Background model for the IAXO experiment

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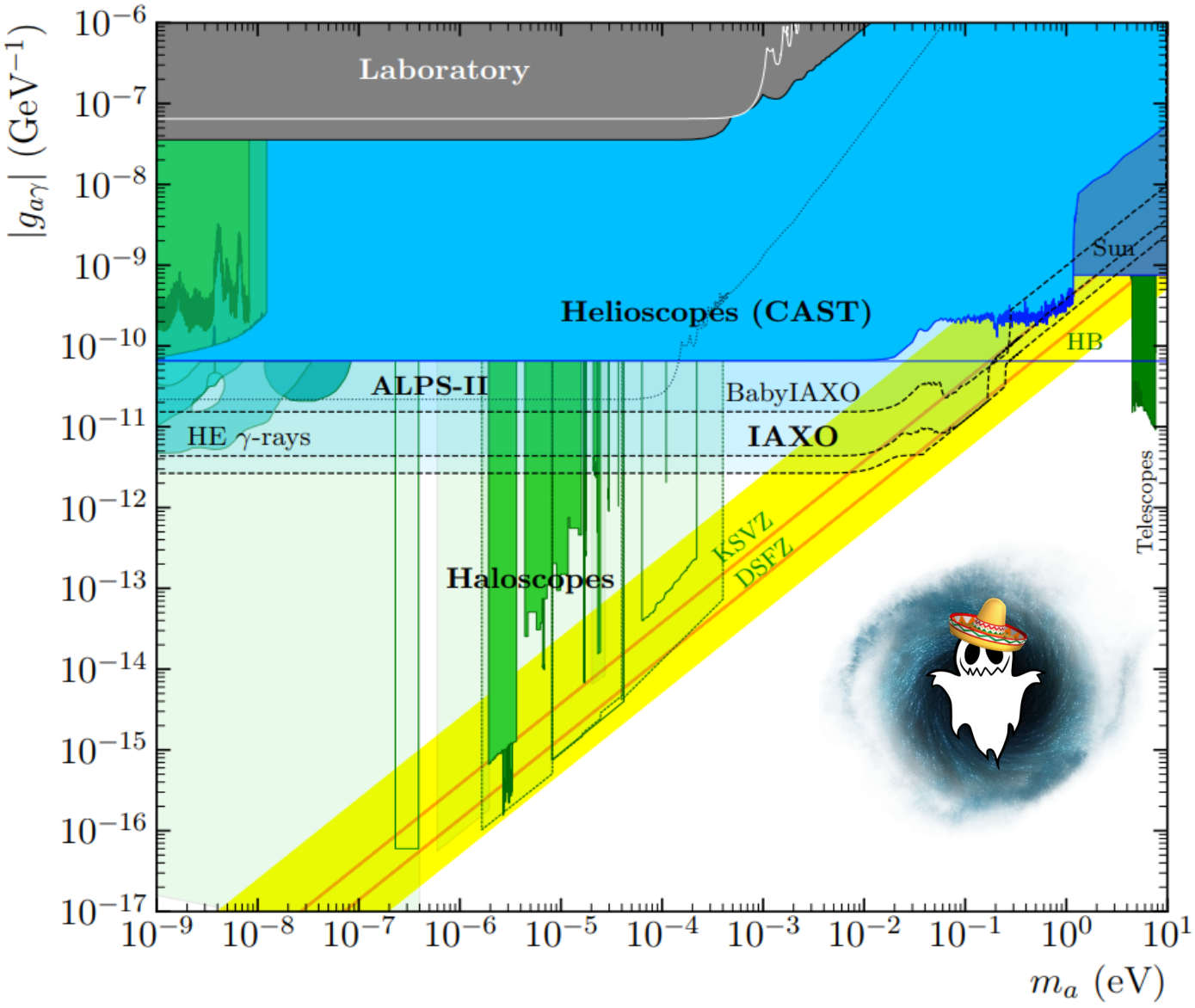
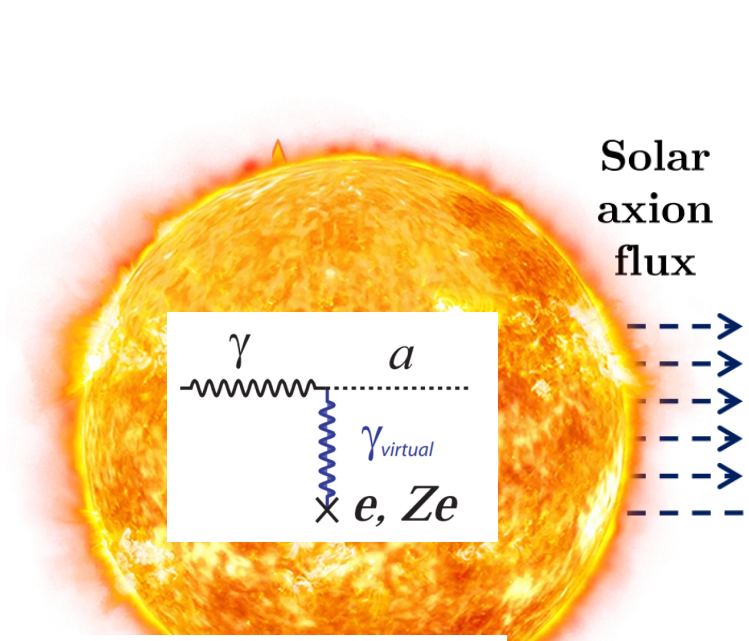
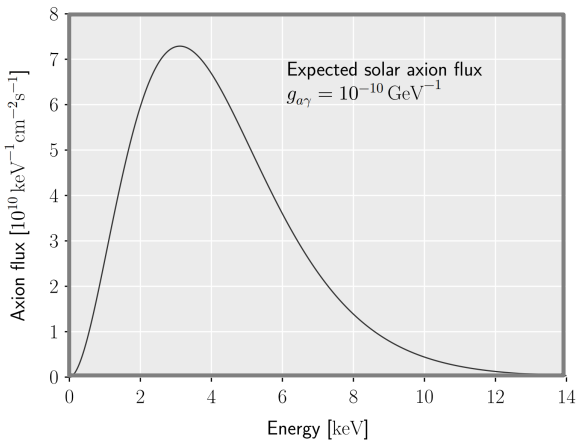
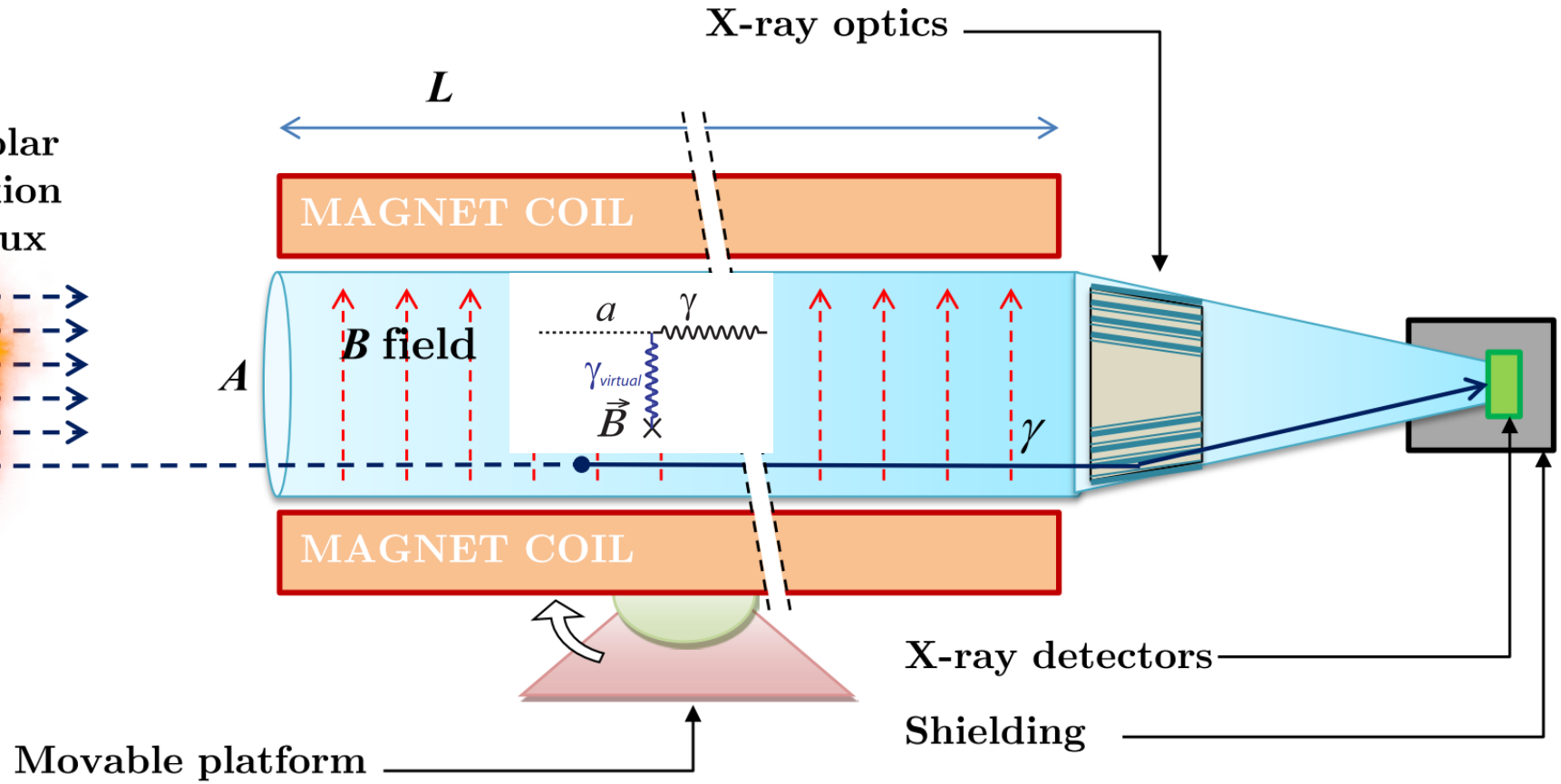
- Elegant solution to the Strong CP Problem of the SM
- Very weakly interacting, light, long-lived
- Dark Matter candidate
- Relevant parameter space at reach
- Hinted by astrophysical data (HE-γ transparency, stellar cooling…)
- More generic ALPs (axion-like particles) predicted by many theories



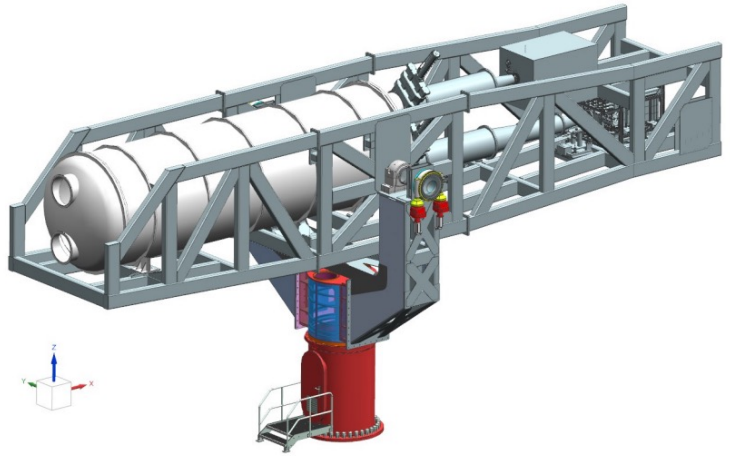


Solar axion flux

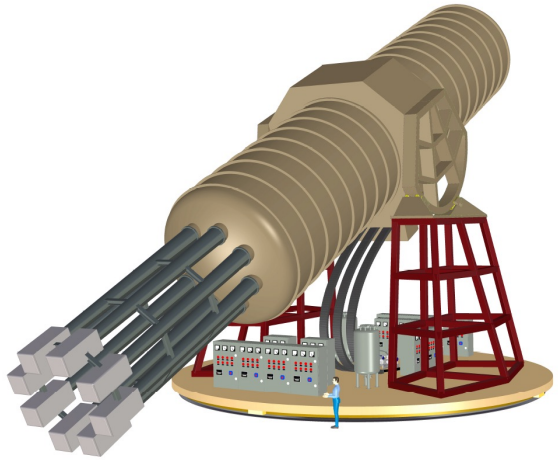




CAST	
Tracking Time	2 x 1.5h / 24h
Magnetic Field	9 T
Length (B)	9.3 m
# Magnet Bores	1*
$f_M\ [T^2m^4]$	21



BabyIAXO	
Tracking Time	12h / 24h
Magnetic Field	~ 2 T
Length (B)	9.3 m
# Magnet Bores	2
$f_M\ [T^2m^4]$	~ 230



