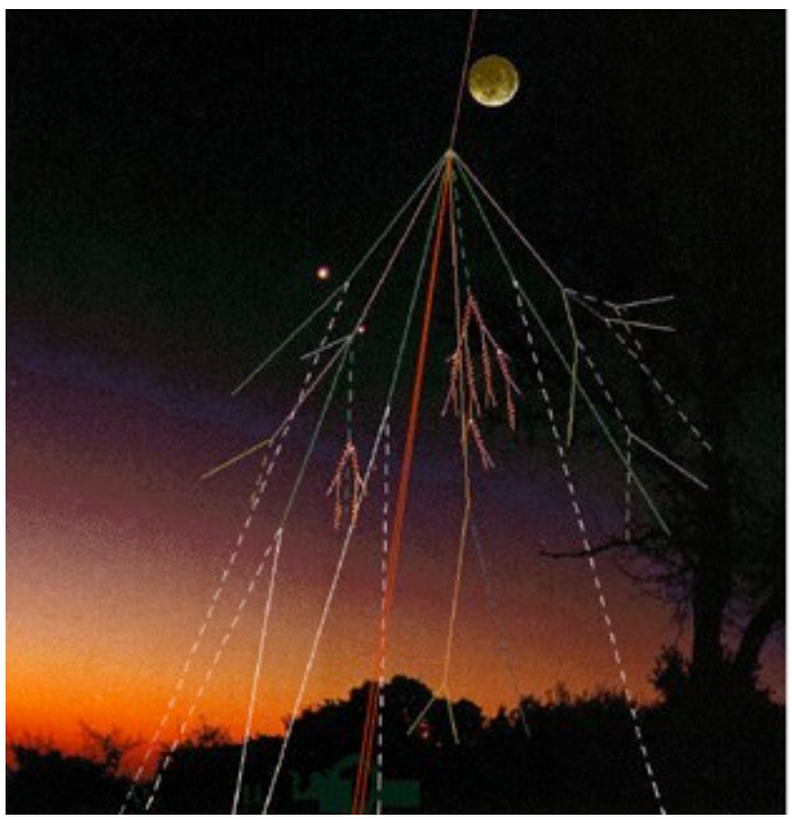
CREAM TEA

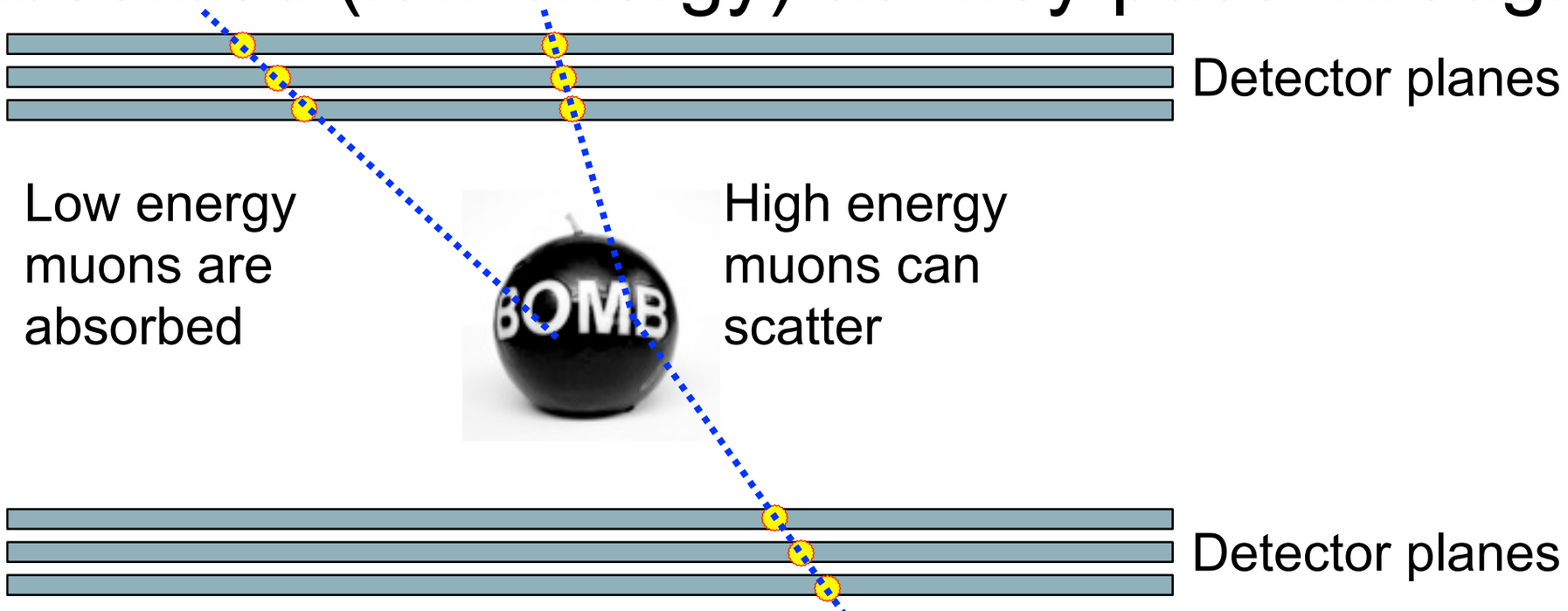
Cosmic Ray Extensive Area Mapping for Terrorism Evasion Application

