

# DATA CHALLENGE INTRODUCTION

Giles Strong

# INTRODUCTION TO THE TASK

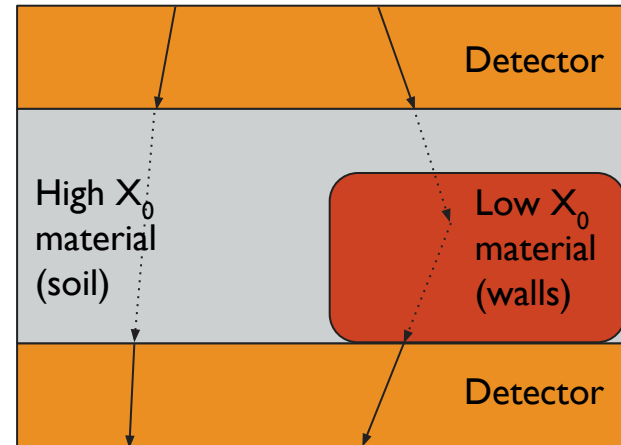
- Britain's oldest city, Colchester, was founded by the Romans around 40AD as a barracks on the site of a Celtic stronghold
- Throughout the 2nd & 3rd centuries, the city expanded, eventually becoming a *colonia* -- an extension of the city of Rome
- Roman landmarks remain to this day, with more discoveries still being made
- Whilst performing some construction, workers uncovered indications of ruined walls in a site that was previously thought to be empty
- You have been brought in to scan the site using *muon tomography* and to map out the locations of the walls to help aid the archeologists
  - They have provided you with a set of simulated data on which to develop a suitable inference algorithm



Example of Roman walls in Colchester,  
credits [Maria](#), CC-BY-SA 3.0

# TOMOGRAPHY VIA MULTIPLE SCATTERING

- Muon tomography allows us to infer the material composition of unknown volumes of space
- Cosmic muons are scattered by materials in the volume according to their radiation-length ( $X_0$  [m]) of the material
  - Radiation-length = average distance between scatterings
- By using detectors, we can measure muons above and below volume
  - The changes in trajectory provide information on material composition



