REINFORCE

REsearch INfrastructures FOR Citizens in Europe

The Cosmic Muon Images demonstrator within the REINFORCE project

Muography2021 - 25/11/2021

Avgitas Theodore

- Citizen Science
- REINFORCE project
- Cosmic Muon Images Demonstrator
- Outlook

GHENT
24-26 NOV.
Muographers
2021

International Workshop on Cosmic-Ray Muography (Muography2021)

H2020-SwafS-2018-2020 funded project Grant Agreement no. 872859

Citizen Science

Active participation of the public in scientific research that generates new knowledge or understanding.

Citizen Scientists participation:

- Data Collection / Volunteer Mapping
- Data Interpretation / Analysis
- Publication / Dissemination of results

Examples:

Amateur Astronomy

Ornithology: Bird Watching
Bird Migration

Butterfly Count:
Monarch Butterfly
Migration monitoring

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REsearch **IN**frastructures **FOR C**itizens in **E**urope

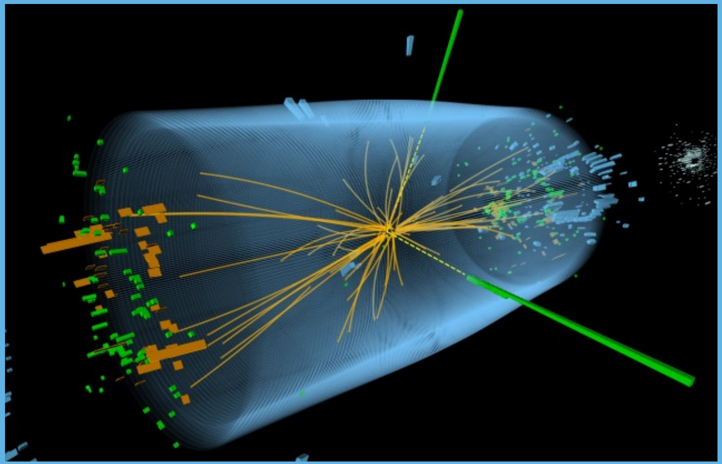
Goal: Decrease the knowledge gap between research and society

Engage Citizens in scientific discovery through **Data Analysis** from **4 Major Physics Domains** Utilizing the **Zooniverse website**

Muon Tomography

Gravitational Waves

High Energy Physics

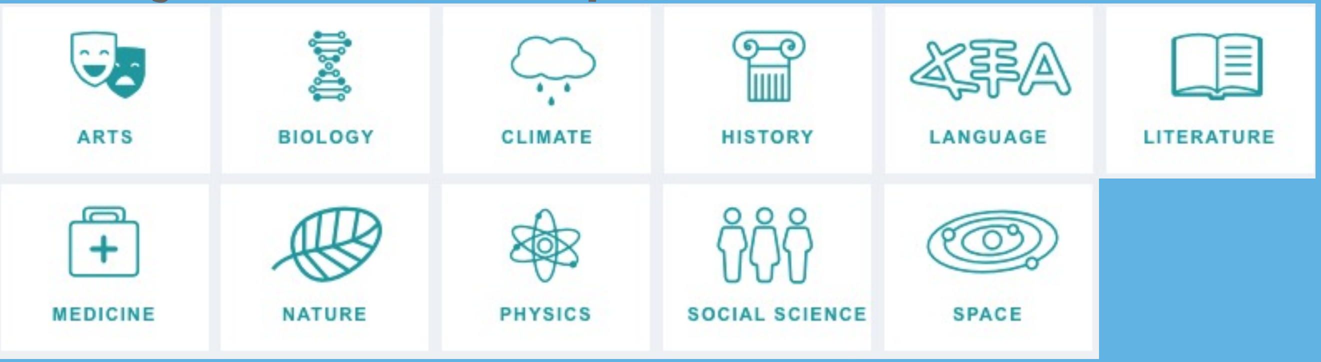


Neutrino Astronomy

What is the Zooniverse?

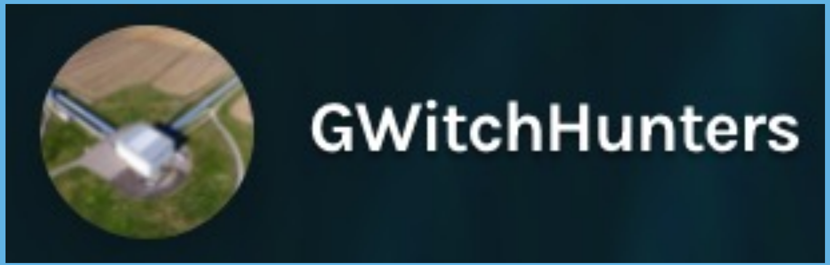
World's largest and most popular platform for people-powered research.

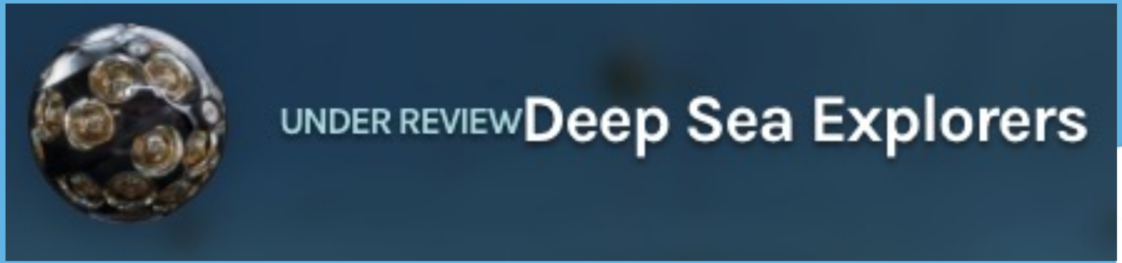
Many Scientific Topics

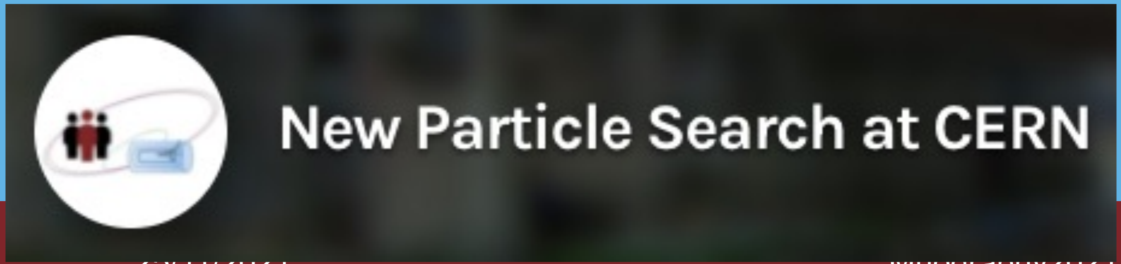


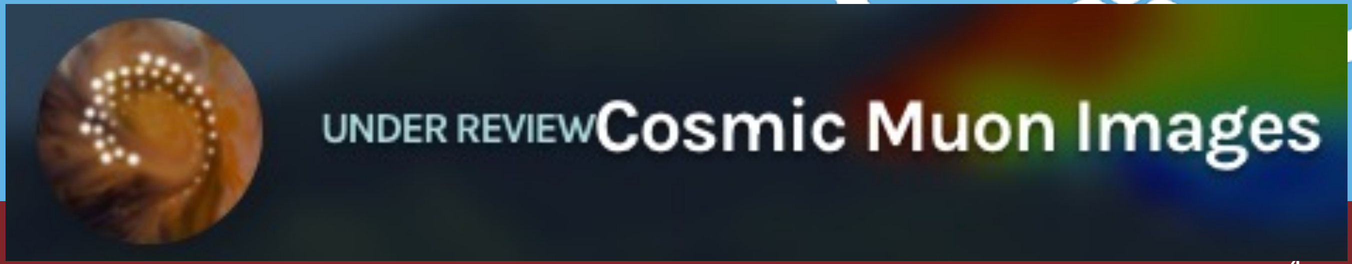
- Researchers upload data to the Site
- Citizens use site tools to Analyze data
- Promotes Citizens & Researchers discussion

Reinforce Zooniverse Demonstrators



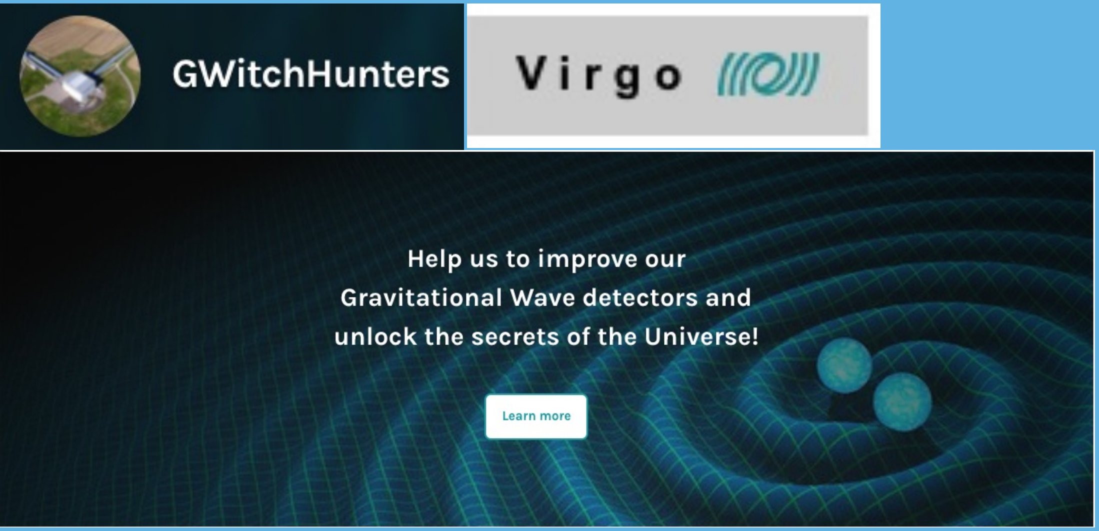


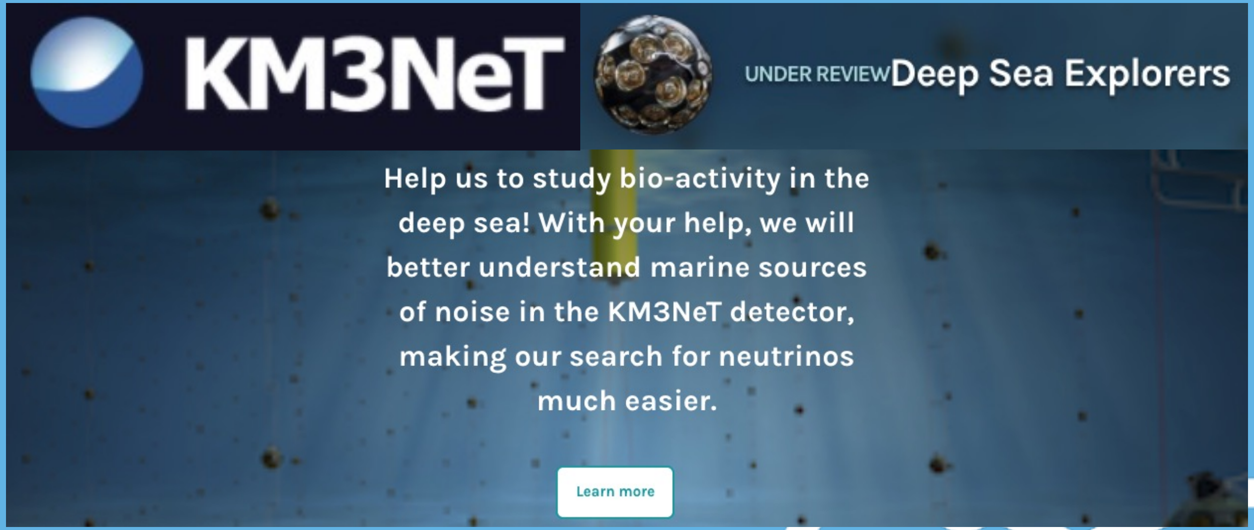


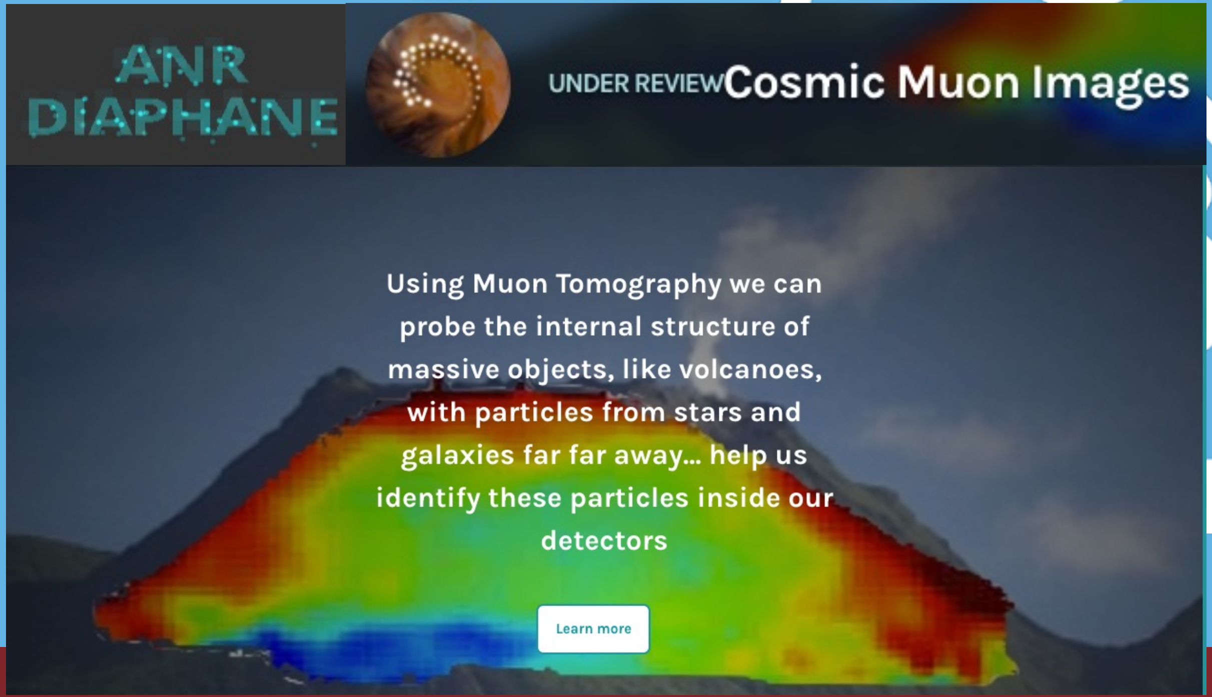


REINFORCE European Research Infrastructures

REsearch INfrastructures FOR Citizens in Europe







Data Sonorisation - SonoUno

Opens a new sensory window for understanding and interpretating data

Software and Online platform
Hear your data on the fly

Huge contribution towards inclusion

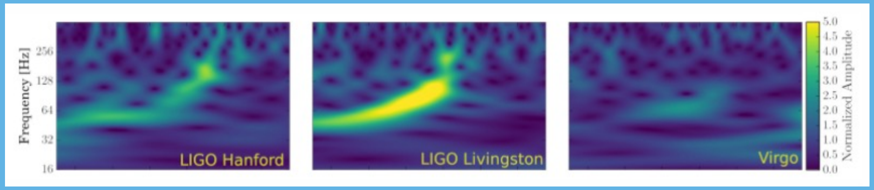
Great Effort towards the sonification of all datasets

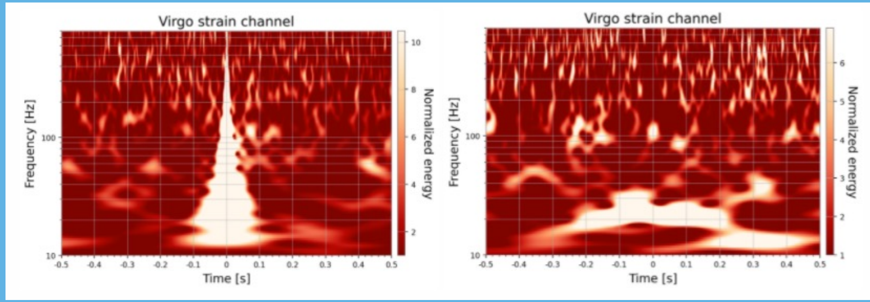
sonoUno is a *User Centered* software that allows people with different sensory styles to explore scientific data, visually and by sonorization,
and make science.

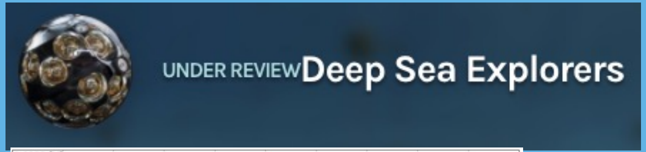
(from sonoUno website)

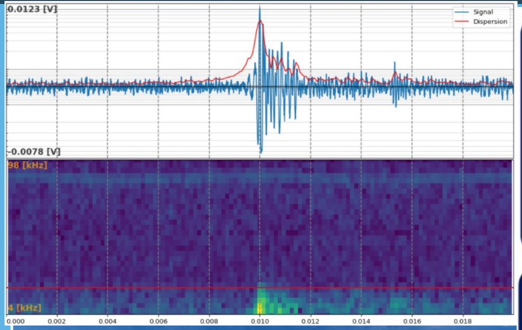
Sonorization shines with timeseries data e.g. Variability in luminescence. Variable Stars, Planets orbiting stars, Solar eclipses etc.

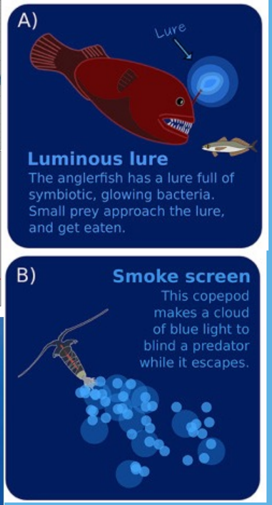
More difficult for Particle Trajectories