IAXO	
Tracking Time	12h / 24h
Magnetic Field	~ 2.5 T
Length (B)	21 m
# Magnet Bores	8
$f_M\ [T^2m^4]$	~ 6000

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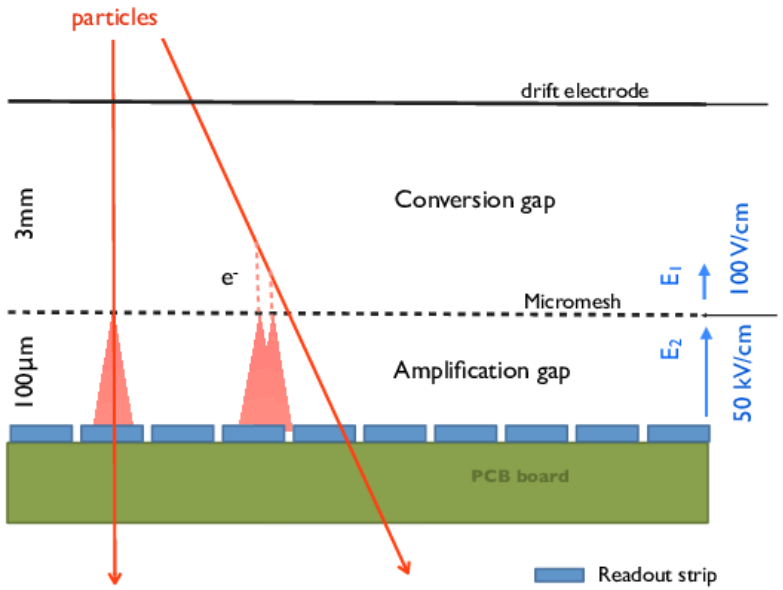
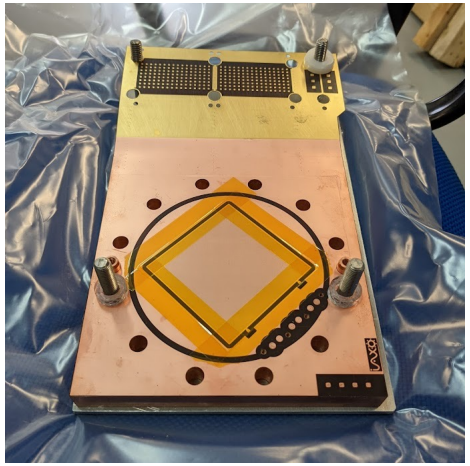
Requirements

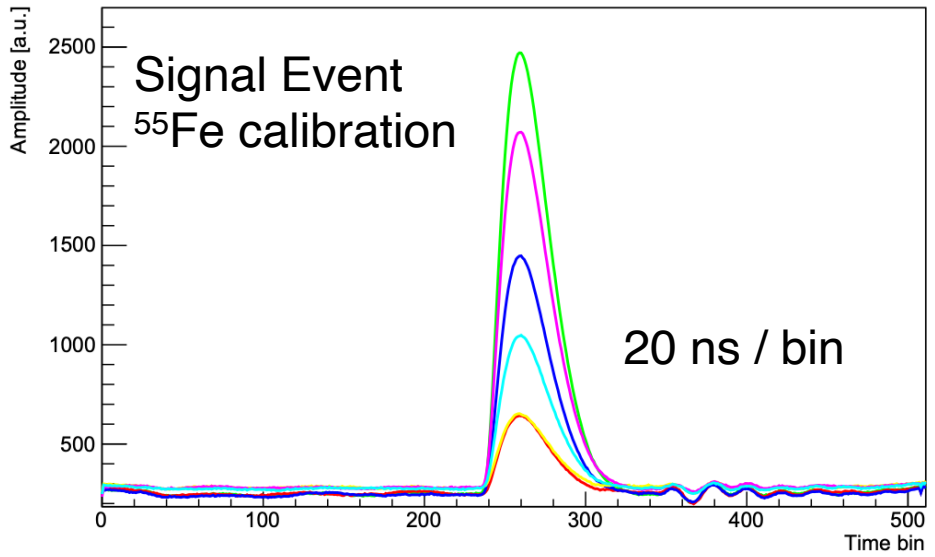
- High efficiency in 0-10 keV (X-ray) RoI (solar axion spectrum)
- Very low background in RoI: < 10^{7} counts $keV^{-1}cm^{-2}s^{-1}$

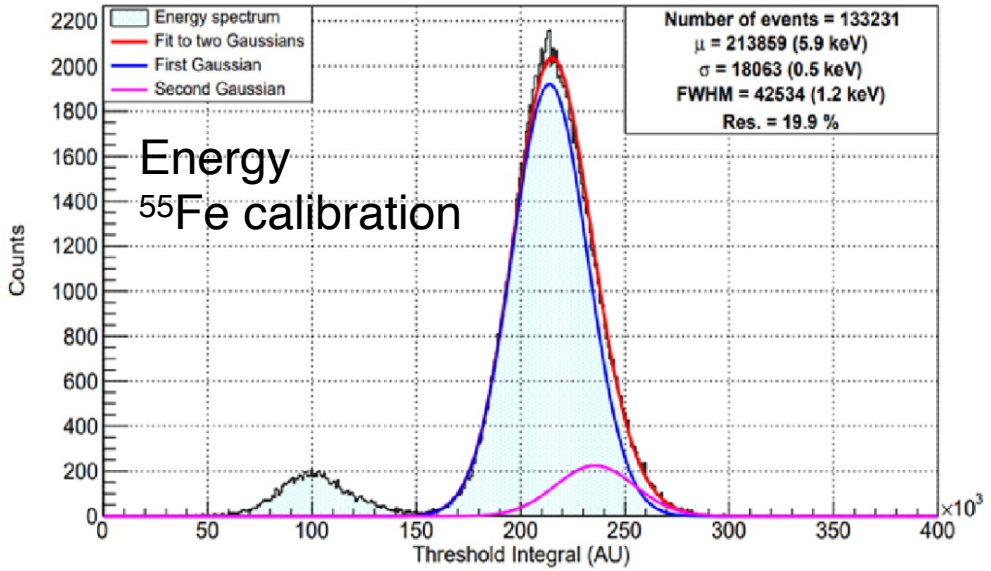
Micromegas Detector

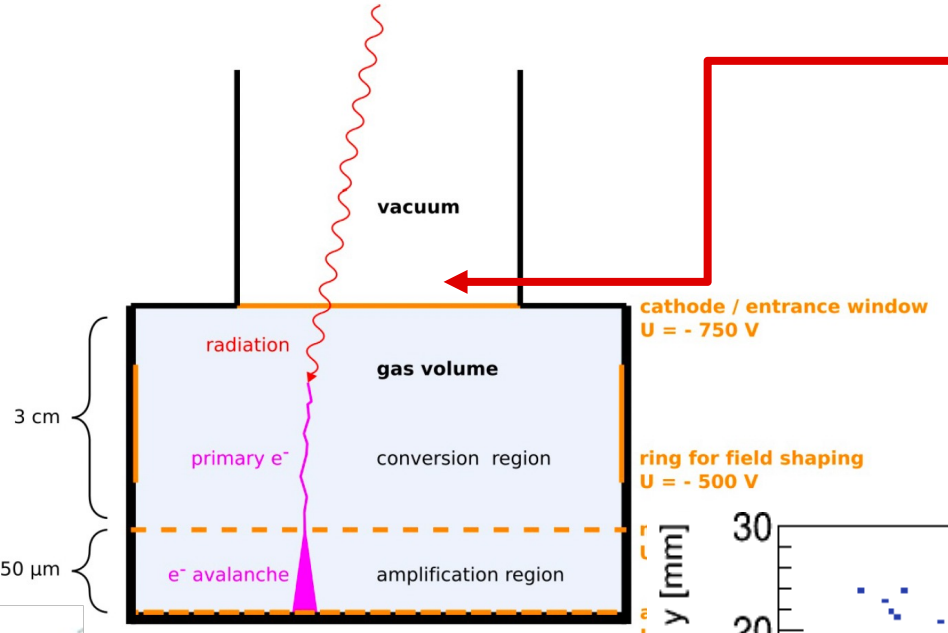
- Gaseous TPC
- Micropattern readout
- Proven technology (CAST)

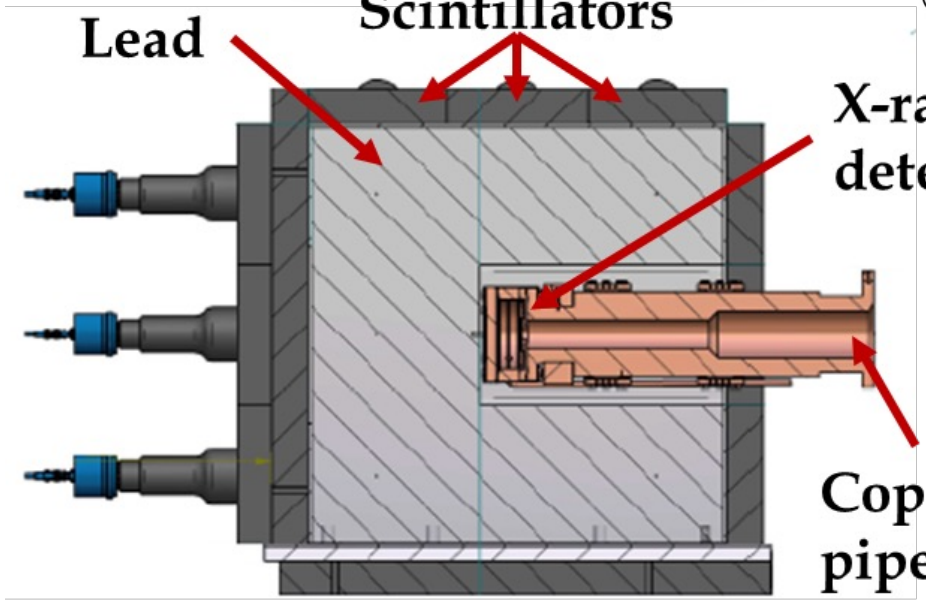


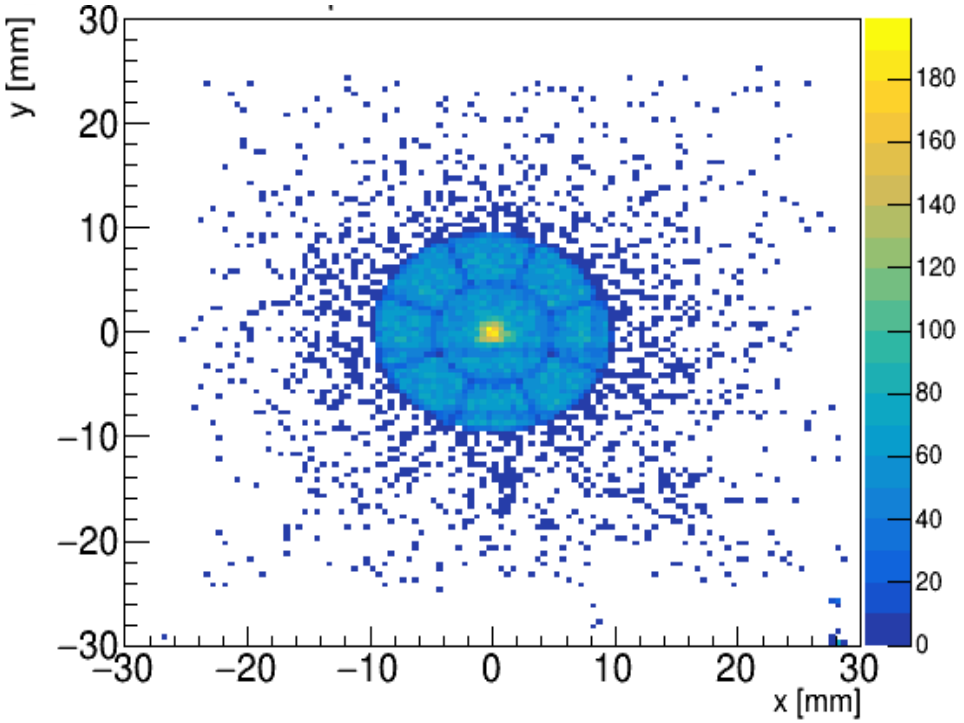







vacuum
cathode / entrance window
U = - 750 V
radiation
gas volume
3 cm
primary e⁻
conversion region
ring for field shaping
U = - 500 V
50 µm
e⁻ avalanche
amplification region