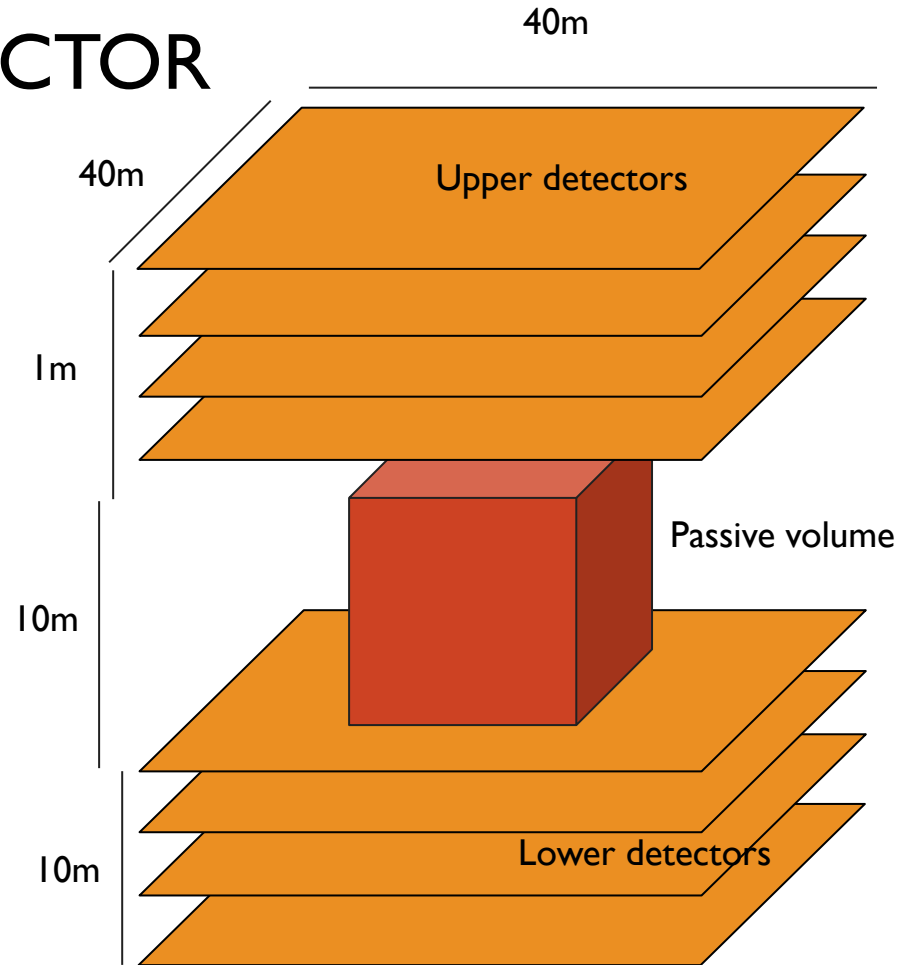
High  $X_0$  = low scattering

Low  $X_0$  = high scattering

$X_0$  = average distance between scatterings

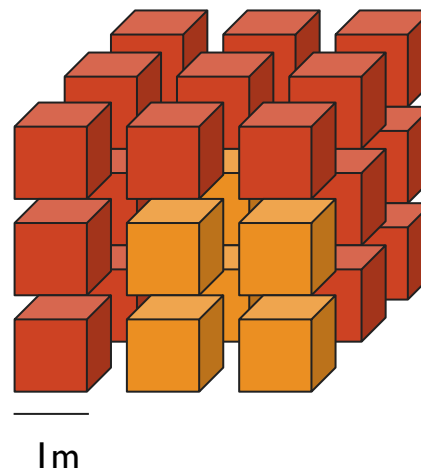
# DETECTOR

- The detector setup used here is quite unrealistic
  - It assumes that a detector panel may be placed underground, directly under the passive volume
  - The simulated detector is very large (40x40m), but this is for simulation convenience; a smaller detector could be used and placed in several spots to create a combined scan
- The detector consists of two layers (1m height), placed above and below the volume
  - Each layer contains 4 equally spaced panels
  - Each panel records muon positions with an xy resolution of 0.1mm