Ryan Nichol



The Idea - Cosmic Ray Muon Tomography

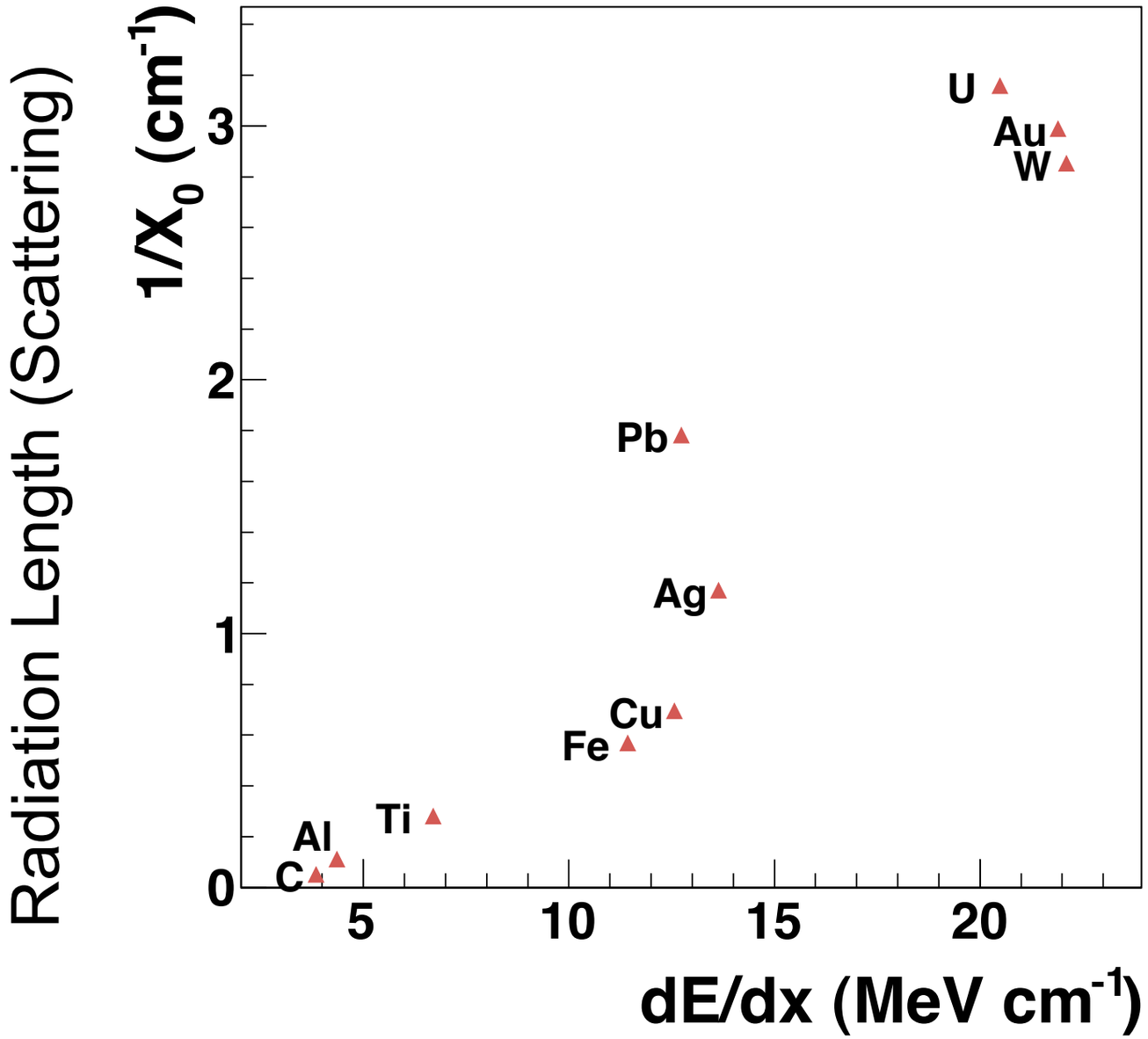
- Over 10,000 cosmic ray muons a minute stream through each square metre of the Earth's surface.
- These particles either scatter (high energy) or are absorbed (low energy) as they pass through matter.



- Creates a three dimensional image.
  - Cosmic ray imaging is an old idea (1950's) and has been used to image: pyramids, volcanoes, mines, ...

Muon Tomography Capabilities

- The scattered and absorbed muons can be used to make two independent measures of the target material



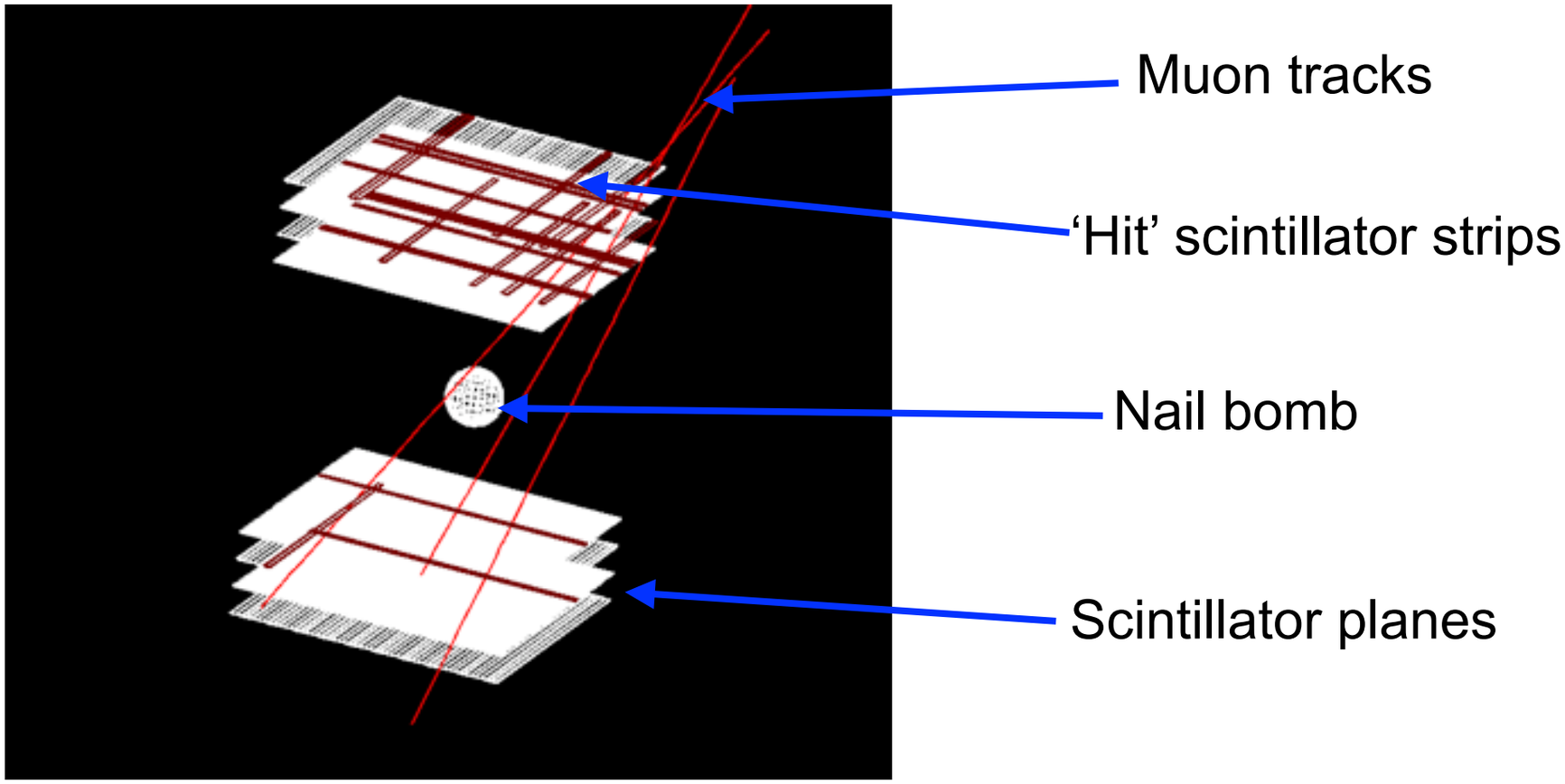
CREAM TEA - Phase I

- Phase I of the project is a 12-month feasibility study with two main strands:
  - Computer simulations (using the high energy physics GEANT Monte Carlo tool) to:
    - Determine the capabilities (and limitations) of the technique for imaging large volumes.
    - Optimise potential detector geometry.
    - Develop image processing tools.
    - Simulate the laboratory test-stand.
  - A laboratory test-stand using plastic scintillator detector modules
    - Validate the simulation results.
    - Perform imaging benchmarking tests.