Lead
Scintillators
X-ray detector
Copper pipe


y [mm]
x [mm]
30
20
10
0
−10
−20
−30
180
160
140
120
100
80
60
40
20
0

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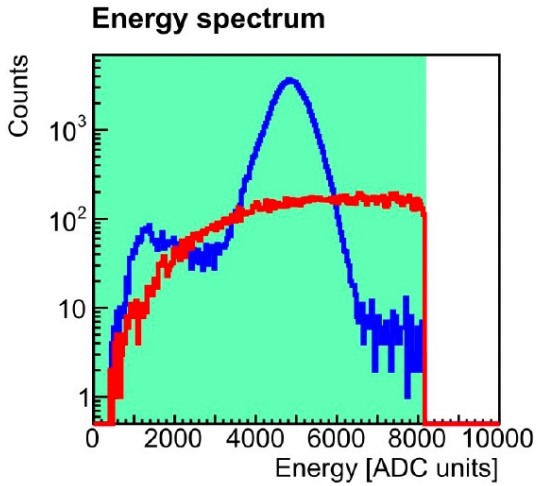
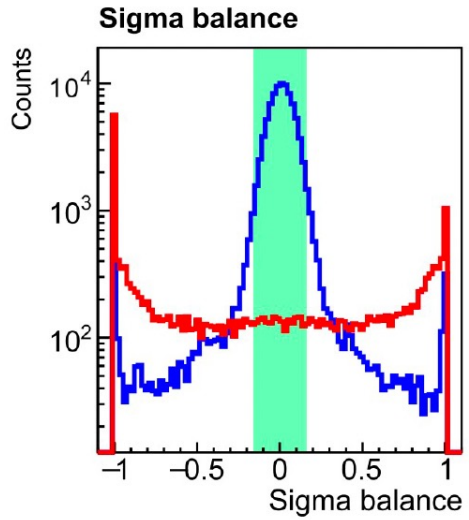
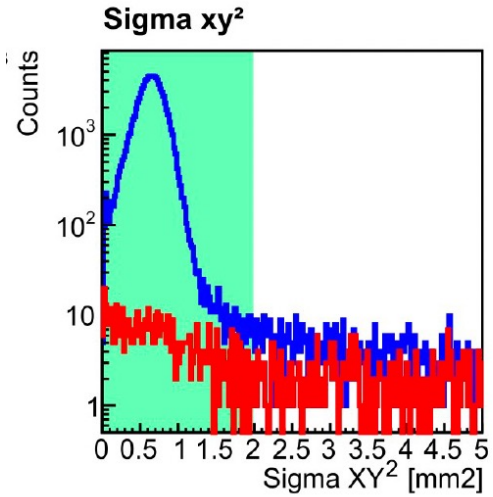
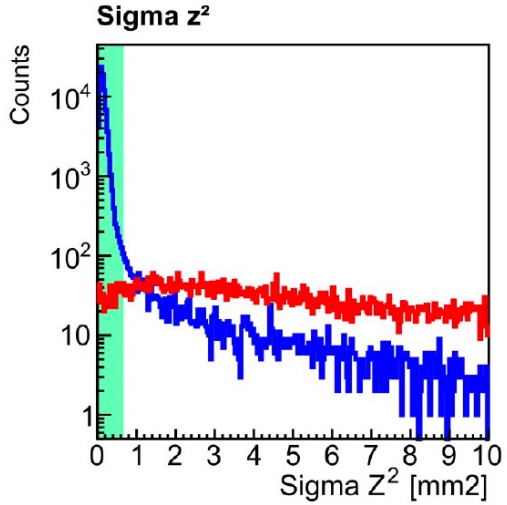
Sample Micromegas discrimination observables

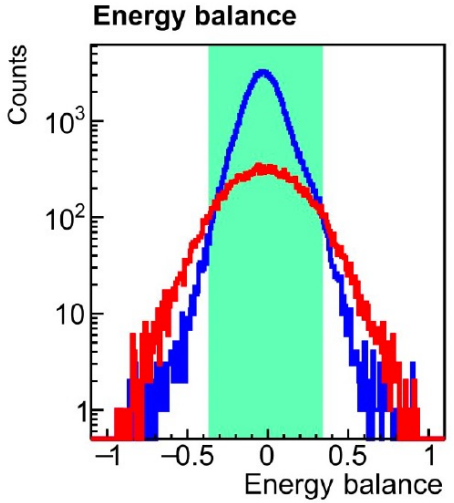
Background vs Calibration











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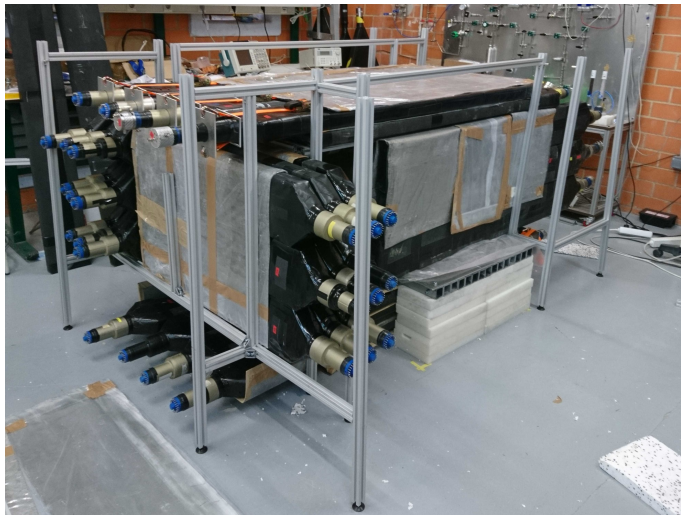
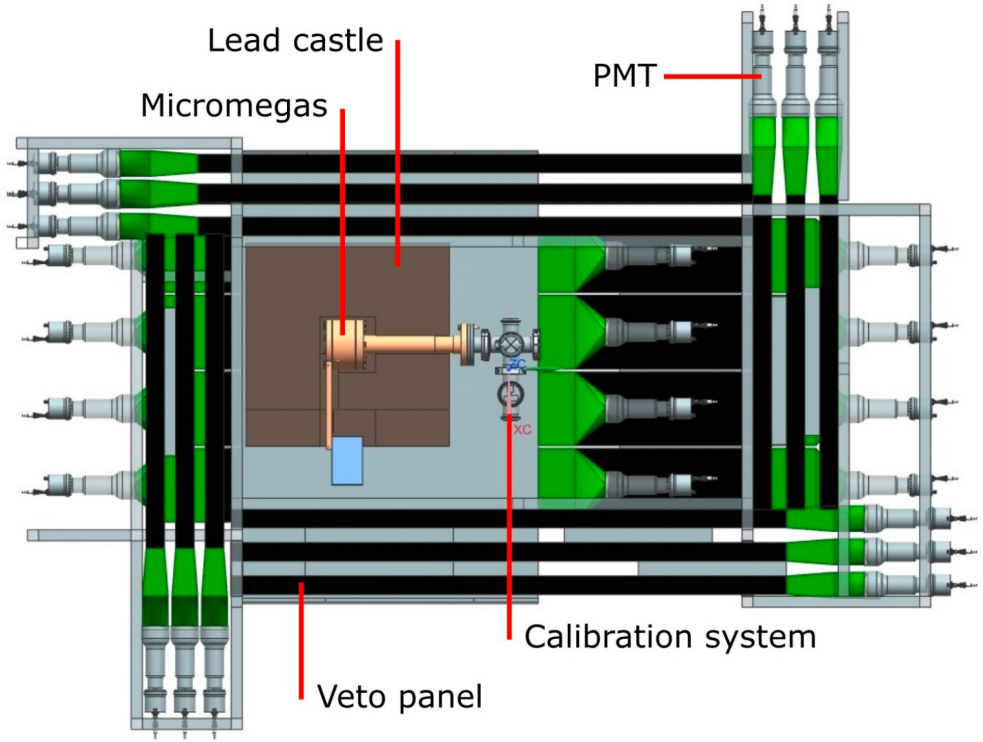
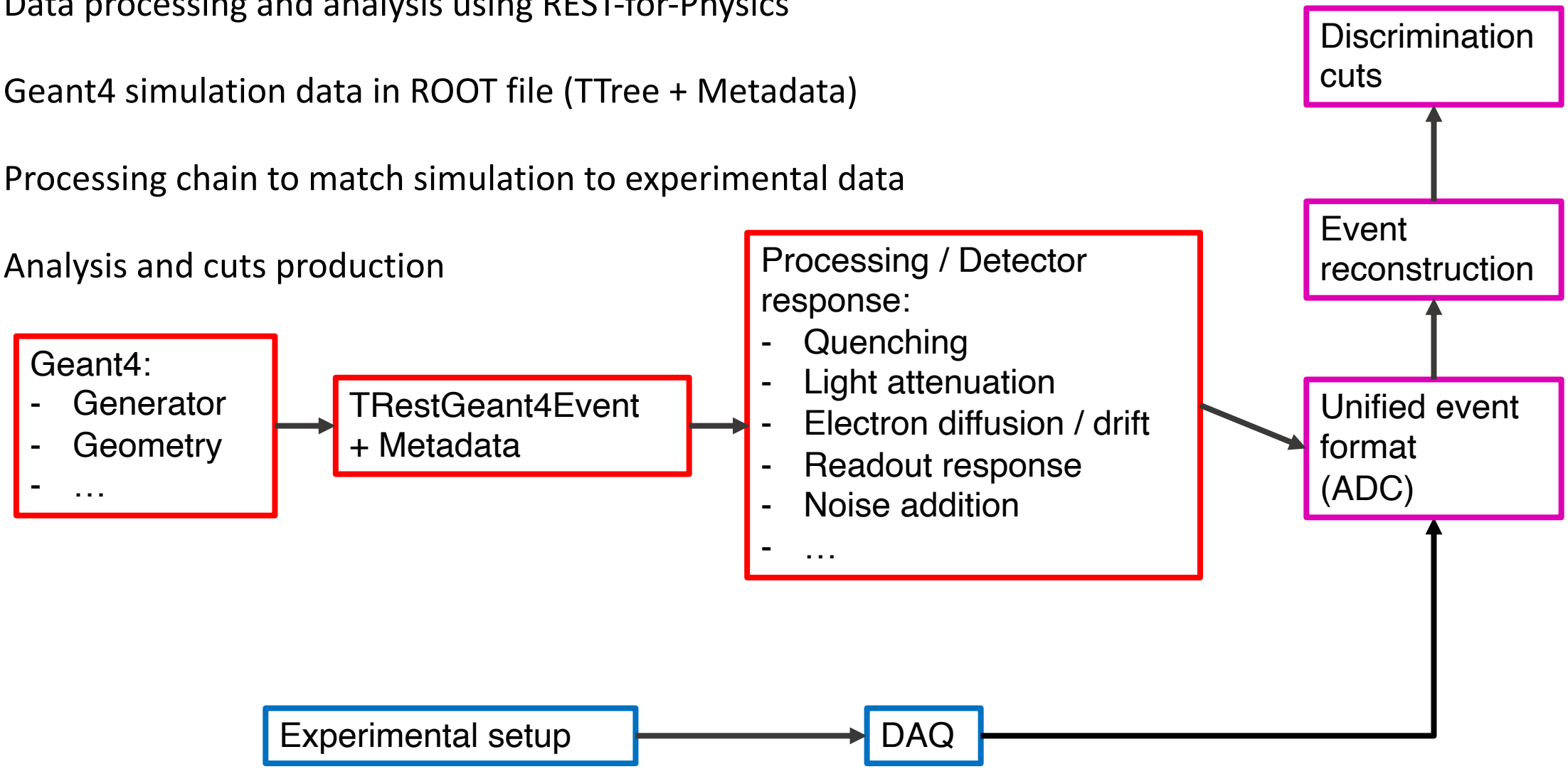
- Rare event search at sea level
- High cosmic ray-induced background
- Cosmic neutrons remain the most challenging
- We developed a prototype veto system (neutron tagger) using existing plastic scintillators
- Working principle: increase efficiency through multiple layers and neutron capture media (cadmium)