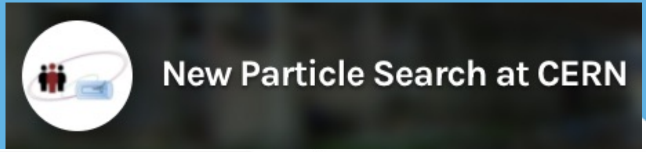


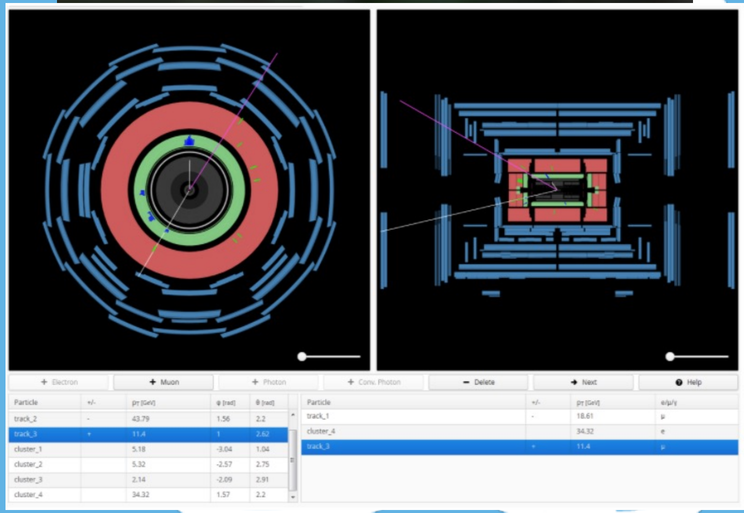








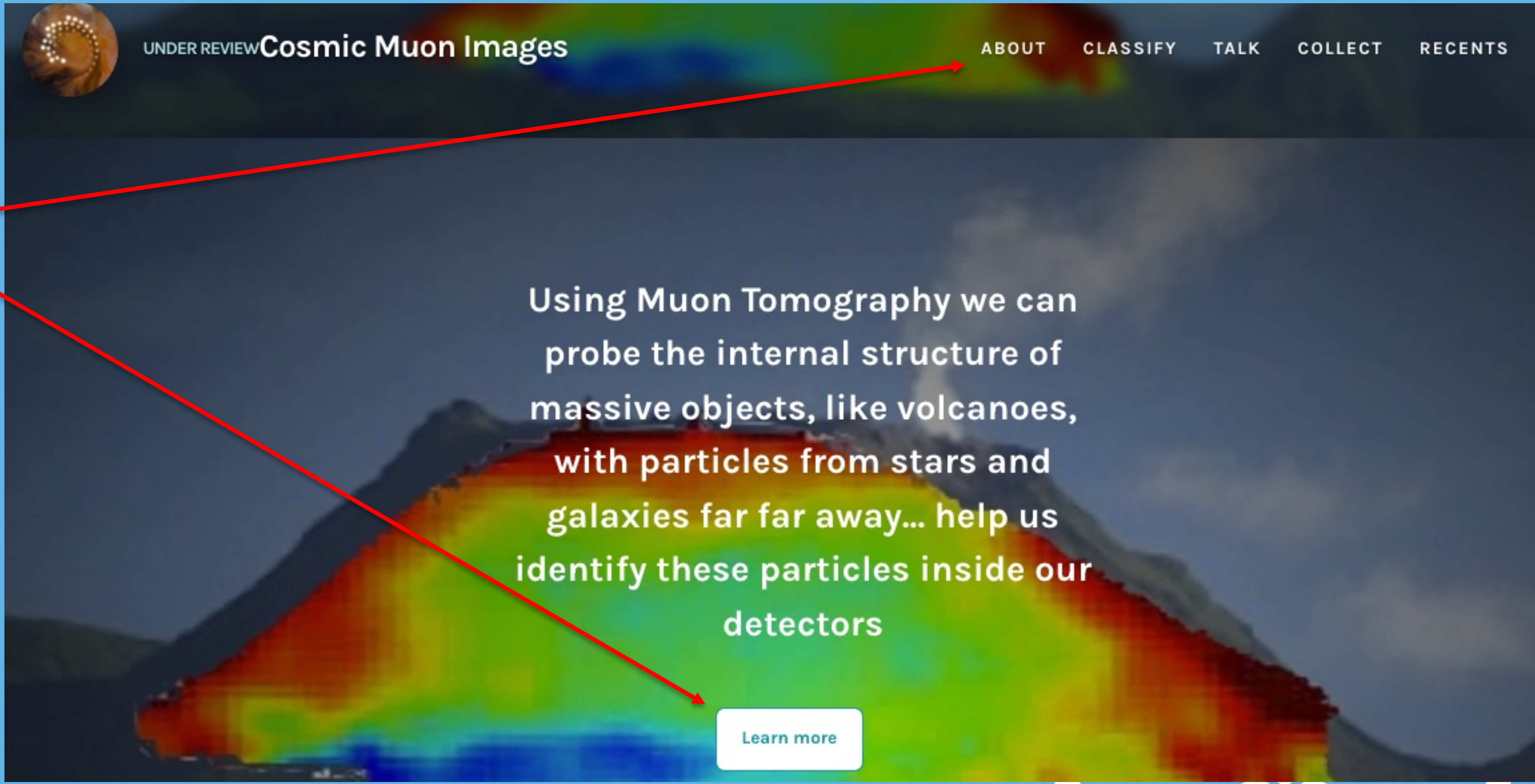




Cosmic Muon Images @ ZOOniverse

Welcome Page Breakdown

Link to the same section

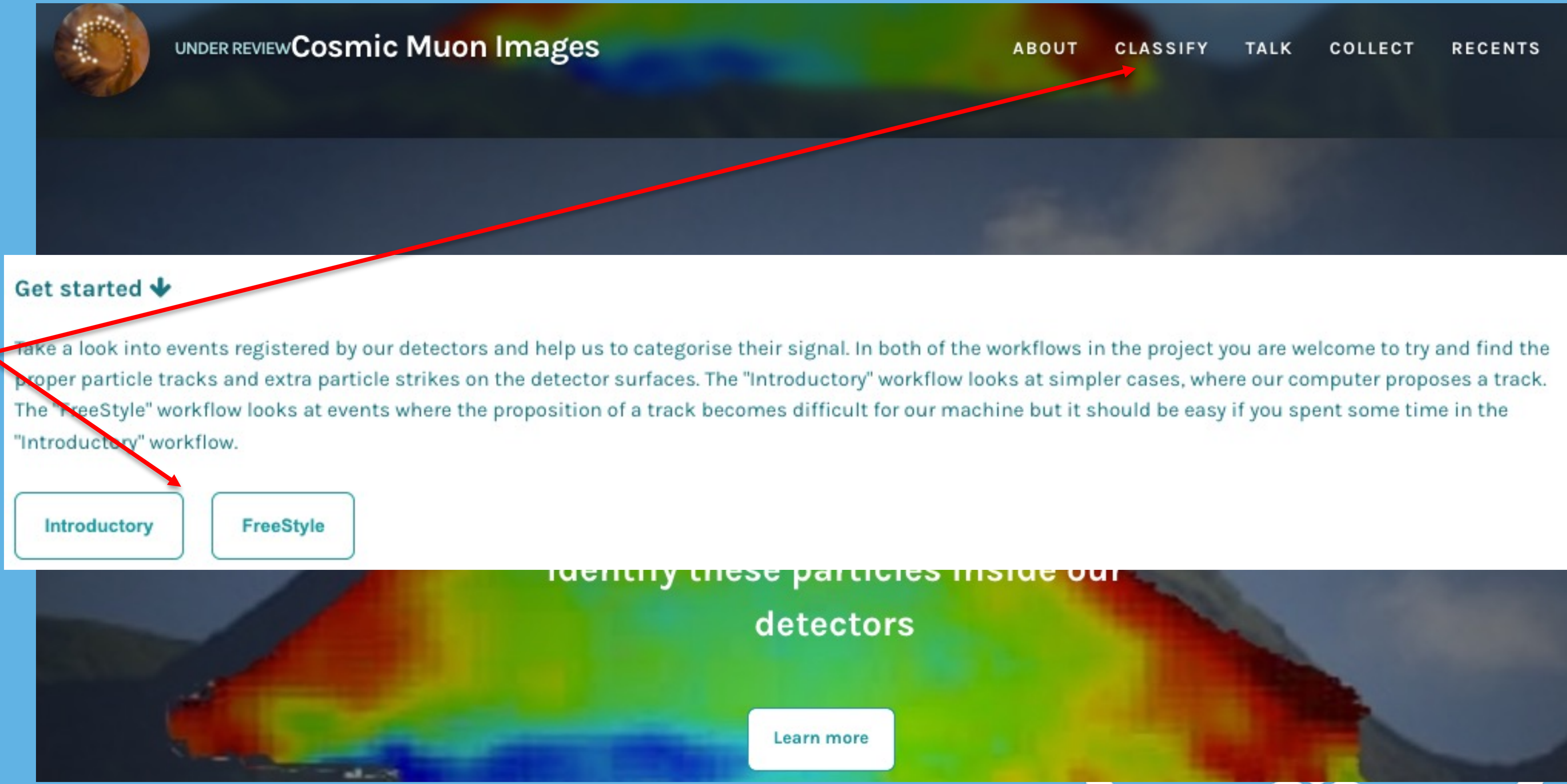


Cosmic Muon Images @ ZOOniverse

Welcome Page Breakdown

Link to the same section

(Scroll down)
Workflow Description



Cosmic Muon Images @ ZOOniverse

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Welcome Page Breakdown

Link to the same section

(Scroll down)
Workflow Description

(Scroll down)
Introduction
Researcher Quote
Related Links

WORDS FROM THE RESEARCHER

"I am very excited about this project because at last we get the chance to investigate our methods in great detail with the help of people from around the world. I look forward to see where this journey will take us."

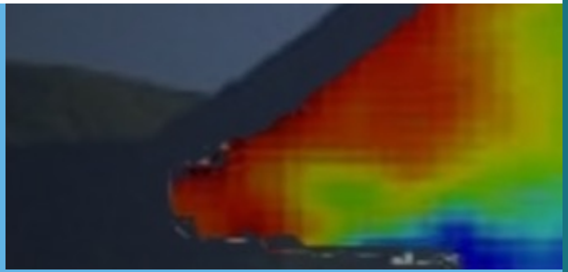
ABOUT COSMIC MUON IMAGES

We are a team of young researchers from different walks of science. We place muon detectors all around the globe and we study the inner structure of massive objects from **volcanoes** to ancient **tombs** and from underground **tunnels** to **blast furnaces**.

Jacques is in charge of the group activities being the most experienced researcher he takes care of the design and the calibration of our detectors, and plans the future missions of the team. **Marina** and **Antoine** perform analyses using muon tomography data creating crisp and beautiful images of Volcanoes and underground tunnels. Where the untrained eye only sees density differences, they see magma highways, underground networks of water pathways and dangerous ground instabilities that are about to catastrophically collapse. **Amelie** and **Matias** study the impact of the earth's environment on the amount of muons our detectors receive, without their work our method wouldn't be that accurate. **Theodore** develops simulations of our detectors and tries to identify the various background sources in our data.

EXTERNAL PROJECT LINKS

- REINFORCE
- Cosmic Muons Images
- Diaphane
- Arche
- Institute des 2 Infinis Lyon
- Webinar
- https://twitter.com/reinforceeu



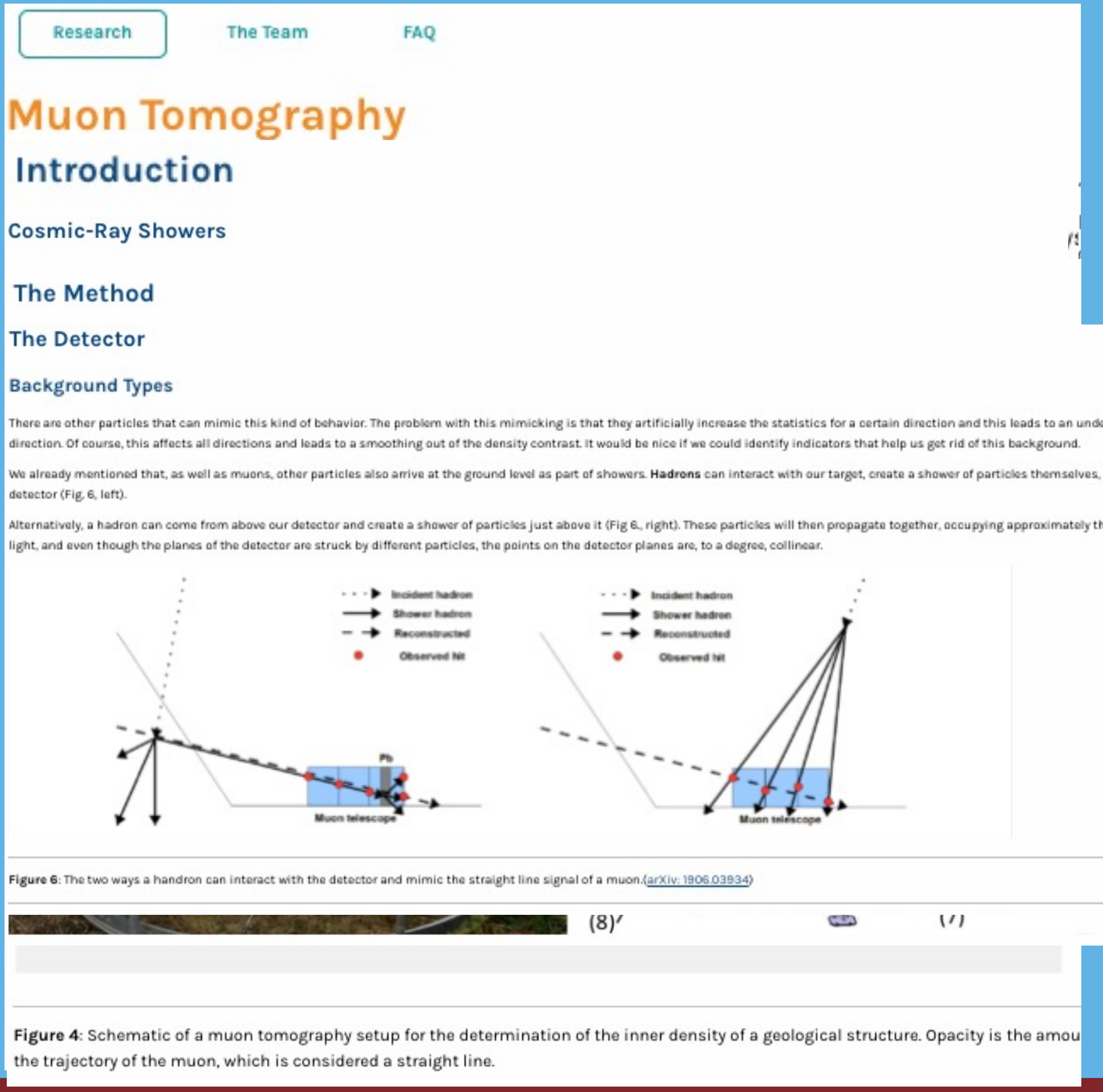
Cosmic Muon Images @ ZOOniverse

About Page Breakdown

Three Sections:
1) Research
2) The Team
3) FAQ

- a) La Soufriere example
- b) X-ray Analogy
- c) EAS
- d) Measurement Principle
- e) Detector Description
- f) Signal vs Background

Goal: Identify patterns from particles inside our detector.



Cosmic Muon Images @ ZOOniverse

About Page Breakdown

Three Sections:
1) Research
2) The Team
3) FAQ

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About Page Breakdown

Three Sections:
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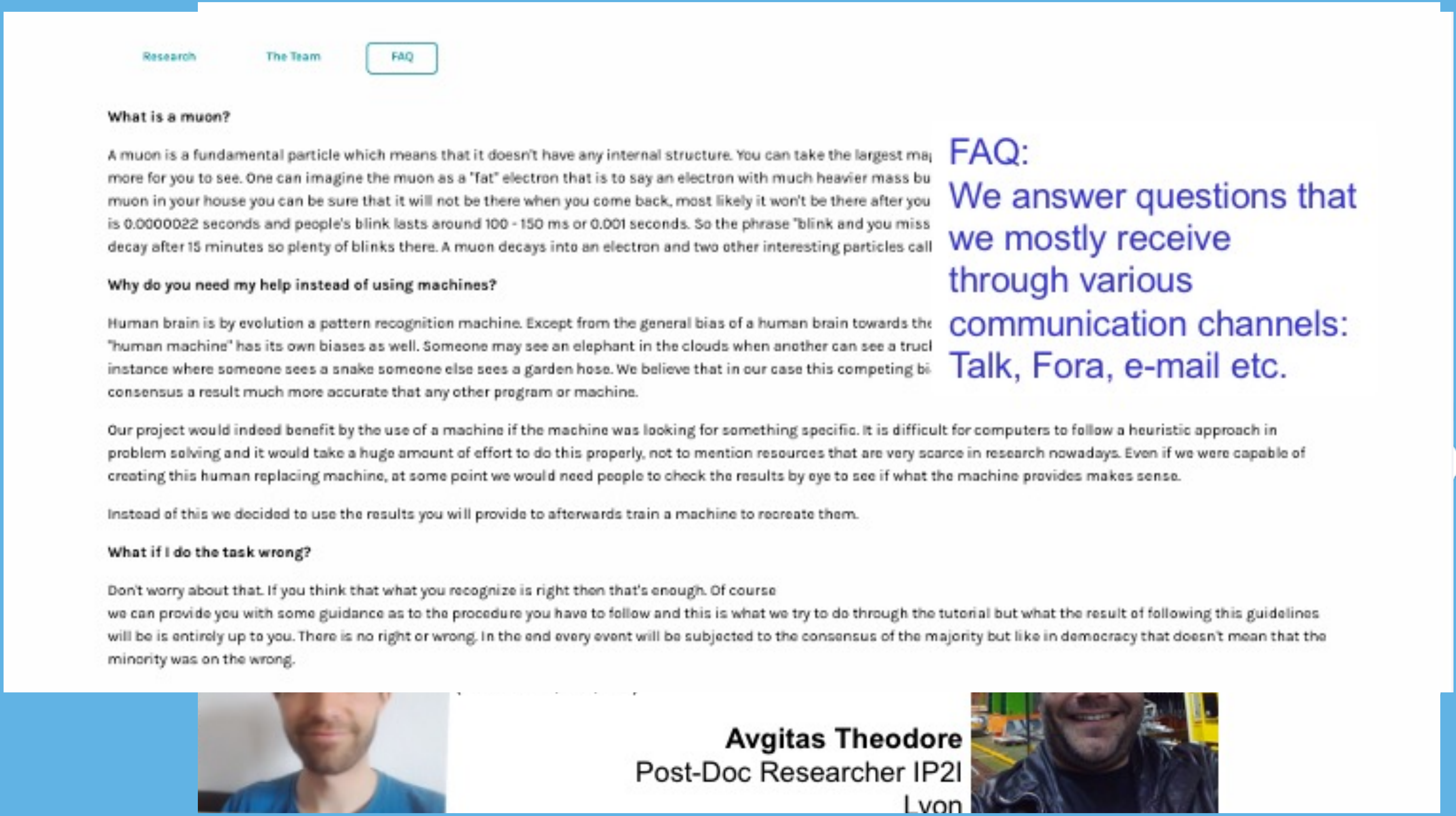
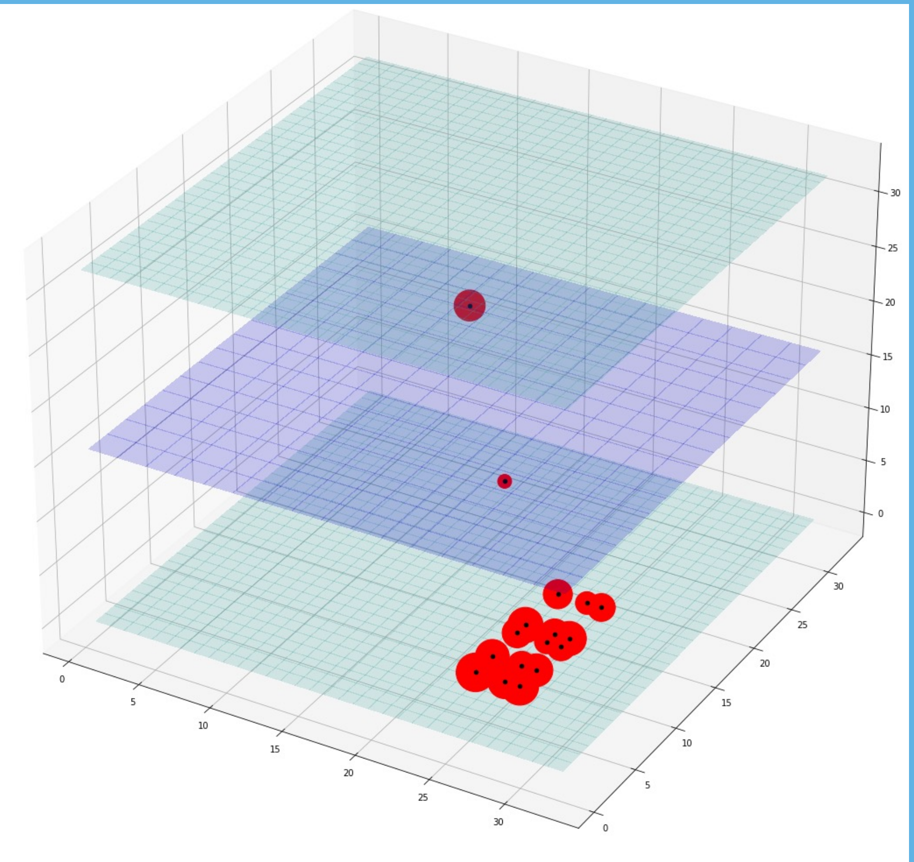
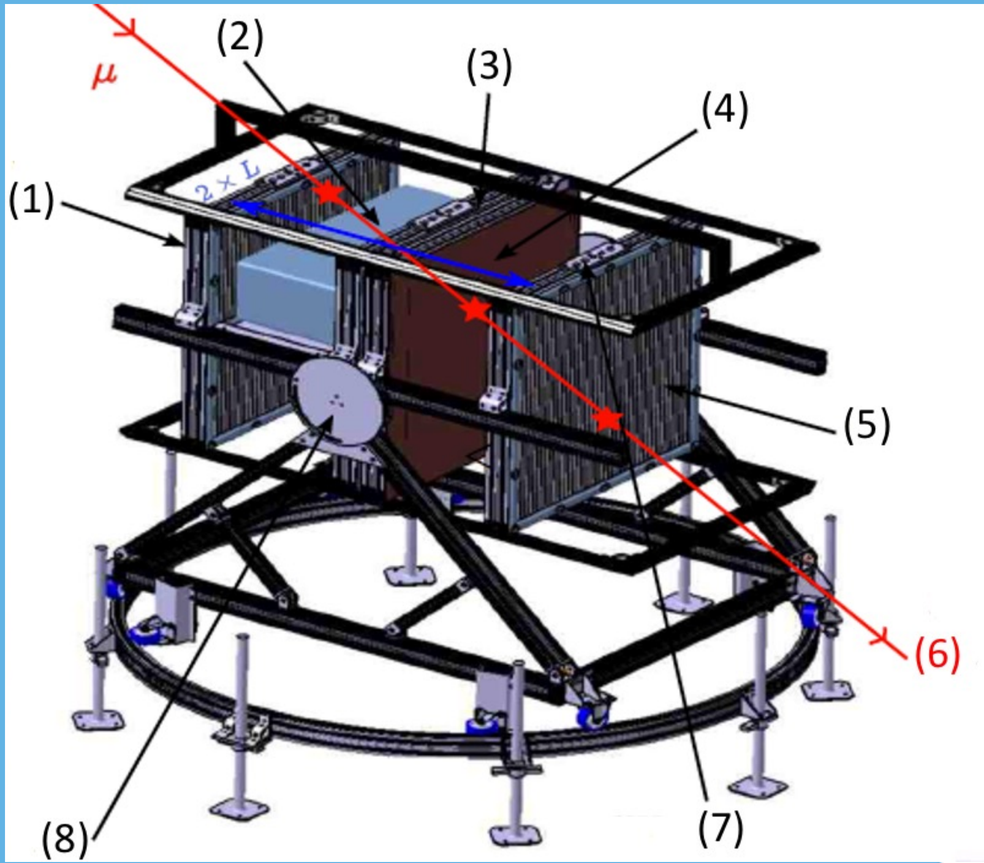


FAQ:
We answer questions that we mostly receive through various communication channels: Talk, Fora, e-mail etc.

The Detector

Muons Travel in straight lines → A detector that can reconstruct straight lines





1-Front matrix
2-Control-box
3-Central matrix
4-Shielding (steel + lead)
5-Back matrix
6-Muon trajectory
7-matrix connections
8- mount swing

Cosmic Muon Images Workflows

Workflow: A series of predetermined steps to guide the citizen scientist through his/her assignment.

Goal: The identification of patterns using a series of straight lines and points on our detector visualization plots.

