Muography at the University of Coimbra

LouMu collaboration meeting, 7th February 2023

Table of contents

1. Review of the method

2. Open-air muon flux

3. Results vs Simulation

4. 3D Reconstruction

1. Review of the method

For the building of a muograph we need:

- Reference muon flux (Open-air muon flux - OAF)

- Measurement of the muon flux under the object (UOF)

- Efficiencies of the detector pads (Eff)

$$T = \frac{UOF}{OAF} \times \frac{1}{Eff}$$

2. Open-air muon flux

Regarding the OAF:

-1st stage: generated it through MC simulation

-2nd stage: derived it analytically

-3rd stage: confirmed it experimentally

$$OAF = \iint dx\,dy \iint d\theta\,d\varphi\,(\cos\theta^2 \cos\theta \sin\theta)$$

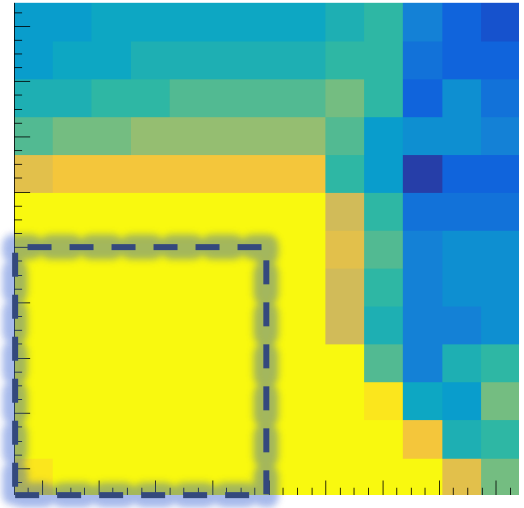
2. Open-air muon flux

Experimental confirmation

Problem: no direct acquisition of the OAF

Approach: look into uniform quadrants

Simulated Muograph
September 2020



2. Open-air muon flux

Experimental confirmation

Problem: no direct measurement of the OAF

Approach: confirm the traversed matter -> transmission model

$$UOF^{\theta=0}_{under\ N\ ceilings} = OAF \times t^{N}$$

$$UOF^{\theta}_{under\ N\ ceilings} = OAF \times t^{N/cos\theta}$$

$$\frac{UOF^{\theta}_{under\ N1\ ceilings}}{UOF^{\theta}_{under\ N2\ ceilings}} = t^{\frac{N1-N2}{\cos\theta}}$$

