Event vertex reconstruction with deep neural networks for the DarkSide-20k experiment

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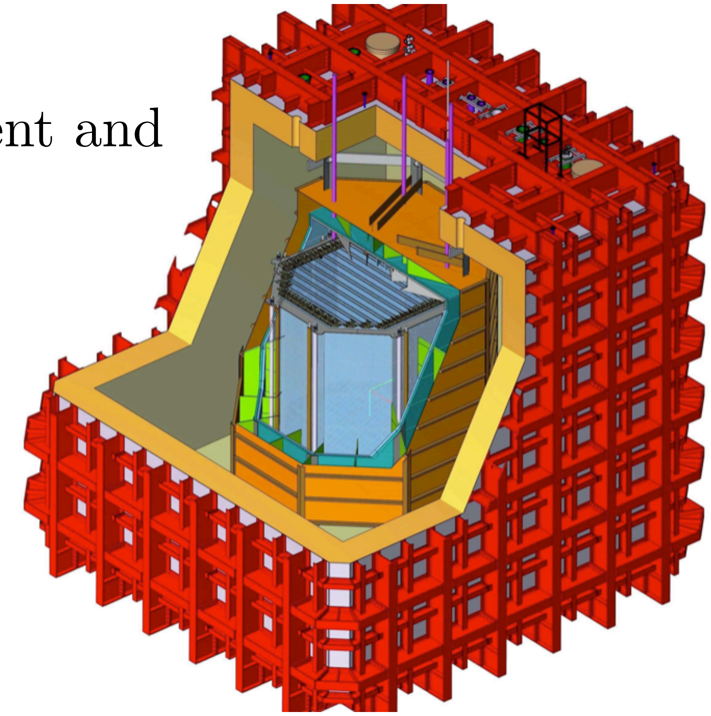
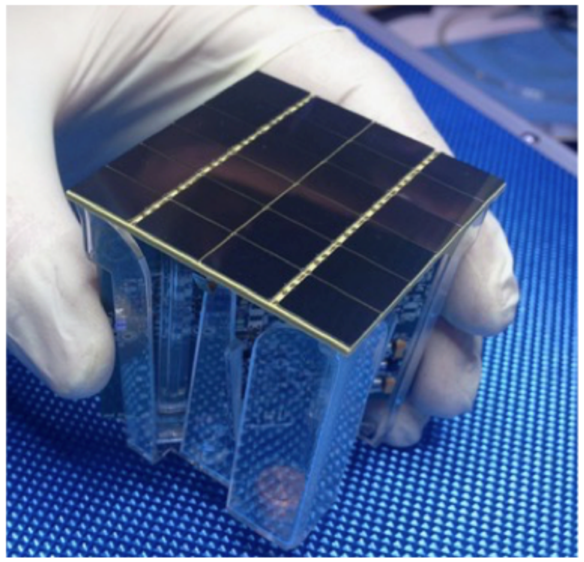
The DS20K Detector

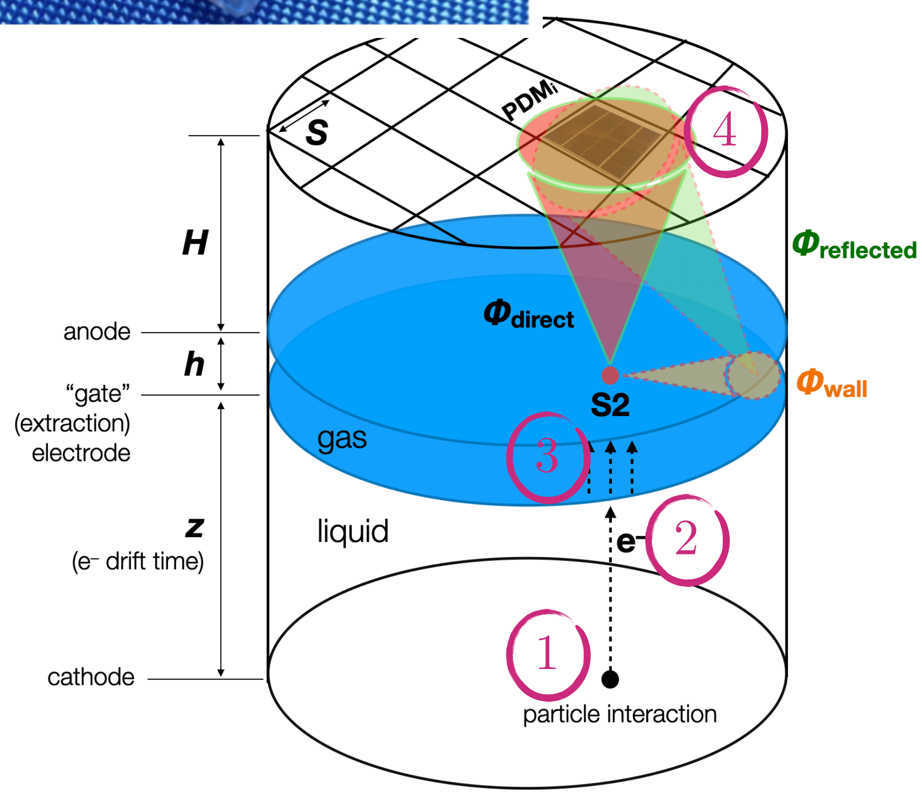
The DS20K Detector will be a dark matter detector commissioned and deployed at LNGS, Gran Sasso, Italy:

- Two Phase Liquid Argon (LAr) Time Projection Chamber (TPC)
- Designed for direct detection of WIMPs, with sensibilities beyond current and planned experiments





- Will have 8200 photosensors, each being an array of 6x4 Silicon Photomultipliers (SiPM), with each photosensors having an area of 5x5 cm^2
- Photo detection pattern complicated by reflections wavelength shifting coating, etc. nevertheless most light seen in the closest photosensor to XY position



The interaction picture:

1. Incoming particle excites and ionizes LAr, produces scintillation light (S1)
2. e$^-$ are drifted to the anode via applied E field
3. Electroluminescent signal from e$^-$ interacting with GAr (S2)
4. Light is detected by photosensors

The light detection pattern is directly correlated to the XY position of the original interaction

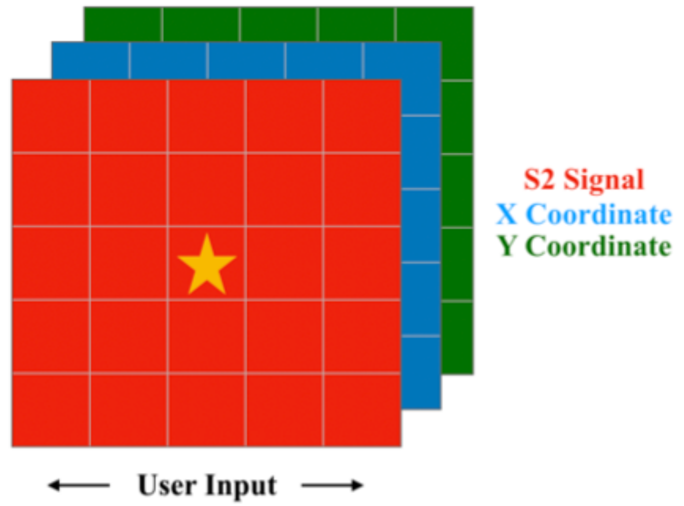
Figure not to scale!

