Optical simulation of the DarkSide-20k Outer Veto

Beyond Standard Model: From Theory to Experiment, 6-9 November 2023

on behalf of the DarkSide Collaboration

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Dark Matter

Optical simulation

Underground experiment

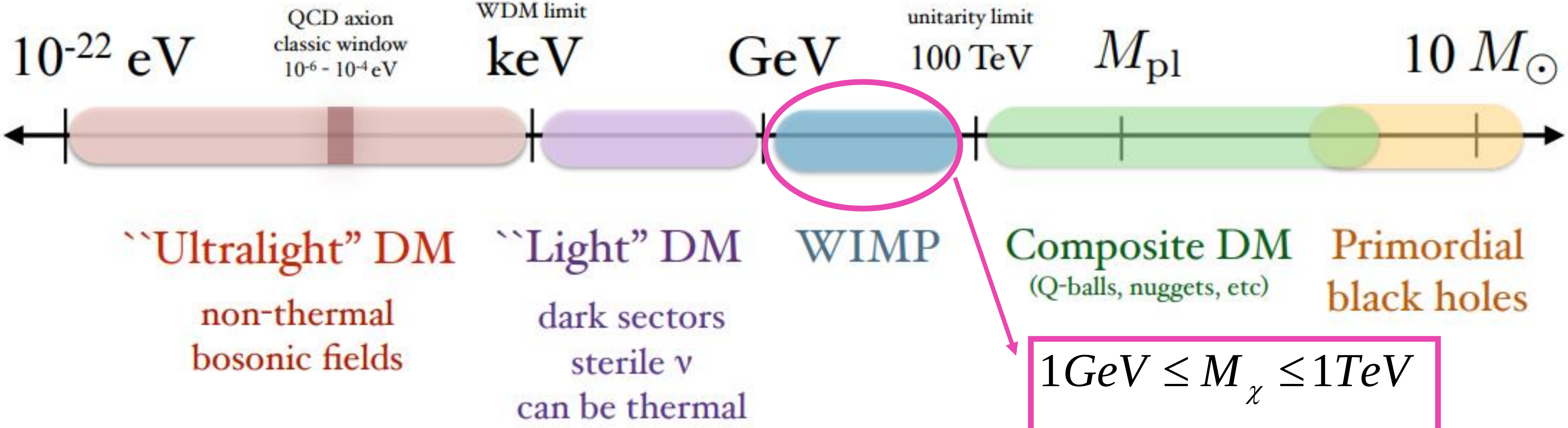
Light yield

Liquid argon

What is Dark Matter?

Mass scale of Dark Matter

(not to scale)   arXiv:1904.07915v1



$1GeV \leq M_{\chi} \leq 1TeV$

XENONnT, PandaX-4T
LZ, CRESST, DEAP-3600,
DarkSide-20k et.al.

Fig.1. The mass range of allowed DM candidates, comprising both particle candidates and primordial black holes. Mass ranges are only approximate (in order of magnitude), and meant to indicate general considerations.

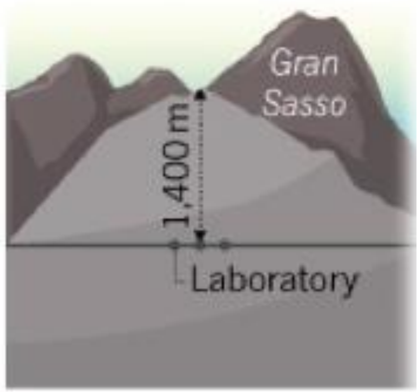
Laboratori Nazionali del Gran Sasso (LNGS)

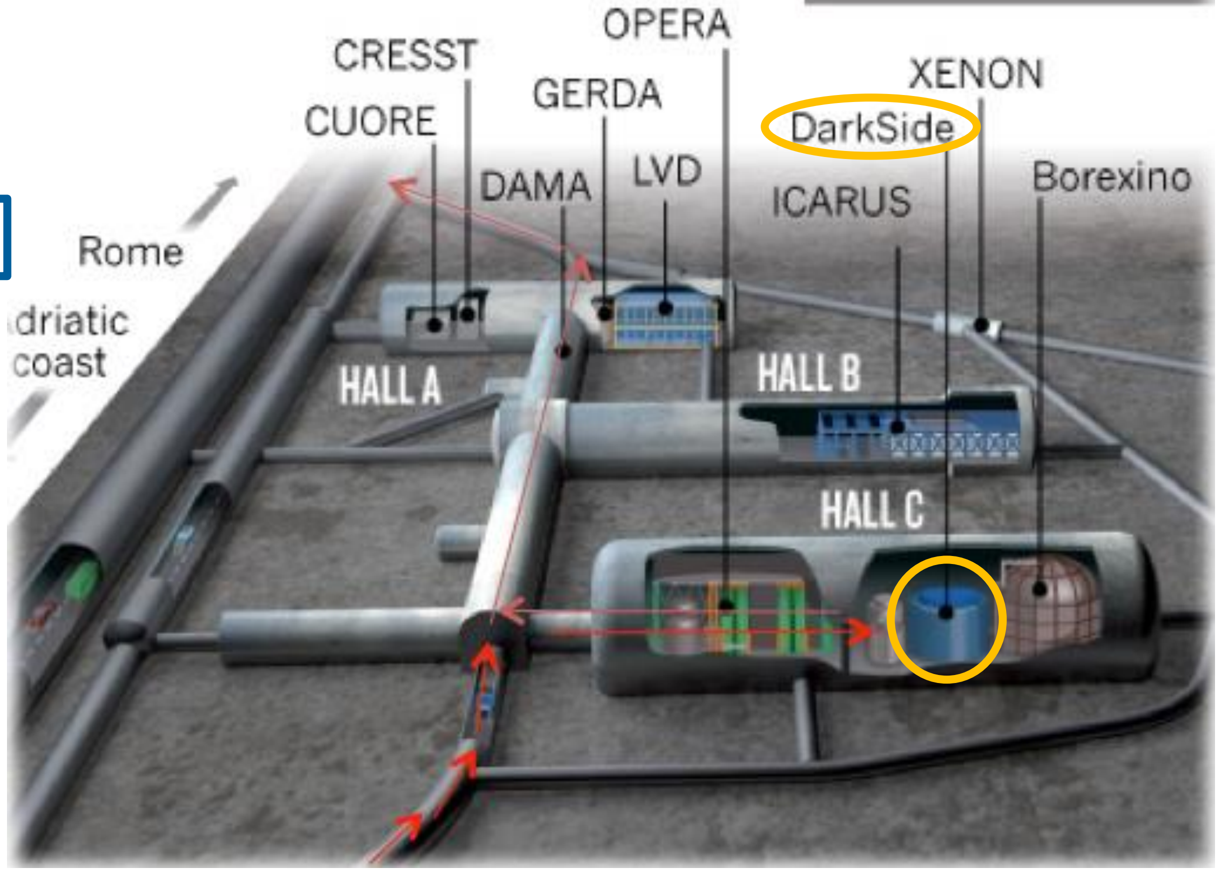
Placement:

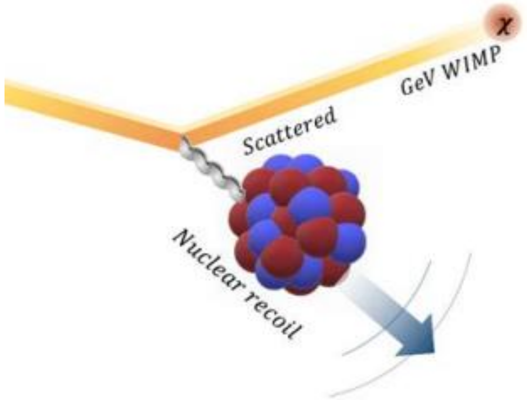
Under mountain peak Corno Grande, at an **average depth of about 1400 m** and at an altitude of about 1000 m above sea level.