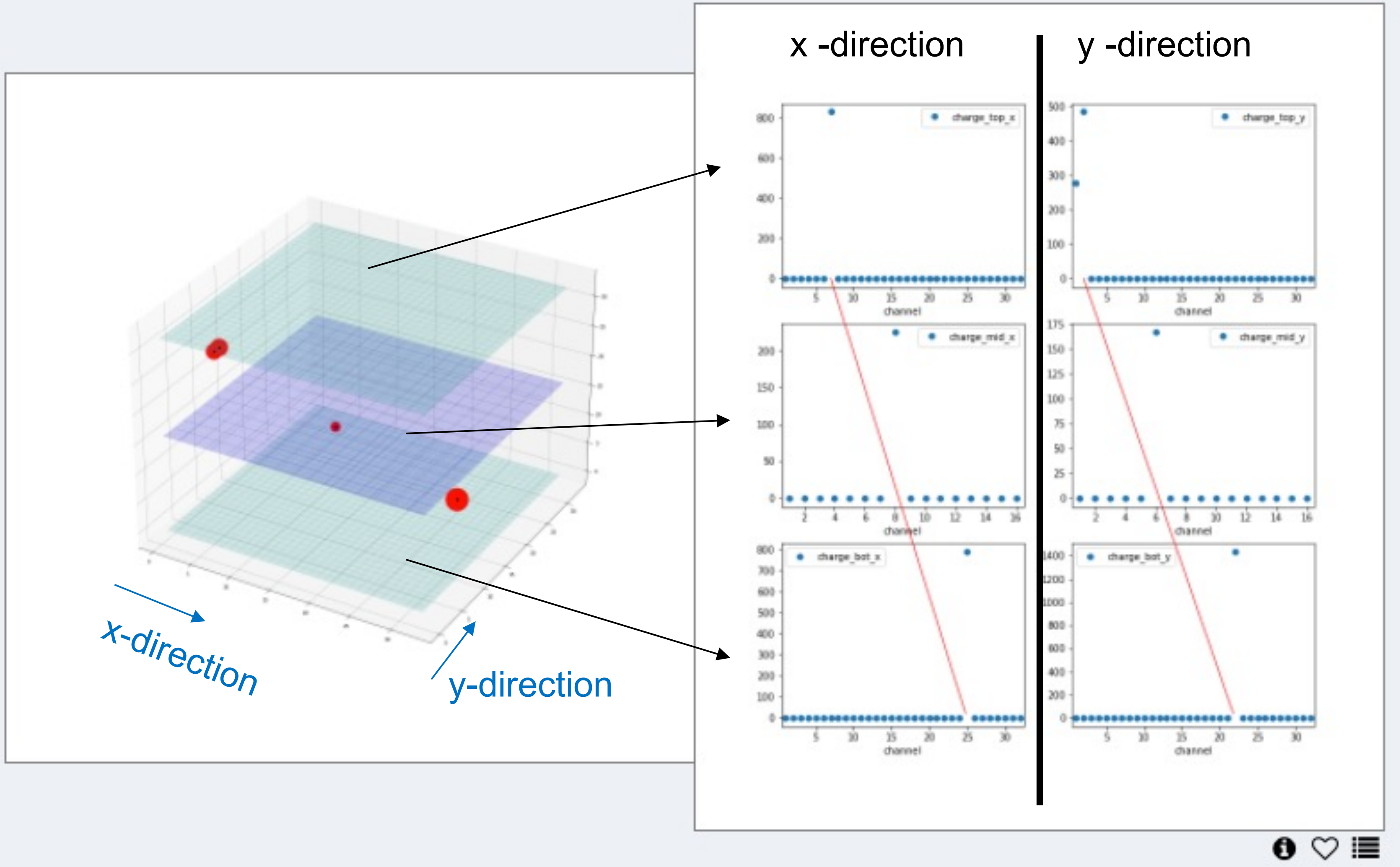
2 Workflows: Introductory, FreeStyle (advance)

Get started ↓

Take a look into events registered by our detectors and help us to categorise their signal. In both of the workflows in the project you are welcome to try and find the proper particle tracks and extra particle strikes on the detector surfaces. The "Introductory" workflow looks at simpler cases, where our computer proposes a track. The "FreeStyle" workflow looks at events where the proposition of a track becomes difficult for our machine but it should be easy if you spent some time in the "Introductory" workflow.

Introductory | FreeStyle

REINFORCE The Workflows



The Detector monitors two directions on its 3 planes.

A 3d line is projected (analyzed) on two planes xz–plane & yz-plane

3D plot on left just for visualization purposes.

All work gets done on the right plot.

What work?

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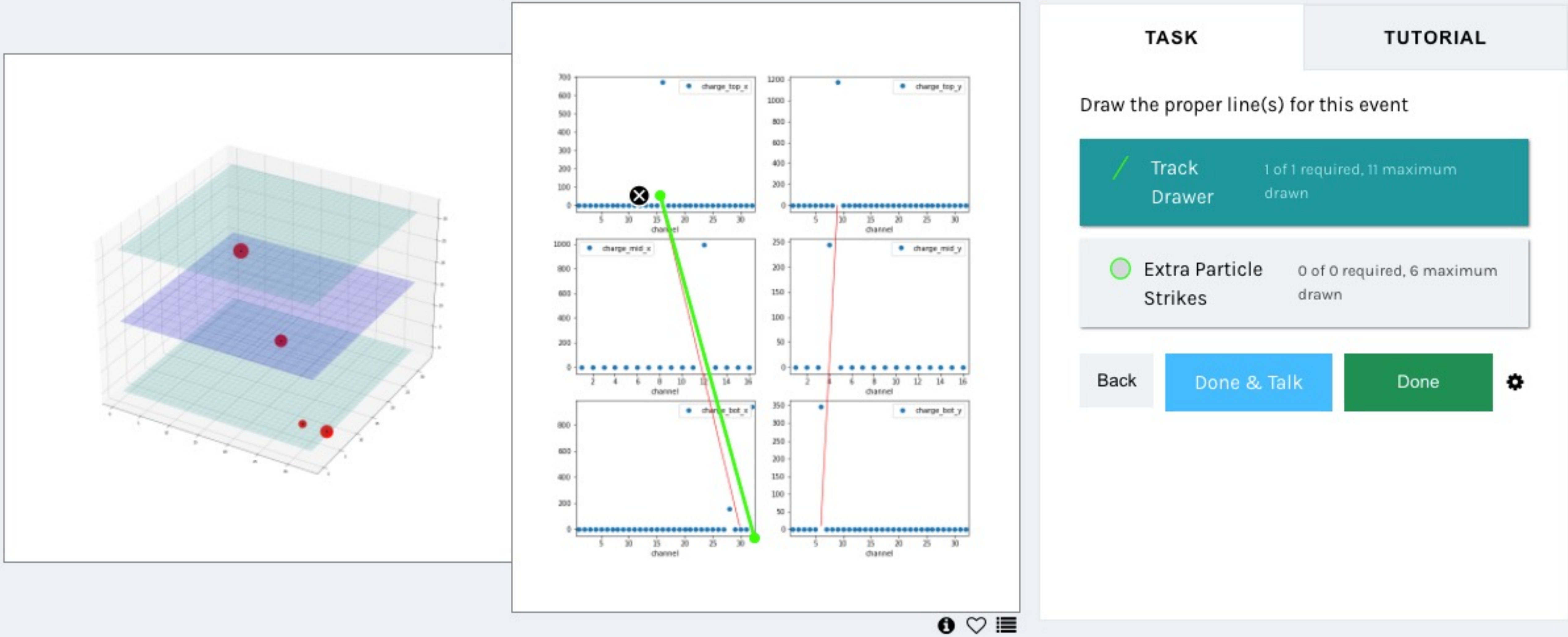
Introductory Workflow Examples

Example 1



REINFORCE Introductory Workflow Examples

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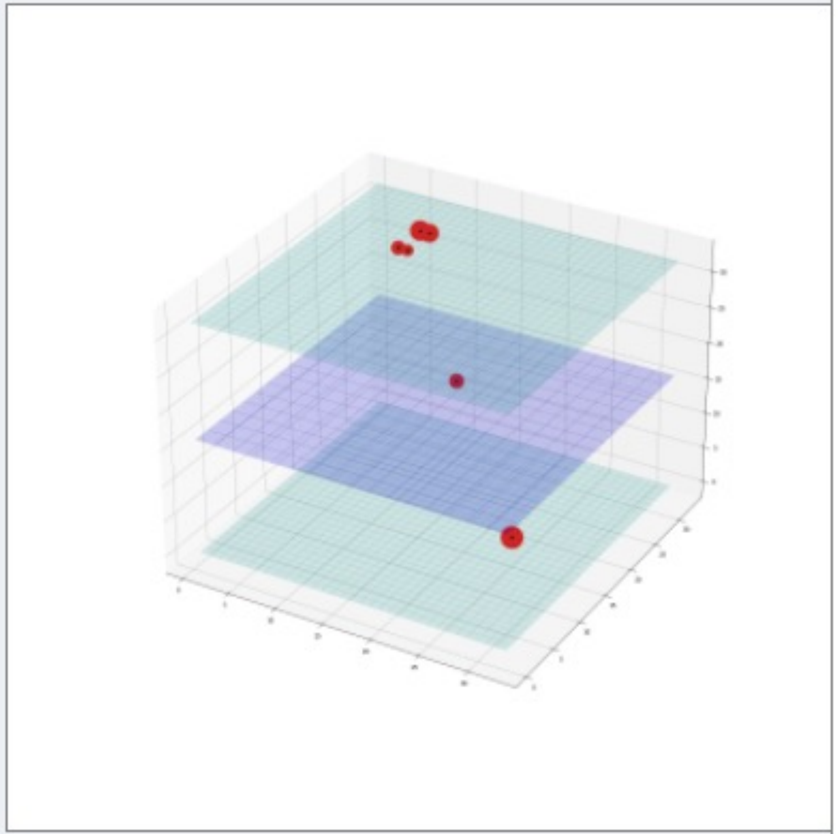
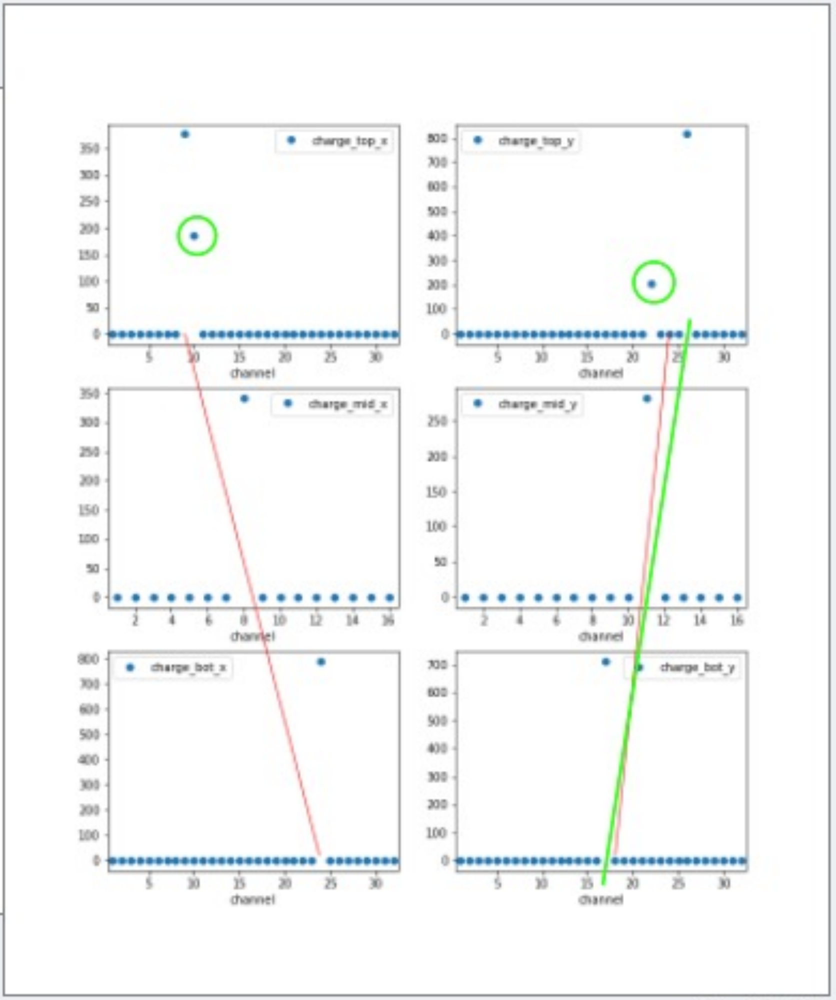
Example 2





TASK | **TUTORIAL**

Draw the proper line(s) for this event

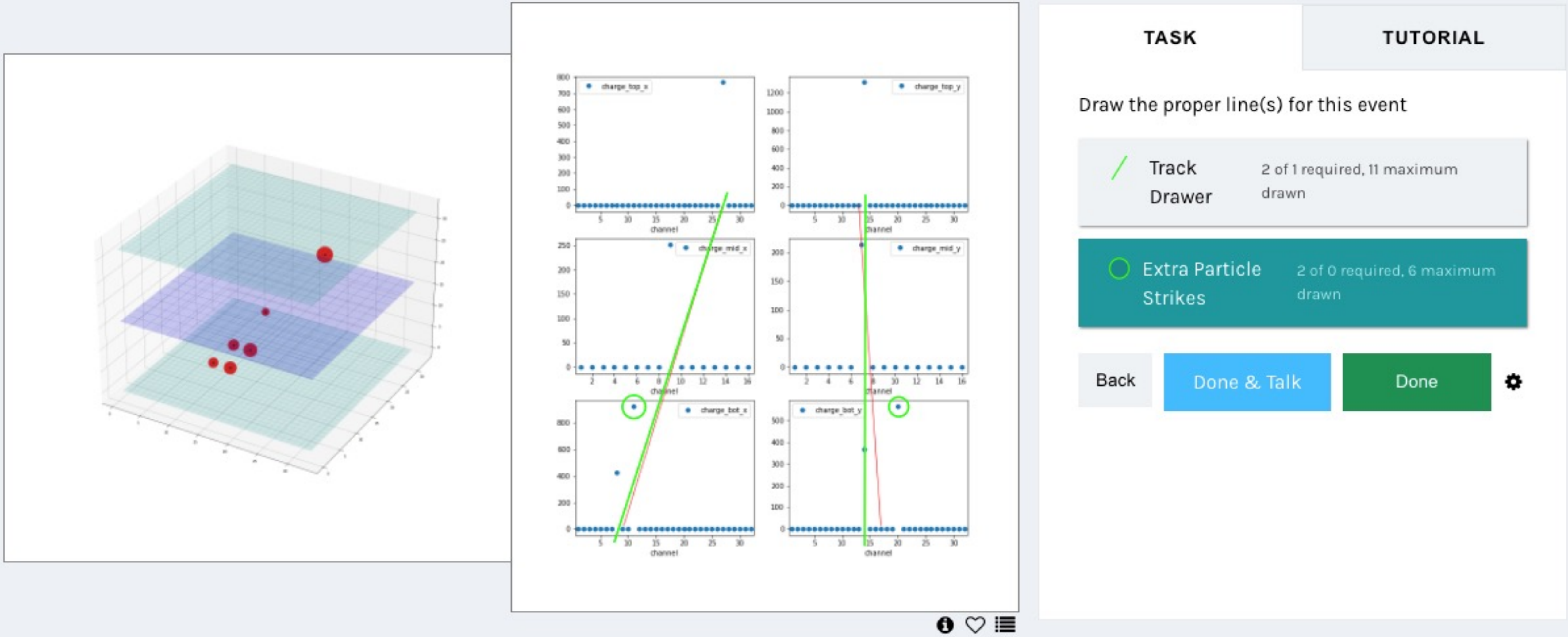
Track Drawer — 1 of 1 required, 11 maximum drawn

Extra Particle Strikes — 2 of 0 required, 6 maximum drawn

Back | Done & Talk | Done

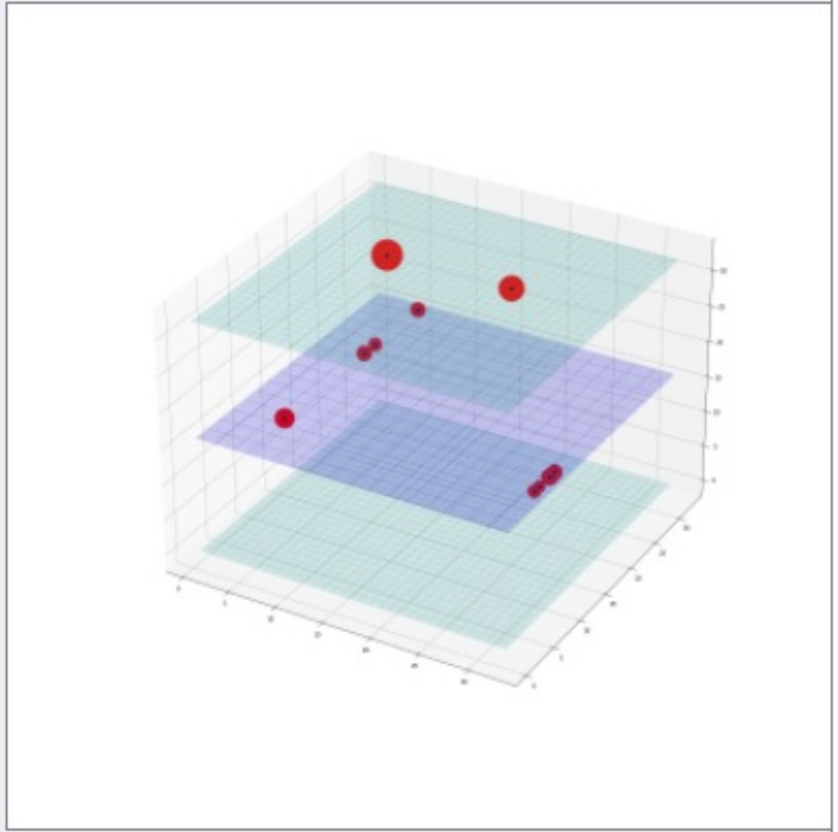
Introductory Workflow Examples

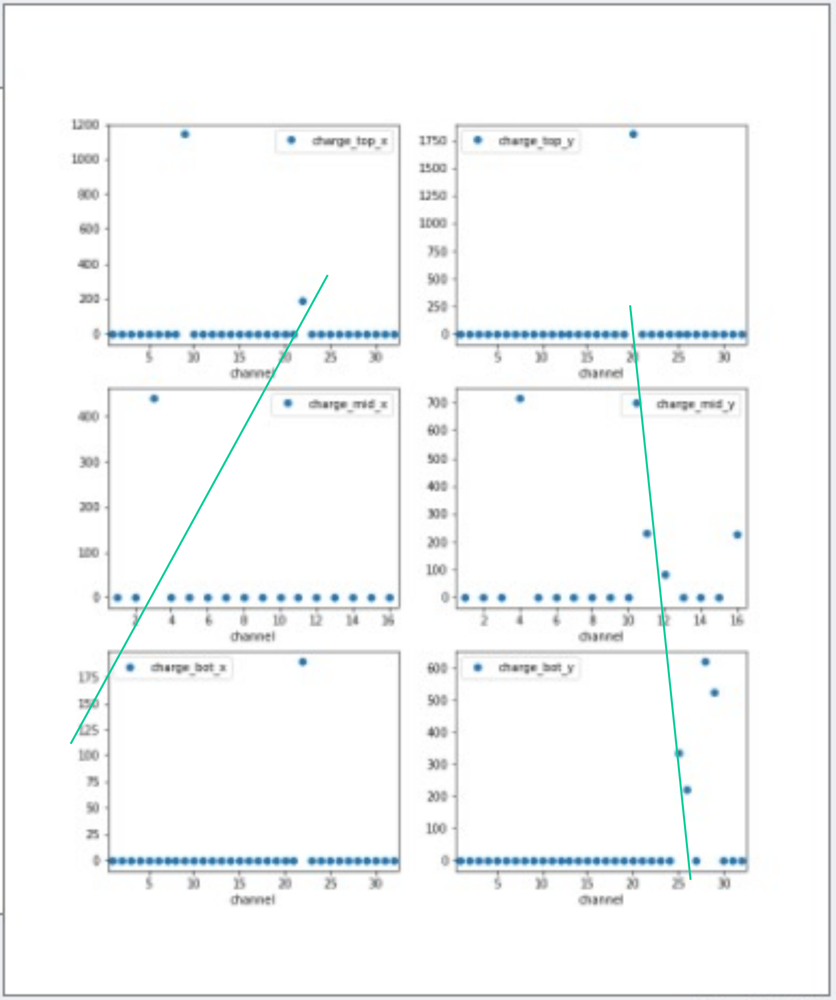
Example 3



Advanced Workflow Examples

Example 1





TASK

TUTORIAL

Is there a pattern?

