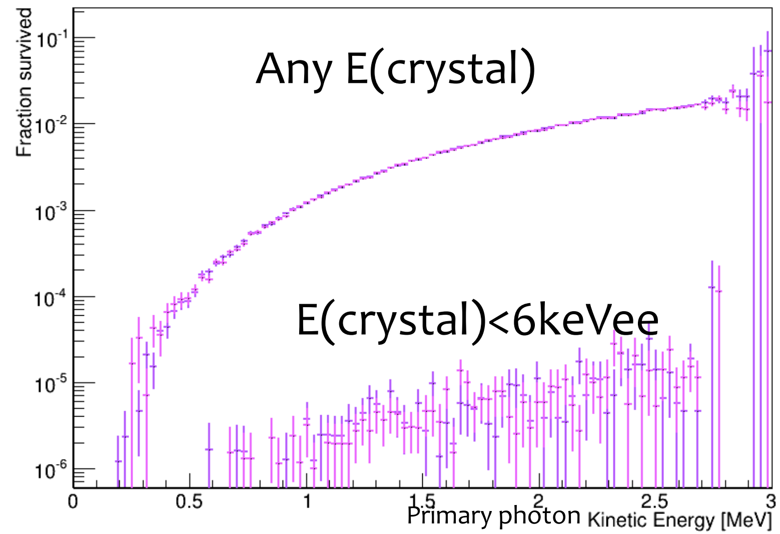
Fifty (1 MeV) neutron interactions are shown

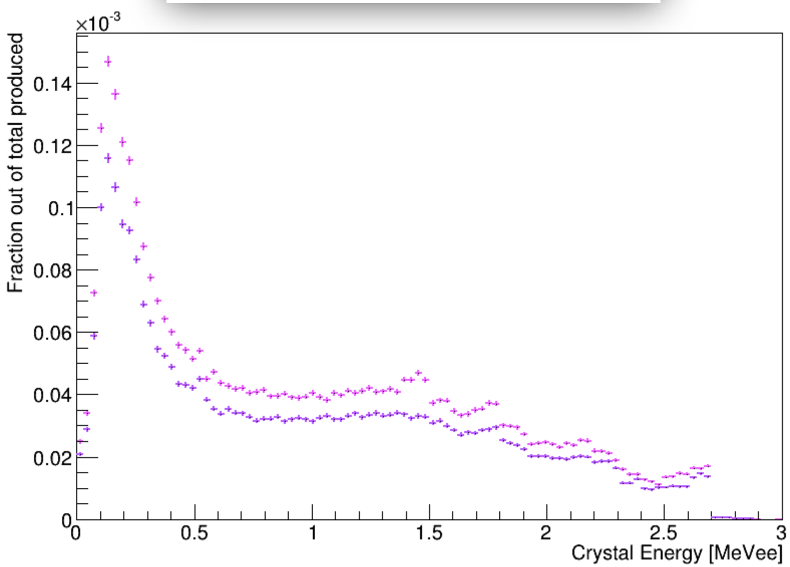
Vessel simulation

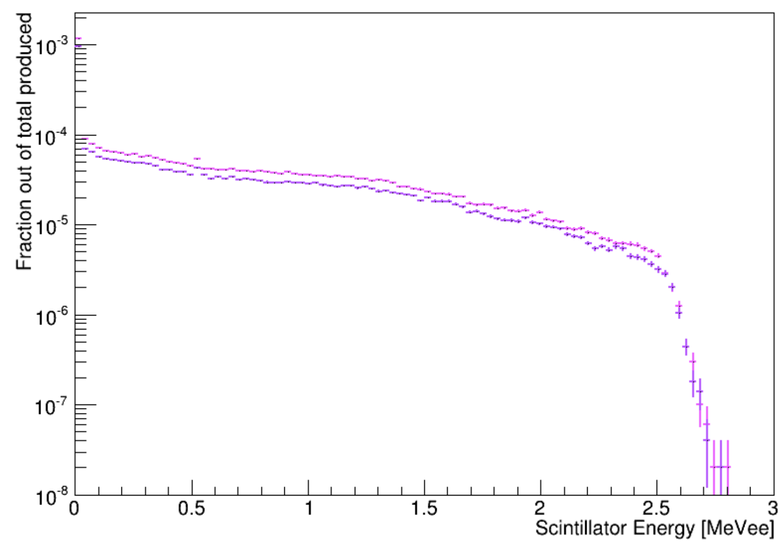
- Propagation of particles through the vessel starting from the fluxes recorded after shieldings
- Particle energy from the most divergent results:
  - Average of PE outside and average of Pb outside for photons (to reduce statistical fluctuations)
  - 1010 PE and 1010 Pb for fast neutrons (E>1 MeV) and slow neutrons (0.4 eV<E<1 MeV)
  - 3773 PE and 3773 Pb for thermal neutrons (E<0.4 eV)
  - Photons produced in the shielding not studied yet
- Generation of particles from a spherical surface (r=1.85m) pointing to the center of the detector
- 100M (50M) events per neutron (photon) simulation
- Energies released in the crystals and in the liquid scintillator are recorded