This reduces the cosmic background

High sensitivity to nuclear events

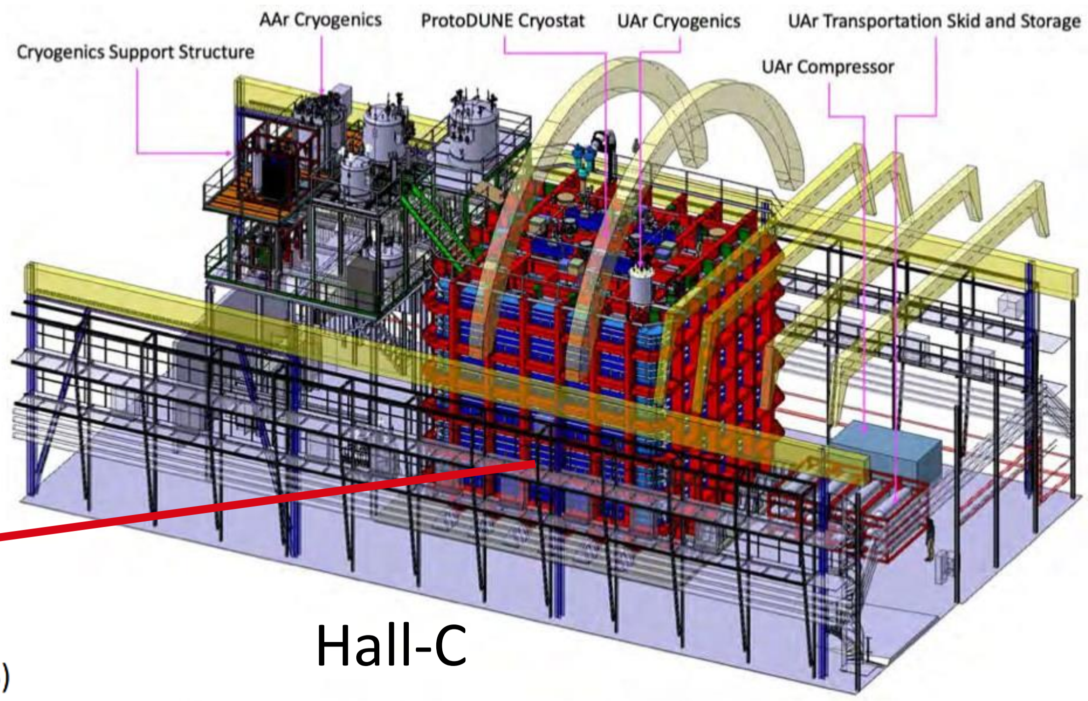




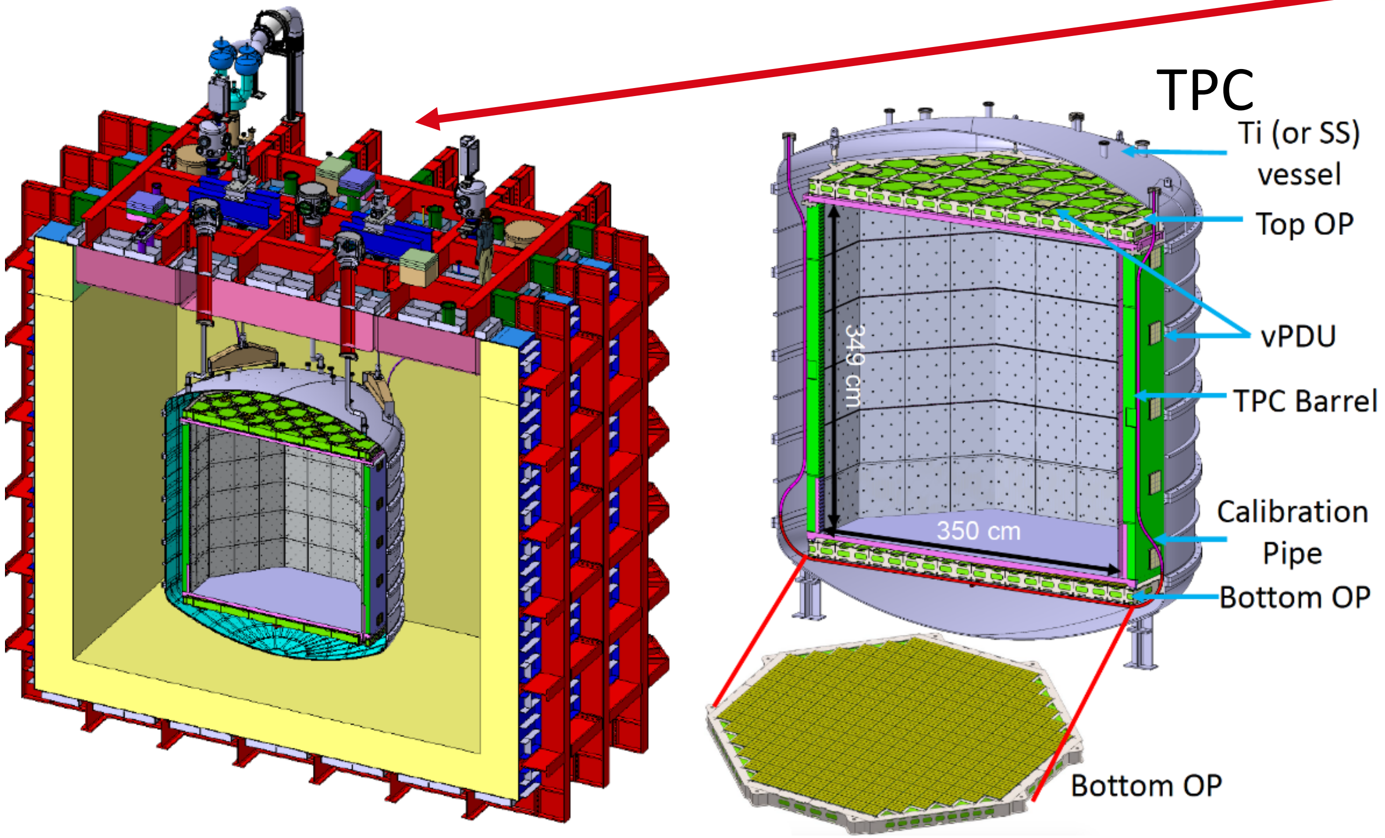


DarkSide-20k

The DarkSide-20k (DS-20k) experiment seeks to **directly detect dark matter** in the form of weakly interacting massive particles (WIMPs). The designed DS-20k detector is a two phase time projection chamber (TPC) filled with 50 tons of underground liquid argon.



Hall-C



arXiv:2301.12970v1

Fig.2. Cross sections of the cryostat (left) and of the vessel containing the inner veto and TPC (right) of the DarkSide-20k detector

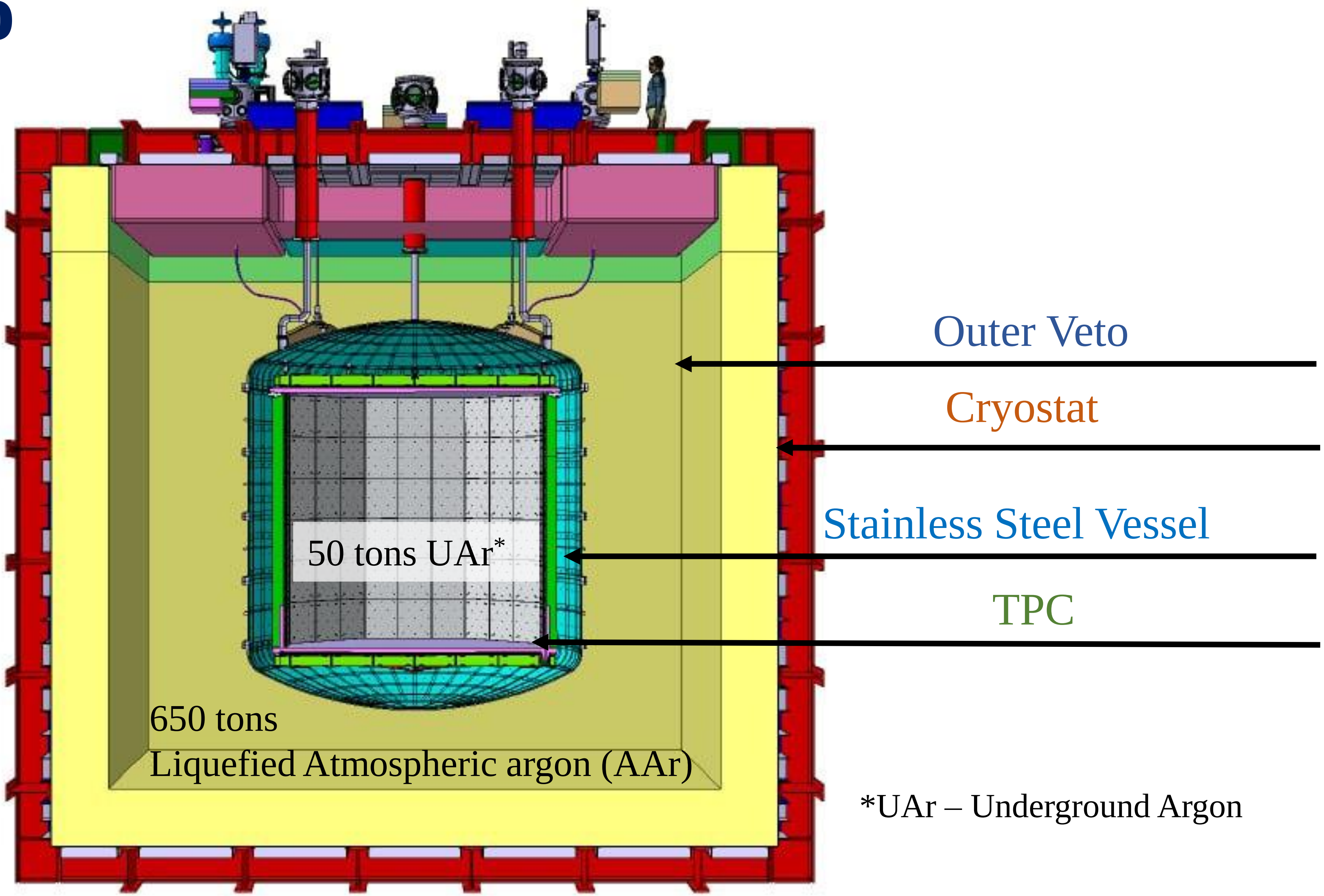
Outer Veto

Motivation:

Registration of background events from cosmogenic muons and related nuclear-active showers that can activate isotopes.

Physics potential:

