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Title: Neutron and Gamma Coincident Muon Tracking for SNM Identification (Powerpoint)

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Neutron And Gamma Coincident Muon Tracking For SNM Identification

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In collaboration with NSTec and Decision Sciences

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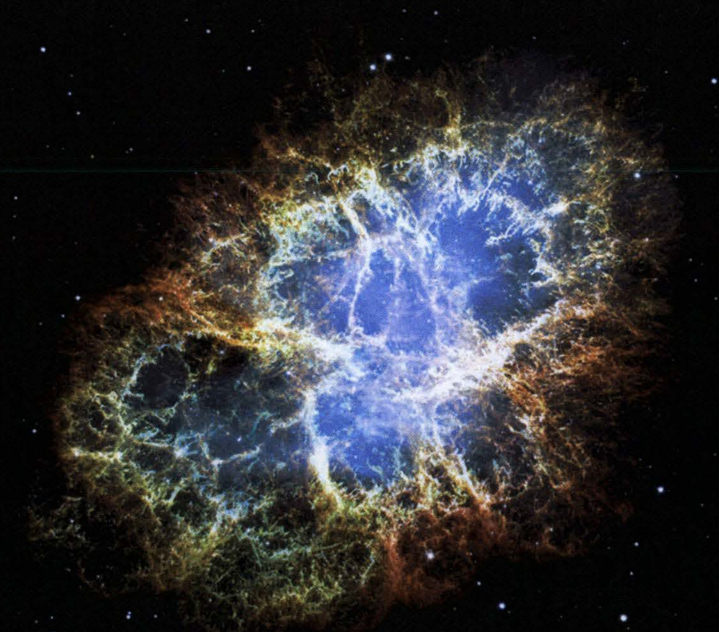
Cosmic Rays: Where Do They Come From?

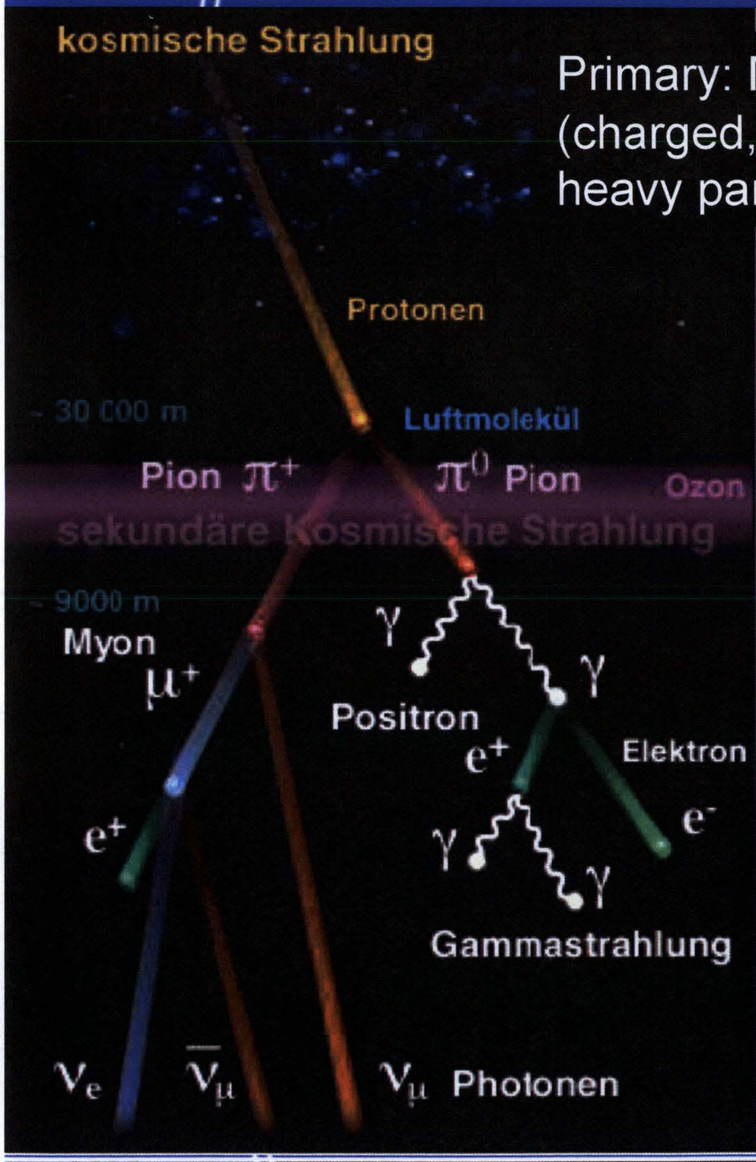
- Discovered by Victor Hess in 1912
- Consist of mainly protons, electrons, and ions
- Ray acceleration can occur in strong magnetic fields from supernova blast wave remnants
- Energies range from MeV to beyond TeV

Victor Hess (1883 – 1964)



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:

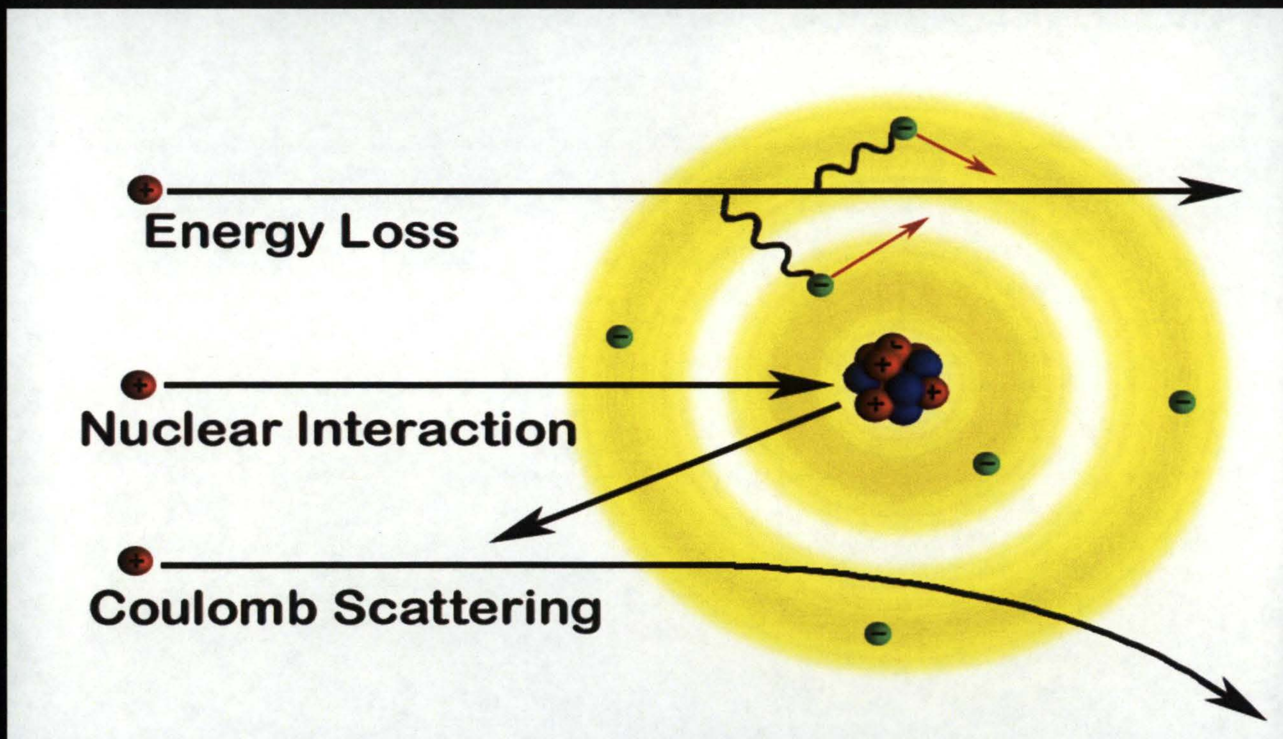
~1 per minute through your fingernail

~1 per second through your open hand

~ 10,000 per sq. meter per minute

Muon Interactions In Materials

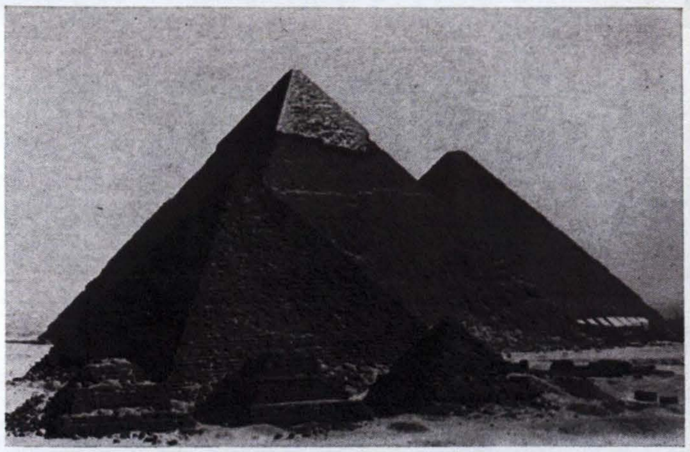
- Energy loss
- Multiple scattering
- Stopping and absorption