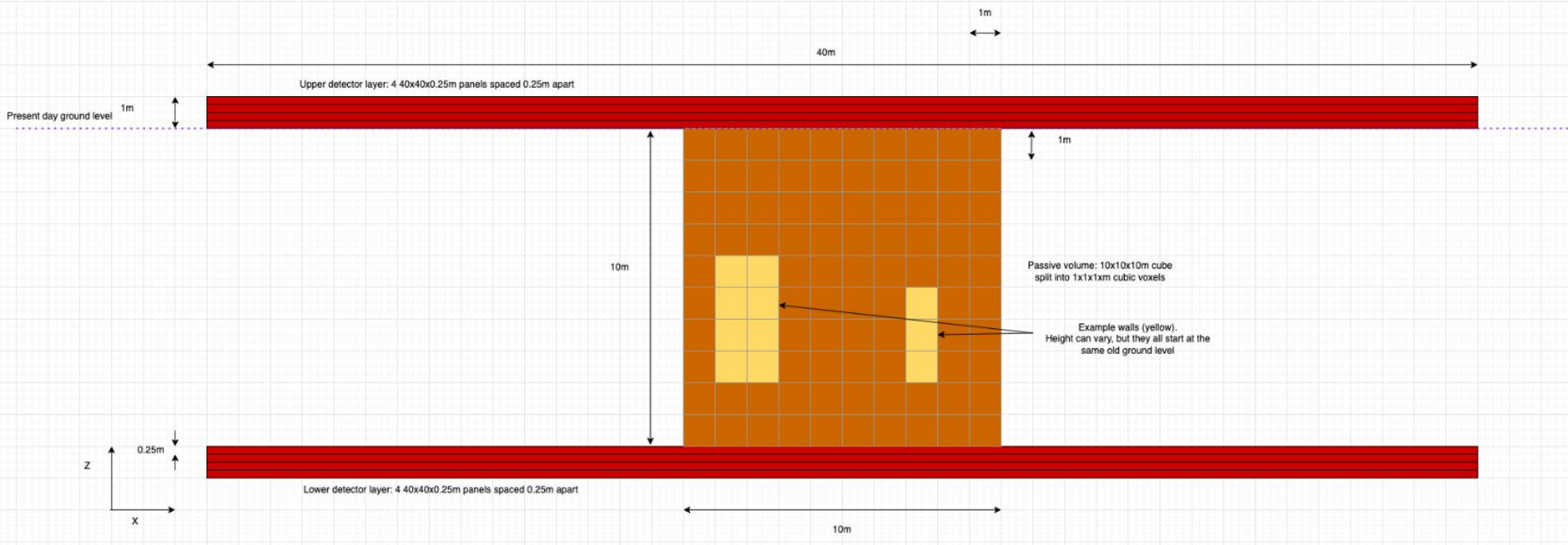


# PASSIVE VOLUME

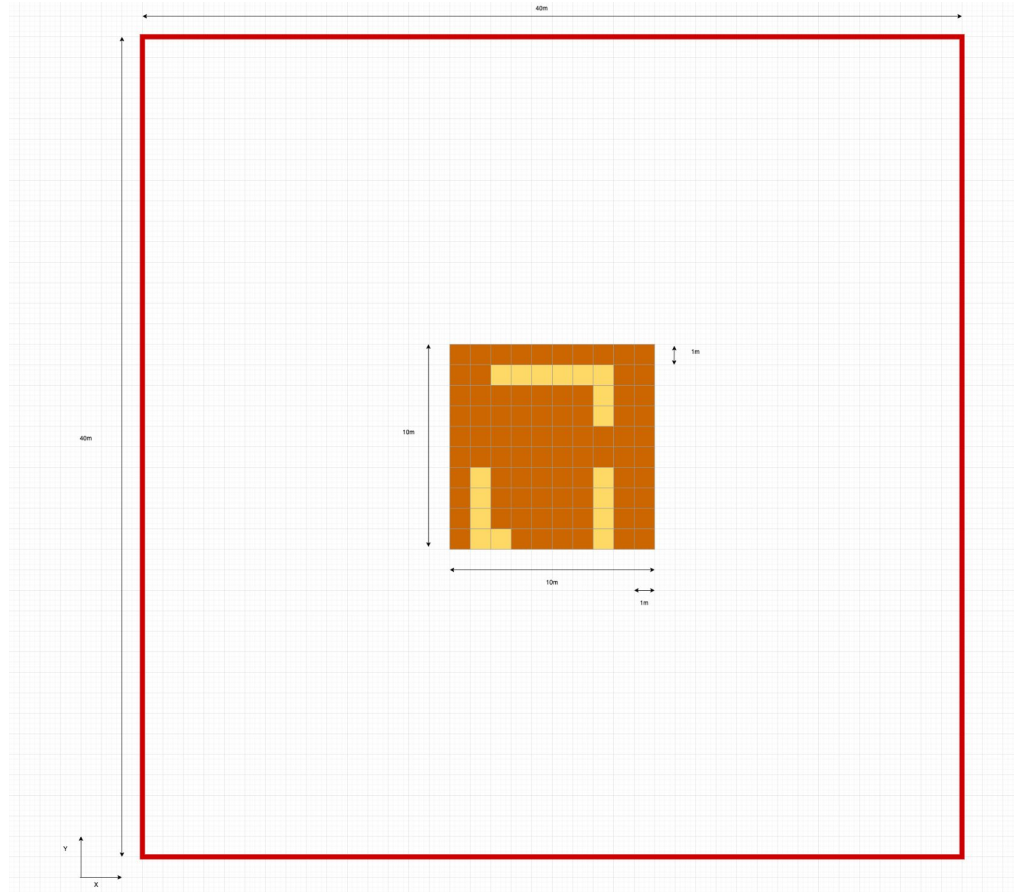
- The passive volume is a  $10 \times 10 \times 10 \text{ m}$  cube
  - It is subdivided into 1000 voxels, each  $1 \times 1 \times 1 \text{ m}$  in size
- Each voxel can either be soil ( $X_0 \sim 0.26 \text{ m}$ ) or wall ( $X_0 \sim 0.08 \text{ m}$ )
  - The amount of muon scattering depends on the voxel  $X_0$ , and scales as  $\sqrt{\text{distance}/X_0}/\text{momentum}$
  - Muon momentum will always be  $1 \text{ GeV}$ , but the distance depends on the incoming angle