- ^{8}B solar neutrinos
- Supernova neutrinos



*UAr – Underground Argon

Outer Veto

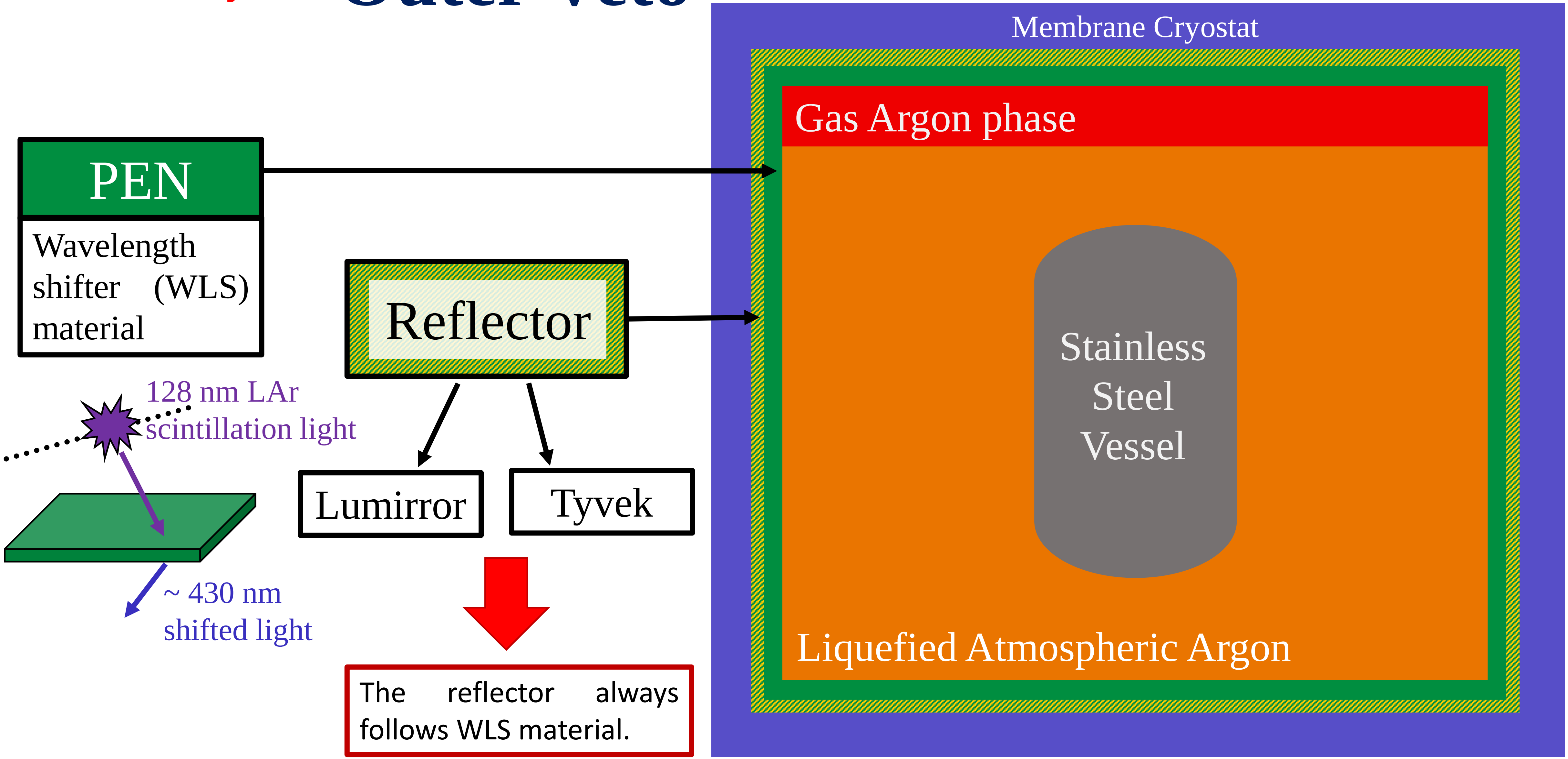
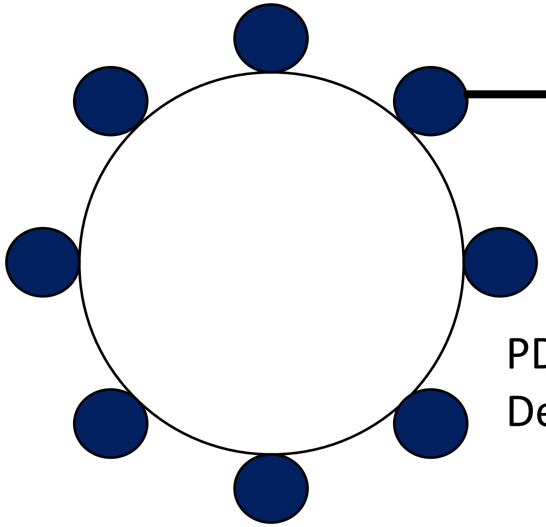
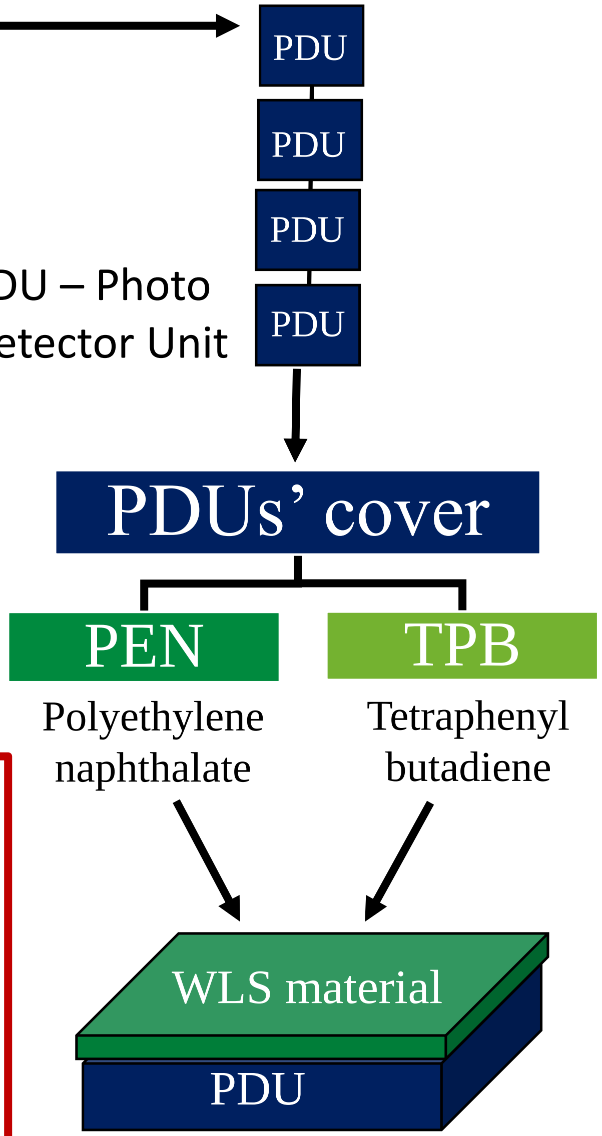


Fig.3. The **preliminary** schematic design DarkSide-20k with Membrane Cryostat and Stainless Steel Vessel

Outer Veto



PDU – Photo Detector Unit



The TPB gives higher LY (light yield) than PEN. However, the technical implementation of PEN is easier, because there is no problem with spraying a uniform layer.

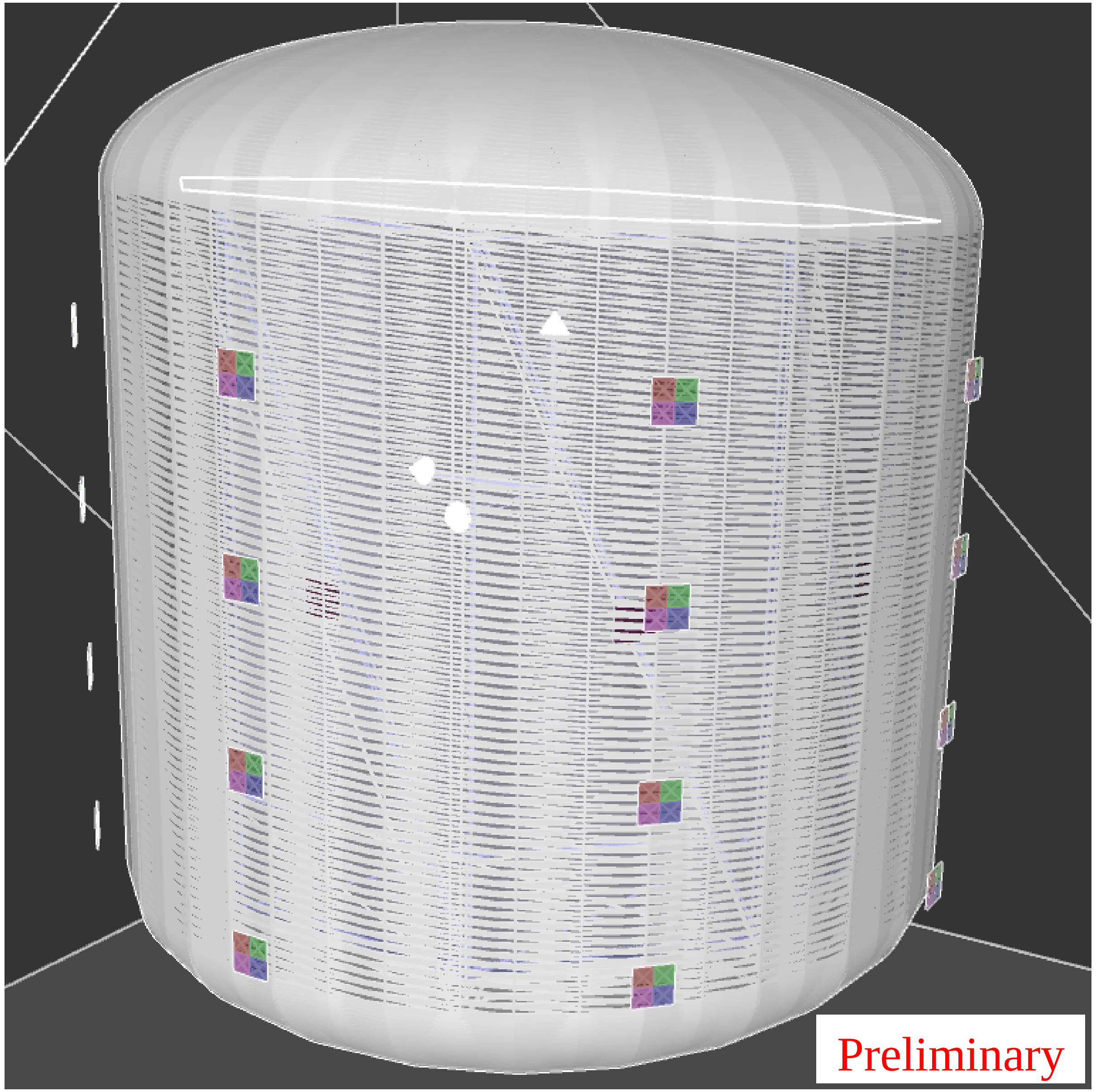


Fig.4. The **preliminary** configuration of PDUs placement on the Stainless Steel Vessel in Geant4

