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Author(s): Guardincerri, Elena
Blasi, Carlo

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Dome of Santa Maria del Fiore: from the construction techniques to monitoring with muons

Carlo Blasi, formerly at the University of Parma, Elena Guardincerri – Los Alamos National laboratory

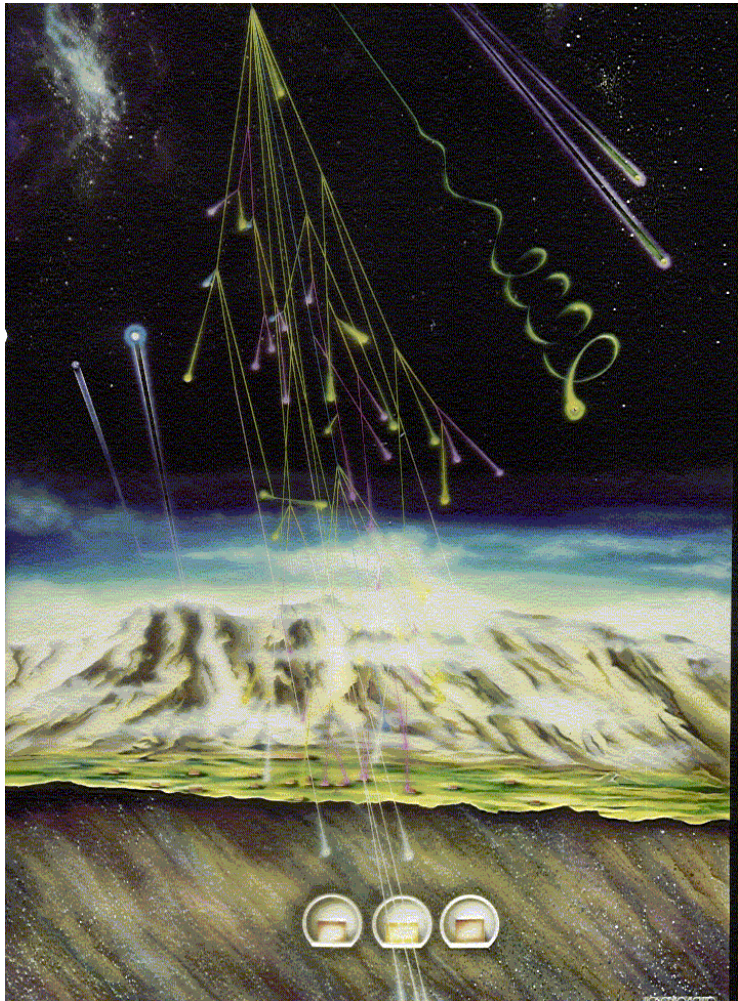
Cosmic ray muons

- Charged leptons with a mass 200 times that of the electrons
- Cosmic rays produce pions that then decay into muons and neutrinos

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \quad \pi^- \rightarrow \mu^- + \overline{\nu_\mu}$$

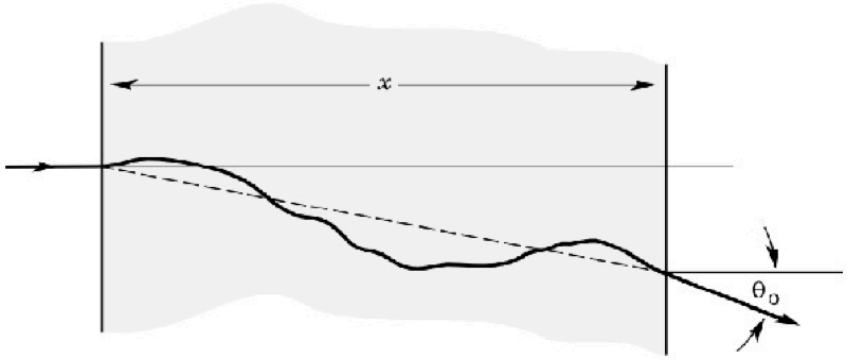
– ~1μ/cm^2/minute at earth

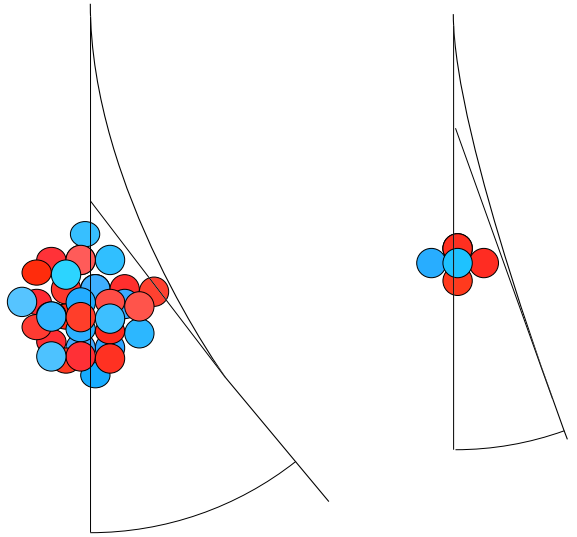
- Extremely penetrating particles



Muon Multiple Coulomb Scattering

- When muons traverse matter they are deflected due to Multiple Coulomb Scattering on the nuclei.





material thickness

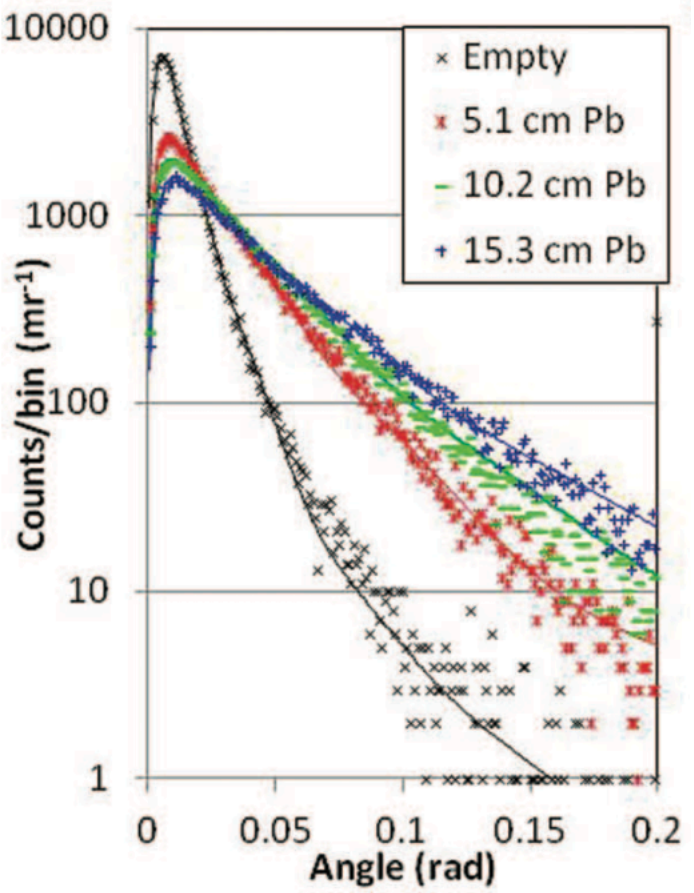
$$\frac{dN}{d\theta} = \frac{N}{2\pi\theta_0^2} e^{-\frac{\theta^2}{2\theta_0^2}} \qquad \theta_0 = \frac{14.1MeV}{pc\beta}\sqrt{\frac{l}{X_0}}$$

