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Title: Concept of One-Sided Imaging of SNM Based on Muon-Induced Fission Detection

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Concept of One-Sided Imaging of SNM Based on Muon-Induced Fission Detection

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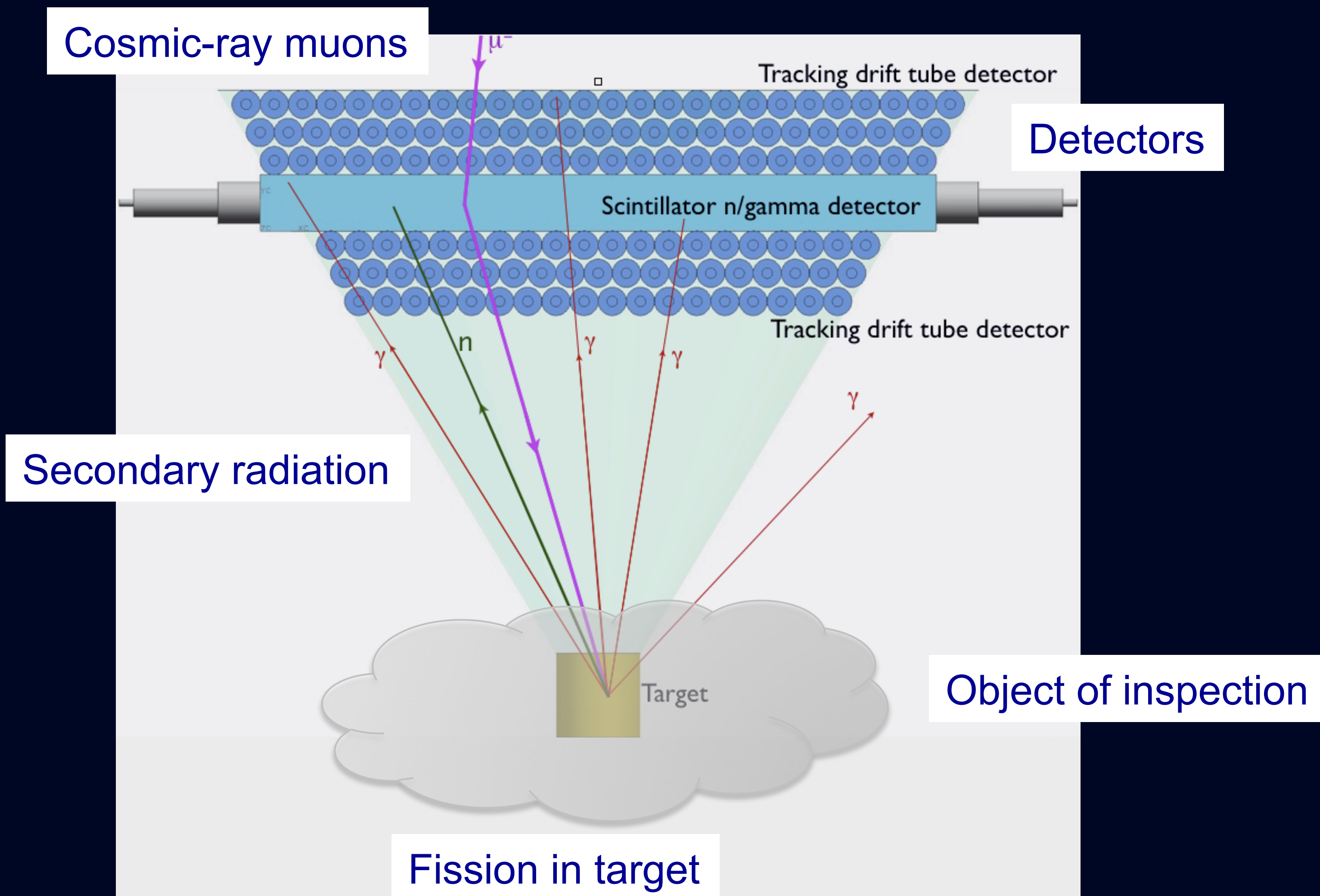
Jeff Bacon

In collaboration with
Dave Schwellenbach and NSTec,
Mike Sossong and Decision Sciences

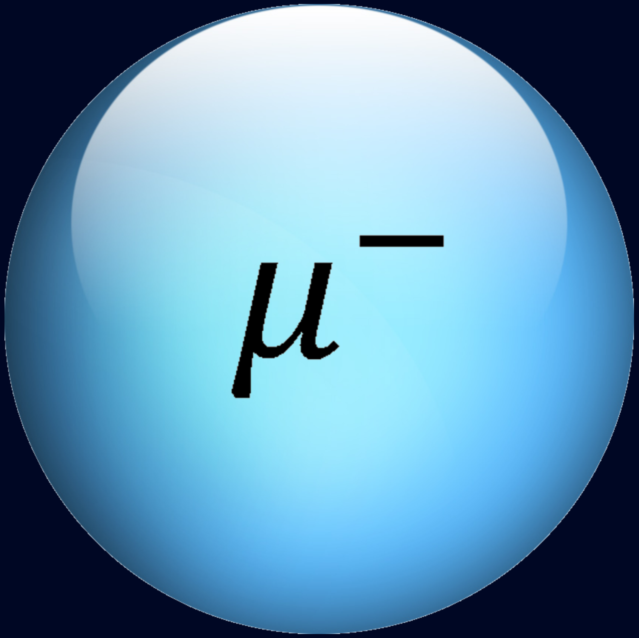
Los Alamos
NATIONAL LABORATORY
EST. 1943

Muon-Induced Fission Imaging Concept



Muon Tomography for Treaty Verification

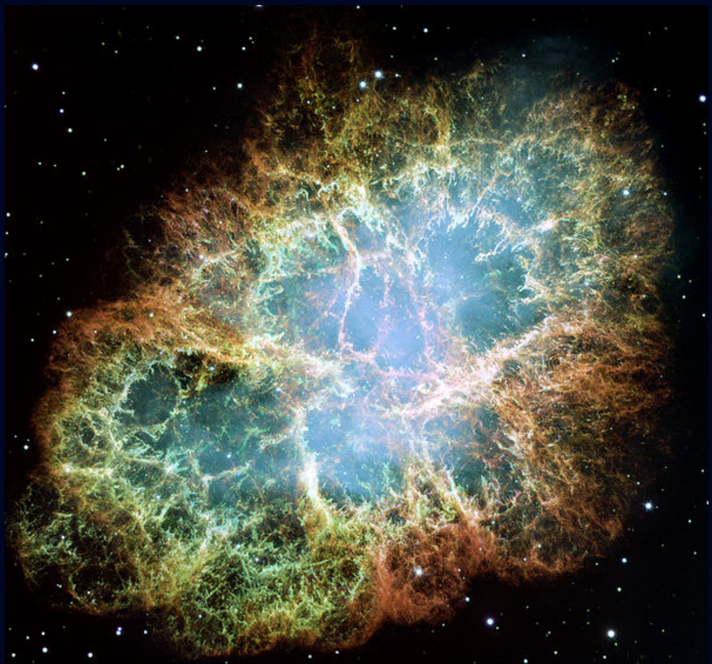
- Single sided imaging
- Distinctive of fissile material
- Passive interrogation
- Good fit for information barrier approach



Cosmic Rays: Where Do They Come From?

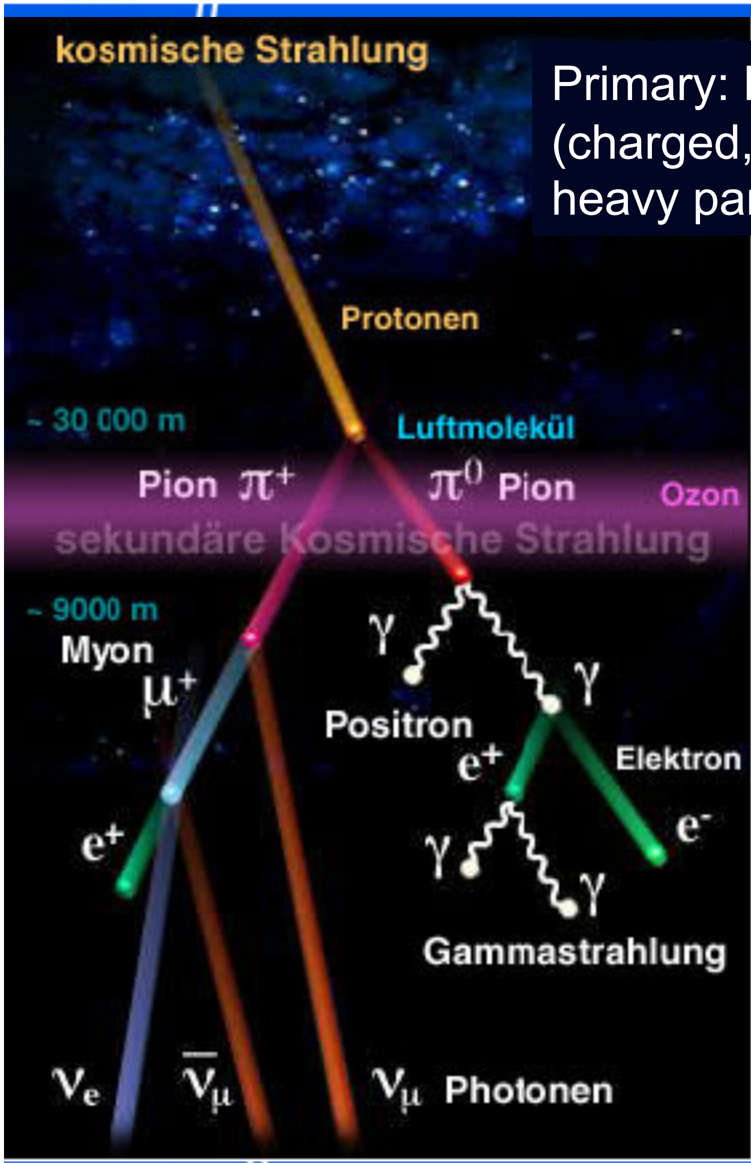
Victor Hess (1883 – 1964)
Nobel Prize in Physics 1936