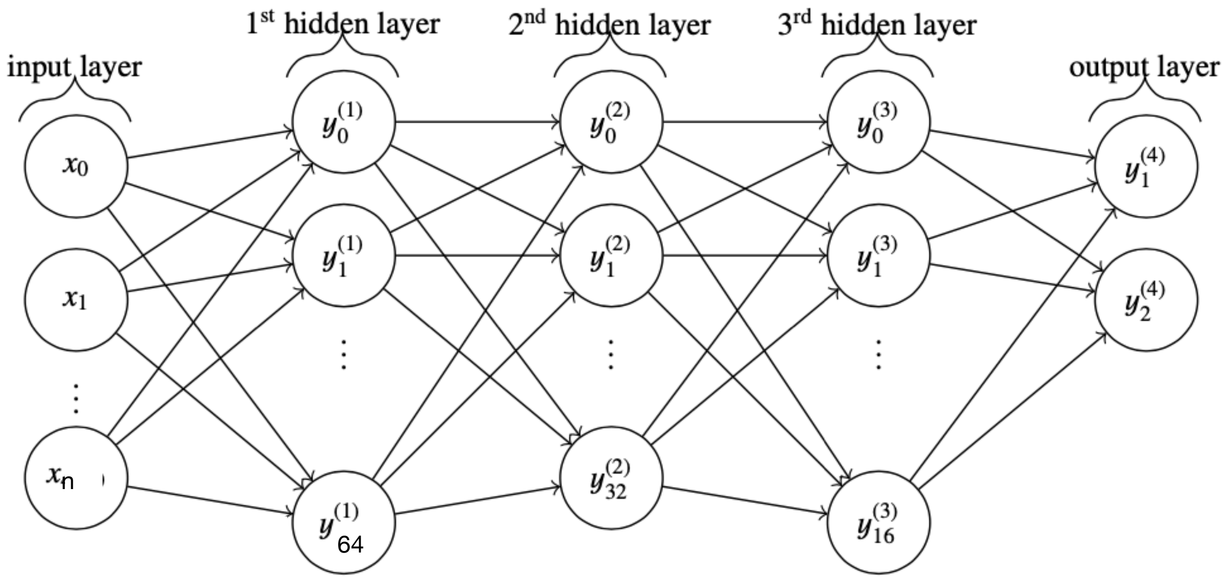
Most background (BG) is of radiogenic nature, detected in the edges of the detector. The fidualization of the active volume reduces this BG, therefore vertex reconstruction is needed.

ML Based Reconstruction:

Model contains a Conv2D block and a fully connected, dense neural network block. Inputs being a 3D n by n array specified by user. Features are time integrated charge of each photosensor, and the XY positions of these. Includes user flexibility to study the XY reconstruction performance under:

- Inactive PDMs
- Saturated PDMs
- Different readout configurations



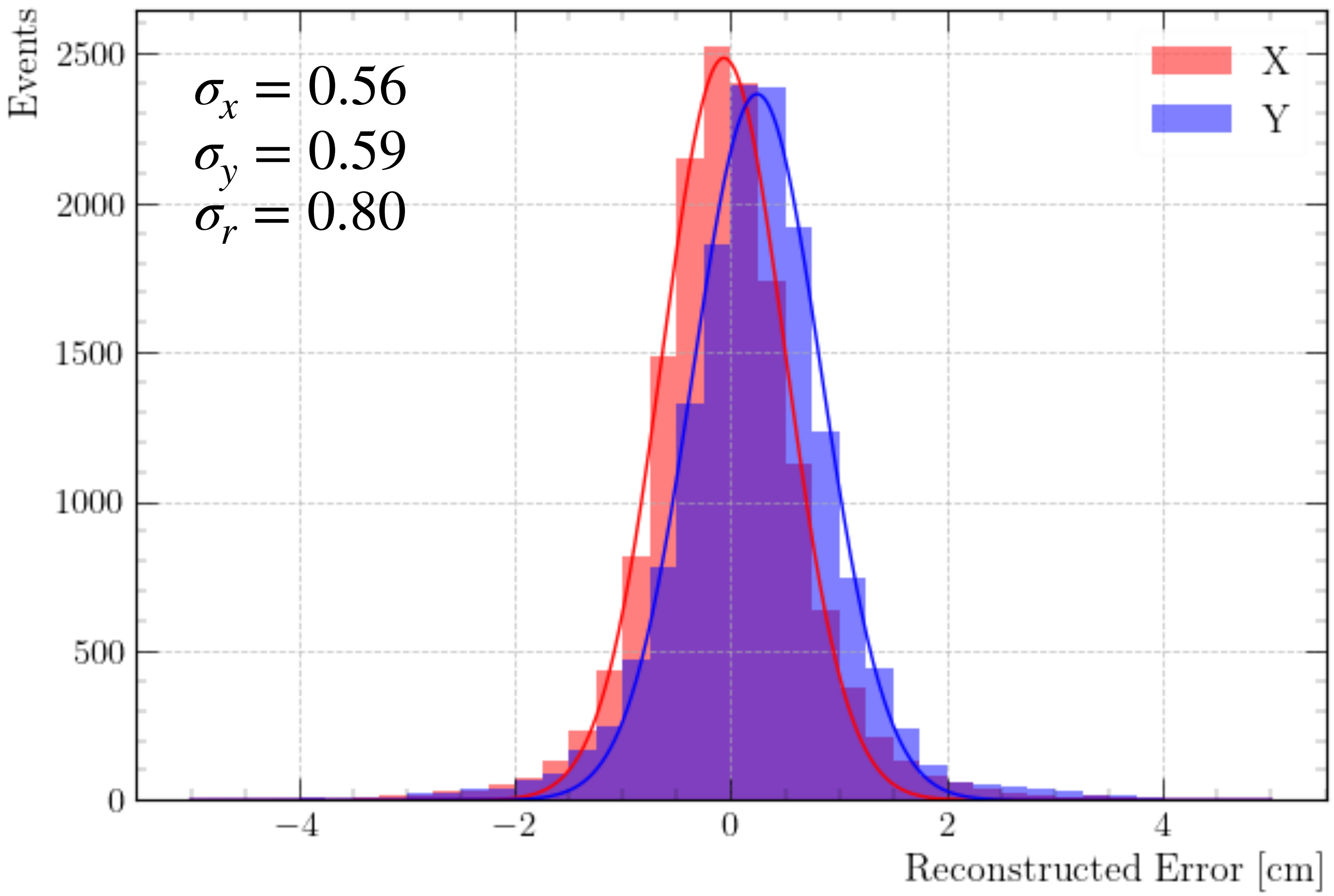


Training phase:

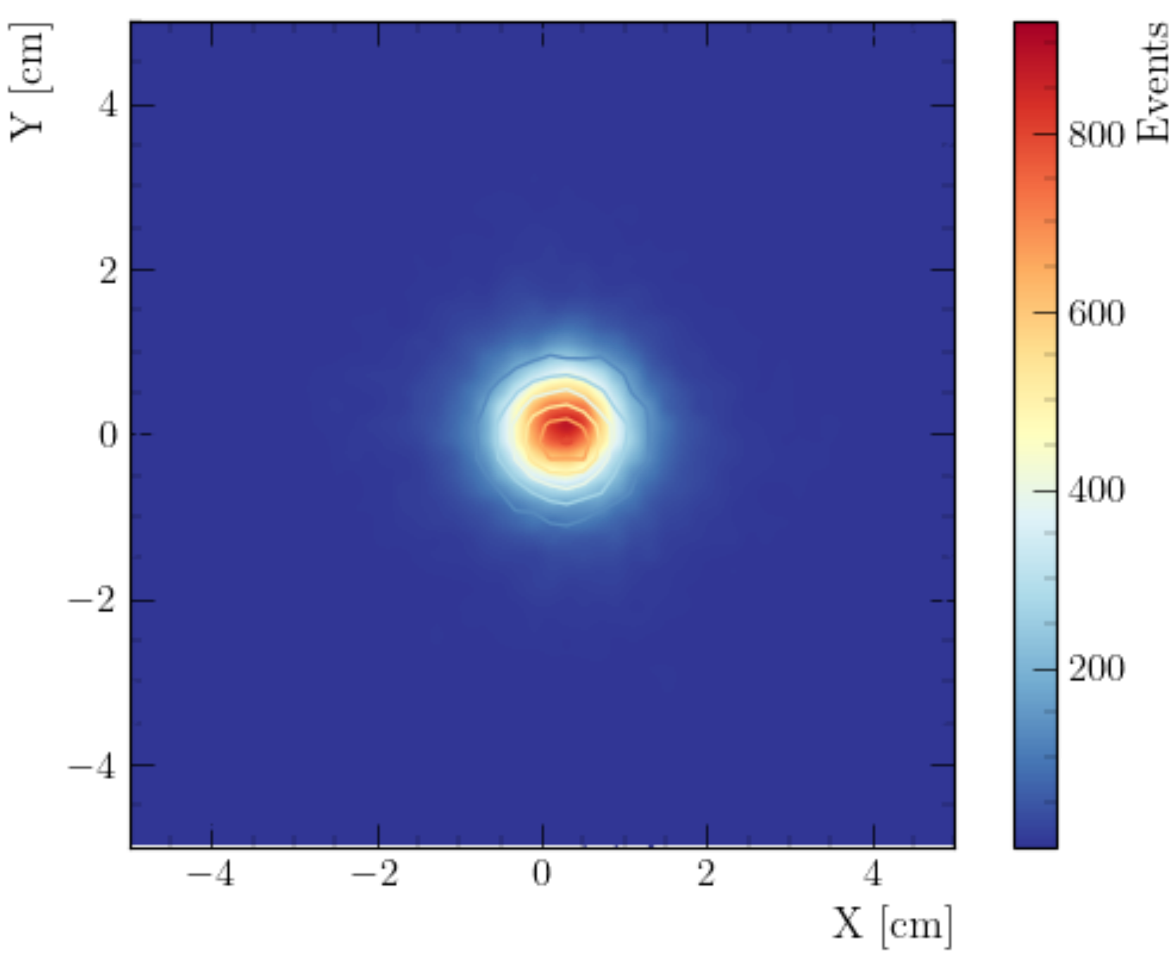
- Training and testing on MC generated dataset, including appropriate geometry and optical propagation of the scintillation light in the detector.
- Optical modeling is developed to include baseline properties, but is missing fine tuning and validation of model/simulation to attain usable results in real like detector, in progress planning

Performance

After training a model on a 5e5 events dataset containing with energies [10-200] KeV (1e3 - 2e4 PE), the reconstruction performances are as follows:



- The reconstruction uncertainty (resolution) is taken to be the sigma of the difference of the true position and the reconstructed position distribution
- 30% improvement over more traditional methods, for instance, Center of Gravity (CoG)

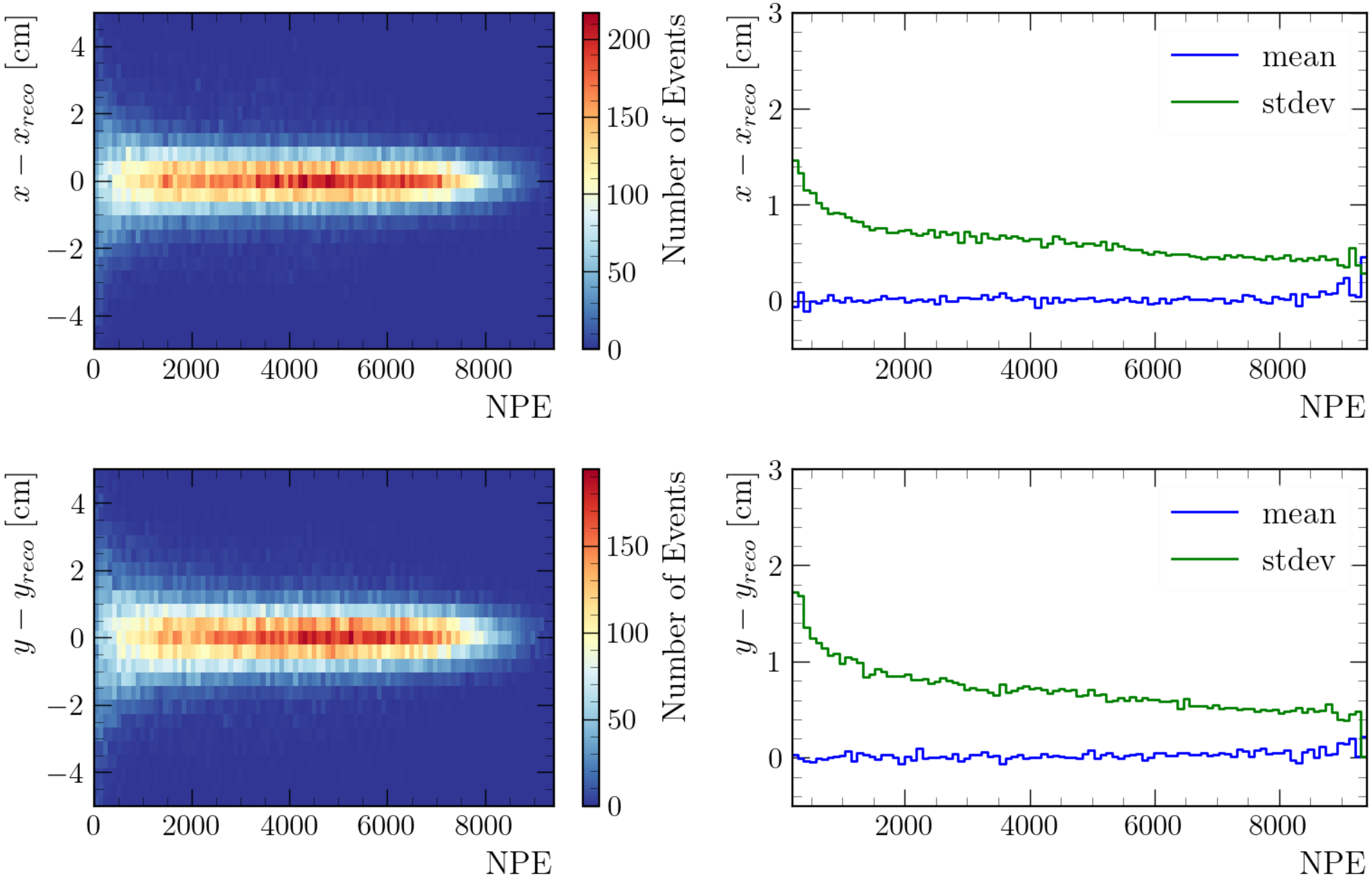


- From the reconstructed positions, the radial distribution is computed, from where the r-resolution follows.
- Due to symmetry of the detector, r distribution is used for fidualization of active volume