Muon Attenuation Radiography: 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/

Predicting Volcanic Eruptions

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

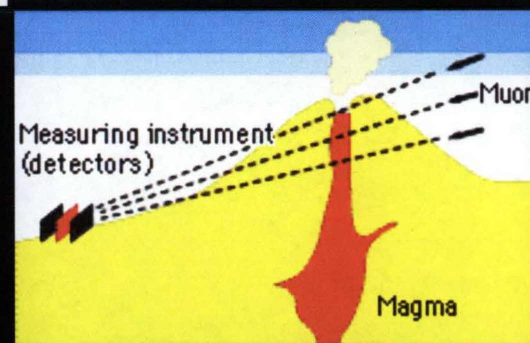
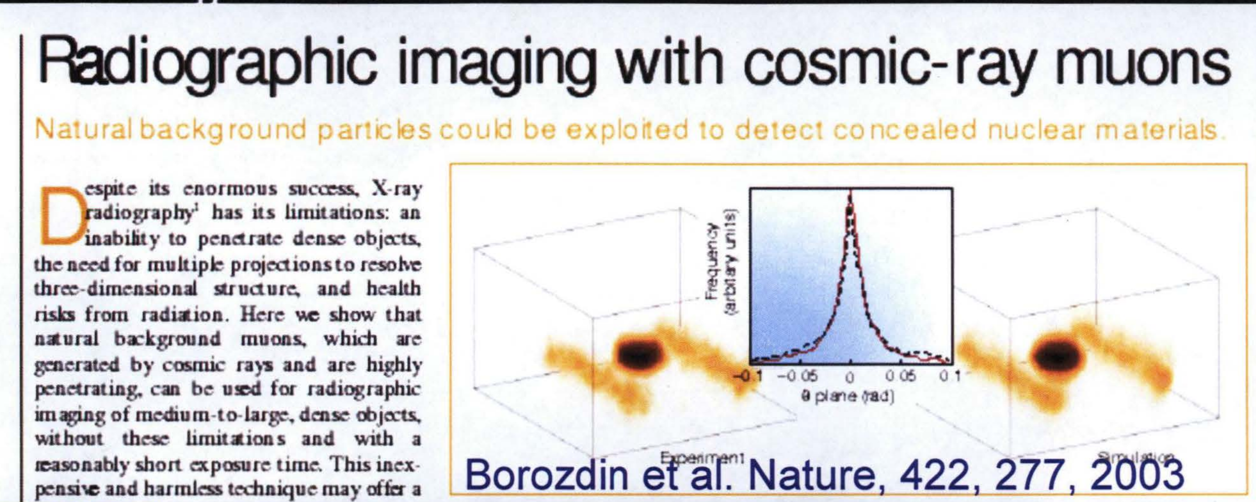


Figure 4: Analyzing the internal structure of a volcanic zone using muons

Cosmic-Ray Muon Tomography

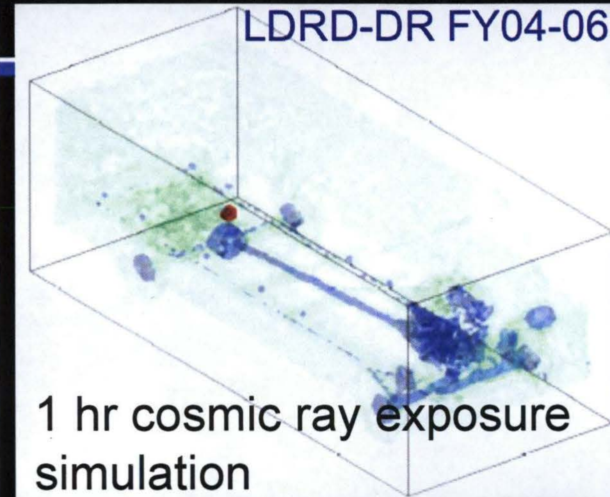


Radiographic imaging with cosmic-ray muons

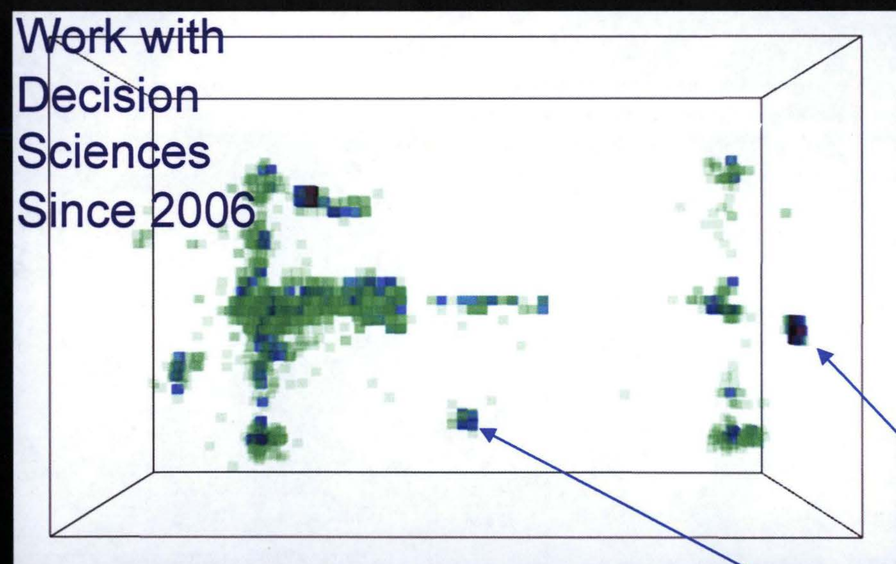
Natural background particles could be exploited to detect concealed nuclear materials.