# COMPLETE VOLUME SETUP: ZX

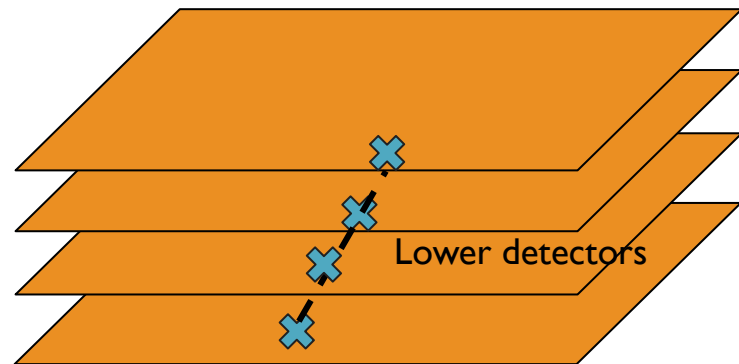
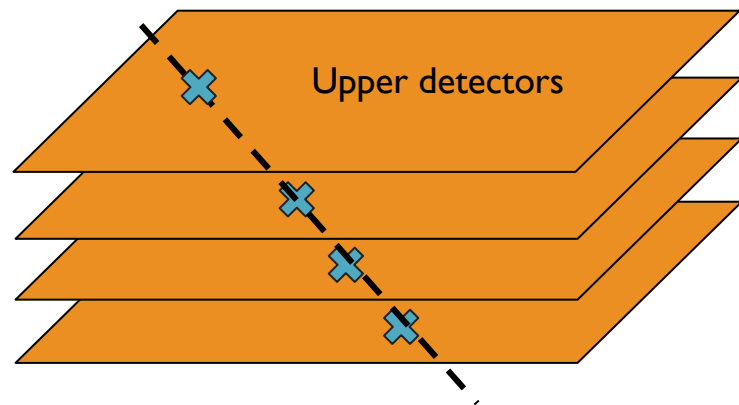


# COMPLETE VOLUME SETUP: XY



# TRACK FITTING

- Fit linear trajectories to the hits
- Can then compute variables about the muon scattering, e.g.:
  - Incoming and outgoing angles
  - Changes in trajectory

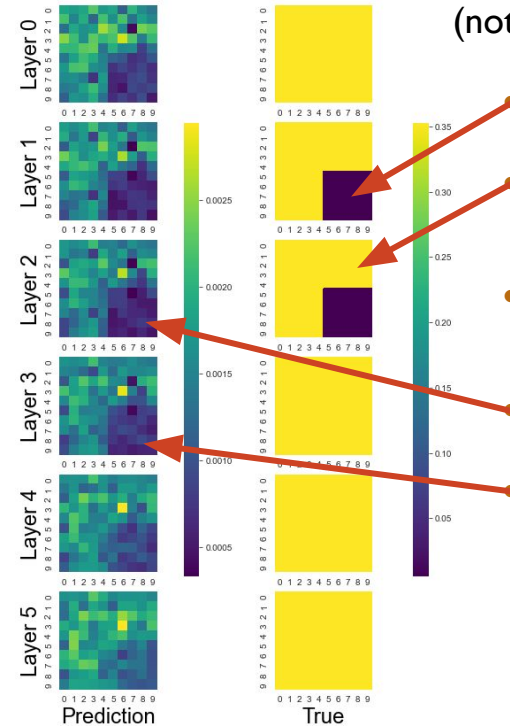




# PoCA INFERENCE

- PoCA method assigns the entirety of the muon scattering to a single voxel
  - The voxel is chosen by extrapolating trajectories inside the passive volume to find the Point of Closest Approach
  - $X_0$  predicted by inverting the scattering model to get  $X_0$  as a function of total scattering, and then averaging over many muons
  - We made a slight modification:  $X_0$  predictions are applied to every voxel, but in an average weighted by the probability of the scattering having occurred there
    - Computed using the uncertainty on the PoCA location
    - This provides a dense set of voxelwise  $X_0$  predictions
- PoCA is a very standard algorithm in tomography, but produces biased and blurred results