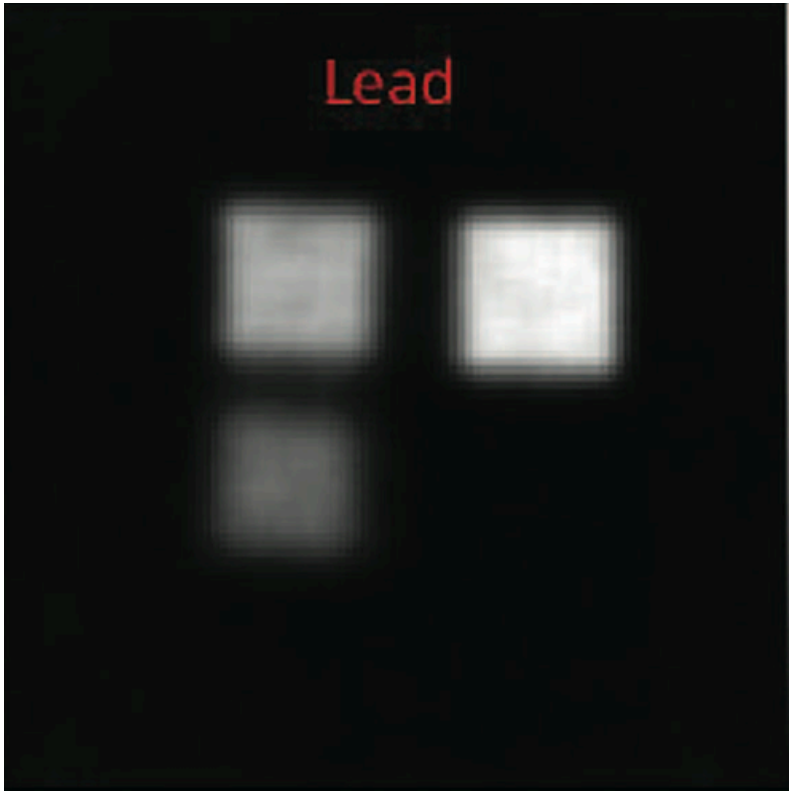
radiation length for material

$$\frac{1}{X_0} = \frac{Z/(Z+1)\ln(287/\sqrt{Z})}{A \cdot 716.4 g \cdot cm^{-2}}$$

MCS technique invented at LANL by C. Morris

Example

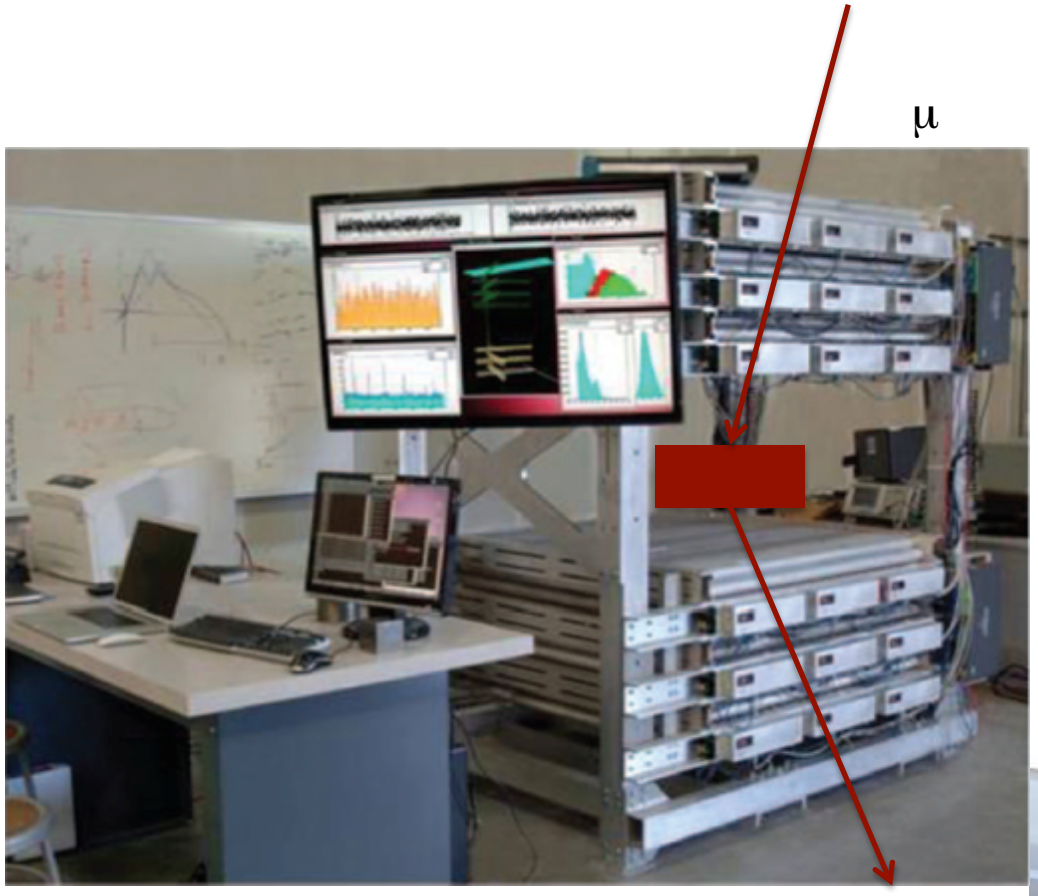




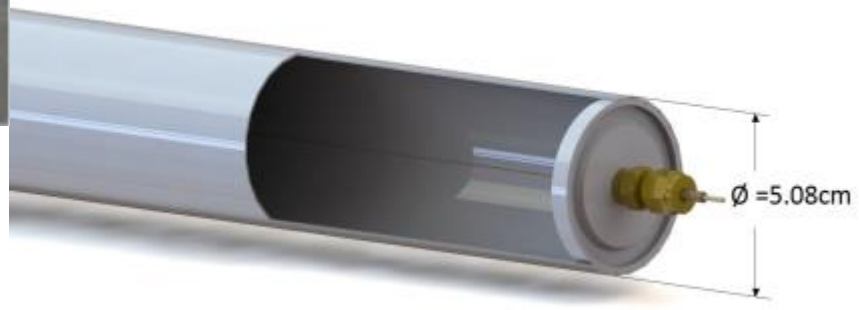
AIP Advances **2**, 042128 (2012)