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



1 hr cosmic ray exposure simulation



Pb

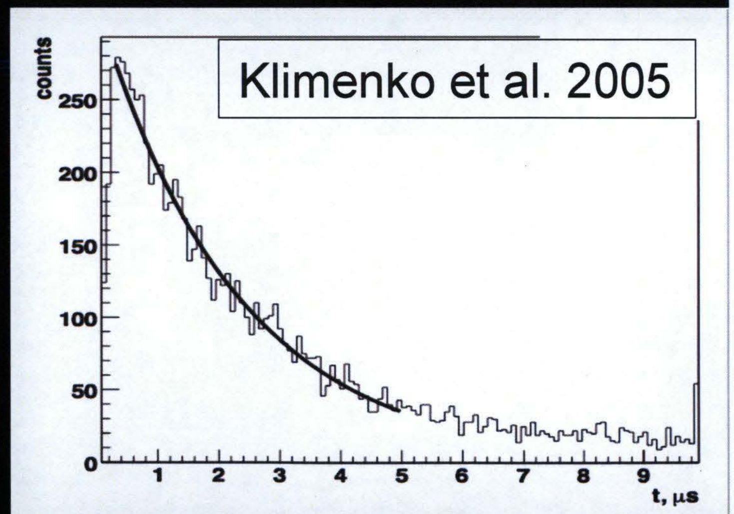
Fe

Reconstruction of Jeep with 3 objects

What Muons Do When They Stop

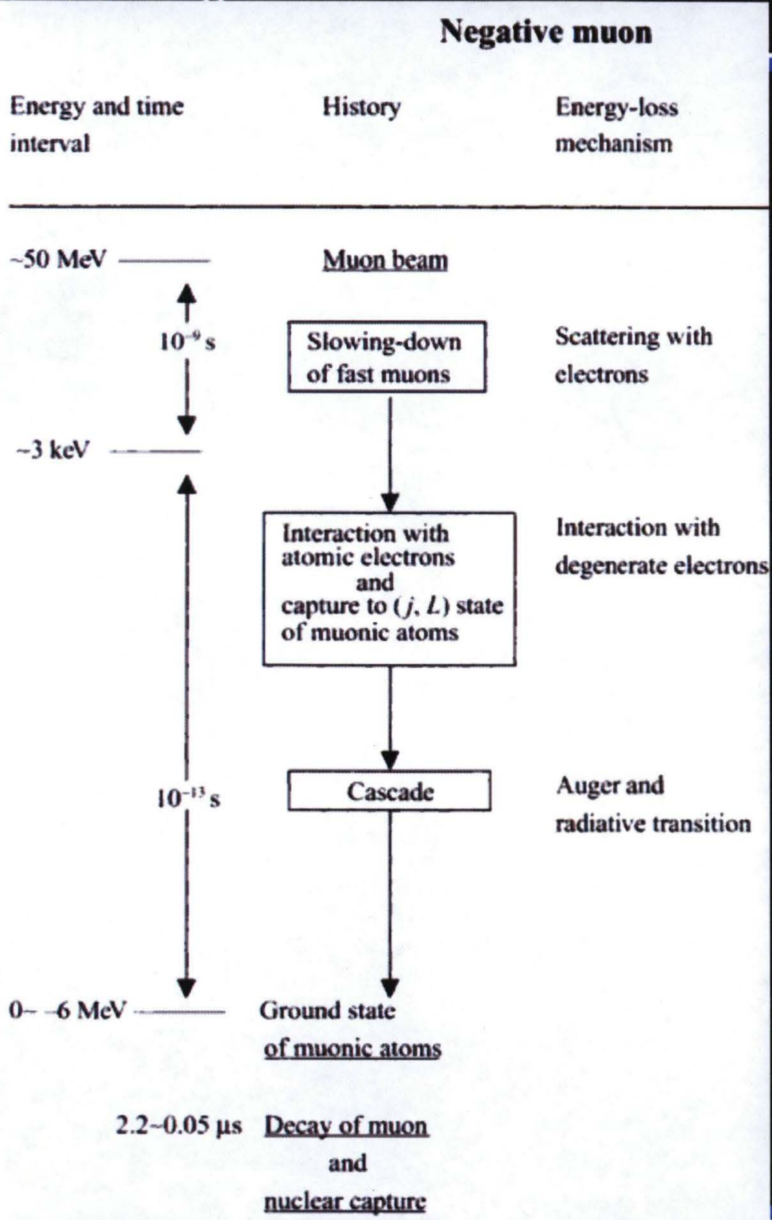
- Cosmic-ray muons: ~60% positive, ~40% negative
- Both absorption and scattering depend on macro properties of materials.
- When stopped, positive muons decay with a half-life

  $\tau_{1/2} = 2.2\mu s$
- Negative muons descend through atomic orbits and are captured by nuclei

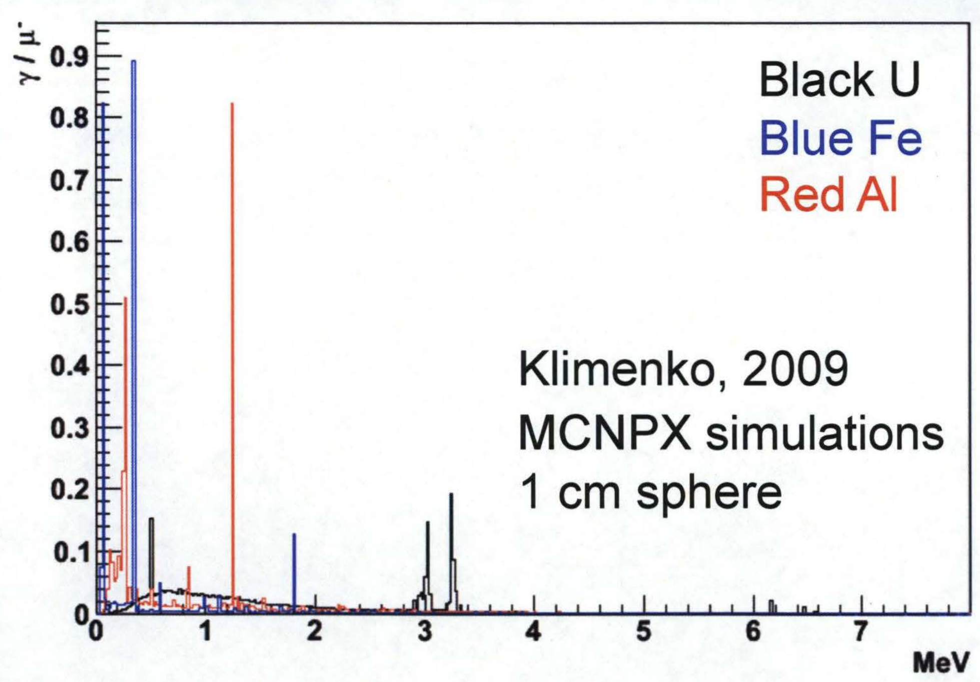


Measurement of cosmic-ray muon decay at LANL

Muonic X-rays From Negative Muon Capture

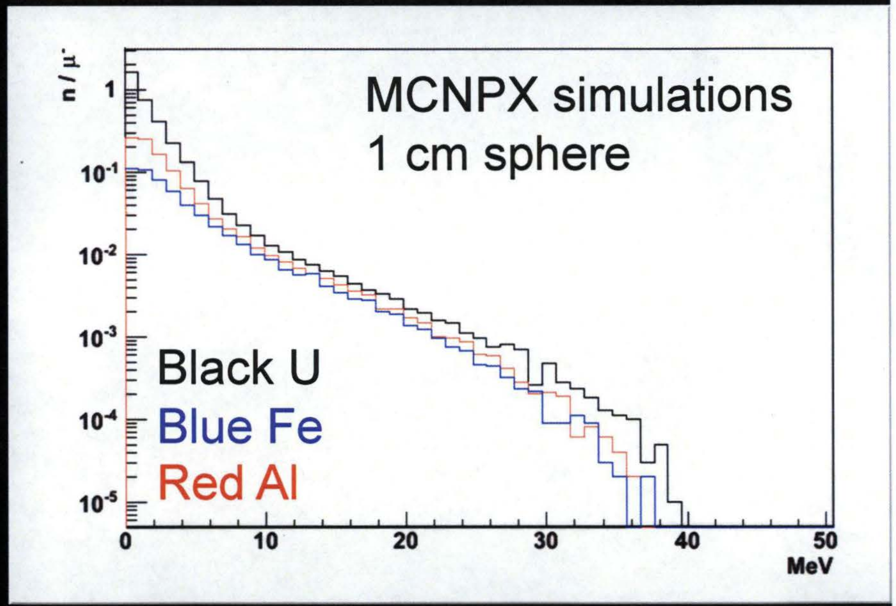


- Low-energy muons (< 300-500 MeV) are stopped in the interrogation object
- Thermalized negative muons are captured into highly excited electron-like orbits
- Multiple muonic x-rays energies are specific for a given atom