PoCA Example  
(not related to out dataset)



Block of lead  
( $X_0=0.005612\text{m}$ )

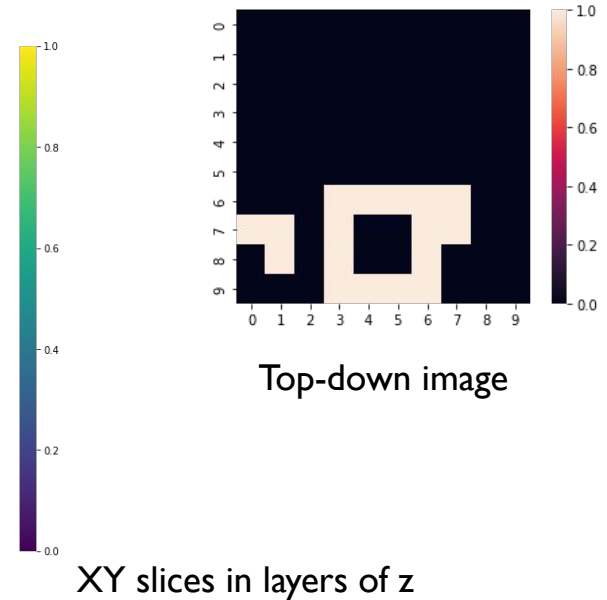
Surrounded by  
beryllium  
( $X_0=0.3528\text{m}$ )

- Predictions highly  
biased to  
underestimate  $X_0$   
Lead block clearly  
visible

but high  $z$  uncertainty  
in scatter location  
causes 'ghosting'  
above and below

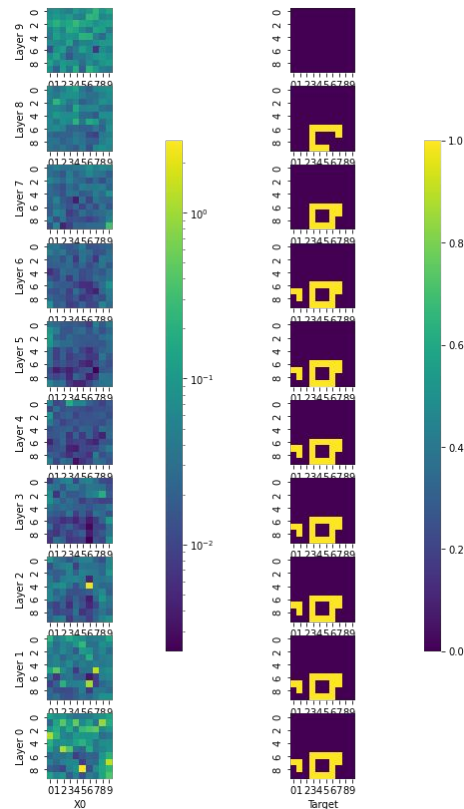
# TARGET

- The passive volumes are randomly generated to simulate stone walls buried underground
  - Each volume contains at least one wall, surrounded by soil
- All walls in a given sample begin on the same z position, but can vary in height
  - The starting z position of the walls can vary between samples



# DATASET

- A sample is created by scanning a newly generated passive volume:
  - 10,000 muons are recorded
    - Incoming angle and initial xy position can vary
    - Momentum is fixed at 1 GeV
  - The scanning process uses the PoCA inference method described on slide 9
  - This results in a biased PoCA image of voxelwise X0 predictions (float32)
  - The target is a map of the wall voxels (int, 0 = soil, 1 = wall)
- Approximately 100k labelled samples are provided along with 30k unlabelled testing samples
  - Your task is to provide predictions on the unlabelled sample