- Discovered by Victor Hess in 1912
- Consist of mainly protons, electrons, and ions
- Ray acceleration can occur in strong magnetic fields from supernova blast wave remnants
- Energies range from MeV to beyond TeV



Crab Nebula (SNR 1054 remnant)

Cosmic Rays Conversion In Atmosphere



Primary: Mostly **protons** (charged, strongly interacting heavy particles, ~99%)

Secondary: Mostly **muons** (charged, EM-interacting heavy particles, ~70%) and electrons (charged, EM-interacting, light particles, ~30%). Neutrinos are weakly interacting and can be ignored.

Rate at sea level:

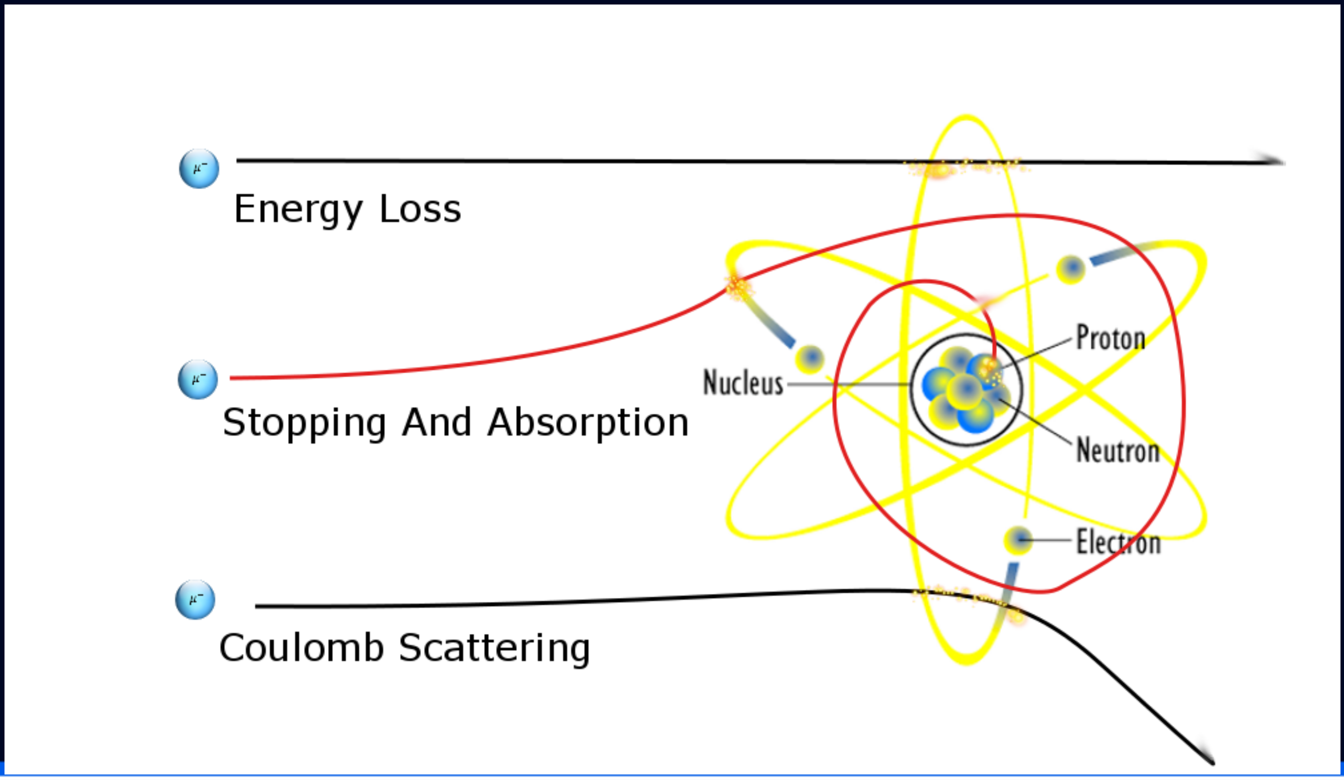
~1 per minute through your fingernail

~1 per second through your open hand

~ 10,000 per sq. meter per minute

Muon Interactions In Materials

- Energy loss
- Multiple scattering
- Stopping and absorption



Cosmic-Ray Muons Penetrate Large Objects

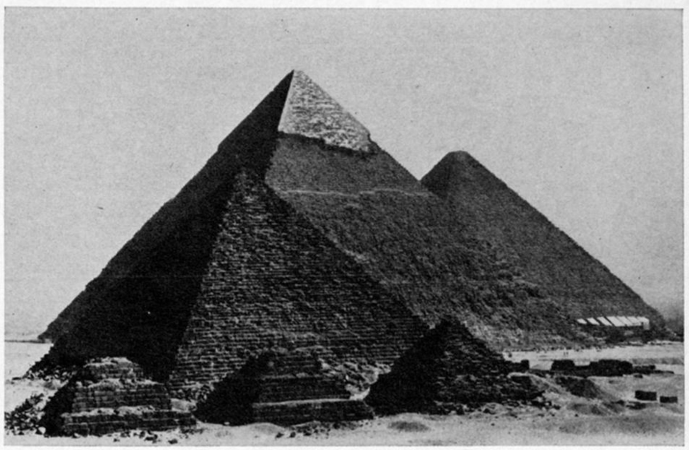
Searching for Hidden Chambers in Pyramids

Fig. 1 (top right). The pyramids at Giza. From left to right, the Third Pyramid of Mycerinus, the Second Pyramid of Chephren, the Great Pyramid of Cheops. [© National Geographic Society]

Luis Alvarez, et. al.
Science **167**, 832 (1970)

Arturo Menchaca, et. al.
current effort, see

http://www.msnbc.msn.com/id/4540266/



Muon attenuation radiography – Well established since the mid 1900s

Measuring Tunnel Overburden

Commonwealth Engineer, July 1, 1955 455

Cosmic Rays Measure Overburden of Tunnel

● Fig. 1—Geiger counter "telescope" in operation in the Guthega-Munyang tunnel. From left are Dr. George and his assistants, Mr. Lehane and Mr. O'Neill.

Geiger counter telescope used for mass determination at Guthega project of Snowy Scheme . . . Equipment described

By Dr. E. P. George*
University of Sydney, N.S.W.

Predicting Volcanic Eruptions

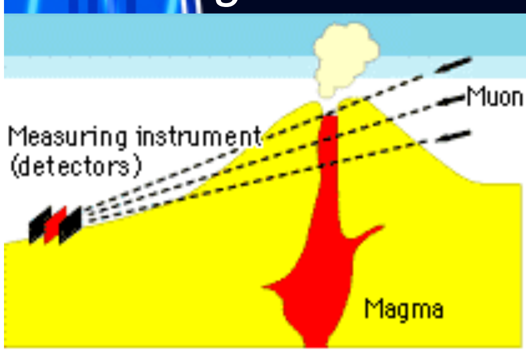
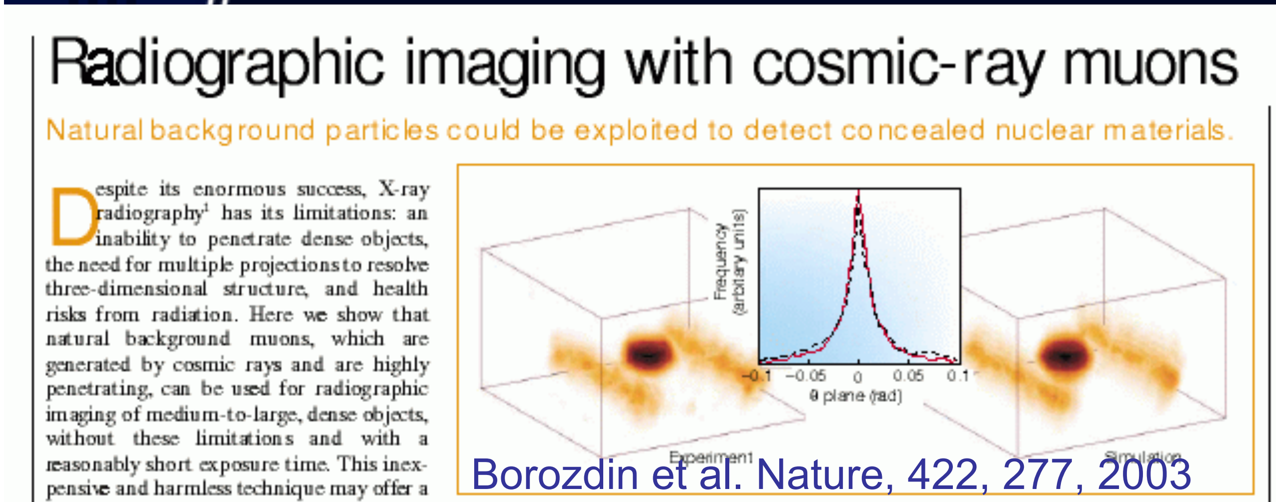