Passive Rejection (Gamma)

- <0.4% of photons reaches the crystals
- Photons with energies below 0.5 MeV are completely absorbed



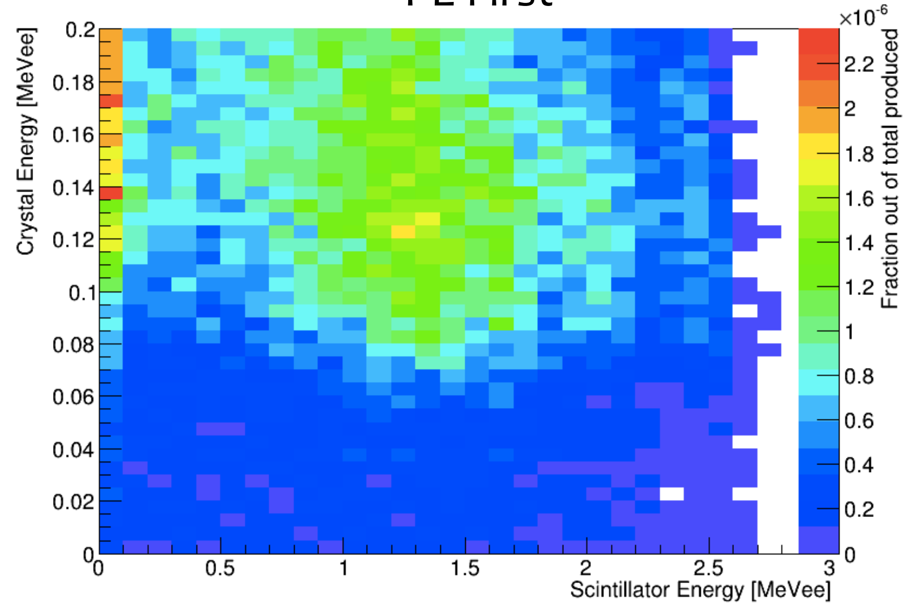


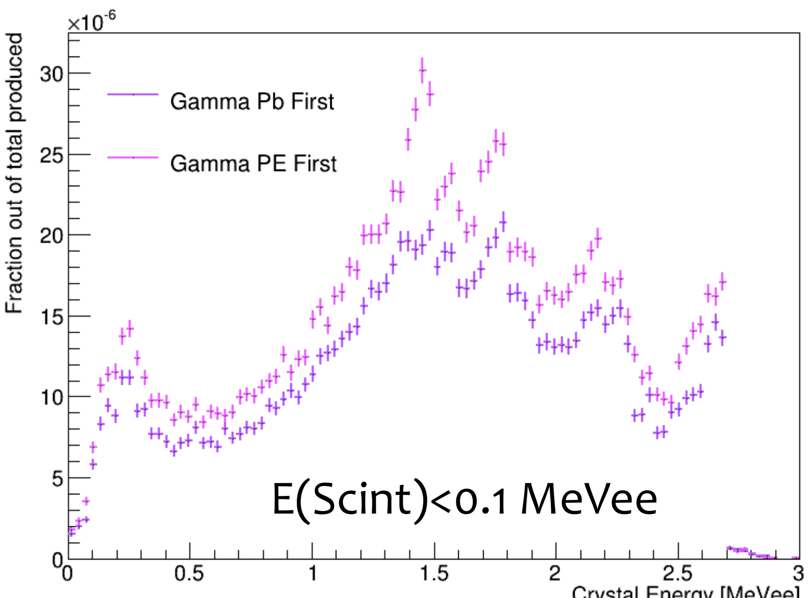


Active Veto (Gamma)

- Veto energy threshold for this system need to be studied: 0.2 MeVee and 0.1 MeVee limits used here
- Veto reduce of 3 the fraction of photons seen and of 10 that of photon depositing < 6 keVee in crystals