Performance: Energy Dependence

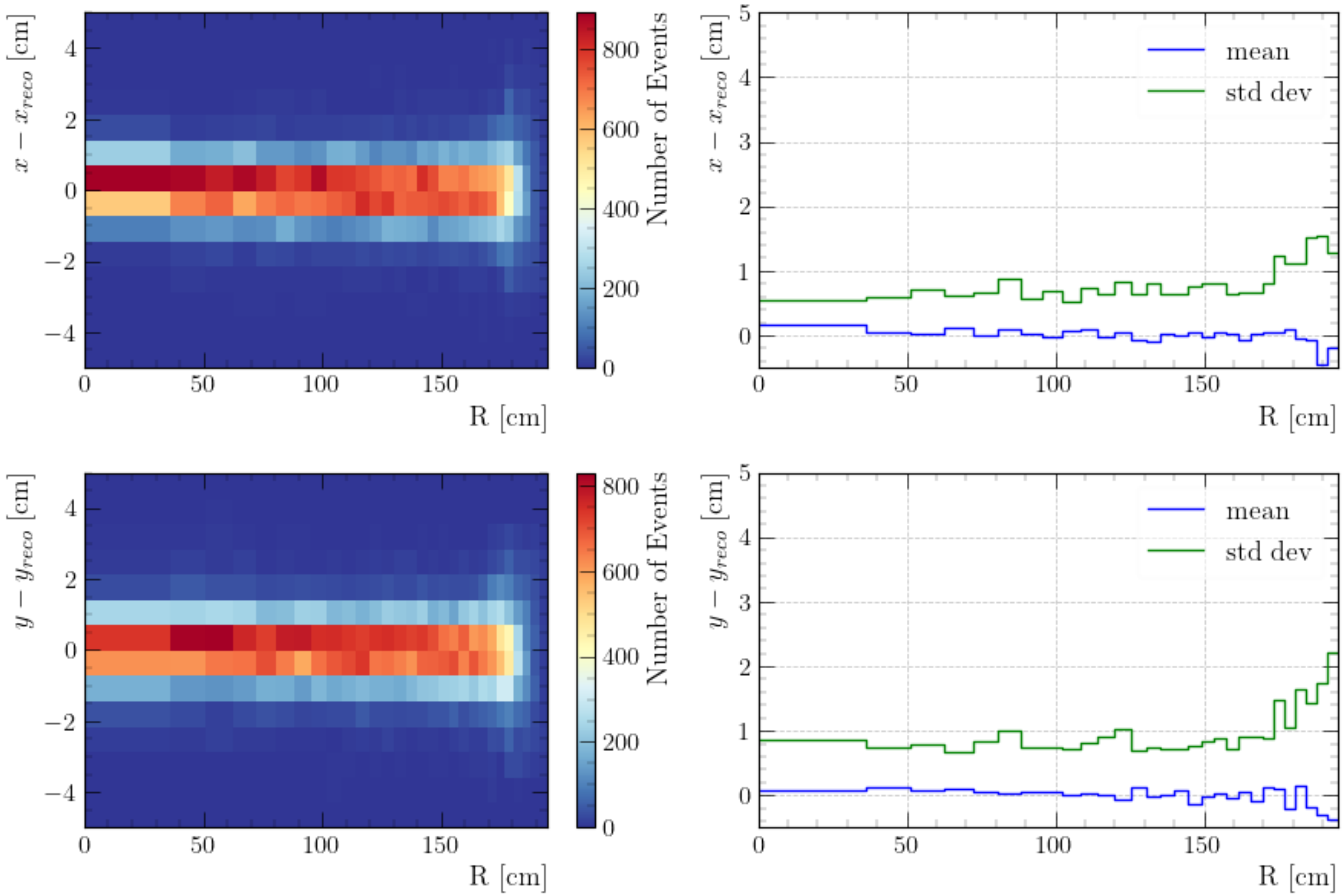
Low energy events are reconstructed slightly worse.

- $\sigma_{x,y} > 1$cm for events below E $\lesssim$ 20 keV
- Reconstruction uncertainty stays consistent above 20 keV



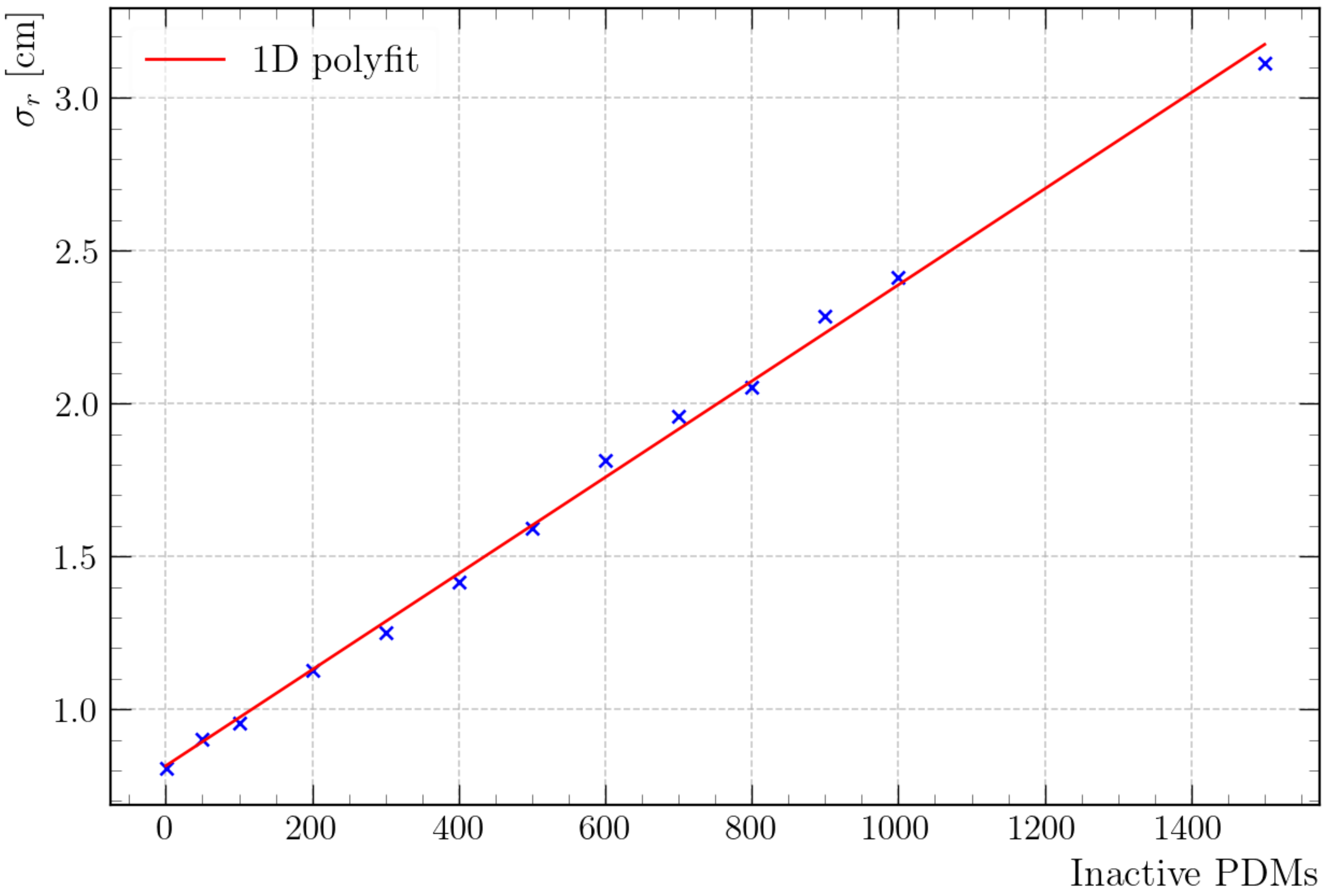
Performance: Radial Dependence

- This reconstruction method stays regular with increasing radial distance
- Regions above 160 cm see a resolution increase, reaching $\sigma_{x,y} > 1.5$ cm
- Other methods like CoG used for event vertex reconstruction show more bias towards the edges of the detector



