Calorimetric reconstruction in DUNE

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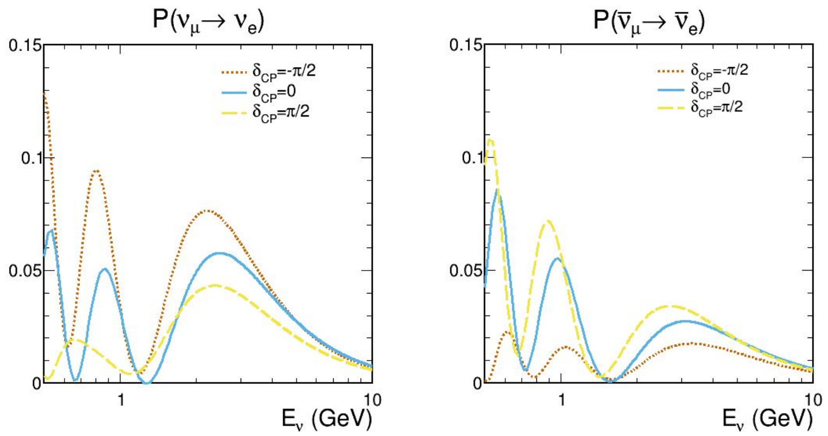
IRN IP2I Lyon

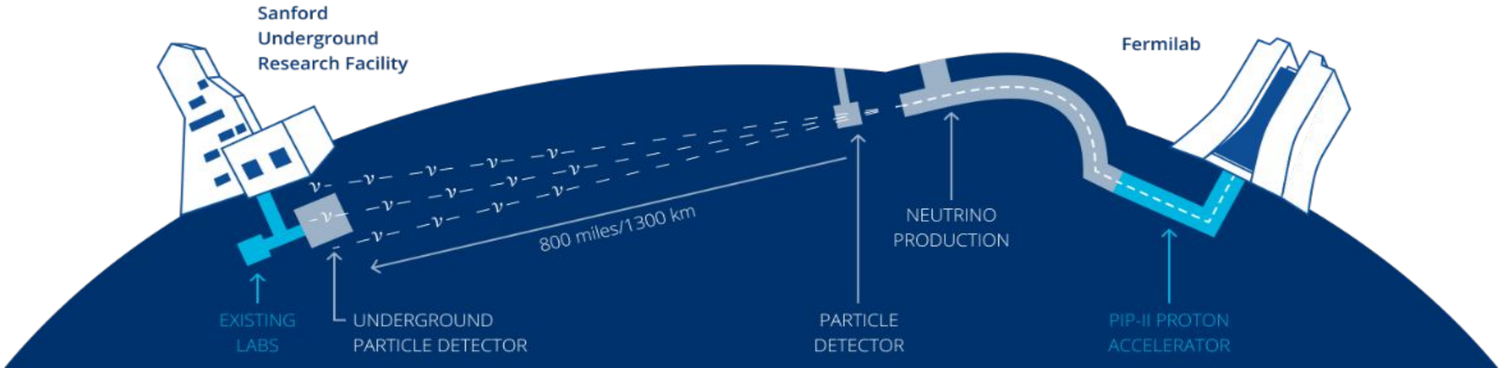
DUNE

Long baseline neutrino experiment

Main goals:
- ➔ Neutrino oscillation measurements
- ➔ CP violation in the neutrino sector
- ➔ Neutrino mass hierarchy



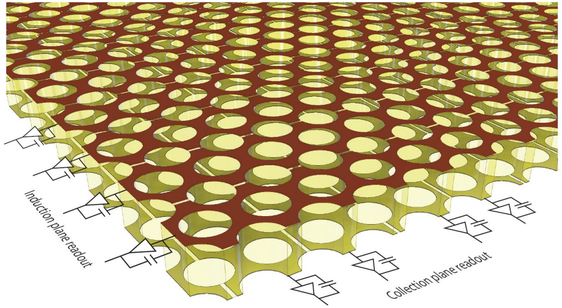
Based on $\nu_\mu \rightarrow \nu_e$ neutrino and antineutrino oscillations: interest in reconstructing the oscillation pattern especially at the second maximum