Figure 4: Analyzing the internal structure of a volcanic zone using muons

Tanaka, Nagamine, et. al.
Nuclear Instruments and Methods A **507**:3, 657 (2003)

Muon Scattering Can Be Used to Find SNM



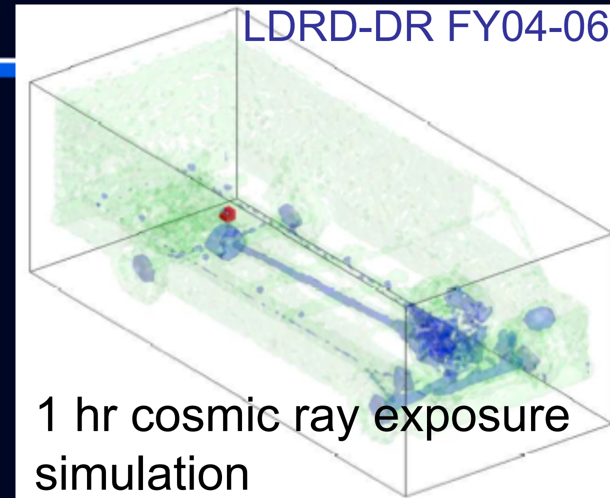
Radiographic imaging with cosmic-ray muons

Natural background particles could be exploited to detect concealed nuclear materials.

Despite its enormous success, X-ray radiography[1] has its limitations: an inability to penetrate dense objects, the need for multiple projections to resolve three-dimensional structure, and health risks from radiation. Here we show that natural background muons, which are generated by cosmic rays and are highly penetrating, can be used for radiographic imaging of medium-to-large, dense objects, without these limitations and with a reasonably short exposure time. This inexpensive and harmless technique may offer a

