PDS membrane-mount layout optimisation: Optical coverage and light yield simulation studies

Michel Sorel

IFIC INSTITUT DE FÍSICA CORPUSCULAR

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS CSIC

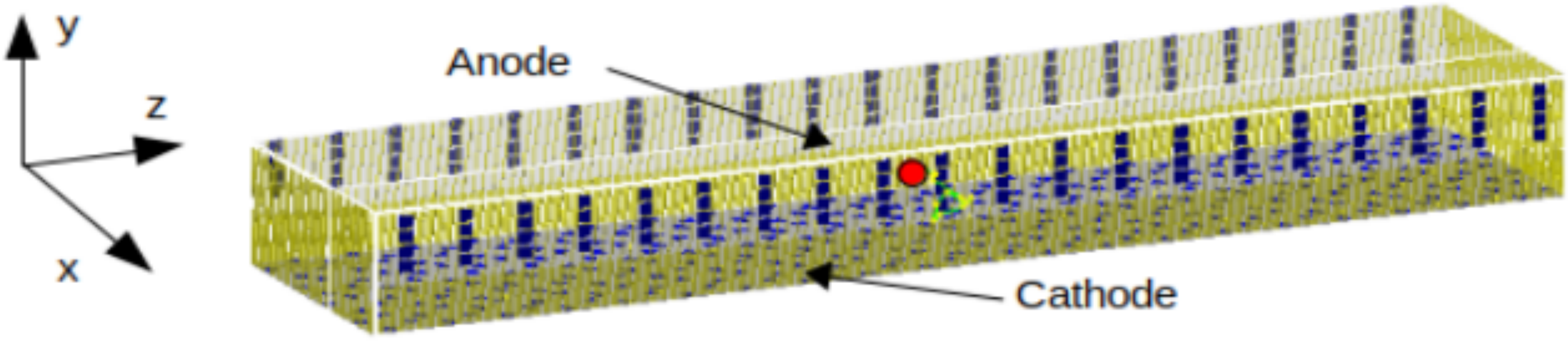
VNIVERSITAT DE VALÈNCIA

In collaboration with: Hamza Amar, Clara Cuesta, Ines Gil, Sergio Manthey, Francio Marinho, Laura Paulucci

Preliminary Design Review of the DUNE FD2-VD PDS
June 2022

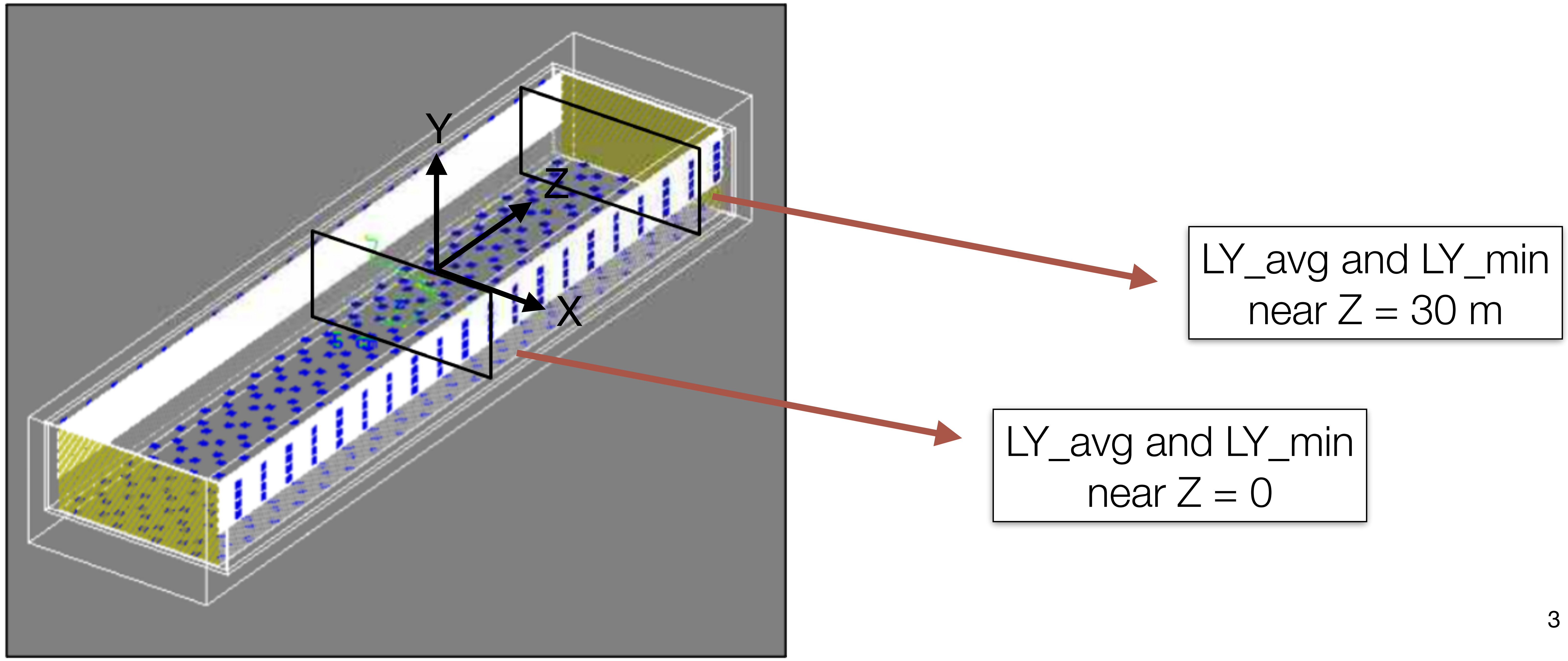
Motivation

- Study in a systematic way the optimal layout of membrane-mount X-Arapucas, 60×60 cm^2 active area each, for a fixed number of modules: **320** modules on long membrane walls.
  - To first order, light yield results scale with number of XAs
- Study the advantages of an additional (limited, i.e. tens of modules) optical coverage along short membrane walls.
- In all cases, the number (**320**) and layout of cathode-mount X-Arapucas is kept fixed to the CDR design.



What is optimal layout? Figures of merit

- Emphasis in spatial uniformity of PDS response:
  - Average (**LY_avg**) and minimum (**LY_min**) light yield in Z=const. plane near detector center (Z=0). Goal: high LY_min/LY_avg ratio → small LY dependence with X/Y.
  - Dependence of LY_avg (and LY_min) in Z=const. plane as a function of Z near detector border (Z=25-30 m). Goal: small LY dependence with Z.



Simulation framework

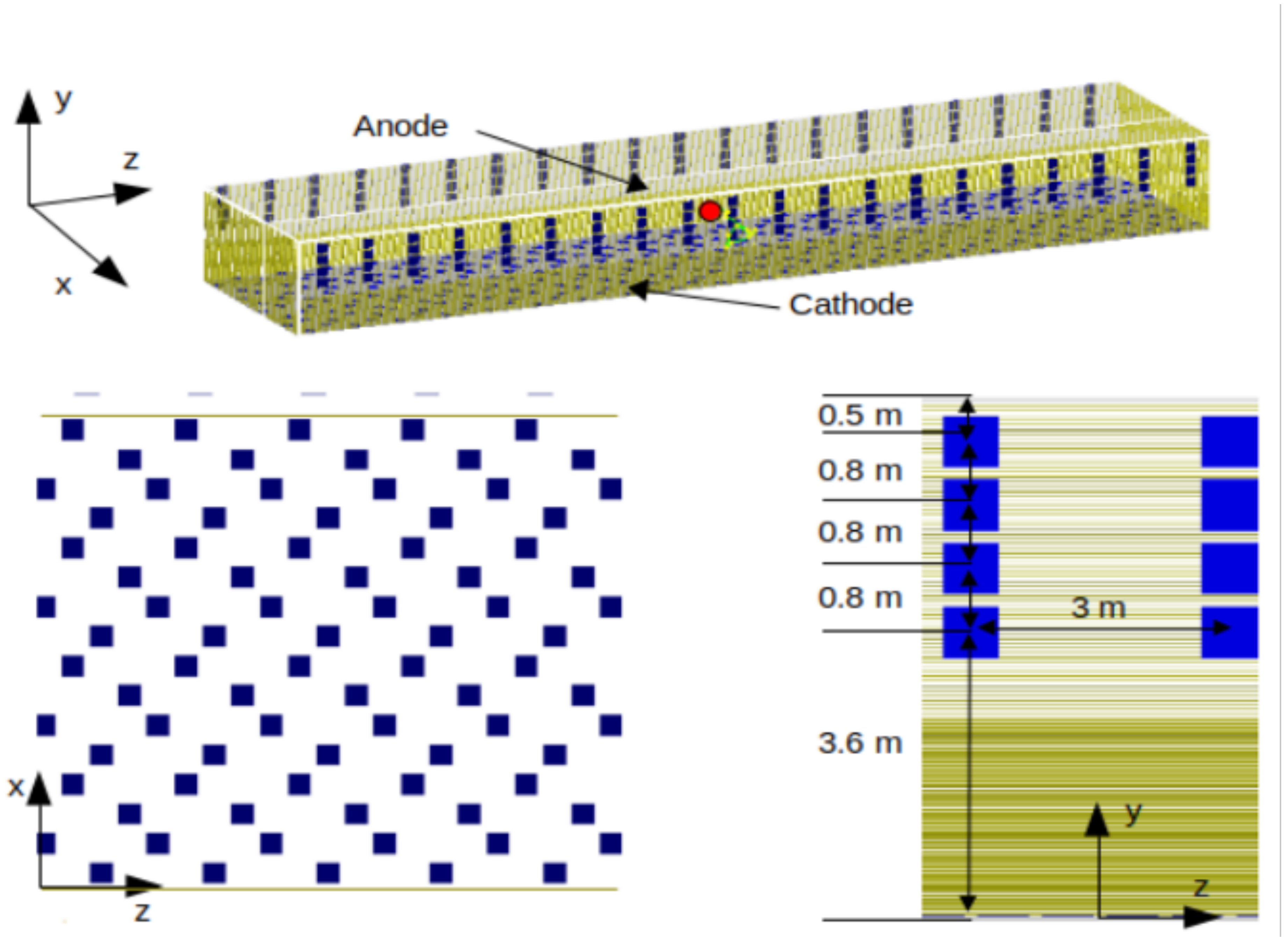
- Standalone Geant4 simulation framework used for this purpose, shooting 175 and 128 nm photons from fixed positions in LAr. No need to use LArSoft for layout optimisation studies.
  - Framework initially developed by L. Paulucci and F. Marinho, later updated at IFIC/CIEMAT.
- 2D LY maps of 400 bins (20x20) in (X,Y) are simulated for Z=const. values between 0 - 6 m (center) and 25 - 30 m (border).
- 175 and 128 nm LY maps weighted according to expectations for LAr doped with 10 ppm of Xe.