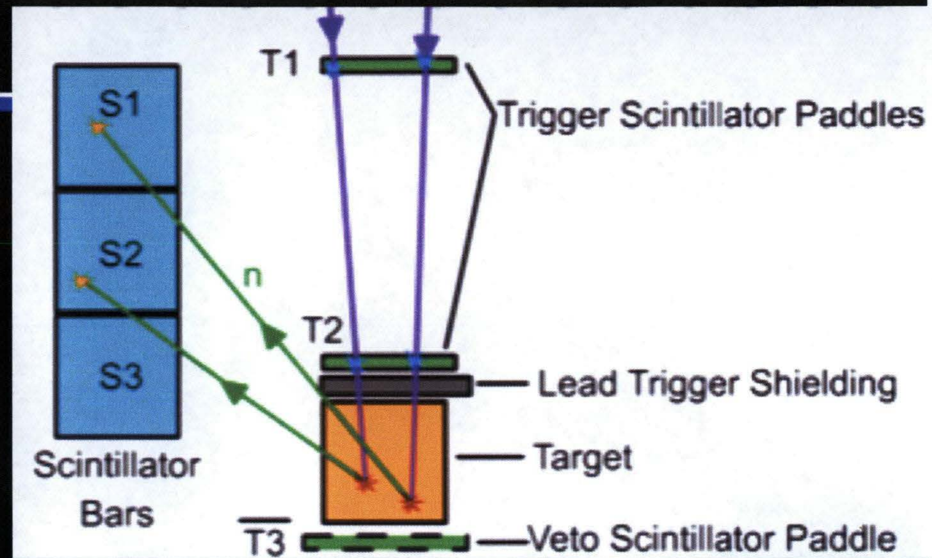
Nuclear Capture

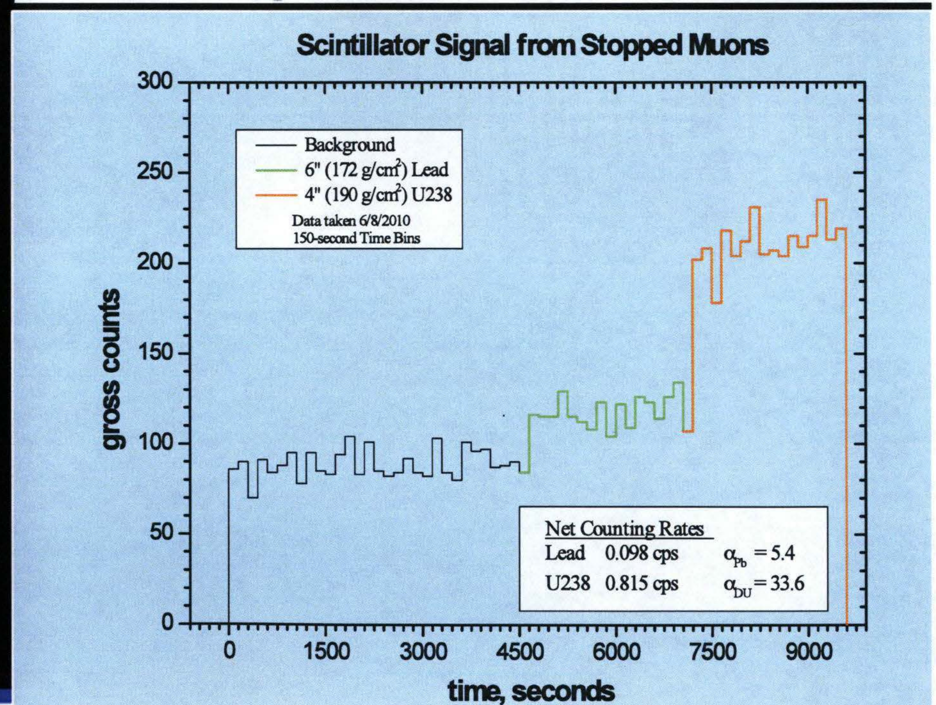
- Negative muons are eventually captured by nuclei
- Nucleus is excited by the muon
- In fissionable materials the nucleus splits with emission of a few neutrons
- Neutrons cause secondary fissions in fissile materials
- Fission yield per muon stop
  - 6.8 ± 1.3 % for ^{238}U
  - 14.2 ± 2.3 % for ^{235}U
- Multiplication enhances



Signature: N/Gamma Count Rate

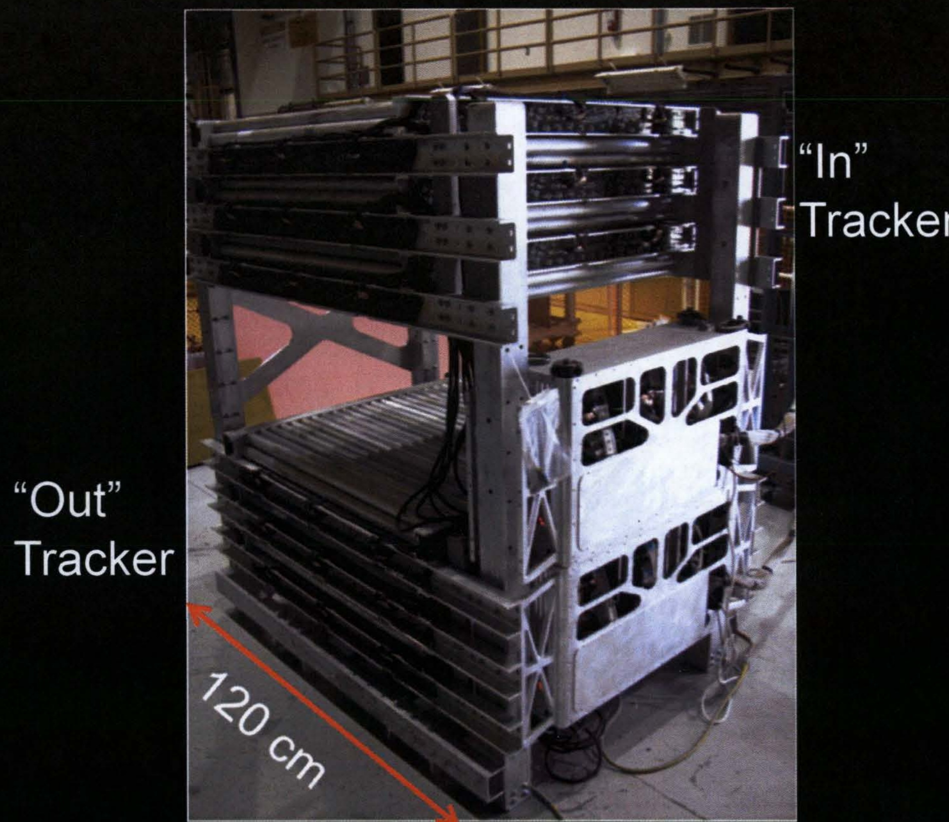
- Trigger scintillator “telescope” constrains directionality of incoming muons
- Large scintillator bars S1, S2, S3, detect secondary neutrons, gammas, etc. produced from muons stopping in target
- High multiplicity of secondary particles →nearly 100% efficiency even for small (~π/2) solid angle
- Pb shielding prevents natural target radiation from causing spurious triggers





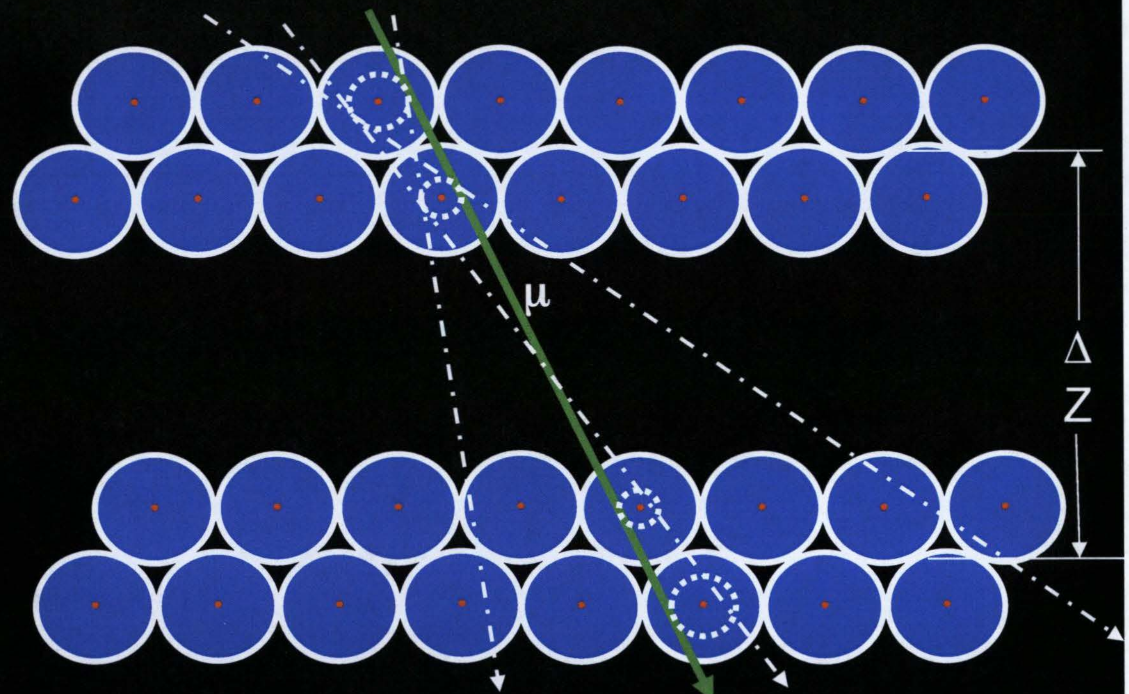
Mini Muon Tracker (MMT) For Muon Tomography