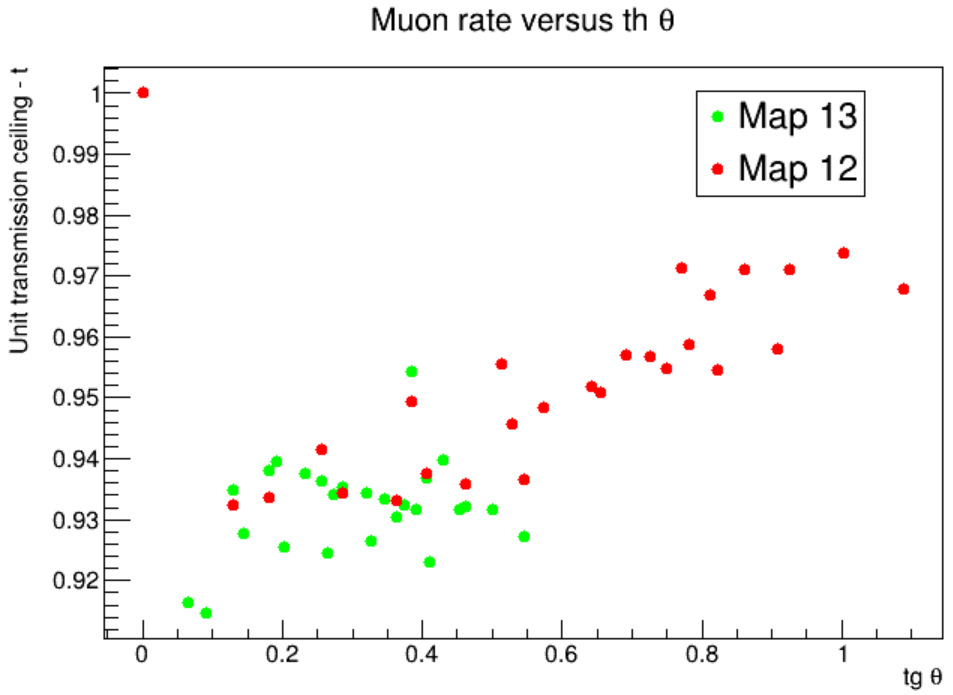
2. Open-air muon flux

Experimental confirmation

Problem: no direct measurement of the OAF

Approach: confirm the traversed matter -> transmission model

$$t = \left(\frac{UOF^{\theta}_{under\ N1\ ceilings}}{UOF^{\theta}_{under\ N2\ ceilings}} \right)^{\frac{\cos\theta}{N1 - N2}}$$