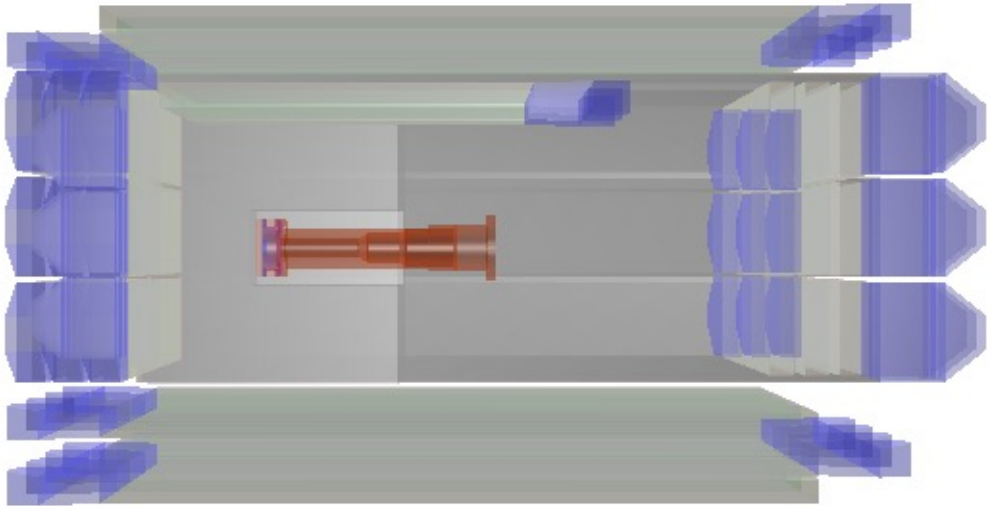


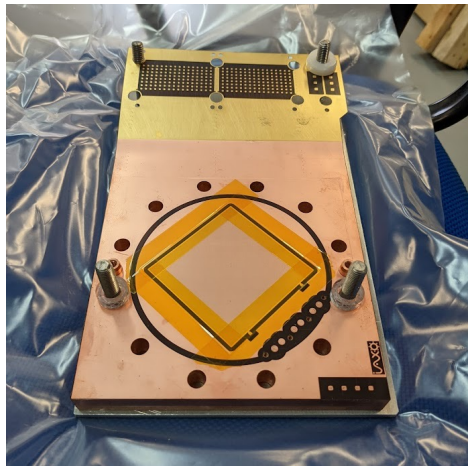


- Data processing and analysis using REST-for-Physics
- Geant4 simulation data in ROOT file (TTree + Metadata)
- Processing chain to match simulation to experimental data
- Analysis and cuts production

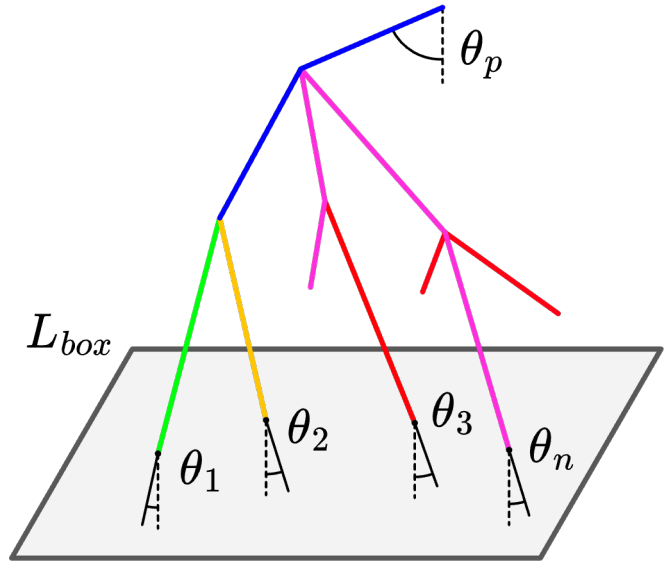


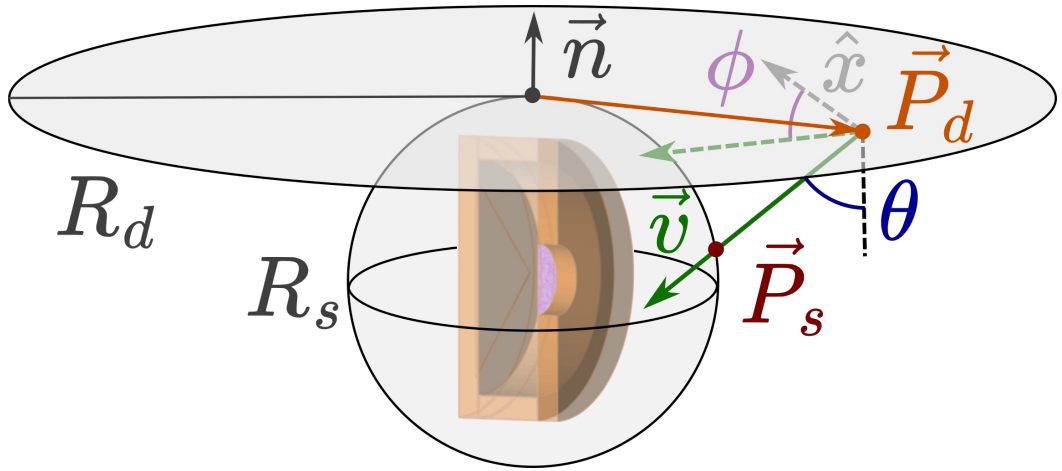
- The detector and surrounding systems are carefully crafted from radiopure materials: copper, Kapton, PTFE…
- Samples of every component are measured for radioactive contamination and inserted into a radiopurity database
- Simulations of every component are combined into the background model for contamination focusing on the following isotopes: ^{210}Pb, ^{238}U, ^{232}Th, ^{40}K, ^{60}Co, …
- Simulations reach an approximate total combined background level of $\sim 1\times10^{-8}\mathrm{keV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ after only applying conservative cuts



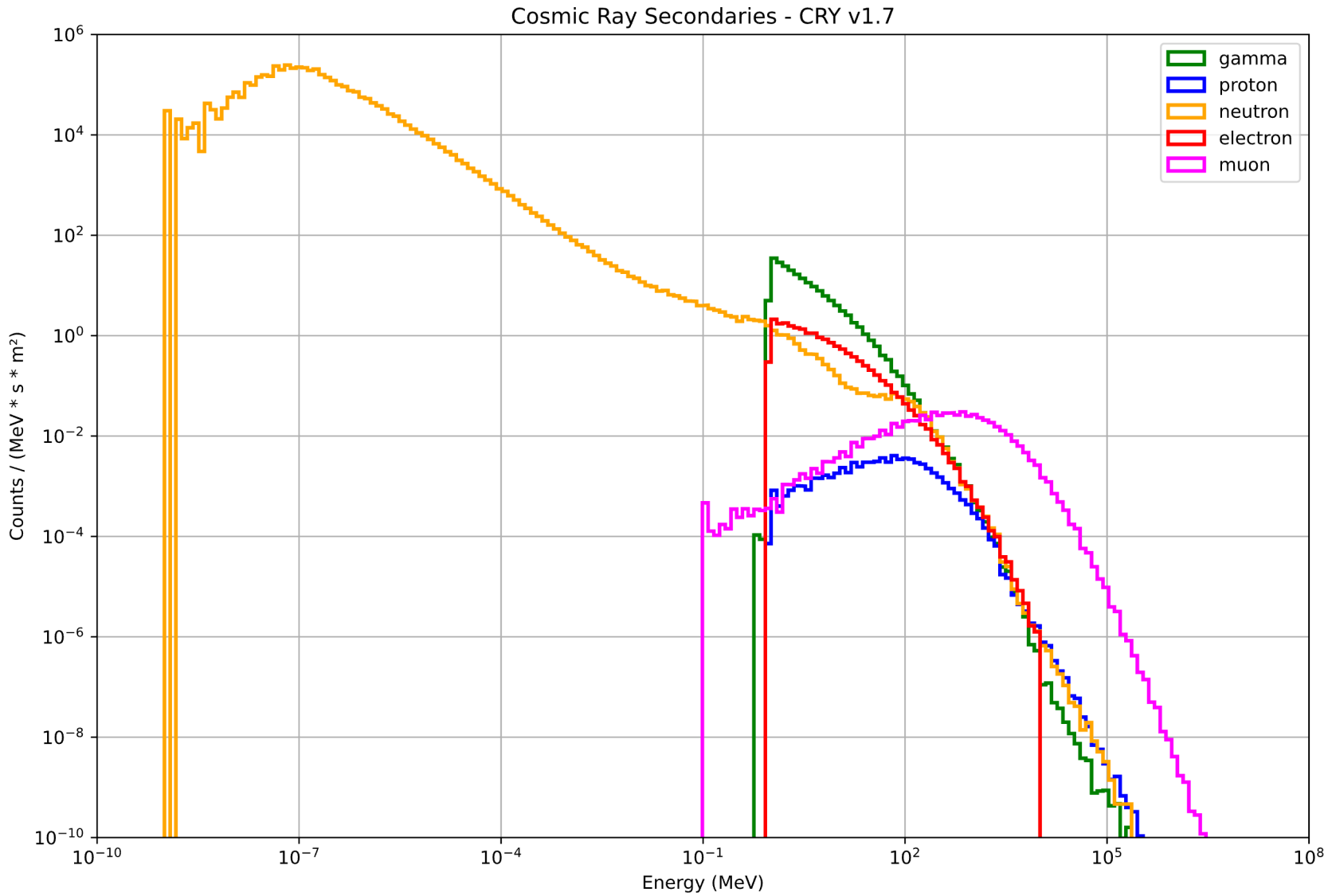


- Use CRY to produce secondaries distributions from primary protons
- Optionally transform this distributions to account for external shielding: concrete ceiling, etc.
- Sample secondaries efficiently following the CRY distributions
- Full simulation of detector and veto system