- 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



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 objects to measure scattering angle (average scattering density)



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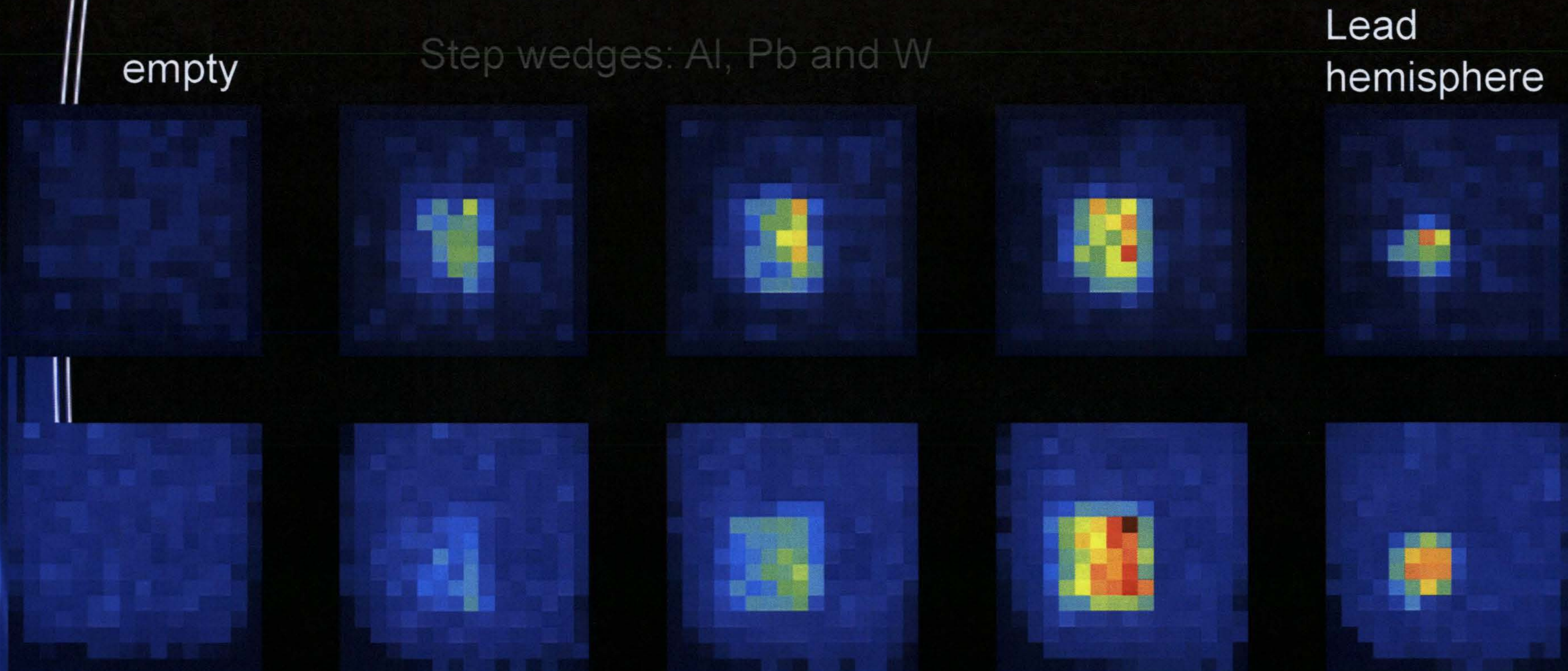
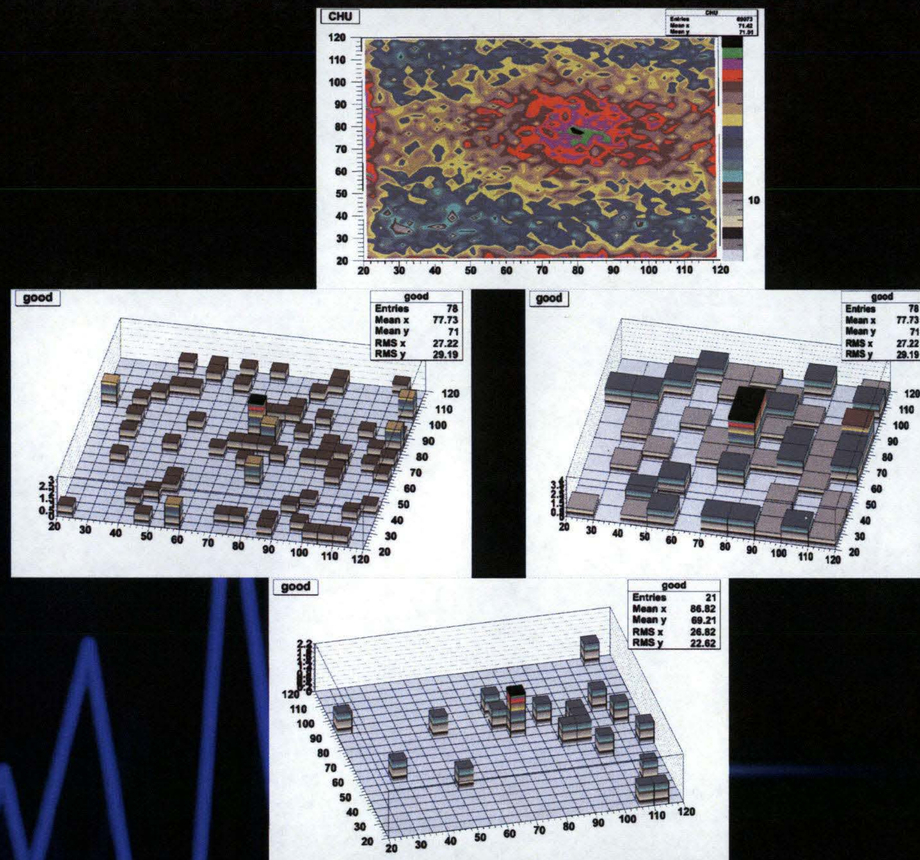
Stopping And Scattering Reconstructions