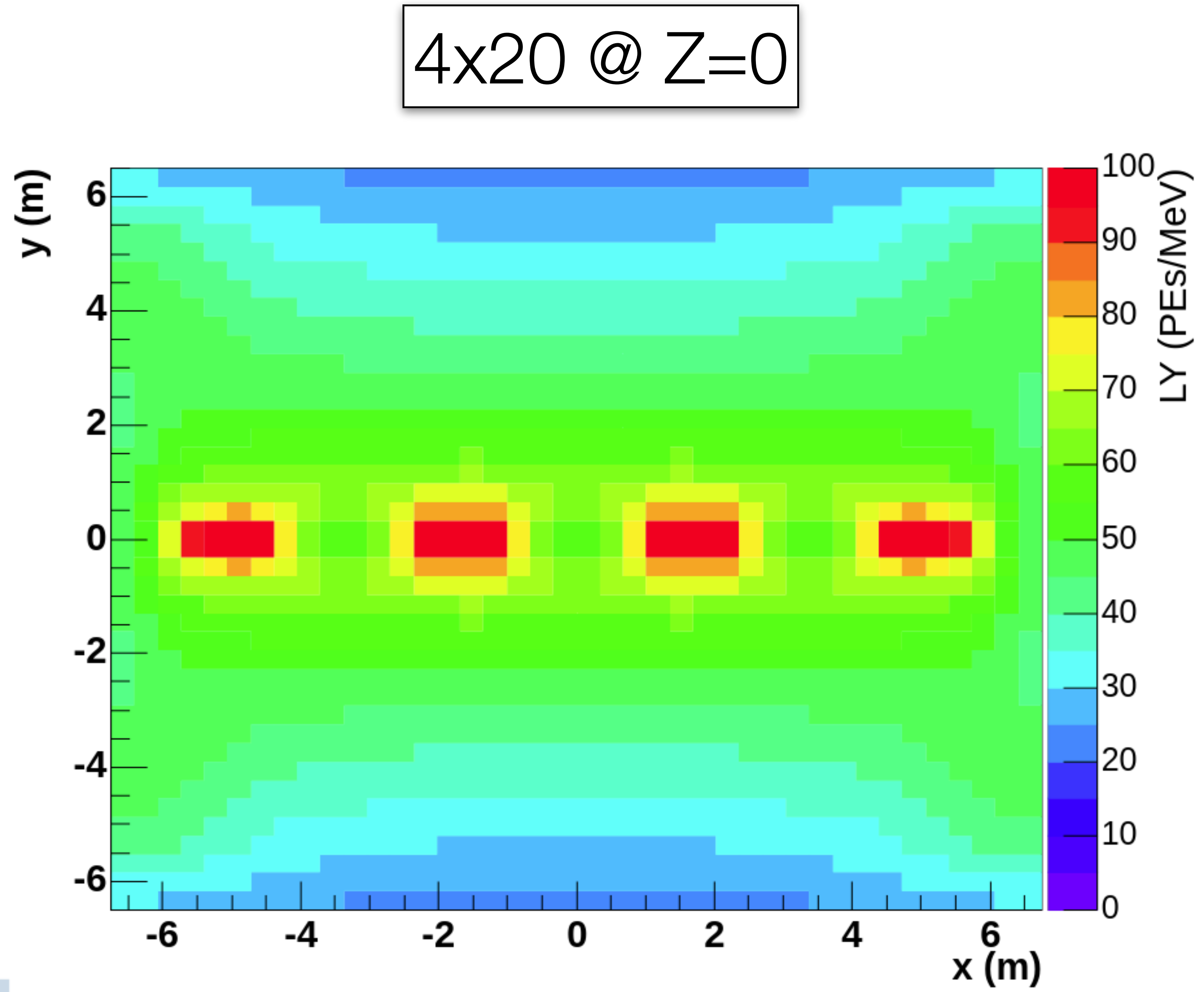
Simulation assumptions

- **Geometry**: full FD2 geometry simulated, including most relevant detector components from PDS point of view
- **Light production**: 12,700 photons/MeV at 175 nm, plus 7,300 photons/MeV at 128 nm, as inferred at 10 ppm Xe from ProtoDUNE-DP Xe-doping data (see slides here)
- **Light propagation in LAr**
  - Absorption length in LAr: 80 m at 175 nm, 20 m at 128 nm
  - Rayleigh scattering length in LAr: ~8.5 m at 175 nm, ~1 m at 128 nm
- **Reflectivity of detector materials**
  - Anode (copper): 0.2 at 175 nm, 0 at 128 nm
  - Field cage (aluminium): 0.7 at 175 and 128 nm
  - Membrane wall (steel): 0.4 at 175 nm, 0.3 at 128 nm
- **Light detection**: XA collection efficiency of 3% at 175 and 128 nm. Cathode-XA: 2-sided, membrane-XA: 1-sided.

CDR layout results with updated optical simulation assumptions

- **LY_avg = 47.22 PEs/MeV**, **LY_min = 23.81 PEs/MeV** → LY_min/LY_avg = 0.50.
- Overall light yield dominated by cathode-mount XAs: **77%** of total detected light
- Vastly better than FD1-PDS, particularly concerning uniformity! From FD1-TDR: LY_avg ~ 20 PEs/MeV, LY_min ~ 1 PE/MeV for 2.6% collection efficiency → LY_min/LY_avg = 0.05

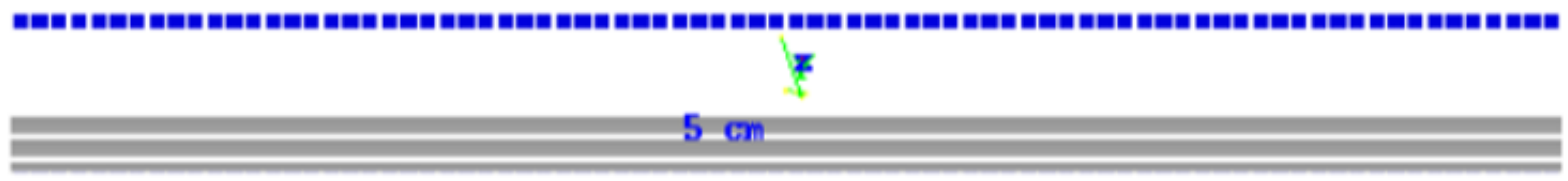




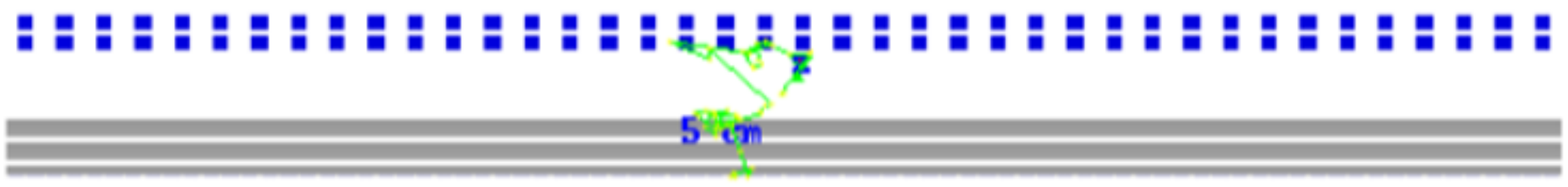
Summary of alternative membrane-mount layouts explored

- Near detector center (Z = 0-6 m):
  - **Optimisation 1**: optimal number of X-Arapuca rows in grid layouts
  - **Optimisation 2**: optimal vertical spacing of grid layouts
  - **Optimisation 3**: comparison of grid and “pyramidal” layouts
- Near detector borders (Z = 25-30 m):
  - **Optimisation 4**: addition of X-Arapucas on membrane short walls

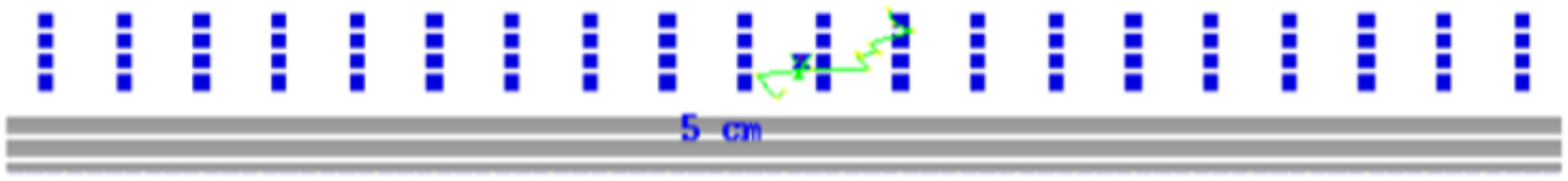
Optimisation 1: optimal number of X-Arapuca rows in grid layouts



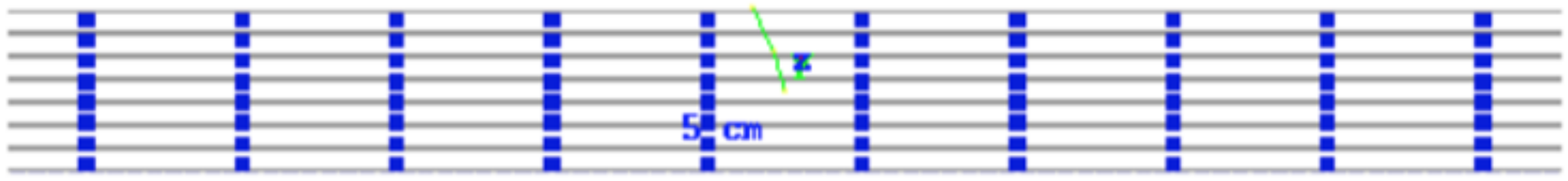
1x80



2x40



4x20



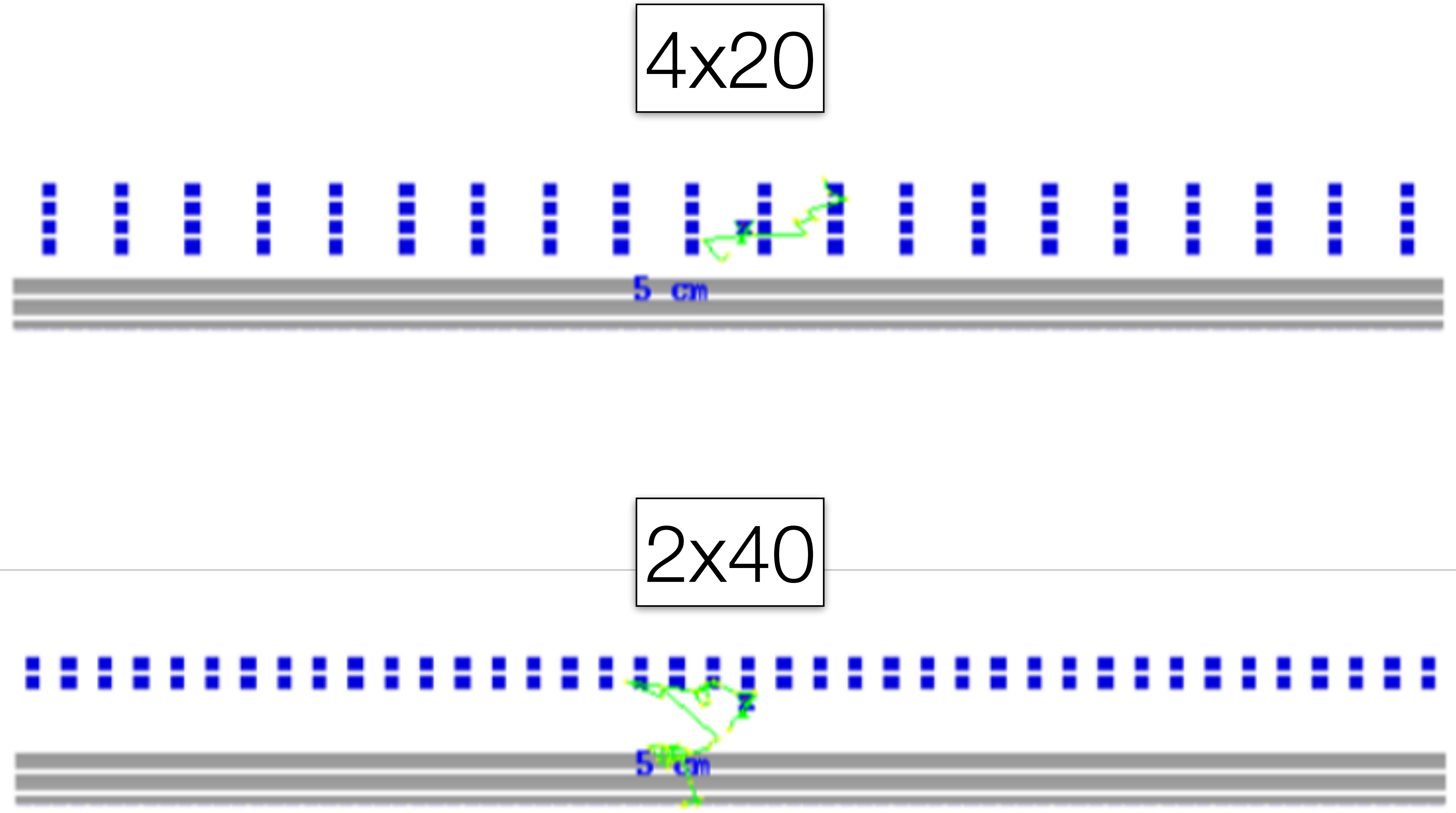
8x10

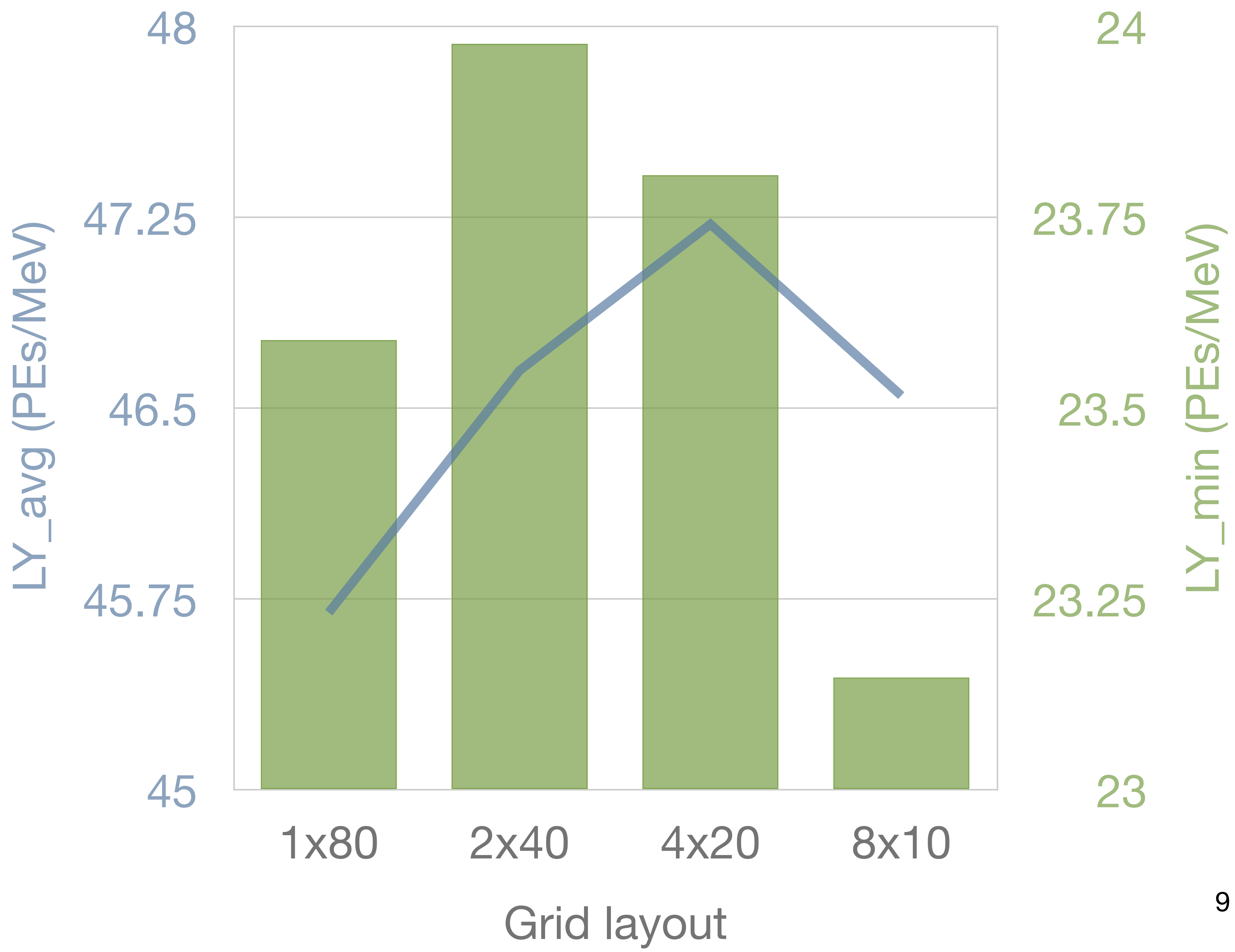
- Vertical offset from anode: 0.5 m
- Vertical spacing among rows: 0.8 m
- Horizontal spacing: from 0.75 m (1x80) to 6 m (8x10)

- Notice the change in the field cage profiles (all with the same width, 7.5 mm) for the 8x10 layout.