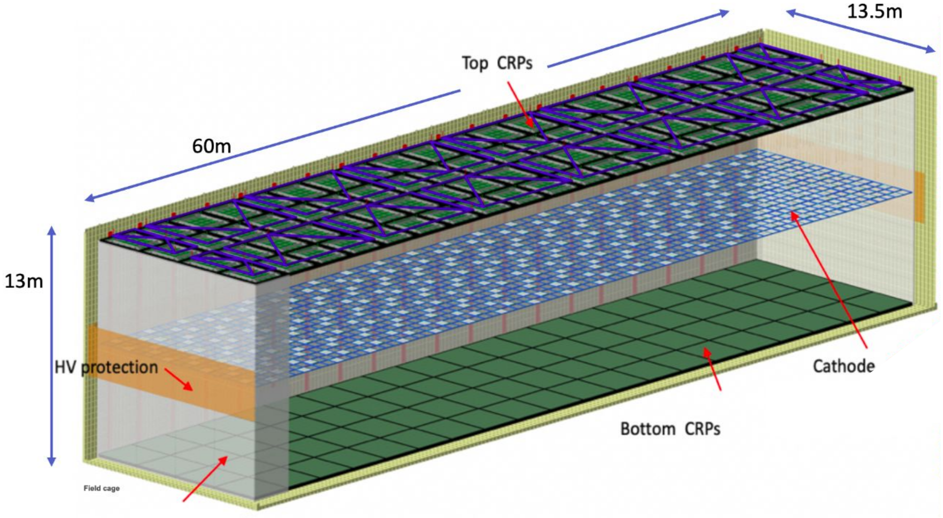


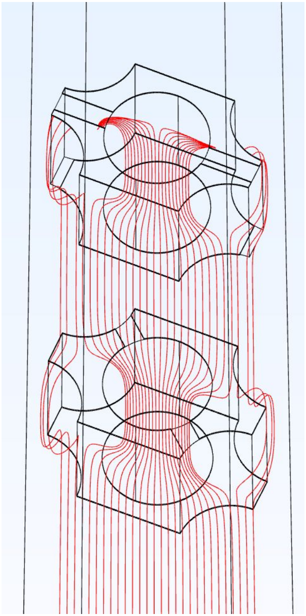
Far Detector Vertical Drift

Liquid Argon TPC:

- Top and bottom CRP anode planes
- Perforated and segmented anode PCB planes
- Electrons are drifted vertically 6.5m drift
- Very high statistics of e⁻/ion pairs ($\sim 3 \cdot 10^7$ e⁻/GeV)