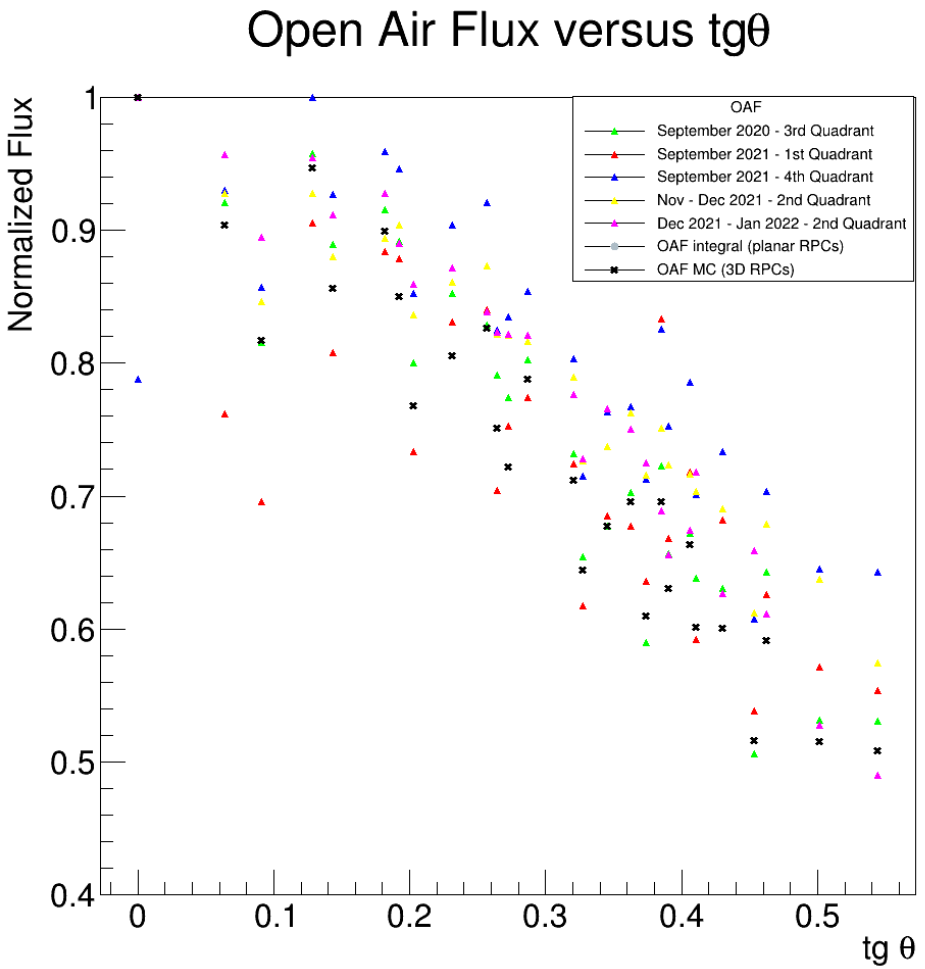
2. Open-air muon flux

Experimental confirmation

Problem: no direct acquisition of the OAF

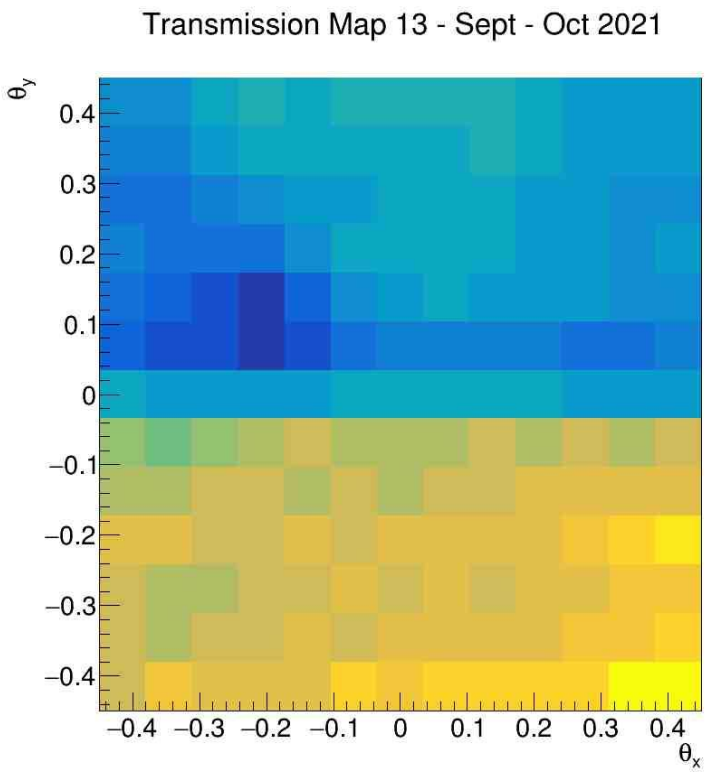
Approach: eliminate the effect of the traversed matter