Comparison of the LY for different OV configurations on the SSVessel

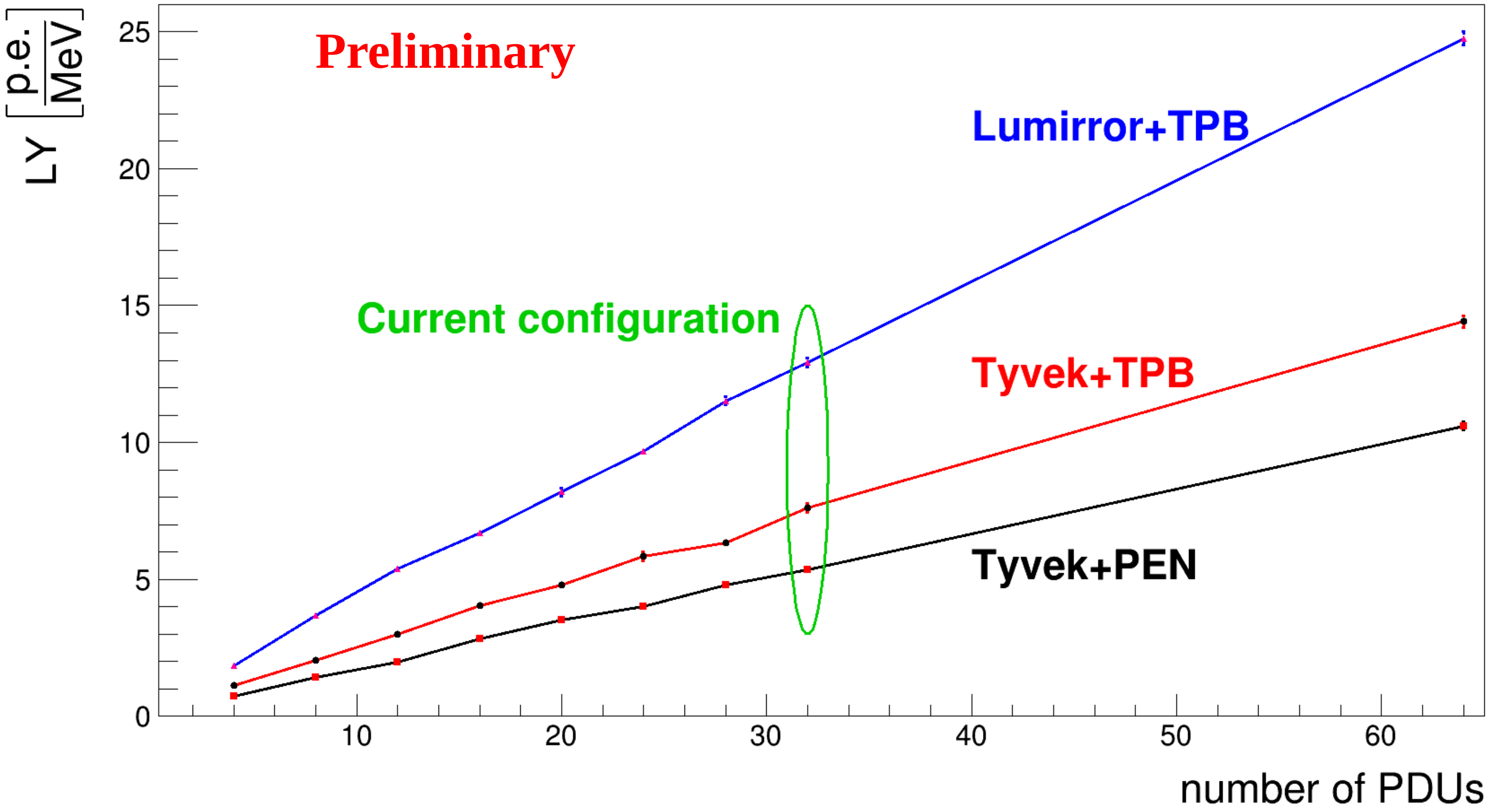


Fig.5. The average value of the LY for different variations of the design of an OV on SSVessel

Conclusions:

- The more number of PDUs used, the higher LY obtained
- When using Tyvek, the value of LY **decreases by 1.7 times**
- When using PEN, the value of LY **decreases by 1.4 times**

Simulation's parameters:

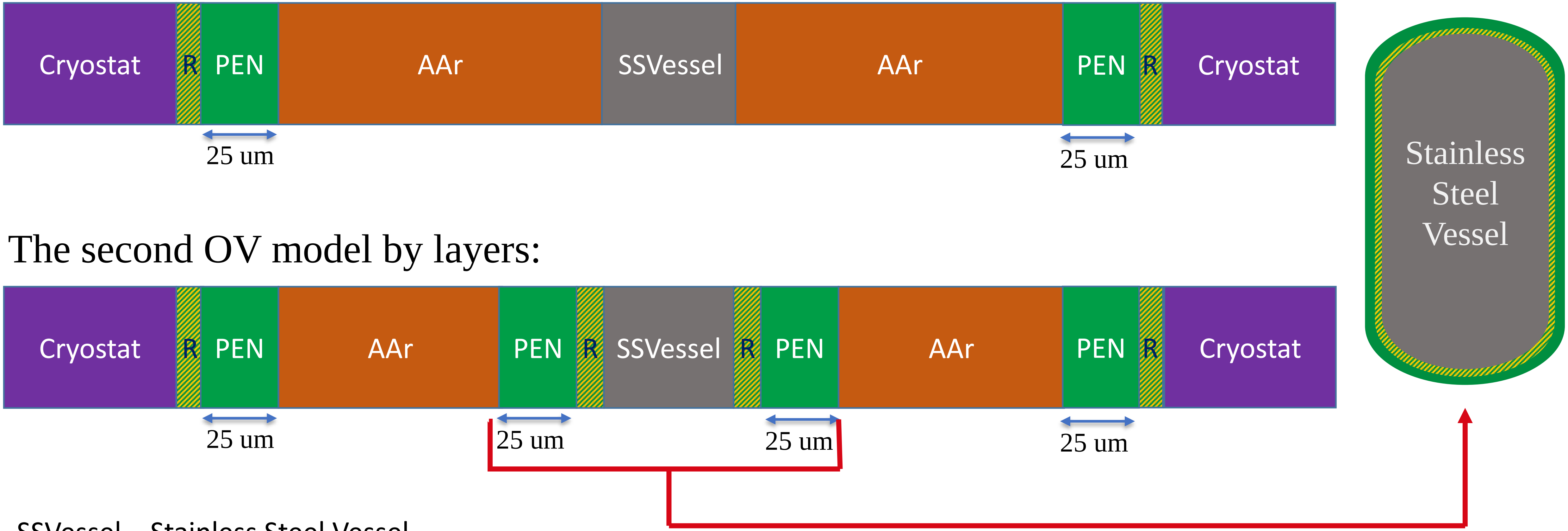
Cosmic muon, events 1000,
LenLArVisAbs = 10 km,
LenLArUVAbs =10 m

Adding PEN + Reflector to the surface of the SSVessel in order to increase the LY value

Preliminary

The first OV model by layers:

The second OV model by layers:



SSVessel – Stainless Steel Vessel

R - reflector

Preliminary Adding PEN + Reflector to the surface of the SSVessel

The first OV model by layers:

Table.1. The values of the LY for case 32 PDUs on SSVessel from ***Fig.5.***

WLS\reflector	Lumirror	Tyvek
TPB on PDUs	12.92 ± 0.16	7.61 ± 0.15
PEN on PDUs	-	5.34 ± 0.08

Simulation's parameters: Cosmic muon, events 1000, LenLArVisAbs = 10 km, LenLArUVAbs = 10 m, 32 PDUs

Conclusion:
Additional PEN cover with a reflector **increases** the LY value

The second OV model by layers:

Table.2. The values of the LY for case 32 PDUs on SSVessel

WLS\reflector	Lumirror	Tyvek
TPB on PDUs	23.26 ± 0.19	9.76 ± 0.15
PEN on PDUs	20.28 ± 0.17	7.67 ± 0.14

Simulation's parameters: Cosmic muon, events 1000, LenLArVisAbs = 10 km, LenLArUVAbs = 10 m, 32 PDUs

Influence of LAr absorption lengths on the LY value

Preliminary

Simulation's parameters:
Cosmic muon, events 1000, 32 PDUs on SSVessel, PEN as WLS, Tyvek as reflector

Table.3. The values of the LY for different values of LAr absorption lengths

LenLArVisAbs*, km	LenLArUVAbs**, m	LY, $\frac{p.e.}{MeV}$
10	10	**7.67 ± 0.14**
10	20	**8.92 ± 0.17**
1	20	**8.51 ± 0.11**

*LenLArVisAbs – absorption length of LAr in visible wavelength

**LenLArUVAbs – absorption length of LAr in UV wavelength

The value of the LY increased by 1.16 times when the **LenLArUVAbs** was increased by 2 times.

When the **LenLArVisAbs** was decreased by 10 times, the LY value decreased by 1.05 times.

Conclusion:
Compared to **LenLArUVAbs**, the **LenLArVisAbs** has less of an impact on the LY.

Preliminary

Remove Reflector + PEN from GAr

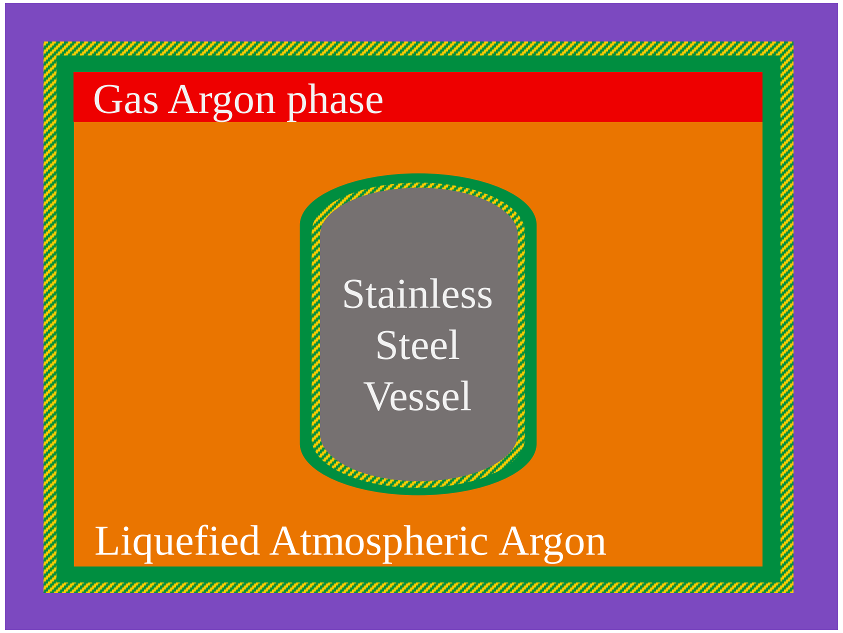


Fig.6. The schematic model DarkSide-20k without TPC: Cryostat, Reflector, PEN, GAr, AAr