Performance: Inactive PDMs

The effect of inactive photosensors is also quantified

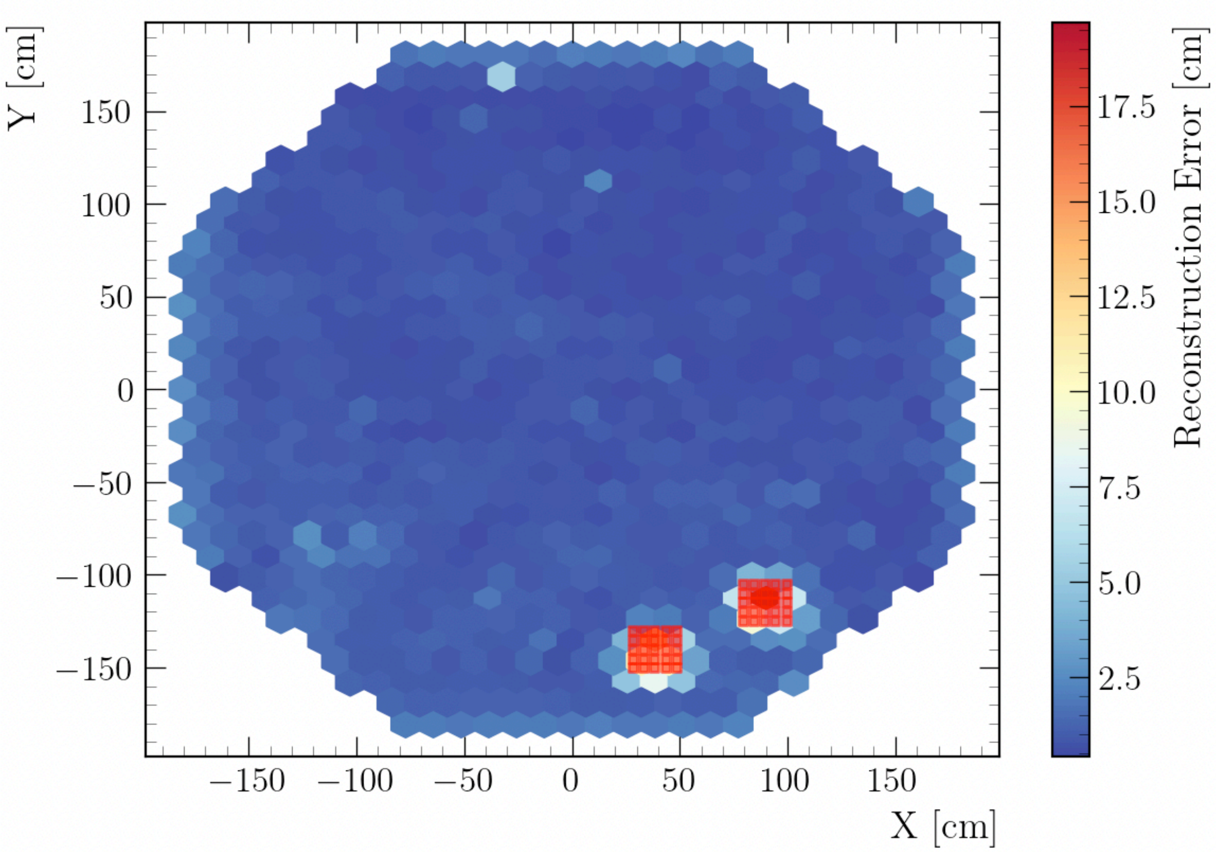


Relationship between the reconstruction error and the number of inactive photosensors:

- Baseline : one photosensor per readout channel

Error map with photosensors in red, marked as inactive in the reconstruction:

- two groups of 5x5 sensors marked as inactive



Conclusions and Ongoing

With ML methods, we successfully develop methods for position reconstruction of a next generation dark matter detector:

- ML is a suitable choice for position reconstruction with high number of photosensors
- Robust methods that can be adapted and perform with inactive, and saturated channels
- The reconstruction model shows radial performance as no major edge effects are observed
- There is still a necessity of tuning the model with data-driven training, for example, with calibrations
- Improvement over more traditional methods at low energy regions

Among the next steps;

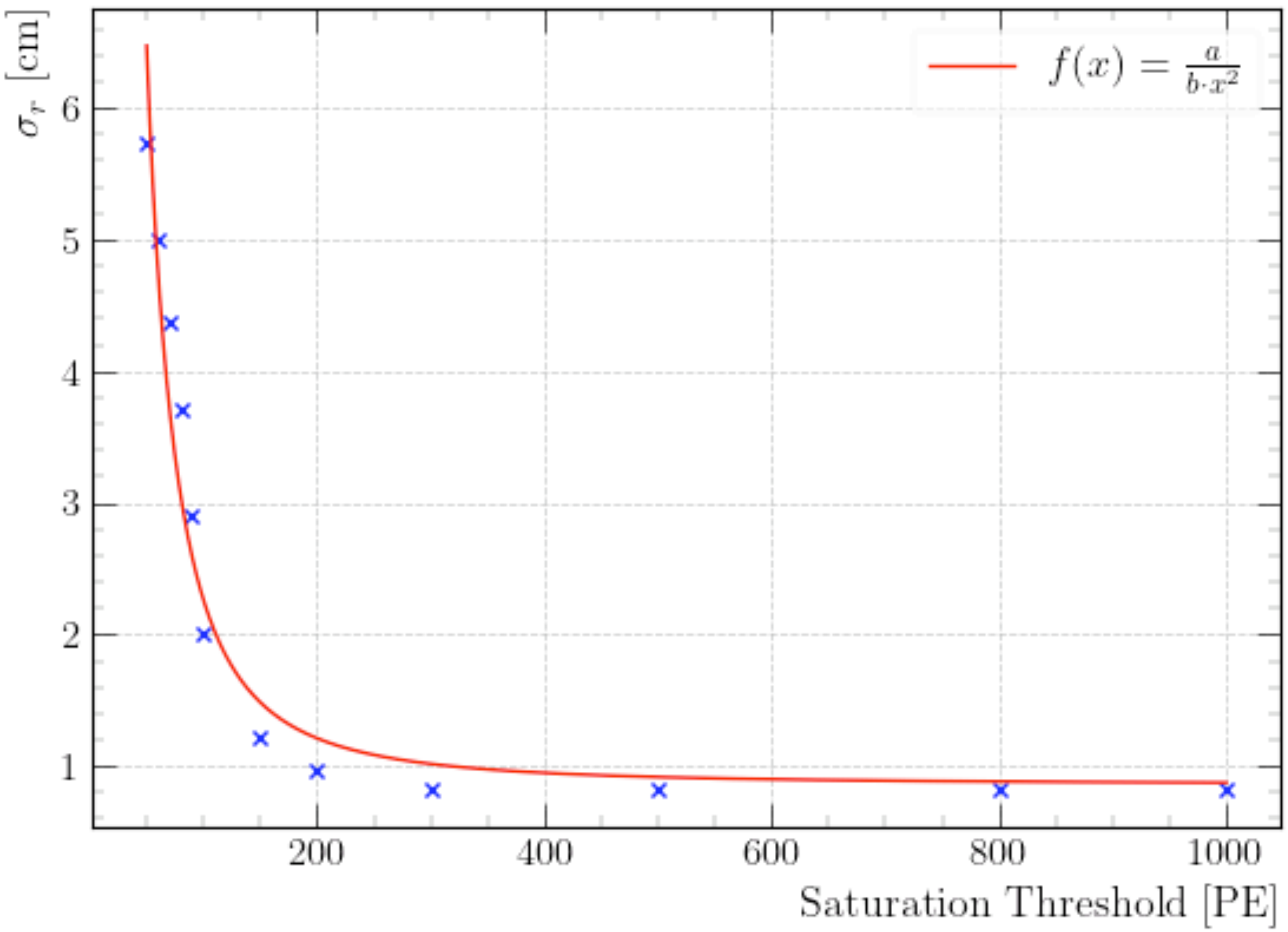
- Developing a generalized MC for production of data for training with basic detector properties and optical propagation.
- Testing with data acquired from collaboration prototype