Optimisation 1: optimal number of X-Arapuca rows in grid layouts

- Best LY_avg results for the original 4x20 arrangement of the CDR, instrumenting half of membrane walls.
- 4x20 layout close to optimal also concerning LY_min (best: 2x40).

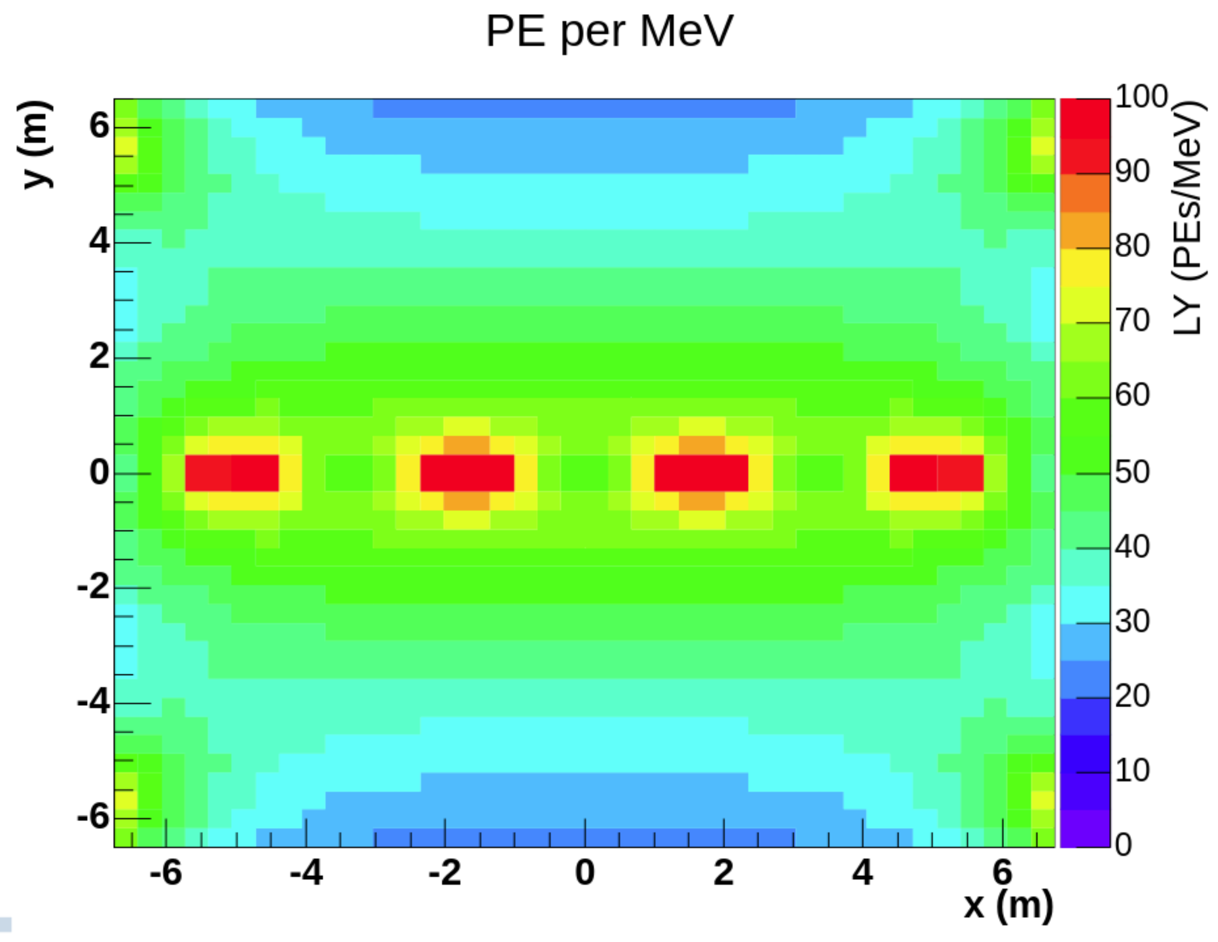




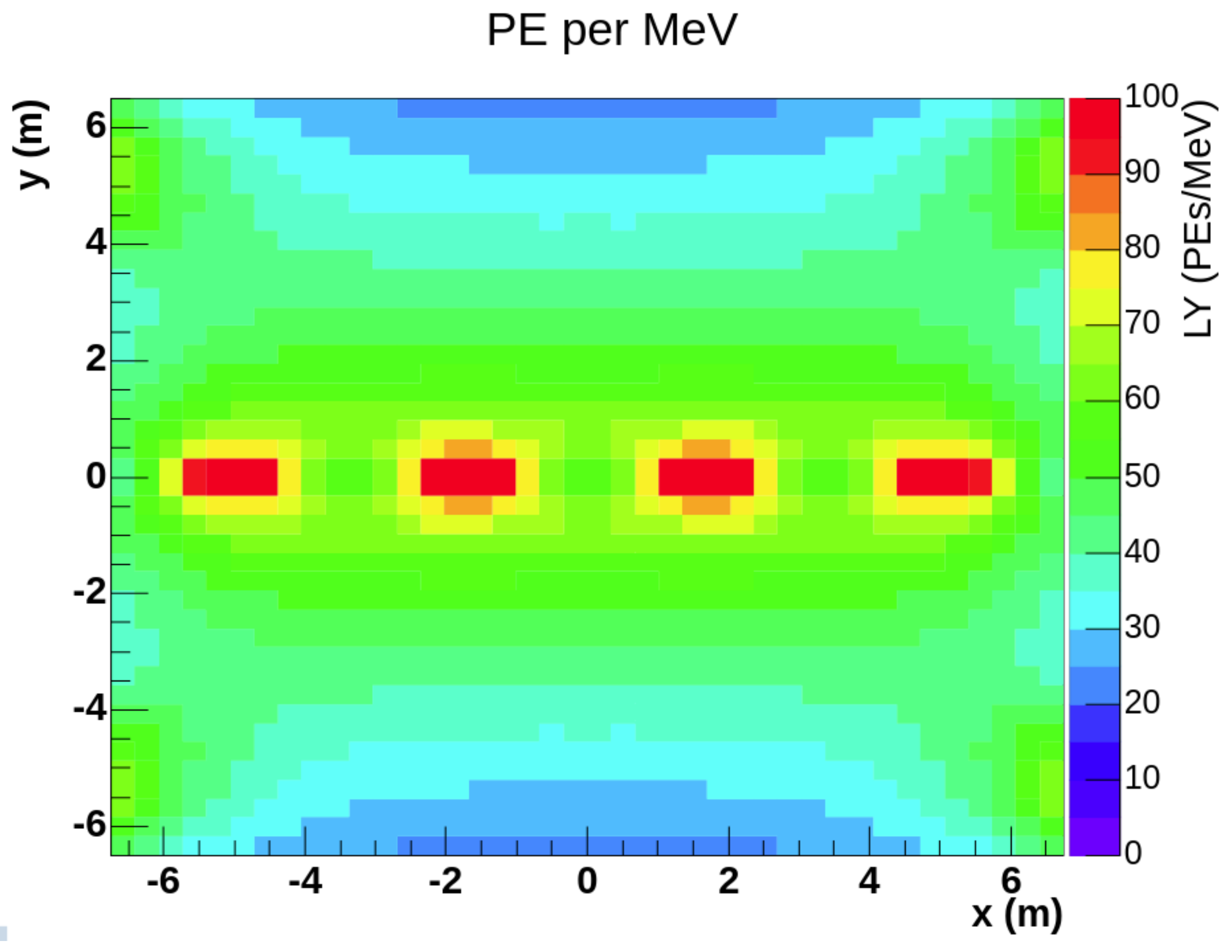
Optimisation 1: optimal number of X-Arapuca rows in grid layouts

- Best LY_avg results for the original 4x20 arrangement of the CDR, instrumenting half of membrane walls.
- 4x20 layout close to optimal also concerning LY_min (best: 2x40).