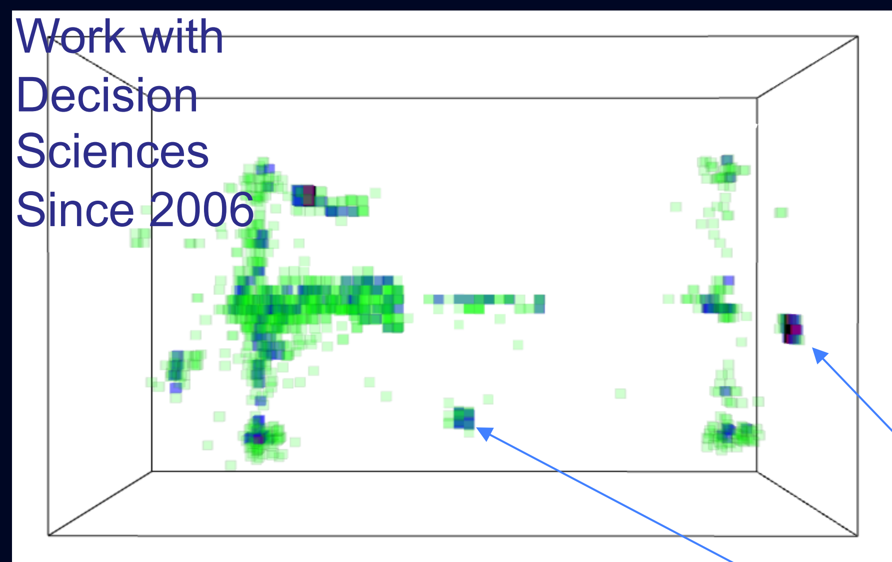
Borozdin et al. Nature, 422, 277, 2003

LDRD-DR FY04-06



1 hr cosmic ray exposure simulation

Work with Decision Sciences Since 2006

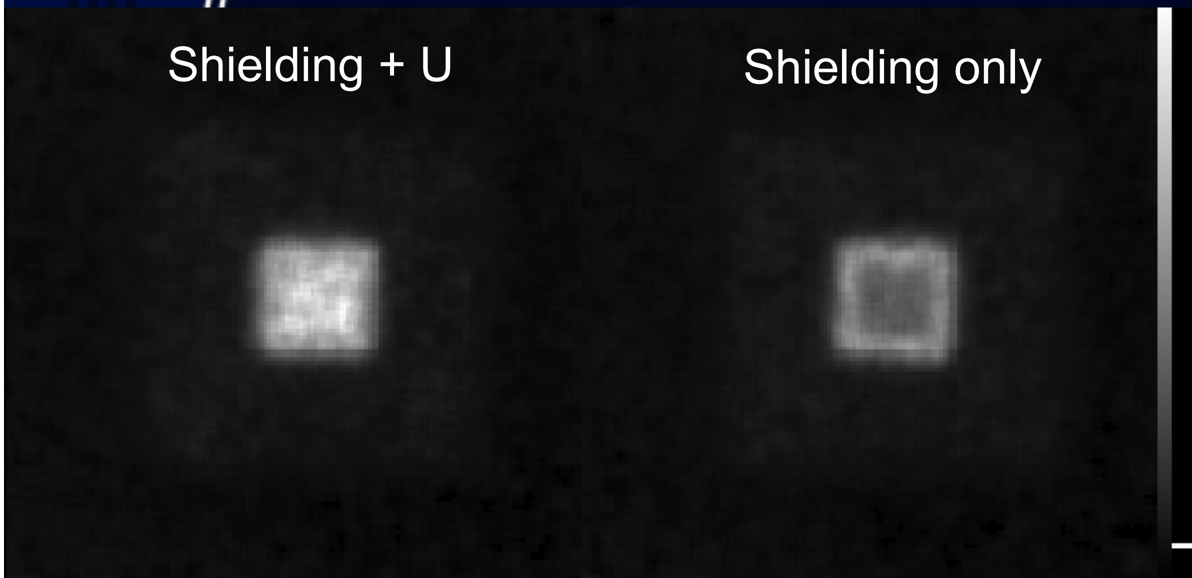


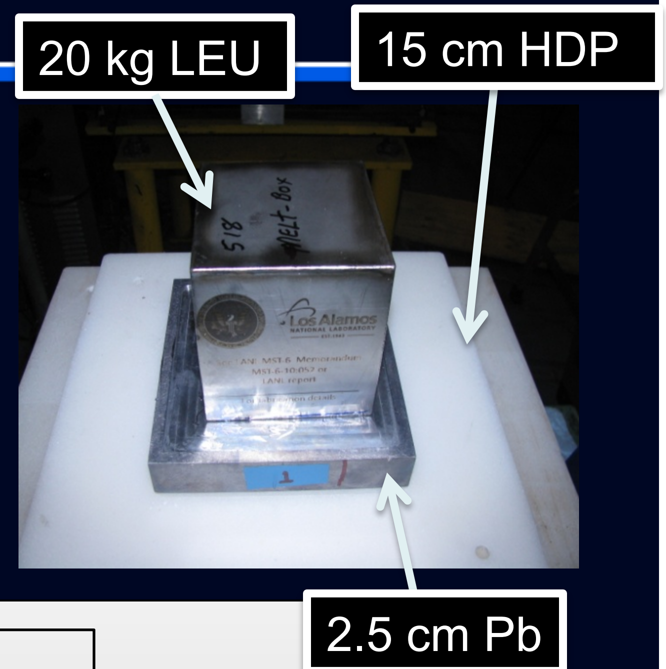
Pb

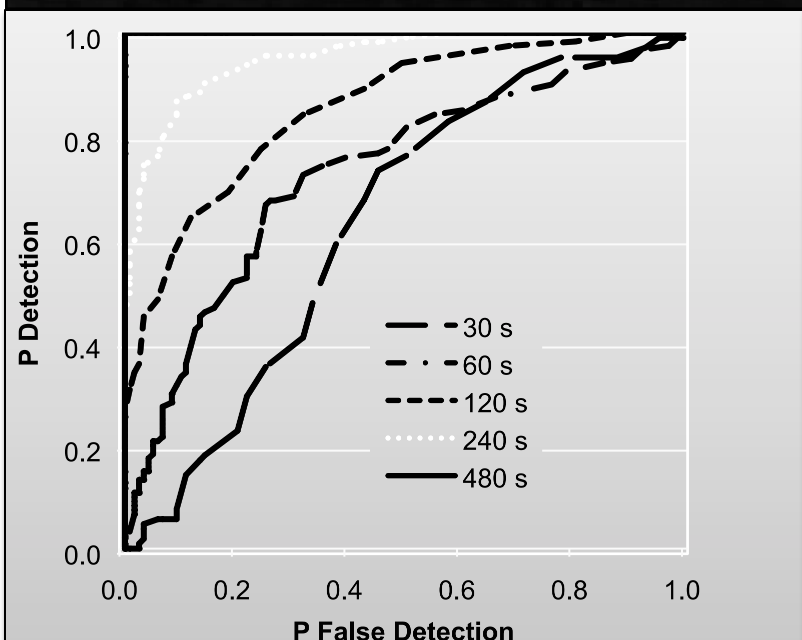
Fe

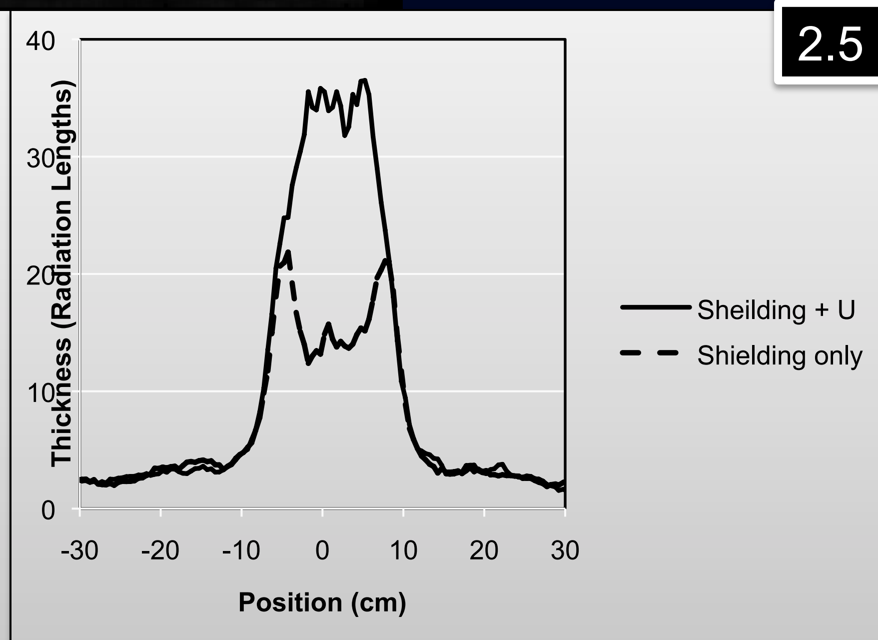
Reconstruction of Jeep with 3 objects

Detecting SNM Inside the Shielding



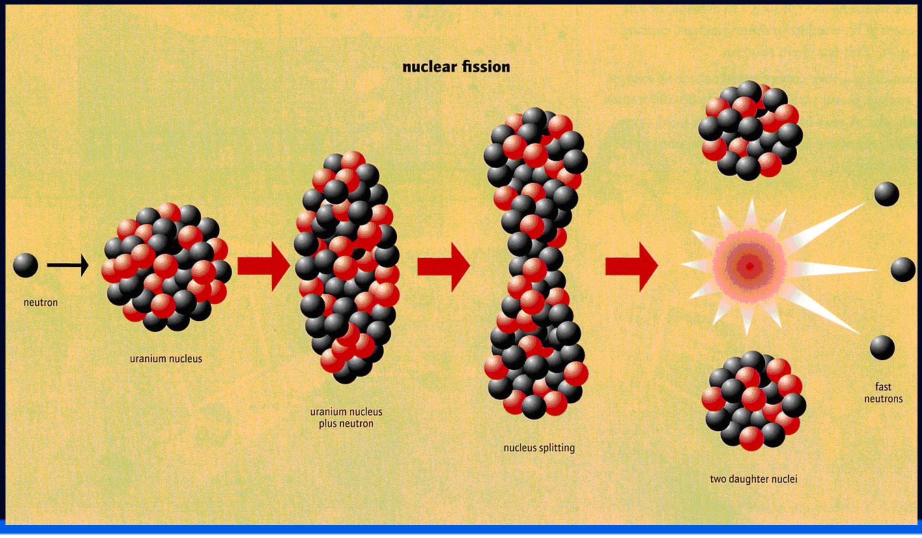






What Muons Do When They Stop

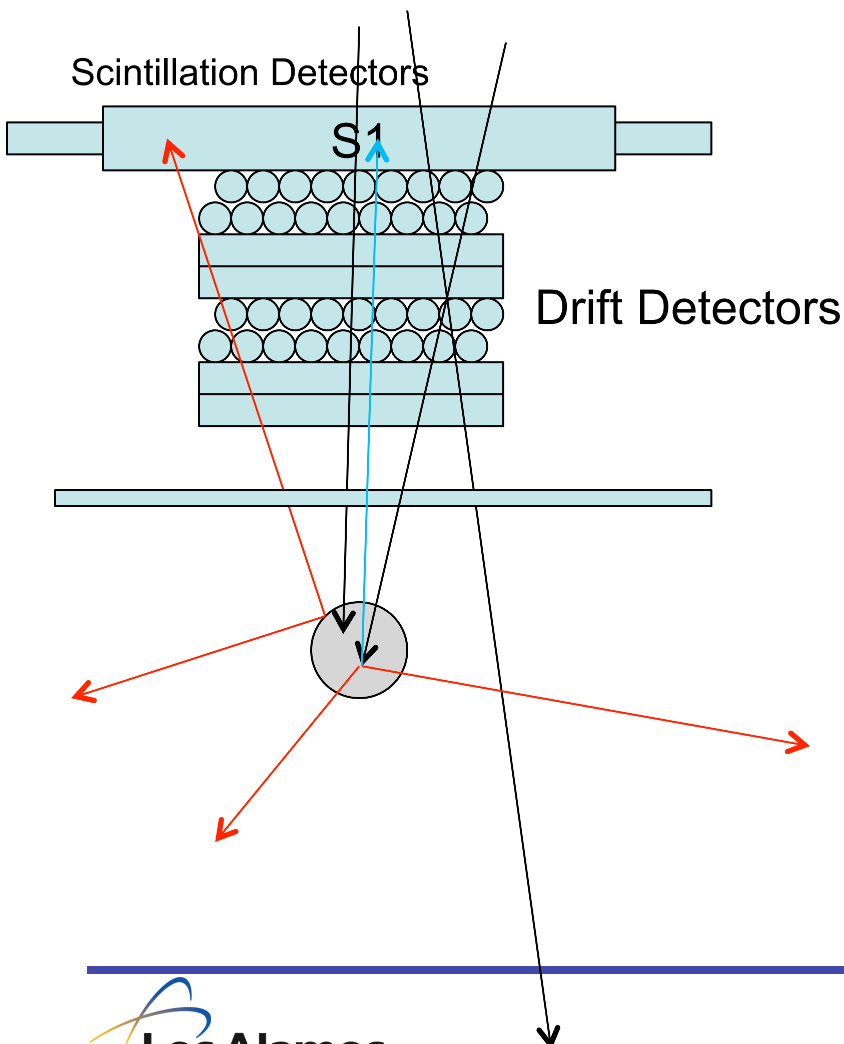
- Get an orbit and cascade down (all materials)
- Get captured by the nucleus, combine with a proton to form a neutron (increasingly high probability for higher Z)
- Nuclear in excited state, goes to main state emitting n, gammas (higher multiplicities for fissionable materials)
- Secondary fissions, chain reactions (for fissile materials)



Physics Works: Muon-Induced Fission Can Be Used to Identify SNM

- More muons stop in high-density material
- Muonic X-rays has higher energy = more penetrating for high-Z materials
- Fission is more likely, and fission products are more numerous
- Chain reaction is likely in fissile materials, not just a single event

Experimental Concept

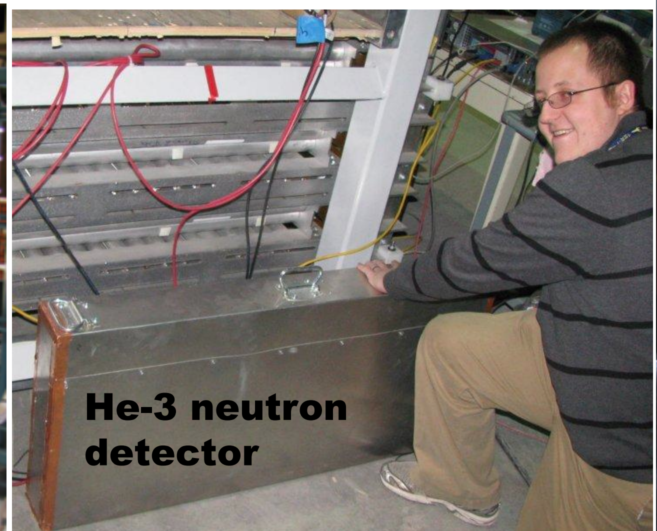


- Use charge particle tracking detectors to measure cosmic ray trajectories.
- Reconstruct dense objects with high stopping power and large secondary multiplicities using tomography.
- Measure fission radiation produced by μ^- stopped in fissile material (Det Eff ~ 100%).
- Ex:~6 μ^- captured/min in 20kg U
- Coincidence counting of resulting fission gammas and neutrons