$$OAF = UOF^{\theta}_{under\ N\ ceilings} : t^{N/cos\theta}$$

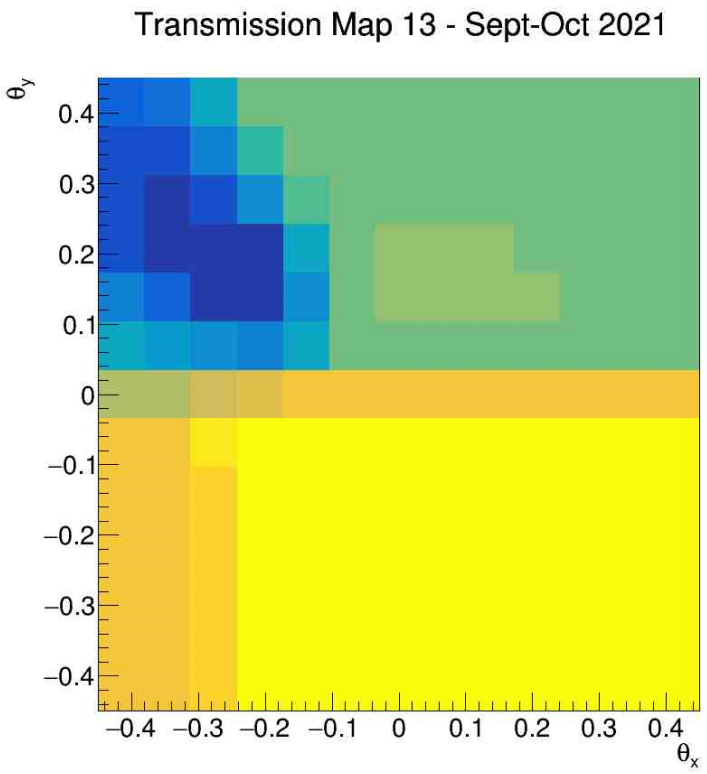


3. Results vs Simulation

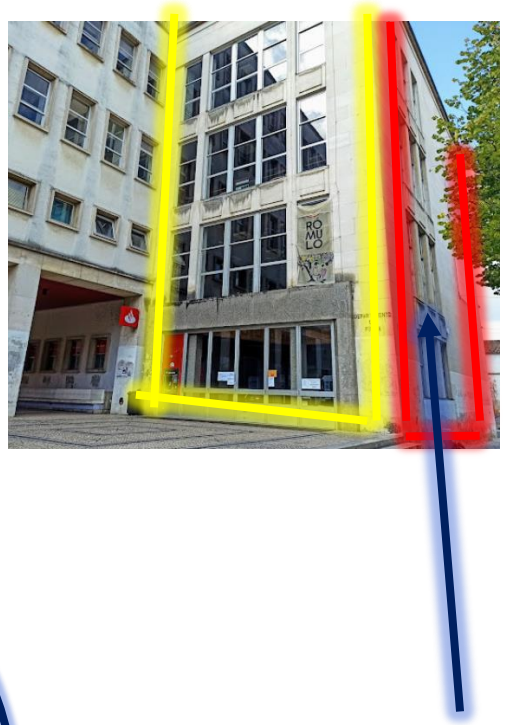
Data



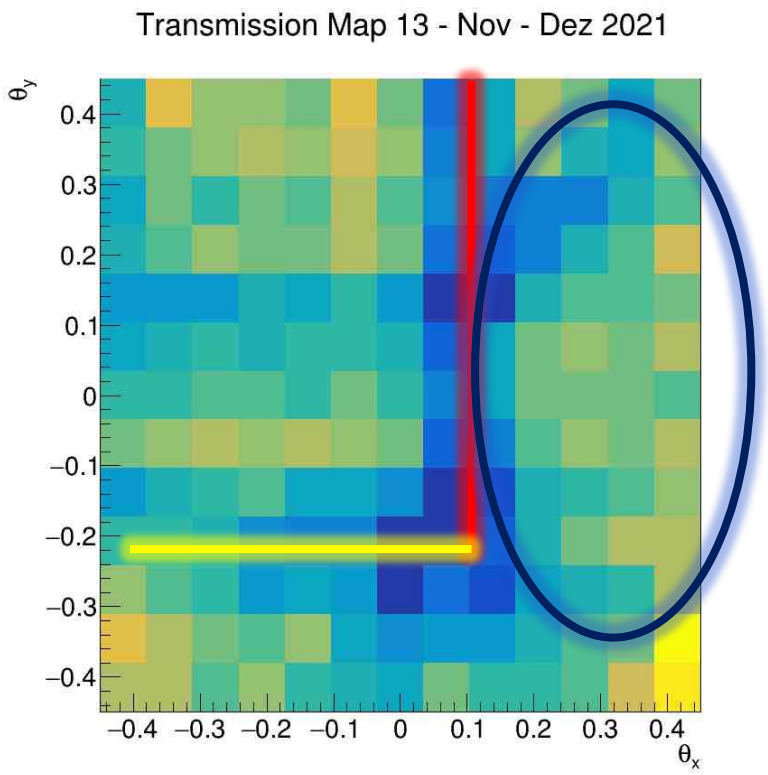
Simulation



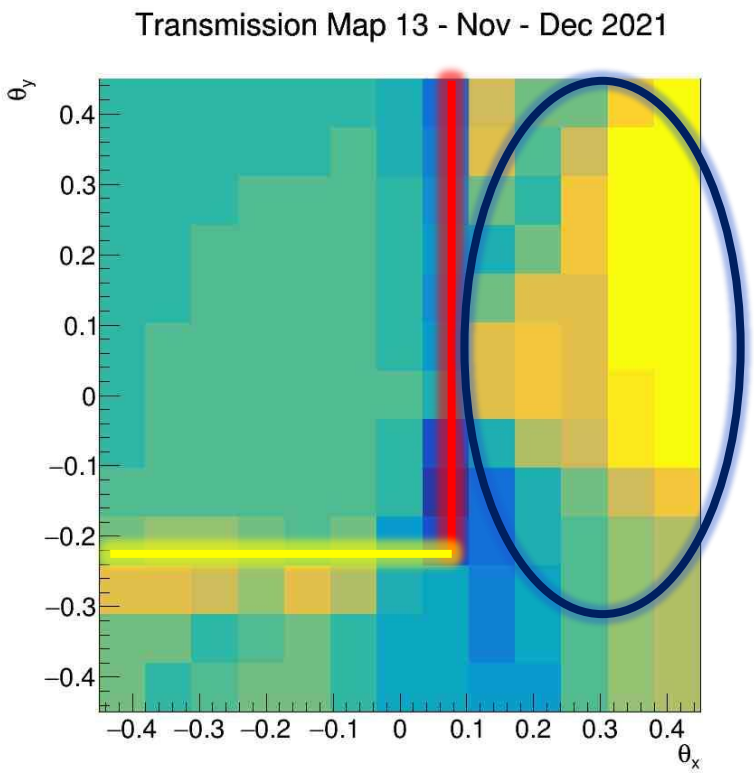
3. Results vs Simulation



Data



Simulation



4. 3D Reconstruction

The 3 methods we intend to experiment:

- Back-projection

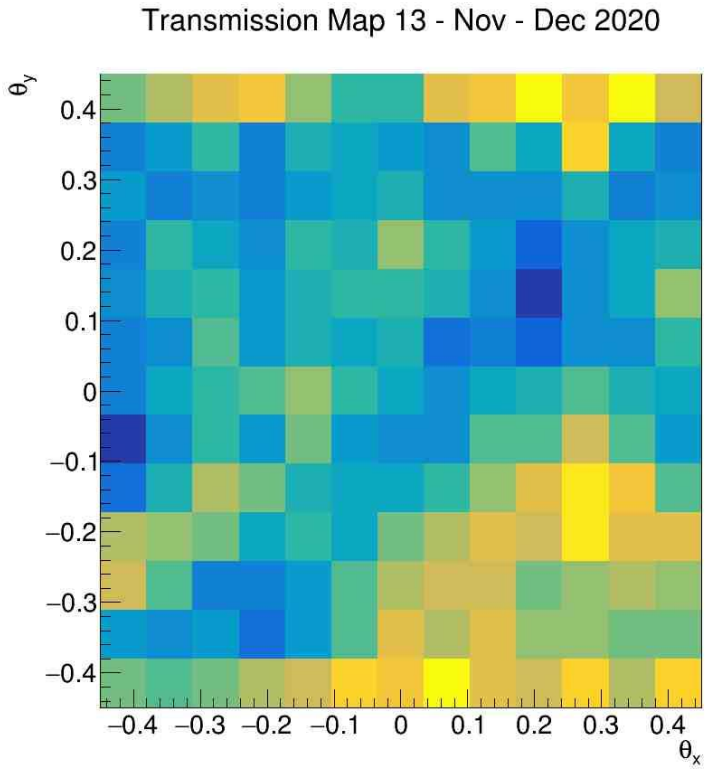
- Analytical

- Iterative

4. 3D Reconstruction

Case-study

Data



4. 3D Reconstruction

Back-projection

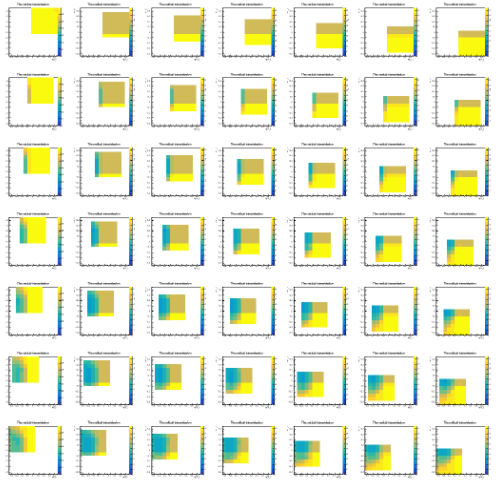
1. Simulate the transmission

2. Back-project directions of each pad

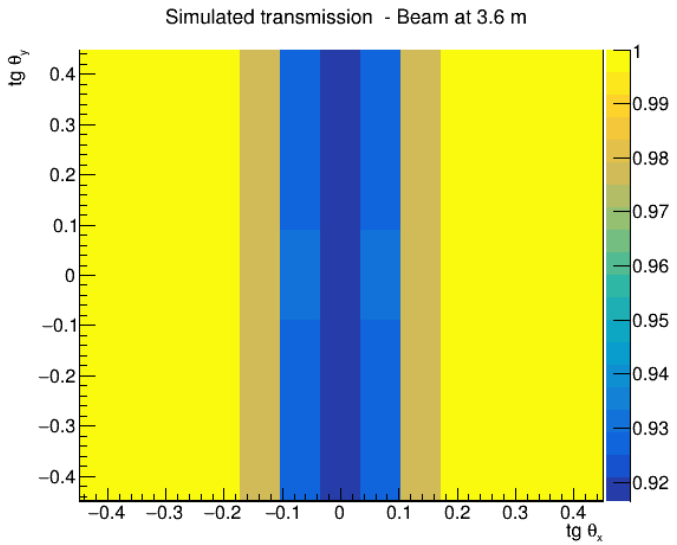
3. Fill the voxels within the inverted pyramid with the transmission value