The Simulation - Current Status

- GEANT4 is the particle physics tool of choice for simulation.
  - Contains all known particle interactions with matter.
- We have a simulation that we can use to test a variety of target geometries

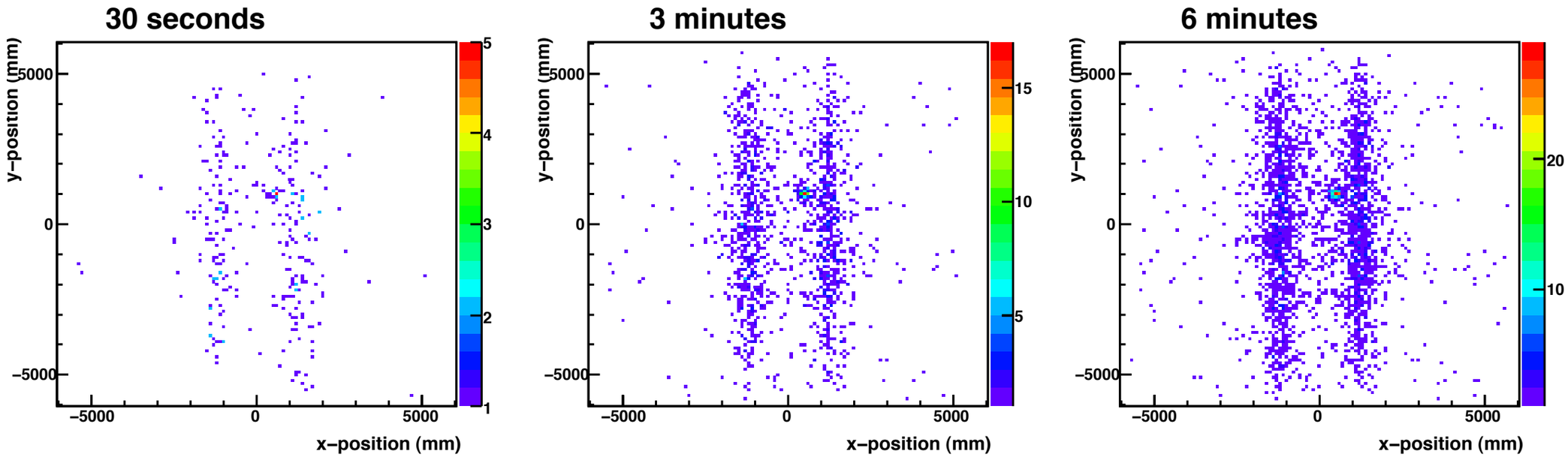
GEANT4 visualisation of CREAM TEA test-stand