  => ~ 10 min count time

Imaging of Cosmic Ray Muon-Induced Fission

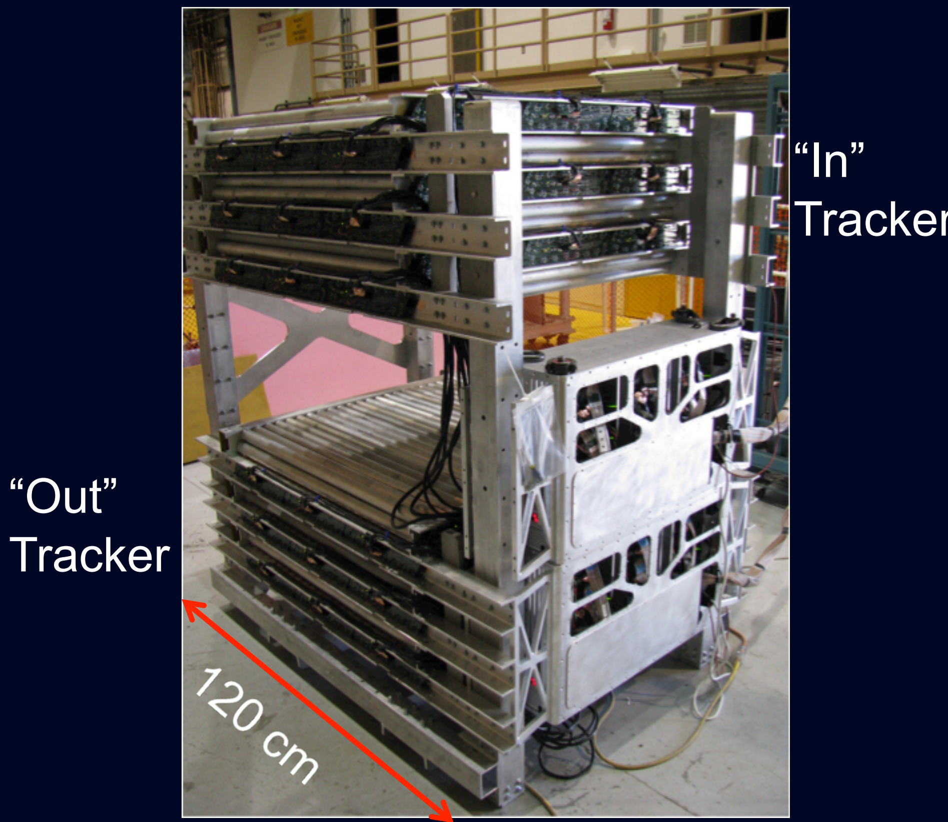
MMT
muon tracker



Mini-muon Tracker builds an image of cosmic-ray tracks. Coincidence with neutron counts localizes fissile material (uranium cube) in the image.

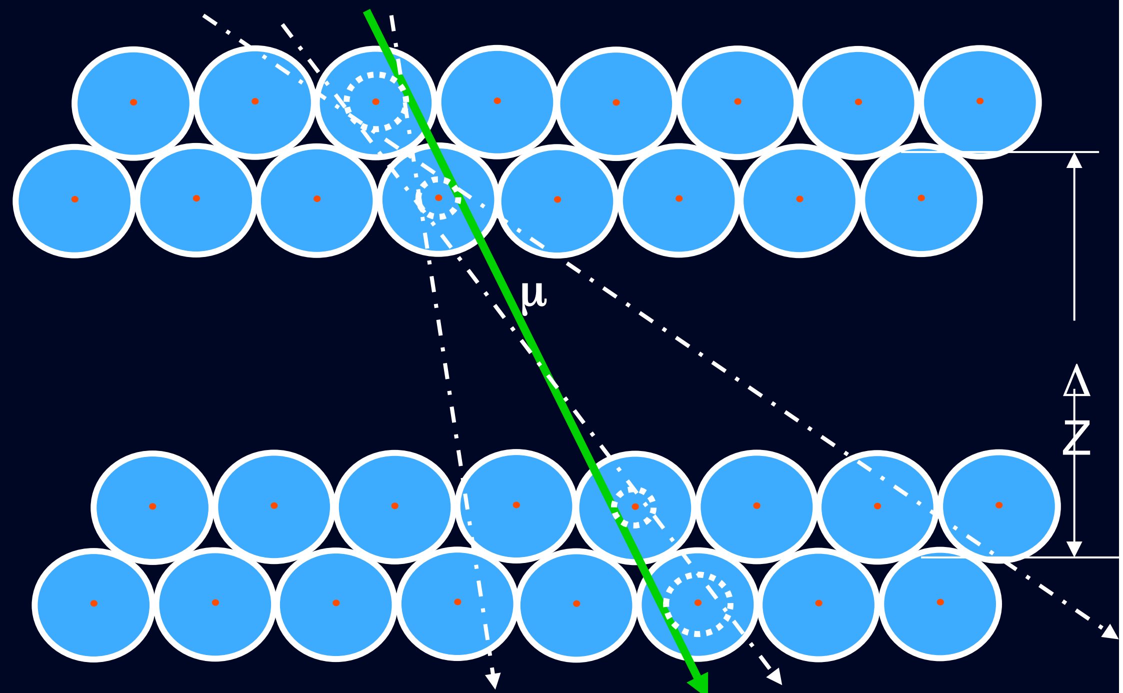
Muon Imaging Detectors

- 576 4-foot long and 2-inch diameter aluminum drift tubes
- Each tracker set has 3 x-y pairs of double planes, for a 12-fold tracking coincidence, in and out
- Neutron detector (“suitcase”: He-3 tubes, moderator, ~0.9 m x 0.5 m area) and gamma-detector (plastic bars with phototubes, ~1 m long x 10 cm^2) have been incorporated into the same data stream
- He-4 tubes are also being investigated



Imaging is Based on Tracking Individual Muons

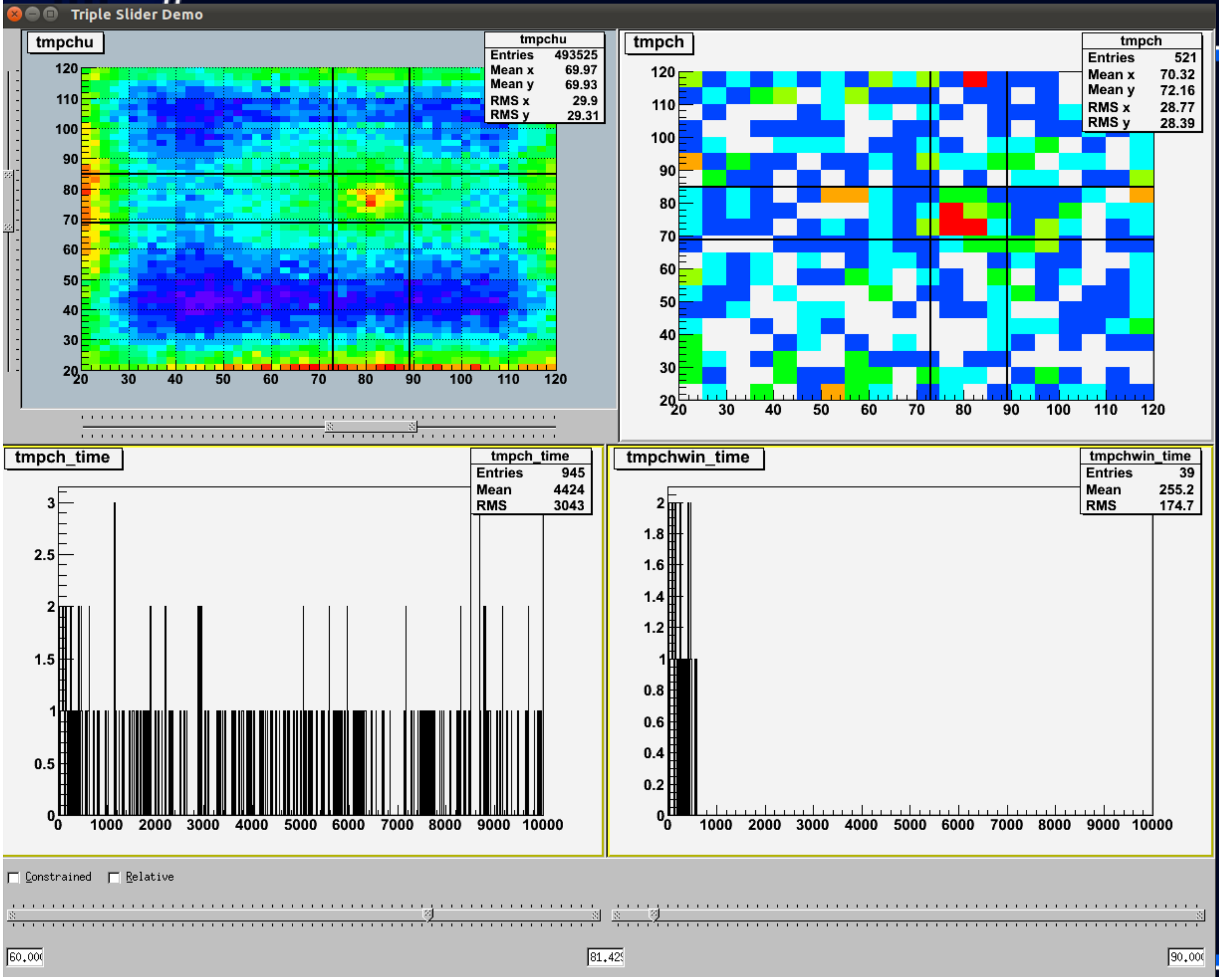
- Cylindrical drift tubes measure radial position of charged particles passing through
- Yields intercept and angle in two dimensions by interleaving tubes having axis oriented in x- and y- directions
- For tomography, banks of tubes are located above and below object to measure scattering angle (average scattering density)



Drift Tube Detectors Work in High-Radiation Field

May 25, 2012 – Fukushima Daiichi Nuclear plant

Muon Stopping and Coincidence

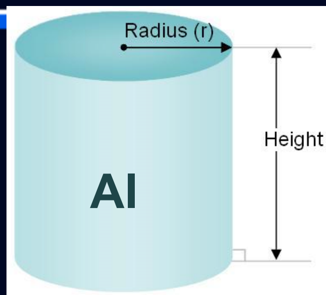


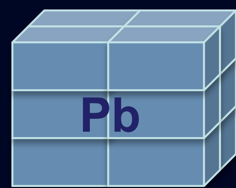
Analysis code processes raw data and creates stopped tracks and full tracks. The neutron timing is also embedded in the post-processed data stream.