Three different thicknesses of lead

Our detector: the Mini Muon Tracker



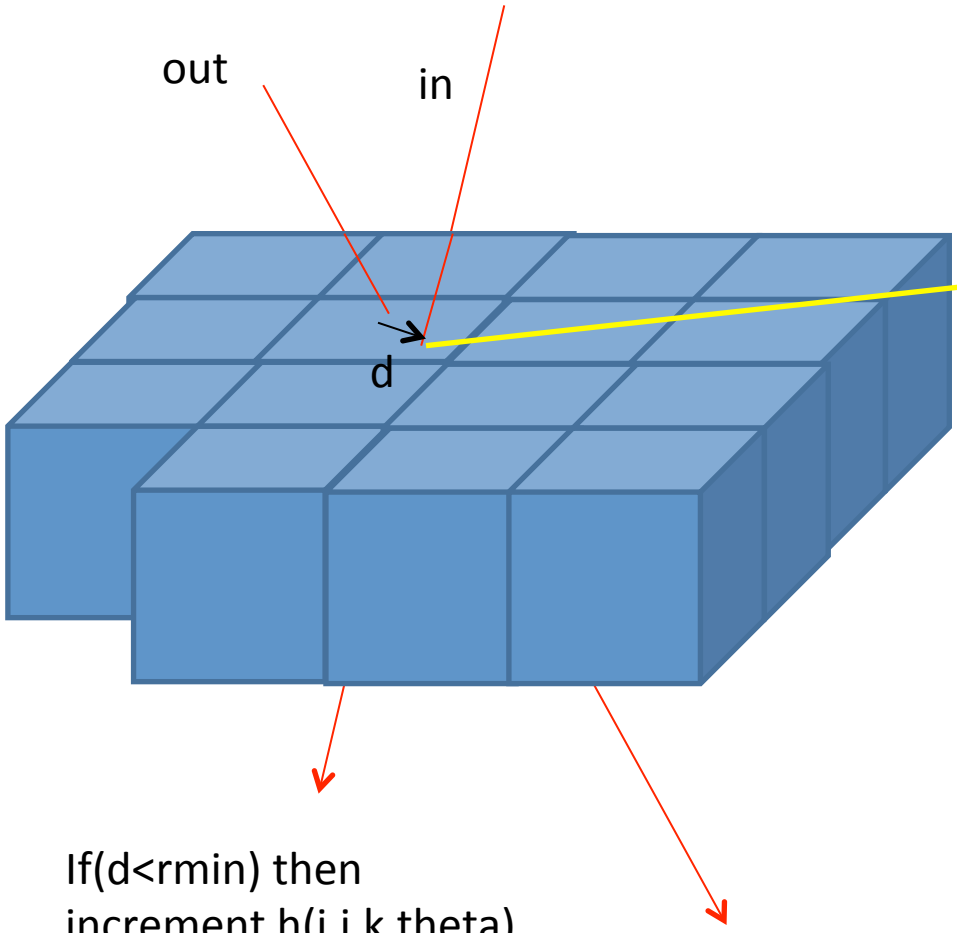
- 576 drift tubes arranged in X and Y layers
- Trackers size: 120 cm x 120 cm x 60 cm
- Trackers weight: ~800 lb/tracker
- The object of interest is placed between the trackers
- The trackers determine the trajectory of the incoming and outgoing muon, hence the scattering angle

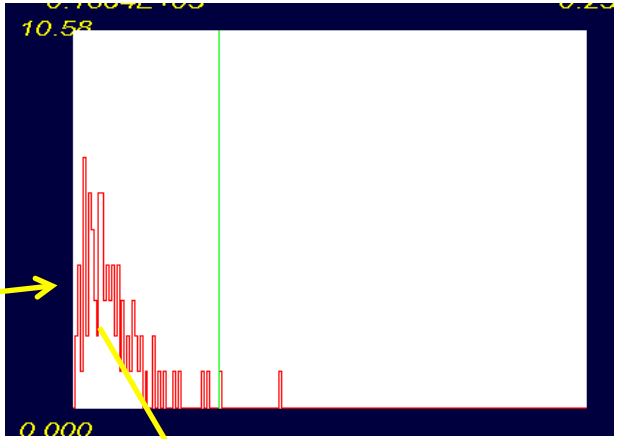


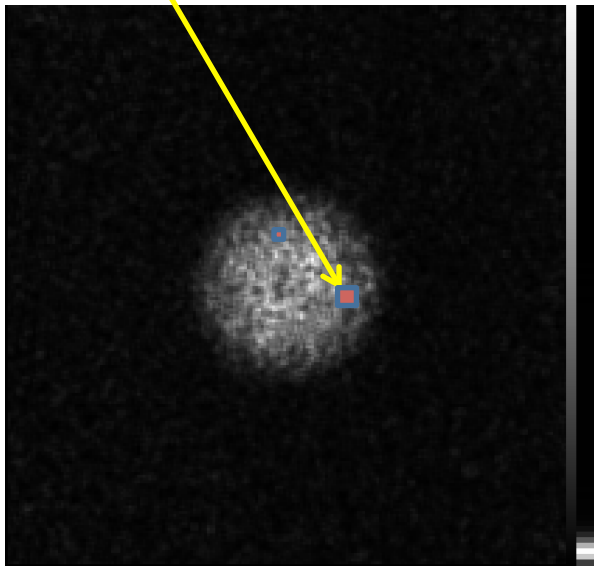
Gas mixture: 47.5% Ar, 42.5% CF_4, 7.5% C_2H_6, 2.5% He