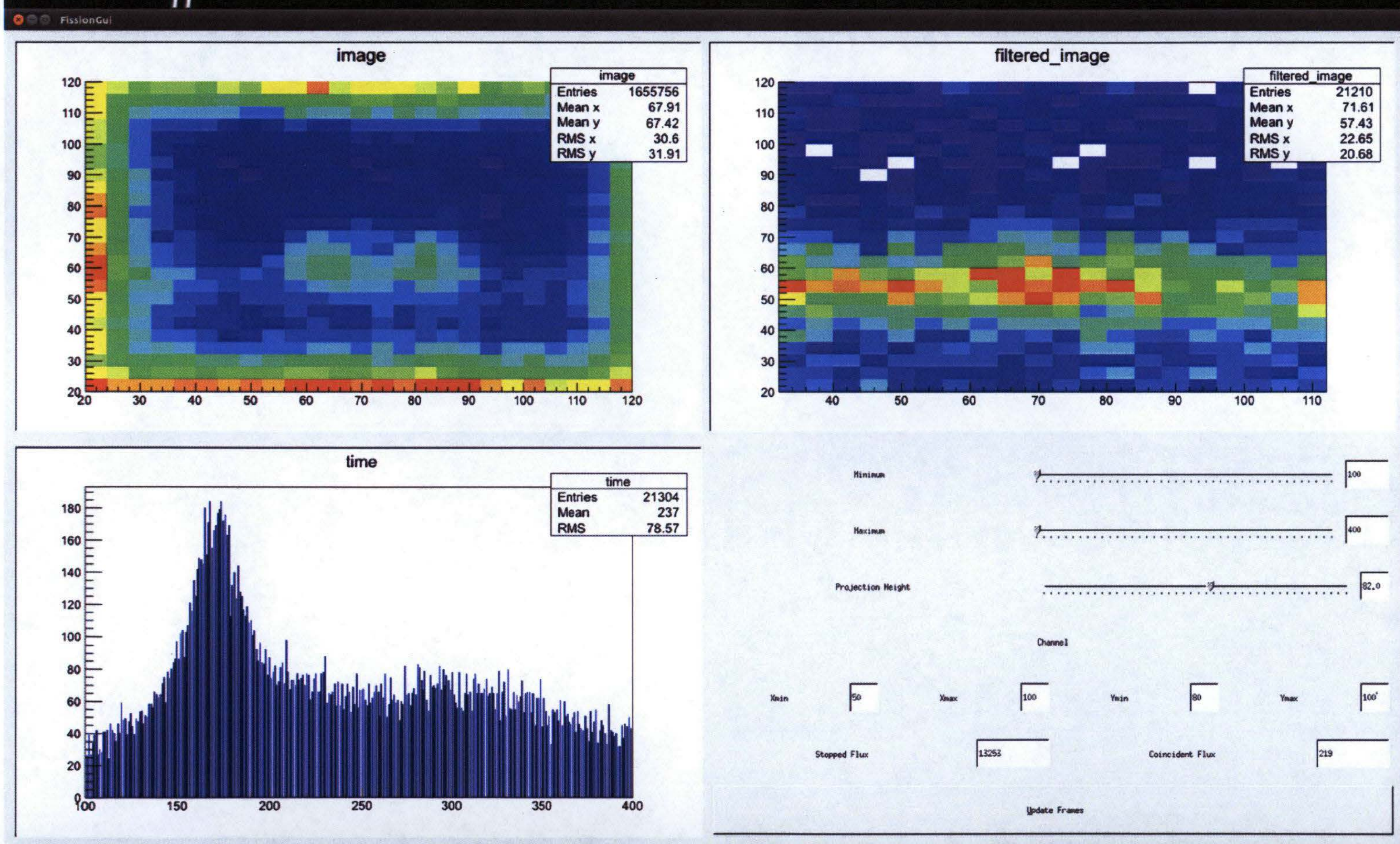
Stopping: upper row, colors represent fraction of stopped muons
Scattering: lower row, colors represent scattering angle

Imaging Cosmic Ray Muon-Induced Fission



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

Muon Stopping and Coincidence

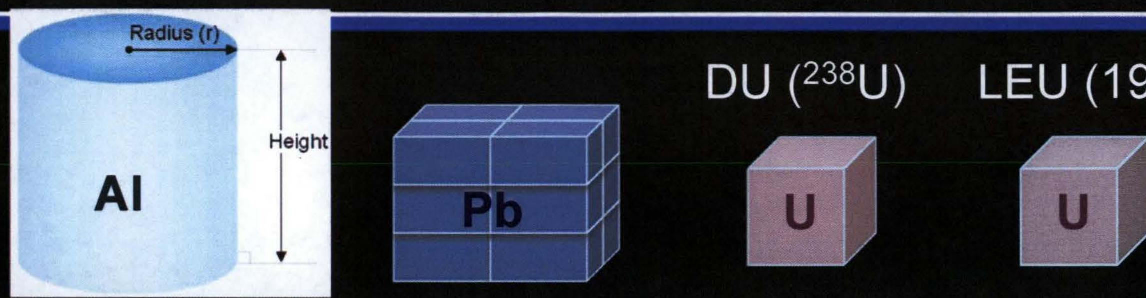


Analysis code processes raw data and creates stopped tracks and full tracks. The neutron timing is also embedded in the post-processed data stream.

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

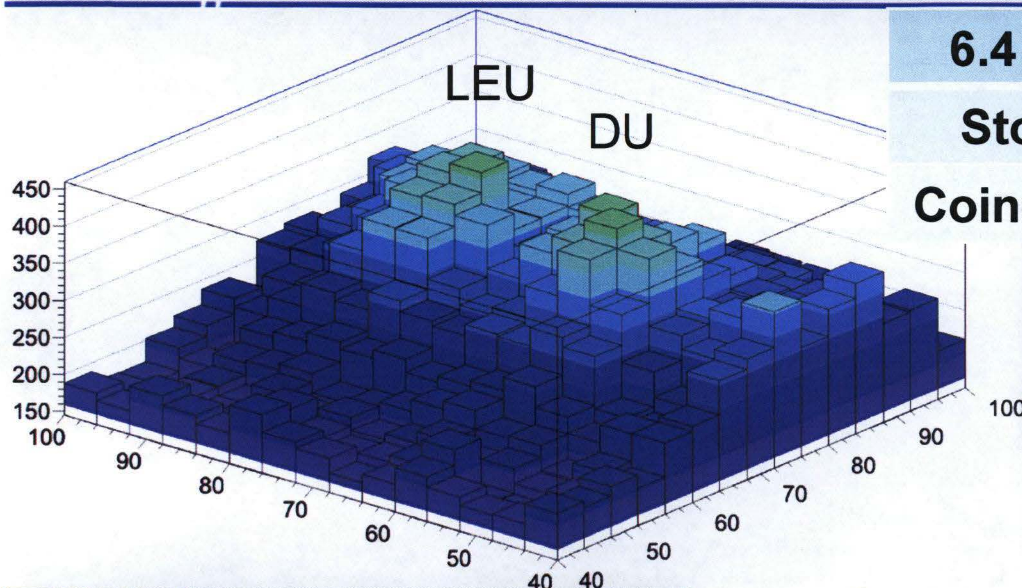


DU (^{238}U) LEU (19.8% ^{235}U)

⦸16cm x 20 cm 20x10x15cm $10cm^3$ $10cm^3$

8 hours	Al	Pb	DU	LEU	bgr
Stopped	22191	33918	24919	26150	8688
Coinc.(plastic)	695	1303	708	989	452
Coinc.(He-3)	169	260	206	254	48
Gammas/cm^3	0.17	0.39	0.71	0.99	
γ error/cm^3	0.007	0.011	0.027	0.031	
Neutrons/cm^3	0.042	0.079	0.206	0.254	
n error/cm^3	0.003	0.005	0.014	0.016	
n/stopped	0.0076	0.0077	0.0083	0.0097	0.0055

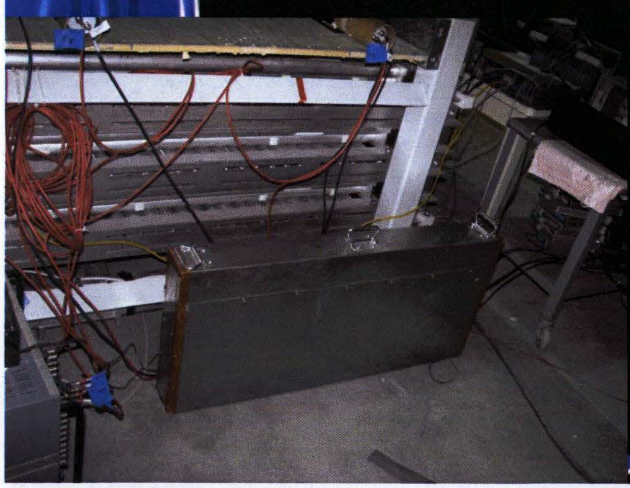
Uranium Isotope Discrimination With He-3