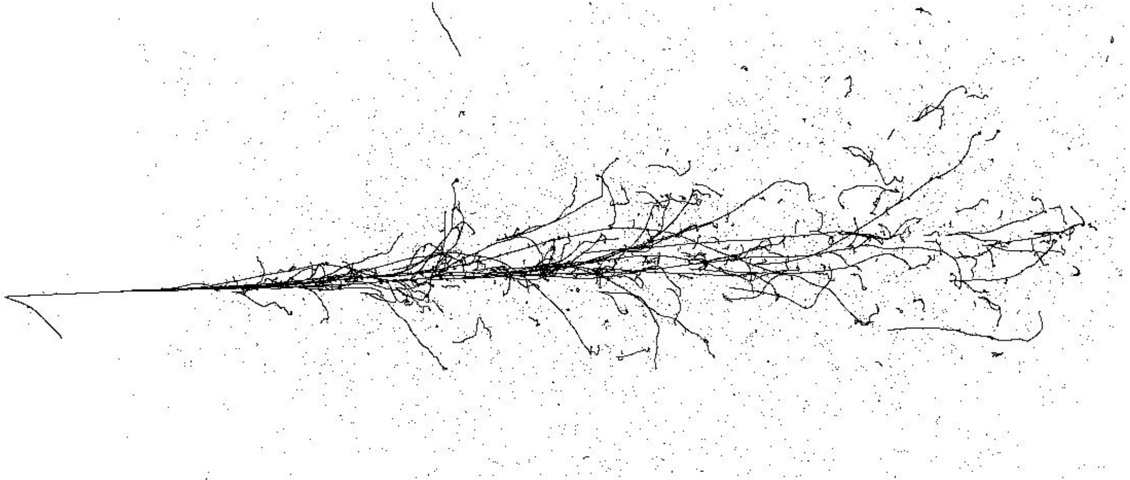
EM showers importance in ν interactions

The energy measurement for ν_eCCQE largely depends on the measurement of the EM shower of the final state

Those events are particularly crucial in DUNE for the oscillation pattern reconstruction at the second oscillation maximum

What should I expect as accuracy in measuring the EM showers?

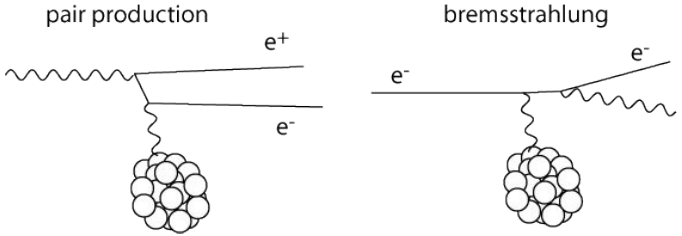
Previous LAr detectors found resolutions of the order of **~2-3%/√(E[GeV])**
What drives this value?
Can we get it also in DUNE?



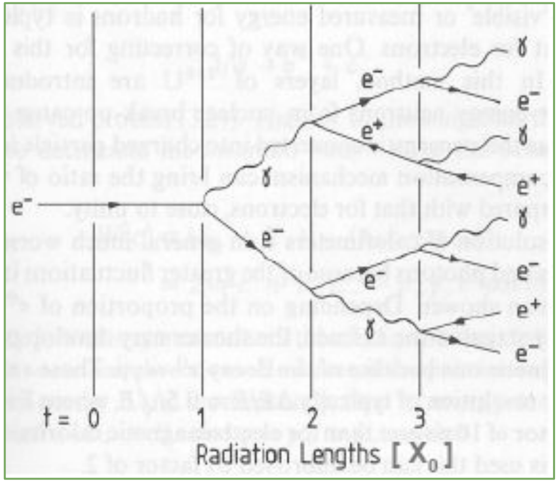
Study to systematically investigate EM calorimetry in LAr TPC and in DUNE

EM showers development

In the classical model an electromagnetic shower can be described as a succession of Bremsstrahlung and pair production events



The simple Rossi-Heitler model where these event happen exponentially as a function of the number of radiation lengths X_0 until electrons go below the critical energy allows to predict the shower profile



EM showers development

In the classical model an electromagnetic shower can be described as a succession of Bremsstrahlung and pair production events

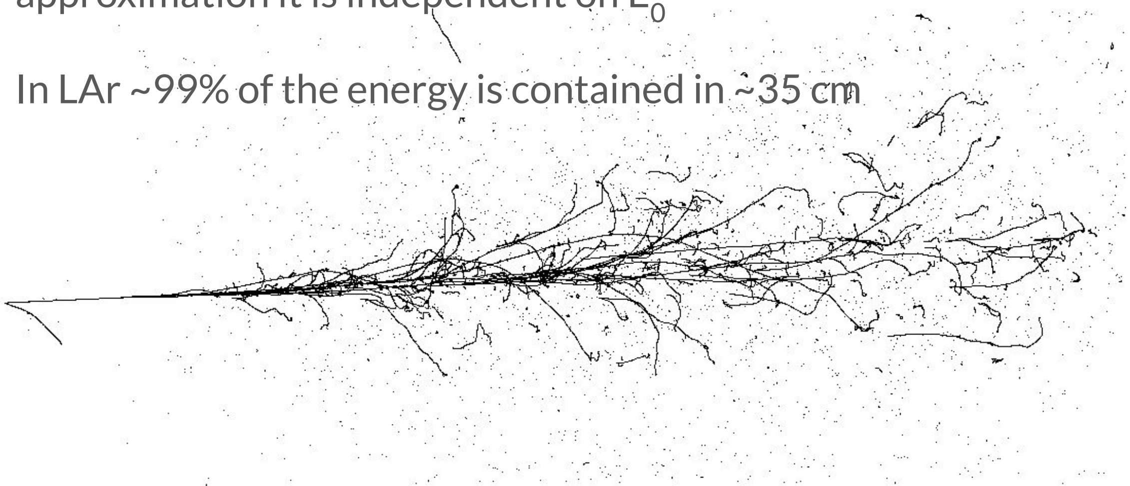
→ logarithmic behaviour with the energy of the incoming e^-, E_0 of the longitudinal development