Example sample:

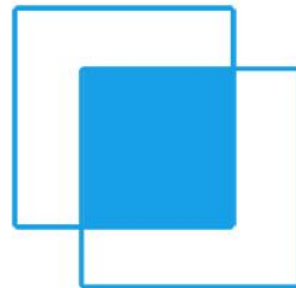
Left = voxelwise  
X0 predictions

Right = map of  
voxels which  
contain wall

# METRIC

- Both predictions and targets will be a voxelwise 0 or 1
- Performance evaluated using the “intersection-over-union” (IOU) metric
  - Intersection is number of wall voxels correctly predicted to be wall
  - Union is the sum of the number of voxels that are either predicted to be wall or are actually wall
- Behaviour:
  - Predicting all walls gets high intersection but also high union = low IOU
  - Predicting no walls gets zero intersection = zero IOU
  - Accurate wall predictions get high intersection and low union = high IOU
- IOU is between 0 and 1, and higher values mean better performance

$$\text{IoU} = \frac{\text{Area of Overlap}}{\text{Area of Union}}$$

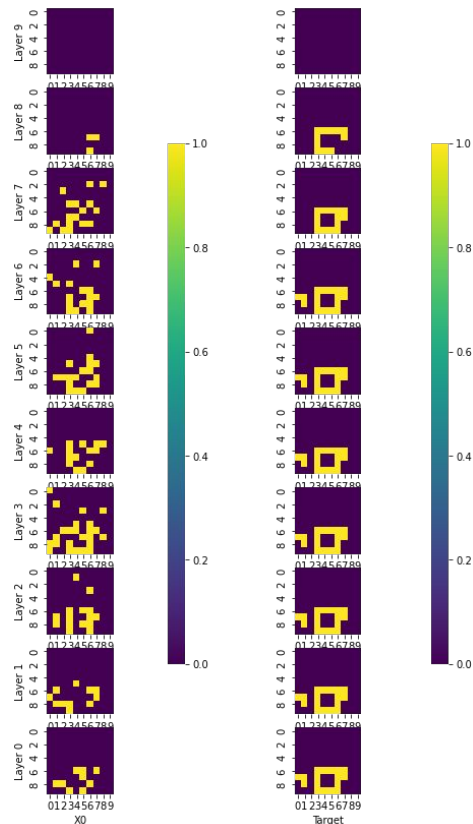


# STARTER PACK

- Starter notebook covers:
  - Loading the data and viewing the data
  - Applying a simple threshold-based approach
  - Evaluating performance using the intersection-over-union metric
  - Creating a submission with predictions for the test data
- Threshold method: prediction based solely on  $X_0$  values:
  - $X_0$  below threshold, predict wall
  - $X_0$  above threshold, predict soil
  - Optimise thresholds by maximising the IOU

Left:  
predictions  
using the  
optimised  
threshold

Resulting  
IOU is 0.63



# SUBMISSIONS

- Submissions must be uploaded in HDF5 format to <https://cernbox.cern.ch/index.php/s/ylsOYg9q7hcRk4l>
  - Format must be a (sample, z, x, y) matrix of integer values stored in a dataset called 'preds'
    - Submissions not in this format will be ignored
  - Order of predictions must be the same as the samples in the testing dataset
  - The starter pack contains instructions on how to do this
  - File names should include your full name and an optional ID number for the submission
    - In case of multiple submissions, I will use the one with the highest ID number
    - Files without a person's name will be ignored
- Deadline is 23:59:59 CEST on 22/09/04
- Submissions can be made anytime before the deadline, and multiple submissions are ok
  - Final results will be based on the latest submission
- Teams are allowed, but we can only offer one prize to each team
- Every Friday I will announce results of performance on a fixed, random subsample of the test data using everyone's latest submissions
  - I will also let anyone know if their submission format was invalid
- The final results will be computed using the remaining samples from the test dataset