WLS\reflector	Lumirror	Tyvek
TPB on PDUs	26.57 ± 0.15	11.67 ± 0.15
PEN on PDUs	22.37 ± 0.12	8.73 ± 0.12

Motivation:
to help with the argon recirculation

Remove PEN + Reflector from GAr

Simulation's parameters:
Cosmic muon, events 1000,
LenLArVisAbs = 1 km ,
LenLArUVAbs=20 m,
32 PDUs on SSVessel

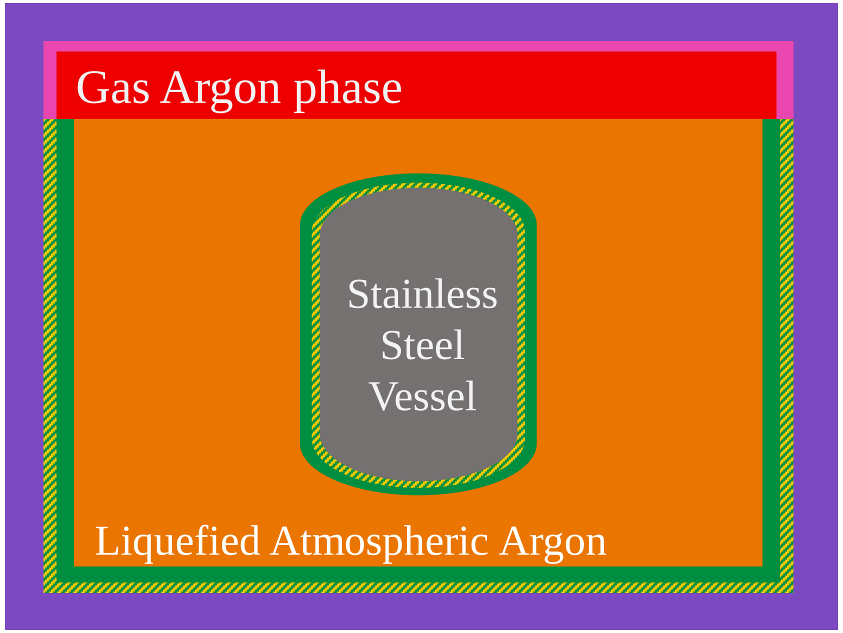


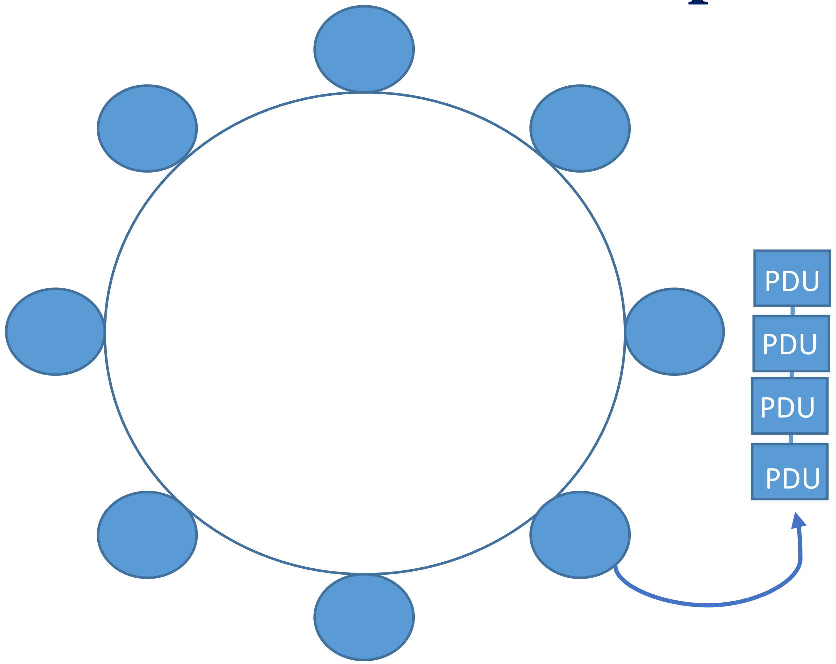
Fig.7. The schematic model DarkSide-20k without TPC: Cryostat, Reflector, PEN, GAr, AAr, EPS Surface

WLS\reflector	Lumirror	Tyvek
TPB on PDUs	19.61 ± 0.19	10.02 ± 0.14
PEN on PDUs	16.29 ± 0.17	7.49 ± 0.12

Conclusion:
After removal, the LY decreased. This is due to the fact that more absorption processes began occur in GAr.

Preliminary

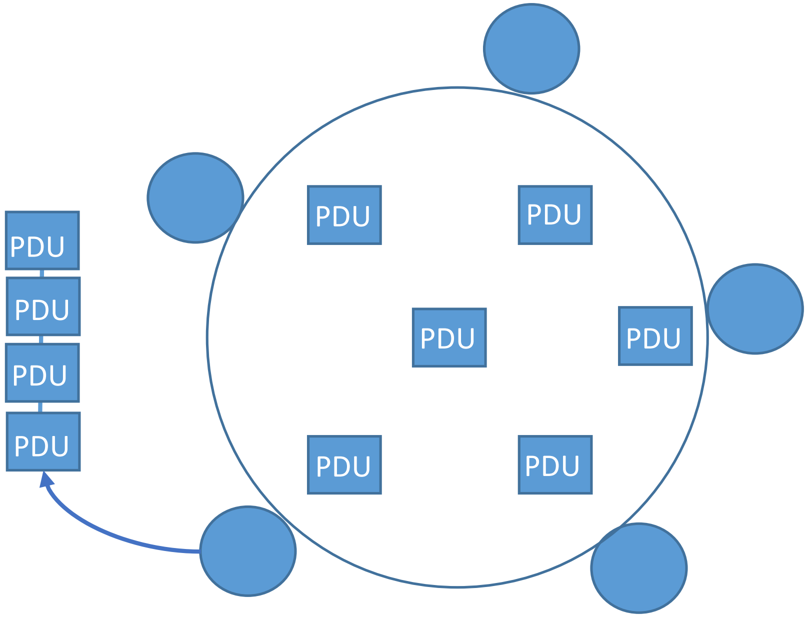
What will be if some PDUs will be place bottom and top on SSVessel?



32 PDUs: All on side

For ***Fig.6.*** schematic model

Simulation's parameters:
Cosmic muon, veto yield 0.02,
events 1000,
LenLArVisAbs = 1 km ,
LenLArUVAbs=20 m



32 PDUs: 6 on bottom, 6 on top, 20 on side

Table.4. The values of the LY

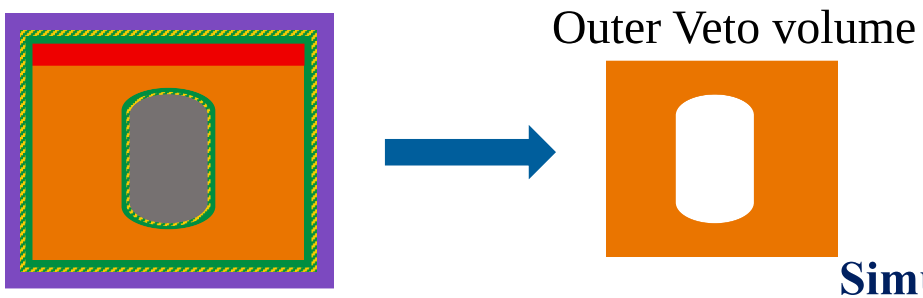
WLS\reflector	Lumirror	Tyvek
TPB on PDUs	26.57 ± 0.15	11.67 ± 0.15
PEN on PDUs	22.37 ± 0.12	8.73 ± 0.12

Table.5. The values of the LY

WLS\reflector	Lumirror	Tyvek
TPB on PDUs	26.91 ± 0.16	11.15 ± 0.15
PEN on PDUs	22.12 ± 0.10	9.09 ± 0.15

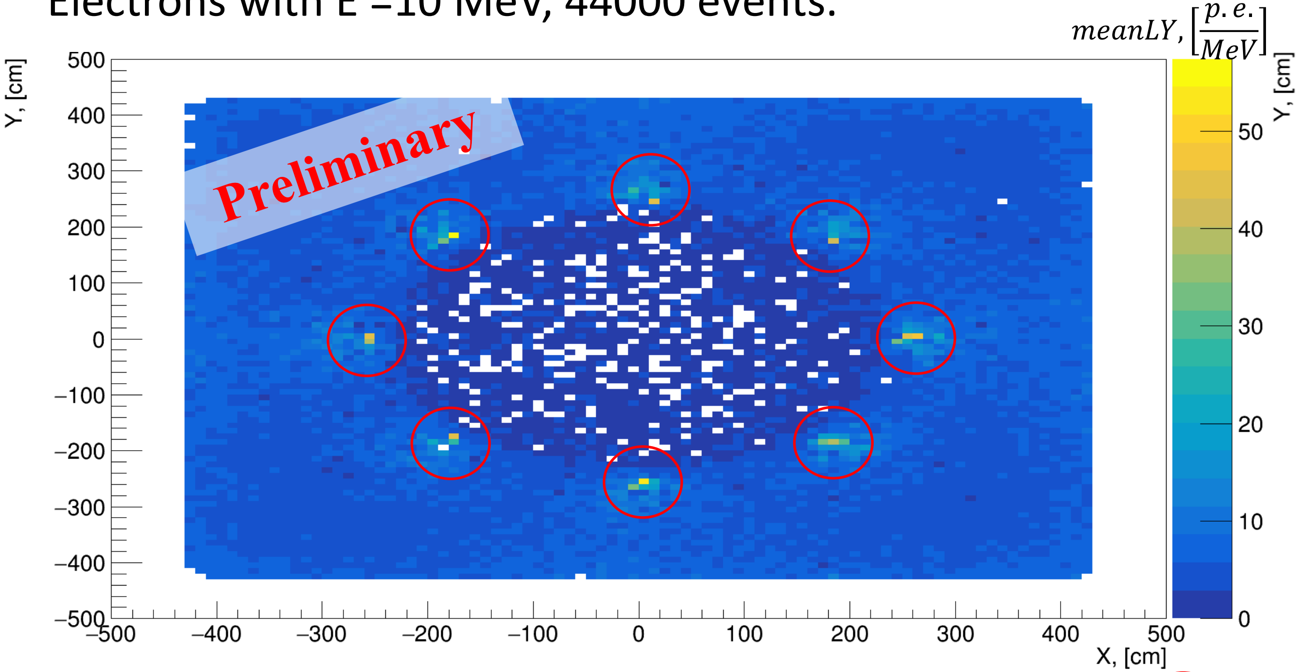
Conclusion:
The arrangement of PDUs on the top and bottom of SSVessel gives a slight increase in LY. Needs more testing.