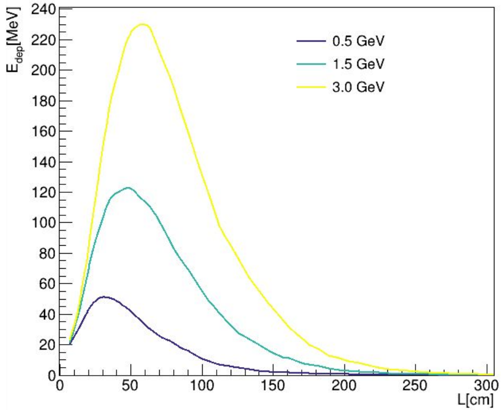
$$t_{max} \simeq \ln \frac{E_0}{\epsilon} + t_0$$

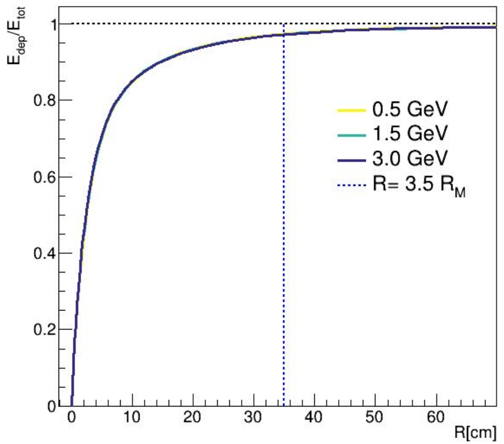
for $E_0 \in$ 0.5-3 GeV then t_{max} ~ 30-60 cm → containment in ~ 3 m

→ transversal development depends on the medium and in first approximation it is independent on E_0

In LAr ~99% of the energy is contained in ~35 cm







development of showers from simulation is compatible with the expectations

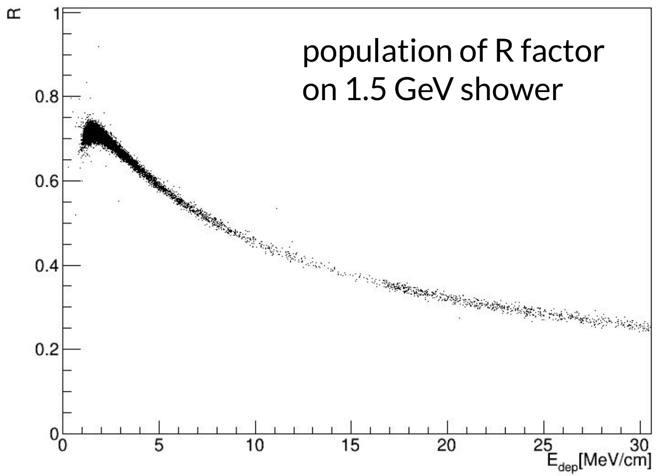
Effects impacting the resolution

Recombination

Effects related to the physics of the detector

- Statistics of the LAr ion-electron pairs produced is very high (~$3 \cdot 10^7$ e^-/GeV)
- There could still be statistical fluctuations introduced by recombination