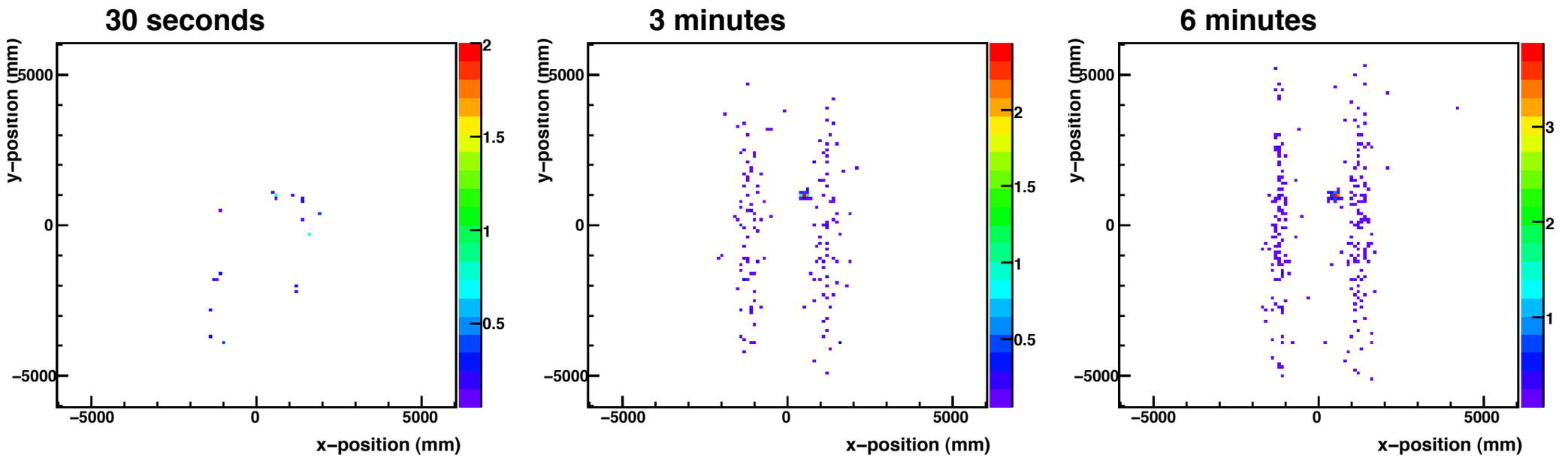
Initial Results -- Absorbed Tracks

- 10cm ‘tungsten’ target in a shipping container

Raw Absorption Slices

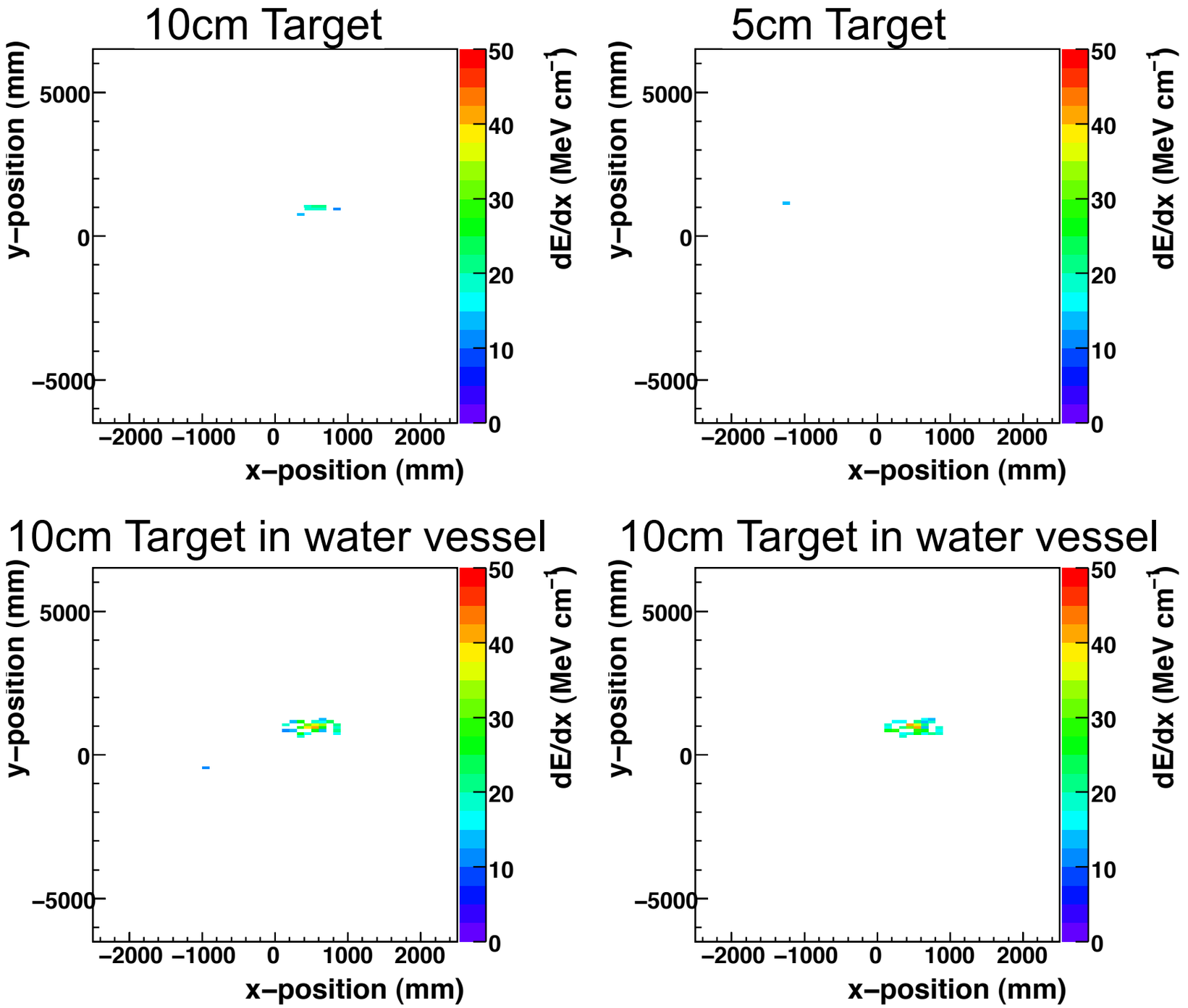


Weighted Absorption Slices



Initial Results -- dE/dx measurement

- Six minute exposures



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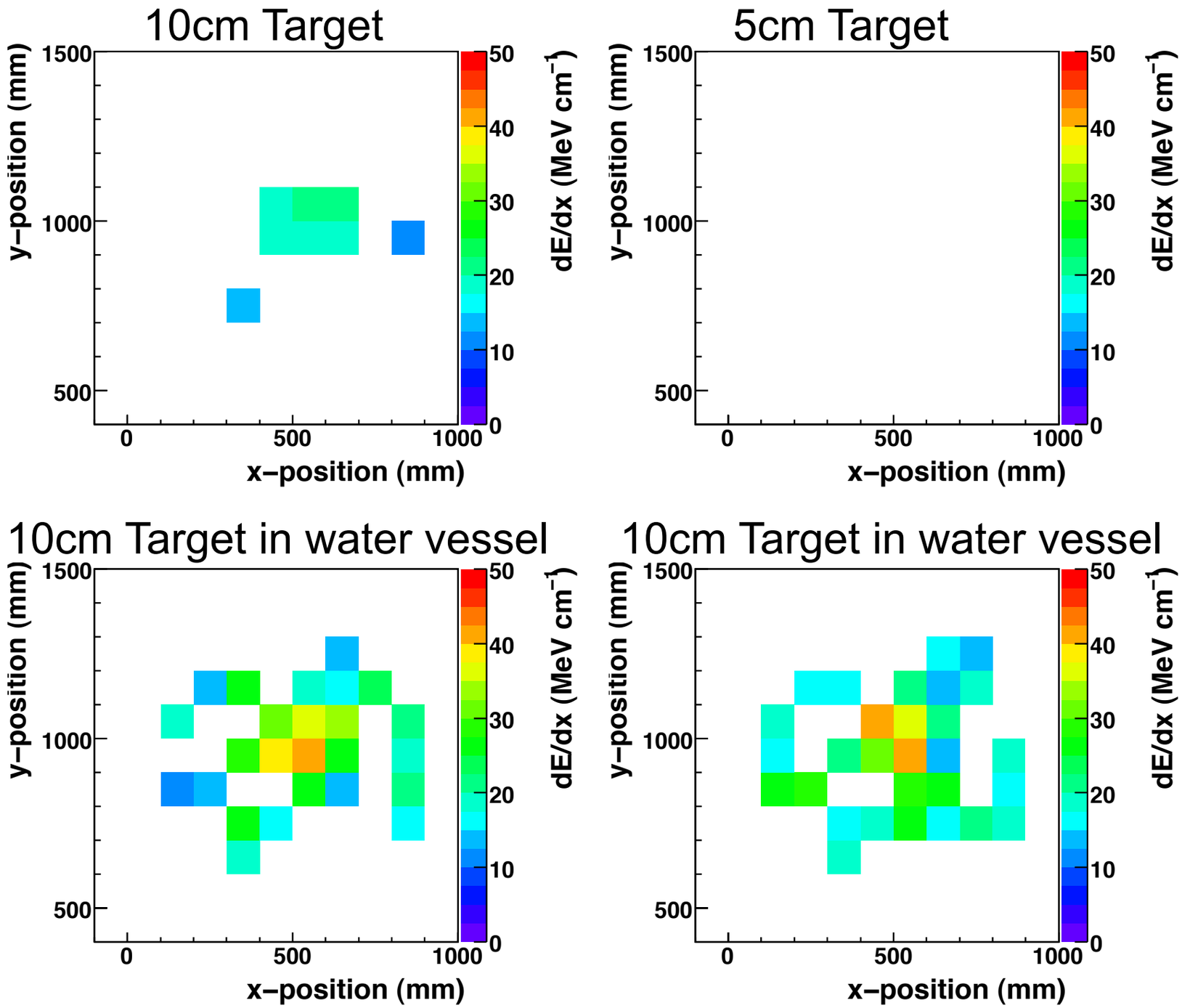
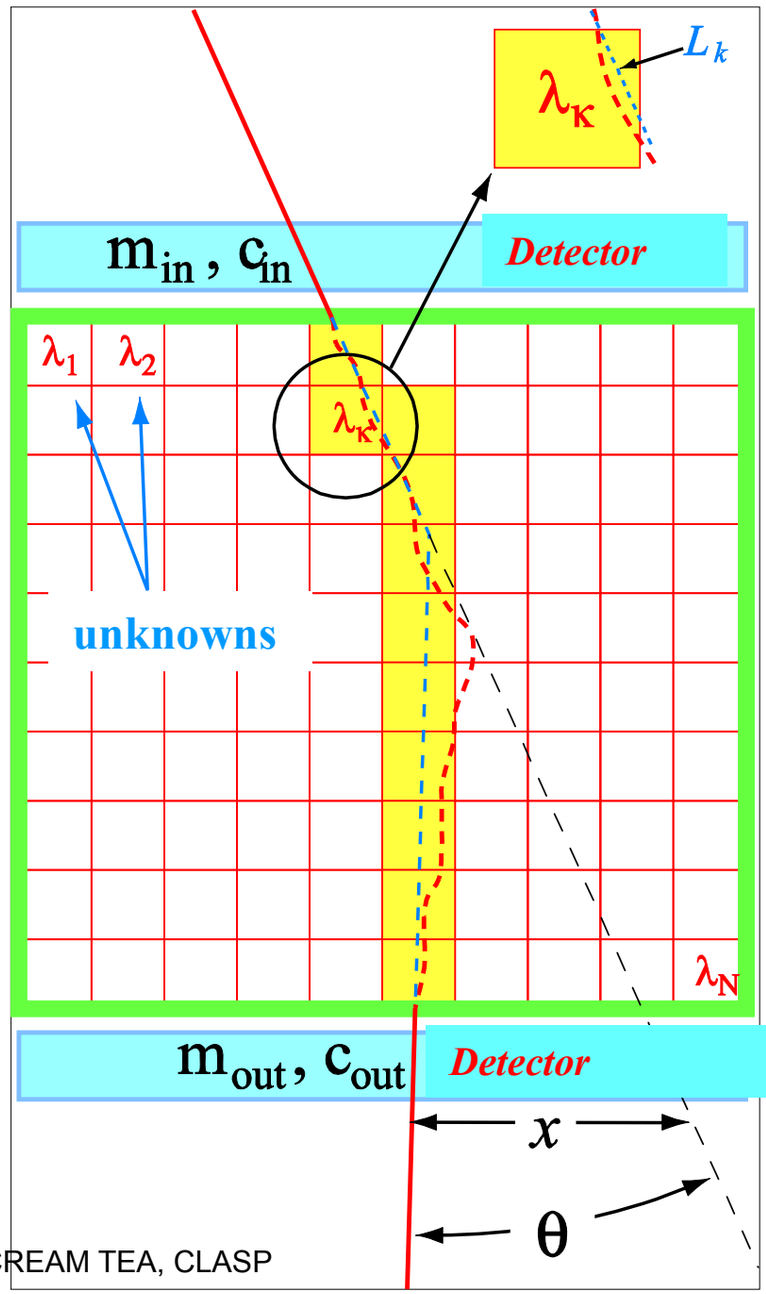