The first step to build LY map for different OV configurations



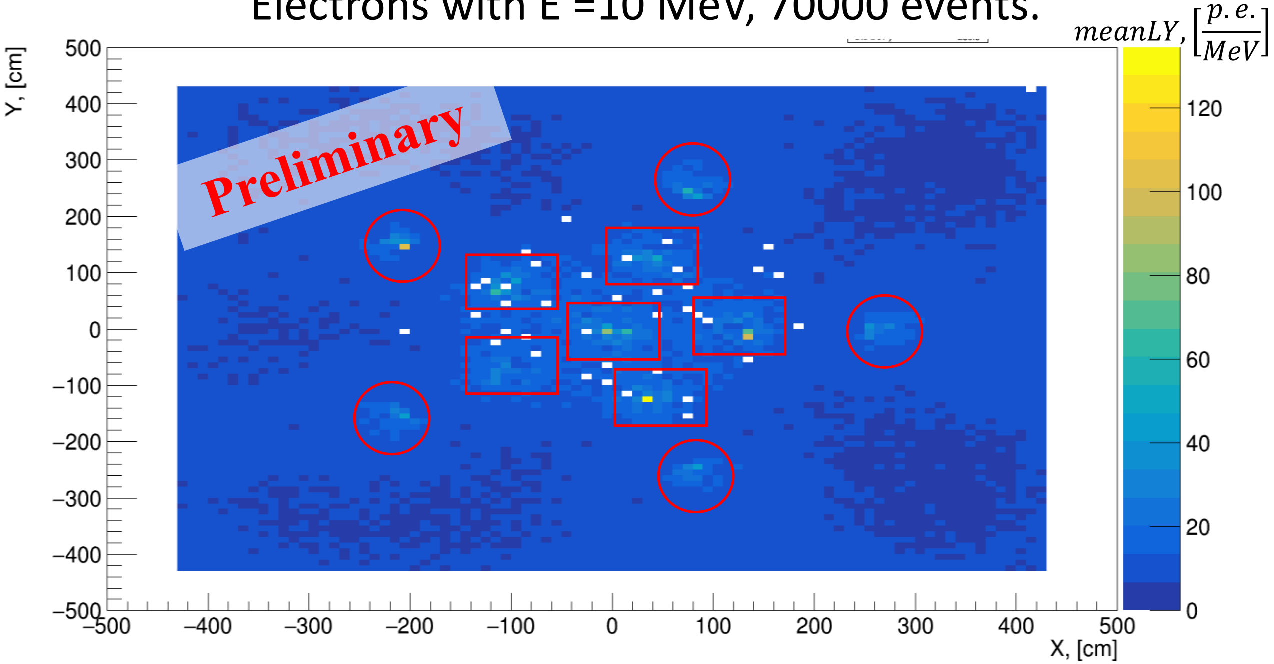
Simulation's parameters:

Electrons with E =10 MeV, 44000 events.



Simulation's parameters:

Electrons with E =10 MeV, 70000 events.

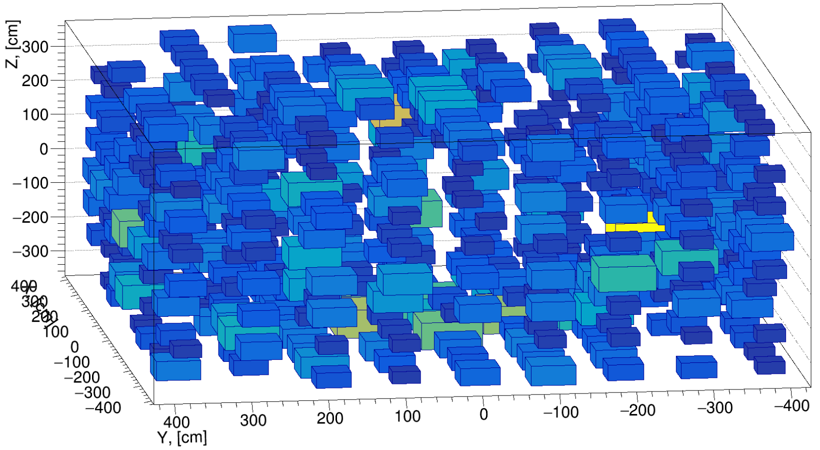


4 PDUs   PDU

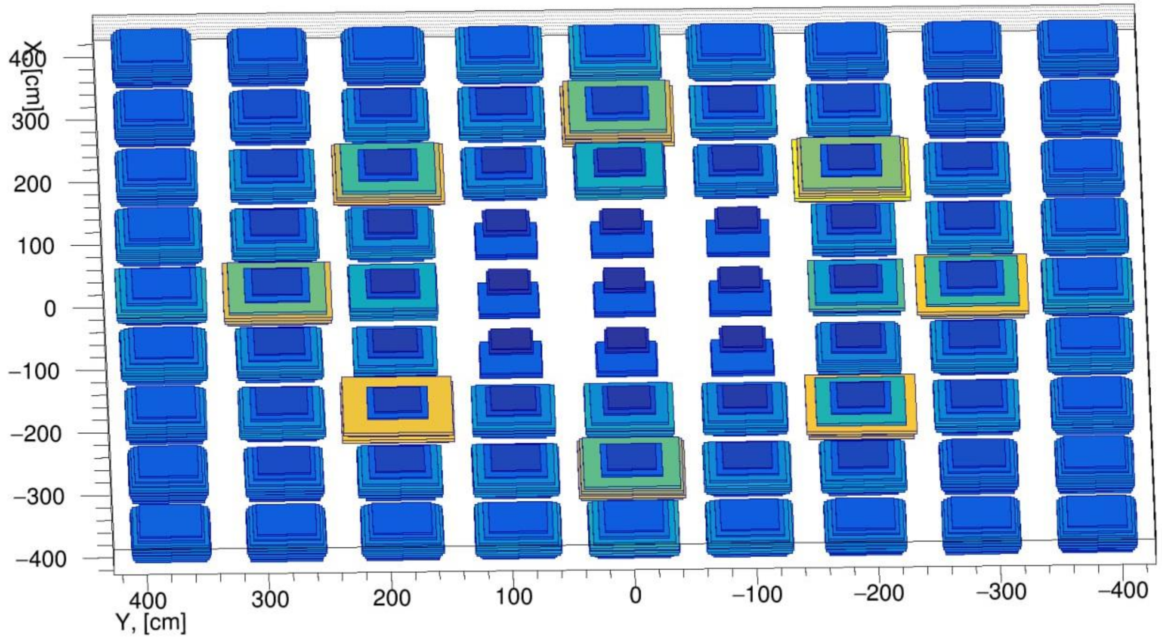
Fig.8. The distribution of mean LY by coordinates XY in case all PDUs on side SSVessel.

Fig.9. The distribution of mean LY by coordinates XY in case PDUs on side and top/bottom SSVessel.

The first step to build LY map for different OV configurations



Preliminary



Preliminary

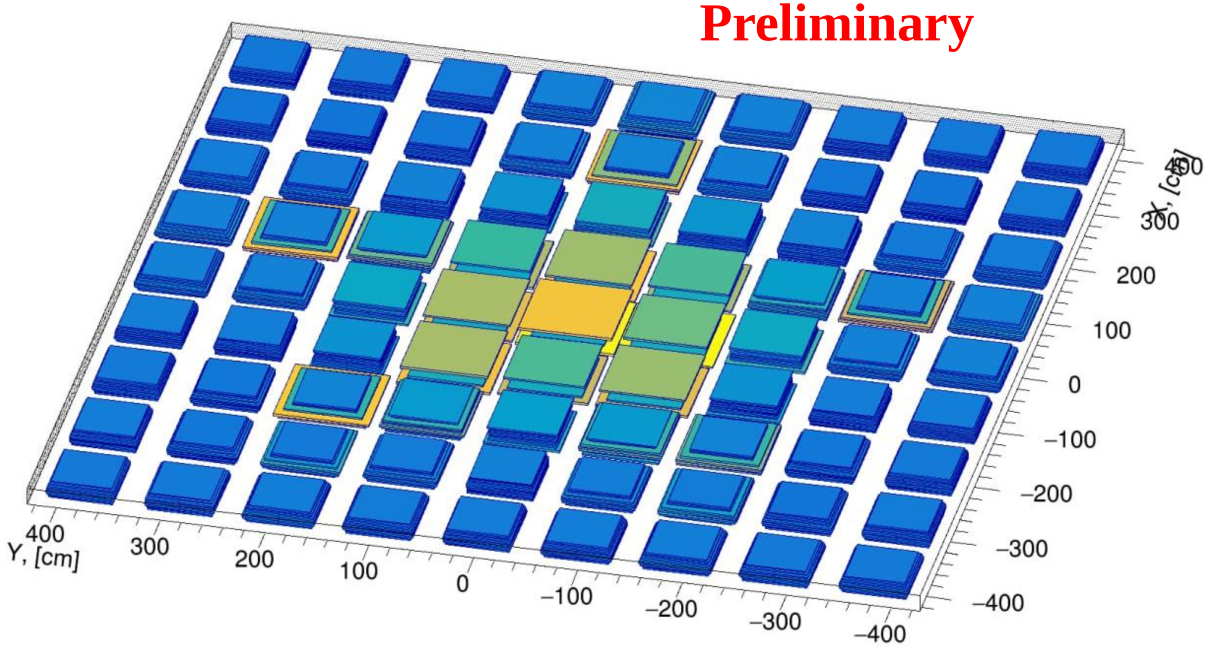


Fig.10. The **preliminary** LY map in case all PDUs on side SSVessel.

Fig.11. The **preliminary** LY map in case PDUs on side and on top/bottom SSVessel.

Conclusions:

- The LY was calculated for different types of reflector and WLS materials for cover for each PDU.
- The LY value was compared between two models of OV with reflector+PEN layer and without them on SSVessel.
- The LY was calculated for different PDU placement options.
- The first step to build LY map for DAQ system has been taken.