Recombination depends on local charge density which fluctuates



The result of this study on **fully contained events** shows that recombination fluctuations worsen the resolution at the level of a **fraction of percent** and **do not** play a major role in the 3%/√E figure

Effects impacting the resolution

Sampling fluctuations

Presence of dead regions inside the detector

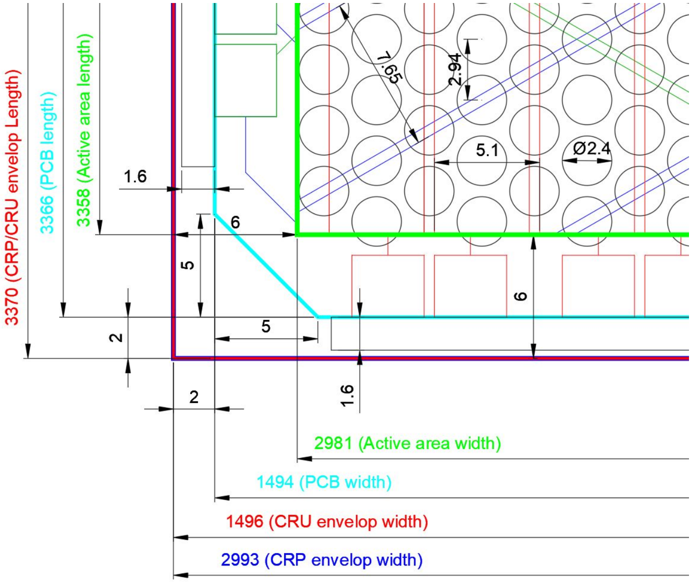
The layout can include regions in which the energy is lost
→ fluctuations on this lost energy fraction

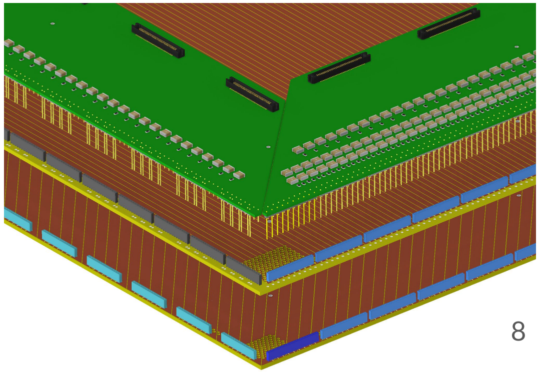
In **DUNE VD FD** module there are dead regions at the borders of the CRPs and of the superstructures which are due to:

- physical gap between two CRPs
- region at the CRPs boundaries in correspondence of the adapter boards

➔ In this work the total gap between CRPs is simulated at 10mm large and assumes that all the energy in the gap is lost, but probably this is not the case, since most of the charge could be recollected

➔ We found it contributes to a level of **~1%**

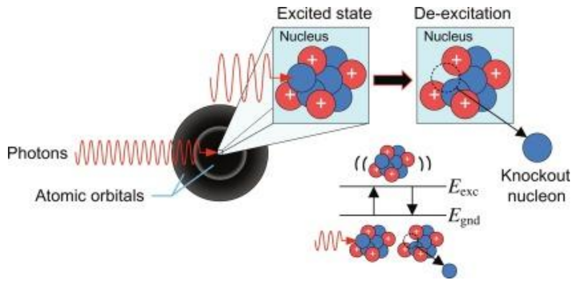




Effects impacting the resolution:

Physics of the EM shower $\rightarrow \gamma$'s photonuclear interactions

Unexpectedly the main driver of the resolution is given by γ's from the shower reinteracting with the Ar nuclei, generating nuclear excited states



This results in a violation of the classical cascade model since part of the initial energy of the electron (or photon) is being lost in the nucleus excitation $\rightarrow$ tail of the energy resolution distribution

The fraction of showers with photonuclear interactions for each energy is:

0.5 GeV	1.5 GeV	3.0 GeV
7.8%	18.8%	38.4%

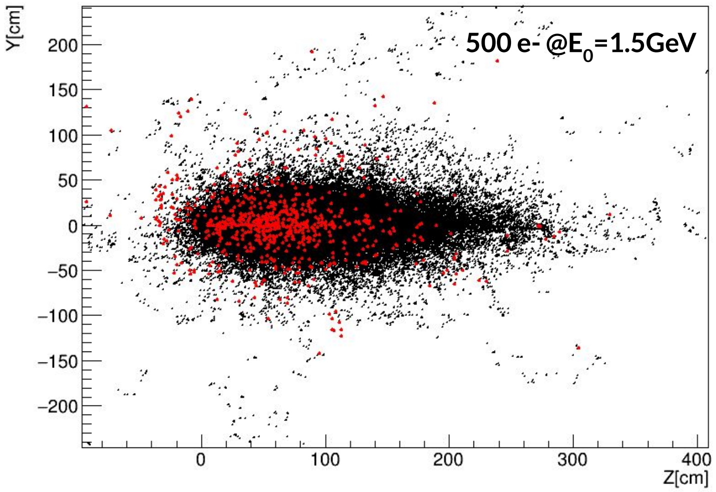
With the help of Paola Sala we checked and the amount of photonuclear effects are also reproduced by FLUKA

Effects impacting the resolution:

Physics of the EM shower → γ's photonuclear interactions

Unexpectedly the main driver of the resolution is given by γ's from the shower reinteracting with the Ar nuclei, generating nuclear excited states

- Energy resolution distribution shows a tail
- Shower development shows deposits far away from the interaction vertex
- These interaction are distributed uniformly along the direction of the shower



With this contribution we reach the **3%/√E**

Effects impacting the resolution:

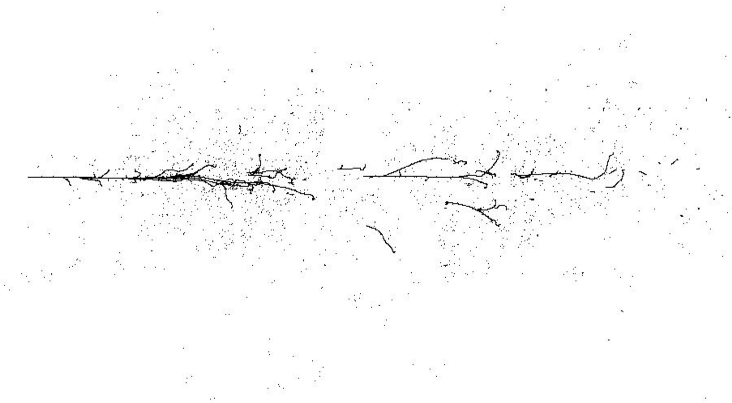
Reconstruction

Signal digitization

The way the deposited energy is converted into hit and the signal processing could affect the resolution

→ **we find a contribution of some fraction of %**

Higher reconstruction



Affected by the difficulties in identification of the shower due to not very compact showers that might present holes and soft electrons energy deposits far away from the main shower region

→ **Worsening in resolution reaches 3-10% in the range 0.5-2 GeV**

The main limitation comes from the capability of the current reconstruction of capturing the EM shower in its entire development → this is under improvement

Conclusions

A systematic investigation of EM calorimetric in LAr showed that at the hits level a 2-3%/√(E[GeV]) is achievable at the shower level for fully contained events, like it has been shown by previous LAr calorimetry studies.

This is particularly relevant at the second oscillation maximum in order to reconstruct the oscillation pattern.

Photonuclear reinteractions proved to be the main effect, together with the presence of gaps at the CRP borders. Each of these effects contribute to the worsening at a level of ~1%.

Recombination and signal digitization are minor effects for the shower resolution and contribute at the level of a fraction of percent.
High level reconstruction brings to a worsening at the level of a few percent.