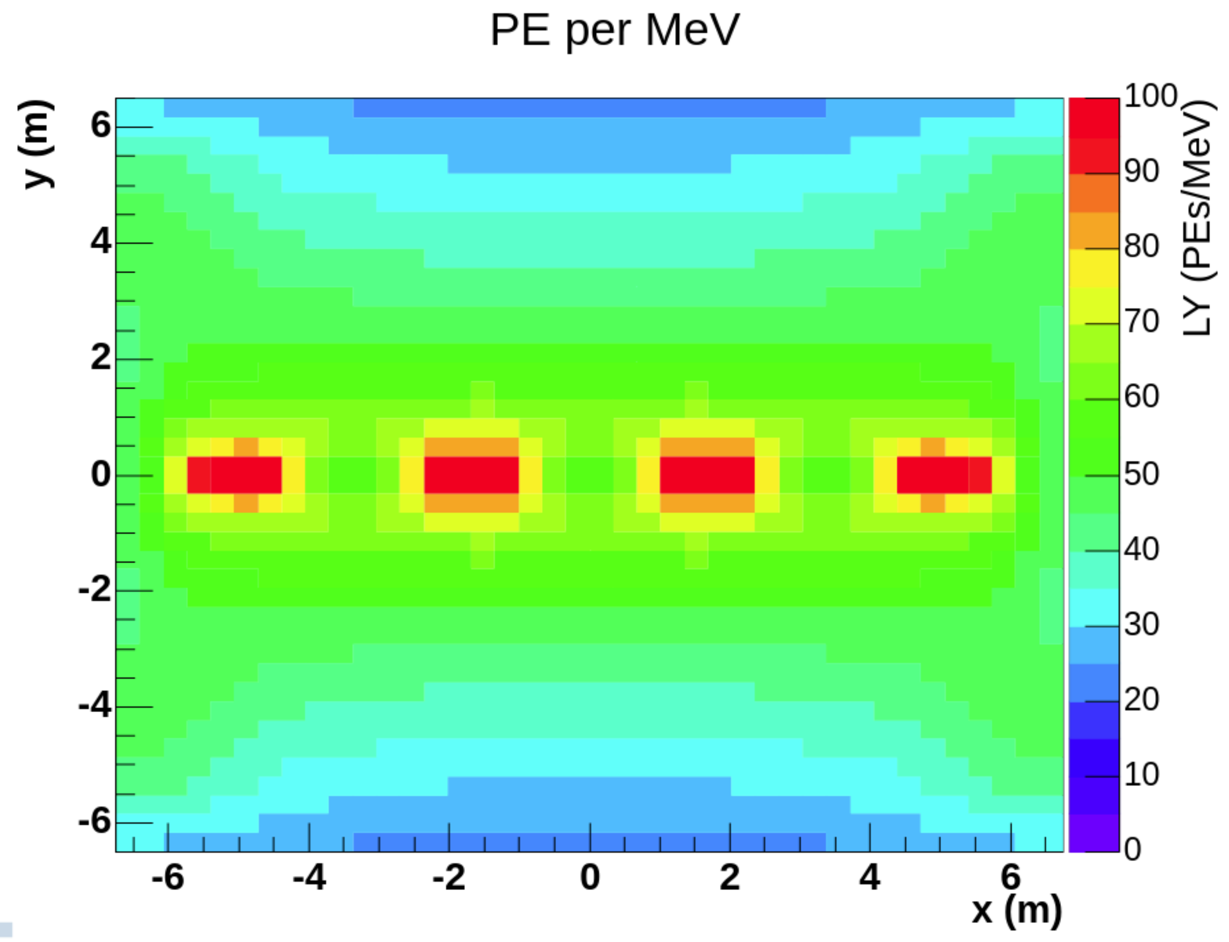
1x80



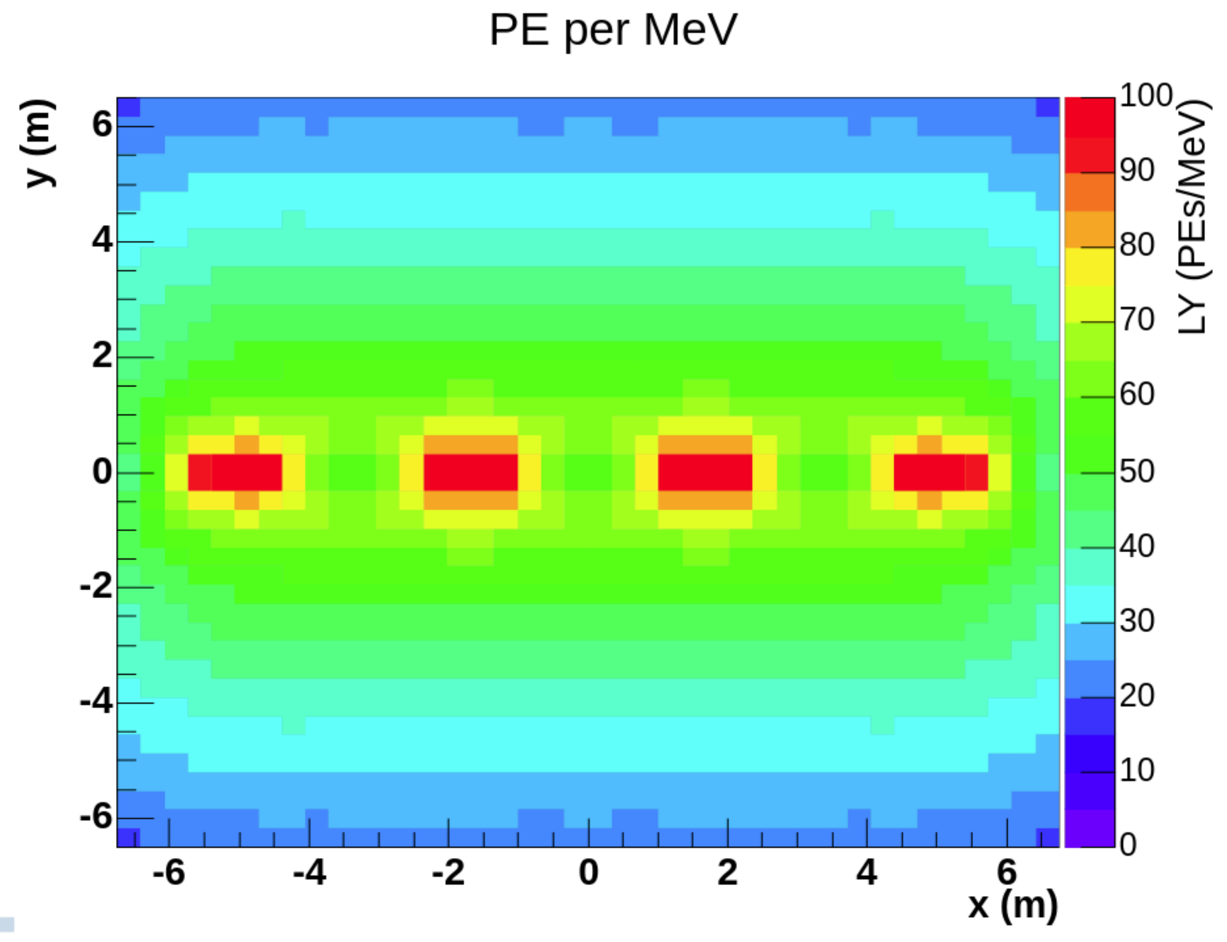
2x40



4x20

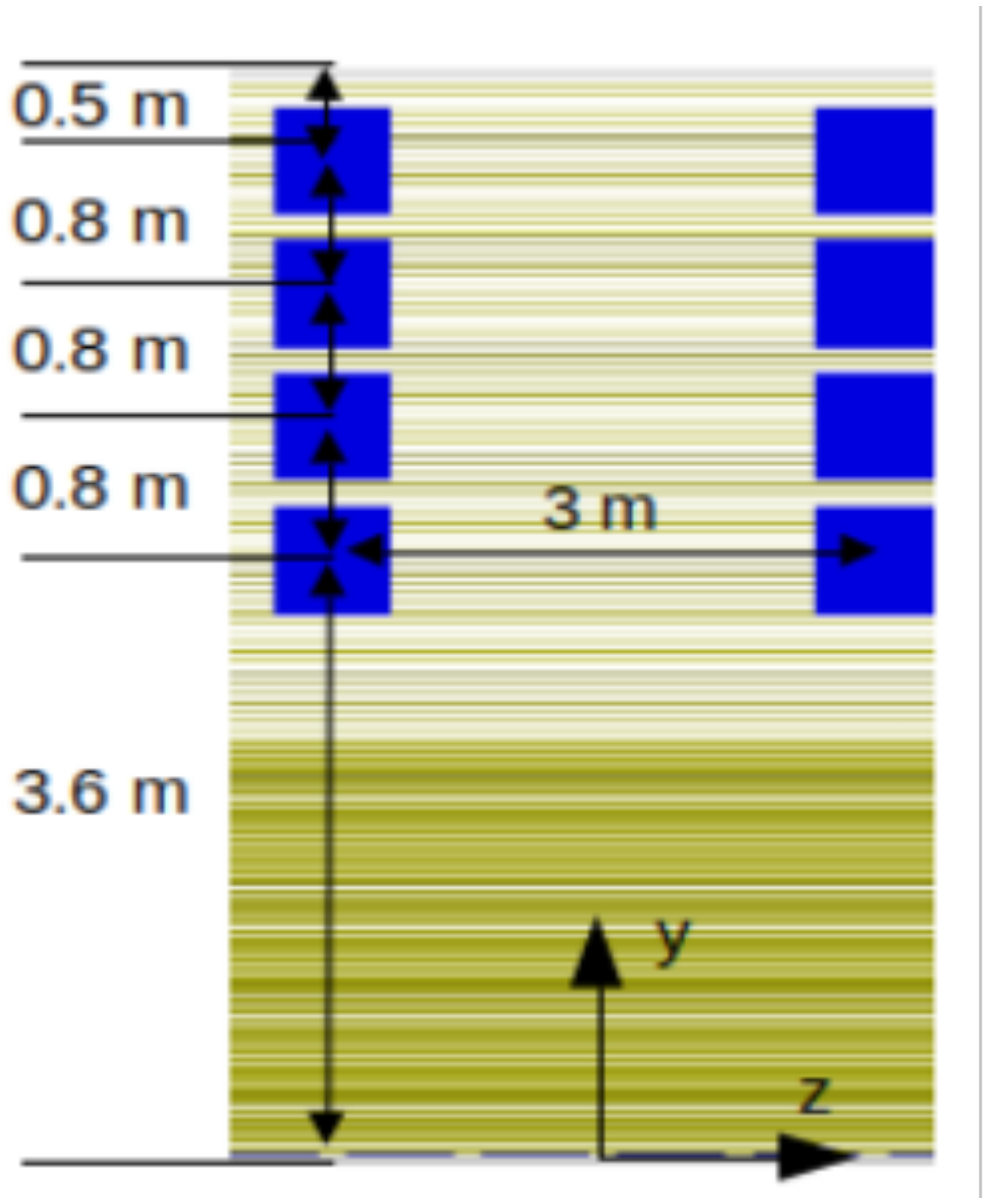


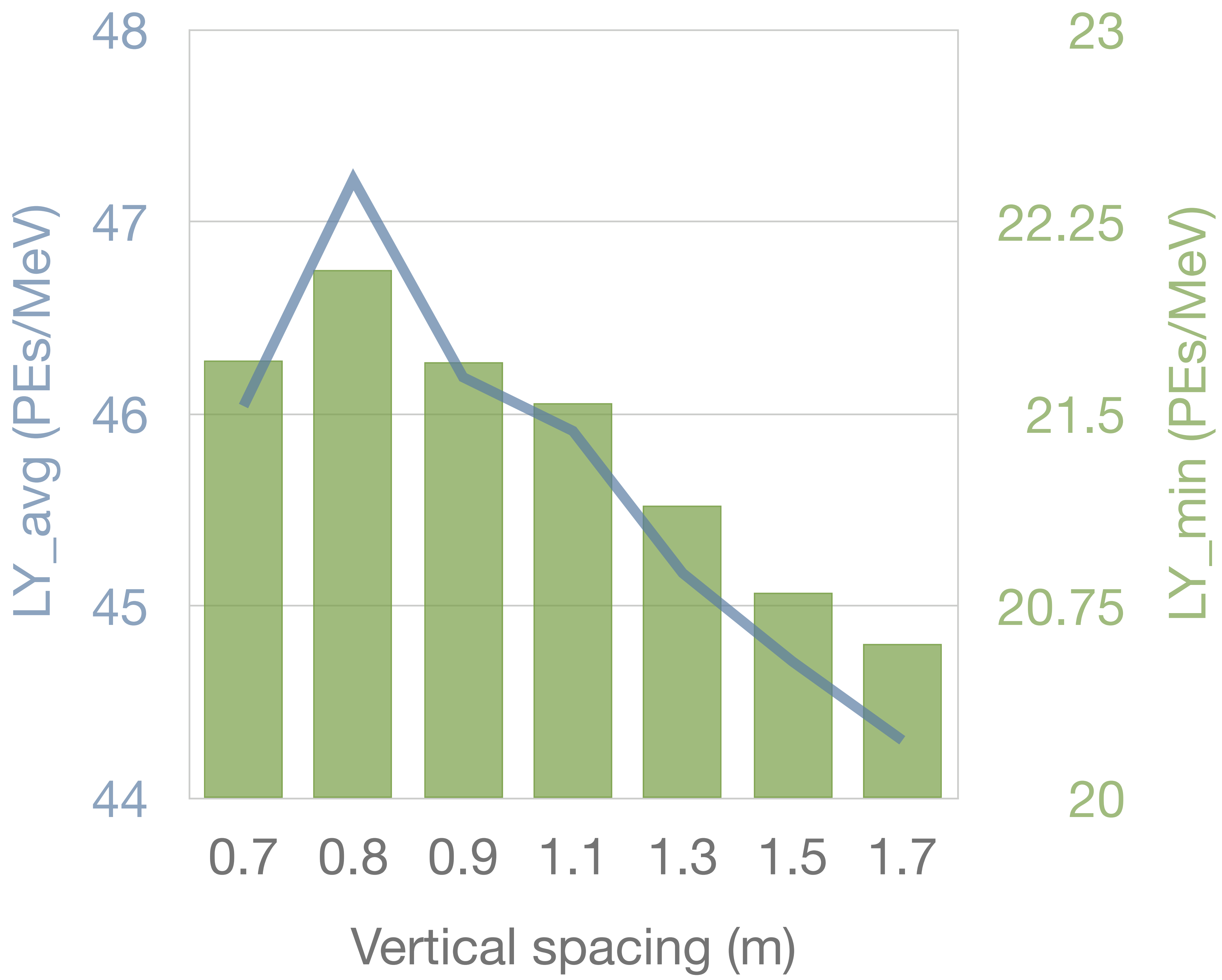
8x10



Optimisation 2: optimal vertical spacing of 4x20 layouts

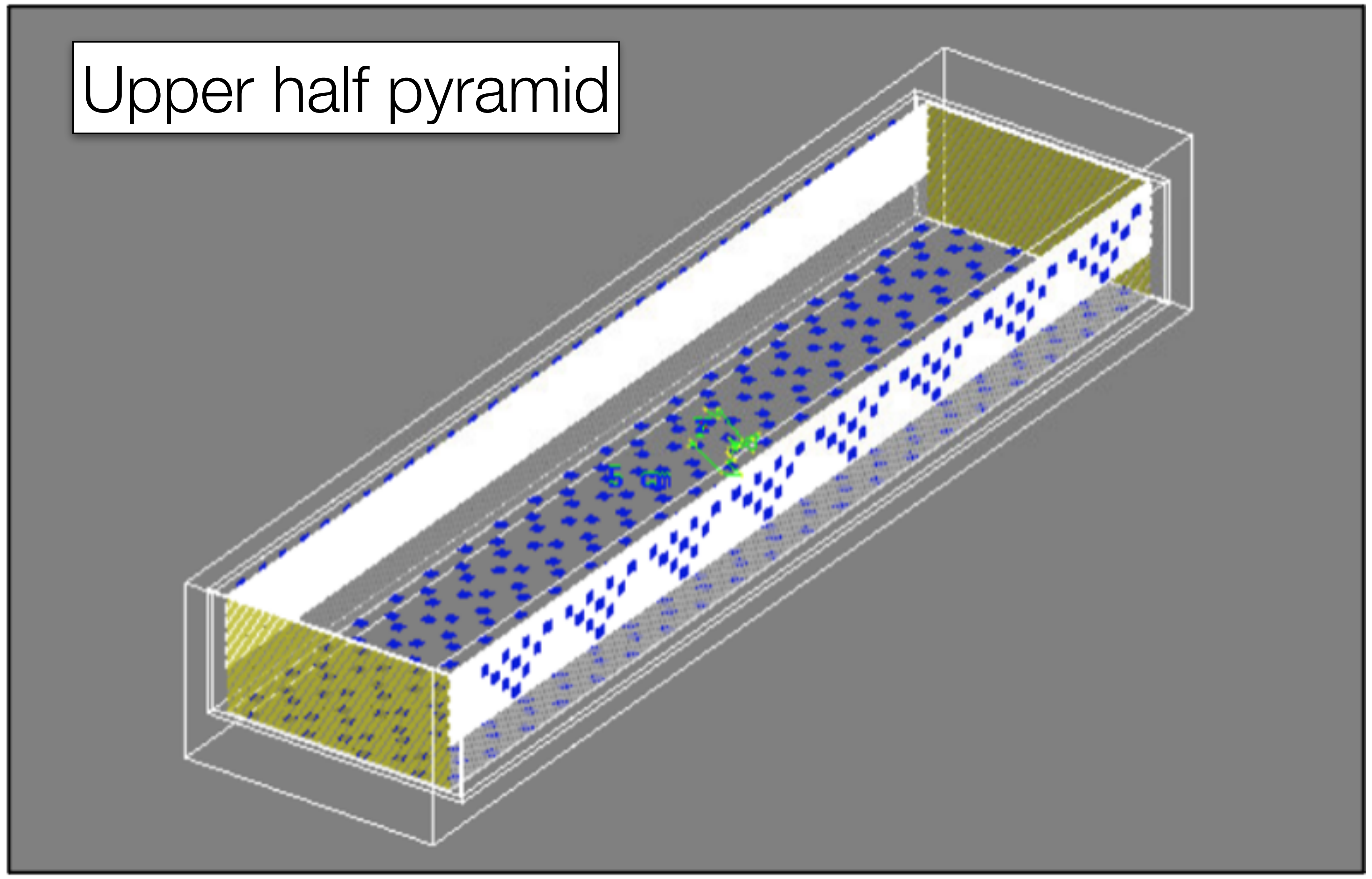
- Keep position of top row fixed, vary vertical spacing and position of three other rows.
- From 0.7 m (min possible) to 1.7 m (max possible) spacing.
- Best results for the original 4x20 arrangement of the CDR, with 0.8 m vertical spacing.