Reconstruction Techniques

Tomographic (List Mode Iterative Algorithm)



Define scattering density for a material: $\lambda_0 = 1/X_0$

the average square deviation expected for a particle i crossing *L*

$$\sigma_i^{\,2} \approx \left(\frac{13.6\,MeV}{p_i c} \right)^2 L\lambda_0$$

If the material is not homogeneous the volume can be divided into N cubic voxels and $L\lambda_0 \rightarrow \sum_k L_{ik}\lambda_k$

where $\{\lambda_k ; k=1,\ldots N\}$ **are N unknowns**

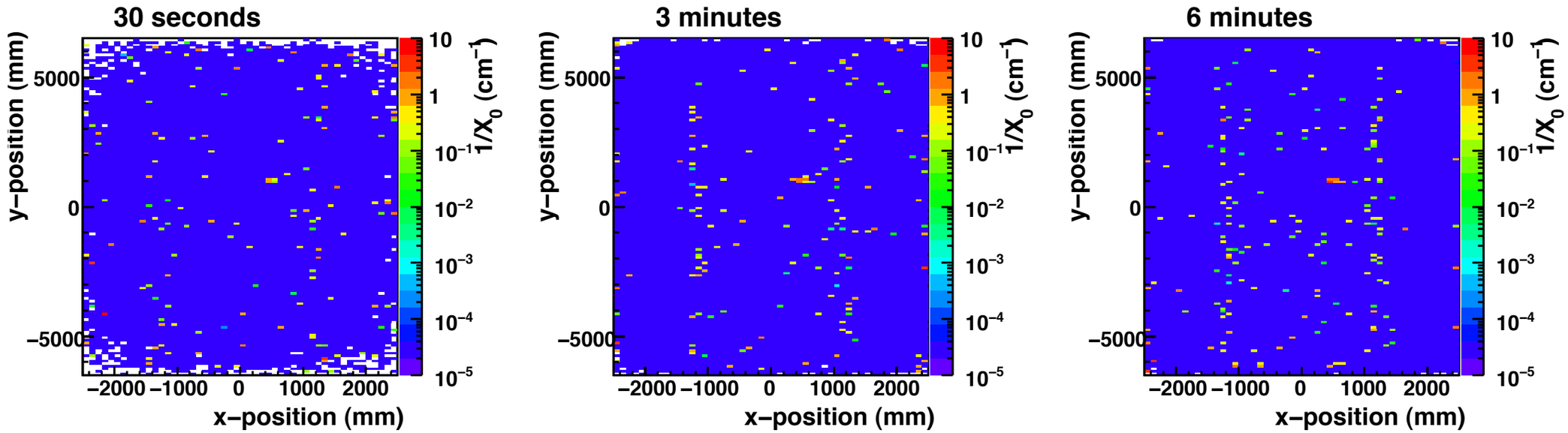
with $\{s_i^2=\Delta\theta_i^2 ; i=1,\ldots M\}$ **M measurements.**

given the Gaussian p.d.f. $P_i = P(s_i \mid \sigma_i) = \frac{1}{\sigma_i\sqrt{2\pi}} e^{-\frac{s_i^2}{2\sigma_i^2}}$

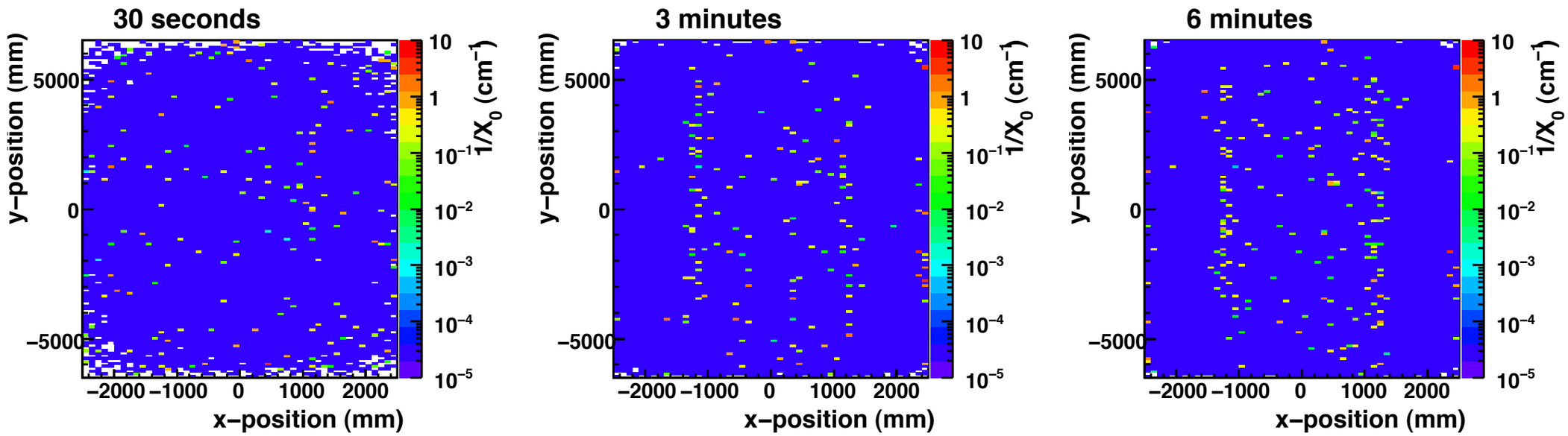
with an iterative optimization algorithm (LMIA) applied to a Maximum Log-likelihood functional the system can be solved