Questions?

Backup Slides

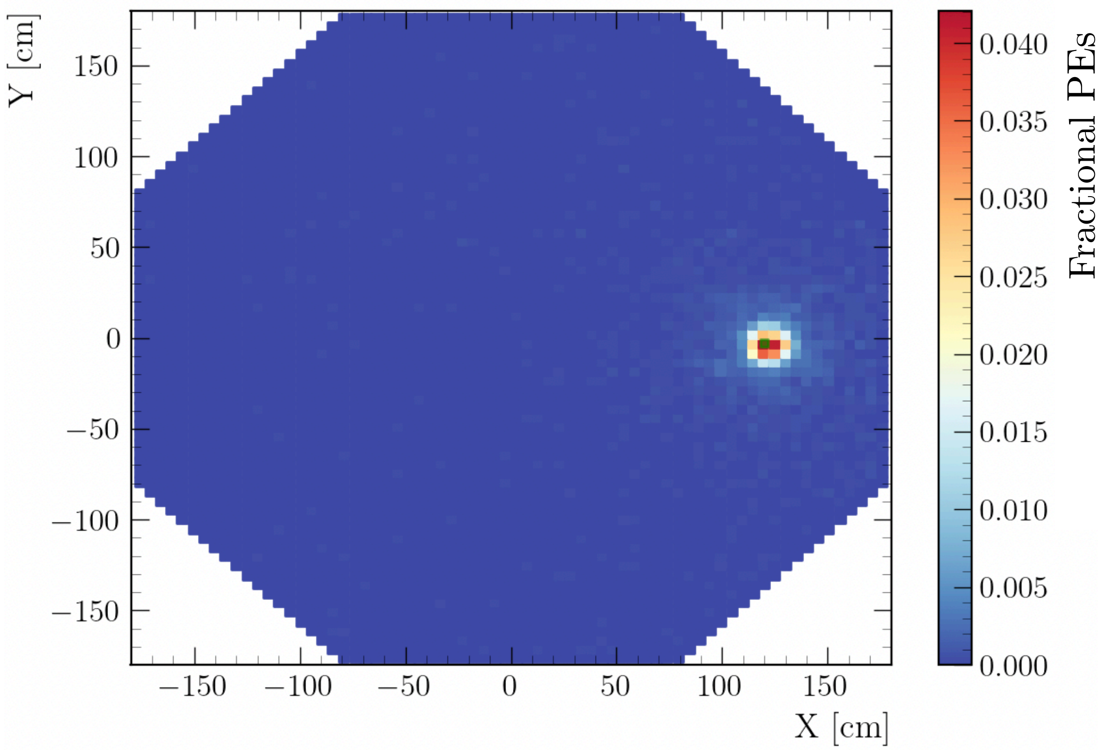
BACKUP

Performance: Saturation

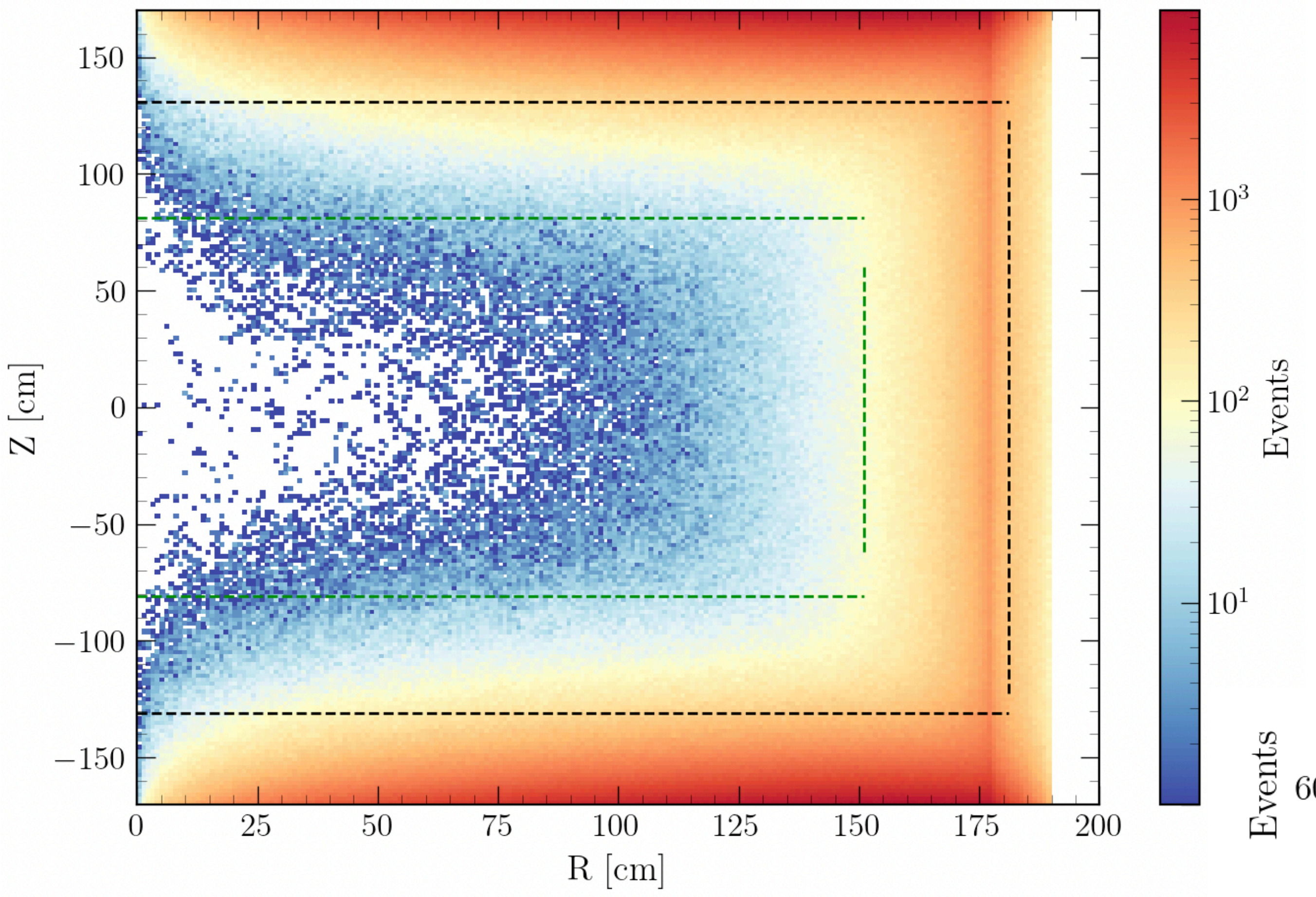


- Next, showing how the reconstruction error is affected as the saturation threshold is changed. The code will set the max number of PEs of a given PDM to the saturation threshold
- It is expected for the saturation threshold to be in the flat region, no deteriorate reconstruction due to saturation is expected

- The hit map for a specific event in which there is one saturated PDM, in green, at 100 PEs.