4. Evaluate angular width of signal region for each z

5. Assess if we find a minimum angular width



1

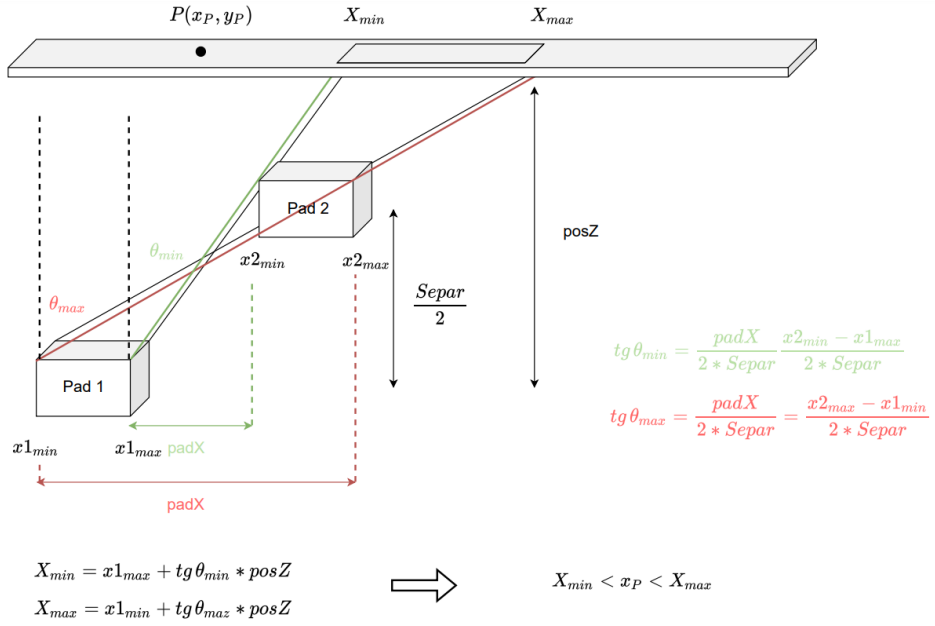


4. 3D Reconstruction

Back-projection

1. Simulate the transmission
2. Back-project directions of each pad
3. Fill the voxels within the inverted pyramid with the transmission value
4. Evaluate angular width of signal region for each z
5. Assess if we find a minimum angular width