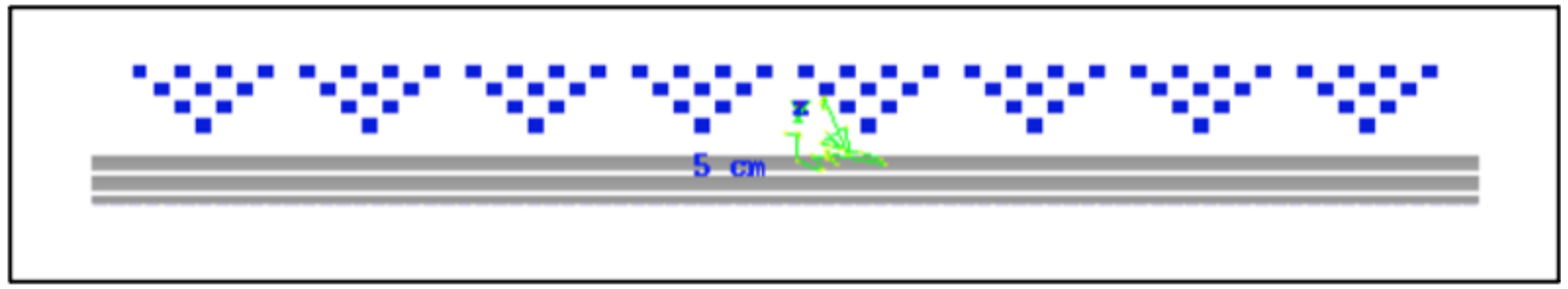


Optimisation 3: comparison of grid and pyramidal layouts

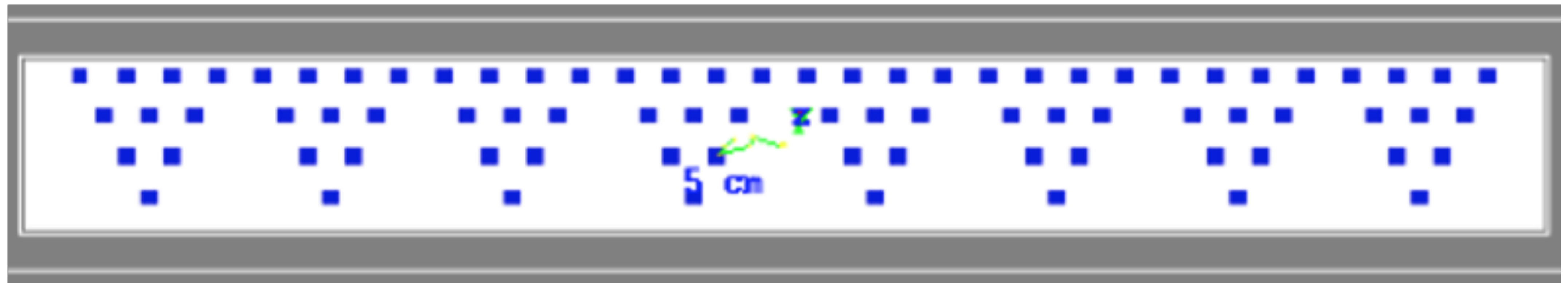
- Pyramidal layout: optical coverage varies gradually with distance from cathode, highest near anode
- Two pyramidal layouts tried, either covering upper half or all of membrane wall.
- Best: upper half pyramid, four rows of 32+24+16+8 = 80 XAs per quadrant



Upper half pyramid (0.8 m vert. spacing)



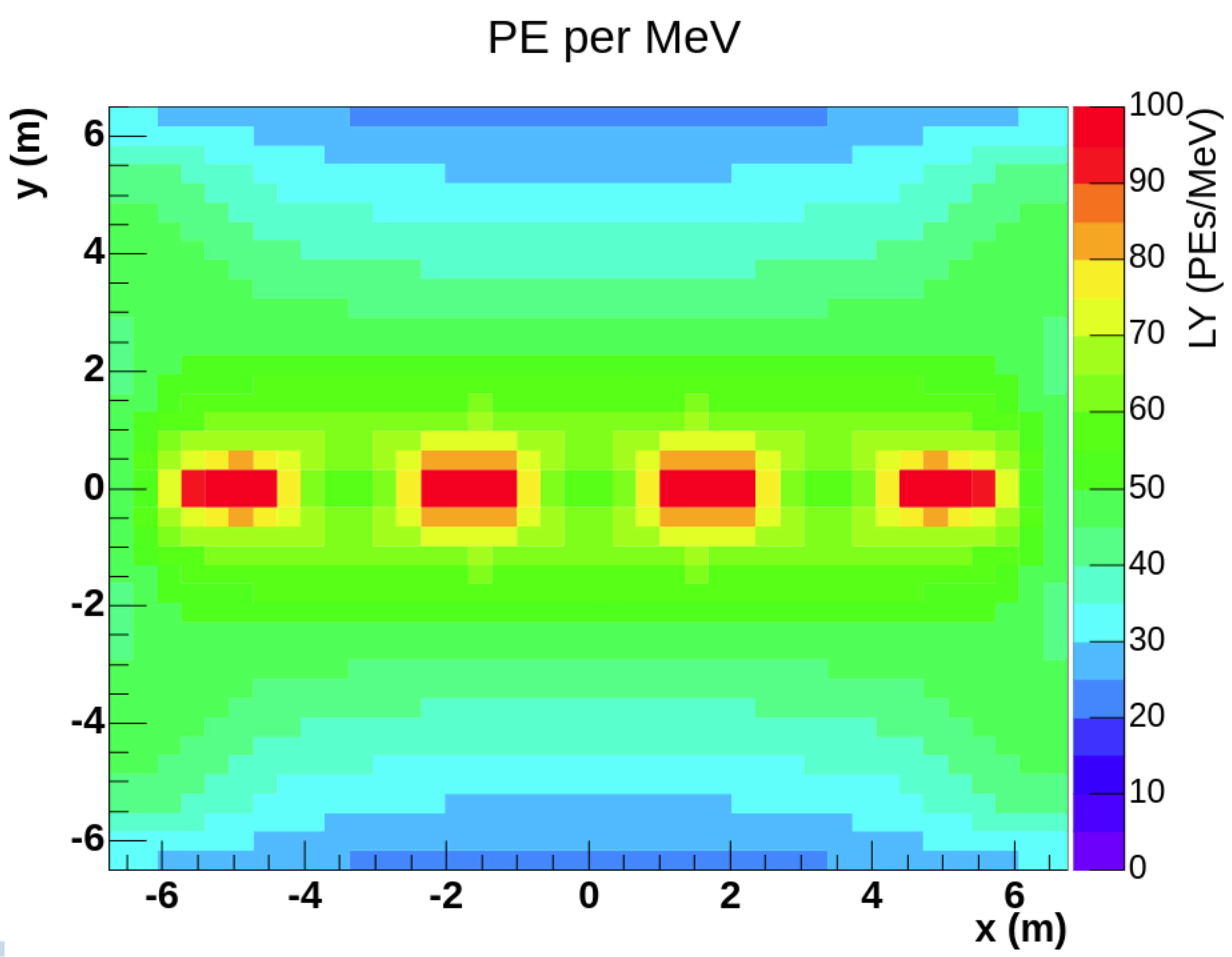
Full height pyramid (1.6 m vert. spacing)



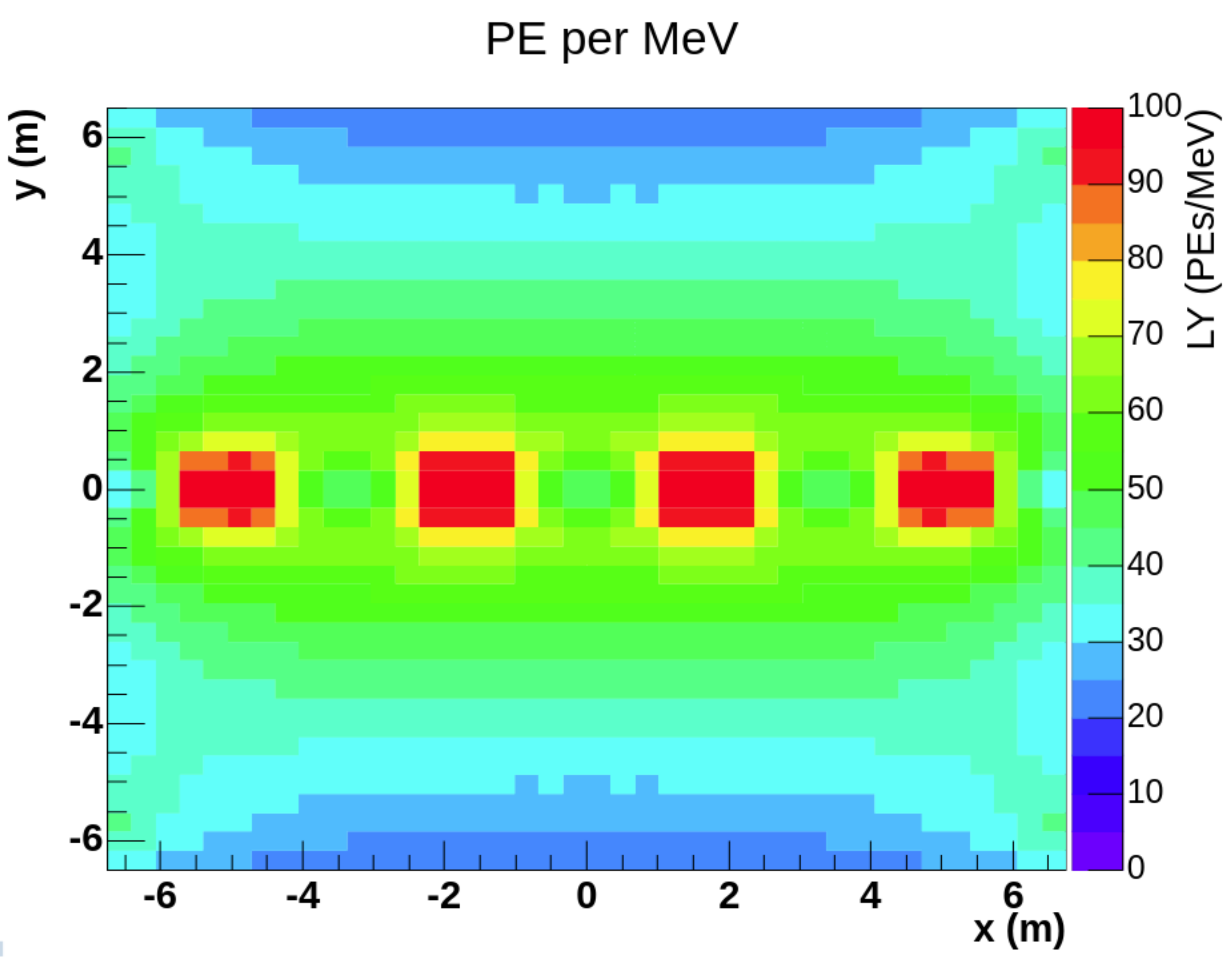
Optimisation 3: comparison of grid and pyramidal layouts

- Best pyramid: **LY_avg = 46.45 PEs/MeV**, **LY_min = 22.05 PEs/MeV**
- No improvement over 4x20 grid layout: LY_avg = 47.22 PEs/MeV, LY_min = 23.81 PEs/MeV