PE First



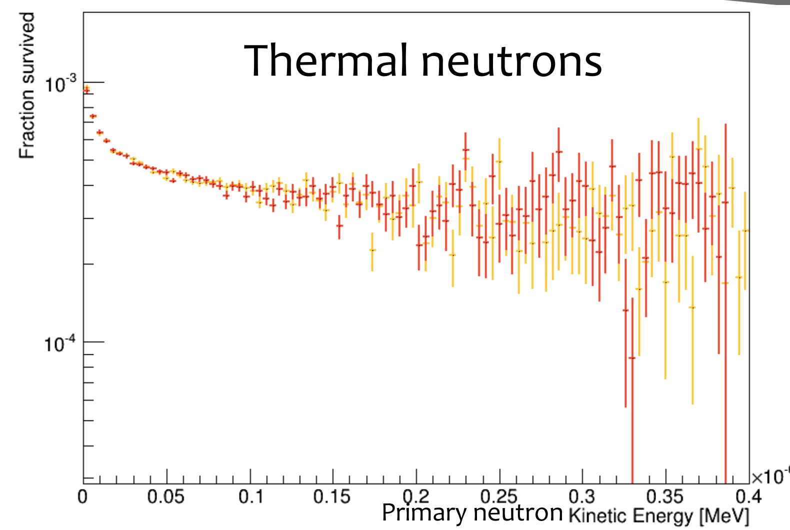


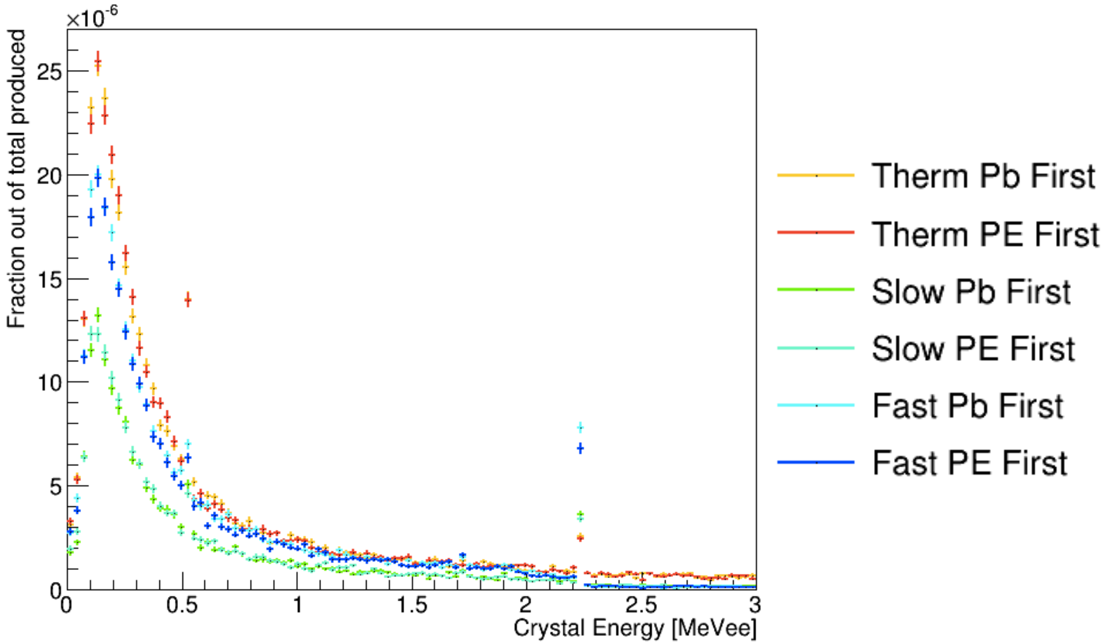
Fraction of surviving photons (upper value: Pb First; lower value: PE First)

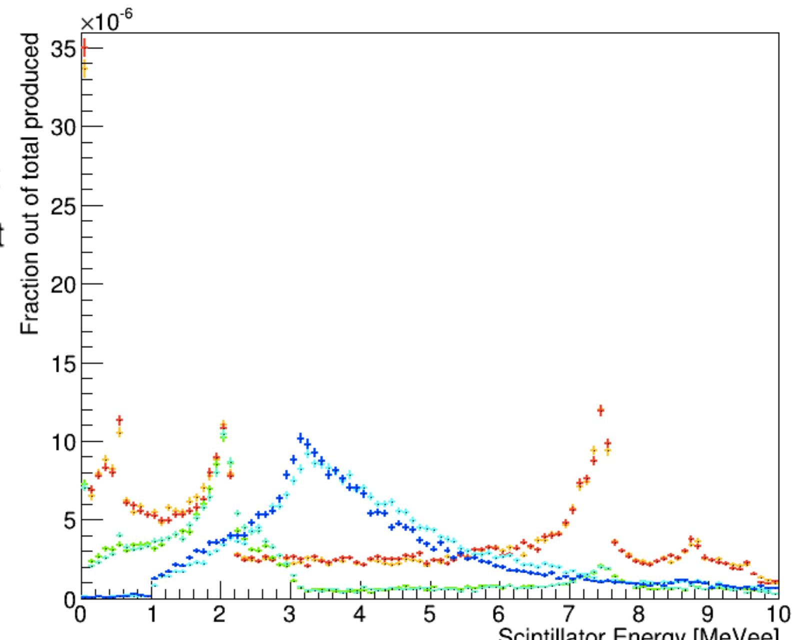
Selections	Any E(Scint)	E(Scint)<0.2 MeVee	E(Scint)<0.1 MeVee
Any E(Crystal)	3.0E-03	1.3E-03	1.1E-03
	3.7E-03	1.6E-03	1.4E-03
E(Crystal)< 6 keVee	3.0E-06	3.0E-07	2.0E-07
	3.8E-06	4.0E-07	2.8E-07

Passive Rejection (neutron)

- <0.05% of neutrons reaches the crystals
- Thermal neutrons generate the larger fraction of detectable signals
- Some thermal neutrons generate also small deposits in the scintillator (harder to veto)







Active Veto (Neutron)