- yes i can see a pattern (line, points or both)
- no track and nothing remarkable

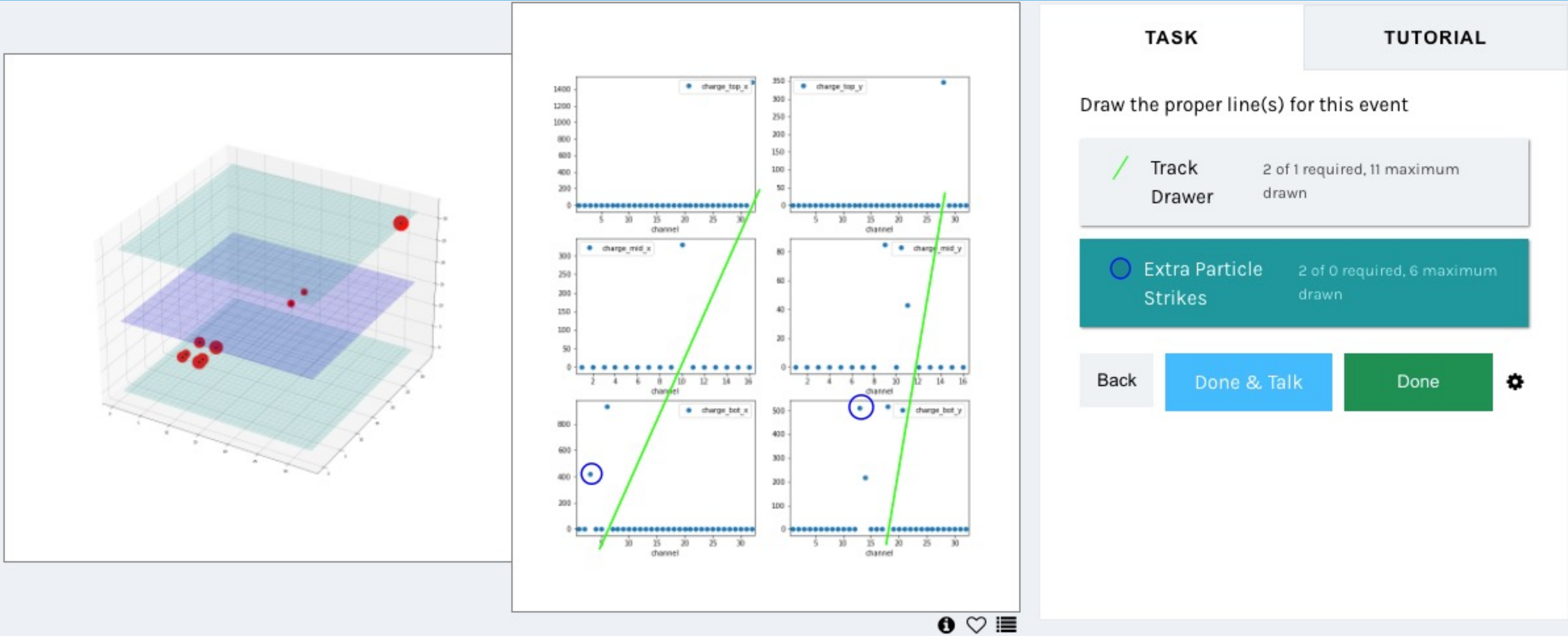
Done & Talk

Done

Proposal: no wrong answers

Advanced Workflow Examples

Example 2



We ’ve made the classifications… Now what?

1) Train Neural Network to retrieve the results (lines vs no lines)
2) Compare its performance to current event selection algorithms
3) Use it for complicated events that current algorithms don’t analyze

a) Catalog patterns: 1 line + 1 extra hit, 1 line + 2 extra hits, 2 lines + …, etc.
b) Neural Network training
c) Theory + Simulation to explain them based on frequency
d) Guided Study of detector response to Air Showers

Beyond ZOOniverse: Organize Virtual visits to Lab
Discuss Detector Calibration techniques
Open to feedback and implementation of new ideas
The entire dataset available -> Tryout your own reconstruction algorithms.

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Summary

Muon tomography has many practical applications

Citizen Scientists can help us understand better our detectors

Important work that can help improve our techniques, analysis and design better detectors.

More resources at https://www.reinforceeu.eu/
and
at our Cosmic Muon Images WEBINAR

Come and Play with our Cosmic Muon Images Zooniverse project at
https://www.zooniverse.org/projects/reinforce/cosmic-muon-images

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Thank you for your attention

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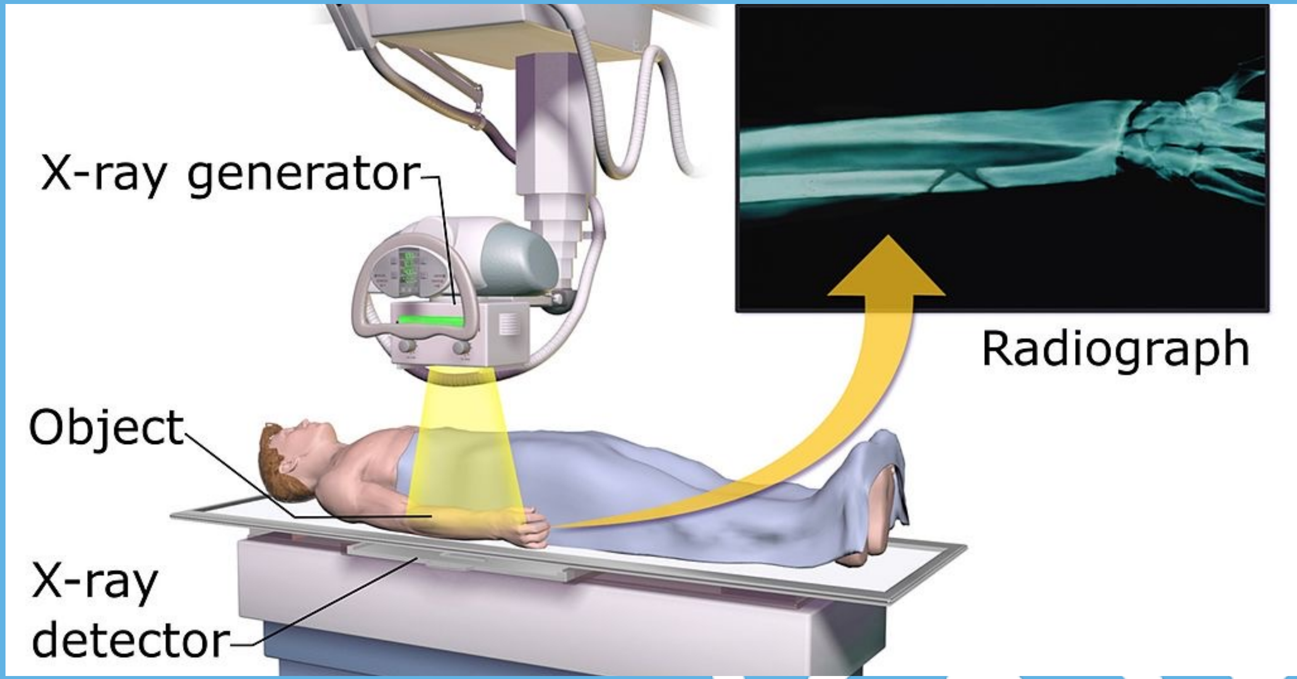
Backup Slides

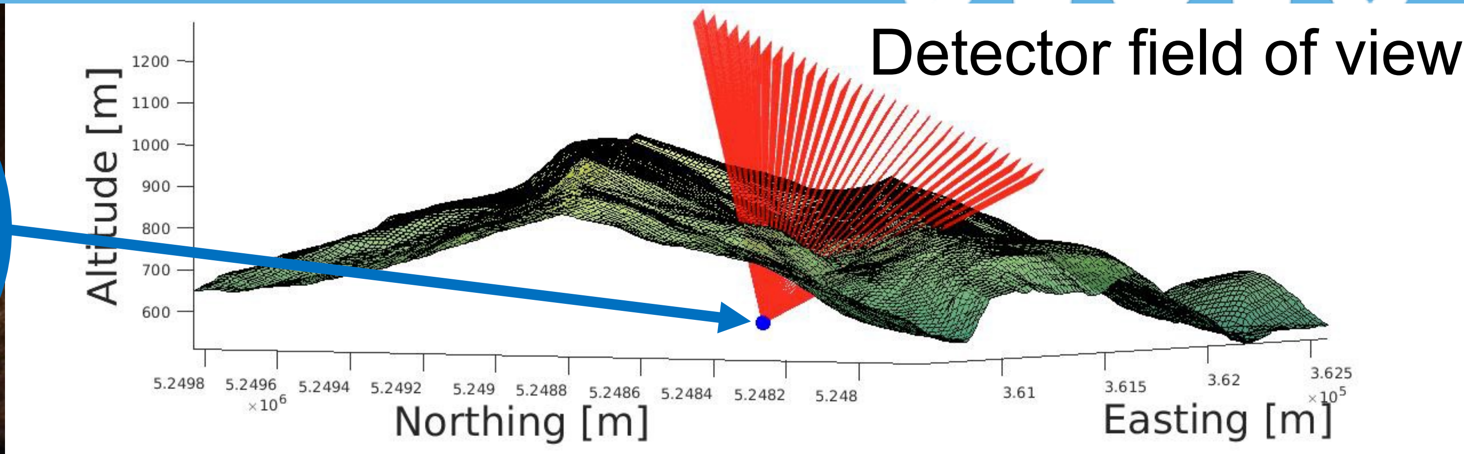
What is Muon Tomography?

Like X-rays scans but for large objects

Purpose: Study the matter density distribution of Massive Objects



Muon Detector placed underground to study the overburden density



Why is it Important?

1. Simple
2. Cost Effective
3. Safe

Geosciences

- Volcanology
- Geology
- Hydrology
- Atmosphere physics
- CR physics
- ...

Archaelogy

- Pyramids
- Tumulus
- Anthropic structures
- Ruins
- ...

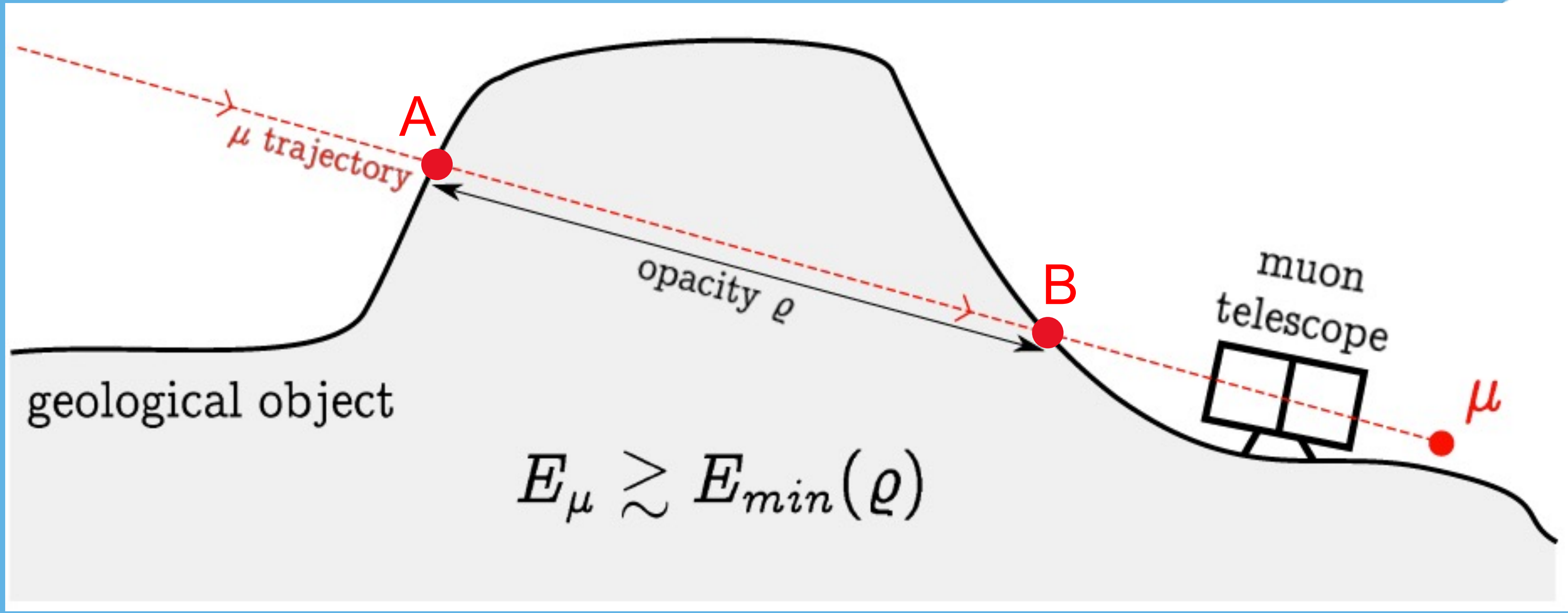
Industrial controls

- Non invasive controls
- Nuclear cycle production
- Civil engineering
- Tunnel boring machines
- Prospection & mining
- ...

How Does it Work?

1. **Measure angular muon flux downstream** of an object.
2. **Compare** with the **expected** angular muon flux **without** the object. (Open Sky)
3. **(**steps 1+2) -> provide the **opacity** of the object

   Opacity: how much **matter** lies in a **certain path**
4. **Topographic map** to calculate **distance** on muon path (A->B)



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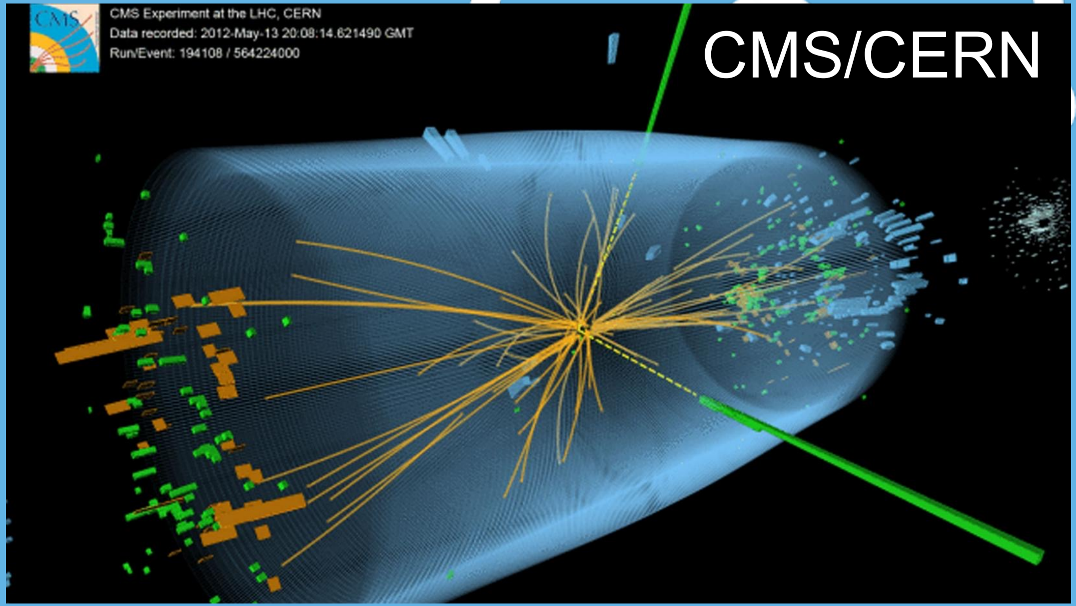
Why does it work?

Primary Reason: Existence of a constant muon Flux. (A present by mother Nature herself)

Second Reason: Our Good Understanding of Particle Physics

100 years of Cosmic Ray Studies
Many ongoing experiments

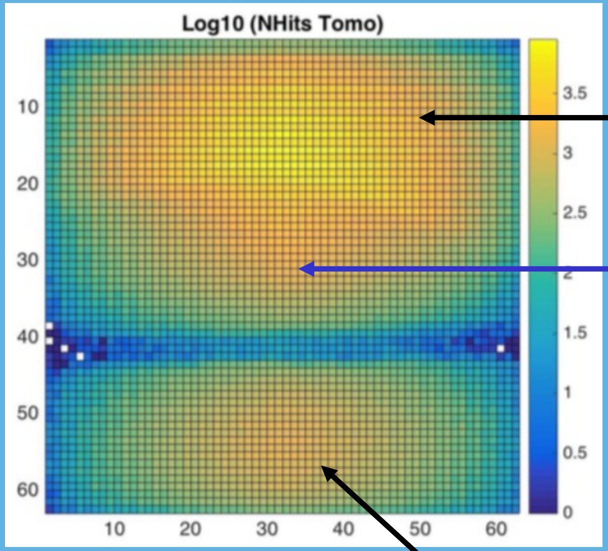
70 years of accelerator physics



Muon Tomography Example

1. **Measure Angular muon flux**.

1.

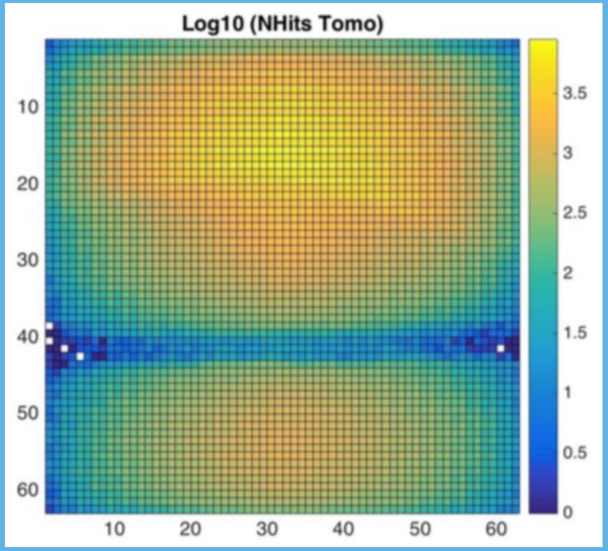


Muons coming from behind

Muon Tomography Example

1. **Measure Angular muon flux.**
2. **Measure Open Sky muon flux.**

1.



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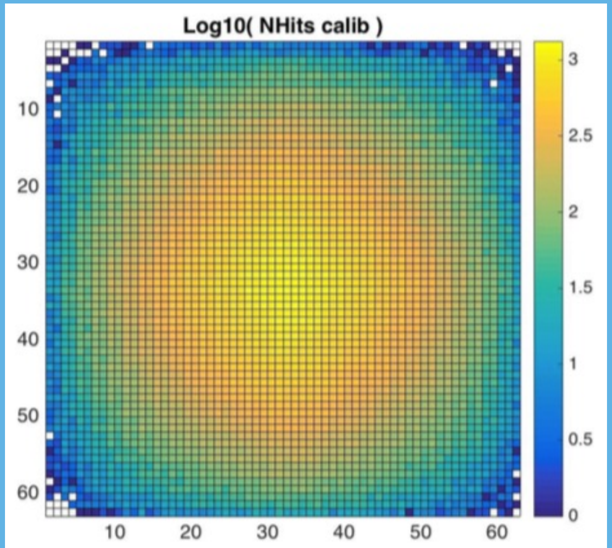
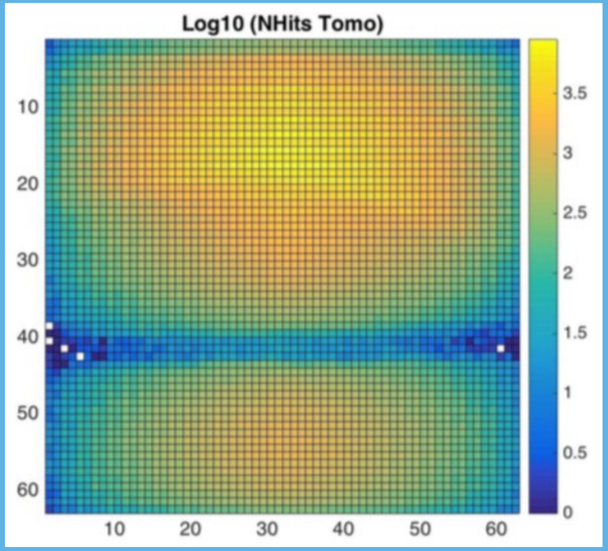


Muon Tomography Example

1. Measure Angular muon flux.
2. Measure Open Sky muon flux.
3. Measured vs Expected -> OPACITY

1.