To-Do List:

- To select reflector for Cryostat and SSVessel.
- To select the coordinates for the location of PDUs.
- Continue work to build LY map for DAQ system.

Thanks for your attention!

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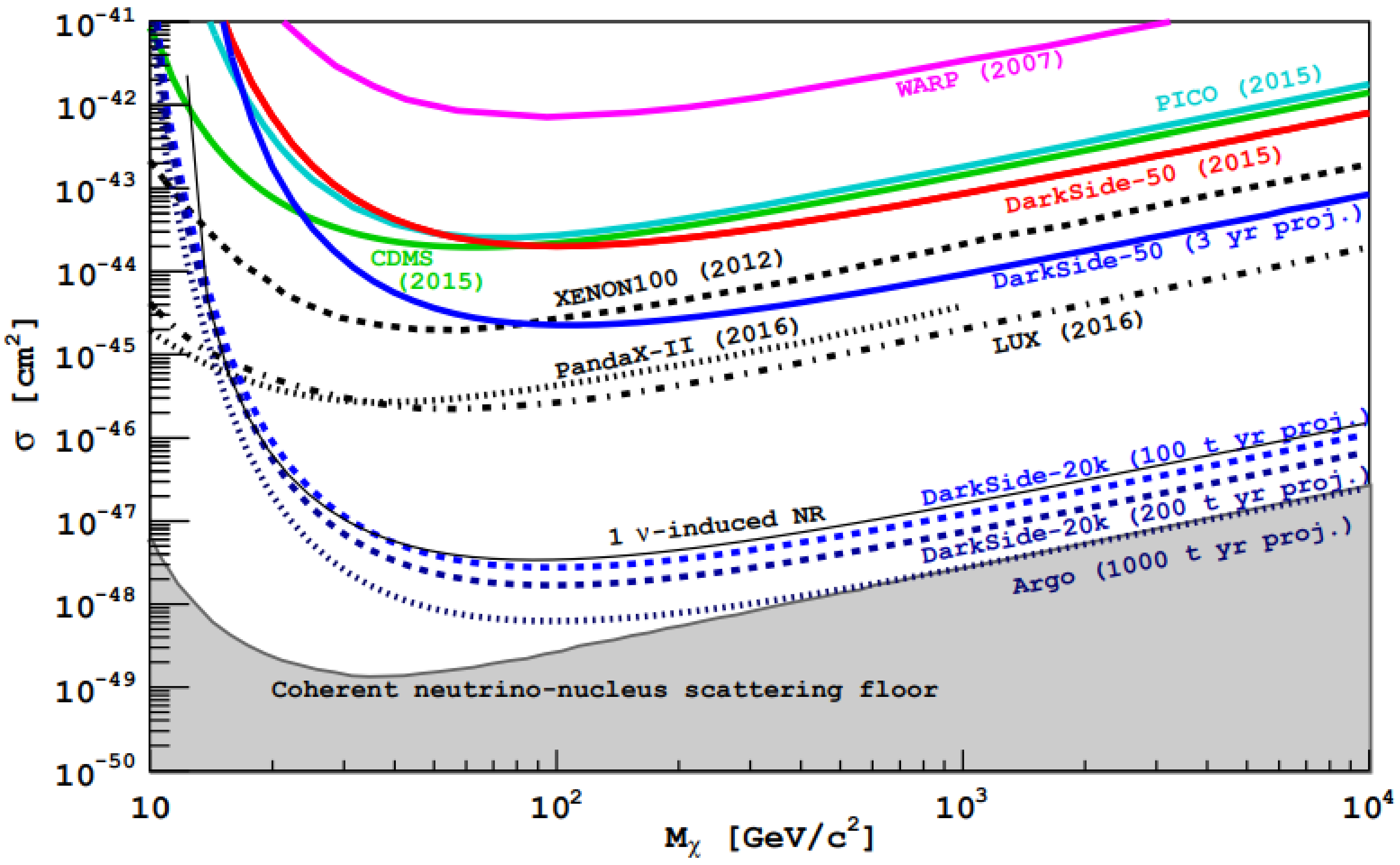
Backups

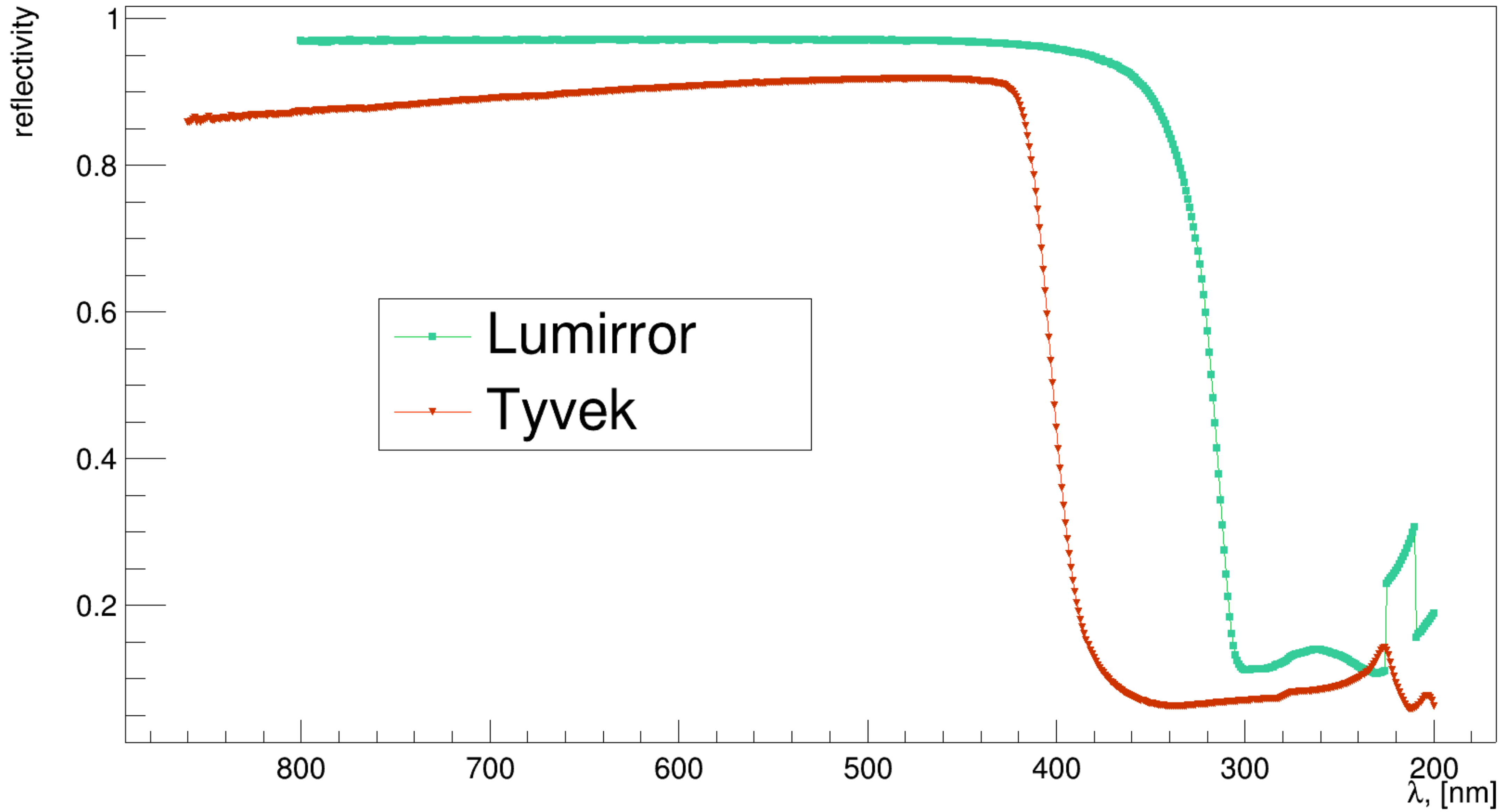
Potential DarkSide-20k



Aalseth, C. E et.al. DarkSide-20k: A 20 tonne two-phase LAr TPC for direct dark matter detection at LNGS, Eur.Phys.J.Plus, 133 (2018), 131.

arXiv: 1707.08145

The comparison between reflectors



The calculation light yield

$$LY = \frac{N_{pe}/scale\ factor}{E_{dep}} \qquad (1)$$

LY – light yield
N_{pe} – number of photo electrons
scale factor – parameter for scaling the number of photons produced, to speed up the simulations
E_{dep} – deposit energy

Influence of LAr absorption lengths on the LY value

Preliminary

WLS on PDUs	Reflector	LenLArVisAbs, km	LenLArUVAbs, m	LY, $\frac{p.e.}{MeV}$
TPB	Lumirror	10	10	23.26 ± 0.19
	Tyvek			9.76 ± 0.15
PEN	Lumirror			20.28 ± 0.17
	Tyvek			7.67 ± 0.14
TPB	Lumirror	10	20	27.92 ± 0.22
	Tyvek			11.78 ± 0.14
PEN	Lumirror			23.66 ± 0.21
	Tyvek			8.92 ± 0.17
TPB	Lumirror	1	20	26.10 ± 0.16
	Tyvek			11.51 ± 0.14
PEN	Lumirror			22.04 ± 0.11
	Tyvek			8.51 ± 0.11