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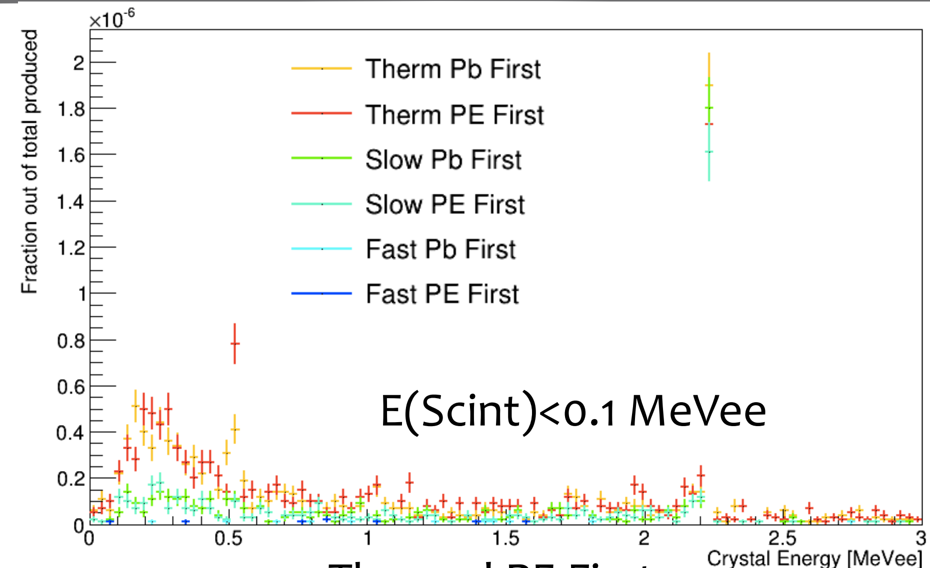
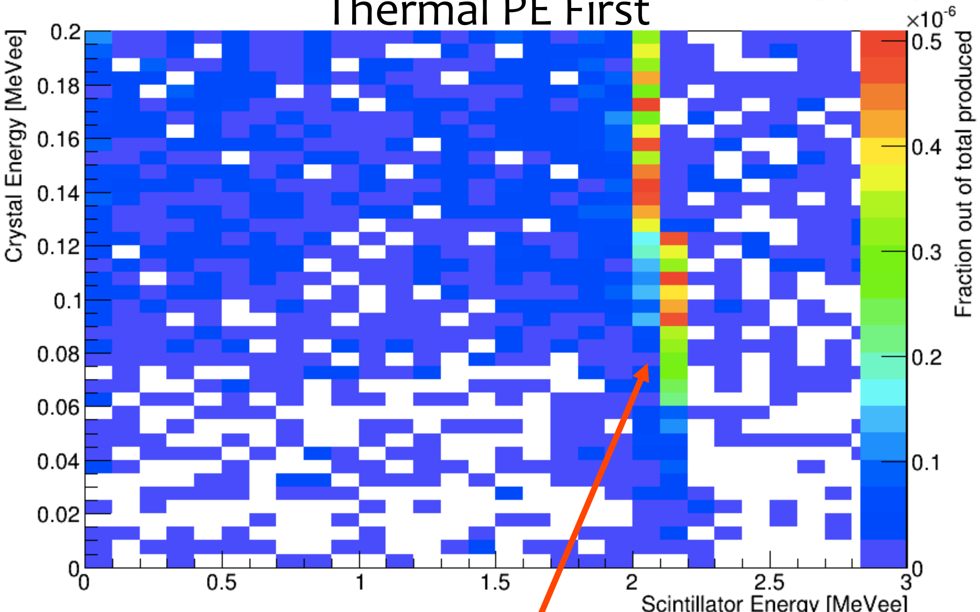


Thermal PE First



Neutron capture in H

- Fraction of events with E(Crys)<6 keVee is O(E-07)
- Veto reduces thermal and slow neutrons 10-30 times and fast neutrons up to 500 times