Al tubes, gold-plated anode wire, 30-μm diameter

Generating multiple scattering images



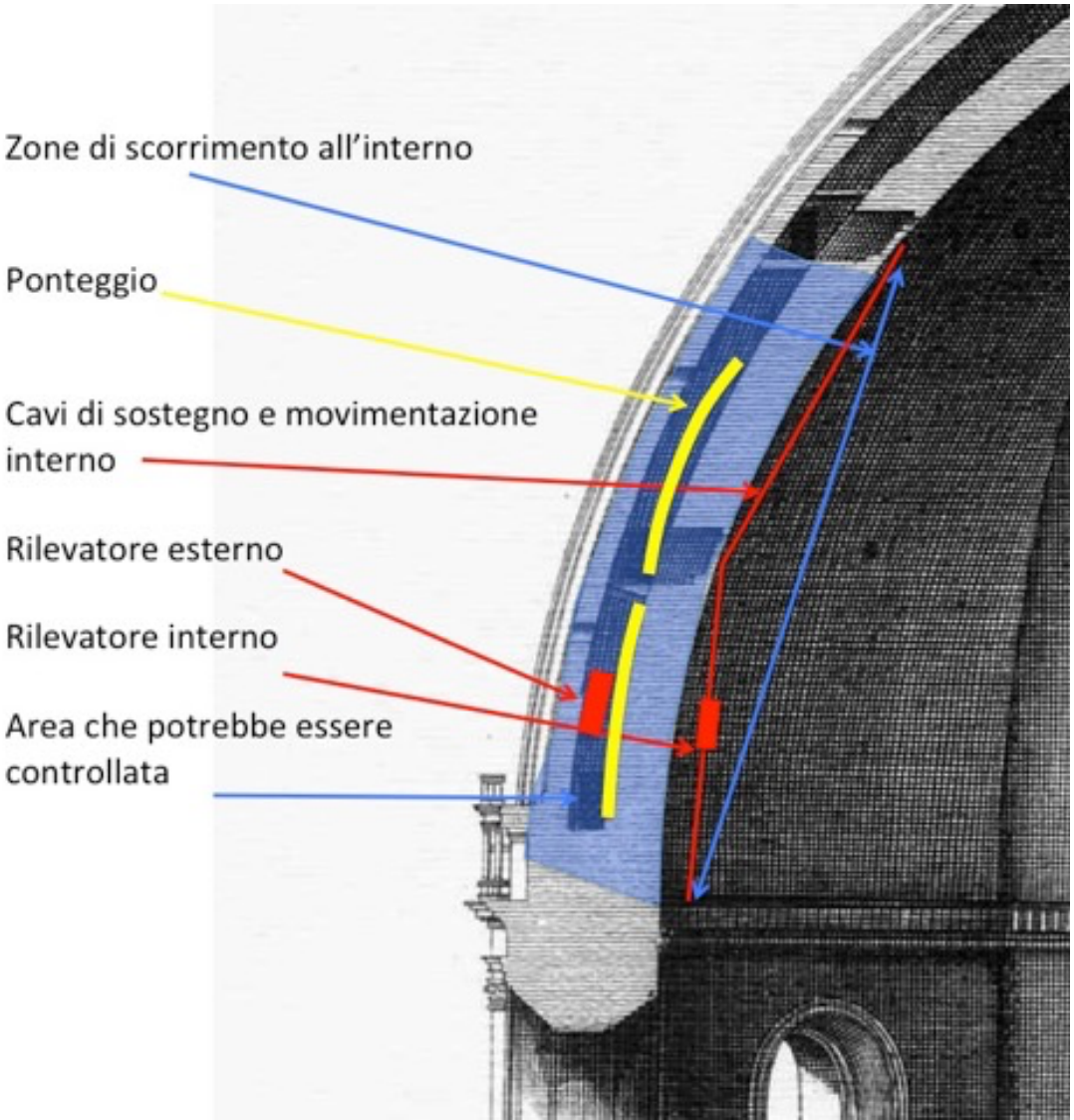




If(d<rmin) then
increment h(i,j,k,theta)

- Santa Maria del Fiore (Saint Mary of the Flower) church in Florence (Florence Cathedral)

Muon radiography of the Dome



Two trackers located on two opposite sides of the interior wall

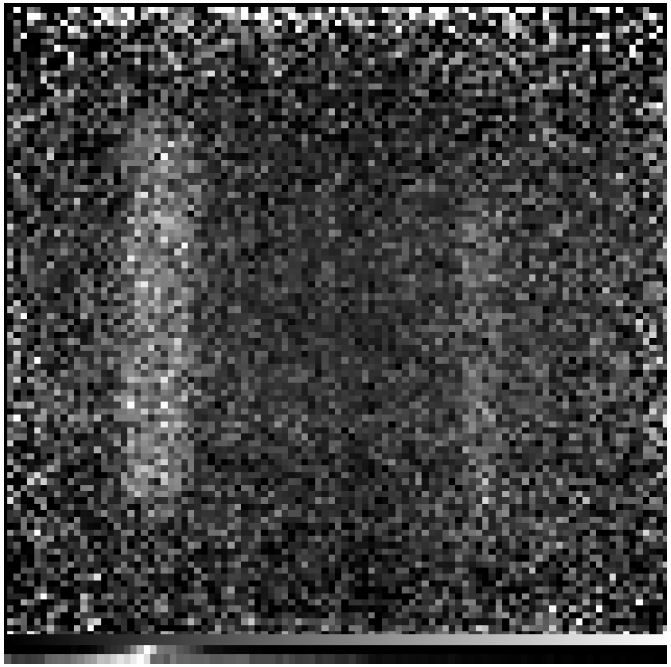
Demonstration measurement at LANL

- Demonstration measurement at LANL, during summer 2015, funded by the LDRD program.
- Built a concrete wall having the same thickness, in radiation lengths, as the inner (and thicker) wall of the Dome, placed three iron bars inside it.
- The cross sections of the bars are square/rectangular.
- Their dimensions were:
- 4.76 cm x 5 cm
- 2 cm x 3 cm (the bars in the Cupola wall are believed to be this size)
- 10 cm x 10 cm.

The mock-up wall after its completion, with the students who built it.

The iron bars inside the wall

Results of the measurement



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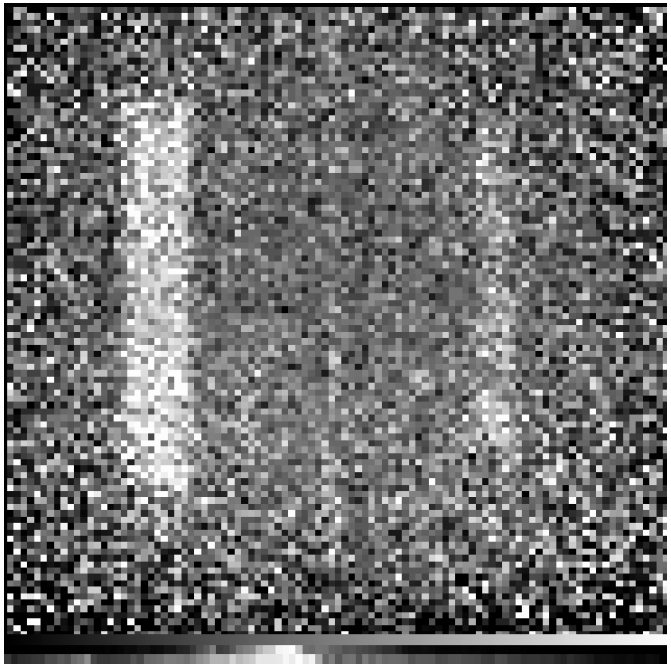