Initial Results -- Scattering

- 10cm Target



- 5cm Target



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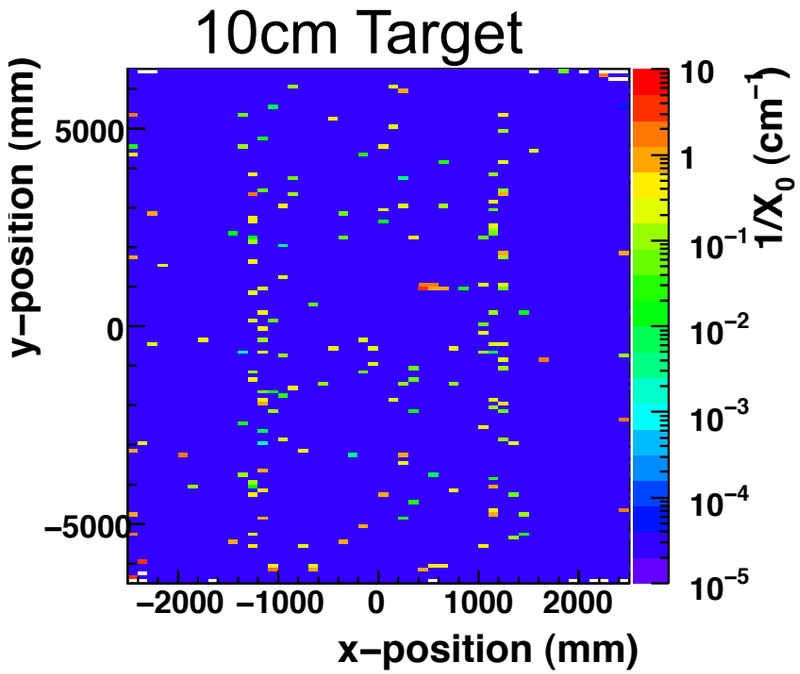
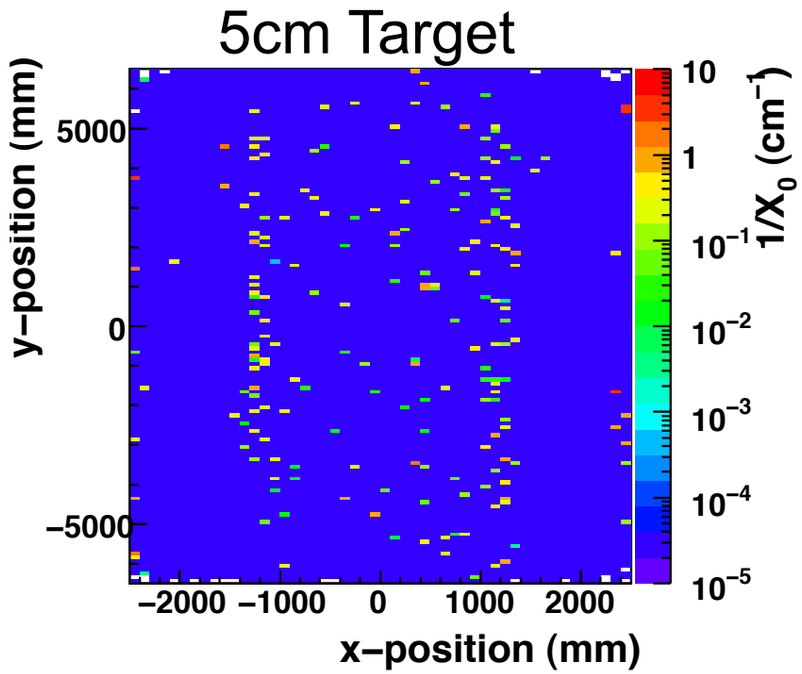
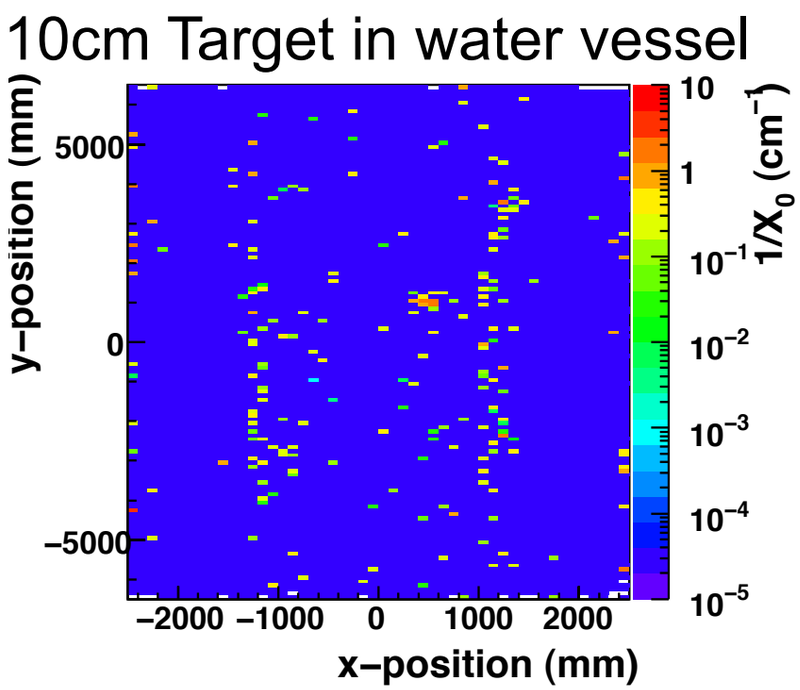
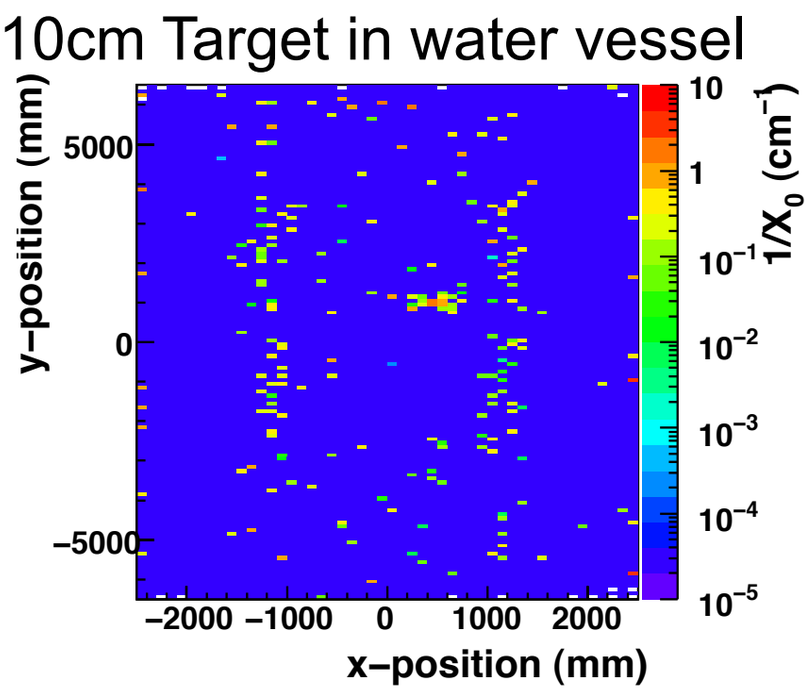
Initial Results -- Scattering