Fraction of surviving neutrons

Pb First

PE First

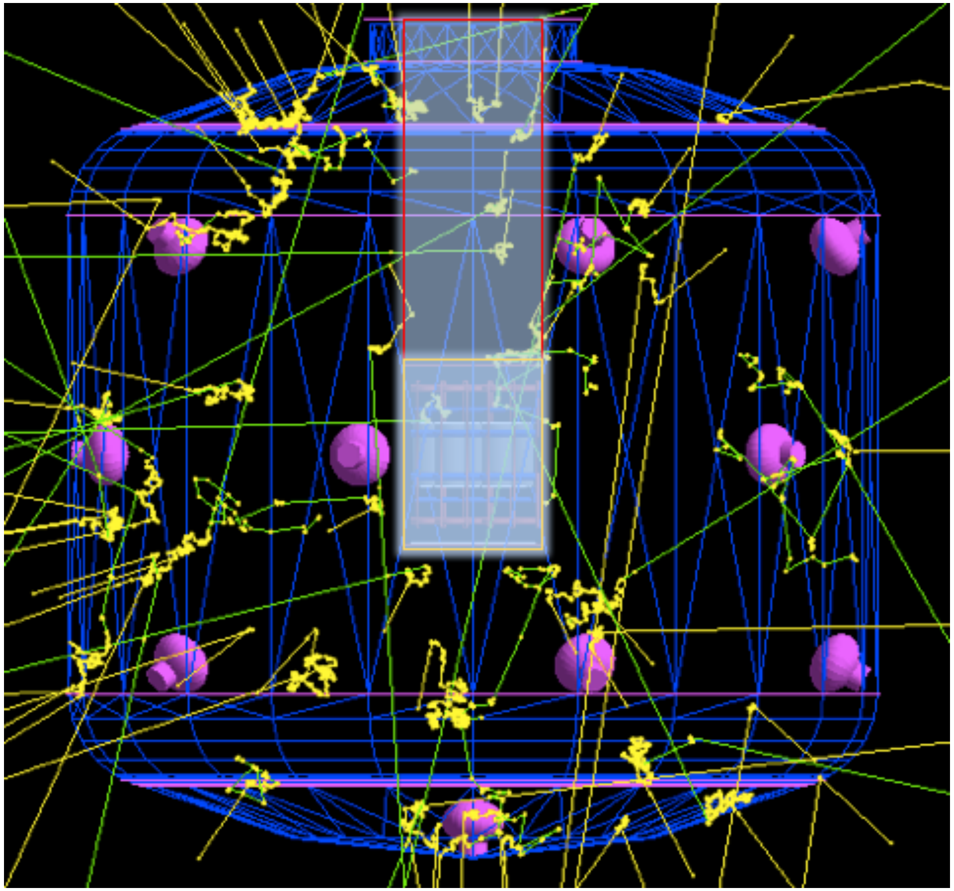
Selections	Thermal	Slow	Fast*
Any Energy	4.7E-04	1.9E-04	3.1E-04
	4.7E-04	2.0E-04	3.0E-04
E(Scint)<0.2 MeVee	4.0E-05	9.6E-06	1.2E-06
	4.2E-05	9.1E-06	1.2E-06
E(Scint)<0.1 MeVee	3.4E-05	7.3E-06	5.3E-07
	3.5E-05	7.3E-06	3.7E-07
E(Crys)<6 keVee	4.2E-07	1.9E-07	4.2E-07
	4.7E-07	3.3E-07	3.2E-07
E(Crys)<6 keVee & E(Scint)<0.2 MeVee	1.0E-08	<1.0E-08	2.0E-08
	2.0E-08	<1.0E-08	1.0E-08
E(Crys)<6 keVee & E(Scint)<0.1 MeVee	1.0E-08	<1.0E-08	1.0E-08
	2.0E-08	<1.0E-08	<1.0E-08

*QF=0.2 is applied to correct both crystal and scintillator deposits

** values in red are not statistically significant. They are limited by the generated statistics (100M)

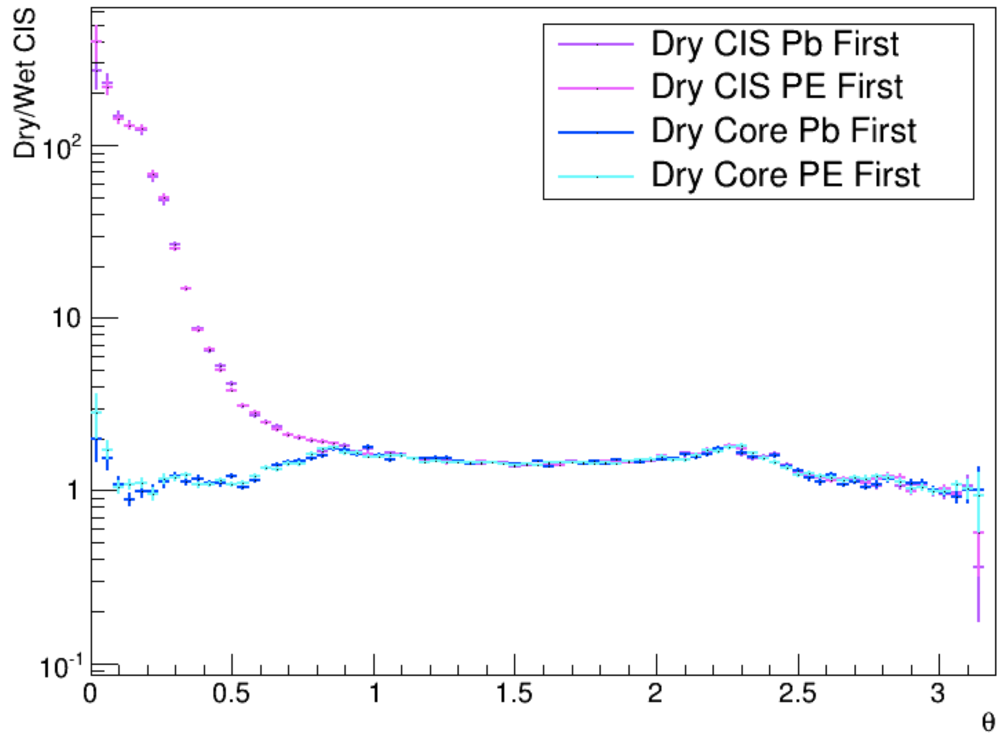
Insertion system

- A dry insertion system implies that a section of the vessel is not sensible to particles
- How worse is background rejection?
- Dry CIS simulated as a hollow cylinder (r= 0.35 m) containing the crystal enclosures and extending up to the top flange
- Another simulation where the hollow cylinder is long enough to contain the enclosures but does not extend upwards is used for comparison (account for the case of a single large enclosure)