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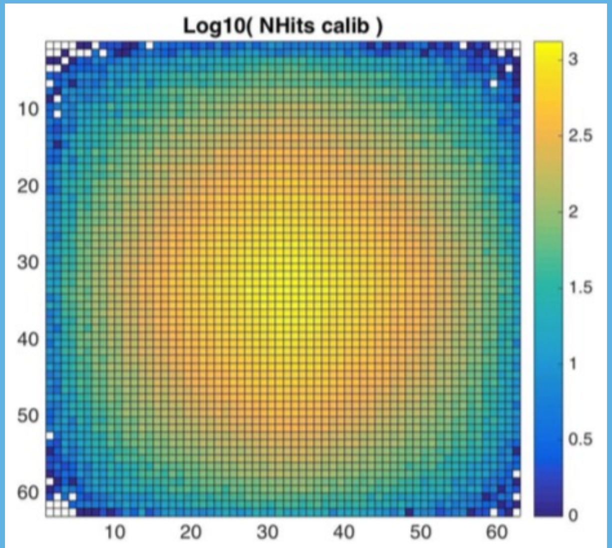

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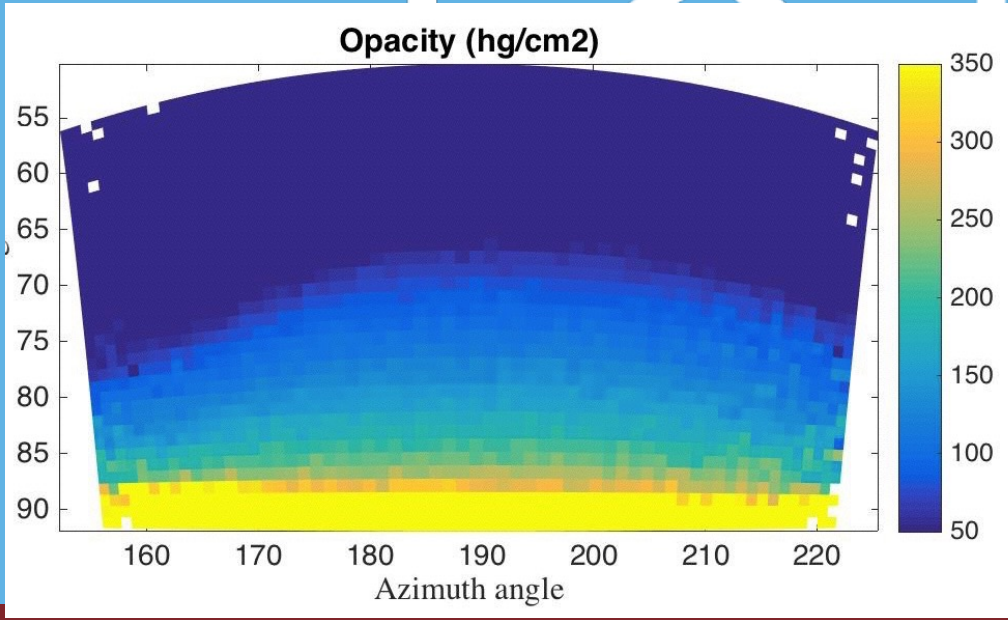

Amount of matter crossed by muons

REINFORCE Muon Tomography Example

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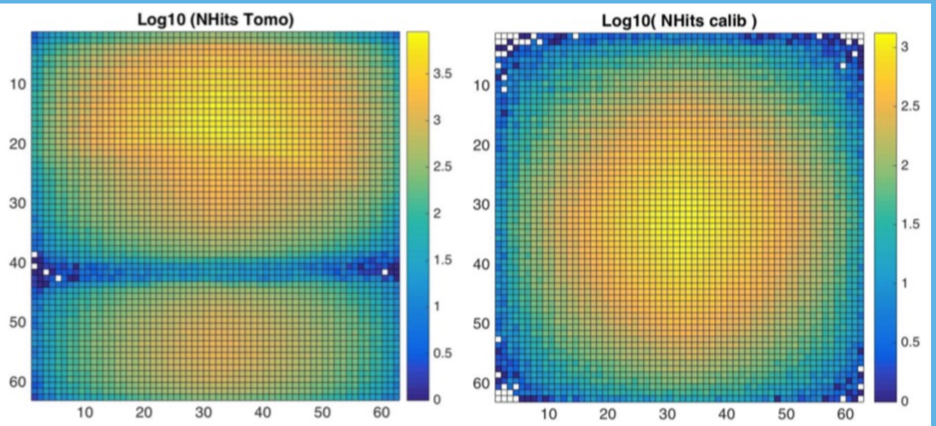
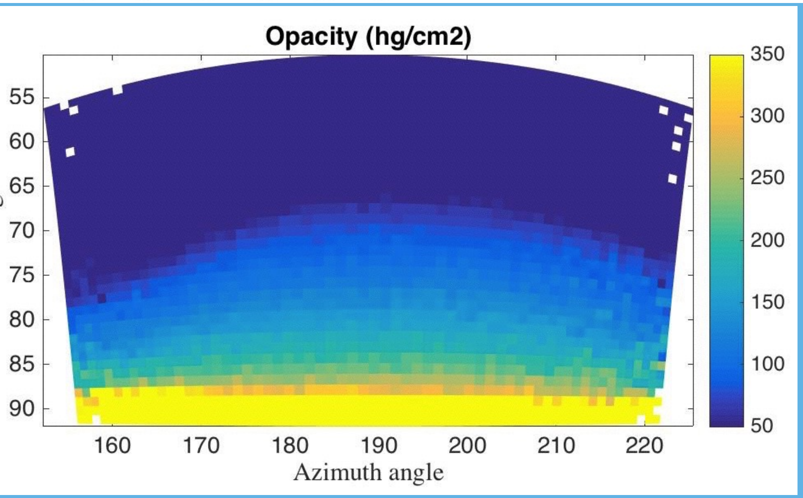
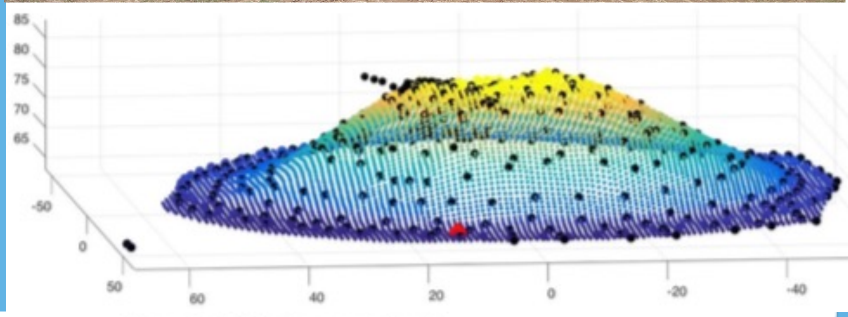
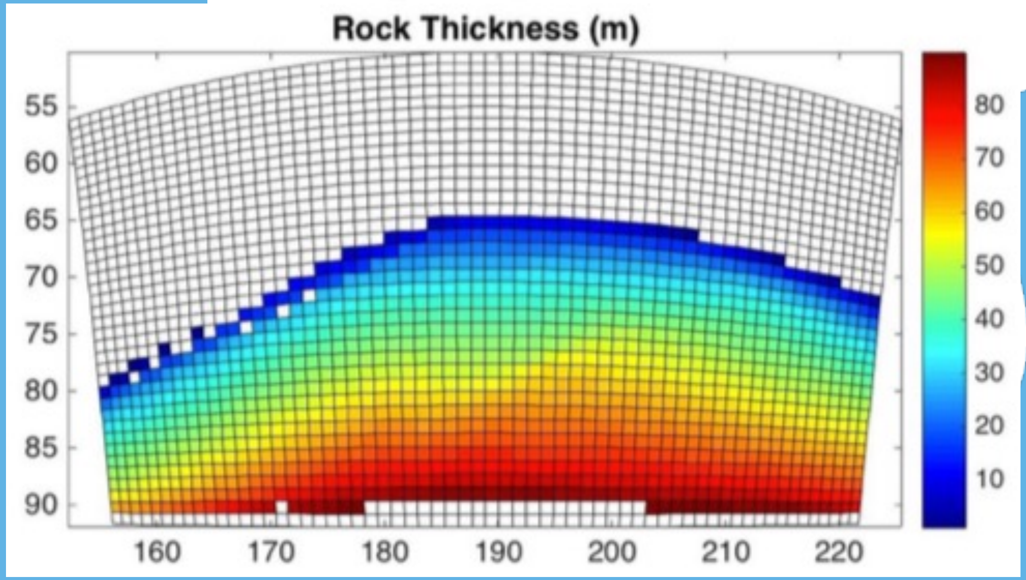
1. **Measure Angular muon flux.**
2. **Measure Open Sky muon flux.**
3. **Measured vs Expected -> OPACITY**
4. **Known muon path distance**







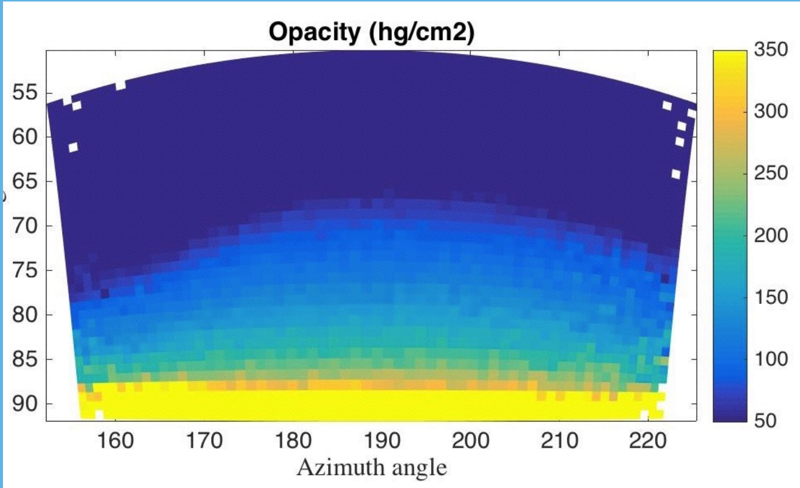
4.

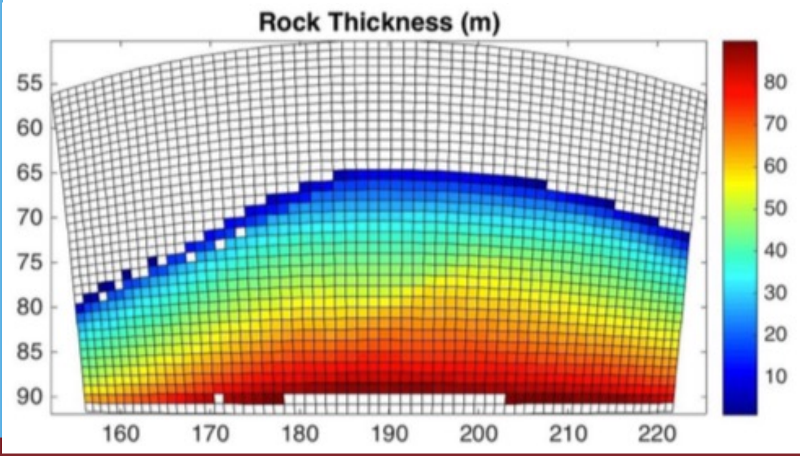


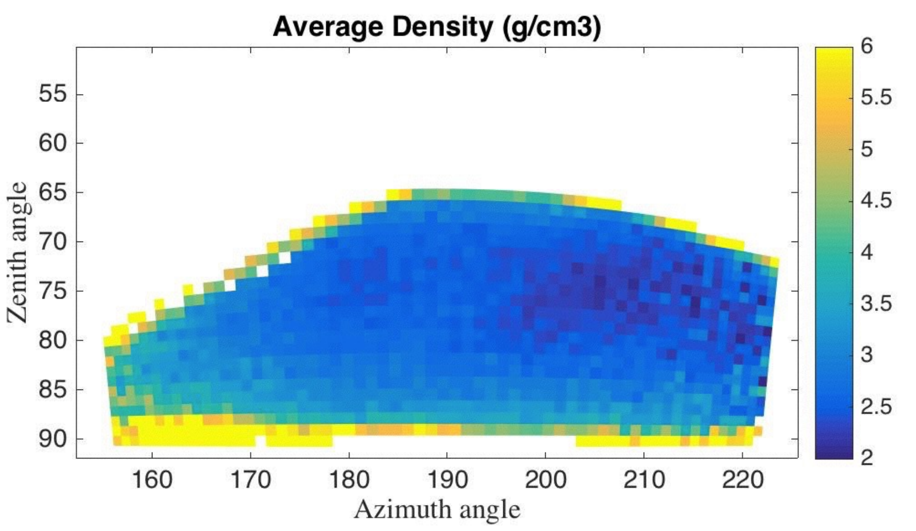
Muon Tomography Example

1. Measure Angular muon flux.
2. Measure Open Sky muon flux.
3. Measured vs Expected -> OPACITY
4. Known muon path distance

→ **Object Density Profile**

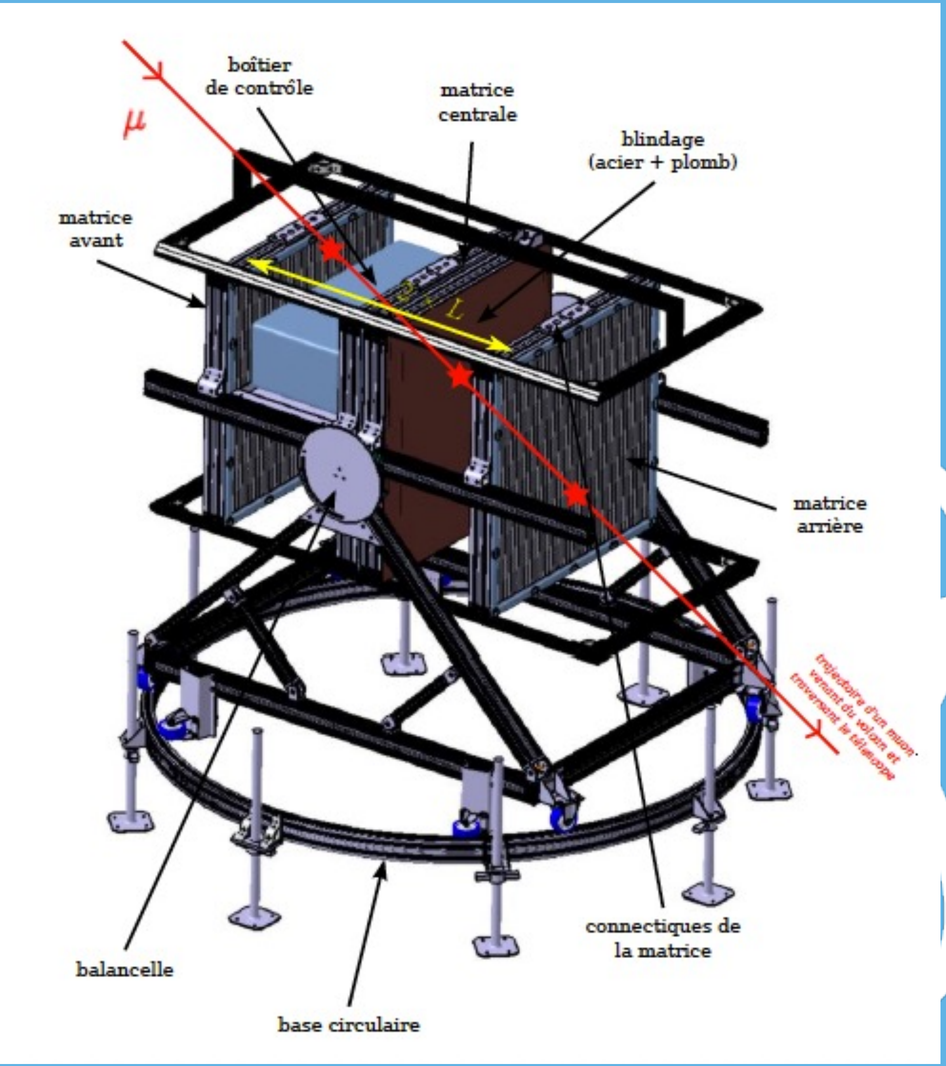






Diaphane Detector

- ✓ Diaphane Muon Telescope
  - 3 Detection Planes
  - x-y orientation strips -> x-y detection matrix
  - time coincidences (Coinc window 200ns)
- ✓ Data output
  - (x, y, t) for every plane
  - Charge
- ✓ Signal - Muons
  - 3 consecutive hits
  - Selection criterion -> Colinearity (or How well can a line be fitted through them)
- ✓ Background
  - Muon Bundles
  - Electrons
  - Particle cascades
  - Random Triggers



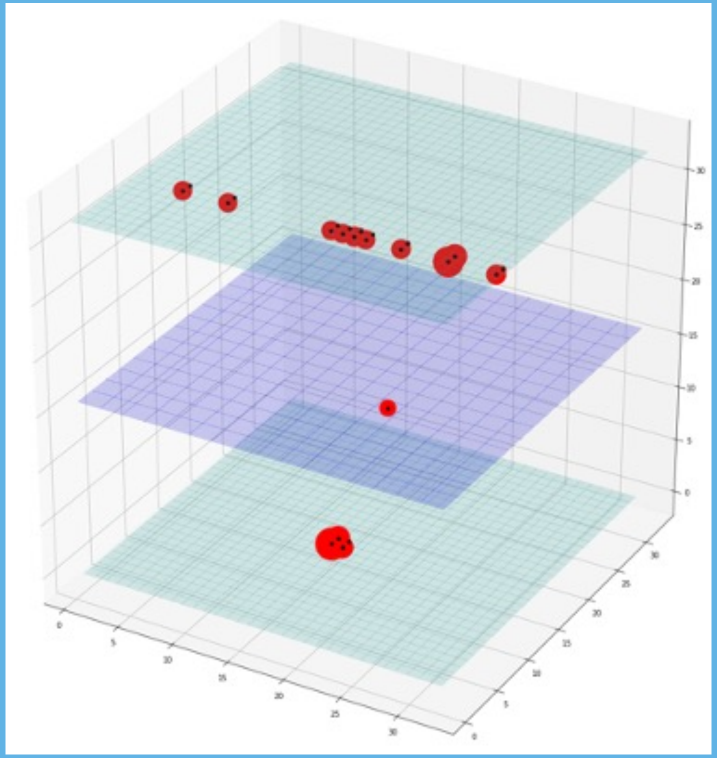
ZOOniverse Demonstrator

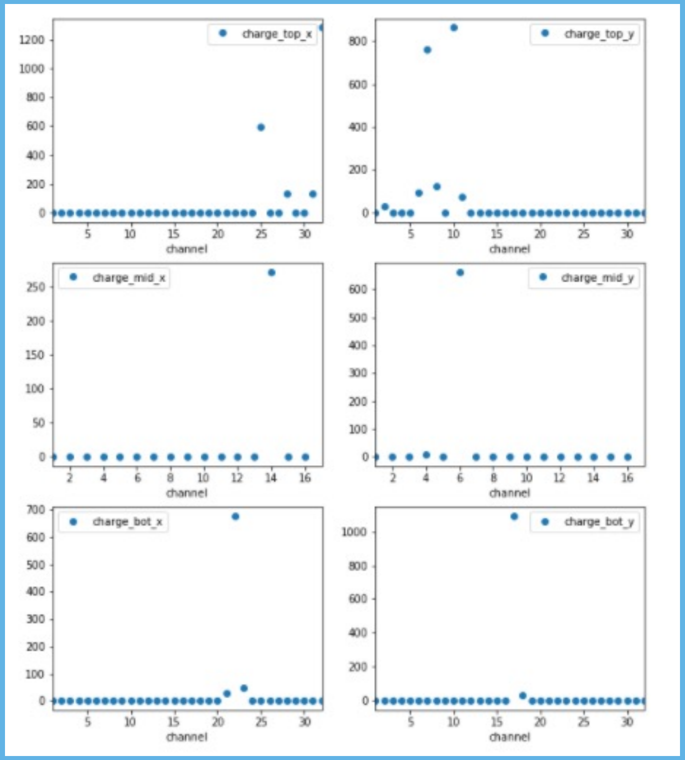
- ✓ Objective: increase our signal to background ratio
- How:

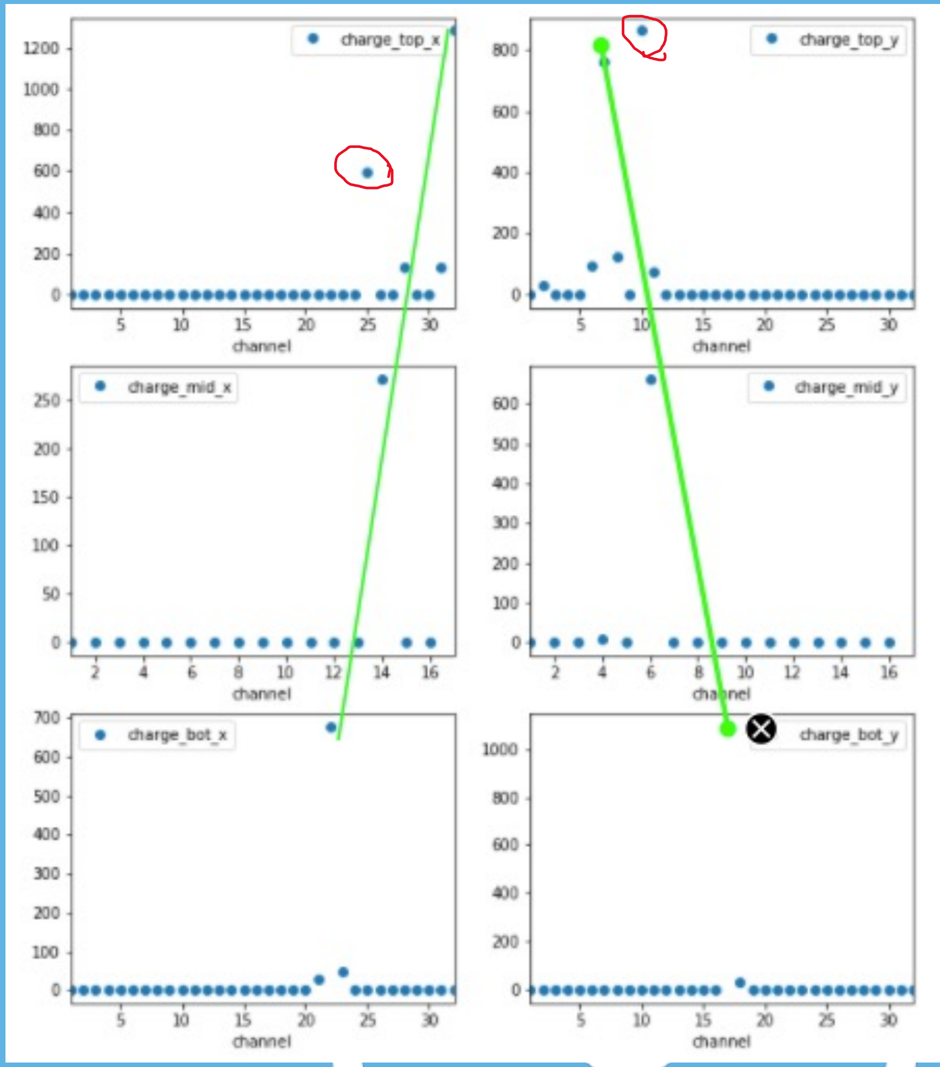
  Show images of:

  1. background events
  2. borderline muon events

  Ask people to identify better lines and denote ”out-of-place” charge points







REINFORCE Cosmic Muon Images @ ZOOniverse

REsearch INfrastructures FOR Citizens in Europe

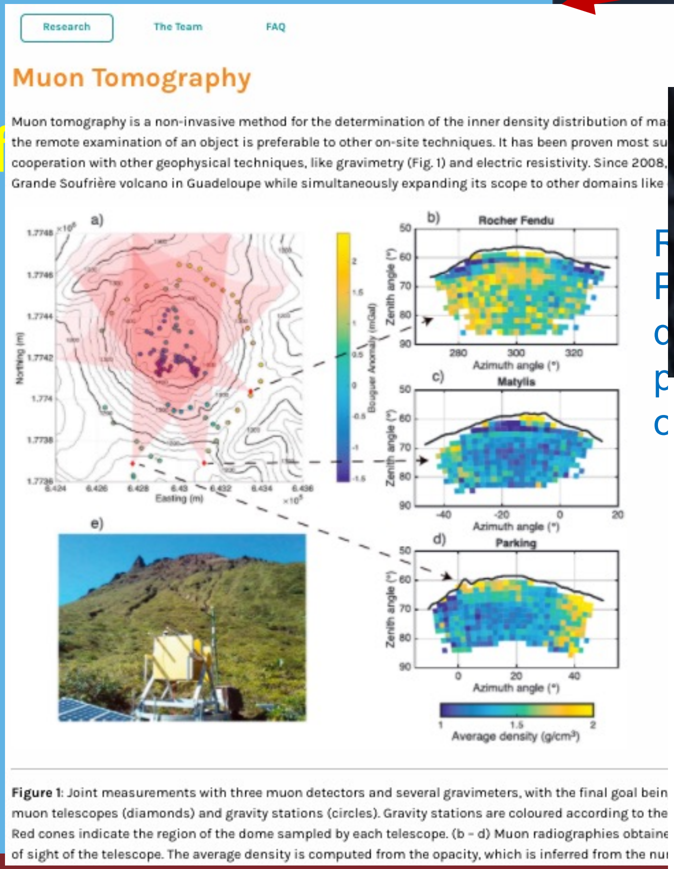
https://www.zooniverse.org/projects/reinforce/cosmic-muon-images

Goal: Identify patterns in recorded events

Most Important Sections:

About

Classif

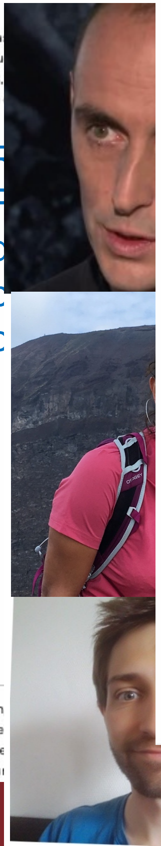


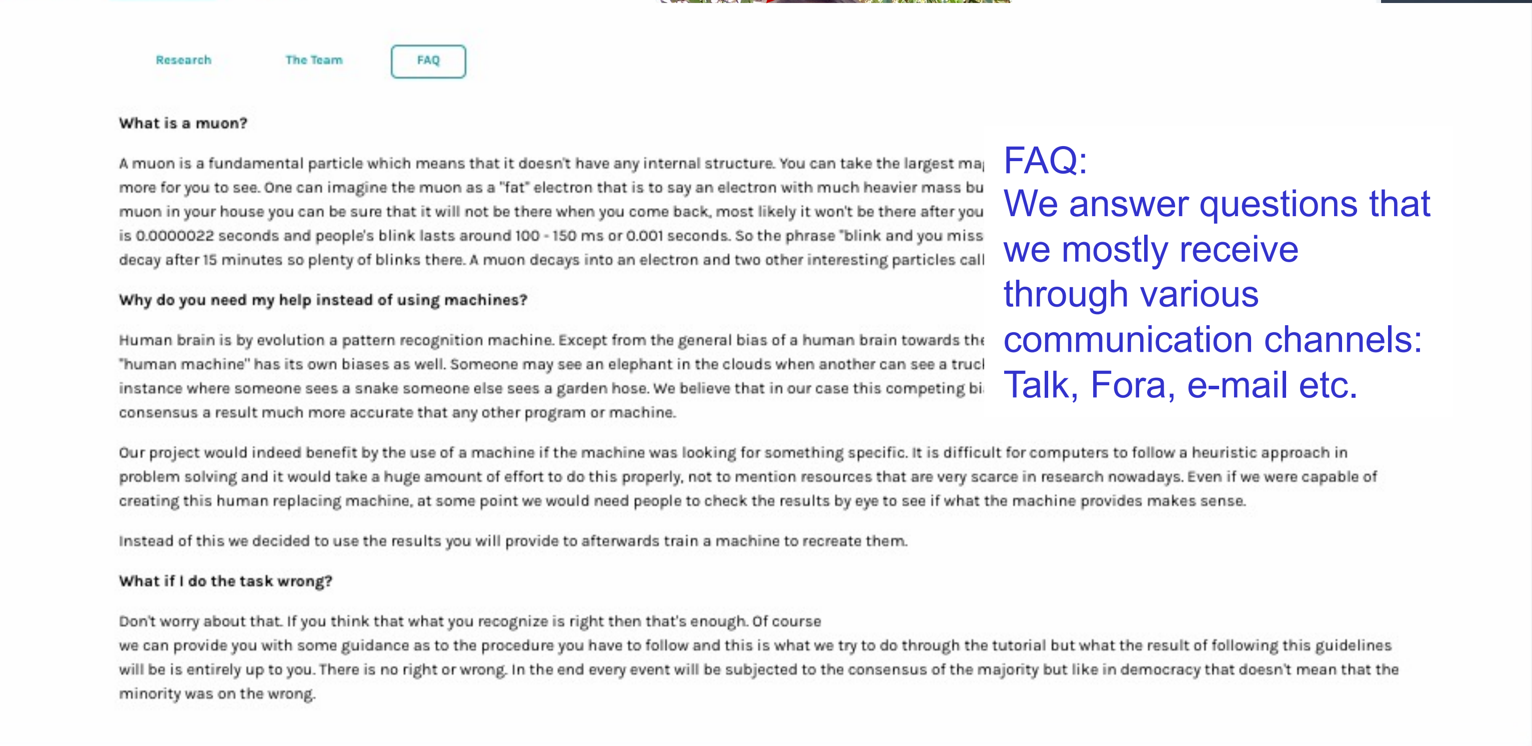
Research The Team FAQ

Muon Tomography

Muon tomography is a non-invasive method for the determination of the inner density distribution of ma
the remote examination of an object is preferable to other on-site techniques. It has been proven most su
cooperation with other geophysical techniques, like gravimetry (Fig. 1) and electric resistivity. Since 2008,
Grande Soufrière volcano in Guadeloupe while simultaneously expanding its scope to other domains like

Figure 1: Joint measurements with three muon detectors and several gravimeters, with the final goal bein
muon telescopes (diamonds) and gravity stations (circles). Gravity stations are coloured according to the
Red cones indicate the region of the dome sampled by each telescope. (b - d) Muon radiographies obtaine
of sight of the telescope. The average density is computed from the opacity, which is inferred from the nu





Research The Team FAQ

What is a muon?

A muon is a fundamental particle which means that it doesn't have any internal structure. You can take the largest ma
more for you to see. One can imagine the muon as a "fat" electron that is to say an electron with much heavier mass bu
muon in your house you can be sure that it will not be there when you come back, most likely it won't be there after you
is 0.0000022 seconds and people's blink lasts around 100 - 150 ms or 0.001 seconds. So the phrase "blink and you miss
decay after 15 minutes so plenty of blinks there. A muon decays into an electron and two other interesting particles call

Why do you need my help instead of using machines?

Human brain is by evolution a pattern recognition machine. Except from the general bias of a human brain towards the
"human machine" has its own biases as well. Someone may see an elephant in the clouds when another can see a truc
instance where someone sees a snake someone else sees a garden hose. We believe that in our case this competing bi
consensus a result much more accurate that any other program or machine.

Our project would indeed benefit by the use of a machine if the machine was looking for something specific. It is difficult for computers to follow a heuristic approach in problem solving and it would take a huge amount of effort to do this properly, not to mention resources that are very scarce in research nowadays. Even if we were capable of creating this human replacing machine, at some point we would need people to check the results by eye to see if what the machine provides makes sense.

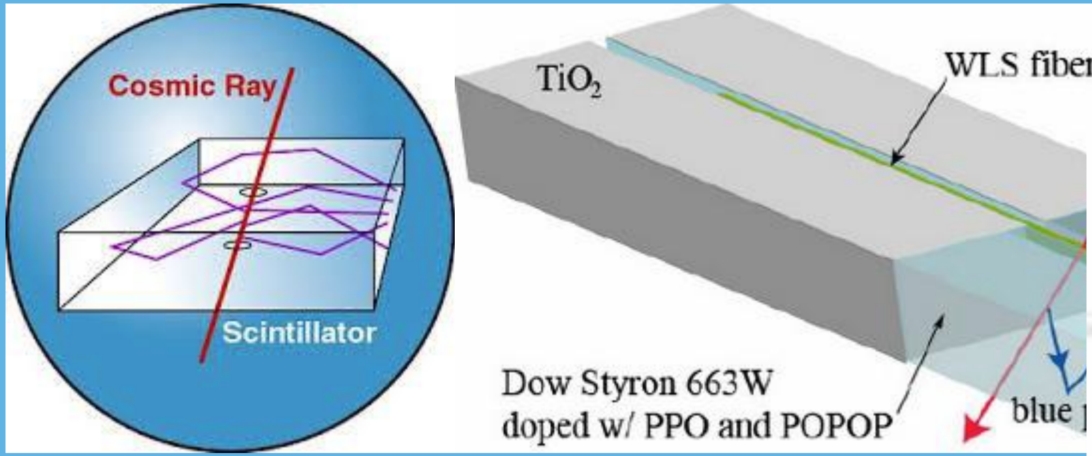
Instead of this we decided to use the results you will provide to afterwards train a machine to recreate them.

What if I do the task wrong?

Don't worry about that. If you think that what you recognize is right then that's enough. Of course
we can provide you with some guidance as to the procedure you have to follow and this is what we try to do through the tutorial but what the result of following this guidelines will be is entirely up to you. There is no right or wrong. In the end every event will be subjected to the consensus of the majority but like in democracy that doesn't mean that the minority was on the wrong.

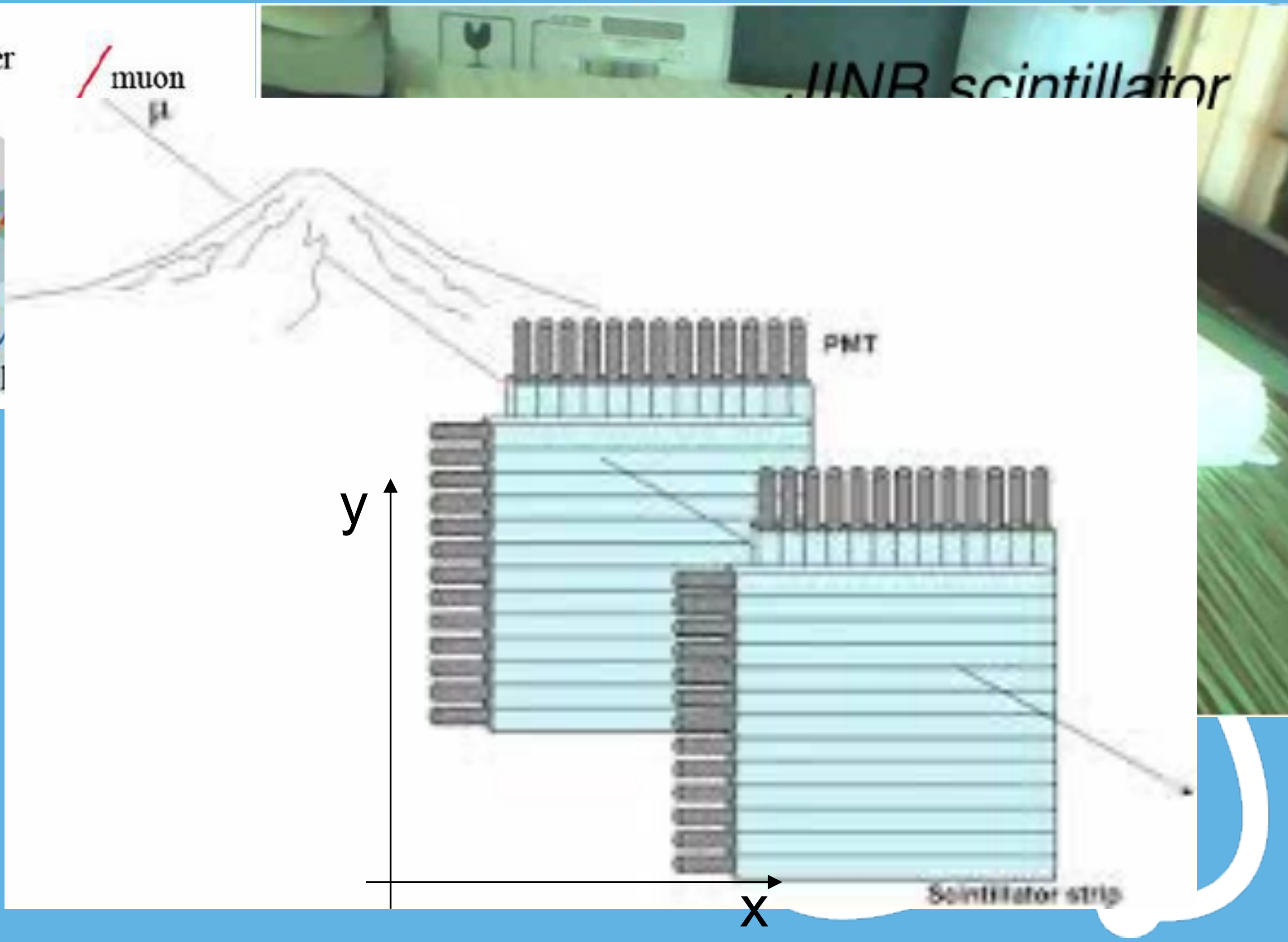
FAQ:
We answer questions that we mostly receive through various communication channels: Talk, Fora, e-mail etc.

Detector Components - Detection Principle



Put such strips one next to the other and you have a plane that monitors one direction

Place two such planes one on top of the other with the strips perpendicular and you monitor both x and y coordinates



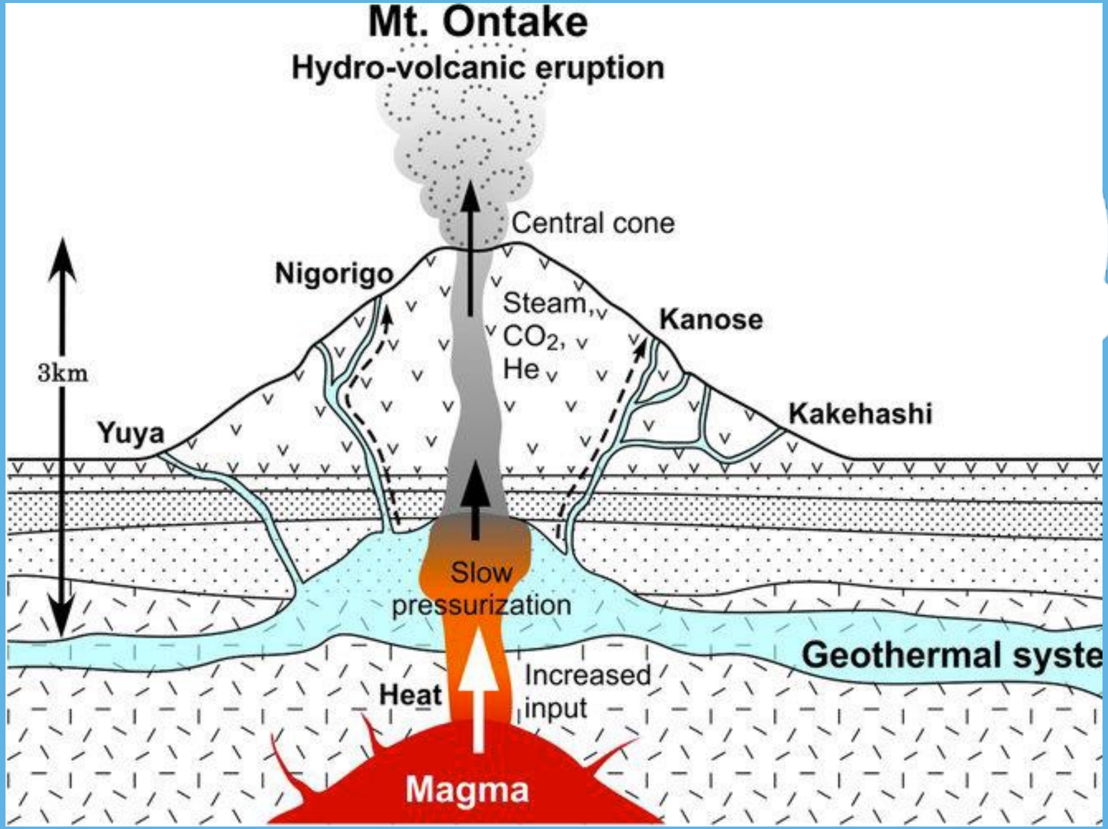
Muon Tomography: Volcanology

Muography Excels in Volcanology → Distant/Safe Measurement → Total Structure Imaging → Monitoring

1) What happens inside a volcano during unrest

2) Links between observations and internal activity

3) Which types of unrest are precursors to (which eruptions)



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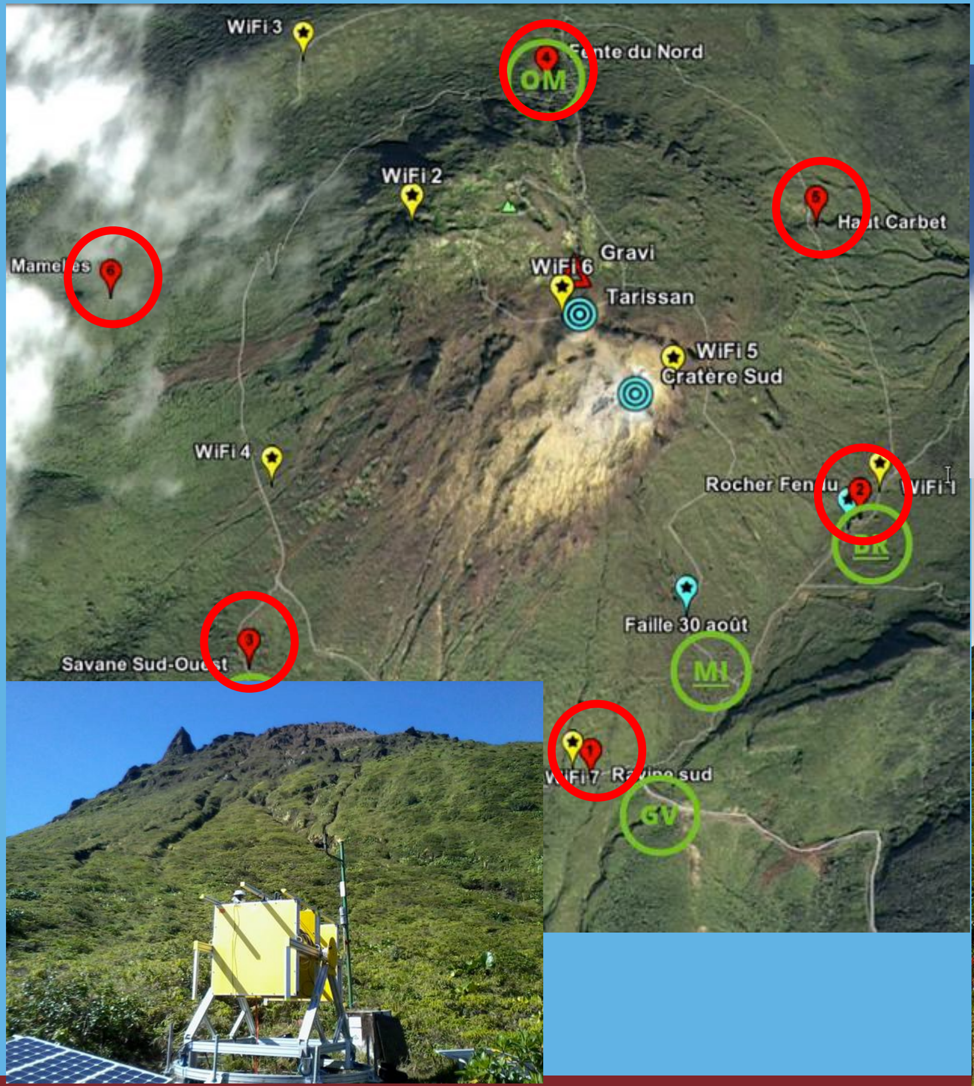
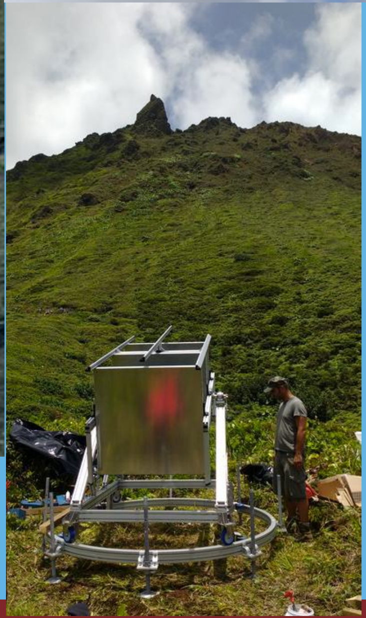
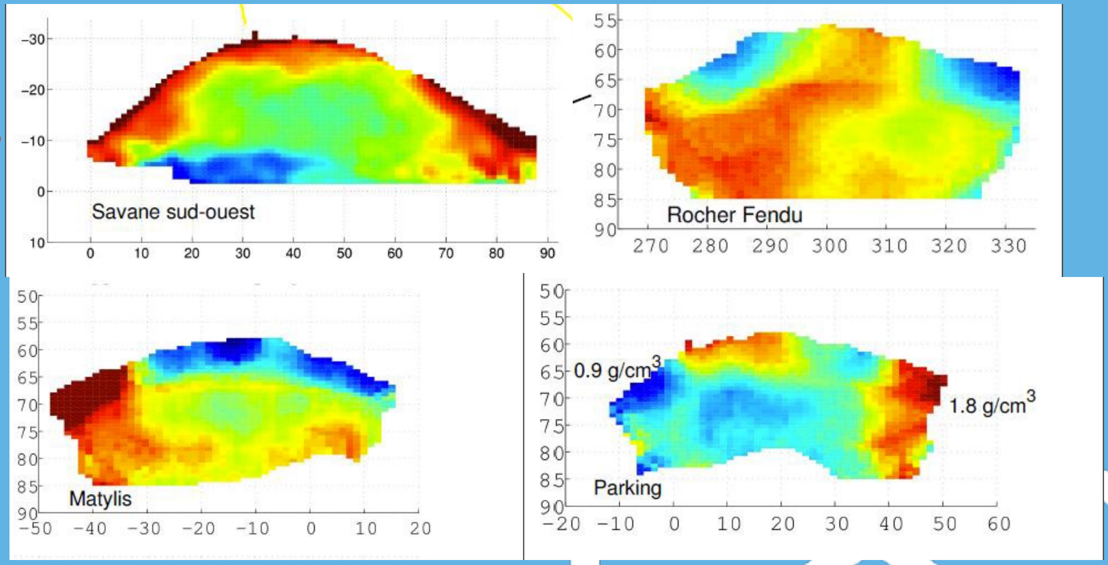
Muon Tomography Volcanology