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

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Lyon 1

Backup slides

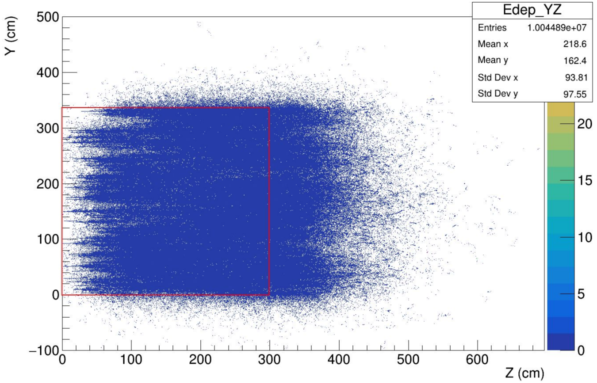
Simulation configuration

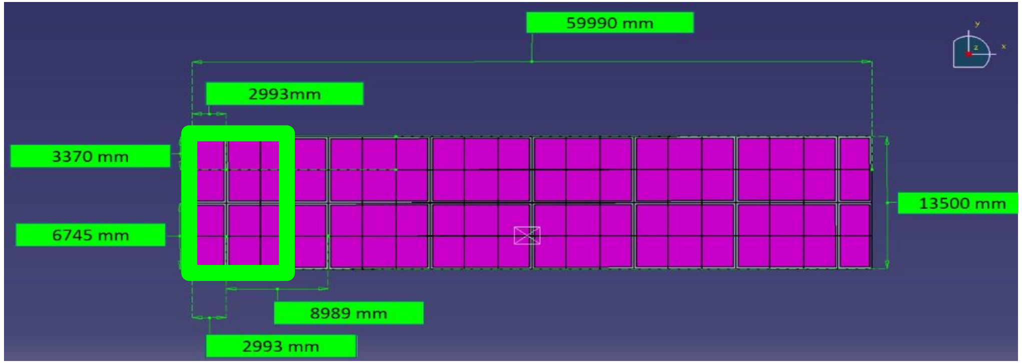
Geometry is the 1x8x6 CRP (taken from official VD simulations):

- ➔ standard_g4_dunevd10kt_1x8x6_3view_30deg.fcl, dunesw v09.92.00d00
- ➔ in order to store the deposits of energy in the CRP gaps the geometry modified for us
- ➔ the CRP gaps are 10mm large

Steps:

1. 500 electrons generated for three different energy values (0.5, 1.5, 3.0 GeV) with vertices distributed uniformly in one of the CRP planes.
2. Volume large enough to contain all the energy → fully contained population
3. Add one by one the detector resolution effects:
   a. Recombination
   b. CRP gaps
   c. Signal digitization
4. Cut on topology to check the effect of photonuclear interactions in the shower development





Resolutions

Res [%]	All topologies		N_{nuclei} = 0	
E_0[GeV]	no gaps	with gaps	no gaps	with gaps
0.5	2.91	3.24	0.60	1.64
1.5	1.62	1.99	0.36	1.28
3.0	0.98	1.46	0.26	1.25

Res [%]	N_{nuclei} = 0			
E_0[GeV]	G4	I&S	Hit	Reco2
0.5	1.61	1.71	1.97	12.48
1.5	1.22	1.28	1.40	2.38
3.0	0.85	0.89	1.00	1.48

1. **Physics of EM shower, photonuclear effect:** it's the most important physical contribution to the resolution, contributing with an increase of ~1.3% in the range 0.5-2 GeV. This contribution has a stronger weight the lower the energy is.
2. **Sampling fluctuations:** the impact of the CRP gaps with the dimensions considered in this study correspond to an increase on the ~1%
3. **Recombination:** it does not seem to play a major role, with an increase of the fraction of %
4. **Signal digitization:** its impact is <0.3% when reconstruction is performed with Hit:HitSumADC (recently add)
5. **Higher reconstruction**: the worsening in resolution reaches 3-10% in the range 0.5-2 GeV

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