The GUI displays the results and allows the user to select regions of interest along with controlling the projection space and timing parameters for neutron coincidence.

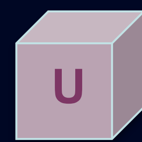
The data shown in this GUI is of an LEU block surrounded by a doghouse of poly. The He-3 detector box was located on top of the doghouse.

Material Identification

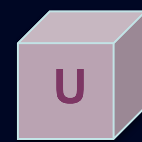




DU (^{238}U)



LEU (19.8% ^{235}U)



⃠16cm x 20 cm

20x10x15cm

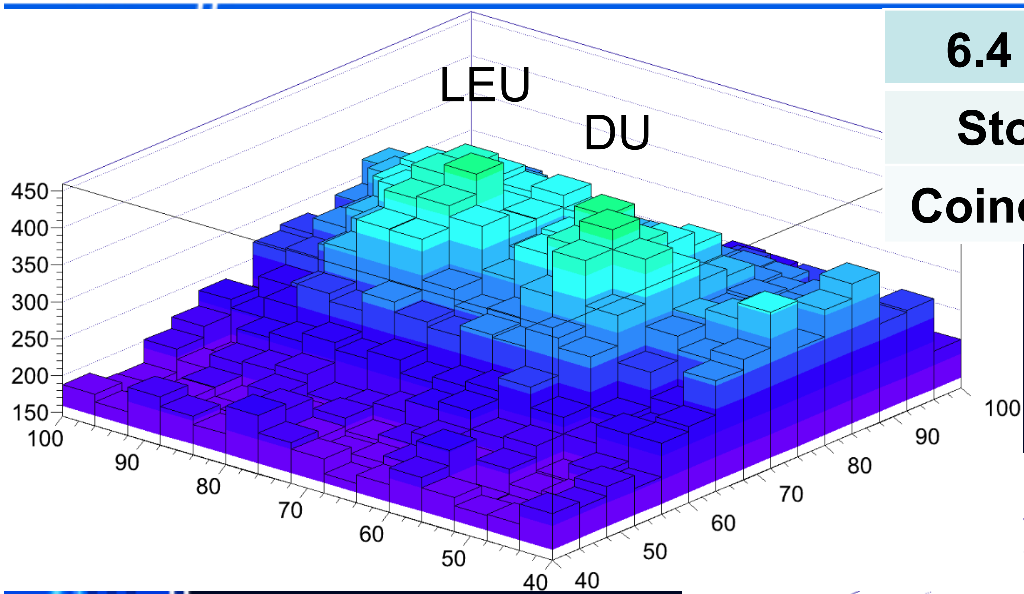
10cm^3

10cm^3

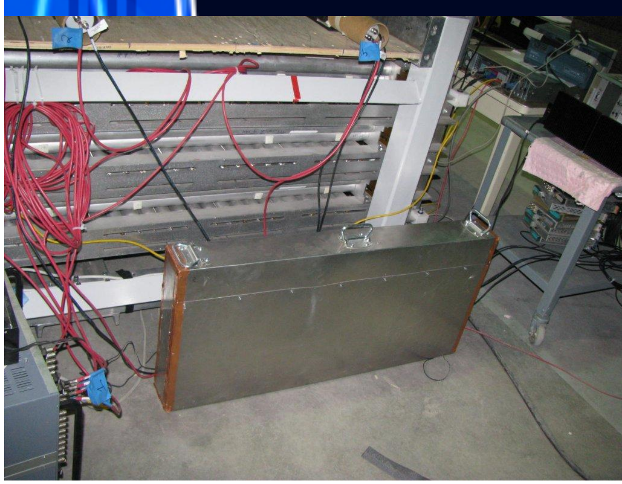
8 hours	Al	Pb	DU	LEU	Bkg
Stopped Tracks	22191	33918	24919	26150	8688
Coinc.(plastic)	695	1303	708	989	452
Coinc.(He-3)	169	260	206	254	48
Area (sq. cm)	400	600	484	484	288
n/stopped	0.0076	0.0077	0.0083	0.0097	0.0055

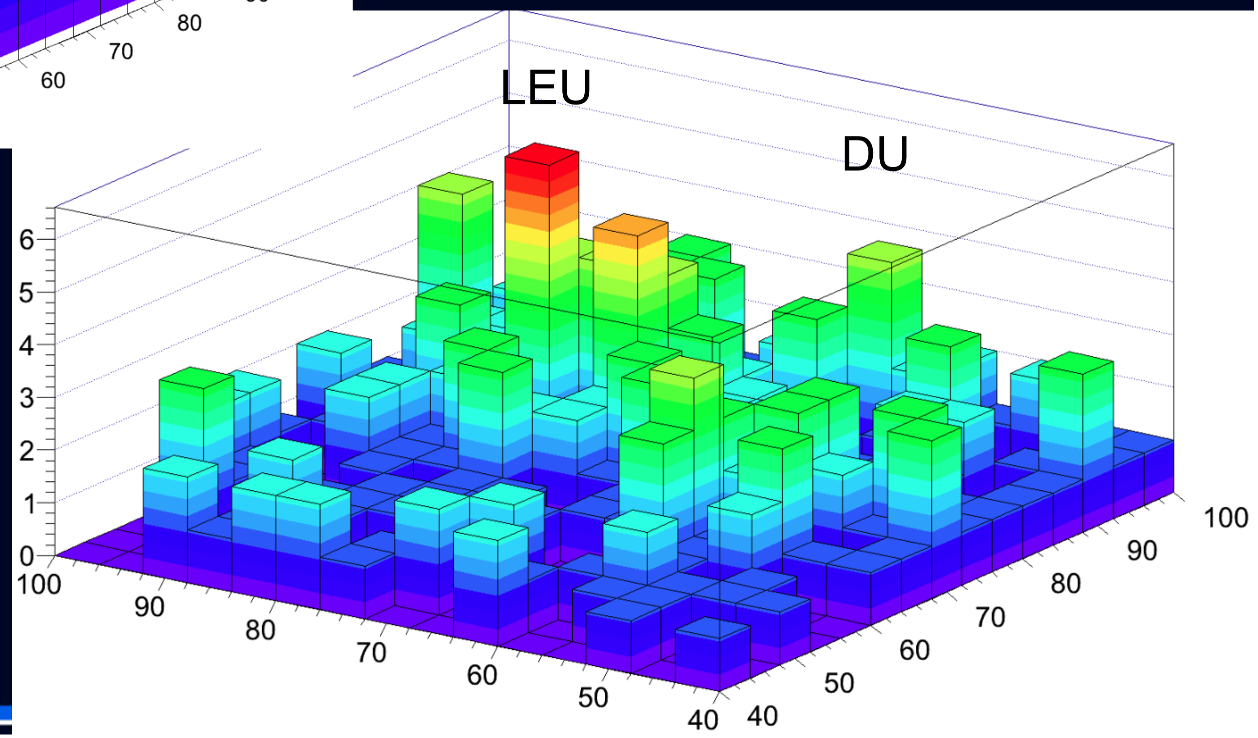
Uranium Isotope Discrimination With He-3