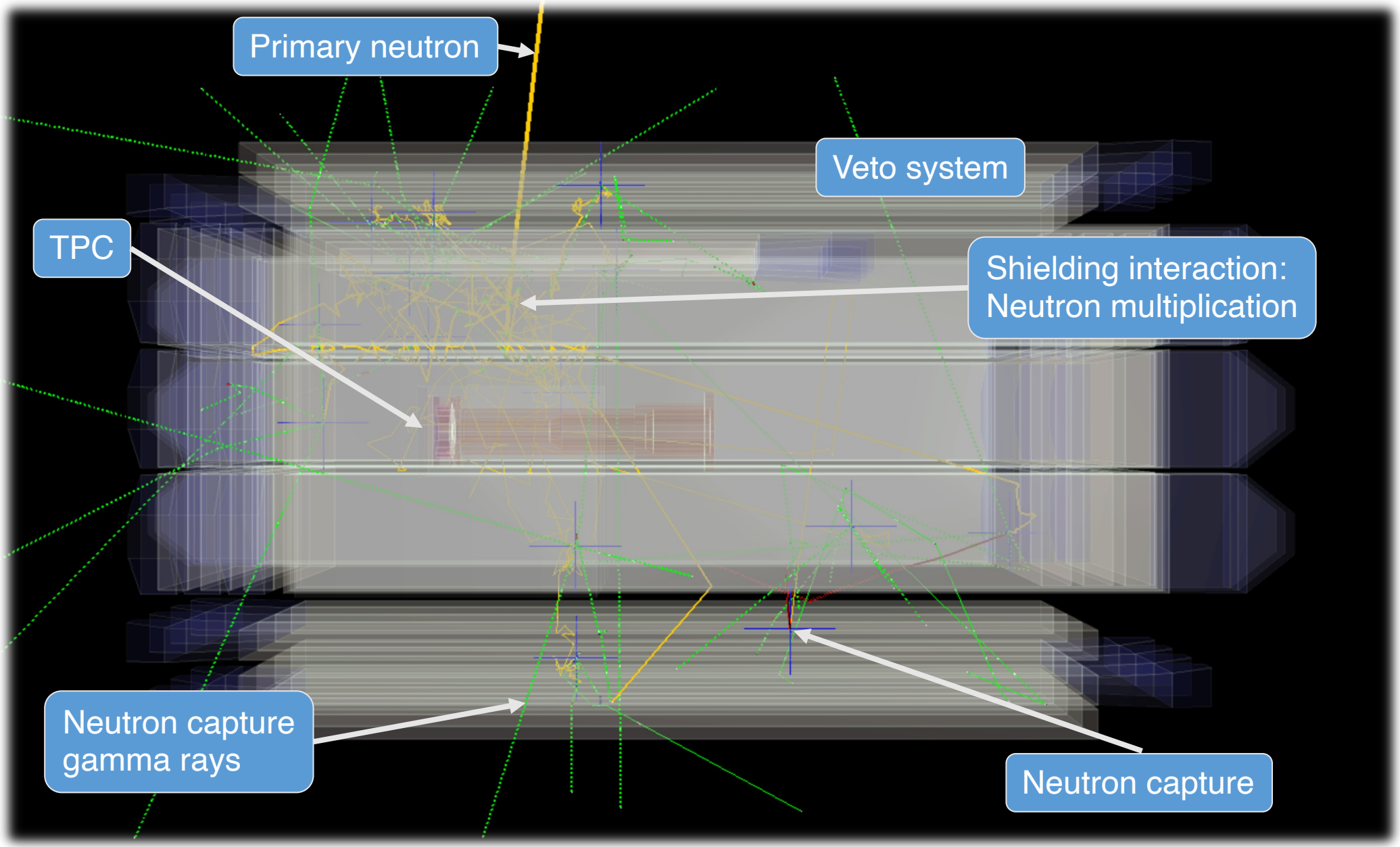


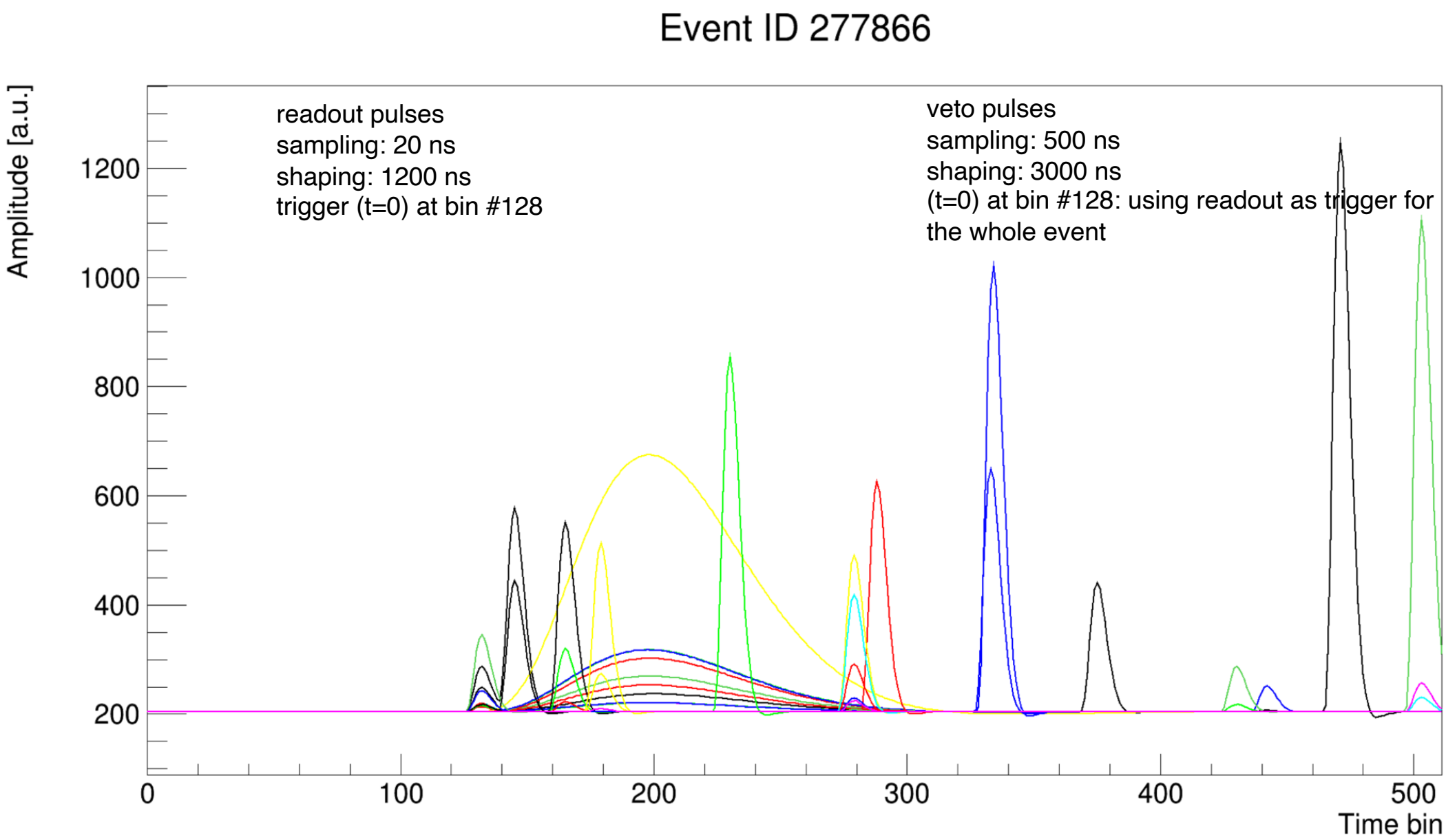


IAXO Background Model: Cosmic background



Cosmic Neutron Event

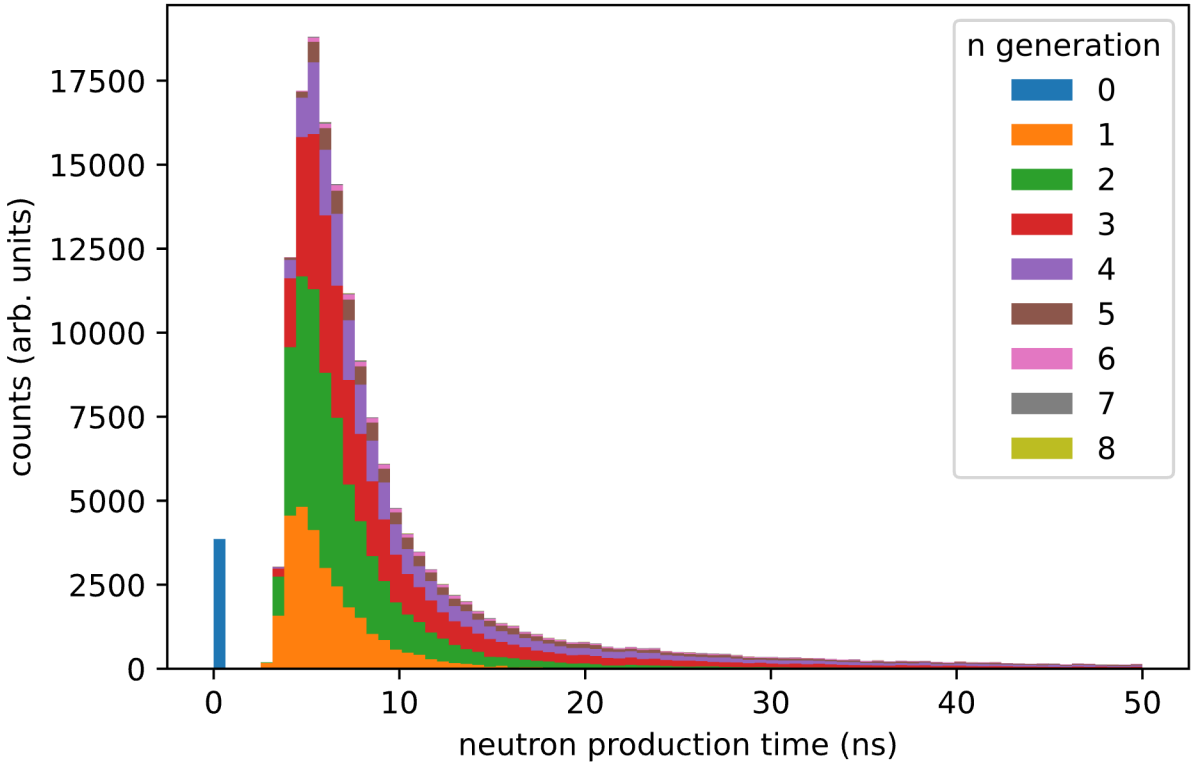


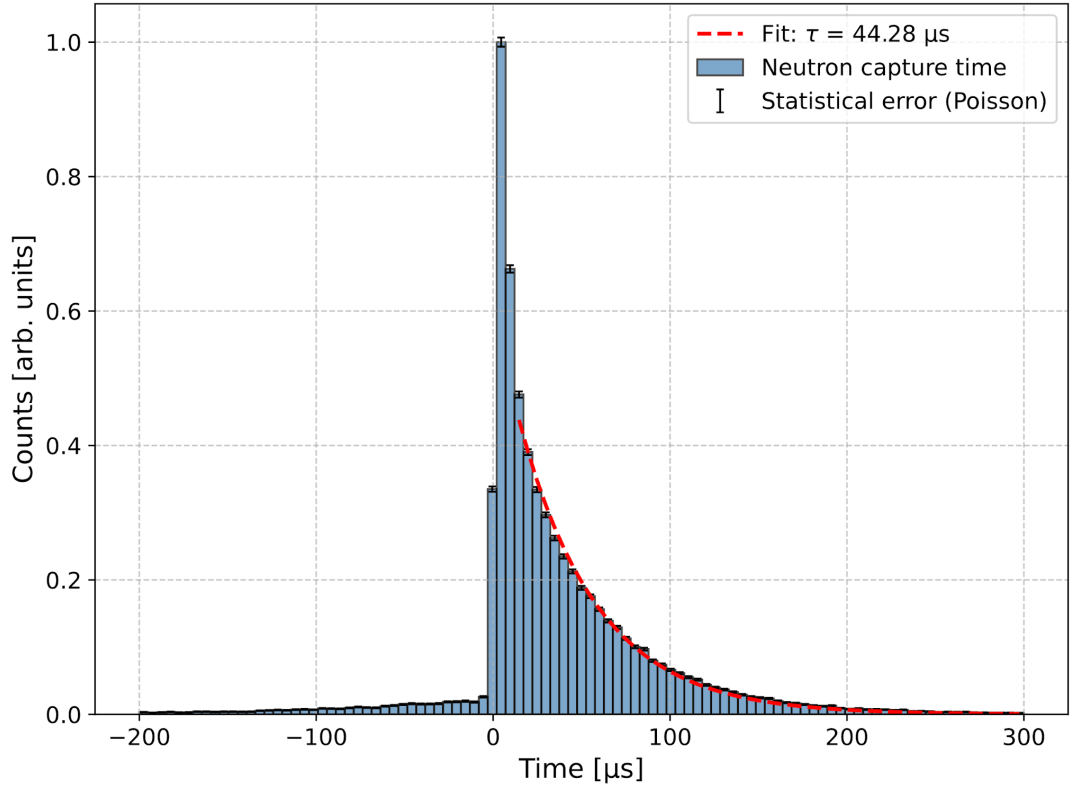

Event ID 277866
readout pulses
sampling: 20 ns
shaping: 1200 ns
trigger (t=0) at bin #128
veto pulses
sampling: 500 ns
shaping: 3000 ns
(t=0) at bin #128: using readout as trigger for the whole event
Amplitude [a.u.]
1200
1000
800
600
400
200
0
100
200
300
400
500
Time bin

The detector time scale is given by the gas drift velocity (order of cm/us)

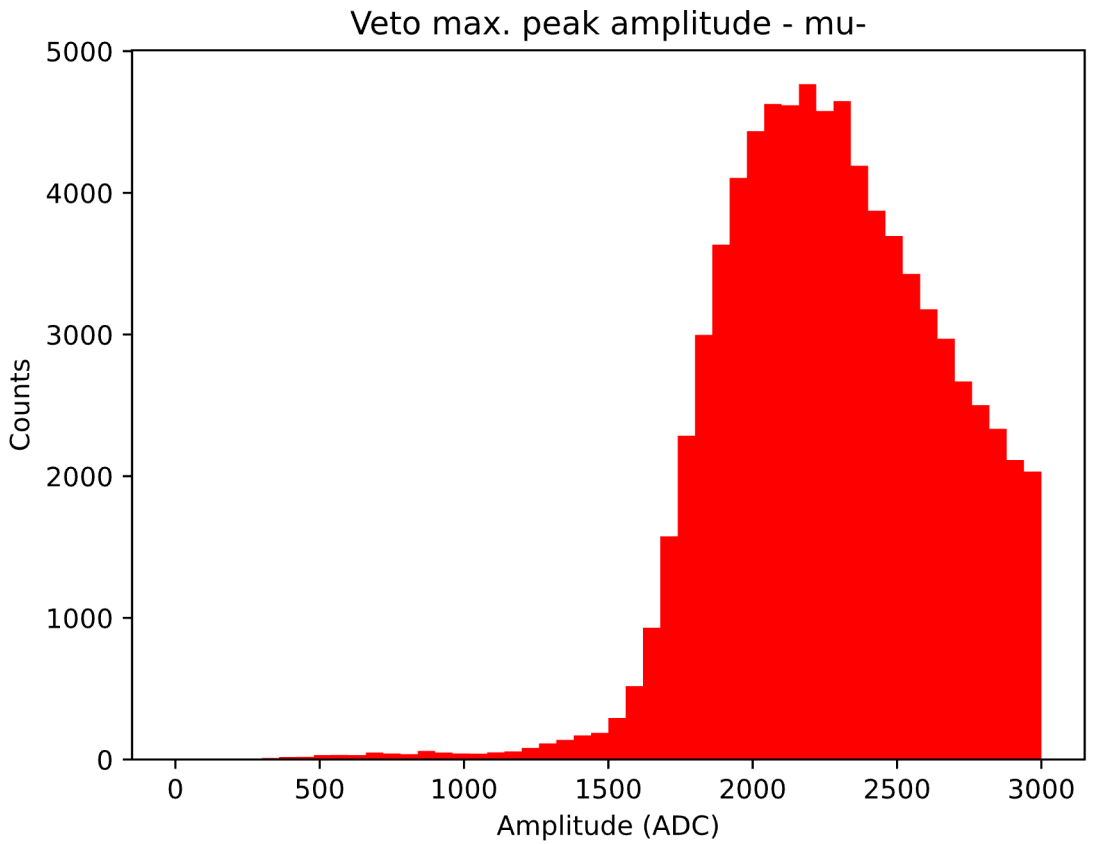
Secondary neutrons are produced virtually instantaneously