Surrounding a Volcano Dome with detectors

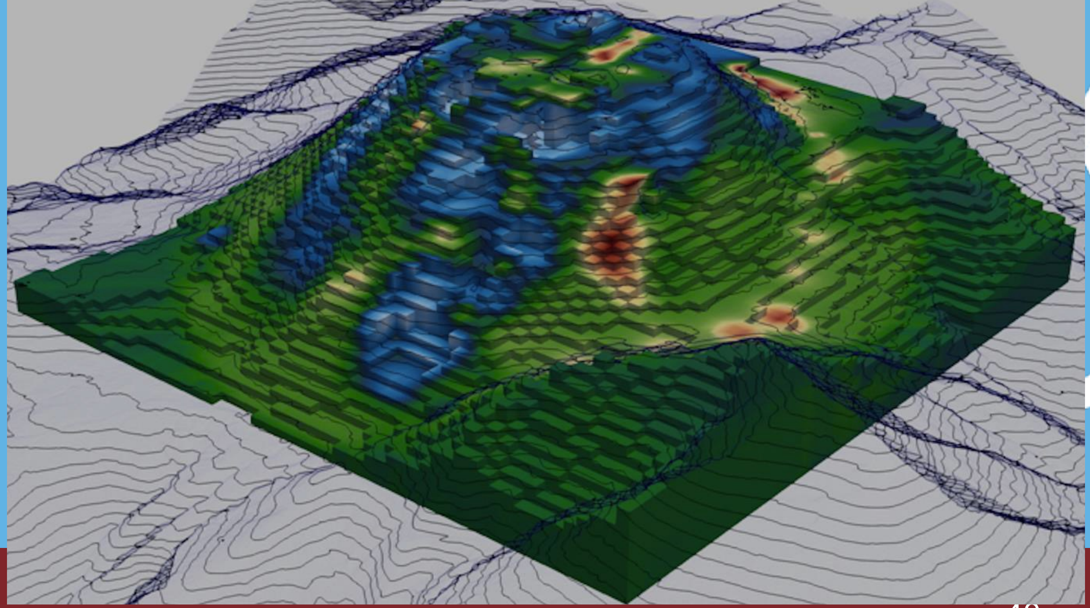
5+1 Detectors







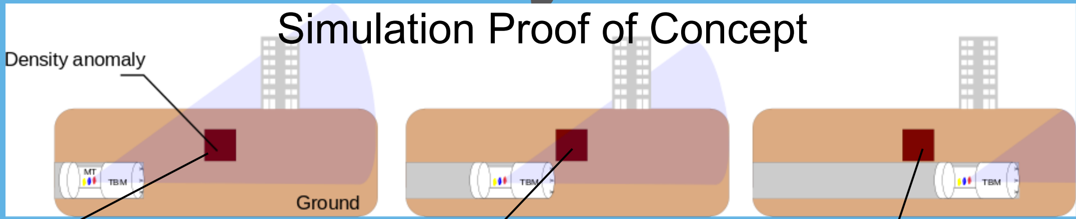
Volcano 3D - Reconstruction

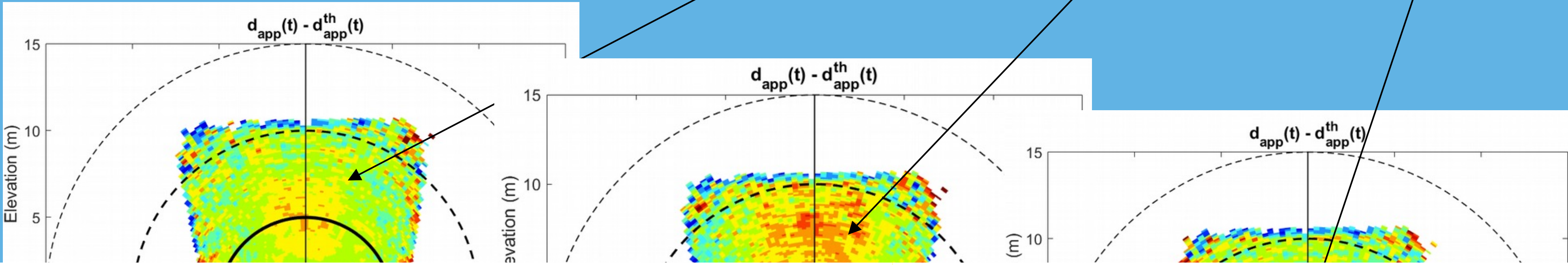


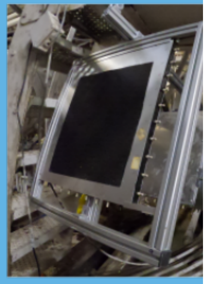
Paris Metro Boring Machine Alert System

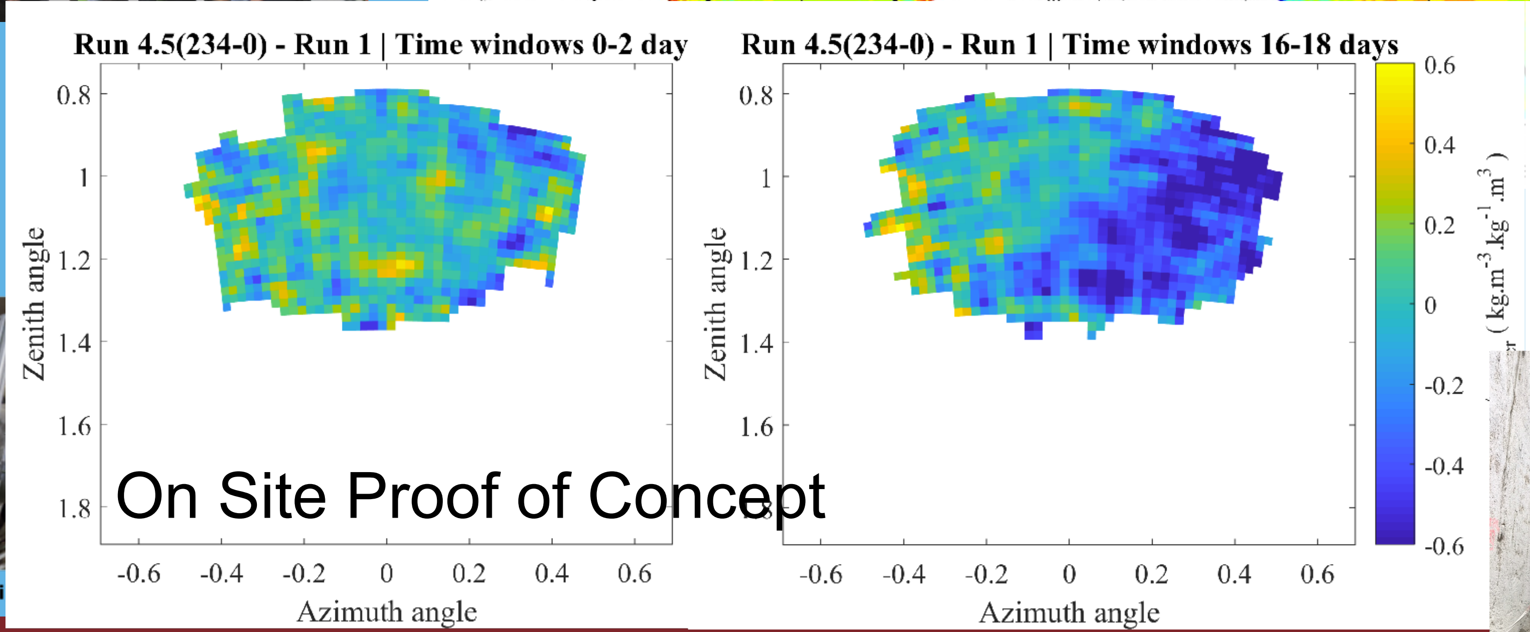
Tunnel Boring Machine:
Builds Tunnel while Digging the Hole
Density Anomalies in Front = Problem

Simulation Proof of Concept

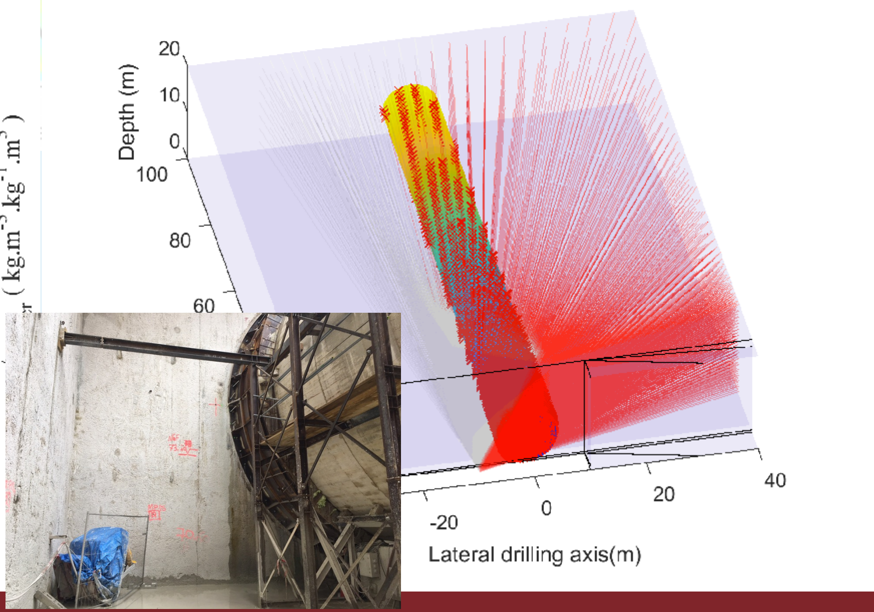






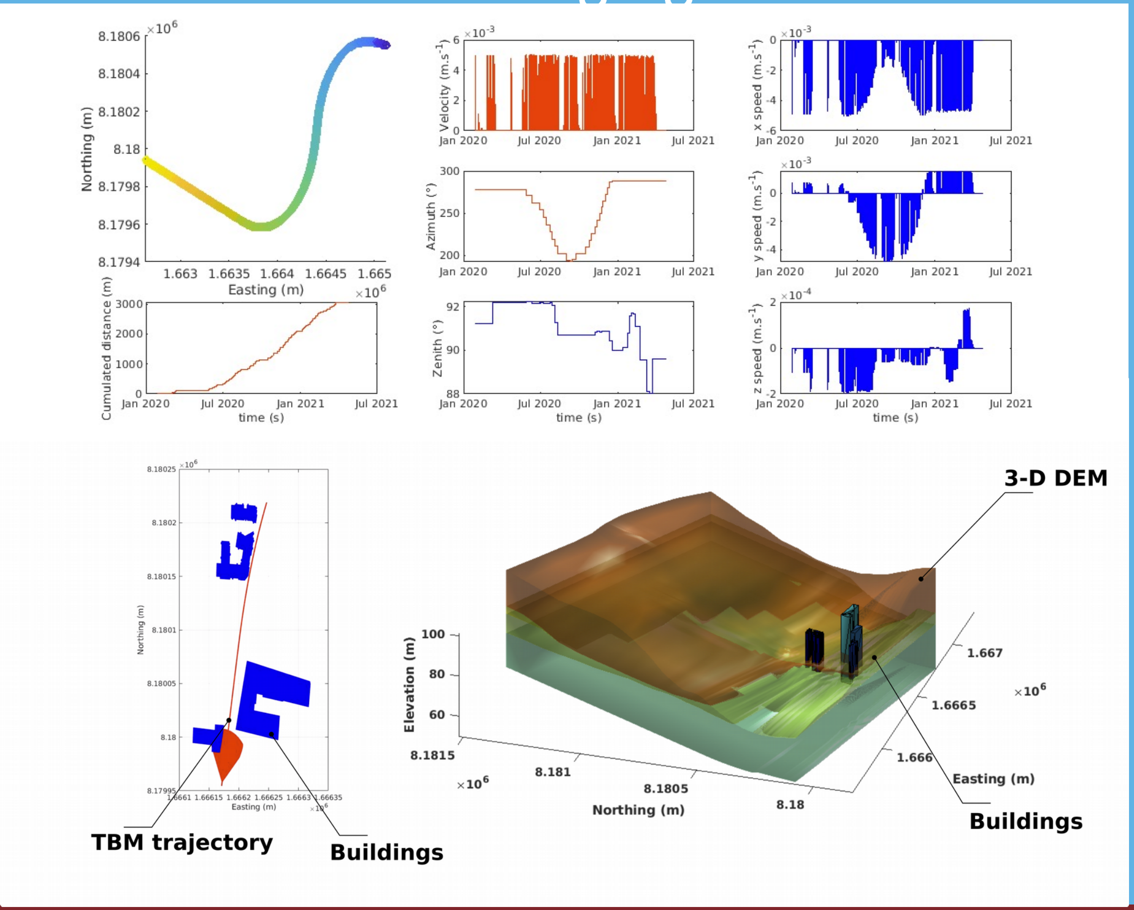


On Site Proof of Concept



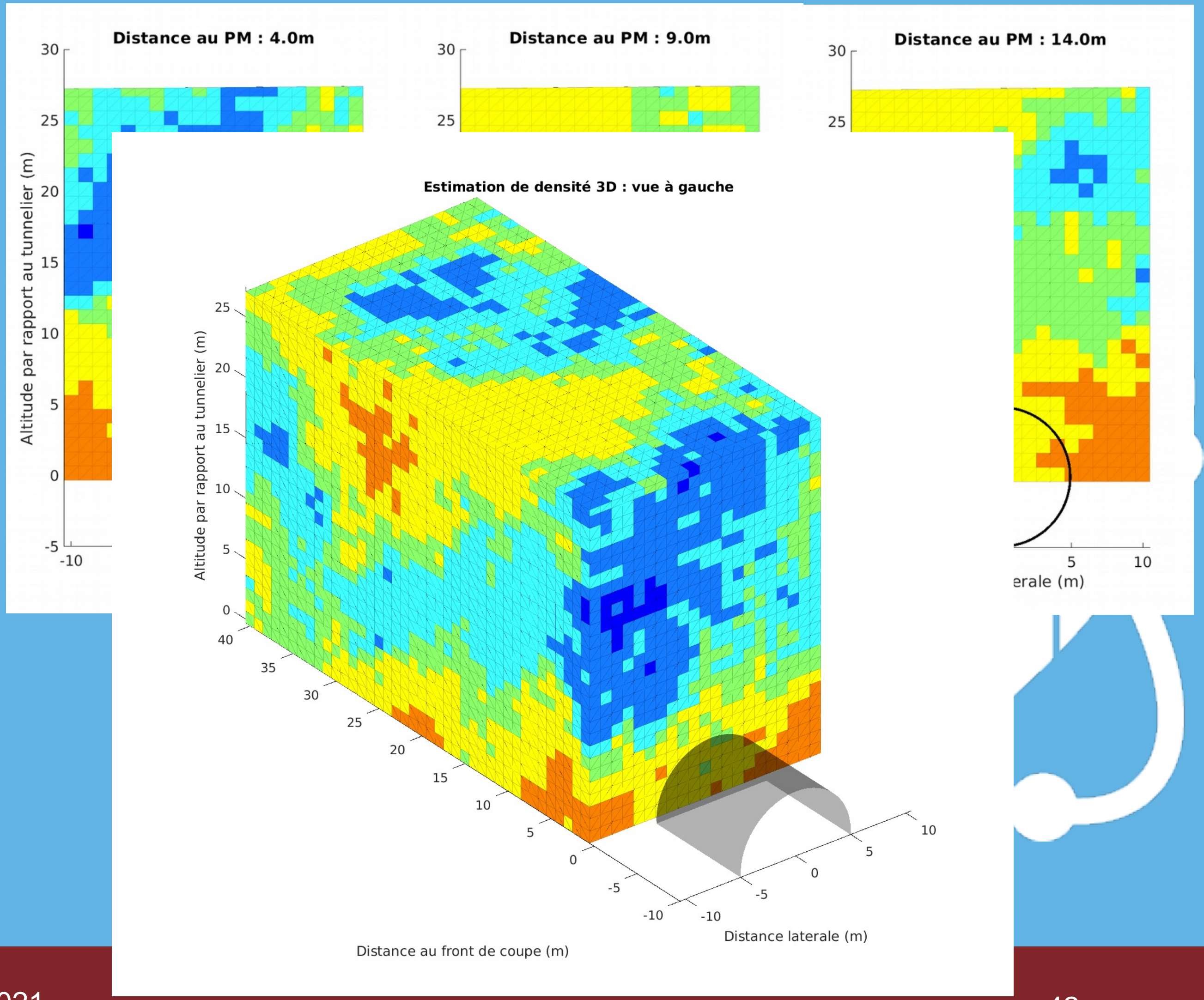
Paris Metro Boring Machine Alert System

Challenges: Moving Detector
Digital Elevation Model (DEM)
Building Footprint Model
3D imaging – 2 Detectors



Results

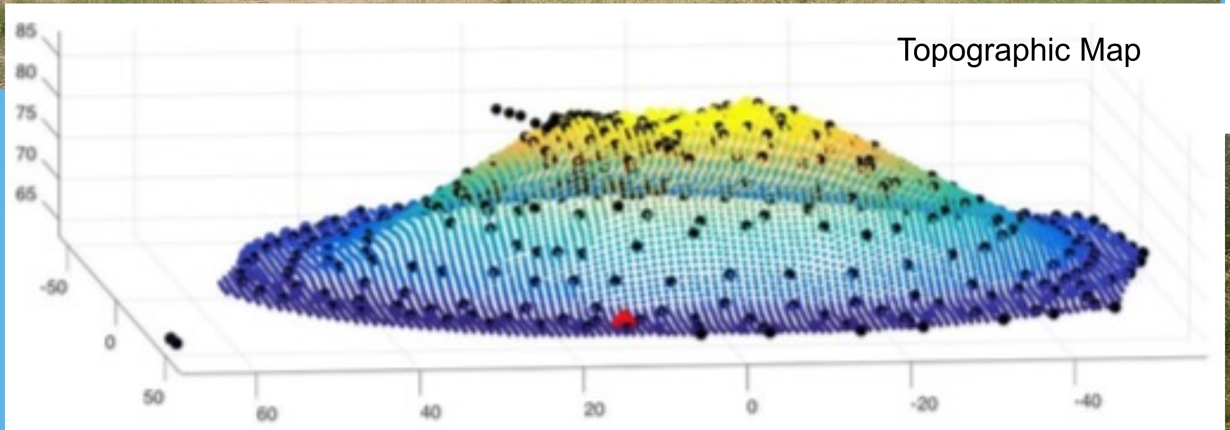
Reconstruction: Walls of Matter at Distances