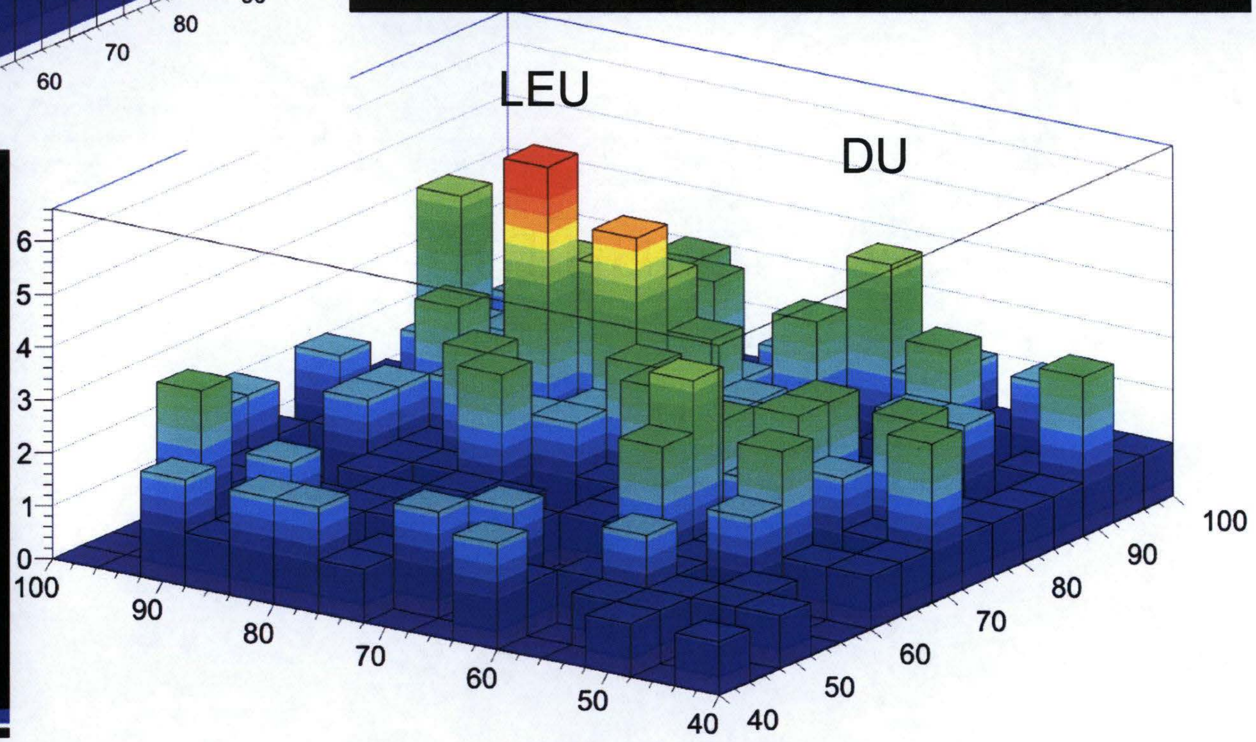


6.4 hours	LEU	DU	bgr
Stopped	13255	13343	7599
Coincidence	77	68	29

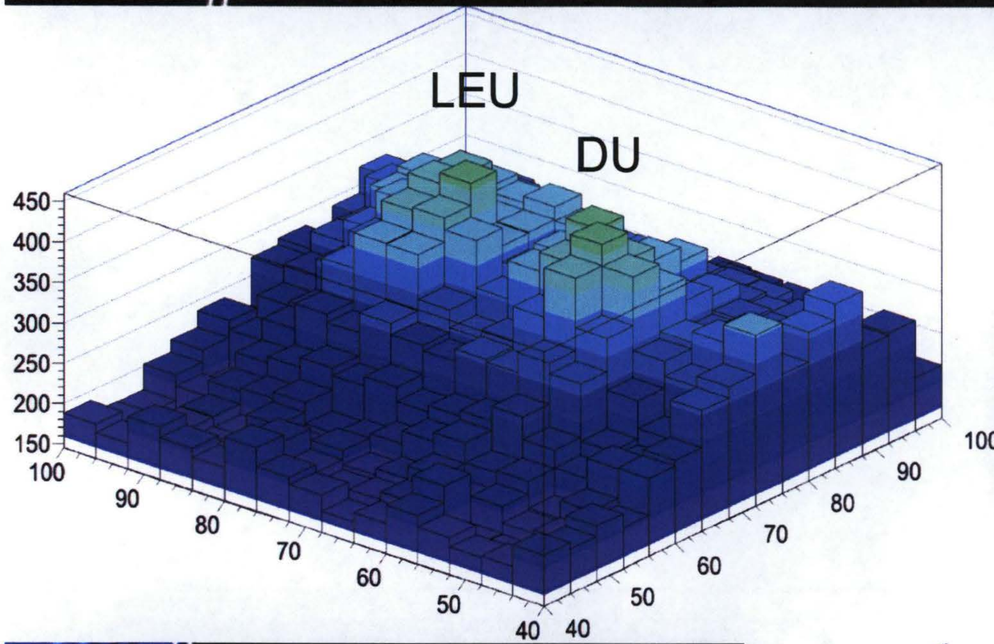
[redacted]

Coincidence 0-250 µs





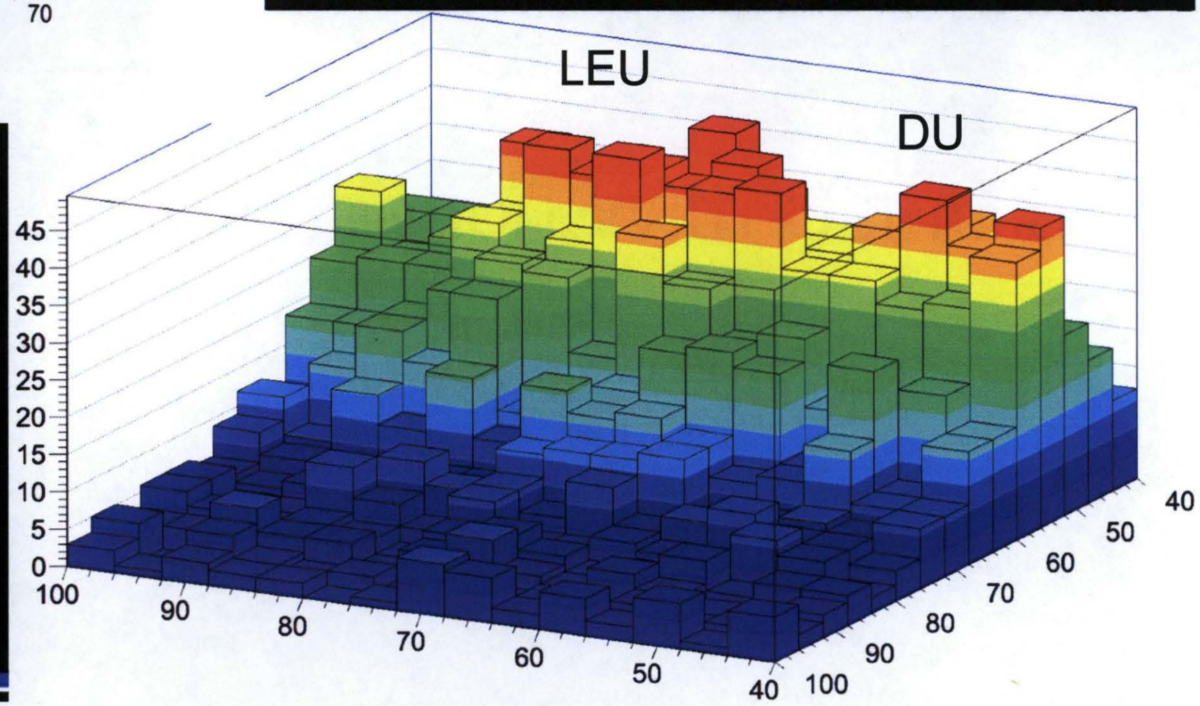
Uranium Isotope Discrimination With Scintillator