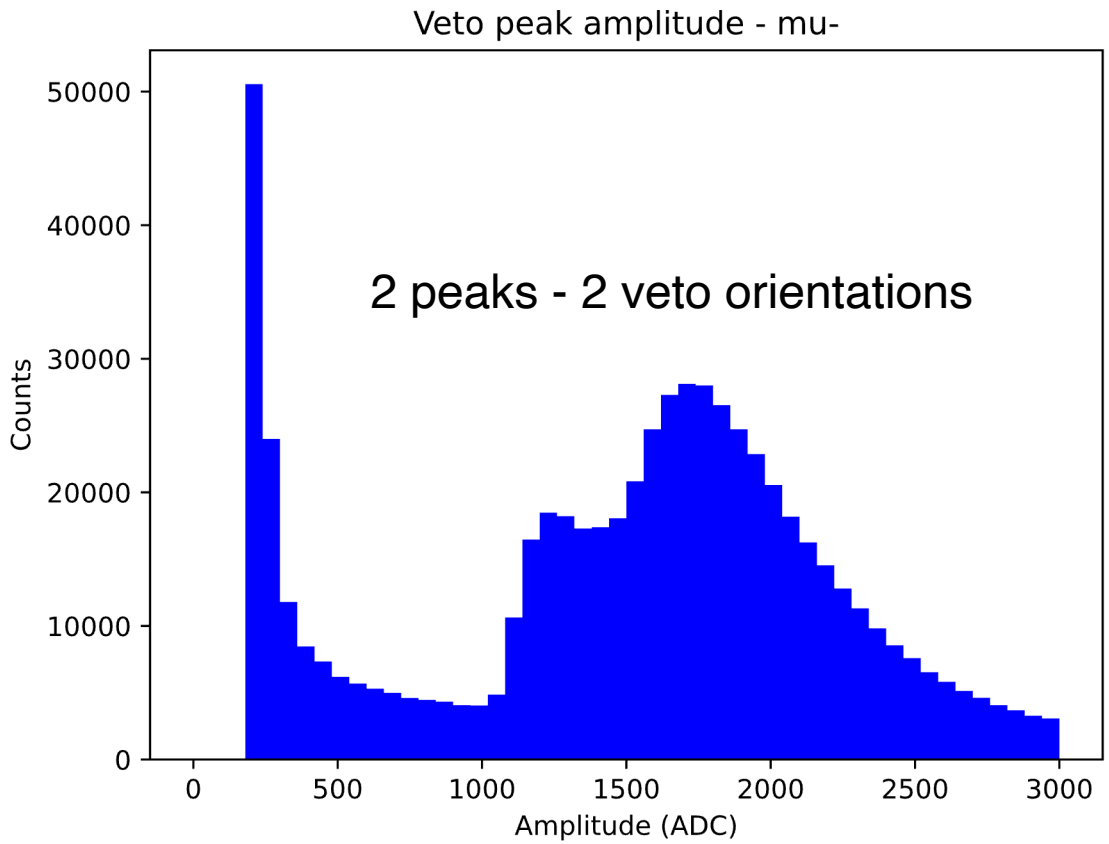
Neutron captures are delayed: need to tune acquisition window



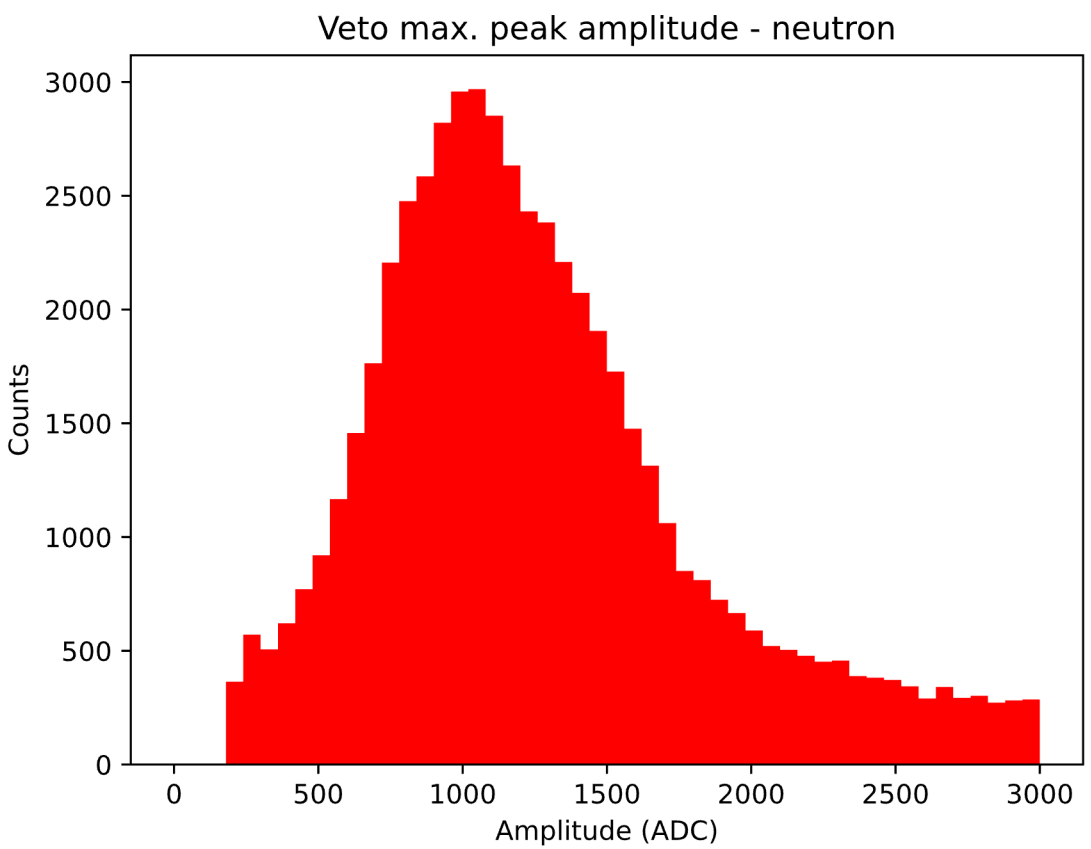


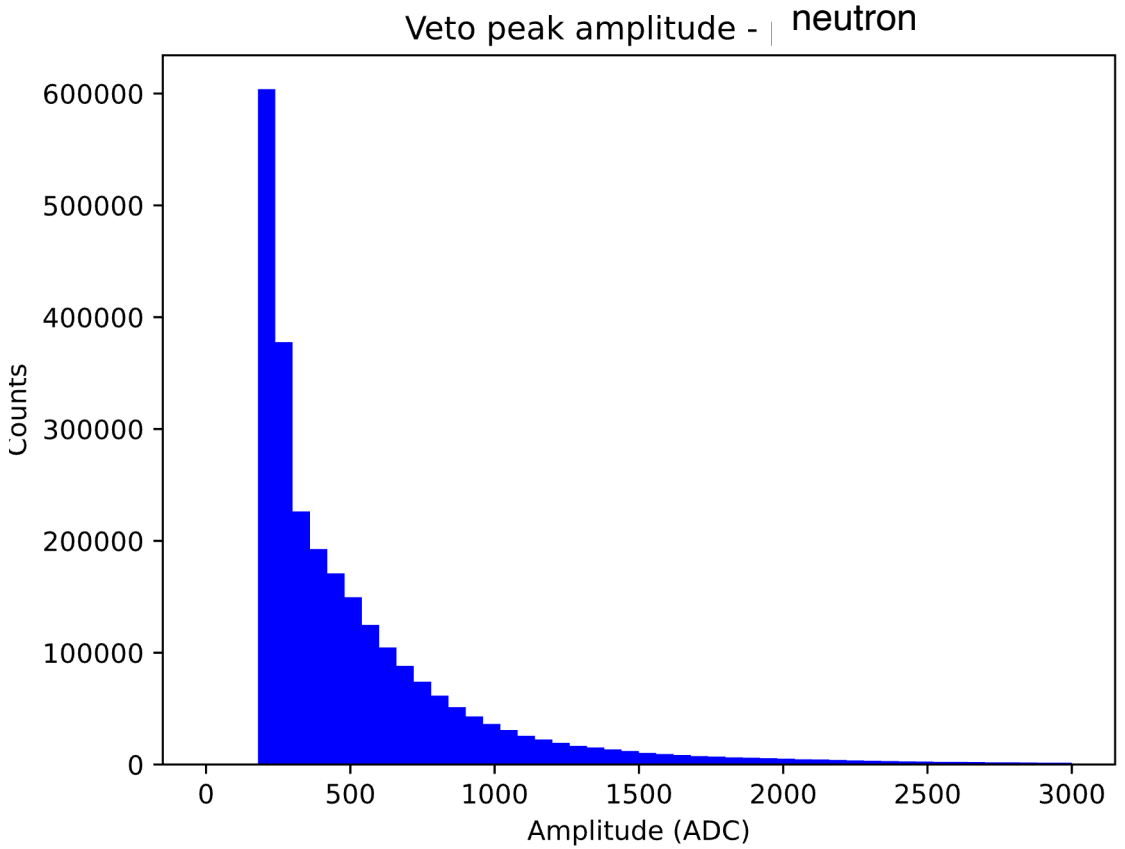
IAXO Background Model: Cosmic background