4x20

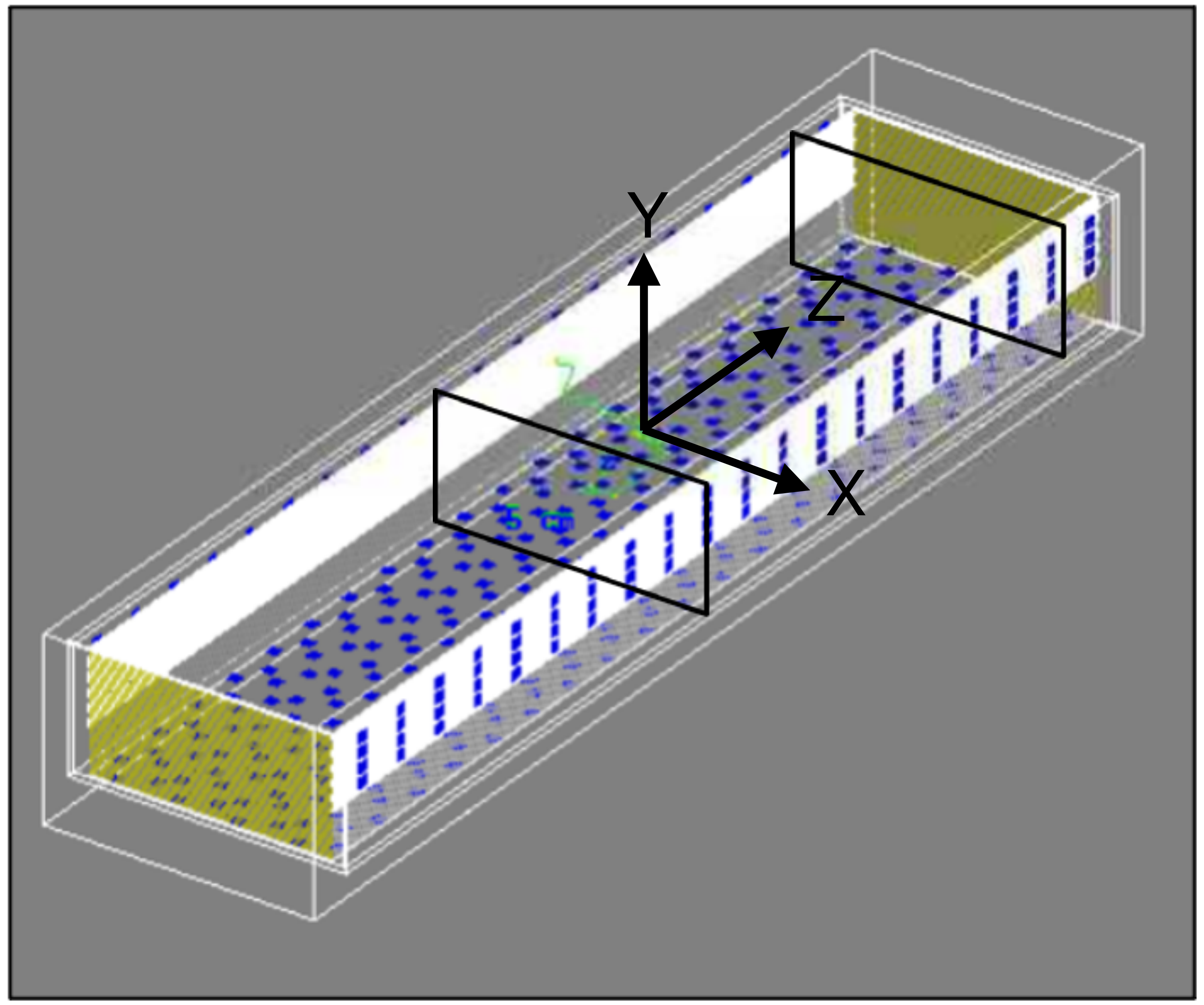


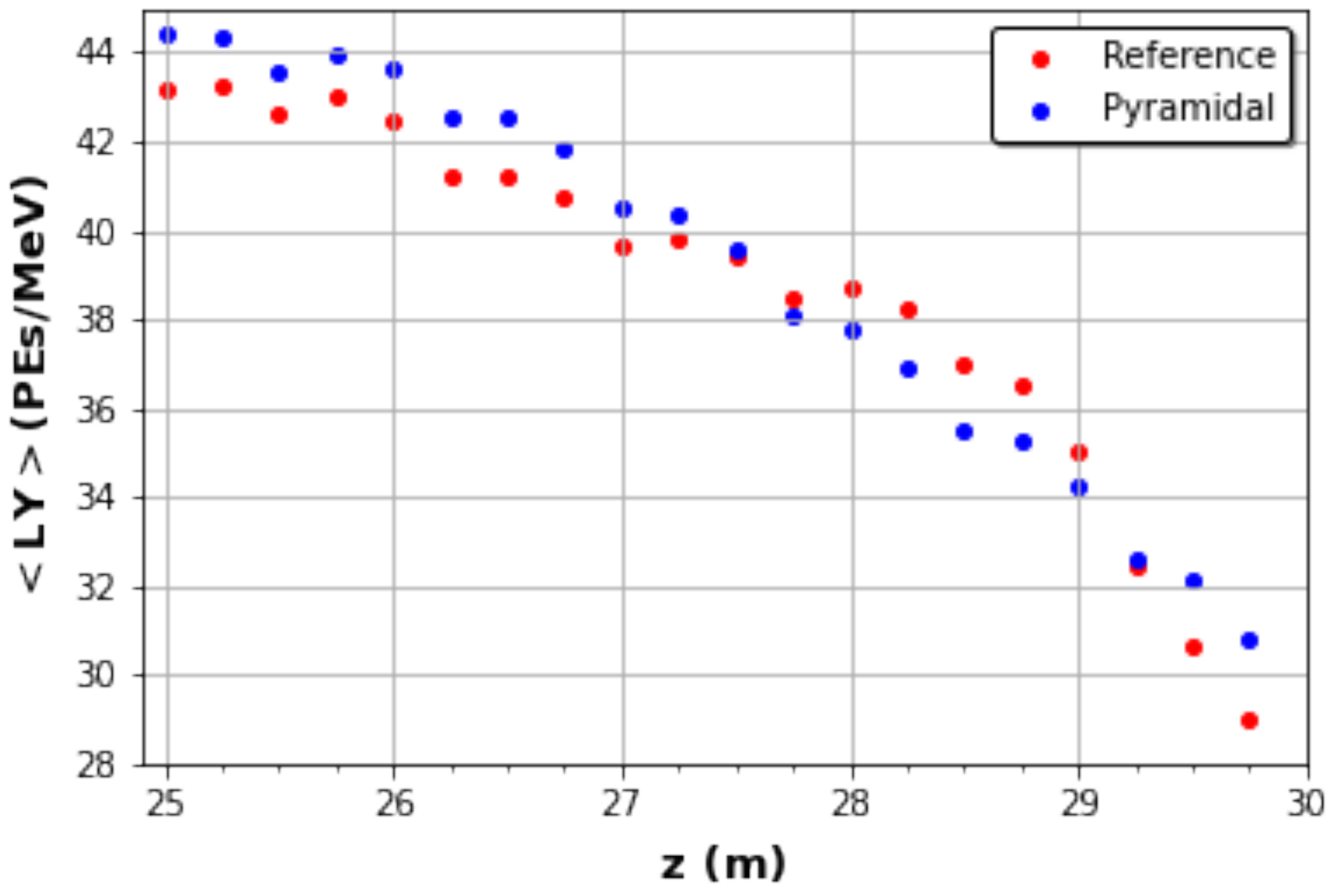
Pyramid

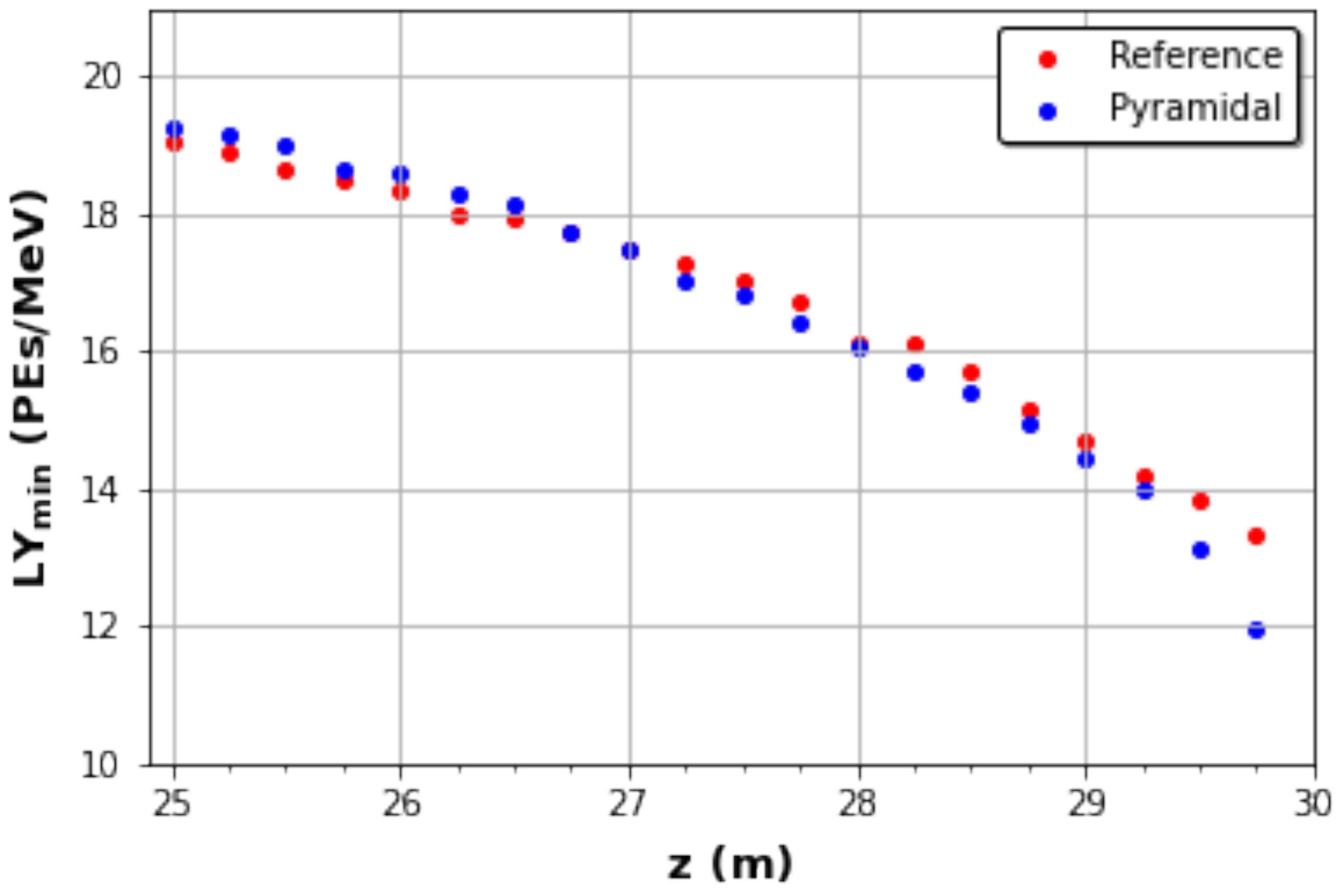


Optimisation 4: addition of X-Arapucas on membrane short walls

- With no optical coverage on short walls, LY drops significantly for Z distances less than a few m away from field cage border at Z = 30 m
  - Both LY_avg and LY_min.
  - Both reference 4x20 arrangement, and alternative pyramidal layout.