- Six Minute Exposure









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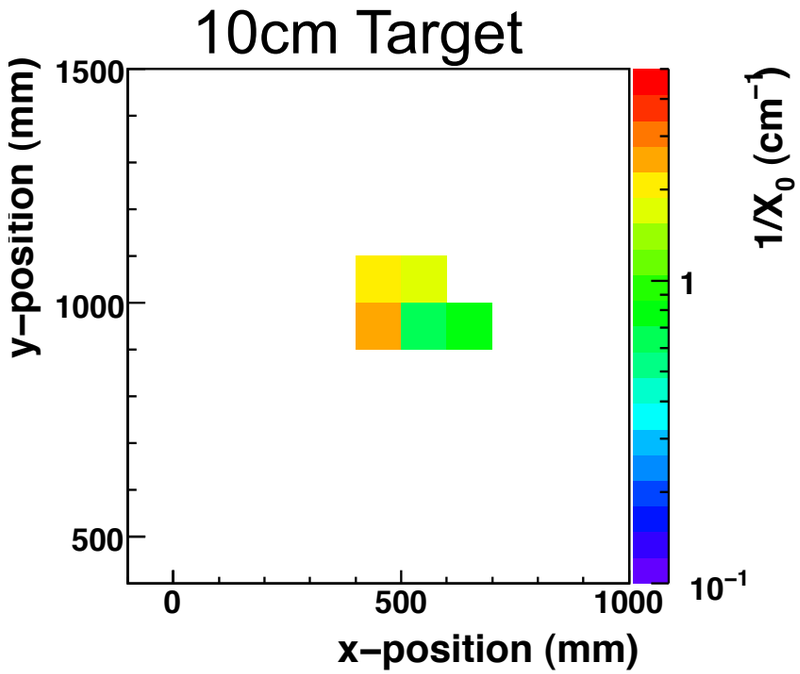
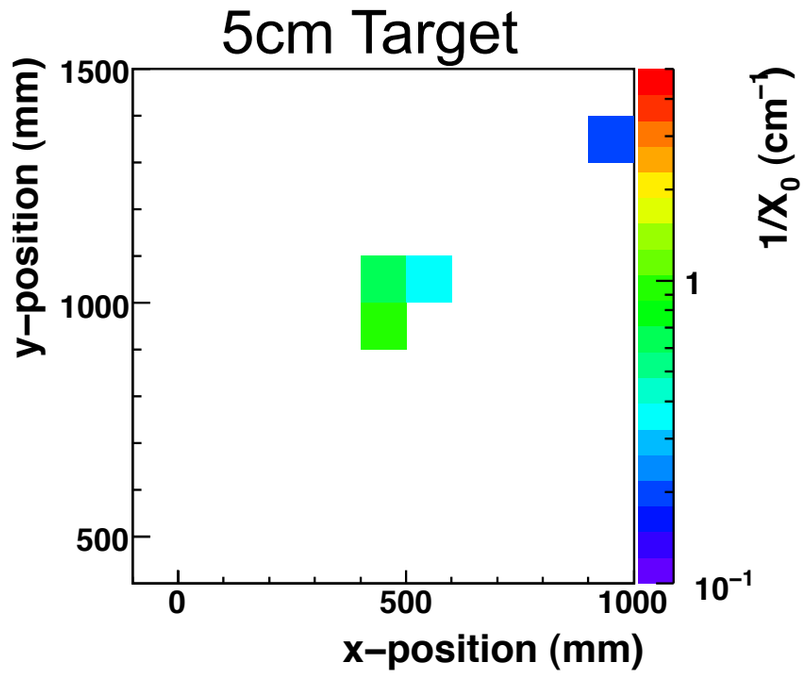
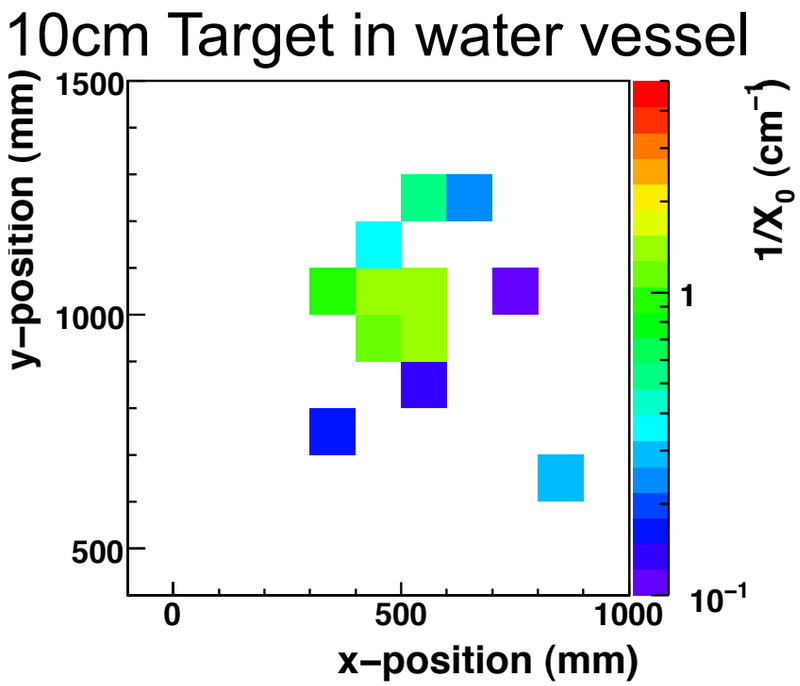
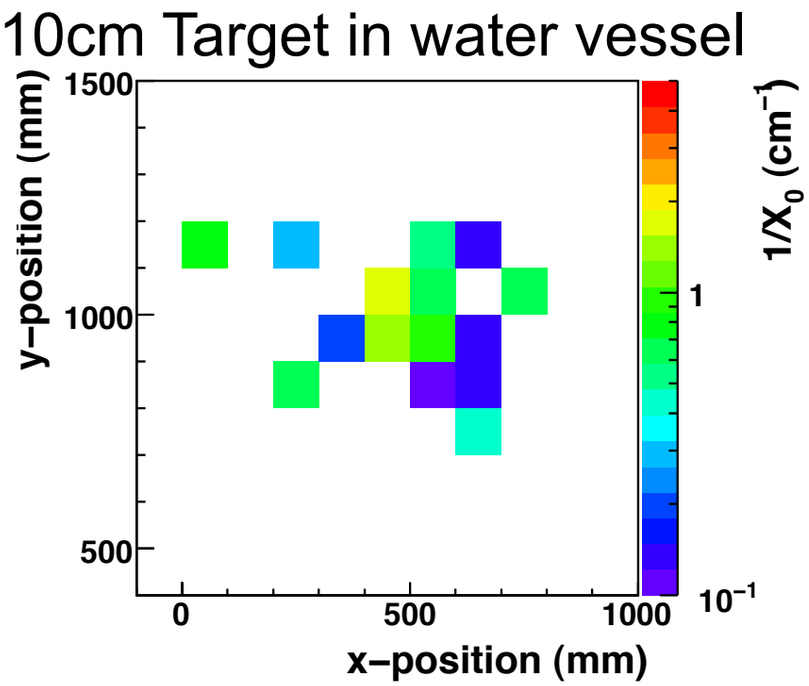


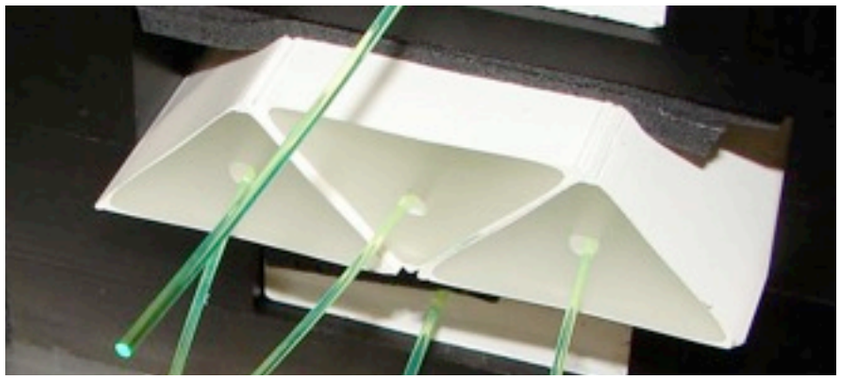






The Test-Stand Detector

- Same detector technology as the MINOS and MINERVA detectors.
  - Plastic scintillator is a solid inert material (so none of the safety concerns of liquid or gas based detectors).
  - The MINOS Far Detector has 25,000 m^2 of scintillator.
  - The test-stand modules are $1m^2$ with 24 strips per plane.