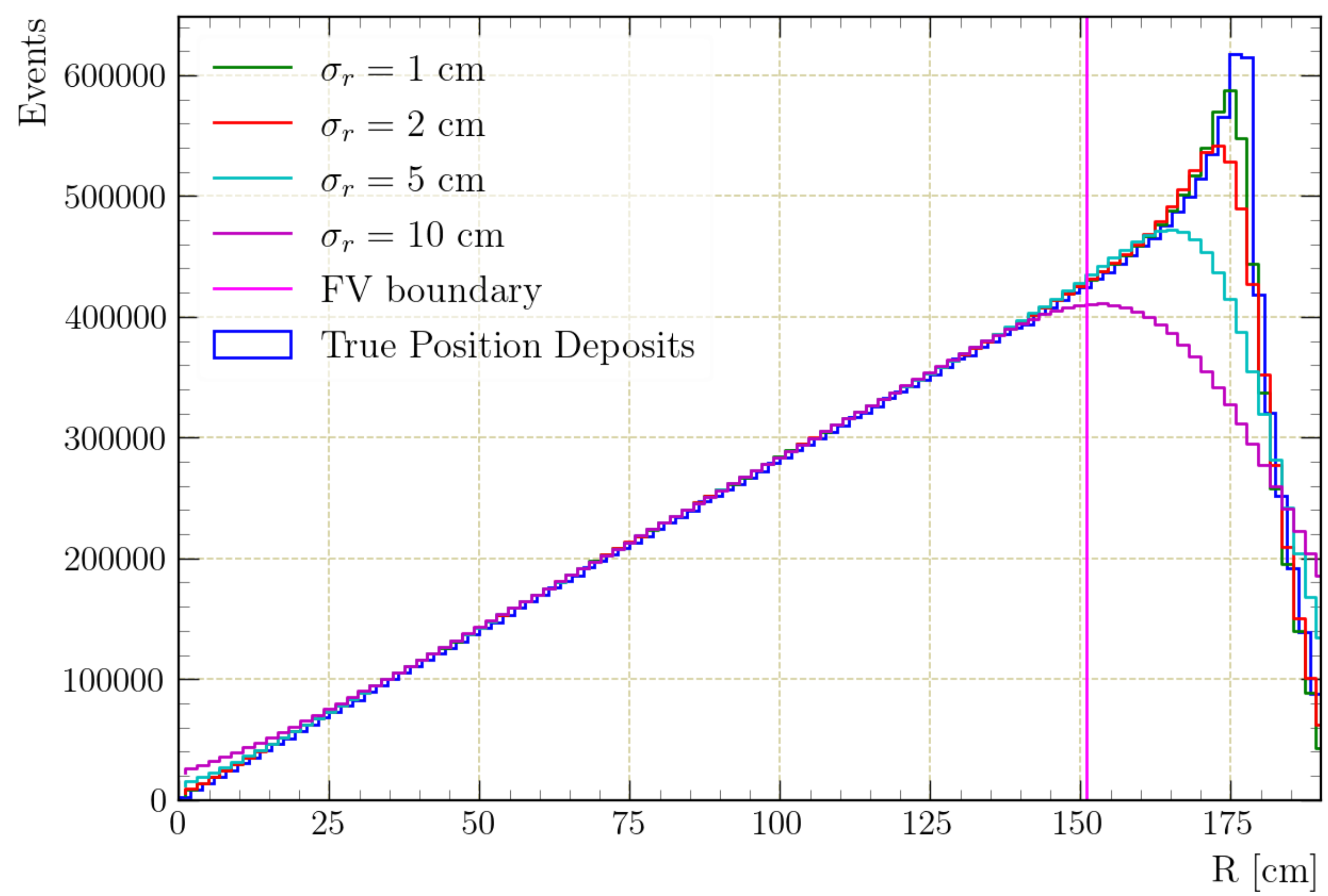


Fidualization and event leakage



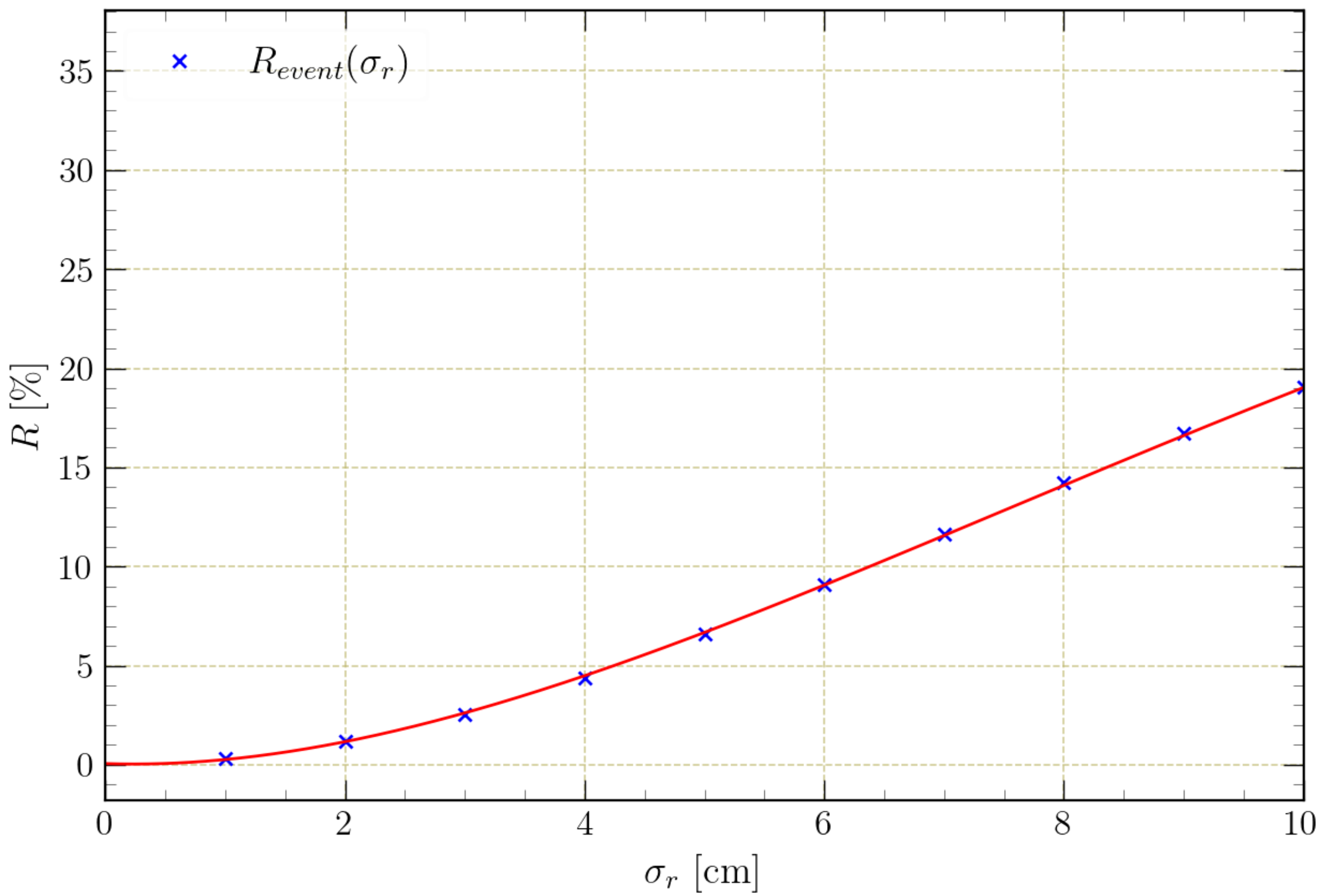
Using radiogenic BG (MC from Paolo) to estimate the XY resolution needed:

- Looking at how many events fall in/out of the FV for different XY resolutions
- Here, events with deposits in the TPC
- Ignoring Z uncertainty



Fidualization and event leakage

- R = abs(events inside before convolution - events inside after convolution) / events inside before convolution * 100 %



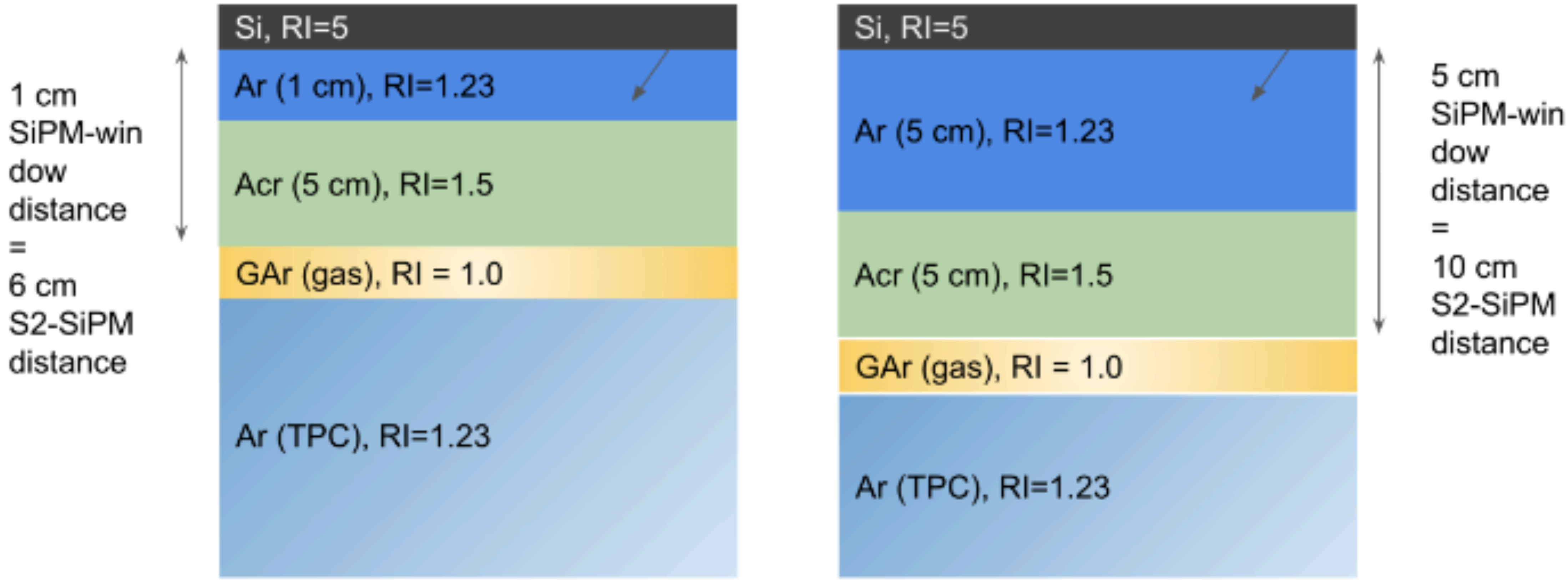


Figure 26: Sequence of materials and refractive indexes in G4DS for S2 simulations.

Radial Distribution of S2

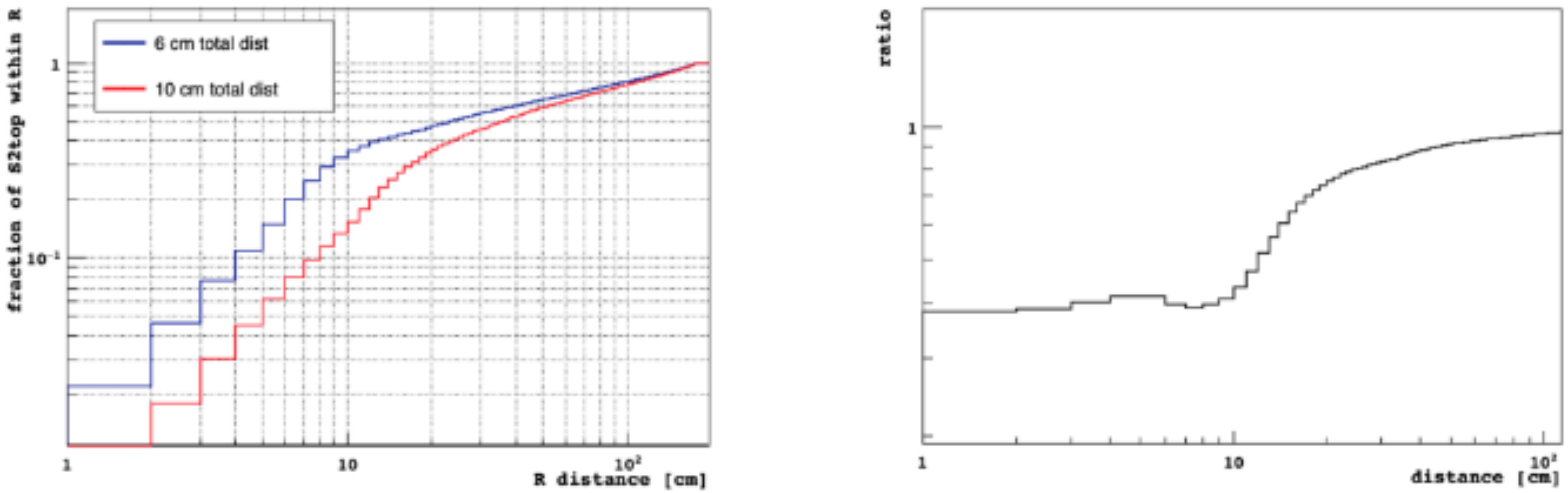


Figure 27: The cumulative distribution of photons collected as a function of the radial coordinate, for events at the TPC center (left). The right-hand-side plot shows the ratio between the red and blue curve of the plot on the left.