Simulazione

~1 month of data
All the bars are visible
Visible after 17 days

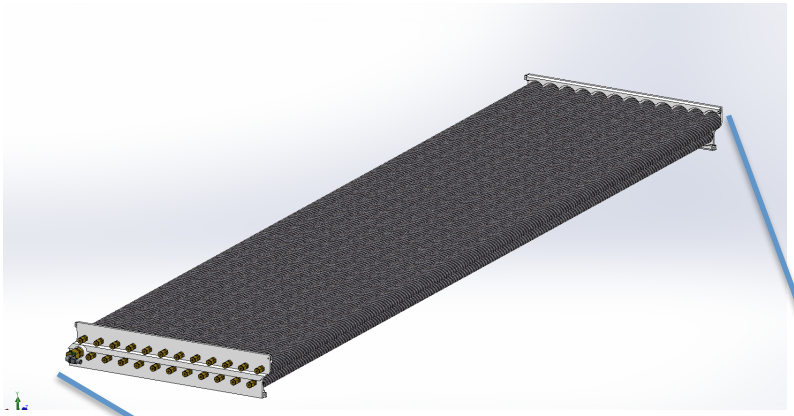
Lightweight detectors

- Need lightweight, modular detectors to be carried up narrow spiral staircases and to be hanged against the wall of the church

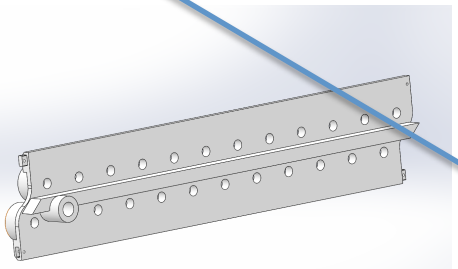
➔Carbon fiber drift tubes with conductive plastic endcaps

- 1 inch diameter tubes to reduce the overall thickness of each tracker to 1 ft
- 24 channel modules that can be carried independently and assembled into a detector in situ
- Detector construction funded by LANL LDRD program

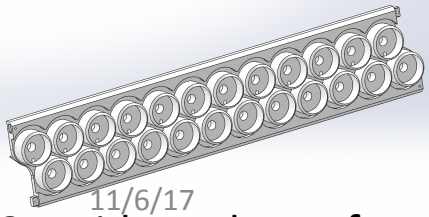
Detector model



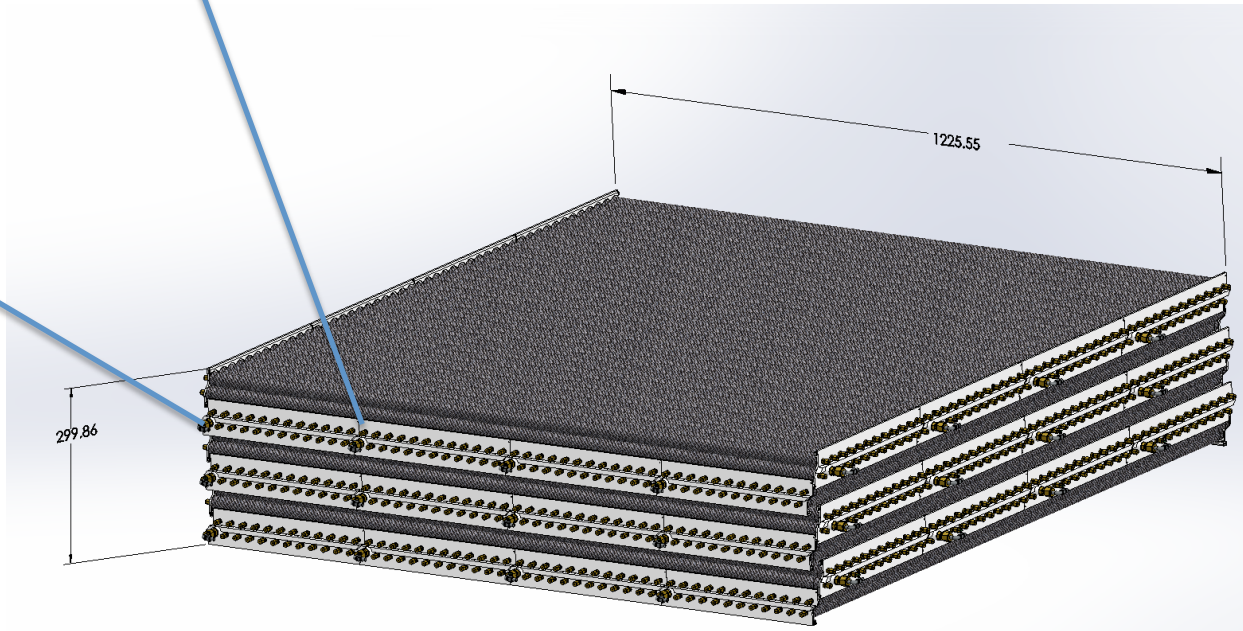
- Two trackers
- 24 modules in each tracker
- Gas manifold 3D printed in the endcap
- Endcaps printed using Selective laser Sintering (SLS) from conductive plastic
- Designed by former student Kenie Plaud-Ramos