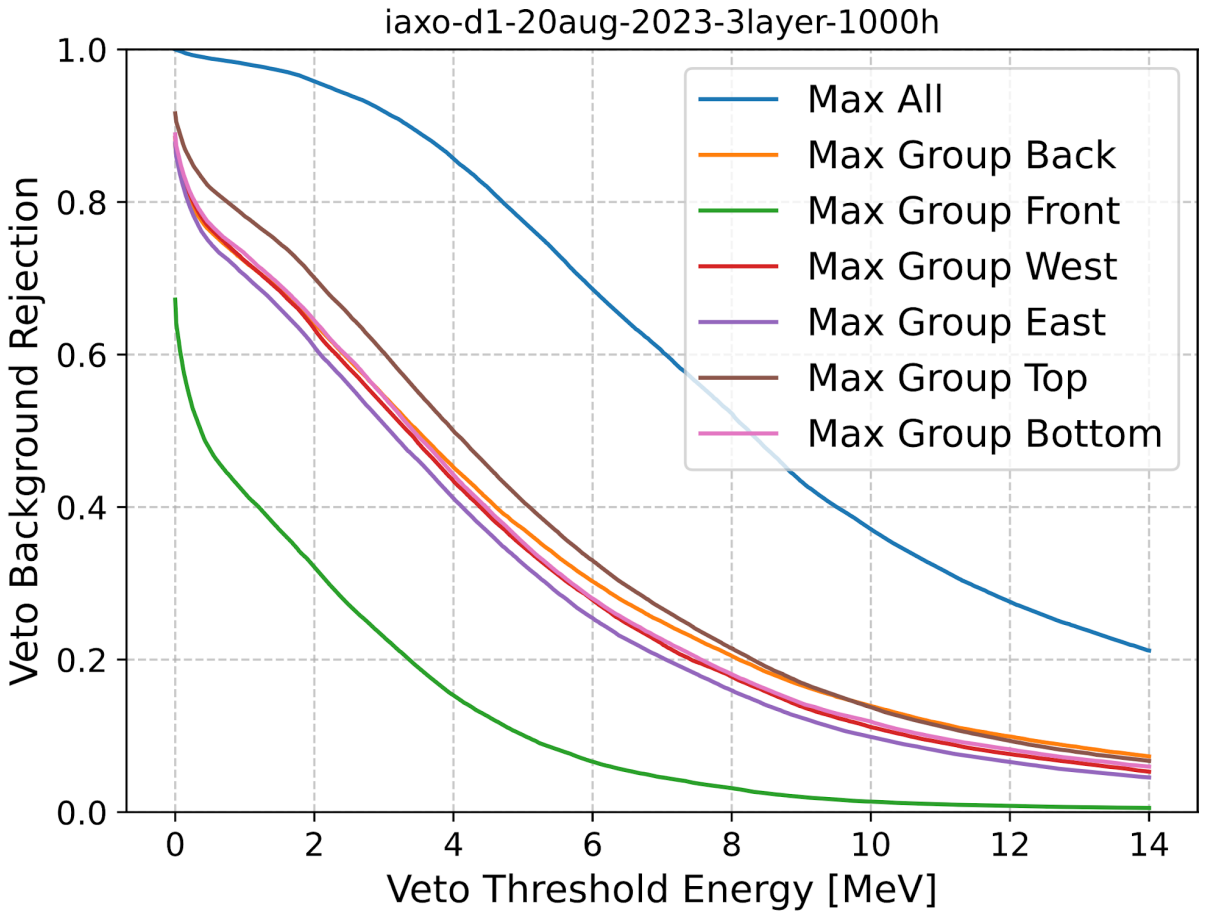


IAXO Background Model: Cosmic background

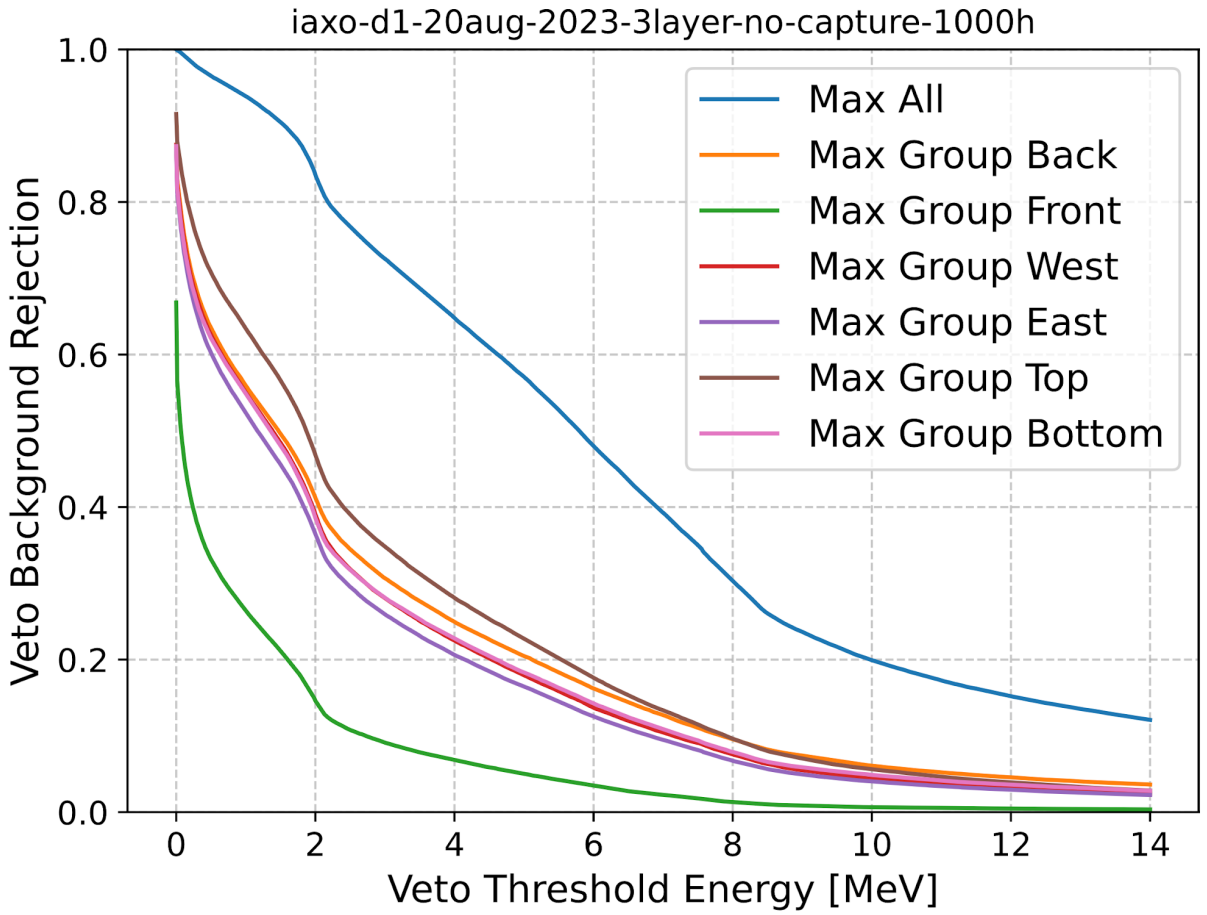




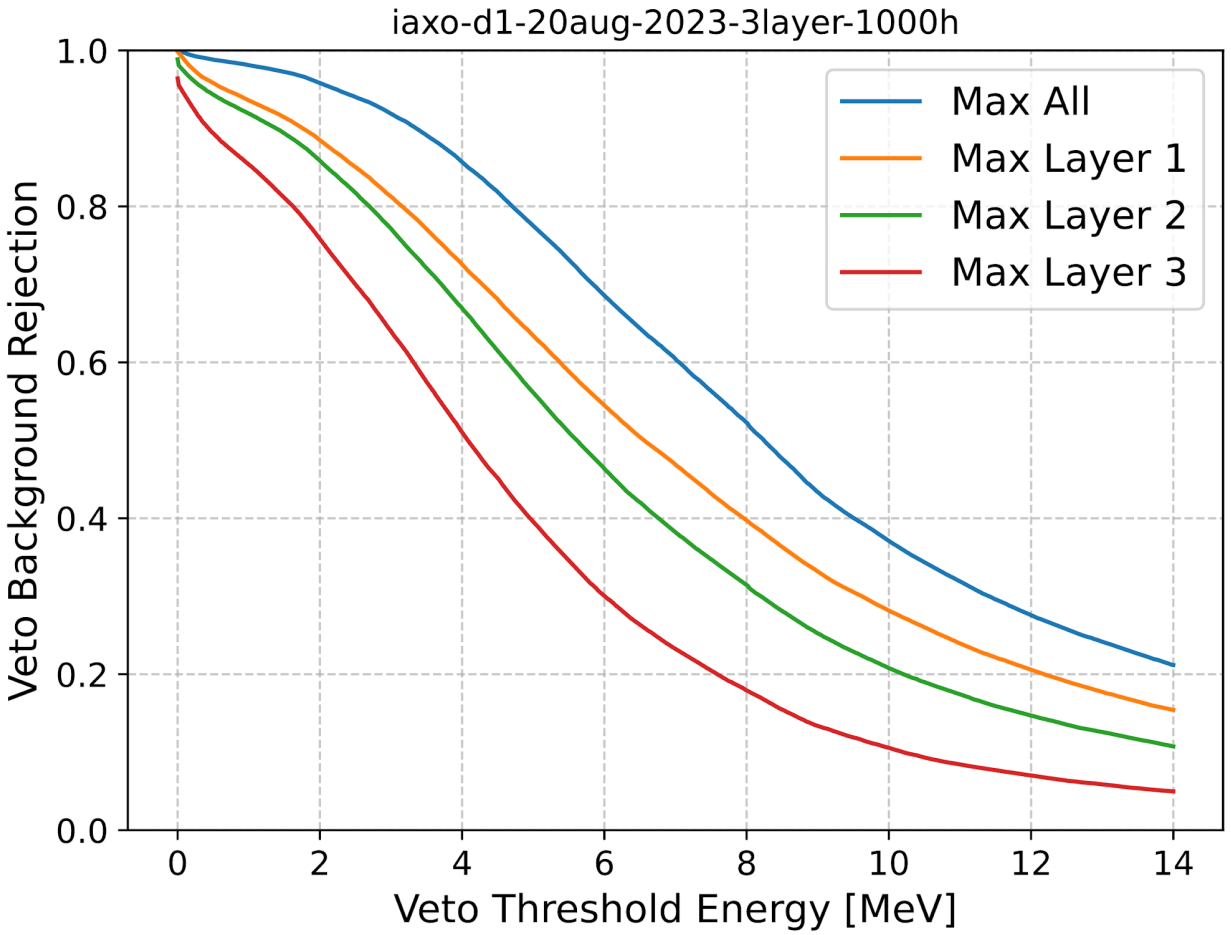
Capture layer



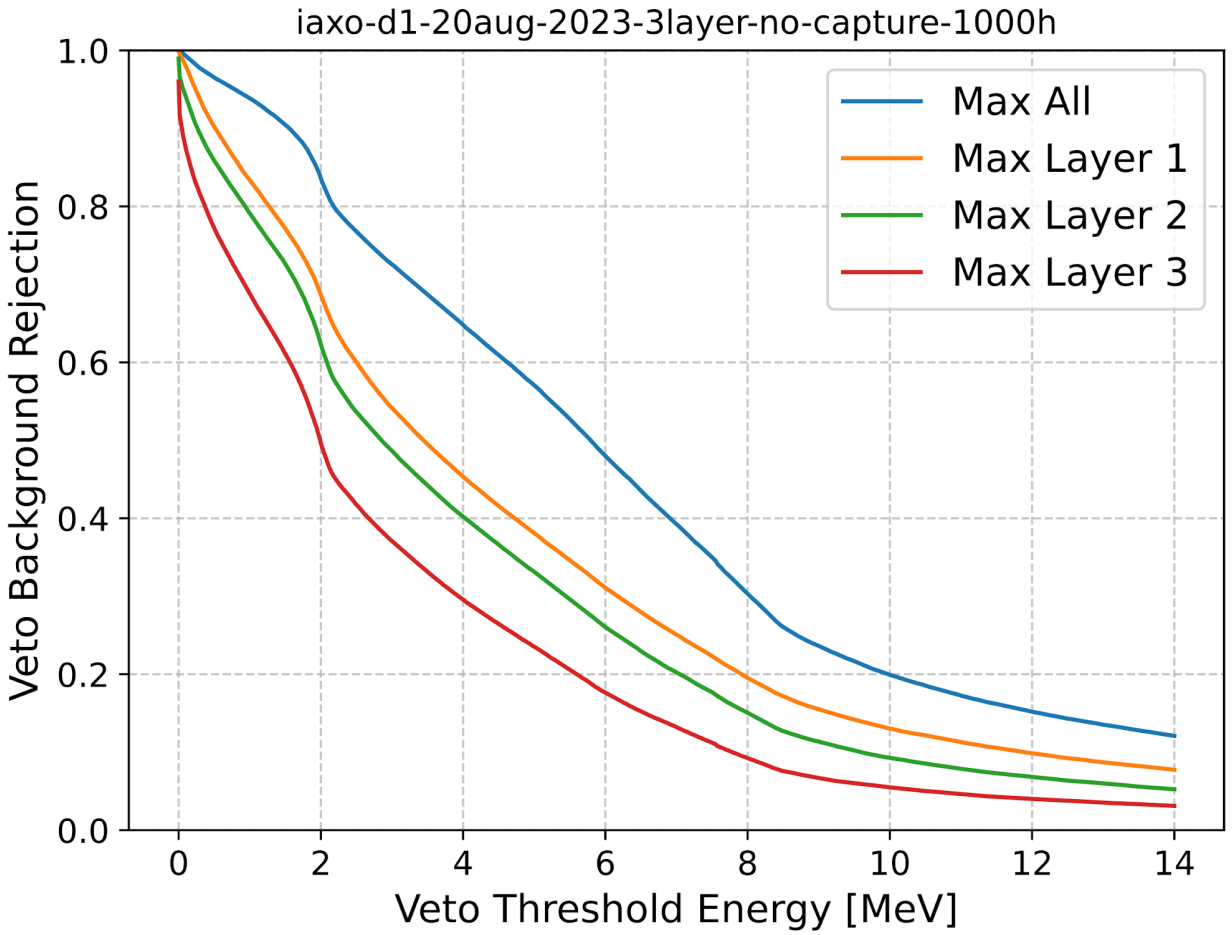
No capture layer



Capture layer



No capture layer



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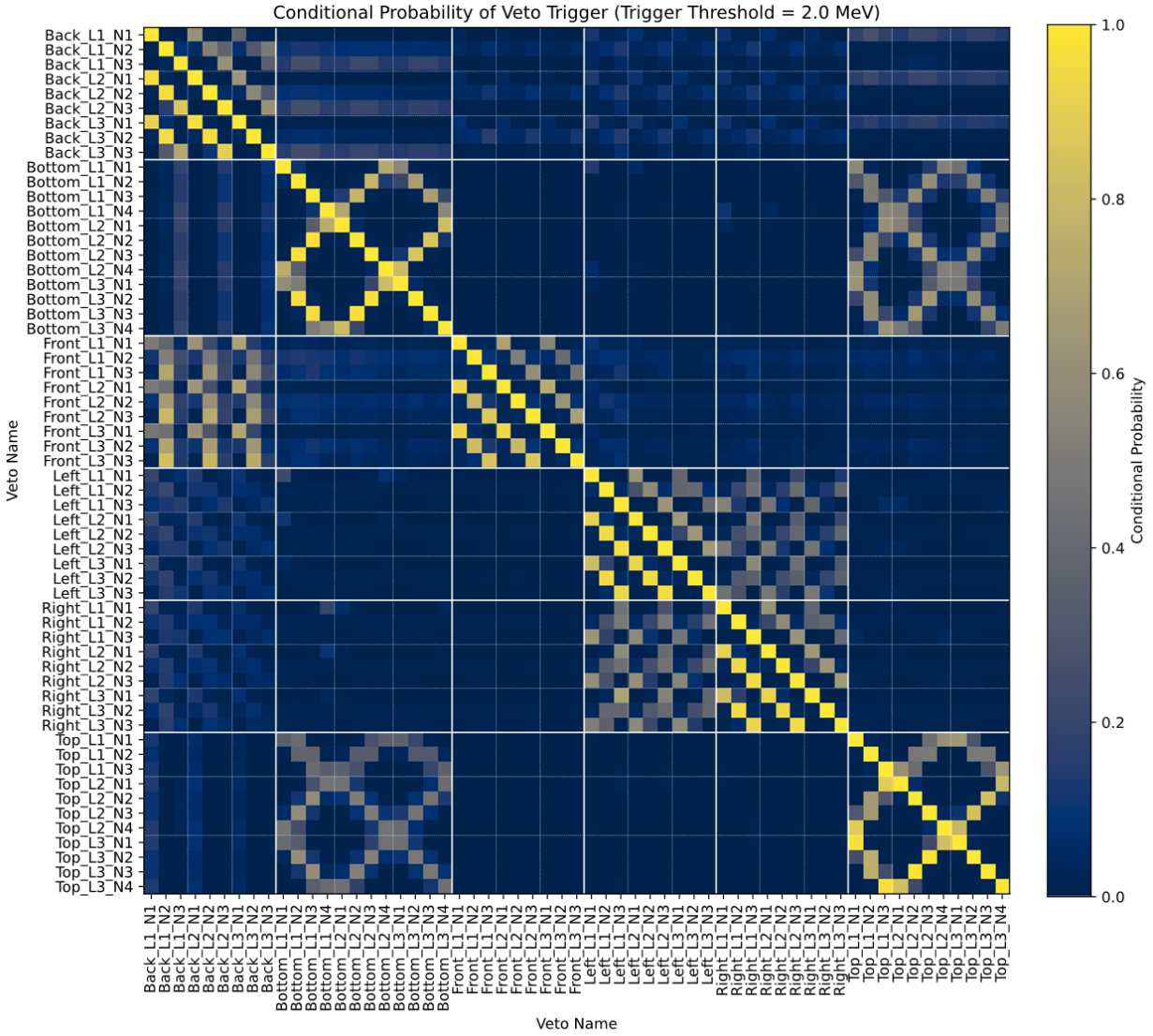
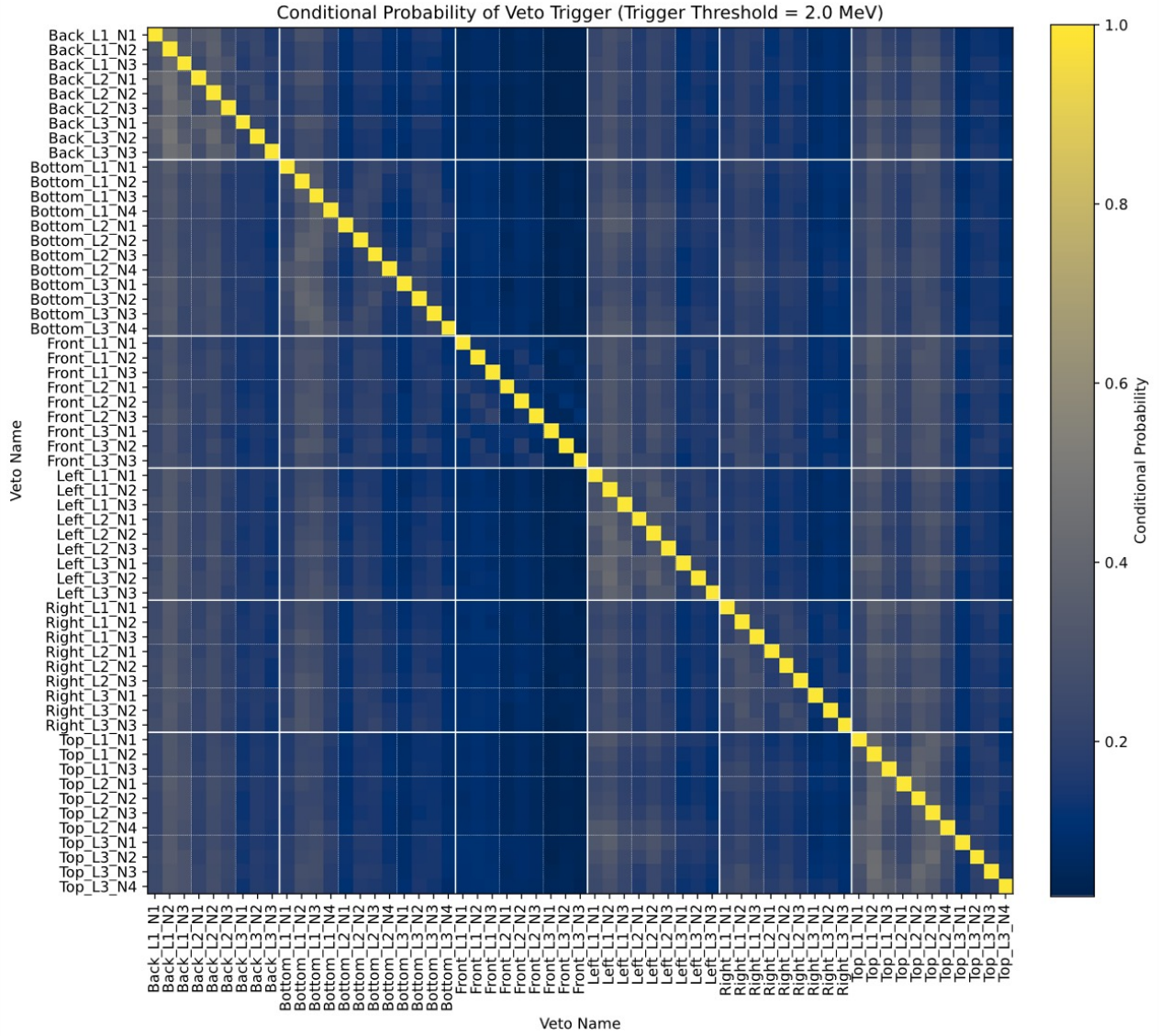
Muons: clear spatial pattern



Neutrons: no significant spatial pattern



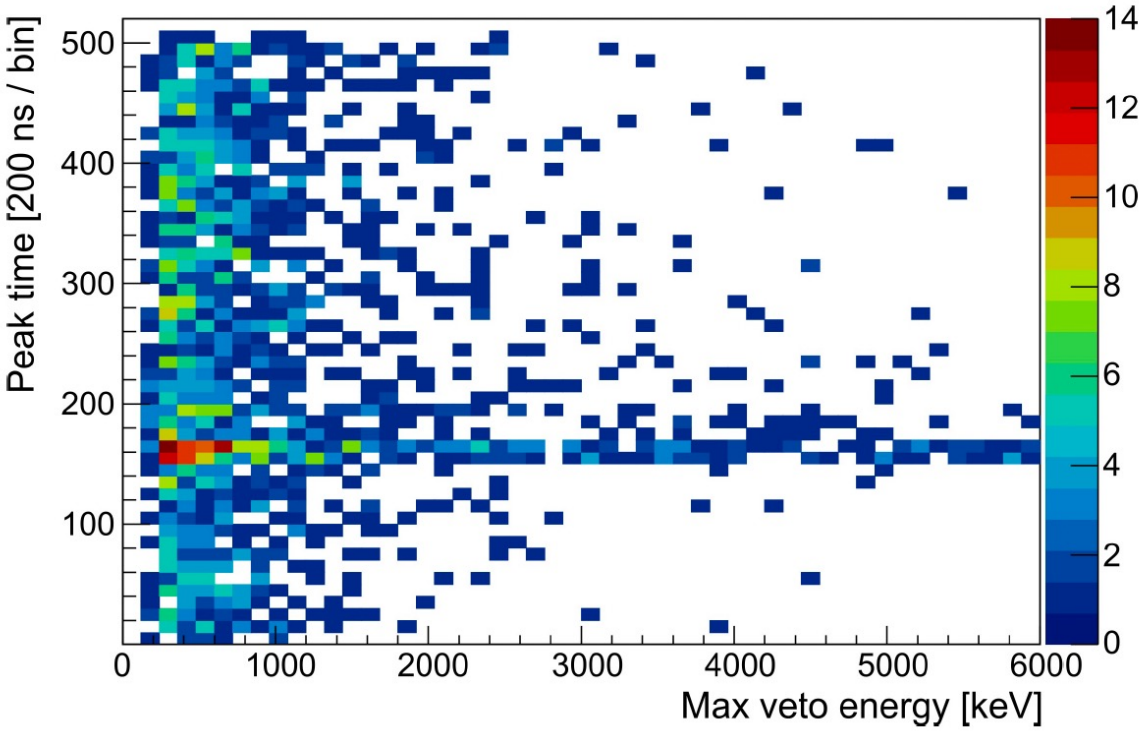
IAXO Background Model: Cosmic background

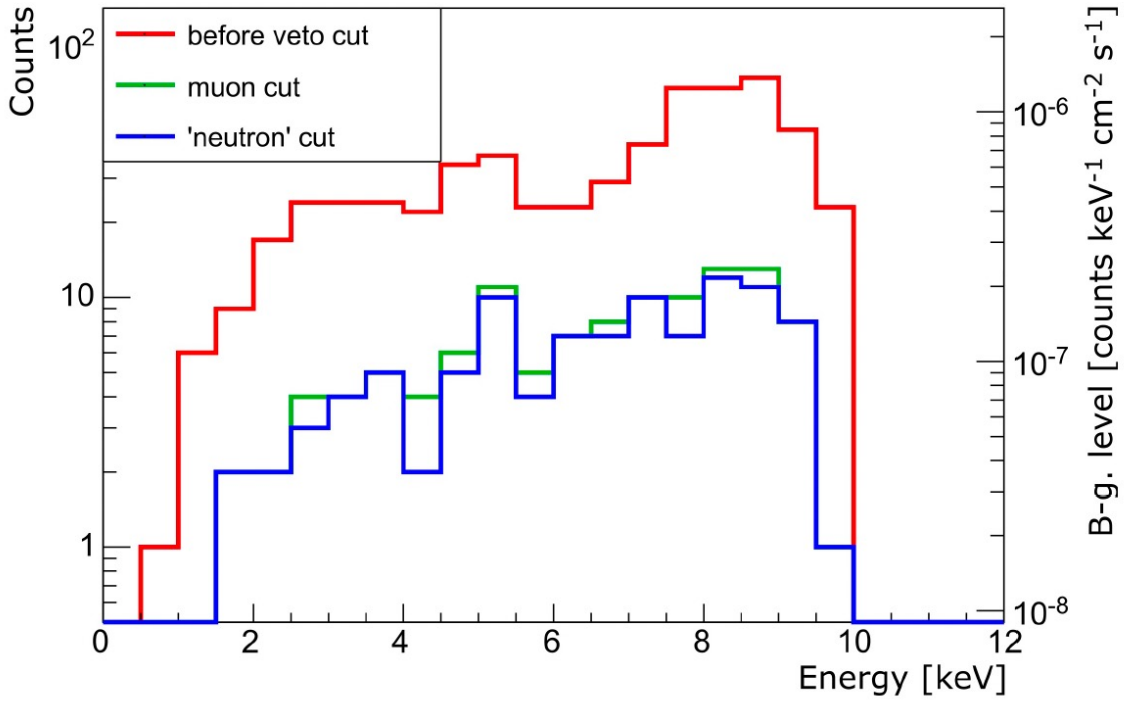
particle	sampling weight	no cuts	energy cuts (1-10 keV)	energy + topological	energy + topological + window	raw bkg (counts / keV / cm2 / s)	energy + topological bkg	energy + topological + window bkg
gamma	49.16%	48	23	2	0	1.67E-07	1.45E-08	0.00E+00
proton	0.49%	343	108	47	2	7.84E-07	3.41E-07	7.40E-08
electron	8.90%	19	7	0	0	5.08E-08	0.00E+00	0.00E+00
muon	34.97%	105937	45852	7042	5	3.33E-04	5.11E-05	1.85E-07
neutron	6.49%	1244	459	130	9	3.33E-06	9.44E-07	**3.33E-07**

Additionally veto cuts can reduce neutron background by ~30% while muon background is reduced by >99%

Absolute background levels subject to renormalization with more accurate flux data (measurements ongoing)

- Cuts on experimental data using veto energy and timing observables
- Increased total background reduction by ~ 13% w.r.t. just muon cuts





- We have developed the background model for the IAXO micromegas detector using the REST-for-Physics framework
- Our framework allows for Monte Carlo data production in the same format as the experimental data
- The cosmic ray-induced background (neutrons) remains especially important and neutron measurements are ongoing to better characterize it
- Using Geant4 simulations we have developed a prototype veto system capable of reducing the background from cosmic ray secondaries