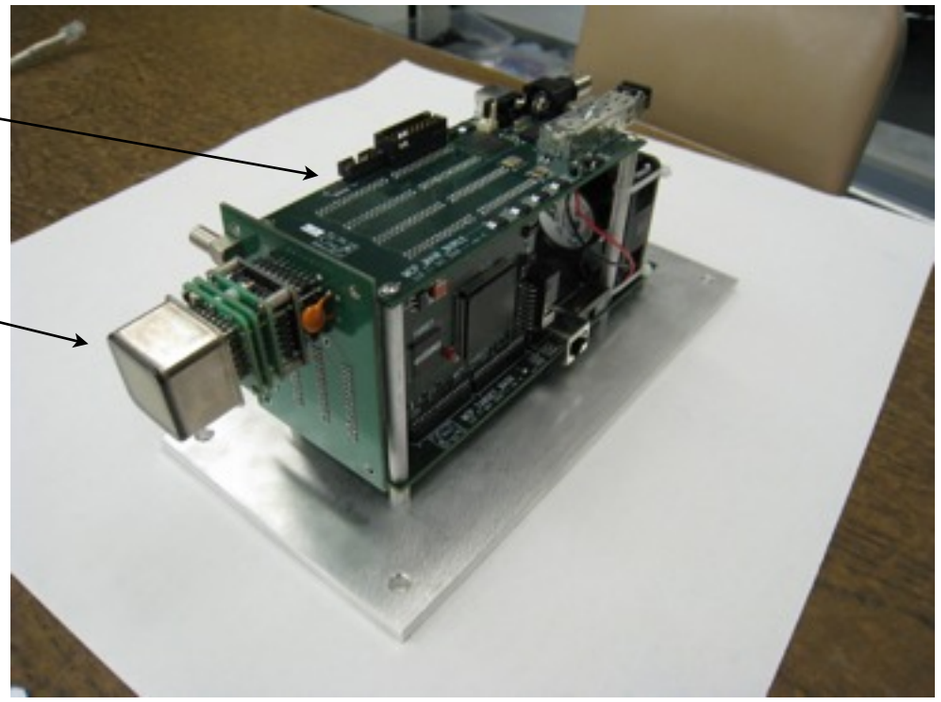
  - MINERVA obtains 1.5mm position resolution using 33x17mm triangular ‘strips’ and signal weighting.

Test Stand Construction Progress

‘Test Stand’ Stand

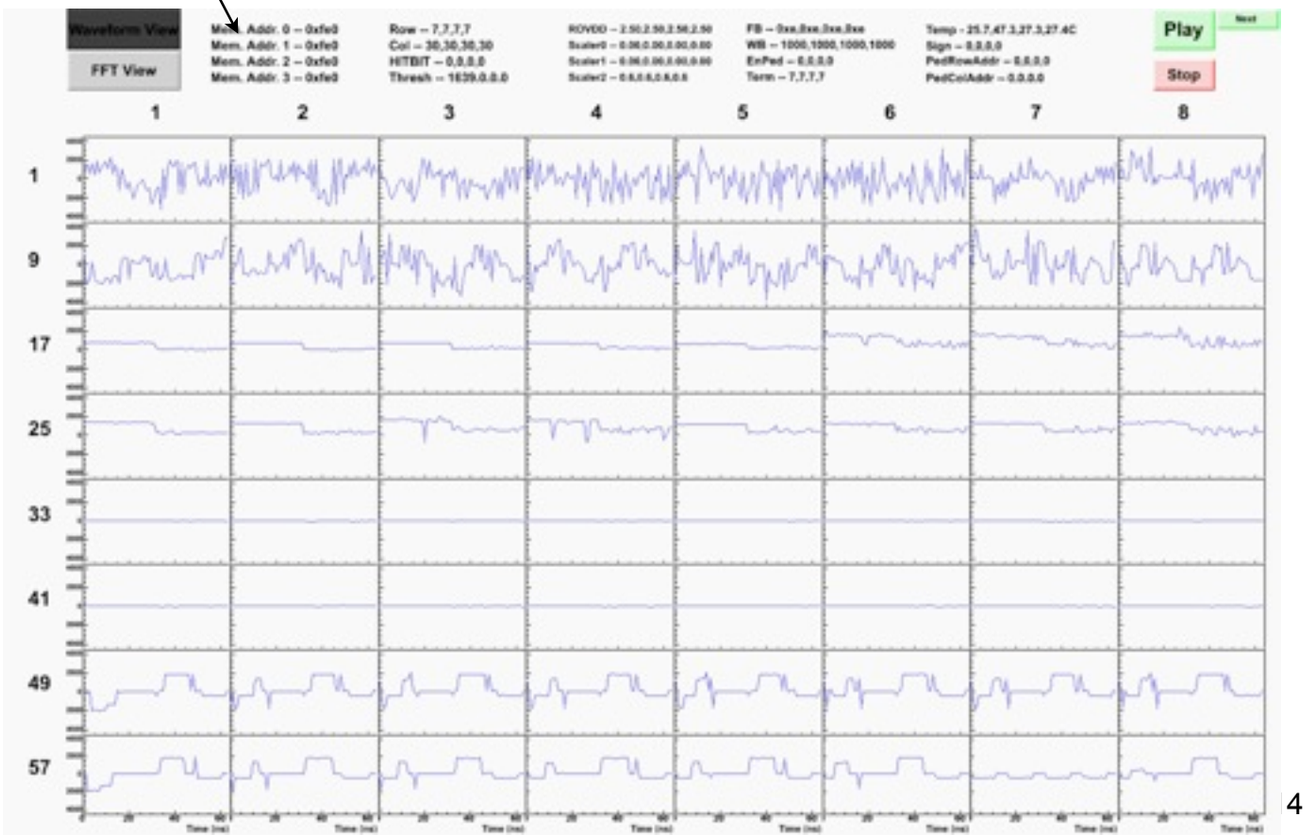
4xTARGET Digitiser

64 Channel PMT



64 Channel Event Display

Scintillator Modules



Summary

- Muon tomography is an old idea (with its roots in London at Birkbeck College) seeing new light with 21st computer image processing techniques.
  - Cosmic ray muons may provide one of the tools with which to tackle the threat of terrorism.
    - In addition to securing large enclosed spaces (train stations, etc.) the technology is easily adaptable for other security purposes (eg. cargo screening).
- The CREAM TEA feasibility study is progressing and early 2010 the test stand will be operational

Task	FTE
1) Phase I -- Feasibility Study	
1.1) Initial Simulations	0.2
1.2) Hardware Benchmarking	0.1
1.3) Further Simulations	0.2
1.4) Test-stand validation of simulation	0.2
1.5) Simulate CREAM TEA detector prototype	0.3
2) Demonstrate Feasibility