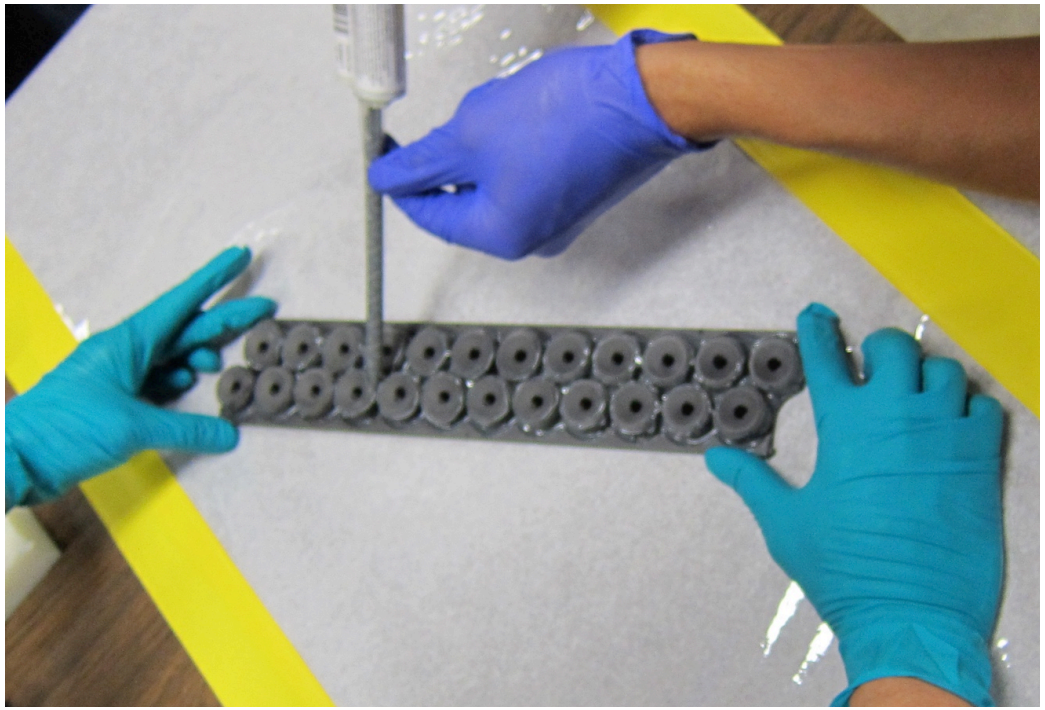
Gas side endcap - back

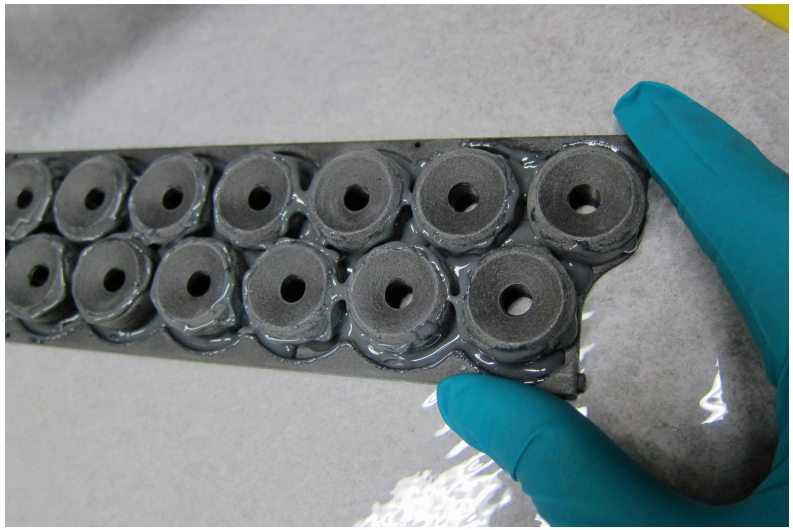


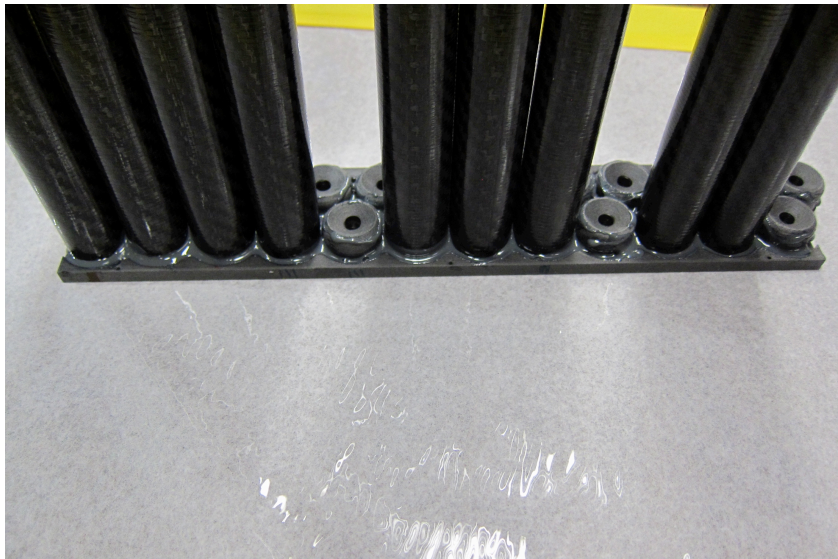
Gas side endcap - front



Detector assembly



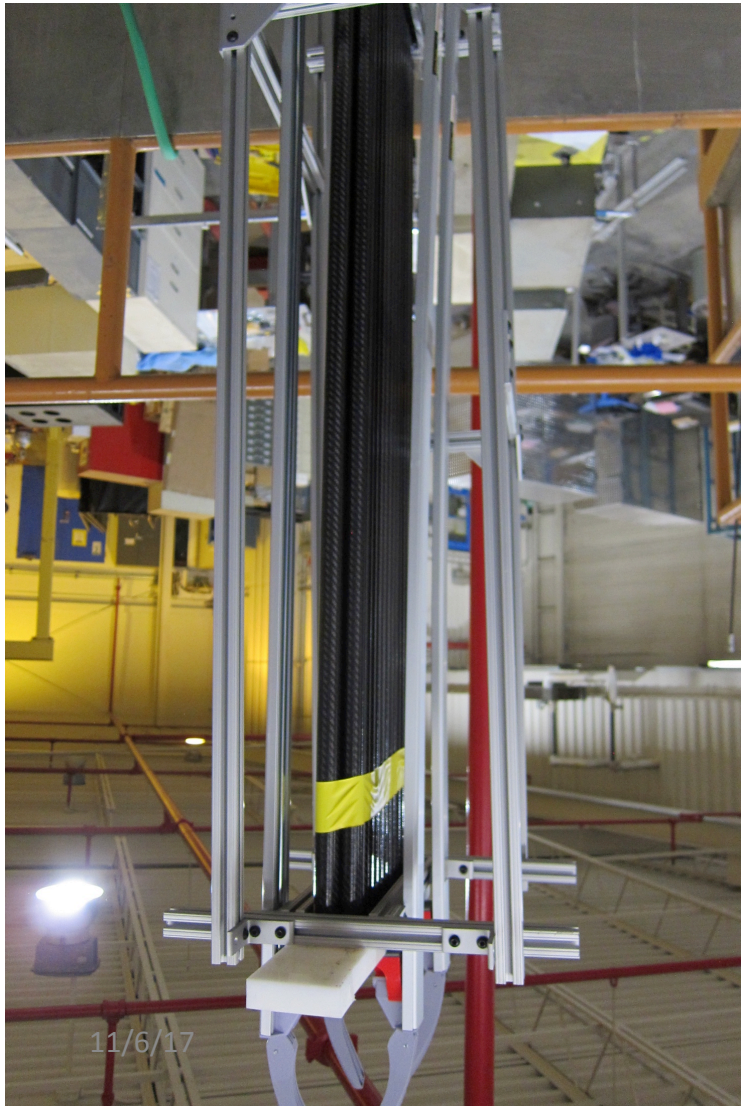


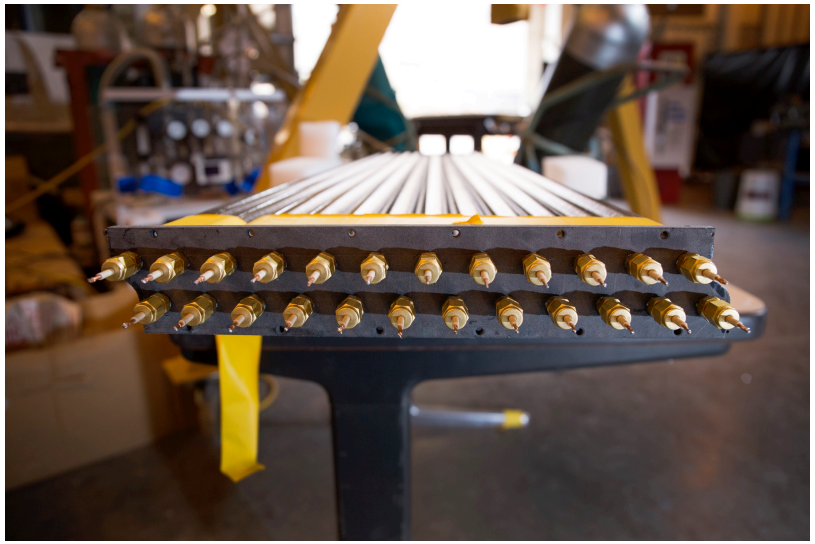


- Endcap glued to tubes with commercial glue, 3M DP190

Detector assembly

Kenie Plaud-Ramos, B.E. (Mechanical)





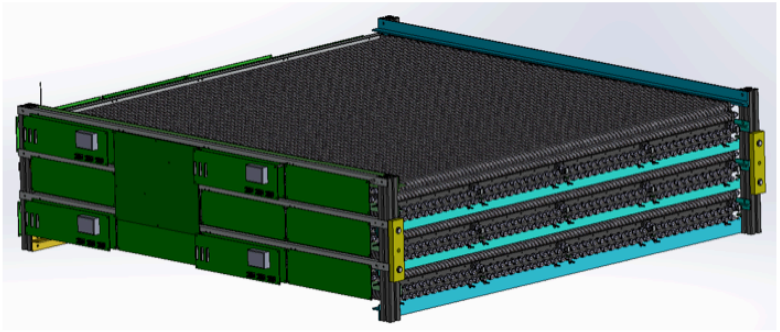
Assembly of the trackers

Jesse Fernandez – Mechanical Engineering Student, Georgia Institute of Technology

Support Structure

Detailed assembly manual

CARBON FIBER
MUON TRACKER
(CFMT) - MANUAL



Few easily available tools needed