6.4 hours	LEU	DU	Bkg
Stopped	13255	13343	7599
Coincidence	77	68	29



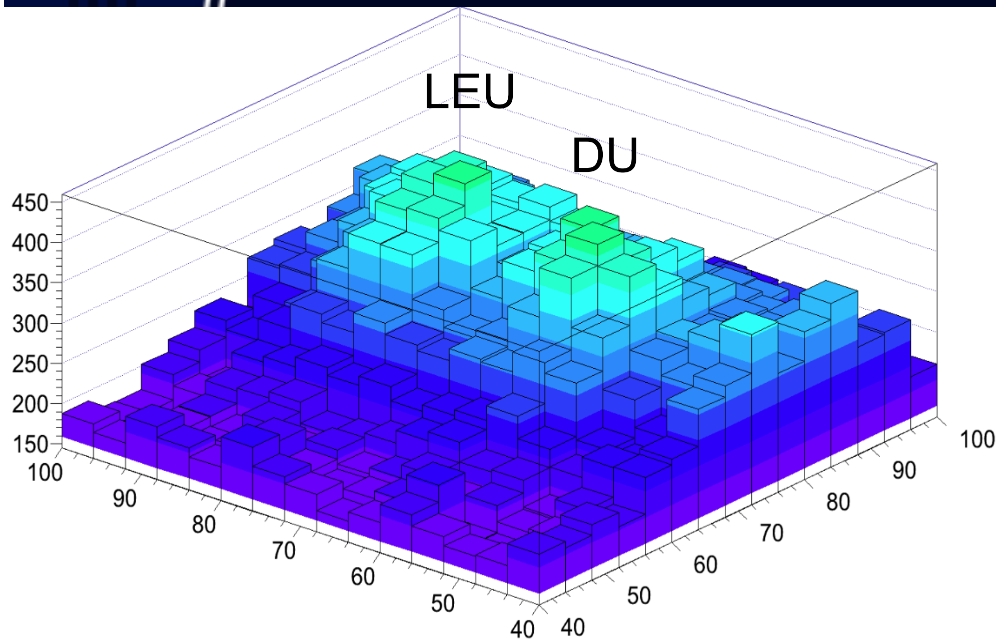
Coincidence 0-250 μs



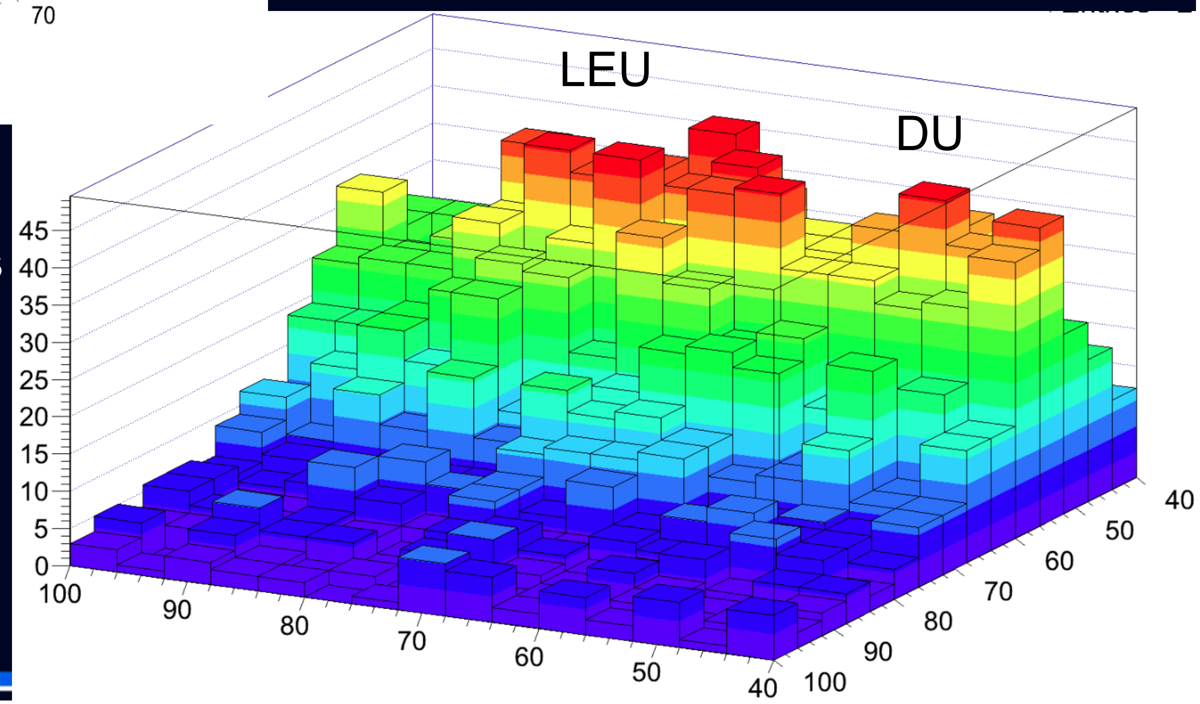


Uranium Isotope Discrimination with Scintillator

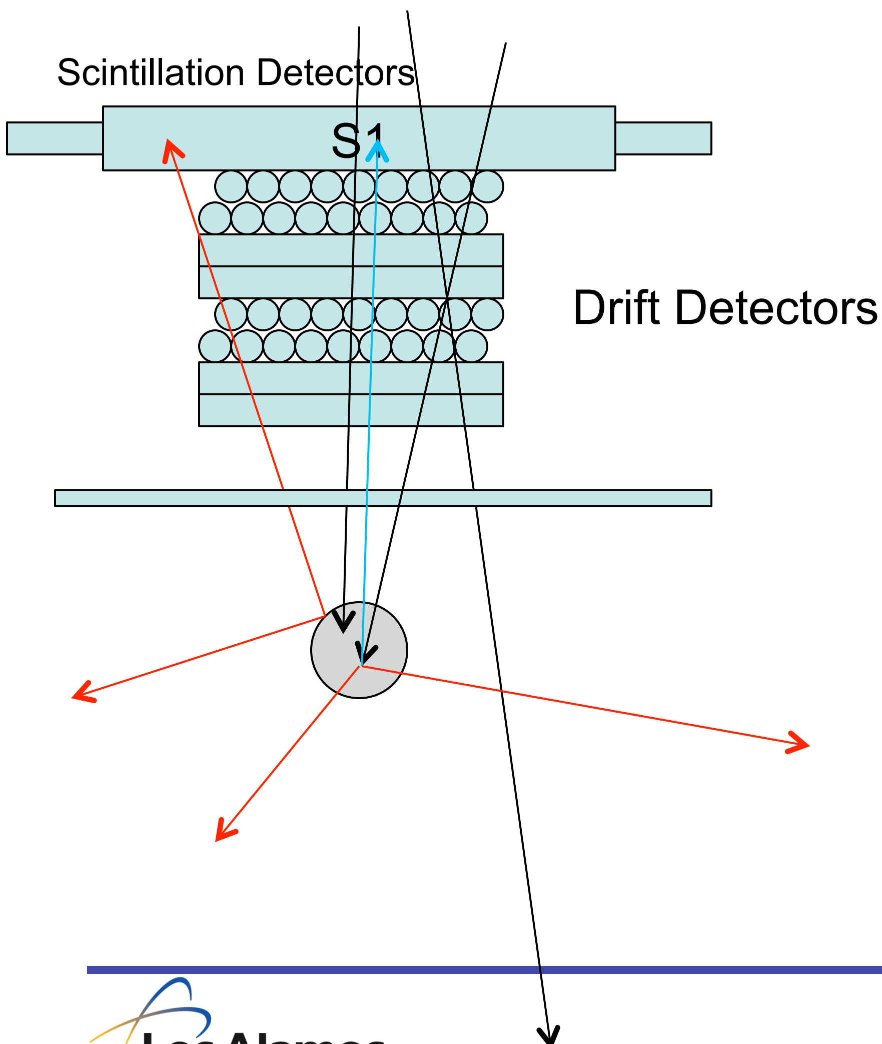
4 hours	LEU	DU	bgr
Stopped	13910	13273	13253
Coincidence	1002	854	219



Coincidence 100-400 ns



Feasibility Study – Phase I



Phase I (FY12 - $370k from DTRA and DoS to LANL)

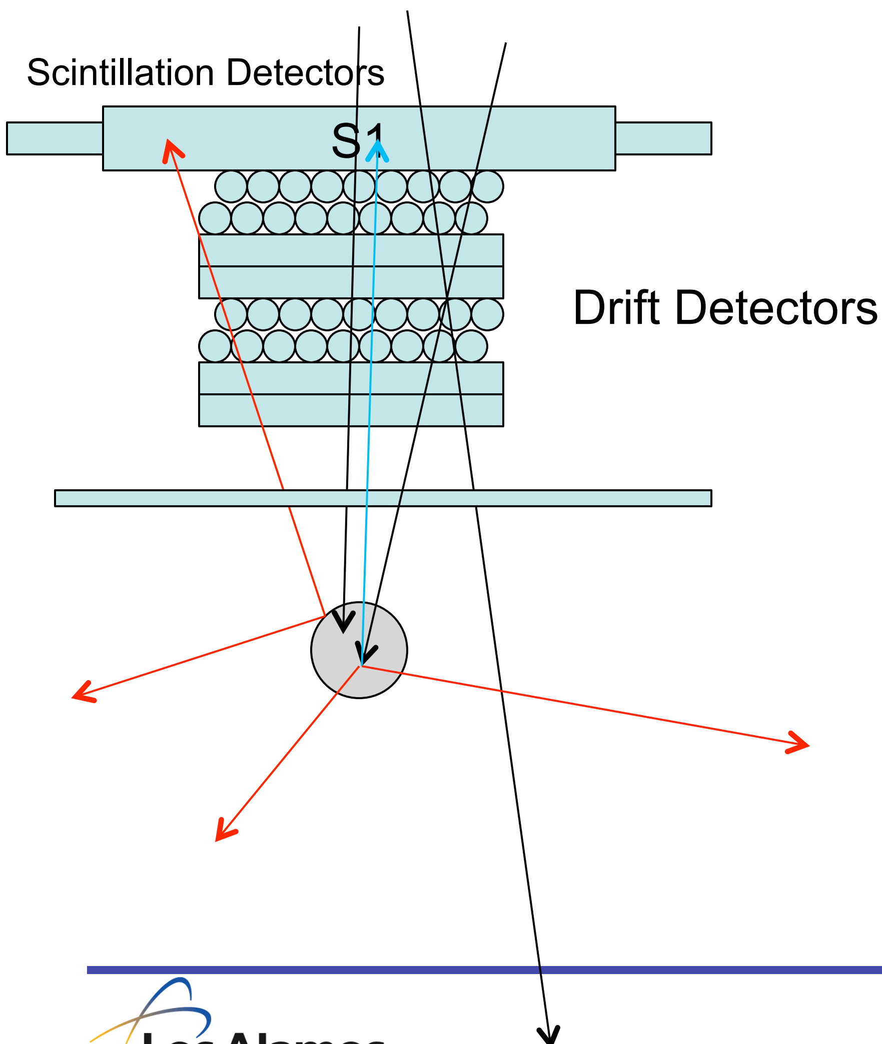
• Instrument prototype tracker and integrate two fission detectors - thermal neutron detector (He-3 based) and fast neutron/gamma detector (scintillator bars)