INSERTION SYSTEM

- Significant increase in background wit dry CIS
  - 5 times more photons
  - 5-hundred times more neutrons
- If Core is dry, the background increases 1.5-2.0 times



Dry/Wet counts (neutrons)				Dry/Wet counts (photons)			
Sel	Any E(Scint)	E(Scint)<0.2 MeVee	E(Scint)<0.1 MeVee	Sel	Any E(Scint)	E(Scint)<0.2 MeVee	E(Scint)<0.1 MeVee
Dry CIS	2.8-20	5.2-O(100)	5.5-O(100)	Dry CIS	2.7	4.4	4.8
Dry Core	1.3-1.5	1.5-2.1	1.6-2.1	Dry Core	1.44	1.84	1.92

Expected Background

- An upper limit on the expected backgrounds can be estimated multiplying the measured flux of photons and neutrons by the attenuation factors in the shielding and the vessel

Rejection power		
	Photons	Neutrons
Shielding	1.5E-04	3.0E-01
Veto	1.4E-03	3.5E-05
Veto and E(Crys)<6keVee	2.8E-07	2.0E-08
Total	4.2E-11	6.0E-09

Flux @ SUPL ($cm^{-2}s^{-1}$)	
Photons	Neutrons
2.5	7.0E-06

Background (cpd/keVee)	
Photons	Neutrons
9.2E-01	3.7E-04

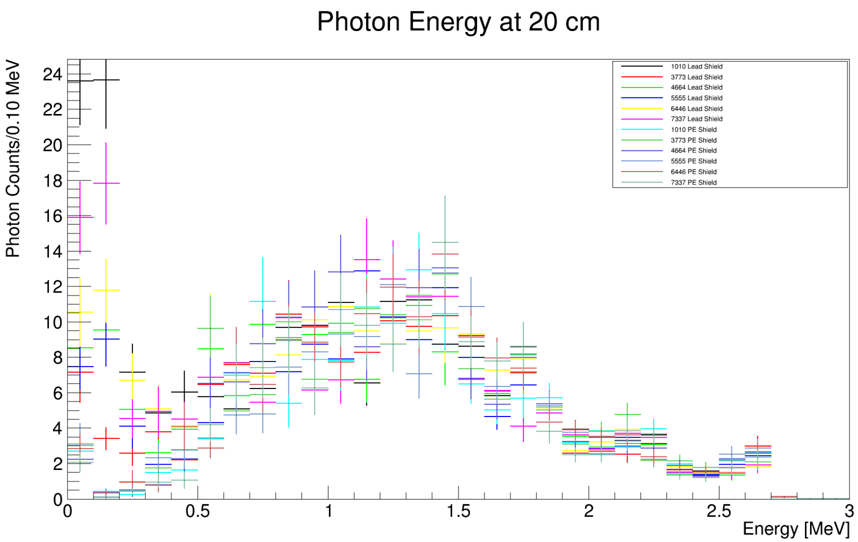
- This estimate is very very conservative because:
  - 100% geometrical acceptance assumed, i.e. particles were generated pointing to the crystal in both shielding and vessel simulations. From a rough estimate this should be around 5%
  - The worst shielding and vessel rejection powers were used