Super module x1 bill of materials

MECHANICAL

Modules----------x24
2x1x.125" T bars----------x4
1x.5x.125" T bars----------x 10
1 ¼" 6-32 button cap screw fully threaded----------x 124
6-32 (5/16-7/64) hex nut ----------x124
Rubber mesh
2" ¼-20 hex head partially threaded screw----------x28
3" ¼-20 hex head partially threaded screw for hoist ring attachment ----------x4
1/4-20 hex nut 7/16 W-7-32 H----------x28

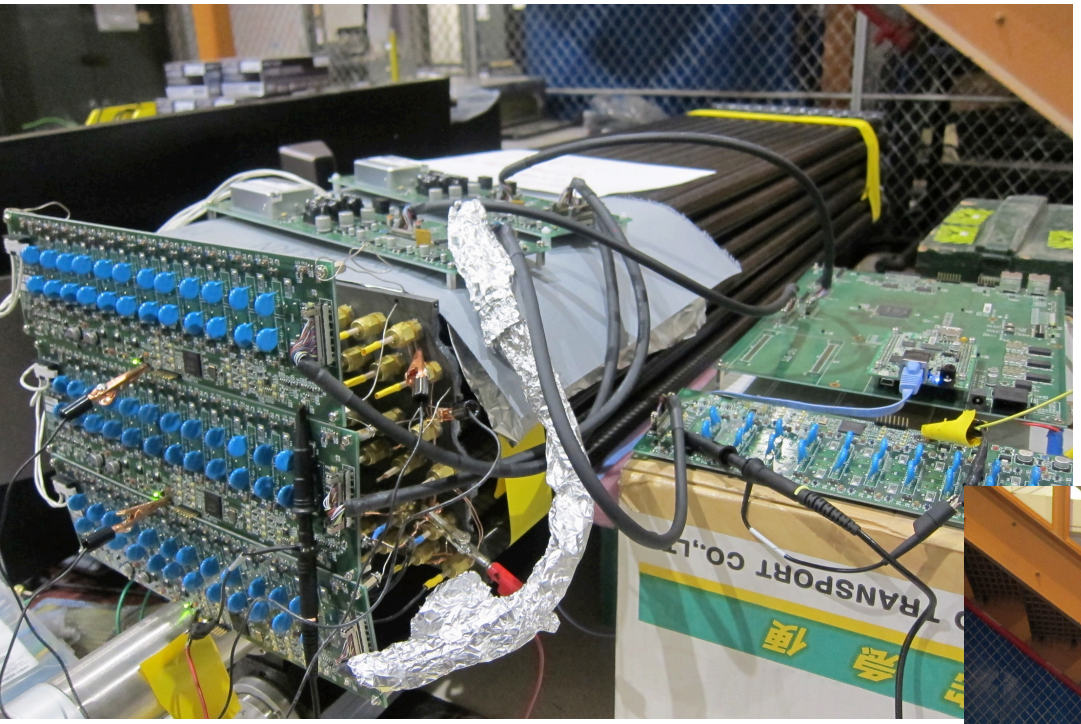
ELECTRONICS FRAME

.75x.75x.0625" aluminum T bars----------x 6
7/8" LG ¼" hex standoff Male-Female (6-32) Aluminum or plastic----------x86
3/8" 6-32 button cap screw fully threaded----------x64
6-32- plastic cap nut----------x68