Simulation's parameters:
Cosmic muon, events 1000,
32 PDUs on SSVessel

Conclusion:
The higher the absorption lengths of LAr, the higher LY obtained

The first step to build LY map for different OV configurations

Preliminary

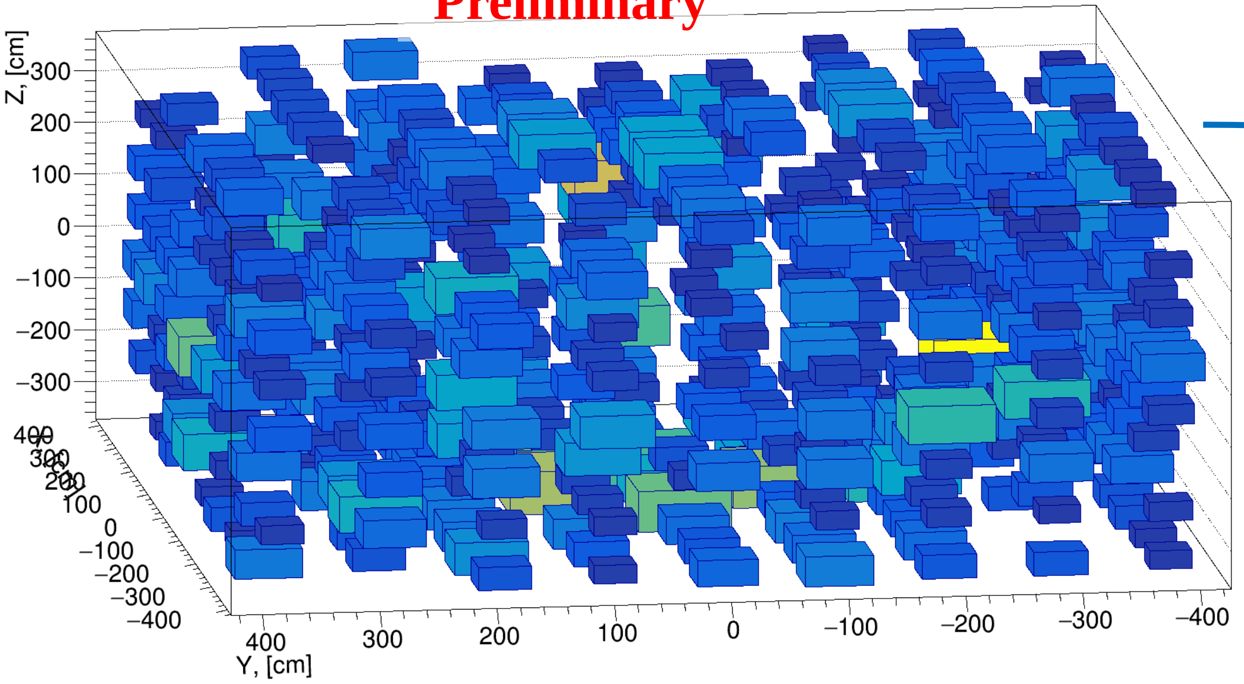


Fig.14. The 3D histogram of voxels with mean LY

Which voxels are empty?

- ✓ Empty inside SSVessel

Preliminary

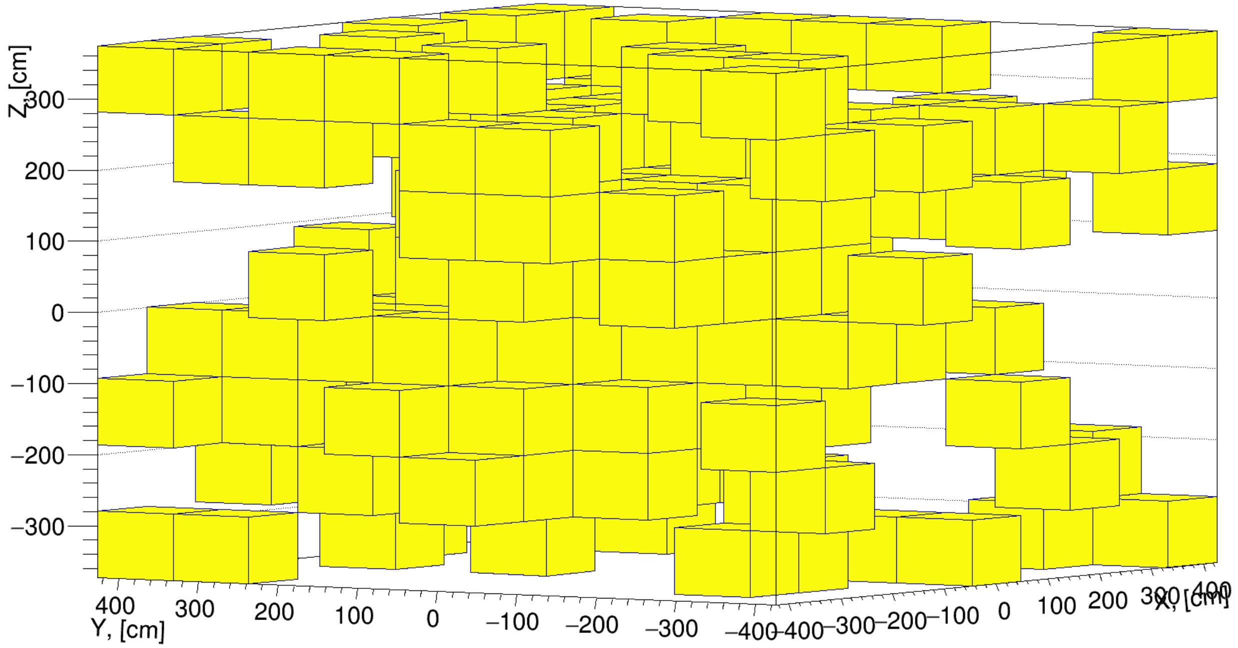


Fig.15. The 3D histogram of empty voxels

Comparison of the LY map for different particle simulations

Simulation parameters:

- electrons;
- E=100 MeV;
- 1000 events;

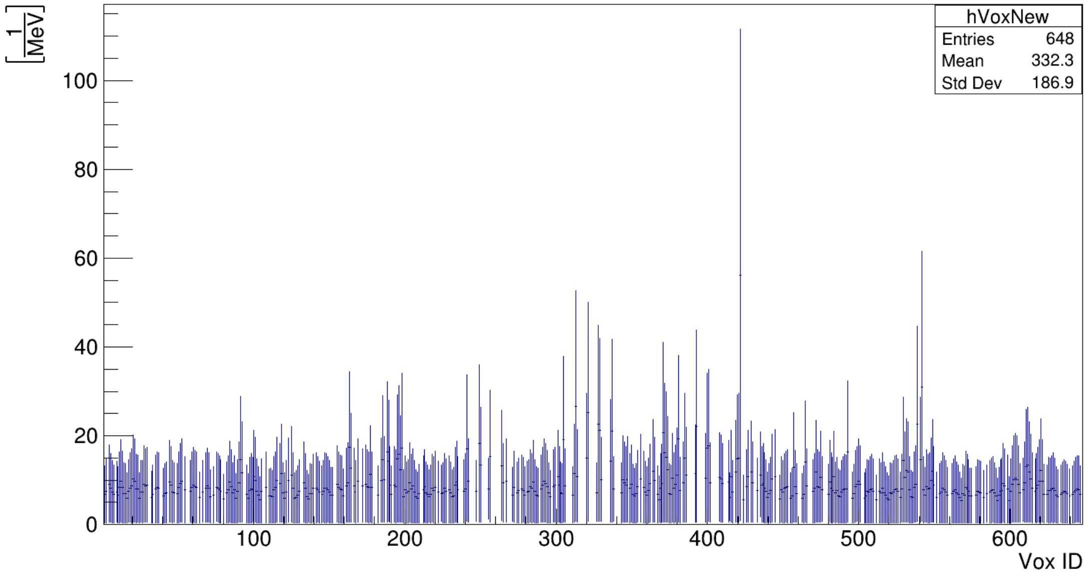


Figure.. The mean LY vs Voxel ID

Simulation parameters:

- optical photons;
- E=9.8 eV;
- 4000000 events;

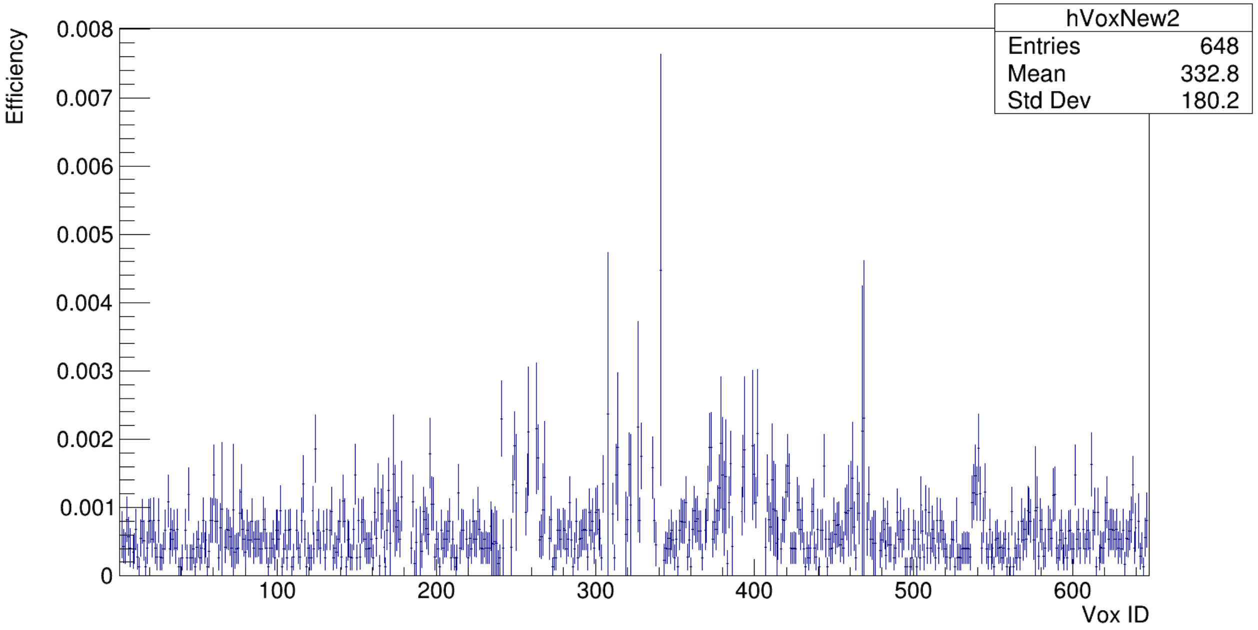


Figure.. The efficiency vs Voxel ID

Influence of LAr absorption lengths on the LY value

Table.. The values of the LY for case 32 PDUs on **SSVessel**

Simulation's parameters: Cosmic muon, veto yield 0.02, events 1000,

WLS\reflector	Lumirror	Tyvek
TPB on PDUs	23.26 ± 0.19	9.76 ± 0.15
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LenLArVisAbs = 10 km,
LenLArUVAbs=10 m

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