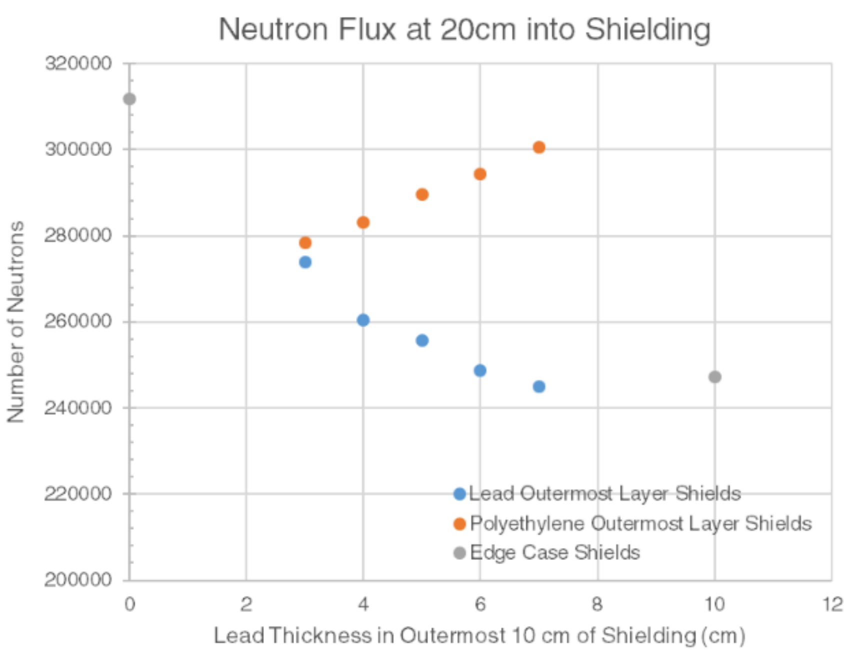
Conclusion

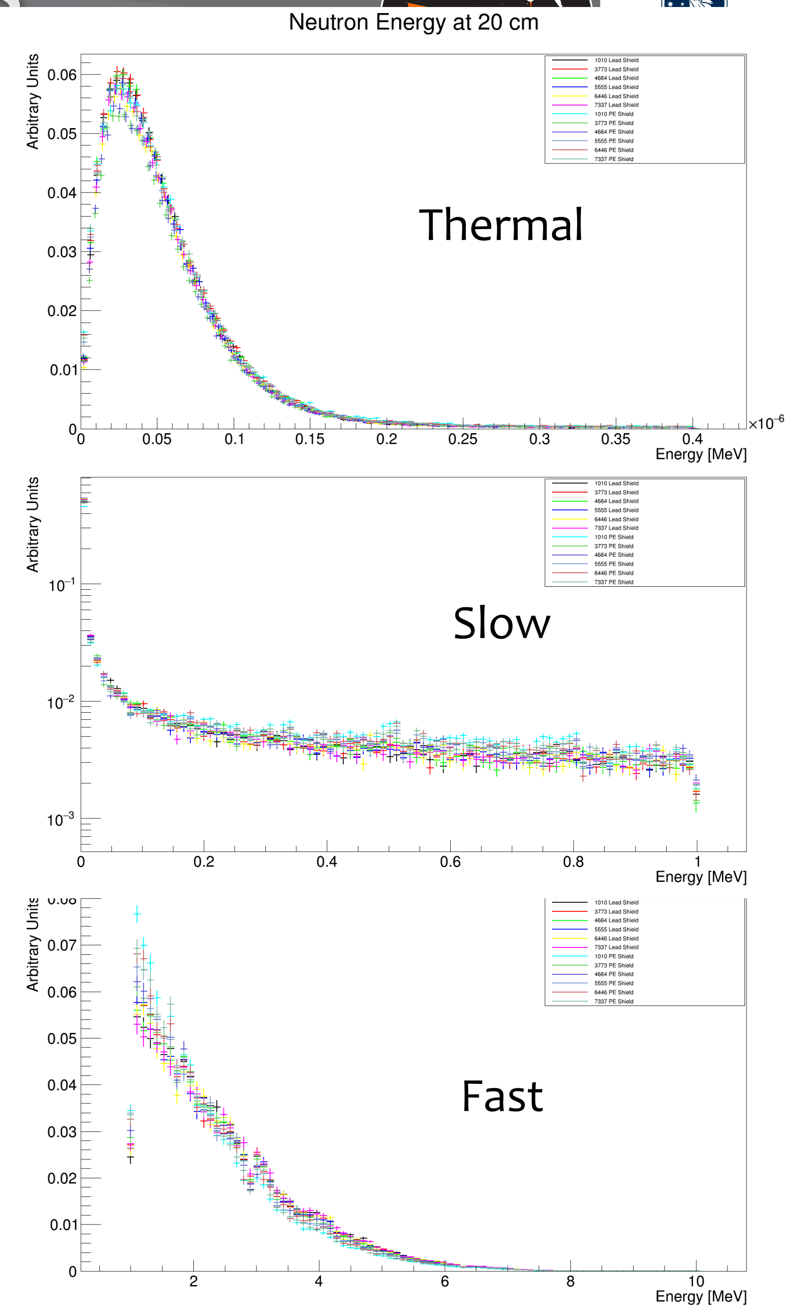
- We studied the attenuation power against photons and neutrons of
  - 20 cm thick PE+Pb shieldings
  - the vessel for (SUPL) full scale experiment
  - CIS
- The background in Dark Matter measurement mode due to radiogenic background expected to be <<1cpd/keVee
- Need to improve passive shielding against photons