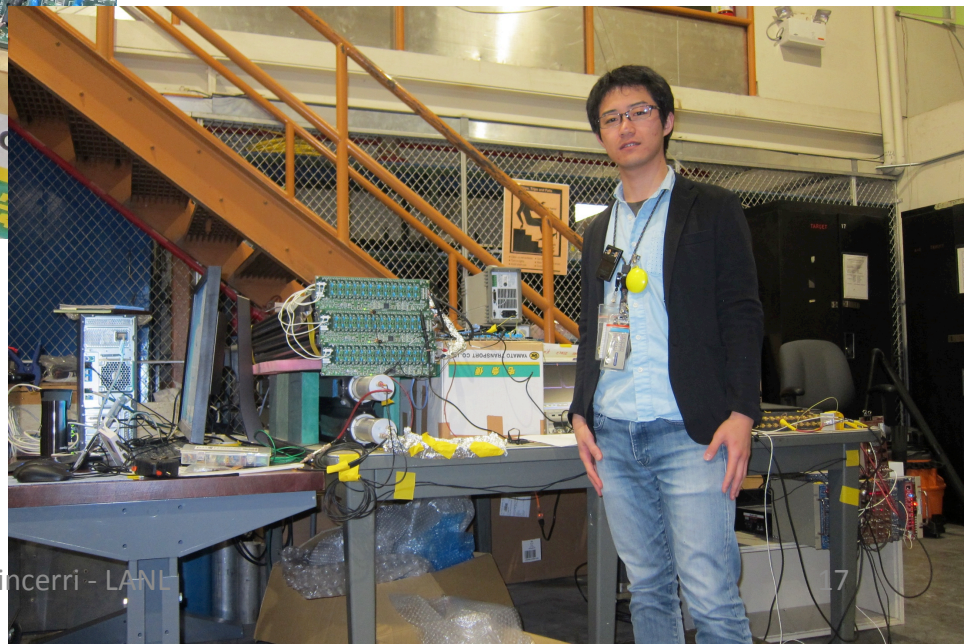
SHIELDING

2" kapton tape ---------- 40 ft.
2" Aluminum tape ---------- 20 ft.
1" aluminum tape ----------50 ft.
1" plastic spacer ID(.140") OD(5/16")----------x288
½" heat shrink (min after shrink 0.25) ----------x575 ft.

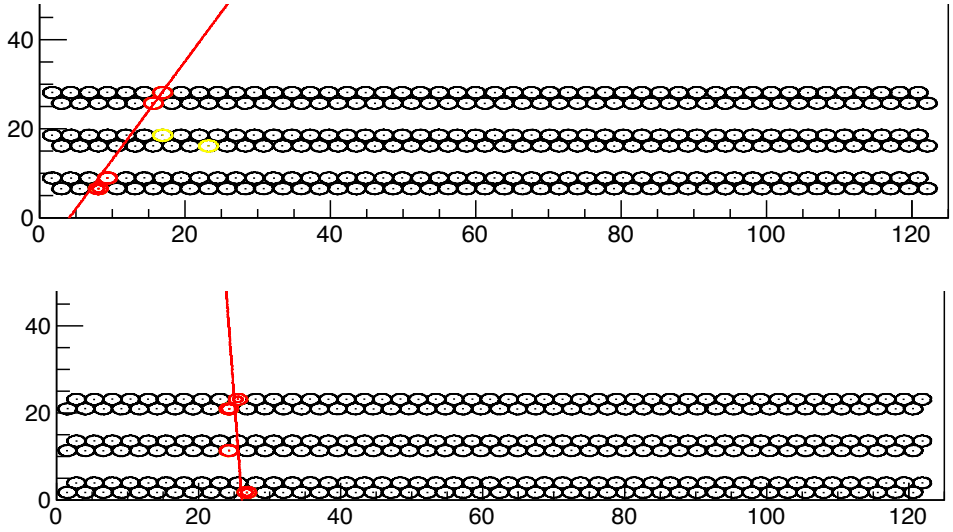
Toshiba Electronics



Takuro Fujimaki, Electrical Engineering Student, University of Yamanashi



First Tracks – June 2015



XZ projection

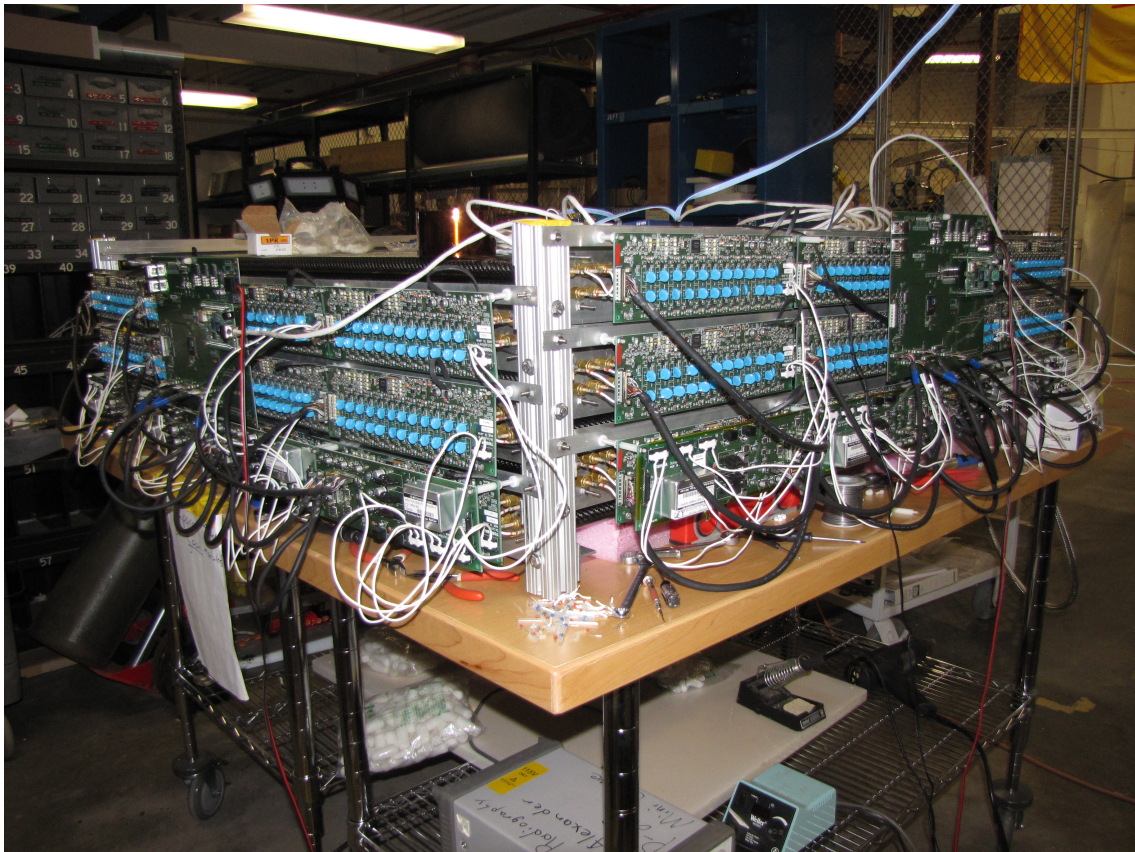
YZ projection

- Yellow: hits were discarded by tracker, likely due to delta rays or random coincidences
- Red: hits were considered.
  - diameter of the circle corresponding to the measured drift time also drawn.
- No systematic calibration of delay line and drift times
  - Will be done when detector is fully instrumented

Current status and plans

- The first tracker is assembled and the electronics is being mounted on it
- The second tracker is being assembled as the remaining modules are being re-tested

- Plan to take data and reconstruct tracks as soon as the electronics is mounted
- Once that is done the two trackers will be deployed on top of each other and an image of an object in the middle will be produced



The end