2



4. 3D Reconstruction

Back-projection

1. Simulate the transmission

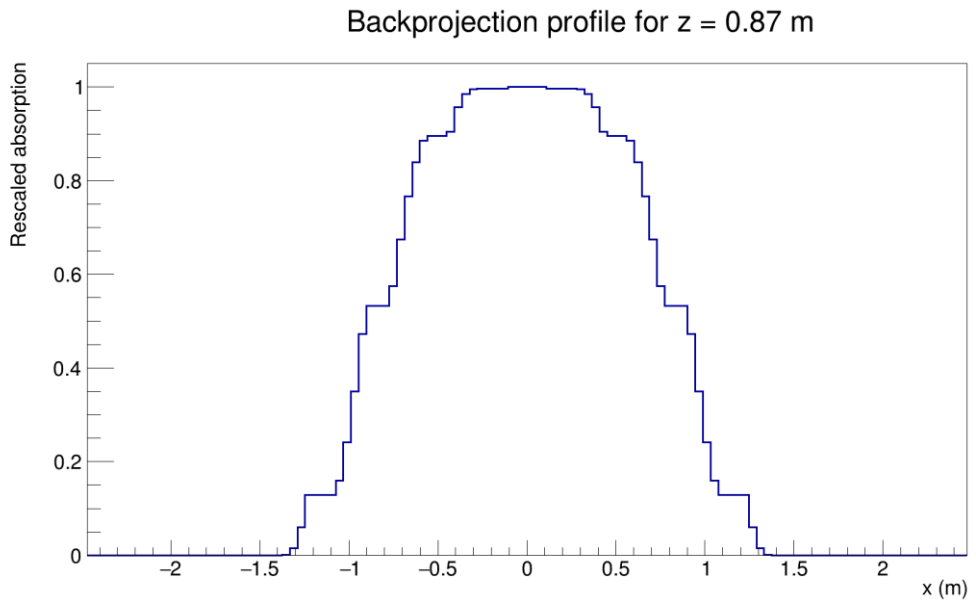
2. Back-project directions of each pad

3. Fill the voxels within the inverted pyramid with the transmission value

4. Evaluate angular width of signal region for each z

5. Assess if we find a minimum angular width

4



4. 3D Reconstruction

Back-projection

1. Simulate the transmission

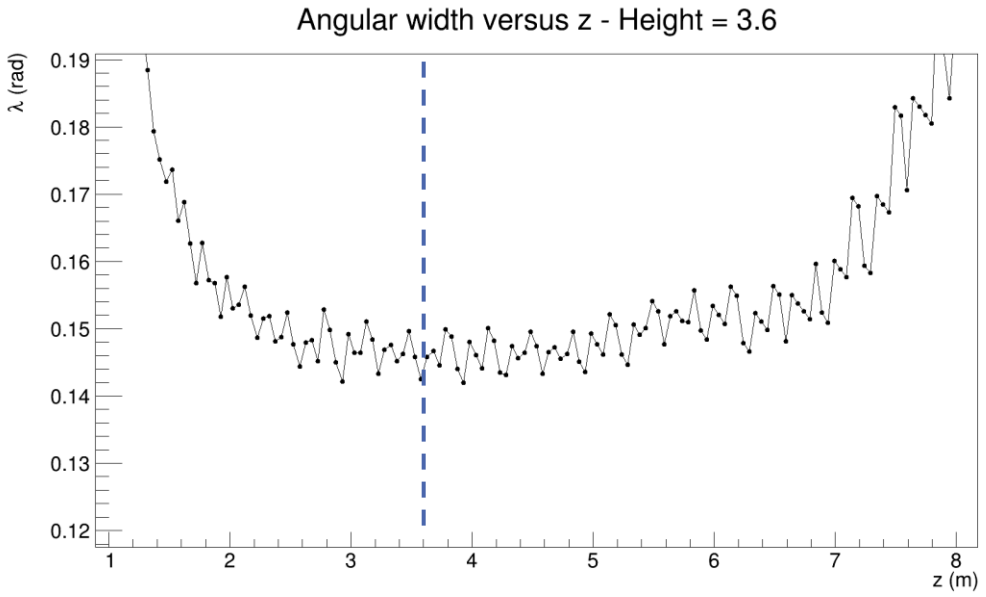
2. Back-project directions of each pad

3. Fill the voxels within the inverted pyramid with the transmission value

4. Evaluate angular width of signal region for each z

5. Assess if we find a minimum angular width

5



4. 3D Reconstruction

Analytical

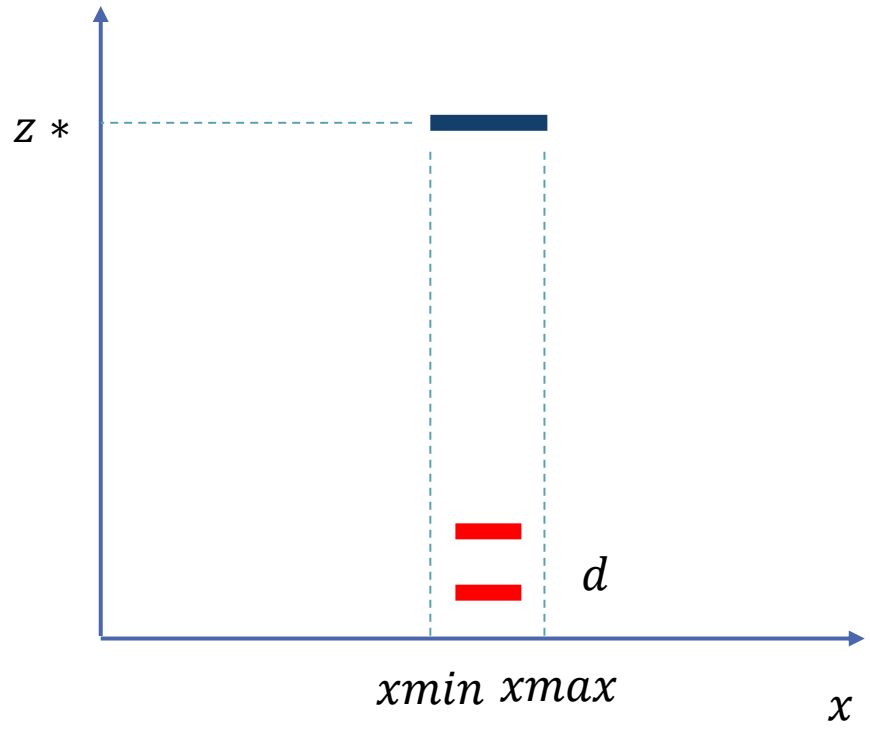
Absorption at height $z*$

$$A = \begin{cases} 1, & xmin < x < xmax \\ 0, & x < xmin \vee x > xmax \end{cases}$$

Pad acceptance

$$P = \begin{cases} 1, & x_p + (x - x_p) \times \frac{d}{z*} \in pad \\ 0, & if\ not \end{cases}$$

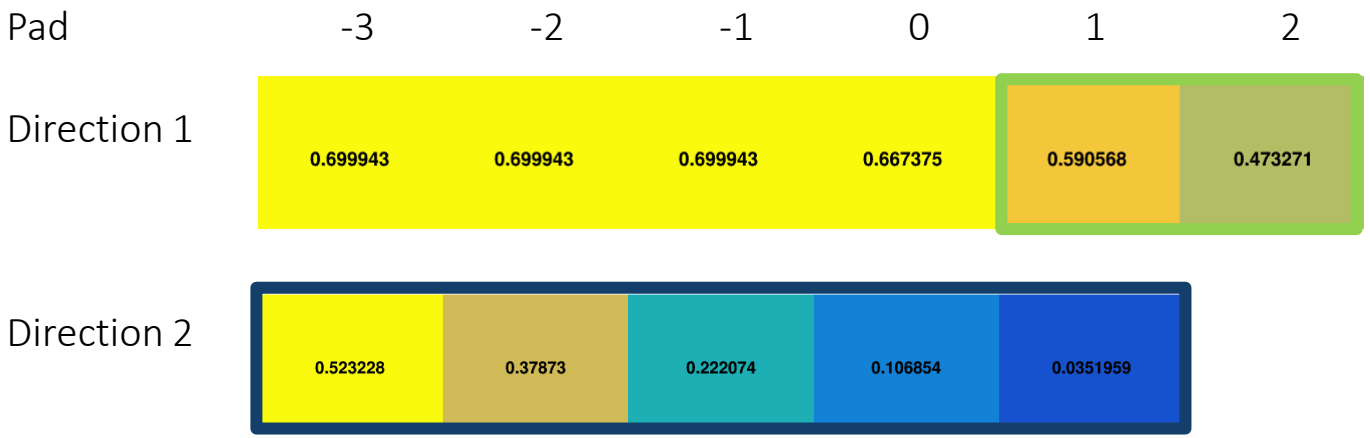
$$T(pad, direction) = \int d\ pad \int d\ space\ (A \times P)$$



4. 3D Reconstruction

Analytical

```
Direction  1  Pad  1 : t =  0.624591147786947
Direction  1  Pad  2 : t =  0.4733008252063019
Direction  2  Pad  -3 : t =  0.5297524381095277
Direction  2  Pad  -2 : t =  0.3784621155288825
Direction  2  Pad  -1 : t =  0.2271717929482373
Direction  2  Pad  0 : t =  0.07588147036759212
Direction  2  Pad  1 : t =  -0.07540885221305293
```



Future work

1. Open-air flux: continuing of its study to obtain a correct OAF for Maps 12 and 23
2. 3D Reconstruction:
    1. Back-projection: refinement of angular width measurement, application to data, study of the effect of detector resolution
    2. Analytical: continuing of its construction, adding of iterative and/or machine-learning features, application to data
    3. Iterative: start of development
    4. We look forward to construct our own method!

Thank you, questions?

LouMu collaboration meeting, 7th February 2023