Backup

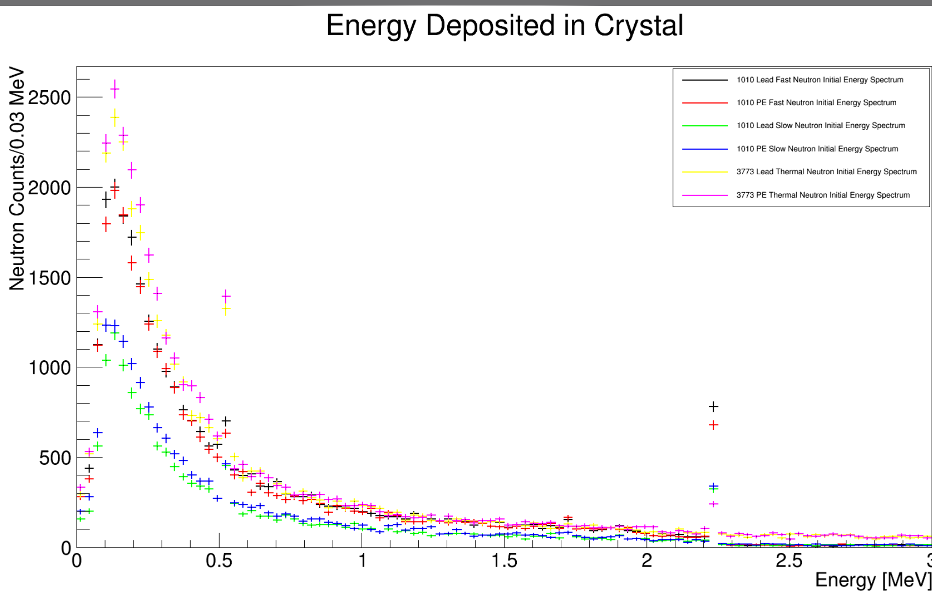
Shielding Simulations

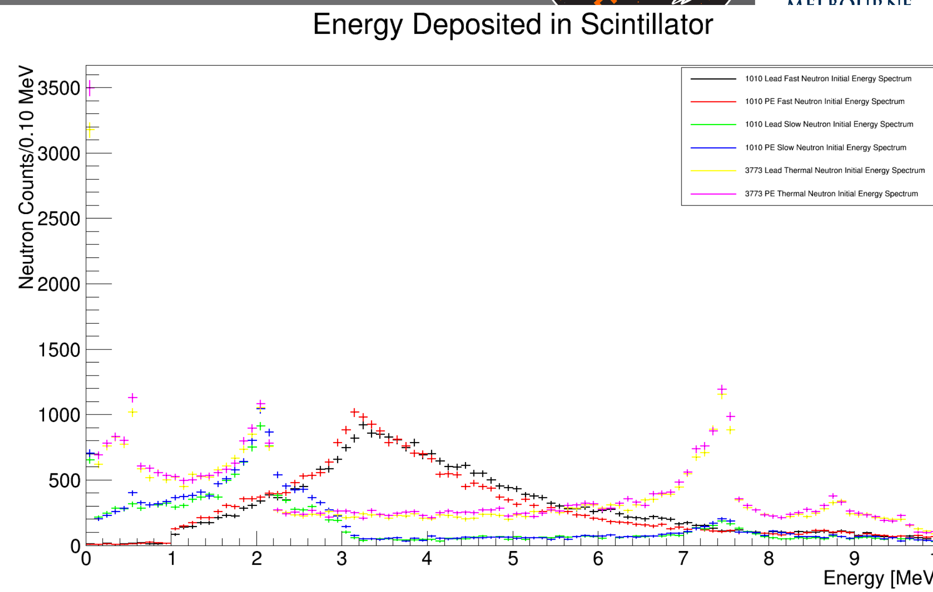


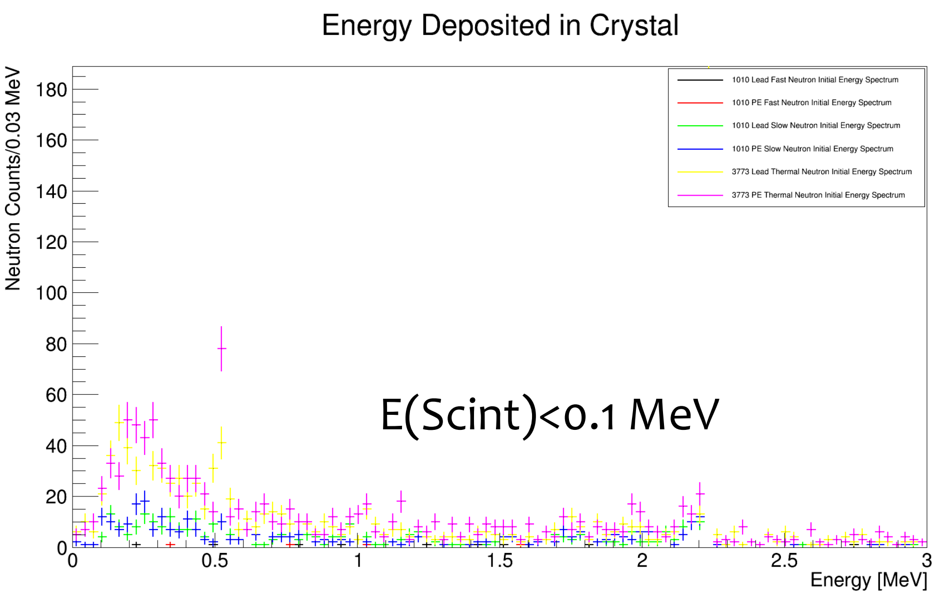




Vessel Simulations (Neutron)







100M events simulated

Fraction in crystal E<30KeV
<e-07 events