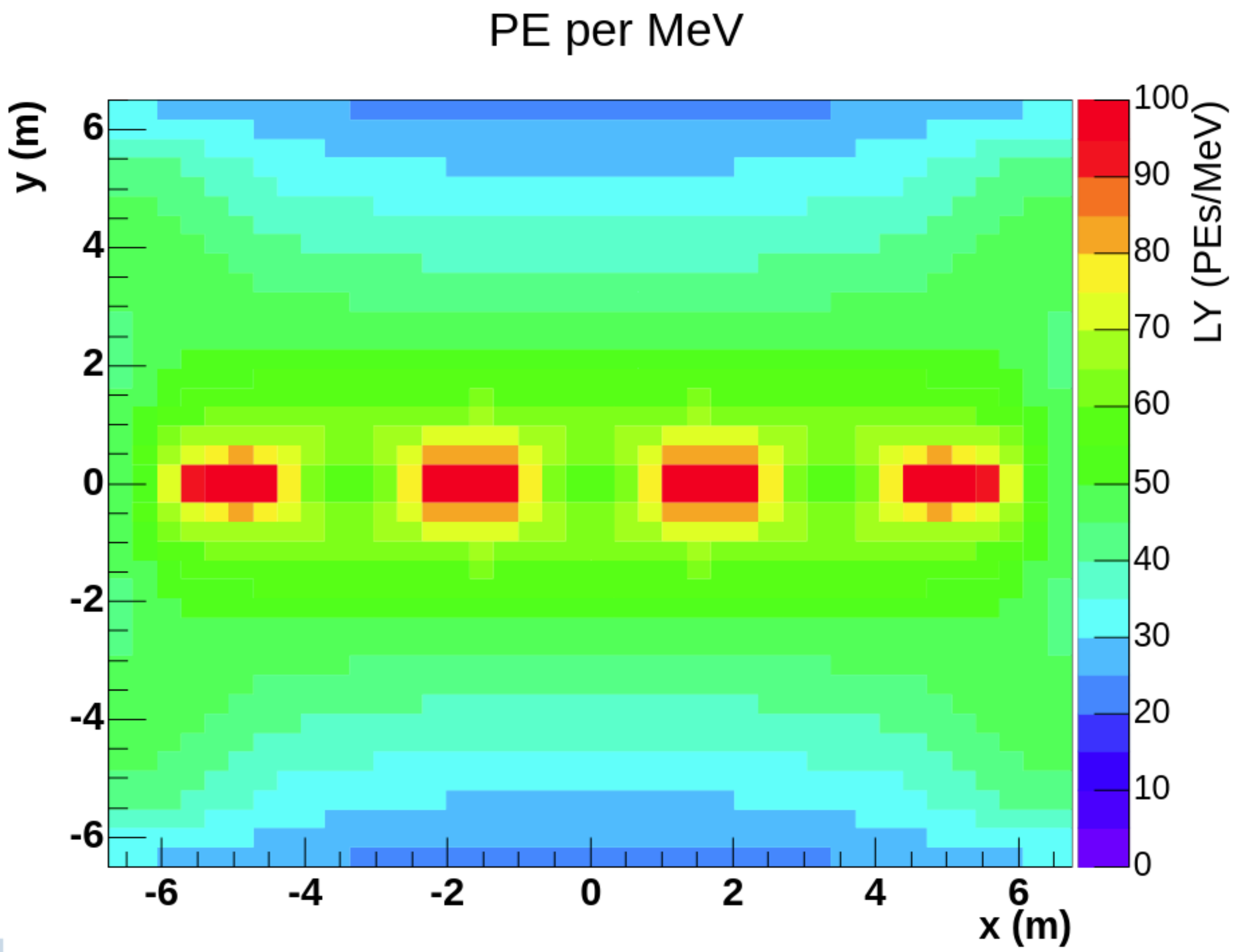




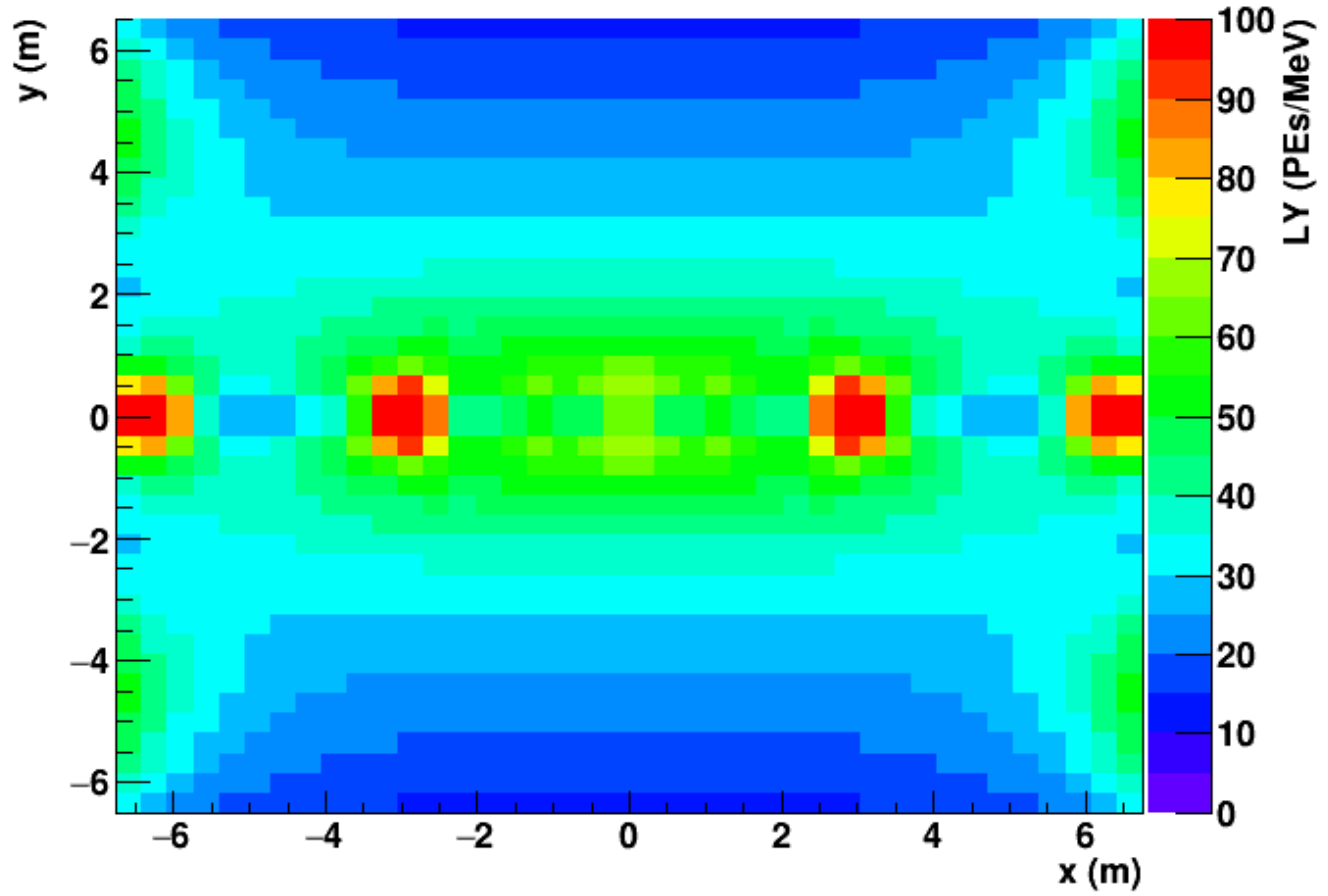
Optimisation 4: addition of X-Arapucas on membrane short walls

- With no optical coverage on short walls, LY drops significantly for Z distances less than a few m away from field cage border at Z = 30 m
  - Both LY_avg and LY_min.
  - Both reference 4x20 arrangement, and alternative pyramidal layout.