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

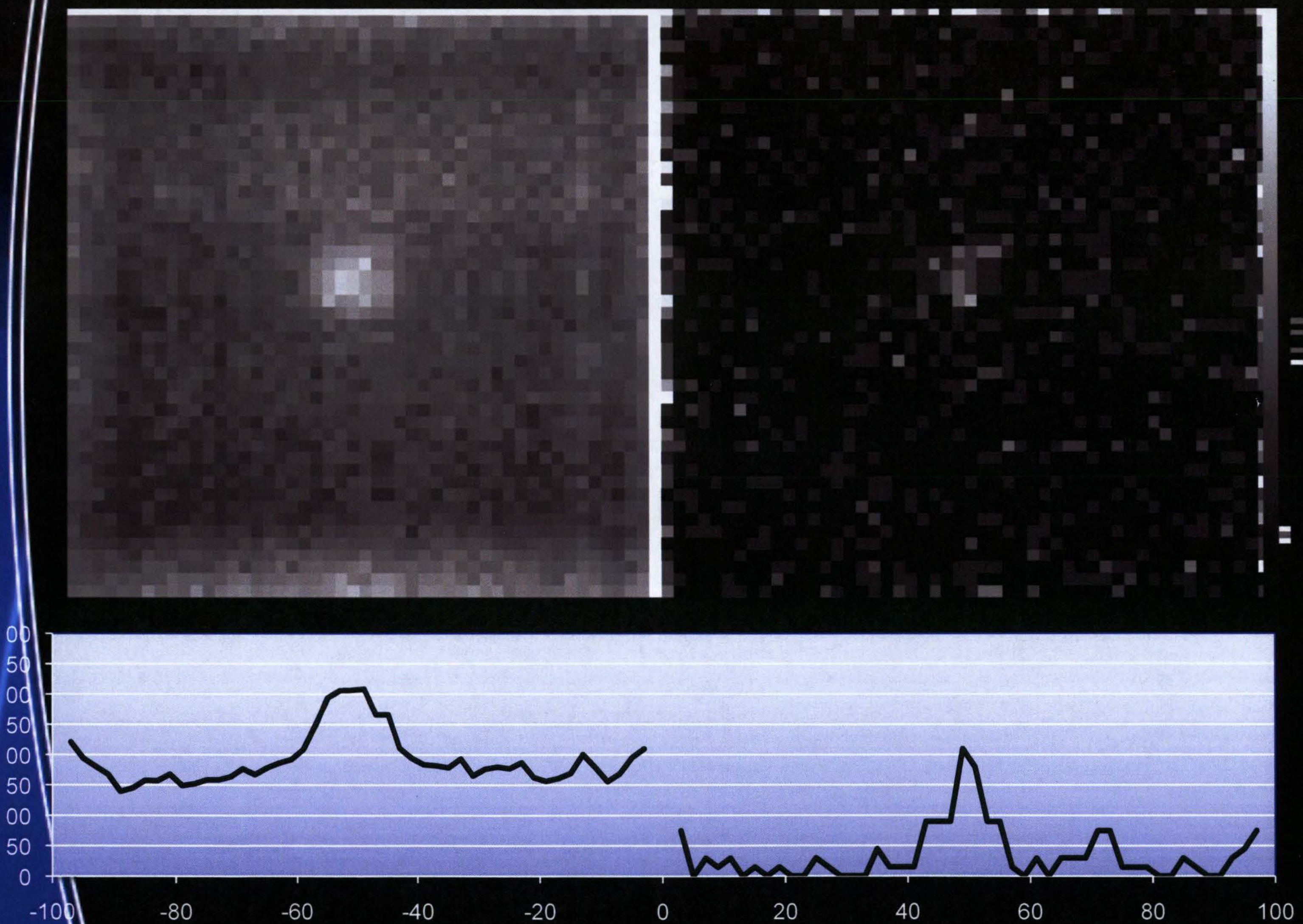
[redacted]

Coincidence 100-400 ns

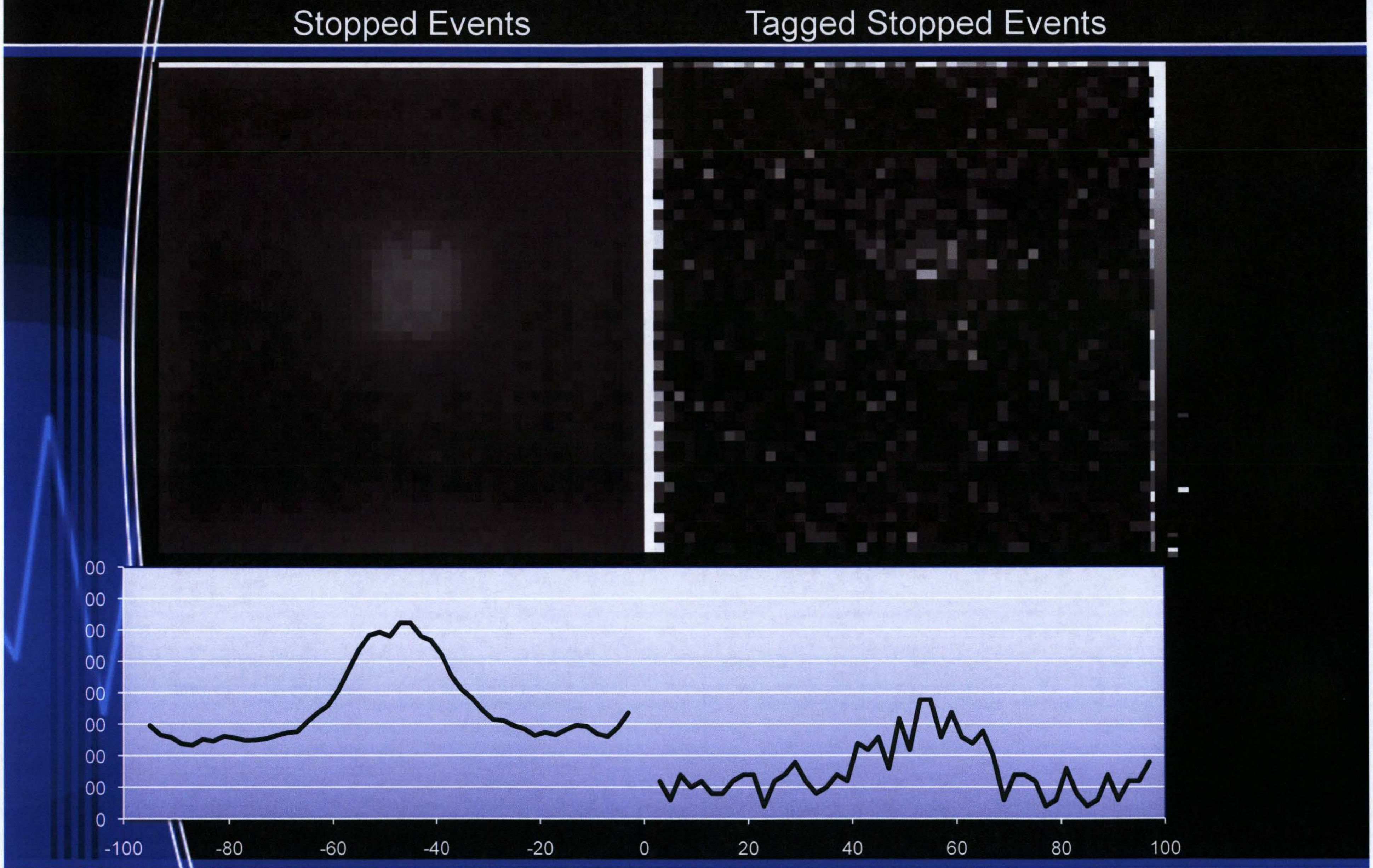


20 kg 20% enriched U

Stopped Events | Tagged Stopped Events



94 kg Lead (20x20x20 cm^3)



Summary

- We demonstrated SNM imaging with cosmic ray muons
- Stopped negative muons are captured by nuclei and cause fission in actinides
- We experimentally showed imaging and isotope identification with muonic fission signals
- Additionally, we have performed classified imaging of nuclear weapons trainers

Acknowledgements

Cas Milner, Randy Spaulding, Kiwhan Chung, Andy Fraser, Andrew Green, Steven Greene, Nicolas Hengartner, Bill Priedhorsky, Alexei Klimenko, Leticia Cuellar, Gary Hogan, Richard Schirato, Haruo Miyadera, Zarija Lukic, Jeff Bacon, Andy Saunders, Debbie Clark, Michael Brockwell, Margaret Teasdale, Jonathan Roybal, Nathan Reimus, Rick Chartrand, Jeff Wang, Pat McGaughey, Mark Makela, John Ramsey, Mark Saltus, Kolo Wamba, et al.

LDRD program at LANL

DHS/DNDO
Department of State
DTRA

Questions?

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