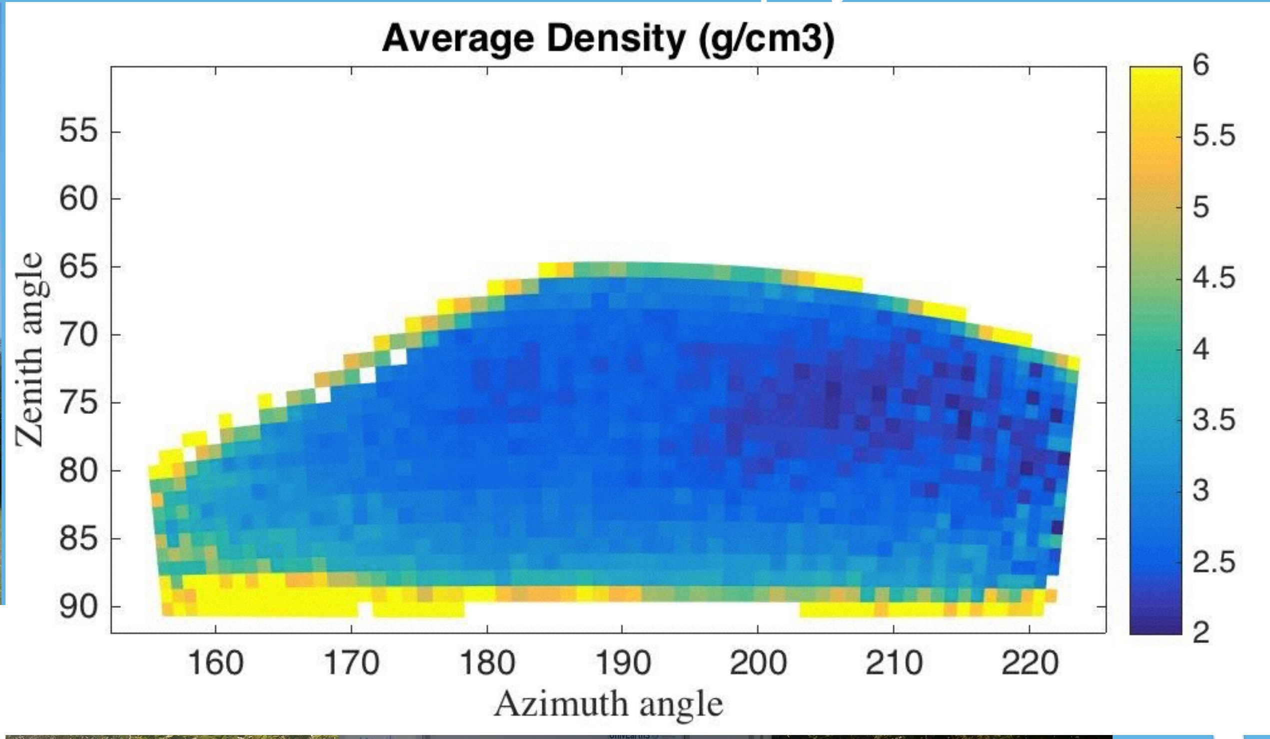


Muon Tomography Archaeology

Apollonia Tumulus: Covered Ancient Tomb
Muon detector placed inside Van

Goal: Muography Discovery Potential
Combined with Geophysical Methods



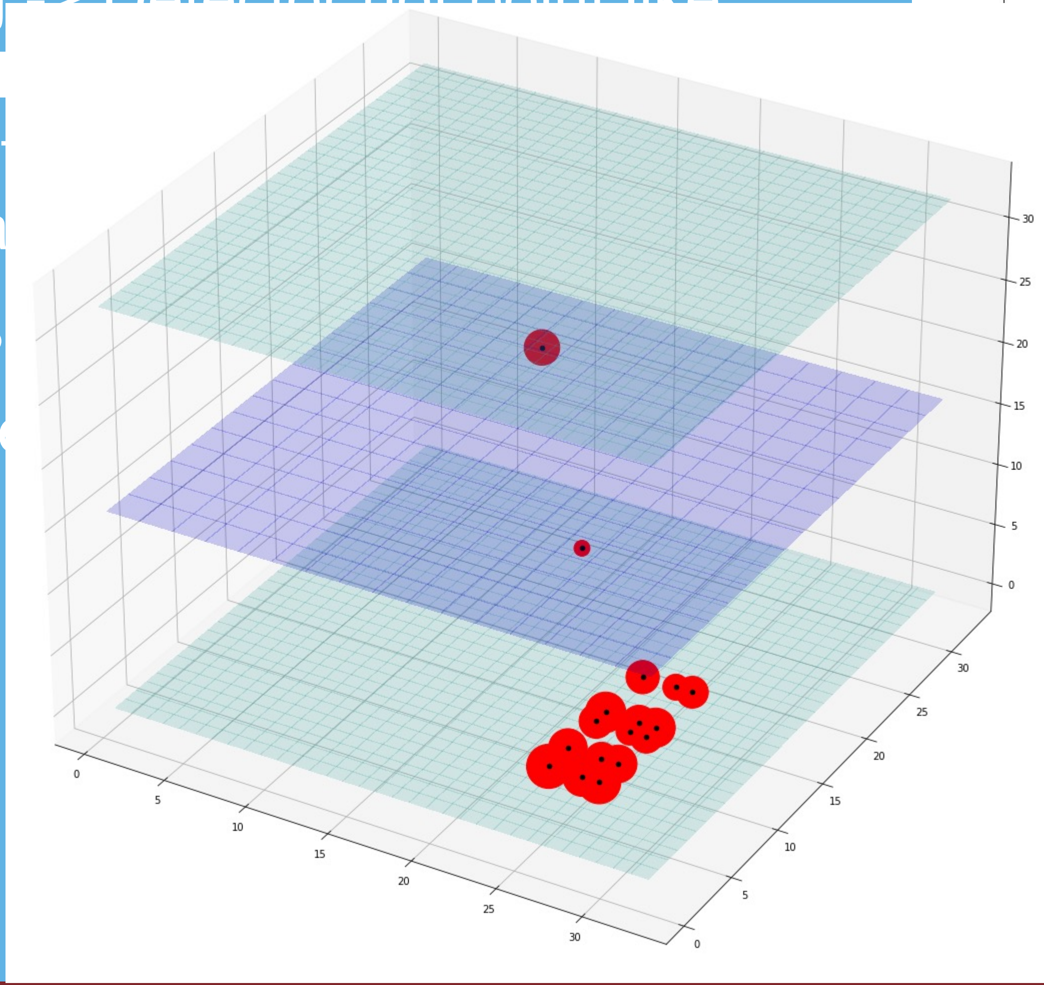


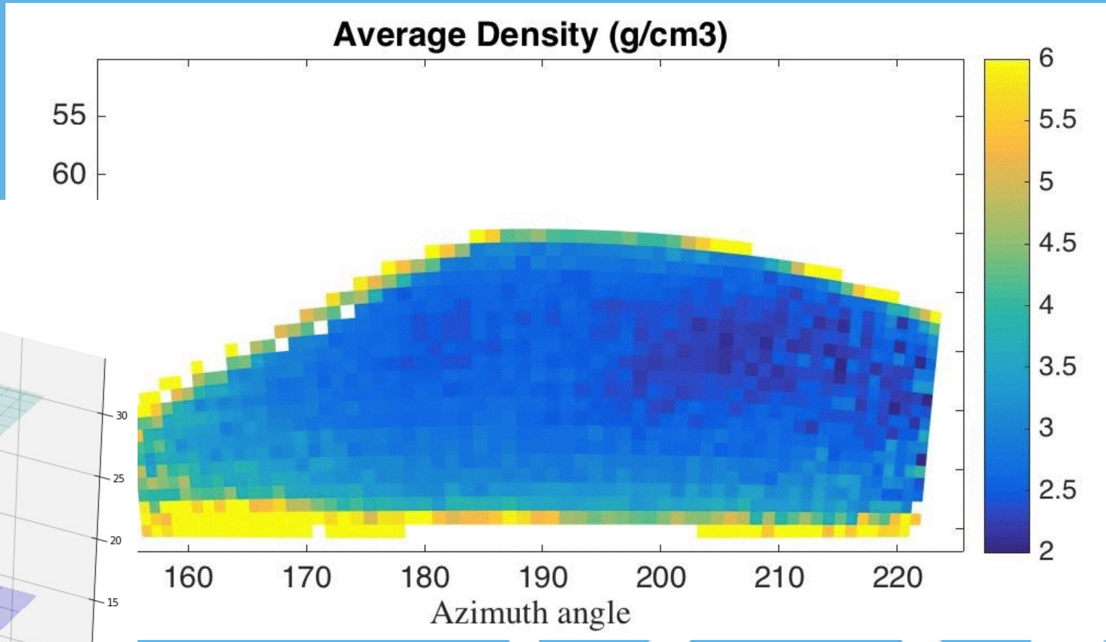
Muon Tomography Archaeology

Same Method – Bad result: Why?
Method reaches its limits:
1) Harder Imaging -> Detector not point like
2) Smaller Target
3) Signal: Horizon
Signal compara

But what is signal?
One (x,y) point on

What about this?

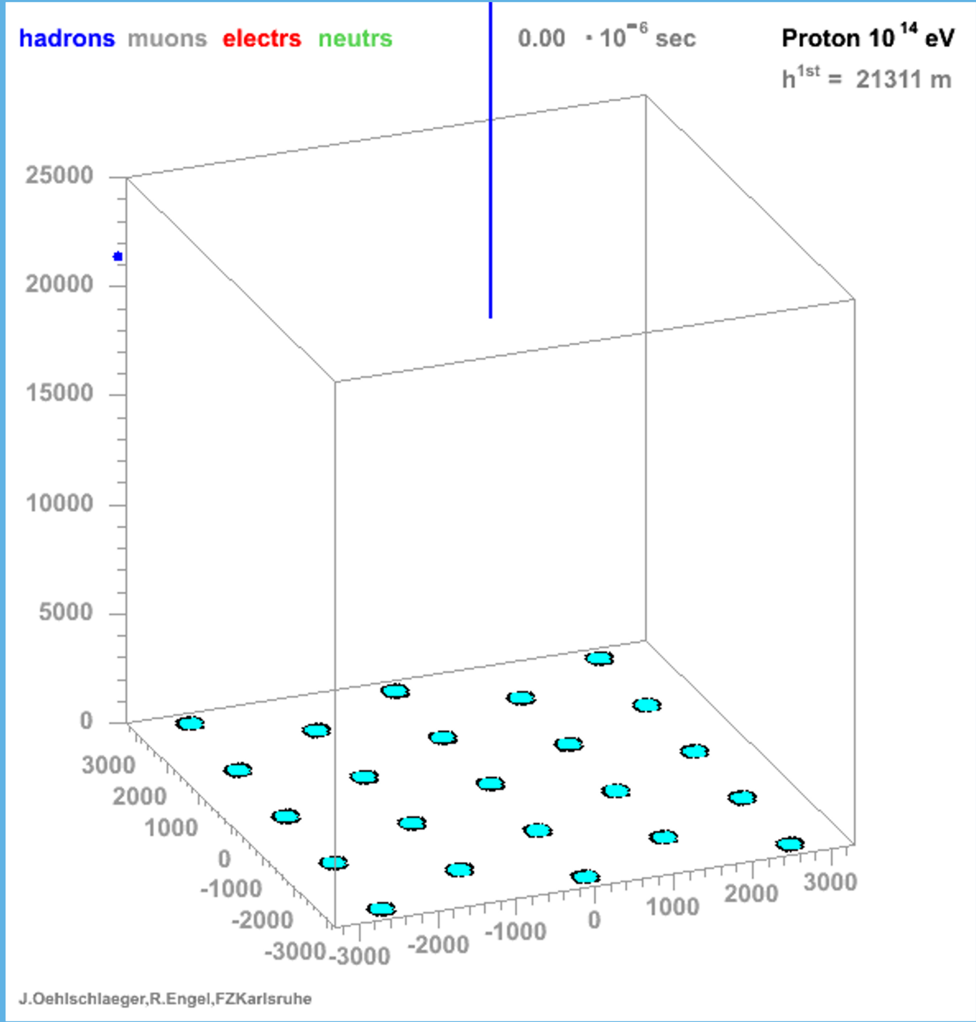




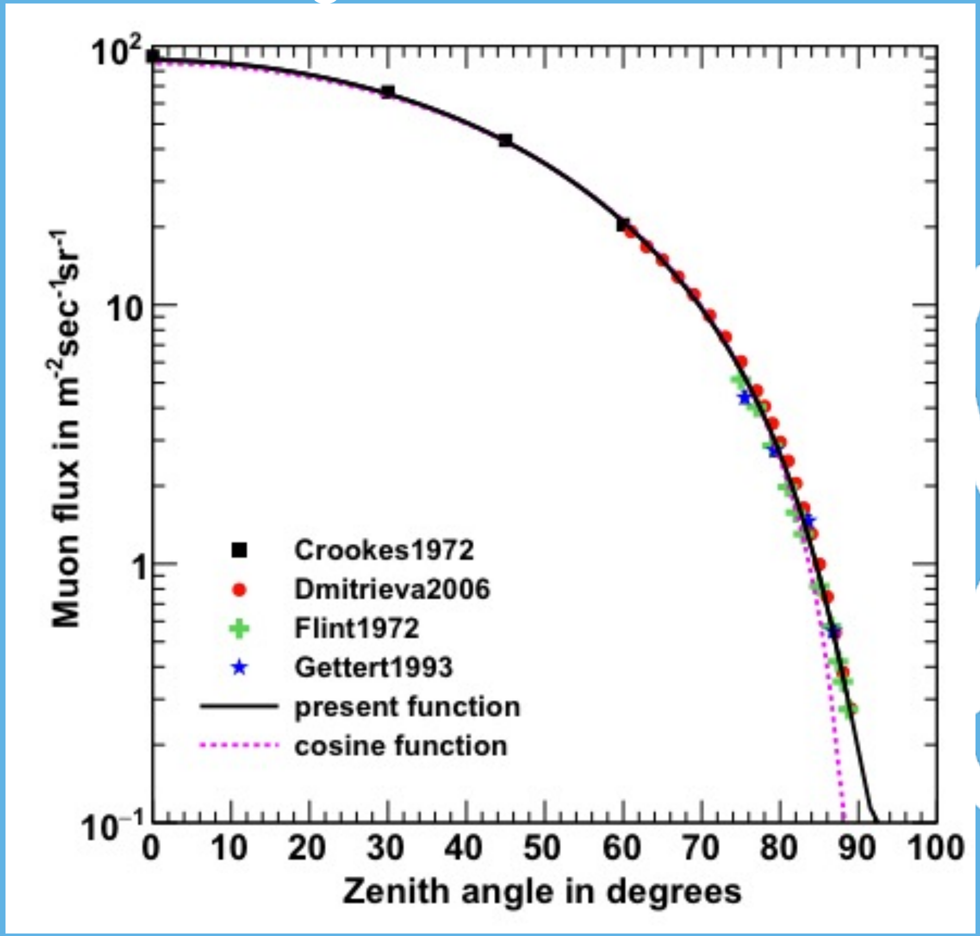
This opens the discussion about background

Showers and Muons

Let's look at a shower



Let's look at
Muon Angular Distribution



Most Background complications arise from the fact that the detector operates within an environment full of Cosmic Ray Cascades

REINFORCE The Background

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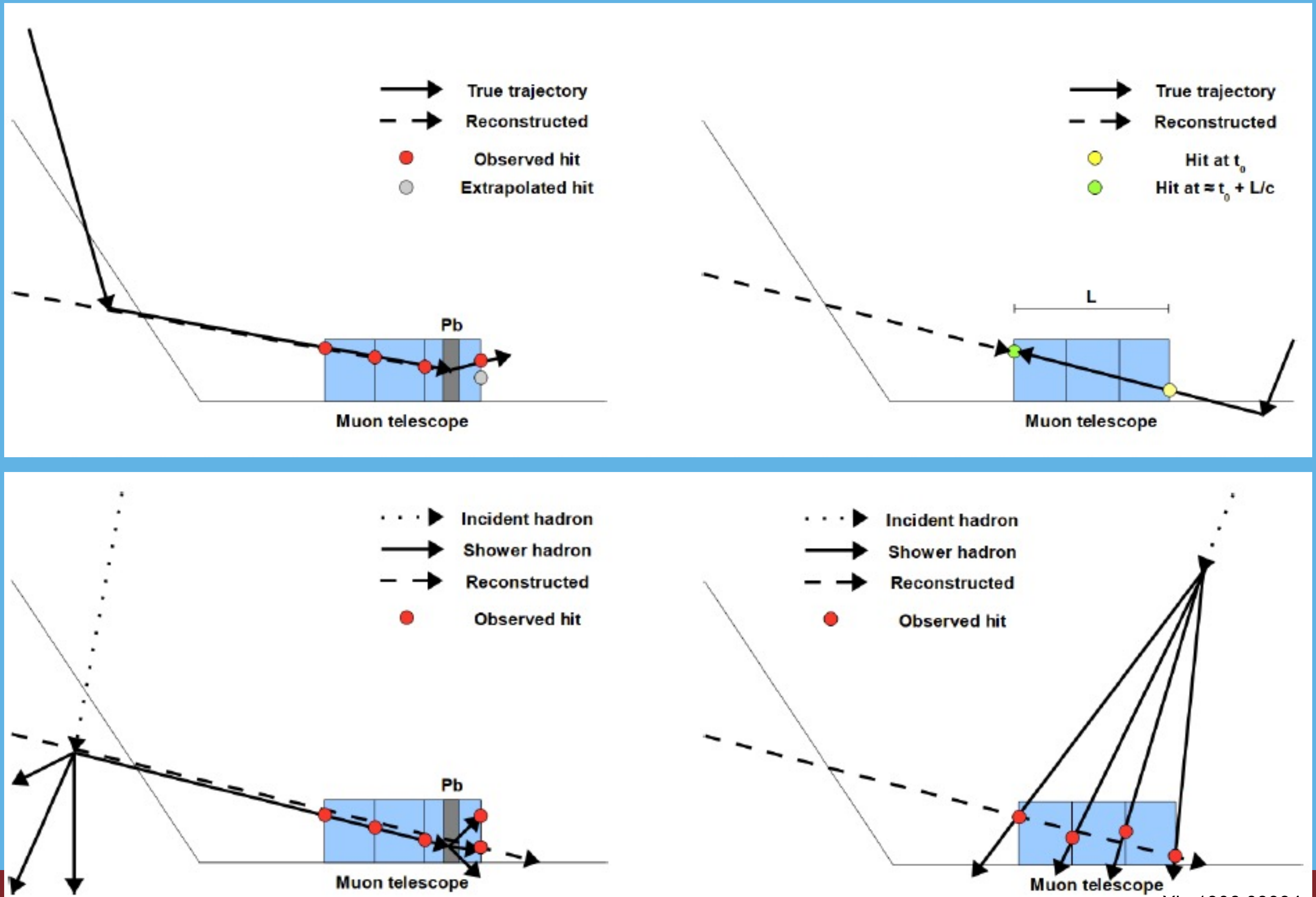

arXiv:1906.03934

Low Energy Muons

Simulation (colleagues Annecy) find electrons in front two panels not arriving on the back one.

Muons accompanied by electrons… why?

Hadrons/Showers

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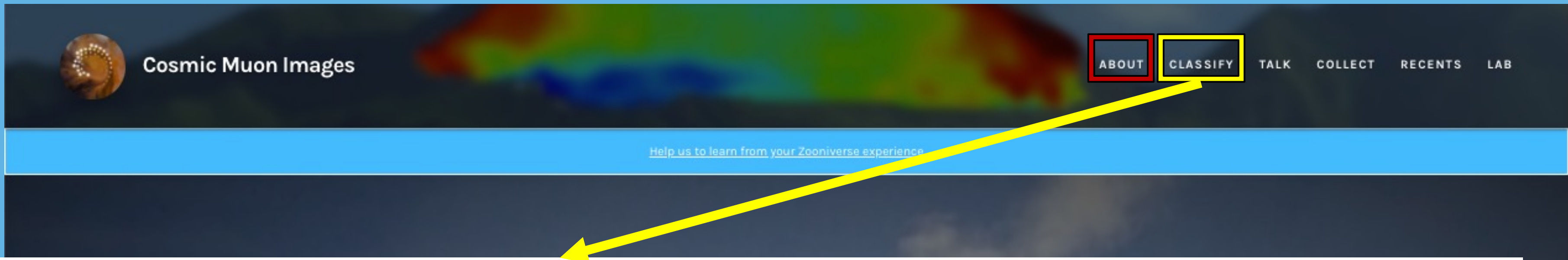
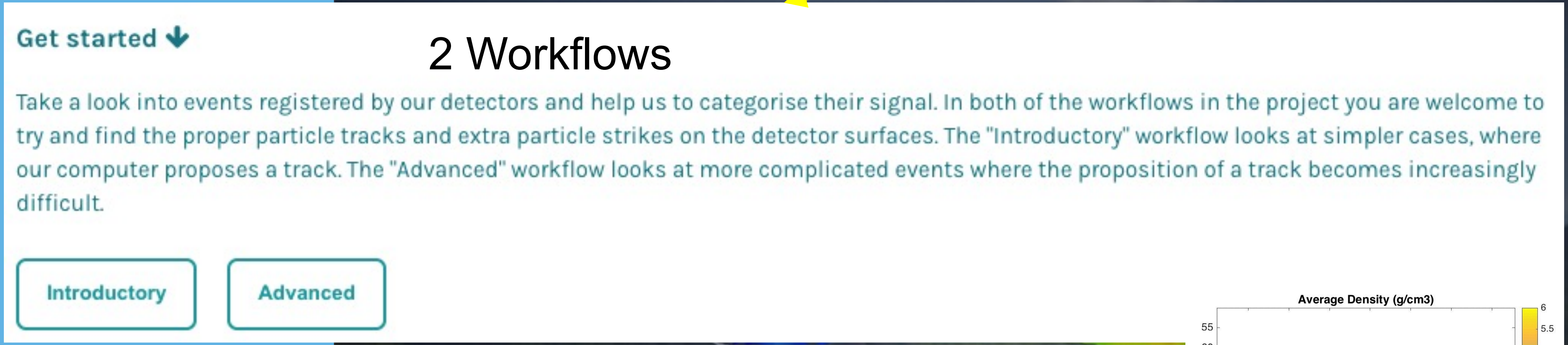
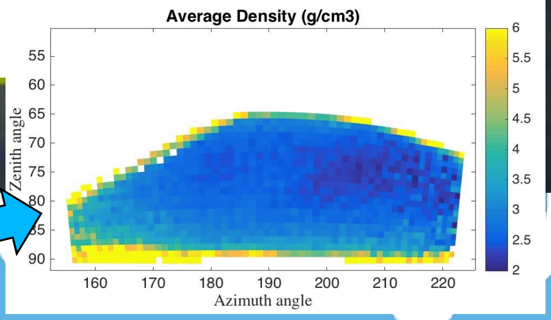




2 Workflows

1) 3-fold coincidences events from Apollonia Dataset
2) Only background – Not those used to produce this
3) Use lines and pair points to give rise to patterns



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Outlook

✓ Data Summary:
- Collected Summer 2018
- Synergies: Muography & Geosciencies
- Diaphane Detector Description
- Detection principle outline

✓ Data Analysis and Selection
- DAQ registers >2-fold coincidences
- ZOOniverse filtering: 3-fold only (minimal bias)
- Conversion: PMT channels -> Scintillator strips and orientation axis

✓ Data Elaboration
- Data -> images 1D, 2D, 3D