4x20 @ Z=0

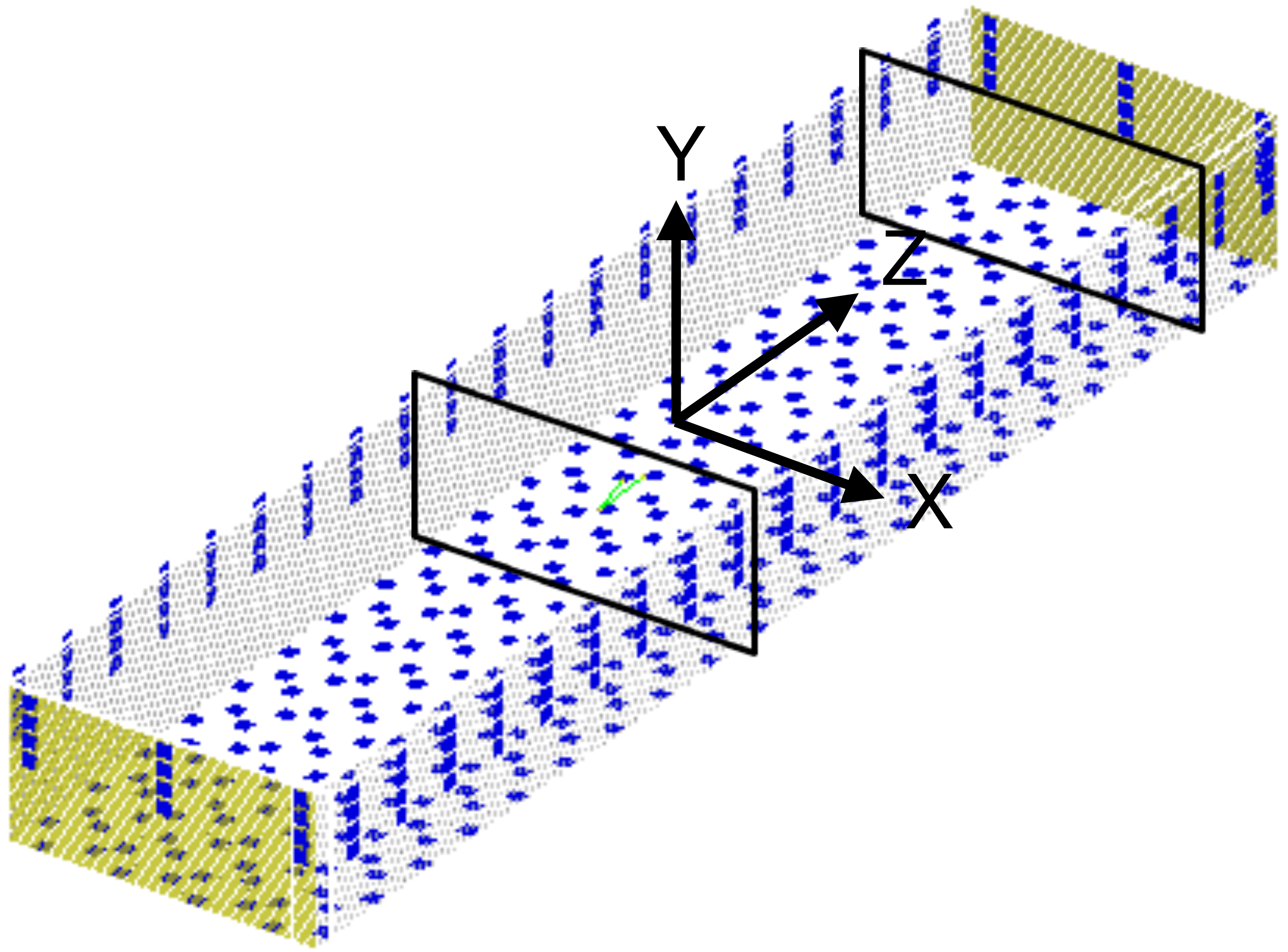


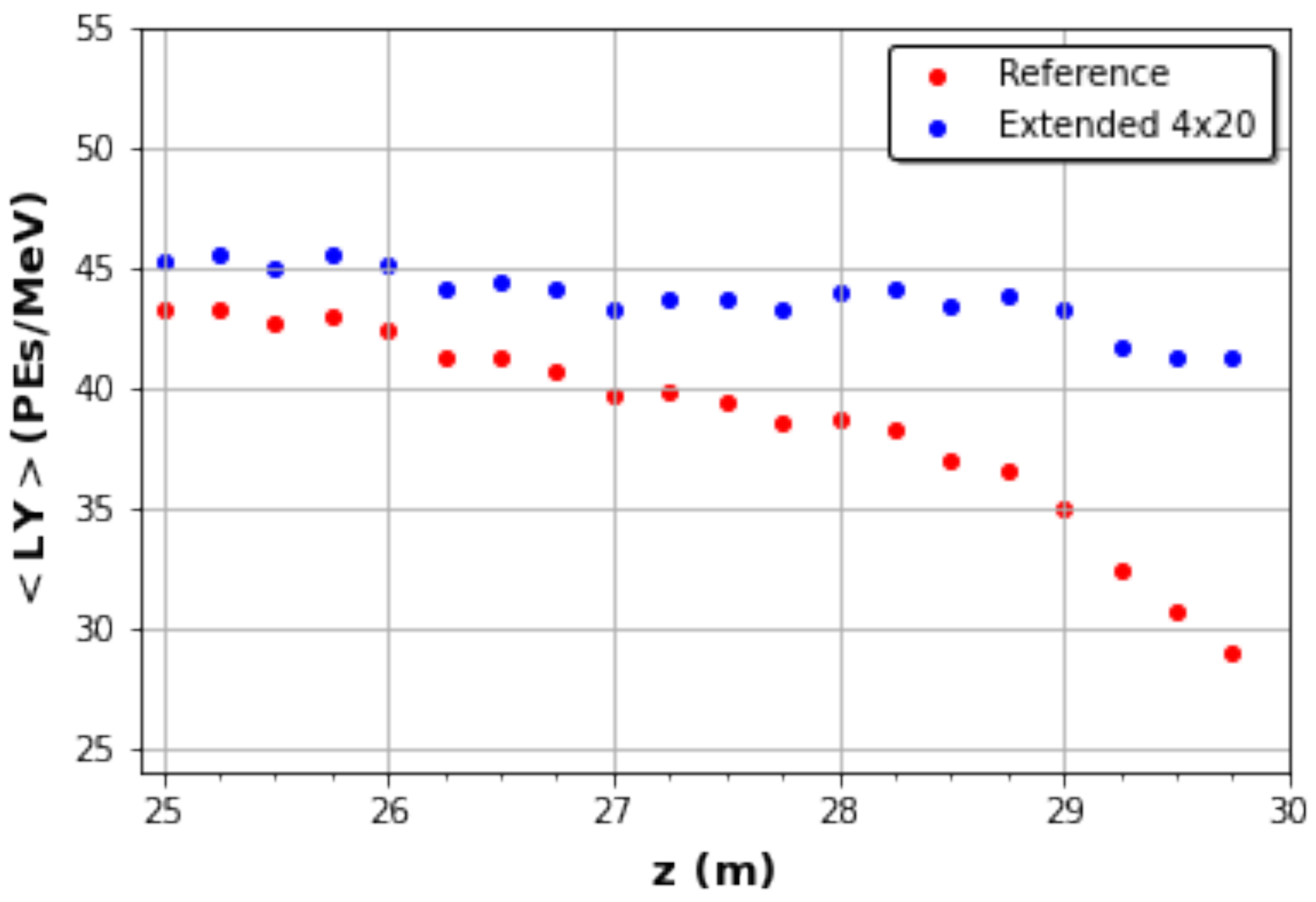
4x20 @ Z=29m

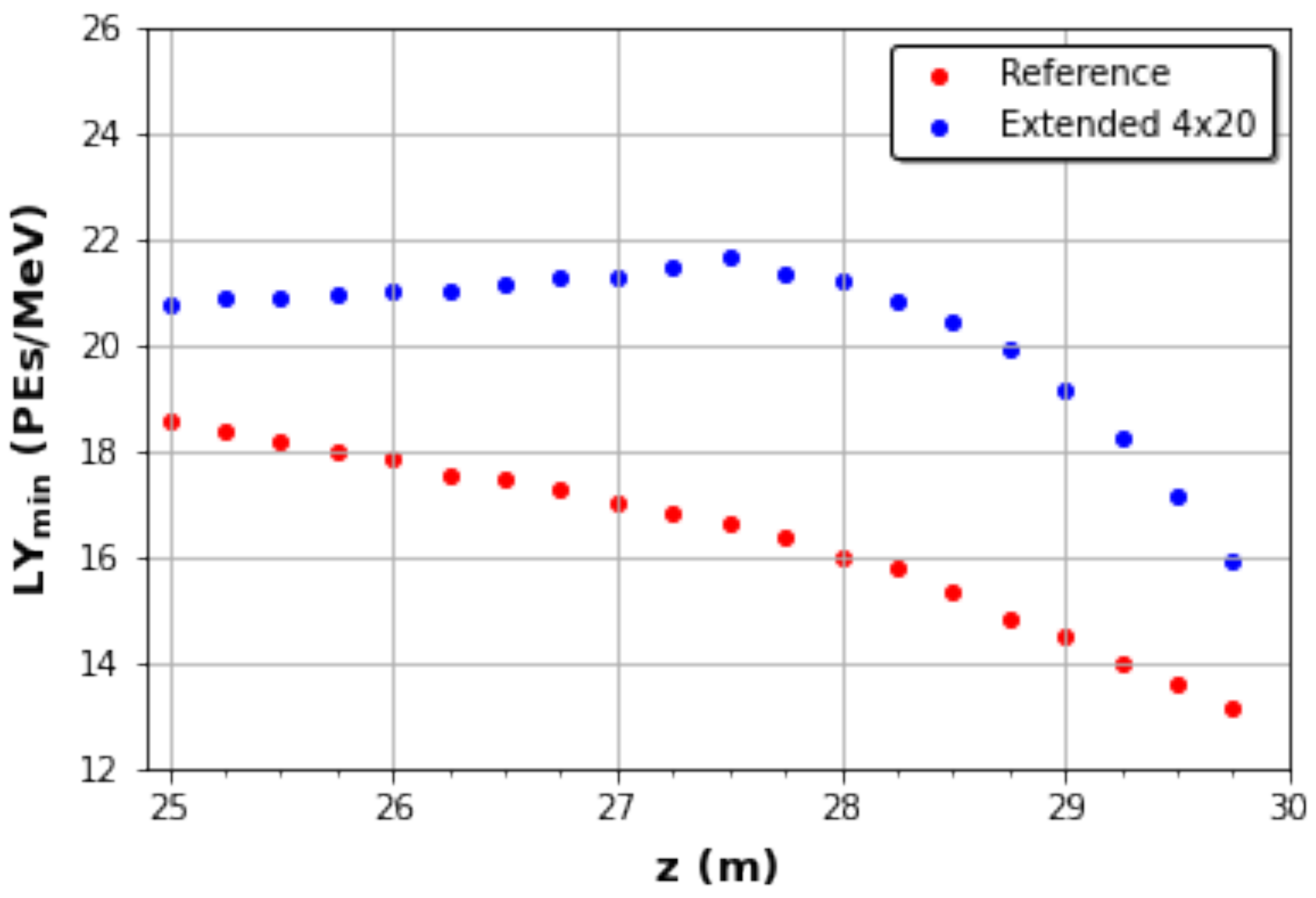


Optimisation 4: addition of X-Arapucas on membrane short walls

- **Solution**: limited optical coverage on membrane short walls, if technically possible.
- Two “extended” layouts tried, both involving 4 X-Arapuca rows, as on long sides and at same height:
  - 4x5 per short side quadrant (80 extra XAs) → overcorrecting response near Z = 30 m.
  - 4x3 per short side quadrant (48 extra XAs) → configuration close to optimal, shown below.



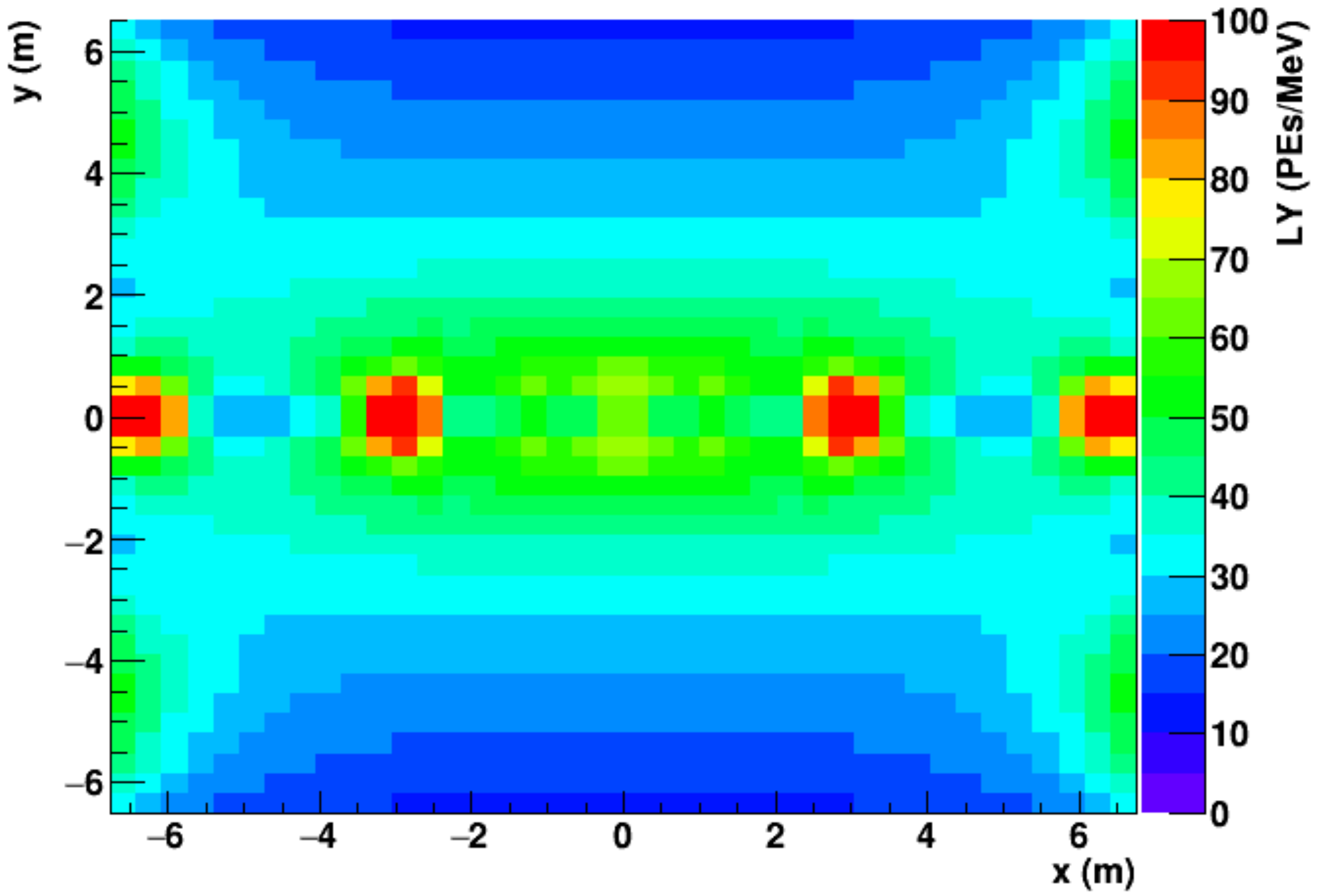




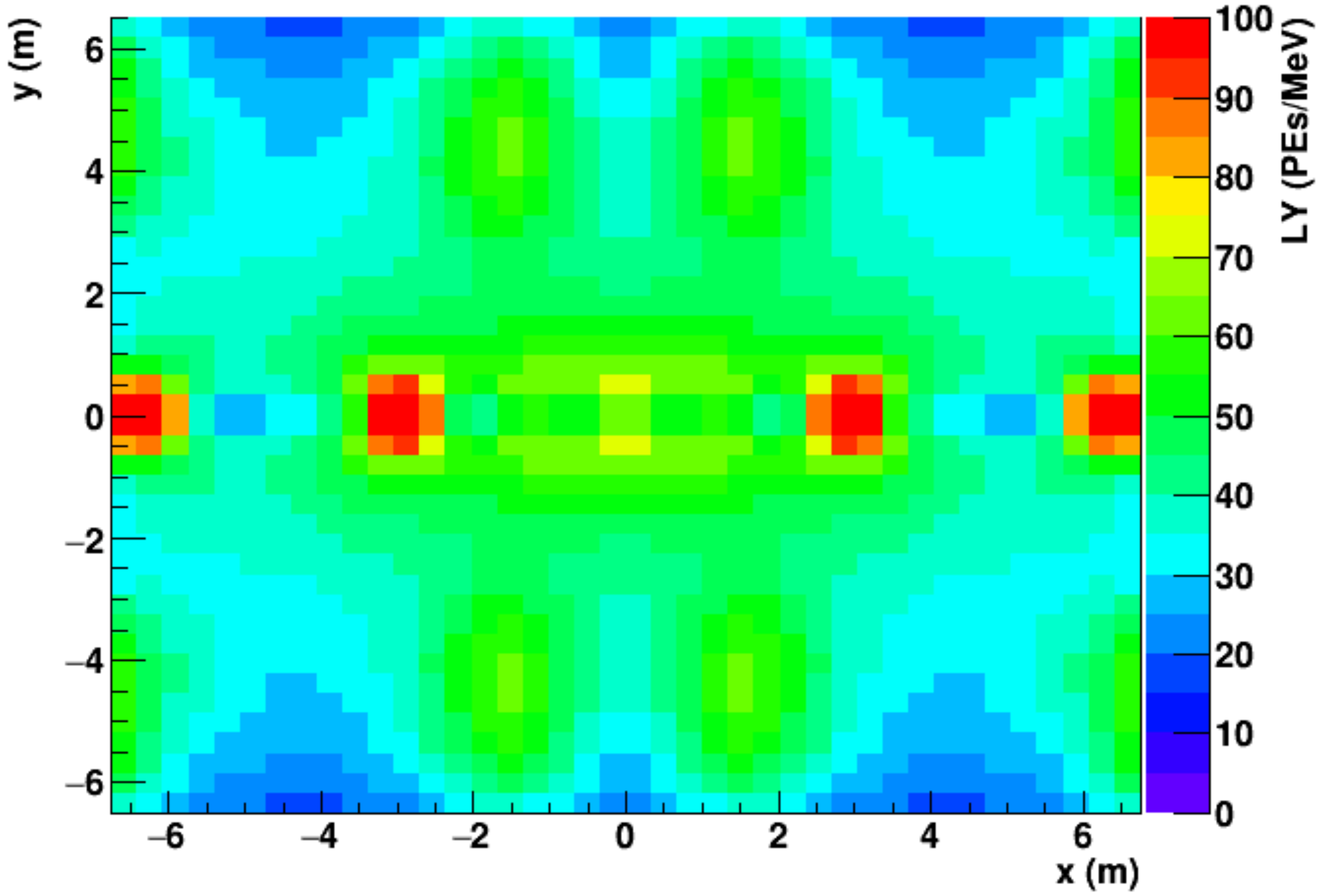
Optimisation 4: addition of X-Arapucas on membrane short walls

- **Solution**: limited optical coverage on membrane short walls, if technically possible.
- Two “extended” layouts tried, both involving 4 X-Arapuca rows, as on long sides and at same height:
    - 4x5 per short side quadrant (80 extra XAs) ➝ overcorrecting response near Z = 30 m.
    - 4x3 per short side quadrant (48 extra XAs) ➝ configuration close to optimal, shown below.

Without short wall XAs @ Z=29m



With short wall XAs @ Z=29m



Conclusions on PDS membrane-mount layout optimisation

- CDR-style arrangement with 4 rows (0.8 m vertical separation) × 20 columns (3 m horizontal separation) per long quadrant is close to optimal for 320 membrane-mount X-Arapucas, as far as detector response is concerned.
  - HV interface: thick field cage profiles can be kept near cathode
- To avoid response degradation in last few meters near borders, limited coverage of short membrane walls with 4 rows × 3 columns per short quadrant (→48 extra X-Arapucas) would be highly beneficial
  - If technically feasible from cryogenic/HV interfaces point of view
  - Realisation of “4π coverage” originally envisaged at the time of the FD-VD proposal!
- These are conceptual layouts that will need to be adapted to mechanical constraints (→ next talk). Nevertheless, minor changes in detector response are expected after accounting for those.