• Validation experiments with low enriched uranium (19 kg at 19.8% 235U):

  • demonstration of the imaging with cosmic-ray tracker

  • demonstration of material discrimination including DU/LEU discrimination

Feasibility Study – Phase II



FY12/13:

- Assessment of high-resolution γ-spectroscopy for cosmic-ray muon-induced fission
- Demonstration of one-sided imaging of muon-induced fission
- Experimental study of shielding effects
- Monte Carlo modeling (GEANT4, MCNPX) and validation of demonstration experiments
- Classified imaging of weapon mock-ups
- Develop information barrier approach for muon imaging

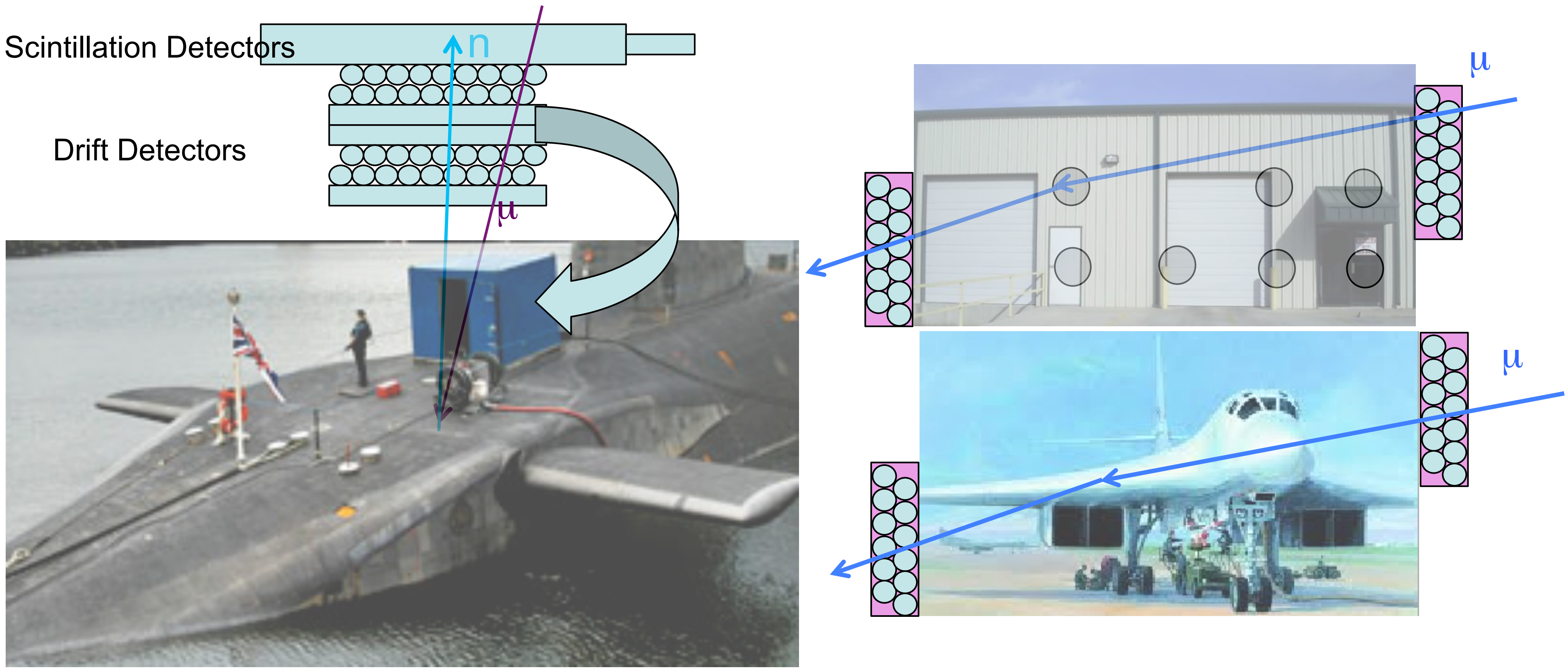
Feasibility Study – Phase III (FY13 and beyond)

- Build a realistic, portable hardware for field trials:
  - 6’ x 6’ muon tracker (to fit into standard shipping sea container for portability)
  - 6’ x 6’ secondary particle detector (scintillator)
  - cabling and integration
  - commissioning
- Perform extensive Monte Carlo capability study, high-performance computing at LANL or Berkeley
- Image reconstruction algorithm and software development, experimental data analysis
- Detailed plan for proof-of-concept demonstration
- Classified/unclassified imaging of realistic objects, proof-of-concept demo

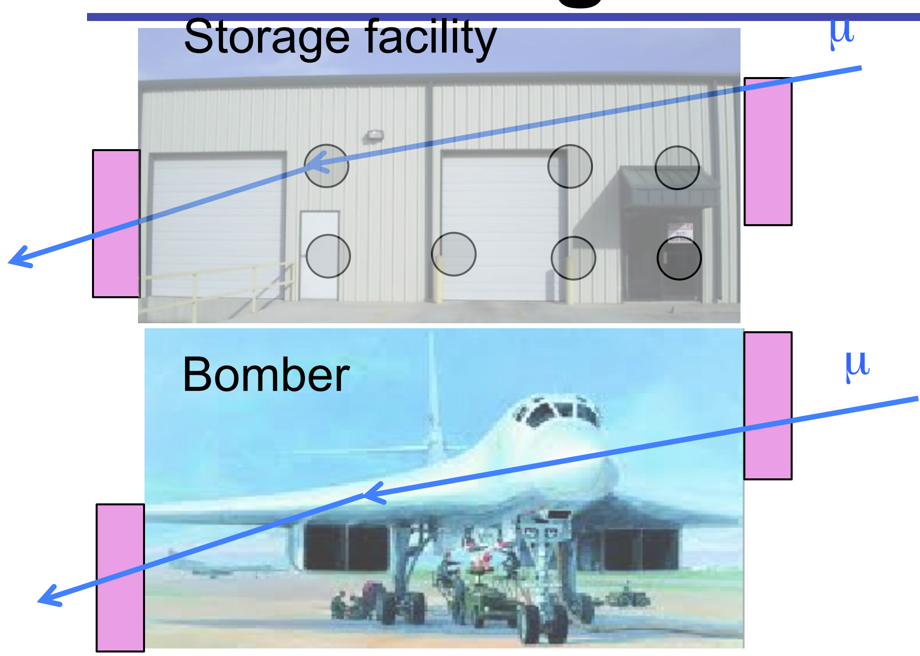
Path Forward

- Complete feasibility study then, if promising, proceed to proof-of-concept demonstration
- Proof-of-concept would involve field trials at Navy, Air Force strategic bases
- Also, this could be a candidate for joint technology development with Russia, other P-5 countries, anticipating future warhead counting arms control requirements; other P-5 countries already investigating muons for rad. detection

Toward Practical Applications



Storage/Bomber Verification



Cosmic-ray muon trackers can be used in one-sided of two-sided (shown) configuration to monitor/inspect both strategic bombers and storage facilities.

If this application is of interest, Los Alamos can perform a feasibility study including:

- experimental demonstration of two-sided and one-sided radiography of SNM inside a building
- Monte Carlo (GEANT4) modeling
- data analysis and reporting

Imaging Warheads for Treaty Verification

- Passive method: safe for humans and will not apply an artificial radiological dose to the warhead.
- Cosmic rays are much more penetrating than gamma or x-rays. Warheads can be imaged behind significant shielding and dense components of the warhead can be penetrated.
- Exposure times ultimately depend on the object and detector configuration. An object can be inspected in its container.
- While the presence of the SNM can be reliably confirmed, and discrete SNM objects can be counted and localized, the system can be designed to not reveal potentially sensitive details of the object design and composition.
- The detectors are scalable and portable, and have been demonstrated to operate for several month with little or no human intervention. The drift tubes of the detectors are sealed and do not need gas replenishment. Gas is not flammable. Detection and localization of SNM is achieved with automatic reconstruction algorithms, which can be run at a standard PC computer.
- The detectors have been demonstrated to be sensitive to gamma-rays offering gamma emitter source and distribution information. The tubes are also configured to detect neutrons giving additional capability for the detection of SNM.

Acknowledgements

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LDRD program at LANL

DHS/DNDO
Department of State
DTRA

Summary

- We demonstrated SNM imaging with cosmic ray muons
- Stopped negative muons are captured by nuclei and cause fission in actinides
- We experimentally showed muon-induced fission imaging
- We demonstrated material and isotope identification
- We have performed classified imaging of nuclear weapons trainers